Heavy flavour observables

Jets

- Energetic partons originate in the hard scattering
  - Back-to-back configurations.
- They evolve as parton showers and hadronize.
  - Experimentally observed as back-to-back jets.

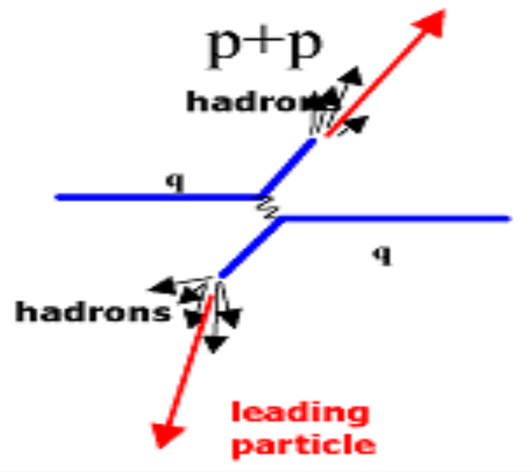
- What is a jet??
  - Group of particles emitted in a narrow cone, expected to be originating from the fragmentation of a parton.

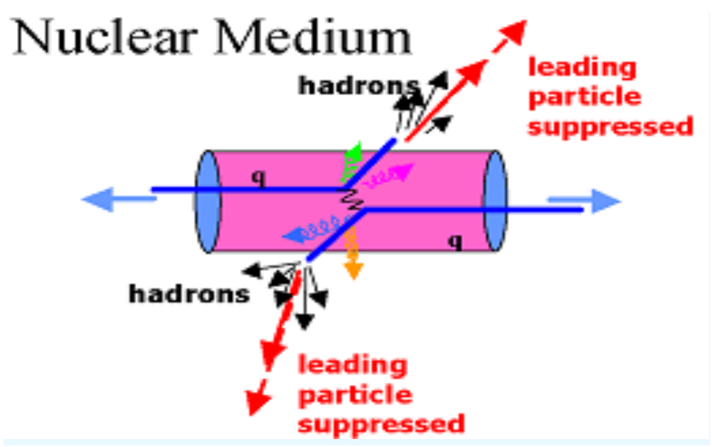
Jet quenching

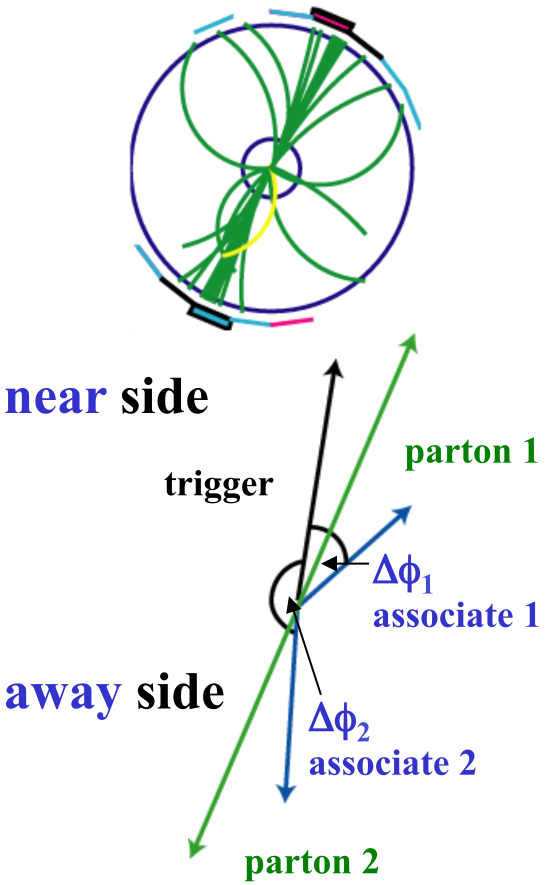
- In QGP, before fragmentation, the partons loose energy in the medium due to gluon radiation and multiple scattering.
  - Jet queching
- Direct measurement of jets is difficult in nuclear collisions due to large background especially for low p_T jets.
- Azimuthal angular correlations of high p_T particles are an alternative probe for these back-to-back jets.
- Particles from a single jet generate an enhances correlation at $\Delta\varphi \sim 0$ (near-side).
- Particles originating from back-to-back jet will jet generate an enhances correlation at $\Delta\varphi \sim \pi$ (away-side).

Azimuthal angular correlation

From Christina's slides





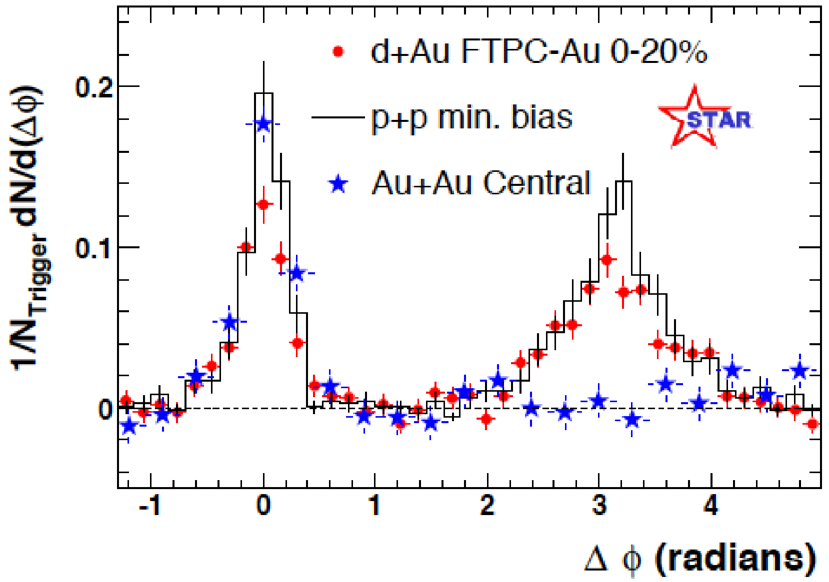


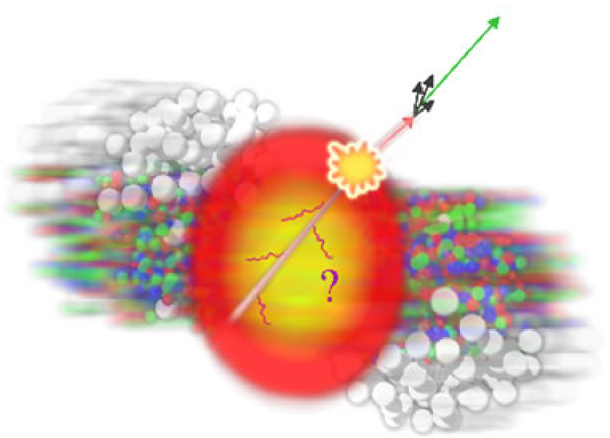
Azimuthal angular correlation

- STAR experiment at RHIC measured the $\Delta\varphi$ correlation of high pT hadrons.
  $p_T^{Trig} > 4$ GeV/c
  $p_T^{Asso} > 2$ GeV/c

