Overview of ALICE results with China involvement

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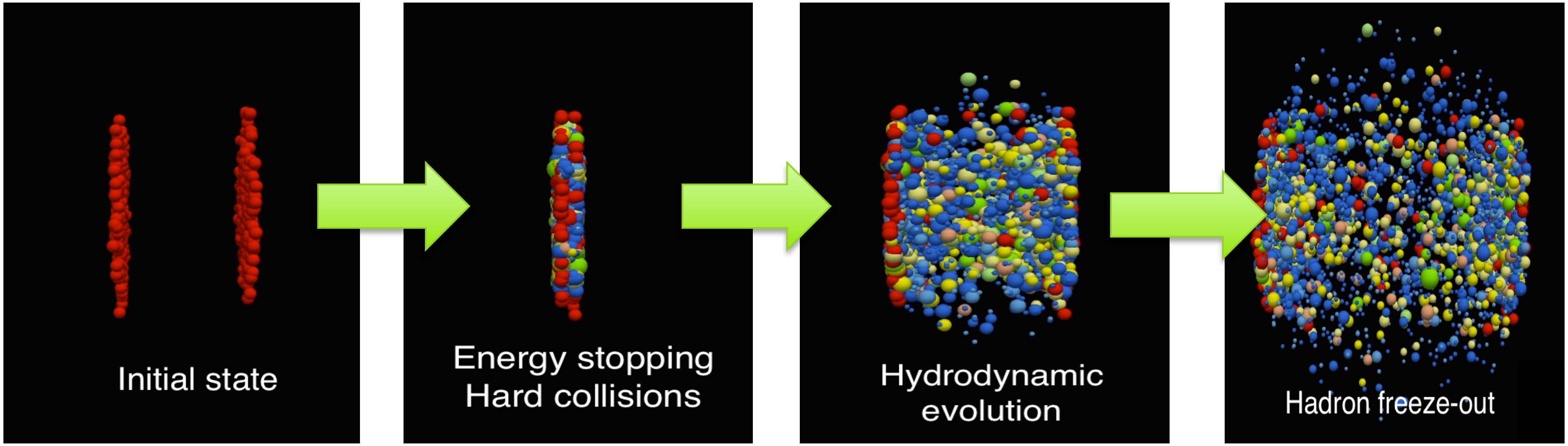
Outline

- Introduction to ALICE
- Physics Results with China Involvement
- Summary and outlook

Introduction

Ultra-relativistic heavy-ion collisions



- Two heavy nuclei approach each other at a speed close to that of light.

- The nuclei collide and the quarks and gluons are released at the extreme temperature.

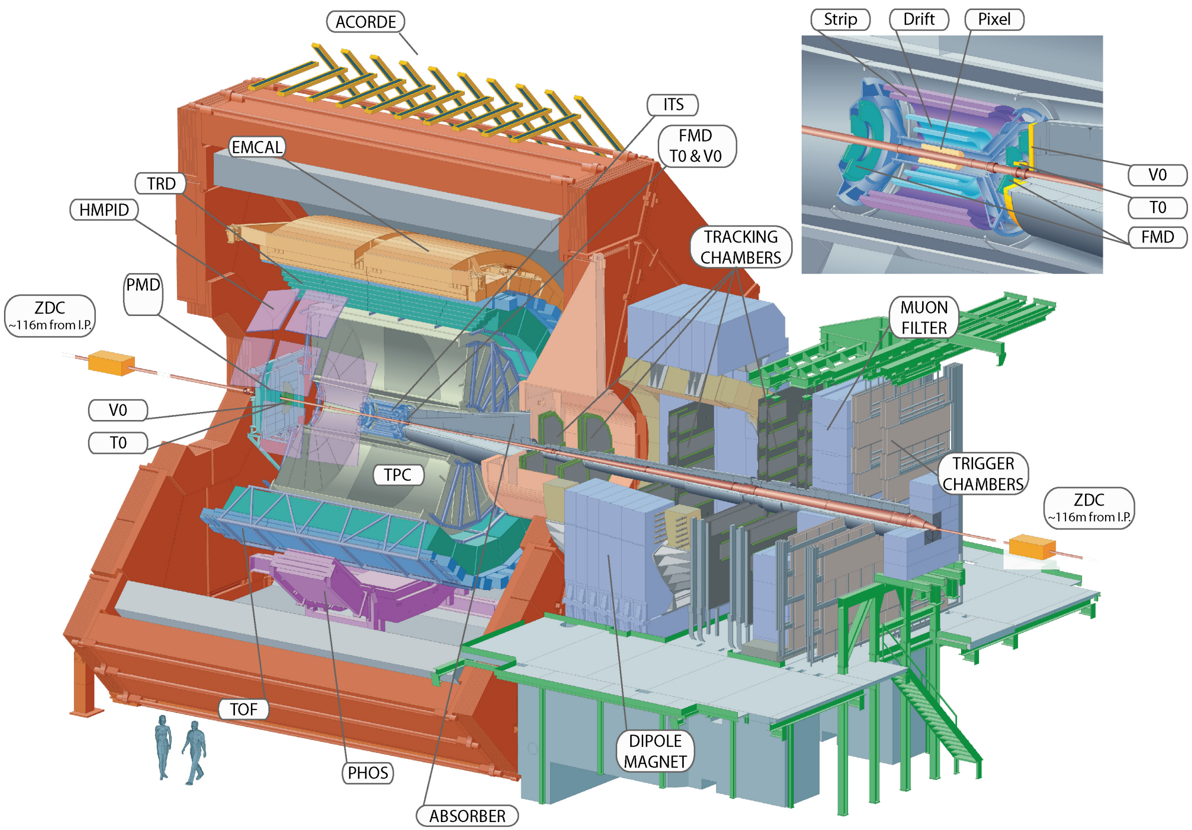
- Quarks and gluons interact with each other creating a thermally equilibrated system: the quark-gluon plasma (QGP).

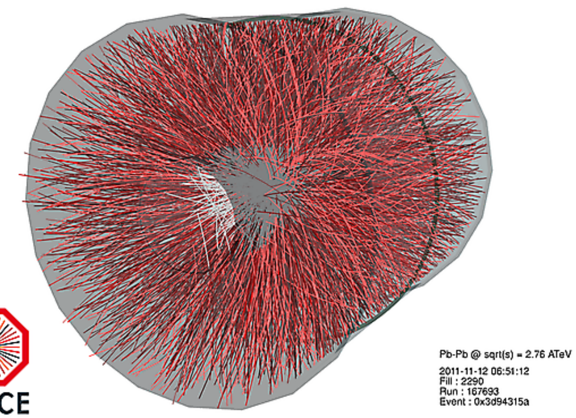
- The plasma expands and cools down to ~160 MeV at which quarks and gluons regroup to form hadrons.

The existence of QGP and its properties are key issues in QCD for understanding of confinement and chiral restoration.

ALICE at the LHC

A dedicated heavy-ion experiment to the physics of strongly-interacting matter at extreme energy densities by carrying out comprehensive study of hadrons, electrons, muons and photons.



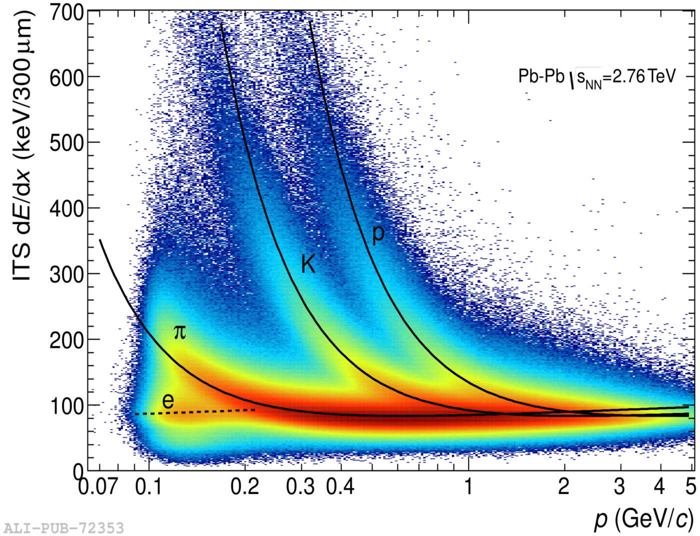


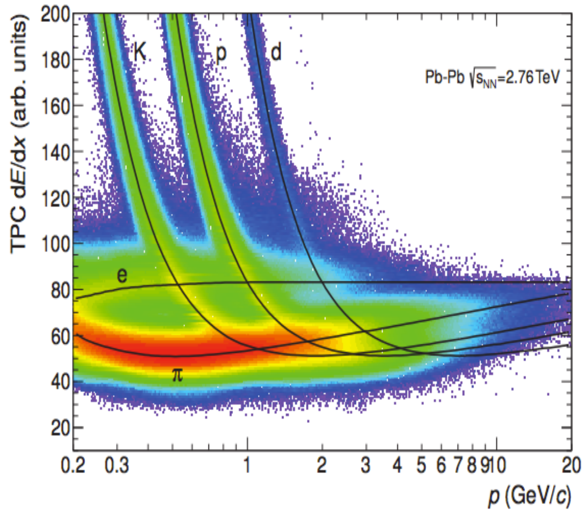
Designed to cope with very high charged particle multiplicities

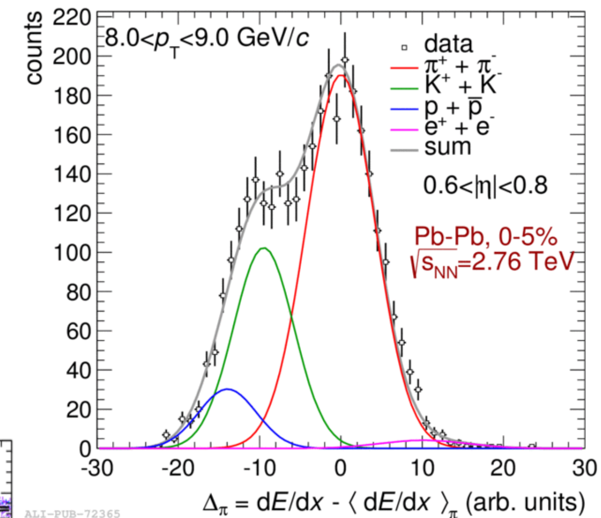
China contribution:

