QUARK MATTER 2015

The XXVth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

ALICE

Overview of recent ALICE results

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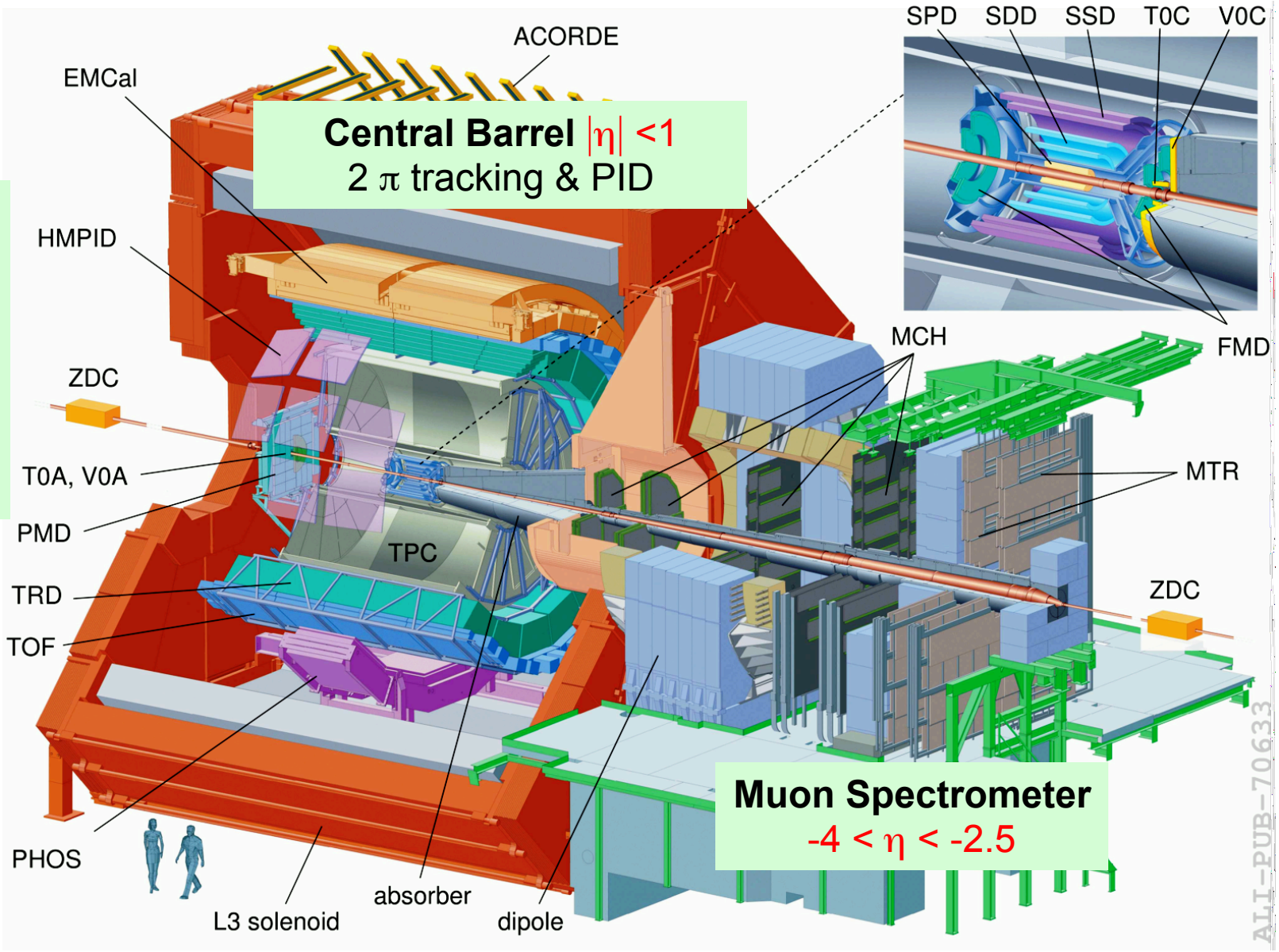
CENTER *for* NUCLEAR STUDY

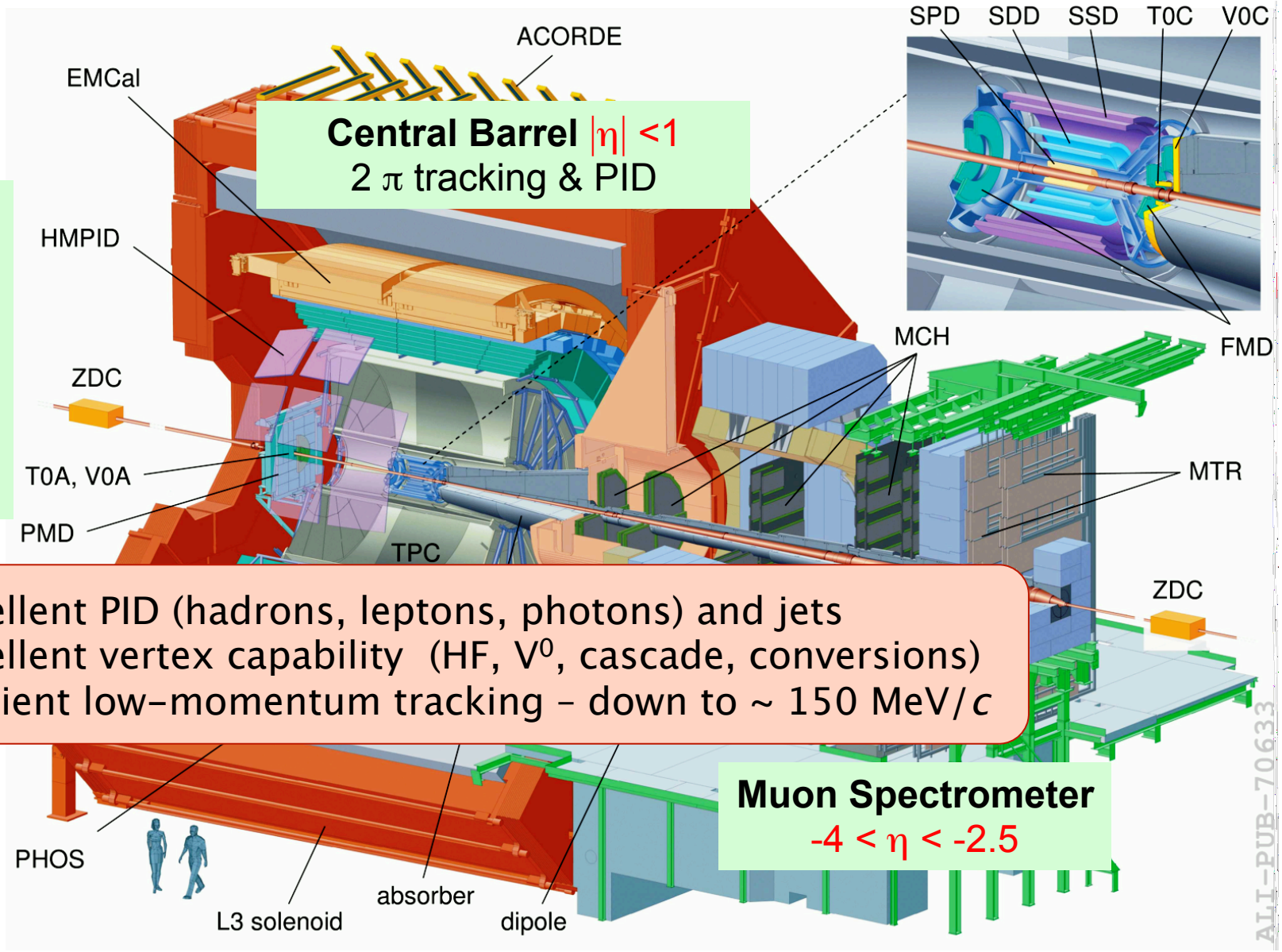
東京大学 THE UNIVERSITY OF TOKYO

ALICE Detectors

Forward Detectors (V0, T0, ZDC)
Trigger, Centrality, timing



ALICE Detectors



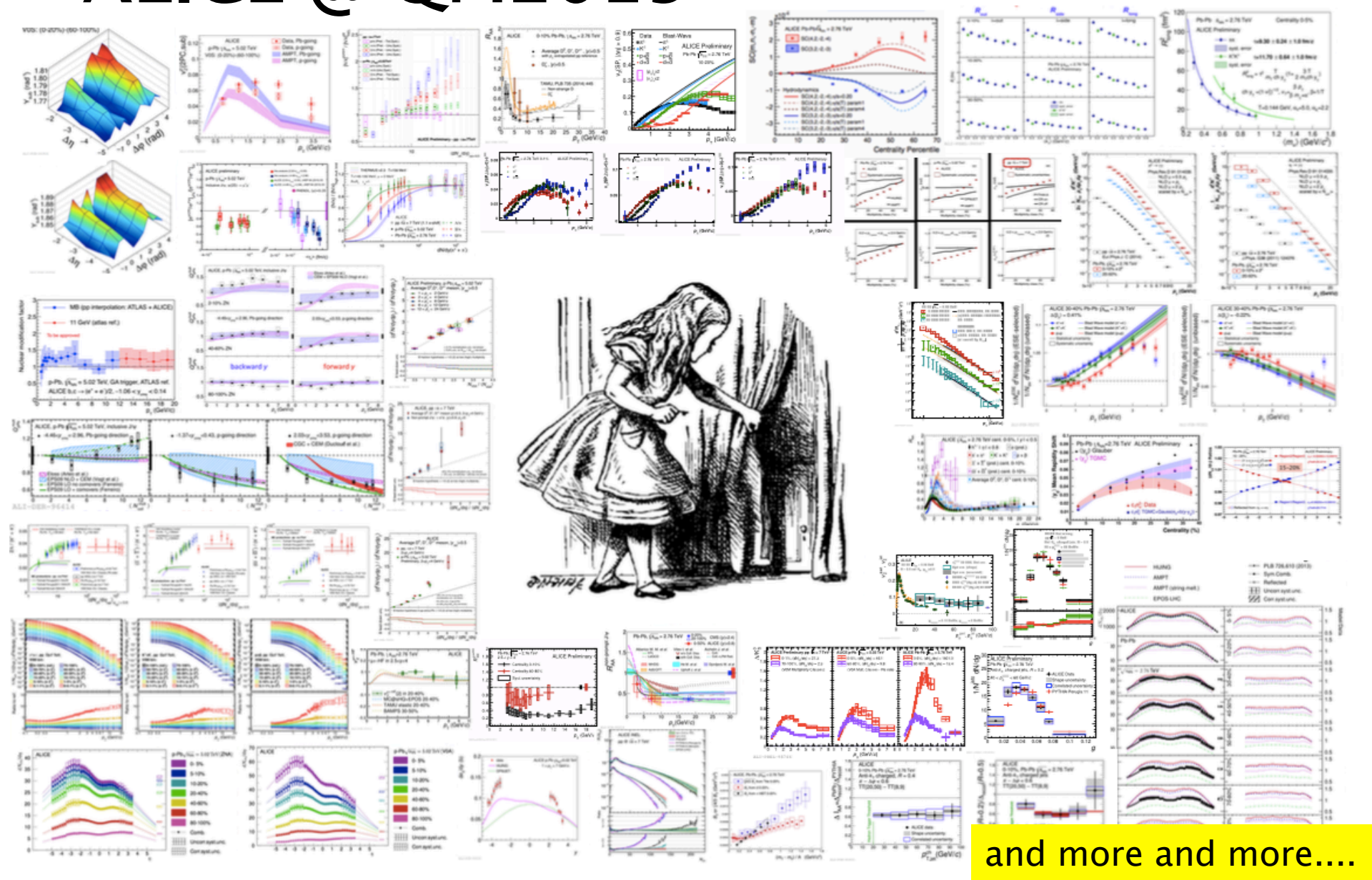
Central Barrel $|\eta| < 1$
2 π tracking & PID

Forward Detectors (V0, T0, ZDC)
Trigger, Centrality, timing

- Excellent PID (hadrons, leptons, photons) and jets
- Excellent vertex capability (HF, V^0, cascade, conversions)
- Efficient low-momentum tracking – down to ~ 150 MeV/c

Muon Spectrometer
$-4 < \eta < -2.5$

ALICE @ QM2015



and more and more....

ALICE @ QM2015

27 talks and 50 posters in QM2015
ALICE's Adventure continues.

Correlations and Fluctuations
- Rashmi Raniwala: Longitudinal Asymmetry in Pb-Pb
- Ludmila Malinina: Femtoscopy in Pb-Pb
- Evgeny Kryshen: F-C correlations in p-Pb
- Panos Christakoglou: Balance function

Quarknoia
- Marco Leoncino: Psi(2S) in p-Pb
- Hugo Denis Antonio Pereira Da Costa: Charmonium in Pb-Pb
- Gines Martinez-Garcia: Low pT J/psi in Pb-Pb
- Indranil Das: Upsilon production in ALICE

Open Heavy Flavors and Strangeness
- Alessandro De Falco: ϕ in p-Pb and Pb-Pb
- Natasha Sharma: (anti-)(hyper-)nuclei and exotics
- Andrea Dubla: Heavy flavors in Pb-Pb
- Jeremy Wilkinson: Heavy flavors in p-Pb
- Fabio Filippo Colamaria: Heavy flavors in pp and correlations

QGP in small systems
- Antonio Ortiz Velasquez: Light flavors in p-Pb
- Livio Bianchi: Strangeness production in p-p

Jets and High pT Hadrons
- Leticia Cunqueiro Mendez: Jet structure in Pb-Pb
- Redmer Alexander Bertens: Charged jet anisotropy
- Astrid Morreale: High p_T photons and π^0 in Pb-Pb

Collective Dynamics
- Ramona Lea: (anti-)deuteron in Pb-Pb
- Anthony Robert Timmins: Event shape engineering
- You Zhou: Correlations of flow harmonics
- Naghmeh Mohammadi: Higher harmonics in Pb-Pb

Initial State Physics and Approach to Equilibrium
- Valentina Zaccolo: Multiplicity over wide rapidity in p-p

Electromagnetic probes
- Baldo Sahlmueller: Direct photons in Pb-Pb
- Patrick Simon Reichelt: Low mass dielectrons

Future Experimental Facilities, Upgrades, and Instrumentation
- Petra Riedler: ALICE ITS upgrade
- Chilo Garabatos Cuadrado: ALICE TPC upgrade

and more and more....

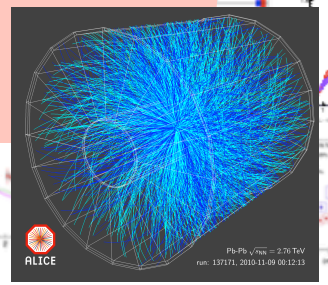
Outline of this talk

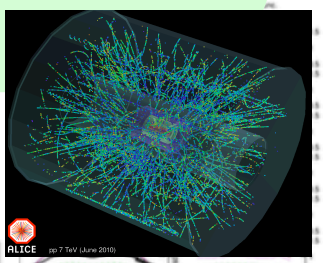
Highlights from Pb–Pb

- **Collectivity, Correlations:**
  - ✓ Deuteron v_2
  - ✓ v_2, v_3, v_4 of identified particles.
  - ✓ Correlation of Flow Harmonics (v_2–v_3, v_2–v_4)
  - ✓ Event Shape Engineering and Particle Spectra
- **Hard Probes:**
  - ✓ Heavy Flavors, Jets
- **Direct Photons**
- **Longitudinal Asymmetry**
- **Excess of low p_T J/ψ**
- **CPT invariance**

Highlights from p–Pb and pp

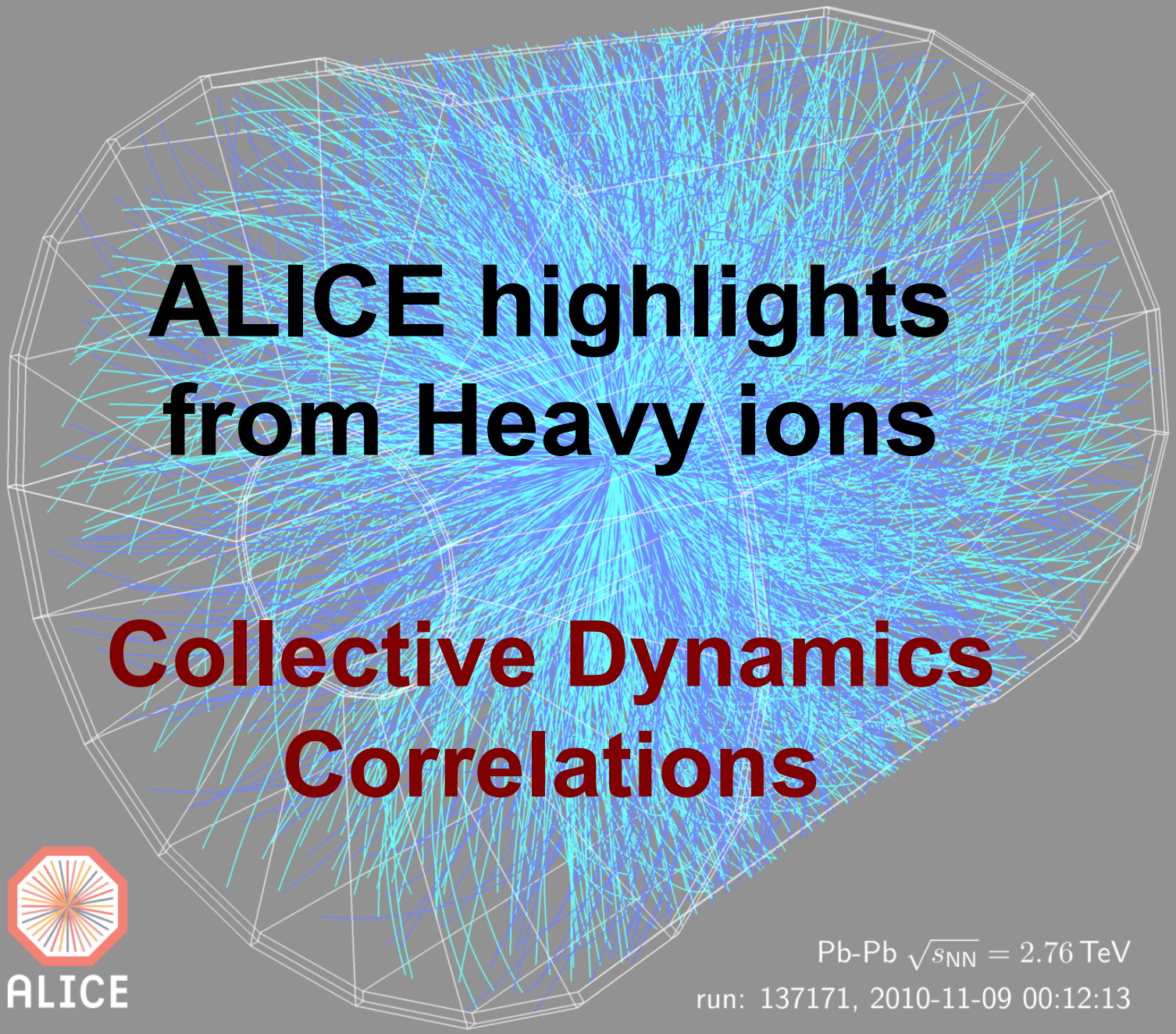
- **Cold (+ Hot?) Matter Effects:**
  - ✓ Q_{pPb} of J/ψ and ψ(2S)
- **Collectivity in p–Pb:**
  - ✓ F–C correlation and Forward muon v_2
- **Event activities:**
  - ✓ HF production
  - ✓ strangeness production





