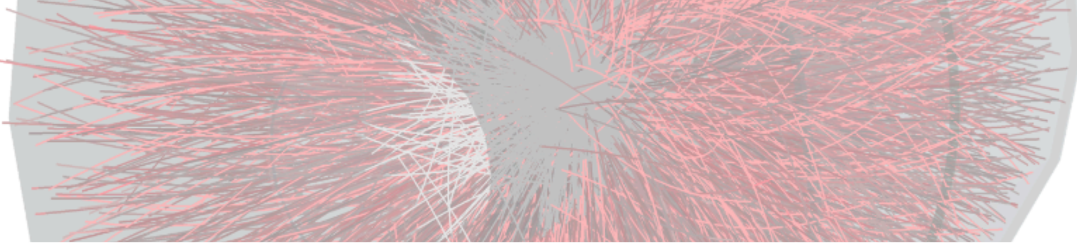
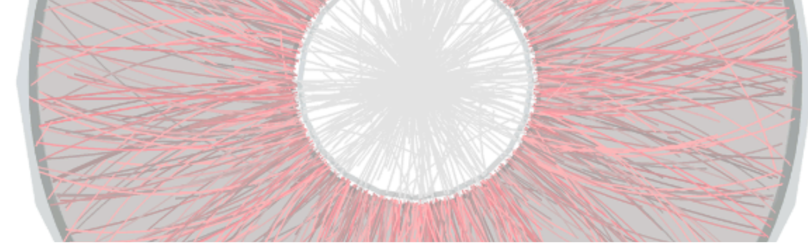




# Identified charged hadron production in Pb-Pb collisions at the LHC with the ALICE experiment

**Leonardo Milano**

*Università degli Studi & INFN, Torino, Italy*

**On behalf of the ALICE Collaboration**

# Outline

- **PID in ALICE: detectors and techniques**
  - some details on Particle Identification (PID) in ALICE

*$p_T$*-shape

- **Identified particle spectra in central (0-5%) Pb-Pb collisions**
  - π, K, p spectra in central (0-5%) Pb-Pb collision at $\sqrt{s}$ = 2.76 TeV
  - comparison with different models and RHIC data

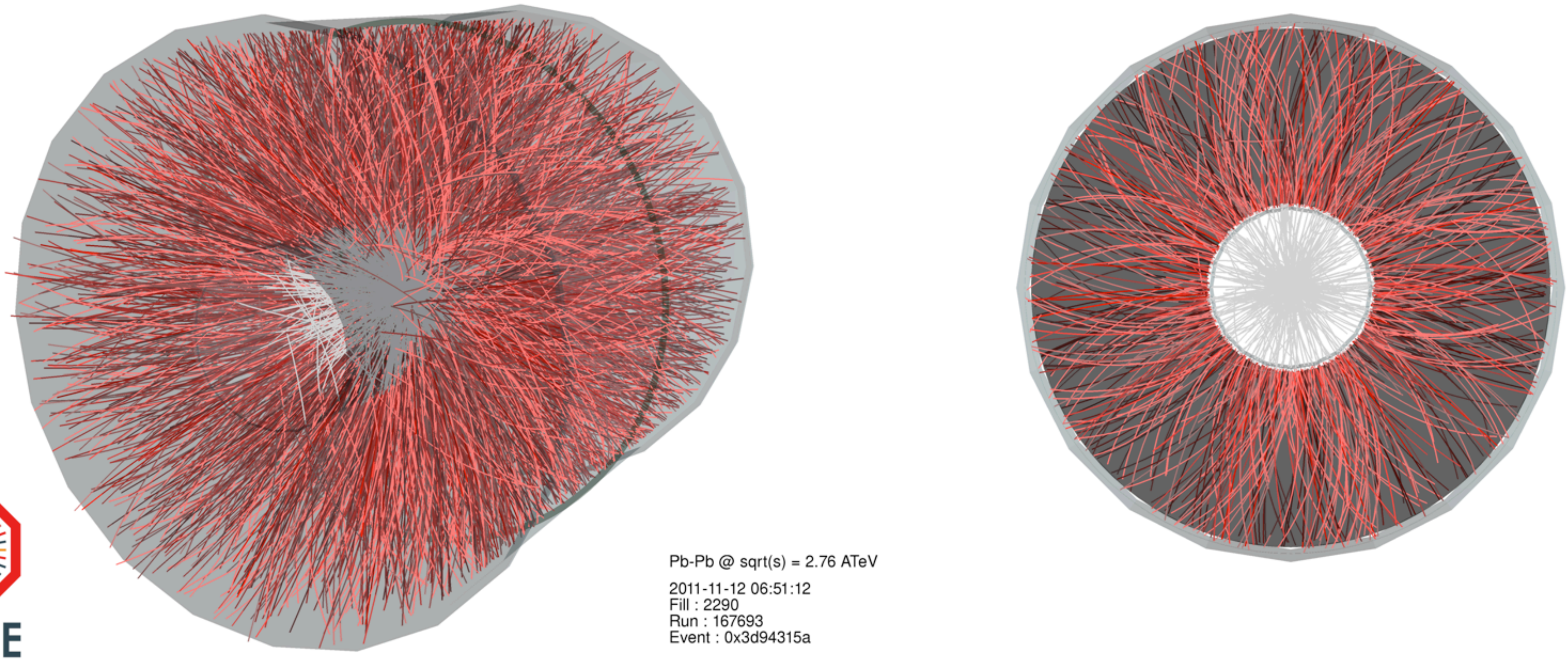
- **$p_T$-spectra as a function of event-by-event flow**
  - flow vector definition
  - jet contamination estimation
  - spectra modification in events with high elliptic flow (30-40% centrality)

Integrated yields

- **Thermal production of hadrons in central (0-20%) Pb-Pb collisions**
  - comparison with RHIC and thermal model prediction
  - thermal fit to integrated particle yields in ALICE

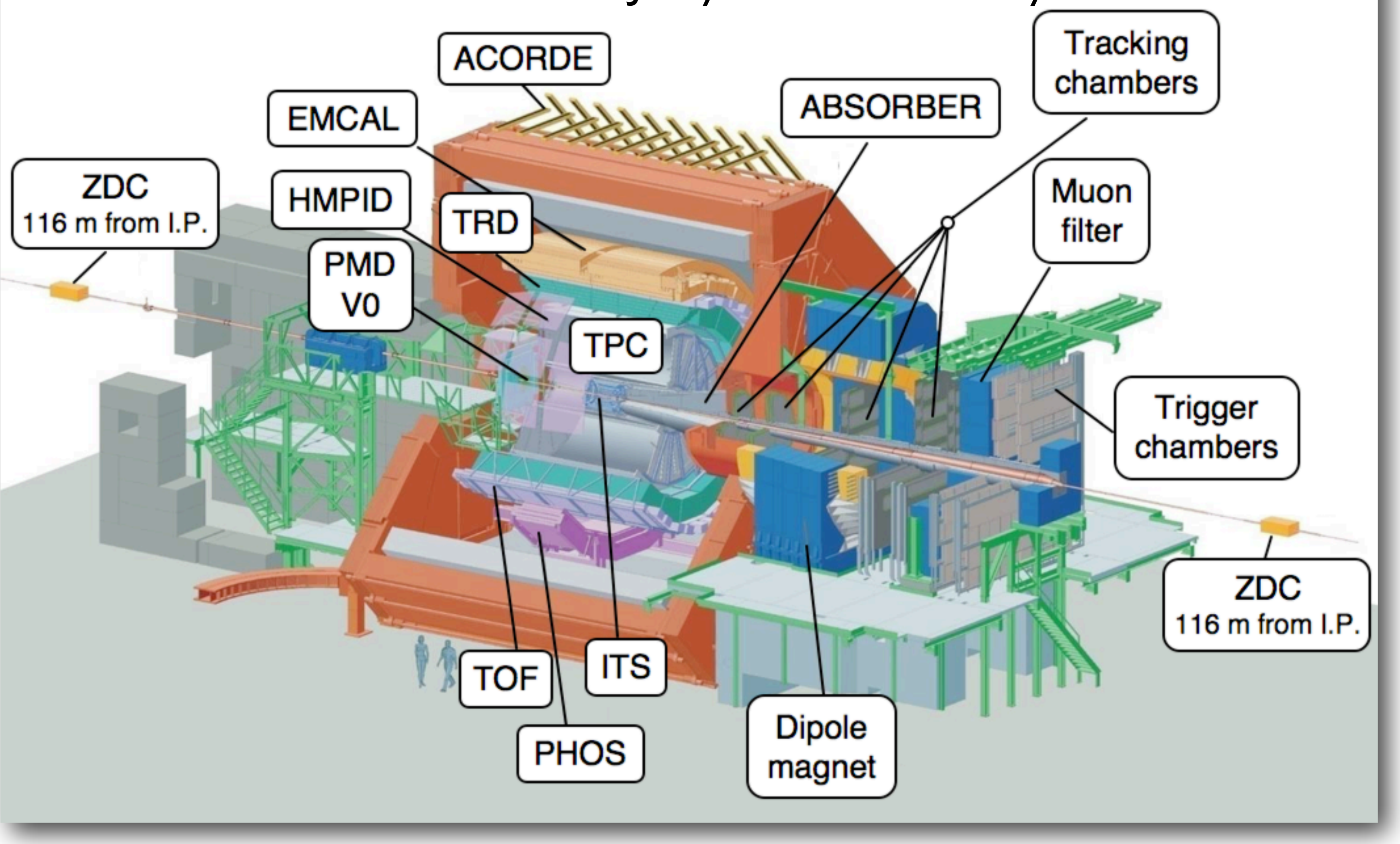
- **Summary**

# PID in ALICE: detectors and techniques



# Detector description

*ALICE Collaboration et al 2004 J. Phys. G: Nucl. Part. Phys. 30 1517*



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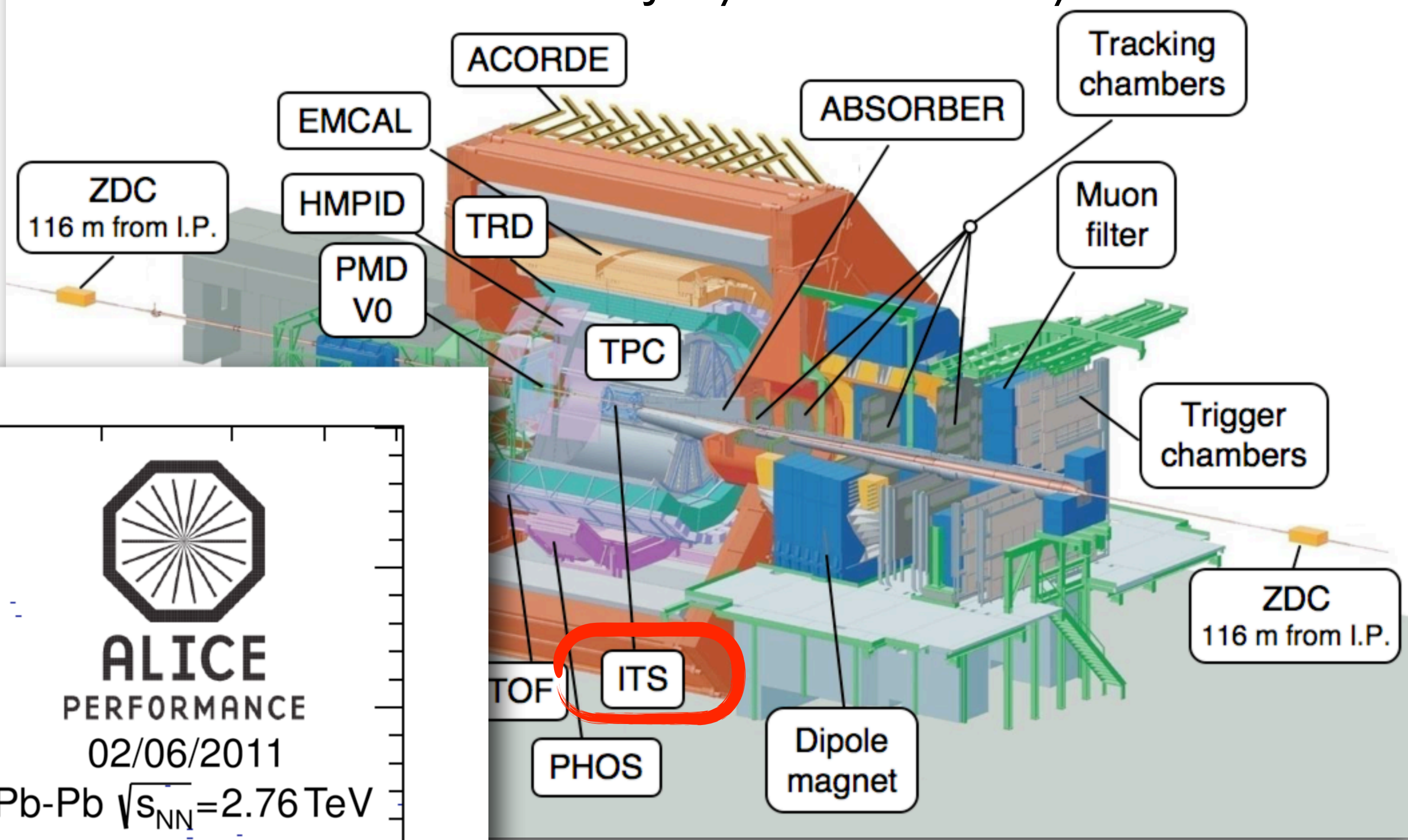


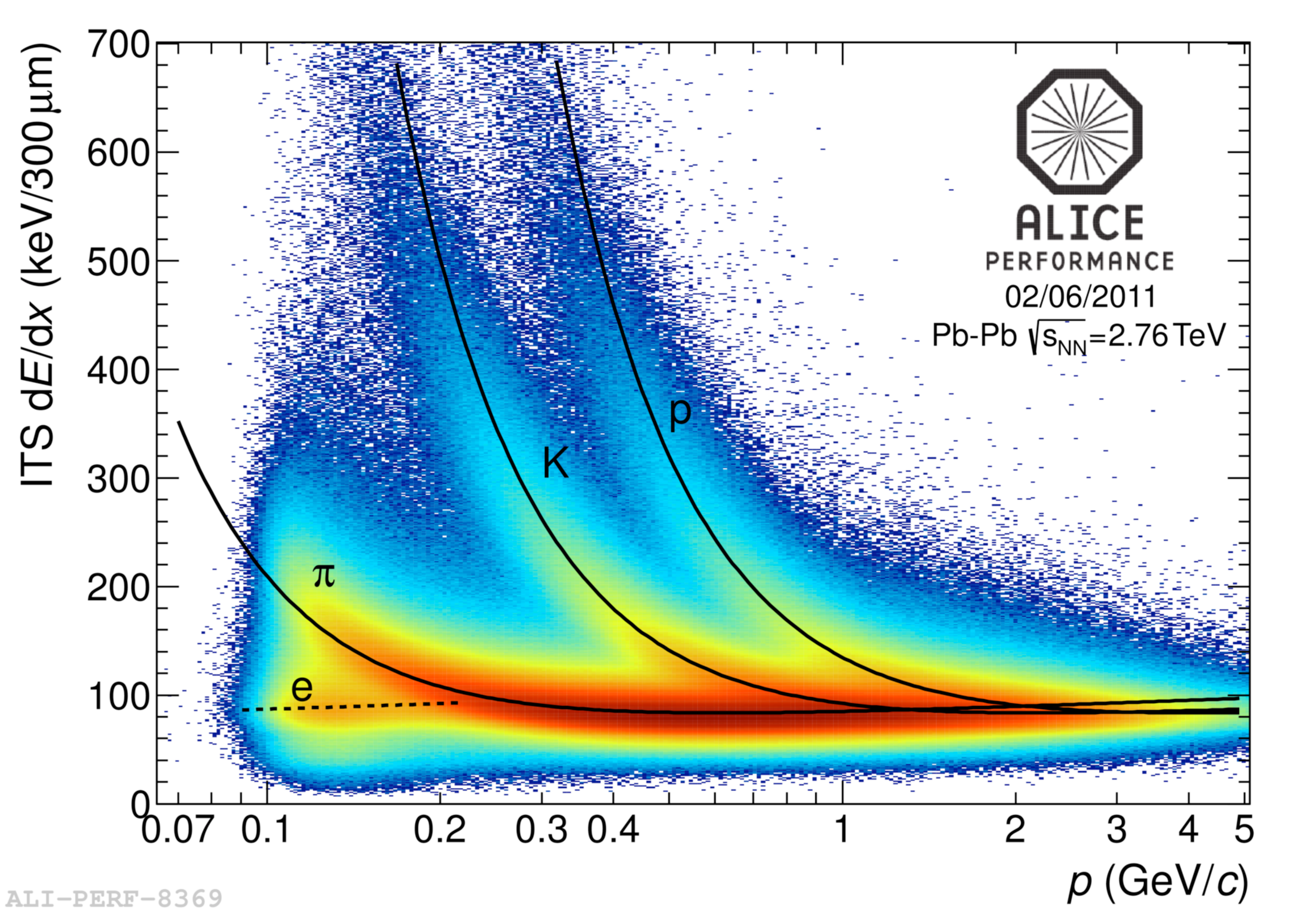

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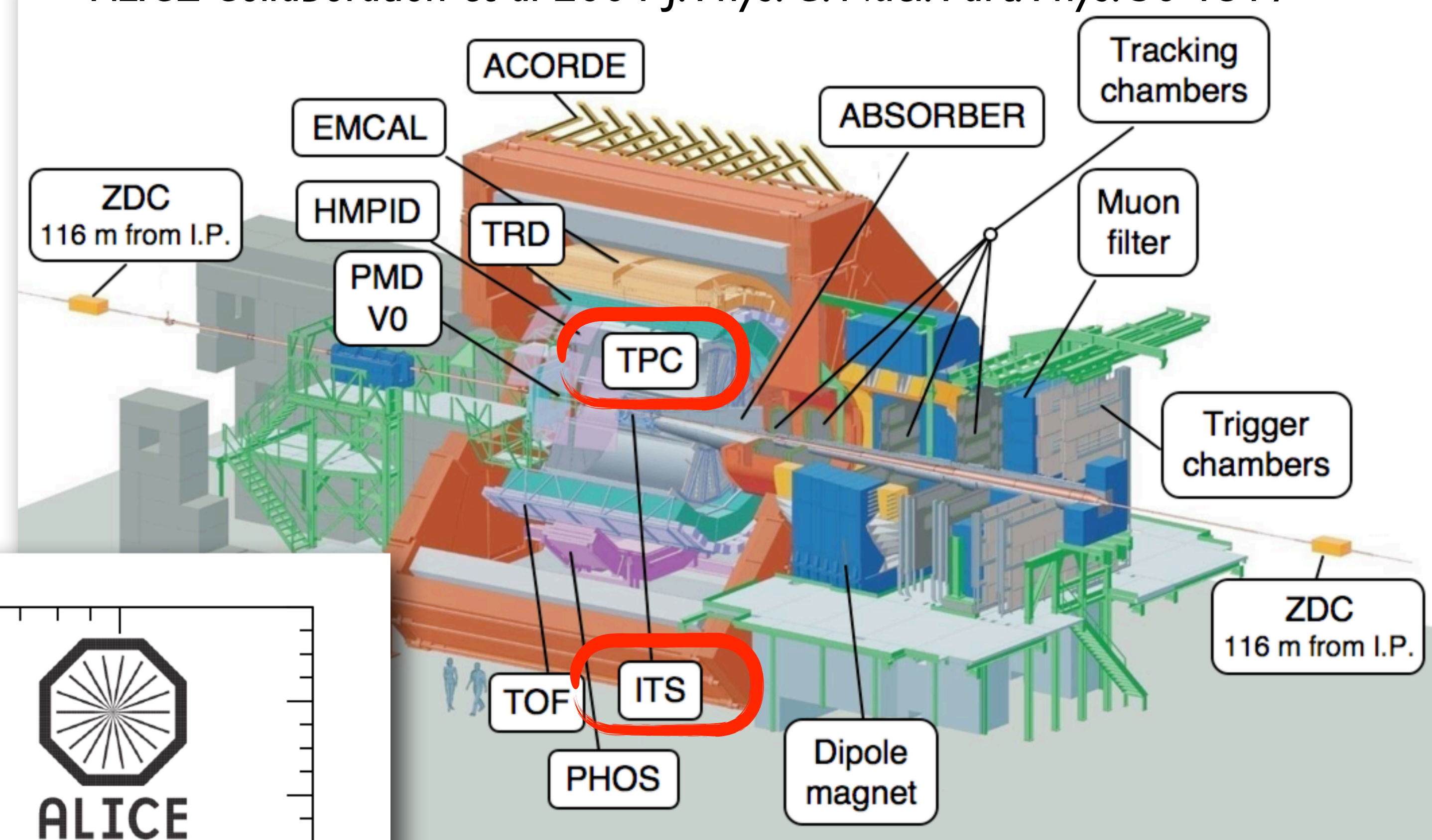