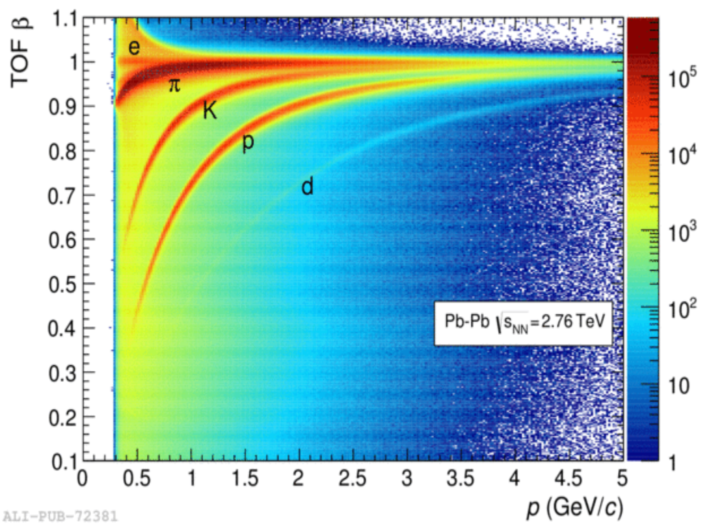
- PHOS FEE
- One DCAL super-module
- PHOS/EMCAL/DCAL SRU firmware

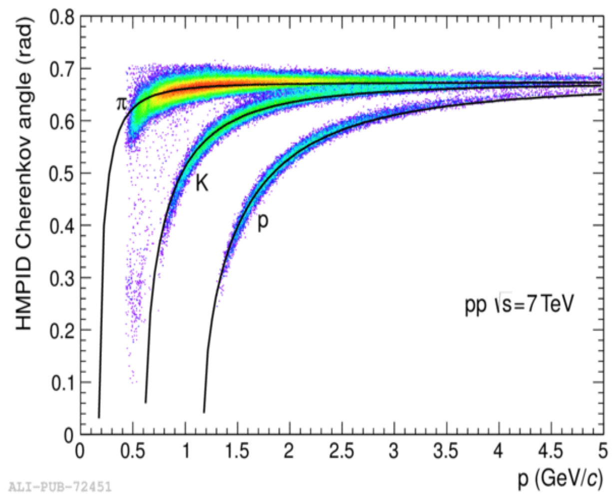
Particle Identification









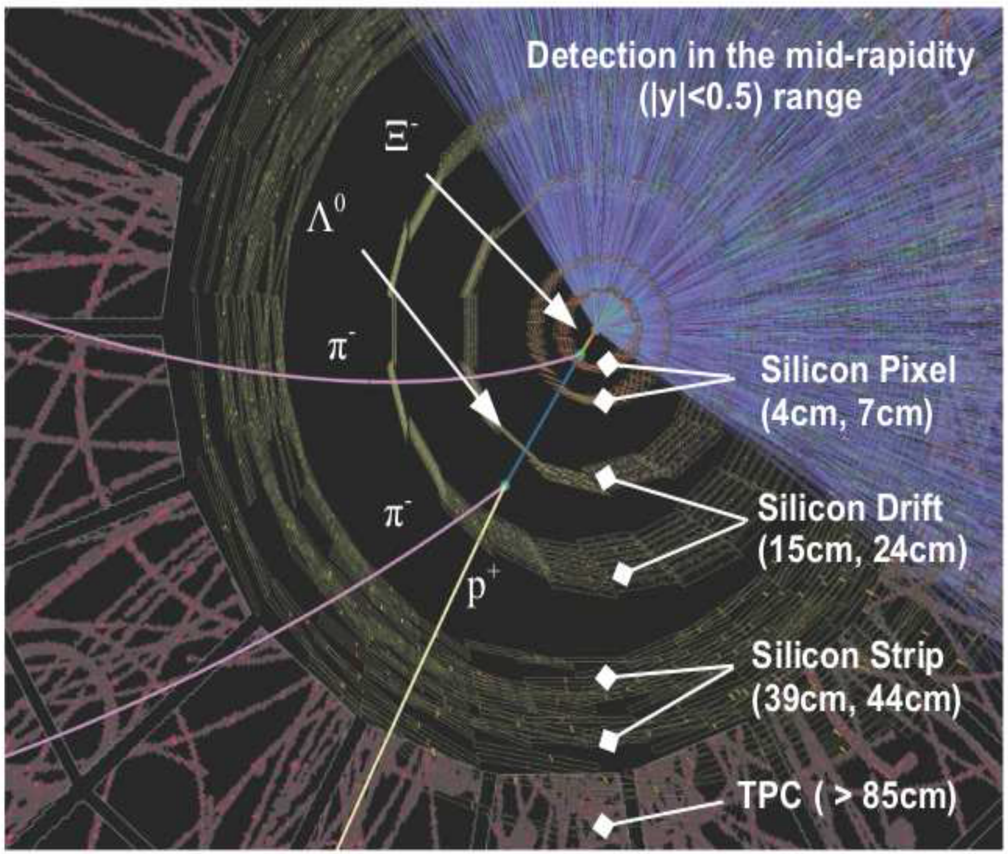


TPC PID (dE/dx in the relativistic rise region)
statistical PID via multi-Gaussian fits

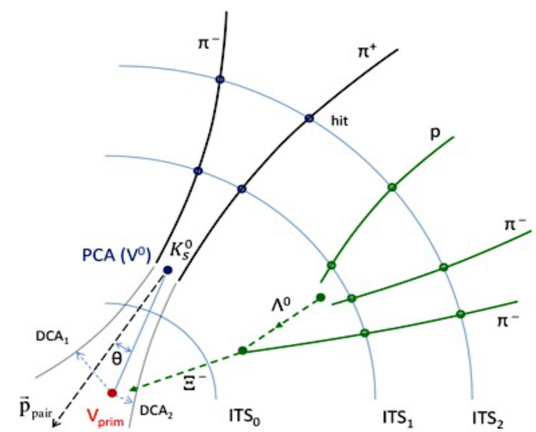
Int. J. Mod. Phys. A 29 (2014) 1430044

Strange and multi-strange particle detection

Pb-Pb 5.5TeV Hijing MC Event, not all tracks shown; Figure from Alice Physics Performance Report, Volume II (Figure IV)



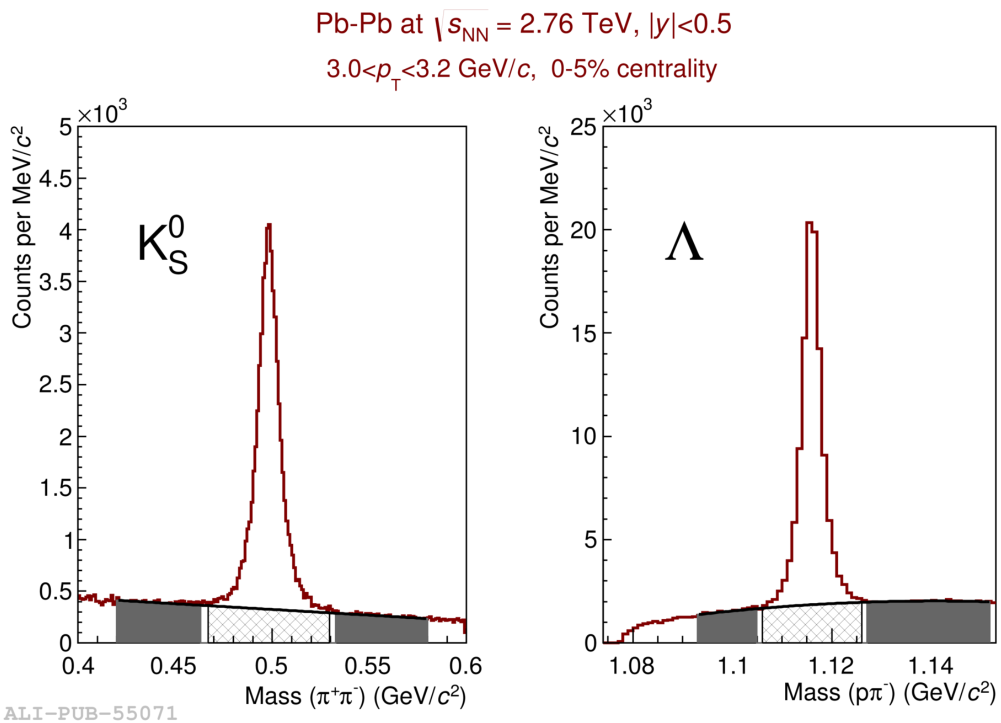
- V-shaped topology for K^0_S and Λ
- Cascade-topology for Ξ and Ω
- TPC for particle identification of daughter tracks



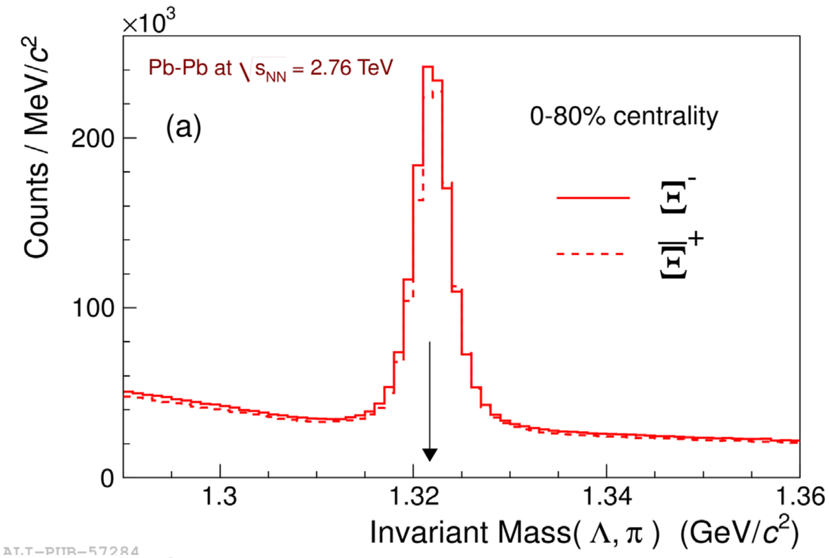
Decay topology

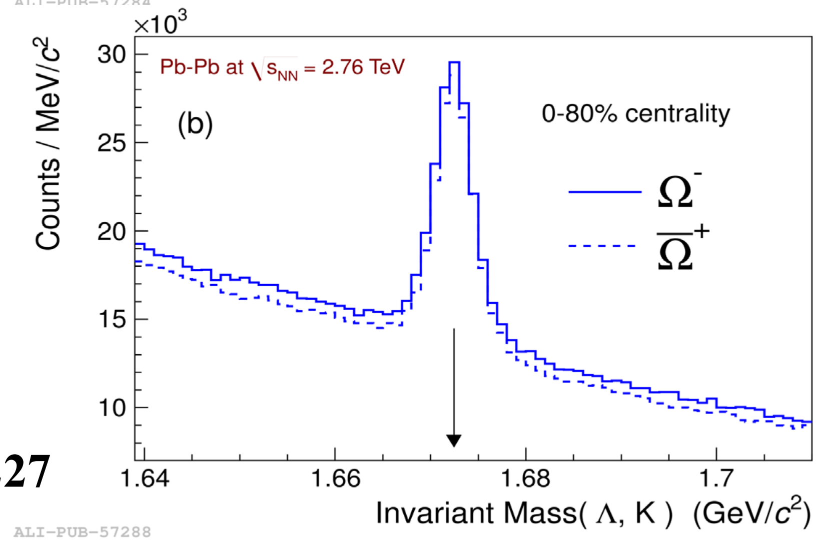
secondary vertex reconstruction + invariant mass analysis

