Heavy ion physics overview
—focus on ALICE-China topics

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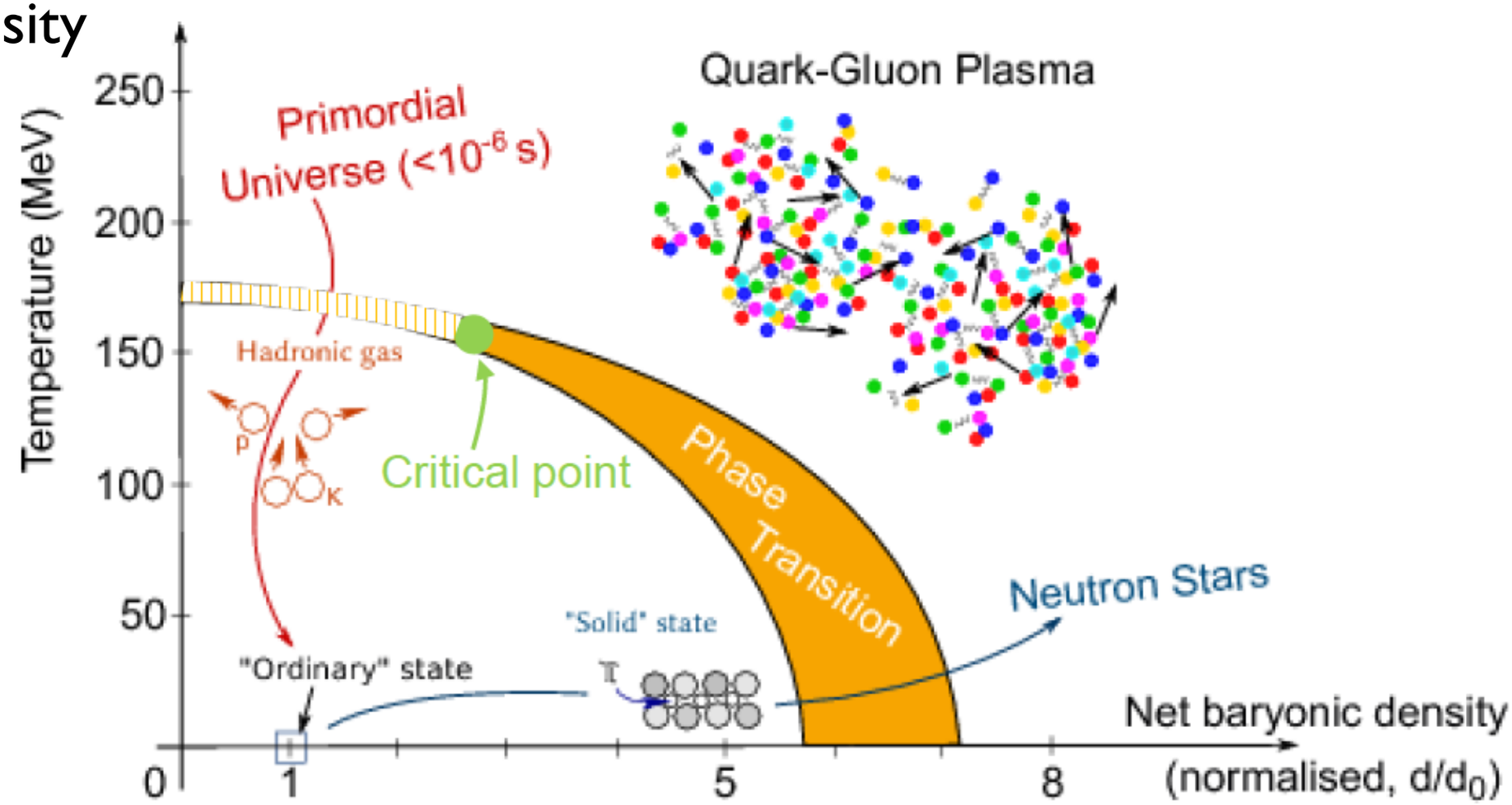
Heavy ions at the LHC

- Investigate the region of the phase diagram of strongly interacting matter corresponding to the highest possible temperature and the lowest net baryon density



- Recreate the first (and hottest!) liquid that ever existed and that gave rise to matter around us …

  … and study its properties in the laboratory

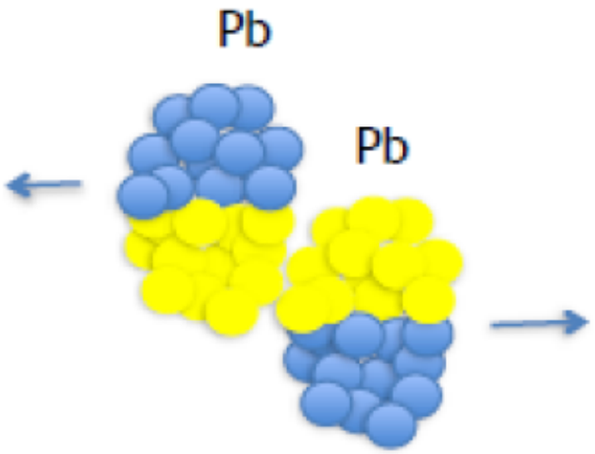
The energy frontier

- Evolution of (some) properties of the system with the collision energy (N. B. approximate values!)

Central collisions	SPS	RHIC	LHC
√s (GeV)	17	200	5000 (today)
dNch/dη (η = 0)	450	650	2000
Energy density (GeV/fm^3)	2.2-3.2	5.4	20
V (fm^3) - from HBT	120	160	300
Decoupling time (fm/c) - from HBT	6	7.5	10.5
Average QGP temperature (MeV) -photons, dileptons			

LHC→ hotter, larger, and longer lived fireball!

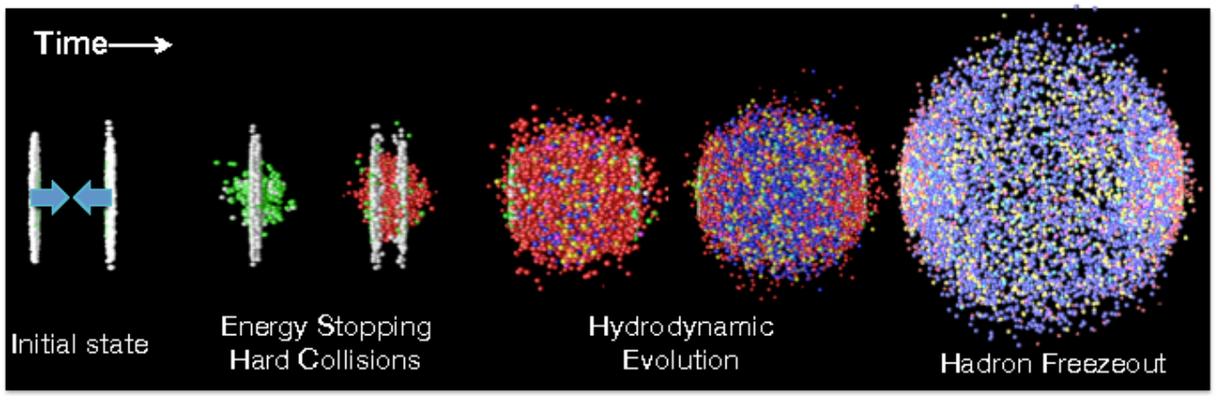
The collision systems

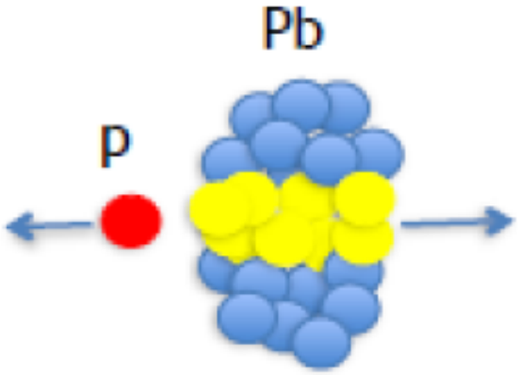


Pb-Pb collisions

Hot matter effects

Soft + hard probes





p-Pb collisions

Calibrate cold nuclear matter effects (CNM)

