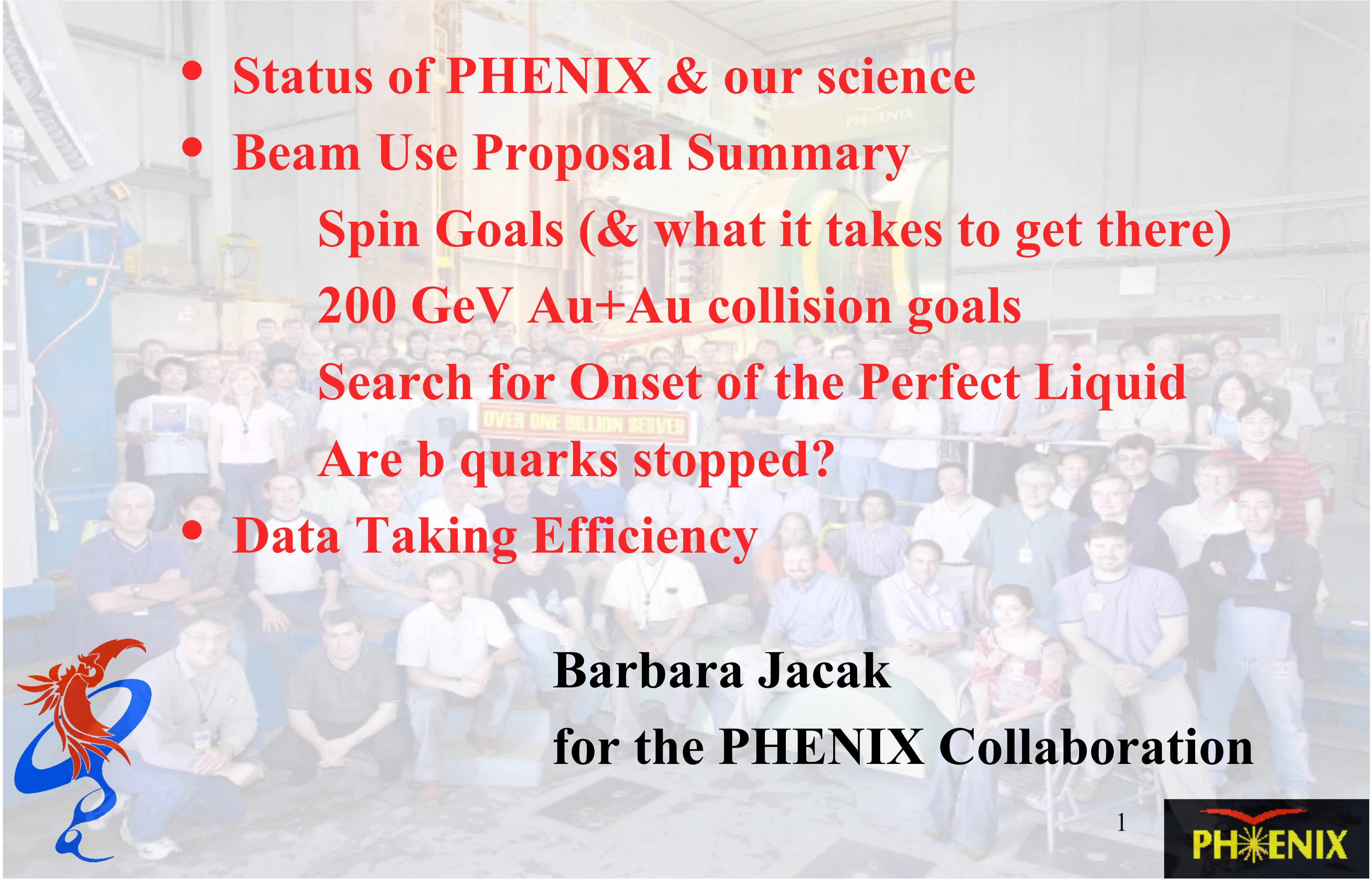
PHENIX Beam Use Proposal for Runs 9-13

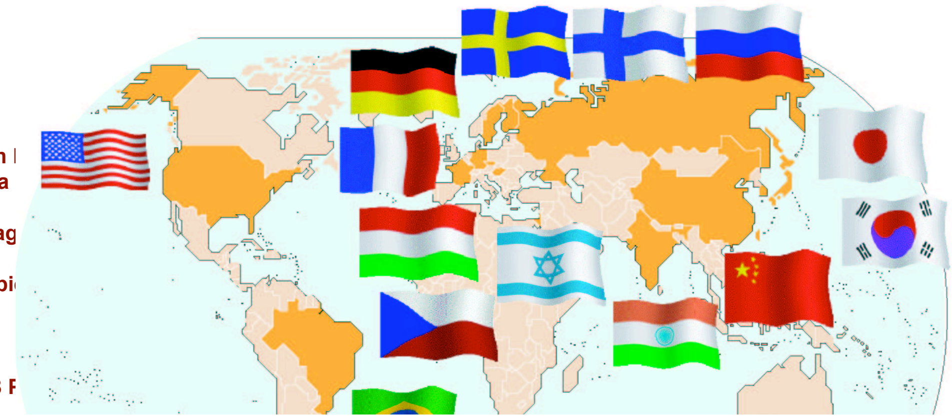


- Status of PHENIX & our science
- Beam Use Proposal Summary
  - Spin Goals (& what it takes to get there)
  - 200 GeV Au+Au collision goals
  - Search for Onset of the Perfect Liquid
  - Are b quarks stopped?
- Data Taking Efficiency

Barbara Jacak

for the PHENIX Collaboration

PHENIX Collaboration



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14 Countries; 68 Institutions; 550 Participants*

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PHENIX

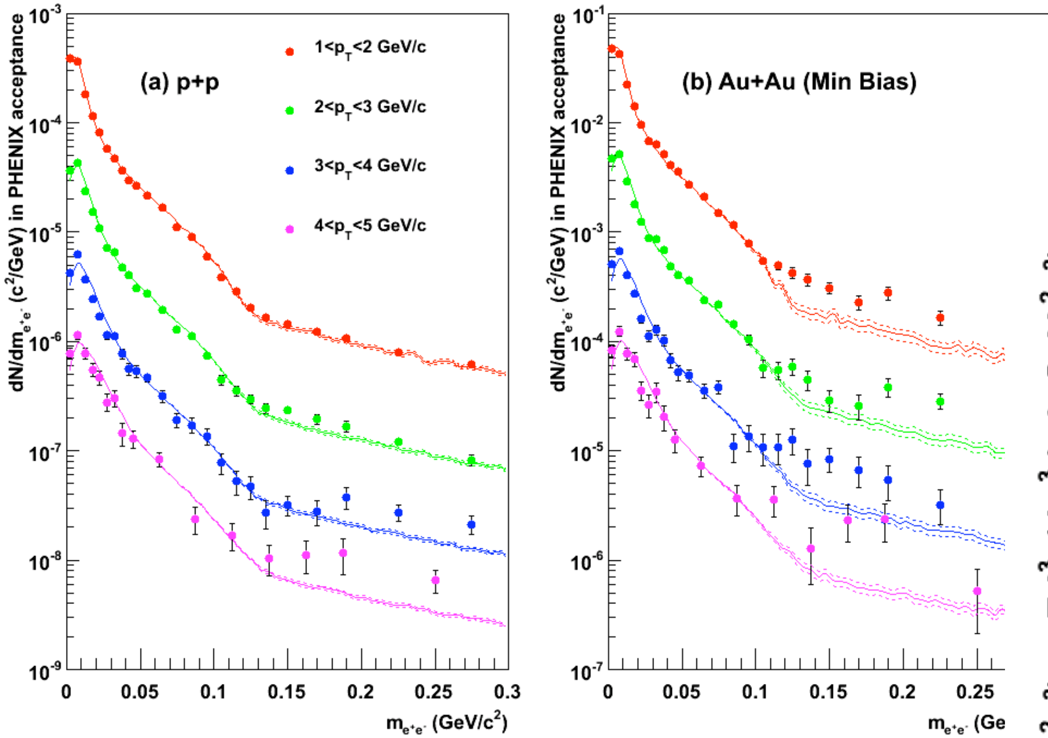
Recent scientific accomplishments

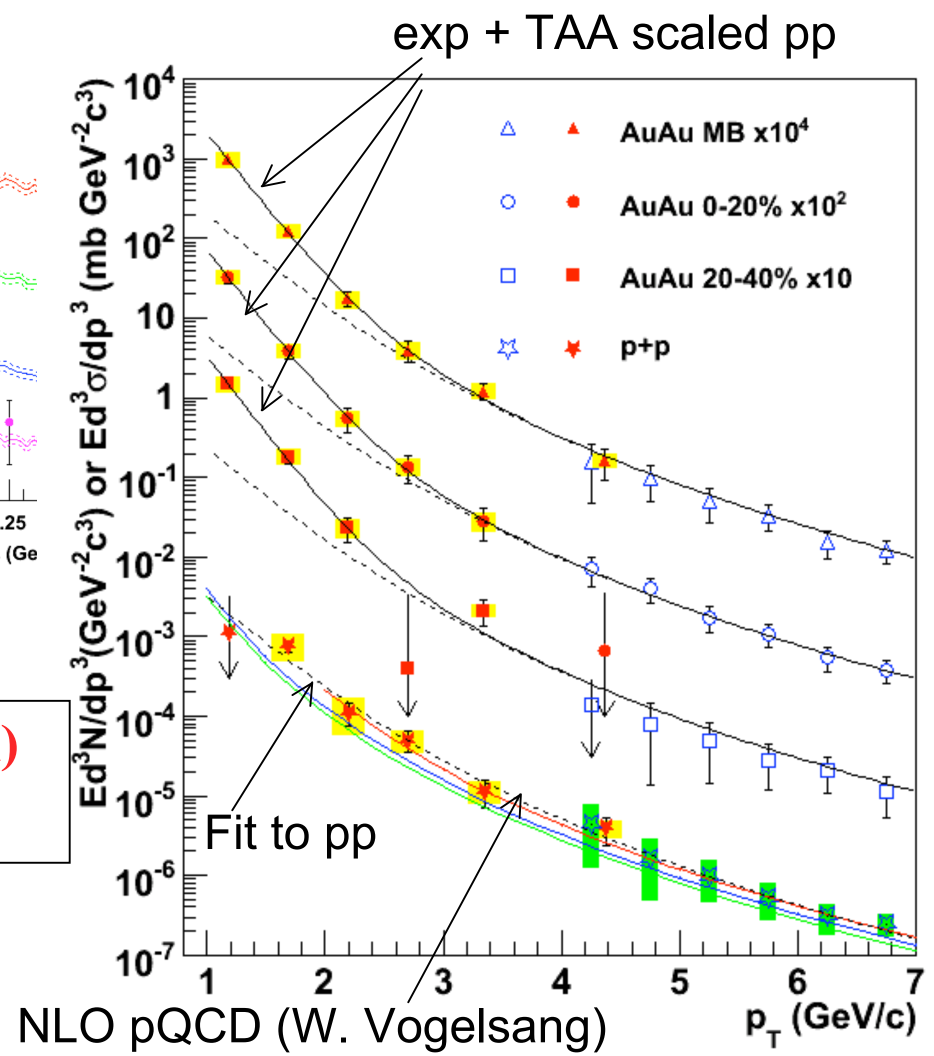
- **First measurement of initial temperature at RHIC** *0804.4168*
- **Discovery of low mass dilepton excess in central Au+Au** *0706.3034*
- **Quantitative analysis of energy loss** *0801.1665; 0801.4020*
- **Opacity emergence between 22.4 and 62.4 GeV $\sqrt{s_{NN}}$** *0801.4555*
- **Mapping the medium response to jets** *0801.4545; 0712.3033; PRC77, 011901(2007)*

+ 8 additional papers: high p_T hadron suppression, J/Ψ suppression, source imaging, dielectrons (p+p), d+Au/p+Au/n+Au, fluctuations, phi flow, A_{LL}.

T_{init} via low mass, high p_T dileptons

arXiv: 0804.4168

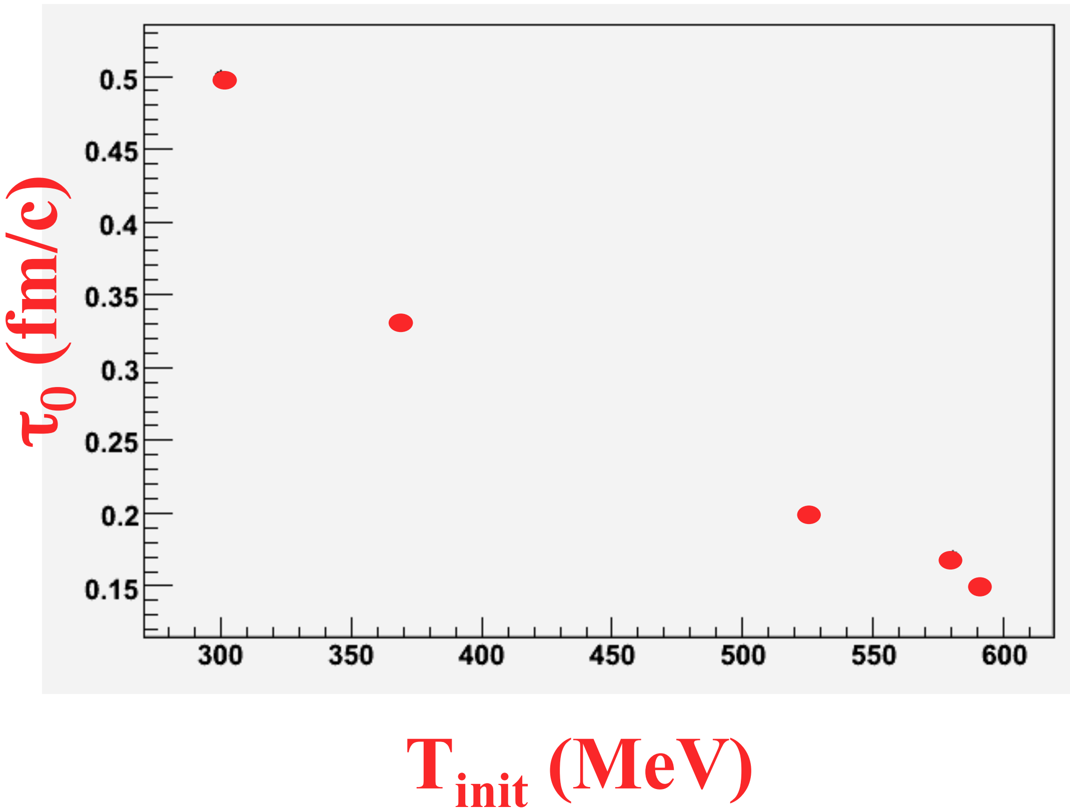




$T = 221 \pm 23 \pm 18$ MeV (central)

$T = 224 \pm 16 \pm 19$ MeV (MB)

Initial temperature (with aid of models)*



Hydrodynamical models in qualitative agreement with the data: Eur.Phys.J. C46 (2006) 451

D.d'Enterria &D.Peressounko
T=590MeV, τ_0=0.15fm/c

S. Rasanen et al.
T=580MeV, τ_0=0.17fm/c

D. K. Srivastava
T=450-600MeV, τ_0=0.2fm/c

S. Turbide et al.
T=370MeV, τ_0=0.33fm/c

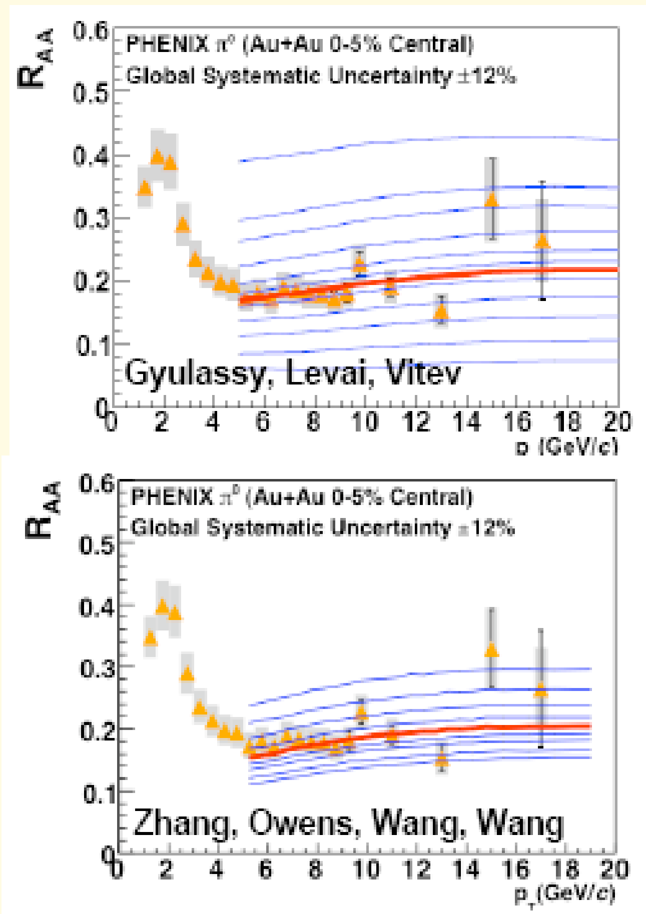
J. Alam et al.
T=300MeV, τ_0=0.5fm/c

$T_{init} > T_c$ even for simple exponential!

*** and 1 billion events …**

Quantitative Analysis of Energy Loss

PHENIX, arXiv:0801.1655 [nucl-ex]



- Fit of model parameters to data requires correct treatment of exp. uncertainties
  - Type A: point-by-point uncorrelated
  - Type B: Correlated (in p_T)
  - Type C: Normalization (constant factor for all points)
- Least square fit for this case

$$\tilde{\chi}^2 = \sum_{i=1}^{n} \frac{\left(y_i + \varepsilon_b \sigma_{b_i} + \varepsilon_c y_i \sigma_c - \mu_i\right)^2}{\tilde{\sigma}_i^2} + \varepsilon_b^2 + \varepsilon_c^2$$

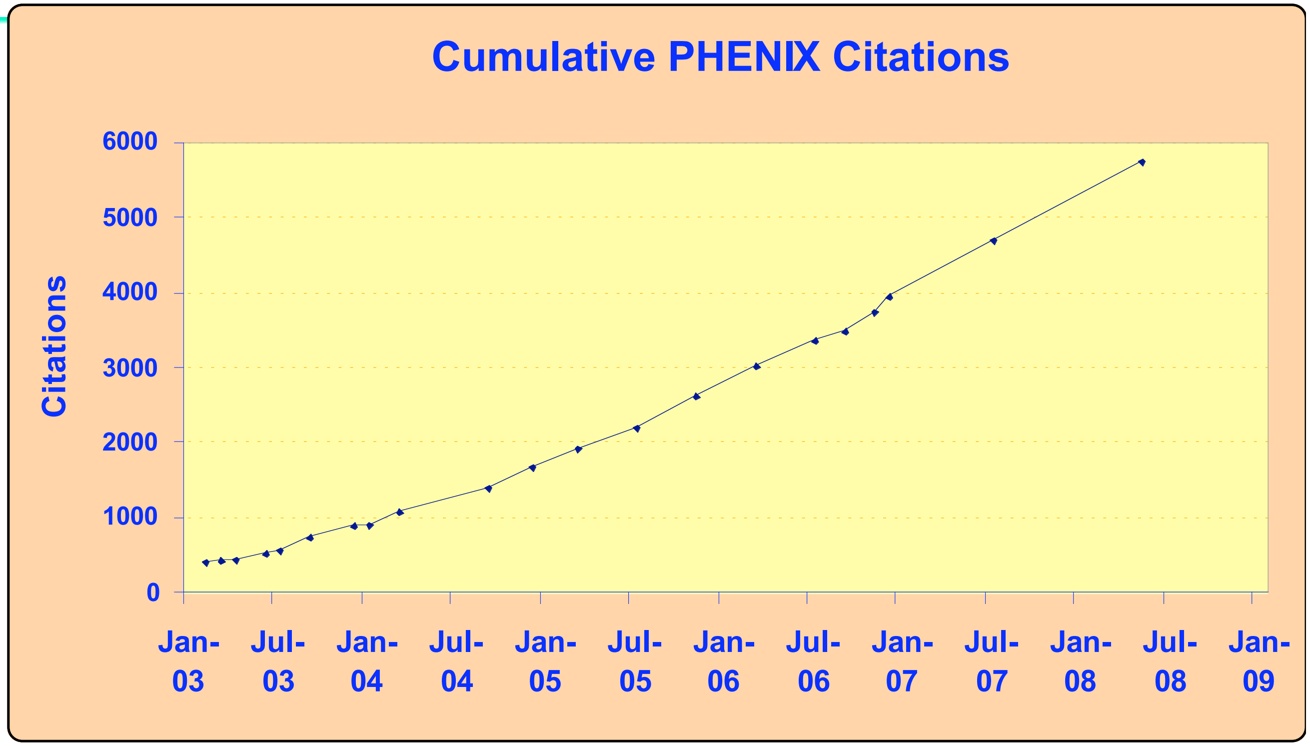
Takes type B and C uncertainties correctly into account

