PHENIX Beam Use Presentation

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for the PHENIX Collaboration

(this talk available at
http://www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/RBUP03/PacSep03.pdf)

PHENIX

12 Countries; 57 Institutions; 460 Participants*

Brazil	University of São Paulo, São Paulo
China	Academia Sinica, Taipei, Taiwan
	China Institute of Atomic Energy, Beijing
	Peking University, Beijing
France	LPC, University de Clermont-Ferrand, Clermont-Ferrand
	Dapnia, CEA Saclay, Gif-sur-Yvette
	IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
	LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
	SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany	University of Münster, Münster
Hungary	Central Research Institute for Physics (KFKI), Budapest
	Debrecen University, Debrecen
	Eötvös Loránd University (ELTE), Budapest
India	Banaras Hindu University, Banaras
	Bhabha Atomic Research Centre, Bombay
Israel	Weizmann Institute, Rehovot
Japan	Center for Nuclear Study, University of Tokyo, Tokyo
	Hiroshima University, Higashi-Hiroshima
	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
	RIKEN, Institute for Physical and Chemical Research, Wako
	RIKEN-BNL Research Center, Upton, NY
	University of Tokyo, Bunkyo-ku, Tokyo
	Tokyo Institute of Technology, Tokyo
	University of Tsukuba, Tsukuba
	Waseda University, Tokyo
S. Korea	Cyclotron Application Laboratory, KAERI, Seoul
	Kangnung National University, Kangnung
	Korea University, Seoul
	Myong Ji University, Yongin City
	System Electronics Laboratory, Seoul Nat. University, Seoul
	Yonsei University, Seoul
Russia	Institute of High Energy Physics, Protovino
	Joint Institute for Nuclear Research, Dubna
	Kurchatov Institute, Moscow
	PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
	St. Petersburg State Technical University, St. Petersburg
Sweden	Lund University, Lund
USA	Abilene Christian University, Abilene, TX
	Brookhaven National Laboratory, Upton, NY
	University of California - Riverside, Riverside, CA
	University of Colorado, Boulder, CO
	Columbia University, Nevis Laboratories, Irvington, NY
	Florida State University, Tallahassee, FL
	Georgia State University, Atlanta, GA
	University of Illinois Urbana Champaign, Urbana-Champaign, IL
	Iowa State University and Ames Laboratory, Ames, IA
	Los Alamos National Laboratory, Los Alamos, NM
	Lawrence Livermore National Laboratory, Livermore, CA
	University of New Mexico, Albuquerque, NM
	New Mexico State University, Las Cruces, NM
	Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
	Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
	Oak Ridge National Laboratory, Oak Ridge, TN
	University of Tennessee, Knoxville, TN
	Vanderbilt University, Nashville, TN

*as of July 2002

Beam Use Proposal

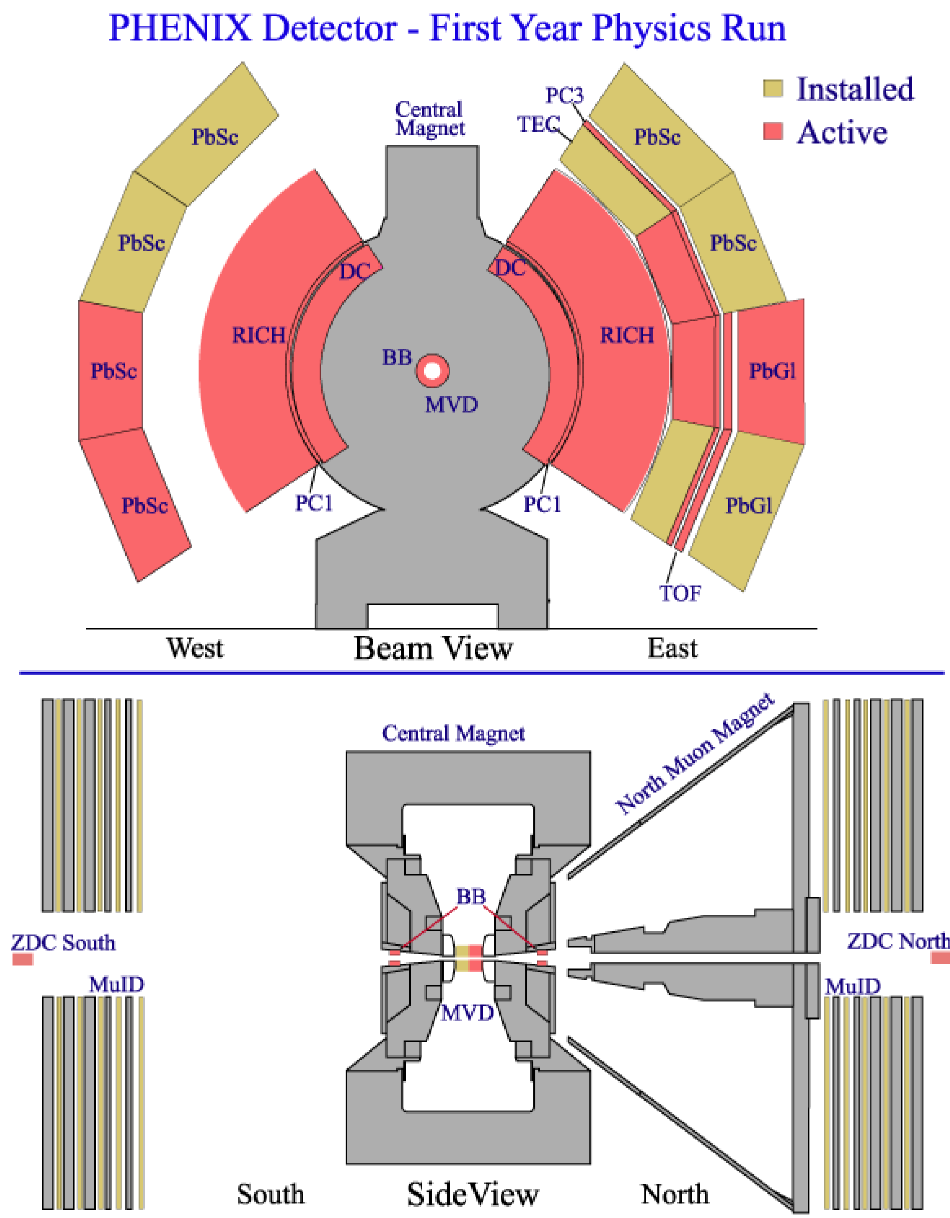
Requested input:

- Desired “beam run segments”
- Physics from same
- Investigate “27” and “37” week scenarios
- Collaboration/experiment status

- **A note on nomenclature:**
  - “Run-1” ≡ Summer-2000 Au+Au run at 130 GeV
  - “Run-2” ≡ 2001/2002 Au+Au/p+p at 200 GeV
  - “Run-3” ≡ 2003 run d+Au/p+p at 200 GeV

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)



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)
- "Measurement of single electrons and implications for charm production in Au+Au collisions at $\sqrt{s_{NN}}$ = 130 GeV", PRL 88, 192303 (2002)

  "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

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

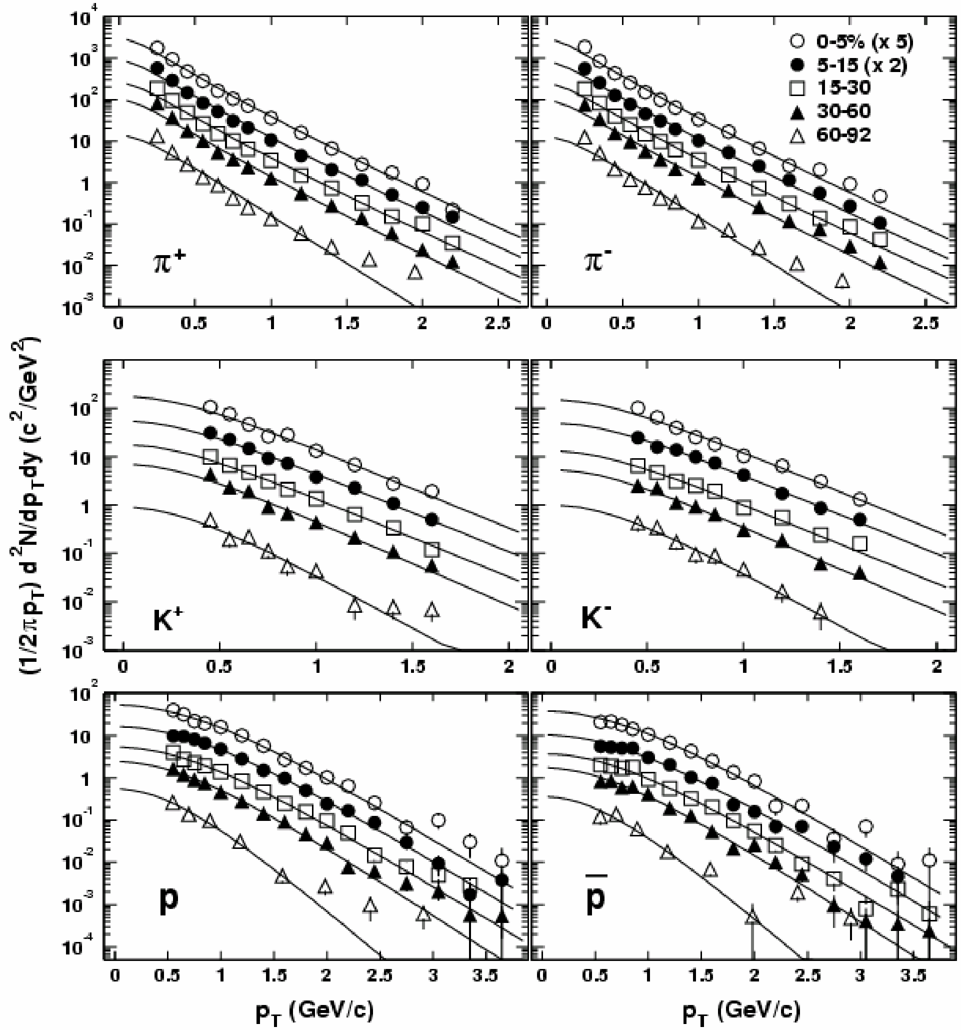


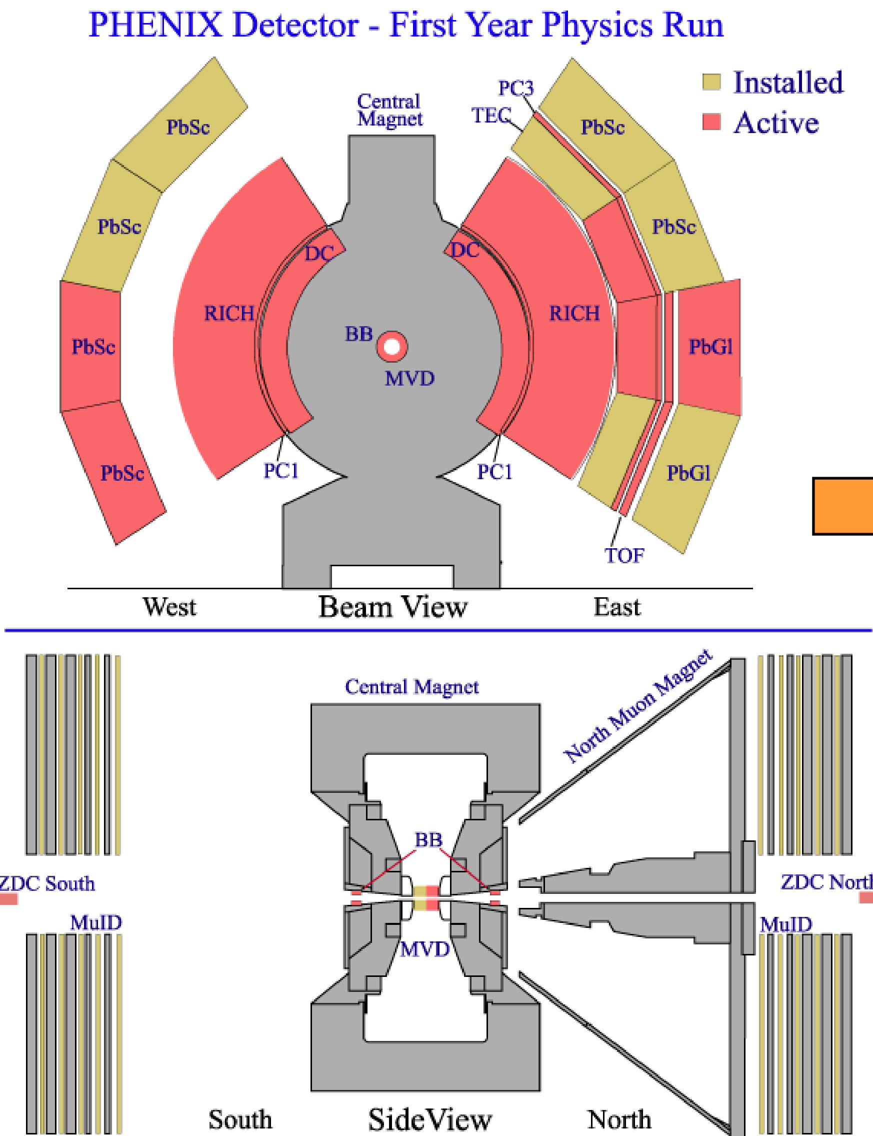
FIG. 19: The parameterization and the p_T hadron spectra for all five centrality selections.

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].