pp collisions

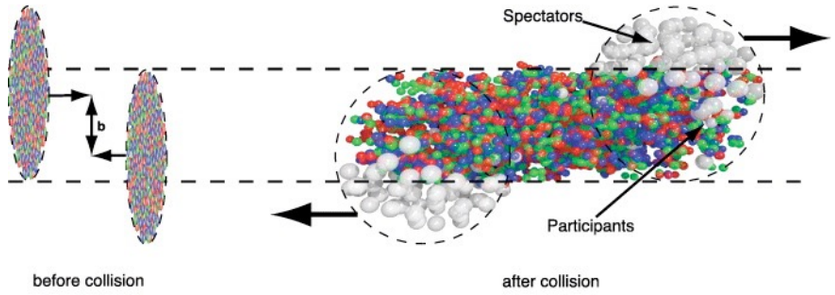
Reference for Pb-Pb collisions, QCD

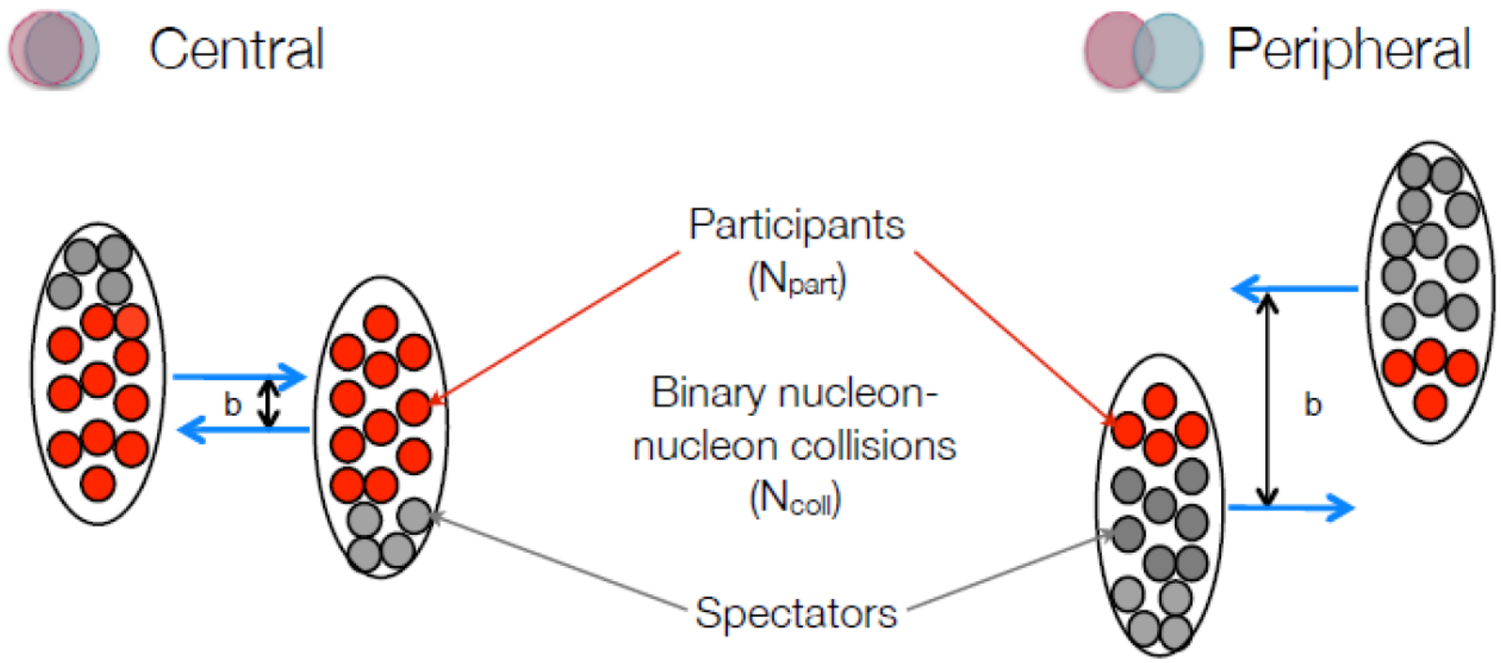
Change of paradigm at LHC energies

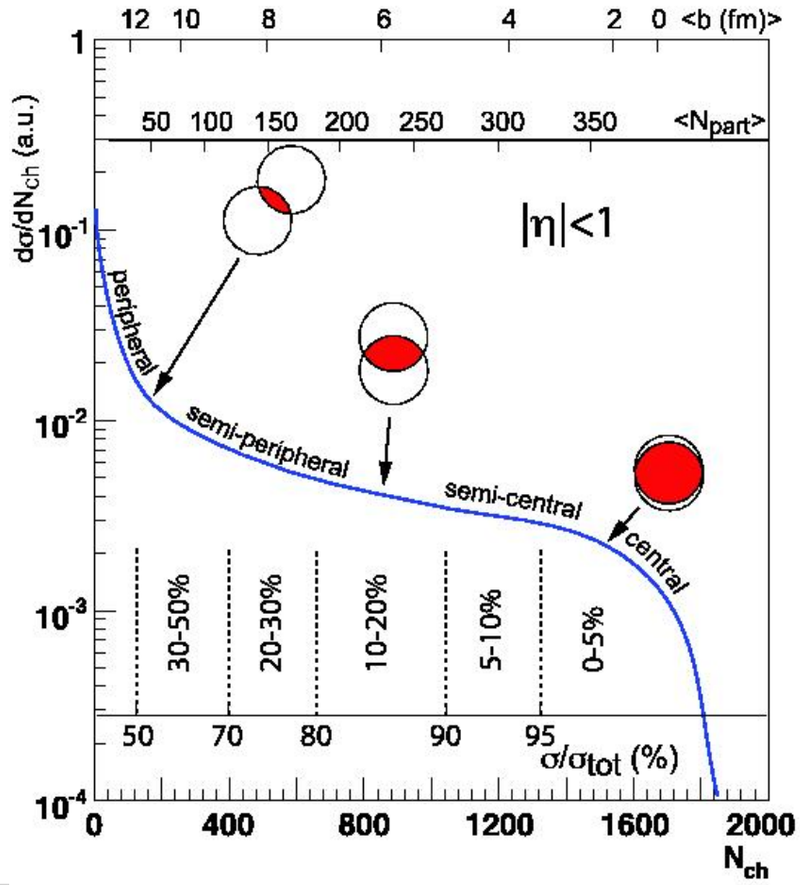
High multiplicity p-Pb and pp collisions show intriguing signal of QGP-like effects

Collision centrality

- Nuclei are extended objects
- Geometry related to observables via Glauber Model
- Related to multiplicity or forward energy (spectators)



