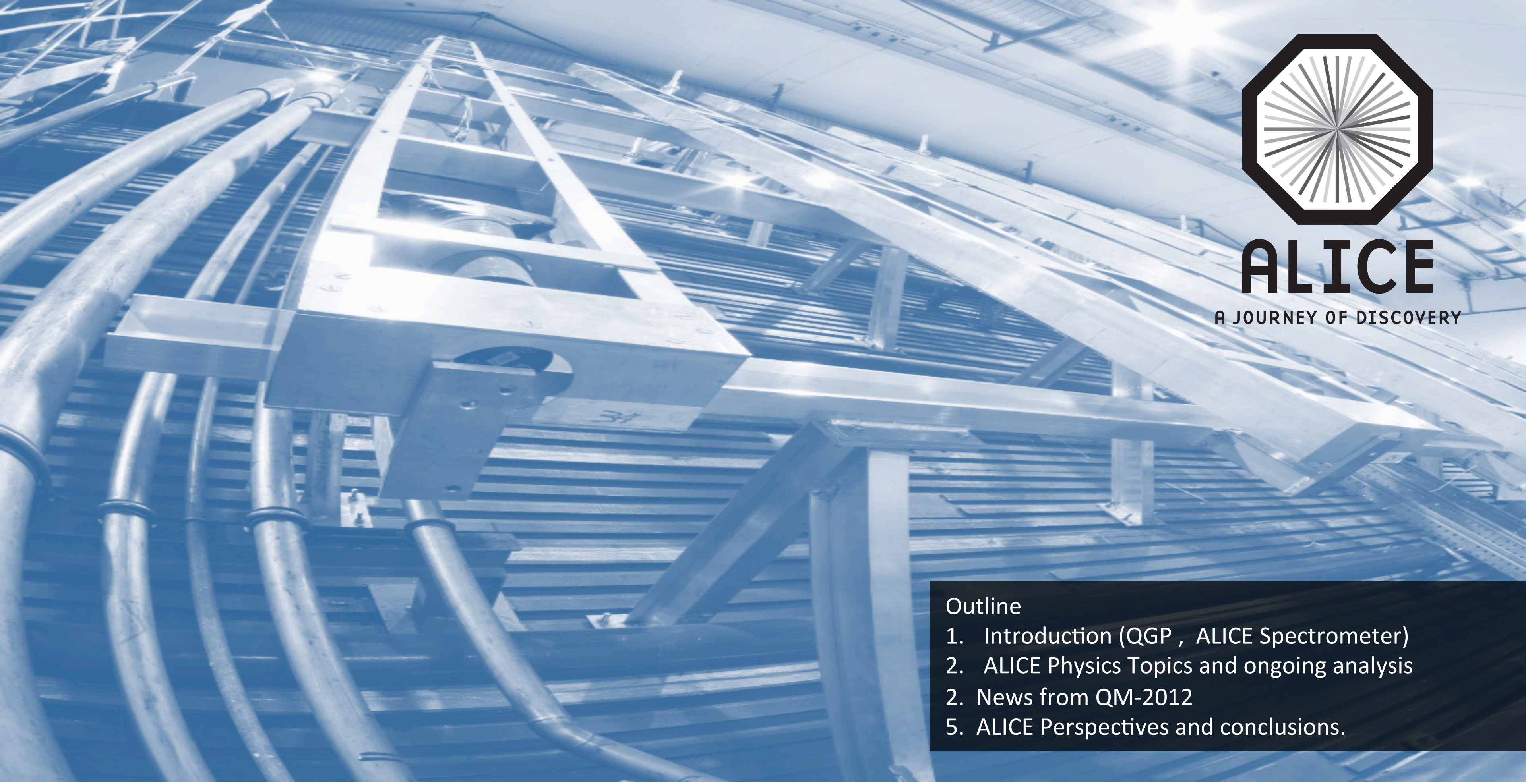


Outline
1. Introduction (QGP , ALICE Spectrometer)
2. ALICE Physics Topics and ongoing analysis
2. News from QM-2012
5. ALICE Perspectives and conclusions.

# Recent Results from ALICE-LHC
# XV MEXICAN SCHOOL OF PARTICLES AND FIELDS
# DPyC, SMF

**Edificio Carolino . BUAP**
**Sept. 10th 2012, Puebla, México**

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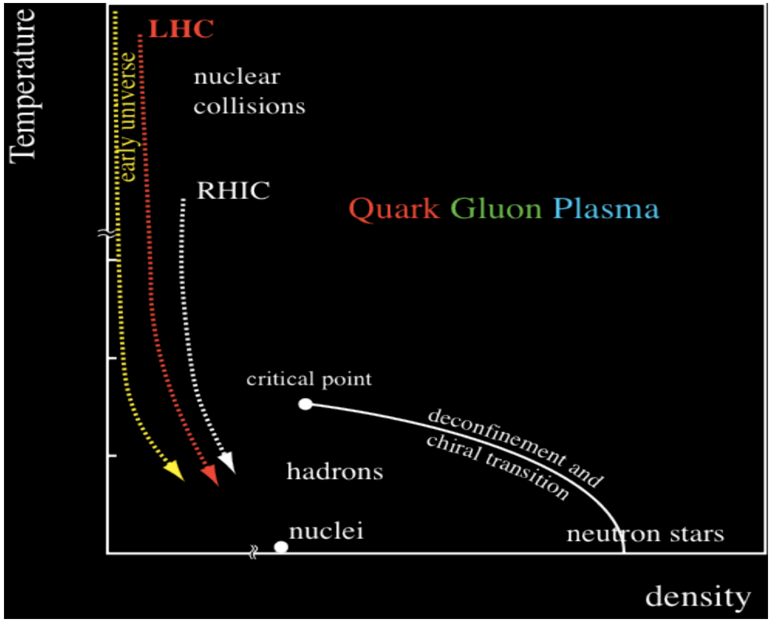
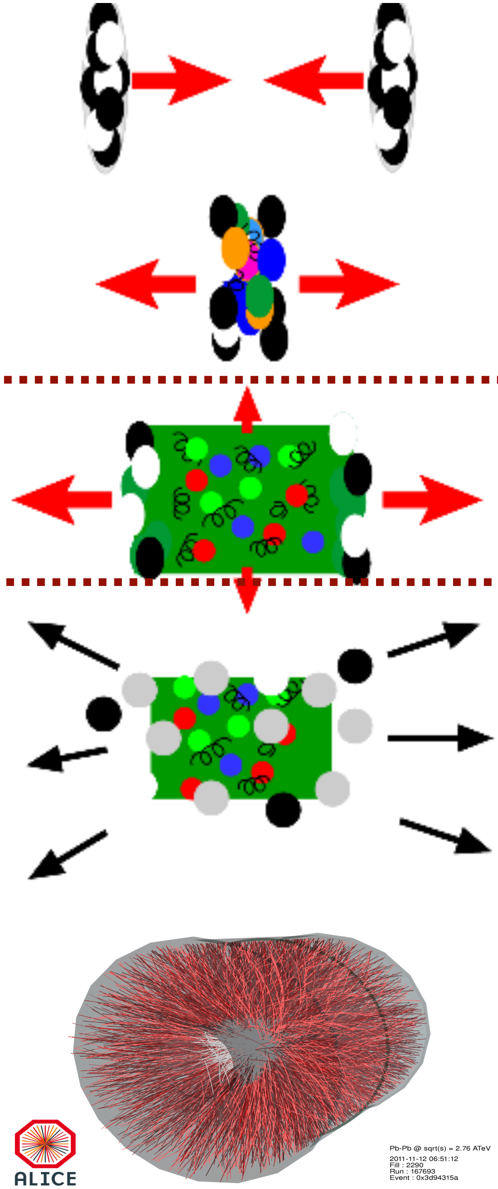
Explore the properties of the Quark Gluon Plasma

- What happens when you heat and compress matter to very high temperatures and densities?
- The macroscopic quantities of the QGP will give us better understanding of the underlying microscopic theory (QCD) in the non-perturbative regime
- Different accelerators have contributed to the mapping of the "experimental phase diagram"

- ❑ At the critical temperature a strong increase in the degrees of freedom
  - o gluons, quarks → deconfinement
- ❑ Transition expected to occur around 0.5 GeV/fm$^3$

Borsanyi et al. JHEP 11 (2010) 077






before collision — initial state (e.g. color glass condensate)

0 fm/c

pre-equilibrium — thermalization (glasma state)

$\sim 0.5$ fm/c

quark-gluon-plasma — Hydrodynamics, Jet quenching, ..

$\sim 3 - 5$ fm/c

hadronization — Hydrodynamics

hadr.rescattering — Hadronic transport

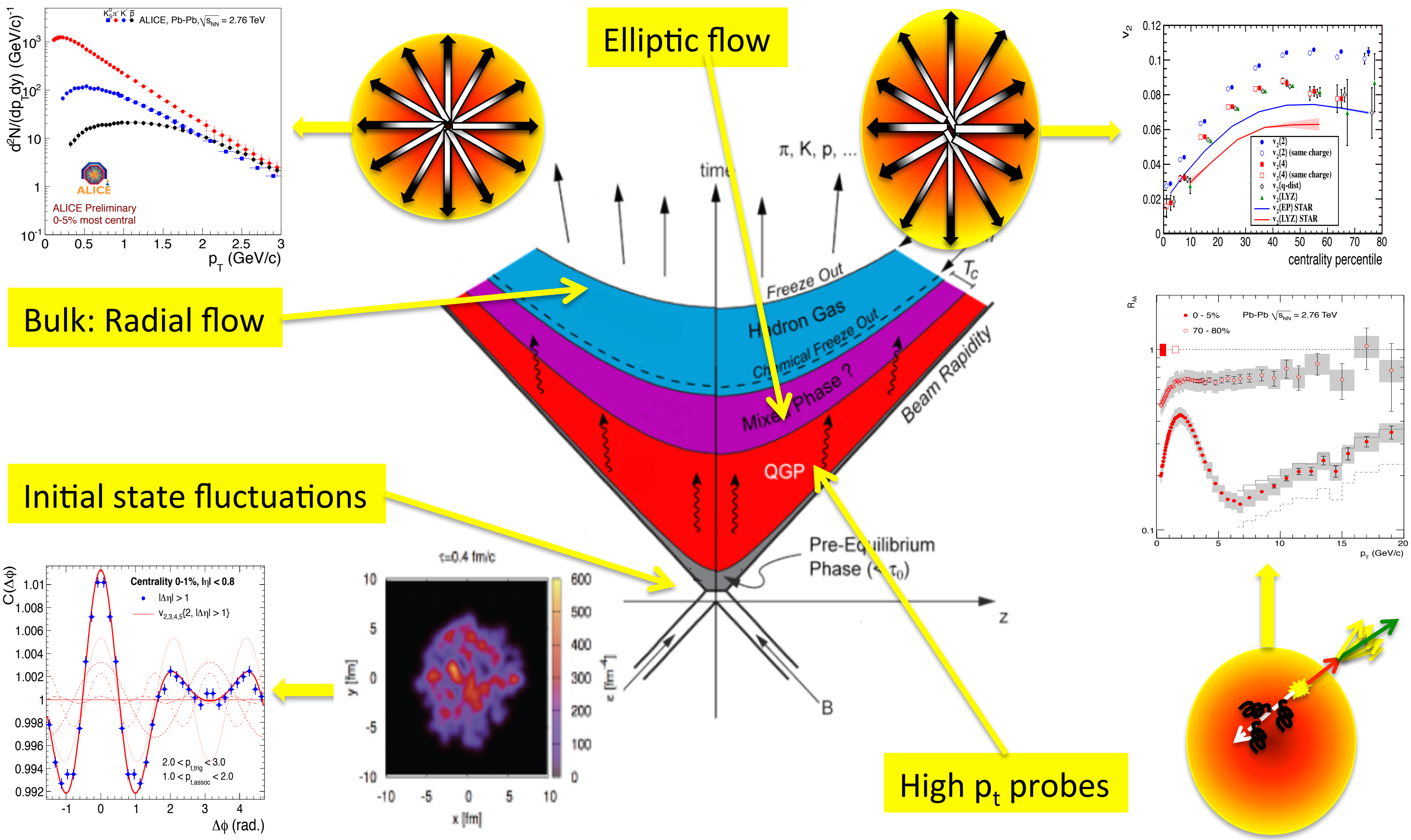
$\sim 10$ fm/c

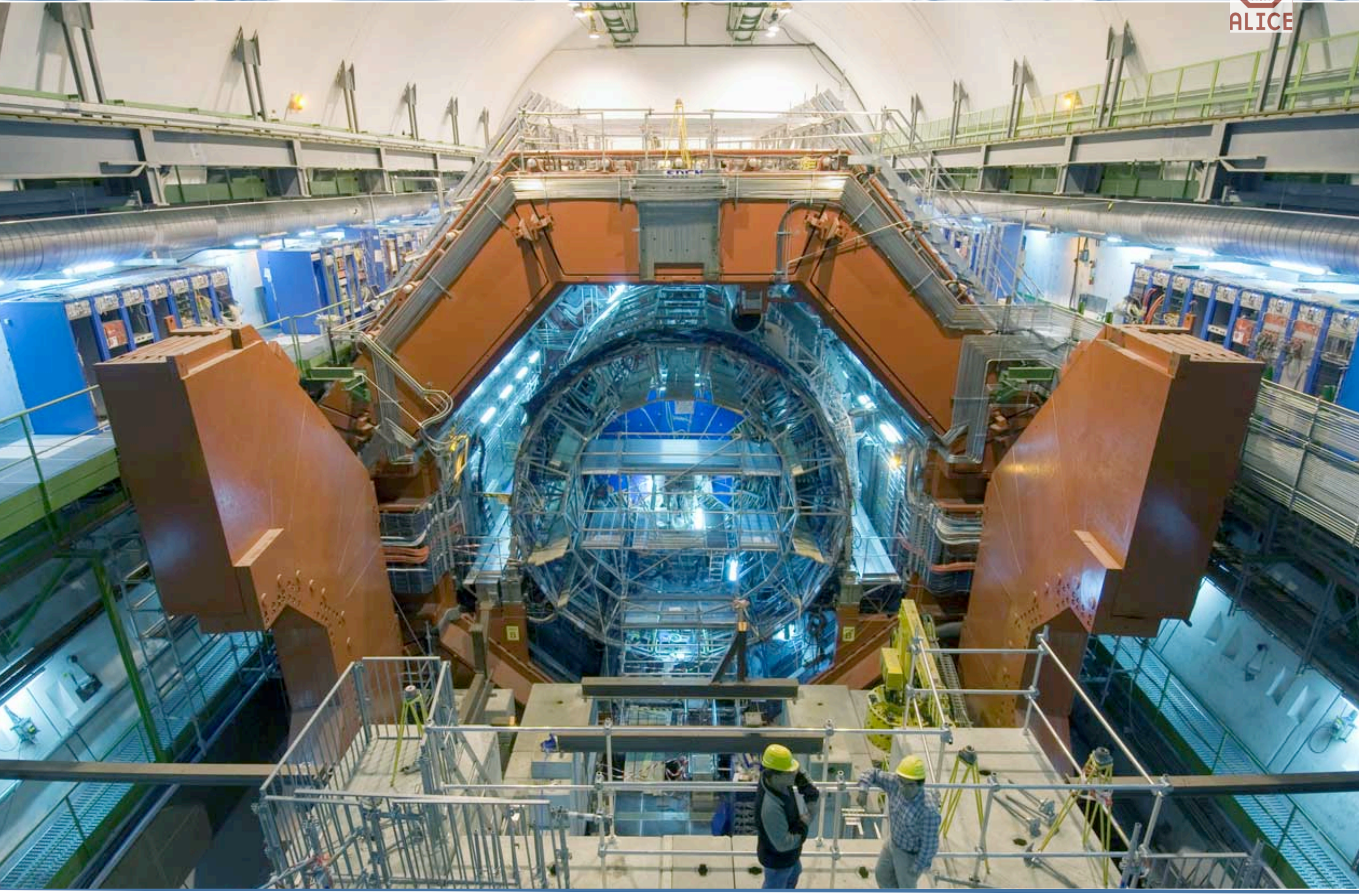
freeze-out — compare theory to experiment

detection

**Characterizing Quark-Gluon Plasma:**

- Phase transition/critical point
- Its properties in different phases of the QGP life (production mechanisms, hardonization, fragmentation)

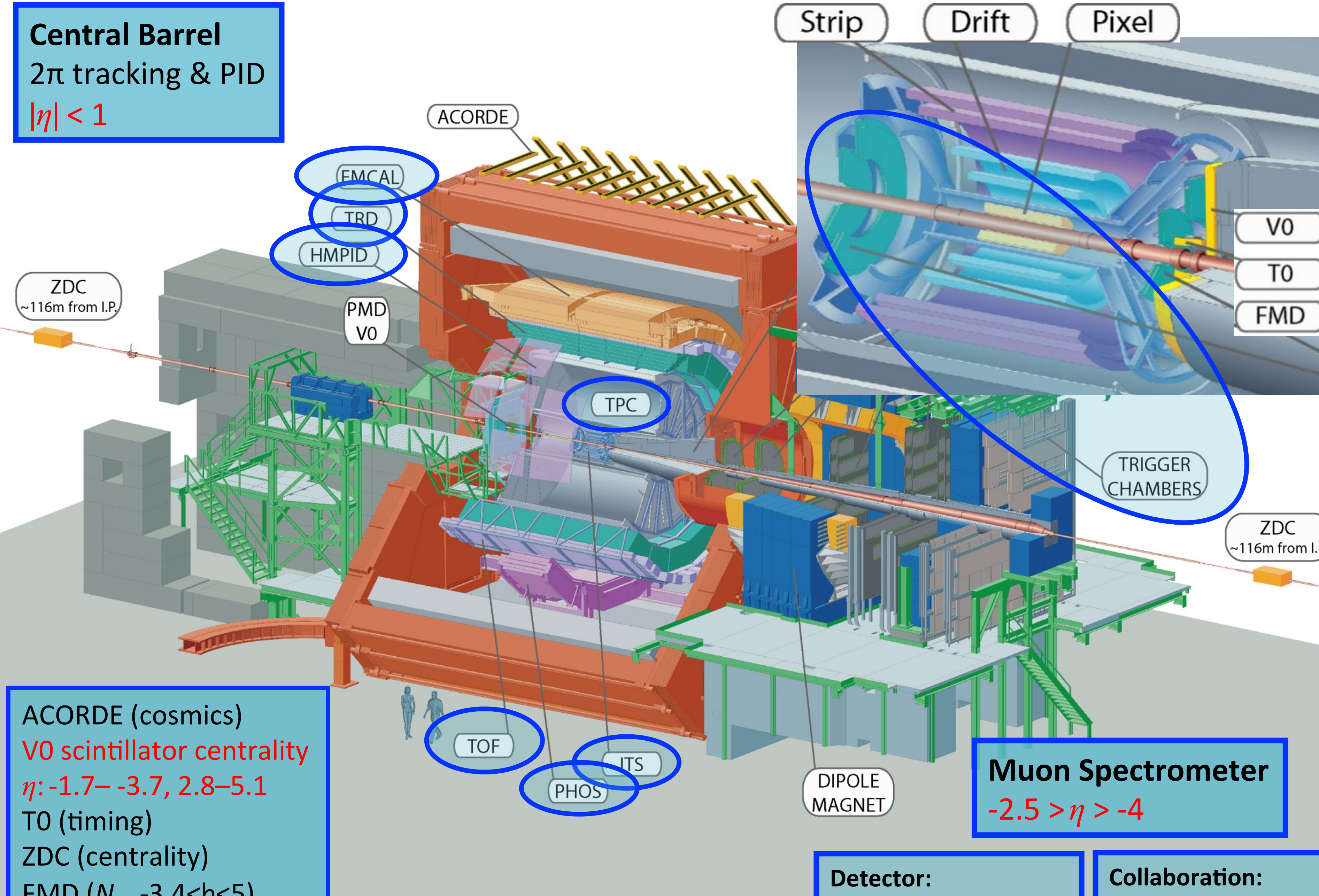

Elliptic flow
Bulk: Radial flow
Initial state fluctuations
High $p_t$ probes
ALICE, Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE Preliminary
0-5% most central
$d^2N/(dp_T dy)$ (GeV/c)$^{-1}$
$p_T$ (GeV/c)
time
π, K, p, ...
Freeze Out
Hadron Gas
Chemical Freeze Out
Mixed Phase ?
QGP
Beam Rapidity
$T_c$
Pre-Equilibrium
Phase (< $\tau_0$)
z
B
τ=0.4 fm/c
y [fm]
x [fm]
ε [fm$^{-4}$]
$v_2$
centrality percentile
$v_2\{2\}$
$v_2\{2\}$ (same charge)
$v_2\{4\}$
$v_2\{4\}$ (same charge)
$v_2\{q\text{-dist}\}$
$v_2\{LYZ\}$
$v_2\{EP\}$ STAR
$v_2\{LYZ\}$ STAR
$R_{AA}$
0 - 5%
70 - 80%
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$p_T$ (GeV/c)
C(Δφ)
Centrality 0-1%, |η| < 0.8
|Δη| > 1
$v_{2,3,4,5}\{2, |\Delta\eta| > 1\}$
2.0 < $p_{t,trig}$ < 3.0
1.0 < $p_{t,assoc}$ < 2.0
Δφ (rad.)



**Central Barrel**

$2\pi$ tracking & PID

$|\eta| < 1$




ACORDE (cosmics)

V0 scintillator centrality

$\eta$: -1.7– -3.7, 2.8–5.1

T0 (timing)

ZDC (centrality)

FMD ($N_{ch}$ -3.4<h<5)

PMD ($N$g, $N_{ch}$)

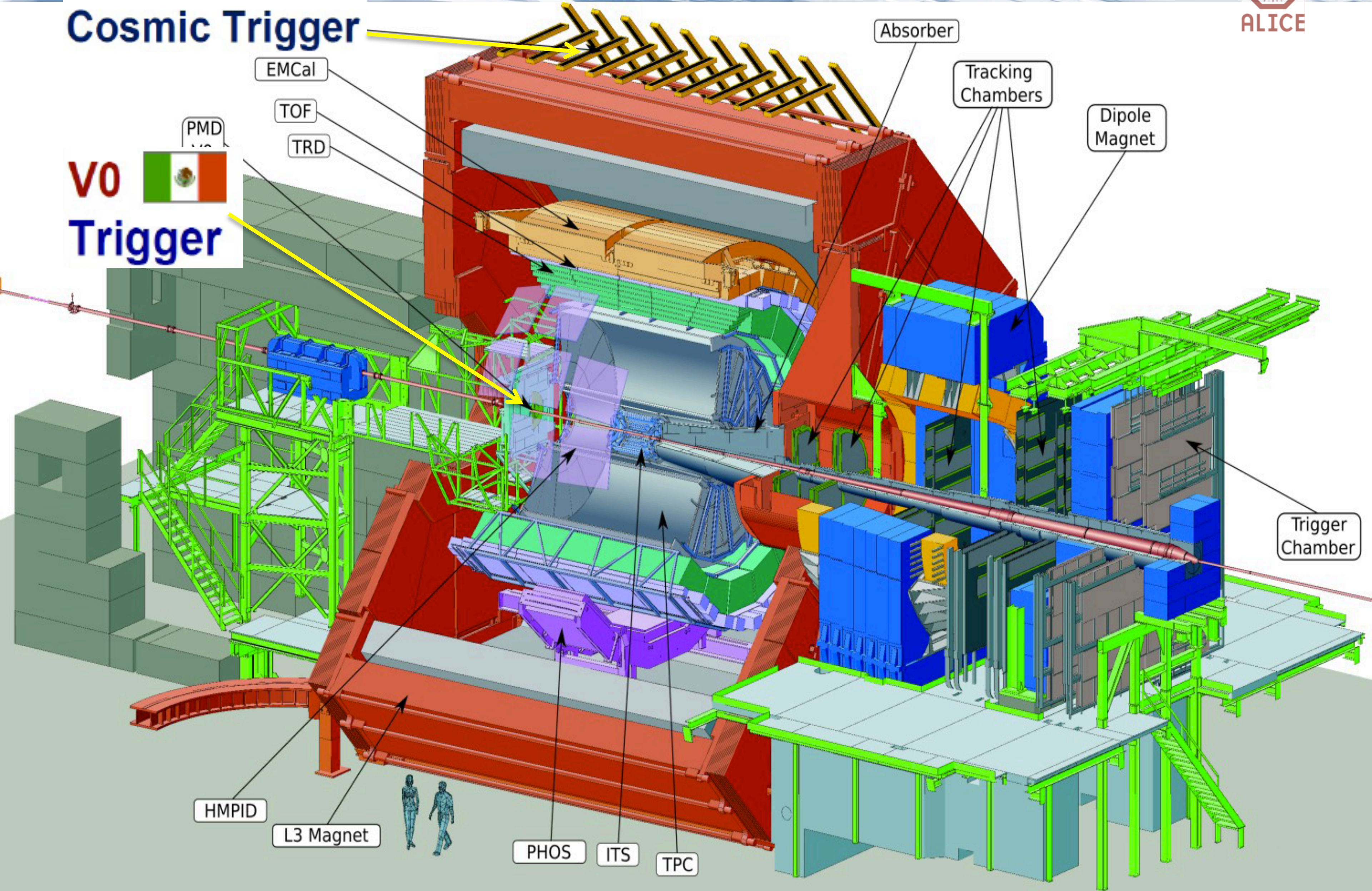
**Muon Spectrometer**

$-2.5 > \eta > -4$

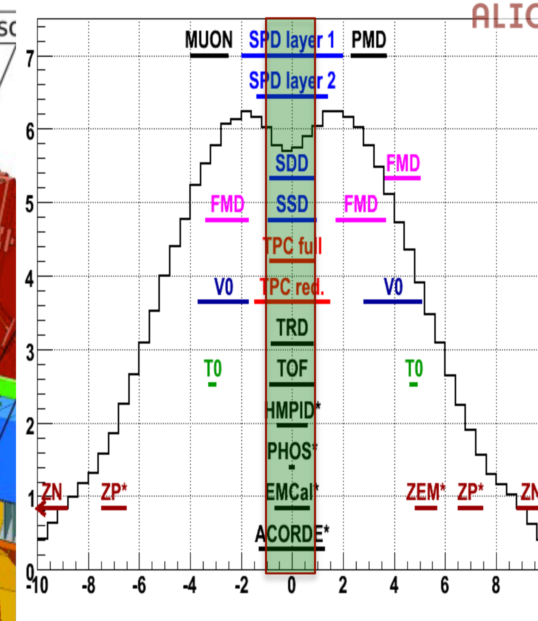
**Detector:**
**Length**: **26** meters
**Height**: **16** meters
**Weight**: **10,000** tons

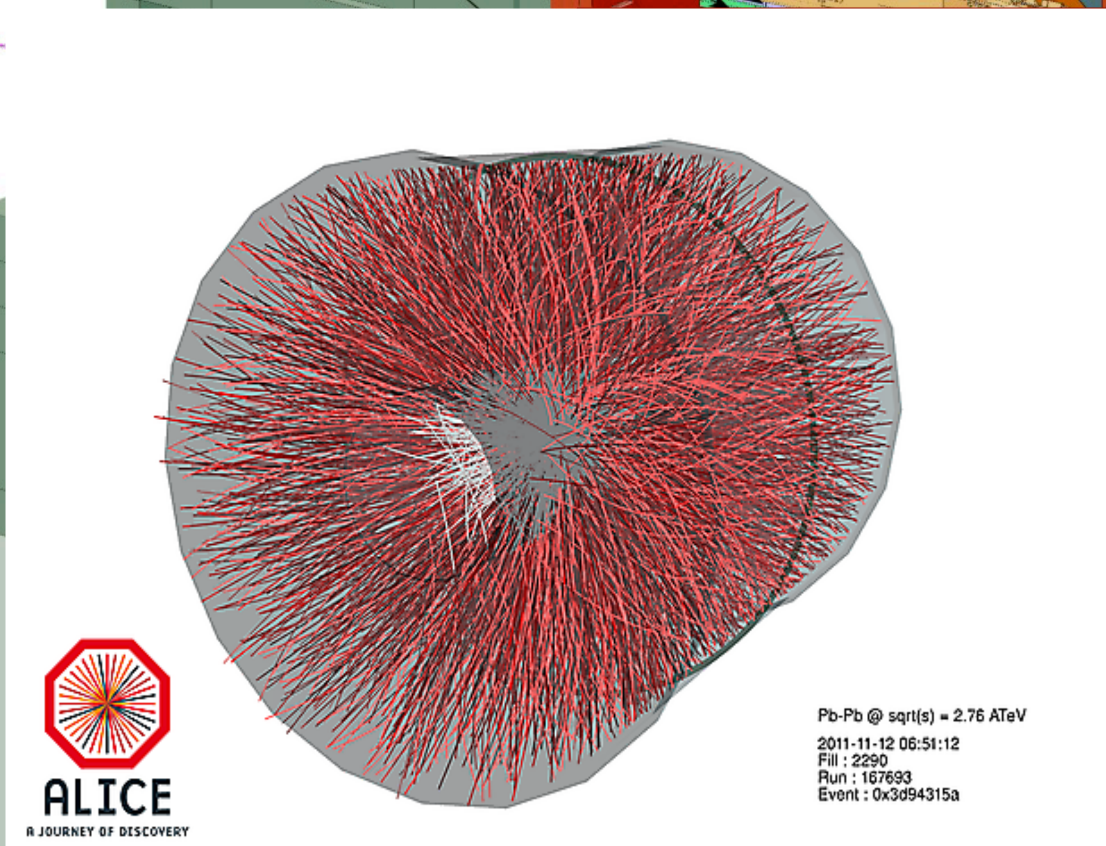
**Collaboration:**
**> 1000 Members**
**> 100 Institutes**
**> 30 countries**

