PHENIX STATUS

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Columbia University
for the PHENIX Collaboration

PHENIX

Outline

- Collaboration Status
- Experiment Status
- Physics Status
  - Run-1
  - Run-2
  - Run-3
- Future Prospects
  - Physics
  - Upgrades
- Conclusions

PHENIX

What is PHENIX?

- Pioneering High Energy Nuclear Interaction eXperiment
- Goals:
  - Broadest possible study of A-A, p-A, p-p collisions to
    - Study nuclear matter under extreme conditions
    - Using a wide variety of probes sensitive to all timescales
    - Study systematic variations with species and energy
  - Measure spin structure of the nucleon

➔ These two programs have produced a detector with unparalleled capabilities

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

Students on PHENIX

Given Name	Fanily Name	Thesis Topic	Completion Date	Institution	Adviser	2nd Adviser	Other Institution
Christine	Aidala	A Measurement of A_LL through Neutral and Charged Pions		Columbia University	Cole		
Ahmed	Al-Jamel	J/psi production properties in 200-GeV polarized p-p		New Mexico State University	Papavassiliou		
Raul	Armendariz	Run-4 Au-Au		New Mexico State University	Pate		
Stefan	Bathe	Momentum Fluctuations and Production of Neutral Mesons in Ultra-Relativis	2002	University of Muenster	Santo		
Henner	Buesching	Azimuthal Photon Correlations in Ultra-relativistic p+A, Pb+Pb and Au+Au R	2002	University of Muenster	Santo		
Jane	Burward-Hoy	Transverse Momentum Distributions of Hadrons Produced in Au+Au Collisio	2001	SUNY-Stony Brook (Physics)	Jacak		
Sergey	Butsyk			SUNY-Stony Brook (Physics)			
Xavier	Camard	Direct Photon Production in Au-Au Collisions at RHIC		SUBATECH	Delagrange	Martines	
Mickey	Chiu	Angular Correlations in High pT Particle Production in Au-Au Collisons at RHIC		Columbia University	Cole	Nagle	Colorado
Yann	Cobigo	Study of J/Psi production in d+Au collisions with the PHENIX muon spectror	2004	Dapnia/Saclay	Gosset		
Paul	Constantin	Two-particle azimuthal correlations in pp and AuAu collisions at sqrt{s_NN} = 200 GeV		Iowa State University	Lajoie		
Kushal	Das	J/Psi Production Measured via e+e- decays in Au-Au Collisions at RHIC		Florida State University	Frawley		
Rickard	du Rietz	Deuteron and anti-deuteron production in sqrts=200GeV AuAu Collisoins at	2002	Lund University	Gustafsson		
Akitomo	Enokizono	HBT Correlations in Au-Au Collisions at RIHC		Hiroshima University	Sugitate		
Justin	Frantz	Direct Photon Production in Au-Au Collisions at RHIC		Columbia University	Cole	Nagle	Colorado
Sebastien	Gadrat	Open charm production in d+Au and p+p at 200 GeV		Clermont-Ferrand	Roche		
Andrew	Glenn			University of Tennessee			
Nathan	Grau	Two Particle correlations in dAu		Iowa State University	Ogilvie		
Takashi	Hachiya			Hiroshima University	Sugitate		
Robert	Hobbs	Asymmetry measurements in dilepton open charm production in Run3 pp		University of New Mexico	Fields		
Andrew	Hoover	The PHENIX Muon Spectrometer and J/psi Production in \sqrt(s)=200 GeV p	2003	New Mexico State University	Pate		
Takuma	Horaguchi	Direct photon production in polarized proton-proton collisions at PHENIX		Tokyo Institute of Technology	Shibata		
Michael	Issah			SUNY-Stony Brook (Chemistry)	Lacey		
Wooyoung	Jang			University of Korea			
Jiangyong	Jia	High pT Charged Particle Production in Au-Au Collisions at RHIC	2003	SUNY-Stony Brook (Physics)	Drees		
Soichiro	Kametani	Measurement of J/Psi suppression in Au+Au collisions at sqrt(s_NN)=200GeV		CNS-Tokyo	Hamagaki		
Nobuyuki	Kamihara	J/Psi formation and decay in polarized proton-proton collisions at PHENIX		Tokyo Institute of Technology	Shibata		
Young Gook	Kim	PHENIX Event Characterization Using Charged Particle Multiplicities measured with the MVD		Yonsei University	Kang		
Dong Jo	Kim	Measurement of J/Psi in the muon arm		Yonsei University	Kang		
Akio	Kiyomichi	Chemical Equilibrium from Measurement of Particle Ratios in sqrt{s_{NN}} = 130 GeV Au+Au Collisi		University of Tsukuba	Miake		
Christian	Klein-Boesing	Photon and Neutral Pion Spectra from the Leadglass Calorimeter in PHENI)	2003?	University of Muenster	Santo		
Ryota	Kohara	J/psi Suppression Mechanism		Hiroshima University	Sugitate		
Dmitri	Kotchetgov	Study of chiral symmetry restoration in relativistic heavy-ion collisions at RHIC		UC-Riverside	Seto		
MinJung	Kweon	J/Psi Production in Au+Au Collision at RHIC		University of Korea	Hong		
Felice	Matathias			SUNY-Stony Brook (Physics)	Hemmick		
Takashi	Matsumoto	Measurements of production cross section of J/psi in $\sqrt{s_{NN}} = 200 GeV Au+Au reactions at		CNS-Tokyo	Hamagaki		
Alexander	Milov	Particle production in heavy ion collisions at RHIC energies	2002	Weizmann Institute	Tserruya		
Mohammed	Muniruzzman	Phi Meson Production in Au-Au Collisions at 200 GeV Measured by the PHI	2003	UC-Riverside	Seto		
Tomoaki	Nakamura			Hiroshima University	Sugitate		
Jason	Newby	J/Psi Production in Heavy Ions at RHIC using PHENIX muon arms		University of Tennessee	Sorensen		
Paul	Nilsson	Experimental studies of particle production in ultra-relativistic heavy ion collis	2001	Lund University	Oskarsson	Gustafsson	
Ken	Oyama	Pizero production in Au+Au Collisions at \sqrt{s_{NN}} = 130 GeV	2002	CNS-Tokyo	Hamagaki		
WooJin	Park	Open Charm Production in Au-Au Collisions at RHIC		University of Korea	Hong		
Hua	Pei			Iowa State University	Ogilvie		
Anuj	Purwar	Deuteron and Anti-Deuteron Production in Au-Au Collisions at RHIC		SUNY-Stony Brook (Physics)			
Sarah	Rosendahl	Resonance studies in Heavy Ion collisions at RHIC		Lund University	Nystrand	Stenlund	
Sang Su	Ryu	Fluctuations in the Charged Particle Multiplicity Distributions		Yonsei University	Kang		
Hiroki	Sato	J/psi Production in p+p Collisions at sqrt(s) = 200 GeV	2003	Kyoto University	Imai		
David	Silvermyr	Aspects of Hadron Production in High-Energy Heavy-Ion Collisions	2001	Lund University	Stenlund	Gustafsson	
Mikhail	Stepanov	Charm production in 200-GeV polarized p-p collisions		New Mexico State University	Papavassiliou		
Peter	Tarjan			Debrecen University	David		
Hisayuki	Torii	Centrality Dependence of High PT Pizero Production in sqrt(s_{NN})=200Ge'	2002?	Kyoto University	Imai		
Vi-Nham	Tram	J/psi production (dimuon channel) in Au-Au at 200 GeV		Laboratoire **L**eprince-**R**inguet	Drapier	Fleuret	
Yuji	Tsuchimoto			Hiroshima University	Sugitate	Homma	
Thomas	Svensson	Tracking Chambers with 2-Dimensional Readout for the PHENIX Experiment	1999	Lund University	Oskarsson	Stenlund	
Henrik	Tydesjo	Net charge fluctuations in AuAu collisions at RHIC		Lund University	Oskarsson		
Maxim	Volkov			Kurchatov Institute			
Hui	Wang			Georgia State University	He		
Qin	Wang			Georgia State University	He		
Igor	Yushmanov			Kurchatov Institute			
Oliver	Zaudtke	Pi0- and direct photon spectra from 200 GeV Au-Au and pp-data		University of Muenster	Wessels	Reygers	
Chun	Zhang	Open Charm Production in Au-Au Collisions at RHIC		Columbia University	Cole	Nagle	Colorado

PHENIX

Thesis Awards

- Two winners of the (new) RHIC/AGS Users' Thesis Award:
  - 2002:
    - Jane Burward-Hoy
    - Title: "Transverse Momentum Distributions of Hadrons Produced in Au+Au Collisions at 130 GeV Measured by the PHENIX experiment at RHIC BNL"
    - Adviser: B. Jacak (SUNY-Stony Brook)
  - 2003:
    - Hiroki Sato
    - Title: "J/psi Production in p+p Collisions at $\sqrt{s}$ = 200 GeV "
    - Adviser: K. Imai (Kyoto)

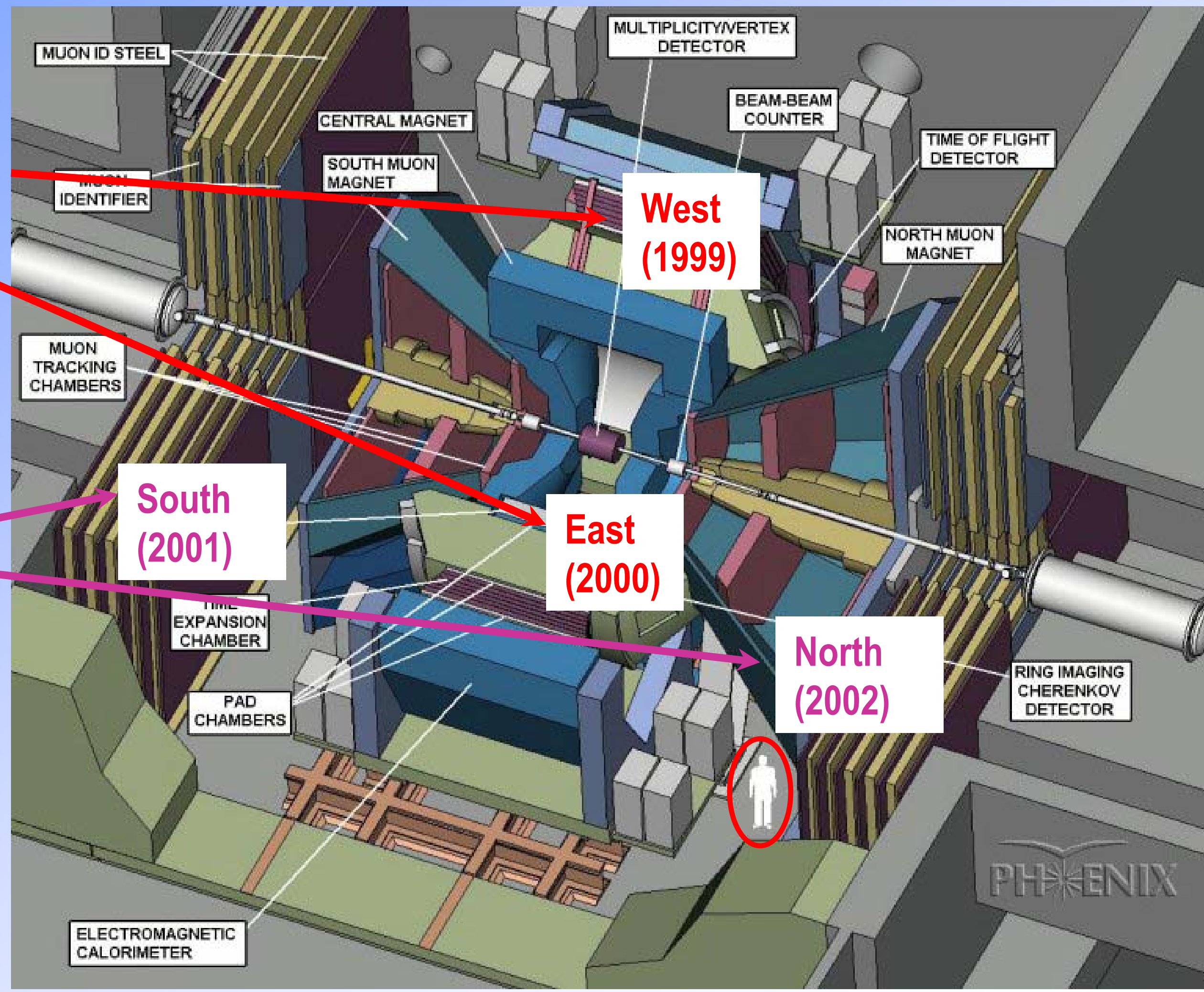
User Community

- Shift support:
  - 230 visiting scientists took PHENIX shifts in 2003
  - 37 BNL staff took PHENIX shifts in 2003
  - 84 paid visitors (could cover per diem, housing, airfare, car)
  - ~167 visitors were non-US citizens
- "Essential personnel" (in response to potential SECON1):
  - 106 essential personnel
  - 28 BNL employees
  - 78 visiting Scientists
  - 59 non-US citizen Visiting Scientists
- Analysis:
  - BNL staff make up >25% of the essential personnel to run PHENIX
  - Non US-citizens from outside institutions make up >50% of PHENIX essential personnel
  - ~1/3 of all PHENIX visitors receive some kind of financial support or subsidy.

☞ *PHENIX operations depends in an essential way on the contributions from both many outside institutions and from non-U.S. citizens. Every effort must be made to make access to BNL as straightforward as possible.*

PHENIX at RHIC

- 2 central spectrometers
- 2 forward spectrometers
- 3 global detectors



PHENIX

The Real Deal

Run-3: Design Configuration!

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

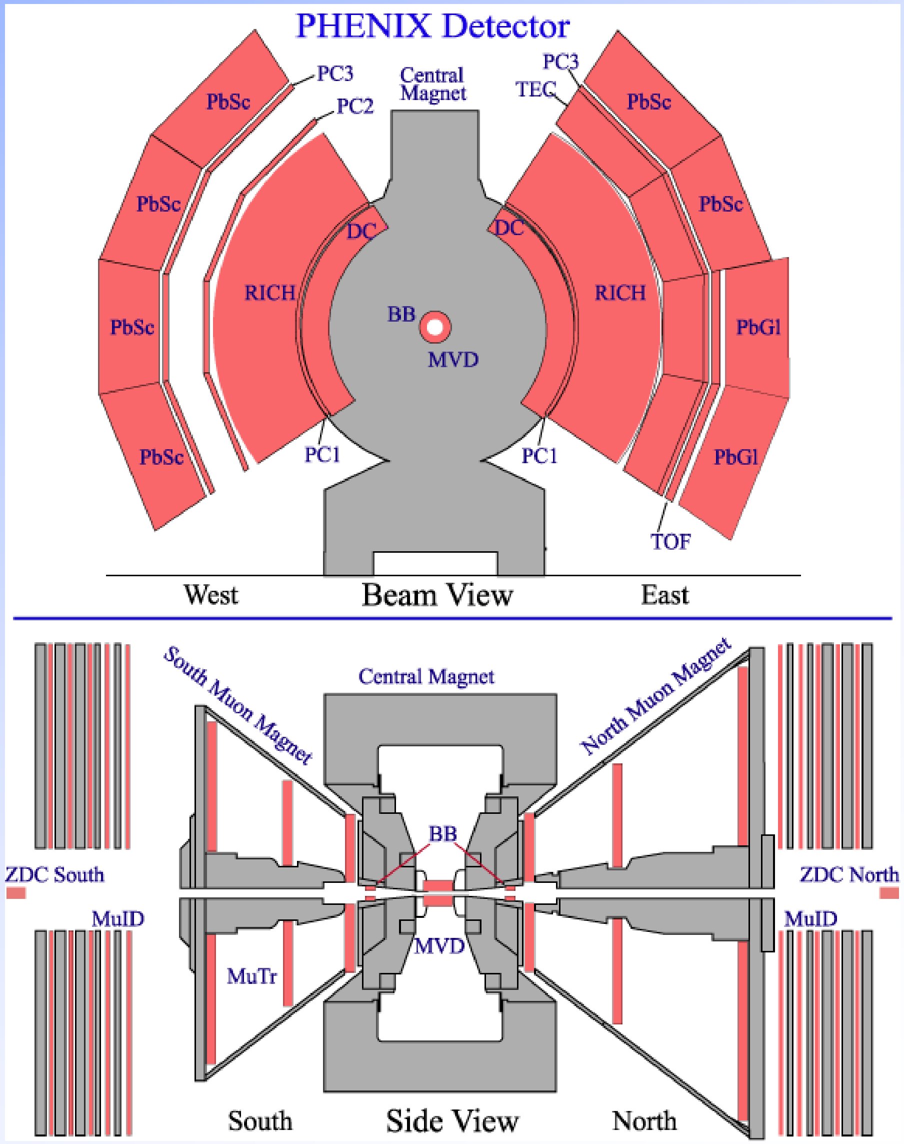
Muon Arm Tracking
- Muon Tracker: **North Muon Tracker**

Calorimetry
- PbGl
- PbSc

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

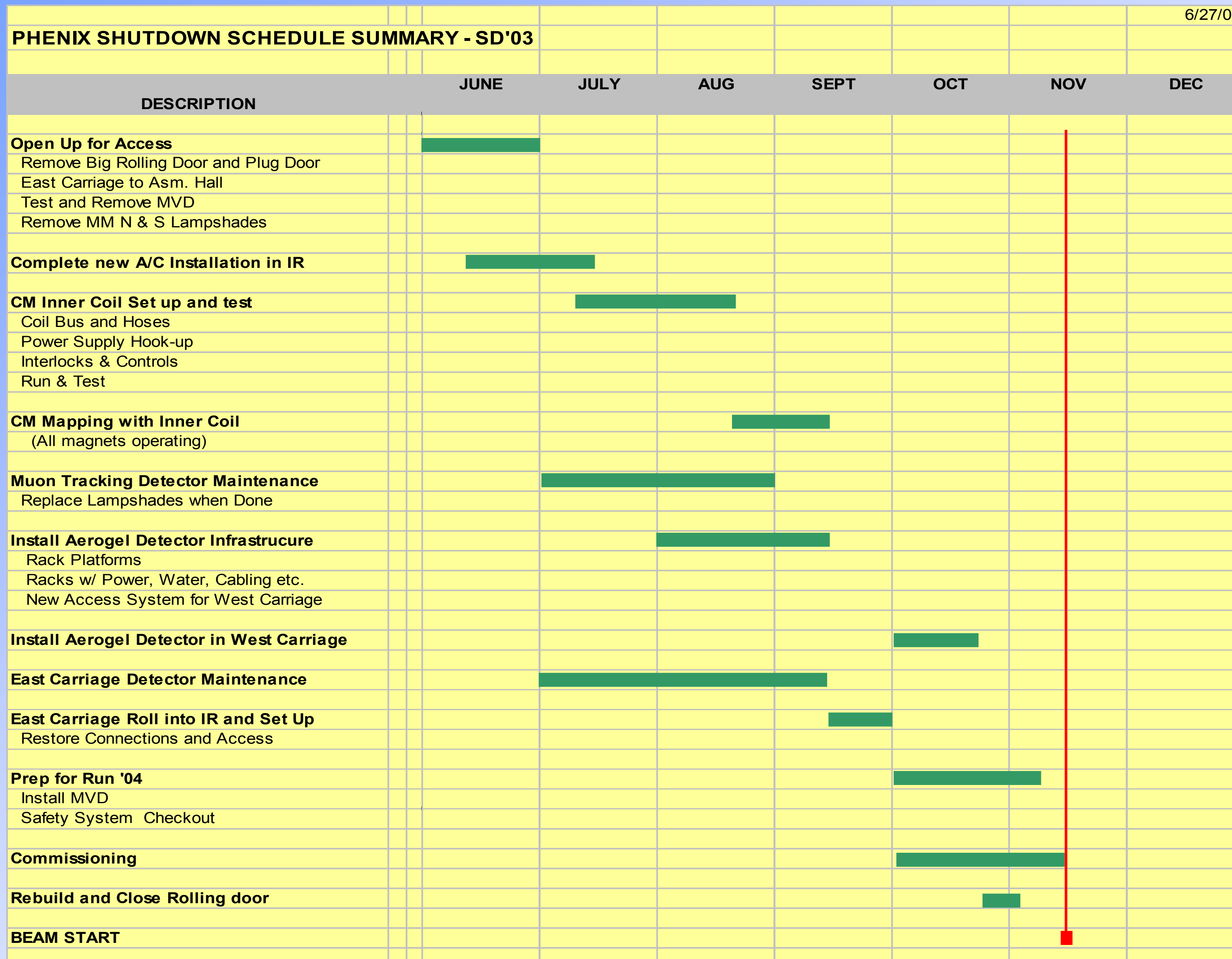
Global Detectors
- BBC
- ZDC/SMD **Local Polarimeter**
- **Forward Hadron Calorimeters**
- NTC
- MVD

Online Calibration and Production



Continued Improvement

- Run-3 to Run-4 shutdown schedule



PHENIX

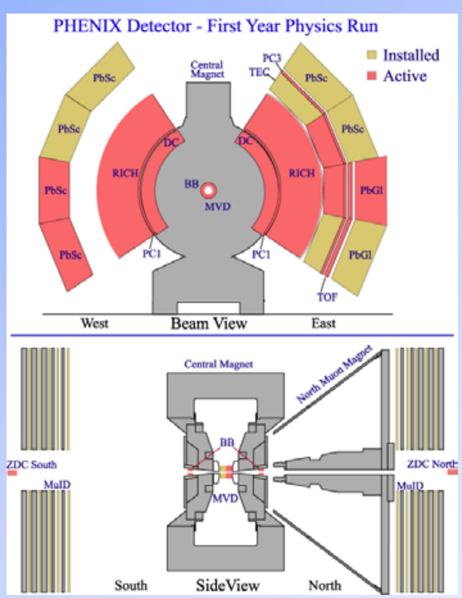
RHIC Runs to Date

- Run-1:
  - Au-Au at 130 GeV
    - Expectation: 20 μb^{-1}
    - Reality : ~ 1 μb^{-1}
    - Output: 11 publications (to date; 1 pending)
- Run-2:
  - Au-Au at 200 GeV
    - Expectation: 300 μb^{-1}
    - Reality : ~ 24 μb^{-1}
    - Output: 4 submissions (to date; 8 others pending)
  - p-p at 200 GeV
    - Expectations: 3 pb^{-1}
    - Reality : 0.15 pb^{-1}
    - Output: 1 submission (to date; 1 other pending)
- Run-3:
  - d-Au at 200 GeV
    - Expectation: 10 nb^{-1}
    - Reality: : 2.7 nb^{-1}
    - Output: 1 submission (to date)
  - p-p at 200 GeV
    - Expectation: 3 pb^{-1}
    - Reality : 0.35 pb^{-1}
    - Output: TBD

