PHENIX Decadal Plan

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for the PHENIX Collaboration

(this talk available at
http://www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/DecadalPlan/PacDec03.pdf)

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	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
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	RIKEN-BNL Research Center, Upton, NY
	University of Tokyo, Bunkyo-ku, Tokyo
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	Kurchatov Institute, Moscow
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*12 Countries; 57 Institutions; 460 Participants**

USA	Abilene Christian University, Abilene, TX
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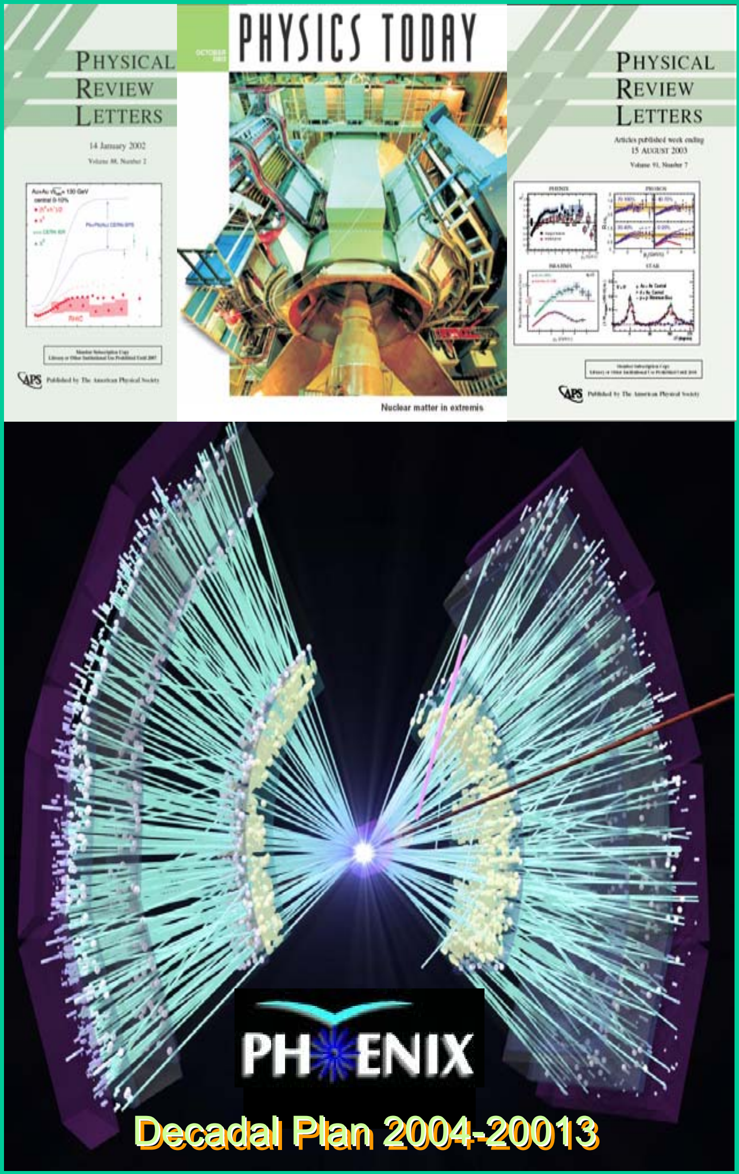
*as of July 2002

The Immediate "Problem"

- How to fit
  - 150+ pages
  - 60+ figures
  - 10+ tables
  - 160+ references

into one 45 minute talk?

- Not to mention PHENIX Beam Use Proposal
  - 30+ pages
  - Explicit run requests for RHIC Run-4 to Run-8
- Not to mention the problem of planning discovery physics for next 10 years…



PHENIX

Approaches

A. Do nothing (maintain status quo)

- PHENIX would have a vital and interesting research program for the next decade
- (for the next next decade as well)
- Summary of the Executive Summary:

  "There's obviously 10 years of physics to do at RHIC"
  (A. Caldwell, 03-Dec-03)

B. Significantly increase RHIC luminosity

- Yes! (RHIC-II)
- Extends PHENIX reach to truly rare probes

C. Install targeted upgrades to PHENIX

- Yes! (ongoing)
- Greatly extends PHENIX sensitivities in various channels (even without extended reach provided by RHIC-II)

D. Do B and C

- Ideal!
- A truly compelling program of broadest possible scope

PHENIX

Executive Summary (1)

- The PHENIX Collaboration has developed a plan for the detailed investigation of quantum chromodynamics in the next decade. The demonstrated capabilities of the PHENIX experiment to measure rare processes in hadronic, leptonic and photonic channels, in combination with RHIC's unparalleled flexibility as a hadronic collider, provides a physics program of extraordinary breadth and depth. A superlative set of measurements to elucidate the states of both hot and cold nuclear matter, and to measure the spin structure of the proton has been identified. The components of this plan include
  - Definitive measurements that will establish the nature of the matter created in nucleus+nucleus collisions, that will determine if the description of such matter as a quark-gluon plasma is appropriate, and that will quantify both the equilibrium and non-equilibrium features of the produced medium.
  - Precision measurements of the gluon structure of the proton, and of the spin structure of the gluon and sea-quark distributions of the proton via polarized proton+proton collisions.
  - Determination of the gluon distribution in cold nuclear matter using proton+nucleus collisions.

Executive Summary (2)

- Each of these fundamental fields of investigation will be addressed through a program of correlated measurements in some or all of the following channels:

   - Particle production at high transverse momentum, studied via single particle inclusive measurements of identified charged and neutral hadrons, multi-particle correlations and jet production.
   - Direct photon, photon+jet and virtual photon production.
   - Light and heavy vector mesons.
   - Heavy flavor production.

Executive Summary (3)

- A portion of this program is achievable using the present capabilities of PHENIX experimental apparatus, but the physics reach is considerably extended and the program made even more compelling by a proposed set of upgrades which include

  - An aerogel and time-of-flight system to provide complete π/K/p separation for momenta up to 10~GeV/c.
  - A vertex detector to detect displaced vertices from the decay of mesons containing charm or bottom quarks.
  - A hadron-blind detector to detect and track electrons near the vertex.
  - A micro-TPC to extend the range of PHENIX tracking in azimuth and pseudo-rapidity.
  - A muon trigger upgrade to preserve sensitivity at the highest projected RHIC luminosities.
  - A forward calorimeter to provide photon+jet studies over a wide kinematic range.

Compare to Conceptual Design Report (29-Jan-93)

- **Conclusions:**
  - ~All goals accomplished
    - *As permitted by available integrated luminosity*
    - For Au+Au (d+Au) only
  - Much remains
    - Truly rare probes in Au+Au
    - Species scans
    - Energy variation
  - Spin!
  - Proton-nucleus!

Table 3.1: Physics Variables to be Measured by the PHENIX Experiment

Quantity to be Measured	Category*	Physics Objective
e^+e^-, $\mu^+\mu^-$		
• $\rho \to \mu^+\mu^- / \rho \to \pi\pi$, $d\sigma/dp_\perp$	BCD	Basic dynamics (T, τ, etc.,) for a hot gas,
$\omega \to e^+e^- / \omega \to \pi\pi$, $d\sigma/dp_\perp$		transverse flow, etc.
• ϕ-meson's width and $m_{\phi \to e^+e^-}$	QGP	Mass shift due to chiral transition (C.T.) [2]
✓ $\phi \to e^+e^- / \phi \to K^+K^-$	QGP	Branching ratio change due to C.T. [3]
ϕ-meson yield (e^+e^-)	ES	Strangeness production ($gg \to s\bar{s}$)
✓ • $J/\psi \to e^+e^-, \mu^+\mu^-$	QGP, QCD	Yield suppression and the distortion
$\psi' \to \mu^+\mu^-$		of p_T spectra due to Debye screening
$\Upsilon, \to \mu^+\mu^-$		in deconfinement transition (D.T.) [4]
• $1 < m_T(l^+l^-) < 3$ GeV	ES, QGP	Thermal radiation of hot gas, and
(rate and shape)		effects of QGP [5, 6, **?**]
• $m_{l^+l^-} > 3$ GeV $\to \mu^+\mu^-$	QCD	A-dependence of Drell-Yan, and
	QGP	thermal $\mu^+\mu^-$ [5, 6, 7, 8]
• $\sigma \to \pi\pi, e^+e^-, \gamma\gamma$	QGP	Mass shift, narrow width due to C.T. [2]
$e\mu$ coincidence		
• $e\mu$, $e(p_T > 1$ GeV/c)	QCD, QGP	$c\bar{c}$ background, charm cross section [9]
Photons		
• $0.5 < p_T < 3$ GeV/c γ	ES, QGP	Thermal radiation of hot gas, and
(rate and shape)		effect of QGP [6, 7]
✓ • $p_T > 3$ GeV/c γ	QCD	A-dependence of QCD γ
✓ • π^0, η spectroscopy	BCD	Basic dynamics of hot gas, strangeness in η
• $N(\pi^0)/N(\pi^+ + \pi^-)$ fluctuations	QGP	Isospin correlations and fluctuations [10, 11]
✓ • High p_T π^0, η from jet	QGP	Reduced dE/dx of quarks in QGP [12]
Charged Hadrons		
✓ • p_T spectra for $\pi^\pm$, $K^\pm$, p, $\bar{p}$	BCD	Basic dynamics, flow, T, baryon density,
		stopping power, etc.
	QGP	Possible second rise of $< p_T >$ [13]
✓ • $\phi \to K^+K^-$	ES, QGP	Branching ratio, mass width [3, 14]
✓ • K/π ratios	ES	Strangeness production
✓ • $\pi\pi$ + KK HBT	BCD	Evolution of the collision, $R_\perp$
	QGP	Long hadronization time ($R_{out} \gg R_{side}$) [15]
✓ • Antinuclei	QGP	High baryon susceptibility due to C.T.? [16]
✓ • high p_T hadrons from jet	QGP	Reduced dE/dx of quarks in QGP [12]
Global		
✓ • N_{tot} (total multiplicity)	BCD	Centrality of the collision
✓ • $dN/d\eta, d^2N/d\eta d\phi, dE_T/d\eta$	BCD	Local energy density, entropy
	QGP	Fluctuations, droplet sizes [17]

* BCD = Basic collisions dynamics. ES = Thermodynamics at early stages.
QGP = Effect of QGP phase transition. QCD = Study of basic QCD processes.

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The Fundamental Issue

- The exciting physics is at the (nb to pb) level
- ➡ The exciting physics requires
  - ➡ Large integrated luminosities
    - ➡ Time
    - ➡ Higher luminosity
    - ➡ Machine development
- The exciting physics spans (at least) 3 programs
- Each is suffering at 27 weeks per year
  - ❑ Example 1: J/Ψ in Au+Au
  - ❑ Example 2: A_{LL}
  - ❑ Example 3: Gluon shadowing

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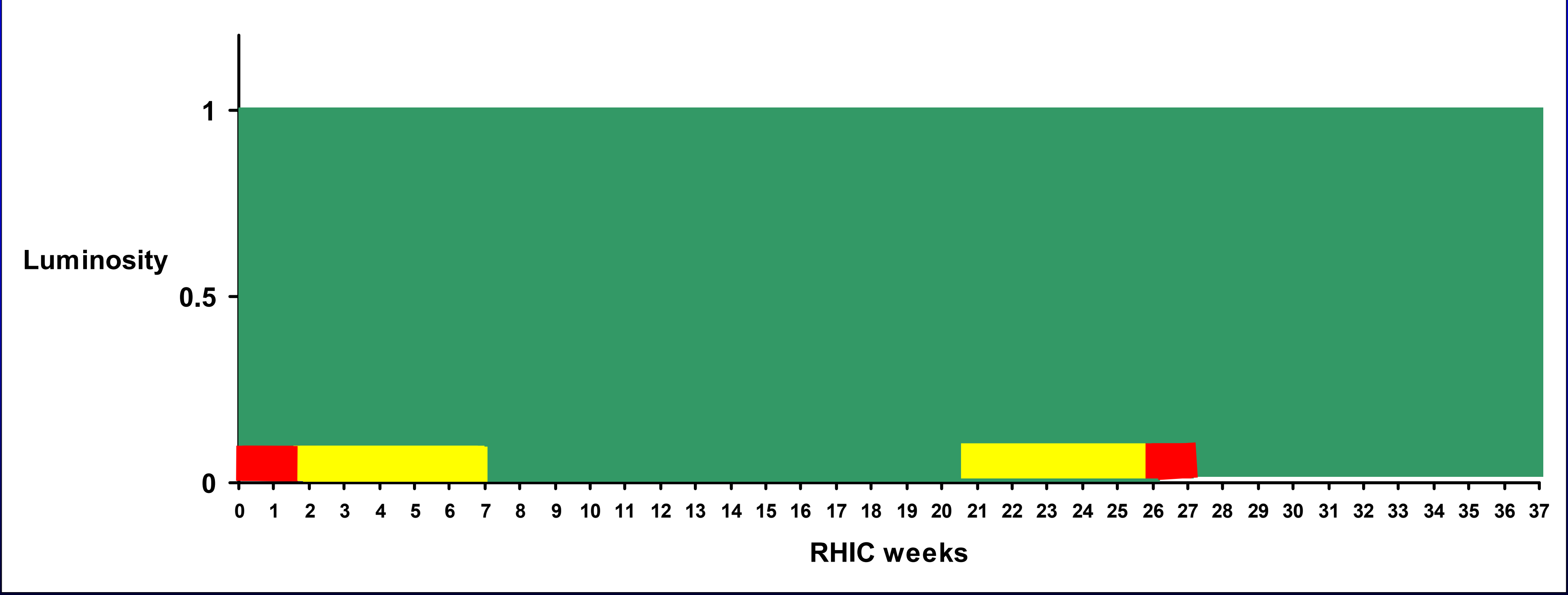
Perspective

Spectacular

- The machine achievements in the first 3 years of RHIC operations have been *spectacular*:
  - 3 different colliding species (Au-Au, p-p, d-Au)
  - 3.5 energies for Au-Au (19, 56, 130, 200) GeV
  - First ever polarized hadron collider
  - Design luminosity for Au-Au
  - (Etc.)
- Physics has been produced at "all" cross-sections:
  - Heavy Ions
    - barn: $dN_{ch}/d\eta$ vs N_{part} PRL 86, 3500 (2001)
    - mb : $v_2(p_T)$ nucl-ex/0305013 (to appear in PRL)
    - μb : $R_{AA}(p_T)$ PRL 88, 022301 (2002)
    - nb : J/Ψ (limit) nucl-ex/0305030 (to appear in PRC)
  - Spin
    - Life (for A_{LL}) begins at ~inverse pb
    - A start from Run-3? (0.35 pb^{-1})
- Future output of the program
  - Depends *crucially* on developing large integrated luminosities
  - Adversely affected by original 37 weeks → 27 weeks per year
  - Enhanced by proposed program of upgrades

Life at RHIC

- A long time ago
  in a place far far away…
- *"37 weeks of operations"*

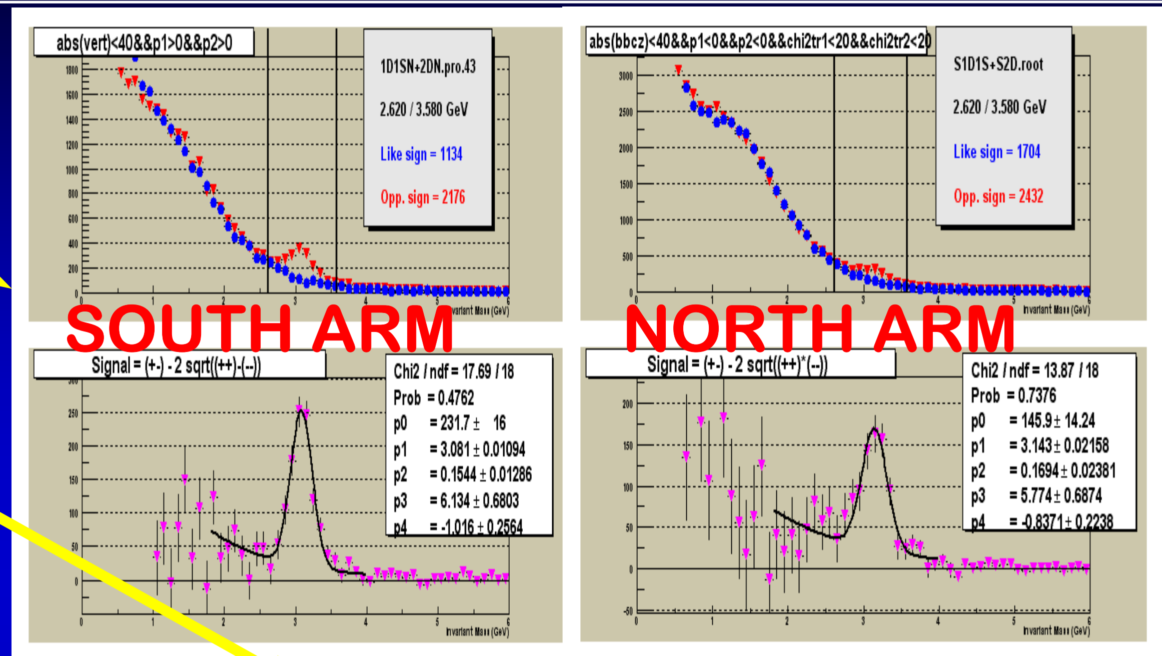


Proton+Nucleus Collisions

- To be sure, a crucial control for A+A measurements
- But an intrinsically valuable program in its own right:
- Executive Summary: "Determination of the gluon distribution in cold nuclear matter using proton+nucleus collisions."
- Together, lead to a broad program:
  - Gluon shadowing over broad kinematic range (J/Ψ and Υ's, γ's, γ+jet)
  - Heavy quark production, propagation in a cold nucleus (high p_T single leptons)
  - Cronin effects, fragmentation function modification, parton energy loss (high p_T hadrons, jet+jet, γ+jet)
  - Correlation of all of the above with precision measurements of "centrality".
- An essential component in our decadal planning
  - Driven in part by success of Run-3 d+Au
  - Difficult to accommodate in near term
  - Will need to periodically revisit as
    - Higher luminosities become available
    - Other systems and/or energies require comparison data

Run-3 J/Ψ's

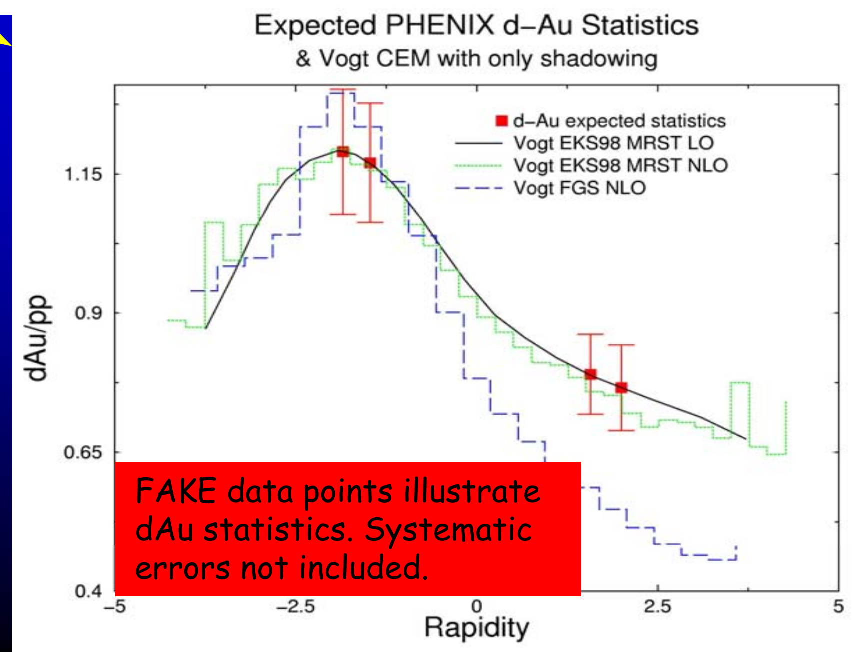
- 2.7 nb^{-1} d+Au
  - Provides clear J/Ψ signals
  - With modest discrimination power to test shadowing models



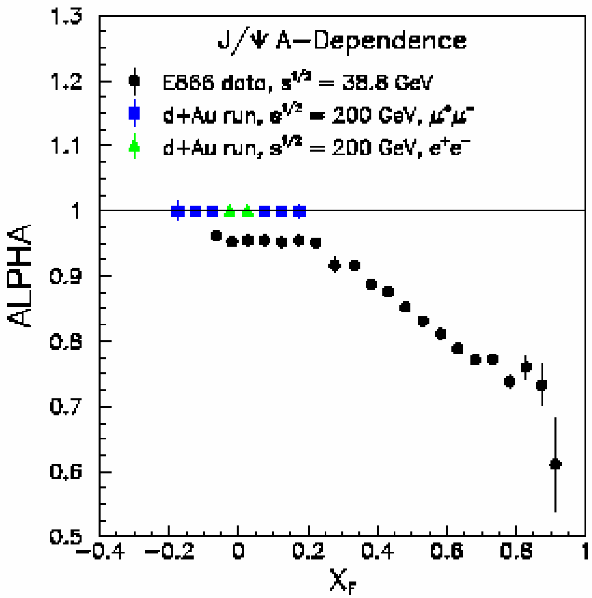
- A clear need for
  - 20 nb^{-1} : shadowing
  - 200 nb^{-1} : Ψ', Drell-Yan
  - 2000 nb^{-1} : Υ's

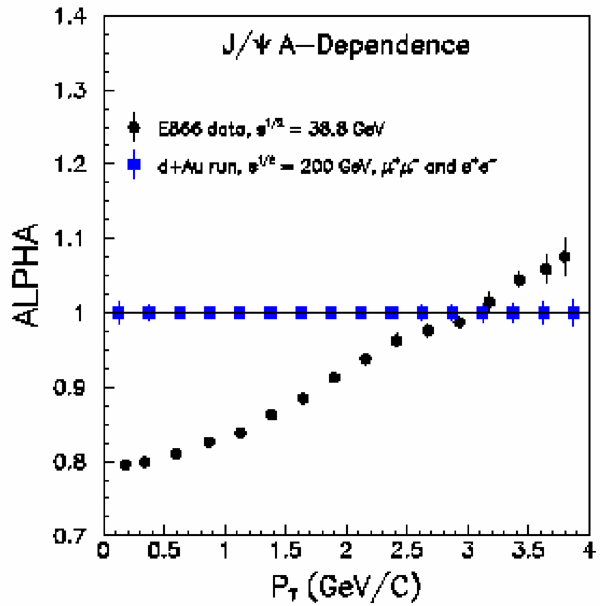
☞ ***We were not able to accommodate these runs in our 5-year planning exercise***

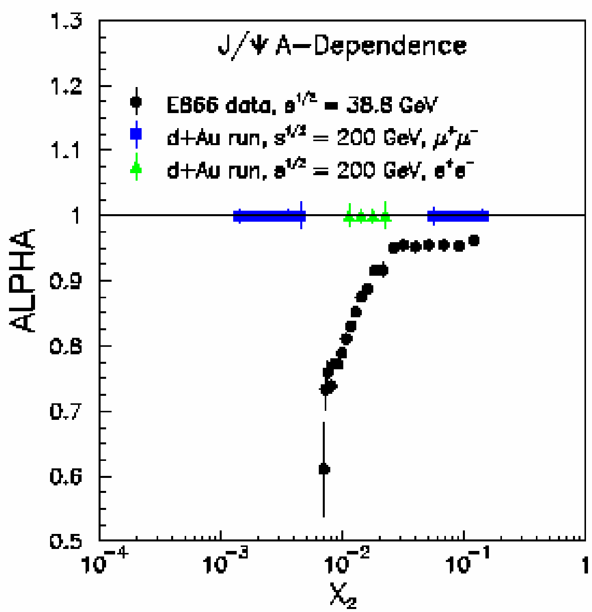
- A high priority item in our decadal planning



Extended Reach in d+Au







- What that first 20 nb^{-1} delivers
  - Extensive measurements
    - at higher √s
    - lower x_2
- Then the next 200 nb^{-1} …

Table 2.10: Estimated physics yields for d+Au collisions for several processes with various integrated luminosities. For the lower rate process such as the Υ this illustrates the much larger luminosities needed in order to reach this physics.