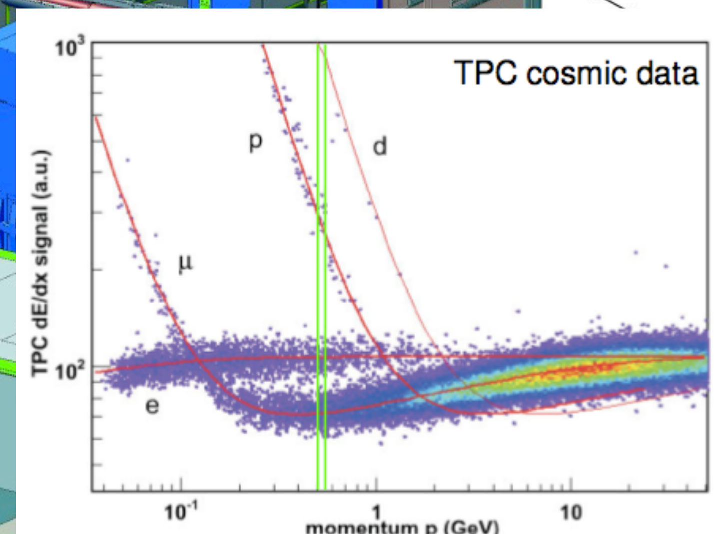
# Introduction

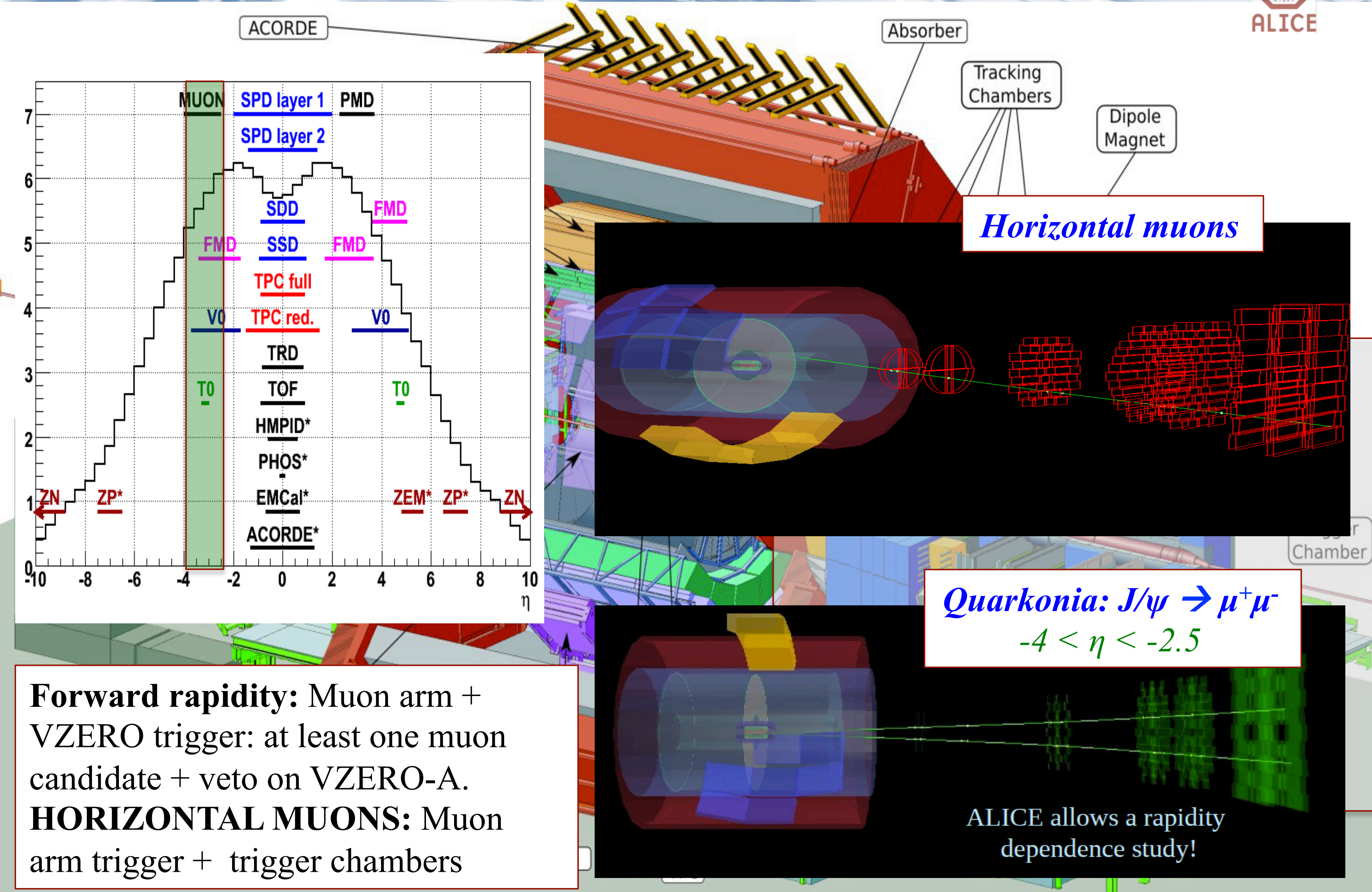


Central detectors
Inner tracking system (ITS)
Time Projection Chamber (TPC)
$|\eta| < 0.9$



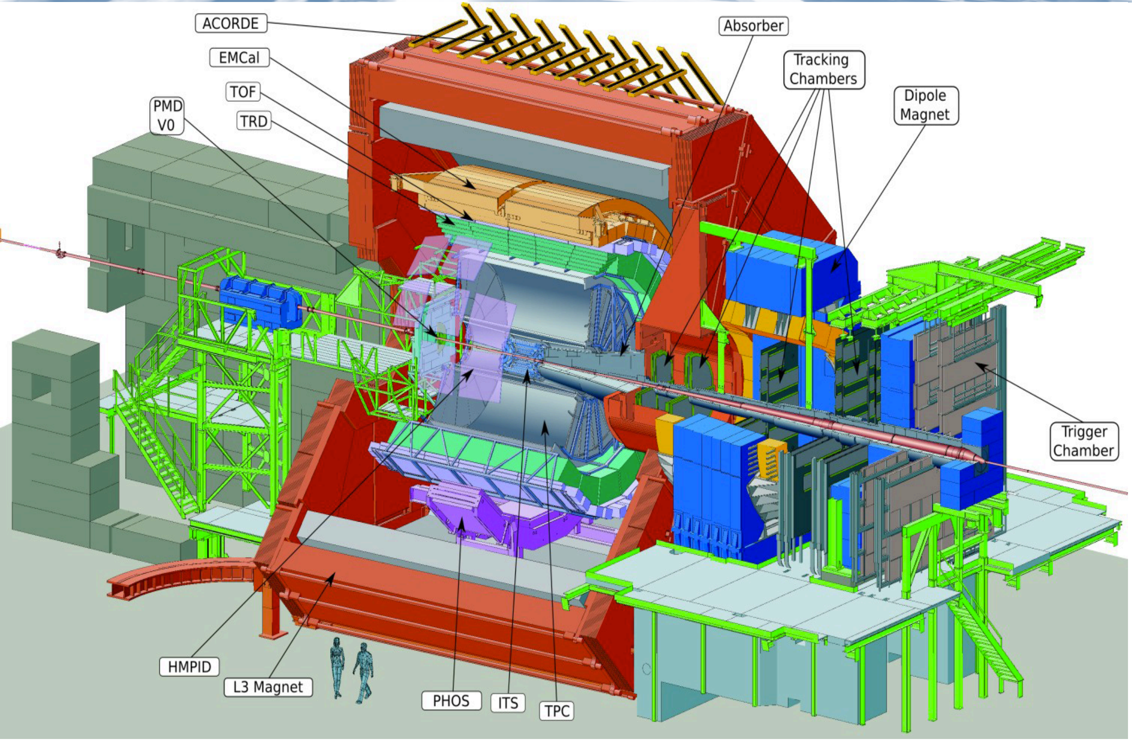



***Horizontal muons***

***Quarkonia: $J/\psi \rightarrow \mu^{+}\mu^{-}$***

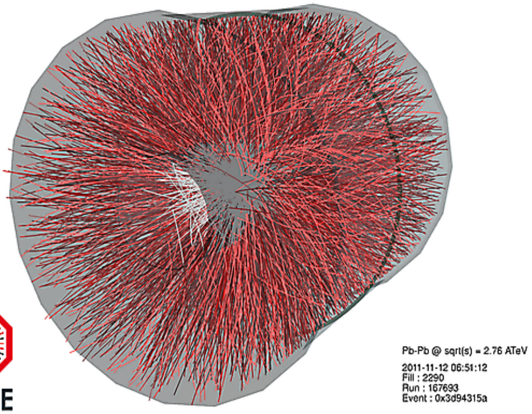
*$-4 < \eta < -2.5$*

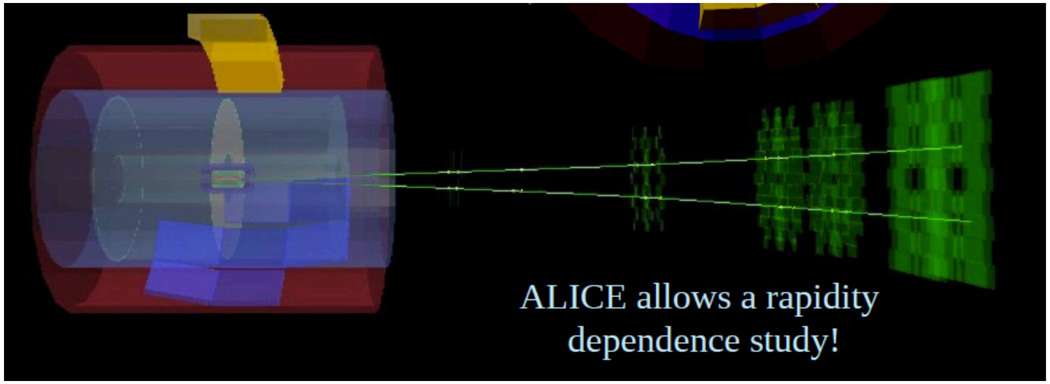
**Forward rapidity:** Muon arm + VZERO trigger: at least one muon candidate + veto on VZERO-A.
**HORIZONTAL MUONS:** Muon arm trigger + trigger chambers



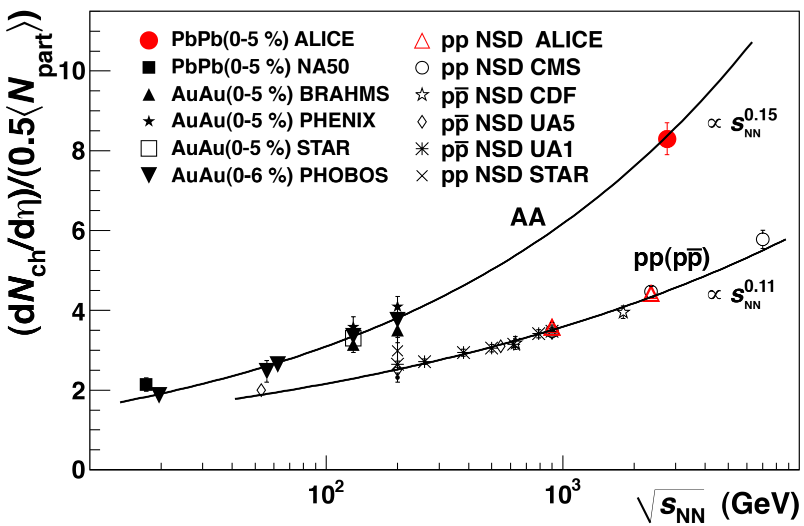

## ALICE Physics Topics:

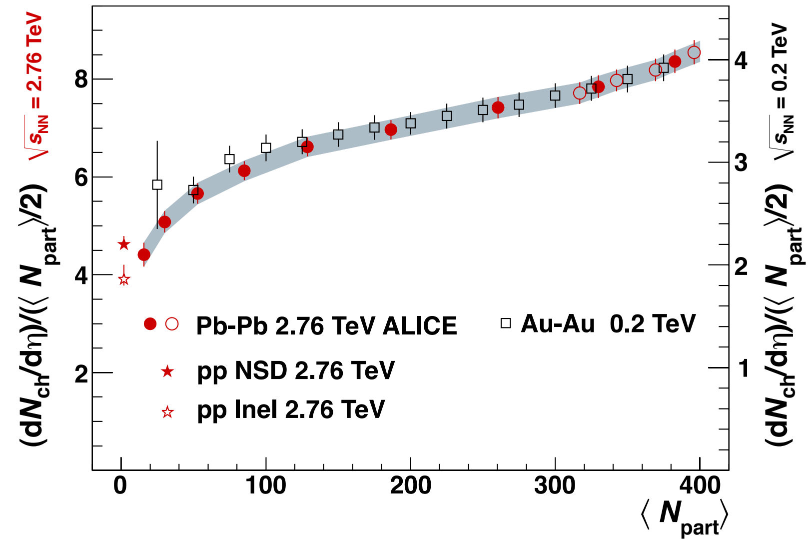
- Multiplicity Measurements
- Elliptic Flow
- Femtoscopy Studies
- High $p_T$ probes
- Nuclear Modification Factor
- Event Shape Studies
- Charm meson production
- B meson/bario production
- Ultra-peripherical collisions
- Cosmic
- etc., etc.



$dN_{ch}/d\eta = 1584 \pm 4 \text{ (stat.)} \pm 76 \text{ (syst.)}$




- Increase of $(dN_{ch}/d\eta)$ larger than ln√s as initially suggested by the RHIC measurements
- Increase of $(dN_{ch}/d\eta)/\langle N_{part}\rangle/2)$ with √s faster in AA than in p-p
  - $\sim s^{0.11}$ for pp
  - $\sim s^{0.15}$ for Pb-Pb
- Larger value than most models predicted

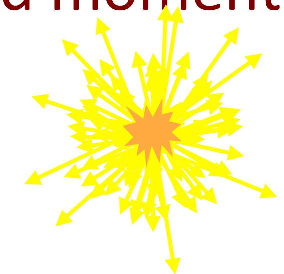
- Centrality dependence at the LHC similar to the one reported at RHIC energies
  - RHIC points scaled by ~2.1
  - Similarity due to centrality dependent shadowing of the nuclear PDF?

Phys. Rev. Lett. 105, 252301 (2010)
Phys. Rev. Lett. 106, 032301 (2011)

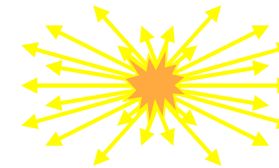
# Elliptic flow

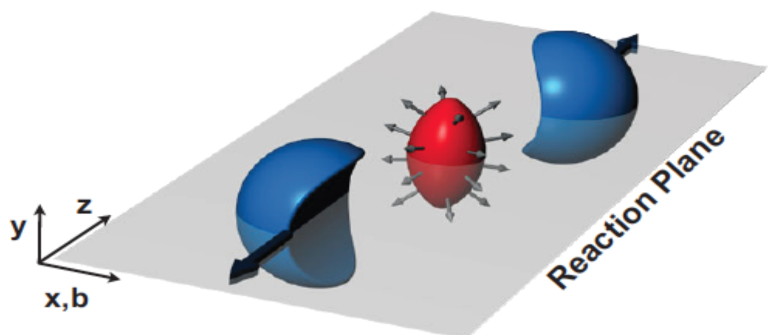
- Pressure gradient transforms the initial spatial anisotropy into the observed momentum-space anisotropy

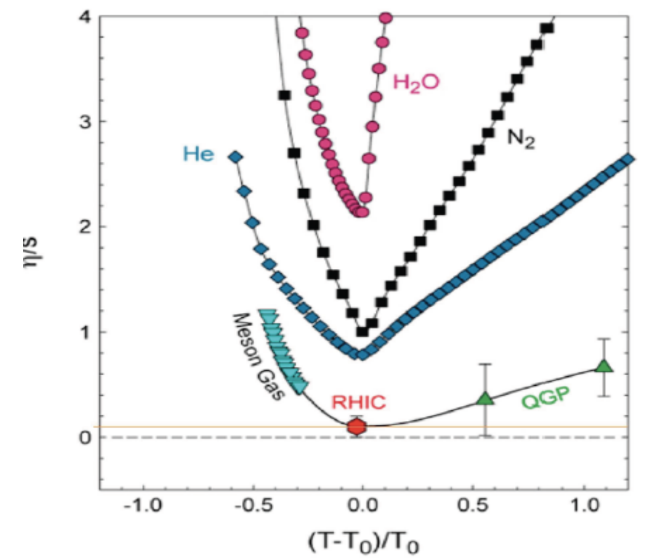
Superposition of independent pp collisions:
momenta pointed at random relative to reaction plane



Evolution as a **bulk system:**
Pressure gradients (larger in-plane) push bulk "out" → "flow"





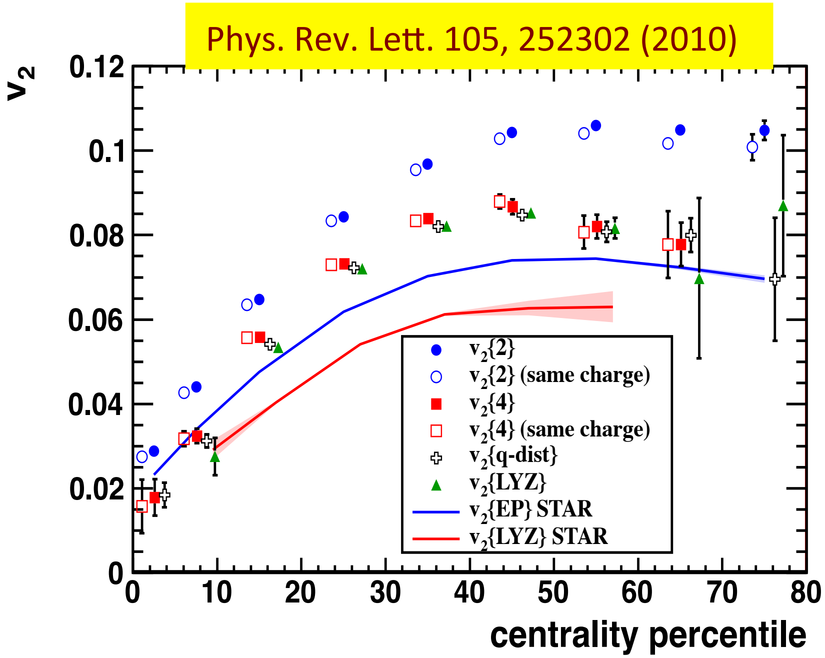

Azimuthal distribution described by a Fourier expansion

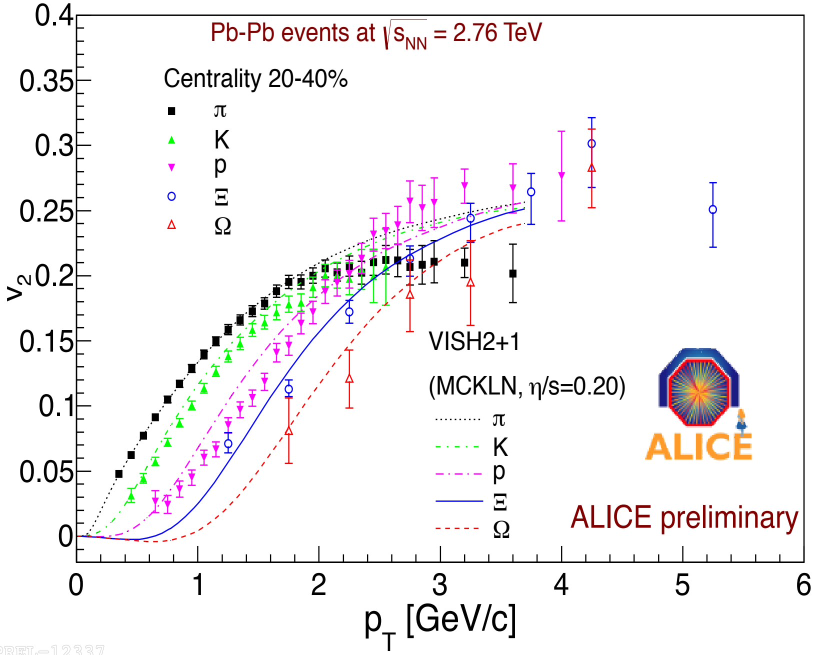
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+2\sum_{n=1}^{\infty} v_n \cos\left[n\left(\phi-\Psi_n\right)\right]\right)$$

$$v_n\left(p_t, y\right) = \left\langle \cos\left[n\left(\phi-\Psi_n\right)\right]\right\rangle$$

Connection to η/s → RHIC values close to the lower bound of 1/4π (hbar=c=1)

S. Voloshin and Y. Zhang, Z. Phys. **C70**, 665 (1996)



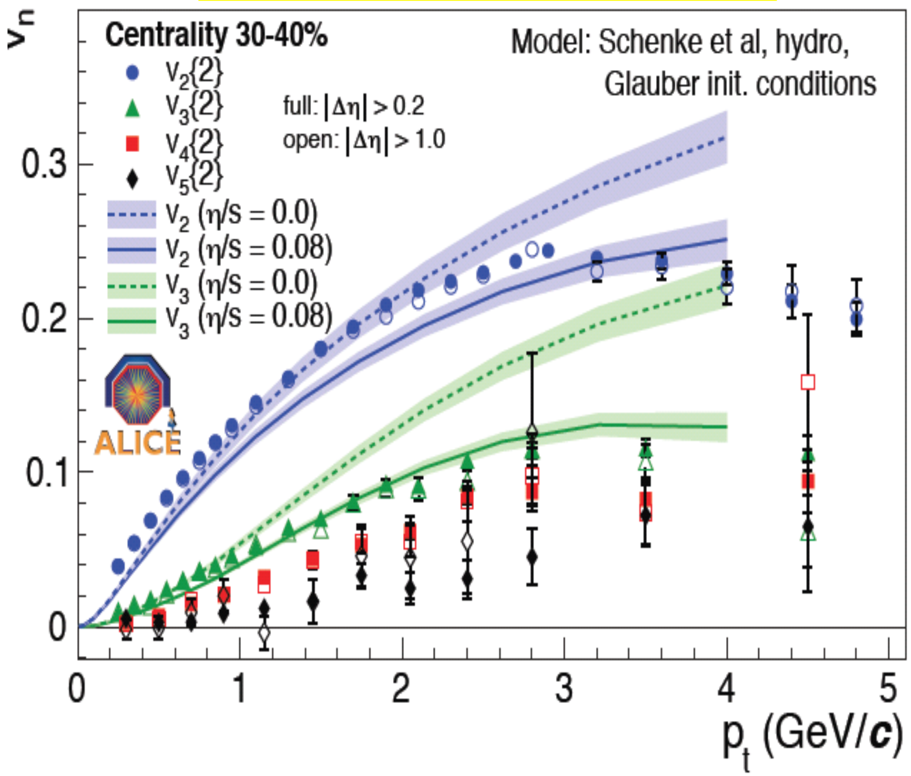



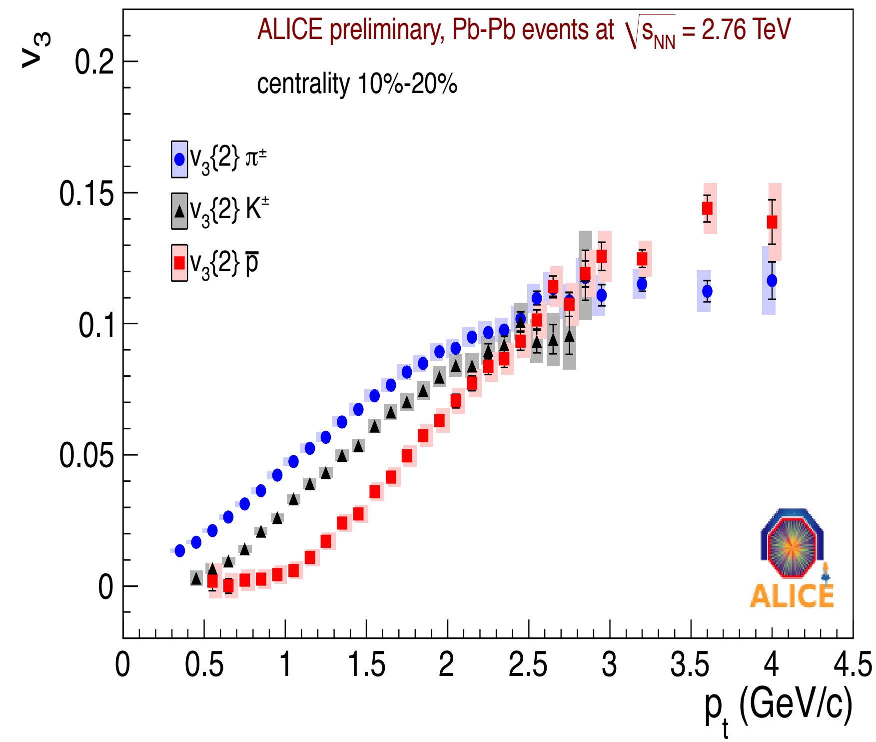

- Similar centrality dependence but ~30% higher integrated $v_2$ value wrt RHIC
- Predicted by hydro for a liquid with small value of shear viscosity
  - "perfect liquid" picture applies also at the LHC

- Particle mass dependence well reproduced by hydro calculations
  - Stronger push for heavier particles by radial flow
- Inclusion of a hadronic afterburner essential to match the differential $v_2$ of protons
- Pure hydro gives reasonable for Ξ and Ω

# Triangular flow results

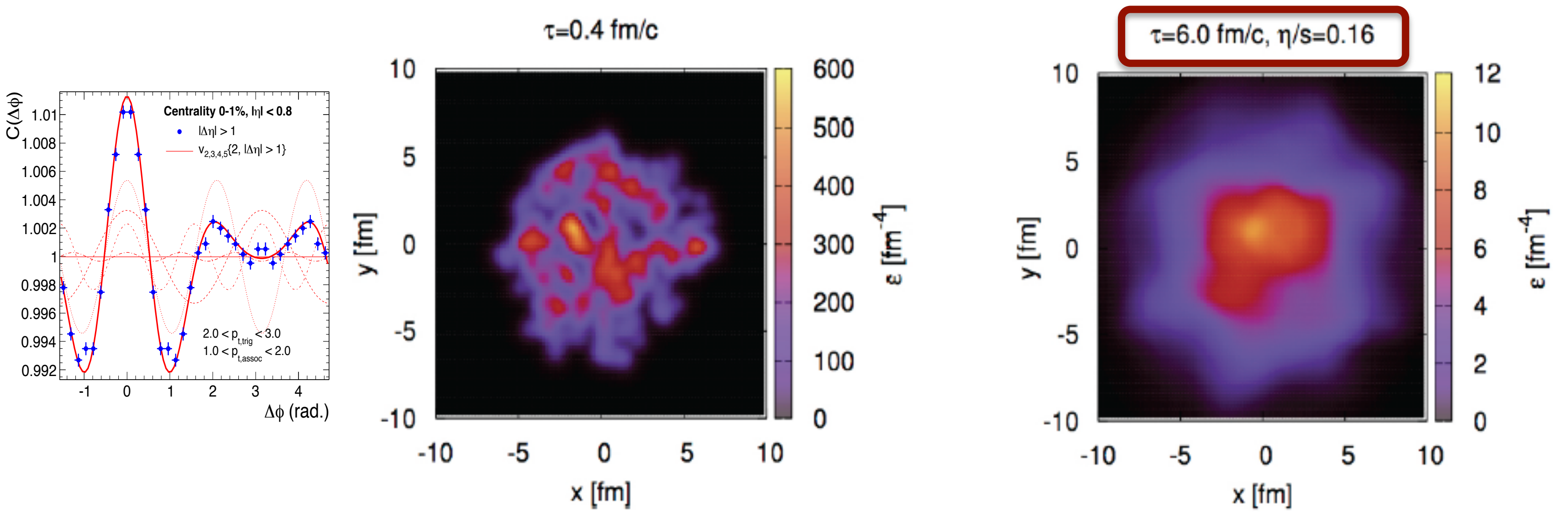
Phys. Rev. Lett. 107, 032301 (2011)