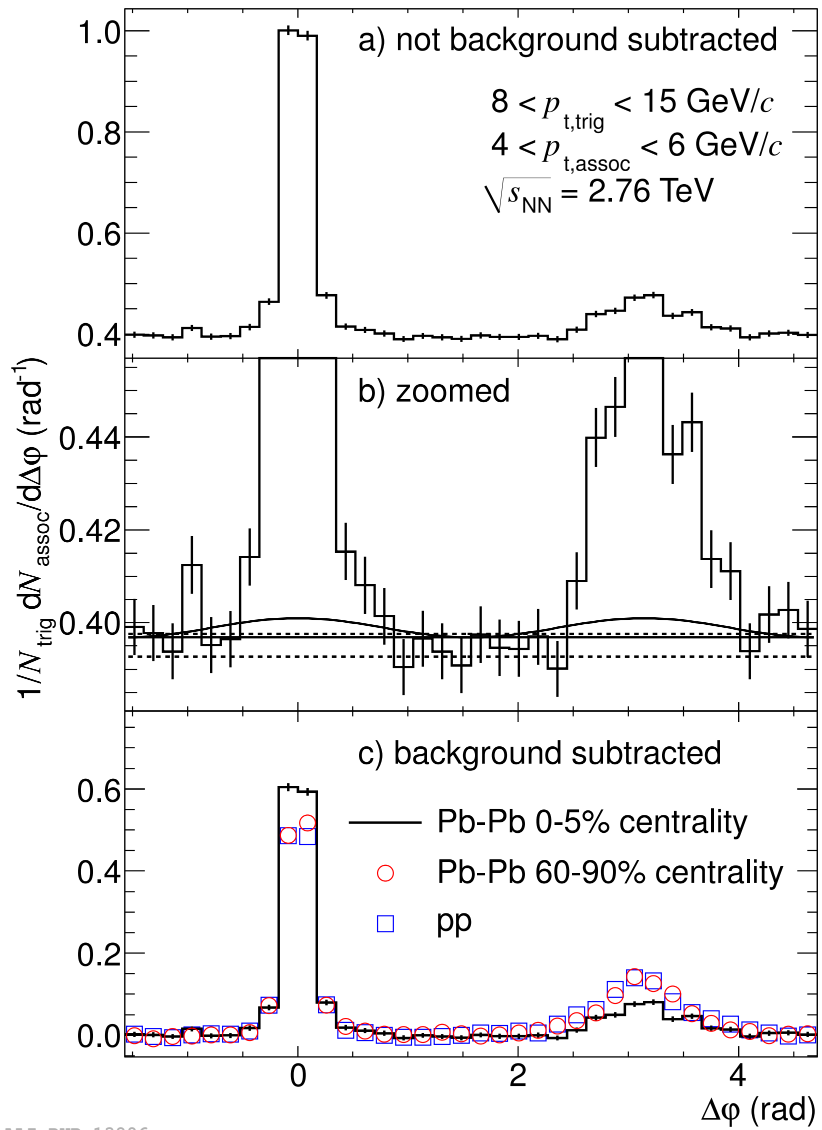
- Away side suppressed for central Au+Au collisions.

- Interpretation of the results
  - Near side : created from partons produced near the surface of medium.
  - Away side : parton has to travel a significant distant, loosing more energy.





Azimuthal angular correlation



In ALICE:

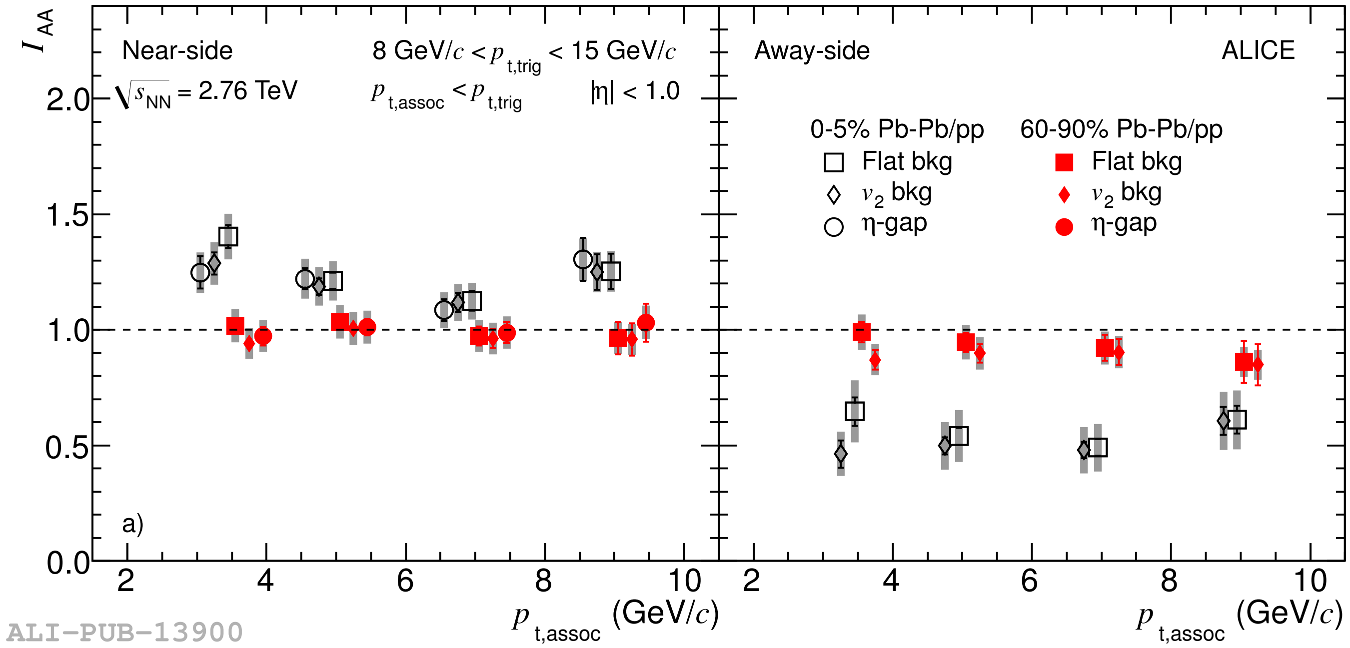
$8 < p_T^{Trig} < 15$ GeV/c

$4 < p_T^{Asso} < 6$ GeV/c

- Quantitative analysis done by measuring the yield on near side and away side (I_{AA}).

