

# Results from heavy-ion collisions by ALICE

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ALICE Collaboration



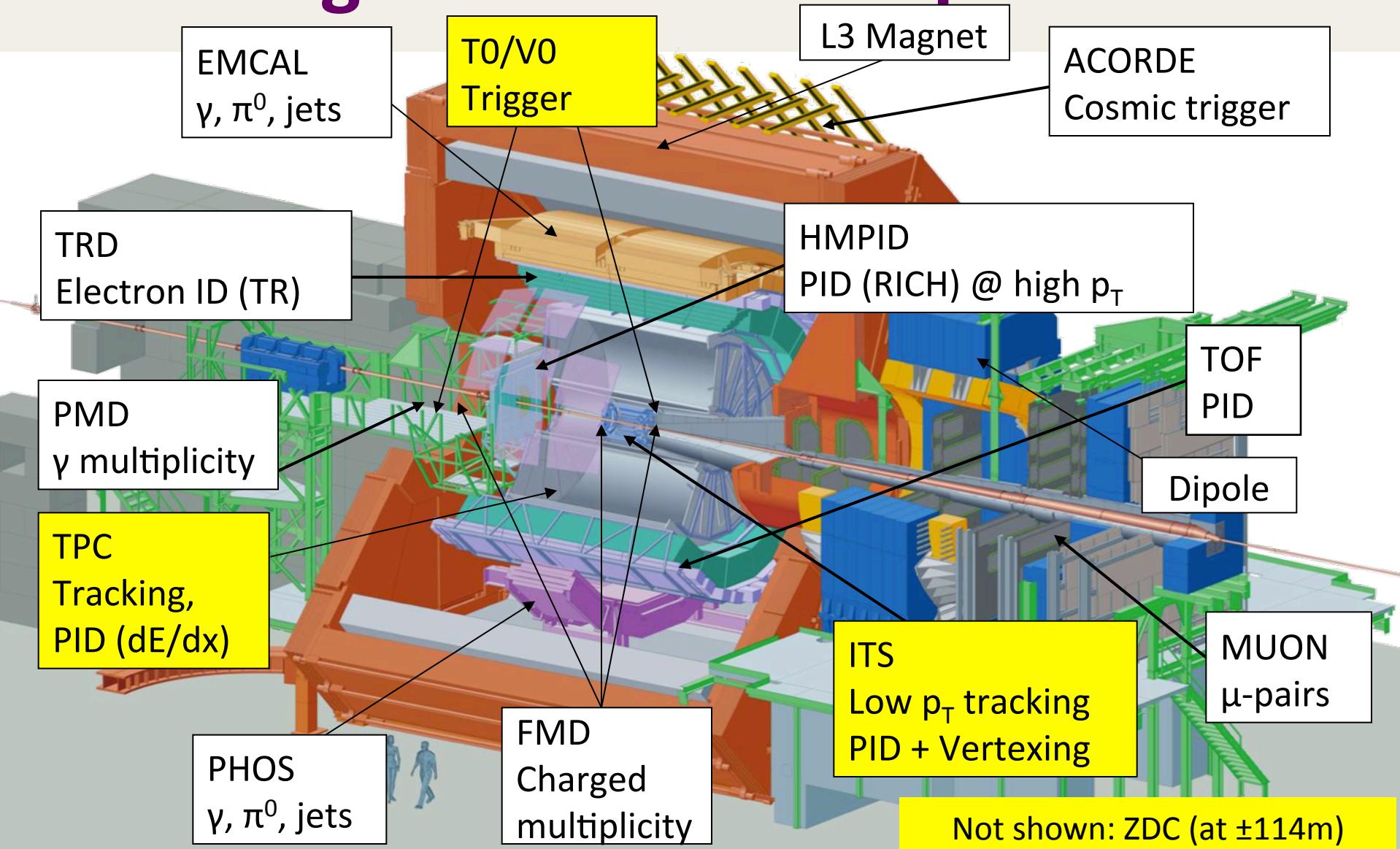
# Strategy: How to study QCD matter experimentally?

- Need to find those observables that:
  - Are sensitive to crucial parameters of hot QCD matter
  - Can be modeled well – theoretical understanding
  - Can be measured well – experimental control
  - Can connect theory and data
- => Inclusive measurements; correlations; compare with more elementary collisions (p-p, p-A); compare different energy regimes

# Outline

- “Calibration”: measurements of ion-collisions vs measurements of partonic plasma – energy density – particle multiplicities
- The medium, equation of state, symmetries
  - hadrochemistry, elliptic flow, energy density fluctuations and their consequences
- Probing the medium with jets
  - Parton energy loss, gluon vs light- vs heavy-quark
  - Hard hadron production and their correlations

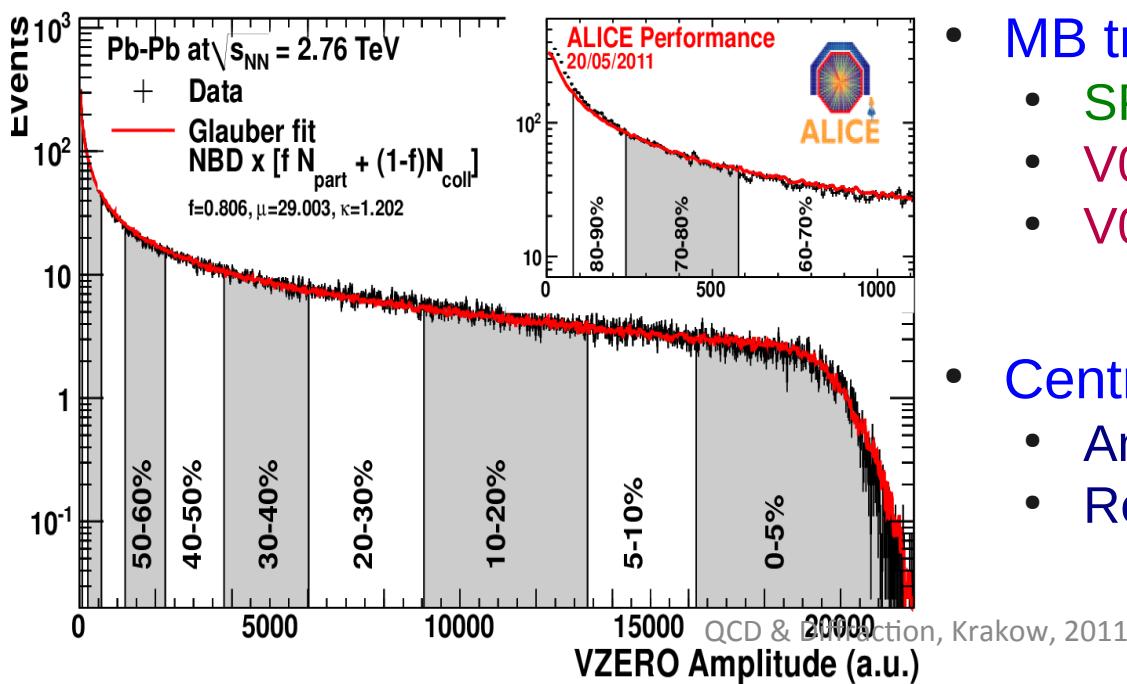
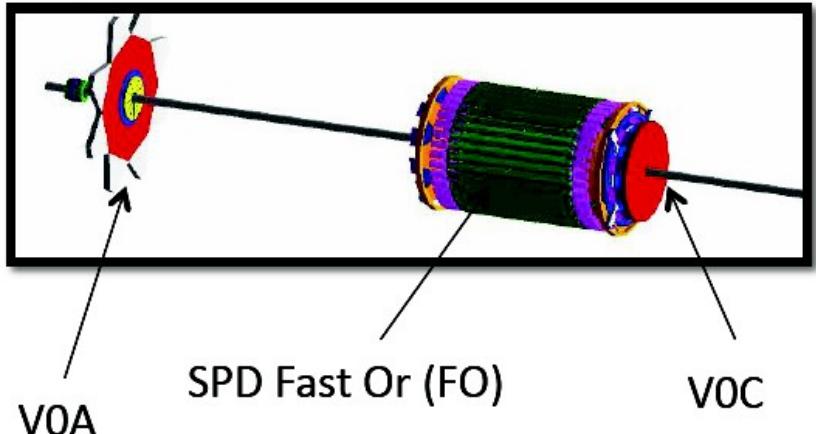
# A Large Ion Collider Experiment



# HEAVY-ION COLLISIONS AND “CALIBRATION” MEASUREMENTS

# Trigger and centrality

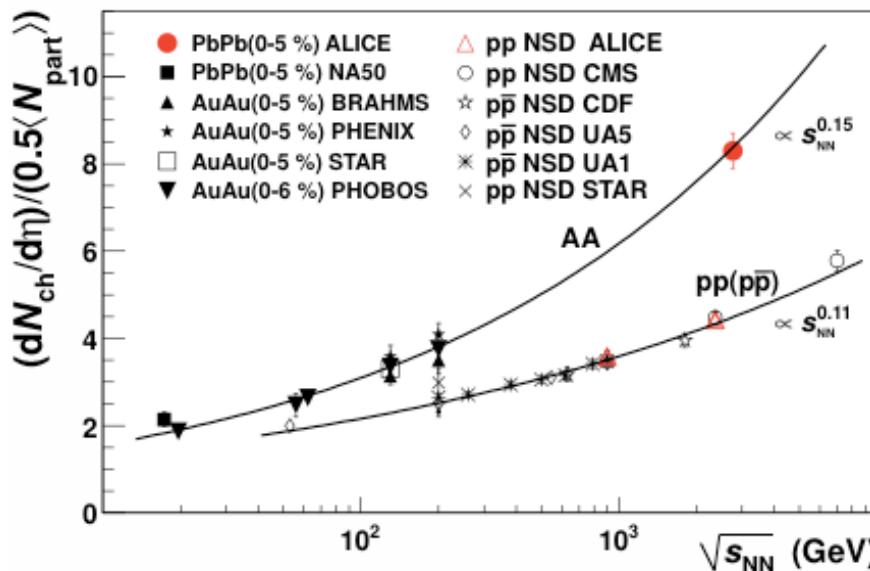
System E (TeV) Trigger Events $\int L dt$				
pp	7	MB Rare	1500M 200M	25 nb <sup>-1</sup> 2 pb <sup>-1</sup>
pp	2.76	MB Rare	65M ~9M	1.1 nb <sup>-1</sup> ~20 nb <sup>-1</sup>
PbPb	2.76	MB	30M	3 $\mu b^{-1}$



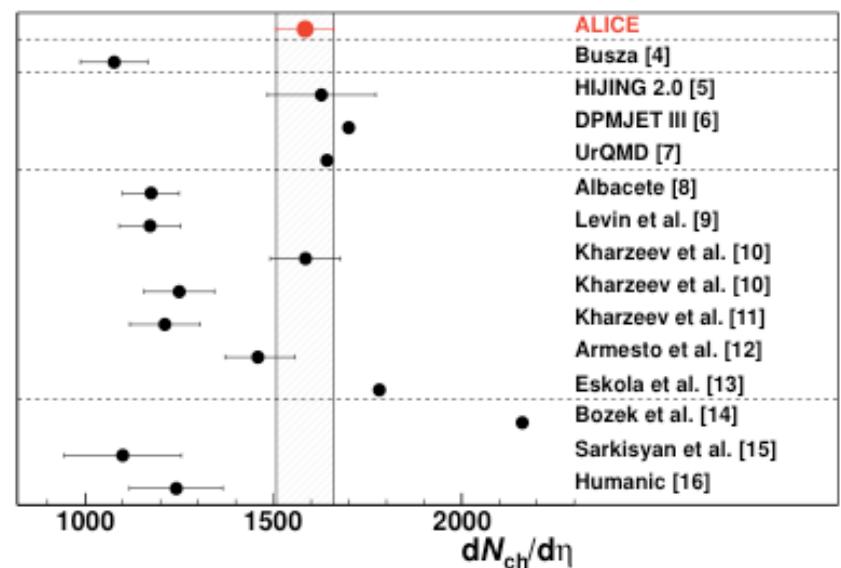
- MB triggers: Coincidences
  - SPD Fast-Or ( $\geq 2$  chip hits)
  - V0 (A side,  $-1.7 < \eta < -3.7$ )
  - V0 (C side,  $2.8 < \eta < 5.1$ )
- Centrality in PbPb
  - Amplitudes in V0 scintillators
  - Reproduced with Glauber Model

# Particle production in Pb-Pb

## Energy dependence



## Comparison to predictions



PRL 105, 252301 (2010)

## Energy dependence

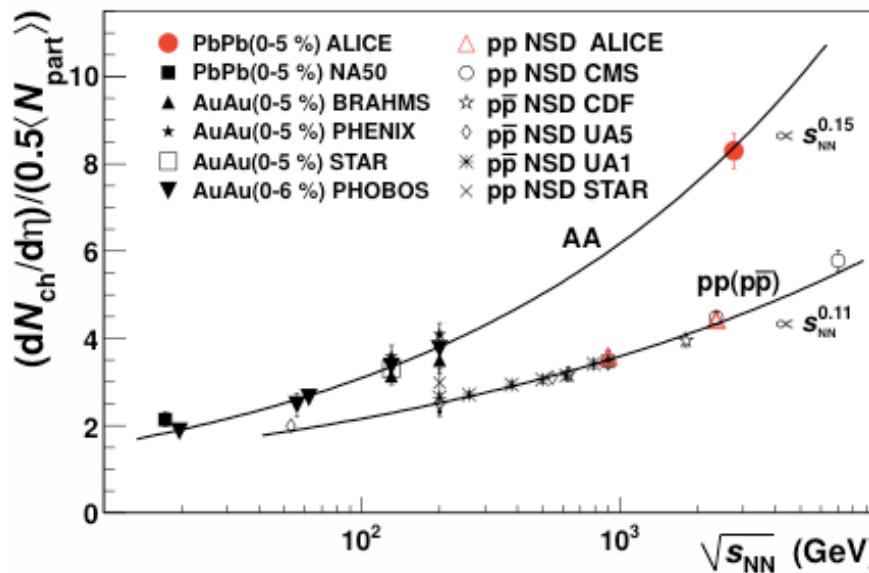
$$p\text{-}p \sim s_{NN}^{0.11}$$

$$A\text{-}A \sim s_{NN}^{0.15} \text{ (most central - 2x RHIC)}$$

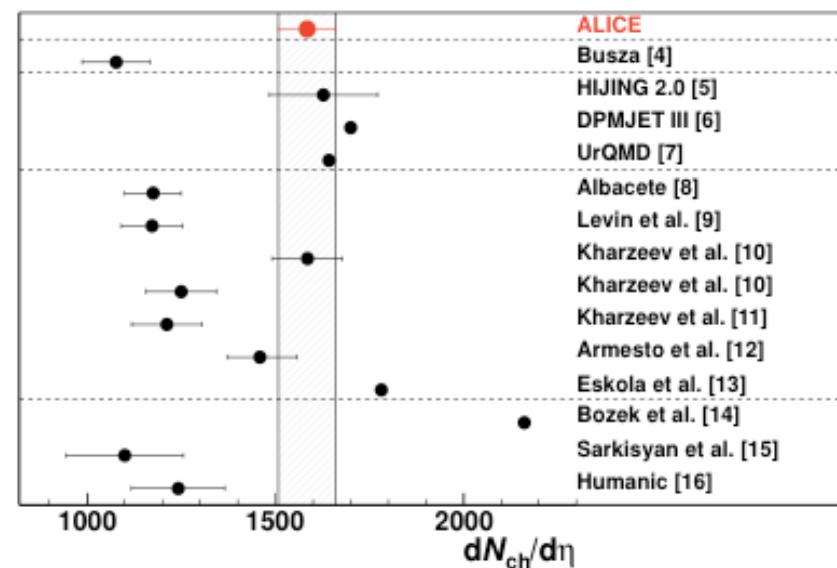
– stronger rise than log extrapolation

# Particle production in Pb-Pb

Energy dependence



Comparison to predictions



PRL 105, 252301 (2010)

*Feedback within the heavy-ion community:*

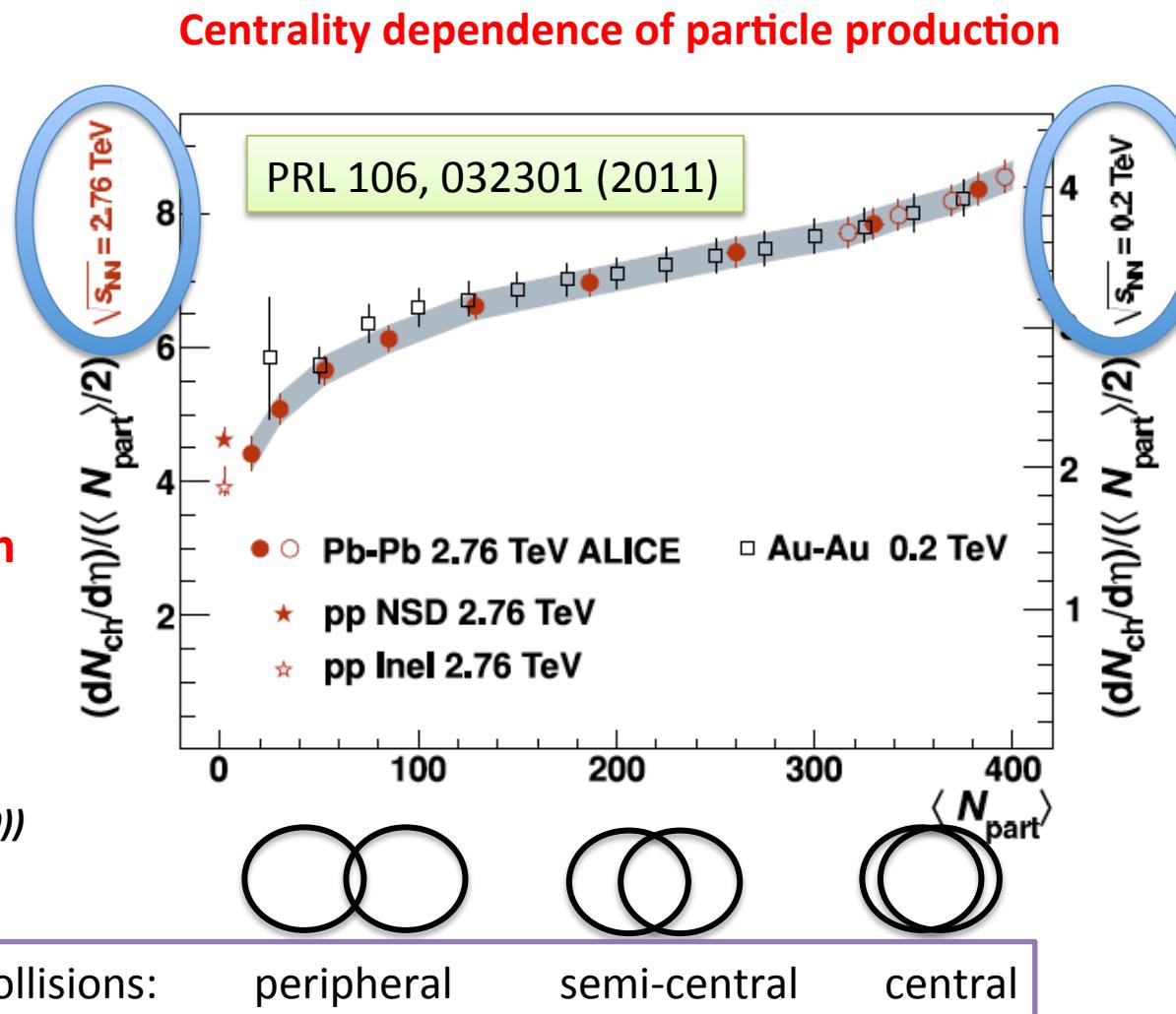
1. Multiplicity is crucial [input] for modeling
2. Saturation models tend to predict lower multiplicity
3. Data driven extrapolations did not seem to anticipate the results

# Systematic control: compare RHIC to LHC

The same experiment under vastly different conditions!

- Identical variation of particle production with centrality (volume) at RHIC and LHC!
    - ⇒ Global features of the system independent on energy
    - ⇒ Initial conditions!

*More on RHIC:  
Phobos (**Phys. Rev. Lett. 102, 142301 (2009)**)*



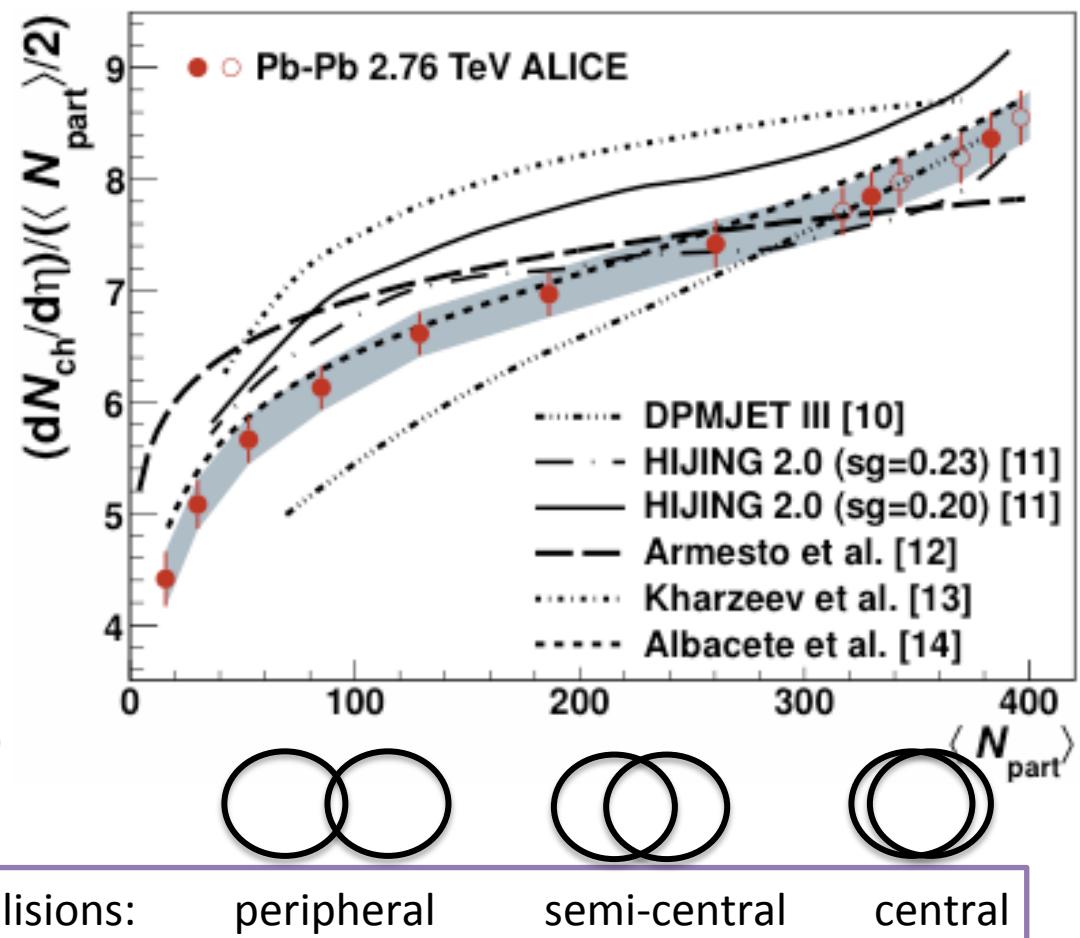
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*Phobos (Phys. Rev. Lett. 102, 142301 (2009))*

Centrality dependence of particle production



# Transverse energy vs centrality

Hadronic transverse energy measured with barrel tracking detectors

- Model dependent correction ( $f \sim 0.55$ ) to convert into total transverse energy

