Обзор материалов конференции Quark Matter 2008

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ОЭФ, ИФВЭ

Семинар ИФВЭ 6 марта 2008

Общая информация

- Полное название: **“20-я международная конференция по ультра-релятивистским ядерным столкновениям”**
- Место проведения: **Индия, Джайпур, 4-10 февраля 2008**
- Всего участников: **около 600 из 31 стран**
- Пленарных докладов: **53**
- Докладов на параллельных секциях: **132**
- Постеров: **около 250**
- Сайт конференции: http://www.veccal.ernet.in/qm2008.html

Эксперименты в области релятивистской ядерной физики

- **SPS @ CERN**: WA98, NA45, NA49, NA60 и др
- **RHIC @ BNL**: PHENIX, STAR, PHOBOS, BRAHMS
- **LHC @ CERN**: ALICE, CMS, ATLAS
- **SIS300 @ FAIR**: CBM

Основные наблюдаемые

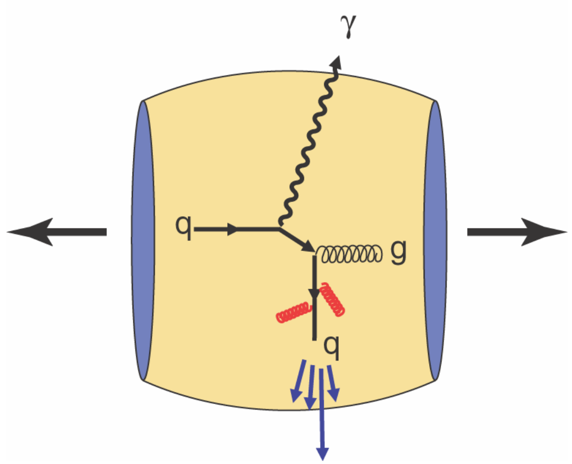
- Hard probes
- Fluctuations
- Strangeness
- Heavy flavours
- Collective effects
- Hadron spectral functions

HARD PROBES

Photons, Leptons, Hadrons

Photons, leptons:

- Penetrating probes that carry information about their production.
- Rare processes
  - Need large data samples
- Large backgrounds
  - Need precise background determination
    - Background γ from decays of π^0 and η
    - Electrons from γ conversions
    - Combinatorial Backgrounds



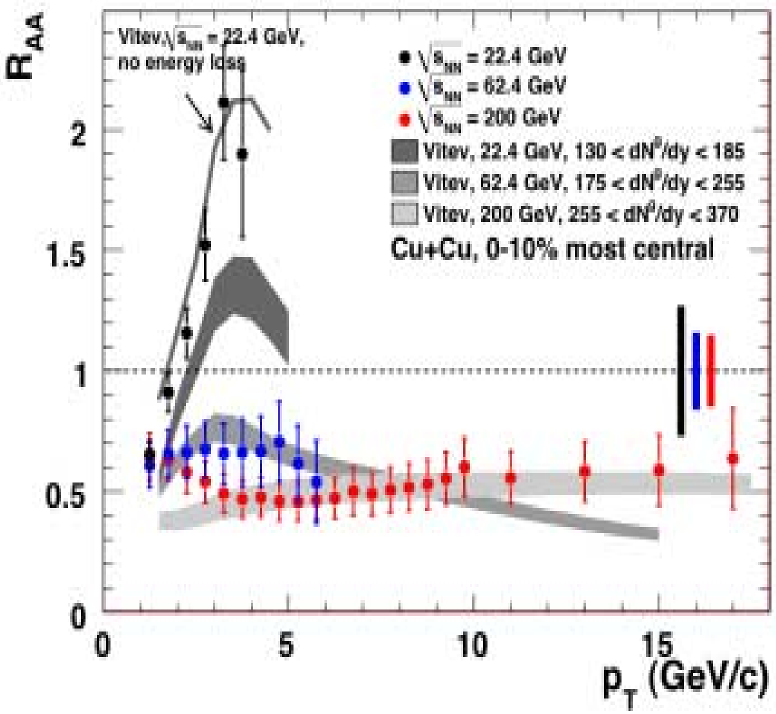
Hadrons

- Products of partons fragmentation
- Partons strongly interact with quark matter and loose energy

Nuclear Suppression Dependence on:

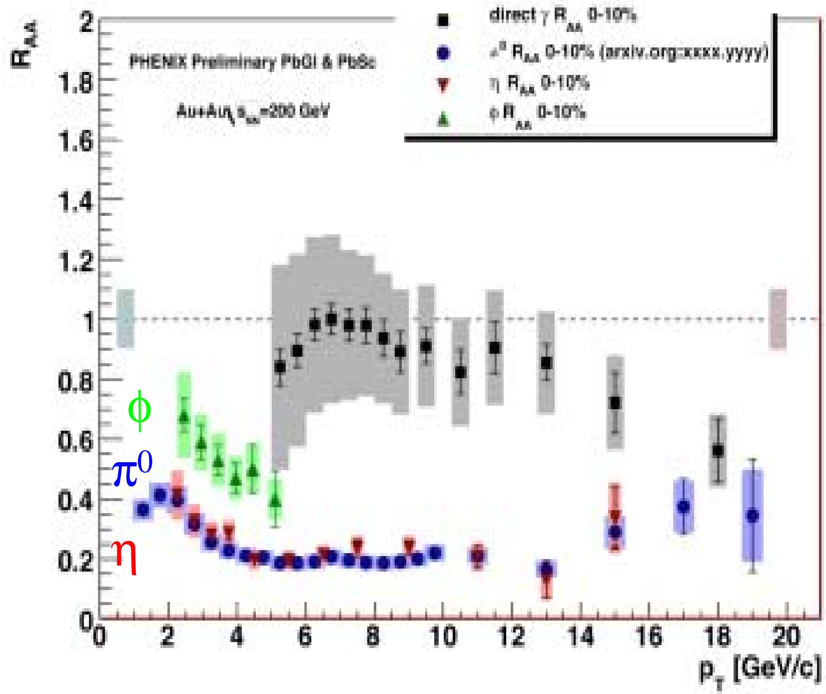
Energy

π^0 Cu+Cu 22,62,200 GeV (Run 5)



Particle Species

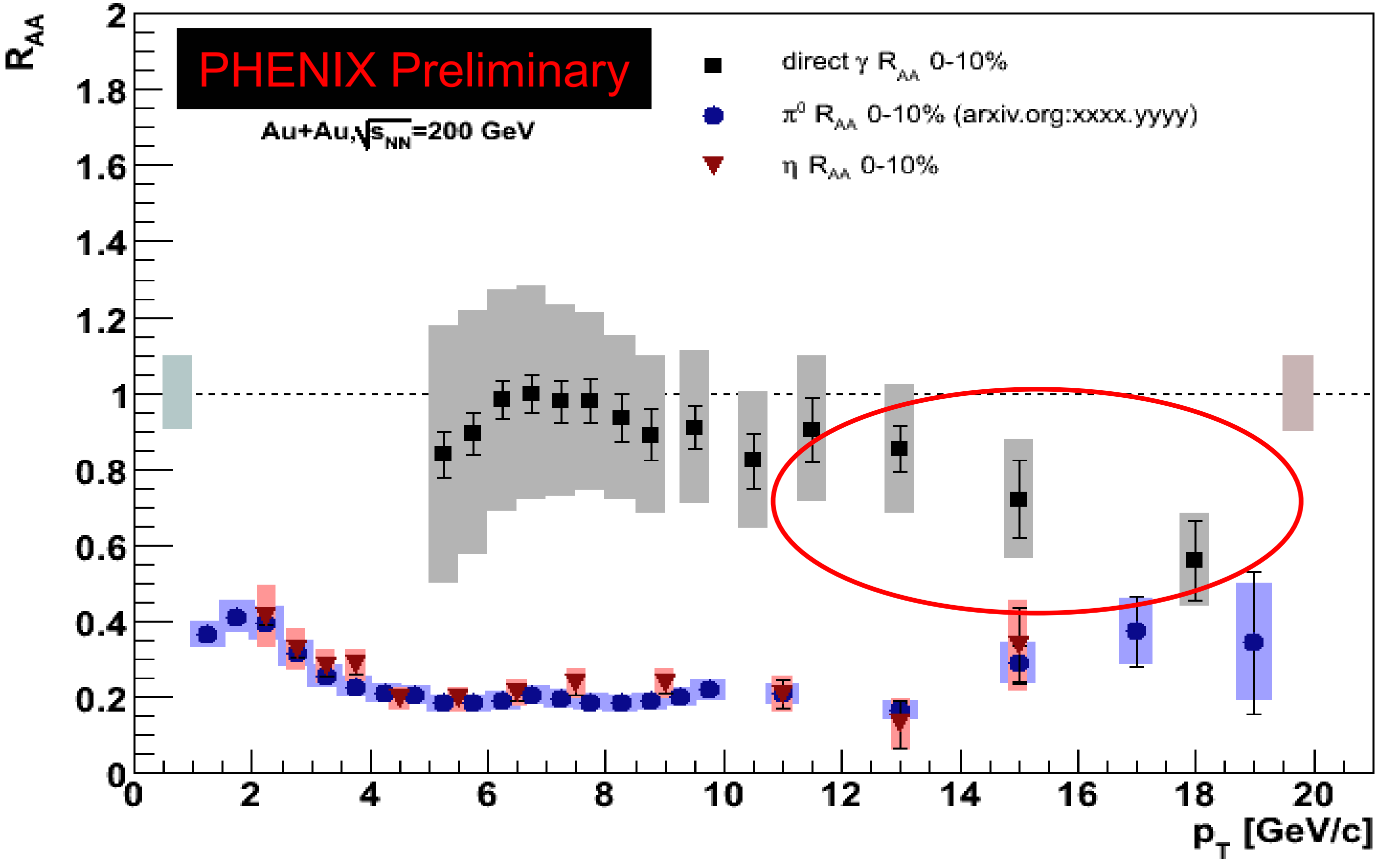
π^0 Au+Au 200 GeV (Run 4)



arXiv:0801.4555

- Model calculations indicate quenching expected at $\sqrt{s_{NN}}$ = 22 GeV
- Species dependence to probe space/time of suppression

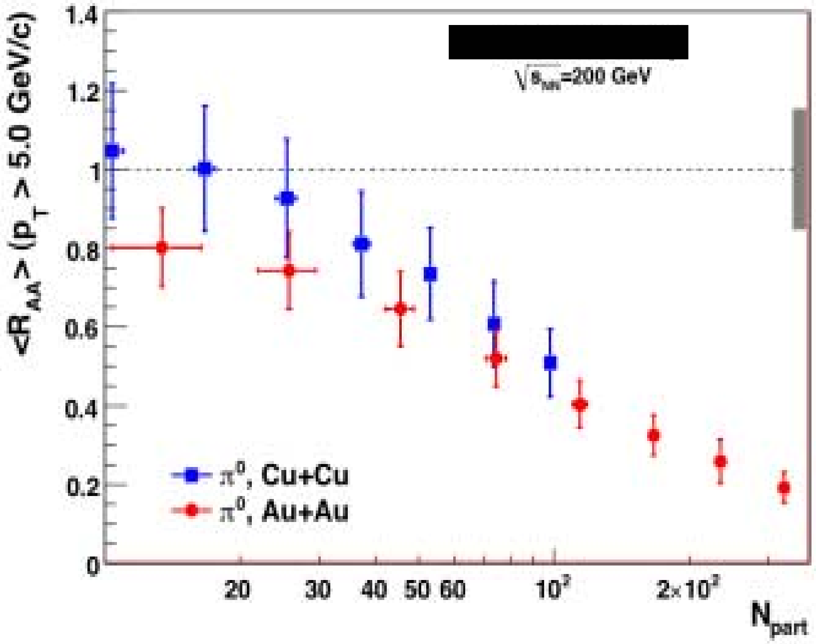
Direct γ Au+Au: $\gamma_{direct} = \gamma_{inclusive} - \gamma_{decay}$



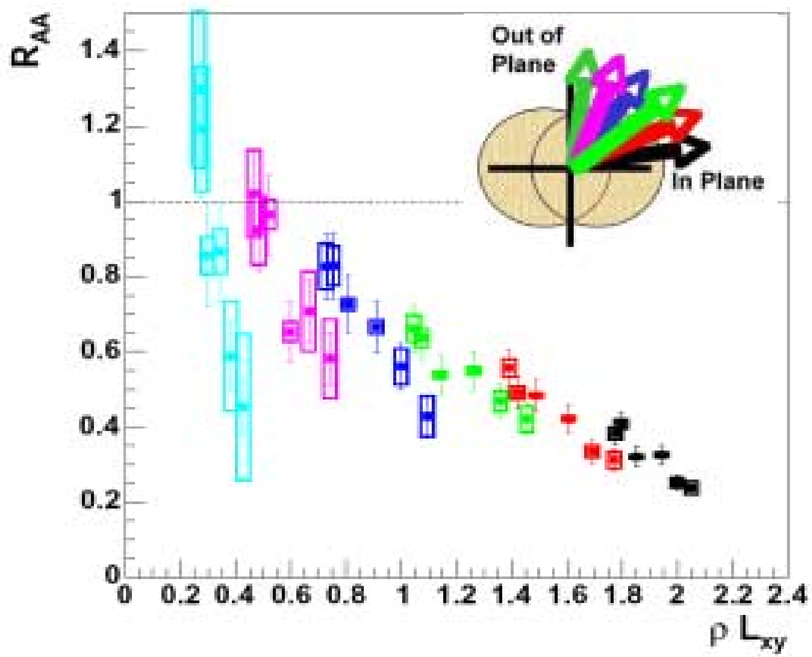
- Run 2: No γ suppression -> Jet quenching (PRL 94, 232301 (2005)).
- Run 4 (QM06): High pT γ suppression
  - Isospin (PDF) effect (+ ?)

Dependence of Nuclear Suppression

N_{Part}



Pathlength

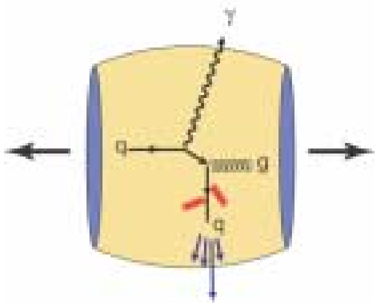


PHENIX PRC 76 034904

- R_{AA} scales with N_{part} at same $\sqrt{s_{NN}}$
  - Some indication for "higher order" effects
- Approximate scaling with <ρL>
- Use $R_{AA}(N_{part}, \sqrt{s_{NN}}$, Species, Pathlength) to illuminate models

Session I: Klaus Reygers

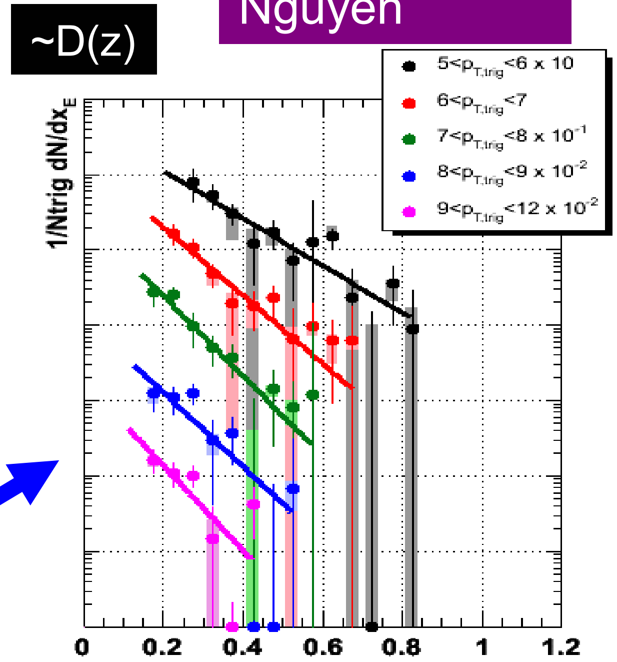
γ-h Correlations



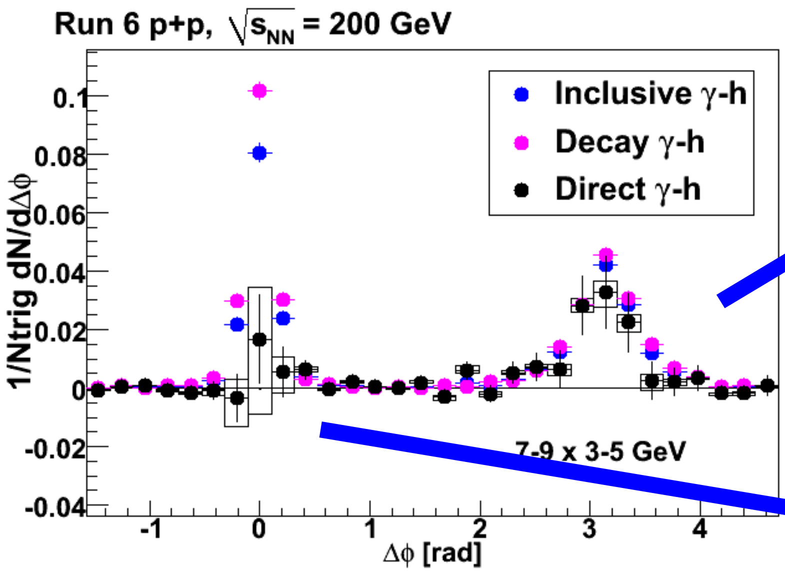
Session XV: Matthew Nguyen

- γ "measures" recoil parton momentum
  - Measure fragmentation function D(Z)

γ-h p+p 200 GeV (Run 5)



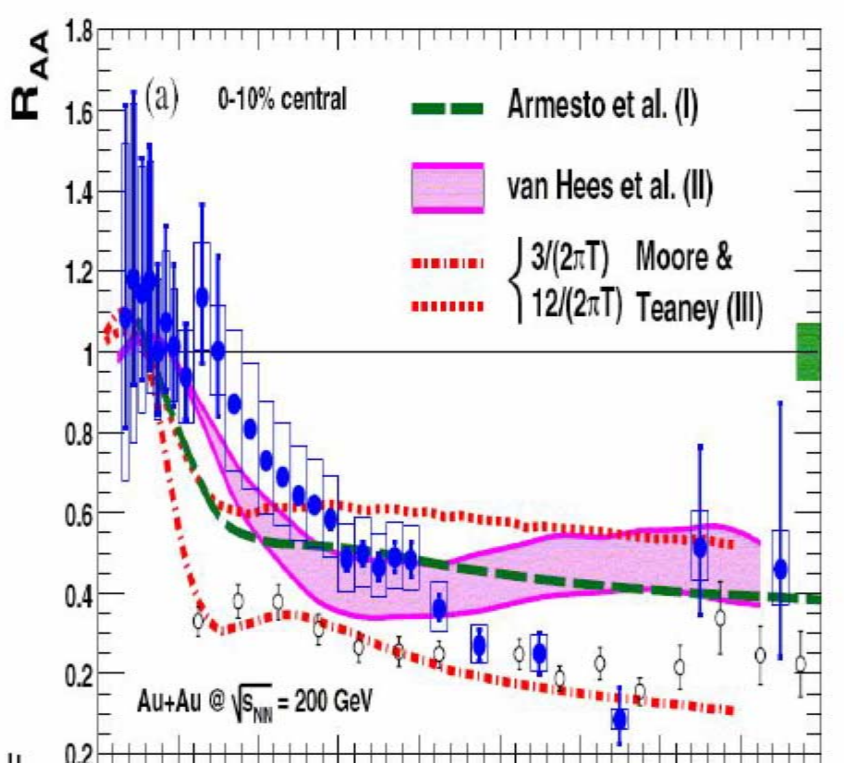
[redacted]



Poster: A.Hanks

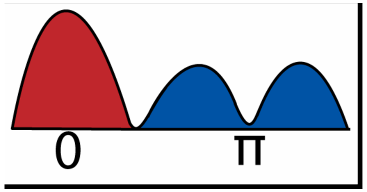
Use Near Side peak to determine direct γ associated with h, I.e. fragmentation photons

Heavy quarks suppression



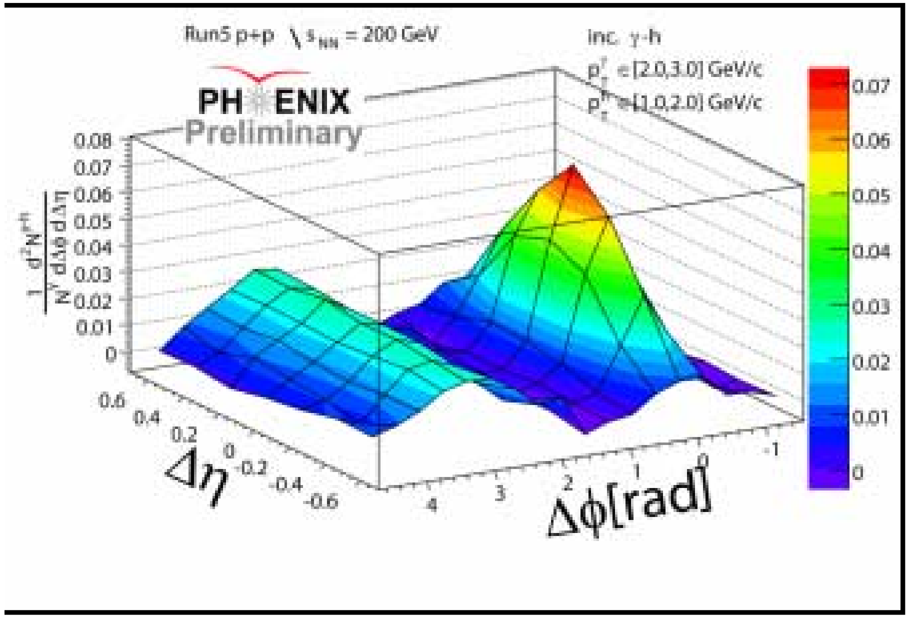
- **Heavy quarks show same suppression as light quarks at high pT?? With substantial bottom contribution??**
- **maybe there is some universal suppression mechanism (i.e. not usual energy loss) ??**