ALICE highlights from Heavy ions

Collective Dynamics Correlations

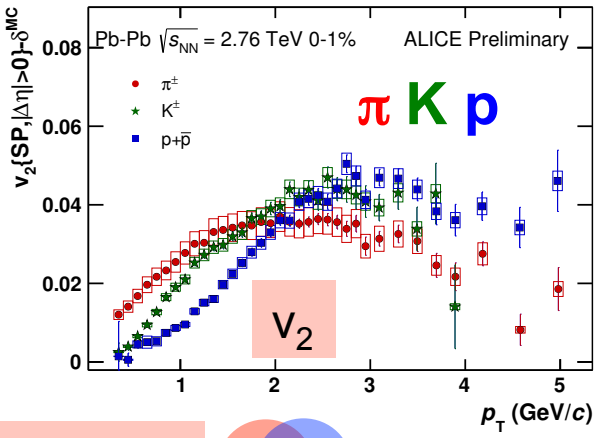


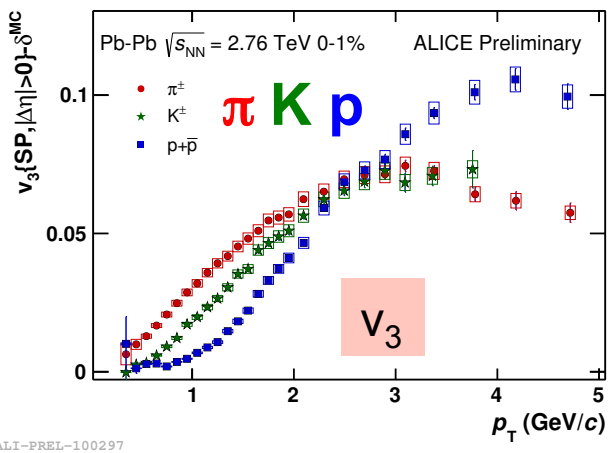
ALICE

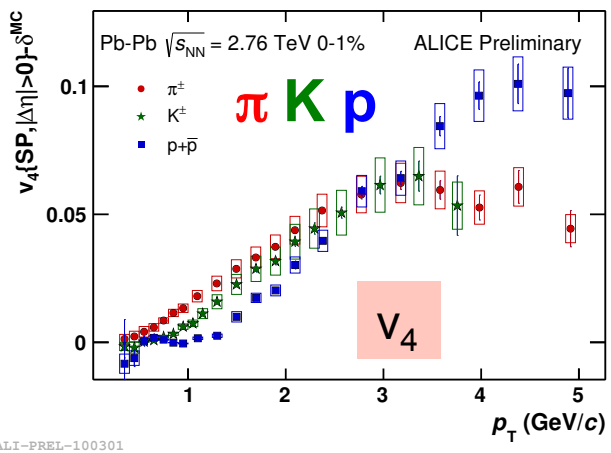
π, K, and Proton v_n vs. p_T

N. Mohammadi (Wed. AM)

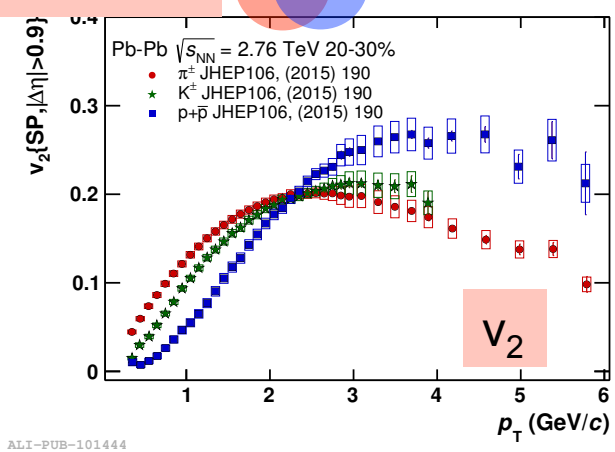
0–1%

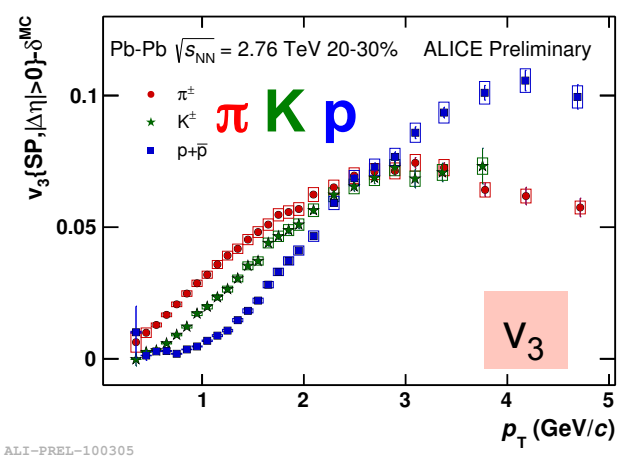


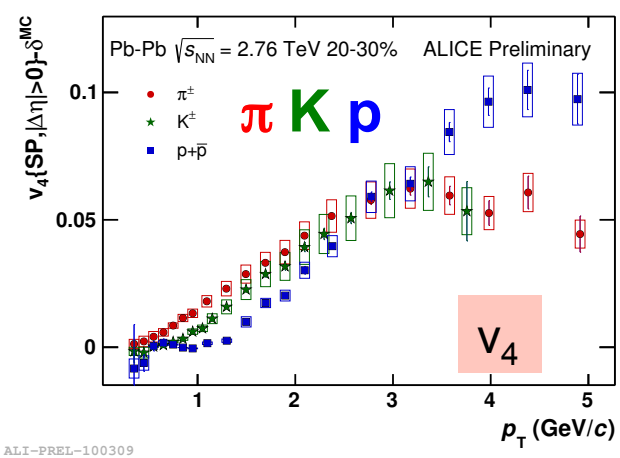




20–30%





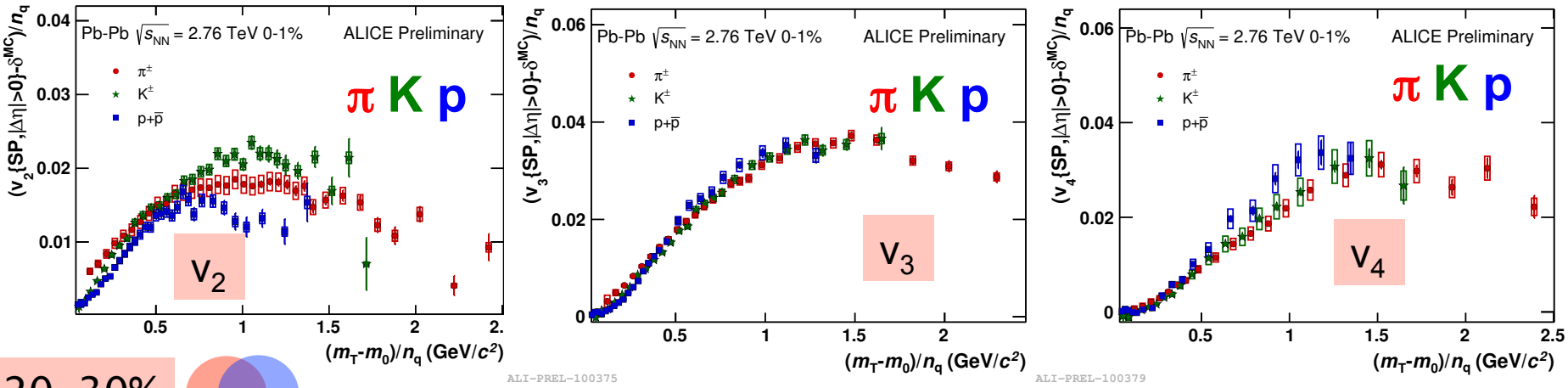


- For p_T<2 GeV/c, mass ordering is visible for all of v_n and seems less visible for higher v_n

KE_T/n_q Scaling

N. Mohammadi (Wed. AM)

0–1%



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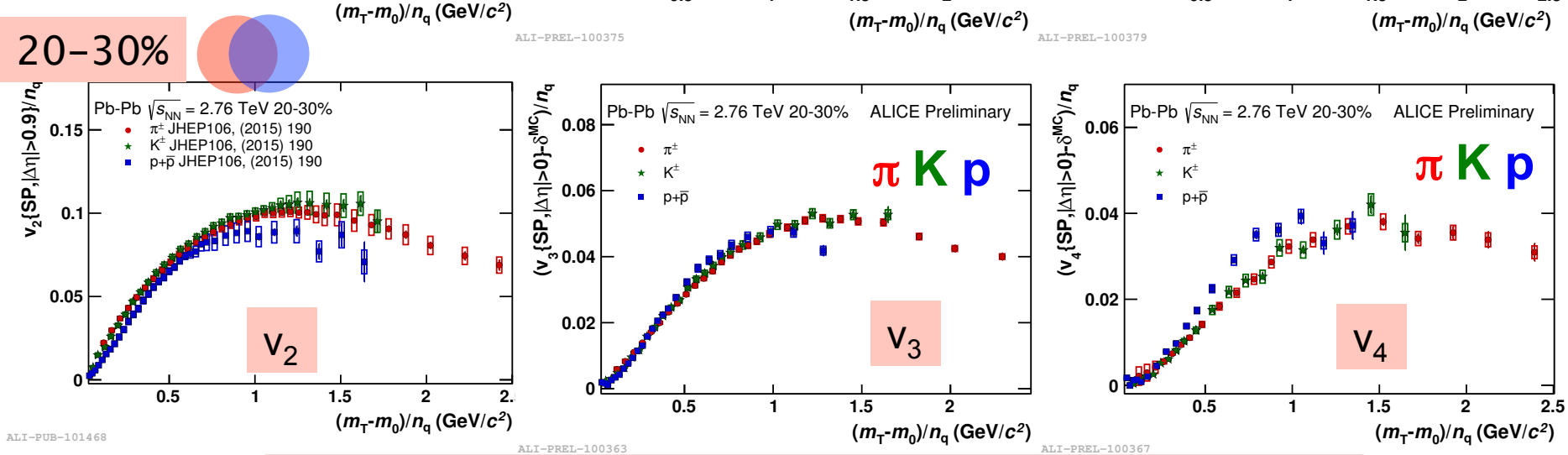
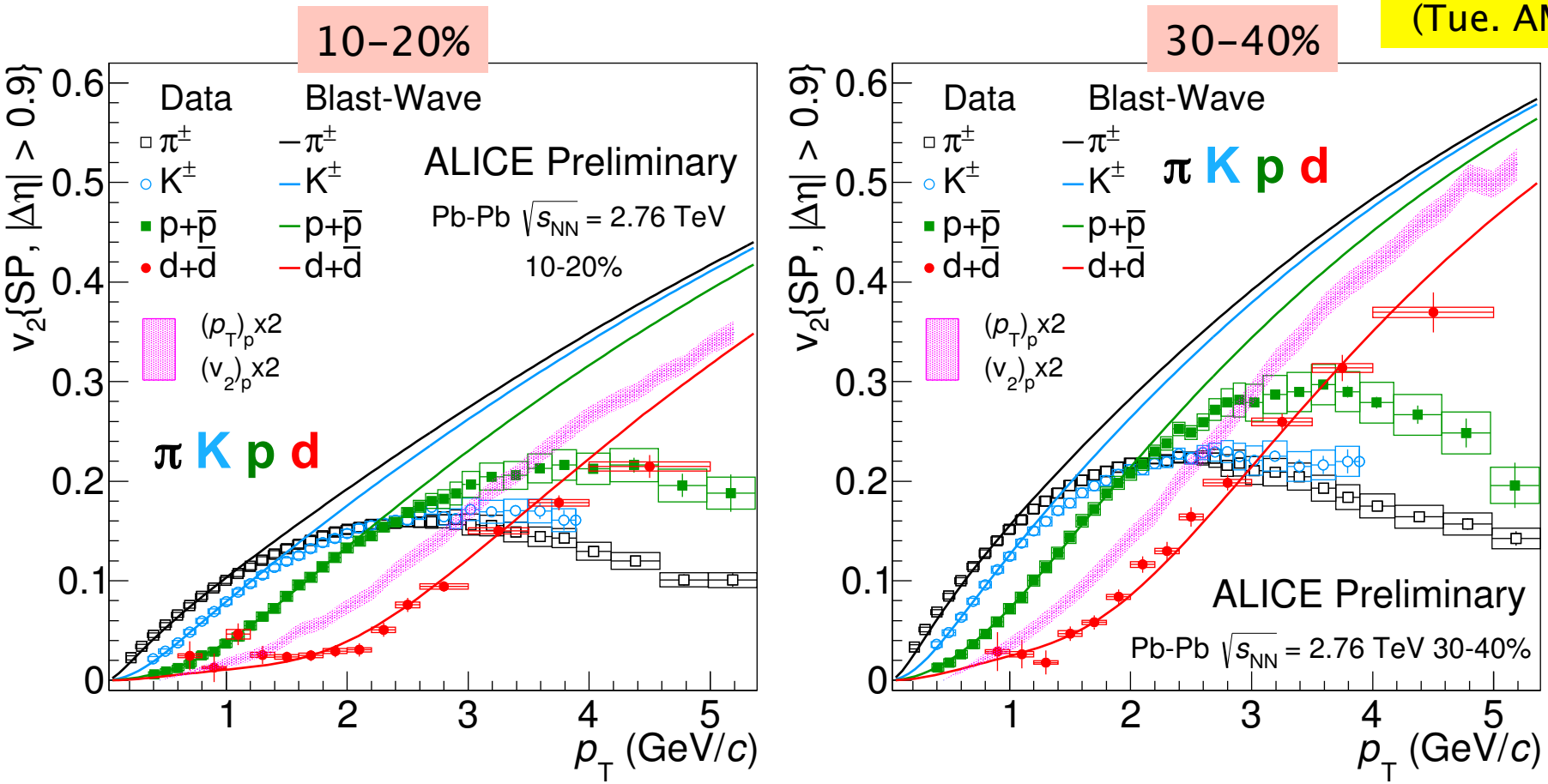


- KE_T/n_q scaling works differently for different v_n and works better for v_3

Deuteron v_2 vs. p_T

R. Lea
(Tue. AM)



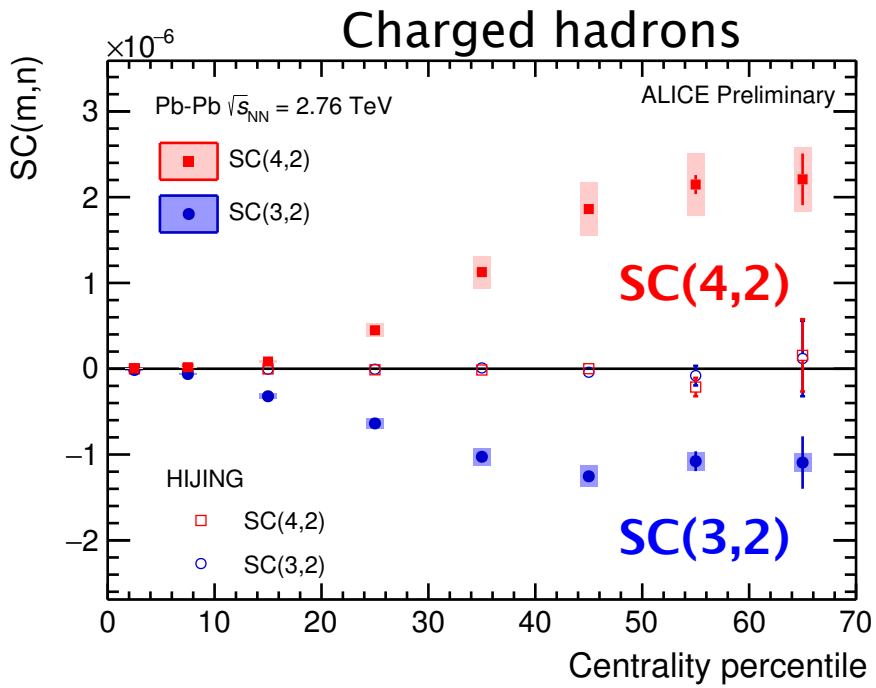
- Deuteron v_2 is well described by Blast-wave model
- Simple coalescence estimated by proton v_2 ($=2v_2(2p_T)$) doesn't work for deuteron v_2

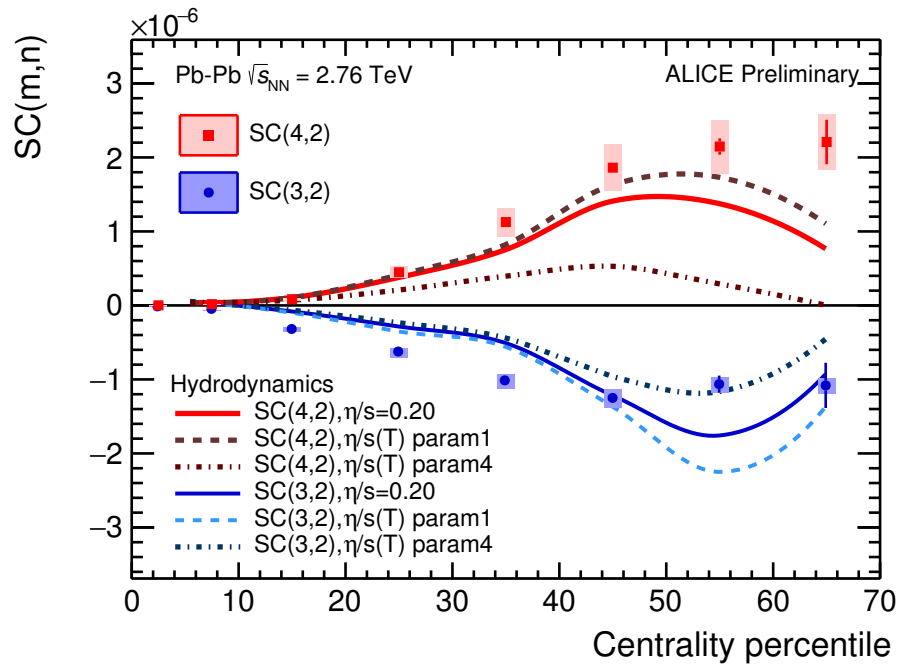
Flow Harmonics Correlations

Y. Zhou (Wed. AM)

- Correlations between different order flow harmonics.

$$SC(m,n) = \langle\langle \cos(m\varphi_1+n\varphi_2-m\varphi_3-n\varphi_4)\rangle\rangle_c = \langle v_n^2 v_m^2\rangle - \langle v_n^2\rangle\langle v_m^2\rangle$$

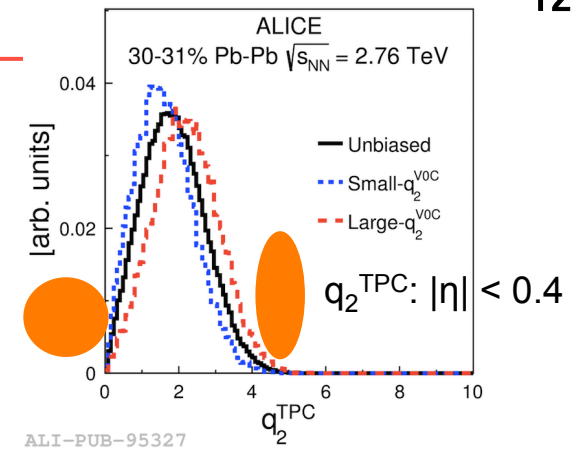




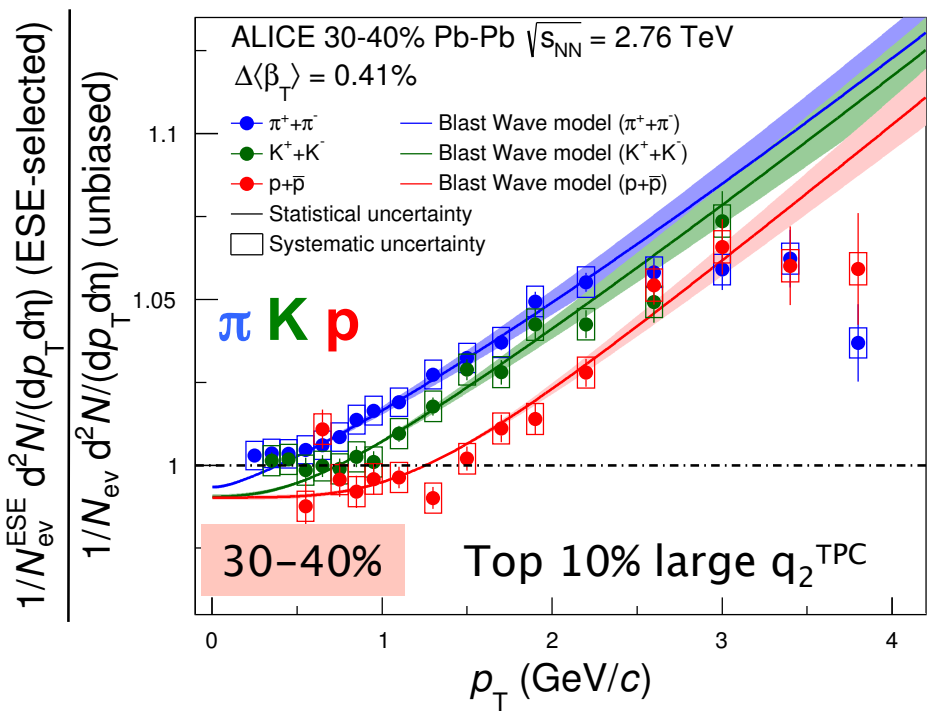
- (anti-)correlations between v_2 and v_4 (v_3) are observed
- Non-flow effects studied by HIJING show no correlations
- These measurements provide further constraints on medium η/s and Initial conditions