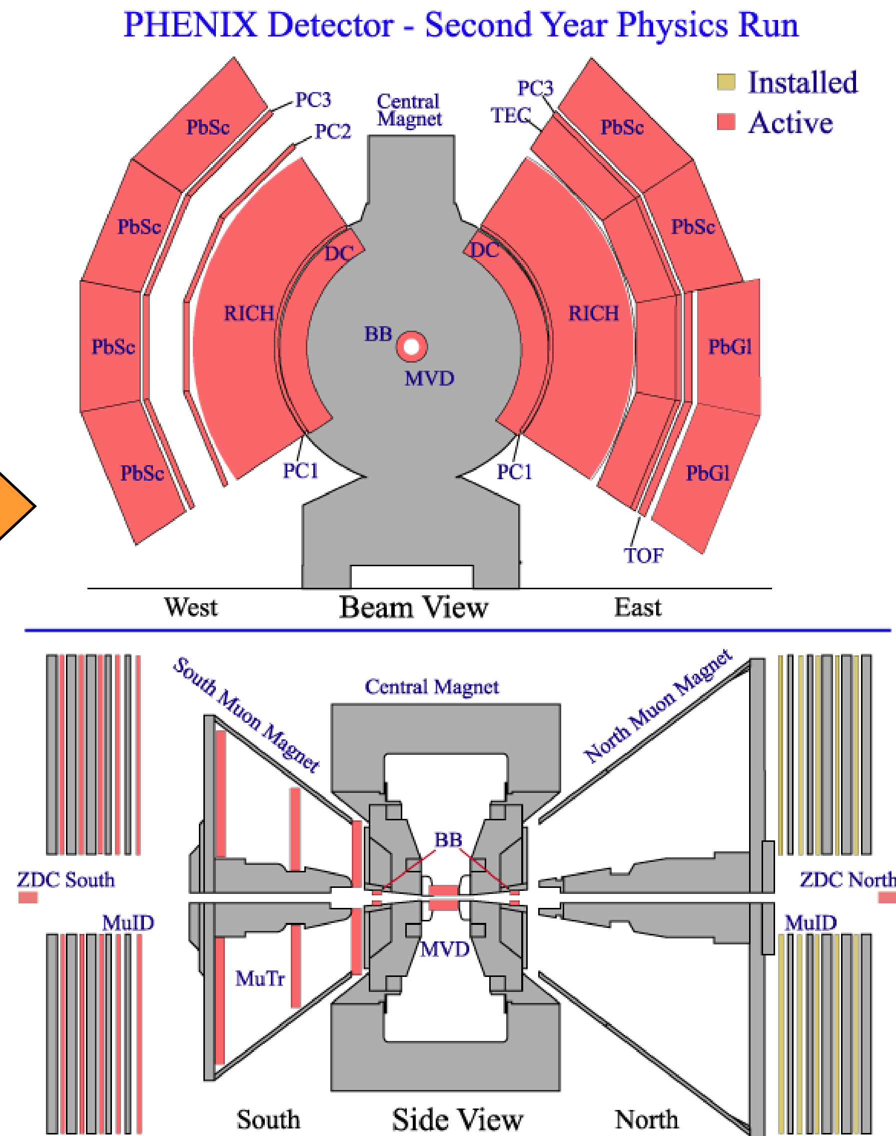
equilibrium time, and the freeze-out temperature which controls the duration of the expansion. The chemical freeze-out temperature is the temperature at which particle production ceases. The initial entropy or energy

From Run-1 to Run-2

Run-1 (2000)



Run-2 (2001-2)

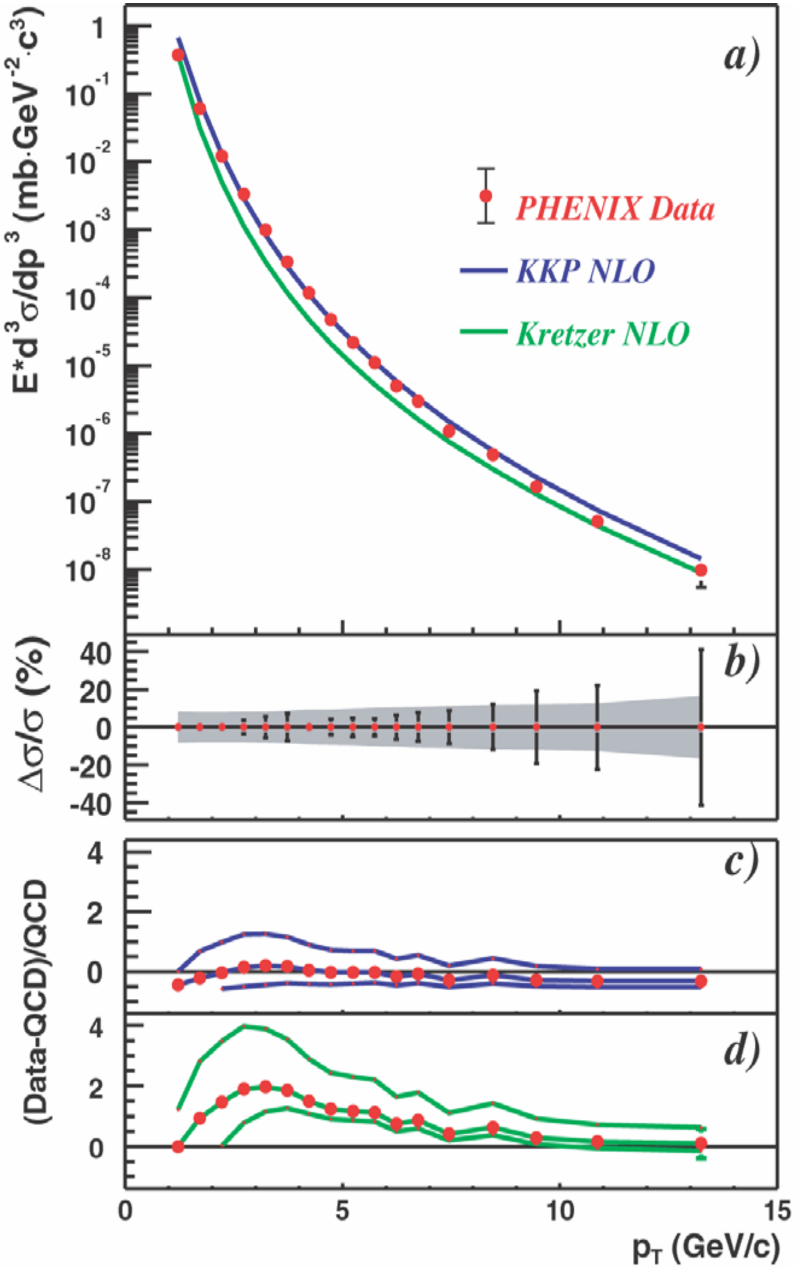


Run-2 Publications

- "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

Our First p+p 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)
- 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



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

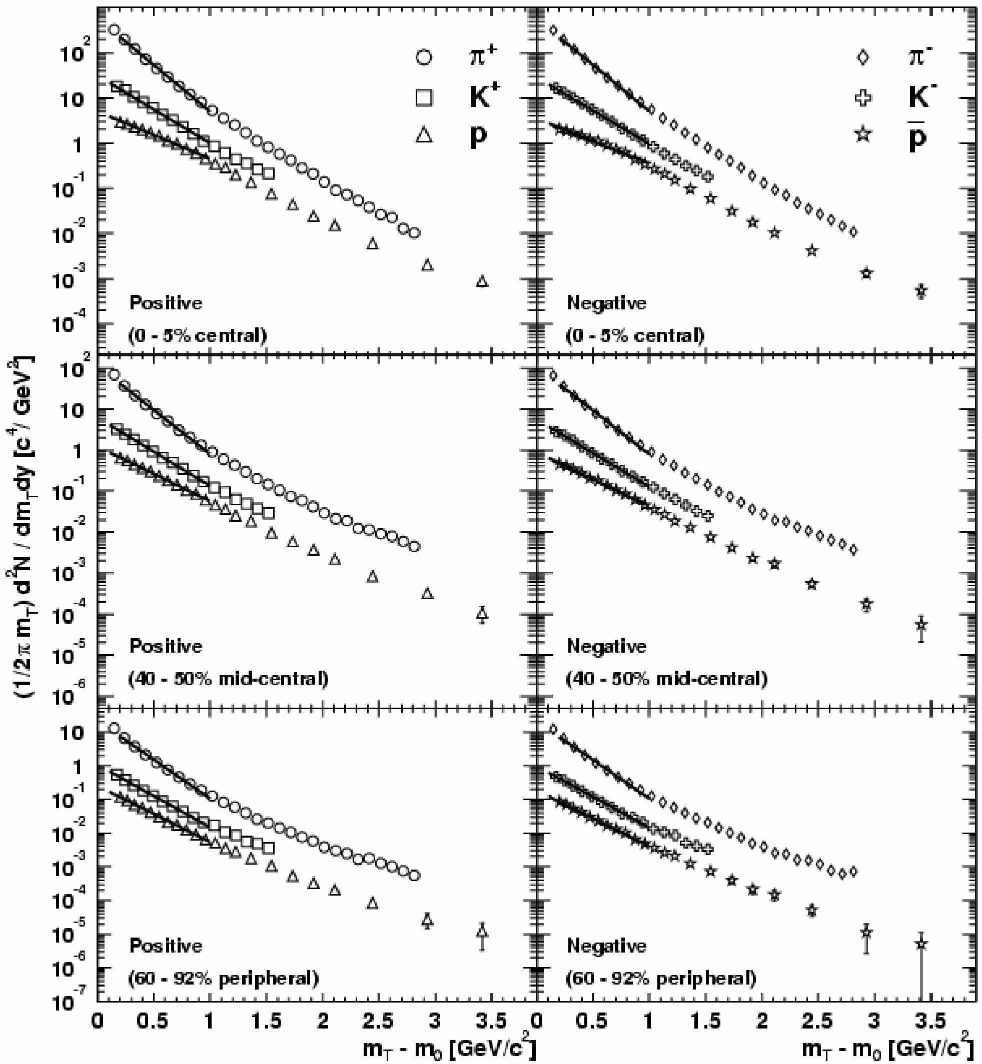
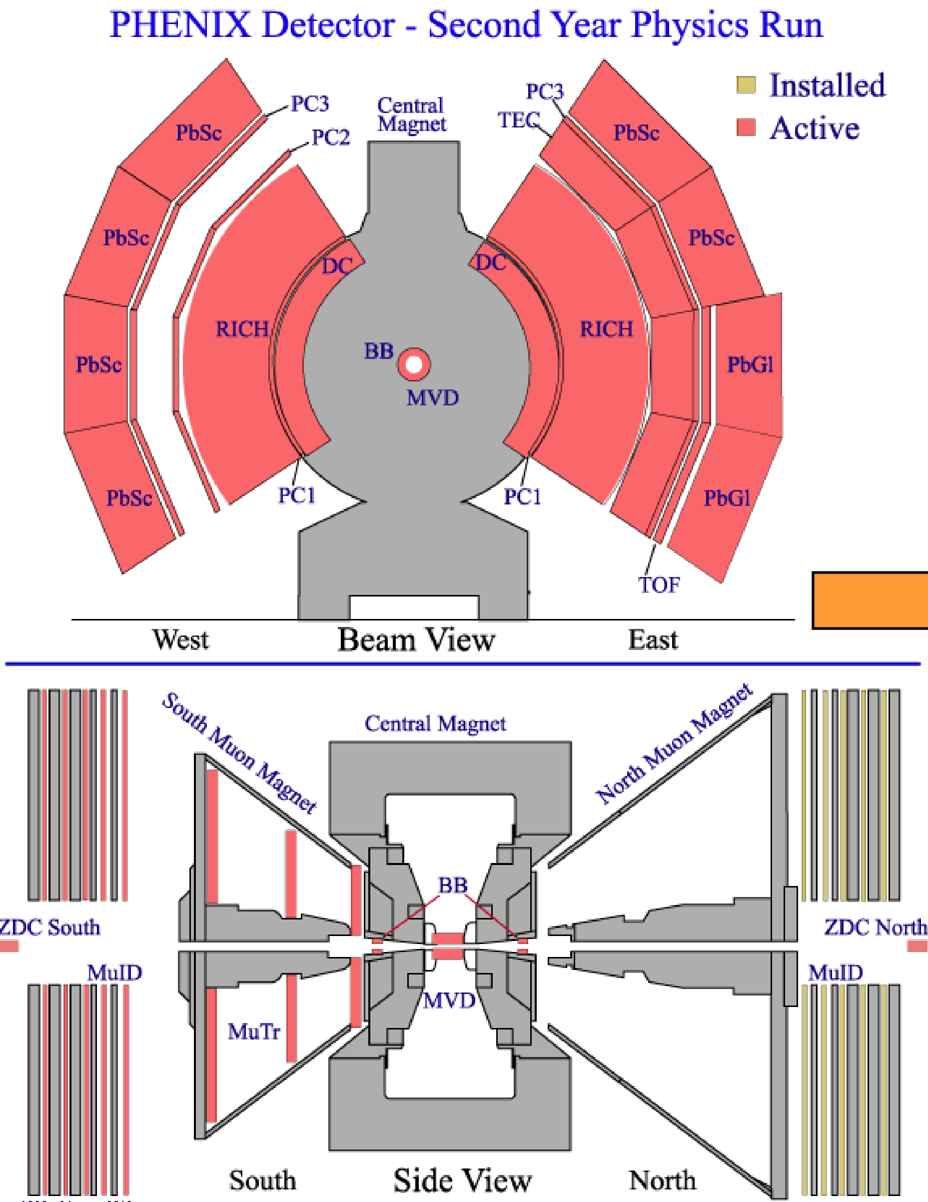
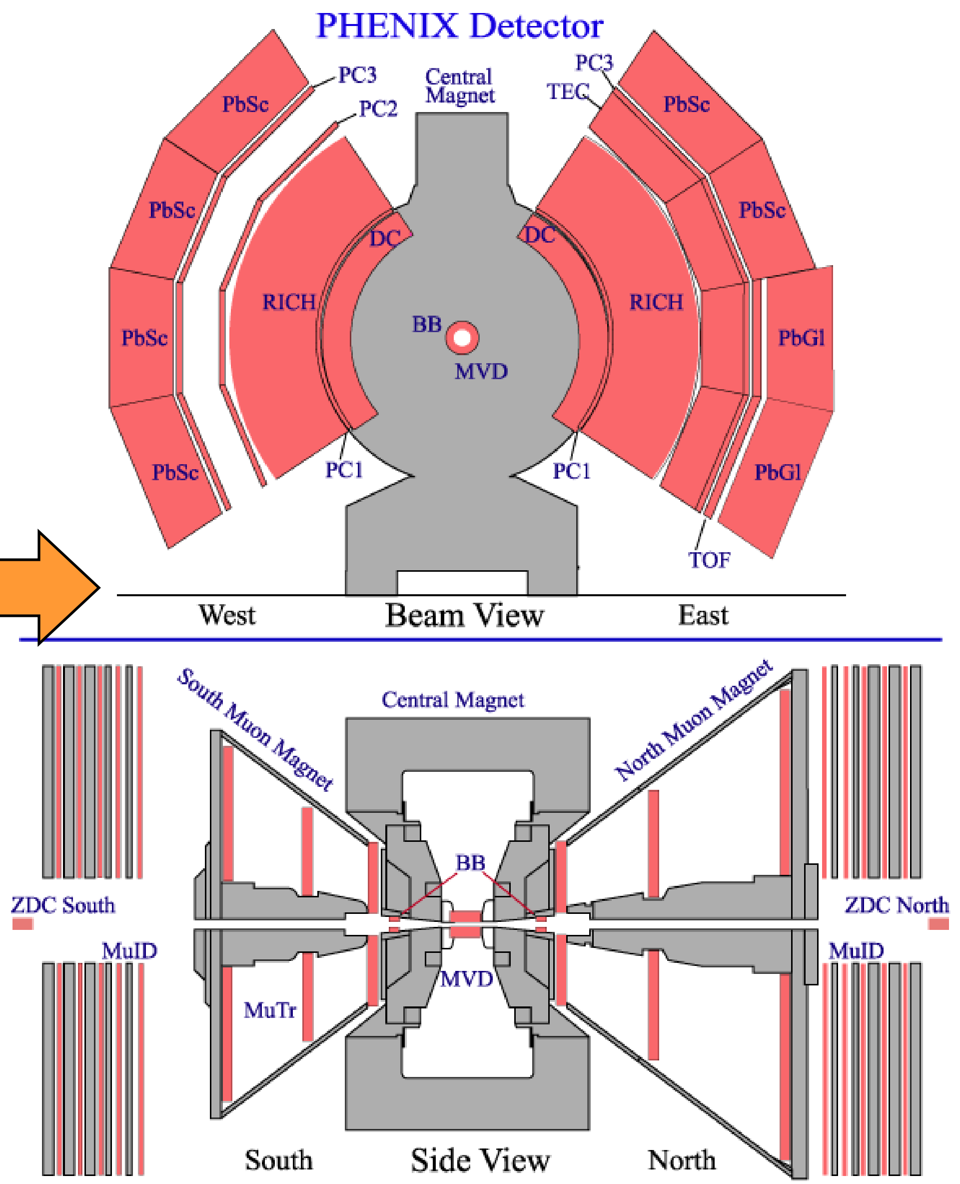


FIG. 9: Transverse mass distributions for $\pi^{\pm}$, $K^{\pm}$, protons and anti-protons for central 0–5% (top panels), mid-central 40–50% (middle panels) and peripheral 60–92% (bottom panels) in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The lines on each spectra are the fitted results using m_T 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-3 and Beyond





Run-3: Design Configuration!