Strangeness signal extraction



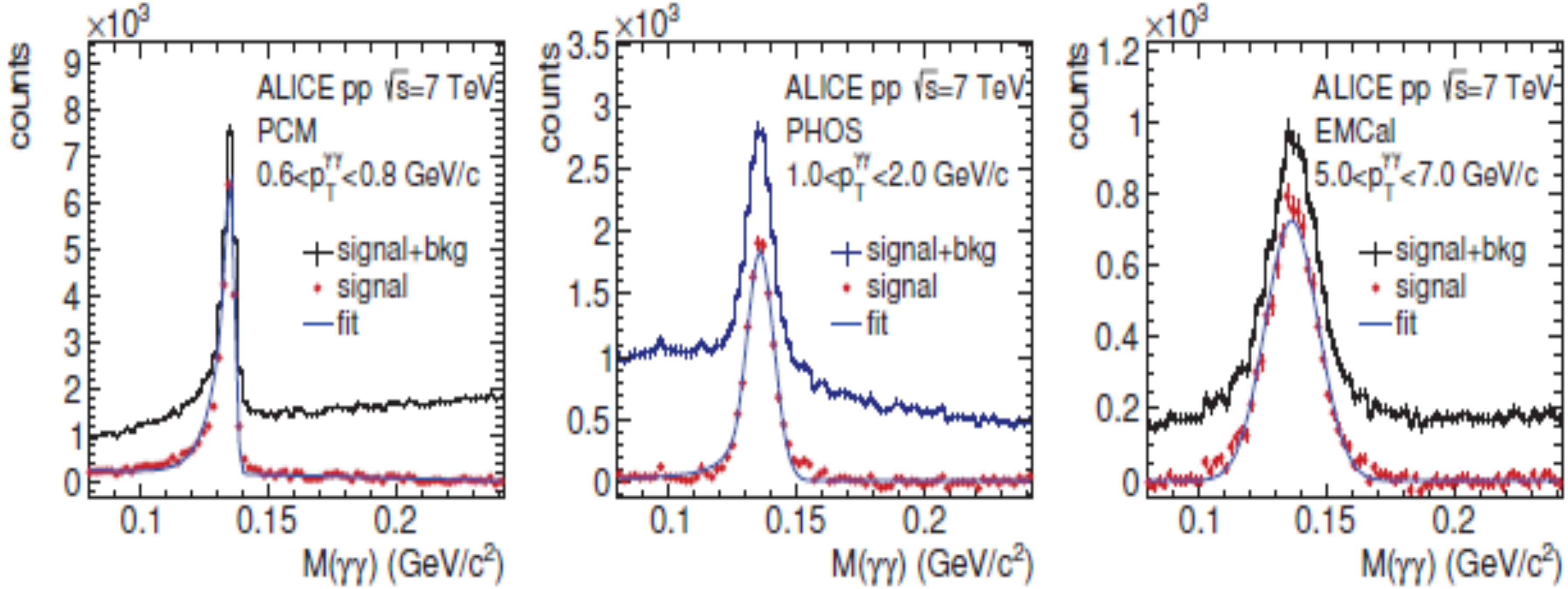
PRL 111 (2013) 222301





PLB 728 (2014) 216-227

π^0 reconstruction



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Physics Results With China Involvement

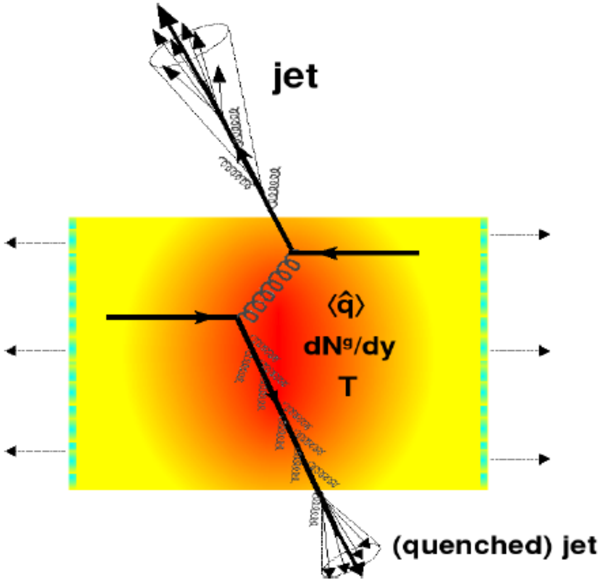
- **Nuclear modification factors to study the parton energy loss mechanism.**
  - **Muons from heavy-flavor hadron decays**
  - **Particle production correlated with high p_T neutral pions**
- **Elliptic flow of identified particles to probe the properties of medium created in heavy-ion collisions.**
  - **(Multi-)strange particles**
  - **Muons from heavy-flavor hadron decay**

- **Results not covered by this talk**
  - **Heavy flavor decay muon production at forward rapidity in pp collisions at 2.76 and 7 TeV. Published in PLB 708 (2012) 265.**
  - **Measurement of charm production at central rapidity in pp collisions at 2.76 TeV. Published in JHEP. 1207 (2012) 191.**
  - **Neutral pion and η meson production in pp collisions at 0.9 TeV and 7 TeV. Published in PLB 717 (2012) 162. Paper proposal on high pT neutral pion production at 2.76 TeV has been approved by ALICE.**
  - **Neutral pion production at midrapidity in p-Pb collisions at 5.02 TeV. Paper proposal approved by ALICE.**

Nuclear modification

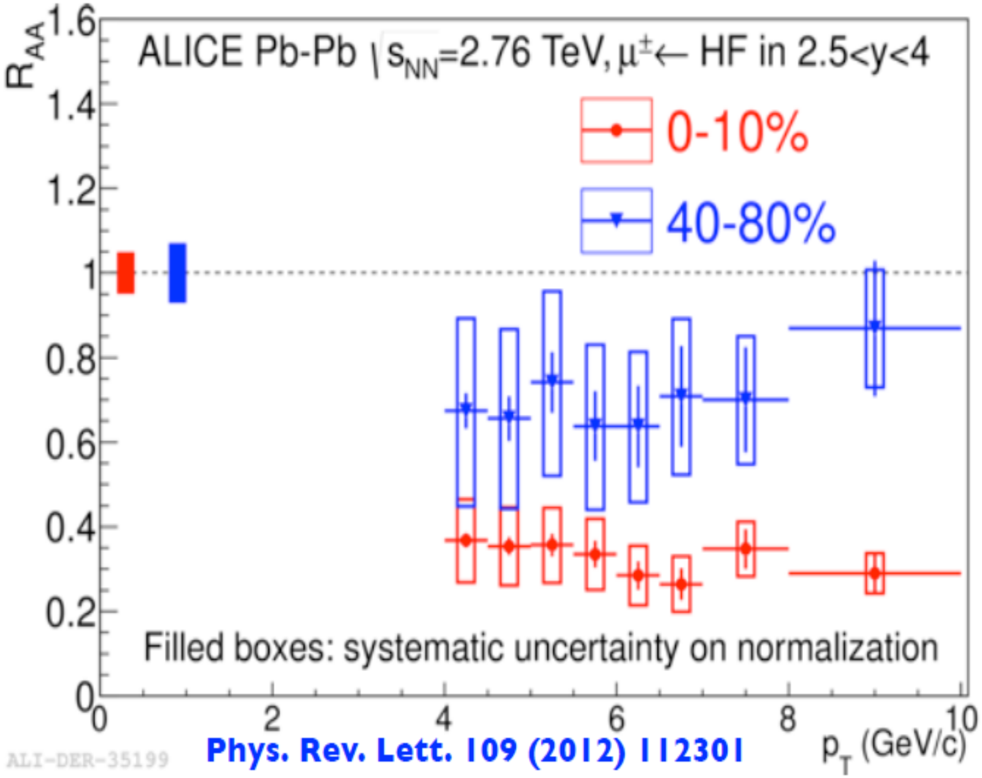
- High p_T particles are produced in hard or semi-hard parton-parton scatterings at the very beginning of heavy-ion collisions.
- High p_T partons will suffer energy loss when interacting with the medium created in heavy-ion collisions, leading to high p_T particle suppression wrt pp collisions.
- Nuclear modification factor:

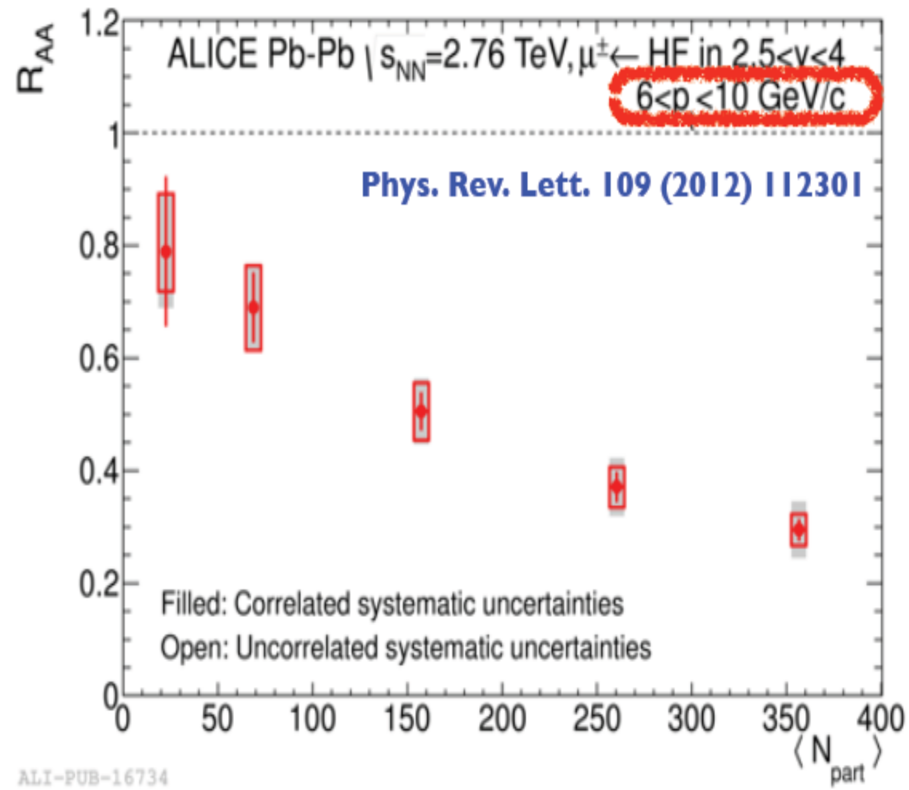
$$R_{AA} = \frac{\frac{dN_{AA}}{dp_T}}{<N_{coll}> \frac{dN_{pp}}{dp_T}}$$