$\int \mathcal{L}dt$	Process	North Muons	South Muons	Electrons
20 nb^{-1}	J/Ψ	8.3k	6.4k	3.3k
200 nb^{-1}	Ψ'	1650	1280	660
200 nb^{-1}	Υ	47	40	56
200 nb^{-1}	Drell-Yan ($M > 4\ GeV$)	4.9k	3.8k	1k ($M > 3\ GeV$)
200 nb^{-1}	$D\bar{D}$ ($M > 1.6\ GeV$)	25k	20k	
200 nb^{-1}	$D \to \mu X$	2B	2B	
200 nb^{-1}	$B \to \mu X$	5M	5M	

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Spin Physics

- Executive Summary: **"Precision measurements of the gluon structure of the proton, and of the spin structure of the gluon and sea-quark distributions of the proton via polarized proton+proton collisions."**
- An integral part of our program, our collaboration, our experiment, our future
- Original desiderata:
  - $\sqrt{s}$ = 200 GeV: 320 pb^{-1}, <P> = 70%
  - $\sqrt{s}$ = 500 GeV: 800 pb^{-1}, <P> = 70%
- Presently
  - $\sqrt{s}$ = 200 GeV: 0.35 pb^{-1}, <P> = 27%
  - Room for "substantial" improvement in $P^4 L$

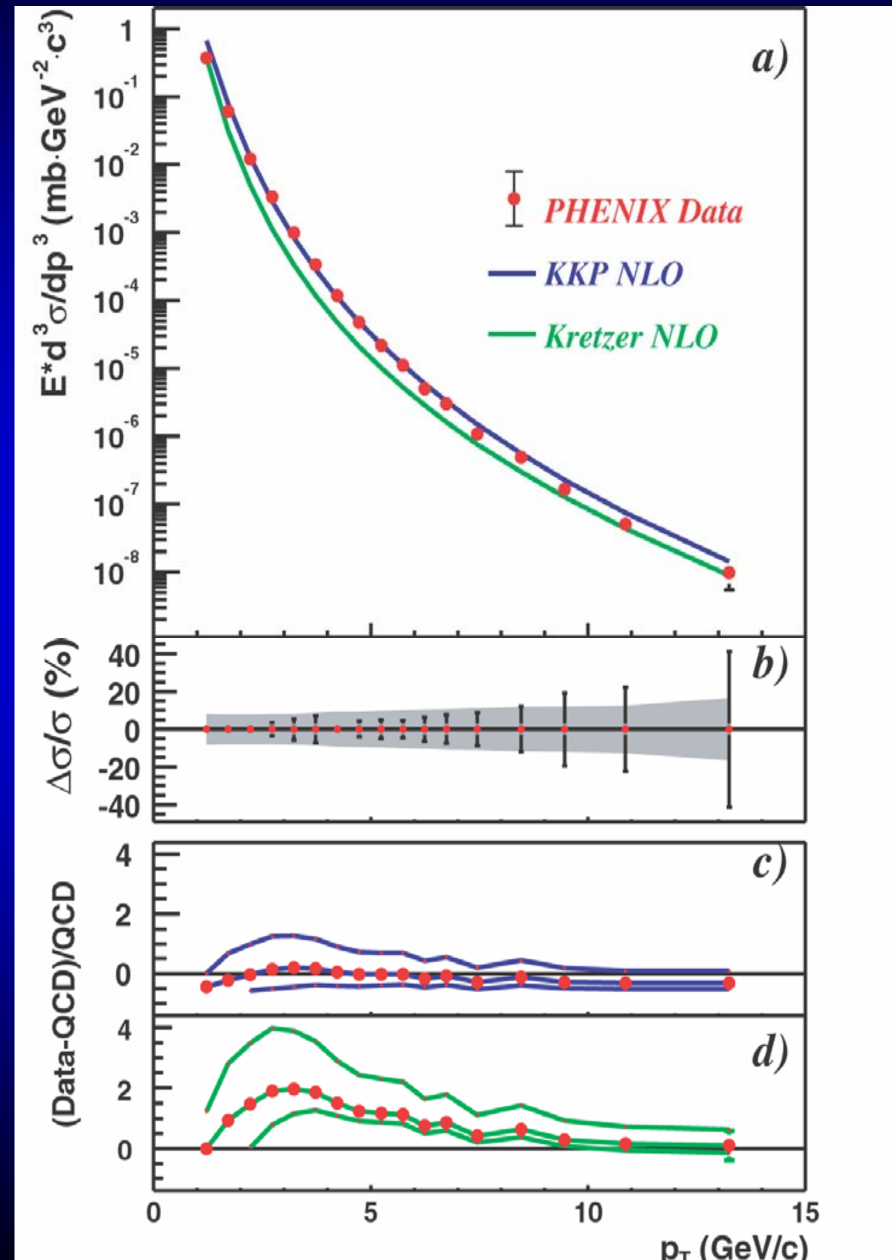
Our First "Spin" Publication

- "Midrapidity Neutral Pion Production in Proton-Proton Collisions at $\sqrt{s}$ = 200 GeV", accepted for publication in PRL on 19 September 2003, hep-ex/0304038

☞ *Important confirmation of of theoretical foundations for spin program*

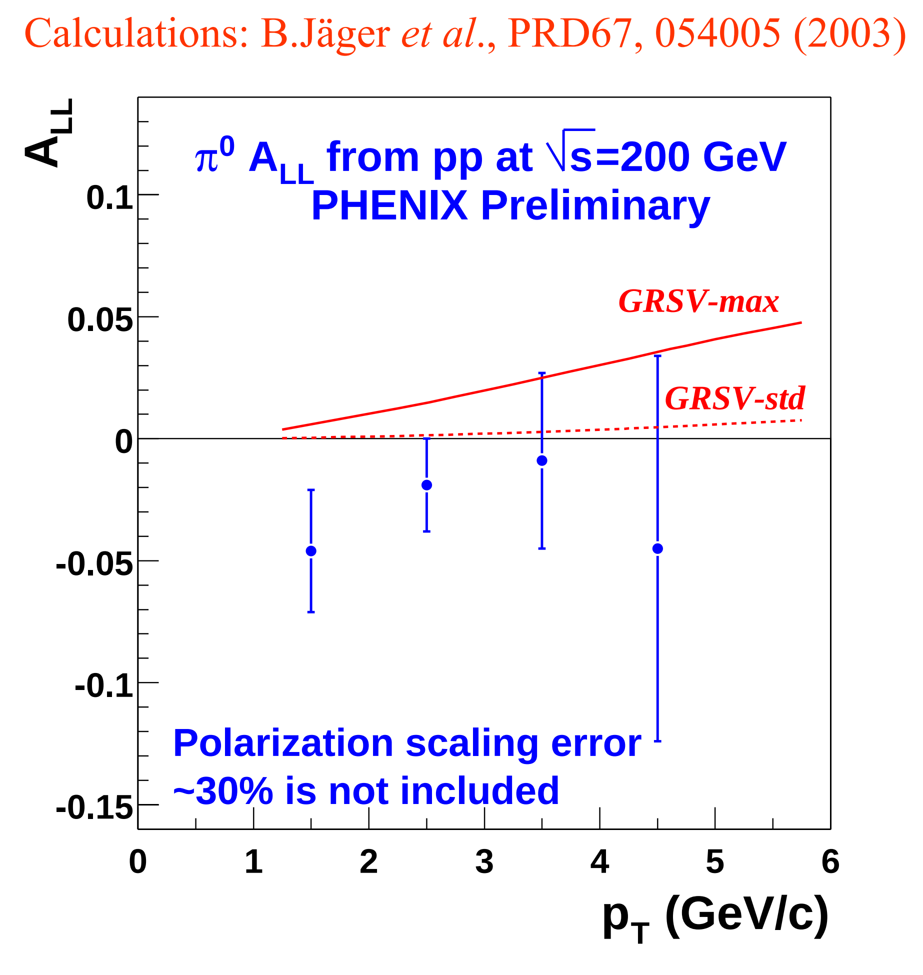
  - Results consistent with pQCD calculation
  - Favors a larger gluon-to-pion FF (KKP)
  - *Provides confidence for proceeding with spin measurements via hadronic channels*

- Run3 results reproduce Run2 results
  - Confirm the Run-3 data reliability and consistency
  - Run3 data reaches even higher p_T's; results will be finalized soon



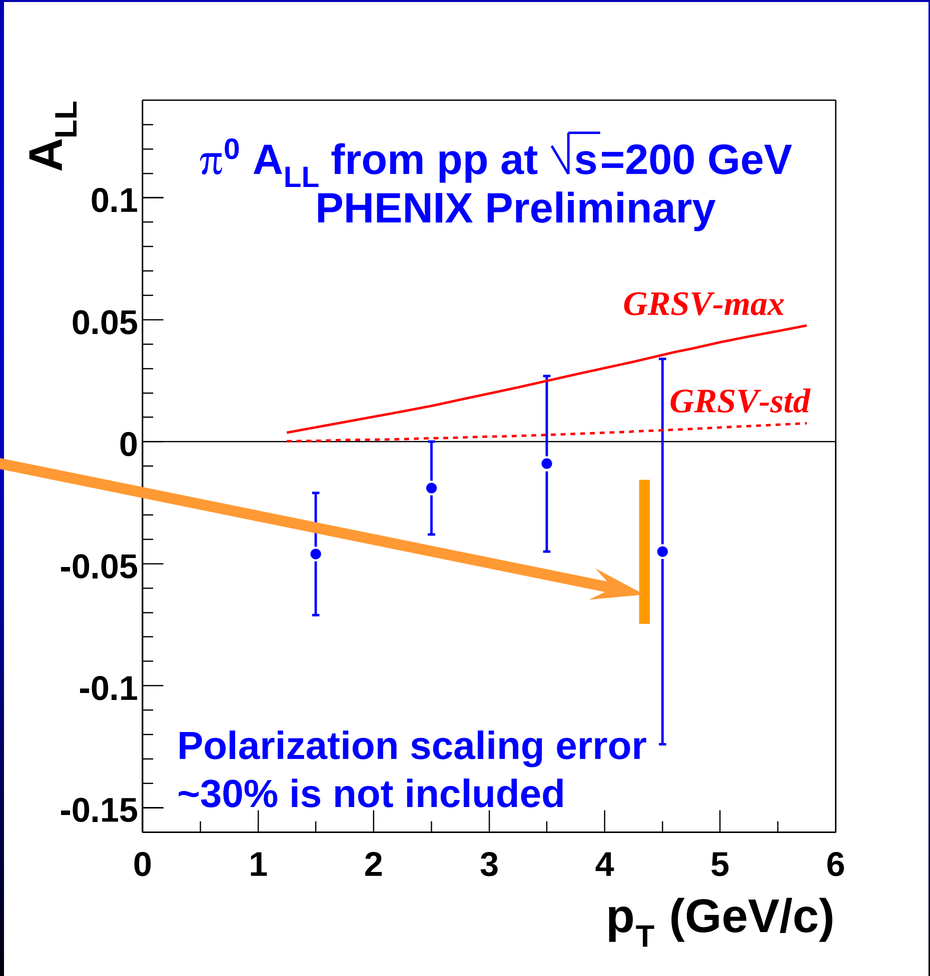
Towards Our First "Real" Spin Publication

- Presented at Dubna spin conference (Sep-03)
- Extensive (ongoing) study of systematics
  - Bunch shuffling, background studies, A_L checks, ...
  - Relative luminosity precision ~ 2.5×10^{-4}
  - ➡ Contribution to A_{LL} < 0.2%
  - ➡ Dominated by statistical errors from 0.22 pb^{-1} sample
- ***A very important proof-of-principle for spin program!***



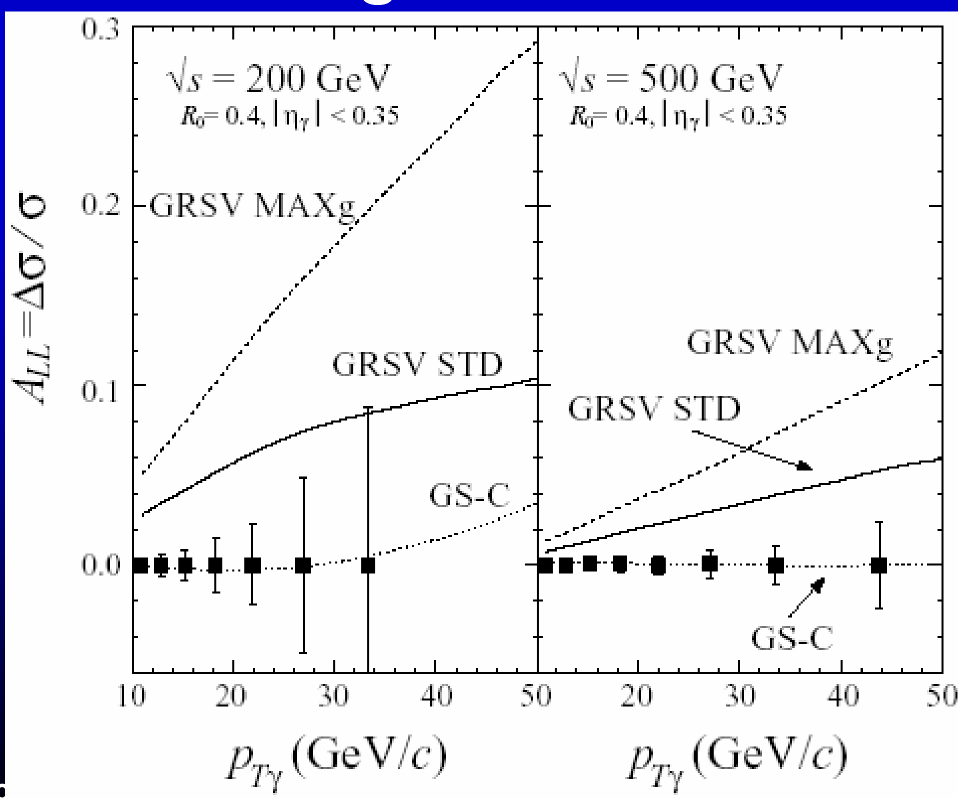
Near-Term Spin Prospects

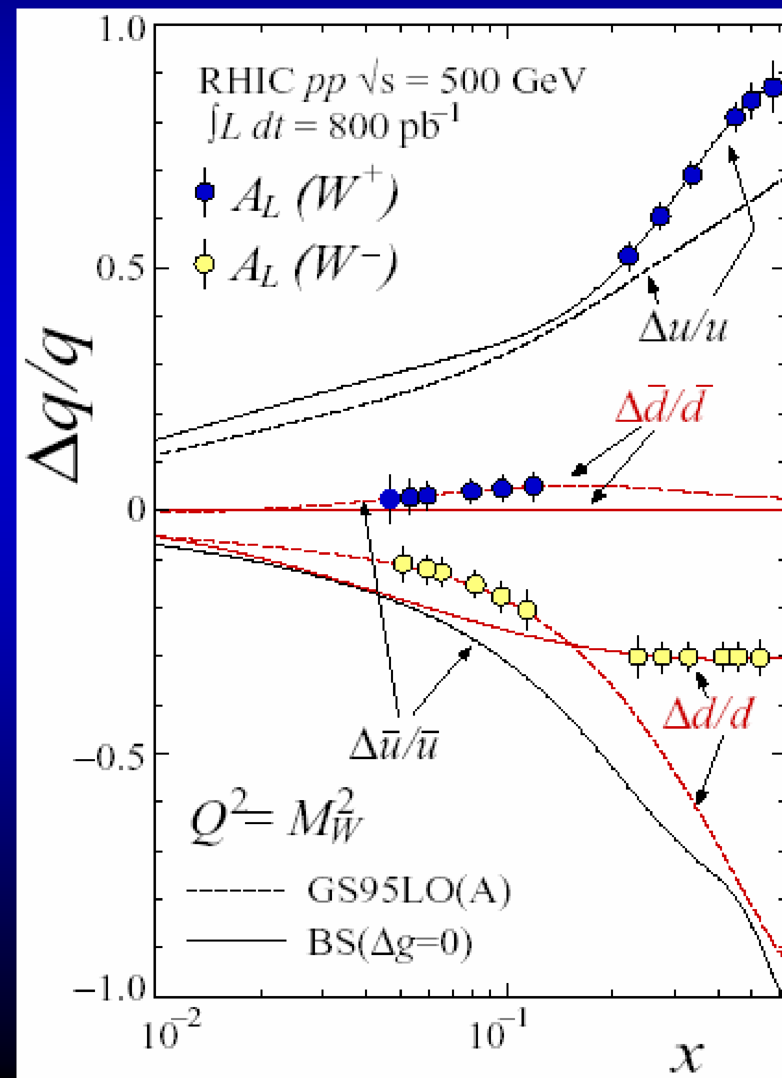
- Run-3 Preliminary result based on
  - <P> = 27%
  - 0.35 pb^{-1} recorded
- For future projections:
- Run-4 (37 weeks only)
  - <P> = 40%
  - 0.5 pb^{-1} recorded
  - Factor 2.8 improvement in statistical error
- Run-5 (27 weeks scenario)
  - <P> = 50%
  - 1.2 pb^{-1} recorded
  - Factor 6.8 improvement in statistical error



Long-Term Spin Prospects

- Given sufficient time/resources/successes to increase
  - Luminosity
  - Polarization
  - Absolute polarimetry
  - Energy
- Outstanding





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What Will It Take?

- A dedicated program of machine development
- A commitment to increase RHIC running time

Run	# of weeks	P_B	$\sqrt{s}$ (GeV)	$\int \mathcal{L}dt$ (pb^{-1})	physics	remarks
Run-1	(3)	-	-	-	One ring commissioned	
Run-2	(5)+3	0.15	200	0.15	$\sigma(\pi^0, J/\psi)$; $\mathcal{A}_N(\pi)$	
Run-3	(3)+5	0.27	200	0.35	First $\mathcal{A}_{LL}(\pi^0)$	
Run-4	(5)+0	0.50	200	-	Machine/PHENIX development towards high $\mathcal{L}$ and P_B	new AGS warm snake
Run-5	5-10	0.50	200	3-10	$\Delta g/g$ with $\mathcal{A}_{LL}(\pi^0)$	new AGS cold snake
Run-6/7	19	0.70	200	158	$\Delta g/g$ with $\mathcal{A}_{LL}(\gamma, \gamma + jet, c/b, J/\psi)$	Si-VTX detector
Run-8/9	19-29	0.70	500	540-966	$\Delta g/g$ with $\mathcal{A}_{LL}(\gamma)$ and $\Delta\bar{q}/\bar{q}$ with $\mathcal{A}_L(W^{\pm})$	W-trigger

Table 2.6: Summary of the PHENIX Spin goals for the upcoming several years. For the "# of weeks", the number in parenthesis shows the beam weeks required for commissioning. All future physics topics presented in the table involve longitudinal polarization; there is ongoing discussion regarding transverse polarization.

☞ ***A decade of only 27 weeks per year severely jeopardizes the spin program (the entire program)***

Heavy Ion Physics

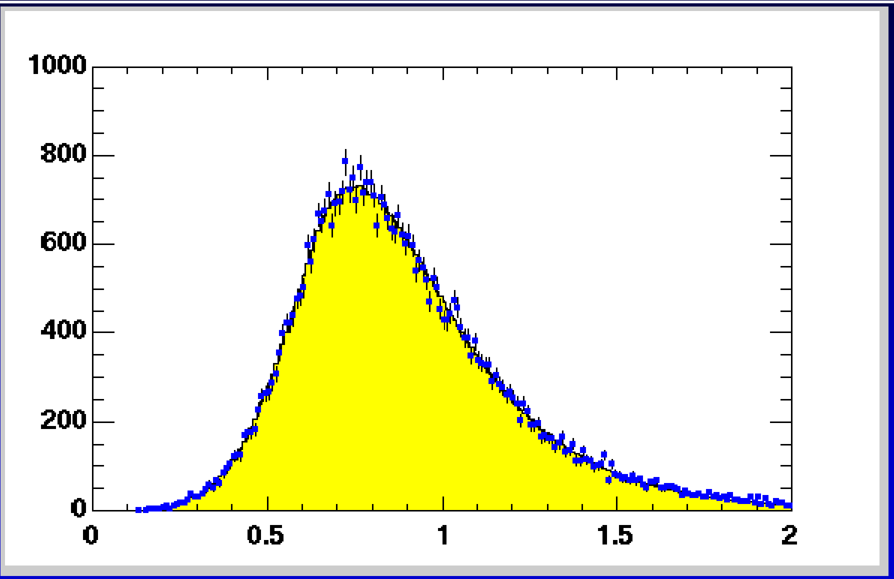
- Executive Summary: "Definitive measurements that will establish the nature of the matter created in nucleus+nucleus collisions, that will determine if the description of such matter as a quark-gluon plasma is appropriate, and that will quantify both the equilibrium and non-equilibrium features of the produced medium."
- *This remains a very challenging task*
- Will require measurement of
  - Particle production at high transverse momentum, studied via single particle inclusive measurements of identified charged and neutral hadrons, multi-particle correlations and jet production.
  - Direct photon, photon+jet and virtual photon production.
  - Light and heavy vector mesons.
  - Heavy flavor production.
- Dominated by rare probes
  - ➡ *This program (too) is luminosity limited*
  - ➡ *This program (too) is compromised by 27 weeks/ year*

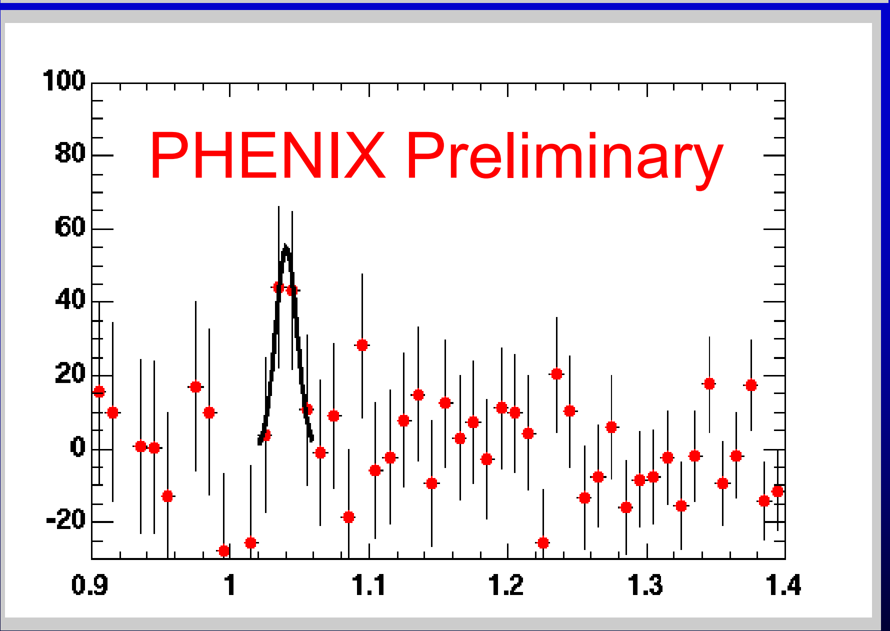
PHENIX Run-4 Luminosity ($\phi \rightarrow e^+e^-$)

- A quest to develop *highest possible integrated luminosity* in full energy Au+Au running
  - To eliminate statistical ambiguity in many production channels
  - Example: $\Phi \rightarrow e^+e^-$
    - Run-2

$$\text{Signal} = 101 \pm 47\,(\text{stat})^{+56}_{-20}\,(\text{sys})$$

    - Run-4
      - x10-15 yield
      - Improved S/B





Run-4 Luminosity (Direct Photons)

- A quest to develop *highest possible integrated luminosity* in full energy Au+Au running
  - To eliminate statistical ambiguity in many production channels
  - Example: Direct photons
    - Run-2
      - Statistics limited at ~4 GeV/c
    - Run-4
      - Extend this to ~10 GeV/c

HIGH-ENERGY PHOTONS FROM PASSAGE OF JETS THROUGH QUARK GLUON PLASMA.

by R. J. Fries, B. Muller and D. K. Srivastava, Phys.Rev.Lett.90:132301,2003

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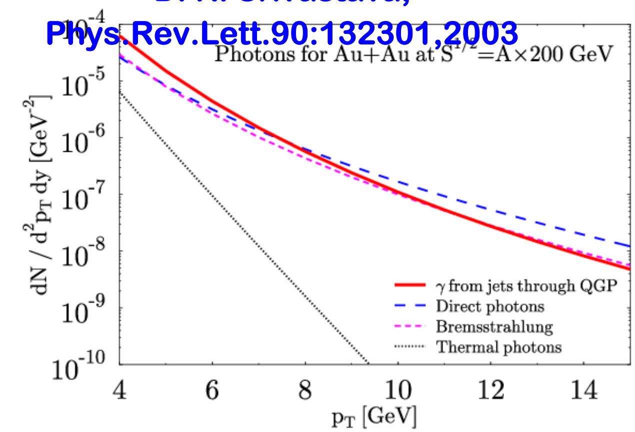
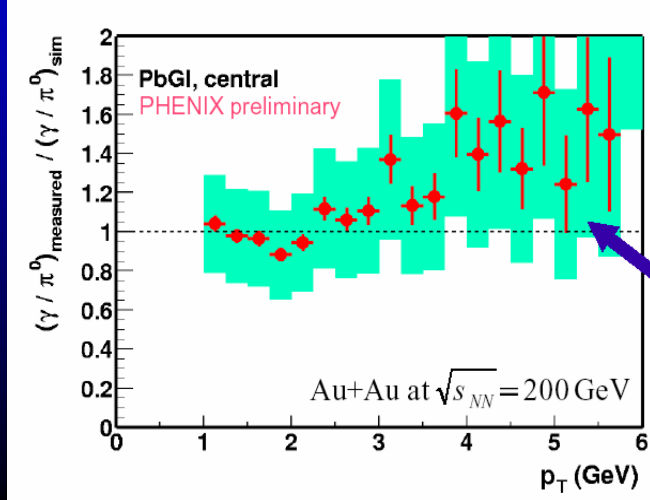
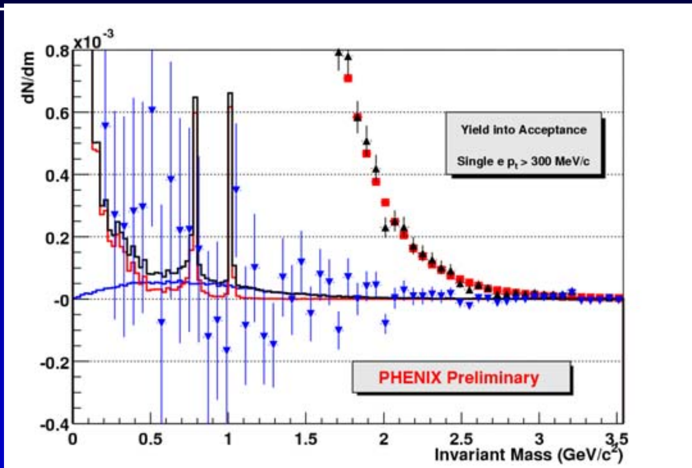


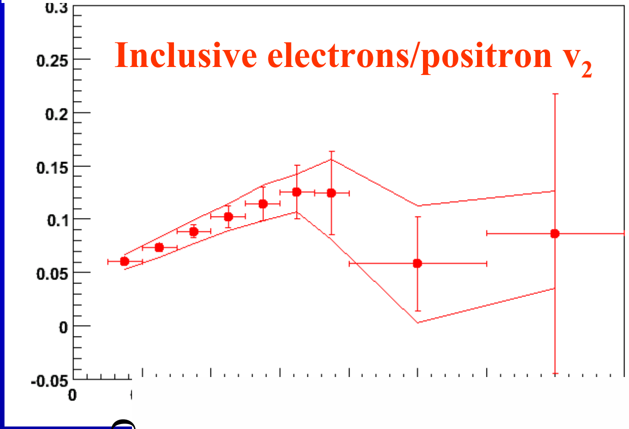
FIG. 1: Spectrum $dN/d^2p_\perp dy$ of photons at $y = 0$ for central collision of gold nuclei at $\sqrt{S_{NN}} = 200$ GeV at RHIC. We show the photons from jets interacting with the medium (solid line), direct hard photons (long dashed), bremsstrahlung photons (short dashed) and thermal photons (dotted).