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

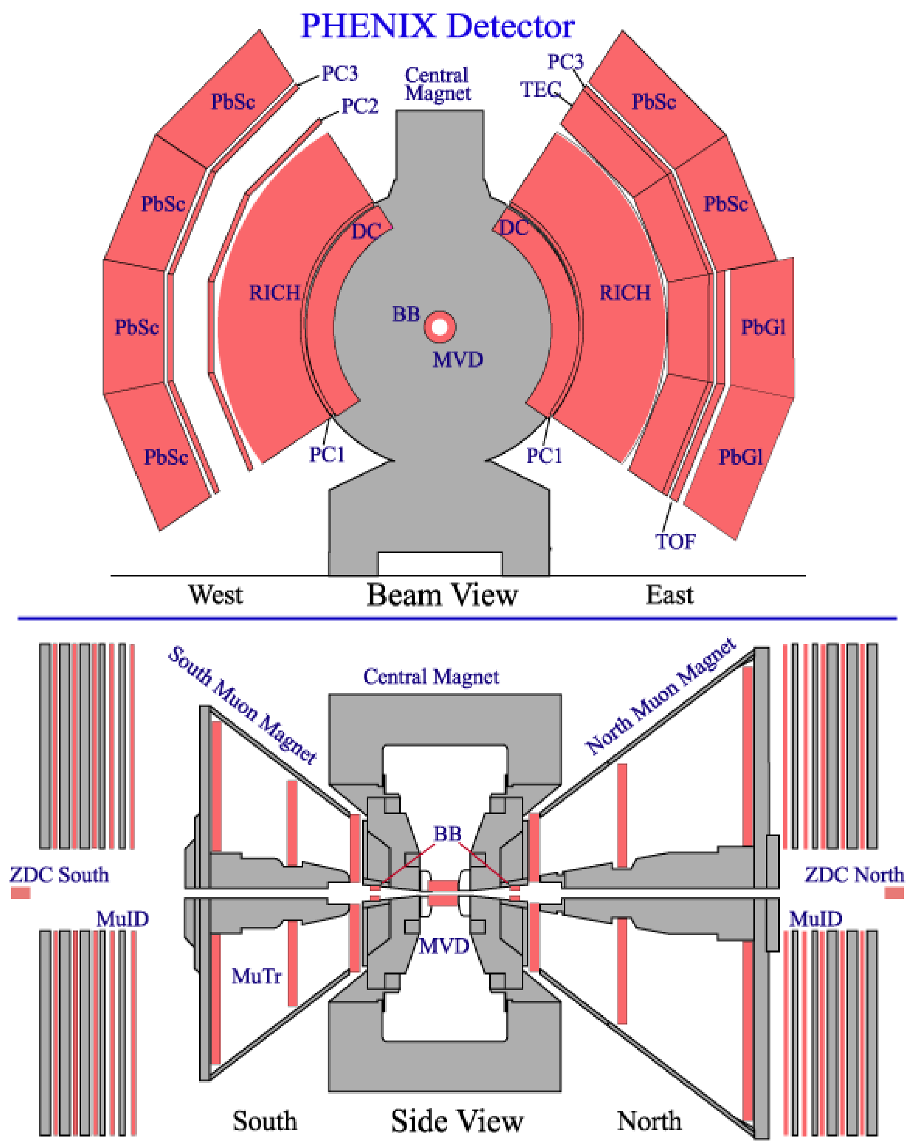
Muon Arm Tracking
- Muon Tracker: **North Muon Tracker**

Calorimetry
- PbGl
- PbSc

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

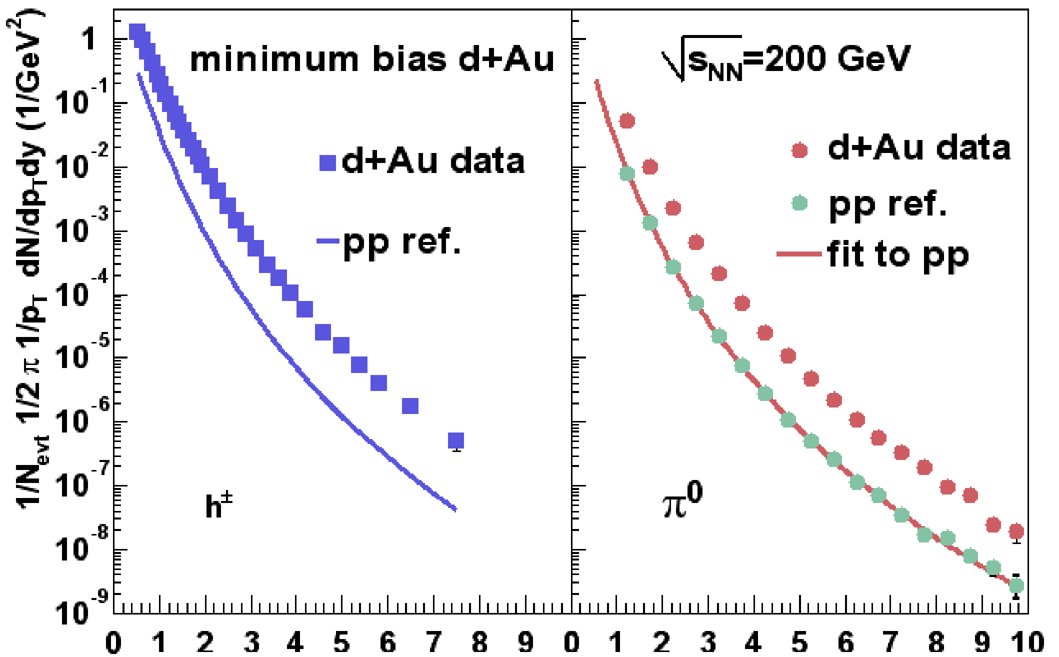
Global Detectors
- BBC
- ZDC/SMD **Local Polarimeter**
- **Forward Hadron Calorimeters**
- NTC
- MVD

Online Calibration and Production

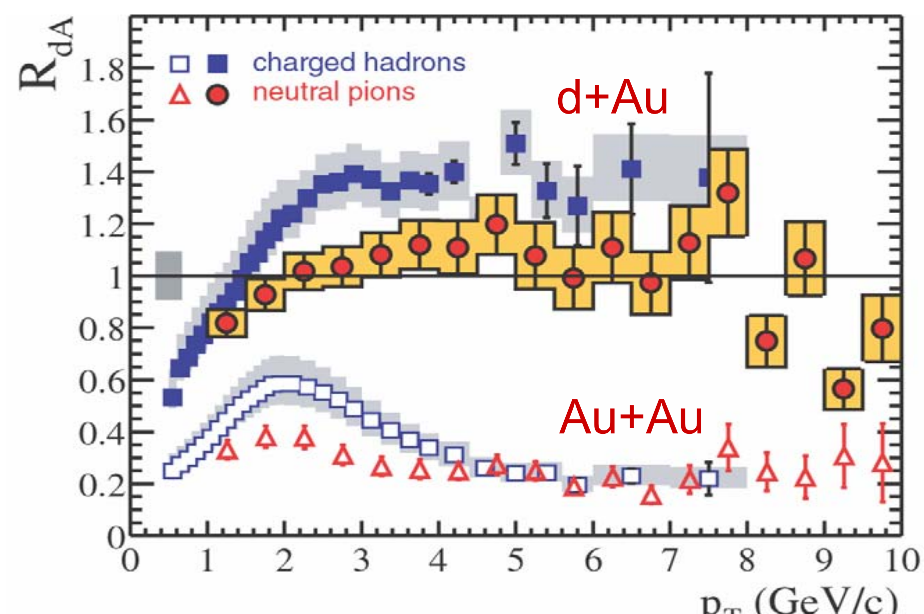


Run-3 Publications

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

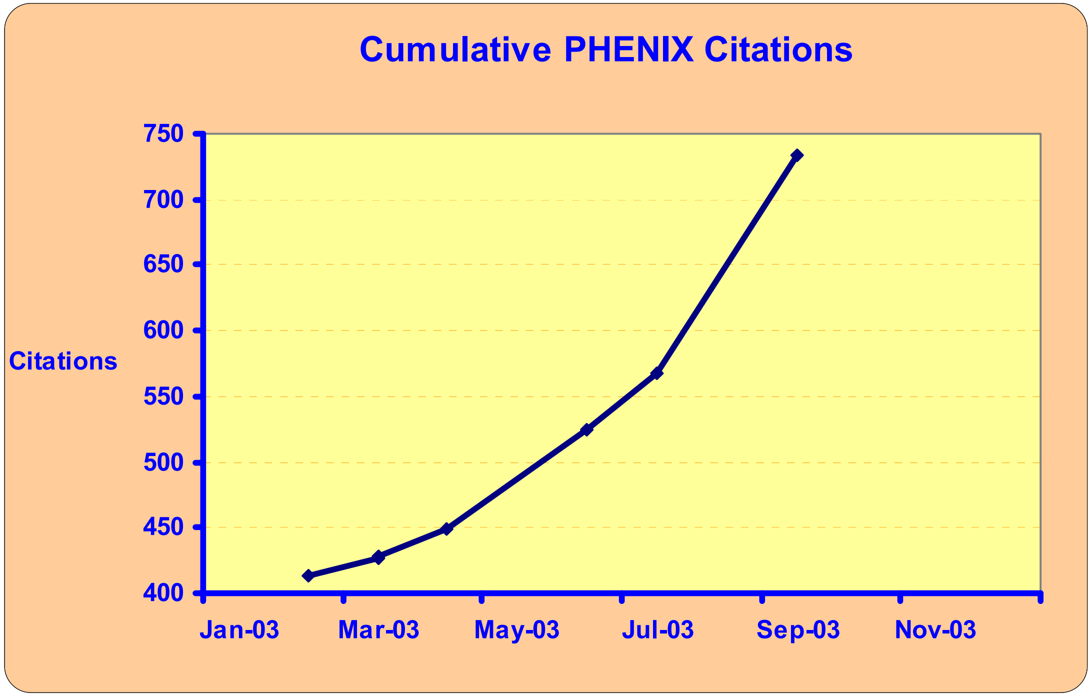


- PID-ed particles (π^0's) out to the highest p_T's PHENIX's unique contribution to the June "press event"



Publication Summary

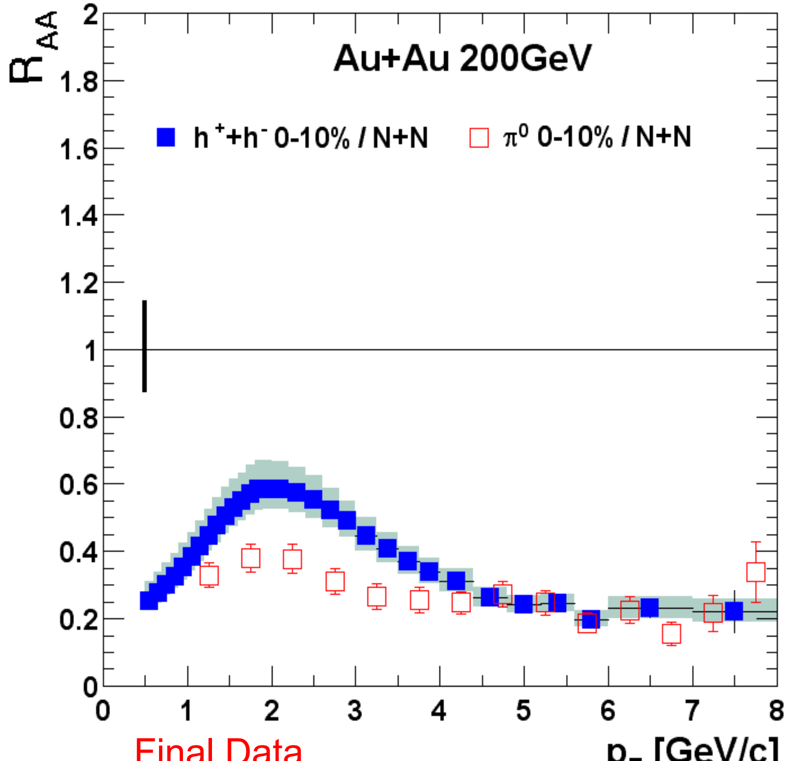
- **Run-1**
  - 12 publications
  - First 5 are "TopCites"
  - One "archival" summary
- **Run-2**
  - 8 submissions to date
  - 6 accepted/published
  - Several more still in progress
  - One "archival" summary
- **Run-3**
  - One publication
  - Many to follow



Forthcoming Run-3 Results

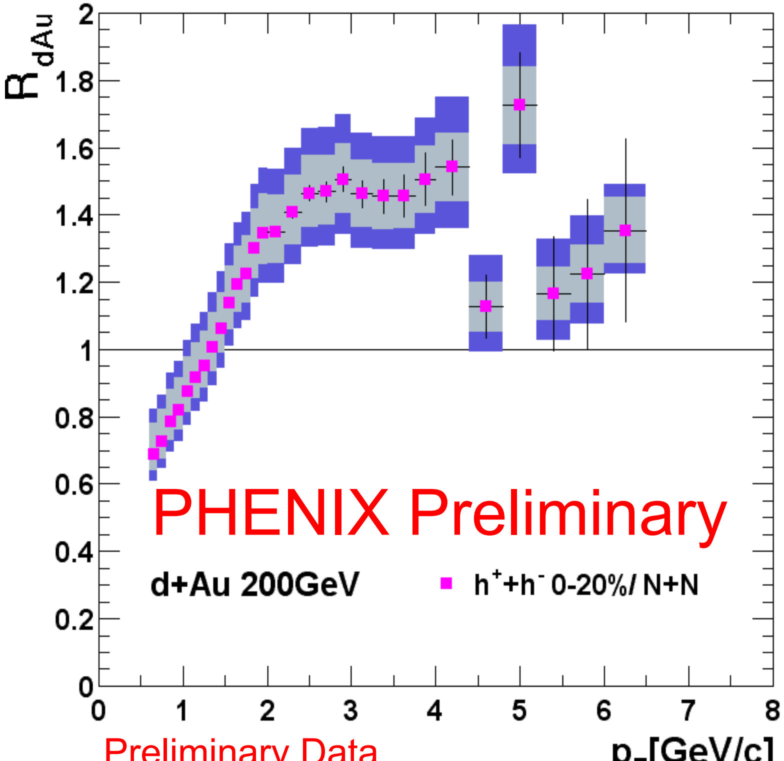
- **Centrality selected**
  - **Charged hadrons**
  - **Identified charged hadrons**
  - **π^0's**
- **Opposite centrality evolution of Au+Au compared to d+Au control.**

