

# PHENIX Beam Use Proposal for Runs 10 and 11

- **Status**
  - Collaboration**
  - Physics goals & achievements**
  - Upgrades (schedule)**
- **Beam use proposal summary**
  - Request & physics impact**
  - Strategy for low energy scan**
- **Issues and Plans for upgraded luminosity**

**Barbara Jacak**  
**for the PHENIX Collaboration**

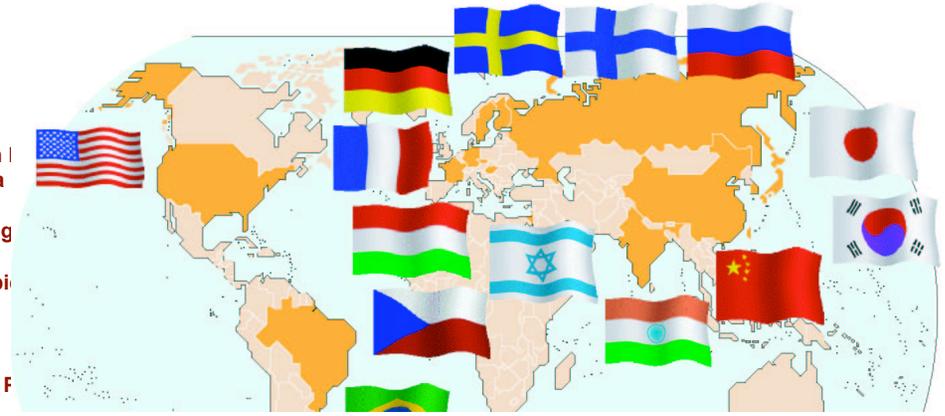
*Thanks to Ops Manager Ed O'Brien & PHENIX speakers at QM08, Users mtg*



**PHENIX**

# PHENIX Collaboration

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**14 Countries; 68 Institutions; ~500 Participants**

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# PHENIX Approach

- Key physics goals of the collision

Definitively establish  
properties

Characterize

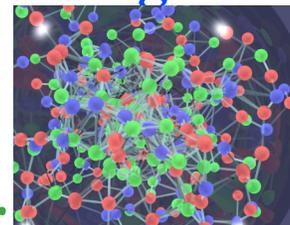
Determine

Run plan based upon  
increased precision for discriminating power

new observables enabled by upgrades, color screening

proton,  $J/\psi$ , correlations

distribution in cold nuclear matter



- PHENIX philosophy

Sensitivity for rare processes → hadrons, leptons, photons

High rate capability and selective triggers

Precision measurement in multiple channels

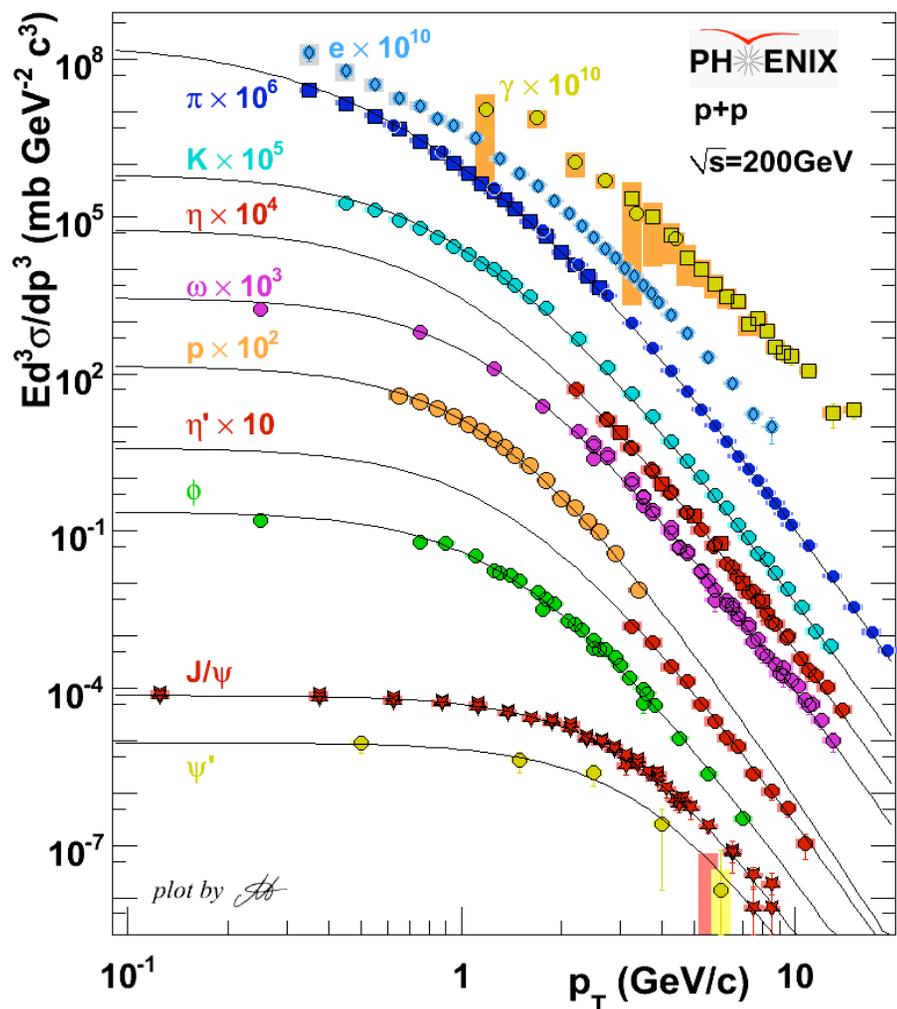
*high  $p_T$  hadrons, multi-particle correlations, jets*

*direct  $\gamma$ ,  $\gamma$  + jet, virtual  $\gamma$  production*

*light & heavy vector mesons, open heavy flavor*

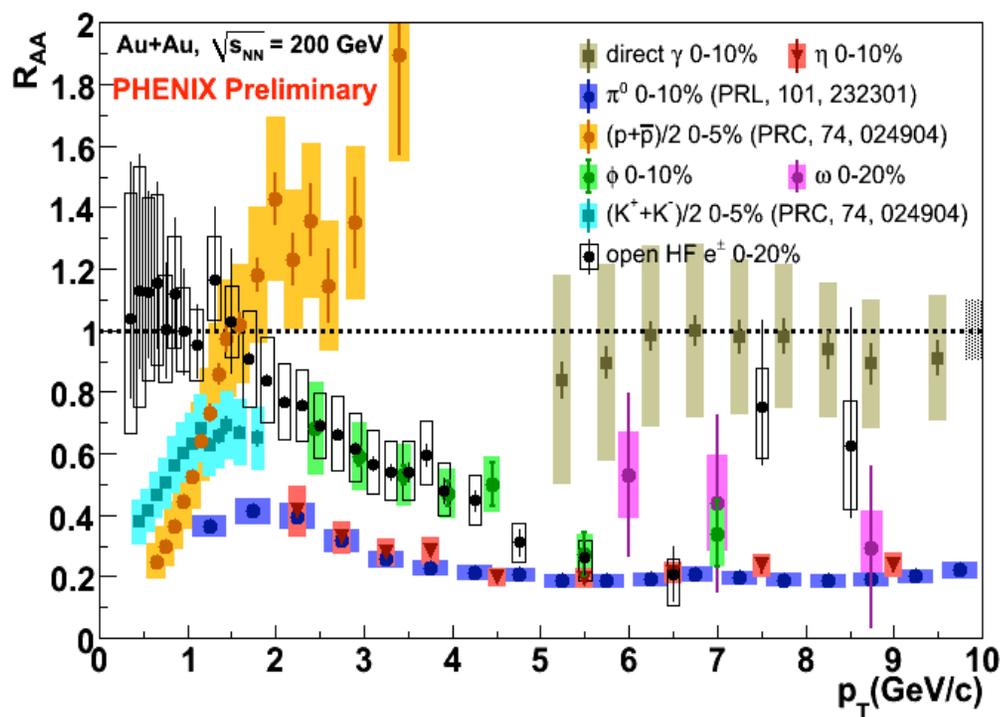


# Unprecedented range & precision



In p+p

## Central Au+Au



# Recent scientific accomplishments

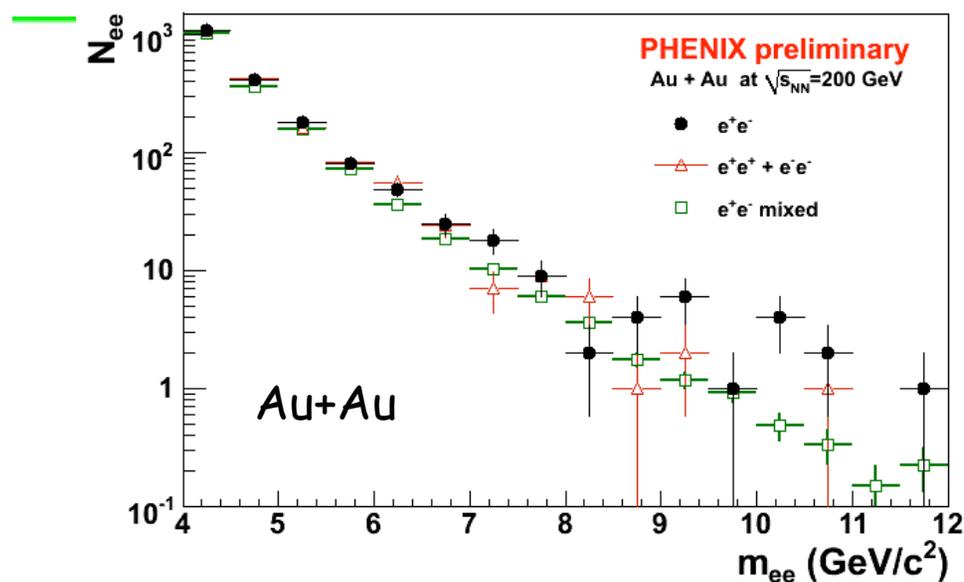
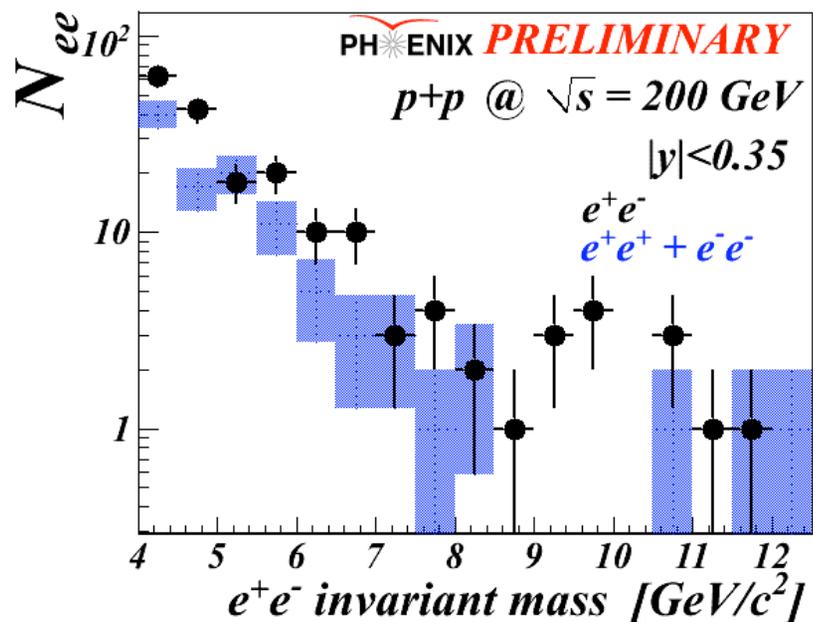
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- **First direct photon-jet correlations at RHIC** *0903.3399*
- **Reaction plane dependence of high  $p_T$   $\pi^0$  suppression** *0903.4886*
- **c/b separation in p+p collisions: e-h/e<sup>+</sup>e<sup>-</sup>** *0903.4851, PLB670,313 ('09)*
- **$\pi^0$   $\sigma$  and  $A_{LL}$  in 62.4 GeV polarized p+p** *PRD79,012003 (2009)*
- **Double helicity asymmetry of  $\pi^0$  in 200 GeV p+p** *0810.0694*
- **$T_{init}$  from thermal photon emission** *0804.4168*
- **First measurement of J/ $\psi$  photoproduction at RHIC** *0903.2041*
- **Charged kaon HBT** *0903.4863*

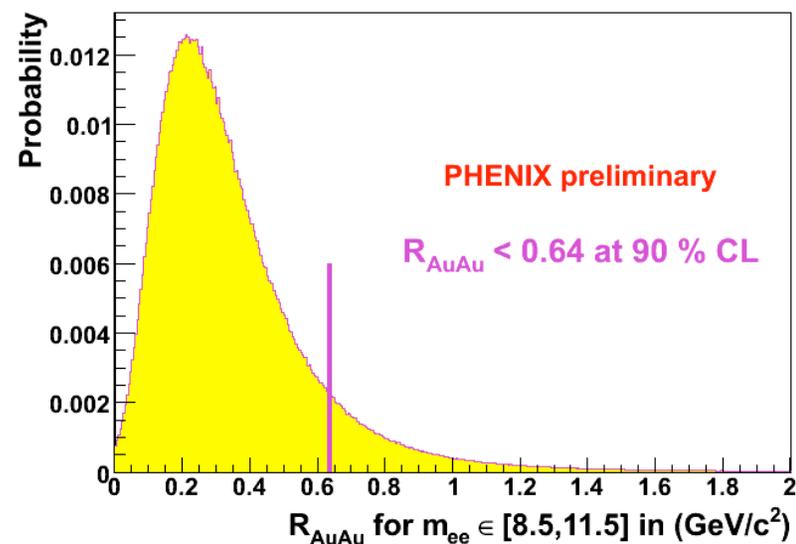
+ additional papers on correlations and fluctuations in

 the bulk medium in Au+Au, as well as systematic studies of elliptic flow measured several different ways

# Upsilon suppressed in Au+Au!



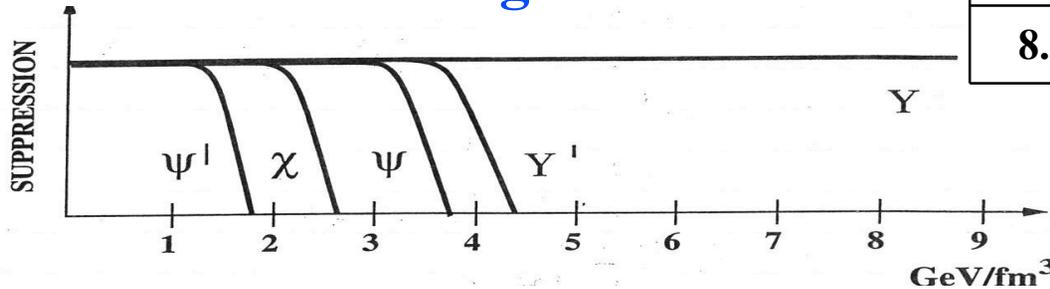
	p+p	Au+Au
$N[8.5,11.5]$	10.5(+3.7/-3.6)	11.7(+4.7/-4.6)
$N_{J/\Psi}$	2653 $\pm$ 70 $\pm$ 345	4166 $\pm$ 442(+187/-304)
$R_{AA}(J/\Psi)$	---	0.425 $\pm$ 0.025 $\pm$ 0.072



$R_{AA} [8.5,11.5] < 0.64$  at 90% C.L.

# Should $\Upsilon$ 's be suppressed?

$\Upsilon$  as onium melting baseline...

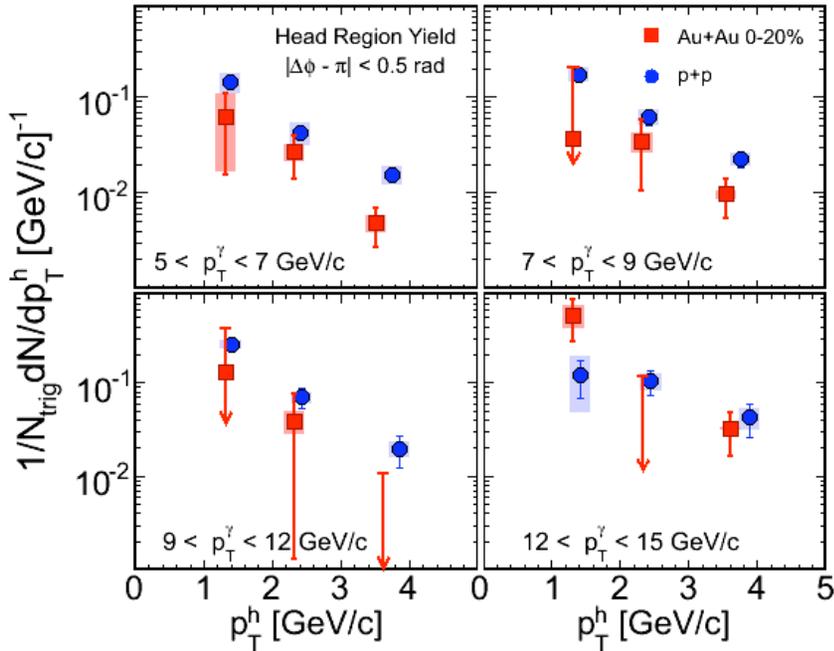


	$R_{AuAu}(y=0)$
J/ $\Psi$	$0.425 \pm 0.025 \pm 0.072$
$8.5 < M < 11.5$ GeV	$< 0.64$ at 90% C.L.

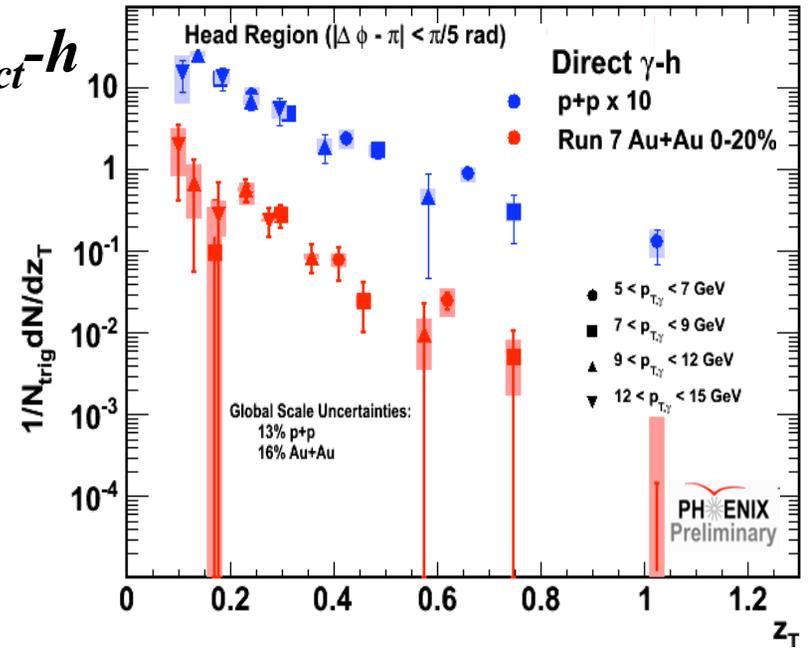
- $\sigma_{abs}$  of  $\Upsilon \sim 1/2$  of J/ $\Psi$ : E772 (PRL 64, 2479 (1990))
- E772  $\Upsilon$  nuclear dependence correction
- Lattice expectations in Au+Au collisions
- absorption in Au+Au collisions
- **Need more data in both Au+Au and p+p**
- **also d+Au to control cold nuclear matter effects**
- **Muon arms with FVTX will contribute tremendously**
- **read of this naïve speculation!**
- $R_{AuAu} = 0.73$
- $0.60$  ???
- hep-ph/0507314
- ALSO:
  - $\Upsilon$  in an shadowing region
  - CDF: 50% of  $\Upsilon$  from  $\chi_b$  ( $p_T > 8$  GeV/c) &  $\sim 25\%$ ? at our  $p_T$
  - PRL84 (2000) 2094

# Medium modification of jet fragmentation

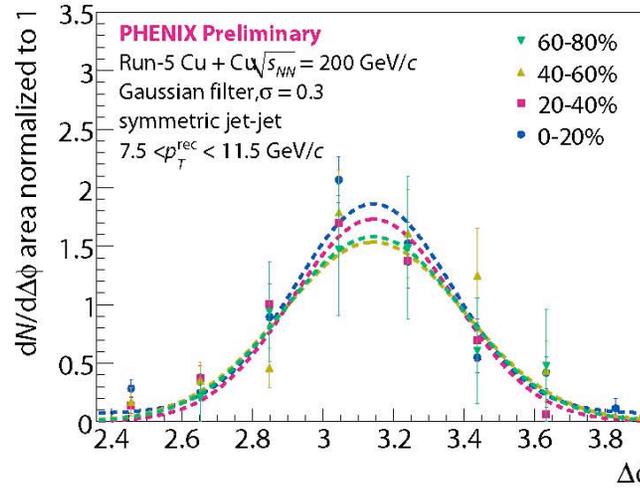
arXiv:0903.3399



$\gamma_{\text{direct}}^{-h}$



*jet-jet*

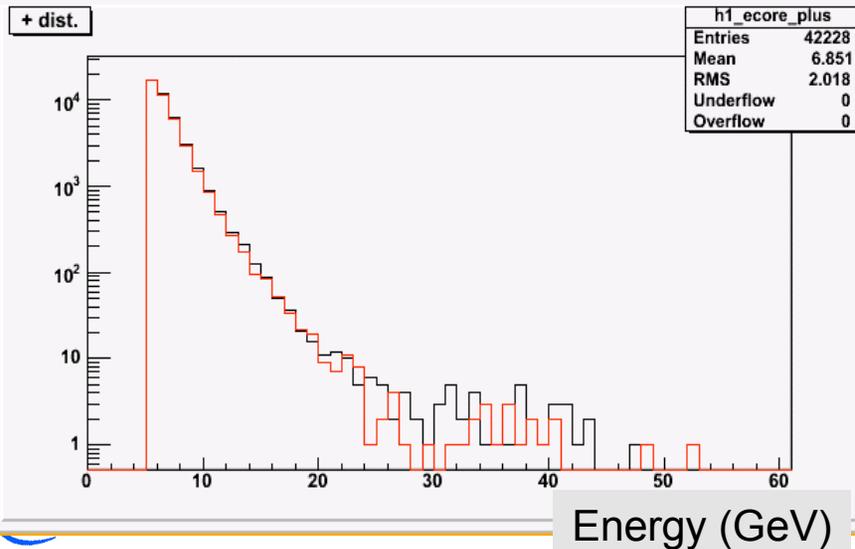
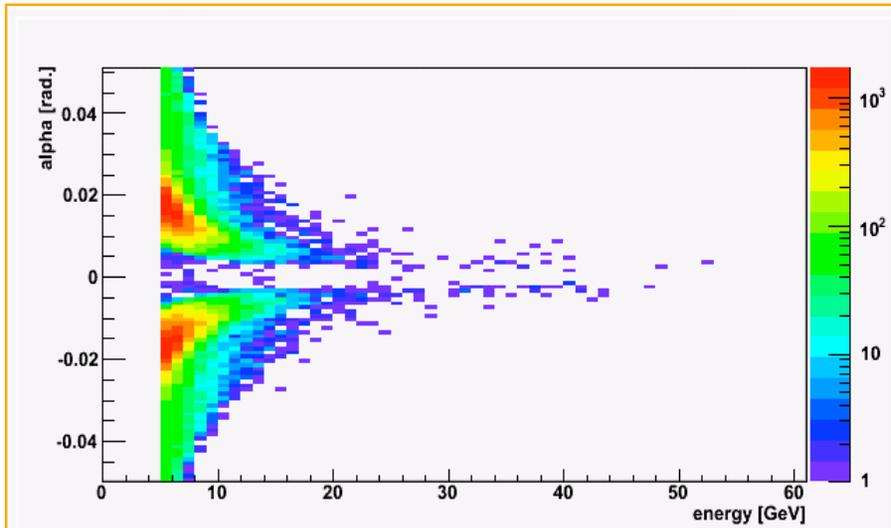


$$z_T = \frac{p_T^h}{p_T^{\text{trig}}}$$



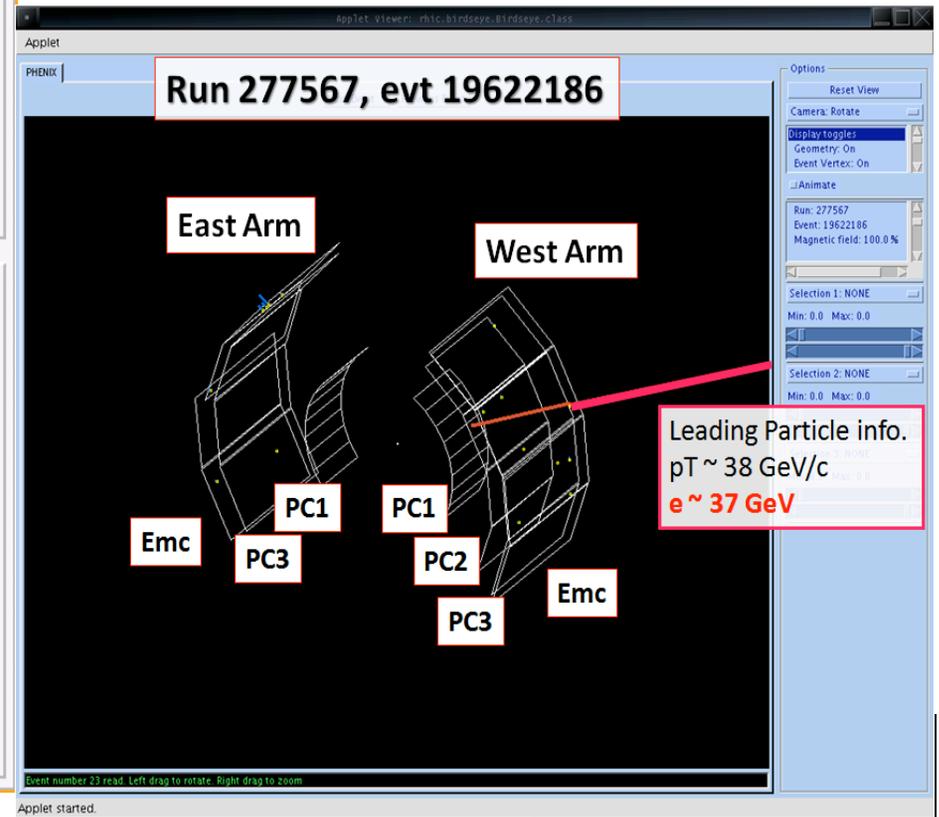
# RUN-9 500 GeV: First Look at W

Goal: sea quark polarization from W-boson asymmetry



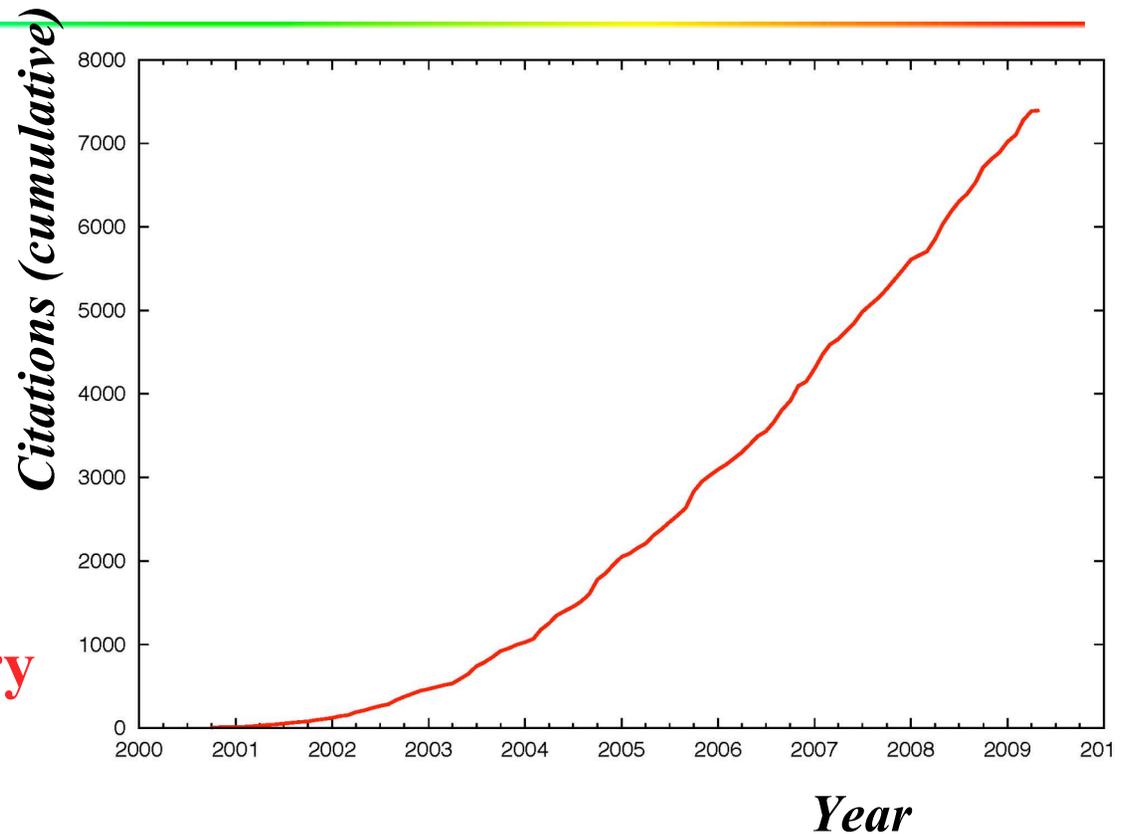
Fast track analysis by  
W task force

A Typical W-like event  
Single electron from W decay



# Scientific impact - high & still growing!

- **Since 2001:**
  - 77 publications**
- **> 7400 citations**
- **Renowned papers!**
- **White paper -**
  - 707 citations**
- **Jet quenching discovery**
  - 506 citations**



