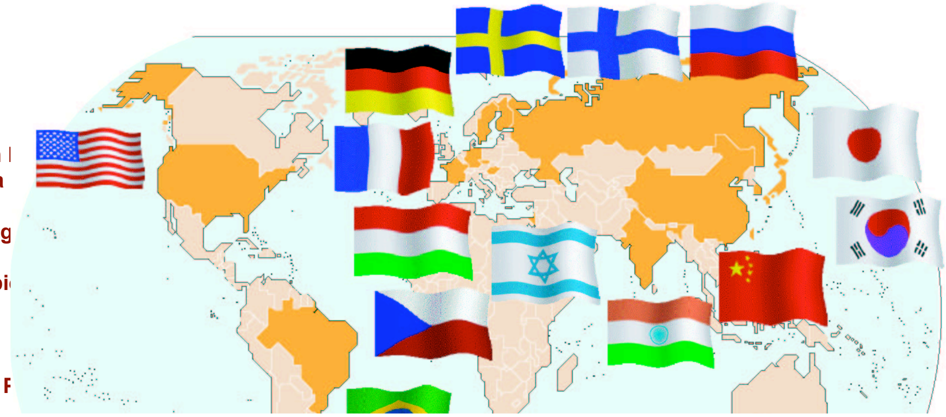
PHENIX Beam Use Proposal for Runs 10 and 11

- **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 Collaboration



14 Countries; 68 Institutions; ~500 Participants

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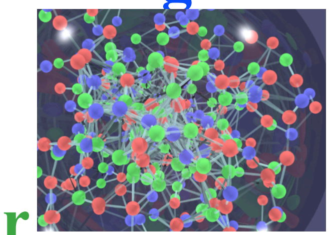
PHENIX Approach

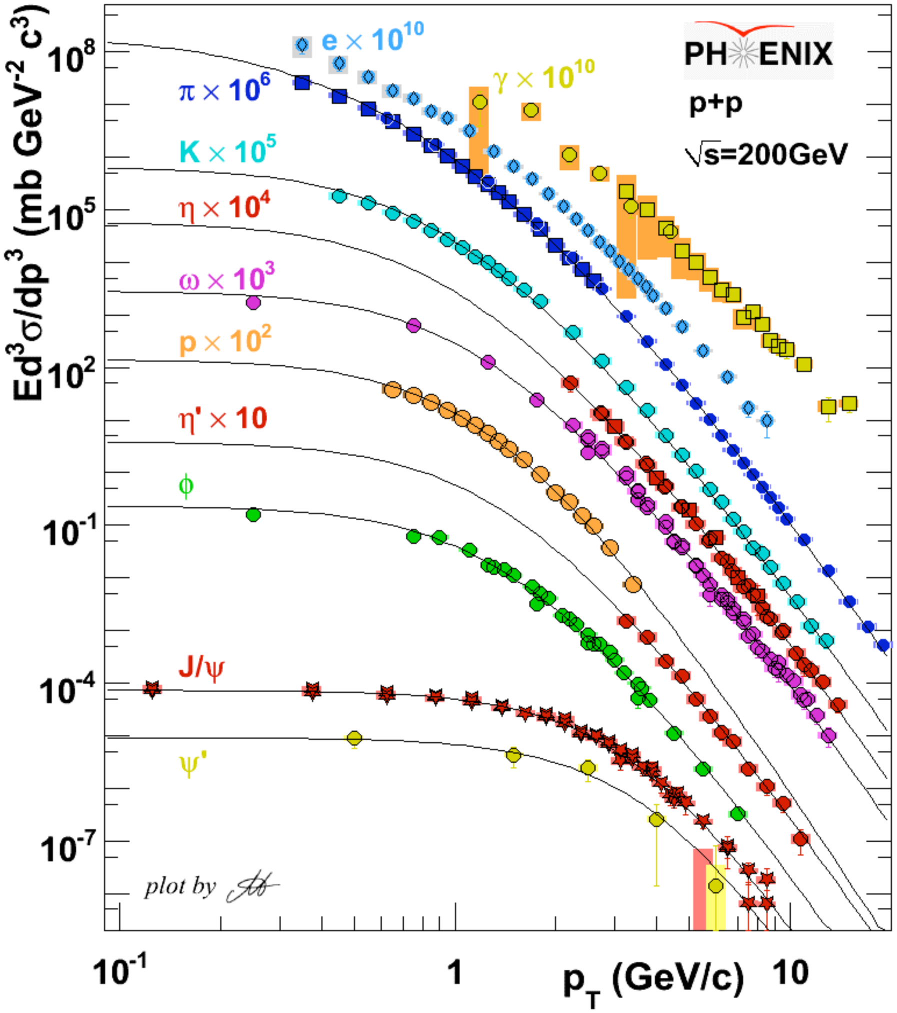
- Key physics goals of the coll…
  - Definitively establi… …of matter
    properties… …, color screening
  - Cha… …via
    …oton, J/ψ, correlations
  - De… …distribution in cold nuclear matter



Run plan based upon
increased precision for discriminating power
new observables enabled by upgrades

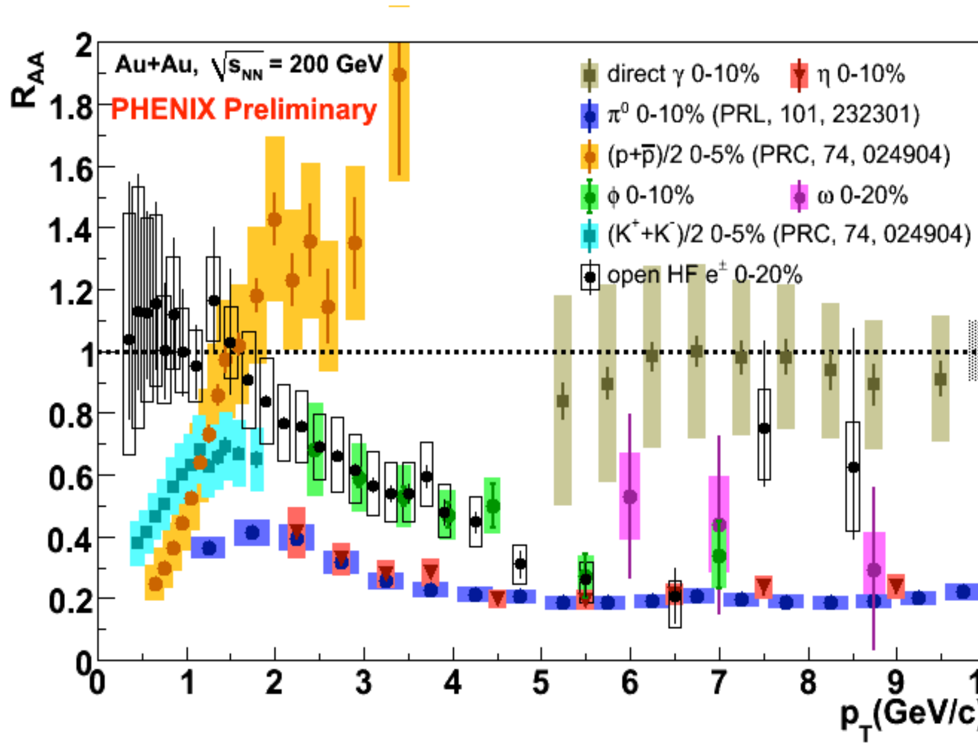
- PHE… philosophy
  - Sensitivity for rare processes → hadrons, leptons, photons
  - High rate capability and selective triggers
  - Precision measurement in multiple channels
    - *high p_T hadrons, multi-particle correlations, jets*
    - *direct γ, γ + jet, virtual γ production*
    - *light & heavy vector mesons, open heavy flavor*

Unprecedented range & precision



In p+p

Central Au+Au

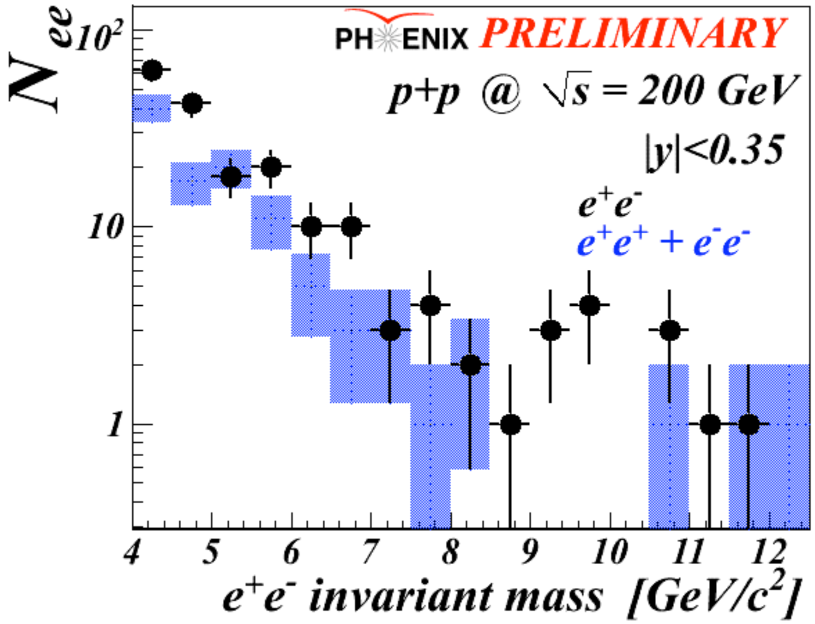


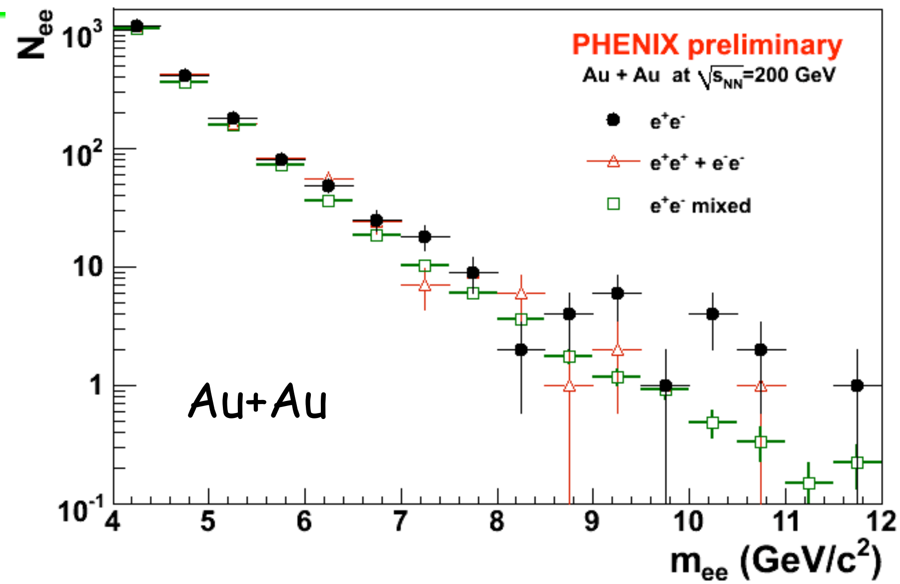
Recent scientific accomplishments

- First direct photon-jet correlations at RHIC *0903.3399*
- Reaction plane dependence of high p_T π^0 suppression *0903.4886*
- c/b separation in p+p collisions: e-h/e^+e^- *0903.4851, PLB670,313 ('09)*
- π^0 σ and A_{LL} in 62.4 GeV polarized p+p *PRD79,012003 (2009)*
- Double helicity asymmetry of π^0 in 200 GeV p+p *0810.0694*
- T_{init} from thermal photon emission *0804.4168*
- First measurement of J/ψ 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

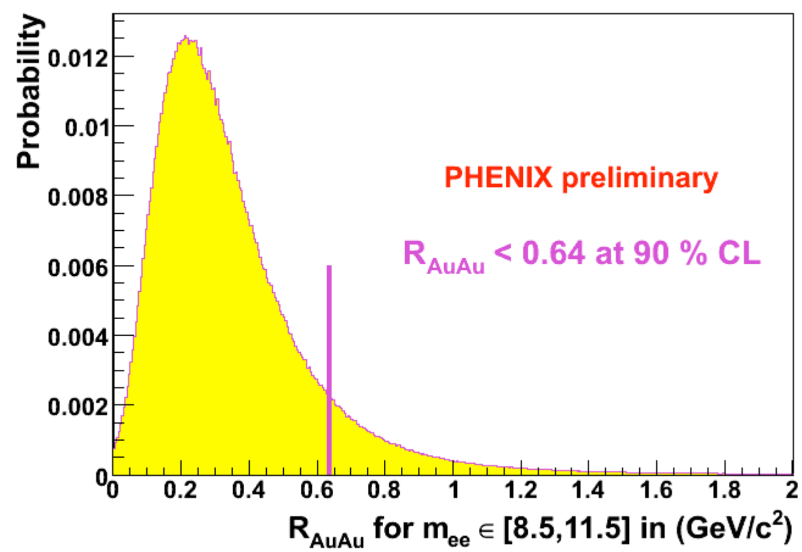
Upsilon suppressed in Au+Au!





	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 ±70±345	4166 ±442(+187/-304)
$R_{AA}(J/\Psi)$	---	0.425 ±0.025±0.072

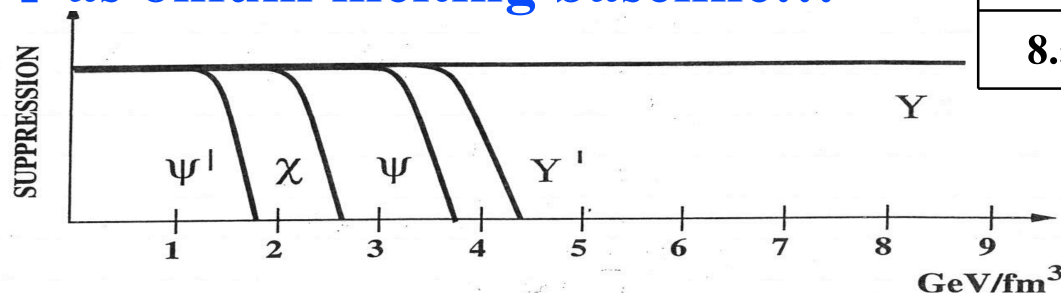
R_{AA} [8.5,11.5] < 0.64 at 90% C.L.



Should Υ's be suppressed?

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

Υ as onium melting baseline…



- σ_{abs} of Υ ~1/2 of J/Ψ: E772 (*PRL 64, 2479 (19*
  - E772 Υ nuclear dependence corr
- Lattice expectations i … $_{AuAu}$ = 0.73
- absorpt … .60 ???

need … ead of this naïve speculation!
  - … hep-ph/0507314

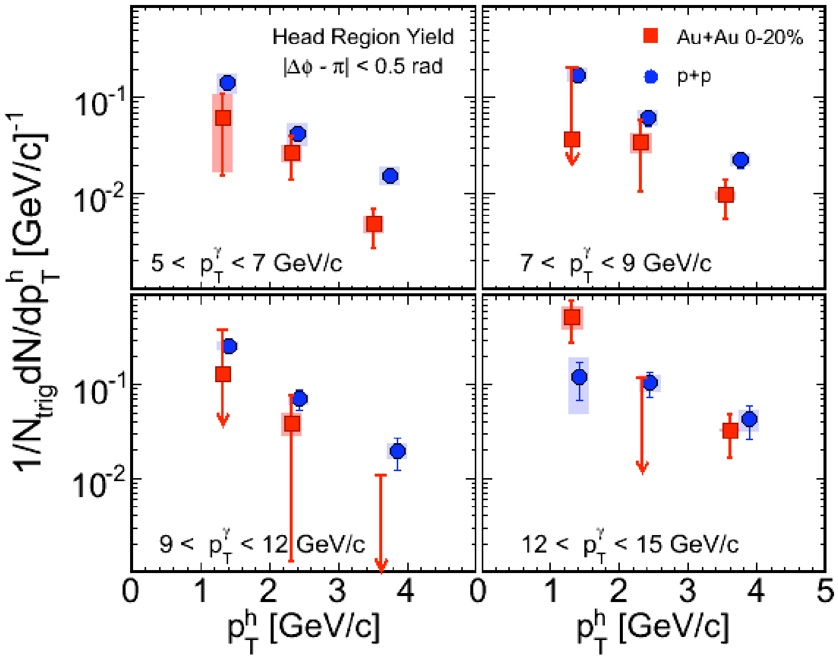
ALSO:
- Υ in a … adowing region
- CDF: 50% of Υ from χ_b (p_T>8 GeV/c) & ~25%? at our p_T
  - *PRL84 (2000) 2094*