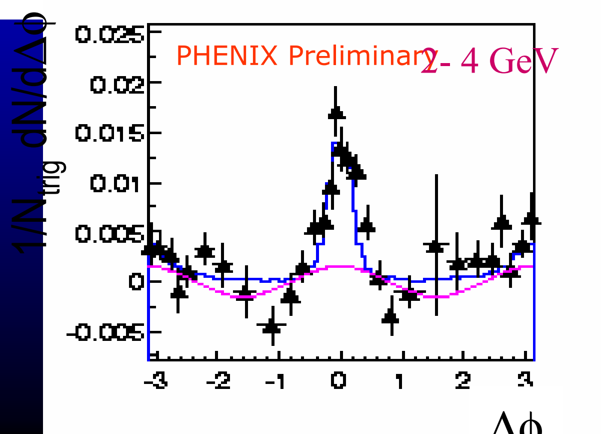


Run-4 Luminosity (Other Examples)

- A quest to develop *highest possible integrated luminosity* in full energy Au+Au running
  - To eliminate statistical ambiguity in many production channels
  - Other examples:
    - Low-mass pairs
    - Charm flow
    - "Jet" correlations







Run-4 Luminosity (J/Ψ)

- A quest to develop *highest possible integrated luminosity* in full energy Au+Au running
  - To eliminate statistical ambiguity in many production channels
  - Example: J/Ψ production
    - 27 week scenario:
      - 2.6σ (e^+e^-)
      - 3.2σ ($\mu^+\mu^-$)
    - (in 0-20% centrality bin)

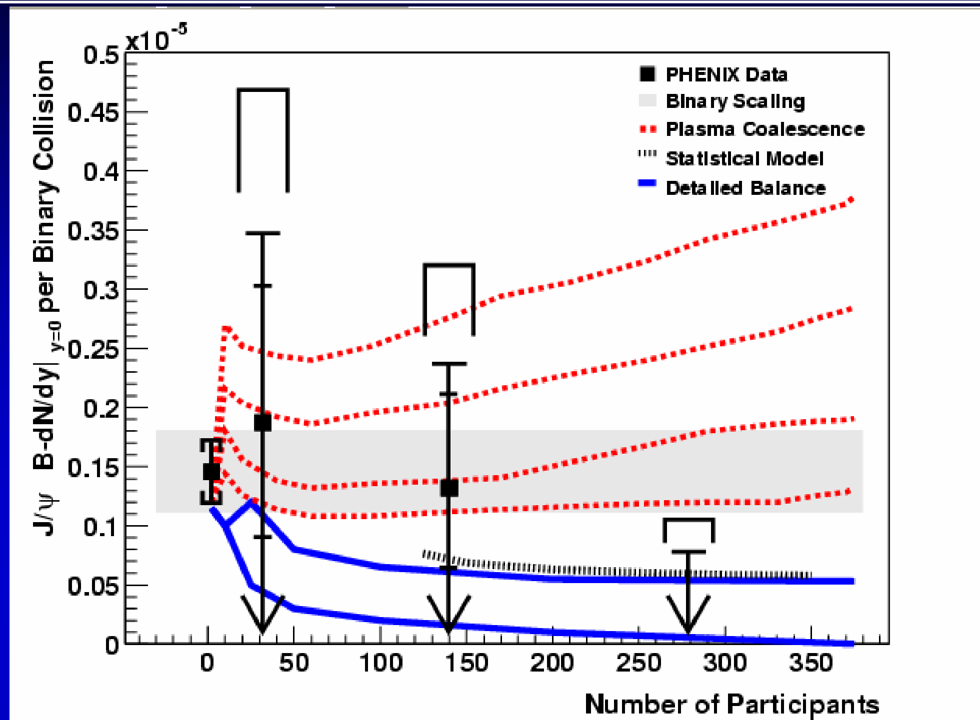


FIG. 6: (Color online) The J/ψ invariant yield per binary collision is shown from proton-proton reactions and three exclusive centrality ranges of Au-Au reactions all at $\sqrt{s_{NN}}$ = 200 GeV. The lowest curve is a calculation including "normal" nuclear absorption in addition to substantial absorption in a high temperature quark-gluon plasma [16]. The curve above this is including backward reactions that recreate J/ψ. The statistical model [17] result is shown as a dotted curve for mid-central to central collisions just above that. The four highest dashed curves are from the plasma coalescence model [15] for a temperature parameter of T = 400 MeV and charm rapidity widths of Δy = 1.0, 2.0, 3.0, 4.0, from the highest to the lowest curve respectively.

Run-4 Luminosity

- The PHENIX Beam Use Proposal anticipates ~120 μb^{-1} (recorded)
- A primary goal of this effort is a definitive measurement of J/Ψ yields
- Recognized by PAC:
  - "The highest priority for heavy ions is a substantial running period of Au+Au at the highest RHIC energy of 200 A-GeV. It is important to integrate sufficient luminosity to open up the channel of heavy quarkonia studies for experimental and theoretical investigation. Measurements of the quarkonium channels are needed to characterize the system created and to complete our baseline program of exploring novel features of dense QCD matter such as the quark-gluon plasma. In addition, high quality measurements of low cross section processes will provide crucial constraints on the nature of the dense medium created.
- The 120 μb^{-1} is *a very significant reduction* from our long-standing request for 300 μb^{-1} .
  Driven by
  - (In part) revised C-A D guidance
  - (In part) desire to include 5 weeks of critically needed beam development for spin
- This too has been recognized by the PAC:
  - "We recommend that a benchmark of 300 inverse microbarns delivered luminosity be set for the Au-Au running period. We urge the laboratory to be flexible in time allocation so that a significant J/Psi signal in central Au+Au collisions is observed."

Hard Processes

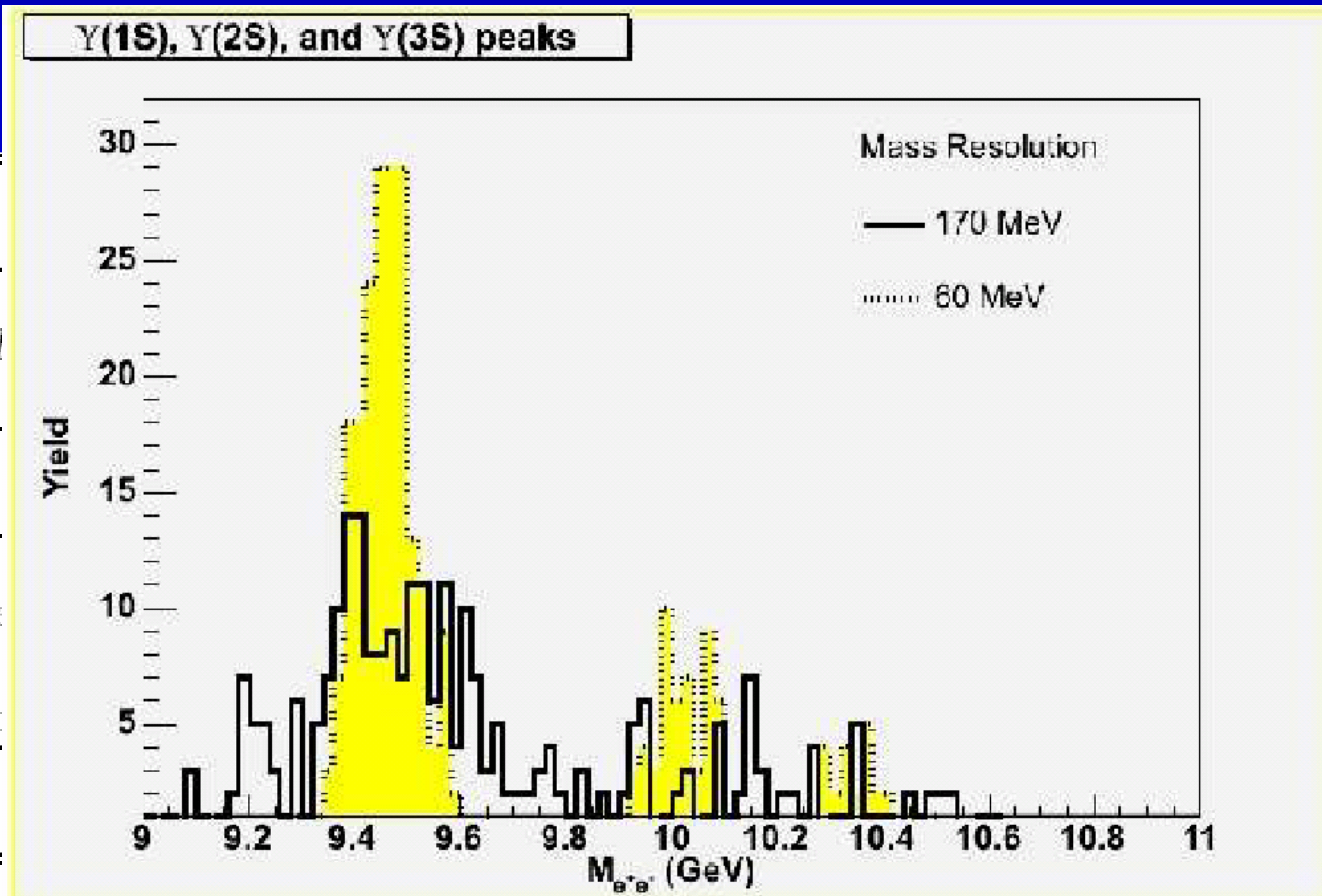
- **Definitive measurements require integrated luminosities well in excess of our Run-4 projections**
- **Of course would like measurements with similar p_T or x_T reach in lighter systems, lower energy**

Topic	Signals	p_T (GeV/c)	$\sim$ Lum (μb^{-1})
hadron suppression	single π^0 (energy loss, flow, pQCD recovered)	17	300
modification of known E_{jet} (energy loss)	γ - charged/neutral correlations	7 GeV γ 7 GeV γ 10 GeV γ	300 300 1000
jet modification	charged-charged and neutral-charged	> 5 GeV leading hadron	300
(back-to-back jets)	2 hadron correlations	> 7 GeV leading hadron	3000
in-medium fragmentation function	identified hadron correlations	3-4 GeV leading hadron + 2-3 GeV partner	300
	$\geq$ 2 particles detected	> 4 GeV leading hadron (requires aerogel)	> 300

Heavy Flavor

- Definitive measurements require integrated luminosities in excess of our Run-4 projections
- Of course would like measurements with similar p_T or x_T reach in lighter systems, lower energy

Topic
open charm (energy loss, $\sigma(c\bar{c})$, fl
open beauty (energy loss, $\sigma(b\bar{b})$)
Prompt charmonium (suppression, coalesc
Charmonium backgr
Bottomonium



PHENIX

Upgrades

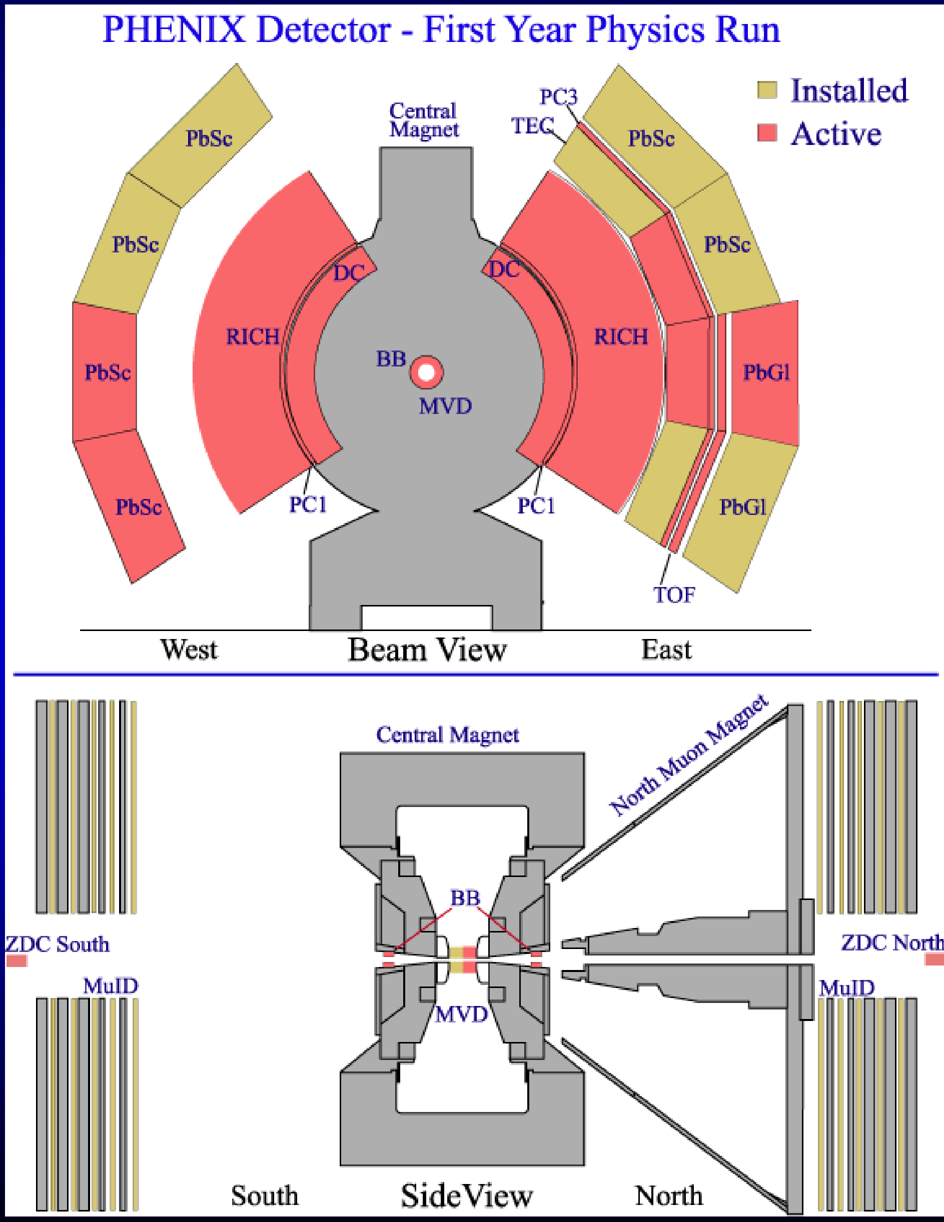
- **Executive Summary: "A portion of this program is achievable using the present capabilities of PHENIX experimental apparatus, but the physics reach is considerably extended and the program made even more compelling by a proposed set of upgrades which include"**
  - An aerogel and time-of-flight system to provide complete π/K/p separation for momenta up to 10~GeV/c. (First portion installed, ready for Run-4)
  - A vertex detector to detect displaced vertices from the decay of mesons containing charm or bottom quarks. (Proposal submitted to DOE)
  - A hadron-blind detector to detect and track electrons near the vertex. (Active R&D program)
  - A micro-TPC to extend the range of PHENIX tracking in azimuth and pseudo-rapidity. (Active R&D program)
  - A muon trigger upgrade to preserve sensitivity at the highest projected RHIC luminosities. (Proposal to NSF)
  - A forward calorimeter to provide photon+jet studies over a wide kinematic range. (Proposal to NSF)

Building on Success

- Upgrades to existing apparatus are a key component of our Decadal Plan
- The PHENIX Upgrades strategy
  - Leverages > $100M investment in PHENIX
  - Takes advantage of already extensive PHENIX experience with
    - Significant year-by-year upgrades
    - High speed DAQ
      - Runs (1, 2, 3, 4): (20, 40, 80, 160) MB/s
      - Front End:
        - Sub-system electronics, Data Collection Modules designed for x10 Au+Au "Blue Book" luminosity
      - Back end:
        - Event Builder, Level-2 (+3?) trigger system commodity based, "upgradeable" via Moore's law
    - Physics-sensitive parallel triggers

Run-1 Configuration

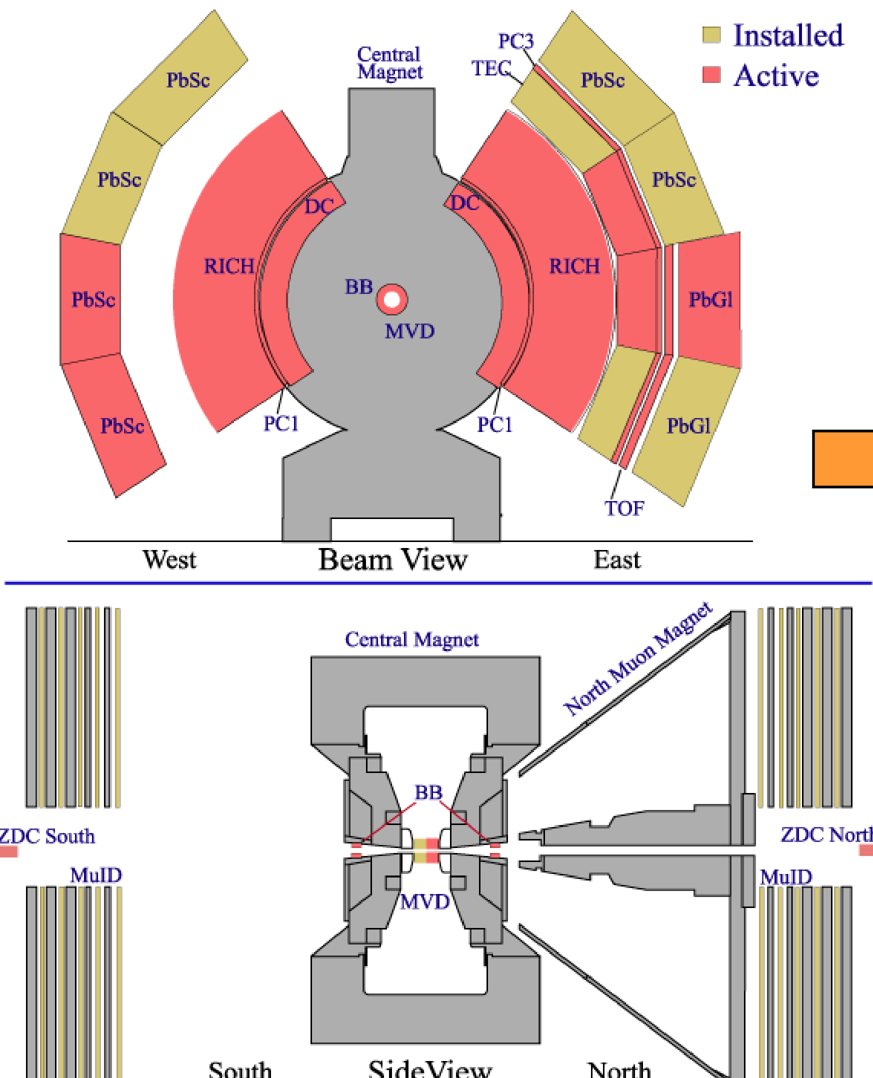
- Two central arms
  - Mechanically ~complete
  - Roughly half of aperture instrumented ■
- Global detectors
  - Zero-degree Calorimeters (ZDCs)
  - Beam-Beam Counters (BBCs)
  - Multiplicity and Vertex Detector (MVD, engineering run)



From Run-1 to Run-2

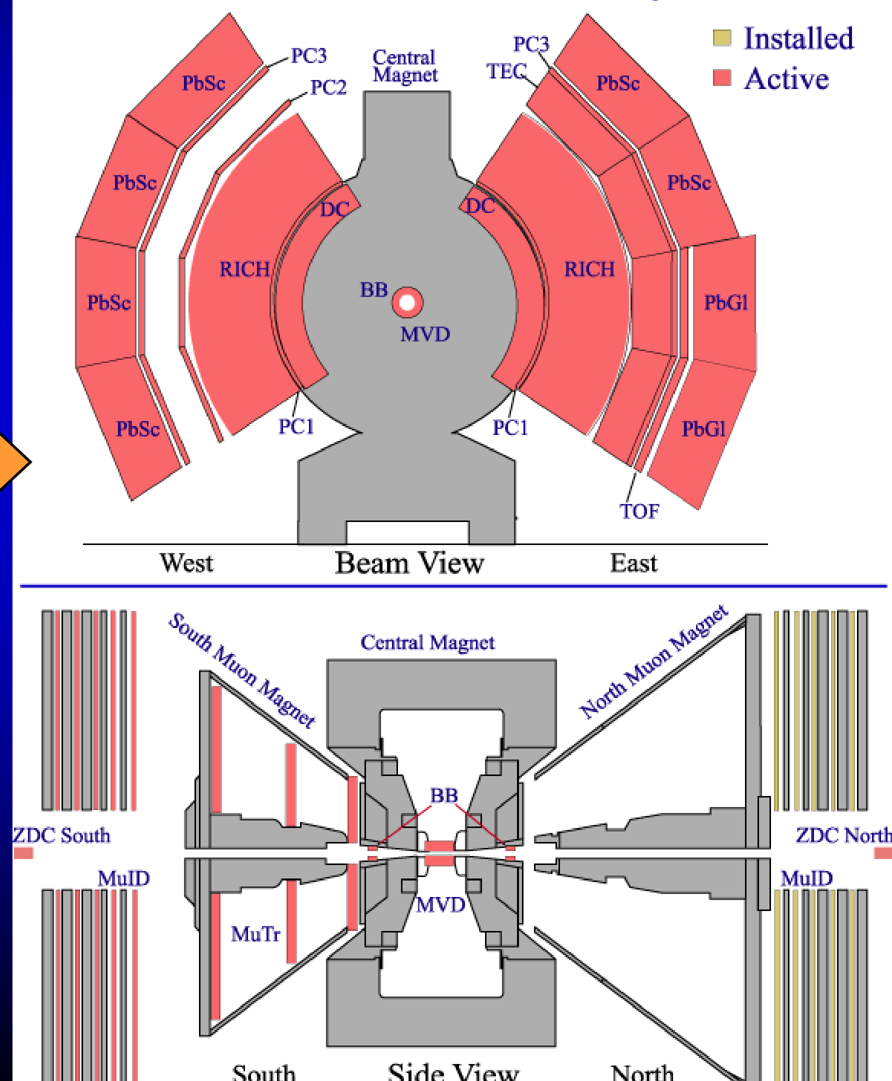
Run-1 (2000)

PHENIX Detector - First Year Physics Run

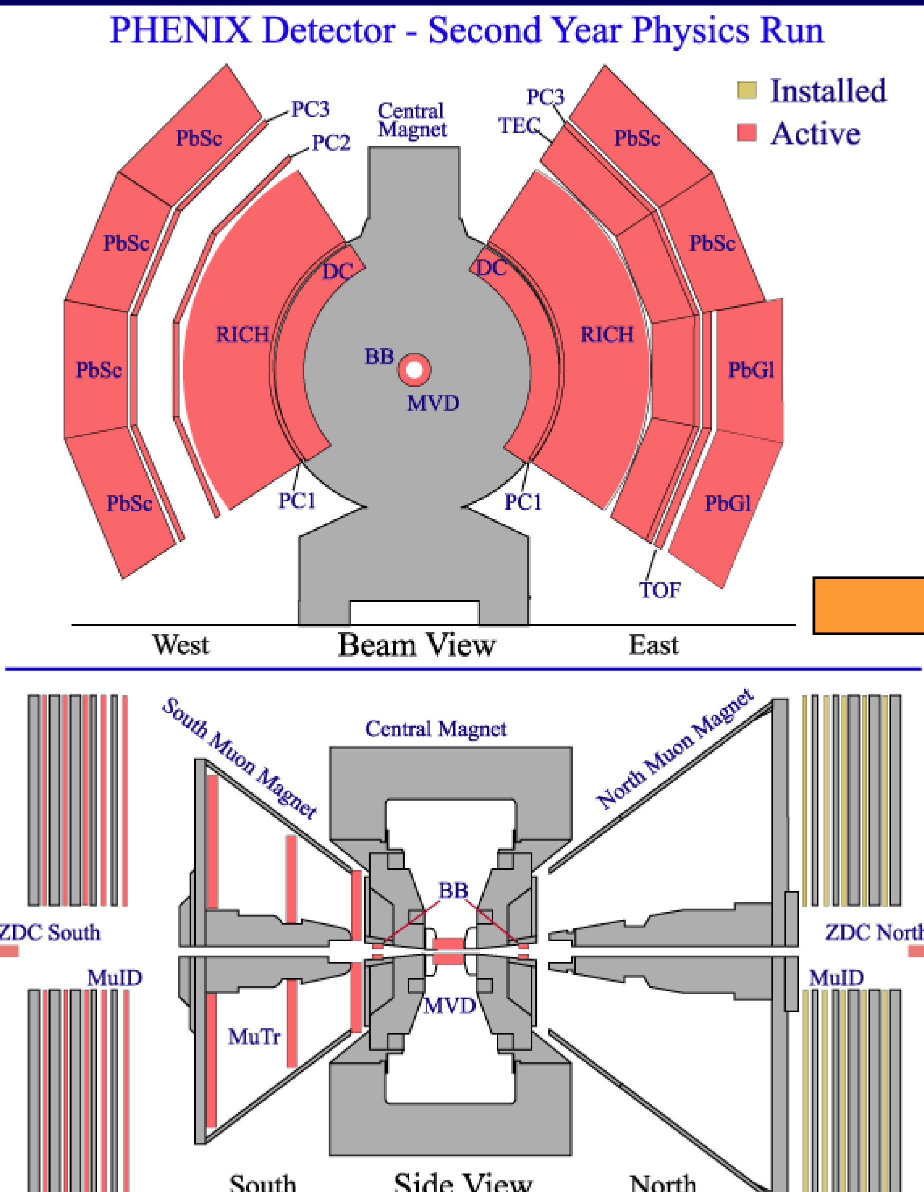


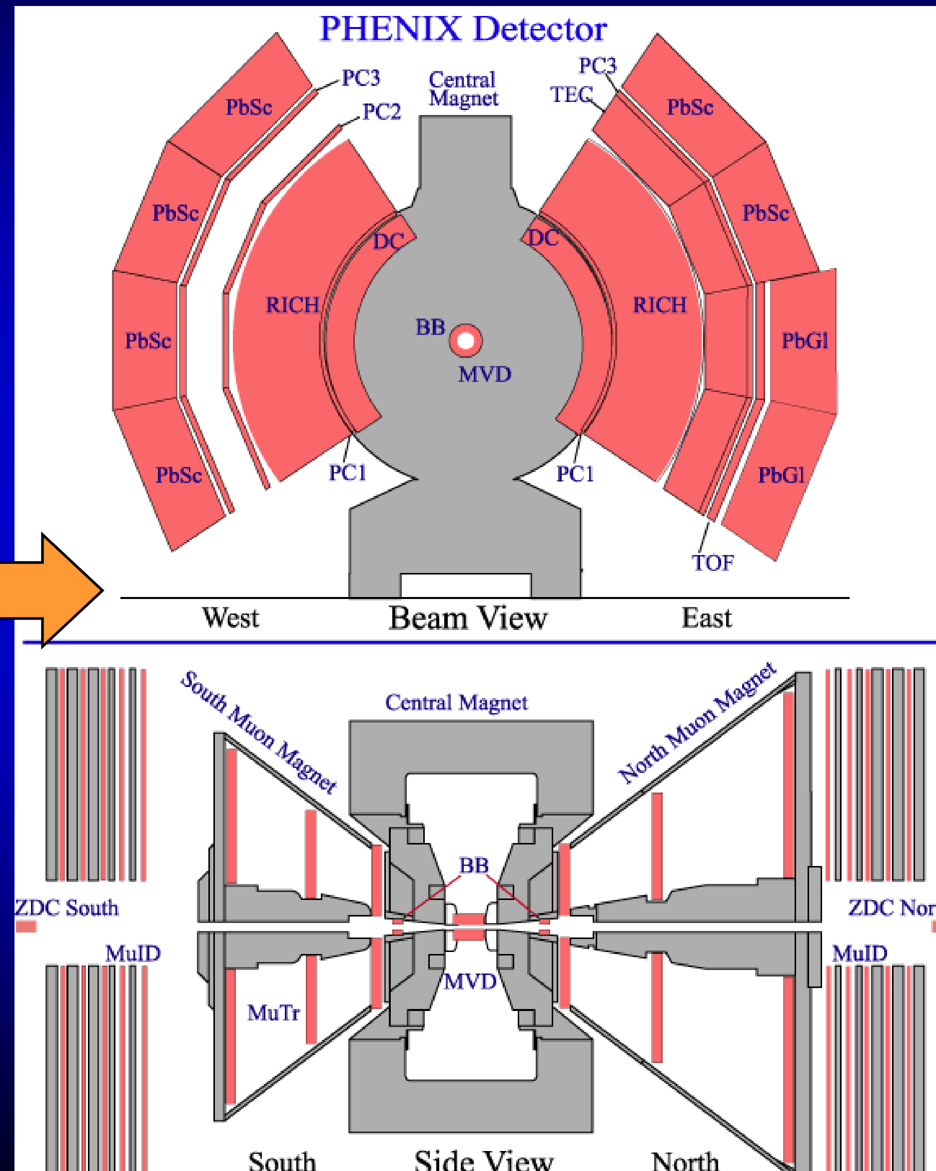
Run-2 (2001-2)

PHENIX Detector - Second Year Physics Run



Run-3 and Beyond





Run-3: Design Configuration!