**+ 5 other physics papers with > 300 citations**

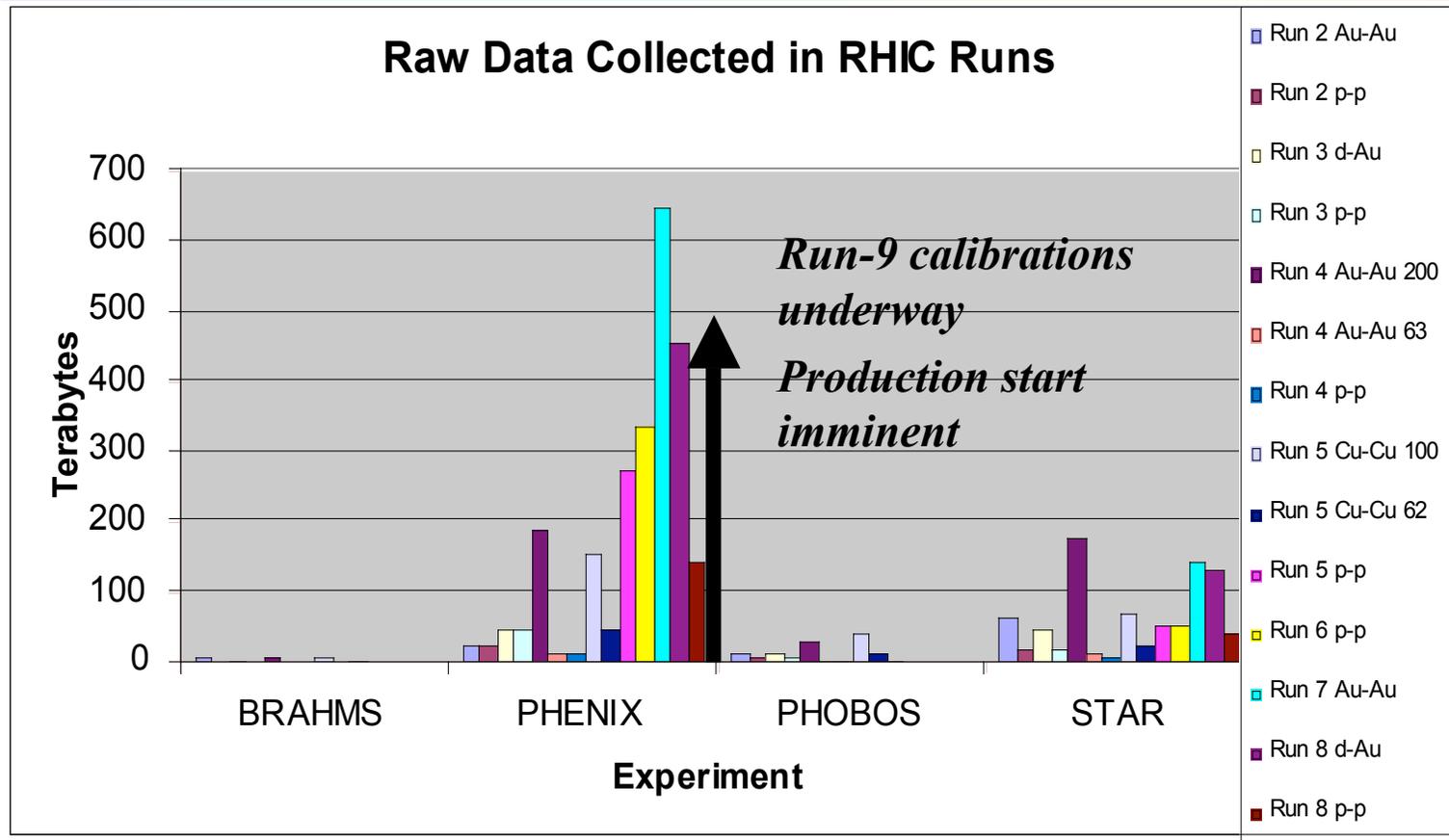
**3 papers with  $\geq 200$  citations**

**23 total papers with  $\geq 100$  citations**

**45 50+ Topcite papers**



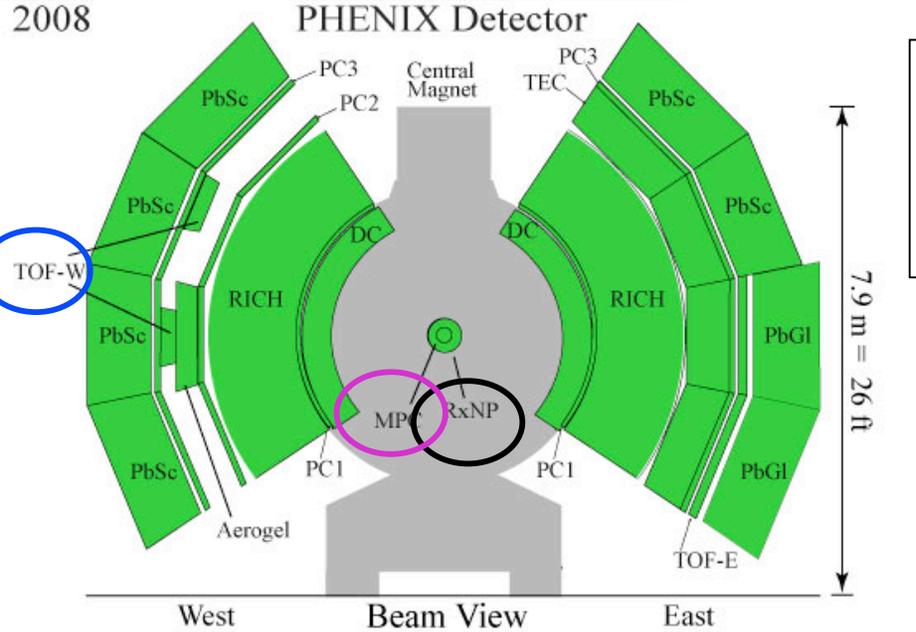
# PB scale data set(s) - fully reconstructed!



**Massive international effort using RCF, CC-J, CC-F**  
**Production team under leadership of Carla Vale,**  
**Alex Linden-Levy, Jeff Mitchell for Run-9**



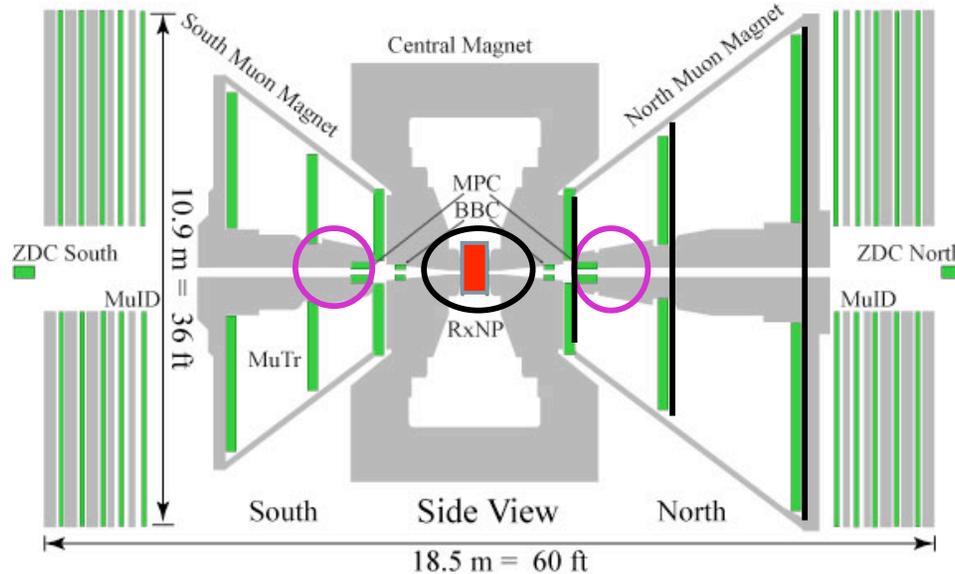
# PHENIX Detector Status for Run-10



TOF-W  
(PID)

**Hadron Blind &  
Reaction Plane  
detectors**

**Muon Piston  
Calorimeters**



**Muon Trigger:  
 $\mu$ Tr FEE  
North & South  
RPC-3 North**



# Upgrades schedule → physics capabilities

upgrade	year	Physics goal	beam/energy
<b>HBD</b>	<b>2009 &amp; 2010 only</b>	<b><math>T_{\text{init}}</math>, thermal <math>e^+e^-</math>, chiral symmetry, mesons in medium</b>	<b>Au+Au at <math>\sqrt{s_{\text{NN}}}</math> = 200, 62.4, 39 GeV</b>
<b>VTX</b>	<b>2011</b>	<b>c, b separation mid-y hadrons in <math>2\pi</math></b>	<b>200 Au+Au,p+p,d+Au 500 p+p; lowE Au+Au</b>
<b>FVTX</b>	<b>2012</b>	<b><math>\psi'</math>, heavy flavor <math>y&gt;1</math></b>	<b>200 Au+Au,p+p,d+Au 500 GeV p+p</b>
<b><math>\mu</math> trigger <math>\mu</math>Tr FEE RPC</b>	<b>2009/10 2011/12</b>	<b>W asymmetry at forward rapidity</b>	<b>500 GeV p+p</b>
<b>DAQTrig 2010</b>	<b>2010-12</b>	<b>Heavy flavor with RHIC-II luminosity</b>	<b>200 GeV Au+Au 200, 500 GeV p+p</b>
<b>FOCAL</b>	<b>2013?</b>	<b><math>\perp</math> spin <math>\gamma</math>, <math>\gamma</math>-jet; yields</b>	<b>p+p, d+Au (Au+Au)</b>



# Added capabilities drive our proposal

RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS *	$\int \mathcal{L} dt$ recorded	EVENTS (million)
10	Au+Au	200	10	1.4 nb <sup>-1</sup>	
	Au+Au	62.4	3.5	56.2 $\mu$ b <sup>-1</sup>	350M
	Au+Au	~39	1.3 + 0.3 E change	8.2 $\mu$ b <sup>-1</sup>	50M
	Au+Au	27	4.5	4.1 $\mu$ b <sup>-1</sup>	25M
	p+p	500	4 (polarization development)		
	p+p	22.4	1		2.5B
11	p+p	500	10	50 pb <sup>-1</sup>	
	Au+Au	200	8	1.4 nb <sup>-1</sup>	

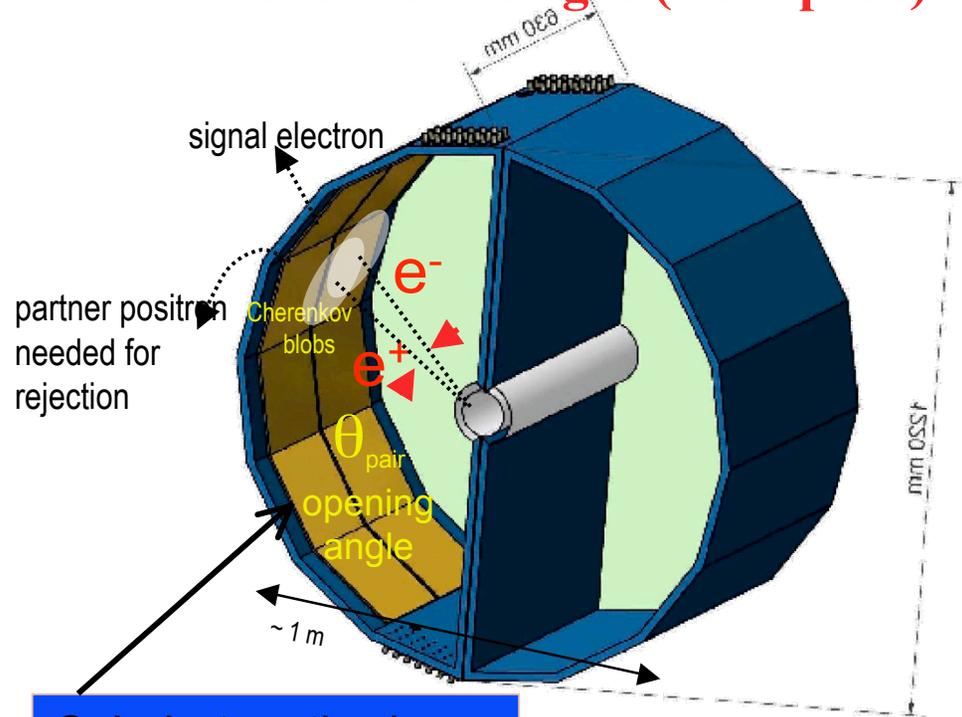
\* estimated with mean of min/max prediction  
includes lumi. ramp up & changeover time



# Hadron Blind Detector (HBD)

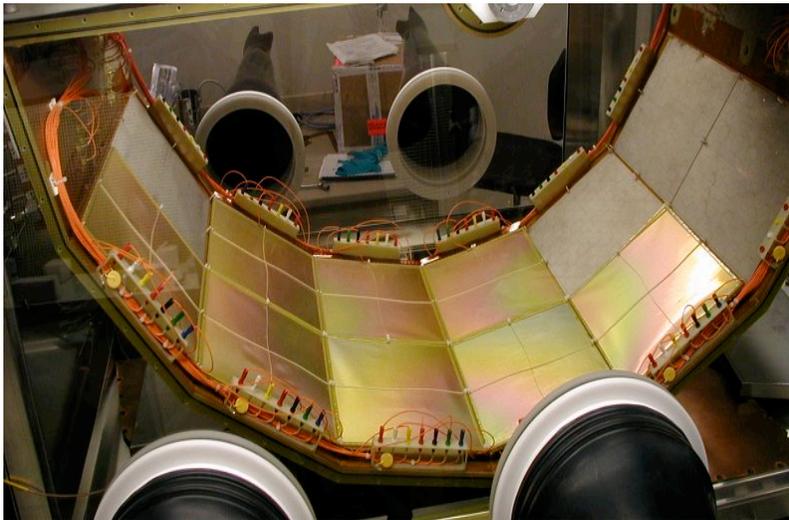


**Windowless Cerenkov detector with CF<sub>4</sub> avalanche/radiator gas (2 cm pads)**

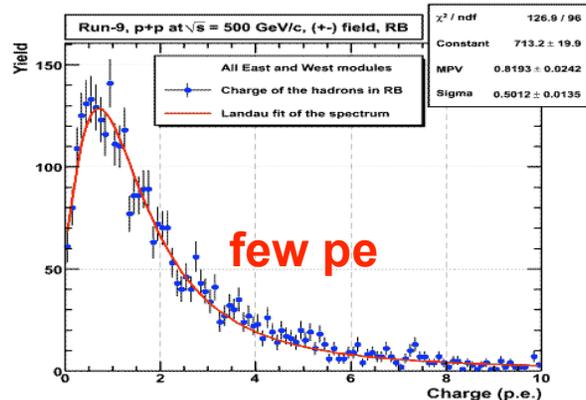


CsI photocathode covering triple GEMs

**Removes Dalitz & conversion pairs  
(small opening angle)**

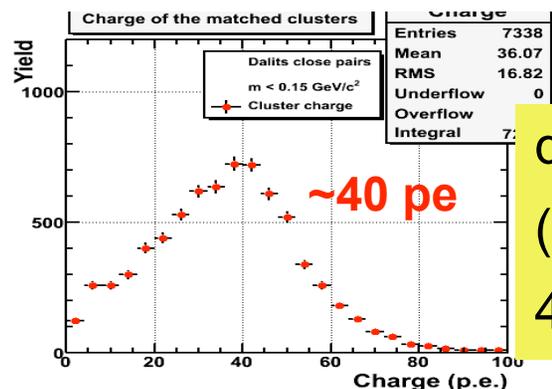


# HBD Works (very well)!



hadron blind!

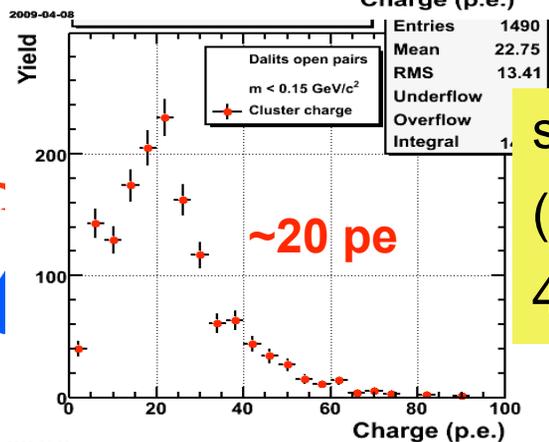
- Rebuilt for Run-9
- Available for use in Runs 9, 10
- Will be replaced by VTX after Run-10



double e background  
(Dalitz, conversion):  
40 photo-electrons

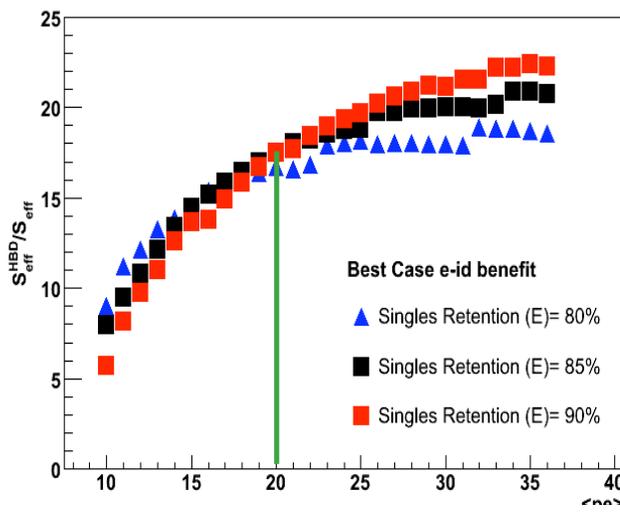
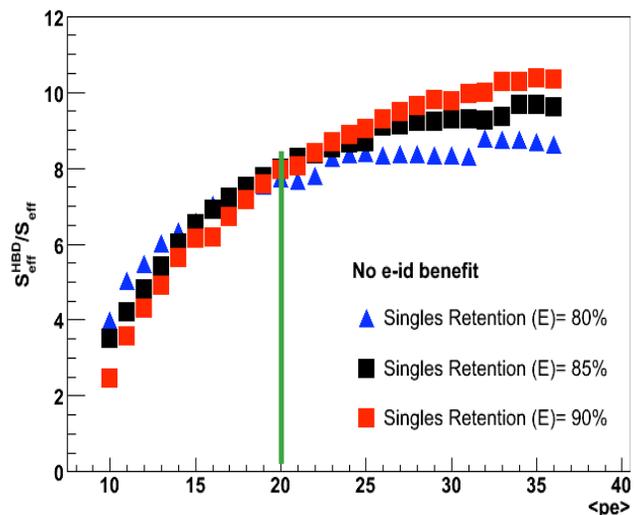
Clear separation of signal and background

Suppression of background pairs increases effective statistics by factor 8-16



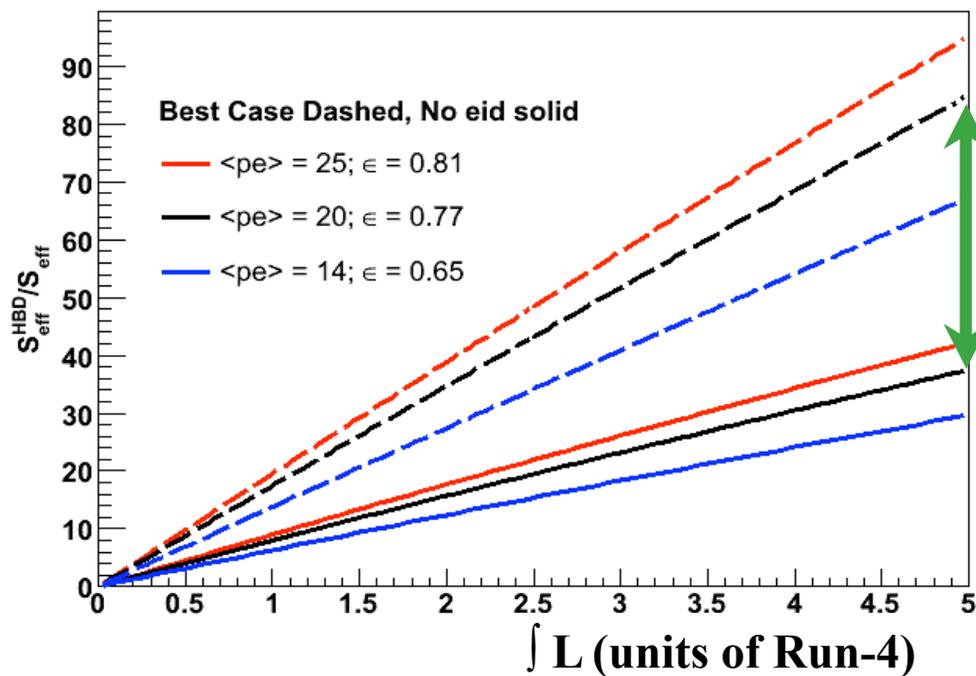
signal  
(separated electrons):  
40 photo-electrons

# HBD impact in Run-10



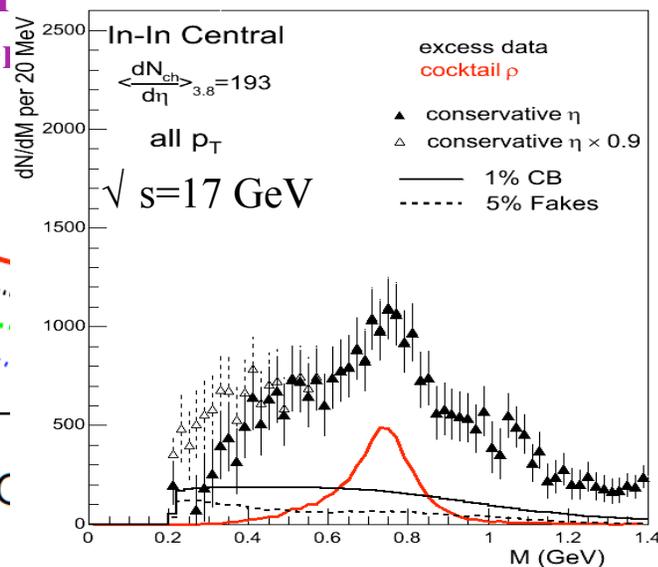
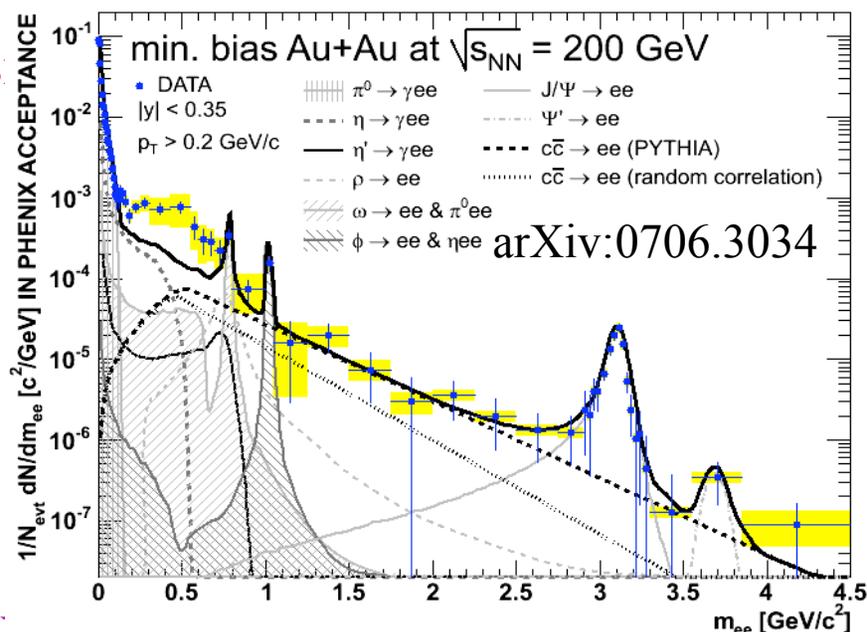
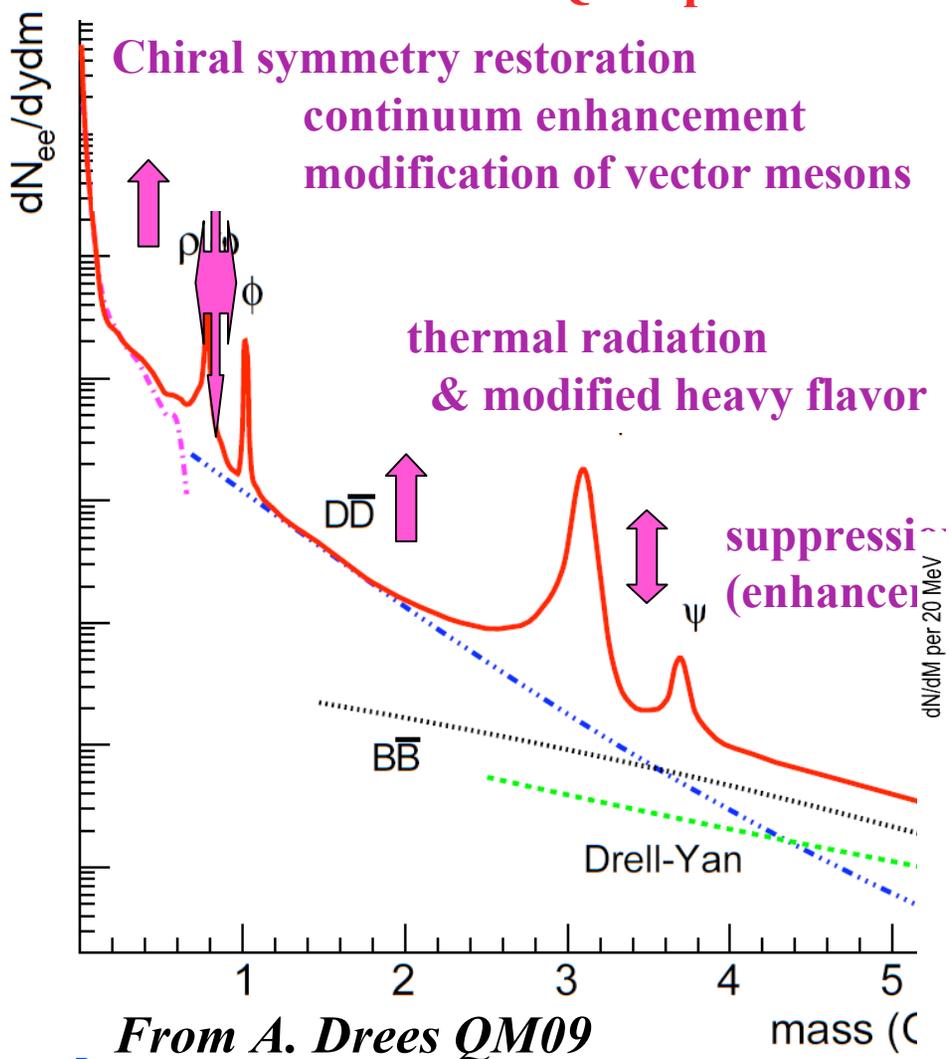
**Improves effective signal by factor of 8-16 (w/o and w/ added e ID effect)**