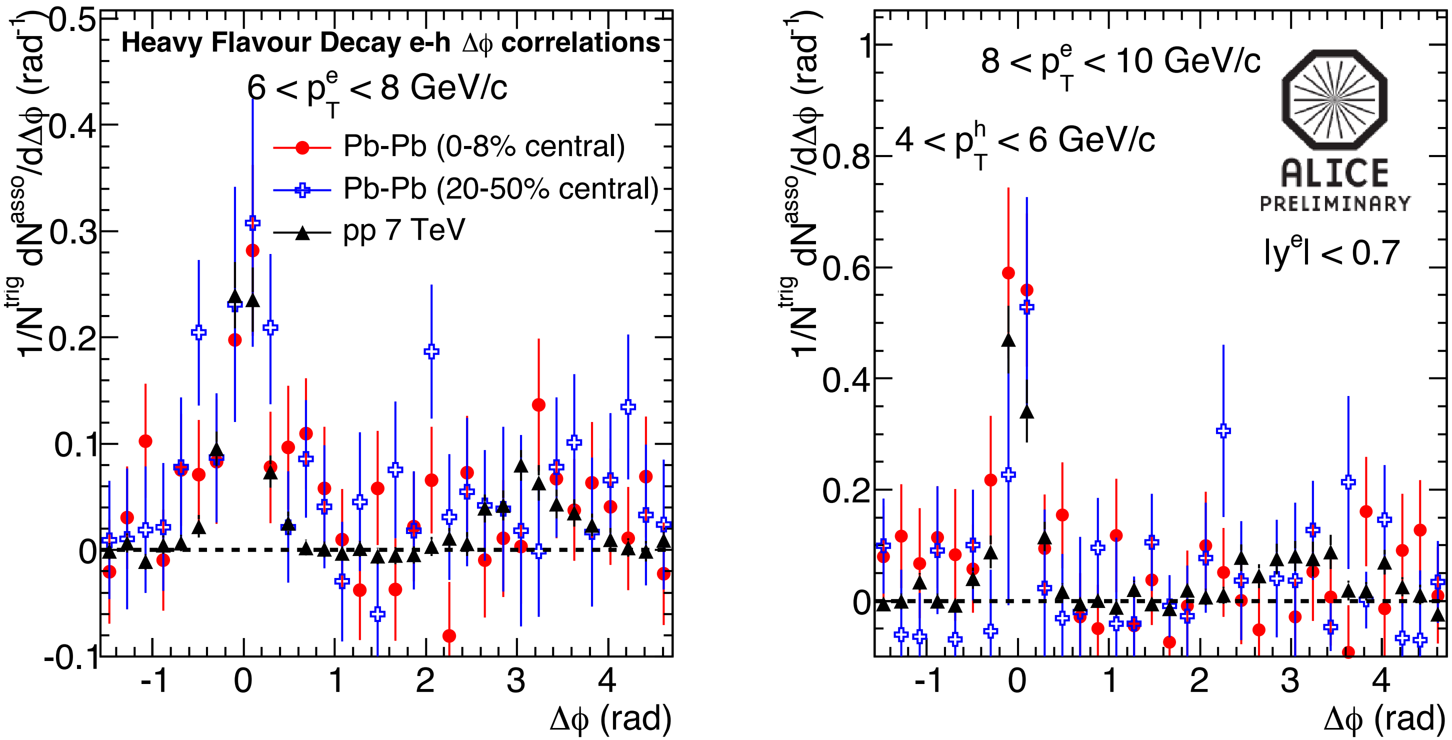
$$I_{AA} = Y_{Pb\text{-}Pb} / Y_{pp}$$

I_{AA}



Away side 50% suppressed.

Azimuthal angular correlation in HF??



Trigger : Electrons from
B/D decay
Associated : Hadrons.

Statistics is too poor to understand anything ☹

Next LHC run??

Homework

From Christina's slides

I created 200 Pythia events p+p at 7 TeV (30 GeV/c hard scattering)

→ ascii file of all charged pions

Particle event px py pz:

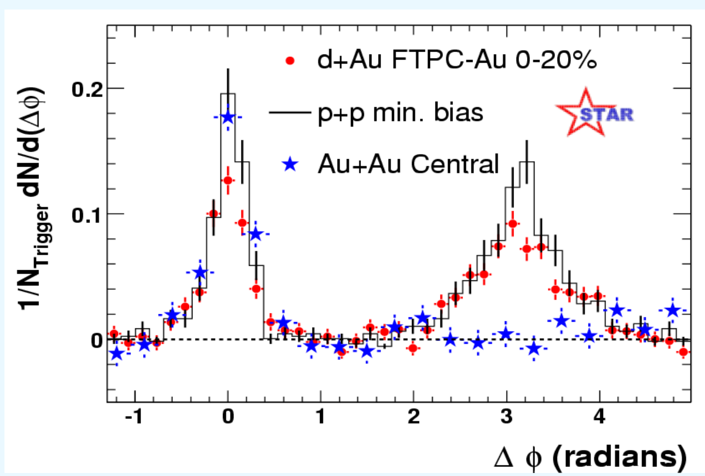
1 1 19.2119 -16.9473 46.836
2 1 2.68818 -2.22436 5.56438
3 2 -0.245131 0.252693 -0.176406
4 2 0.81093 -0.684846 1.60133
5 2 -0.137333 0.218012 -0.495384
6 3 -1.44181 0.977279 -3.12299