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

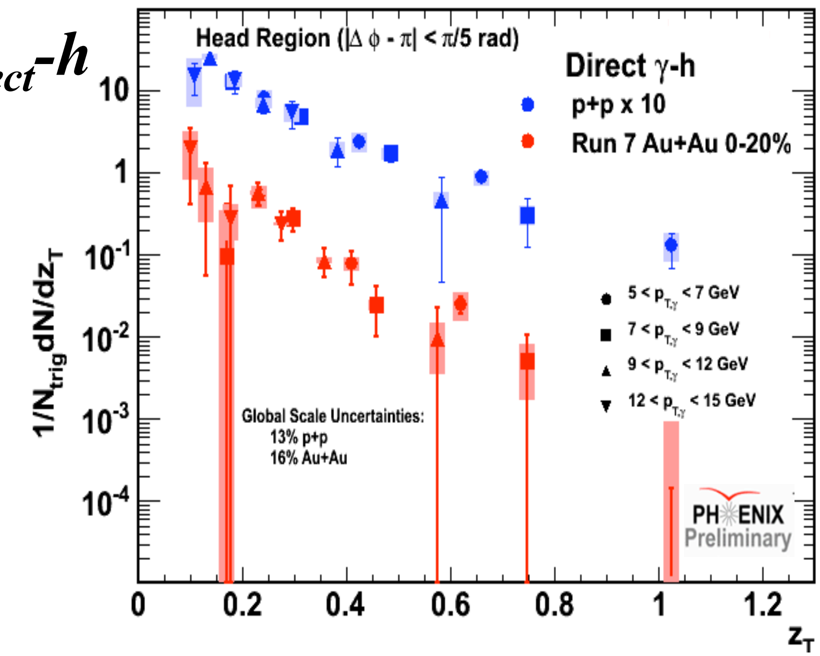
PHENIX

Medium modification of jet fragmentation

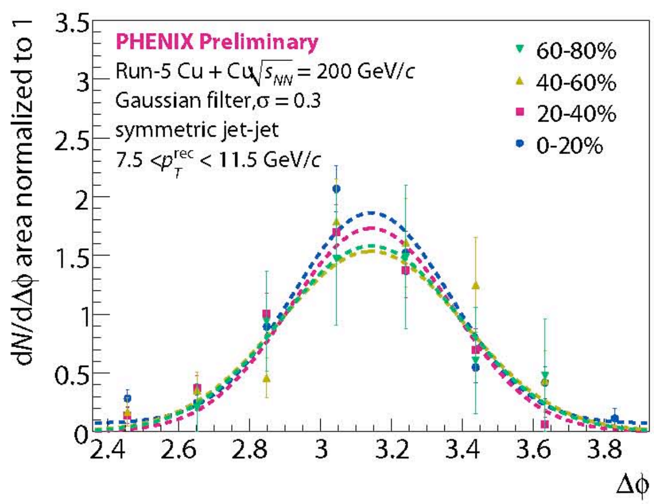
arXiv:0903.3399



γ_{direct}-h



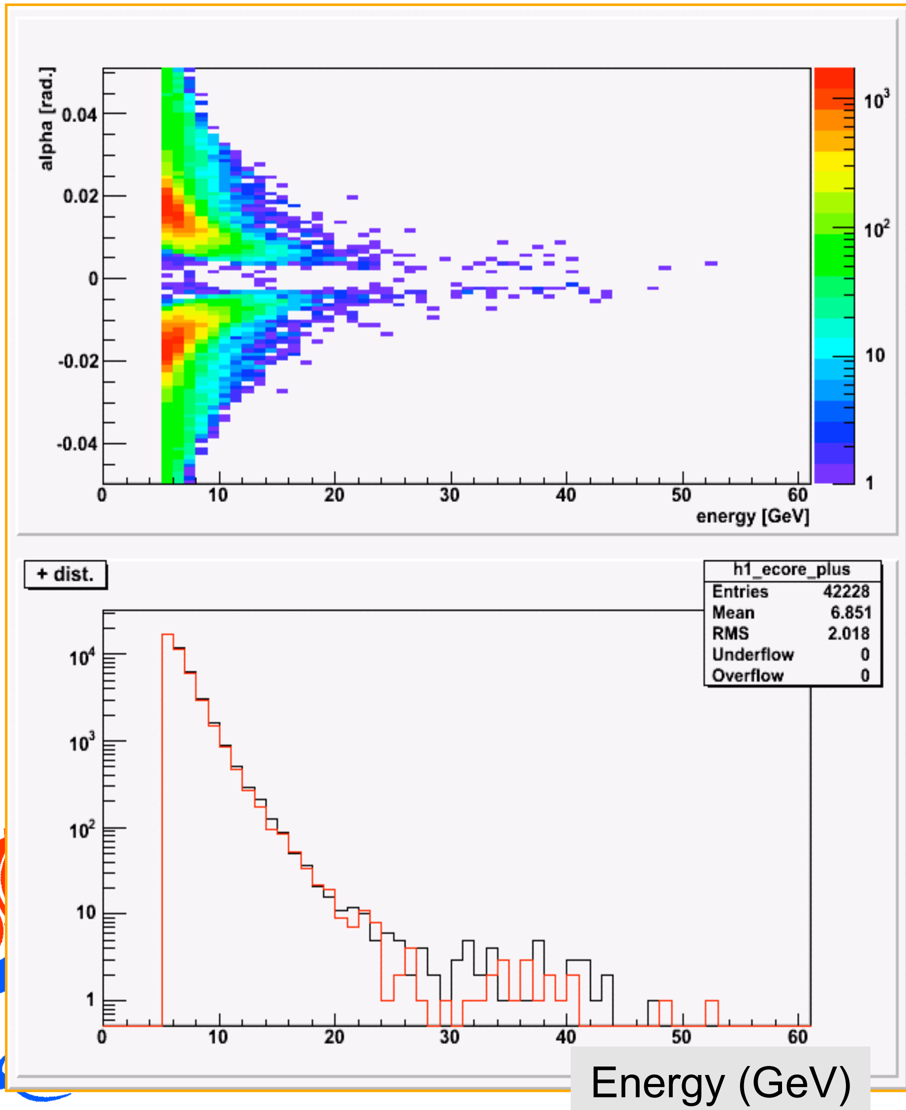
jet-jet



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

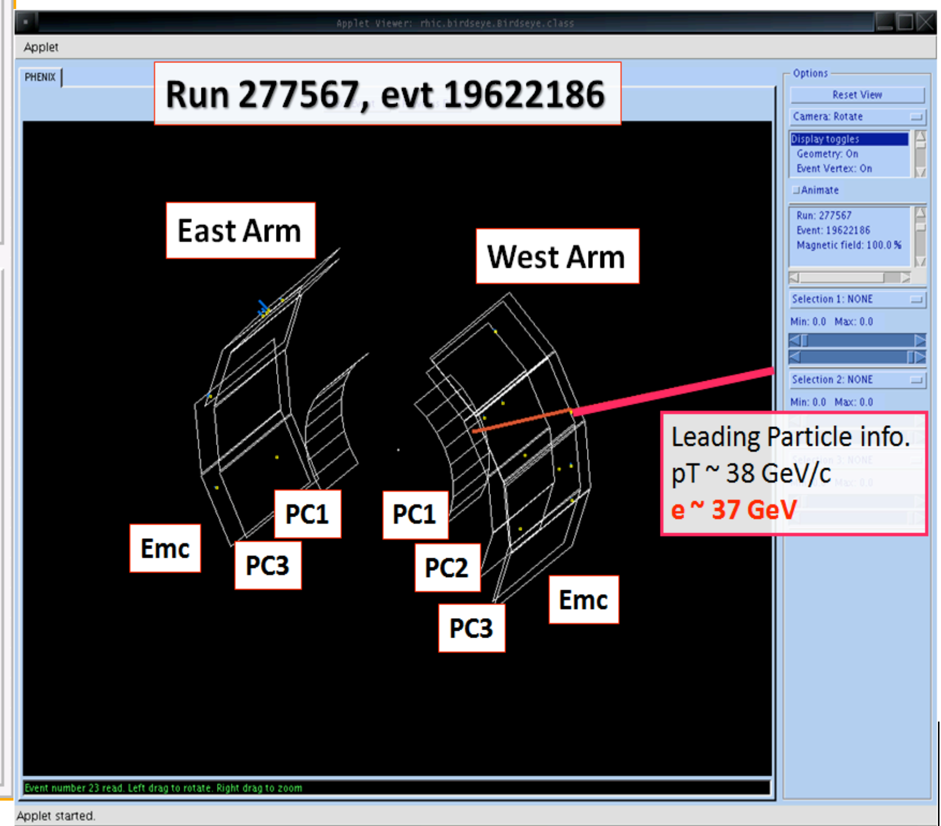
RUN-9 500 GeV: First Look at W

Goal: sea quark polarization from W-boson asymmetry



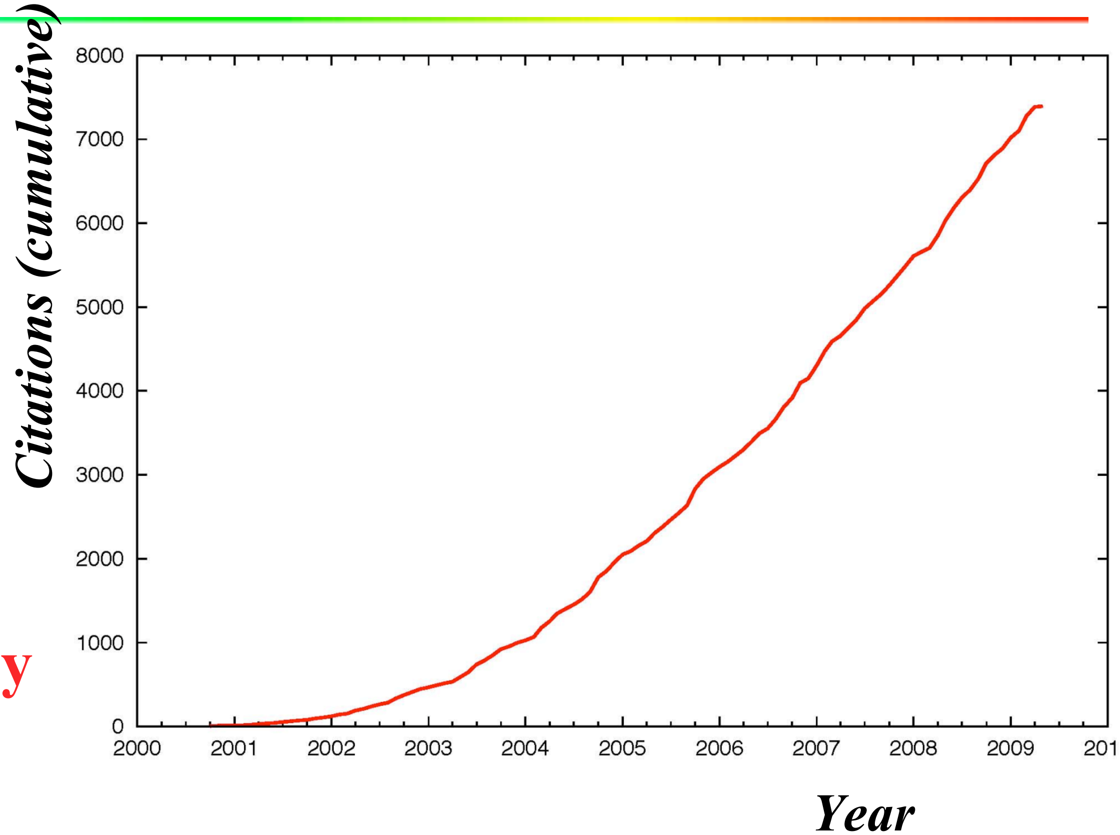
Fast track analysis by W task force

A Typical W-like event
Single electron from W decay



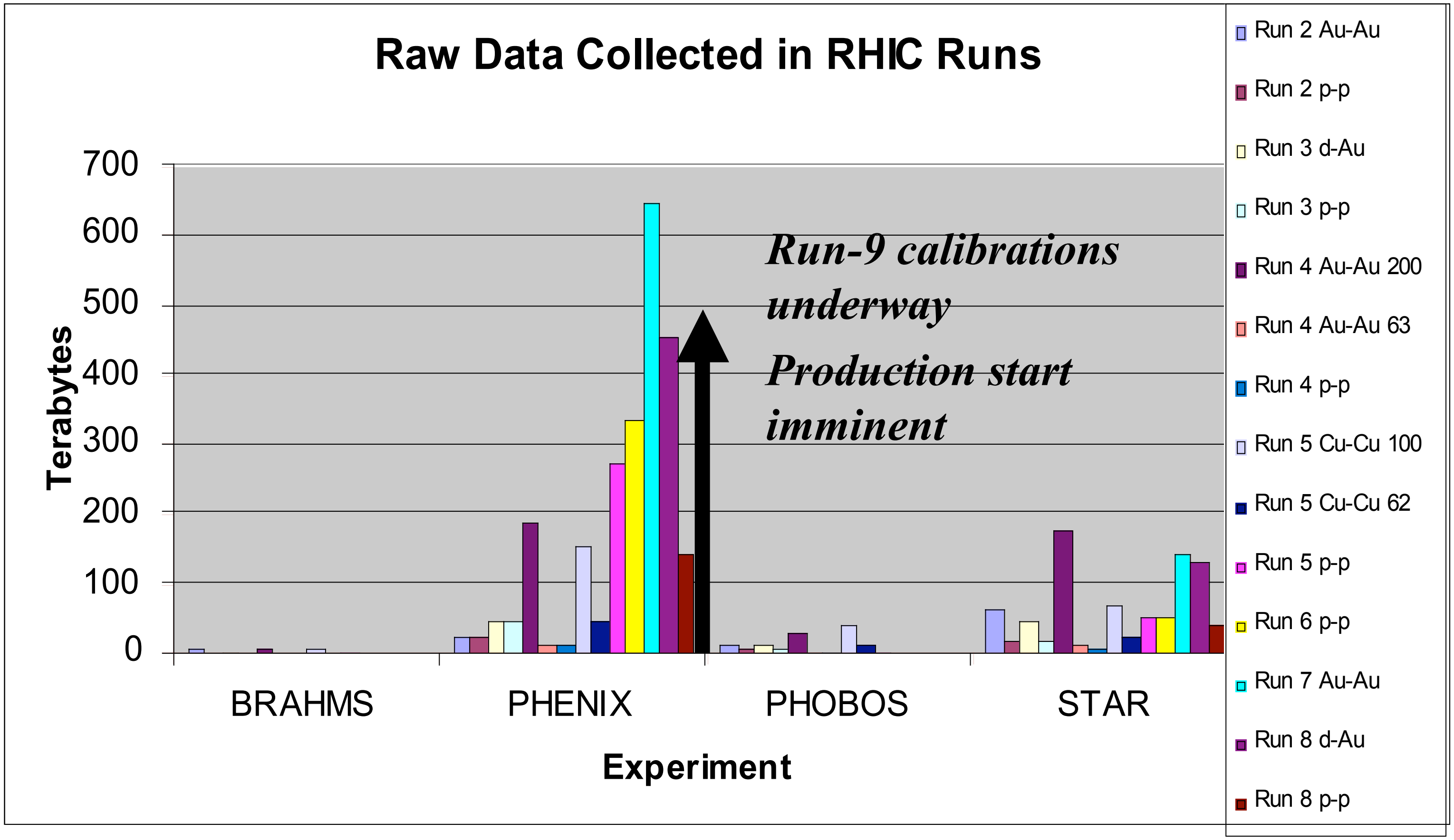
Scientific impact - high & still growing!

- 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 ≥ 200 citations
23 total papers with ≥ 100 citations
45 50+ Topcite papers

PB scale data set(s) - fully reconstructed!

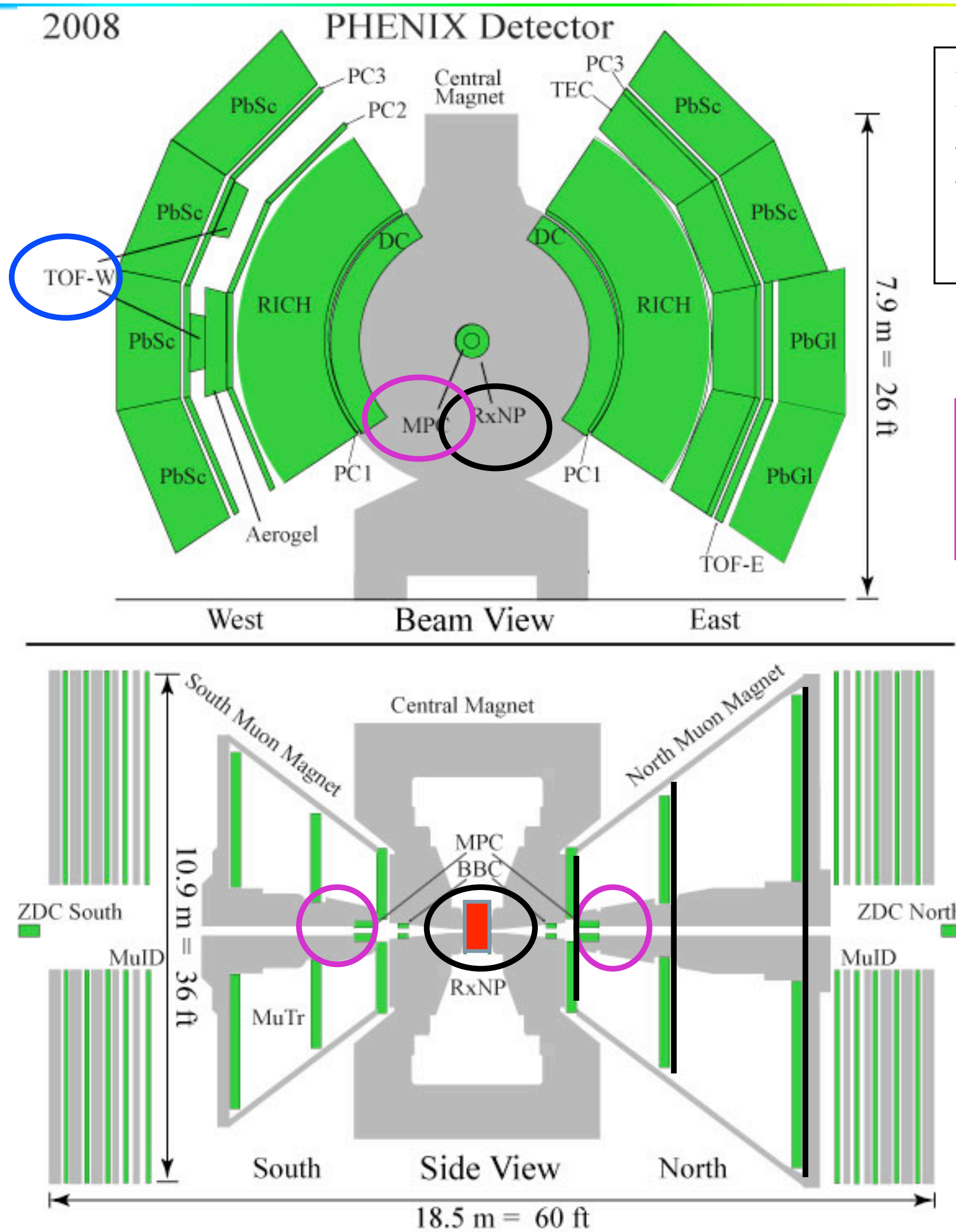


Massive international effort using RCF, CC-J, CC-F

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

<u>Muon Trigger:</u>
μTr FEE
North & South
RPC-3 North

Upgrades schedule → physics capabilities

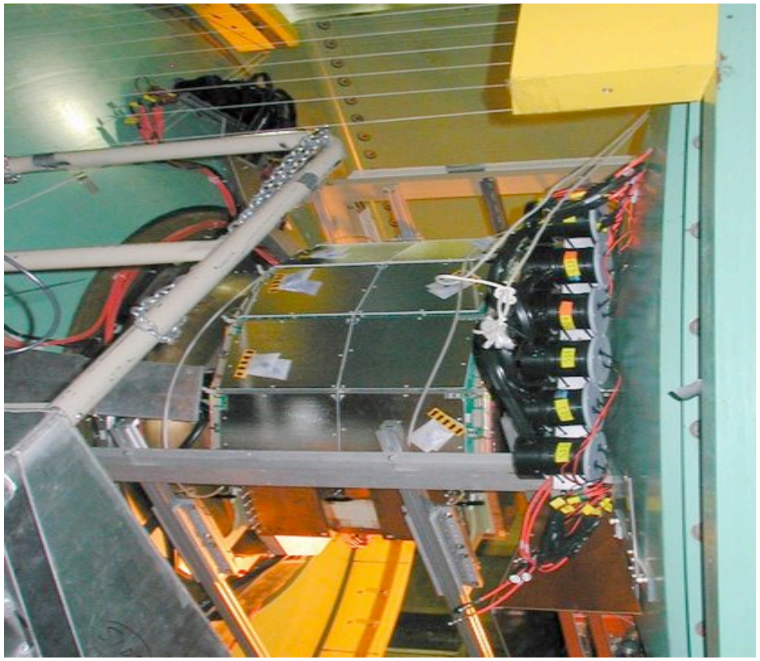
upgrade	year	Physics goal	beam/energy
HBD	2009 & 2010 only	T_{init}, thermal e^+e^-, chiral symmetry, mesons in medium	Au+Au at $\sqrt{s_{NN}}$= 200, 62.4, 39 GeV
VTX	2011	c, b separation mid-y hadrons in 2π	200 Au+Au,p+p,d+Au 500 p+p; lowE Au+Au
FVTX	2012	ψ', heavy flavor y>1	200 Au+Au,p+p,d+Au 500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

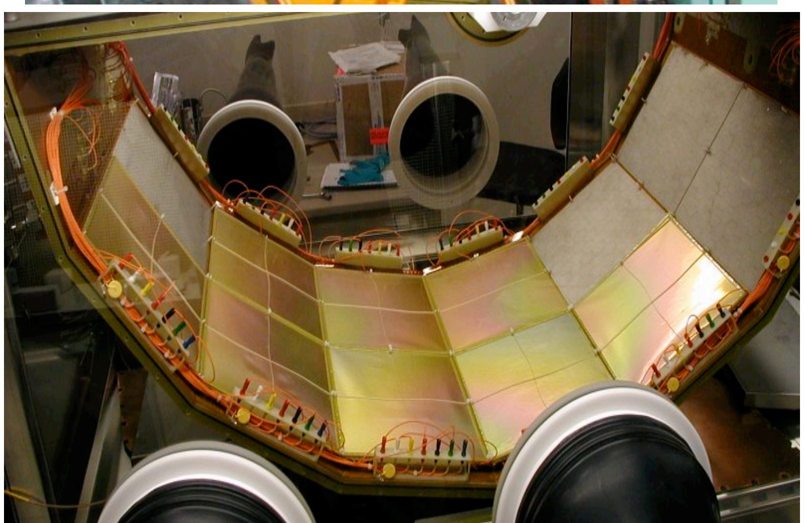
Added capabilities drive our proposal

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

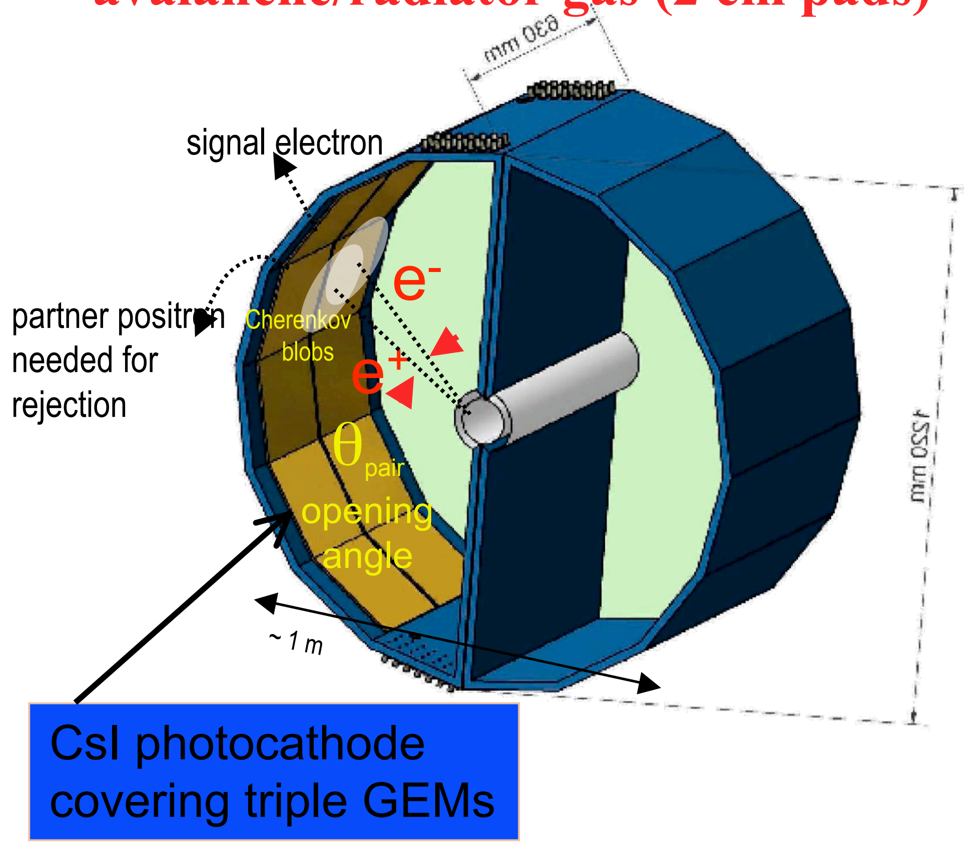
* estimated with mean of min/max prediction includes lumi. ramp up & changeover time

Hadron Blind Detector (HBD)



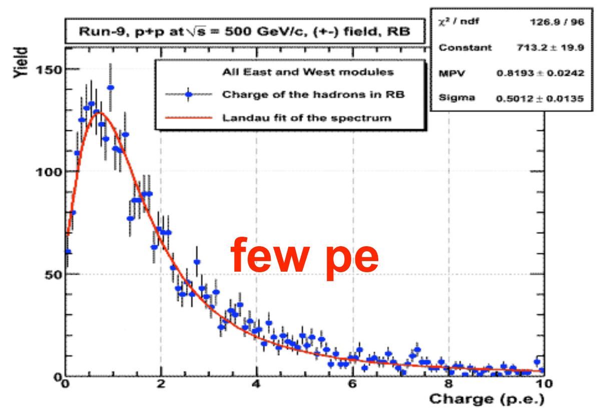


Windowless Cerenkov detector with CF4 avalanche/radiator gas (2 cm pads)



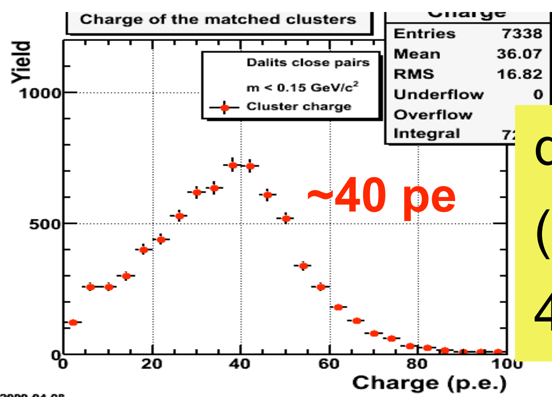
Removes Dalitz & conversion pairs (small opening angle)

HBD Works (very well)!

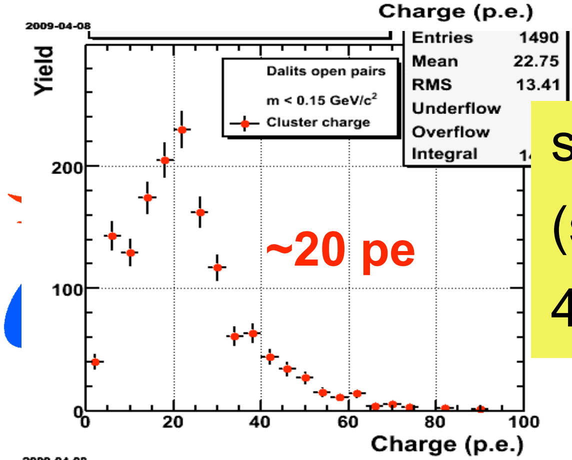


hadron blind!

- 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

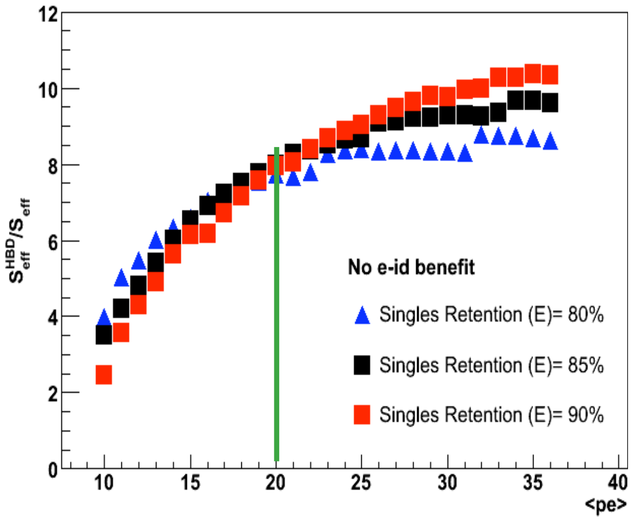


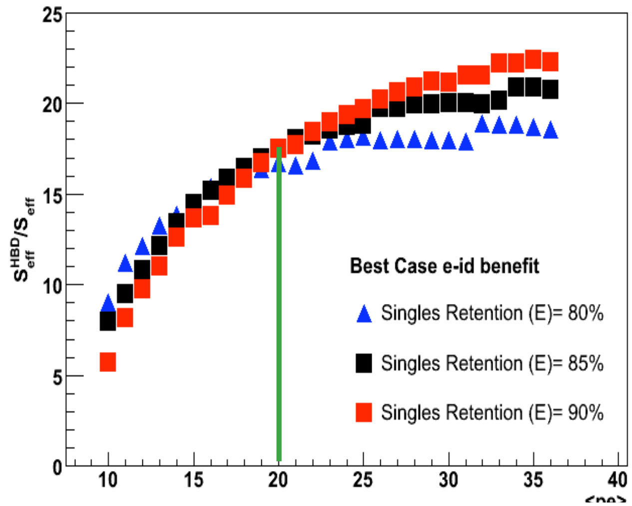
signal
(separated electrons):
40 photo-electrons

Clear separation of signal and background

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

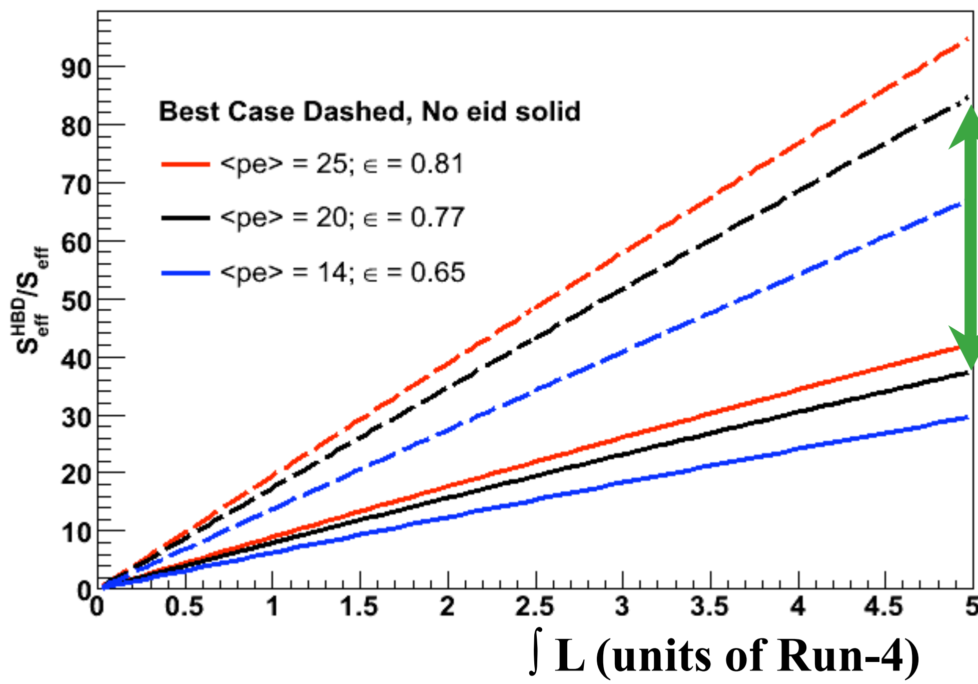
HBD impact in Run-10



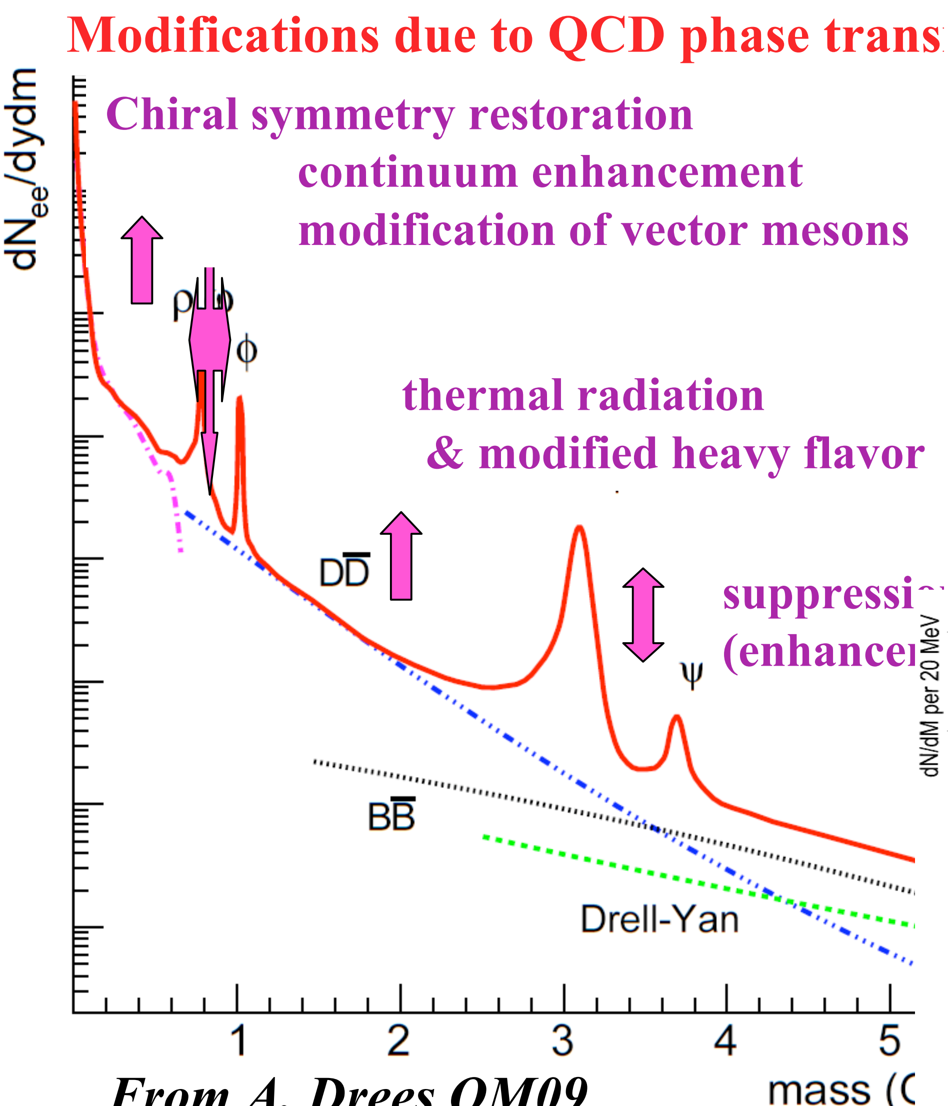


Improves effective signal by factor of 8-16 (w/o and w/ added e ID effect)