**1.4 /nb recorded improves effective statistics by  $\geq 35$  vs. old Run-4 result**



# Low mass dielectron physics

## Modifications due to QCD phase trans



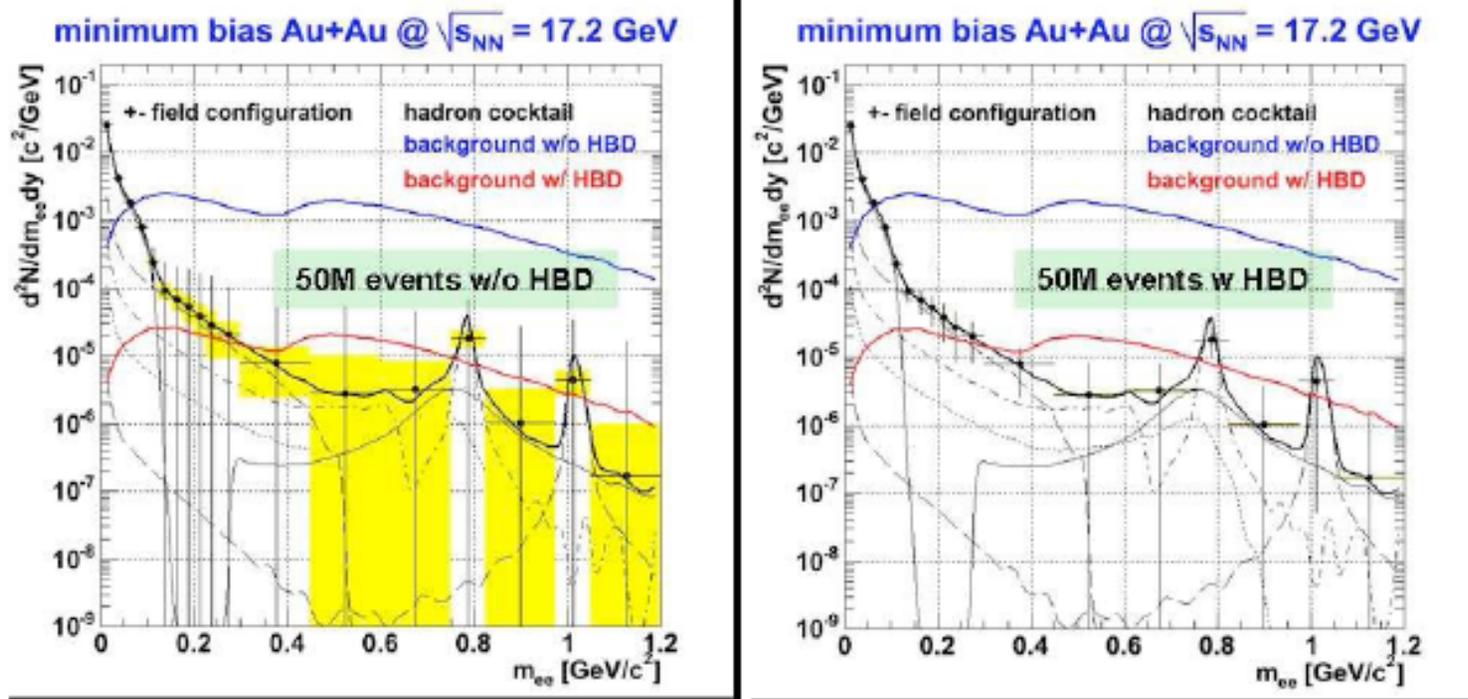
from 6 to  
24 bins in  
 $0.5 < M < 1$   
GeV;  
vs.  $N_{part}$



# Dielectron continuum between 17 & 200 GeV

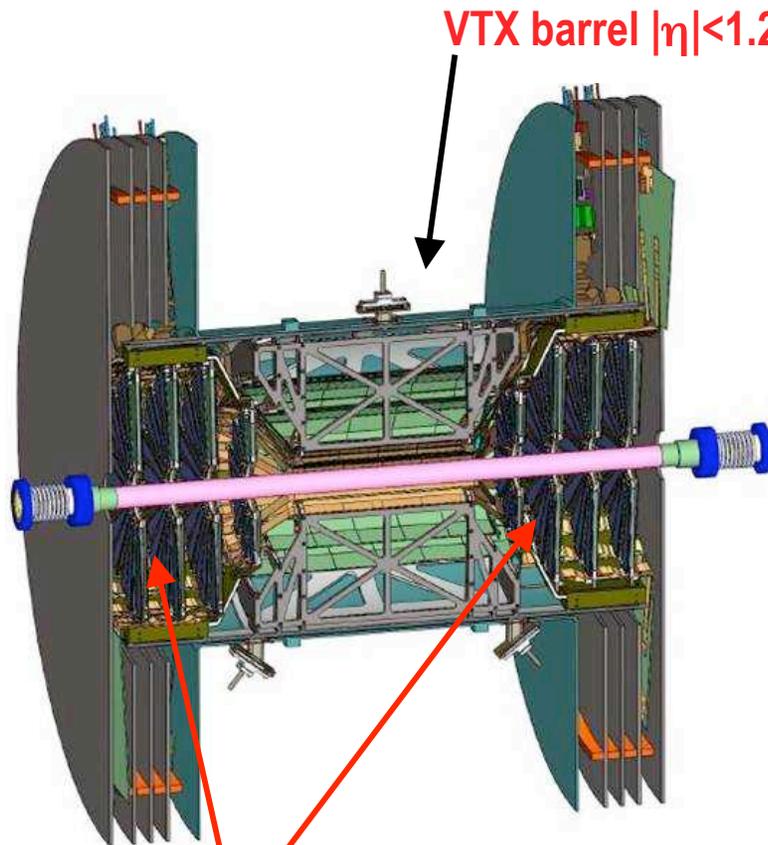
- Excess reaches lower mass at RHIC than at SPS
- *Unique opportunity in Run-10!*

Background rejection with HBD → measure at lower  $\sqrt{s}$



*How do dilepton excess and  $\rho$  modification at SPS evolve into the large low-mass excess at RHIC?*

# Silicon Vertex (VTX & FVTX)



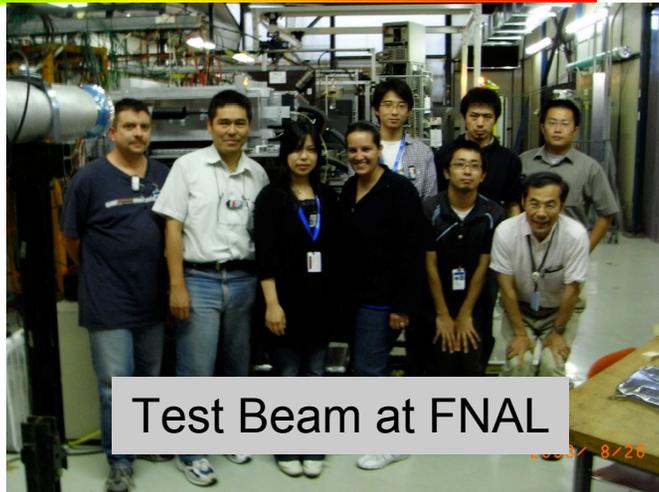
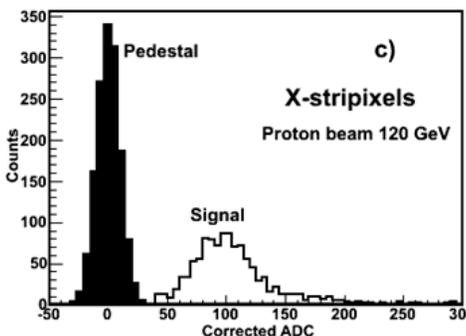
- **VTX: silicon VerTeX barrel tracker**  
**Fine granularity, low occupancy**  
50 $\mu\text{m}$ ×425 $\mu\text{m}$  pixels for L1 and L2  
R1=2.5cm and R2=5cm  
**Stripixel detector for L3 and L4**  
80 $\mu\text{m}$ ×1000 $\mu\text{m}$  pixel pitch  
R3=10cm and R4=14cm  
**Large acceptance**  
| $\eta$ |<1.2, almost  $2\pi$  in  $\phi$  plane  
**Standalone tracking**
- **FVTX: Forward silicon VerTeX tracker**  
2 endcaps with 4 disks each  
pixel pad structure (75 $\mu\text{m}$  x 2.8 to 11.2 mm)

FVTX endcaps  
1.2<| $\eta$ |<2.7  
mini strips



# VTX Progress

Pixel Detector Ladder



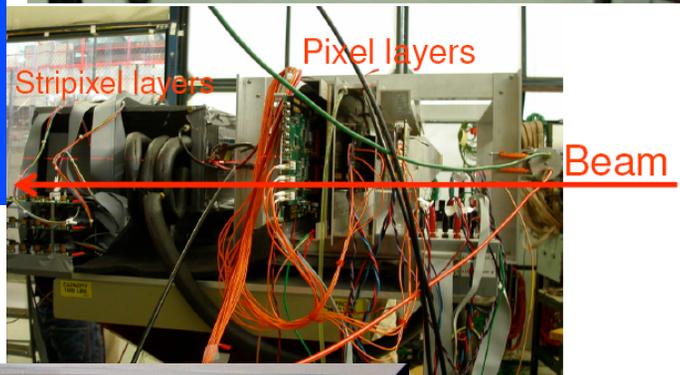
Test Beam at FNAL

Pixel read-out

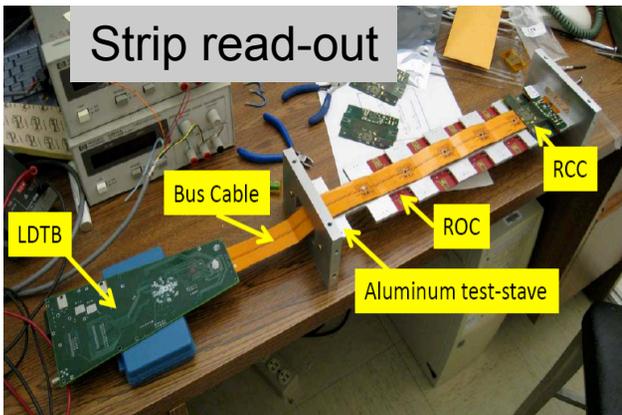


Successful DOE review last week: "very impressed by and pleased with the great progress"

Install for Run-11



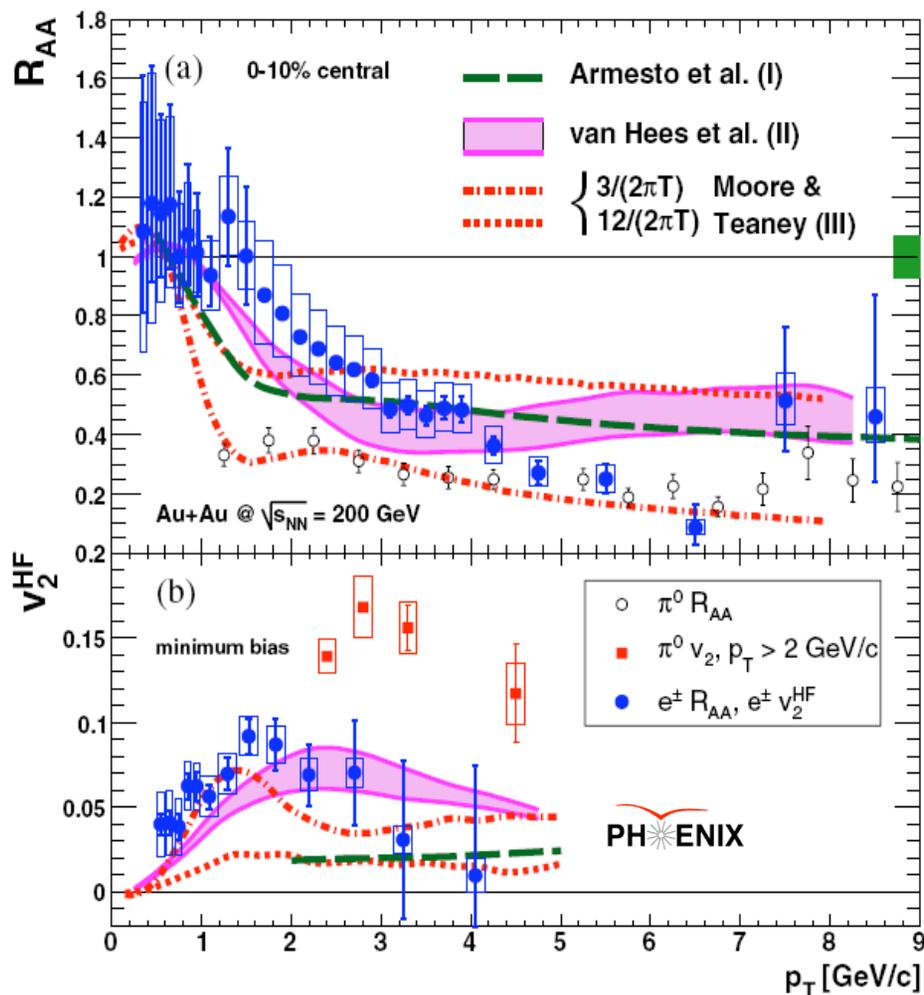
Strip read-out



Strip Detector Ladder



# VTX Physics



- Heavy Flavor as probe of dense partonic matter in A+A

$R_{AA}(p_T)$  of single electron from charm decay and beauty decay separately

$v_2(p_T)$  of single electron from charm decay and beauty decay separately

- Jet tomography (di-hadron,  $\gamma$ -hadron, and c-hadron correlation)

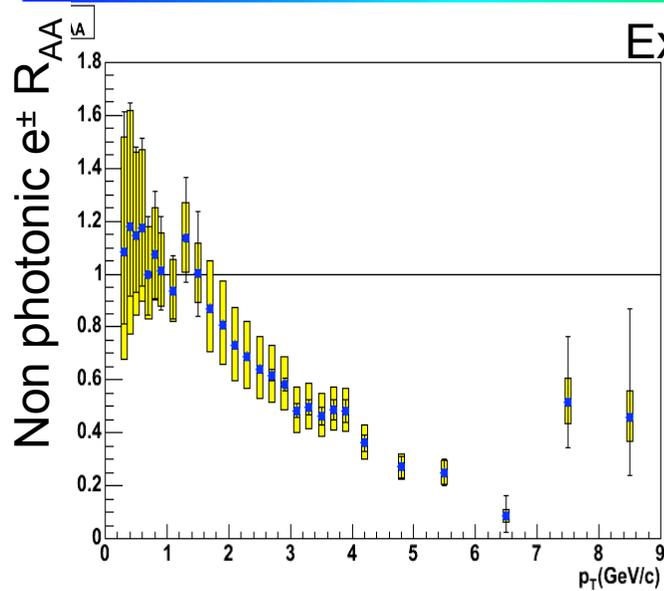
- Gluon polarization  $\Delta G(x)$  in polarized p+p

Double spin asymmetry  $A_{LL}$  of heavy flavor production (charm and beauty, separately)

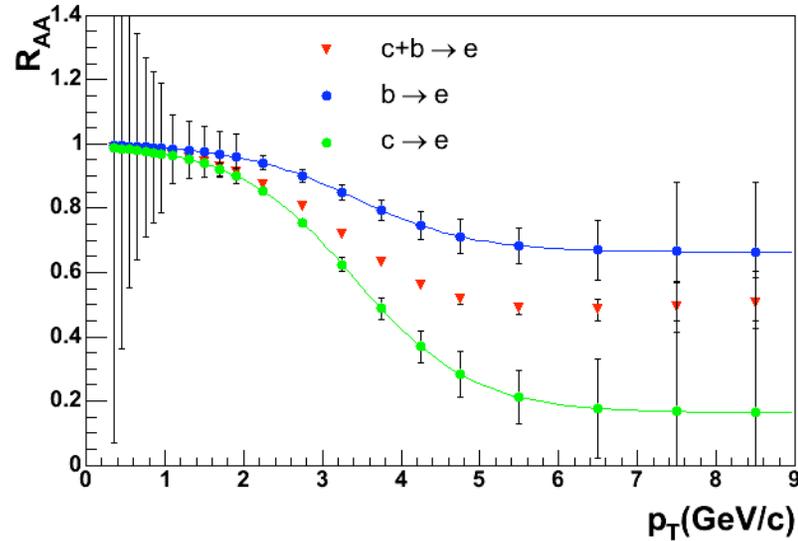
$A_{LL}$  of  $\gamma$ -jet



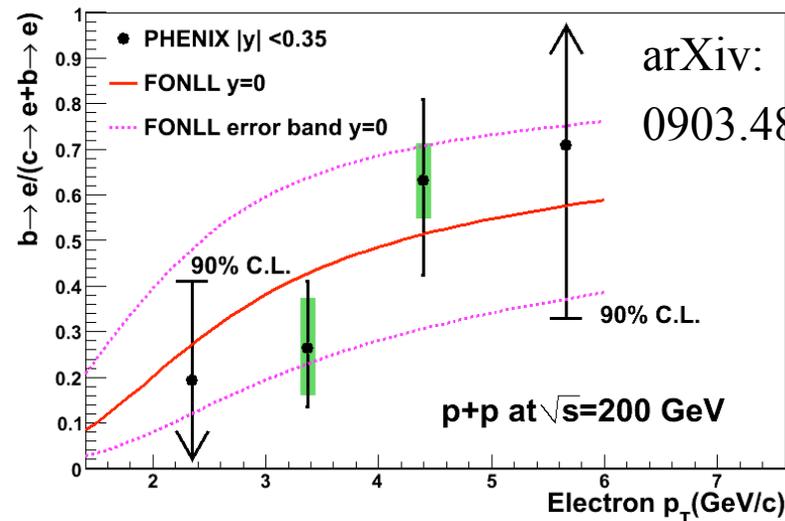
# VTX Performance



Expected with VTX (0.4/nb ~3 weeks in RUN11)



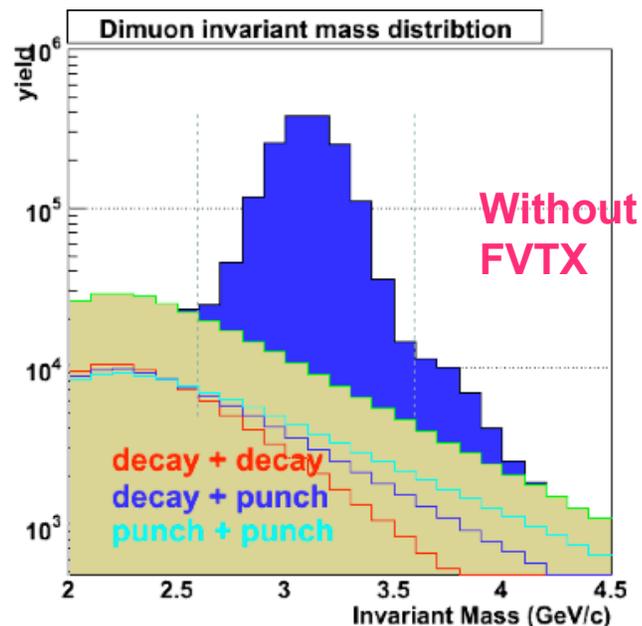
- In single electrons at high  $p_T$  b component is not small
- VTX can separate b and c (full MC chain with detector response & analysis code)



# FVTX Physics & Schedule

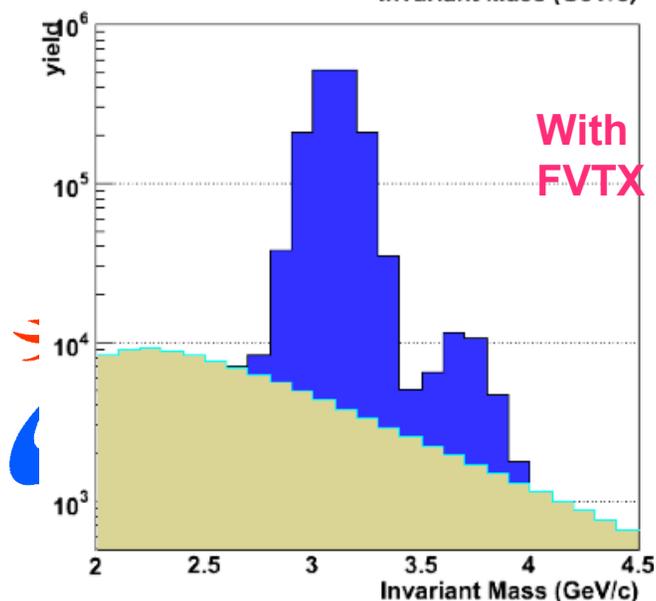


Prototype DAQ Electronics



- High resolution track points for muons before hadron absorber  
Improve mass resolution
- Quarkonium spectroscopy to probe color screening in medium
- Single muons from c,b decays
- Background suppression for direct photons in FOCAL

Install for Run-12

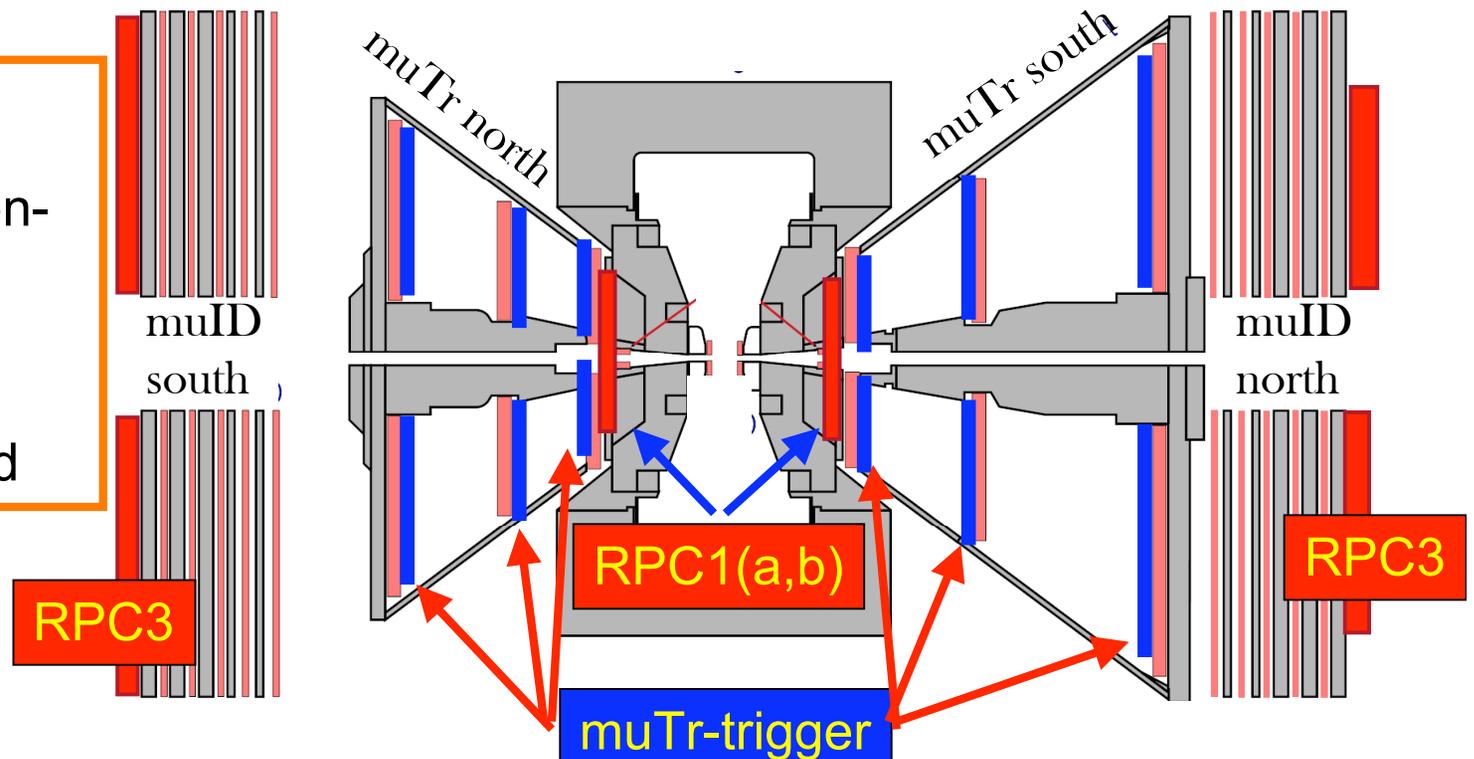


# Muon Trigger Upgrade

## Trigger idea:

Reject low momentum muons

Cut out-of-time beam background



## Upgrade:

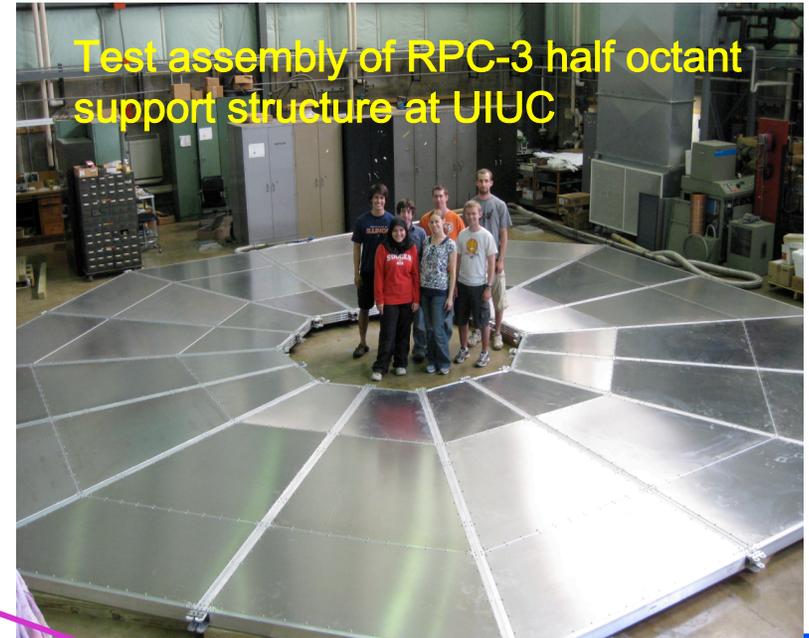
- o muTr trigger electronics: muTr 1-3 → send tracking info to level-1 trigger
- o RPC stations: RPC 1+3 → tracking + timing info to level-1 trigger

note: RPC1 has larger acceptance than RPC3 at large radii,  
RPC1+ RPC3 give best coverage for timing needed for background rejection.