Single electron (c, b semi-leptonic decay) RAA

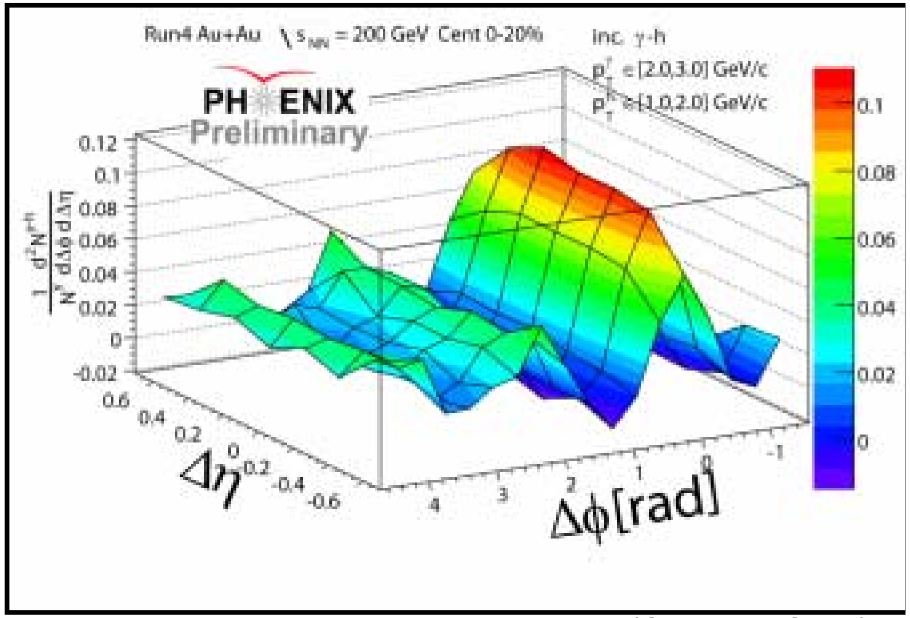


Medium Response

p+p, peripheral Au+Au



central Au+Au



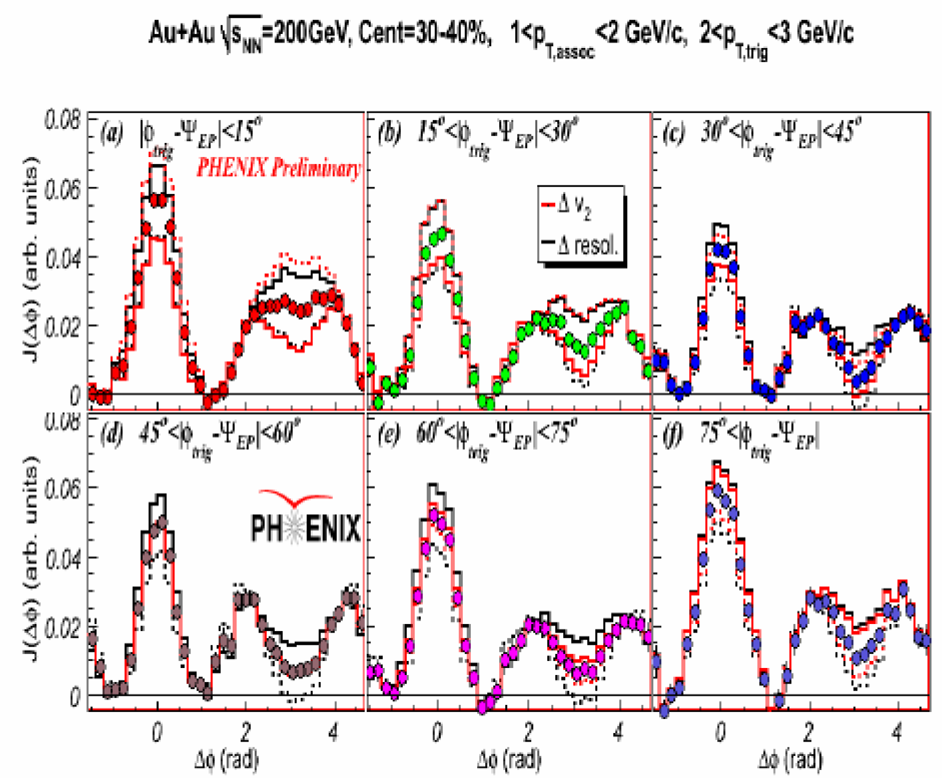
PHENIX poster (Chin-Hao Chen)

<u>Typical:</u>
- Near-side Jet
- Away-side Jet – "Head"

<u>New:</u>
- Near-side Modification – "Ridge"
- Away-side Modification – "Shoulder"

Near-side Ridge theories: Boosted Excess, Backsplash, Local Heating,…
Away-side Shoulder theories: Mach, Jet Survival + Recom, Scattering,…

Conical? flow – RP dependence



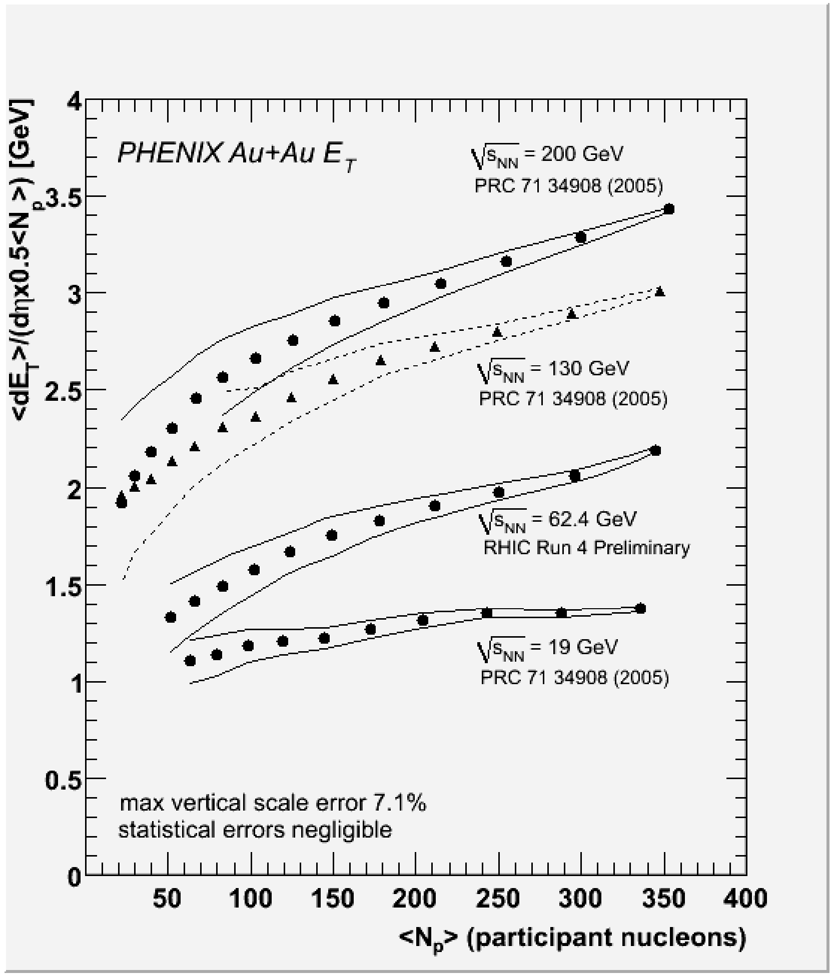
The position of the cone? does not change with angle of trigger hadron *wrt reaction plane.*

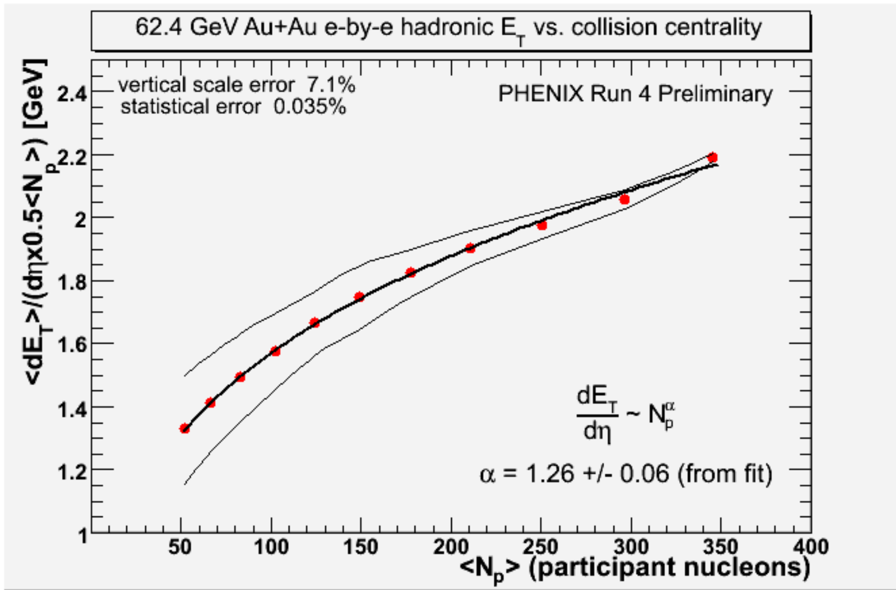
– But we do see the di-jet remnant behave as expected

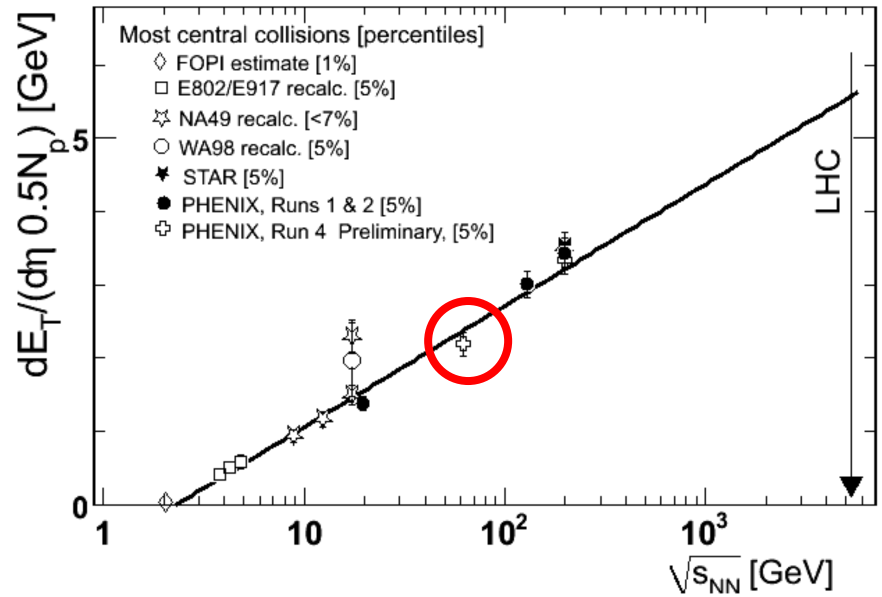
Decreases as φ_t - Ψ_{RP} increases

GLOBAL EVENT CHARACTERISTICS

Transverse Energy







$dE_T/d\eta/N_{part}$

inceases with $\sqrt{s}$ and N_{part}

FLUCTUATIONS AND CORRELATIONS

Correlations and Fluctuations

- Look for discontinuities or changes in experimental results for correlations and fluctuations as a function of incident energy
  - K/π Fluctuations
  - Balance Function
  - Net Charge Fluctuations
  - Multiplicity Fluctuations - several approaches
  - p_t Correlations

Particle Ratio Fluctuations @ PHENIX

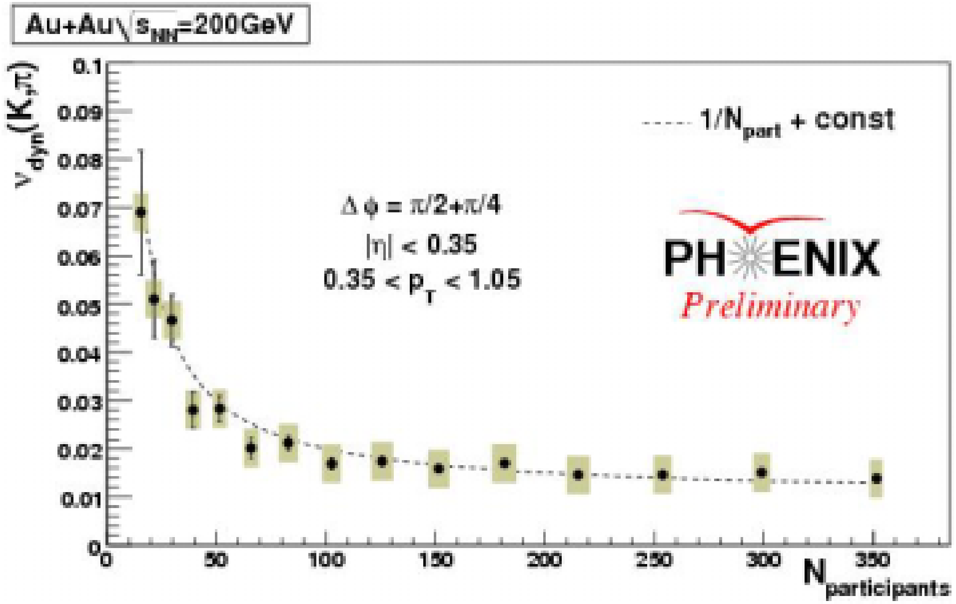
$$\nu_{dyn}(K,\pi) = \frac{\langle \pi(\pi-1)\rangle}{\langle \pi\rangle^2} + \frac{\langle K(K-1)\rangle}{\langle K\rangle^2} + \frac{\langle K\pi\rangle}{\langle K\rangle\langle \pi\rangle}$$

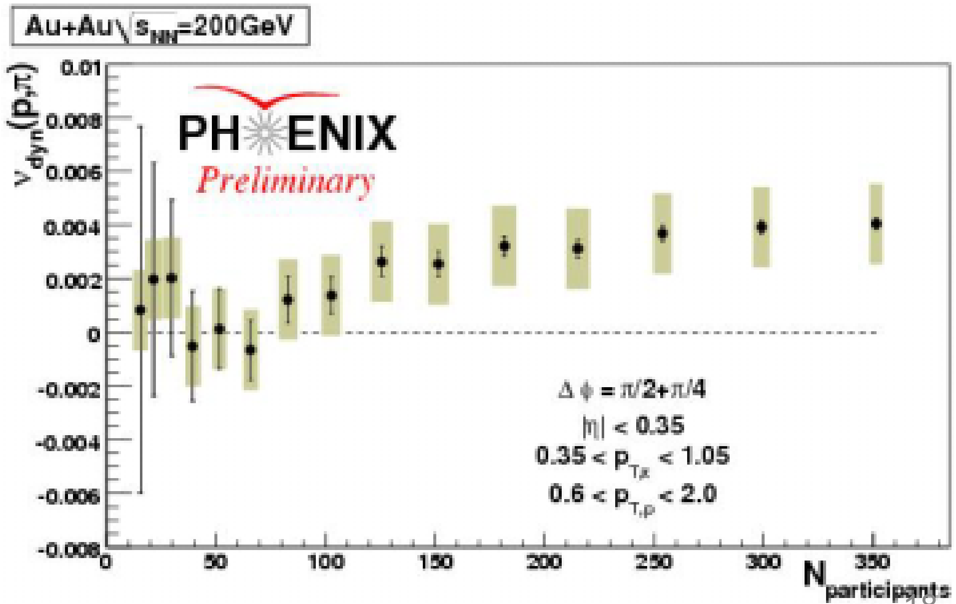
Fluctuation in the ratio of two particle species:

- ν_{dyn} = 0 : only statistical fluctuations
- ν_{dyn} > 0 : larger fluctuations
- ν_{dyn} < 0 : damped fluctuations

C. Pruneau, S.Gavin, S.Voloshin,
Phys. Rev. C 66 044904 (2002)

Particle ratio fluctuation show no indication of critical behaviour



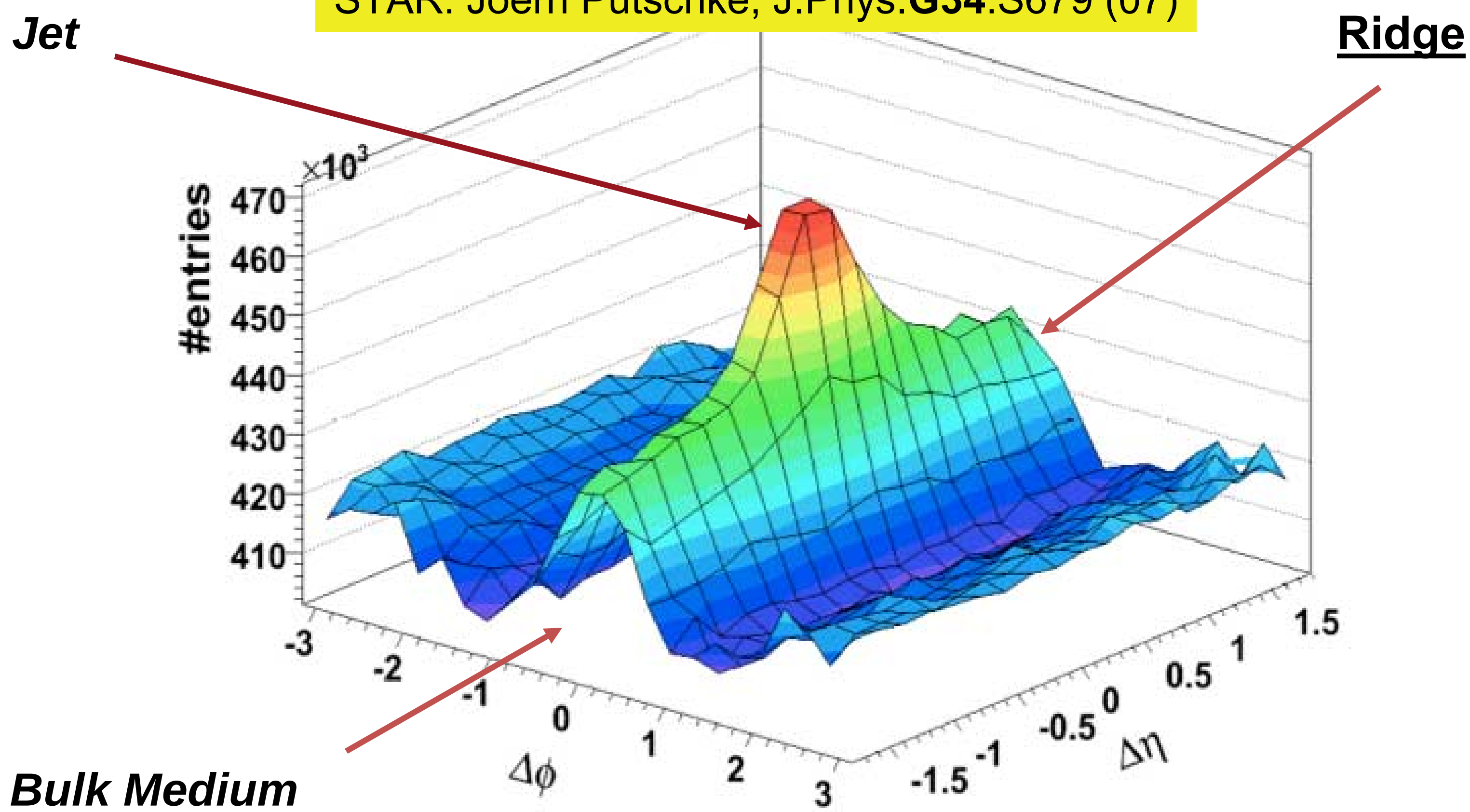


Fluctuations: Conclusions

- We have experimental results for correlations and fluctuations covering incident energies where one might expect effects from the QCD critical point and we have some hints in the
- However, the results are not conclusive
- In particular, we have several different variables, acceptances, and interpretations that need to be unified
- We need to measure correlation fluctuation variables over the broadest range in incident energy and system size
- The SPS and RHIC scans will provide an excellent opportunity to study the QCD critical point