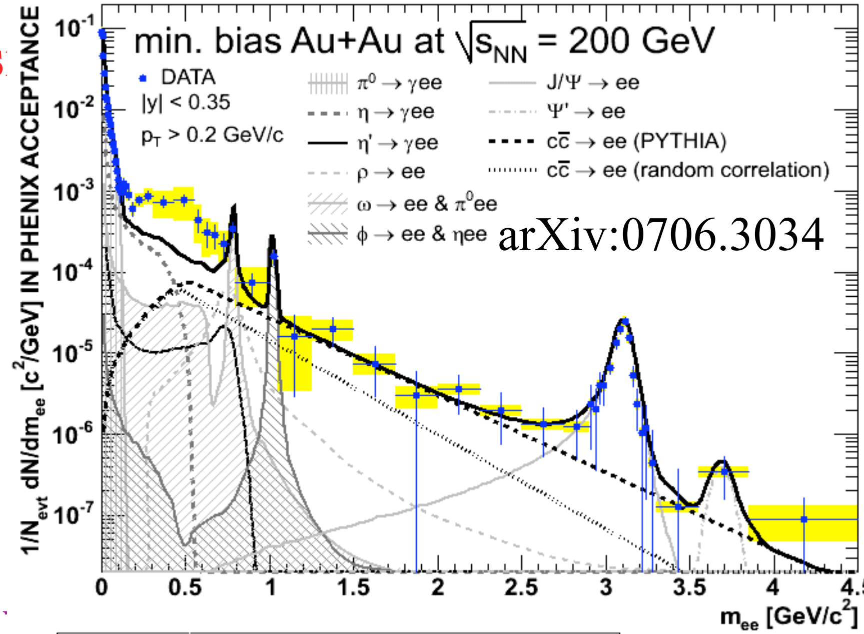
1.4 /nb recorded improves effective statistics by ≥ 35 vs. old Run-4 result

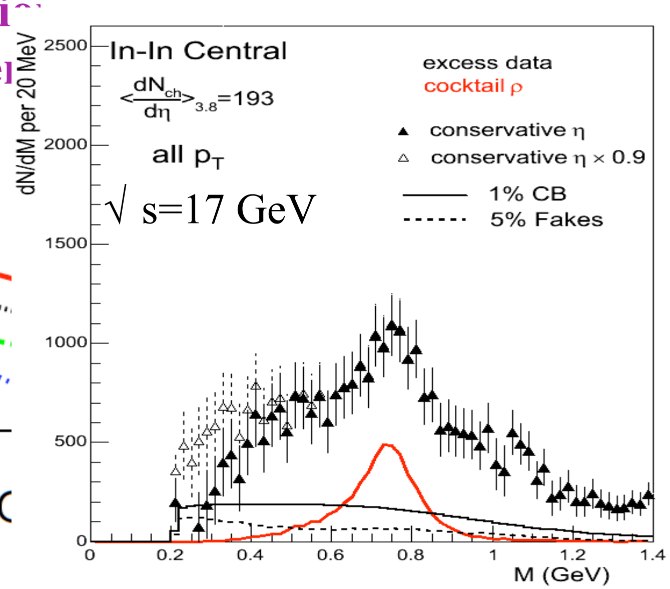


Low mass dielectron physics



From A. Drees QM09



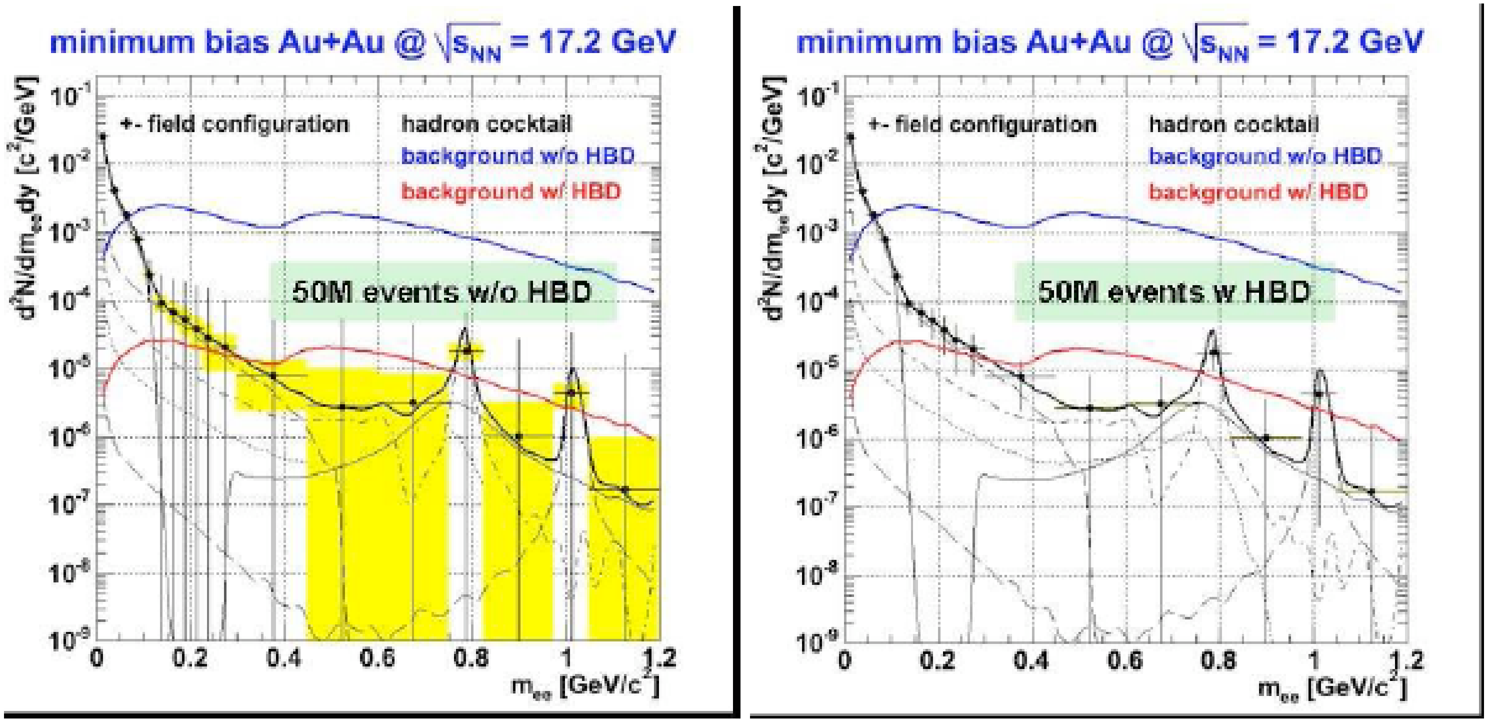


from 6 to 24 bins in 0.5<M<1 GeV; vs. N_{part}

Dielectron continuum between 17 & 200 GeV

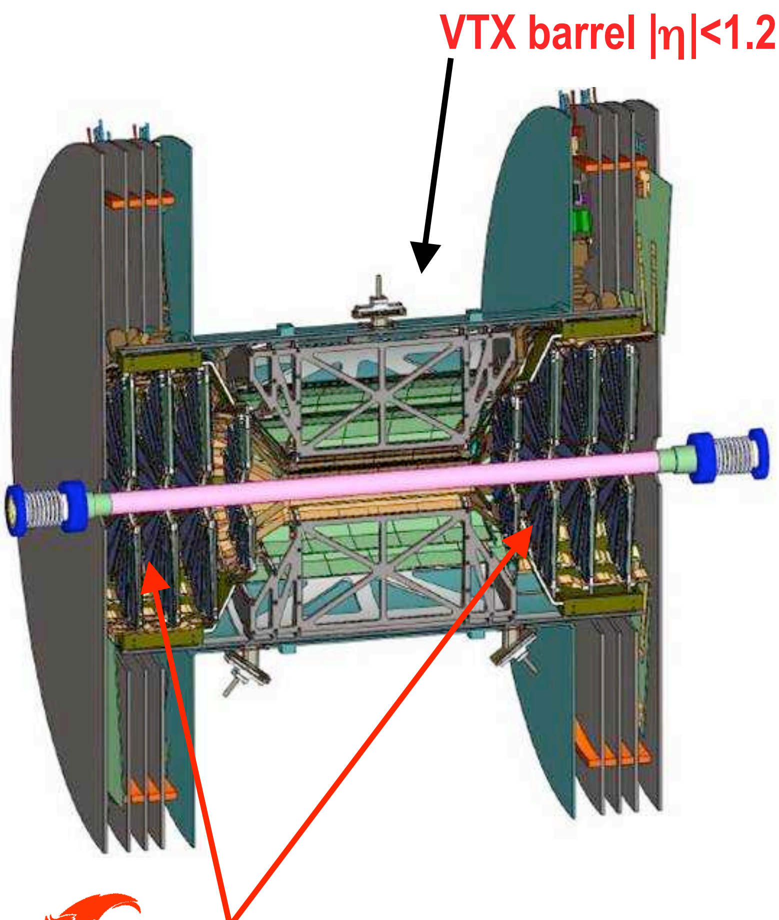
- **Excess reaches lower mass at RHIC than at SPS**
- ***Unique opportunity in Run-10!***

Background rejection with HBD → measure at lower √ s



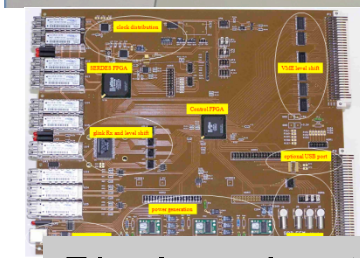
How do dilepton excess and ρ modification at SPS evolve into the large low-mass excess at RHIC?

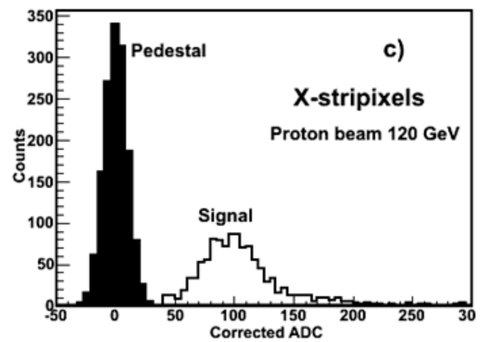
Silicon Vertex (VTX & FVTX)

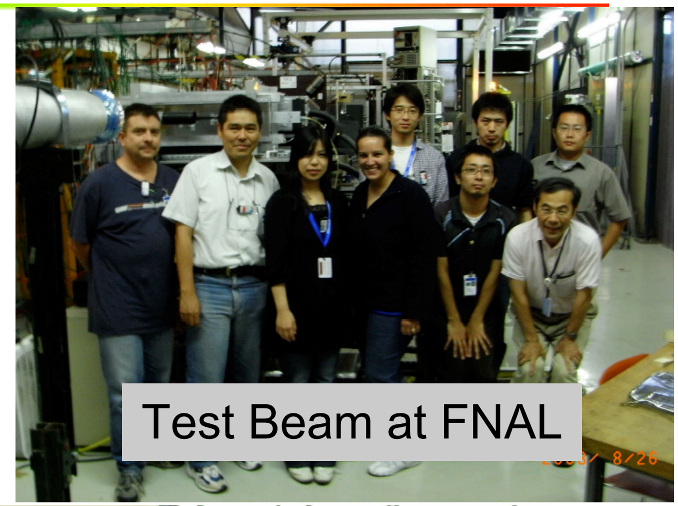


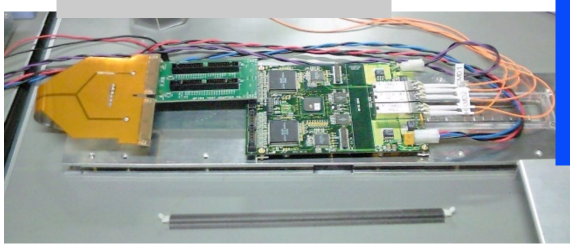
- VTX: silicon VerTeX barrel tracker
  - Fine granularity, low occupancy
    - 50μm×425μm pixels for L1 and L2
    - R1=2.5cm and R2=5cm
  - Stripixel detector for L3 and L4
    - 80μm×1000μm pixel pitch
    - R3=10cm and R4=14cm
  - Large acceptance
    - |η|<1.2, almost 2π in ϕ plane
  - Standalone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

VTX Progress



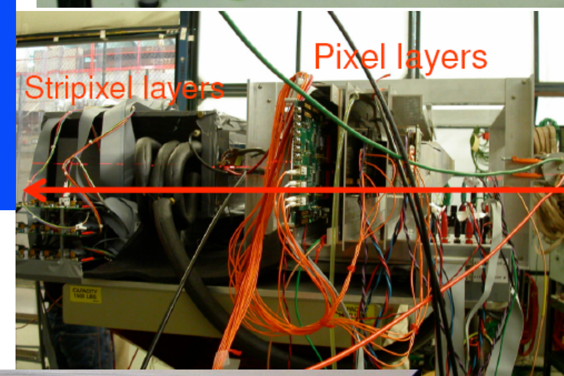


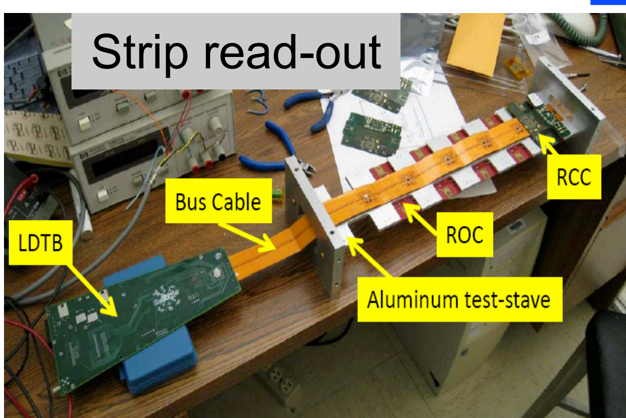


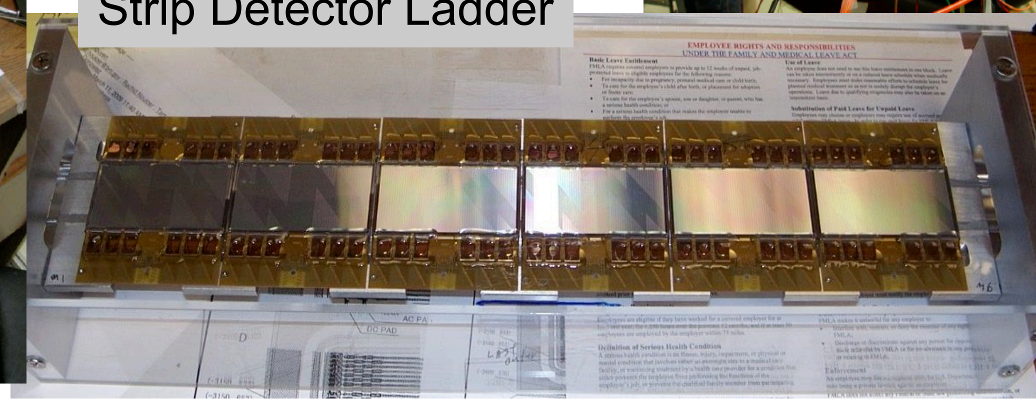


Successful DOE review last week: *"very impressed by and pleased with the great progress"*

Install for Run-11







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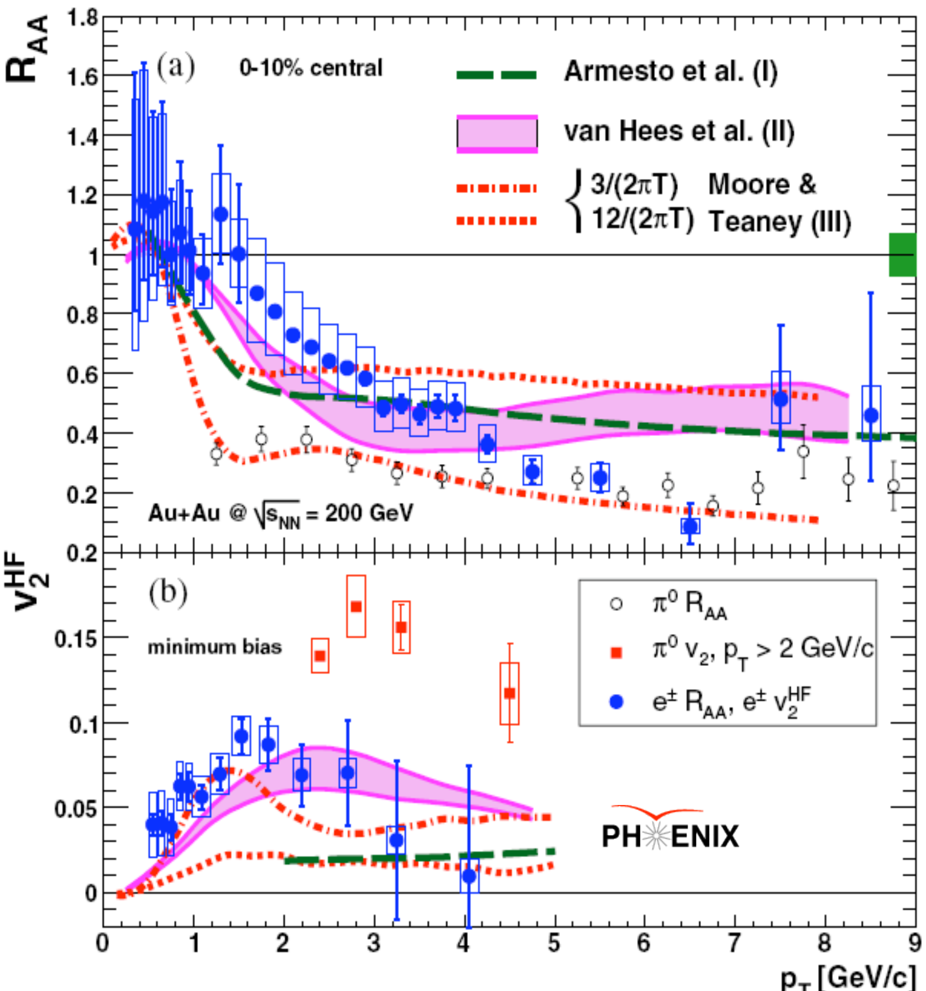
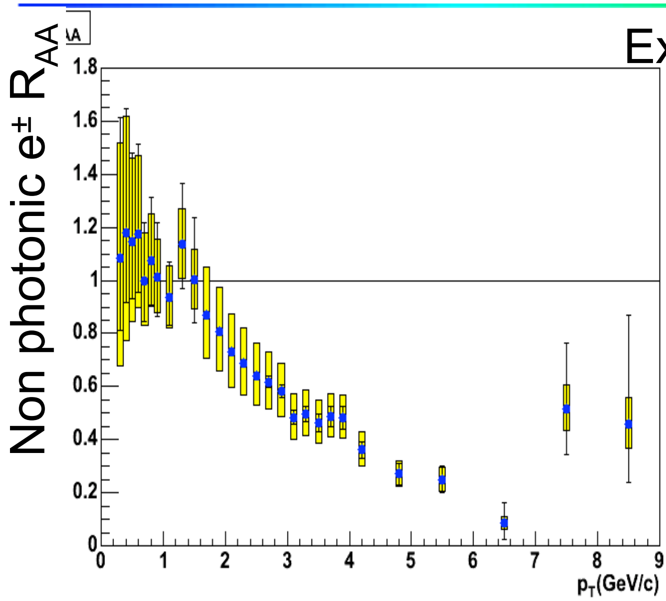
VTX Physics



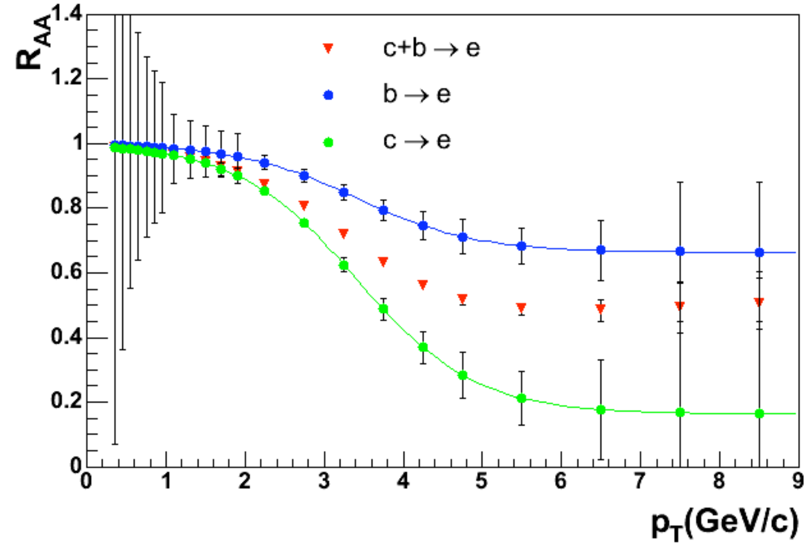
PRL 98, 172301 (2007)

- **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, γ-hadron, and c-hadron correlation)**
- **Gluon polarization ΔG(x) in polarized p+p**
  - Double spin asymmetry A_{LL} of heavy flavor production (charm and beauty, separately)
  - A_{LL} of γ-jet

VTX Performance

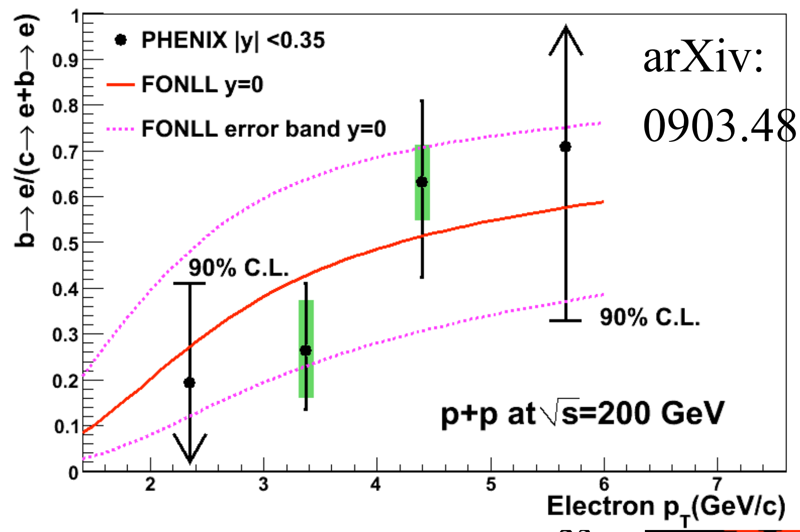


Expected with VTX (0.4/nb ~3 weeks in RUN11)



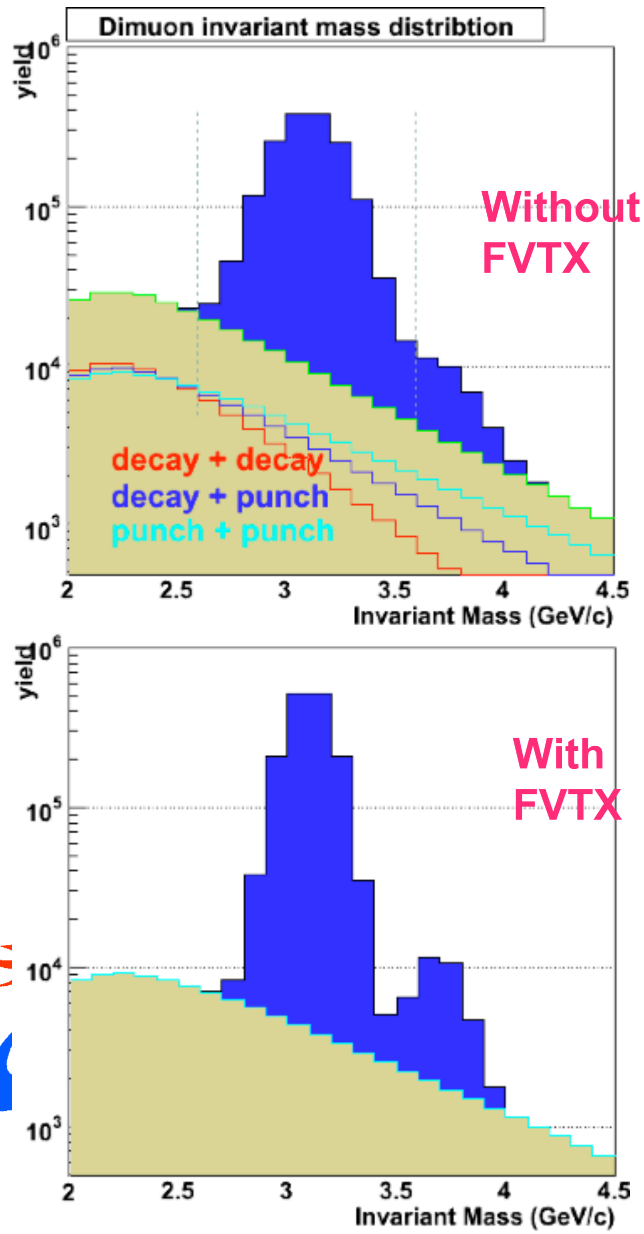
- In single electrons at high p_T b component is not small
- VTX can separate b and c

