QM2012 EXPERIMENTAL REVIEW II + SOME MORE FROM ALICE

@ HIM2012-12

Pusan Nat'l Univ. In-Kwon Yoo

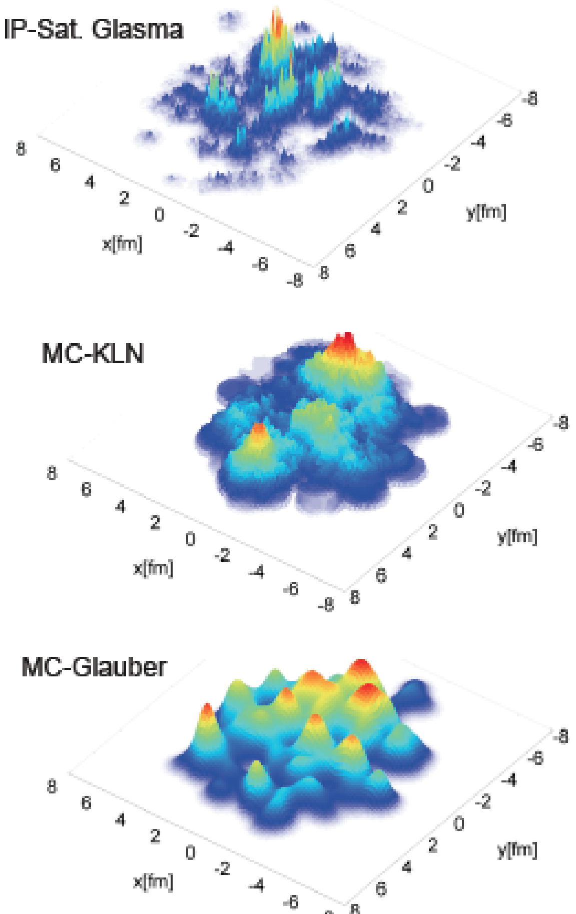
Outline

- Global Variables and Correlations (Hyppolyte, Rischke)
- High pT and Jets (Solana, Milov)
- EW Probes (L. Ruan)
- Summary

INITIAL CONDITIONS AND FLUCTUATIONS...

- cross roads: state-of-the-art modeling of initial conditions meets extremely precise experimental measurements of fluctuations !

Initial energy density (arb. units)



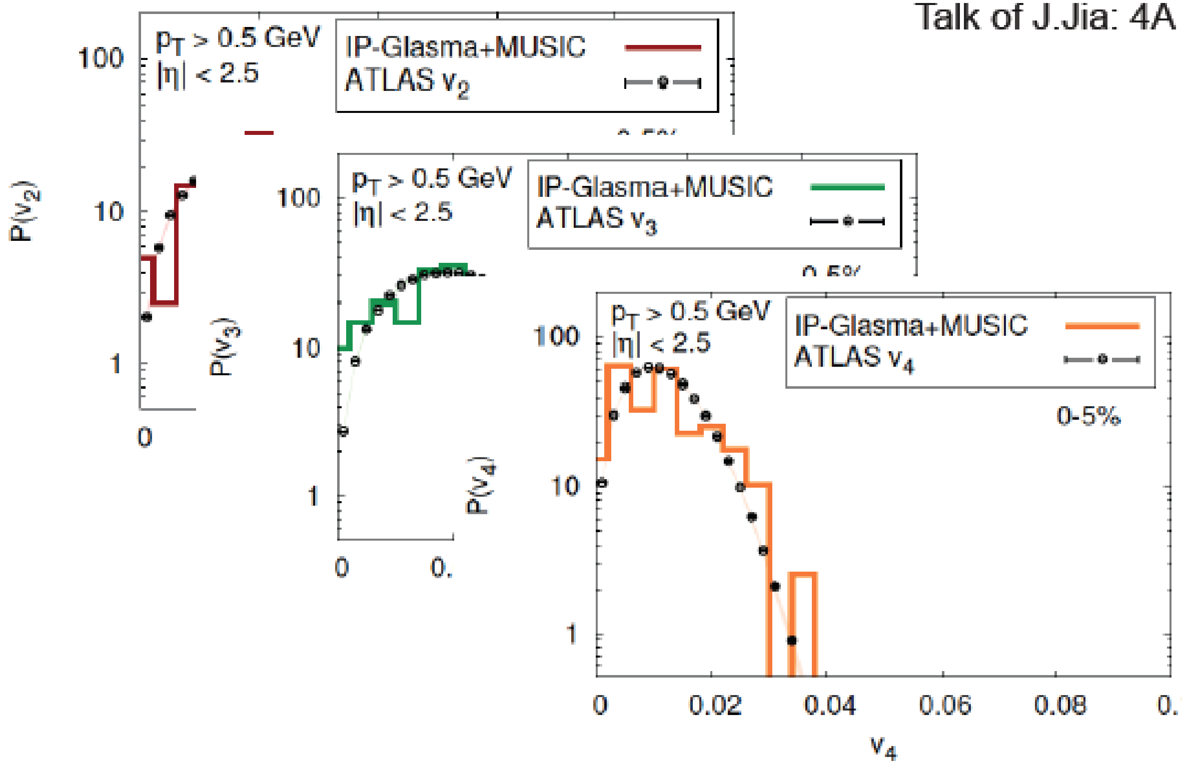
B.Schenke, P.Tribedy and R.Venugopalan, Phys. Rev. Lett.108, 252301 (2012)

Spectacularly good level of agreement:

Talk of B.Schenke: 3A

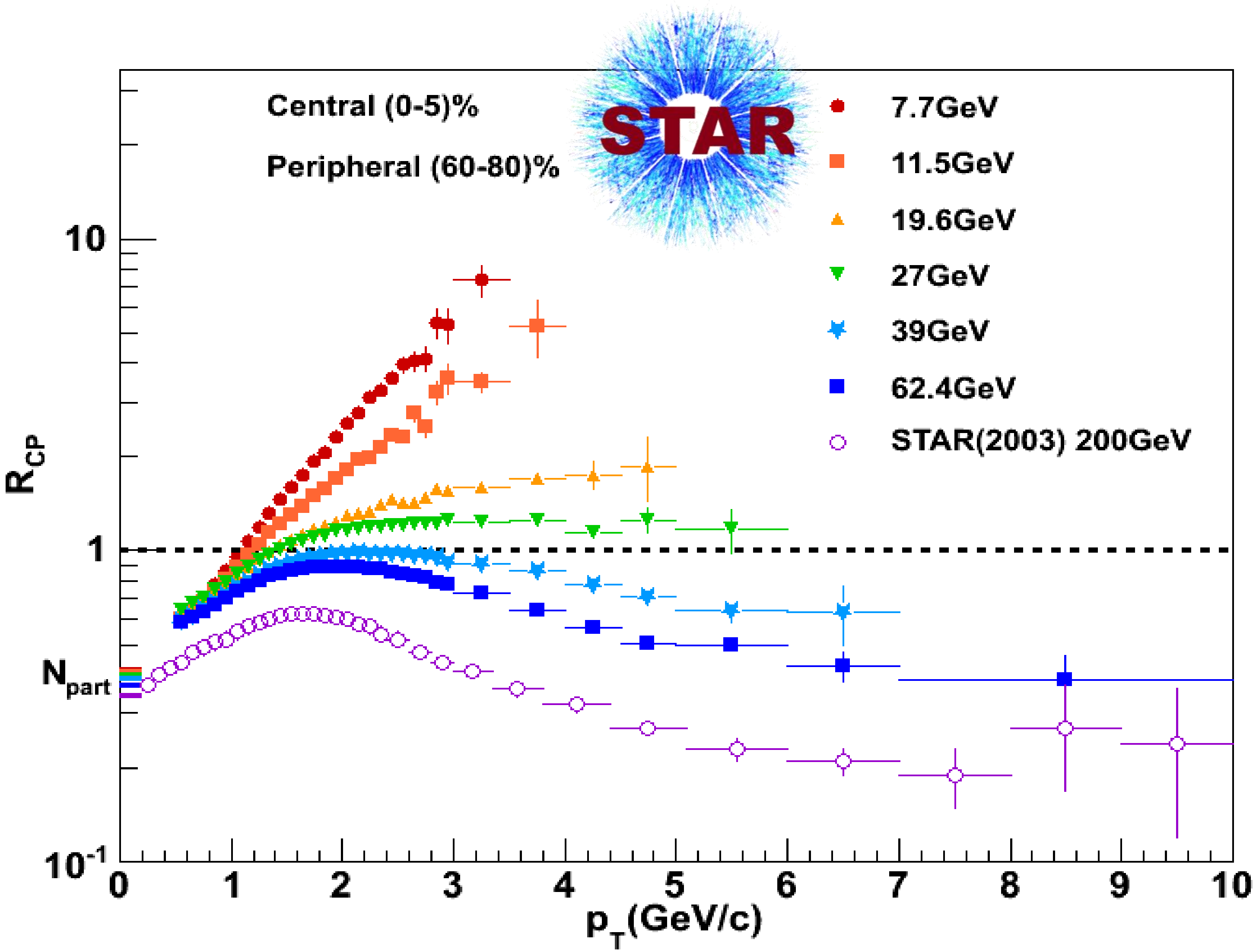
“real QM time” matching of EbyE $P(v_{n=2\text{-}4})$ vs. $v_{n=2\text{-}4}$ by ATLAS

Talk of J.Jia: 4A

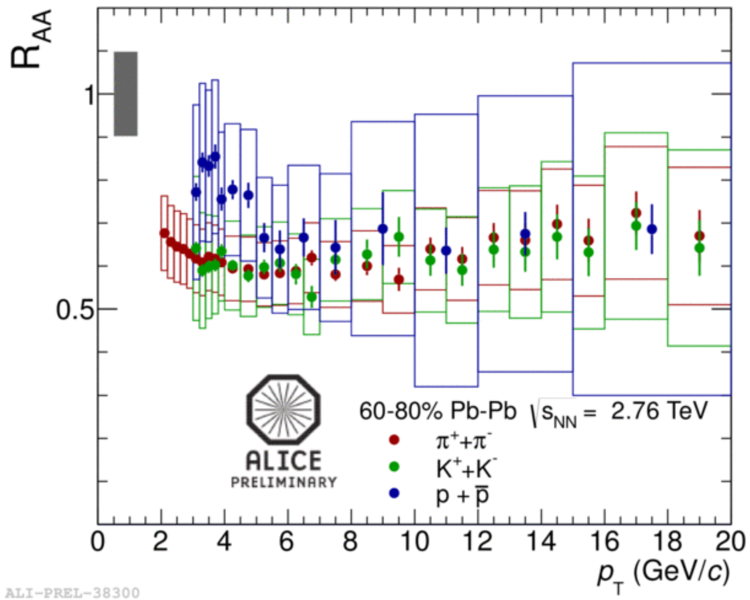


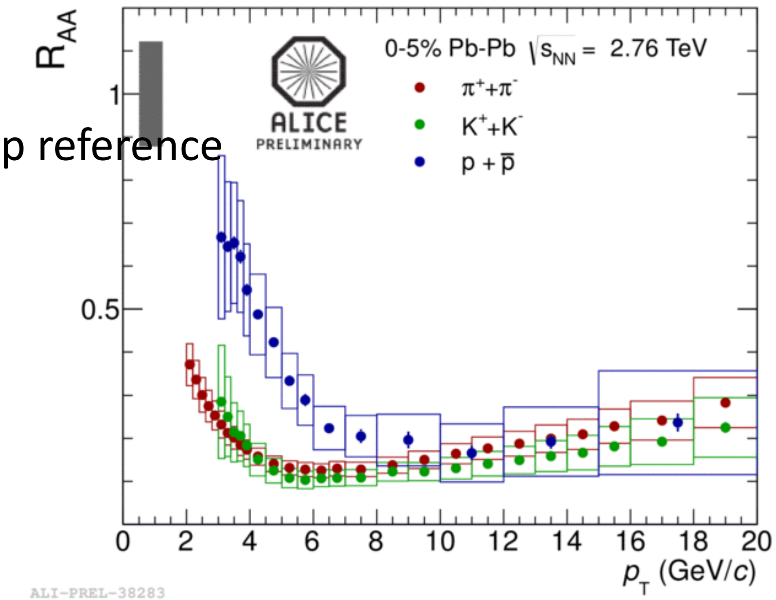
1. Hadron suppression

“Re-discovery” of suppression

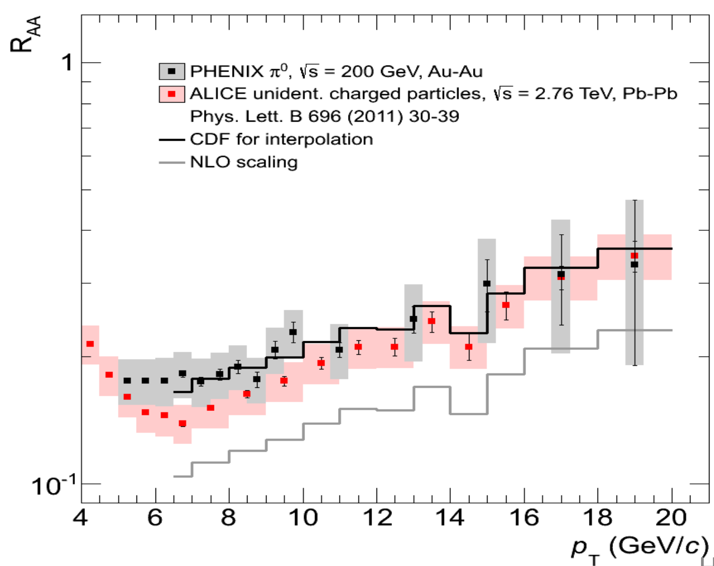


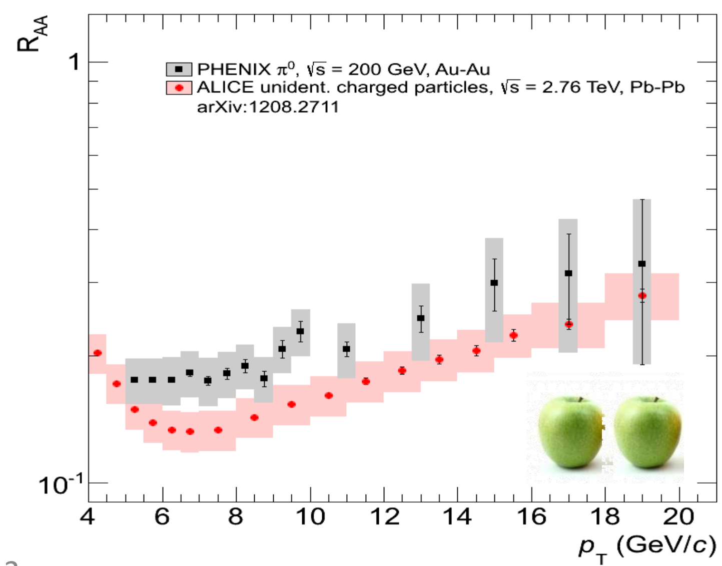
Suppression at RHIC and LHC



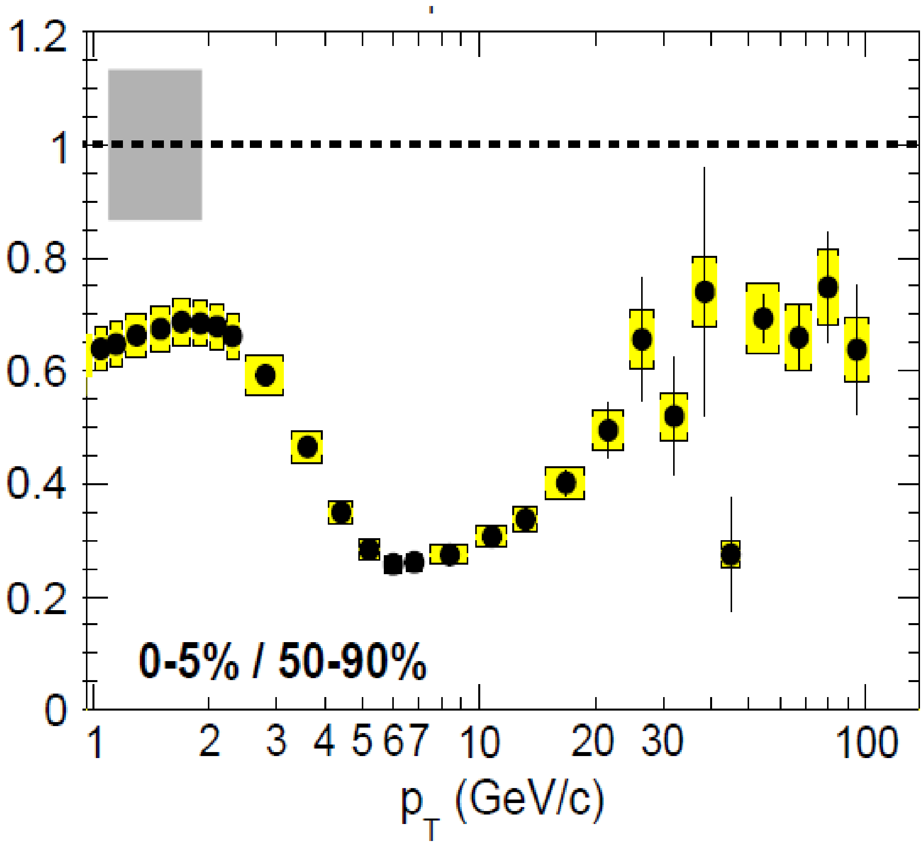


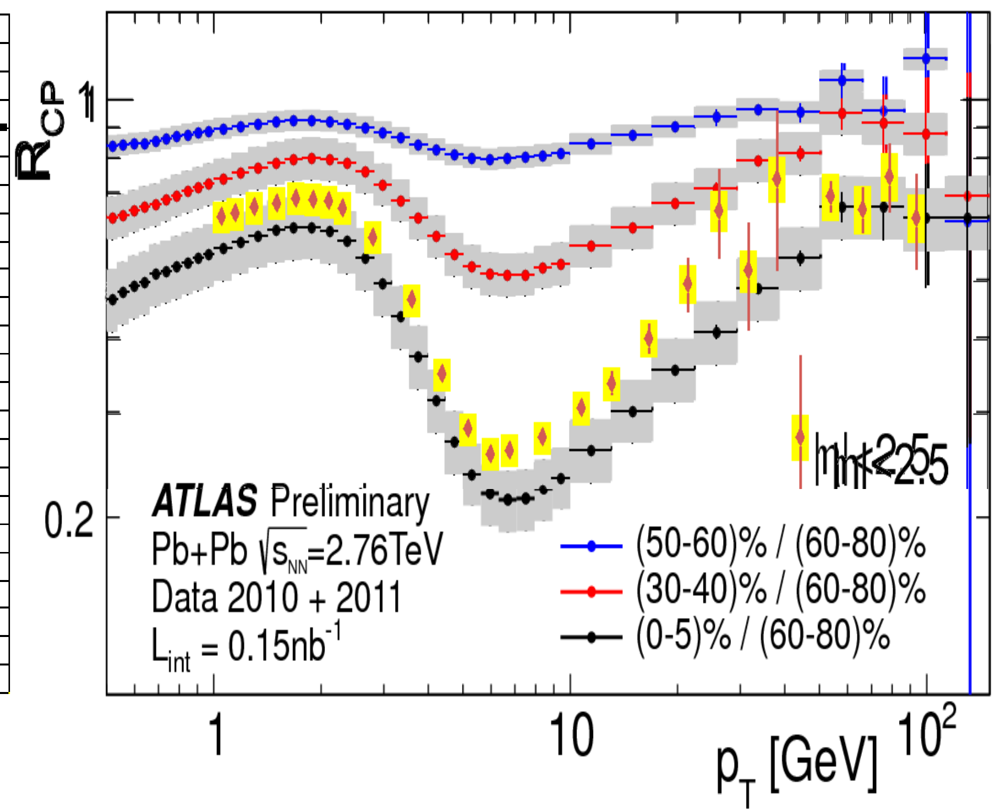
p+p reference

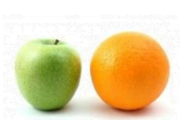




Suppression at high-p_T







Different peripheral bins **ATLAS: 60-80% CMS: 50-90%**

Summary of hadron R_{AA}

Suppression turns on at around $\sqrt{s_{NN}}$ = 30 GeV

At high $\sqrt{s_{NN}}$ for p_T>10 GeV/c all particle species are equally suppressed

Suppression reaches minimum at ~ 7GeV/c

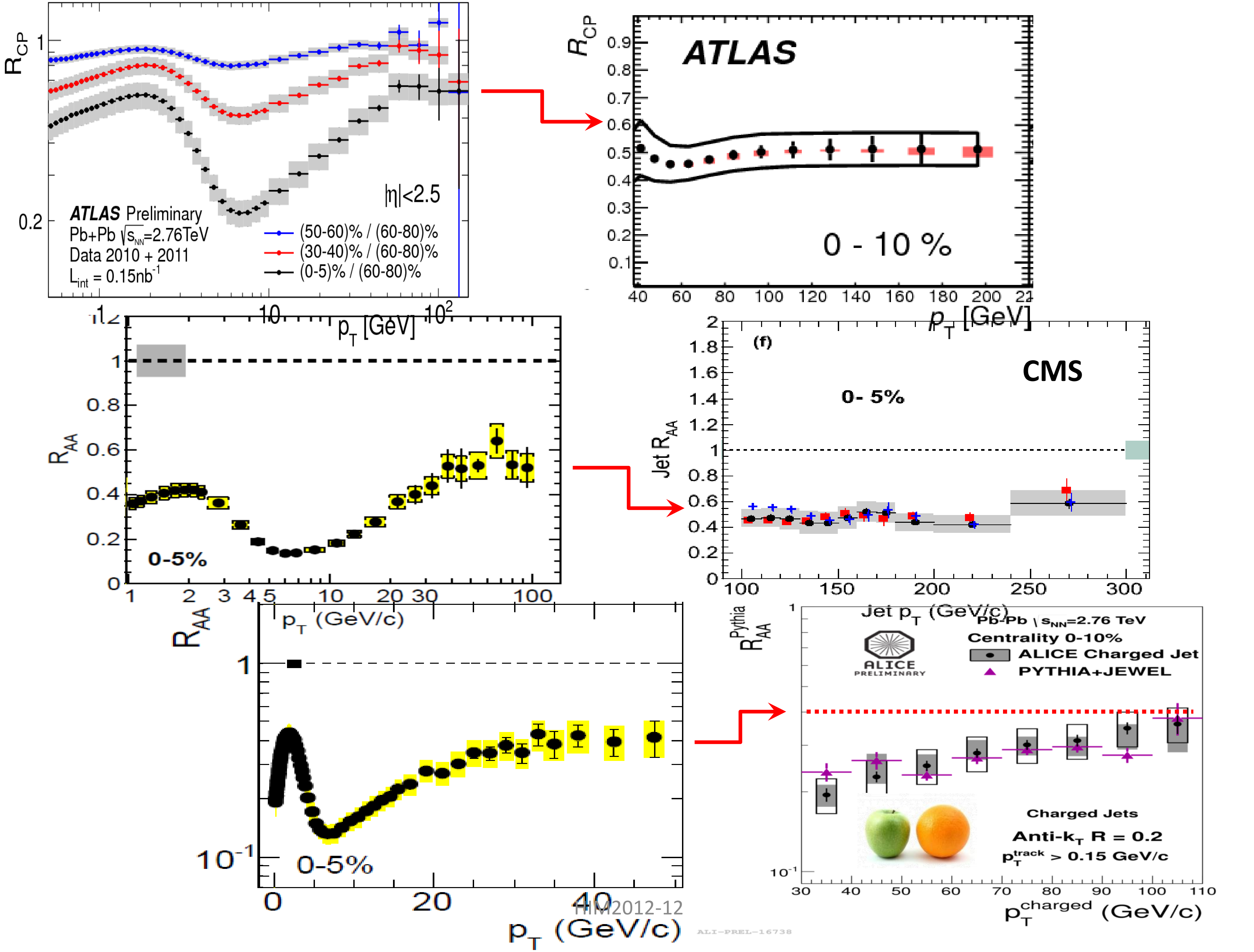
LHC results are consistent between experiments

At minimum, suppression at LHC is ~50% larger than at RHIC

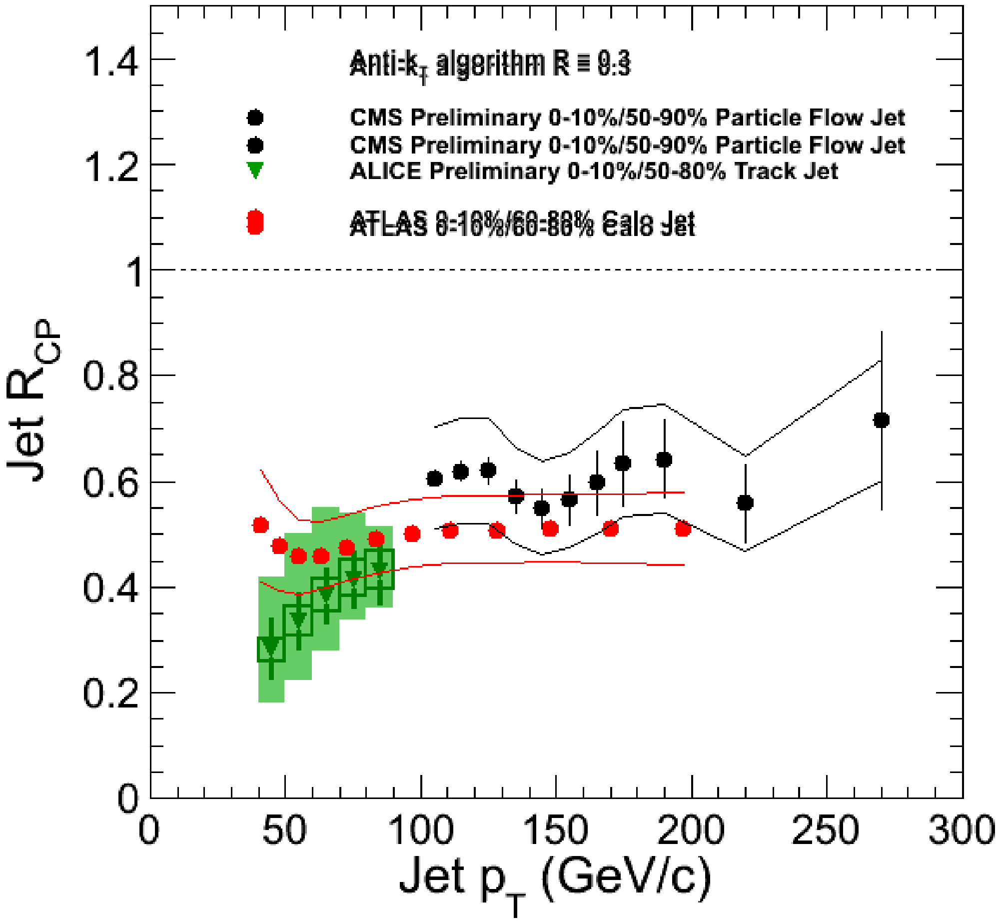
A combination of elastic and inelastic processes can provide a consistent picture for RHIC to LHC

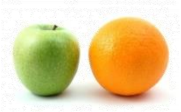
Many uncertainties in medium models still remain.