The Ridge from RHIC

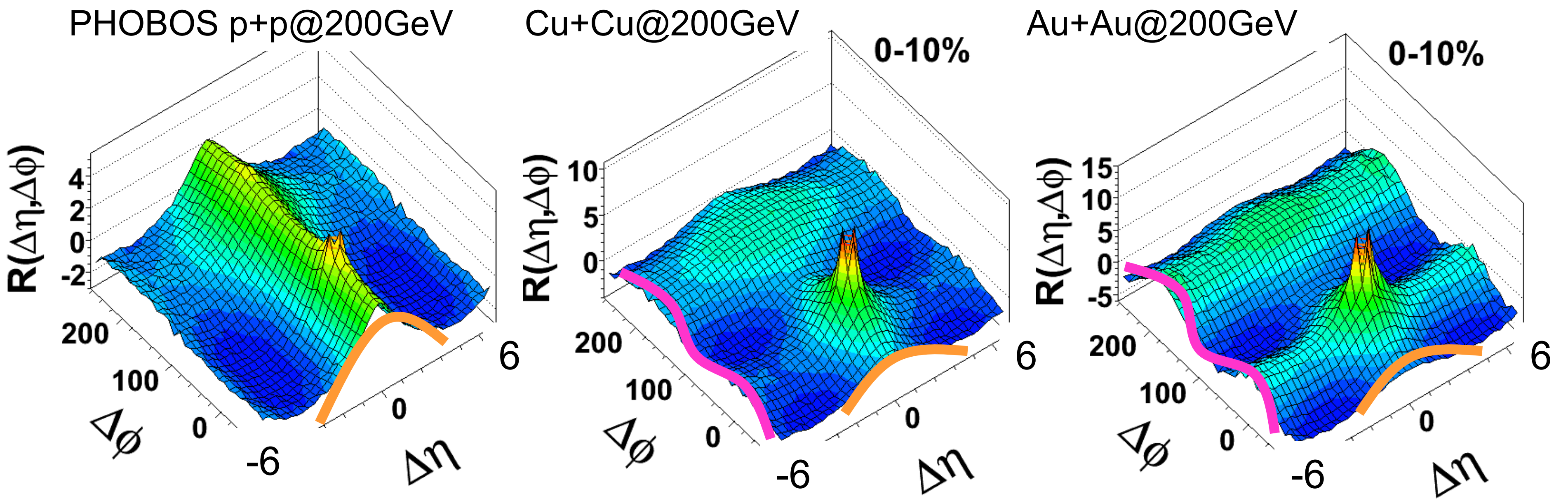
STAR: Joern Putschke, J.Phys.**G34**:S679 (07)



Rich underlying physics: jet, bulk, jet-medium interaction,
medium responses,…

N. Armesto et al.; R. Hwa; A. Majumder, et al.; E. Suryak; S. Voloshin; C.Y. Wong

Two-particle Correlations in Cu+Cu and Au+Au Collisions



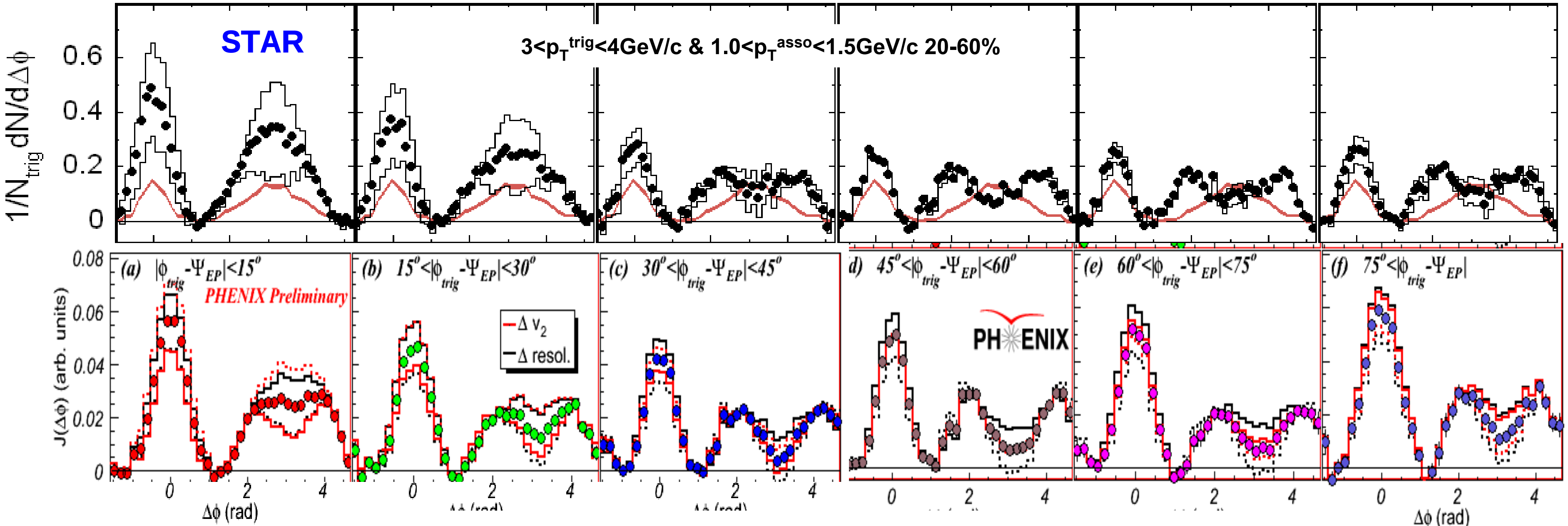
Phys. Rev. C75(2007)054913

PHOBOS preliminary

Parallel: W. Li

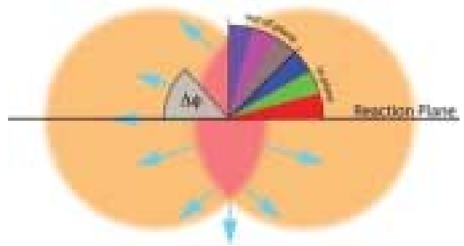
1) Short range cluster-like structure in A+A as in p+p.
2) Elliptic flow over large range of $\Delta\eta$ in A+A collisions.

Reaction Plane Dependence



$\Delta\phi = \phi_{associate} - \phi_{trigger}$ (rad)

Parallel: M. McCumber; O. Catu; H. Pei
A. Feng; O. Barannikova; A. Adare

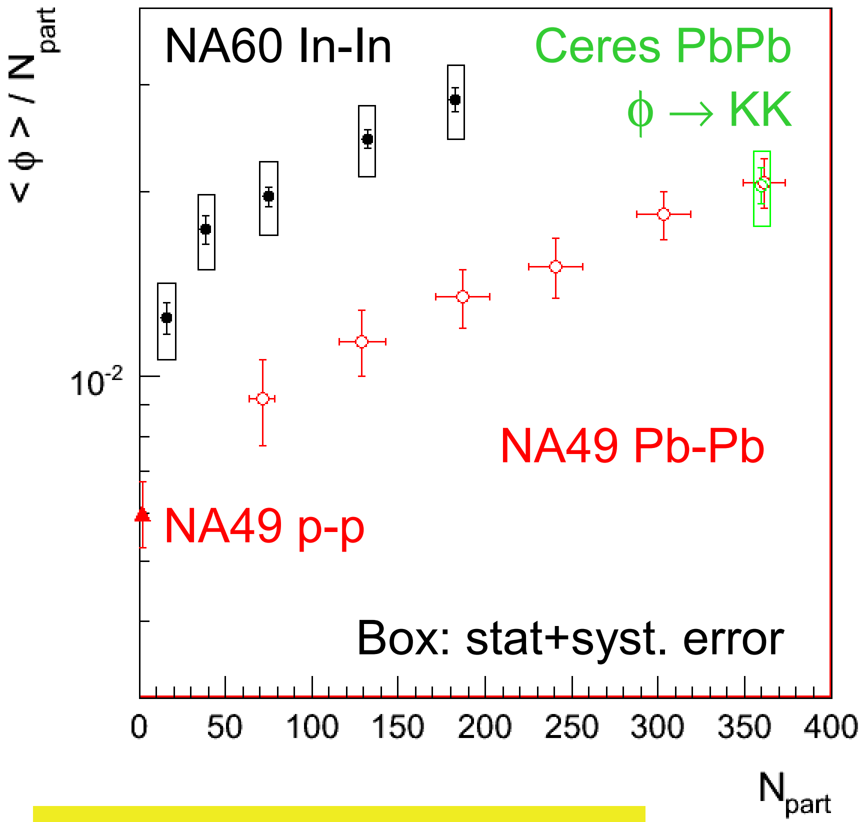


At low p_T region, study the medium response to jets

- Away side (medium side): single ⇒ double peaks
- Near side (jet side): amplitude reduced

STRANGNESS PRODUCTION

New ϕ Puzzle from SPS



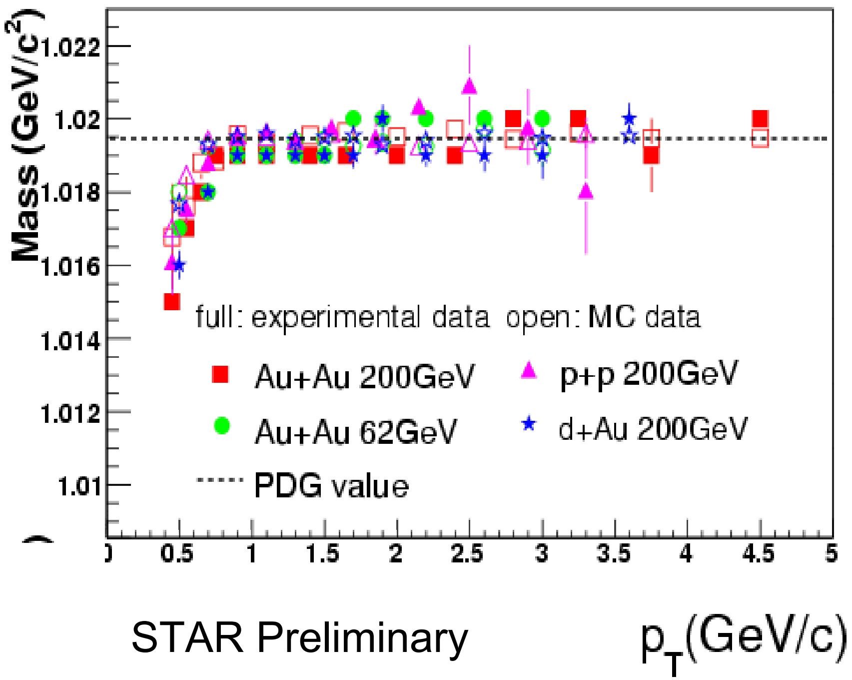
NA60 vs NA49 (full phase space):
Also $\phi \rightarrow \mu\mu$ in In-In higher than NA49 yield (like NA50).

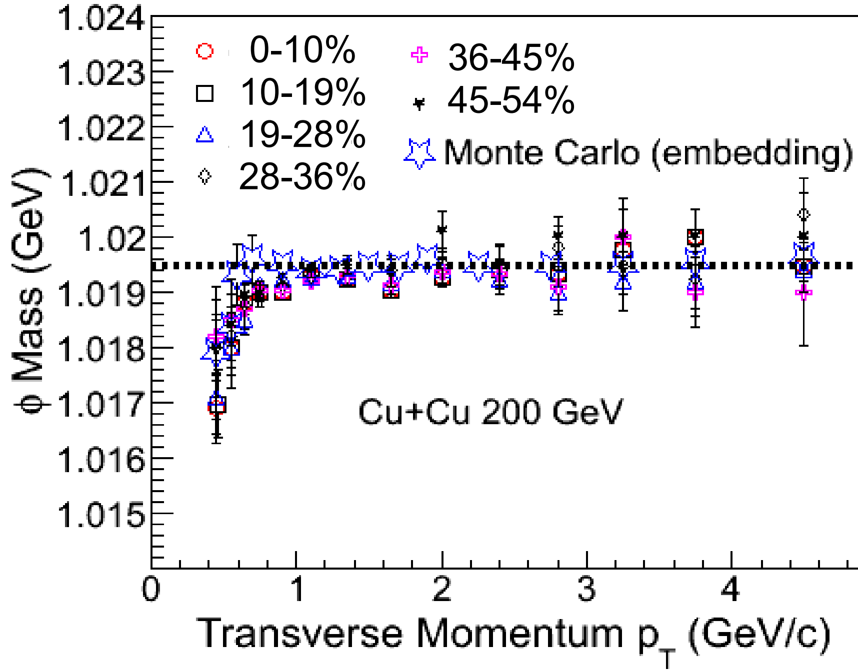
Looking forward to the NA60 $\phi \rightarrow KK$ results from In-In collisions.

Parallel: F. Arleo; D. Jouan

"Difference in $\phi \rightarrow \mu\mu$ and $\phi \rightarrow$KK yields seems confirmed - related to a real physics mechanism (kaon absorption)?"

ϕ mass @ STAR

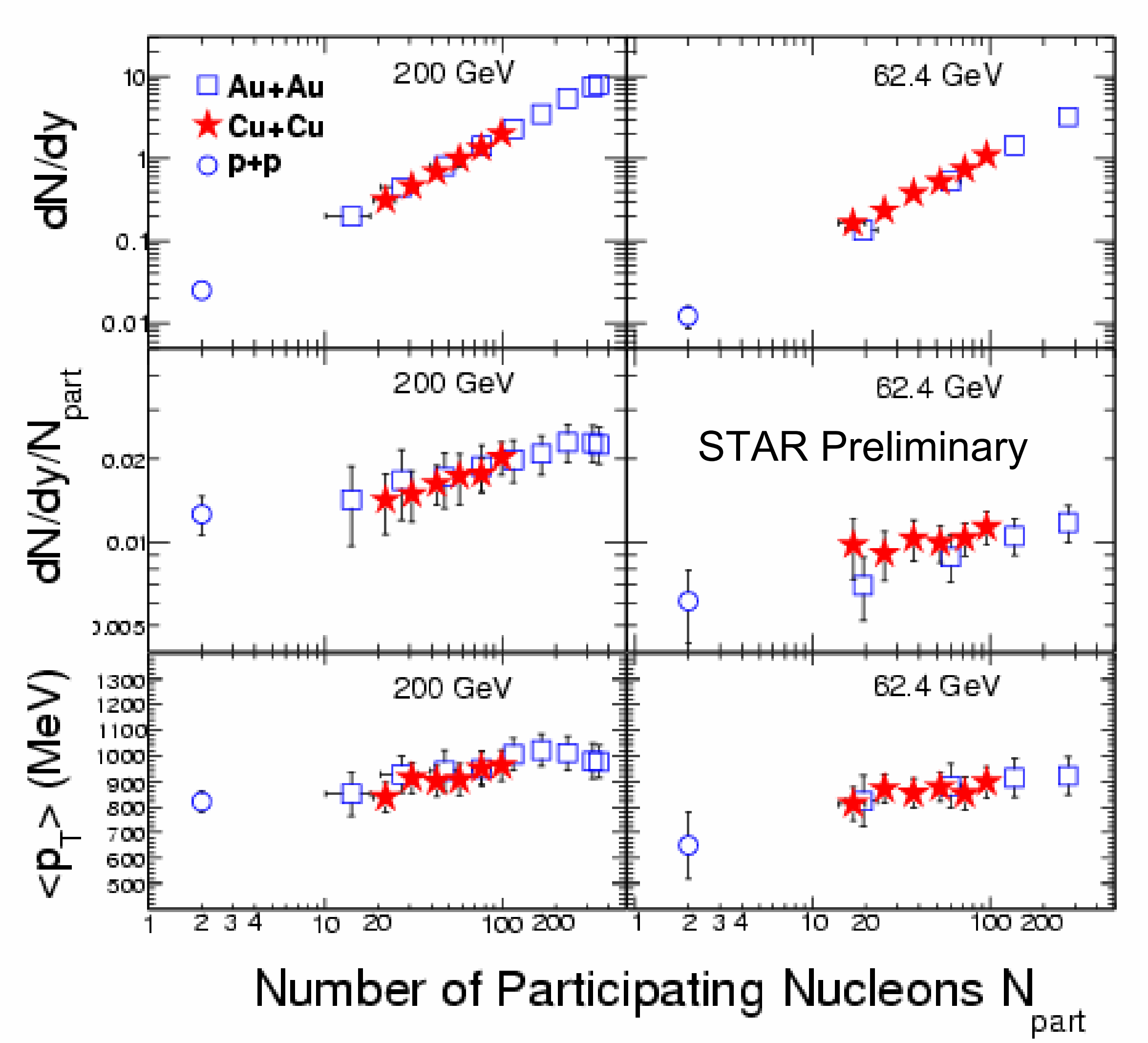




– The ϕ mass is consistent with PDG value at p_T>0.7 GeV/c while a drop of ~2.5 MeV at lower p_T

– The ϕ mass value from data and simulation are consistent and the drop at low p_T is understood within detector effects

ϕ dN/dy and $<p_T>$



– The dN/dy and $<p_T>$ are similar for Cu+Cu and Au+Au at similar N_{part} bin for the same collisions energy.

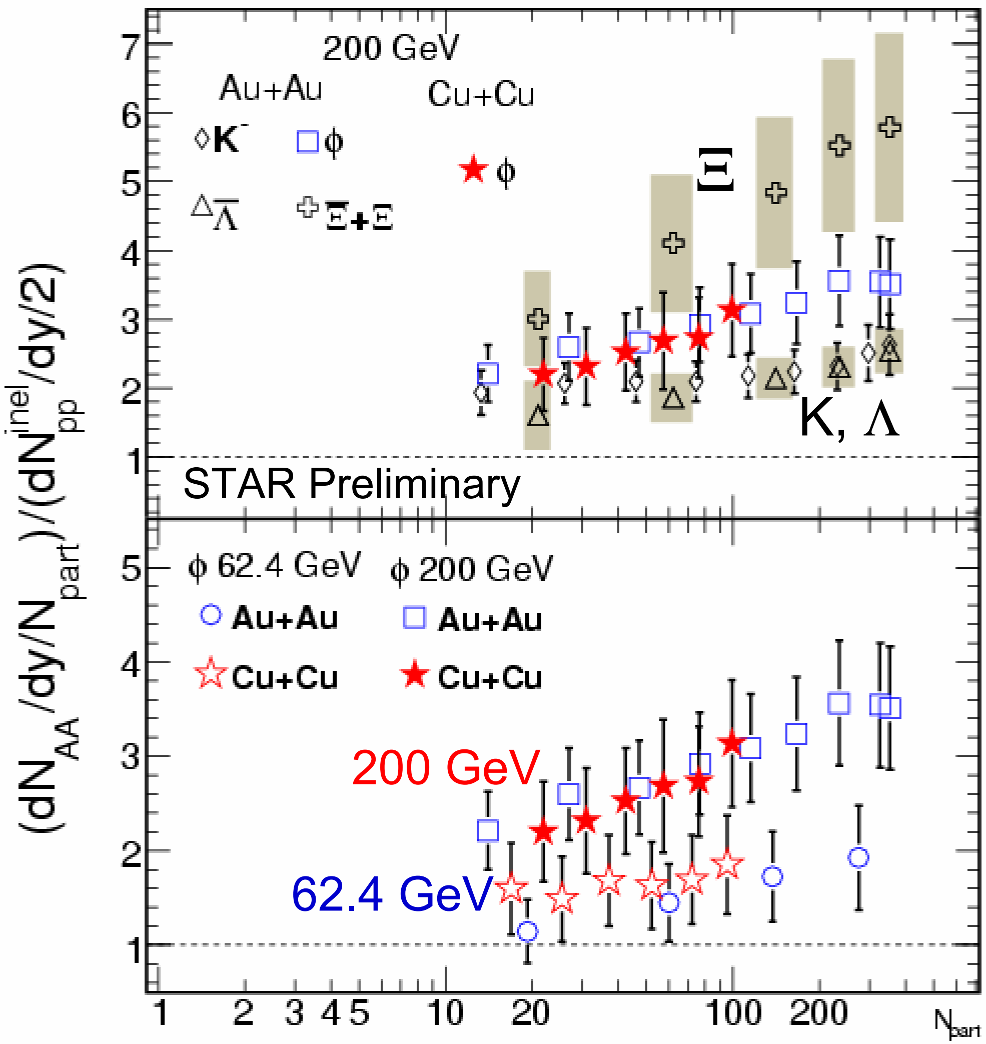
– ϕ yields from Au+Au and Cu+Cu collisions depend on the number of participant nucleons only, unlike Kaon and hyperons.

see STAR Xiaobin Wang – parallel session VII

1] NA49 Col. Phys. Rev. Lett. 96, 052301 (2005);

2] E-802 Col. Phys. Rev. C 60, 044904 (1999).

Strangeness enhancement @ STAR



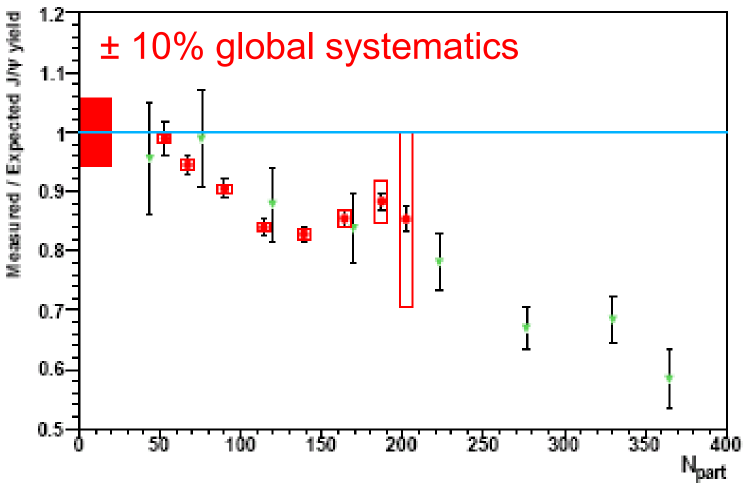
ϕ-meson enhancement shows a distinct collision centrality and energy dependence.