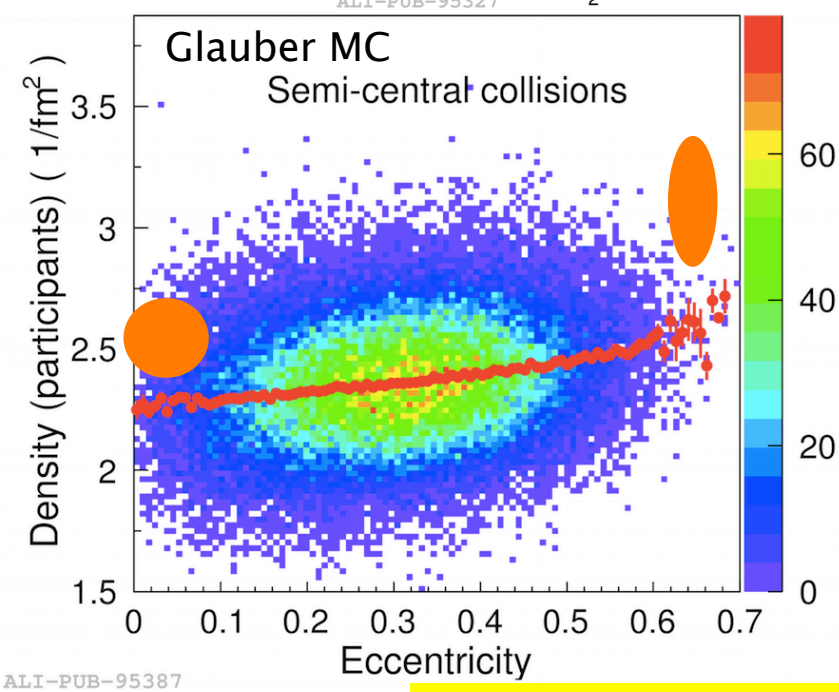
ESE and PID Spectra

- Split events by q_2^{TPC}, q_2^{V0C} vector
- PID spectra in $0.5 < |\eta| < 0.8$



ALICE, arXiv:1507.06194



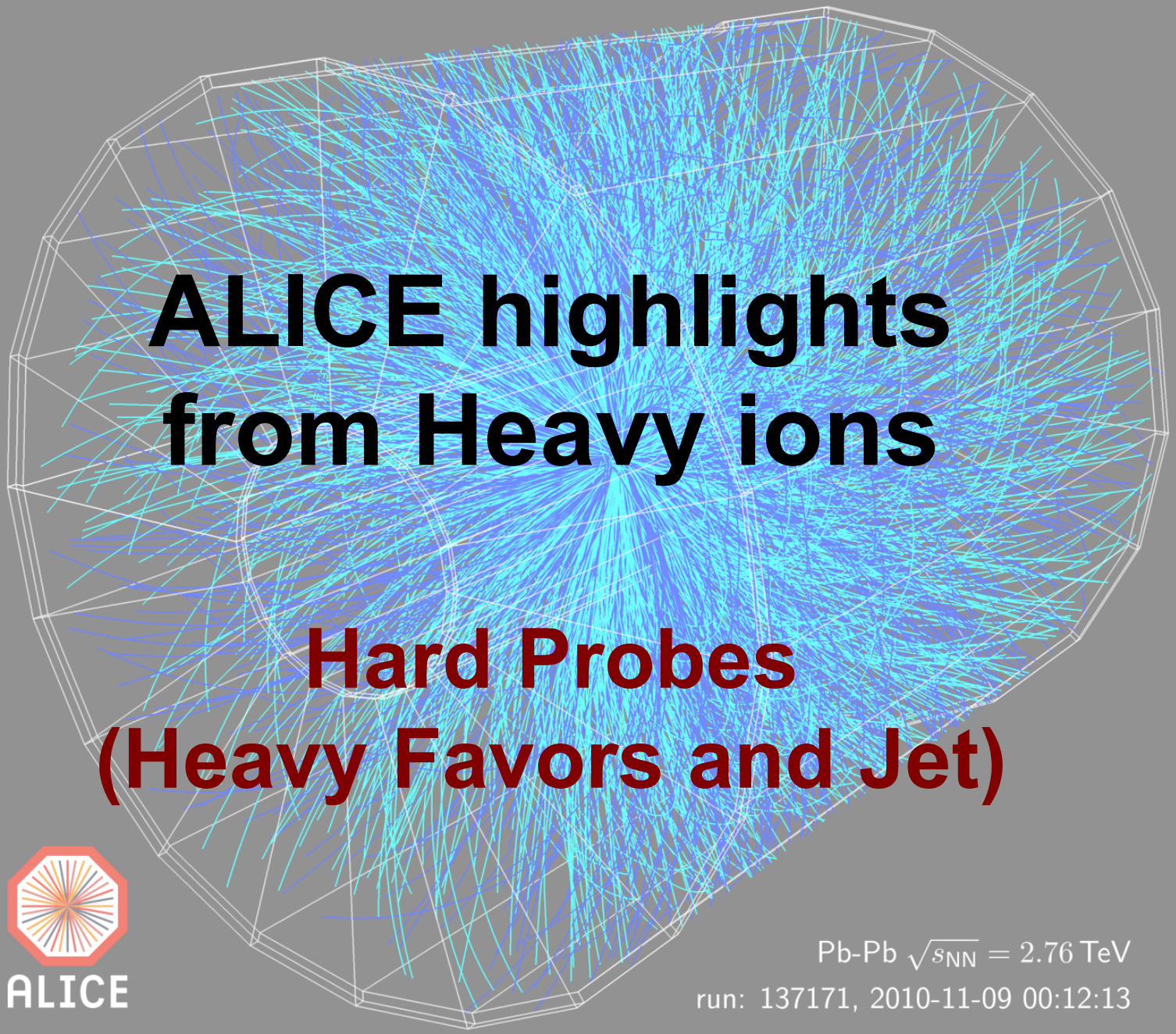


A. Timmins (Tue. AM)

- Spectra in top 10% large q_2 events get harder.
- BW fitting shows larger radial flow
- Radial flow correlates with eccentricities
  - ✓ Weak correlation between eccentricities and participant densities

ALICE highlights from Heavy ions

Hard Probes (Heavy Favors and Jet)



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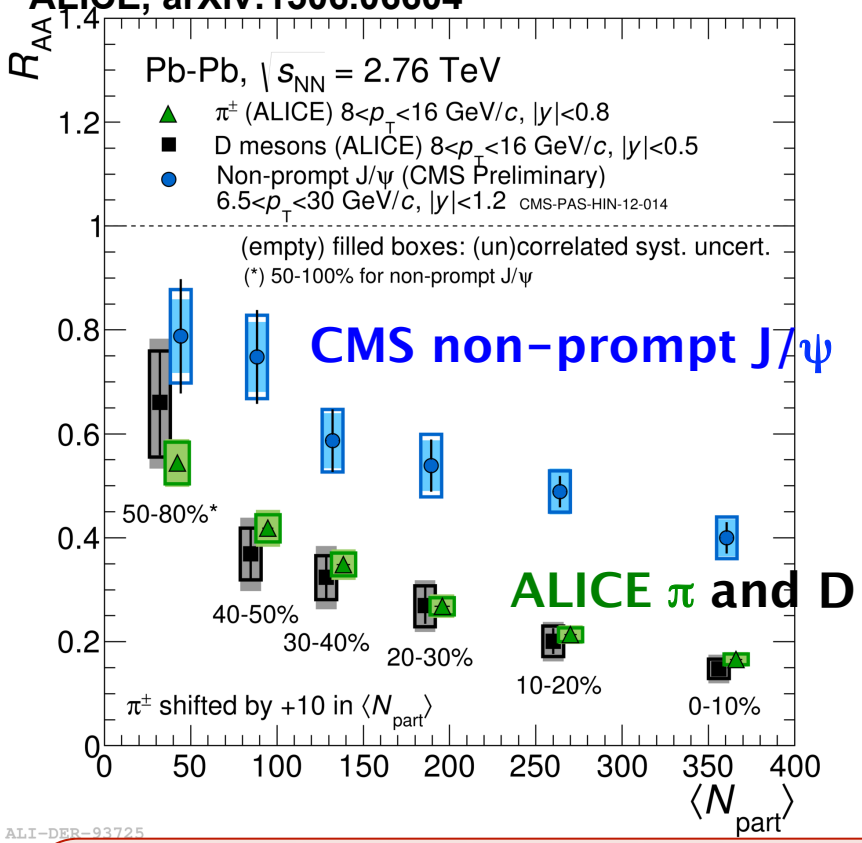
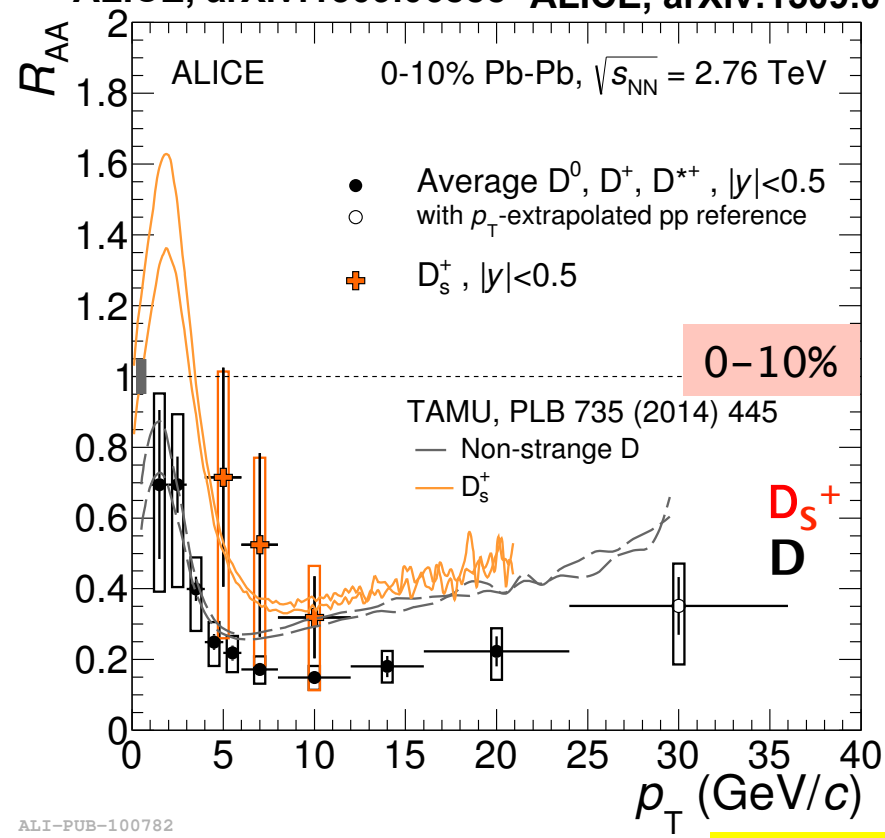
R_{AA} of D, D_s^+, and non-prompt J/ψ

ALICE, arXiv:1506.06604



ALICE, arXiv:1509.06888 ALICE, arXiv:1509.07287



A.Dubla (Mon. PM)

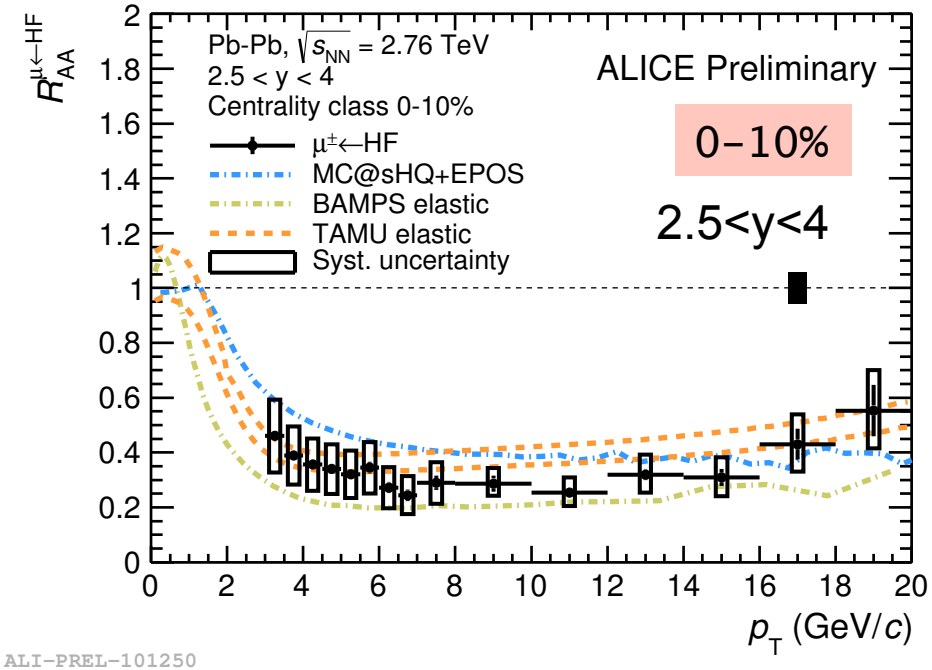
- R_{AA} of D meson is much smaller than R_{AA} of non-prompt J/ψ
- Similar R_{AA} between π and D
  - ✓ $\Delta Eg > \Delta Eu,d,s > \Delta Ec$ + different shape of the parton p_T spectra + different parton fragmentation function

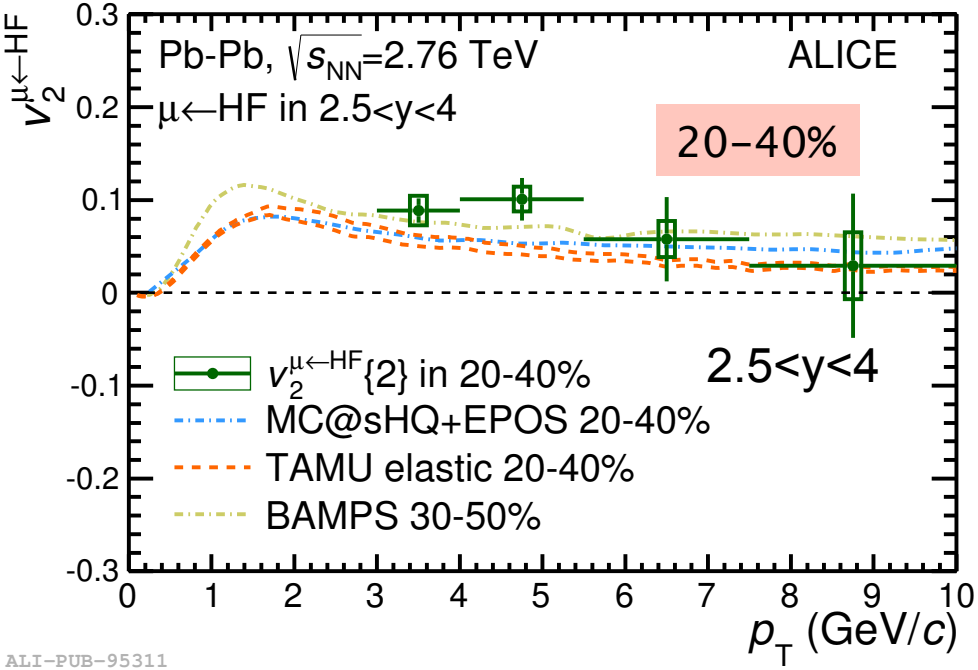
Djordjevic: PLB 737 (2014) 298

- Hint of less suppression of D_s^+ at intermediate p_T

Heavy Flavor muon R_{AA} and v_2

ALICE, arXiv:1507.03134



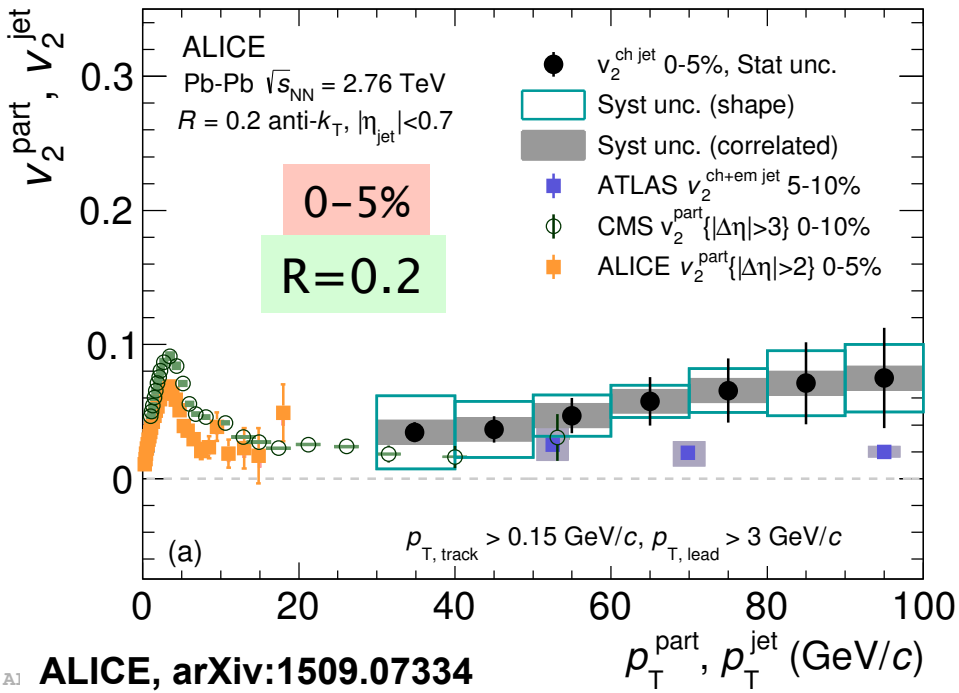


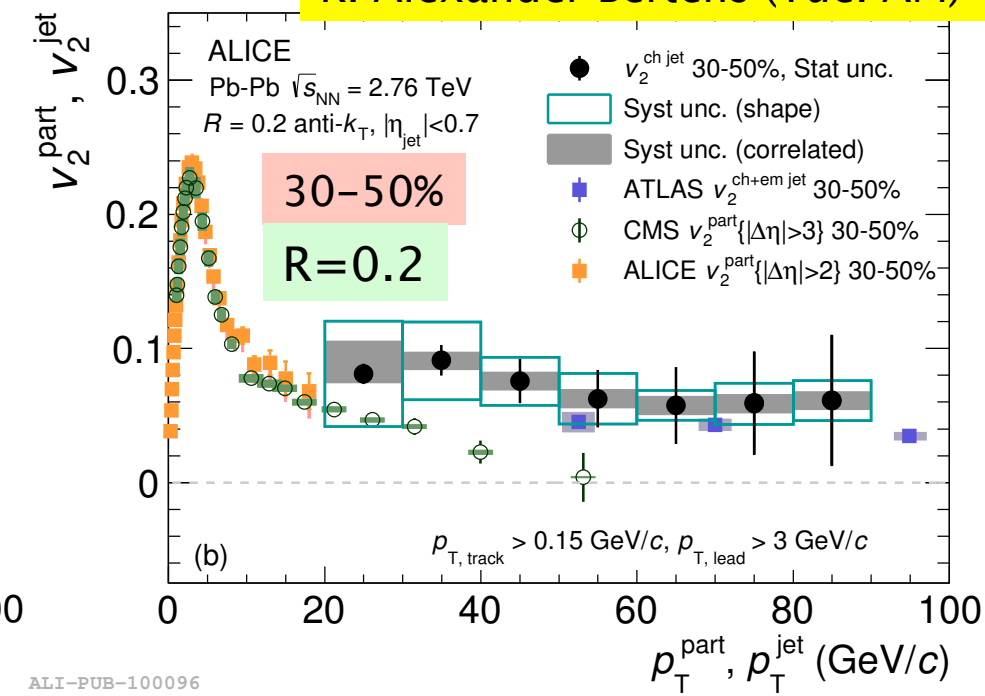
A. Dubla

- Forward muon R_{AA} measurement extended up to 20 GeV
  - ✓ W contribution subtracted
- $R_{AA}^{\mu\leftarrow HF}$~0.3 ($6<p_T<16$ GeV/c) between R_{AA}^{D}~0.2 and $R_{AA}^{\text{non prompt } J/\psi}$~0.4
- R_{AA} and v_2 are described by transport model calculations