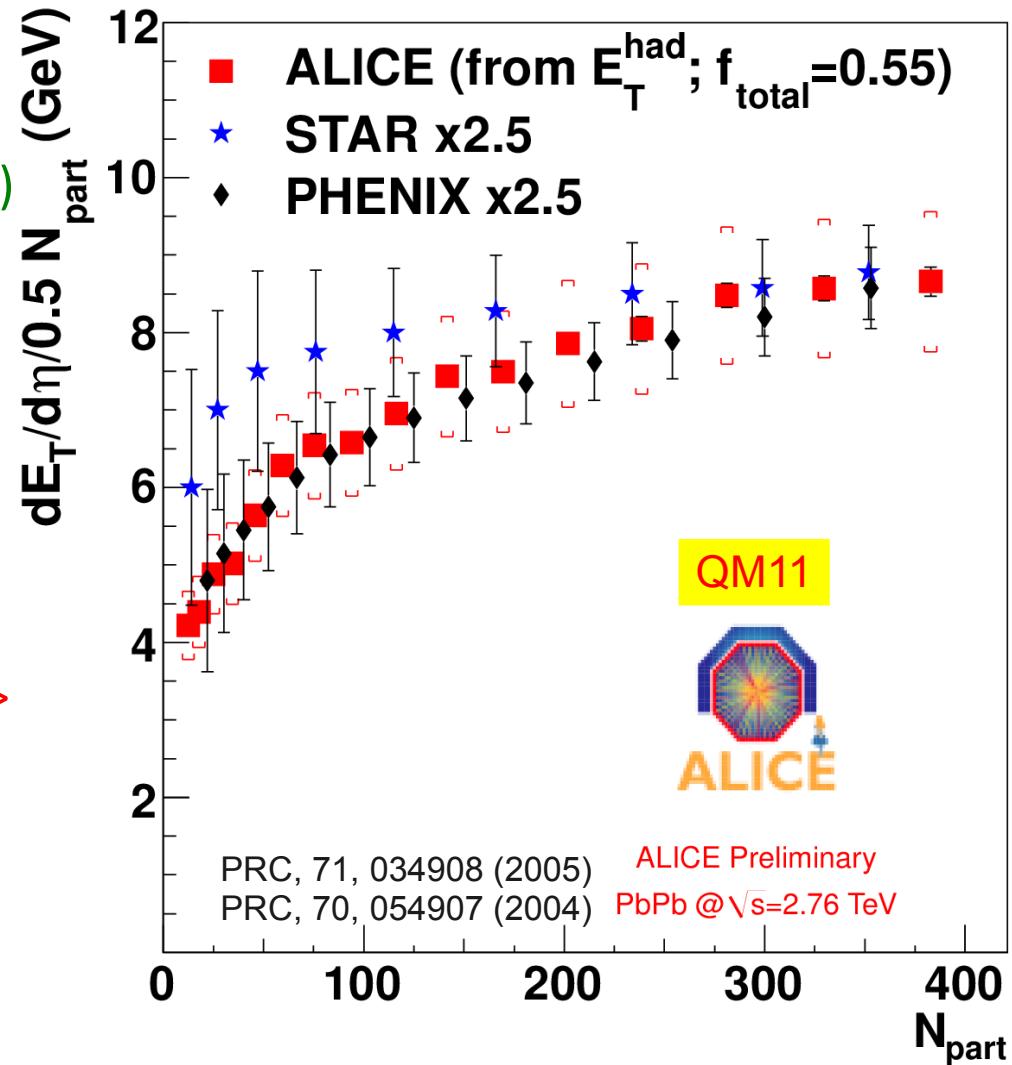
RHIC to LHC:

- Similar centrality dependence
- $\sim 2.5$  increase in  $2dE_t/d\eta/N_{\text{part}}$
- $\sim 2.7$  increase in  $dE_t/d\eta$ 
  - Consistent with increase of  $\langle pT \rangle$

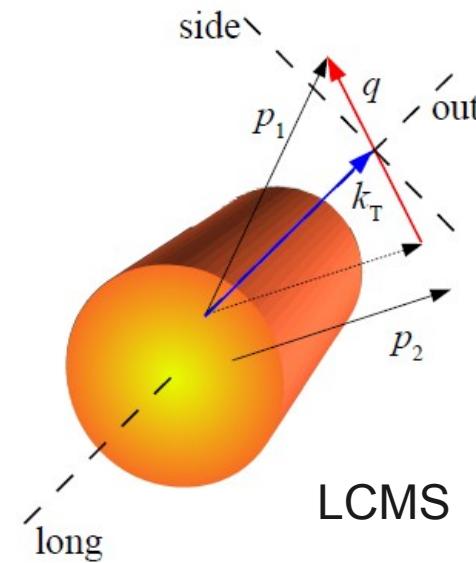
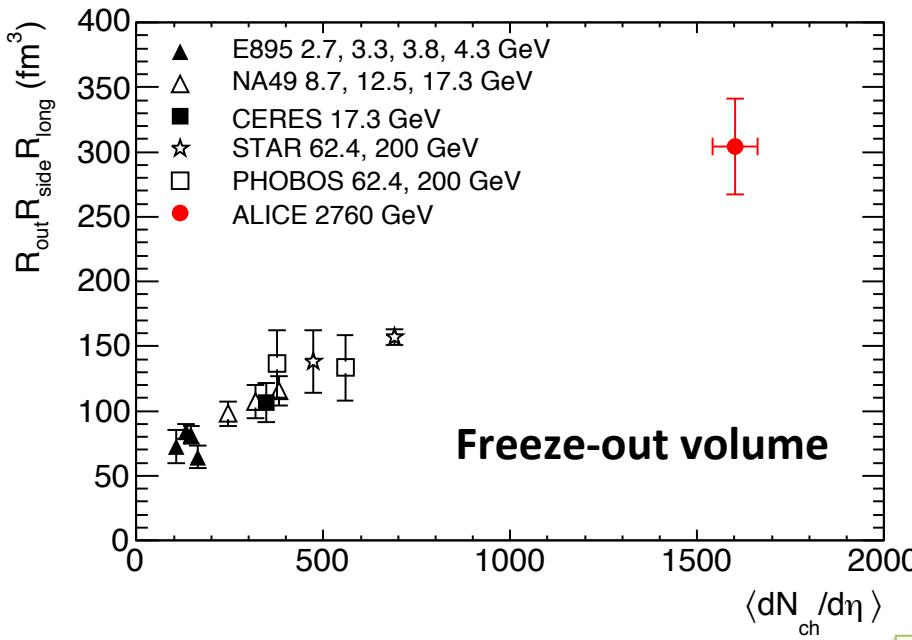
Bjorken energy density

$$\epsilon(\tau) = \frac{1}{A\tau} \frac{dE_T}{d\eta}$$

$$\tau \epsilon_{LHC} \approx 2.5 \times \tau \epsilon_{RHIC}$$



# Particle production in Pb-Pb: Measurements of source dimensions



## 1. Energy dependence:

- system with larger (2x) volume and (1.4x) lifetime (w.r.t RHIC); follows the trend of multiplicity; faster expansion  $\Leftrightarrow$  larger collective flow

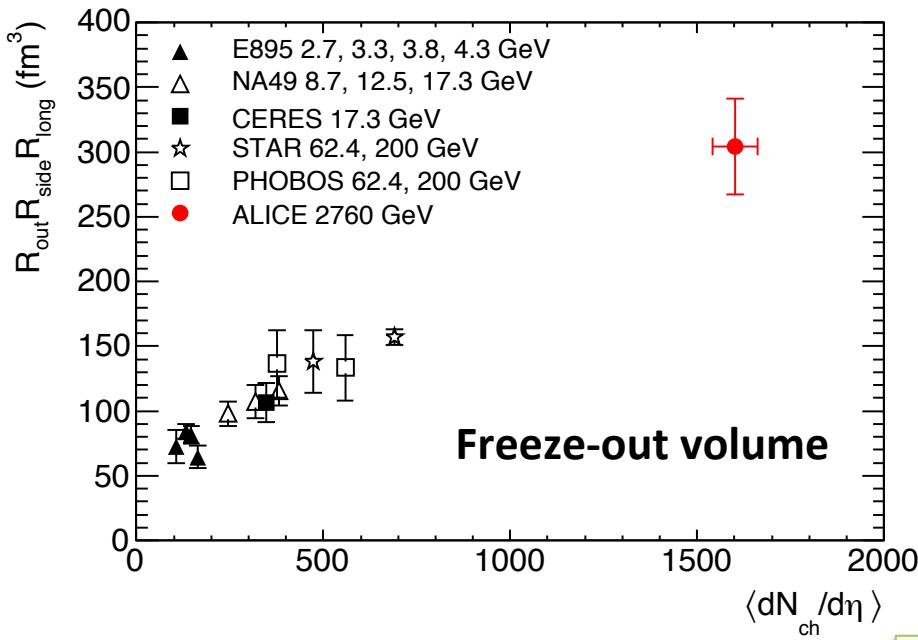
Phys.Lett.B 696:328-337,2011

## 2. Pair momentum dependence:

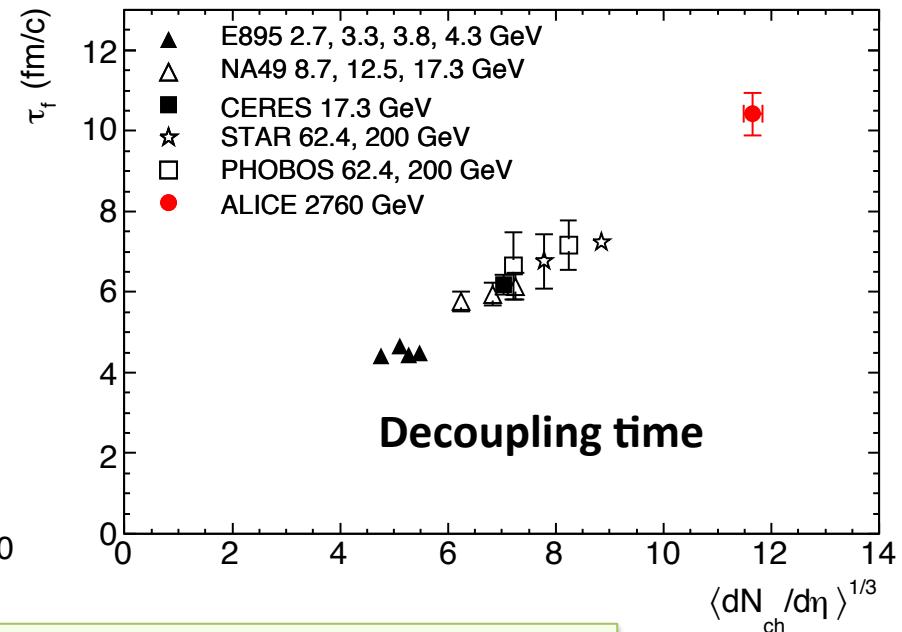
- larger radii, strong dependence on  $kT$ ;  $R_{out}/R_{side}$  smaller than at RHIC; overall agreement with extrapolations

## 3. Important constraints to [hydrodynamical] modelling

# Particle production in Pb-Pb: Measurements of source dimensions



Freeze-out volume



Decoupling time

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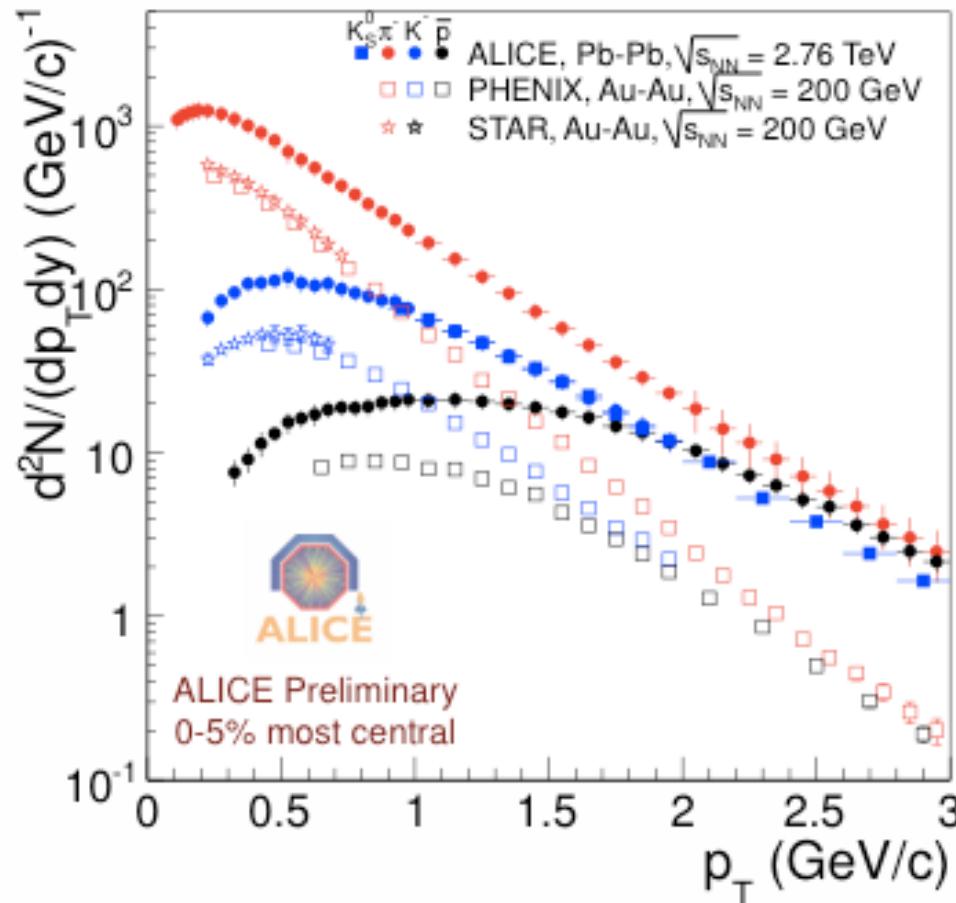
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# Identified particle spectra



LHC: Much harder spectra – excellent kinematic reach to explore  
ALICE: excellent particle identification capabilities at the LHC

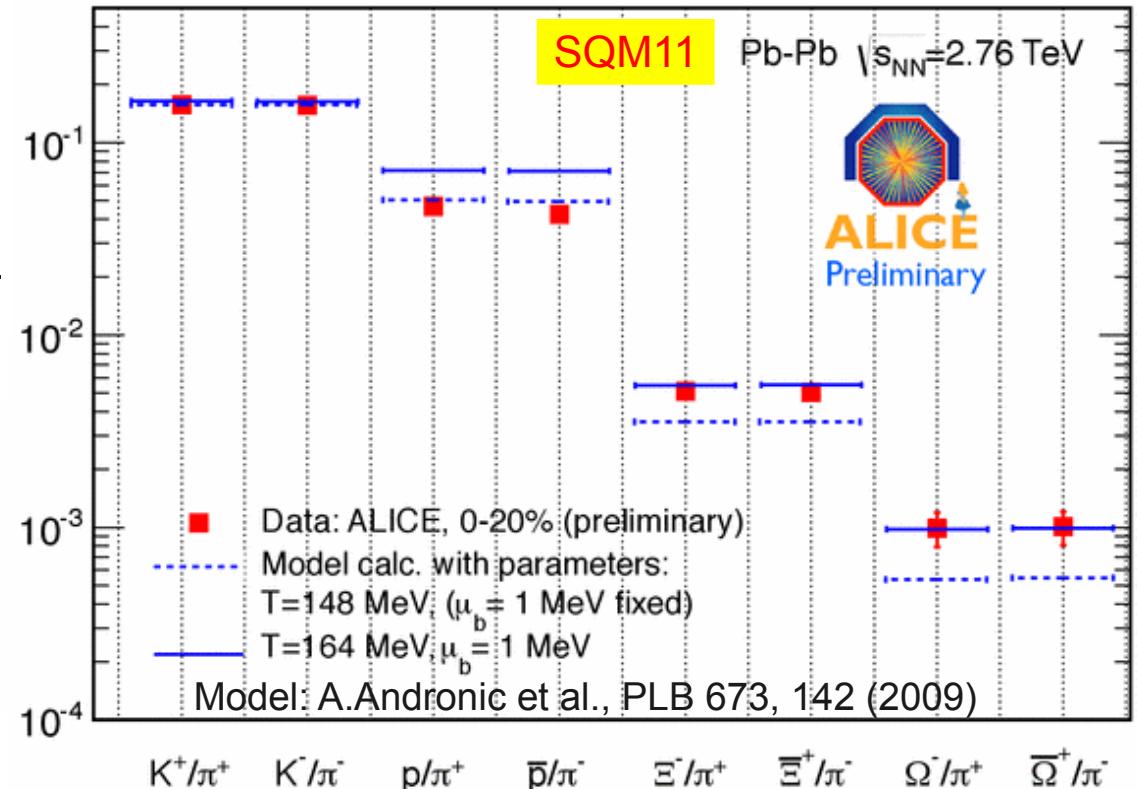
# Particle ratios and thermal model

Grand-canonical ensemble analysis

$$N_i \propto V \int \frac{d^3 p}{2 \pi^3} \frac{1}{e^{(E_i - \mu_B B_i)/T_{ch}} \pm 1}$$

$T_{ch}$  Chemical freeze-out temperature

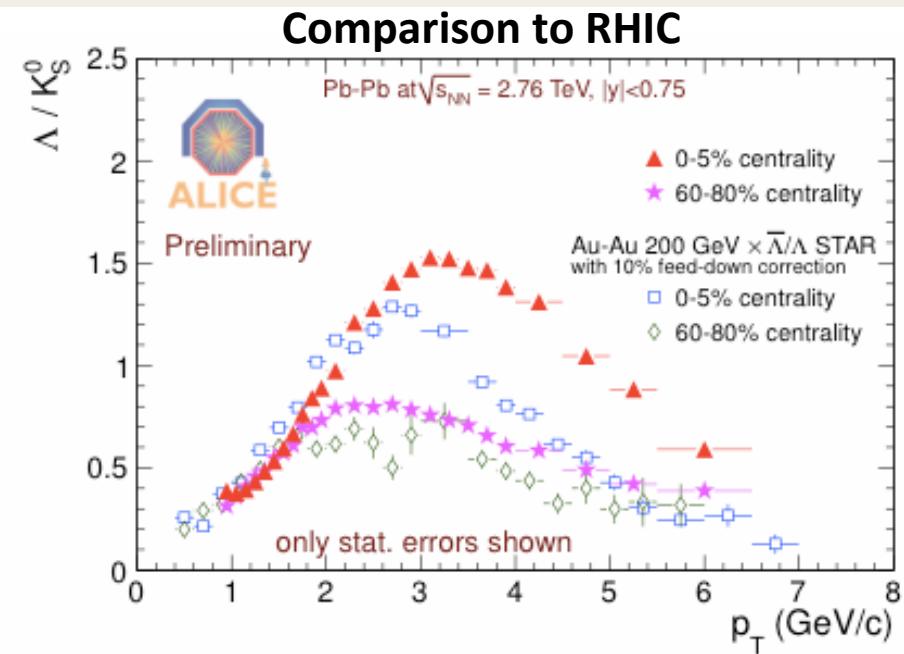
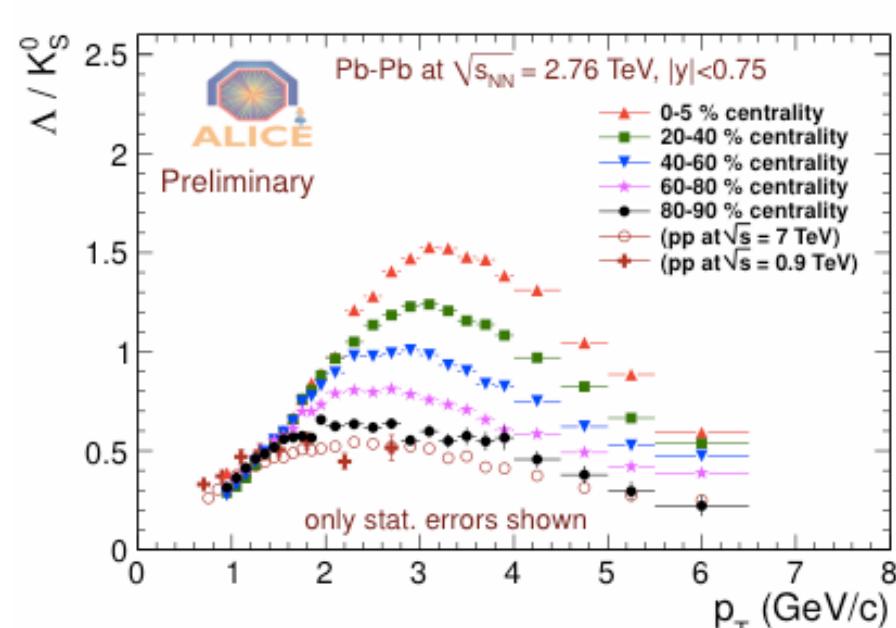
$\mu_B$  Baryochemical potential



All yields (but protons) described by thermal model with  $T_{ch}=164 \text{ MeV}$  (and  $\mu_b=1 \text{ MeV}$ )

- Similar temperature as at RHIC, however proton/pion below the fit – the tension already present at RHIC
- Strange particles constrain fit
- Conclusions are model independent (confirmed with THERMUS)

# Baryon/meson ratios: RHIC vs LHC



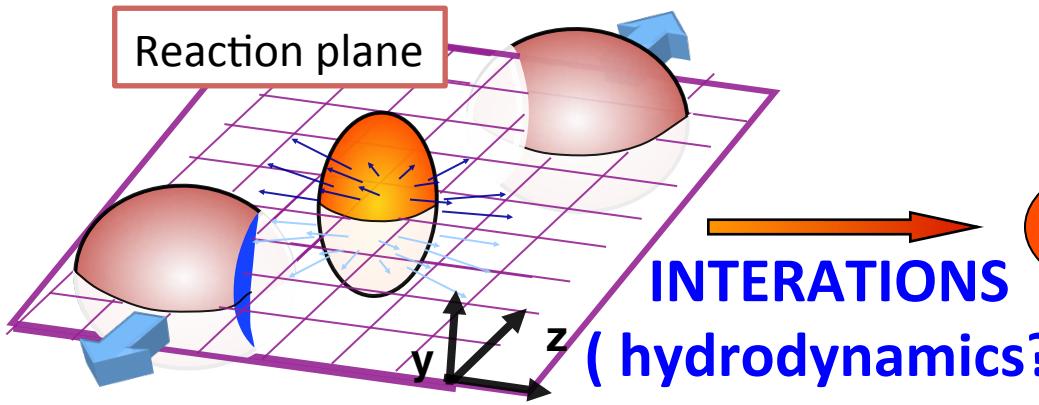
The  $\Lambda / K^0_S$  ratio in peripheral Pb–Pb collisions is slightly larger than that for pp interactions at  $\sqrt{s} = 7$  TeV where  $\Lambda / K^0_S \sim 0.5$ .

For more central collisions, the  $\Lambda / K^0_S$  ratio increases and develops a maximum, reaching a ratio  $\Lambda / K^0_S \sim 1.5$  for  $p_T \sim 3-3.5$  GeV/c in 0-5% central collisions.

Only slightly larger ratios as compared to 0-5% central and 60-80% peripheral Au-Au collisions at RHIC, but perhaps ratios larger than those of pp out to higher pT.