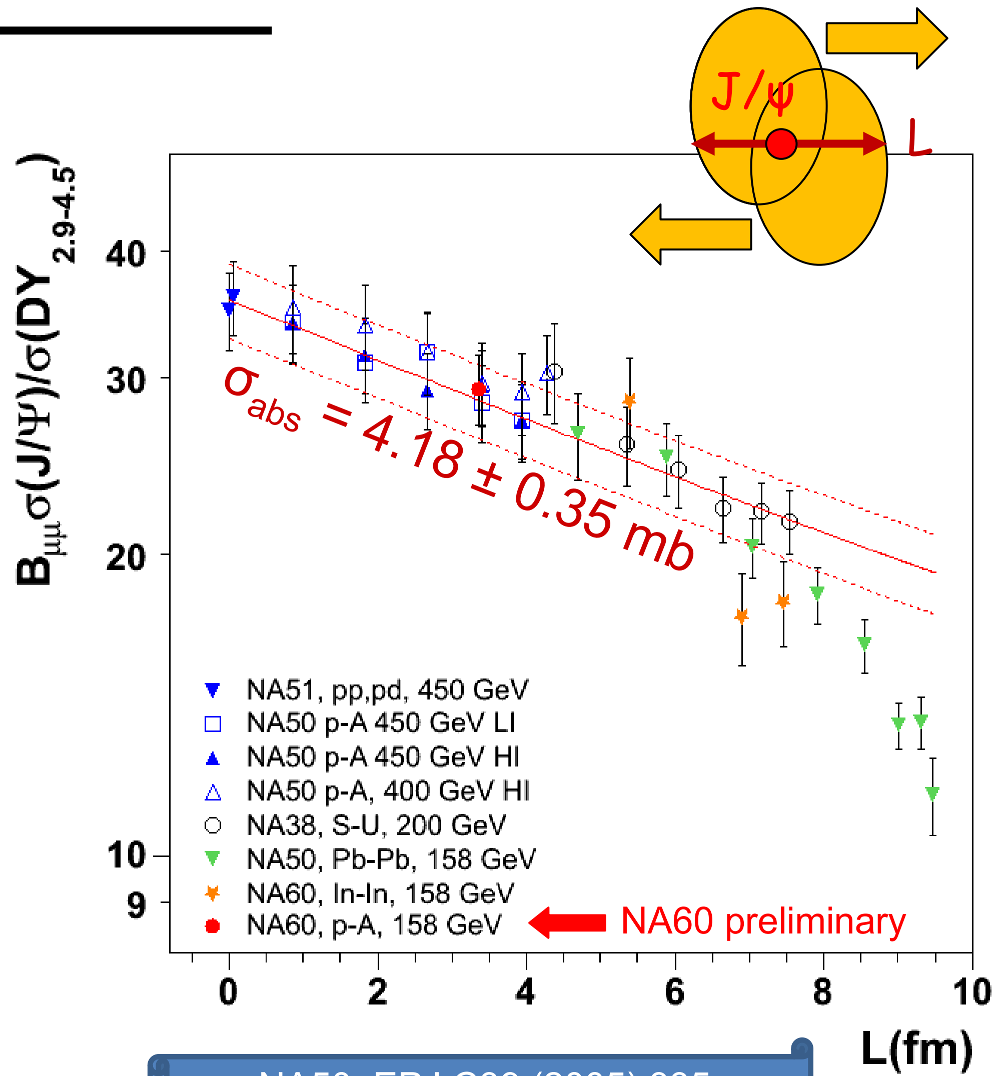
The enhancement factor of the ϕ-meson production (yield per Npart) lies between those of K/Λ and Ξ, and decreases from 200 GeV to 62.4 GeV data unlike hyperons.

HEAVY FLAVOURS

Cold and hot matters @ SPS

- <u>Normal nuclear absorption alone</u> does a splendid job describing pA, SU and peripheral InIn and PbPb:
  - σ_{abs} = 4.18 ± 0.35 mb
- Beyond is "anomalous suppression"
- Observed suppression exceeds nuclear absorption
- Onset of the suppression in In-In at N ~ 80

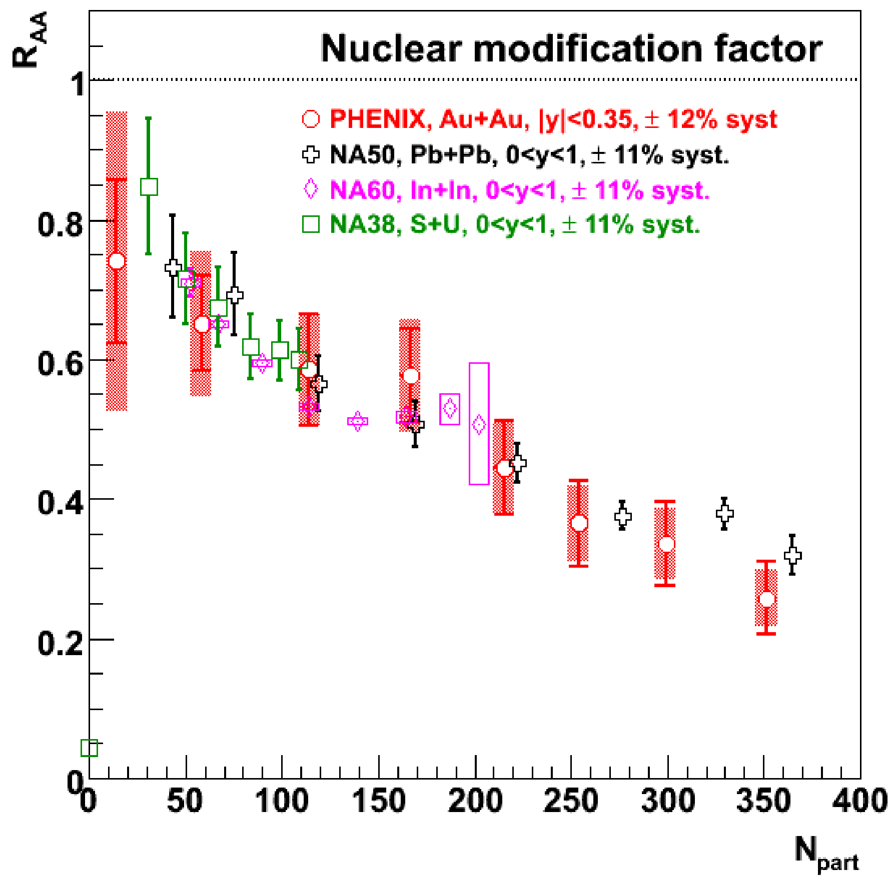




NA50, EPJ C39 (2005) 335
NA60, PRL99 (2007) 132302

R_{AuAu} (y≈0 in PHENIX) ≈ R_{PbPb} (@ SPS)

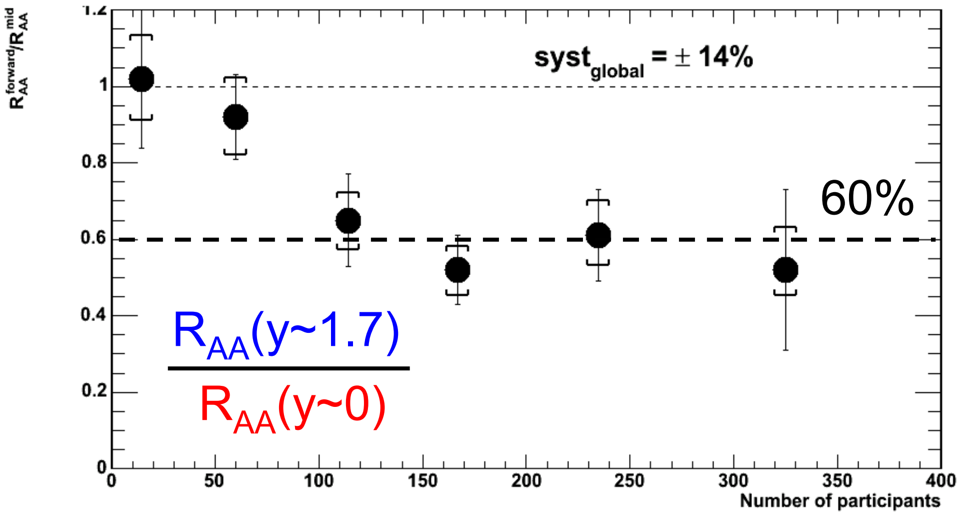
- Lower rapidity R_{AA} looks surprisingly similar, while there are obvious differences:
  - At a given N_{part}, different energy densities…
  - Cold nuclear matter effects ($x_{Bjorken}$, σ_{abs}…)
  - …

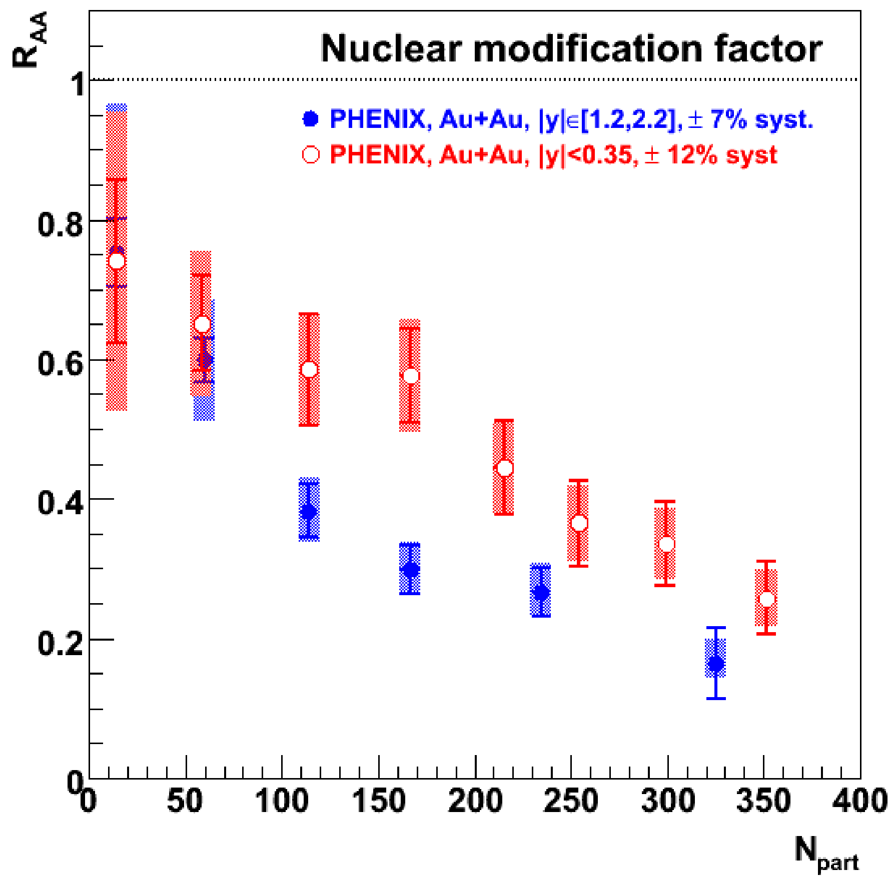


PHENIX, PRL98 (2007) 232301
SPS from Scomparin @ QM06

R_{AuAu} (y≈1.7) < R_{AuAu} (y≈0) in PHENIX

- @ RHIC, more J/ψ suppression at forward rapidity !
- While energy density should be smaller…

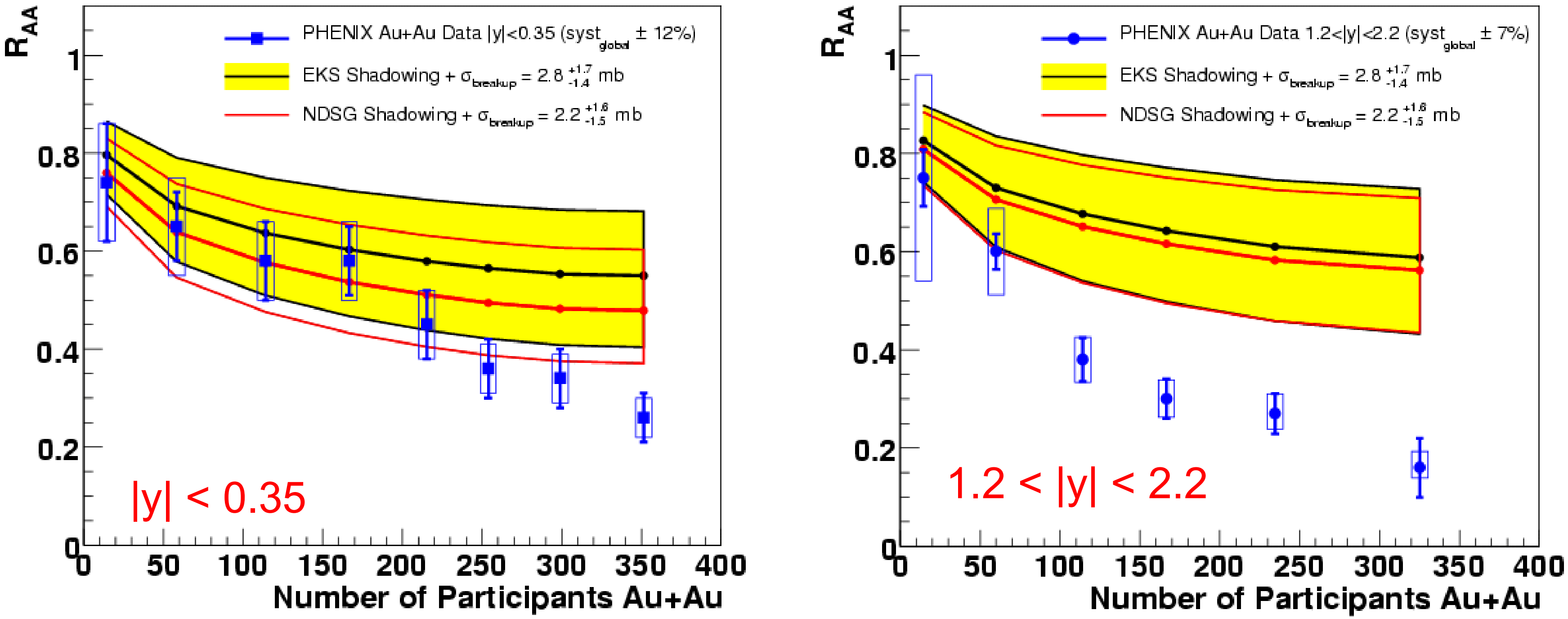




PHENIX, PRL98 (2007) 232301

J/ψ Au+Au @ PHENIX

J/ψ R_{AuAu} 200 GeV (Run4)



arXiv:0711.3917

- Large errors still (need Run 8 d+Au, Run 7 Au+Au)
  - Comparison suggests more forward suppression beyond CNM than at mid-rapidity
  - BUT models shown don’t describe R_{dAu} impact parameter dependence

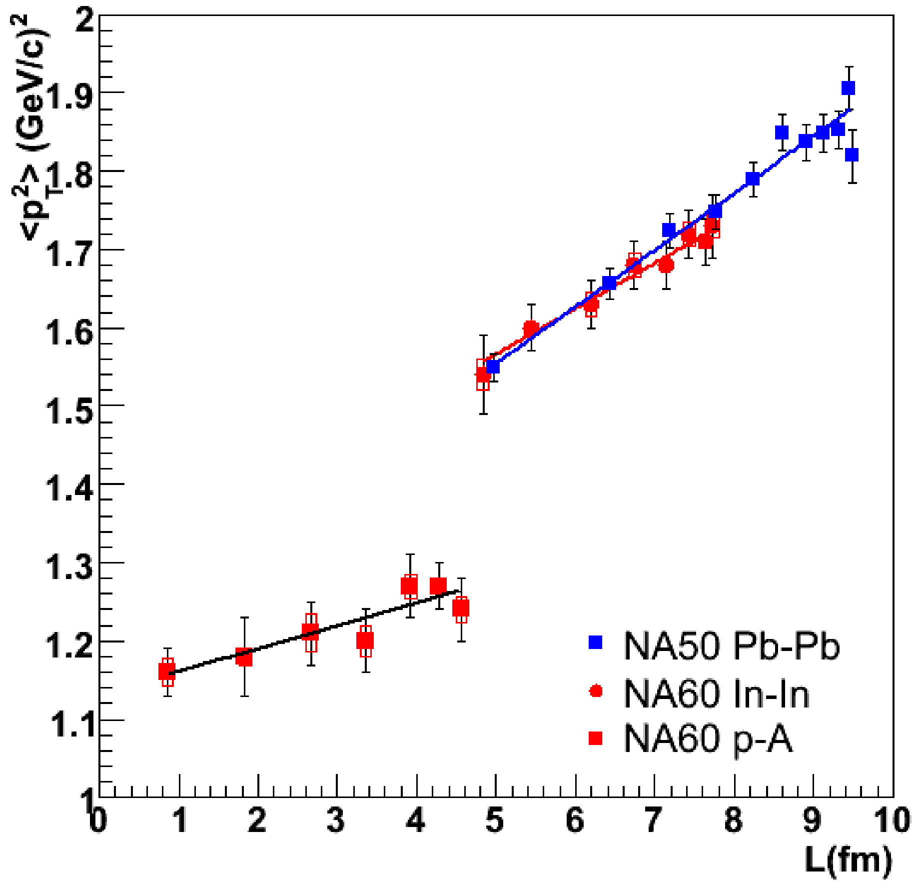
R. Arnaldi, Session 18, Saturday

p_T broadening @ SPS ?

NEW

- Different scaling in pA and AA collisions
- Something else going on in AA?
  - High p_T J/ψ escape?

- **Linear increase of $\langle p_T^2 \rangle$ with L**, consistent with gluon scattering in the initial state



Open charm: physics motivations

Charm:
- is primarily
  - little
  (see t
- **is sensitiv**
  (quark prod
- has an unc
- **large** unce
  - α_s la
  - **glu**
  for P_T <
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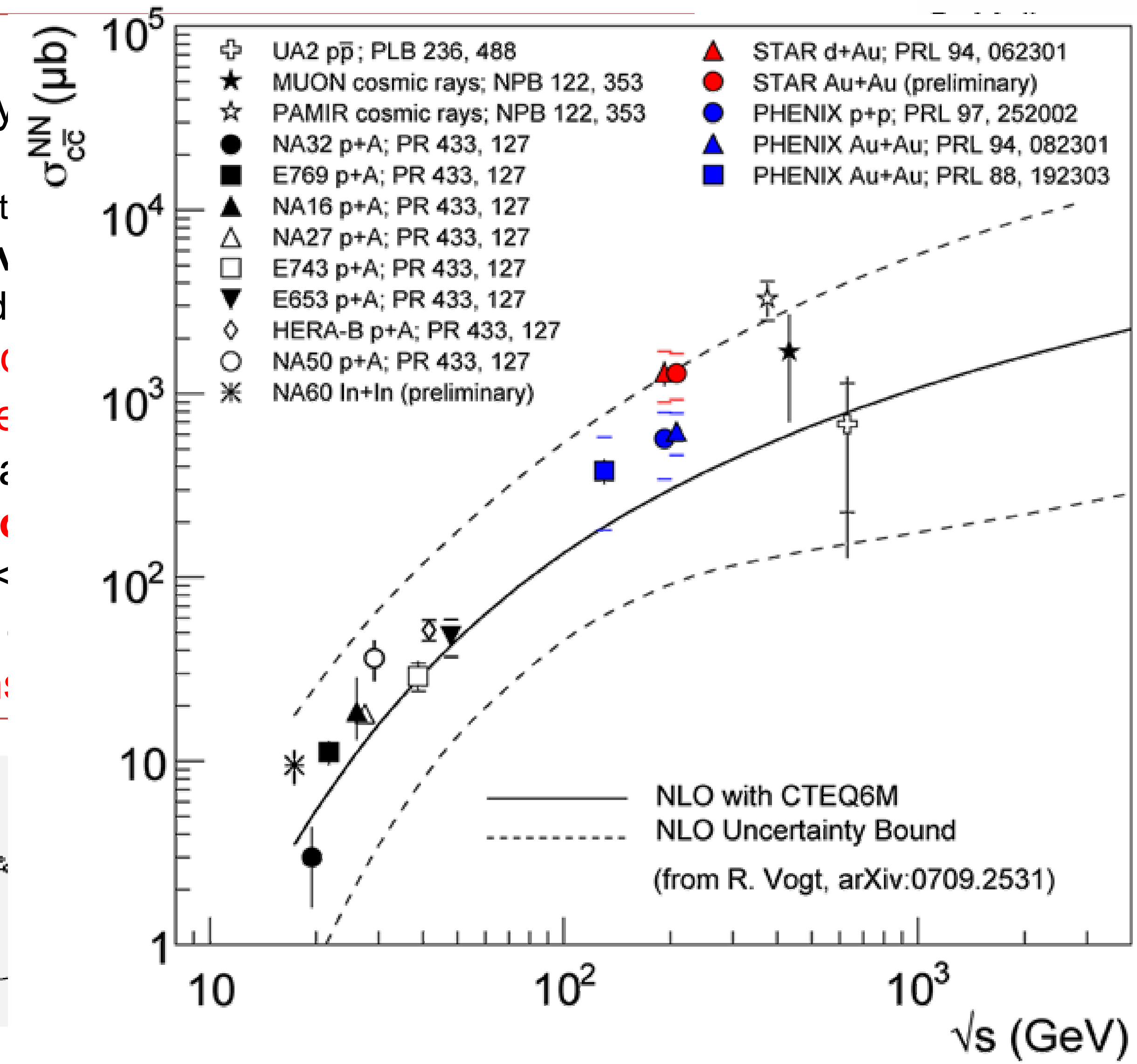