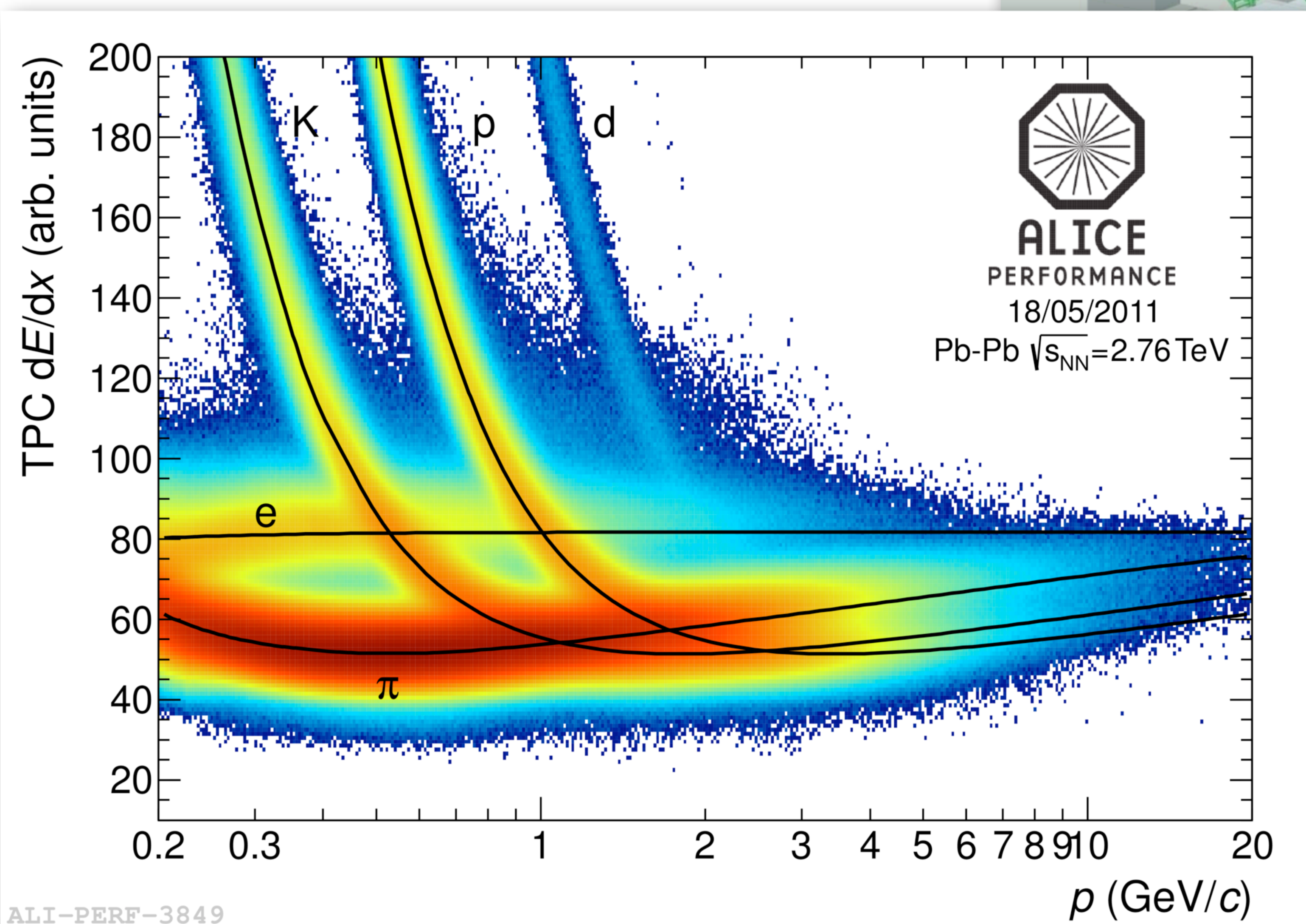


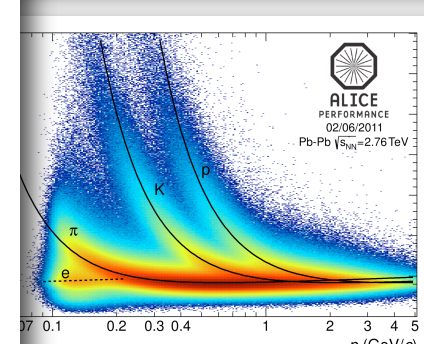

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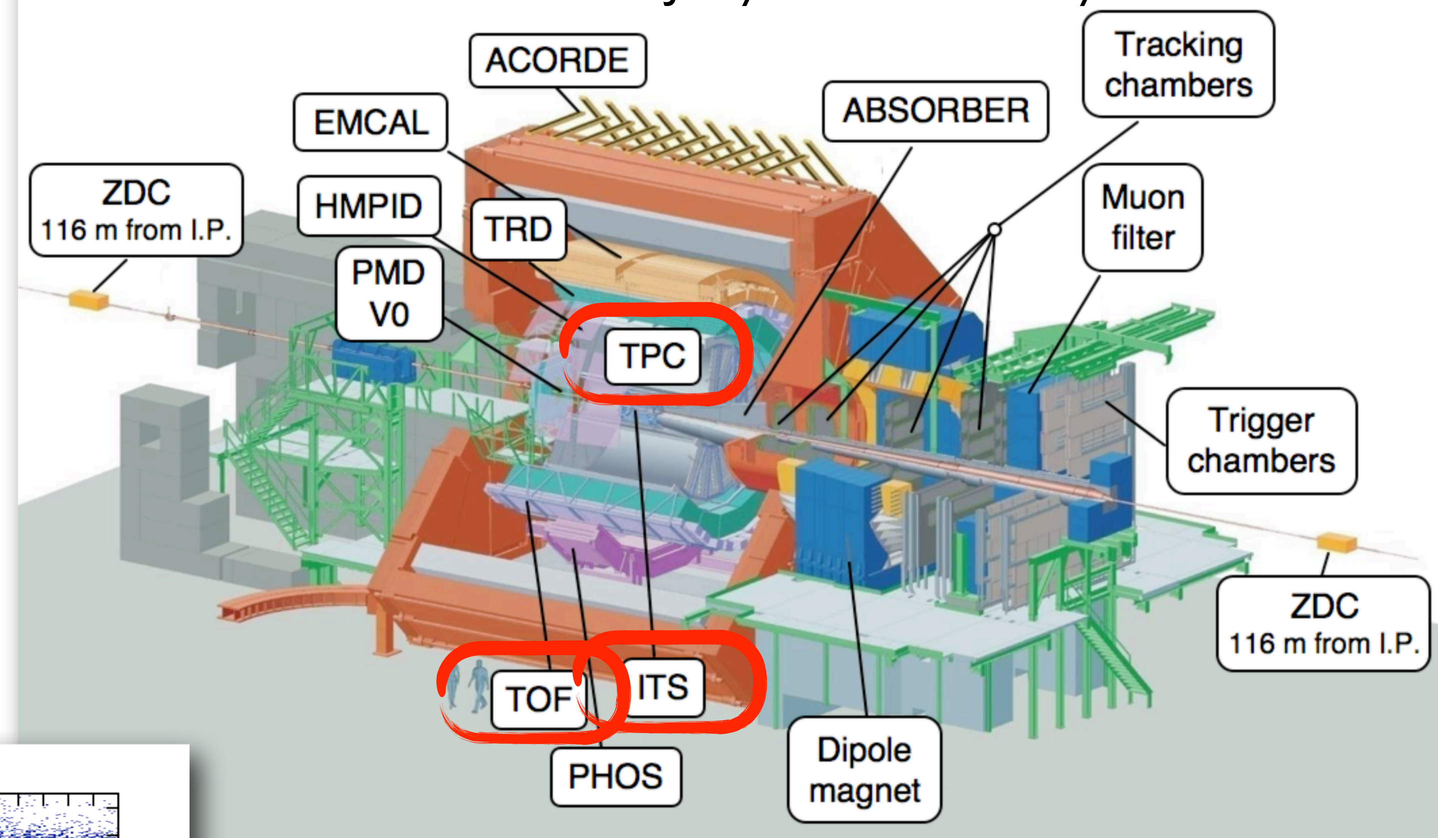
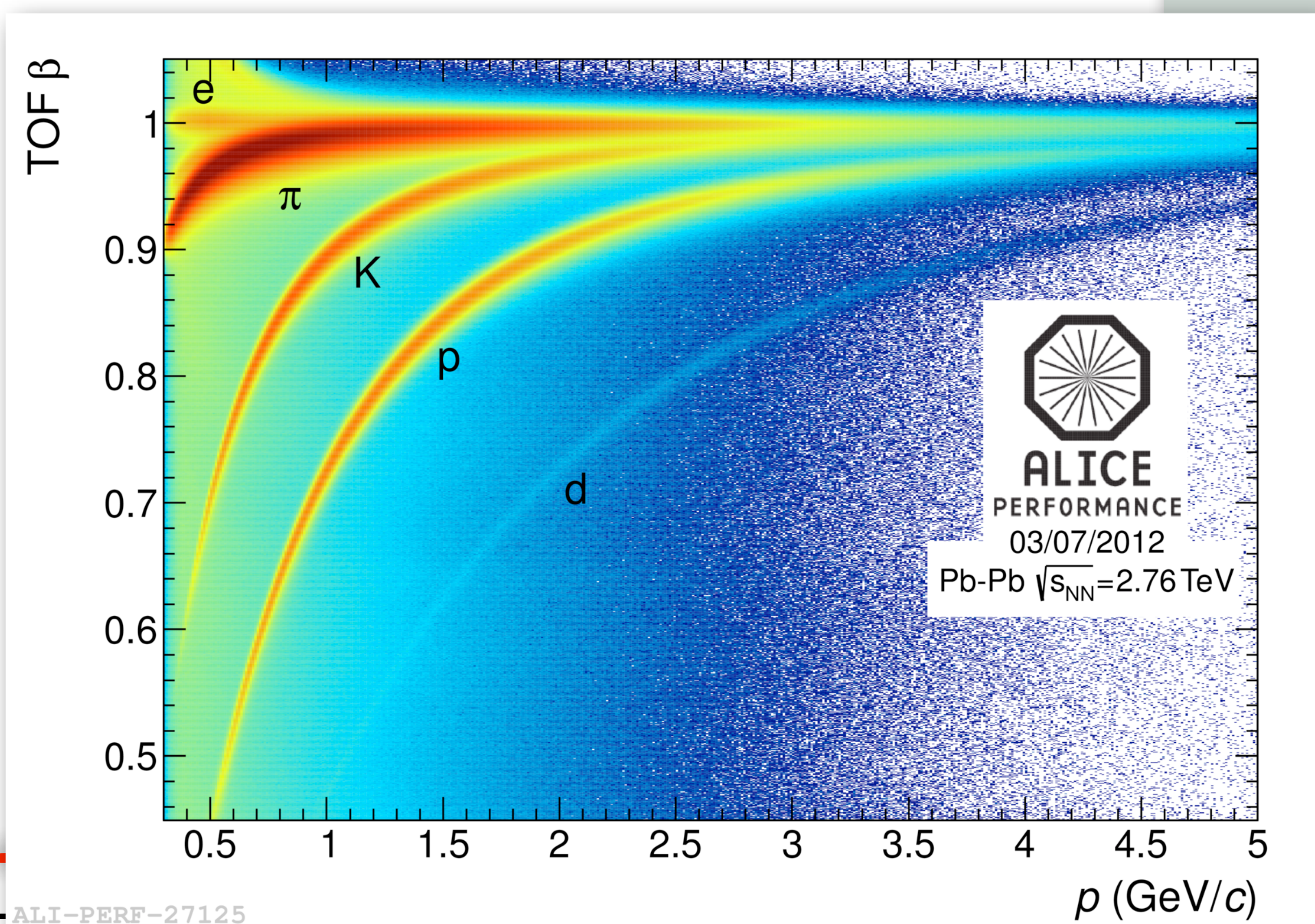
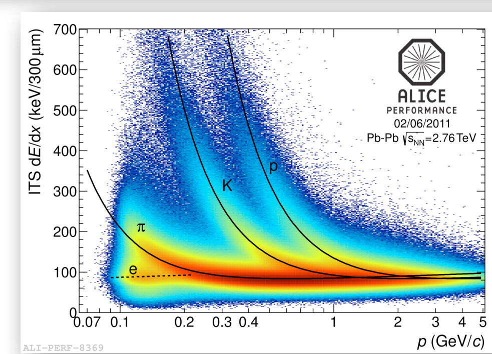
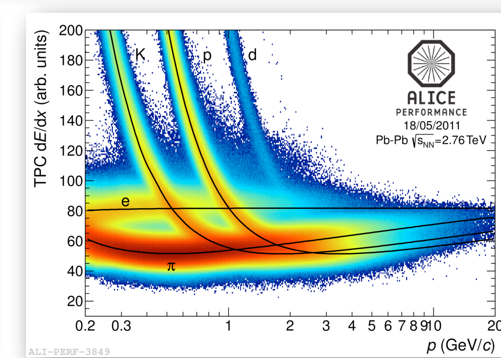
  - tracks extrapolated from ITS-TPC
  - resolution ~85ps (Pb-Pb)

*ALICE Collaboration et al 2004 J. Phys. G: Nucl. Part. Phys. 30 1517*



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  - VZERO A (2.8<η<5.1)
  - VZERO C (-3.7<η<-1.7)
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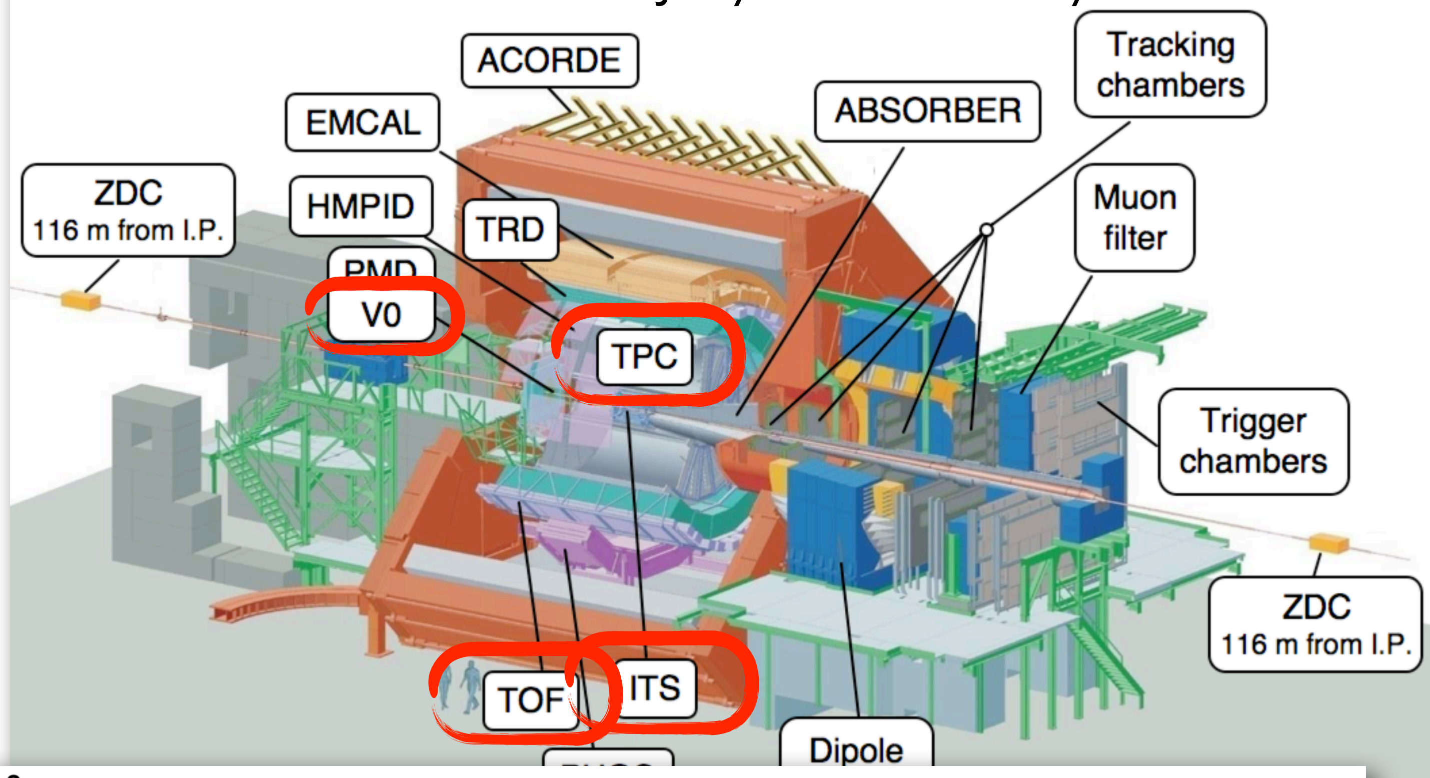