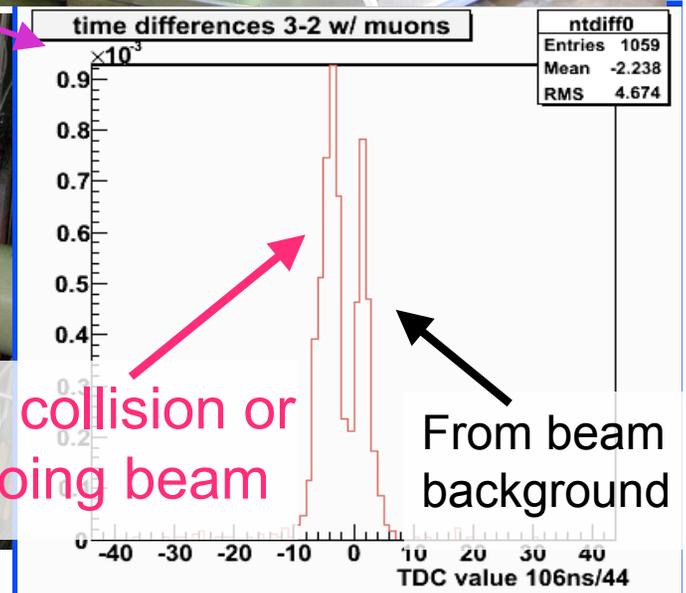
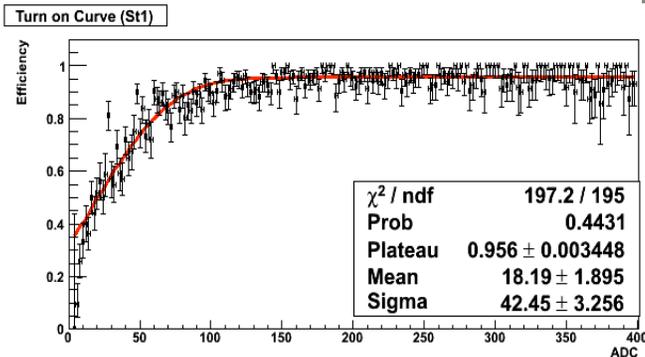
# MuTrig Status: ready for Physics in Run-11



- Engineering run for sectors in 2 RPC planes on south arm
- Timing info helped understand background in first 500 GeV run

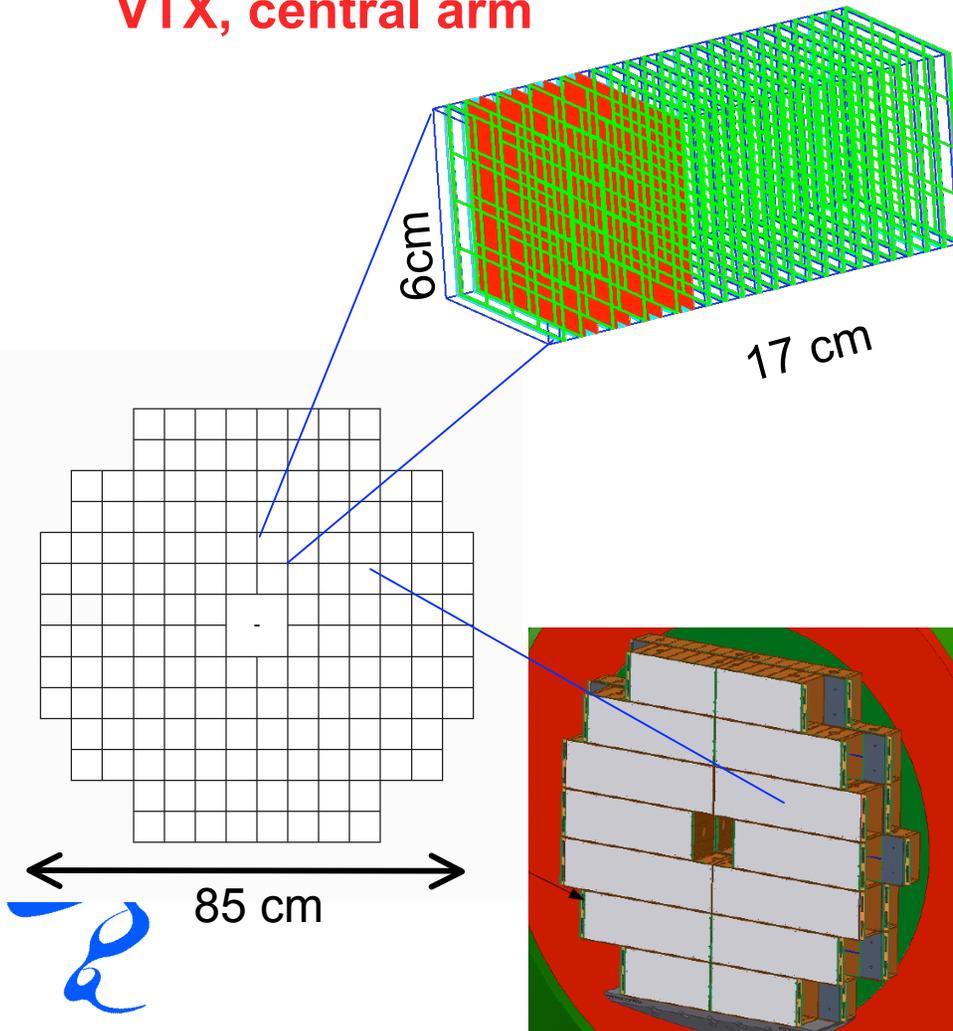


**MuTr.N operational in Run-9**  
**Good efficiency!**

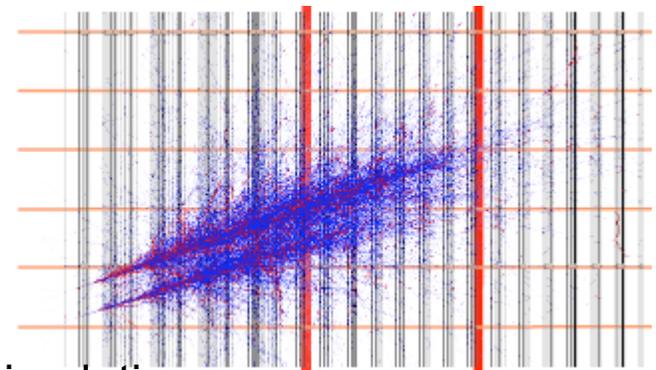


# FOrward CALorimeter (FOCAL)

- Trigger on  $\pi^0$  and  $\gamma$
- Provide coincidence with VTX, central arm



- W absorber, Si pad readout  
 $1 < \eta < 3$ ,  $2\pi$  azimuth  
24  $X_0$  deep
- 3 layers pad readout for lateral and longitudinal shower profile  
Reject hadronic background
- 4 layers of Si strips within first  $X_0$  for  $\gamma/\pi^0$  separation



Geant simulation  
 $20 \text{ GeV } \pi^0$

27

# FOCAL R&D ongoing

Test beam to demonstrate response, benchmark simulation



# Beam Use Proposal

RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS *	$\int \mathcal{L} dt$ recorded	EVENTS (million)	DRIVER
10	Au+Au	200	10	1.4 nb <sup>-1</sup>		l+l-, $\gamma$ -h
	Au+Au	62.4	3.5	56.2 $\mu$ b <sup>-1</sup>	350M	e R <sub>AA</sub> , e <sup>+</sup> e <sup>-</sup>
	Au+Au	~39	1.3 + 0.3 E change	8.2 $\mu$ b <sup>-1</sup>	50M	e <sup>+</sup> e <sup>-</sup> $\pi^0$ R <sub>AA</sub>
	Au+Au	27	4.5	4.1 $\mu$ b <sup>-1</sup>	25M	v <sub>2</sub> , $\pi^0$ R <sub>AA</sub>
	p+p	500	4 (polariz. development)			
	p+p	22.4	1		2.5B	$\pi^0$ R <sub>AA</sub>
11	p+p	500	10	50 pb <sup>-1</sup>		W, $\pi^0$ A <sub>LL</sub>
	Au+Au	200	8	1.4 nb <sup>-1</sup>		c/b, J/ $\psi$ v <sub>2</sub>

\* estimated with mean of min/max prediction  
includes lumi. ramp up & changeover time

# PHENIX plan delivers new physics each year

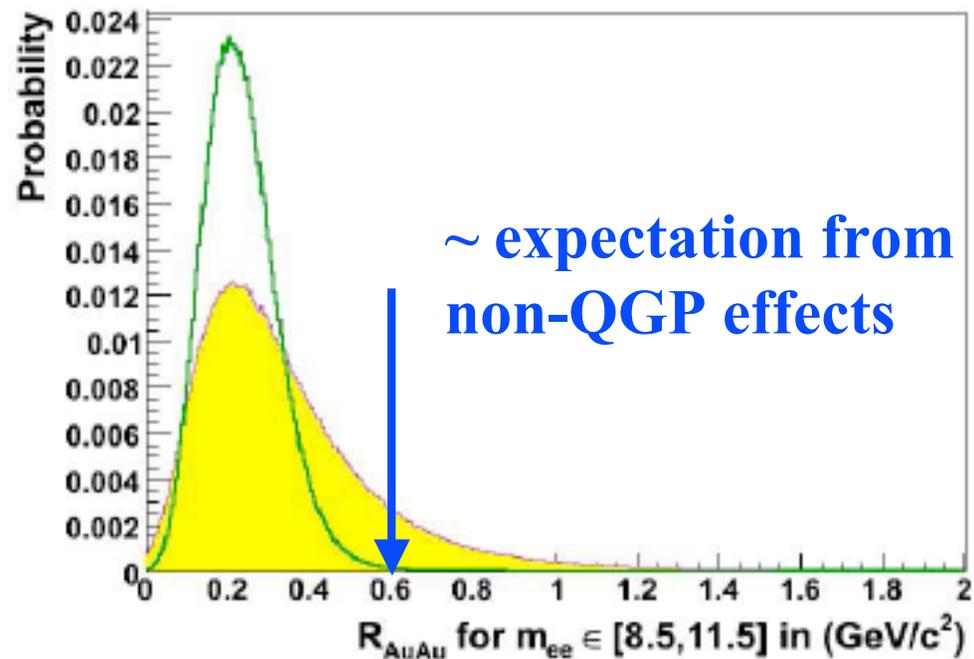
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- **Dielectrons - one-shot opportunity in Run-10!**
- **Other Run-10 full energy Au+Au goals**
  - Is  $\Upsilon$  suppressed? How does medium induce gluon radiation?
- **Run-10 energy scan - above 20 GeV to allow rare probes**
  - Is heavy quark suppression onset same as light quarks?
  - How do dilepton excess and  $\rho$  modification at SPS evolve into the large low-mass excess at RHIC?
  - Where do liquid properties ( $v_2$  & jet suppression) set in?
- **Run-11 500 GeV p+p**
  - What do W asymmetries tell about sea quark polarization?
- **Run-11 200 GeV Au+Au - with VTX!**
  - Do b quarks lose energy? Does  $J/\psi$  flow?



# Is $\Upsilon$ suppressed?

*Run-7+Run-10 (with reference from Run-9 p+p)  
will allow measurement of  $R_{AA}$*



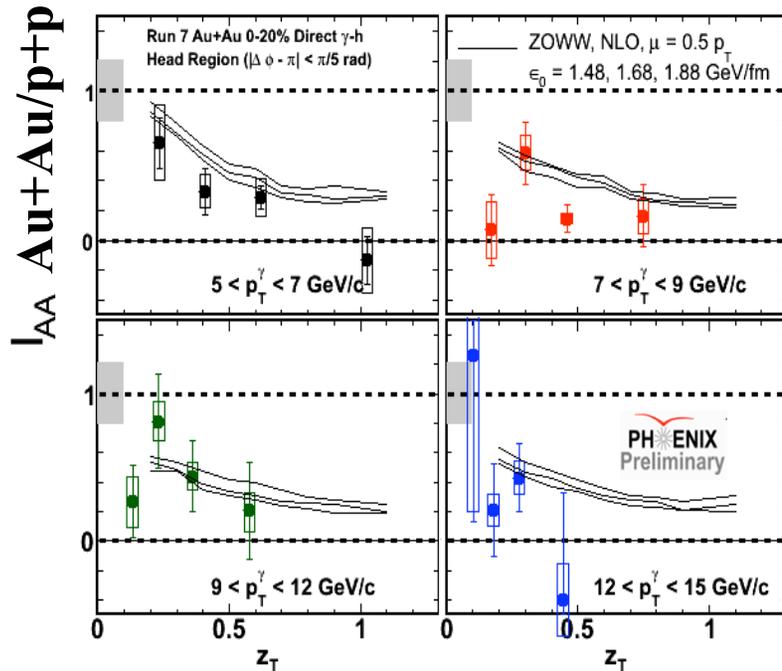
→ maximum integrated luminosity at 200 GeV,  
consistent with goals for lower  $\sqrt{s}$

# Energy loss mechanism? $\gamma$ -h “golden channel”

Run-7

Medium-enhanced gluon splitting  
(enhanced soft radiation)

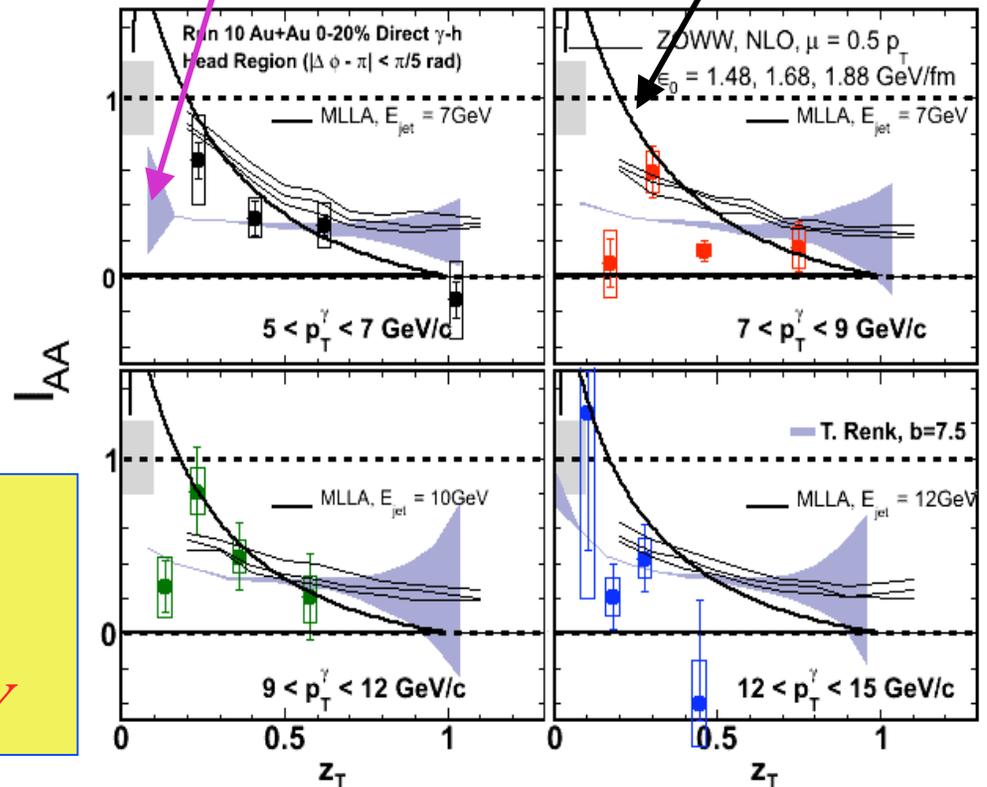
In-medium shower evolution  
averaging over expansion



Curves: NLO calculation of  
induced radiation



*Run-7 + Run-10 will  
allow to differentiate:  
2nd driver for 200 GeV*



# PHENIX strategy for low energy scan

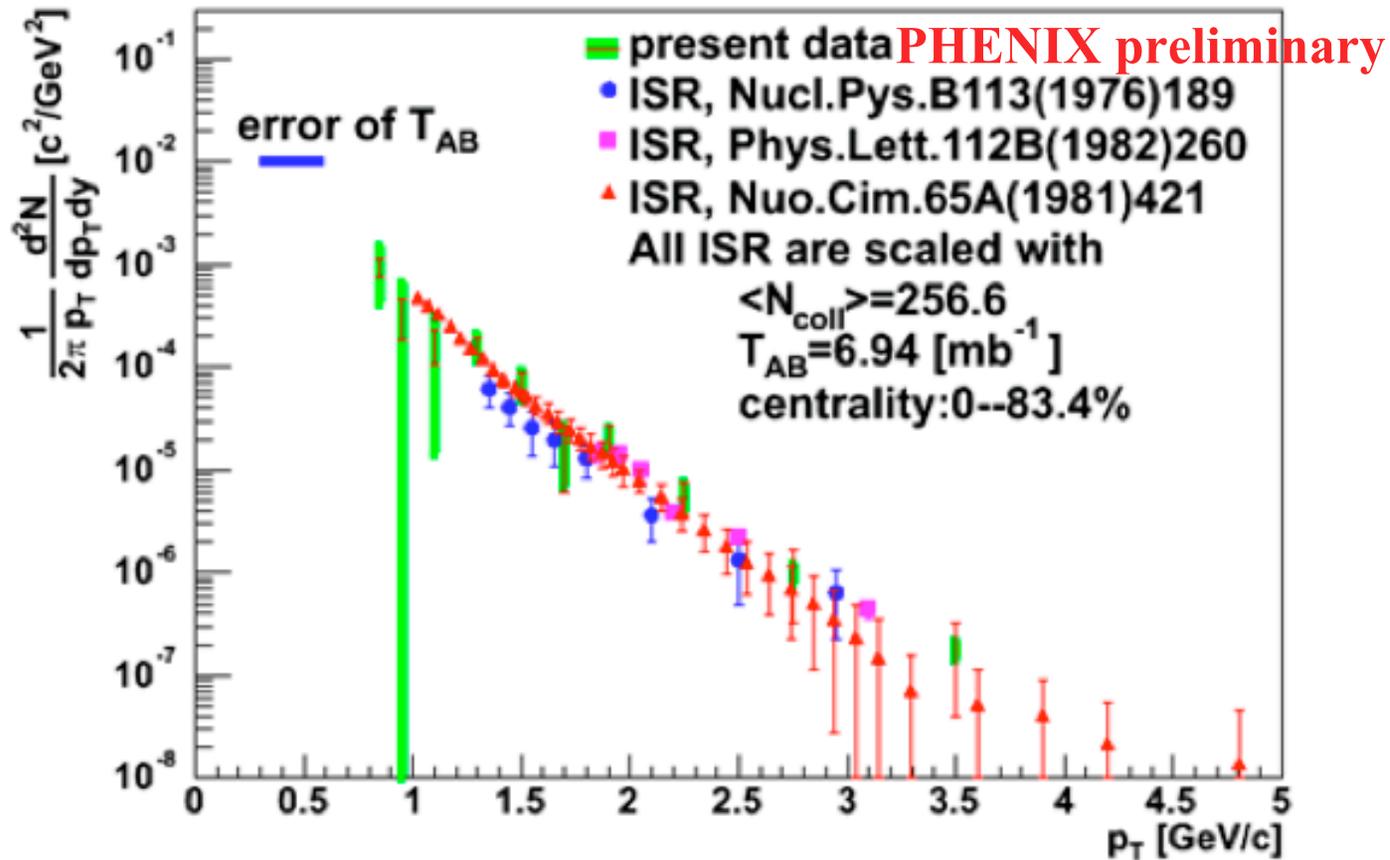
---

- Focus first on *rare* probes that are unique to RHIC
  - Chiral order parameter → dielectron probes!
  - Opacity & critical opalescence →  $R_{AA}$ , HBT vs. rxn plane
  - Identified particle  $v_2$  & scaling breaking to probe  $\eta/s$
- *Second step: high  $\sigma$  observables*
  - Novel fluctuation & correlation observables utilizing VTX
  - But diluted by finite size & lifetime, quantum fluctuations...
  - Will benefit from more thought (theory & experiment) on quantum criticality study → requirements on data
- Require new T0/trigger detector for sub-injection energy
  - scintillator barrel surrounding VTX
- ● Higher luminosity due to cooling → reasonable run length
  - measure MULTIPLE predicted signals of QCD endpoint
- Modest-sized but interested community within PHENIX

# Lower $\sqrt{s}$ : onset of heavy quark energy loss?

Non-photonic  $(e^+e^-)/2$ , minimum bias, (cent:0--83.4%)

62.4 GeV Au+Au

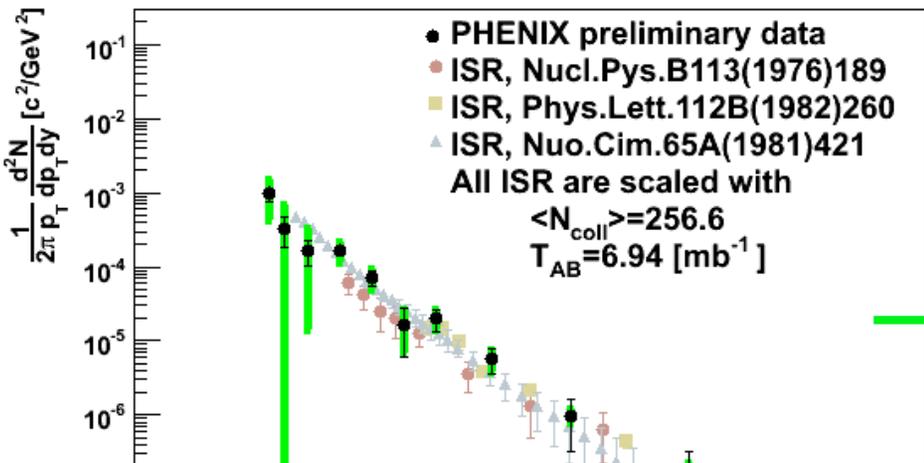


*Heavy flavor does not appear to be suppressed!*  
*Theoretical guidance: Absent!!*

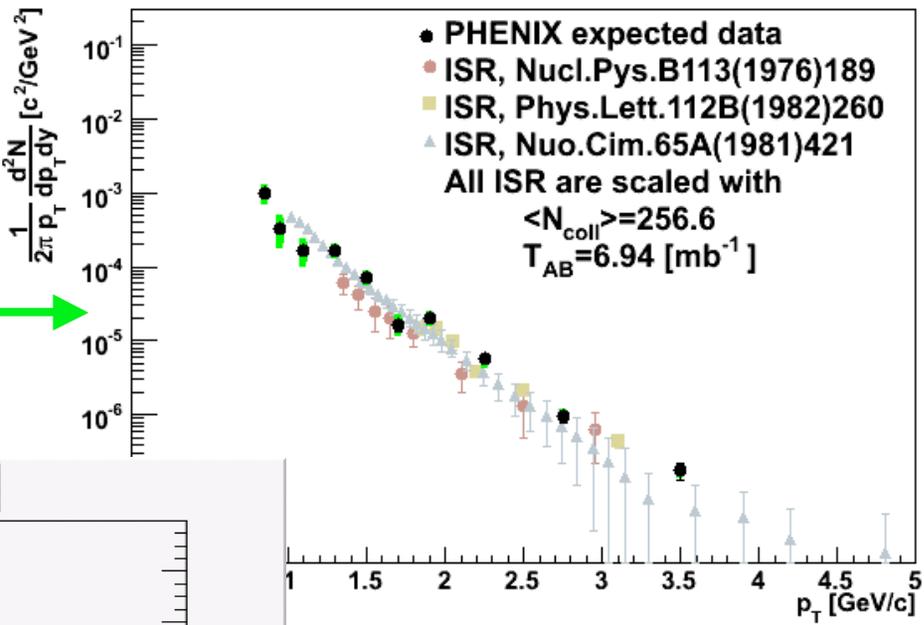
PHENIX

# Answer in Run-10!

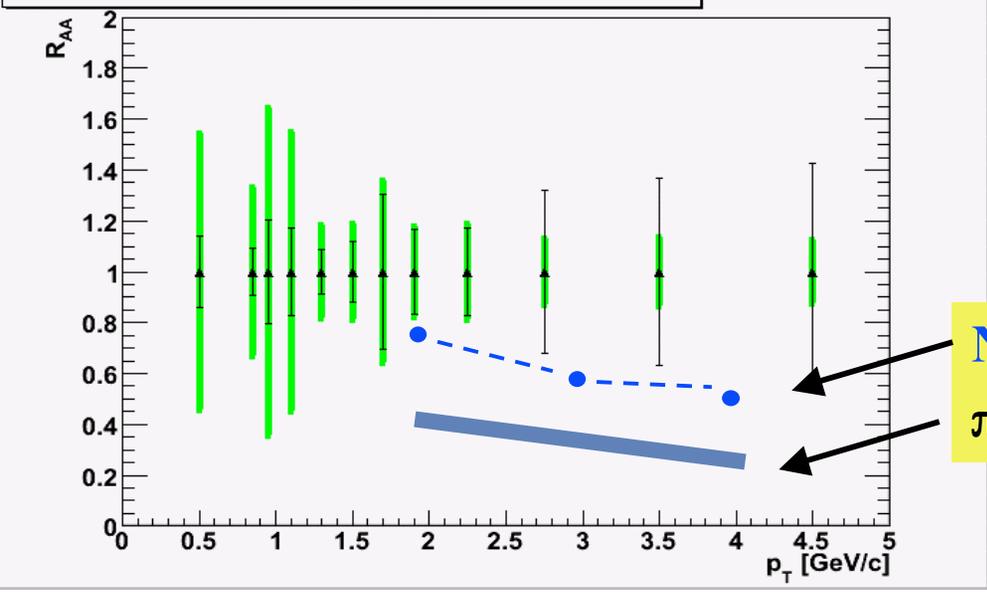
HF ( $e^+e^-$ )/2 in min bias Au+Au collisions at 62.4 GeV