- N_{coll} is the number of binary collisions
- For perturbative QCD processes
  - ➢ $R_{AA}<1$: suppression
  - ➢ $R_{AA}=1$: no nuclear effects
  - ➢ $R_{AA}>1$: enhancement

Nuclear modification factors

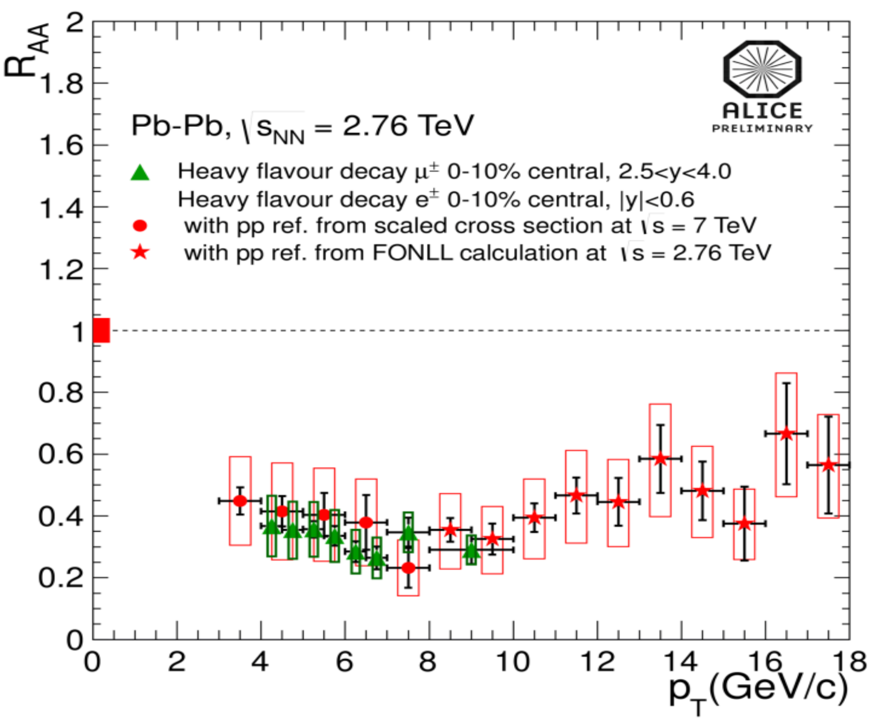




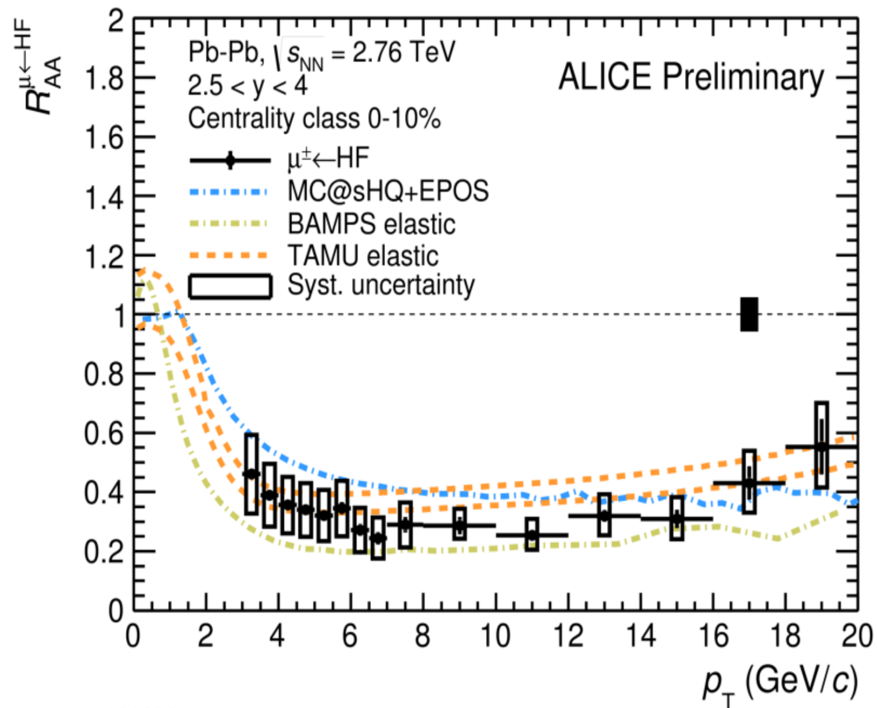
- **Strong suppression of heavy-flavor decay muon production at forward rapidity in central Pb-Pb collisions at 2.76 TeV.**

- **Increasing suppression with increasing centrality**
- **Indication of b suppression as it is expected to be dominant component in the considered p_T region.**

Comparison to measurement at mid-rapidity



ALI-DER-36791

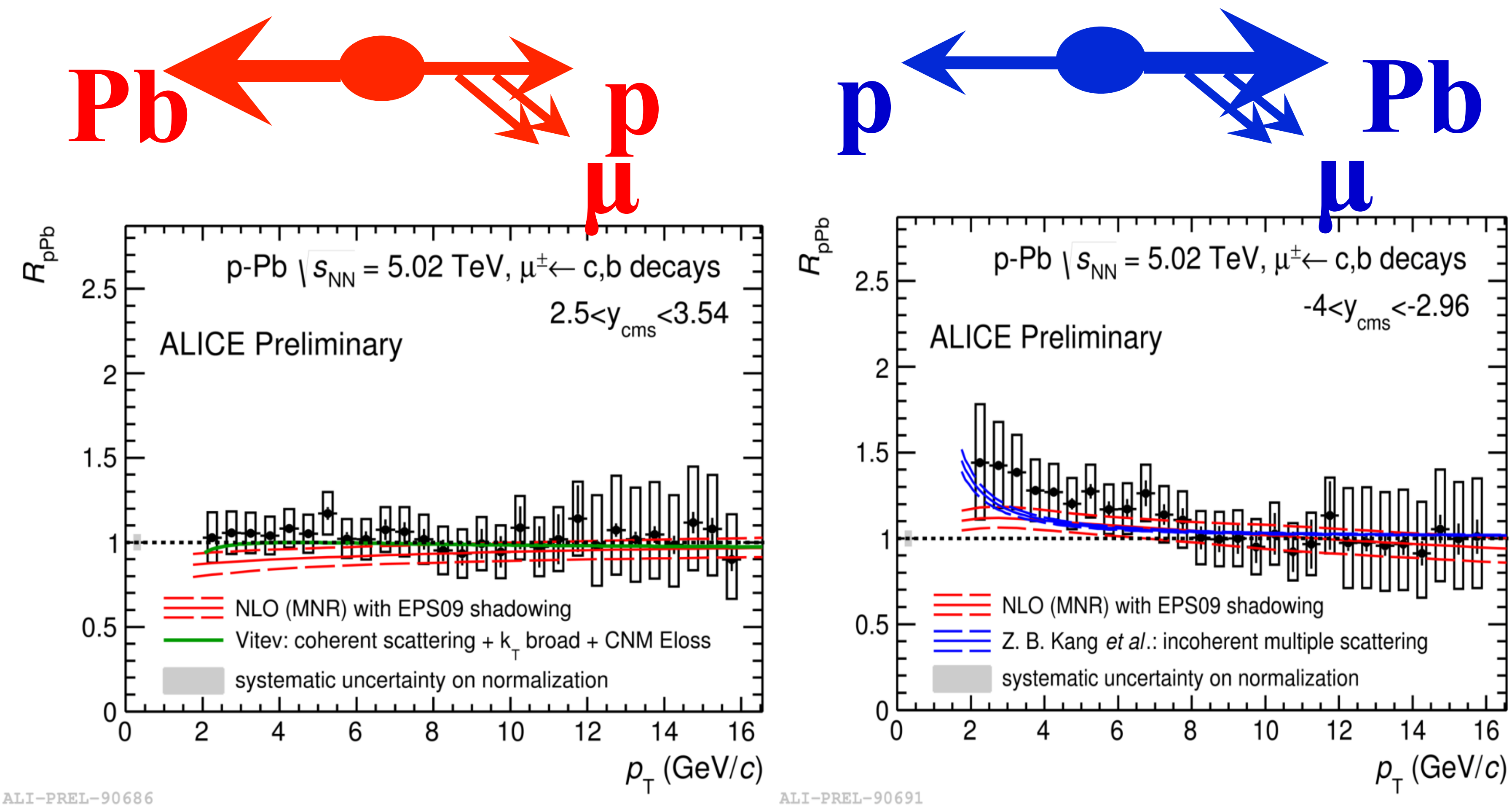


ALI-PREL-101250

- **The suppression of heavy-flavor decay muons at forward rapidity is similar to that of heavy-flavor decay electrons at mid-rapidity.**

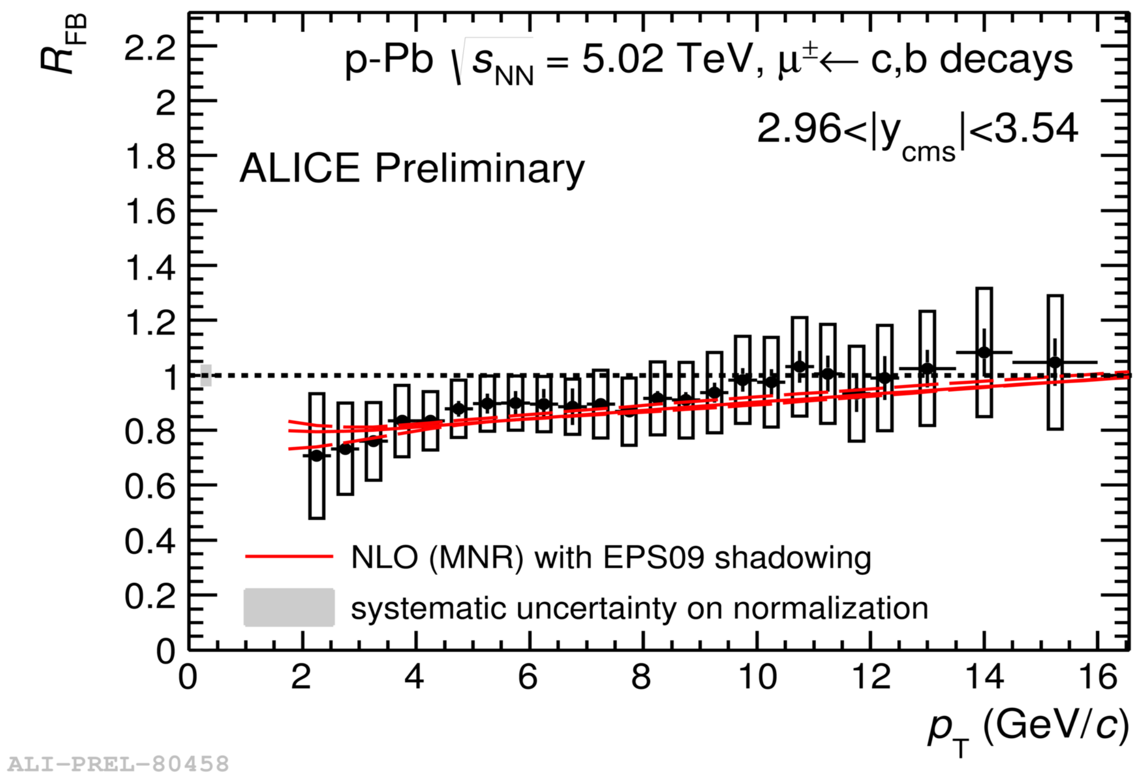
- **Measurement extended to higher p_T confirms the trend of increasing with p_T**
- **Results approved as Preliminary for QM2015**

Initial- or final-state effect?