(full MC chain with detector response & analysis code)



arXiv: 0903.4851

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

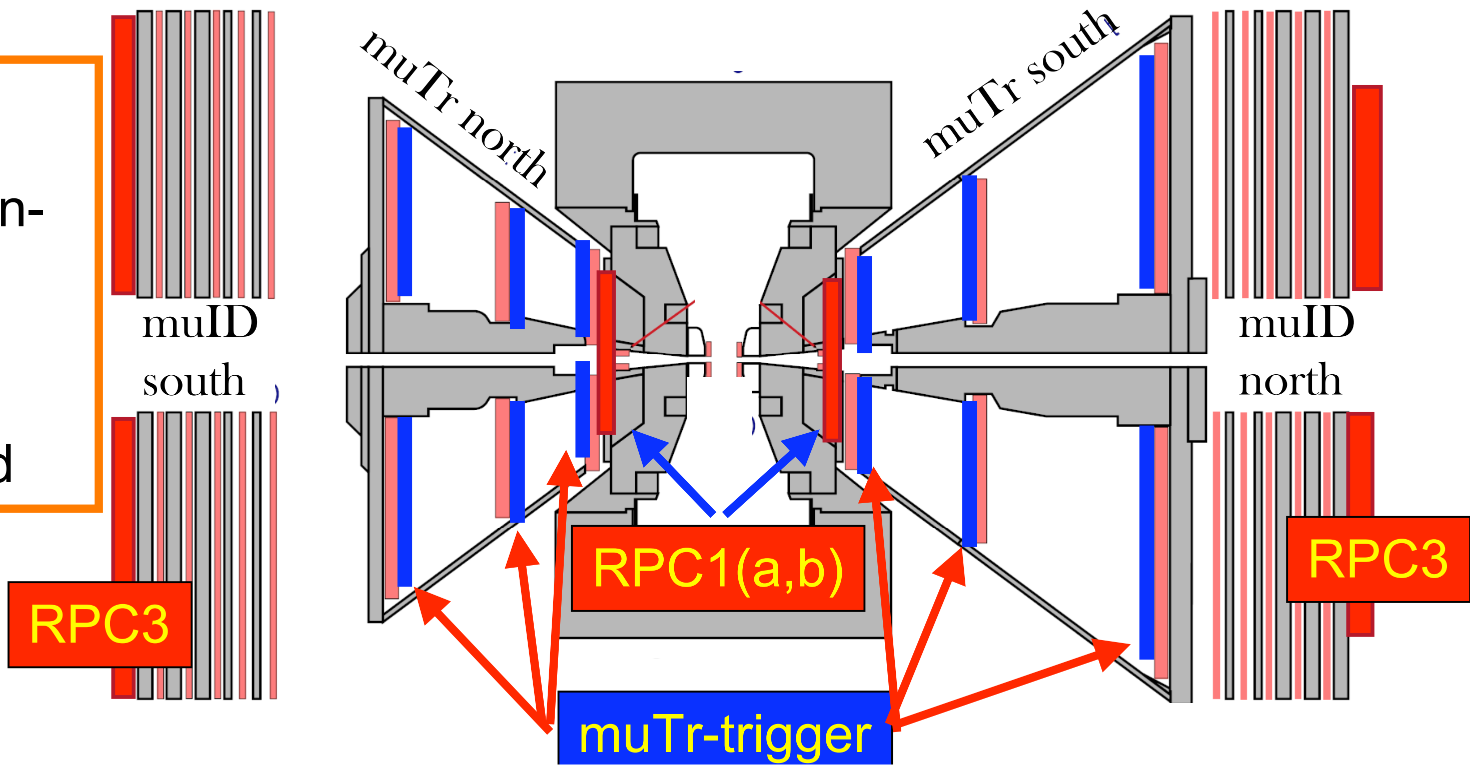
Install for Run-12

Muon Trigger Upgrade

Trigger idea:

Reject low momentum muons

Cut out-of-time beam background



Upgrade:

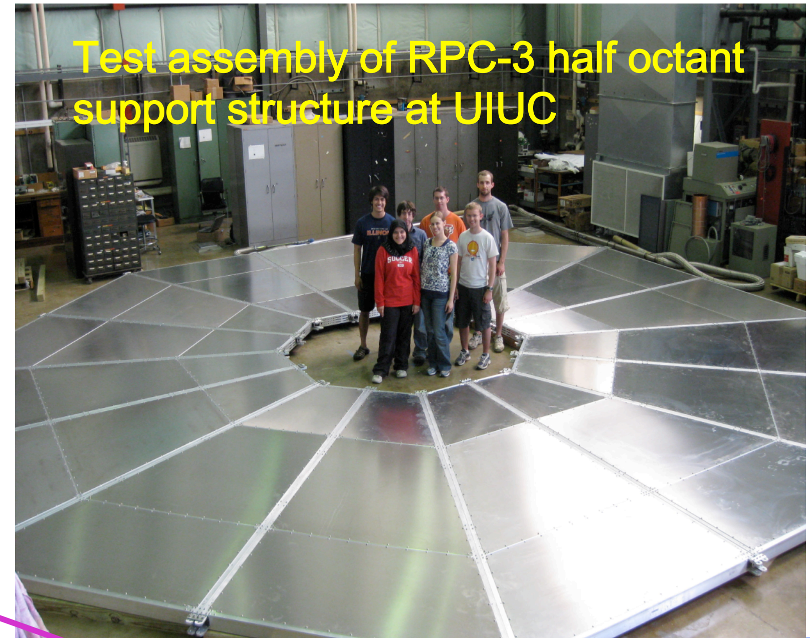
o muTr trigger electronics: muTr 1-3 ➔ send tracking info to level-1 trigger

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.

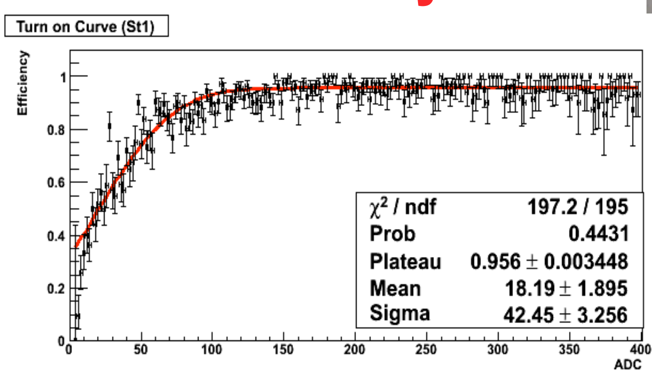
MuTrig Status: ready for Physics in Run-11

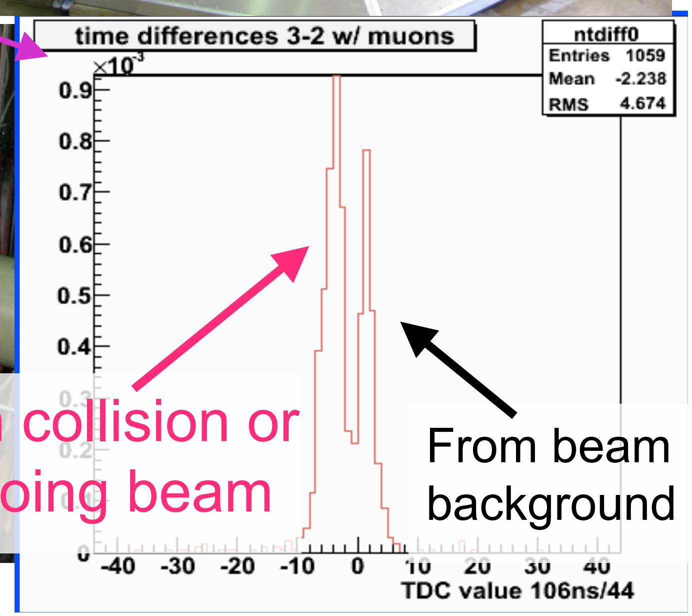
- Engineering run for sectors in 2 RPC planes on south arm
- Timing info helped understand background in first 500 GeV run



MuTr.N operational in Run-9

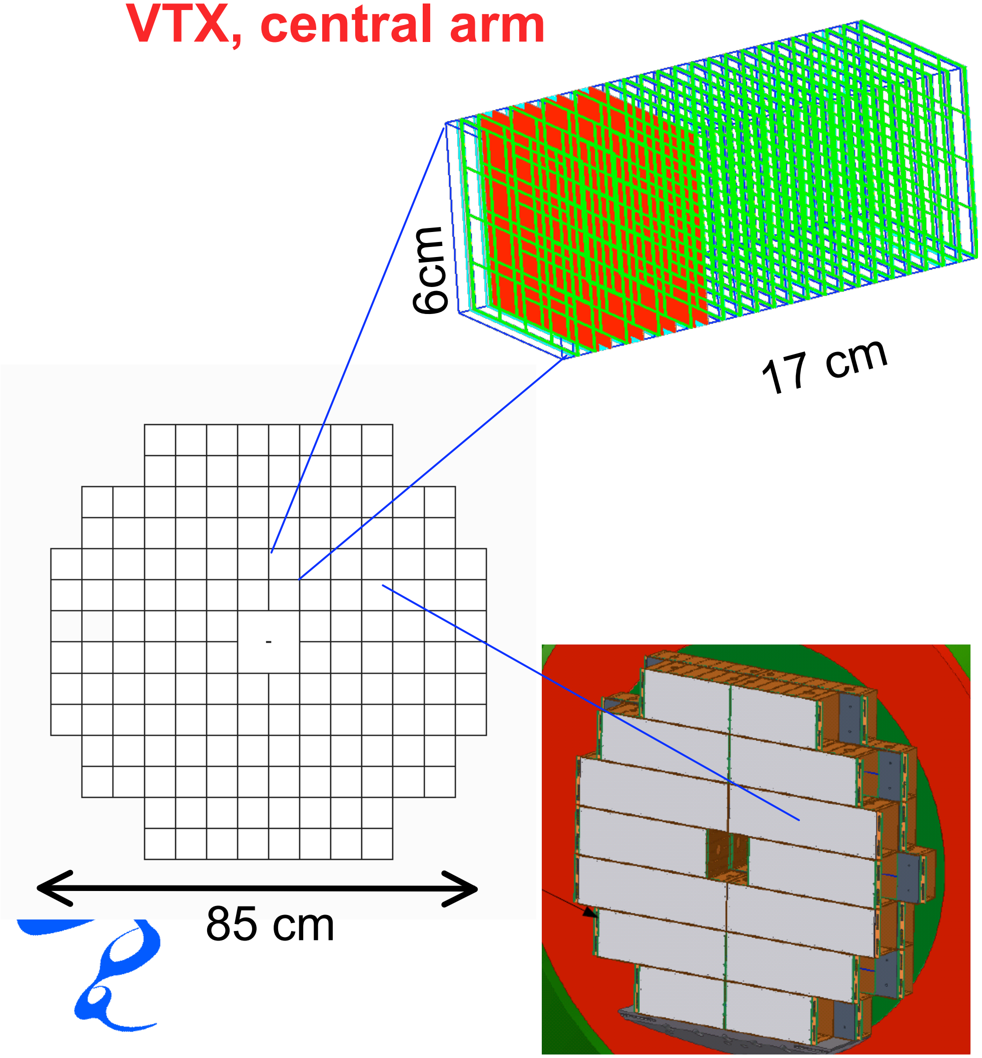
Good efficiency!



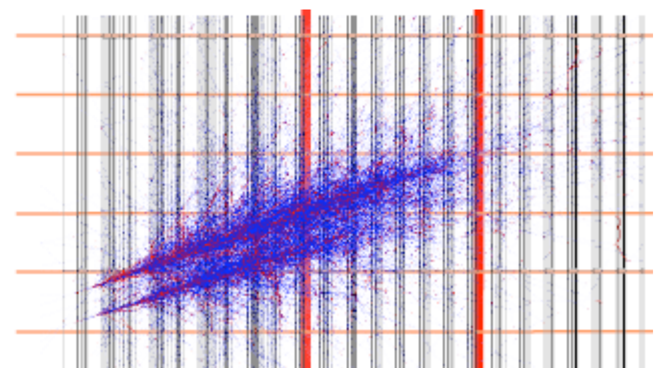


FOrward CALorimeter (FOCAL)

- Trigger on π^0 and γ
- Provide coincidence with VTX, central arm



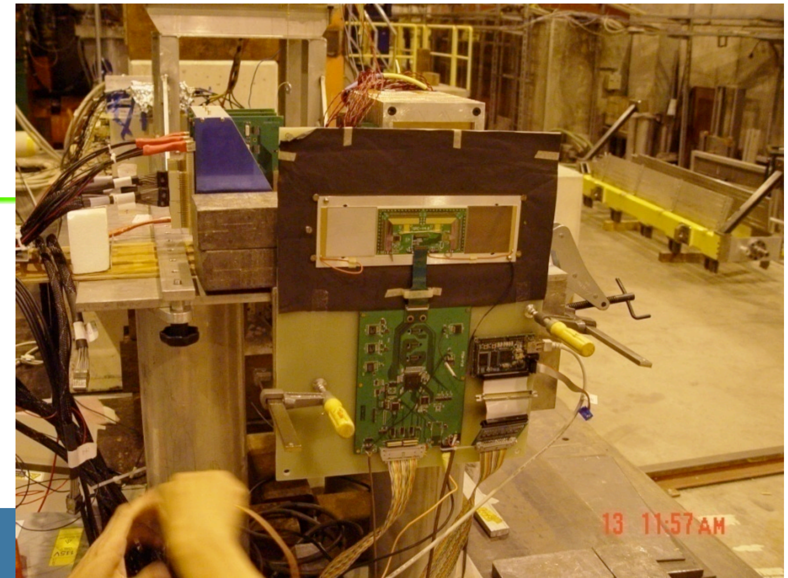
- **W absorber, Si pad readout**
  $1< \eta <3$, 2π azimuth
  $24 X_0$ deep
- **3 layers pad readout for lateral and longitudinal shower profile**
  Reject hadronic background
- **4 layers of Si strips within first X_0 for γ/π^0 separation**

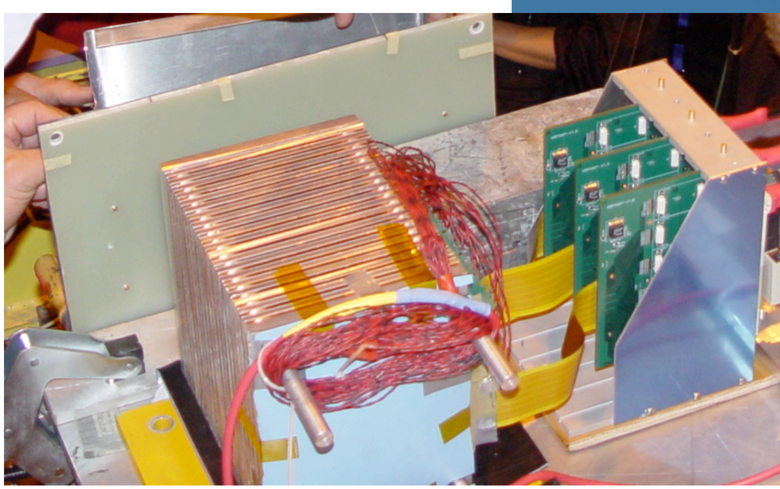


Geant simulation
20 GeV π^0

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^{-1}		l^+l^-, γ-h
	Au+Au	62.4	3.5	56.2 μb^{-1}	350M	e R_{AA},e^+e^-
	Au+Au	~39	1.3 + 0.3 E change	8.2 μb^{-1}	50M	e^+e^- π^0 R_{AA}
	Au+Au	27	4.5	4.1 μb^{-1}	25M	v_2, π^0 R_{AA}
	p+p	500	4 (polariz. development)			
	p+p	22.4	1		2.5B	π^0 R_{AA}
11	p+p	500	10	50 pb^{-1}		W, π^0 A_{LL}
	Au+Au	200	8	1.4 nb^{-1}		c/b,J/ψ v_2

* estimated with mean of min/max prediction

includes lumi. ramp up & changeover time

PHENIX plan delivers *new* physics each year

- Dielectrons - one-shot opportunity in Run-10!
- Other Run-10 full energy Au+Au goals

  Is ϒ 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 ρ modification at SPS evolve into the large low-mass excess at RHIC?

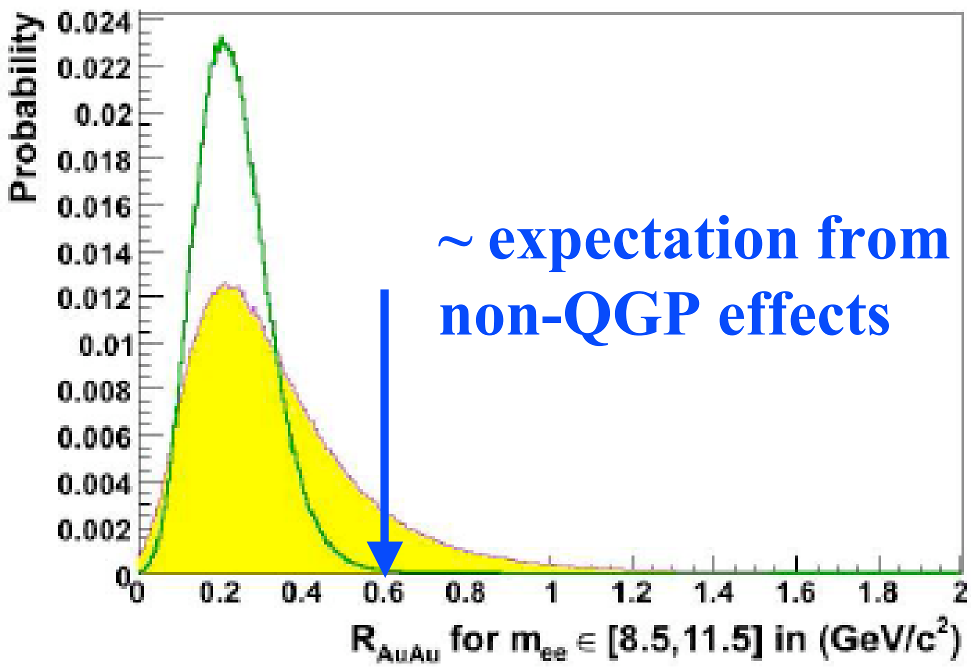
  Where do liquid properties (v_2 & jet suppression) set in?
- Run-11 500 GeV p+p

  What do W asymmetries tell about sea quark polarization?
- Run-11 200 GeV Au+Au - with VTX!

  Do b quarks lose energy? Does J/ψ flow?

Is ϒ suppressed?

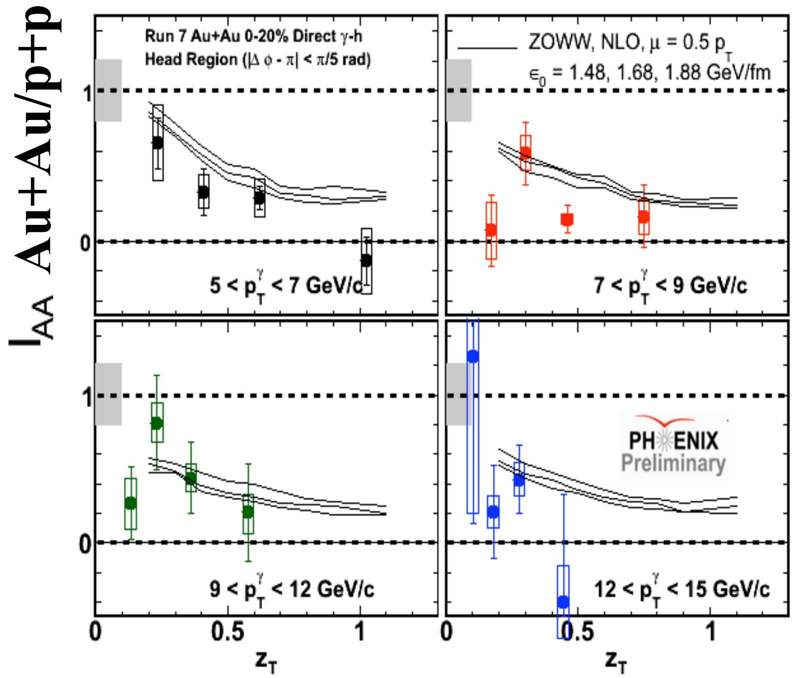
Run-7+Run-10 (with reference from Run-9 p+p) will allow measurement of R_{AA}



→ maxmum integrated luminosity at 200 GeV, consistent with goals for lower √ s

Energy loss mechanism?
γ-h "golden channel"

Run-7

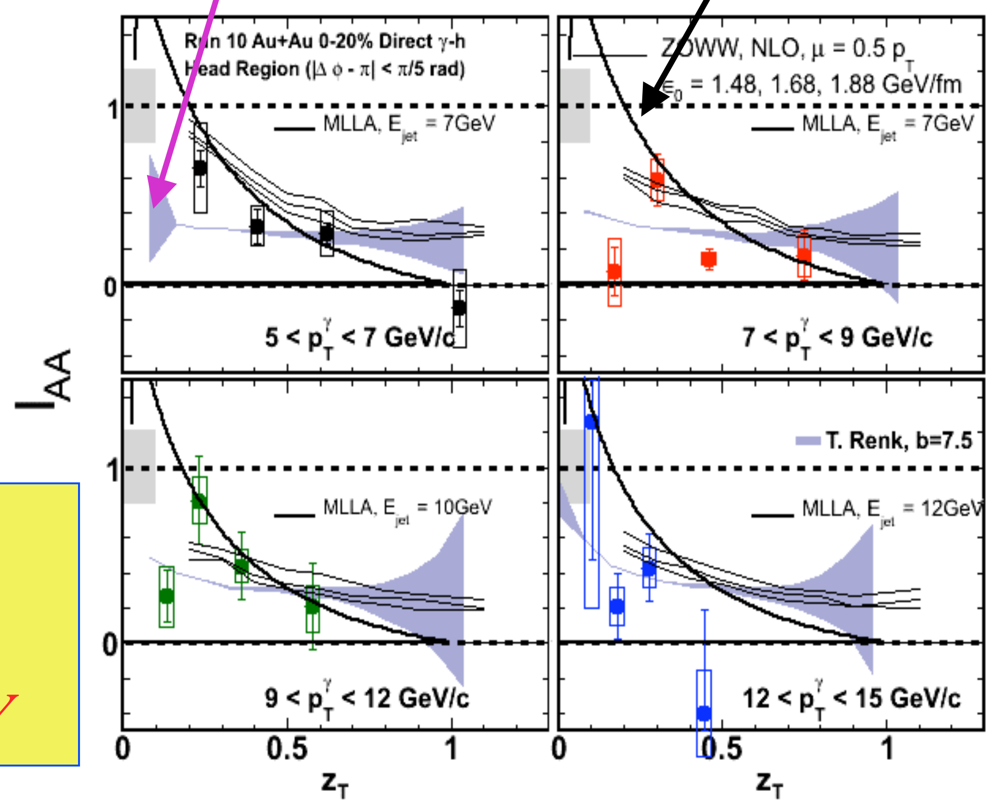


Curves: NLO calculation of induced radiation

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

Medium-enhanced gluon splitting (enhanced soft radiation)

In-medium shower evolution averaging over expansion



[redacted]

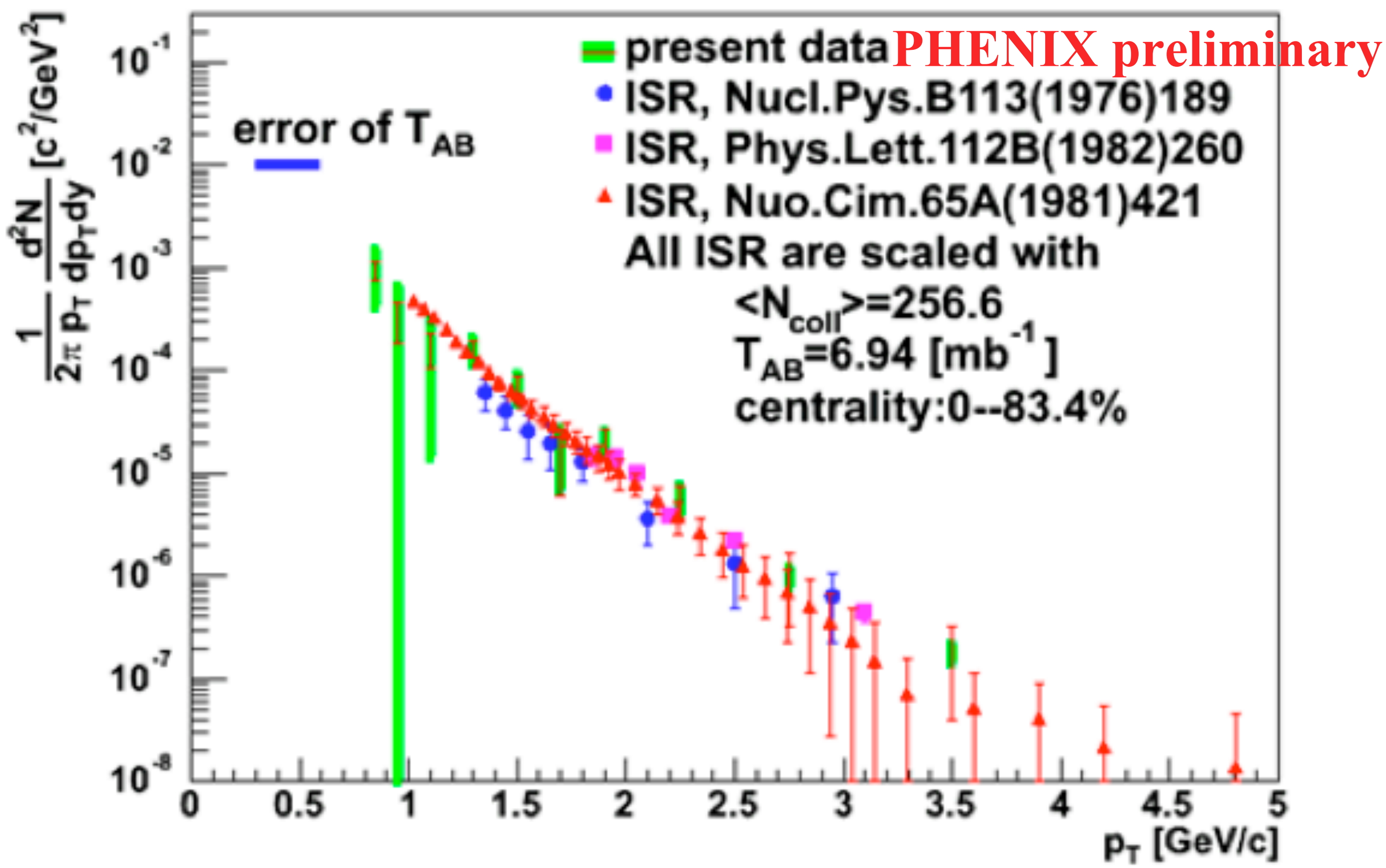
PHENIX strategy for low energy scan

- 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 η/s
- *Second step: high σ 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 √s: onset of heavy quark energy loss?