2. Jet suppression


ATLAS Preliminary
Pb+Pb √s_NN=2.76TeV
Data 2010 + 2011
L_int = 0.15nb^-1
|η|<2.5
(50-60)% / (60-80)%
(30-40)% / (60-80)%
(0-5)% / (60-80)%
R_CP
p_T [GeV]
ATLAS
0 - 10 %
p_T [GeV]
R_AA
0-5%
p_T (GeV/c)
CMS
(f)
0- 5%
Jet R_AA
Jet p_T (GeV/c)
R_AA
0-5%
p_T (GeV/c)
R_AA^Pythia
Pb-Pb √s_NN=2.76 TeV
Centrality 0-10%
ALICE Charged Jet
PYTHIA+JEWEL
ALICE PRELIMINARY
Charged Jets
Anti-k_T R = 0.2
p_T^track > 0.15 GeV/c
p_T^charged (GeV/c)
ALI-PREL-16738

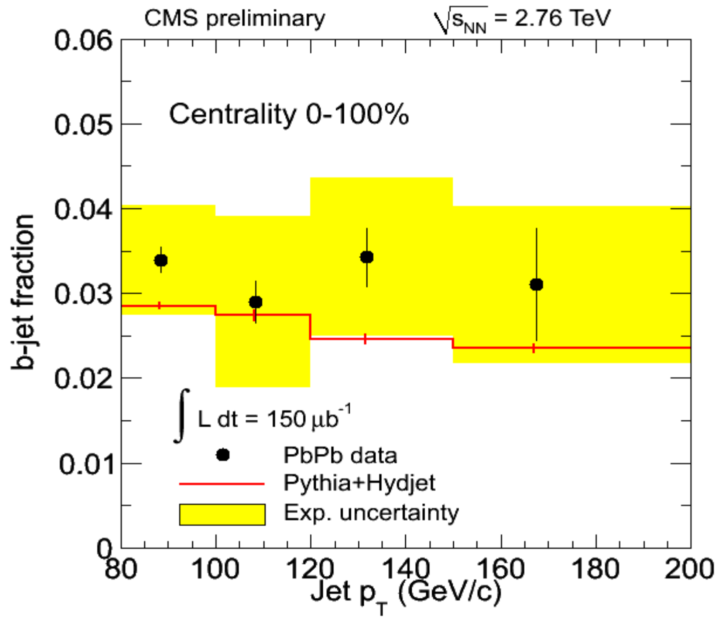
Jet R_{AA} at LHC

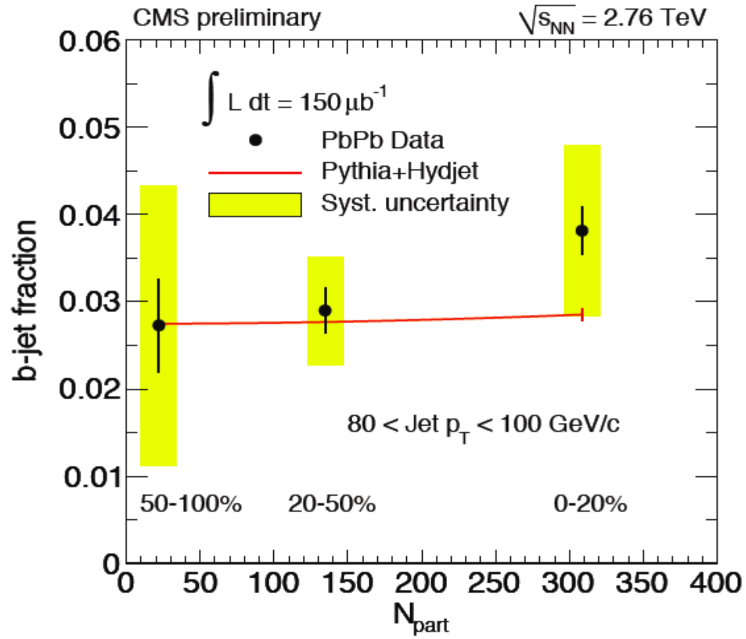


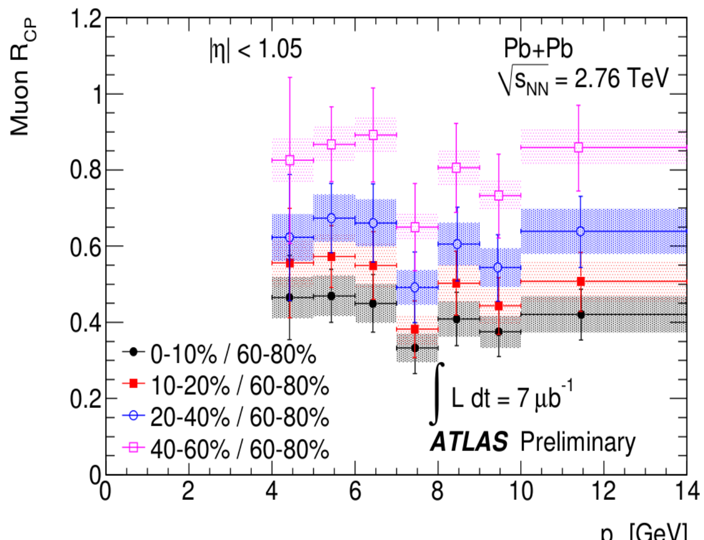


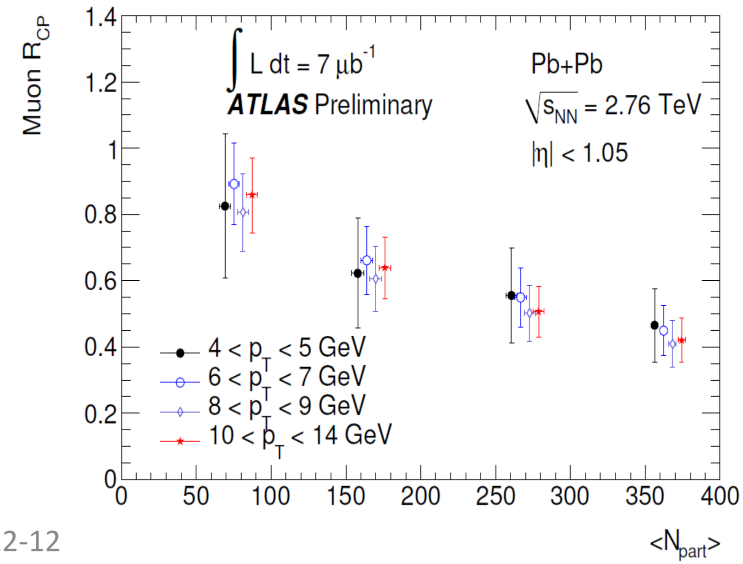
Using track-jets for ALICE

B-jet suppression



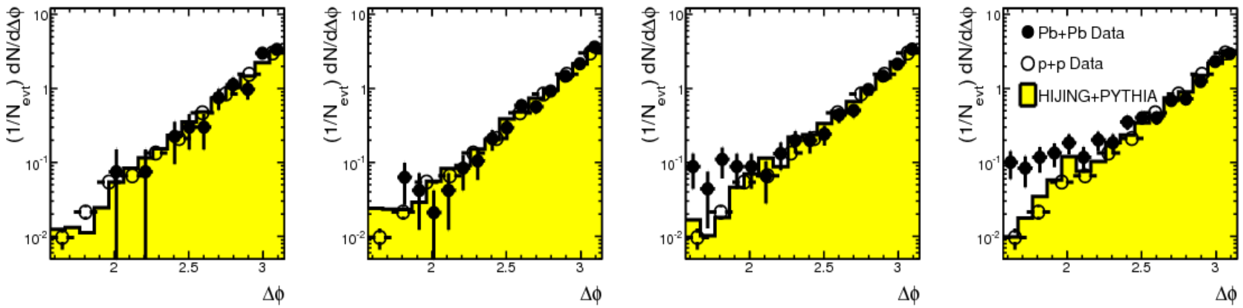


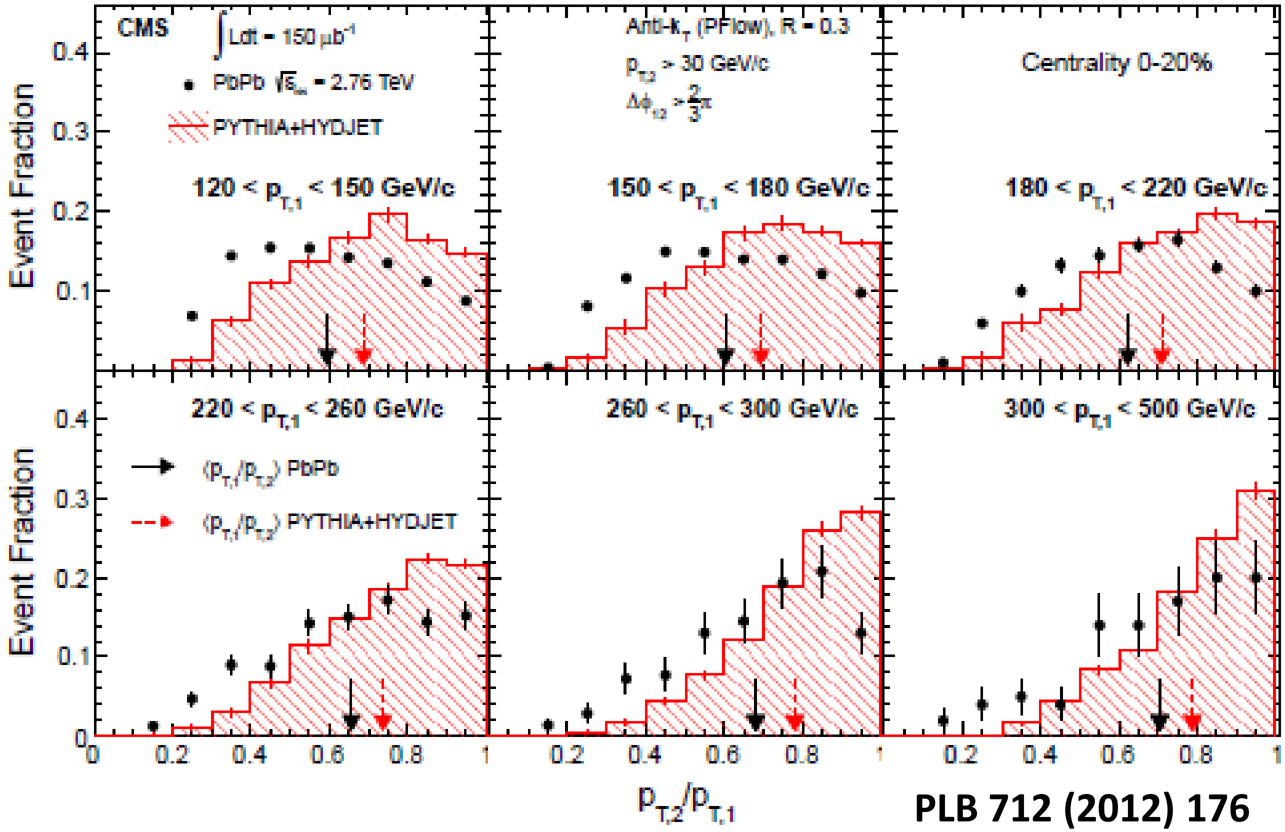




Di-jet correlation

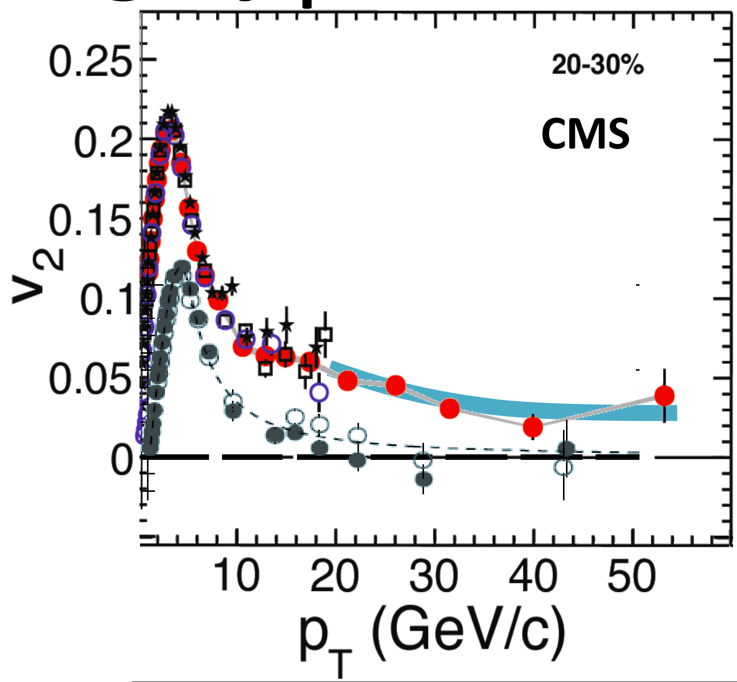
PRL 105 (2010) 252303

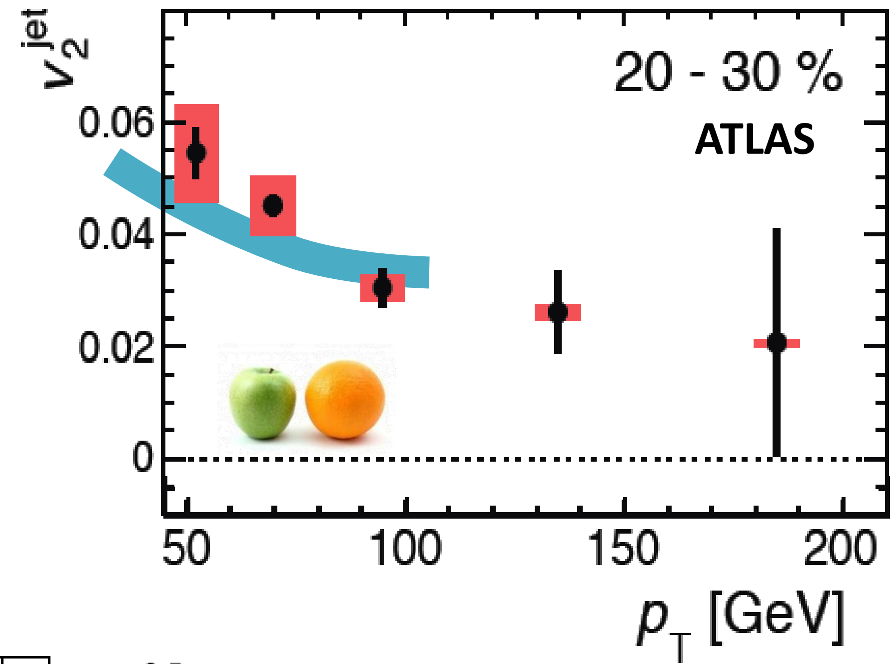


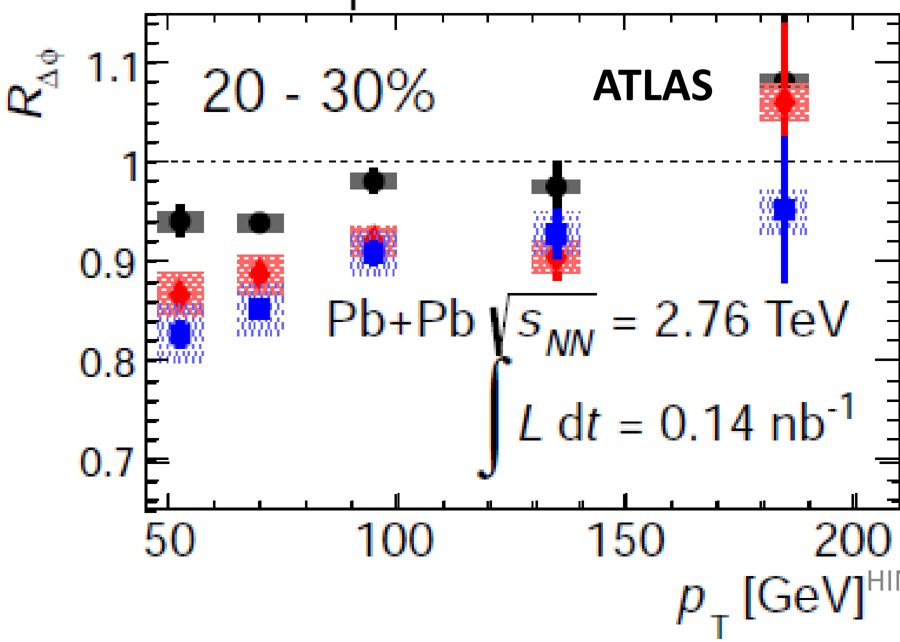


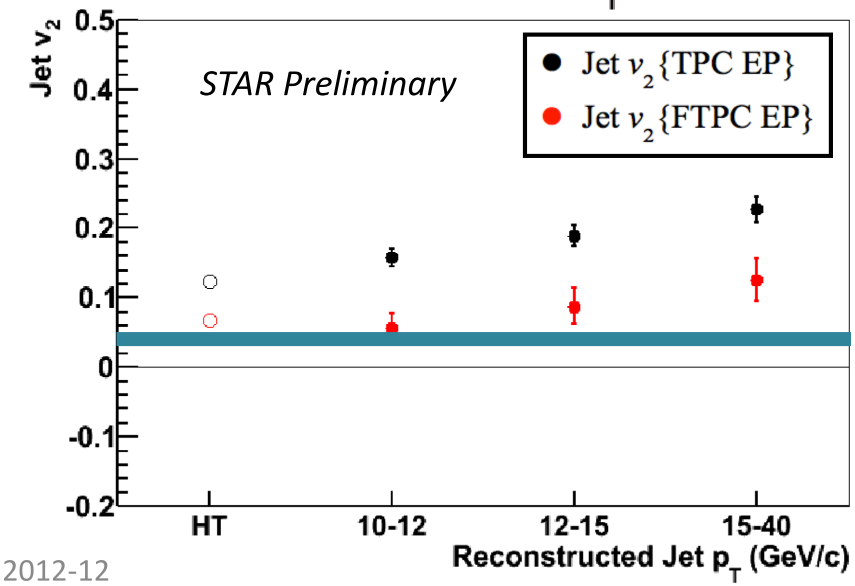
PLB 712 (2012) 176

High p_T hadron and jet v_2



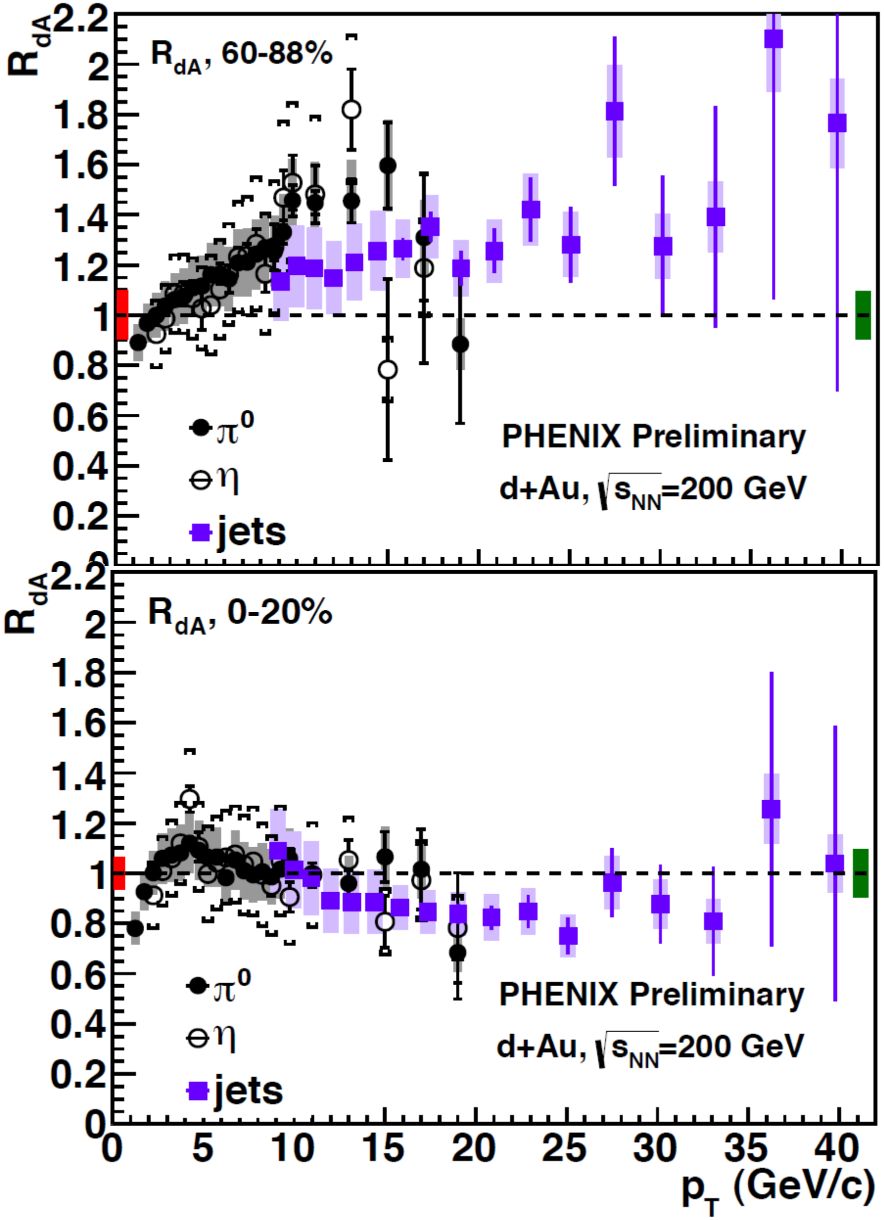


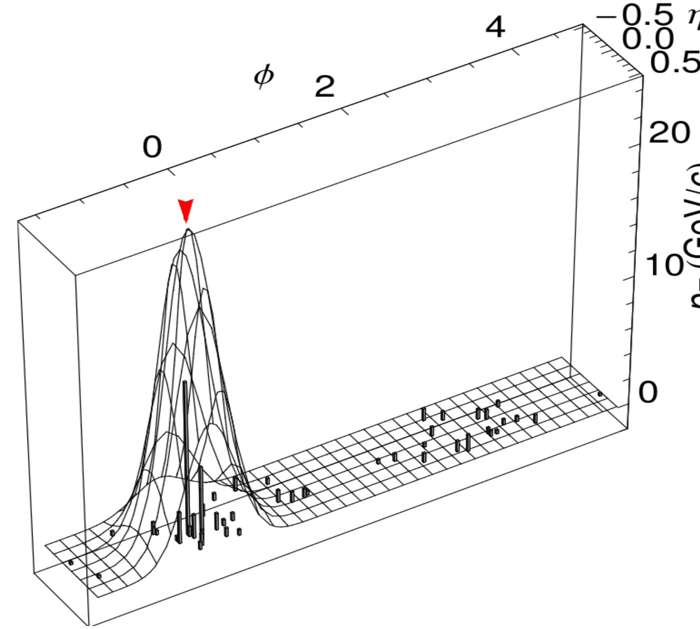


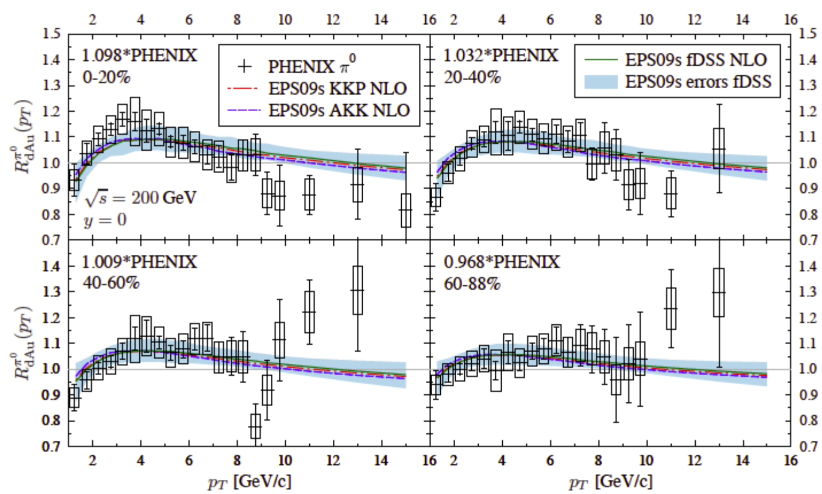


3. CNM effects

Enhancement in dAu







HIM2012-12

arXiv:1205.5359

Potentially Devastating Consequences

- IF these preliminary data are confirmed:

Change in min-bias data demands a new nPDF fit
(eps 09 used the older data)

- It is very hard to imagine how to incorporate the peripheral enhancement into an nPDF with any reasonable $s_\perp$ dependence
(educated opinion of K. Escola and I. Helenius)
- This would mean that collinear factorization approach to nuclear effects does not apply to pT as high as 30 GeV!

This is a basic assumption of all high pT calculations

- This behavior could persist in p-Pb collisions at the LHC at very high pT (~ 100 GeV).

The experimental results

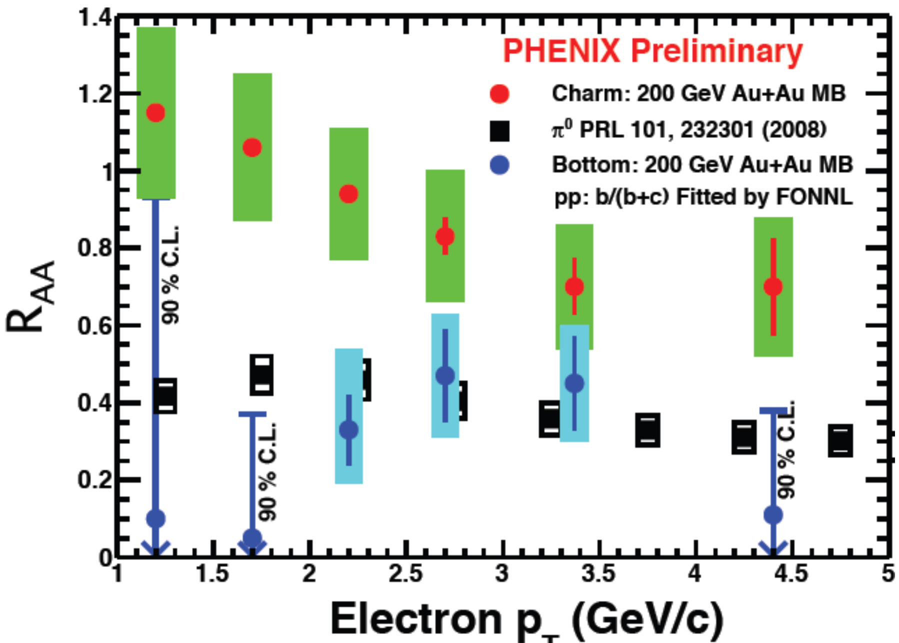
Outline:

- **Heavy flavor: D, B, and their decayed e and μ**
- **Quarkonia: J/ψ, Υ and their excited states**
- **Controlled Probes: W, Z, and γ**
- **Thermal di-leptons and photons: γ, e^+e^-, and $\mu^+\mu^-$**

