QUARK MATTER 2011
23-28 May 2011 – Annecy, France

# La frontière de haute energe en collisions noyau-noyau

Federico Antinori
INFN, Padoue, Italie

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# The High Energy Frontier of AA

Federico Antinori
INFN, Padua, Italy

# Intro

- my charge:

  perspective on high energy AA frontier in the aftermath of QM2011
  - high energy = top RHIC and upwards

- disclaimers:
  - you will get my own biased (and “immediate”) perspective
    - but with a little help from my friends…
  - I had to make hard decisions on what to show…
    - I had to leave out many beautiful measurements and important details…
  - I will mostly reuse slides presented at this conference

# Contents

- The bulk
- Correlations
- Quarkonia
- High $p_T$ Suppression
- Identified Particles
- Jets
- Heavy Flavour

# Le “Bulk”

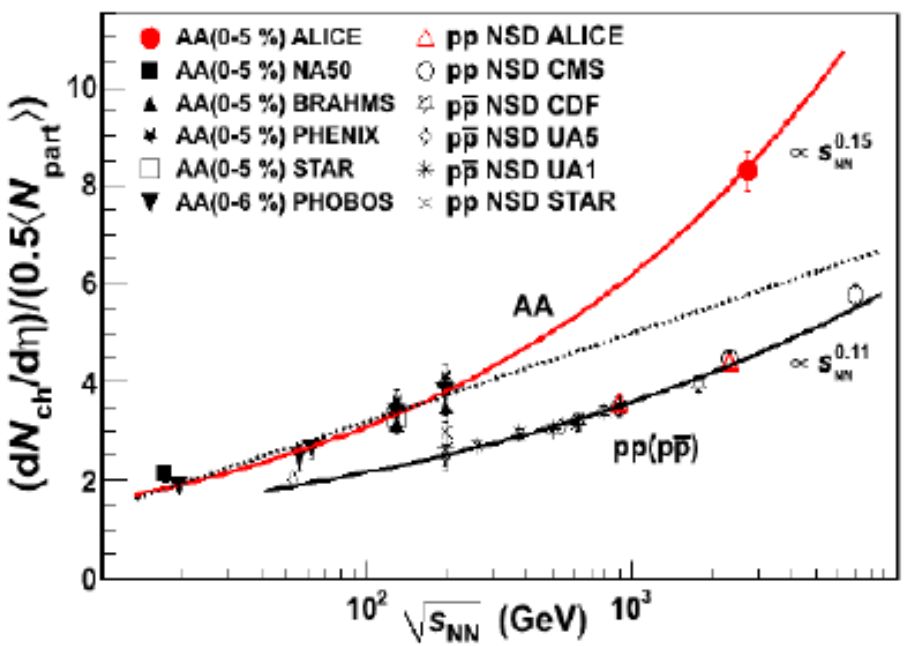
# √s dependence

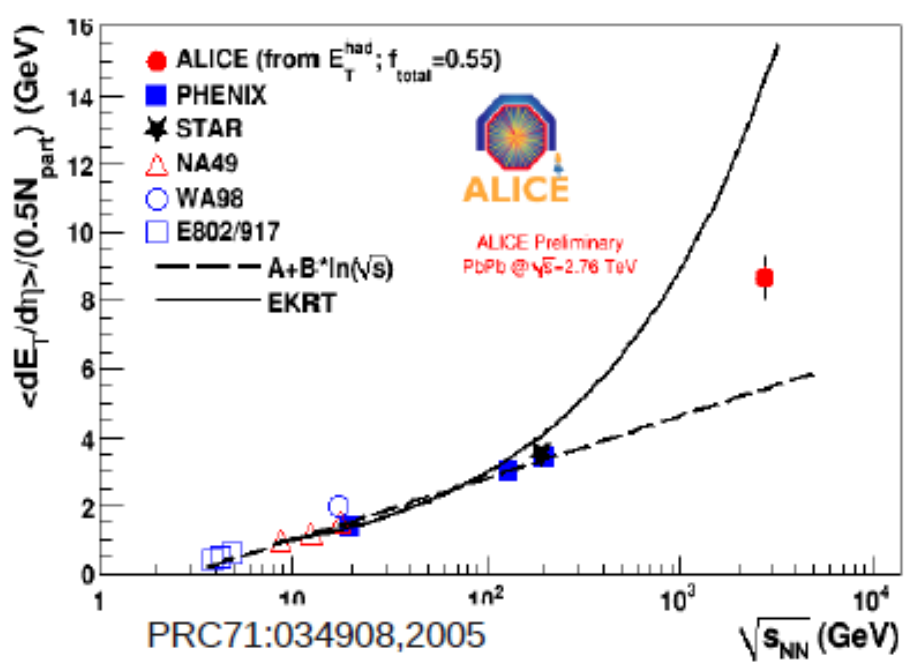
Alberica Toia - ALICE

- $dN_{ch}/d\eta/(0.5*N_{part}) \sim 8$
- **2.1 x RHIC**
  1.9 x pp (NSD) at 2.36 TeV
- growth with √s faster in AA than pp

- $dE_T/d\eta/(0.5*N_{part}) \sim 9$ in 0-5%
- ~5% increase of $N_{part}$ (353 → 383)
  → **2.7 x RHIC**
  (consistent with 20% increase of $\langle p_T \rangle$)

Grows with power of CM energy faster than simple logarithmic scaling extrapolated from lower energy

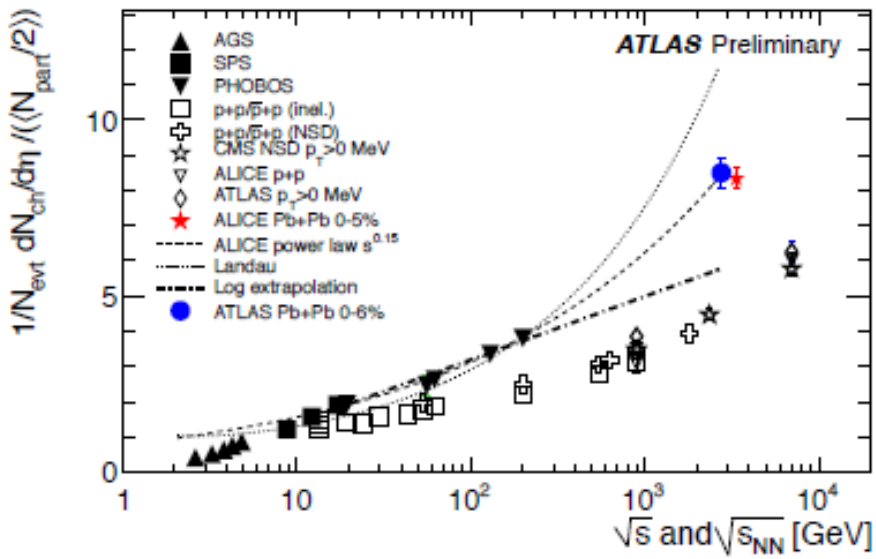


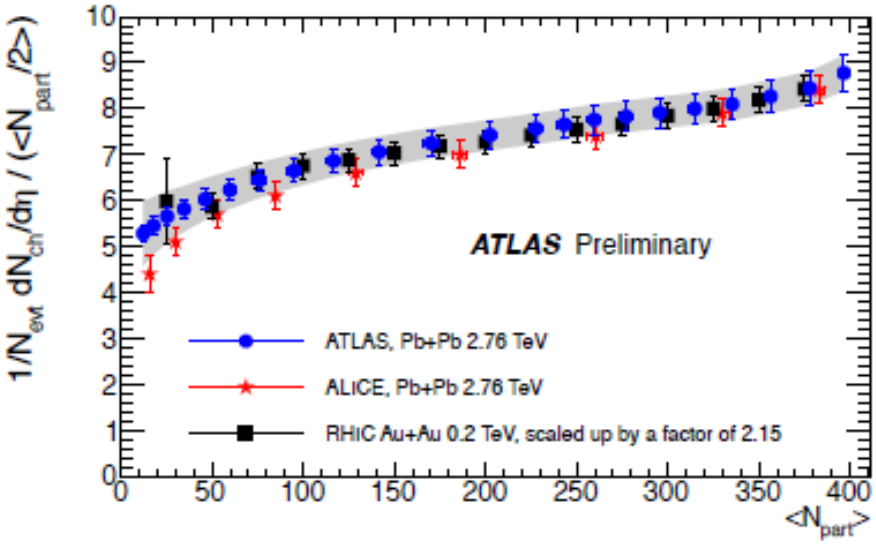




PRC71:034908,2005

Peter Steinberg – ATLAS

# Charged particle multiplicity




Pixel "tracklets" in solenoid-off data, to measure down to $p_T>0$

Yield per participant pair increases by factor of two relative to RHIC, in agreement with ALICE measurement

Similar centrality dependence to that found at RHIC (which itself was similar to top SPS energies):

Confirmation of what appears to be a robust scaling feature in HI

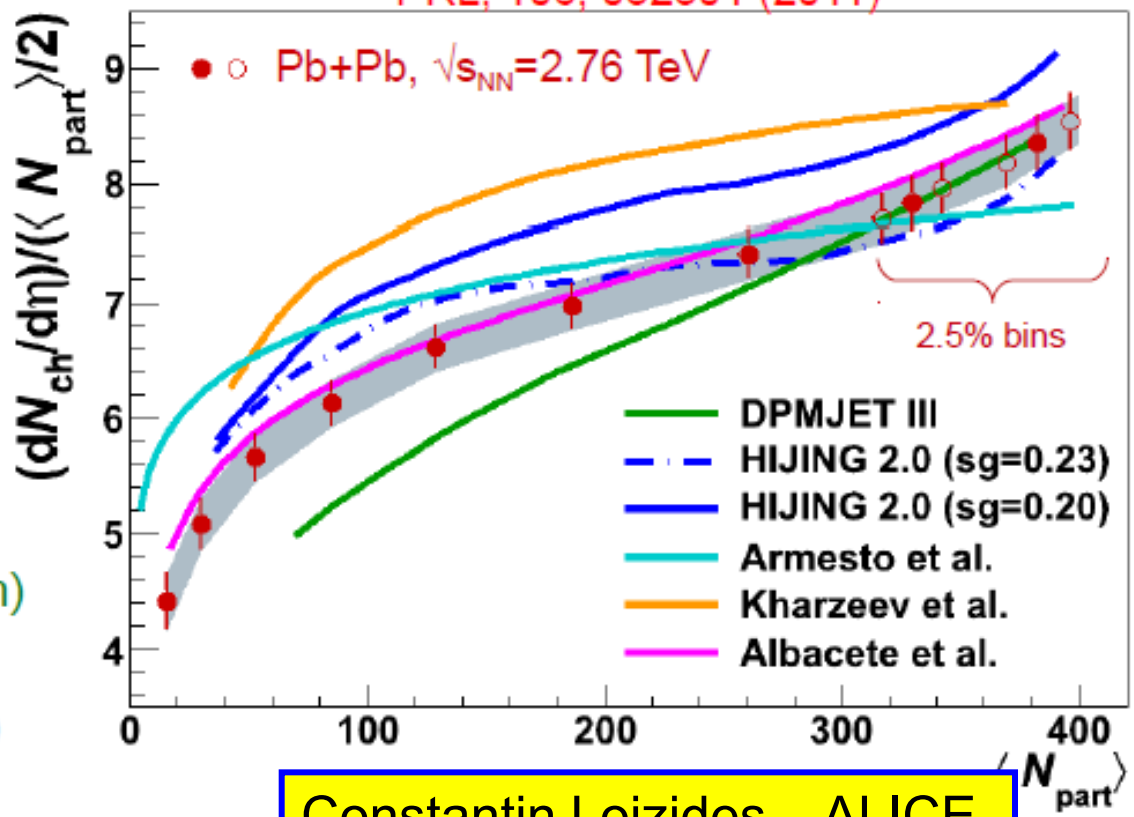
**for details, see talk by Yujiao Chen (4pm Mon.)**

# dNch/dη: Centrality vs models



- Two-component models
  - Soft (~Npart) and hard (~Ncoll) processes
- Saturation-type models
  - Parametrization of the saturation scale with energy (s) + centrality (A)
- Comparison to data
  - DPMJET (with string fusion) stronger rise than data
  - HIJING 2.0 (no quenching)
    - Strong centrality dependent gluon shadowing
    - Fine-tuned to 0-5% dN/dη
  - Saturation models
    - Some saturate too much

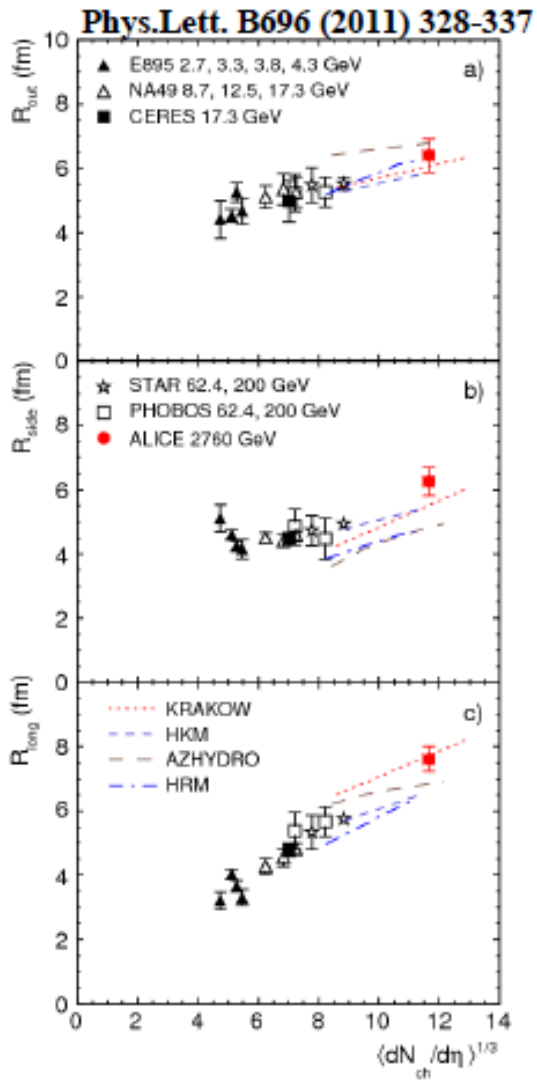
PRL, 106, 032301 (2011)



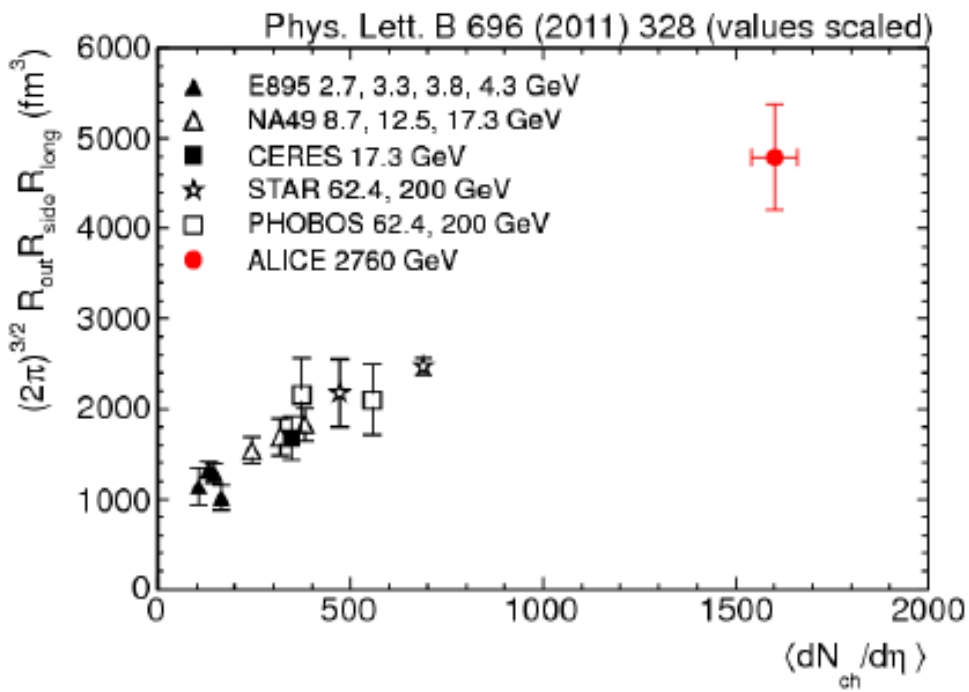

Constantin Loizides – ALICE

Models incorporating a moderation of the multiplicity with centrality are favored by the data (as at RHIC)

# Scaling vs. $dN_{ch}/d\eta$




- Increase of the radii with $dN_{ch}/d\eta$ for central collisions consistent with models
- Increase of the "homogeneity volume" over most central RHIC by a factor of ~2



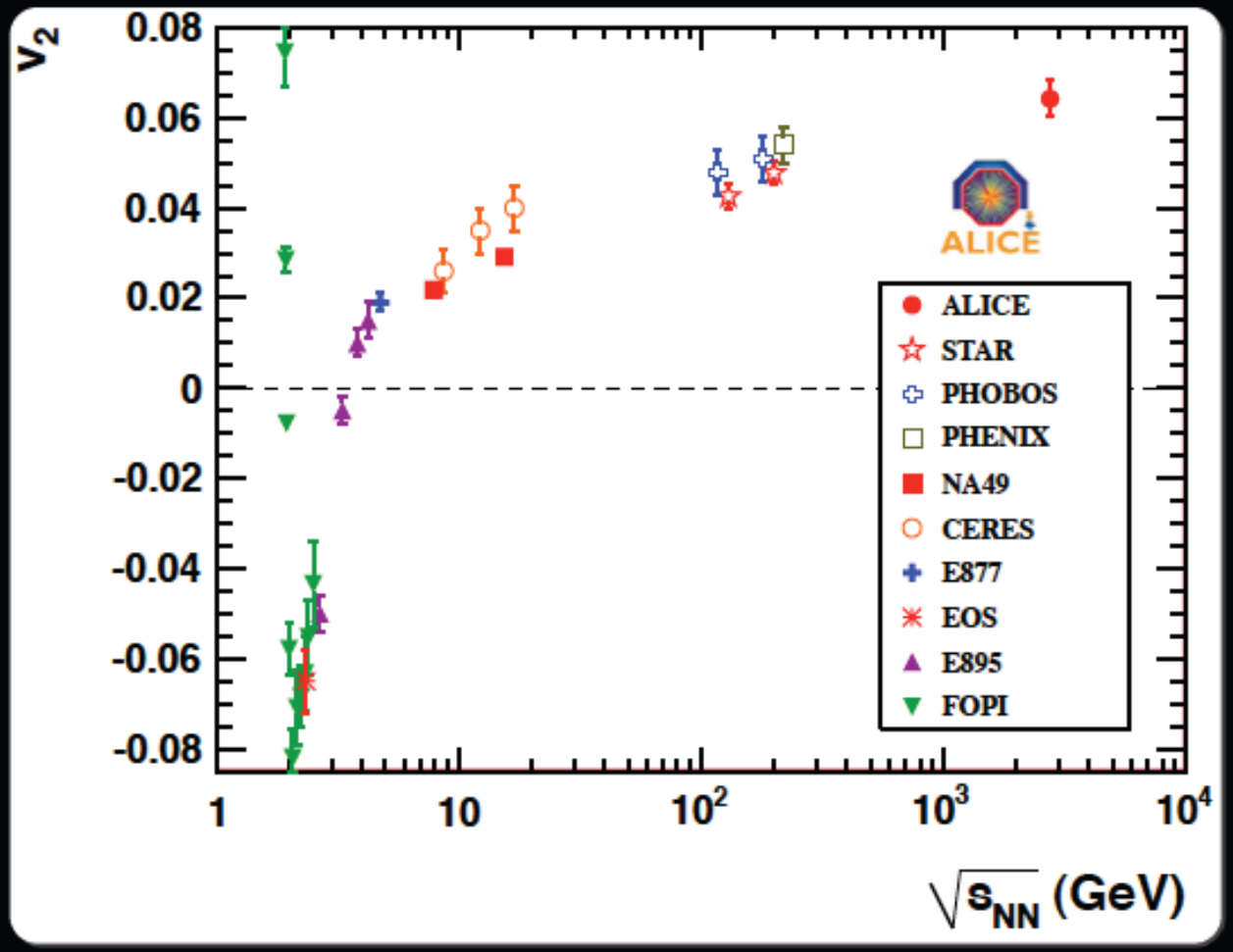
# La frontière

- explore forward rapidities
  - multiplicities vs η
  - CGC/saturation effects?
  - pA !!
- identified particle HBT

# Les corrélations

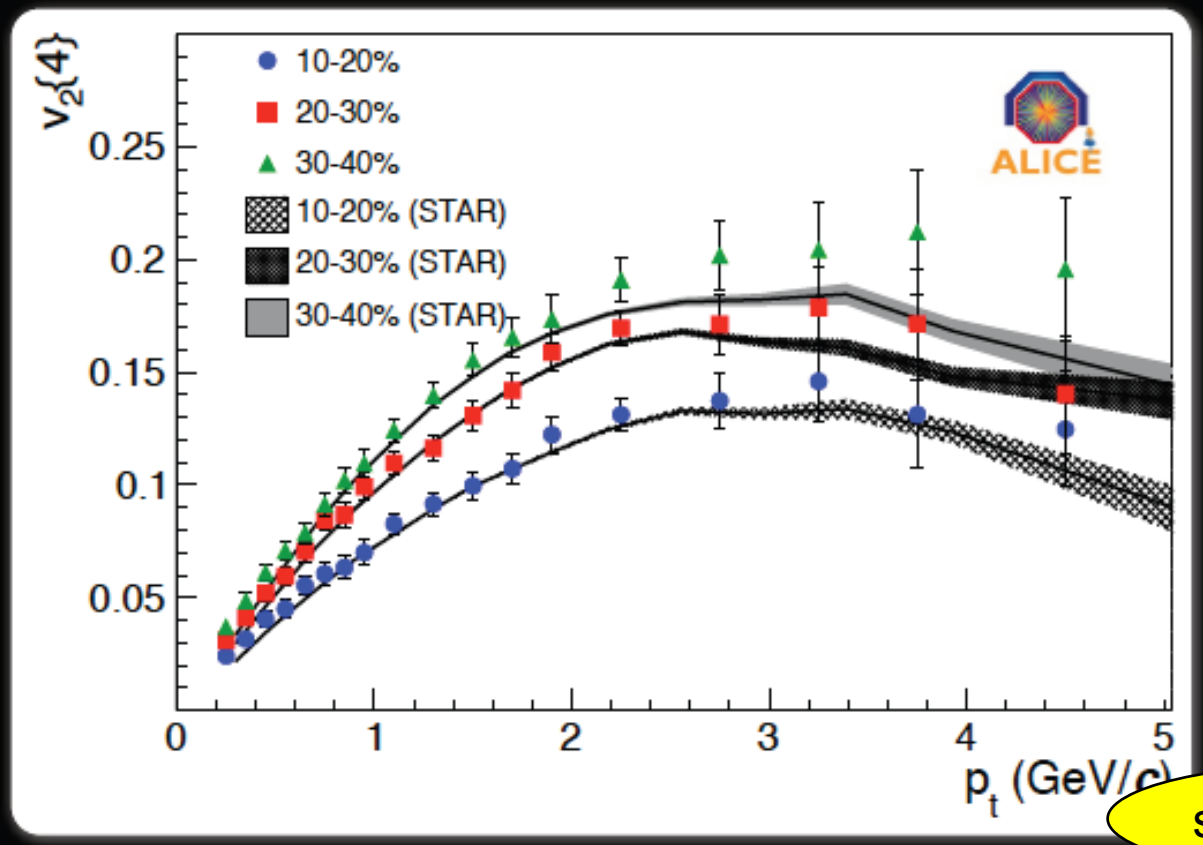
# The Perfect Liquid

K. Aamodt et al. (ALICE Collaboration)
PRL 105, 252302 (2010)




The system produced at the LHC behaves as a very low viscosity fluid (a perfect fluid)

# $v_2$ as function of $p_t$



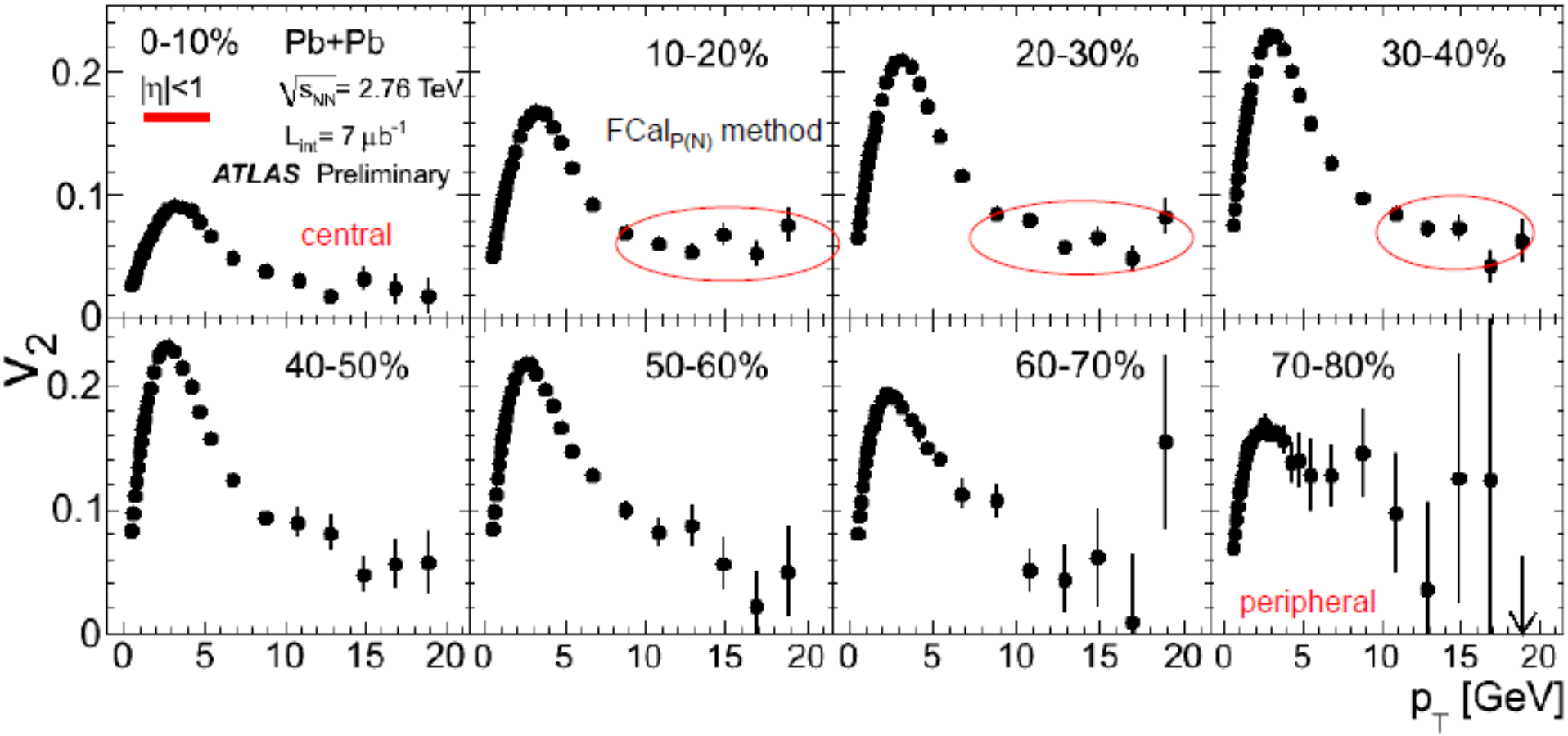

K. Aamodt et al. (ALICE Collaboration)
PRL 105, 252302 (2010)

same hydro?