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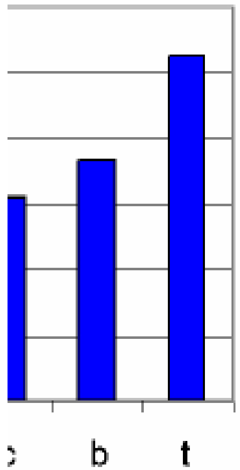

> Λ_{QCD}

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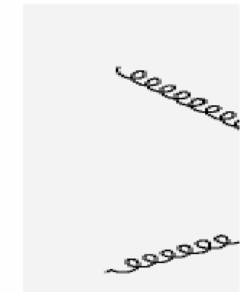
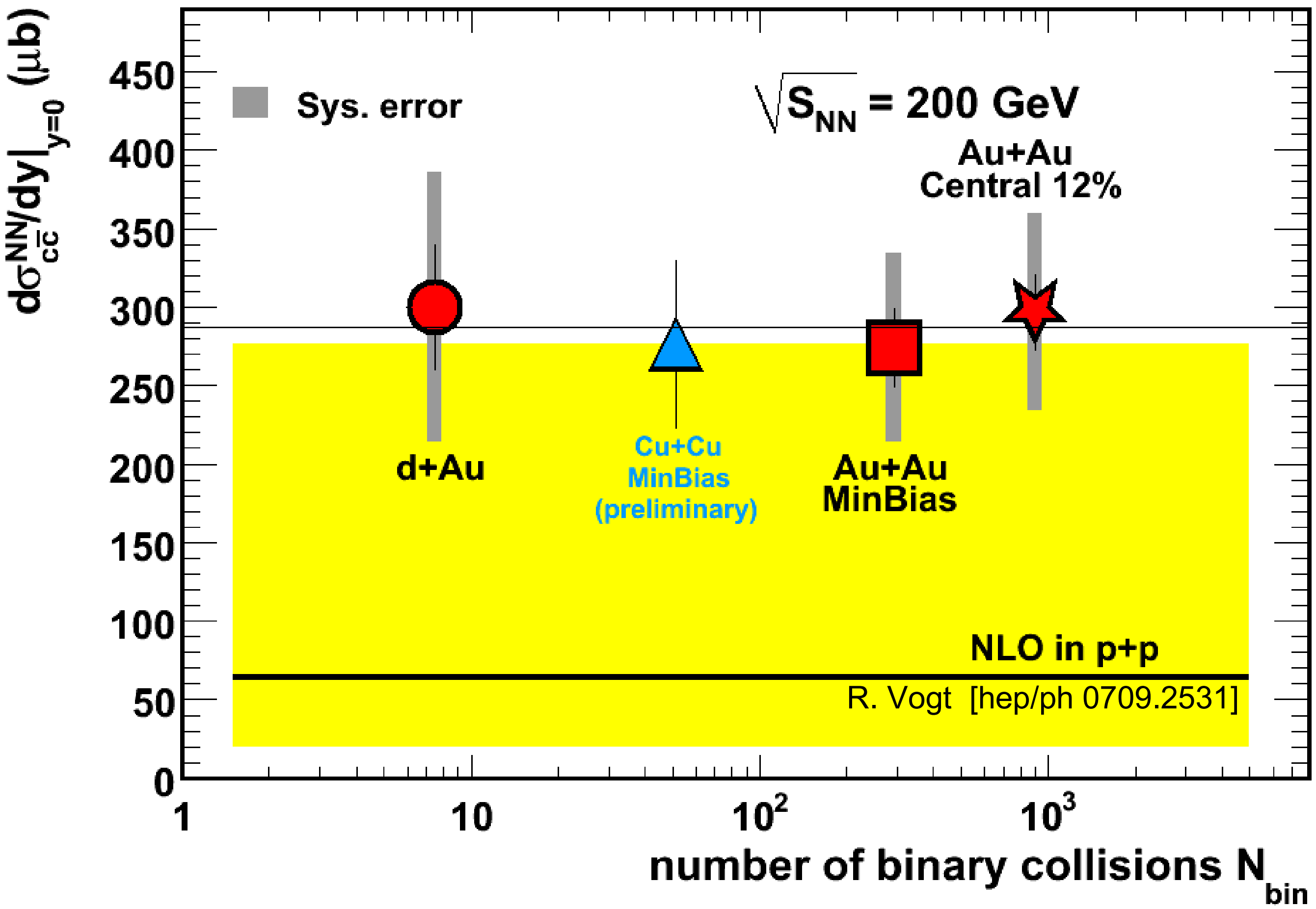


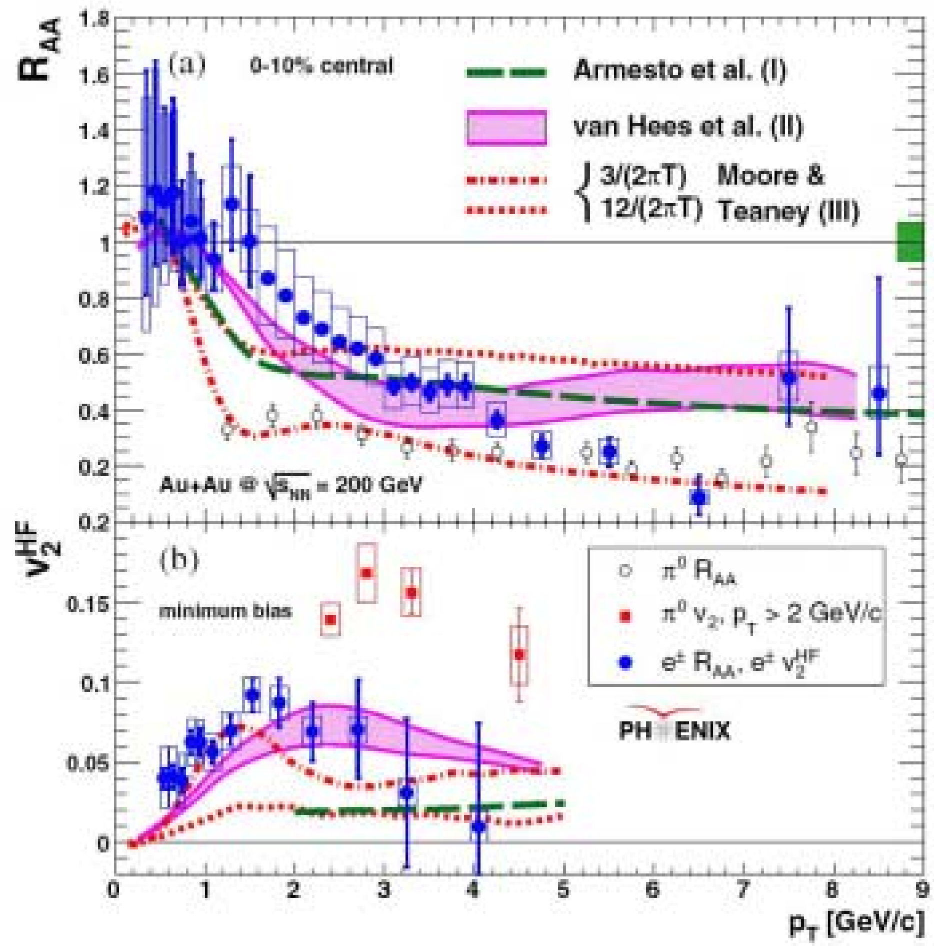
Open charm: dσ/dy in STAR…



- ❖ Accurate background subtraction is crucial
- ❖ Systematic study is ongoing

Scaling with the number of binary collisions from d+Au to Au+Au **confirmed in Cu+Cu.**

Heavy Flavor via non-photonic Electrons

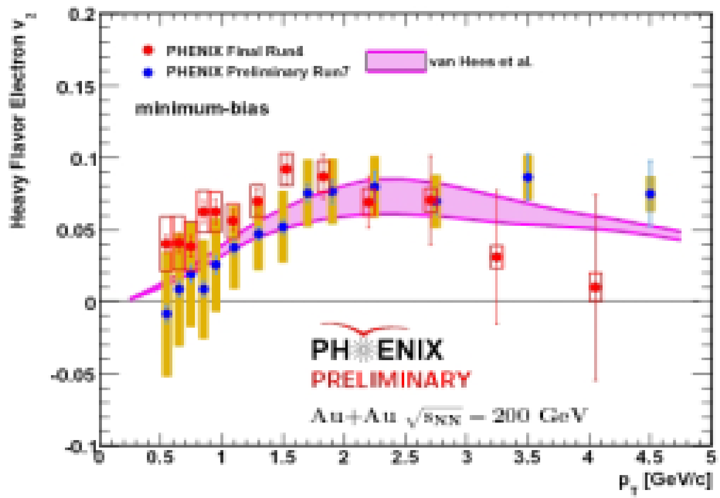


PHENIX : PRL98, 172301 (2007)

HF strongly suppressed, Significant v_2

- Implies high density, small diffusion coefficient
- Estimate $\eta/s = (1.3\text{-}2)/4\pi$
- Very close to conjectured limit

Session XIV: Ralf Averbeck



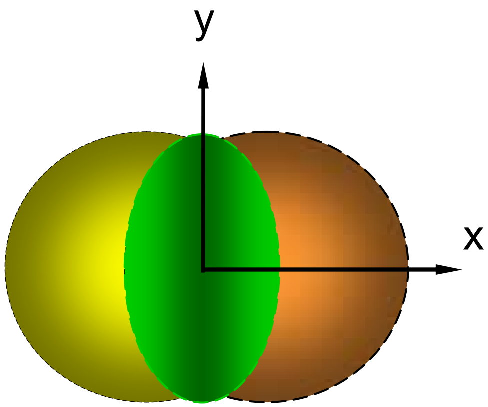
Preliminary Run 7 HF v_2 result:

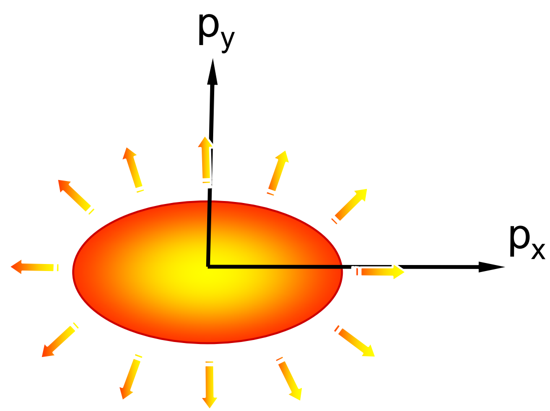
Poster: A.Dion

COLLECTIVE EFFECTS

Anisotropy Parameter v_2

coordinate-space-anisotropy ⇨ momentum-space-anisotropy

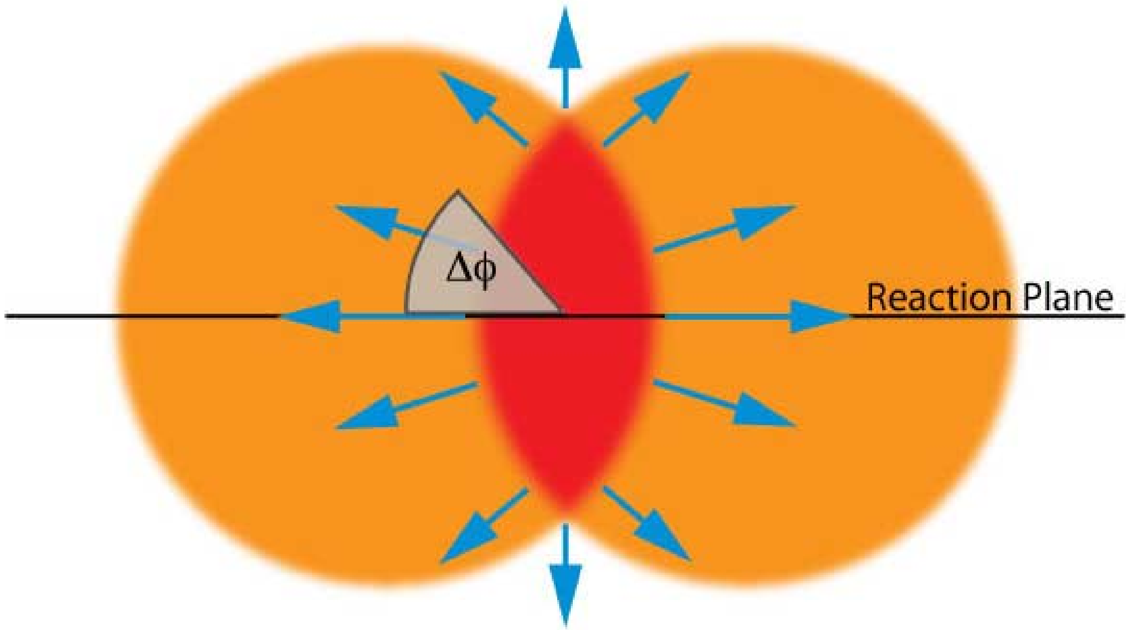




$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

Flow



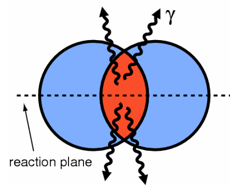
$$\frac{dN}{p_T dp_T dy d\varphi} = \frac{1}{2\pi}\frac{dN}{p_T dp_T dy}\left[1 + \sum_{i=1} 2 v_i \cos\left(i(\varphi - \Psi_{RP})\right)\right]$$

$$v_1 = \left\langle \frac{p_x}{p_y} \right\rangle = \left\langle \cos(\varphi - \Psi_{RP}) \right\rangle \qquad p_t = \sqrt{p_x^2 + p_y^2}$$

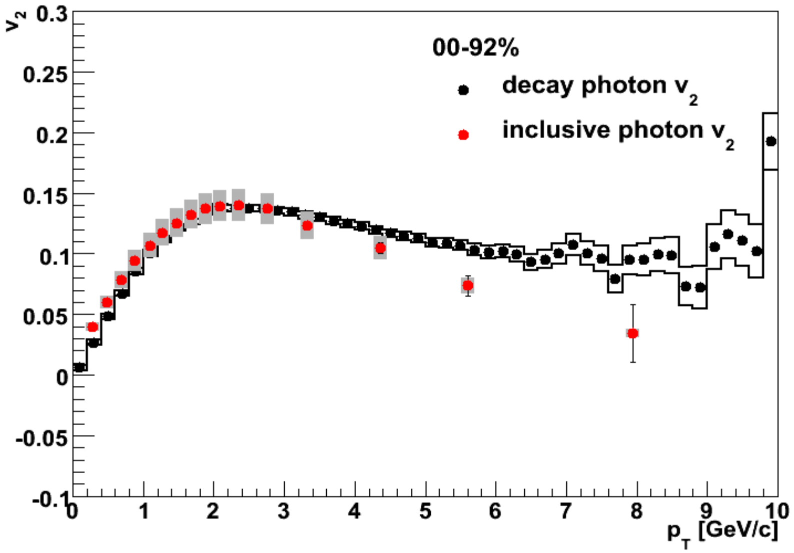
$$v_2 = \left\langle \left(\frac{p_x^2}{p_T^2} - \frac{p_y^2}{p_T^2} \right) \right\rangle = \left\langle \cos 2(\varphi - \Psi_{RP}) \right\rangle$$

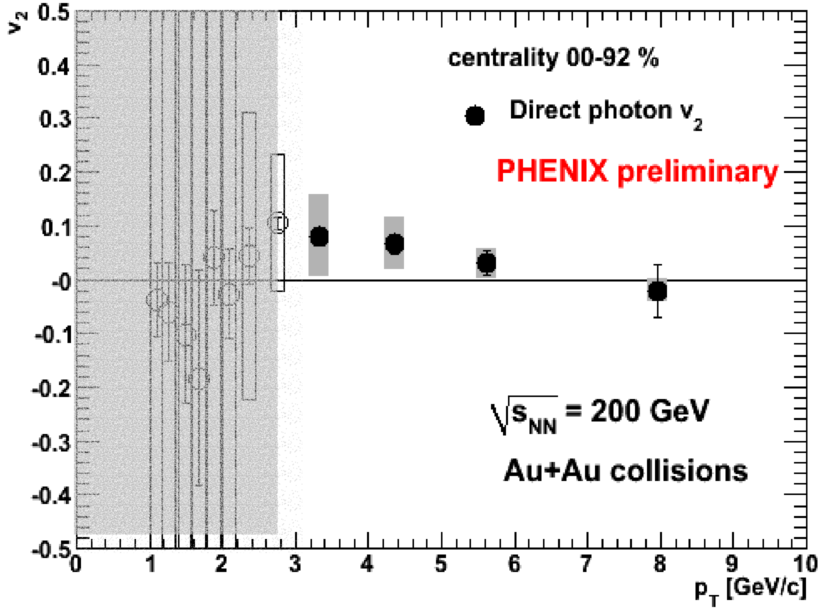
- azimuthal anisotropy,
- pressure gradient from initial spatial asymmetry or eccentricity
- second moment of Fourier coefficient, v_2, shows good agreement with hydrodynamical models of low viscosity fluid

Direct γ v_2 : Au+Au 200 GeV



Direct γ v_2 Min Bias Au+Au 200 GeV (Run 4)





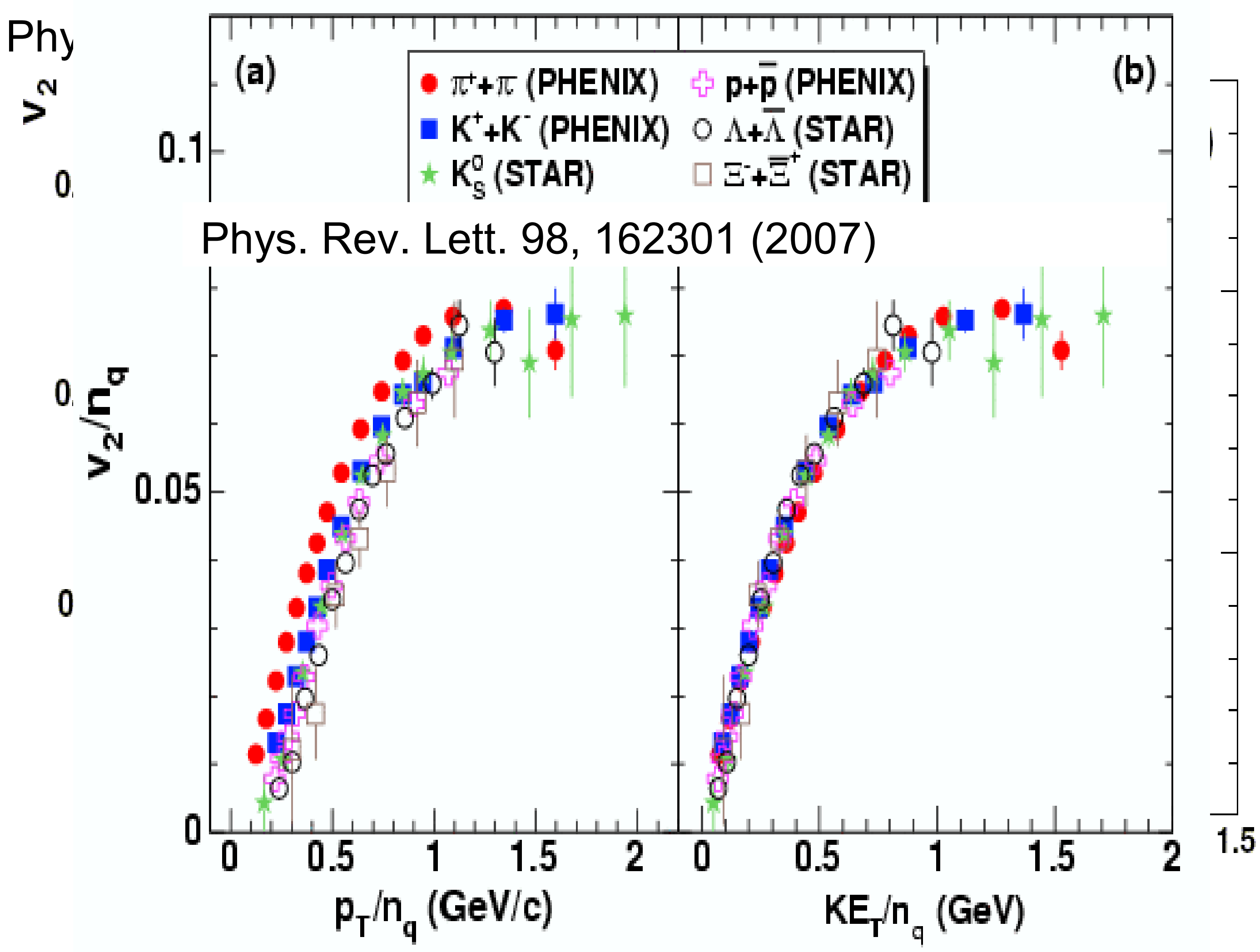
$$v_2^{dir.photon} = \frac{R * v_2^{inc photon} - v_2^{BG\_photon}}{R-1}$$