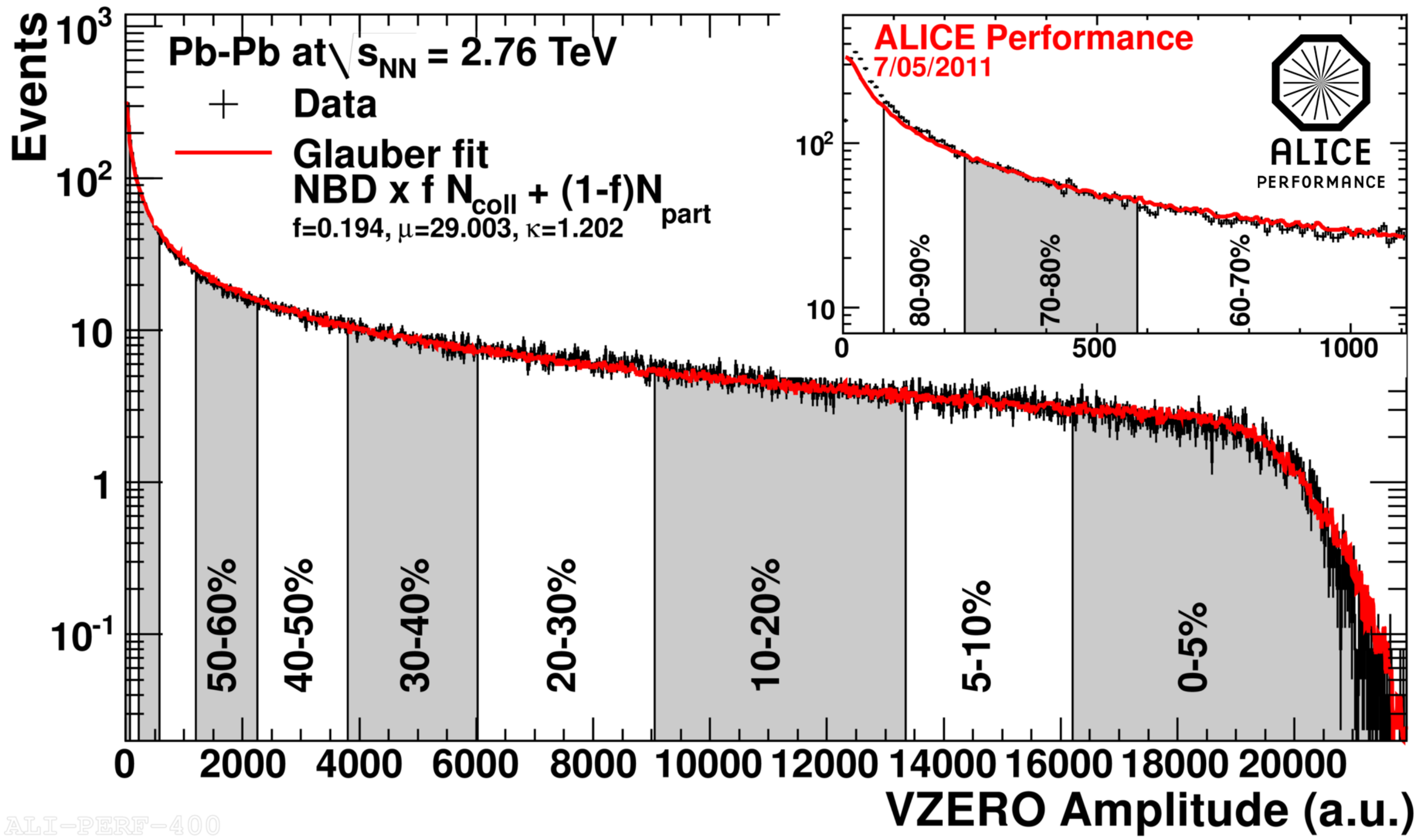

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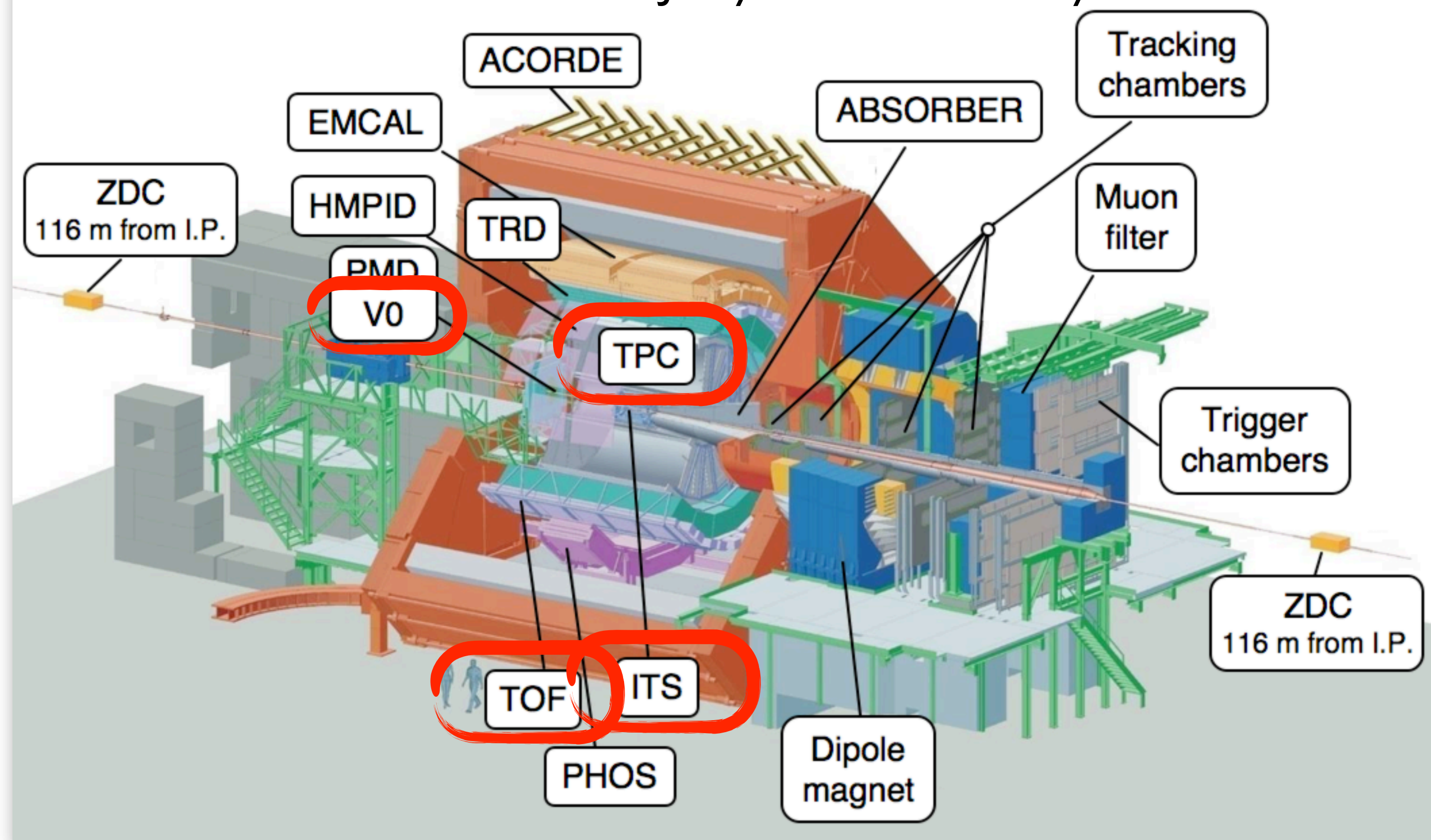
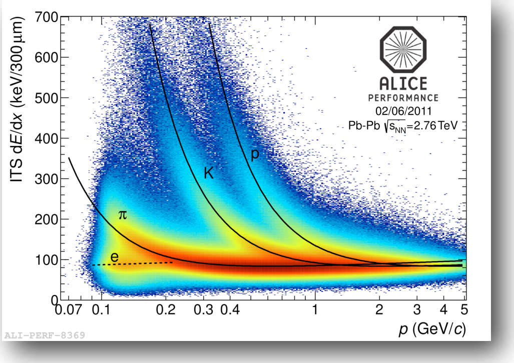
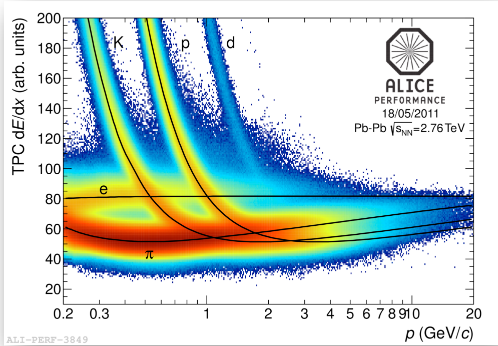
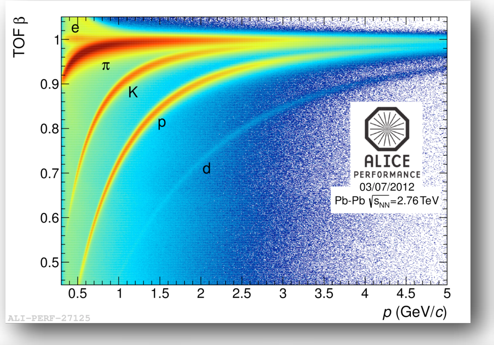
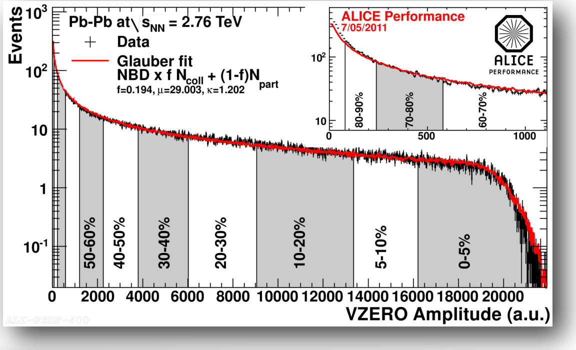


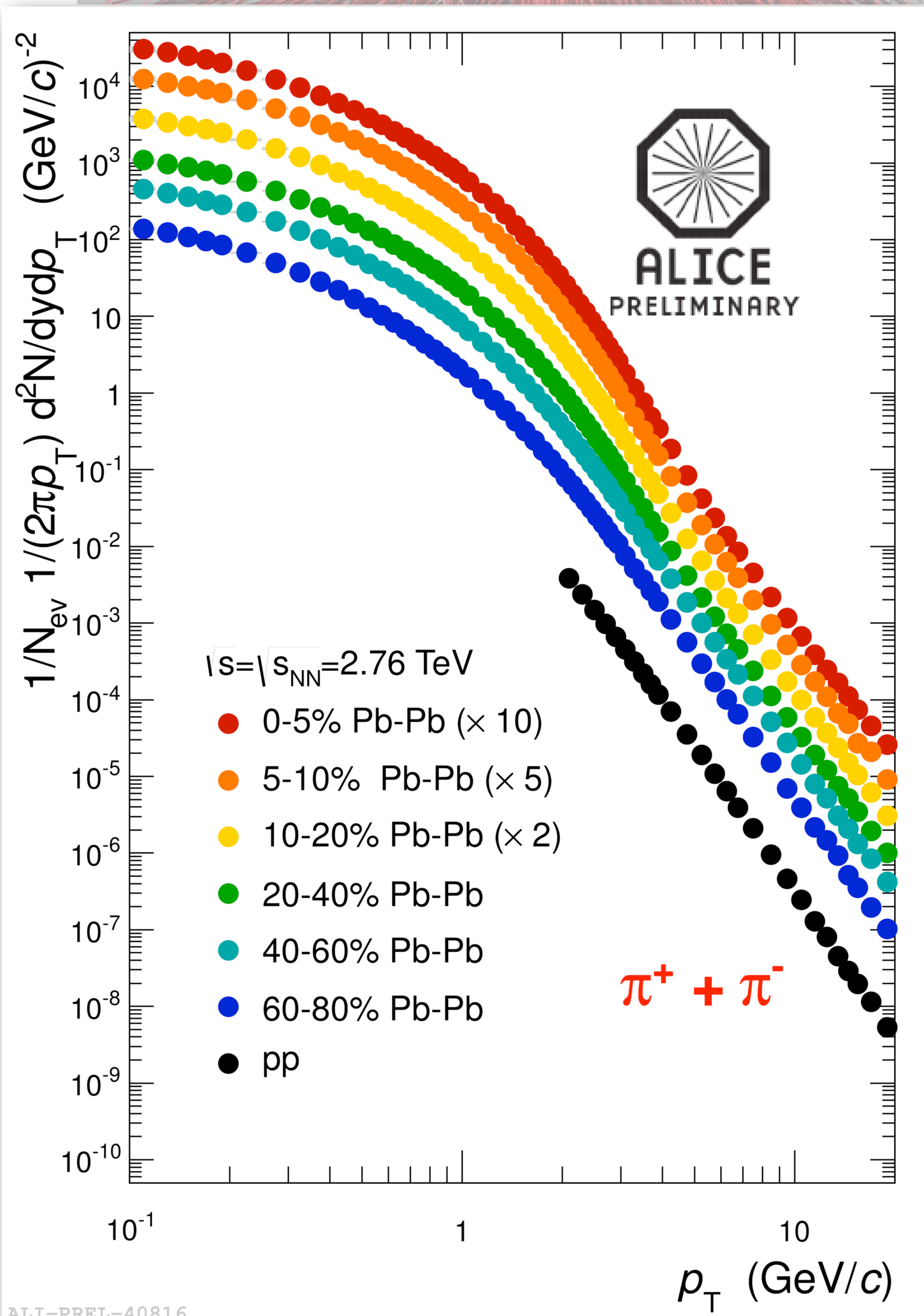



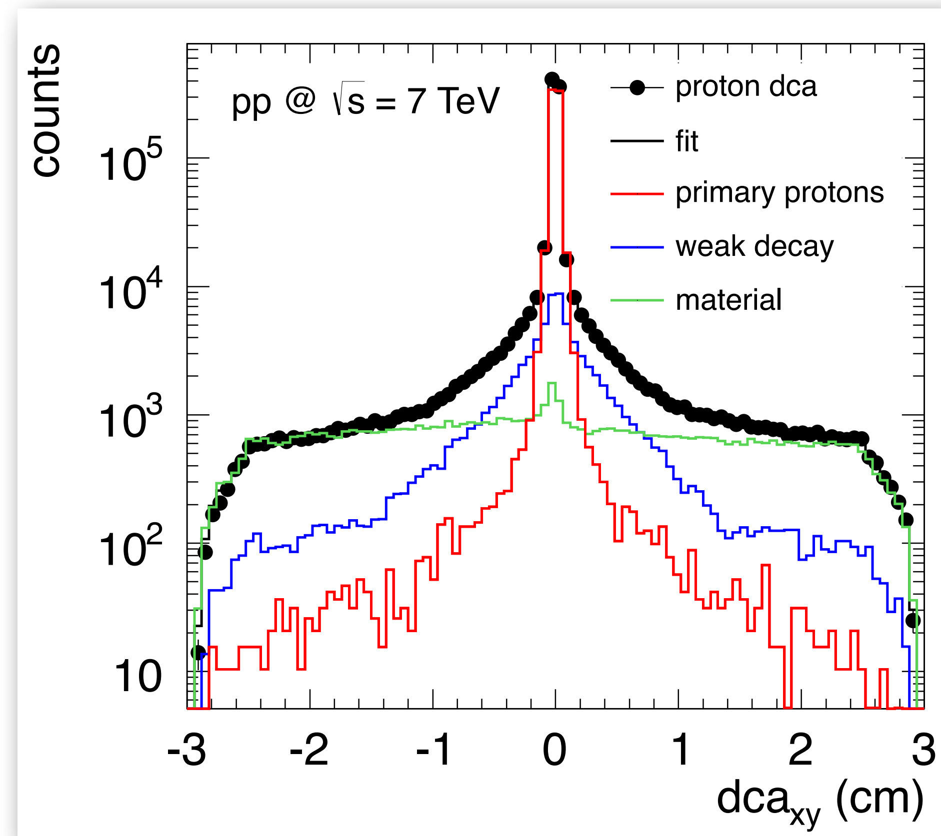
# PID Analyses




ITS
TPC
TOF
TPC

**Secondary subtraction**

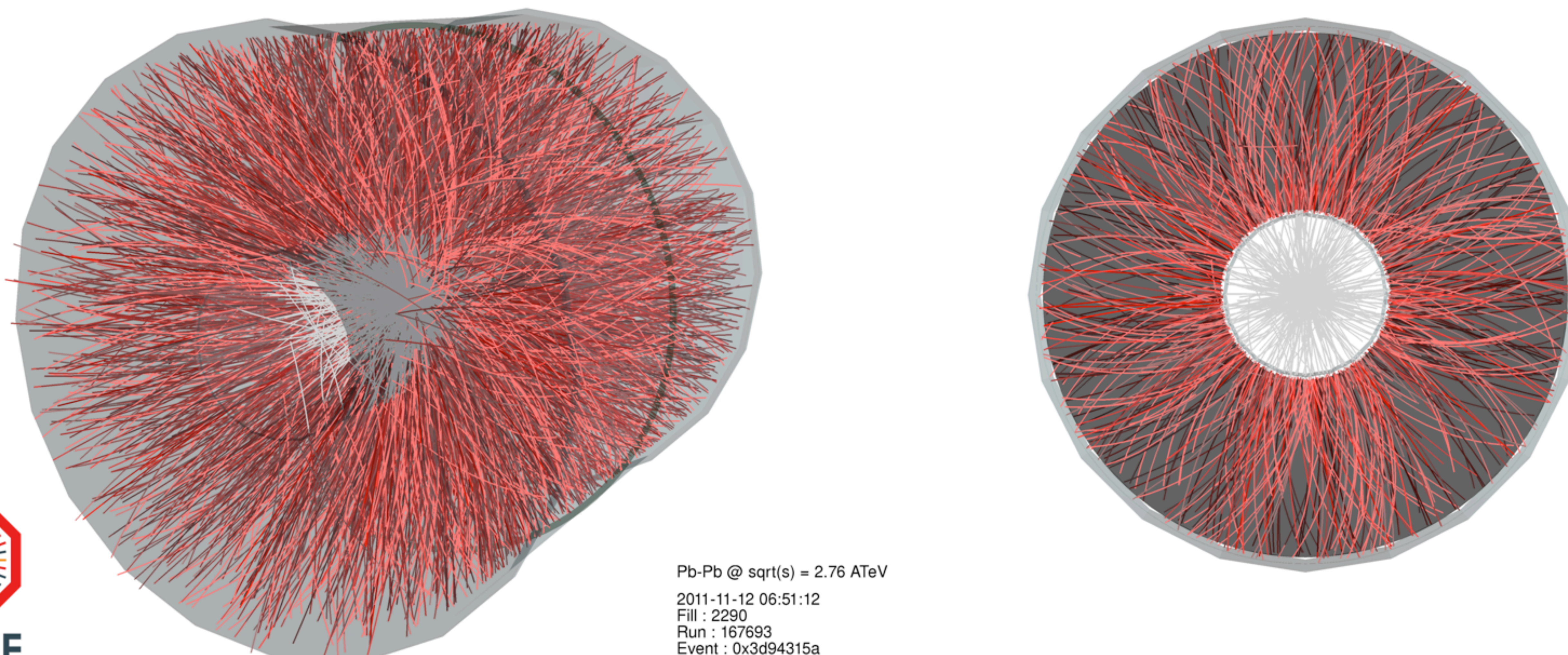
DCA fit*




*A. Kalweit (ALICE), J. Phys. G38, 124073 (2011)

*see Antonio Ortiz Velasquez (16 August)*

# Identified particle spectra in central (0-5%) Pb-Pb collisions

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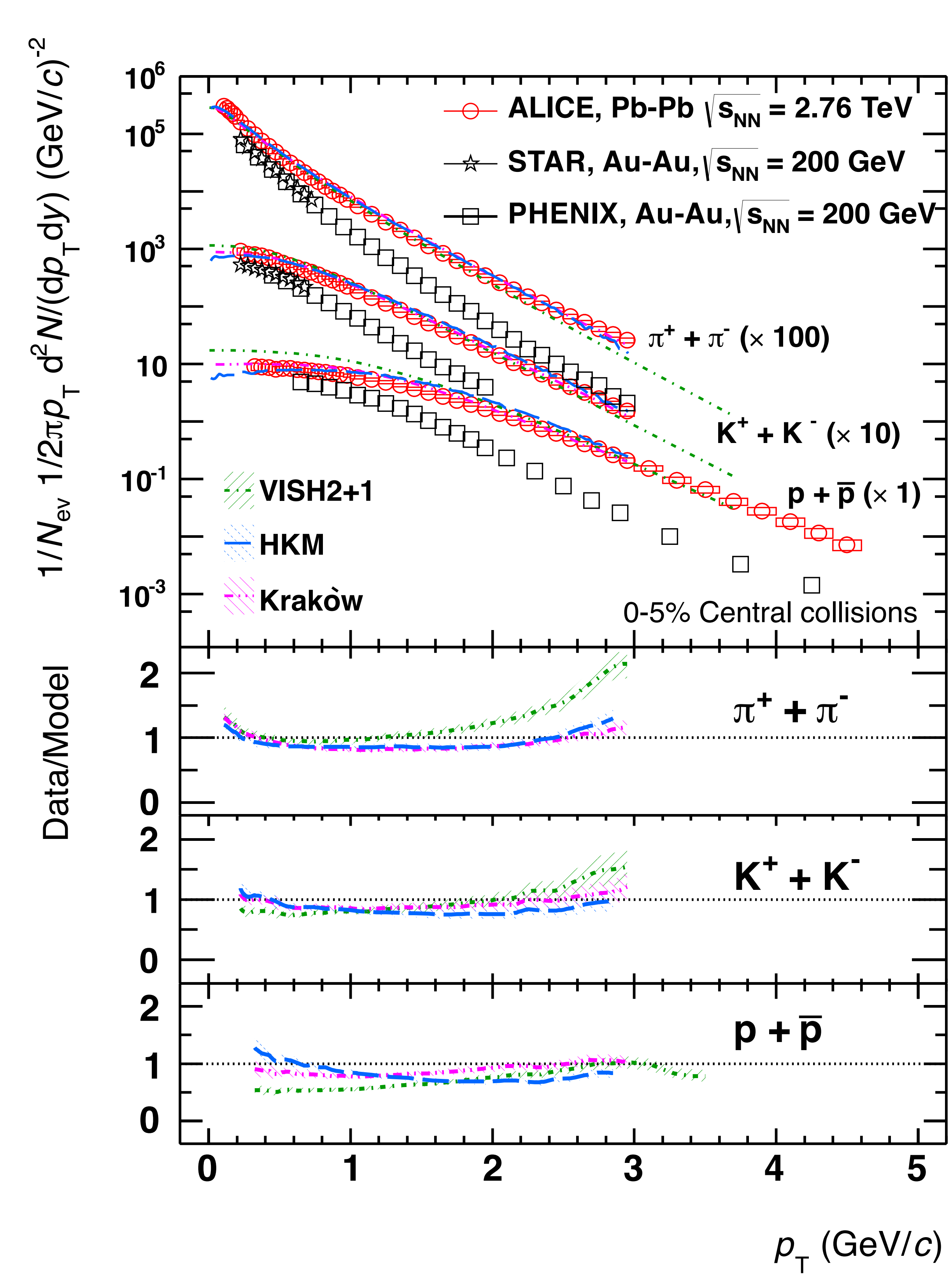