Results (1σ range): Caveat: theoretical uncertainties not included

PQM	GLV	WHDG	ZOWW
$\hat{q} = 13.2^{+2.1}_{-3.2}$ GeV^2/fm	$dN^g/dy = 1400^{+270}_{-150}$	$dN^g/dy = 1400^{+200}_{-540}$	$\varepsilon_0 = 1.9^{+0.2}_{-0.5}$ GeV/fm^3

Impact

- Since 2001:
  41 PRL's
  18 Phys. Rev. C
  5 Phys. Rev. D
  2 Phys. Lett. B
  1 Nucl. Phys. A (White Paper)
- > 5700 citations

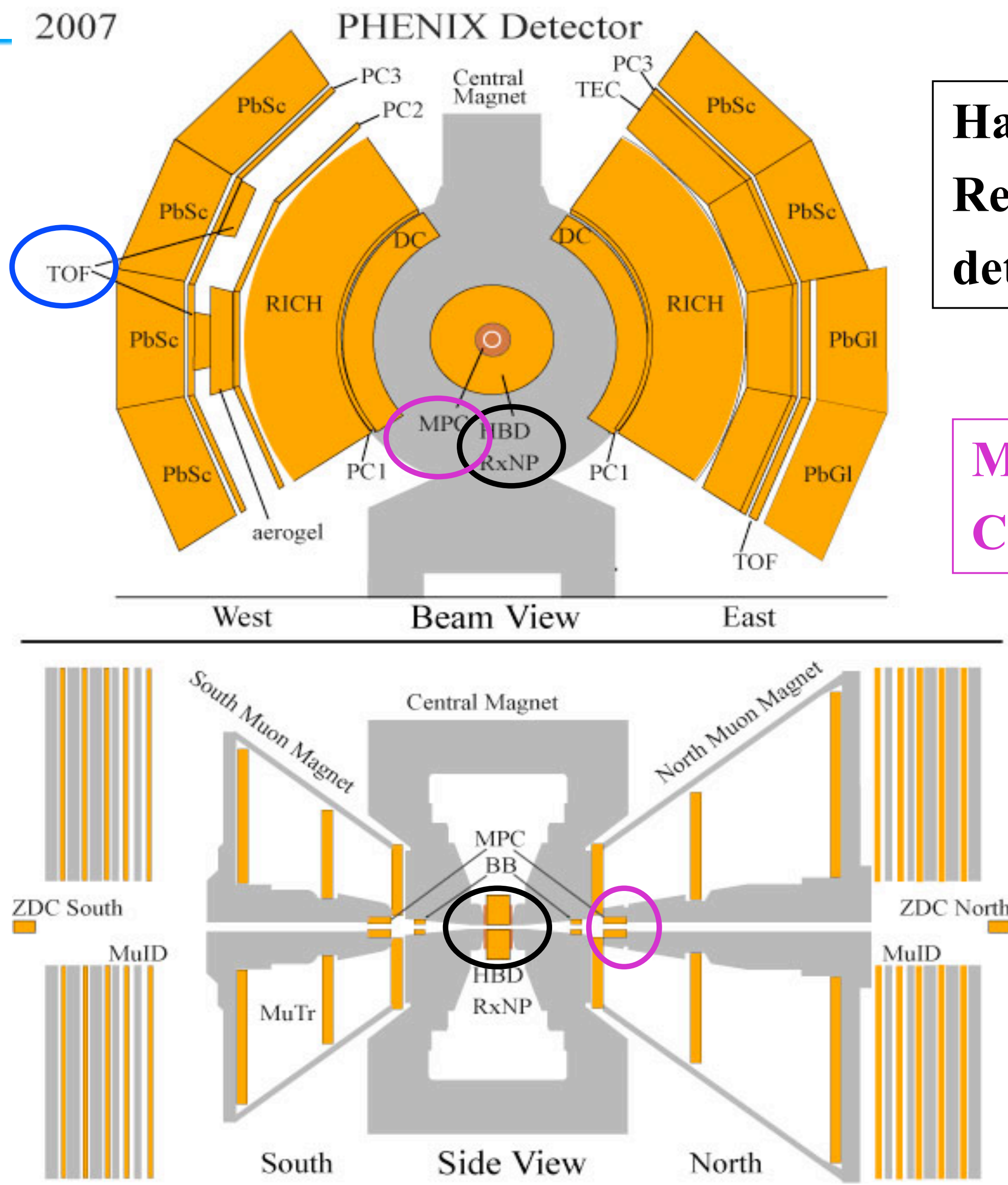


- Most-cited single result from RHIC (421 citations):
  "*Suppression of hadrons with large transverse momentum in central Au+Au collisions at* $\sqrt{s_{NN}} = 130$ *GeV*",
  K. Adcox *et al.* , Phys.Rev.Lett. 88:022301 (2002), nucl-ex/0109003

  + 5 other papers with > 250 citations

PHENIX Detector Status

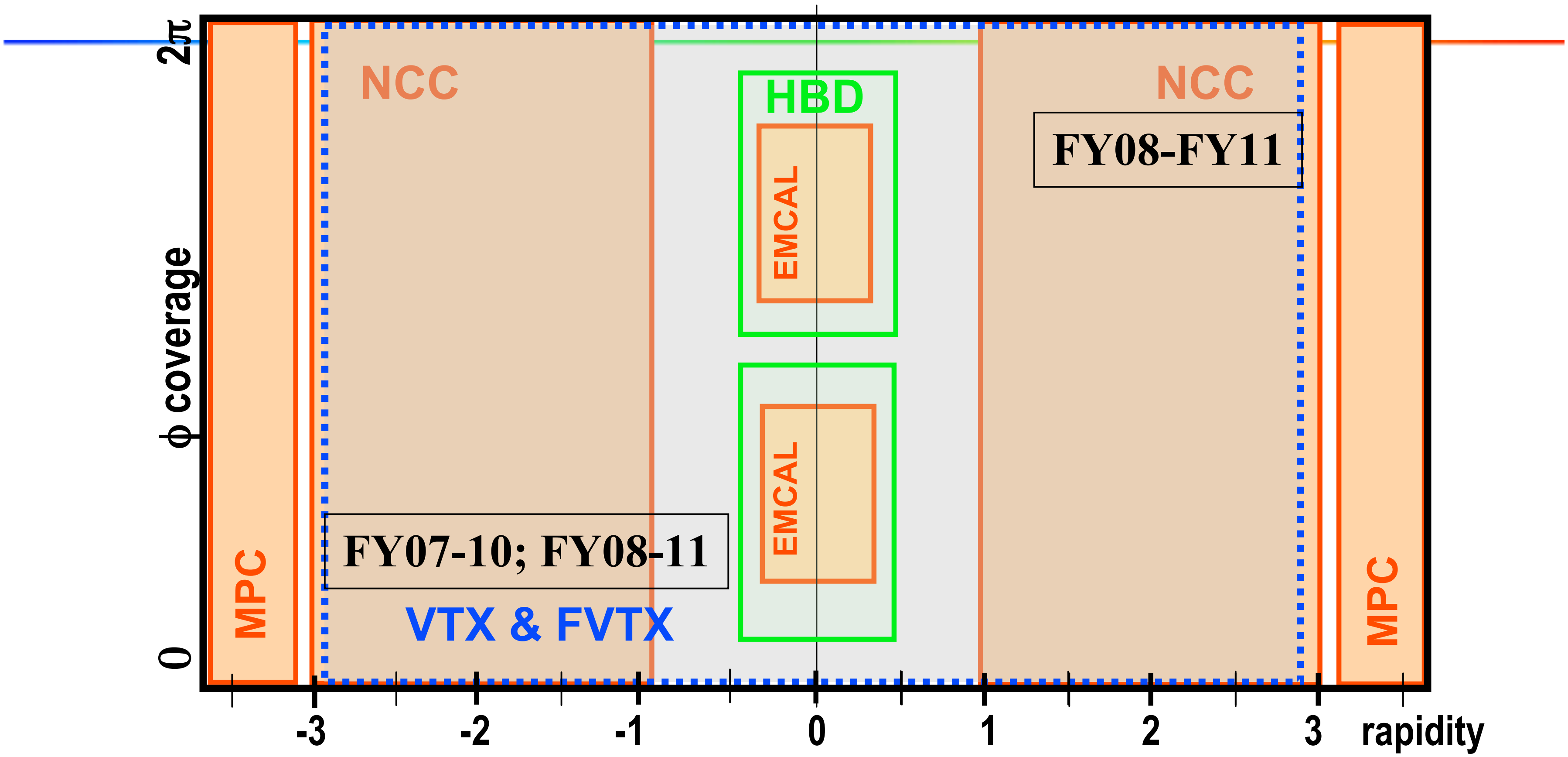
TOF-W (PID)



Hadron Blind, Reaction Plane detectors

Muon Piston Calorimeter (N & S)

Detector Upgrades



(i) *π^0 and direct γ* with additional forward EM calorimeters (NCC)

(ii) *heavy flavor* with silicon vertex trackers (VTX, FVTX)

(i)+(ii) for large acceptance *γ-jet*

PHENIX Beam Use Proposal*

RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS	$\int \mathcal{L}dt$ (recorded)
9	p+p	200	10	25 pb^{-1}
	OR $\vec{p}+\vec{p}$	500	5	25 pb^{-1}
	Au+Au	200	10	1.4 nb^{-1}
10	p+p	500	5	25 pb^{-1}
	OR $\vec{p}+\vec{p}$	200		
	p+p	62.4, 39, 28, 22.4	2.5	
	Au+Au	62.4, 39, 28	15	
11	Au+Au	200	M	
	p+p	500	25-M	
12	U+U	200	N	
	p+p	200	25-N	
13	p+p	500	Q	
	Au+Au	various	25-Q	

1.2-1.4nb^{-1}

8-10 weeks

*** Complexity from $ uncertainty**

Driving the requested schedule

- ***Spin Program***

  Progress hampered by ~ no p+p since Run-6

  → p+p highest priority for Run-9

- ***Physics Opportunities + Upgrades***

  Rare Probes with good precision in near term

  Plan to replace HBD by VTX (pixels) for Run-10

  → low mass e^+e^-: 200 GeV Au+Au run with HBD

  Full VTX in Run-11

  →first look at b quark: 200 GeV Au+Au (or U+U)

- ***Search for onset of perfect liquid behavior***

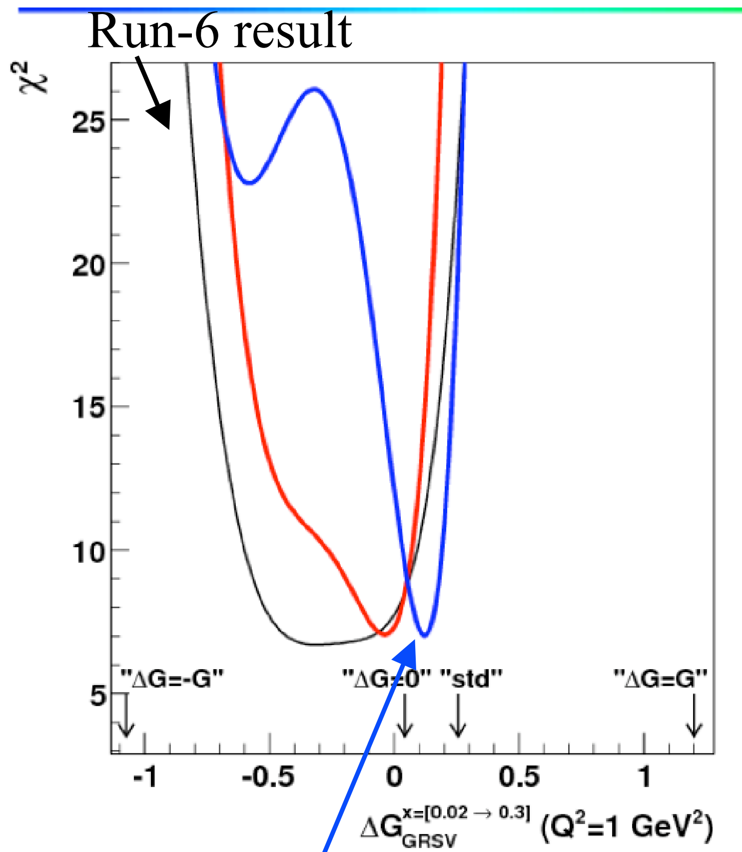
  → Au+Au from 29-62.4 GeV

- ***Milestones***

  First W physics in 2011 (RIKEN)

  Di-electrons in $0.5 < m_{ee} < 1.0$ GeV in 2010

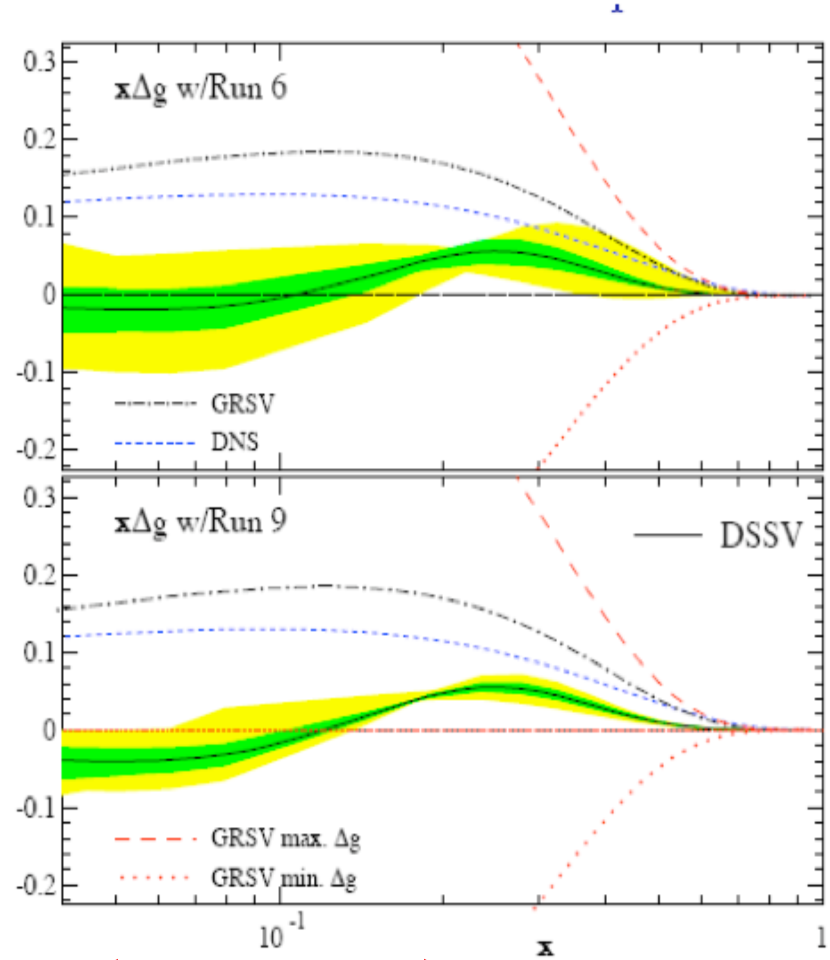
200 GeV polarized protons - the elusive ΔG



Run-9 sensitivity for $\Delta G_{\text{GRSV-std}}(x)/2$ (i.e. total=0.2, or 0.1 in measured region)

Sensitivity if ΔG=0

Global fits, DSSV arXiv:0804.0422

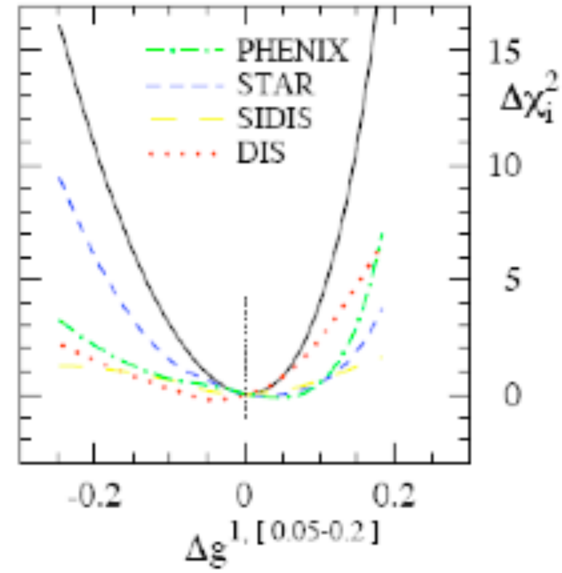


RHIC Constraint

The role of PHENIX

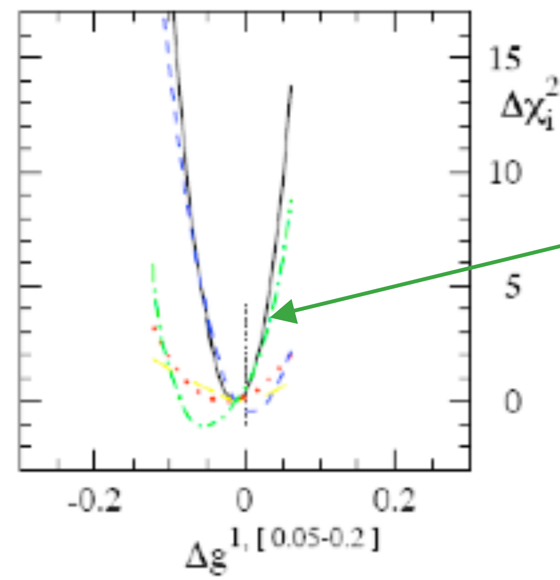
PHENIX will provide best constraint if ΔG is positive (in the range $0.05<x<0.2$)

In that case, the best sensitivity is via gluon-gluon interactions - high rates at low p_T.



Run-6

status

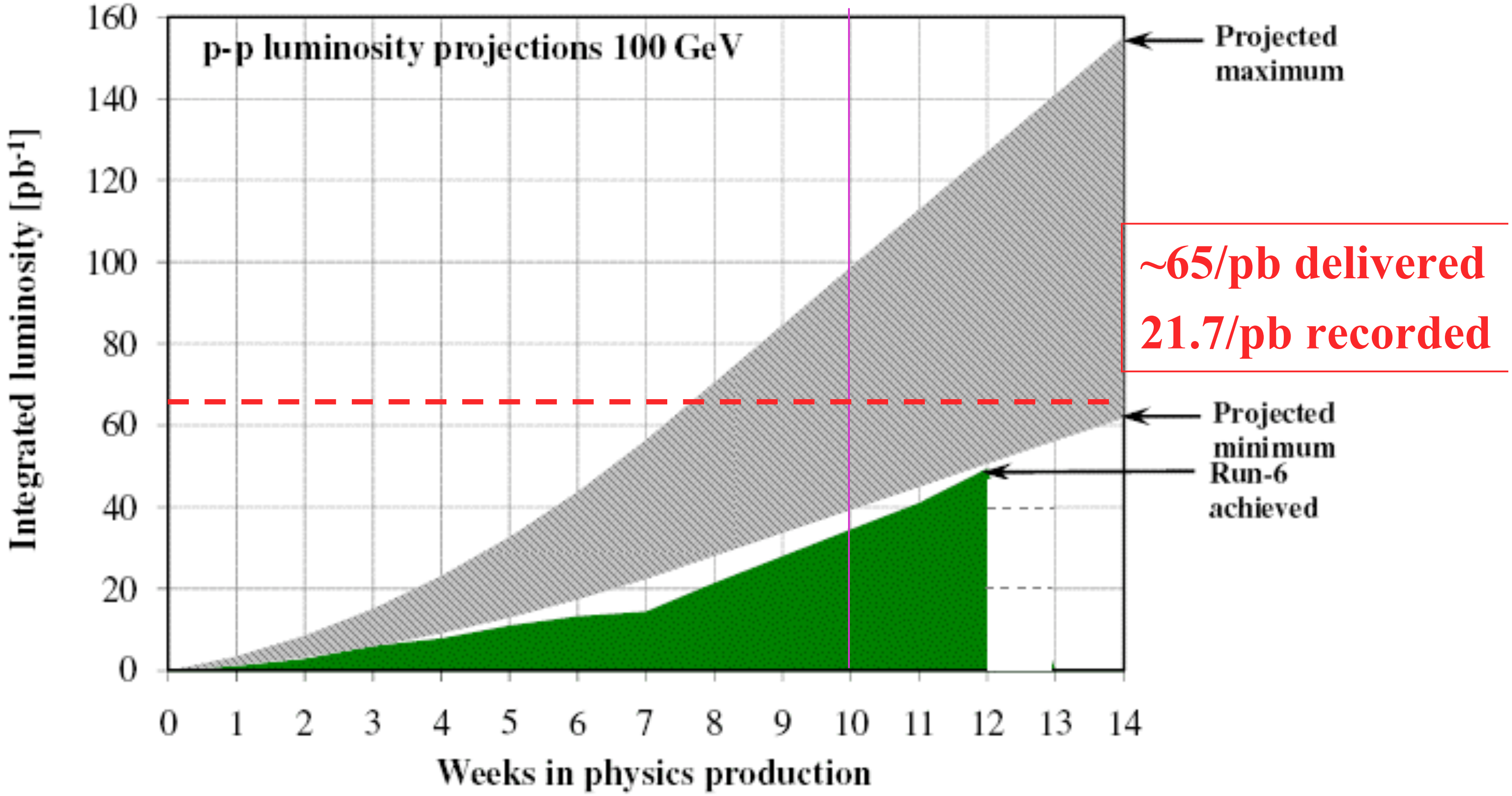


Run-9

Projection

200 GeV p+p (65% polarization)*

* assumed, and projected by CAD



Run-8 ratio recorded/delivered = 0.3

500 GeV p+p goals for Run-9

- Measure backgrounds under high p_T muons
- Test muon trigger electronics (currently being installed)
- Measure production cross sections

  π^0, γ to $p_T \sim 30$ GeV, J/ψ, Υ
- With 25 /pb can record W's in central arm

  ~ 500 W+ and ~ 90 W-

  First look at A_L with $\Delta A_L \sim 0.05$.