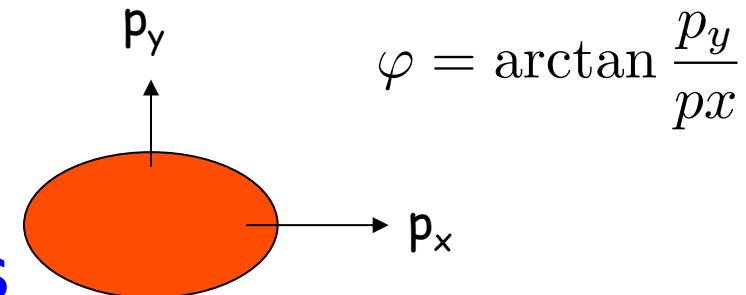
# ANISOTROPY OF THE PRODUCED MATTER - ELLIPTIC FLOW

# Collective Flow of QCD Matter



$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

**Initial spatial anisotropy**



$$\varphi = \arctan \frac{p_y}{p_x}$$

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

**Final momentum anisotropy**

Reaction plane defined by  
“soft” (low  $p_T$ ) particles

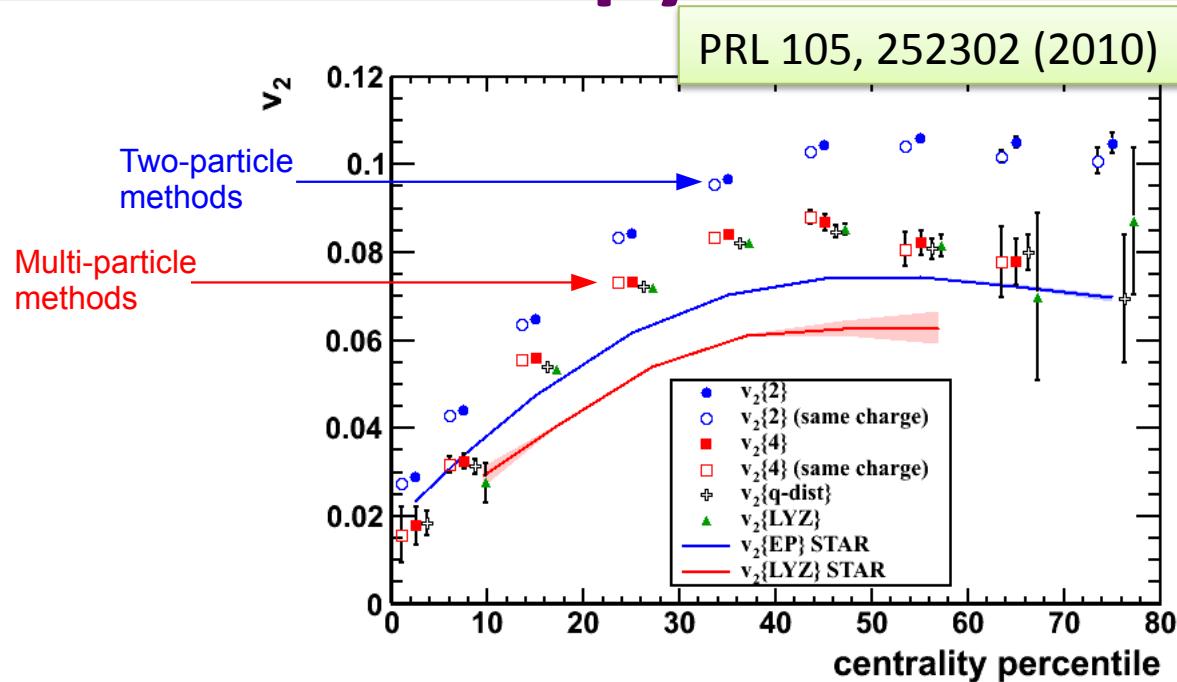
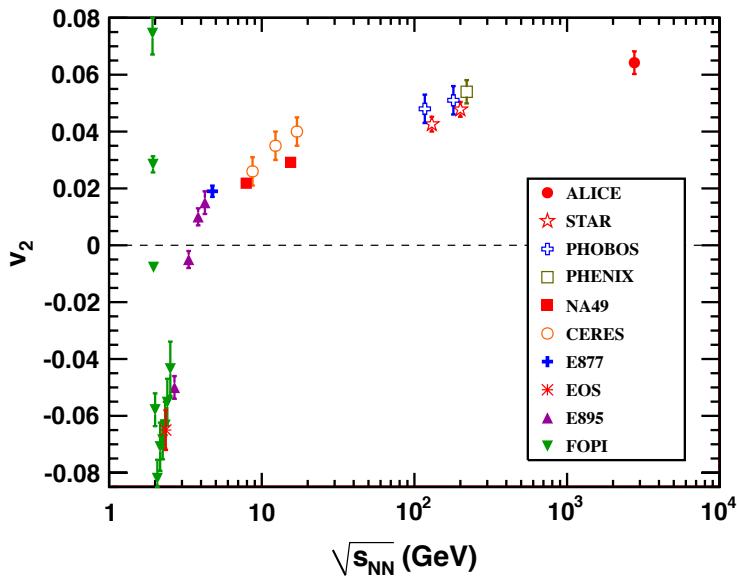
$$\Delta\varphi = \varphi - \varphi^{\text{Reaction Plane}}$$

Elliptic flow

$$\frac{dN}{d\Delta\varphi} \propto 1 + 2v_2 \cos(2\Delta\varphi)$$

# ALICE measurements: Azimuthal anisotropy

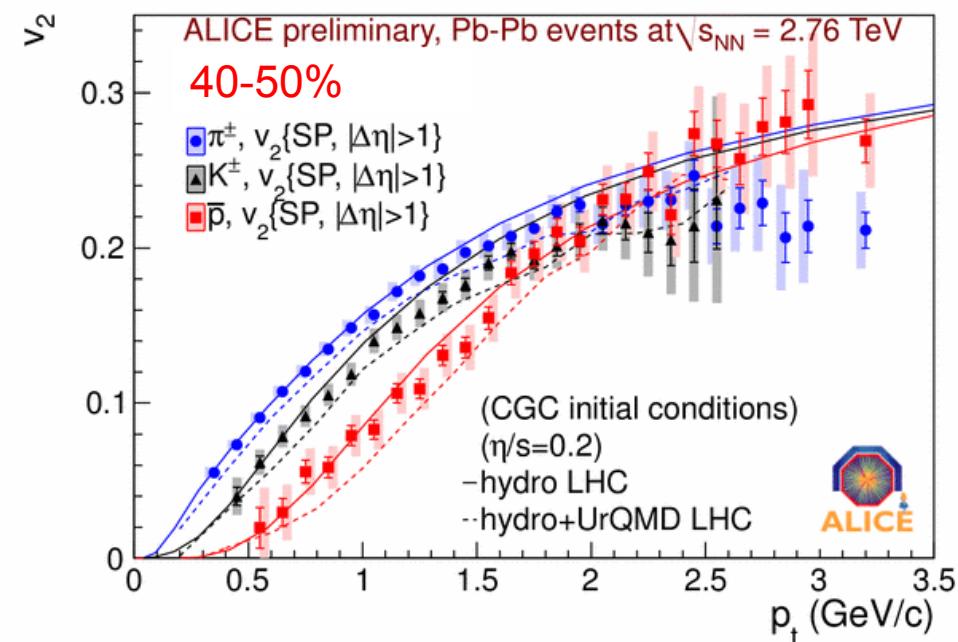
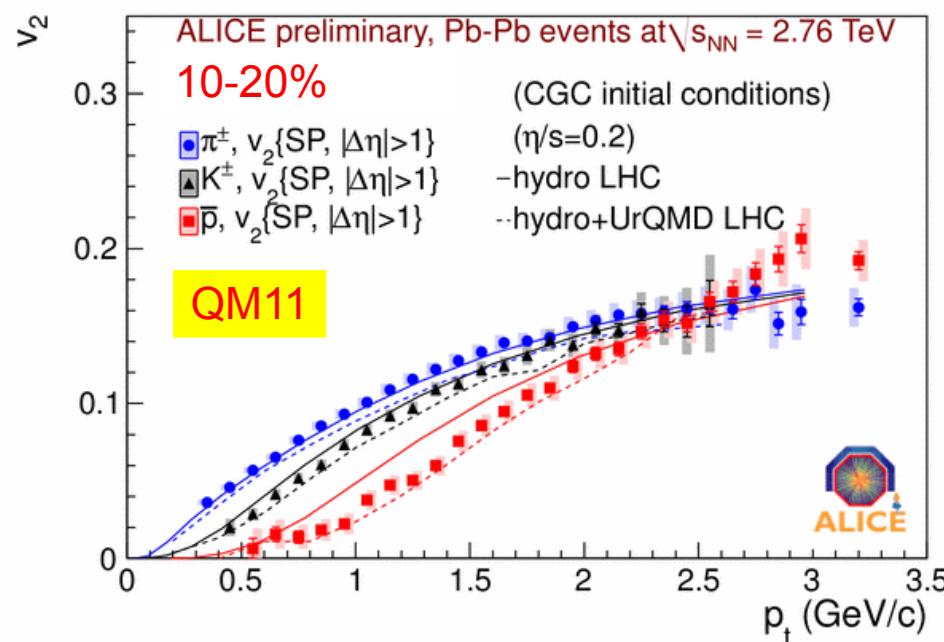
Energy dependence of  $v_2$



APS Viewpoint: A “Little Bang” arrives at the LHC by Edward Shuryak

1. Collective behavior observed in Pb-Pb collisions at LHC (integrated:  $+0.3 v_2^{\text{RHIC}}$  – consequence of larger  $\langle p_T \rangle$ )  $\rightarrow v_2(p_T)$  similar to RHIC – almost ideal fluid at LHC ?
2. New input to the energy dependence of collective flow
3. Additional constraints on Eq-Of-State and transport properties

# Elliptic flow of identified particles



Pronounced mass dependence due to radial flow

Viscous hydro predictions are able to describe the data

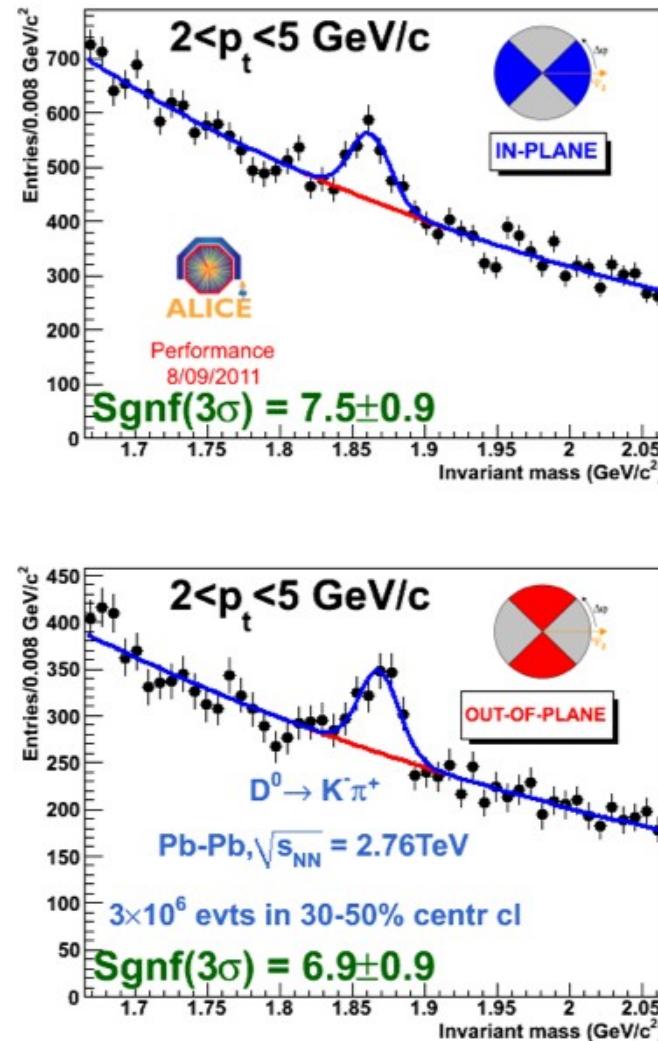
Similar to RHIC: rescattering in the hadronic phase (UrQMD afterburner) is needed to describe the anti-protons

Hydro: U.Heinz et al., arXiv: 1105.3226 +UrQMD: U.Heinz et al., arXiv: 1108.5323

QCD & Diffraction, Krakow, 2011

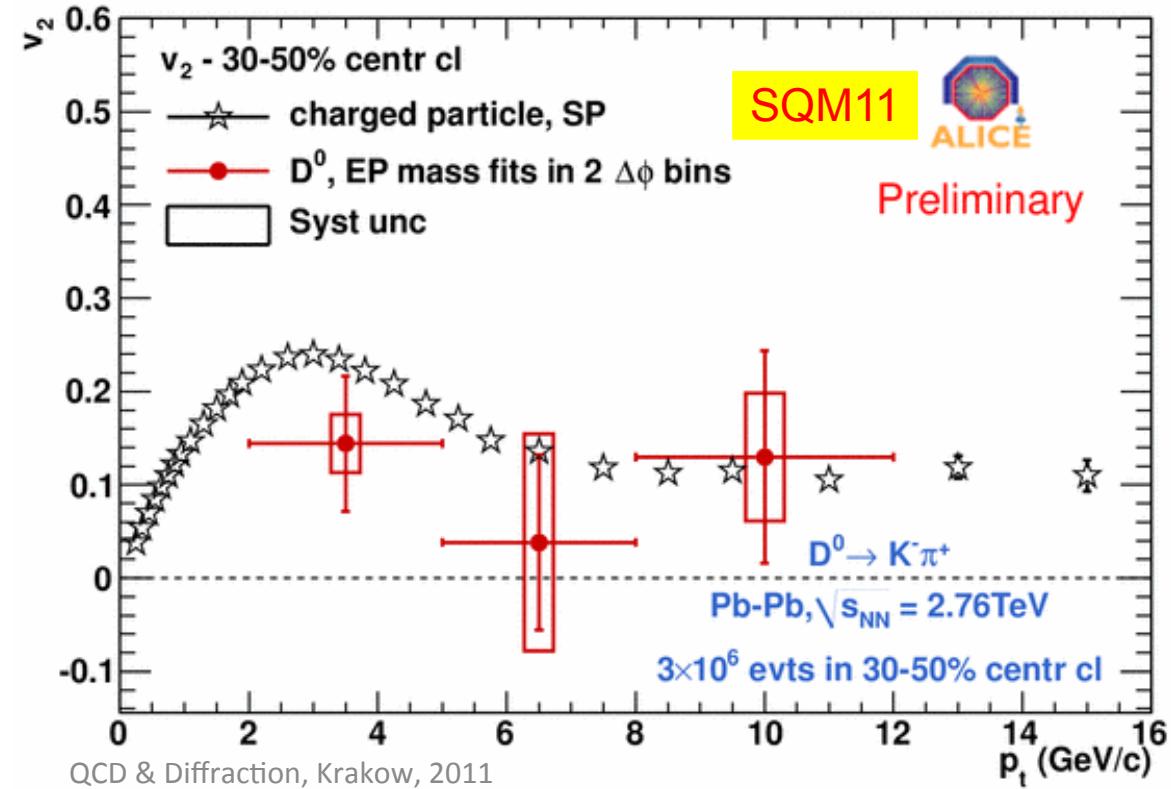
# Flow of heavy quarks

First D-meson elliptic flow measurement in heavy-ion collisions



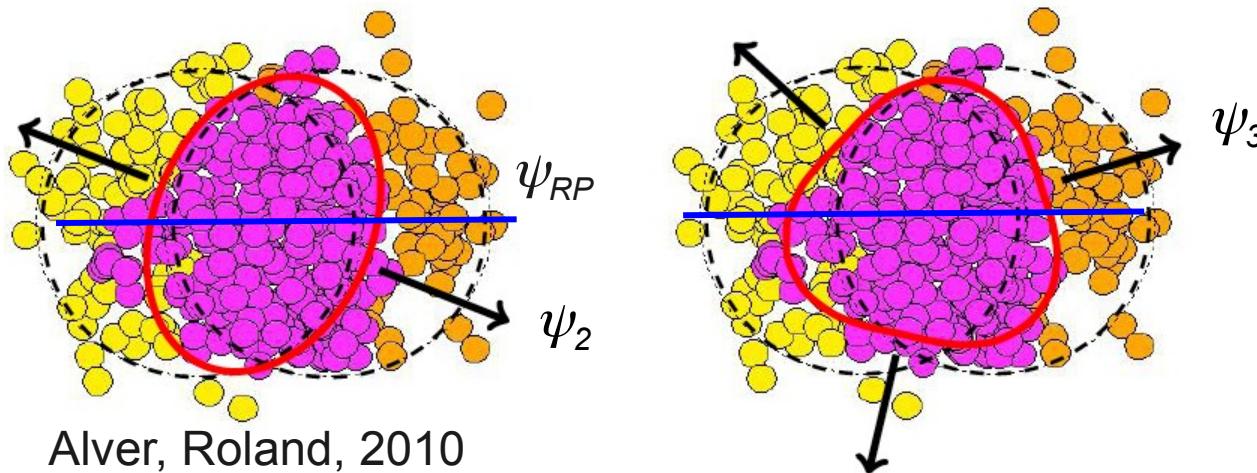
Measured via  $K\pi$  invariant mass – in- and out- of plane

$$v_2 = \frac{\pi}{4} \frac{N_{IN} - N_{OUT}}{N_{IN} + N_{OUT}}$$



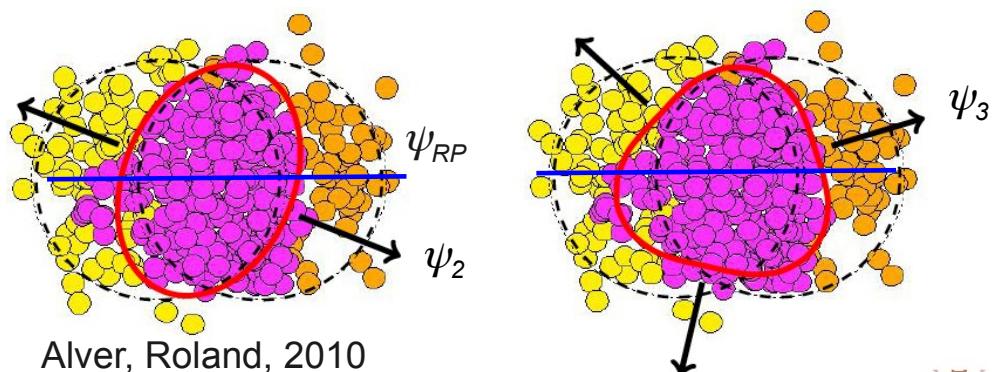
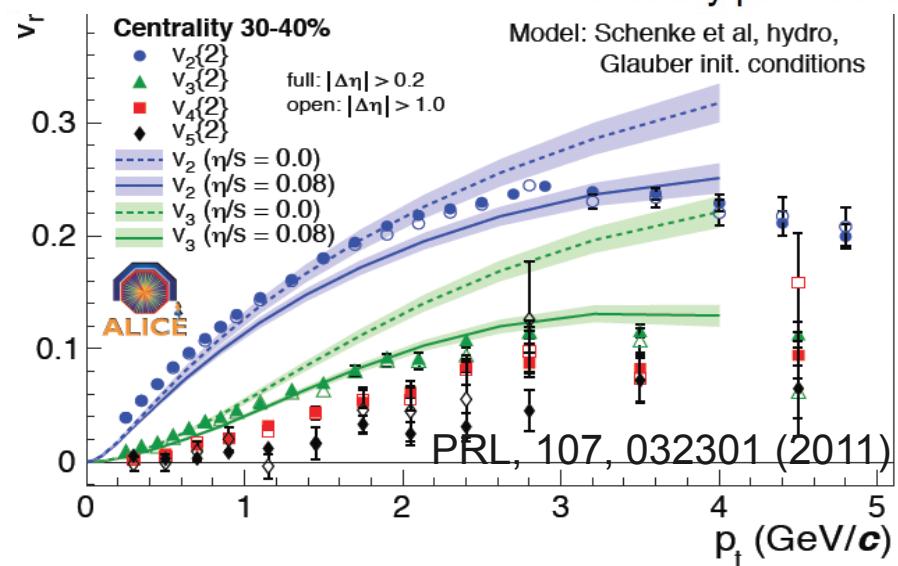
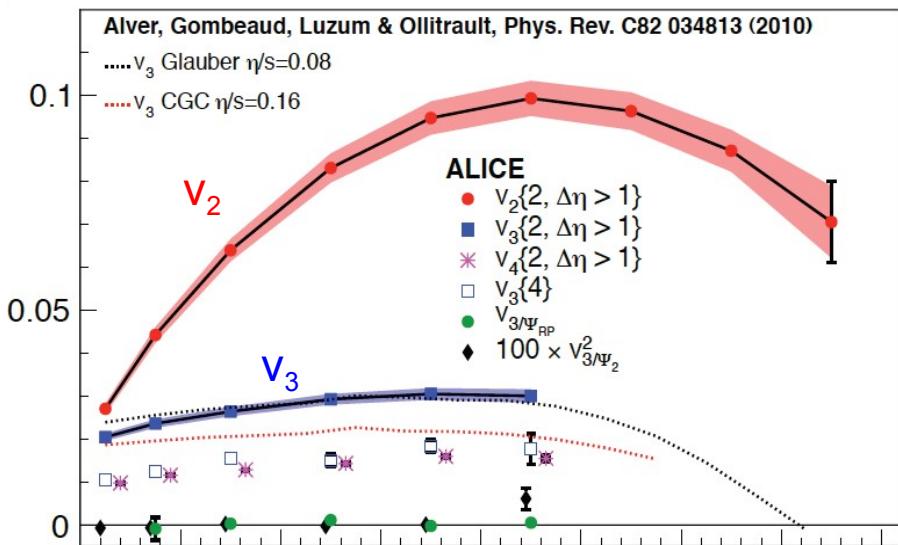
# Particle production and higher harmonics<sup>22</sup> in azimuthal decomposition

$$\frac{dN}{d\Delta\varphi} \sim 1 + 2v_2 \cos(2\Delta\varphi) + \dots$$



Fluctuations in initial state lead to e-by-e fluctuating symmetry planes  
=> Odd harmonics are not zero

# Higher harmonics – the measurements



$v_3$  - triangular flow :  
- weak centrality dependence  
- vanishes as expected when measured w.r.t. reaction plane

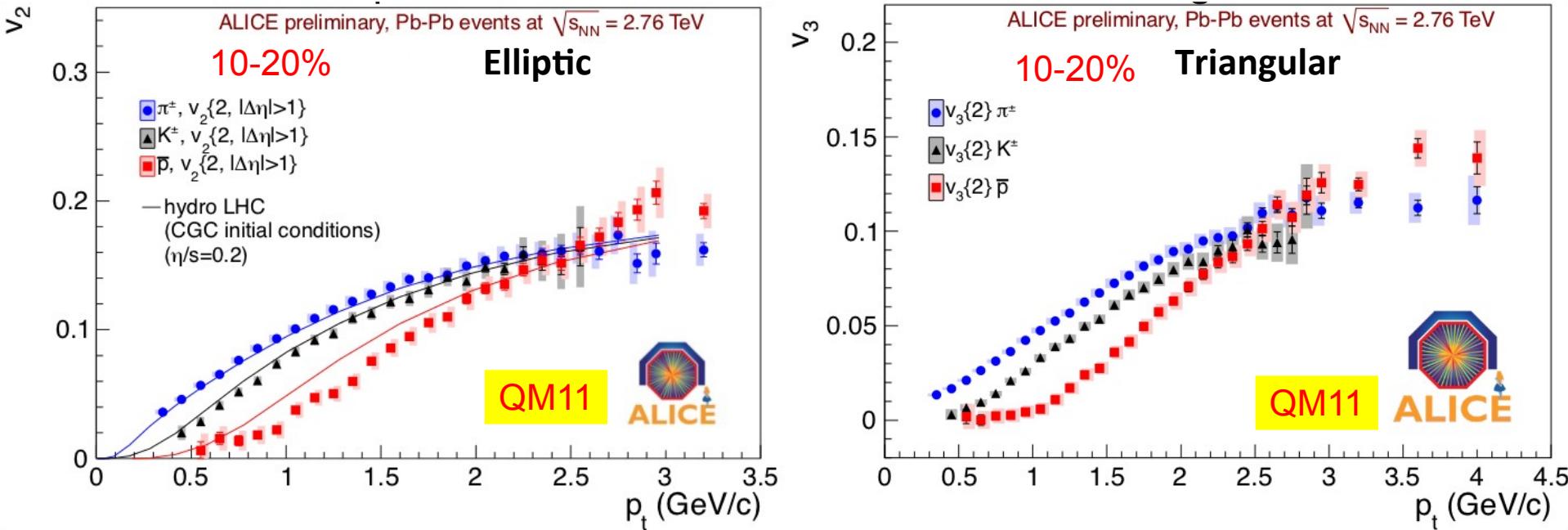
Similar pT dependence for all  $v_n$

Higher harmonics - additional constraints on  $\eta/s$

Krakow, 2011

$\eta/s$  small, similar as at RHIC

# Elliptic vs triangular flow for identified particles



Similar mass dependence in  $v_2$  and  $v_3$  – support for hydrodynamic nature of  $v_3$