Charged Jet v_2

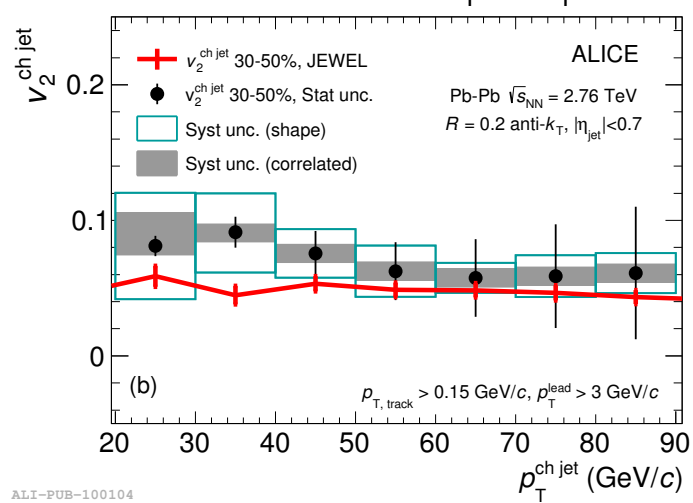
R. Alexander Bertens (Tue. AM)





ALICE, arXiv:1509.07334

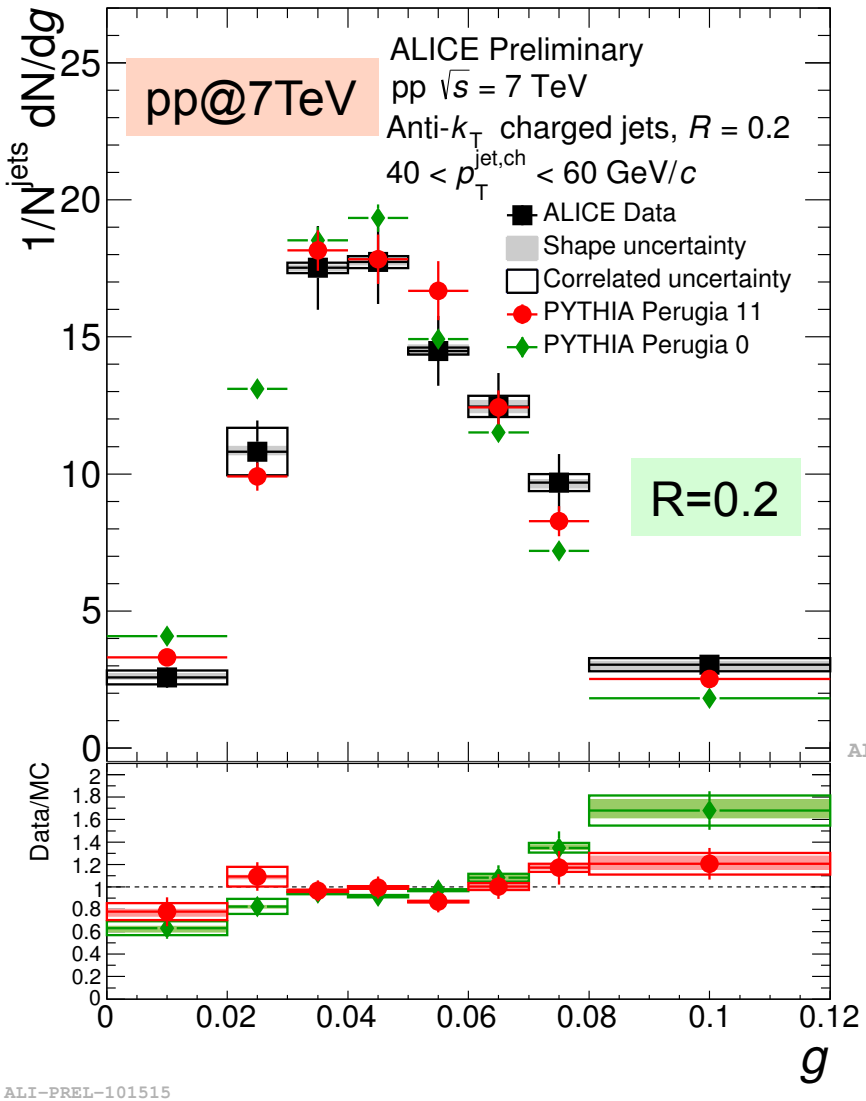
ALI-PUB-100096

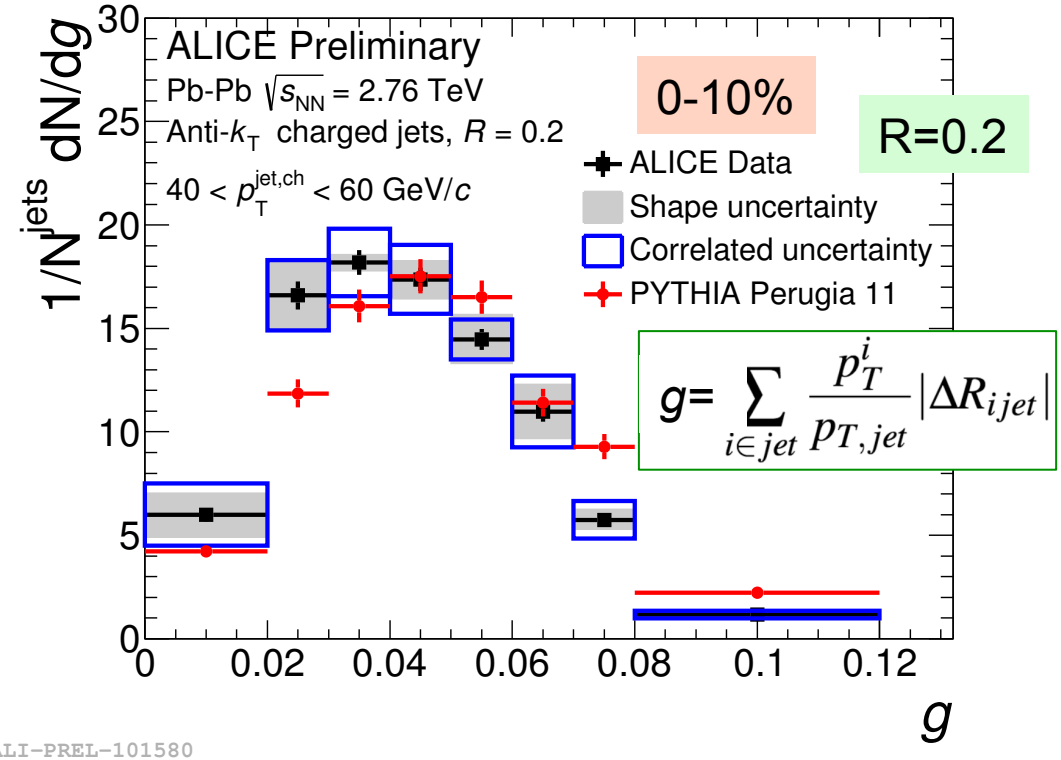


ALI-PUB-100104

- Jet v_2 is measured up to 100 GeV/c
- v_2 at 0–5% centrality
  - ✓ Consistent with zero v_2 within 1–2σ
- v_2 at 30–50% centrality
  - ✓ 3–4σ from v_2=0
  - ✓ Path length dependence of energy loss (consistent with JEWEL)

Shapes of Jet-core

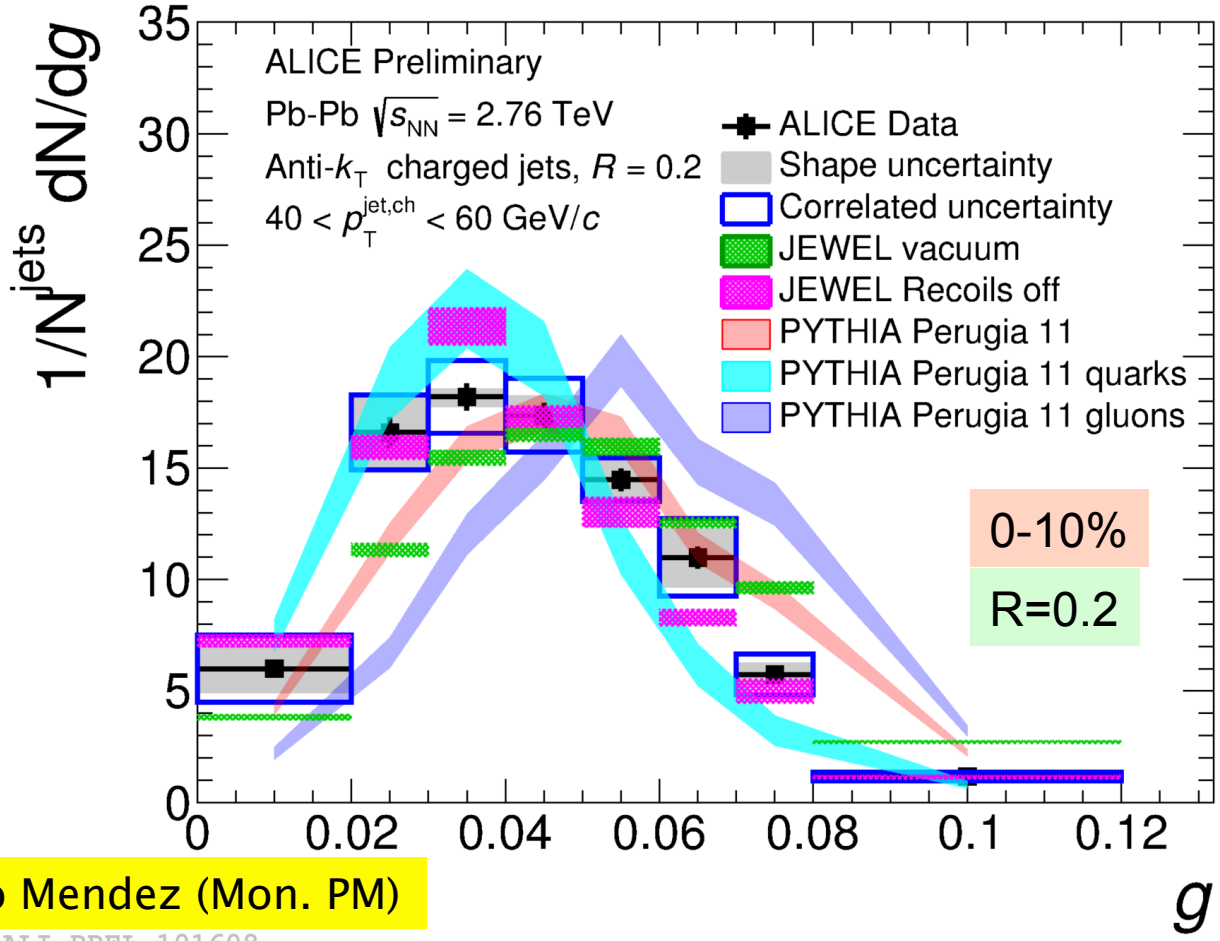




- New variables to characterize Jet-core shapes (constituents in R=0.2)
  - ✓ Radial moment (g), Dispersion in p_T, leading-sub leading p_T
- Consistent with PYTHIA in pp
- Core of Pb-Pb jets more collimated than pp jets

L. Cunqueiro Mendez (Mon. PM)

Comparison to models

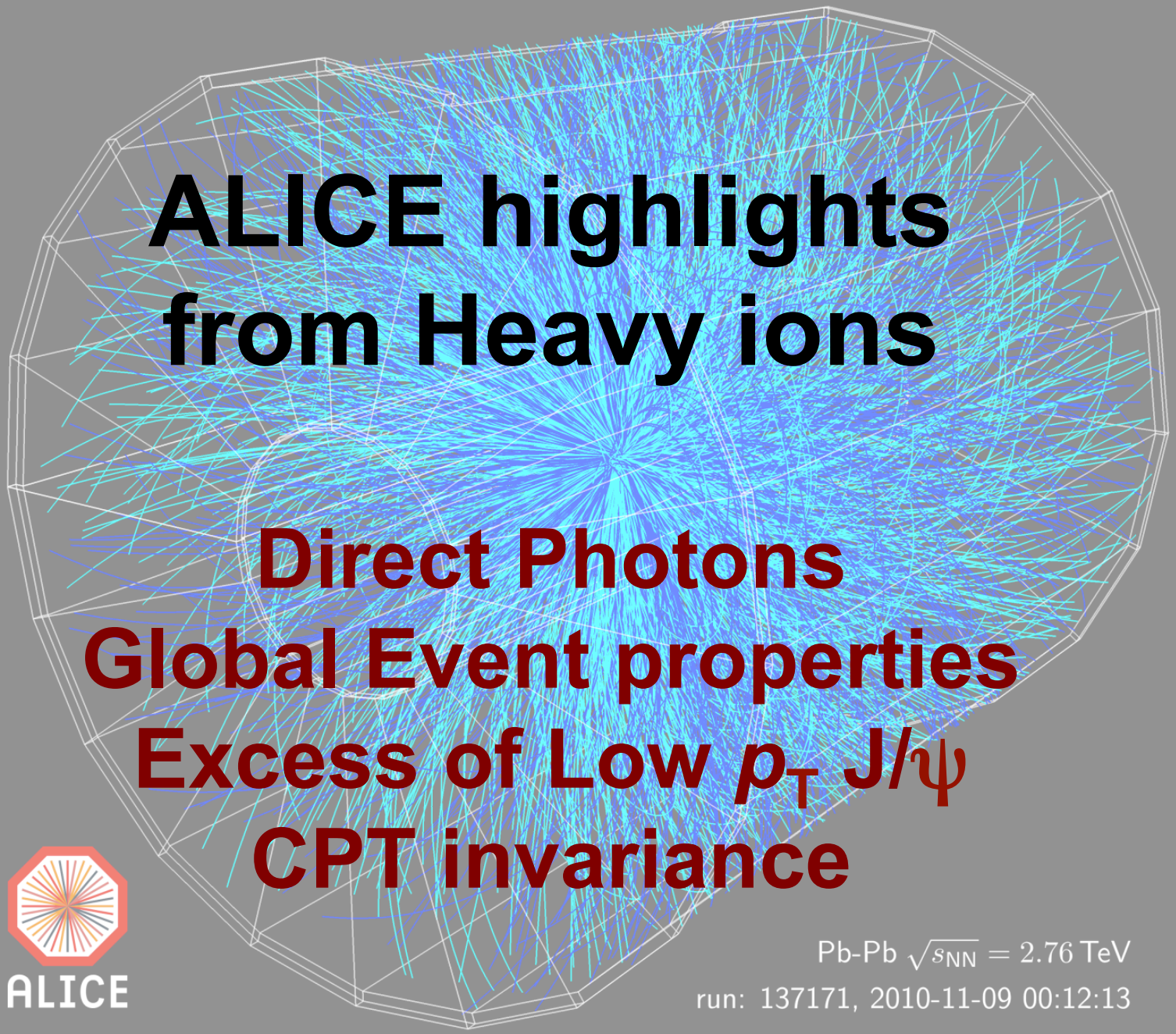


L. Cunqueiro Mendez (Mon. PM)

- Quark jets more collimated than gluon jets (PYTHIA)
- JEWEL is in qualitative agreement with data
- Hint of jet-core modifications in Pb-Pb

ALICE highlights from Heavy ions

Direct Photons
Global Event properties
Excess of Low p_T J/ψ
CPT invariance



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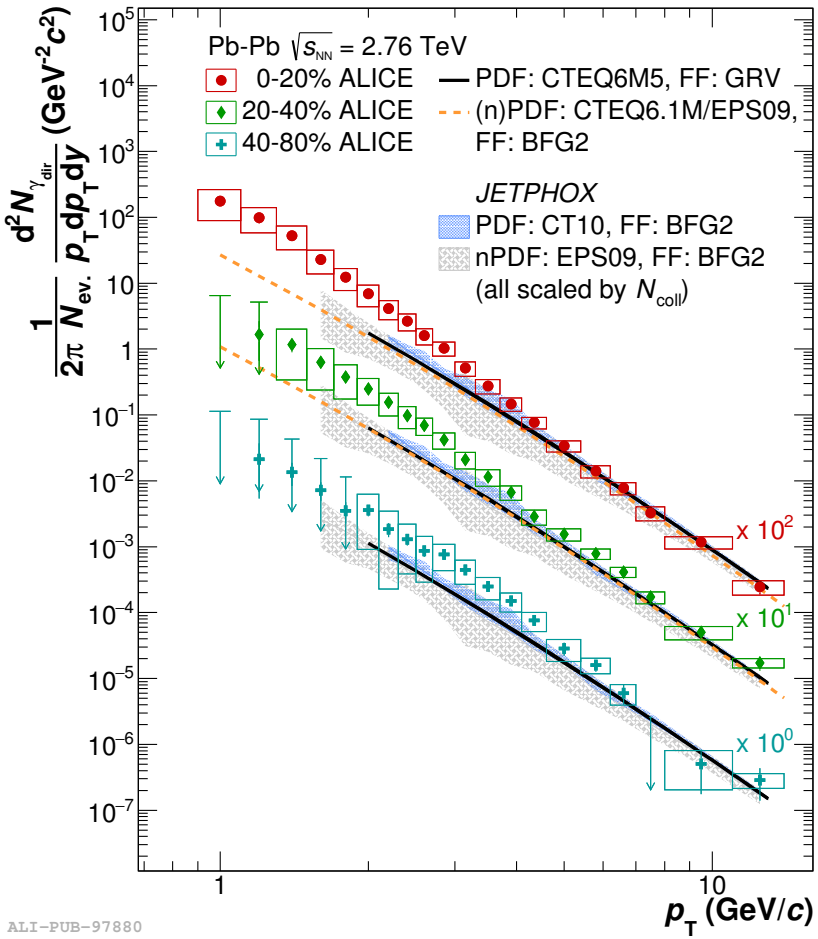
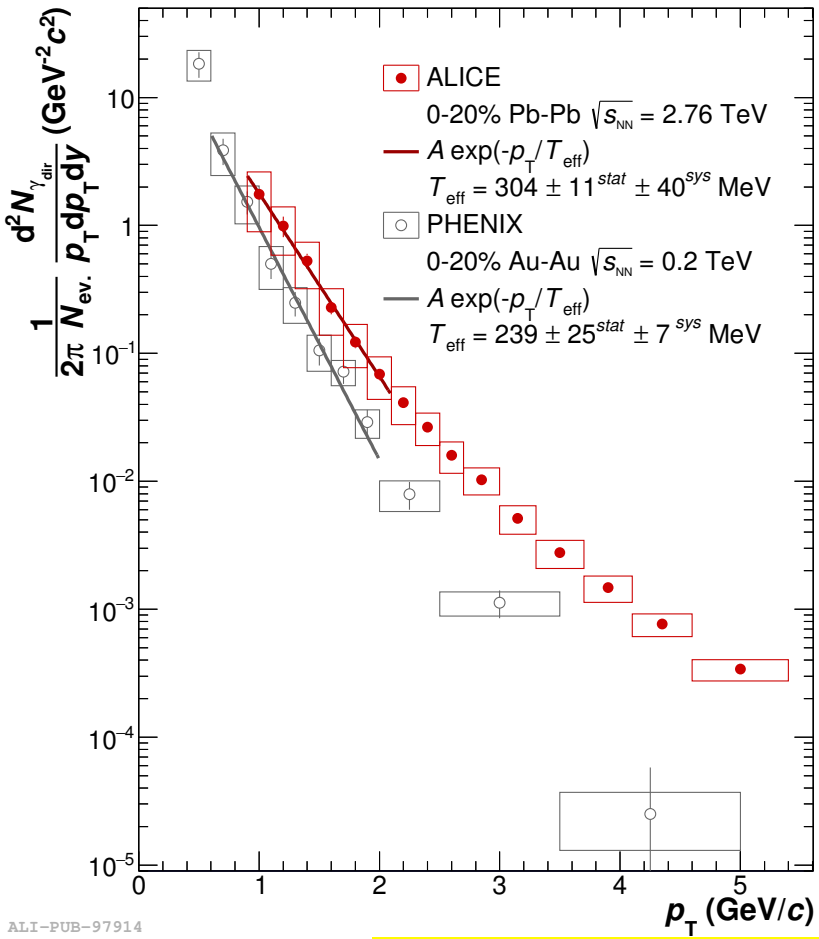
Direct Photons in Pb–Pb