- Estimate 4 or 5 Physics Weeks needed

Compelling questions in Au+Au at $\sqrt{s_{NN}}$=200 GeV

- Does J/ψ flow (final state coalescence)?
  J/ψ v_2
- How is energy deposited to/transported in the medium?
  γ-h correlations, h-h correlations, fate of direct γ?
- Source of the low mass dileptons? Evidence for chiral symmetry restoration?
- Are b quarks stopped by the medium?
- How do highest energy densities differ?

→ **Extend sensitivity via increased integrated luminosity**

Order of magnitude $\int\mathcal{L}$ over existing Run-4!

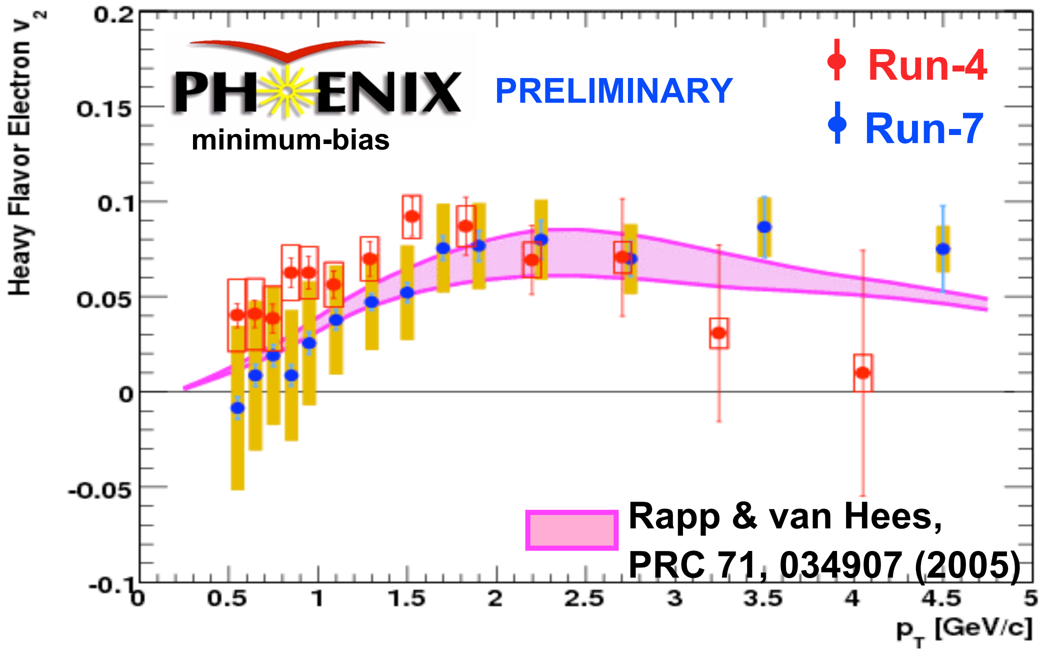
Collect in Run-7 + Run-9

→ **Run full energy Au+Au with VTX for c,b separation**

→ **U+U in Run-12**

Open charm flows!

Elliptic flow of non-photonic electrons

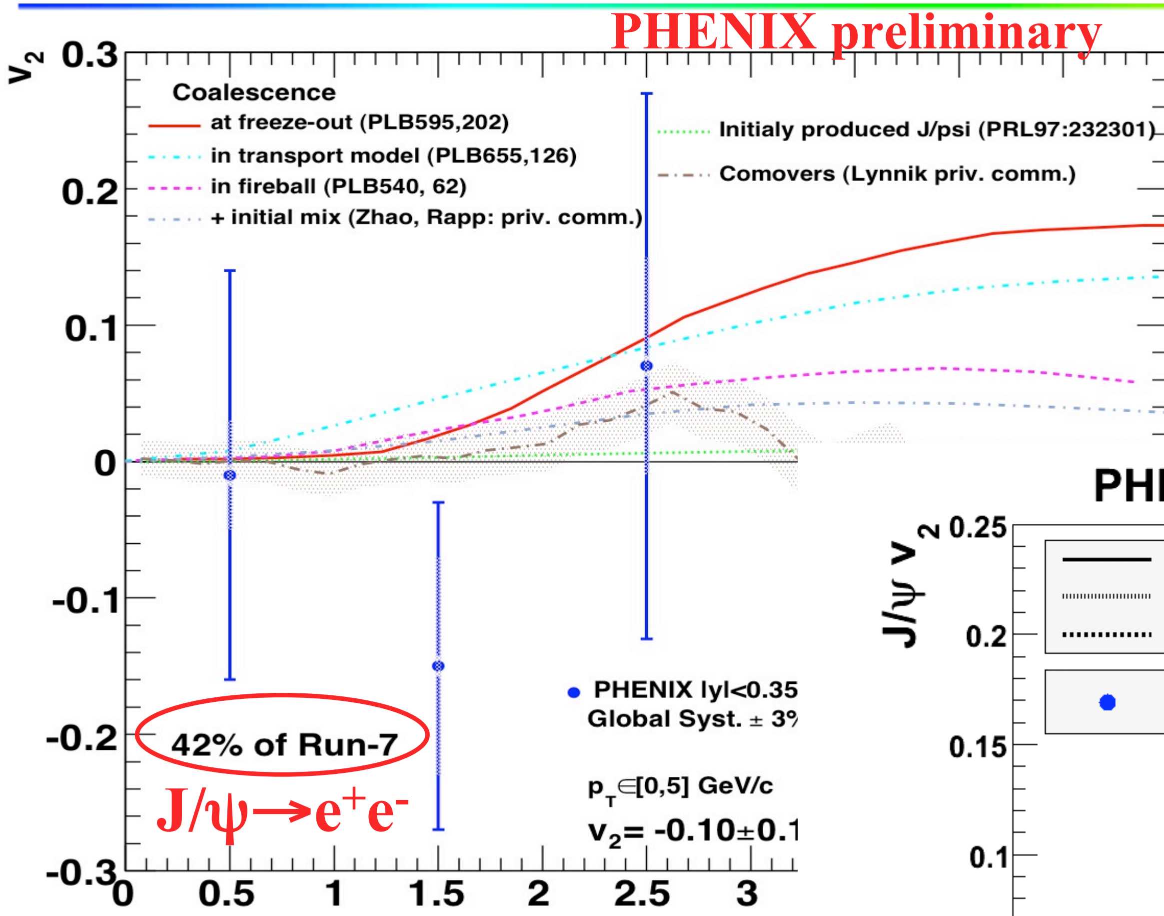


●Do b’s flow too, or just charm? ***ANS: VTX in Run-11***

●Does thermalized charm contribute to J/ψ?

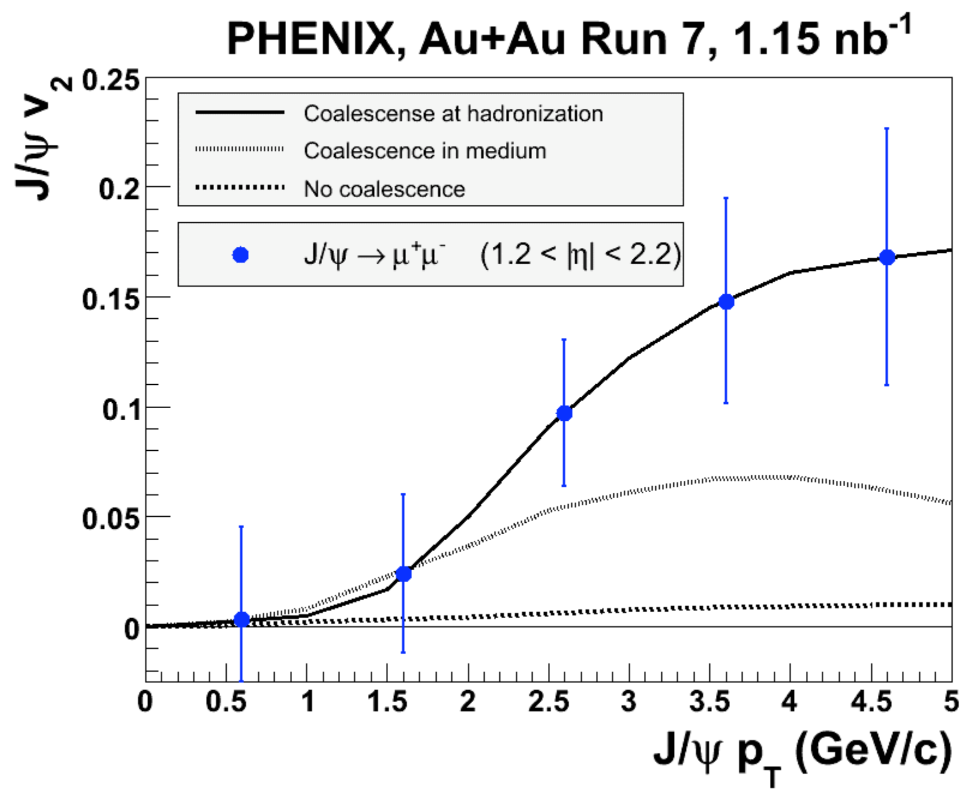
i.e. does J/ψ flow too? ***ANS: Run-9 + Run-7!***

J/ψ v_2

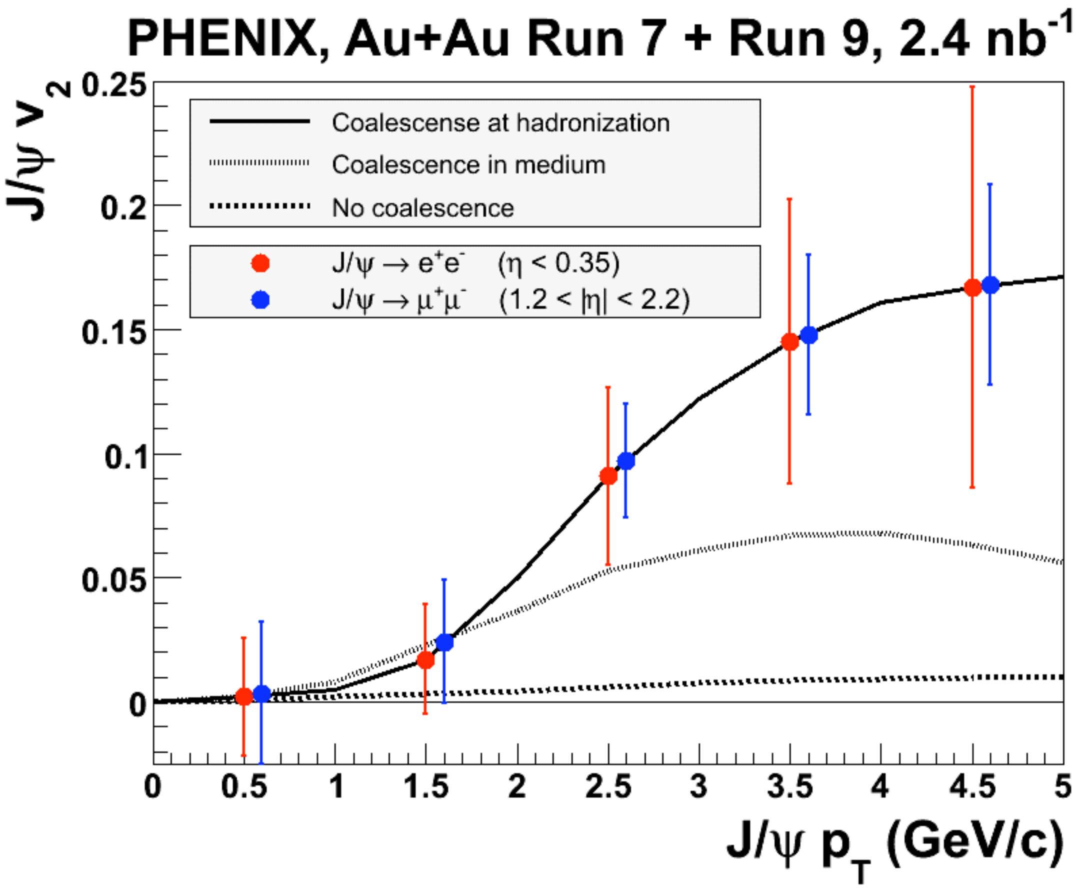


But we only got

0.8 nb^{-1} !



Precision of J/ψ v_2 measurement

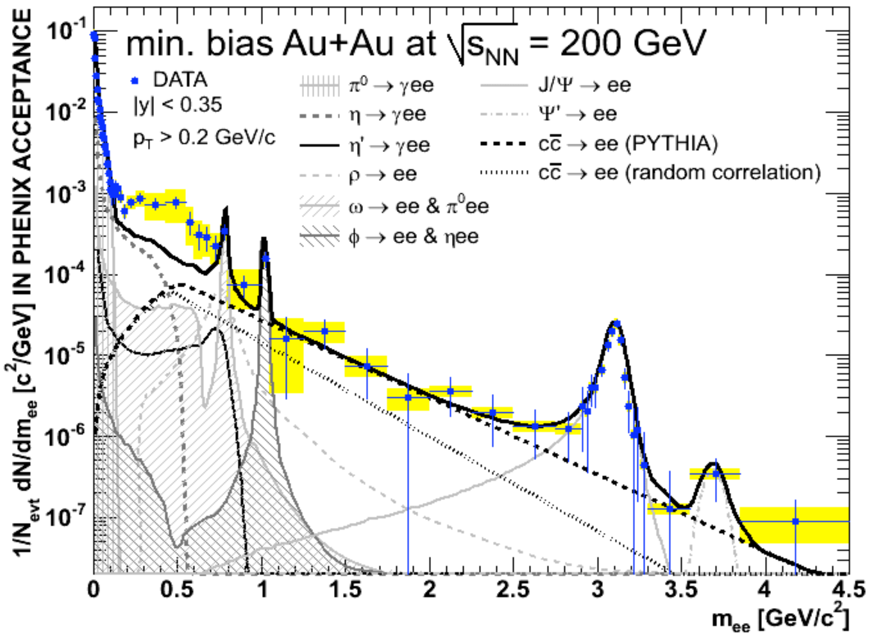


This would require 1.6 nb^{-1} in Run-9

PHENIX would be happy with 1.4 nb^{-1}

Low mass dielectrons

arXiv:0706.3034

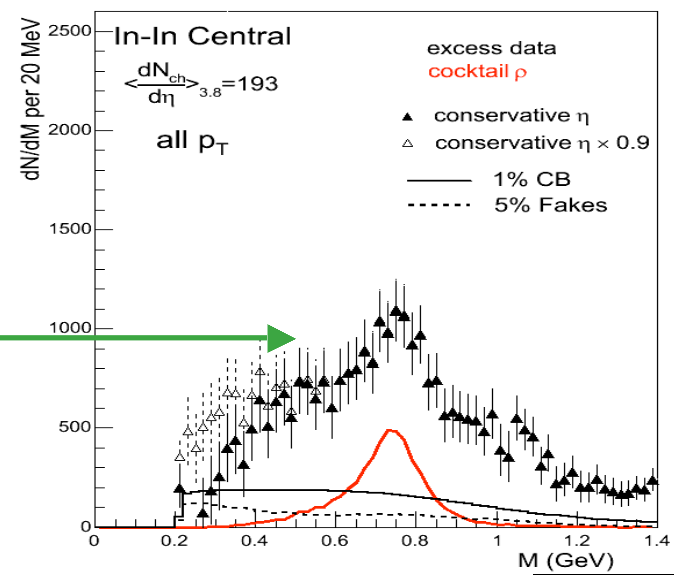


We have 6 bins

from 0.5 - 1 GeV mass

We need more

like 24 bins



Hadron Blind Detector

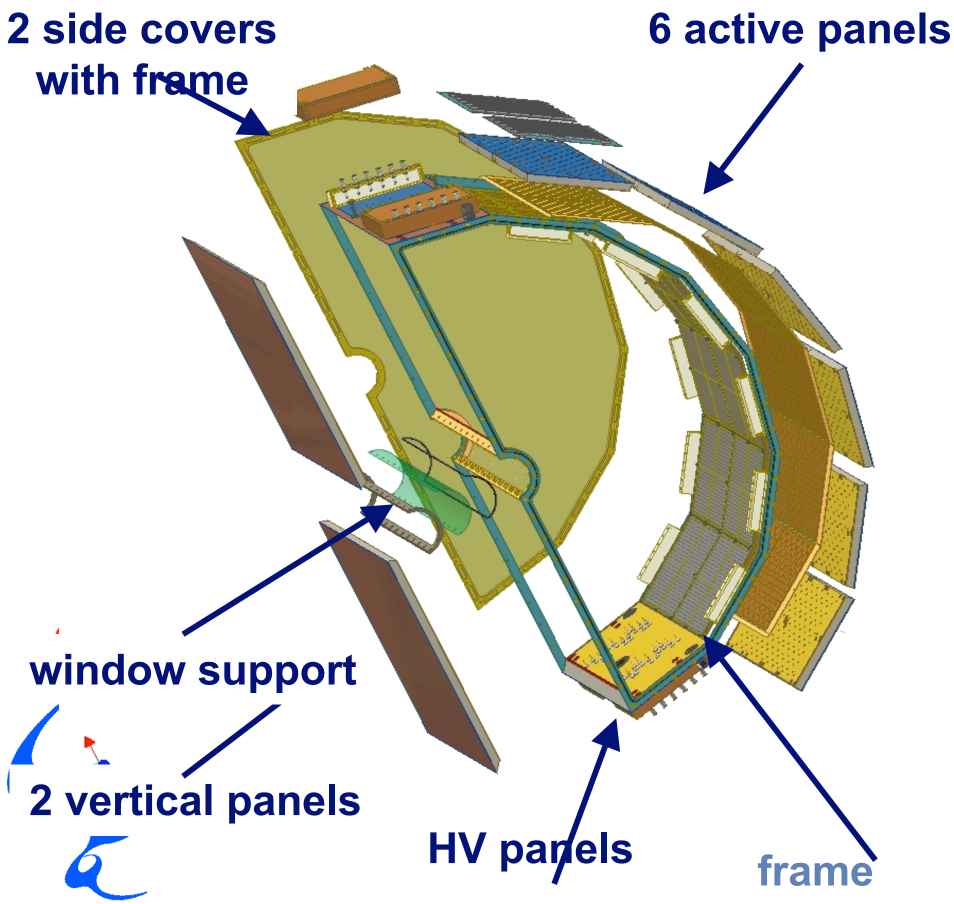
novel concept for e ID → Dalitz rejection