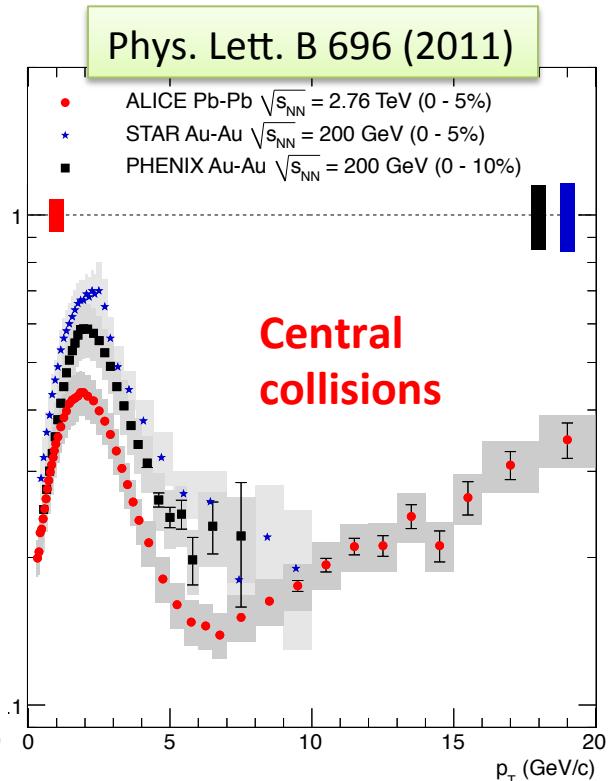
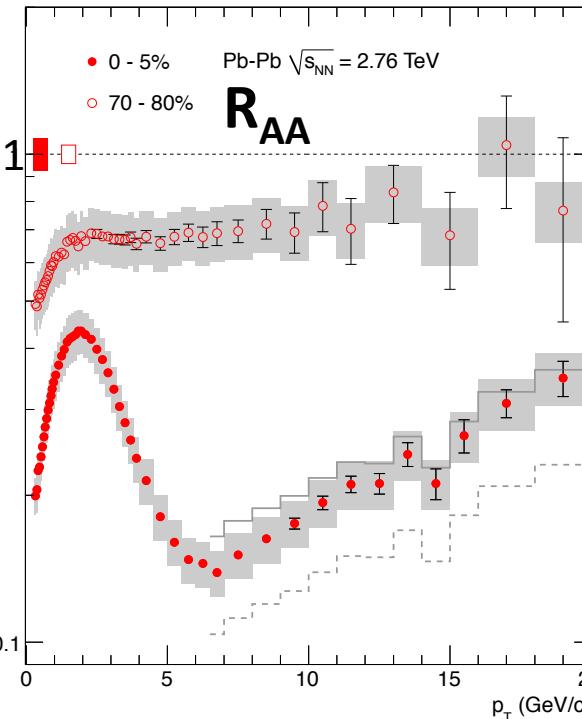
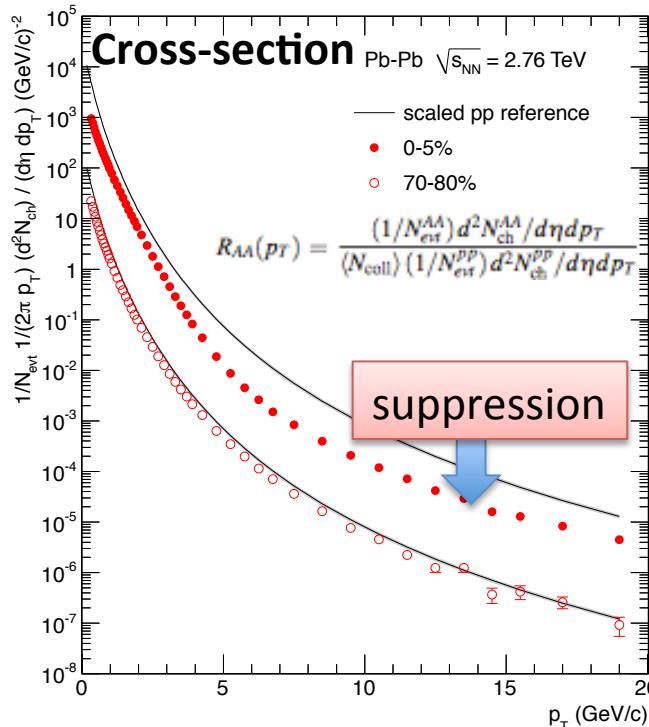
Note: Curves for both  $v_2$  and  $v_3$  for (anti-)protons and pions cross at  $pT \sim 2.5$  GeV/c  
 - In the case of  $v_2$  at RHIC it was discussed as a signature of recombination

# PROBING THE HOT QCD MATTER

# Jet quenching via hadron suppression

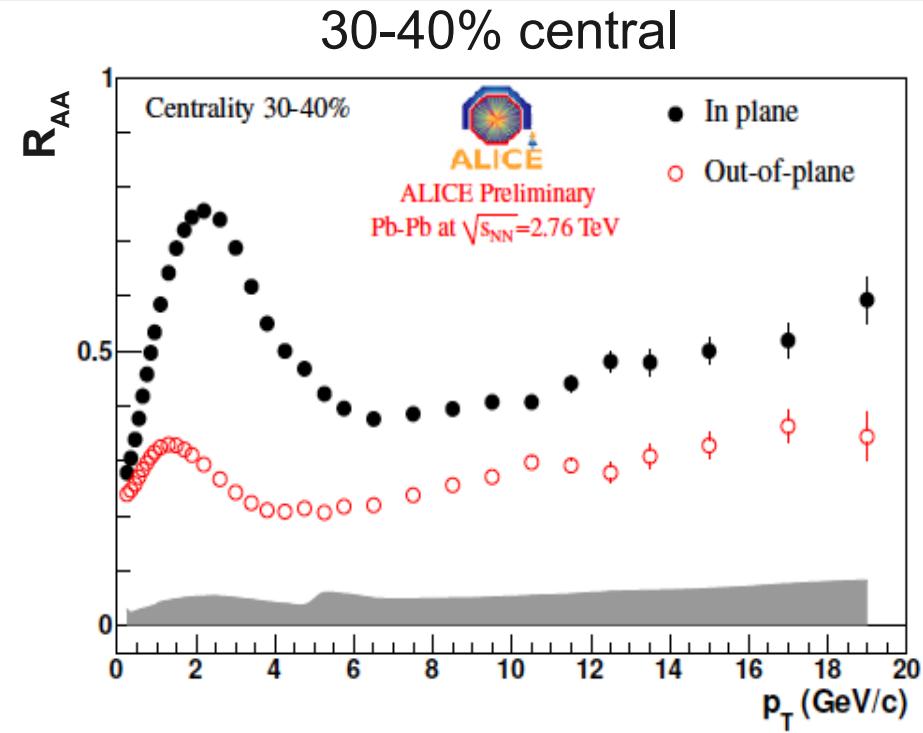
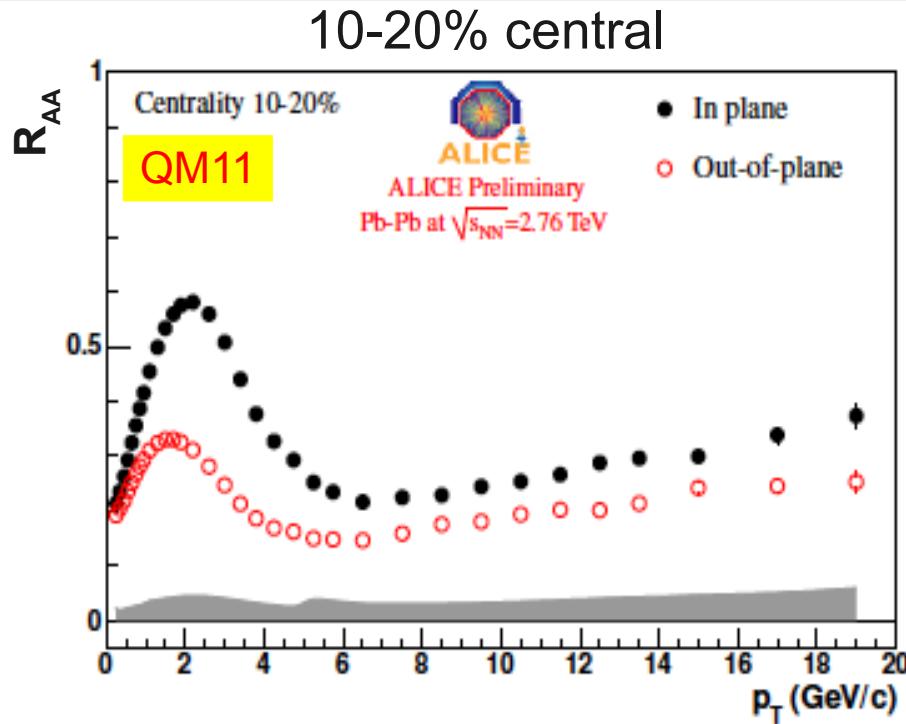
#(particles observed in AA collision per N-N (binary) collision)

$$\text{Ratio} = \frac{\text{(particles observed in AA collision per N-N (binary) collision)}}{\text{(particles observed per p-p collision)}}$$

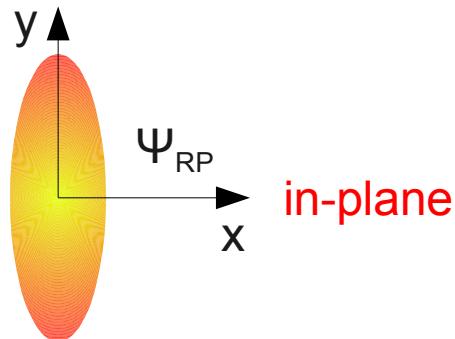


1. Strong depletion of high- $p_T$  hadrons in A-A collisions – consistent with parton energy loss (jet quenching)
2. Qualitatively new feature : evolution of  $R_{AA}$  as a function of  $p_T$
3. New, much anticipated constraint for parton energy-loss models

# Differential RAA w.r.t. reaction plane



out-of-plane



Suppression out-of-plane stronger  $\leq$  longer in-medium path length - significant effect even at 20 GeV/c  
 => Path length dependence of energy loss  
 Additional constraints to energy loss models (?) - similar information from v2 at high  $p_T$

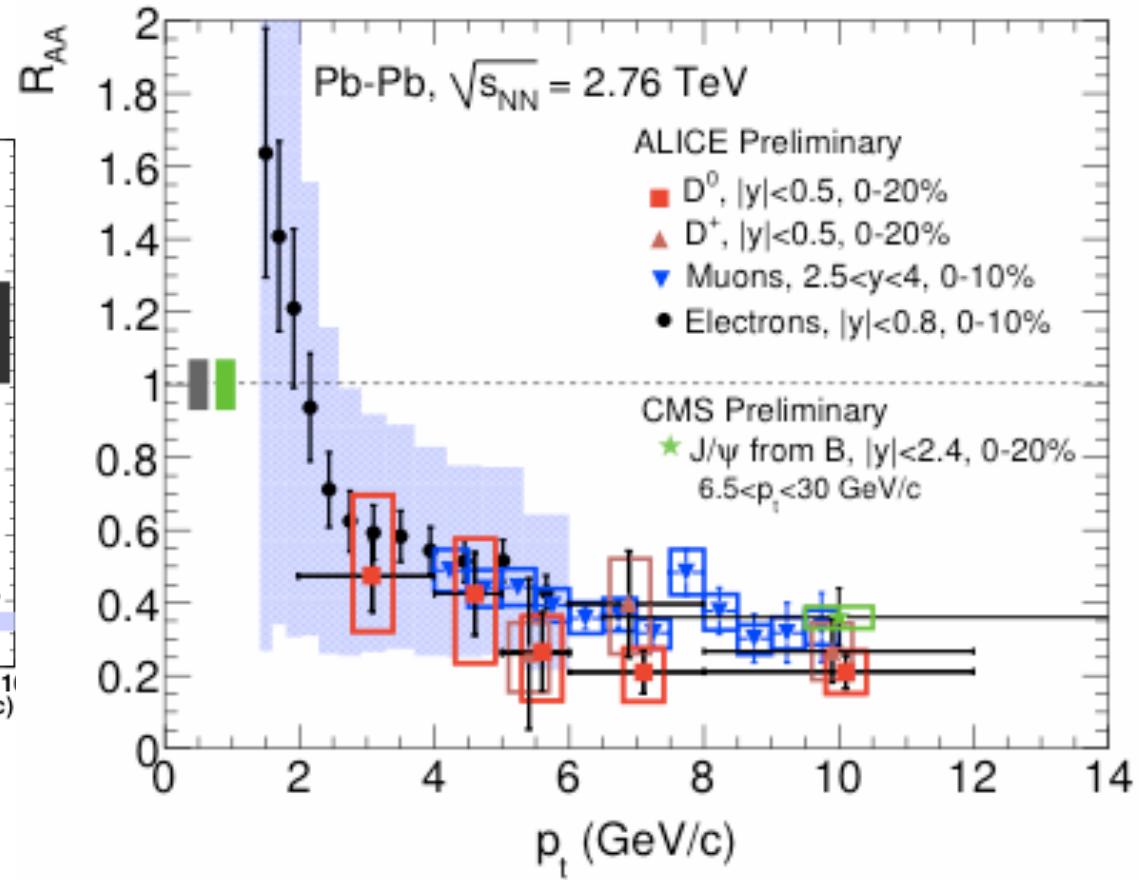
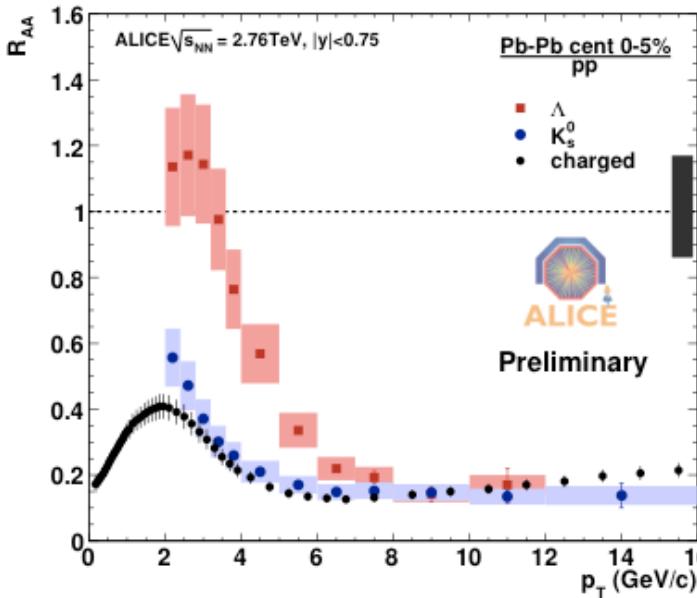
# Flavor dependence of jet quenching

$$\Delta E_{\text{gluon}} > \Delta E_{\text{light-q}} > \Delta E_{\text{heavy-q}}$$

A hint of the above only at low  $p_T$

New insight to theory? Better precision measurements needed...

## Strange baryons vs mesons



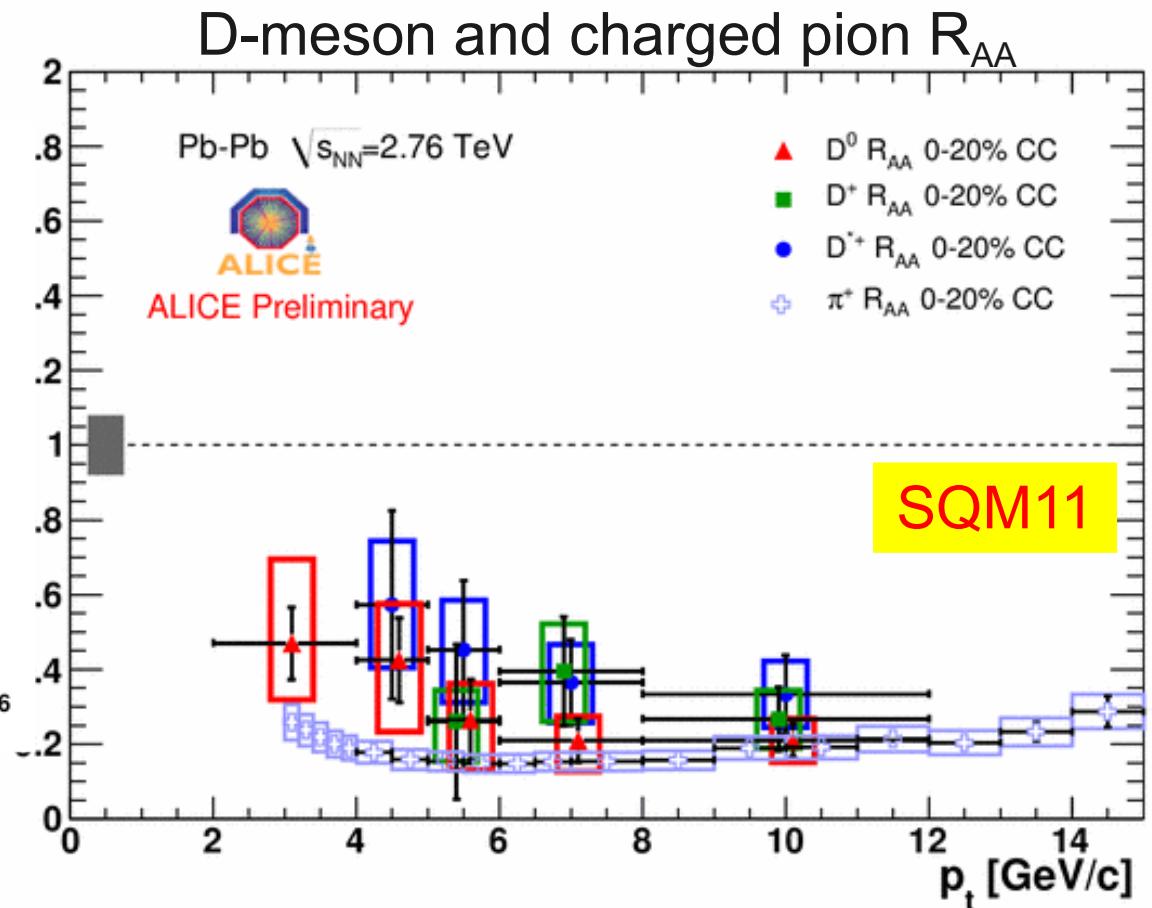
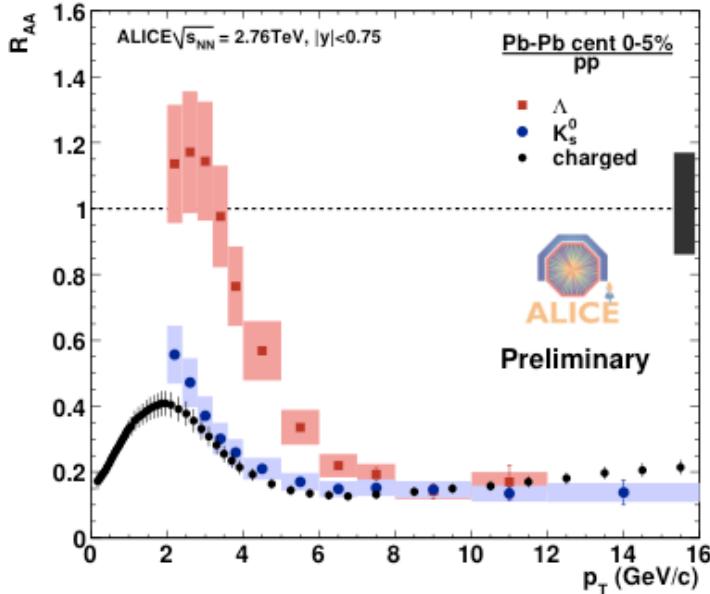
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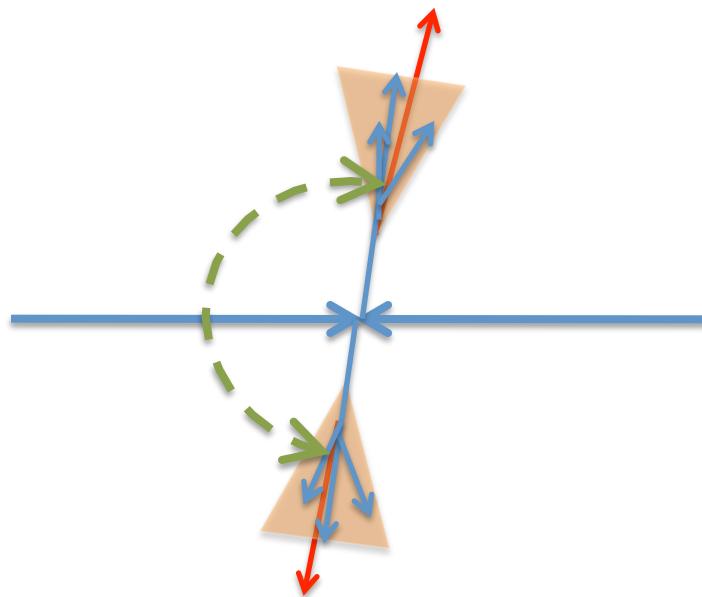
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## Strange baryons vs mesons





## TWO PARTICLE CORRELATIONS

# Di-hadron Correlations

## Two-particle correlations

- conditional [per-trigger] yields

$$\frac{1}{N_{trig}} \frac{dN_{assoc}}{d\Delta\varphi} \quad \text{and} \quad \frac{1}{N_{trig}} \frac{d^2N_{assoc}}{d\Delta\varphi d\Delta\eta}$$

**At Low- $p_T$ :**

Ridge

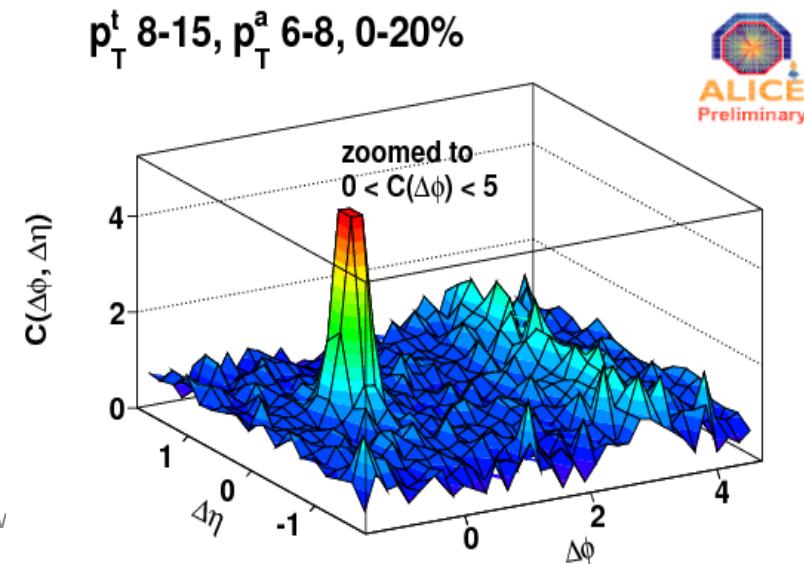
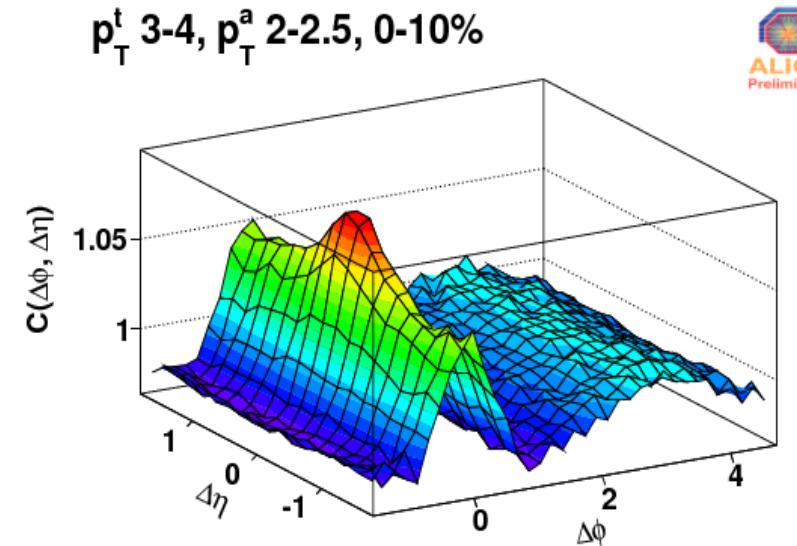
Hydrodynamics, flow