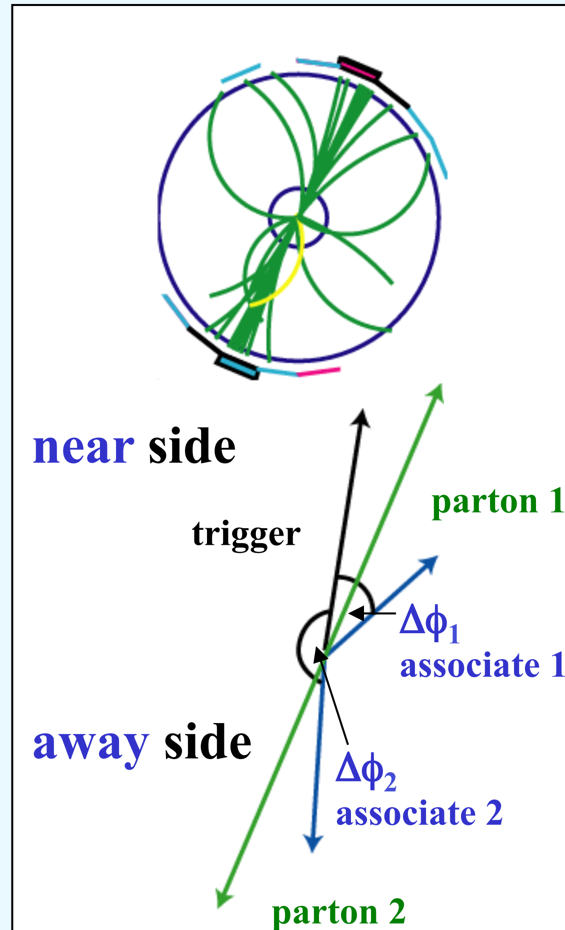
200 events, 1379 changed pions

Homework

From Christina's slides

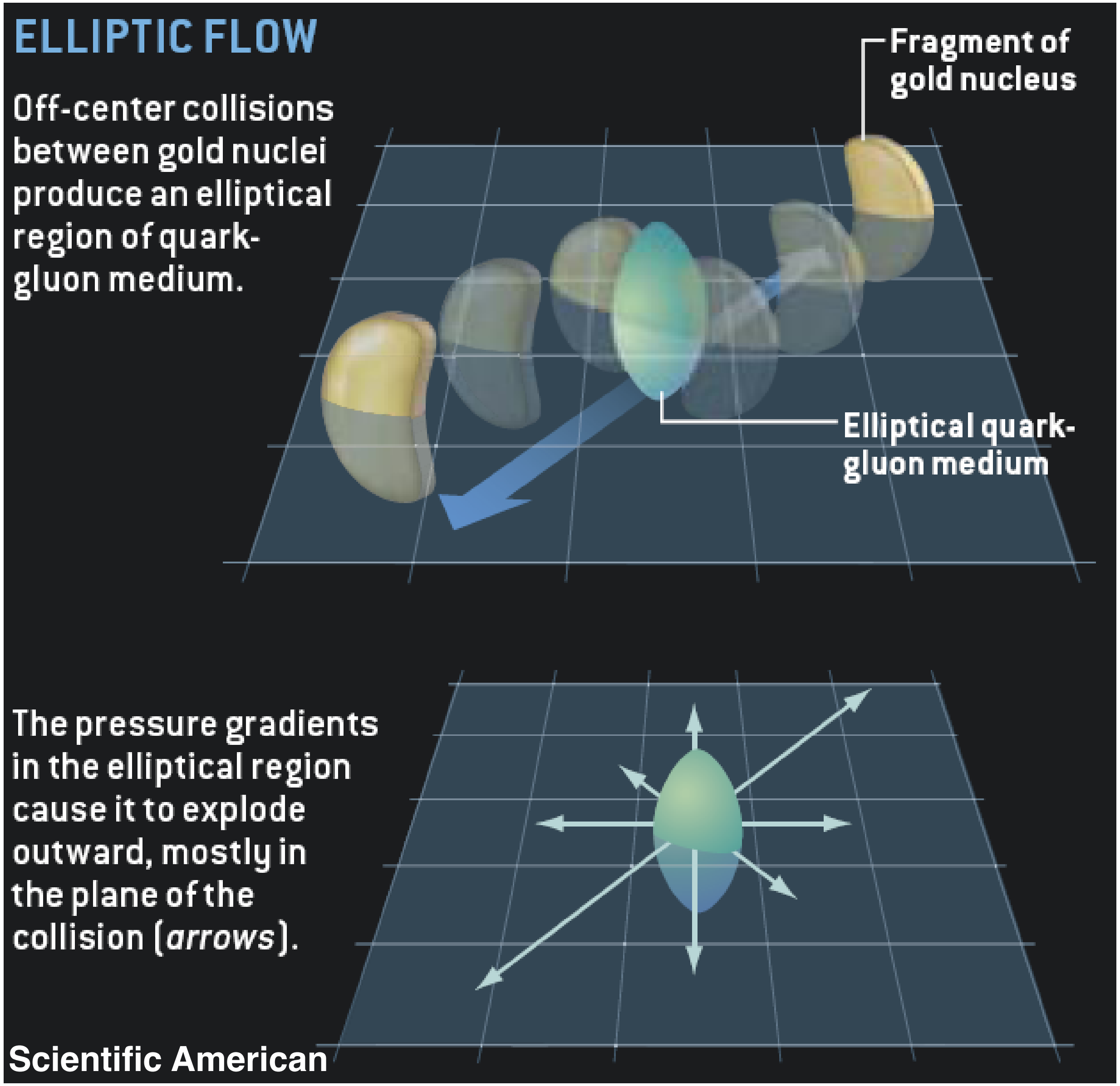
1.) calculate and plot pt distribution of all pions
2.) calculate and plot phi angle in pt plane of all pions
3.) calculate and plot phi angle difference between high trigger pt particle pt> 4 GeV/c and low pt associated particle 1<pt< 4 GeV/c
4.) How many particles are in a jet ?
(hint:jet identification is one particle with pt> 4 GeV/)





Elliptic flow

From Christina's slides

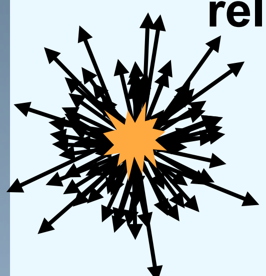


Elliptic flow

From Christina's slides

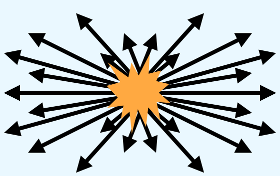
1) Superposition of independent p+p:

momenta pointed at random relative to reaction plane

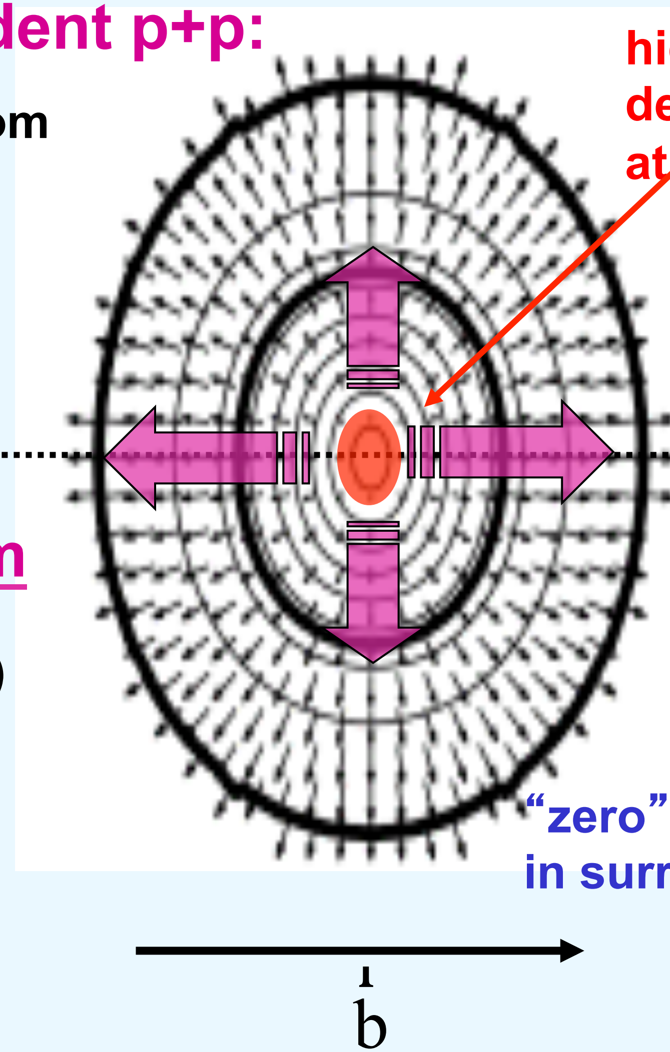


2) Evolution as a bulk system

Pressure gradients (larger in-plane) push bulk "out" → "flow"