- Interested in sign of direct γ v_2 (at high p_T):
  - Positive == parton emission quenched
  - Negative == parton emission (Brems.) enhanced
- Results suggest positive v_2

Session XV:
Kentaro Miki

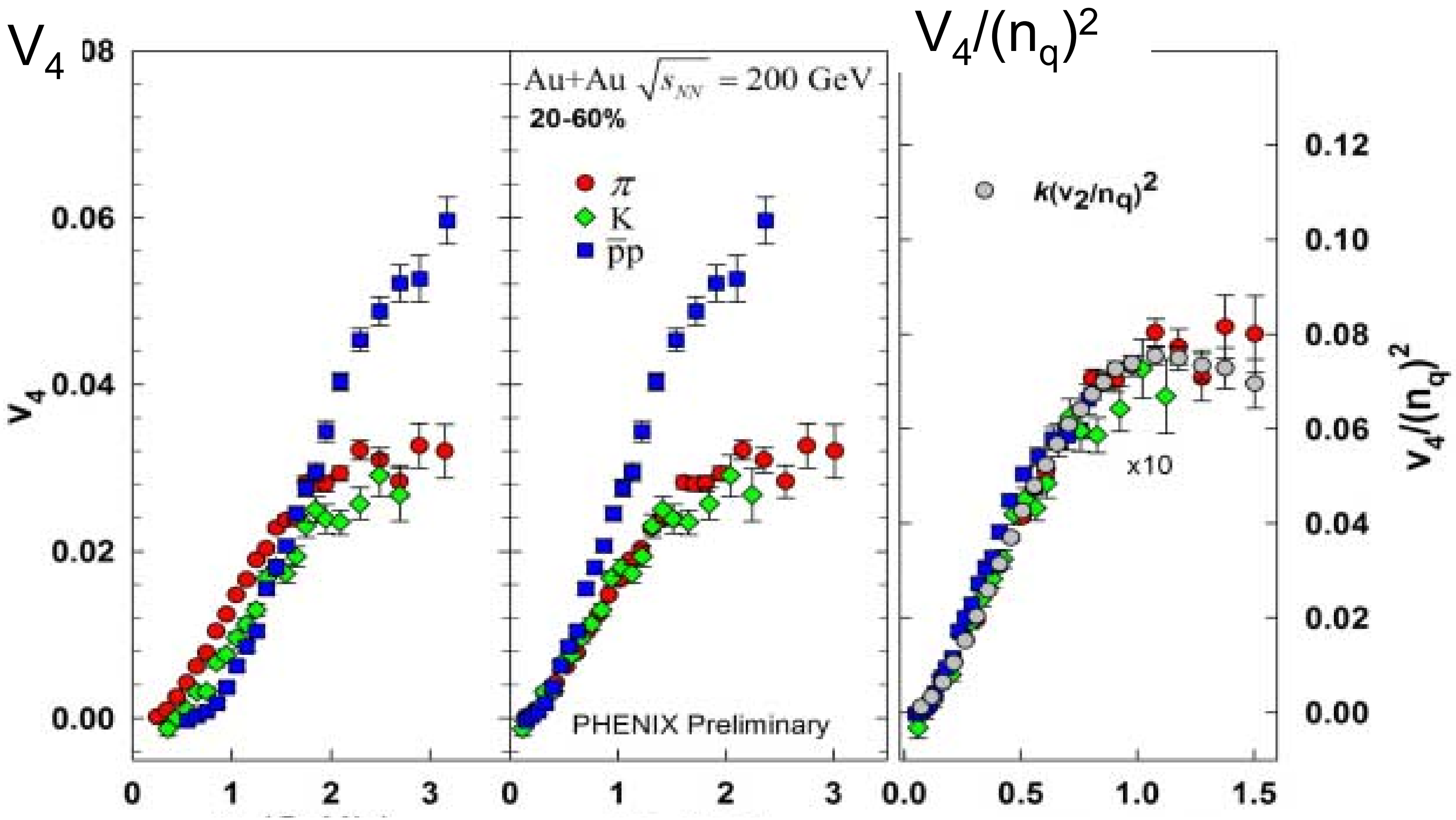
v_2 - constituent quark flow - QM06

v_2 - constituent quark flow



observed quark DOF scaling up to KE_T/n_q ~ 1GeV/c^2 for p,K,p,d,ϕ

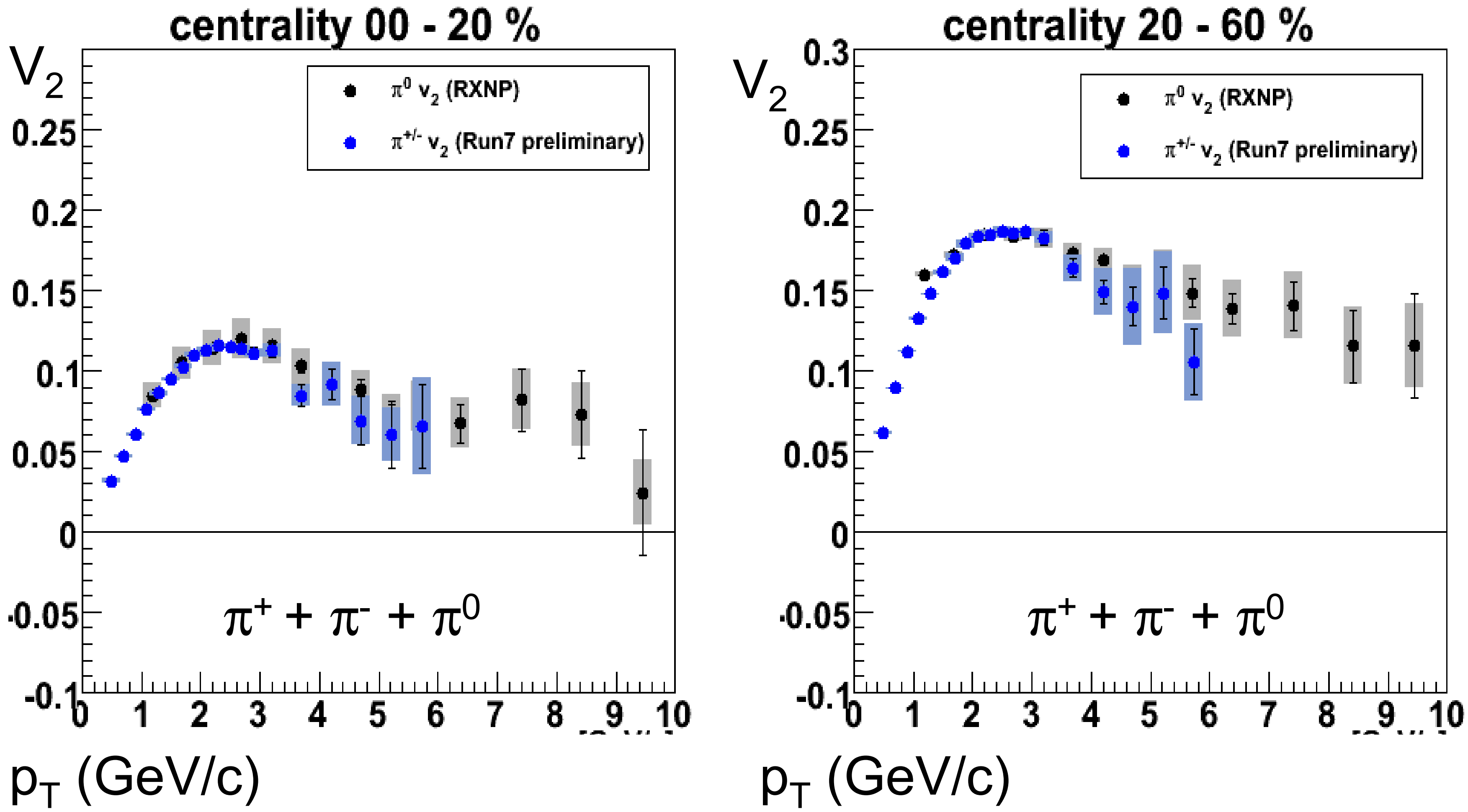
v_4 - scales with v_2



p_T (GeV/c) KE_T (GeV/c^2) KE_T/n_q (GeV/c^2)

v_2 scales with n_q, v_4 with n_q^2 partonic degree of freedom

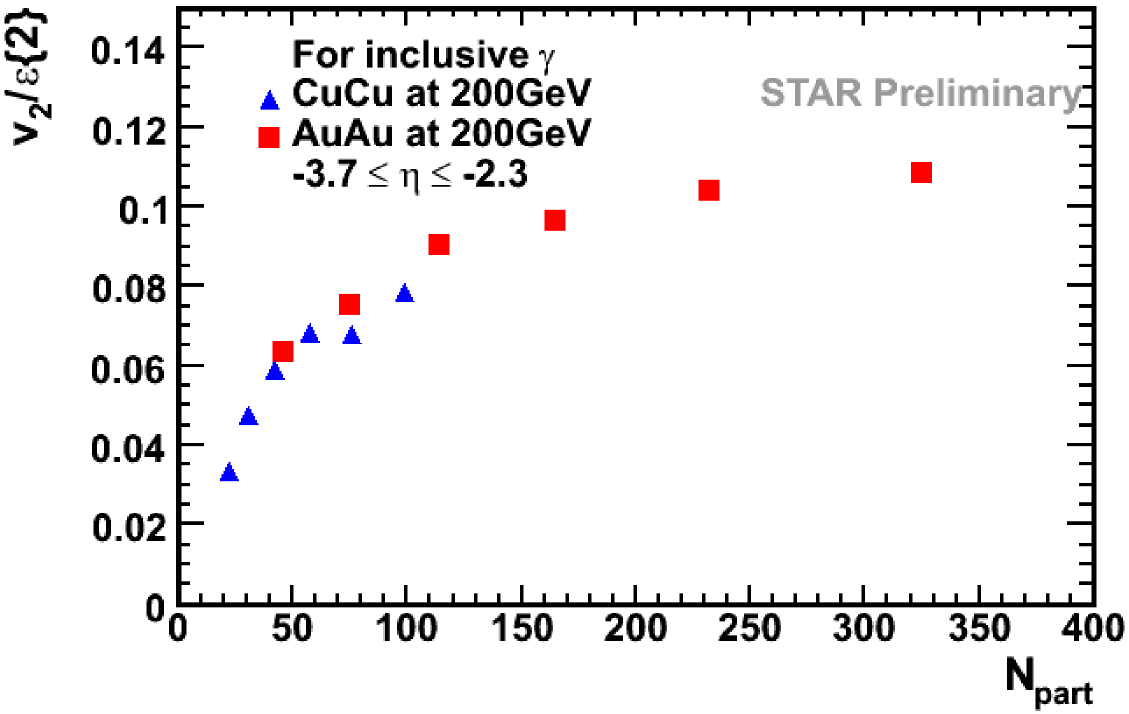
v_2 - identified particles @ high p_T



charged and neutral pions agree well

Forward Inclusive γ v_2

from Cu+Cu and Au+Au collisions at 200 GeV



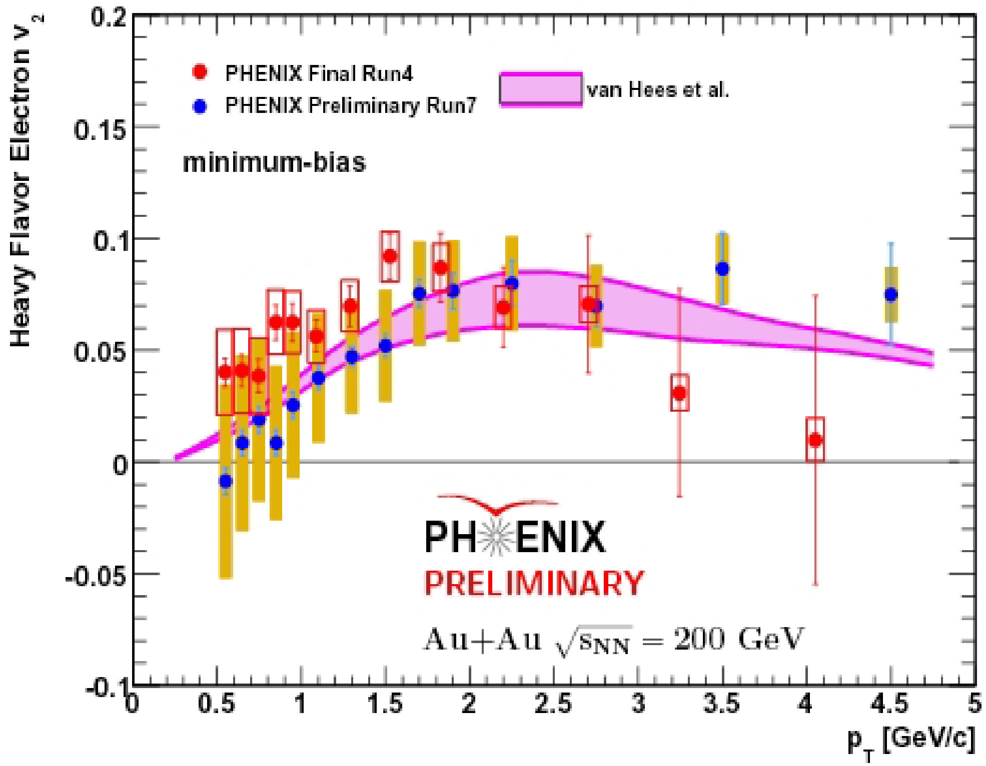
STAR PMD Detector used in the analysis

Parallel: R. Raniwala
S.M. Dogra

1) v_2 scaled with eccentricity increase with centrality: reflects the strength of collective expansion.

2) For large values of N_{part}, scaled v_2 tends to saturate, as expected in an equilibrium scenario.

New Results Non-photonic e v_2



PHENIX run-IV:
*PRL, **98**, 172301 (2007)*

Parallel: R. Averbeck;
Poster: A. Dion

1) Heavy quark collectivity => light quark thermalization! Muller *nucl-th/0404015*
2) Non-photonic electron v_2 indicates non-zero v_2 of Charm-hadrons.
3) Large systematic errors.

Need *directly reconstructed* heavy quark-hadrons!!

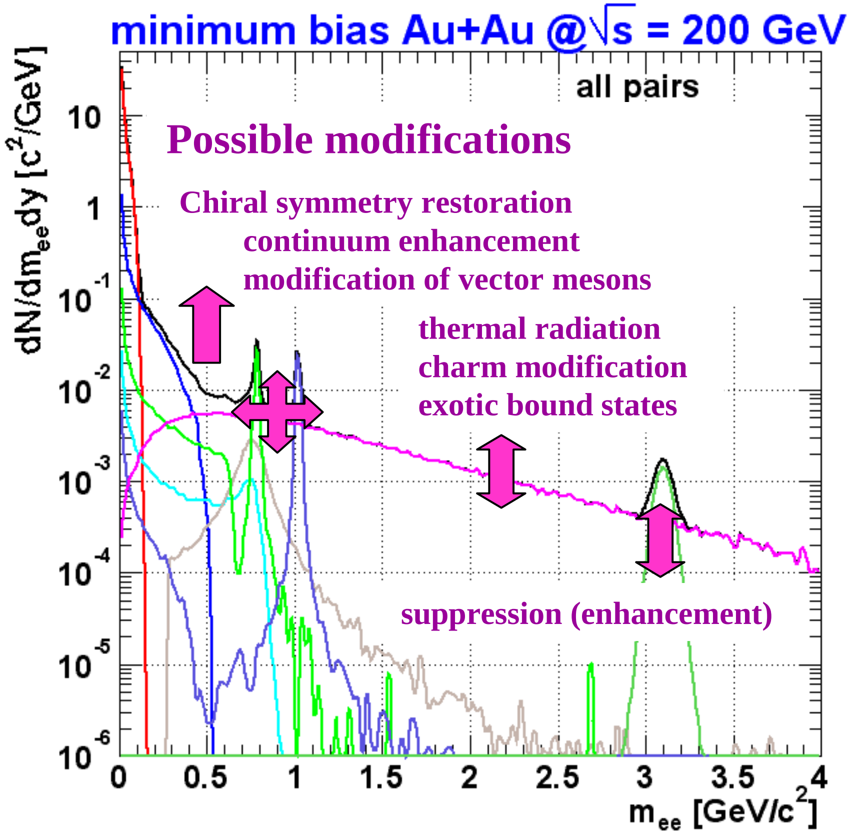
HADRON SPECTRAL FUNCTIONS

Dileptons at RHIC

Expected sources

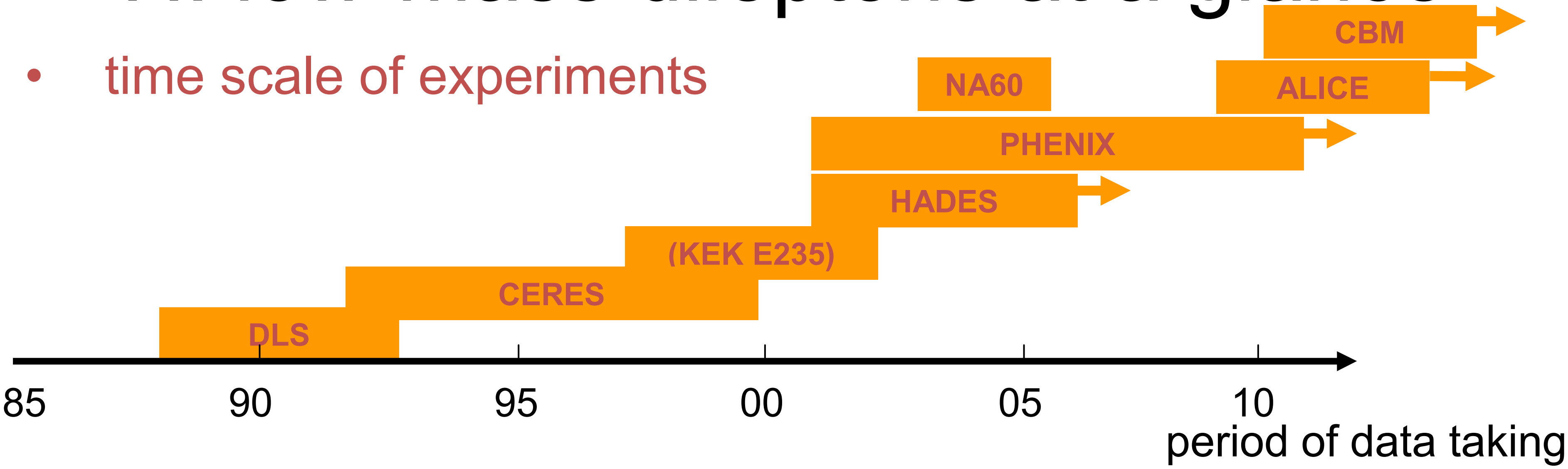
- **Light hadron decays**
  - Dalitz decays π^0, η
  - Direct decays ρ/ω and ϕ
- **Hard processes**
  - Charm (beauty) production
  - Much larger at RHIC than at SPS

- Photons and dileptons: radiation from the media
  - direct probes of any collision stages (no final-state interactions)
  - large emission rates in hot and dense matter
  - according to the VMD their production is mediated in the hadronic phase by the light neutral vector mesons (ρ, ω, and φ) which have short life-time
- Changes in position and width: signals of the chiral transition?