HF ( $e^+e^-$ )/2 in min bias Au+Au collisions at 62.4 GeV



expected uncertainties of  $R_{AA}$  of HF ( $e^+e^-$ )/2 at 62.4 GeV

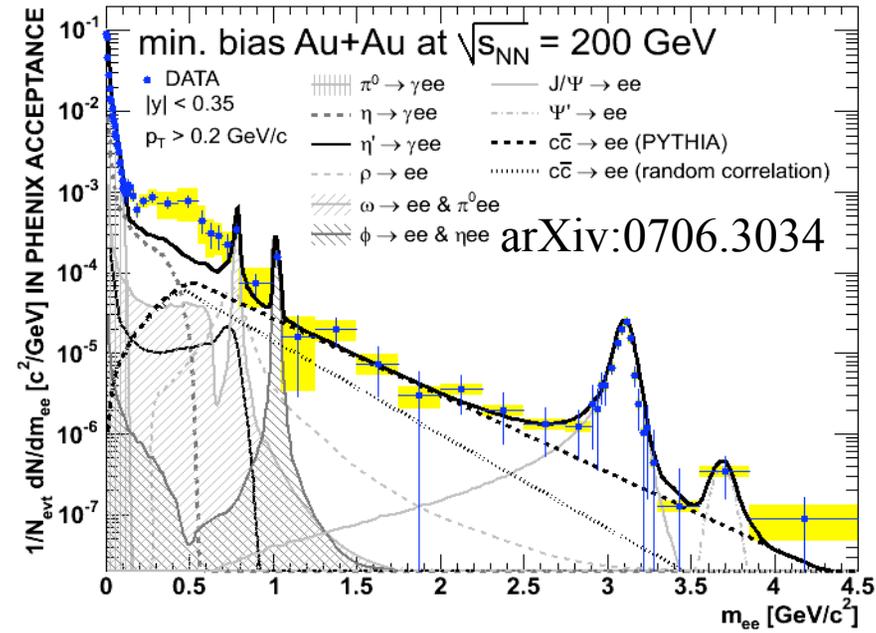
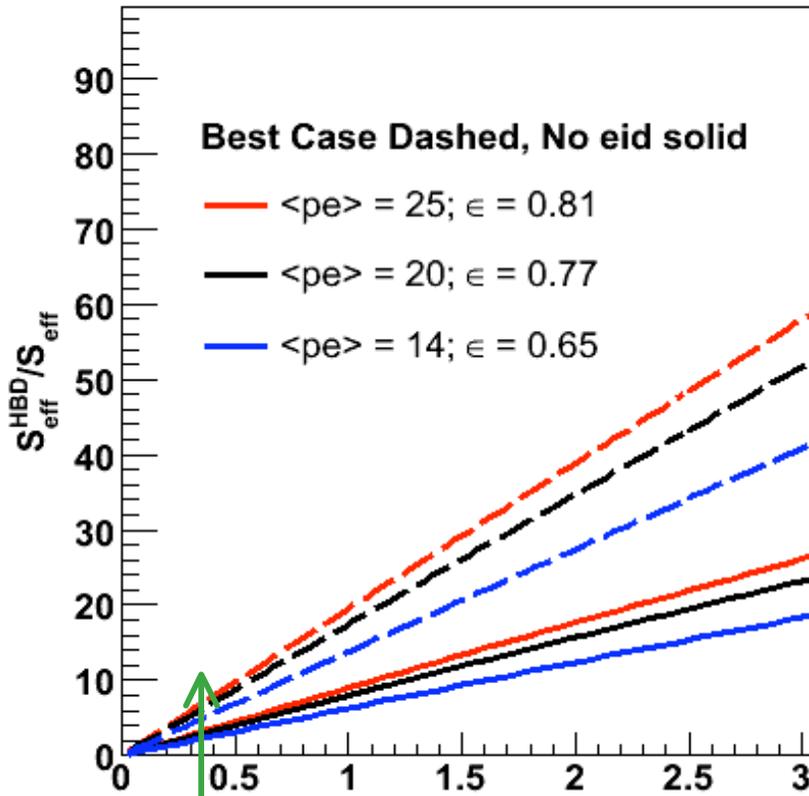


*Need 350M events*

**Non-photonic  $e^\pm R_{AA}$**   
 **$\pi^0 R_{AA}$  at 200 GeV**



# Also dielectrons at 62.4 GeV



**TERRA INCOGNITA!**

*350M events with HBD*  
*3-5 x better than Run-4*  
*w/o “credit” for lower multiplicity*

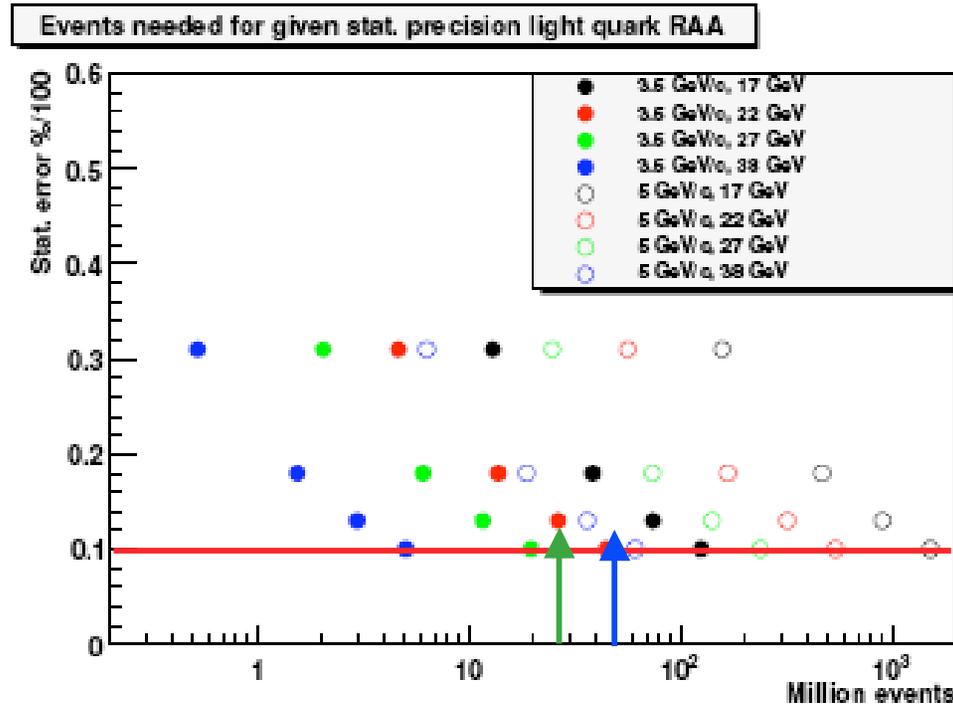


# Observables below $\sqrt{s} = 62.4$ GeV

$\sqrt{s_{NN}}$	Fluctuations in $\langle n \rangle$	Fluctuations in $\langle p_t \rangle$	PID spectra, identified particle ratios	longitudinal density correlations critical exponent $\eta$	1D imaging of pion source Lévy exponent $\alpha$	3d Gaussian HBT radii for pions $R_i(m_T)$	HBT intercept parameter $\lambda(m_T)$	dielectron spectra fluctuations if $\langle K/\pi \rangle$	dihadron correlations	nuclear modification factor $R_{AA}$ optical opacity $\kappa$	heavy flavour electrons 1d image of kaon source 3d image of pion source Kaon 3d Gaussian HBT radii $R_i(m_T)$
5.5	0.01	0.03	0.03	2	54		50	375	NA	NA	953
7.7	0.01	0.03	0.02	2	33		50	246	NA	NA	586
11.5	0.01	0.03	0.02	2	24		50	160	NA	NA	431
17.3	0.01	0.03	0.01	2	19		50	109	157	NA	340
27	0.01	0.03	0.01	2	16		50	68	24	NA	276
39	0.01	0.03	0.01	2	14		50	48	6.3	700	239



# Excitation function of $R_{AA}$



*Expect 10%  
systematic uncertainty*

*Can measure up to  
5 GeV/c  $p_T$  at 39 GeV  
3.5 GeV/c  $p_T$  at 27 GeV  
with 10%  $\sigma$  statistical*

*Are jets suppressed at  $\sqrt{s} = 39$  and 27 GeV?*

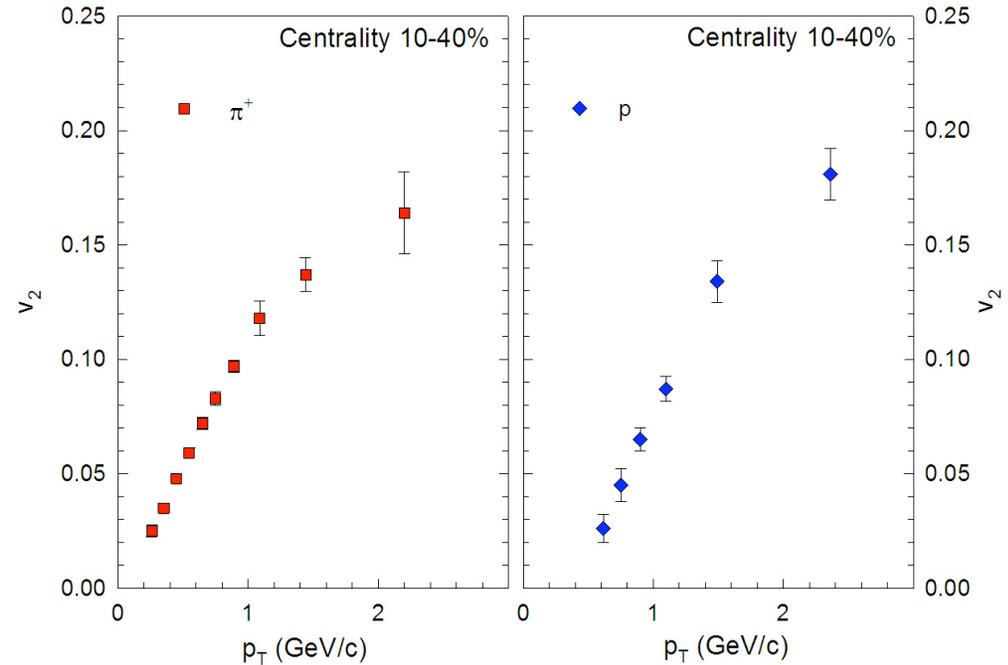
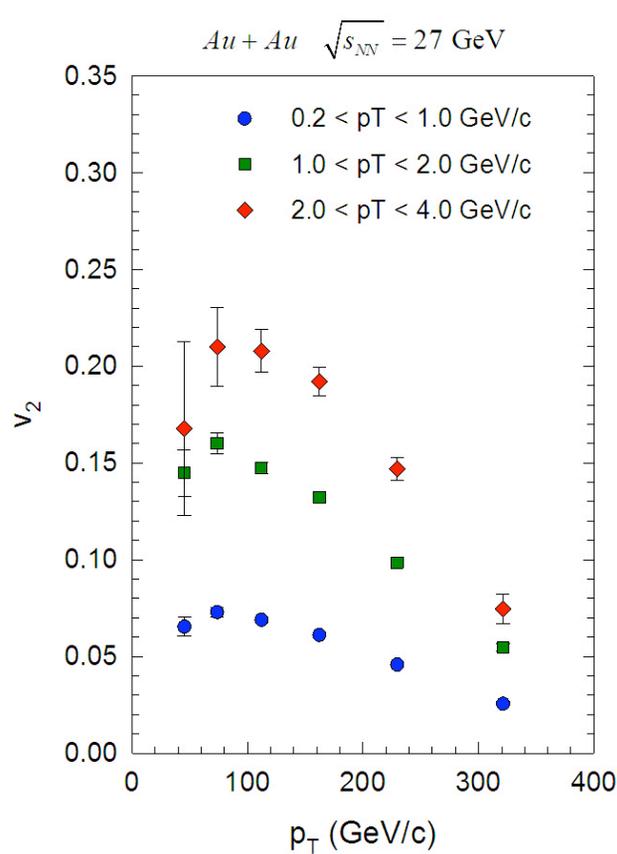
*Unsuppressed at 22.4 (modulo Cronin effect errors)*

*at 200 GeV we see QGP, 22.4 GeV not*

*Search for a clear (deconfinement) transition*



# 25 Million events at 27 GeV (4.5 weeks)



*$v_2$  magnitude & location of break  
in constituent quark scaling  
→  $\eta/s$  and post-hadronization viscosity*

# p+p development in Run-10

- **The problem:**

Polarization < 60 not 65%  
Anticipate  $\int \mathcal{L} = 15$  not 25 pb<sup>-1</sup>  
FOM lower than expected  
 $0.72 \times 0.6 = 0.43$

- **We have learned so far:**

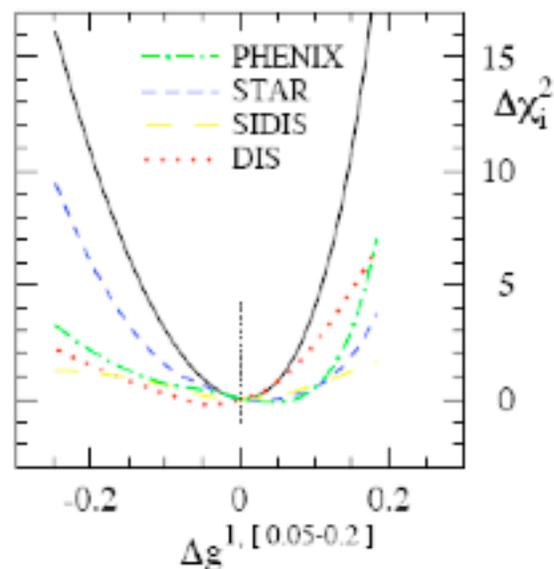
$\Delta G(x 0.02)$  small!  
→ **diminishing returns!**

- **The solution: 500 GeV**

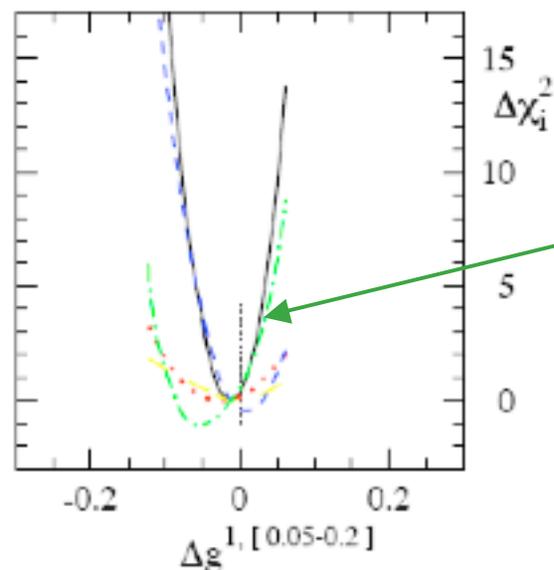
**Higher luminosity &  
access lower x**

**Look at sea quarks**

*Desperately needs  
polarization development!  
35% polarization in Run-9*



**Run-6  
status**



**Run-9  
Projection**

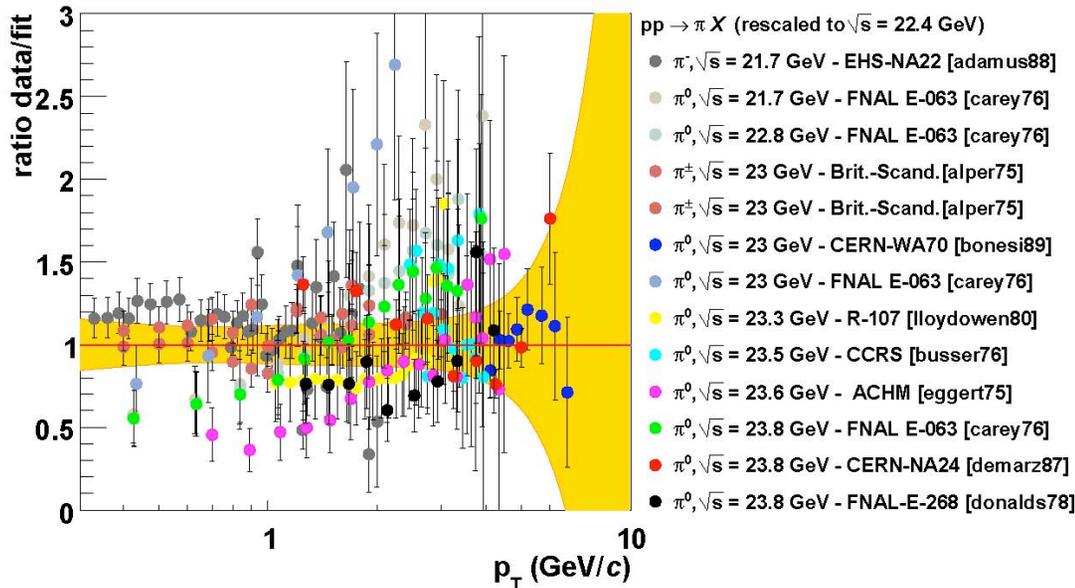
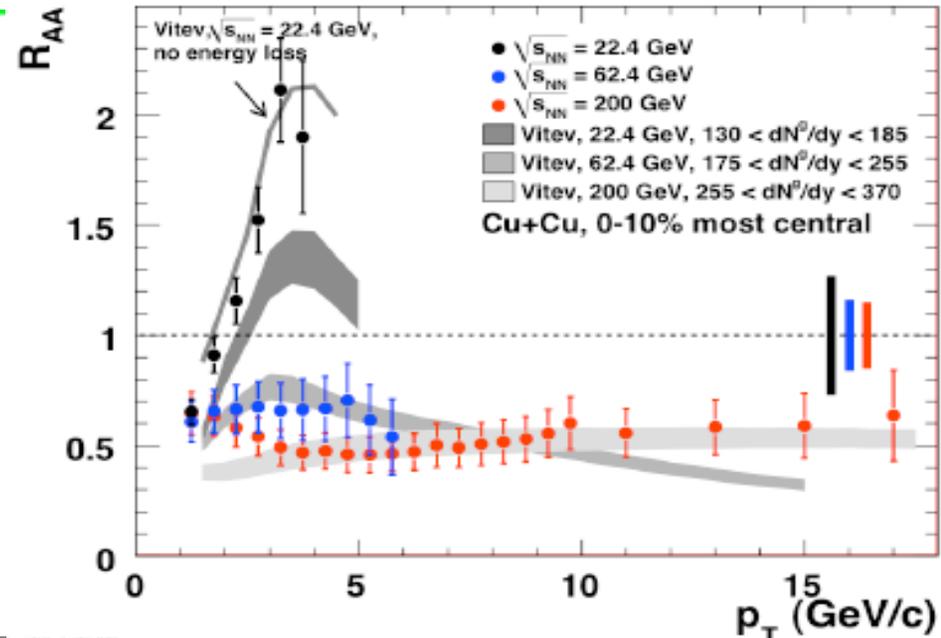
**PHENIX**

# p+p run at 22.4 GeV

PRL101, 162301 (2008)

- Uncertainty in p+p reference dominates 22.4 GeV  $\sigma_{\text{syst}}$
- Need 2.5B events recorded  
1 week run w/changeover

Arleo & d'Enterria,  
Phys.Rev.D78:094004,2008



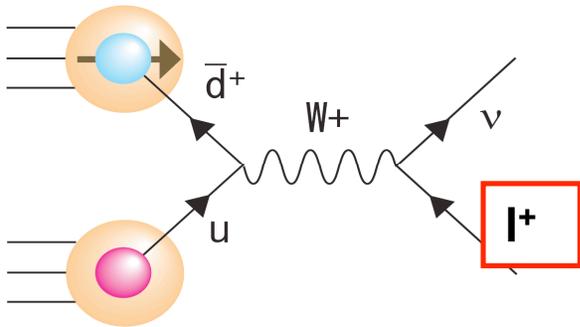
*Measure p+p reference at same  $\sqrt{s}$  and apparatus*  
*Reduce uncertainty for interpolation between 22.4 & 62.4 GeV*

# 500 GeV p+p in Run-11

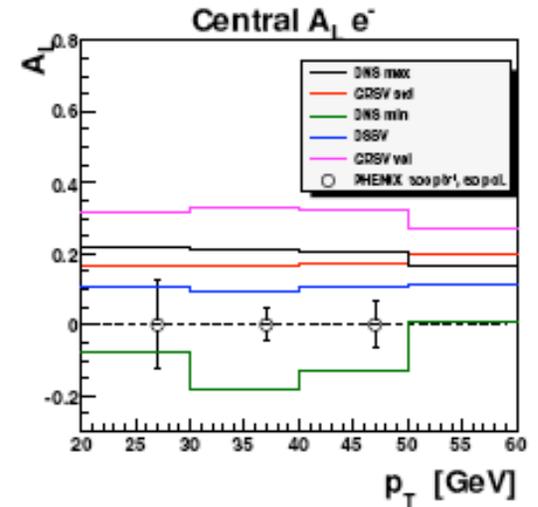
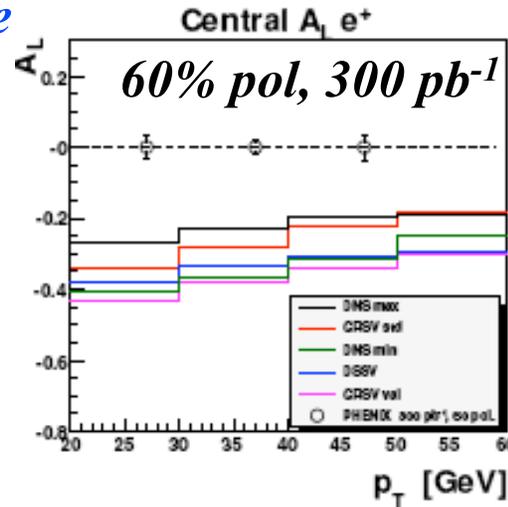
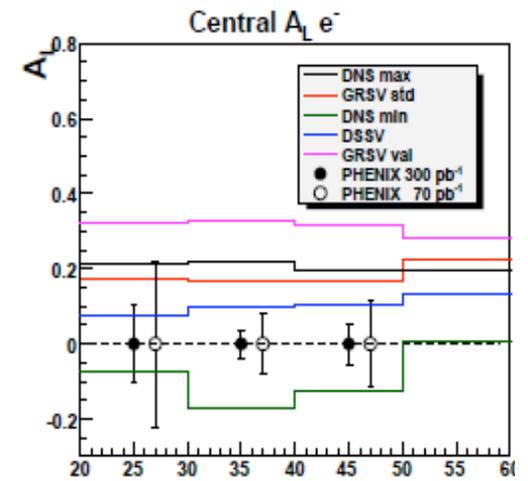
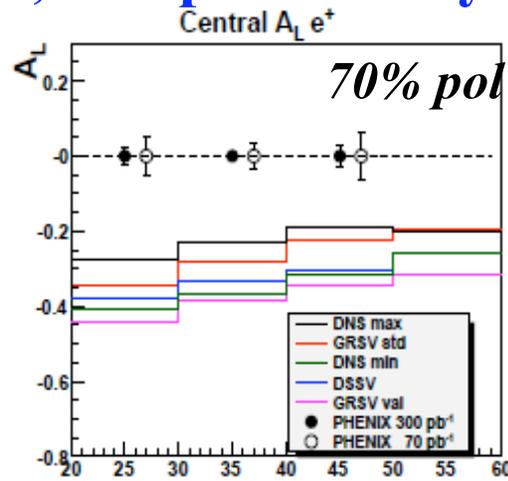
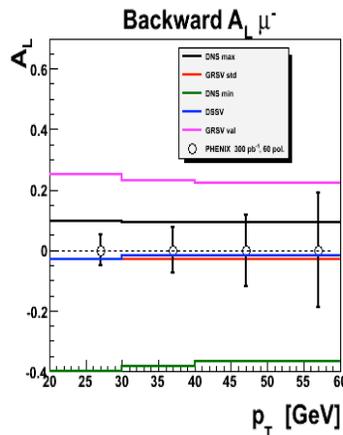
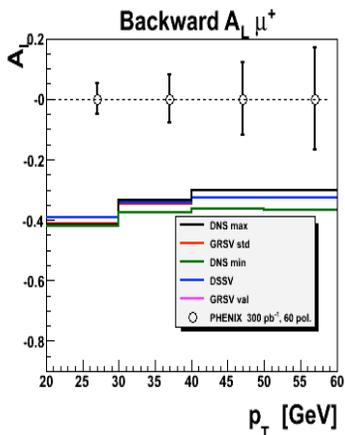
- first data on the parity-violating asymmetry  $A_L$  in the observation of leptons from  $W$  production

$u$  &  $d$   $\bar{q}$  &  $q$  polarization; complementary to SI DIS

$$A_L^{l^\pm} (W^\pm \rightarrow l^\pm \nu)$$

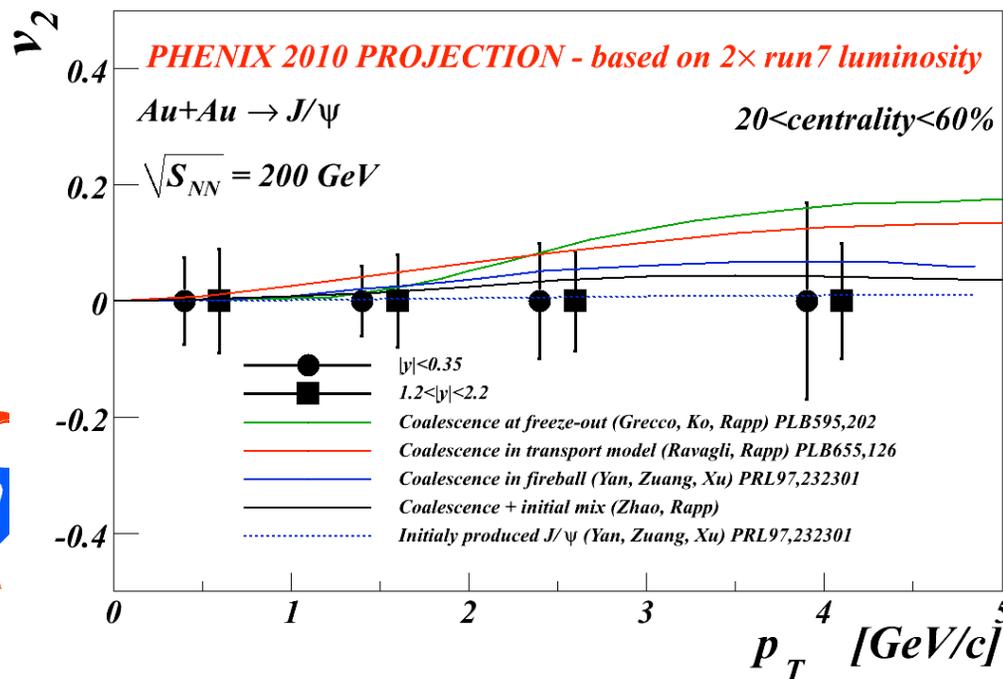


Both  $\mu$  &  $e$  final state



# Drivers for 200 GeV Au+Au in Run-11

- **VTX opens new physics by separating c,b !**  
**Commission with p+p (run p+p first!)**  
**Au+Au vs. U+U: higher  $\mathcal{L} \rightarrow$  rate into  $\pm 10$  cm**
- **Ability to combine Run-11 with Run-10 for  $J/\psi$   $v_2$**



**Run-7+10+11 will tell:  
 $c\bar{c}$  coalescence or not?**



# Beam Use Proposal (in priority order)

RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS *	$\int \mathcal{L} dt$ recorded	EVENTS (million)
10	Au+Au	200	10	1.4 nb <sup>-1</sup>	
	Au+Au	62.4	3.5	56.2 $\mu$ b <sup>-1</sup>	350M
	Au+Au	~39	1.3 + 0.3 E change	8.2 $\mu$ b <sup>-1</sup>	50M
	Au+Au	27	4.5	4.1 $\mu$ b <sup>-1</sup>	25M
	p+p	500	4 (polarization development)		
	p+p	22.4	1		2.5B
11	p+p	500	10	50 pb <sup>-1</sup>	
	Au+Au	200	8	1.4 nb <sup>-1</sup>	

\* estimated with mean of min/max prediction  
includes lumi. ramp up & changeover time



# Utilizing increased luminosity

---

- **Now:**

**DAQ 5kHz bandwidth**

**Before Run-7:**

**record every Au+Au  
mbias event**

**In Run-7: 80% of 7 kHz**

**In p+p, Lvl1 triggers  
reduce 200-400 kHz  
rate to 6kHz of useful  
events**

**→ PHENIX is able to  
effectively sample full  
luminosity for all rare  
channels**

- **Future:**

- **7MHz p+p@500GeV**
- **2MHz p+p@200GeV**
- **40kHz Au+Au**

**Event size \*1.7 with Si  
detectors**

- **Previous trigger  
strategy insufficient**



# DAQ/Trigger Upgrade Plan

<b>Replace</b>	EMCAL FEE trigger match/rejection ( $e^{\pm}$ )	Need by 2012
<b>Develop</b>	Upgrade Local Level 1 trigger (multiple z vx)	Ready in 2011
	Faster DCM-II	Ready in 2010
	Upgrade EVB switch (10 Gb/s) & machines	Need by 2011
	De-multiplex FEE	
<b>Purchase</b>	Real Time Trigger Analysis Farm	
<b>Construct</b>	T0/trigger barrel	Need by 2013



# Detector issues with high luminosity?

---

- **PHENIX detectors are primarily fast detectors**  
**High rate anticipated in original design**
- **Wire chamber aging at more rapid rate**  
**Beginning evaluation of options**
- **Change in calibration strategies, particularly for DC**  
**Completed & implemented**  
**Use hits from reconstructed tracks to calibrate drift time**