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

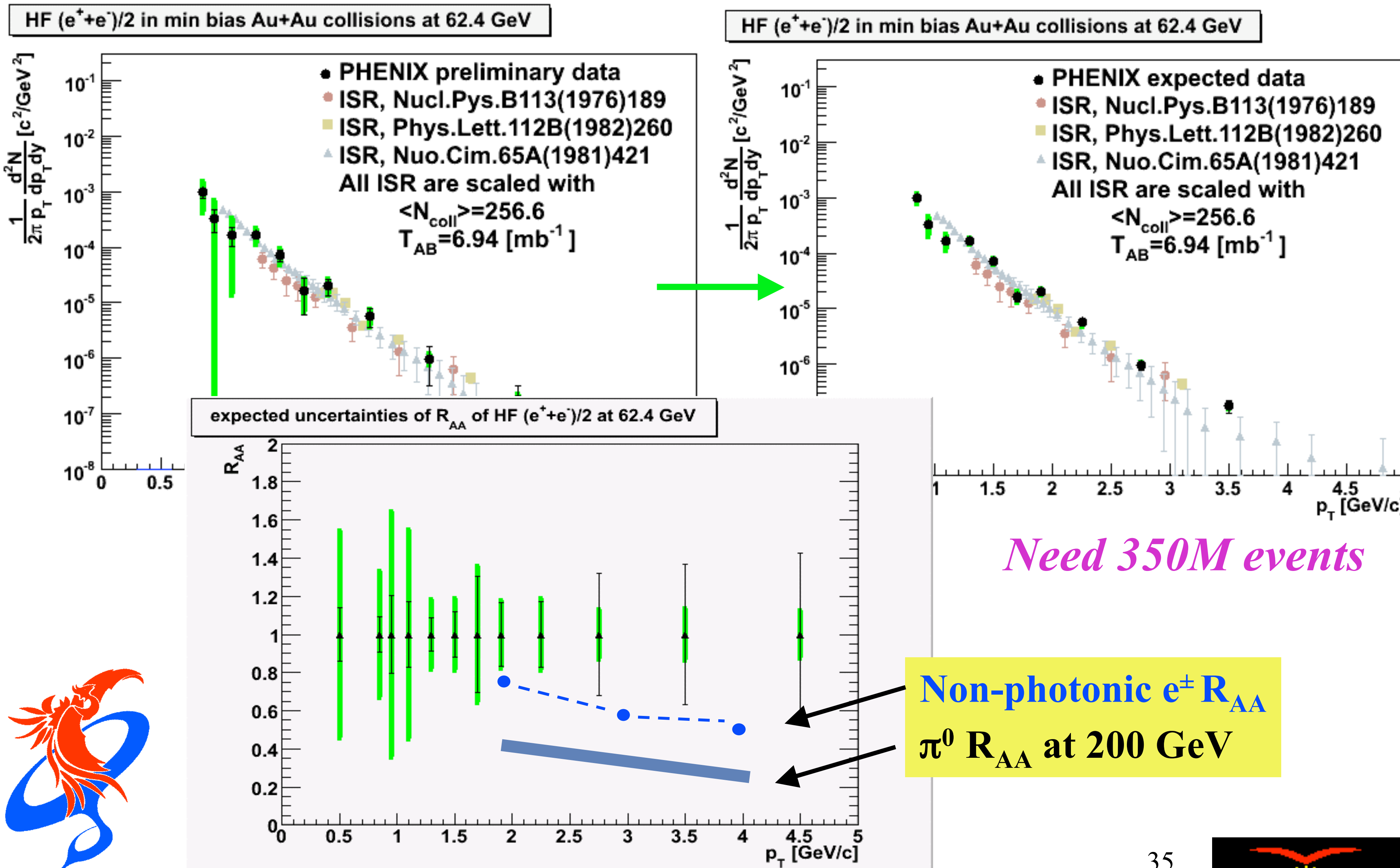
62.4 GeV Au+Au



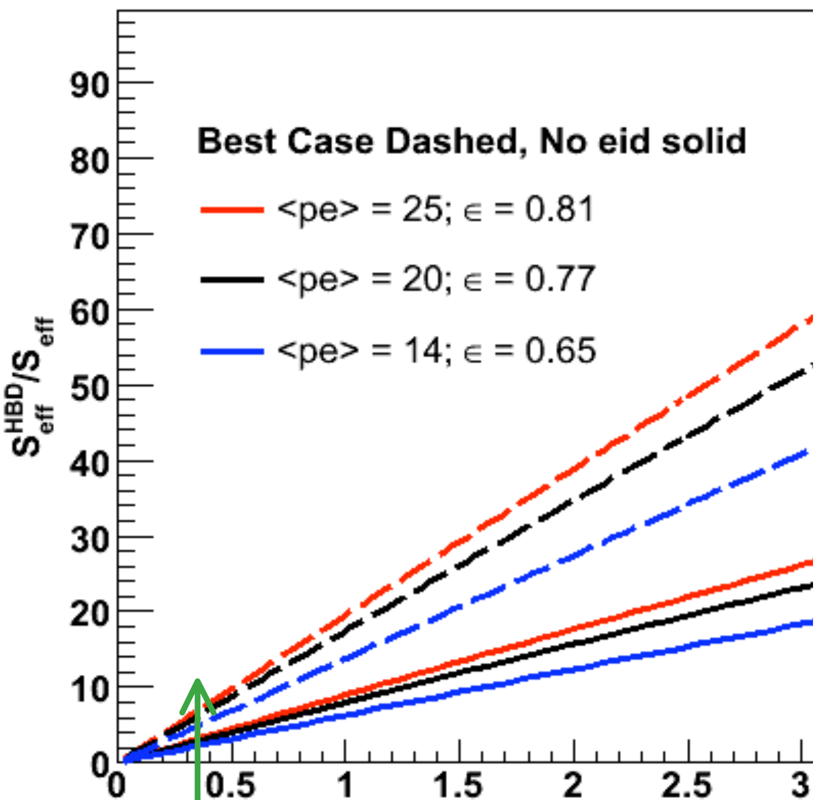
Heavy flavor does not appear to be suppressed!

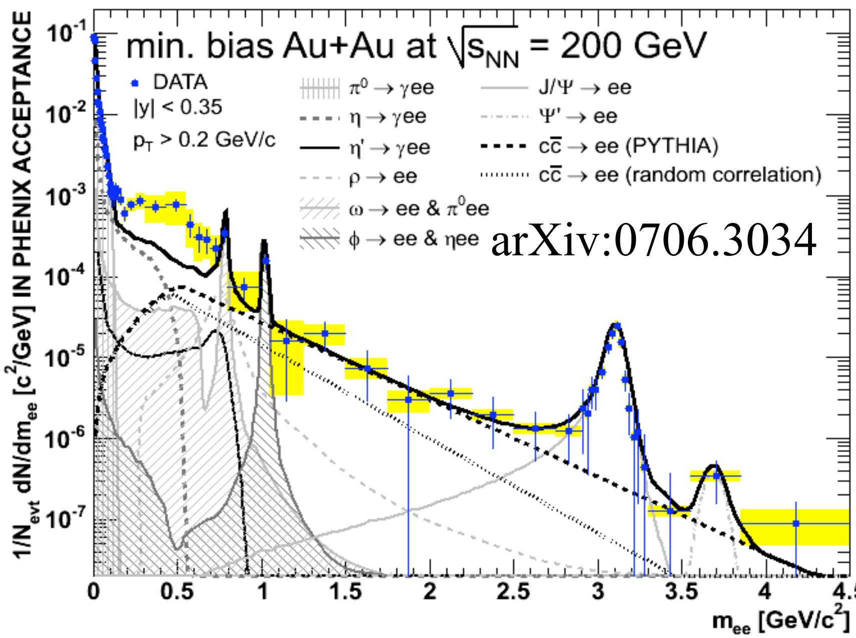
Theoretical guidance: Absent!!

Answer in Run-10!



Also dielectrons at 62.4 GeV





TERRA INCOGNITA!

350M events with HBD

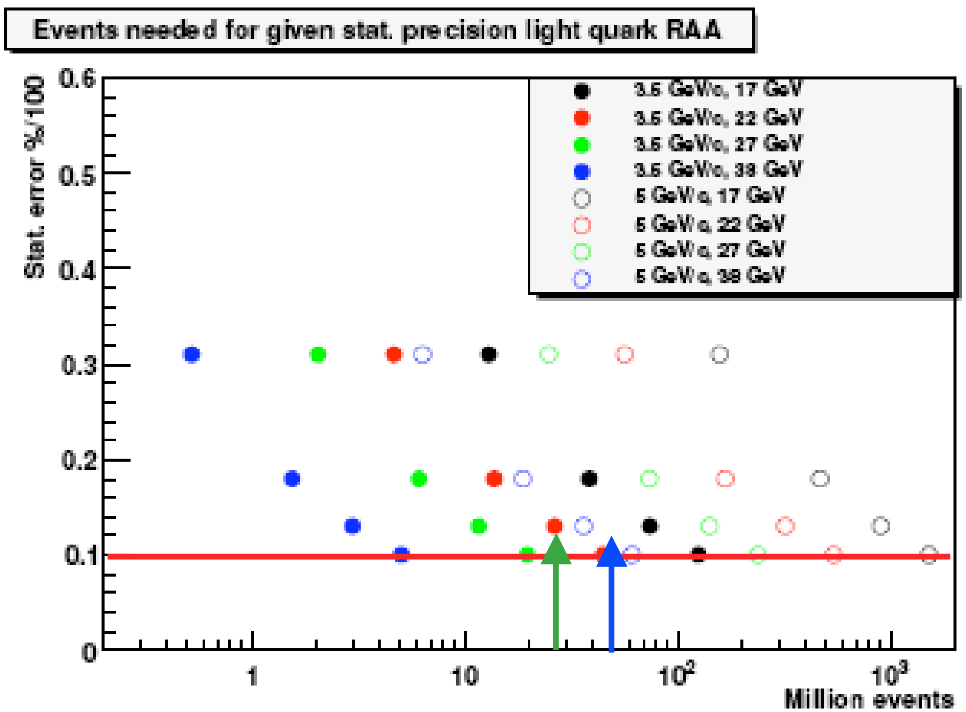
3-5 x better than Run-4

w/o "credit" for lower multiplicity

Observables below √ 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 η	1D imaging of pion source Lévy exponent α 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 κ	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% σ statistical

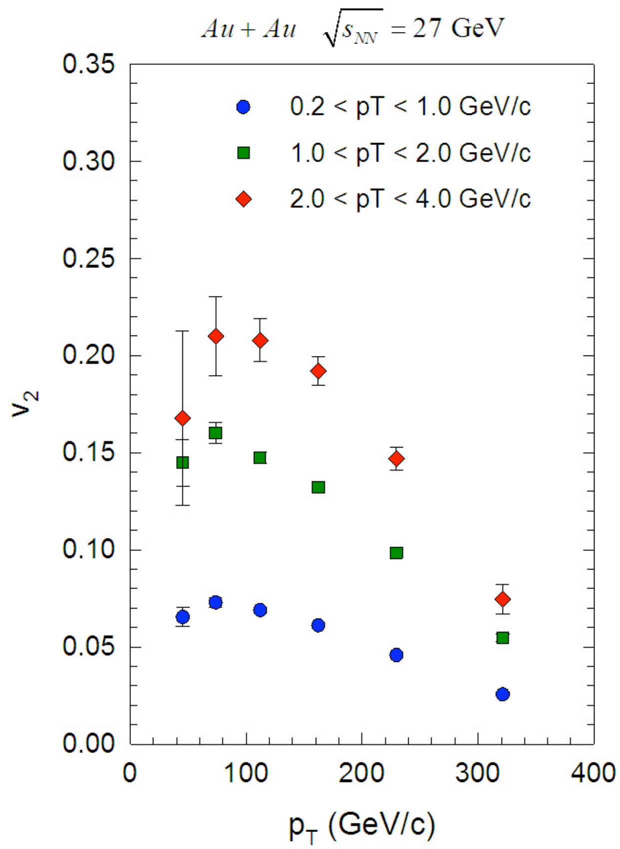
Are jets suppressed at √ s = 39 and 27 GeV?

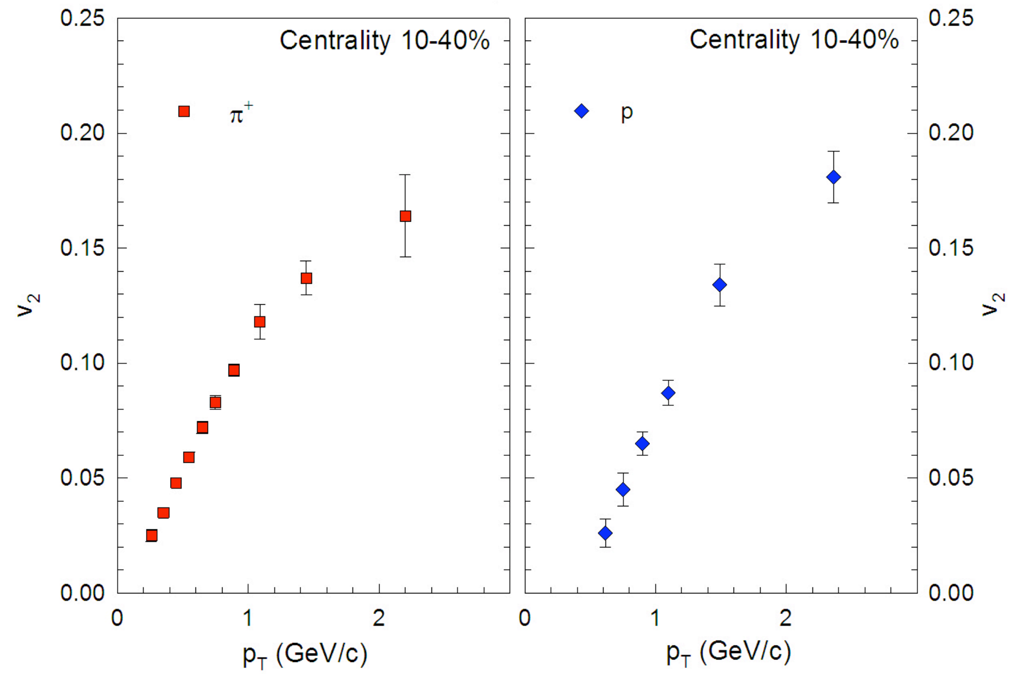
Unsuppressed at 22.4 (modulo Cronin effect errors)

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)

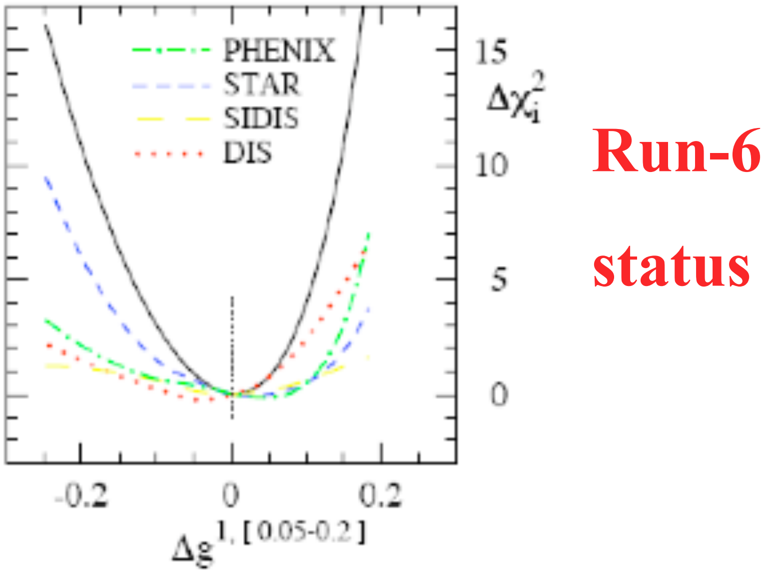


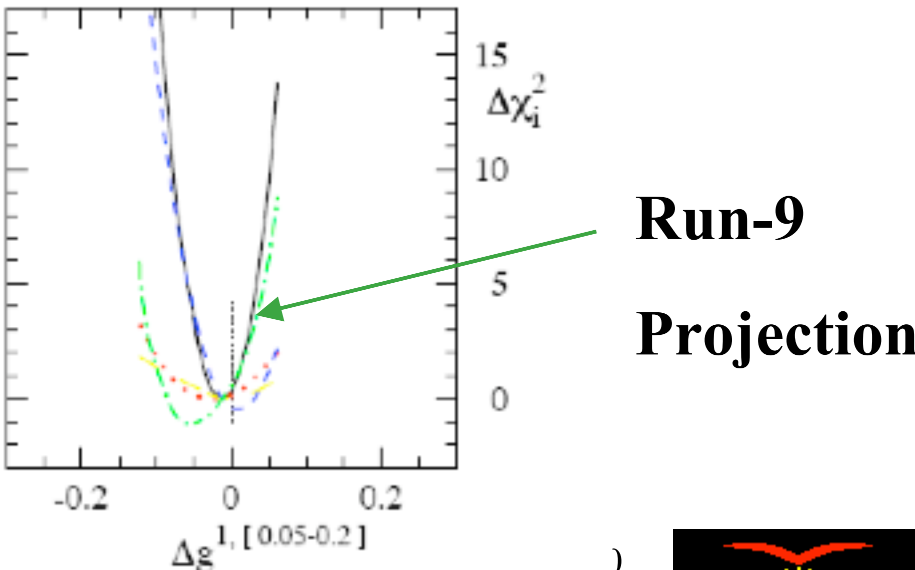


v_2 magnitude & location of break
in constituent quark scaling
→ η/s and post-hadronization viscosity

p+p development in Run-10

- **The problem:**
  Polarization < 60 not 65%
  Anticipate $\int \mathcal{L}$ = 15 not 25 pb^{-1}
  FOM lower than expected
  0.72 x 0.6 = 0.43
- **We have learned so far:**
  ΔG(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



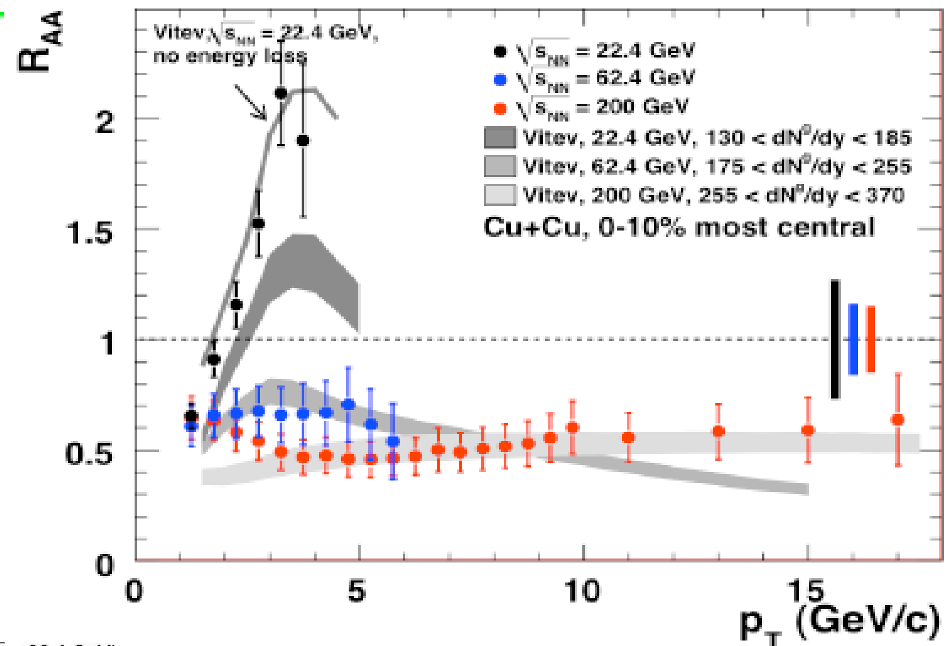


)

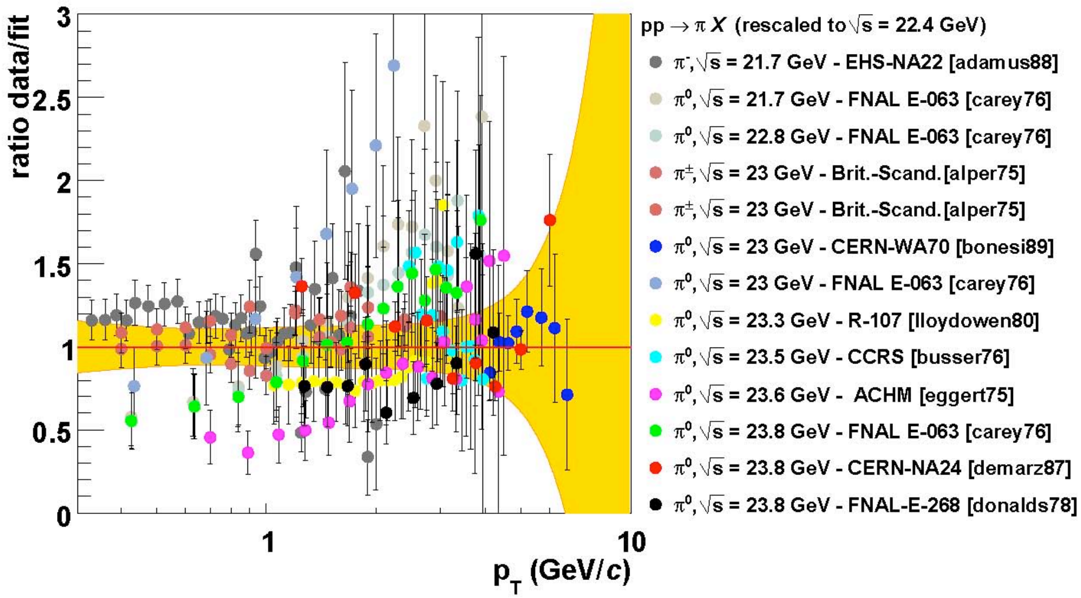
p+p run at 22.4 GeV

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

PRL101, 162301 (2008)



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



Measure p+p reference at same √ s and aparatus

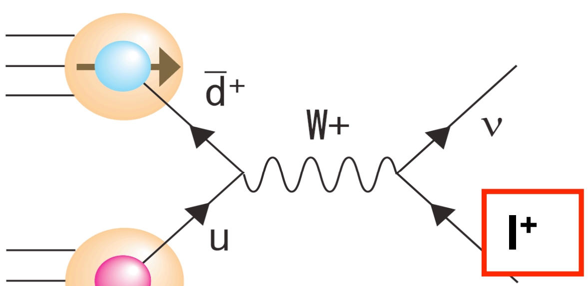
Reduce uncertainty for interpolation between 22.4 & 62.4 GeV

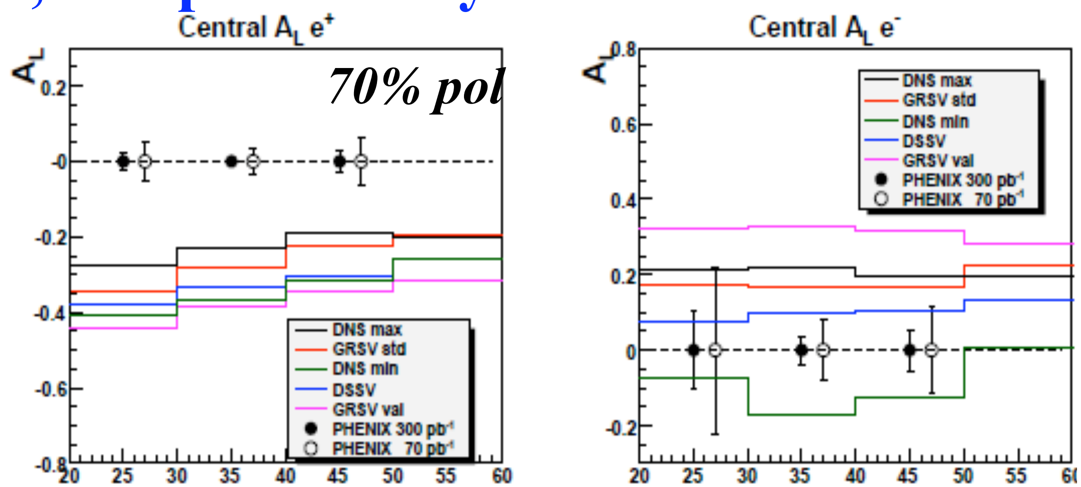
500 GeV p+p in Run-11

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

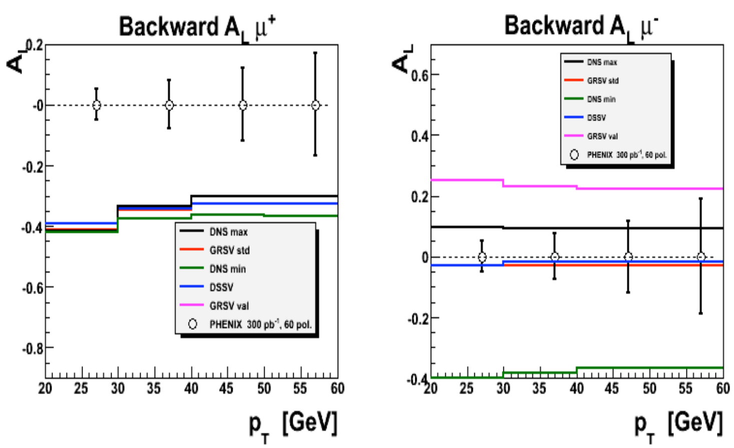
***u* & *d* $\bar{q}$ & q polarization; complementary to SI DIS**

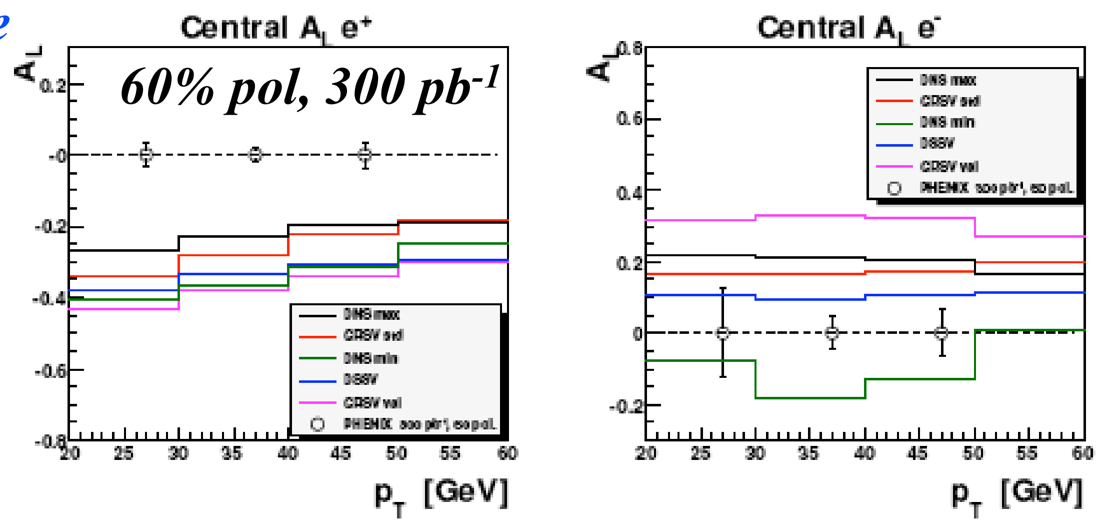
$$A_L^{l^\pm}(W^\pm \rightarrow l^\pm \nu)$$