*data:*

- small extrapolation at low $p_T$
- large radial flow

($\langle\beta_T\rangle$ = 0.65 ± 0.02 ~10% higher w.r.t. RHIC)

*model comparison:*

- **VISH2+1** (Viscous hydro)
- **HKM** (Hydro+ UrQMD)
- **Krakow** (viscous corrections that lower the effective $T_{ch}$)


- (***ALICE Collaboration***) *arXiv:1208.1974v1 [hep-ex]*
- (***STAR Collaboration***) *Phys.Rev. C79,034909 (2009)*
- (***PHENIX Collaboration***) *Phys.Rev.C69, 034909 (2004)*
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- (***VISH2+1***) *C. Shen, U.W. Heinz, P. Huovinen and H. Song, (2011), arXiv:1105.3226 [nucl-th]*
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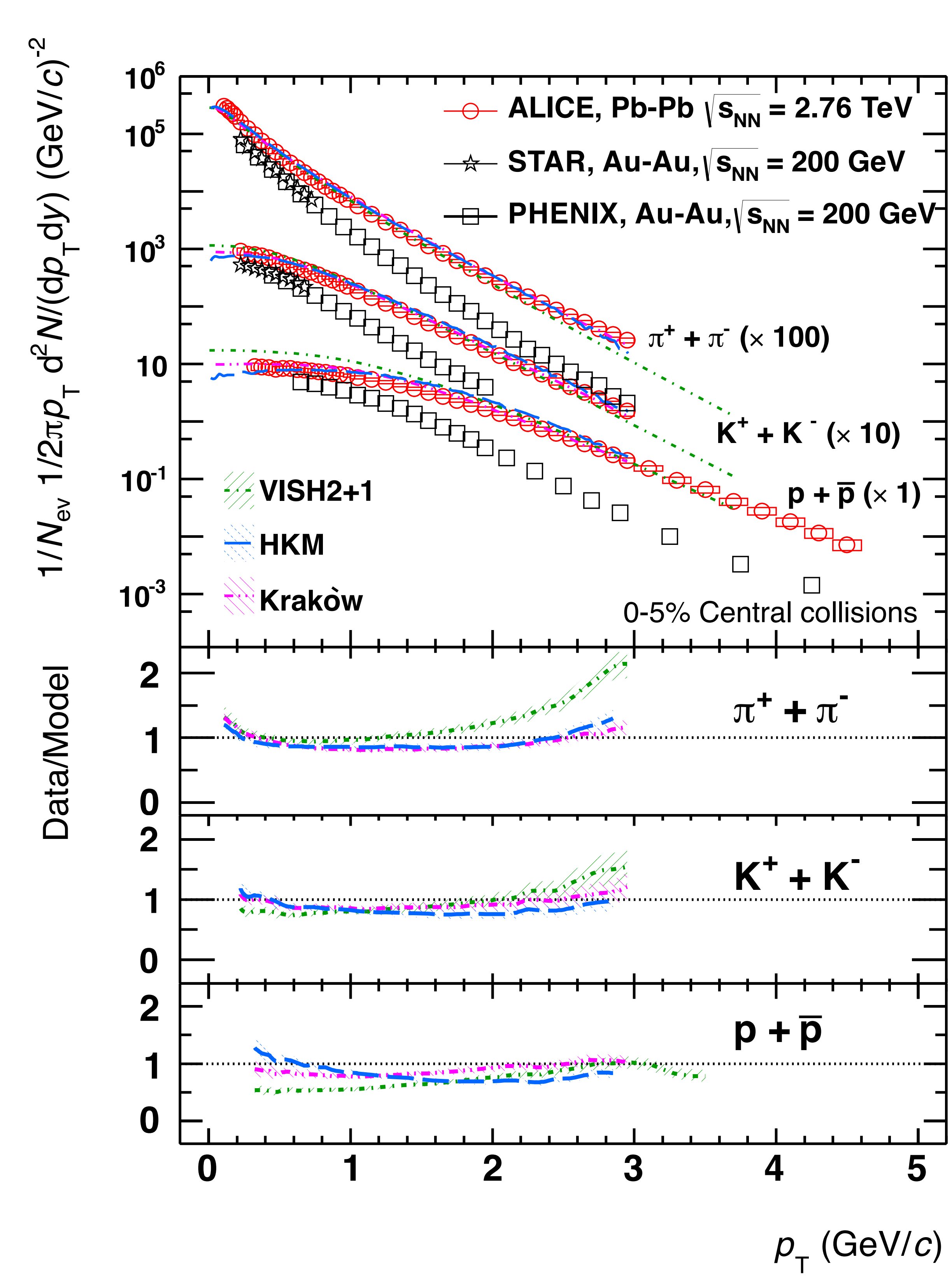


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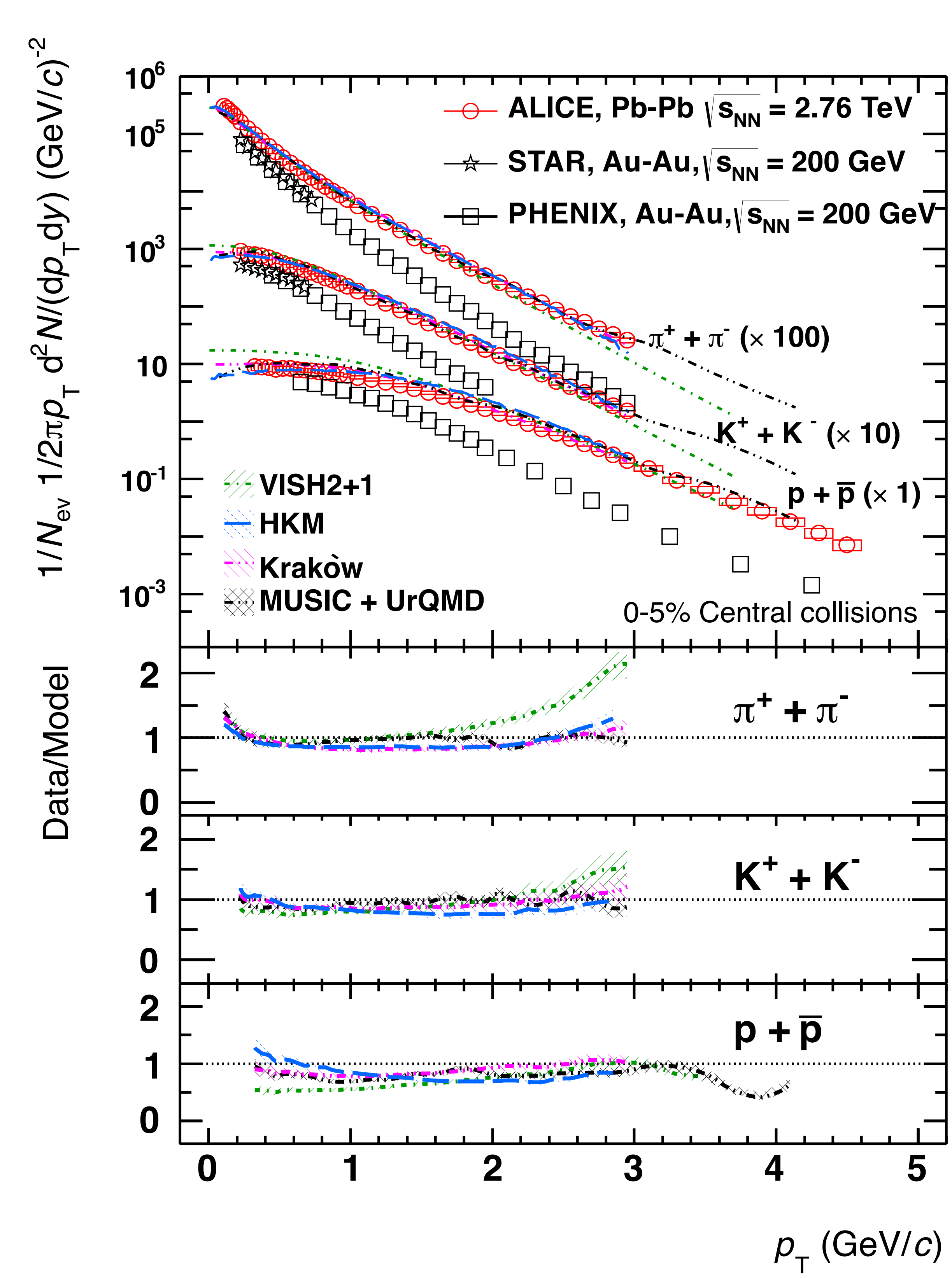


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**QM update**

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- **HKM** (Hydro+ UrQMD)
- **Krakow** (viscous corrections that lower the effective $T_{ch}$)
- **MUSIC** (EbyE, 3+1D Hydro, UrQMD):100 events

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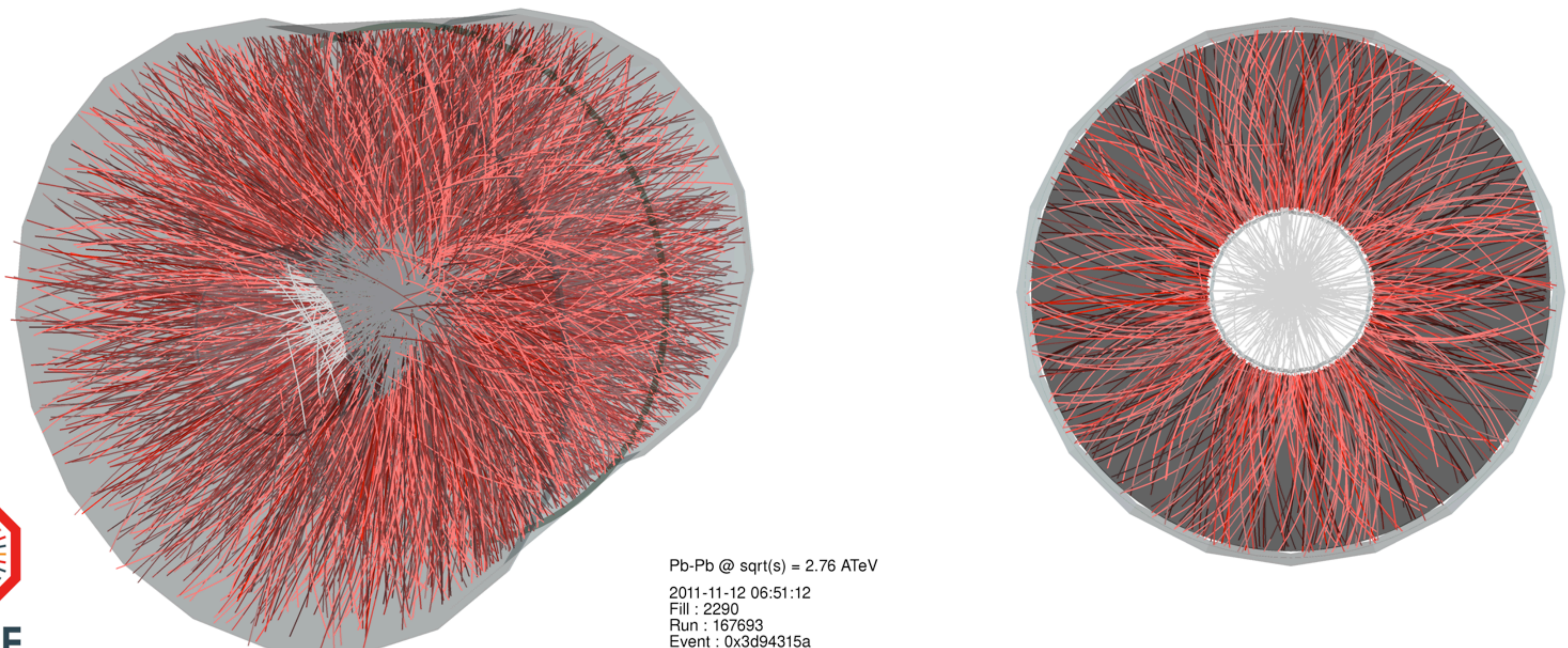
# $p_T$-spectra as a function of event-by-event flow

**...to further investigate the hydro behavior of $p_T$-spectra...**

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# Flow vector definition

Flow vector definition:

$$Q_{n,x} = \sum_i w_i \cos(n\phi_i),$$

$$Q_{n,y} = \sum_i w_i \sin(n\phi_i),$$

i = channels of VZERO detector
$w_i$ = multiplicity of channel i
$\Phi_i$ = angle of channel i

flow vector is a powerful tool to select events with different $v_2$

*see Sergey Voloshin (13 August)*

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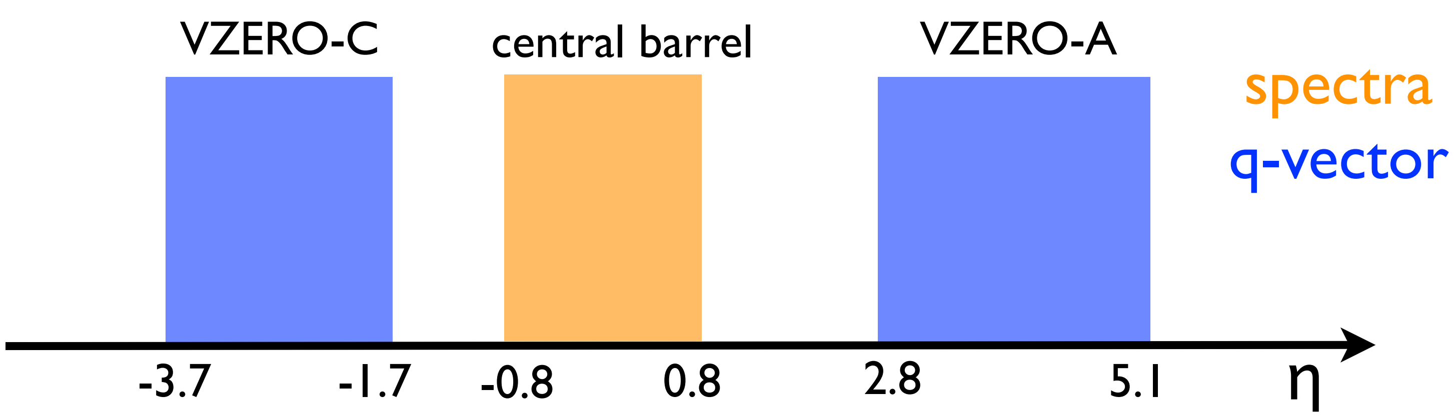


**large rapidity gap**

centrality selected: 30-40%

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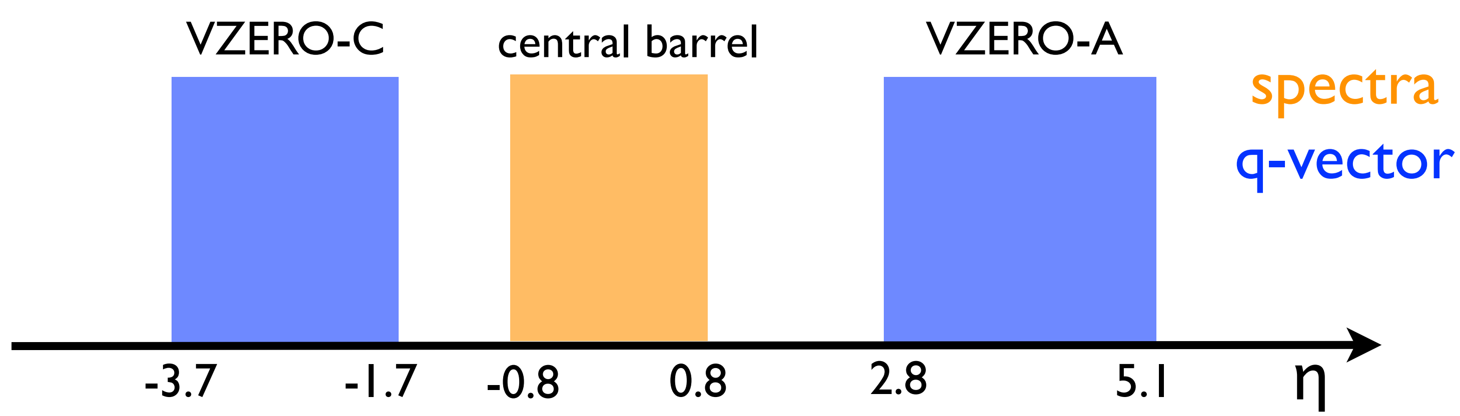


**large rapidity gap**

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- Integrated elliptic flow at the LHC is ~ 30% larger w.r.t. RHIC*
- Event-by-event this increase can be much larger

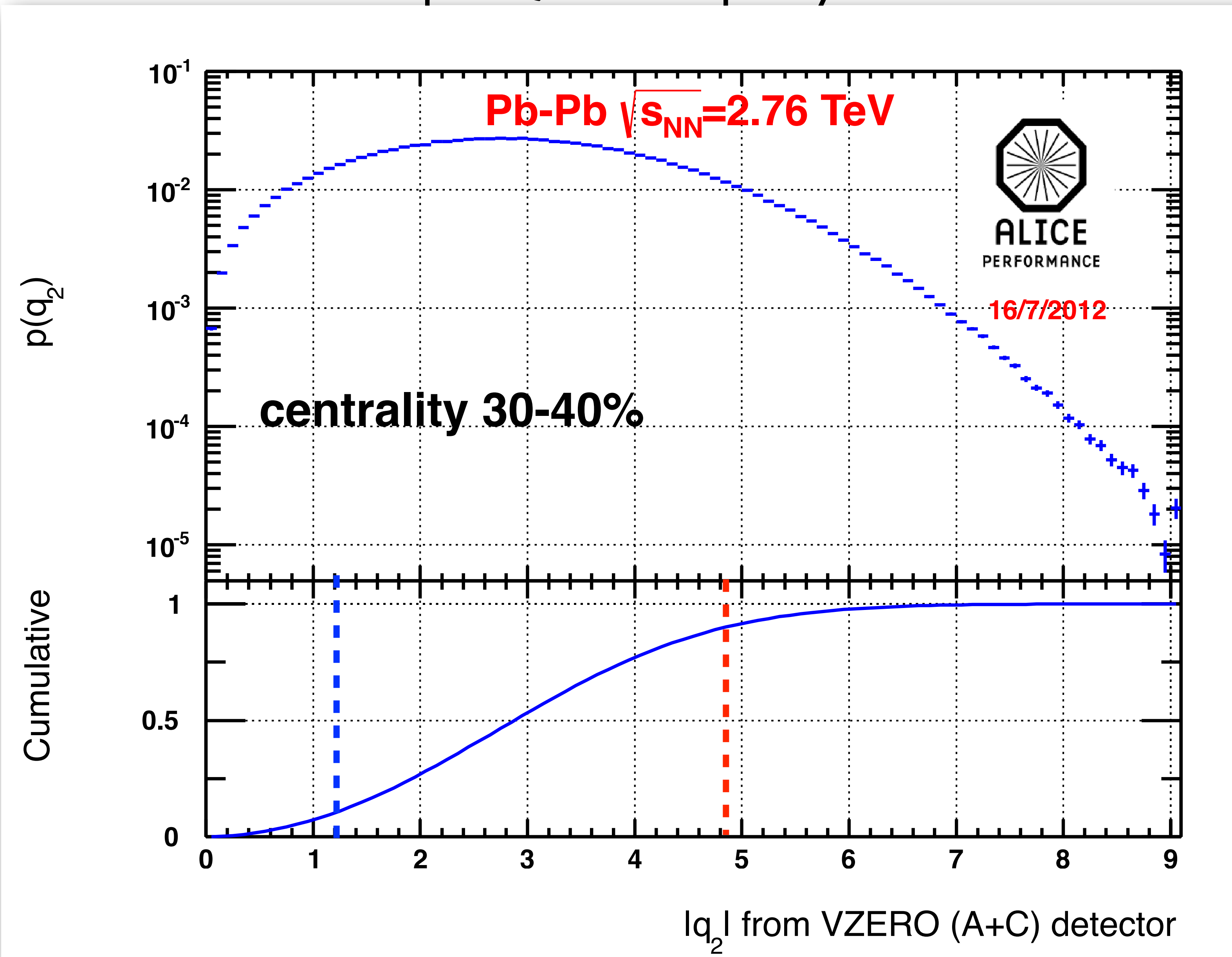
**ALICE Collaboration, Phys. Rev. Lett. 105, 252302 (2010)*

- If we integrate cos(2Φ) in 2π we do not expect any modification of the $p_T$-spectrum

- we look at $q_2$ distribution: $Q_2/\sqrt{\text{multiplicity}}$

# Flow vector distribution

$q_2 = Q_2/\sqrt{\text{multiplicity}}$




Keep potential biases under control:

- *multiplicity bias*
  - $v_2$ increases with decreasing centrality*
- *jet contribution*
  - is the large $q_2$ due to an increased jet contribution?