Central Arm Tracking
- Drift Chamber
- Pad Chambers
- Time Expansion Chamber

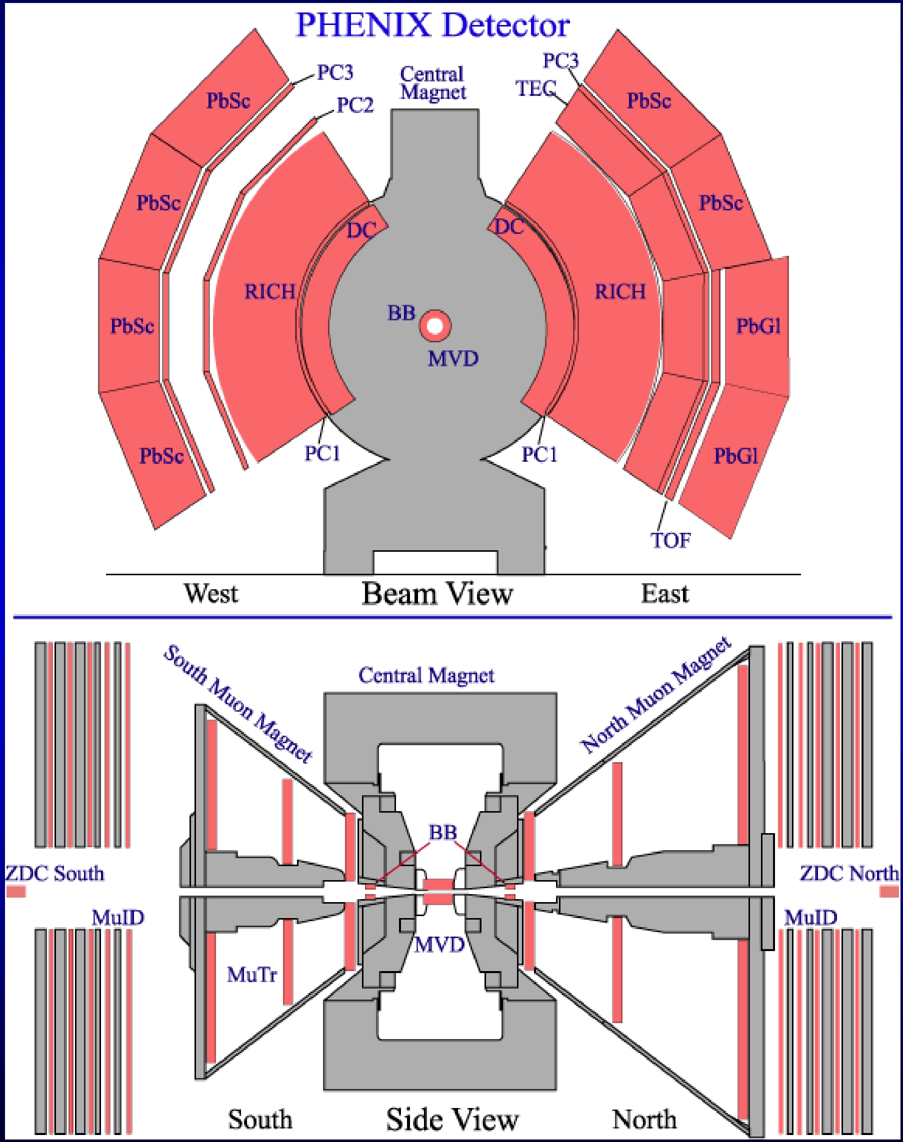
Muon Arm Tracking
- Muon Tracker: North Muon Tracker

Calorimetry
- PbGl
- PbSc

Particle Id
- Muon Identifier: North Muon Identifier
- RICH
- TOF
- TEC

Global Detectors
- BBC
- ZDC/SMD Local Polarimeter
- Forward Hadron Calorimeters
- NTC
- MVD

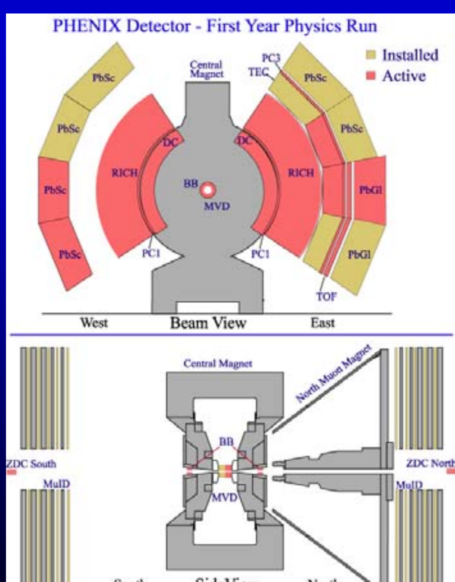
Online Calibration and Production



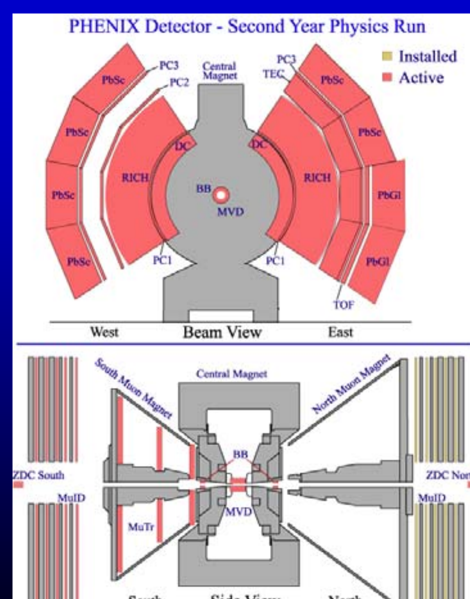
Run-1 to Run-3 Capsule History

Run	Year	Species	$s^{1/2}$ [GeV]	∫Ldt	N_{tot}	p-p Equivalent	Data Size
01	2000	Au-Au	130	1 μb^{-1}	10M	0.04 pb^{-1}	3 TB
02	2001/2002	Au-Au	200	24 μb^{-1}	170M	1.0 pb^{-1}	10 TB
		p-p	200	0.15 pb^{-1}	3.7G	0.15 pb^{-1}	20 TB
03	2002/2003	d-Au	200	2.74 nb^{-1}	5.5G	1.1 pb^{-1}	46 TB
		p-p	200	0.35 pb^{-1}	6.6G	0.35 pb^{-1}	35 TB

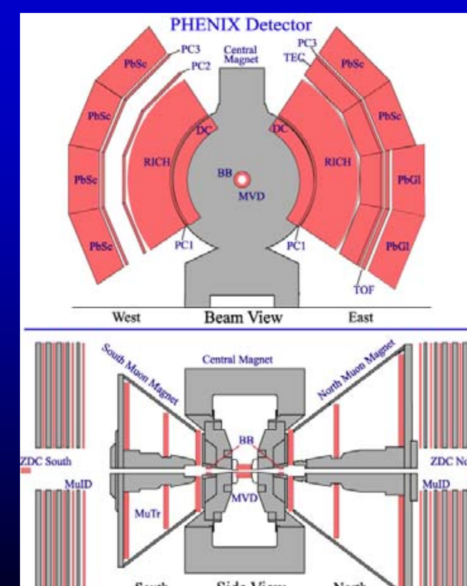
Run-1



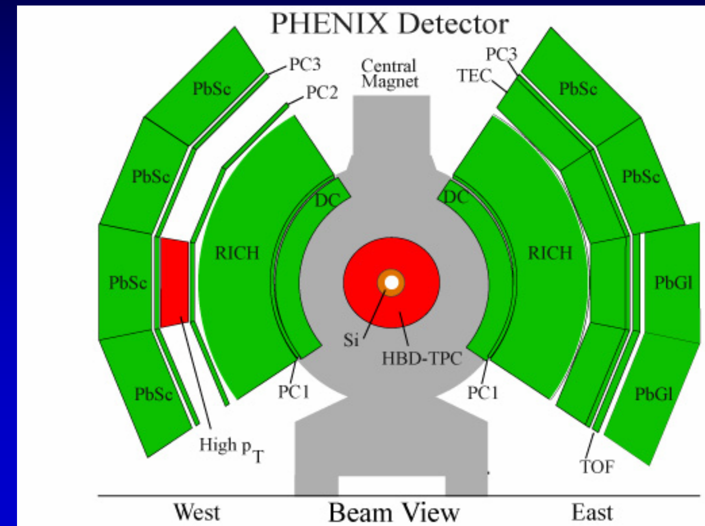
Run-2

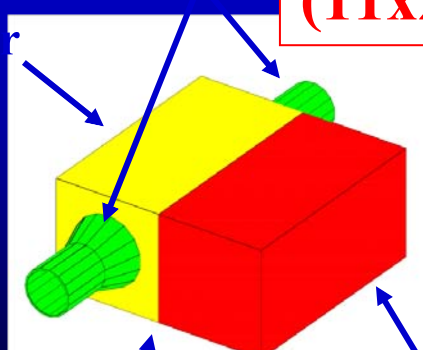


Run-3



Run-4 Additions



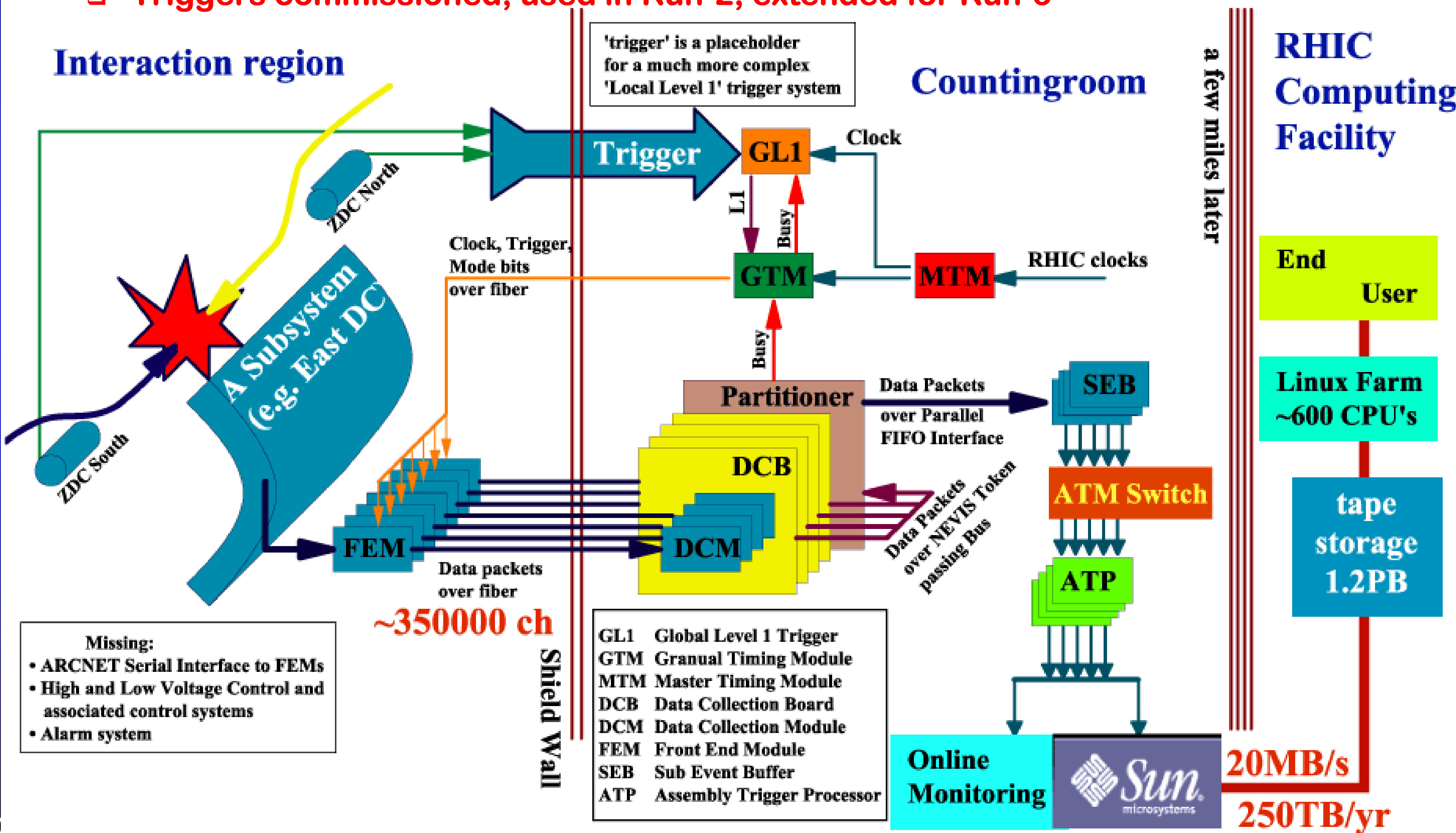


- The Aerogel detector is a threshold Cerenkov counter
- Aerogel is a very low density, SiO_2 – based solid
- Aerogel has index of refr. between gases & liquids.
- Ident. charged particles in a range inaccessible with other technologies.

DAQ and Trigger

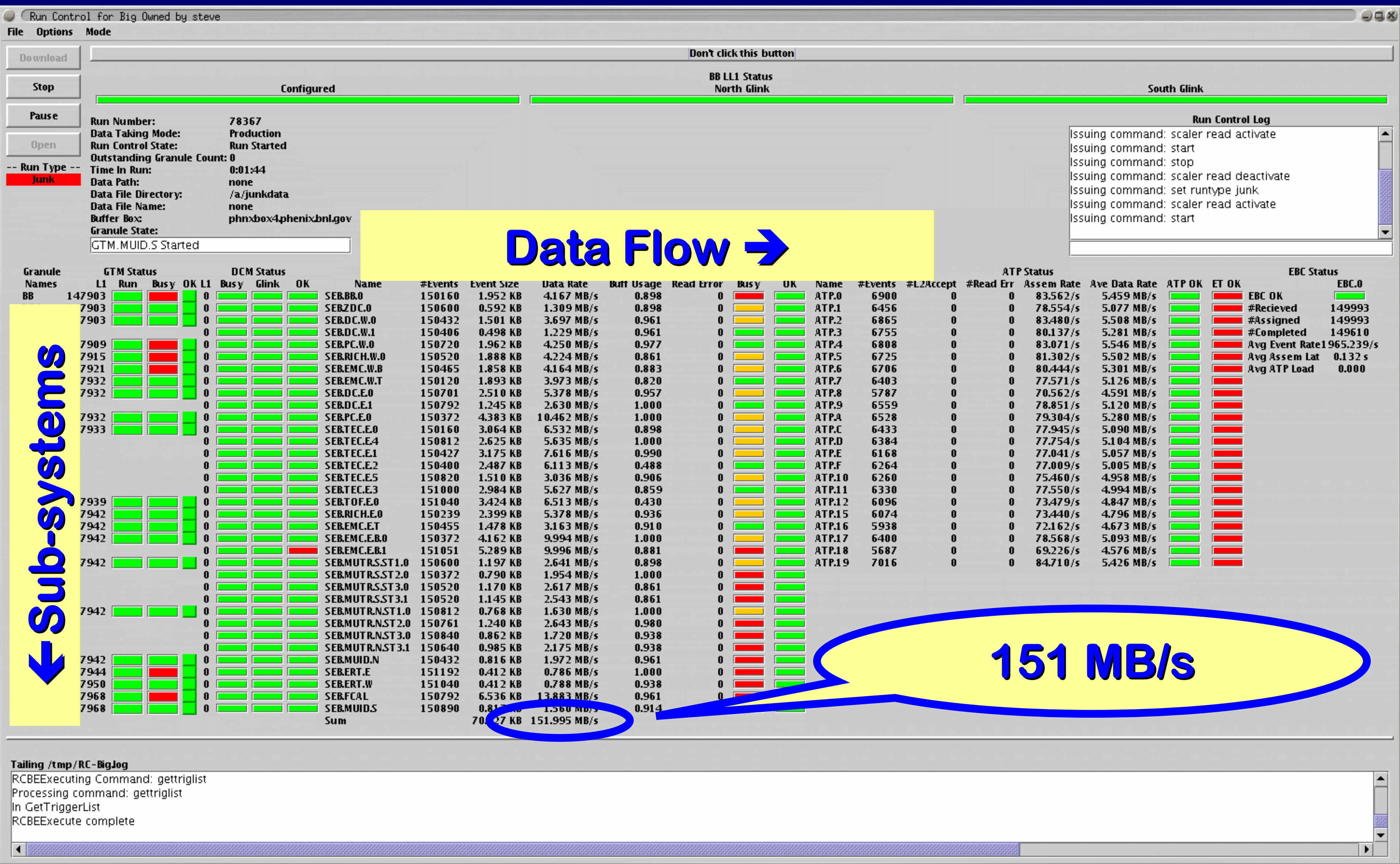
PHENIX has made a *major* effort to

- Design and build a system capable of extracting all physics at ≥ design luminosity
- Triggers commissioned, used in Run-2, extended for Run-3



(Existing) PHENIX DAQ

- A high BW system that smoothly accommodates additional sub-systems



(Existing) PHENIX Triggers

- Extensive experience with running (and using) many parallel triggers to
  - Preserve bandwidth
  - Access rare signals (e.g., high p_T photons, electrons)

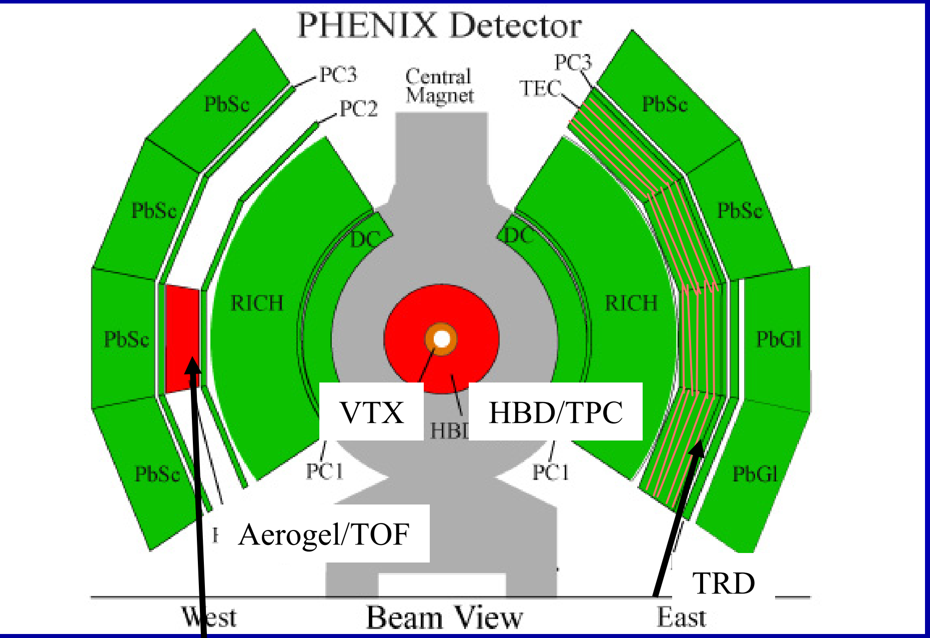
Detached Panel

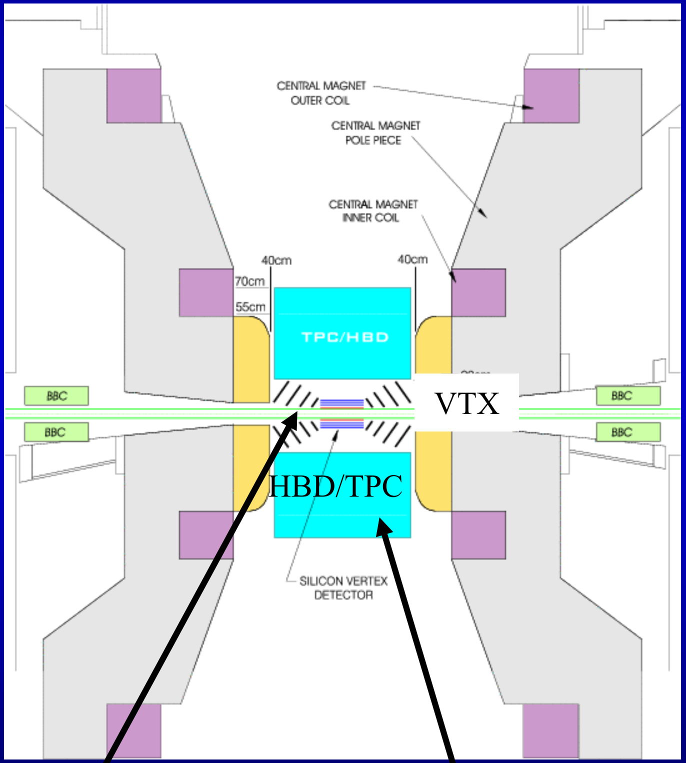
Scaler Monitor

Trig	Status	Raw	Live	Scaled	Raw Rate	Live Rate	Scaled Rate	Live Time	Live Time (RA)	Raw/Ref	Live/Ref	Scaled/Ref
Clock	Enabled	-868843911	-1424211516	6820	9.383 MHz	7.899 MHz	18.786 Hz	1.639	0.842	1.0000	1.0000	1.0000
BBCLL1>=1	Enabled	5420766	4544244	44992	14.669 KHz	12.362 KHz	122.396 Hz	0.838	0.843	0.0016	0.0016	6.5152
ZDCNS	Enabled	3553046	2978694	5945	9.621 KHz	8.098 KHz	16.150 Hz	0.838	0.842	0.0010	0.0010	0.8597
ERT_2x2	Disabled	3730471	0	0	10.109 KHz	0.000 Hz	0.000 Hz	0.000	0.000	0.0011	0.0000	0.0000
ERT_2x2&BBCLL1	Enabled	1374115	1155670	1	3.714 KHz	3.136 KHz	0.000 Hz	0.841	0.844	0.0004	0.0004	0.0000
MUIDLL1_S_Hor&MUIDS_1D	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--	0.0000	0.0000	0.0000
ERT_Gamma1&BBCLL1	Enabled	31272	26283	26283	86.577 Hz	73.031 Hz	73.031 Hz	0.840	0.844	0.0000	0.0000	3.8875
ERT_Gamma2	Enabled	11494	9632	9632	31.656 Hz	27.465 Hz	27.465 Hz	0.838	0.867	0.0000	0.0000	1.4620
ERT_Gamma2&BBCLL1	Enabled	9098	7622	7622	25.580 Hz	22.227 Hz	22.227 Hz	0.838	0.866	0.0000	0.0000	1.1832
MUIDLL1_S_Horizontal	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--	0.0000	0.0000	0.0000
ERT_Electron&BBCLL1	Enabled	97065	81802	81802	251.030 Hz	210.536 Hz	210.536 Hz	0.843	0.838	0.0000	0.0000	11.2070
MUIDLL1_S_Vertical	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--	0.0000	0.0000	0.0000
MUIDLL1_S_Vert&MUIDS_1D	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--	0.0000	0.0000	0.0000
ERT_Phi&BBCLL1	Enabled	402045	340575	6677	1.044 KHz	881.646 Hz	17.254 Hz	0.847	0.845	0.0001	0.0001	0.9184
ERT_Gamma3&BBCLL1	Enabled	136997	115617	11561	372.946 Hz	315.807 Hz	31.533 Hz	0.844	0.848	0.0000	0.0000	1.6785
MUIDS_1D	Disabled	2392654	0	0	6.591 KHz	0.000 Hz	0.000 Hz	0.000	0.000	0.0007	0.0000	0.0000
MUIDS_1D&BBCLL1	Enabled	140005	117087	10644	381.937 Hz	321.240 Hz	29.249 Hz	0.836	0.840	0.0000	0.0000	1.5570
MUIDS_1D1S*BBCLL1	Enabled	91982	76758	76758	249.172 Hz	209.587 Hz	209.587 Hz	0.834	0.840	0.0000	0.0000	11.1565
MUIDN_1D	Disabled	2056883	0	0	5.612 KHz	0.000 Hz	0.000 Hz	0.000	0.000	0.0006	0.0000	0.0000
MUIDN_1D&BBCLL1	Enabled	43034	36047	12015	117.680 Hz	99.366 Hz	33.093 Hz	0.838	0.847	0.0000	0.0000	1.7616
BBCLL1_SyncErr	Disabled	221976	0	0	8.760 Hz	0.000 Hz	0.000 Hz	0.000	0.000	0.0000	0.0000	0.0000
MUIDN_1D1S*BBCLL1	Enabled	4032	3370	3370	10.662 Hz	9.418 Hz	9.418 Hz	0.836	0.879	0.0000	0.0000	0.5014
ZDCS|ZDCN	Enabled	21769707	18260976	6086	59.037 KHz	49.769 KHz	16.569 Hz	0.839	0.843	0.0063	0.0063	0.8820
MUIDLL1_S_Ver&Hor	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--	0.0000	0.0000	0.0000
NTCNSwide	Disabled	13418995	0	0	36.440 KHz	0.000 Hz	0.000 Hz	0.000	0.000	0.0039	0.0000	0.0000
PPG(Pedestal)	Enabled	364	292	292	1.017 Hz	0.923 Hz	0.923 Hz	0.802	0.905	0.0000	0.0000	0.0491
PPG(Test Pulse)	Enabled	363	312	312	0.973 Hz	0.791 Hz	0.791 Hz	0.860	0.850	0.0000	0.0000	0.0421
PPG(Laser)	Enabled	363	302	302	0.973 Hz	0.695 Hz	0.695 Hz	0.832	0.700	0.0000	0.0000	0.0370
BBCLL1>=1(noVertexCut)	Enabled	11680613	9789626	3263	31.702 KHz	26.711 KHz	8.932 Hz	0.838	0.843	0.0034	0.0034	0.4755