ALICE, ArXiv:1509.07324





B. Sahlmueller (Wed. AM)

- 2.6σ excess in low p_T in 0–20% central
- T_{eff} = 304±11±40 MeV (30% larger than at RHIC)
  - ✓ Higher initial temperature and larger blue-shift by stronger radial flow

Longitudinal Asymmetry

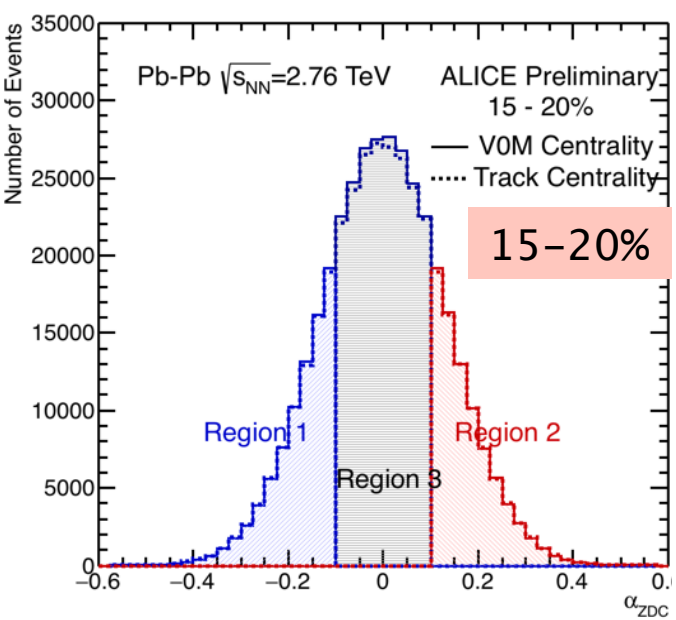
R. Raniwala (Mon. PM)

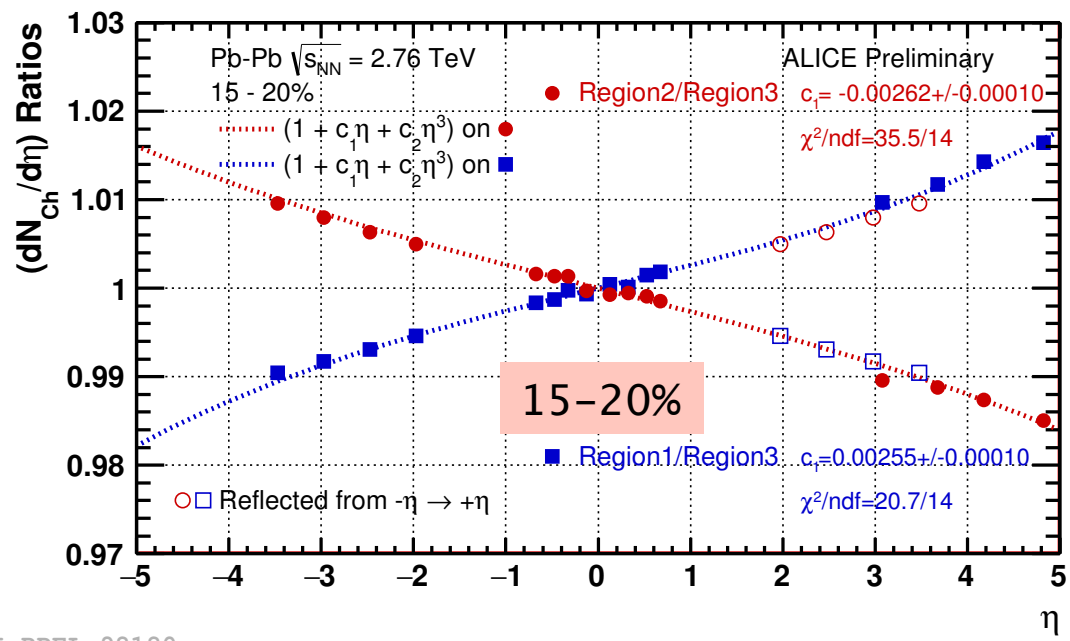
- Energy asymmetry between two ZDCs
  - ✓ Asymmetry in the number of participants
  - ✓ Shift of $dN_{ch}/d\eta$ distributions

$$\frac{(dN/dy)_2}{(dN/dy)_1} = \frac{Nexp(-\frac{(y-y_0)^2}{2\sigma_y^2})}{Nexp(-\frac{y^2}{2\sigma_y^2})}$$

$$\frac{(dN/dy)_2}{(dN/dy)_1} \approx 1 + \frac{yy_0}{\sigma_y^2}$$

α_{ZDC} = (ZNA – ZNC)/(ZNA + ZNC) → α_{part} = (A –B)/(A + B) → y_0 = 1⁄2 ln (A/B)





ALI-PREL-98180

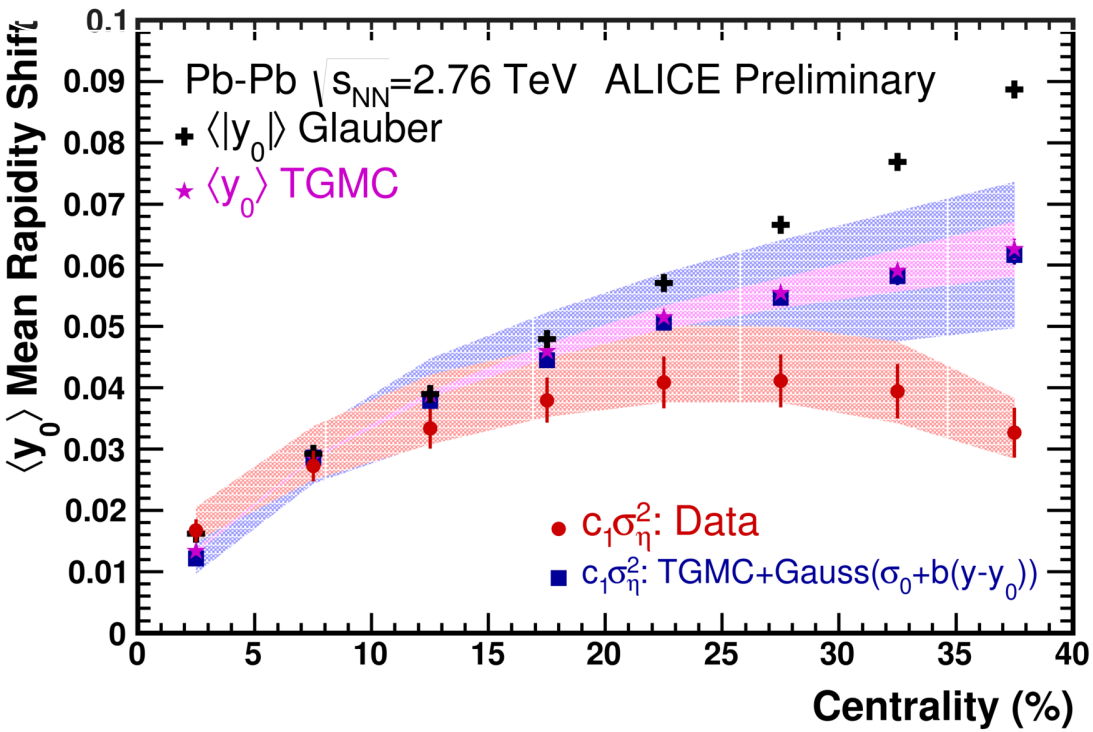
- The change in dN/dη distribution has been measured
  - ✓ This is related to the shift in the rapidity of participant zone
  - ✓ Ratio is fitted by $c_0+c_1\eta+c_3\eta^3$ (c_1 related to rapidity shift y_0)

Rapidity Shift $<y_0>$

R. Raniwala (Mon. PM)

$$\frac{(dN/dy)_2}{(dN/dy)_1} \approx 1 + \frac{yy_0}{\sigma_y^2}$$

- Estimation of $<y_0>$
  - ✓ Ratio of dN/dη ($y_0=c_1\sigma_\eta{}^2$) from data
  - ✓ Tuned Glauber MC
  - ✓ Ratio of dN/dη ($y_0=c_1\sigma_\eta{}^2$) from MC simulations
  - ✓ Glauber MC ($<|y_0|>$)

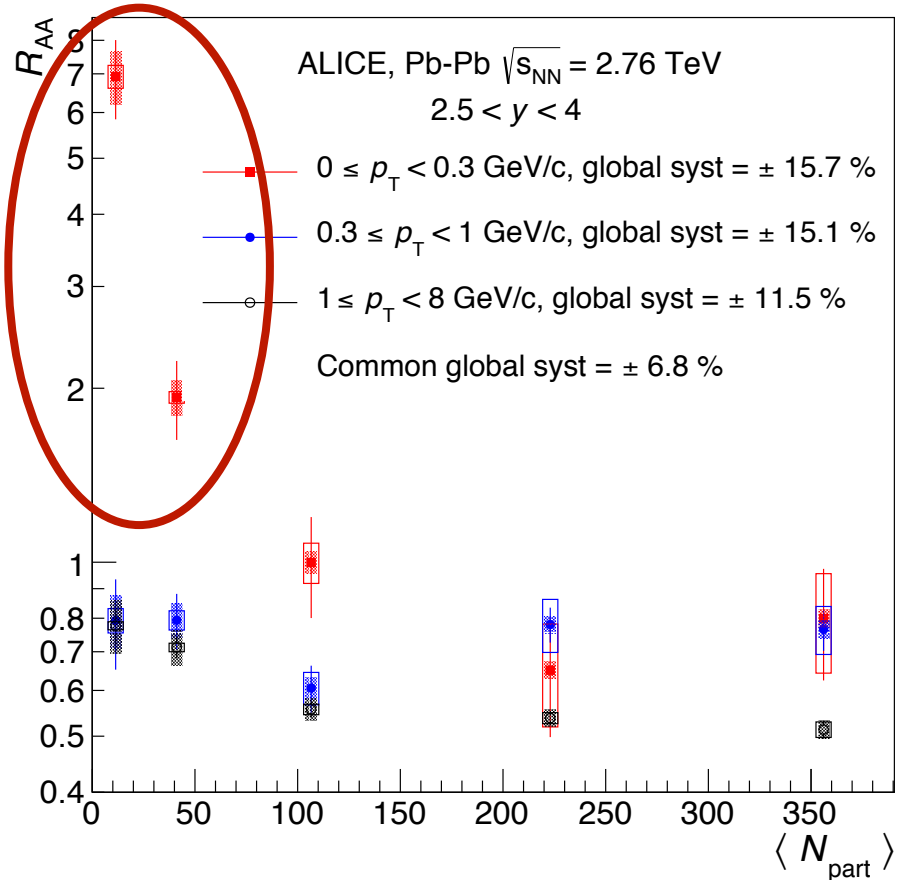


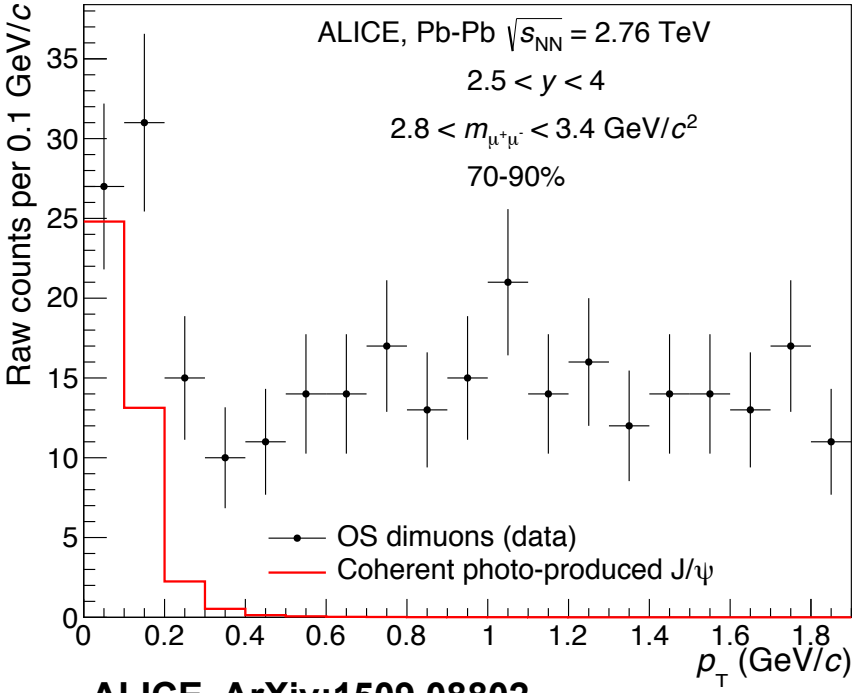
ALI-PREL-98188

- First results on estimates of rapidity shift in data
- Future prospects:
  - ✓ Use asymmetry as a classifier and study its effects on source size, flow and its fluctuations, F–B correlations, other global observables

Excess of Low p_T J/ψ

G. Martinez-Garcia (Wed. AM)





ALICE, ArXiv:1509.08802

- Strong excess of 0-0.3 GeV J/ψ in peripheral Pb-Pb collisions
  - ✓R_{AA} ~7 (2) for the 70-90% (50-70%) centrality
- Shape of STARLIGHT calculation in UPC in good qualitative agreement
  Photo-production of J/ψ in peripheral Pb-Pb collisions

Mass Difference of (anti-)Nuclei

CERN Press Release
Nature Physics (2015)
doi:10.1038/nphys3432

- Highest precision measurements of mass difference in the nuclei sector
- Improvement by 1-2 orders of magnitude compared to earlier measurements
- Constraint on CPT symmetry violation improved by a factor 2 for deuteron. First measurement of Δε for (anti-)^{3}He

Mass difference

$$\frac{\Delta\mu_{d\bar{d}}}{\mu_d} = [0.9 \pm 0.5(\text{stat.}) \pm 1.4(\text{syst.})] \times 10^{-4}$$

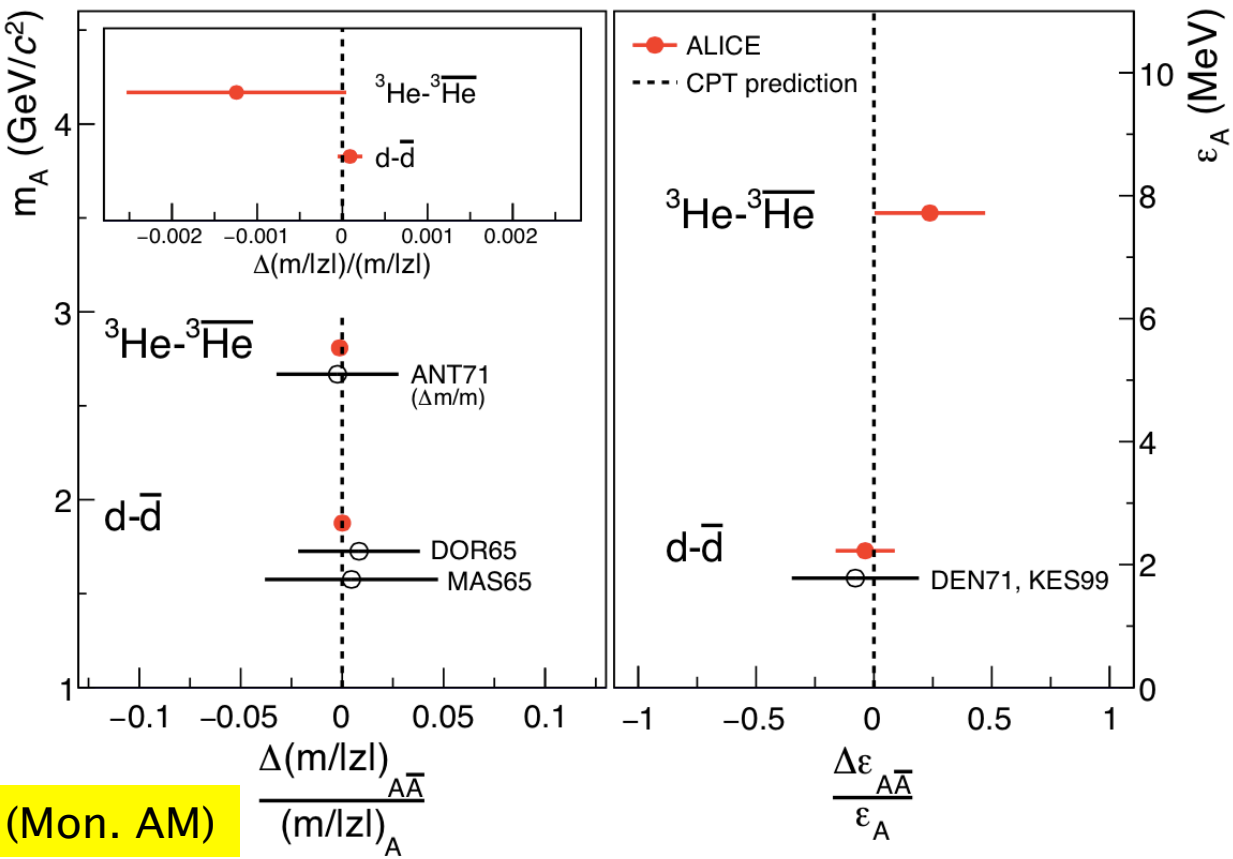
$$\frac{\Delta\mu_{^3\text{He}^3\overline{\text{He}}}}{\mu_{^3\text{He}}} = [-1.2 \pm 0.9(\text{stat.}) \pm 1.0(\text{syst.})] \times 10^{-3}$$

Binding energy difference

$$\Delta\varepsilon_{A\bar{A}} = Z\Delta m_{p\bar{p}} + (A-Z)\Delta m_{n\bar{n}} - \Delta m_{A\bar{A}}$$

$$\frac{\Delta\varepsilon_{d\bar{d}}}{\varepsilon_d} = -0.04 \pm 0.05\ (\text{stat.}) \pm 0.12\ (\text{syst.})$$

$$\frac{\Delta\varepsilon_{^3\text{He}^3\overline{\text{He}}}}{\varepsilon_{^3\text{He}}} = 0.24 \pm 0.16\ (\text{stat.}) \pm 0.18\ (\text{syst.})$$



N. Sharma (Mon. AM)

ALICE Highlights from p-Pb and pp collisions

Cold (+Hot?) Matter Effects
Collectivity
HF and strangeness vs. Event multiplicities