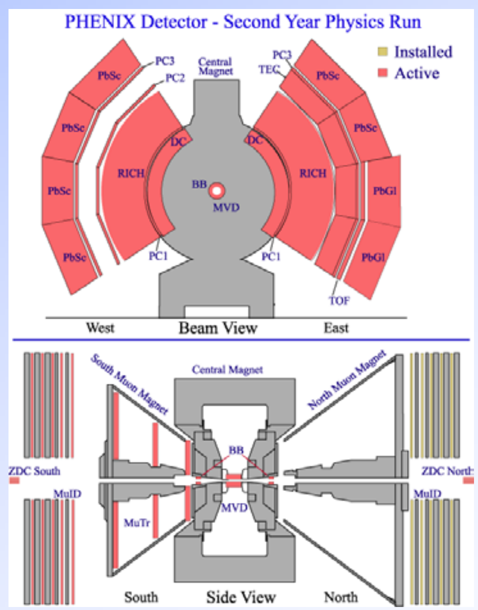
PHENIX: Run History

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

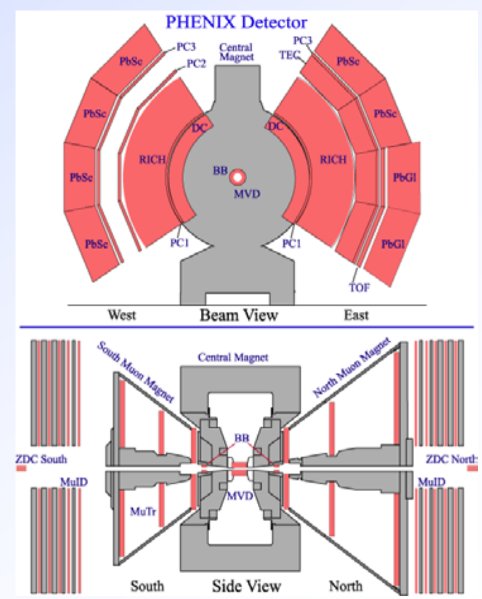
Run-1



Run-2

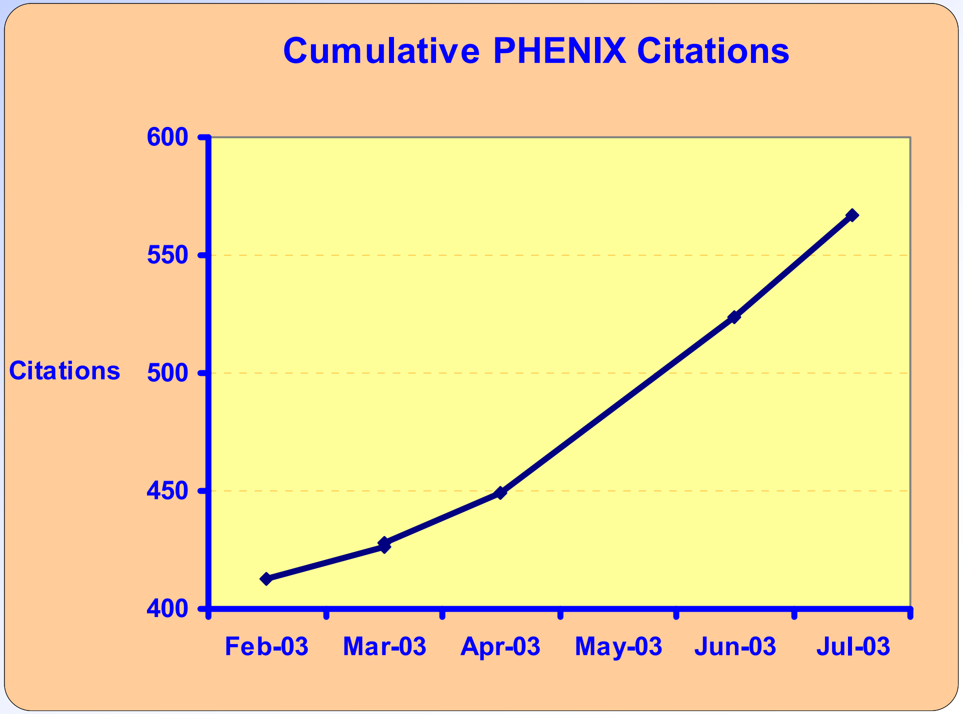


Run-3



Publication Summary

- Run-1
  - 11 publications, 1 submission
  - 4 "TopCites"
- Run-2
  - Au-Au: 4 submissions
  - p-p : 2 submissions
- Run-3
  - d-Au : 1 submission (accepted)



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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 $\sqrt{s_{NN}}$ = 130 GeV 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 p_T Charged Hadron Suppression in Au+Au collisions at $\sqrt{s_{NN}}$ = 130 GeV", accepted for publication in Physics Letters B (28 March 2003) nucl-ex/0207009

Recent PHENIX results

- Run -2 final results:
  - **High p_T π^0 (Au+Au @ 200 GeV): submitted to PRL nucl-ex/0304022**
  - **High p_T π^0 (p+p @ 200 GeV): submitted to PRL hep-ex/0304038**
  - **Elliptic flow of identified particles (Au+Au @ 200 GeV): nucl-ex/0305013**
  - **J/Psi yields (Au+Au @ 200 GeV): submitted to PRC nucl-ex/0305030**
  - **J/Psi yields (p+p @ 200 GeV) to be submitted to PRL**
  - **Inclusive charged particle at high p_T (Au+Au @ 200 GeV) to be submitted to PRC**
  - **Identified charged particle spectra/yields (Au+Au @ 200 GeV), to be submitted to PRC**
  - **p,pbar high p_T enhancement (Au+Au @ 200 GeV): submitted to PRL nucl-ex/0305036**
- Run-2 preliminary results:
  - dN/dy and dE_T/dy (Au+Au @ 200 GeV)
  - phi -> KK (Au+Au @ 200 GeV)
  - Event-by-event fluctuations (Au+Au @ 200 GeV)
  - Di-Lepton continuum (Au+Au @ 200 GeV)
  - Two-pion correlations (Au+Au @ 200 GeV)
  - d and dbars (Au+Au @ 200 GeV)
- Run-3 final results:
  - **High p_T π^0 (d+Au @ 200 GeV) nucl-ex/0306021**
  - **High p_T inclusive charged particles (d+Au @ 200 GeV) nucl-ex/0306021**

Run-2 Au-Au Results on High p_T Yields (Peripheral)

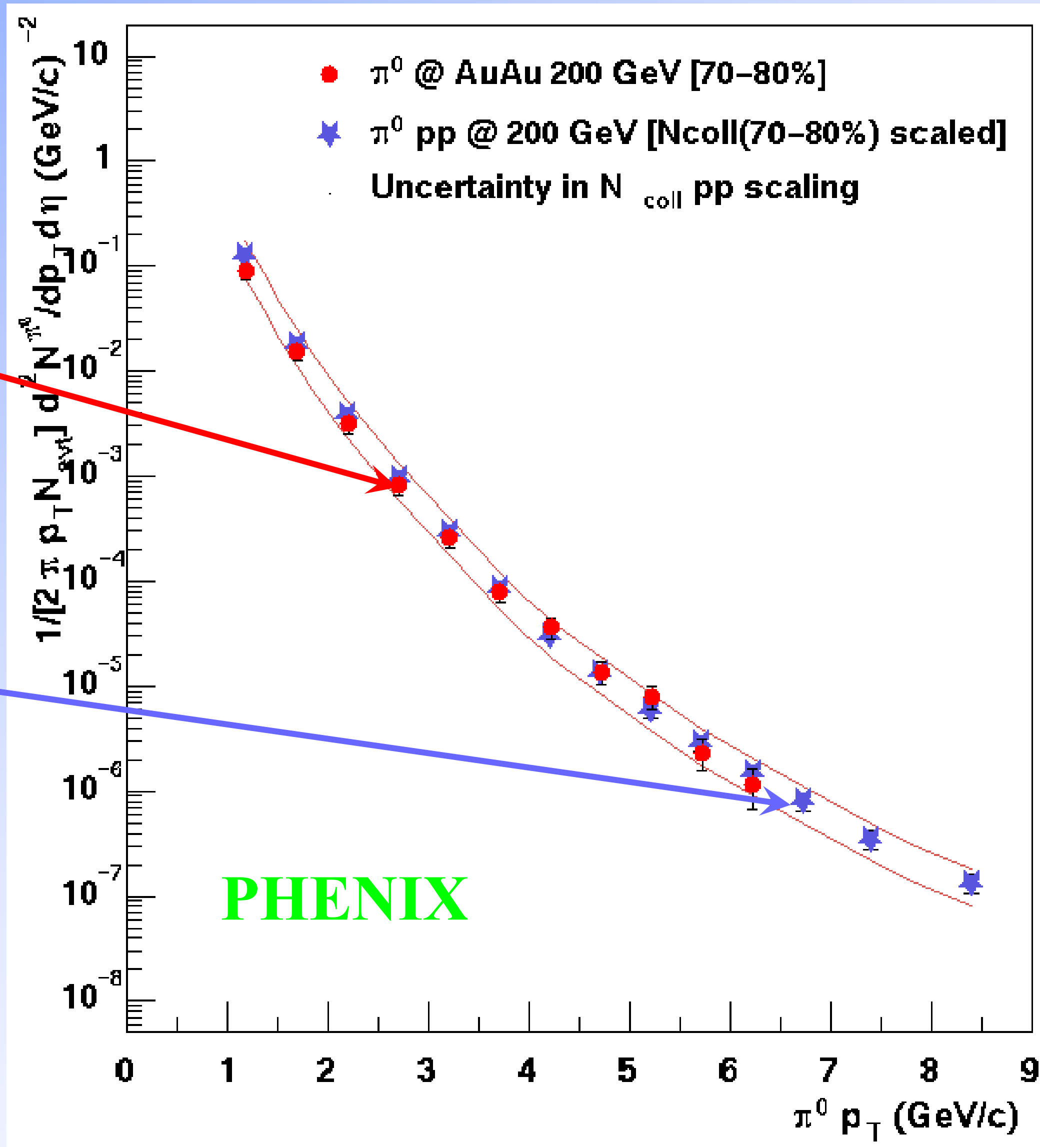
- PHENIX (Run-2) data on π^0 production in peripheral collisions:
- Excellent agreement between
  - PHENIX measured π^0's in p-p collisions

    and

  - PHENIX measured π^0's in Au-Au *peripheral* collisions
- scaled by the number of collisions

$$N^{70-80\%}_{collisions} = 12.4 \pm 4.2$$

over ~ 5 decades



Central Collisions Are *Profoundly Different*

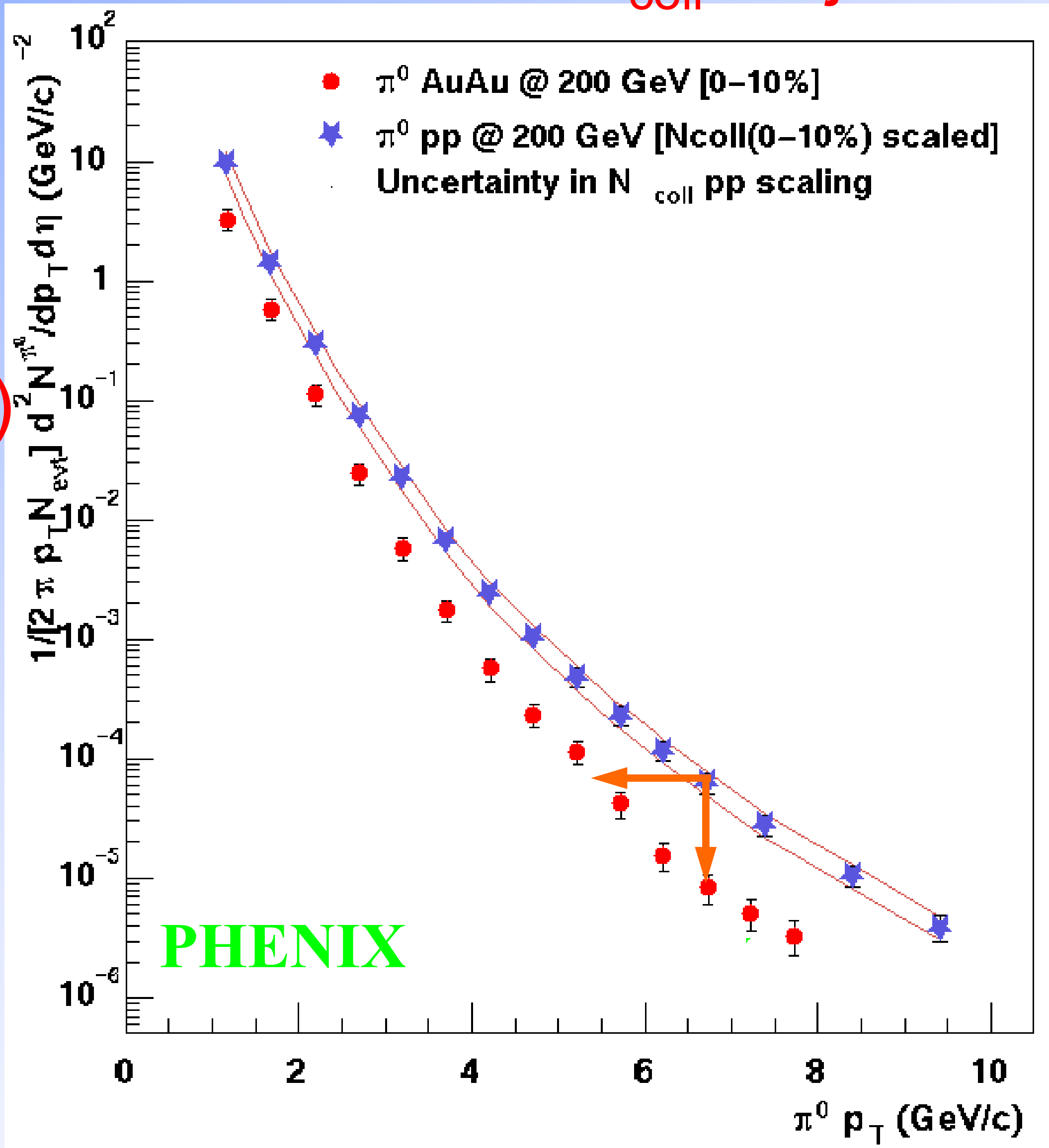
Q: Do all processes that *should* scale with N_{coll} do just that?

A: No!

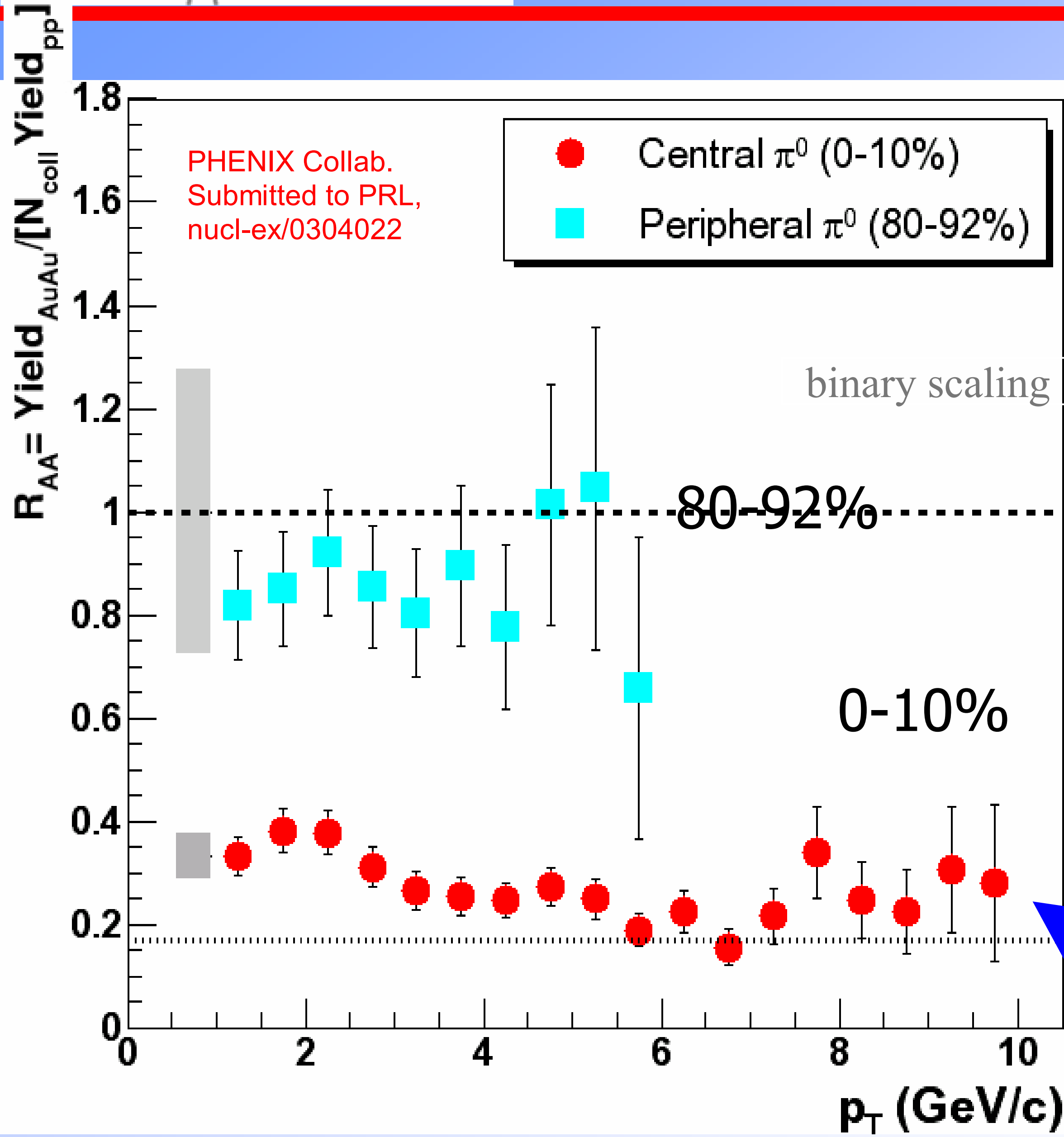
➔Central collisions are *different* . (Huge deficit at high p_T)

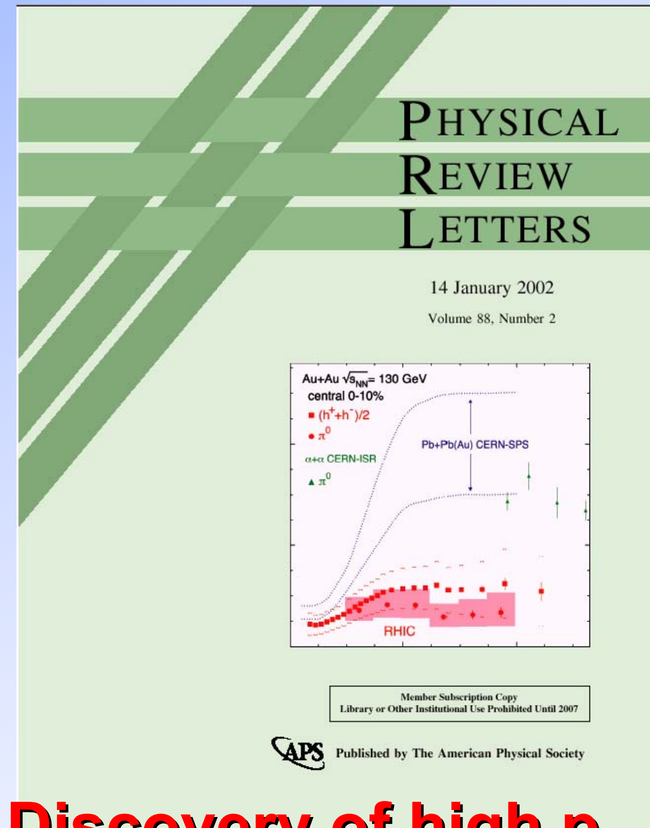
- This is a *clear* discovery of *new* behavior at RHIC

  - Suppression of low-x gluons in the initial *state*?
  - Energy loss in a new state of *matter*?



π^0 yield in Au+Au vs. p+p collisions



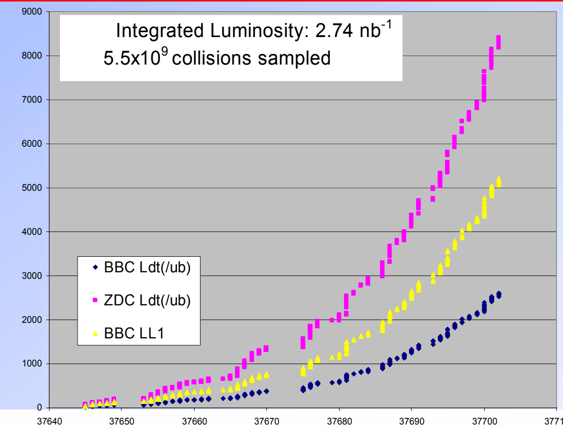


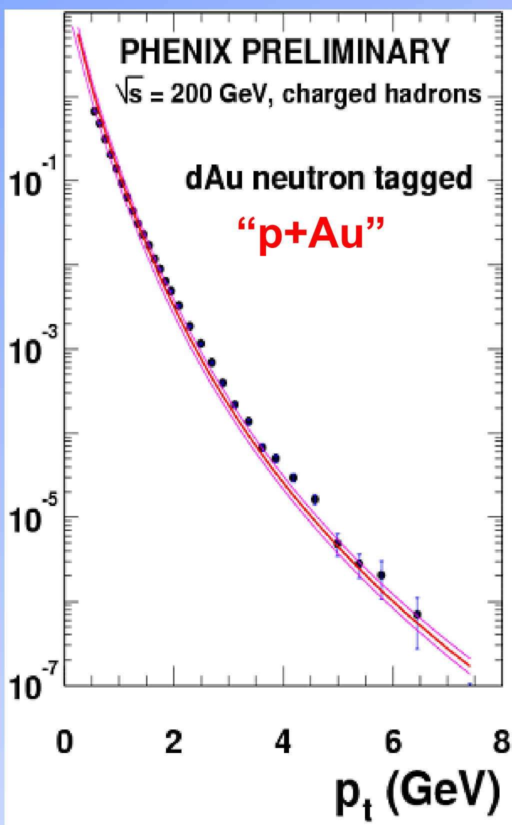
Discovery of high p_T suppression (Run-1)