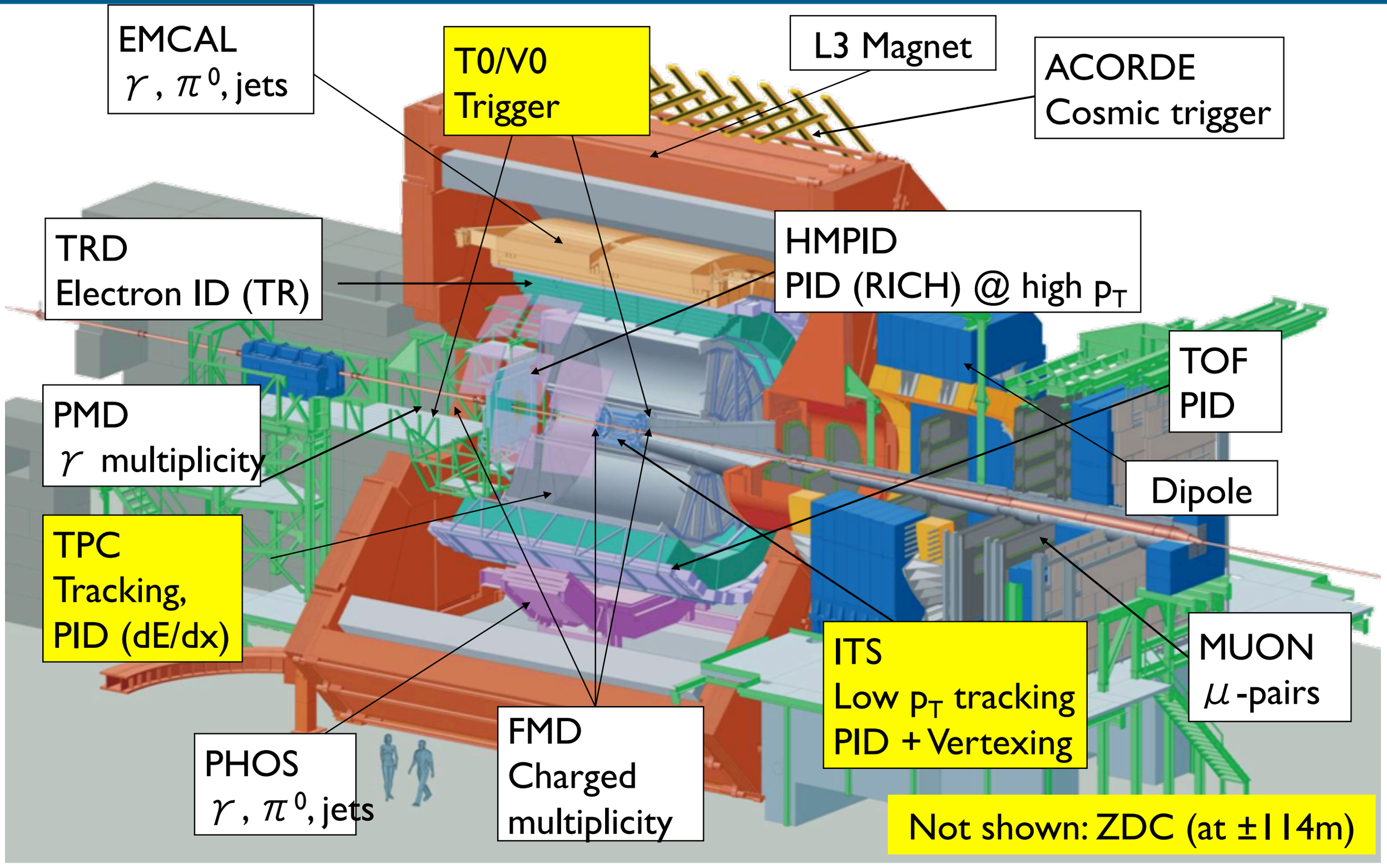




Soft processes: long timescale, large σ, $\sigma_{tot} \propto N_{part}$

Hard processes: short timescale, large σ, $\sigma_{tot} \propto N_{coll}$

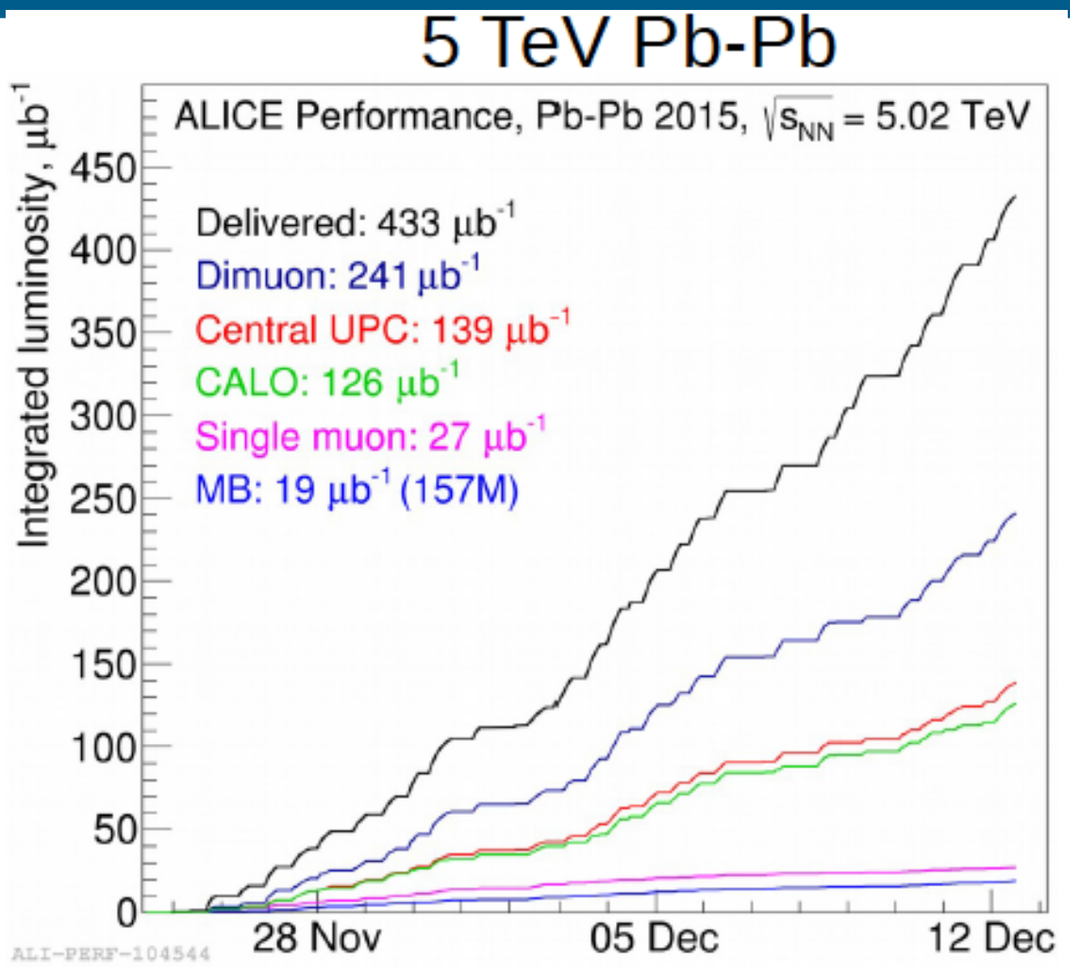
ALICE: A Large Ion Collider Experiment

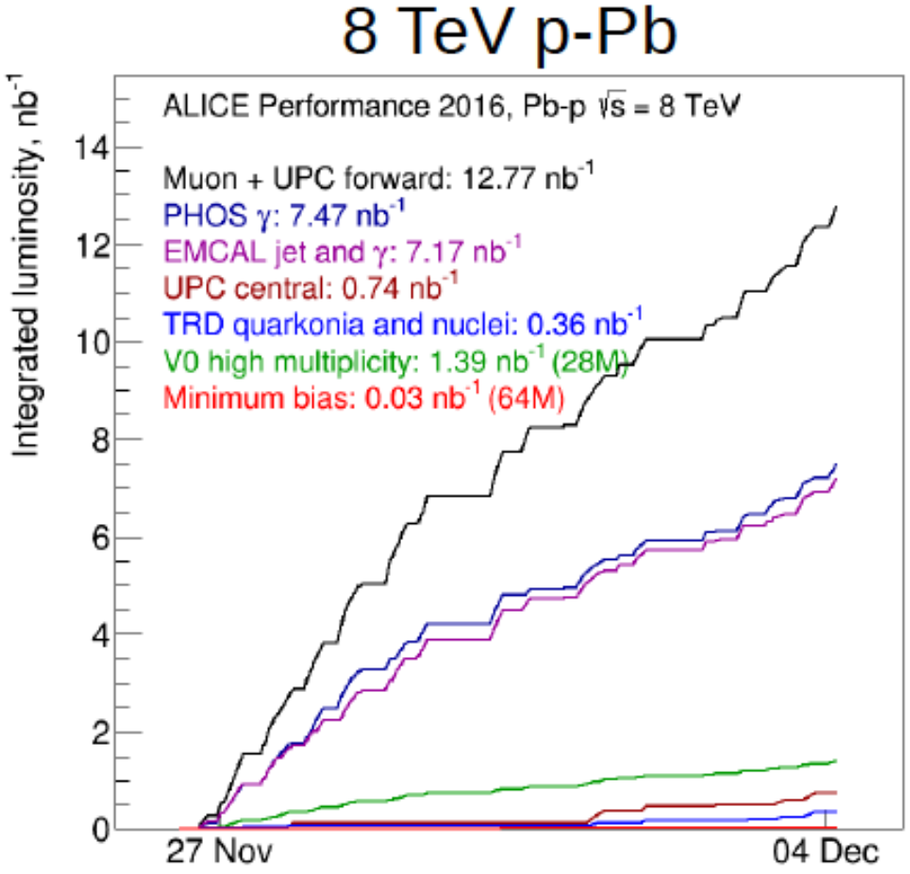


- General-purpose detector for the study of QGP-related signals at the LHC, with several unique features

ALICE Run2 data samples

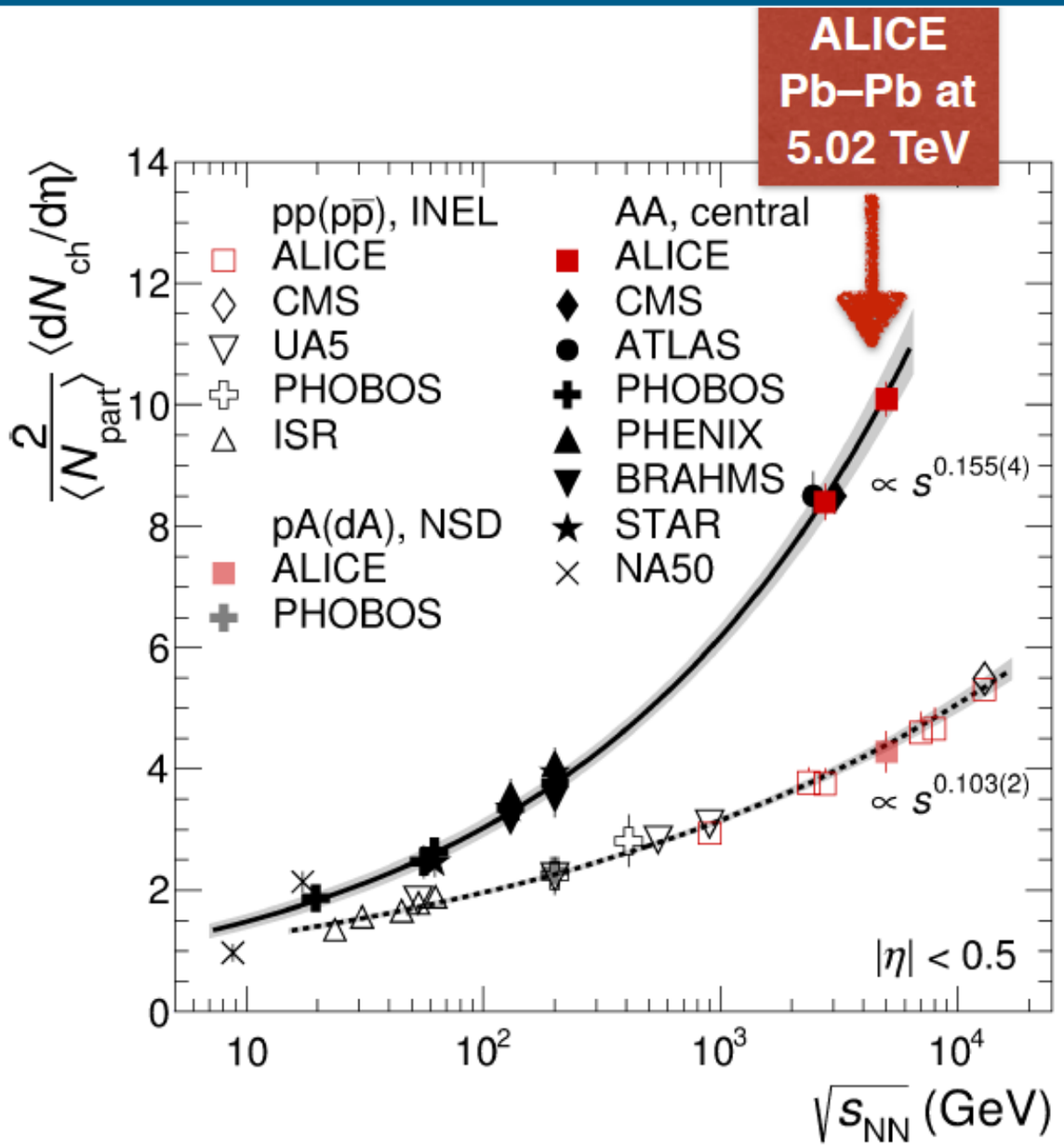
System	$\sqrt{s_{NN}}$ (TeV)	L_{int}	Year
pp	13	14 pb^{-1}	2015-2016
Pb-Pb	5.02	0.4 nb^{-1}	2015
pp	5.02	100 nb^{-1}	2015
p-Pb	5.02	3 nb^{-1}	2016
p-Pb	8.16	~20 nb^{-1}	2016