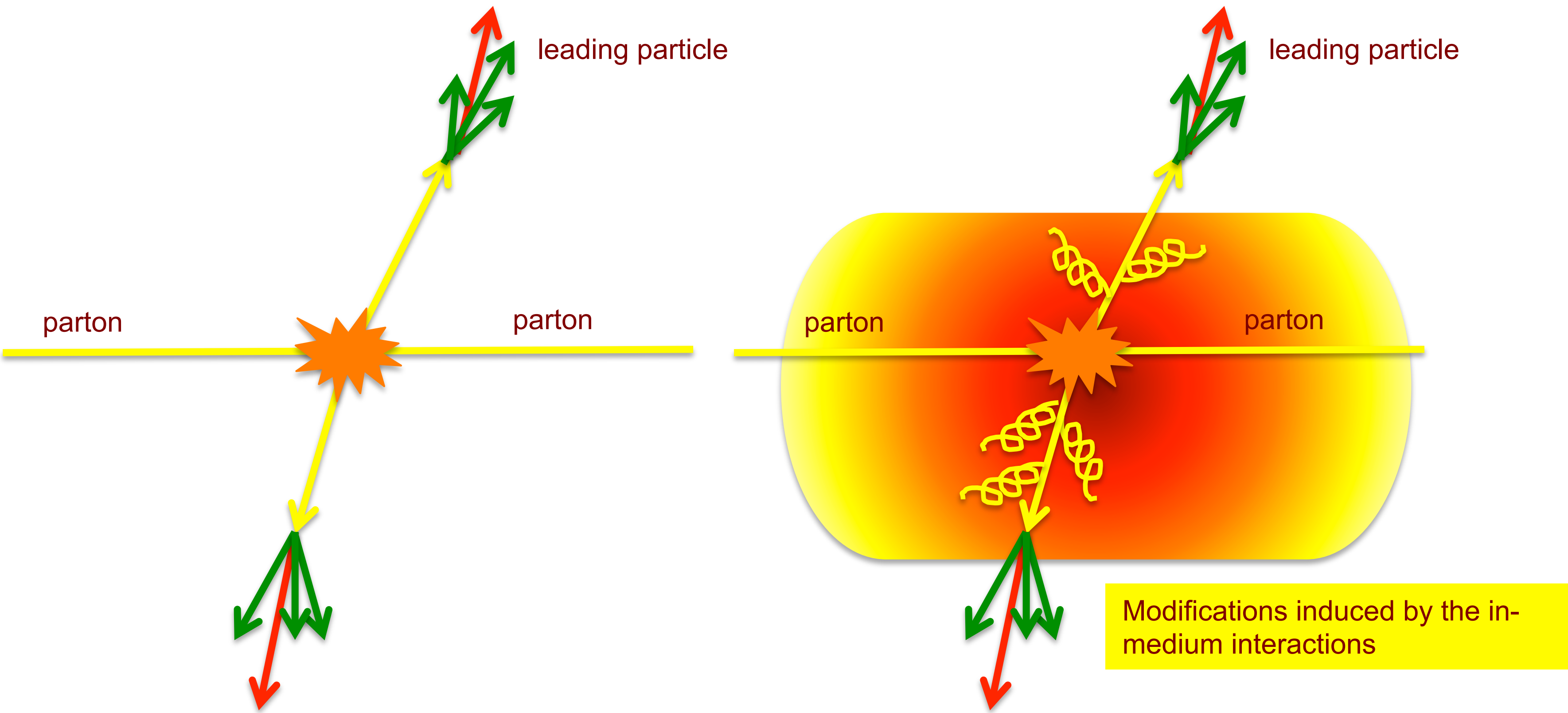

- Models can not describe successfully the elliptic and triangular flow with the same values of $\eta/s$
- Similar mass splitting expected by hydro

- Initial geometry not described by the ideal almond shape
  - Fluctuations of initial energy/pressure distributions lead to "irregular" shapes that fluctuate event-by-event
  - Higher (odd) harmonics each having its own symmetry plane
- Higher harmonics more sensitive to the value of shear viscosity



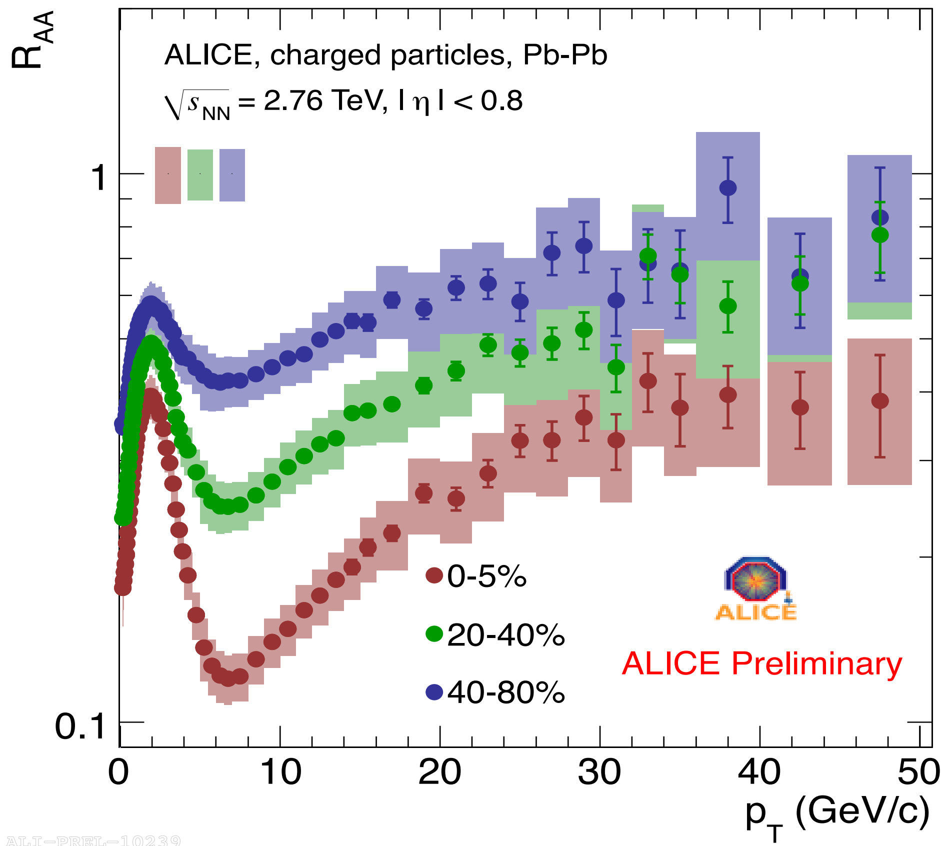

- But…initial conditions not known precisely enough (model dependent)
  - Data can be described by different combinations of initial conditions + η/s

- LHC offers the possibility to study hard processes
  - larger cross sections for high-$p_t$ and larger mass particles
- Two ways of studying the medium effects
  - Compare yields of high-$p_t$ particles in A-A to pp collisions
  - Jet reconstruction



$$R_{AA}(p_t) = \frac{\left(1/N^{AA}_{events}\right) d^2N^{AA}/dp_t d\eta}{\langle N_{coll}\rangle \left(1/N^{pp}_{events}\right) d^2N^{pp}/dp_t d\eta}$$

- At low $p_t$: $R_{AA} < 1$ and rising due to thermal production
- At high $p_t$: $R_{AA} = 1$ in case there are no modifications from the medium




- ❑ Clear deviation of $R_{AA}$ from unity, even for peripheral events
- ❑ Larger suppression for central collisions
- ❑ Consistent with the picture of radiative energy loss due to increasing path length of partons in the medium

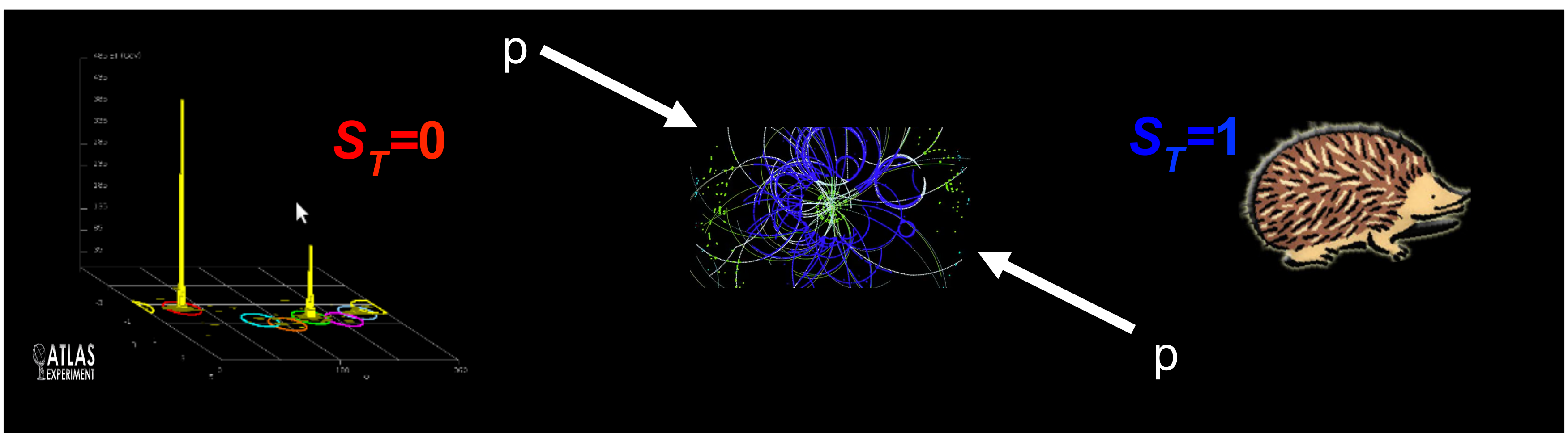
# Global Properties of High-multiplicity events in ALICE

Transverse Sphericity:

$$\mathbf{S^{L}_{xy}} = \frac{1}{\sum_i p_{Ti}} \sum_i \frac{1}{p_{Ti}} \begin{pmatrix} {p_{xi}}^2 & p_{xi}p_{yi} \\ p_{xi}p_{yi} & {p_{yi}}^2 \end{pmatrix}$$

$$S_T \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$

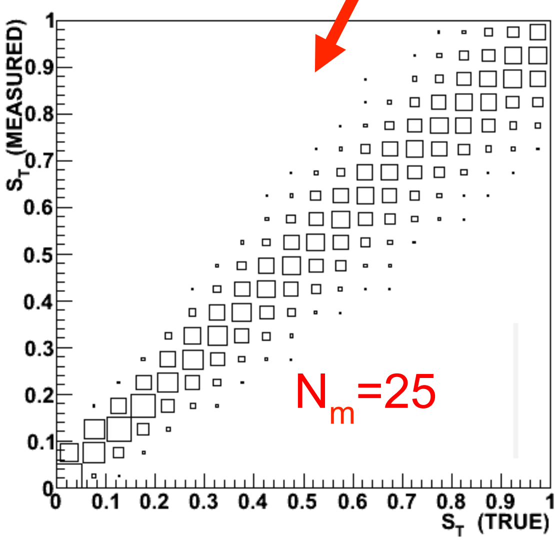
**Remarks:** linearized version, IR&C safe

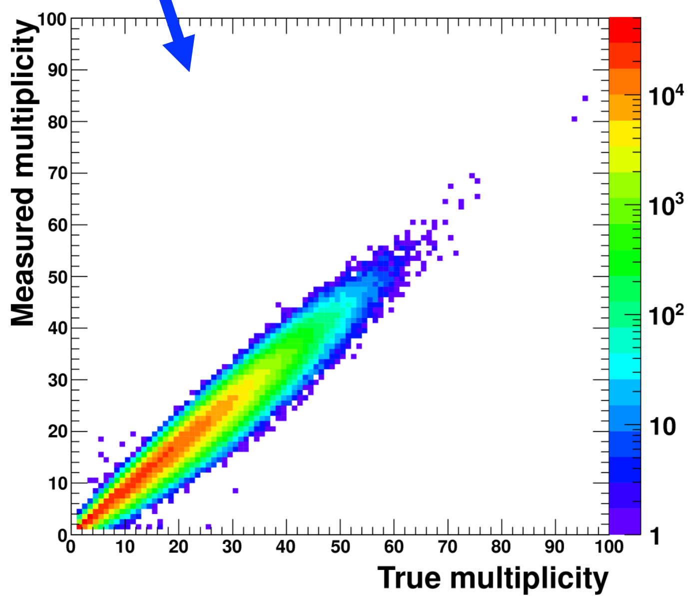


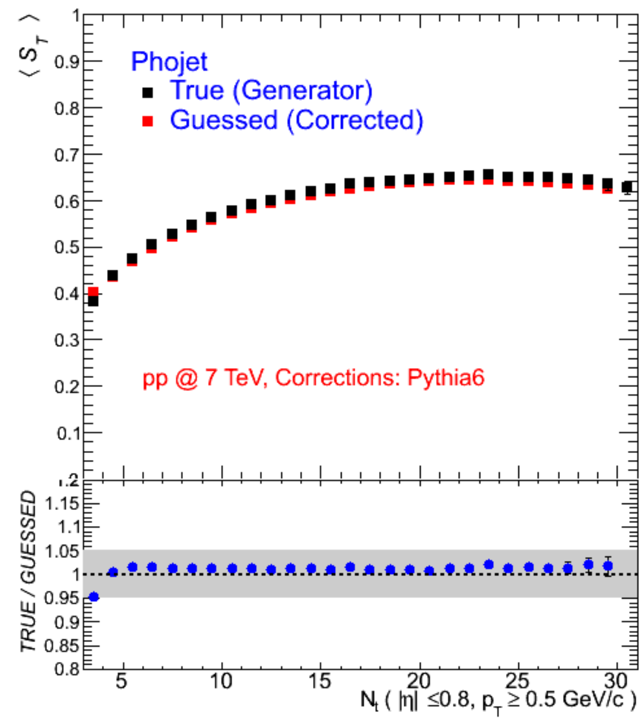
# The goal is to measure the average sphericity as a function of multiplicity...

Correction procedure:

$$\langle S_T\rangle(N_t) = \sum_m \langle S_T^{unfolded}\rangle(N_m)\, R(N_t, N_m)$$



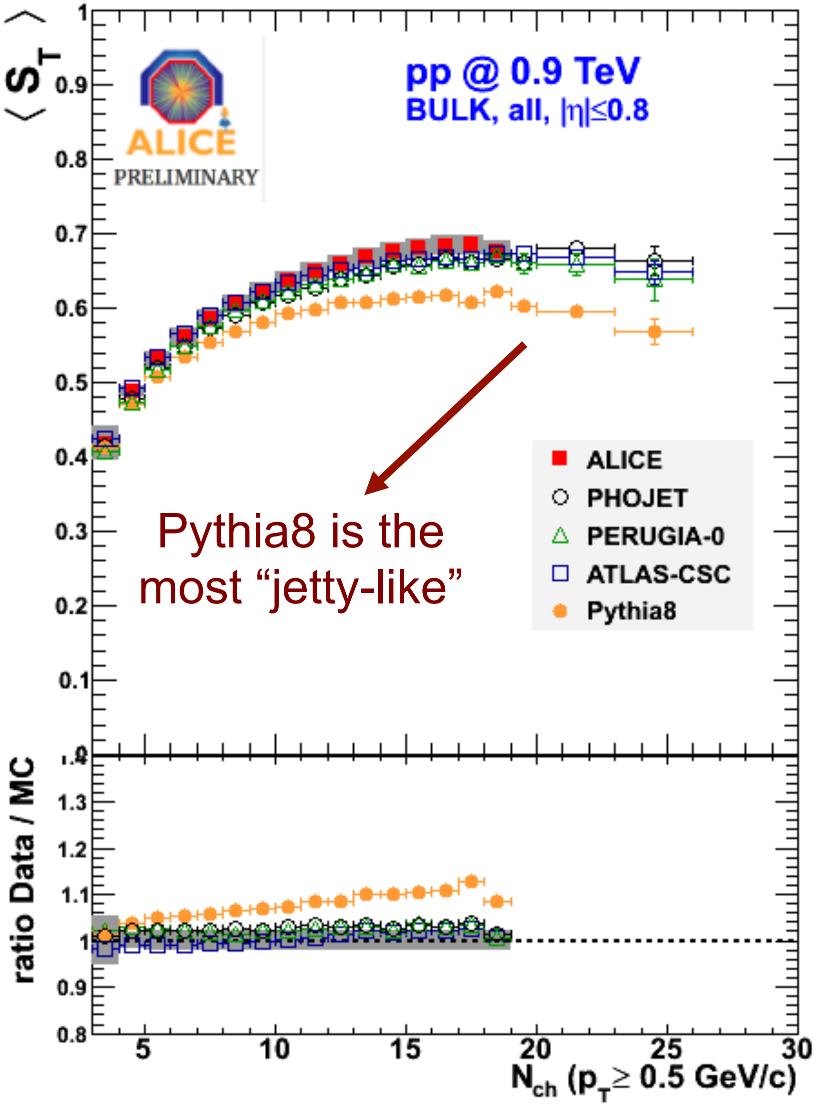



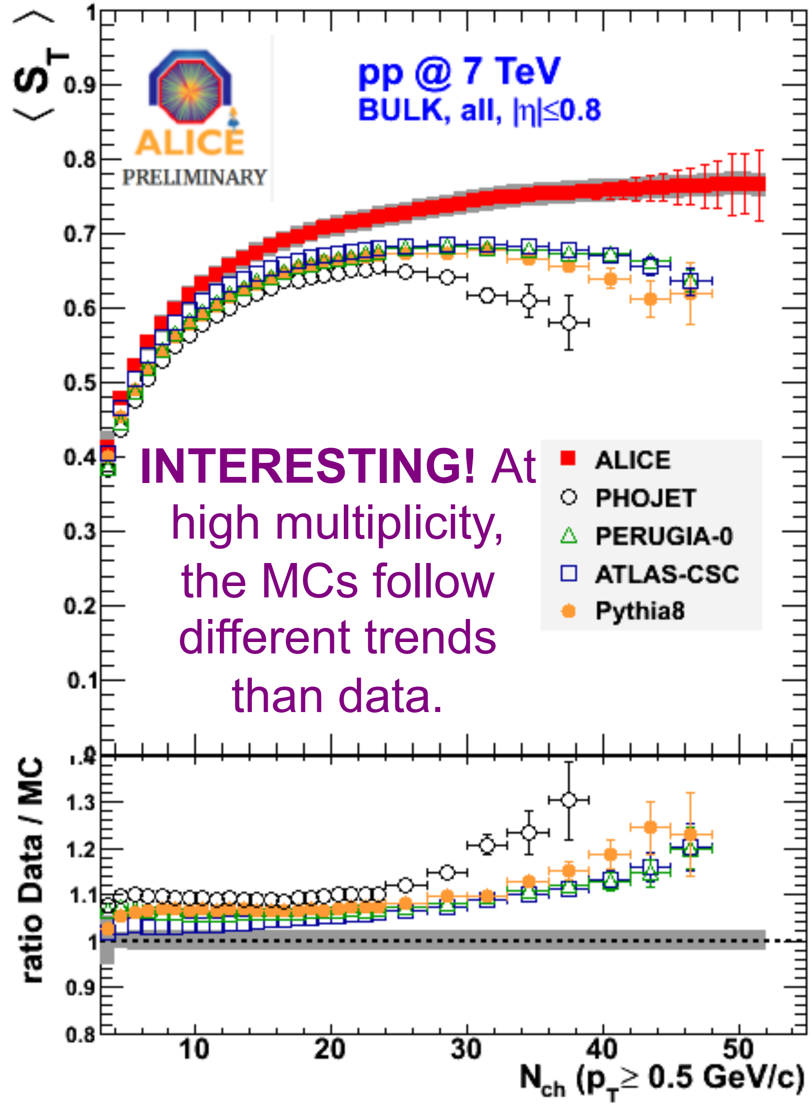

1. Unfolding of $S_T$ spectra.

2. Correction by multiplicity.

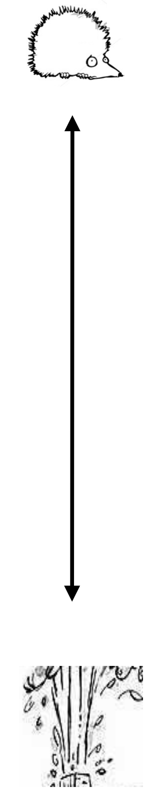
# Evolution of $<S_T>$ with the multiplicity

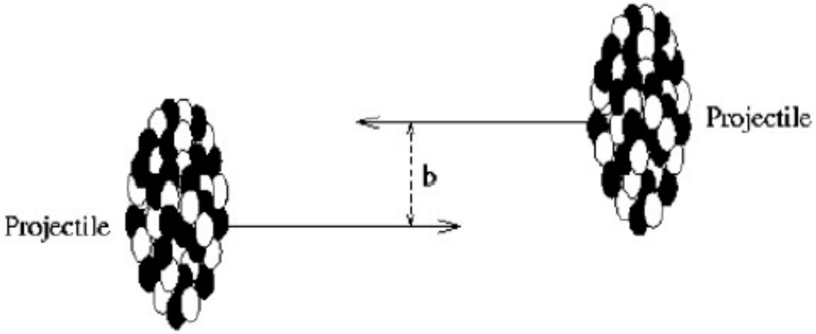



Pythia8 is the most “jetty-like”



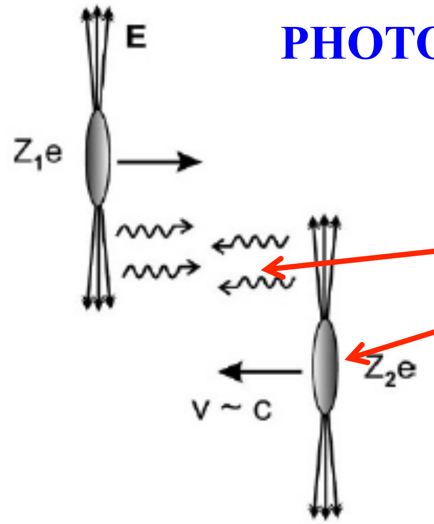

**INTERESTING!** At high multiplicity, the MCs follow different trends than data.



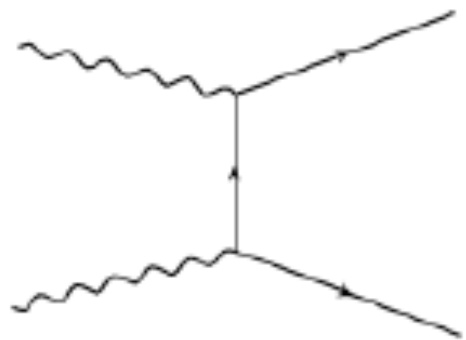




**The ultra peripheral collisions occur if b >R1+R2 ➔ the photons and nuclei can interact in several ways.**

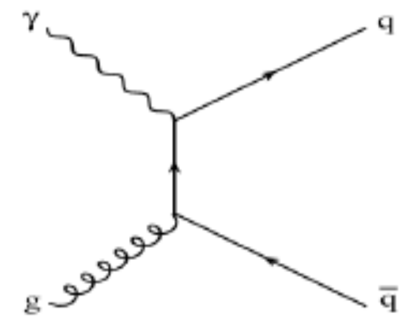
## PHOTON-PHOTON COLLISIONS



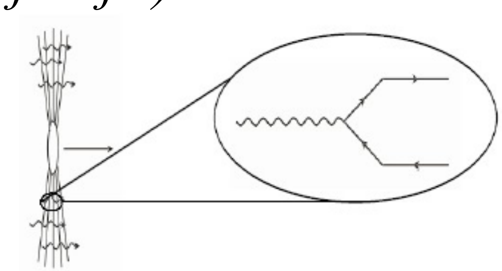

**Two ions (or protons) pass by each other with impact parameters b > 2R**



1. Electromagnetic interaction: $\gamma + \gamma$

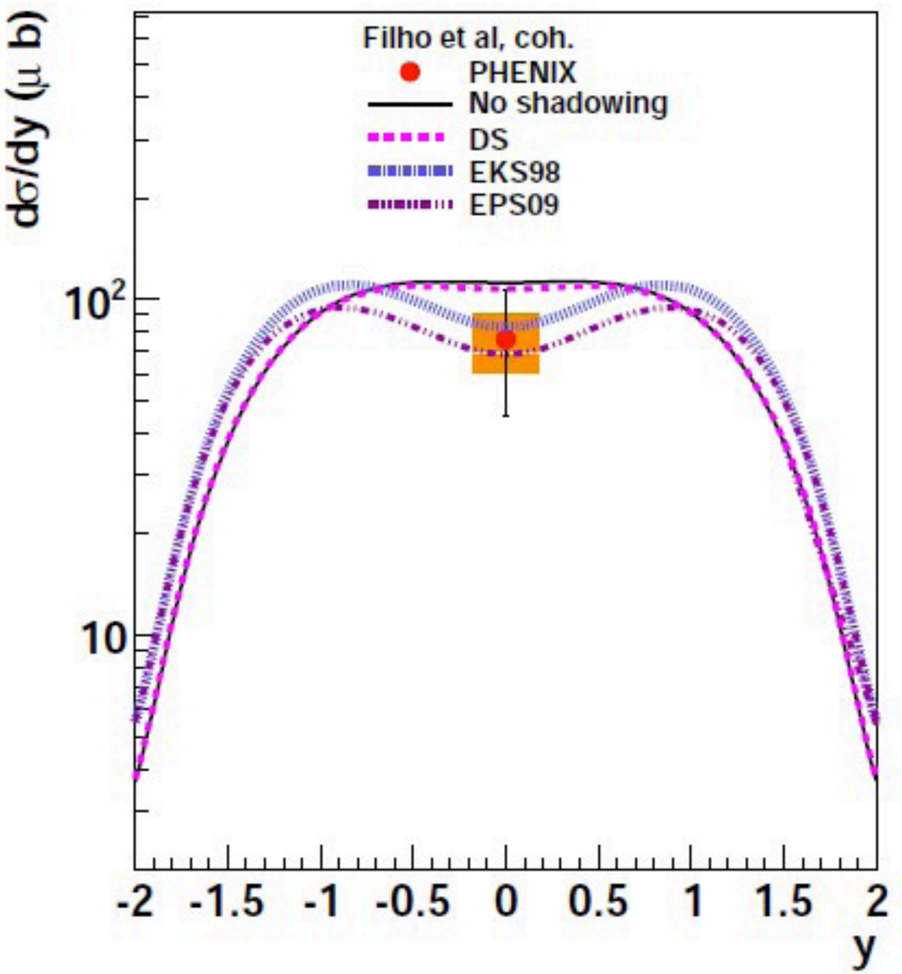


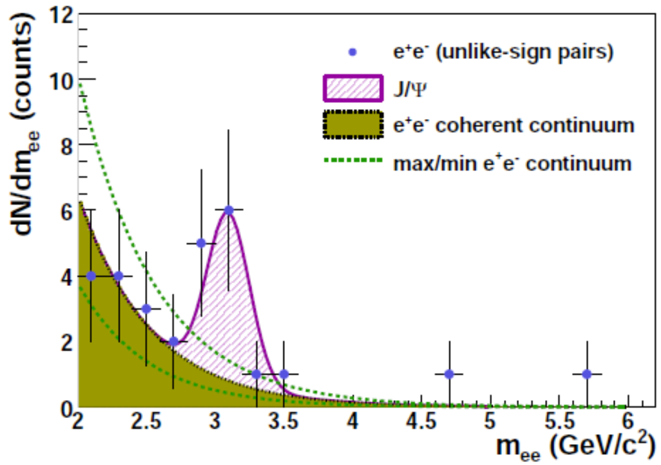

2. Direct photonuclear interaction: $\gamma$ +*parton* ($\gamma$+*g* → *qq*, *g*+*q* →*jet*+*jet*)



3. Resolved photonuclear interaction (VMD), elastic or inelastic

# RHIC - PHENIX RESULTS




- Two processes
  - **Coherent:** $\gamma + A \rightarrow J/\psi + A$
  - **Incoherent:** $\gamma + A \rightarrow J/\psi + X$, dominated by $\gamma + N \rightarrow J/\psi + N$
- Predicted cross sections
  - Models differ by the way shadowing is taken into account

*Au+Au collisions at 200 GeV*
*PHENIX study:*
*PLB Vol 679, issue 4, p. 321-333*

## Probe the gluon distribution of the nuclei

Total J/ψ cross section: 23 mb (STARLIGHT) *v* 10.3 mb Strikman, Zhalov, et al.

$$\frac{d\sigma_{\gamma T\to J/\psi T}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{em}M^5_{J/\psi}}\left[\alpha_s(\mu^2)xG_T(x,\mu^2)\right]^2$$