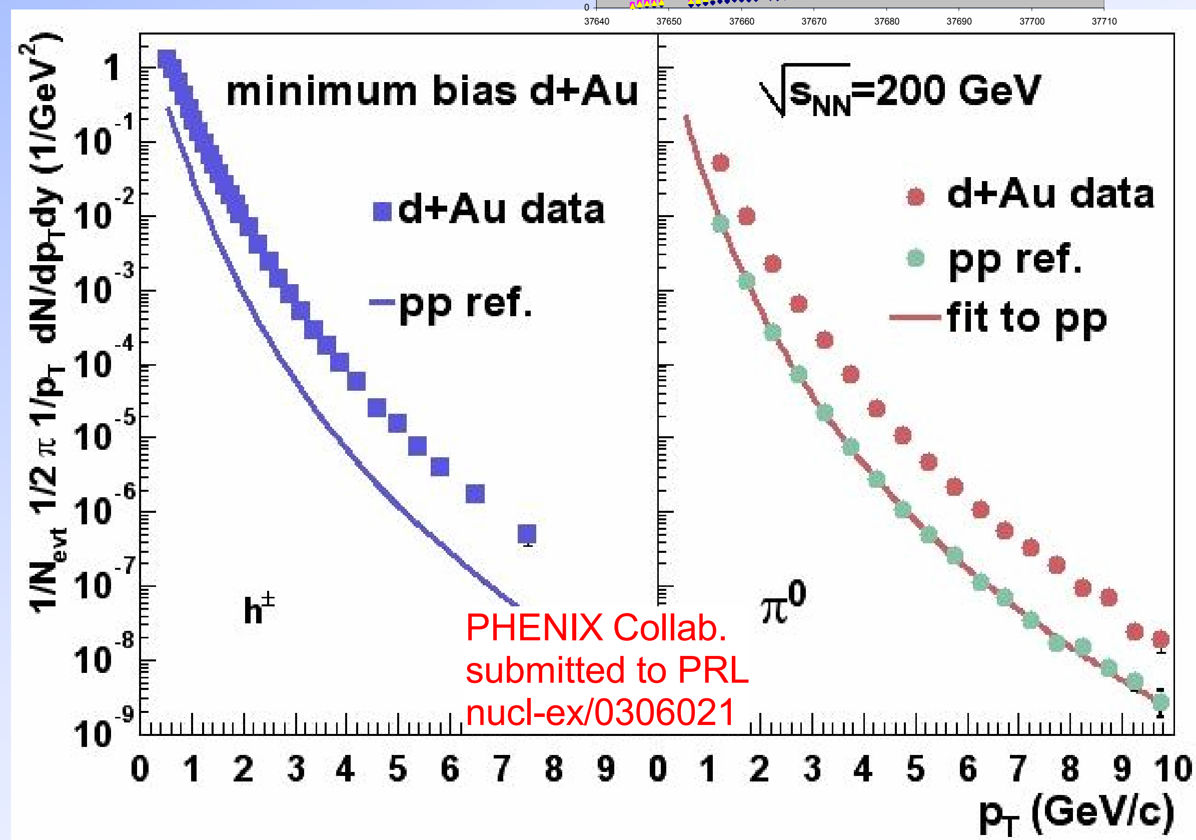
Extended to truly high p_T (Run-2)

d+Au Spectra

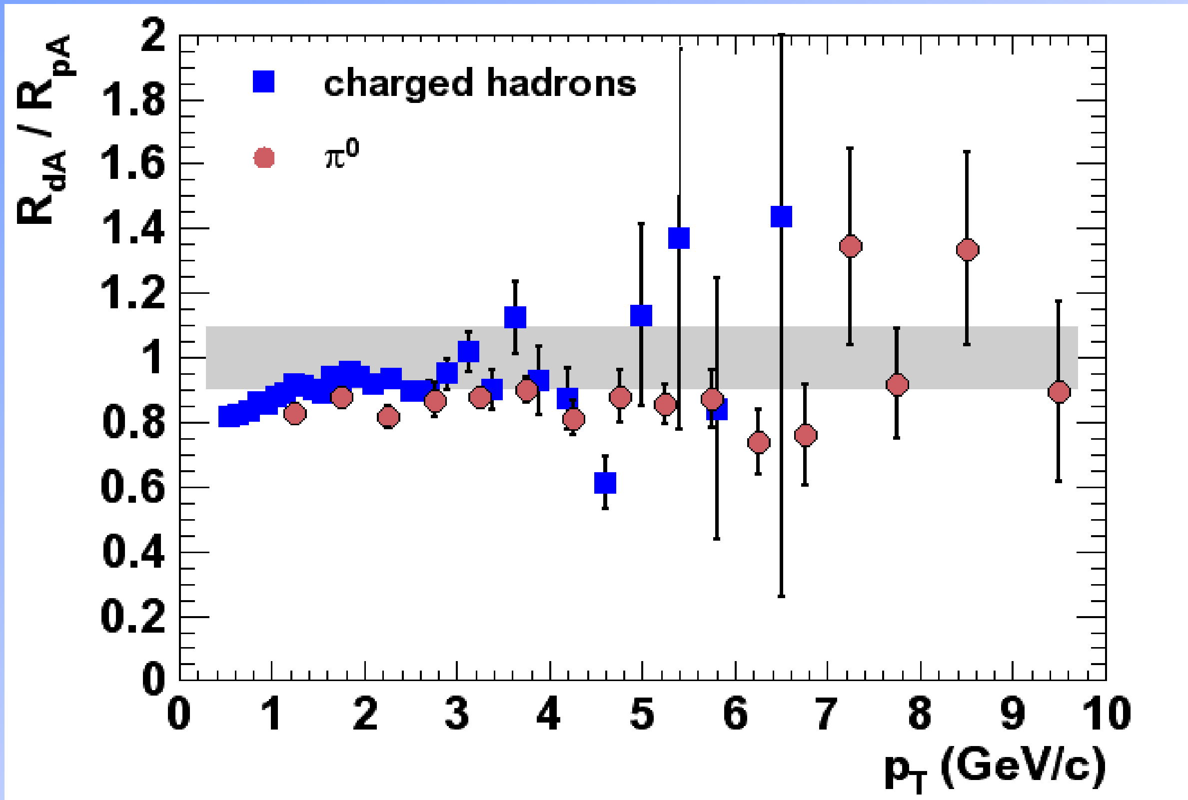
- d-Au proposed as a critical test of the suppression
  - 2.7 nb^{-1} collected in Run-3
  - Recall this ~equivalent to Run-2 Au-Au "parton-parton" flux
  - ➡ p_T spectra of similar reach





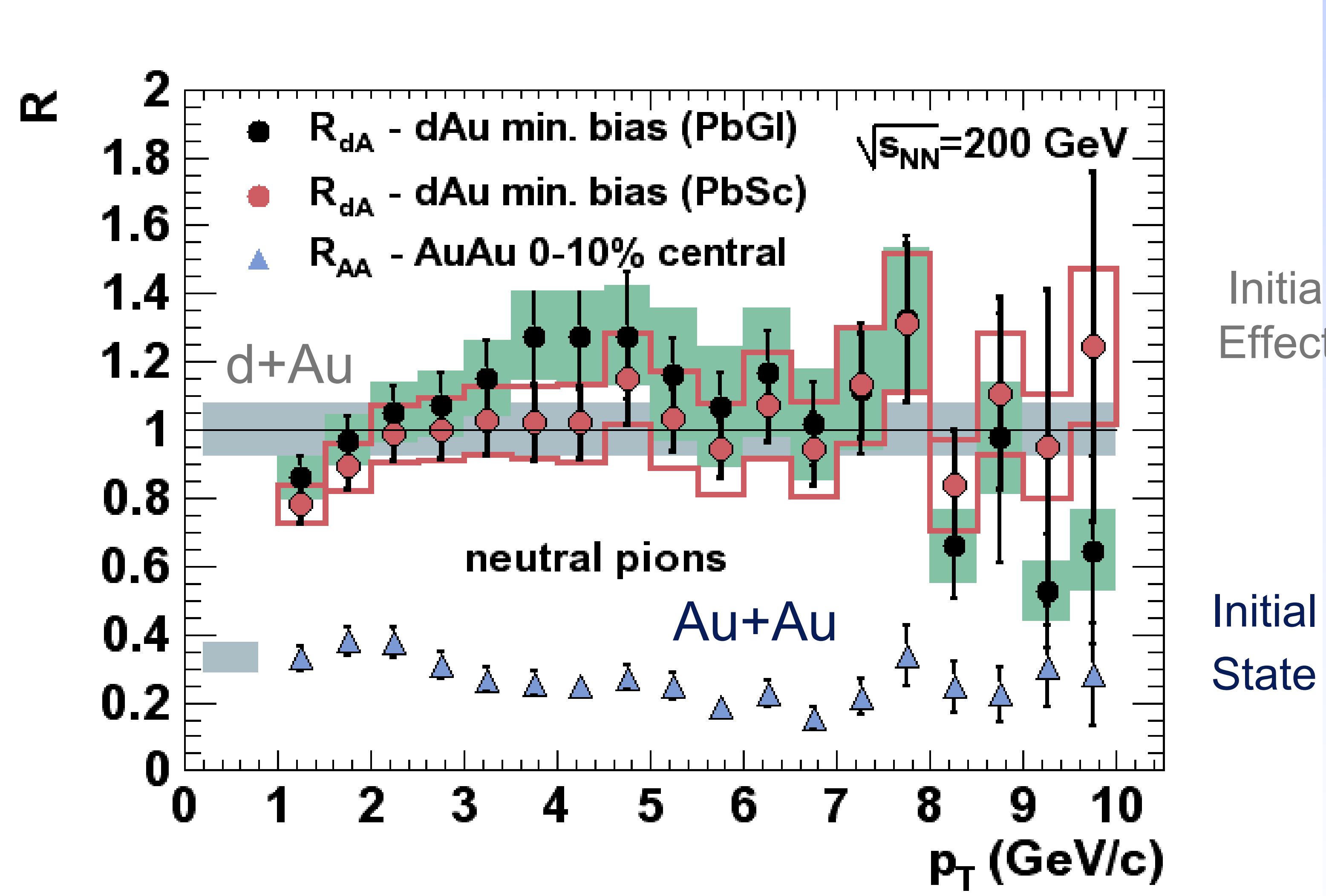


Is d+A a good approximation for p+A?



- **Min Bias:**
  - 1.7 deuteron participants
  - 8.5 collisions
  - 5 coll./part.
- **Tagged neutron:**
  - 1.0 deuteron participants
  - 3.6 collisions
  - 3.6 coll./part.

R_{AA} vs. R_{dA} for Identified π^0

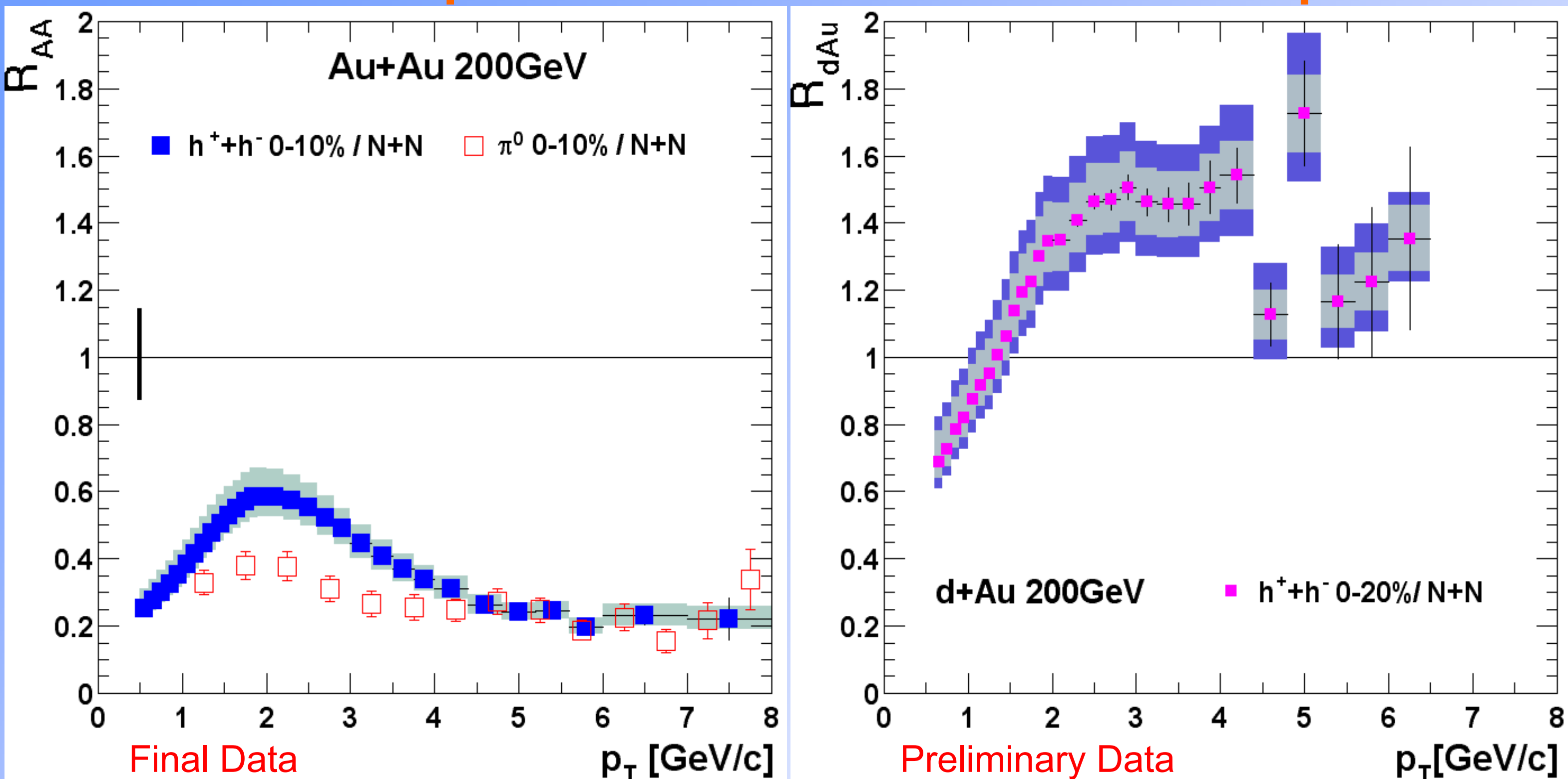


Initial State Effects Only

Initial + Final State Effects

PHENIX Centrality Dependence

Au + Au Experiment | **d + Au Control Experiment**



- Dramatically different and opposite centrality evolution of Au+Au experiment from d+Au control.
- Jet Suppression is clearly a final state effect.

The Reviews Are In

- "Truly delighted by this news and very proud of the achievement."
  - R. Orbach (via Peter Rosen)
- "My own congratulations on what appears to be the discovery of a new phenomenon."
  - Peter Rosen
- "...the data came out remarkably fast- it's truly impressive."

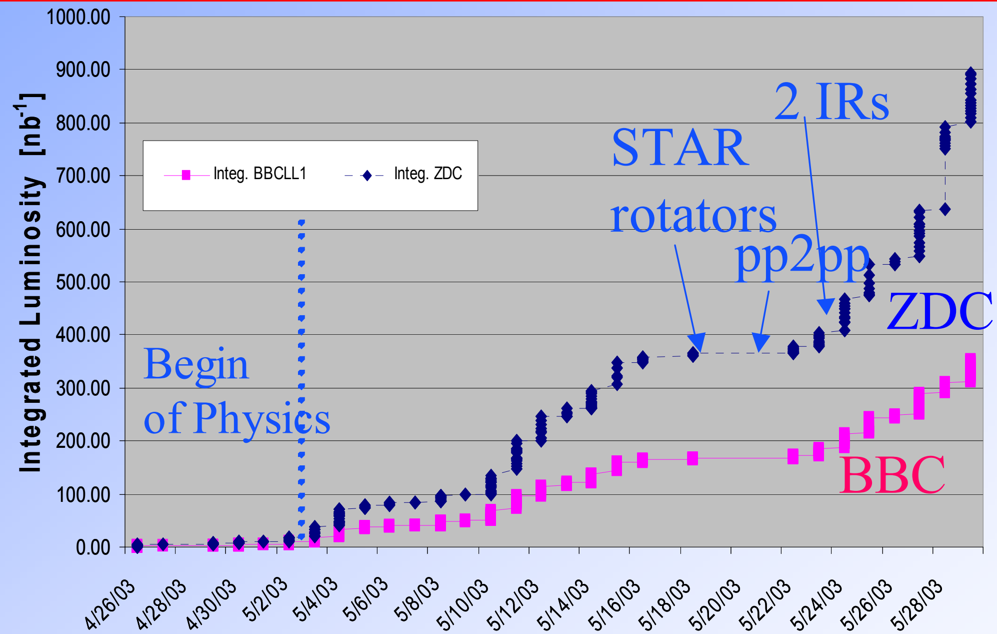
  "This milestone is what RHIC was built to do"

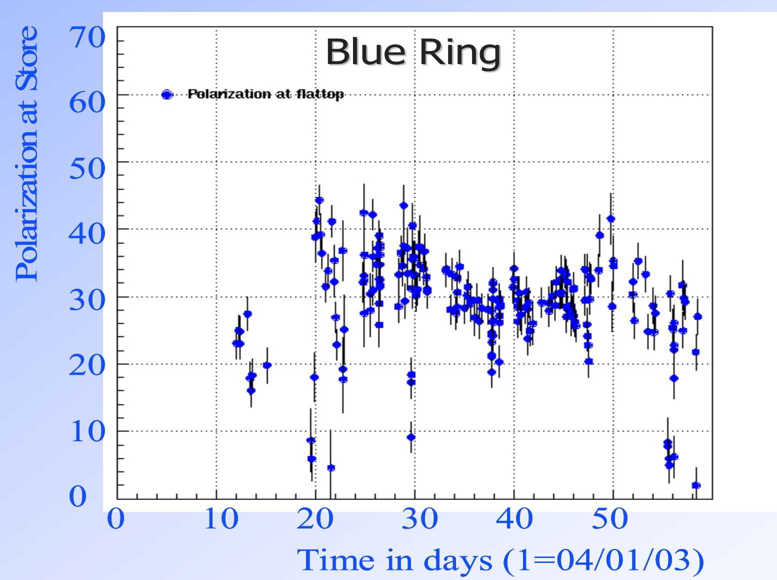
  "It has the potential for changing the way we look at the universe"
  - Dennis Kovar

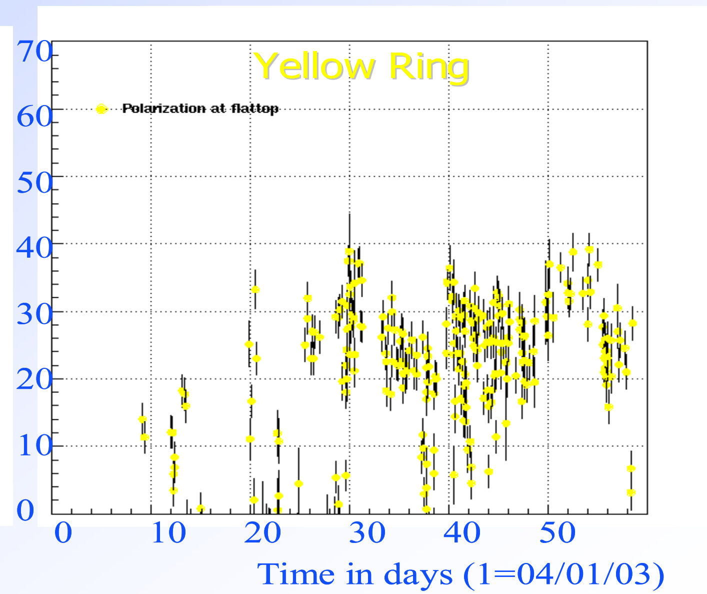
2002-2003 p+p run

- Integrated luminosity $350 nb^{-1}$ from 6.6×10^9 BBCLL1 triggers
- Average polarization ~27%
- Figure of merit

$$\int P_Y^2 P_B^2 L dt = 1.8\ nb^{-1}$$

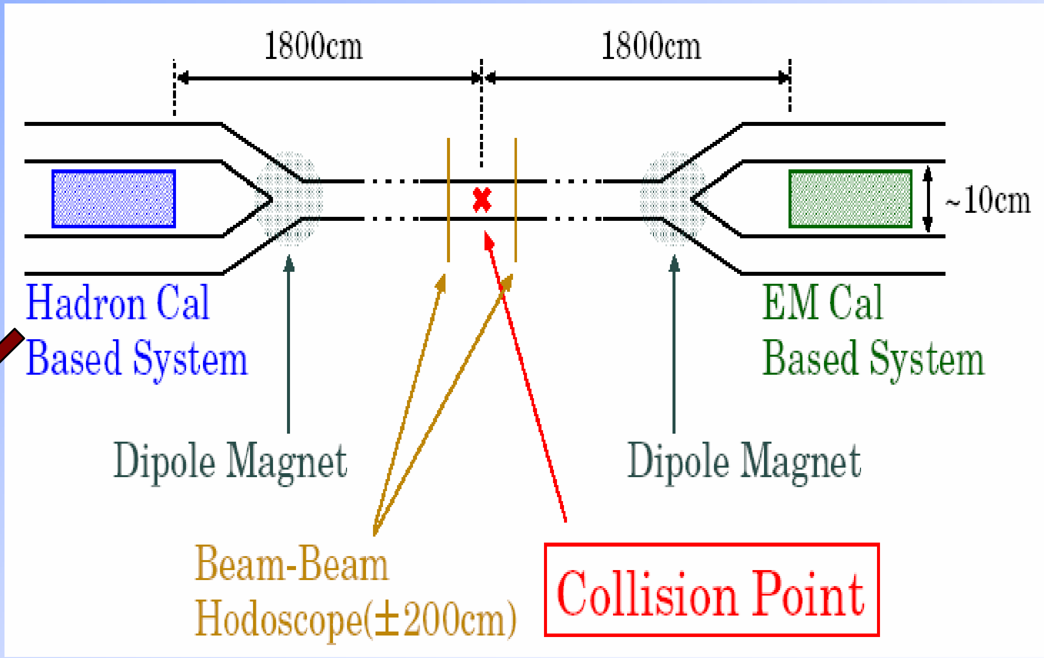


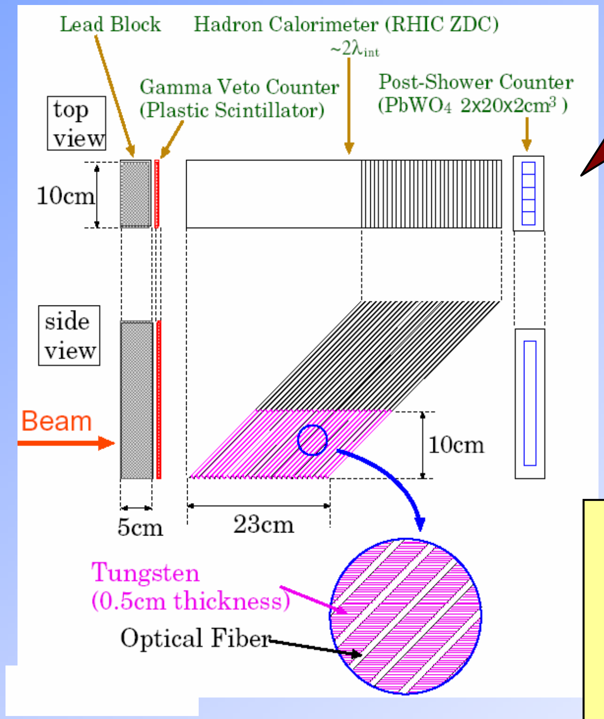




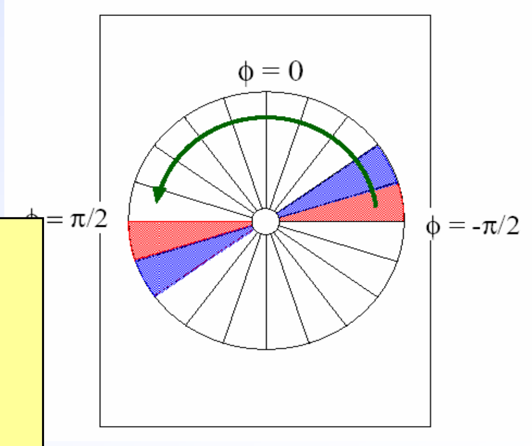
PHENIX Transverse Spin Asymmetries

- RUN-2: *Neutron* asymmetry observed in IP12 while testing a local polarimeter designed to look for π^0, γ asymmetries:





- “Left-Right” asymmetry measured for different slices in phi:



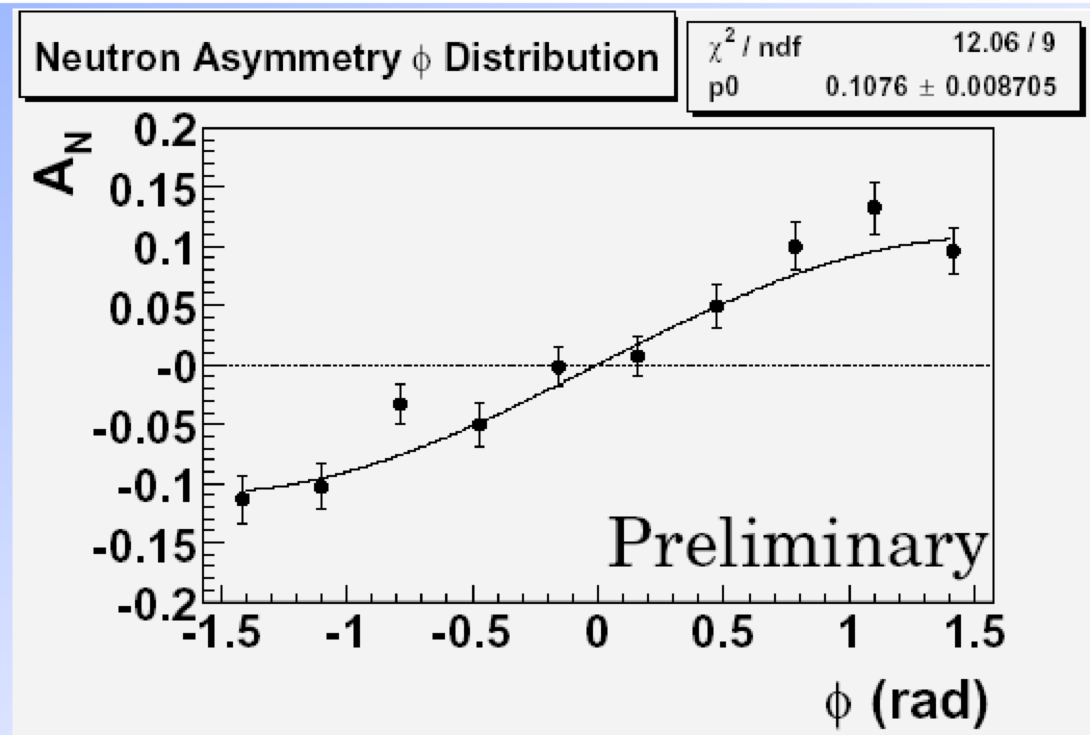
Phi Asymmetry

Run-2

- Successful measurement of forward neutron asymmetry.
- Understood (?) in terms of single pion exchange.
- Large asymmetry gives good figure of merit for local (PHENIX) polarimetry.