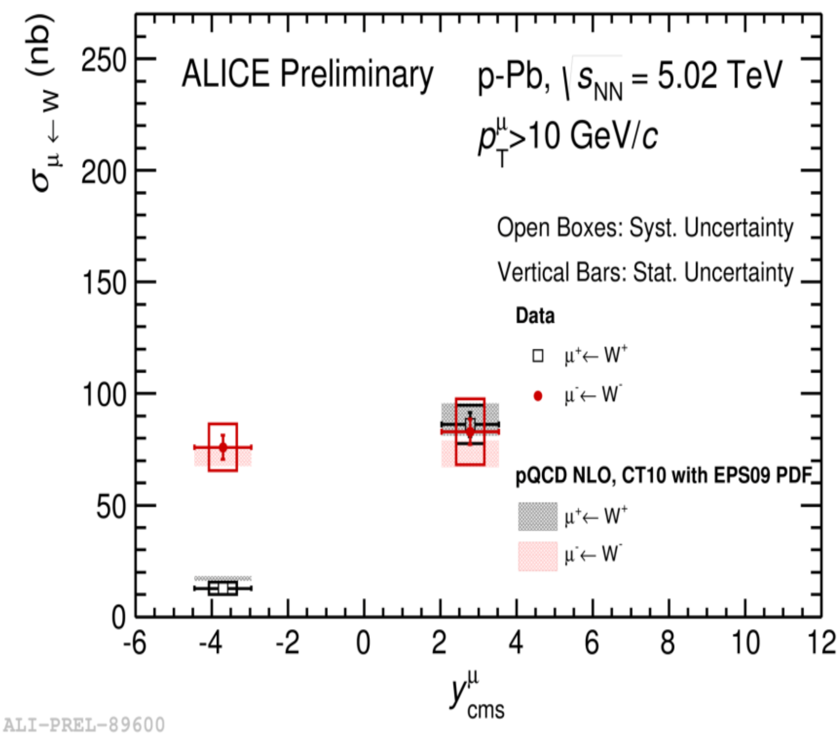
- **Measurements at both forward and backward rapidity indicate that cold nuclear medium effects are small.**
- **Thus the suppression observed in Pb-Pb collisions is due to the hot and dense medium.**

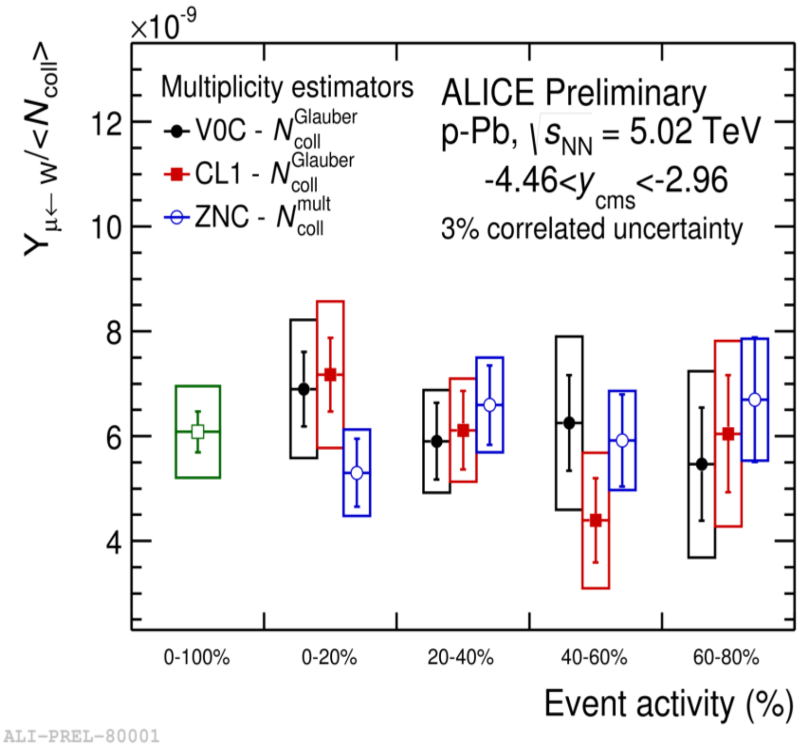
Forward-backward ratio



- **Forward-backward ratio can be well described by NLO pQCD calculation with shadowing effect.**
- **Paper in discussion with the Internal Review Committee**

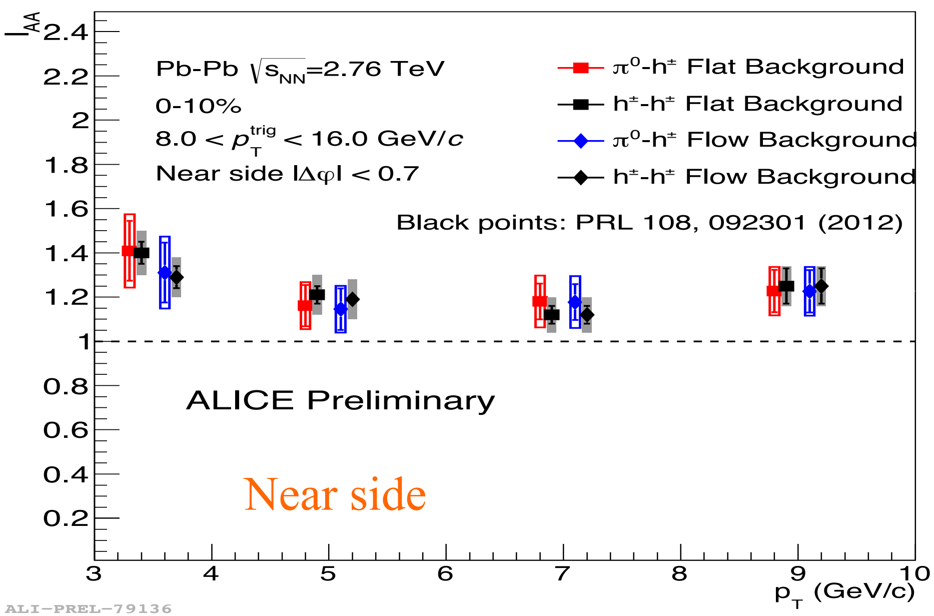
W production

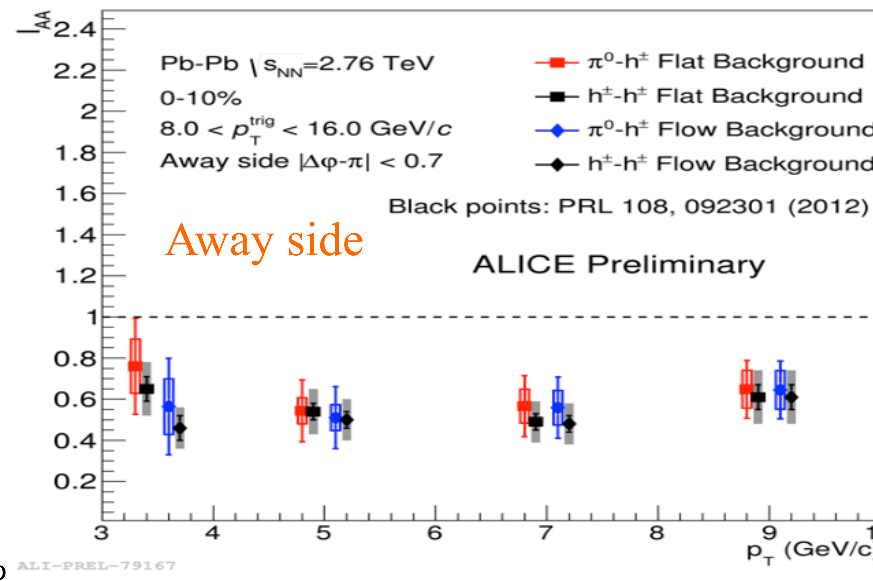




- **Measurement of the W production cross section in p-Pb collisions via the semi-leptonic decays of W bosons in the muon channel.**
- **Measured cross section well described by NLO pQCD calculation with CT10 PDF and EPS09 shadowing parameterization**
- **Yield/<N_{coll}> vs. event activity with different estimators is constant within uncertainties**
- **Paper proposal has been approved by ALICE**

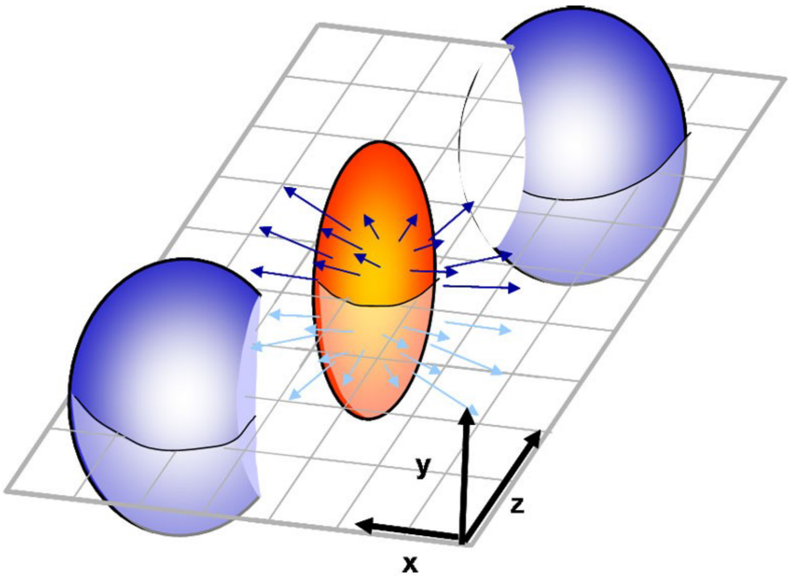
Modification of per-trigger yield of associated hadrons: I_{AA}