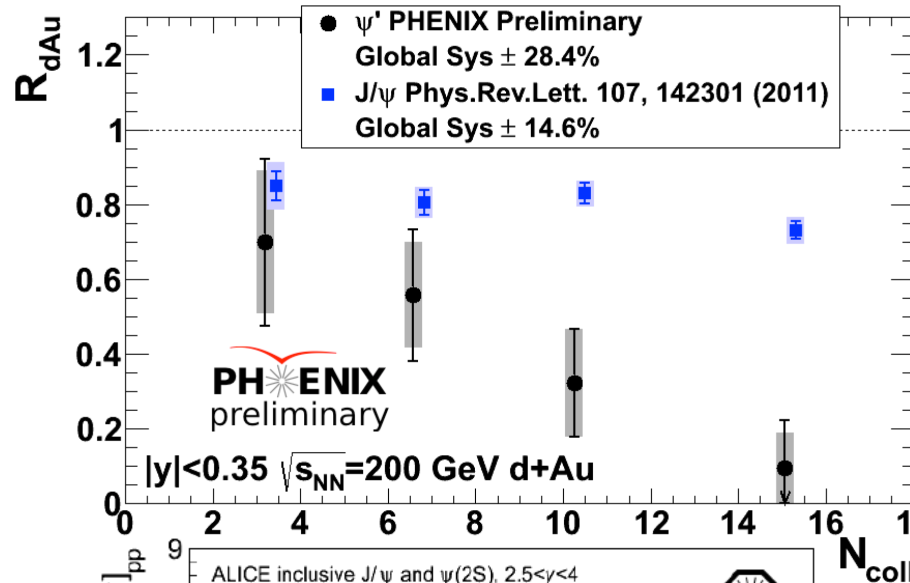
The measurements presented at QM2012

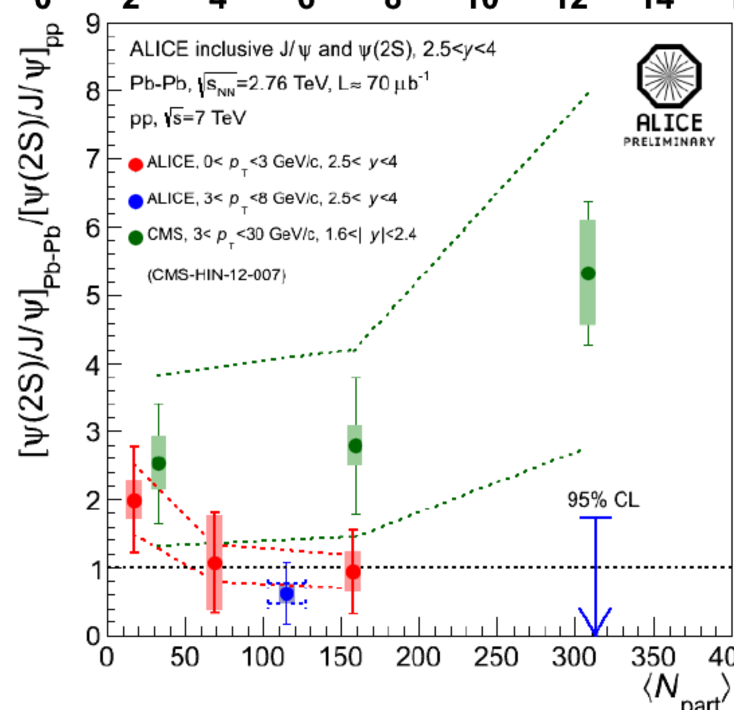
Experiment	Heavy flavor	Quarkonia	Electroweak
PHENIX	μ: 1.2<|y|<2.2 e: |y|<0.35	J/ψ, $\Upsilon \rightarrow \mu\mu$ J/ψ, $\Upsilon \rightarrow ee$	γ, di-electron
STAR	e, D: |y|<1	J/ψ, $\Upsilon \rightarrow ee$	di-electron
ALICE	μ: 2.5<|y|<4 e,D: |y|<0.9 $B \rightarrow J/\psi X \rightarrow eeX$	$J/\psi \rightarrow \mu\mu$ $J/\psi \rightarrow ee$	γ
ATLAS	μ: |y|<1.05, p_T>4 GeV/c		γ: |y|<1.3, E_T (45-200 GeV) $W \rightarrow \mu\nu$: $\|\eta^{\mu}\|<2.7, p_T(\mu)>7$ GeV/c $Z \rightarrow \mu\mu$ (ee): |y|<2.7 (|y|<2.5)
CMS	$B \rightarrow J/\psi X \rightarrow \mu\mu X$	$J/\psi \rightarrow \mu\mu$: |y|<2.4, p_T>6.5 GeV/c $\Upsilon \rightarrow \mu\mu$ |y|<2.4	γ: |y|<1.44, E_T (20-80 GeV) $W \rightarrow \mu\nu$: $\|\eta^{\mu}\|<2.1, p_T(\mu)>25$ GeV/c $Z \rightarrow \mu\mu$: |y|<2.1

Surprising results at QM2012



PHENIX: McGlinchey, Nouicer, Rosati, Sakaguchi, Wysocki

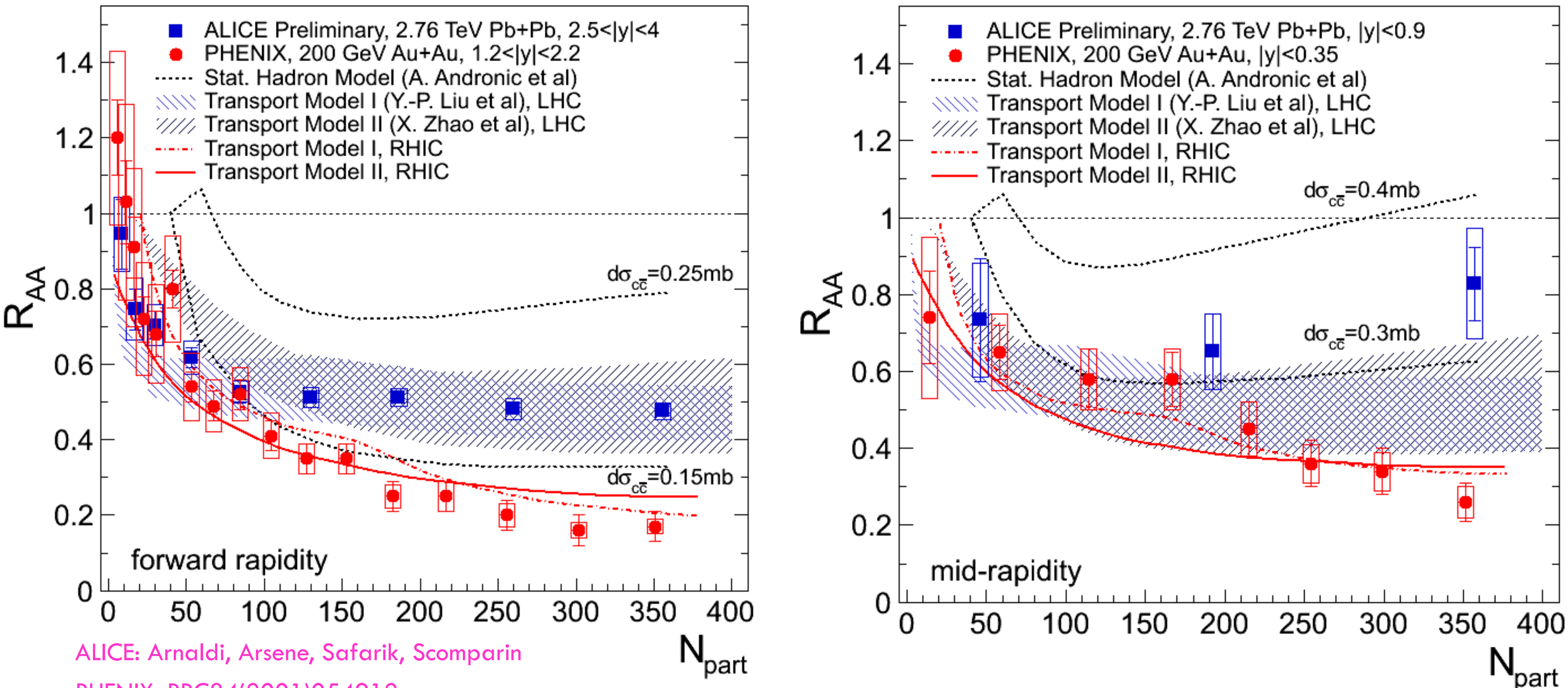




- **PHENIX: R_{AA}(b→e) < R_{AA} (c→e)**
  at p_T=1-5 GeV/c in 200 GeV Au+Au
- **PHENIX: R_{dAu}(ψ') < R_{dAu}(J/ψ) by a factor of 5 in most central d+Au**
- **CMS: At 1.6<|y|<2.4, 3<p_T<30 GeV, ψ(2S) less suppressed than J/ψ in central Pb+Pb, not confirmed by ALICE with 2.5<|y|<4, 3<p_T<8 GeV.**

CMS: Mironov, Moon, Roland; ALICE: Arnaldi, Safarik, Scomparin

J/ψ results in A+A: centrality dependence



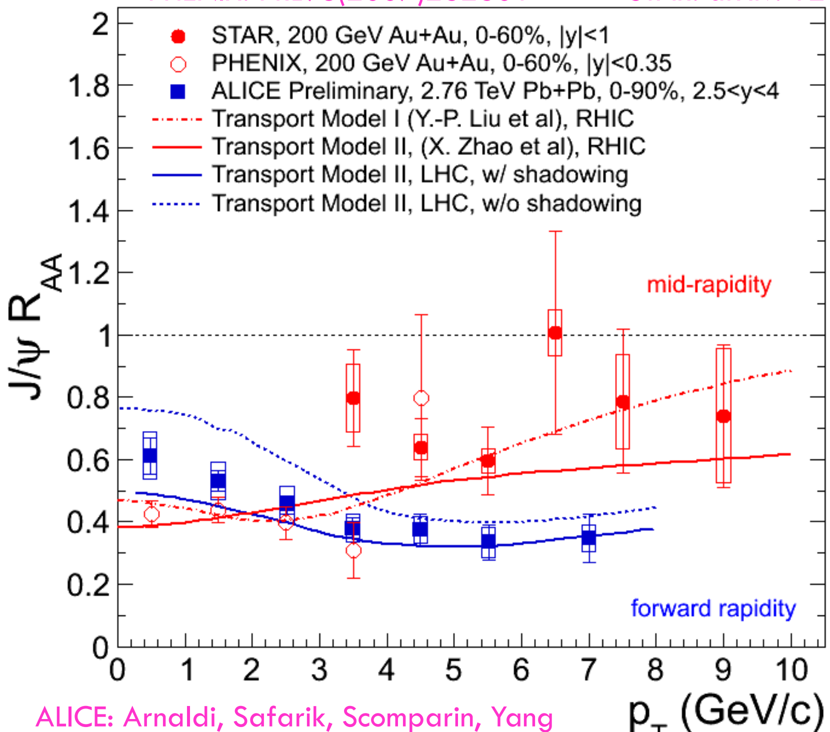
ALICE: Arnaldi, Arsene, Safarik, Scomparin

PHENIX: PRC84(2001)054912

- N_{part} dependence of J/ψ R_{AA}: less suppression at LHC compared to at RHIC in central collisions
- interplay between CNM, color screening and ccbar recombination
- consistent with more significant contribution from ccbar recombination at LHC energies

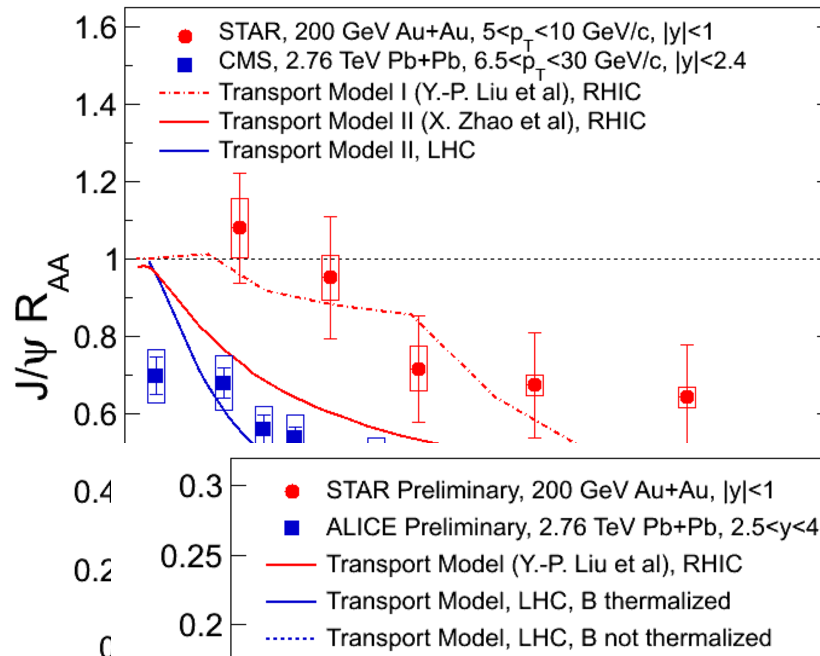
J/ψ results in A+A: p_T dependence

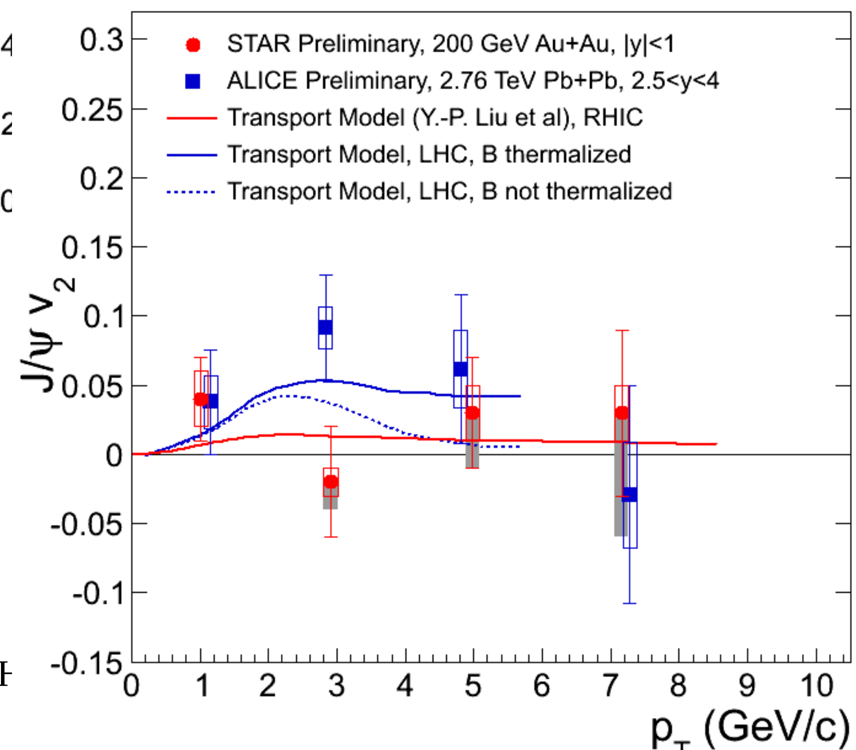
PHENIX: PRL98(2007)232301 STAR: arXiv: 1208.2736, Trzeciak, Xie



ALICE: Arnaldi, Safarik, Scomparin, Yang

CMS: Mironov, Moon, Roland





J/ψ R_{AA} decreases from low to high p_T at LHC.

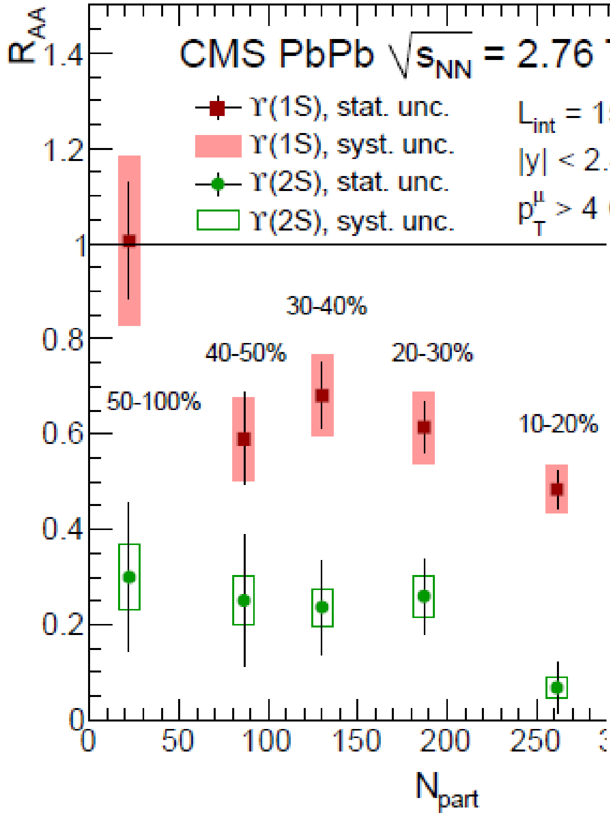
J/ψ R_{AA} increases from low to high p_T at RHIC.

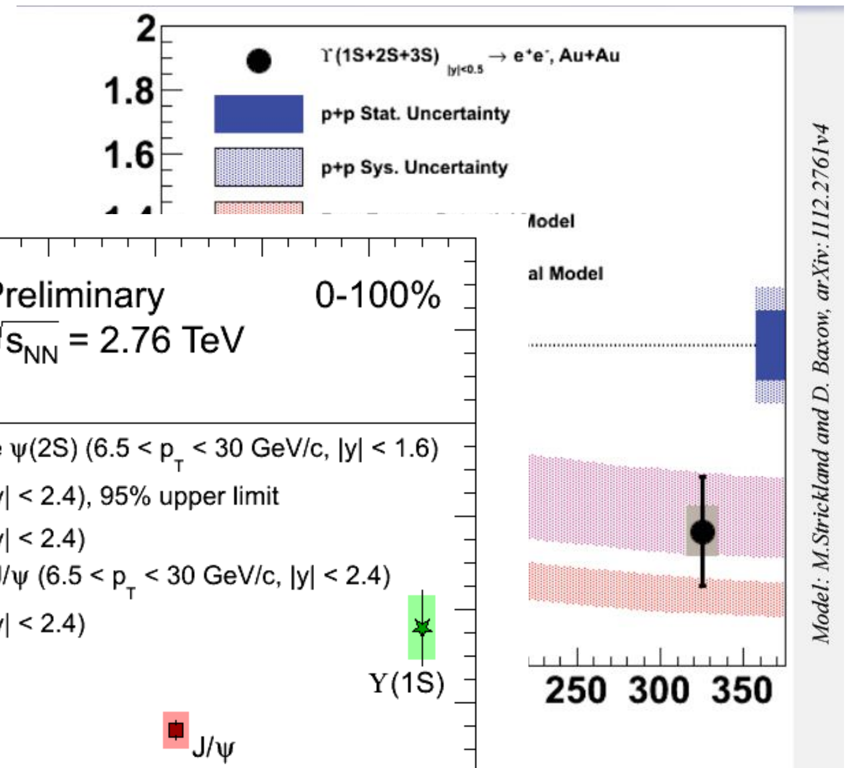
At high p_T, J/ψ more suppressed at LHC.

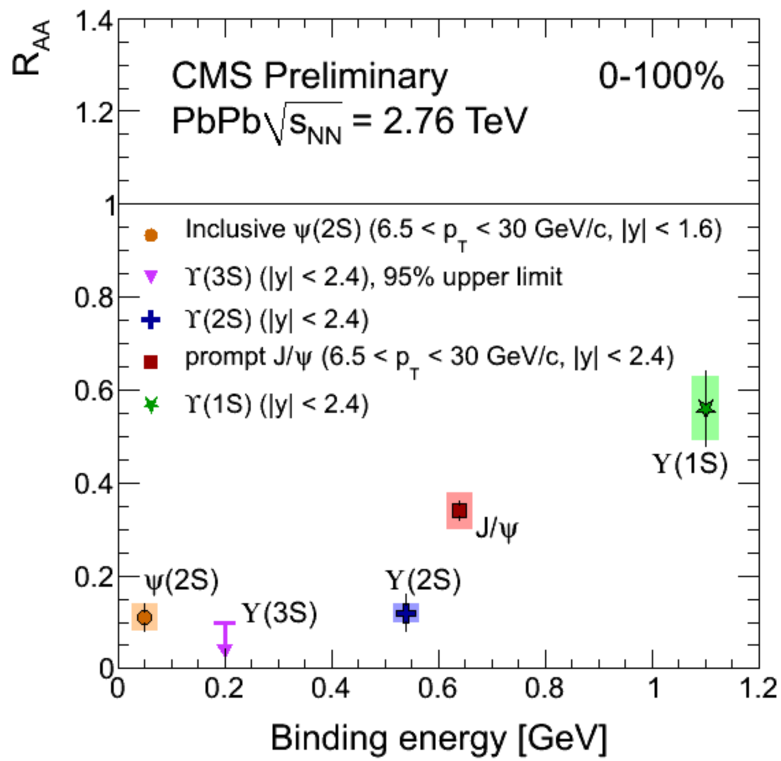
Hint for possible J/ψ flow at p_T=3 GeV/c at LHC.

Models incorporating color screening and recombination can consistently describe the J/ψ suppression pattern and flow measurements.

ϒ results in A+A







STAR: Dong, Trzeciak, Xie

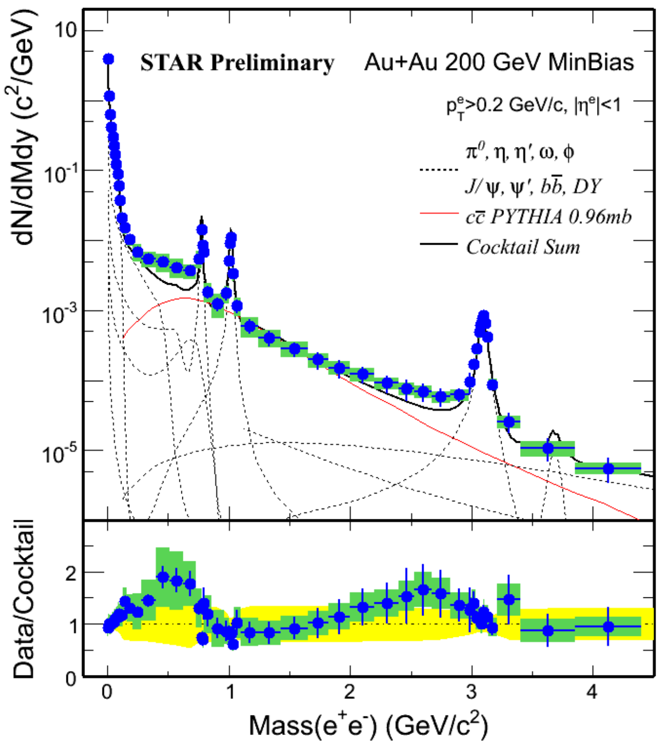
CMS: arXiv: 1208.2826, Mironov, Ro

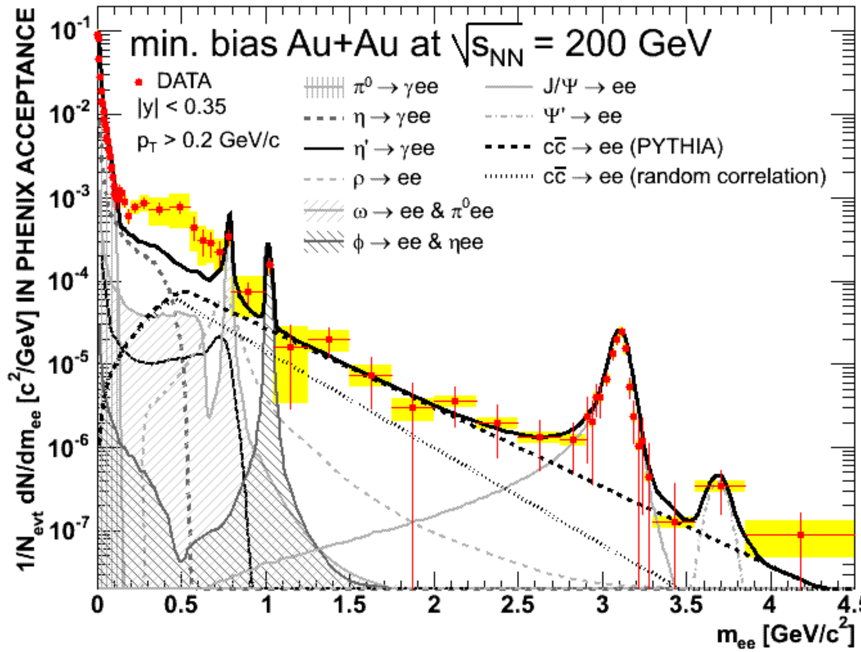
ϒ(1s) suppression magr ... **suppression.**

ϒ(2S) strongly suppress

Now is the perfect time to study color screening features of hot, dense medium in light of RHIC and LHC precise quarkonium measurements.

RHIC di-lepton results at last QM





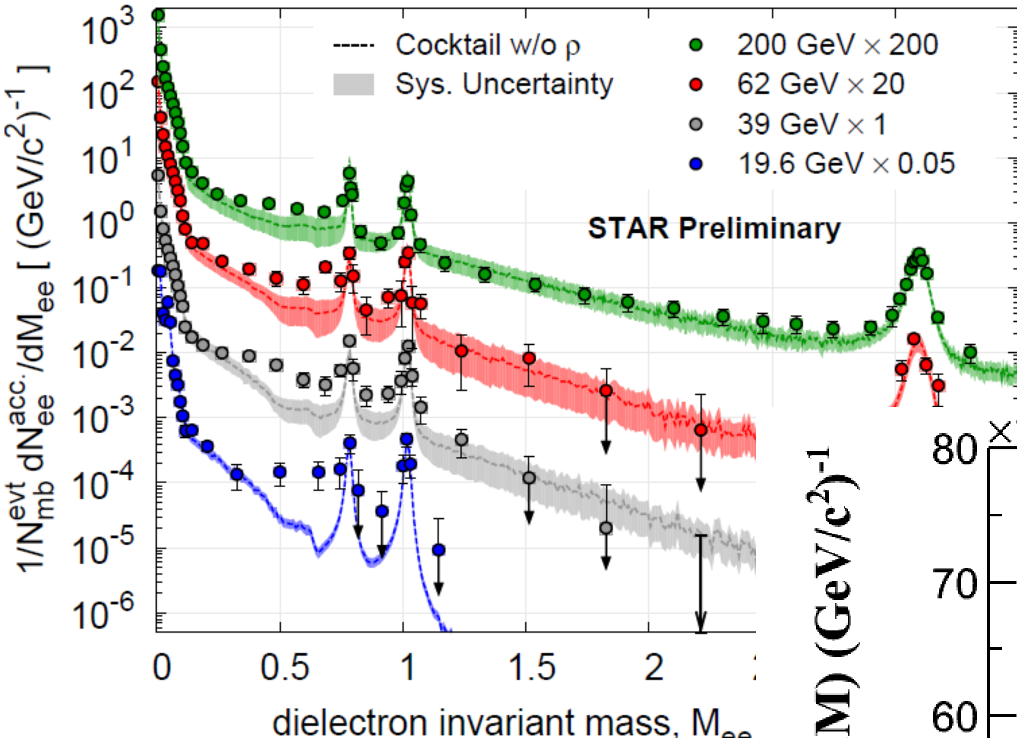
PHENIX PRC 81 (2010) 034911

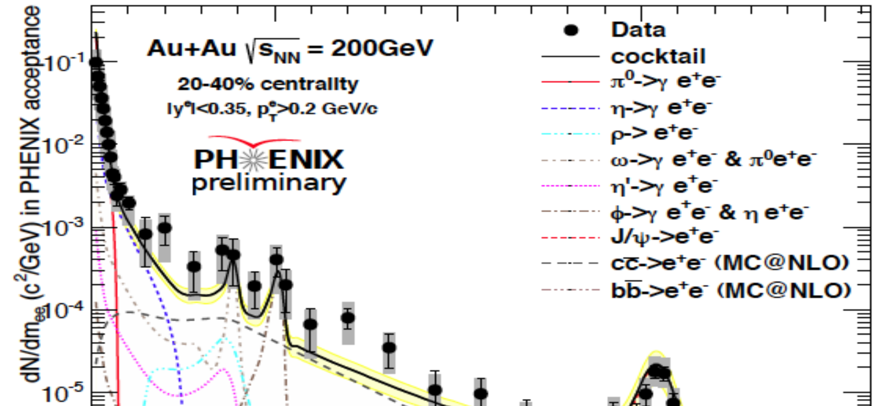
Enhancement factor in $0.15<M_{ee}<0.75$ Gev/c2

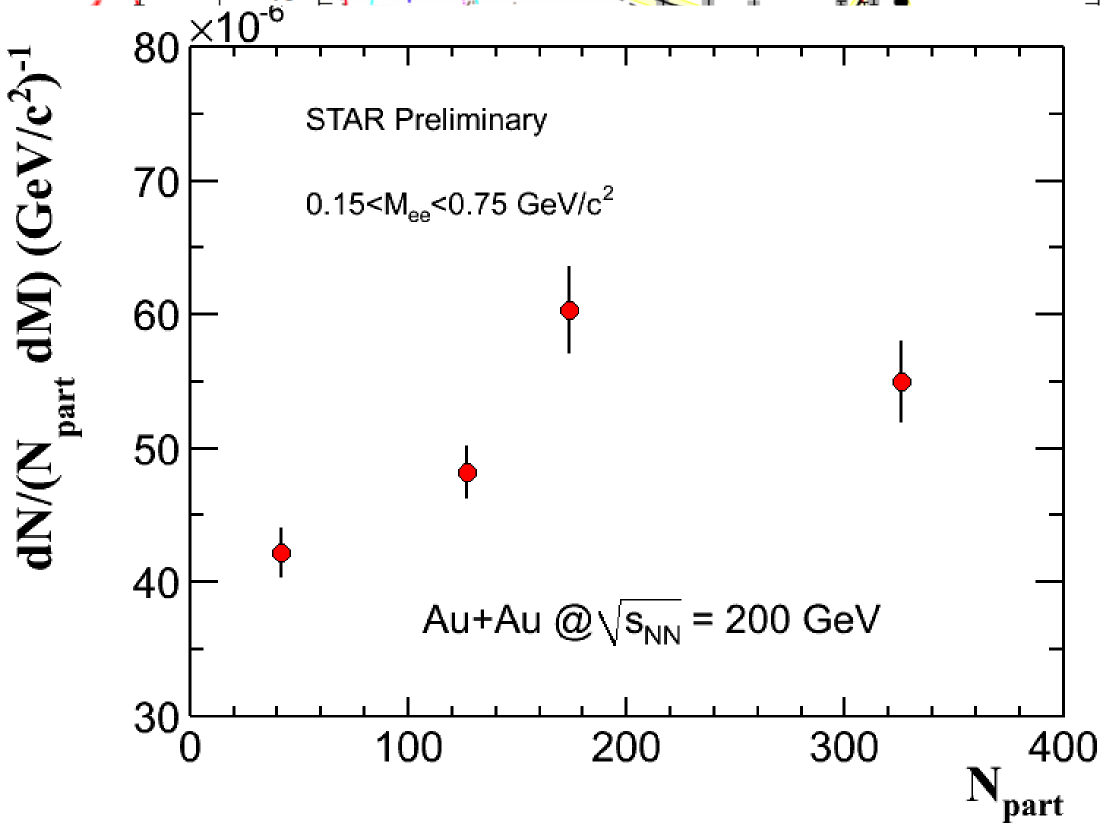
	Minbias (value ± stat ± sys)	Central (value ± stat ± sys)
STAR	1.53 ± 0.07 ± 0.41 (w/o ρ) 1.40 ± 0.06 ± 0.38 (w/ ρ)	1.72 ± 0.10 ± 0.50 (w/o ρ) 1.54 ± 0.09 ± 0.45 (w/ ρ)
PHENIX	4.7 ± 0.4 ± 1.5	7.6 ± 0.5 ± 1.3
Difference	2.0 σ	4.2 σ

The discrepancy is in 0-20% central Au+Au collisions. The 0-20% HBD results will be important to clarify the discrepancy experimentally.