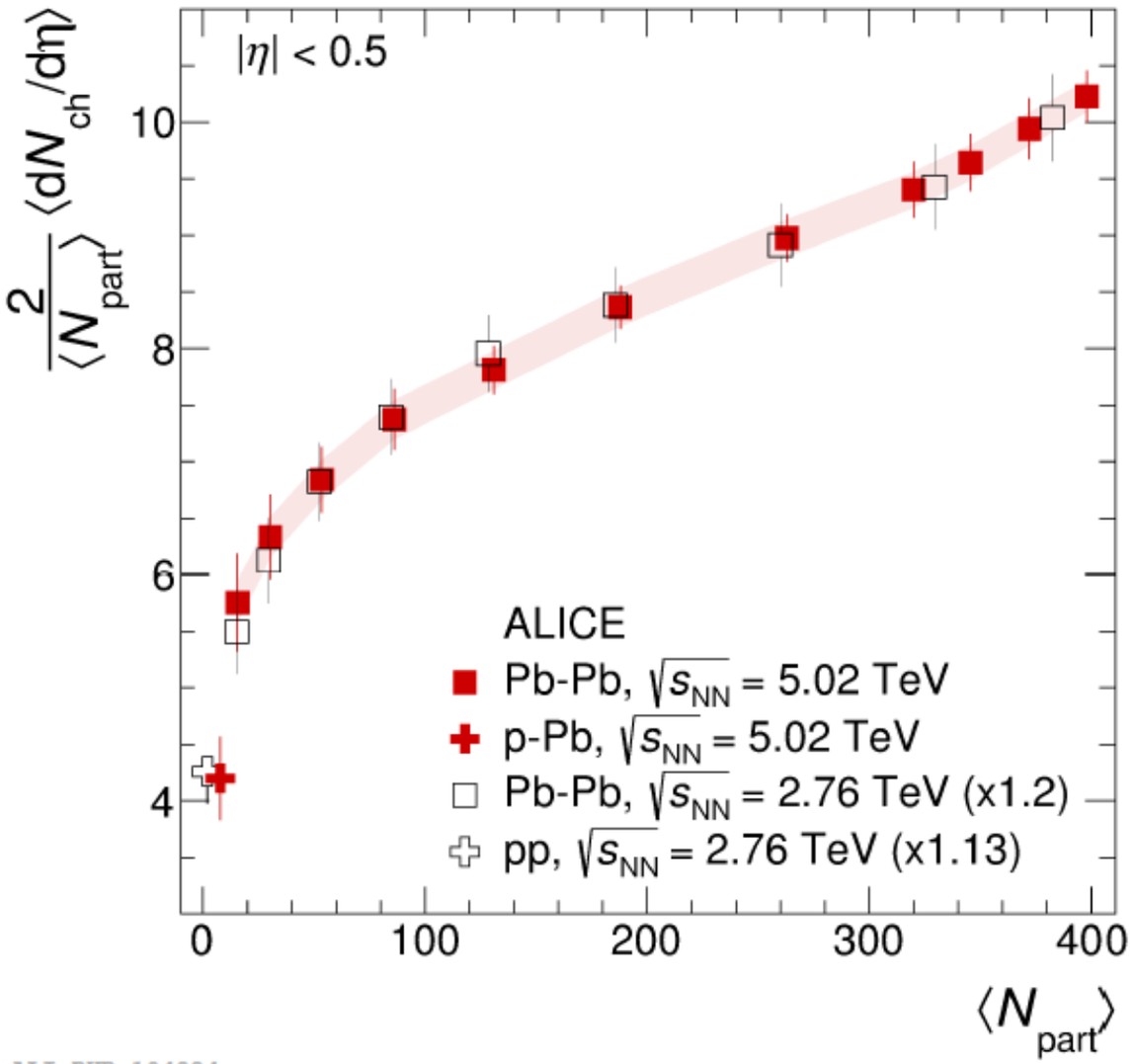


- Versatile and challenging trigger mix
- Extremely stable operations
  - Thanks to CERN accelerator teams
  - ALICE efficiency > 90%

Charged particle multiplicity

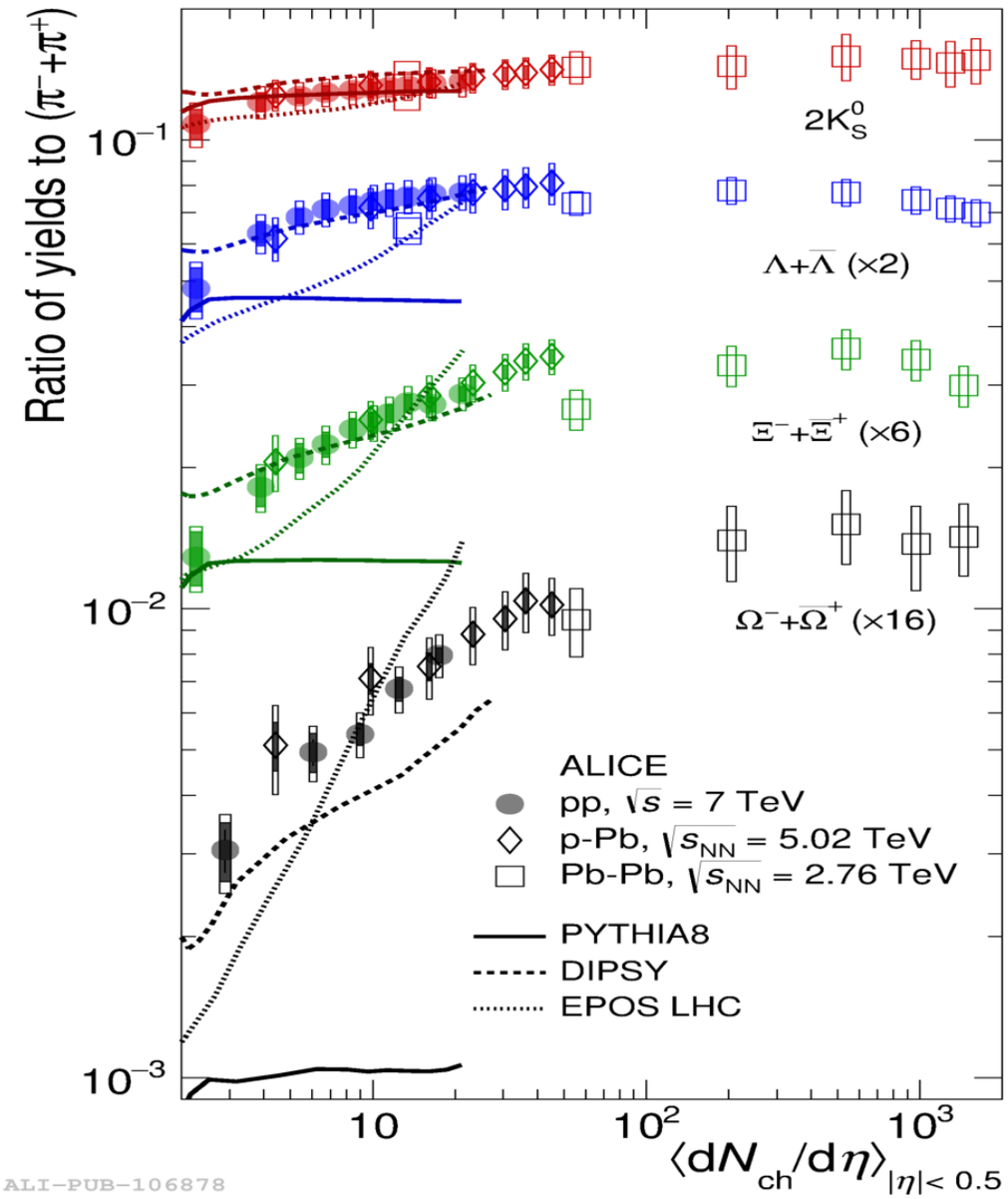


ALICE Phys. Rev. Lett. 116 (2016) 222302

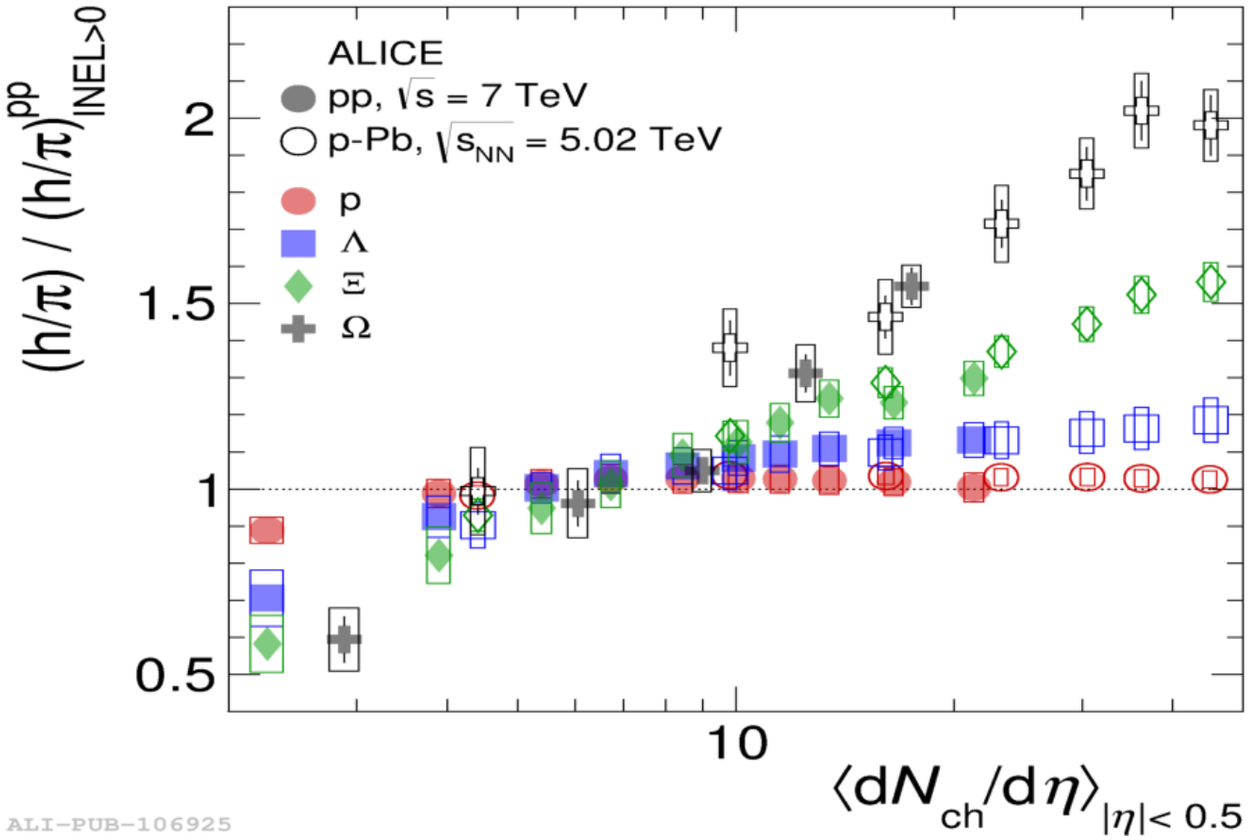


- ALICE: Pb-Pb at 5.02 TeV, highest energy reached so far → confirms trend from lower energies
- Similar evolution with centrality between 5.02 and 2.76 TeV
- Provides further constraints for model