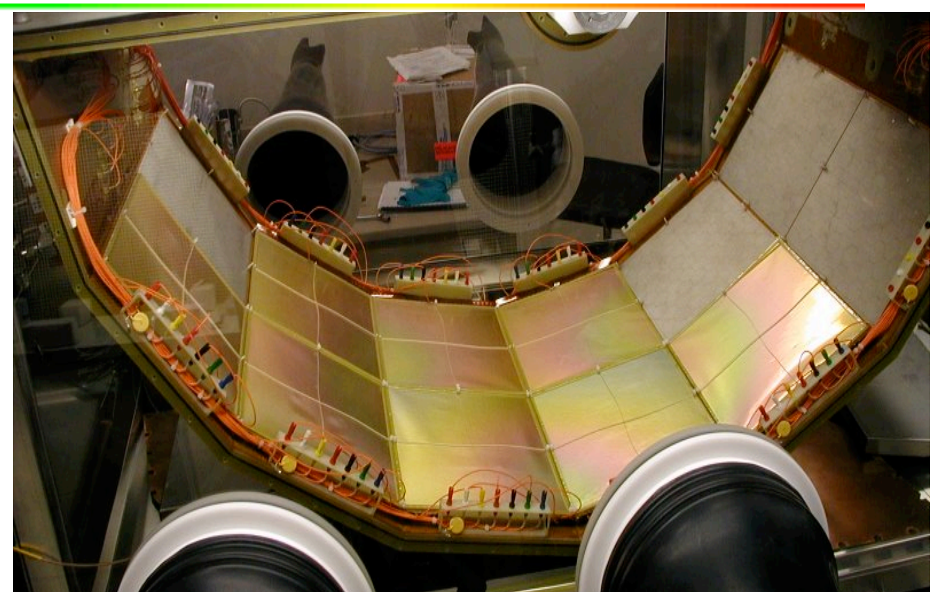
windowless CF_4 Cherenkov detector

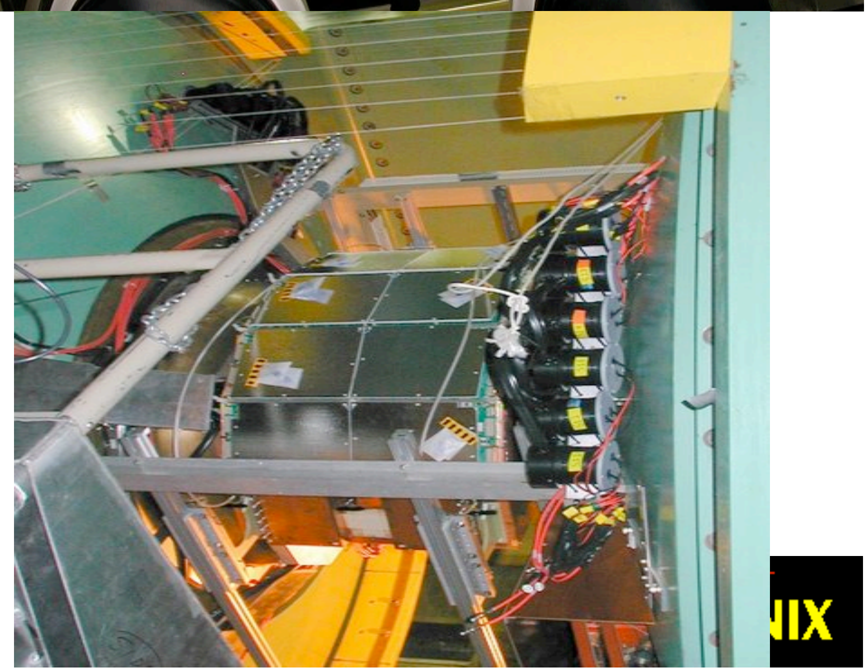
50 cm radiator length

CsI reflective photocathode

Triple GEM with pad readout



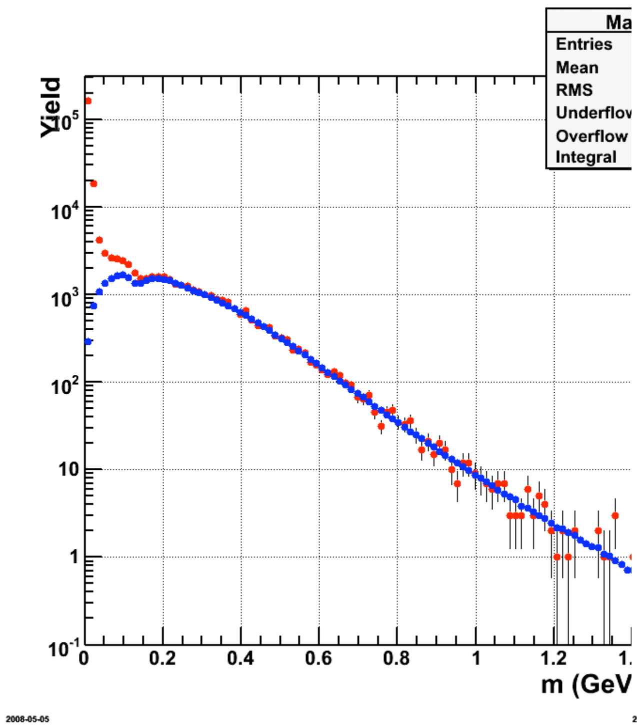




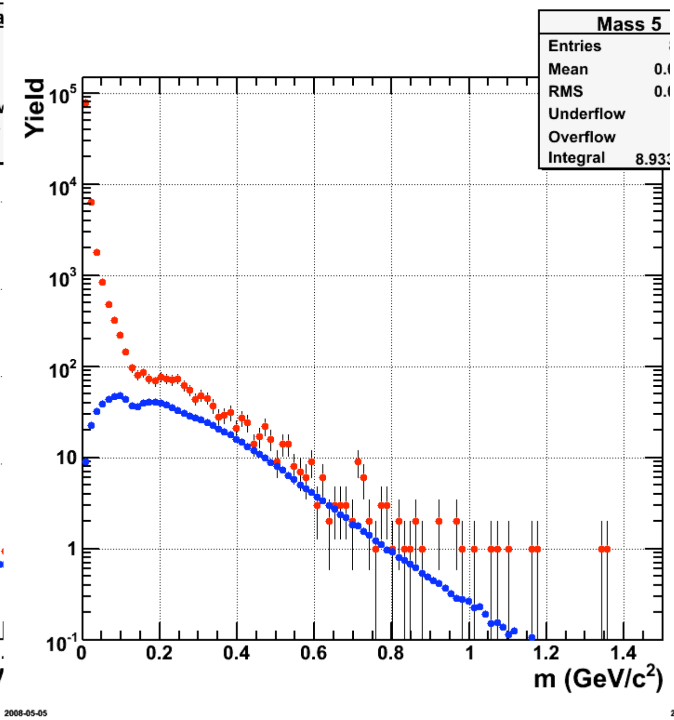
HBD current status

- Rebuild underway at Stony Brook
  - Previous problems diagnosed
  - Damaged GEMs replaced
  - HV distribution replaces, operating point optimized
  - All surfaces cleaned
- Run-7 data being analyzed
  - Only partial coverage with functioning modules
  - Diagnostics, software development using electrons identified in PHENIX central arms
- Performance
  - 14 photoelectrons in Run-7
  - Up to 25% improvement anticipated

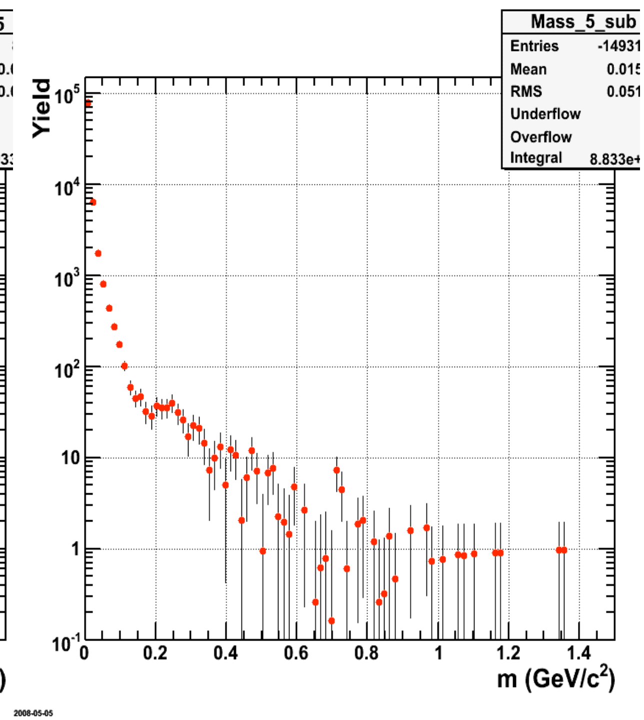
HBD performance study from Run-7 data



e+e- no HBD info



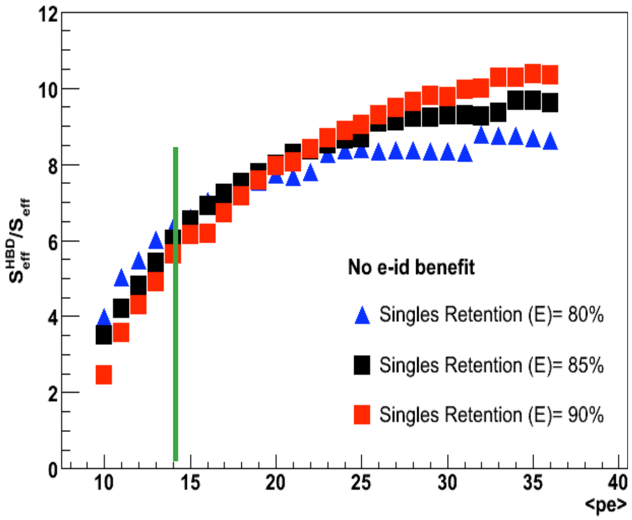
After HBD cuts

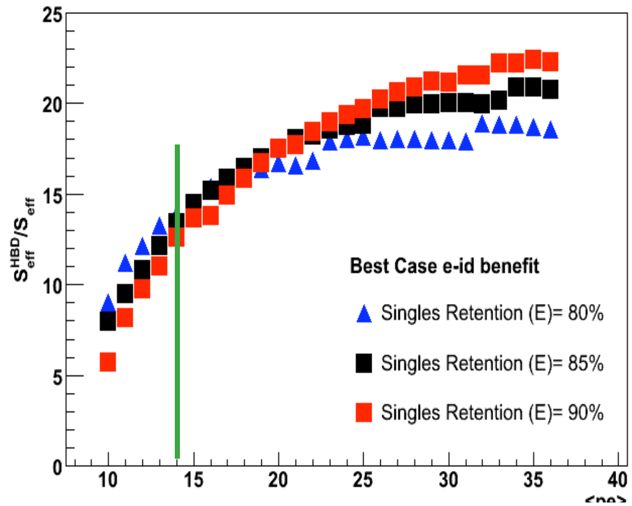


combinatorial subtracted

Functioning modules being analyzed, approx. order of magnitude improvement in S/B

HBD impact in Run-9





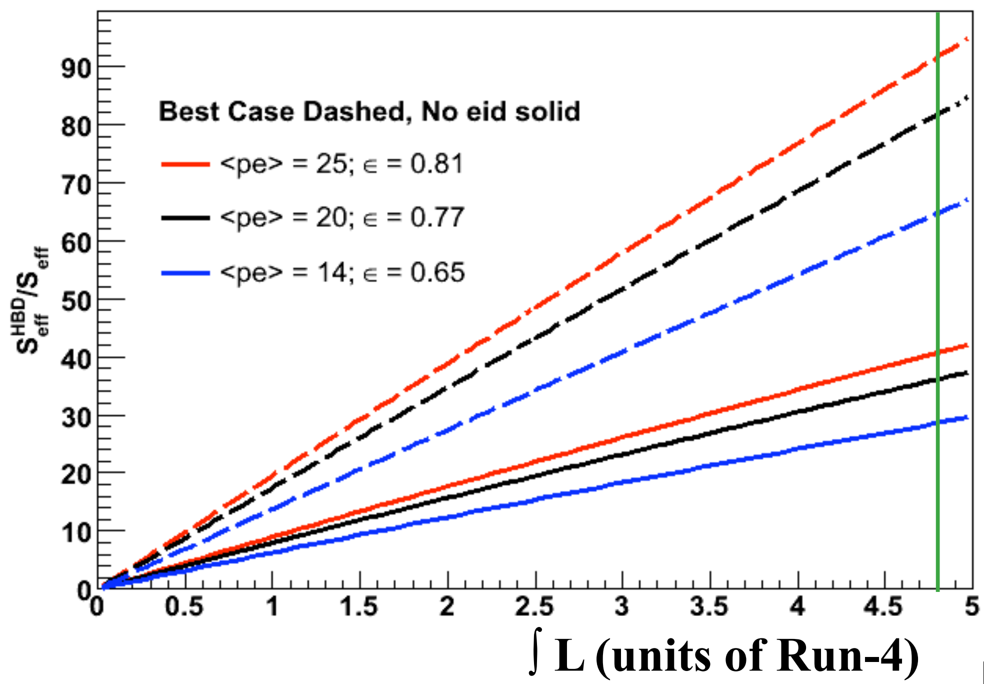
Improves effective signal by factor 6-16

1.2 /nb recorded improves effective statistics by ≥ 25

error bars ÷ 5

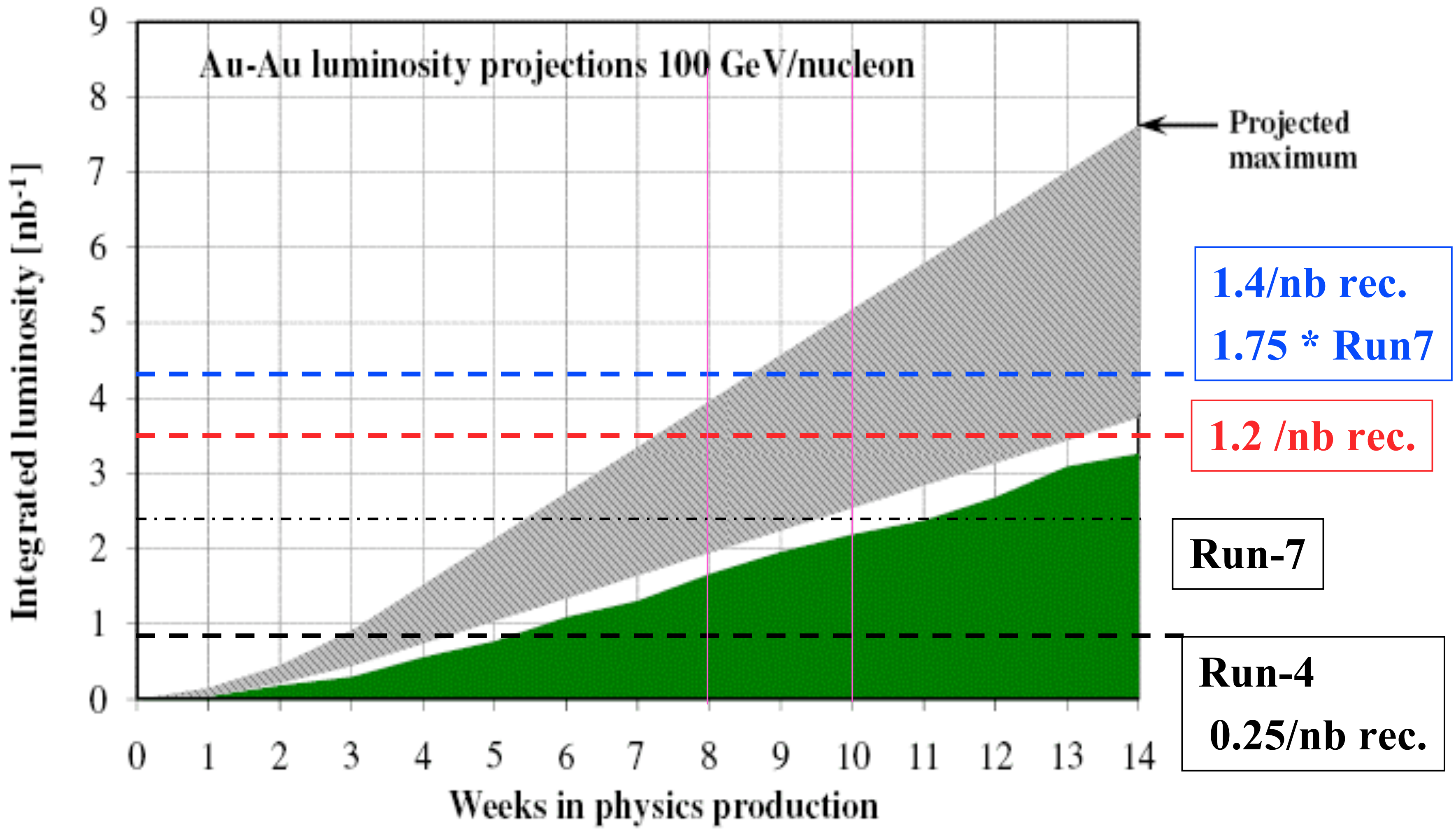
→ finer mass bins!

~ what's needed



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

Third Priority

- After p+p and 1.4 /nb of 200 GeV Au+Au

- For Run-10

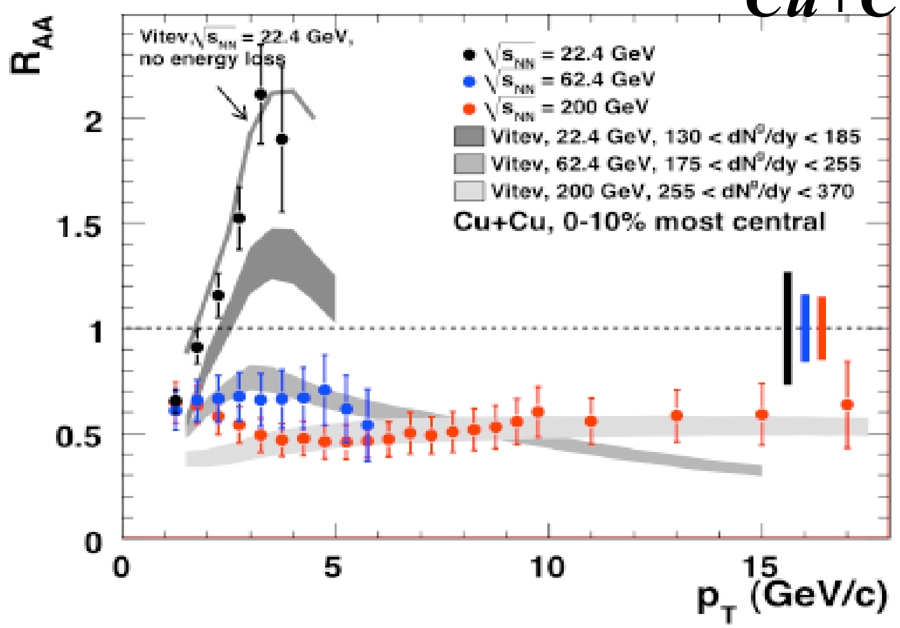
  Lower energy running

  Address two questions

  (which may not be different …)

Onset of RHIC's perfect liquid

Cu+Cu

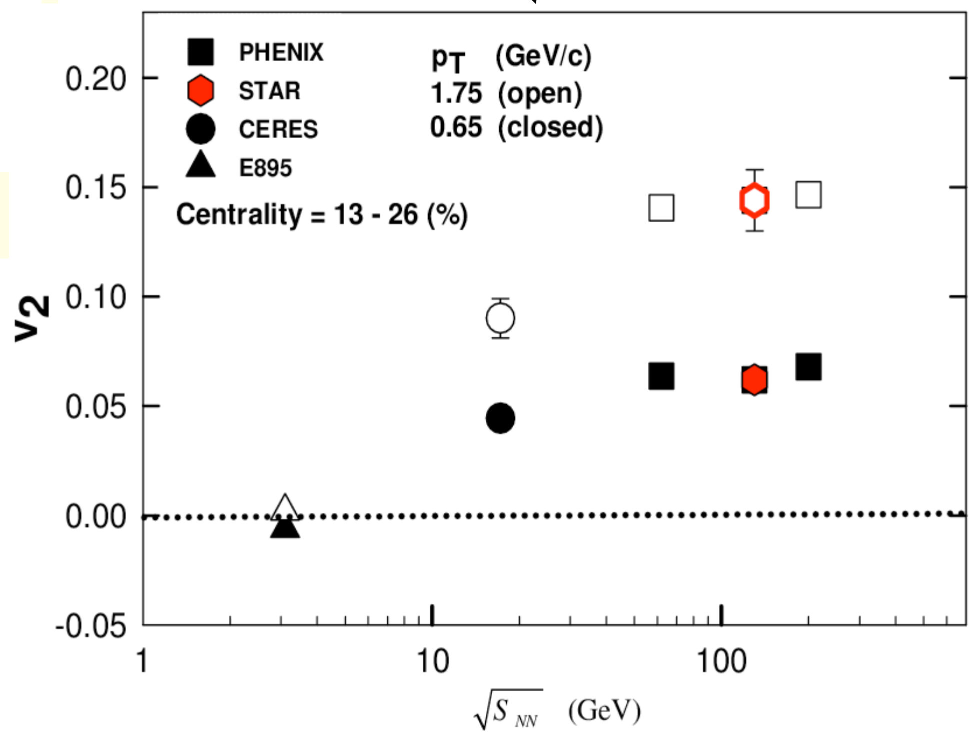


PHENIX, arXiv:0801.4555 [nucl-ex]

Emergence of opacity

Approach to constant v_2 and hydrodynamic limit?