Au + Au



Final Data

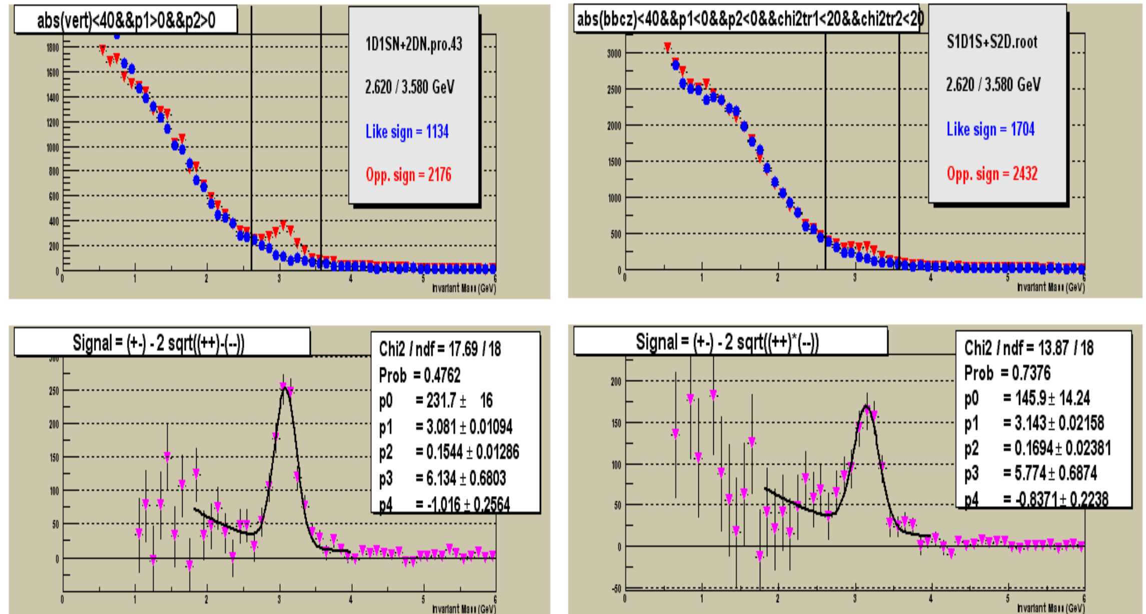
d + Au Control



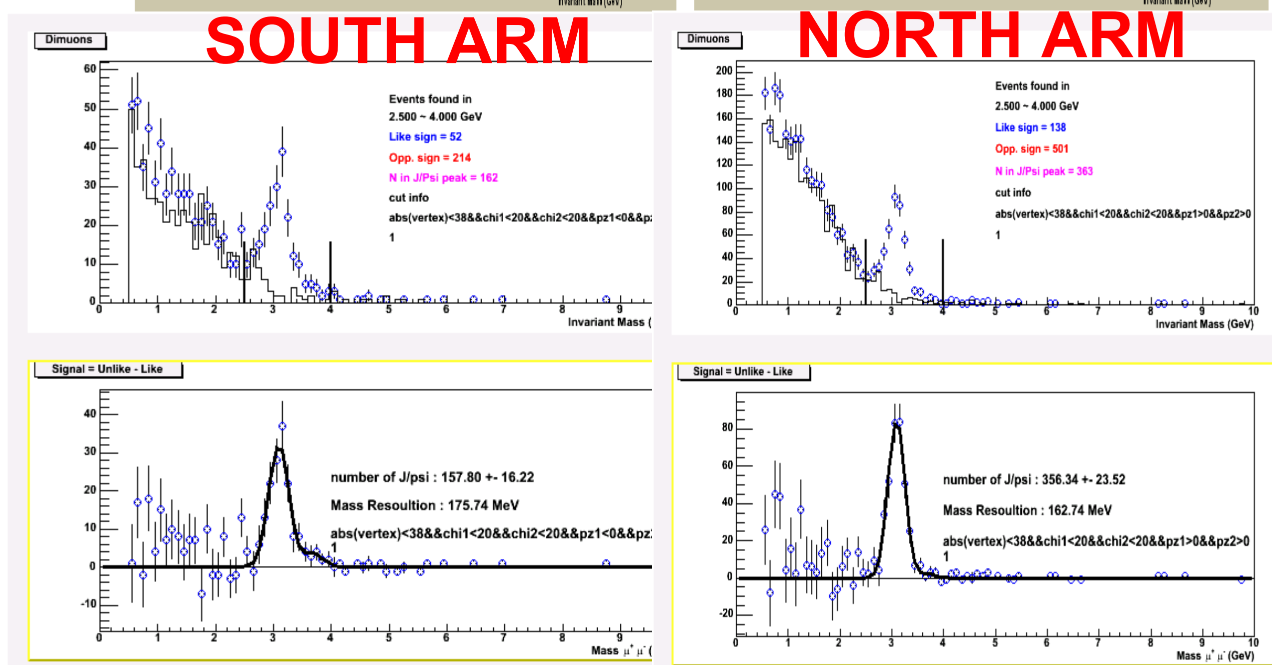
Preliminary Data

Run-3 J/Ψ's

- d+Au



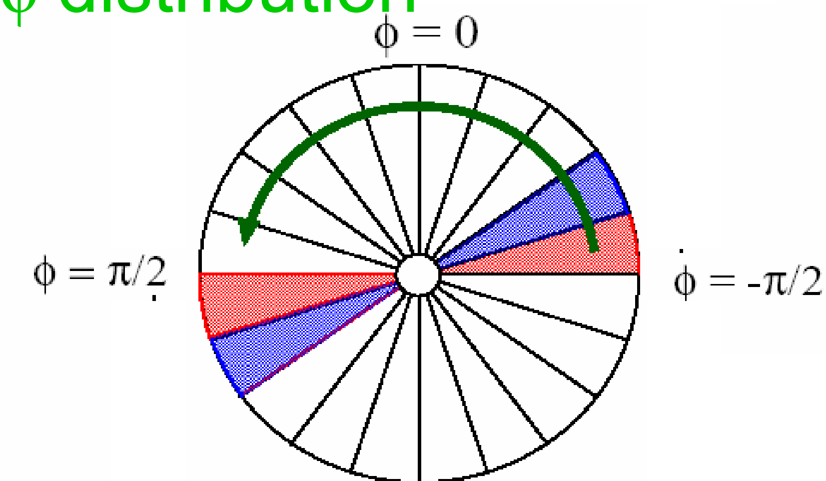
- p+p



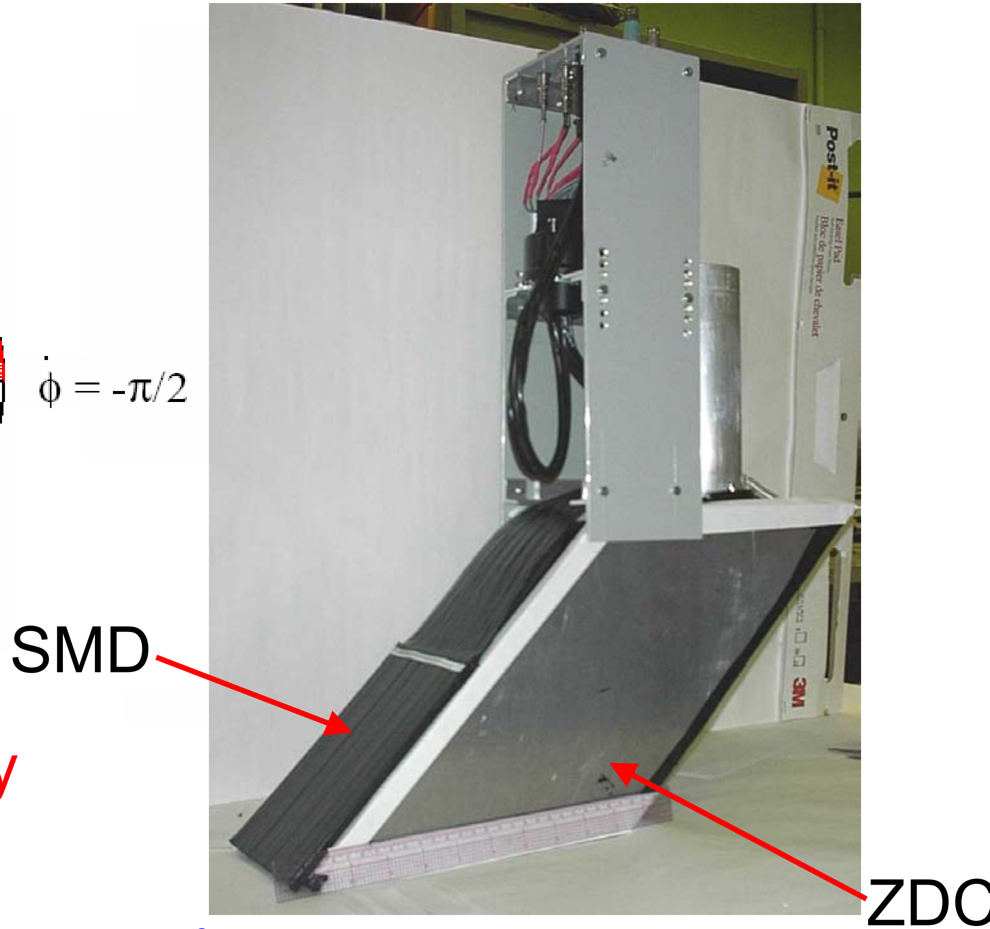
Run-3 Spin Results

- **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

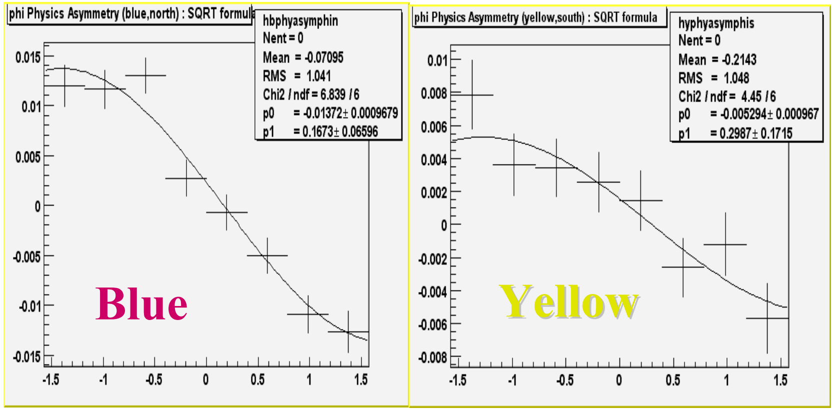


- Then longitudinally polarized protons used to obtain first glimpse of $\mathbf{A_{LL}}(\pi^0)$

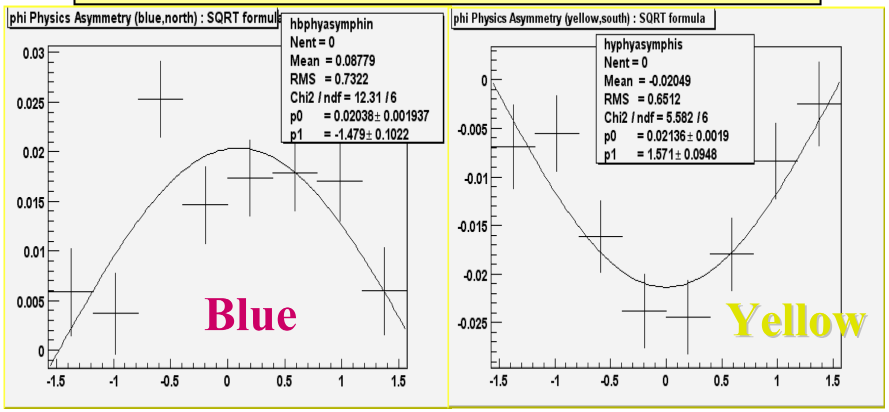
Local Polarimeter at PHENIX

Run-3

Spin Rotators OFF

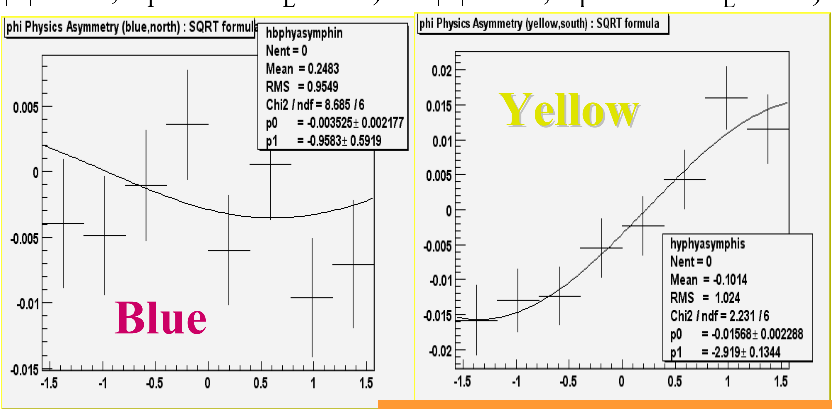


Spin Rotators ON, Current Reversed



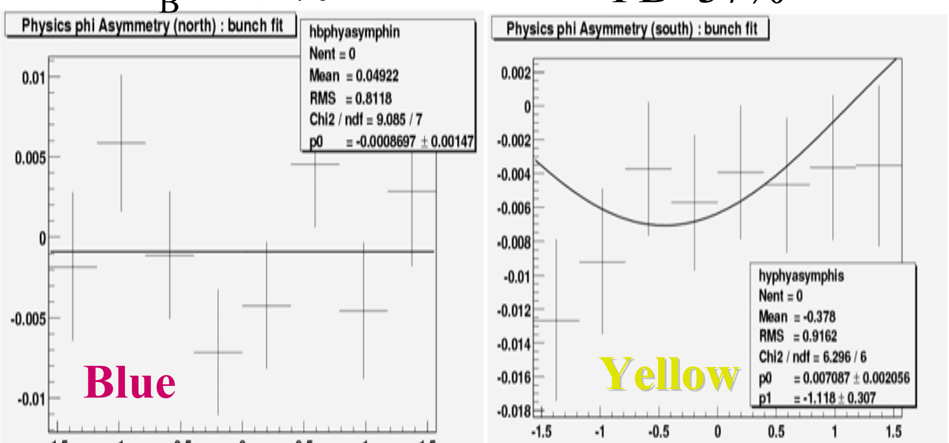
Spin Rotators ON, Almost…

|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%

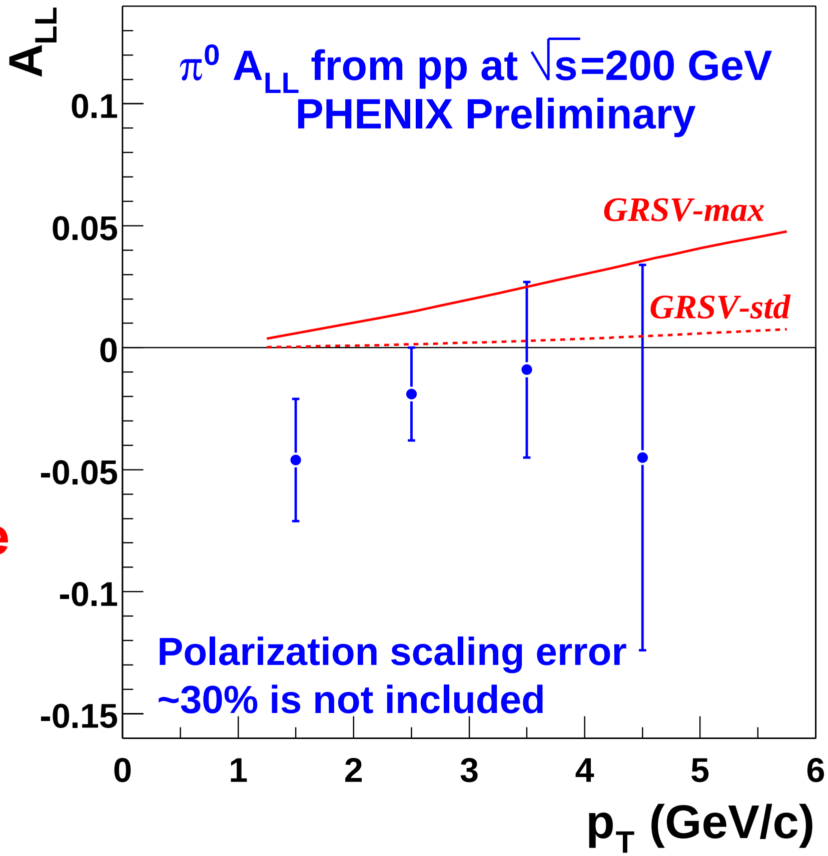


Essential to success of Run-3 spin physics!