We want to select the 10% highest (lowest) elliptic flow events

*see Alexandru Dobrin Florin (14 August)*

**ALICE Collaboration, Phys. Rev. Lett. 105, 252302 (2010)*

# Checks on potential biases

- *Multiplicity bias*
  - centrality from tracks in the central barrel instead of VZERO
  - bin 30-40% obtained as the sum of 10 bins 1% wide

*shift negligible*

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- *Jet contribution:*

**Background:**

*$p_T$_tot* = total $p_T$ in the event

*density* = $p_T$_tot/acceptance

**Energy in a cone:**

- seed particle: ($p_T$>5GeV/c)
- *$p_T$_sum* = sum of $p_T$ in R<0.3
- *area*=π x R^2
- *$p_T$_jet*= *$p_T$_sum* - *density* x *area*

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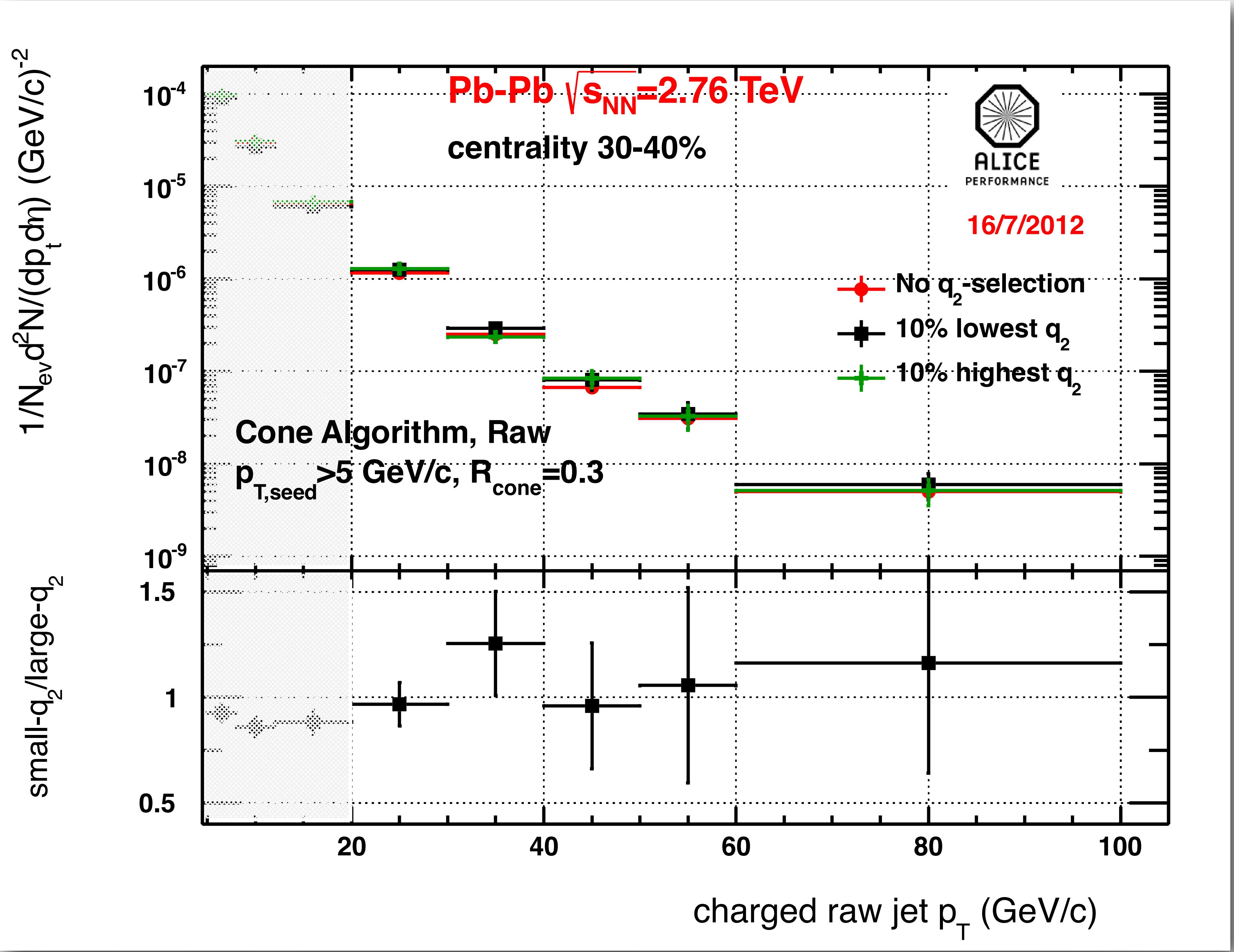
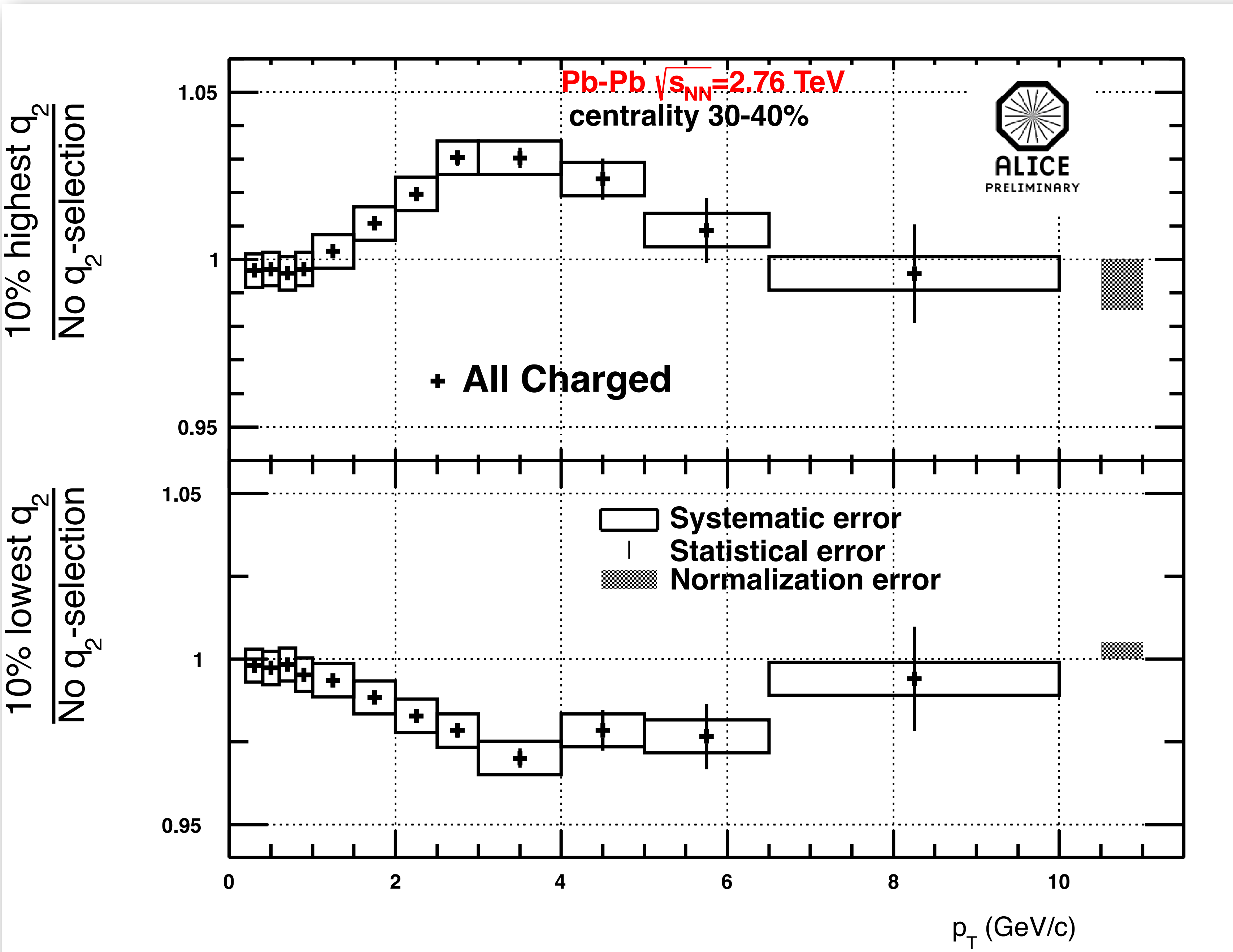



- method reliable only above ~20 GeV/c
- ratio is flat, "jet" contribution similar

# $p_T$-spectra vs E-by-E flow




- Ratio of raw spectra, efficiency does not depend on $q_2$ selection

- Modification of the $p_T$-spectrum: large $q_2$ ⇒ harder spectrum, opposite for small $q_2$

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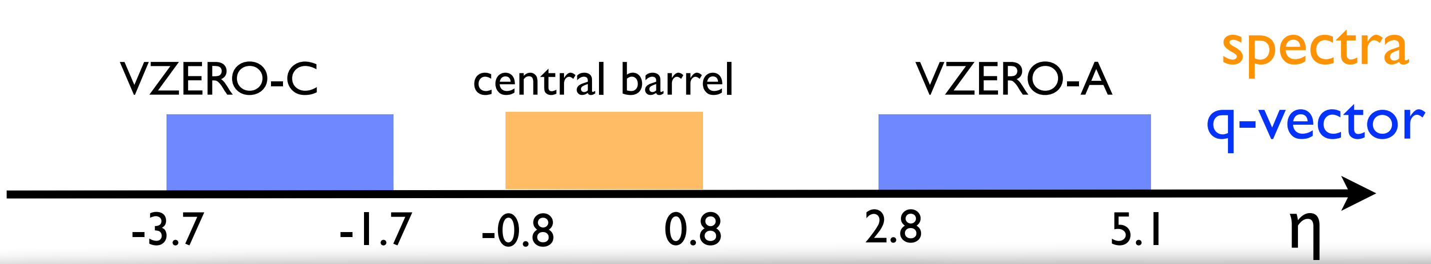

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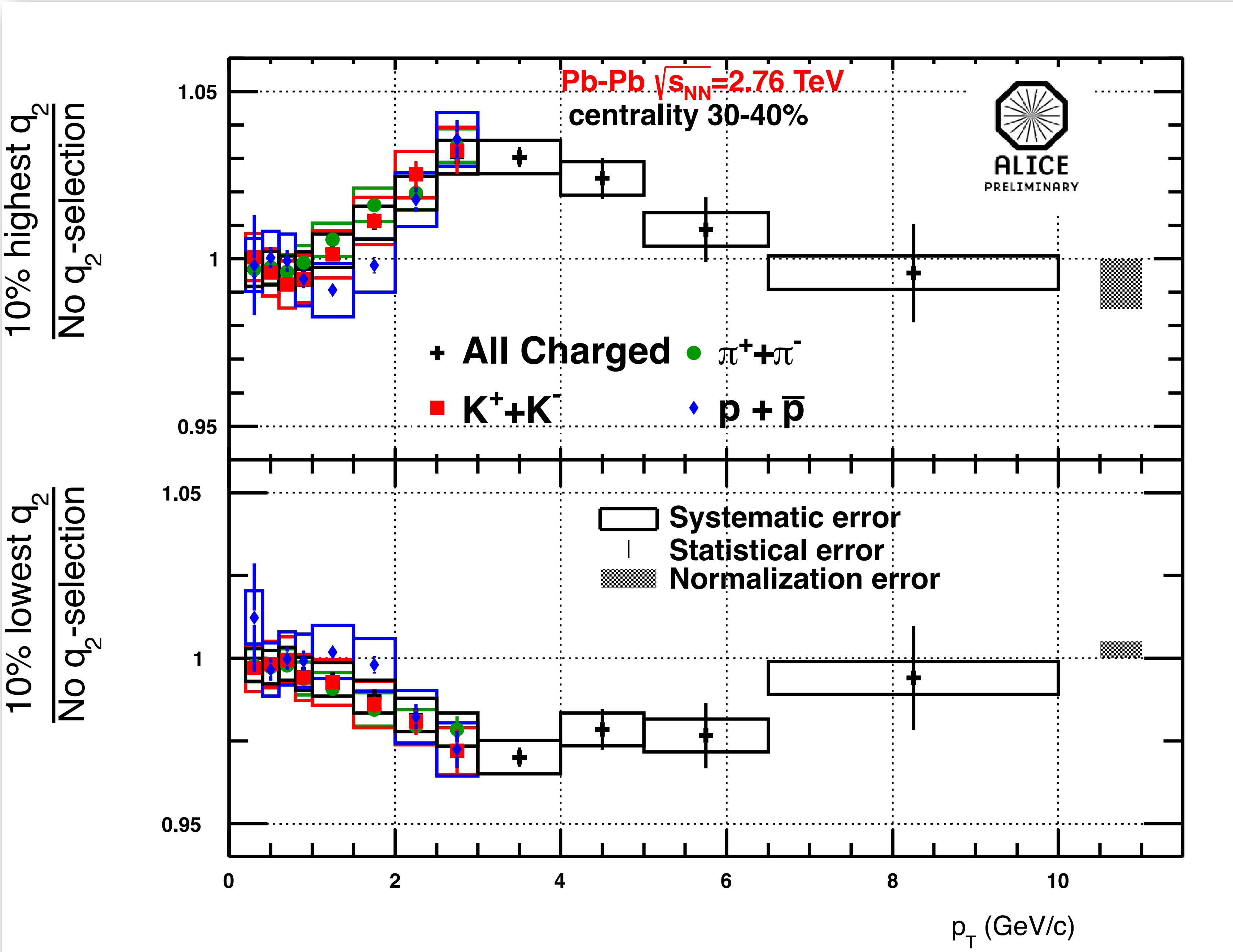


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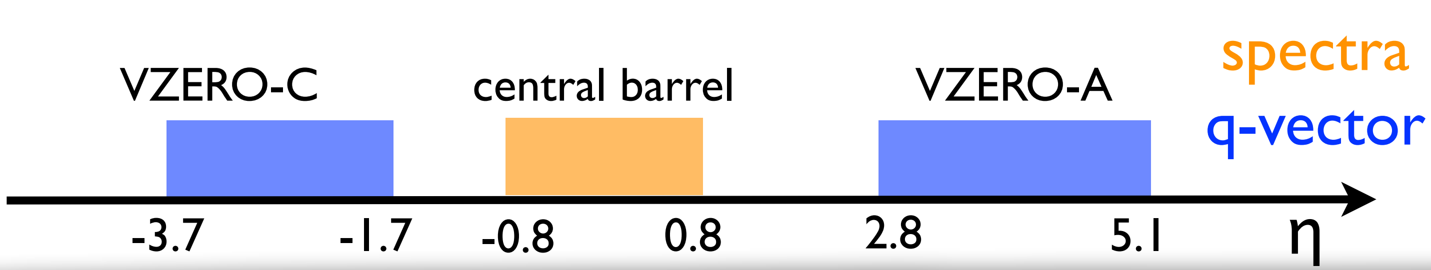
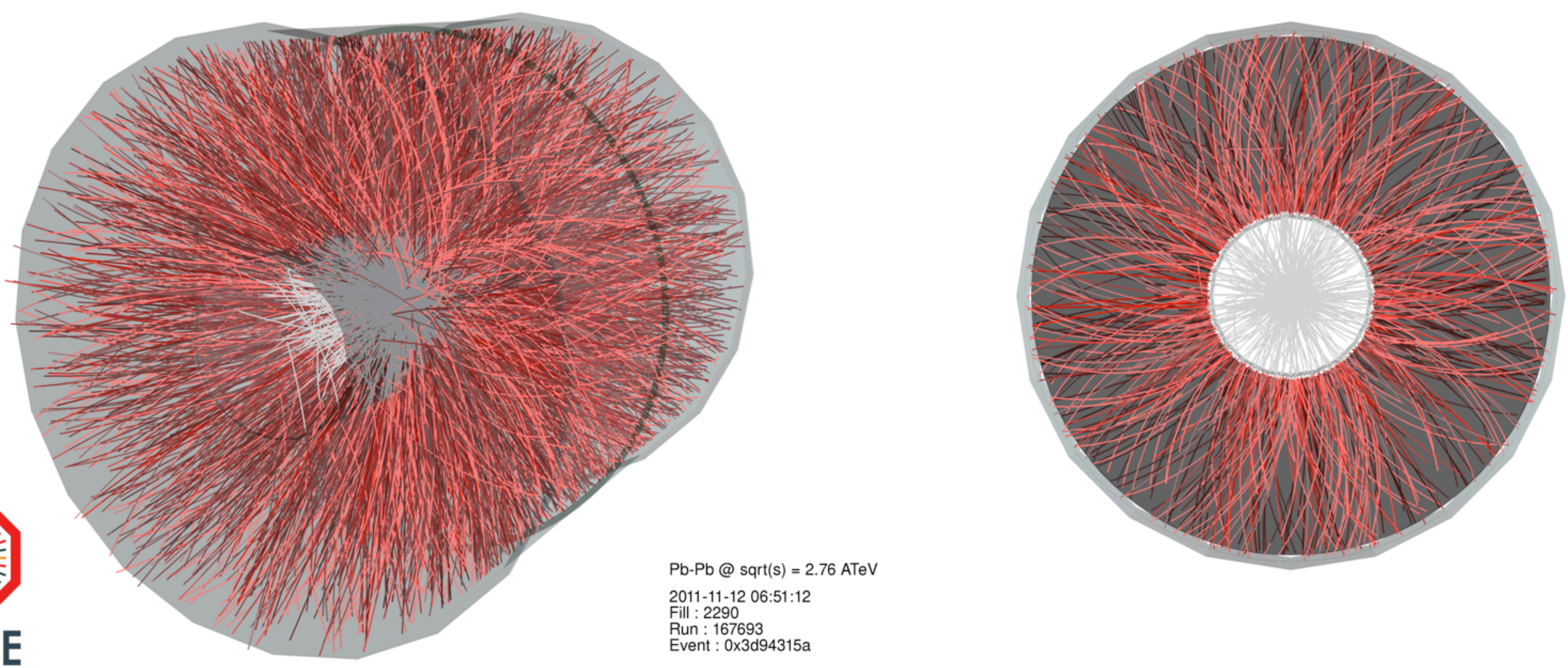
- Modification of the $p_T$-spectrum: large $q_2$ ⇒ harder spectrum, opposite for small $q_2$
- Vanishing at high $p_T$ : not due to jet contribution
- same effect for all the particles
- hint of mass ordering?