Elliptic flow as function of transverse momentum does not change much from RHIC to LHC energies, can we understand that?

# $v_2$ measured out to 20 GeV

- Charged hadrons, $p_T$=0.5-20 GeV, mid-rapidity, $|\eta|<1$




**Weak $p_T$ dependence beyond 8-10 GeV out to 20 GeV**
**Important constraint on jet quenching models!**

Adam Trzupek, Friday 15:00

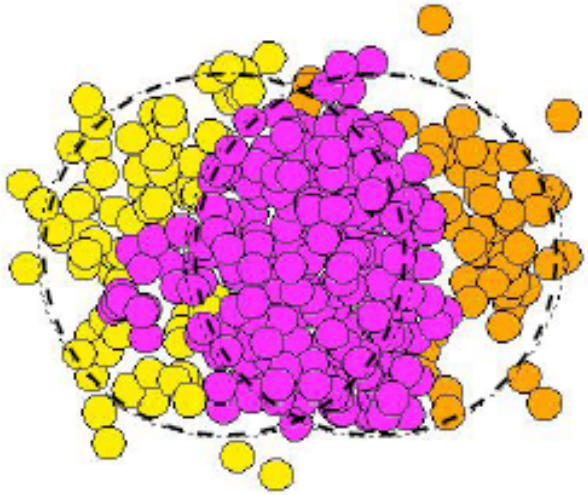
Jiangyong Jia – ATLAS

# Flow fluctuations

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2 v_n \cos n(\phi - \psi_n)$$

$$\Longrightarrow \left\langle \frac{dN_{\text{pairs}}}{d\Delta\phi} \right\rangle \overset{(\text{flow})}{\propto} 1 + \sum_{n=1}^{\infty} 2 \left\langle v_n^2 \right\rangle \cos n(\Delta\phi)$$

Matthew Luzum



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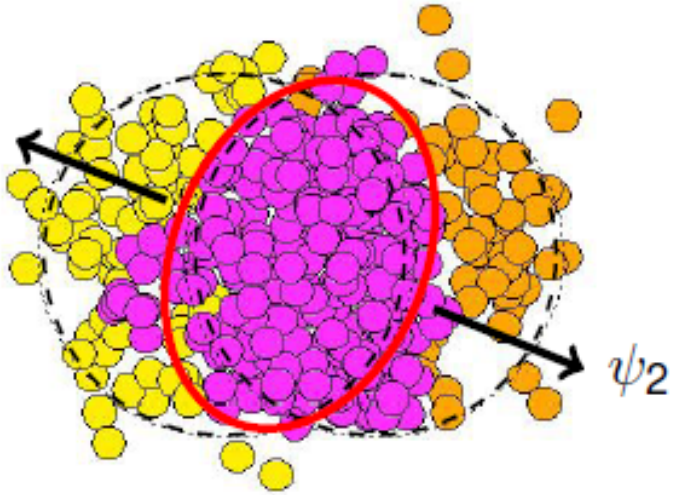

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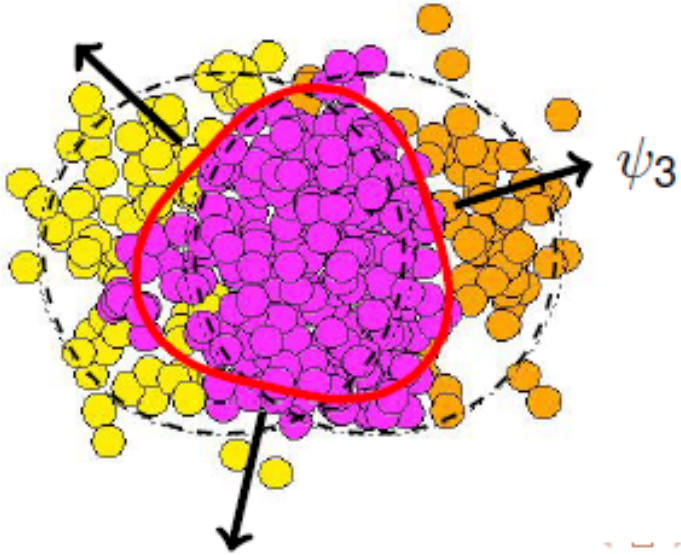
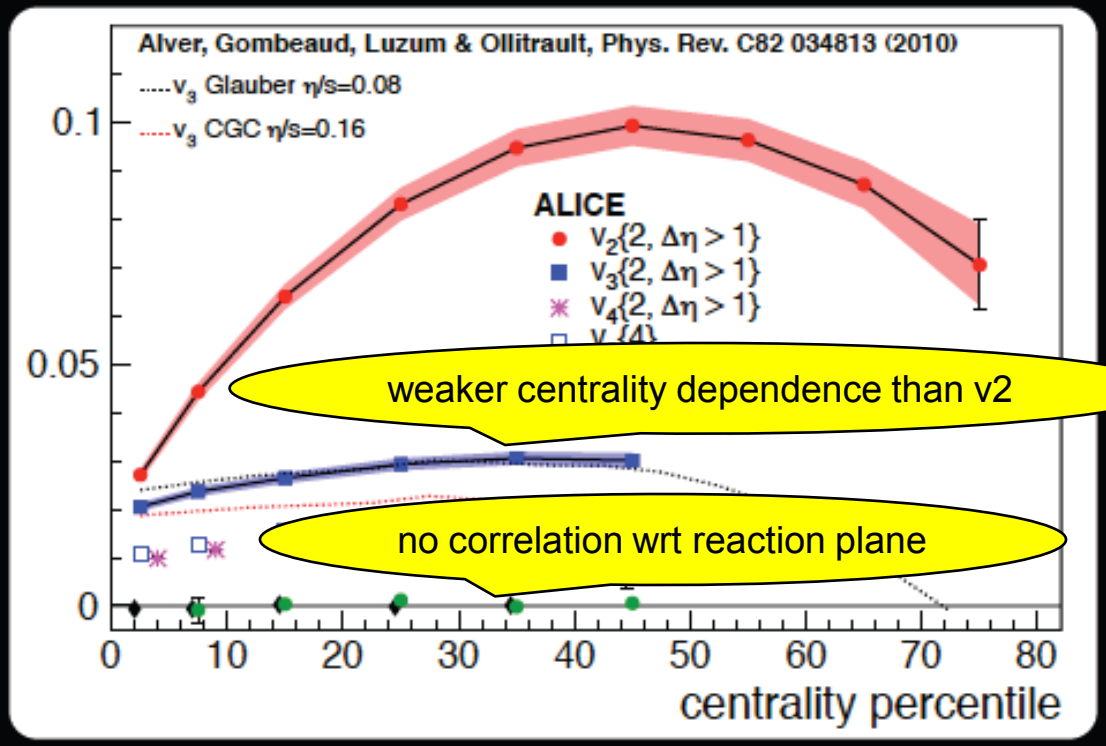


# Triangular Flow

We observe significant $v_3$ which compared to $v_2$ has a different centrality dependence

The centrality dependence and magnitude are similar to predictions for MC Glauber with $\eta/s=0.08$ but above MC-KLN CGC with $\eta/s=0.16$




ALICE Collaboration, arXiv:1105.3865

The $v_3$ with respect to the reaction plane determined in the ZDC and with the $v_2$ participant plane is consistent with zero as expected if $v_3$ is due to fluctuations of the initial eccentricity

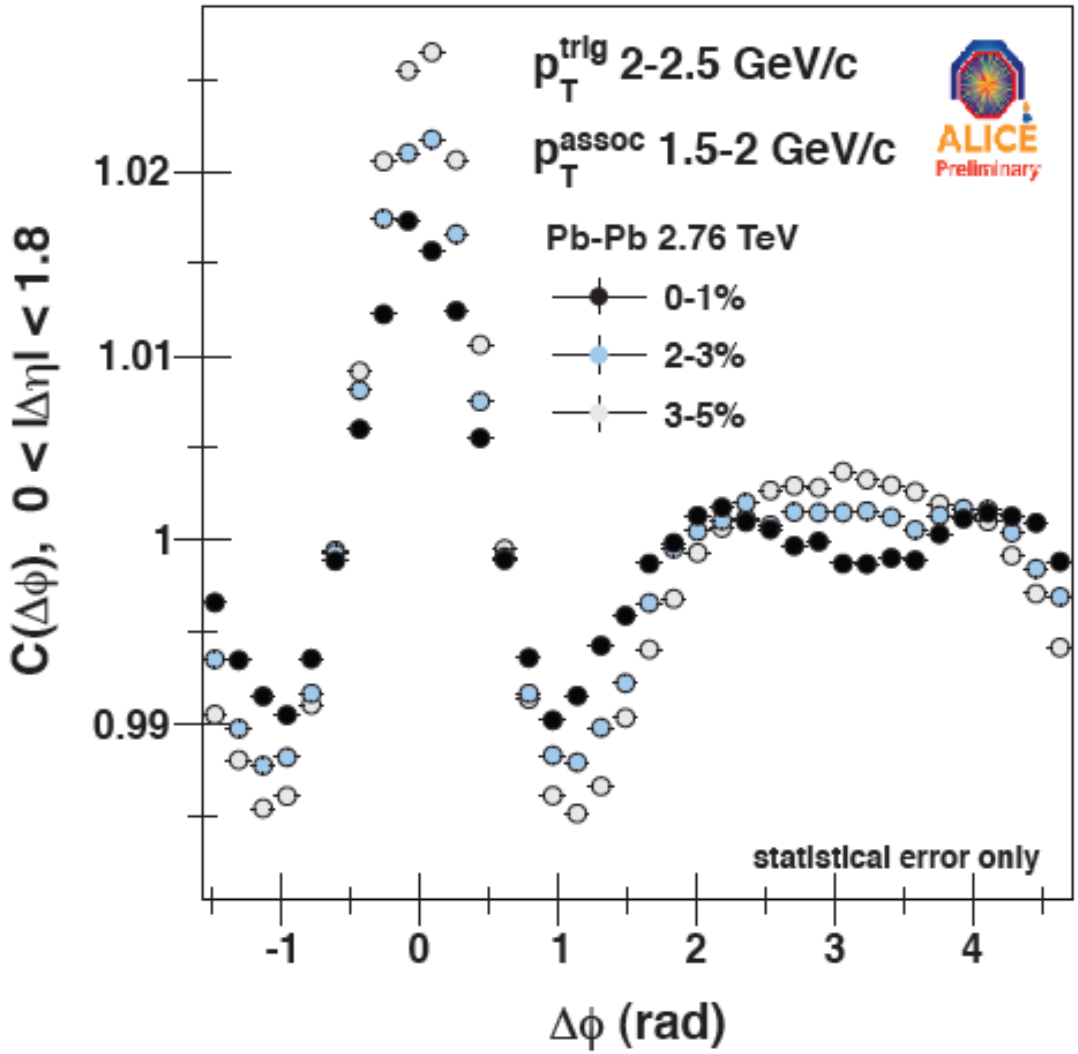
The $v_3\{2\}$ is about two times larger than $v_3\{4\}$ which is also consistent with expectations based on initial eccentricity fluctuations

# Approaching ultracentral Pb+Pb events

**At 1-3 GeV/c, a dramatic shape evolution is observed within a small centrality range.**

**Double-peak away side structure in 1% most-central events**

Andrew Adare – ALICE



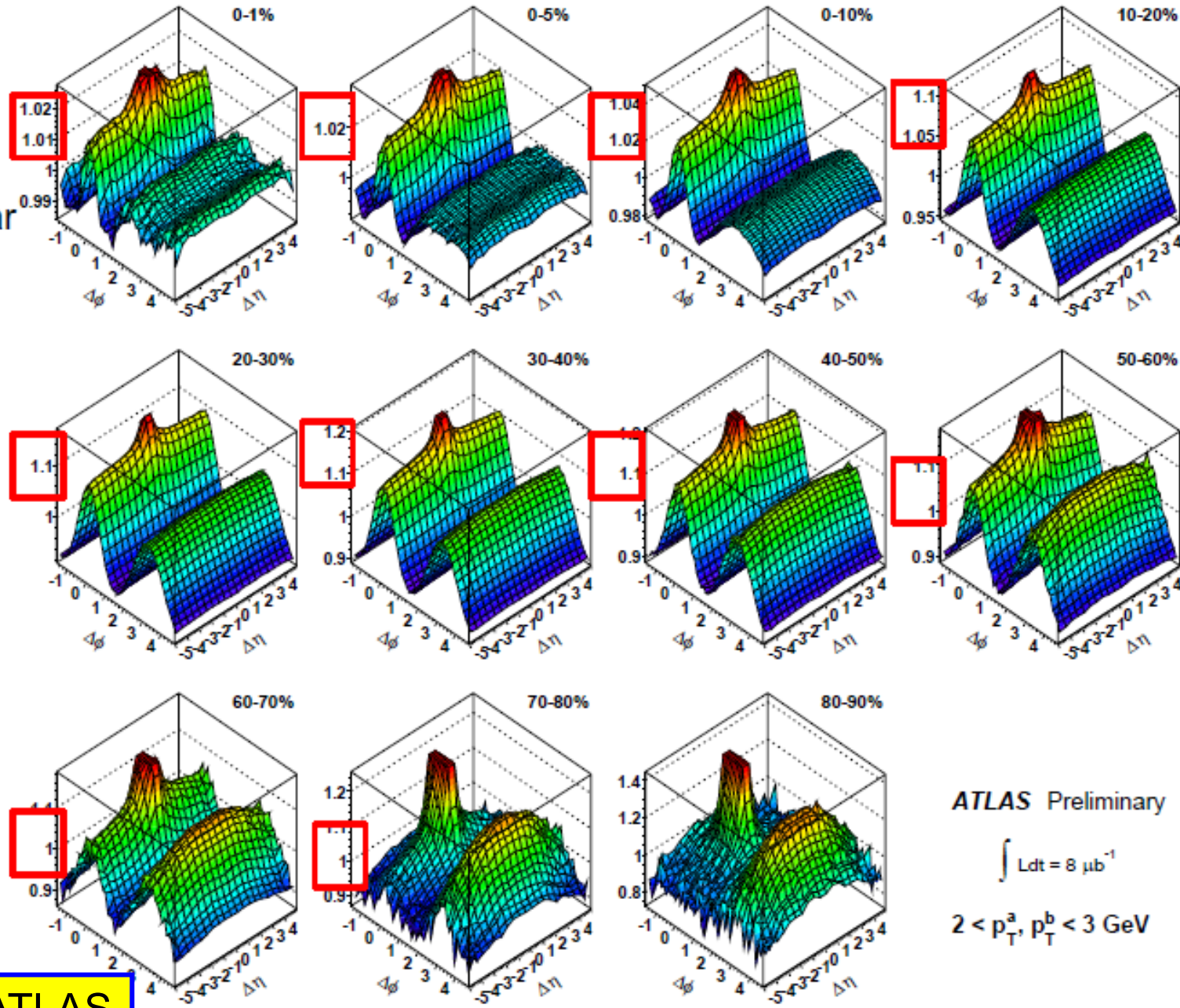

**No background subtracted**

# Rise and fall of "ridge/cone"—Centrality evolution

Pay attention to how long-range structures disappear and clear jet-related peaks emerge on the away-side

Strength of soft component increase and then decrease

Near-side jet peak is truncated from top to better reveal long range structure




Jiangyong Jia – ATLAS

# Fourier analysis at large Δη, moderate $p_T$

**Near side jet excluded by |Δη| > 0.8 gap**

**Ridge at Δφ=0 remains**

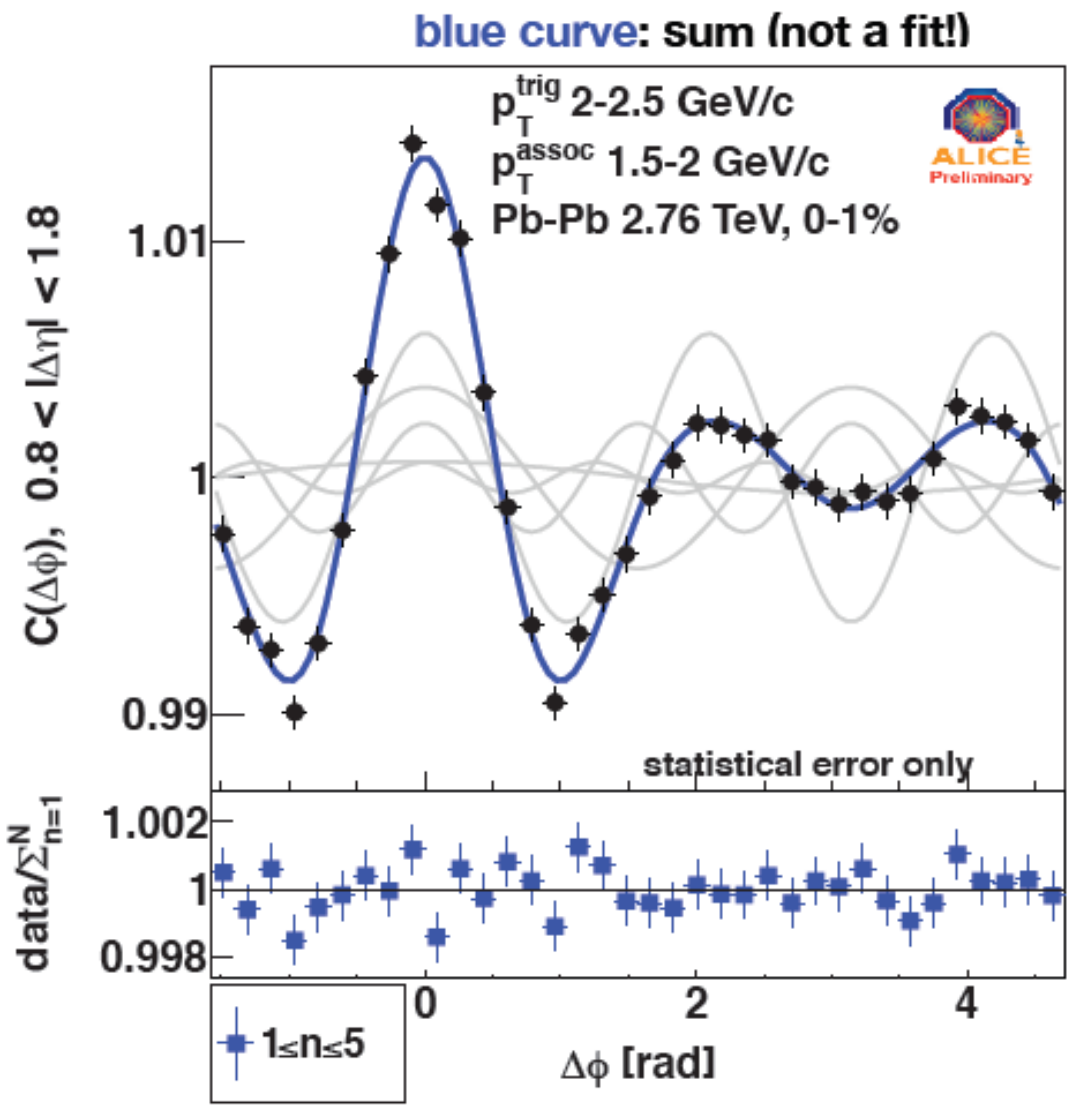
**2-particle Fourier coeffs.**

**Extract directly from C(Δφ):**

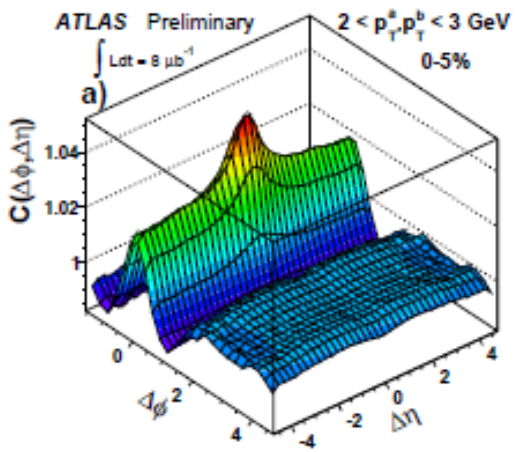
$$\langle \cos n\Delta\phi \rangle = \frac{\int d\Delta\phi\, C(\Delta\phi) \cos n\Delta\phi}{\int d\Delta\phi\, C(\Delta\phi)}$$

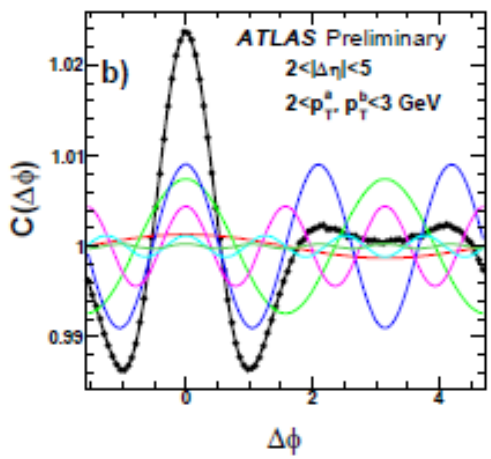
**Here, the first 5 moments describe shape at per-mille level.**

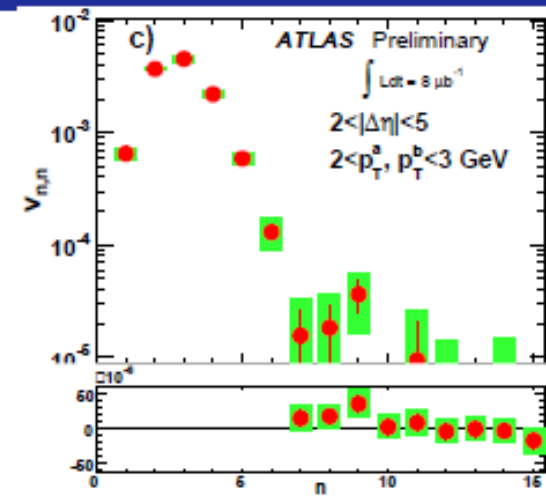
Andrew Adare – ALICE



# Two-particle correlation method



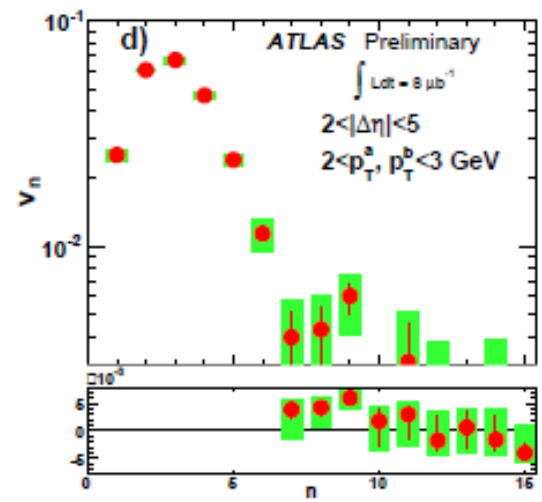




Jiangyong Jia – ATLAS

Fourier decompose the 1D $\Delta\phi$ correlation in given $\Delta\eta$ slice

$$\frac{dN}{d\Delta\phi} \propto 1 + \sum_n 2 v_{n,n} \cos(n\Delta\phi) \qquad v_{n,n} = \langle \cos(n\Delta\phi) \rangle$$

**No fitting! $v_{n,n}$ calculated directly via DFT for n=1-15**




$v_{n,n}$ is expected to factorize into single $v_n$ for flow

$$v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a)\, v_n(p_T^b)$$

➔ $v_n$ from "fixed-$p_T$" correlation

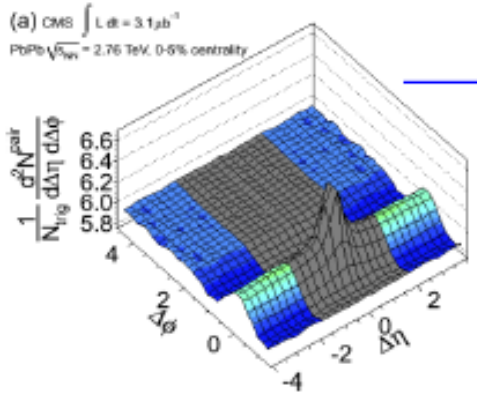
$$v_n(p_T^a) = \sqrt{v_{n,n}(p_T^a, p_T^a)}$$

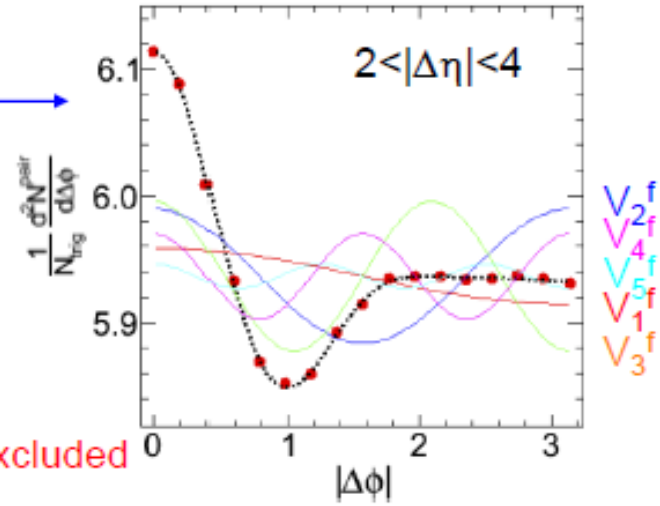
➔ cross-check via "mixed-$p_T$" correlation

$$v_n(p_T^b) = v_{n,n}(p_T^a, p_T^b) \Big/ v_n(p_T^a)$$

# Fourier analysis of $\Delta\phi$ correlations

Fourier decomposition: $\frac{1}{N_{trig}}\frac{dN^{pair}}{d\Delta\phi} = \frac{N_{assoc}}{2\pi}(1+2\sum_{n=1} V_n^f \cos(n\Delta\phi))$