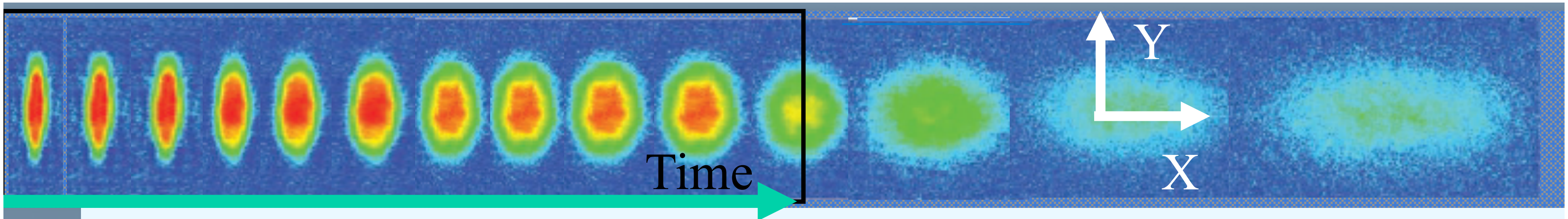


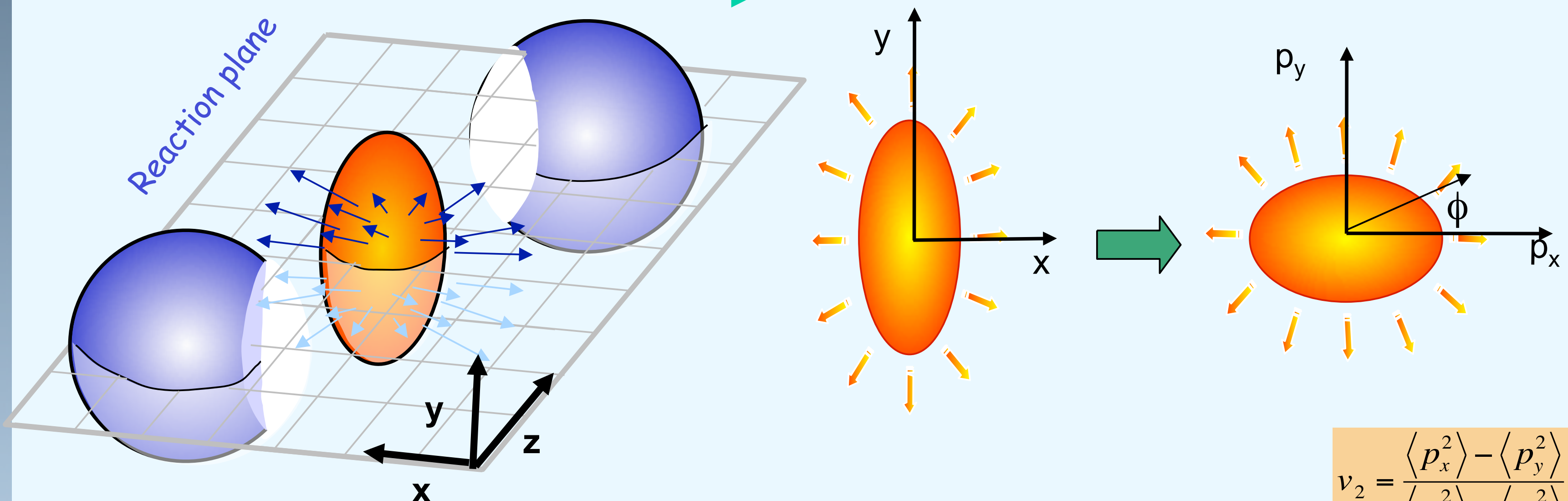
more, faster particles seen in-plane



Elliptic flow

From Christina's slides





$$v_2 = \frac{\langle p_x^2 \rangle - \langle p_y^2 \rangle}{\langle p_x^2 \rangle + \langle p_y^2 \rangle}$$

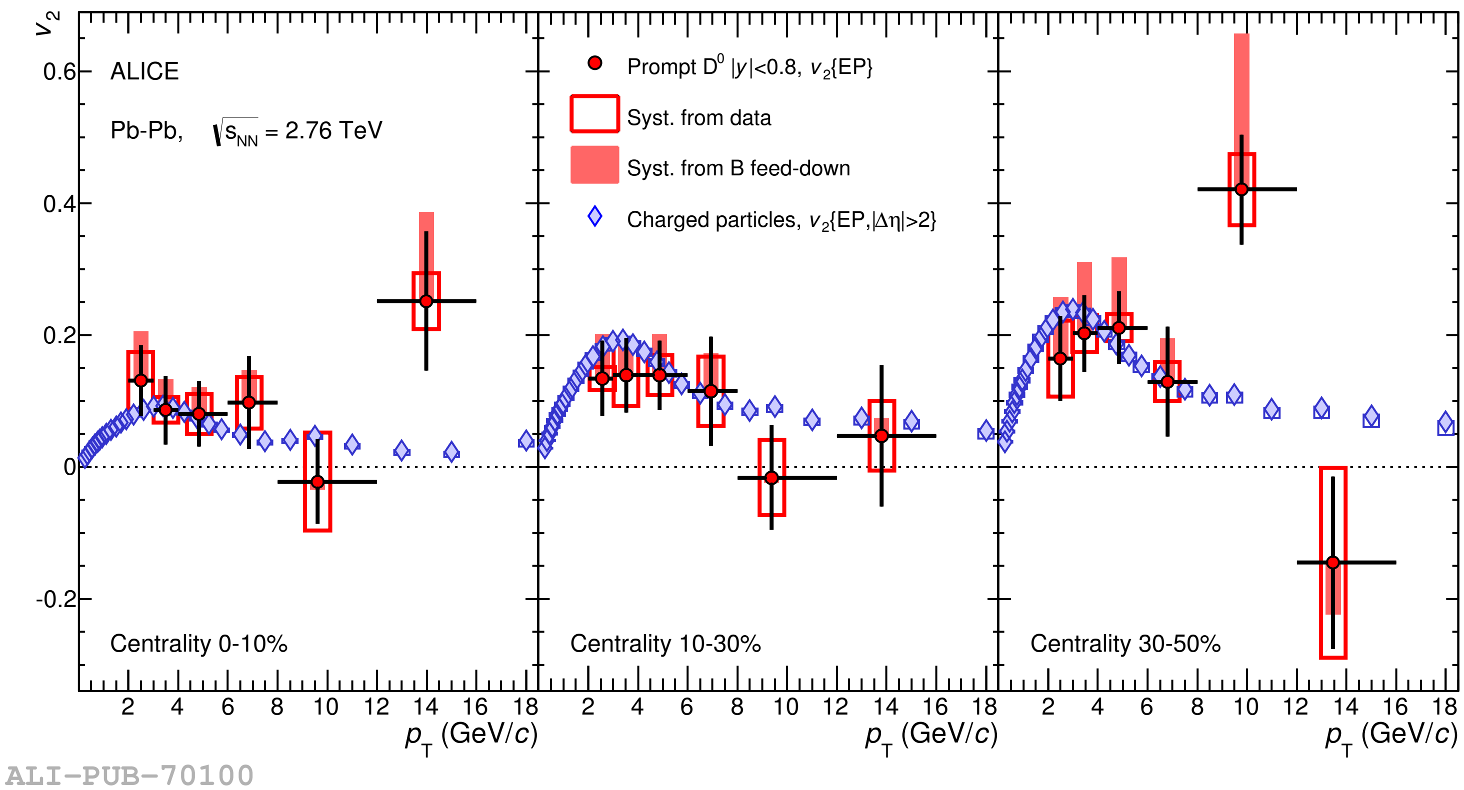
- non-central collisions: azimuthal anisotropy in coordinate-space.
- interactions ➔ asymmetry in momentum-space.
- sensitive to early time in the system's evolution.
- Measurement:
  Fourier expansion of the azimuthal p_T distribution.