Energy dependence of di-electron spectra







STAR: Dong, Geurts, Huang, Huck

PHENIX HBD results at 200 GeV : co

STAR results: systematically study t

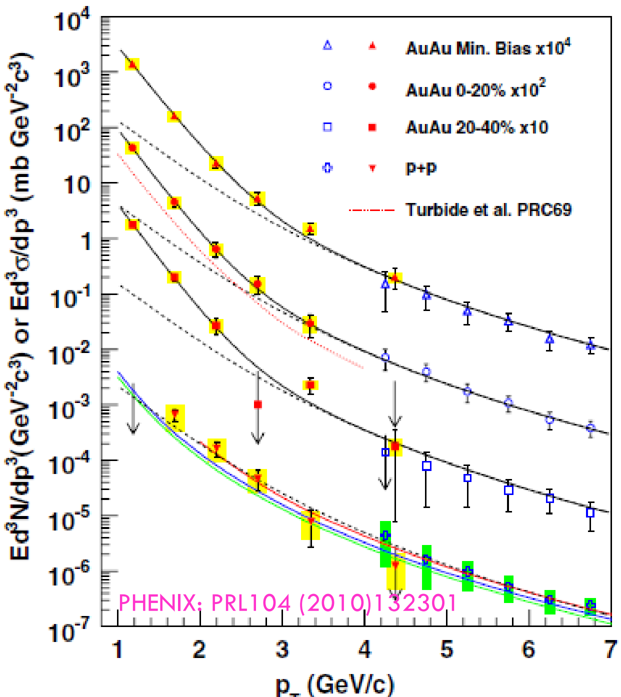
GeV. Note: enhancement factor (EF

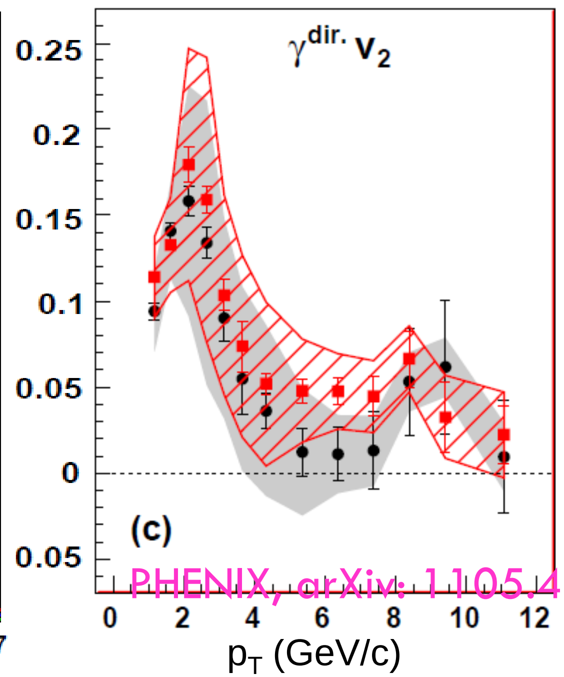
using cocktail as a reference, which

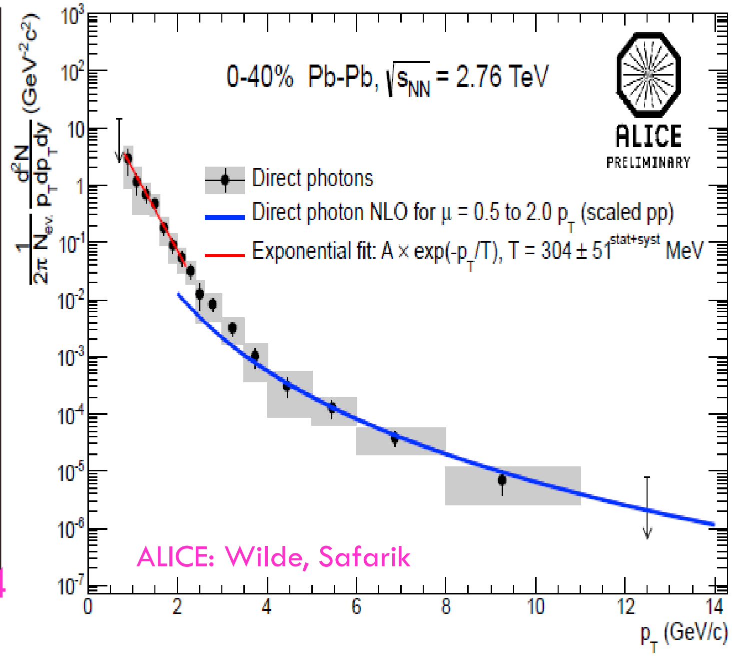
centrality dependence from STAR ex

using N_{part} as a reference, there is ce

Direct photon spectra and elliptic flow v_2







- Low p_T direct photon elliptic flow measurement could provide direct constraints on QGP dynamics (η/s, T, t_0…).
- Excess of direct photon yield over p+p: T_{eff}=221 ± 19 ± 19 MeV in 0-20% Au+Au; substantial positive v_2 observed at p_T<4 GeV/c.
- Excess of direct photon yield over p+p at p_T<4 GeV/c: T_{eff}=304 ± 51 MeV in 0-40% Pb+Pb.
- Di-lepton v_2 versus p_T & M_{ll}: probe the properties of the medium from hadron-gas dominated to QGP dominated.
  (R. Chatterjee, D. K. Srivastava, U. Heinz, C. Gale, PRC75(2007)054909)

The objectives of heavy-ion physics

OBJECTIVES

- EXTEND THE STANDARD MODEL OF PARTICLE PHYSICS (SM) TO DYNAMICAL COMPLEX SYSTEM OF FINITE SIZE

OBJECTIVES

ALICE

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- UNDERSTAND HOW MACROSCOPIC PROPERTIES OF MATTER EMERGE FROM THE FUNDAMENTAL MICROSCOPIC LAWS OF PARTICLE PHYSICS

OBJECTIVES

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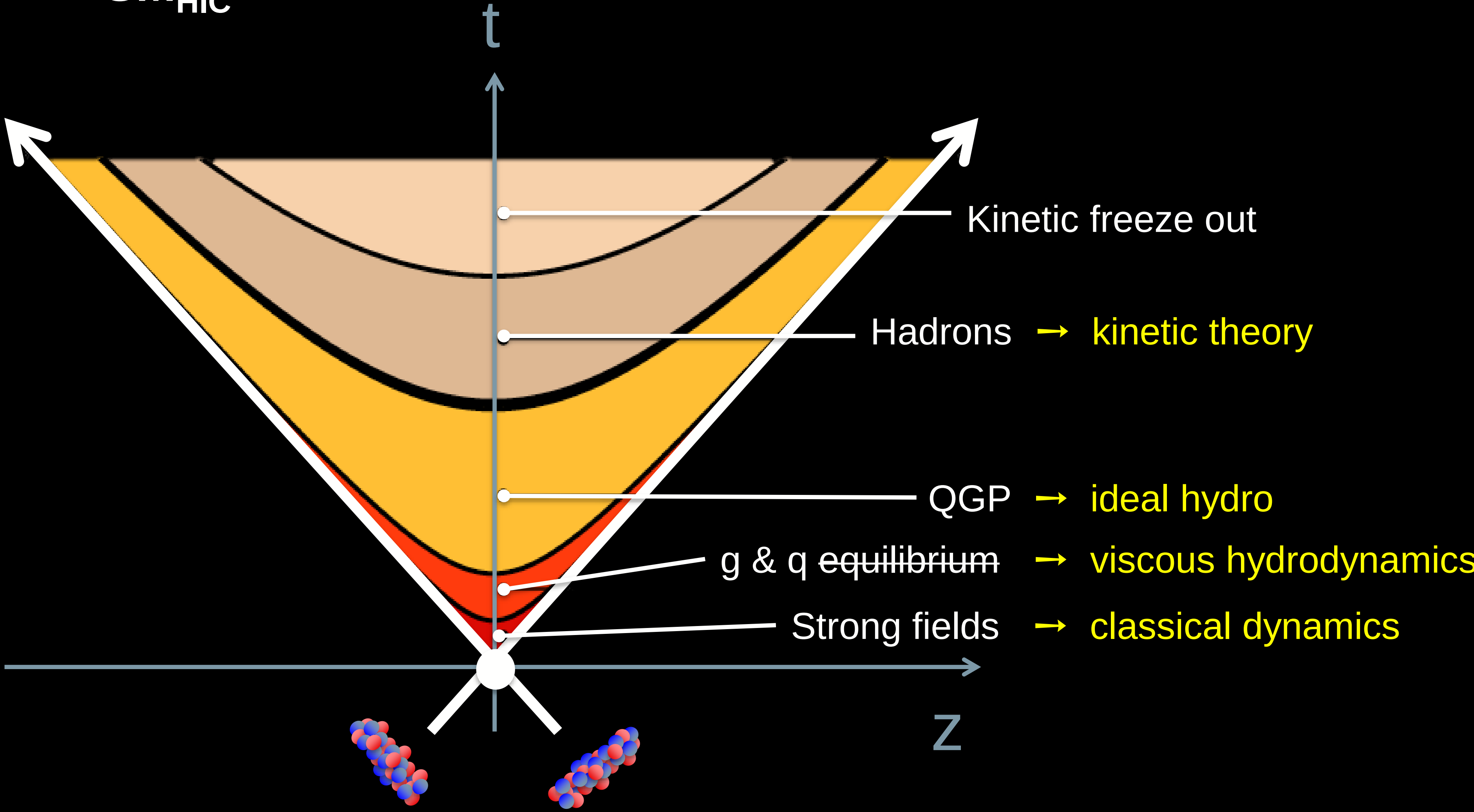
- EXTEND THE STANDARD MODEL OF PARTICLE PHYSICS (SM) TO DYNAMICAL COMPLEX SYSTEM OF FINITE SIZE
- UNDERSTAND HOW MACROSCOPIC PROPERTIES OF MATTER EMERGE FROM THE FUNDAMENTAL MICROSCOPIC LAWS OF PARTICLE PHYSICS
- **STUDY THE QGP, THE STATE OF MATTER BETWEEN THE ELECTROWEAK PHASE TRANSITION (T ~ 100 GEV) AND THE HADRON PHASE TRANSITION (T ~ 170 MEV)**

ALICE

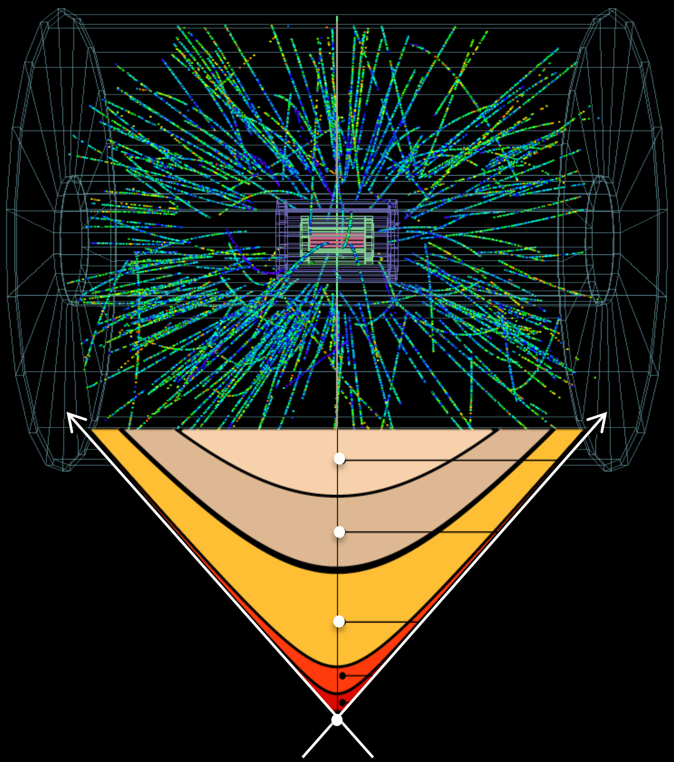
THE STANDARD MODEL OF HEAVY-ION COLLISIONS: SM_{HIC}

SM_{HIC}



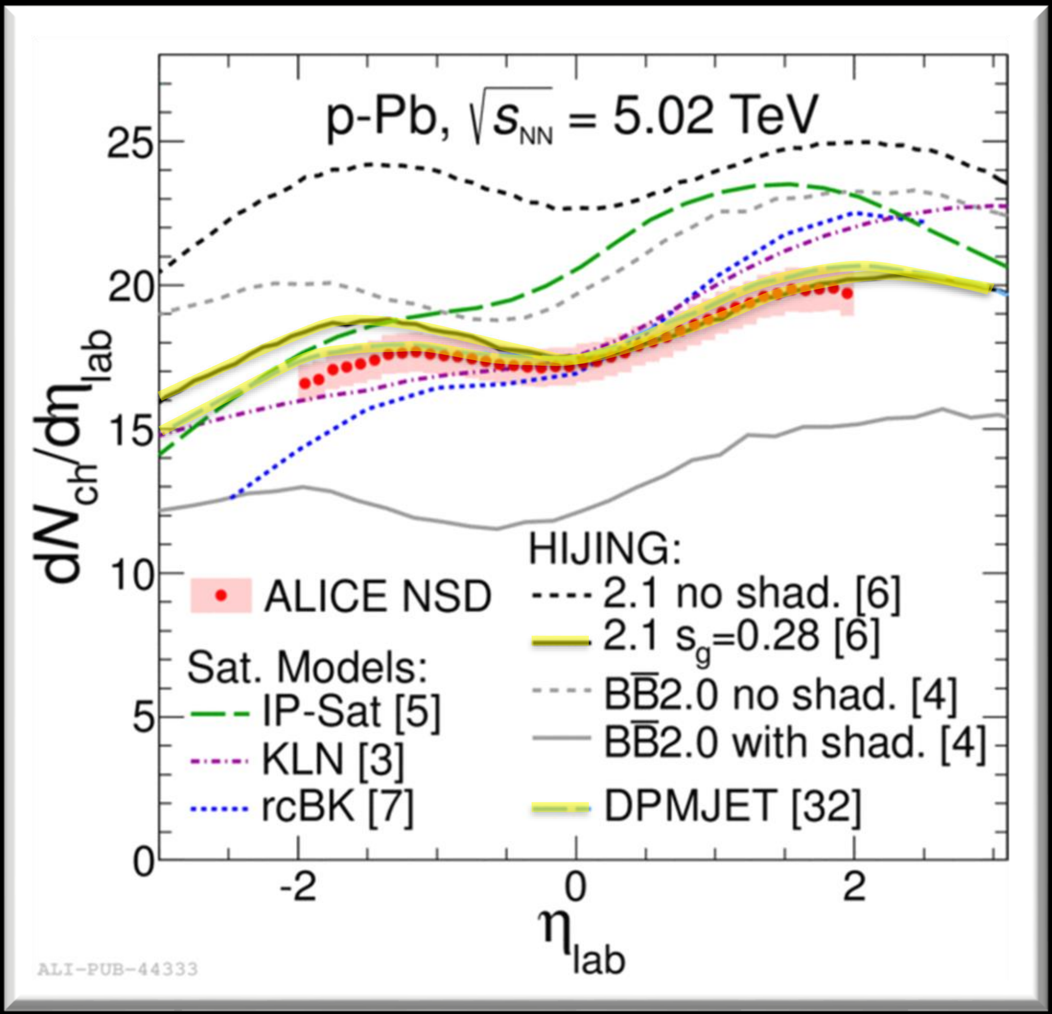
t
z
Kinetic freeze out
Hadrons → kinetic theory
QGP → ideal hydro
g & q ~~equilibrium~~ → viscous hydrodynamics
Strong fields → classical dynamics

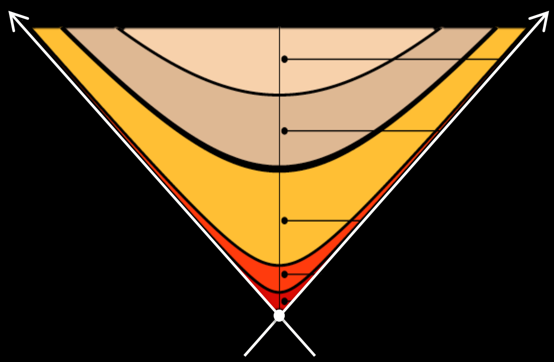
A Large Ion Collider Experiment



WHERE DO WE START FROM AND WHERE TO WE END AT ?

TEST THE INITIAL STATE

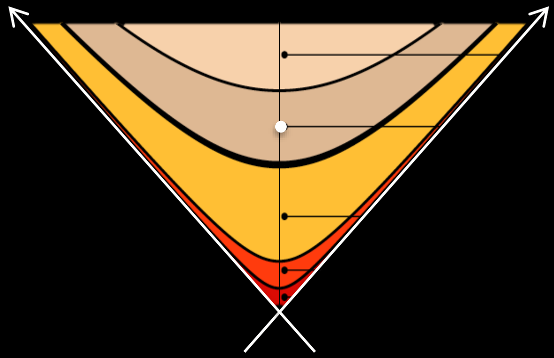


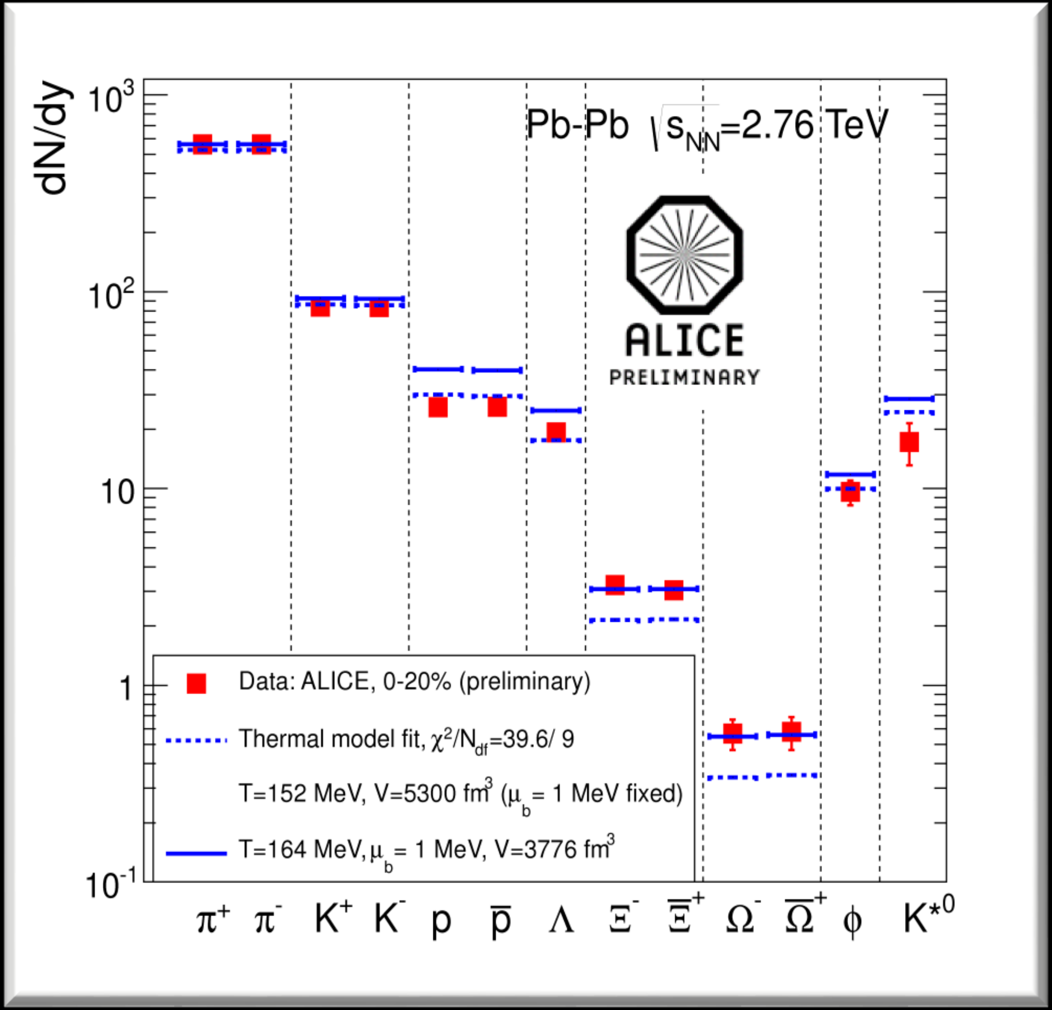


- pQCD processes + soft interactions + shadowing models
- Saturation models in difficulty ?

arXiv:1210.3615v1

TEMPERATURE: CHEMICAL FO

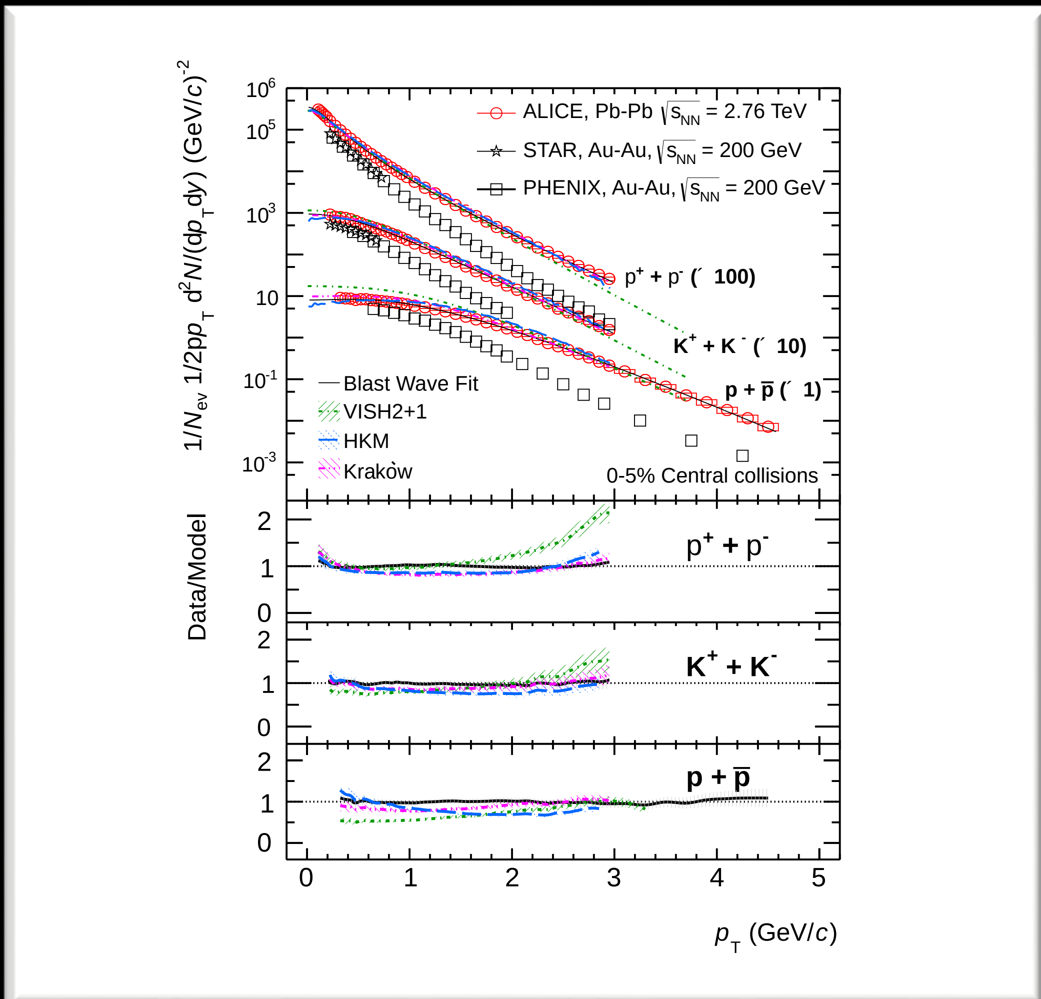


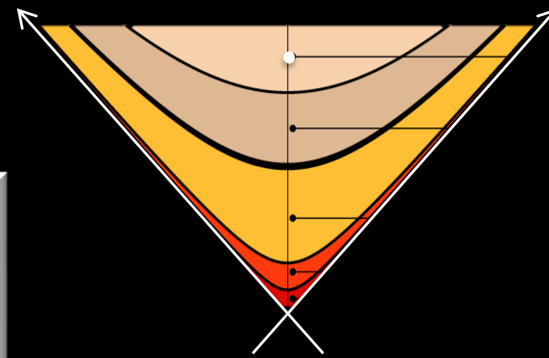


- Particle abundance described by statistical thermal model:
  T = 152 MeV !!, μ_B = 1 MeV
- Extrapolation from lower energies ?
- Do final state interactions in hadronic phase modify the chemical composition ?