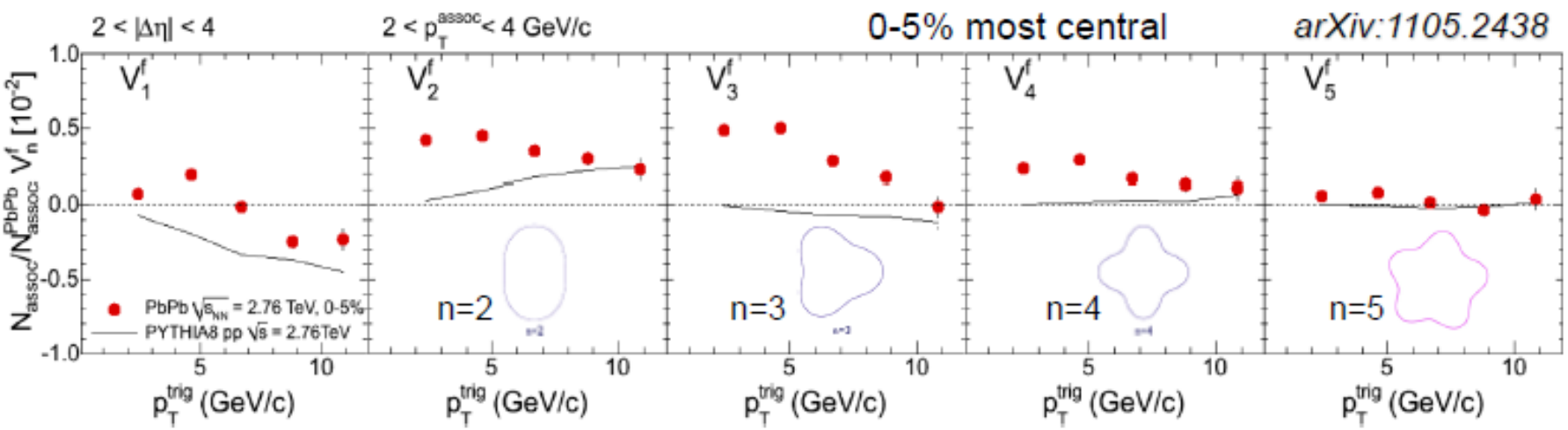

Short-range non-flow effects excluded

Flow driven correlations:

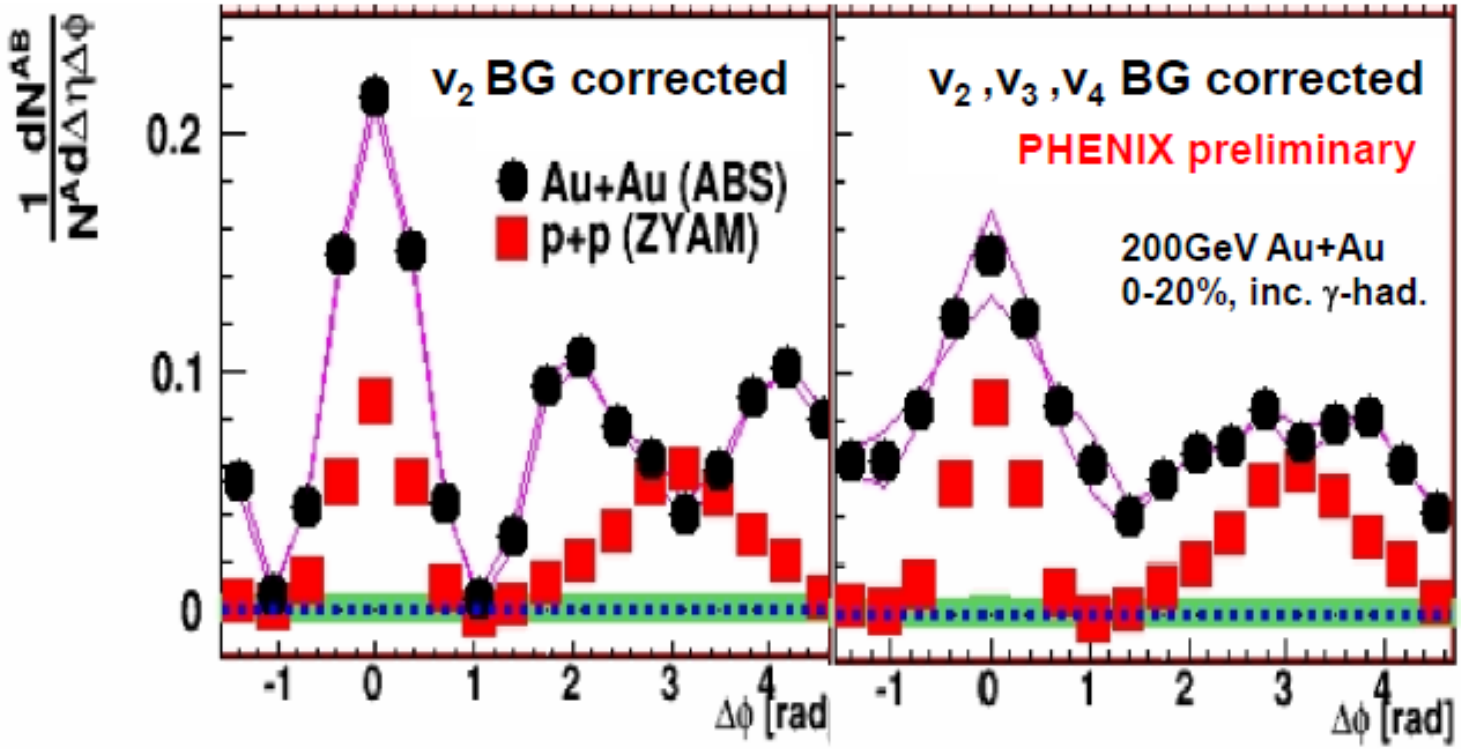
$$V_n^f = v_n^f(p_T^{trig}) \times v_n^f(p_T^{assoc})$$

(f: Fourier analysis of long-range dihadron correlations)

**Wei Li – CMS**



# Flow subtraction/correction with measured $v_n$ for central-central 2-particle correlation




mach-cone is mostly gone

remaining medium effect seen

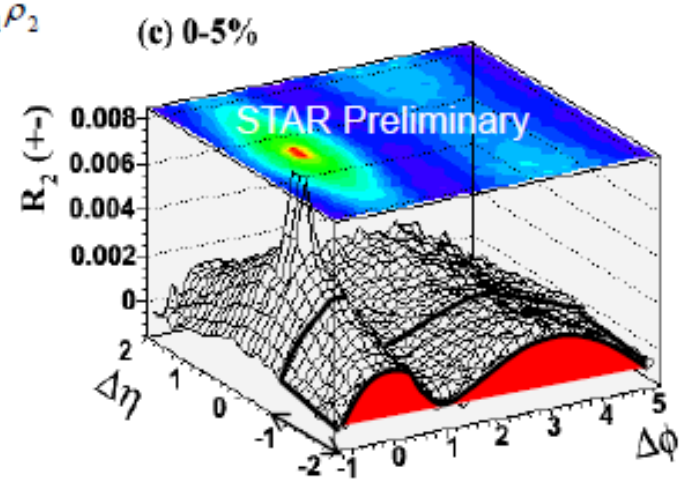
(correlated pair yield by absolute normalization)

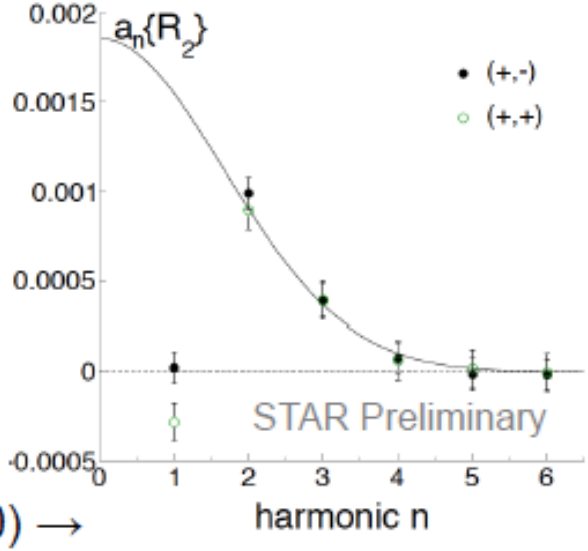
ShinIchi Esumi – PHENIX

# Large Δη $a_n$necy spectrum

if flow dominates the correlations $a_n \approx v_n^2$

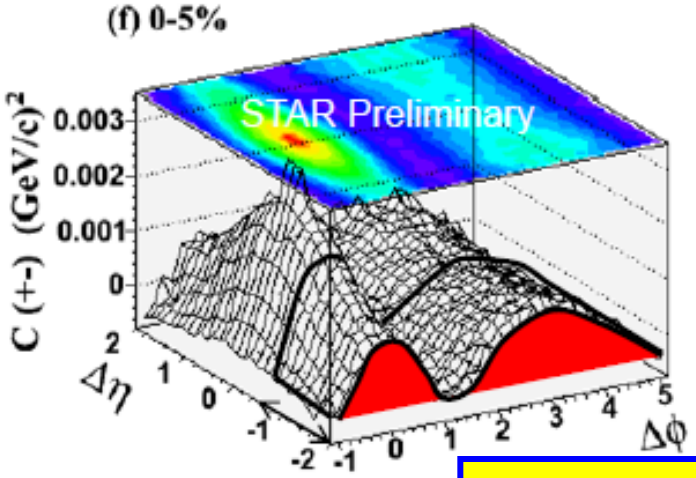
$$R_2 = \frac{\rho_{12}}{\rho_1 \rho_2} - 1$$

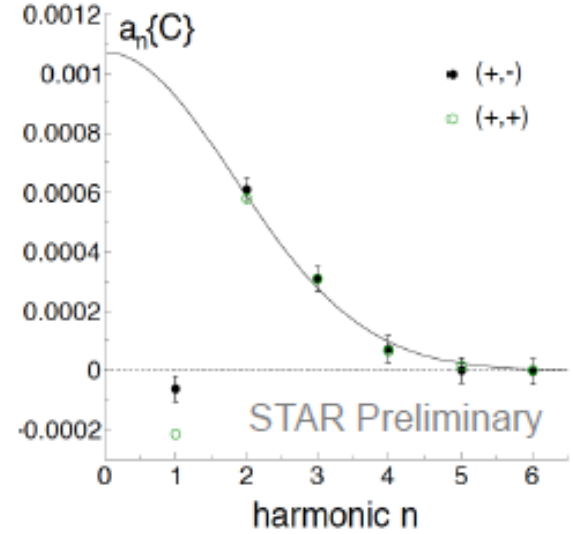



→ Fourier Tr. (0.7<Δη<2.0) →

$$C = \frac{\left\langle \sum_{i=1}^{n_1} \sum_{j=1 \neq i}^{n_2} p_{T,i} p_{T,j} \right\rangle}{--} - \bar{p}_{T,1} \bar{p}_{T,2}$$



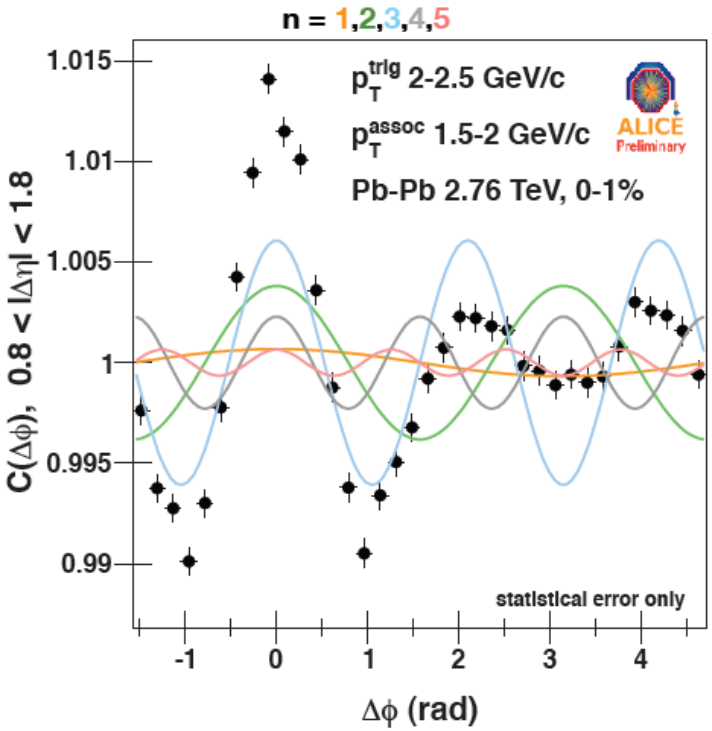

also: A. Mocsy, P. S., arXiv:1008.3381 [hep-ph]

Paul Sorensen – STAR

# Death of ridge and cone?

- “le ridge” and “le Mach cone” seem to be in serious trouble…
- Le Roi est mort…?
- … vive le Roi !

→ la symphonie des corrélations…



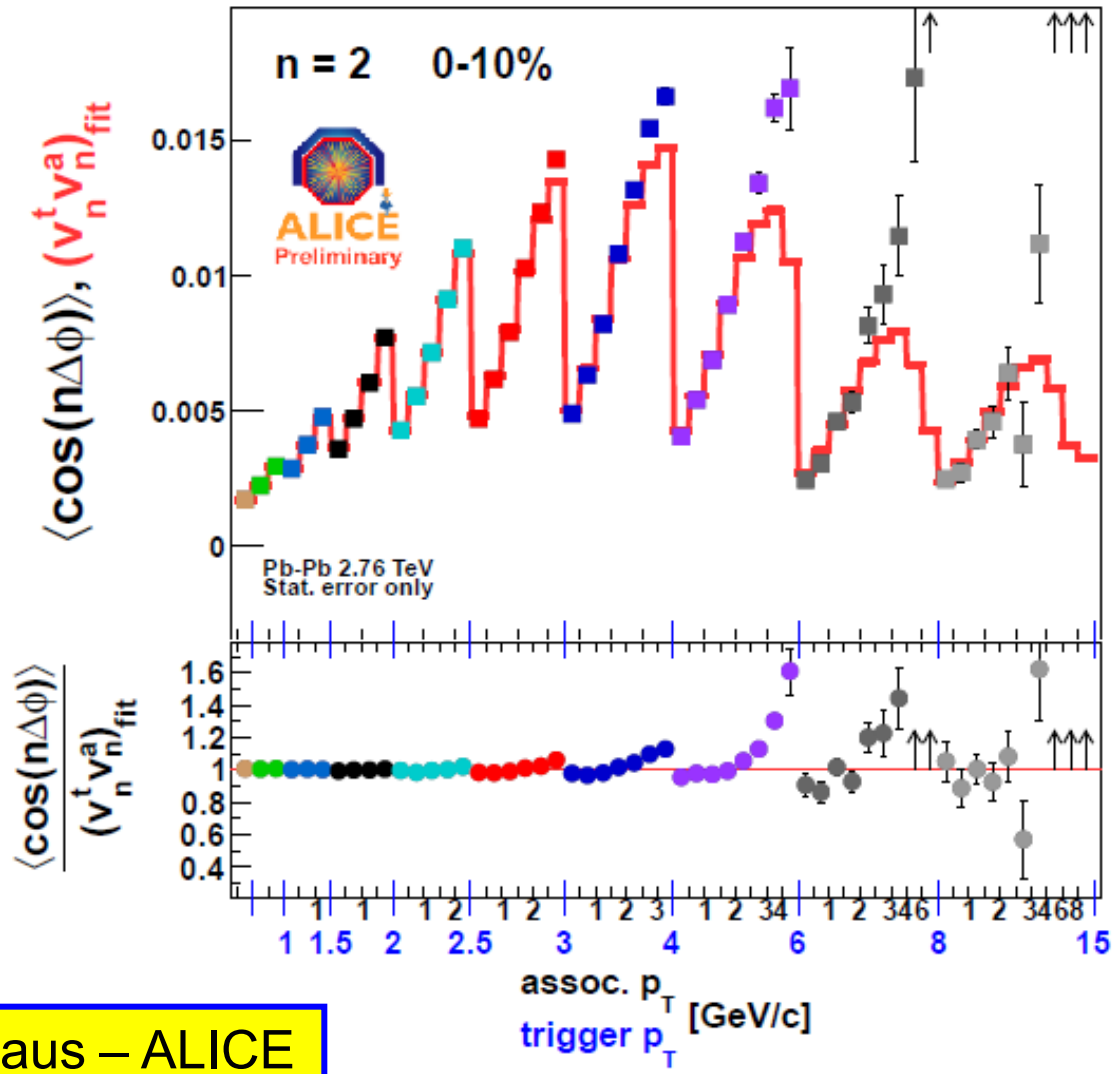
# Flow vs Non-Flow Correlations

- Flow-related effects imply correlation of two particles through a plane of symmetry $\psi_n$
  - $v_n$ factorizes: $V_{n\Delta} = v_n^{trig} v_n^{assoc}$
- Jets cause correlations of a few energetic particles by fragmentation
  - There can be indirect correlations: length-dependent quenching
  - Would be largest w.r.t. $\psi_2$ since it reflects the collision geometry
- Assess flow vs. non-flow by testing the collectivity relation $V_{n\Delta} = v_n^{trig} v_n^{assoc}$
  - Instead of calculating $V_{n\Delta}$ in each $p_{T,assoc}$ x $p_{T,trig}$ bin (N(N-1)/2=55 bins), allow only one $V_{n\Delta}$ per $p_T$ bin (11 parameters)

Jan Fiete Grosse-Oetringhaus – ALICE

# Flow vs Non-Flow Correlations

- Compare single calculated values with global fit
- To some extent, a good fit suggests flow-type correlations, while a poor fit implies non-flow effects
- $v_2$ to $v_5$ factorize until $p_T$ ~ 3-4 GeV/c, then jet-like correlations dominate
- $v_1$ factorization problematic (influence of away-side jet)




Jan Fiete Grosse-Oetringhaus – ALICE

# La frontière

- any residual room for medium response?

→look at the small print on the away side

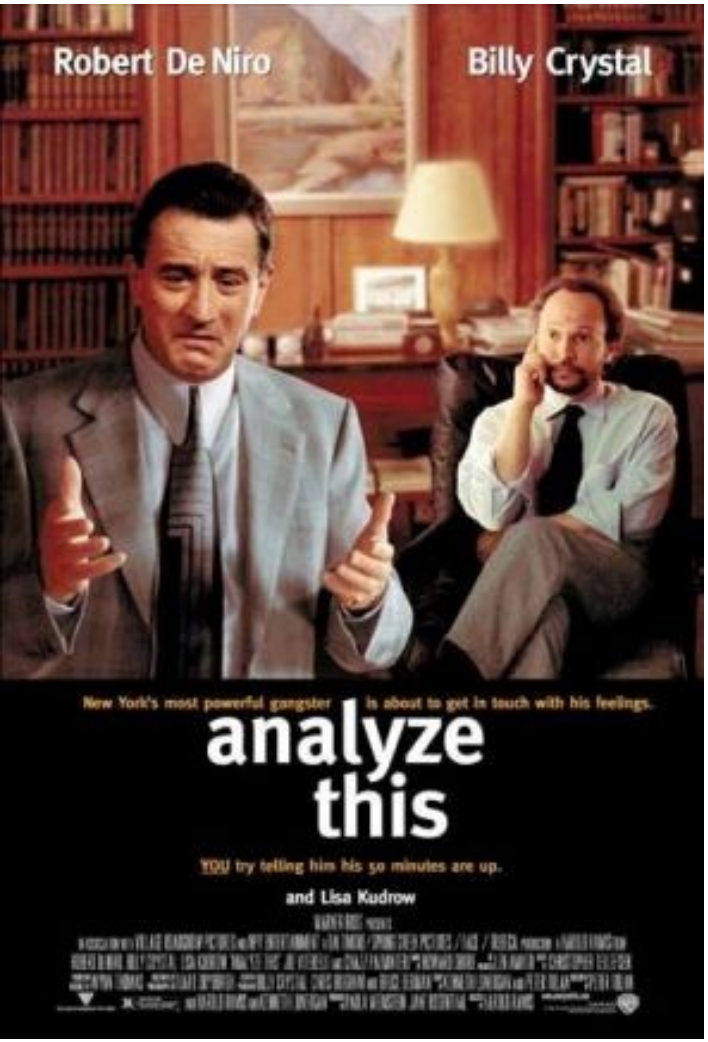
  – two-dimensional in η,φ
  – use information on direction of recoiling parton
    - around re-emerging away-side jets
    - around away-side heavy flavour

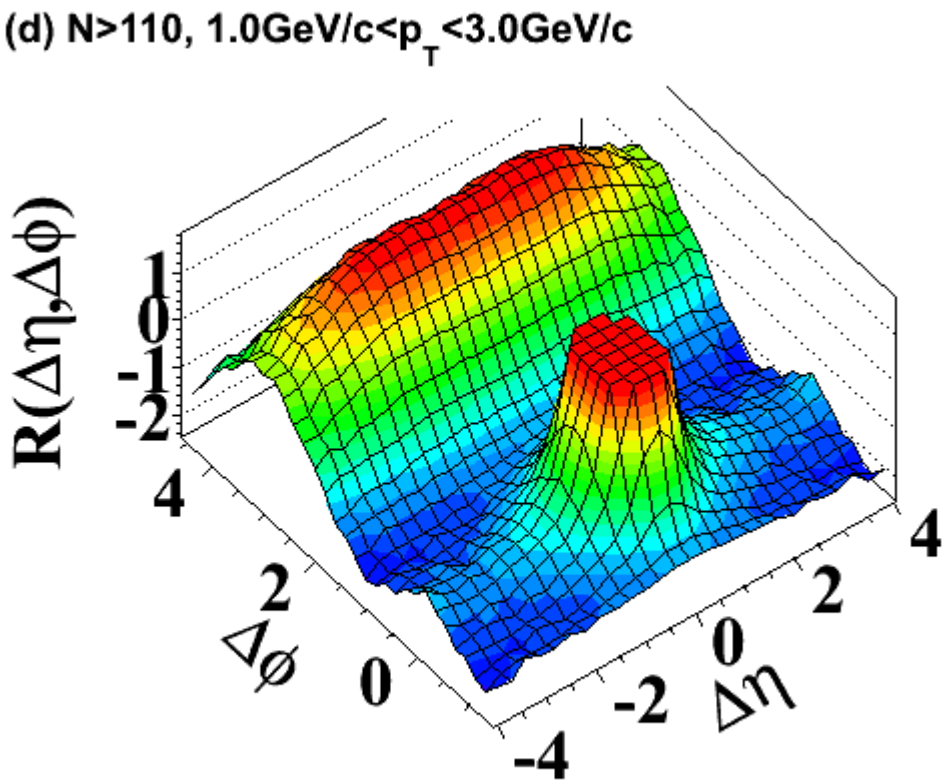
- "Annecy spectrum" promises a beautiful tool

→quantitative comparisons with full hydro

  – extract information on η/s, initial conditions (Glauber, CGC, …)

# Speaking of which…



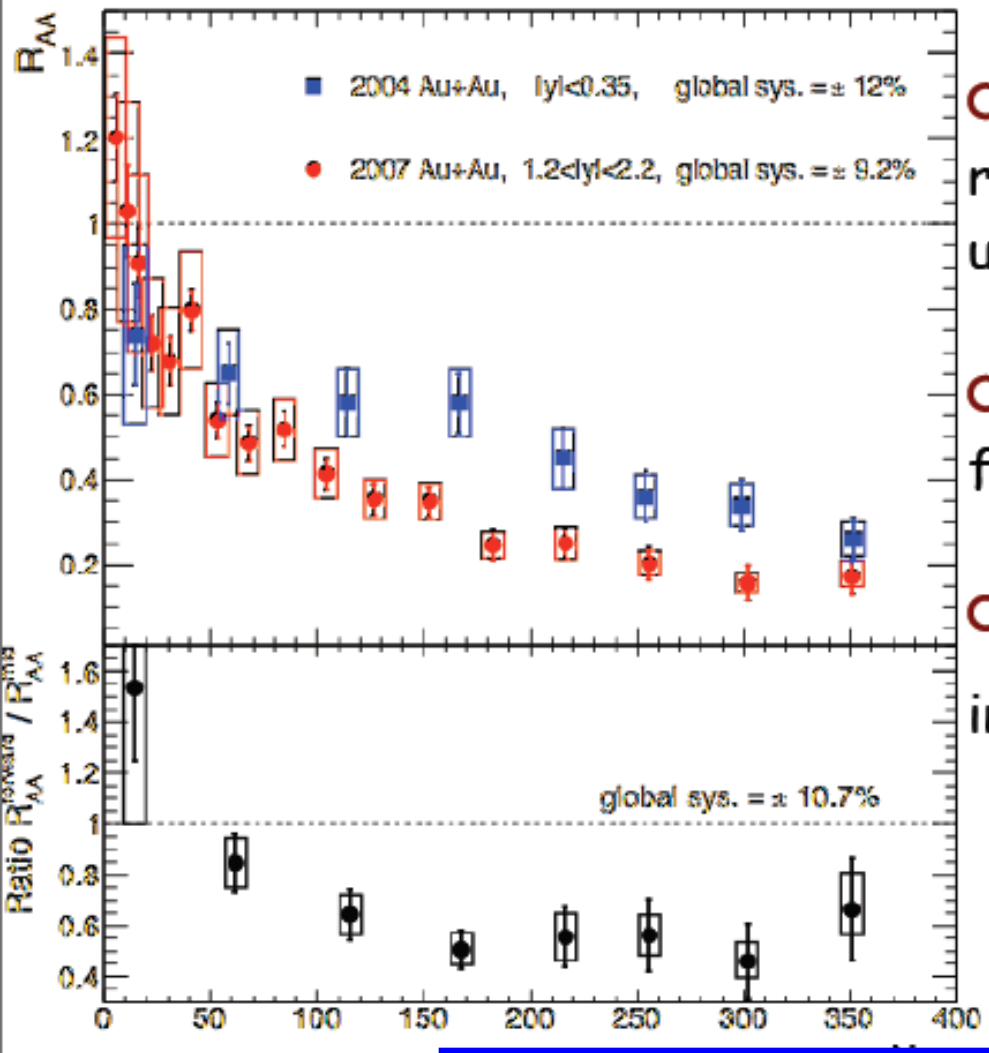




- "how 'bout a fulla Fourier decomposition of de CMS pp ridge?"