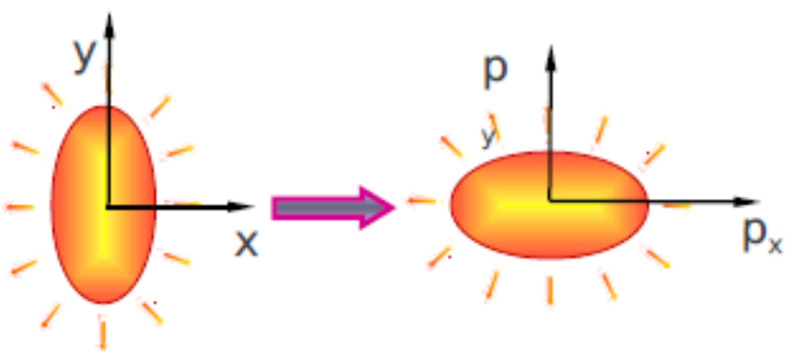


- I_{AA} shows the ratio of per trigger yield of associated hadrons in Pb-Pb collisions with respect to that in pp collisions.
- A near-side enhancement and an away-side suppression shows strong hot nuclear medium effect on the traversing hard partons.
- The measurement has been extended to low p_T.
- **Paper proposal accepted by ALICE.**

Elliptic flow (v_2)



- **Interactions among constituents transform the initial spatial anisotropy into momentum anisotropy**
- **Anisotropic flow of identified particles allows to probe the properties of medium created in heavy-ion collisions**
  - **Adds further constraints to initial conditions, deconfined phase, particle production mechanisms**
  - **Probes the freeze-out conditions of the system (temperature, radial flow, ...)**
  - **Checks the number of constituent quarks (NCQ) scaling**



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

$$v_n = <\cos[n(\phi - \Psi_{RP})]>$$

- v_n to quantify the event anisotropy
  - ➢ v_2 elliptic flow
- Ψ_{RP} can be estimated from particle azimuthal distribution

Elliptic flow

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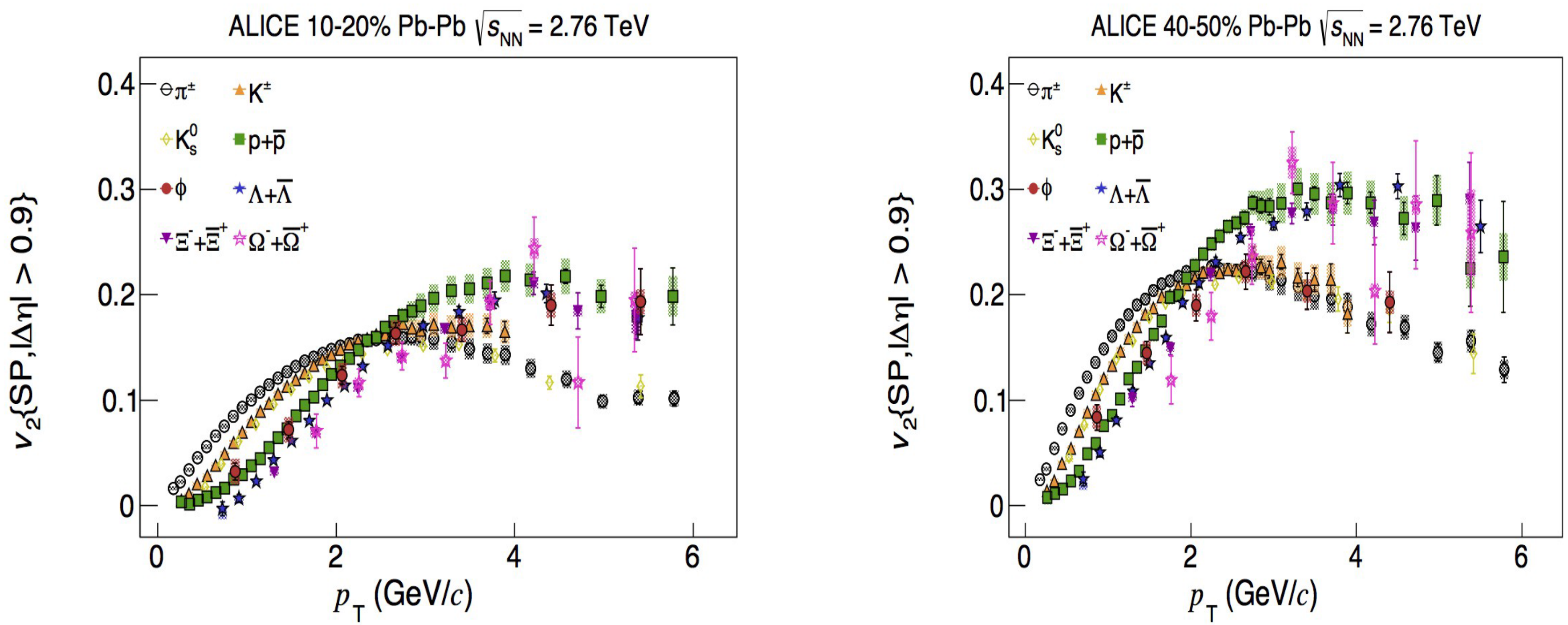

- **For p_T<2 GeV/c mass ordering indicates radial flow effect**
- **For p_T~2-3.5 GeV/c crossing between v_2 of p and $\pi^\pm$**
- **For p_T>3 GeV/c particles tend to group into mesons and baryons**
- **v_2 of ϕ follows baryons for central collisions and shift progressively to mesons for peripheral collisions**

p_T/n_q scaling?

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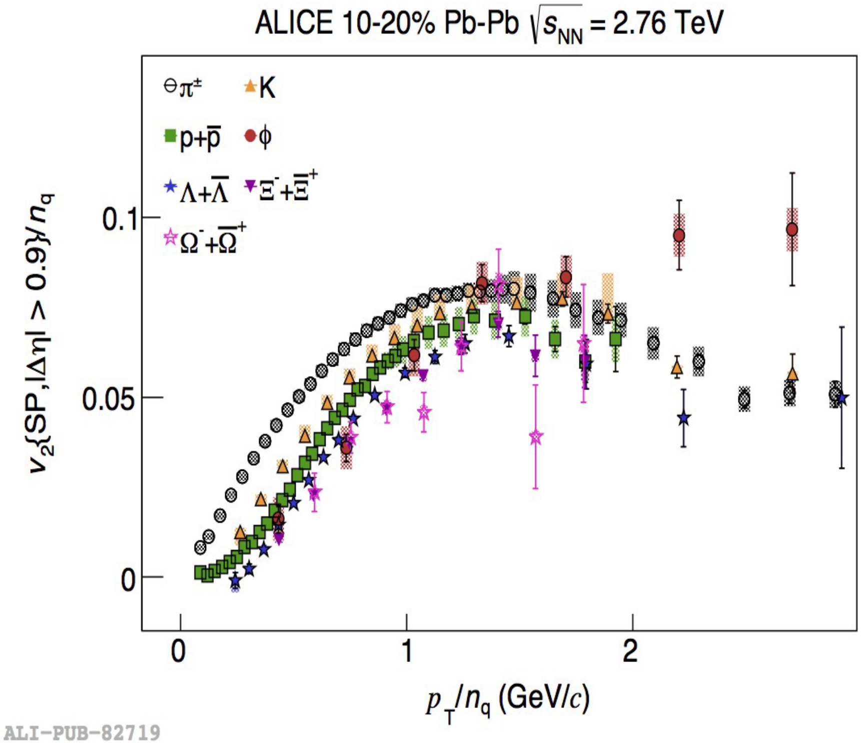
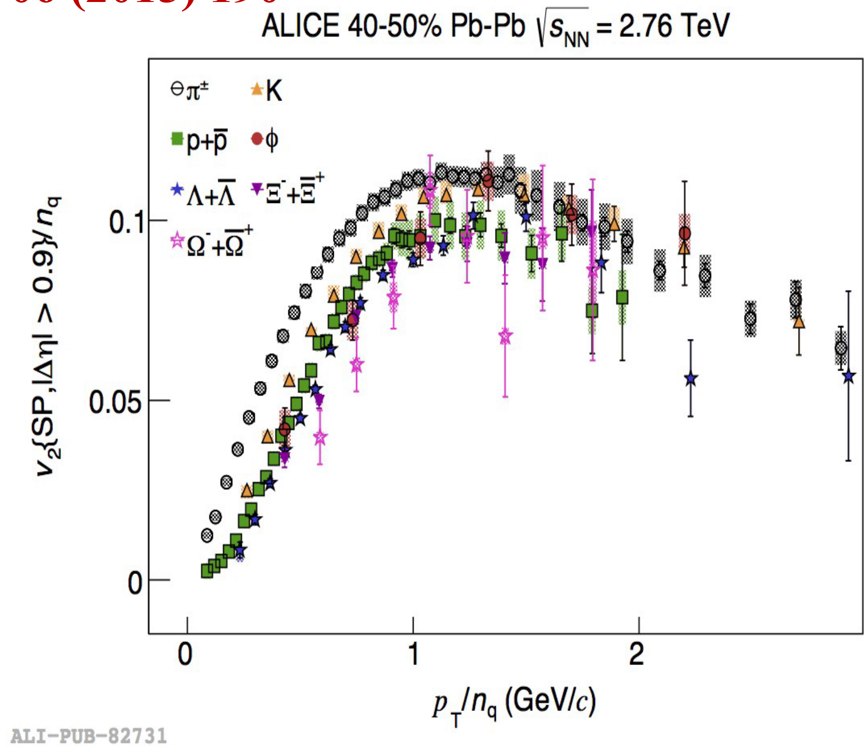
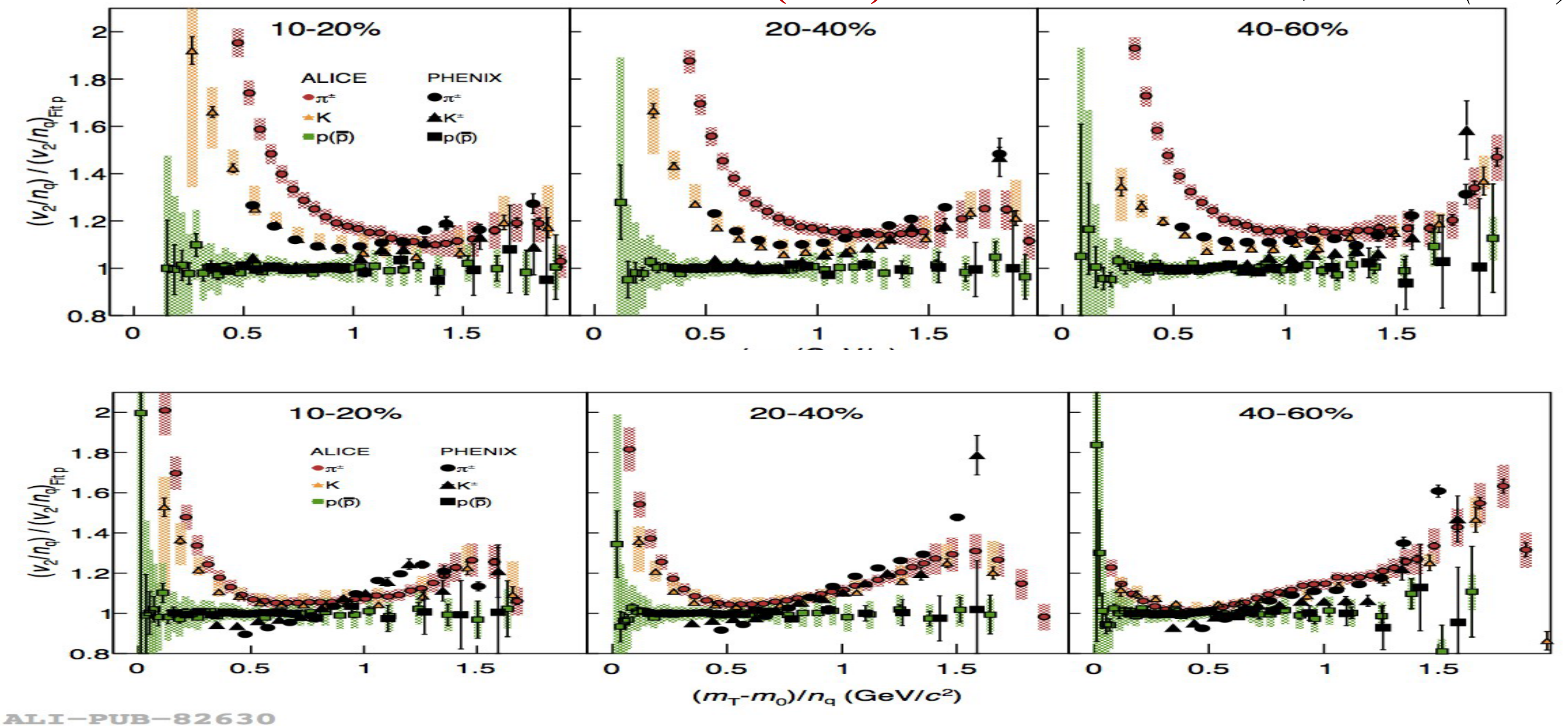