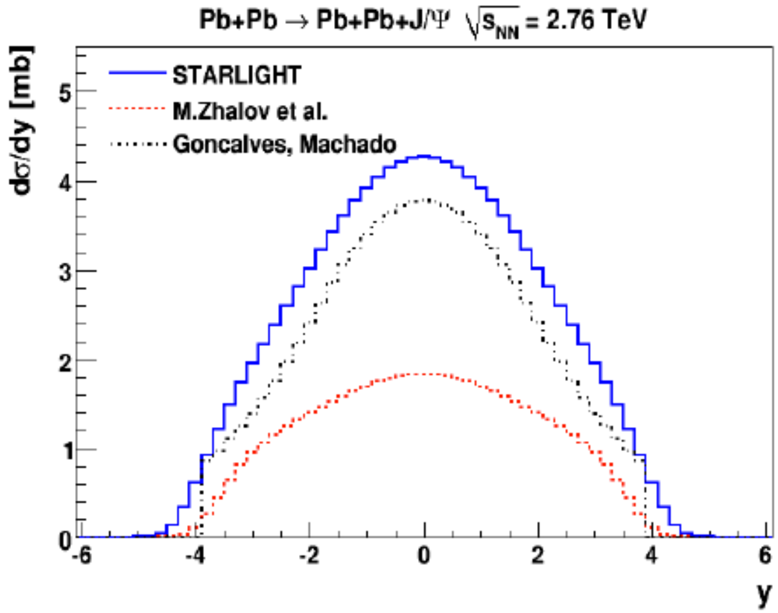
At leading order perturbative QCD, it depends quadratically on the gluon distribution

**LHC: W,max ~ 950 GeV**

**HERA: W,max ~ 300 GeV**

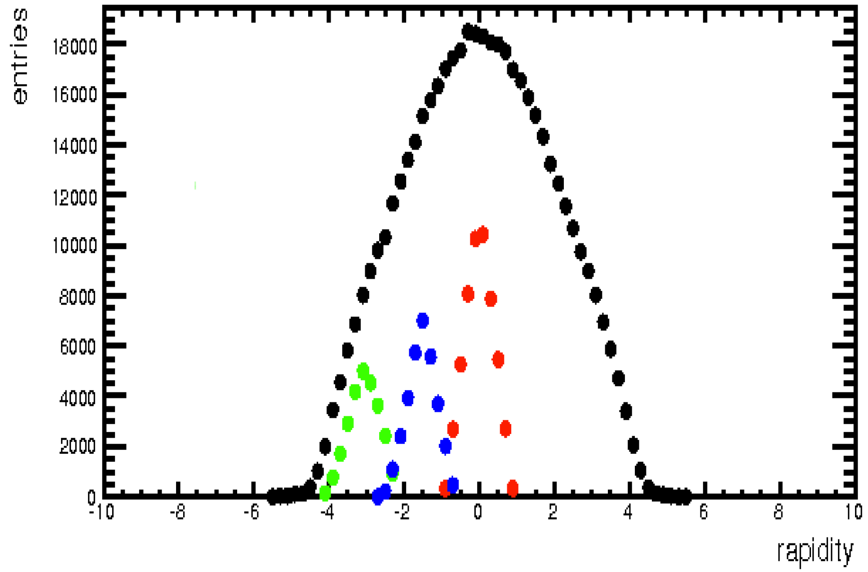
**RICH : W,max ~ 34 GeV**

*STARLIGHT: S.R.Klein, J.Nystrand*
*Phys. Rev. C 60 (1999) 014903.*
*L. Frankfurt, M. Strikman, M. Zhalov*
*Phys. Lett. B 626 (2005) 72.*
*V.P. Goncalves, M.V.T. Machado*
*Phys. Rev. C 84 (2011) 011902.*




Should provide a measure of the nuclear gluon shadowing

# Starlight simulations for coherent *J/ψ*

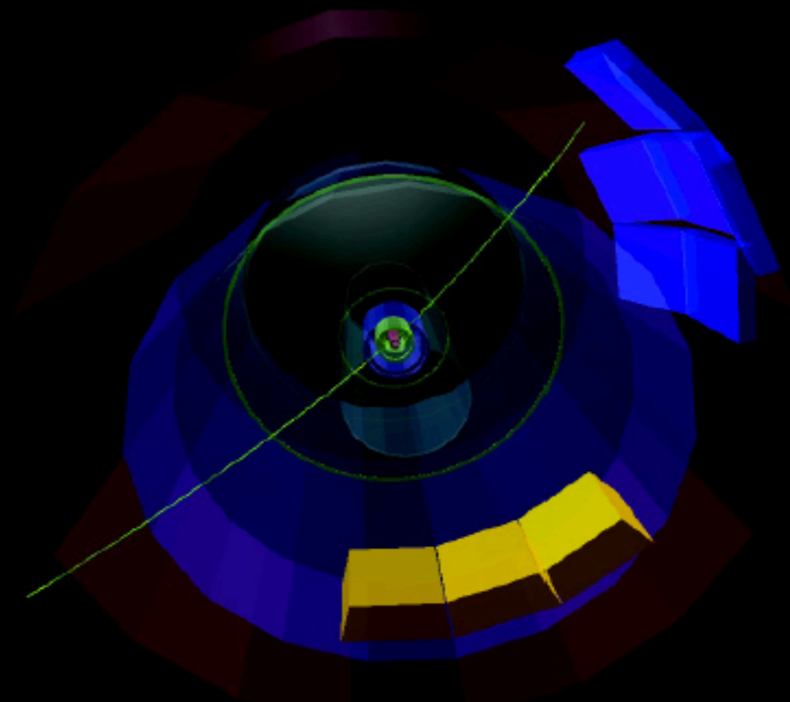


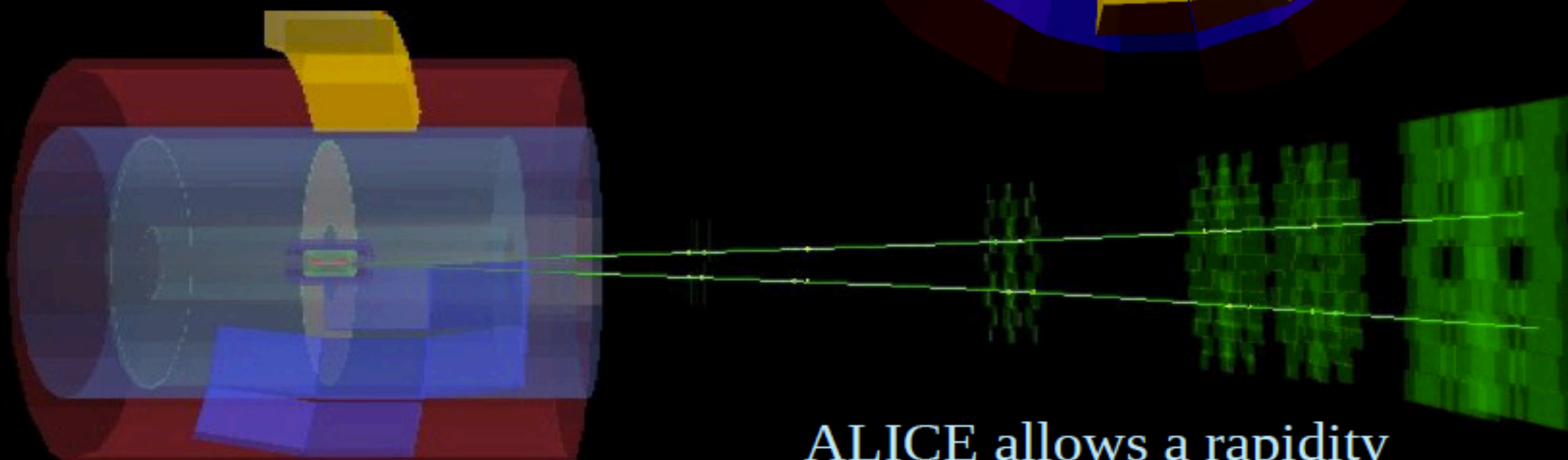

## Three *J/ψ* analysis are possible in ALICE

1. **Both dileptons (muons or electrons) at central rapidity, $-0.9<y<0.9$**
2. **Both muons at forward rapidity, $-4.0 <y< -2.5$**
3. **3.- One forward muon and the other at mid-rapidity**

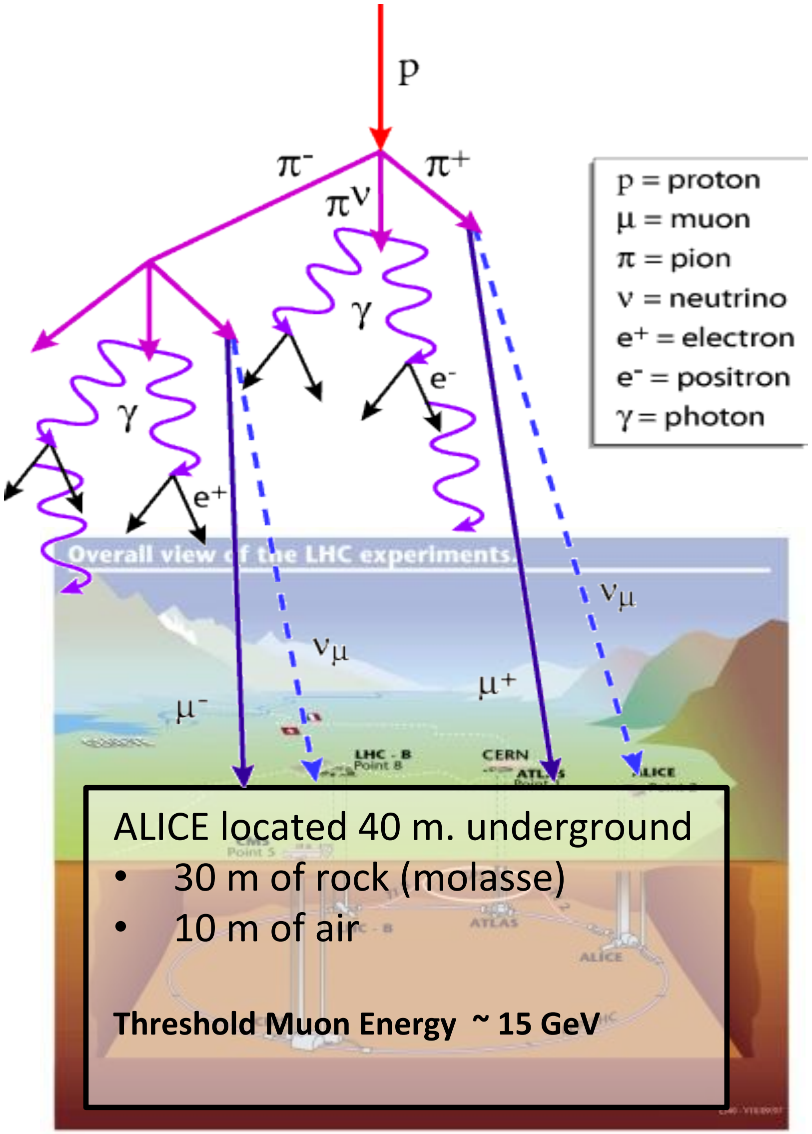
# Exclusive J/ψ production

**Two tracks in otherwise an empty detector**





ALICE allows a rapidity dependence study!




**The bulk of the primary particle production is dominated by forward and soft QCD interactions, modeled commonly in Regge-Gribov-based approaches with parameters constrained by the existing collider data. When extrapolated to energies around the GZK-cutoff, the current MCs predict energy and multiplicity flows differing by factors as large as three, with significant inconsistencies in the forward region.**

**With the ALICE's detectors it is possible to detect those muons coming from the cosmic ray that reaches the P2.**

**Topics of interest in Cosmic ray analysis in ALICE:**

- ❑ **Muon multiplicity distribution**
    - ❑ **Study of cosmic muon bundles**
- ❑ **$\mu^+/\mu^-$ charge ratio measurement**
- ❑ **Study of cosmic horizontal muons**

- Two main aspects in which ALICE can be involved in the physics of cosmic rays
- Better knowledge - through the study of pp, pA and AA collision events - of the hadronic interactions at high energy

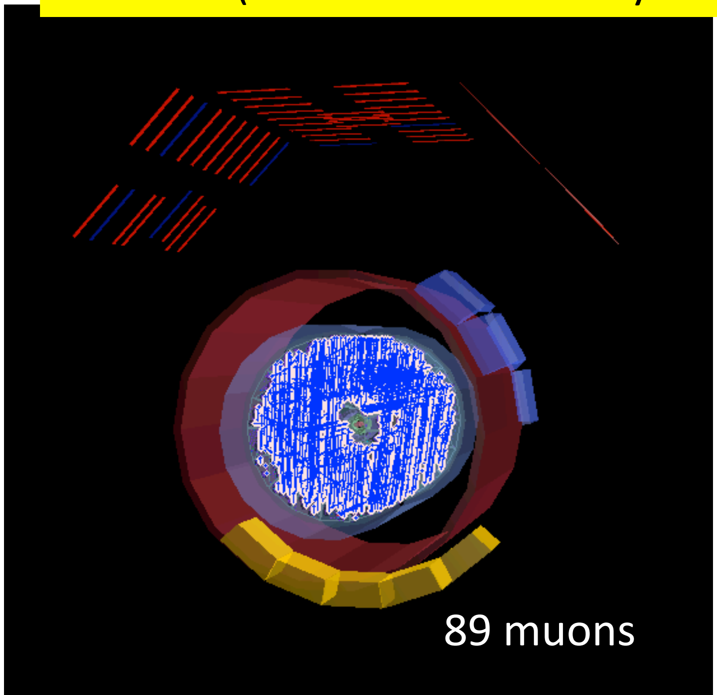
----> interest in the interaction of CR with atmosphere

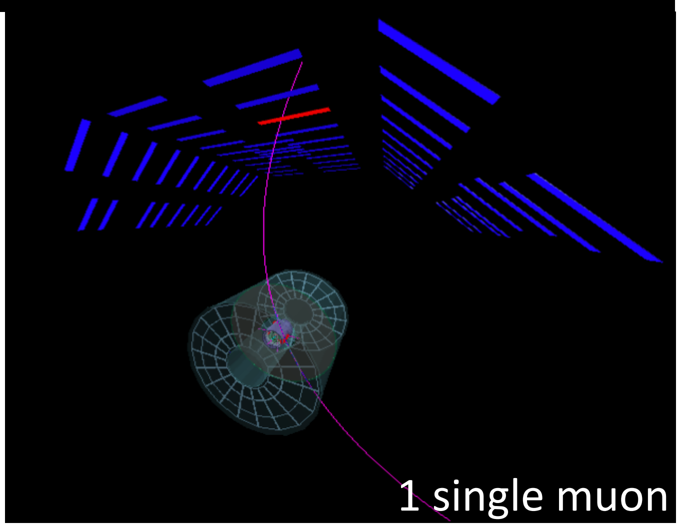
- Measurements of cosmic rays with ALICE itself and (possibly) additional detectors

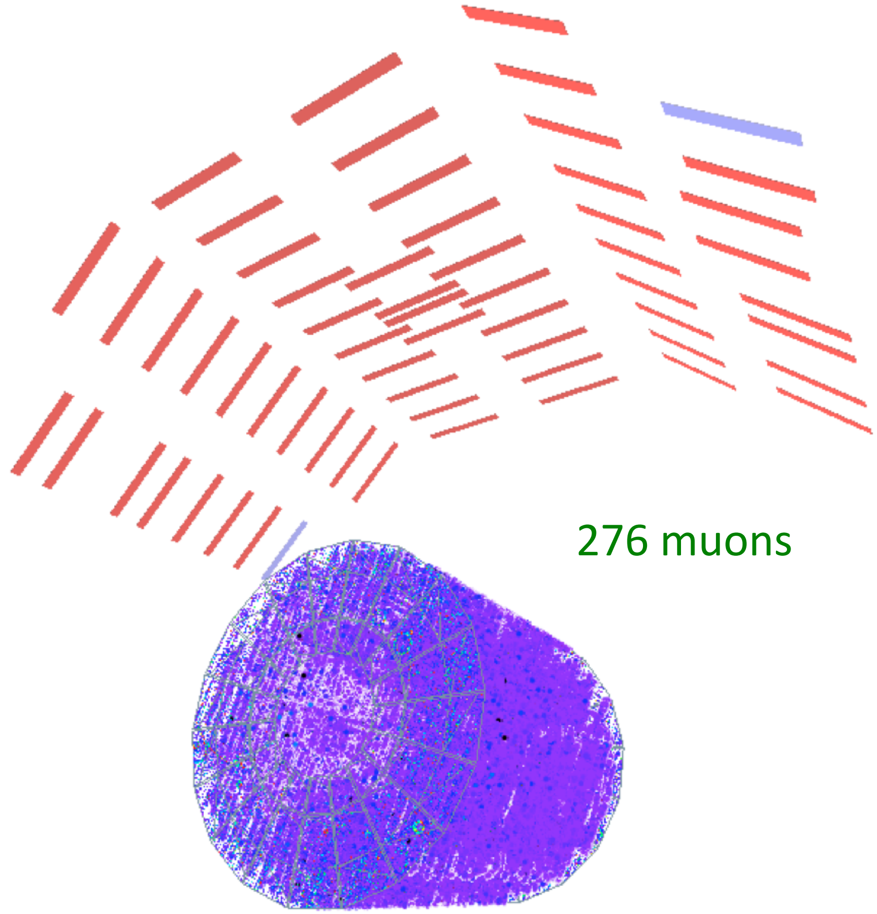
---> properties of the muon spectrum at ground

- Additional use of cosmics in ALICE for calibration and alignment
- Transport equations describe the propagation of particles through the atmosphere, resulting in a muon flux (zenith angle and energy dependent) and muon charge ratio at sea level.
- Muon momentum spectrum
- Muon charge ratio

# ACORDE (the Alice Cosmic Ray DEtector)



276 muons

Visualization of the events triggered by ACORDE and reconstructed by the TPC

# Quark Matter Conference

# ALICE @ QM2012

**6 more plenary talks:**

- S Voloshin — Flow overview
- A Morsch — Jets and Jet structure
- M Ivanov — Identified particle spectra
- Z Conesa del Valle — Heavy flavour
- E Scomparin — Quarkonia production
- A M Adare — Correlations

**30 parallel talks**

**Global and collective dynamics**

- M R J Guilbaud, dN/dη at large pseudo-rapidity
- M Broz, Anti-baryon to baryon ratio
- L Milano, Identified particle production
- S Singha, Strangeness production
- B Doenigus, (Anti-)hyper nuclei

**Azimuthal flow**

- A F Dobrin. Event shape engineering
- Y Hori, Charge dependent azimuthal flow
- F Noferini, Identified particle azimuthal flow
- A Bilandzic, Multi-particle azimuthal correlations
- A Hansen, Anisotropic flow in pseudo-rapidity

**Correlations and fluctuations**

- M Weber, Charge fluctuation and balance function
- M P Szymanski, Baryon and meson femtoscopy

# ALICE @ QM2012

**High $p_T$ identified particles**
- D Peresunko, Neutral meson production
- A Ortiz Velasquez ,High $p_T$ PID spectra

**Jets**
- N Arbor, Photon–charged hadron correlations
- R Reed, Inclusive jet spectra
- L Cunqueiro Mendez, Jet structure
- F Krizek, Jet fragmentation with particle correlations
- J G Ulery, Jet–medium correlations

**Heavy flavours**
- G M Innocenti, $D_s$ production
- A Grelli, D meson $R_{AA}$
- D Caffarri, D meson elliptic flow
- X Zhang, Heavy flavour muons $R_{AA}$ and elliptic flow
- S Sakai, Heavy flavour electrons $R_{AA}$ and elliptic flow

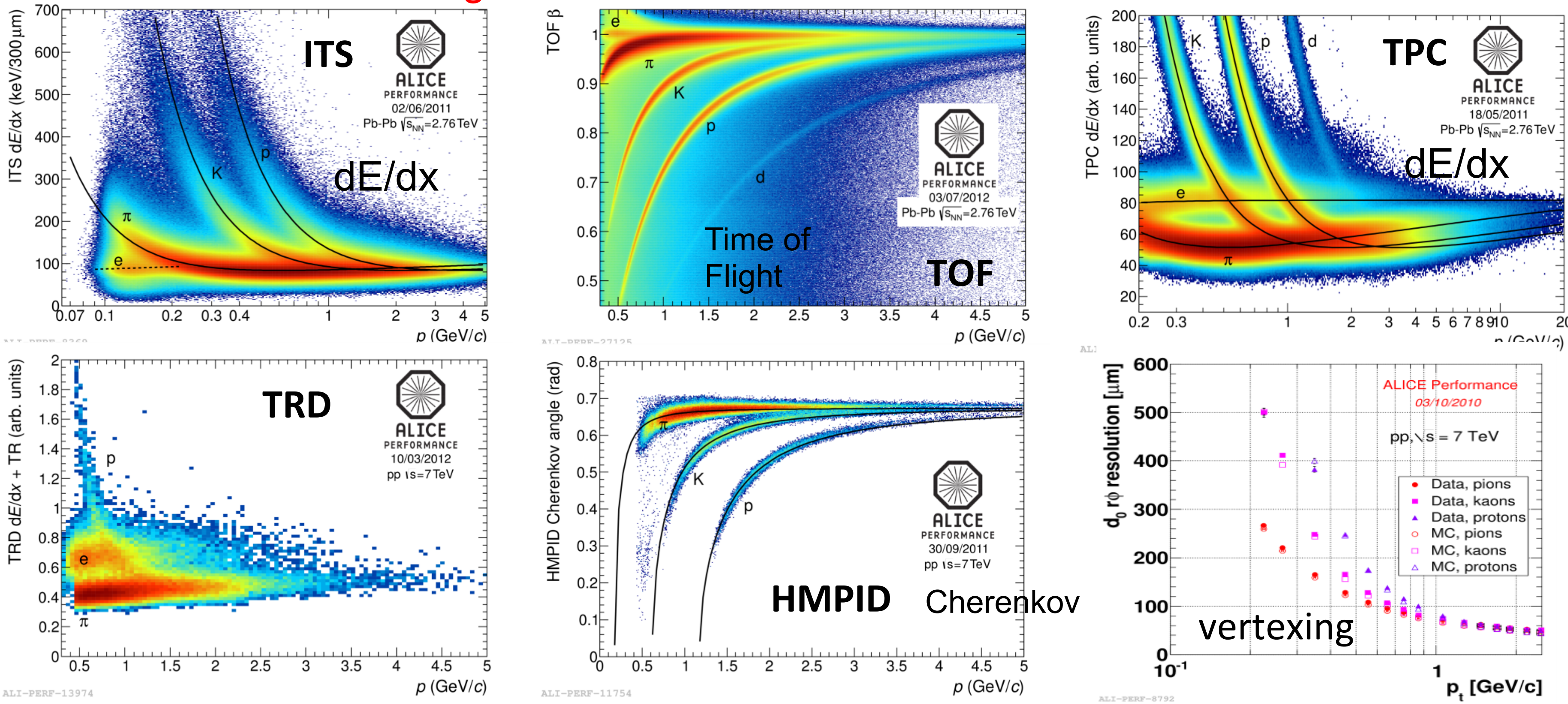
**Quarkonia**
- R Arnaldi, J/y and y' in forward region
- I Ch Arsene, J/y at mid-rapidity
- H Yang, J/y elliptic flow in forward region

**Direct photons**
- M R Wilde, Direct photons

**Detector upgrade**
- Th Peitzmann Upgrade of ALICE detector
- R C Lemmon, ITS upgrade

**… and 45 posters**

The design is optimized for reconstruction and identification of particles in a wide range of transverse momentum.



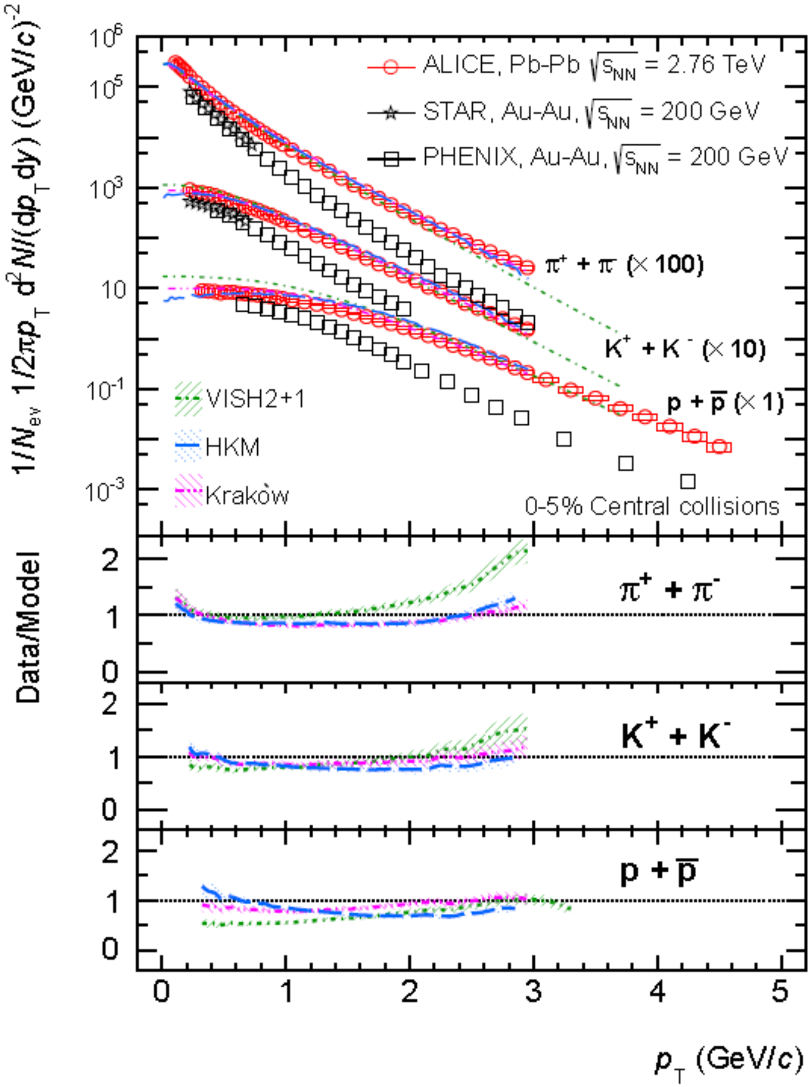

- particle identification (practically all known techniques)
- extremely low-mass tracker ~ 10% of $X_0$
- excellent vertexing capability
- efficient low-momentum tracking – down to ~ 100 MeV/$c$

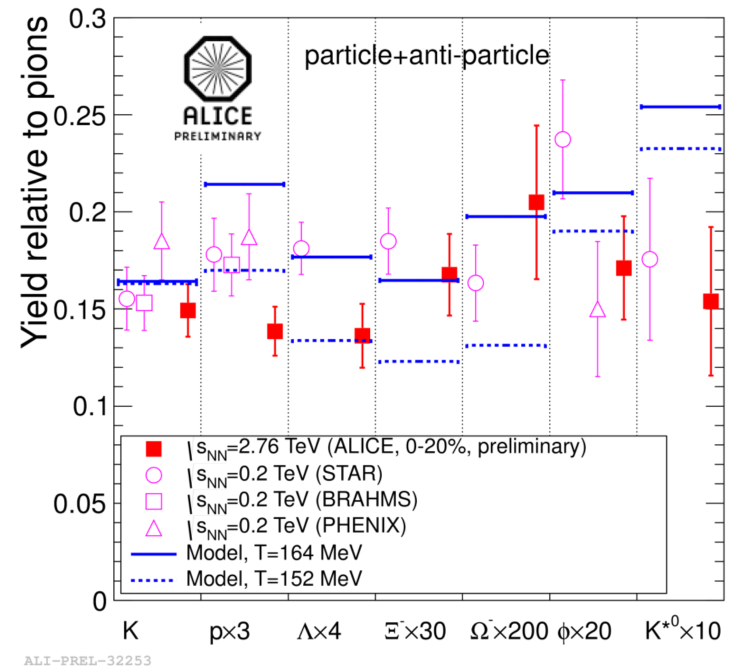
# LHC Heavy-Ion running

- Two heavy-ion runs at the LHC so far:
  - in 2010 – commissioning and the first data taking
  - in 2011 – already above nominal instant luminosity!
- p–Pb run moved to beginning of next year
  - plan for ~ 30 $nb^{-1}$
    - (for rare-probe statistics equivalent to ~0.15 $nb^{-1}$ of Pb–Pb)
- Followed in 2013 by Long Shutdown–1 (LS1)

| year | system | energy $\sqrt{s_{NN}}$ TeV | integrated luminosity |
|---|---|---|---|
| 2010 | Pb – Pb | 2.76 | ~ 10 $mb^{-1}$ |
| 2011 | Pb – Pb | 2.76 | ~ 0.1 $nb^{-1}$ |
| 2013 | p – Pb | 5.02 | ~ 30 $nb^{-1}$ |