First Results on A_{LL}

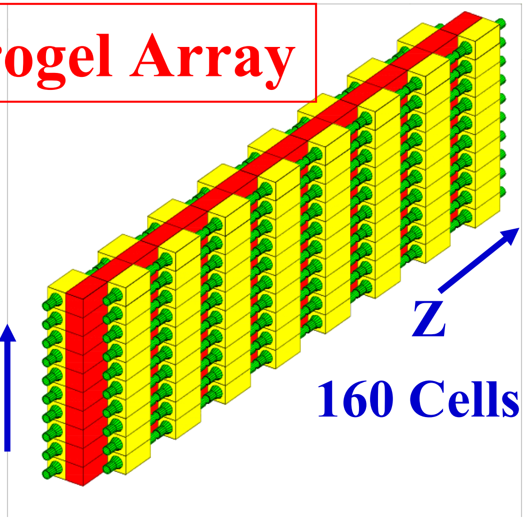
- Presented this month at Dubna spin conference
- Extensive (ongoing) study of systematics
  - Bunch shuffling, background studies, A_L checks, ...
  - Relative luminosity precision ~ 2.5×10^{-4}
  - Contribution to A_{LL} < 0.2%
  - Dominated by statistical errors from 0.22 pb^{-1} sample
- A very important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

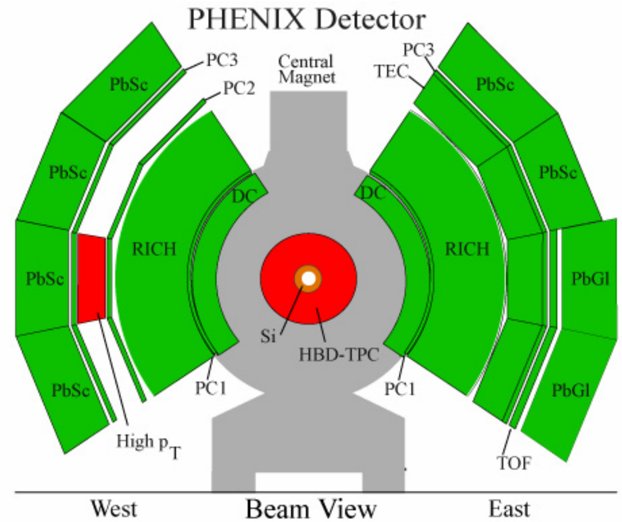
Calculations: B.Jäger *et al.*, PRD67, 054005 (2003)



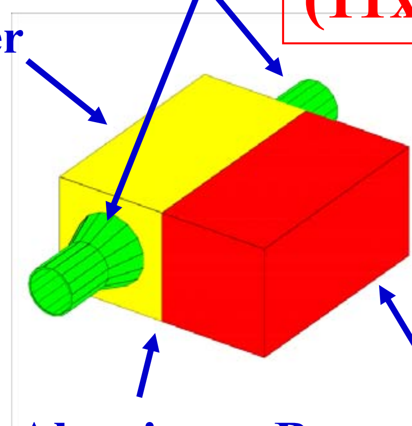
Run-4 Additions

Aerogel Array



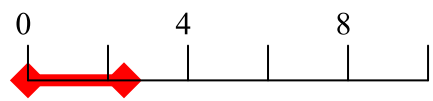
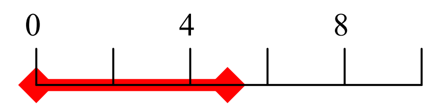
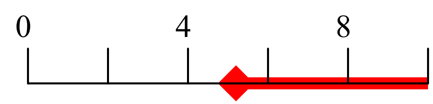
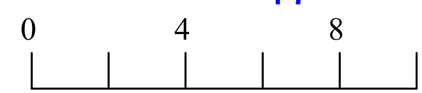


Aerogel Cell (11x22x11 cm^3)



- 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.

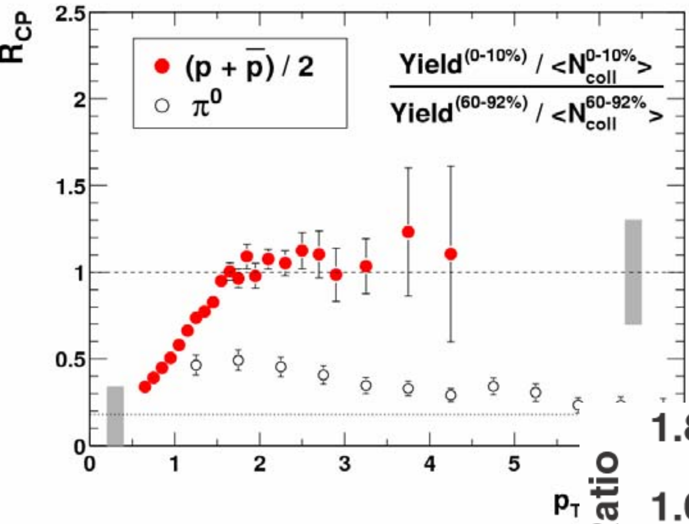
Extended PID with Aerogel

		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 - 

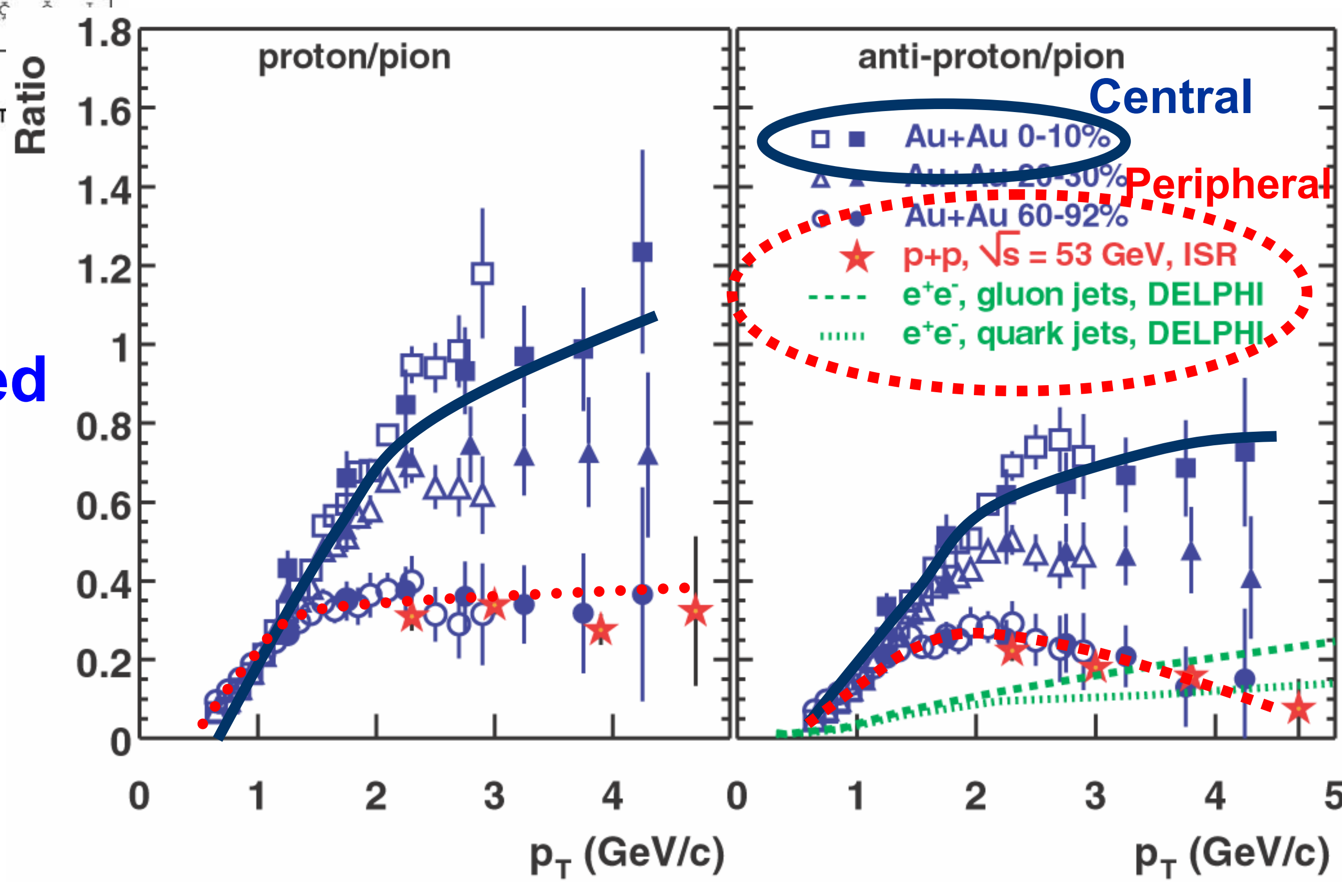
PHENIX

Physics Motivations

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



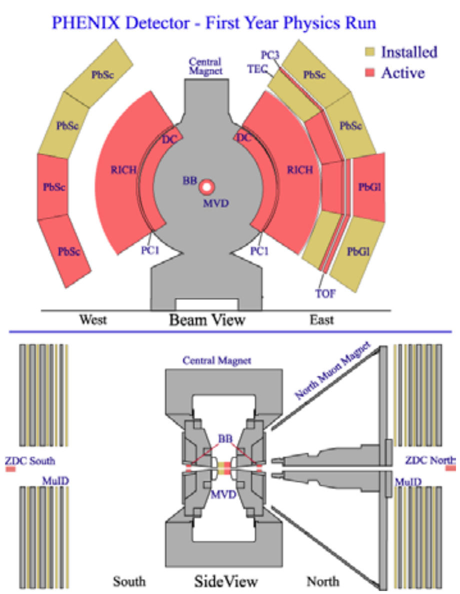
- **Run-4 request should extend results for PID-ed K's and p's into the 5-7 GeV/c range**



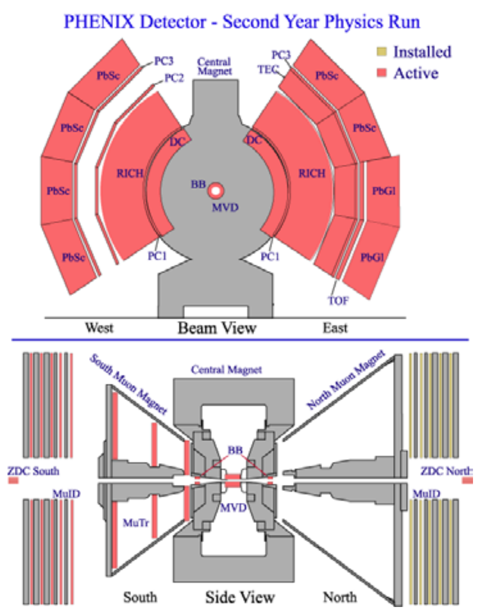
PHENIX: Run History

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

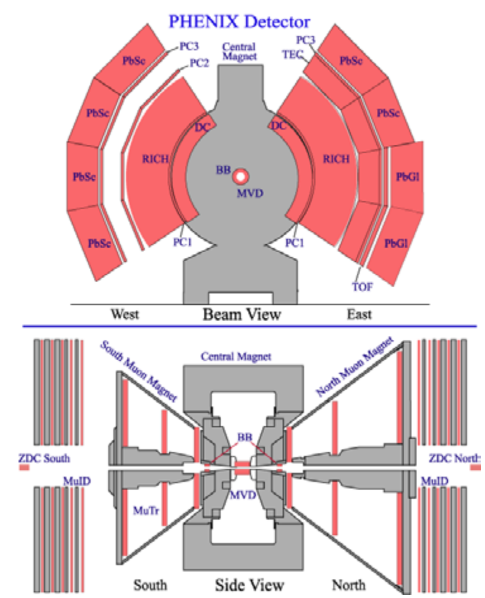
Run-1



Run-2



Run-3



Run Request Summary

- **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	200	14	316 μb^{-1}	12.3 pb^{-1}
	p+p	200	(5 development)	-	
5	Si+Si	200	9	5.5 nb^{-1}	4.3 pb^{-1}
	p+p	200	5	3.0 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	200	19	521 μb^{-1}	20.2 pb^{-1}
	p+p	200	5	1.2 pb^{-1}	1.2 pb^{-1}
5	Si+Si	200	14	12 nb^{-1}	9.6 pb^{-1}
	p+p	200	10	10 pb^{-1}	10 pb^{-1}
6	Au+Au	62.4	19	117 μb^{-1}	4.3 pb^{-1}
	p+p	500	2	5.4 pb^{-1}	5.4 pb^{-1}
7	p+p	200	19	158 pb^{-1}	158 pb^{-1}
	p+p	62.4	5	7 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}

The Run Plan At A Glance

PHENIX

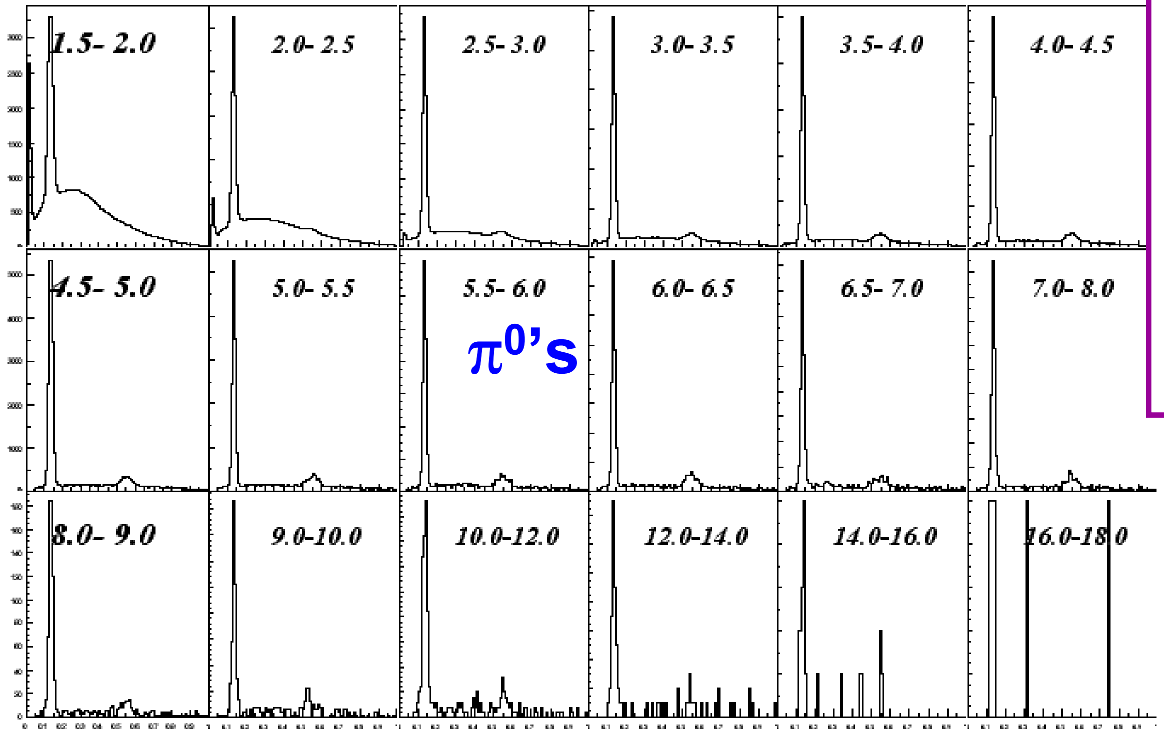
- An quantitative, integrated, planning exercise:
  - Quantitative:
    - Direct implementation of CAD guidance
    - Yield estimates (whenever possible) based on existing PHENIX measurements and known scaling laws