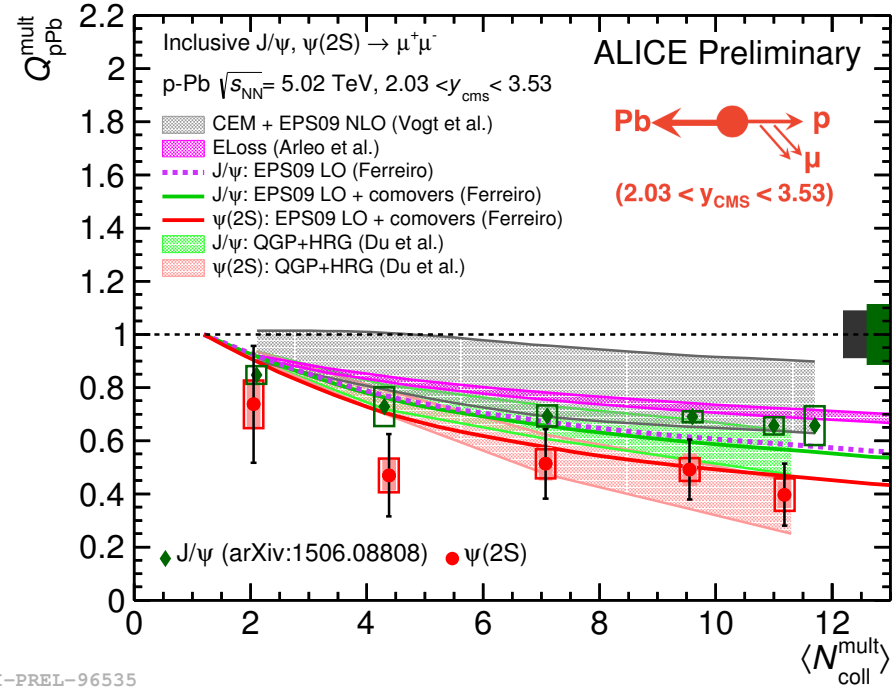
ALICE

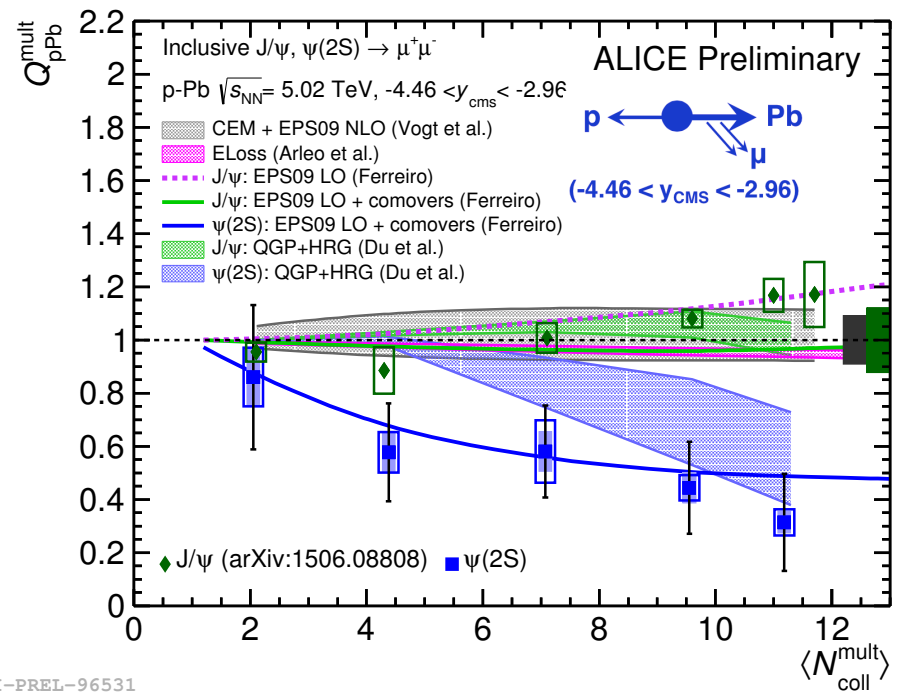
pp 7 TeV (June 2010)

J/ψ and ψ(2S) Q_{pPb}

M. Leoncino (Mon. AM)

J/ψ: ALICE, arXiv:1506.08808



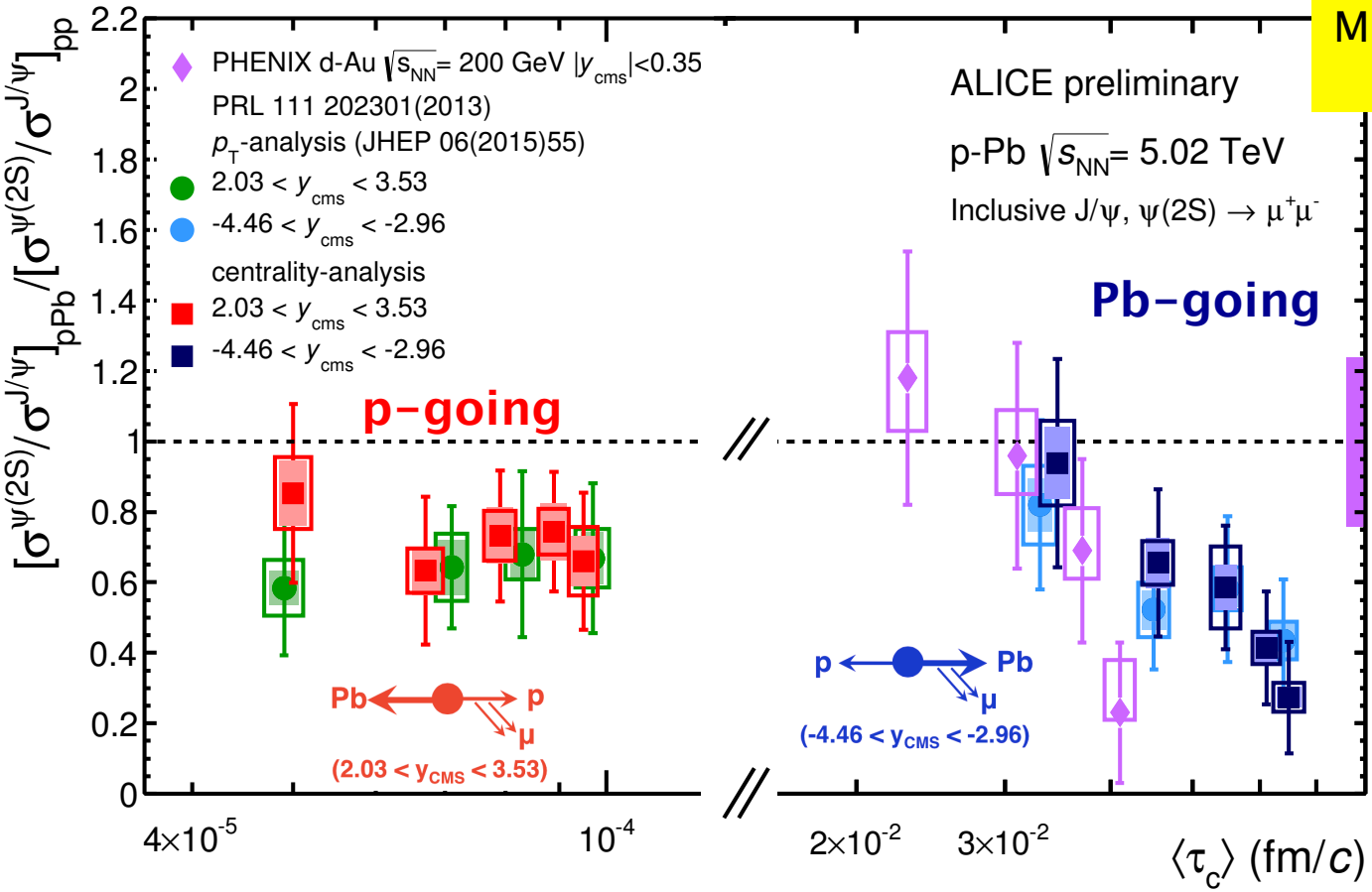


- Centrality based on ZNA (least biased estimator)
- J/ψ suppression at forward rapidity
  - ✓ Shadowing and E-Loss
- ψ(2S) is more suppressed at both rapidities
  - ✓ Shadowing and E-Loss only are not sufficient
  - ✓ Suppression by final state interactions

ALICE,
PRC 91, 064905, (2015)

Suppression vs. Crossing time

M. Leoncino (Mon. AM)



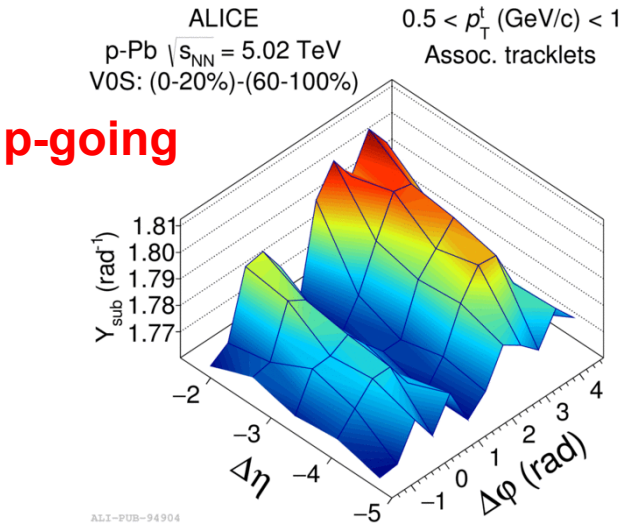
ALI-PREL-96723

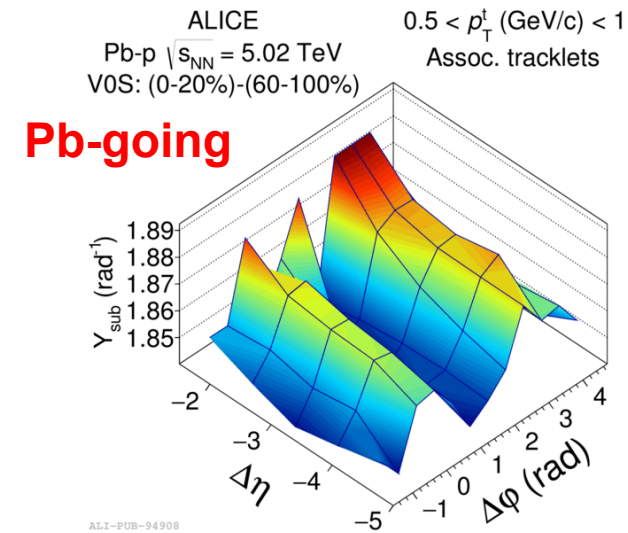
- Estimation of ccbar crossing time using Glauber model $\tau = \langle L \rangle / \beta_z \gamma$
- could be an indication of an effect related with break-up in the nucleus (even if $\tau_c < \tau_f$)

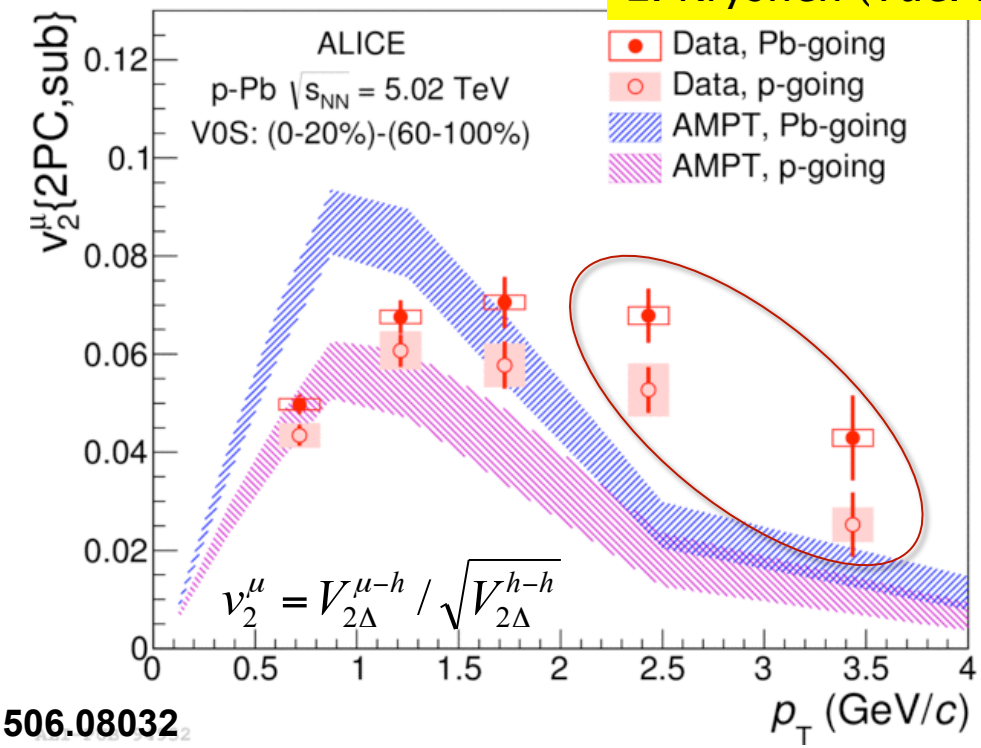
Forward Muon v_2 in p–Pb

E. Kryshen (Tue. PM)

fw. muon – midrapidity tracklet correlation (high–low mult.)





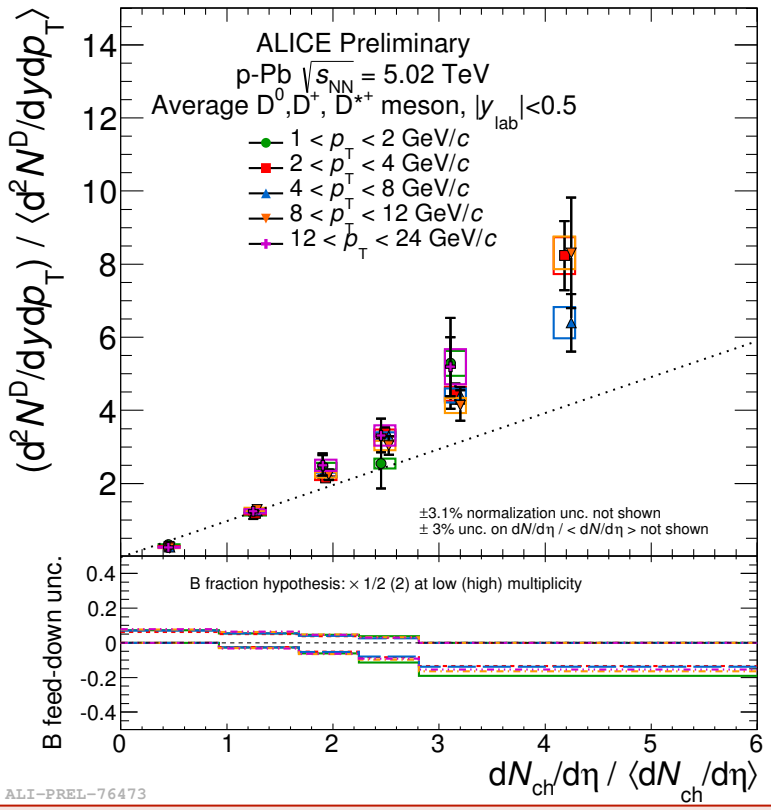


ALICE, arXiv:1506.08032

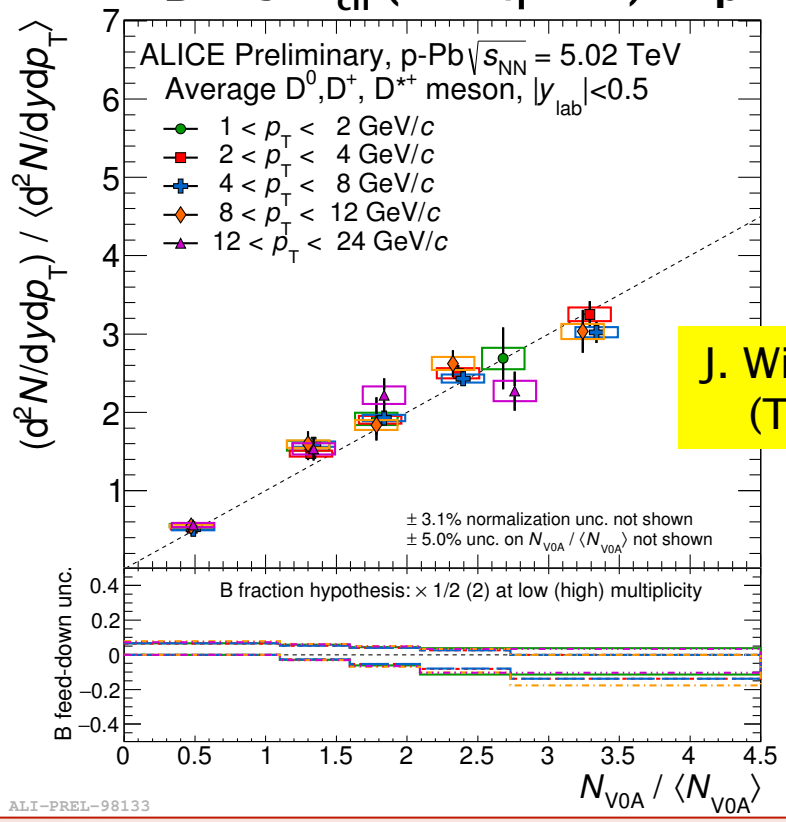
- Double ridge up to $\Delta\eta \sim 5$
- **v_2(Pb–going)>v_2(p–going)** as expected in AMPT and hydro
- v_2 at $p_T > 2$ GeV/c (>60% is HF→μ)
  - ✓ v_2 (heavy flavour) > 0 (as is seen in Pb–Pb)
  - ✓ Different composition of the parent distributions and their v_2

HF and Event Activities in p-Pb

D vs. N_{ch} ($|\eta|<1$) in p-Pb



D^0 vs. N_{ch} ($2.8<\eta<5.1$) in p-Pb

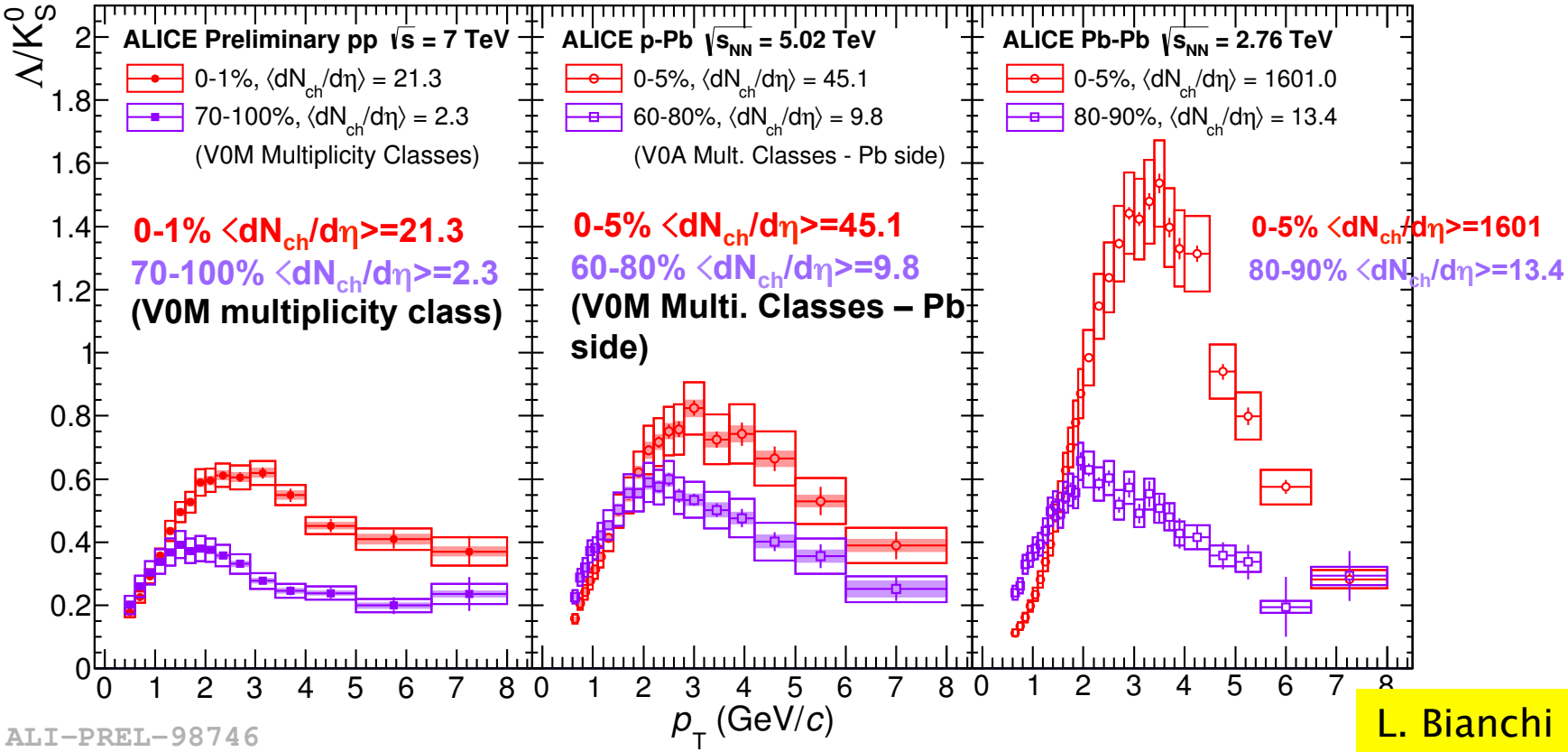


J. Wilkinson (Tue. AM)

- Self-normalized yield vs. Multiplicity from two estimators
  - ✓ Tracklets in SPD ($|\eta|<1$) and backword (Pb-going) multiplicity in V0A ($2.8<\eta<5.1$)
- ✓ Slight greater-than-linear increase with N_{ch} ($|\eta|<1$)
- ✓ Linear increase in measured multiplicity with V0A estimator.
  - ✓ **consistent with mid-rapidity result** in measured multiplicity interval