Are $v_2$ and radial flow correlated?

# Thermal production of hadrons



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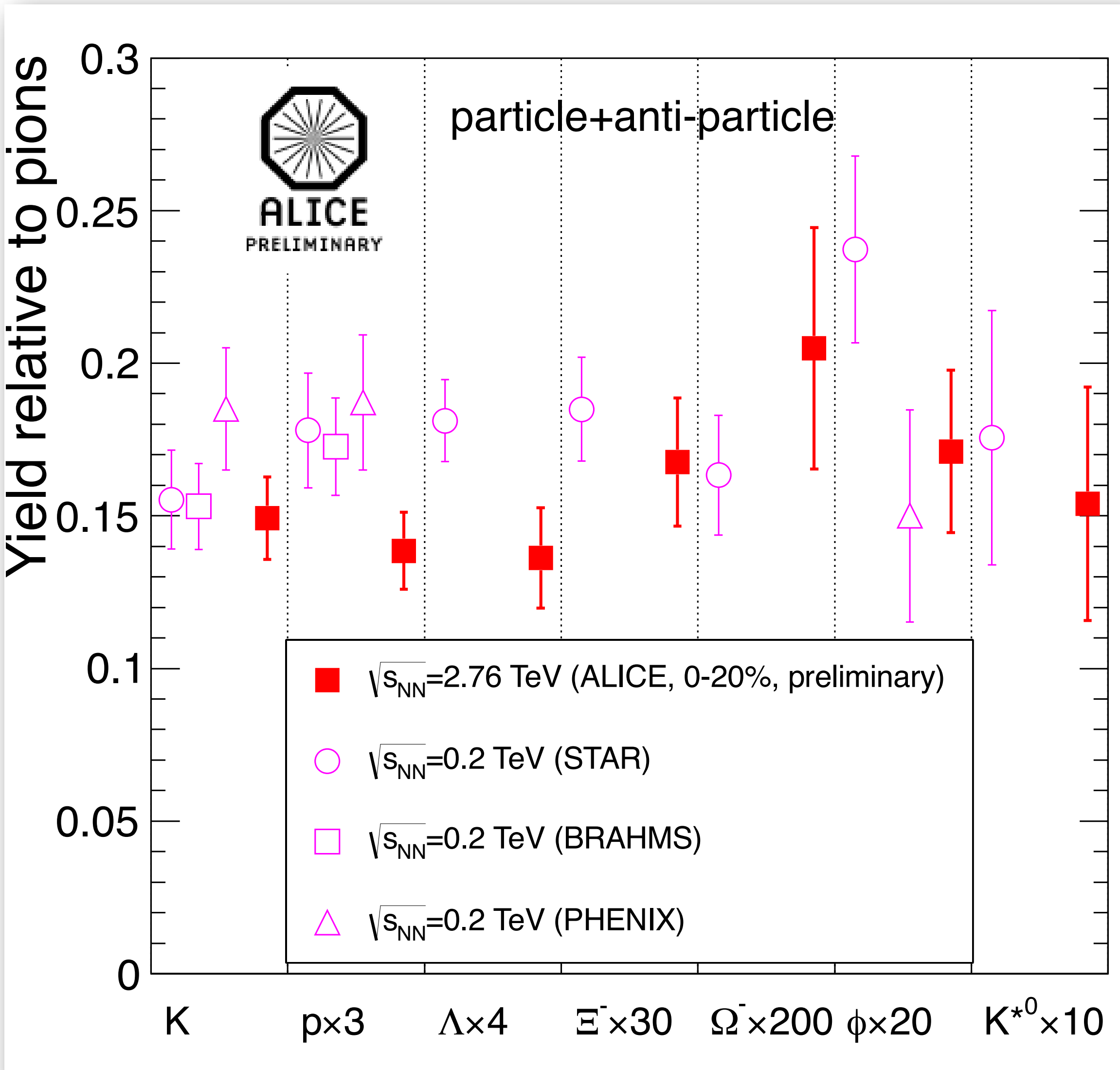


- feed down correction: $p_{STAR}$ (-37%) $\pi_{PHENIX}$ (-10%)
- decreasing ratios at the LHC?
- p/π and Λ/π different at the LHC

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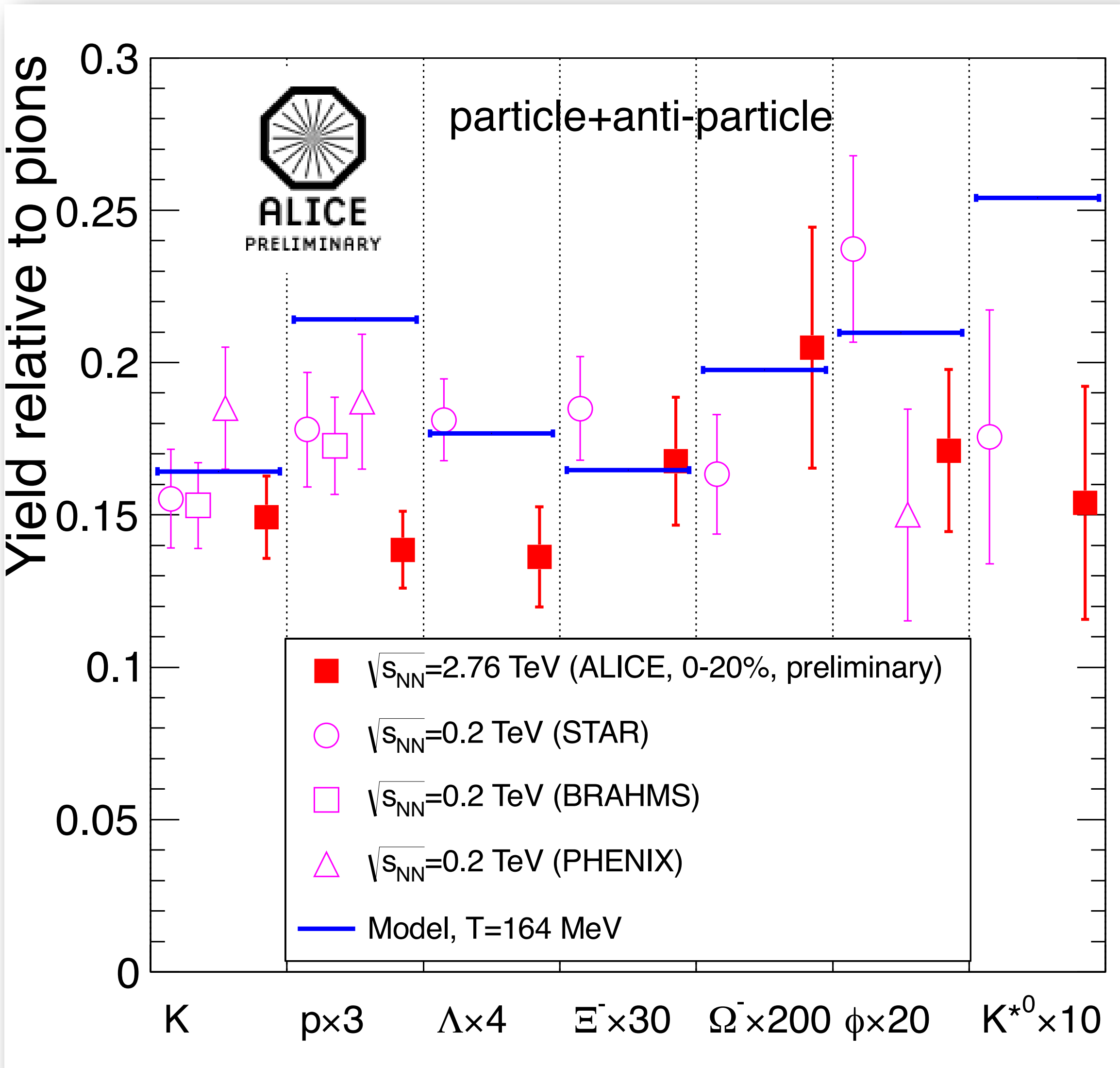


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*A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A 772 (2006) 167*

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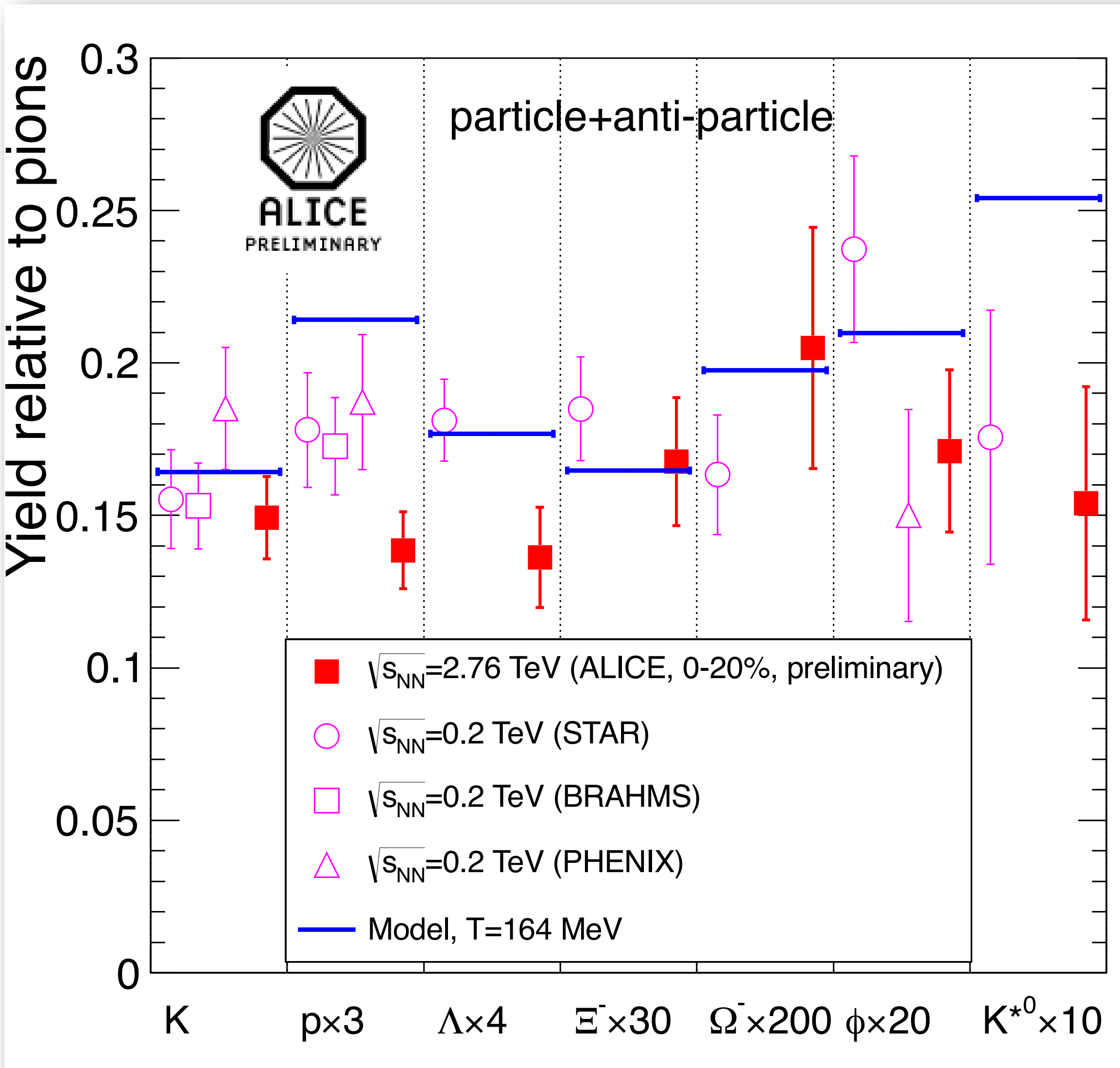


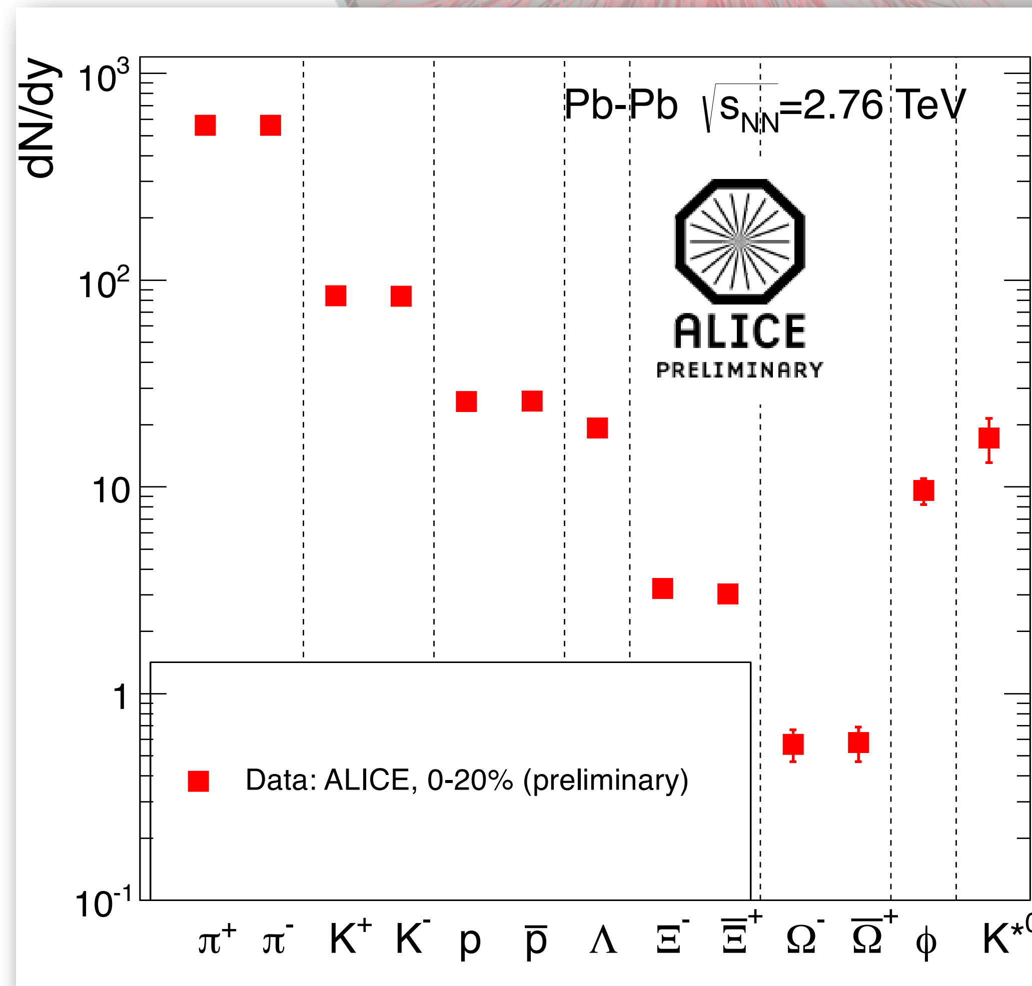


Integrated yields at midrapidity:
- data are feed down corrected,

- feed down correction: $p_{STAR}$ (-37%) $\pi_{PHENIX}$ (-10%)
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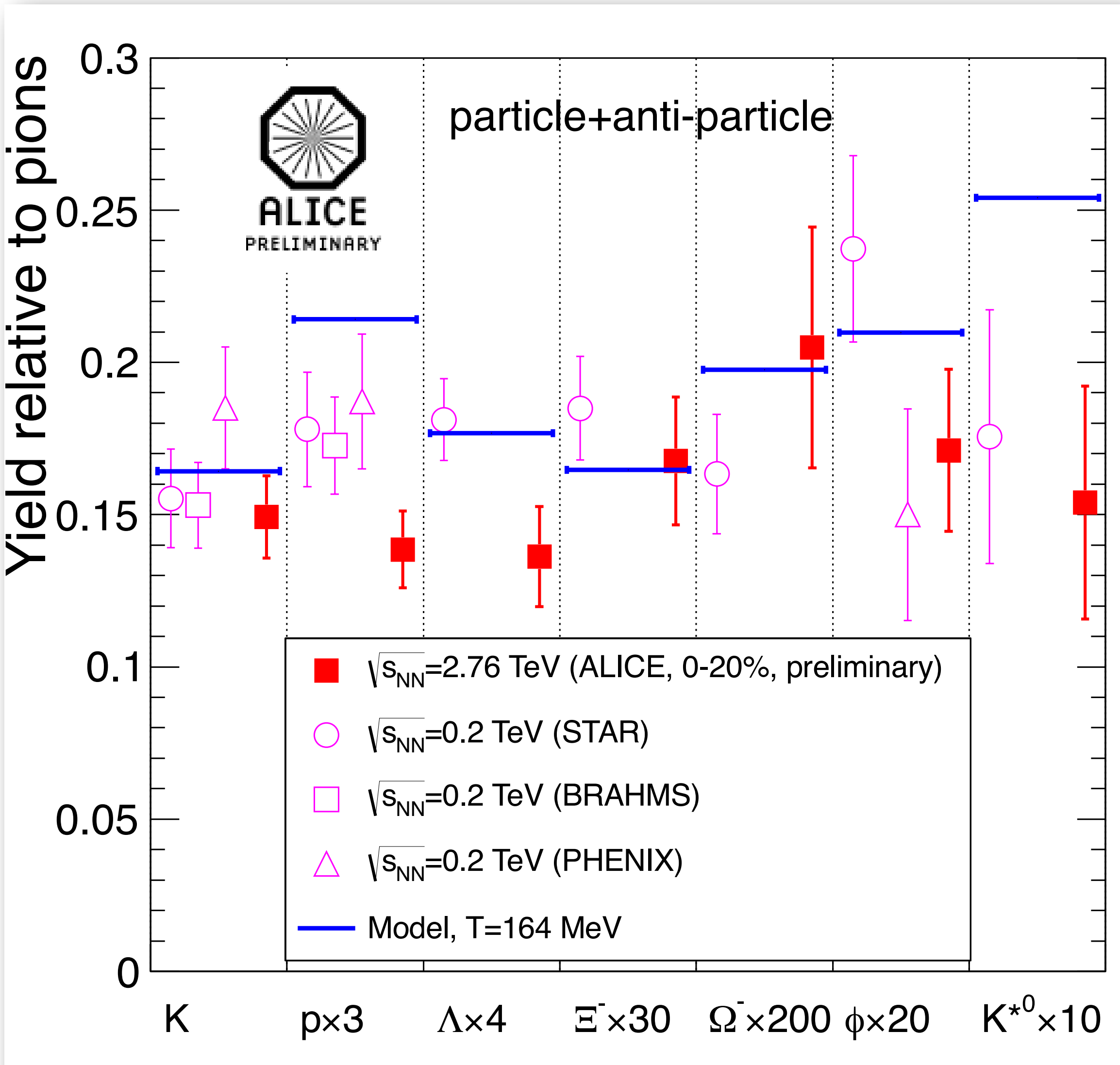
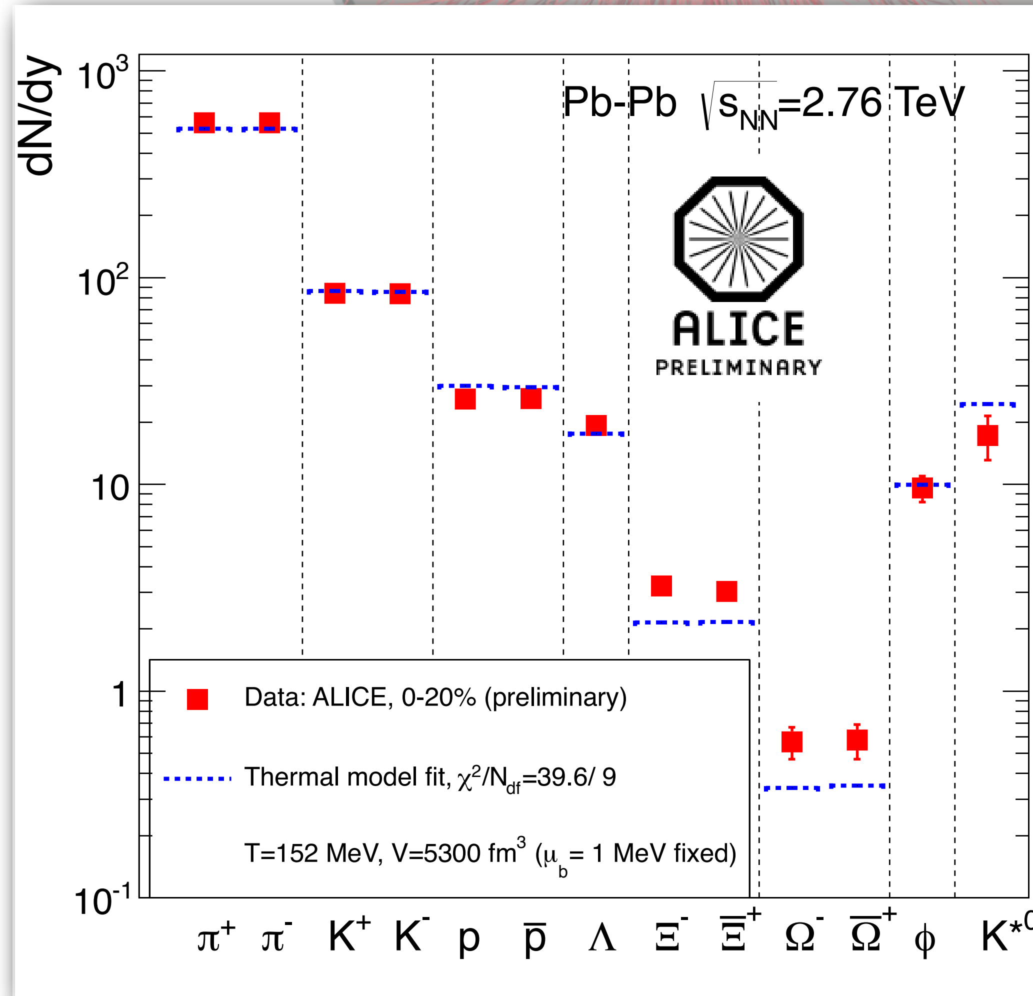
*A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A 772 (2006) 167*