# Les Quarkonia

# New $J/\psi$ $R_{AA}$ result at forward rapidity

[arXiv:1103.6269v1]

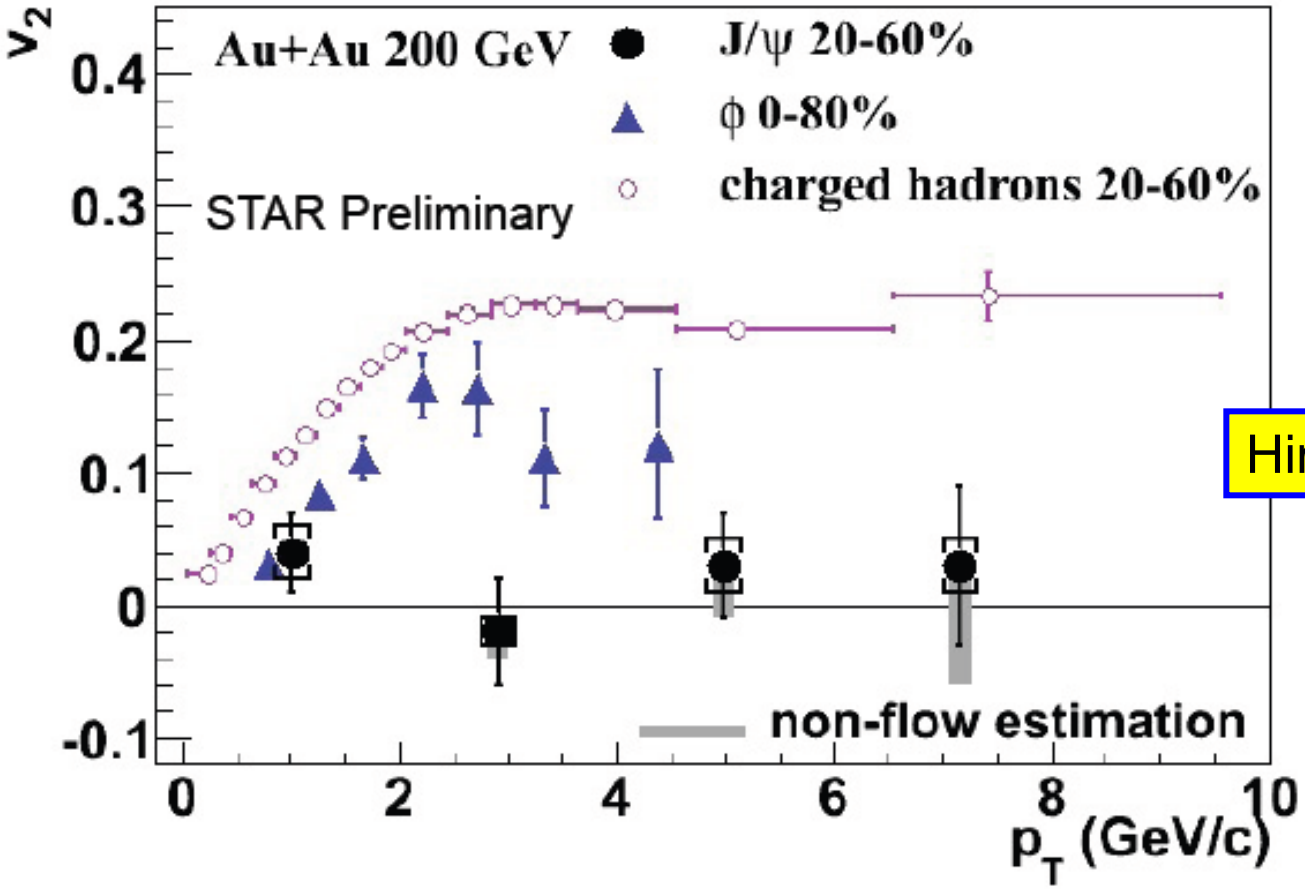



- new measurement at 1.2<|y|<2.2 with reduced statistical and systematic uncertainties.
- still shows stronger suppression at forward rapidity
- let's study $J/\psi$ suppression using information from
  - p+p (production mechanism)
  - d+Au (cold nuclear matter effects)

Cesar da Silva – PHENIX

# J/Ψ $v_2$

charged hadrons, STAR, **PRL93**, 252301 (2004)
$\phi$, STAR, **PRL99**, 112301 (2007)




Hao Qiu, poster board 60, Thu/26

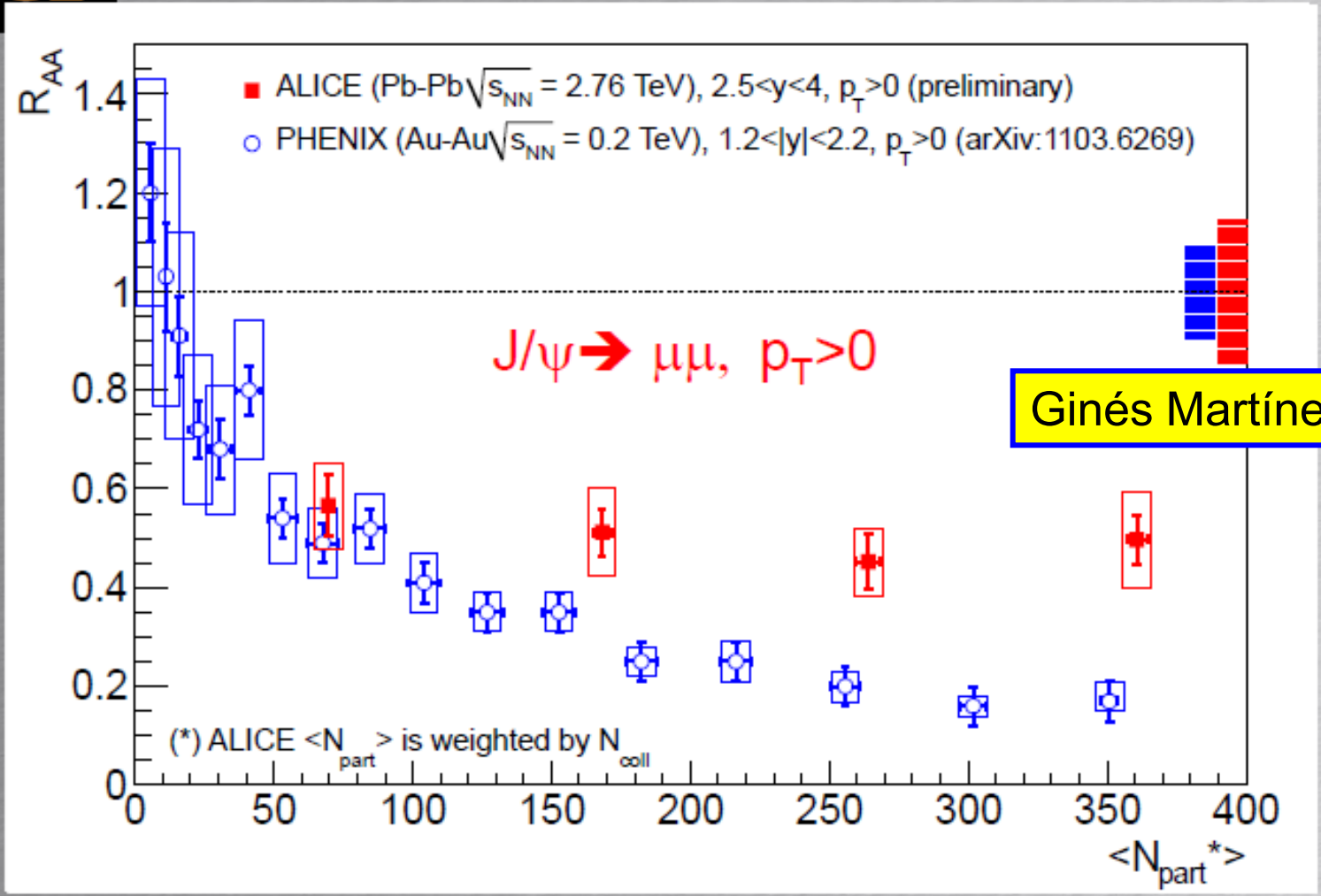
Zebo Tang, Tue/24 15:40

Hiroshi Masui – STAR

- $J/\psi$ $v_2$ ~ 0 up to $p_T$ ~ 8 GeV/c in mid-central 20-60%

➡ Disfavors coalescence from thermalized charm quarks

# J/ψ $R_{AA}$ 0.2 / 2.76 TeV



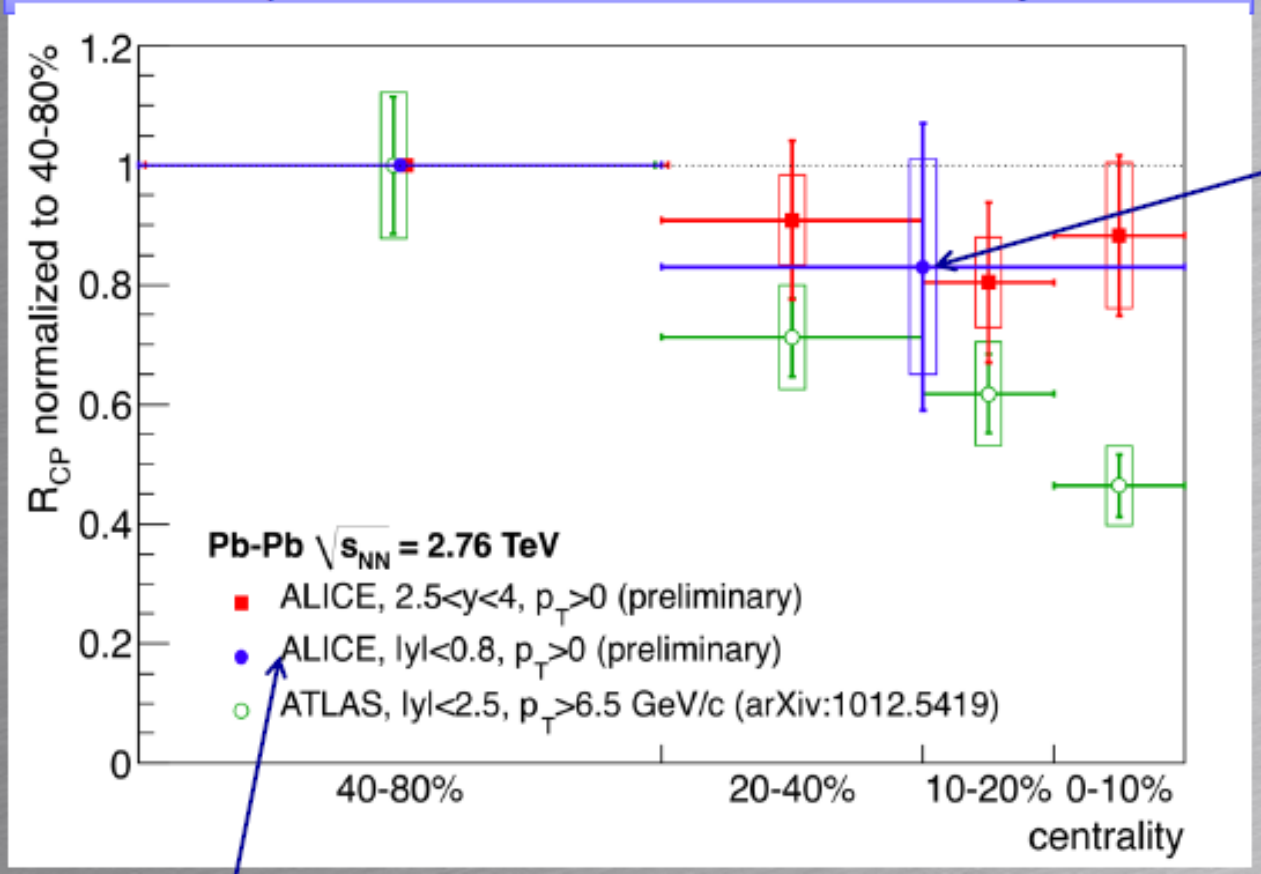

Ginés Martínez – ALICE

J/y $R_{AA}$ larger at LHC (2.5<y<4) than at RHIC (1.2<|y|<2.2);
Similar as RHIC (|y|<0.35), except for the most central bin;
$dN_{ch}/d\eta(N_{part})^{LHC} \sim 2.1 \times dN_{ch}/d\eta(N_{part})^{RHIC}$ (A. Toia talk).

# J/ψ $R_{CP}$ ATLAS/ALICE

Ginés Martínez – ALICE

« Peripheral » reference 40-80% centrality bin




Poster #75 of J. Book, J. Wiechula

## ALICE:

- 2.5<y<4.0;
- |y|<0.8
- $p_T \geq 0$ GeV/c;

## ATLAS:

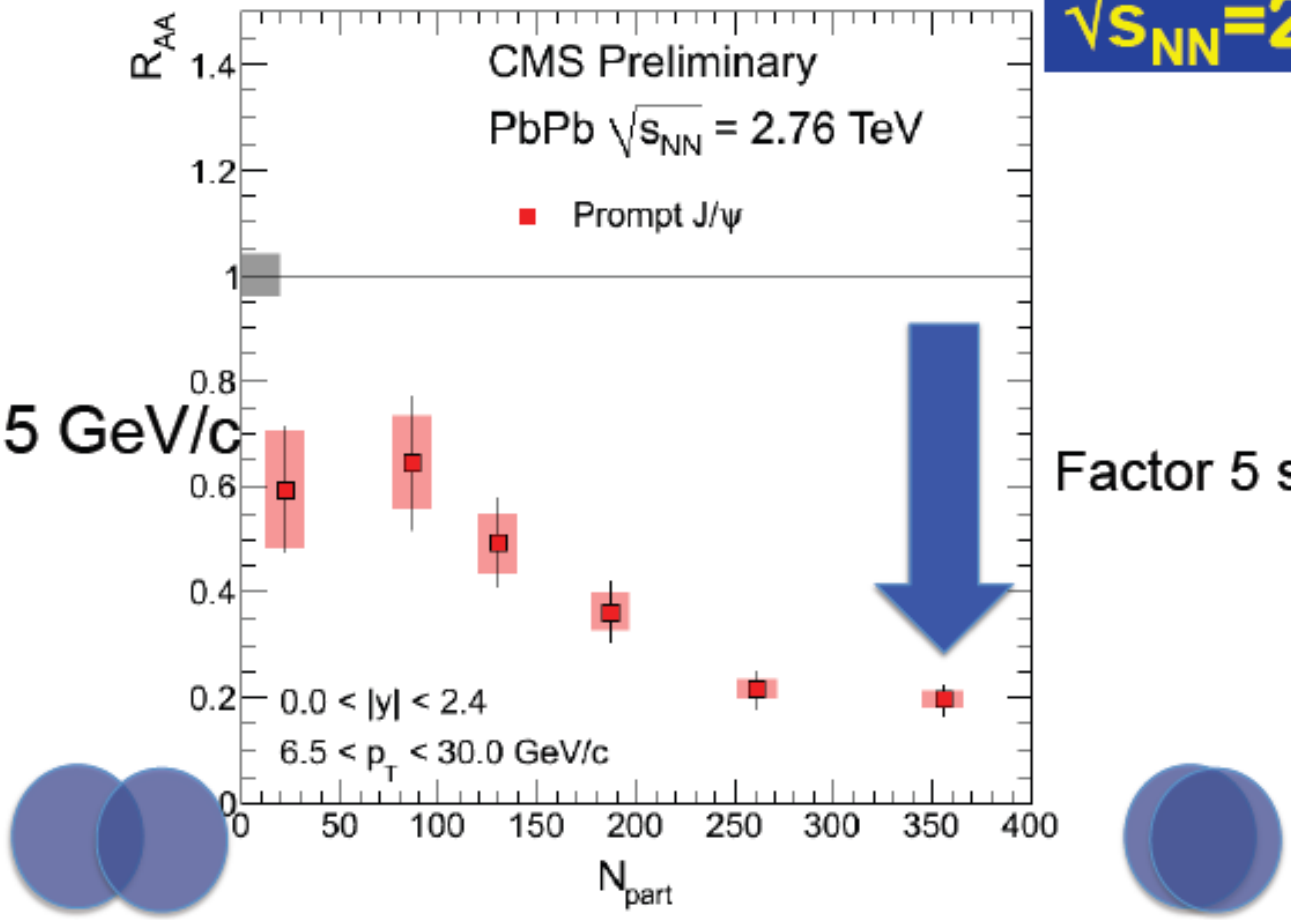
- |y|<2.4
- 80% J/ψ, $p_T \varepsilon 6.5$ GeV/c;
- Error in 40-80% centrality bin not propagated.

ALICE 2.5<y<4.0 exhibits less suppression than ATLAS data (high $p_T$, |y|<2.4); Challenging measurement in the dielectron channel.

# Prompt J/ψ $R_{AA}$

**PbPb**
**$\sqrt{s_{NN}}$=2.76 TeV**

CMS
$p_T^{J/\psi}$ > 6.5 GeV/c




Factor 5 suppression

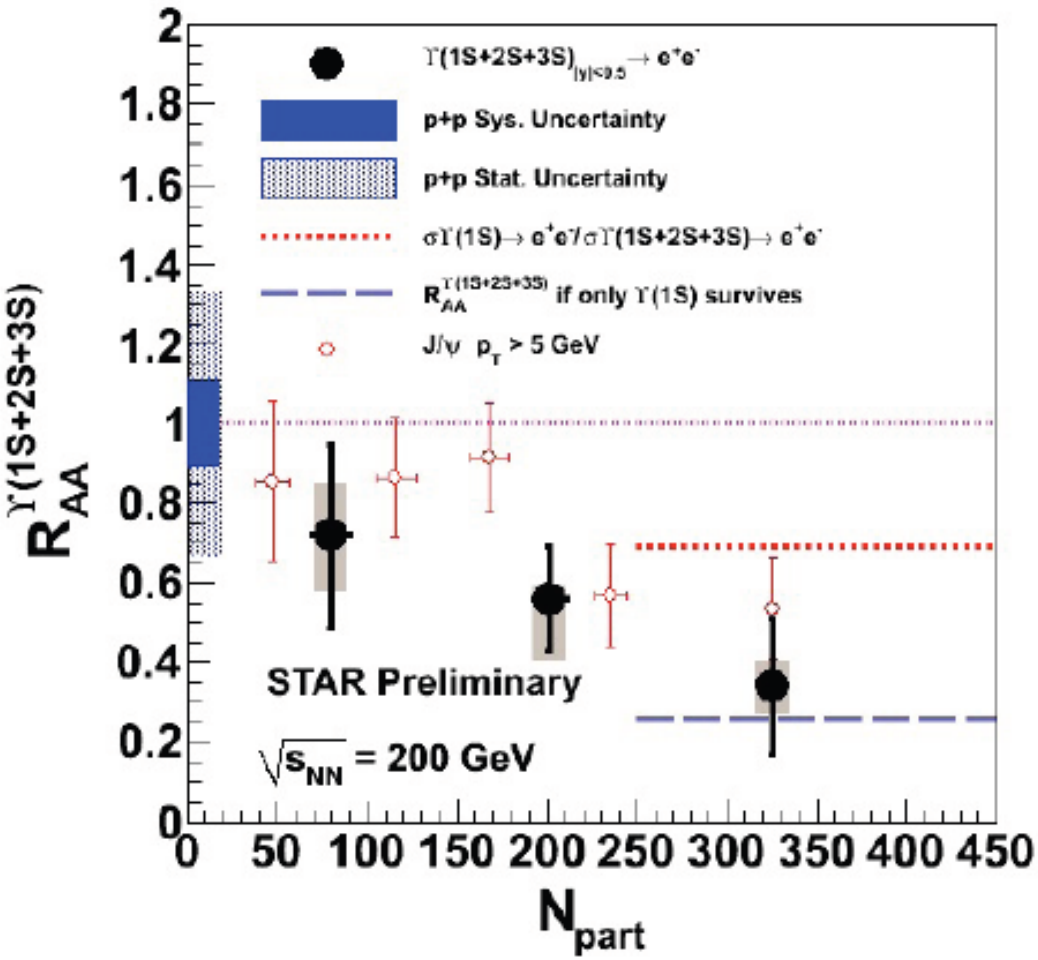
**Central 0-10%** $R_{AA}$= 0.20 ± 0.03 ± 0.01

**Peripheral 50-100%** $R_{AA}$= 0.59 ± 0.12 ± 0.10

# $\Upsilon$ $R_{AA}$

Hiroshi Masui – STAR

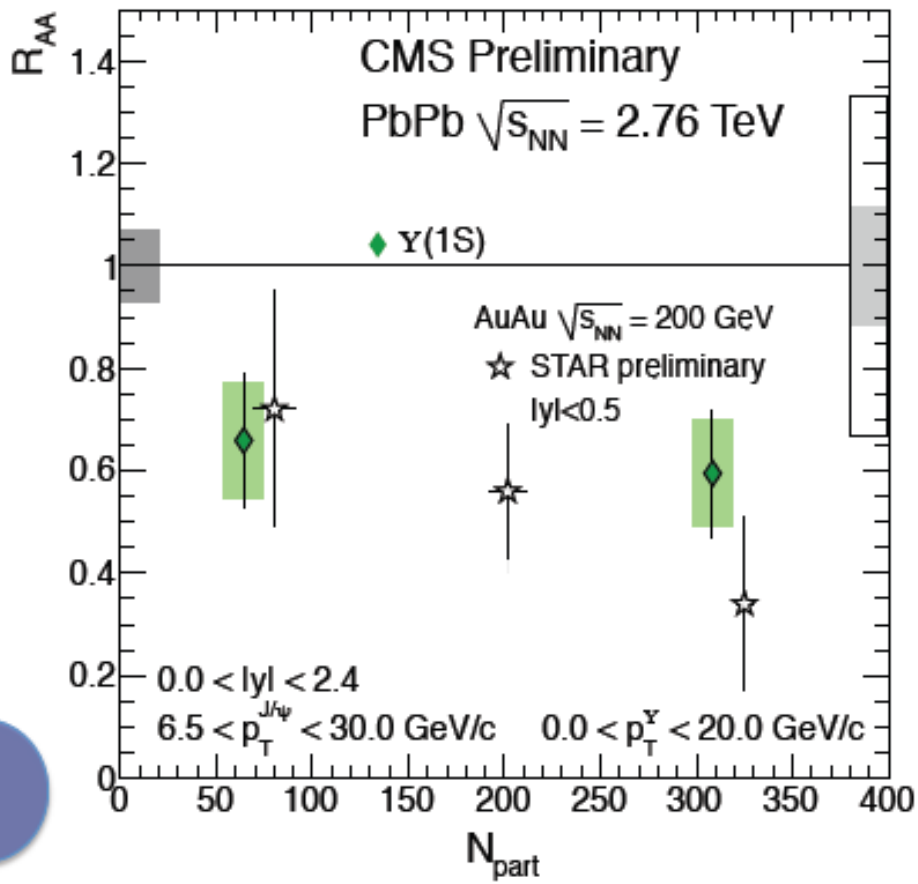
Rosi Reed, poster board 48, Thu/26




- $\Upsilon$(1S+2S+3S) suppression at central collisions
  - Similar suppression with high $p_T$ $J/\psi$
- First measurement of $\Upsilon$ suppression
- Statistical uncertainty will be improved by more than a factor of 2
  - $\times$ 3 in p+p 2009
  - $\times$ 2 in Au+Au 2011

# $\Upsilon(1S)$ $R_{AA}$

**PbPb**
**$\sqrt{s_{NN}}$=2.76 TeV**



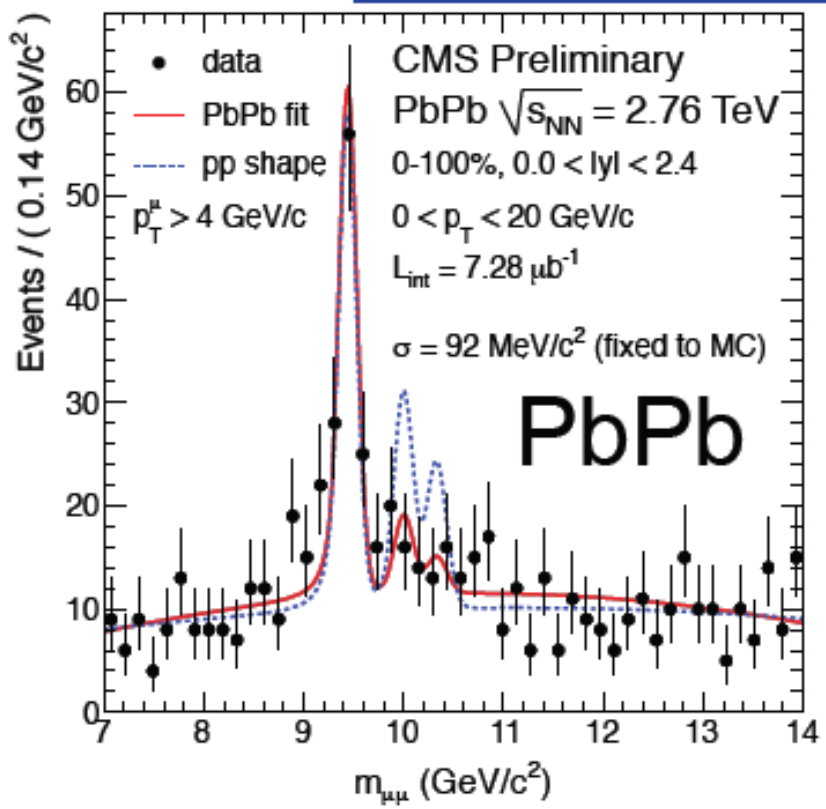

- **Comparison with STAR**
  - CMS $\Upsilon(1S)$ $R_{AA}(0\text{-}100) = 0.62 \pm 0.11 \pm 0.10$
  - STAR $\Upsilon(1+2+3S)$ $R_{AA}(0\text{-}60) = 0.56 \pm 0.11\ ^{+0.02}_{-0.10}$

R. Reed (poster)

# $\Upsilon$(2S+3S) Suppression PbPb $\sqrt{s_{NN}}$=2.76 TeV

$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp}}$$

- **Pros of a double ratio**
  - Acceptance cancels
  - Efficiency cancels
- **Potential differences**
  - Remaining systematics 9%, from line shapes




$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

arXiv : 1105.4894
Submitted to PRL

**Hypothesis: no suppression ⇒ p-value 1%**
**Significance of the suppression 2.4 $\sigma$**

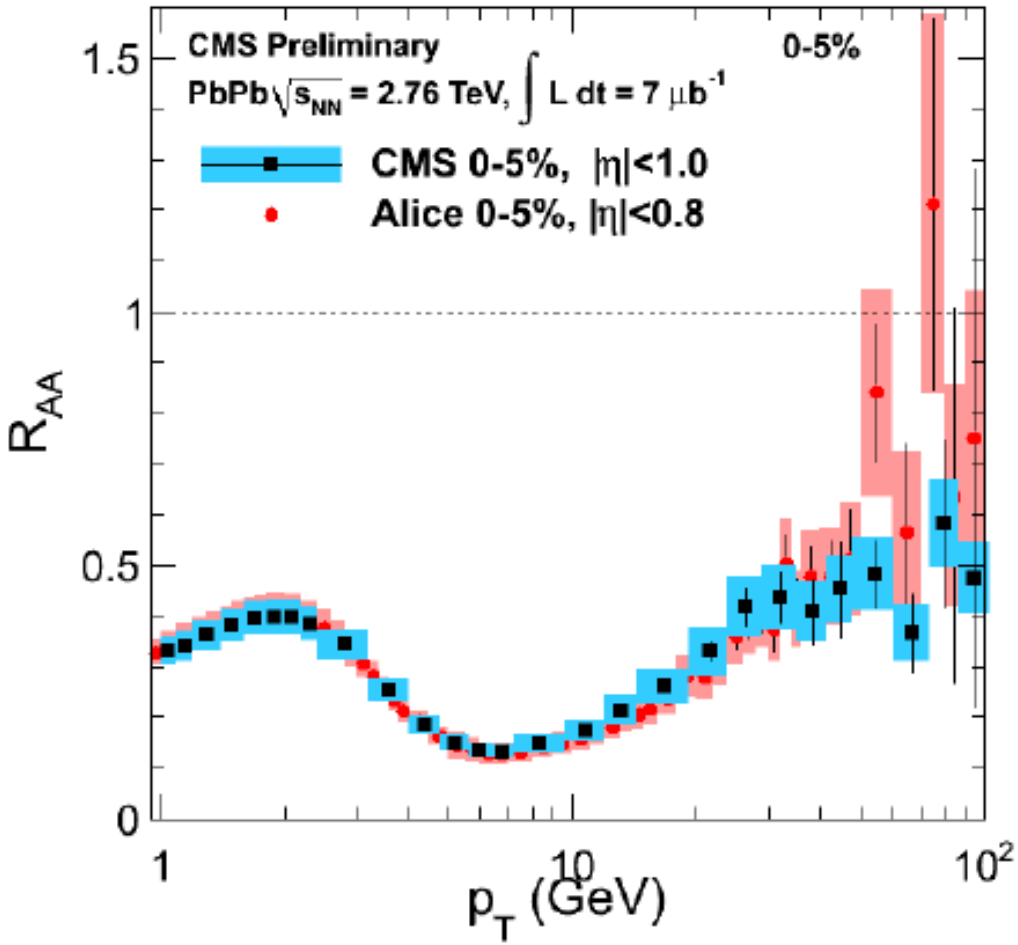
# La frontière

- establish charmonium, bottomonium suppression(/recombination?) pattern in full glory
  - high statistic measurements
  - open flavour baseline / contamination
  - pA baseline