Multiplicity dependent strangeness production

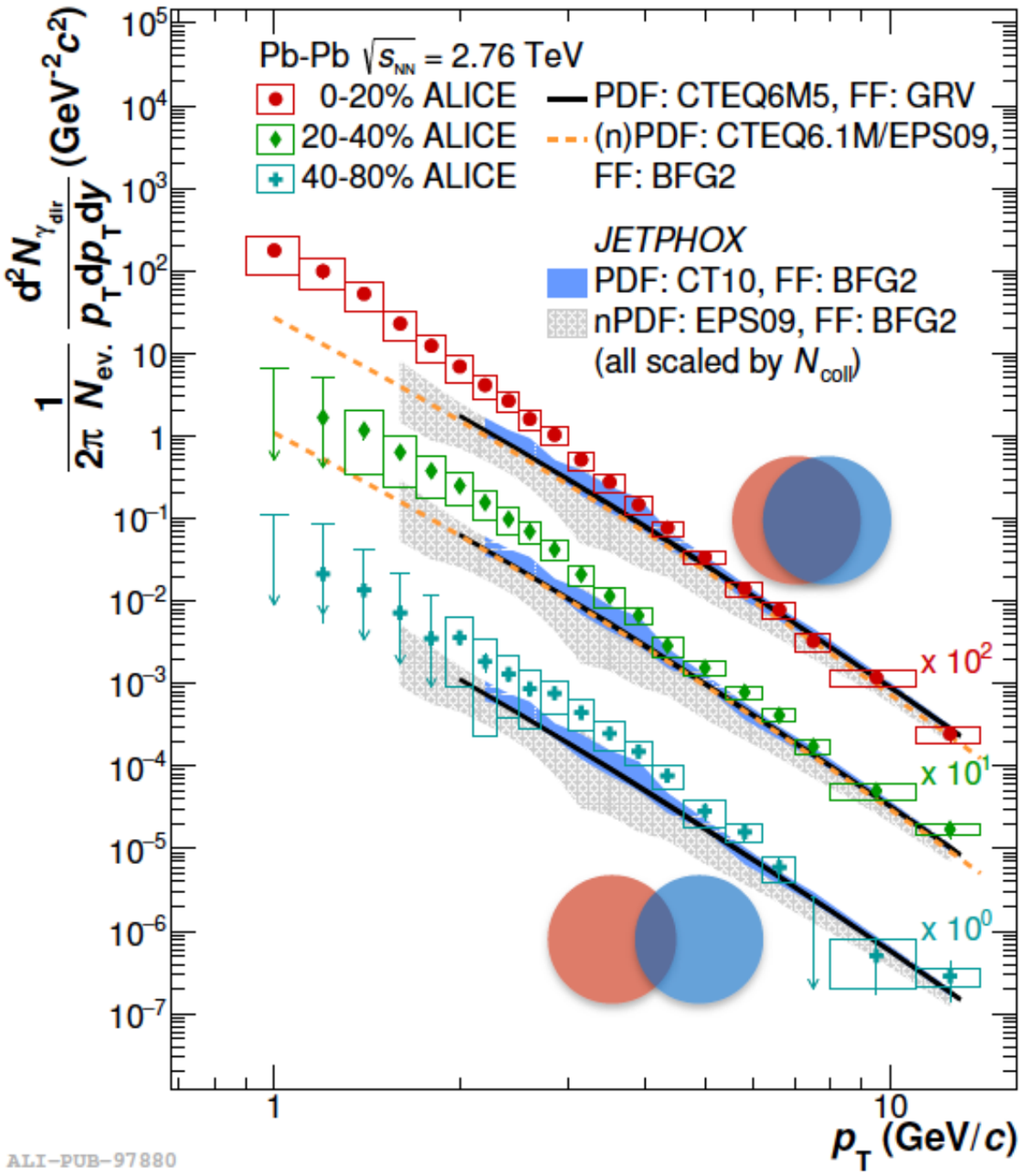


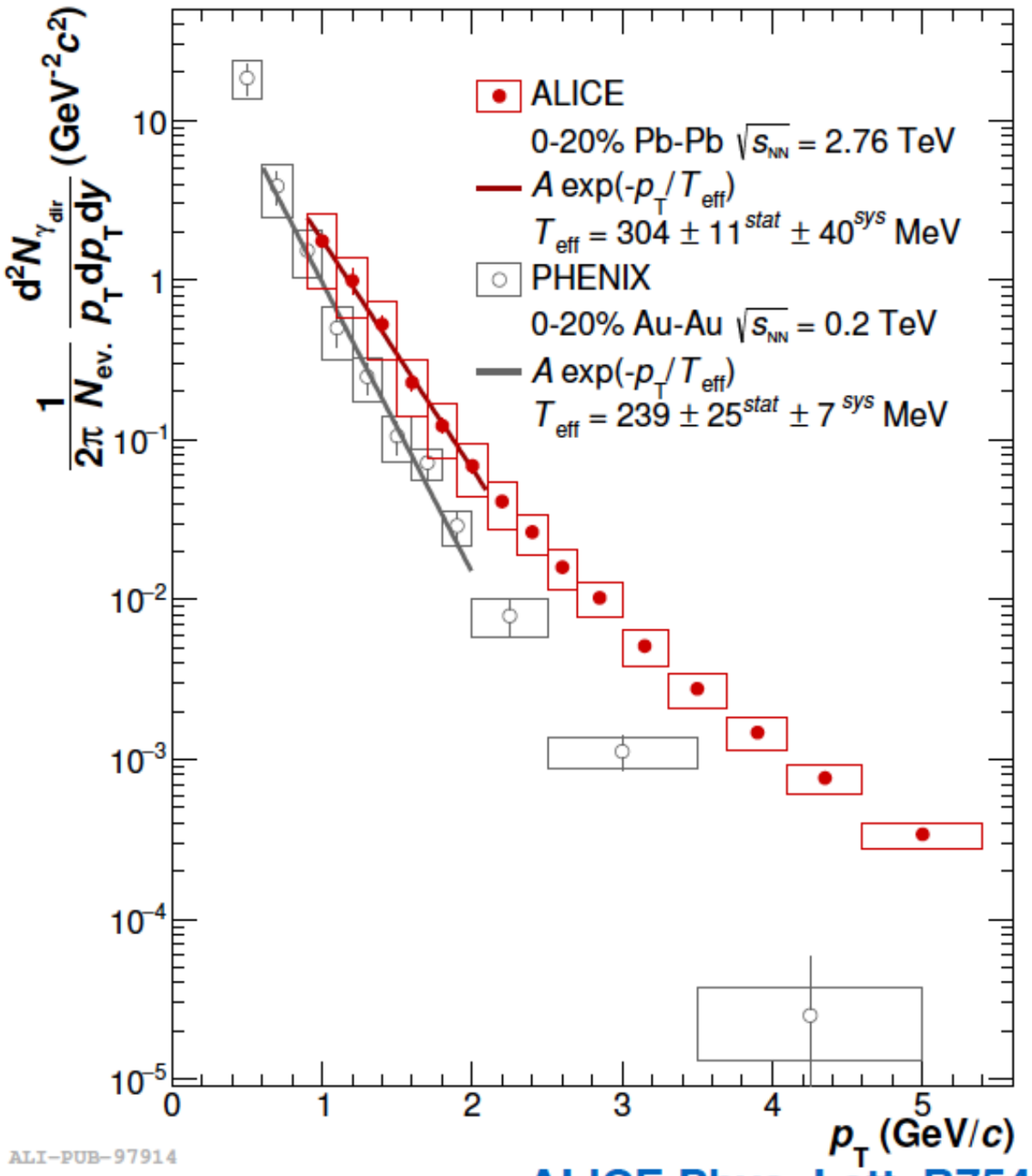
arXiv:1606.07424



- Significant enhancement of strange and multi-strange particle production
- Follows the trend observed in p-Pb, despite differences in initial state
- MC predictions do not describe this observation satisfactorily
- Observed increase is more pronounced for baryons with higher strangeness content