Λ/K^0_S vs. p_T in pp, p–Pb, and Pb–Pb

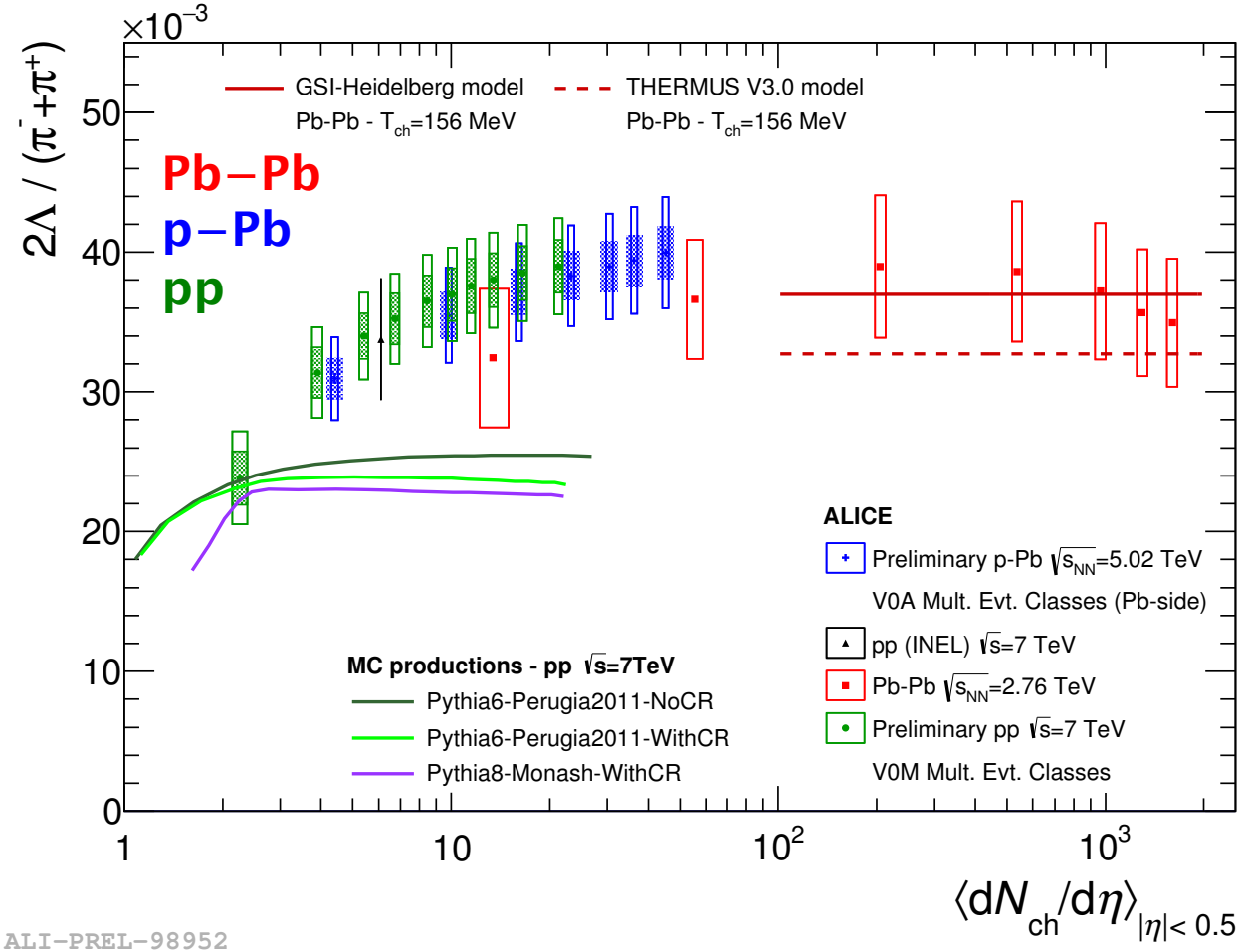
p-Pb, Pb-Pb: ALICE, PLB 728(2014) 25-38



L. Bianchi (Tue. PM)

- The ratio depends on the event multiplicity
- Trend in pp is qualitatively similar as in p–Pb and Pb–Pb
- The magnitude is smaller in pp with respect to p–Pb and Pb–Pb

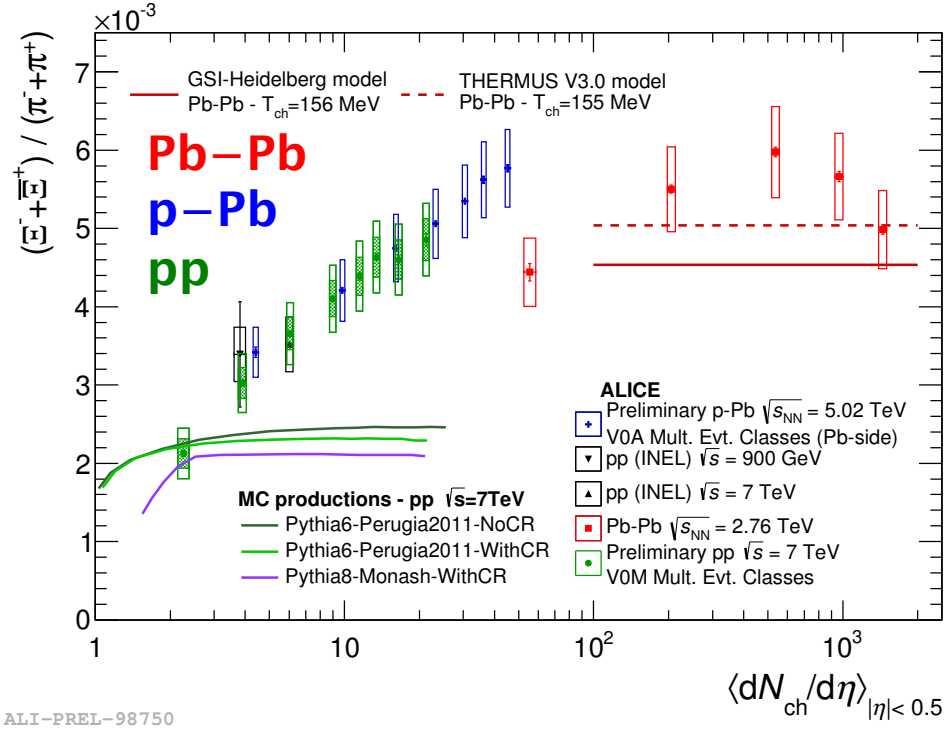
Λ/π vs. $dN_{ch}/d\eta$

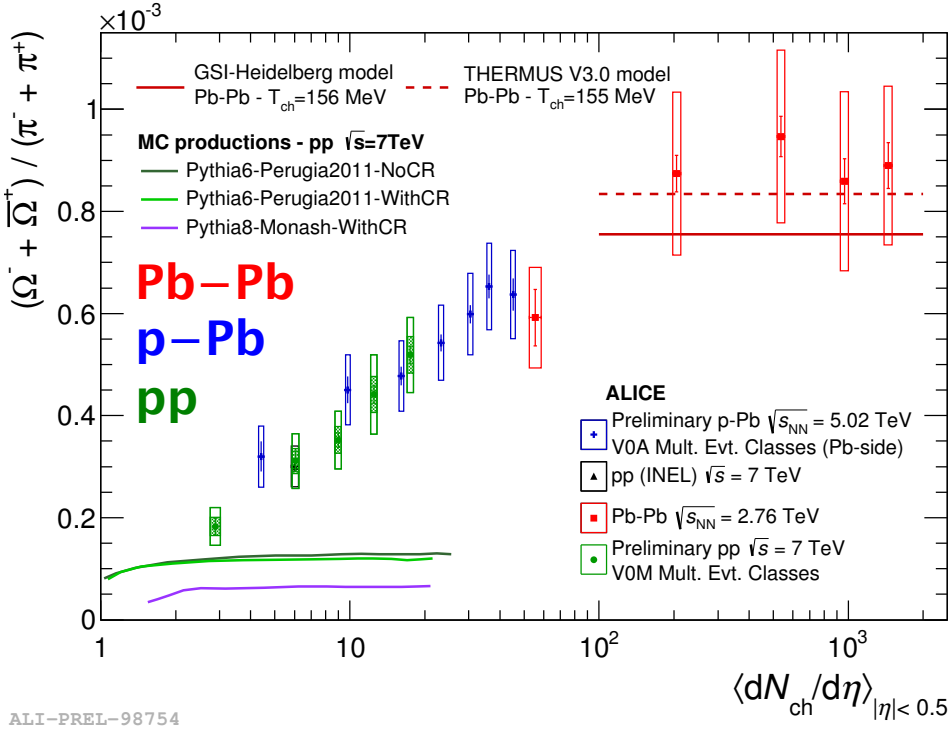


L. Bianchi (Tue. PM)

- Λ/π ratio reaches Grand Canonical limit in Pb-Pb
- Similar multiplicity dependence in pp and p-Pb
  - ✓ Neither PYTHIA6 nor 8 reproduce data in any of the tunes tested

Ξ/π and Ω/π vs. $dN_{ch}/d\eta$



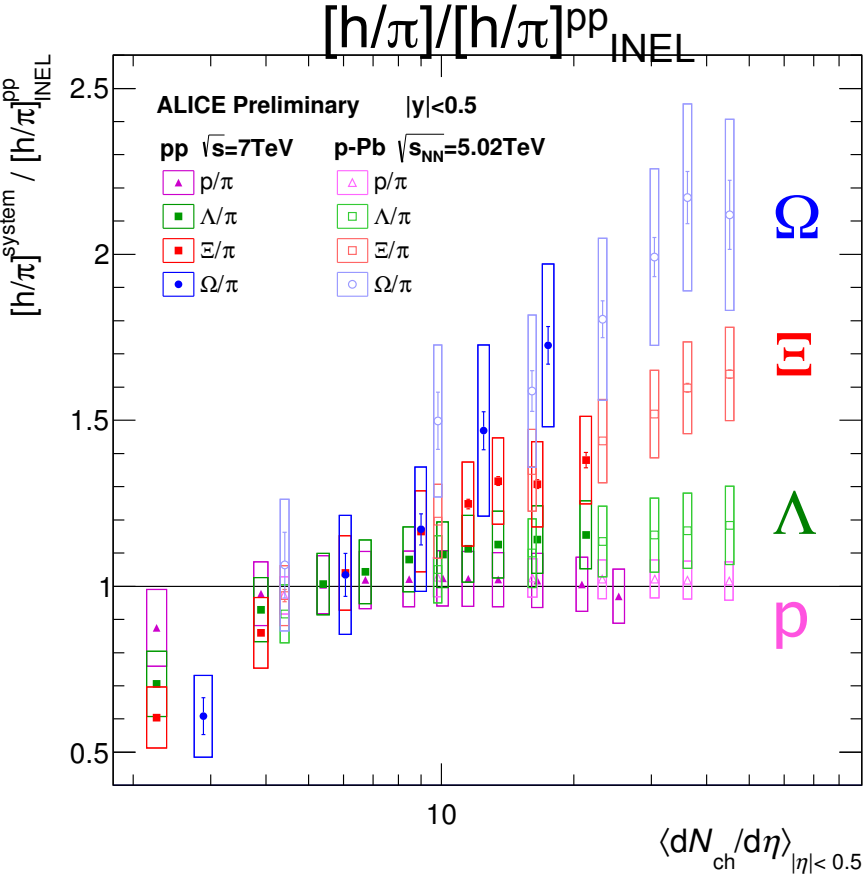


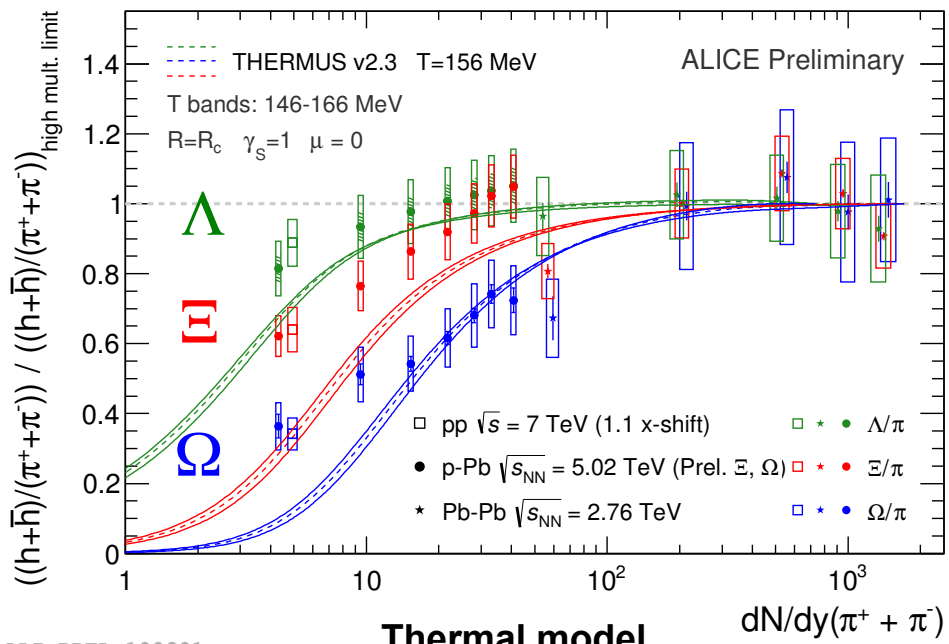
L. Bianchi
(Tue. PM)

- Ξ/π and Ω/π reach Grand Canonical limit in Pb–Pb
- Similar multiplicity dependence in pp and p–Pb
  - ✓ Neither PYTHIA6 nor 8 reproduce data in any of the tunes tested

Canonical Suppression

L. Bianchi (Tue. PM)

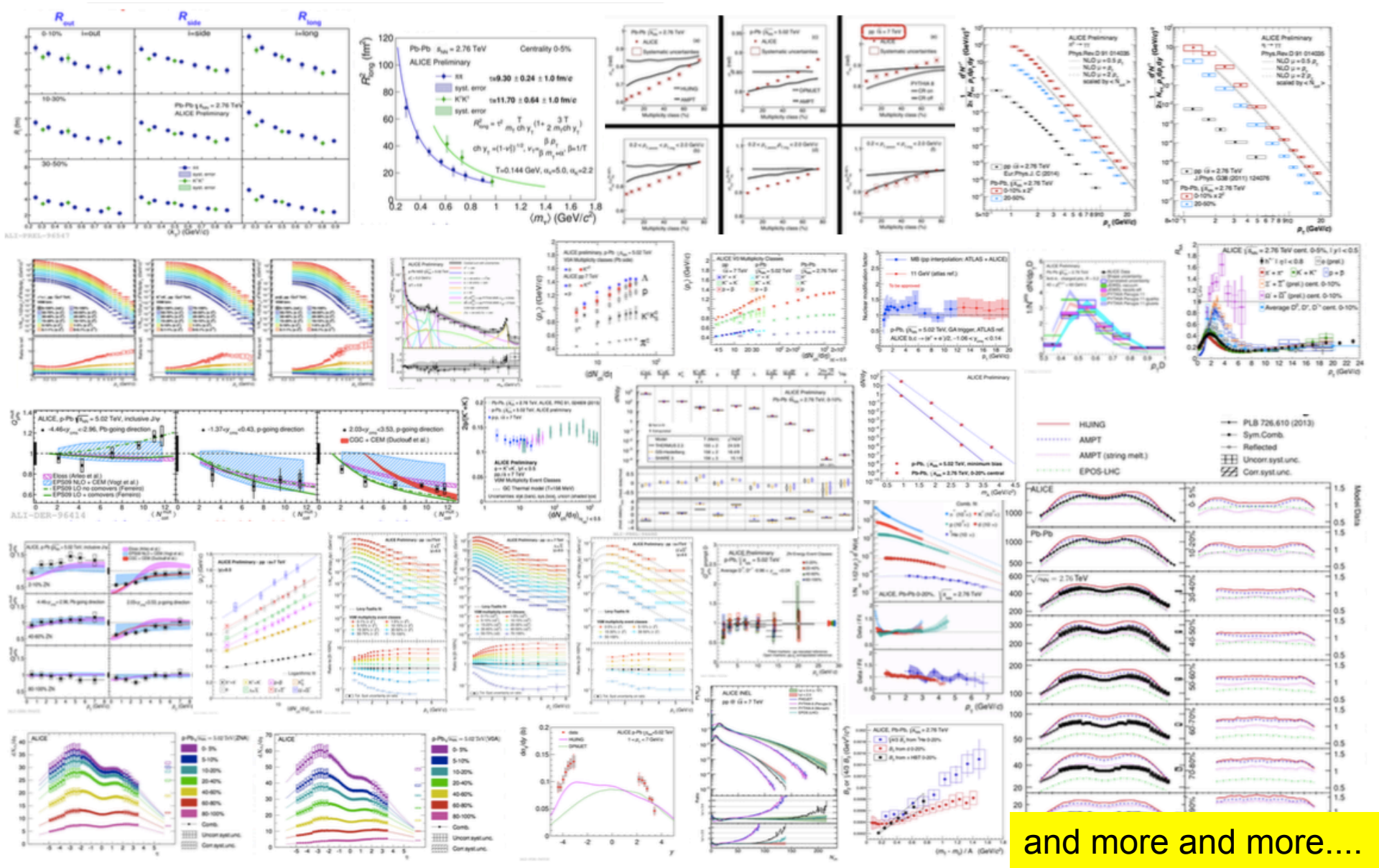




Thermal model
T=146-166MeV
R=Rc, γ_s=1, μ=0

- Faster enhancement for Ω > Ξ > Λ and similar trends between pp and p-Pb collisions
  - ✓ The effect is strangeness-related and not baryon-related
- Decrease is qualitatively described by canonical suppression

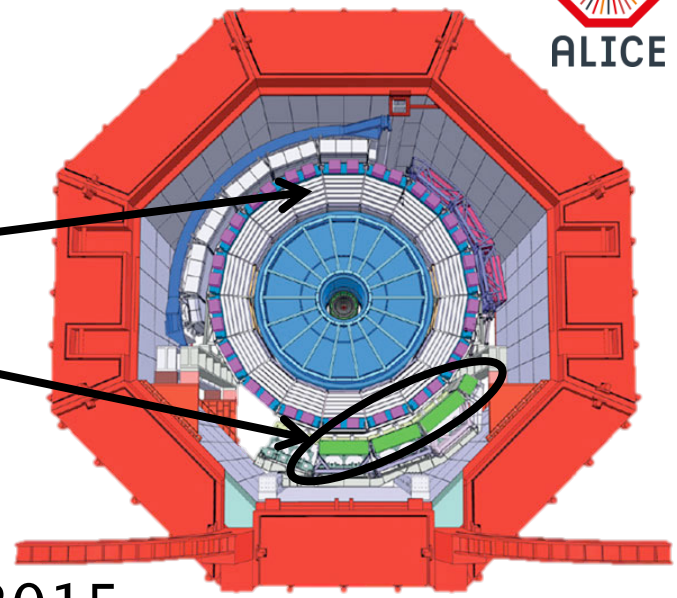
And More…

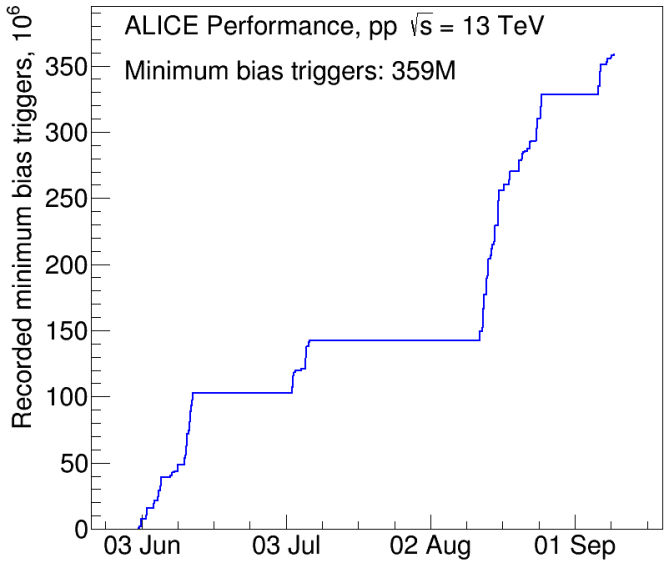

ALICE
HIJING
AMPT
AMPT (string melt.)
EPOS-LHC
PLB 726,610 (2013)
Sym.Comb.
Reflected
Uncorr.syst.unc.
Corr.syst.unc.
and more and more....