# Studying the collective and thermal properties of the matter (low pT)



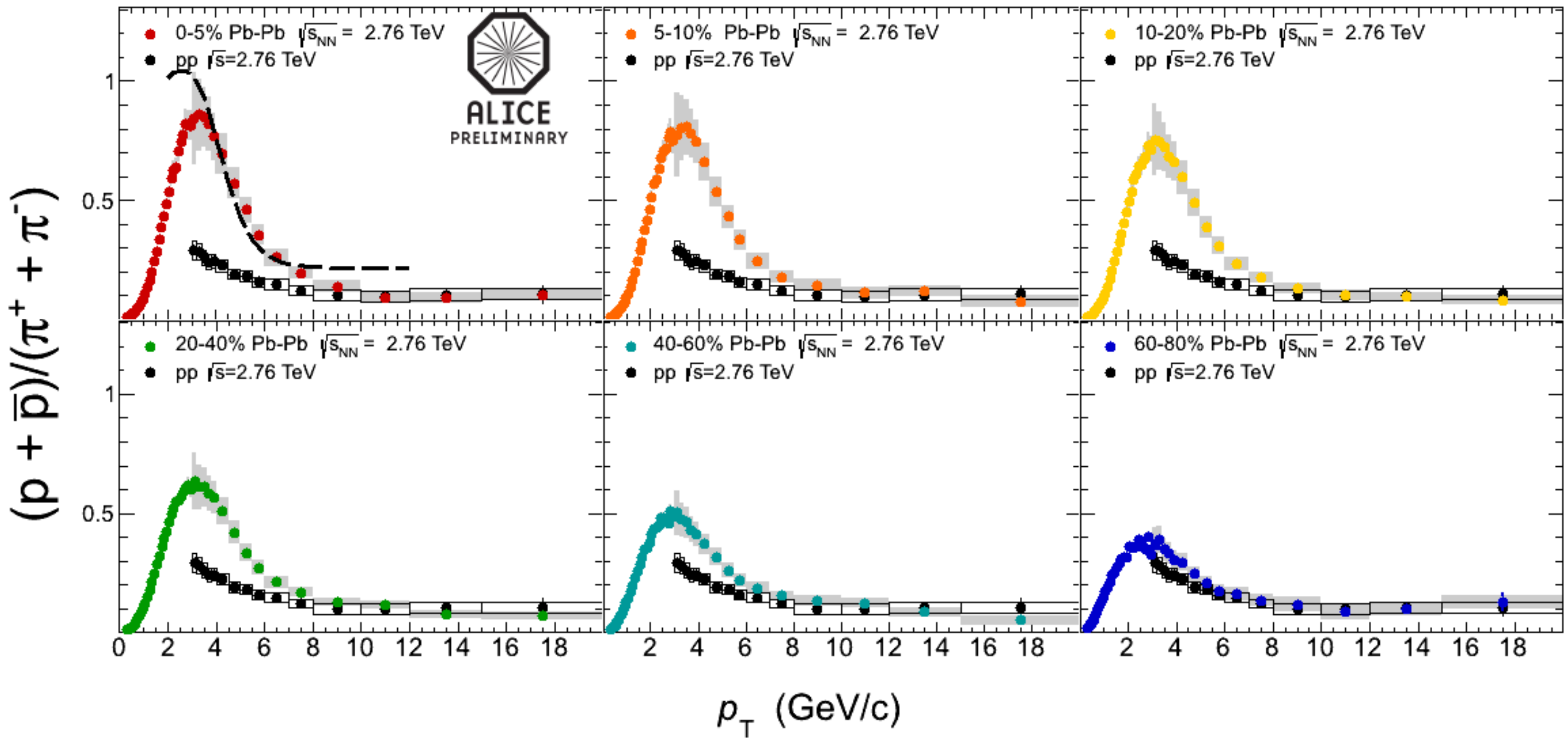




Predicted temperature T=164 MeV
*A.Andronic, P.Braun-Munzinger, J.Stachel NP A772 167*
Thermal fit (w/o res.): T=152 MeV ($\chi^2/ndf$ = 40/9)
Ξ and Ω significantly higher than statistical model

p/p and Λ/p ratios at LHC lower than at RHIC
Hadronic re-interactions ?
*F.Becattini et al. 1201.6349 J.Steinheimer et al. 1203.5302*

# Intermediate pT (recombination ↔ fragmentation?)

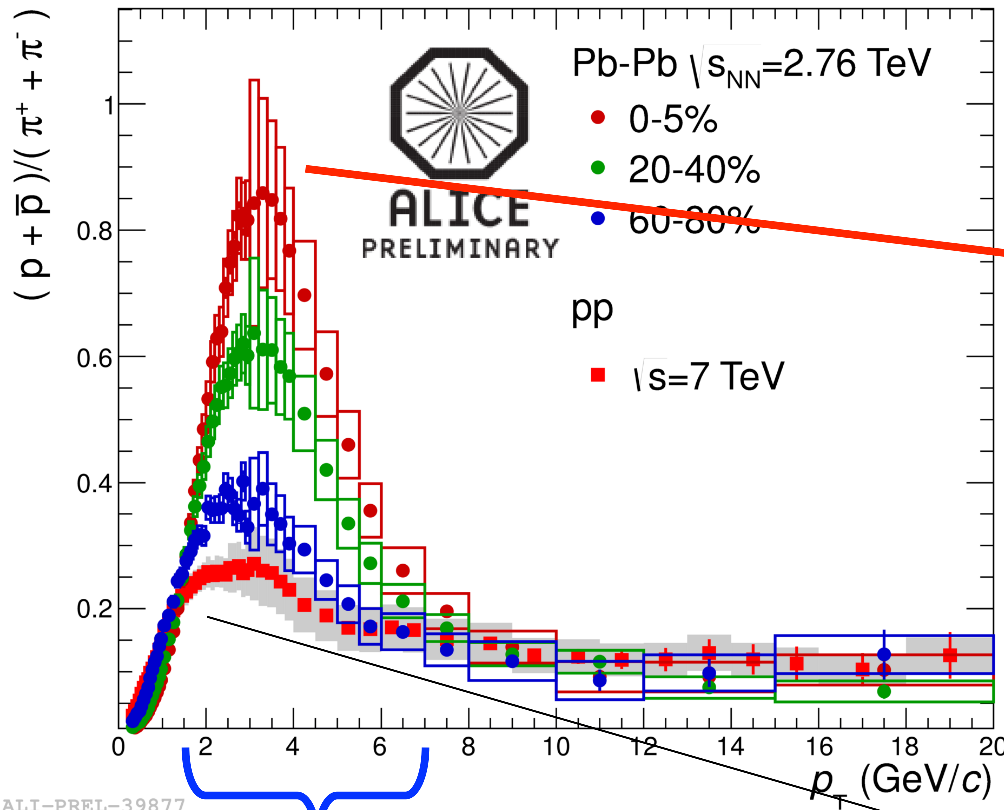
## Baryon-to-meson ratio: p/π

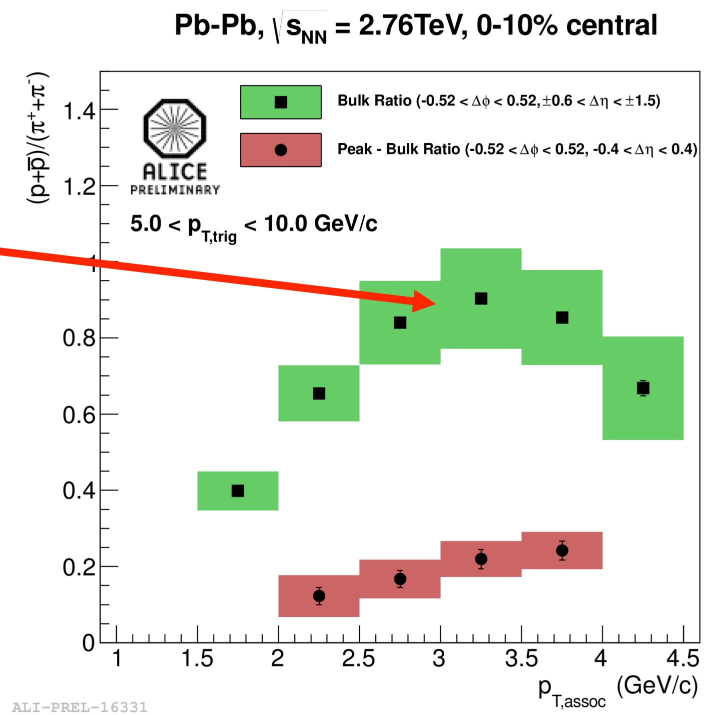



Enhancement of the p/π ratio at $p_T \approx 3$ GeV/$c$ (in 0–5% factor ~ 3 higher than in pp).
At $p_T$ above ~ 10 GeV/$c$ w/o medium effect

In general the recombination model does not describe data.

# Is p/π enhancement a bulk or jet effect?



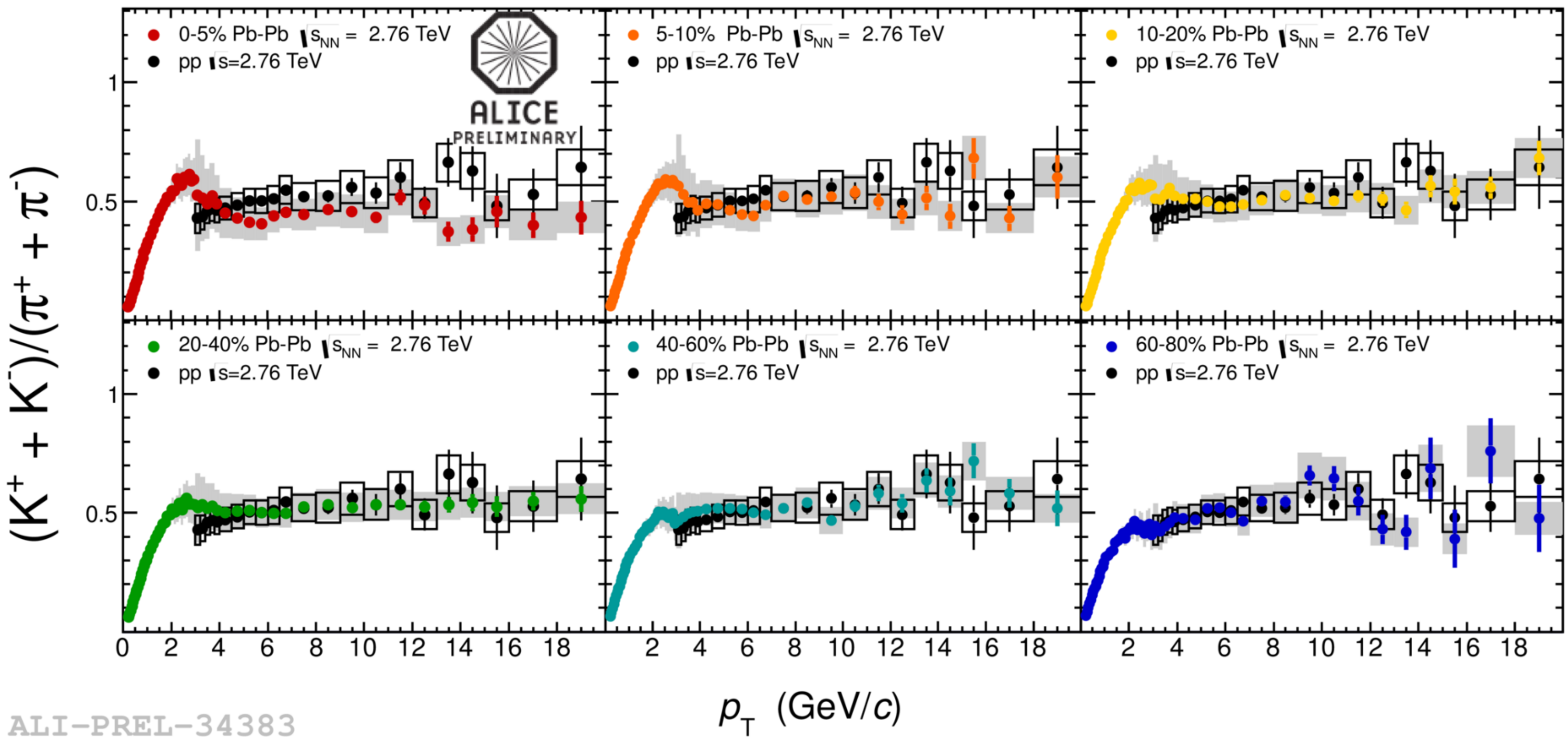




Particle production in jets is not affected by medium.

The enhancement seems to be a bulk effect (arXiv:1207.7195).

Small enhancement in pp?

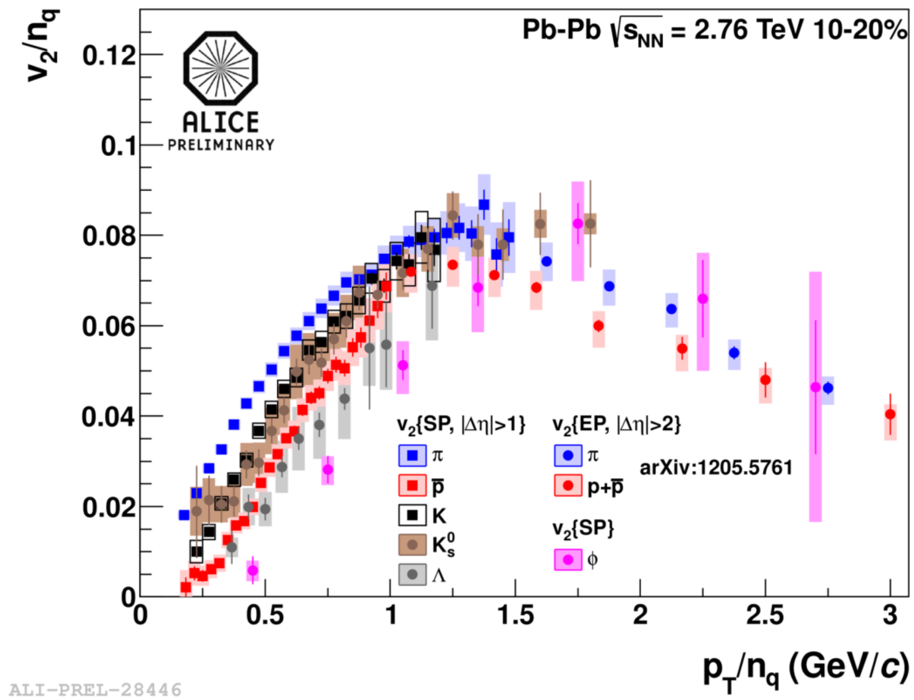
Studying the fraction of strange to non-strange particles

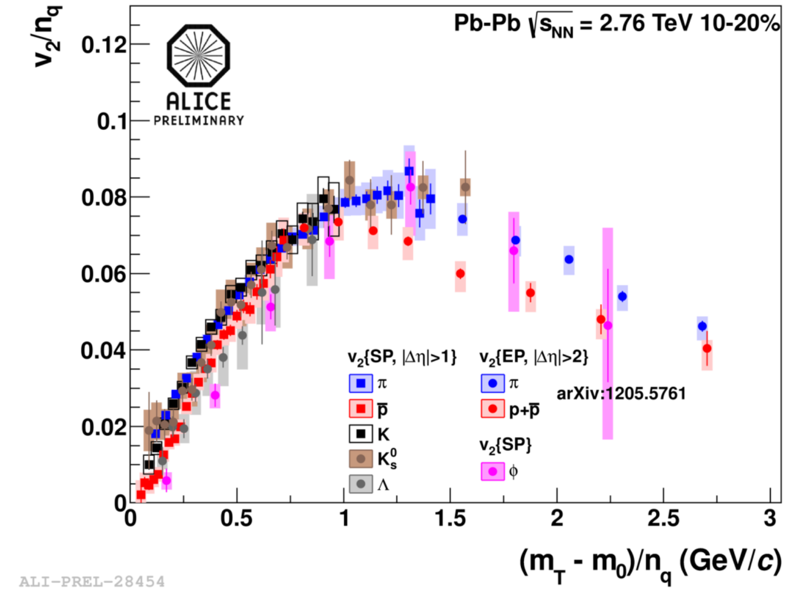



In the intermediate $p_T$ region: 2-7 GeV/c, the ratio exhibits an evolution from the most central to the most peripheral Pb-Pb collisions (radial flow?).

Ratio for pp seems to be the same as the Pb-Pb (pT>4 GeV/c), very difficult task for MC generators

# Measurement of v2 for different particle species



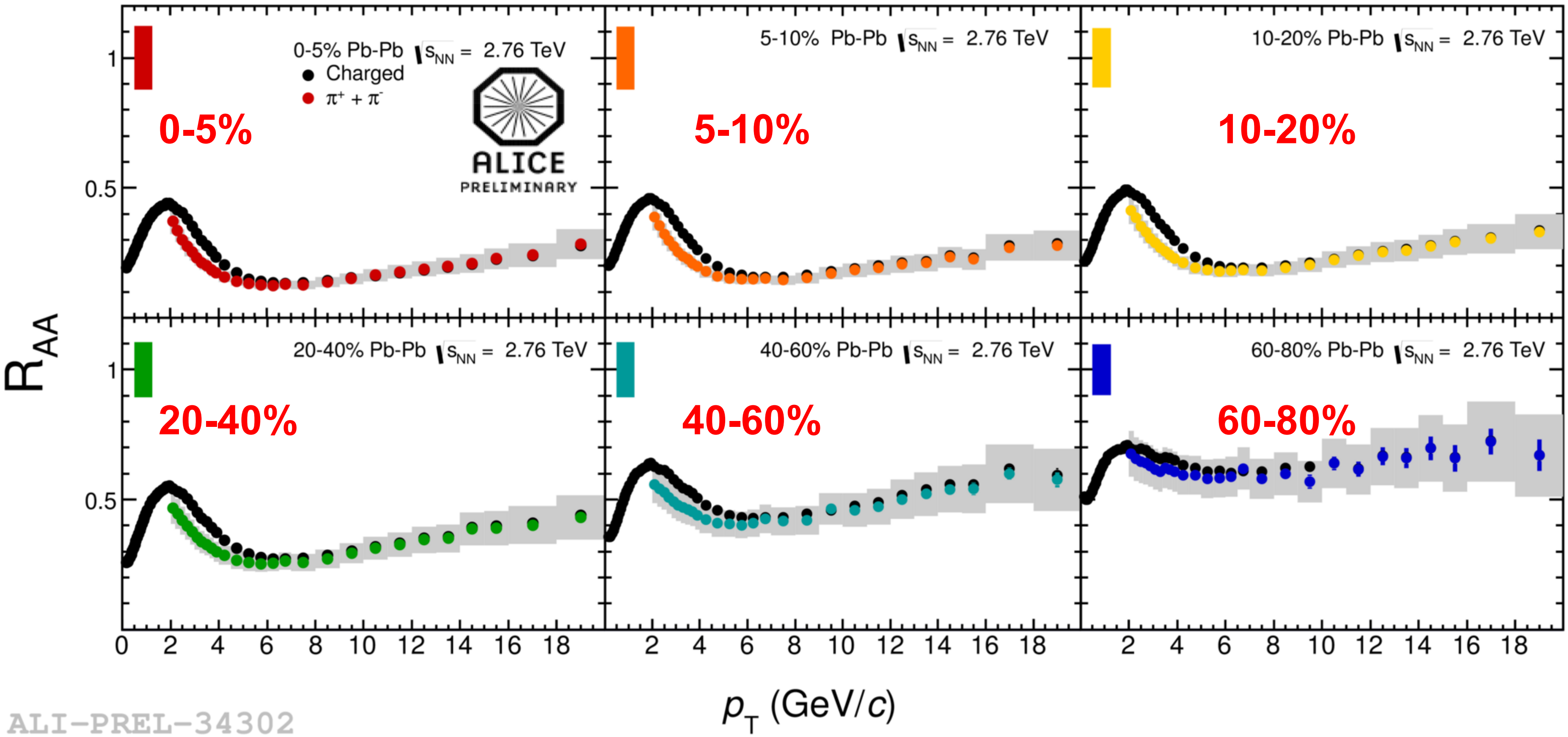




$v_2$ for p, π, K±, $K^0_s$, Λ, ϕ (not shown for Ξ, Ω) at low $p_T$ (<3 GeV/*c*) follows mass hierarchy

*n*q(*m*T)-scaling worse than at RHIC, $n_q(p_T)$-scaling violation (pT>1.2 GeV/c)

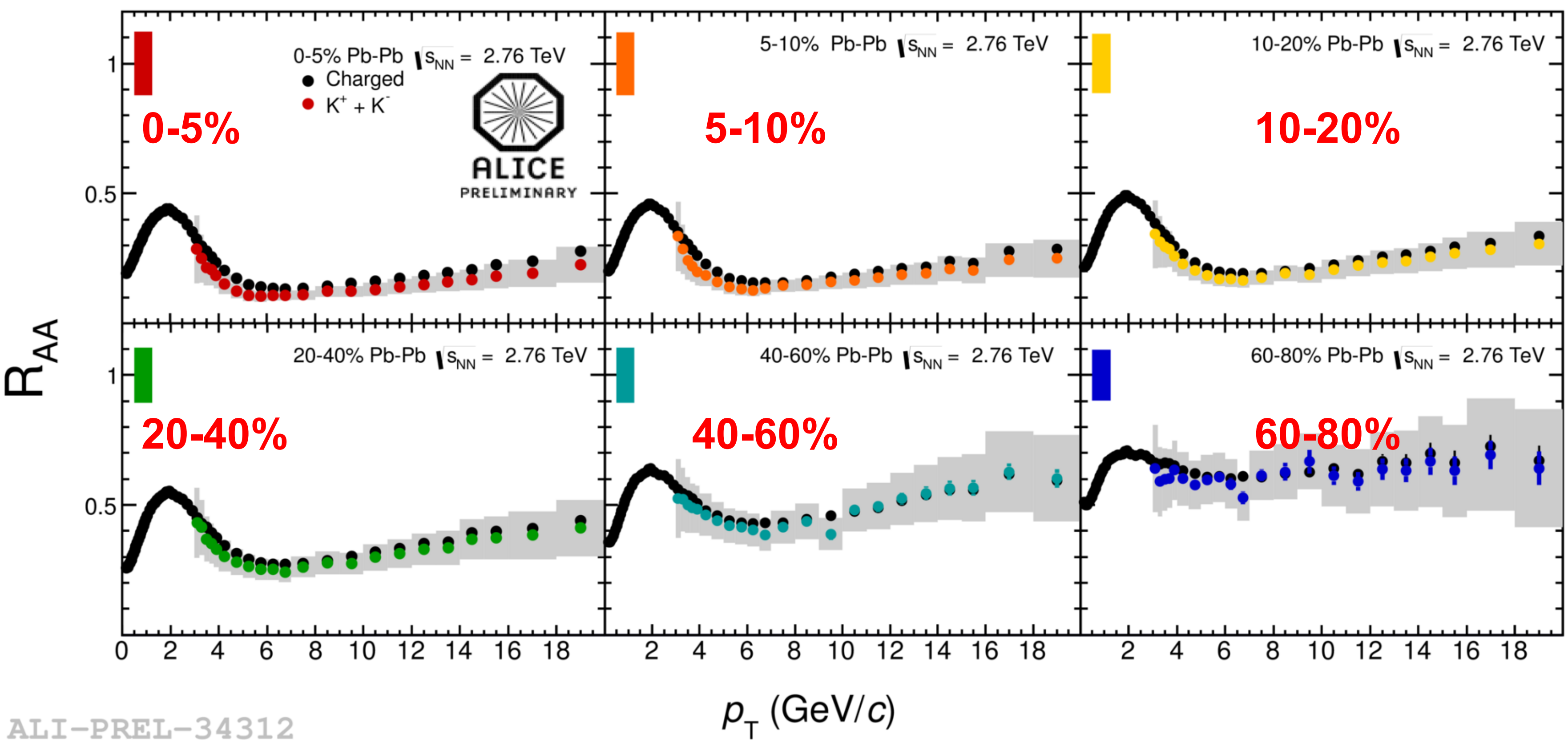
Recombination model predicts $n_q(p_T)$ scaling

# $R_{AA}$ for charged pions



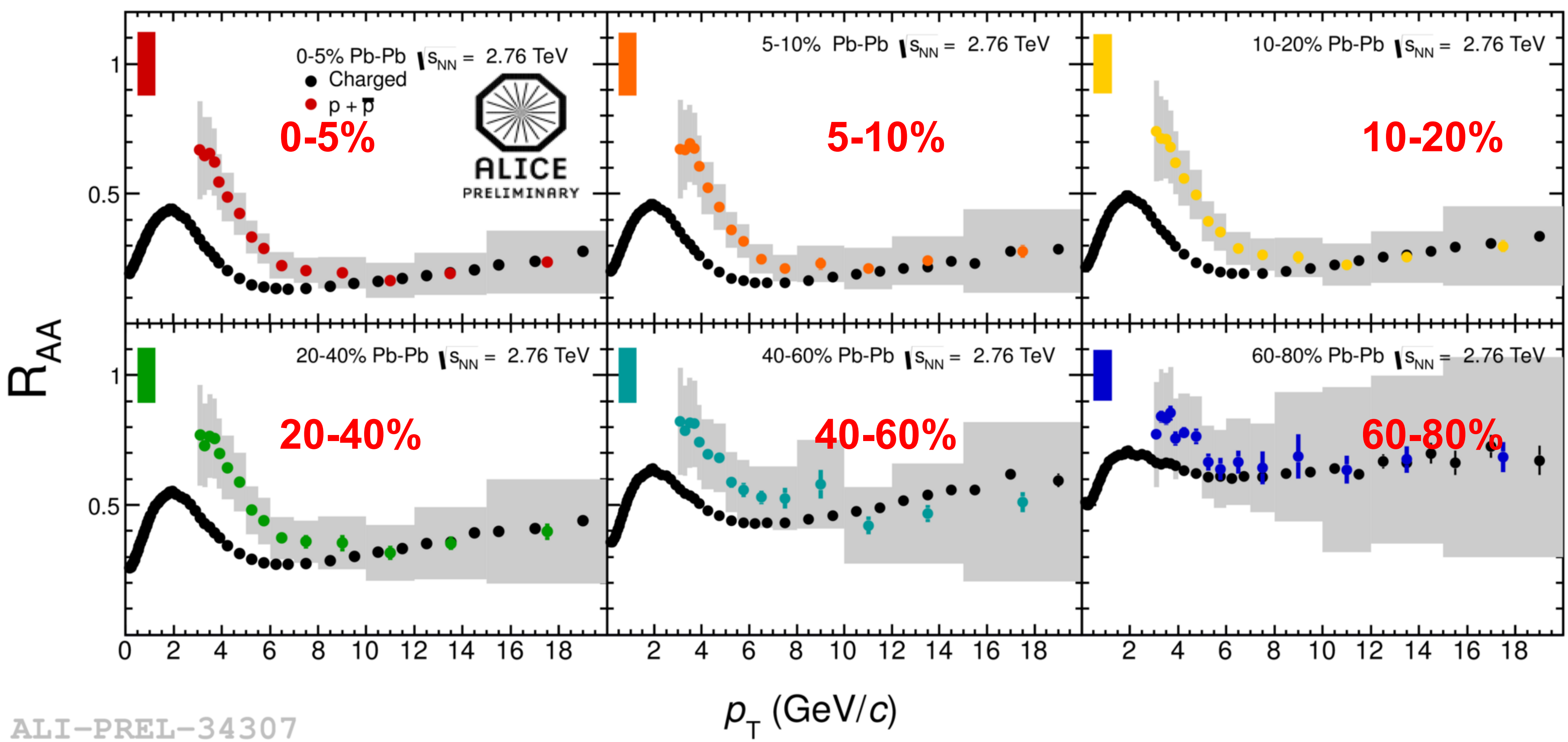

**$p_T$< 7 GeV/c, $R_{AA}$ for charged pions < $R_{AA}$ for inclusive charged particles.**
**$p_T$ > 7 GeV/c, $R_{AA}$ for charged pions ~ $R_{AA}$ for inclusive charged particles.**

# $R_{AA}$ for charged kaons




**$R_{AA}$ for charged kaons compatible with $R_{AA}$ for inclusive charged particles.**

# $R_{AA}$ for (anti-)protons



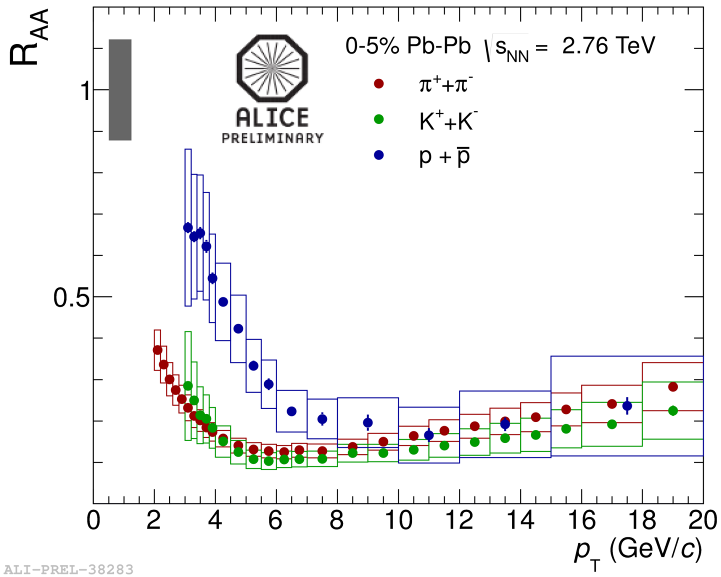

**$p_T < 7$ GeV/c, $R_{AA}$ for (anti-)protons > $R_{AA}$ for charged pions.**
**$p_T > 7$ GeV/c, $R_{AA}$ for (anti-)protons compatible with $R_{AA}$ for inclusive charged particles.**

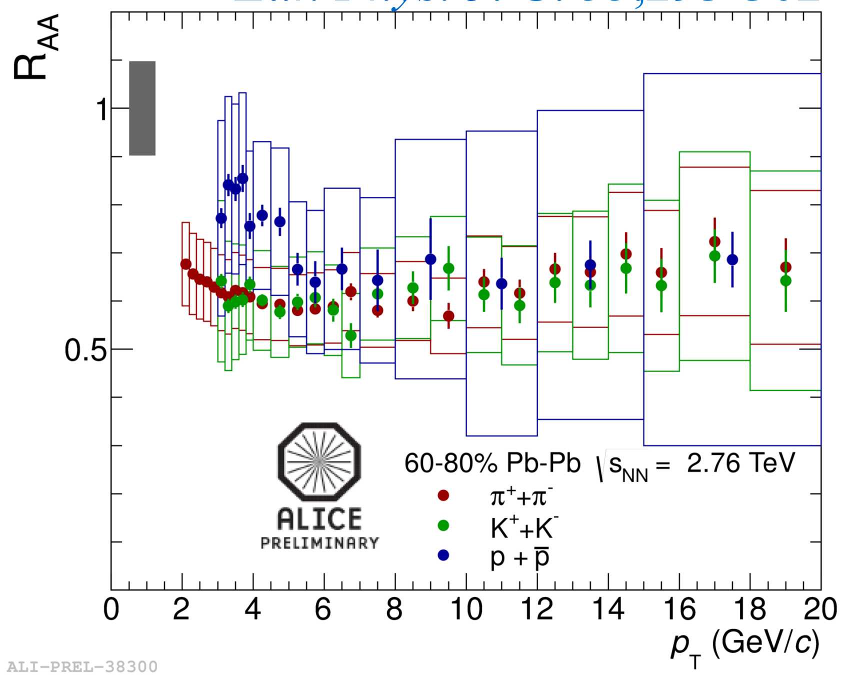
# $R_{AA}$ for π/K/p

**Several medium-induced which can modify the jet hadrochemistry:**

- Propagation: flavor and baryon number exchange between medium and projectile.
- Energy loss: color transfer effects. Is there an interplay between energy loss and fragmentation?
- Fragmentation in medium?: recombination of partons from jet and medium.