Central Arm Upgrades

- Enhanced Particle ID
  - ☑ TRD (east)
  - ❑ Aerogel/TOF (west)
- Vertex Spectrometer
  - ☑ flexible magnetic field
  - ❑ VTX: silicon barrel vertex tracker
  - ❑ HBD and/or TPC





charm/beauty:
TRD e/π above 5 GeV/c

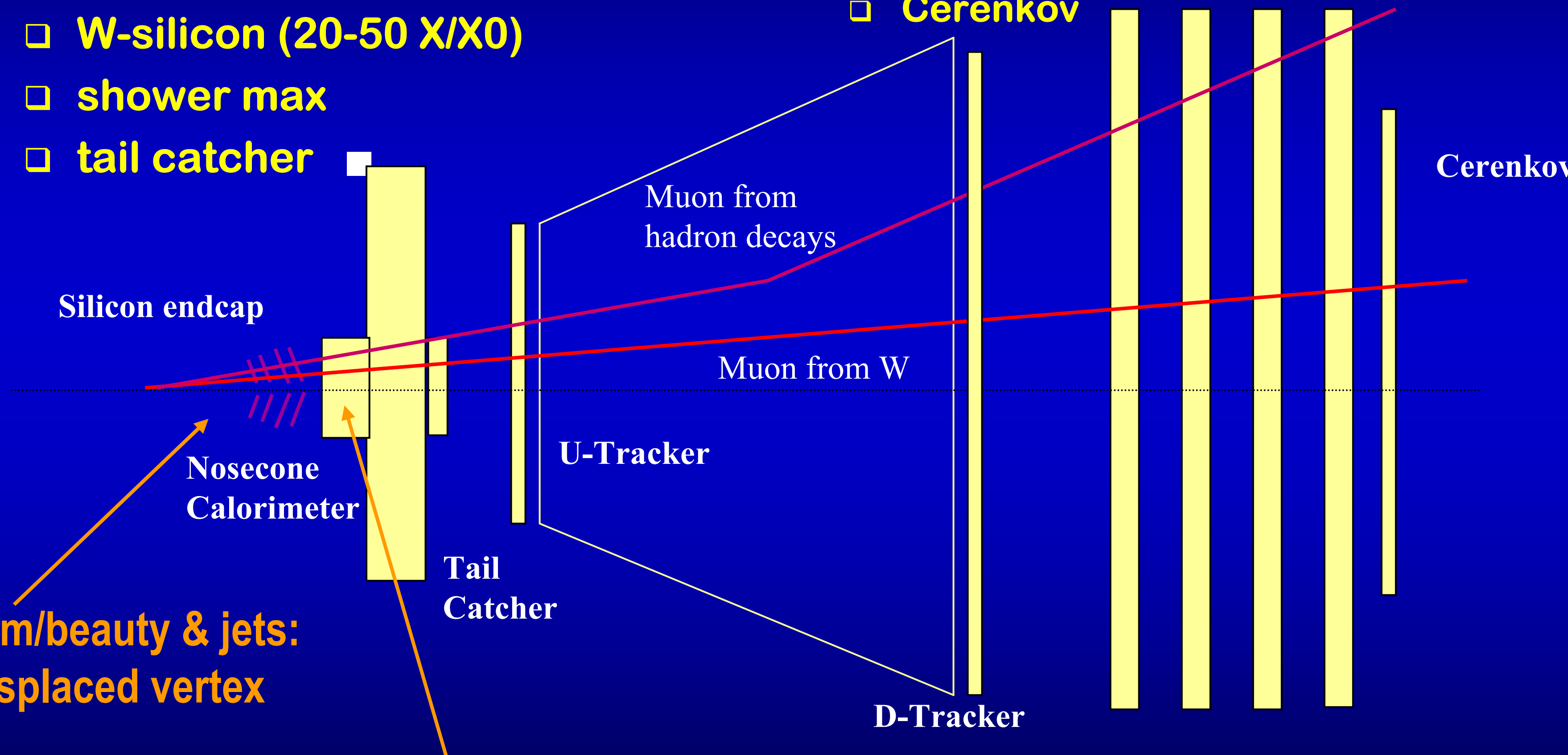
High p_T phenomena:
π, K, p separation to 10 GeV/c

charm/beauty:
displaced vertex

e+e- continuum:
Dalitz rejection

Forward Upgrade Components

- Endcap Vertex Tracker
  - silicon pixel detectors
- Nosecone EM Calorimeter
  - W-silicon (20-50 X/X0)
  - shower max
  - tail catcher
- Muon trigger
  - U-tracker (MuTr or new)
  - D-tracker (timing with RPC's?)
  - Cerenkov



charm/beauty & jets: displaced vertex

γ,γ-jet, W, π^0,η,χ_c: calorimeter

W and quarkonium: improved μ-trigger rejection

Upgrades Physics Summary

- Details in A. Drees talk tomorrow
- Note: This provides (first!) ~complete mapping of ρ ω φ J/Ψ Υ states

Importance of Luminosity and Detector Upgrades

RHIC II Au-Au luminosity increase 10x (lifetime) + 2-3x (bunch length)

Physics topic		Run-8 ($<1nb^{-1}$)	RHIC II ($>10nb^{-1}$)	
High p_T	inclusive π^0	$p_T < 20$ GeV	$p_T > 25$ GeV	
	γ-jet	$E_\gamma < 10$ GeV	$E_\gamma > 15$ GeV	TPC/ VTX
Lepton pairs	LMR	75000		HBD/TPC
	ρ,ω,φ	6000-8000 each	>50000 each	
Charmonium	J/ψ	4500	>50000	
	ψ'	900	>10000	
	Υ	-	>800	VTX/ TPC
Open heavy flavor	c → e	$1 < p_T < 6$ GeV		
	b → e	$1 < p_T < 6$ GeV	$p_T > 6$ GeV	VTX
	D → πk	$p_T < 4$ GeV	$p_T > 6$ GeV	
μ-arms	J/ ψ (ψ')	20000 (5000)	>200000 (50000)	
	χ	~20000	>200000	NEMC
	Υ	250	>2500	μ-trigger
	B → J/ ψ → μμ	2000	>20000	fVTX

critical for measurement | desirable for precision measurement

(Draft) NSAC Performance Guidelines

- The PHENIX Decadal Plan addresses issues in
  - **"Physics of High Temperature and High Density Hadronic Matter"**
  - **"Hadronic Physics"**

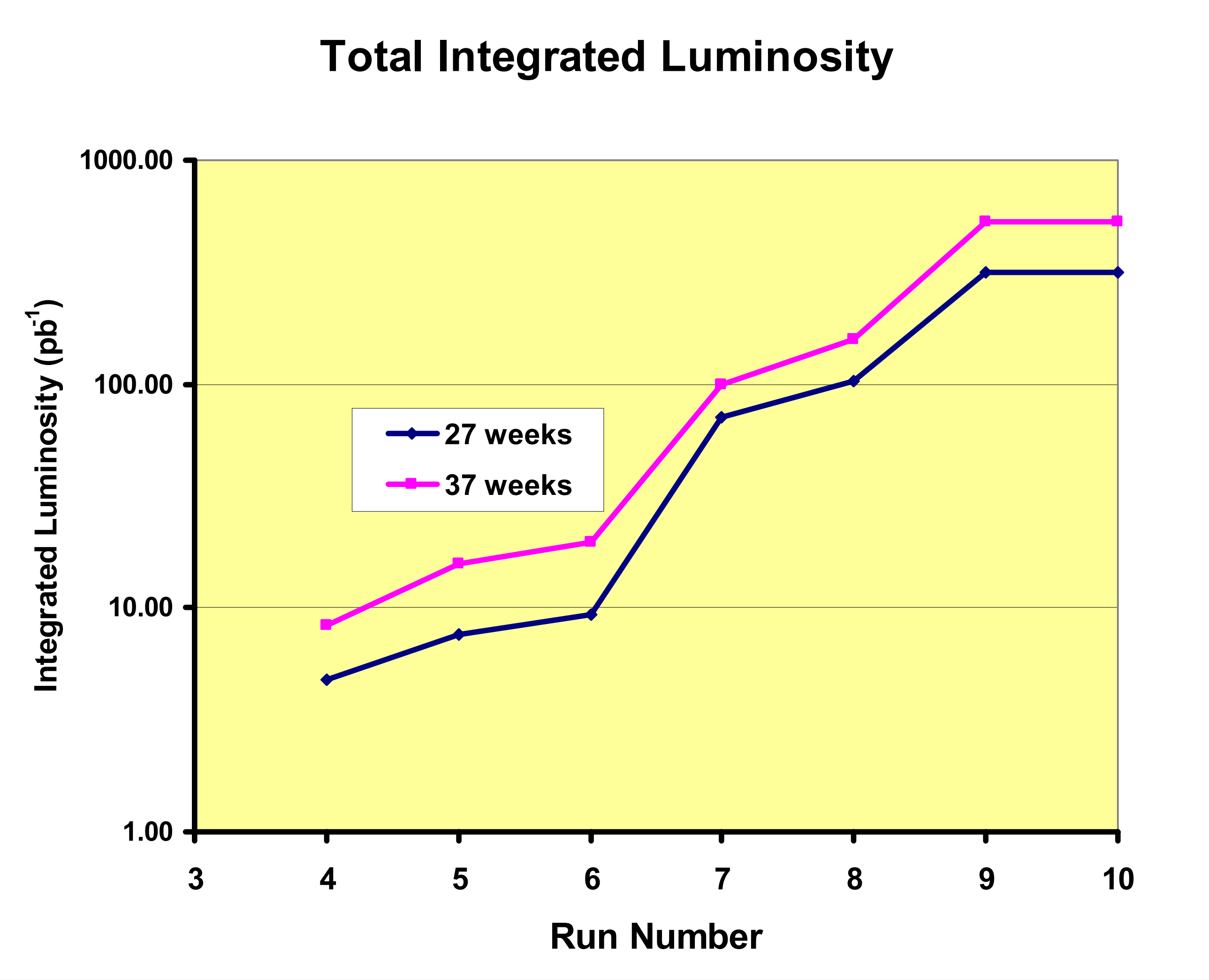
Year	**Milestones:**
2005 ✓	Measure J/ψ production in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.
2005 ☆	Measure flow and spectra of multiply-strange baryons in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.
2007 ✓	Measure high transverse momentum jet systematics vs. $\sqrt{s_{NN}}$ up to 200 GeV and vs. system size up to Au + Au.
2009 NA	Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC
2010 ✓	Measure the energy and system size dependence of J/ψ production over the range of ions and energies available at RHIC.
2010 ✓	Measure e^+e^- production in the mass range 500 ≤ m_{e+e-} ≤ 1000 MeV/c^2 in $\sqrt{s_{NN}}$= 200 GeV collisions.
2010 NA	Complete realistic calculations of jet production in a high density medium for comparison with experiment.
2012 ✓	Determine gluon densities at low x in cold nuclei via p + Au or d +Au collisions

This is an extraordinarily broad physics program that can be accomplished within the existing and upgraded PHENIX experiment

Year	**Milestones:**
2008 ✓	Make measurements of spin carried by the glue in the proton with polarized proton-proton collisions at center of mass energy, $\sqrt{s_{NN}}$ = 200 GeV.
2008 NA	Extract accurate information on generalized parton distributions for parton momentum fractions, x, of 0.1 - 0.4 , and squared momentum change, –t, less than 0.5 GeV^2 in measurements of deeply virtual Compton scattering.
2009 NA	Complete the combined analysis of available data on single π, η, and K photo-production of nucleon resonances and incorporate the analysis of two-pion final states into the coupled-channel analysis of resonances.
2010 NA	Determine the four electromagnetic form factors of the nucleons to a momentum-transfer squared, Q^2, of 3.5 GeV^2 and separate the electroweak form factors into contributions from the u, d and s-quarks for Q^2 < 1 GeV^2.
2010 NA	Characterize high-momentum components induced by correlations in the few-body nuclear wave functions via (e,e'N) and (e,e'NN) knock-out processes in nuclei and compare free proton and bound proton properties via measurement of polarization transfer in the $^4He(\vec{e},e'\vec{p})^3H$ reaction.
2011 NA	Measure the lowest moments of the unpolarized nucleon structure functions (both longitudinal and transverse) to 4 GeV^2 for the proton, and the neutron, and the deep inelastic scattering polarized structure functions $g_1(x, Q^2)$ and $g_2(x,Q^2)$ for x=0.2-0.6, and 1 < Q^2 < 5 GeV^2 for both protons and neutrons.
2012 NA	Measure the electromagnetic excitations of low-lying baryon states (<2 GeV) and their transition form factors over the range Q^2 = 0.1 – 7 GeV^2 and measure the electro- and photo-production of final states with one and two pseudoscalar mesons.
2013 ✓	Measure flavor-identified q and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
2014 NA	Perform lattice calculations in full QCD of nucleon form factors, low moments of nucleon structure functions and low moments of generalized parton distributions including flavor and spin dependence.
2014 NA	Carry out ab initio microscopic studies of the structure and dynamics of light nuclei based on two-nucleon and many-nucleon forces and lattice QCD calculations of hadron interaction mechanisms relevant to the origin of the nucleon-nucleon interaction.

The Benefits of the Original 37 weeks

- The C-A D guidance provide a quantitative model in which we can assess the severe impact of 37 → 27 weeks
- It's "only" a factor of 2??
- A factor of 2 is HUGE !
- *It's our challenge as a community to make this case as loudly and as strongly as possible!*



Summary

- PHENIX successes in Runs 1-3 have paralleled those of the accelerator
- Ongoing, productive enterprise engaged in timely publication of an extraordinarily broad spectrum of results (Au+Au, p+p, d+Au)
- Proposed program will extend
  - Investigation of rare processes to address fundamental questions in heavy ion physics
  - Demonstrated spin physics capabilities to higher p_T and to new channels
  - Existing d+Au results to much greater levels of sensitivity
- Proposed program depends critically on timely development of luminosity and polarization through extended periods of beam development and steady running
- Immense benefit from incremental cost of additional weeks of running time

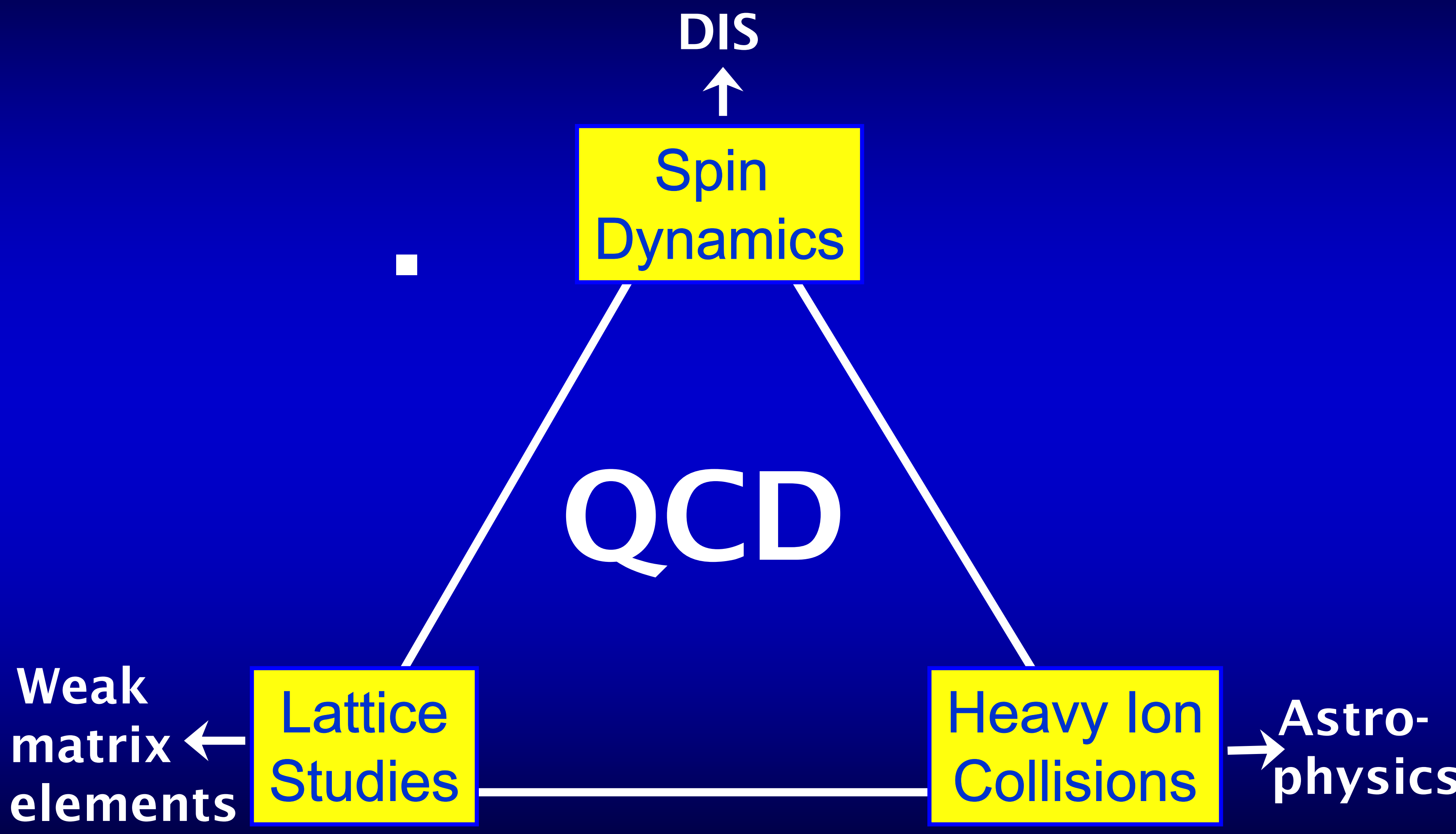
RHIC vs. "XXX"

- Those of us of "a certain age" still recall "parasitic running" at the
  - Bevalac
  - AGS
  - SPS
- As well as trying to do physics with
  - Inadequate p+p baseline data
  - Inadequate p+A comparison data
  - Minimal overlap between experiments
- RHIC's greatest strength is that it is a
  - dedicated facility with
  - strong overlaps between programs and experiments

☞ *This extraordinary strength will serve us well into the next decade*

PHENIX

RHIC/BNL/RBRC Physics



Backup Slides Follow

PHENIX The Run Plan At A Glance

- An quantitative, integrated, planning exercise:
  - **Quantitative:**
    - Direct implementation of CAD guidance
    - Yield estimates (whenever possible) based on existing PHENIX measurements and known scaling laws

		2004 (Run-4)	2005 (Run-5)	2006 (Run-6)	2007 (Run-7)	2008 (Run-8)	2009 (Run-9)	2010 (Run-10)
27 Weeks	J/Ψ p_T(max)	14 weeks Au+Au 200 GeV 123 μb^{-1} 197 197 4.78 pb^{-1} 1641 J/Ψ's 17.8 GeV/c	9 weeks Si+Si 200 GeV 2.2 nb^{-1} 28 28 1.69 pb^{-1} 1574 J/Ψ's 15.8 GeV/c	19 weeks Au+Au 62.4 GeV 45 μb^{-1} 197 197 1.76 pb^{-1} 124 J/Ψ's 10.4 GeV/c	0 weeks Au+Au 200 GeV 0 μb^{-1} 197 197 0.00 pb^{-1} 0 J/Ψ's 0.0 GeV/c	19 weeks Au+Au 200 GeV 841 μb^{-1} 197 197 32.64 pb^{-1} 11213 J/Ψ's 22.5 GeV/c	0 weeks Au+Au 200 GeV 0 μb^{-1} 197 197 0.00 pb^{-1} 0 J/Ψ's 0.0 GeV/c	19 weeks d-Au 62.4 GeV 1.3 nb^{-1} 2 197 0.51 pb^{-1} 102 J/Ψ's 9.0 GeV/c
	J/Ψ p_T(max) $A_{LL}(\pi^0)$ p_T(max)	0 weeks p+p 200 GeV 0.0 pb^{-1} 30% 0 J/Ψ's 0.0 GeV/c 0.0 GeV/c	5 weeks p+p 200 GeV 1.2 pb^{-1} 50% 1864 J/Ψ's 15.1 GeV/c 6.2 GeV/c	0 weeks p+p 200 GeV 0 pb^{-1} 50% 0 J/Ψ's 0.0 GeV/c 0.0 GeV/c	19 weeks p+p 200 GeV 62 pb^{-1} 60% 98572 J/Ψ's 24.3 GeV/c 11.0 GeV/c	0 weeks p+p 500 GeV 0 pb^{-1} 70% 0 J/Ψ's 0.0 GeV/c 0.0 GeV/c	19 weeks p+p 500 GeV 211 pb^{-1} 70% 943740 J/Ψ's 39.1 GeV/c 19.0 GeV/c	0 weeks p+p 500 GeV 0 pb^{-1} 70% 0 J/Ψ's 0.0 GeV/c 0.0 GeV/c
		4.78 pb^{-1}	7.64 pb^{-1}	9.40 pb^{-1}	71.01 pb^{-1}	103.65 pb^{-1}	314.41 pb^{-1}	314.92 pb^{-1}
37 Weeks	J/Ψ p_T(max)	19 weeks Au+Au 200 GeV 203 μb^{-1} 197 197 7.88 pb^{-1} 2707 J/Ψ's 19.0 GeV/c	14 weeks Si+Si 200 GeV 4.7 nb^{-1} 28 28 3.72 pb^{-1} 3459 J/Ψ's 17.3 GeV/c	19 weeks Au+Au 62.4 GeV 45 μb^{-1} 197 197 1.76 pb^{-1} 124 J/Ψ's 10.4 GeV/c	5 weeks p-p 62.4 GeV 2.7 pb^{-1} 1 1 2.70 pb^{-1} 882 J/Ψ's 11.0 GeV/c	29 weeks Au+Au 200 GeV 1503 μb^{-1} 197 197 58.34 pb^{-1} 20043 J/Ψ's 24.1 GeV/c	0 weeks d-Au 62.4 GeV 0 nb^{-1} 2 197 0.00 pb^{-1} 0 J/Ψ's 0.0 GeV/c	29 weeks d-Au 62.4 GeV 2.3 nb^{-1} 2 197 0.91 pb^{-1} 182 J/Ψ's 9.6 GeV/c
	J/Ψ p_T(max) $A_{LL}(\pi^0)$ p_T(max)	5 weeks p+p 200 GeV 0.5 pb^{-1} 40% 746 J/Ψ's 13.5 GeV/c 5.0 GeV/c	10 weeks p+p 200 GeV 3.8 pb^{-1} 50% 6025 J/Ψ's 17.3 GeV/c 7.2 GeV/c	2 weeks p+p 500 GeV 2.1 pb^{-1} 50% 9391 J/Ψ's 22.4 GeV/c 9.3 GeV/c	22 weeks p+p 200 GeV 76 pb^{-1} 60% 121857 J/Ψ's 24.9 GeV/c 11.2 GeV/c	0 weeks p+p 500 GeV 0 pb^{-1} 70% 0 J/Ψ's 0.0 GeV/c 0.0 GeV/c	29 weeks p+p 500 GeV 377 pb^{-1} 70% 1686843 J/Ψ's 41.9 GeV/c 20.4 GeV/c	0 weeks p+p 500 GeV 0 pb^{-1} 70% 0 J/Ψ's 0.0 GeV/c 0.0 GeV/c
		8.34 pb^{-1}	15.83 pb^{-1}	19.69 pb^{-1}	98.55 pb^{-1}	156.90 pb^{-1}	533.61 pb^{-1}	534.52 pb^{-1}

  - **Integrated:** Sequential set of measurements designed to deliver comparable sensitivities in ~ all channels
  - **Planning:** Based on *current* knowledge of machine, detector, physics and future developments

Run-4

- 27 weeks
  - Au+Au 200 GeV
    - 5+14 weeks
    - Many rare channels
  - p+p 200 GeV
    - 5+0 weeks
    - Beam development
- 37 weeks
  - Au+Au 200 GeV
    - 5+19 weeks
    - Many rare channels
  - p+p 200 GeV
    - 5+5 weeks
    - Beam development
    - $A_{LL}(\pi^0)$