- **ϕ does not follow the band of mesons for central collisions**
- **For p_T/n_q>1 GeV/c NCQ scaling is only approximate**

n_q scaling?

JHEP 06 (2015) 190 *PHENIX: PRC 85, 064914 (2012)*



- **Number of constituent quark scaling violated by ~20% at p_T/n_q > 1 GeV/c**
- **Deviations at intermediate p_T are qualitatively similar at LHC and RHIC**
  - **Evolution is different for π and K**

Comparison with a hybrid hydrodynamic model calculation

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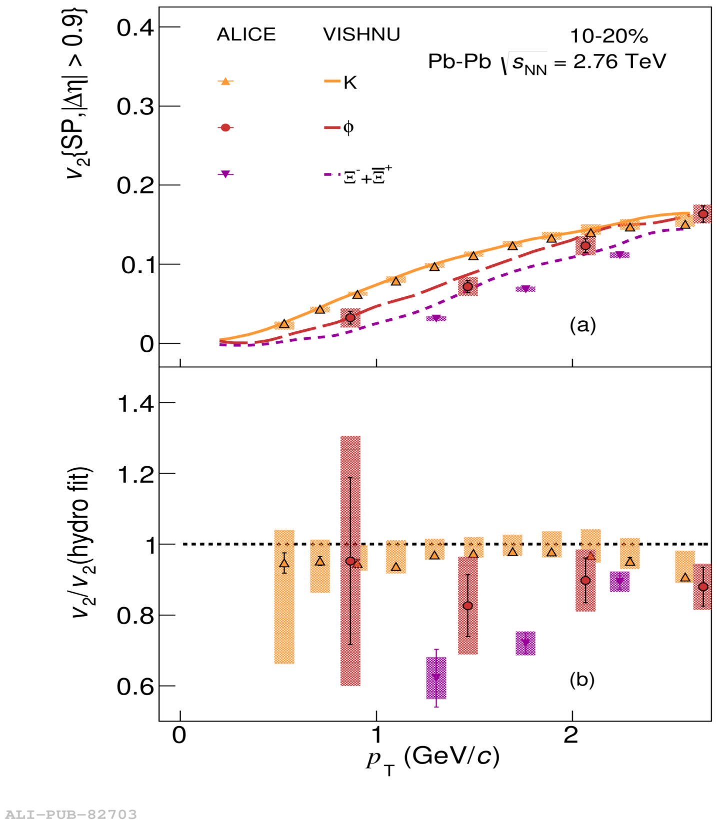
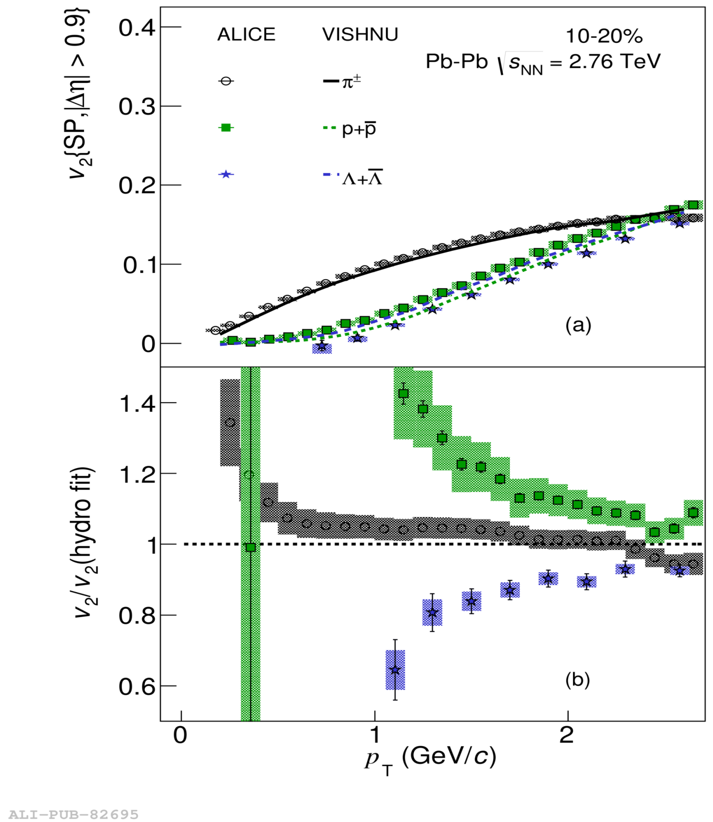
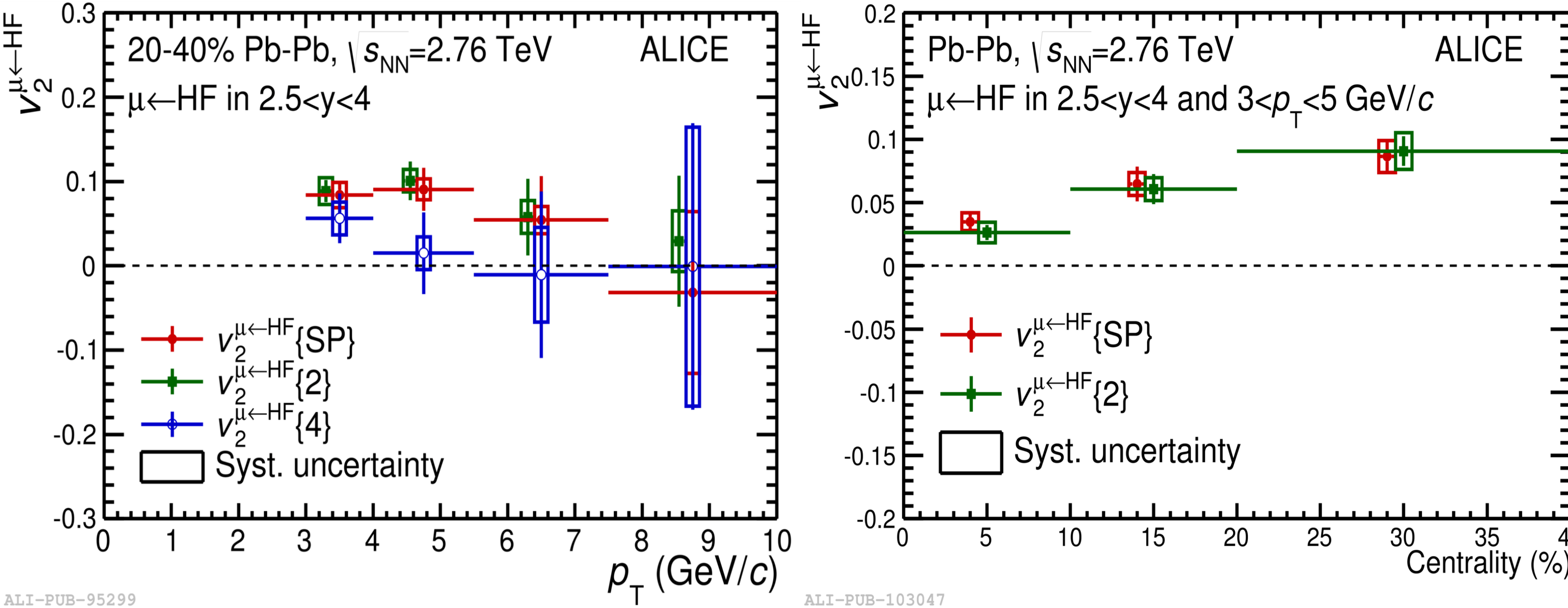