*Eur. Phys. J.* C. 55,293-302 (2008)

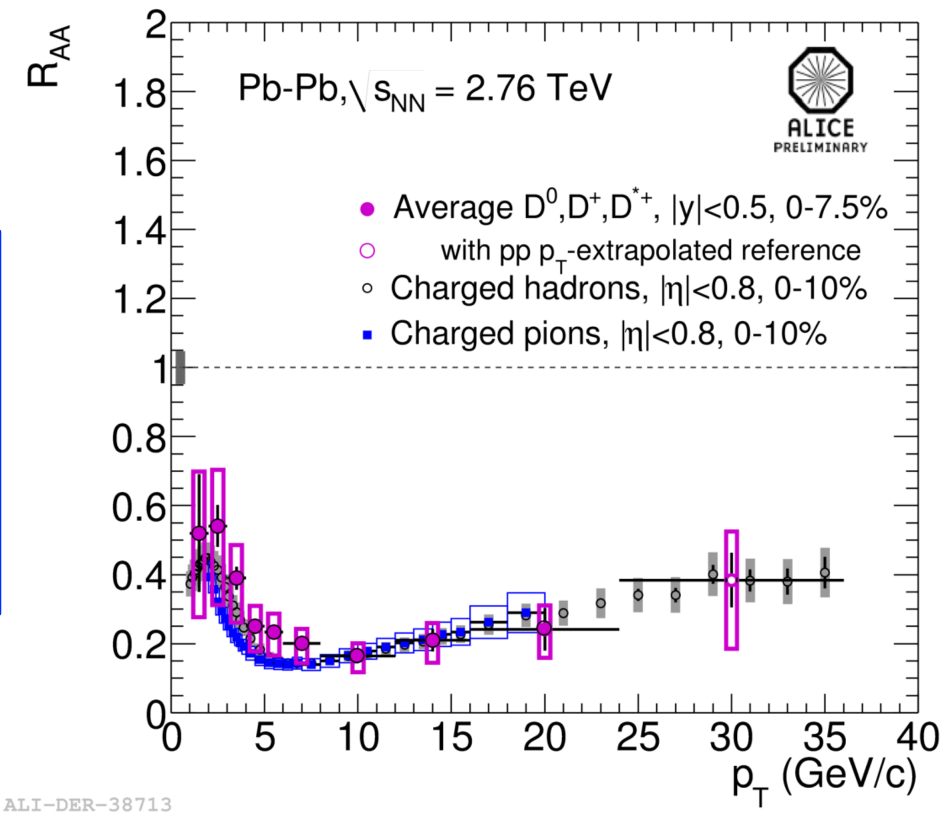


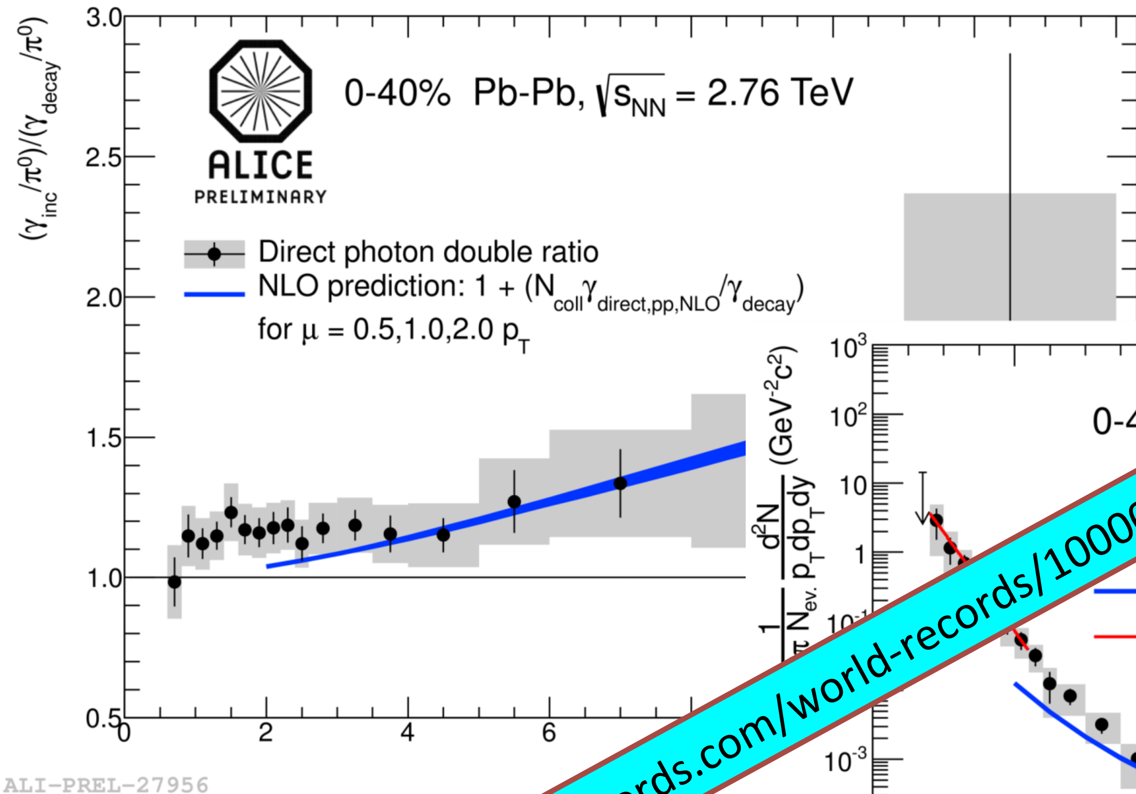

The results indicate that medium does not affect the fragmentation

Similar suppression for D mesons at high pT

Average D-meson *RAA*:
– *p*T < 8 GeV/*c* hint of slightly less suppression than for light hadrons
– *p*T > 8 GeV/*c* both (all) very similar no indication of colour charge dependence



ALICE



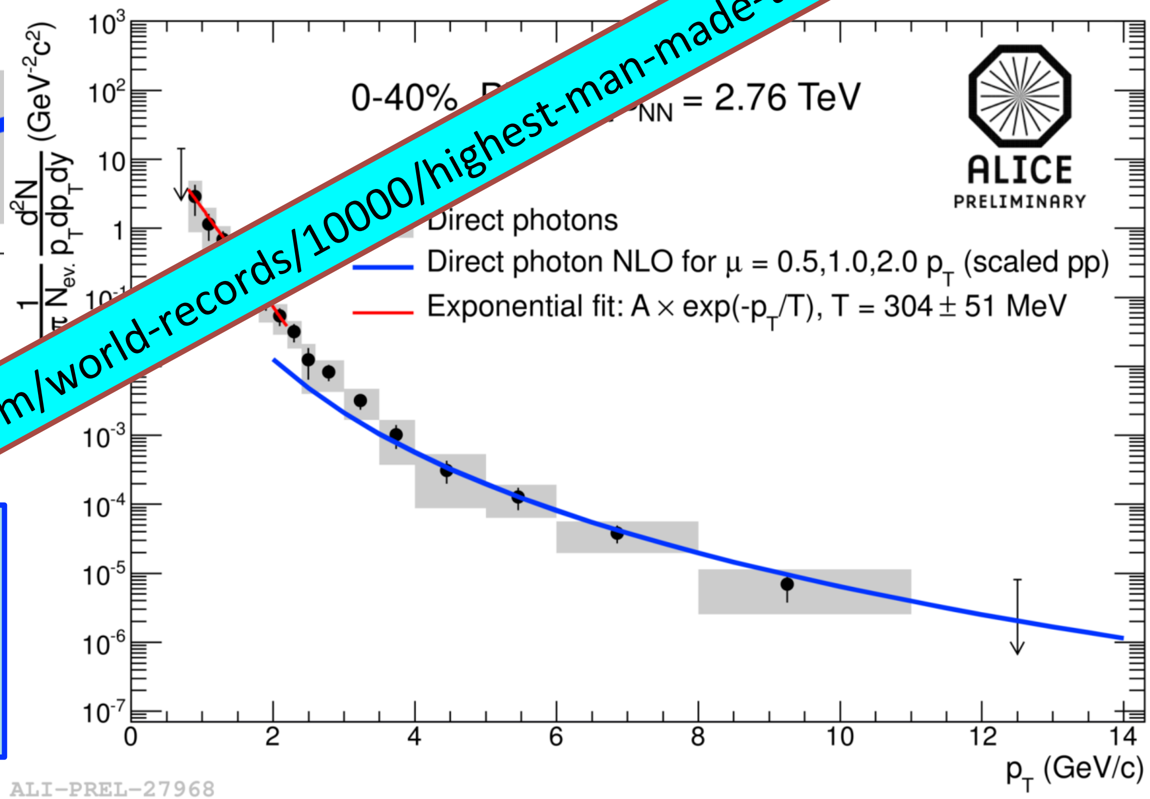

Exponential fit for $p_T$ < 2.2 GeV/$c$

inv. slope $T$ = 304±51 MeV

for 0–40% Pb–Pb at √$s$ 2.76 T

PHENIX: $T$ = 221±19±19

for 0–20% Au–Au 00 GeV



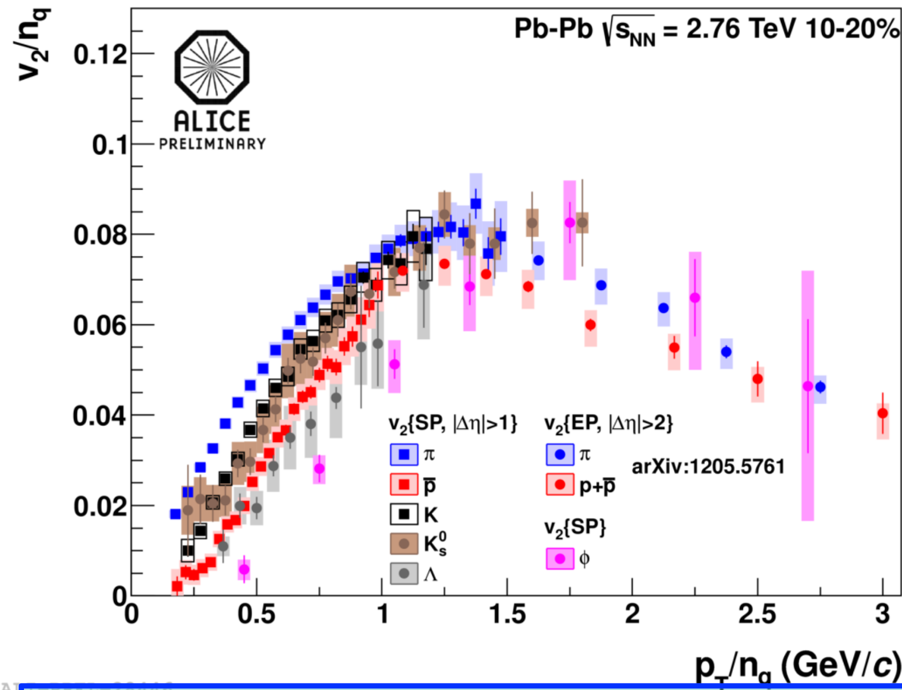

$p_T$ < 2 GeV/$c$

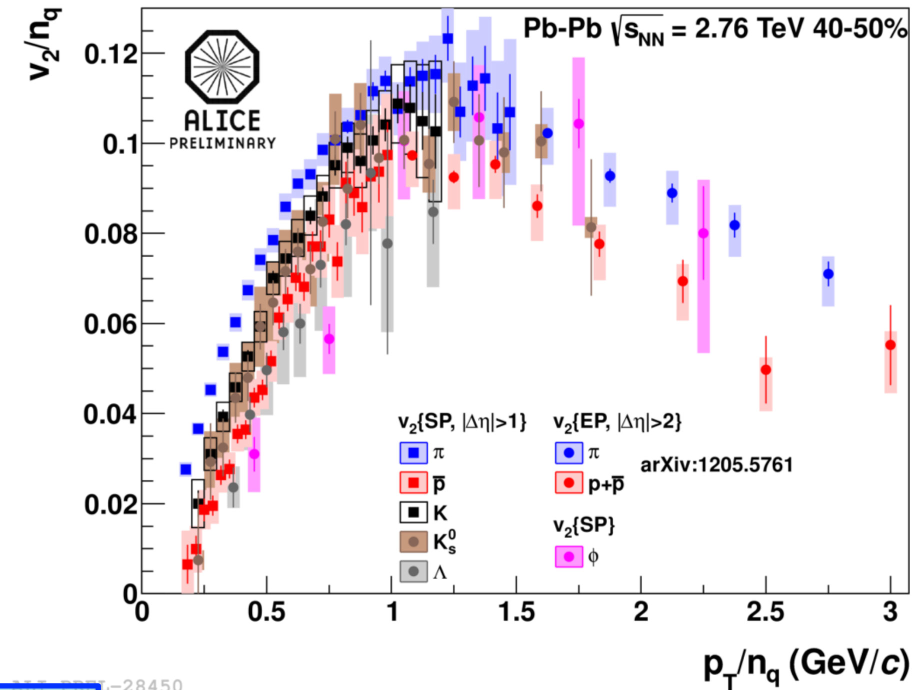
~20% excess of photons

$p_T$ > 4 Ge

agr with $N_{coll}$-scaled NLO

http://www.guinnessworldrecords.com/world-records/10000/highest-man-made-temperature

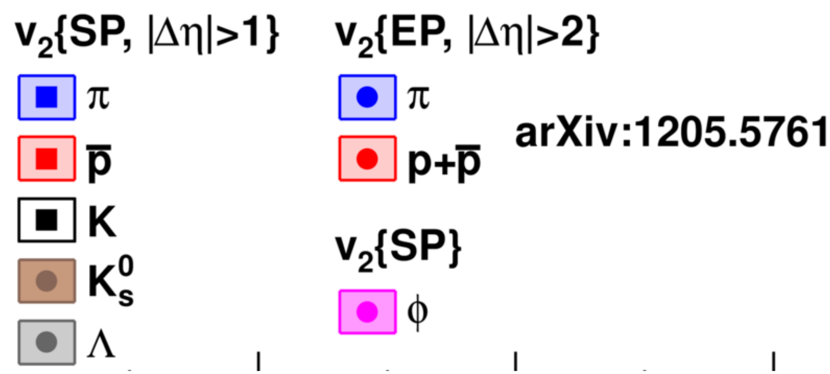



$v_2$ for p, p, $K^\pm$, $K^0_s$, Λ, ϕ (not shown for Ξ, Ω)

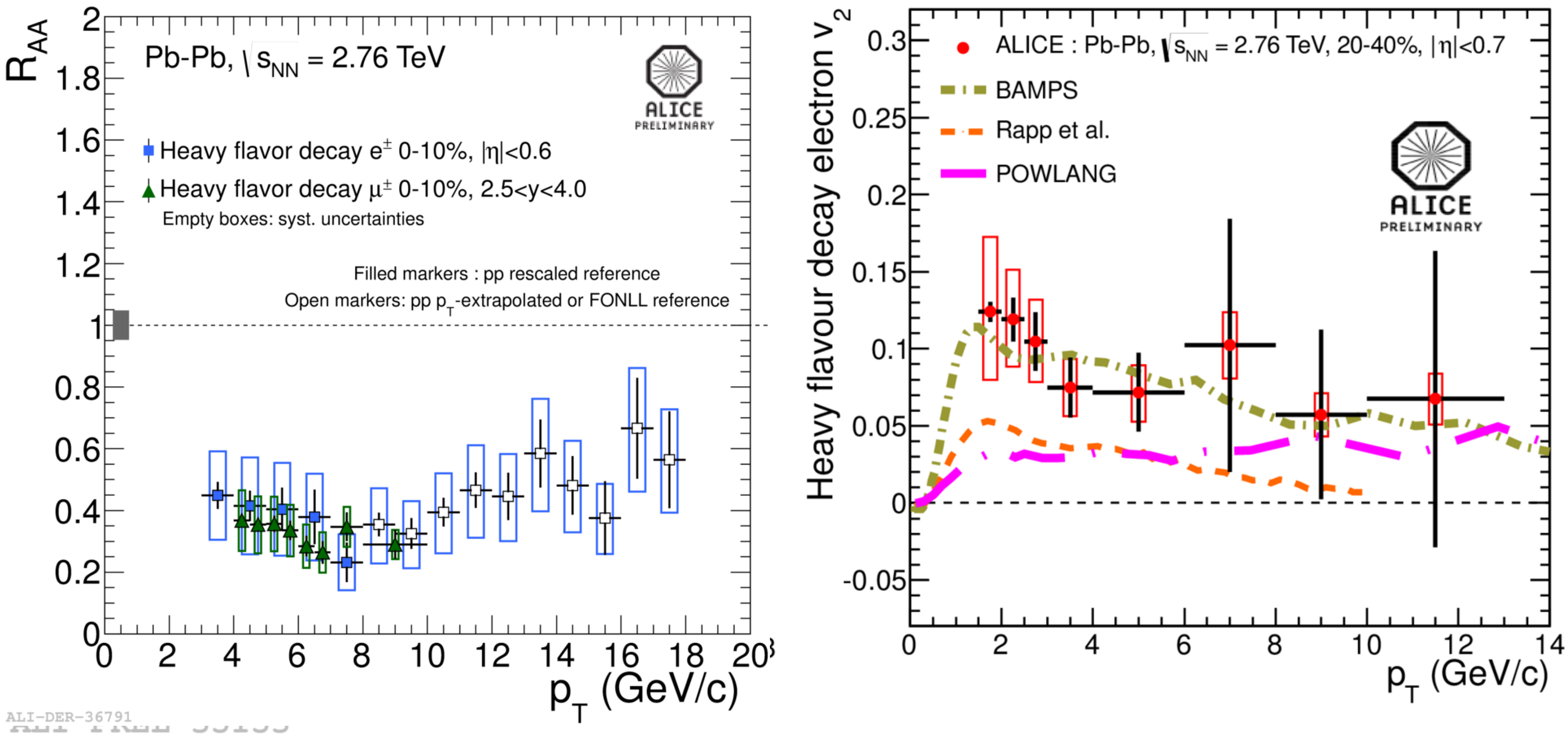
ϕ (at low $p_T$ (<3 GeV/$c$) follows mass hierarchy at higher $p_T$ joins mesons

overall qualitative agreement with hydro up to $p_T$ 1.5–3 GeV/$c$ (p–p); quantitative precision needs improvements – hadronic afterburner




$n_q(m_T)$-scaling worse than at RHIC

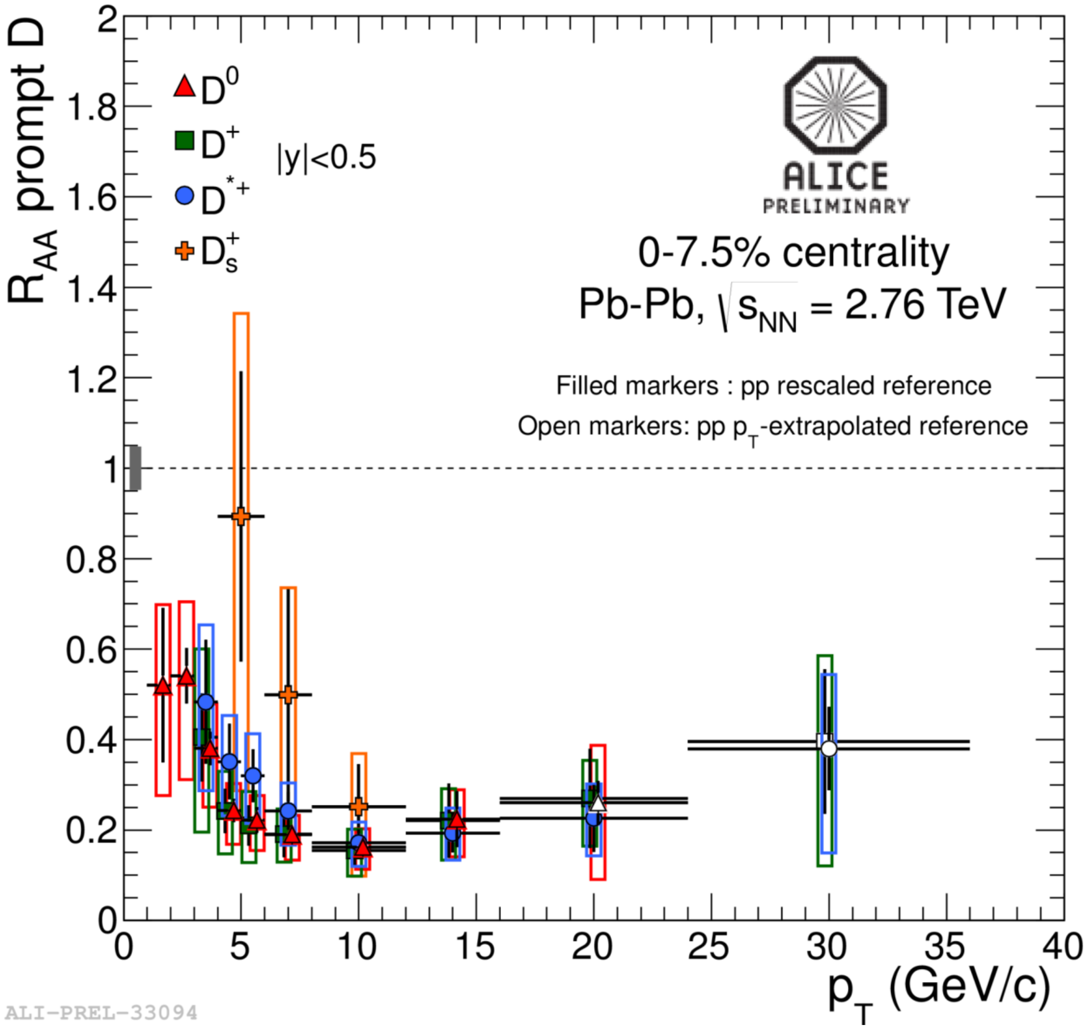
$n_q(p_T)$-scaling at $p_T$ > 1.2 GeV/$c$ violation 10–20%

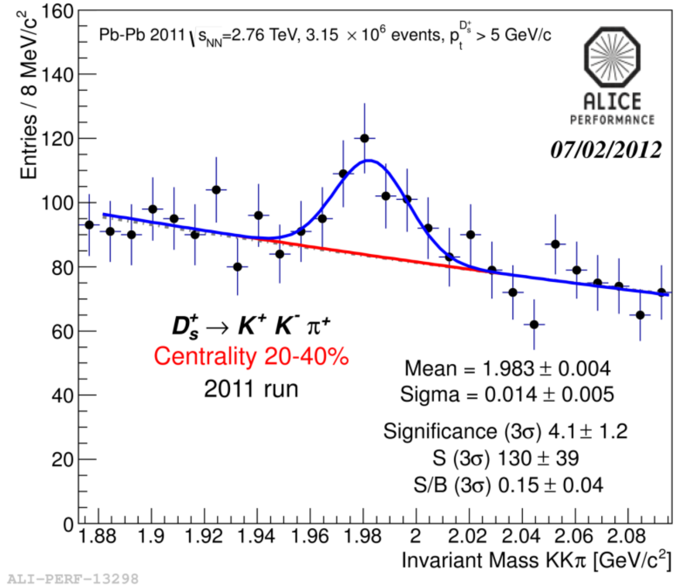



Strong suppression of heavy-flavour e up to $p_T$ 18 GeV/$c$ in 0–10% centrality and non-zero $v_2$ in 20–40% centrality class

Ongoing effort to separate beauty contribution…

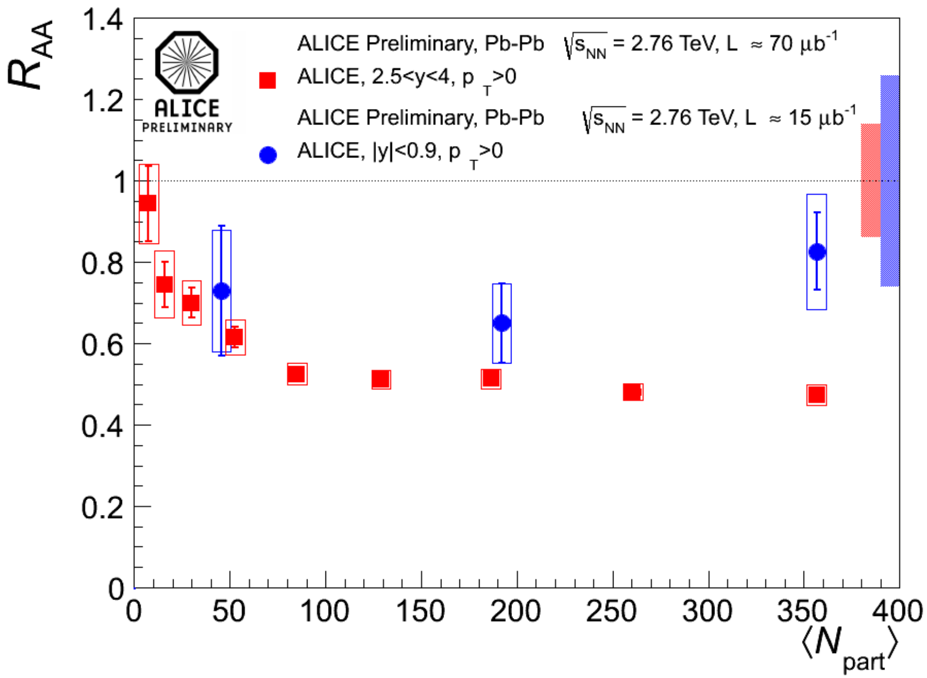
Suppression of heavy-flavour m in forward region very similar to that of e