$$A_N = \frac{1}{P_B} \frac{\sqrt{N_{\uparrow L} N_{\downarrow R}} - \sqrt{N_{\uparrow R} N_{\downarrow L}}}{\sqrt{N_{\uparrow L} N_{\downarrow R}} + \sqrt{N_{\uparrow R} N_{\downarrow L}}}$$

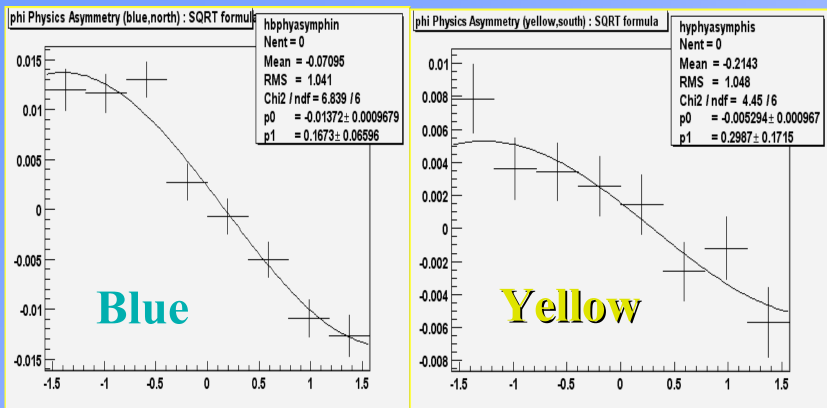
calculated using square root formula



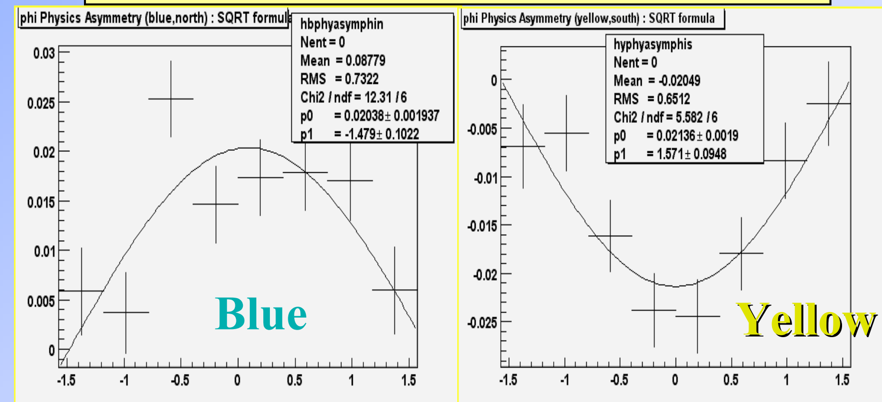
Y. Fukao et al., "Proceedings of the 15th International Spin Physics Symposium (SPIN2002)

Local Polarimeter at PHENIX

Spin Rotators OFF



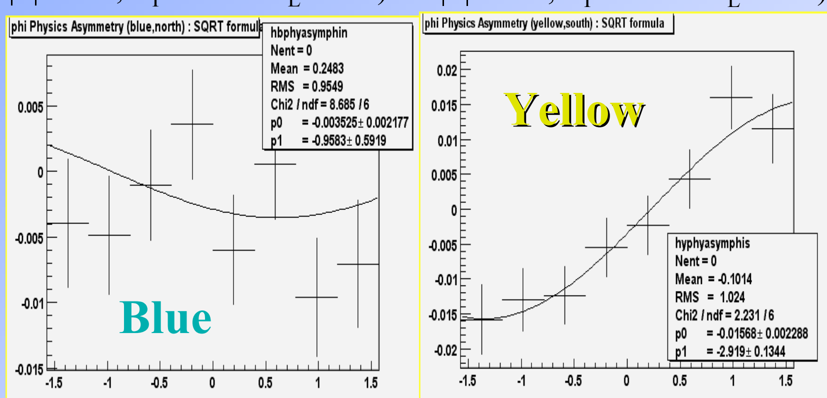
Spin Rotators ON, Current Reversed



Run-3

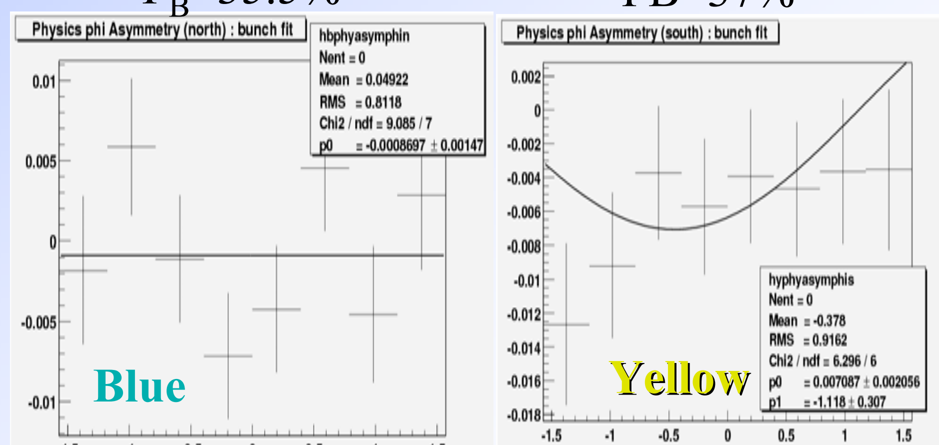
Spin Rotators ON, Almost…

|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%

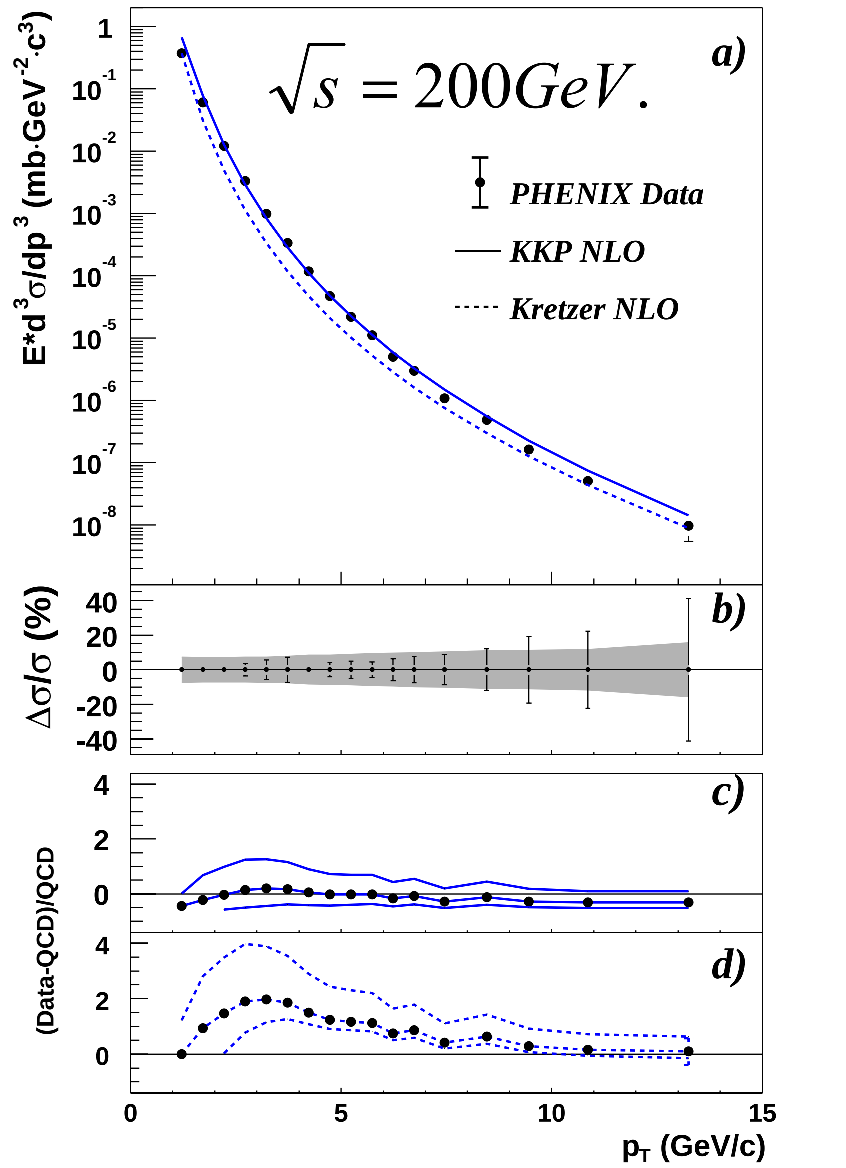


Essential to success of Run-3 spin physics!

PHENIX

Gluon Polarization

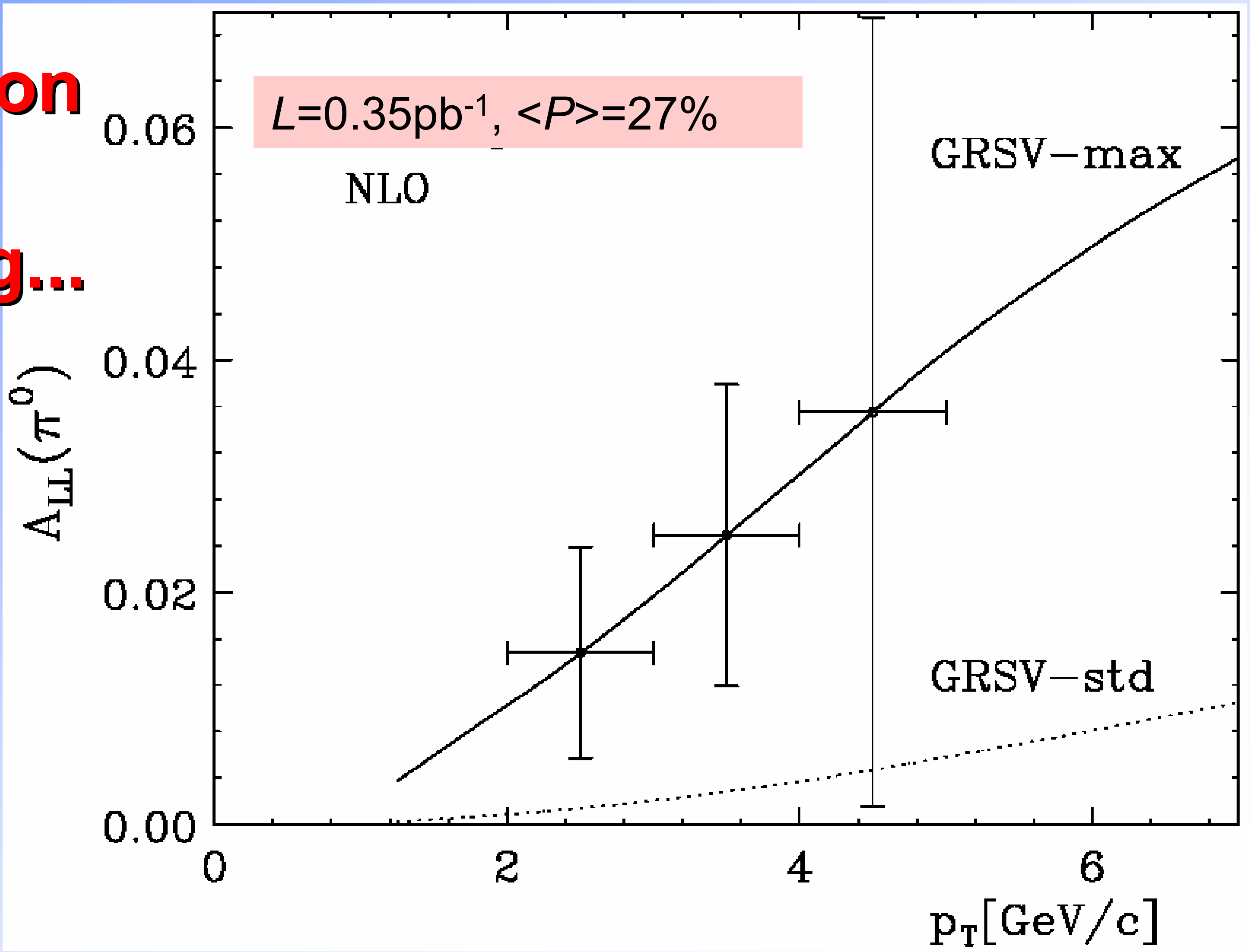
- Next step: Measure cross-section as a test for perturbative QCD at
- In Run-2, precise measure of π^0 cross-section.
- Agreement with pQCD indicates we can extend A_{LL} analysis to lower p_T, important for increasing statistical precision with Run-3 data set.



submitted to PRL, hep-ex/0304038

Projected Run-3 A_{LL} sensitivity

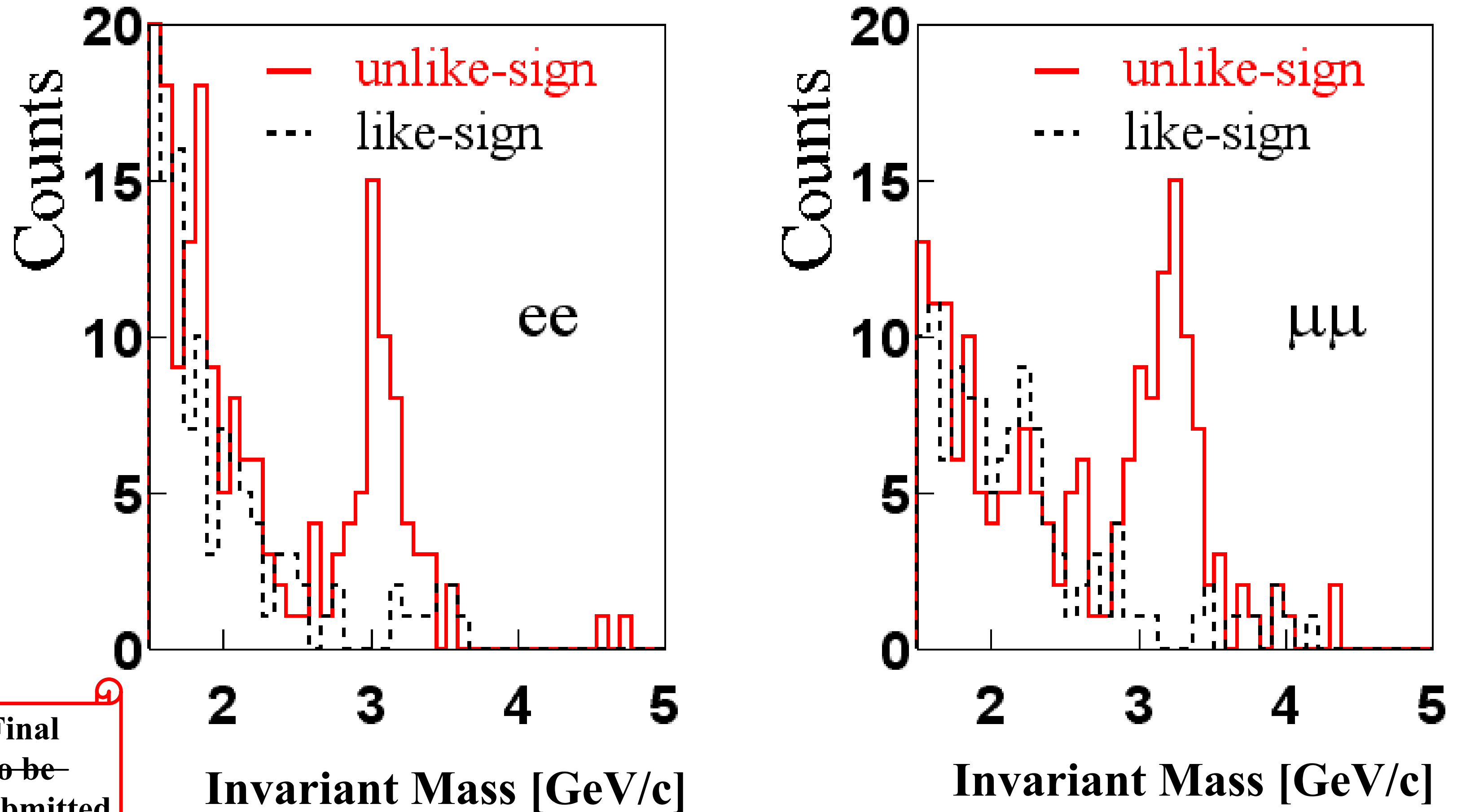
- π^0 A_{LL} expectation
- Only the beginning...



Spin Summary

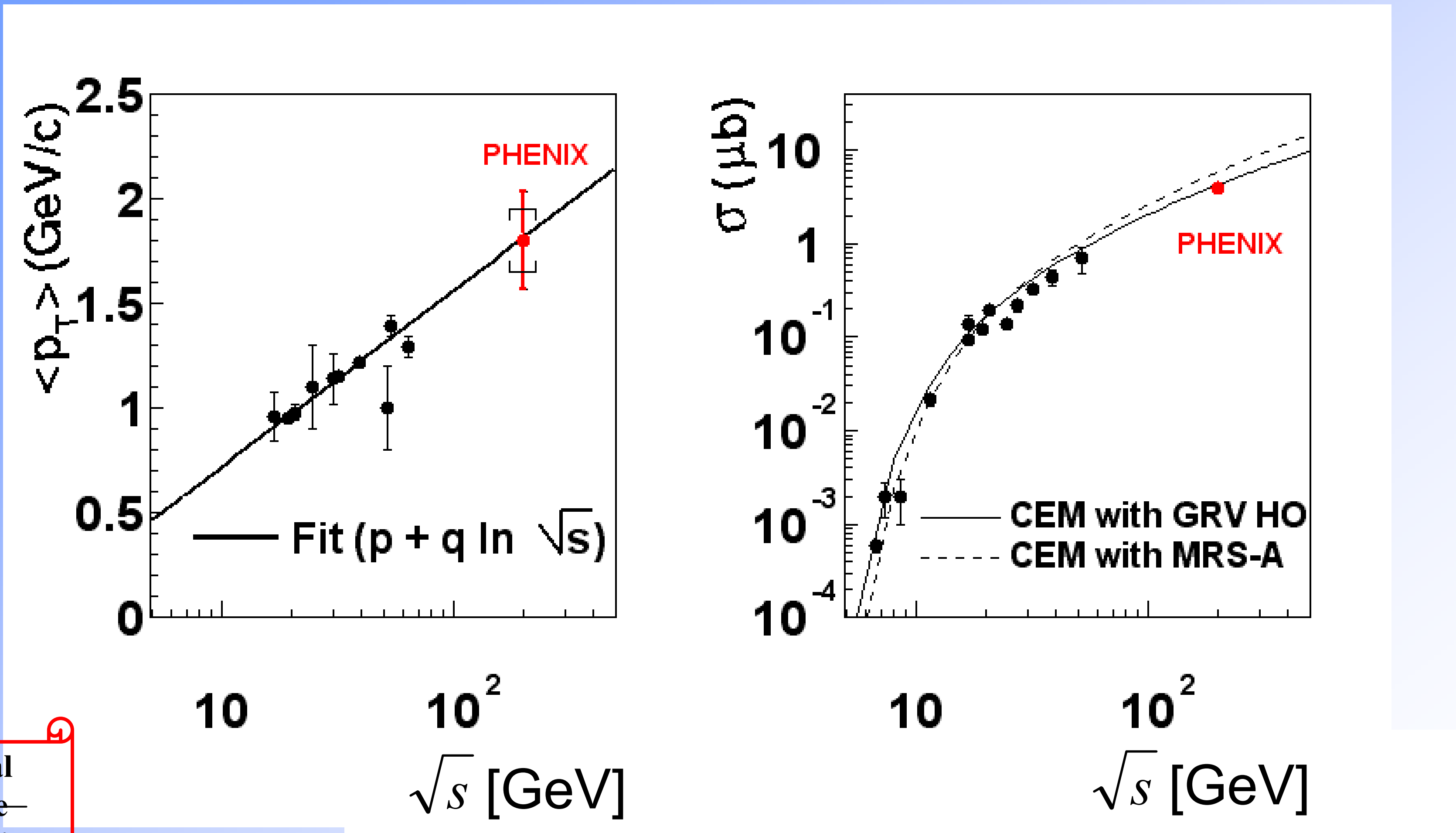
- PHENIX is well suited to the study of spin physics with a wide variety of probes.
  - ΔG with prompt γ, heavy flavor via electrons, light hadrons
  - Anti-quark helicity distribution via W decay
  - Transversity
  - Physics beyond the standard model
- Run-2 gave us a baseline for transverse spin asymmetry and cross-sections (and local polarimetry)
- In Run-3, we commissioned with longitudinal polarized protons (successful spin rotators) and took data for our first A_{LL} measurements using π^0.
- We have studied our relative luminosity systematics and can make an A_{LL} measurement that is statistics limited.
- We have an upgrade plan that will give us the triggers and vertex information that we need for precise future measurements of ΔG, Δq and new physics at higher luminosity and energy.