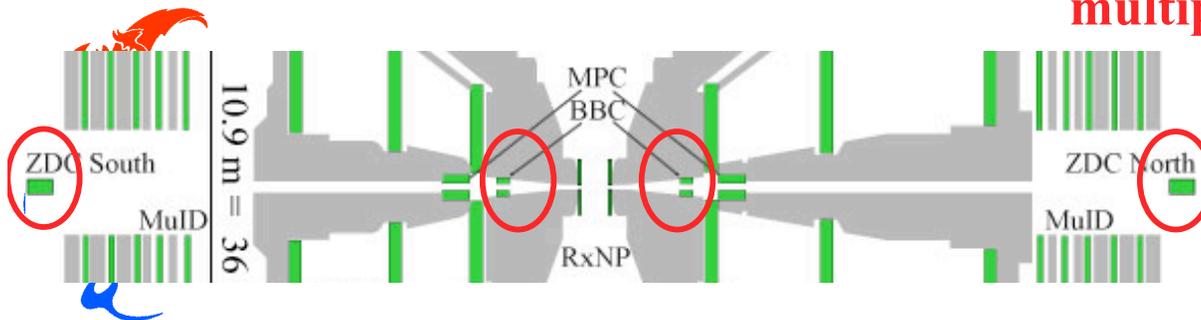


**Pattern recognition and efficiency under study**

# Rate Effects on Luminosity Monitoring

*Kieran Boyle, lumi monitor task force*

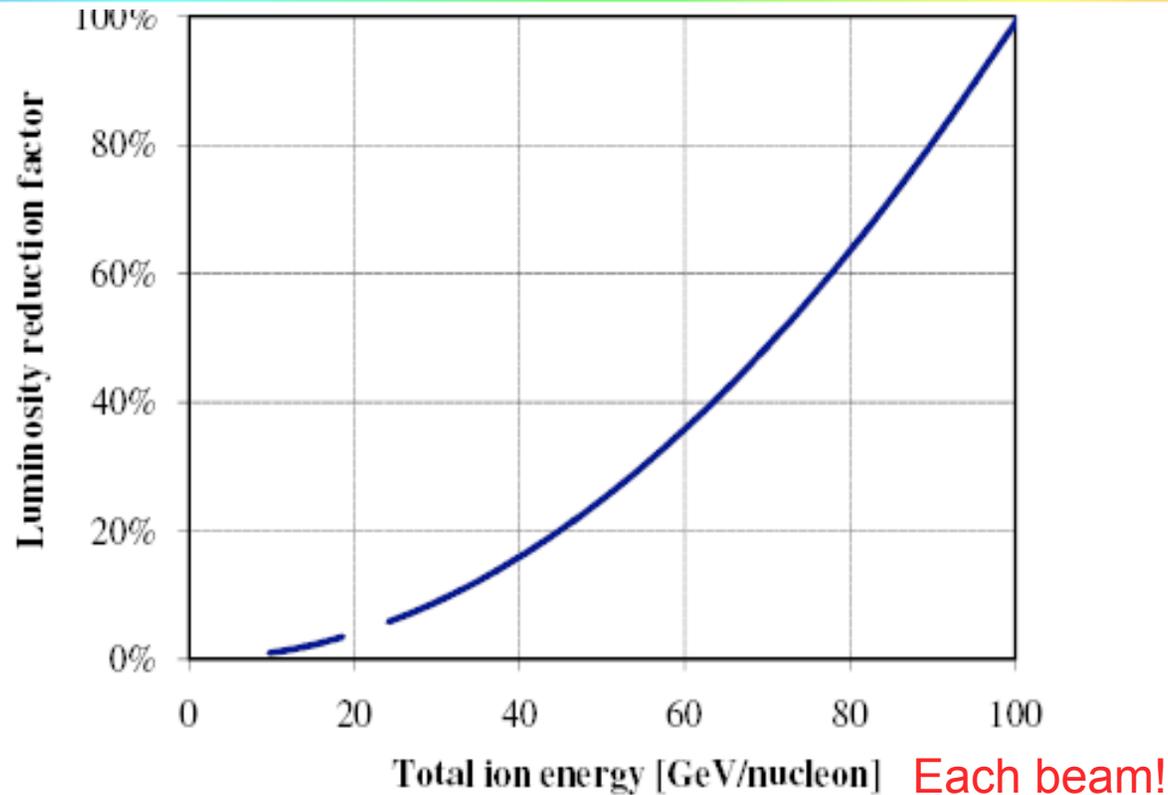
- **Run3-6:**
  - Primary luminosity detector: BBC
  - ZDC: check systematic uncertainties
- **Run9 and beyond:**
  - Multiple collisions increase with luminosity, and can affect the accuracy of the relative luminosity measurement.
- **Both the BBC and ZDC triggers cannot distinguish multiple collisions**
- **RHIC-wide monitor in study**
- **In Run9, added bunch by bunch luminosity monitors:**
  - ❁ **Single sided ZDC triggers**
    - ❁ *Multi. coll. affect luminosity in simpler (Poissonian) way than coincidence detector*
  - ❁ **Number of charged tracks in central arms**
    - ❁ *Correctly count multiple coll.*
    - ❁ *Extracted from 500 kHz of minimum bias data*
  - ❁ **BBC multiplicity**
    - Recorded in scalars*
- **From Run-11: VTX determines multiple collisions**



- 
- **backup slides**



# The problem



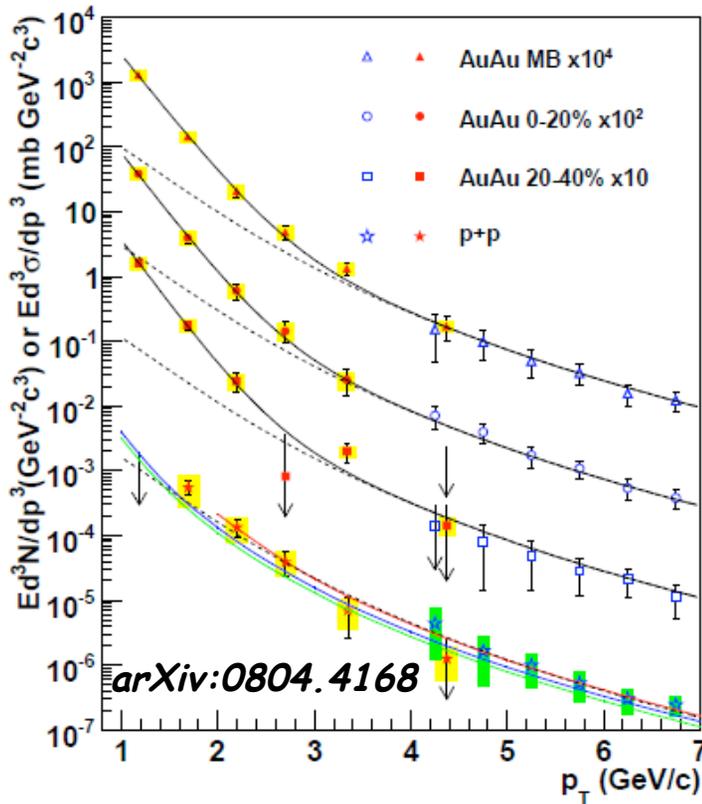
**Collision rates drop to Hz level (lower beam stiffness)**

**No storage RF below  $\sqrt{s} \sim 40$  GeV: beams fill time bucket**

$$\sigma_{\text{vertex}} \sim 150 \text{ cm}$$



# PHENIX Measurement of Early Collision Temperature via photon spectrum



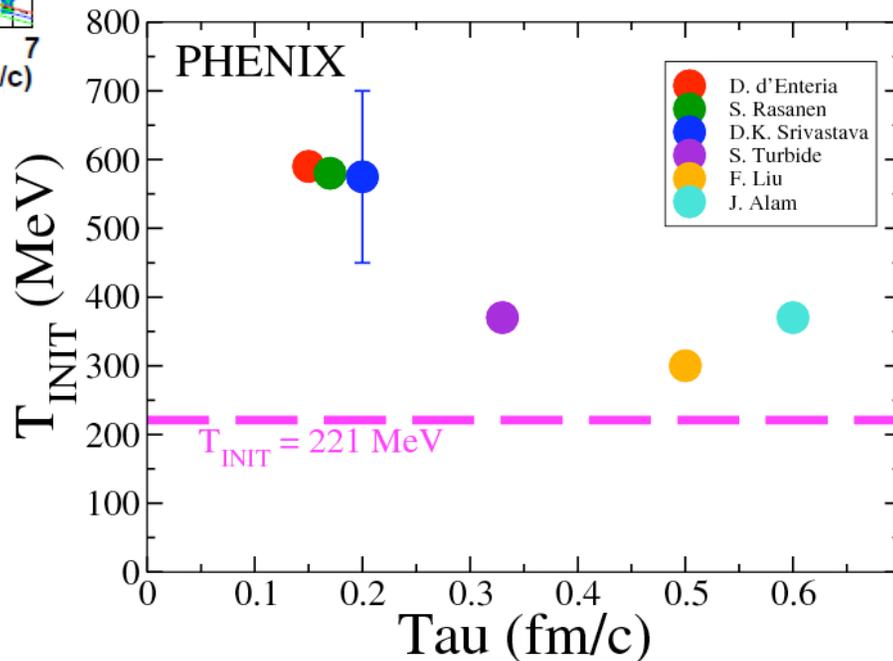
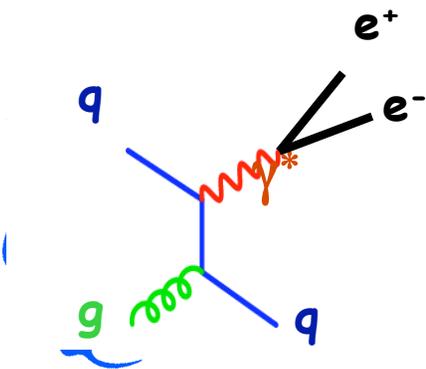
enhancement vis-à-vis p+p.

exponential fit to  $p_T$  slope  $\Rightarrow$

$$T_{avg} = 221 \pm 23 \pm 18 \text{ MeV}$$

hydrodynamics models  $\Rightarrow T_{init} > 300 \text{ MeV}$

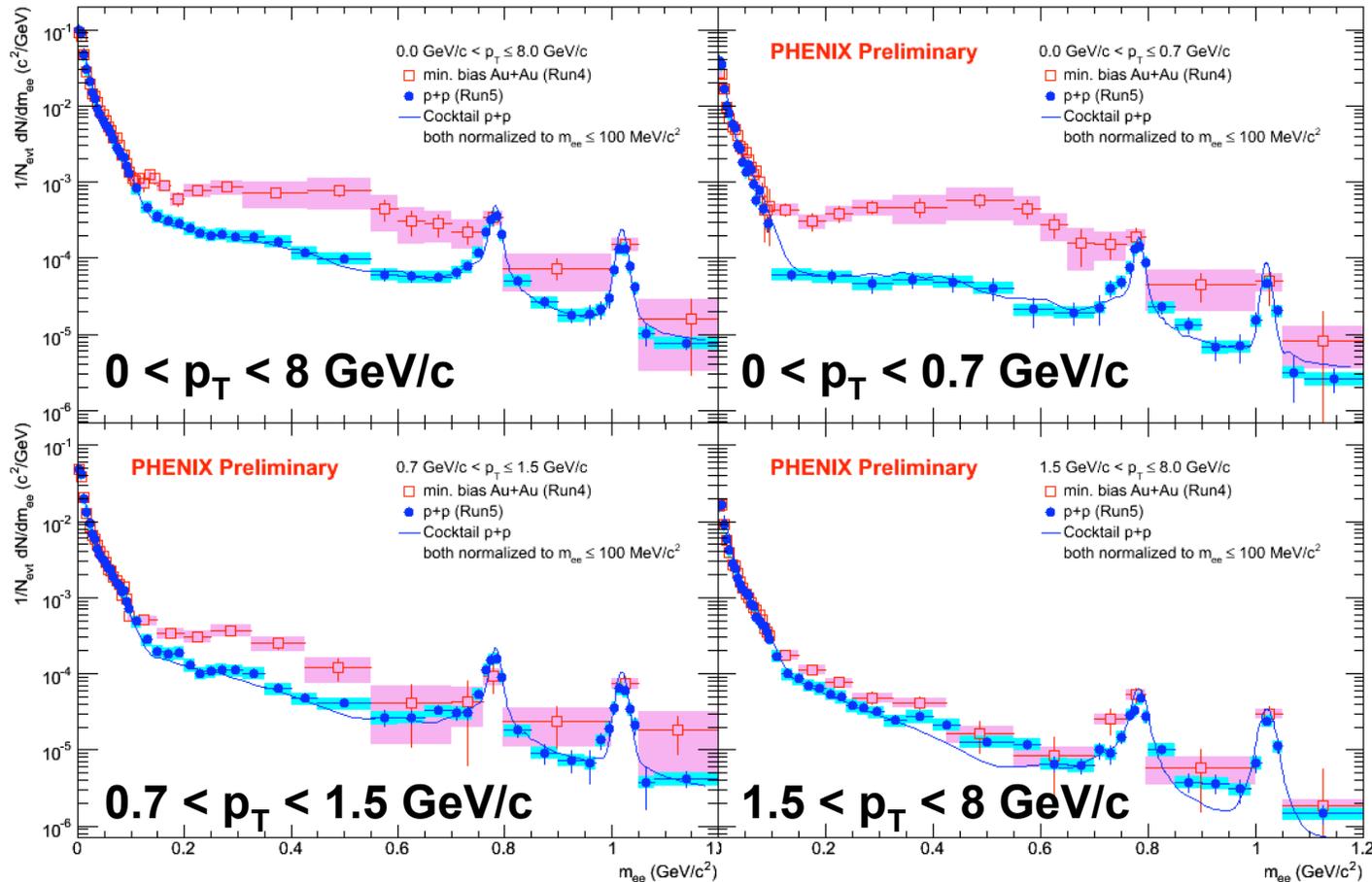
Low-mass di-electrons  
 $\Rightarrow$  nearly real photons



$$T_{init} \gg T_c$$

(!)

# Large low mass dilepton excess at low $p_T$



Low  $p_T$  shape of the excess seems incompatible with a constant virtual photon emission rate...

Large enhancement of EM correlator at low mass, low  $p_T$ ?

# Lepton pair emission $\leftrightarrow$ EM correlator

Emission rate of dilepton per volume

e.g. Rapp, Wambach Adv.Nucl.Phys 25 (2000)

$$\frac{dR_{ll}}{d^4q} = -\frac{\alpha^2}{3\pi^3} \frac{L(M)}{M^2} \text{Im}\Pi_{em,\mu}^\mu(M, q; T) f^B(q_0, T)$$

$$f^B(q_0, T) = 1/(e^{q_0/T} - 1)$$

$$L(M) = \sqrt{1 - \frac{4m_l^2}{M^2}} \left(1 + \frac{2m_l^2}{M^2}\right)$$

$\gamma^* \rightarrow ee$   
decay

EM correlator  
Medium property

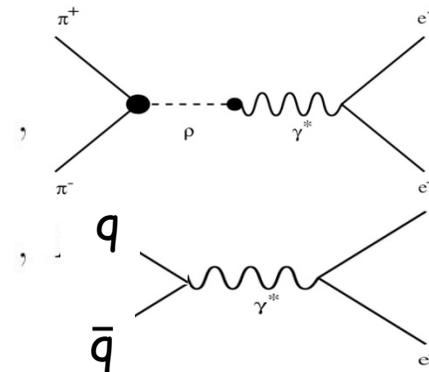
Boltzmann factor  
temperature

Hadronic contribution  
Vector Meson Dominance

$$\text{Im}\Pi_{em}^{\text{vac}}(M) = \left\{ \begin{array}{l} \sum_{V=\rho,\omega,\phi} \left(\frac{m_V^2}{g_V}\right)^2 \text{Im}D_V(M) \\ -\frac{M^2}{12\pi} \left(1 + \frac{\alpha_s(M)}{\pi} + \dots\right) N_c \sum_{q=u,d,s} (e_q)^2 \end{array} \right.$$

qq annihilation

Medium modification of meson  
Chiral restoration



Thermal radiation from  
partonic phase (QGP)



From emission rate of dilepton, the medium effect on the EM correlator as well as temperature of the medium can be decoded.

# Relation of dileptons and virtual photons

Yasuyuki Akiba - PHENIX QM09

Emission rate of dilepton per volume

$$\frac{dR_{ll}}{d^4q} = -\frac{\alpha^2}{3\pi^3} \frac{L(M)}{M^2} \text{Im}\Pi_{em,\mu}^\mu(M, q; T) f^B(q_0, T)$$

Emission rate of (virtual) photon per volume

$$q_0 \frac{dR_{\gamma^*}}{d^3q} = -\frac{\alpha}{2\pi^2} \text{Im}\Pi_{em,\mu}^\mu(M, q; T) f^B(q_0, T).$$

Relation between them Prob.  $\gamma^* \rightarrow l+l$

$$\underbrace{q_0 \frac{dR_{ll}}{dM^2 d^3q}}_{\text{Dilepton}} = \frac{1}{2} \frac{dR}{d^4q} = \underbrace{\left( \frac{\alpha}{3\pi} \frac{L(M)}{M^2} \right)}_{\text{virtual photon}} \underbrace{q_0 \frac{dR_{\gamma^*}}{d^3q}}_{\text{virtual photon}}$$

This relation holds for the yield after space-time integral

*Virtual photon emission rate can be determined from dilepton emission rate*

$$\begin{aligned} q_0 \frac{dn_{\gamma^*}}{d^3q} &\simeq \frac{3\pi}{\alpha} M^2 q_0 \frac{dn_{ll}}{d^3q dM^2} \\ &= \frac{3\pi}{2\alpha} \underbrace{M q_0 \frac{dn_{ll}}{d^3q dM}}_{\text{Virtual photon yield}} \end{aligned}$$

M x dN<sub>ee</sub>/dM gives  
Virtual photon yield

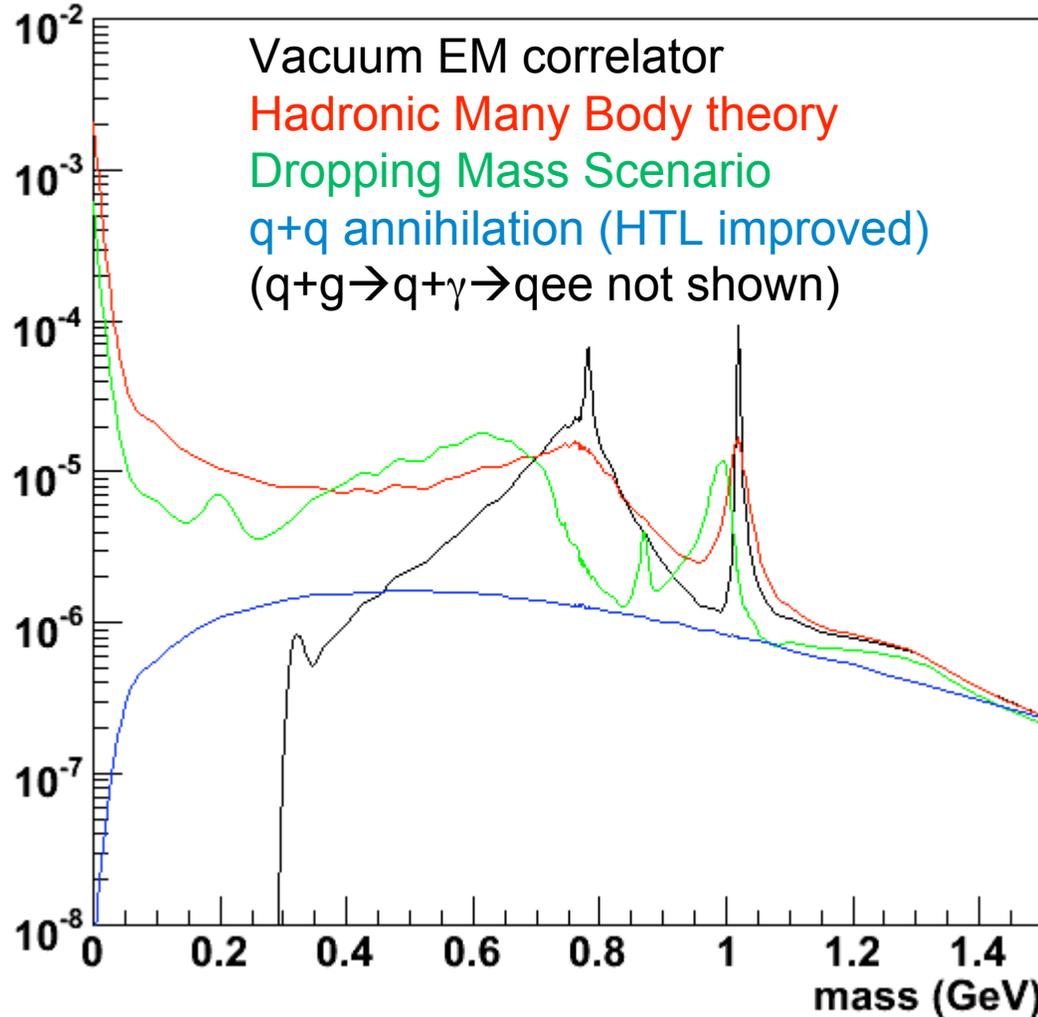
For  $M \rightarrow 0$ ,  $n_{\gamma^*} \rightarrow n_{\gamma}$  (real) so real photon emission rate can also be determined



# Theory prediction of dilepton emission

$$\frac{dN_{ee}}{p_t dp_t dM dy} \quad \text{at } y=0, p_t=1.025 \text{ GeV}/c$$

Theory calculation by Ralf Rapp



Usually the dilepton emission is measured and compared as  $dN/dp_t dM$

The mass spectrum at low  $p_T$  is distorted by the virtual photon → ee decay factor  $1/M$ , which causes a steep rise near  $M=0$

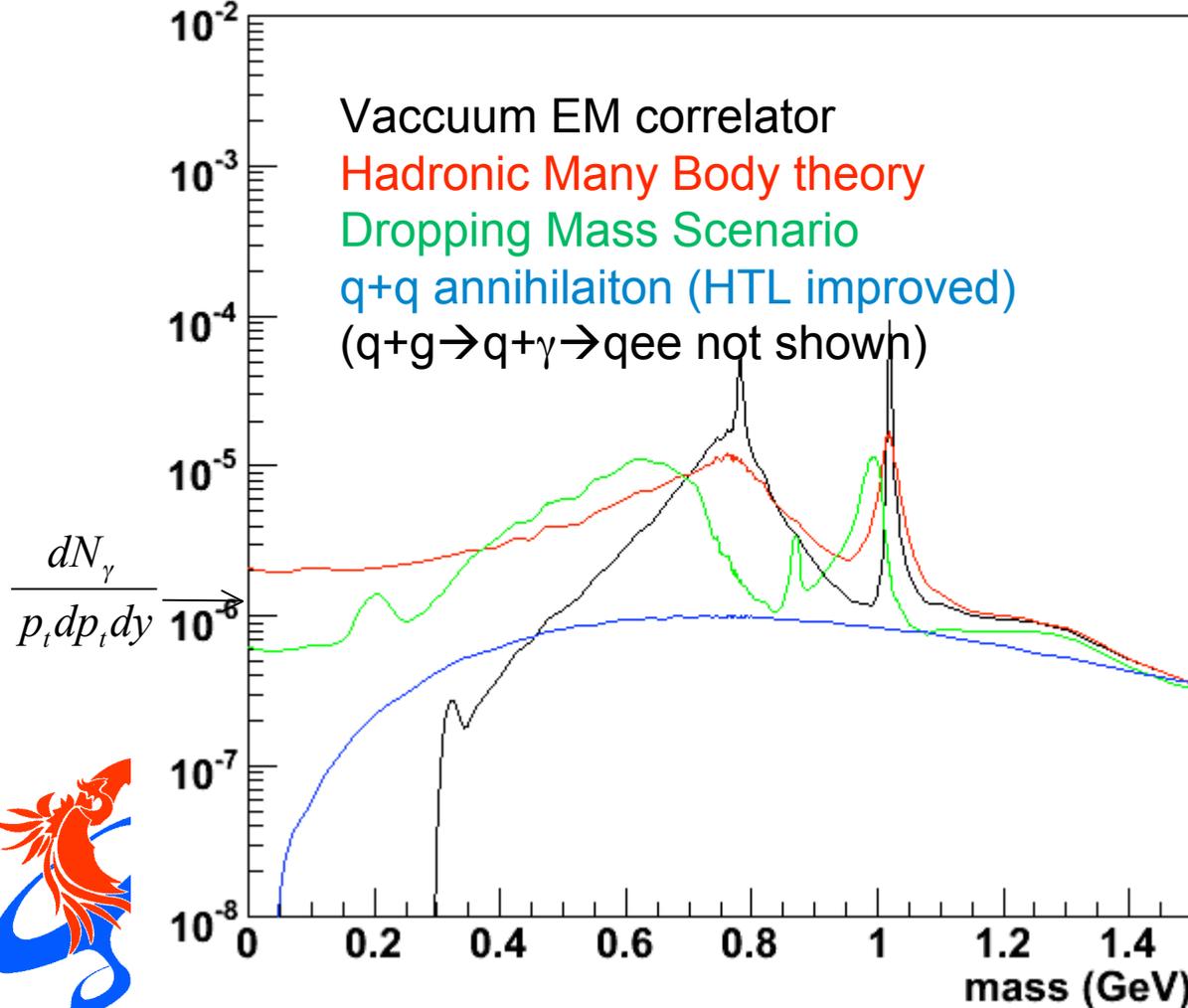
qq annihilation contribution is negligible in the low mass region due to the  $m^{**2}$  factor of the EM correlator

In the calculation, partonic photon emission process  $q+g \rightarrow q+\gamma \rightarrow q+e^+e^-$  not included



# Virtual photon emission rate

$$M \times \frac{dN_{ee}}{p_t dp_t dM dy} \propto \frac{dN_{\gamma^*}}{p_t dp_t dy} \text{ at } y=0, p_T=1.025 \text{ GeV}/c$$



The same calculation, but shown as the virtual photon emission rate.

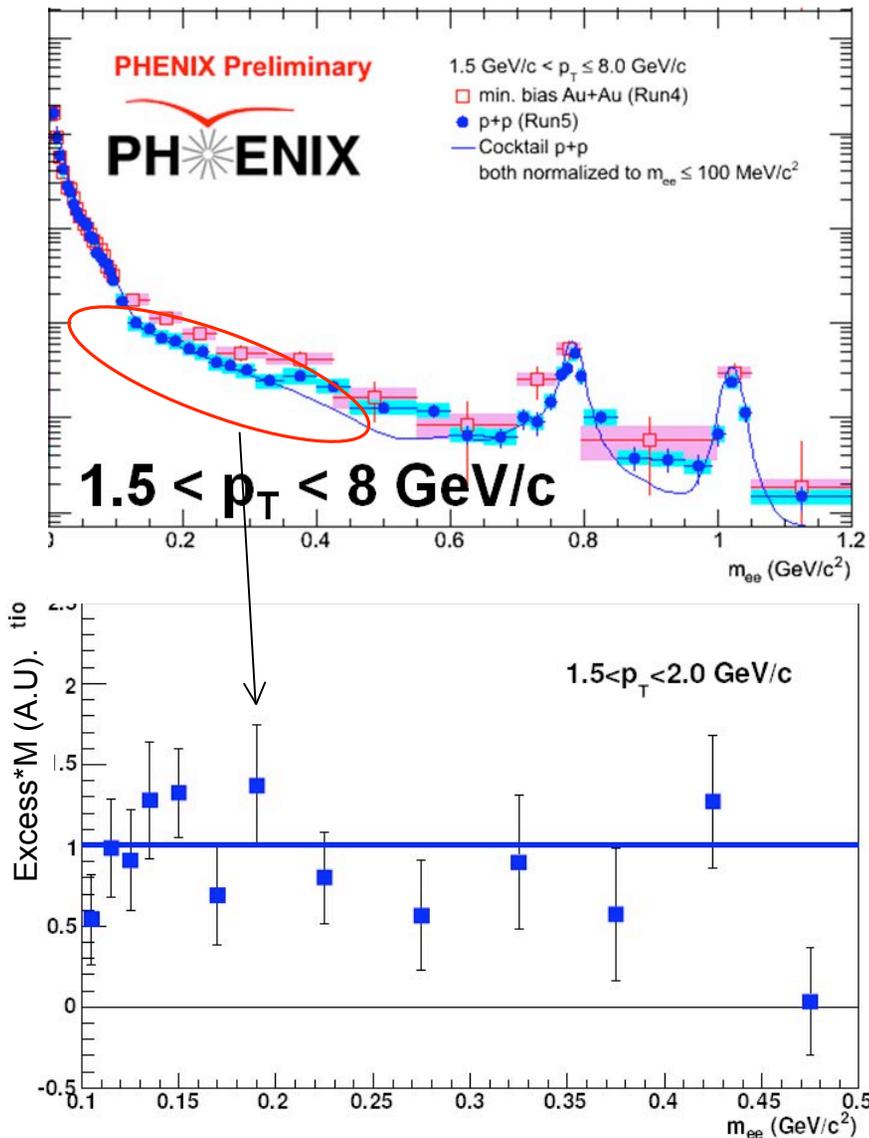
The steep raise at  $M=0$  is gone, and the virtual photon emission rate is more directly related to the underlying EM correlator.