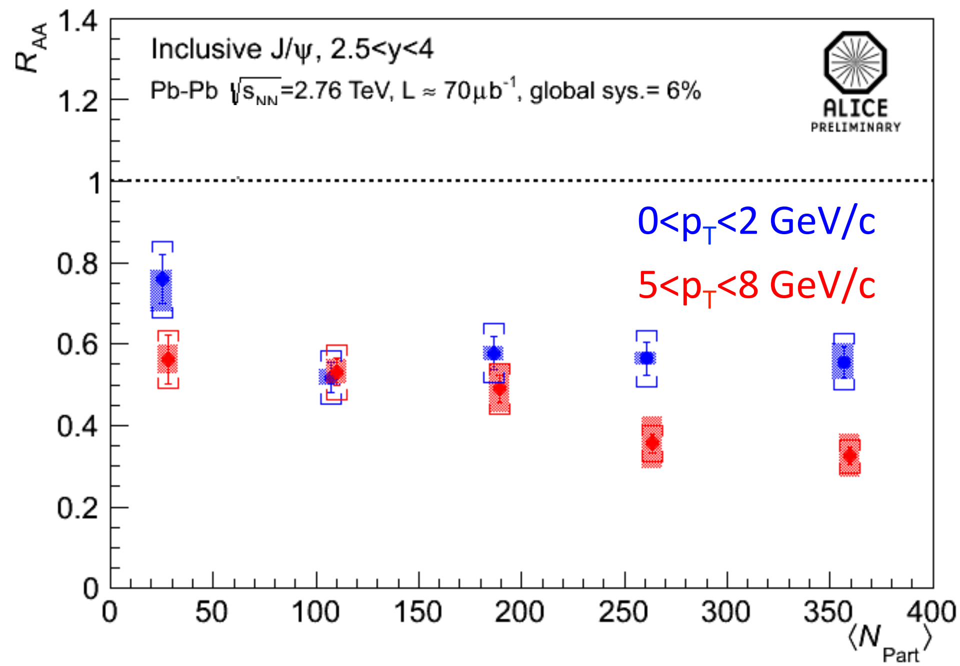



Strong suppression (~ 4–5 ) at $p_T$ above 8 GeV/$c$

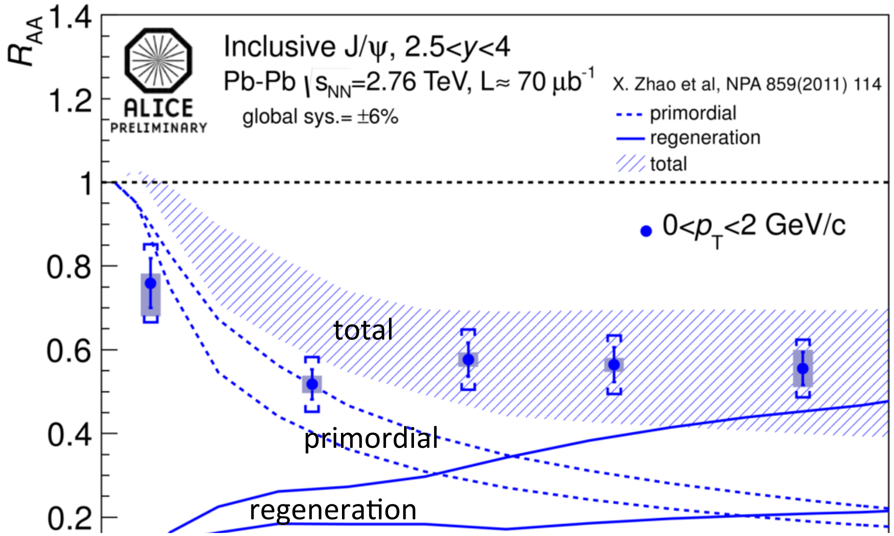
Uncertainty will improve with future pp and Pb–Pb data taking

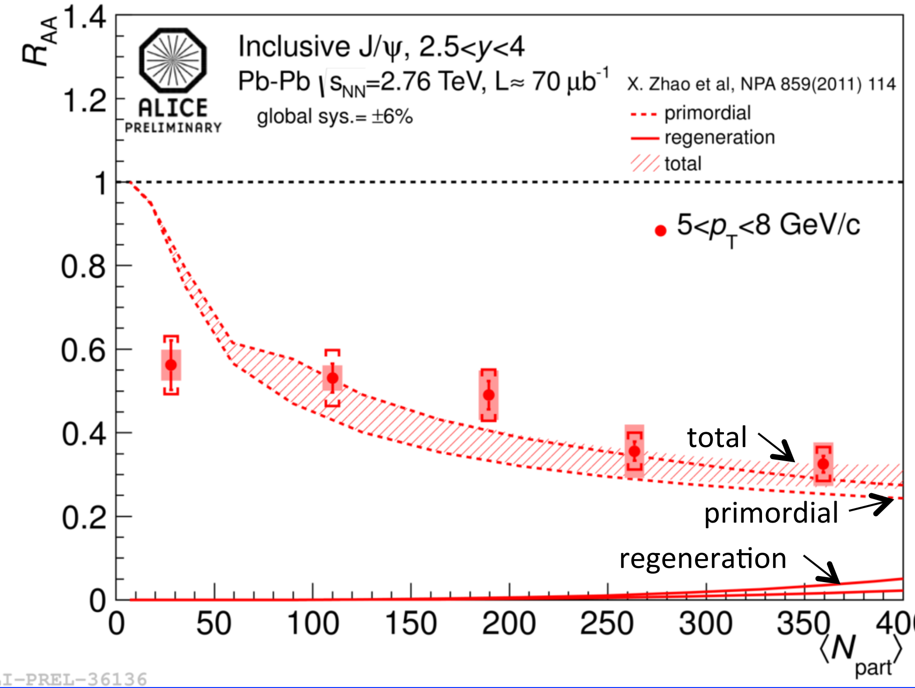


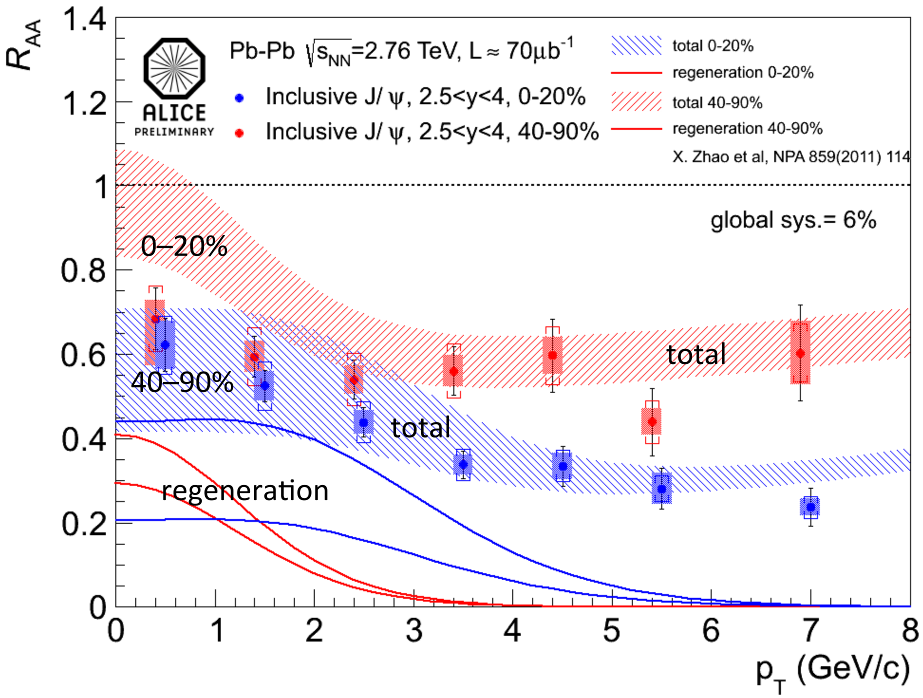




J/y suppression measurements both in central and forward regions
– from $N_{part}$ > 100 suppression independent of centrality
– in central collisions, less suppression than at RHIC
– at low $p_T$ (< 2 GeV/$c$) less suppression than at high $p_T$, especially in more central collisions

Indication of J/y regeneration at low $p_T$ ?




Comparison to regeneration model:
*X.Zhao, R.Rapp NPA 859 114*
Different suppression pattern at low/high-$p_T$
At low $p_T$ ~50% J/y from recombination
Fair agreement for different centralities
Statistical hadronization model also
describes the data: *P.Braun-Munzinger et al.*

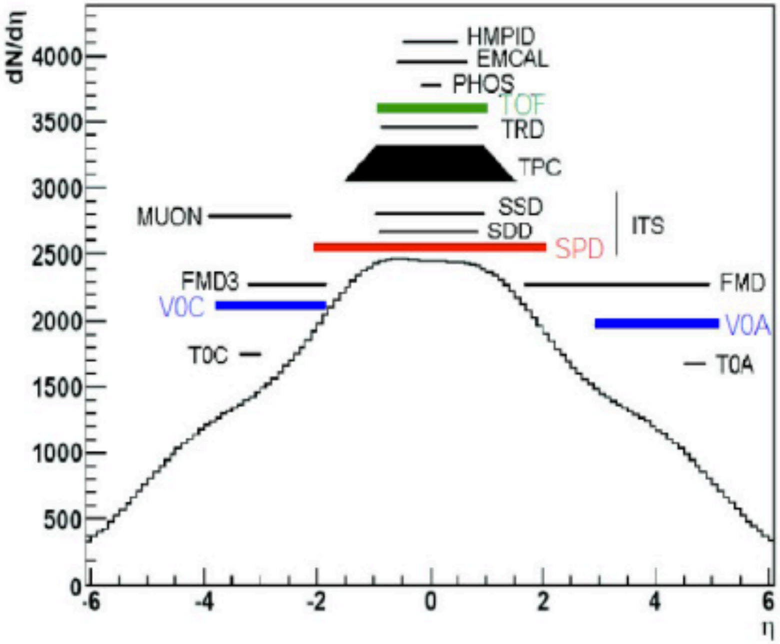
## Ultra-peripherical Collisions, 2010 data

***3 UPC triggers were active in 2010:***

1. TOF-only trigger >= 2 hits in TOF

2. TOF + SPD + VZERO trigger:
>= 2 hits in TOF + >= 2 hits in SPD
+ veto on both VZERO detectors

3. Muon arm + VZERO trigger:
at least one muon candidate +
veto on VZERO-A

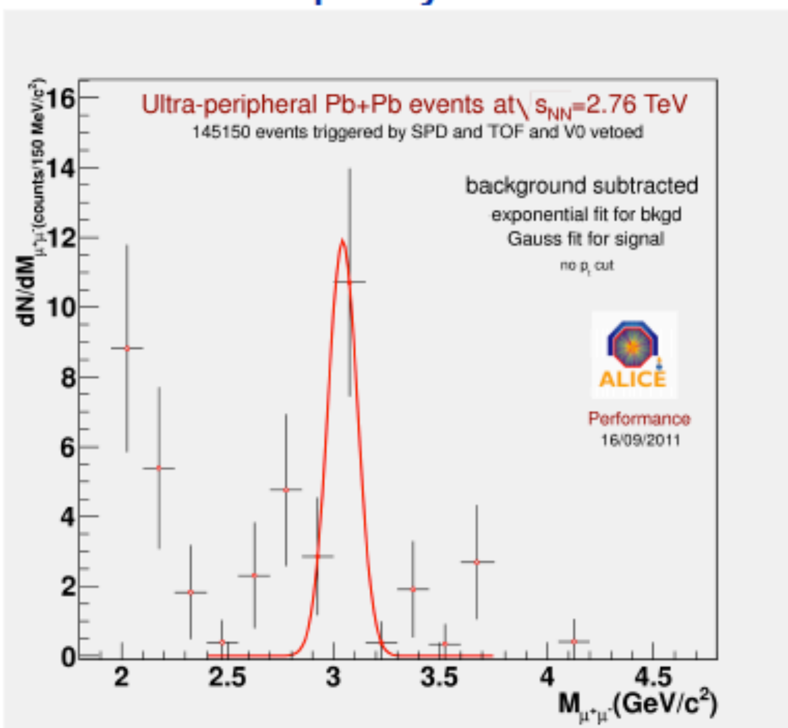



Exclusivity by vetoing on ALICE detectors at several rapidities
~ 8 units of rapidity → both online and offline selections

The UPC triggers sensitive to a variety of final states:
$\gamma\gamma \rightarrow e^+e^-$, $\gamma\gamma \rightarrow \mu^+\mu^-$, $\gamma\gamma \rightarrow f_2(1270) \rightarrow \pi^+\pi^-$,
$\gamma IP \rightarrow J/\Psi \rightarrow e^+e^-$ etc.

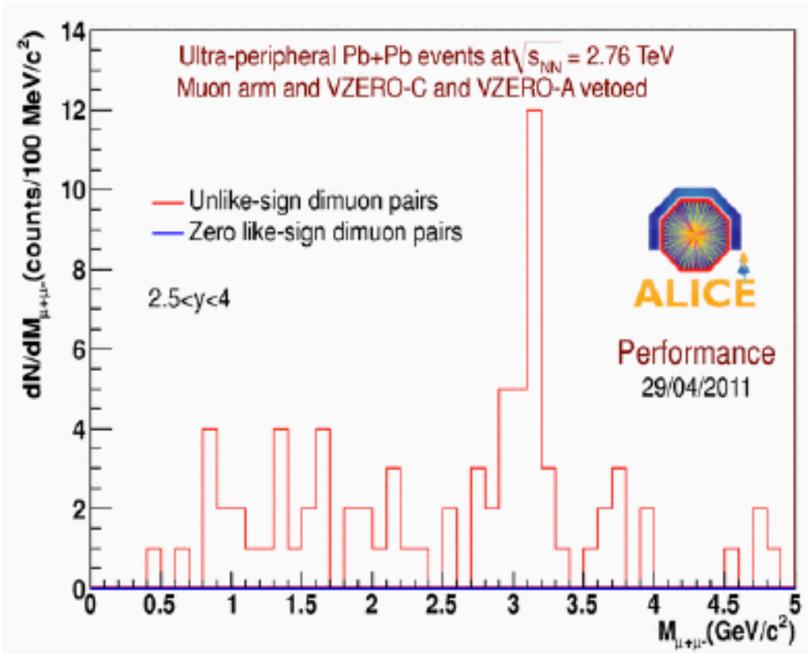
# PERFORMANCE RESULTS: 2010

## Central rapidity




## Forward rapidity

trigger on Muon in coincidence with VZERO-C,
but VZERO-A is vetoed
offline veto on TPC, ITS, FMD




After background subtraction
No particle ID was applied

## PERFORMANCE RESULTS: 2011

2 ***UPC triggers were active in 2011:***

**Central rapidity:** TOF trigger requiring a hit multiplicity to be between 2 and 6, vetoing signals from both VZERO detectors, and with at least 2 hits in SPD. In addition, at least one of the triggered tracks by TOF has the angular correlation 150 < $\Delta\phi$ < 180 degrees

~8 M central barrel UPC triggers collected in 2011

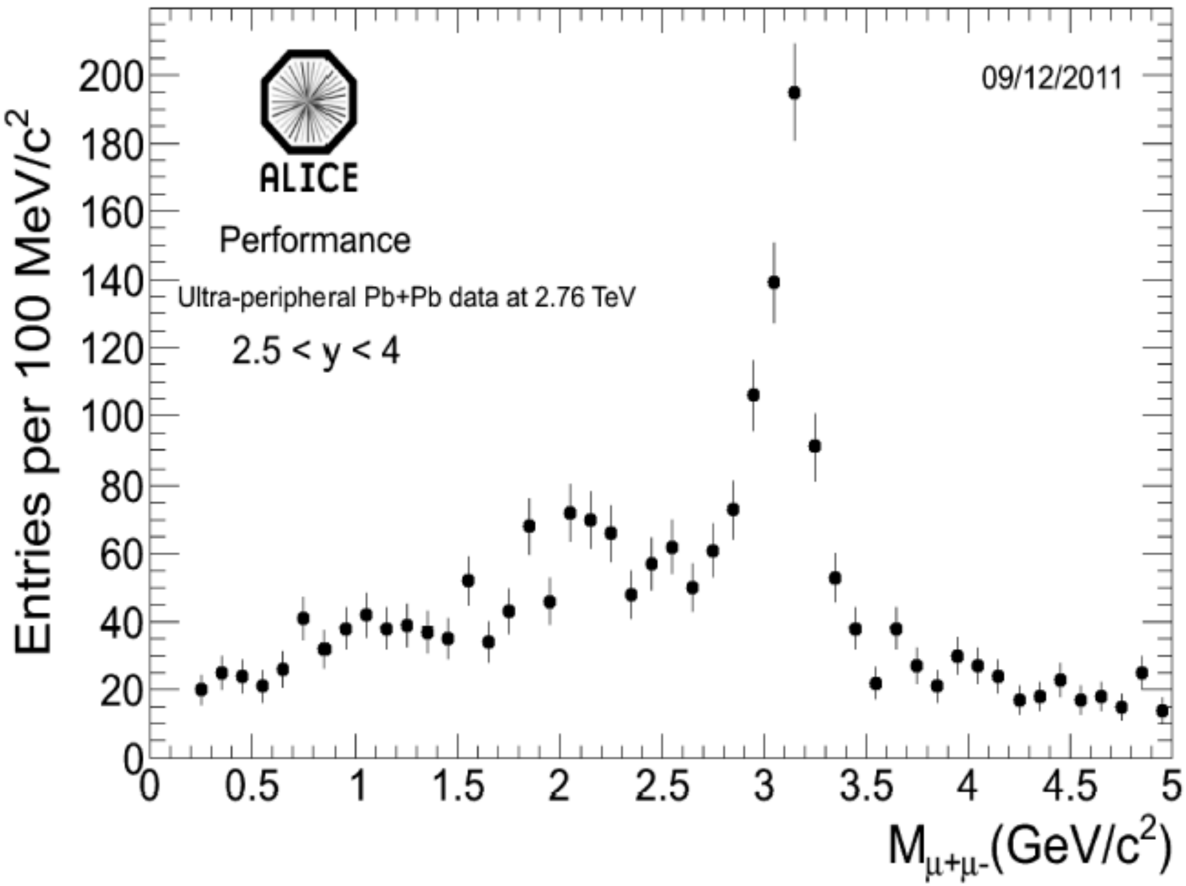
**Forward rapidity:** Same as in 2010. Muon arm + VZERO trigger: at least one muon candidate + veto on VZERO-A.

~ 3.4 M muon UPC triggers collected in 2011

**Collected statistics:**

**an order of magnitude larger than in 2010**

## PERFORMANCE RESULTS: 2011



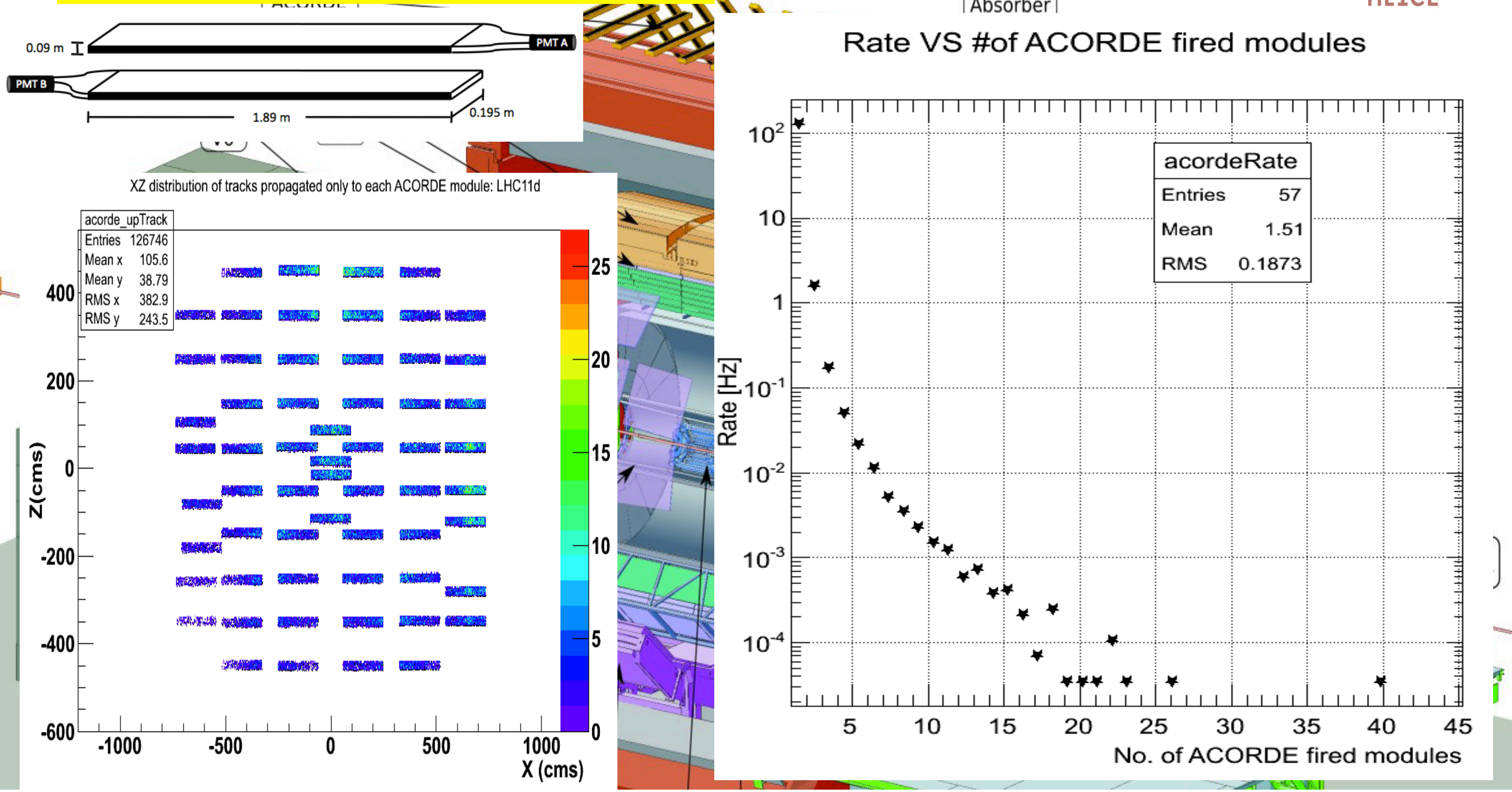

**MUON in coincidence with VZERO-C, but VZERO-A vetoed**

For the moment, no veto at central rapidity

M. Rodriguez

Veto activity on VZERO-C outside muon acceptance
Exactly two good tracks in the muon acceptance
Both tracks match the trigger
At least one track has a $P_t >$ 1 GeV/*c*

# ACORDE (the Alice Cosmic Ray DEtector)

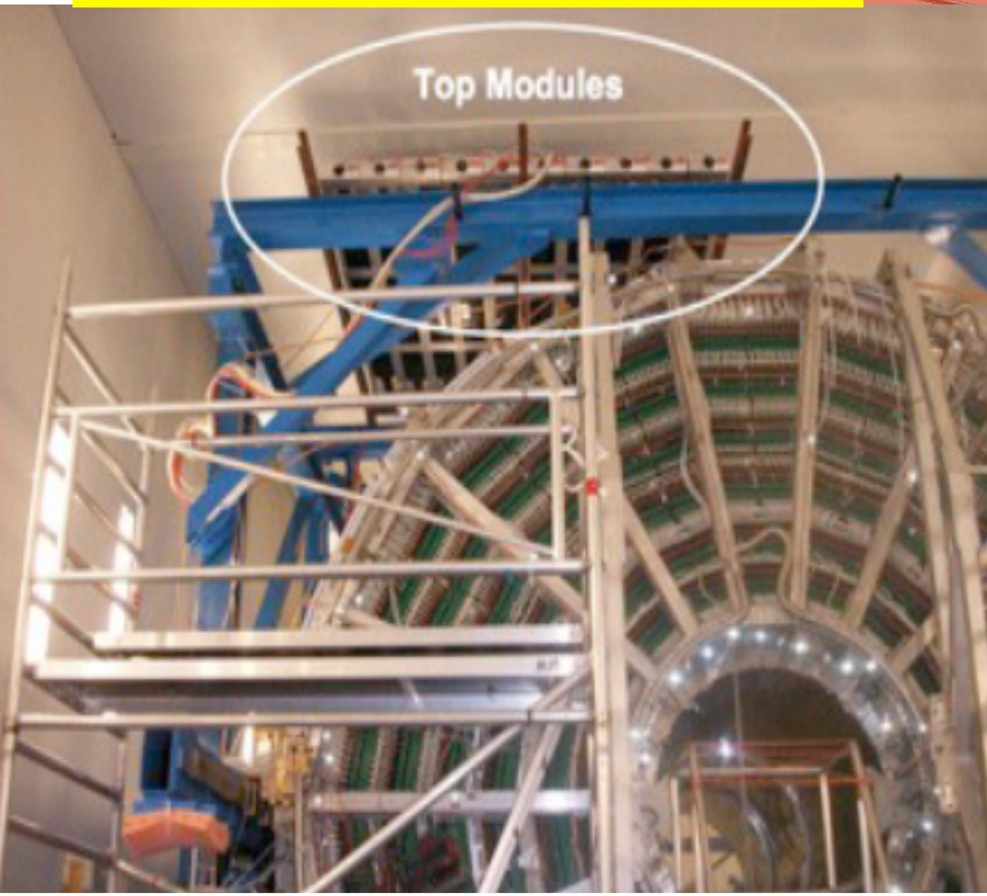


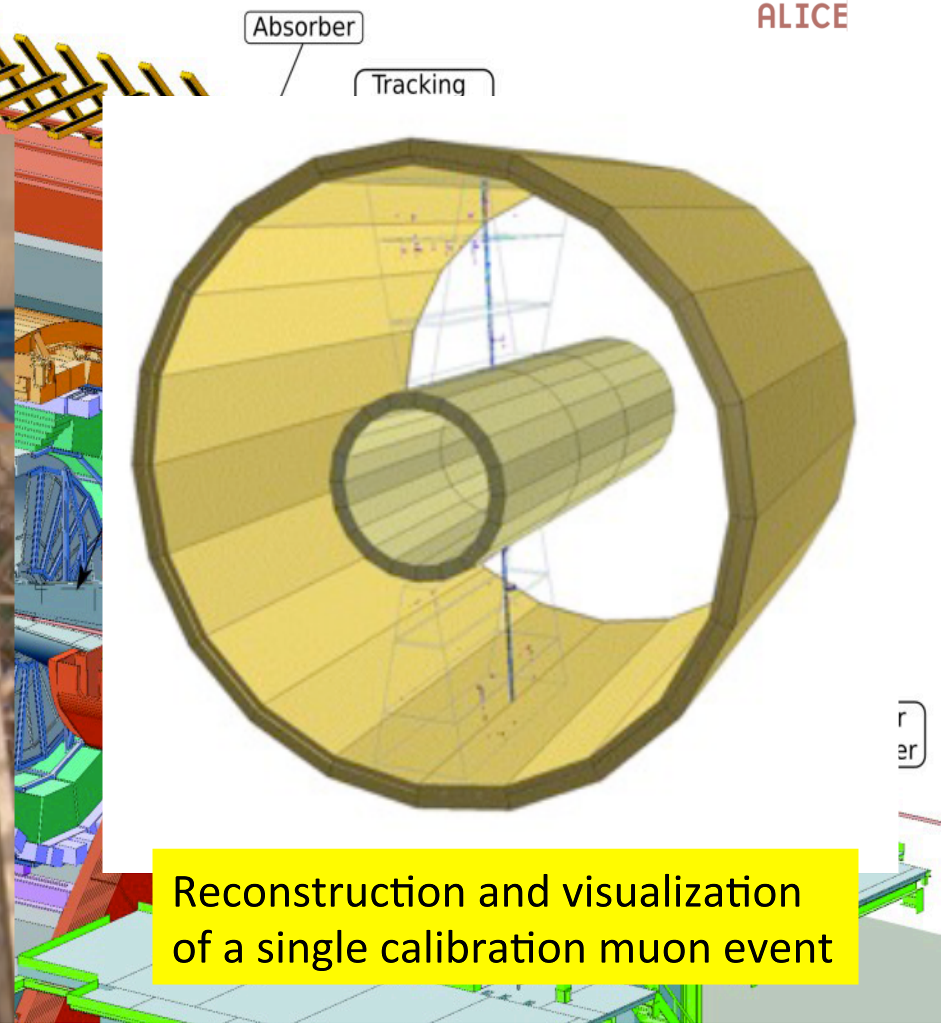

**ACORDE is used to:**

- **Trigger events of atmospheric muons. identify events with high multiplicity of atmospheric muons.**
- **Generate a fast signal of level zero that has been used for alignment and calibration of the inner central detectors in ALICE(single or multicoincidence mode).**

# ACORDE (the Alice Cosmic Ray DEtector)

TPC calibration on surface @ ALICE-P2

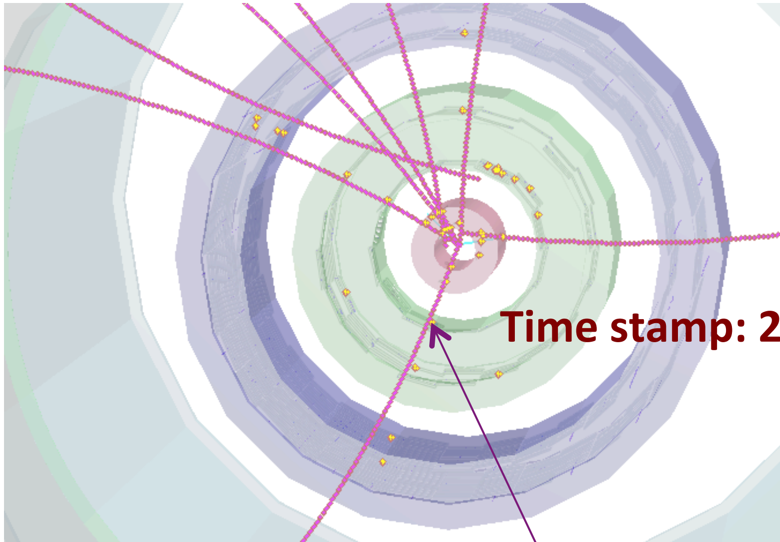


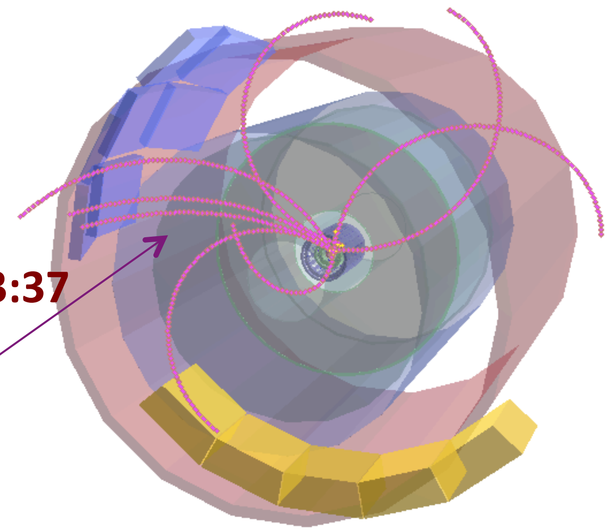




Reconstruction and visualization of a single calibration muon event

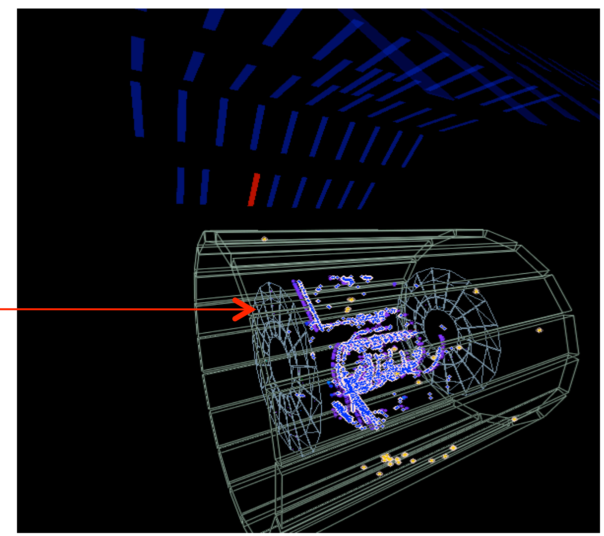
**ACORDE is used to:**

- **Trigger events of atmospheric muons. identify events with high multiplicity of atmospheric muons.**
- **Generate a fast signal of level zero that has been used for alignment and calibration of the inner central detectors in ALICE(single or multicoincidence mode).**





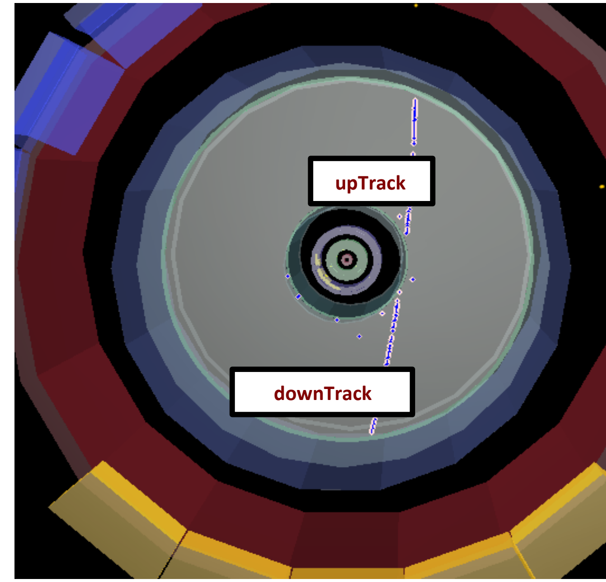
Time stamp: 2009-11-23 16:13:37



The algorithms for reconstruction of tracks in the TPC have been created mainly for protons and heavy ions collisions.
These methods have been adapted and improved continuously during the analysis of CR – events which have a completely different topology.