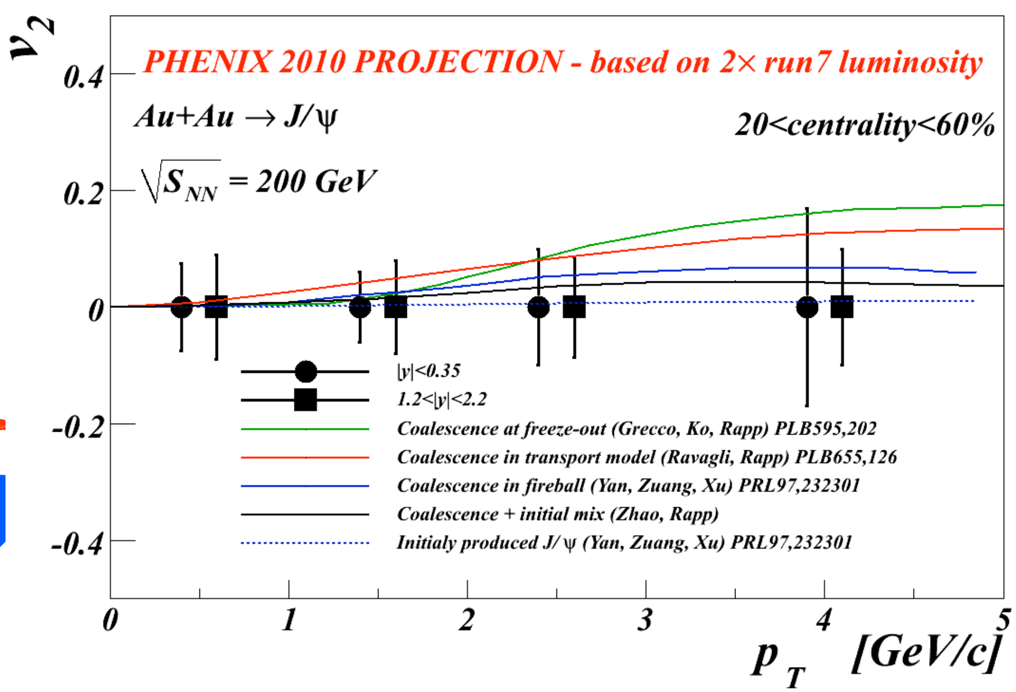
Both μ & e final state





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 ±10 cm
- Ability to combine Run-11 with Run-10 for J/ψ 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^{-1}	
	Au+Au	62.4	3.5	56.2 μb^{-1}	350M
	Au+Au	~39	1.3 + 0.3 E change	8.2 μb^{-1}	50M
	Au+Au	27	4.5	4.1 μb^{-1}	25M
	p+p	500	4 (polarization development)		
	p+p	22.4	1		2.5B
11	p+p	500	10	50 pb^{-1}	
	Au+Au	200	8	1.4 nb^{-1}	

*** 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

Replace	EMCAL FEE trigger match/rejection ($e^{\pm}$)	Need by 2012
Develop	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	
Purchase	Real Time Trigger Analysis Farm	
Construct	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

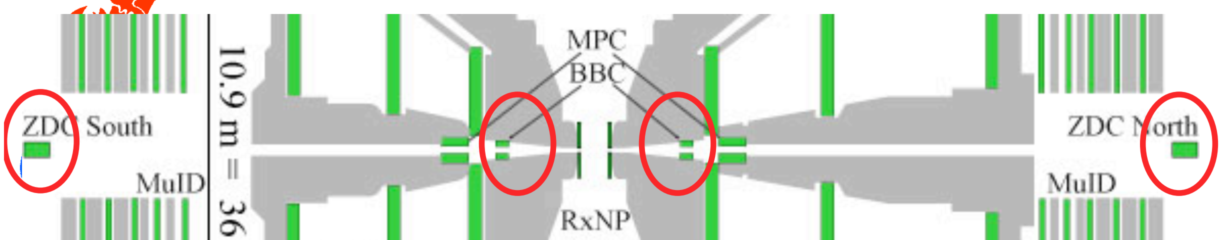
- Pattern recognition and efficiency under study

Rate Effects on Luminosity Monitoring

Kieran Boyle, lumi monitor task force

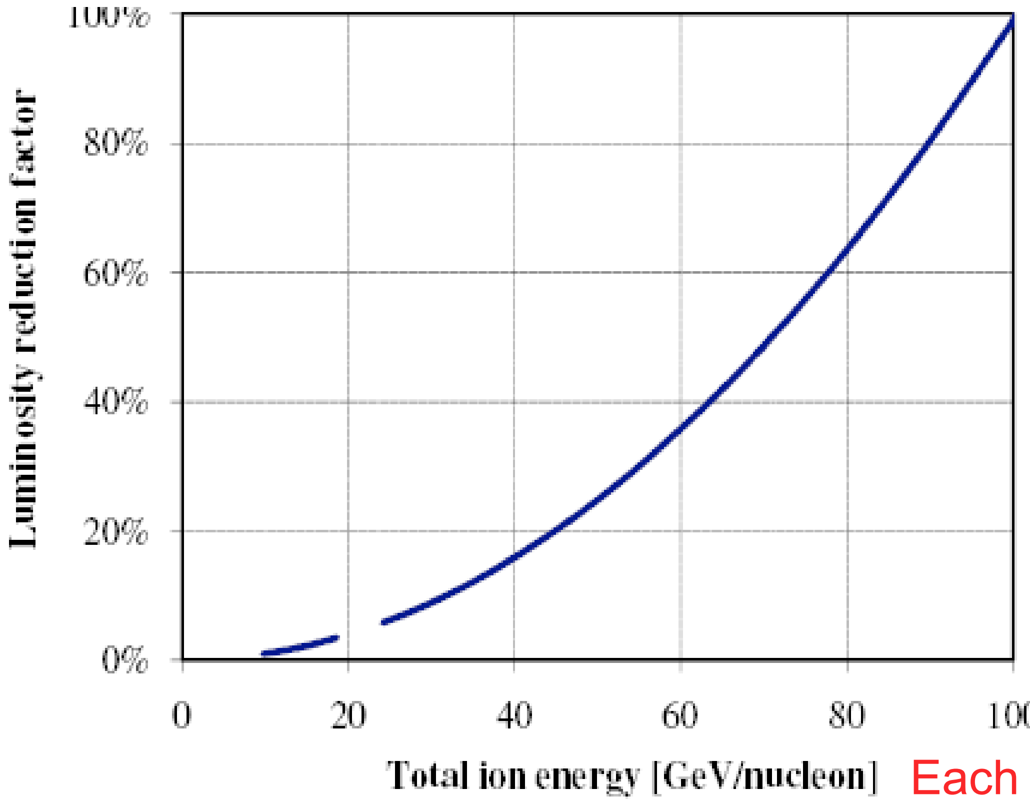
- **Run3-6:**
  - **Primary luminosity detector: BBC**
  - **ZDC: check systematic uncertainties**
- **Run9 and beyond:**
  - **Multiple collisions increase with luminosity, and can affect the accuracy of the relative luminosity measurement.**
- **Both the BBC and ZDC triggers cannot distinguish multiple 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 scalers***
- **From Run-11: VTX determines multiple collisions**



- **backup slides**

The problem



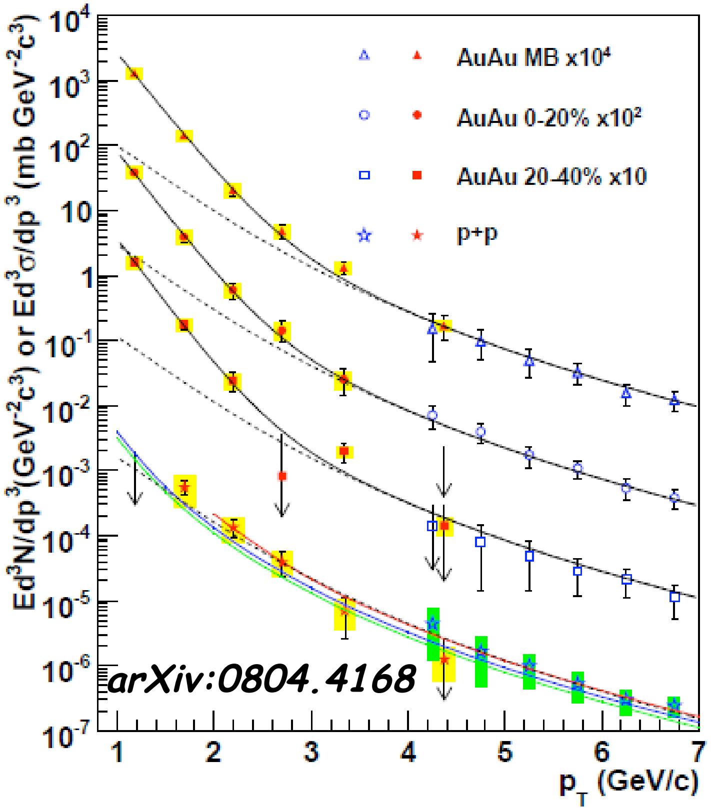
Each beam!

Collision rates drop to Hz level (lower beam stiffness)

No storage RF below √ s~ 40 GeV: beams fill time bucket

σ_{vertex} ~ 150 cm

PHENIX Measurement of Early Collision Temperature via photon spectrum



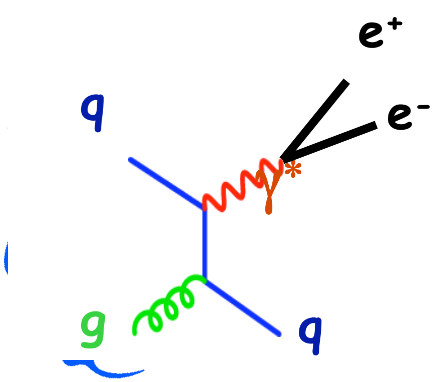
enhancement vis-à-vis p+p.

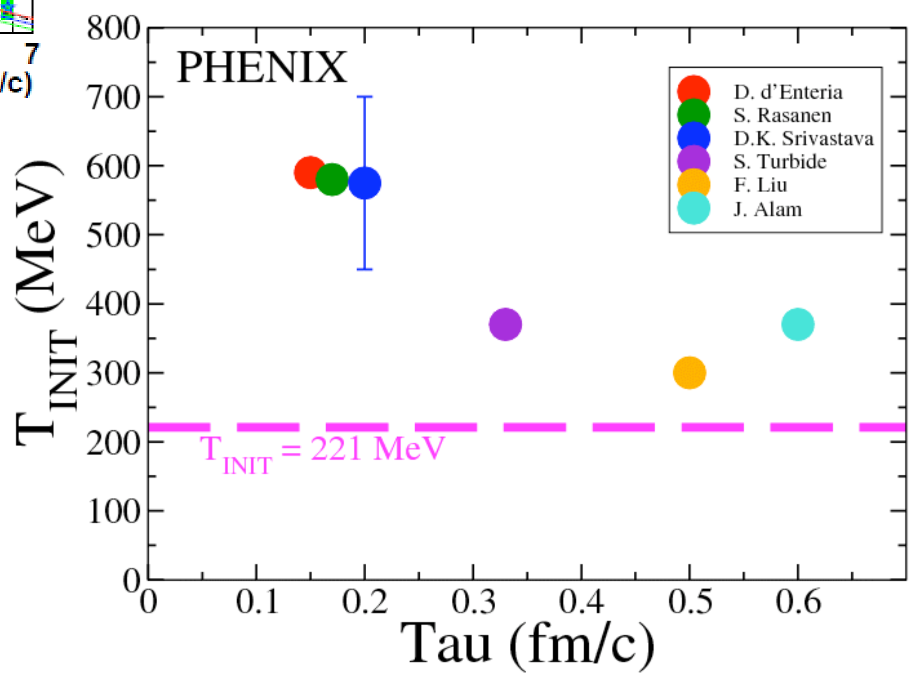
exponential fit to p_T slope ⇒

T_{avg} = 221 ± 23 ± 18 MeV

hydrodynamics models ⇒ T_{init} > 300 MeV

Low-mass di-electrons
⇒ nearly real photons

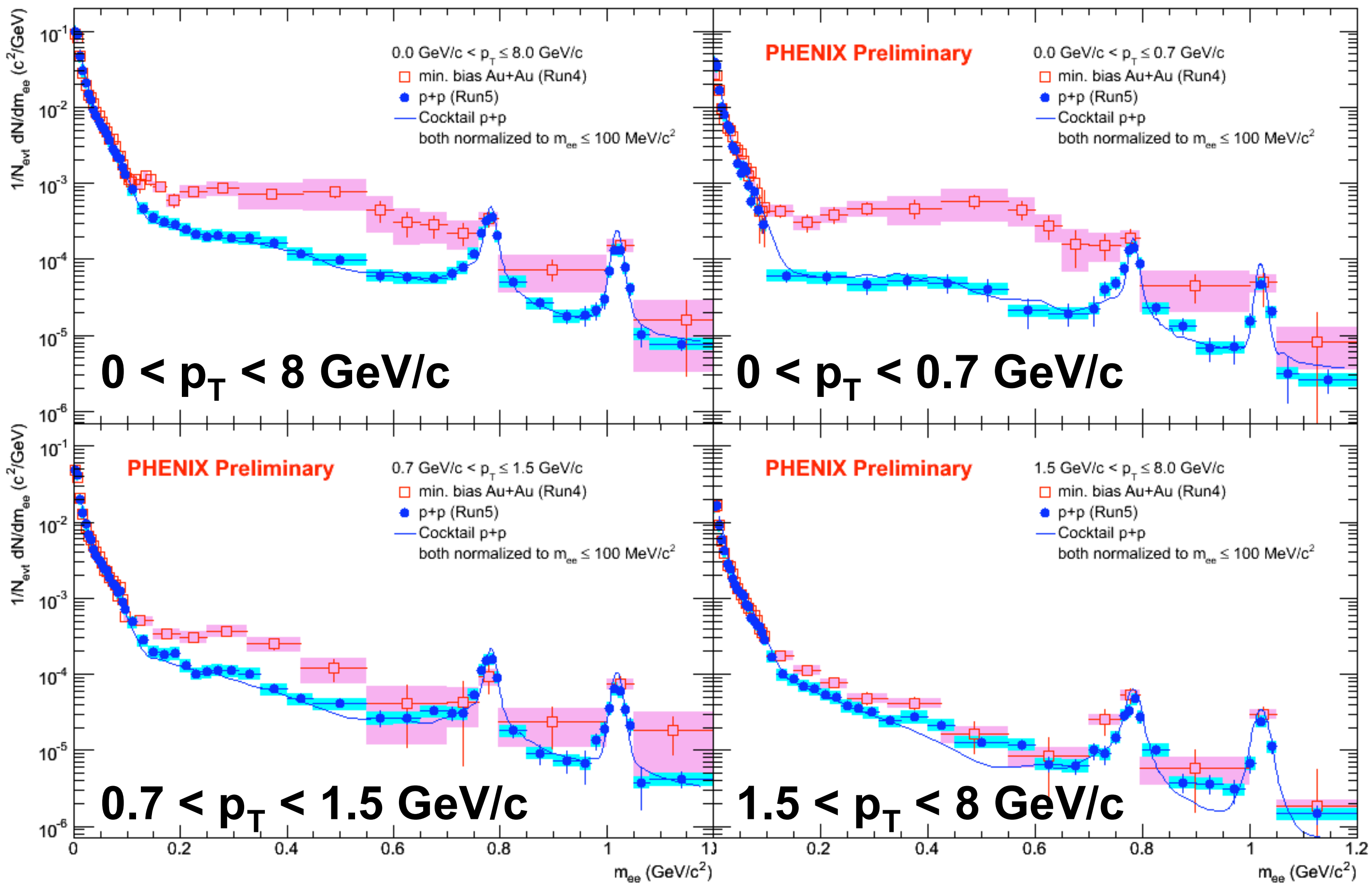




$T_{init} >> T_C$

(!)

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 ↔ EM correlator

Emission rate of dilepton per volume

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

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

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

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

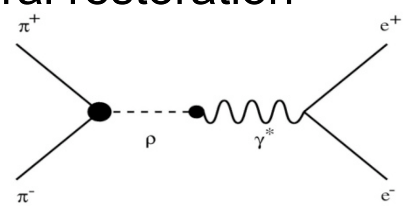
γ*→ee decay

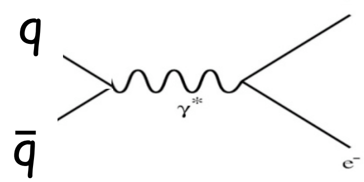
EM correlator
Medium property

Boltzmann factor
temperature

Hadronic contribution
Vector Meson Dominance → Medium modification of meson
Chiral restoration

$$\mathrm{Im}\Pi^{\mathrm{vac}}_{\mathrm{em}}(M) = \begin{cases} \sum_{V=\rho,\omega,\phi}\left(\frac{m_V^2}{g_V}\right)^2 \mathrm{Im}D_V(M) \\ -\frac{M^2}{12\pi}\left(1+\frac{\alpha_s(M)}{\pi}+\ldots\right) N_c \sum_{q=u,d,s}(e_q)^2 \end{cases}$$





qq annihilation → 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

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

Emission rate of (virtual) photon per volume

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

Relation between them

Prob. $\gamma^* \rightarrow l^+l^-$

$$q_0\frac{dR_{ll}}{dM^2d^3q} = \frac{1}{2}\frac{dR}{d^4q} = \frac{\alpha}{3\pi}\frac{L(M)}{M^2}q_0\frac{dR_{\gamma^*}}{d^3q}$$

Dilepton

virtual photon

This relation holds for the yield after space-time integral

Virtual photon emission rate can be determined from dilepton emission rate

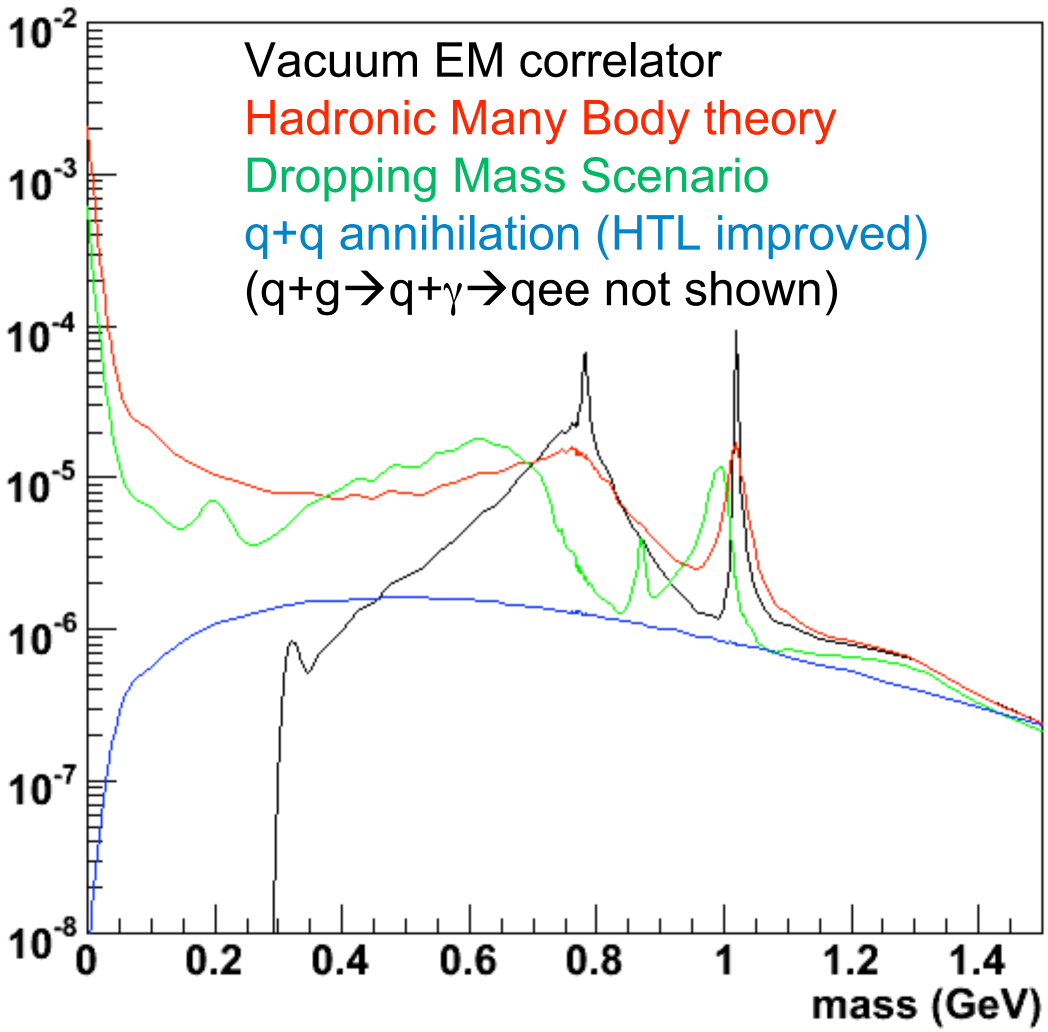
$$q_0\frac{dn_{\gamma^*}}{d^3q} \simeq \frac{3\pi}{\alpha}M^2 q_0\frac{dn_{ll}}{d^3q\,dM^2} = \frac{3\pi}{2\alpha}Mq_0\frac{dn_{ll}}{d^3q\,dM}.$$

M x dNee/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

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



Theory calculation by Ralf Rapp

Usually the dilepton emission is measured and compared as dN/dptdM

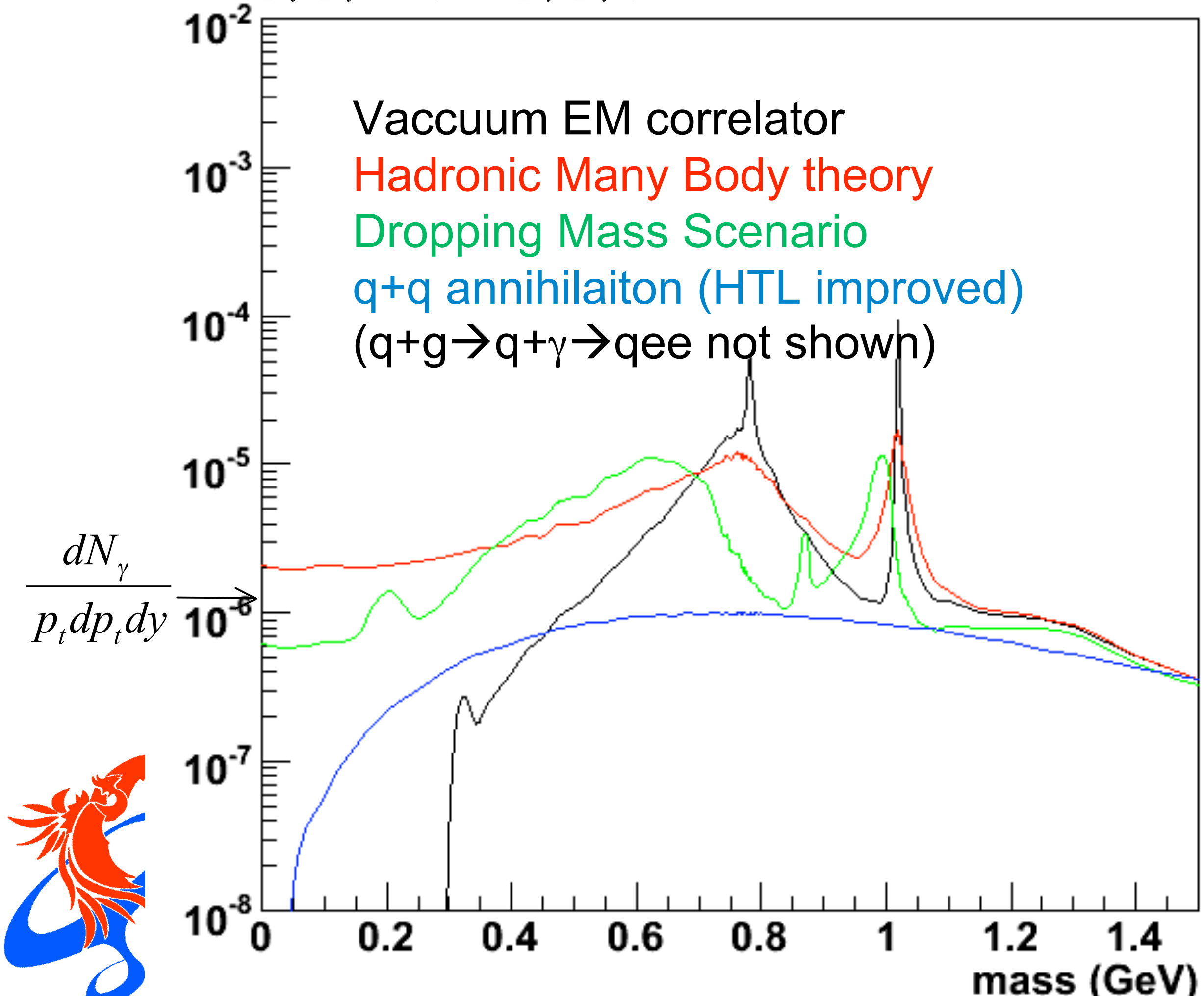
The mass spectrum at low pT is distorted by the virtual photon→ ee decay factor 1/M, which causes a steep rise near M=0

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→q+γ→q+e^+e^- not included

Virtual photon emission rate

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



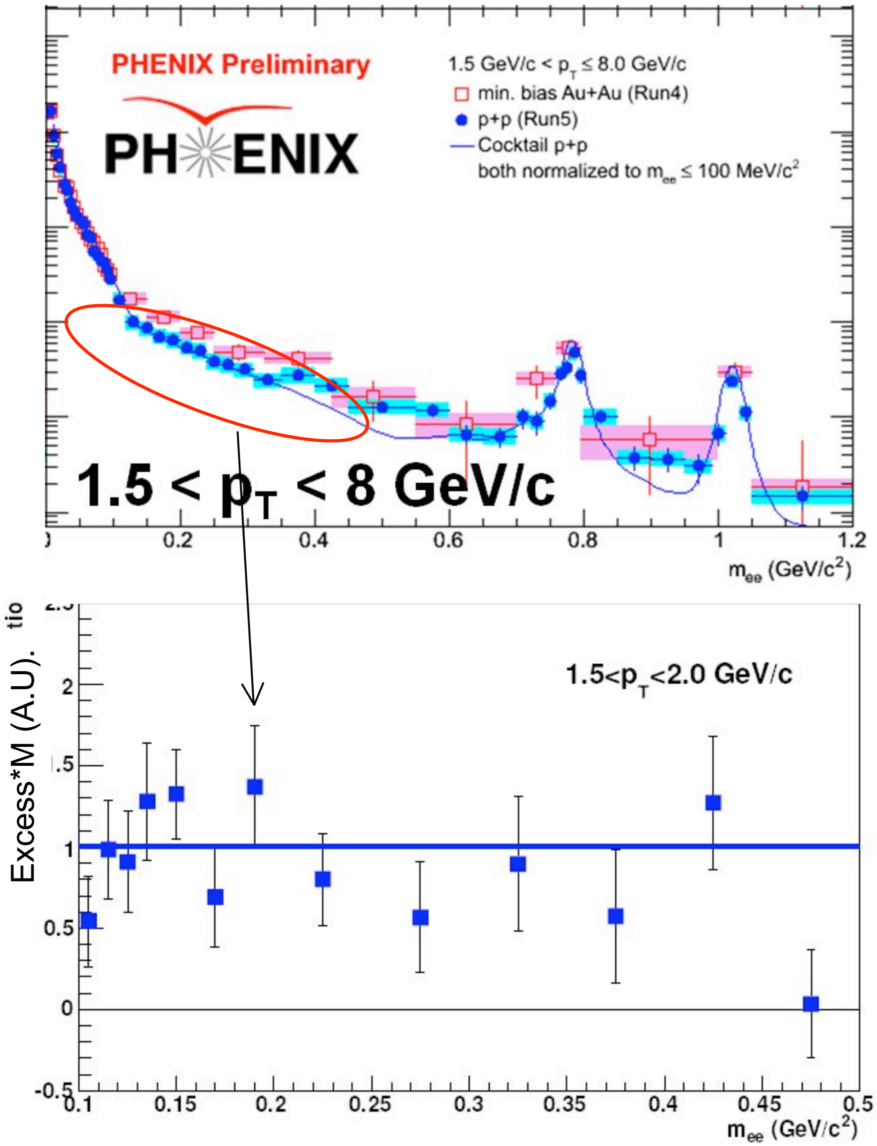
The same calculation, but shown as the virtual photon emission rate.