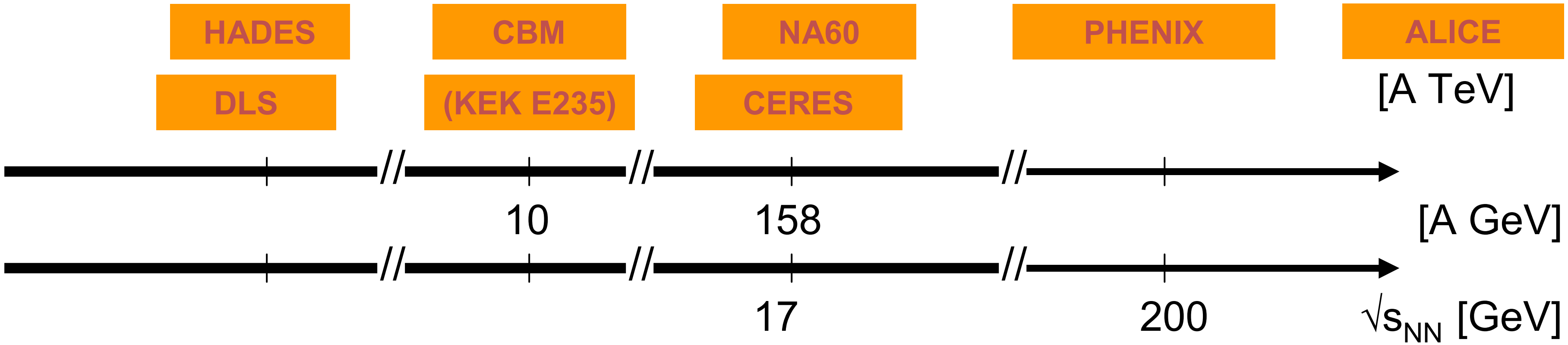


HI low-mass dileptons at a glance

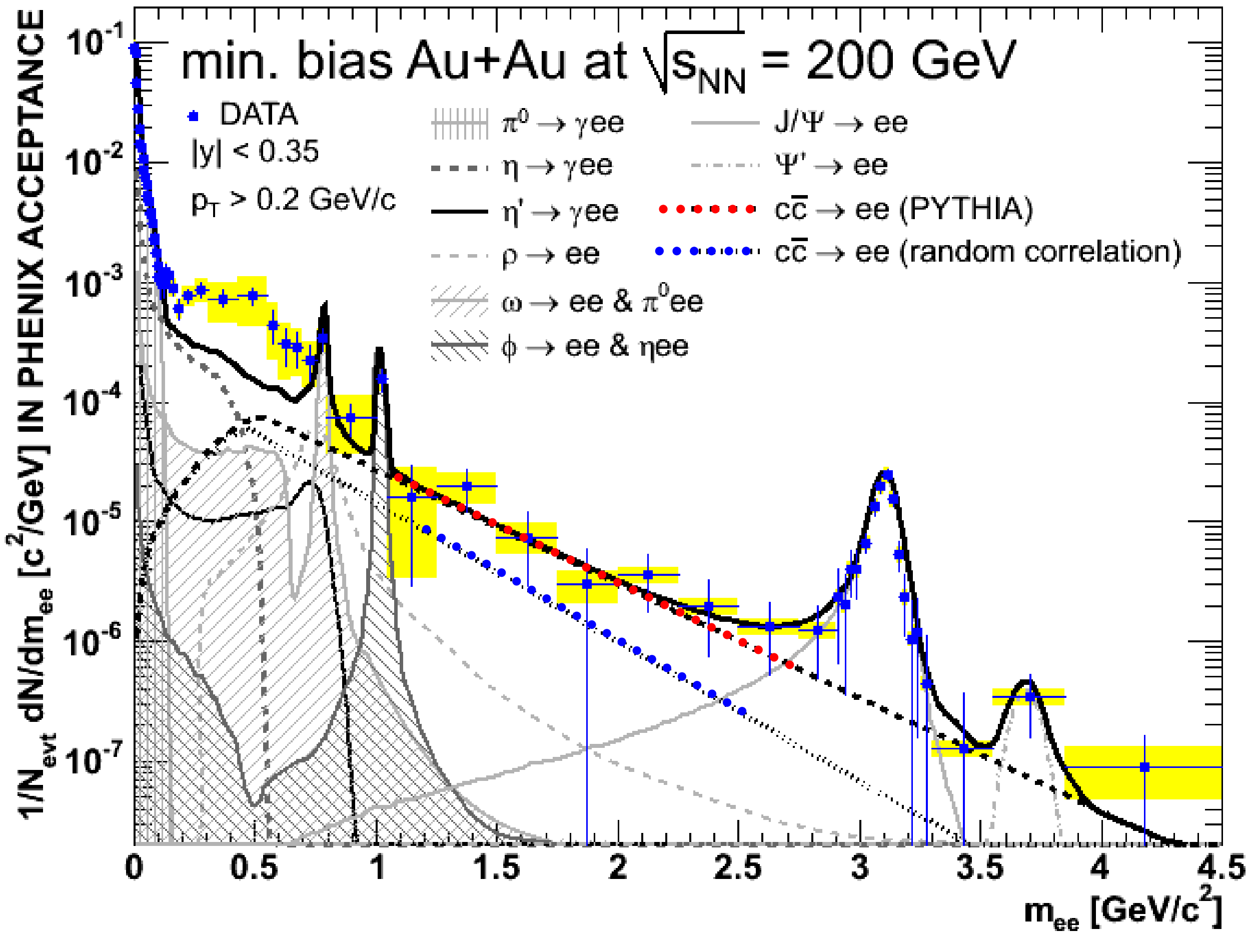
- time scale of experiments



- energy scale of experiments



Au+Au M_{ee} at PHENIX



arXiv:0706.3034

Data and Cocktail absolutely normalized

- Cocktail normalized to Au+Au measurements
  - Except ccbar

Low mass excess

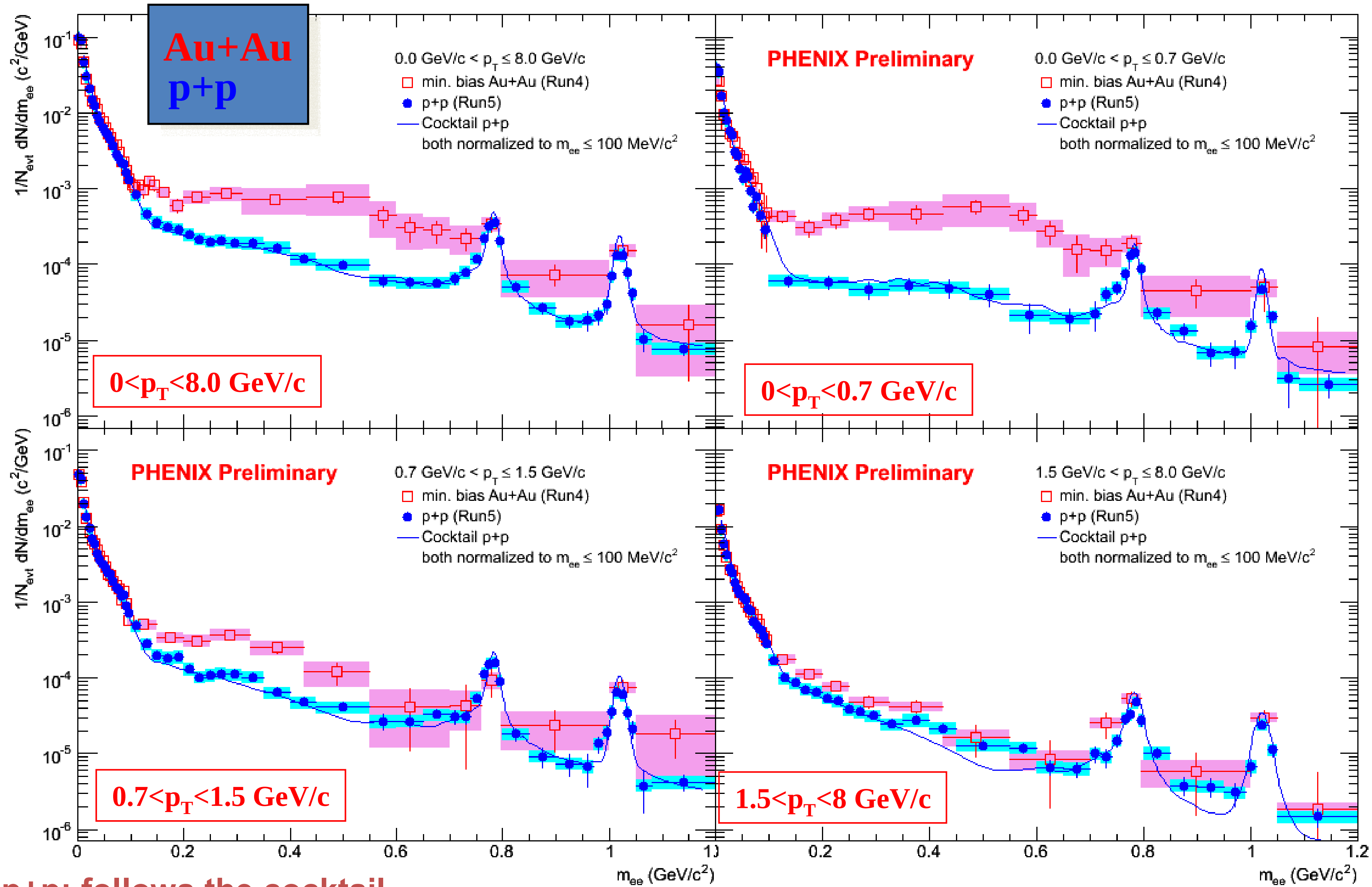
- $150 < M_{ee} < 750$
- X 3.4±0.2(stat.) ±1.3(syst.)±0.7(model)

Intermediate mass agreement

- Thermal contribution perhaps if ccbar mass spectrum softened by rescatt.

PHENIX: LM dileptons vs p_T

arXiv: 0706.3034
arXiv: 0802.0050



p+p: follows the cocktail

Au+Au: enhancement concentrated at low p_T

PHENIX, A.Toia, Quark Matter 2008

PHENIX LM dileptons summary

- First measurements of dielectron continuum at RHIC

p+p

Low mass

- Excellent agreement with cocktail

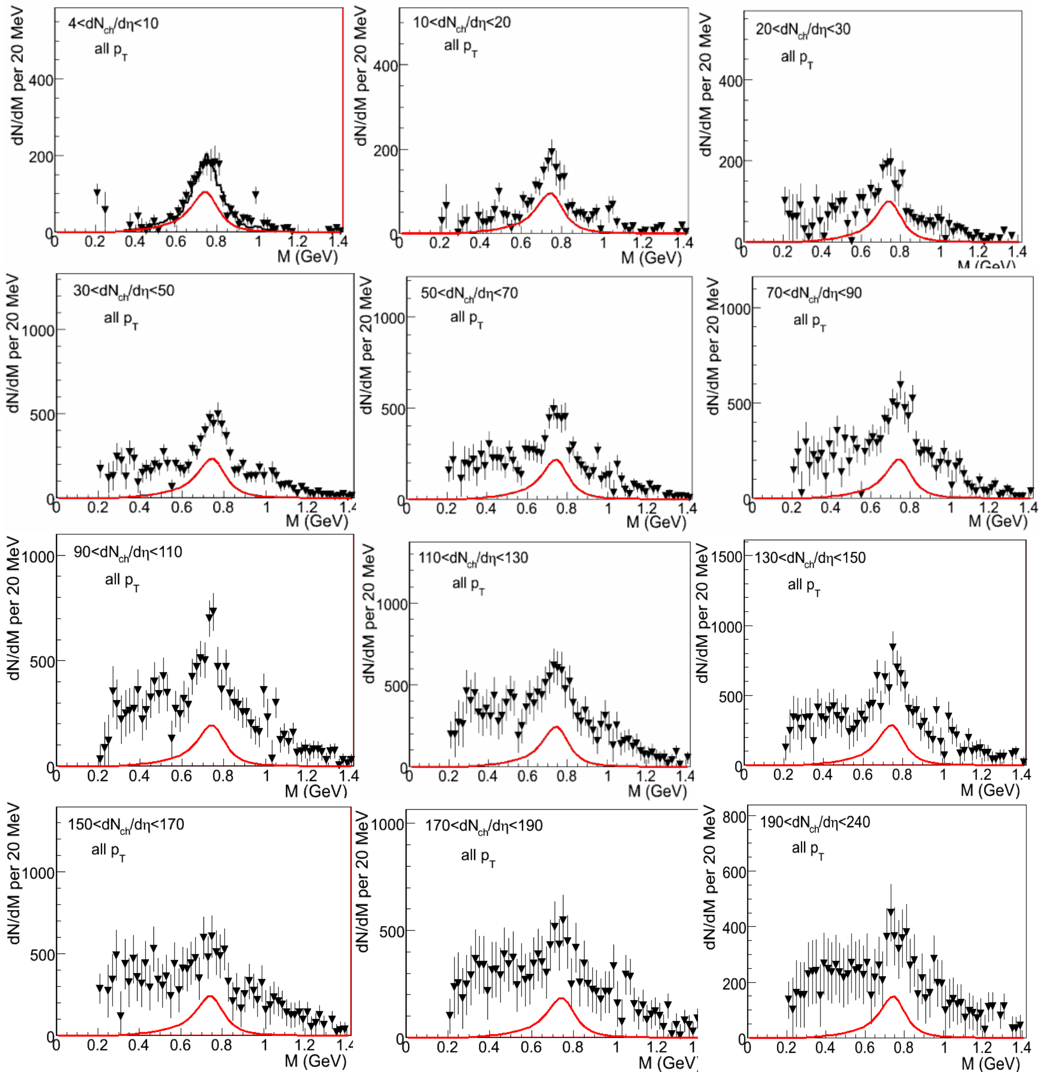
Au+Au

Low mass

- Enhancement above the cocktail expectations: 3.4±0.2(stat.) ±1.3(syst.)±0.7(model)
- Centrality dependency: increase faster than N_{part}
- p_T dependency: enhancement concentrated at low p_T

NA60: Excess e^+e^- mass spectra vs centrality

Eur.Phys.J.C 49 (2007) 235



clear excess above the cocktail ρ (bound to the ω with ρ/ω=1.0)

excess centered at the nominal ρ pole rising with centrality
monotonic broadening with centrality

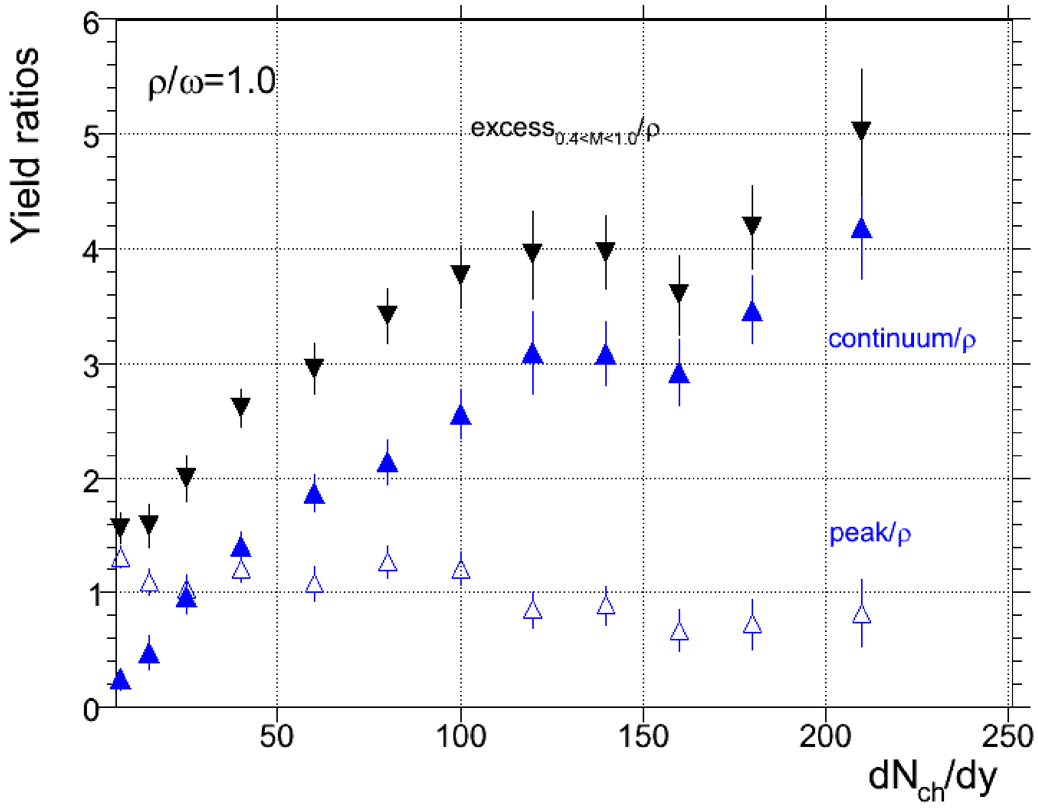
↓

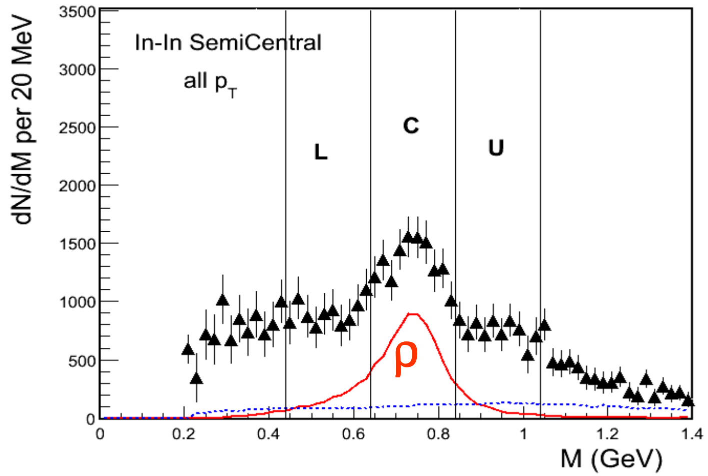
"melting" of the ρ

In-medium ρ spectral function identified; no significant mass shift of the intermediate ρ, only broadening;
connection to chiral restoration?

NA60, S. Damjanovic, Quark Matter 2008

NA60: Centrality dependence of e^+e^- excess yields





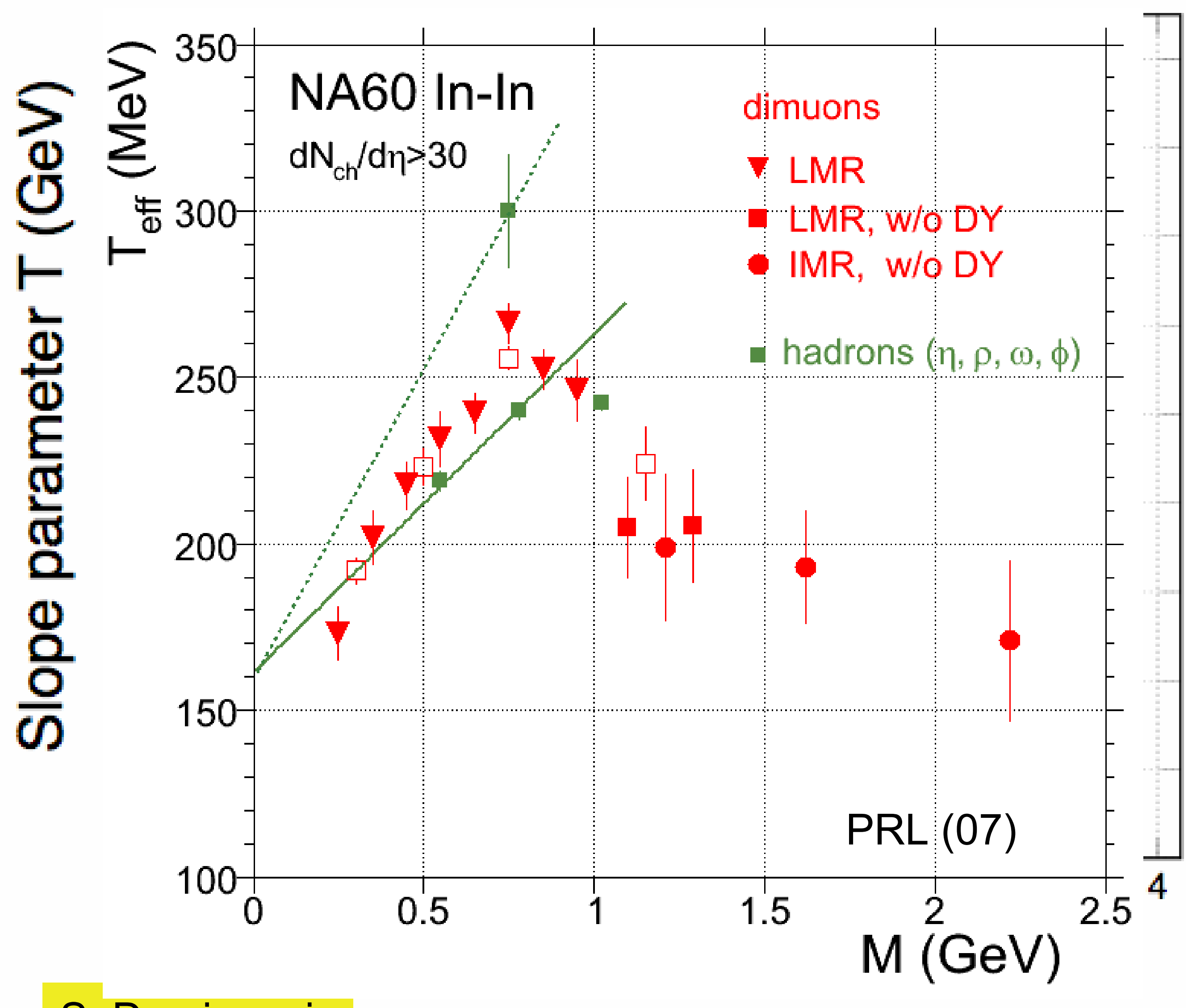
peak: R=C-1/2(L+U)
continuum: 3/2(L+U)

normalization to cocktail ρ, bound to ω with ρ/ω=1.0

- strong increase of continuum (by a factor of >10)
- decrease of ρ peak (nearly a factor of 2)
- rapid initial increase of total, reaching already 3 at $dN_{ch}/d\eta=N_{part}=50$

NA60, S. Damjanovic, Quark Matter 2008

Direct Radiation from the Matter



S. Damjanovic

Di-leptons allow us to measure the direct radiation from the matter with partonic degrees of freedom, no hadronization!