Run-2 p-p: J/ψ Invariant Mass Distribution



Final
~~to be~~
submitted
to PRL

Run-2 p-p: Comparison with Previous Experiments



Final ~~to be~~ submitted to PRL

Luminosity in RHIC Runs to Date

- Run-1:
  - Au-Au at 130 GeV
    - Expectation: 20 μb^{-1}
    - Reality : ~ 1 μb^{-1}
    - Output: 11 publications (to date; 1 pending)

Shortfall: factor of 20

- Run-2:
  - Au-Au at 200 GeV
    - Expectation: 300 μb^{-1}
    - Reality : ~ 24 μb^{-1}
    - Output: 4 submissions (to date; 8 others pending)

Shortfall: factor of 12

  - p-p at 200 GeV
    - Expectations: 3 pb^{-1}
    - Reality : 0.15 pb^{-1}
    - Output: 1 submission (to date; 1 other pending)

Shortfall: factor of 20 (∞)

- Run-3:
  - d-Au at 200 GeV
    - Expectation: 10 nb^{-1}
    - Reality: : 2.7 nb^{-1}
    - Output: 1 submission (to date)

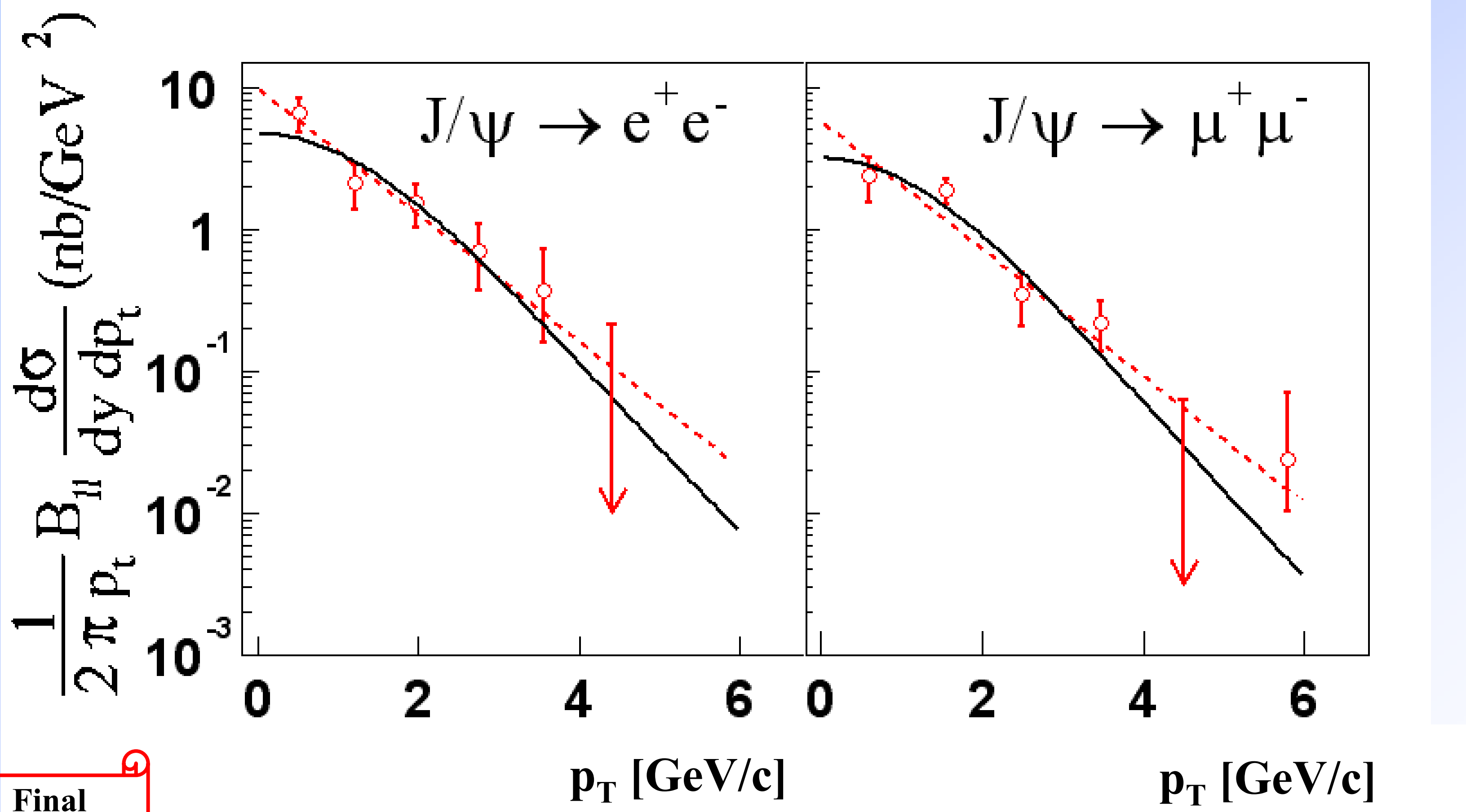
Shortfall: factor of 4

  - p-p at 200 GeV
    - Expectation: 3 pb^{-1}
    - Reality : 0.35 pb^{-1}
    - Output: TBD

Shortfall: factor of 9 (30-60)

N.B. “Shortfall” defined wrt “optimistic guidance”

Run-2 J/ψ pT Distribution from pp

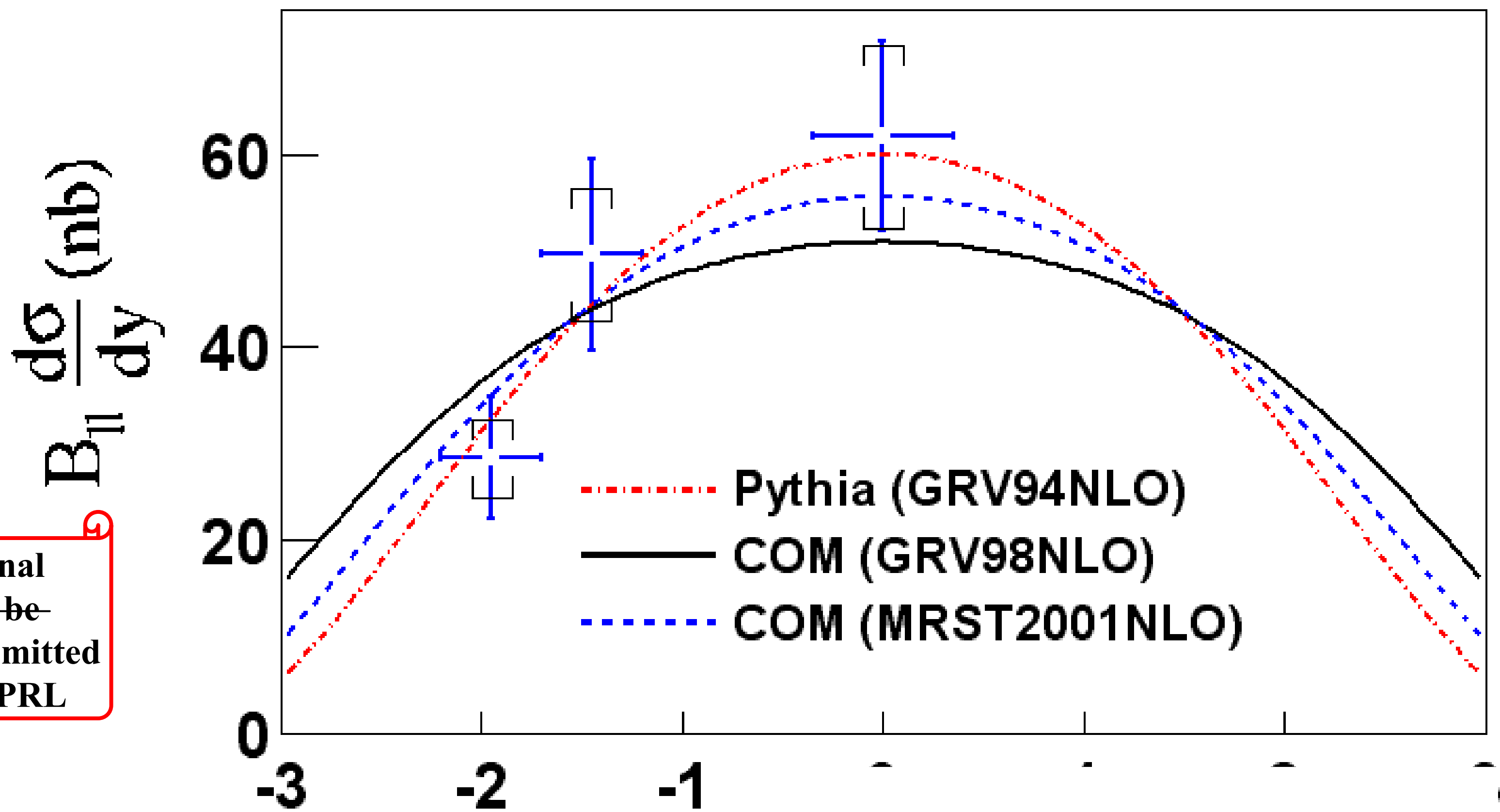


Final
~~to be~~
submitted
to PRL

$\langle p_T \rangle = 1.83 \pm 0.25$ (stat) ± 0.20 (sys) GeV

PHENIX

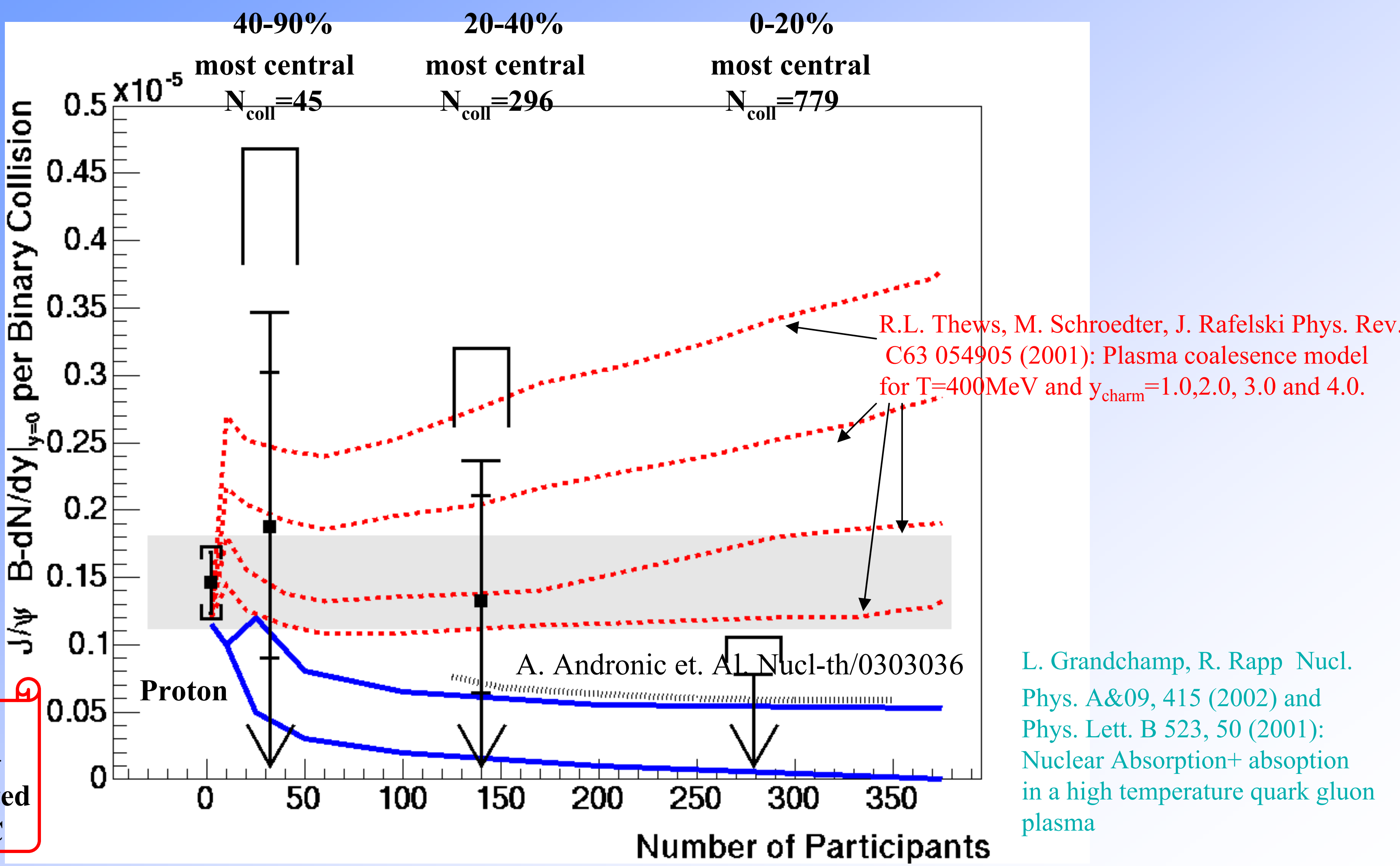
Run-2 J/ψ Rapidity Distribution from pp



Final
~~to be~~
submitted
to PRL

- Integrated cross-section :
- 3.99 ± 0.61 (stat) ± 0.58 (sys) ± 0.40(abs) μb

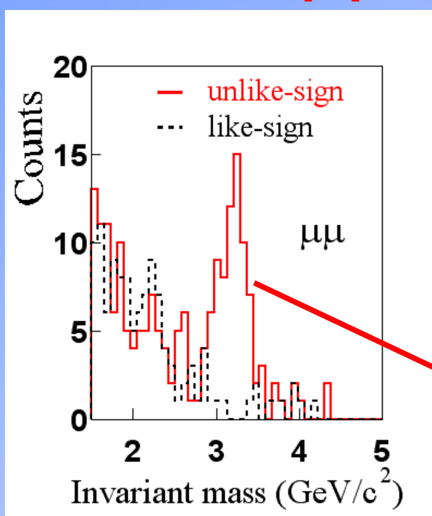
Run-2 J/ψ Centrality Dependence from Au-Au



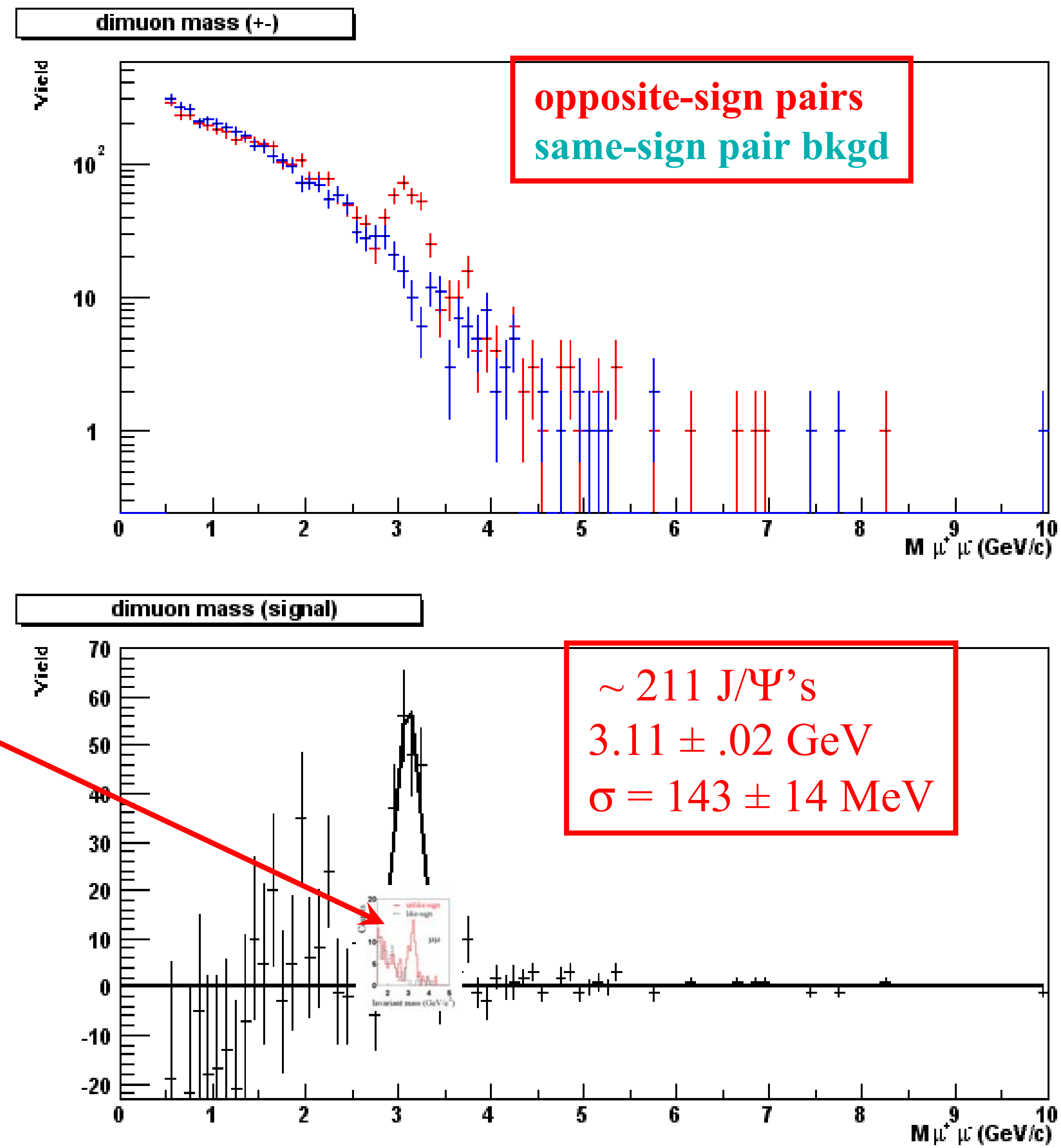
Final ~~to be~~ submitted to PRC

Run-2 to Run-3

- Our total di-muon sample from Run-2 pp:



- Compared to ~1/3 of our d-Au sample



Compare to our 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 scans

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

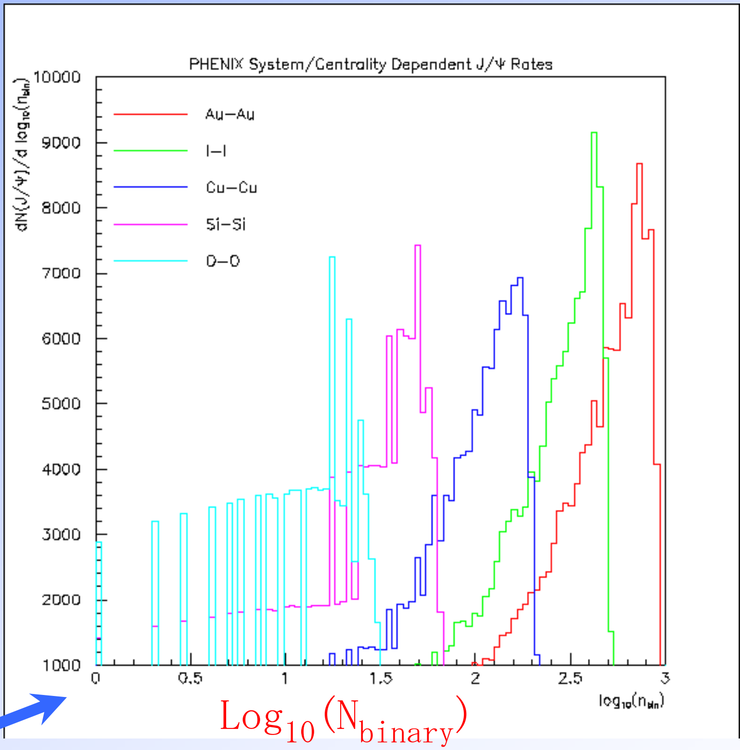
- The machine achievements in the first 3 years of RHIC operations have been **Spectacular**
  - 3 different colliding species (Au-Au, p-p, d-Au)
  - 3.5 energies for Au-Au (19, 56, 130, 200) GeV
  - First ever polarized hadron collider
  - Design luminosity for Au-Au
  - (Etc.)
- Physics has been produced 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
    - μb : $R_{AA}(p_T)$ PRL 88, 022301 (2002)
    - nb : J/Ψ (limit) nucl-ex/0305030
  - 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

Looking Ahead

Runs 4, 5, 6 ... :

(Subject to the usual caveats about surprises and flexibility):

- Au-Au
  - Major goal: First definitive measurement of J/Ψ production systematics
  - Also: direct photons, γ+"jet", light vector mesons, continuum, ...
- Polarized protons
  - Major goal: First definitive measurement of ΔG via π^0 channel
  - Also: beginning of spin physics with rare probes (direct photons, J/Ψ, open charm)
- Light ions
  - Full exploration of J/Ψ production versus "N_{binary}" ~ A(b)*A(b) via a series of shorter(?) runs with light ions



N.B.: The complexity of species available at RHIC is *unprecedented for a collider*

➡ *unprecedented scheduling challenge*

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Looking Further Ahead

- Runs 1-5: ***EXPLORATION***
  - Well underway!
  - "Complete" data sets for full energy
    - Au-Au
    - d-Au
  - 200 GeV p-p
    - "Complete" data set for A-A comparison
    - Strong start on ΔG physics
- Runs 5-10: ***CHARACTERIZATION***
  - Ion program
    - Species scans
    - Energy "scans"
    - d-A, p-A
  - Spin program
    - "Complete" program of $\Delta G(x)$ at 200 GeV
    - 500 GeV running, sea quark contributions
    - Study of G(x) via direct photons, heavy flavor (energy scan?)
  - Upgrades (as available) to extend reach of both programs
- Runs 11-15: ***EXPLOITATION***
  - Full upgrades available
  - Repeat "complete" measurements with x10-100 sensitivity

PHENIX

Fitting It All In

RHIC Weeks

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

COOL DOWN | SETUP | ← RUNNING → | SETUP | ← RUNNING → | WARM UP

Run-3 mode:
10 + 3 weeks of physics running in "27 week" run
3 weeks in "high performance" mode

COOL DOWN | SETUP | ← RUNNING → | WARM UP

Run-4 mode (?):
18 weeks of physics running in "27 week" run
11 weeks in "high performance" mode

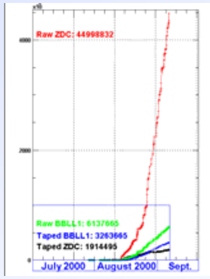
Observations:

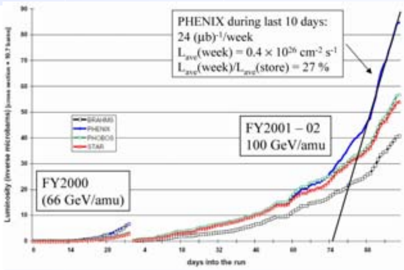
1) Two-mode running has worked well in initial phase of RHIC Ops to
   - Develop many programs (Au-Au, p-p, d-Au, spin)
   - Identify issues with same

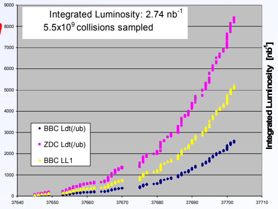
2) It is not conducive to efficient usage of machine in "steady-state"

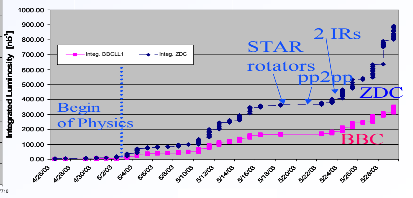
3) If restricted to 27 weeks/year, a transition to one-mode running will
   a) Create short-term dislocations
   b) ***Result in greater efficiencies for any luminosity-limited program***

4) Alternate solution (as per original 37 weeks/year):
   a) ***Significant increase in running time per year***
   b) ***Major effort to decrease present long setup times***









Upgrades in PHENIX

- ***Driven*** by (new) physics opportunities
- ***Conditioned*** by available resources
- ***Permitted*** by new technologies
- ***Endorsed*** by Detector Advisory Council:
  - "emphasis will shift toward studies with improved sensitivity for rare phenomena.."
    - 1) Measurement of identified hadron yields in the p_T range 3-10 GeV/c and hadron yields beyond 10 GeV/c
    - 2) Charm ... as a valuable probe of QCD dynamics of hot matter
    - 3) Low mass e+e- pairs ... (as) a uniquely sensitive probe of the structure of dense and hot QCD matter

New Physics to be Addressed with an Upgraded PHENIX Detector

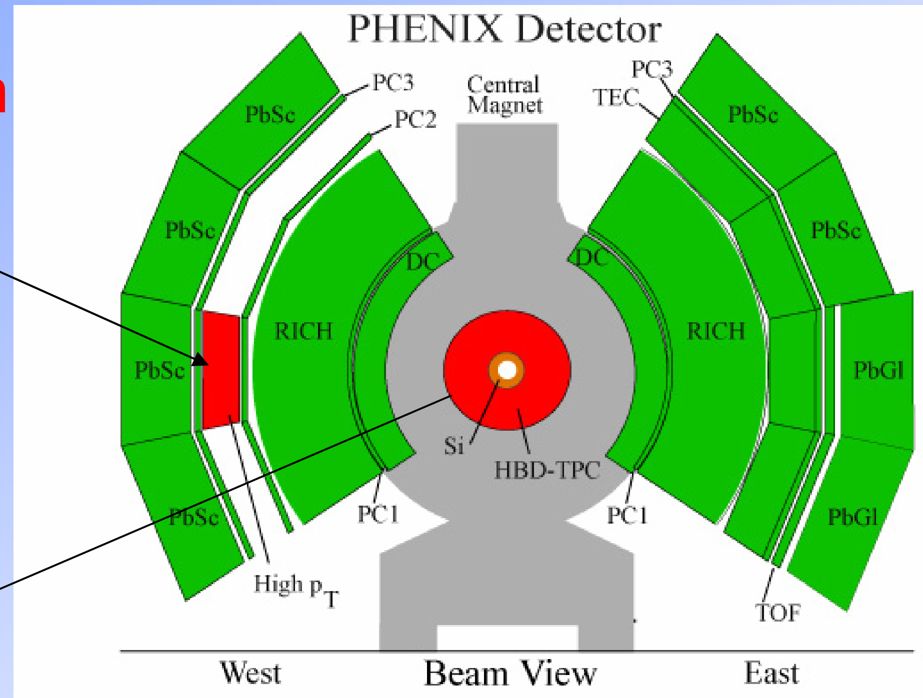
- Low mass dilepton pairs
  - Chiral symmetry restoration and modification of ρ,ω,ϕ
  - Thermal di-leptons
  - Di-leptons from charm pairs
- Improved measurements of heavy flavor (c,b) production
  - Beauty measurement in Au+Au collisions
  - Energy loss of charm/beauty in hot matter
  - ΔG measurement by heavy quark production in wide x range
  - Gluon shadowing in wide x range
- Jet studies and γ-jet correlations
- High p_T identified particles
  - meson/baryon ratio in pt>5 GeV
  - Quark recombination or jet fragmentation?
- Truly rare processes
  - Inclusive particle spectra and direct photons out to high p_T
  - Drell-Yan continuum above the J/Ψ
  - Upsilon spectroscopy - Υ(1S),Υ(2S),Υ(3S)
  - W-production