Direct photons in Pb-Pb collisions



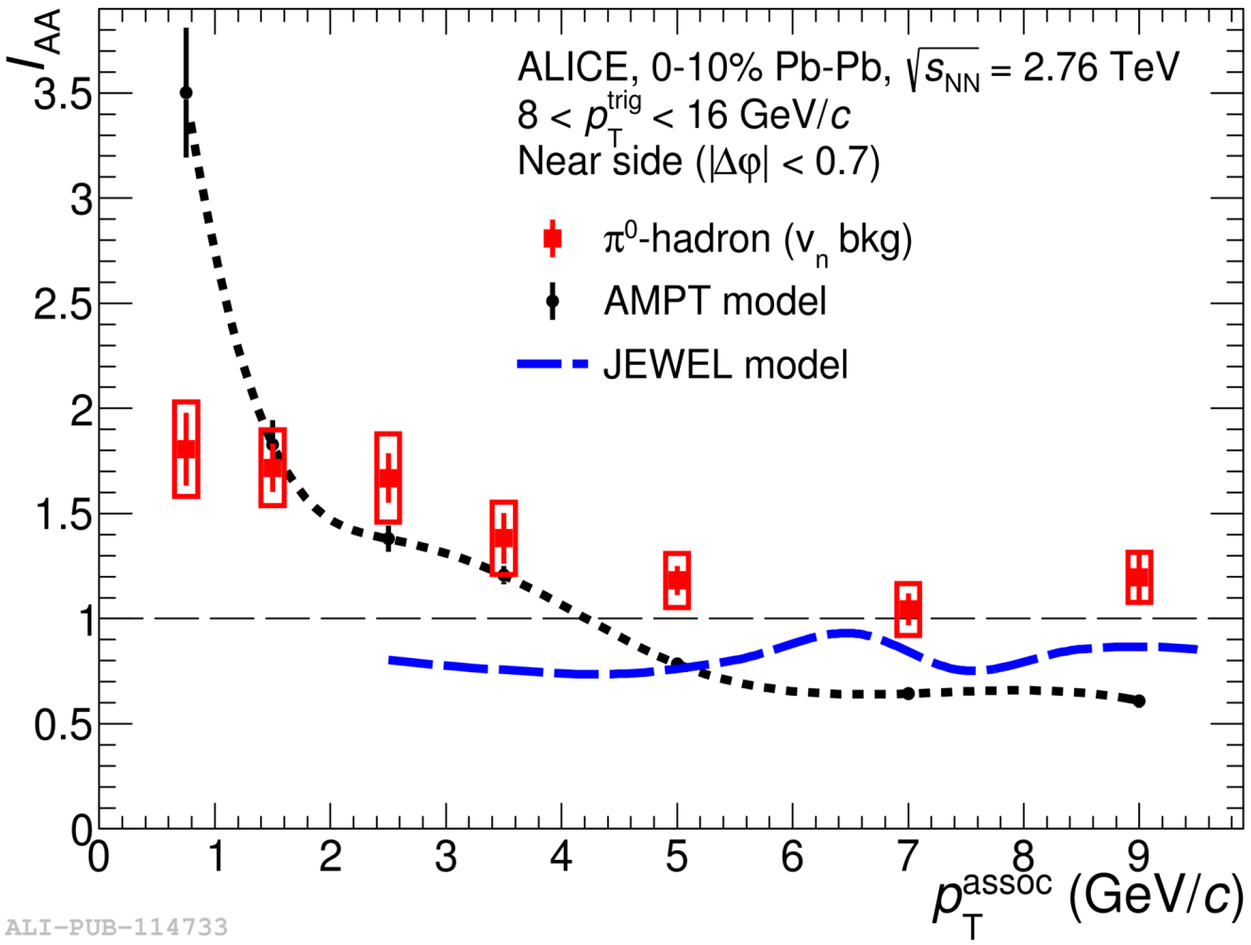


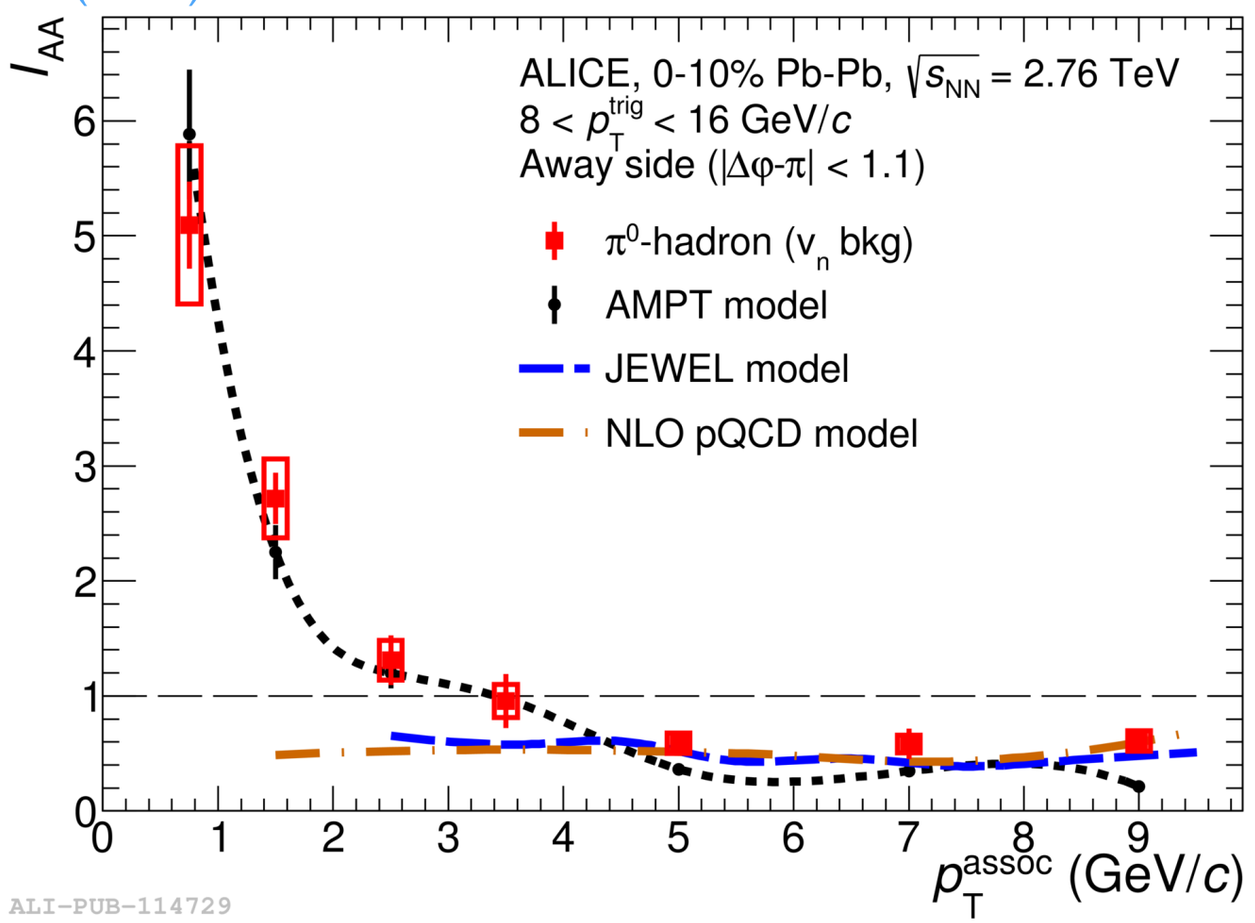
ALICE Phys. Lett. B754 (2016) 235

- Low p_T: 2.6 σ excess w.r.t. models in 0-20% central → thermal radiation
- T_{eff} = 304 ±11(stat.)±40(sys) MeV extracted in 0-20% central
  - 30% higher than at RHIC @ 200 GeV

π^0-hadron correlations at LHC

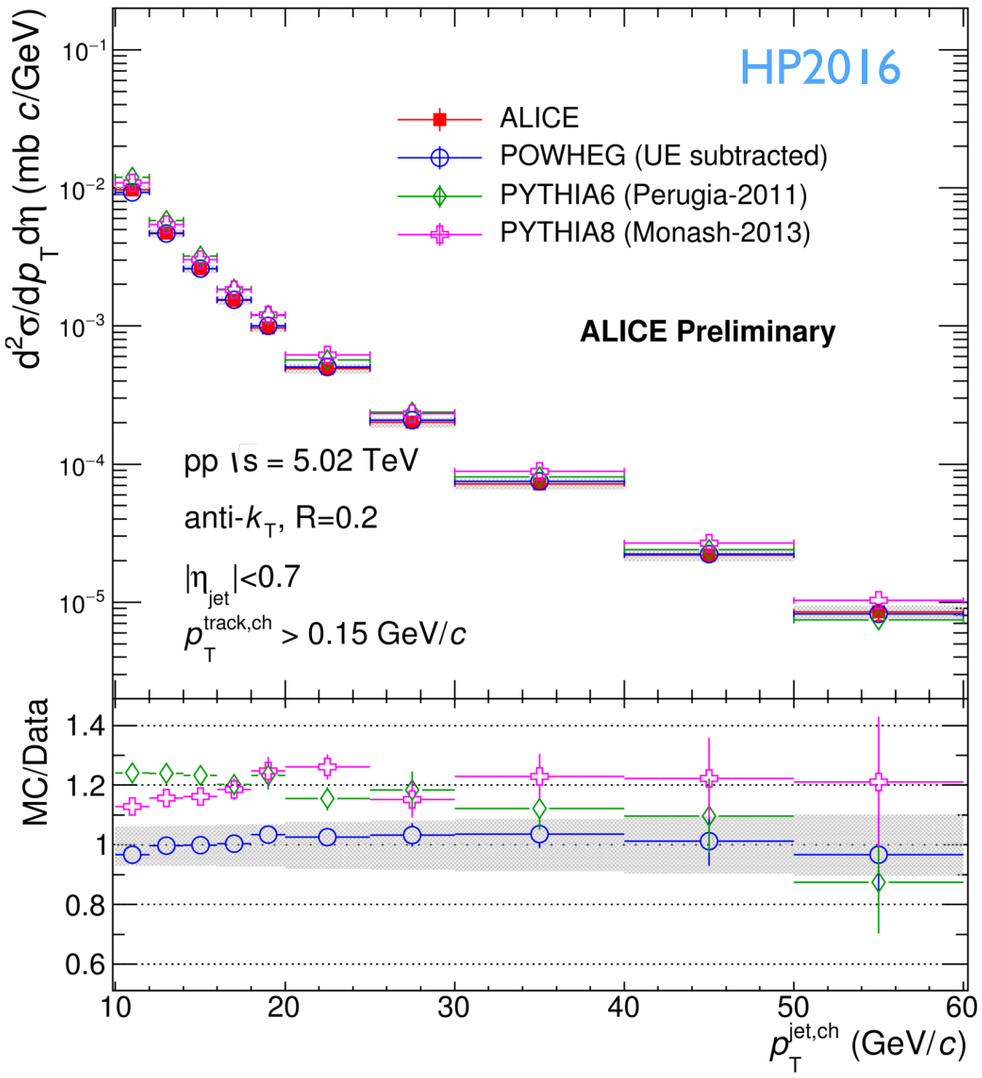
PLB 763 (2016) 238





- Extend the measurement to lower p_T compared to charged di-hadron correlation measurements
- Enhancement at very low p_T, indicating extra particles from soften of fragmentation functions
- Suppression on the away side for high pT, consistent with "conformal" quenching