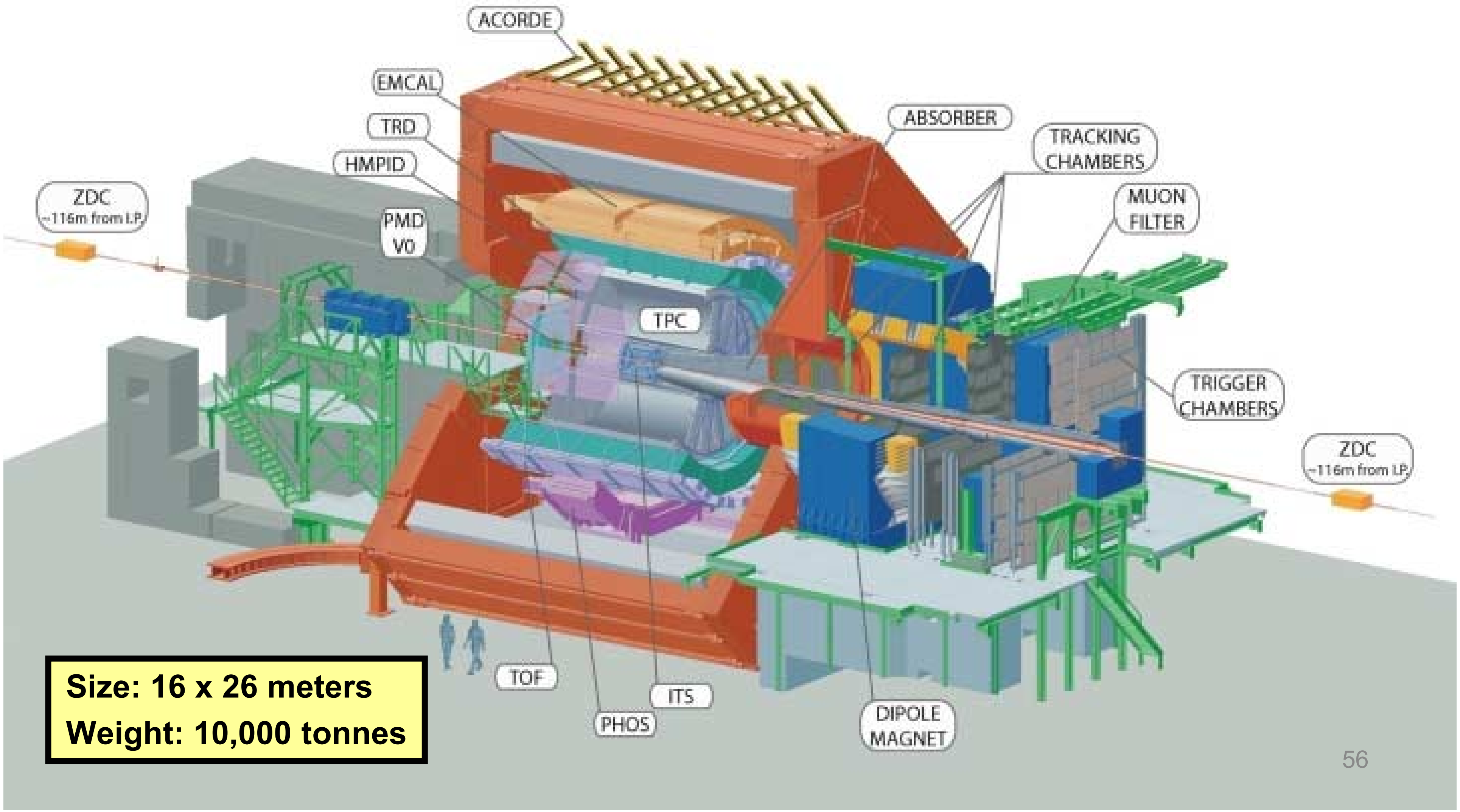
Puzzle 1: dramatic change of the slope parameter at *m ~ 1* GeV

Puzzle 2: source of T at *m* ≥ *1.5* GeV

RHIC & LHC:
T will increase with mass!

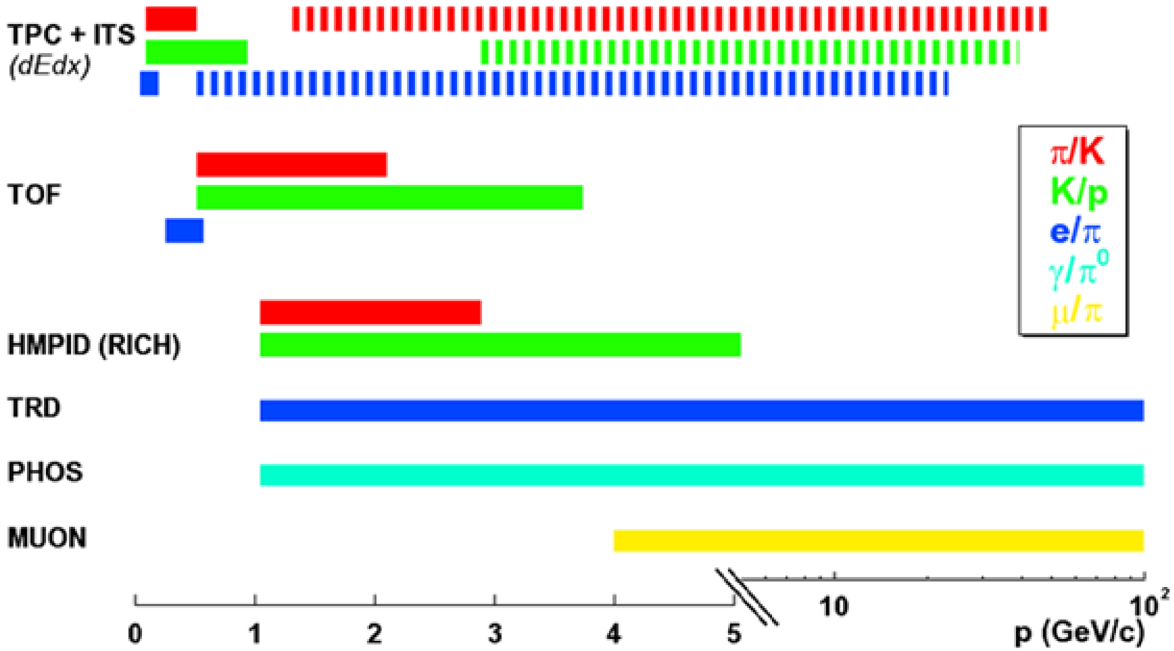
FUTURE PROGRAMS

ALICE: A Large Ion Collider Experiment at CERN-LHC



Size: 16 x 26 meters
Weight: 10,000 tonnes

Particle Identification in ALICE



- 'stable' hadrons (π, K, p): 100 MeV/c < p < 5 GeV/c; (π and p with ~ 80 % purity to ~ 60 GeV/c)
  - dE/dx in silicon (ITS) and gas (TPC) + time-of-flight (TOF) + Cherenkov (RICH)
- decay topologies (K^0, K^+, K^-, Λ, D)
  - K and L decays beyond 10 GeV/c
- leptons (e,μ), photons, π^0
  - electrons TRD: p > 1 GeV/c, muons: p > 5 GeV/c, π^0 in PHOS: 1 < p < 80 GeV/c

• excellent particle ID up to ~ 50 to 60 GeV/c

The LHC Ion Collider

- Running conditions for 'typical' Alice year:

Collision system	$\sqrt{s_{NN}}$ (TeV)	L_0 ($cm^{-2}s^{-1}$)	$\langle L \rangle / L_0$ (%)	Run time (s/year)	σ_{geom} (b)
pp	14.0	10^{31*}		10^7	0.07
PbPb	5.5	10^{27}	70-50	10^{6} **	7.7

- + other collision systems: pA, lighter ions (Sn, Kr, Ar, O)
- energies (pp @ 5.5 TeV).

* L_{max} (ALICE) = 10^{31}
** Lint (ALICE) ~ 0.7 nb^{-1}/year

The CBM experiment

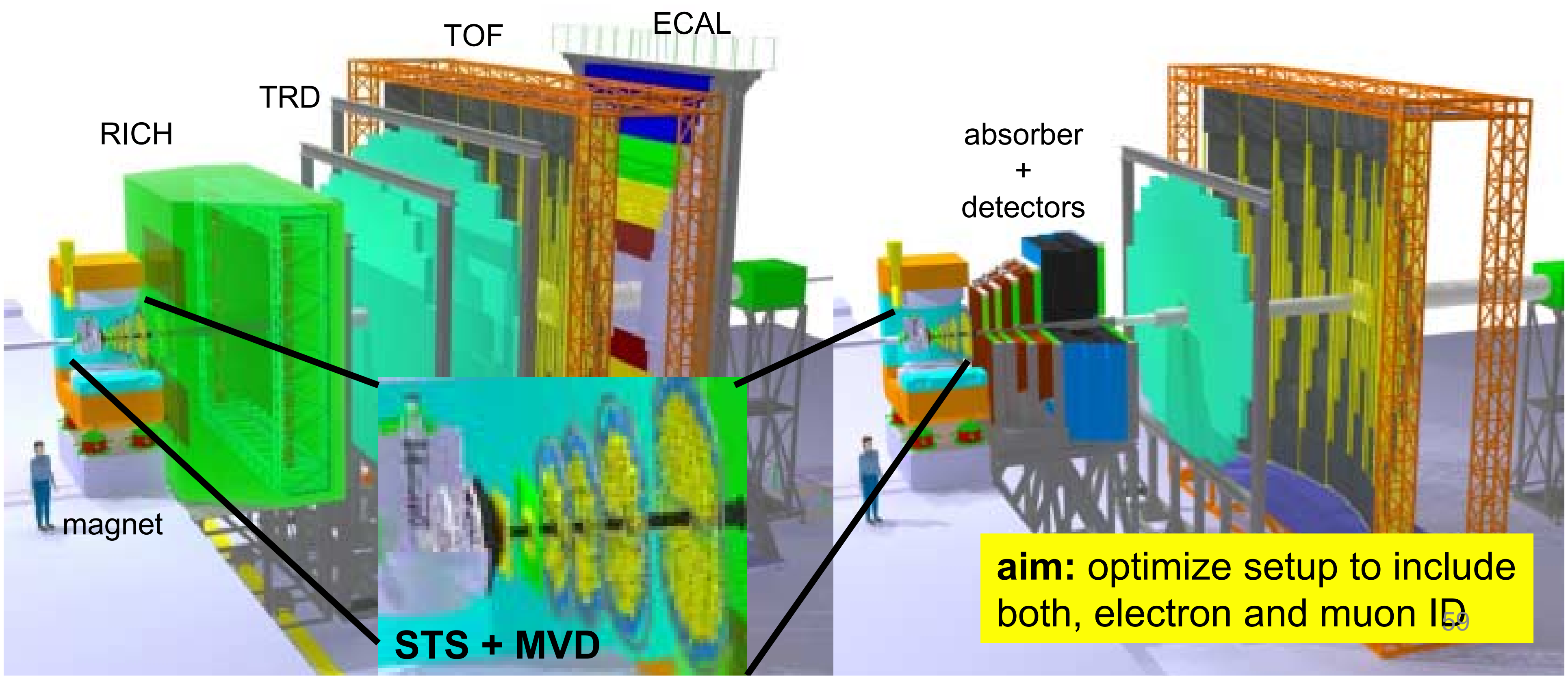
• tracking, momentum determination, vertex reconstruction: radiation hard silicon pixel/strip detectors (STS) in a magnetic dipole field

• hadron ID: TOF (& RICH)
• photons, π^0, η: ECAL

• PSD for event characterization
• high speed DAQ and trigger → **rare probes!**

• **electron ID**: RICH & TRD
→ π suppression $\geq 10^4$

• **muon ID**: absorber + detector layer sandwich
→ move out absorbers for hadron runs



aim: optimize setup to include both, electron and muon ID

Dileptons in CBM

- **dileptons are only one of several very interesting physics topics of CBM**
  CBM: comprehensive measurement of A+A interactions from 10-45 AGeV
  including rare probes (charm, dileptons), flow, correlations, fluctuations

- **measurement of dileptons (low and high masses) very interesting at FAIR:**
  CBM: 10-45 AGeV, HADES 2-10 AGeV
    - highest baryon densities reached, phase border to partonic phase
    - restoration of chiral symmetry? critical point?
    - charm production at threshold? charm propagation in-medium?

- **dileptons from ρ to ψ' measurable in electron and muon channel**
- similar performance – although background is of very different origin
- good phase-space coverage
    - low-mass dielectrons even down to lowest masses and pt
- detector development started

- CBM will (hopefully) not be limited by statistics
- systematic uncertainties might be limiting in the end

→ a measurement of both, muons and electrons will be the best systematic study we can ever do!

Beam Energy Scan at RHIC: $\sqrt{s_{NN}} \sim 5\text{-}50$ GeV

experimental window to QCD phenomenology

at finite temperature and and baryon number density

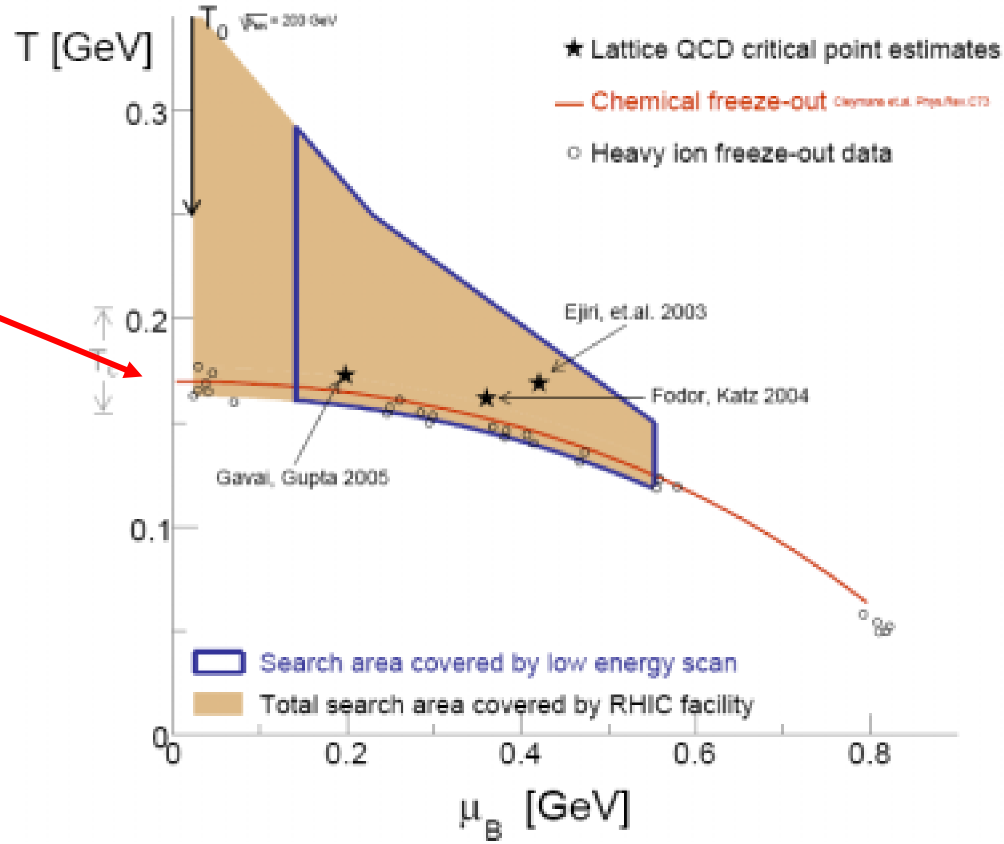
At RHIC : indications of sQGP found

but remain unknown:

(1) properties of hypothesized sQGP

(2) boundary between hadronic and partonic phases

(3) possible critical point



RHIC run 10 (fall 2009)

(1) Large energy range accessible
(2) Collider geometry (acceptance won't change with $\sqrt{s}$, track density varies slowly)
(3) STAR detectors well suited (large acceptance), tested & understood

STAR PAC 2007 Strawman proposal:

$\sqrt{s_{NN}}$ [p_{ft}] GeV [GeV/c]	μ_B [MeV]	<BBC Rate> [Hz]	Days/ Mevent	# events	# beam days
4.6 [9.6]	570	3	9	5M	45
6.3 [18.8]	470	7	4	5M	20
7.6 [27.9]	410	13	2	5M	10
8.8 [37.7]	380	20	1.5	5M	7.5
12 [71.0]	300	54	0.5	5M	2.5
18 [161]	220	>100	0.25	5M	1.5
28 [391]	150	>100	0.25	5M	1.5

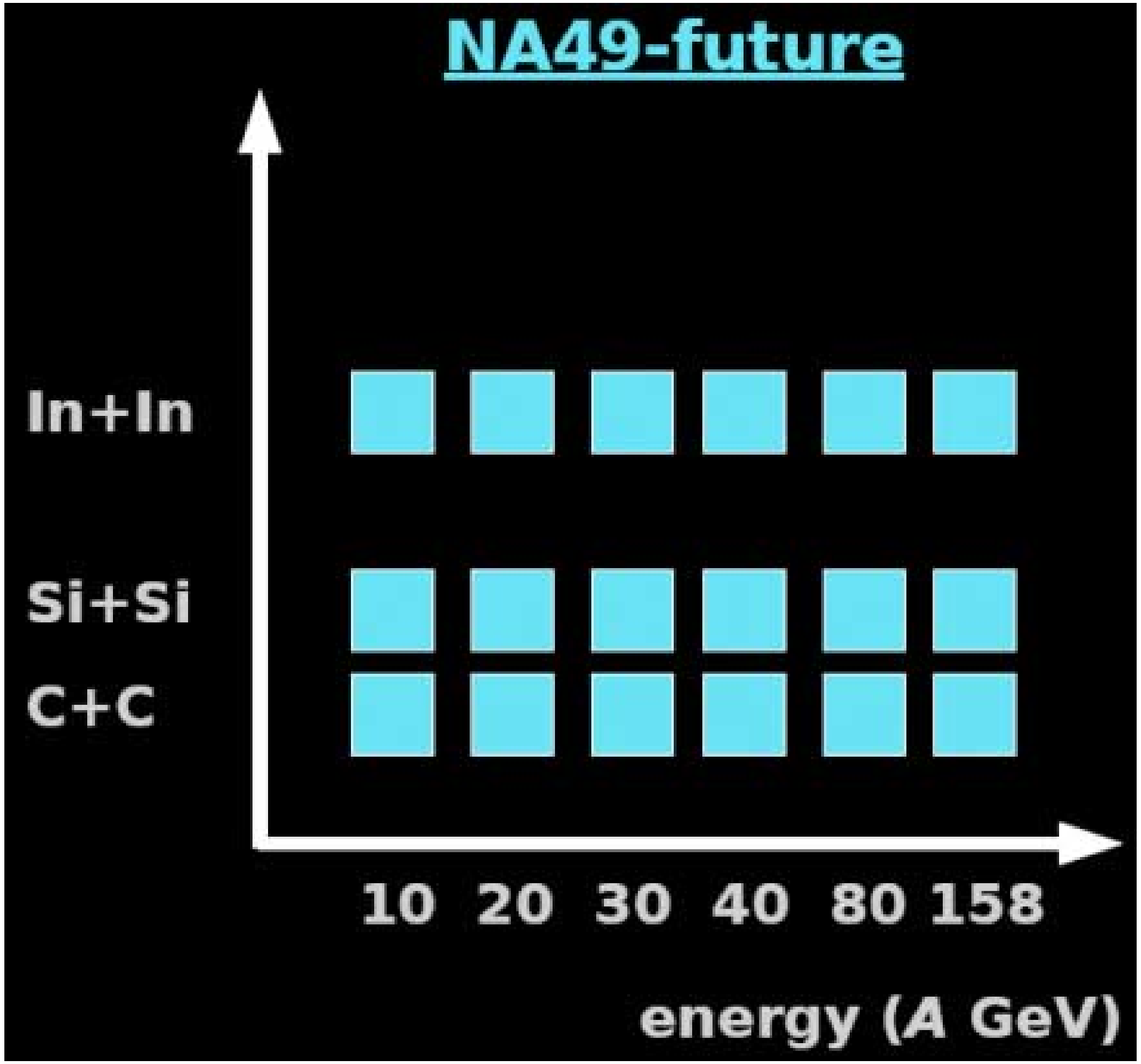
Note: NA61 @ CERN (starting in 2010): 10, 20, 30, 40, 80, 158 GeV/c

STAR future:

- The unique RHIC energy scan program will map the QCD diagram in $\sqrt{s_{NN}}$ =5-50 GeV, (corresponding to μ_B ~ 600-150 MeV)
  - systematic study of collective dynamics and fluctuations with p, Λ, Ξ, Ω, π, K, K*, ρ, ϕ...
  - turning off partonic activities (e.g. v_2 of ϕ, Ω, D – no NQ scaling, quenching ->0, …)

- STAR detector with 2π acceptance is ready to carry out this program
  - can trigger on low energy events (tests)
  - full TOF in 2010 -> PID
  - low energy e-cooling at RHIC extremely beneficial

NA 49/61 Future Program



M. Gazdzicki

Virtual Journal on QCD Matter

- Digest of preprints on
  - ❖ hot & dense QCD matter
  - ❖ the QGP
  - ❖ relat. heavy-ion collisions
- Targeted at graduate students & junior postdocs
- Aims to provide a bigger picture, on how individual publications shape the advancement of the field

http://qgp.phy.duke.edu/