		2004 (Run-4)			
27 weeks		14	weeks		
		Au+Au	200 GeV	123 μb^{-1}	
		197	197	4.78 pb^{-1}	
	J/Ψ			1641 J/Ψ's	
	$p_T(max)$			17.8 GeV/c	
		0	weeks		
		p+p	200 GeV	0.0 pb^{-1}	30%
	J/Ψ			0 J/Ψ's	
	$p_T(max)$			0.0 GeV/c	
	$A_{LL}(\pi^0)$ $p_T(max)$			0.0 GeV/c	
				4.78 pb^{-1}	
37 weeks		19	weeks		
		Au+Au	200 GeV	203 μb^{-1}	
		197	197	7.88 pb^{-1}	
	J/Ψ			2707 J/Ψ's	
	$p_T(max)$			19.0 GeV/c	
		5	weeks		
		p+p	200 GeV	0.5 pb^{-1}	40%
	J/Ψ			746 J/Ψ's	
	$p_T(max)$			13.5 GeV/c	
	$A_{LL}(\pi^0)$ $p_T(max)$			5.0 GeV/c	
				8.34 pb^{-1}	

Run-5

- 27 weeks
  - Si+Si 200 GeV
    - 5+9 weeks
    - Many rare channels
  - p+p 200 GeV
    - 5+5 weeks
    - $A_{LL}(\pi^0)$
- 37 weeks
  - Si+Si 200 GeV
    - 5+14 weeks
    - Many rare channels
  - p+p 200 GeV
    - 5+10 weeks
    - Beam development
    - Quality $A_{LL}(\pi^0)$

		2005 (Run-5)			
27 weeks		9	weeks		
		Si+Si	200 GeV	2.2 nb^{-1}	
		28	28	1.69 pb^{-1}	
	J/Ψ			1574 J/Ψ's	
	$p_T(max)$			15.8 GeV/c	
		5	weeks		
		p+p	200 GeV	1.2 pb^{-1}	50%
	J/Ψ			1864 J/Ψ's	
	$p_T(max)$			15.1 GeV/c	
	$A_{LL}(\pi^0)$ $p_T(max)$			6.2 GeV/c	
				7.64 pb^{-1}	
37 weeks		14	weeks		
		Si+Si	200 GeV	4.7 nb^{-1}	
		28	28	3.72 pb^{-1}	
	J/Ψ			3459 J/Ψ's	
	$p_T(max)$			17.3 GeV/c	
		10	weeks		
		p+p	200 GeV	3.8 pb^{-1}	50%
	J/Ψ			6025 J/Ψ's	
	$p_T(max)$			17.3 GeV/c	
	$A_{LL}(\pi^0)$ $p_T(max)$			7.2 GeV/c	
				15.83 pb^{-1}	

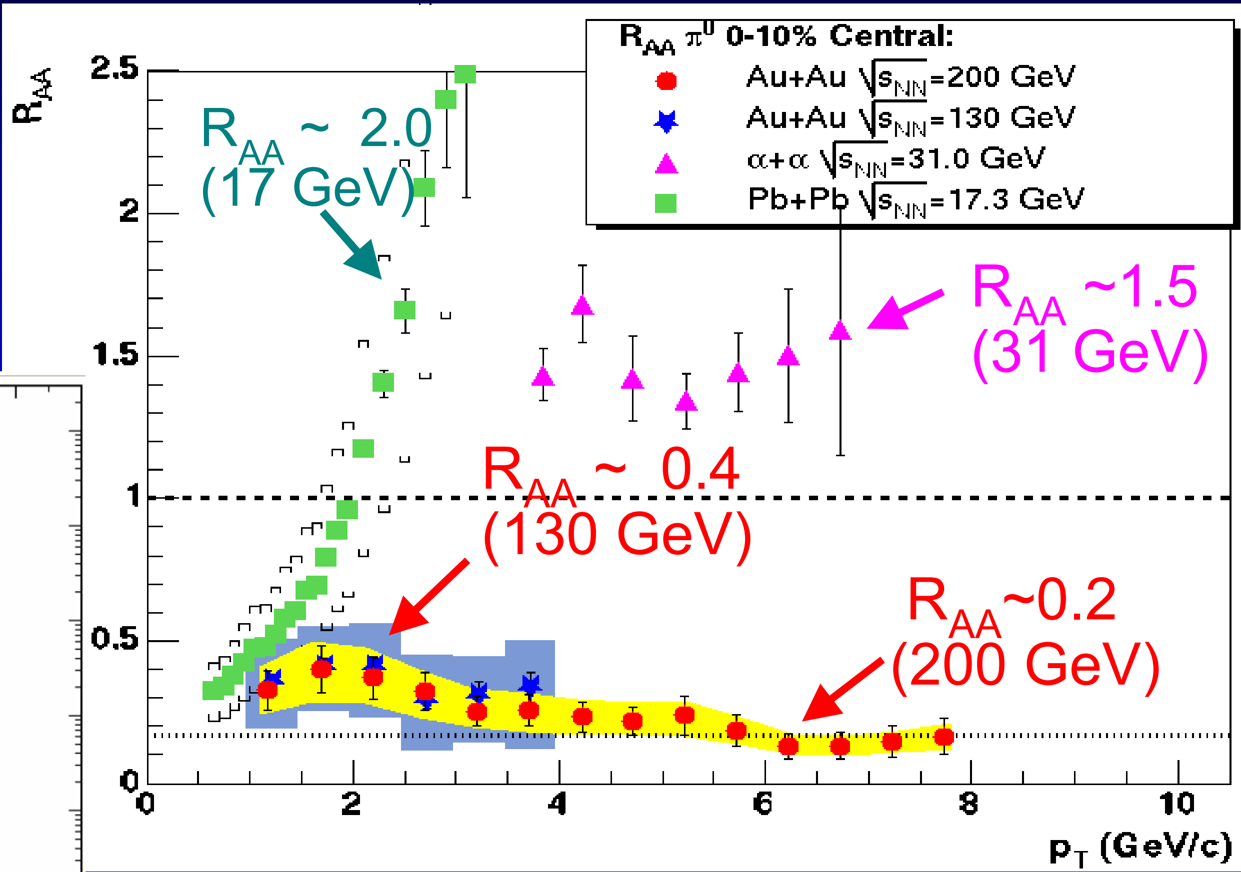
PHENIX Run-6

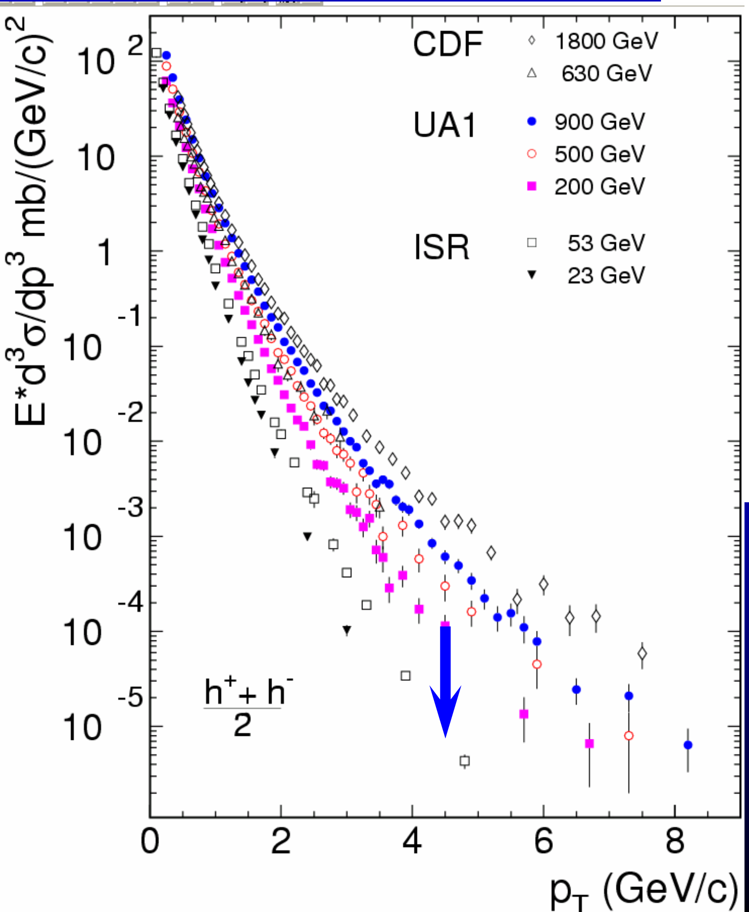
- 27 weeks
  - Au+Au 62.4 GeV
    - 5+19 weeks
    - *Some* rare channels
    - ISR comparison
- 37 weeks
  - Au+Au 62.4 GeV
    - 5+19 weeks
    - *Some* rare channels
    - ISR comparison
  - p+p 500 GeV
    - 5+2 weeks
    - Beam development
    - New $A_{LL}(\pi^0)$

		2006 (Run-6)			
27 weeks		19	weeks		
		Au+Au	62.4 GeV	45 μb^{-1}	
		197	197	1.76 pb^{-1}	
	J/Ψ			124 J/Ψ's	
	p_T(max)			10.4 GeV/c	
		0	weeks		
		p+p	200 GeV	0 pb^{-1}	50%
	J/Ψ			0 J/Ψ's	
	p_T(max)			0.0 GeV/c	
	$A_{LL}(\pi^0)$ p_T(max)			0.0 GeV/c	
				9.40 pb^{-1}	
37 weeks		19	weeks		
		Au+Au	62.4 GeV	45 μb^{-1}	
		197	197	1.76 pb^{-1}	
	J/Ψ			124 J/Ψ's	
	p_T(max)			10.4 GeV/c	
		2	weeks		
		p+p	500 GeV	2.1 pb^{-1}	50%
	J/Ψ			9391 J/Ψ's	
	p_T(max)			22.4 GeV/c	
	$A_{LL}(\pi^0)$ p_T(max)			9.3 GeV/c	
				19.69 pb^{-1}	

Why 62.4 GeV?

- Select an energy to make the suppression go away





- *At a $\sqrt{s}$ that still allows "full" coverage in p_T.*
- **Nota Bene:**
  - **RHIC luminosity scales as *s* (i.e., E^2)**

Run-7

- **27 weeks**
  - p+p 200 GeV
    - 5+19 weeks
    - Spin *production* run
    - "Ultimate" comparison set
- **37 weeks**
  - p+p 62.4 GeV
    - 5+5 weeks
    - *Some* rare channels
    - ISR *extension*
    - (No species change)
  - p+p 200 GeV
    - 5+22 weeks
    - Spin *production* run
    - "Ultimate" comparison set

		2007 (Run-7)			
27 Weeks		0	weeks		
		Au+Au	200 GeV	0 μb^{-1}	
		197	197	0.00 pb^{-1}	
	J/Ψ			0 J/Ψ's	
	p_T(max)			0.0 GeV/c	
		19	weeks		
		p+p	200 GeV	62 pb^{-1}	60%
	J/Ψ			98572 J/Ψ's	
	p_T(max)			24.3 GeV/c	
	$A_{LL}(\pi^0)$ p_T(max)			11.0 GeV/c	
				71.01 pb^{-1}	
37 Weeks		5	weeks		
		p-p	62.4 GeV	2.7 pb^{-1}	
		1	1	2.70 pb^{-1}	
	J/Ψ			882 J/Ψ's	
	p_T(max)			11.0 GeV/c	
		22	weeks		
		p+p	200 GeV	76 pb^{-1}	60%
	J/Ψ			121857 J/Ψ's	
	p_T(max)			24.9 GeV/c	
	$A_{LL}(\pi^0)$ p_T(max)			11.2 GeV/c	
				98.55 pb^{-1}	

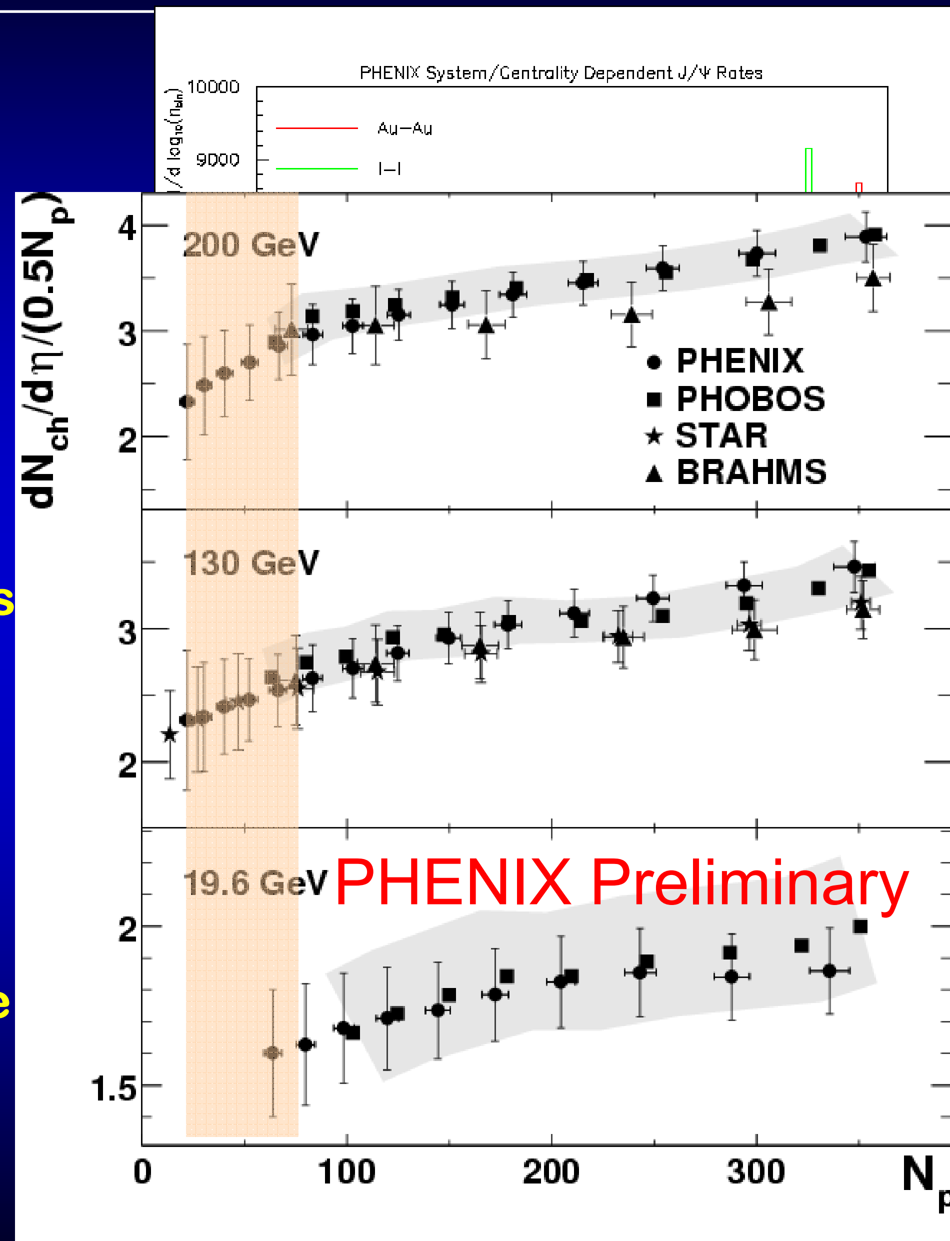
Run-8

- 27 weeks
  - Au+Au 200 GeV
    - 5+19 weeks
    - “Penultimate” Au+Au run
    - Needed to access Upsilons
- 37 weeks
  - Au+Au 200 GeV
    - 5+29 weeks
    - “Ultimate” Au+Au run
    - Needed to access Upsilons

		2008 (Run-8)			
27 weeks		19	weeks		
		Au+Au	200 GeV	841 μb^{-1}	
		197	197	32.64 pb^{-1}	
	J/Ψ			11213 J/Ψ's	
	p_T(max)			22.5 GeV/c	
		0	weeks		
		p+p	500 GeV	0 pb^{-1}	70%
	J/Ψ			0 J/Ψ's	
	p_T(max)			0.0 GeV/c	
	$A_{LL}(\pi^0)$ p_T(max)			0.0 GeV/c	
				103.65 pb^{-1}	
37 weeks		29	weeks		
		Au+Au	200 GeV	1503 μb^{-1}	
		197	197	58.34 pb^{-1}	
	J/Ψ			20043 J/Ψ's	
	p_T(max)			24.1 GeV/c	
		0	weeks		
		p+p	500 GeV	0 pb^{-1}	70%
	J/Ψ			0 J/Ψ's	
	p_T(max)			0.0 GeV/c	
	$A_{LL}(\pi^0)$ p_T(max)			0.0 GeV/c	
				156.90 pb^{-1}	

To Fe or not to Fe?

- 0-th order:
  - We desire the species that will lead to highest possible integrated (parton-parton) luminosities
  - CAD guidance neutral in this respect (but perhaps Si set-up is easier?)
- 1^{st}-order:
  - Clearly depends on assumptions regarding (length, surface, volume) effects
  - We have consistently requested a spectrum of species (Run-2, 3 Beam Use Proposals)
  - This is now tempered with reality from CAD guidance
  - Makes choice of "A" all the more important, since you get only one per running period
  - Concern is that we will not vary it *enough:*
    - ☞ All of the action seems to be at low N_{part}



Run-8+

		2009 (Run-9)
2 7	J/Ψ	0 weeks Au+Au 200 GeV 0 μb^{-1} 197 197 0.00 pb^{-1} 0 J/Ψ's

- 27 weeks
  - p+p 500 GeV
    - 5+19 weeks
    - "Penultimate" spin run
- 37 weeks
  - p+p 500 GeV
    - 5+29 weeks
    - "Ultimate" spin run
    - Approaches original RSC goal of 800 pb^{-1}
    - (Modulo CAD remarks re optimistic out-year projections in PHENIX Beam Use Proposal..)

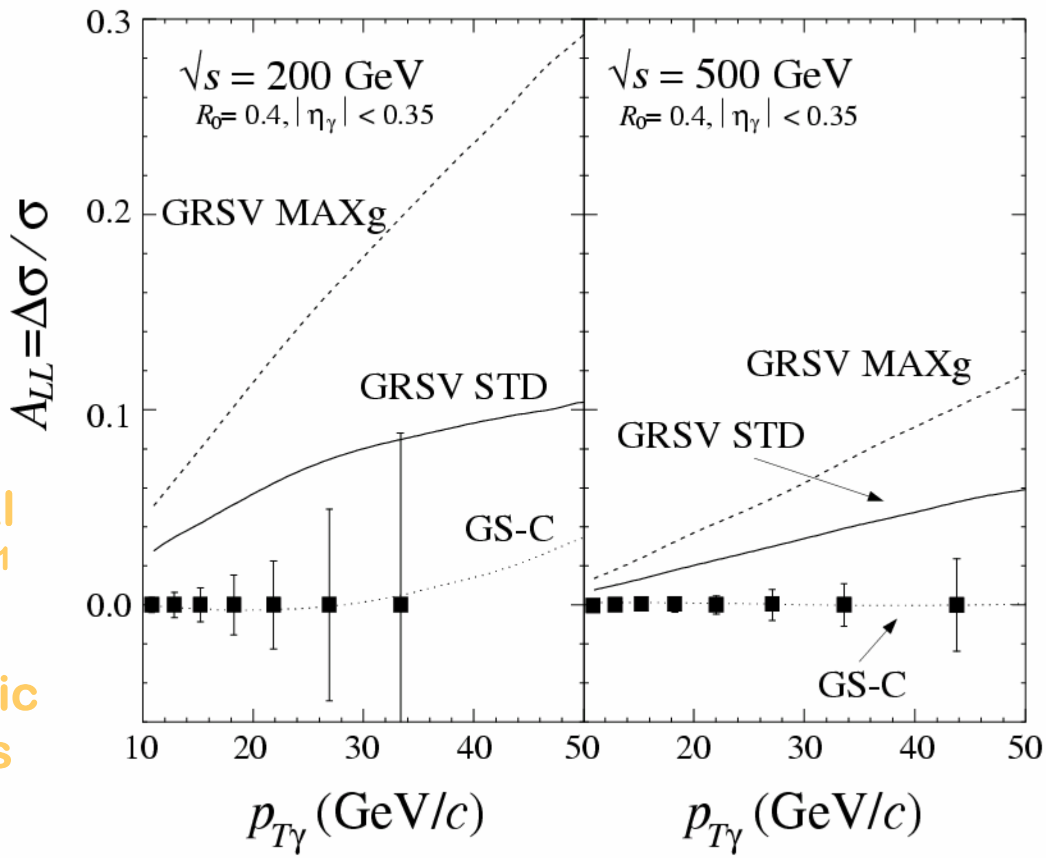
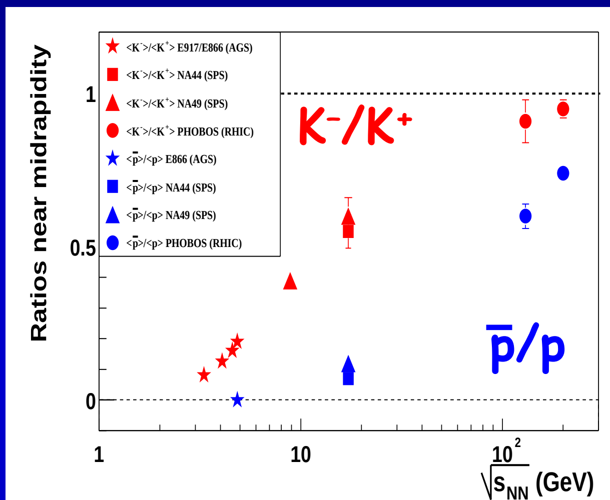
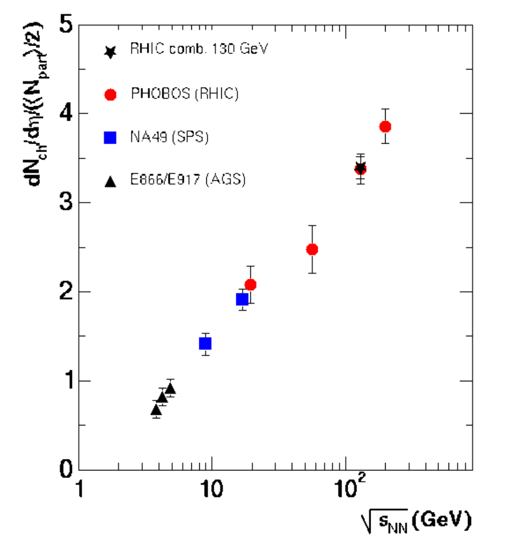


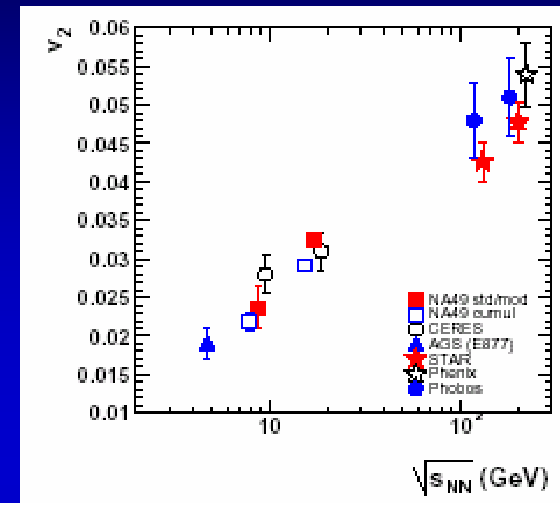
Figure 9: Asymmetry as a function of transverse momentum, for various polarized parton densities, at different cms energies [60]. The expected statistical errors for the PHENIX experiment are also shown.