jet cross sections in pp at 5.02 TeV



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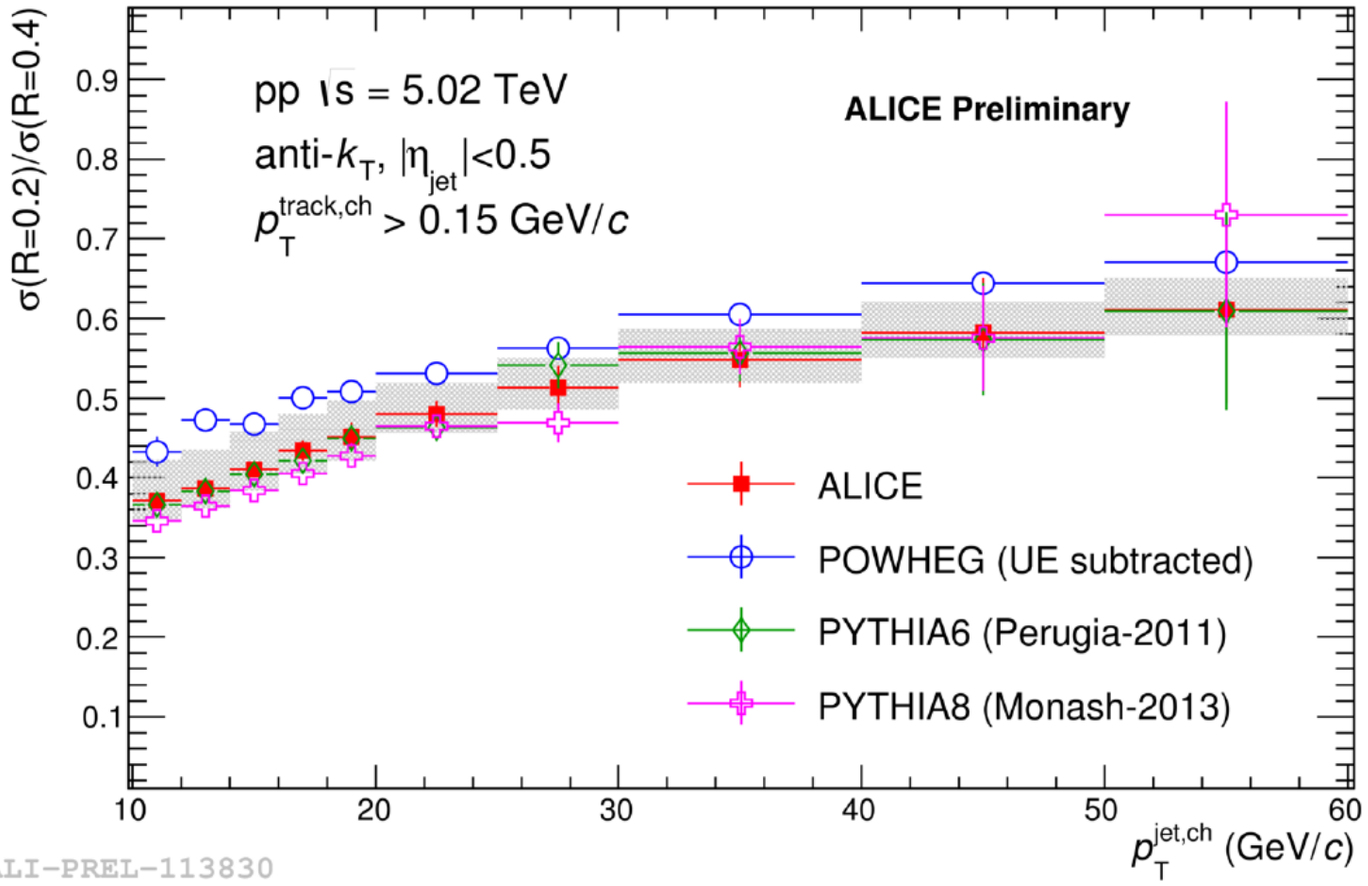
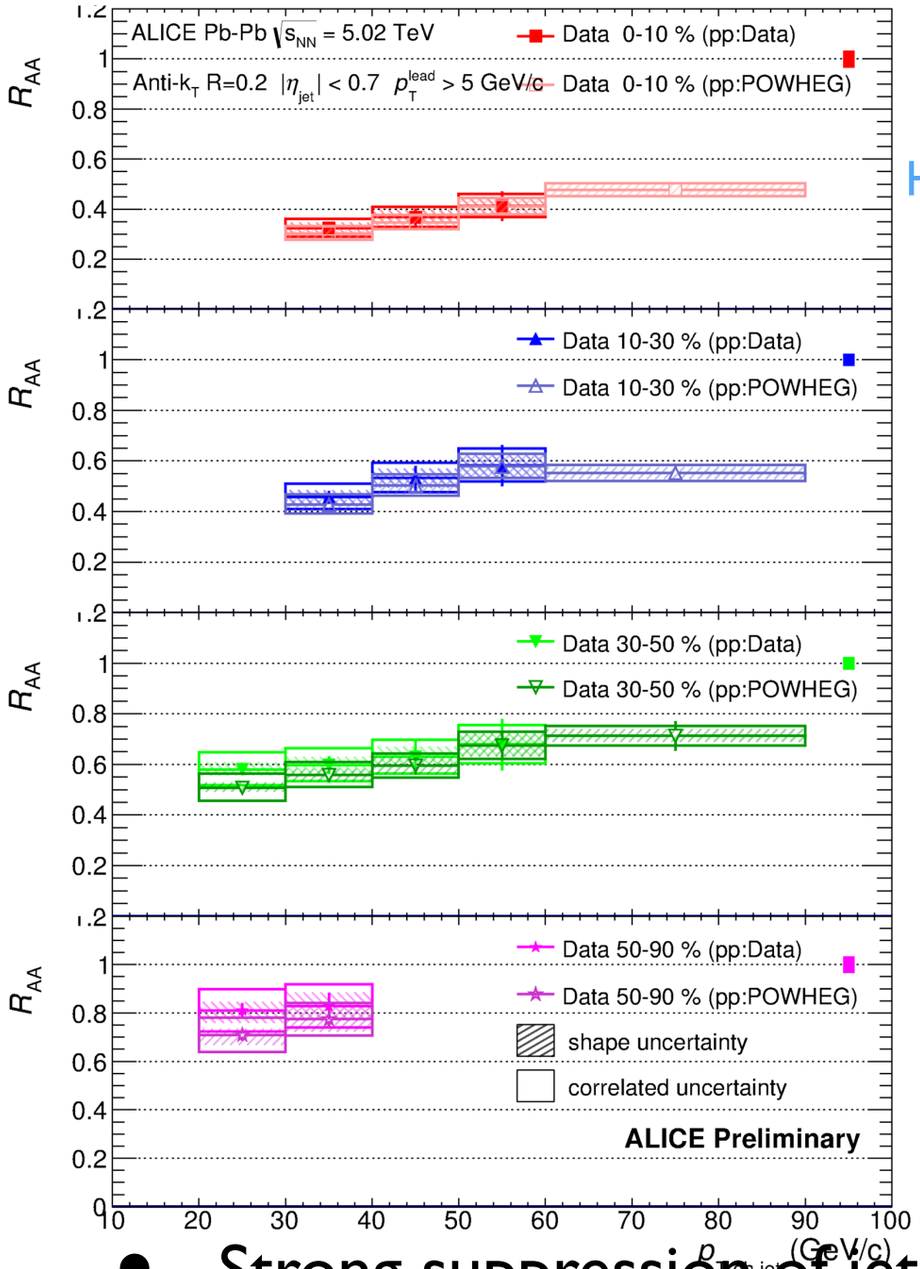


ALI-PREL-113830

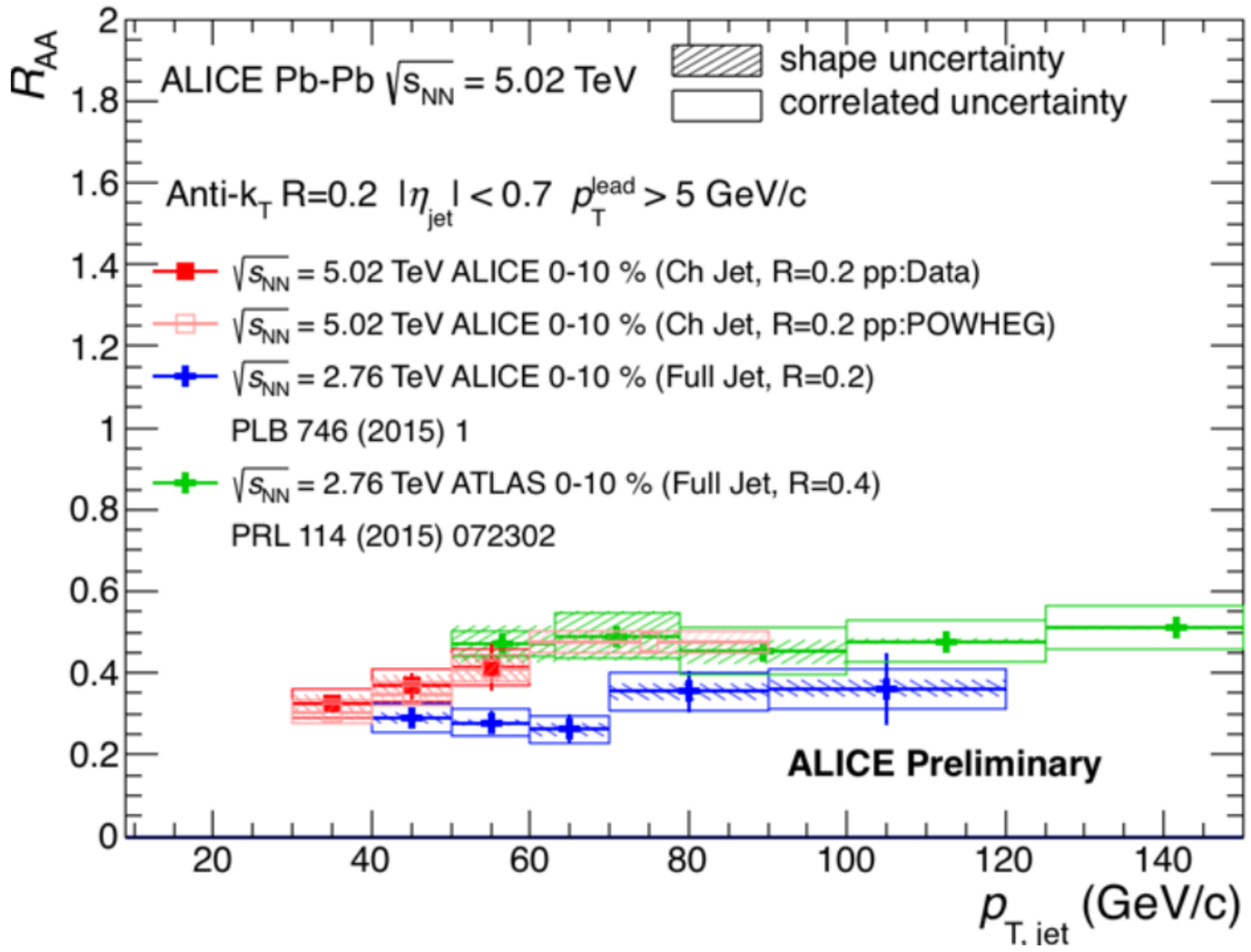
- Jet cross section is well described by POWHEG NLO calculations within systematic uncertainties
- Cross section ratio between R = 0.2/R = 0.4 consistent with model calculations, slightly increasing with jet p_T → reflect jet collimation information info