arXiv:1208.1974v1

TEMPERATURE: KINETIC FO

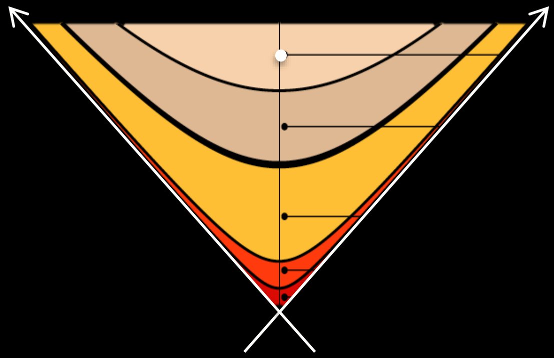


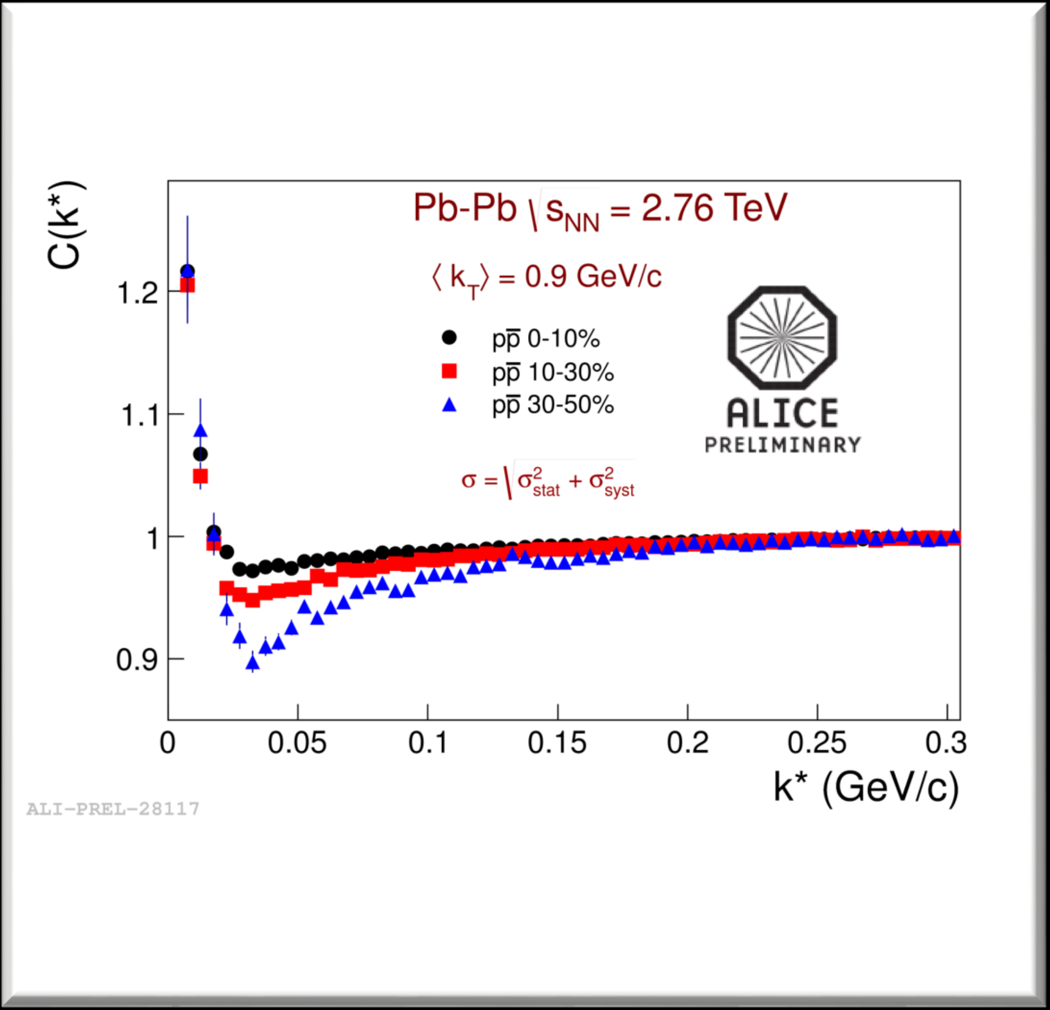


- Collective transverse expansion + hadronic FSI: $\langle \beta_T \rangle = 0.65$, $T_{kin} = 95$ MeV
- Final state interactions in the hadronic phase may modify the chemical composition
- $B\overline{B}$ annihilation ?

arXiv:1208.1974v1

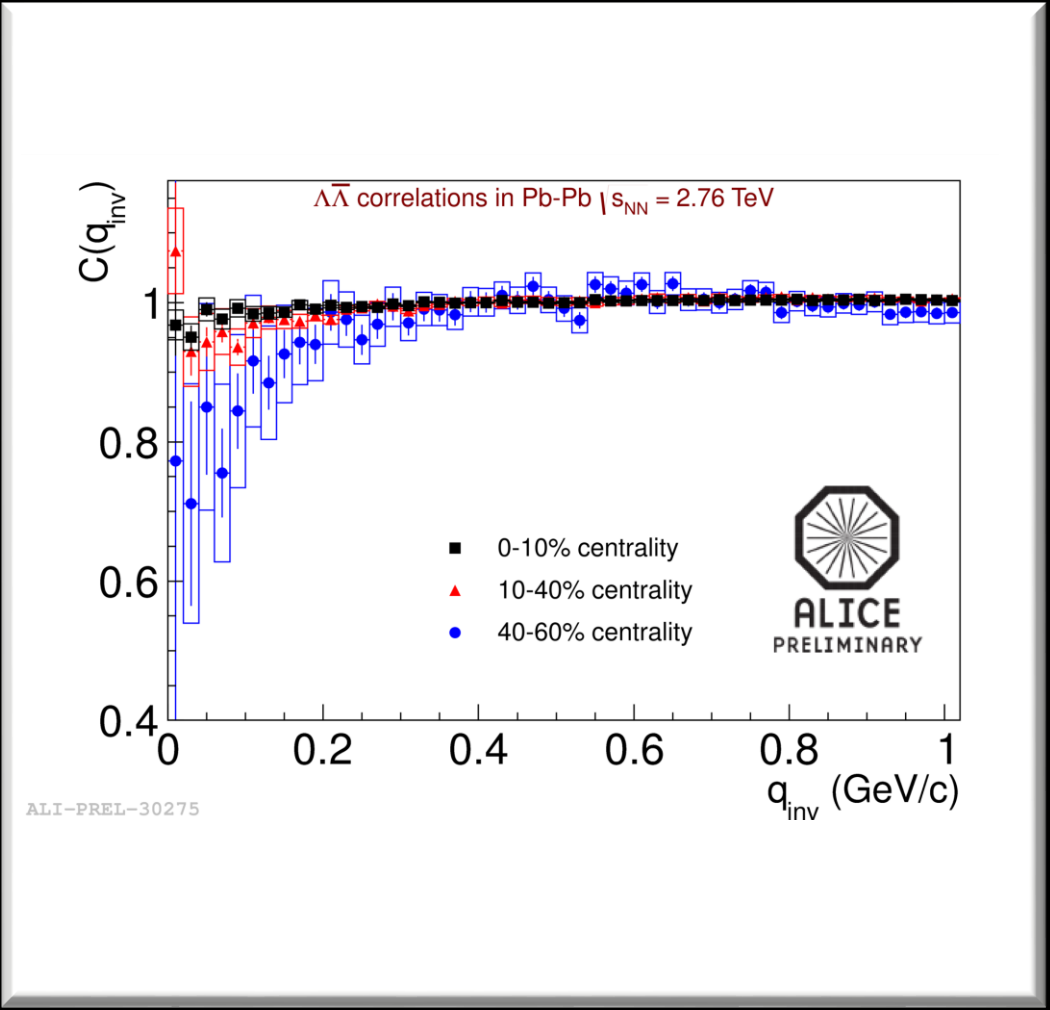
FSI: PROTON–ANTI-PROTON

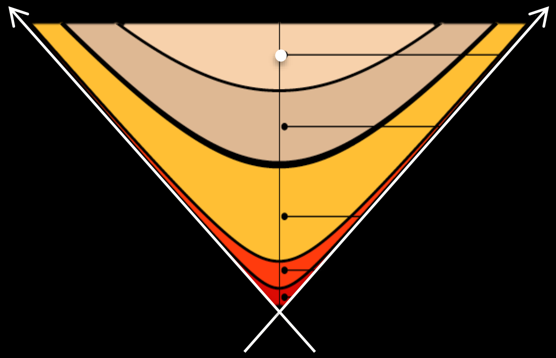




- $B\bar{B}$ femtoscopy
- Large densities may suppress p and Λ by annihilation

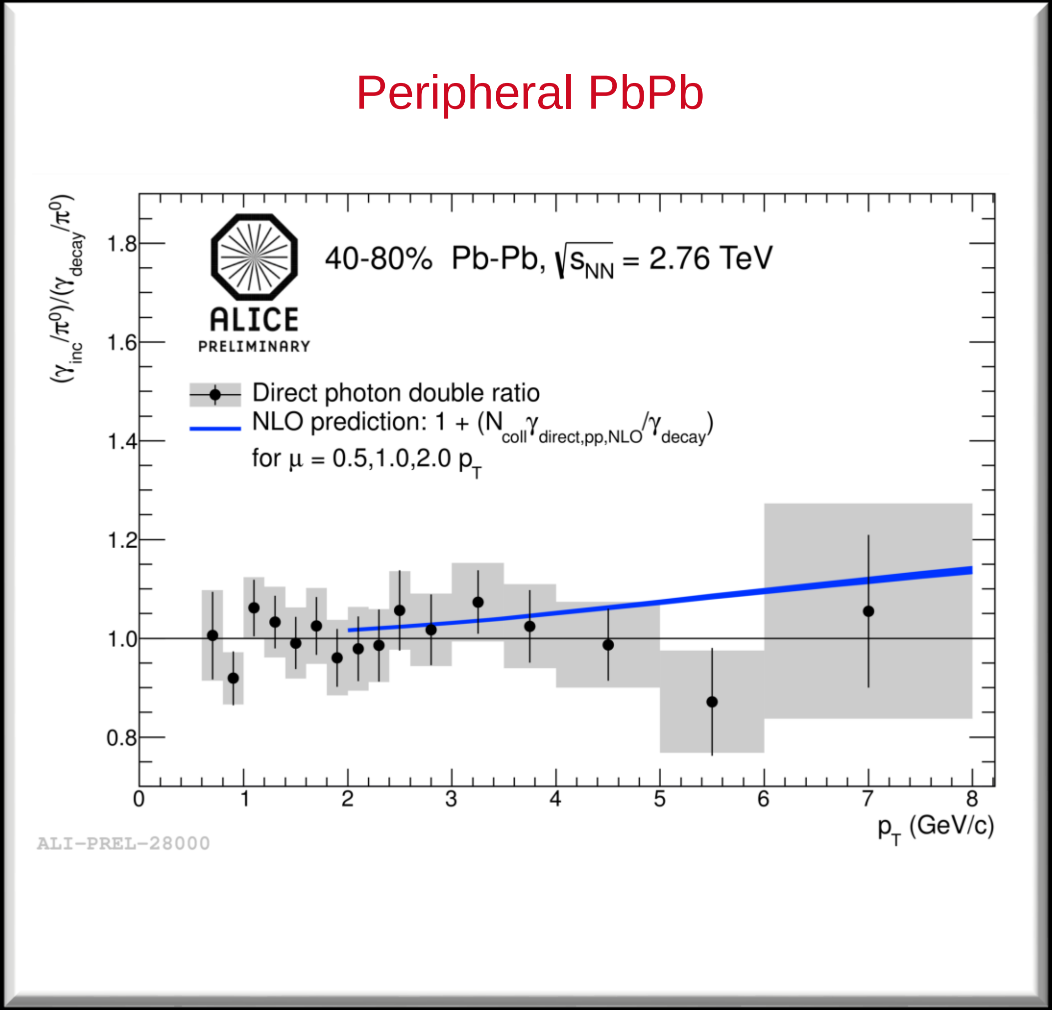
FSI: Λ–ANTI-Λ

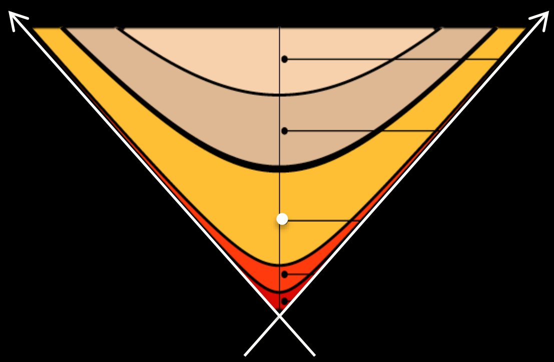




- $\bar{B}B$ femtoscopy
- Large densities may suppress p and Λ by annihilation

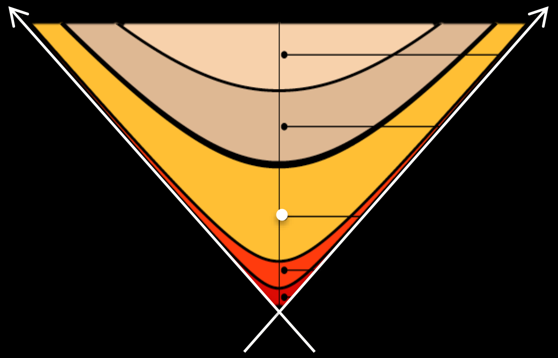
DIRECT PHOTONS



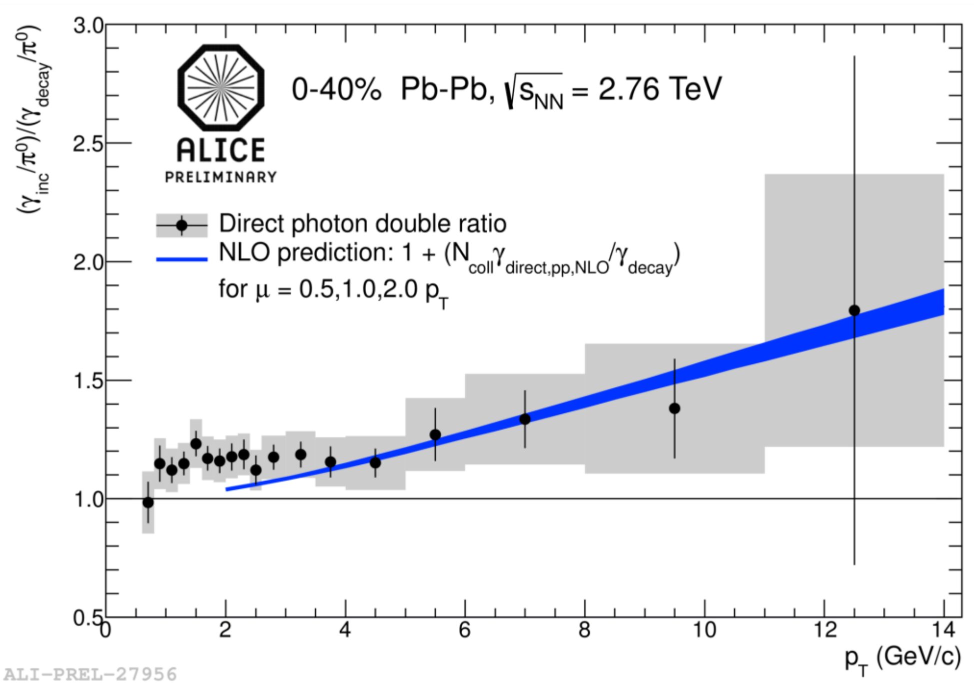


- pQCD direct photons

DIRECT PHOTONS

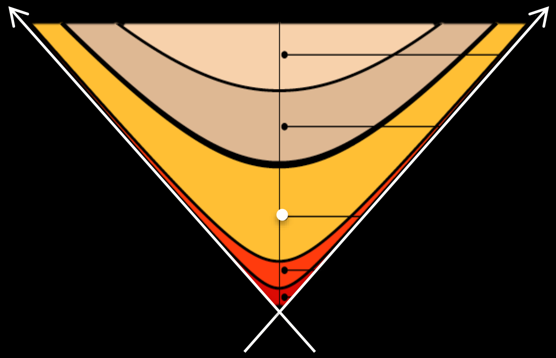


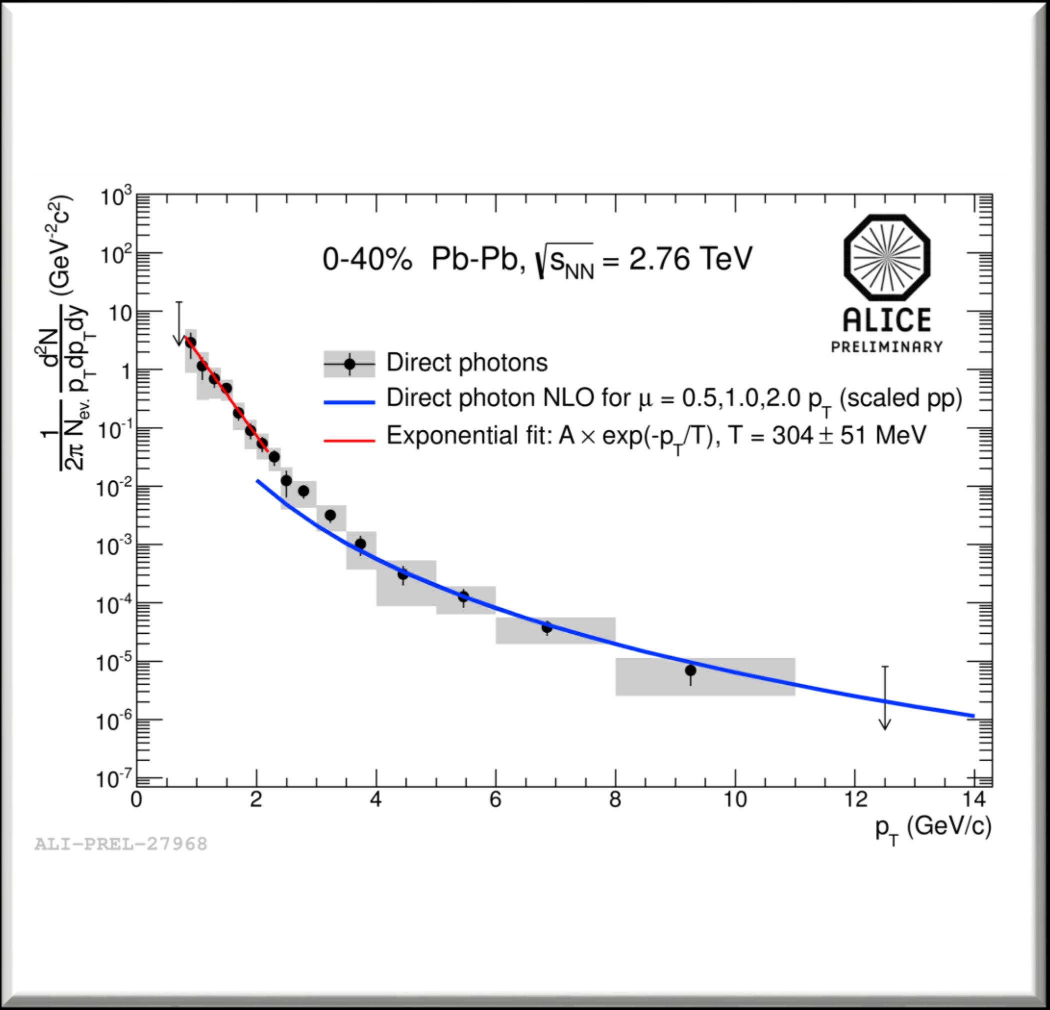
Central PbPb



- pQCD direct photons
- Thermal direct photons

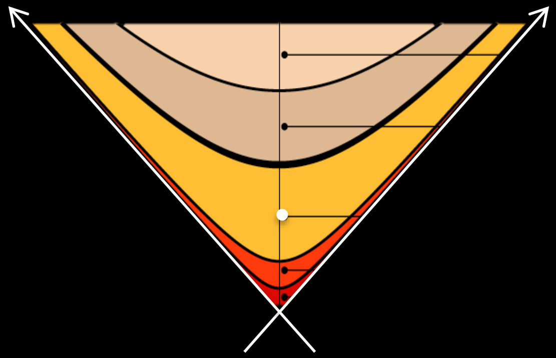
INITIAL TEMPERATURE





- T > 300 MeV
- Remember
  - ε > 15 GeV/fm^3
  - V > 5000 fm^3
  - τ ~ 10 fm/c
  - μ_B = 1 MeV

QGP

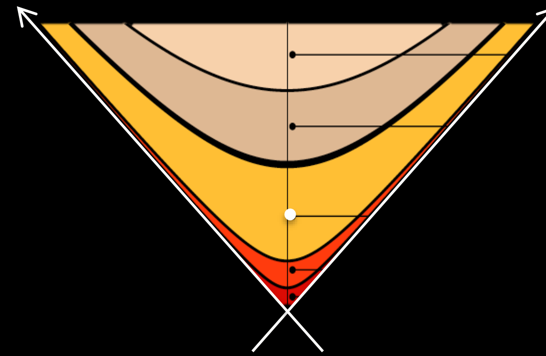


Learning about the properties of hot QCD matter

EVERYTHING FLOWS (dynamics)

EVERYTHING IS QUENCHED (transport)

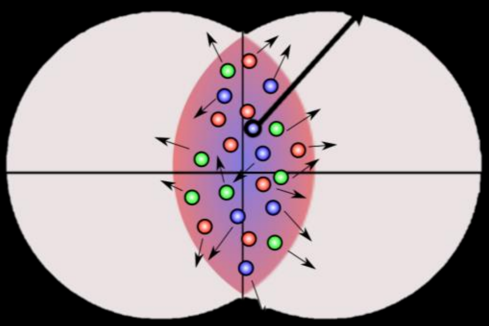
QGP



Learning about the properties of hot QCD matter

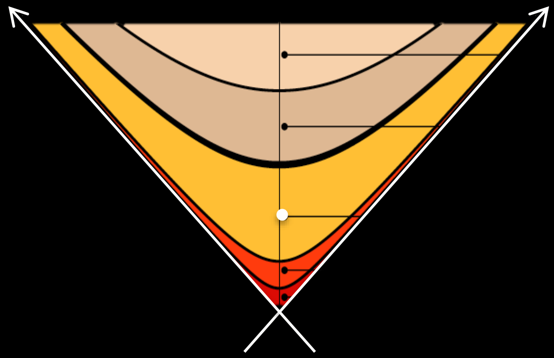
EVERYTHING FLOWS

EVERYTHING IS QUENCHED

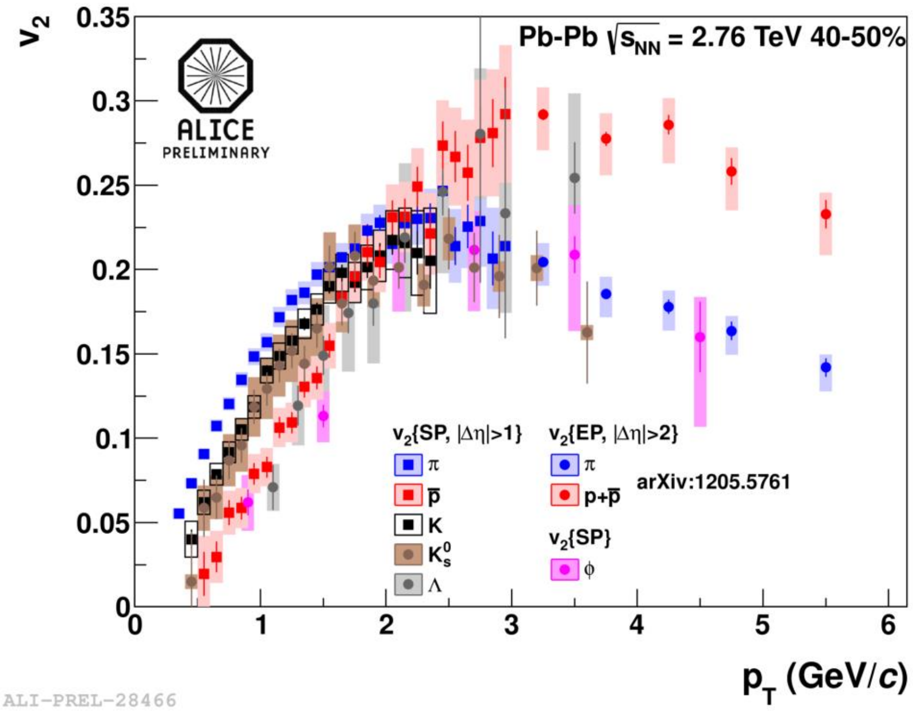


$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}\left(1 + 2v_1\cos(\varphi - \Psi_1) + 2v_2\cos\left[2(\varphi - \Psi_2)\right] + \ldots\right)$$

LIGHT FLAVOURS FLOW

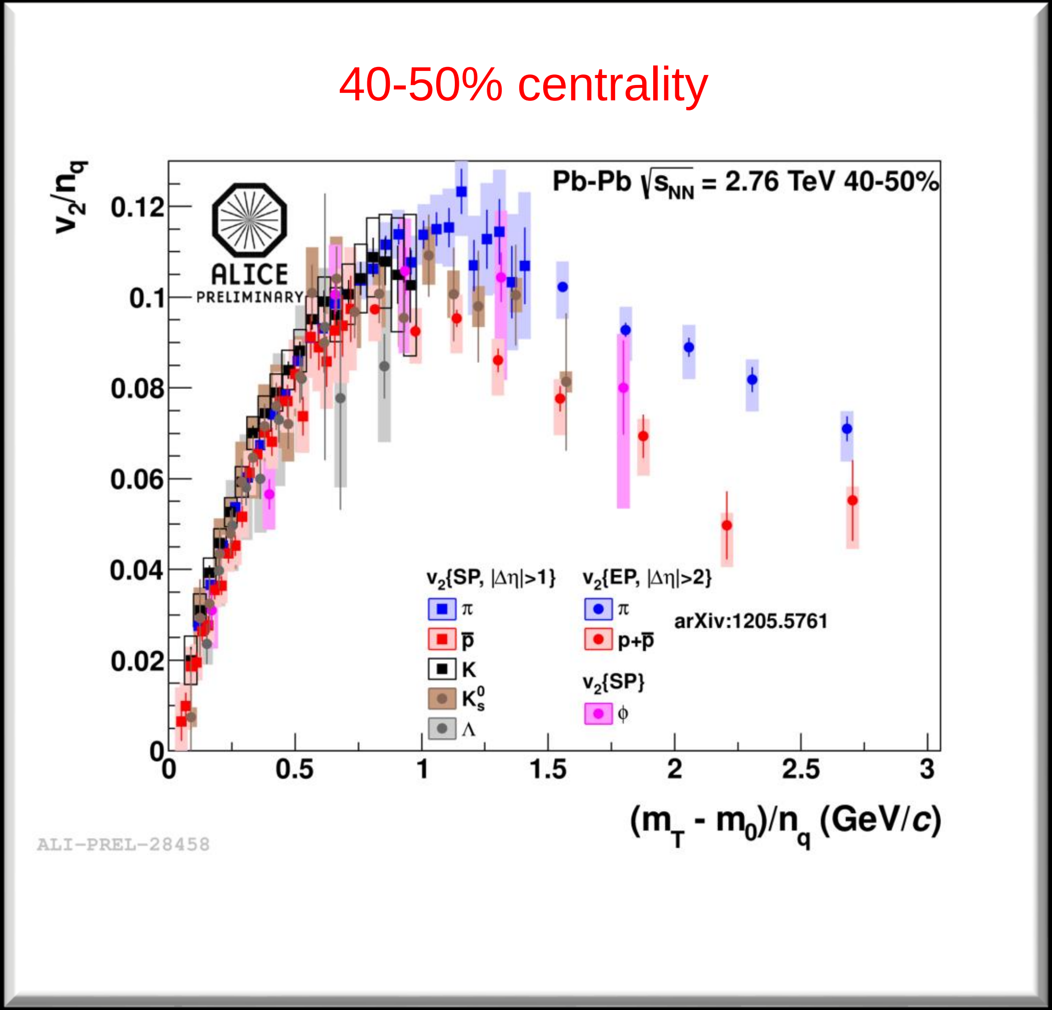


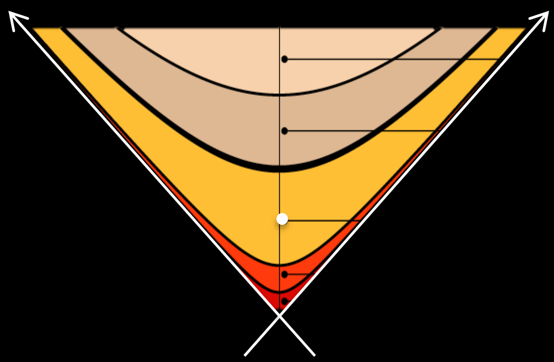
40-50% centrality



- Mass ordering
  p_T < 2.5 GeV/c
- Baryon/meson ordering
  p_T > 2.5 GeV/c

QUARK SCALING



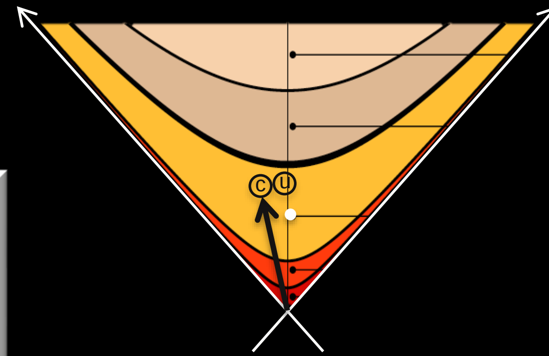


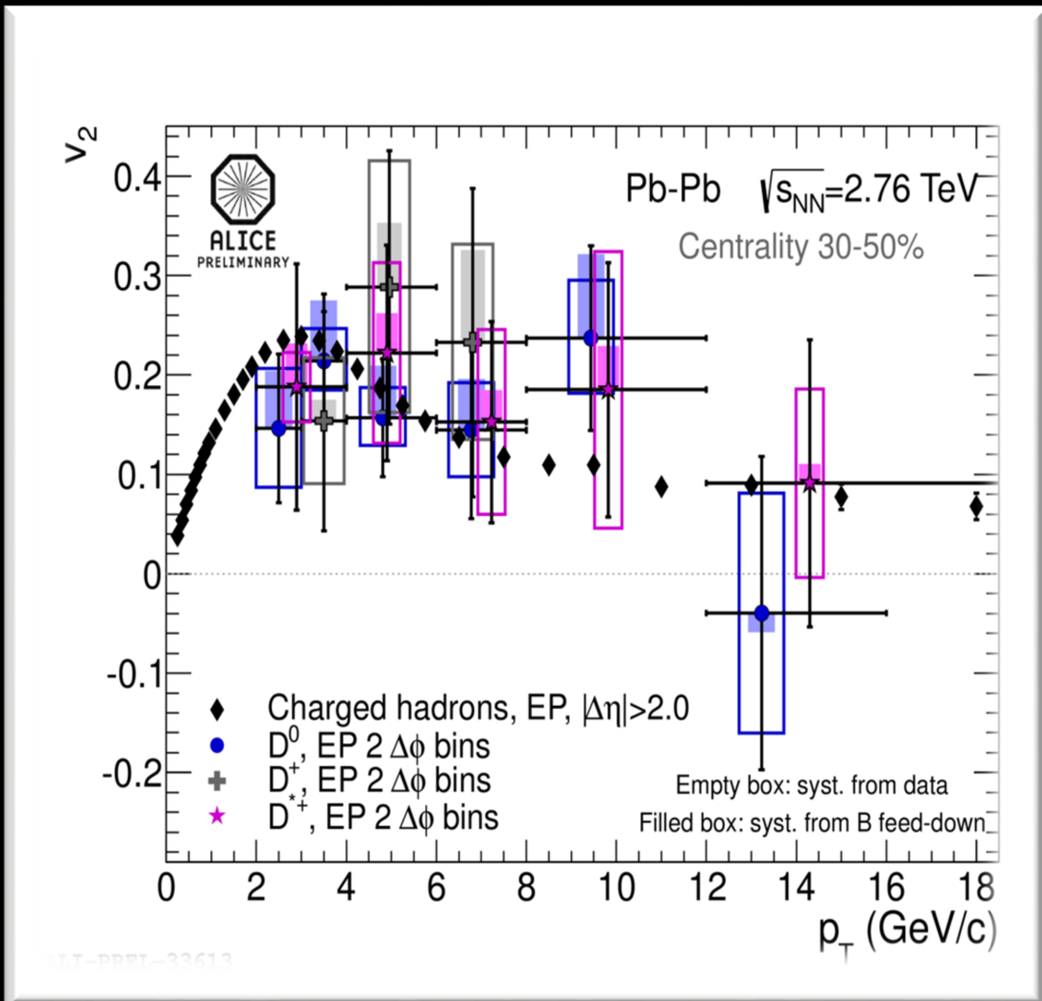
- Hydro flow at partonic level
  $p_T < 2.5$ GeV/c
- Quark coalescence
  $p_T > 2.5$ GeV/c