When extrapolated to  $M=0$ , the real photon emission rate is determined.

$q+g \rightarrow q+\gamma^*$  is not shown; it is similar size as **HMBT** at this  $p_T$



# Excess of virtual photons



Excess of electron pairs over the cocktail  
 $\sim$  constant with mass at high  $p_T$ .

Excess converted to virtual photon yield  
 dividing by  $1/M$  shape from the virtual  
 photon decay.

The distribution is  $\sim$ flat over half GeV/c<sup>2</sup>

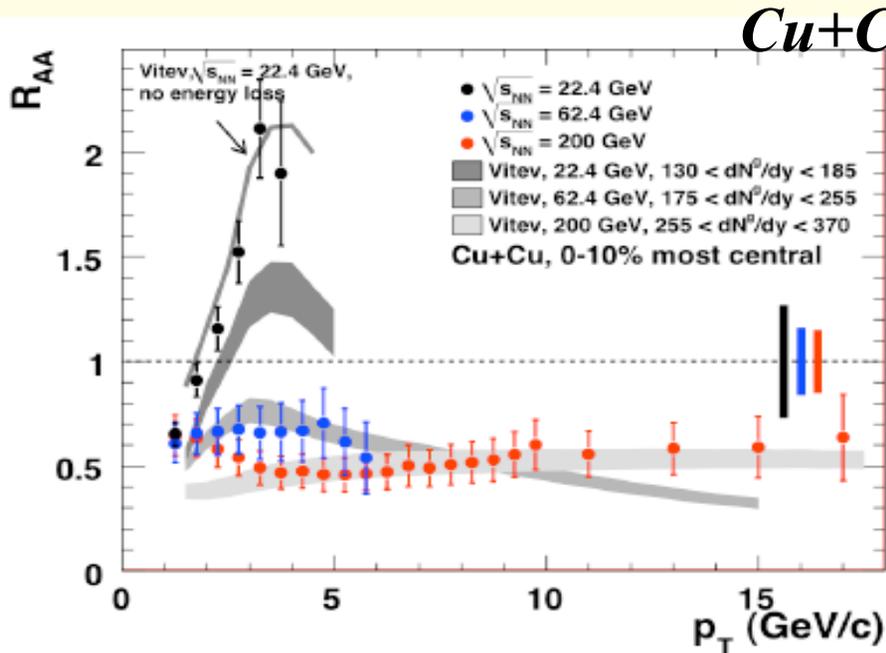
Extrapolation to  $M=0$  should give the real  
 photon emission rate.

No indication of strong modification of EM  
 correlator at high  $p_T$  !

presumably the virtual photon emission is  
 dominated by processes

$$\text{e.g. } \pi + \rho \rightarrow \pi + \gamma^* \text{ or } q + g \rightarrow q + \gamma^*$$

# Onset of RHIC's perfect liquid

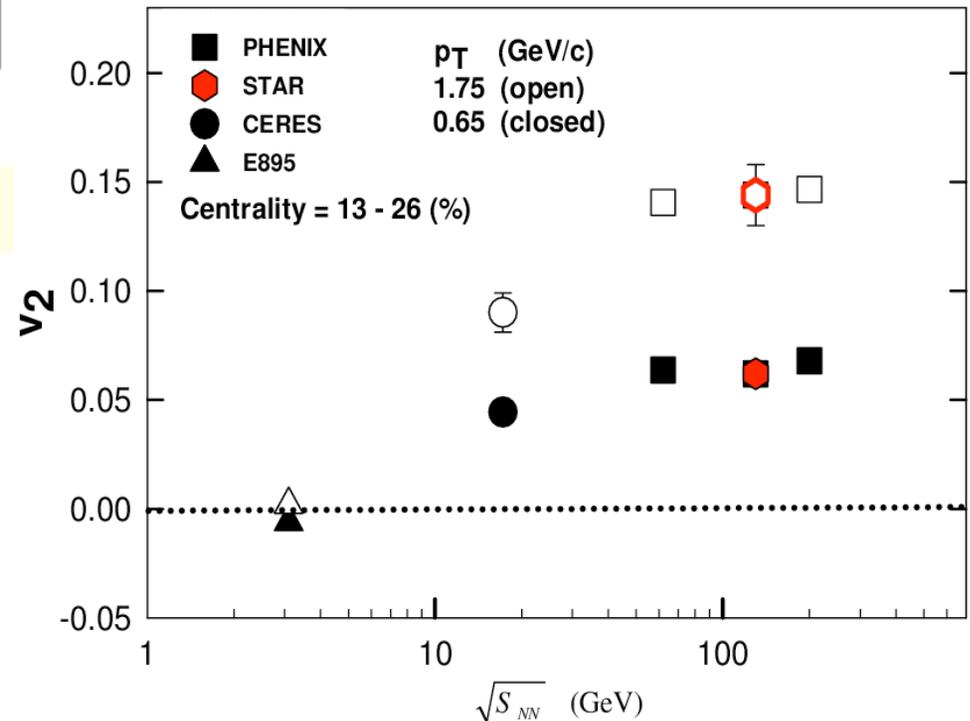


PHENIX, arXiv:0801.4555 [nucl-ex]

Emergence of opacity

Approach to constant  $v_2$  and hydrodynamic limit?

**Au+Au**



Somewhere between  
22.4 and 62.4!  
Where? Properties?  
(temperature, etc.)



## PHENIX data sets

Run	Year	Species	$\sqrt{s_{NN}}$ (GeV)	$\int L dt$	$N_{Tot}$	p+p Equivalent	Data Size
01	2000	Au+Au	130	1 $\mu\text{b}^{-1}$	10M	0.04 $\text{pb}^{-1}$	3 TB
02	2001/2002	Au+Au	200	24 $\mu\text{b}^{-1}$	170M	1.0 $\text{pb}^{-1}$	10 TB
		p+p	200	0.15 $\text{pb}^{-1}$	3.7G	0.15 $\text{pb}^{-1}$	20 TB
03	2002/2003	d+Au	200	2.74 $\text{nb}^{-1}$	5.5G	1.1 $\text{pb}^{-1}$	46 TB
		p+p	200	0.35 $\text{pb}^{-1}$	6.6G	0.35 $\text{pb}^{-1}$	35 TB
04	2004/2004	Au+Au	200	241 $\mu\text{b}^{-1}$	1.5G	10.0 $\text{pb}^{-1}$	270 TB
		Au+Au	62.4	9 $\mu\text{b}^{-1}$	58M	0.36 $\text{pb}^{-1}$	10 TB
05	2004/2005	Cu+Cu	200	3 $\text{nb}^{-1}$	8.6G	11.9 $\text{pb}^{-1}$	173 TB
		Cu+Cu	62.4	0.19 $\text{nb}^{-1}$	0.4G	0.8 $\text{pb}^{-1}$	48 TB
		Cu+Cu	22.5	2.7 $\mu\text{b}^{-1}$	9M	0.01 $\text{pb}^{-1}$	1 TB
		p+p	200	3.8 $\text{pb}^{-1}$	85G	3.8 $\text{pb}^{-1}$	262 TB
06	2006	p+p	200	10.7 $\text{pb}^{-1}$	230G	10.7 $\text{pb}^{-1}$	310 TB
		p+p	62.4	0.1 $\text{pb}^{-1}$	28G	0.1 $\text{pb}^{-1}$	25 TB
07	2007	Au+Au	200	0.813 $\text{nb}^{-1}$	5.1G	33.7 $\text{pb}^{-1}$	650 TB
08	2008	d+Au	200	80 $\text{nb}^{-1}$	160G	32.1 $\text{pb}^{-1}$	437 TB
		p+p	200	5.2 $\text{pb}^{-1}$	115G	5.2 $\text{pb}^{-1}$	118 TB
09	2009	p+p	500	$\approx 10$ $\text{pb}^{-1}$	308G	$\approx 10$ $\text{pb}^{-1}$	223 TB
		p+p	200	ongoing			>220 TB

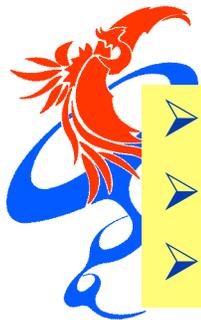
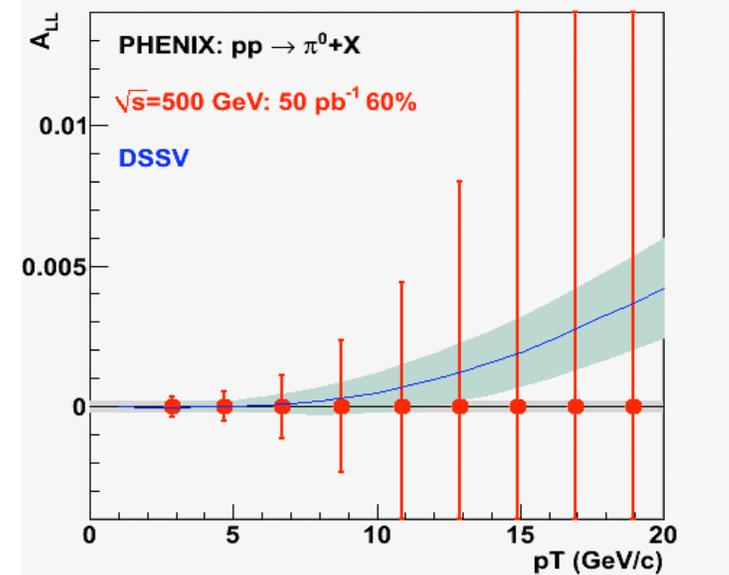
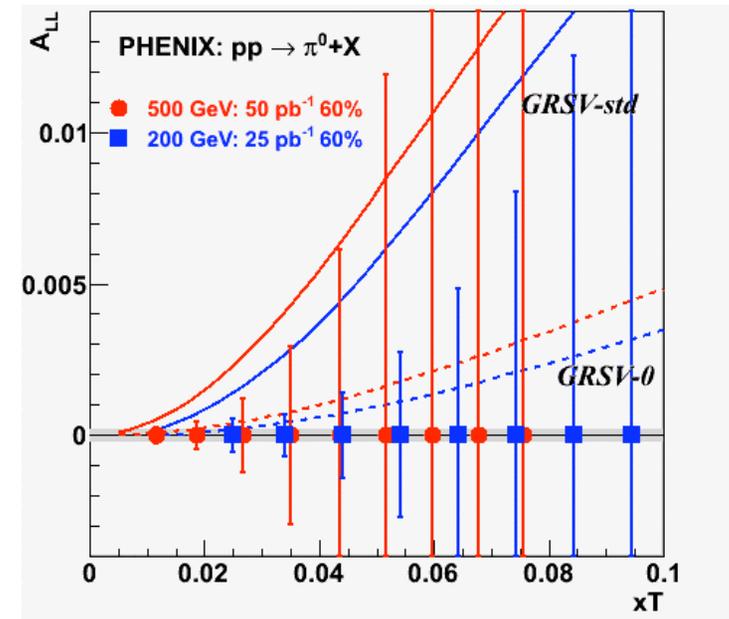
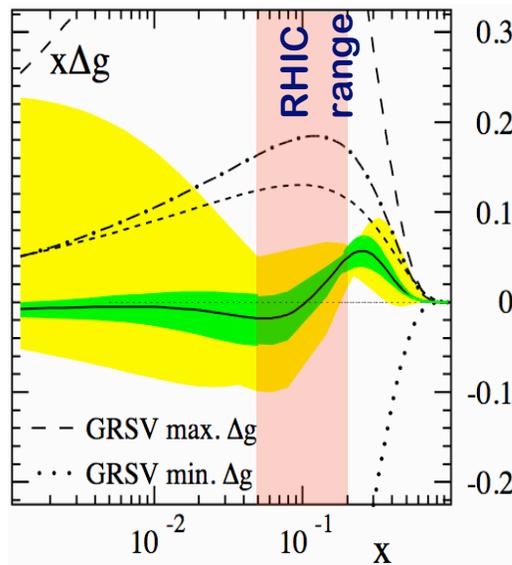
# $\Delta G$ at lower x using 500 GeV

In 10-weeks at 500 GeV PHENIX can extend its x-range significantly and check gluon spin “wisdom”

Can be done in Run 11, if polarization of 250 GeV beams is improved in Run 10 machine development

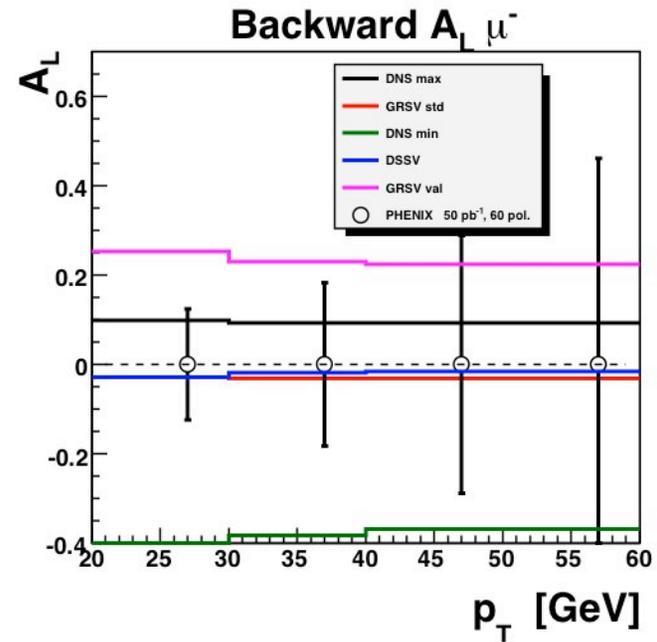
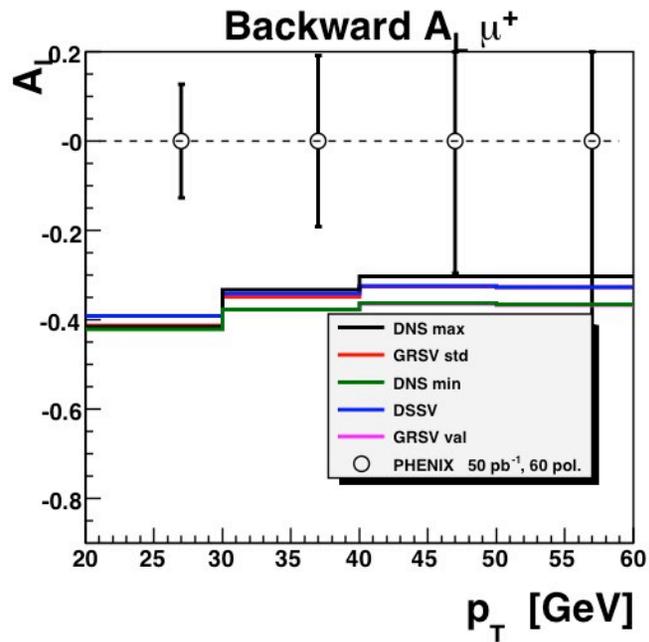
Explore also  $\pi, h^\pm, \gamma, \eta$ , heavy flavor for additional  $\Delta g(x)$  shape constraints

de Florian, Sassot, Stratmann, Vogelsang  
PRL 101, 072001(2008)



- $\Delta g(x)$  small in current RHIC range
- Best fit has a node at  $x \sim 0.1$
- Low-x less constrained

# Run-11 W measurement



# RPC Installation Schedule

Shutdown	muTr-trigger electronics	RPC	Absorber
2008	north: 1+2+3 south: 2 octants	south: 2 half octants	south: octant prototype
2009	south: 1+2+3	north: RPC3	
2010		south: RPC3	absorber
2011		RPC1	

-----north + south ready for first W-physics-----

Improved rejection of beam backgrounds for highest lumi.

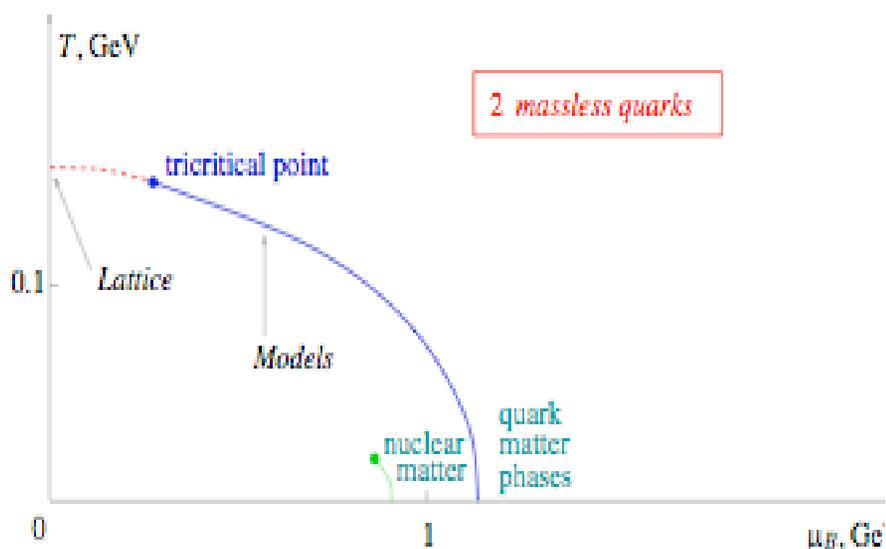
on schedule!

Before the arrival of the forward vertex detector (FVTX) in 2011 an absorber may be necessary to suppress off-line Backgrounds (based on detailed MC-study of off-line backgrounds).

Thickness and schedule for the absorber will be decided based on results from run 9 absorber tests: one octant in the south was equipped with a prototype absorber.

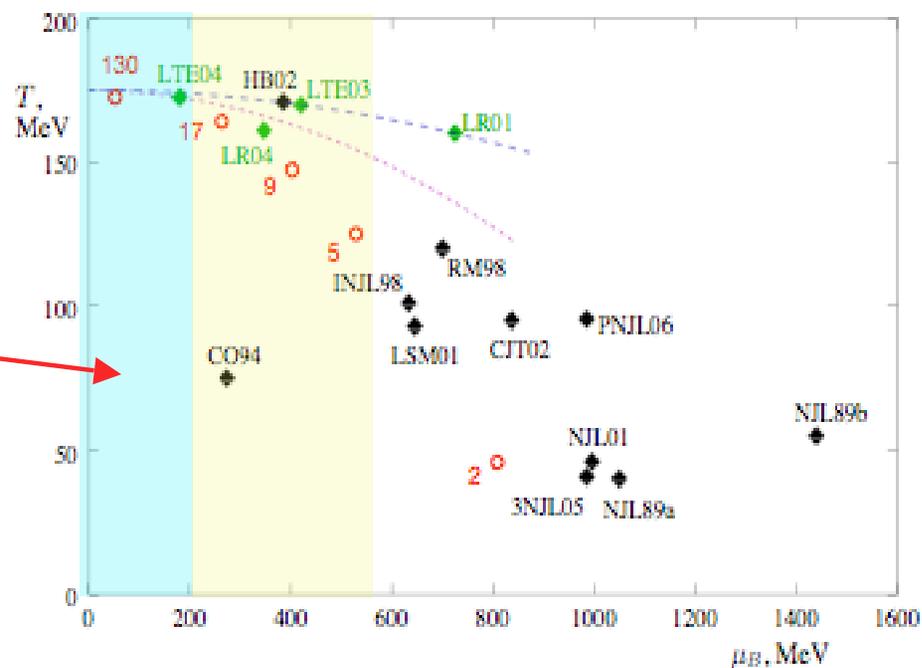
# Where is the critical end point?

M.A. Stephanov, PoS(LAT2006)024



Range accessible with RHIC with substantial luminosity (above

$$\sqrt{s_{NN}} = 22 \text{ GeV}$$



# Predicted observables of interest

---

- **Perfect liquid onset:**

**Emergence of opacity (heavy quarks too?)**

**Departure of  $v_2$  from hydrodynamic prediction**

**Di-electrons for hadron modification, temperature**

- **Critical endpoint:**

**$v_2$  centrality dependence,  $p$  vs.  $\pi$**

***Fluctuations in  $N_{ch}$ , baryon number  
(to find susceptibility divergence)***

***K/ $\pi$ ,  $p/\pi$  ratios and their fluctuations***

***$p_T$  fluctuations***



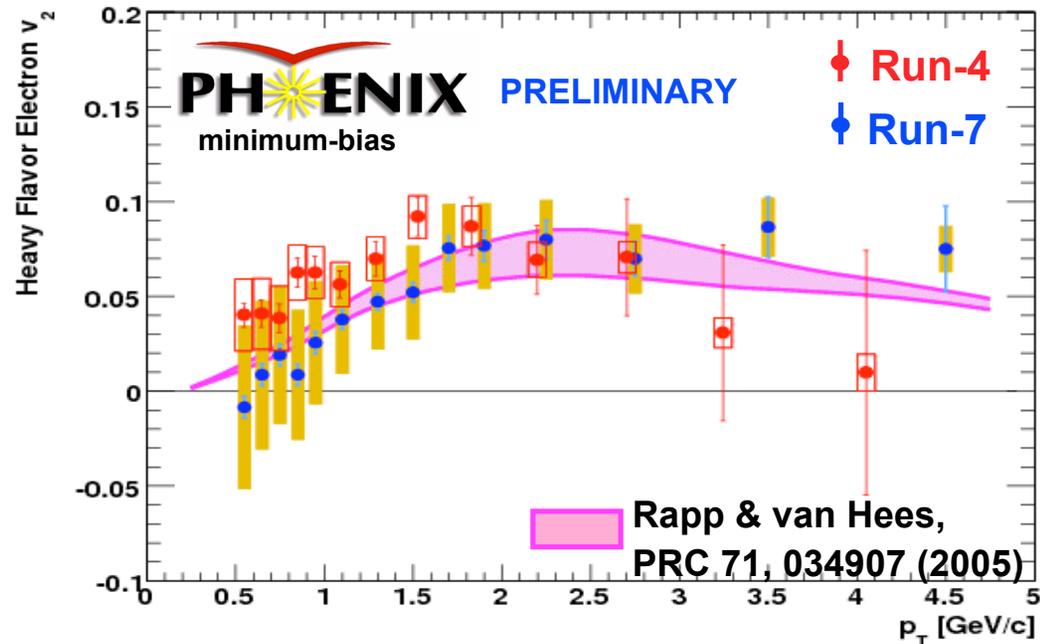
*were investigated  
At CERN SPS*



**NB: need p+p reference data!!**

# Open charm flows!

Elliptic flow of non-photonic electrons

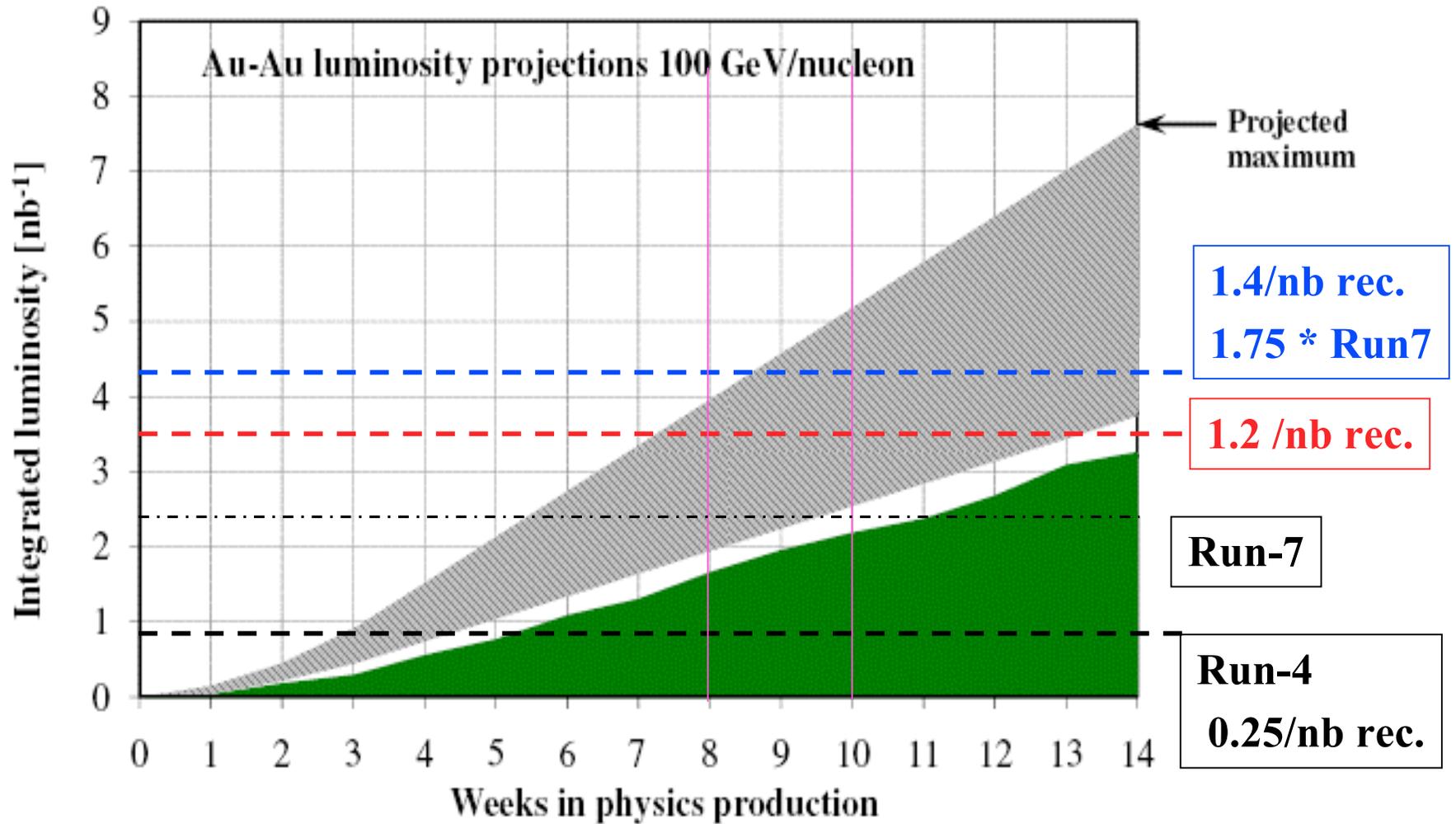


- Do b's flow too, or just charm? *ANS: VTX in Run-11*
- Does thermalized charm contribute to  $J/\psi$ ?  
i.e. does  $J/\psi$  flow too? *ANS: Run-9 + Run-7!*



# Run-9 200 GeV/A Au+Au projection

assume efficiency factor 0.33, as in Run-8 d+Au



8 weeks  $\rightarrow$  1-1.2 times Run-7; 10 weeks  $\rightarrow$  1.75 x Run-7

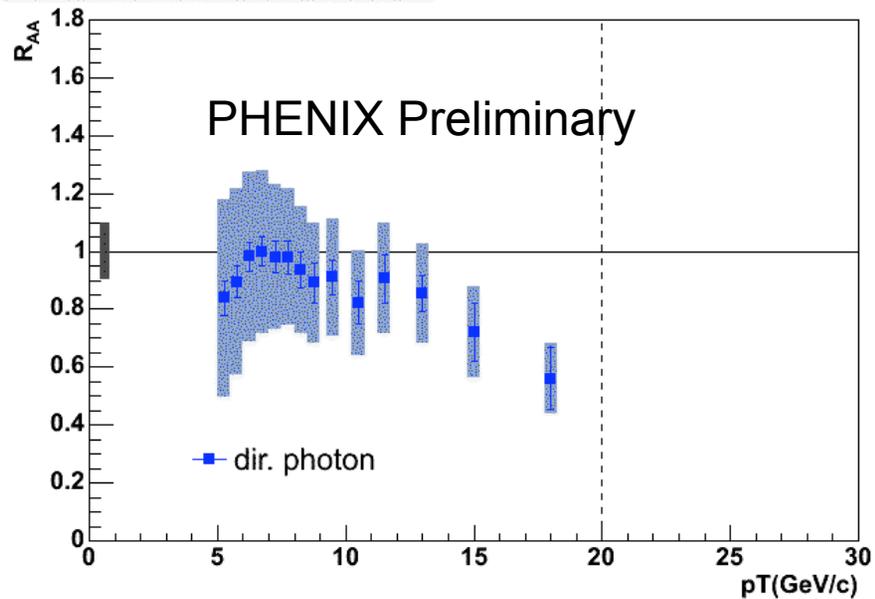


# NSAC performance measures

- RHIC program of sufficient breadth that it encompasses two broad categories in the **NSAC Performance Measures** :
  - **Physics of High Density and Hot Hadronic Matter:**
    - ✓ 2005 Measure  $J/\psi$  production in Au+Au at  $\sqrt{s_{NN}} = 200$  GeV.
    - ✓ 2005 Measure flow and spectra of multiply-strange baryons in Au+Au at  $\sqrt{s_{NN}} = 200$  GeV.
    - ✓ 2007 Measure high transverse momentum jet systematics vs.  $\sqrt{s_{NN}}$  up to 200 GeV and vs. system size up to Au+Au.
    - 2009 Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC
    - ✓ 2010 Measure the energy and system size dependence of  $J/\psi$  production over the range of ions and energies available at RHIC.
    - ✓ 2010 Measure  $e^+e^-$  production in the mass range  $500 \leq m_{e^+e^-} \leq 1000$  MeV/ $c^2$  in  $\sqrt{s_{NN}} = 200$  GeV collisions.
    - 2010 Complete realistic calculations of jet production in a high density medium for comparison with experiment.
    - ✓ 2012 Determine gluon densities at low  $x$  in cold nuclei via p+Au or d+Au collisions
  - **Hadronic Physics**
    - ✓ 2008 Make measurements of spin carried by the glue in the proton with polarized proton-proton collisions at center of mass energy  $\sqrt{s} = 200$  GeV.
    - ✓ 2013 Measure flavor-identified  $q$  and  $\bar{q}$  contributions to the spin of the proton via the longitudinal-spin asymmetry of  $W$  production.