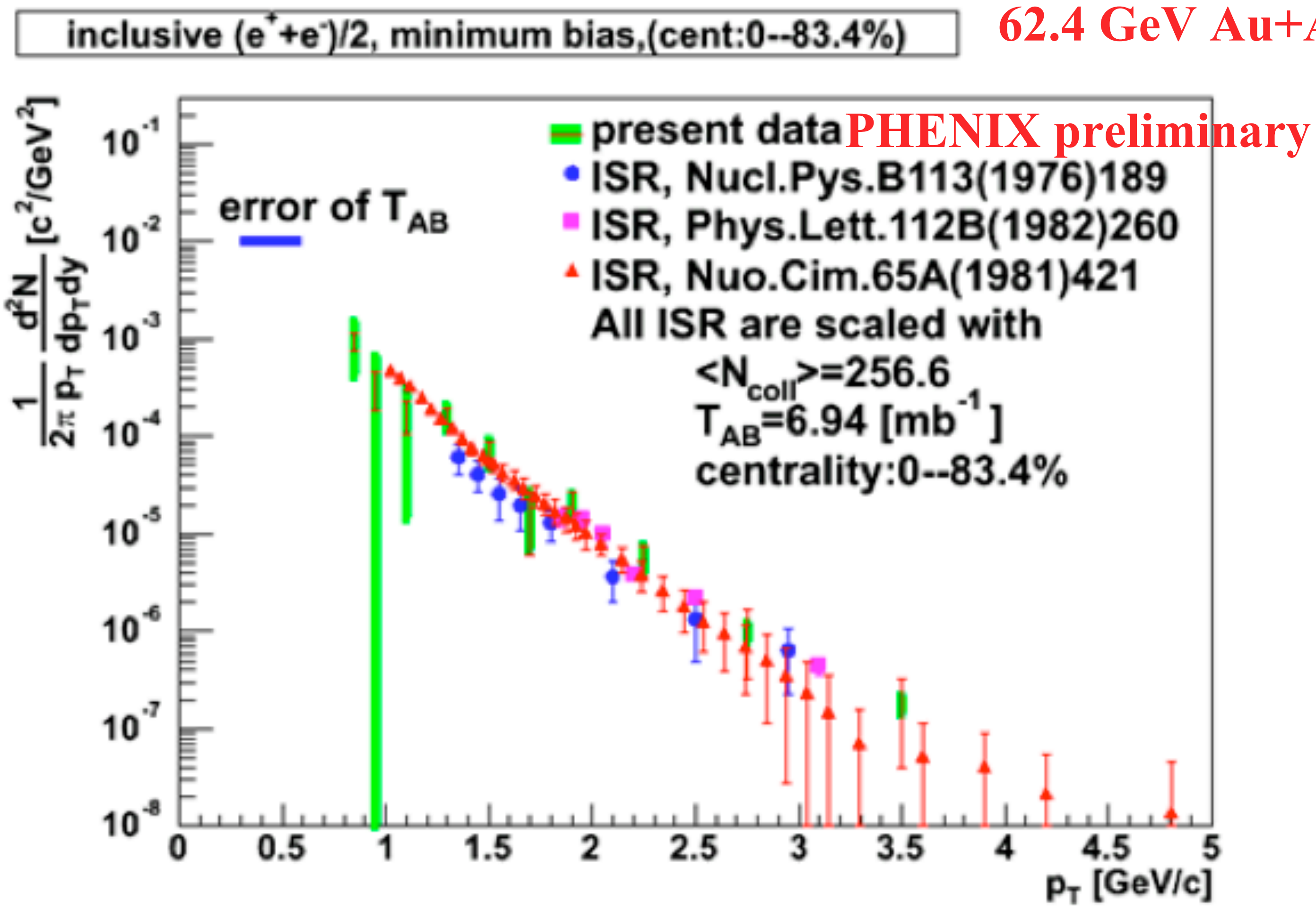
Au+Au



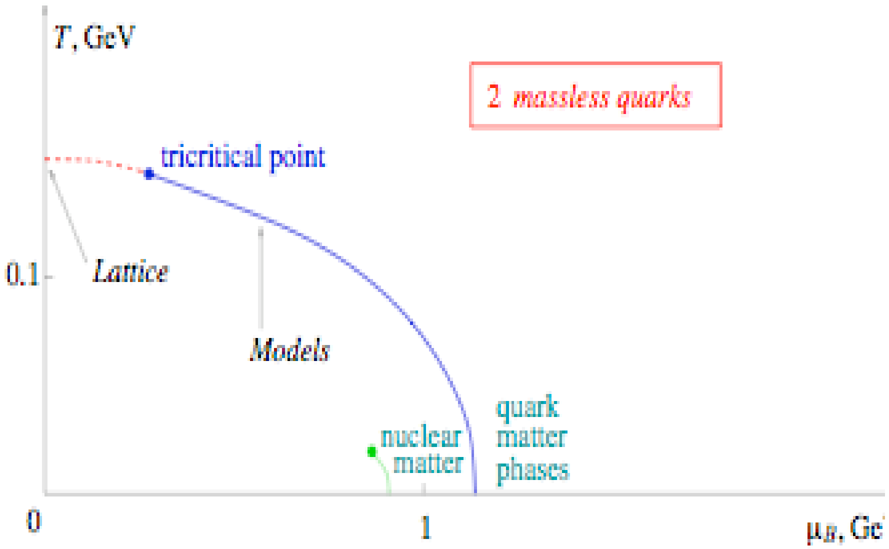
Somewhere between 22.4 and 62.4!
Where? Properties?
(temperature, etc.)

Onset of heavy quark energy loss?

62.4 GeV Au+Au

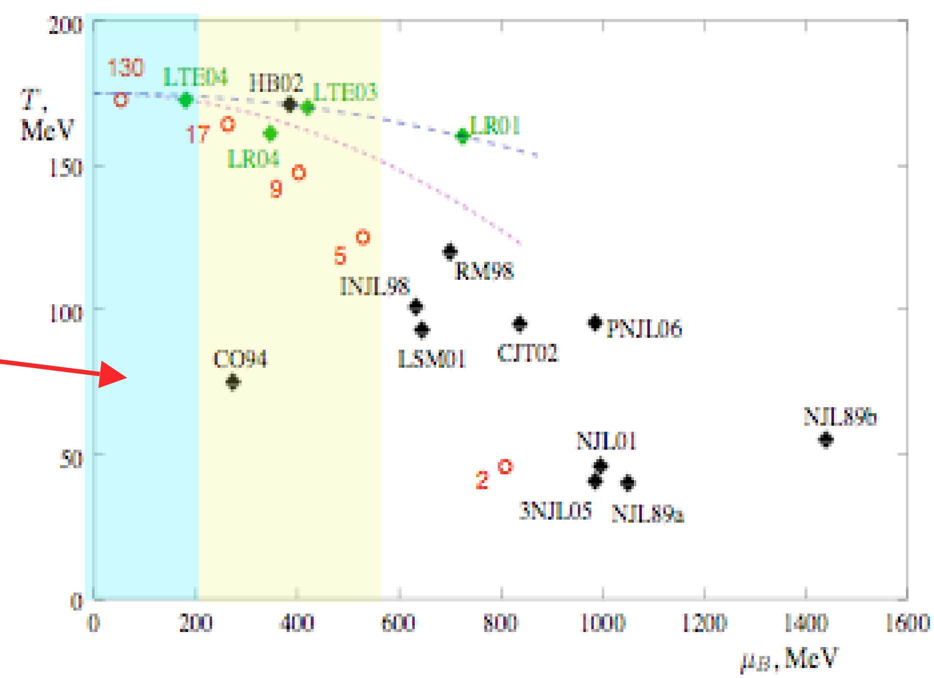


Where is the critical end point?



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!!

What does it take to do this well?

Measure multiple signals

with good statistical and systematic precision

make a significant improvement over existing SPS results

# events	Signatures that become available
1 M	$\langle N_{ch}\rangle$ (integral), $\langle p_T\rangle$ fluctuations, min bias PID spectra
5 M	PID vs. centrality, minimum bias v_2
50 M	v_2 vs. centrality, "basic" HBT, di-electrons, **K/pi fluctuations**
100 M	$\pi^0 R_{AA}$ (Full centrality dependence), di-hadrons

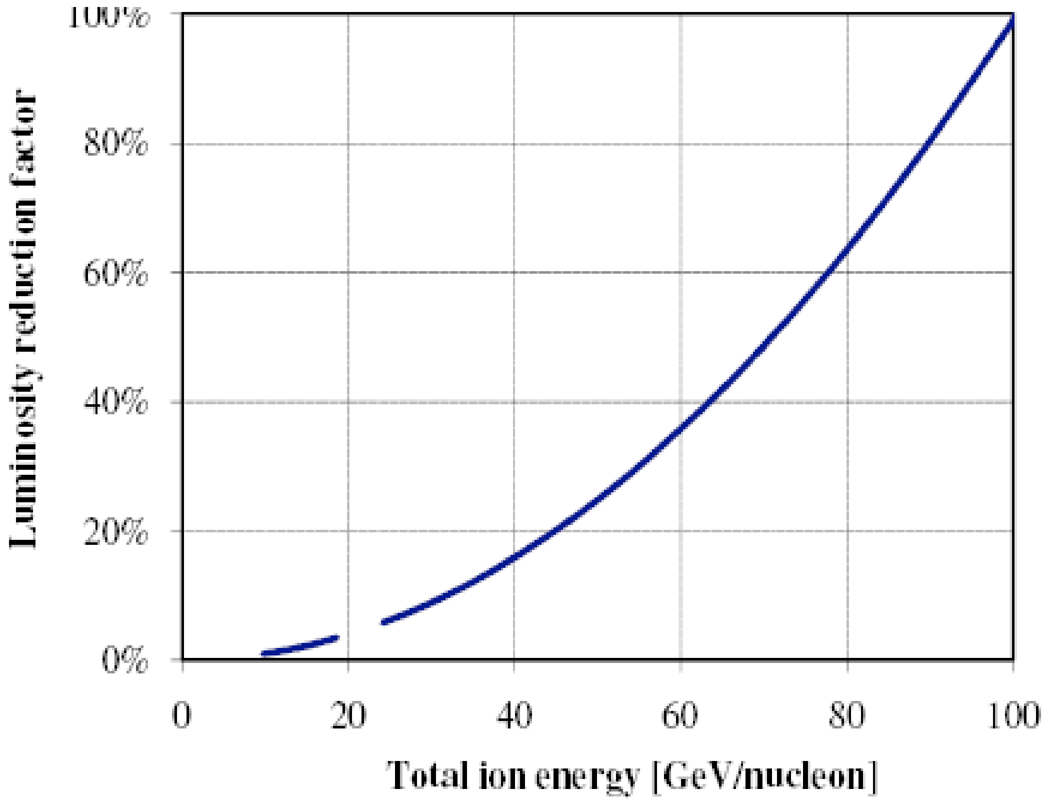
To do this well need 50M events at least!

300M for charm, J/ψ (at higher $\sqrt{s}$)

300M for pi,p v_2 vs. centrality

MUST also take p+p, d+Au comparison data!

The problem



+ technical challenges in triggering, timing, rejection of beam-gas interactions at the lowest energies

(solving these is cheaper, but not free)

Run time required grows for low energy

Run-10 plan assuming 200 GeV Au+Au in Run-8

	$\sqrt{s_{NN}}$	weeks	events	comment
cooldown		2		
p+p start/rampup	500	3		
p+p physics	500	5		record 25pb^{-1}
	62.4	0.5	6.5B	comparison
	39	0.5	$\approx$1B	
	28	0.5	1.2B	
	22.4	1.0	2.5B	
Au+Au startup	62.4	2		
Au+Au energy changes	39, 28	0.5		
Au+Au physics	62.4	2	300M	
	39	5	300M	no charm measurement
	28	7.5	$\approx$ 250M	
warm-up		0.5		
TOTAL		30		

Lower energies offer insufficient bang per operations buck without very substantial luminosity increase & vertex tightening

U+U for increased energy density: Run-12

Heinz & Kuhlman, PRL94, 132301(2005)

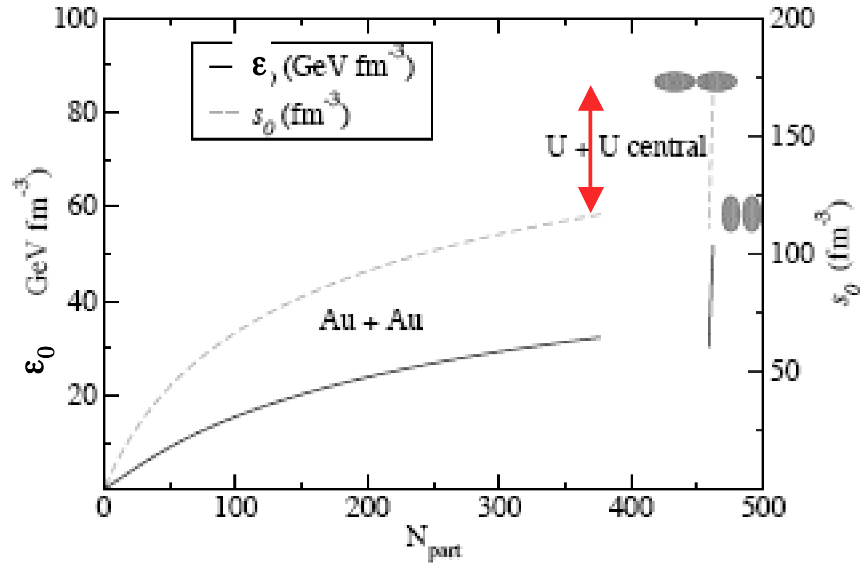
& PRC72, 037901 (2005)

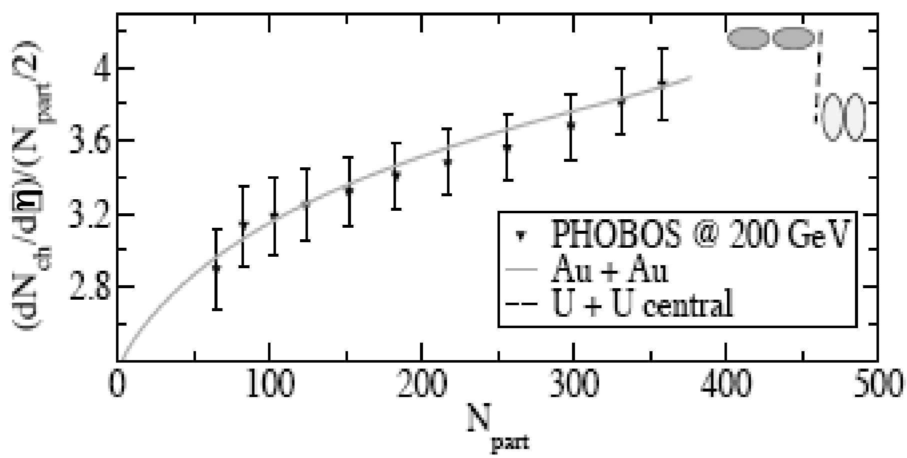
Conditions bridge between RHIC Au+Au and LHC

Energy density ~60% more than central Au+Au

Control the geometry

Orientations differ by ~15% in dN/dy





Summary of proposal for Run 9-13

RUN	SPECIES	$\sqrt{s}_{NN}$ (GeV)	PHYSICS WEEKS	$\int L\,dt$ (recorded)	p+p Equiv.
9	p+p Au+Au	200 or 500 200	10 or 5 ~10	25/25 pb^{-1} 1.2-1.4 nb^{-1}	25 pb^{-1} 56 pb^{-1}
10	p+p p+p Au+Au	500/200 62.4,39,28, 22.4 62.4, 39. 28	5 or 10 2.5 15	25 pb^{-1}	25 pb^{-1}
11	Au+Au p+p	200 500	M 25-M		
12	U+U p+p	200 200	N 25-N		
13	p+p Au+Au	500 various	Q 25-Q		

PHENIX

Concluding Remarks

- Running Priorities for Run-9 + Run-10:
  1) Constrain ΔG from positive side with π^0, charged π and/or First look at 500 GeV p+p
  2) Low mass dileptons at 200 GeV Au+Au
  3) Onset/critical point scan between 22.4 and 62.4 GeV Au+Au

- Running Priorities for Run-11 + Run-12: *
  1) Heavy Quark separation with vertex detector in full energy Au+Au
  2) W asymmetry measurement with 500 GeV p+p
  3) Increase energy density using U+U collisions

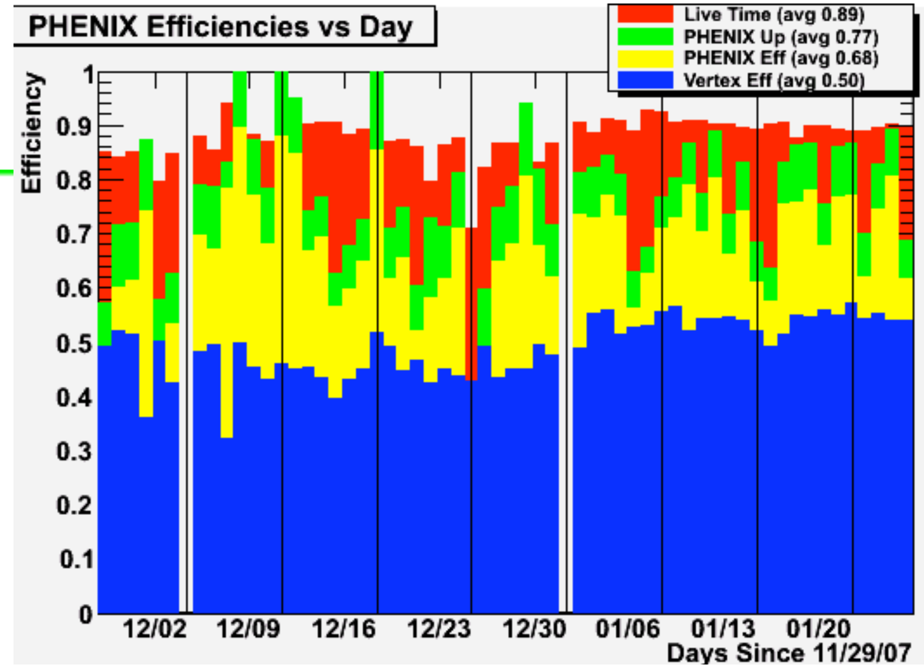
* top priority is not necessarily finishing the first list

Data Taking Efficiency

PHENIX response to S&T review charge

200 GeV d+Au

- Live Time – 89%
- PHENIX up – 77%
- Overall (w/o vertex) – 68%



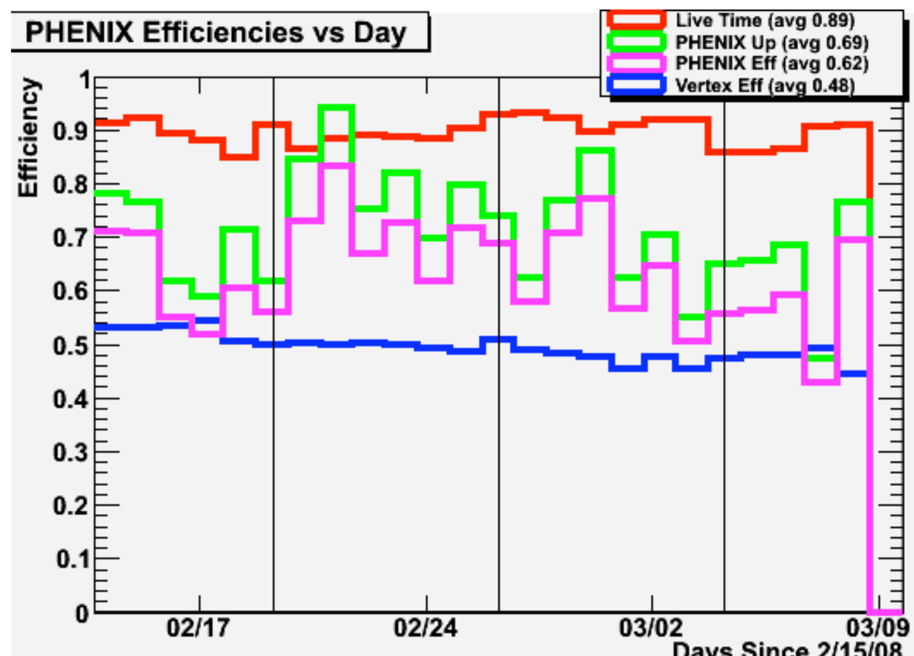
Vertex eff ~50% in both cases!

- will be improved by Stochastic Cooling (SC) & RF advances
- but vertex detector upgrades use ±10 cm so even with SC can expect only 38% eff!!