**At High- $p_T$ :**

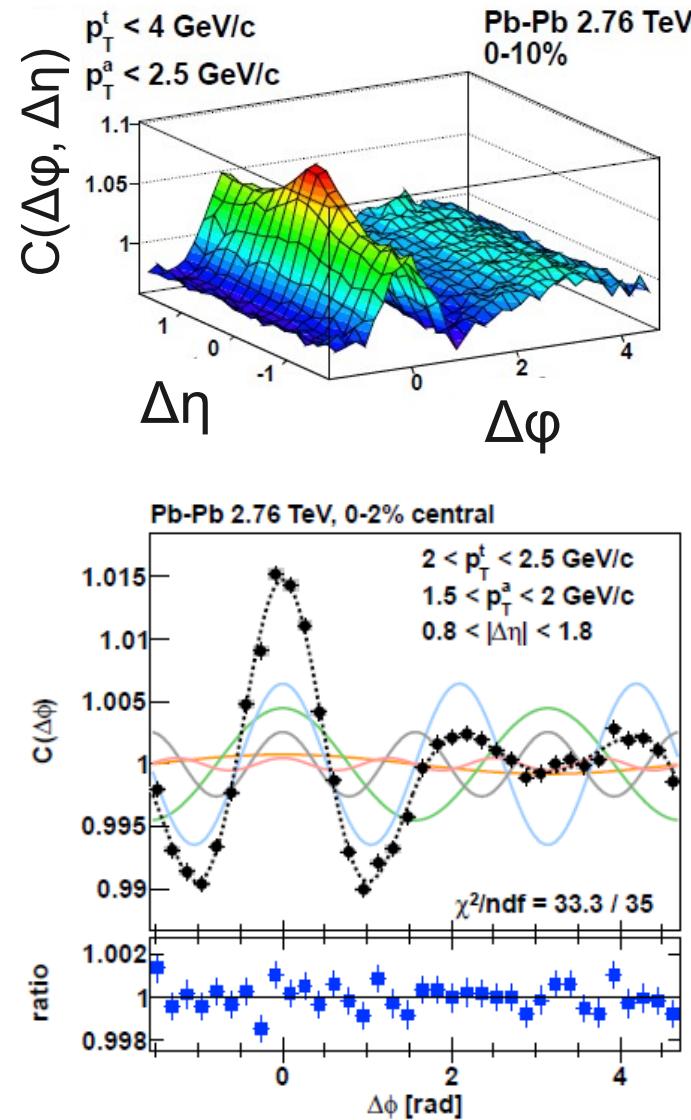
Quenching/suppression,  
broadening

$I_{CP}$ : Yields in central v.s. peripheral  
collisions

$I_{AA}$ : Yields in A-A compared to p-p

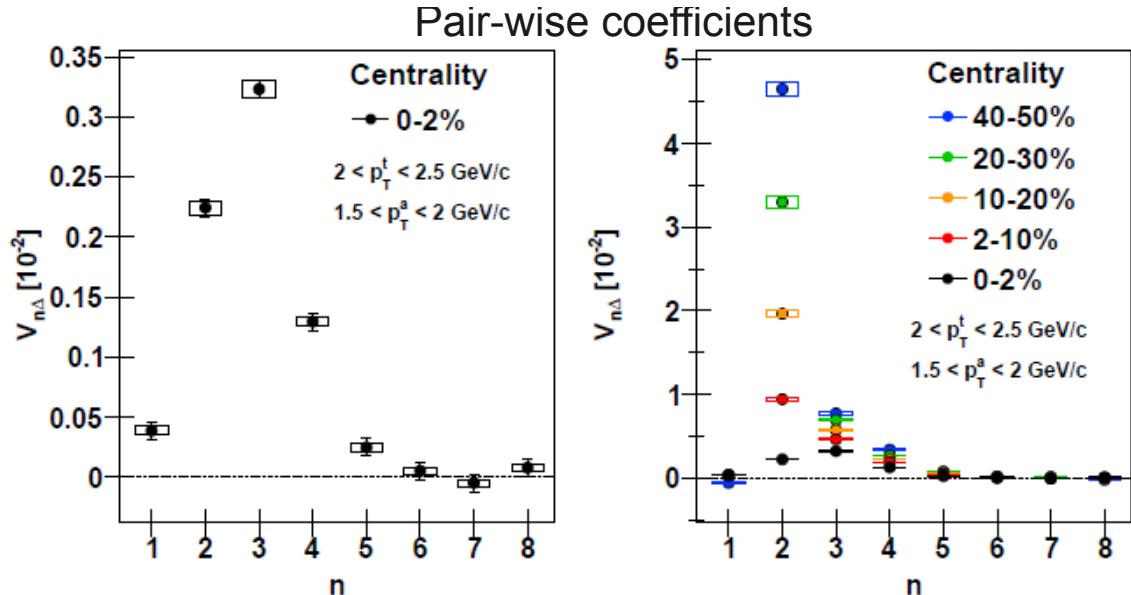


# Two particle correlations – fourier decomposition – long range correlations



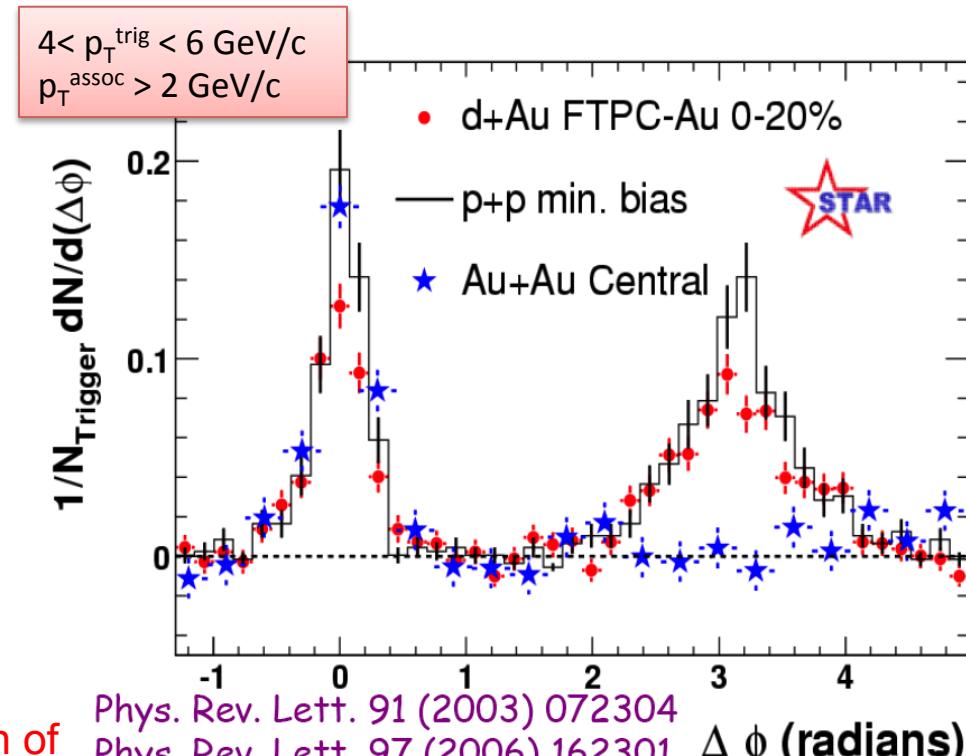
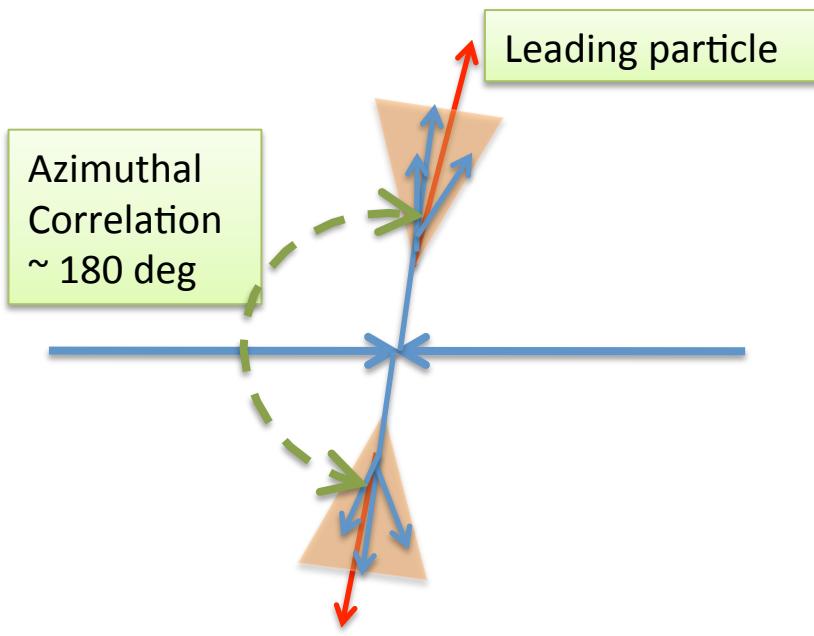
Integration of the correlation function in  $0.8 < |\Delta\eta| < 1.8$  (long) and Fourier decomposition  
Collective flow: the coefficients factorize  $V_{n\Delta} = v_n(p_T^T)v_n(p_T^A)$

$$C(\Delta\phi) = \frac{1}{\Delta\eta_{\max} - \Delta\eta_{\min}} \int_{\Delta\eta_{\min}}^{\Delta\eta_{\max}} C(\Delta\eta, \Delta\phi) \sim 1 + 2 \sum_{n=1} V_{n\Delta} \cos(n\Delta\phi)$$



Few components describe the low-pT correlations  
⇒ Strong near side ridge and double-peak on the away  
⇒ Also recoil jet up to  $p_T^{\text{trig}} > 8$  &  $p_T^{\text{assoc}} 6-8$  in central

# Jet quenching: recoil jet suppression via $^{33}$ leading hadron azimuthal correlations

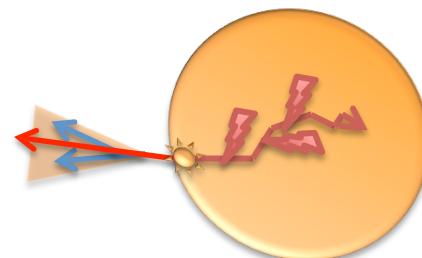


Intermediate pT di-hadrons: Strong modification of the recoil-jet indicates **substantial partonic interaction within the medium**  $\rightarrow$  quenching

High-pT di-hadrons: Selection of non-interacting jets

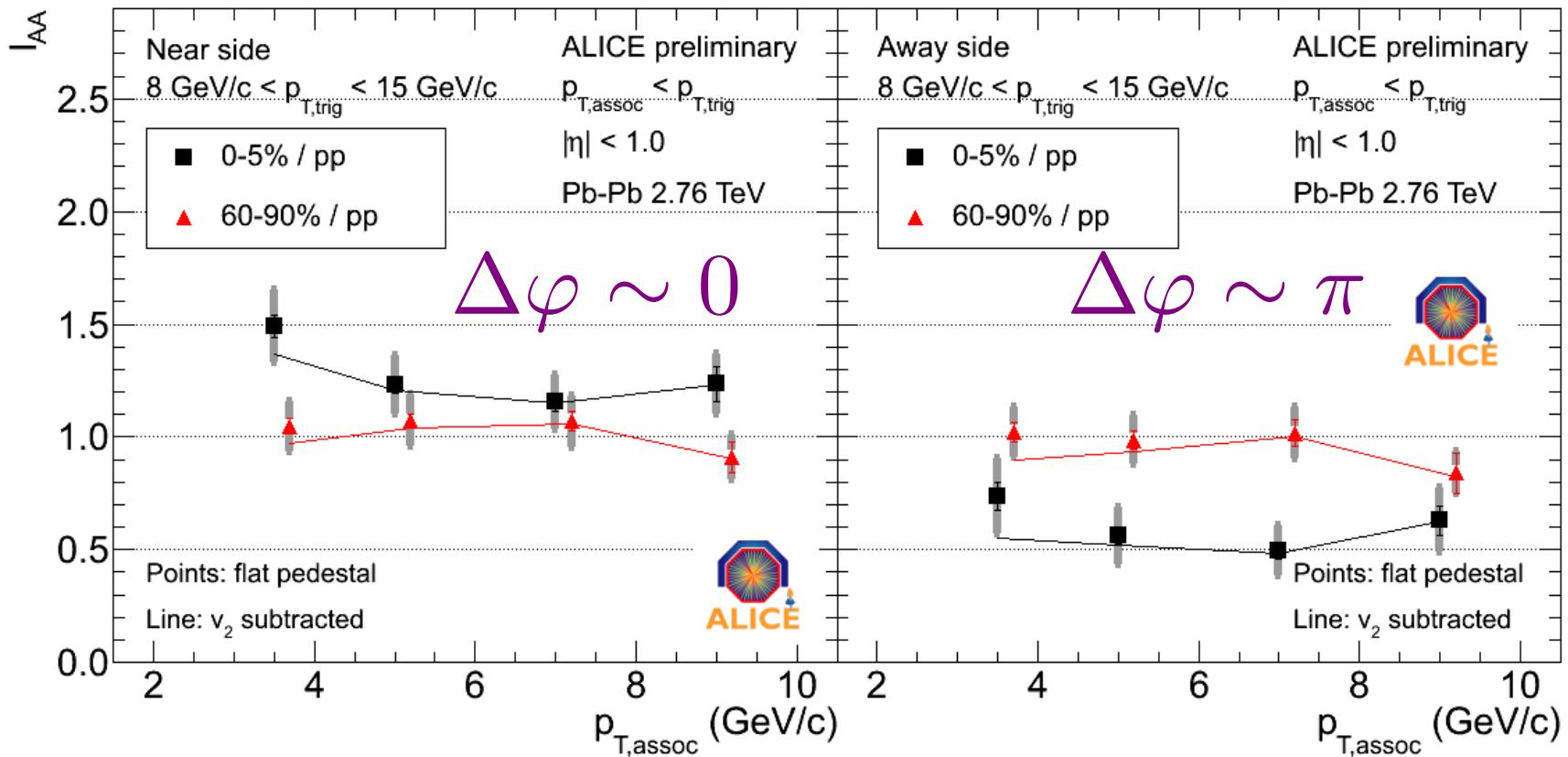
=> Limited sensitivity to quenching details

Phys. Rev. Lett. 91 (2003) 072304  
Phys. Rev. Lett. 97 (2006) 162301



# Ratio of conditional yields: $I_{AA}$

Conditional yields in AA divided by yields in p-p



## Central events

Near side slightly enhanced  $I_{AA} \sim 1.2$

Away side suppressed  $I_{AA} \sim 0.5 - 0.7$

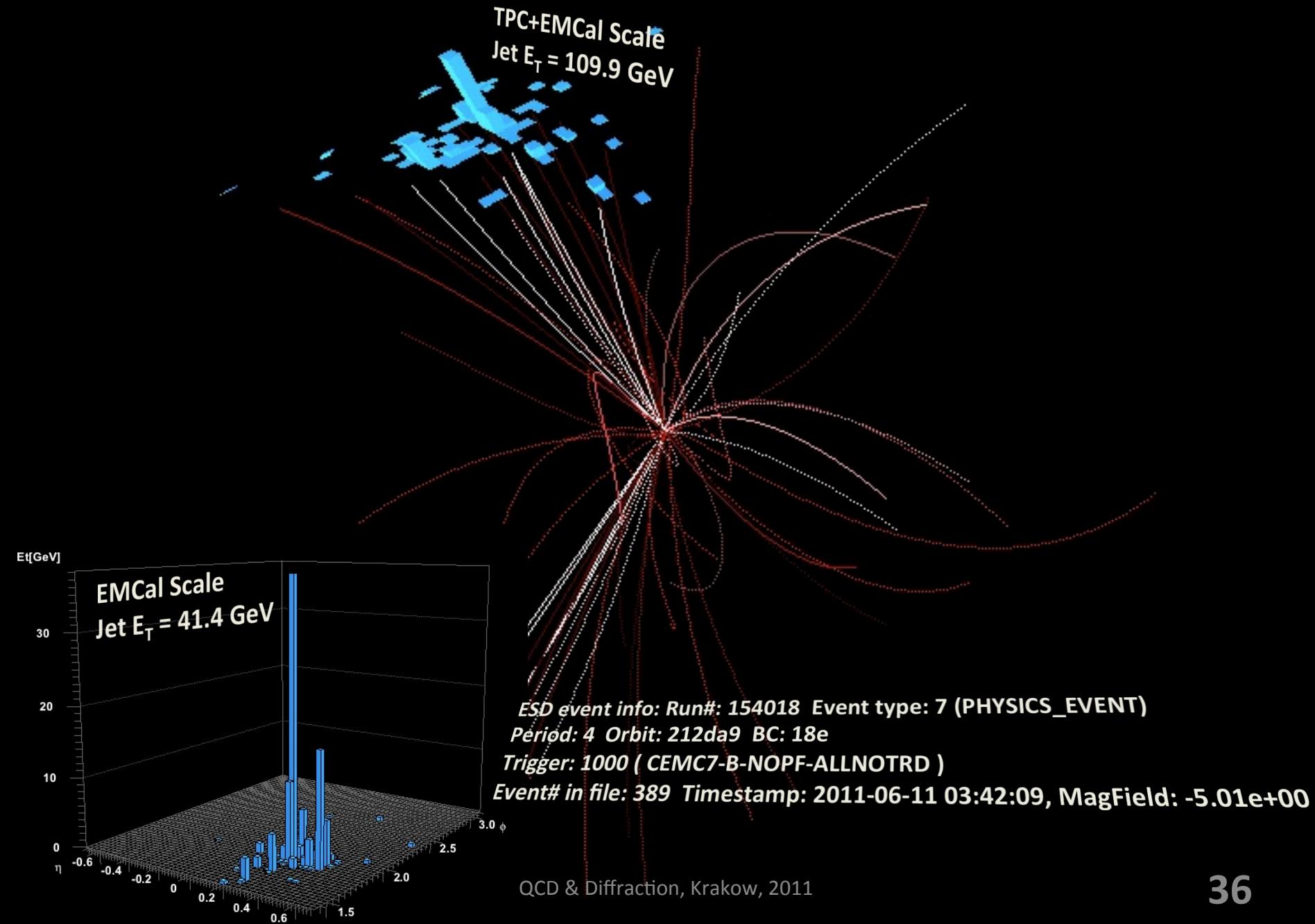
## Peripheral events

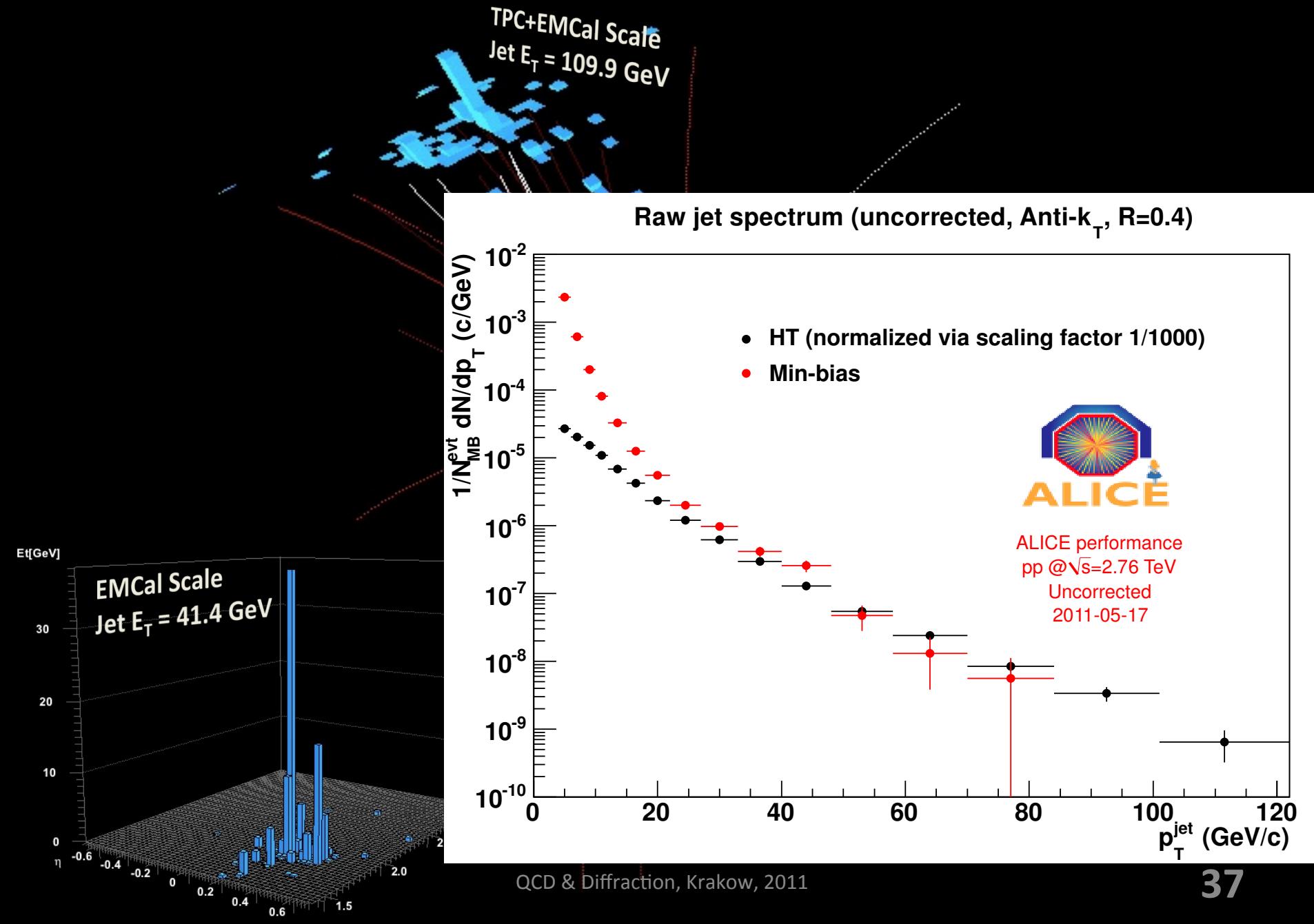
$I_{AA}$  consistent with 1

$v2$  contribution small except the lowest bin, therein  $v3$  of same order

2011 complete Electromagnetic Calorimeter

## **PREREQUISITES FOR COMPLETE JET RECONSTRUCTION IN ALICE**





# Summa summarum

## “SOFT & BULK”

- RHIC vs LHC: Larger (2x), longer-lived (1.4x) and denser (2.5x) system produced with strong radial flow,  $\beta=0.66c$
- Same (RHIC&LHC) chemical freeze-out temperatures
- Thermal fits fail with proton/pion ratio
- Strangeness saturates
- Same elliptic flow as at RHIC
- Flow dominates out to  $pT = 3\text{-}4 \text{ GeV}$
- “Intermediate”  $pT$  region up to  $8 \text{ GeV}/c$
- Higher harmonics can explain low- $pT$  correlations
- Heavy quarks  $v_2 > 0$

## “HARD PROBES”

- Mach cone and ridge not jet phenomena
- Jet particle yields enhanced on near-, suppressed on away-side
- Strong high  $pT$  suppression observed for all particles
  - Minimum at about  $6\text{-}8 \text{ GeV}/c$ , strong rise for  $pT>8 \text{ GeV}/c$
- Reaction-plane dependent suppression
- $R_{AA}$ : Slight mass dependence at low to intermediate  $pT$  - data converge at high  $pT$
- Charm mesons strongly suppressed

*Thank you!*

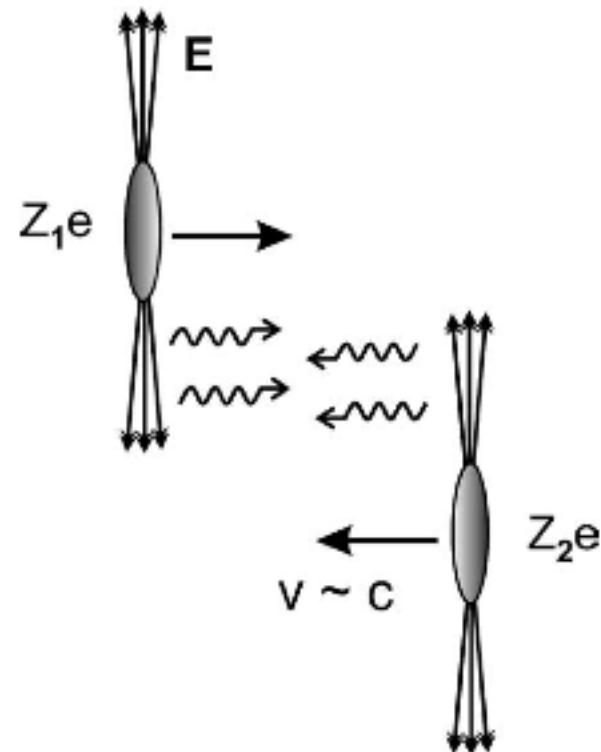
NOTE: Central diffraction covered by Jan Figiel

**ALICE IS A VERSATILE EXPERIMENT  
OTHER MEASUREMENTS...**

# Particle production in ultra-peripheral Pb-Pb collisions



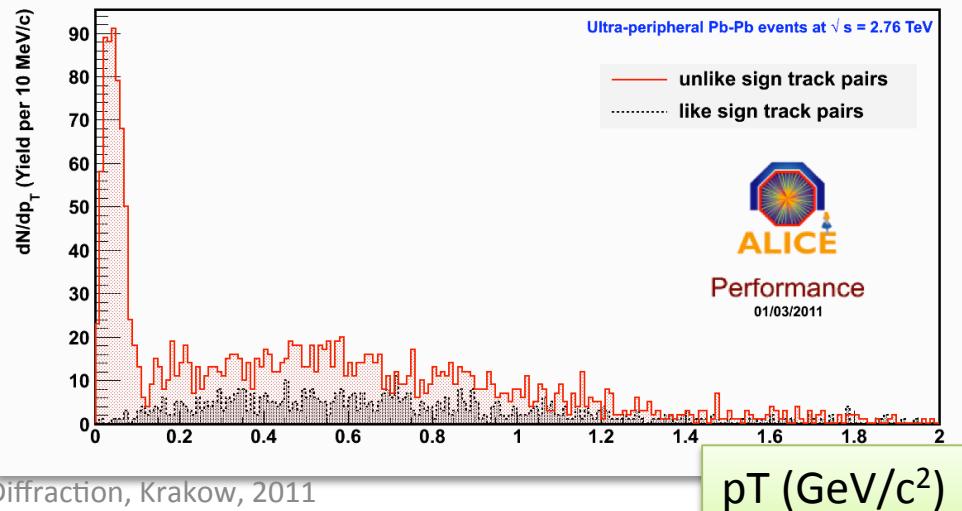
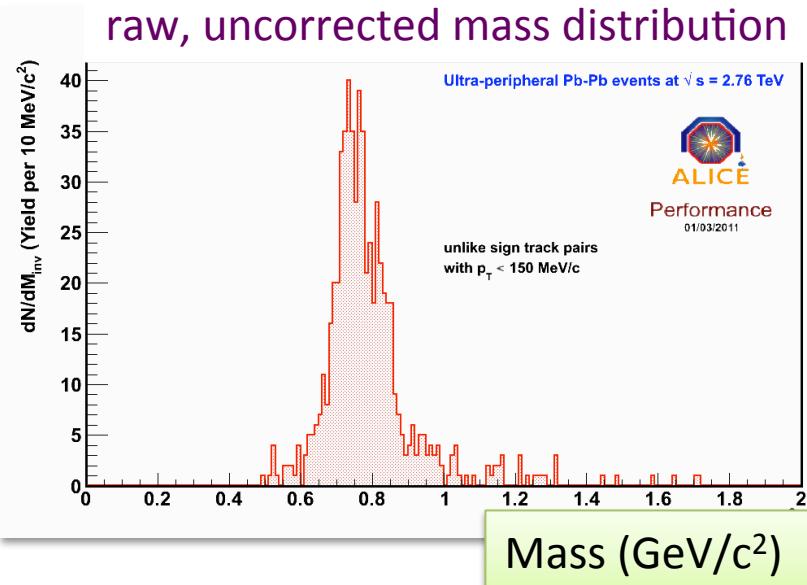
- Invariant mass of **unlike sign** (2-track) events with **event  $p_T < 0.15 \text{ GeV}/c$**
- Pion mass is assumed.
- **Trigger: both tracks with hits in Silicon-Pixel-Detector and Time-Of-Flight**
- **Expect a low mean  $p_T$**