- the full picture should unravel before our eyes in the near future

# La suppression à haut $p_T$

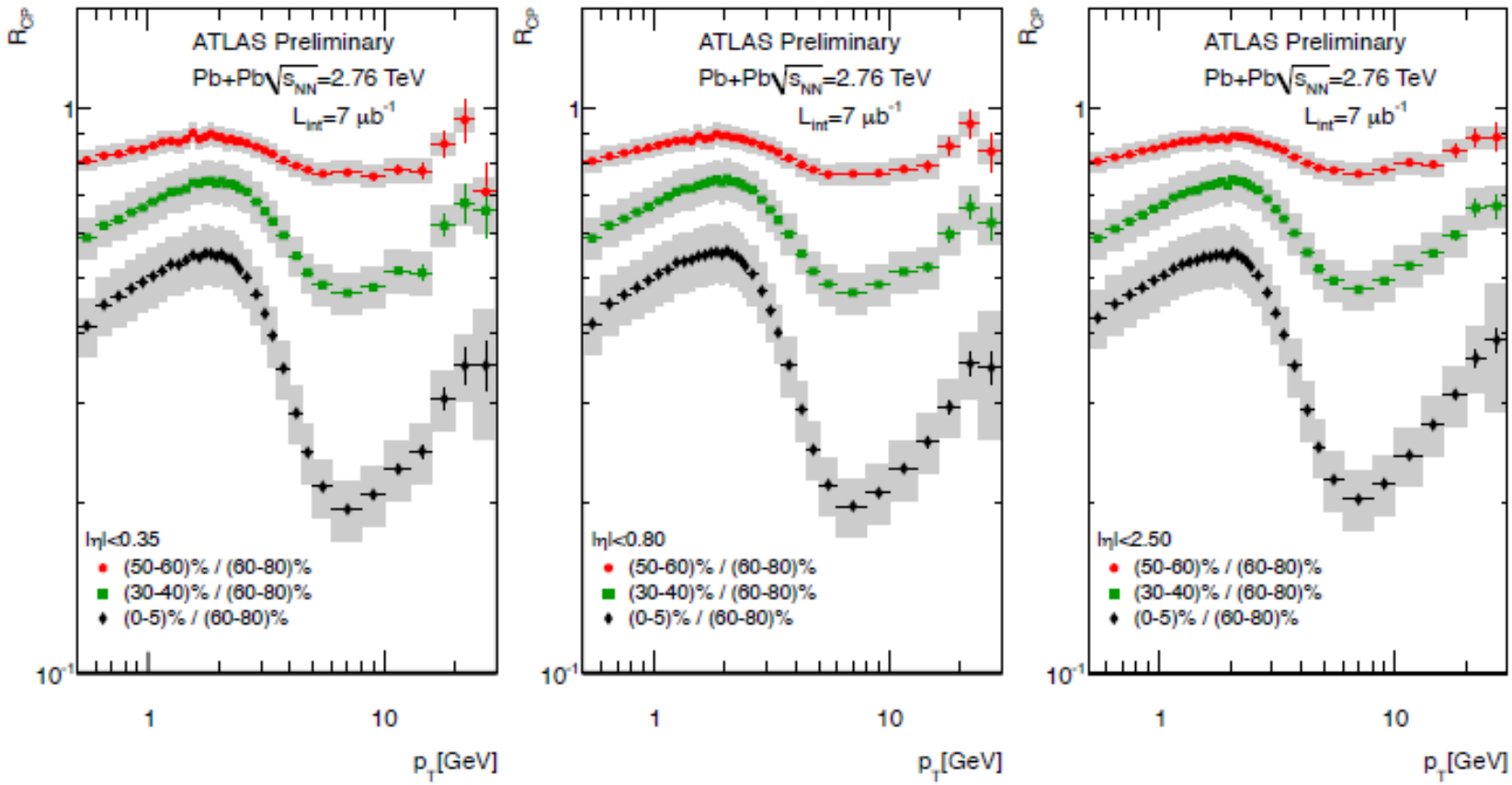
# Comparison between CMS and ALICE $R_{AA}$




Harald Appelshäuser (ALICE), Yen-Jie Lee (CMS) & Co

Peter Steinberg – ATLAS

# Charged particle $R_{CP}$

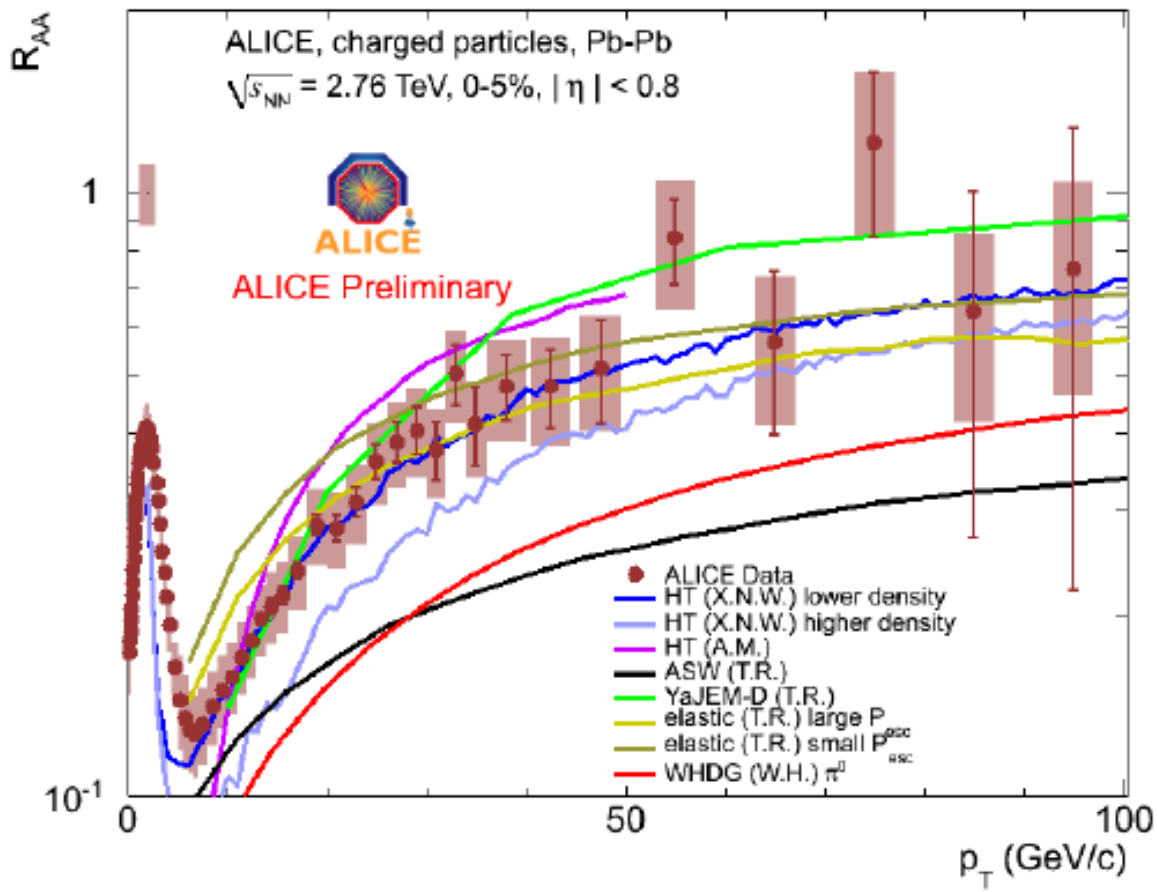


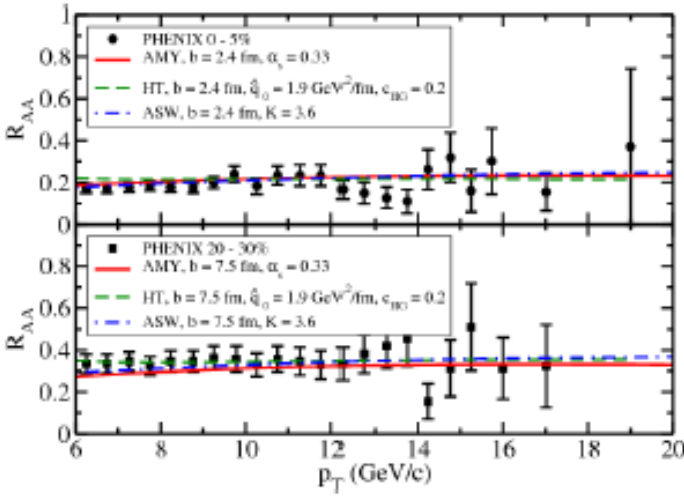

Strong suppression seen in more central events via charged $R_{CP}$

No η dependence observed

**for details, see talk by Sasha Milov (3:20pm Thurs.)**

# charged particle $R_{AA}$ - models



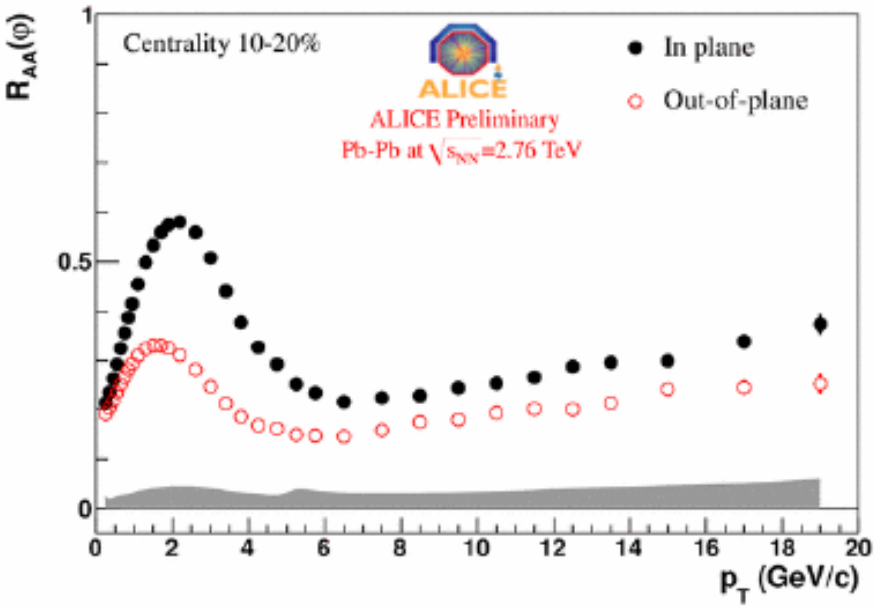

- pronounced $p_T$ dependence of $R_{AA}$ at LHC

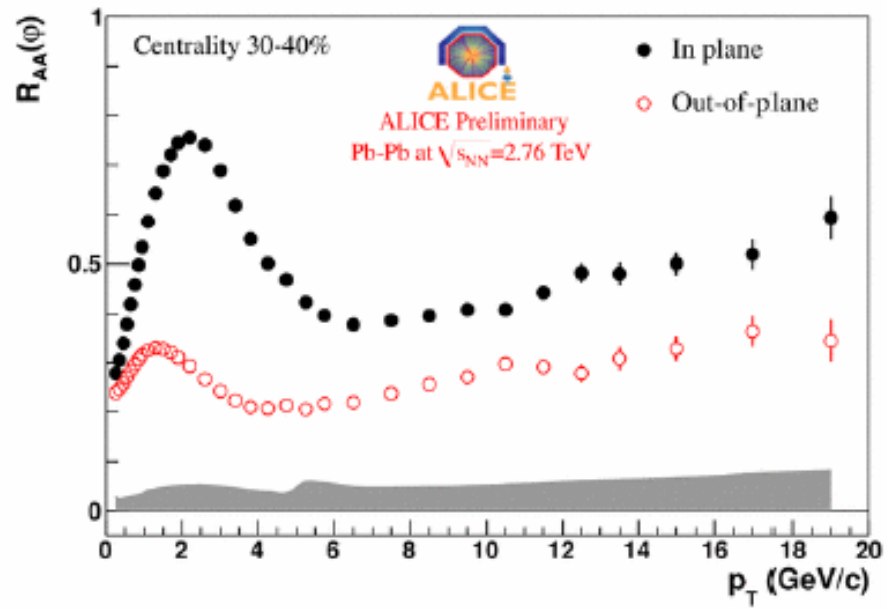
→ sensitivity to details of the energy loss distribution

# reaction plane dependent $R_{AA}$

further constraint to models ($l^2$, $l^3$, …)

Talk: A Dobrin



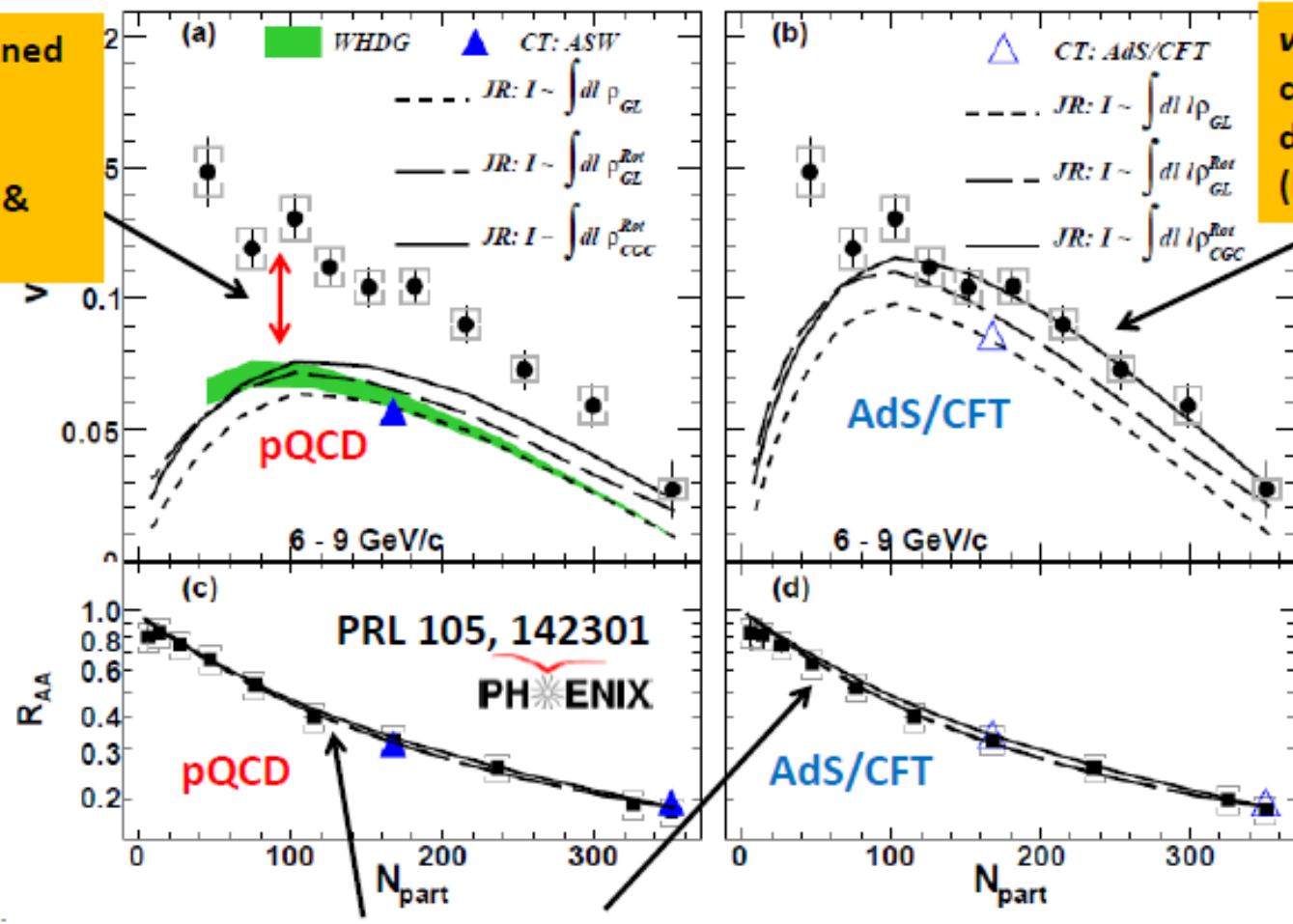

$$R_{AA}(\varphi) = R_{AA}(1 + 2v_2 \cos(2\varphi))$$

# Path-length dependence of E loss



$v_2$ not explained by pQCD (even with fluctuations & saturation)

$v_2$ explained by cubic path length dependence (like AdS/CFT)




Theory calculations:
Wicks et al., NPA784, 426
Marquet, Renk, PLB685, 270
Drees, Feng, Jia, PRC71, 034909
Jia, Wei, arXiv:1005.0645

$R_{AA}$ explained by both models

Stefan Bathe - PHENIX

# La frontière…

- $R_{AA}$ from 100's MeV to 100 GeV and beyond!
- dependence on orientation wrt reaction plane
  - $l^2$, $l^3$, $l^?$ behaviour !
- asymmetric collisions at RHIC (U-U, Cu-Au,…)

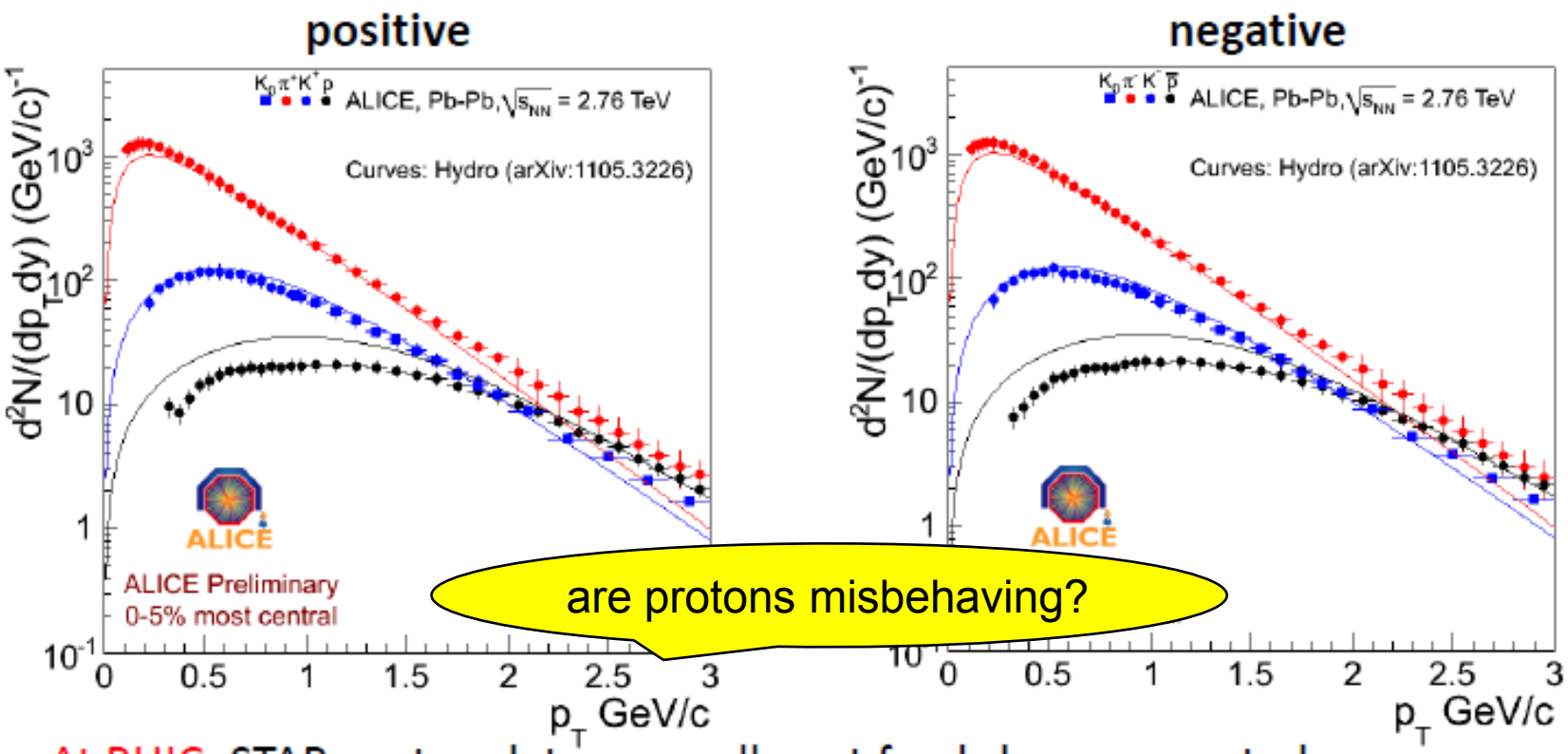
→tight constraints on energy loss models

# Les particules identifiées

ainsi font, les protons:

… trois p’tits tours, et puis s’en vont!

Michele Floris – ALICE




are protons misbehaving?

At RHIC: STAR proton data generally not feed-down corrected.

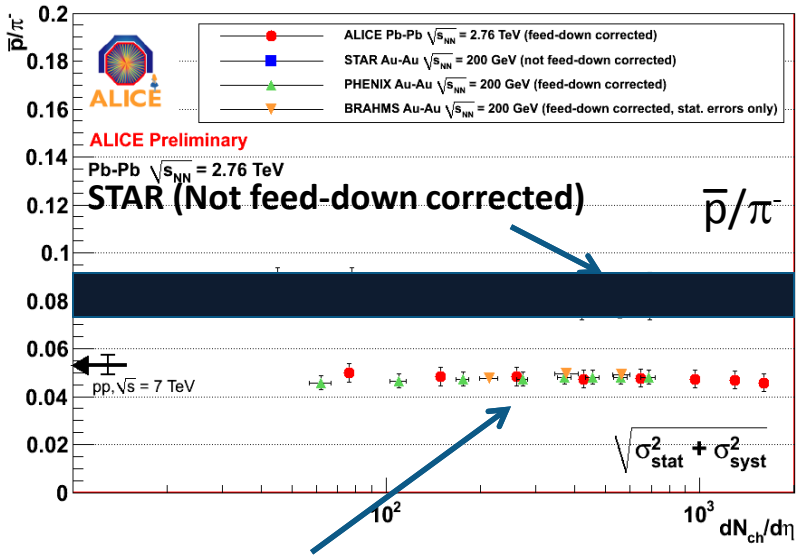
Large feed down correction

➔ Consistent picture with feed-down corrected spectra

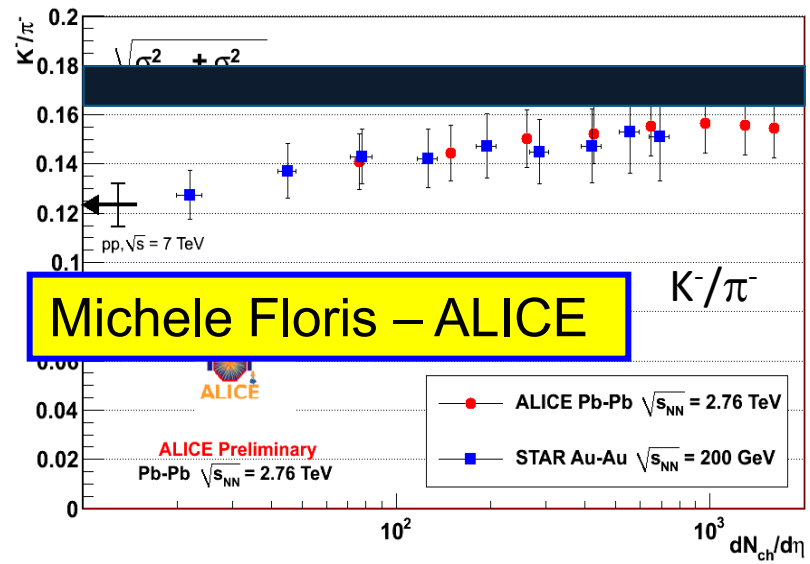
At LHC: ALICE spectra are feed-down corrected

- Harder spectra, flatter p at low pt
- Strong push on the p due to radial flow?