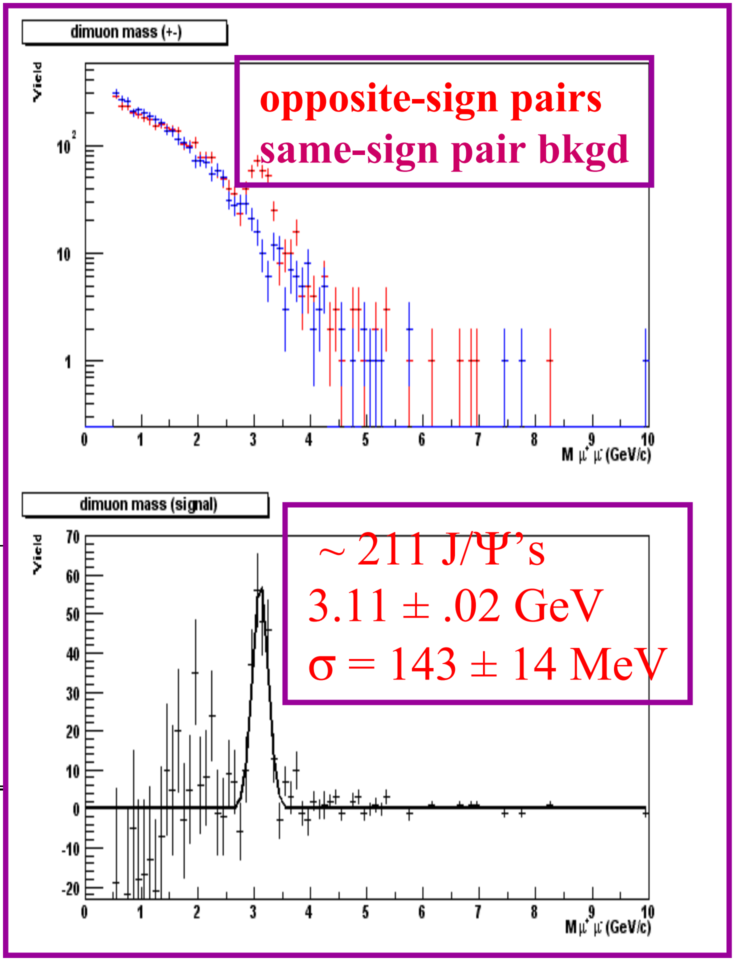
		2004 (Run-4)	2005 (Run-5)	2006 (Run-6)	2007 (Run-7)	2008 (Run-8)	2009 (Run-9)	2010 (Run-10)
27 Weeks	J/Ψ p_T(max)	14 weeks Au+Au 200 GeV $123\ \mu b^{-1}$ 197 197 $4.78\ pb^{-1}$ 1641 J/Ψ's 17.8 GeV/c	9 weeks Si+Si 200 GeV $2.2\ nb^{-1}$ 28 28 $1.69\ pb^{-1}$ 1574 J/Ψ's 15.8 GeV/c	19 weeks Au+Au 62.4 GeV $45\ \mu b^{-1}$ 197 197 $1.76\ pb^{-1}$ 124 J/Ψ's 10.4 GeV/c	0 weeks Au+Au 200 GeV $0\ \mu b^{-1}$ 197 197 $0.00\ pb^{-1}$ 0 J/Ψ's 0.0 GeV/c	19 weeks Au+Au 200 GeV $841\ \mu b^{-1}$ 197 197 $32.64\ pb^{-1}$ 11213 J/Ψ's 22.5 GeV/c	0 weeks Au+Au 200 GeV $0\ \mu b^{-1}$ 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
27 Weeks	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
27 Weeks		$4.78\ pb^{-1}$	$7.64\ pb^{-1}$	$9.40\ pb^{-1}$	$71.01\ pb^{-1}$	$103.65\ pb^{-1}$	$314.41\ pb^{-1}$	$314.92\ pb^{-1}$
37 Weeks	J/Ψ p_T(max)	19 weeks Au+Au 200 GeV $203\ \mu b^{-1}$ 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 $45\ \mu b^{-1}$ 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 $1503\ \mu b^{-1}$ 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
37 Weeks	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
37 Weeks		$8.34\ pb^{-1}$	$15.83\ pb^{-1}$	$19.69\ pb^{-1}$	$98.55\ pb^{-1}$	$156.90\ pb^{-1}$	$533.61\ pb^{-1}$	$534.52\ pb^{-1}$

  - **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

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





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

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

Quantity to be Measured	Category*	Physics Objective
e^+e^-, $\mu^+\mu^-$		
• $\rho \to \mu^+\mu^-/\rho \to \pi\pi$, $d\sigma/dp_\perp$ $\omega \to e^+e^-/\omega \to \pi\pi$, $d\sigma/dp_\perp$	BCD	Basic dynamics (T, τ, etc.,) for a hot gas, 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 ($gg \to s\bar{s}$)
✓ $J/\psi \to e^+e^-, \mu^+\mu^-$ $\psi' \to \mu^+\mu^-$ $\Upsilon, \to \mu^+\mu^-$	QGP, QCD	Yield suppression and the distortion of p_T spectra due to Debye screening in deconfinement transition (D.T.) [4]
• $1 < m_T(l^+l^-) < 3$ GeV (rate and shape)	ES, QGP	Thermal radiation of hot gas, and effects of QGP [5, 6, ?]
• $m_{l^+l^-} > 3$ GeV $\to \mu^+\mu^-$	QCD QGP	A-dependence of Drell-Yan, and 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 (rate and shape)	ES, QGP	Thermal radiation of hot gas, and 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 QGP	Basic dynamics, flow, T, baryon density, stopping power, etc. 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 QGP	Evolution of the collision, $R_\perp$ 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 QGP	Local energy density, entropy 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.

PHENIX

Perspective

- **The machine achievements in the first 3 years of RHIC operations have been** *spectacular* **:**

  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**

PHENIX

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-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)

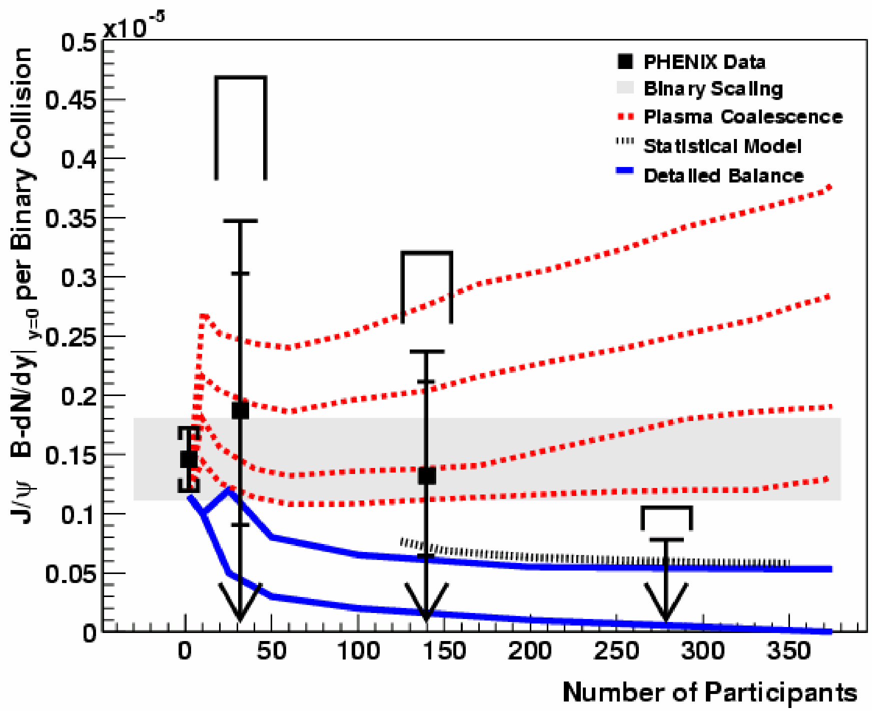


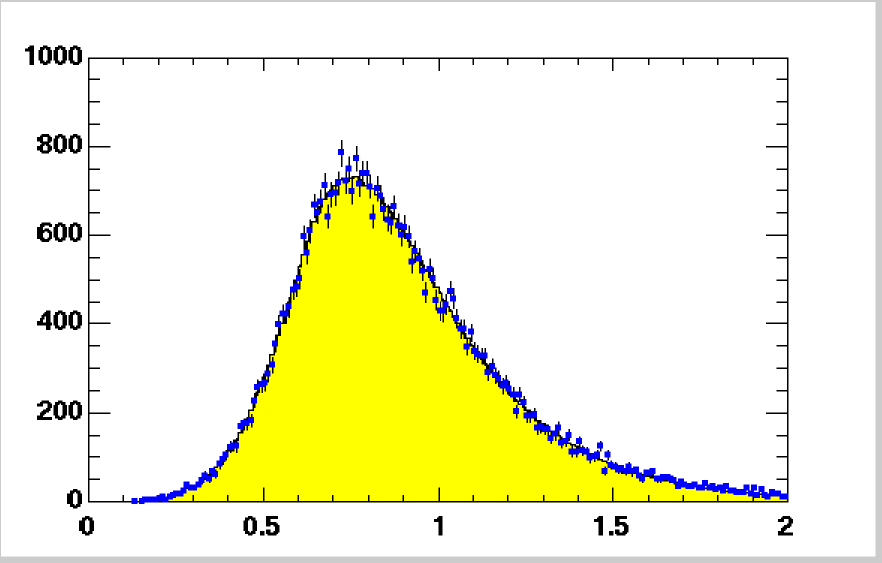
FIG. 6: (Color online) The J/ψ invariant yield per binary collision is shown from proton-proton reactions and three exclusive centrality ranges of Au-Au reactions all at $\sqrt{s_{NN}}$ = 200 GeV. The lowest curve is a calculation including "normal" nuclear absorption in addition to substantial absorption 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.

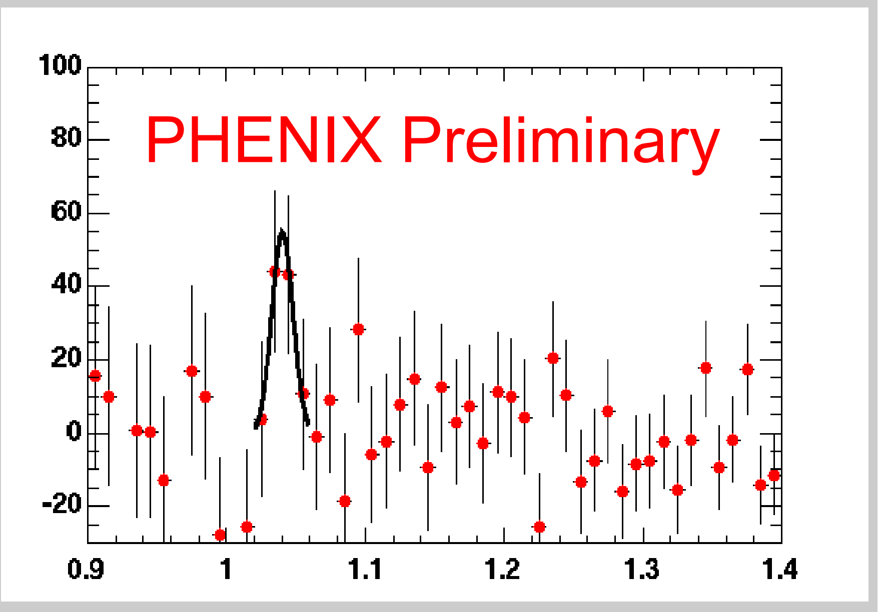
Run-4 Luminosity ($\phi \rightarrow e^+e^-$)

- 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)

PHENIX

- **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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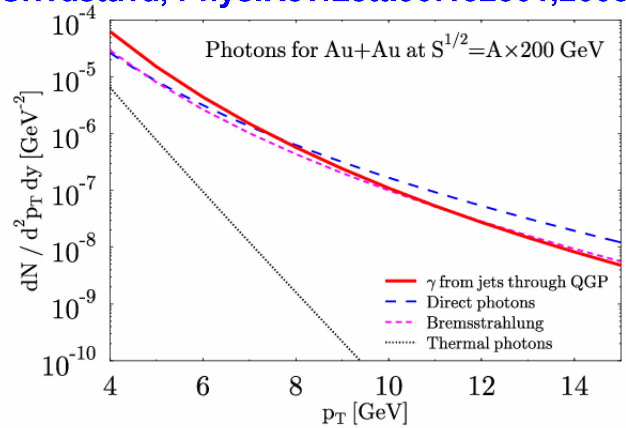
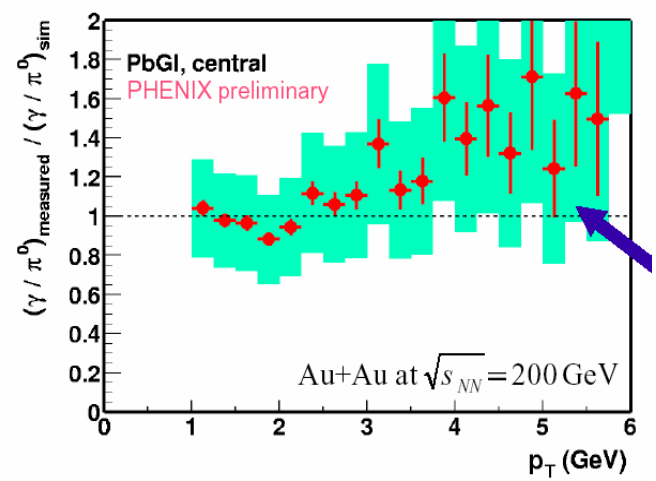
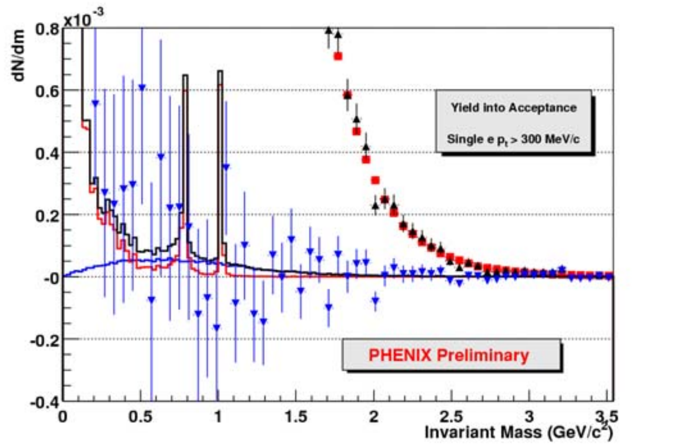


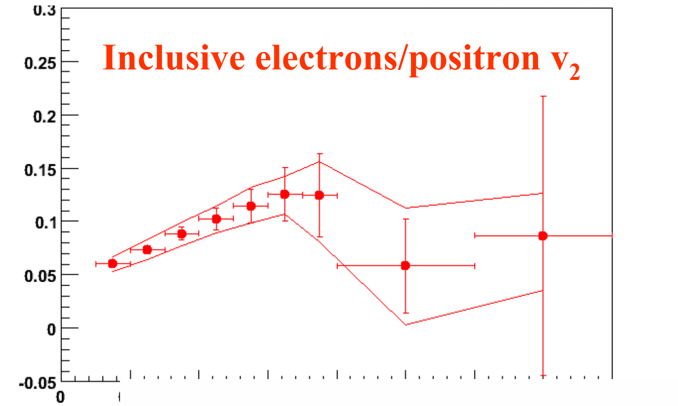
FIG. 1: Spectrum $dN/d^2p_\perp dy$ of photons at $y = 0$ for central collision of gold nuclei at $\sqrt{S_{NN}} = 200$ GeV at RHIC. We show the photons from jets interacting with the medium (solid line), direct hard photons (long dashed), bremsstrahlung photons (short dashed) and thermal photons (dotted).