# Particle production in ultra-peripheral Pb-<sup>41</sup>Pb collisions



- Invariant mass of **unlike sign** (2-track) events with **event  $p_T < 0.15 \text{ GeV}/c$**
- Pion mass is assumed.
- **Trigger: both tracks with hits in Silicon-Pixel-Detector and Time-Of-Flight**
- **Mean  $p_T \sim 0.05 \text{ GeV}/c$**



# Electromagnetic dissociation (EMD) with<sup>42</sup> ALICE ZDC's

Ultra-peripheral heavy-ion interaction -> EMD of nuclei

Most probable channel:  
GDR followed by neutron emission

ZDCs: 115 meters away from  
IP2 on both (A,C) sides,

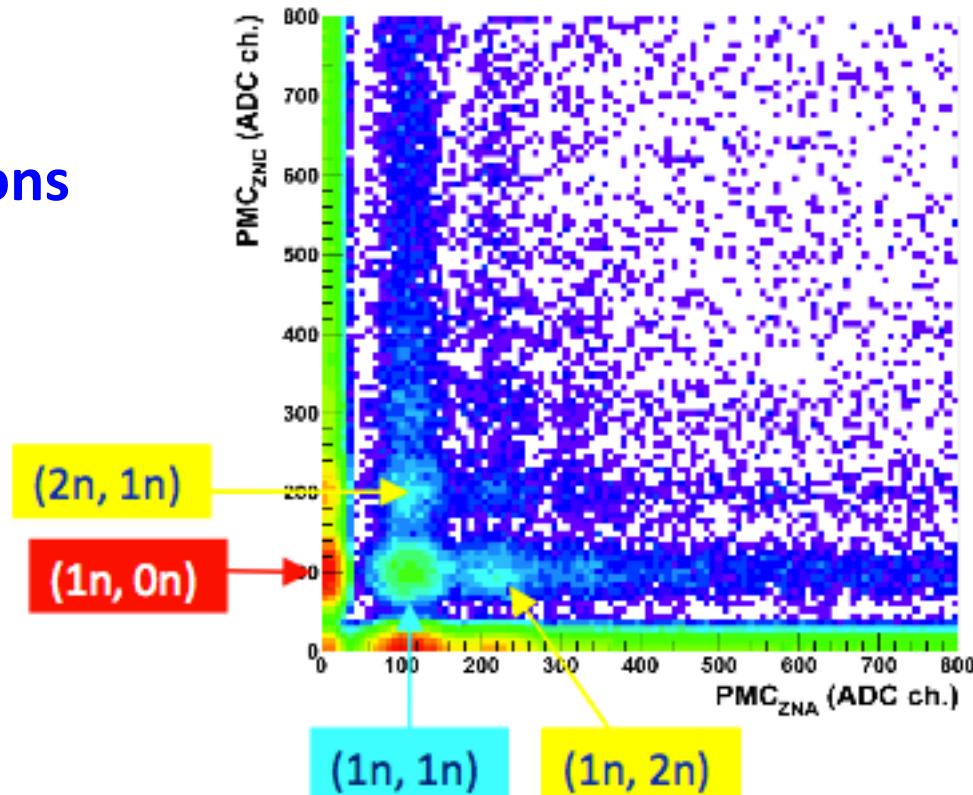
Model QED description: RELDIS

– EMD events and cross-sections

Pshenichnov, I.A., et al.

- Phys.Rev. C60 (1999) 044901
- Phys.Rev. C64 (2001) 024903

Trigger ZNA || ZNC selects:  
single EMD (~185b);  
mutual EMD (~5.9 b)  
nuclear (7.8 b)



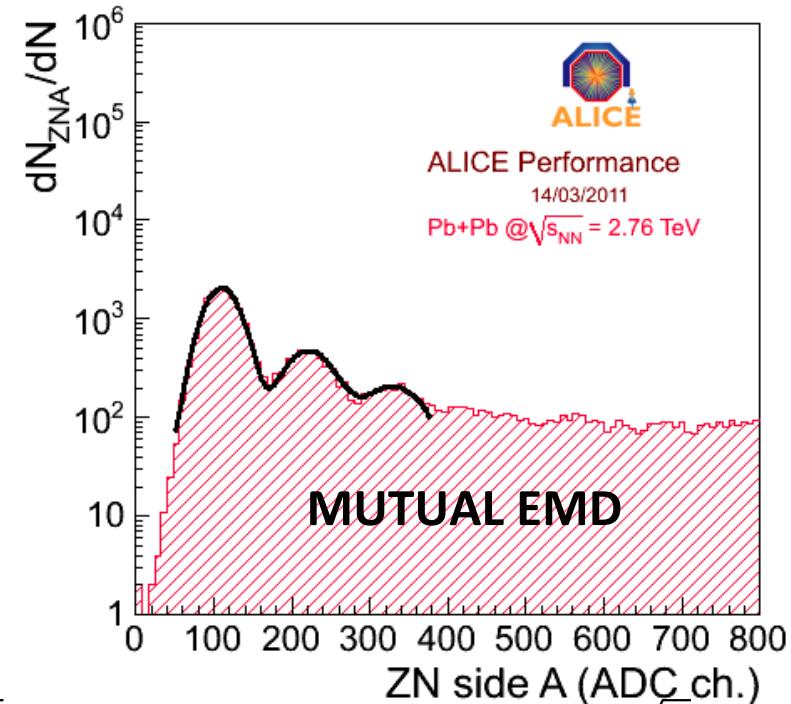
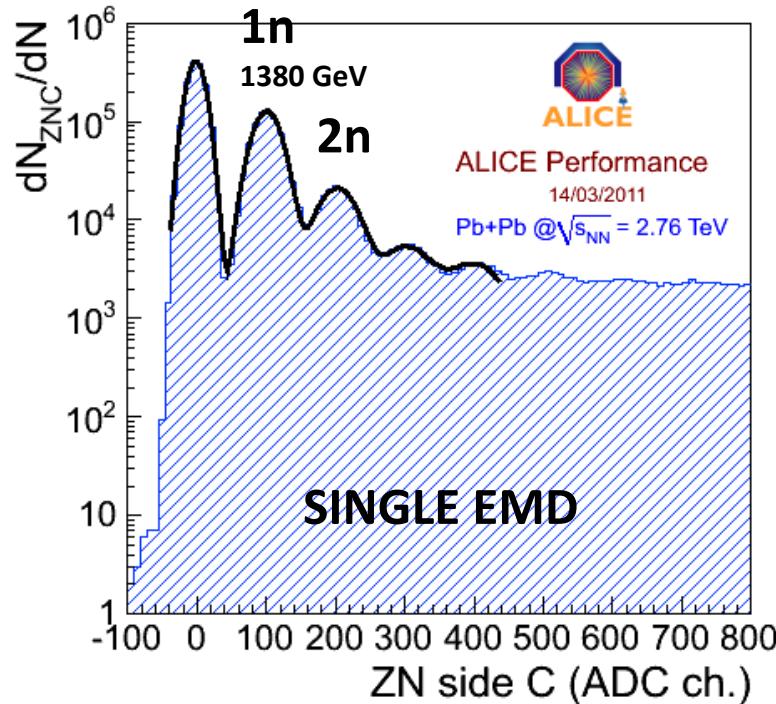
# Single and mutual EMD with ZDC

ZDC signal: Single EMD + Mutual EMD + Nuclear effects

Mutual EMD event selection: ZNC && ZNA + ZDC time selection +  
 $(ZEM1<10 \text{ || } ZEM2<10)$  estimated from simulations to reject nuclear events

Data: 1n peak resolution ~20% consistent with RELDIS calculation

Ratios: 1n/2n; 1n/3n; 2n/3n are under investigation



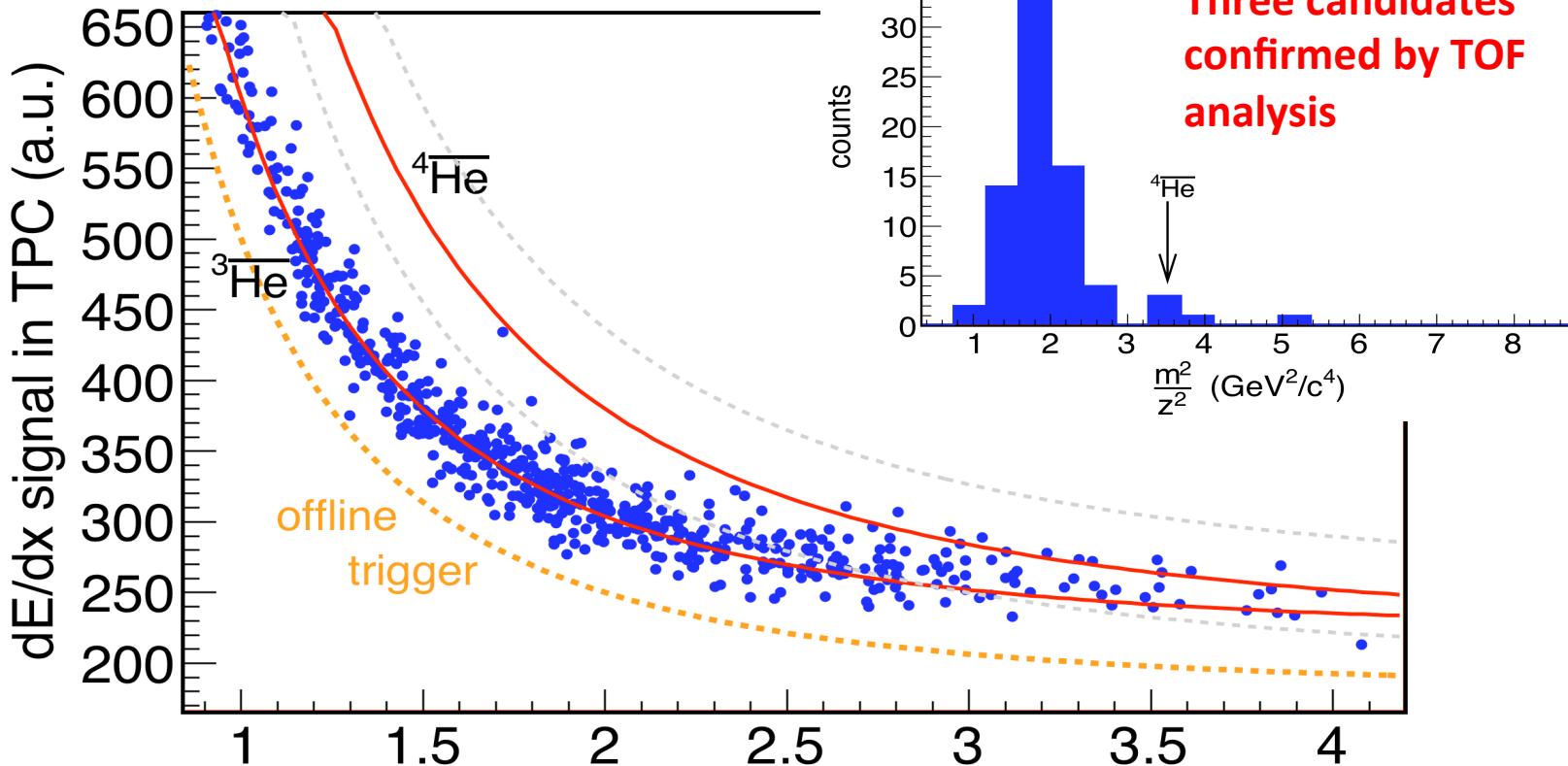
Fit constrains:  $\mu_{2n} = 2\mu_{1n}$ ;  $\sigma_{2n} = \sqrt{2}\sigma_{1n}$ ;  $\mu_{3n} = 3\mu_{1n}$ ;  $\sigma_{3n} = \sqrt{3}\sigma_{1n}$

QCD & Diffraction, Krakow, 2011

# Anti-Alpha candidates in Pb-Pb

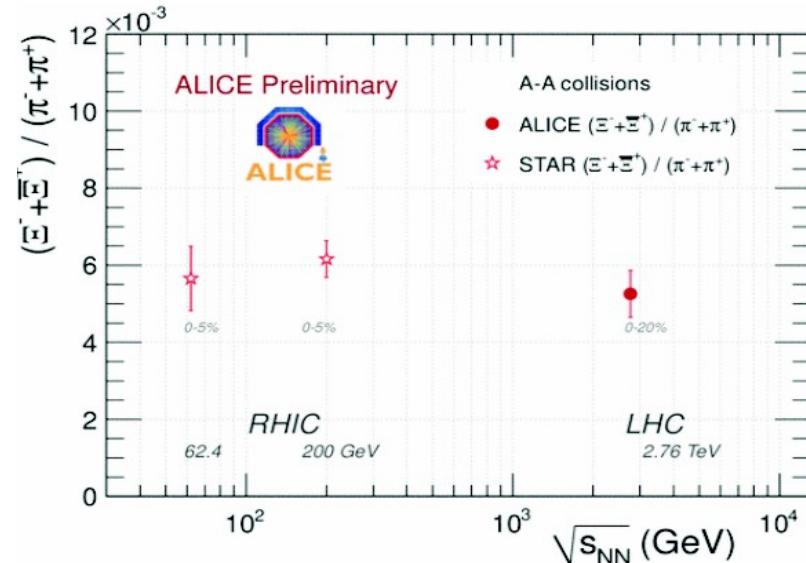
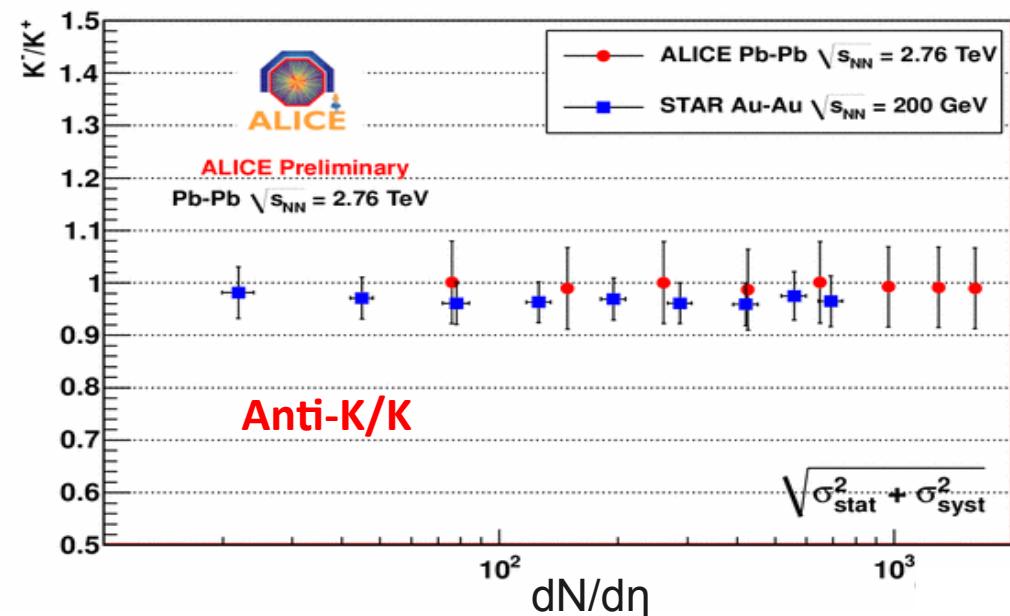
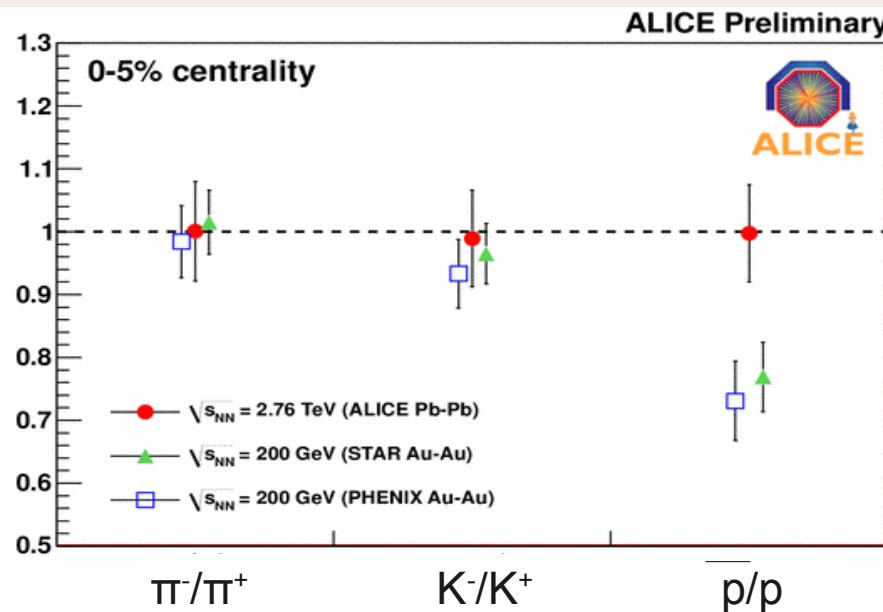
Time of flight (sensitive to m/z-ratio):  $m = \frac{z \cdot R}{\sqrt{\gamma^2 - 1}}$

$$\langle \frac{dE}{dx} \rangle = \frac{4\pi Ne^4}{mc^2} \frac{z^2}{\beta^2} \left( \frac{1}{2} \ln \frac{2mc^2 E_{max} \beta^2 \gamma^2}{I^2} - \frac{\beta^2}{2} - \frac{\delta(\beta)}{2} \right)$$



# EXTRA SLIDES

# Particle ratios – PbPb at 2.76 TeV

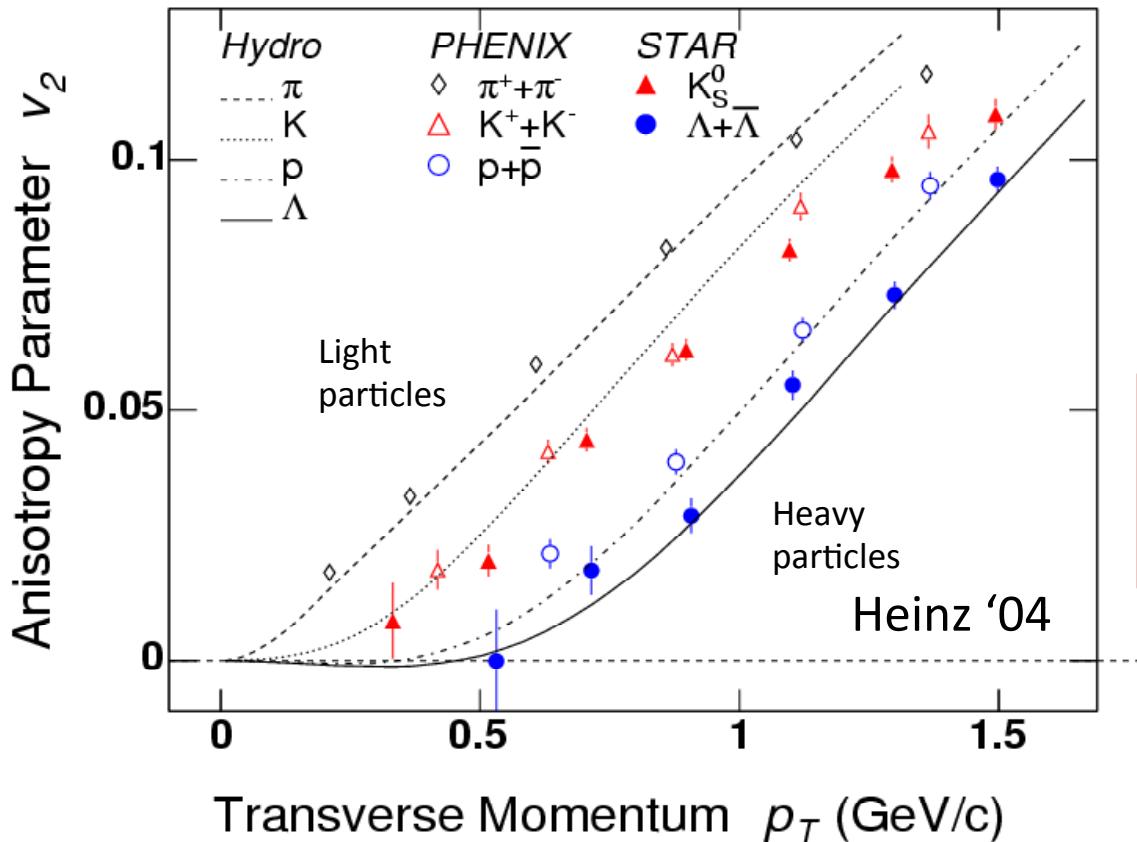


Anti-particle/particle ratios  $\sim 1$   
 $\Leftrightarrow \text{LHC: } \mu_b \approx 0$

Strange/non-strange ratio constant  
Above SPS energies, strange quarks are thermalized

Diffraction, Krakow, 2011

# Relativistic (Ideal) Hydrodynamics



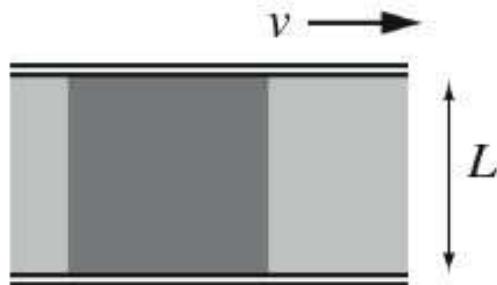
$$\partial_\mu T^{\mu\nu} = 0$$

Shear viscosity  $\eta = 0$

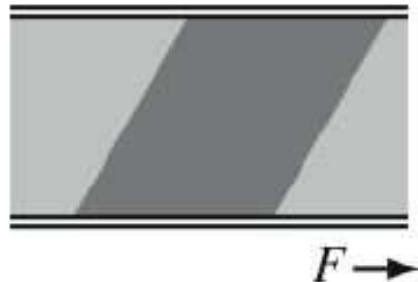
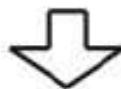
Mass hierarchy vs *momentum*  
is characteristic of common  
*velocity distribution*

Ideal hydro: qualitative agreement but missing the details

# Shear viscosity in fluids



$$\frac{F}{A} = \eta \frac{v}{L}; \quad \eta \sim \rho \langle v \rangle \lambda_{mfp}$$