Measurements complement and enhance the present physics program

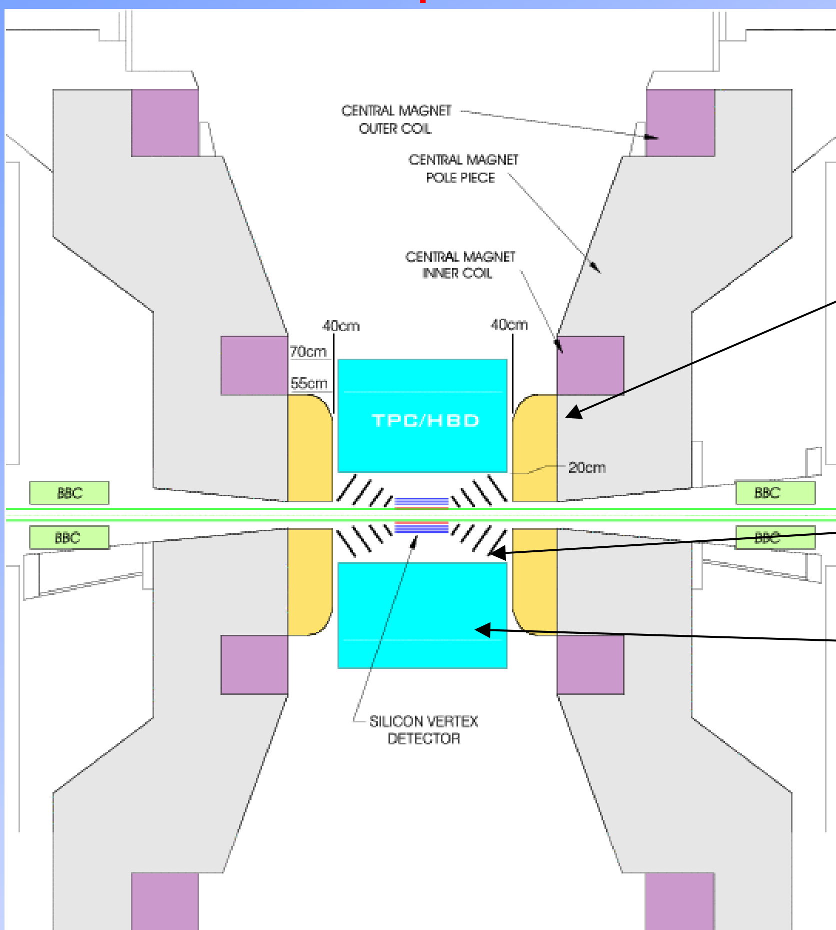
- **fully exploit existing rare event capabilities of PHENIX**
- **PHENIX central and muon spectrometer are essential**

Upgrades to PHENIX Detector

- High p_T particle Identification
  - Aerogel/TOF (west)



Vertex Spectrometer



- Charm/Beauty measurement
  - Silicon Vertex Tracker
- Low mass di-leptons
  - TPC/HBD
- High p_T and jets
  - TPC/Silicon Vertex Tracker
- High p_T muons (W, Upsilon)
  - Enhanced muon LVL1 trigger

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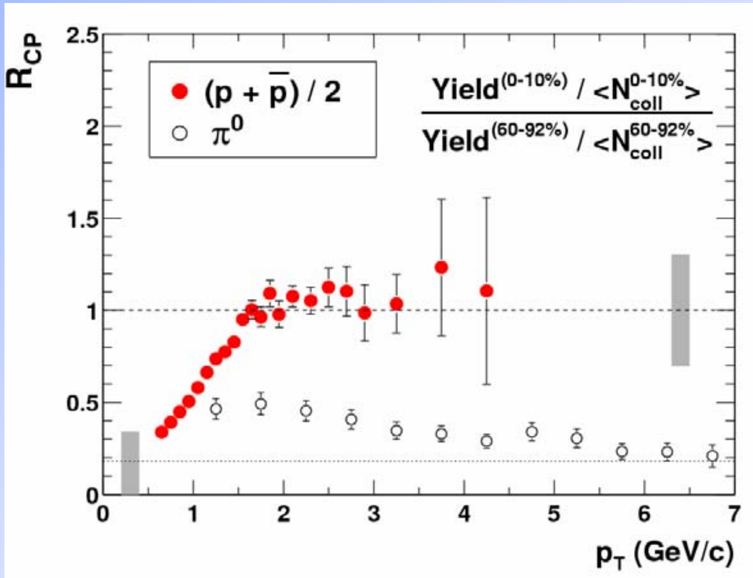
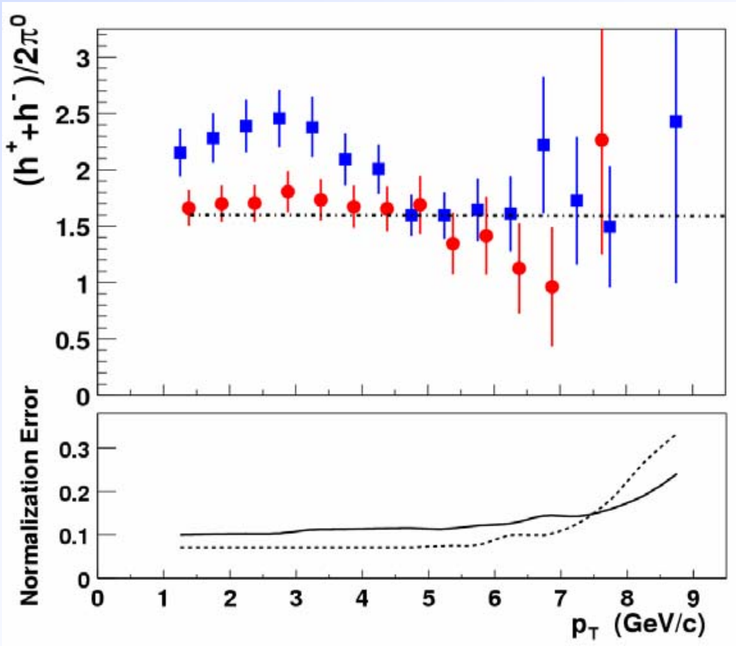
Physics driving Extended Particle Identification

- From the DAC:
  - “Measurement of identified hadron yields in the pT range 3-10 GeV/c and hadron yields beyond 10 GeV/c”
  - Why?:
    - Different flavor yields in Au-Au collisions indicate
      - Modified fragmentation functions?
      - Recombination of quarks from a plasma state?
- Present capabilities:
  - π/K to ~ 2 GeV/c
  - p(π+K) to ~4.5 GeV/c
- Goal: Extend π, K, p separation to ~10 GeV/c





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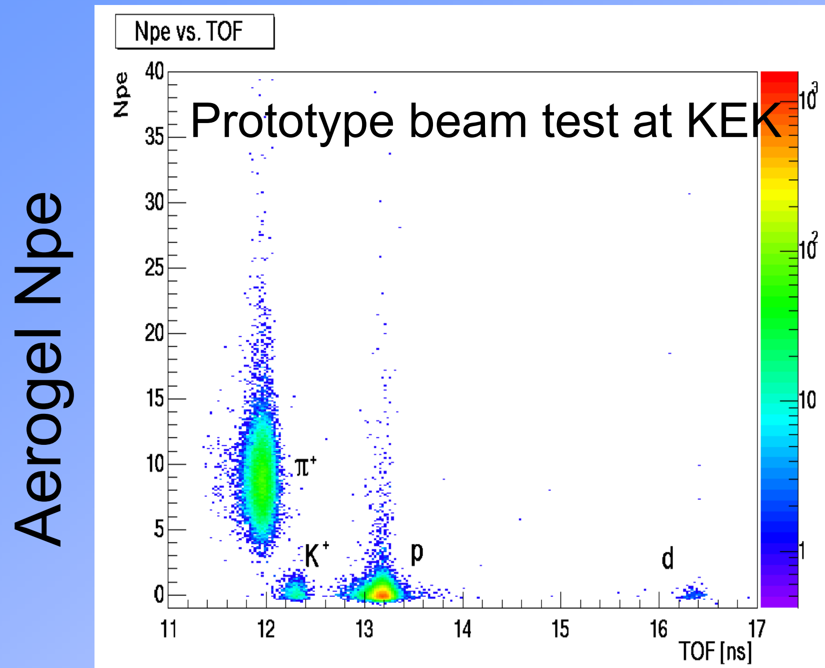
Extended PID with Aerogel

		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

Aerogel Status

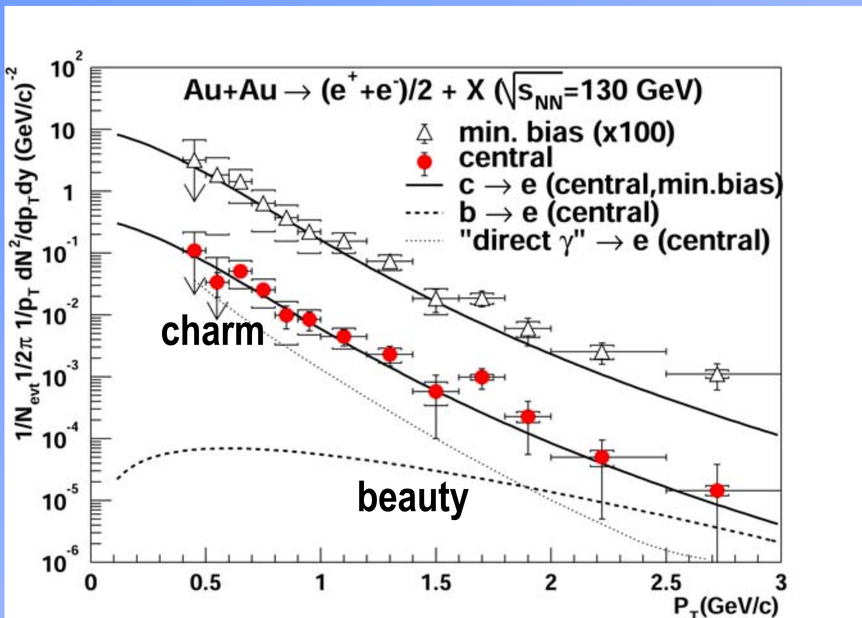


- R&D ~complete
  - 3 test beam periods at KEK
  - homogenous ~ 15 p.e. over 12x12x12 cm^2 block
- Participating institutions
  - BNL, Dubna, Tokyo, Tsukuba
- Schedule:
  - Run-3: Prototype test
  - Run-4: Partial installation
  - Run-5: Full installation

Prototype test at PHENIX

Prototype installed in West Arm of PHENIX

Physics Driving (Open) Charm and Beauty Detection



- From the DAC:
  - "Charm ...
    as a valuable probe of QCD dynamics of hot matter"
  - Why?
    - Heavy Ions
      - Do heavy quarks
        lose energy in quark matter?
      - charm can be produced thermally → charm enhancement
      - critical base line for J/ψ and Y production & dilepton continuum
    - Spin
      - Gluon polarization in wide x range
- Present capabilities
  - via inclusive electrons
  - can not distinguish charm
    and beauty for $p_T > 4$ GeV/c
- Goal: separate charm and beauty by vertex tagging

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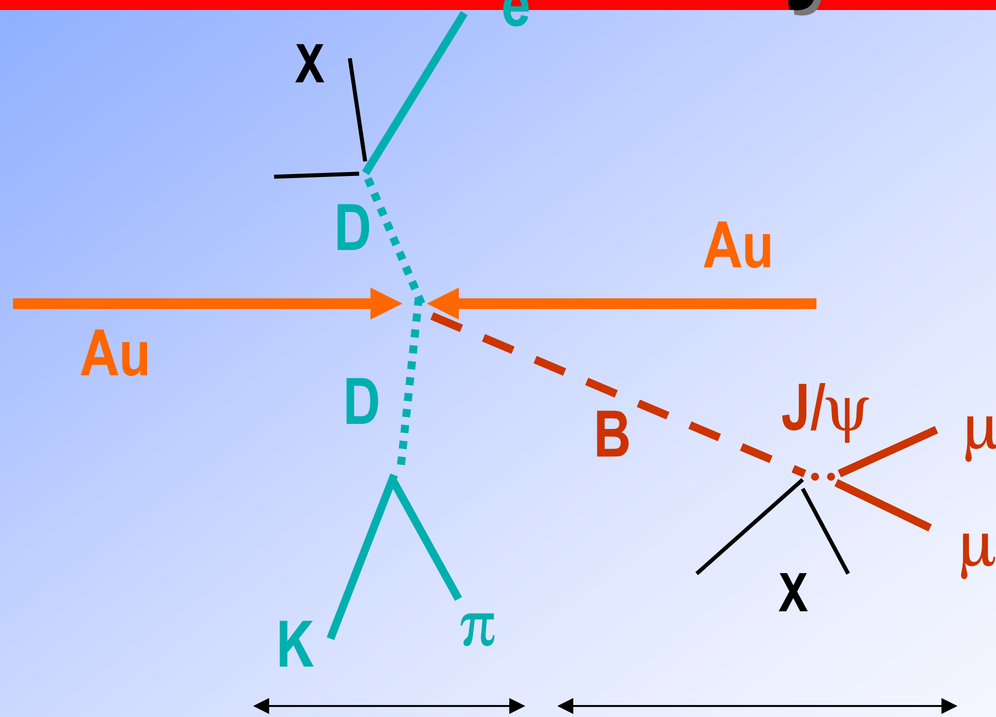
Direct Observation of Open Charm and Beauty

Detection of decay vertex will allow a clean identifications of charm and bottom decays

	m GeV	cτ μm
D^0	1865	125
$D^\pm$	1869	317
B^0	5279	464
$B^\pm$	5279	496



Central arm & barrel

Detection options:

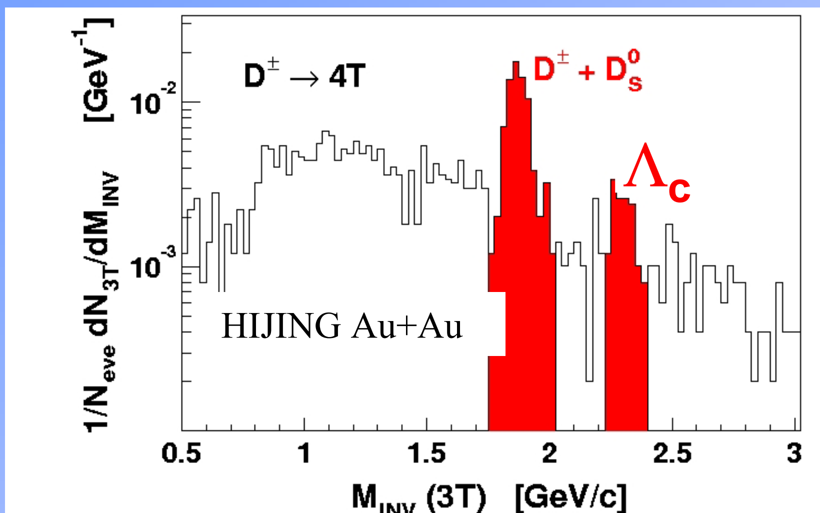
- **Beauty and low p_T charm through displaced e and/or μ**
- **Beauty via displaced J/ψ**
- **High p_T charm through $D \rightarrow \pi K$**

Need secondary vertex resolution < 50 μm

Beauty and high p_T charm will require high luminosity

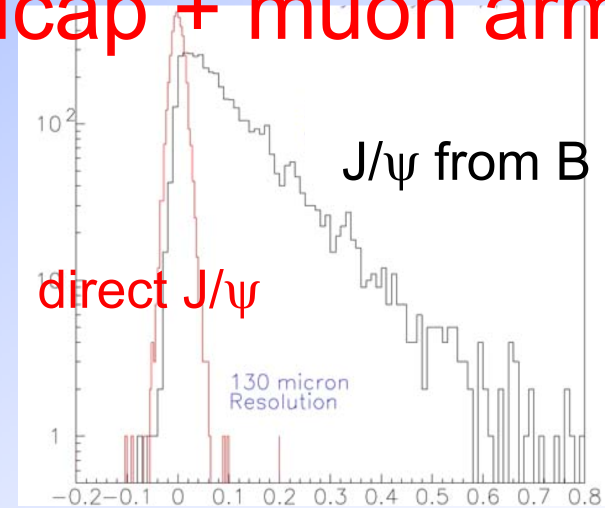
Charm/Beauty measurements in Au+Au with SVT

- Charm Measurement by barrel + central arm

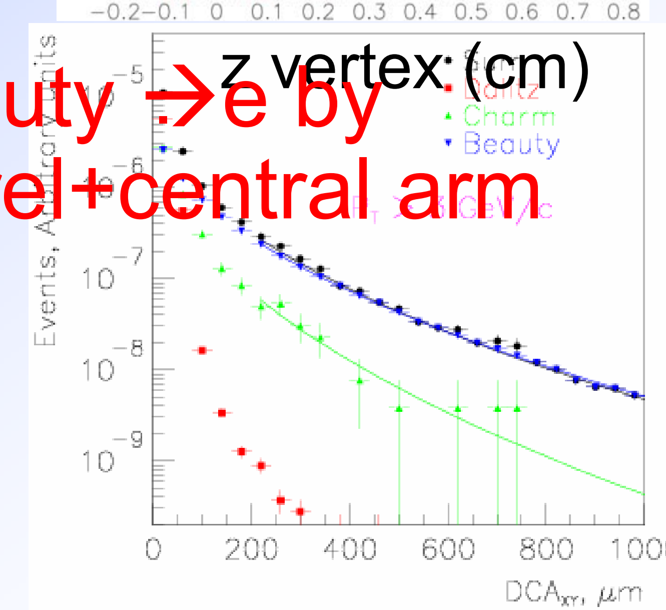


- Au+Au
  - Robust charm/beauty measurement in Au+Au
  - Energy loss of charm at high Pt
  - Energy loss of beauty

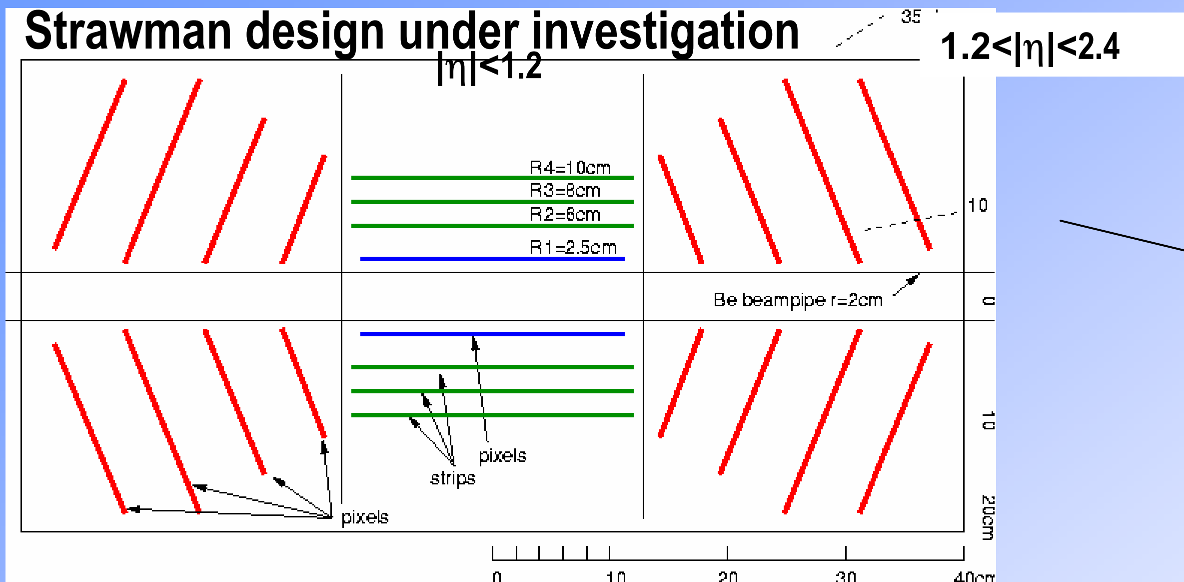
- Beauty → J/ψ in endcap + muon arm

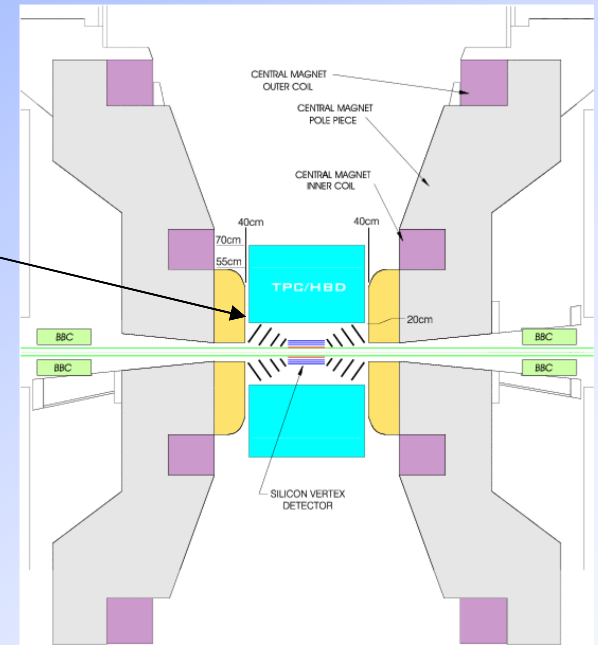


- Beauty → e by barrel+central arm



Proposed Silicon Vertex Tracker (SVT)



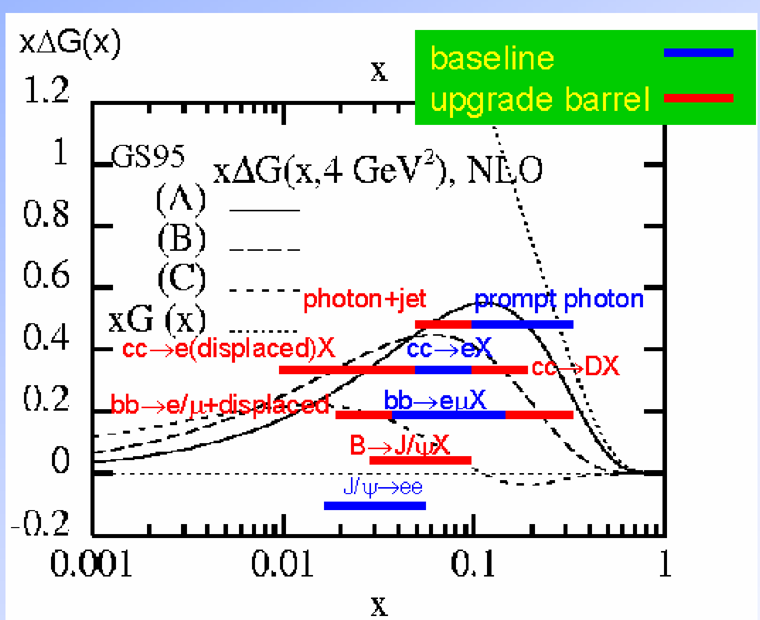


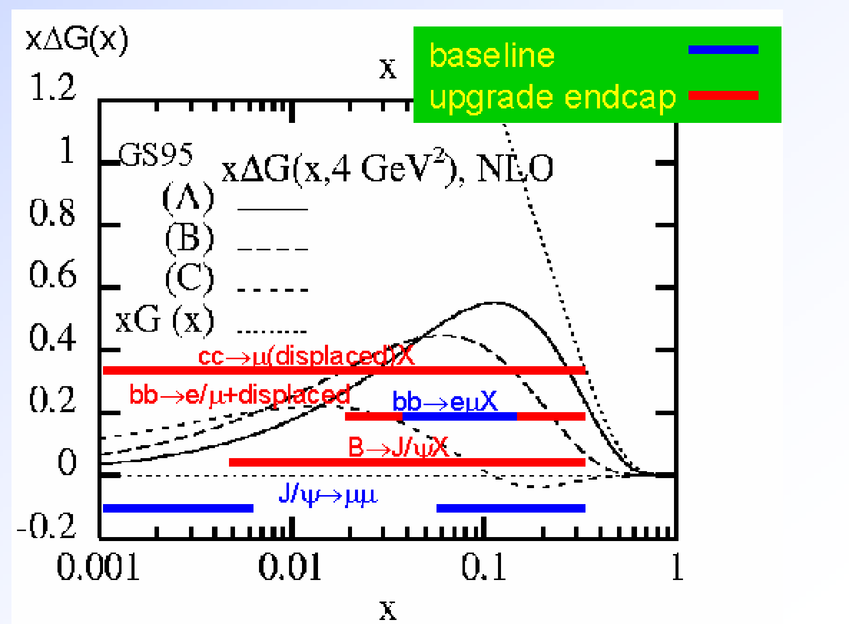
Pixel barrels (50 μm x 425 μm)
Strip barrels (80 μm x 3 cm)
Pixel disks (50 μm x 2 mm)