*STAR, PRL97, 152301 (2006)*
*STAR, PRC 79 , 034909 (2009)*
*PHENIX, PRC69, 03409 (2004)*




ALICE, BRAHMS, PHENIX (feed-down corrected)




*STAR, PRC 79 , 034909 (2009*
*PHENIX, PRC69, 03409 (2004*
*BRAHMS, PRC72, 014908 (2005*

## *Predictions for the LHC*

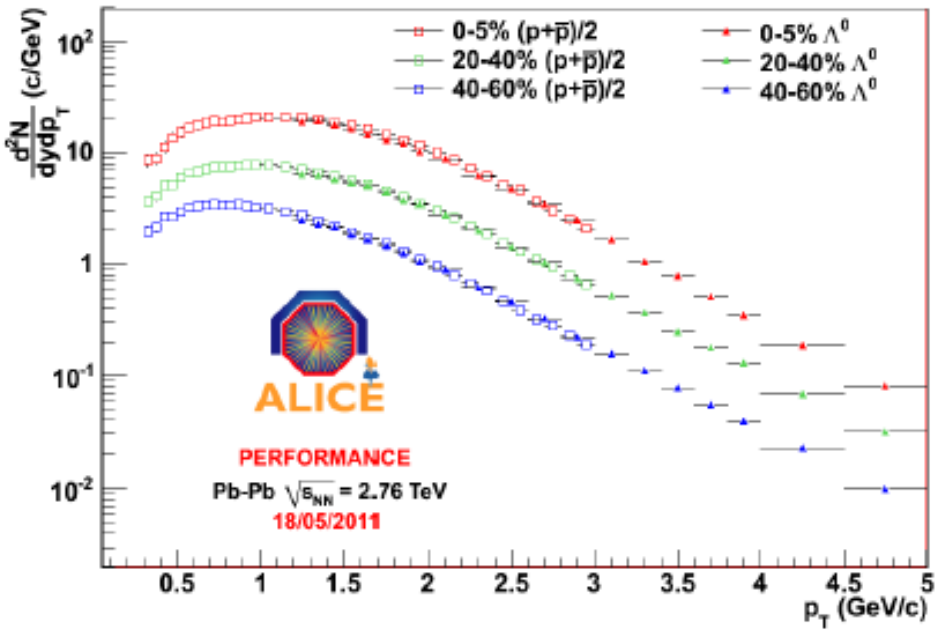
| Ratio | Data | (1) | (2) |
|---|---|---|---|
| $p/\pi^+$ | 0.0454+-0.0036 | 0.072 | 0.090 |
| $p/\pi^-$ | 0.0458+-0.0036 | 0.071 | 0.091+0.009-0.007 |
| $K/\pi^+$ | 0.156 +- 0.012 | 0.164 | 0.180+0.001-0.001 |
| $K/\pi^-$ | 0.154 +- 0.012 | 0.163 | 0.179+0.001-0.001 |

**(1) A. *Andronic et al, Nucl. Phys. A772 167 (2006)*** **(2) *J. Cleymans et al, PRC74, 034903 (2006)***

T = 164 MeV, $\mu_B$ = 1 MeV

T = (170±5) MeV and $\mu_B$ =1+4 MeV

Michele Floris – ALICE

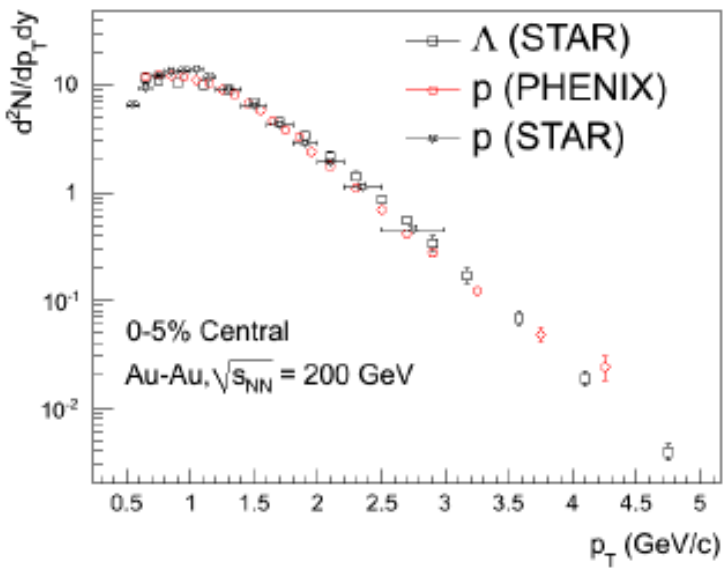



Lambda very similar to protons in shape and yield

Feed-down correction:

- p corrected for weak decays
- Λ corrected for f.d. from the Ξ

naughty protons…

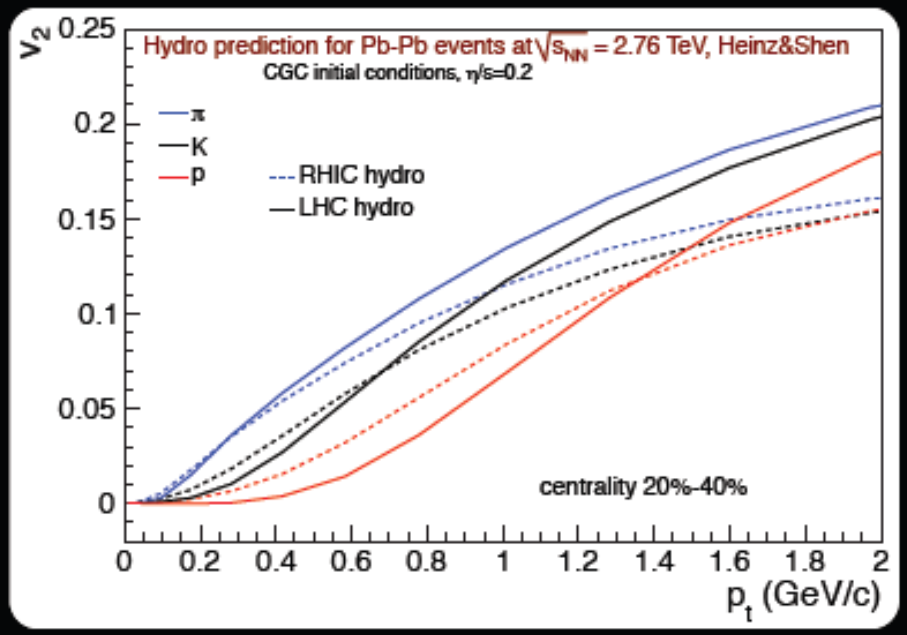


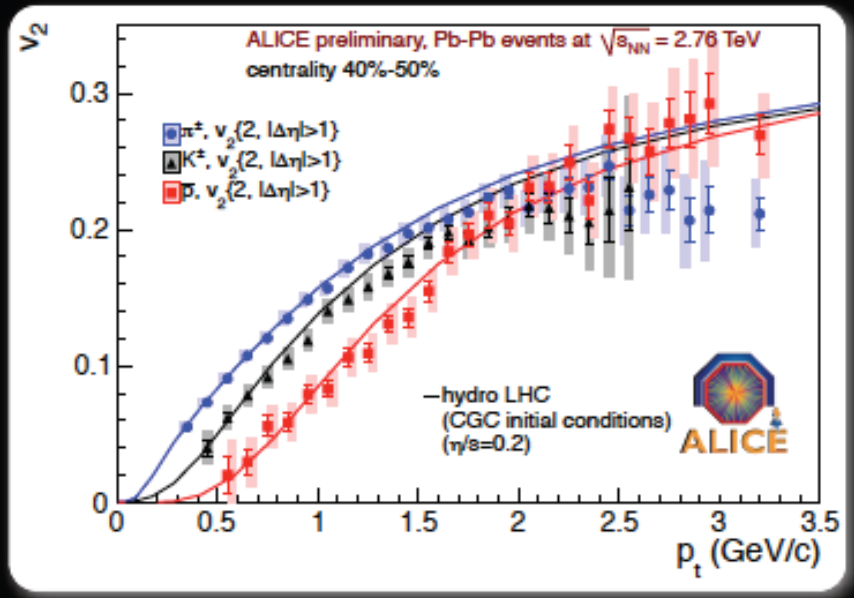

… this was similar at RHIC, if one compares feed-down corrected spectra

*STAR, PRL98, 062301 (2007)*
*PHENIX, PRC69, 03409 (2004)*

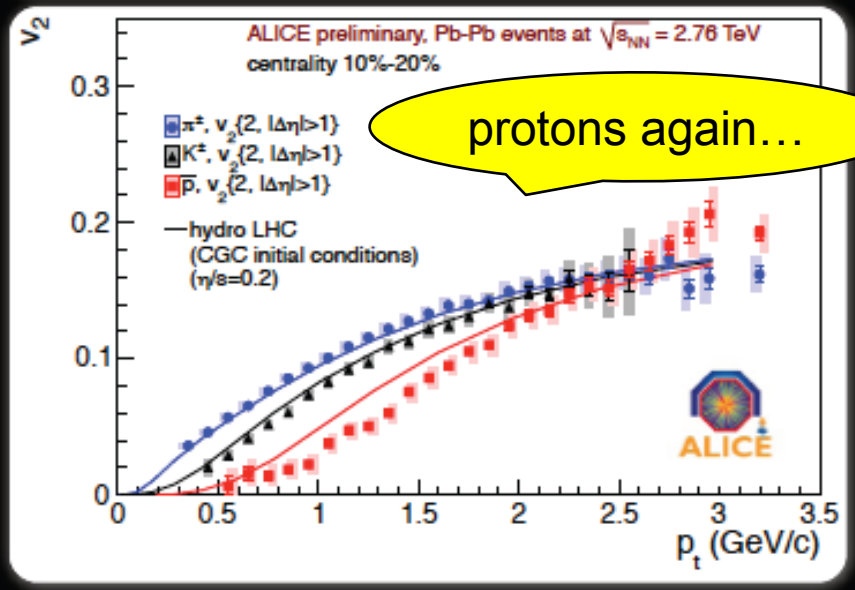
# $v_2$ for identified particles

Hydro: Shen, Heinz, Huovinen & Song, arXiv:1105.3226




Hydro: Shen, Heinz, Huovinen & Song, arXiv:1105.3226




protons again…

hydro models predict larger mass splitting
data shows mass splitting and agrees well with hydro predictions for mid-central collisions
for more central collisions the anti-proton flow is not described by the same calculations

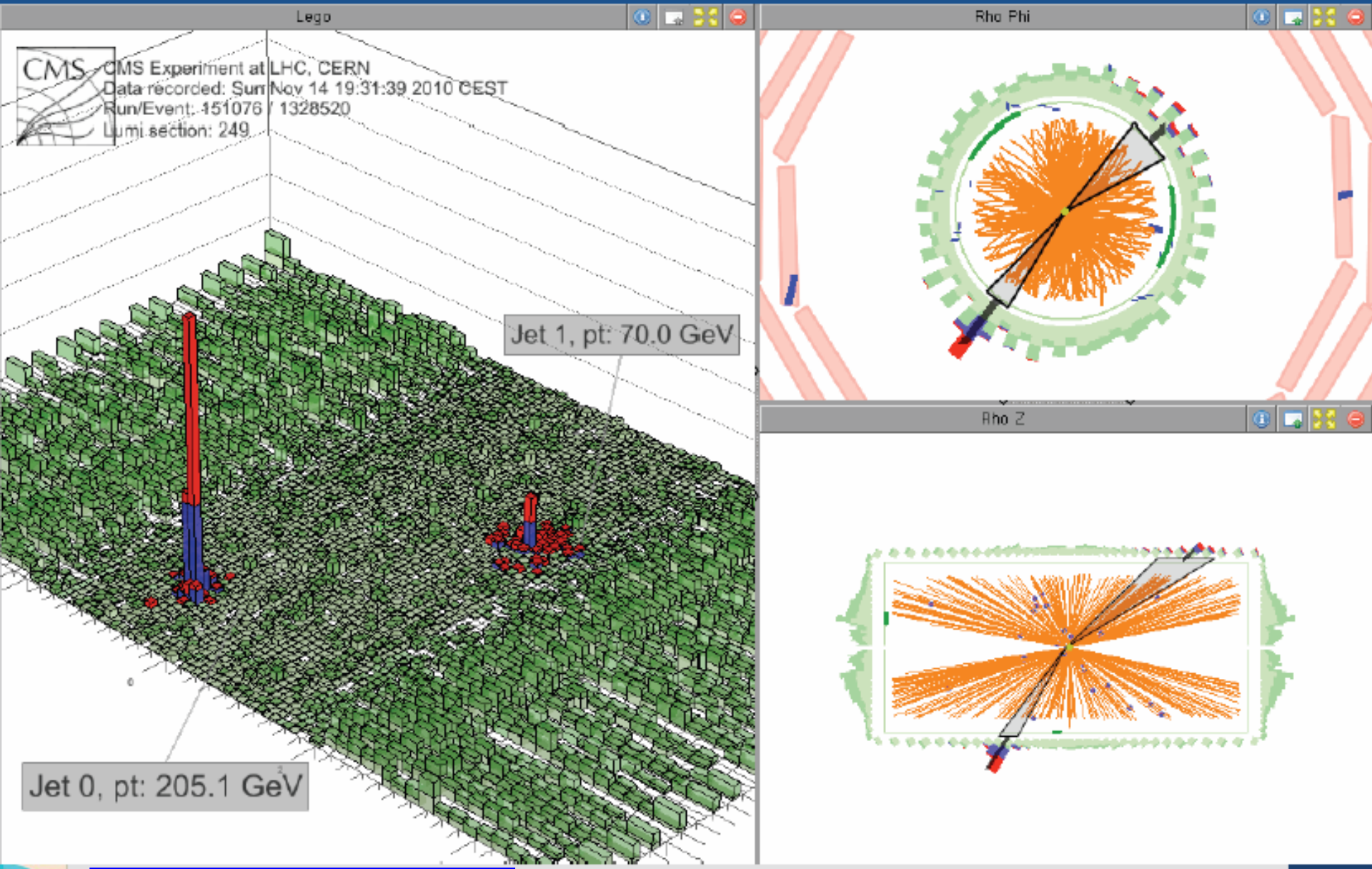
Raimond Snellings – ALICE

# La frontière

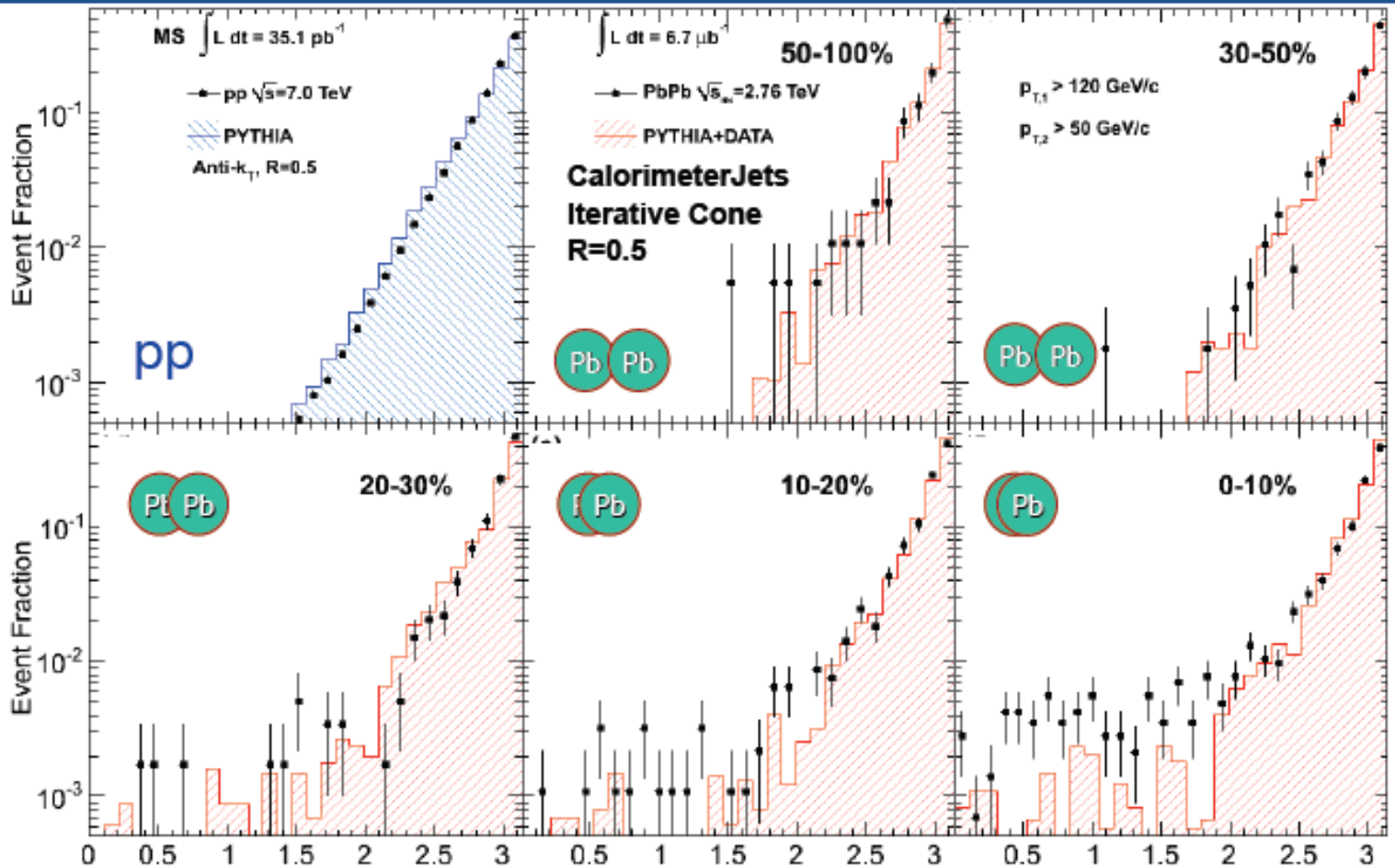
- understand protons' hydrodynamics
  - fly in the ointment of otherwise triumphant hydro …
- how about the thermal model?
  - took a bit of a beating this time
  - need full-glory, high stats fits including $\Xi^-$, $\Omega^-$, $\varphi$, …
  - can it be cured?
  - at what price? ($\gamma_s$, $\gamma_q$, anyone?)

# Les Jets

# Jets in the CMS detector



# Jet Angular Correlation




1st lesson learned:

The propagation of high $p_T$ partons in a dense nuclear medium does not lead to a visible angular decorrelation

# Di-jet Asymmetry, R = 0.4

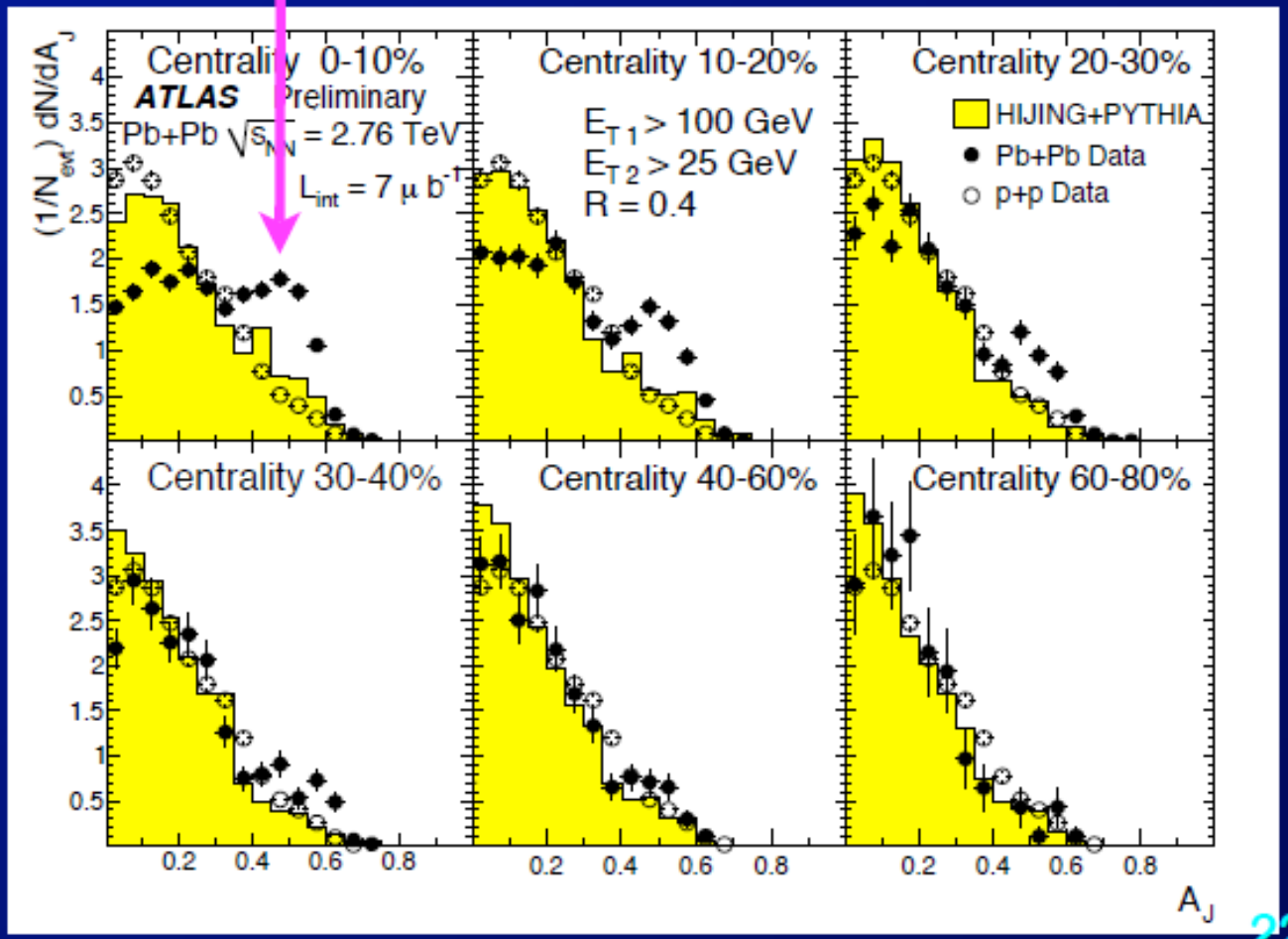
30 Gev

Brian Cole – ATLAS

R = 0.4

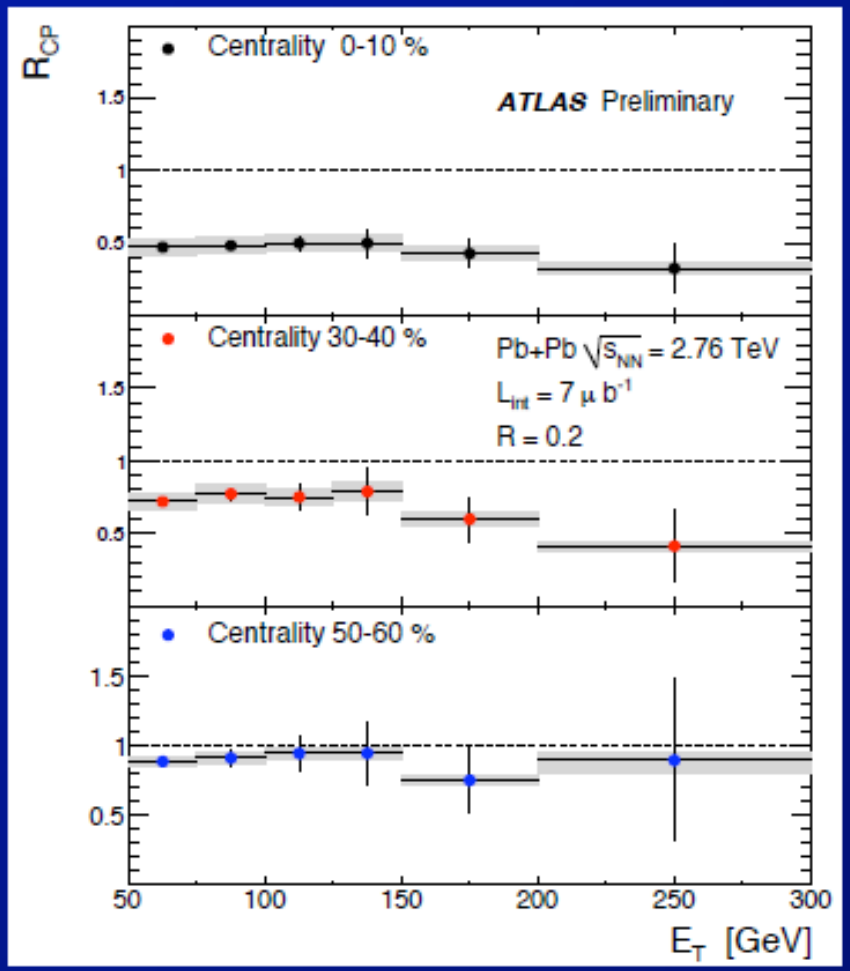
$E_{T1}$ > 100 GeV

$E_{T2}$ > 25 GeV

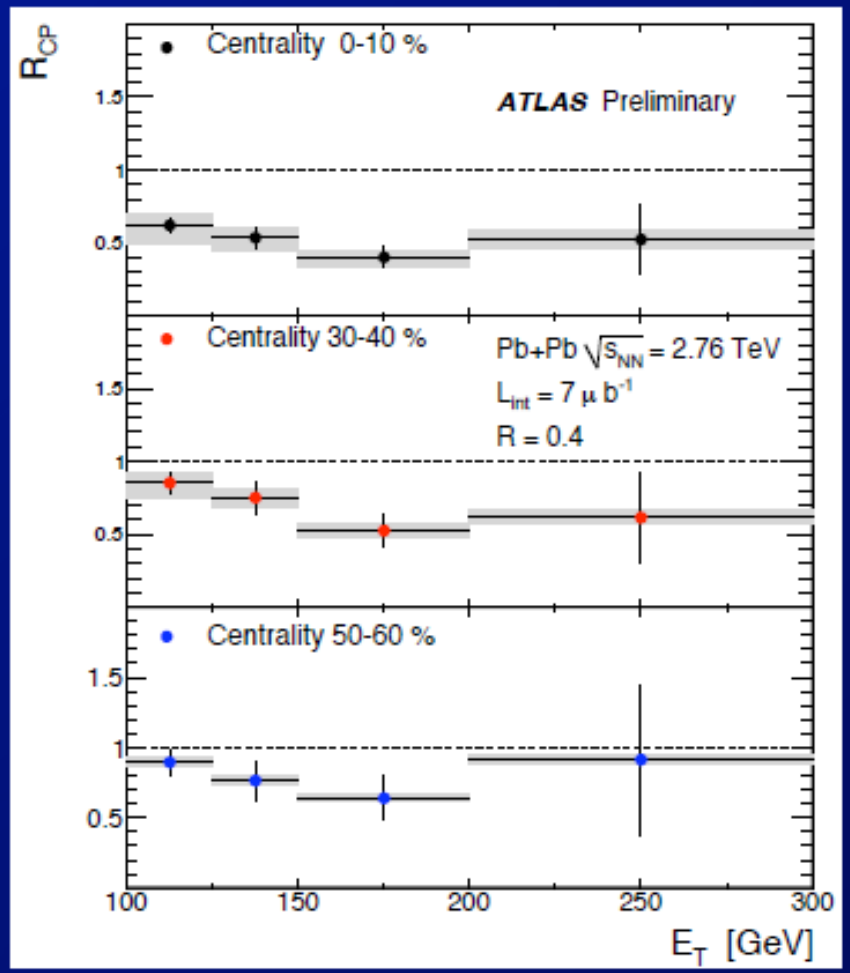


# Single Jet central to peripheral ratio: $R_{cp}$

R = 0.2




R = 0.4

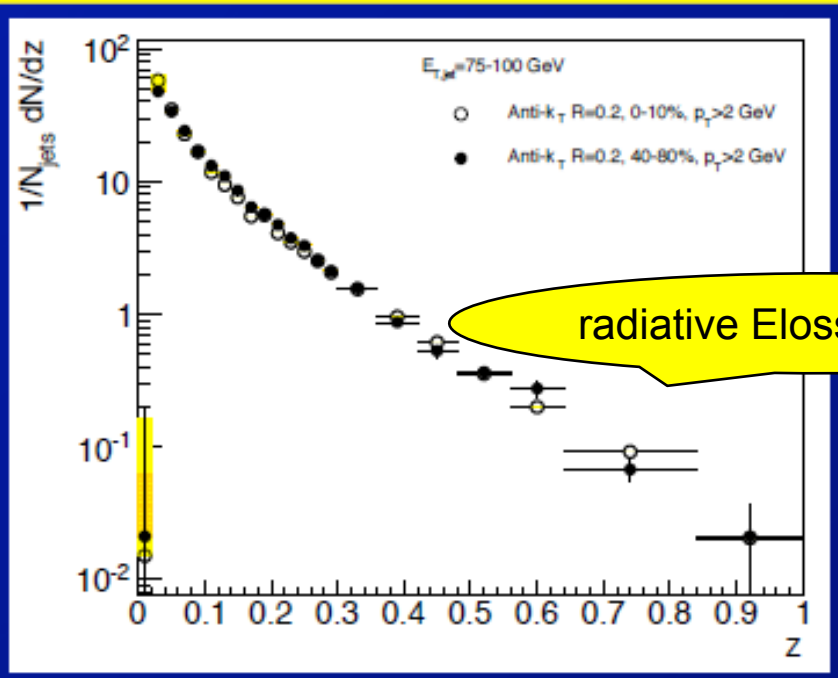


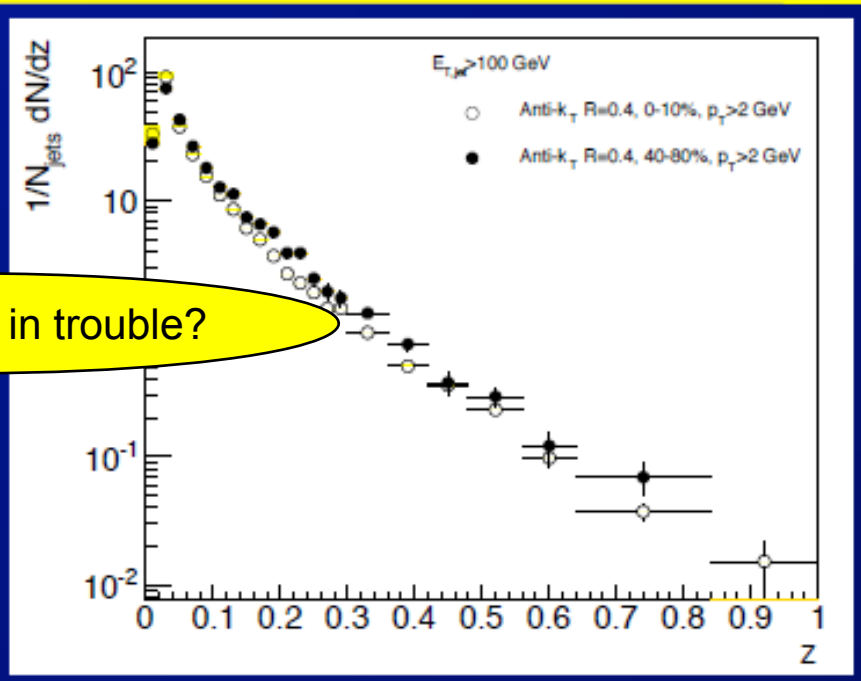

- **Observe:**

Brian Cole – ATLAS

⇒ Suppression independent of jet $E_T$ within statistical ⊕ systematic errors

# Jet Fragmentation (Longitudinal)




radiative Eloss in trouble?