200 GeV p+p

- Live Time – 89%
- PHENIX up – 69%
- Overall (w/o vertex) – 62%

(where 10% correction for loss due to CNI measurements is made)



Black vertical lines are markers for Maintenance and/or APEX days

Recorded/Delivered Luminosity Ratio

The useful delivered luminosity is the fraction within z_{vtx} = ±30 cm, about 50% of what CA quotes

$$\varepsilon_{vtx} = N_{BBC}^{\pm 30cm} / N_{BBC}^{Wide}$$

The recorded and delivered luminosity come from the BBC and ZDC, respectively; and their ratio with a small loss due to livetime (LT), gives the PHENIX efficiency

$$\varepsilon_{PHENIX} = \frac{(n_{BBC}^{\pm 30cm} * LT) / \sigma_{BBC}^{eff}}{n_{ZDC} / \sigma_{ZDC}^{eff} * \varepsilon_{vtx}}$$

Uncertainty is from σ_{ZDC} & what fraction of n_{ZDC} to count (stable beam at beginning of store, not during CNI measurements, etc)

	σ_{BBC}^{eff}	σ_{ZDC}^{eff}
dAu	**2.26 b x 88%**	**0.52 b**
pp	**42 mb x 53%**	**0.31 mb**
AuAu	**9.8 b x 92%**	**?**

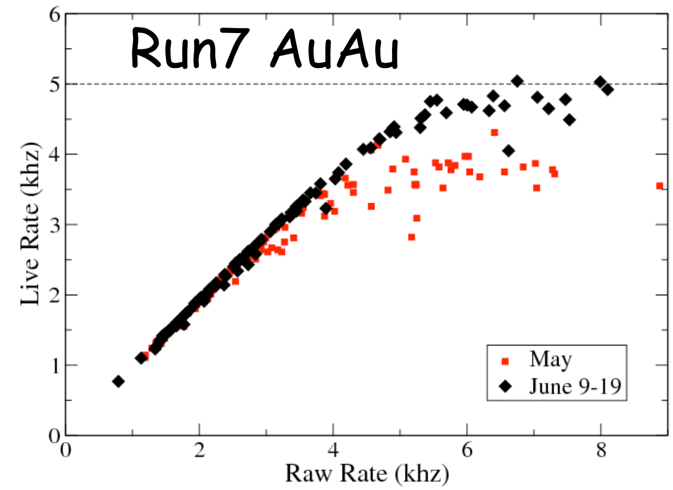
	ε_{PHENIX}	LT
dAu	**68%**	**89%**
pp	**62%**	**89%**
AuAu*	**65%**	**90%**

* Last two weeks of Run7 AuAu

$$\boxed{\varepsilon_{PHENIX} * \varepsilon_{VTX} = 0.68 * 0.5 = 0.34}$$

Run control improvements

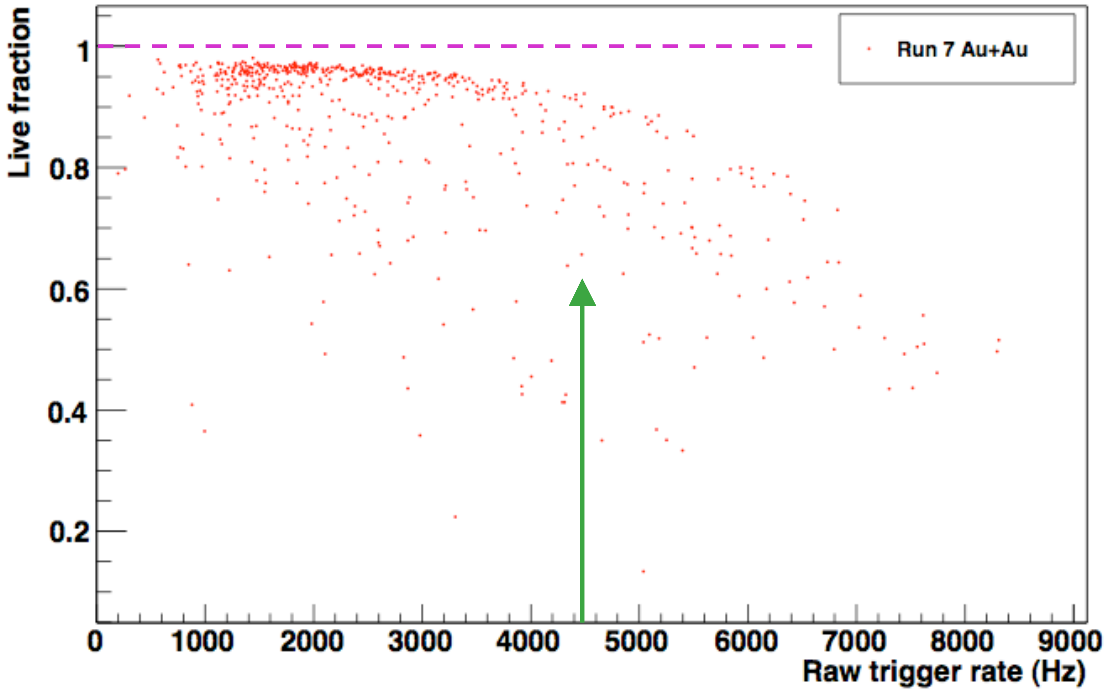
Extensive DAQ development in Run7 →
≈ 5 khz rate (AuAu)
•Run8 "easy" with up to 7 khz dAu event rates
Improvements for Run8:
• zero-suppression
• front-end (FPGA) data compression
• upgrade HV control –reliable turn-on & off



<u>Improvements planned for Run9 → 7 khz pp event rate</u>
• faster recovery from timing glitches
• improved buffer-box disks for local data storage
• fix recurring small problems, especially in event builder
• improve HV control & reliability
• explore clock stabilization through ramps & dumps
• faster RHIC work/improved communication with us
  collimation & background cleanup at beginning of store
  faster dump at end
  faster polarization measurements

PHENIX

PHENIX DAQ efficiency



Fraction of presented collisions recorded

While DAQ is running

- In Run 4, 7, 9 PHENIX takes ~ ALL Au+Au collisions
- In the future (RHIC-II): luminosity goes up

  PHENIX event size also increases

  → *Need to upgrade DAQ & Trigger accordingly*

DAQ/Trigger Upgrade Plan

Replace	EMCAL FEE better trigger match/rejection	*~$2M?*
Development	Upgrade Local Level 1 trigger	*~$200-400K*
	Faster DCM-II	*~$700K*
	Upgrade EVB switch (10 Gb/s)	*~$625K*
	Upgrade EVB machines	*~$185K*
	De-multiplex FEE	*Manpower, planning, $*
Purchase	Real Time Trigger Analysis Farm	*$500-700K*

- **backup slides**

PHENIX data sets

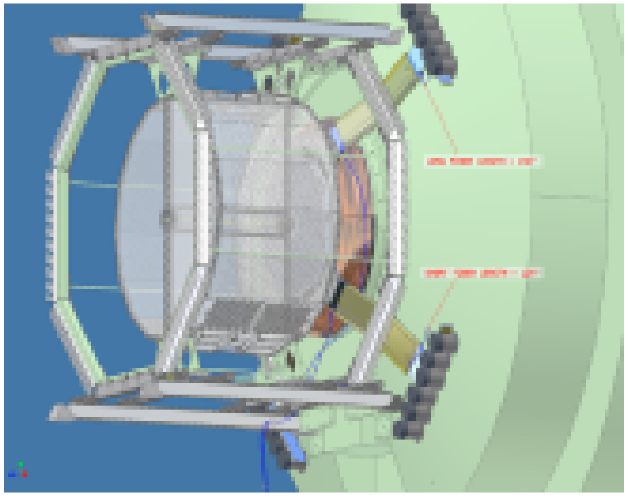
Run	Year	Species	$\sqrt{s_{NN}}$ (GeV)	$\int L\,dt$	N_{Tot}	p+p Equivalent	Data Size
01	2000	Au+Au	130	1 μb^{-1}	10M	0.04 pb^{-1}	3 TB
02	2001/2002	Au+Au	200	24 μb^{-1}	170M	1.0 pb^{-1}	10 TB
		p+p	200	0.15 pb^{-1}	3.7G	0.15 pb^{-1}	20 TB
03	2002/2003	d+Au	200	2.74 nb^{-1}	5.5G	1.1 pb^{-1}	46 TB
		p+p	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

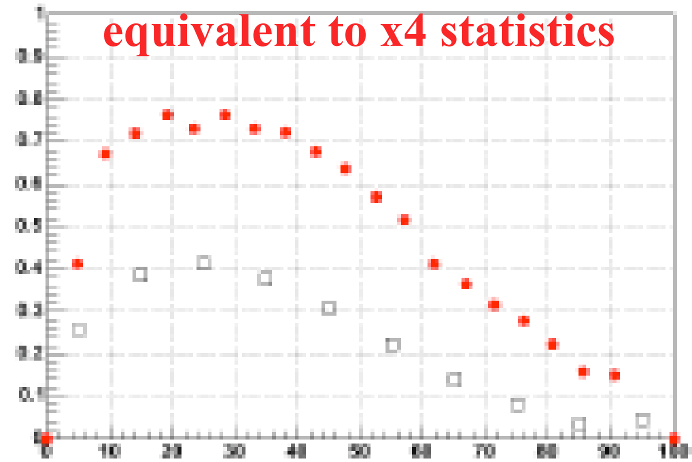
Table 1: Summary of the PHENIX data sets acquired in RHIC Runs 1 though 8. All integrated luminosities listed are *recorded* values.

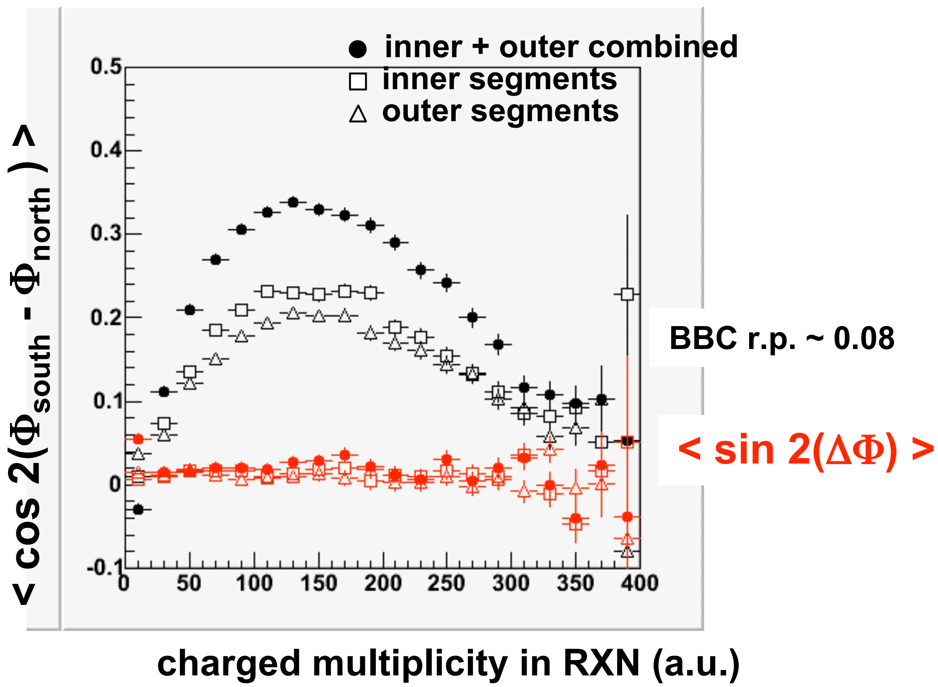
NSAC performance measures

- 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 $500 \le m_{e^+e^-} \le 1000$ 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.

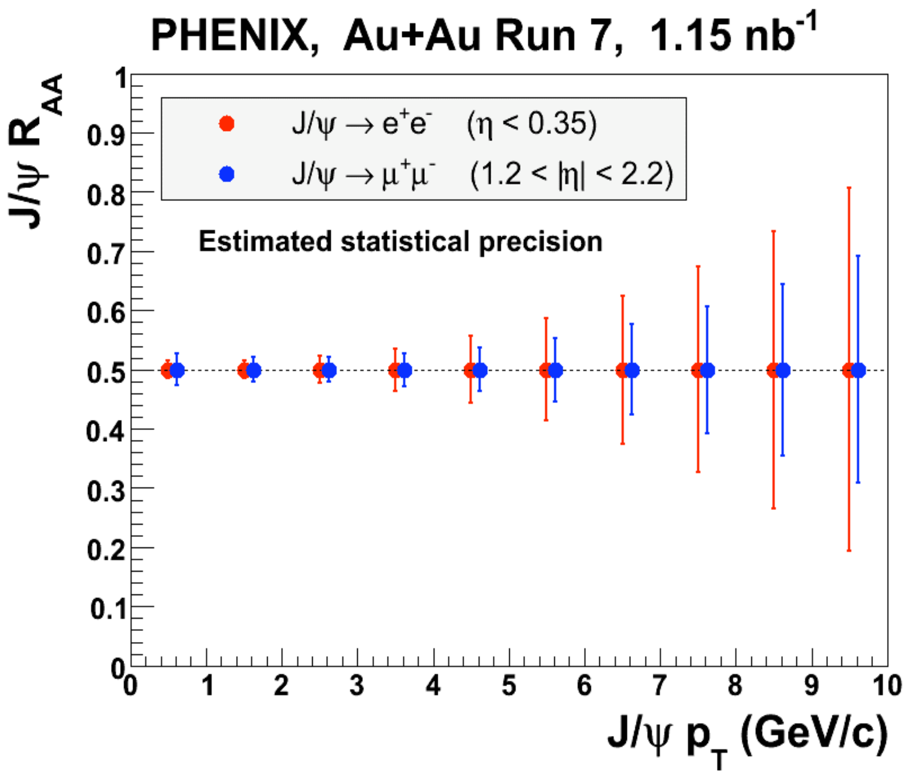
RXNP: 2x better reaction plane resolution

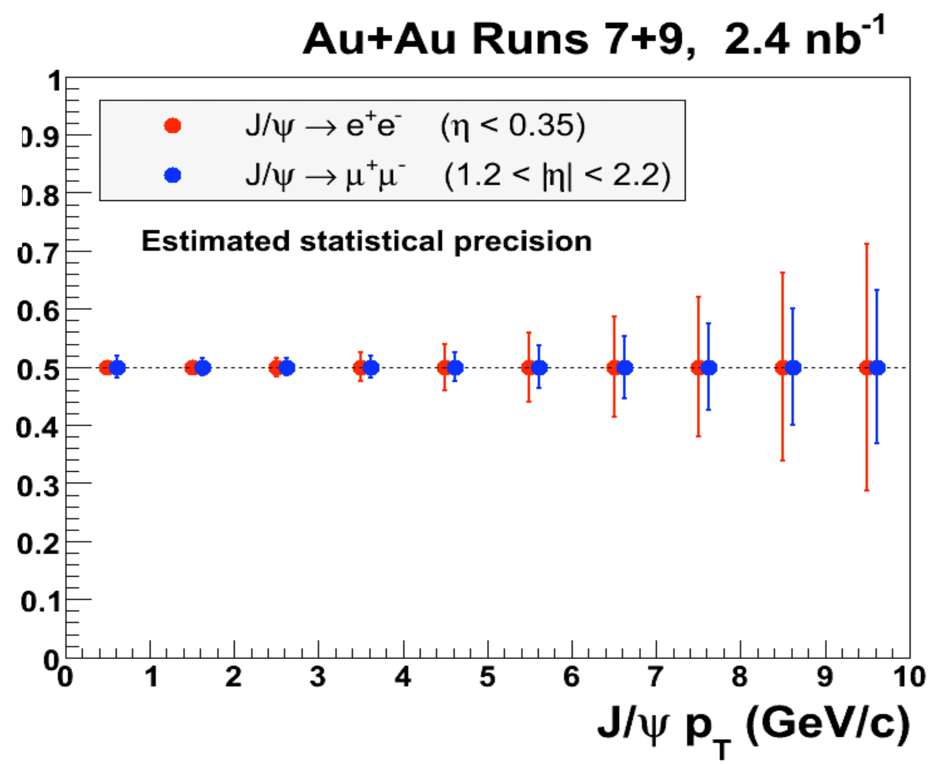




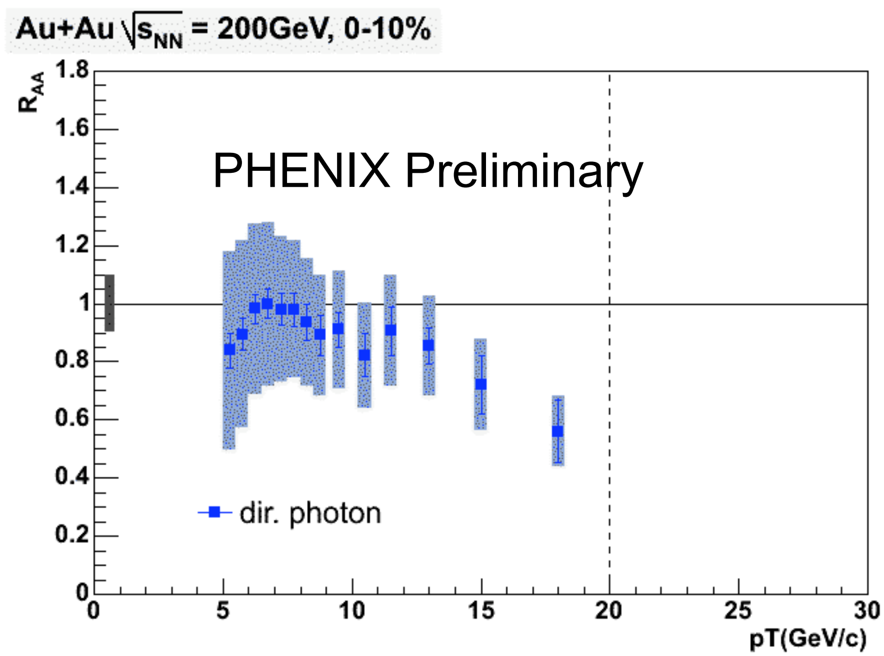


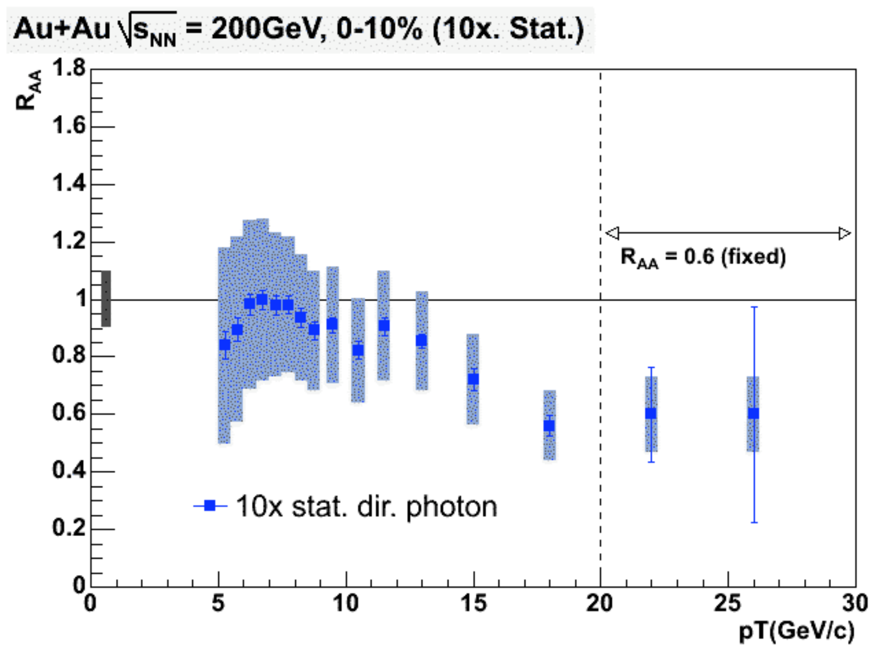
J/ψ p_T spectrum precision





Direct photons – suppressed or not?

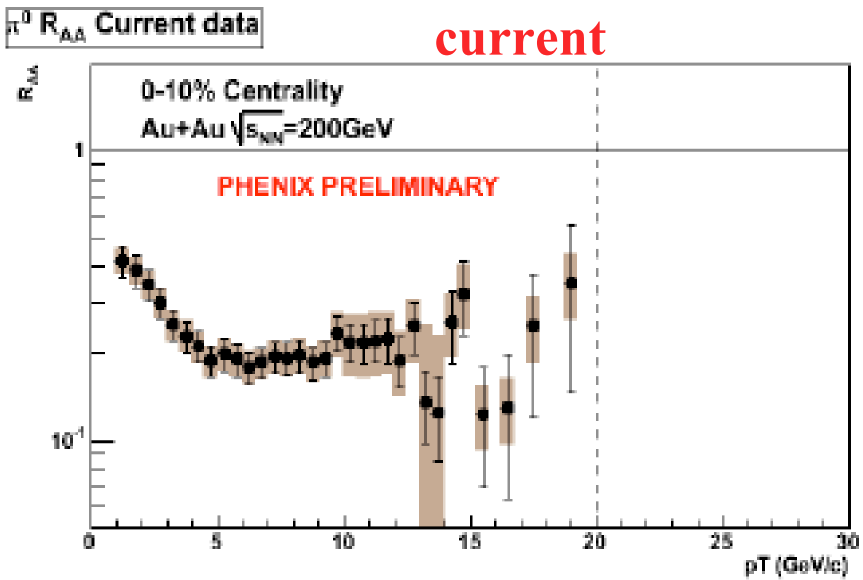


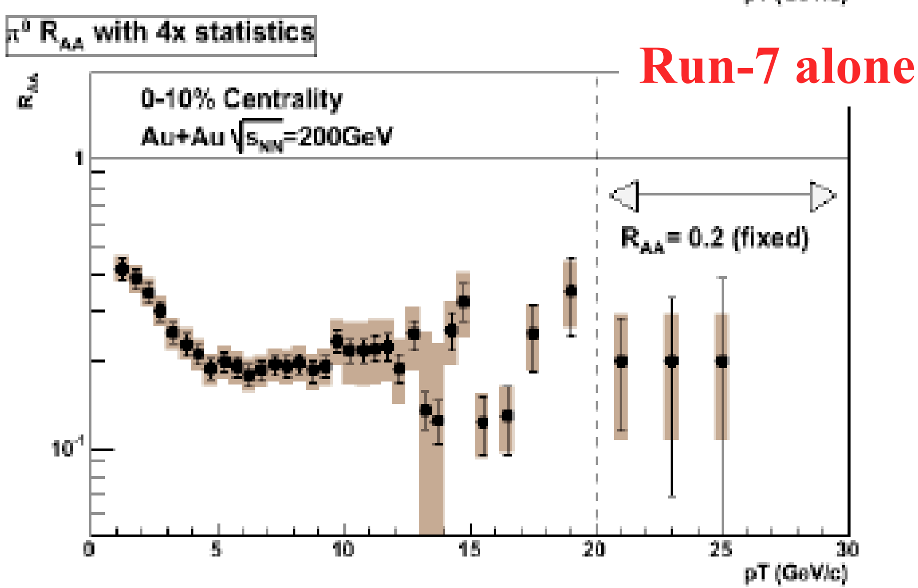


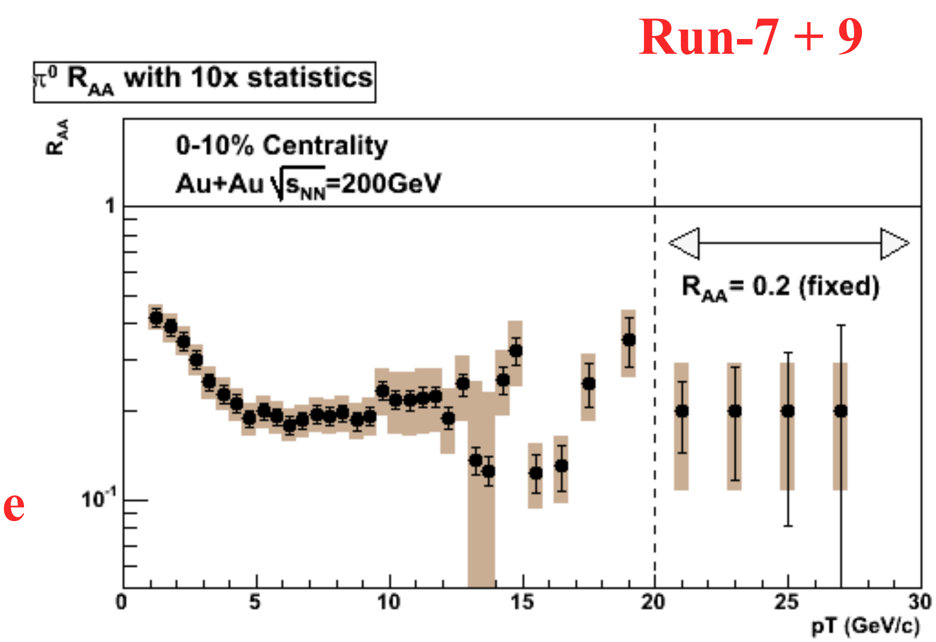
Current result

w/ 10x Run4 Stats.