$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos[2(\phi - \Psi_R)]$$

Elliptic flow (v_2) — Reaction plane (Ψ_R)

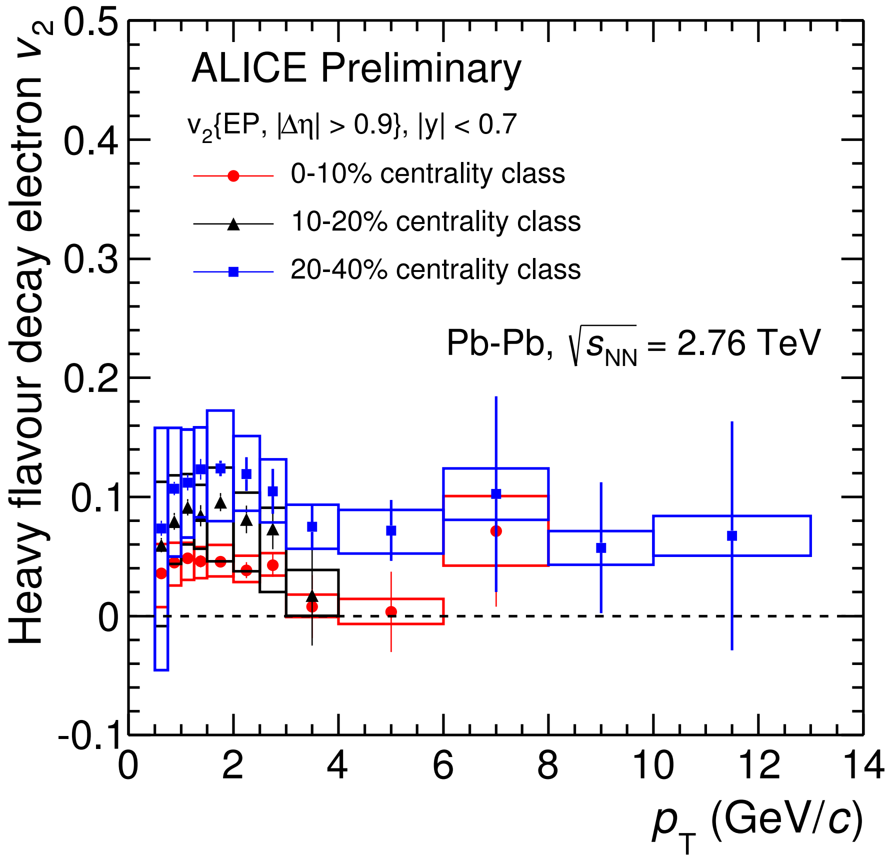
Does Heavy flavour flow??

- D^0 meson in different centrality bins.
- Compared to charged hadrons.
- v_2 increases from central to semi-central Pb-Pb events
- v_2 D^0 similar to charged hadrons



Does Heavy flavour flow??

- Heavy flavour decay electron in different centrality bins.
- v_2 increases from central to semi-central Pb-Pb events



ALI-PREL-77592

Quarkonia in QGP

Introduction

- Quarkonia (Q-Qbar)
- c-cbar family
  - η_c, J/ψ, ψ(2S), χ_c…
- b-bbar family
  - Υ(1S) Υ(2S), Υ(3S) and χ_b

- The colour-screening model predicts that charmonia and bottomonia dissociate in the medium.

- This results in a suppression of the observed yields.

- More specifically, the quarkonium binding properties are expected to be modified in the deconfined medium.

- The less tightly bound might melt close to T_c (170 MeV) and the most tightly bound well above T_c

Description

- In vacuum the quarkonium spectrum can be described via non relativistic models based on a potential interaction like:

$$V(r) = \sigma r - \frac{\alpha}{r}$$

σ : string tension between Q-Qbar

α : Coulombian-like constant.

- For simplicity consider σ = 0.

- If Q-Qbar state is embedded in QGP at a temp T, the interaction potential between the heavy quarks will be affected by the presense of the free color charges in the QGP.

- This is called screening of the potential.

- In EM plasma, the coulombian potential replaced by a potential with a screening constant.

$$V(r) = -\frac{\alpha}{r} \times e^{(-r/\lambda_D)}$$

λ_D : Debye length.

Description

- Lets assume the average distance between the heavy quarks in the 1S state (J/Ψ or Υ(1S)) can be estimated by the Bohr radius expression

$$r_B = \frac{1}{\alpha m_Q}.$$

- Consider for

J/Ψ : m_c = 1250 GeV

$\alpha(m_c)$ = 0.36

r_B = 0.44 fm

Υ(1S) : m_b = 4200 GeV

$\alpha(m_b)$ = 0.22

r_B = 0.22 fm

- If $r_B \ll \lambda_D$: potential Coulombian type and quarkonia exhibits same properties in QGP as in vacuum.

- If $r_B \geq \lambda_D$: quarkonia properties modified by the medium.
  - Quarkonia becomes unstable and could melt.

Description

- For EM plasma Debye length depends on temperature of the plasma and charge density ρ

$$\lambda_D = \sqrt{\frac{T}{8\pi\alpha\rho}}$$

- Assume valid for QGP and ideal ultra relativistic gas $\rho \; \alpha \; T^3$

$$\lambda_D \sim \frac{1}{\sqrt{8\pi\alpha}T}.$$

- So quarkonia could melt for Temp above T_d

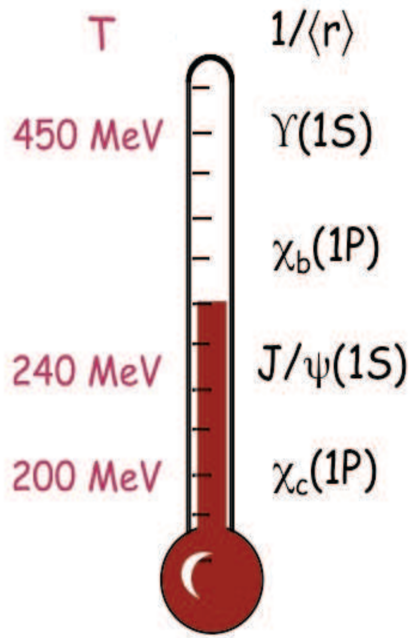
$$T_d \sim \frac{1}{\sqrt{8\pi\alpha(T)}r_B}.$$

- For α ~ 0.2, T_d ~ 200 MeV (1.3 T_c) for J/Ψ, T_d ~ 400 MeV (2.6 T_c) for Υ(1S).

- Assuming 2S states have r_B twice as large, the dissociation temperature for Ψ' < T_c and for Υ(2S) similar to that of J/Ψ.