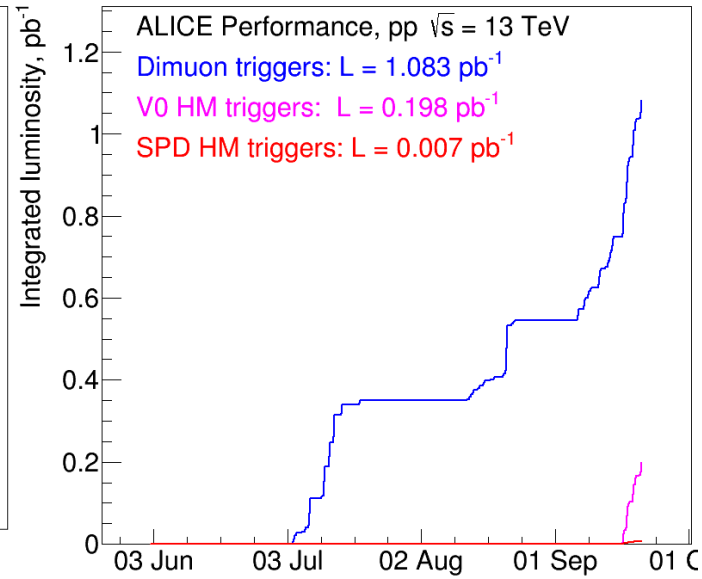
ALICE in Run2 and Run3

ALICE in Run2

- ALICE Upgrade for Run2
  - Full TRD sectors
  - Dijet Calorimeter, PHOS
  - AD (for diffractive physics)
  - Trigger systems
  - New TPC gas mixture (Ar/CO_2)
- pp at 13 TeV started since June in 2015.
  - MB, High luminosity running with rare triggers (muon, SPD, V0 for HM)

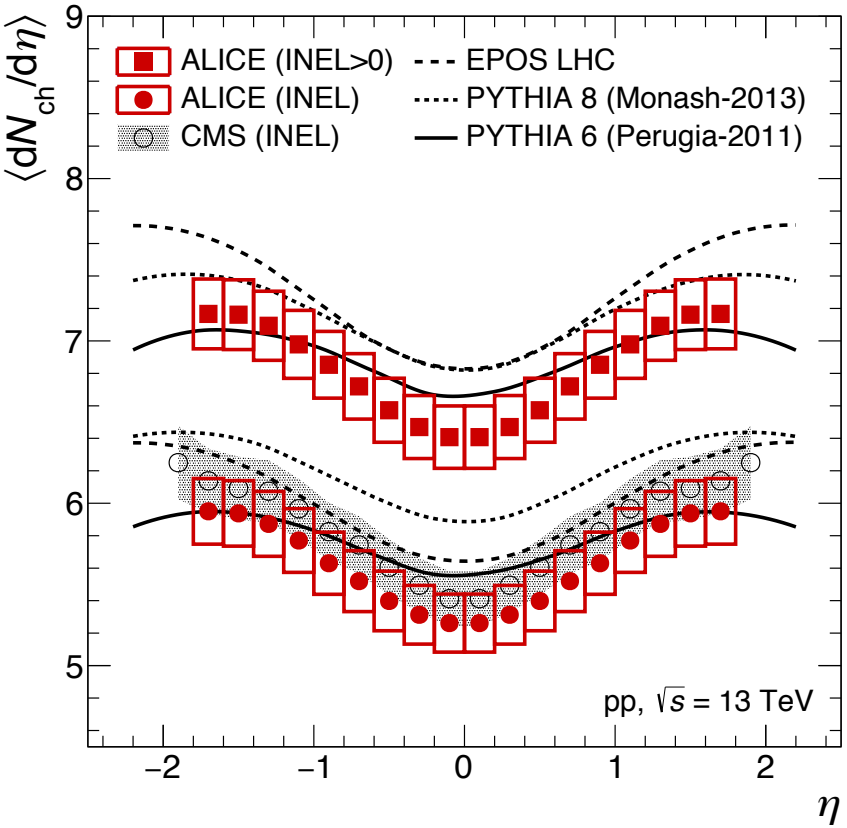


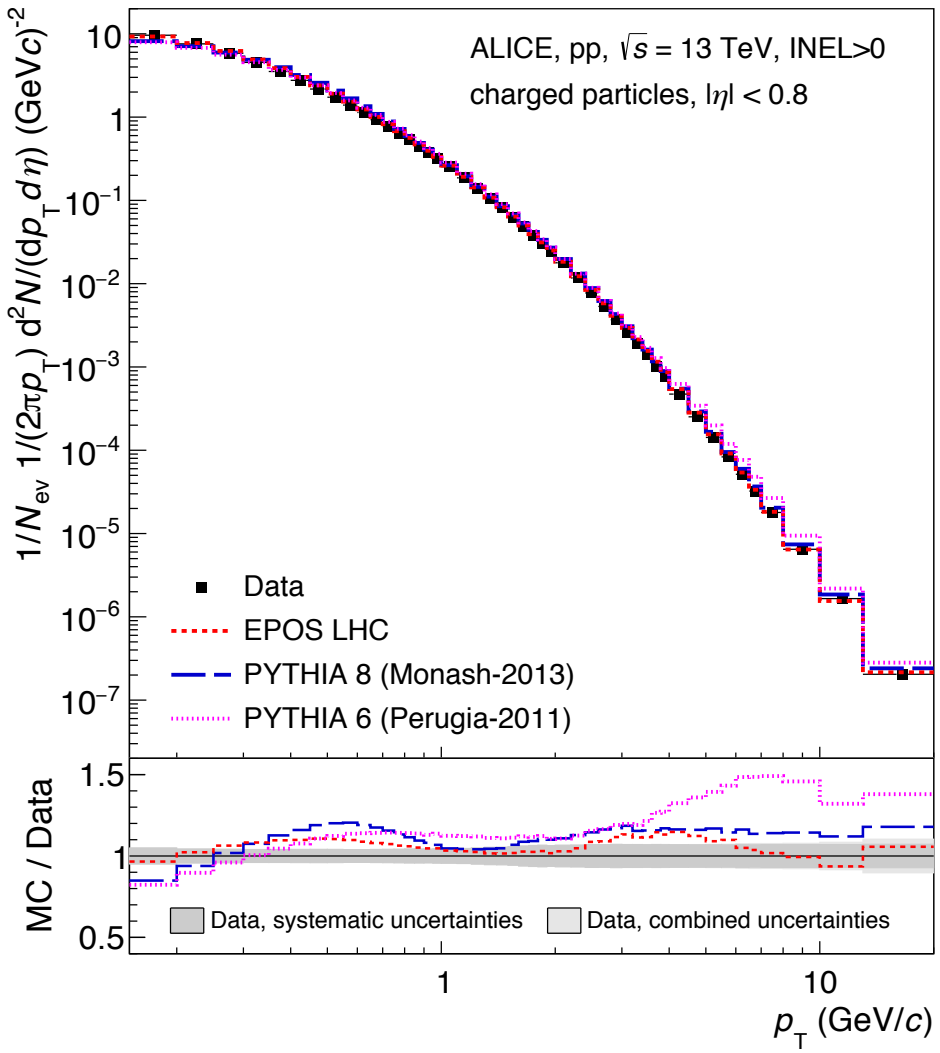




New Results at 13 TeV

ALICE, arXiv:1509.08734

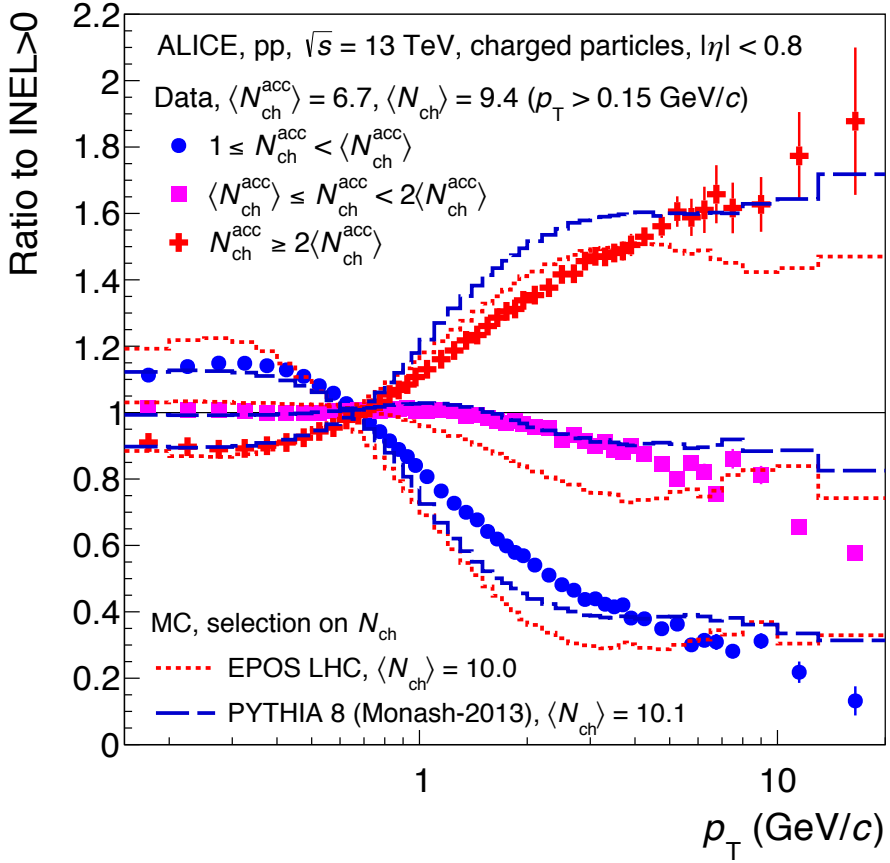


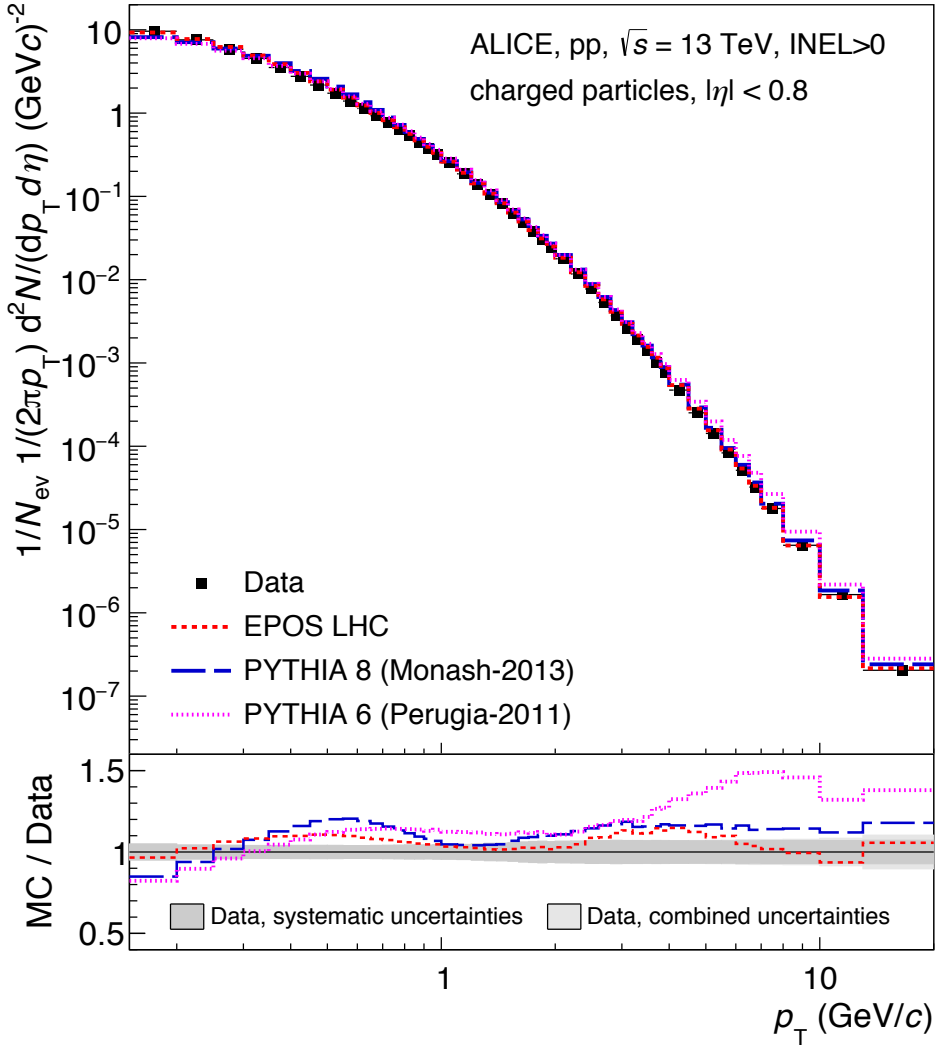


- Measure multiplicity of tracklets in SPD
- Charged particle yields vs. p_T

New Results at 13 TeV

ALICE, arXiv:1509.08734

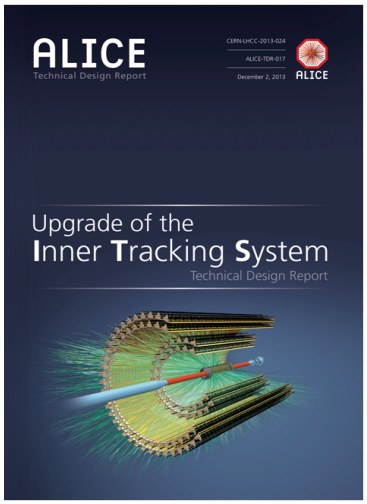


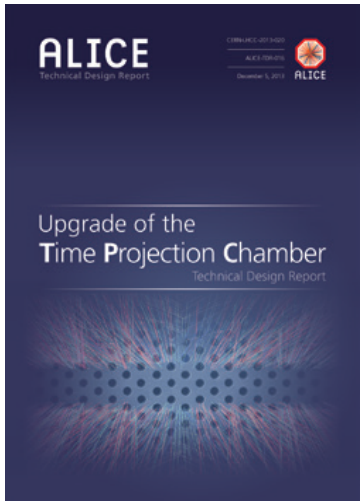


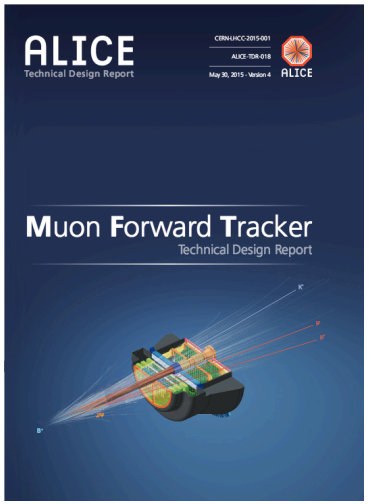
- Ratios of p_T distributions of charged particles in three intervals of multiplicities

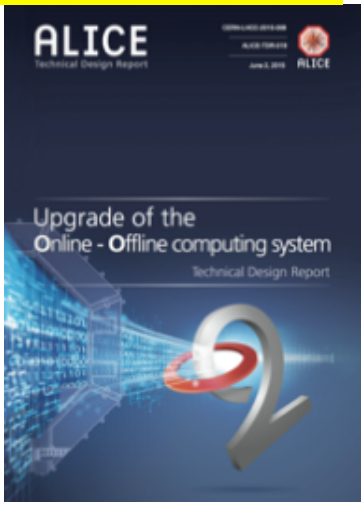
ALICE Upgrade for Run3

P. Riedler (Tue. PM)
C. Garabatos (Tue. PM)

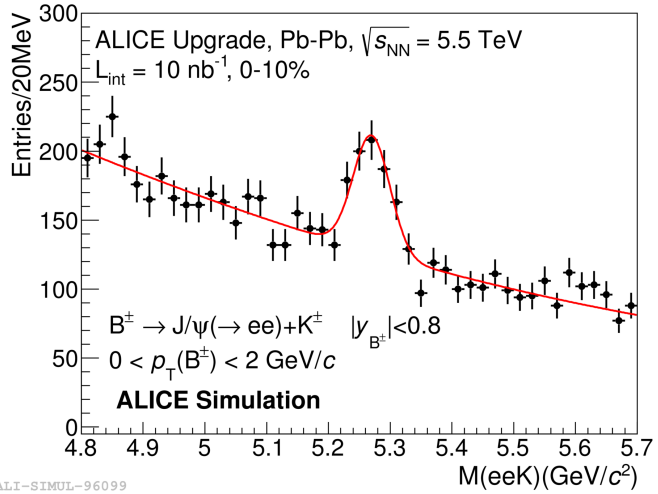


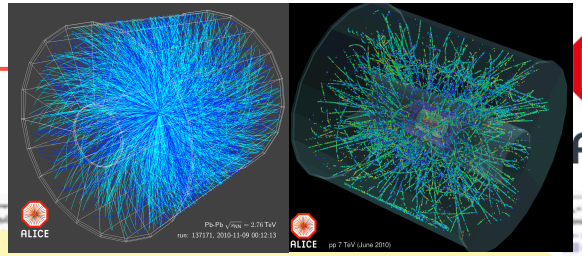






- Major ALICE detector/system upgrades
  - Read out Pb–Pb MB collisions at 50kHz
- Unique Physics program with x100 larger statistics
  - Dileptons, Quarkonia, Heavy flavors, Jets, heavy-nuclei (exotica)
- Many activities are on-going.





Summary

- **Significant number of results comes from Pb–Pb collisions**
  - ✓ Collectivity and Correlations
    - ✓ New measurements of PID v_n, deuteron v_2, SC, ESE and radial flow
  - ✓ Hard Probes
    - ✓ Jet v_2, Jet core shapes, HF energy loss
  - ✓ Photons, Longitudinal asymmetry and $dN/d\eta$
  - ✓ Low p_T J/ψ enhancement and photo-production of J/ψ
- **New exciting results for small system physics from pp and p–Pb collisions**
  - ✓ $\psi(2S)$ suppression, forward muon v_2 in p–Pb
  - ✓ Similarity in HF production and strangeness (canonical suppression) vs. event activities in pp and p–Pb
- **ALICE Upgrade for Run2 and Run3**
  - ✓ Ready to provide more scientific results in Run2
  - ✓ Many activities are being made for Run3 toward more precision measurements


Thank you for your attention.

Thank you for your attention.

List of ALICE Contributions
27 talks and 50 posters

Correlations and Fluctuations
- Rashmi Raniwala: Longitudinal Asymmetry in Pb-Pb
- Ludmila Malinina: Femtoscopy in Pb-Pb
- Evgeny Kryshen: F-C correlations in p-Pb
- Panos Christakoglou: Balance function

Quarknoia
- Marco Leoncino: Psi(2S) in p-Pb
- Hugo Denis Antonio Pereira Da Costa: Charmonium in Pb-Pb
- Gines Martinez-Garcia: Low pT J/psi in Pb-Pb
- Indranil Das: Upsilon production in ALICE

Open Heavy Flavors and Strangeness
- Alessandro De Falco: ϕ in p-Pb and Pb-Pb
- Natasha Sharma: (anti-)(hyper-)nuclei and exotics
- Andrea Dubla: Heavy flavors in Pb-Pb
- Jeremy Wilkinson: Heavy flavors in p-Pb
- Fabio Filippo Colamaria: Heavy flavors in pp and correlations

QGP in small systems
- Antonio Ortiz Velasquez: Light flavors in p-Pb
- Livio Bianchi: Strangeness production in p-p

Jets and High pT Hadrons
- Leticia Cunqueiro Mendez: Jet structure in Pb-Pb
- Redmer Alexander Bertens: Charged jet anisotropy
- Astrid Morreale: High p_T photons and π^0 in Pb-Pb

Collective Dynamics
- Ramona Lea: (anti-)deuteron in Pb-Pb
- Anthony Robert Timmins: Event shape engineering
- You Zhou: Correlations of flow harmonics
- Naghmeh Mohammadi: Higher harmonics in Pb-Pb

Initial State Physics and Approach to Equilibrium
- Valentina Zaccolo: Multiplicity over wide rapidity in p-p

Electromagnetic probes
- Baldo Sahlmueller: Direct photons in Pb-Pb
- Patrick Simon Reichelt: Low mass dielectrons

Future Experimental Facilities, Upgrades, and Instrumentation
- Petra Riedler: ALICE ITS upgrade
- Chilo Garabatos Cuadrado: ALICE TPC upgrade