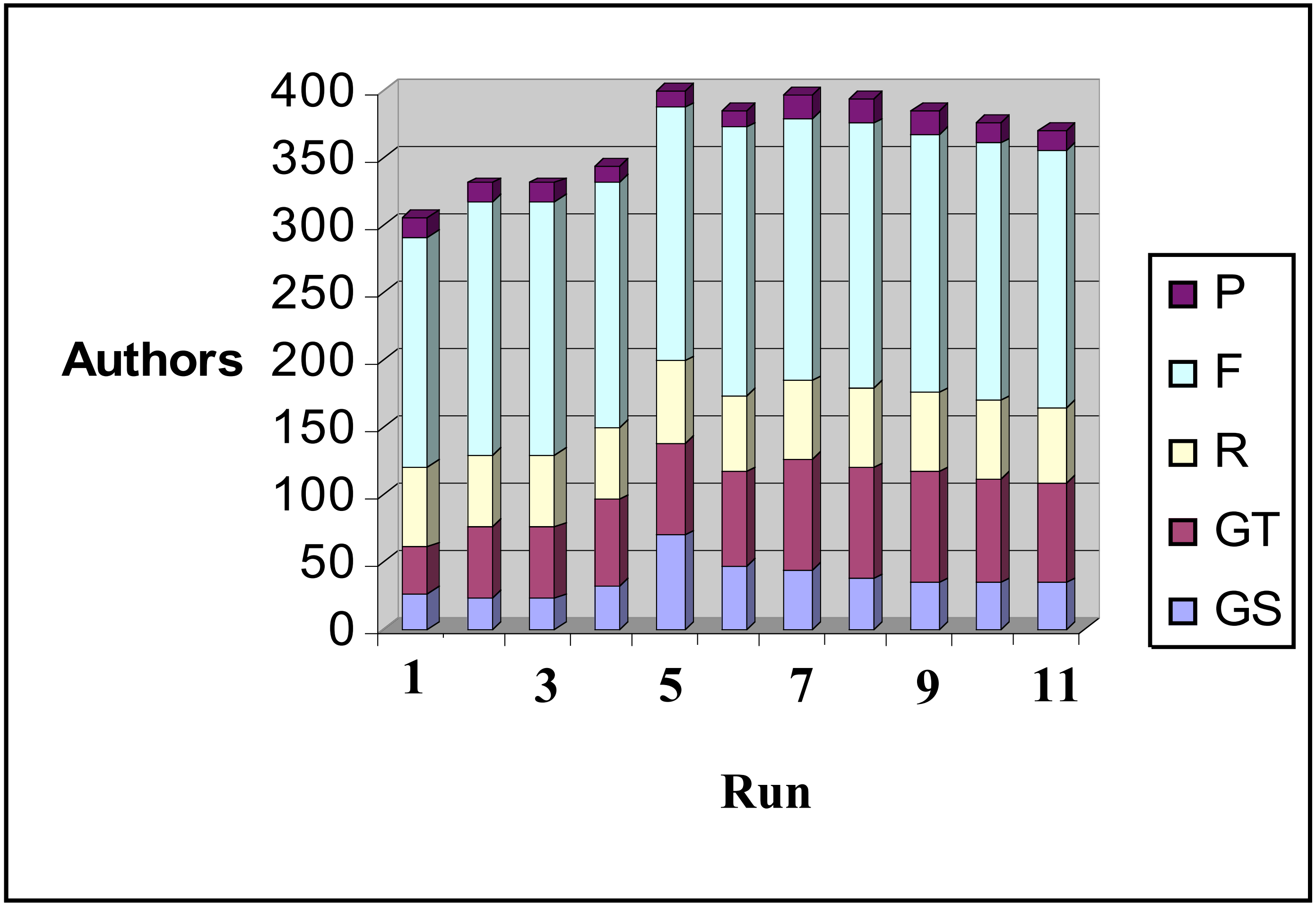
Inmprove p_T range & errors



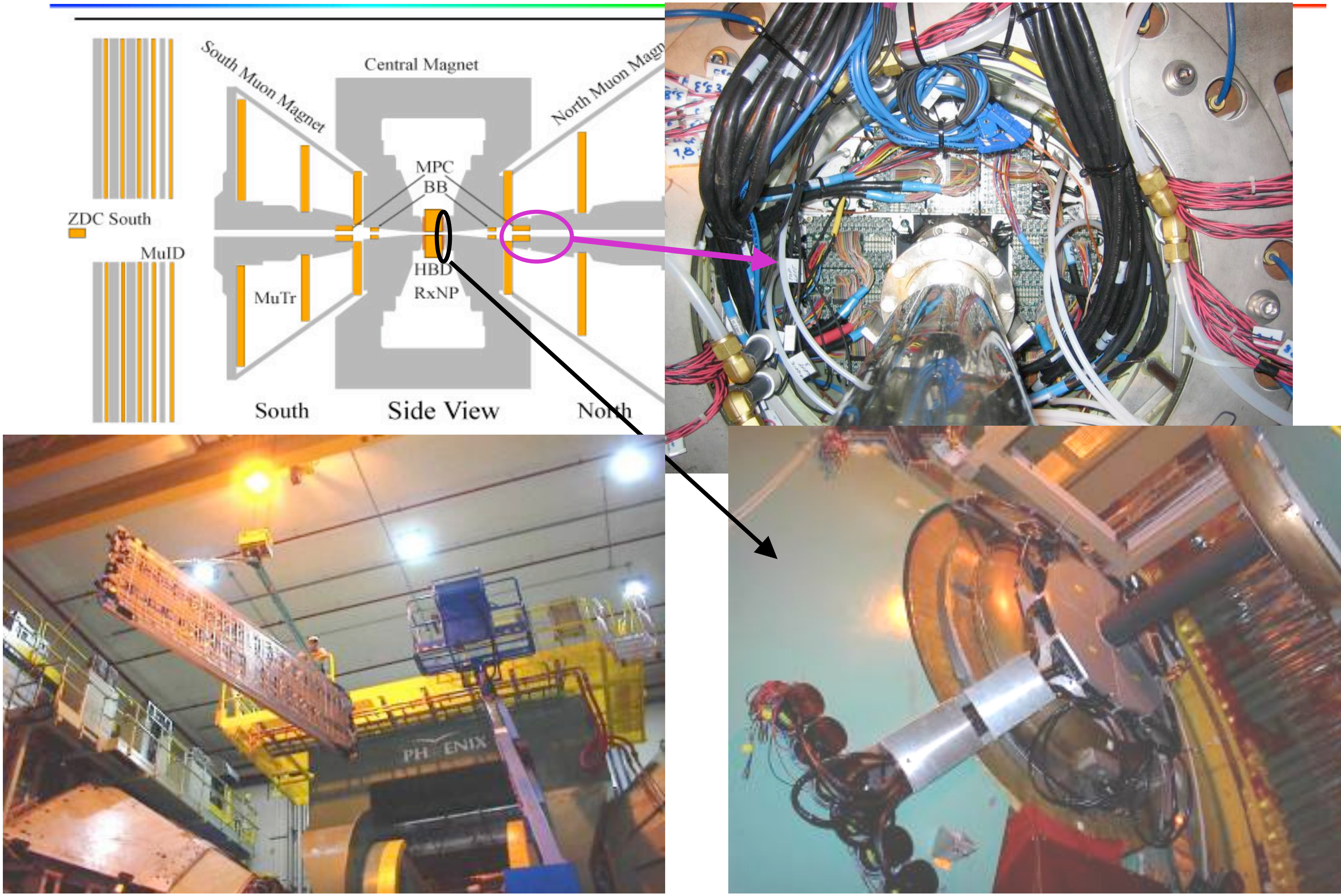




PHENIX is, and will remain, strong



a closer look



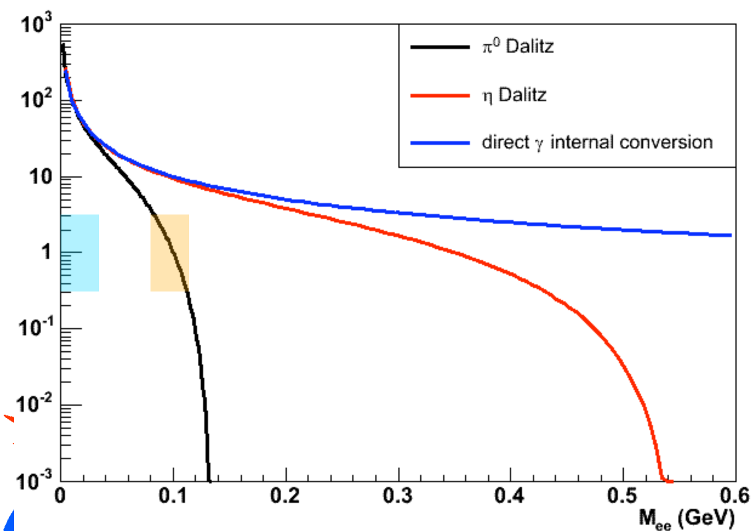
Virtual Photon Measurement

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

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

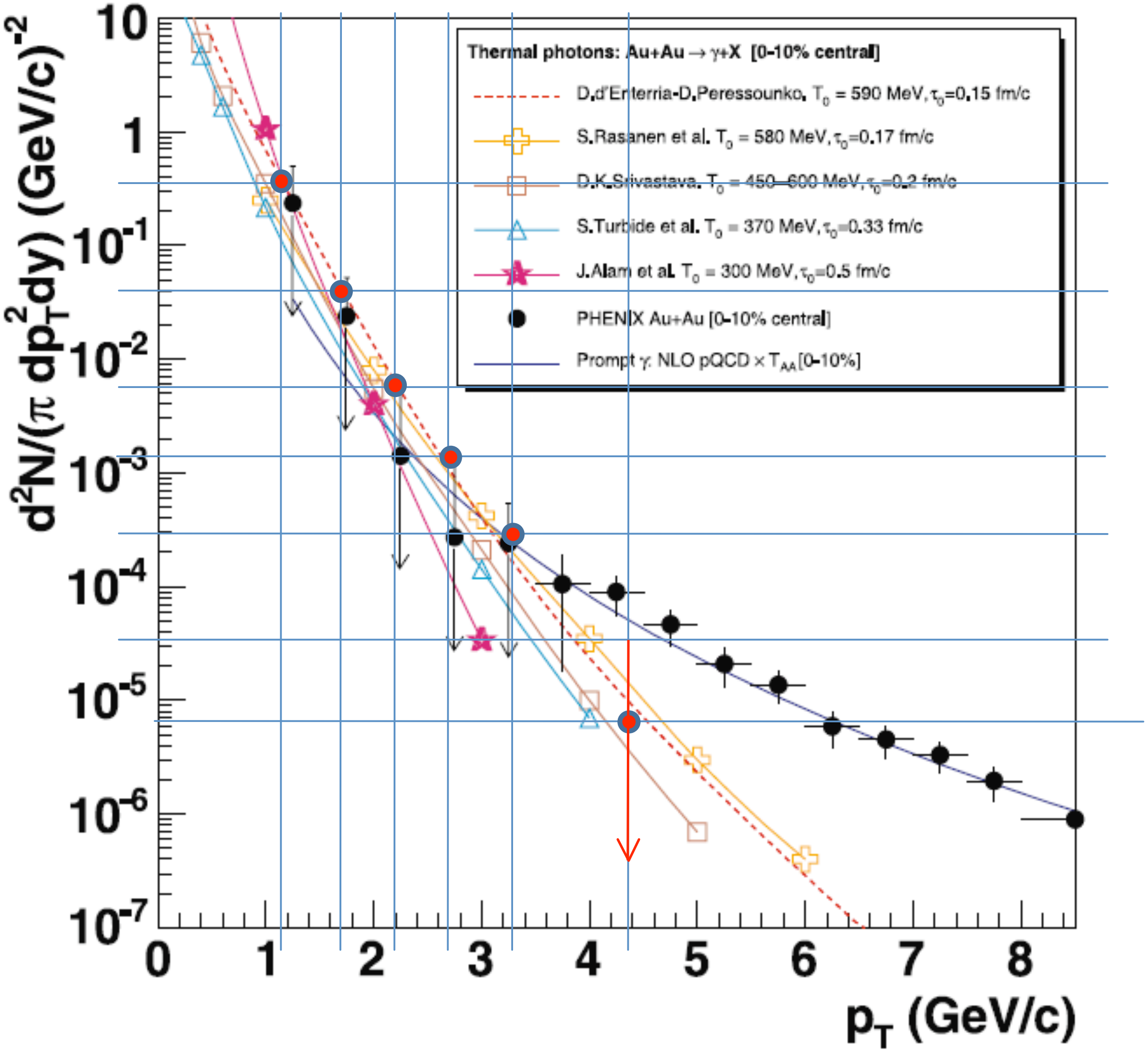
S : Process dependent factor

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

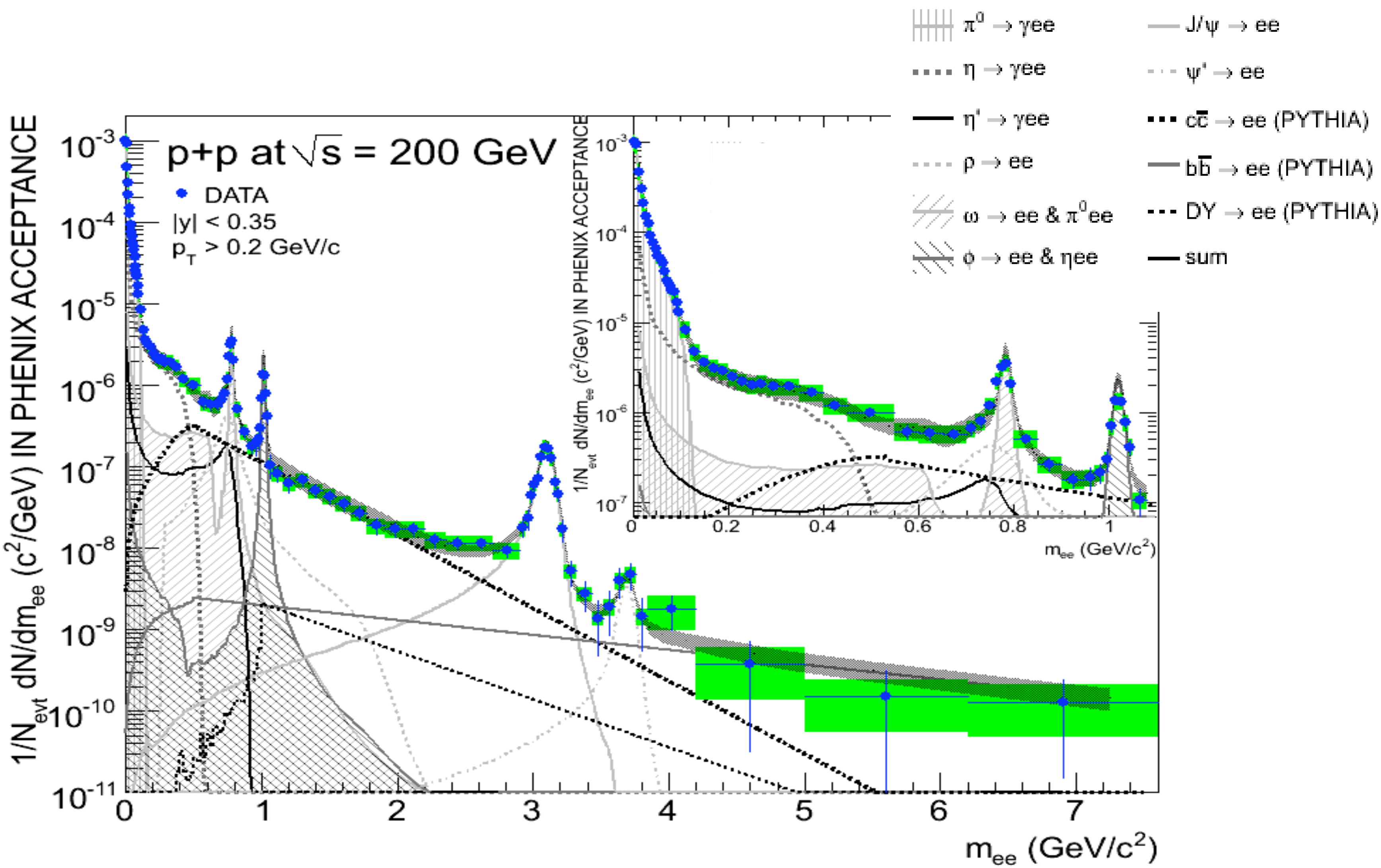


PHENIX

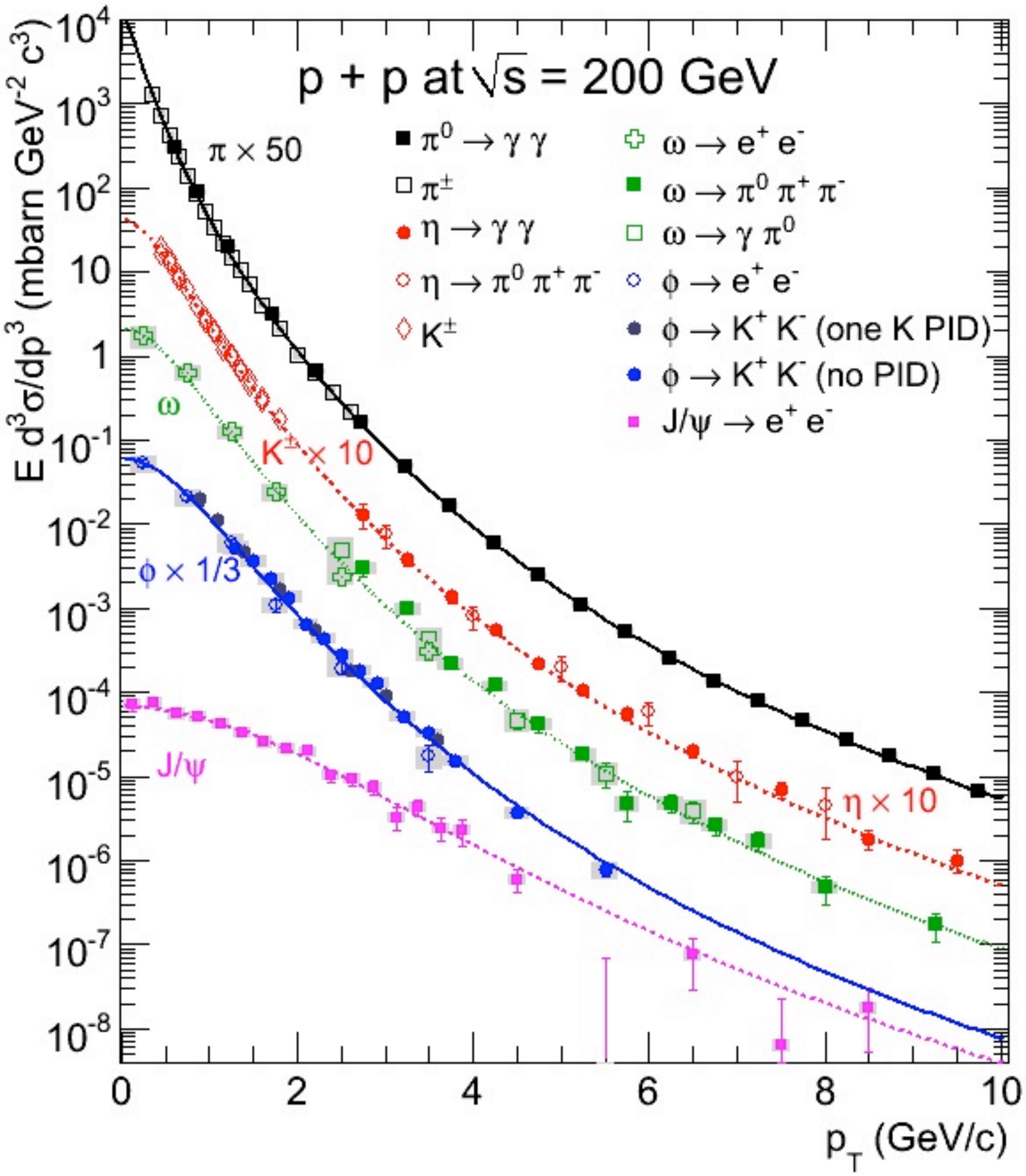
Comparison of hydro models to photons



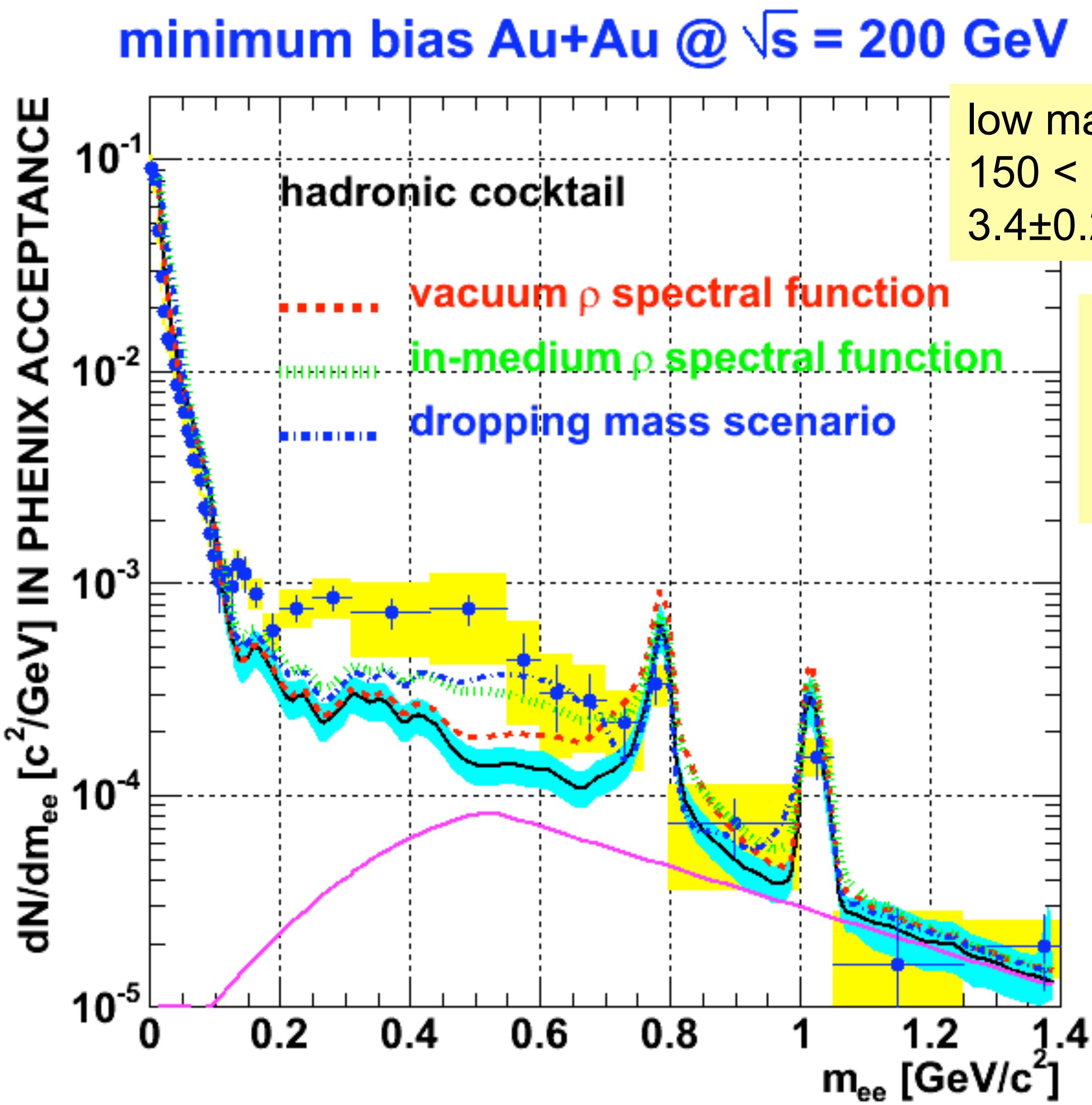
dielectron spectrum vs. hadronic cocktail



MEASURE the hadron cocktail ingredients!



Comparison with conventional theory

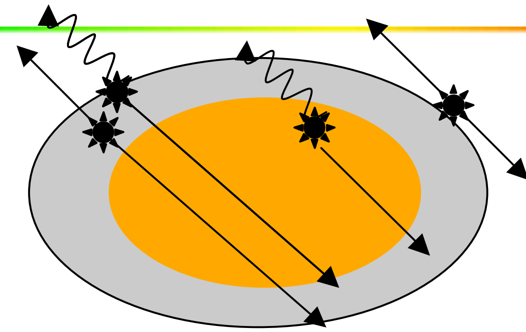


low mass enhancement at
150 < m_{ee} < 750 MeV