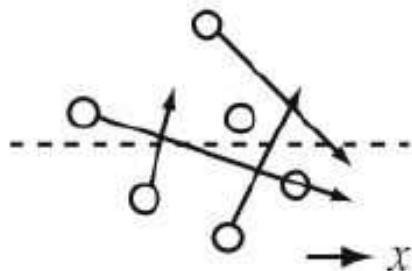


Weak coupling

- small cross section, long mean free path  
⇒ large viscosity

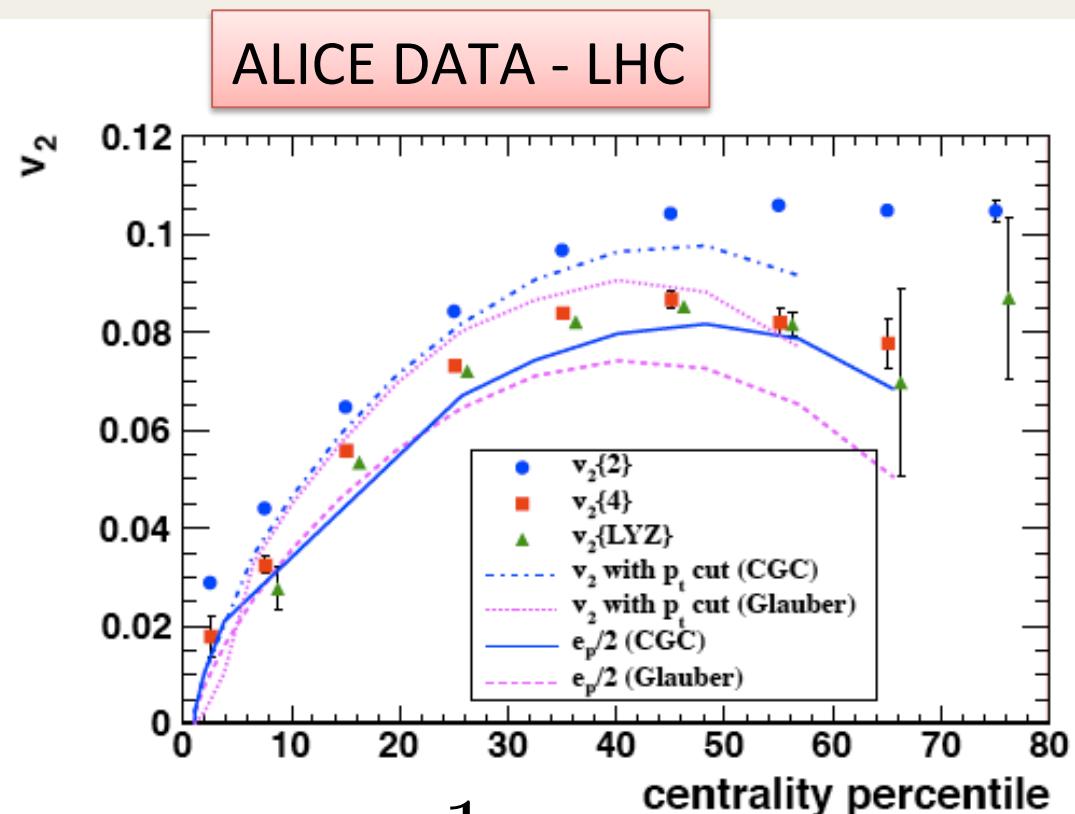
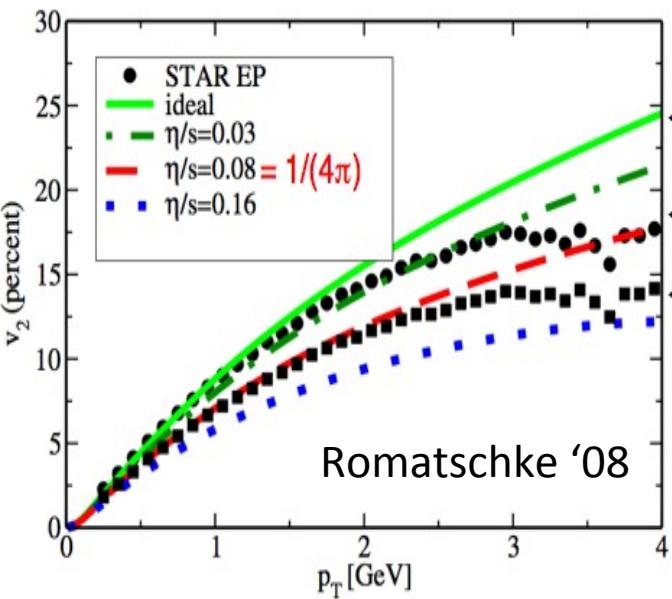
Strong coupling

- large cross section, small mean free path  
⇒ small viscosity



$\eta \rightarrow 0$ : strongly coupled (perfect) fluid  
 $\eta \rightarrow \infty$ : weakly coupled (ideal) gas

# How perfect fluid is QCD Matter?



Shear viscosity – lower limit:

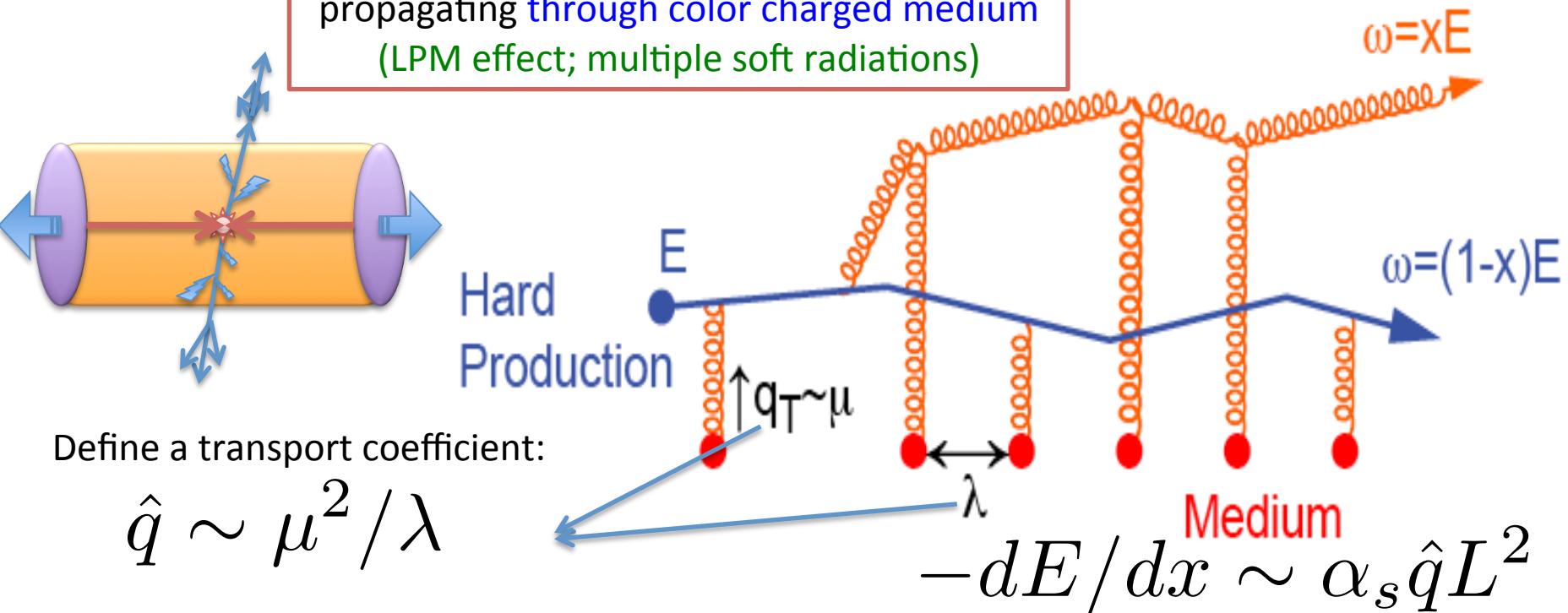
KSS (string theory); Gyulassy-Danielewicz  
(quantum mechanics + ballistic theory)

$$\frac{\eta}{s} > \frac{1}{4\pi}$$

**Hot, deconfined QCD matter flows as an almost perfect fluid**

# Bremsstrahlung energy loss in QCD

High energy **color charged probe**  
 propagating through color charged medium  
 (LPM effect; multiple soft radiations)



Define a transport coefficient:

$$\hat{q} \sim \mu^2 / \lambda$$

Partonic energy loss in QCD medium is proportional:

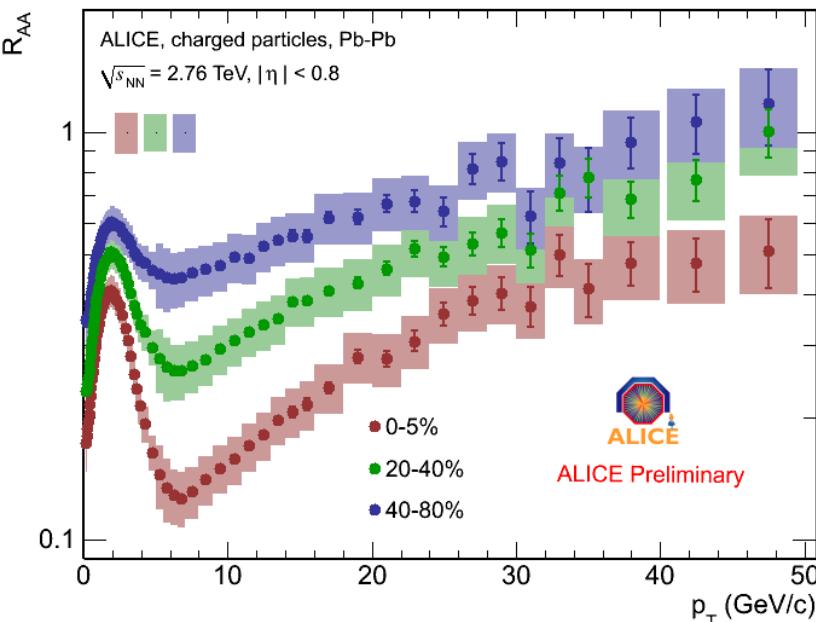
- to squared average path length (Note: QED  $\sim$  linear)

- to density of the medium

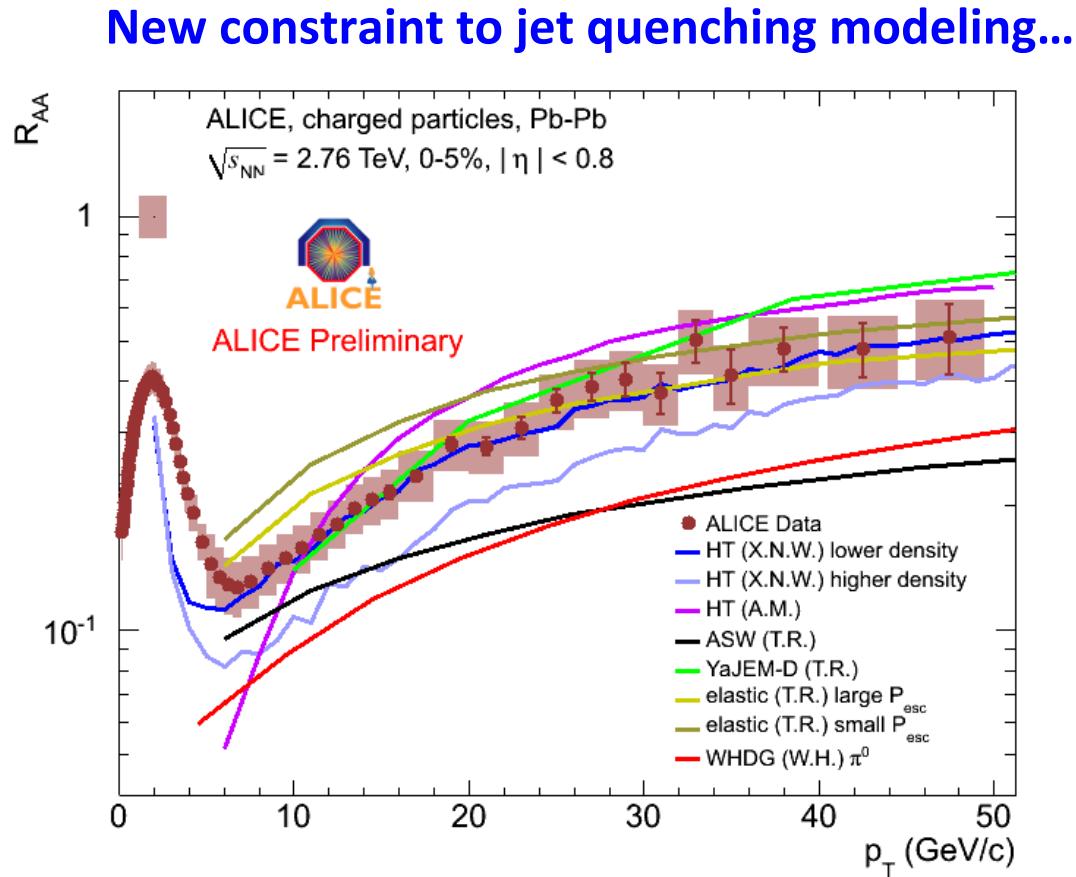
$\Rightarrow$  **energy flow (parton+radiation) modified as compared to jet in vacuum**

$\Rightarrow$  **jet “quenched” (“softened” fragmentation)**

# Jet quenching via hadron suppression



Expected evolution with centrality

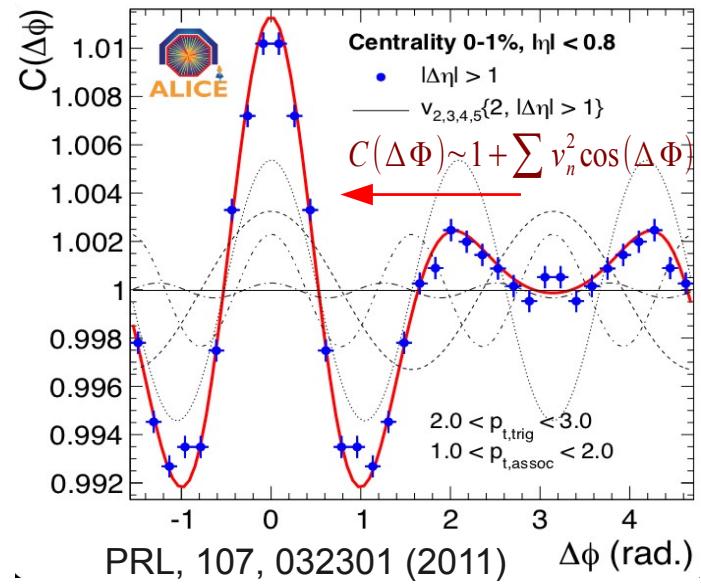
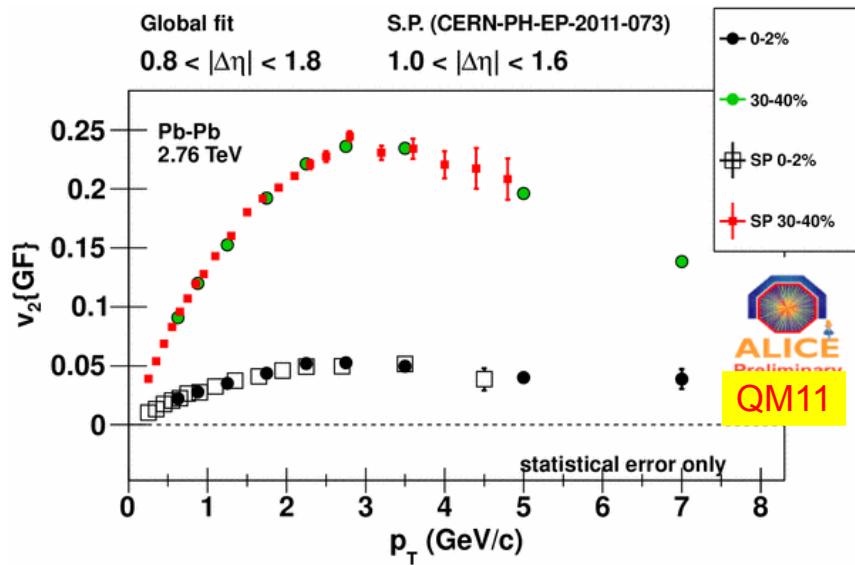


# Fourier coefficients of 2-particle correlations – relation to hydrodynamics

Long range correlations – collective flow: the coefficients must factorize such that:

$$V_{n\Delta} = \langle \cos[n(\phi_{trig} - \phi_{assoc})] \rangle = \langle \cos[n(\phi_{trig} - \Psi_n)] \rangle \langle \cos[n(\phi_{assoc} - \Psi_n)] \rangle = v_n(p_t^{trig}) \cdot v_n(p_t^{assoc})$$

arXiv:1109.2501



Global fits show:

- Collective flow dominates to about 3-4 GeV/c for all  $n > 1$
- Description breaks for high pT or peripheral collisions
- For low pT: double peak and ridge structures seen in two particle correlations are naturally explained by measured anisotropic flow coefficients

# Charged jets and backgrounds in Pb-Pb

Detailed characterization of the background is a prerequisite for jet reconstruction in Pb-Pb

Shown: FastJet Anti- $k_T$  ( $R=0.4$ )

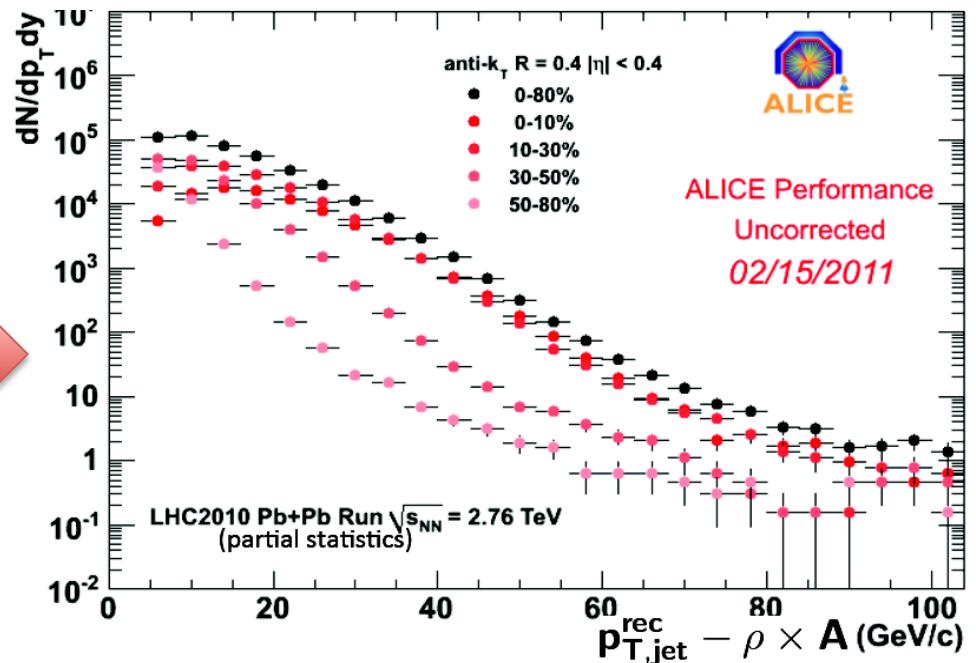
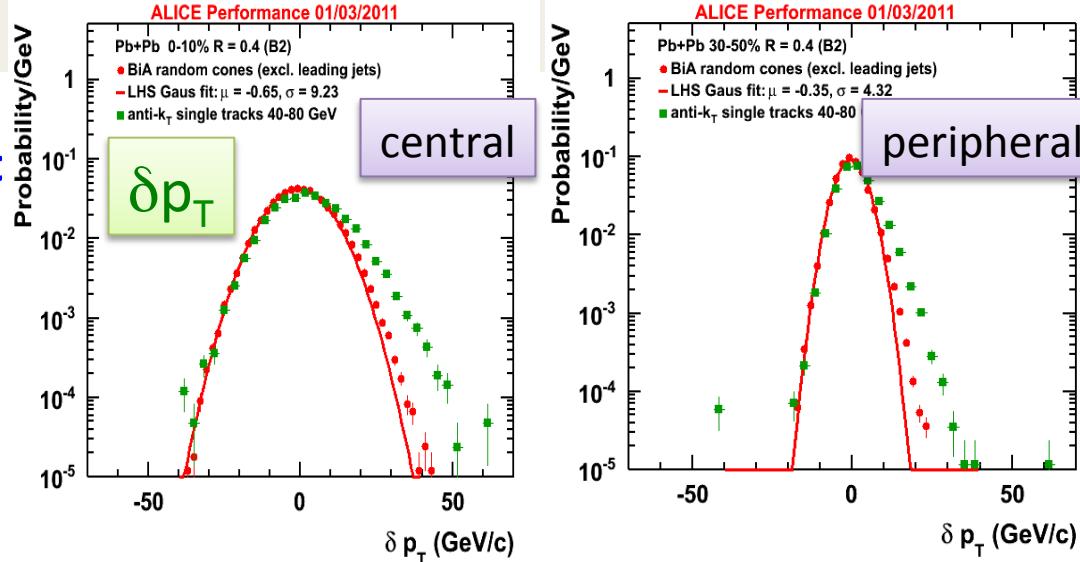
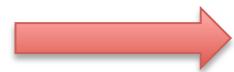
Definition of  $\delta p_T$ :

$$p_T^{rec} = p_T^{true} + \delta p_T$$

Measurement:

$$\delta p_T = p_T^{cluster} - \rho \cdot A - p_T^{probe}$$

Effect on inclusive spectrum in A-A:  
Demonstration of the  $p_T$  smearing  
( $f(\delta p_T)$ ) due to background  
fluctuations.

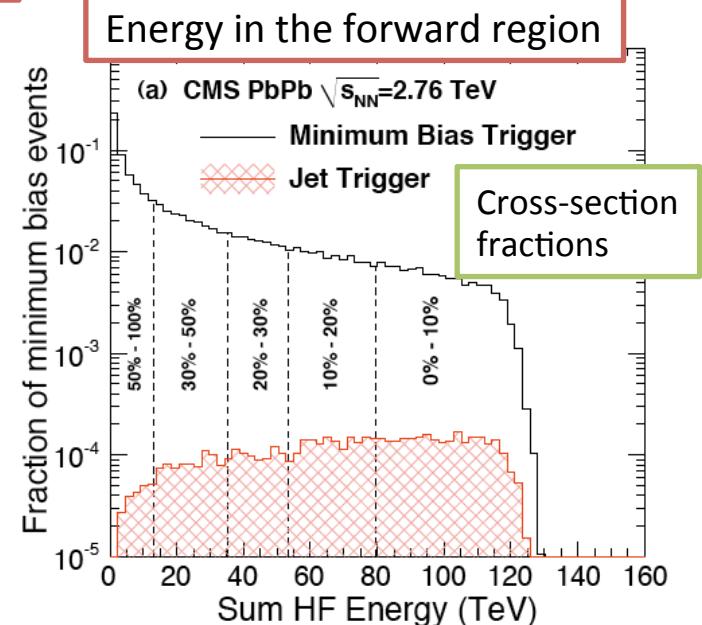
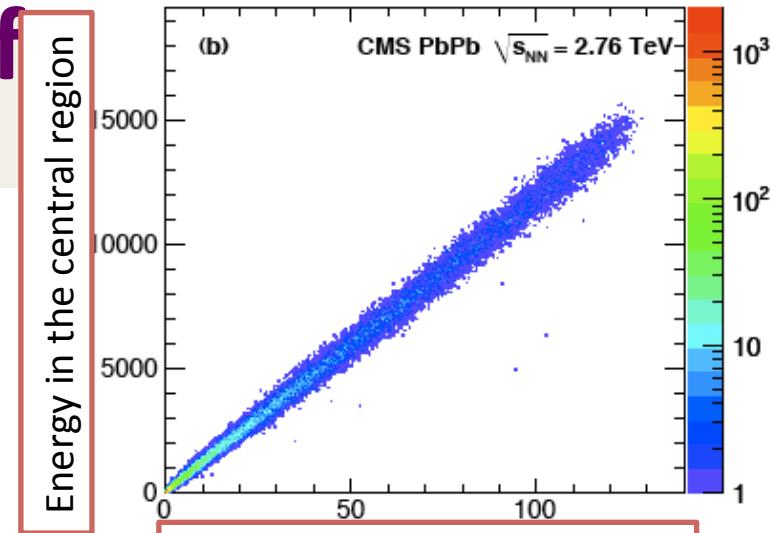
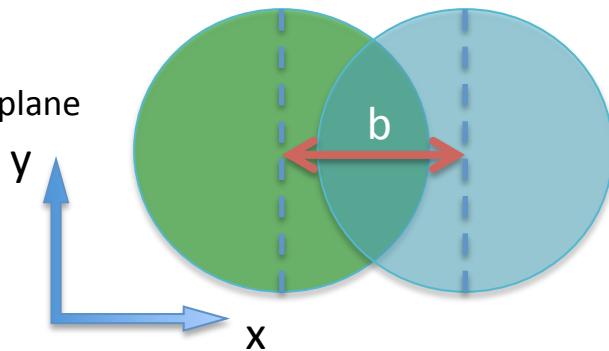


Detailed correction under preparation.