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→q+γ* is not shown; it is similar size as HMBT at this pT

Excess of virtual photons



Excess of electron pairs over the cocktail ~ 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 ~flat over half GeV/c^2

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

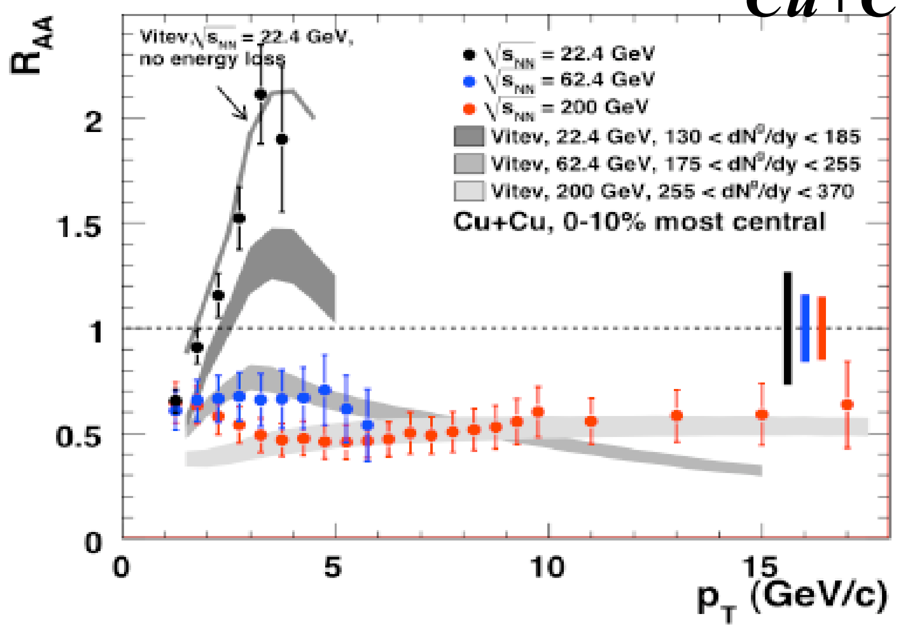
No indication of strong modification of EM correlator at high p_T !

presumably the virtual photon emission is dominated by processes

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

Onset of RHIC's perfect liquid

Cu+Cu

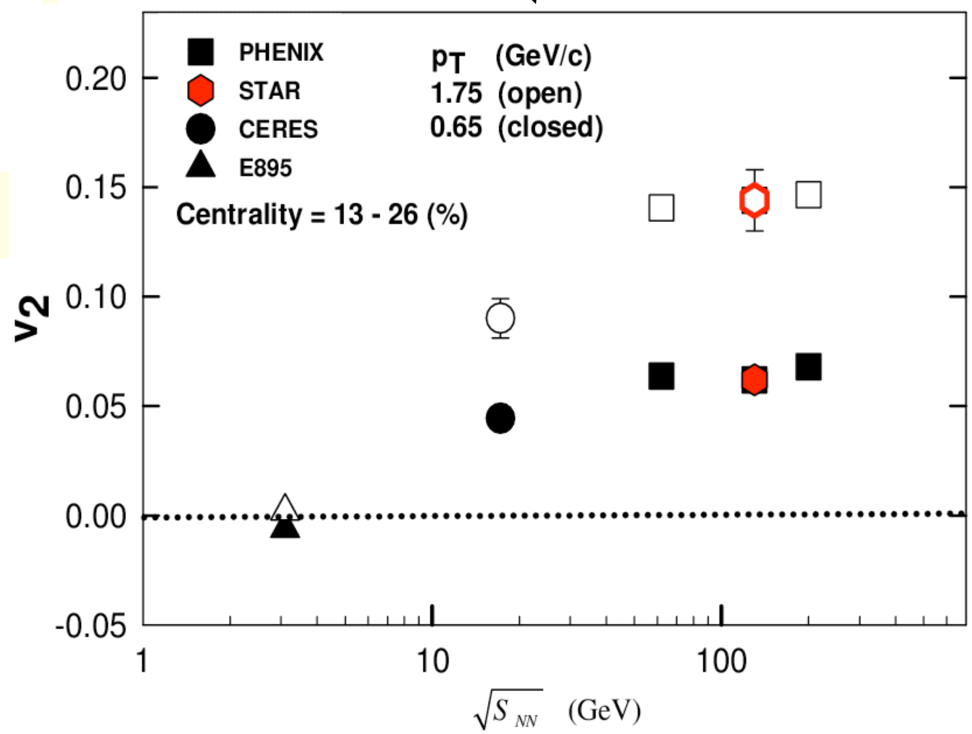


PHENIX, arXiv:0801.4555 [nucl-ex]

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 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
04	2004/2004	Au+Au	200	241 μb^{-1}	1.5G	10.0 pb^{-1}	270 TB
		Au+Au	62.4	9 μb^{-1}	58M	0.36 pb^{-1}	10 TB
05	2004/2005	Cu+Cu	200	3 nb^{-1}	8.6G	11.9 pb^{-1}	173 TB
		Cu+Cu	62.4	0.19 nb^{-1}	0.4G	0.8 pb^{-1}	48 TB
		Cu+Cu	22.5	2.7 μb^{-1}	9M	0.01 pb^{-1}	1 TB
		p+p	200	3.8 pb^{-1}	85G	3.8 pb^{-1}	262 TB
06	2006	p+p	200	10.7 pb^{-1}	230G	10.7 pb^{-1}	310 TB
		p+p	62.4	0.1 pb^{-1}	28G	0.1 pb^{-1}	25 TB
07	2007	Au+Au	200	0.813 nb^{-1}	5.1G	33.7 pb^{-1}	650 TB
08	2008	d+Au	200	80 nb^{-1}	160G	32.1 pb^{-1}	437 TB
		p+p	200	5.2 pb^{-1}	115G	5.2 pb^{-1}	118 TB
09	2009	p+p	500	$\approx$ 10 pb^{-1}	308G	$\approx$10 pb^{-1}	223 TB
		p+p	200	ongoing			>220 TB

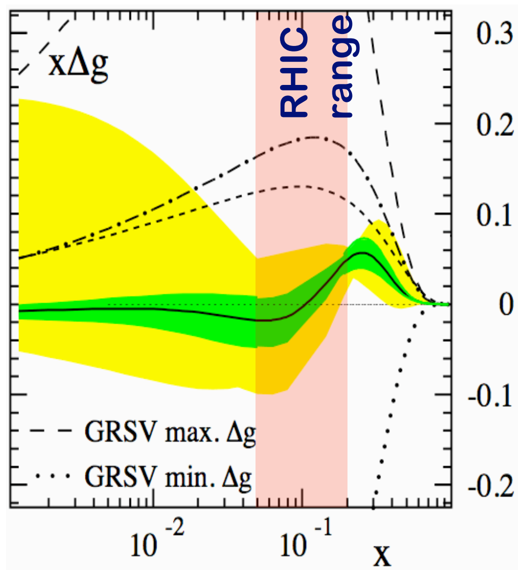
ΔG at lower x using 500 GeV

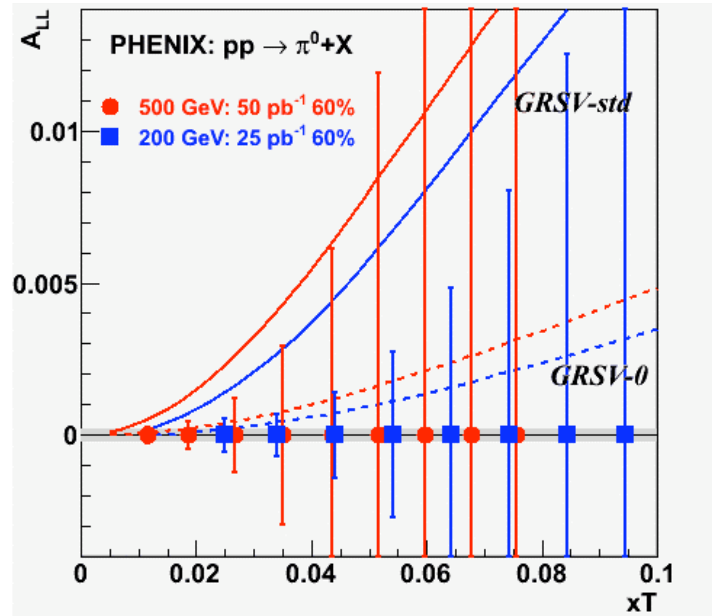
In 10-weeks at 500 GeV PHENIX can extend its *x*-range significantly and check gluon spin “wisdom”

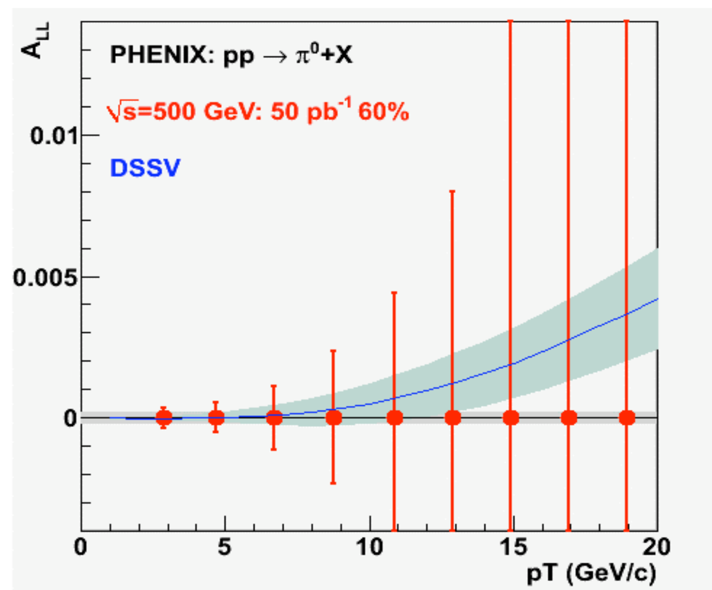
de Florian, Sassot, Stratmann, Vogelsang PRL 101, 072001(2008)

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

Explore also π,h$^{\pm}$,γ,η, heavy flavor for additional Δg(x) shape constraints

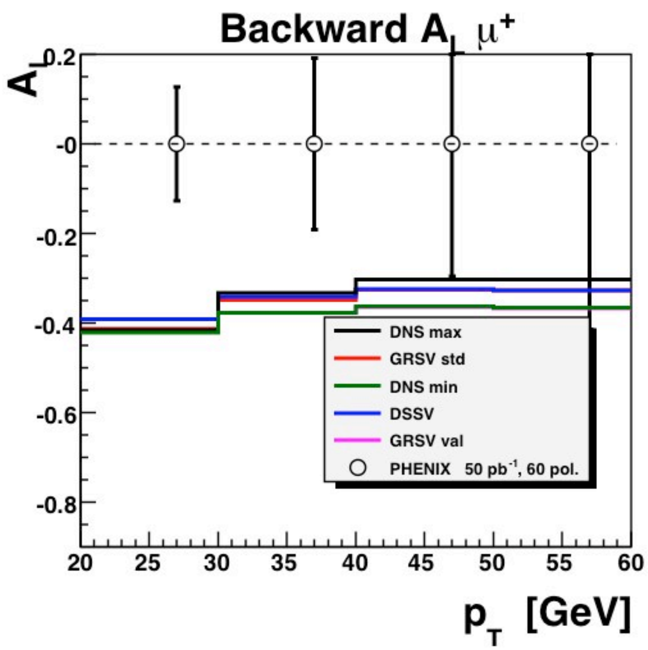


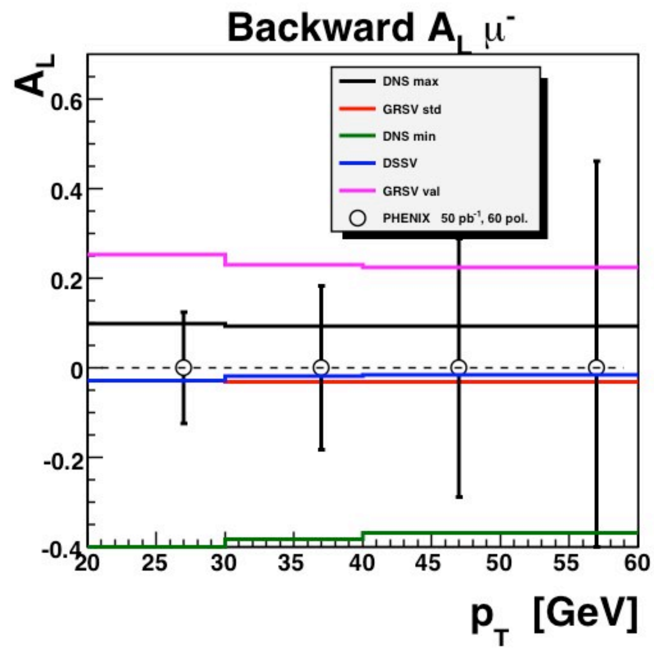




- Δg(x) small in current RHIC range
- Best fit has a node at x~0.1
- Low-x less constrained

Run-11 W measurement





as presented at BNL review of muTr and RPCs

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	

on schedule!

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

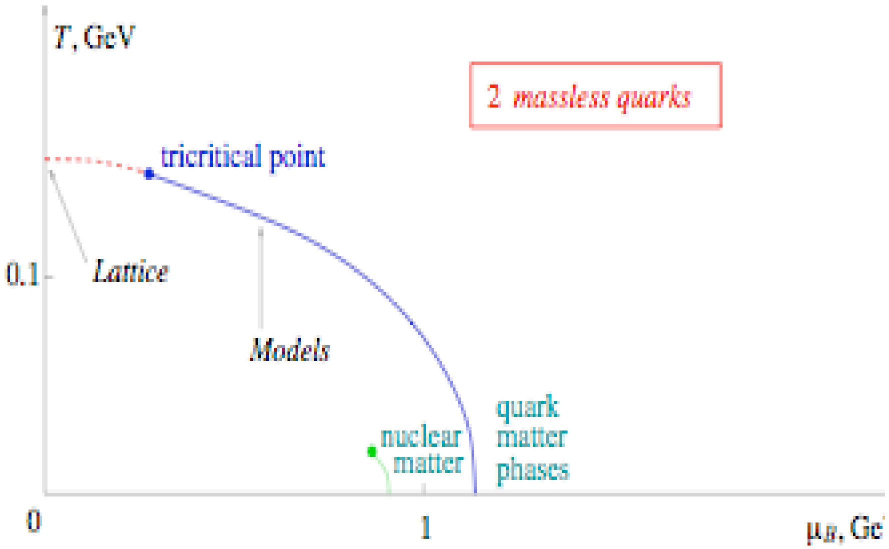
Improved rejection of beam backgrounds for highest lumi.

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 equiped with a prototype absorber.

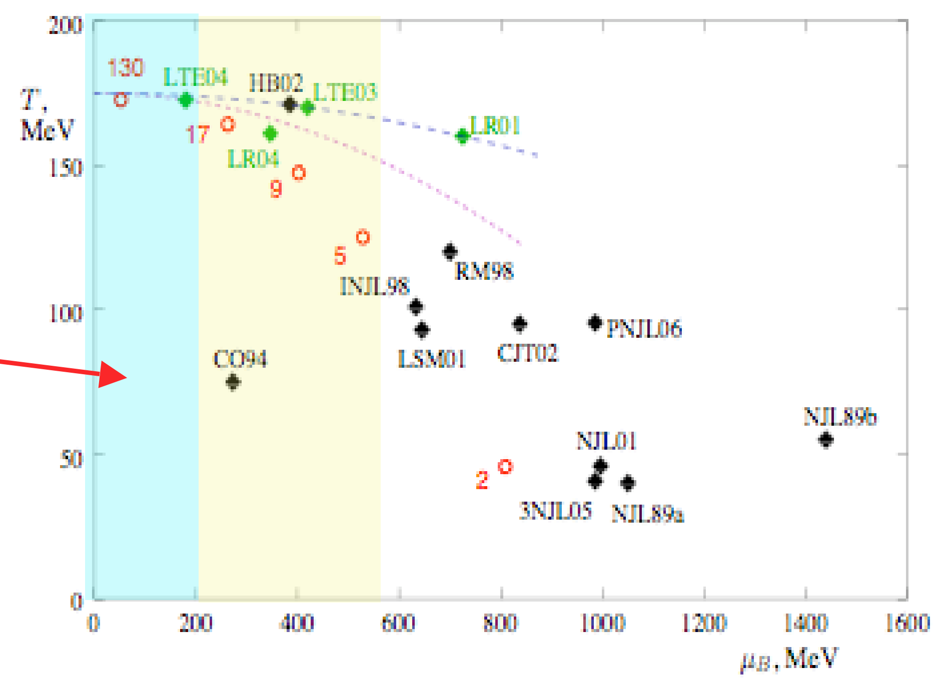
PHENIX

Where is the critical end point?



M.A. Stephanov, PoS(LAT2006)024

Range accessible with RHIC with substantial luminosity (above $\sqrt{s_{NN}} = 22$ 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

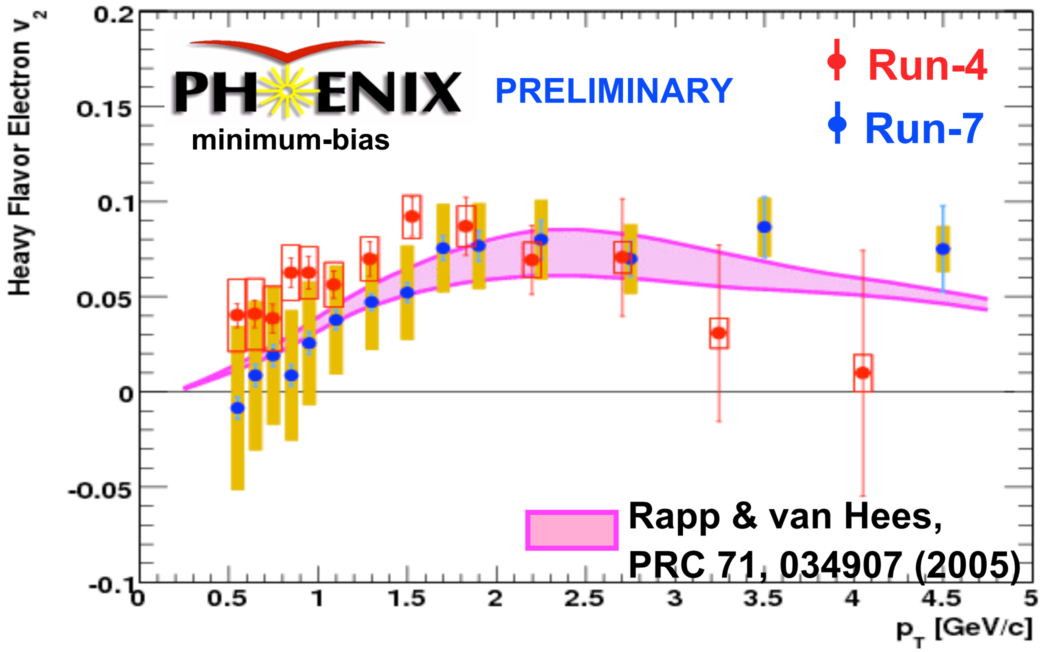
- **Critical endpoint:**
  v_2 centrality dependence, p vs. π
  Fluctuations in N_{ch}, baryon number
  (to find susceptibility divergence)
  K/π, p/π ratios and their fluctuations
  p_T fluctuations

were investigated At CERN SPS

NB: need p+p reference data!!

Open charm flows!

Elliptic flow of non-photonic electrons

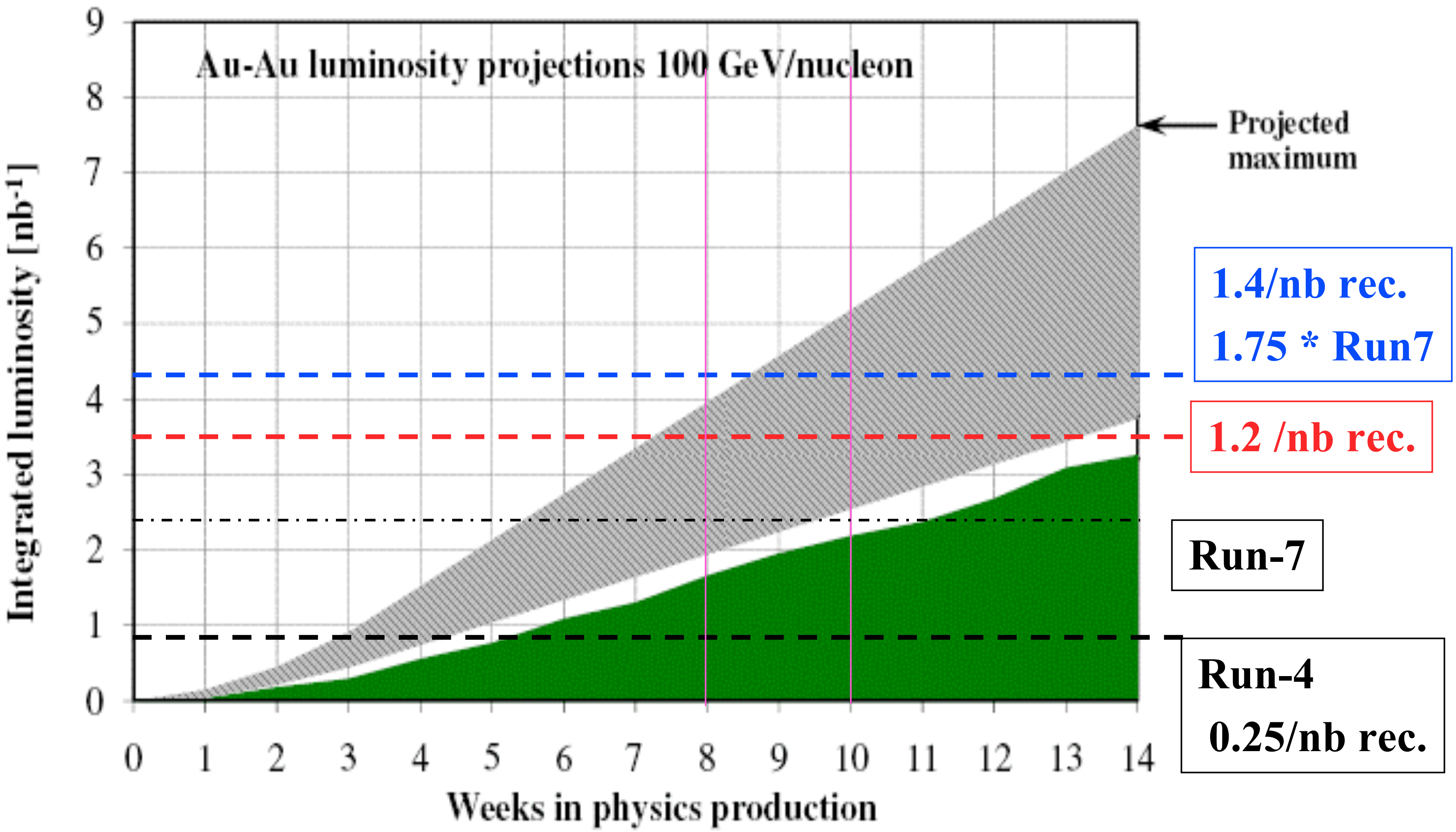


- **Do b's flow too, or just charm?** ***ANS: VTX in Run-11***
- **Does thermalized charm contribute to J/ψ?**