~1.0% X_0 per layer
barrel resolution < 50 μm
forward resolution < 150 μm

PHENIX Spin Physics with SVT Upgrade

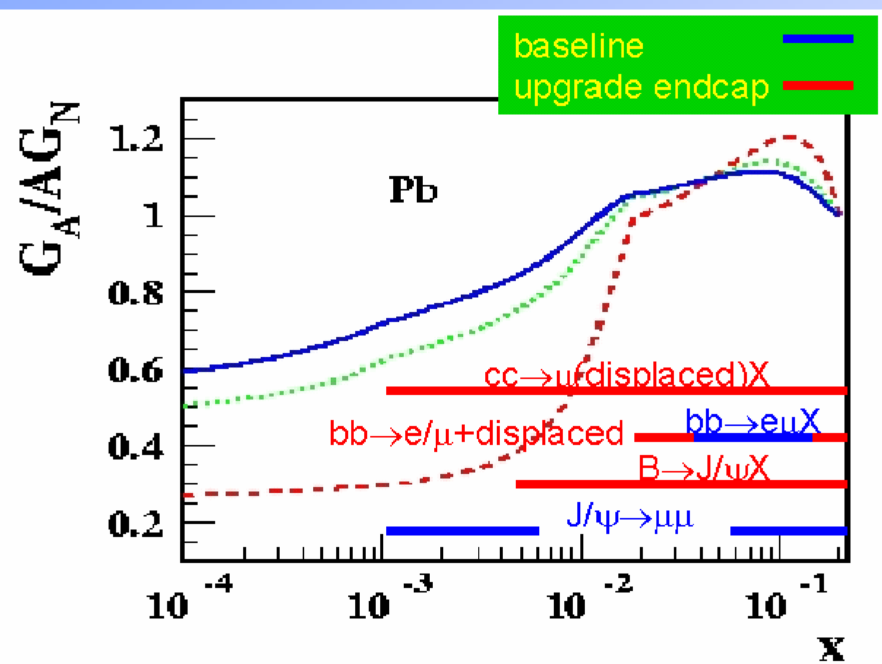
- Measurement of Gluon polarization by Heavy flavor production
  - c, b → e, μ + displaced vertex
  - B→ displaced J/ψ
  - D→Kπ at high pt
- SVT measurement of displaced vertex
  - Improved S/B → higher sensitivity to ΔG(x)
  - Much broader x-range coverage

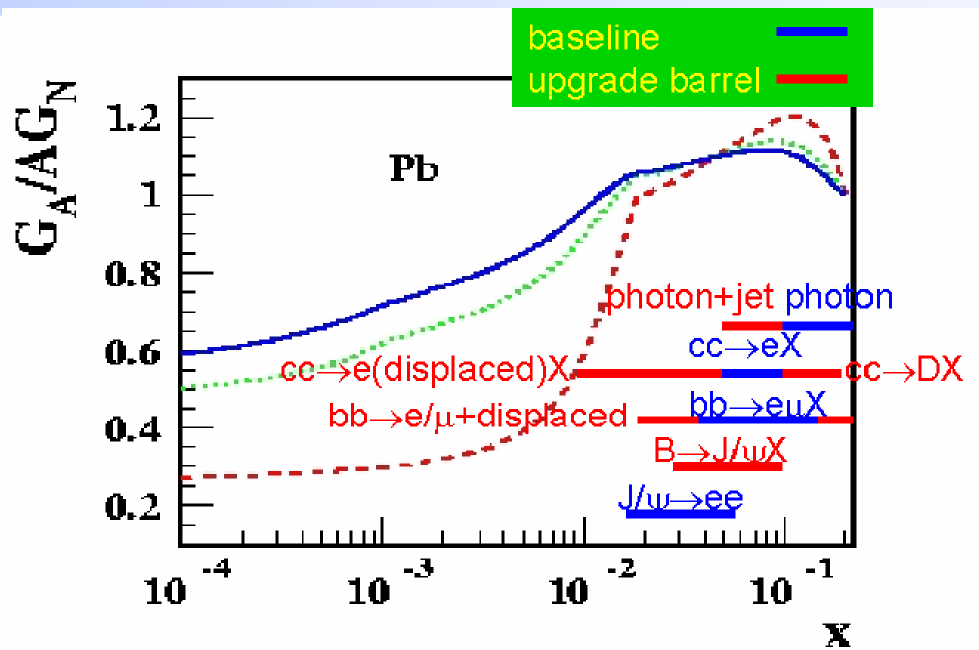




Measurement of gluon shadowing with SVT

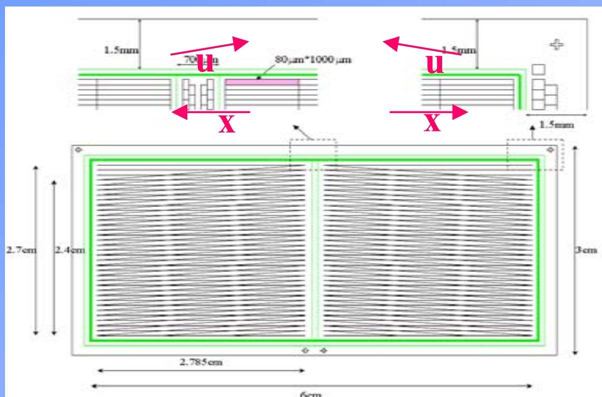
- Heavy-flavor measurement in p+A
  - Single lepton and J/Ψ with displaced vertex
- Heavy-flavor production via g+g → q+ $\bar{q}$
- Extracting gluon structure function nuclei, shadowing
  - vertex detector provides broader range in x into predicted shadowing region (x ~ 10^{-2} - 10^{-3})



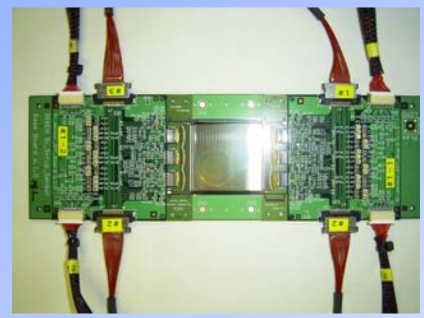


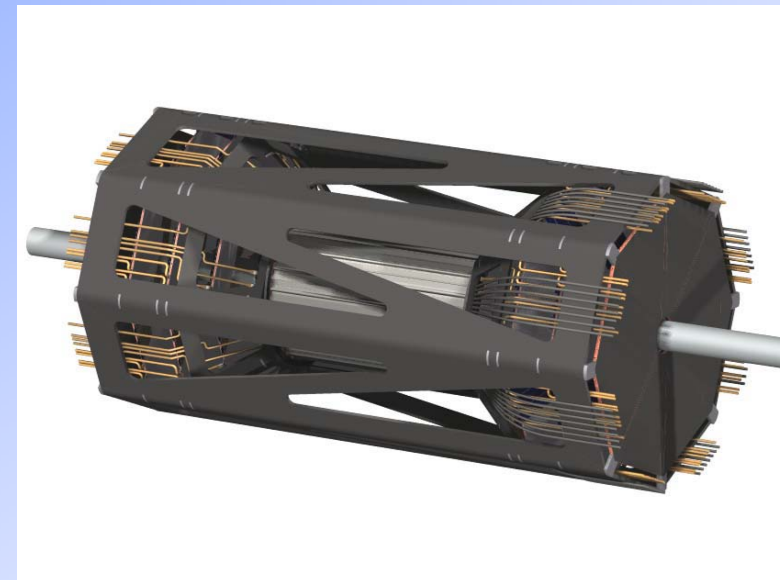
PHENIX Silicon Vertex Tracker R&D

strip sensor design Z.li, BNL



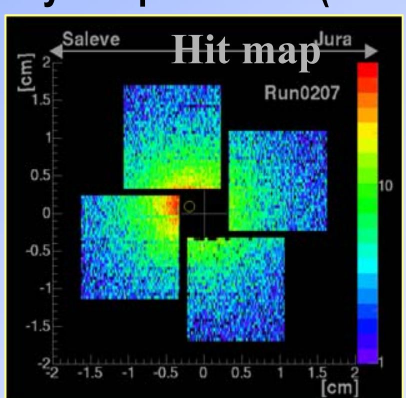
strip sensor test RIKEN





- Ongoing R&D
  - Silicon strip sensor development
  - Hybrid pixels (with ALICE and NA60)
  - design of support structure

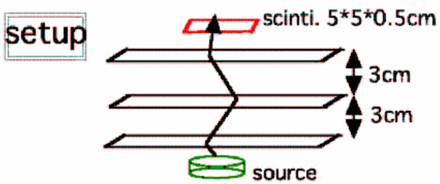
NA60 hybrid pixel tests (RIKEN,SB)

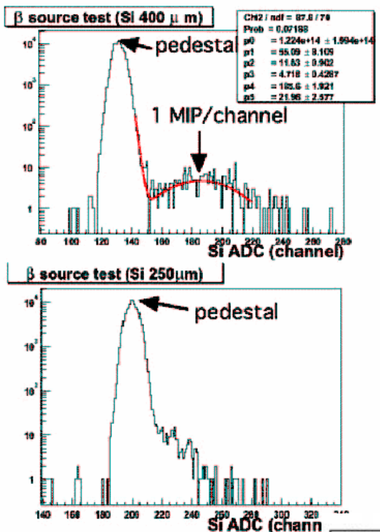


- Critical contributions supported by R&D proposal
  - silicon strip readout & integration into PHENIX
  - hybrid pixel integration, thinning & bump bonding
  - development of monolithic active pixel sensors
  - design of support structure including cooling etc
- Participating institutions
  - BNL, ISU, Kyoto U., LANL, ORNL, RIKEN, Stony Brook U.

PHENIX Silicon Vertex Tracker R&D

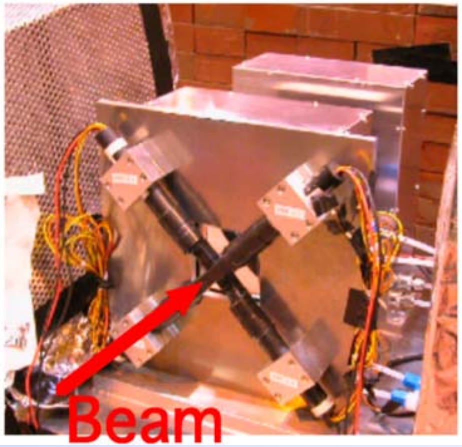
Source test at RIKEN

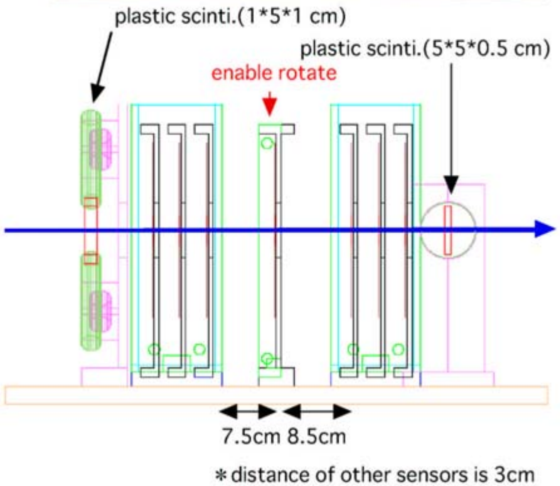


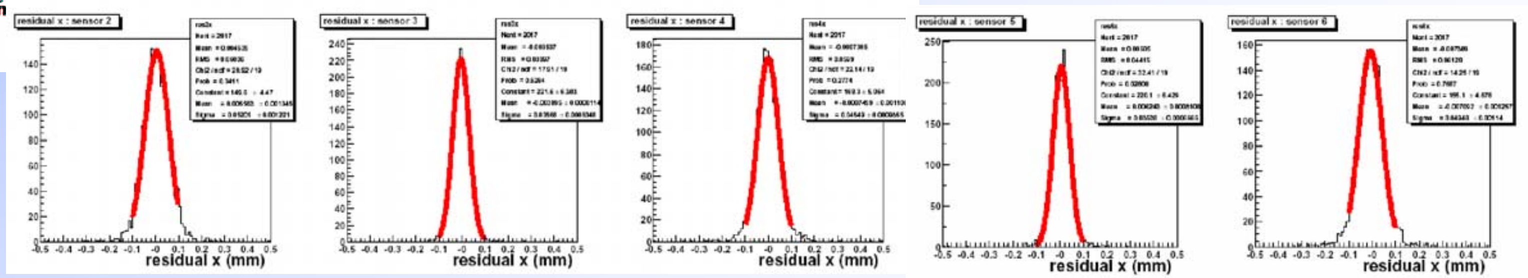


Beam test at KEK by RIKEN/Kyoto

- Location at KEK-PS T1 beam line
- Various particles(0.5-2.0GeV/c)
- We put 7 silicon sensors and 3 scintillators for trigger counters
- CAMAC and VME hybrid







σ =52μ σ =35μ σ =45μ σ =35μ σ =49μ

SVT Status

- PHENIX Internal Letter of Intent prepared, presented to collaboration
- Active R&D effort::
  - Ongoing barrel R&D with ALICE&NA60 on pixel detectors
  - Ongoing barrel R&D RIKEN/BNL/ORNL strip+SVX4
  - Technology research for endcap strips or mini strips (LANL+FNAL(?))

- Presentation of proposal for barrel to PAC in September including endcap option
- Proposal for barrel to DOE at ~same time
- Within next weeks present drafts of management plan to DOE including WBS structure

Physics Driving Low-Mass e+e- Pairs

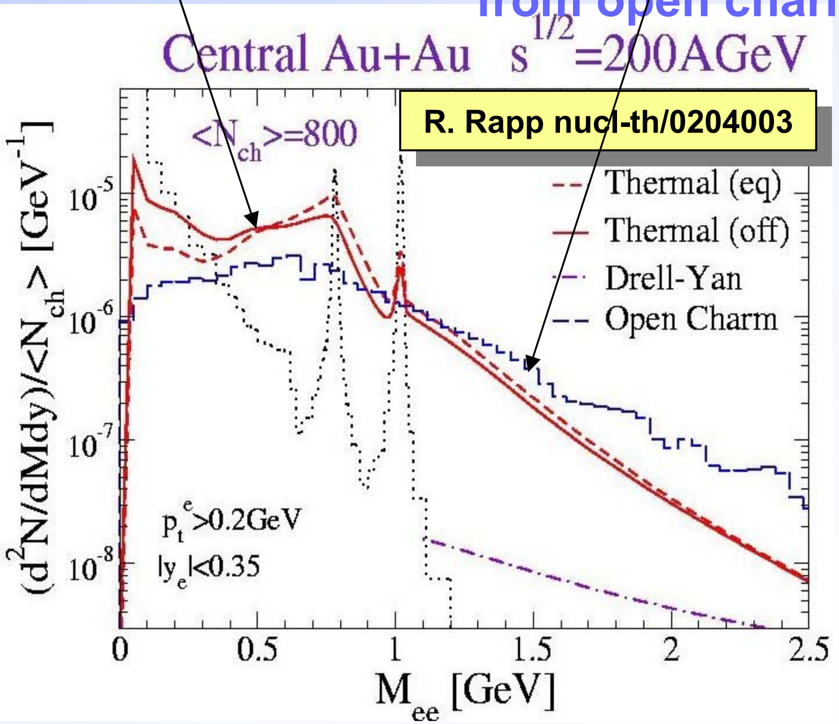
Prime goal of future PHENIX program (as anticipated in 1993 CDR)

- From the DAC:
  - "Low mass e+e- pairs ... (as) a uniquely sensitive probe of the structure of dense and hot QCD matter"
  - Why?
    - Directly sensitive to
      - In-medium modification of meson masses, widths
      - Chiral symmetry restoration
- Present capabilities:
  - Very limited (due to unrejected Dalitz and conversion backgrounds)
- Goal: Open this channel for exploration at RHIC

Prediction at RHIC

Strong enhancement of low-mass pairs

Significant contribution from open charm



PHENIX The Experimental Challenge at RHIC

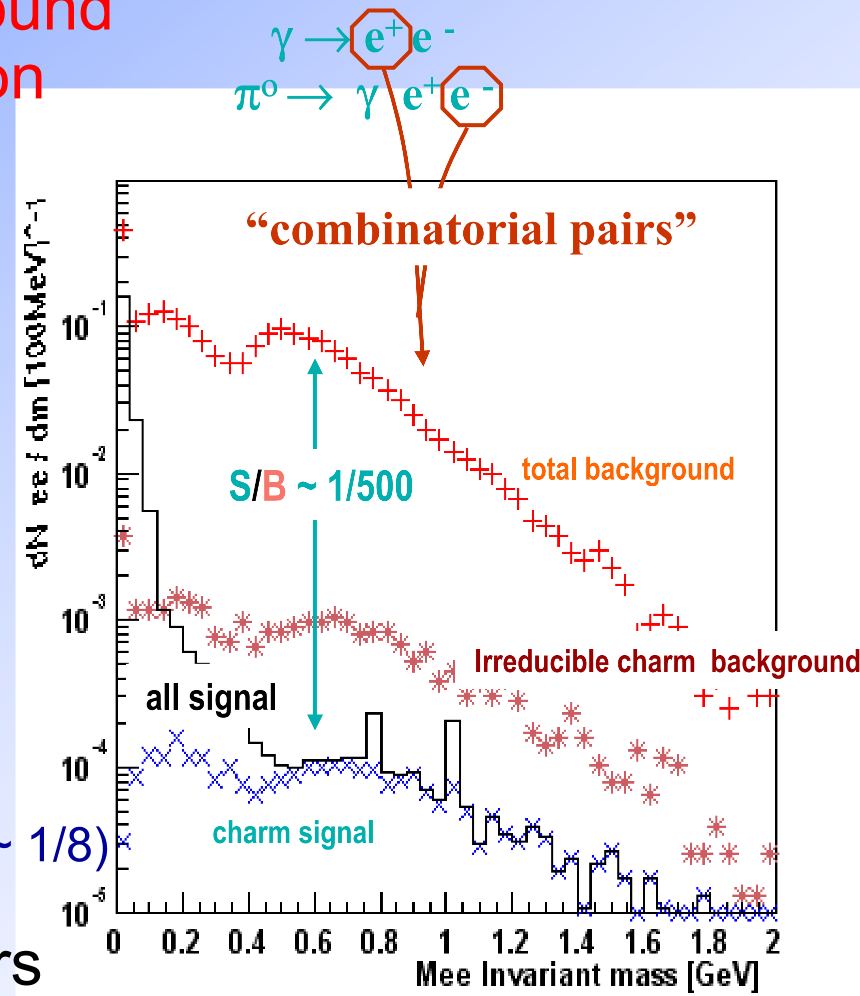
- Huge combinatorial pair background due to copiously produced photon conversion and Dalitz decays :

	dN/dy	dN/dy $p_T > 0.2$ GeV
$e^{\pm}$ from charm	0.68	0.54
$e^{\pm}$ from $\pi^o \rightarrow e^+e^-\gamma$	8.4	1.1
$e^{\pm}$ from $\gamma \rightarrow e^+e^-$ (1.5 X/X_0)	18	2.25

- Need rejection factor >> 90% of $\gamma \rightarrow e^+ e^-$ and $\pi^o \rightarrow \gamma\ e^+ e^-$

S/B improved by >> 20

(irreducible background form charm S/B ~ 1/8)

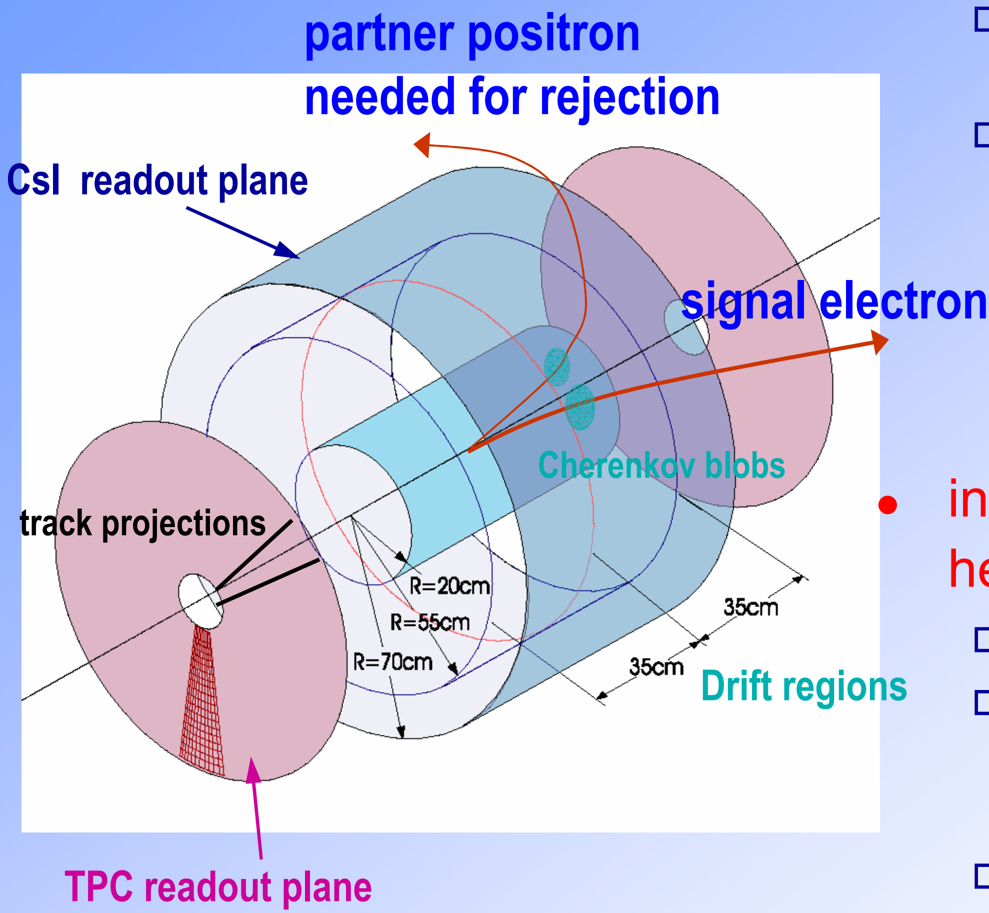


- tool to rejection background pairs
  - pair with small opening angle/or mass

Need Dalitz and Conversion rejection

PHENIX Dalitz Rejector and Inner Tracker

$\Delta\phi \sim 2\pi, \ |\eta| < 1.0$



GEMs are used for both TPC and HBD

- Dalitz rejection via opening angle in HBD
  - HBD is a proximity focused Cherenkov detector with ~ 50 cm radiator length
  - Provides minimal signals for charged particles

"Hadron Blind Detector"