More

Minwoo Kim (id flow)
Zhong Bao Yin (s & ms)

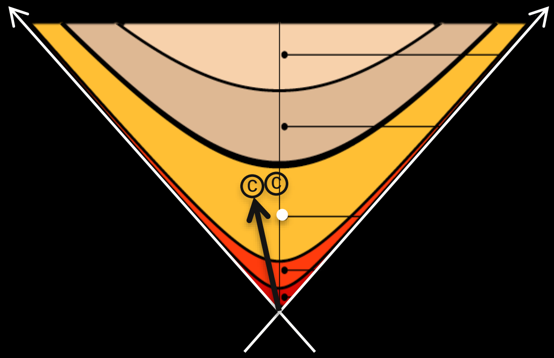
CHARM FLOW

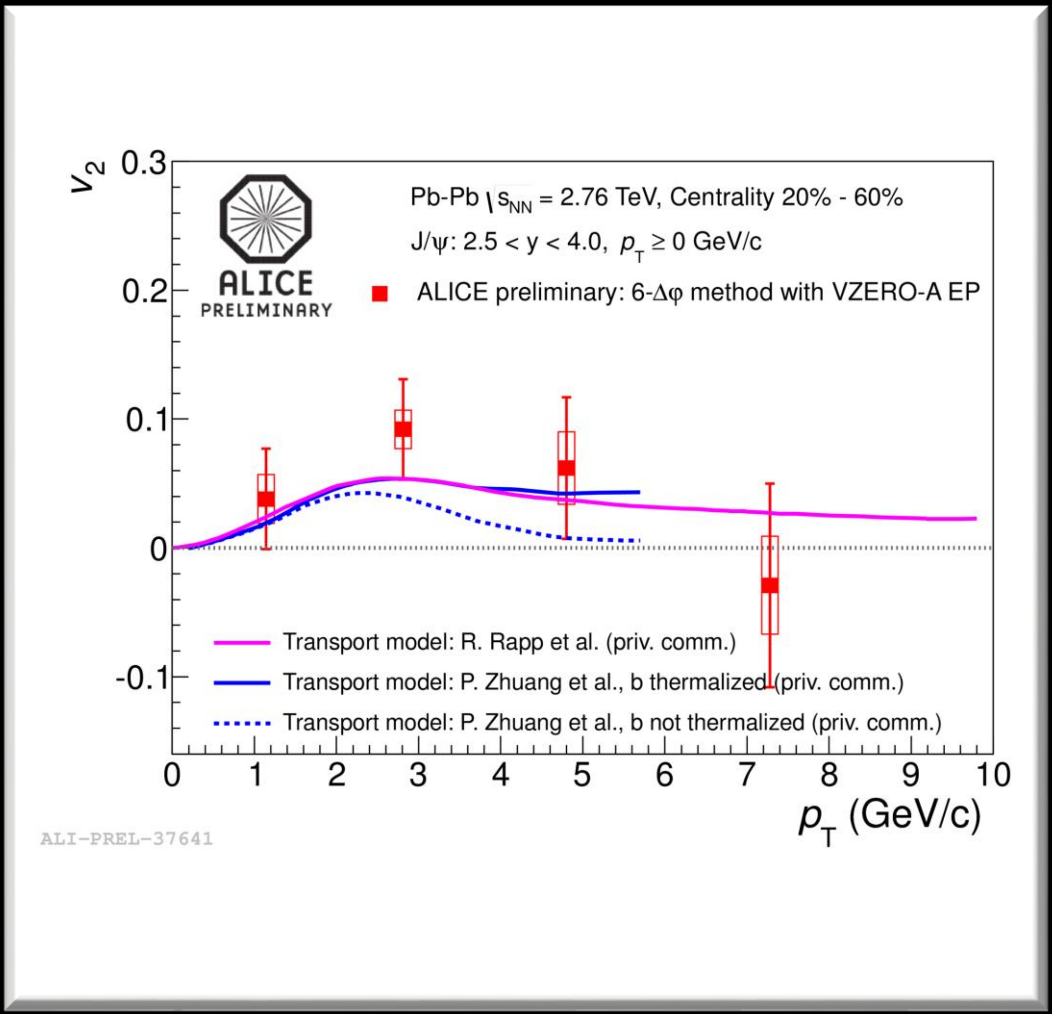




- c quarks produced in early stage of collision
- thermalize in the medium and hadronize via recombination ?

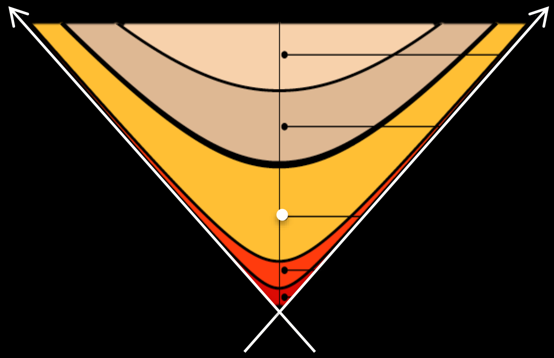
HIDDEN CHARM (J/Ψ) FLOW

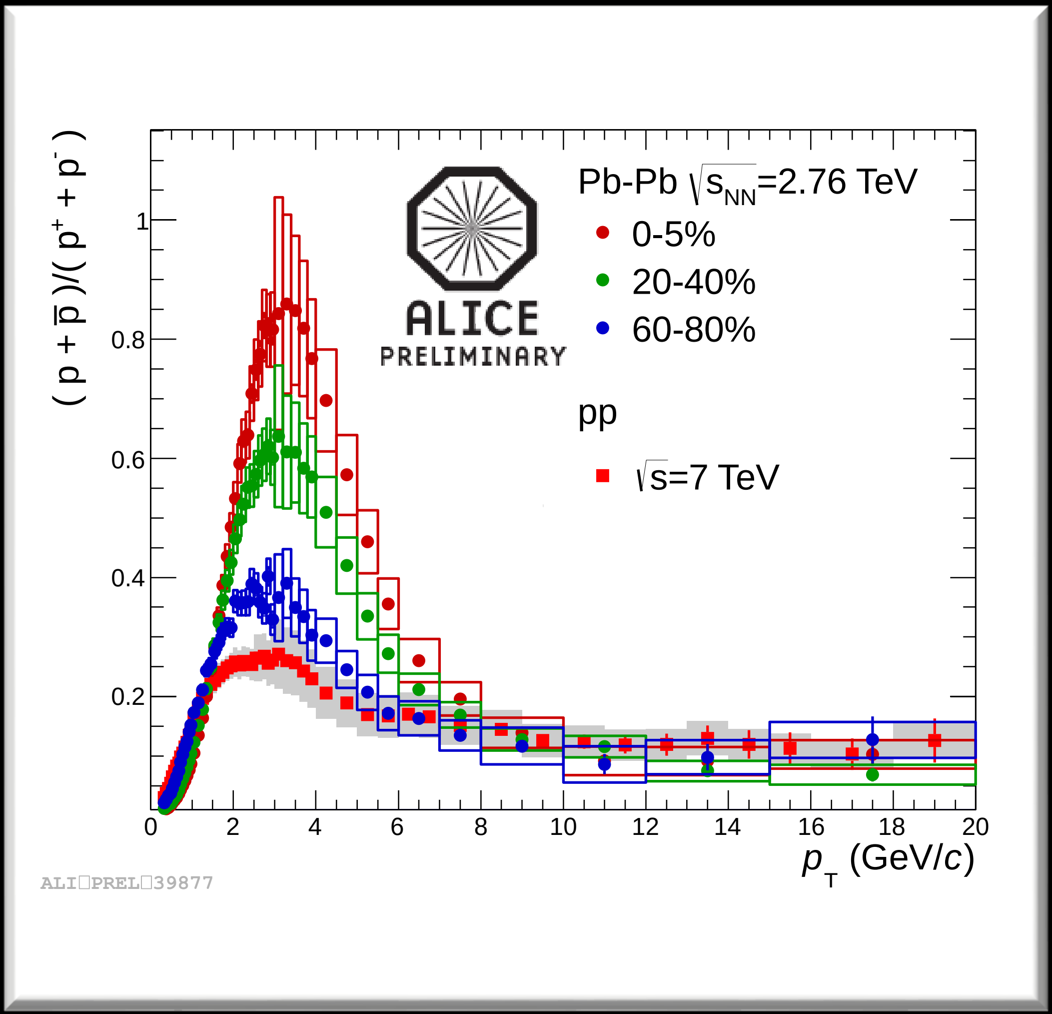




- Hint for finite flow, an additional indication for charm recombination

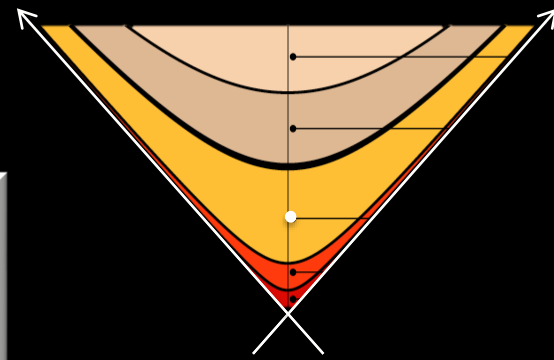
HADRONIZATION

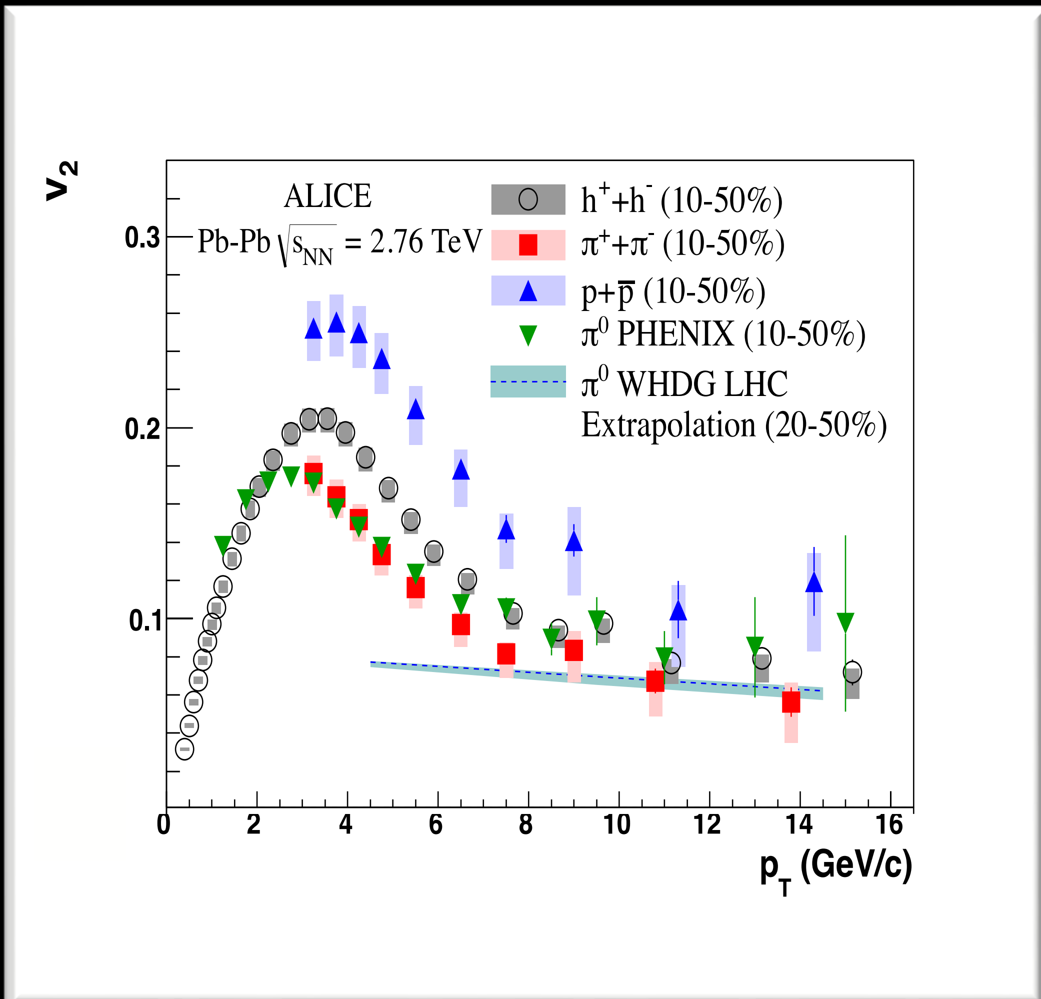




- hydrodynamic flow
  p_T < 2.5 GeV/c
- recombination
  2.5 < p_T < 10 GeV/c
- parton fragmentation
  p_T >10 GeV/c

HIGH p_T ANISOTROPY

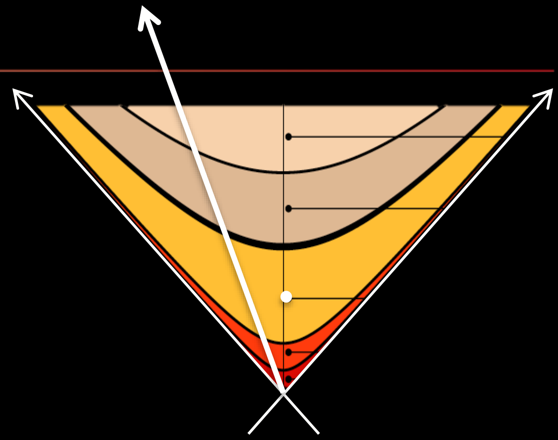




- Anisotropy from jet quenching
  p_T > 10 GeV/c

arXiv:1205.5761v1

QGP

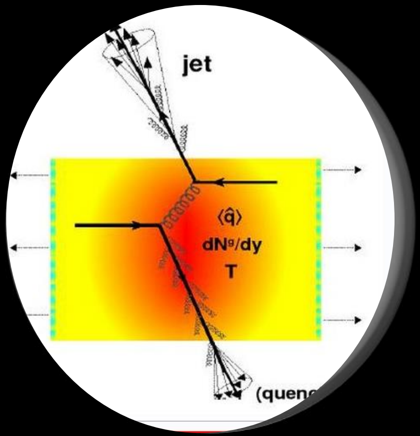


Learning about the properties of hot QCD matter

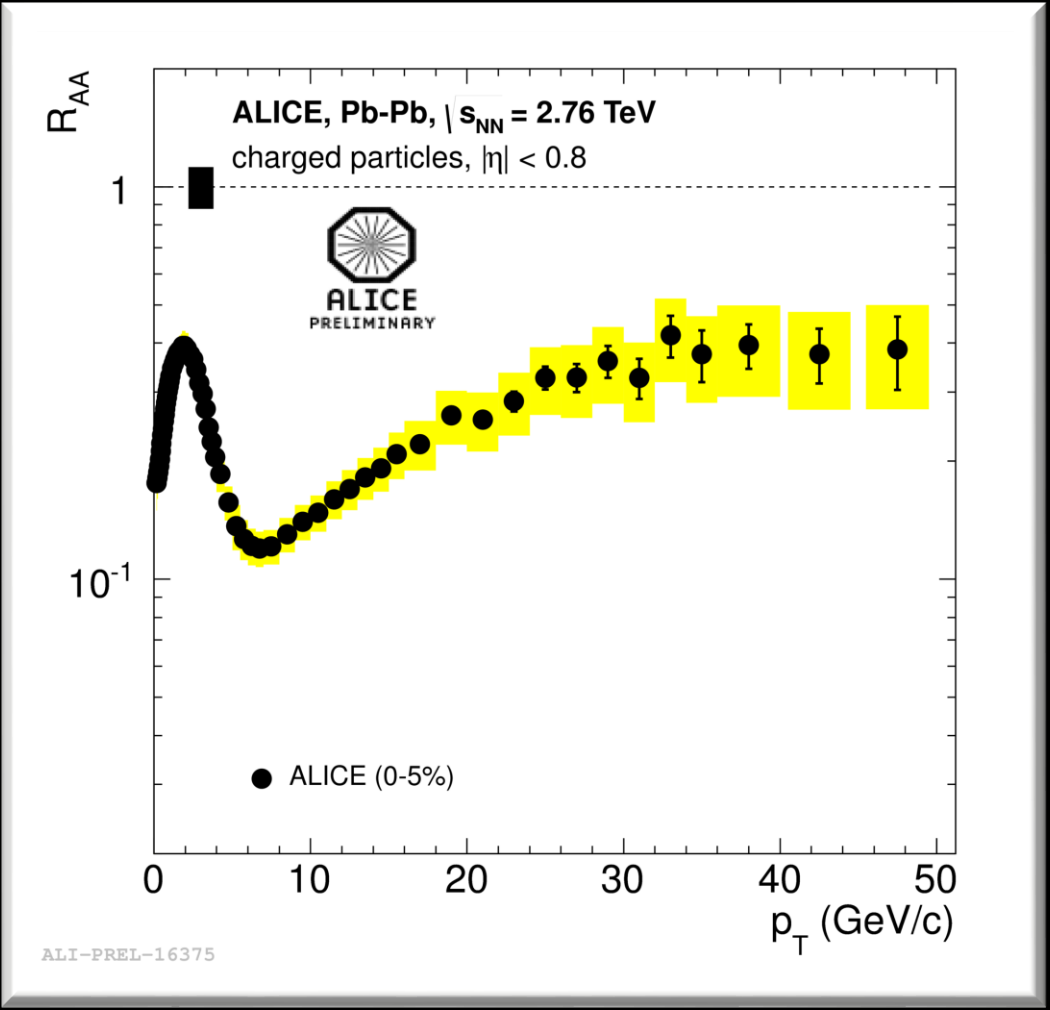
EVERYTHING FLOWS

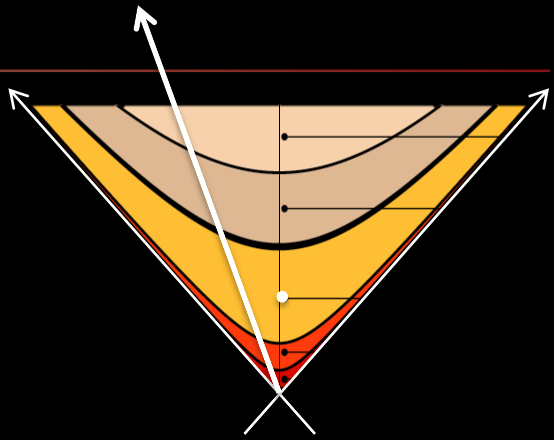
EVERYTHING IS QUENCHED

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \left(\frac{\dfrac{dN_{AA}}{dp_{\mathrm{T}}}}{\dfrac{d\sigma_{pp}}{dp_{\mathrm{T}}}} \right)$$



CHARGED HADRONS

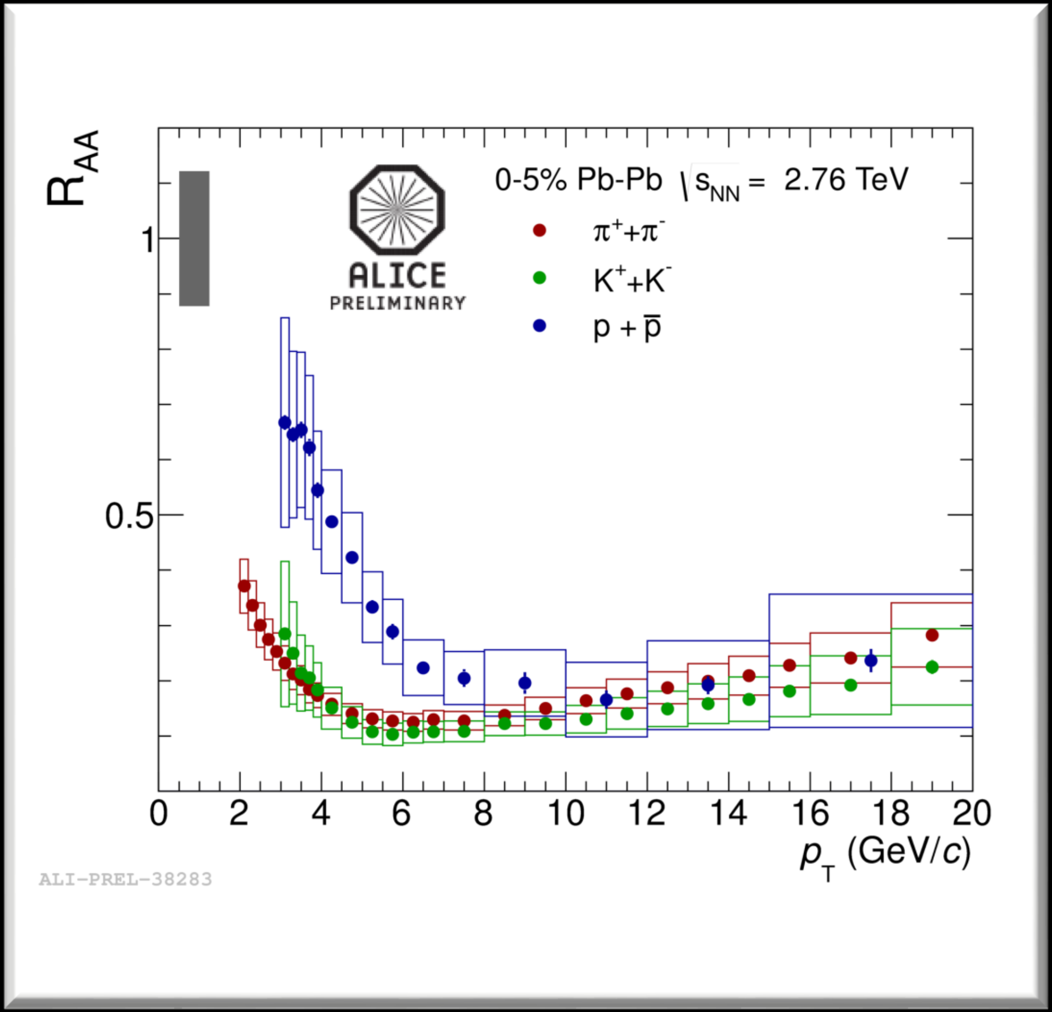


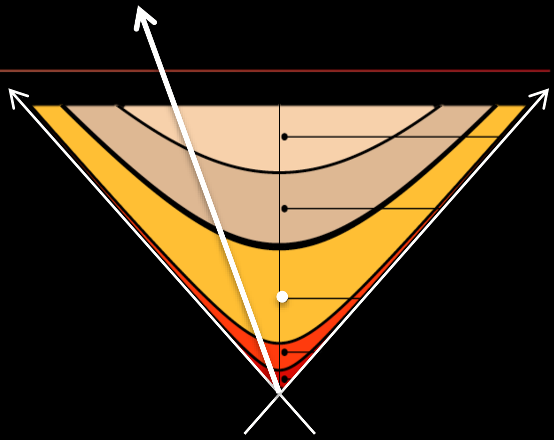


- Energy loss in medium

Phys. Lett. B 696 (2011) 30-39,

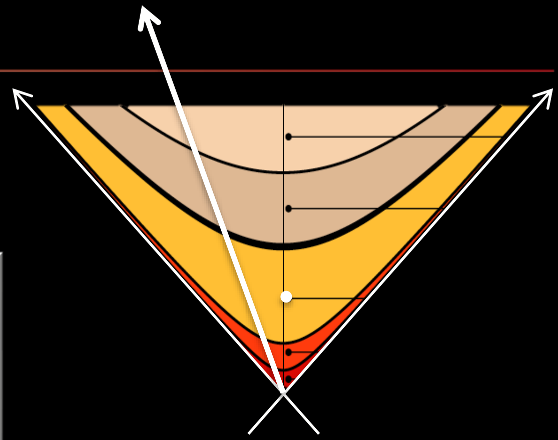
IDENTIFIED HADRONS

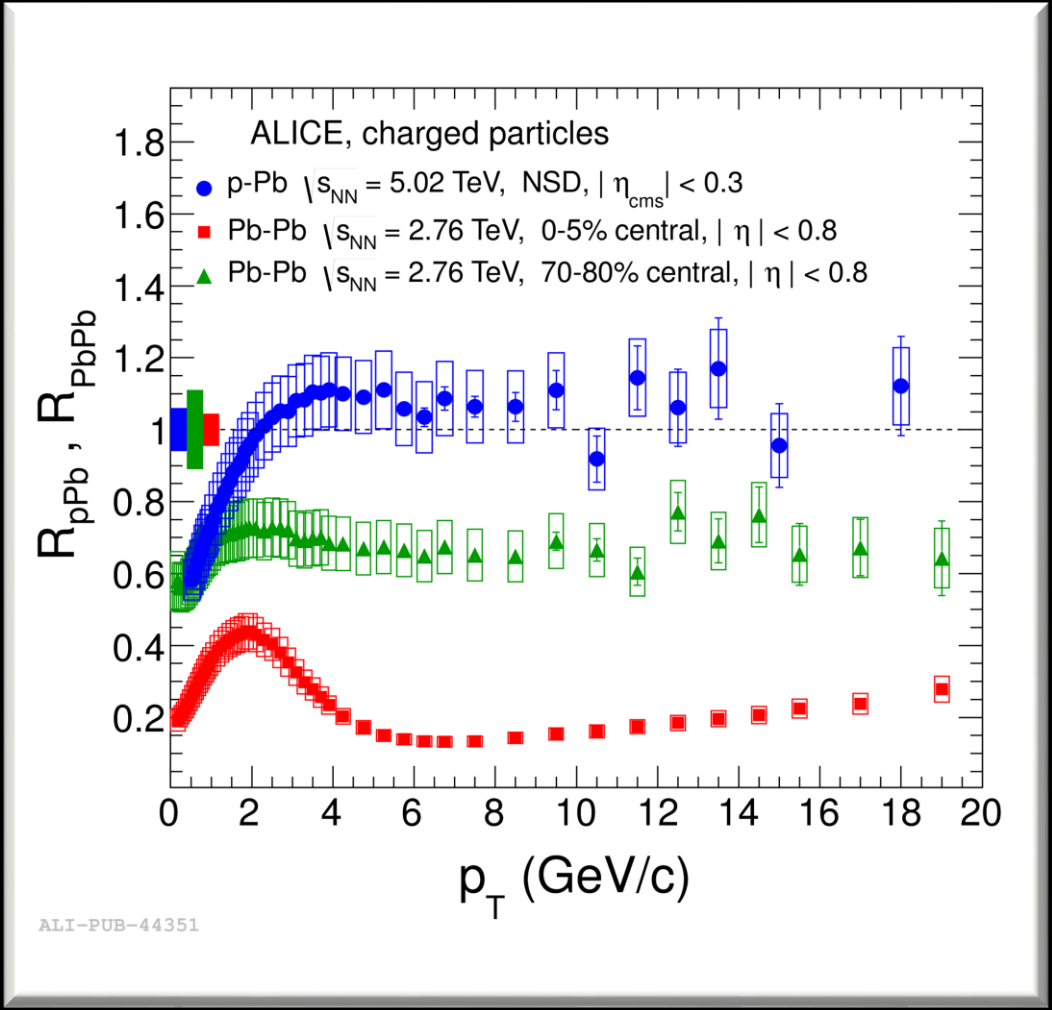




- Identical quenching magnitude for baryons and mesons at high p_T
- Baryon to meson anomaly at low p_T