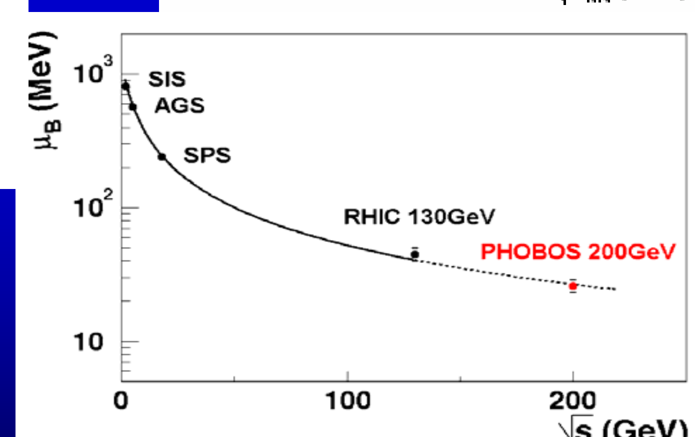
On Energy Scans

- Nearly all phenomena measured thus far exhibit smooth variation with energy:









- Those that don't(?)
  (e.g., kaon slopes)
  already present in pp data (next slide)
- Absent compelling arguments, and given
  - ❑ Natural smearing from Fermi momentum
  - ❑ Scarce beam hours

➡ Give higher priority to investigating with highest possible sensitivity the signals that are new at RHIC

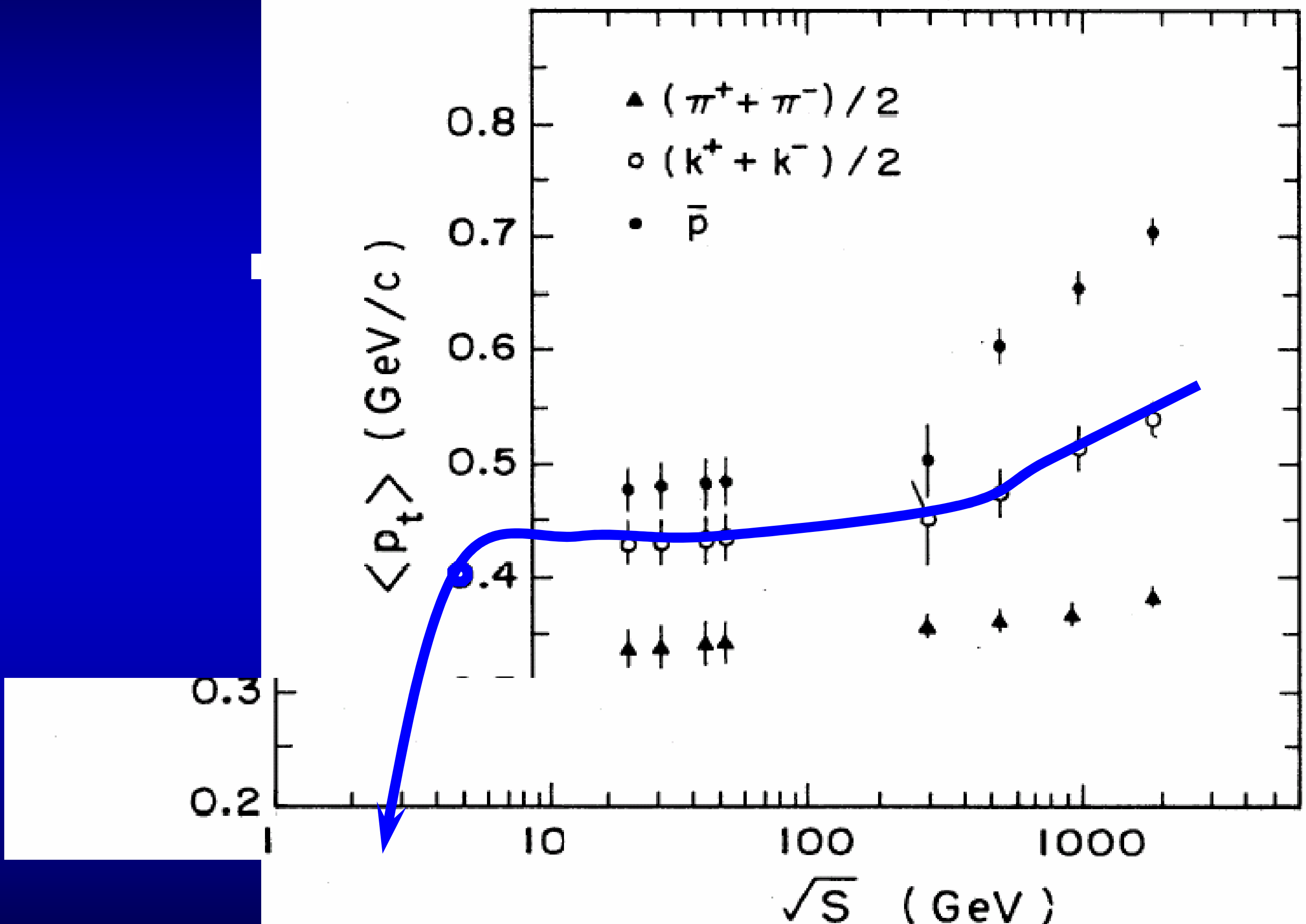


FIG. 13. Plot of $\langle p_t \rangle$ as a function of $\sqrt{s}$; the data for $\sqrt{s} < 100$ GeV are from Ref. [18].

Run Request Summary

PHENIX

- Au+Au at 200 GeV, with goal of developing highest possible integrated luminosity
- An aggressive program of luminosity and polarization development for p+p, with the goal of the earliest practicable measurement of ΔG
- Light-ion running, to investigate dependence on system size
- A reduced energy run, again with emphasis on obtaining highest possible integrated luminosity
- High integrated luminosities achieved via minimal variations in species and energies, as per CAD guidance

Table 2: The PHENIX Beam Use Proposal for 27 cryo weeks per year

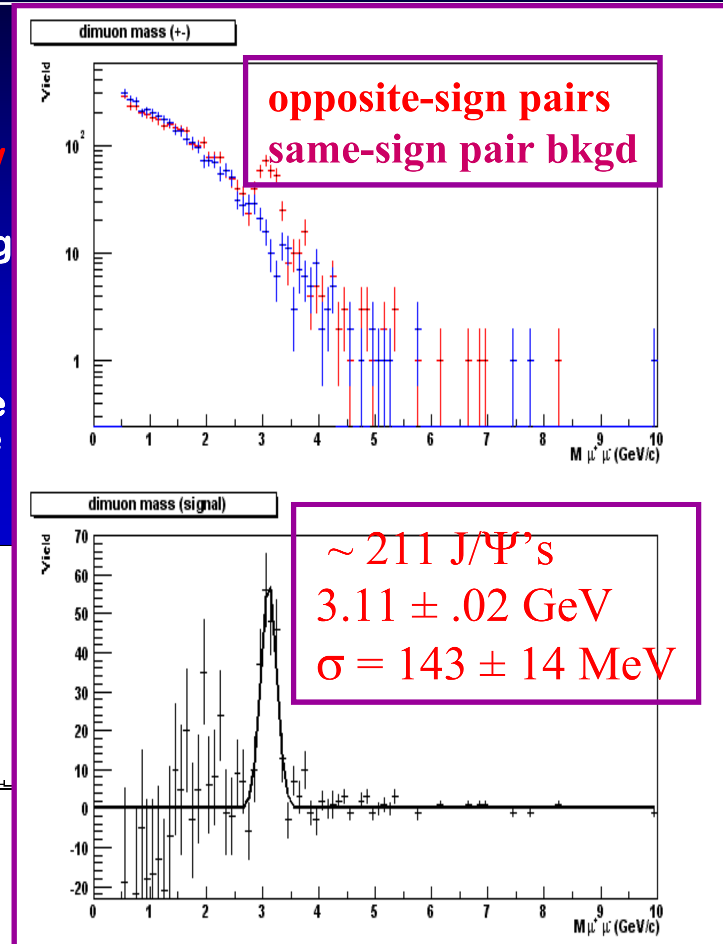
RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS	$\int \mathcal{L}dt$ (delivered)	p+p Equivalent
4	Au+Au p+p	200 200	14 (5 development)	316 μb^{-1} -	12.3 pb^{-1}
5	Si+Si p+p	200 200	9 5	5.5 nb^{-1} 3.0 pb^{-1}	4.3 pb^{-1} 3.0 pb^{-1}
6	Au+Au	62.4	19	117 μb^{-1}	4.3 pb^{-1}
7	p+p	200	19	158 pb^{-1}	158 pb^{-1}
8	Au+Au	200	19	2157 μb^{-1}	84 pb^{-1}
9	p+p	500	19	540 pb^{-1}	540 pb^{-1}
10	d+Au	62.4	19	3.3 nb^{-1}	1.3 pb^{-1}

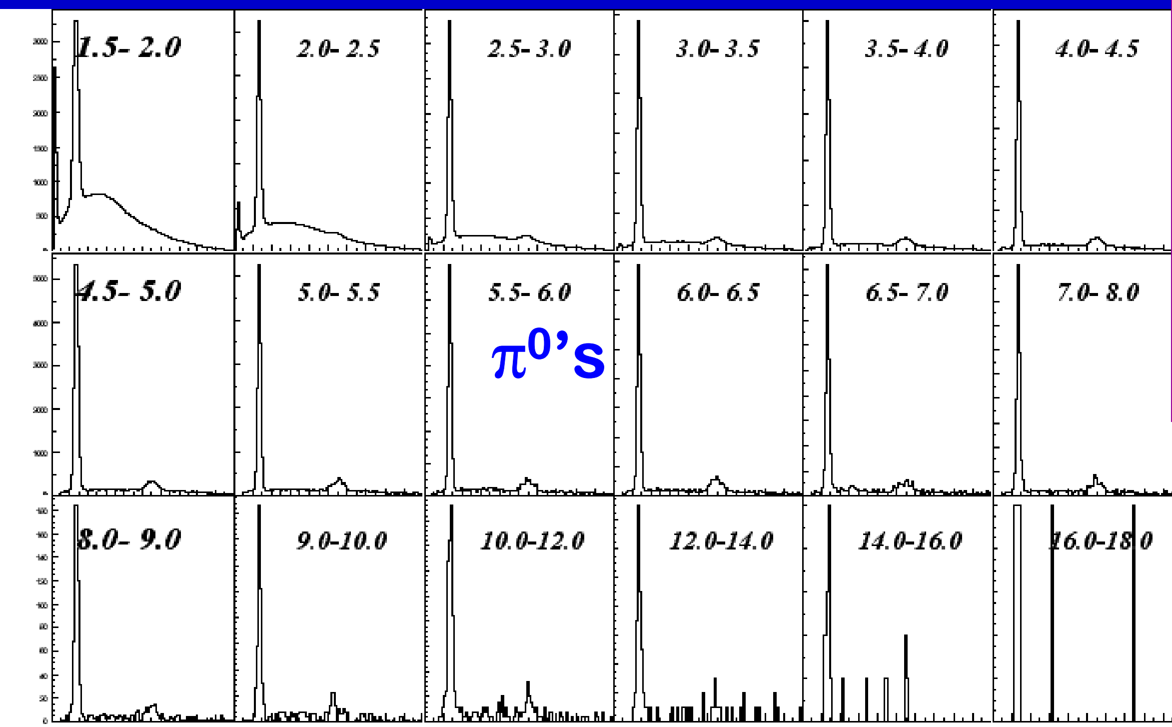
Table 3: The PHENIX Beam Use Proposal for 37 cryo weeks per year

RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS	$\int \mathcal{L}dt$ (delivered)	p+p Equivalent
4	Au+Au p+p	200 200	19 5	521 μb^{-1} 1.2 pb^{-1}	20.2 pb^{-1} 1.2 pb^{-1}
5	Si+Si p+p	200 200	14 10	12 nb^{-1} 10 pb^{-1}	9.6 pb^{-1} 10 pb^{-1}
6	Au+Au p+p	62.4 500	19 2	117 μb^{-1} 5.4 pb^{-1}	4.3 pb^{-1} 5.4 pb^{-1}
7	p+p p+p	200 62.4	19 5	158 pb^{-1} 7 pb^{-1}	158 pb^{-1} 7 pb^{-1}
8	Au+Au	200	29	3855 μb^{-1}	150 pb^{-1}
9	p+p	500	29	966 pb^{-1}	966 pb^{-1}
10	d+Au	62.4	29	5.9 nb^{-1}	2.3 pb^{-1}

Note on Methodology

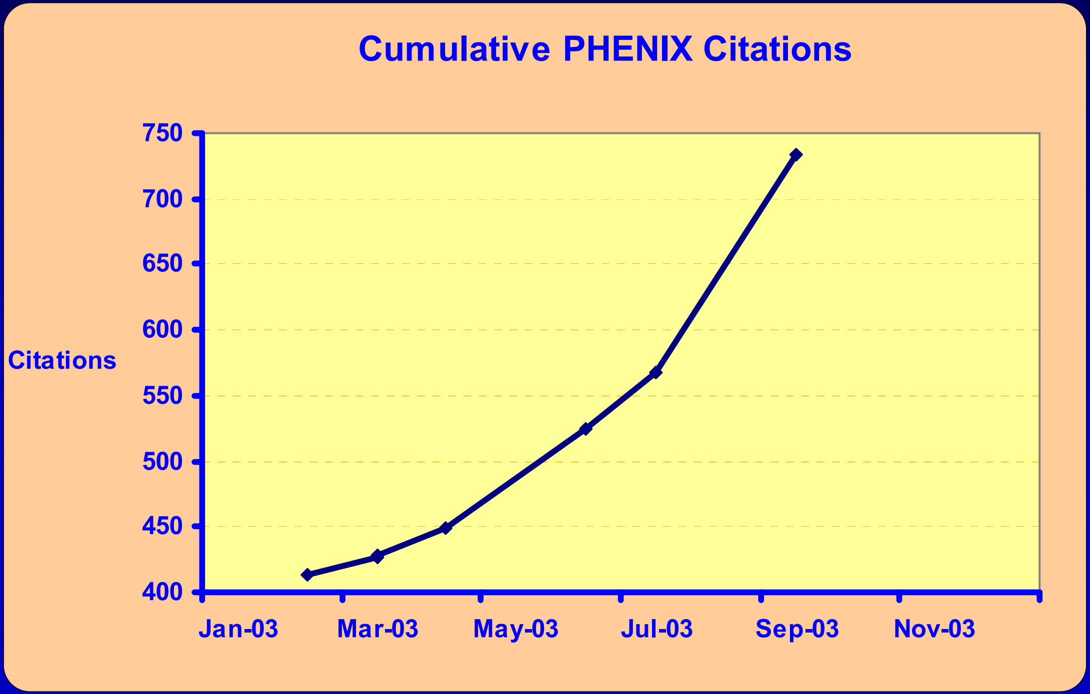
- CAD guidance, “linear growth model” implemented in spreadsheet
- Physics yields for representative measurements *calibrated* based on PHENIX *measurements*
- Extensive “phase space” of options explored in the planning process
- Were led back to a position consistent with our previous multi-year proposals to PAC
- Exploits the *demonstrated* capabilities of PHENIX to use the full luminosity of RHIC to measure identified particles to the highest possible transverse momenta





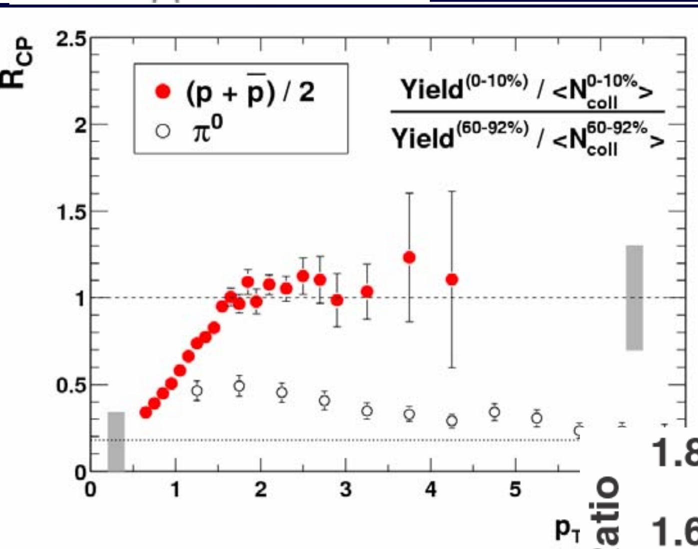
Publication Summary

- **Run-1**
  - 12 publications
  - First 5 are "TopCites"
  - One "archival" summary
- **Run-2**
  - 8 submissions to date
  - 6 accepted/published
  - Several more still in progress
  - One "archival" summary
- **Run-3**
  - One publication
  - Many to follow

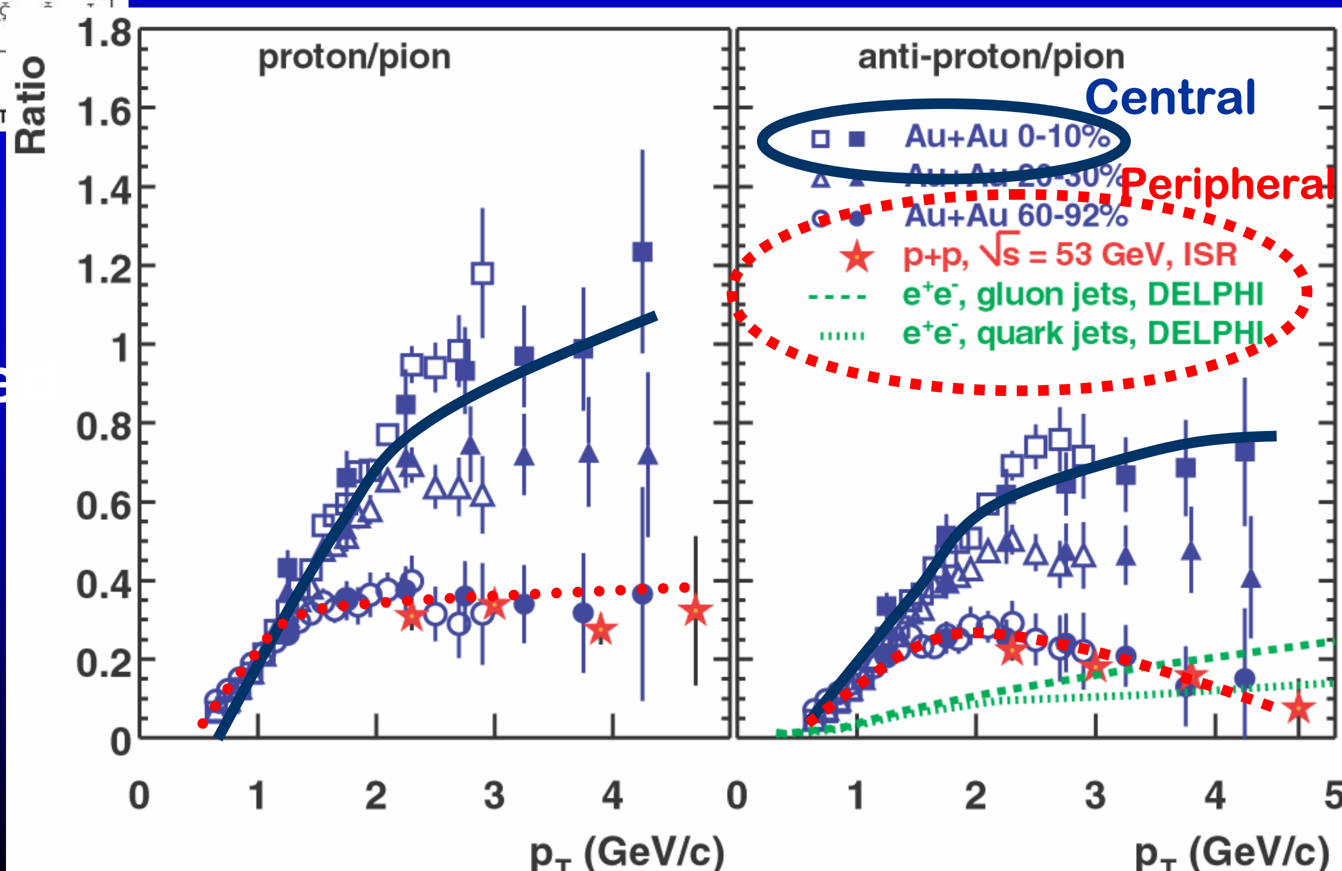


Physics Motivations

- Strong motivation given
  - Jet Quenching!?
  - Predictions of quark recombination models (and their provocative conclusions)



- Run-4 request should extend results for PID-e K's and p's into the 5-7 GeV/c range



Extended PID with Aerogel

		Pion-Kaon separation	Kaon-Proton separation
TOF	σ~100 ps	0 - 2.5	0 - 5
RICH	n=1.00044 γ_{th}~34	5 - 17	17 -
Aerogel	n=1.007 γ_{th}~8.5	1 - 5	5 - 9

Y. Miake

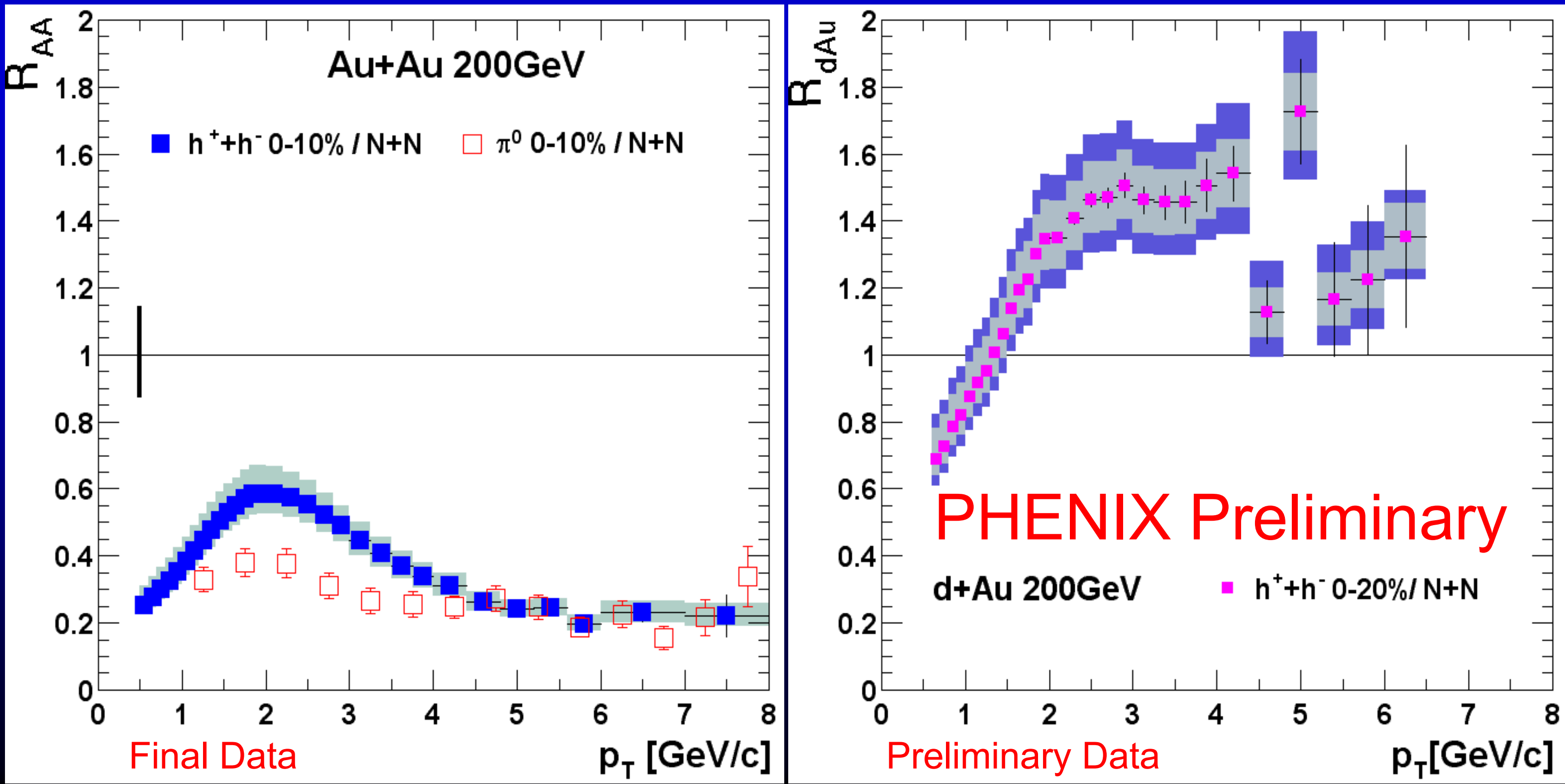
Aerogel together with TOF can extend the PID capability up to 10 GeV/c

Forthcoming Run-3 Results

- Centrality selected
  - Charged hadrons
  - Identified charged hadrons
  - π^0's
- Opposite centrality evolution of Au+Au compared to d+Au control.

Au + Au

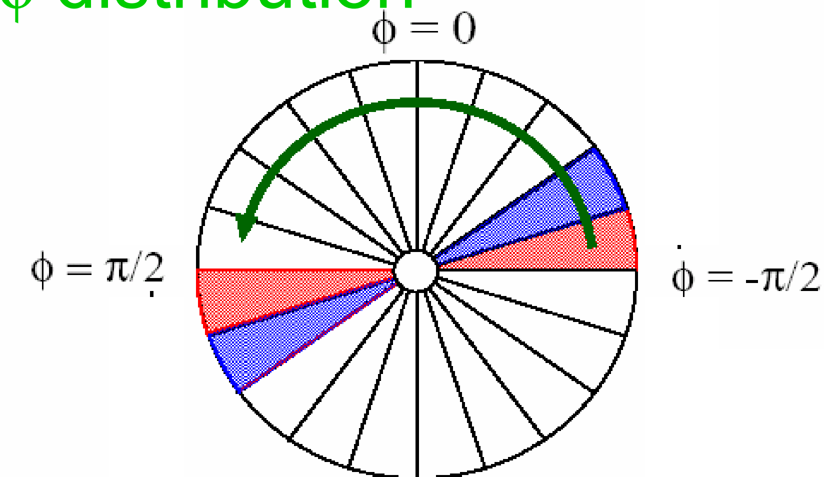
d + Au Control



Run-3 Spin Results

- **Rotators at IP8 commissioned via local polarimeters**
  - Forward neutron transverse asymmetry (AN) measurements
  - SMD (position) + ZDC (energy)

ϕ distribution

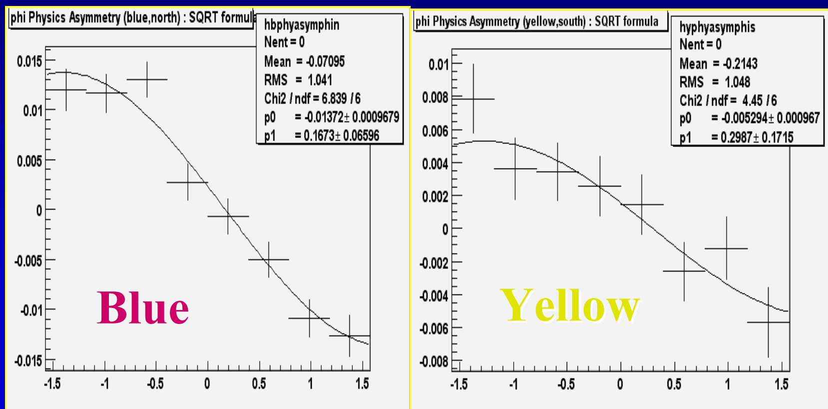


Vertical → $\phi \sim \pm\pi/2$
Radial → $\phi \sim 0$
Longitudinal → no asymmetry

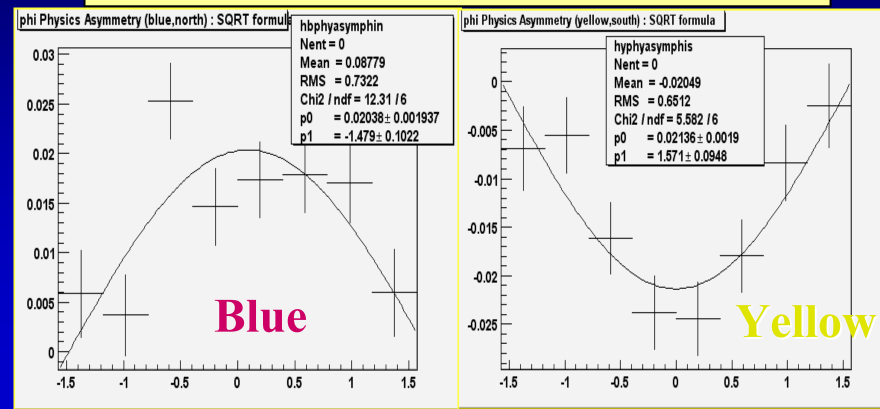
- **Then longitudinally polarized protons used to obtain first glimpse of $A_{LL}(\pi^0)$**

Local Polarimeter at PHENIX

Spin Rotators OFF



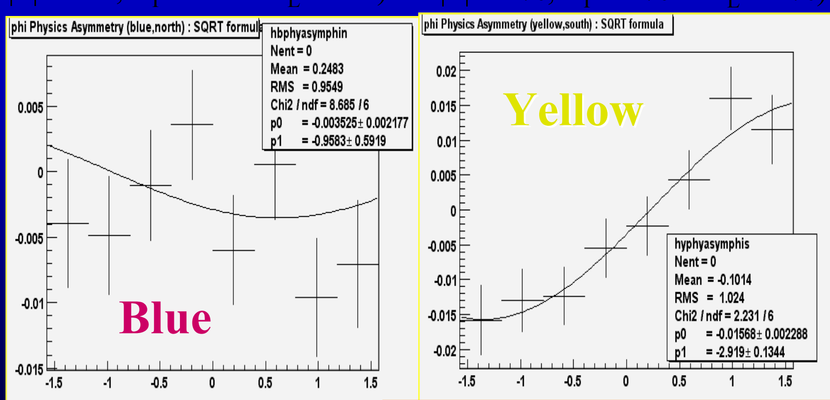
Spin Rotators ON, Current Reversed



Run-3

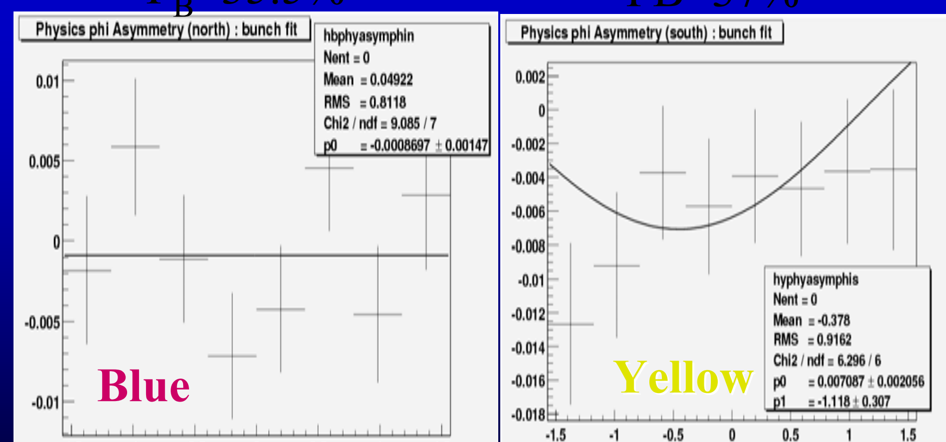
Spin Rotators ON, Almost…

|P|=30%, P_T=0% → P_L=30%) |P|=37%, P_T=24% → P_L=28%)



Spin Rotators ON, Correct!