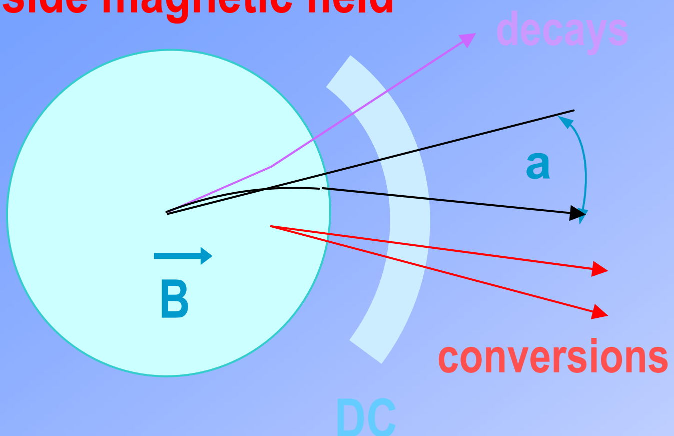
- inner tracker with fast, compact TPC helps Dalitz rejection via inv. Mass
  - R<70 cm, L< 80 cm, T_{drift} < 4 μsec
  - provides tracking through the central magnetic field

    $\delta p/p \sim 2\%\ p$
  - Provides electron ID by dE/dx

    e/π separation below 200 MeV

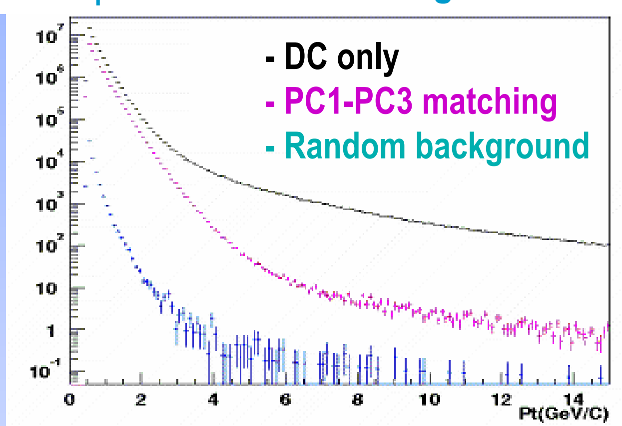
PHENIX Additional benefit: High p_T with TPC

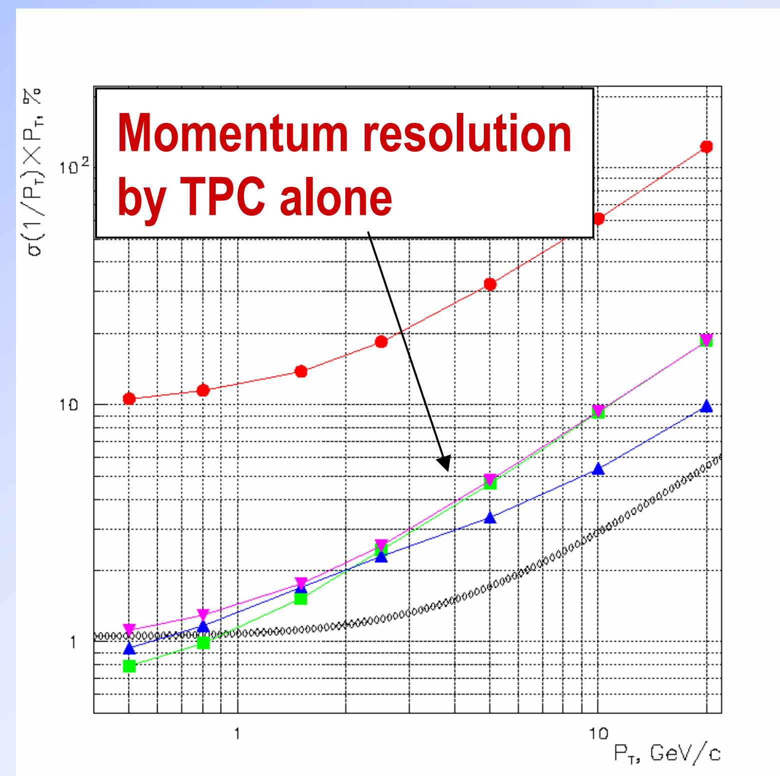
PHENIX presently has no tracking inside magnetic field → Tracking in the TPC in the magnetic field will eliminate background



Decay and conversion background limits the high pt charged particle measurements

P_T distribution of charged tracks





TPC alone can provides a good momentum measurement in large solid angle → Jets measurement

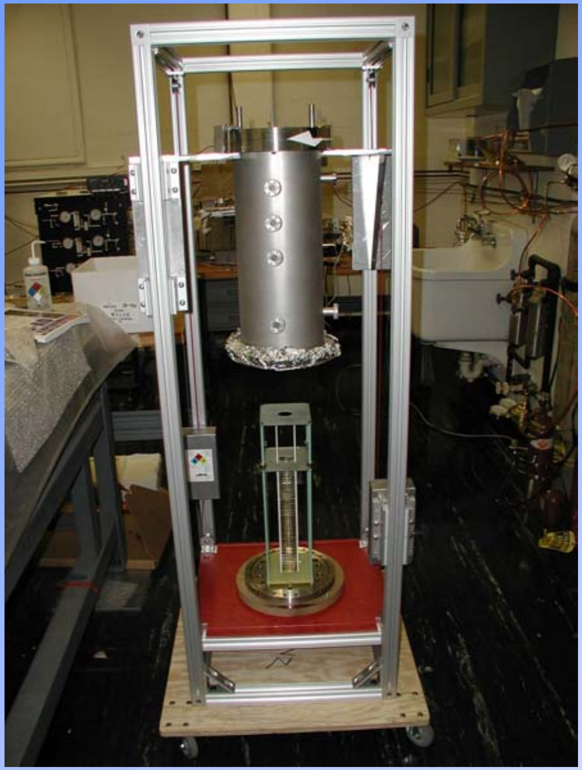
Enhanced Physics with a High Precision Vertex and Tracking Detector

- Separation of charm and bottom decays through inclusive electrons (Central Arm)
  - improve measurement accuracy of c and b cross sections to ~ 10%
  - separate c and b in each p_T bin => flavor dependence of QCD energy loss
- Direct measurement of D mesons
  - combined with particle ID, can measure D -> $K\pi$ modes
  - ➔ p_T spectrum of D's, flavor dependence of QCD energy loss
- Open heavy flavor (Muon Arms)
  D-> μX, B -> J/ψ -> μ+μ-
- Improved momentum resolution for Upsilon spectroscopy
- Enhanced capabilities for spin physics
  wider acceptance (g-jet & jet-jet studies, transversity), b-tagging
- Enhanced physics capabilities for charm and bottom in pA

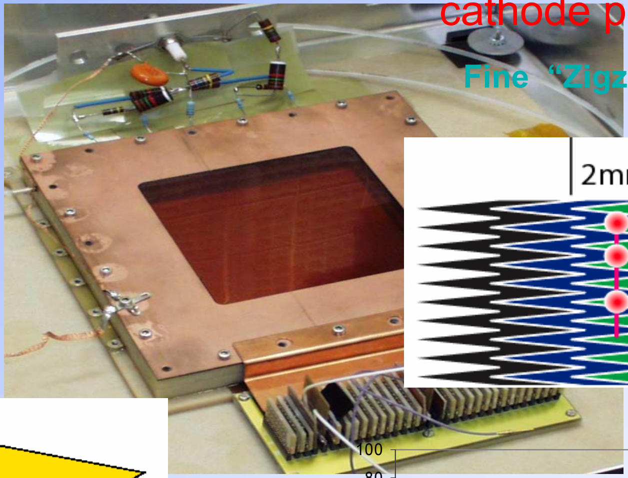
PHENIX

HBD/TPC R&D at BNL

TPC drift cell (BNL)

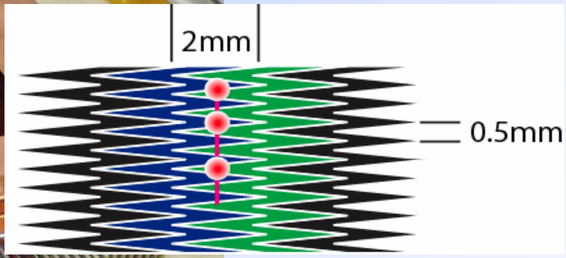


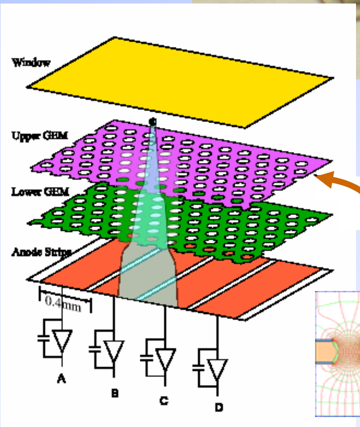
GEM prototype assembly (BNL)

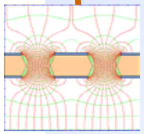


High resolution position measurements by zig-zag cathode pad

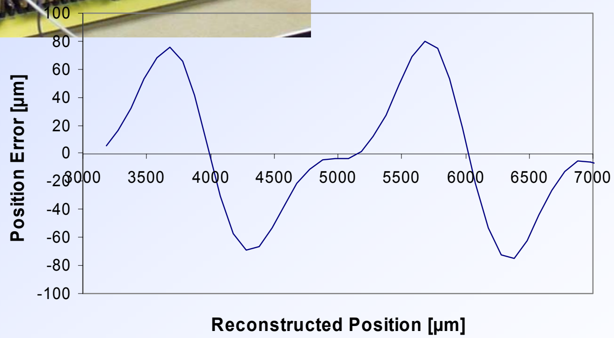
Fine "Zigzag" pattern







GEM read-out



Overall position error: 93µm rms
Including ~ 100µm fwhm x-ray p.e. range, 100µm beam width, alignment errors

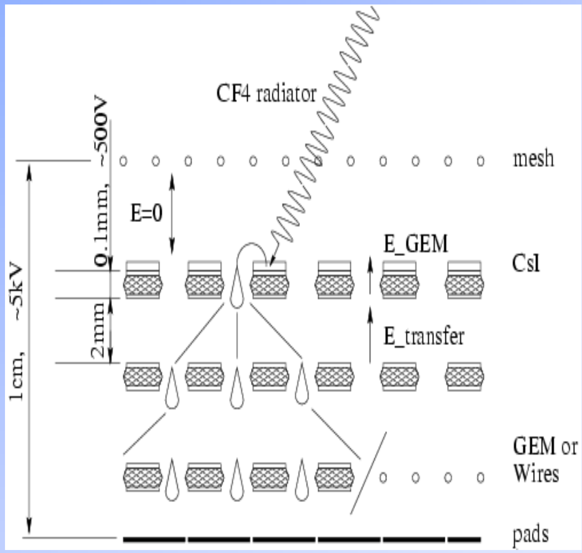
HBD/TPC R&D

Participating institutions

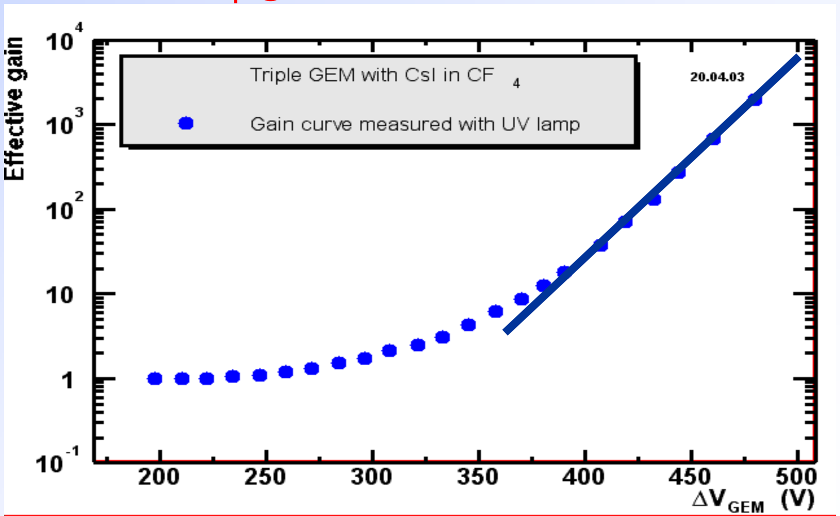
BNL, Columbia, Stony Brook U., Tokyo U., Weizmann Institute

HBD/TPC R&D at Weizmann Institute

HBD test setup and GEM+CsI layout (WIS)

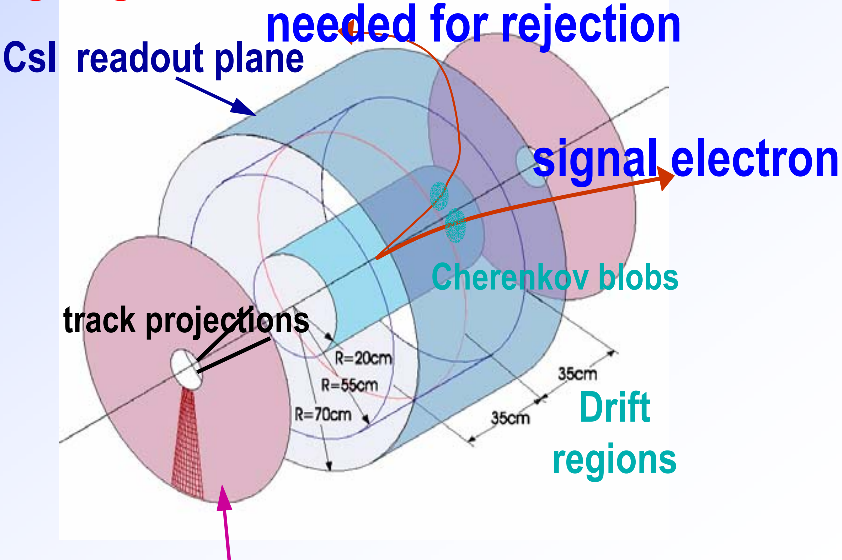


- CsI Photo-cathode coated on GEM
- CF_4 for Cerenkov radiator and detector gas (No UV window)
- Large N_0
- Large Gain by triple GEM with CsI in CF_4 gas has been observed!



HBD/TPC Status

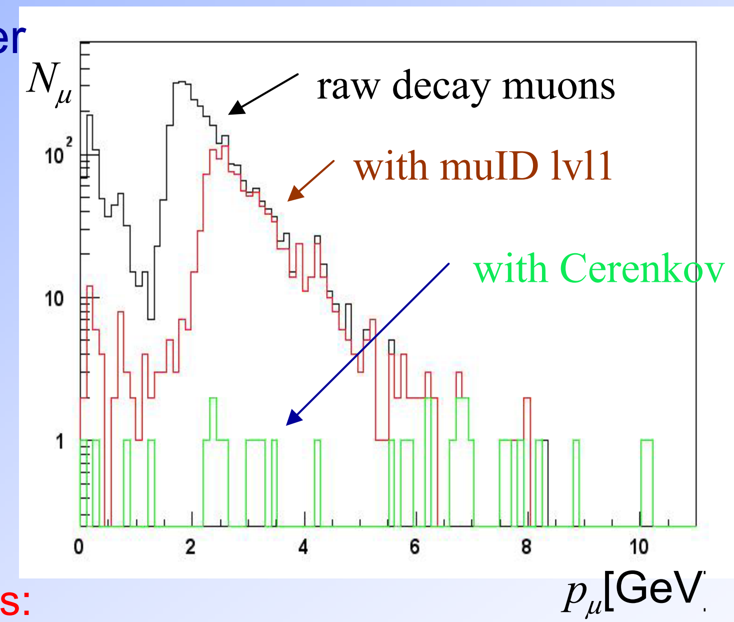
- Generic detector R&D completed successfully
- Full scale prototype development starts later this year
- Feasibility of HBD without TPC to be studied within next 6 months
(as per DAC recommendation)
- Decision on proposal to follow

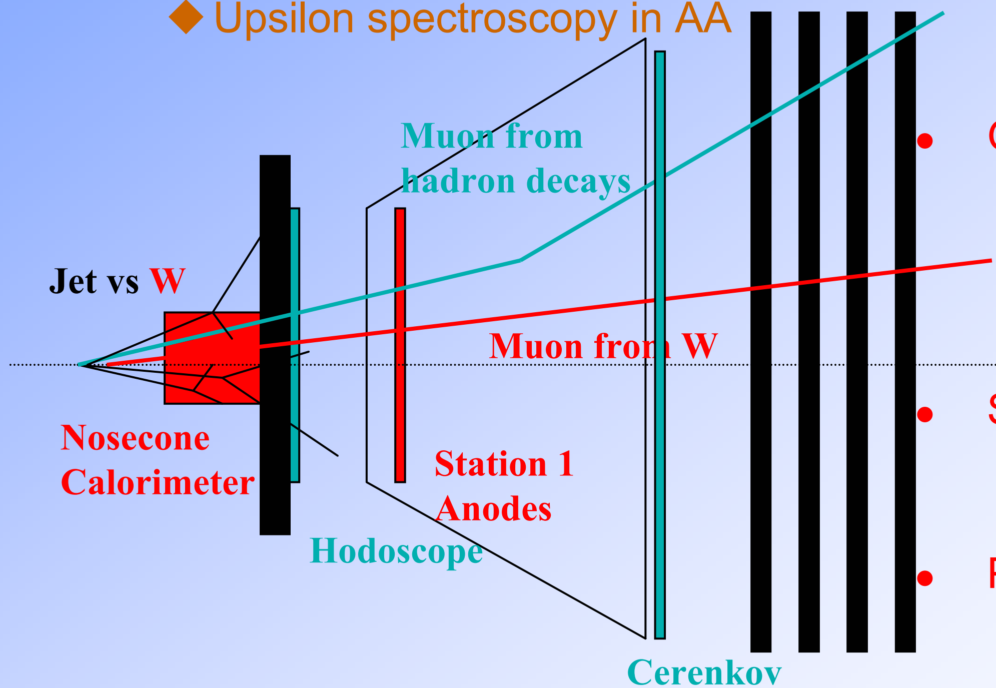


Physics Driving an Enhanced First Level Muon Trigger

- From the DAC:
  - “Good vertex identification and a muon trigger will also allow for a significantly improved measurement of the gluon structure of the nucleon and of nuclei by means of heavy quark pair production”
  - Why?
    - W production in pp (@ 500 GeV)
    - single muon (c/b) → gluon shadowing
    - Upsilon spectroscopy in AA

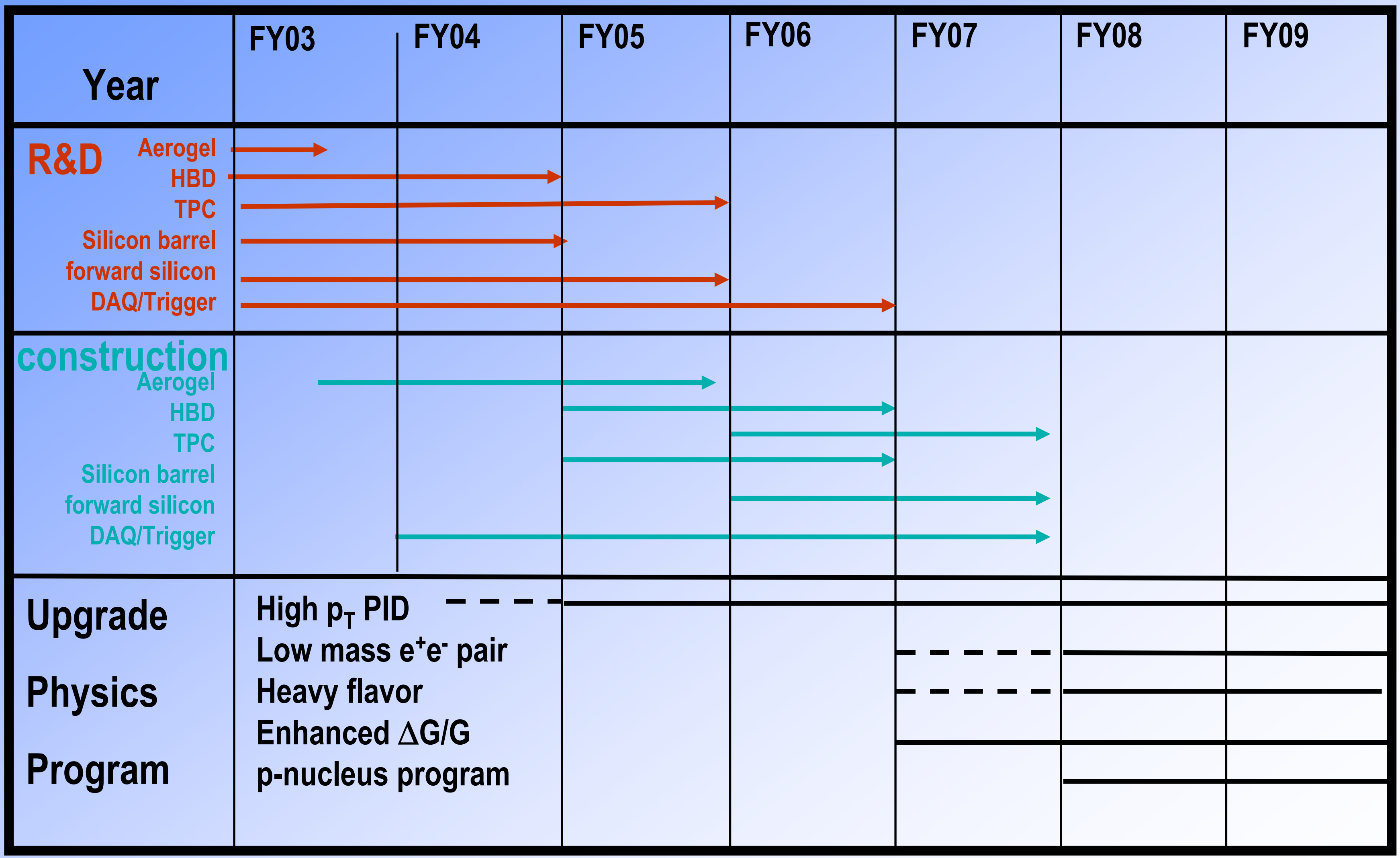
Simulation: Muon tracking & Cherenkov





- Goals:
  - LVL1 trigger for high p_T muons with much higher rejection power
    - Present muID Local Level 1 rejection ~500
    - 10,000 rejection required at 2 x 10^{32} $cm^{-2}s^{-1}$
    - ~15,000 from muID x Cerenkov
- Status:
  - \$120K UIUC-NSF, \$80K UIUC R&D funds
  - NSF MRI to be submitted Jan-04
- Participating institutions:
  - Ecole Polytechnique, Iowa State U., Kyoto U., RBRC, RIKEN, UCR, UIUC, UNM

Time Line for PHENIX Upgrades



PHENIX

Upgrades Summary

- Goal:
  - extended physics program beyond present PHENIX capabilities
- Physics observables:
  - Extended PID at High p_T
  - Heavy flavor
  - Low mass lepton pairs
  - High p_T muons (W, Upsilon)
- Required detector additions:
  - Aerogel Cerenkov
  - Silicon Vertex Tracker
  - HBD/TPC
  - Enhanced muon LVL1 trigger
- Active R&D program by institutional contributions
  - Aerogel (BNL, Dubna, Tokyo, Tsukuba)
  - SVT (BNL,ISU,Kyoto,LANL,ORNL,RIKEN, Stony Brook)
  - HBD/TPC (BNL,Columbia,Stony Brook,Tokyo,WIS)
  - Muon trigger (Ecole Polytechnique, ISU., Kyoto, RBRC, RIKEN, UCR, UIUC,UNM)

☞ DOE support for upgrade R&D is critical for timely development of this exciting program

PH✳ENIX

Outline (and Summary)

- Collaboration Status — Healthy
- Experiment Status — Complete
- Physics Status — Excellent
  - Run-1 — Data analyzed, published
  - Run-2 — Data being analyzed, published
  - Run-3 — First data analyzed, published
- Future Prospects — Tremendous
  - Physics — Critically dependent on *integrated* luminosity, *increased* running time
  - Upgrades — Critically dependent on R&D and future funding
- Conclusions — (See next slide)

The Real Summary

- "The goal of RHIC is not isolated discovery of QGP or anything else. The goal of RHIC is exploration of the complex and ubiquitous environment in which we isolated creatures live"
  - J. Marburger
- "It's very clear a new fundamental phenomenon has been discovered here...I look forward to a future occasion when we'll hear about such things as J/Ψ suppression or direct photons."
  - Peter Rosen
- "Congratulations, well done, keep up the good work. There's much still to be done."
  - Dennis Kovar