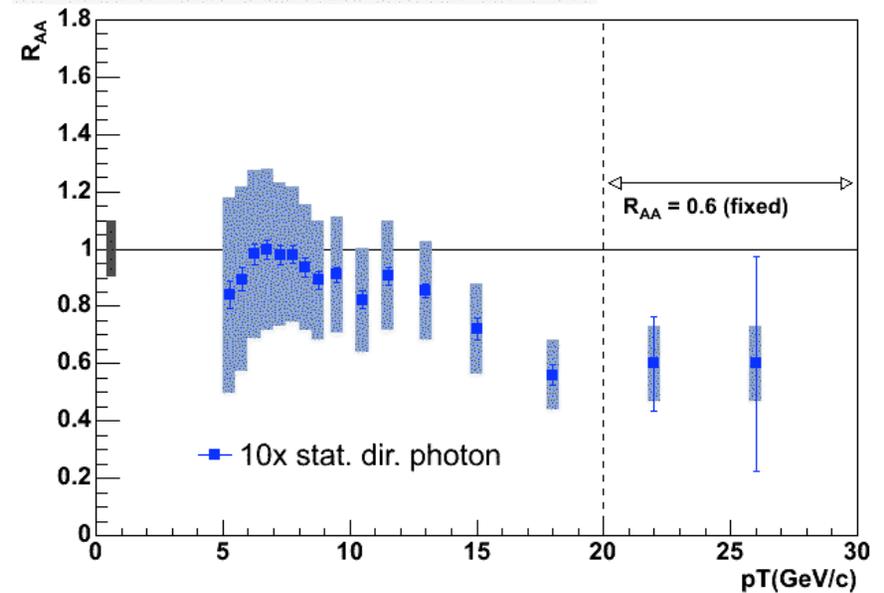
# Direct photons – suppressed or not?

Au+Au  $\sqrt{s_{NN}} = 200\text{GeV}$ , 0-10%



Current result

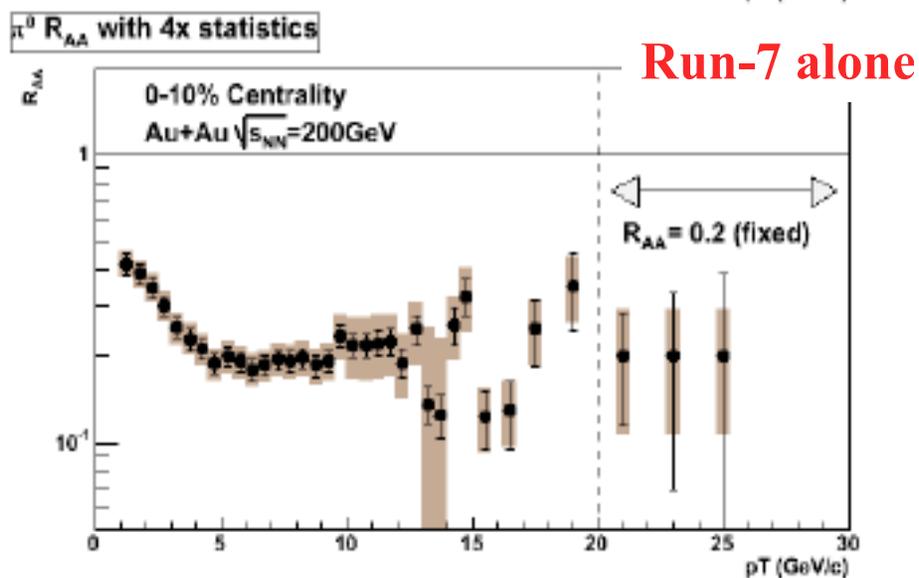
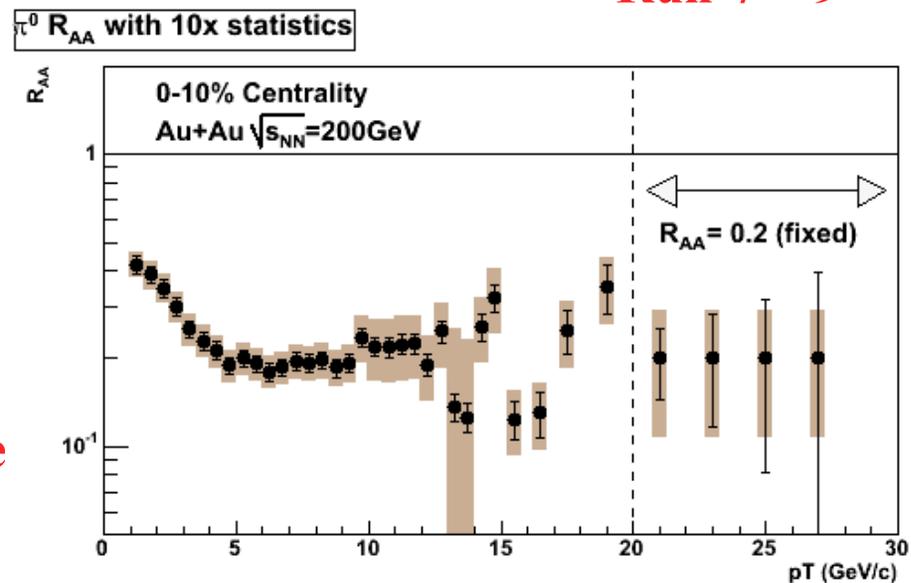
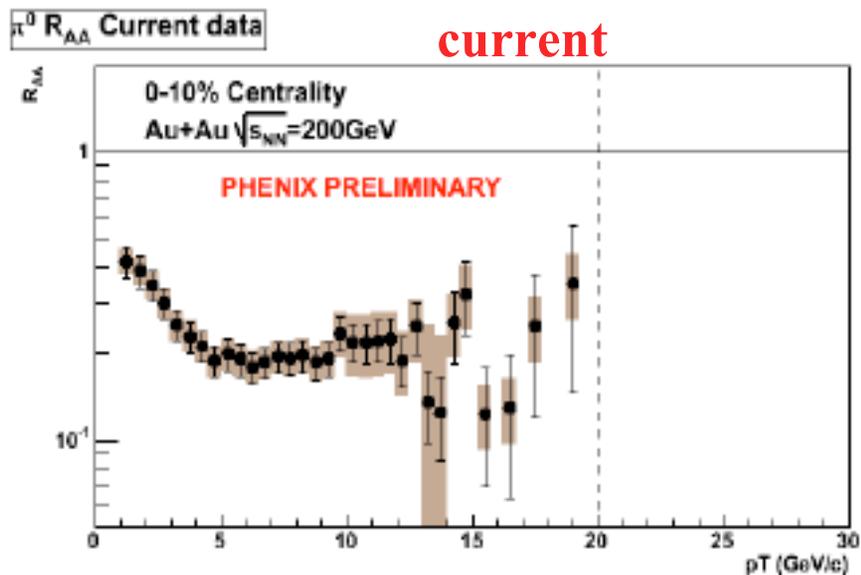
Au+Au  $\sqrt{s_{NN}} = 200\text{GeV}$ , 0-10% (10x. Stat.)



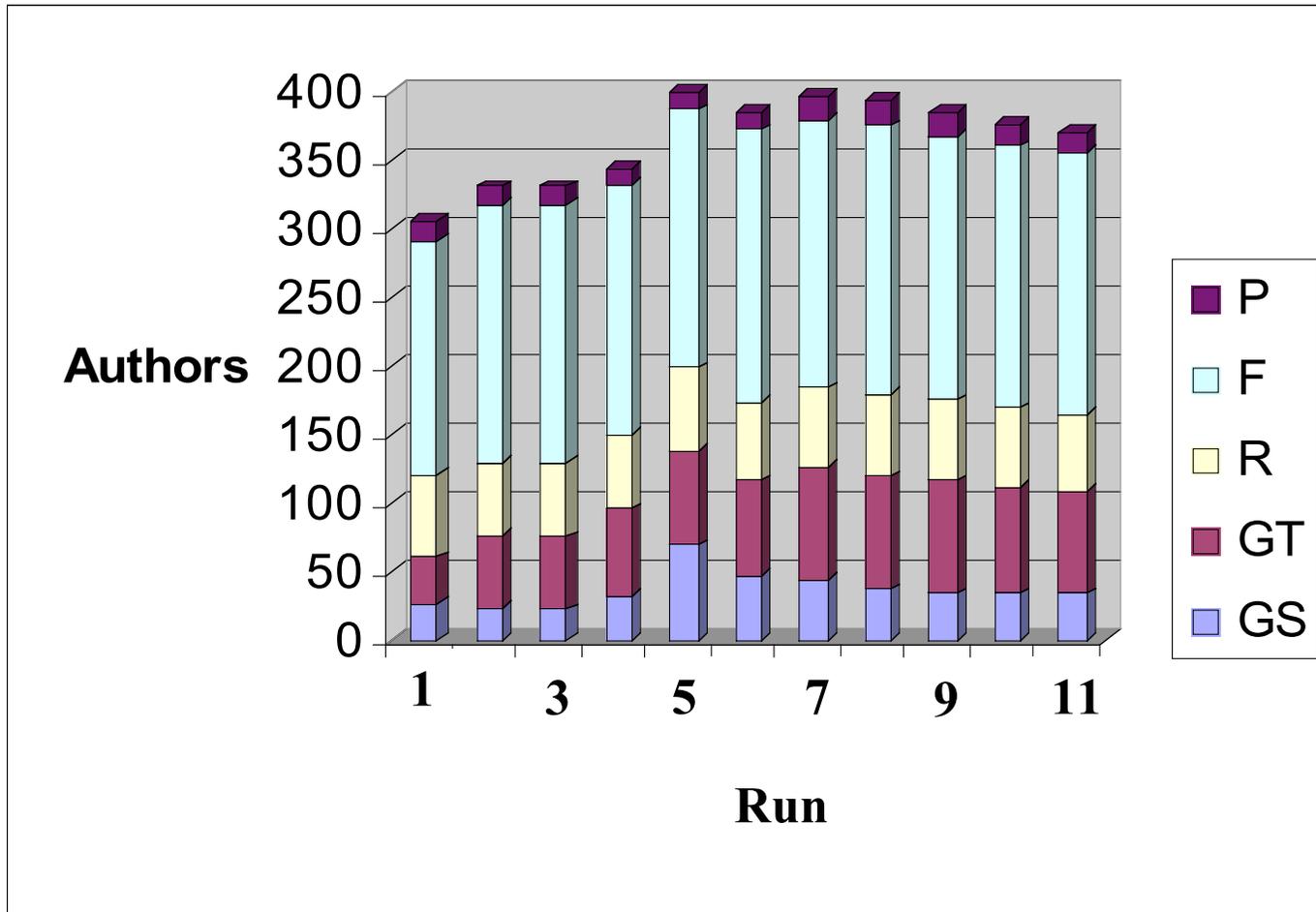
w/ 10x Run4 Stats.



# Inmprove $p_T$ range & errors



# PHENIX is, and will remain, strong



# Virtual Photon Measurement

- Any source of real  $\gamma$  can emit  $\gamma^*$  with very low mass.
- Relation between the  $\gamma^*$  yield and real photon yield is known.

$$\frac{d^2 N}{dM_{ee}} = \frac{2\alpha}{3\pi} \sqrt{1 - \frac{4m_e^2}{M_{ee}^2}} \left( 1 + \frac{2m_e^2}{M_{ee}^2} \right) \frac{1}{M_{ee}} S dN_\gamma \quad \text{Eq. (1)}$$

**S** : Process dependent factor

- Case of Hadrons

$$S = |F(M_{ee}^2)|^2 \left( 1 - \frac{M_{ee}^2}{M_{hadron}^2} \right)^3$$

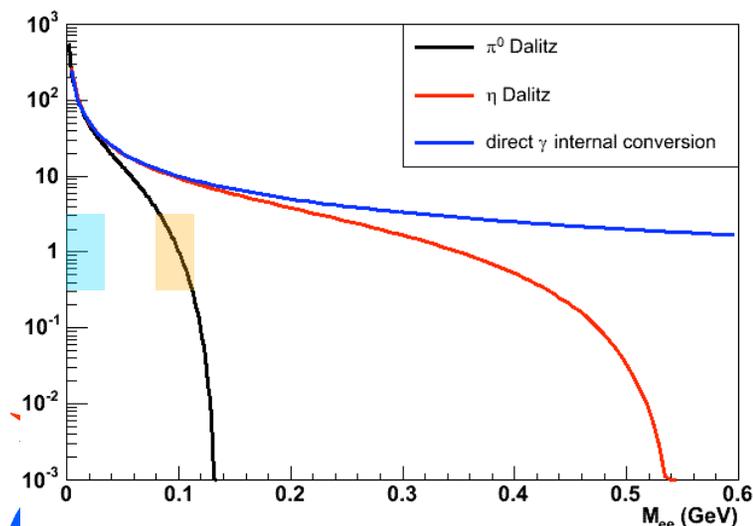
Obviously  $S = 0$  at  $M_{ee} > M_{hadron}$

- Case of direct  $\gamma^*$

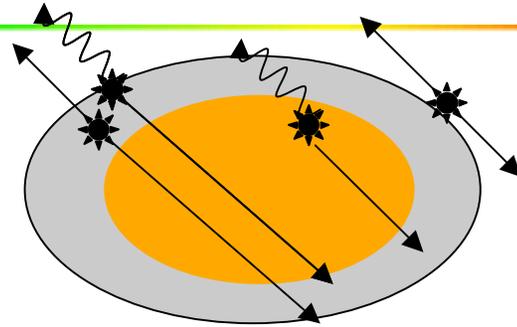
– If  $p_T^2 \gg M_{ee}^2$

$$S = 1$$

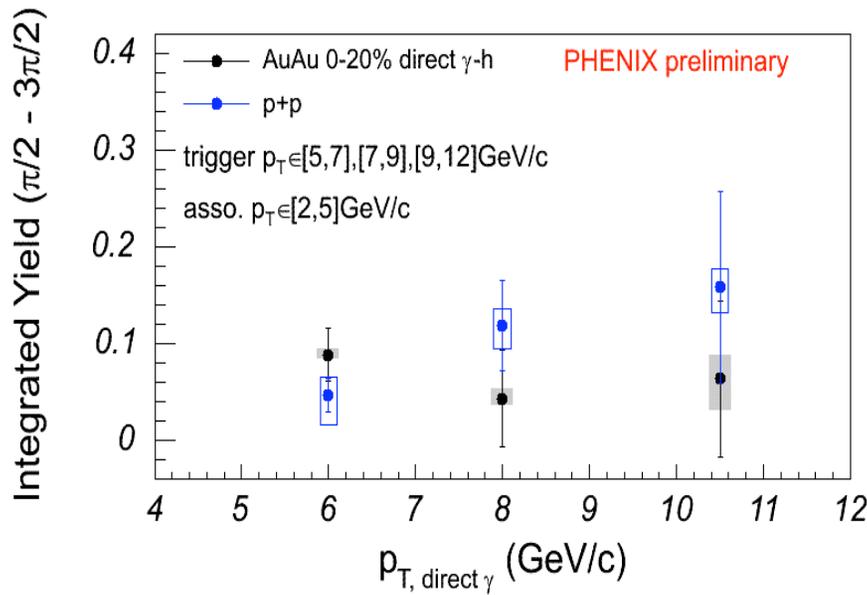
- Possible to separate hadron decay components from real signal in the proper mass window.



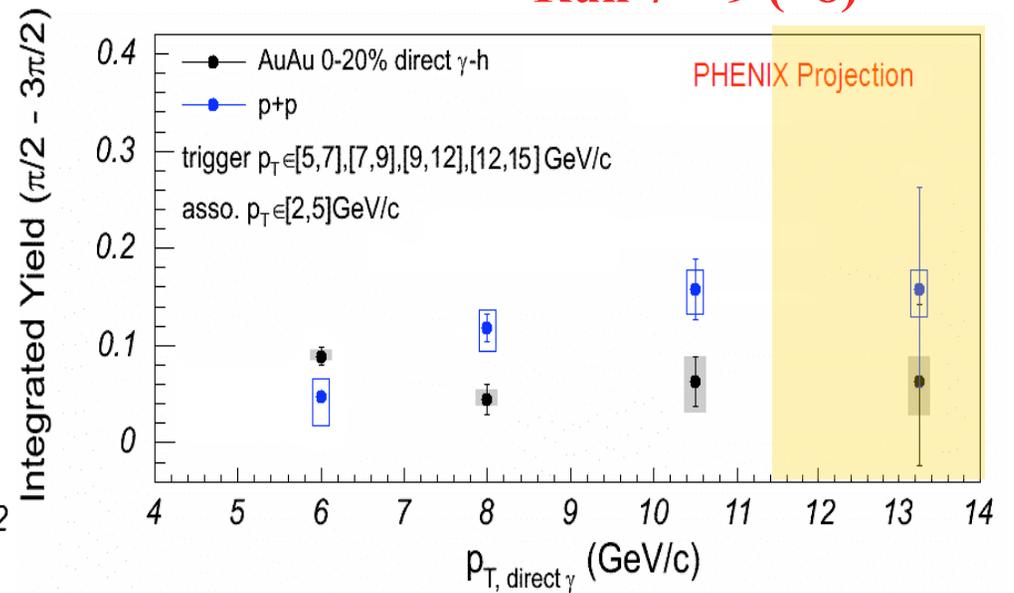
# direct $\gamma$ – jet coincidence: calibrated jet probe



**current result**

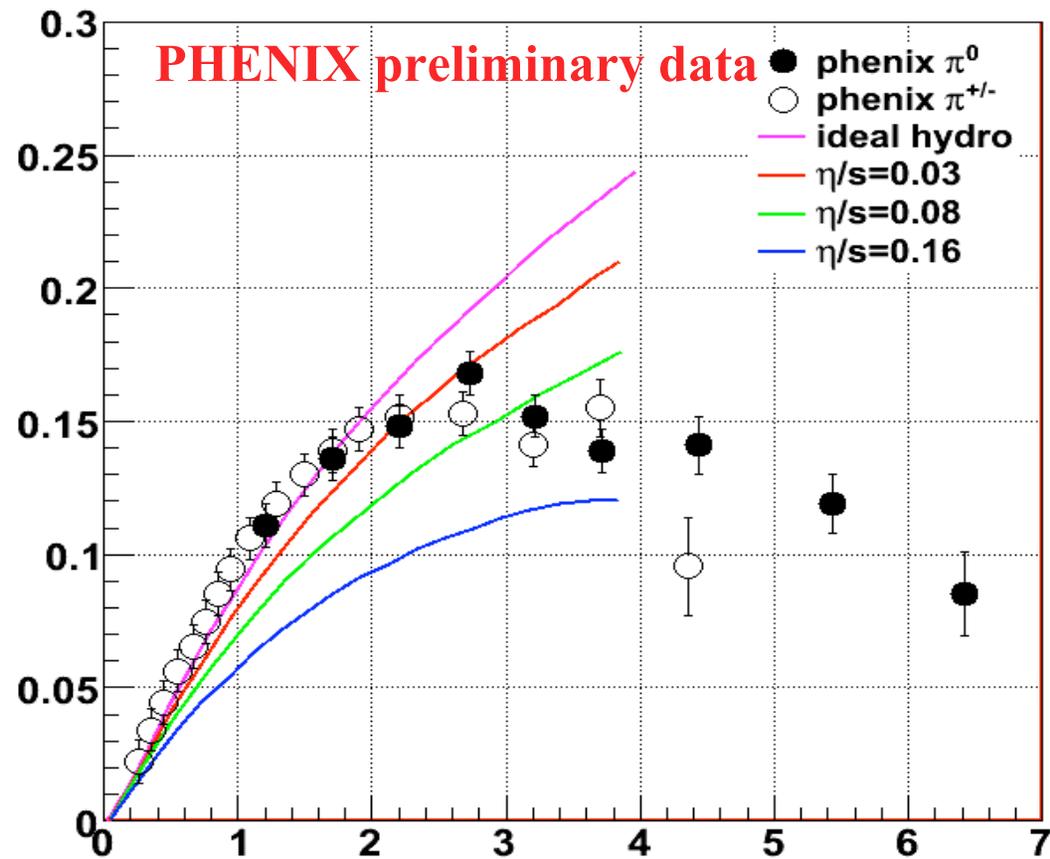


**Run 7 + 9 (+8)**

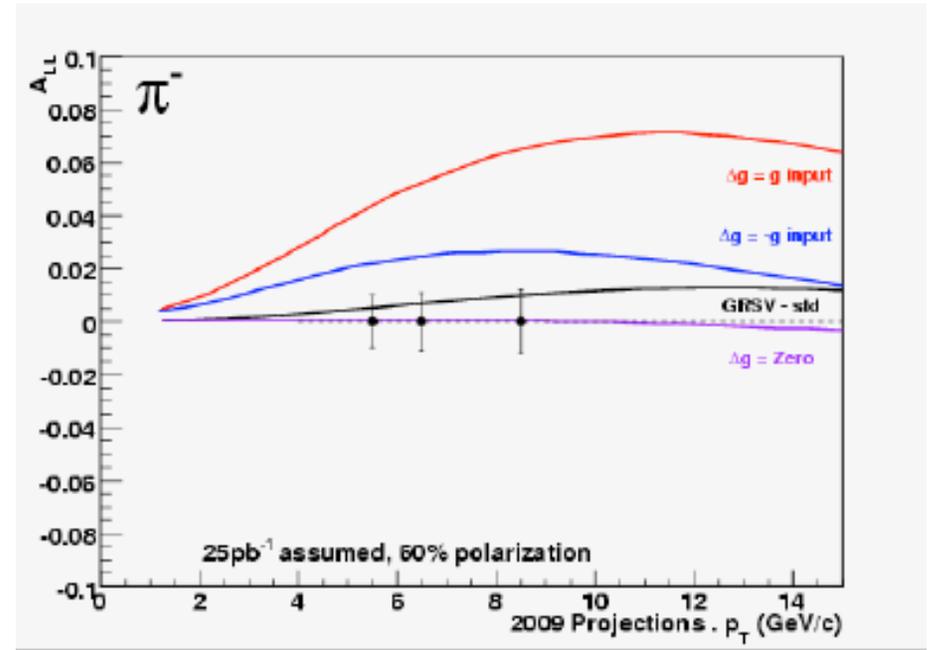
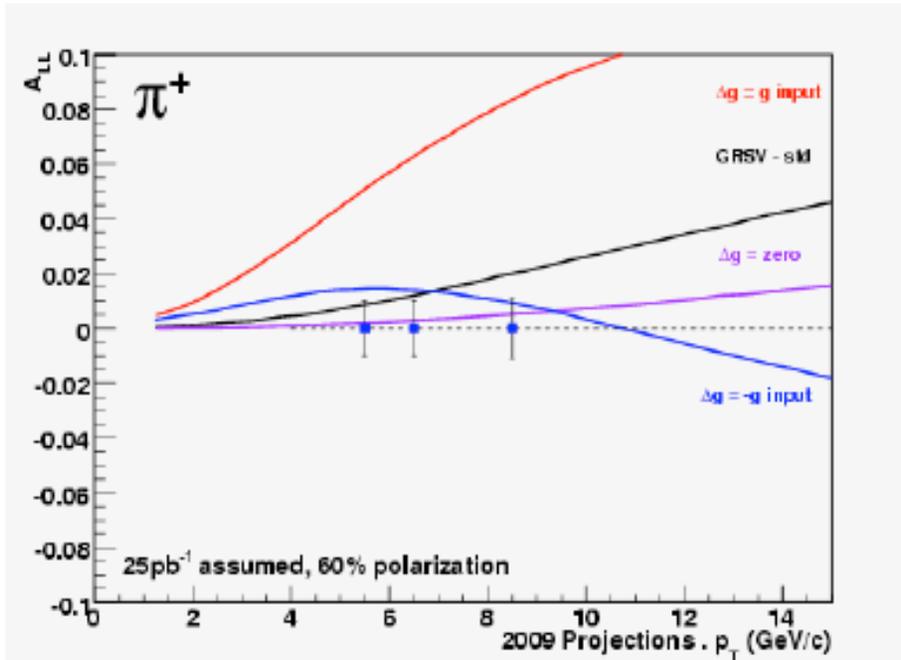


# Toward quantifying $\eta/S$

Curves from  
Romatschke & Romatschke,  
arXiv:0706.1522



# Charged pions sensitive to sign of $\Delta G$



$q+g$  dominates for  $p_T > 5$  GeV/c,  $A_{LL} \sim$  linear with  $\Delta G$