  i.e. does J/ψ 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

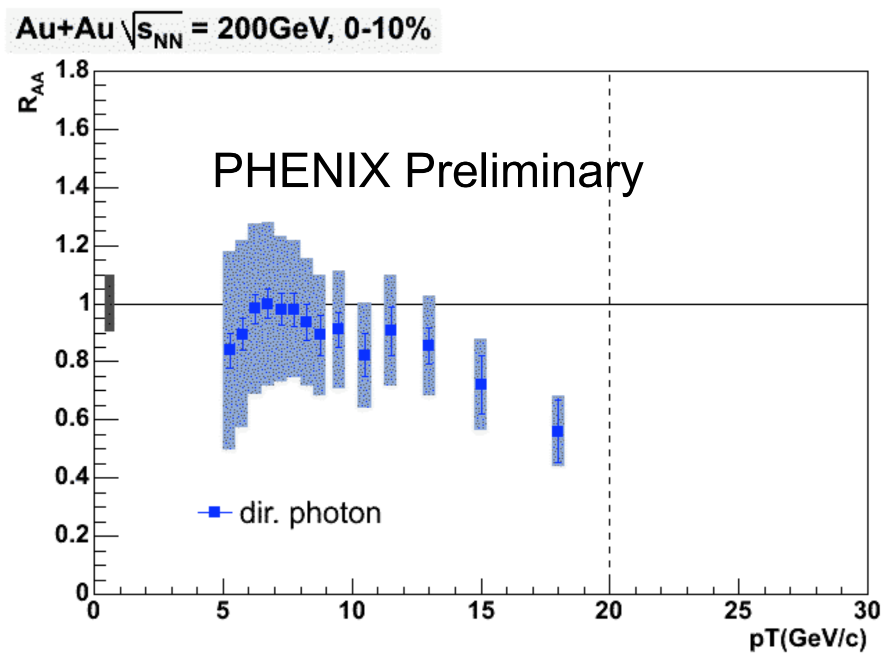


8 weeks → 1-1.2 times Run-7; 10 weeks → 1.75 x Run-7

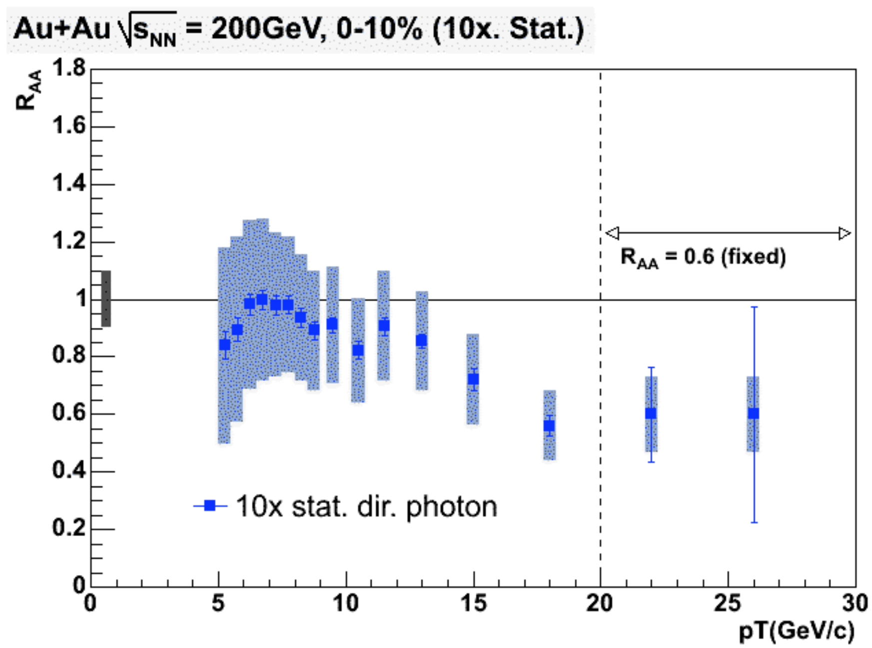
NSAC performance measures

- 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/ψ production in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV.
    - ✓2005 Measure flow and spectra of multiply-strange baryons in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV.
    - ✓2007 Measure high transverse momentum jet systematics vs. $\sqrt{s_{NN}}$ up to 200 GeV and vs. system size up to Au+Au.
    - 2009 Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC
    - ✓2010 Measure the energy and system size dependence of J/ψ production over the range of ions and energies available at RHIC.
    - ✓2010 Measure e^+e^- production in the mass range $500 \leq m_{e+e-} \leq 1000$ 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 q contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.

Direct photons – suppressed or not?



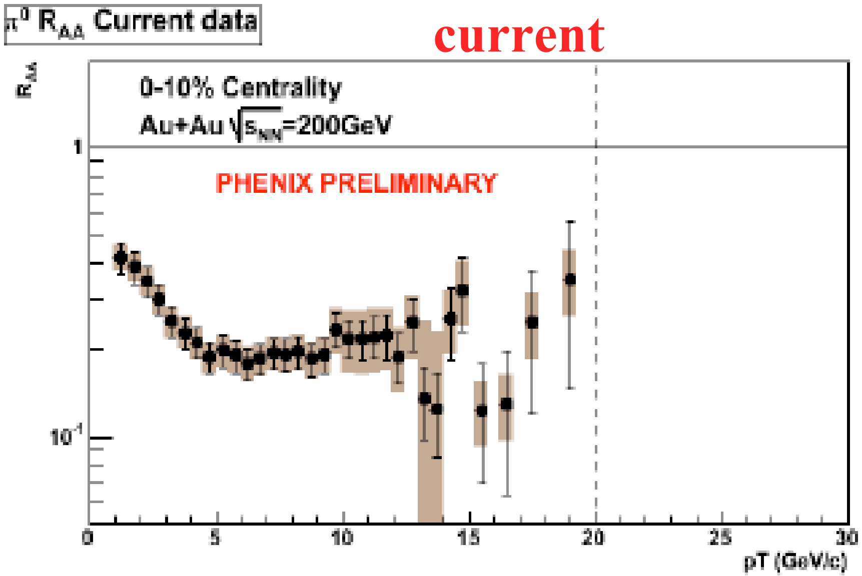
Current result



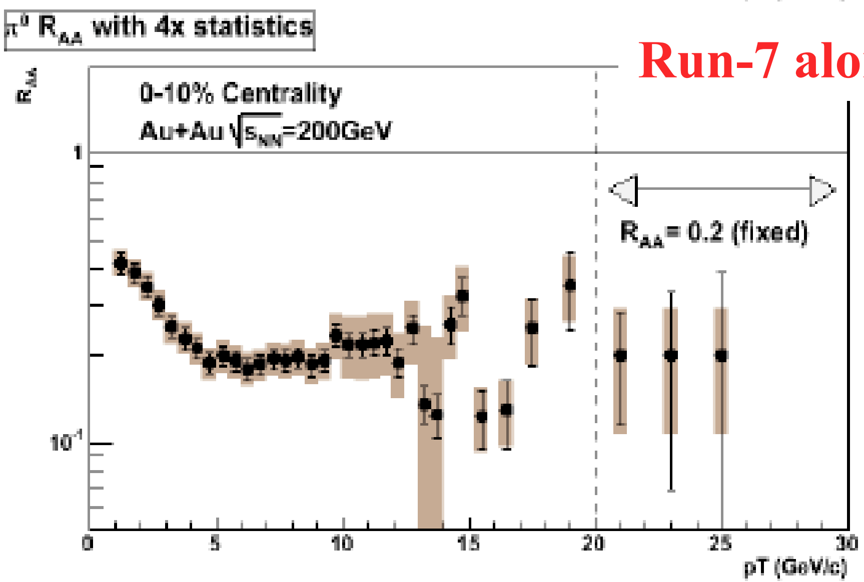
w/ 10x Run4 Stats.

Inmprove p_T range & errors

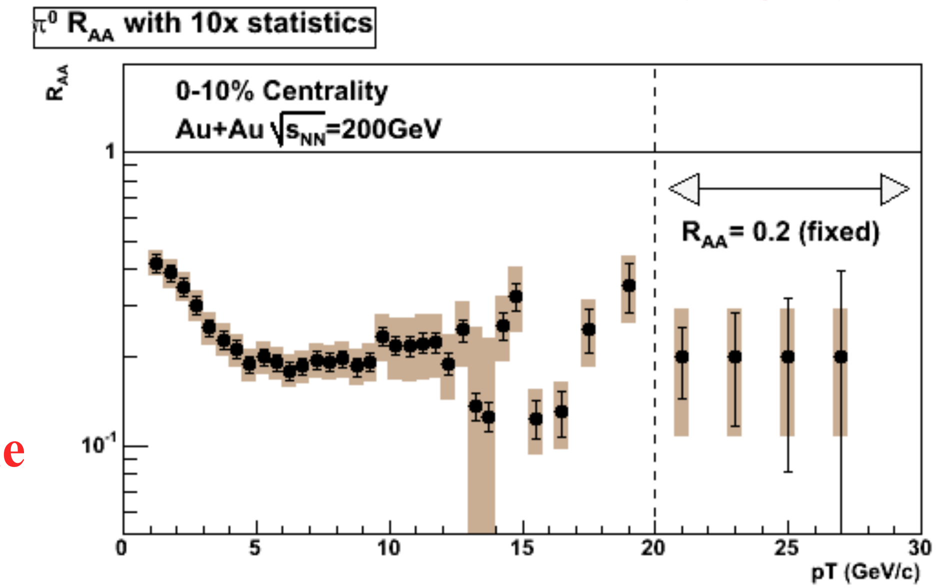
current



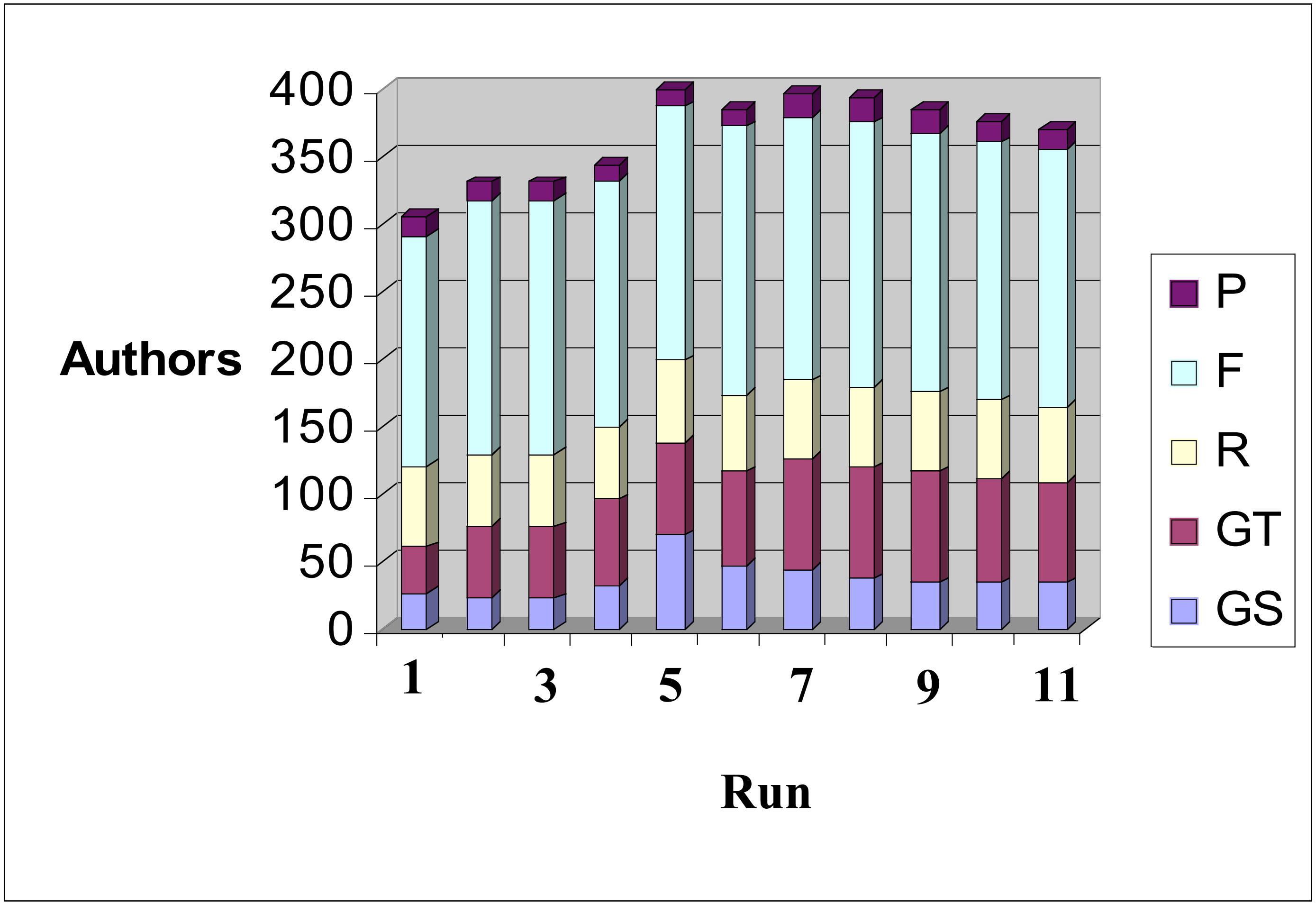
Run-7 alone



Run-7 + 9



PHENIX is, and will remain, strong

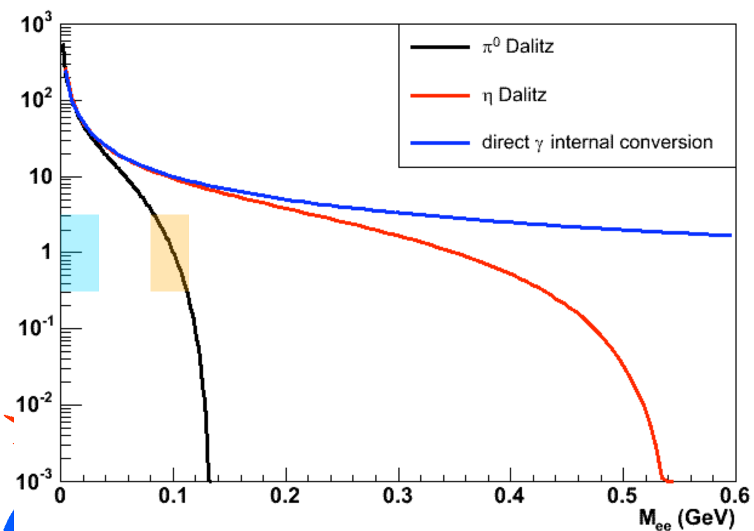


Virtual Photon Measurement

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

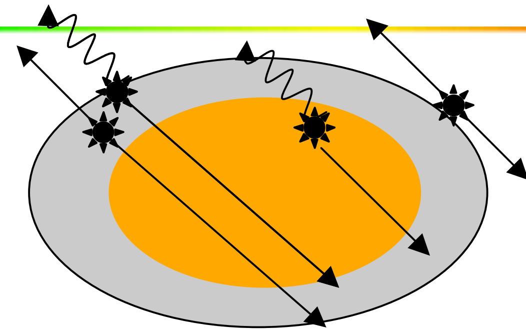
$$\frac{d^2N}{dM_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{M_{ee}^2}}\left(1+\frac{2m_e^2}{M_{ee}^2}\right)\frac{1}{M_{ee}} S dN_\gamma \qquad \text{Eq. (1)}$$

S : Process dependent factor

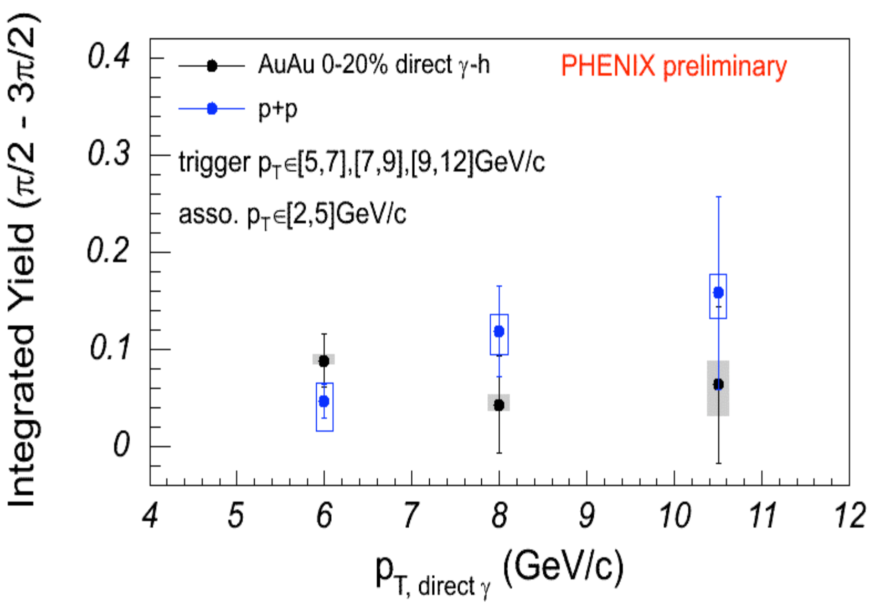


- Case of Hadrons
  - $S = \left|F(M_{ee}^2)\right|^2 \left(1-\frac{M_{ee}^2}{M_{hadron}^2}\right)^3$
  - Obviously $S = 0$ at $M_{ee} > M_{hadron}$
- Case of direct γ^*
  - If $p_T^2 \gg M_{ee}^2$
    - $S = 1$
- Possible to separate hadron decay components from real signal in the proper mass window.

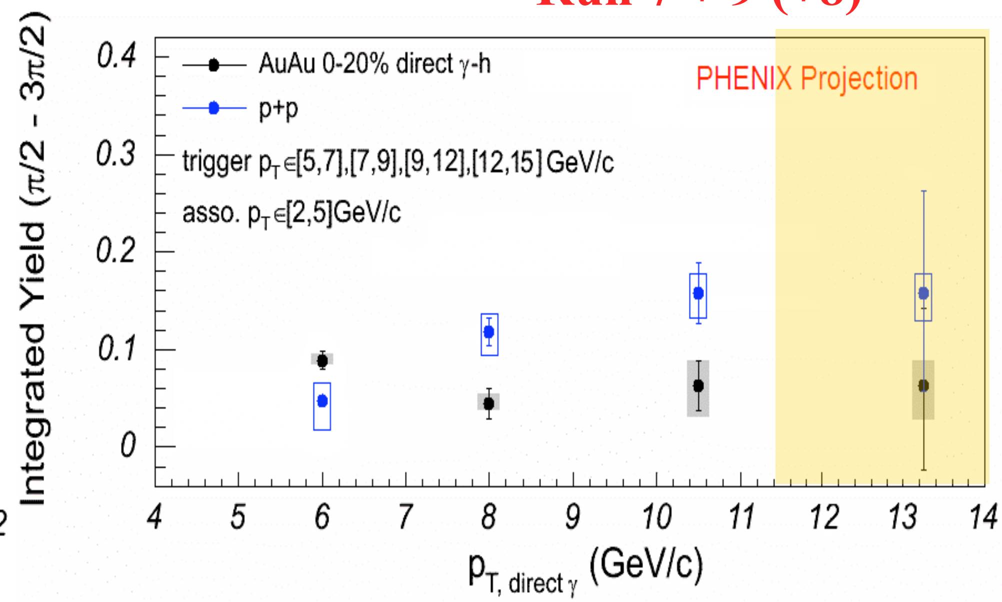
direct γ – jet coincidence: calibrated jet probe



current result



Run 7 + 9 (+8)

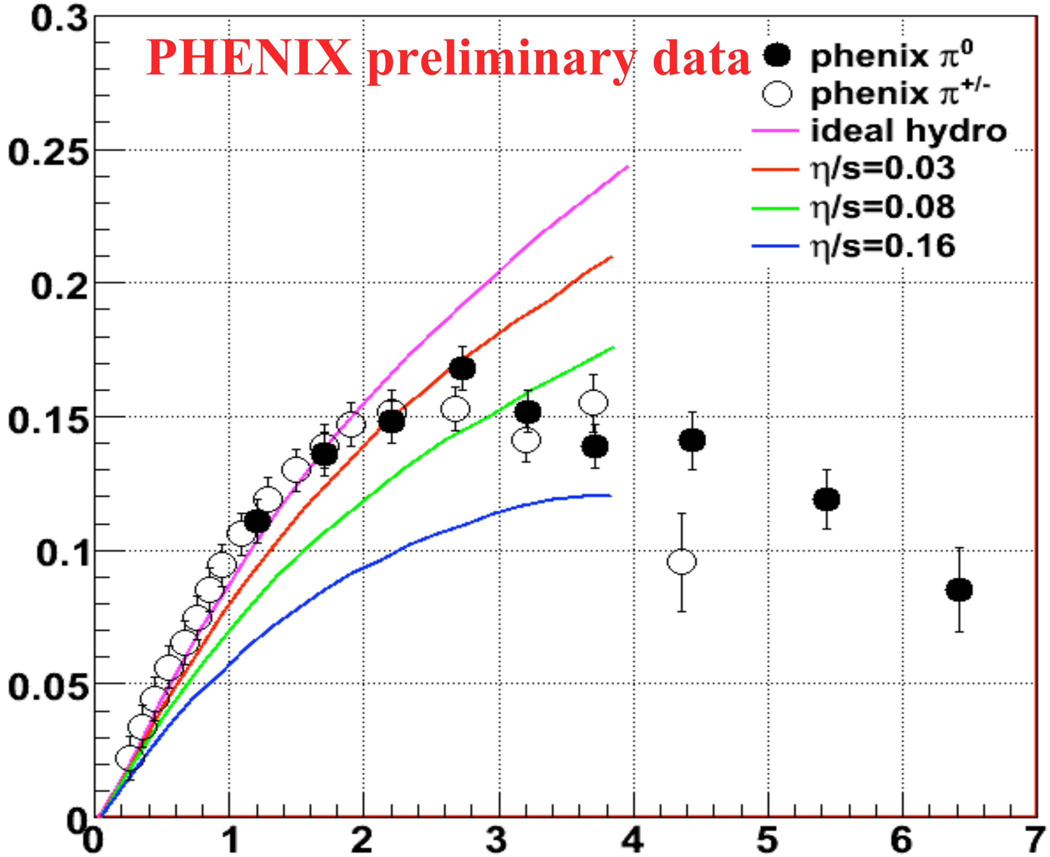


Toward quantifying η/S

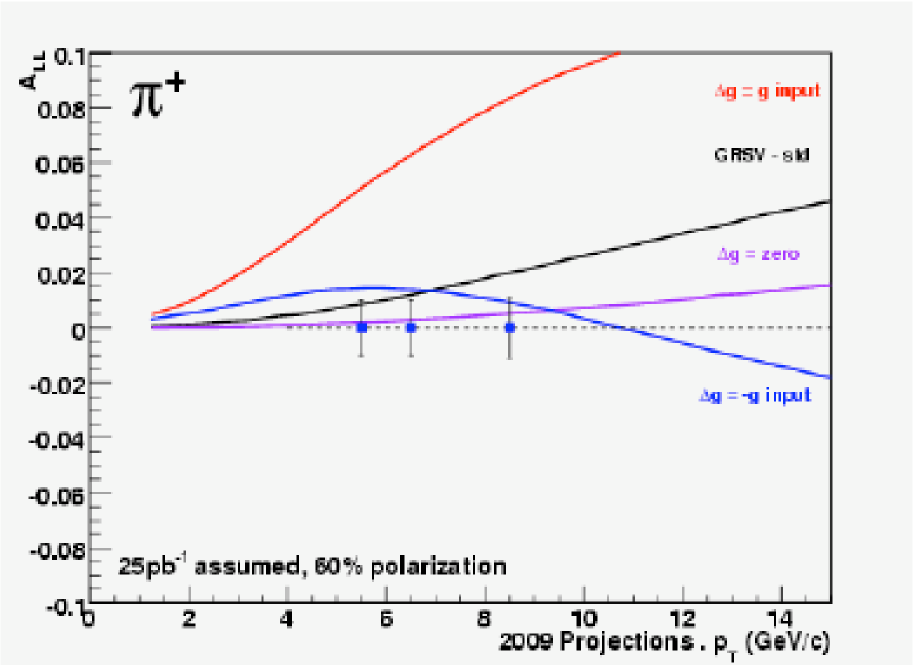
Curves from

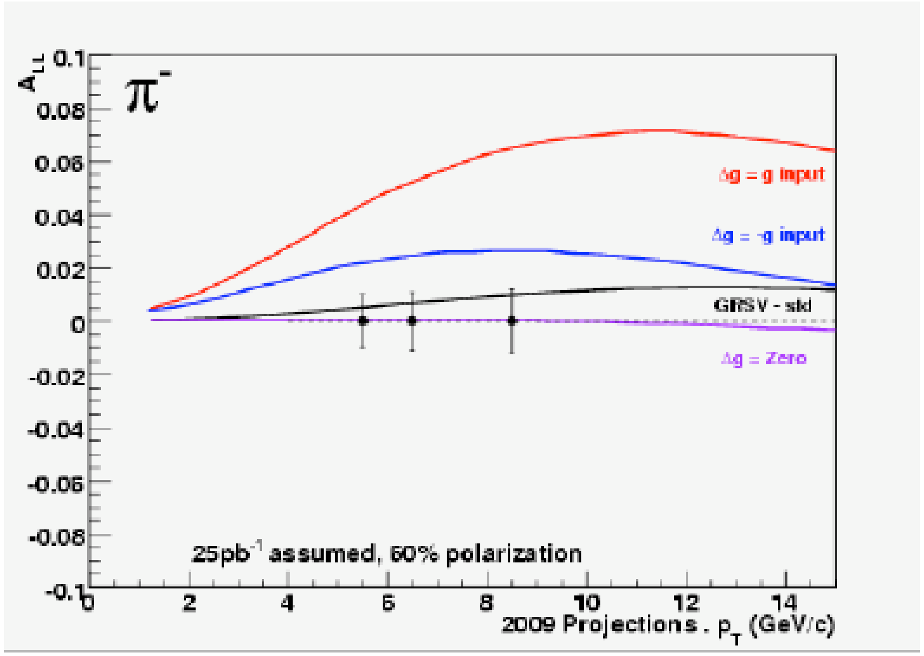
Romatschke & Romatschke,

arXiv:0706.1522



Charged pions sensitive to sign of ΔG





q+g dominates for p_T > 5 GeV/c, A_{LL} ~ linear with ΔG