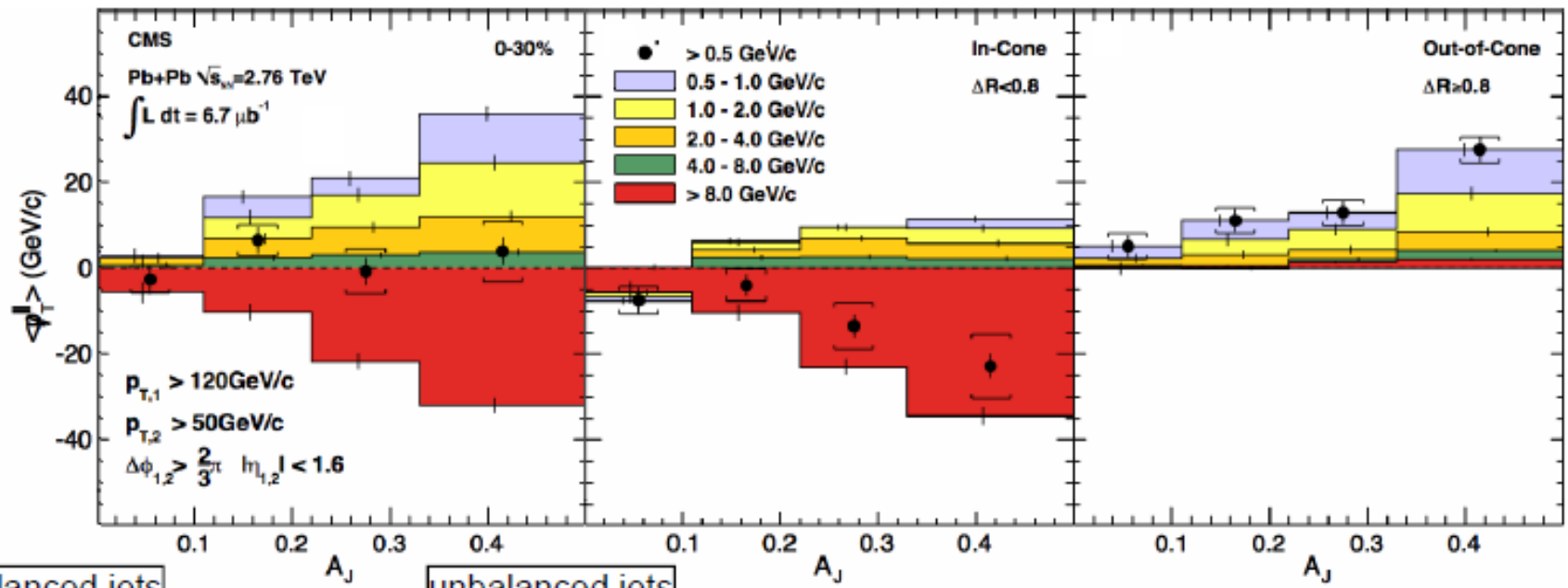
- Measure distribution of fragment $p_T$ along jet axis: $z \equiv \left(\frac{p_T^{had}}{E_T}\right) \cos \Delta R$
  - For both R = 0.2 and R = 0.4 jets
  - Systematic uncertainties from jet energy resolution, centrality dependence of jet energy scale.
- Compare central (0-10%) to peripheral (60-80%)

Brian Cole – ATLAS

# Where is the energy? spread out low $p_T$ particles

$$\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$

0-30% Central PbPb


balanced jets

unbalanced jets

Low $p_T$, full acceptance
Momentum is balanced

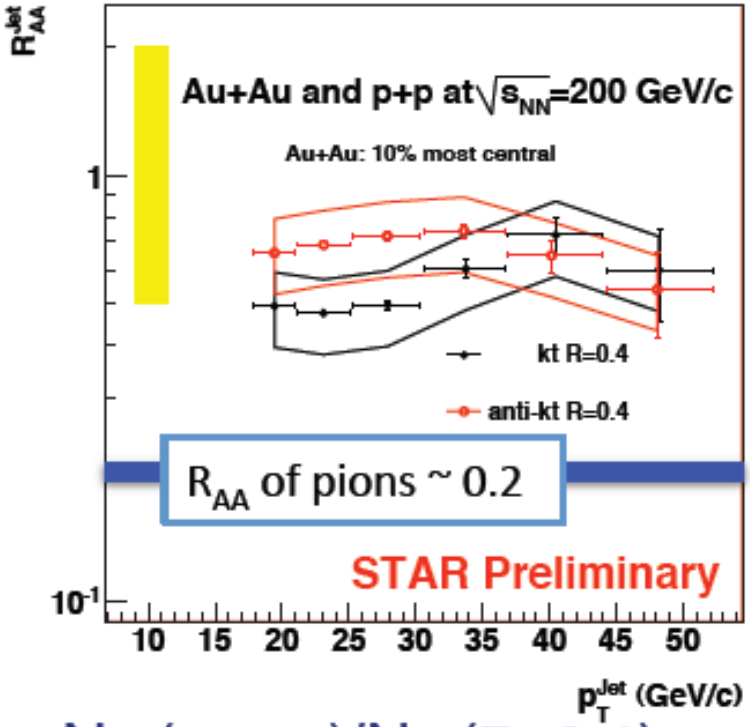
In-cone large momentum imbalance at high $p_T$
Consistent with calorimetry

Out-off-cone low $p_T$ particles balance the complete event

arXiv:1102.1957

M. Tonjes (Tue), C. Roland (Wed)

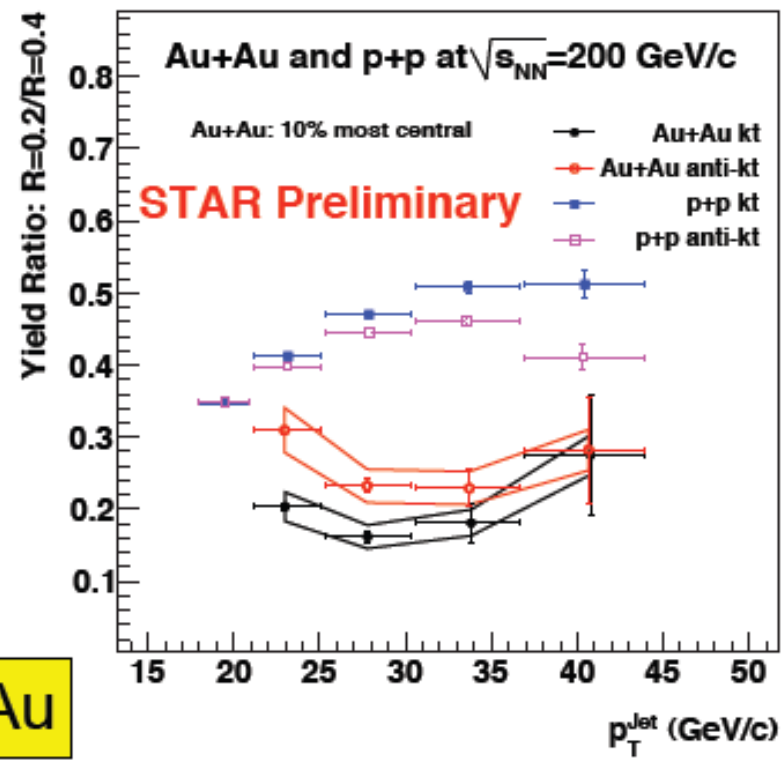
# Evidence of jet broadening




$k_T$ and Anti-$k_T$ known to have different sensitivities to background

Jet $R_{AA} < 1 (R=0.4)$

Algorithms fail to recover all jet




$N_{jet}(R=0.2)/N_{jet}(R=0.4)$ vs $p_{T,jet}$

p-p:

"Focussing" of jet with jet energy

Au-Au:

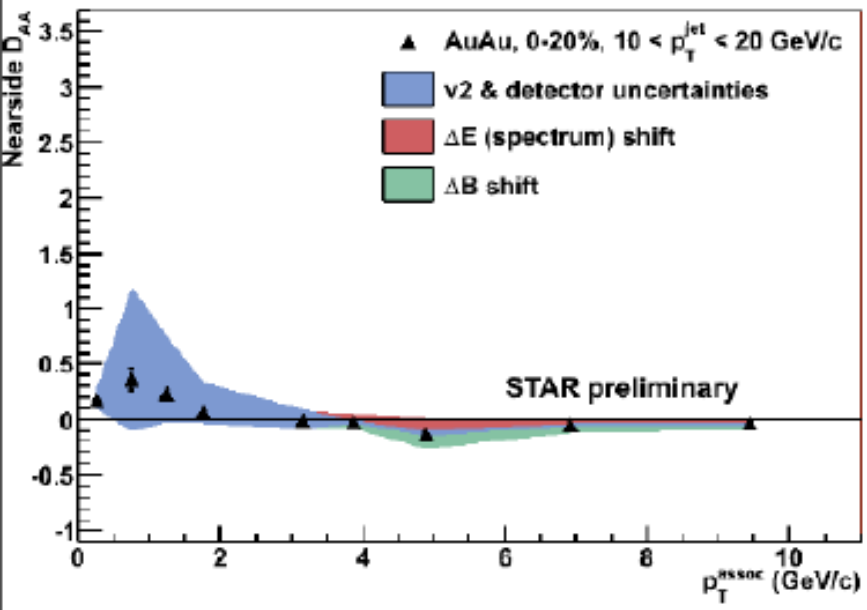
"Broadening" of jet compared to p-p

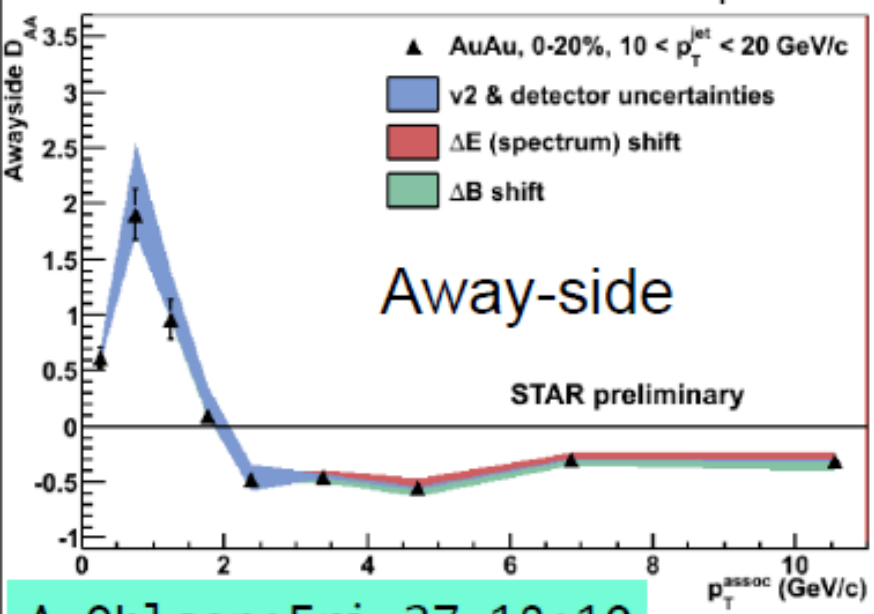
Jet fragmentation broader in Au-Au

Helen Caines – STAR

# Jet-hadron: Energy balance

Helen Caines – STAR




A.Ohlson:Fri 27-18:10

$D_{AA}$ = Au-Au - p-p Energy difference

$$D_{AA}(p_T^{assoc}) = Y_{AA}(p_T^{assoc}) \cdot p_{T,AA}^{assoc} - Y_{pp}(p_T^{assoc}) \cdot p_{T,pp}^{assoc}$$

$$\Delta B = \int dp_T^{assoc} D_{AA}(p_T^{assoc})$$

Near-side:

$$\Delta B = 0.6 \; {}^{+1.9\,+\,0.5}_{-1.0\,-\,0.4} \text{(sys) GeV/c}$$

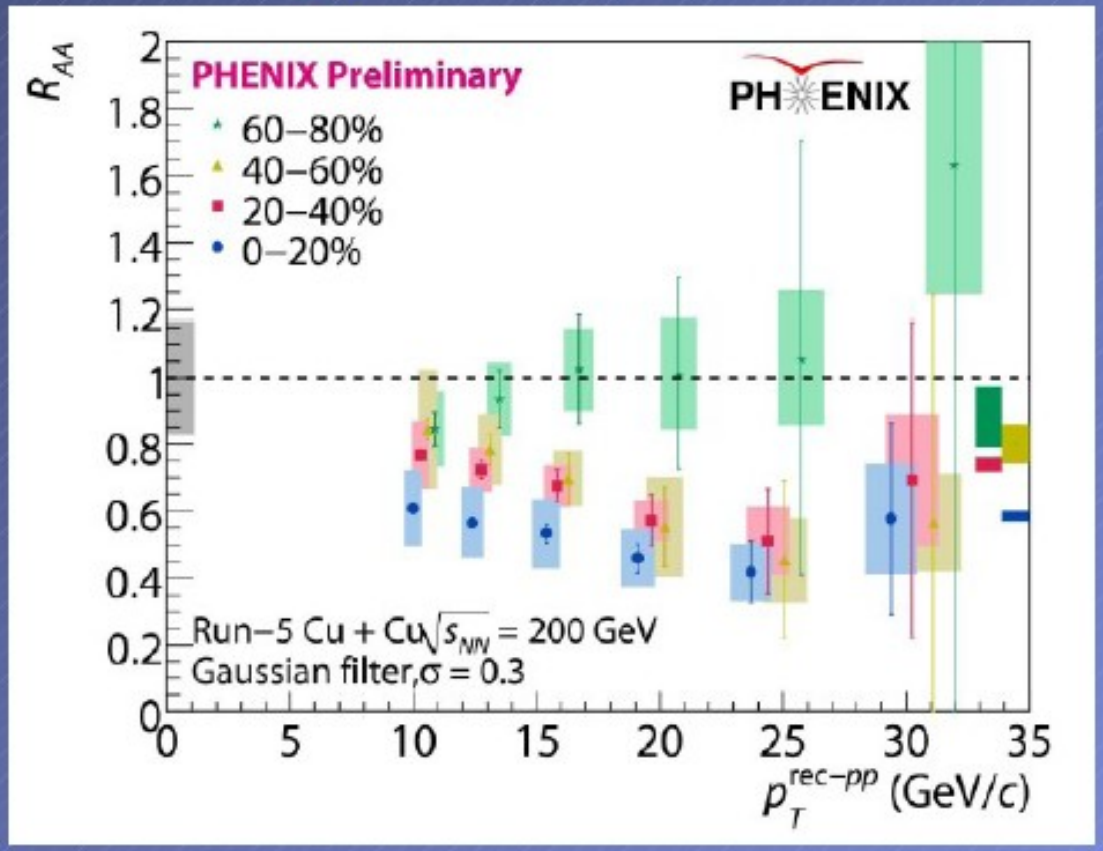
Away-side:

$$\Delta B = 1.5 \; {}^{+1.7\,+\,0.5}_{-0.4\,-\,0.4} \text{(sys) GeV/c}$$

Energy lost at high $p_T$ approximately recovered at low $p_T$ and high R

# Jet $R_{AA}$ in 200 GeV Cu-Cu

## $R_{AA}$ of fully reconstructed jets




Centrality-dependent suppression of jet yields observed.

Could be out-of cone radiation from medium interaction

Or the jet shape or other properties are modified and makes the jet fail the rejection cut

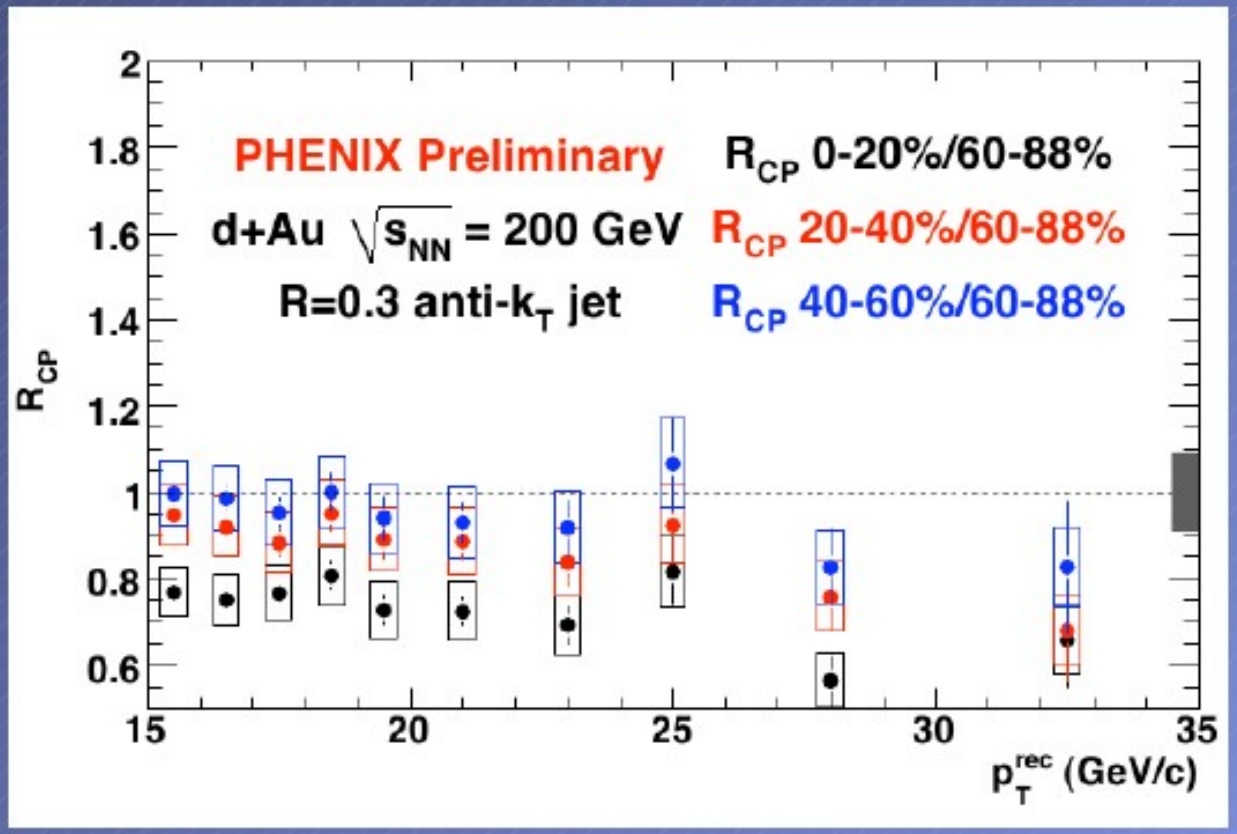
Either one would be a *really* interesting result

N. Grau

Martin Purschke – PHENIX

# Caveat: Know your Reference

$R_{CP}$ of fully reconstructed jets from d+Au




All $R_{AA}$ measurements need a corresponding $R_{dA}$ measurement as crosscheck

The data are presently $R_{CP}$ but may indicate that CNM effects should not be ignored.

Stay tuned.

Martin Purschke – PHENIX

# La frontière…

- up to the stratosphere…
  - $\gamma$/W/Z-jet fragmentation functions!
- and down to the fertile soil again…
  - explore the surroundings of away-side jets
    - broadening? softening? re-heating?
  - more “organic” jet algorithms?
    - can one catch the whole jet, and then look inside as a function of distance?
  - in-medium fragmentation vs reaction plane
    - path length dependence!
  - hadrochemistry of in-medium fragmentation
  - jet-hadron correlations
- b-tagged jets (quark vs gluon jets)
- extreme suppression?
  - true “mono-jet” events? what do they look like?
- pA reference, reconstructed jets at RHIC, …

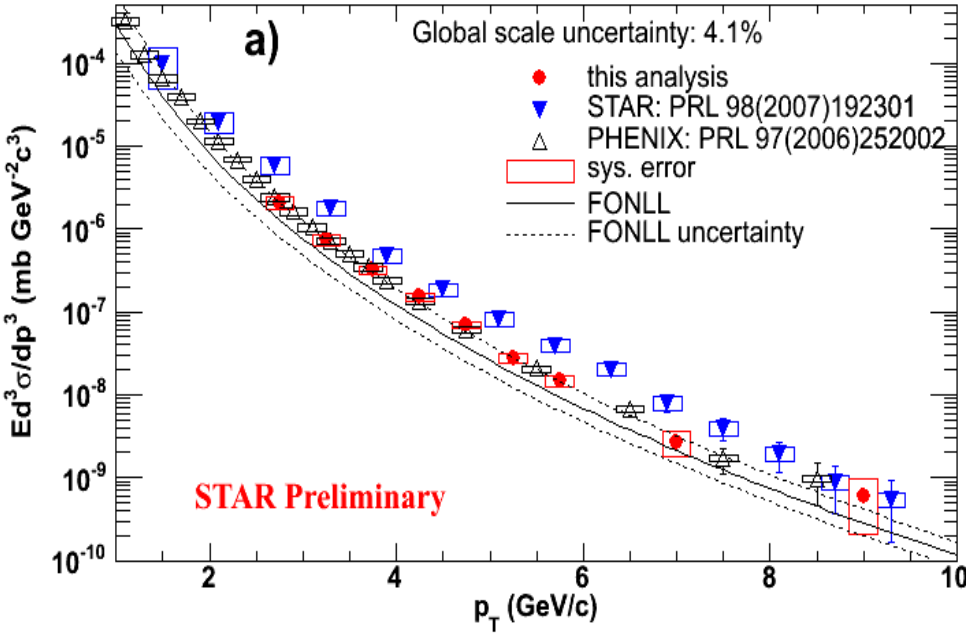
# Les Saveurs Lourdes

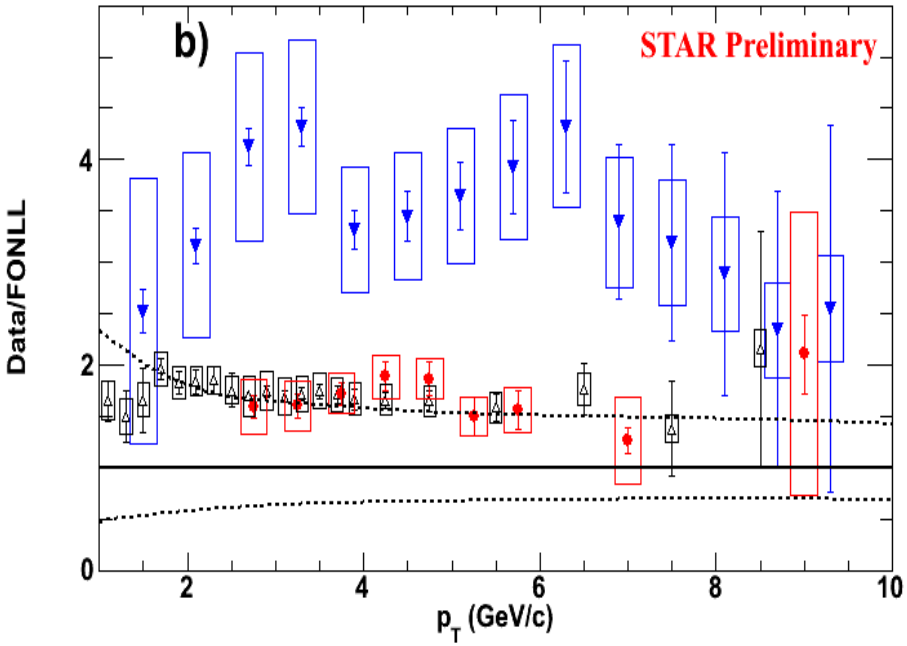
# PHENIX v STAR electrons

- progress since QM2009 on NPE discrepancy

→ new result from STAR in pp

  – e.g.: Wei Xie (STAR) @ Hard Probes 2010

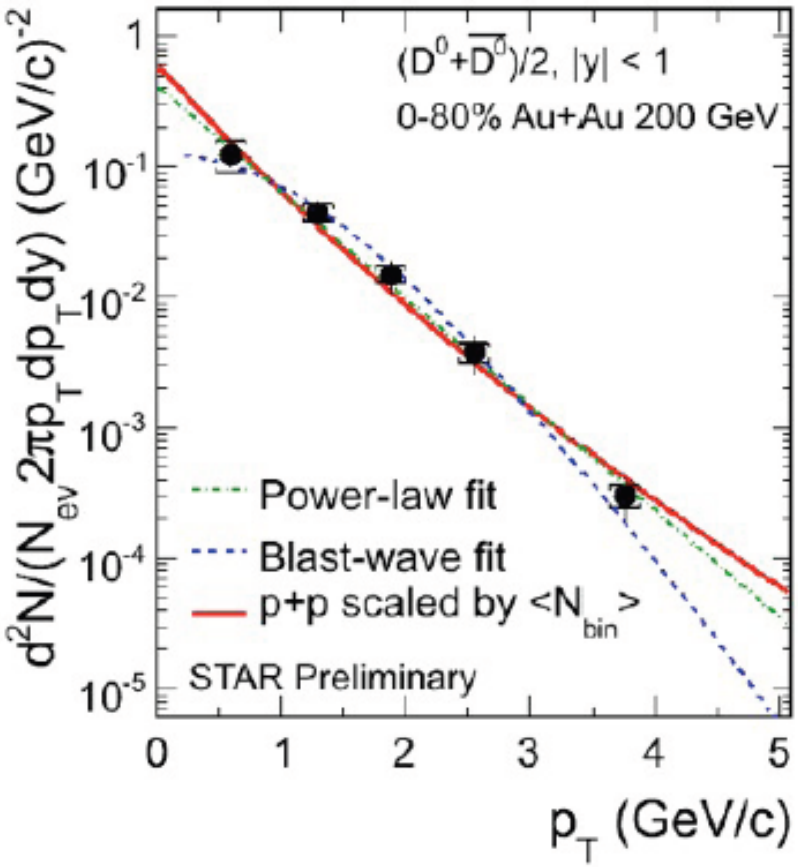


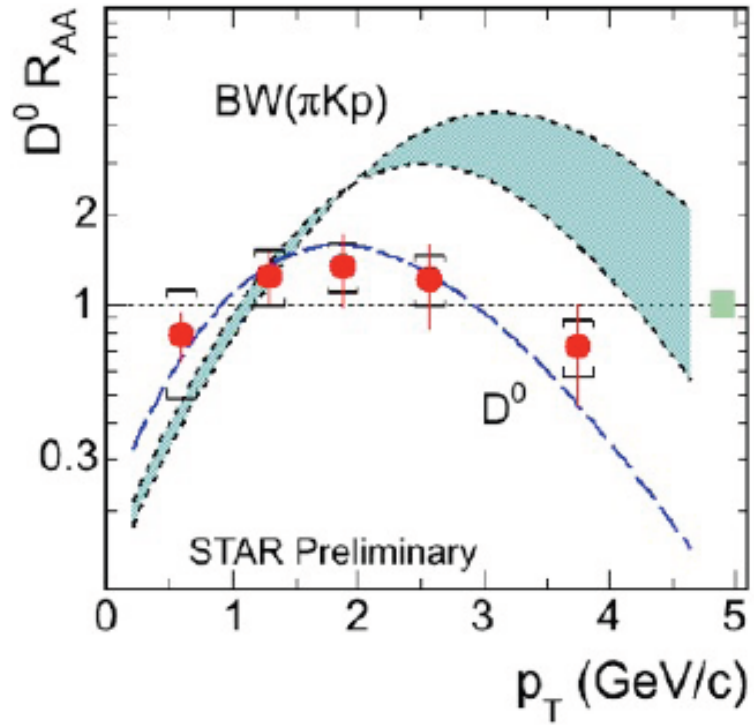



# $D^0$ $R_{AA}$

Hiroshi Masui – STAR

Yifei Zhang, Fri/27 16:00




*BW(πKp) Blast-wave fit results, STAR, **PRC79**, 034909 (2009)*

- First measurement of $D^0$ $R_{AA}$, $R_{AA} \sim 1$ in $p_T < 3$ GeV/c
- Blast-wave fit favors higher $T_{kin}$, smaller $\beta_T$ for $D^0$ than light hadrons