- **Reproduce the mass ordering but overestimate the Λ and Ξ v_2**

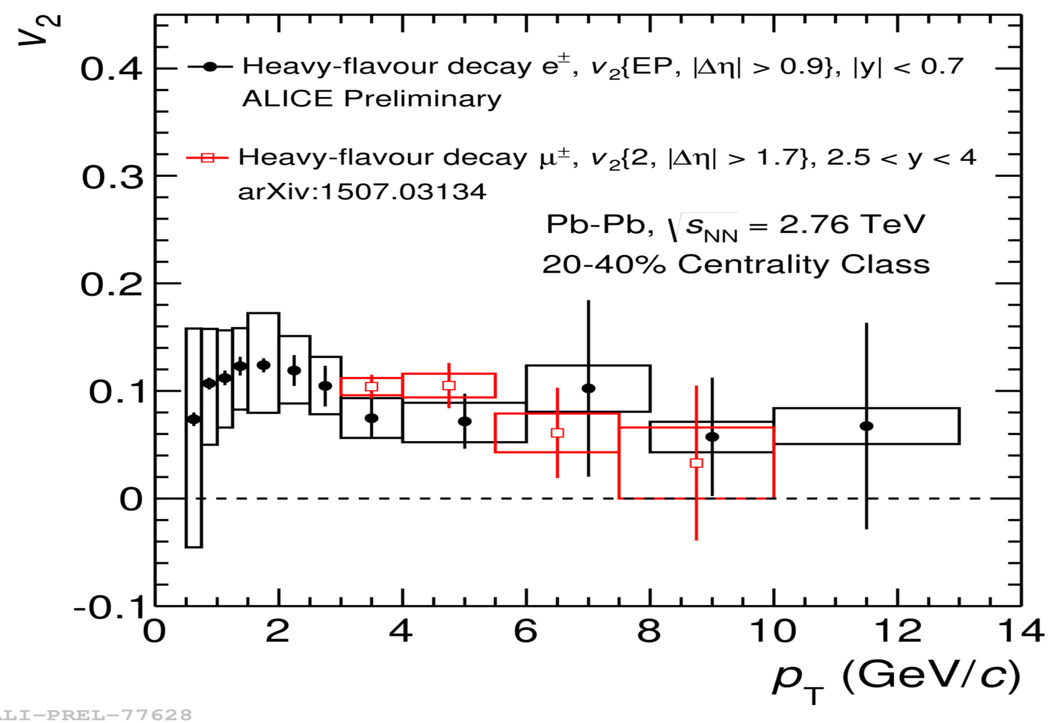
Elliptic flow of muons from heavy-flavor hadron decays

arXiv:1507.03134, accepted by PLB, in press



- **p_T-differential v_2 of muons from heavy-flavour decays measured in $3 < p_T < 10$ GeV/c;**
- **Clear increase of v_2 from central to semi-central collisions in centrality range 0-40%;**
- **Observation of a positive v_2 in semi-central collisions at intermediate p_T with a significance larger than 3σ when combining statistical and systematic uncertainties.**

Comparison with v_2 of heavy-flavor decay electrons at midrapidity



- v_2 of heavy-flavor decay muons at forward rapidity ($2.5<\eta<4$) is compatible with that of heavy-flavour decay electrons at mid-rapidity ($|\eta|<0.7$) within uncertainties.
- Indication of strong interaction of heavy flavors with the hot and dense medium.

Summary

- Our study is mainly focused on hard probes and collectivity of the strongly-interacting matter created in heavy-ion collisions at LHC.
- It is observed a strong nuclear medium effect on the heavy-flavor hadron decay muon production at forward rapidity and the per-trigger associated hadron production in Pb-Pb collisions at 2.76 TeV
- Significant anisotropic flow has been observed both for identified hadrons at mid-rapidity and for heavy-flavor decay muons at forward rapidity.
  - Mass ordering of identified particles' v_2 is qualitatively reproduced by VISHNU.
  - NCQ scaling of v_2 is approximate

On-going analyses

- **Elliptic flow of π^0 in Pb-Pb collisions at 2.76 TeV.**
- **Triangular flow of multi-strange hadrons in Pb-Pb collisions at 2.76 TeV.**
- **Λ/K^0_S ratio in jet and bulk for pp at 7 TeV and p-Pb at 5.02 TeV.**
- **Heavy-flavor decay muon production versus event activity in p-Pb collisions at 5.02 TeV.**
- **Neutral pion production at high p_T in p-Pb collisions at 5.02 TeV.**

Toward RUN-II

- **Elliptic and triangular flow of multi-strange hadrons in Pb-Pb collisions at 5.02 TeV**
- **Hadron-(multi)strange correlations in pp and Pb-Pb collisions at 5.02 TeV**
- **π^0 and η triggered correlation in pp and Pb-Pb**
- **π^0 and η spectrum in pp and Pb-Pb at 5.02 TeV**
- **Direct gamma spectrum and correlation in pp**
- **Jet production in Pb-Pb collisions at 5.02 TeV**
- **Production of muons from heavy-flavor hadron decays in pp and Pb-Pb collisions**
- **Pseudorapidity density distribution and transverse momentum spectrum of charged particles in high multiplicity pp events at 13 TeV**
- ……

Study of High Multiplicity (HM) final states in small systems

Prof. Paolo Bartalini and Dr. Prabhakar Palni

Big interest in this research field triggered by the observation of flow-like effects in HM final states of small interacting systems (i.e. pp and pA). **There's still no widely agreed interpretation of these results. Ridge structures in pp and pA now reported by all the LHC collaborations**

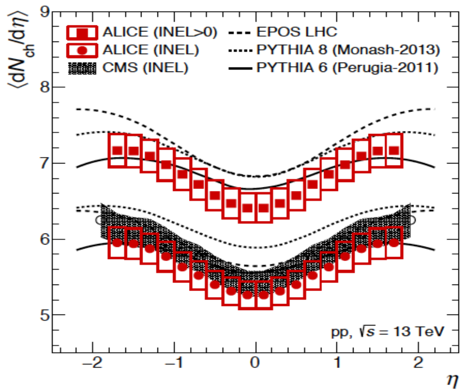
Focus on RUN II. ALICE is currently leading the effort at the LHC. Its HM triggers will provide a sample of low pile-up data for rare pp interactions having a multiplicity around ten times higher than the average, with the goal of collecting an integrated luminosity of 10 pb^{-1}

Ongoing paper contributions. Study of charged multiplicity distribution and Pseudorapidity distribution of charged tracks in HM pp collisions at 13 TeV

Strategy. work in the context of the ALICE High Multiplicity Task Force and in close collaboration with the ALICE Light Flavour Physics Working Group

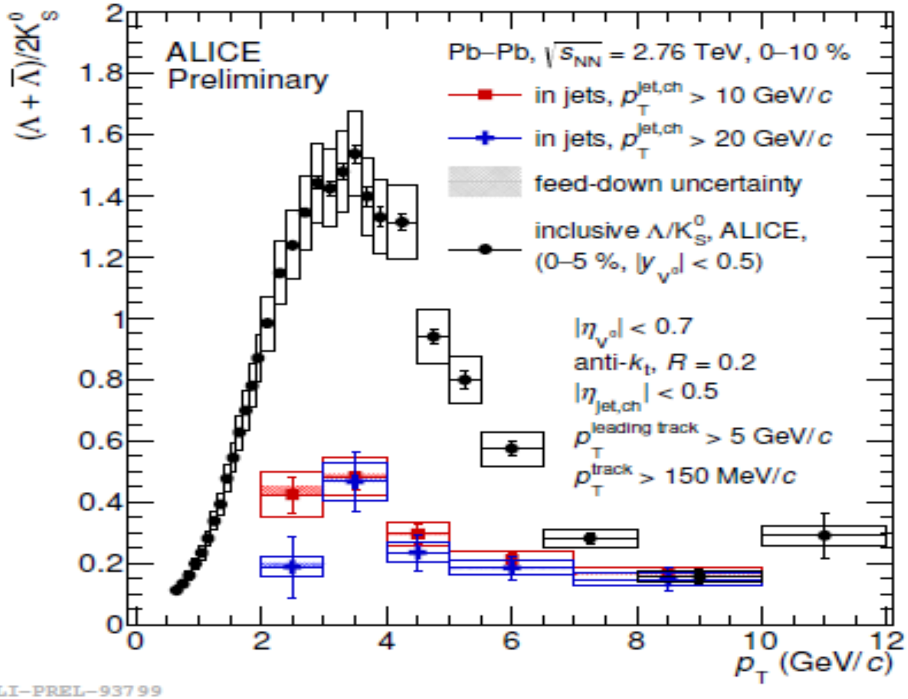
Early contributions. Data validation & study of trigger performances relevant to arXiv:1509.08734 "Pseudorapidity and transverse-momentum distributions of charged particles in proton-proton collisions at $\sqrt{s}$= 13 TeV"

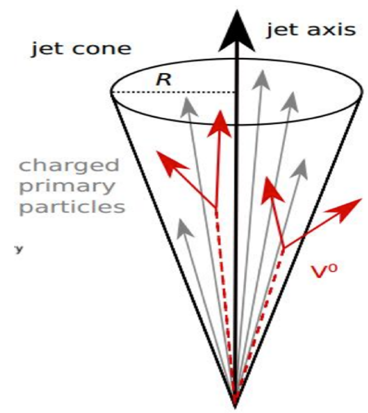
- **Poster presentation of Prabhakar Palni, QM 2015 (Kobe)**
- **Talk of Prabhakar Palni, MPI@LHC 2015 (Trieste)**
- **Talk of Prabhakar Palni, this conference**

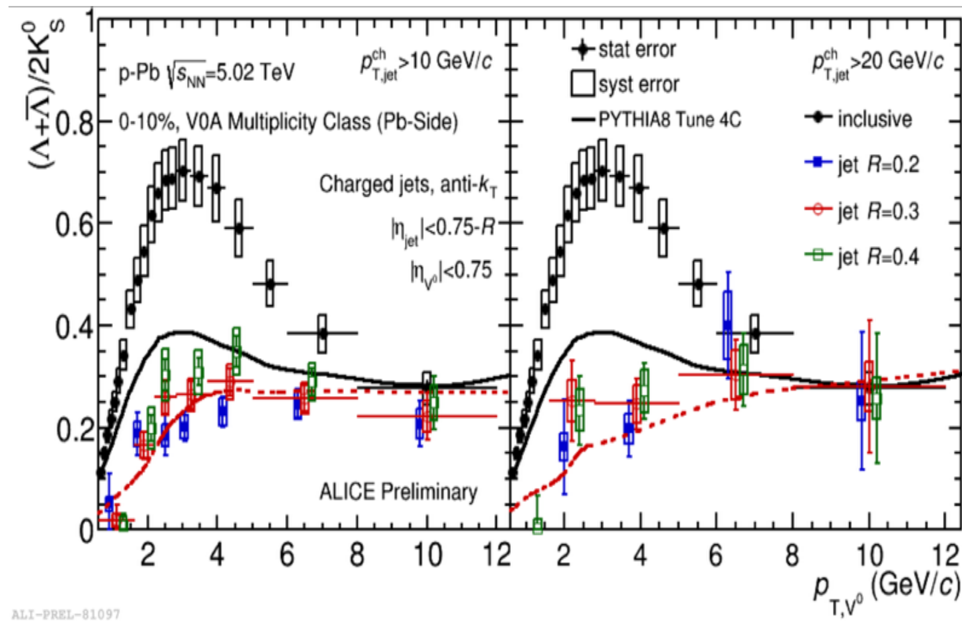


Thank you very much for your attention!

Origin of the B/M anomaly







It is a bulk effect, not a jet effect!