# Thermal production of hadrons




Integrated yields at midrapidity:
- data are feed down corrected,
- φ and $K^{*0}$ not included in the fit

$T_{ch}$ = **152** MeV from fit to LHC dN/dy

- feed down correction: $p_{STAR}$ (-37%) $\pi_{PHENIX}$ (-10%)
- decreasing ratios at the LHC?
- p/π and Λ/π different at the LHC
- $T_{ch}$ =164 MeV from lower energies extrapolation

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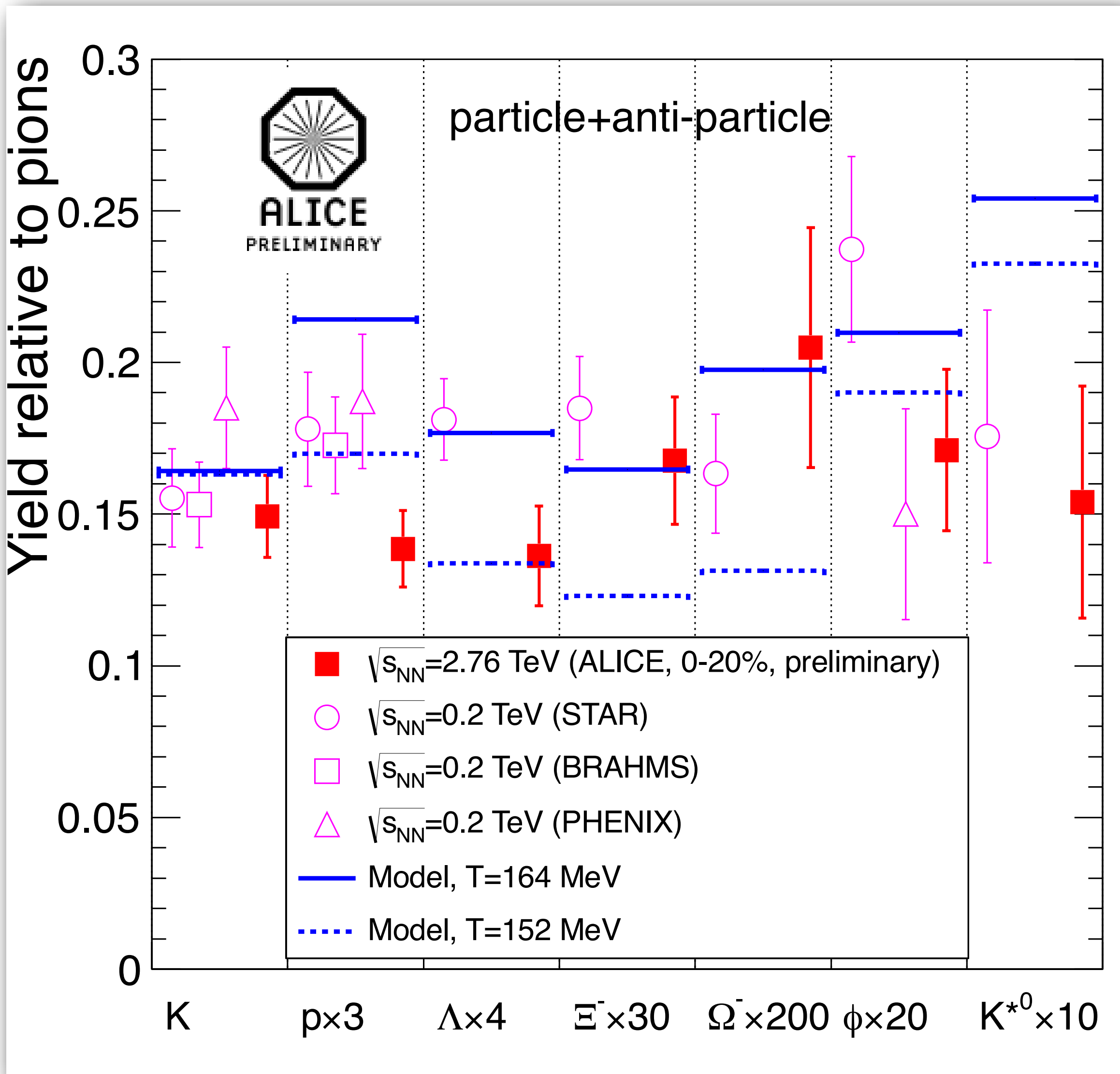


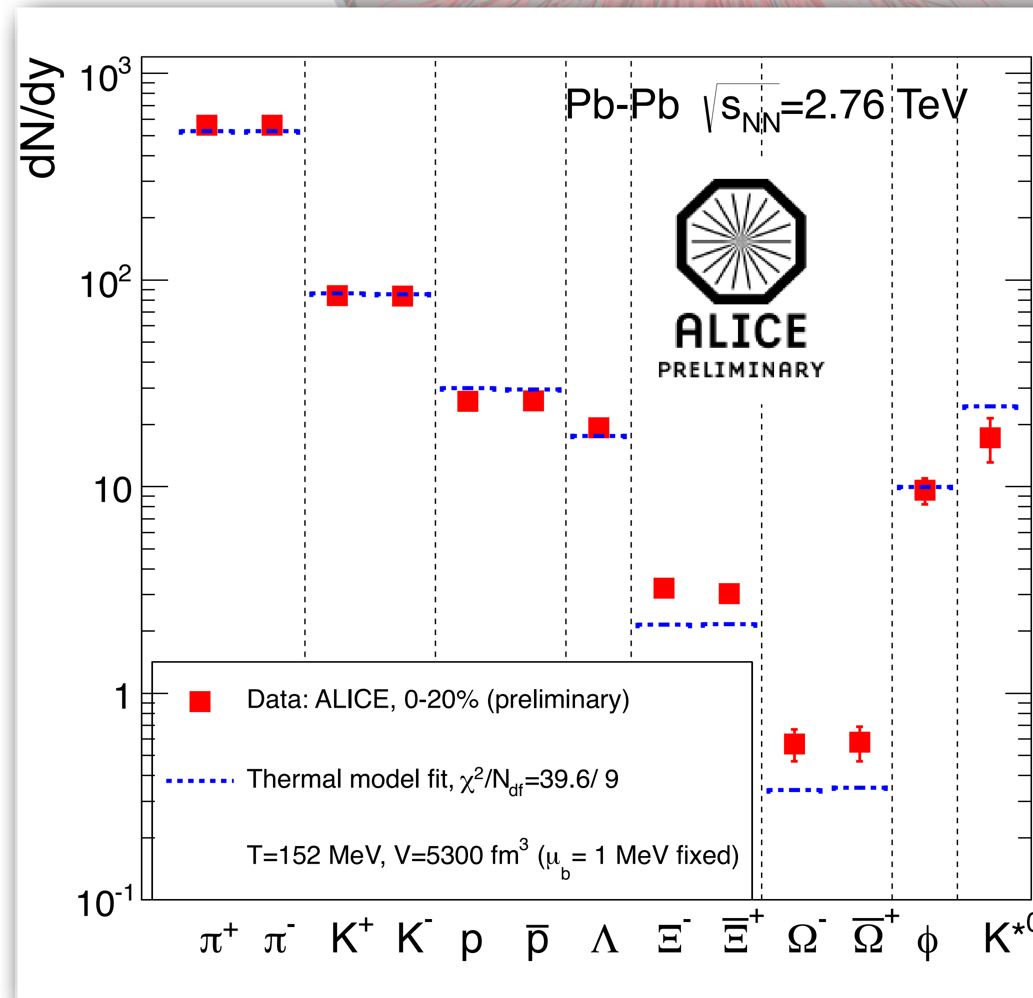


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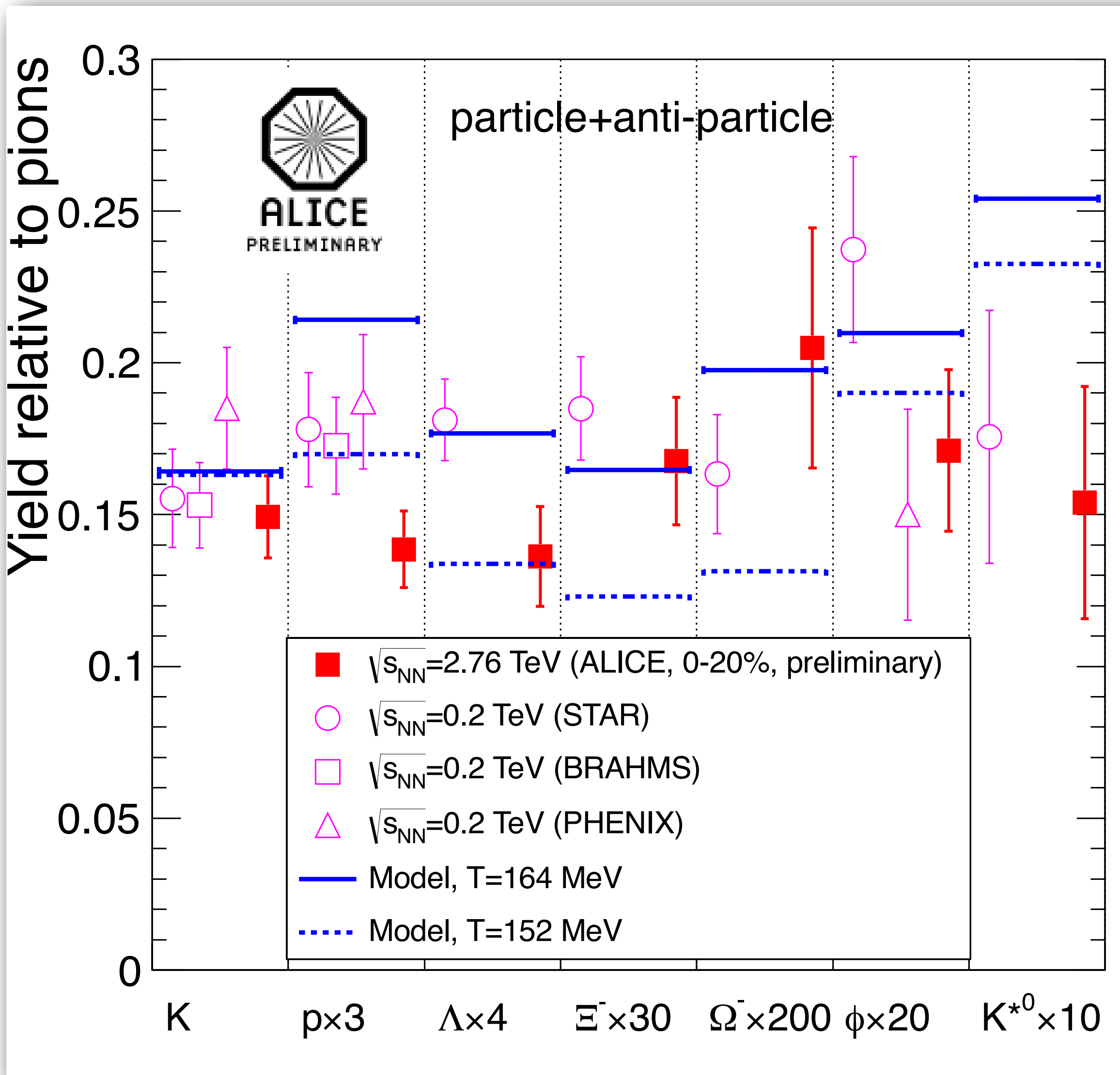


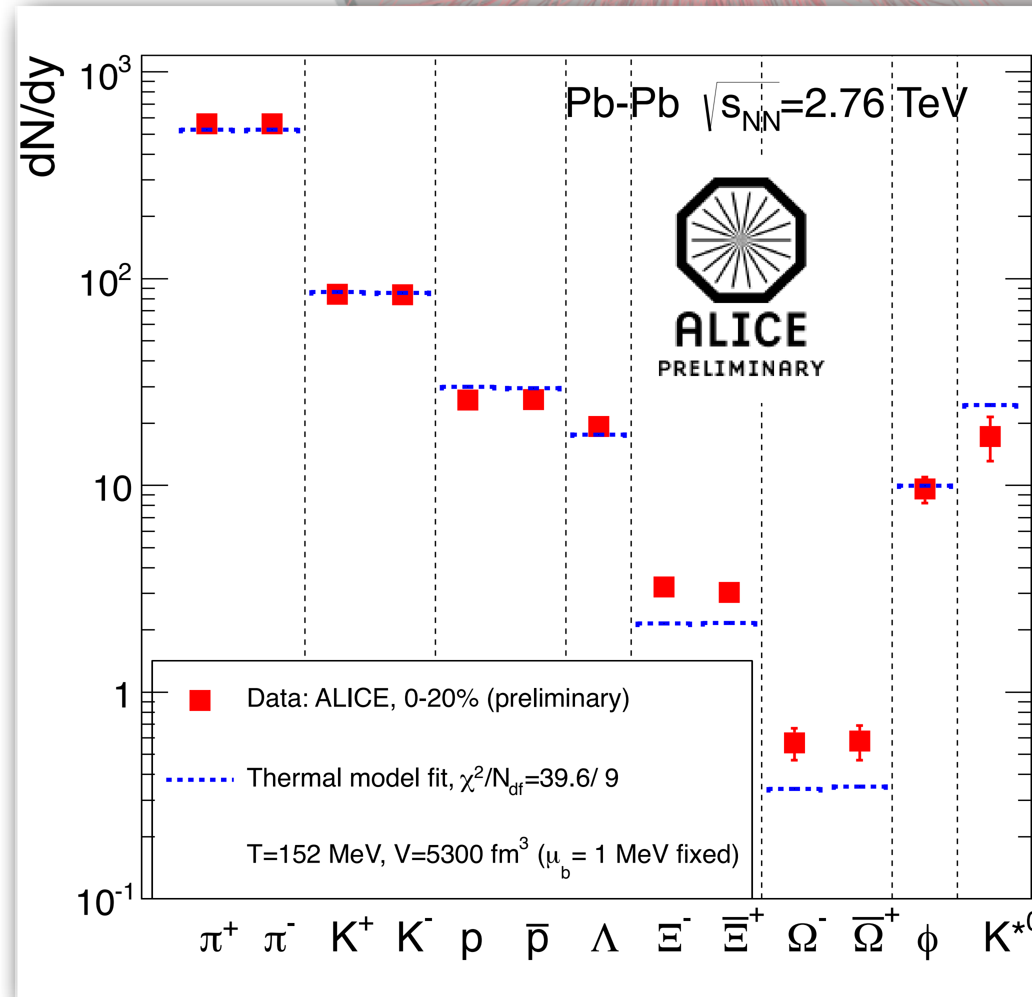


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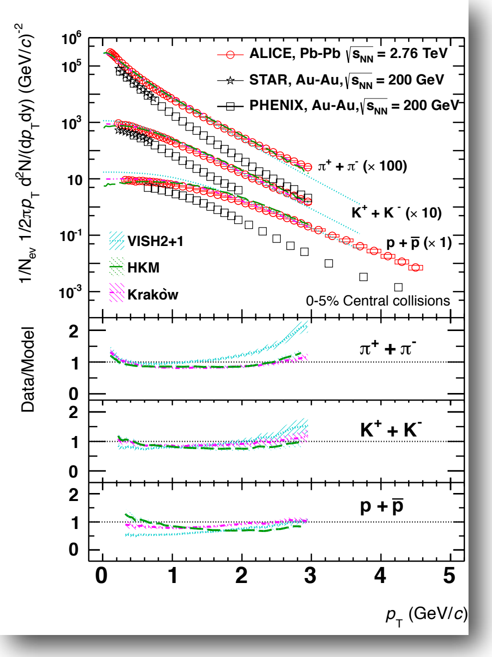
- possible extension*: hadronic interactions
  **Jan Steinheimer, Jörg Aichelin, Marcus Bleicher, arXiv:1203.5302v1 [nucl-th]*
  **Francesco Becattini, Marcus Bleicher, Thorsten Kollegger, Michael Mitrovski, Tim Schuster, Reinhard Stock, arXiv:1201.6349v1 [nucl-th]*

# Summary

- **Identified particle spectra in central (0-5%) Pb-Pb**
  - Strong radial flow in central collisions (~10% larger with respect to RHIC)
  - Models with a refined late fireball description are able to reproduce better the experimental data



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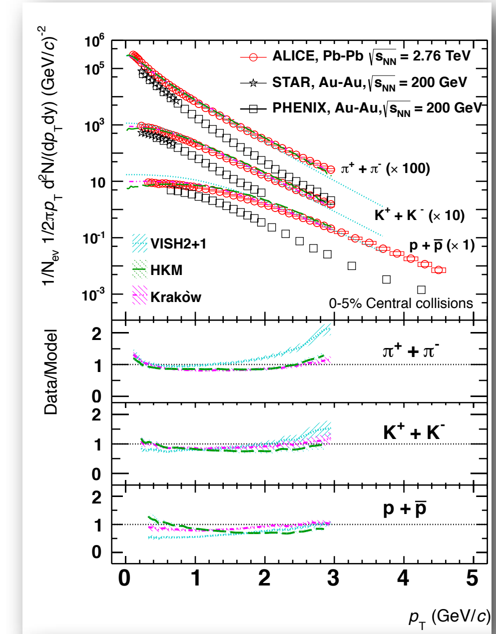
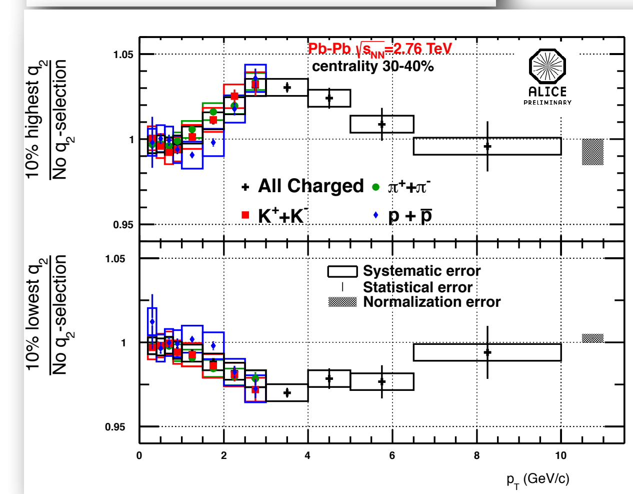