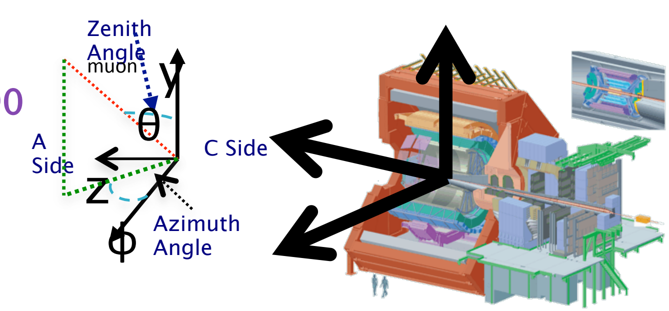
**The event selection it is done with the following considerations:**

- TOF TRIGGER
- ACORDE TRIGGER
- TPC LASER REJECTION
- Fe-mu interaction events rejected
- Two cases:
  - # tracks > 0 (muon multiplicity analysis)
  - # tracks ==2 (muon charge ratio analysis)




- Find parallel tracks, match the TPC tracks, count the muons (single TPC track, matched TPC tracks)
  - Number of TPC clusters > 50
  - Reconstructed momentum of the track > 0.5 GeV
  - |scalar product between unitary vectors of both tracks| > 0.990
  - |Z–Zo| < 250 cm     |X–Xo| < 250 cm
  - Distance between both tracks < 3 cm
- Tested with real multimuon events (up to ~ 282 muons)

- **Zenith Angle** $\theta_c$ increases from ($\theta_c = 0$) in the $xy$ plane to ($\theta_c = \pi/2$)
- **Azimuth angle** $\phi_c$ increases clockwise from $x(\phi = 0)$ to $z(\phi_c = \pi/2)$ till $x(\phi = 2\pi)$

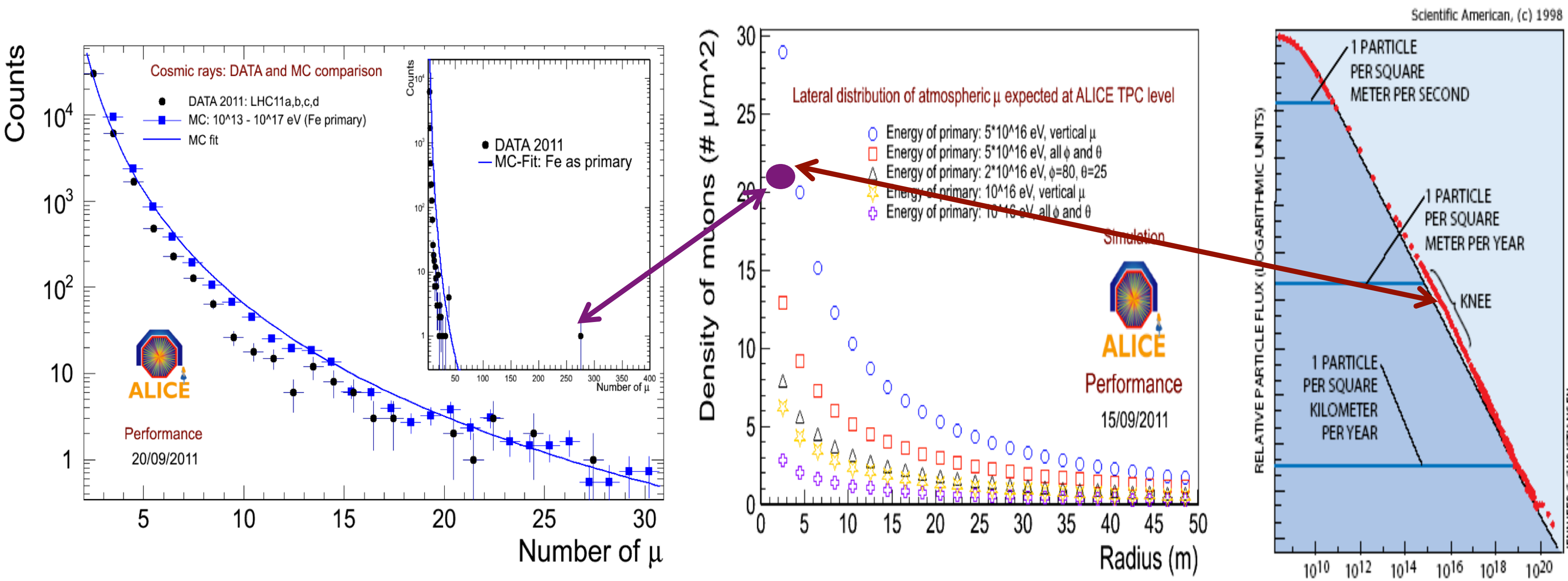


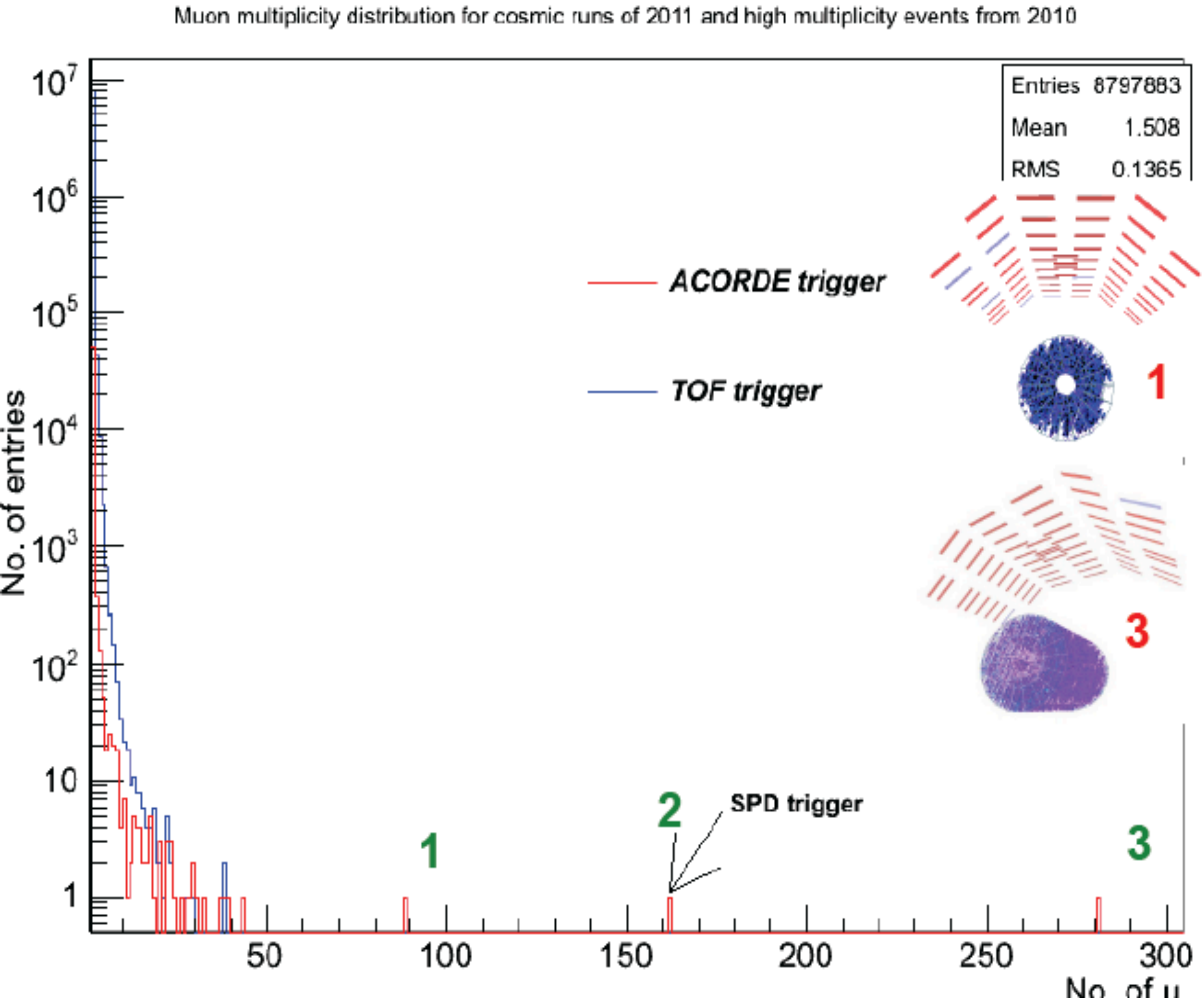
### MUON MULTIPLICITY ANALYSIS

To try to understand the events with high muon multiplicity that we have found with the ALICE detectors it is necessary to compare with the existing hadronic interaction models used in cosmic ray physics. One of the most MC tool used in cosmic ray analysis is given by the CORSIKA software.

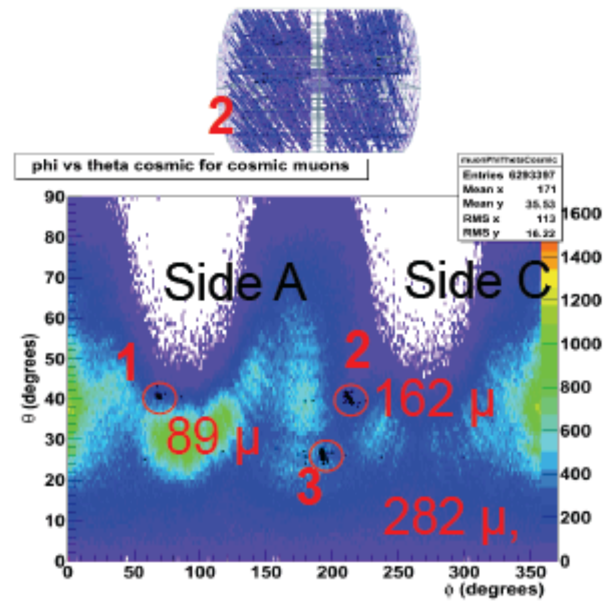
For the 2011 data sample, a generation with CORSIKA (from last version of 2011, v-6.990) was performance with the following considerations:

- Level observation: P2-ALICE
- Composition of the primary cosmic ray: p & Fe nuclei.
- Range of energy of the primary cosmic ray: $10^{13}$ eV – $10^{17}$ eV
- Propagation with AliRoot of those muons that can reach the ALICE's detectors through the molasse (muons with energy > 15 GeV)
- HADRONIC MODEL: QGSJET



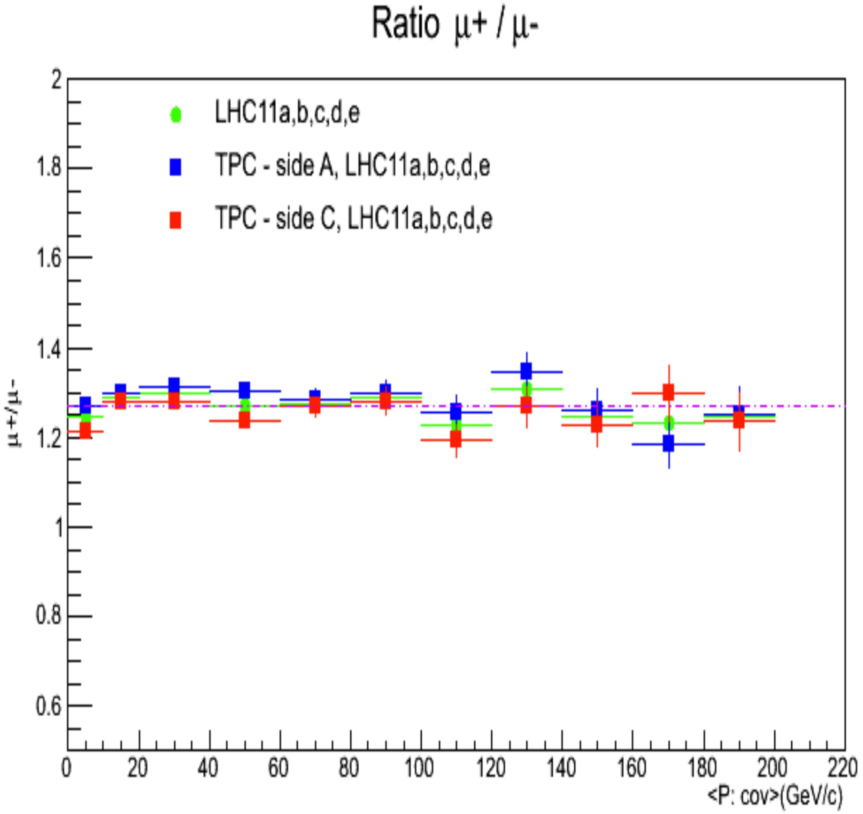


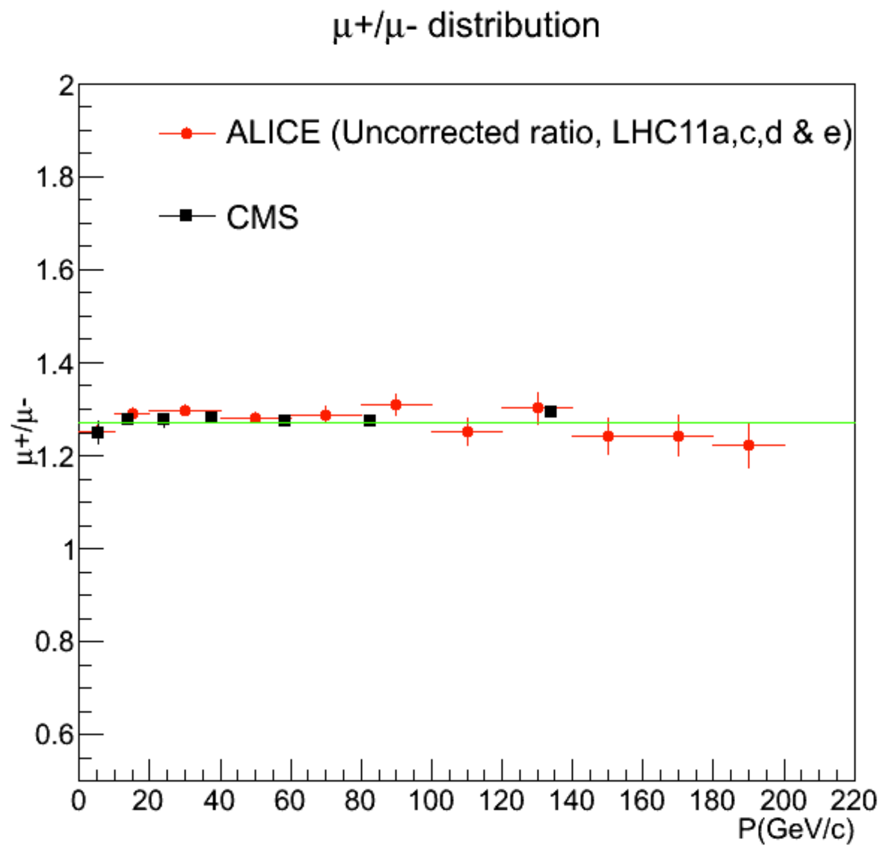

***THE EVENT #2 WAS NOT REGISTERED BY ACORDE BECAUSE IT WAS NOT PARTICIPATING IN THE DATA TAKING AT THE SAME PARTITION**




* TOF L0 triggers arrives later than the ACORDE one.

## MUON CHARGE RATIO ANALYSIS



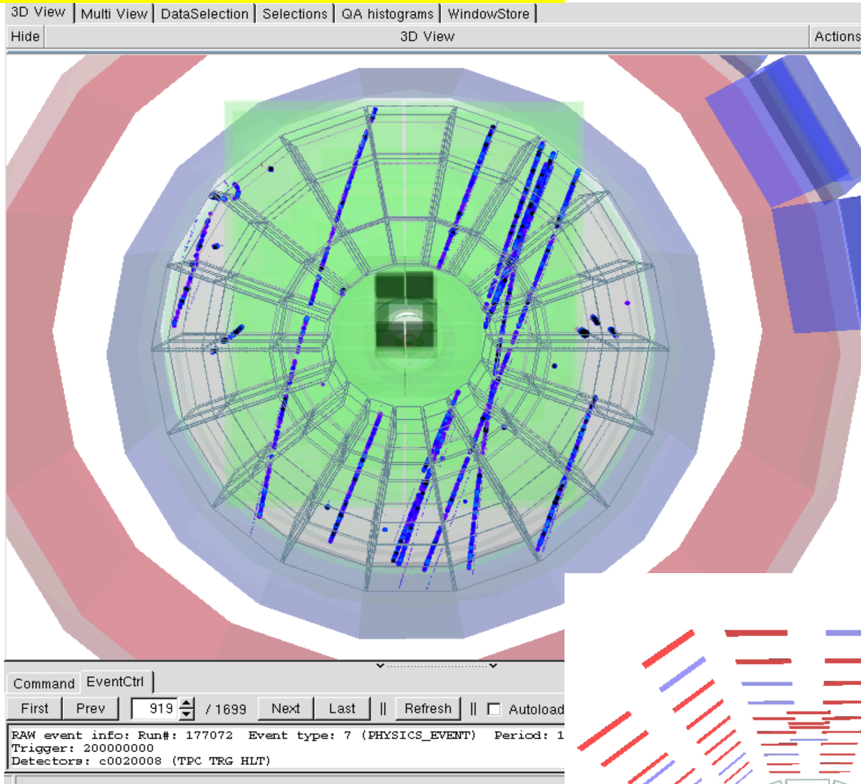



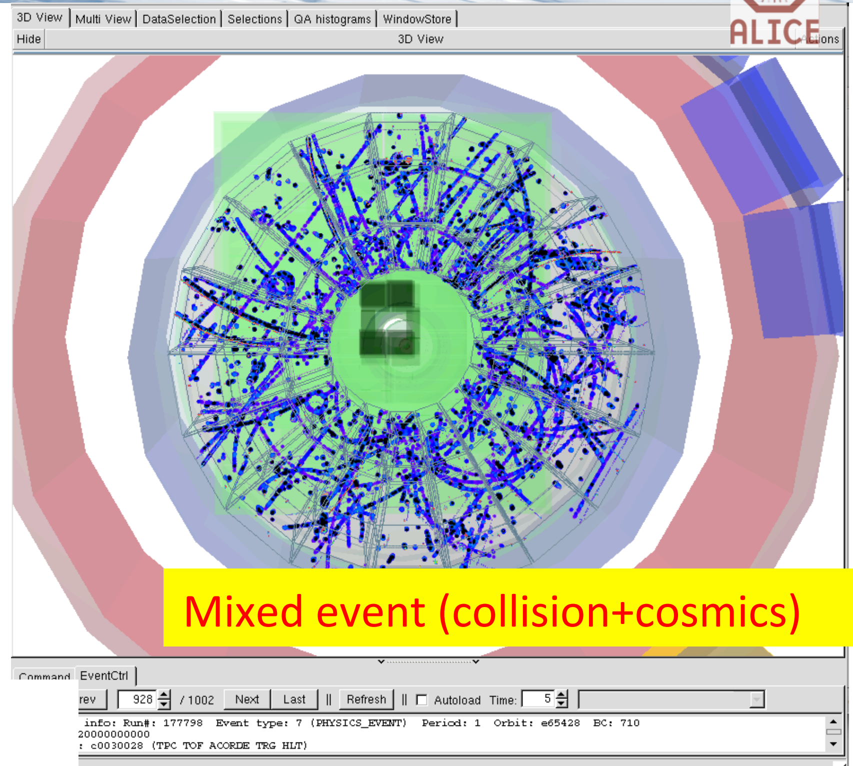

**The measurement of the charge ratio is in good shape for both sides of the TPC (left plot). An improvement of the reconstruction of the momentum is needed to be competitive with the result already published by CMS (http://arxiv.org/abs/1005.5332 )**

# ACORDE IN 2012 during pp Runs

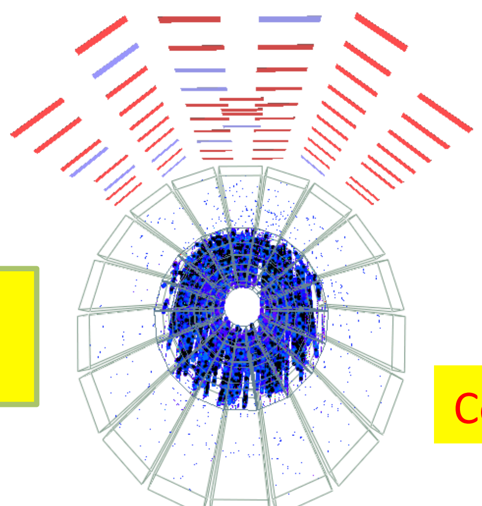


Cosmic event (collision run)




Mixed event (collision+cosmics)



Fired modules: RED
Not fired modules: BLUE

Cosmic event (cosmic run)

International Journal of High-Energy Physics

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ACORDE @ CERN COURIER JOURNAL IN AN SPECIAL EDITION ON BEHALF OF THE 100 CR OBSERVATION (JULY/AUG. 2012)



**CERN COURIER**

Jul 18, 2012

## ALICE looks to the skies

**The ALICE experiment uses special triggers to keep an eye on high-multiplicity atmospheric muon events – and has made some intriguing observations.**

**Résumé**

*ALICE lève les yeux au ciel*

*ALICE est l'une des quatre grandes expériences LHC du CERN. Le détecteur est principalement dédié à l'étude d'un nouvel état de la matière, le plasma quark–gluon, créé lors de collisions entre ions lourds à de très grandes énergies. Cependant, bien que situé dans une caverne à 52 m de profondeur et recouvert de 28 m de roche, il peut aussi détecter les muons produits par les interactions des rayonnements cosmiques avec l'atmosphère. L'expérience utilise un déclencheur spécifique pour surveiller les événements muoniques atmosphériques de haute multiplicité et a déjà réalisé quelques observations intéressantes.*

ALICE is one of the four big experiments at CERN's LHC. It is devoted mainly to the study of a new phase of matter, the quark–gluon plasma, which is created in heavy-ion collisions at very high energies. However, located in a cavern 52 m

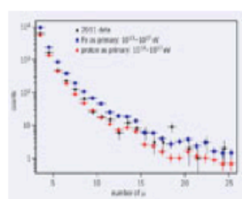

Fig. 1.





## 100 years of cosmic rays

(TPC), which is 5 m long and has a diameter of 5 m. The cosmic trigger requires a signal in a read-out channel (a pad) in the upper part of the TOF and another in a pad in the opposite lower part. The SPD consists of two layers of silicon pixel modules located close to the interaction point. The cosmic trigger is given by the coincidence of two signals in the top and bottom halves of the outer layer.

The track of an atmospheric muon crossing the apparatus can be reconstructed by the TPC. This detector's excellent tracking performance can be exploited to measure the main characteristics of the muon – such as momentum, charge, direction and spatial distribution – with good resolution, while the arrival time can be measured with a precision of 100 ps with the TOF. In particular the ability for tracking a high density of muons – unimaginable with a standard cosmic-ray apparatus, together with the measurement of all of these observables at the same time – permits a new approach to the analysis of cosmic events, which has so far not been exploited. For these reasons, the main research related to the physics of cosmic rays with the ALICE experiment has centred on the study of the muon-multiplicity distribution and in particular high-density events.

### High-multiplicity events

The analysis of the data taken in 2010 and 2011 revealed a muon multiplicity distribution that can be reproduced only by a mixed composition. Figure 1 (previous page) shows the multiplicity distribution for real data taken in 2011, together with the points predicted for pure-proton and pure-iron composition for the primaries. It is clear from the simulation that the lower multiplicities are closer to the pure-proton points, while at higher multiplicities the data tend to approach the iron points. This behaviour is expected from

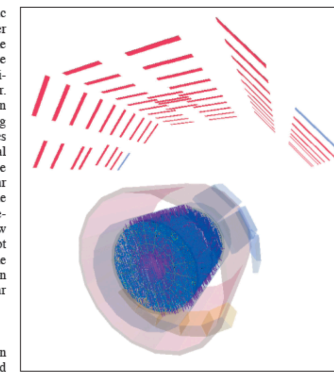

*Fig. 2. Display of a very high muon-multiplicity event. The event has given a signal in 58 ACORDE modules (red rectangles above the cylinder of the TPC).*

rate. To this end, in addition to standard cosmic runs, a special trigger with requiring the coincidence of at least four ACORDE

- ALICE heavy-ion programme approved for ~ 1 $nb^{-1}$:
  - 2013–14 Long Shutdown 1 (LS1)
    - completion of TRD and CALs
  - 2015 Pb–Pb at $\sqrt{s_{NN}}$ = 5.1 TeV
  - 2016–17 (maybe combined in one year) Pb–Pb at $\sqrt{s_{NN}}$ = 5.5 TeV
  - 2018 Long Shutdown 2 (LS2)
  - 2019 probably Ar–Ar high-luminosity run
  - 2020 p–Pb comparison run at full energy
  - 2021 Pb–Pb run to complete initial ALICE programme
  - 2022 Long Shutdown 3 (LS3)
- This will improve statistical significance of our main results by a factor about 3
  - physics reach extended by the new energy and completion of TRD and CALs

- ALICE is obtaining a wealth of physics results from the first two LHC heavy-ion runs:
  - bulk, soft probes:
    - spectra and flow of identified particles, thermal photons
  - high-$p_T$ probes:
    - jet quenching and fragmentation, particle-type dependent
  - heavy-flavour physics:
    - suppression and flow of D mesons, leptons, J/y
- Entering the precision measurement era – charmed era of the QGP
  - before LS2 (2018): p–Pb and Pb–Pb, higher energy and complete approved ALICE detector
- Long-term upgrade for high-luminosity LHC based on:
  - ambitious physics programme
  - clear detector upgrade plan for improved vertexing and tracking
  - high-rate capability of all subdetectors