Description

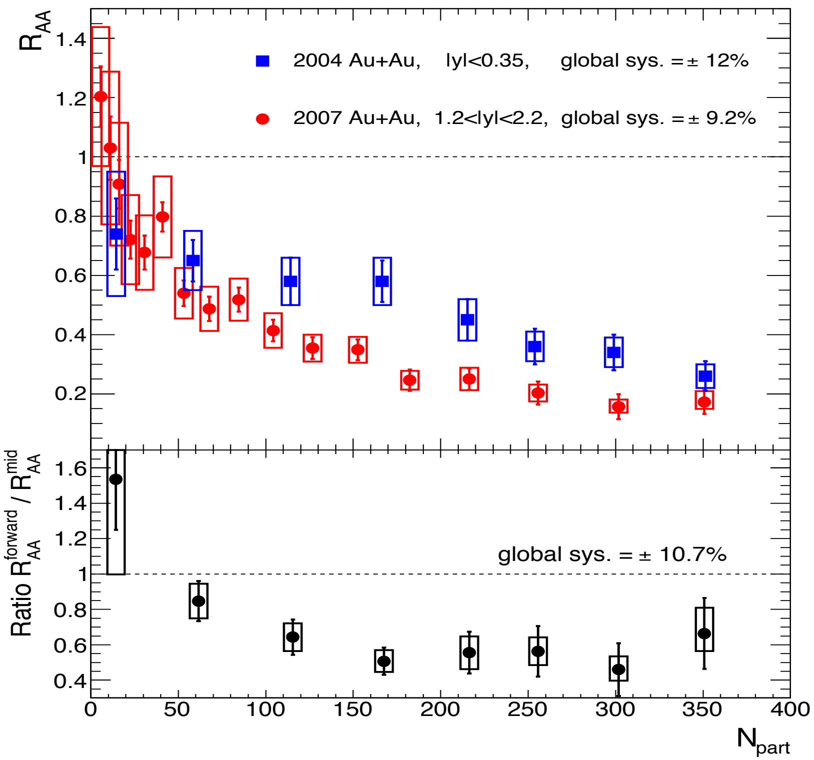
Bound state	χ_c	ψ'	J/ψ	$\Upsilon(2S)$	χ_b	$\Upsilon(1S)$
T_d	$\lesssim T_c$	$\lesssim T_c$	$\sim 1.2T_c$	$\sim 1.2T_c$	$\sim 1.3T_c$	$\sim 2.0T_c$

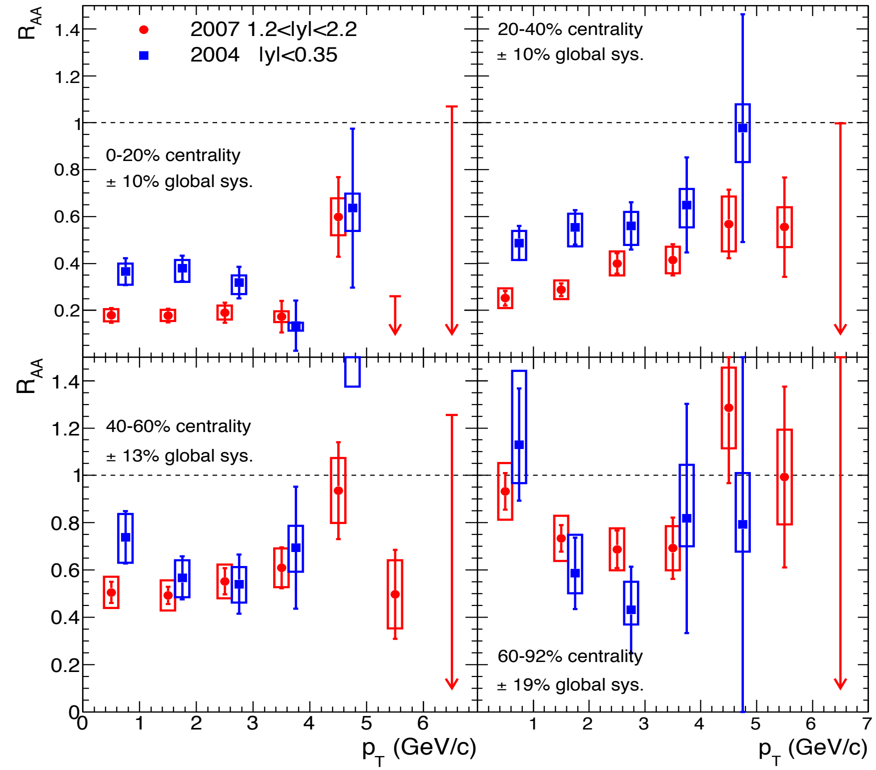


Experimental results

- First observation of J/Ψ suppression at SPS by the NA50 ($\sqrt{s_{NN}}$ = 17.2 GeV) experiment.
- Many models predicted – some invoking QGP and others not.
- Larger suppression expected at RHIC ($\sqrt{s_{NN}}$ = 200 GeV) compared to SPS.
  - Due to larger energy density of the medium created.
- But some models predicted enhancement due to coalescence of uncorrelated c-cbar pairs.