P_B=35.5% PB=37%



Essential to success of Run-3 spin physics!

PHENIX

Run-1 Publications

- "Centrality dependence of charged particle multiplicity in Au-Au collisions at $\sqrt{s_{NN}}$ = 130 GeV", PRL 86 (2001) 3500
- "Measurement of the midrapidity transverse energy distribution from $\sqrt{s_{NN}}$ = 130 GeV Au-Au collisions at RHIC", PRL 87 (2001) 052301
- "Suppression of hadrons with large transverse momentum in central Au-Au collisions at $\sqrt{s_{NN}}$ = 130 GeV", PRL 88, 022301 (2002).
- "Centrality dependence of $\pi^{+/-}$, $K^{+/-}$, p and pbar production at RHIC," PRL 88, 242301 (2002).
- "Transverse mass dependence of the two-pion correlation for Au+Au collisions at $\sqrt{s_{NN}}$ = 130 GeV", PRL 88, 192302 (2002)
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"Net Charge Fluctuations in Au+Au Interactions at $\sqrt{s_{NN}}$ = 130 GeV," PRL. 89, 082301 (2002)

- "Event-by event fluctuations in Mean p_T and mean e_T in sqrt(s_NN) = 130GeV Au+Au Collisions" Phys. Rev. C66, 024901 (2002)
- "Flow Measurements via Two-particle Azimuthal Correlations in Au + Au Collisions at $\sqrt{s_{NN}}$ = 130 GeV" , PRL 89, 212301 (2002)
- "Measurement of the lambda and lambda^bar particles in Au+Au Collisions at $\sqrt{s_{NN}}$ =130 GeV", PRL 89, 092302 (2002)
- "Centrality Dependence of the High pT Charged Hadron Suppression in Au+Au collisions at $\sqrt{s_{NN}}$ = 130 GeV", Phys. Lett. B561, 82 (2003)
- "Single Identified Hadron Spectra from $\sqrt{s_{NN}}$ = 130 GeV Au+Au Collisions", to appear in Physical Review C, nucl-ex/0307010

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Run-2 Publications

- "Suppressed π^0 Production at Large Transverse Momentum in Central Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV" , PRL 91, 072301 (2003)
- "Scaling Properties of Proton and Anti-proton Production in $\sqrt{s_{NN}}$ = 200 GeV Au+Au Collisions“, accepted for publication in PRL 21 August 2003, nucl-ex/0305036
- "J/Psi Production in Au-Au Collisions at $\sqrt{s_{NN}}$ =200 GeV at the Relativistic Heavy Ion Collider", accepted for publication in Phys. Rev. C on 6 September 2003, nucl-ex/0305030
- "Elliptic Flow of Identified Hadrons in Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV" , accepted for publication in PRL 9 September 2003, nucl-ex/0305013
- "Midrapidity Neutral Pion Production in Proton-Proton Collisions at $\sqrt{s}$ = 200 GeV“, accepted for publication in PRL on 19 September 2003, hep-ex/0304038
- "Identified Charged Particle Spectra and Yields in Au-Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV" , accepted for publication in Physical Review C on 23 Sep 2003, nucl-ex/0307022
- "J/psi production from proton-proton collisions at $\sqrt{s}$ = 200 GeV“, submitted to PRL July 8 2003, hep-ex/0307019
- "High-pt Charged Hadron Suppression in Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 Gev”, submitted to Physical Review C on 11 August 2003, nucl-ex/0308006

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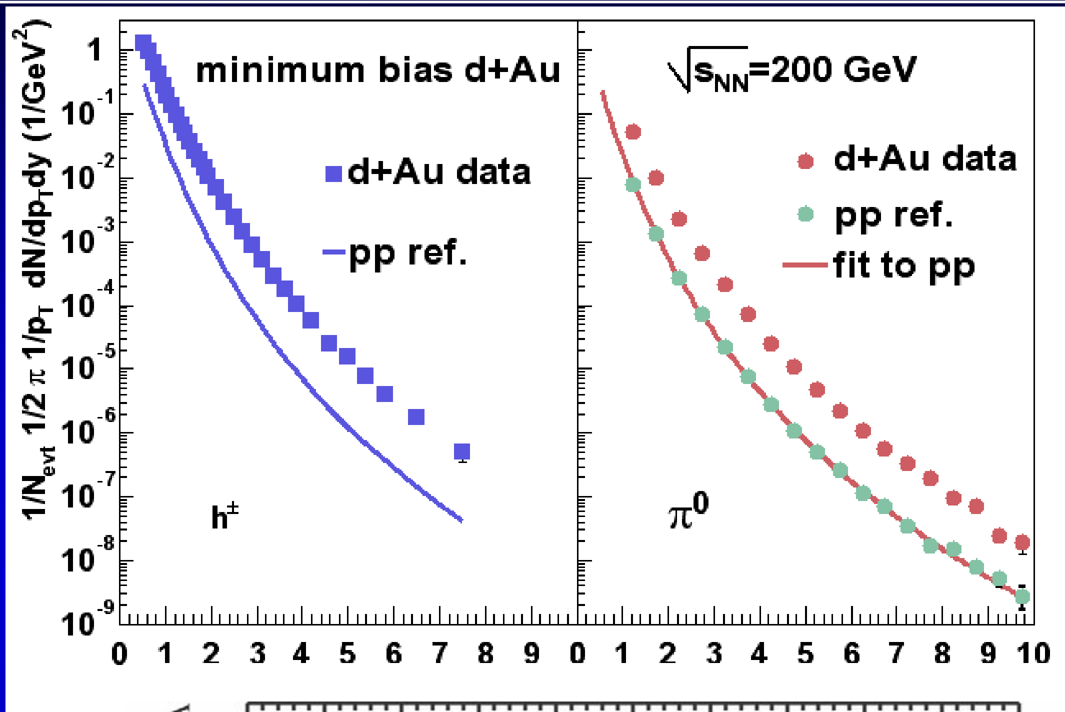
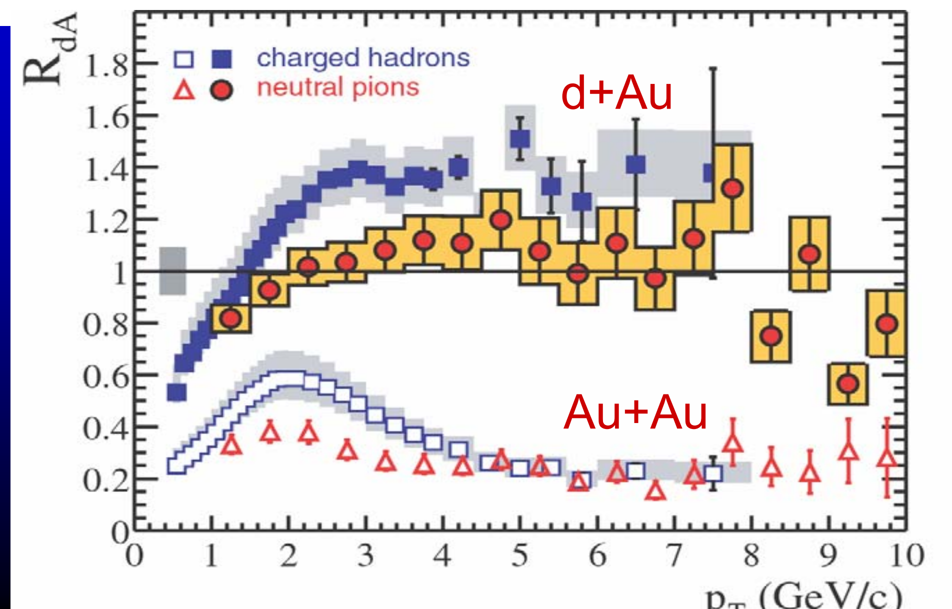
Run-3 Publications

- "Absence of Suppression in Particle Production at Large Transverse Momentum in $\sqrt{s_{NN}}$ = 200 GeV d+Au Collisions", PRL 91, 072303 (2003)



- PID-ed particles (π^0's) out to the highest p_T's PHENIX's unique contribution to the June "press event"



Our latest Run-1 Publication

- "Single Identified Hadron Spectra from $\sqrt{s_{NN}}$ = 130 GeV Au+Au Collisions", to appear in Physical Review C nucl-ex/0307010
- An "archival" publication detailing our entire analysis methodology for identified particles
  - 37 pages
  - 3 appendices
  - 28 figures
  - 16 tables

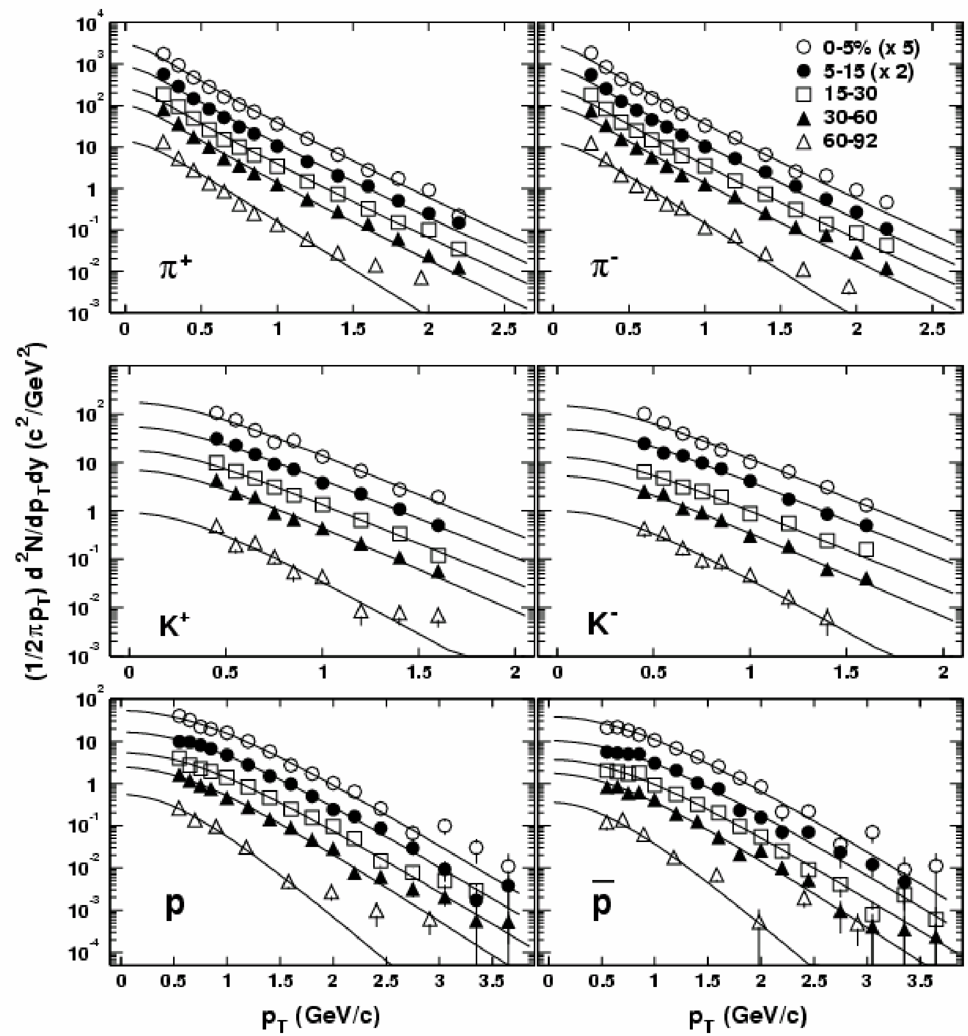


FIG. 19: The parameterization and the p_T hadron spectra for all five centrality selections.

namics calculation, followed by a hadronic cascade after chemical freeze-out. The cascade step utilizes the Relativistic Quantum Molecular Dynamics (RQMD) model, developed for lower energy heavy ion collisions [59].

equilibrium time, and the freeze-out temperature which controls the duration of the expansion. The chemical freeze-out temperature is the temperature at which particle production ceases. The initial entropy or energy

One archival Run-2 Publication

- "Identified Charged Particle Spectra and Yields in Au-Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV" , accepted for publication in ■ Physical Review C on 23 Sep 2003, nucl-ex/0307022

- An "archival" publication extending our identified particles analysis methodology to Run-2
  - 37 pages
  - 24 figures
  - 29 tables

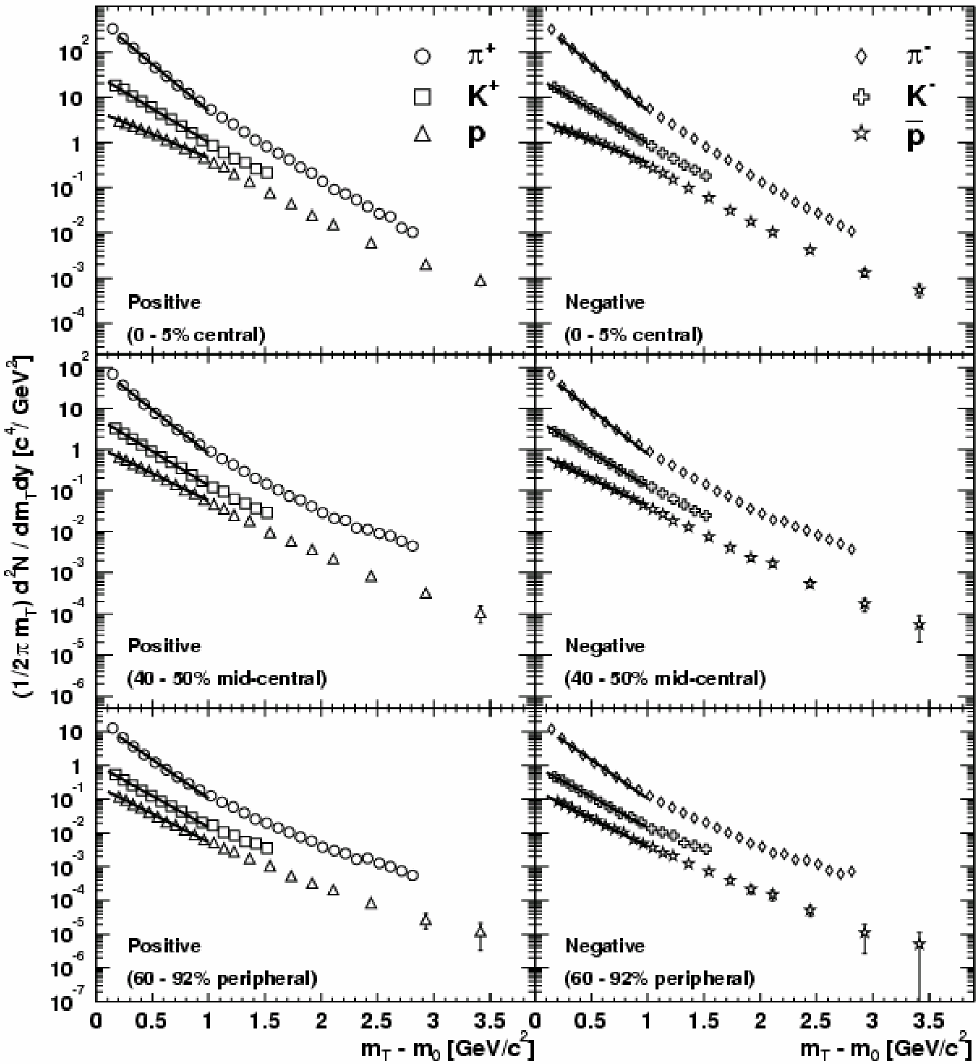


FIG. 9: Transverse mass distributions for $\pi^\pm$, $K^\pm$, protons and anti-protons for central 0–5% (top panels), mid-central 40–50% (middle panels) and peripheral 60–92% (bottom panels) in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The lines on each spectra are the fitted results using m_T exponential function. The fit ranges are 0.2 − 1.0 GeV/c^2 for pions and 0.1 − 1.0 GeV/c^2 for kaons, protons, and anti-protons in $m_T - m_0$. The error bars are statistical errors only.

Run-4 Luminosity (J/Ψ)

- A quest to develop ***highest possible integrated luminosity*** in full energy Au+Au running
  - To eliminate statistical ambiguity in many production channels
  - Example: J/Ψ production
    - 27 week scenario:
      - 2.6σ (e^+e^-)
      - 3.2σ ($\mu^+\mu^-$)
    - (in 0-20% centrality bin)

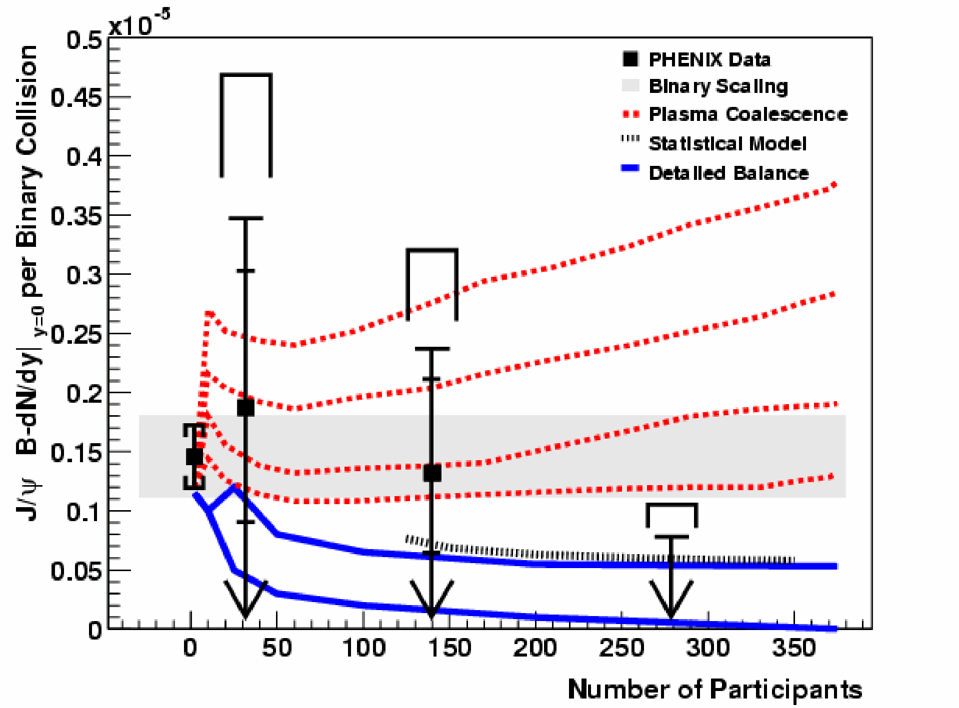


FIG. 6: (Color online) The J/ψ invariant yield per binary collision is shown from proton-proton reactions and three exclusive centrality ranges of Au-Au reactions all at $\sqrt{s_{NN}}$ = 200 GeV. The lowest curve is a calculation including "normal" nuclear absorption in addition to substantial absorption in a high temperature quark-gluon plasma [16]. The curve above this is including backward reactions that recreate J/ψ. The statistical model [17] result is shown as a dotted curve for mid-central to central collisions just above that. The four highest dashed curves are from the plasma coalescence model [15] for a temperature parameter of T = 400 MeV and charm rapidity widths of Δy = 1.0, 2.0, 3.0, 4.0, from the highest to the lowest curve respectively.

Recombination Tested

The *complicated* observed flow pattern in $v_2(p_T)$

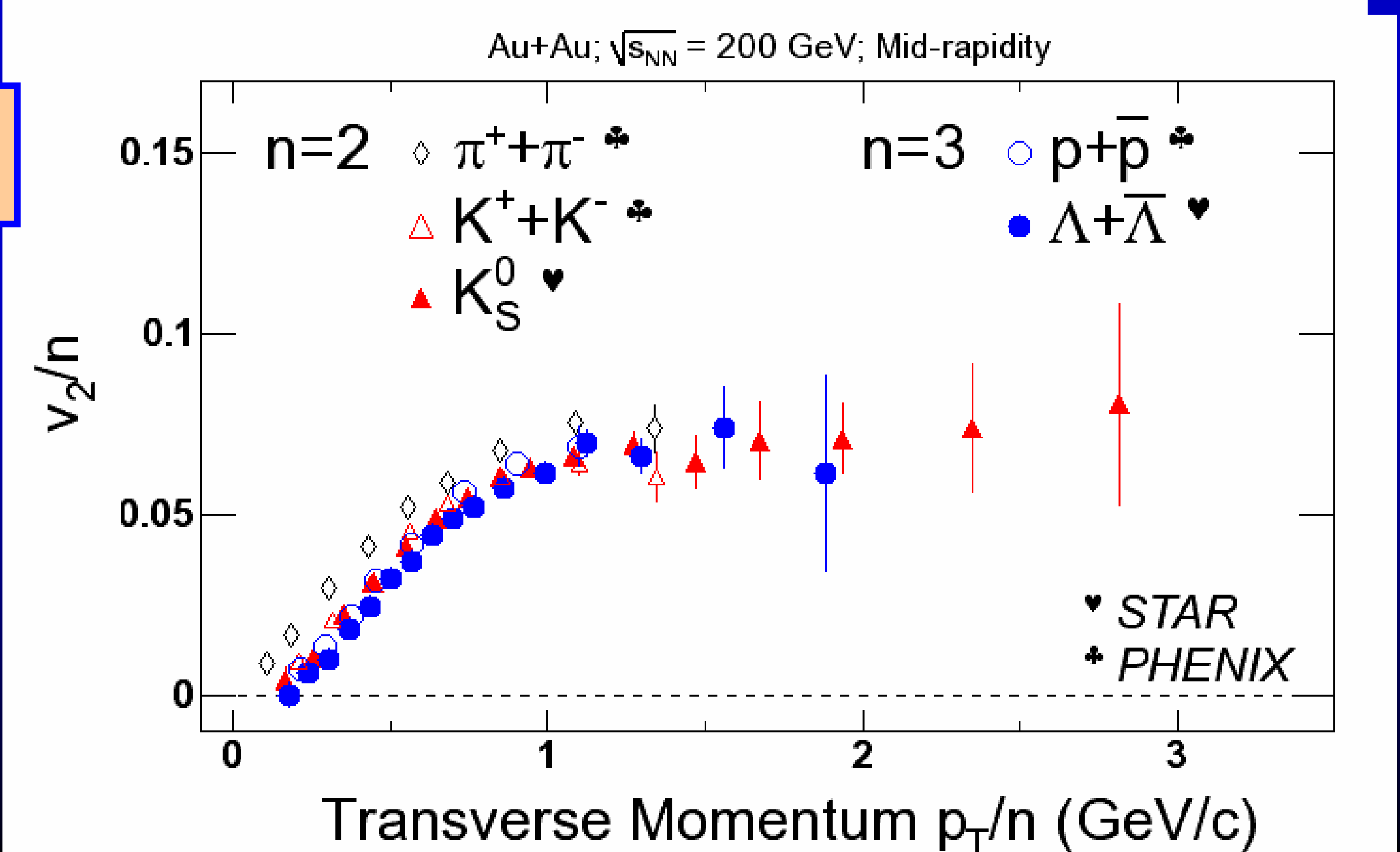
$d^2n/dp_Td\phi \sim 1 + 2\, v_2(p_T) \cos(2\phi)$

is predicted to be *simple* at the quark level under

$p_T \rightarrow p_T / n$, $v_2 \rightarrow v_2 / n$, n = 2,3 for meson,baryon

if the flow pattern is established at the quark level

Compilation courtesy of H. Huang



Yet Another Luminosity Limited Observable

- New PHENIX Run-2 result on v2 of π^0's:

- Clearly would benefit from Run-4 statis