➡ $D^0$ freeze-out earlier than light hadrons

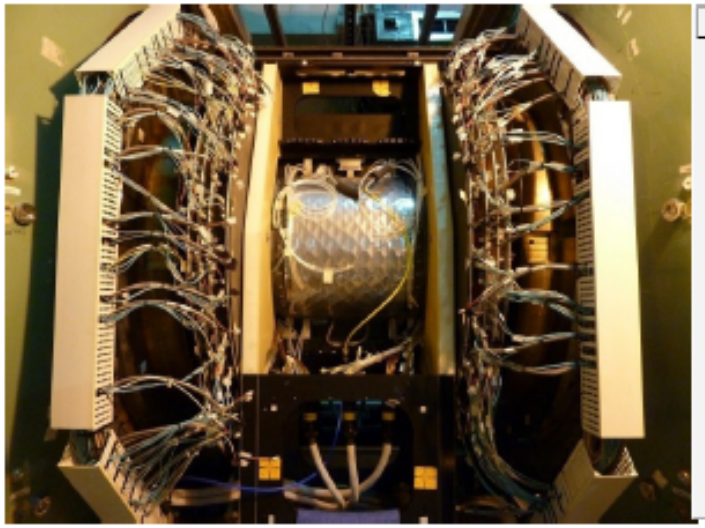
# Near-Term Future: Silicon Vertex Detector

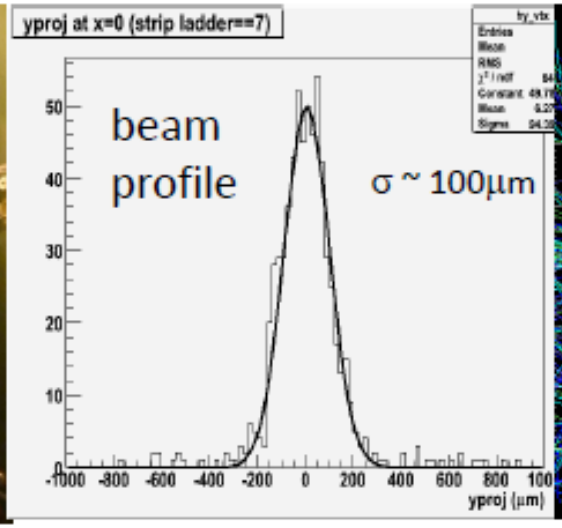


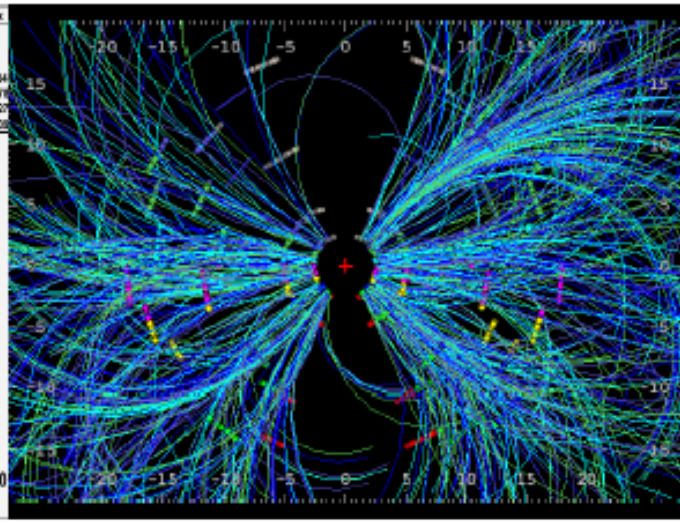
**Status**

- VTX successfully commissioned in 2011 *p+p* run
- VTX taking data in Au+Au now!

Data: Au+Au@200 GeV, 2011





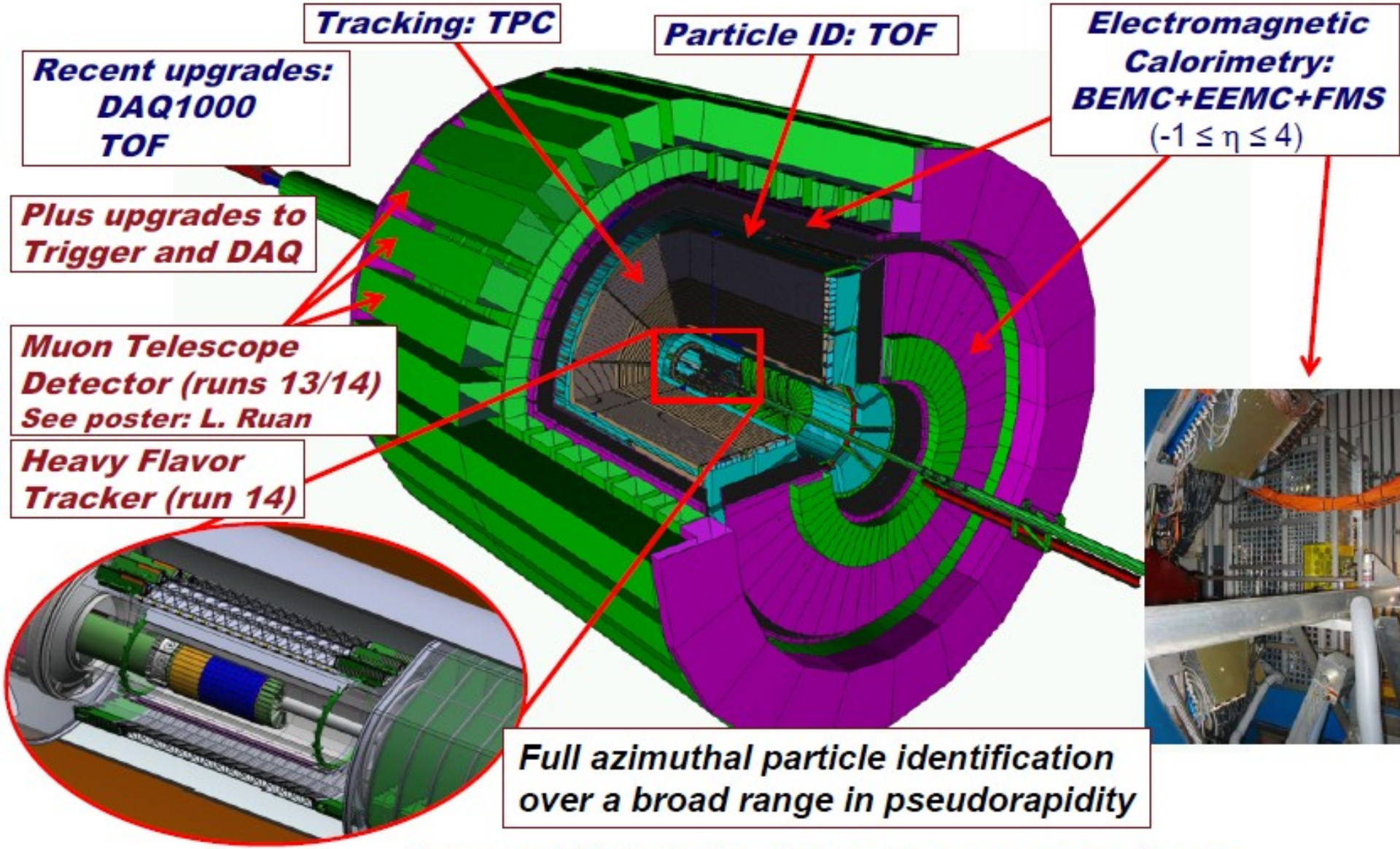



**Physics**

- $R_{AA}$ of *c*, *b* separately
- $v_2$ of *c*, *b* separately
- Jet tomography (di-hadron, $\gamma$-*h*, *c*-*h*, *c*-$\bar{c}$)

Parallel: A. Sickles (Decadal Plan) Thu
Poster: M. Chiu (Fast TOF, 10 ps)
Poster: M. Kurosawa (VTX (pixel))
Poster: T.Hachiya (VTX (pixel))
Poster: R. Akimoto (VTX (pixel))

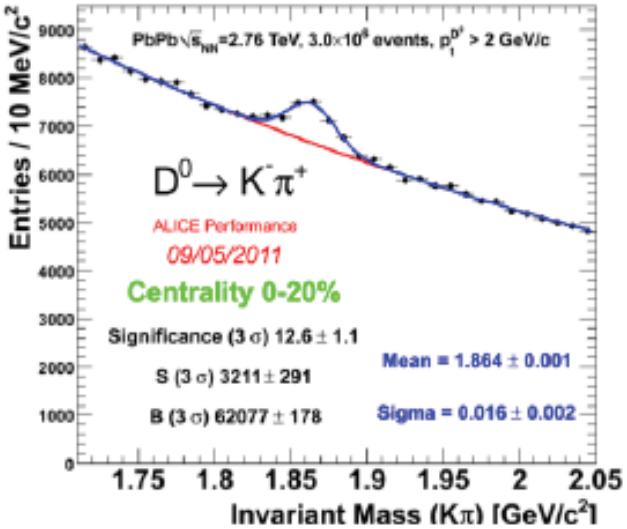
# Mid-rapidity *STAR*: now to mid-decade

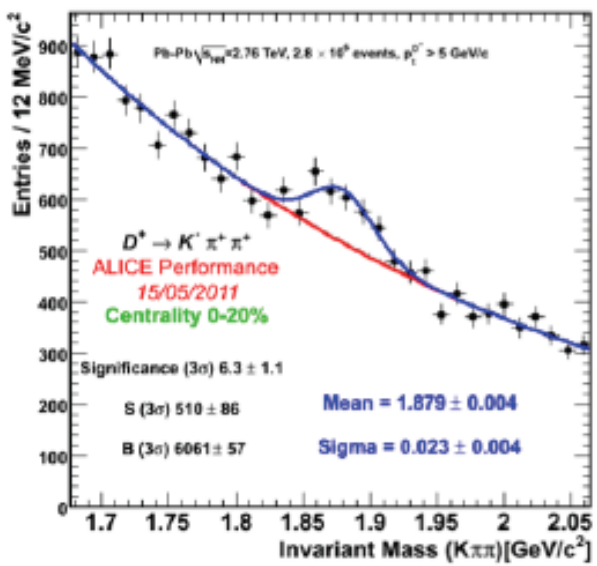



**A beautiful detector gets even better!**

Carl Gagliardi – STAR

# $D^0$ and $D^+$ reconstruction in Pb-Pb



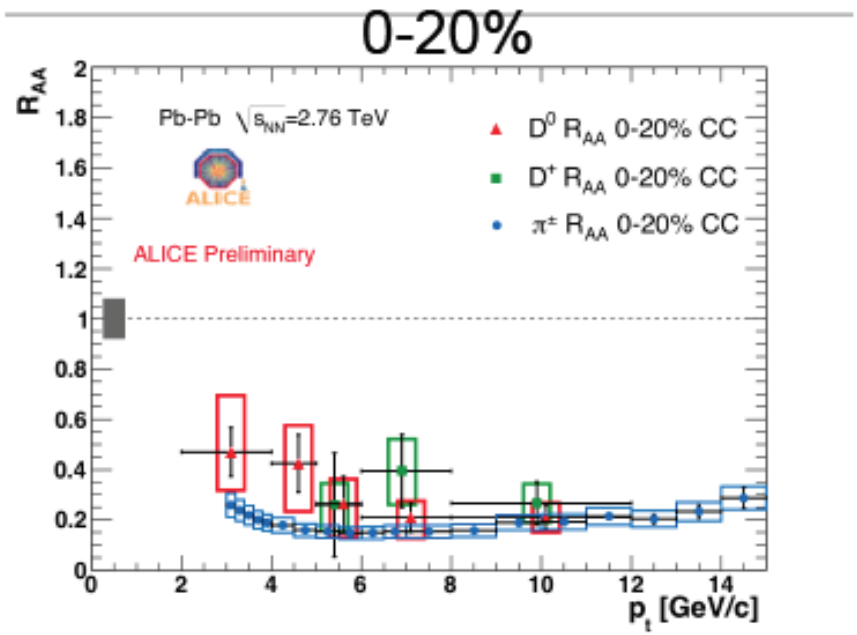

- In ~3M central collisions (0-20%):
  - $D^0$ : 5 $p_t$ bins in 2-12 GeV/*c*
  - $D^+$ : 3 $p_t$ bins in 5-12 GeV/*c*
- Reconstruction efficiency ~1-10%
  - evaluated from MC simulation
    - detector status and performance described by the MC to few % level
    - no centrality dependence found
- Feed-down from B decays ~10-15% after cuts
  - subtracted based on FONLL with hypothesis on $R_{AA}^B$ (→ more later)

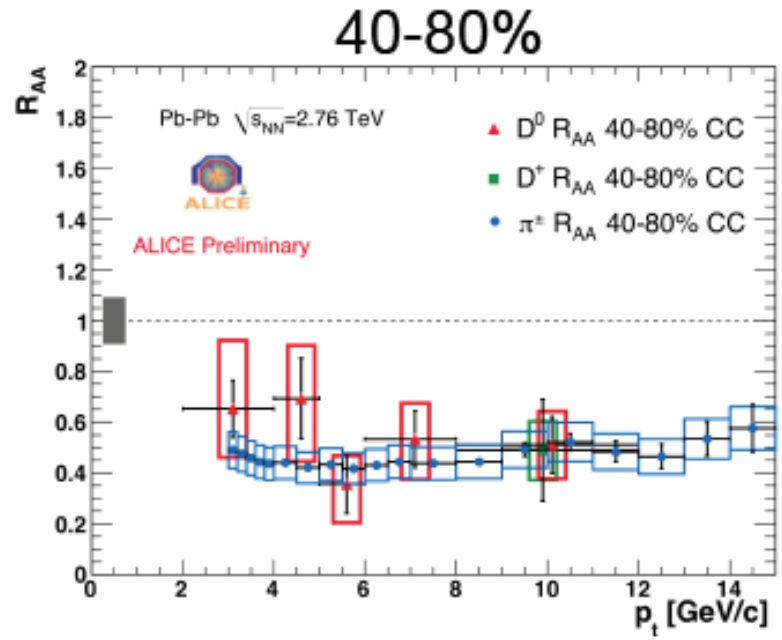
**→ A.Rossi, Fri parallel**



Andrea Dainese – ALICE

# Data Comparisons: D and $\pi^{\pm}$




- Suppression for charm is a factor 4-5 above 5 GeV/*c*
- Compatible with pions $R_{AA}$ (slightly larger below 5 GeV/*c*)
  - maybe hint for $R_{AA}^{D} > R_{AA}^{\pi}$ ? stay tuned for 2011 Pb-Pb run results

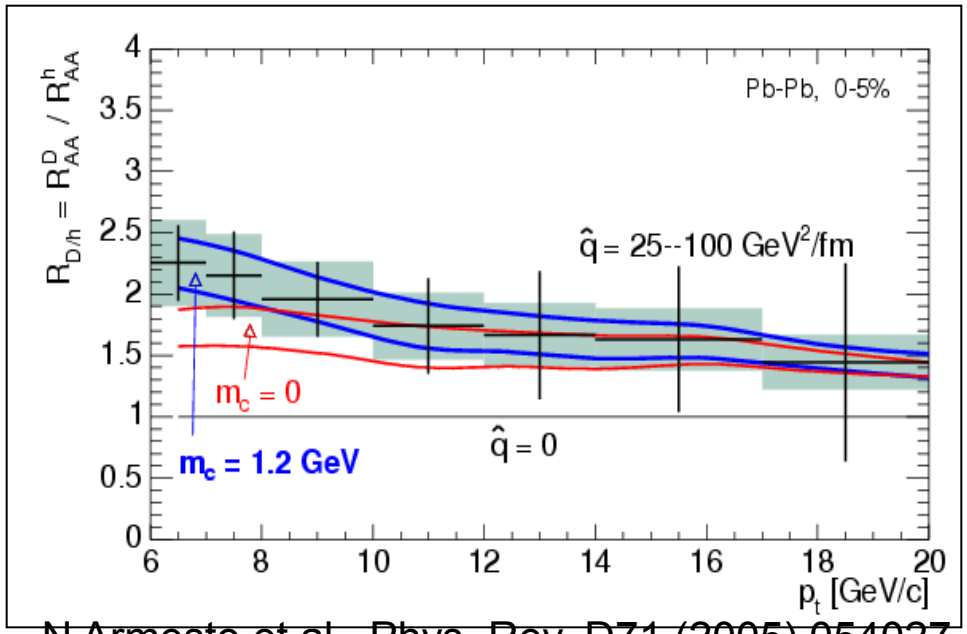


Andrea Dainese – ALICE

# How about the colour factor?

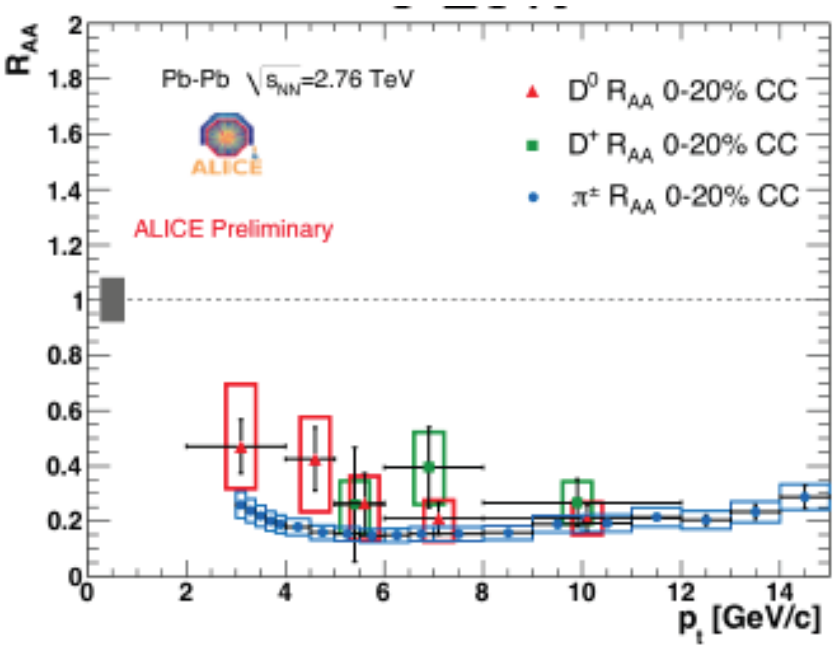
- quarks ($C_R$ = 4/3) expected to couple weaker than gluons ($C_R$ = 3)

→ at $p_T$ ~ 8 GeV, factor ~ 2 less suppression expected for D than for light hadrons in BDMPS-ADSW



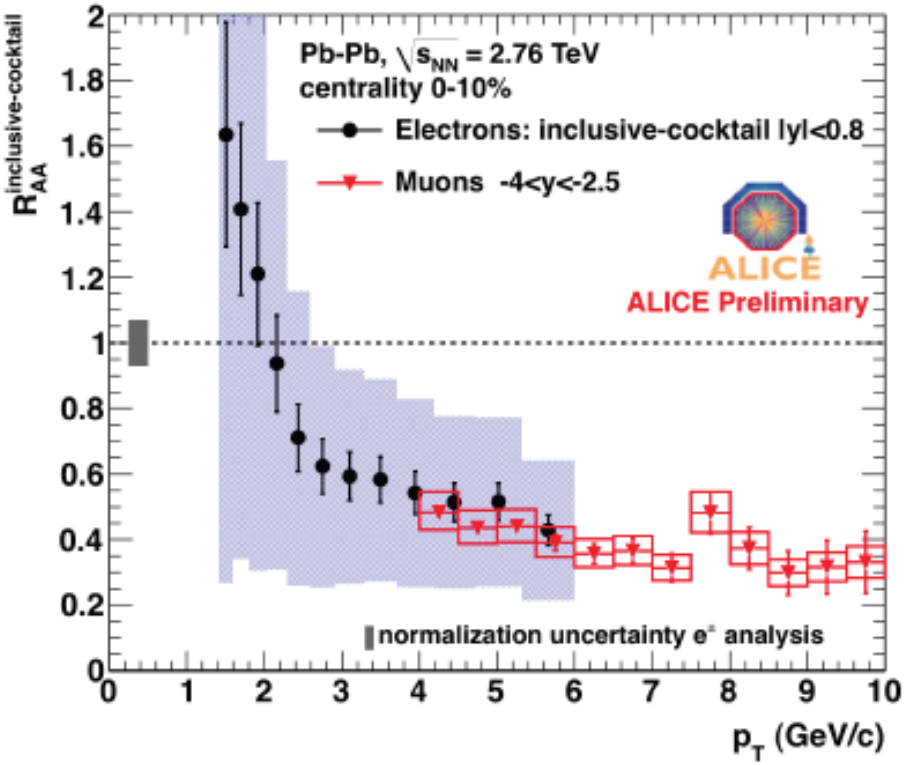

N Armesto et al., Phys. Rev. D71 (2005) 054027

- data do show a hint of deviation ($R_{AA}^D > R_{AA}^\pi$), but at much lower $p_T$ …




… to be continued with higher statistics…

# Data Comparison: Leptons y~0, y~3




- Consistent with the large uncertainties of electron PID

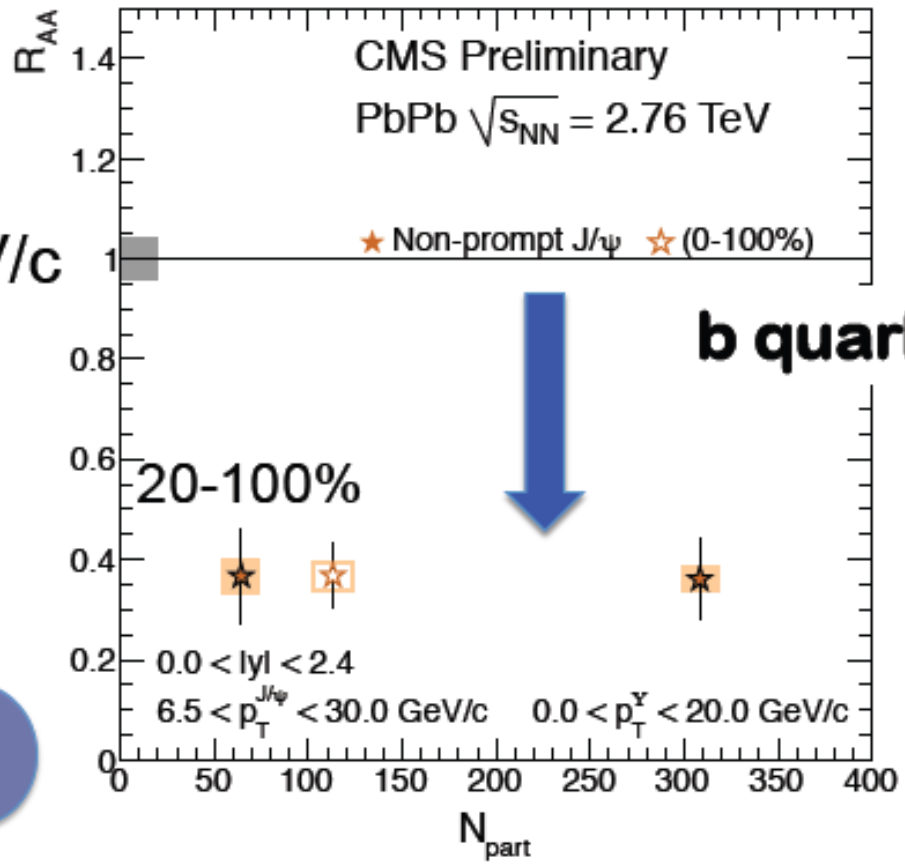


Andrea Dainese – ALICE

# First B → J/ψ $R_{AA}$

**PbPb**
**$\sqrt{s_{NN}}$=2.76 TeV**

$p_T^{J/\psi}$ > 6.5 GeV/c




**b quark energy loss ?**

**Minimum bias $R_{AA}$ = 0.37 ± 0.07 ± 0.03**

**Central 0-20% $R_{AA}$= 0.36 ± 0.08 ± 0.03**

# La frontière…

- high statistics D measurements
  → are really D as suppressed as light hadrons?
- charm thermalisation?
  → measure D mesons v2
- subtract D background → pure B electron spectrum
  – beauty energy loss in wide $p_T$ range
- in-medium fragmentation of b-tagged jets !
- results from RHIC upgrades

# Conclusions

- high energy AA collisions have entered an era of high precision measurements
  - LHC, RHIC upgrades
  - constrain dynamic and coupling properties of medium
- many ideas we were taking more or less for granted at QM 2009, are now being seriously questioned
  - death of Mach cone and ridge?
  - thermal yields, radiative Eloss are challenged
- the outlook is bright
  - high lumi (5×) Pb-Pb run this year, possibly p-Pb next year

  →<u>there could be some serious paradigm shifting at QM 2012!</u>

# Un grand merci…

- … aux organisateurs

  for the invitation to present this closing talk

- … à:

  Peter Braun-Munzinger, Brian Cole, Andrea Dainese, David d'Enterria, Paolo Giubellino, Barbara Jacak, Peter Jacobs, Karel Šafařík, Carlos Salgado, Jürgen Schukraft, Edward Shuryak, Peter Steinberg, Xin-Nian Wang, Urs Wiedemann, Nu Xu and many others…

- … à vous tous