pA

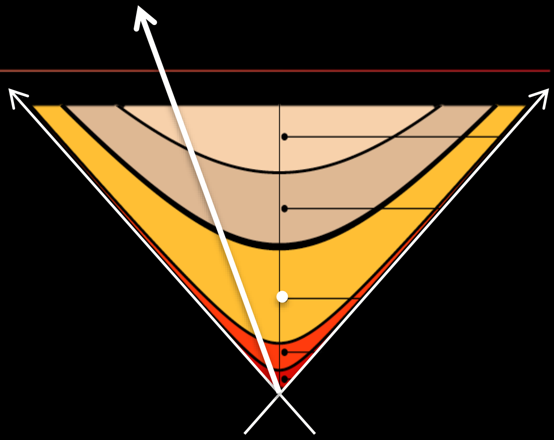


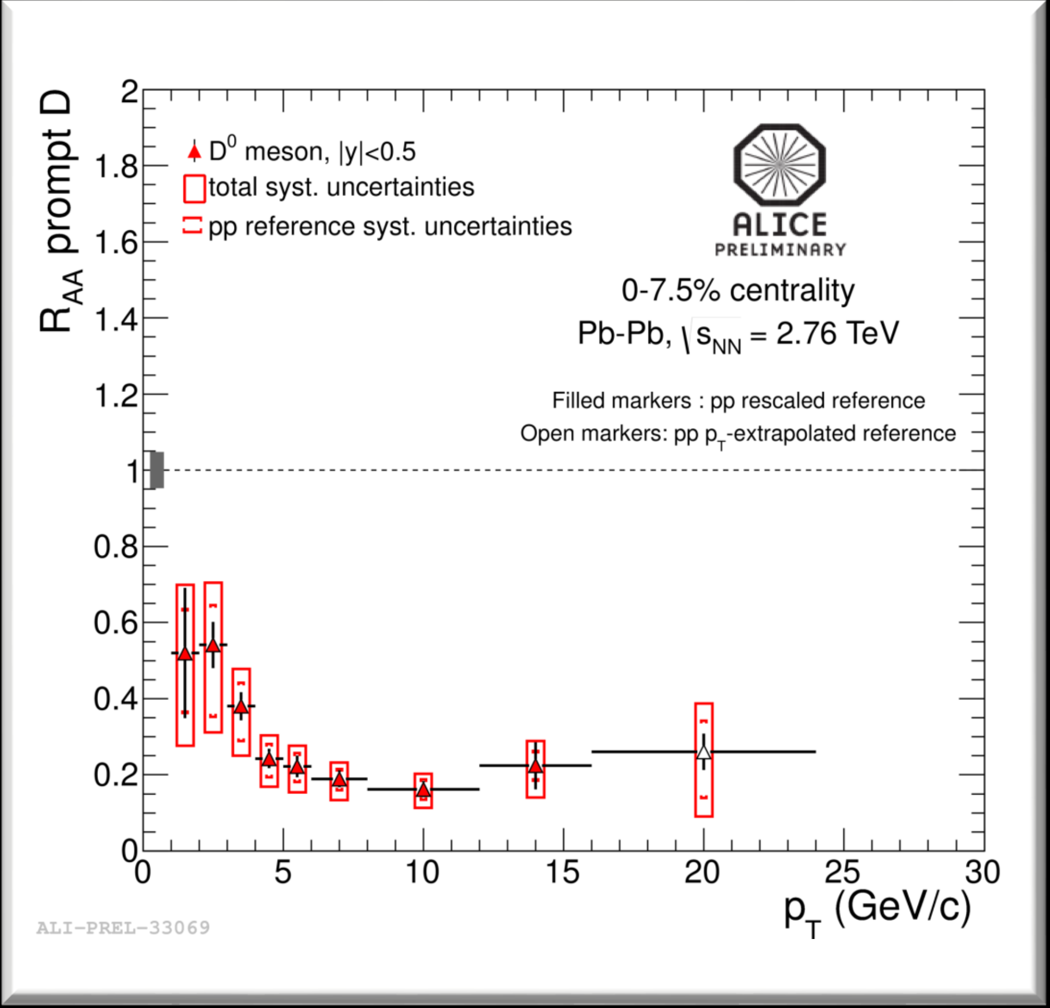


- The quenching effect is definitively a final state effect due to QGP !

http://arxiv.org/abs/1210.4520v1

CHARMED MESONS

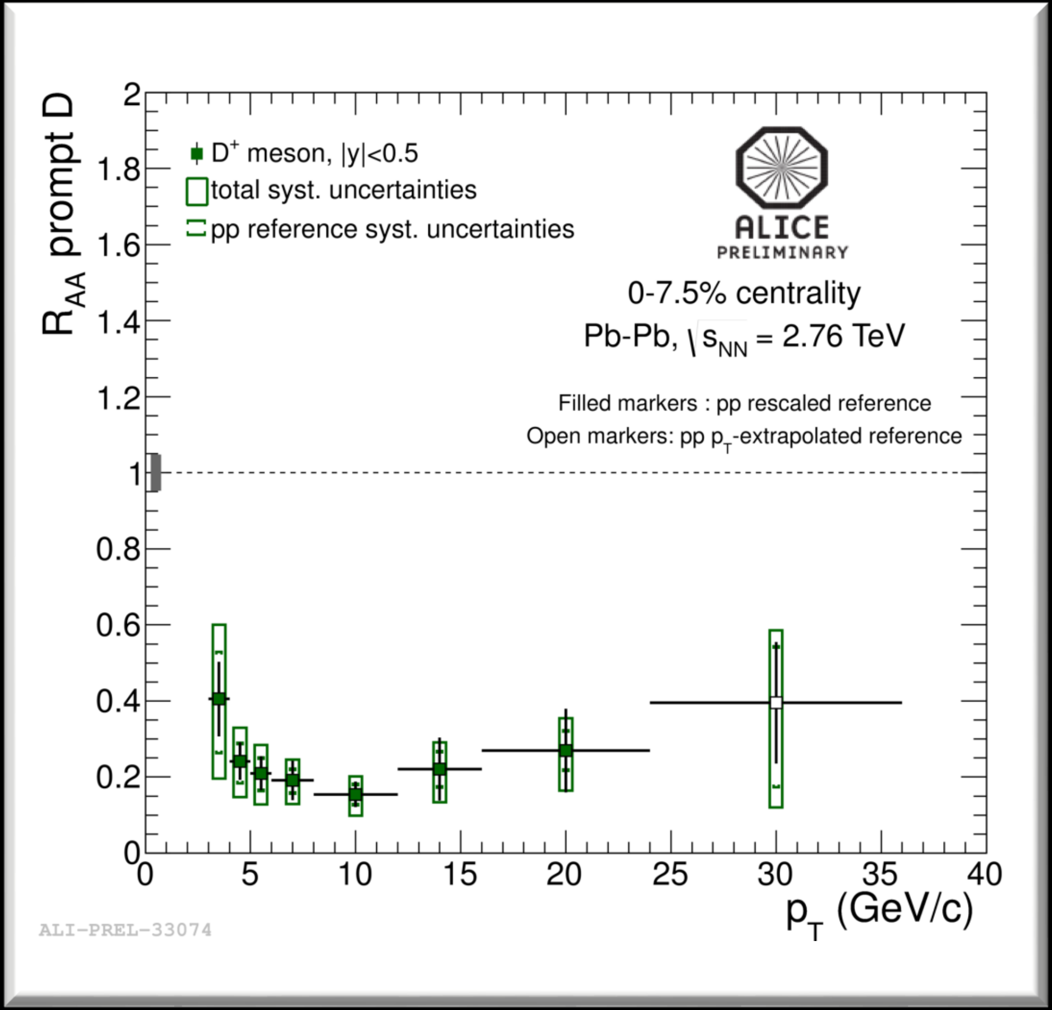


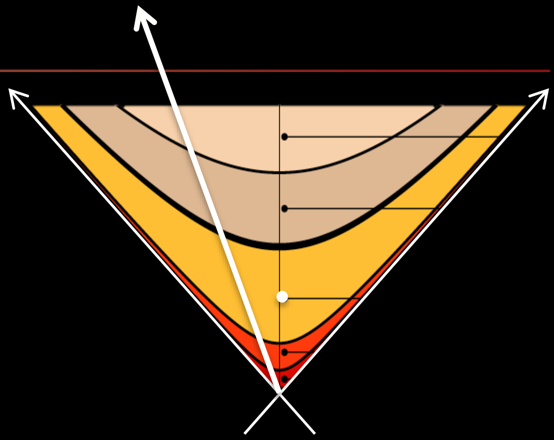


- D^0

arXiv:1203.2160

CHARMED MESONS

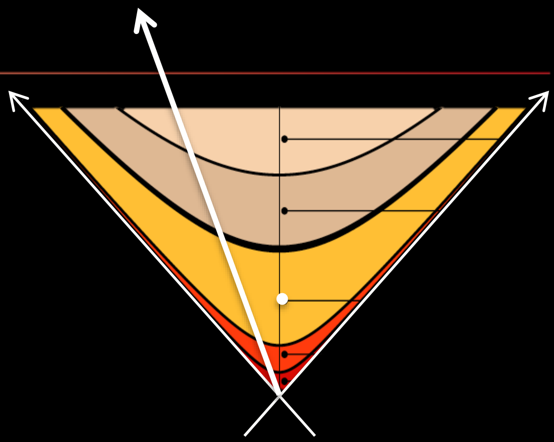




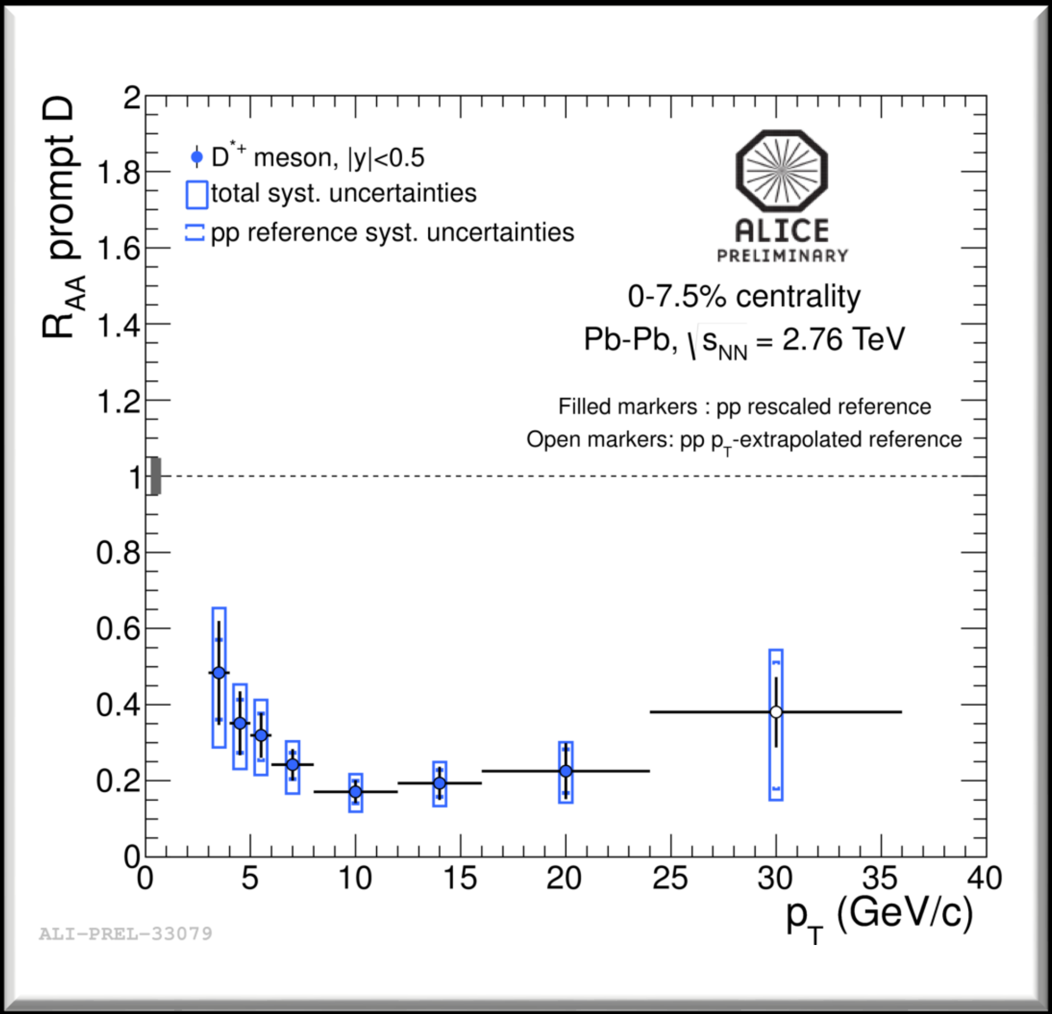
- D^0
- D^+

arXiv:1203.2160

CHARMED MESONS



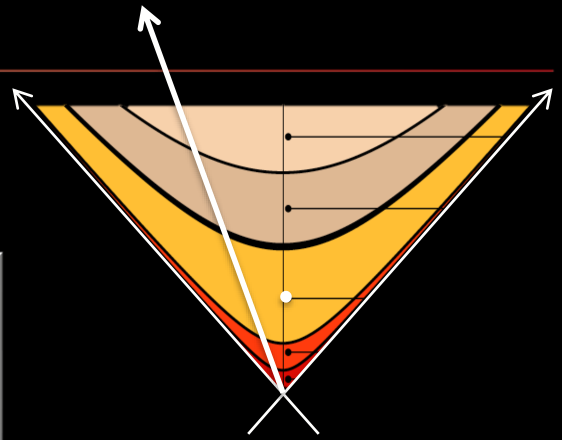
ALICE

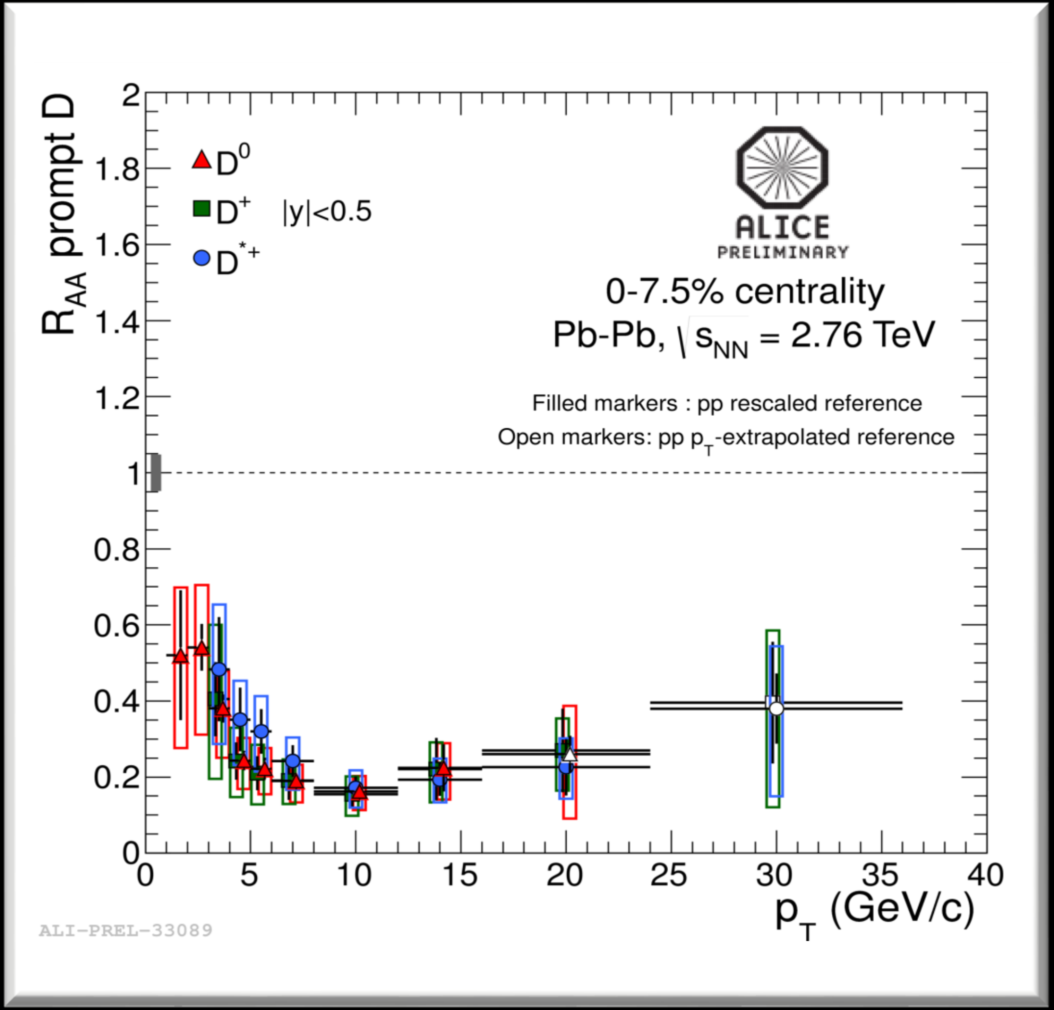


- D^0
- D^+
- D^{*+}

arXiv:1203.2160

CHARMED MESONS

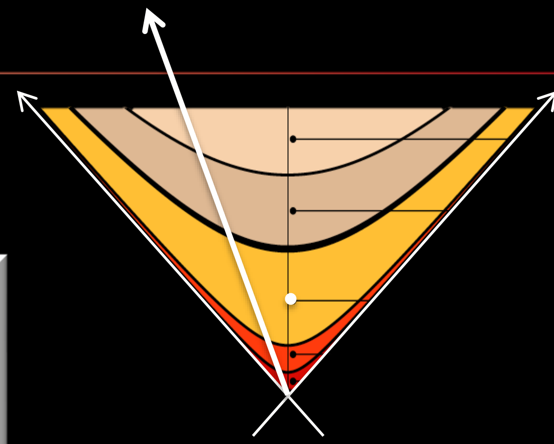




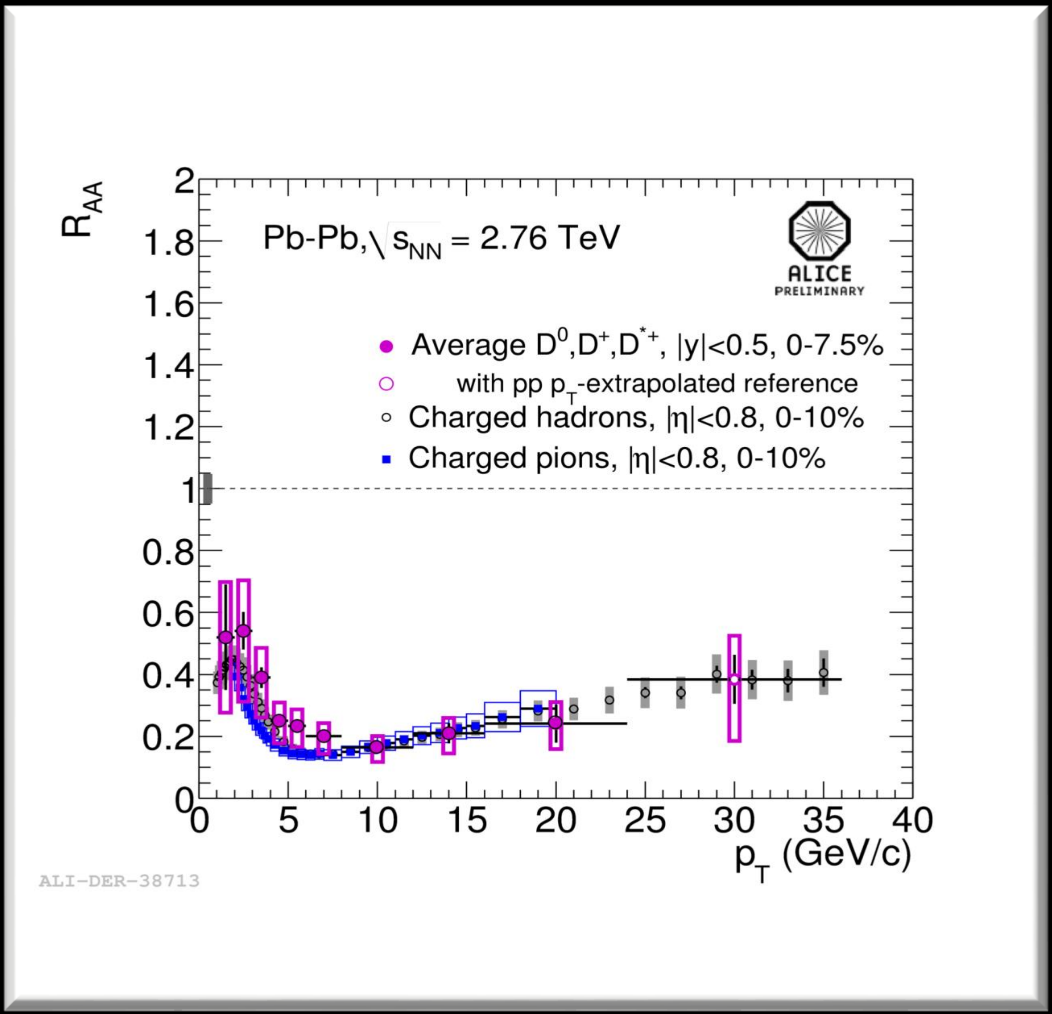
- D^0
- D^+
- D^{*+}

arXiv:1203.2160

g, q, Q TRANSPORT



ALICE



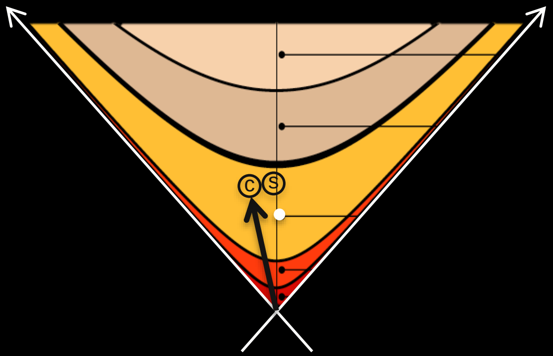
- Heavy quarks suppressed as light quark and gluons !
- Color charge and mass dependence of parton transport ?