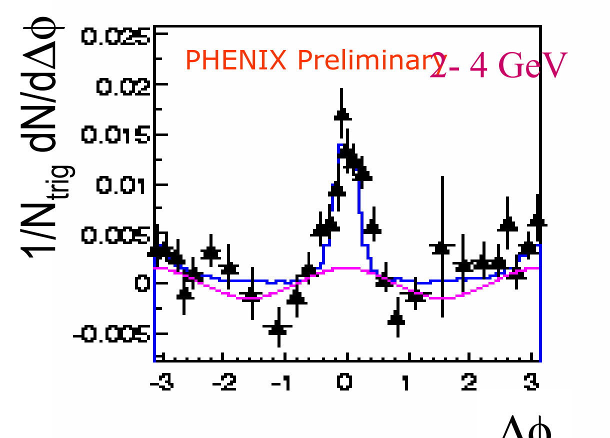


Run-4 Luminosity (Other Examples)

- 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







Recombination Tested

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

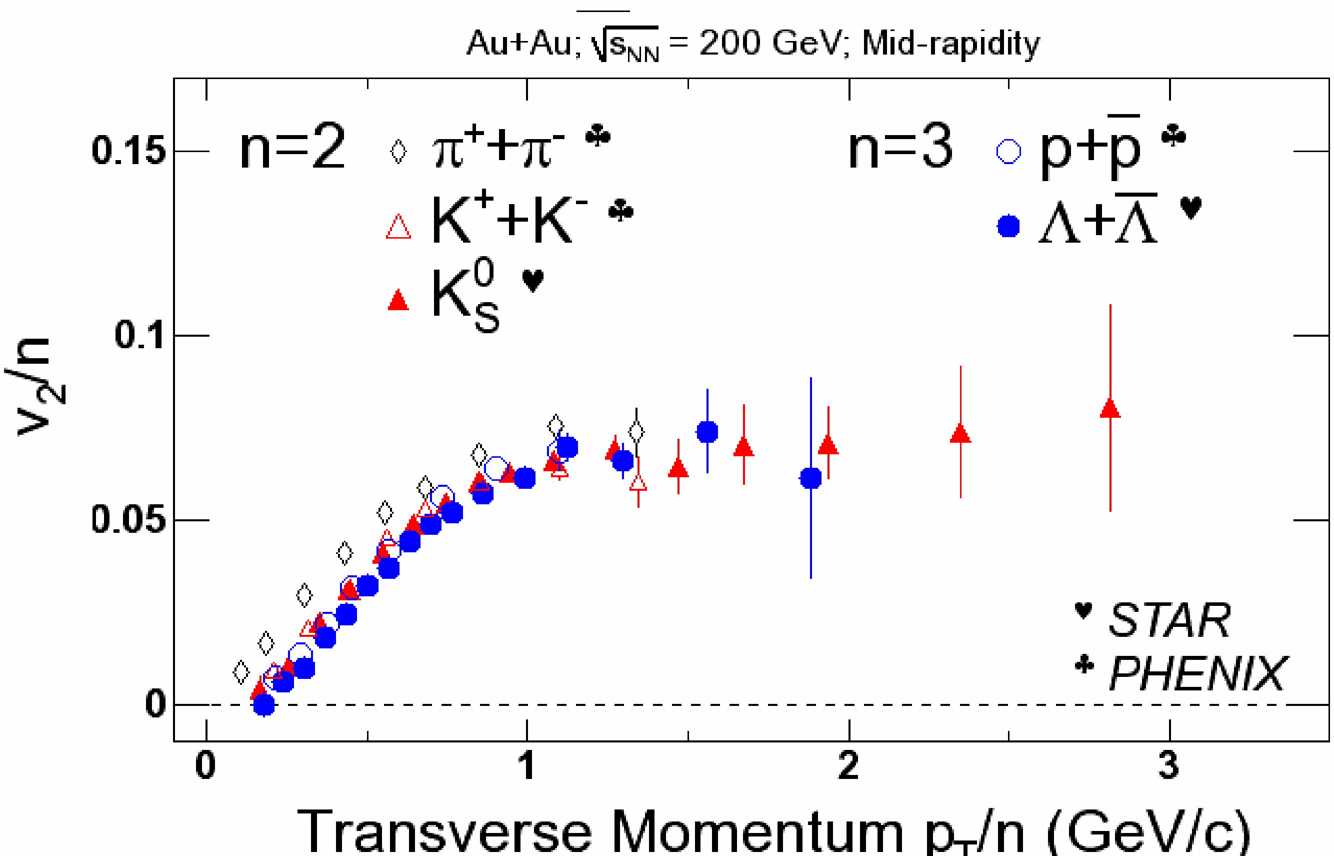
$$d^2n/dp_T d\phi \sim 1 + 2\, v_2(p_T) \cos(2\phi)$$

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

$$p_T \rightarrow p_T / n\ ,\ v_2 \rightarrow v_2 / n\ ,\quad n = 2,3 \text{ for meson,baryon}$$

if the flow pattern is established at the quark level

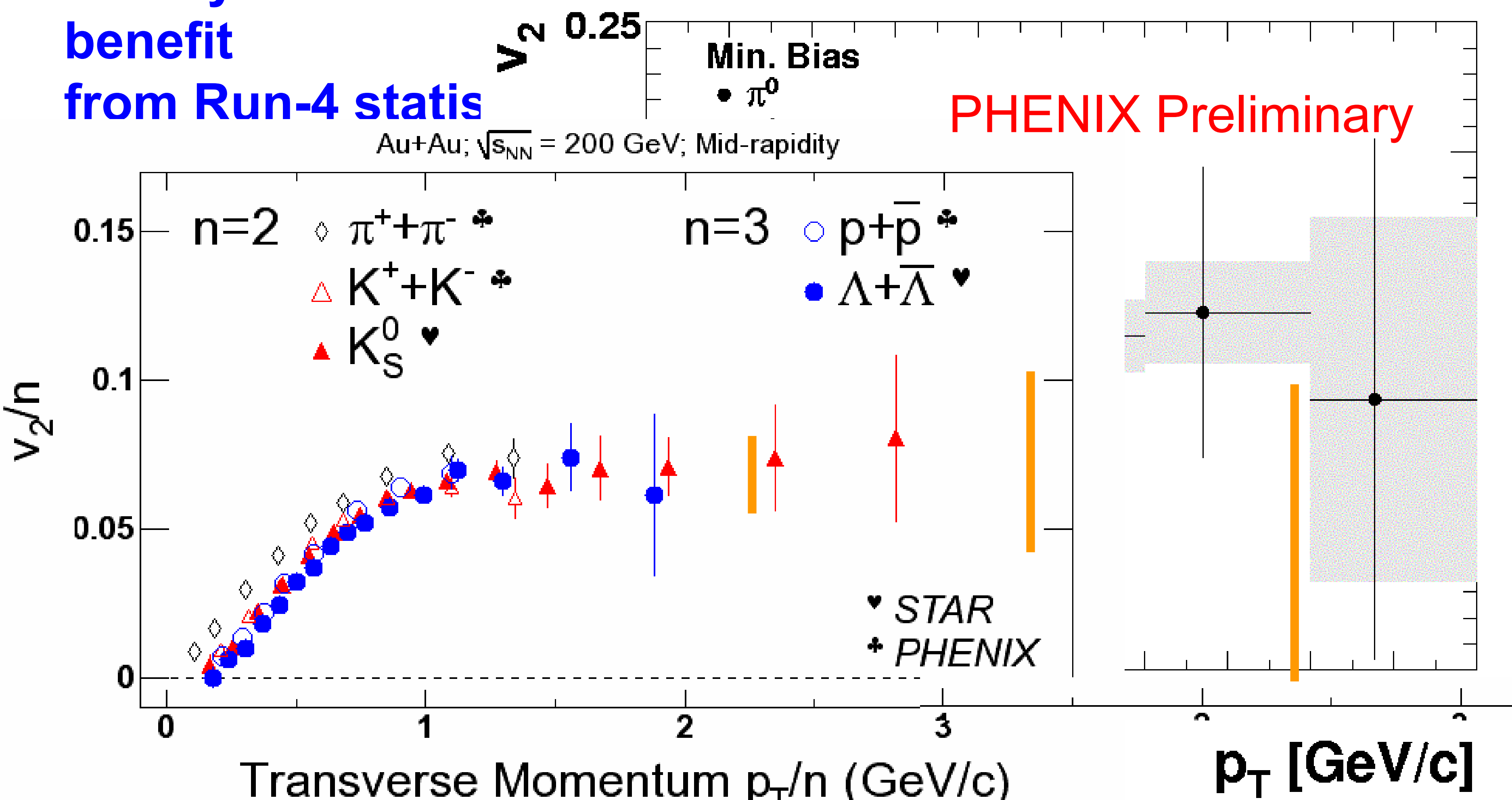
Compilation courtesy of H. Huang



Yet Another Luminosity Limited Observable

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

- Clearly would benefit from Run-4 statis



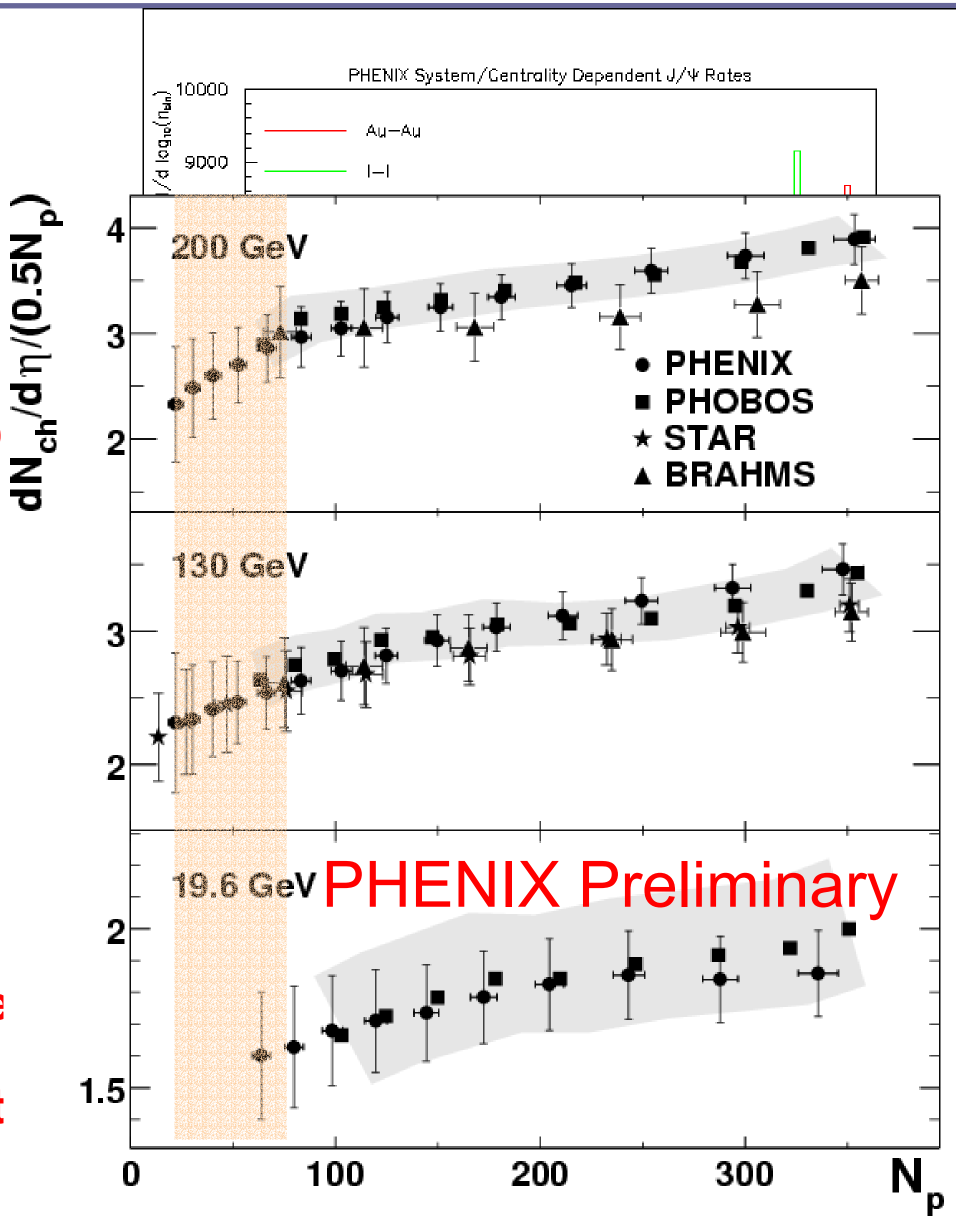
Run-5

- **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}	

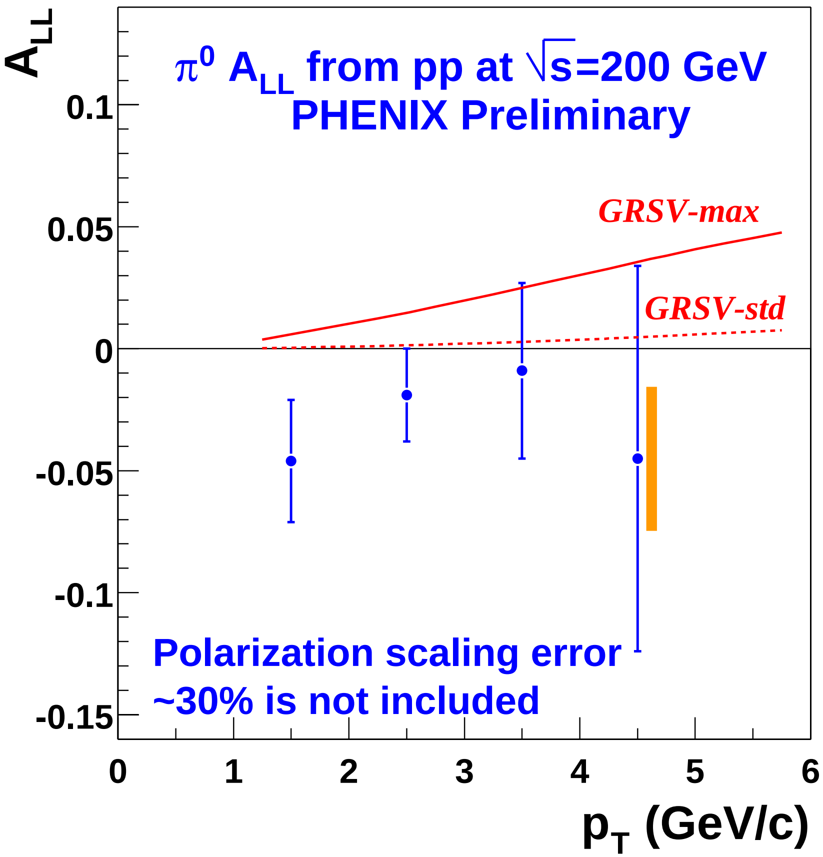
To Fe or not to Fe?