Results from RHIC

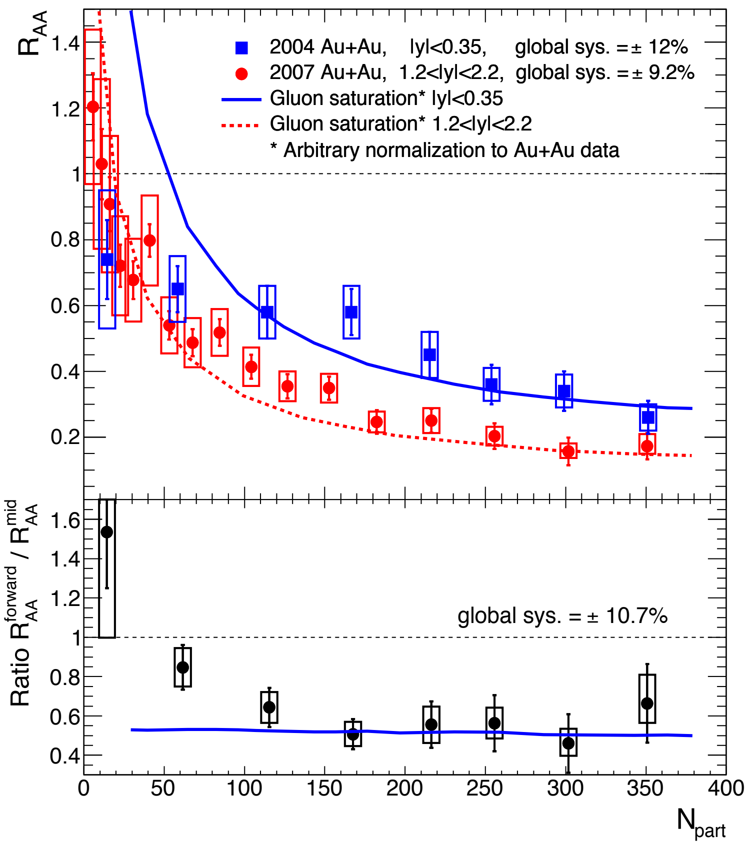


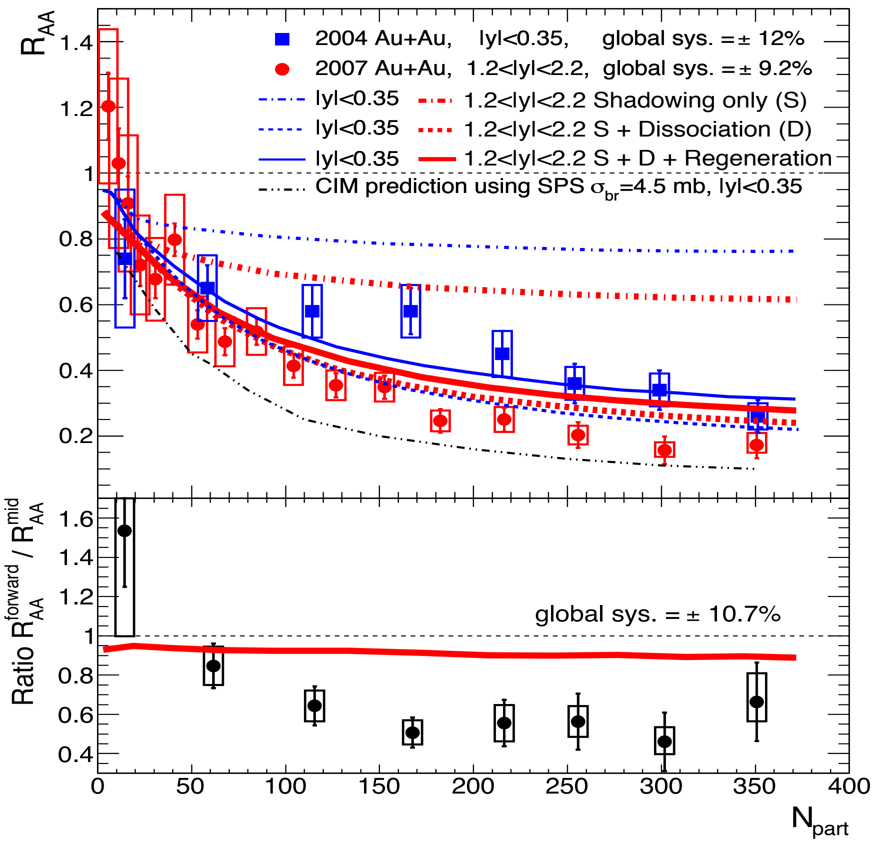


- J/Ψ suppression observed.
- Magnitude of suppression was similar to SPS.
- Models had predicted that suppression at RHIC would be higher.
  - Suppression at mid rapidity higher than at forward rapidity.
- Measurements contradict models.
- The suppression in forward rapidity should be lower because the energy density is lower.

Model predictions

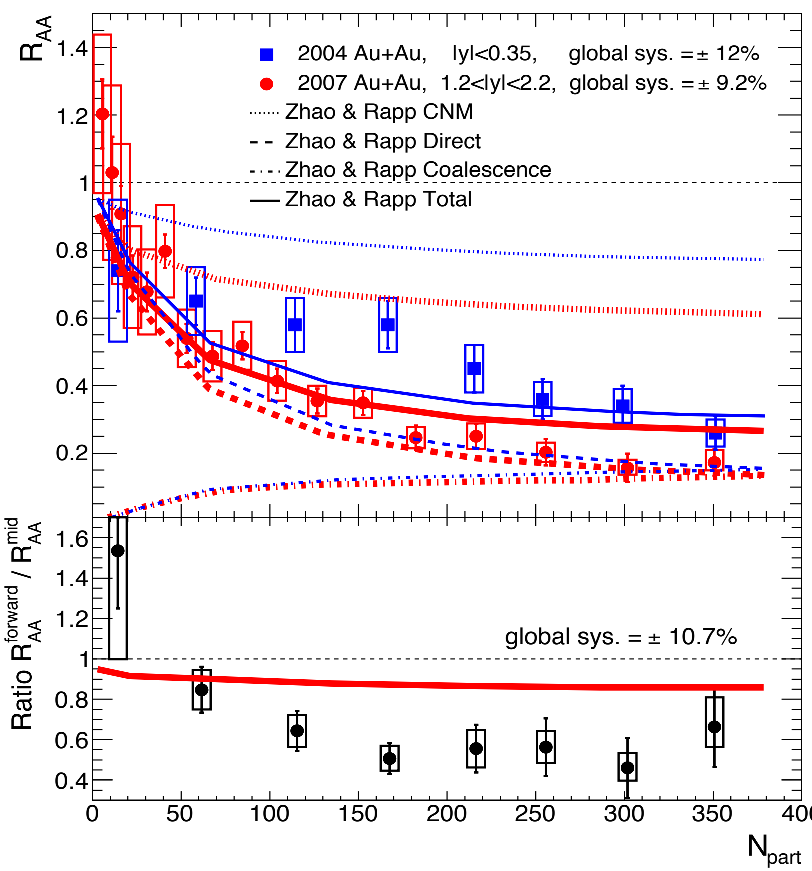
Model predictions including cold nuclear matter effects to try to explain large suppression in forward rapidity.

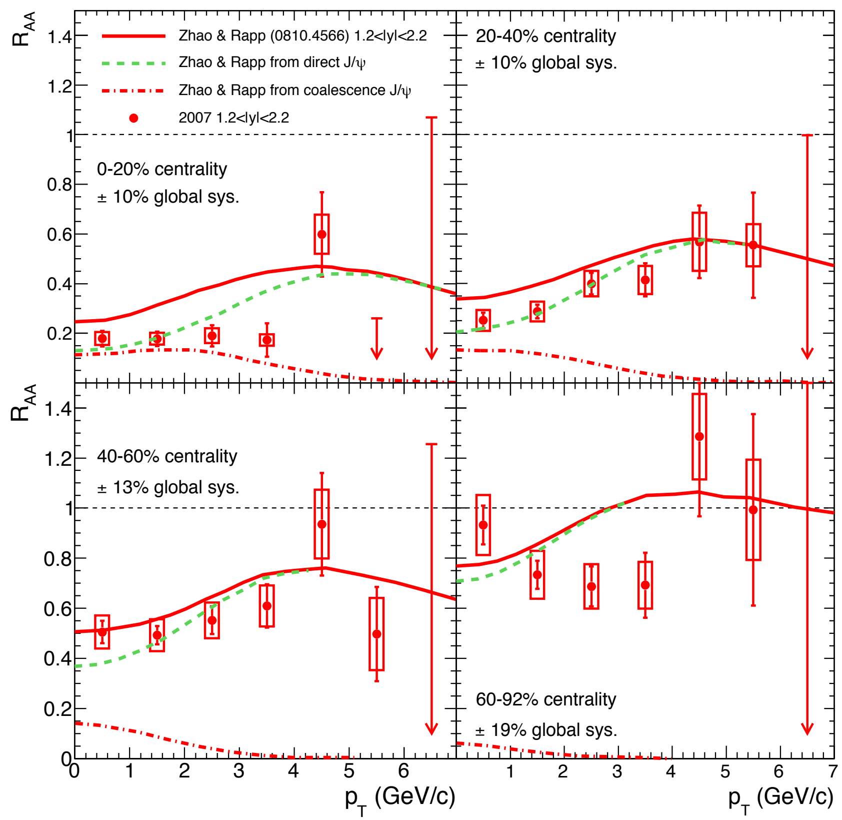




Model predictions

Model predictions including cold nuclear matter effects + QGP to try to explain large suppression in forward rapidity.





Still a puzzle…..