3.4±0.2(stat.) ±1.3(syst.)±0.7(model)

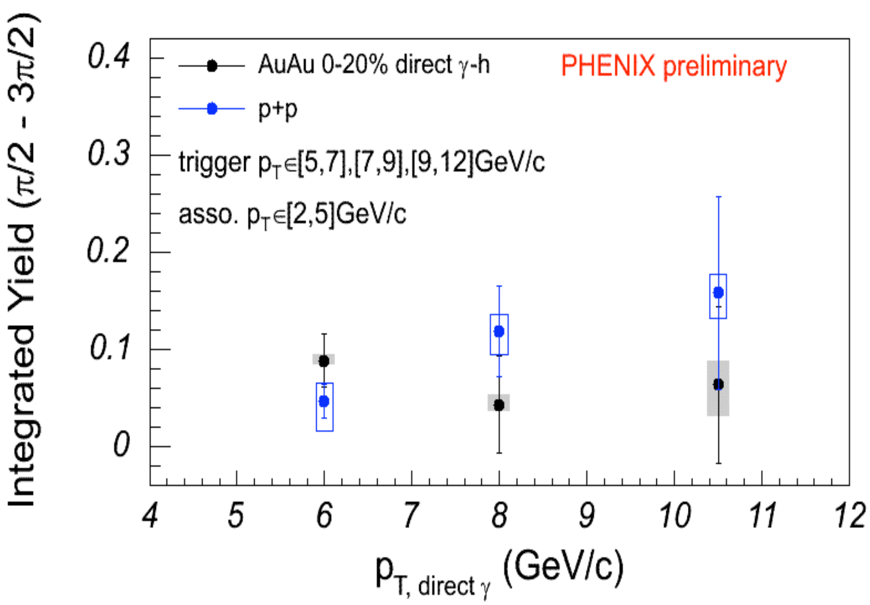
calculations: min bias Au+Au
they include:
QGP thermal radiation
chiral symmetry restoration

R.Rapp, Phys.Lett. B 473 (2000)
R.Rapp, Phys.Rev.C 63 (2001)
R.Rapp, nucl/th/0204003

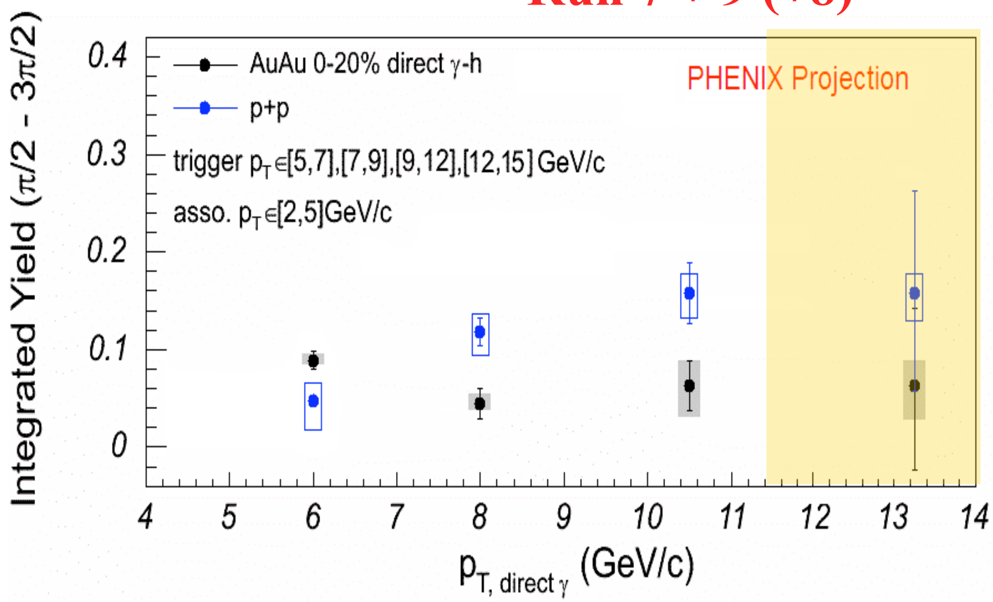
direct γ – jet coincidence: calibrated jet probe



current result



Run 7 + 9 (+8)

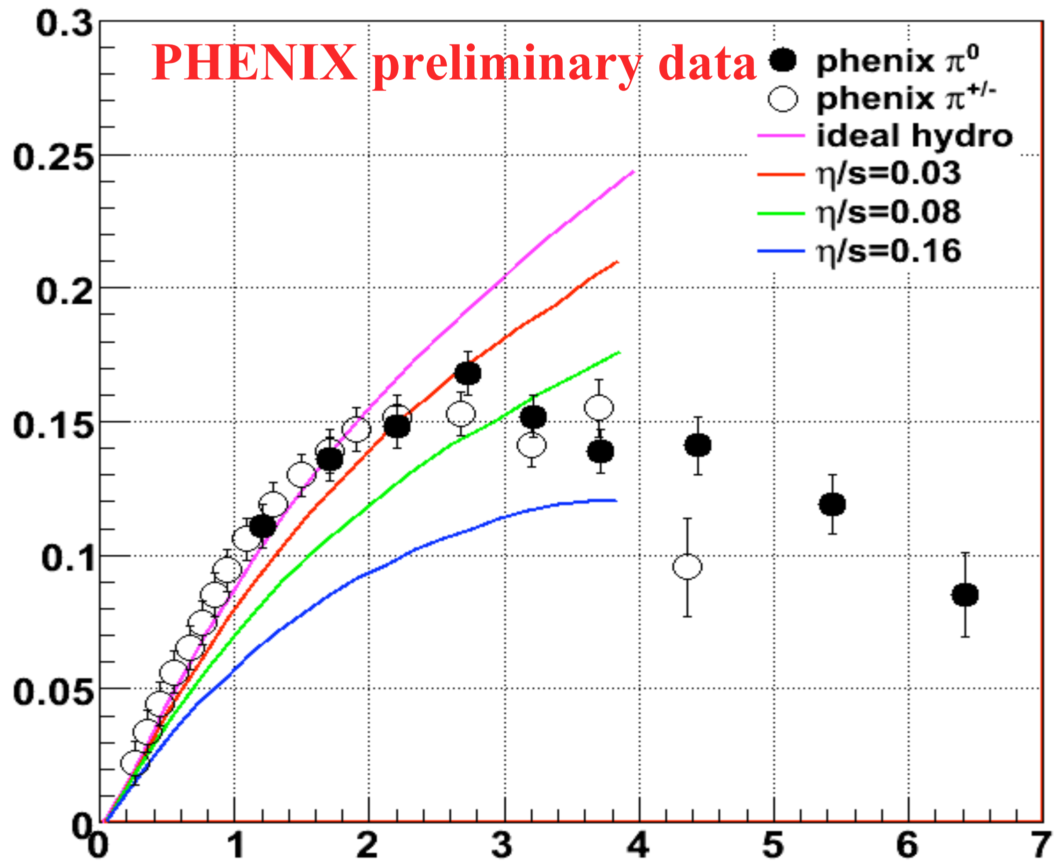


Toward quantifying η/S

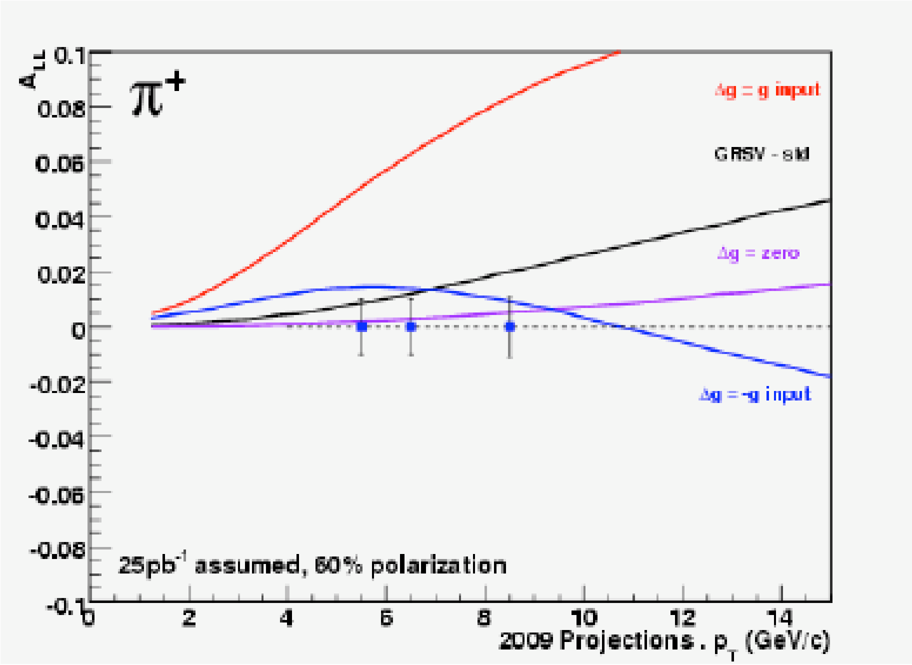
Curves from

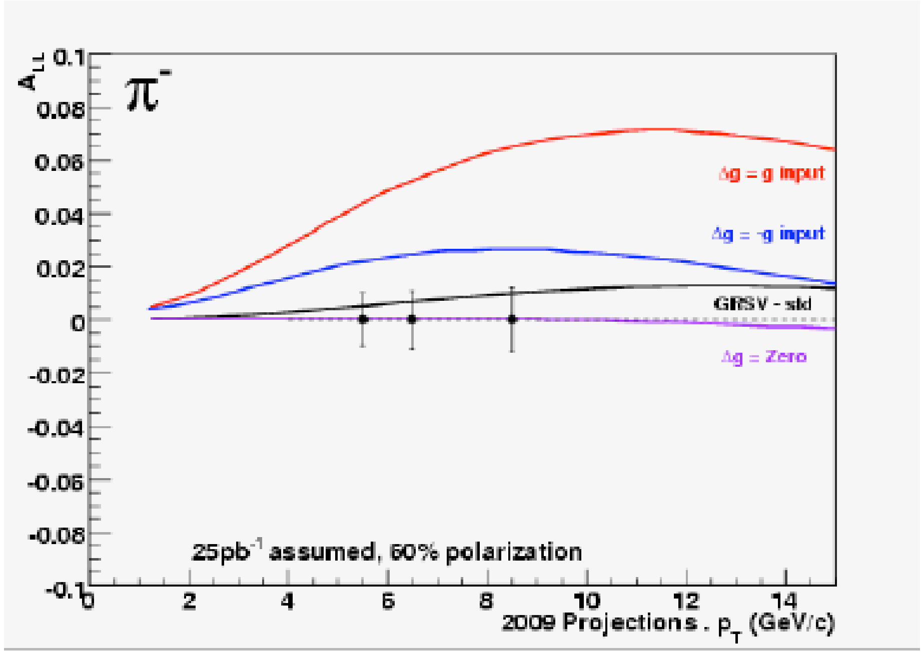
Romatschke & Romatschke,

arXiv:0706.1522



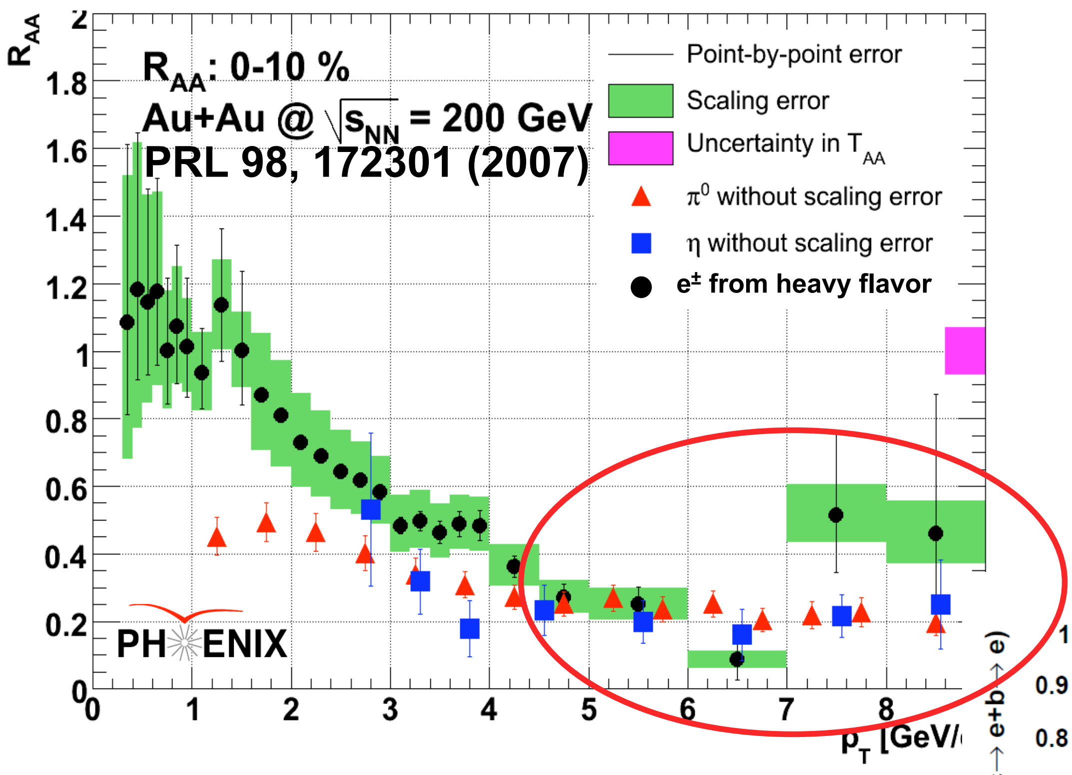
Charged pions sensitive to sign of ΔG

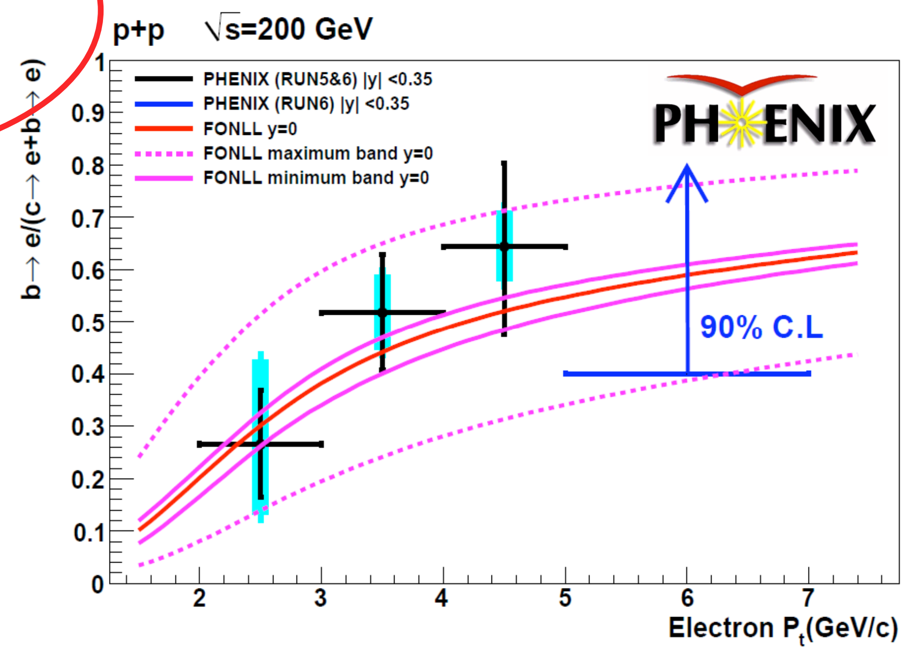




q+g dominates for $p_T > 5$ GeV/c, A_{LL} ~ linear with ΔG

What about b quarks?





b quark contribution to single electrons becomes significant. do they also lose energy?