- ***p*T-spectra as a function of event-by-event flow**
  - Modification of the $p_T$-shape in the intermediate $p_T$-range when selecting high (low) elliptic flow events



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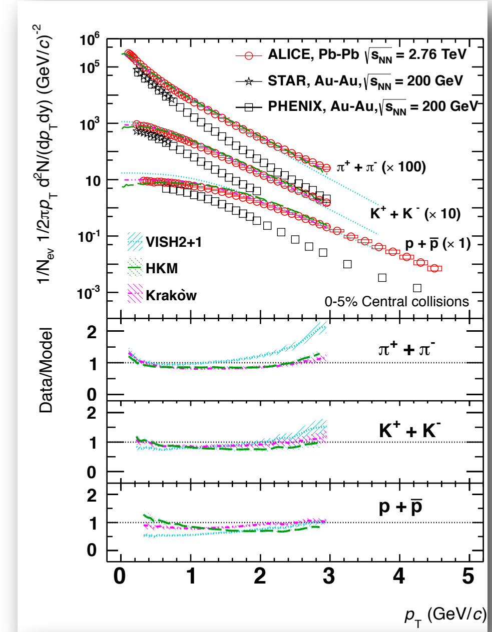


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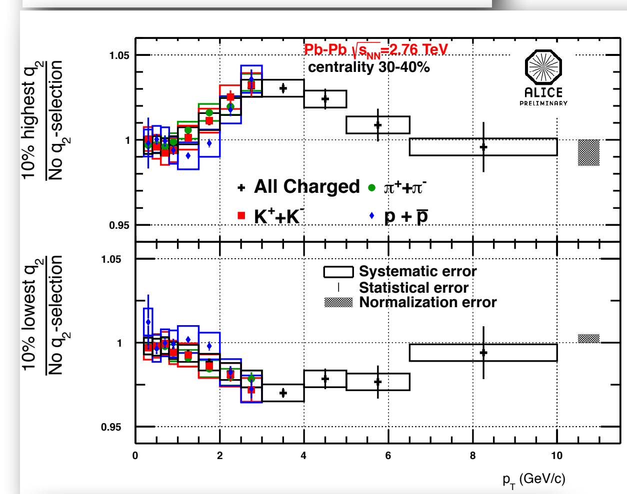
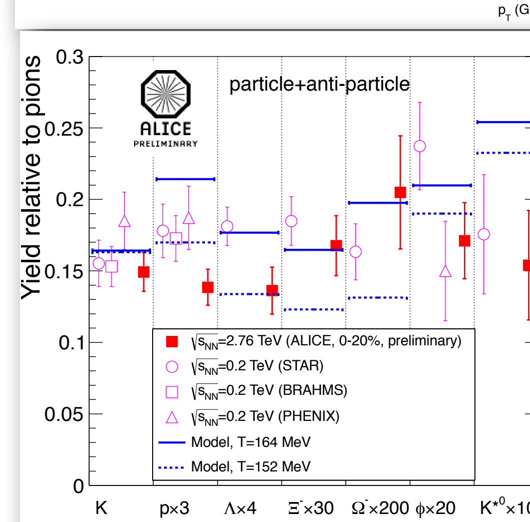
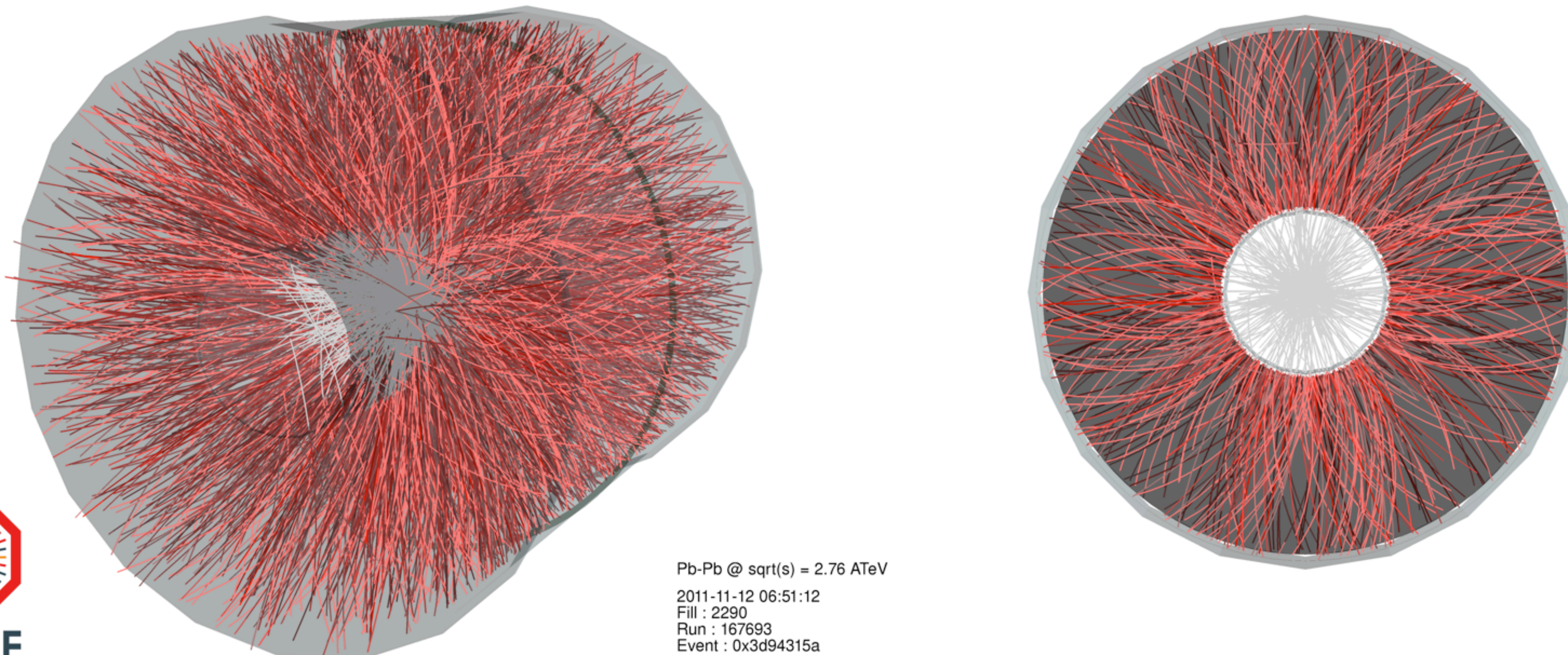



- **Thermal production of hadrons**
  - Particle ratios consistent with RHIC except for p/π and Λ/π
  - Studies ongoing... improvement from experiments + feedback from theory

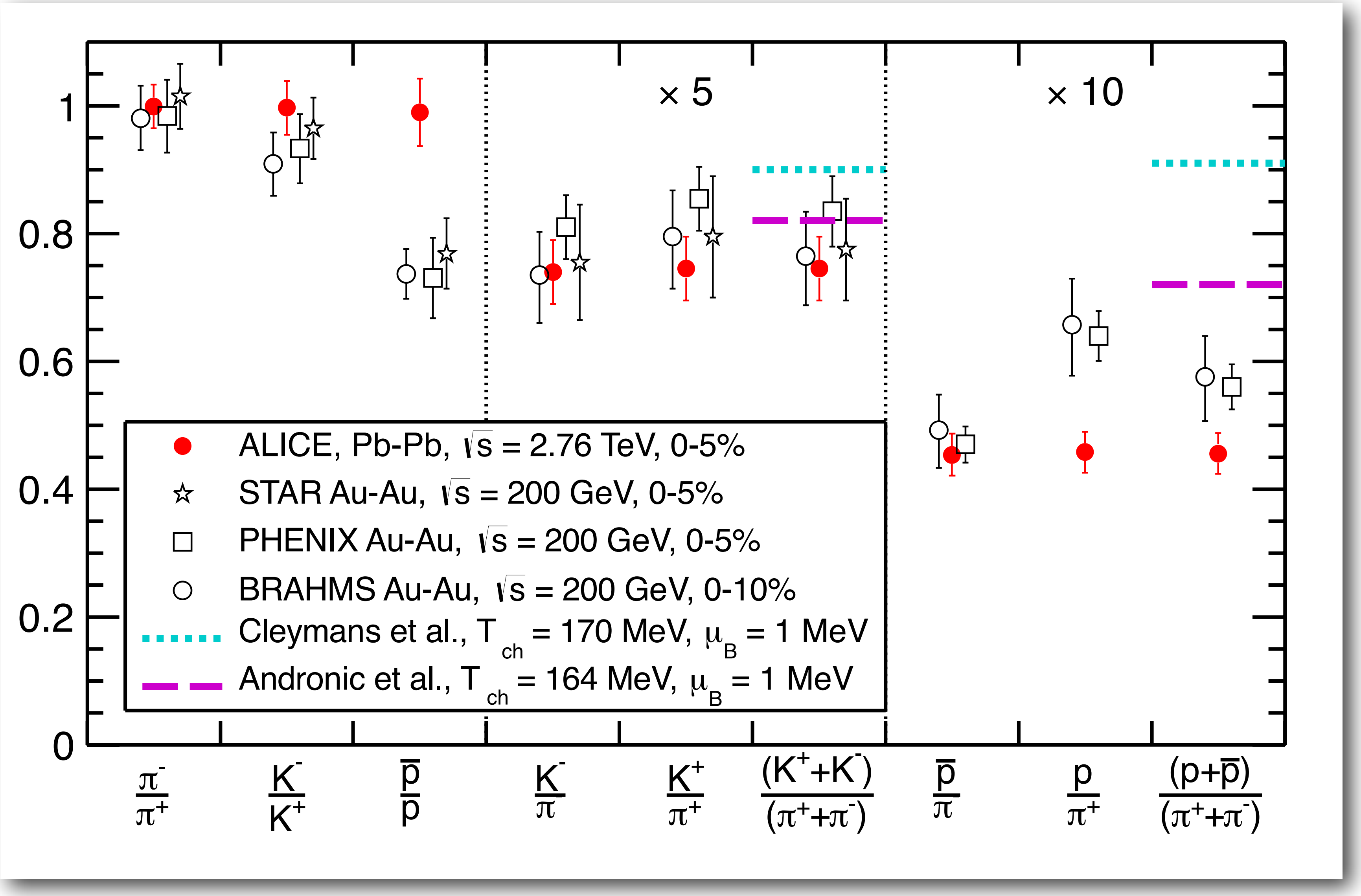


# THANKS


Pb-Pb @ sqrt(s) = 2.76 ATeV
2011-11-12 06:51:12
Fill : 2290
Run : 167693
Event : 0x3d94315a

# BACKUP

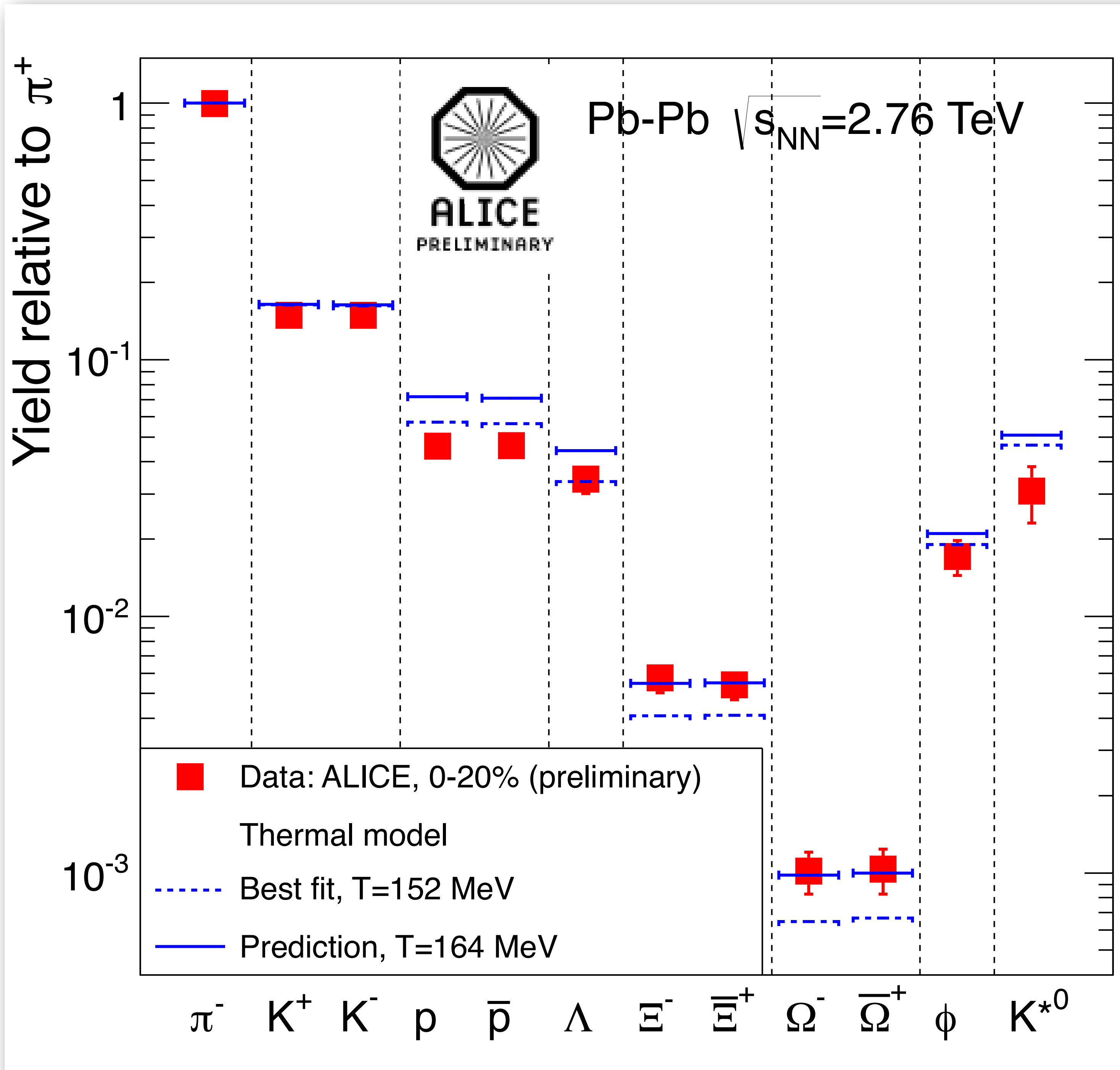
# Thermal model prediction




(***ALICE Collaboration***) *arXiv:1208.1974v1 [hep-ex]*

- $\mu_B$ vanishing at the LHC
- K/π similar to RHIC, in agreement with thermal model prediction
- p/π below the expectations, same behavior observed in hydro model without explicit description of hadronic phase

# Particle ratios

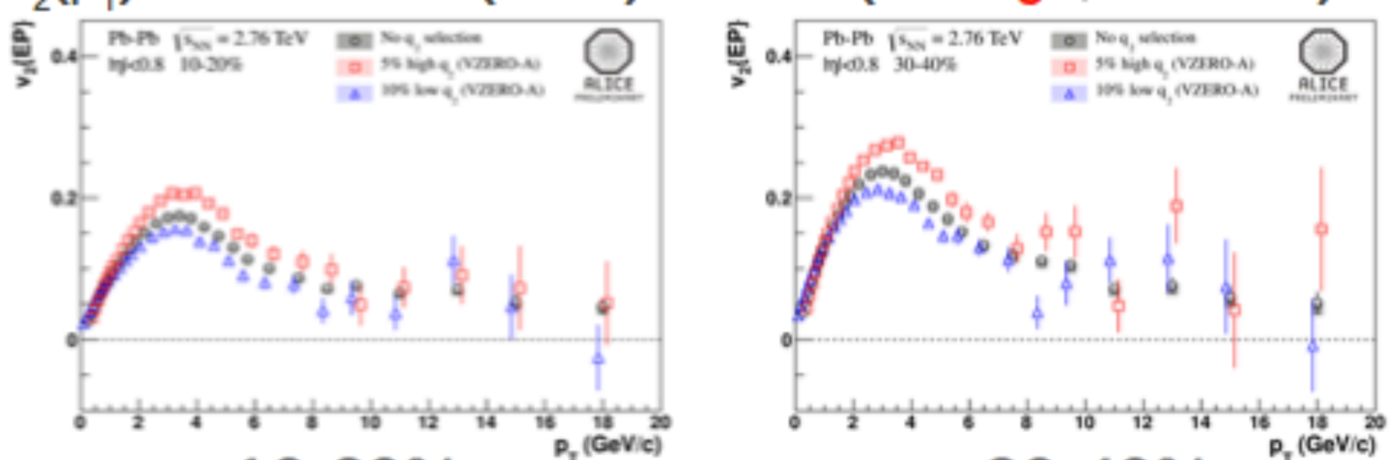


# $v_2(p_T)$: SE ($q_2$ VZERO-A) vs unbiased

Cutting on $q_2$ from VZERO-A (2.8<η<5.1) and correlate tracks from TPC (-0.8<η<0.8) with EP from VZERO-C (-3.7<η<-1.7)
Cutting on $q_2$ from VZERO-C also investigated (see backup)

*see Alexandru Dobrin Florin (14 August)*

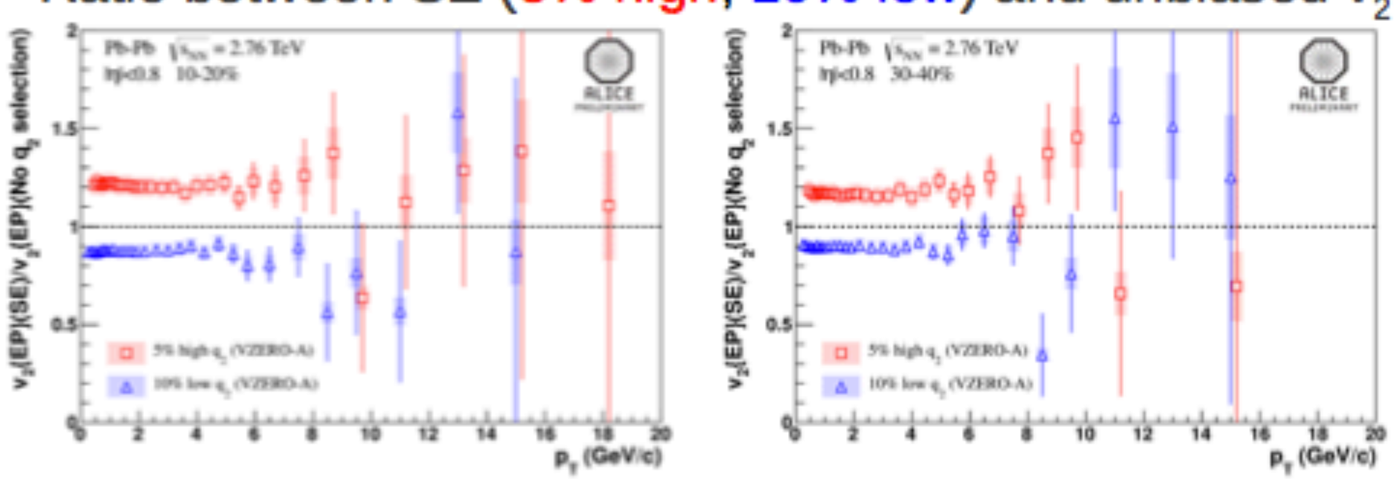
$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events




10-20% 30-40%

5% high $q_2$
10% low $q_2$
No $q_2$ selection

Ratio between SE (5% high, 10% low) and unbiased $v_2$




- Non-flow contributions significantly reduced using η gap
- Smaller ratios due to smaller flow and multiplicity → method sensitivity to the event shape
- $v_2$ ~ shape (ratio almost constant) at least up to $p_T$=6 GeV/c
- Effect of event shape fluctuations becomes small for $p_T$>6 GeV/c

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