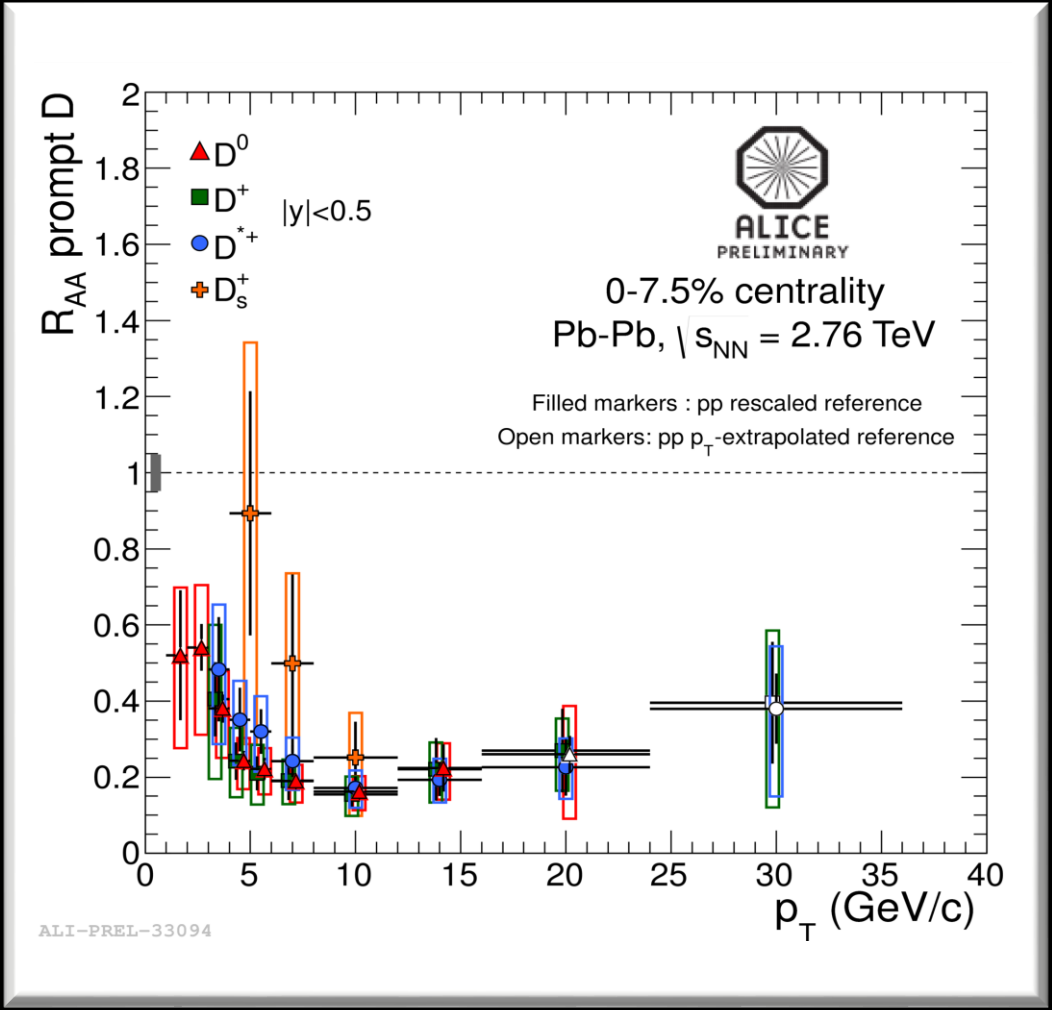
More

Renu Bala (HF)
Jianhui Zhu (single μ)
Shingo Sakai (HF e)
Tomoya Tsuji (π^0)

arXiv:1203.2160

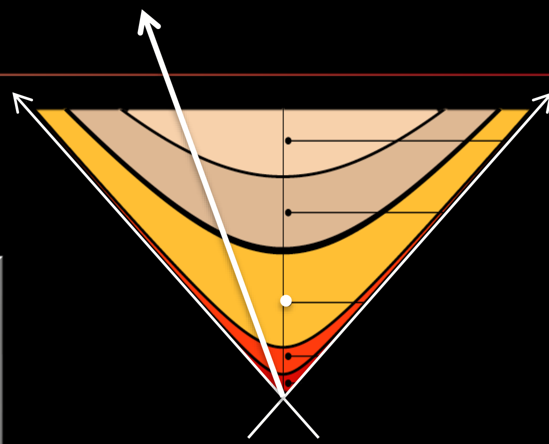
c, s RECOMBINATION

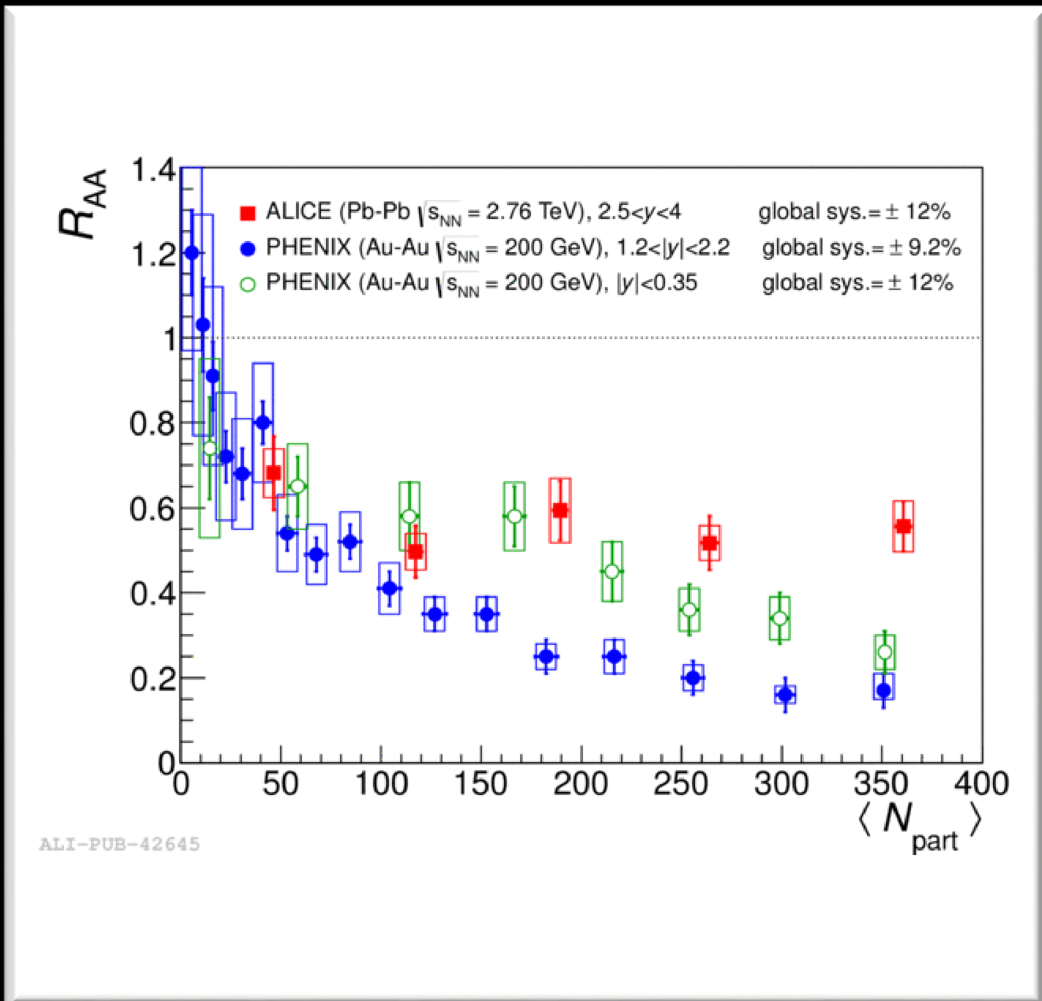




- c quarks from hard processes hadronize with s quarks from the QGP ?

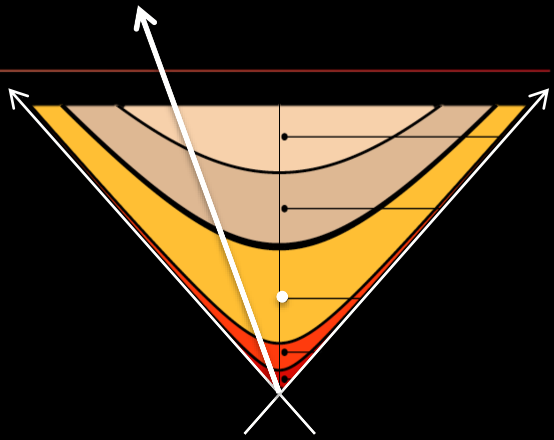
J/ψ transport in QGP

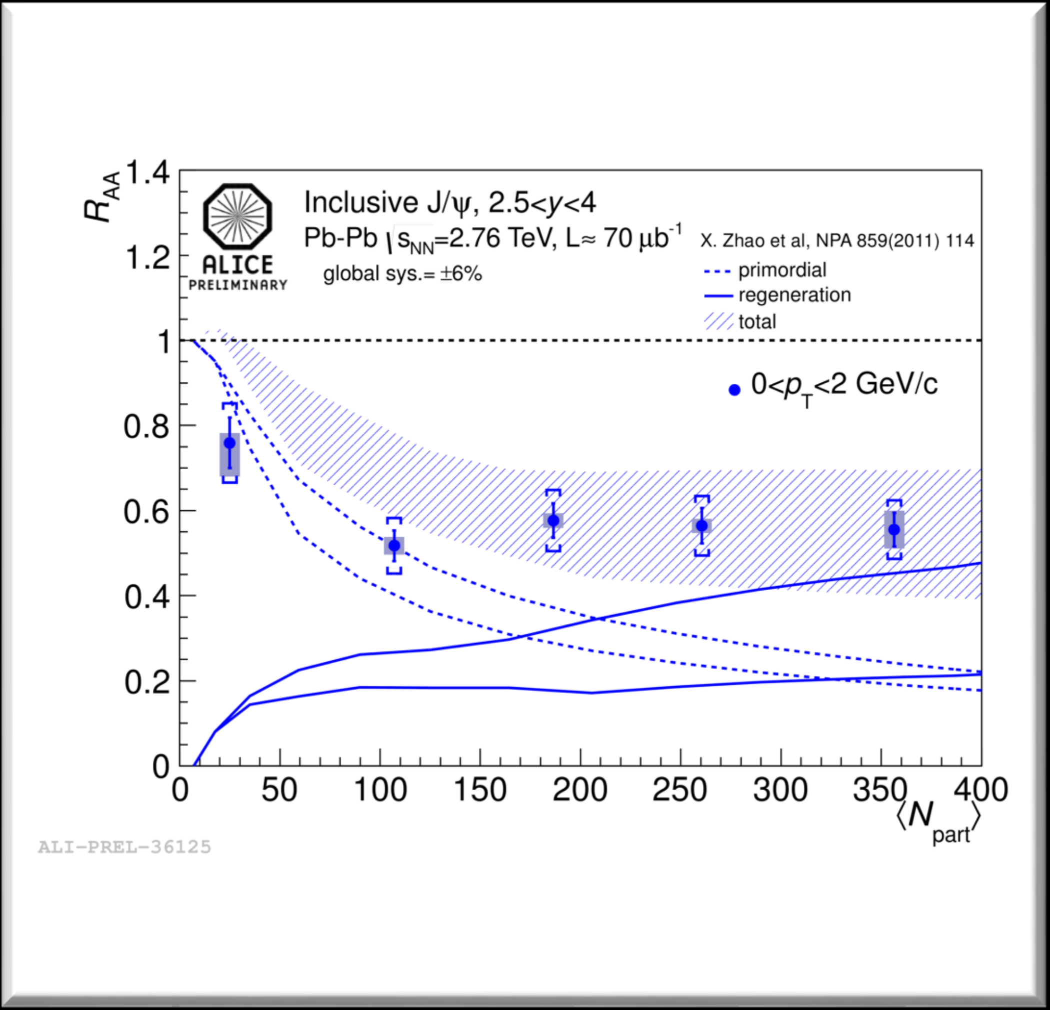




- Less suppression at LHC than at RHIC !
  - ➢ Suppression via Debye screening
  - ➢ Regeneration via $c\bar{c}$ recombination

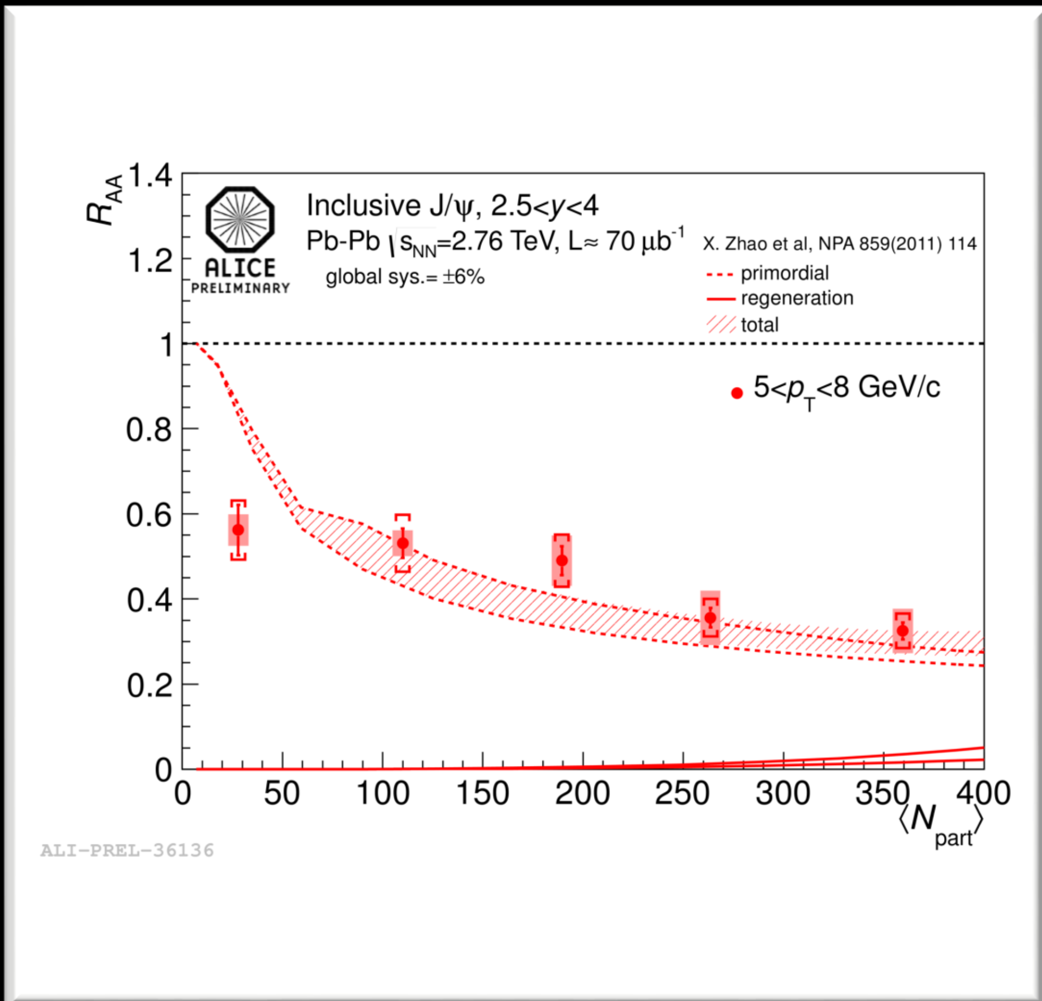
J/ψ transport in QGP

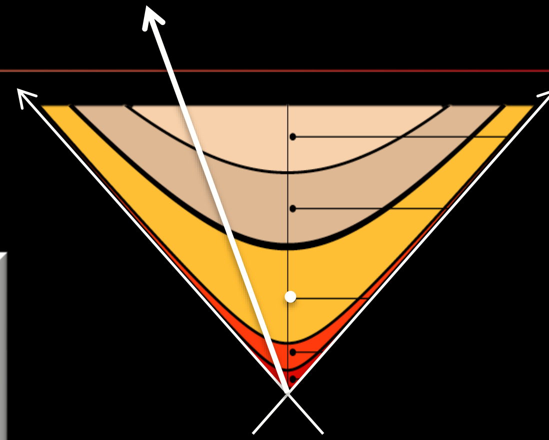




- At low p_T suppression compensated by regeneration
- Remember finite v_2

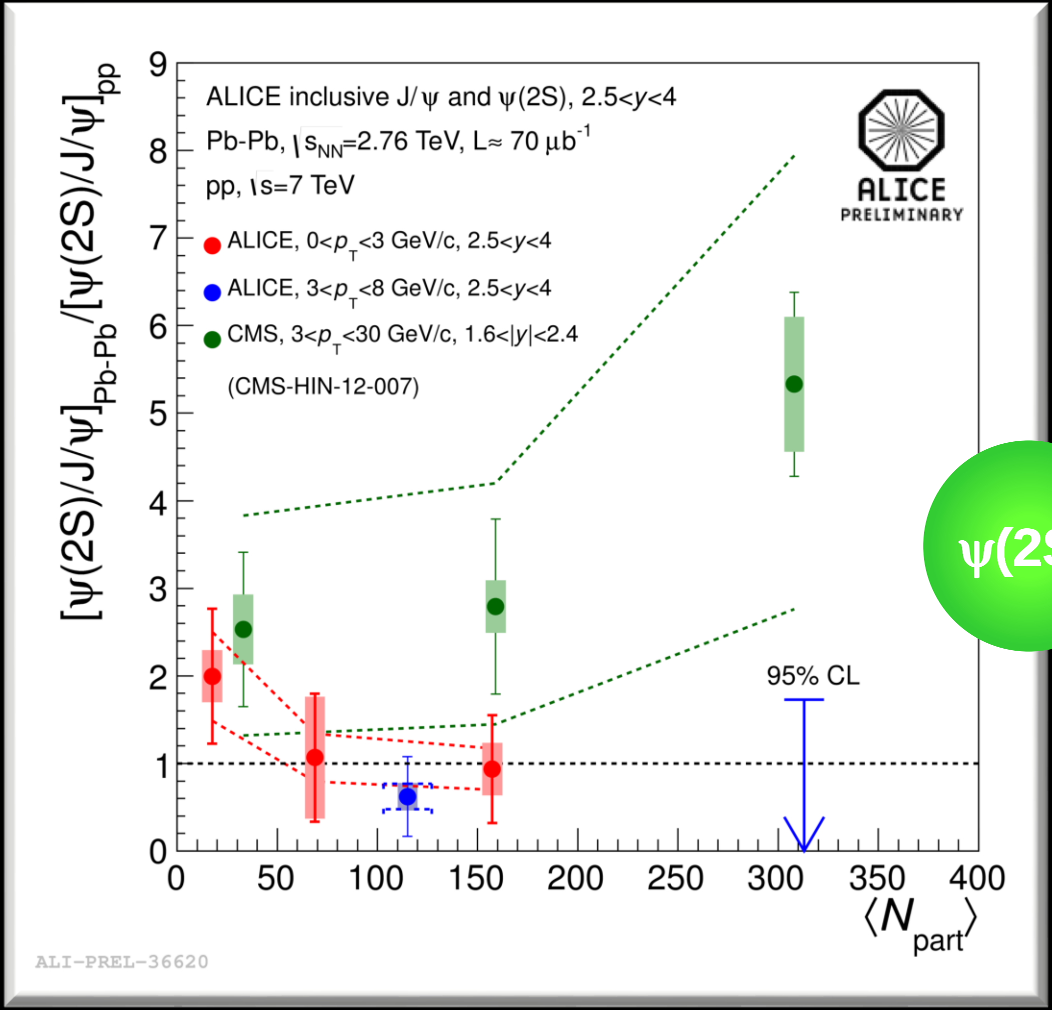
J/ψ transport in QGP

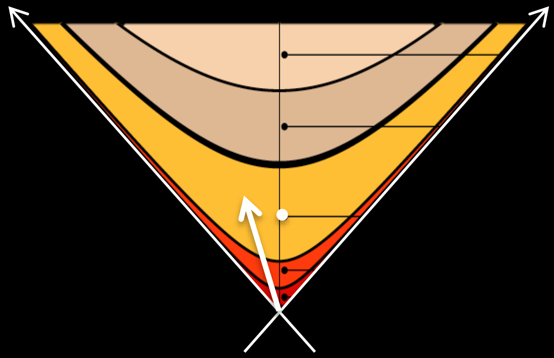


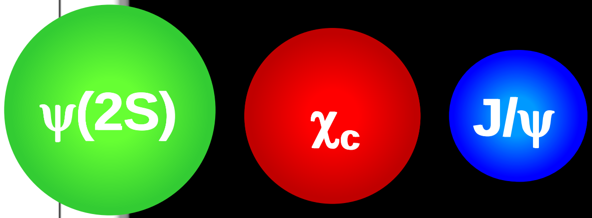


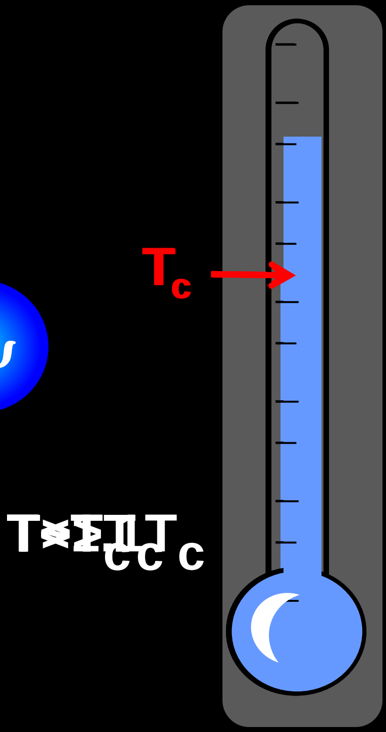
- At high p_T regeneration vanishes
- Debye screening, thermometer ?

ψ' different from J/ψ ?

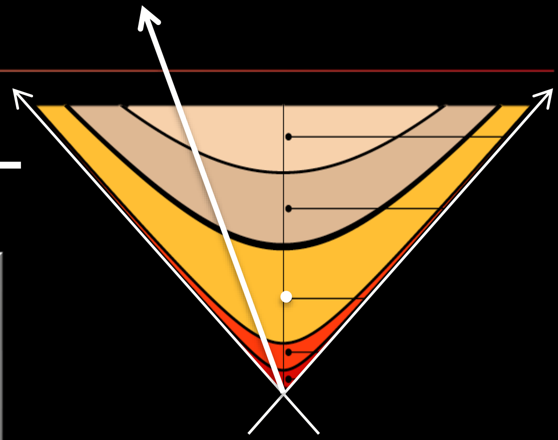


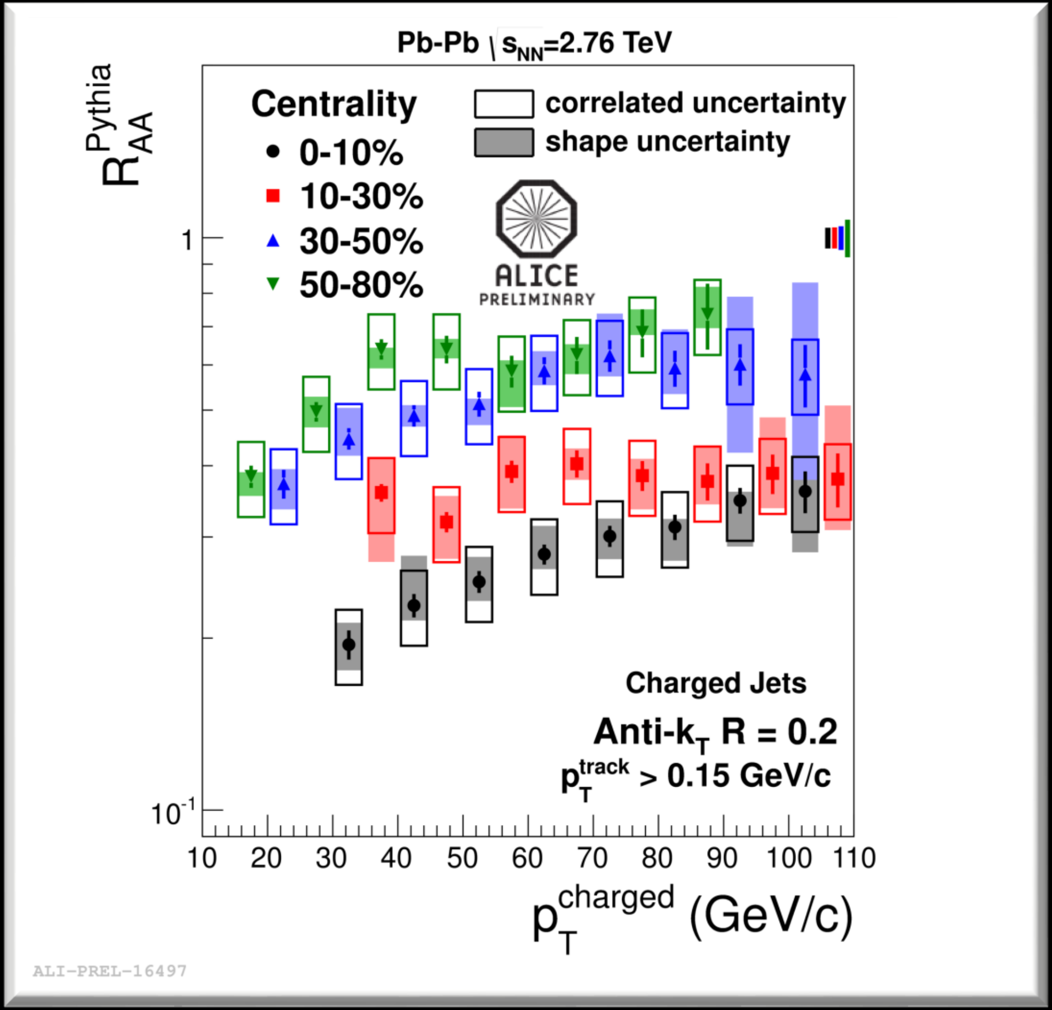






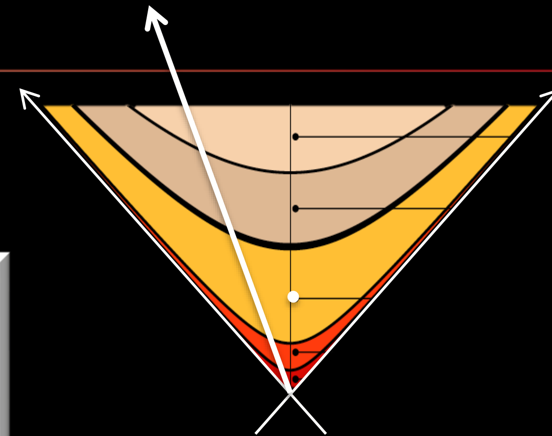
JETS ARE QUENCHED AS WELL



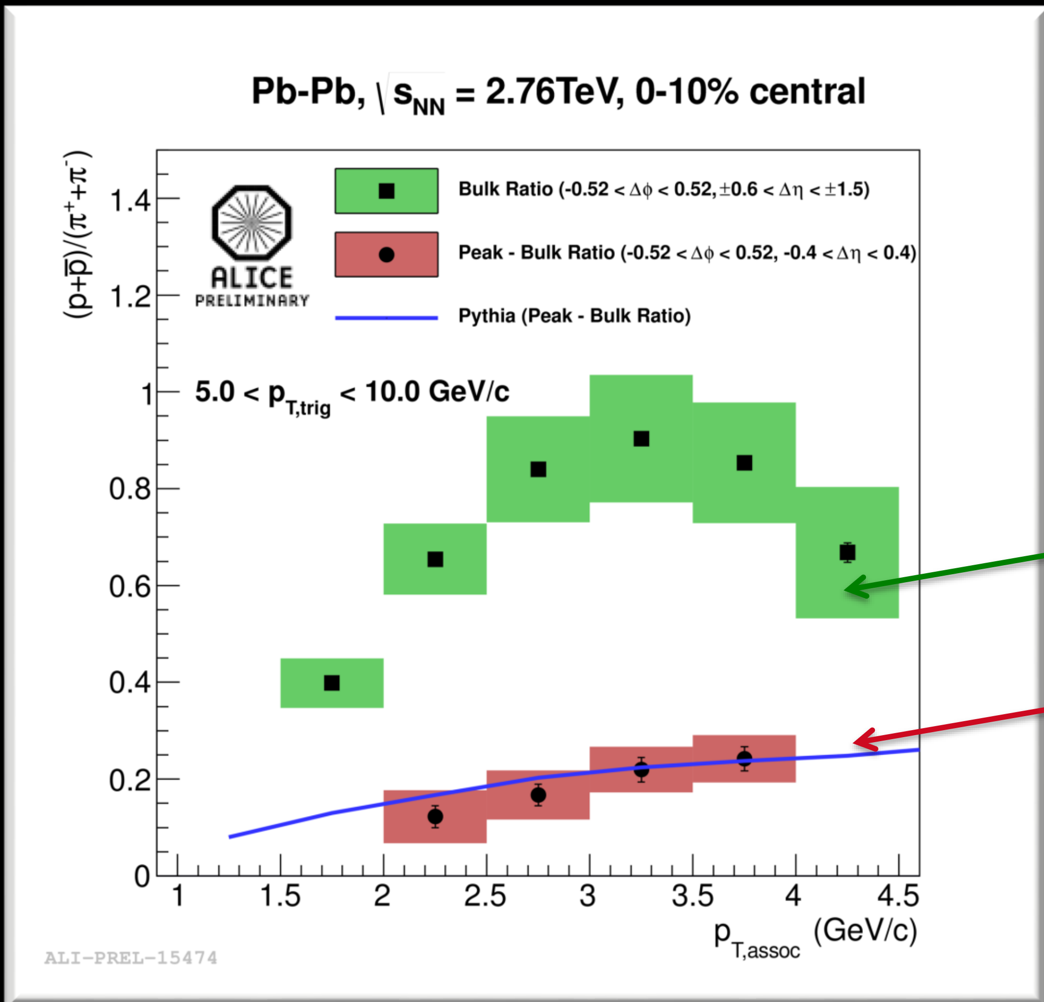


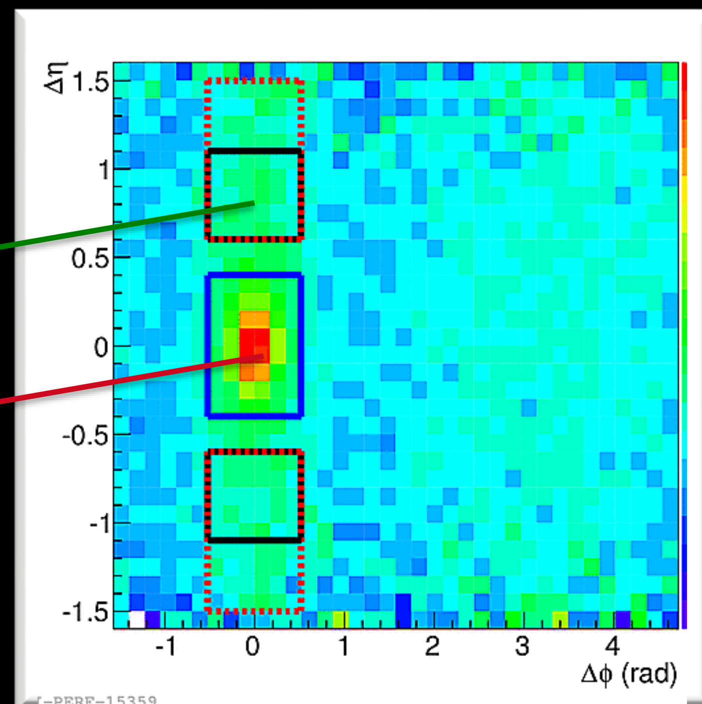
- But this is a different story
- How is energy inside jet redistributed ?

JET ANATOMY



- Baryon/meson content





MANY MORE RESULTS …

LHC: pp, pA, AA, γA