# Experimental control of collision geometry

- How can we measure impact parameter in heavy-ion collisions?
- => Correlate observables connected **only** by geometry

Collision in transverse plane

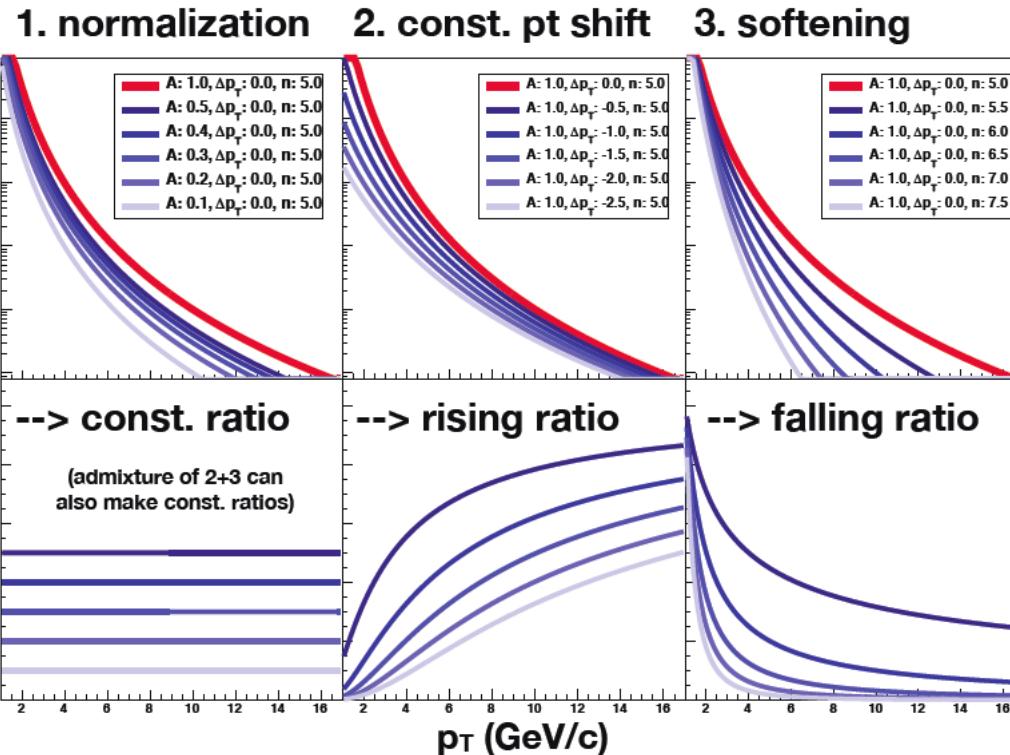


# Considerations:

## Near Side Enhancement ( $I_{AA} > 1$ )

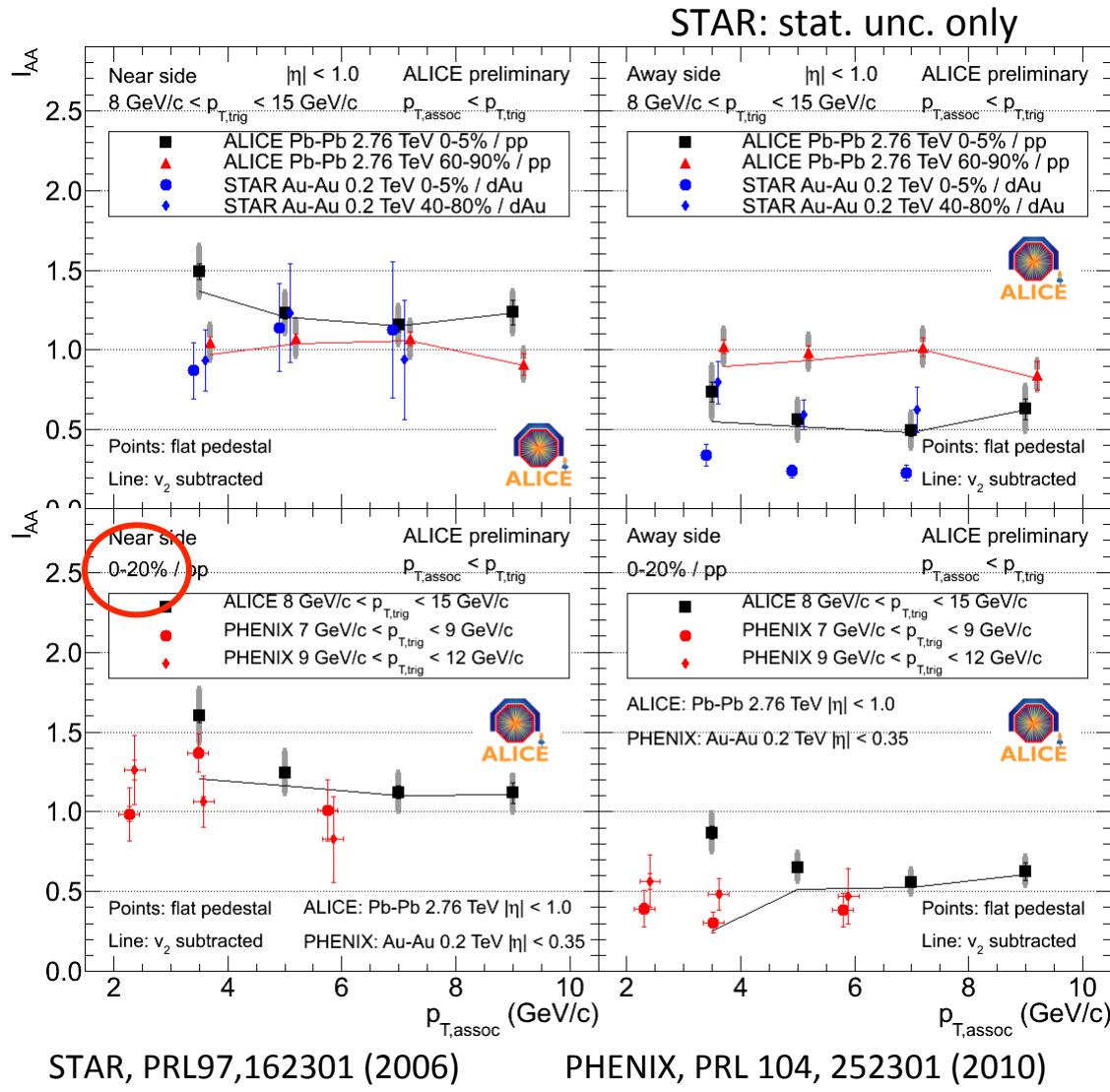
- Near side enhancement in  $I_{CP}$  and  $I_{AA,Pythia}$  in central events
  - Near side is modified  
→ trigger particle interacts with the medium
- Possible explanation
  - In the presence of quenching same trigger  $p_T$  might probe higher parton  $p_T$
  - Increased trigger  $p_T$  → increased  $I_{AA,Pythia}/I_{CP}$
  - $I_{AA,Pythia}/I_{CP}$  on away side would be even lower without this effect!

Toy power law example:  $A/(p_T - \Delta p_T)^n$

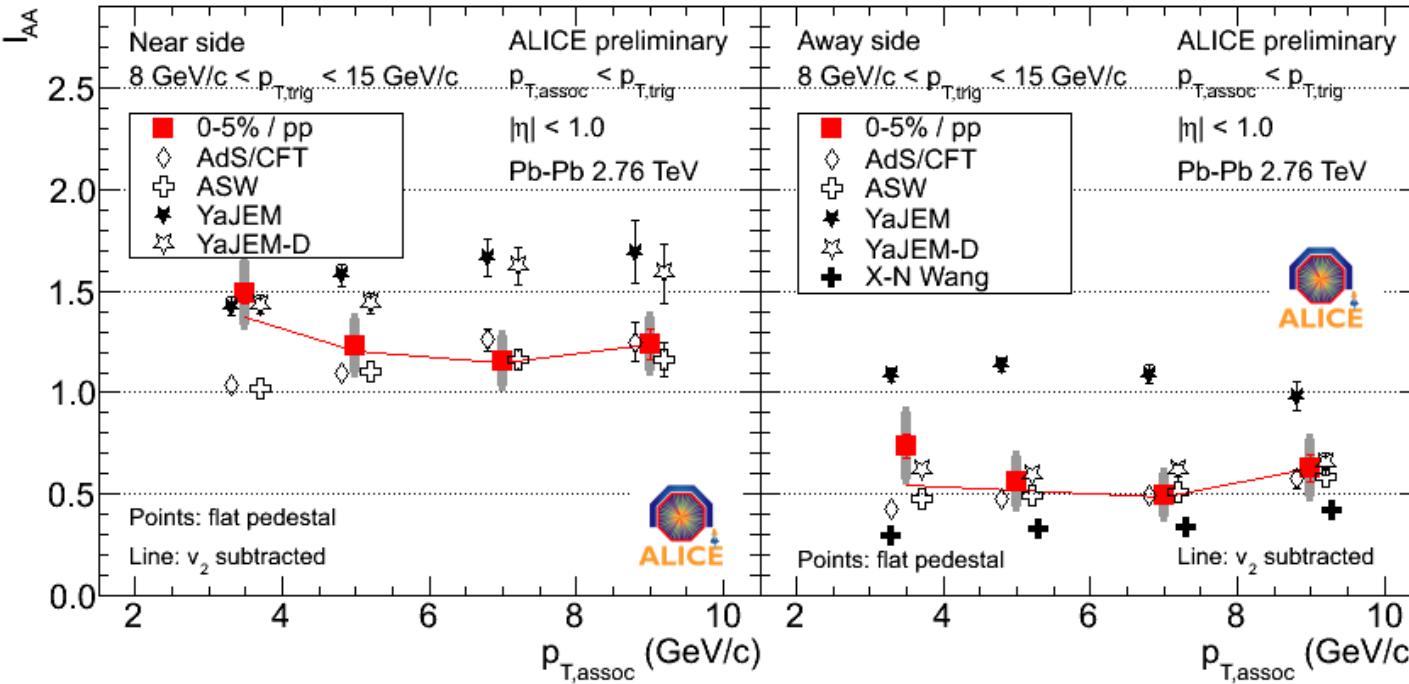


# Comparison with RHIC

- Caveat: same trigger  $p_T$  probes different parton  $p_T$  at different  $\sqrt{s}_{NN}$
- STAR and PHENIX subtract  $v_2$  → compare with ALICE line
  - STAR  $I_{AA}$  w.r.t. to dAu reference
  - STAR has different centrality for peripheral events
  - Away side larger than at STAR
  - PHENIX has (slightly) different  $p_{T,trig}$  ranges
- No evidence for near-side  $I_{AA} > 1$  at RHIC, but not excluded



# Theory Comparison



Near-side enhancement:

- reproduced by AdS/CFT pQCD hybrid ( $L^3$  path length dependence) and ASW ( $L^2$  dependence)
- YaJEM(-D) too high

Away-side suppression:

- reproduced by AdS/CFT, ASW, YaJEM-D
- YaJEM too high ( $L$  dependence)
- X N Wang slightly too low

AdS/CFT,ASW,YaJEM(-D) simulations from T Renk [private communication, to appear; talk Tu 16:40]

X N Wang [private communication, following calculation in PRL98:212301 (2007)]

QCD & Diffraction, Krakow,  
2011

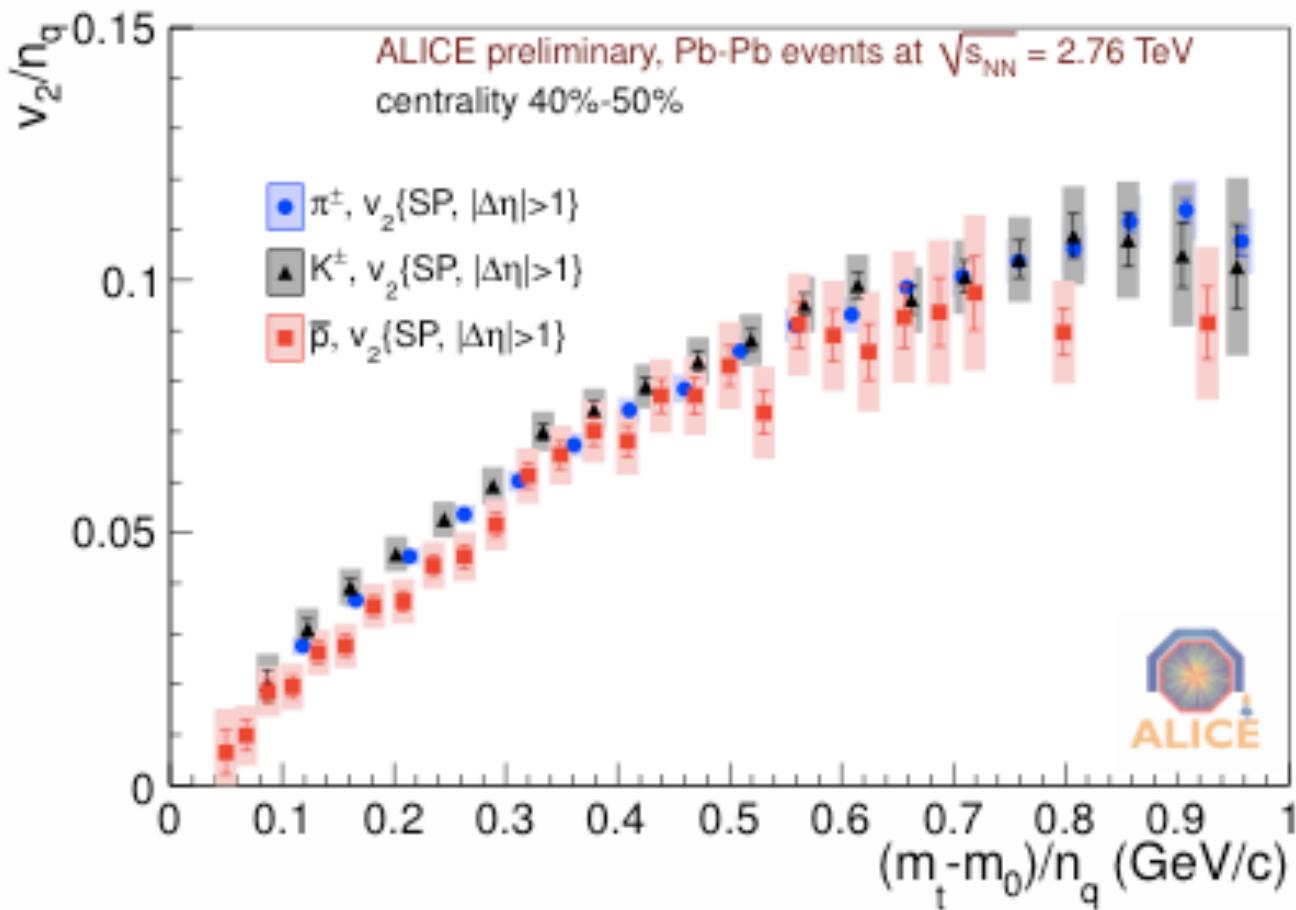
AdS/CFT,ASW,  
Yajem(-D):

- LO pQCD
- WS matter dist.
- Ideal 2+1d hydro
- Different e-loss scenarios

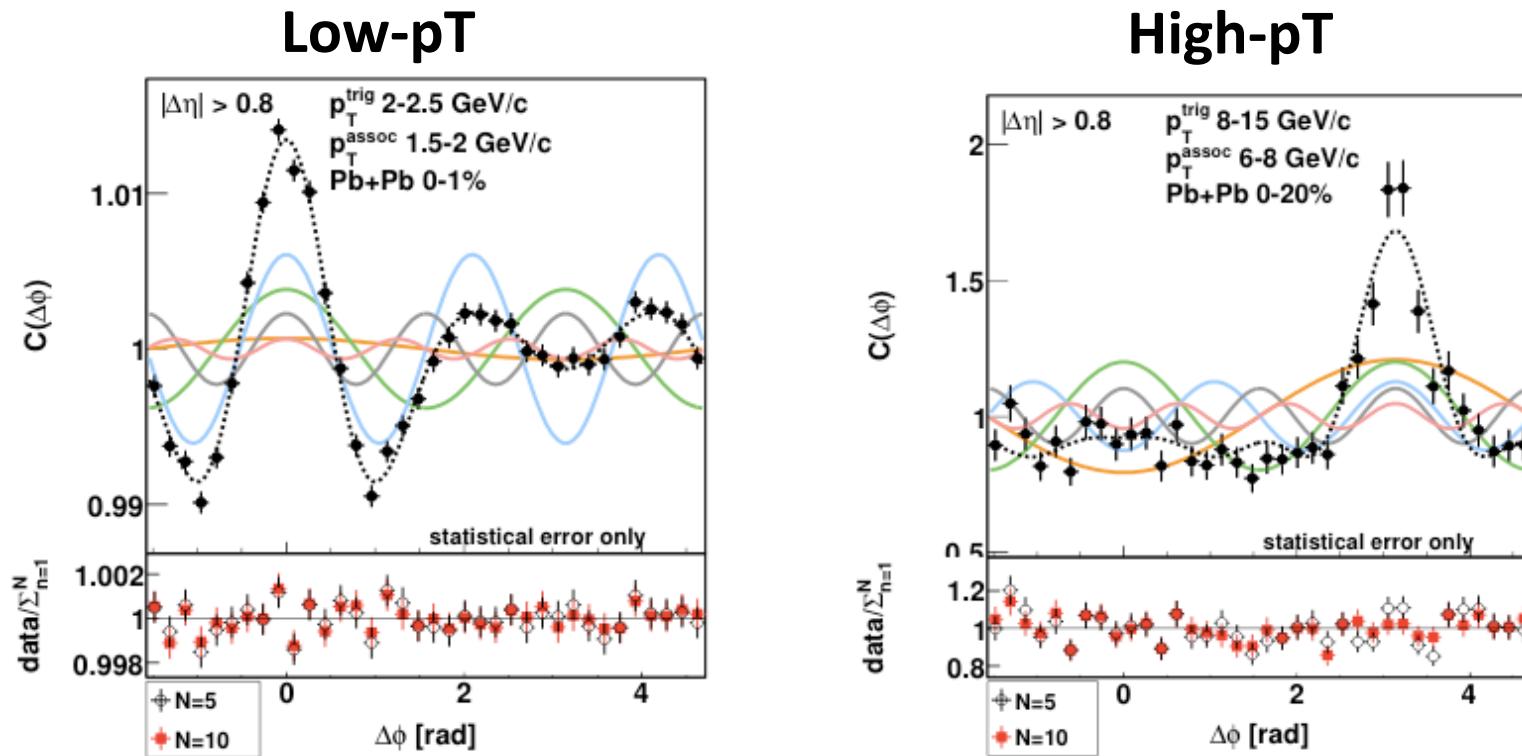
X N Wang:

- Hard sphere matter dist.
- NLO pQCD
- Avg. e-loss
- 1D expansion

# V2/nq scaling at LHC

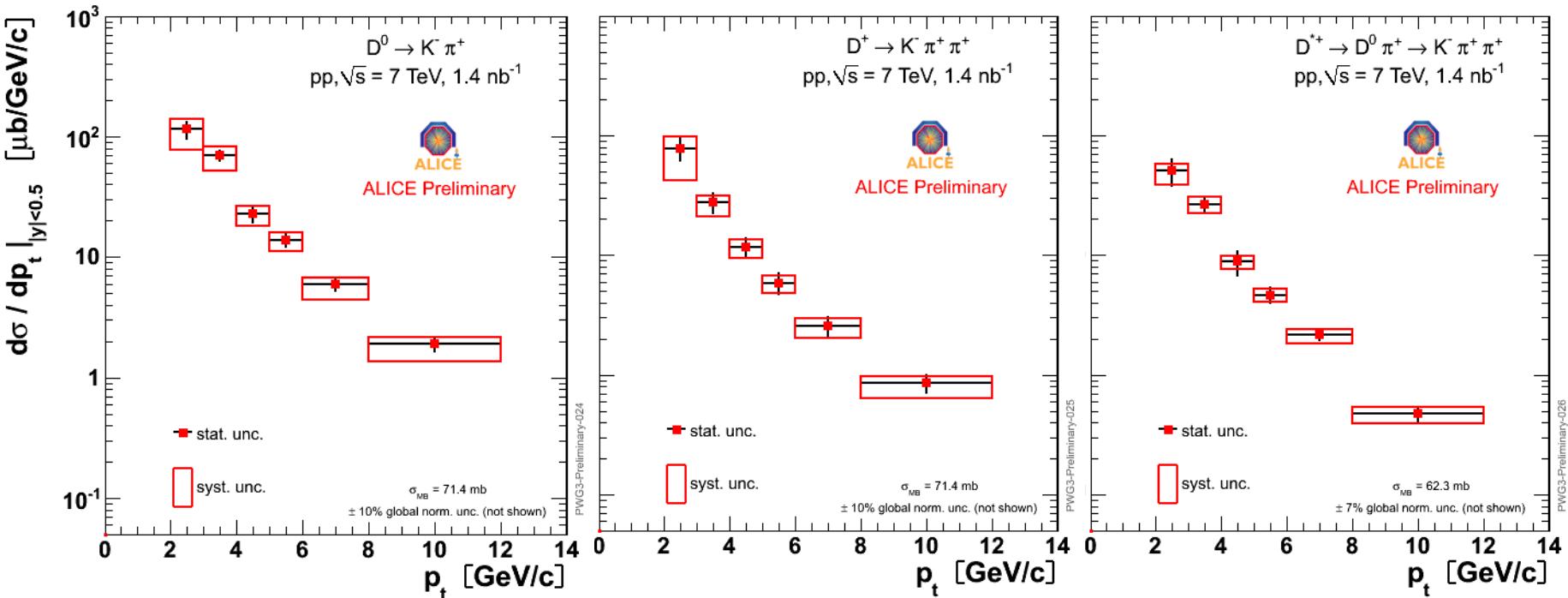


# Fourier decomposition for higher pTs



# D meson production in p-p

Preliminary cross sections (with  $10^8$  m.b. events):  $D^0$ ,  $D^+$ ,  $D^*$



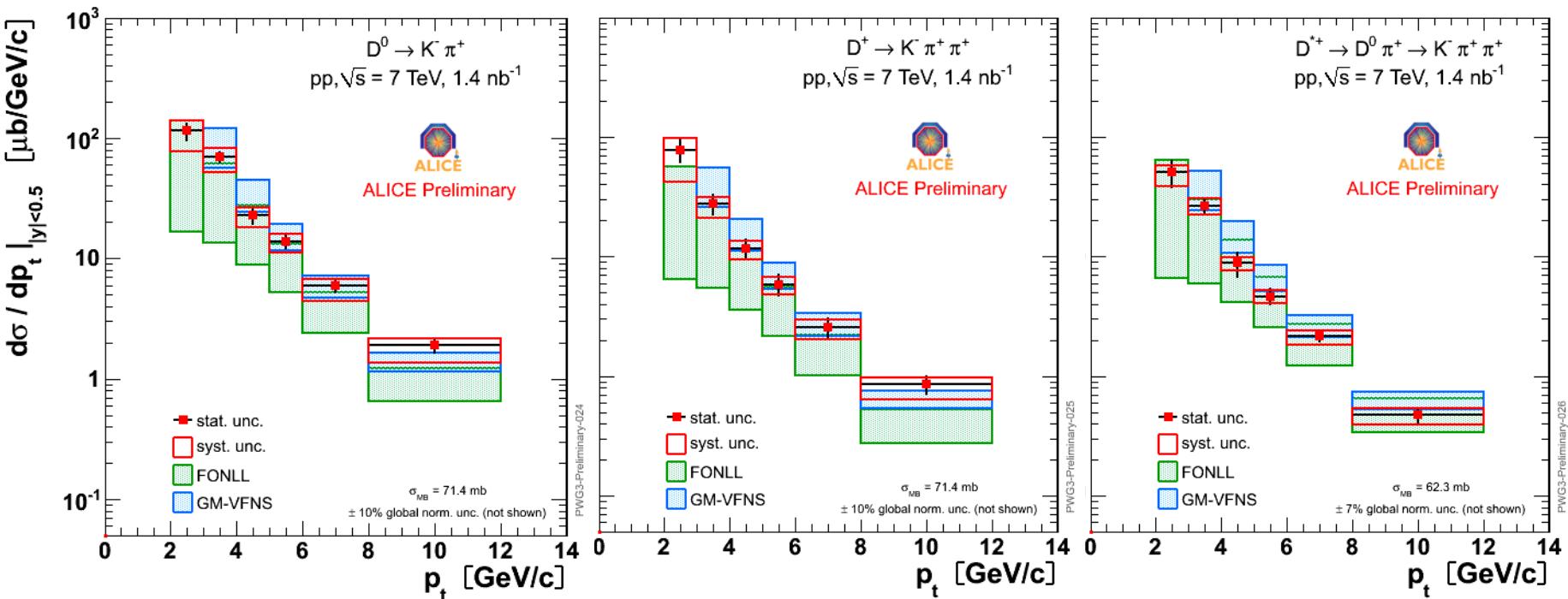
Feed-down from B mesons (after cuts ~10-15% for  $D^0$ ,  $D^+$ , 5% for  $D^*$ )  
 subtracted based on FONLL b cross section

Will be done based on data (displaced D mesons) with full 2010 sample  
 (5x more statistics)

In addition: extended reach towards  $p_t=0$  and  $p_t=20-25 \text{ GeV}$  possible

# D meson production in p-p

Preliminary cross sections (with  $10^8$  m.b. events):  $D^0$ ,  $D^+$ ,  $D^*$



pQCD predictions (FONLL and VFNS) consistent with the data

FONLL: Cacciari et al. in preparation,  
GMVFNS, Kniehl et al. in preparation