- **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?)
- **1st-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}



Spin Prospects in Run-5

- **Run-3 Preliminary result based on**
  - **<P> = 26%**
  - **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**



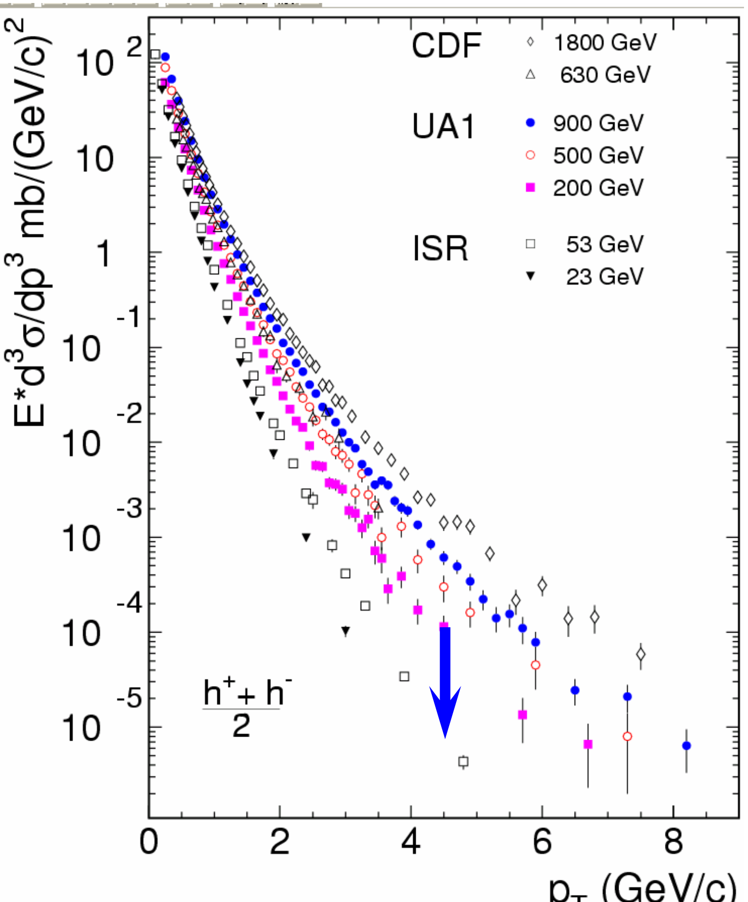
Run-6

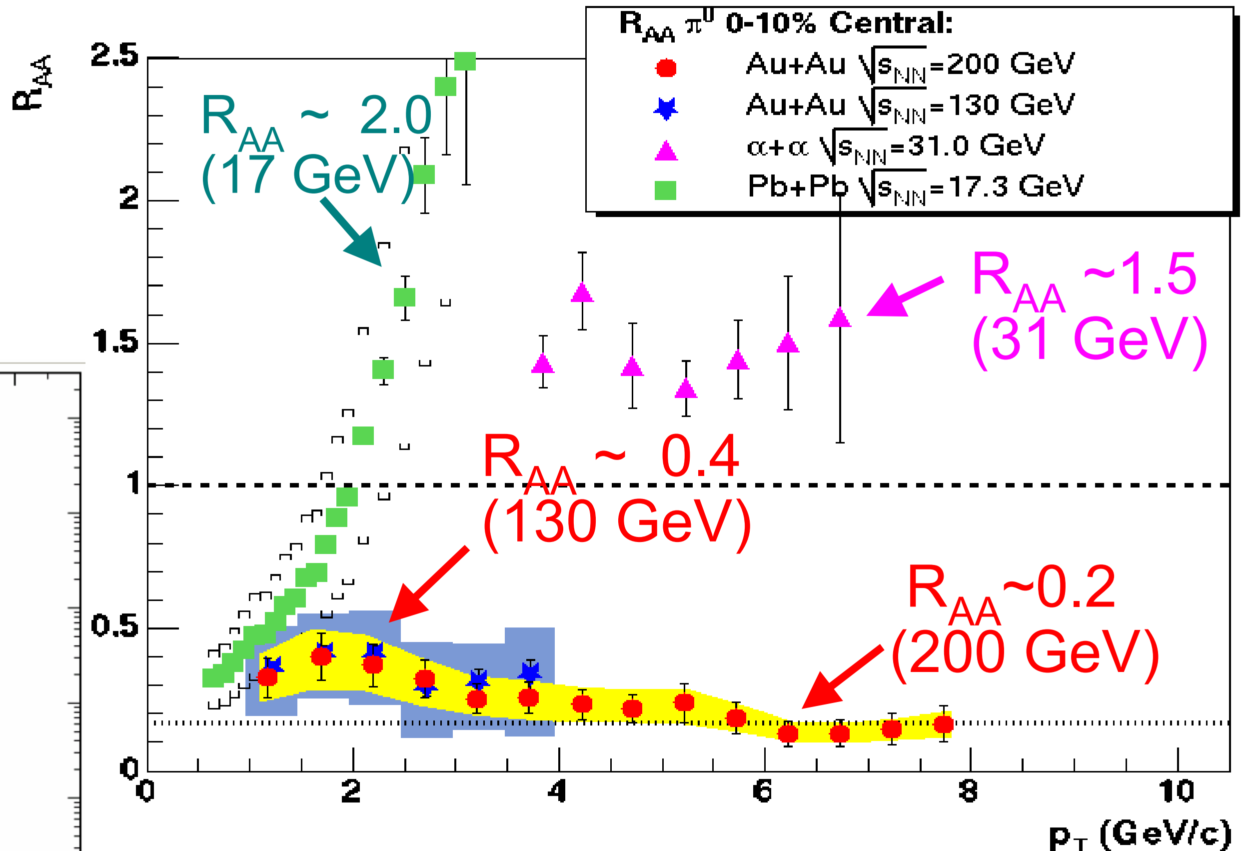
- **27 weeks**
  - Au+Au 62.4 GeV
    - 5+19 weeks
    - *Some* rare channels
    - ISR comparison
- **37 weeks**
  - Au+Au 62.4 GeV
    - 5+19 weeks
    - *Some* rare channels
    - ISR comparison
  - p+p 500 GeV
    - 5+2 weeks
    - Beam development
    - New $A_{LL}(\pi^0)$

		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 √s that still allows "full" coverage in p_T.***
- **Nota Bene:**
  - **RHIC luminosity scales as *s* (i.e., E^2)**
  - **ISR p+p comparison data**

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}	

Run-8+

- **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..)

		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

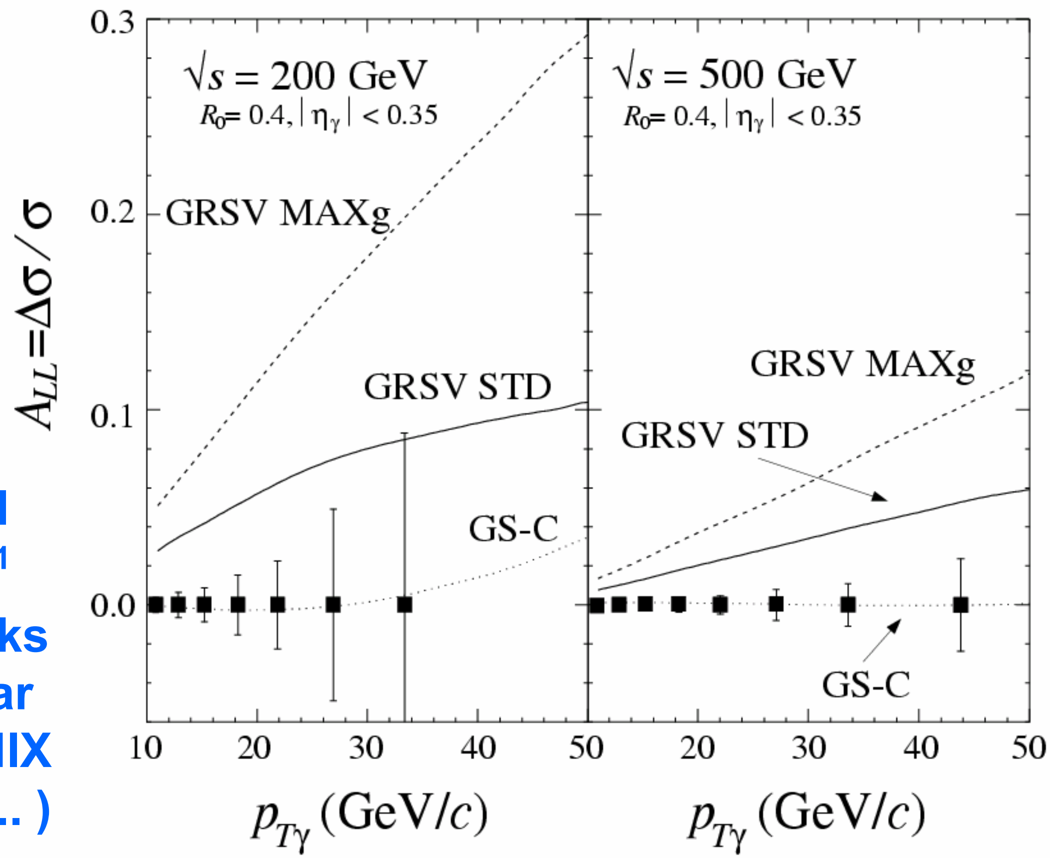


Figure 9: Asymmetry as a function of transverse momentum, for various polarized parton densities, at different cms energies [60]. The expected statistical errors for the PHENIX experiment are also shown.

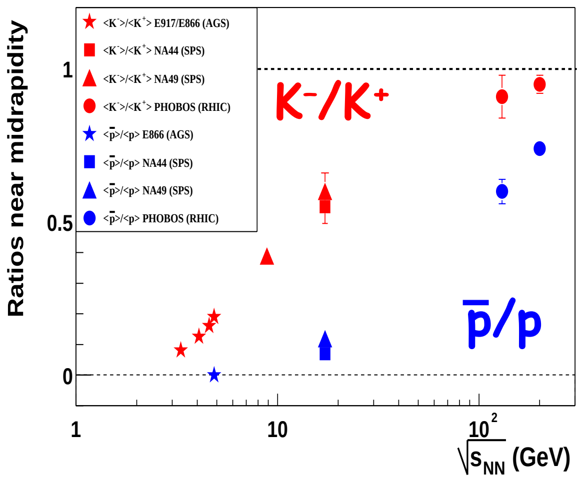
Summary

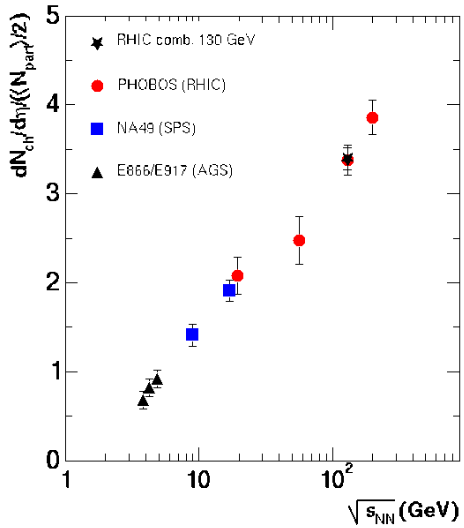
- PHENIX successes in Runs 1-3 have paralleled those of the accelerator
- Ongoing, productive enterprise engaged in timely publication of an extraordinarily broad spectrum of results (Au+Au, p+p, d+Au)
- Proposed program will extend
  - Investigation of rare processes to address fundamental questions in heavy ion physics
  - Demonstrated spin physics capabilities to higher p_T and to new channels
- 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

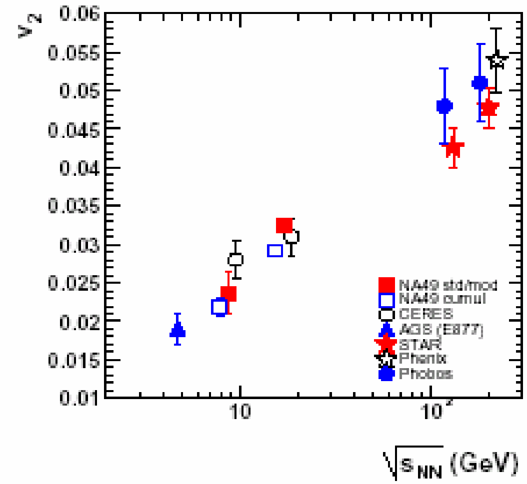
PHENIX

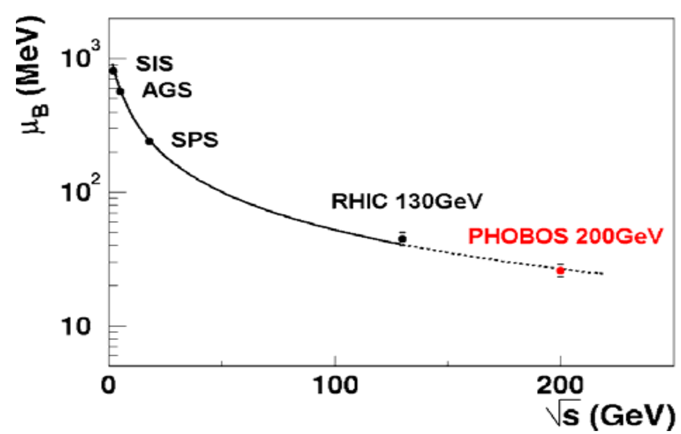
On Energy Scans

- 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

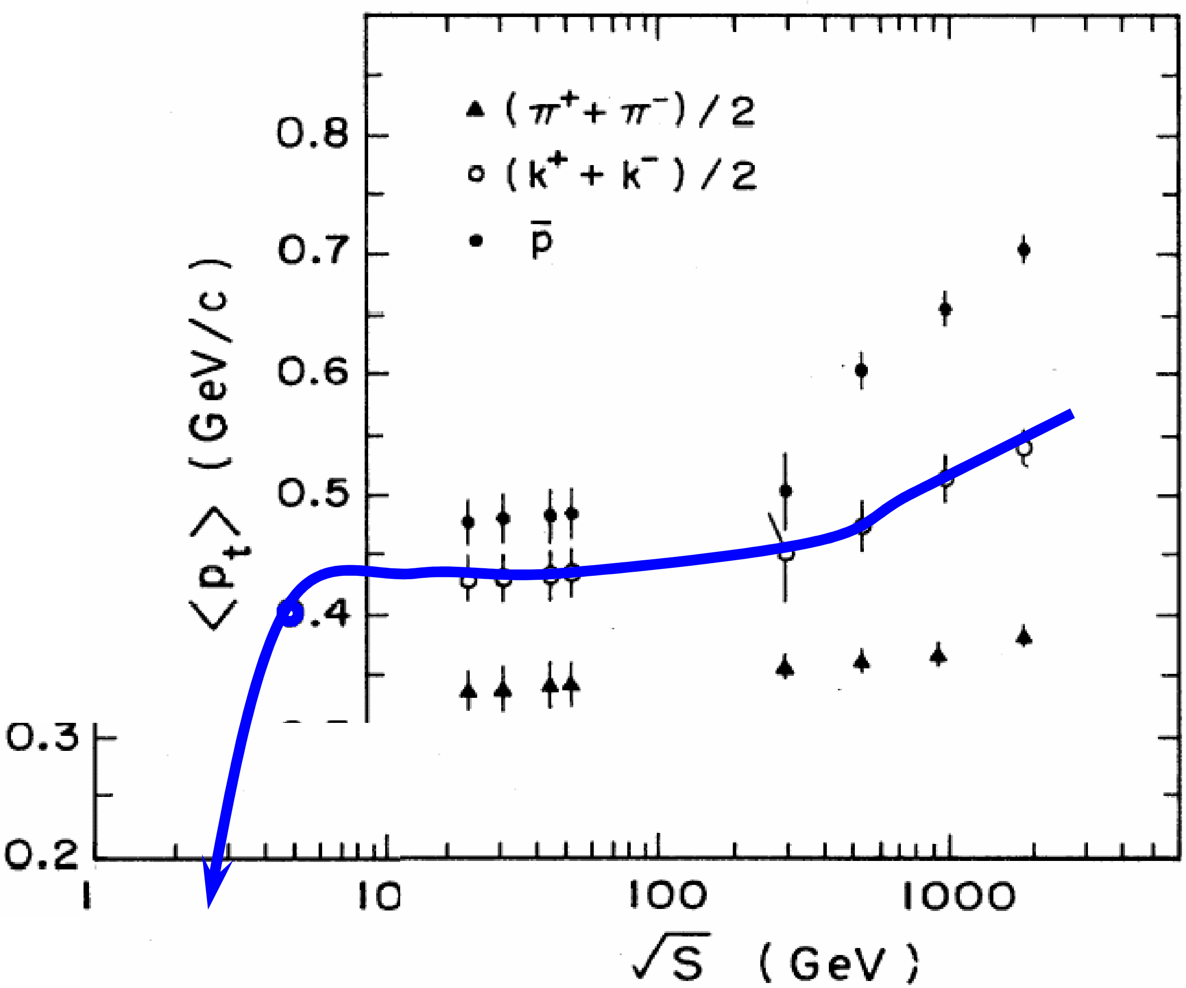


FIG. 13. Plot of $\langle p_t \rangle$ as a function of $\sqrt{s}$; the data for $\sqrt{s} < 100$ GeV are from Ref. [18].