Jet nuclear modification factor R_{AA}



HP2016

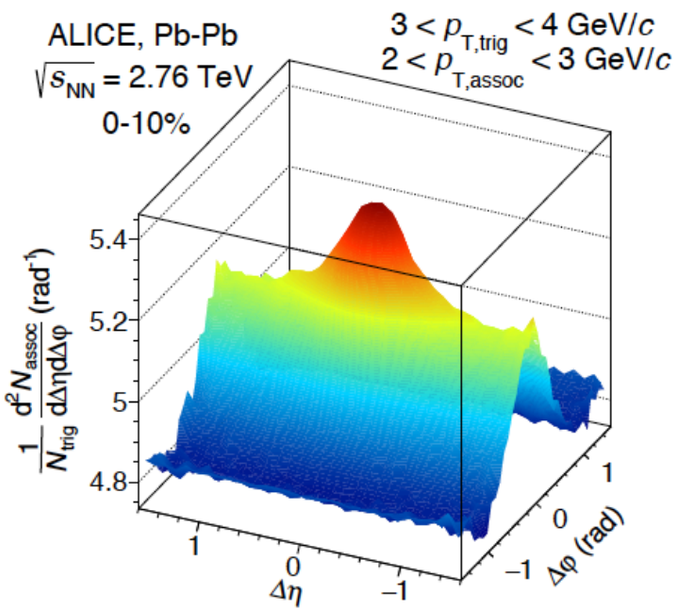
$$R_{AA} = \frac{1}{< N_{coll} >} \frac{d^2 N_{AA} / dp_T d\eta}{d^2 N_{pp} / dp_T d\eta}$$

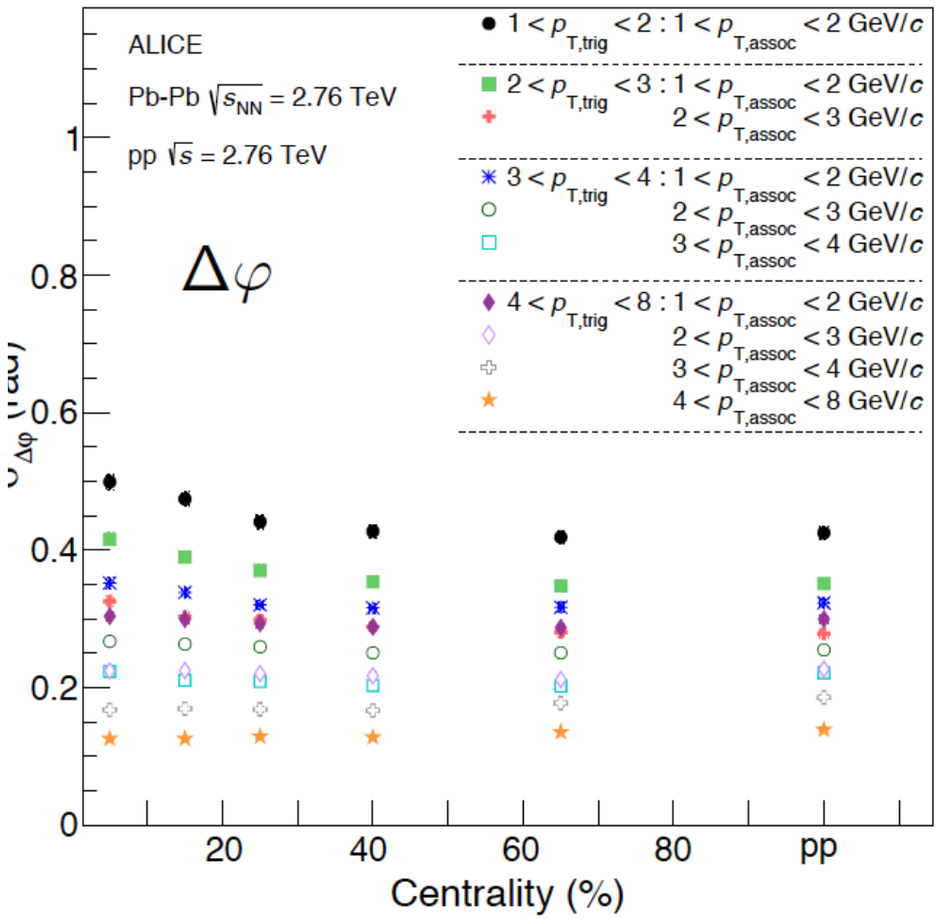


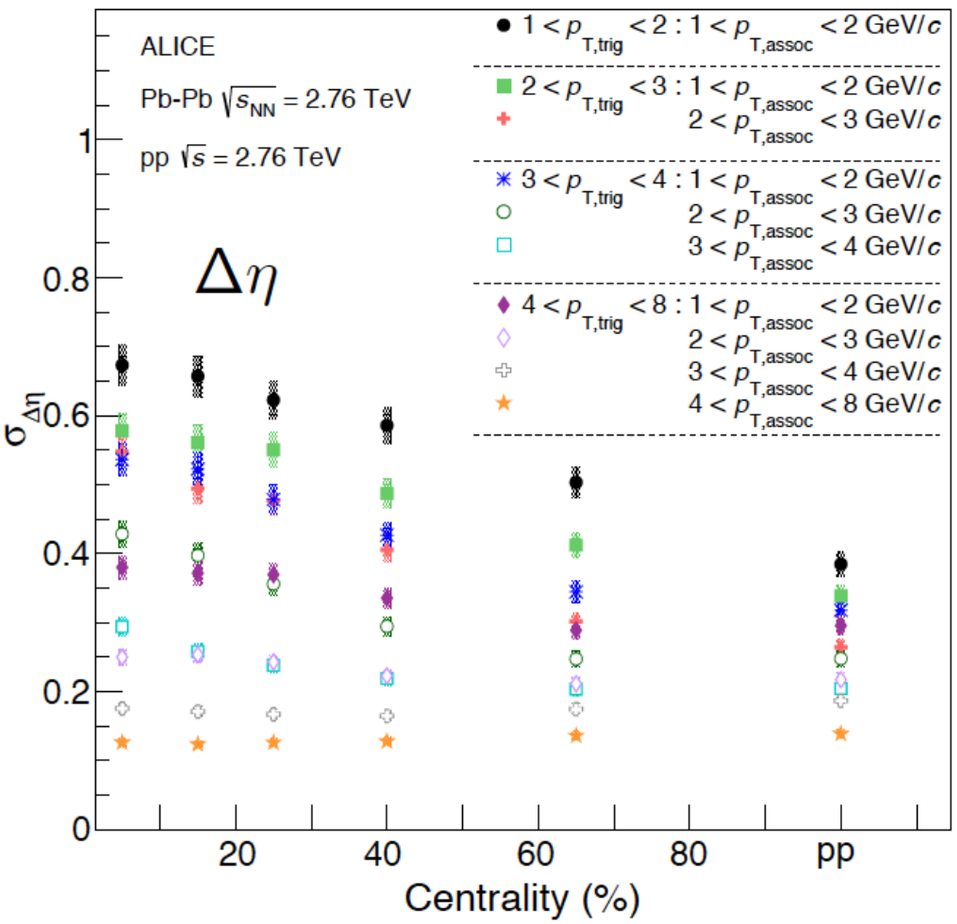
- Strong suppression of jet yield in most central collisions
- R_{AA} at 5.02 TeV similar to 2.76 TeV

➡ "compensation" between increasing suppression and modification of the shape of the spectra

Jet peak broadening



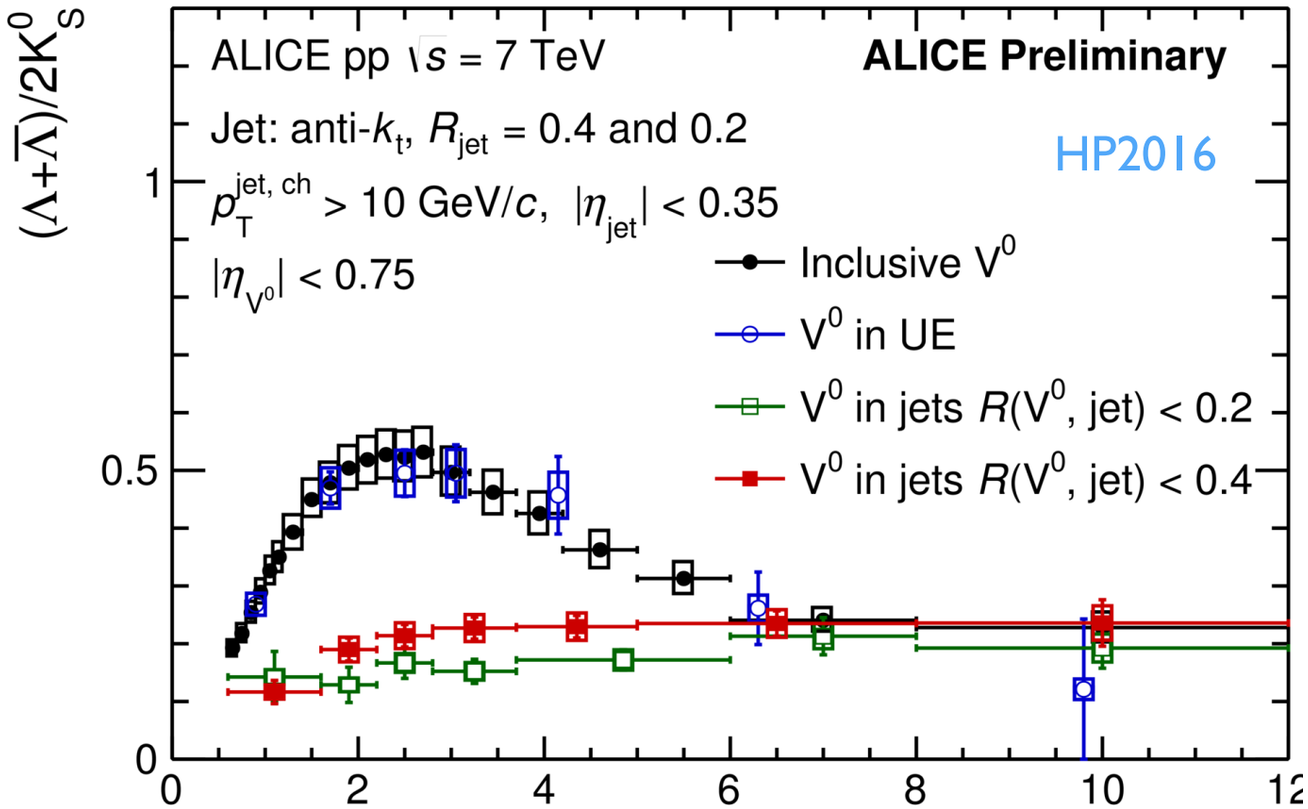


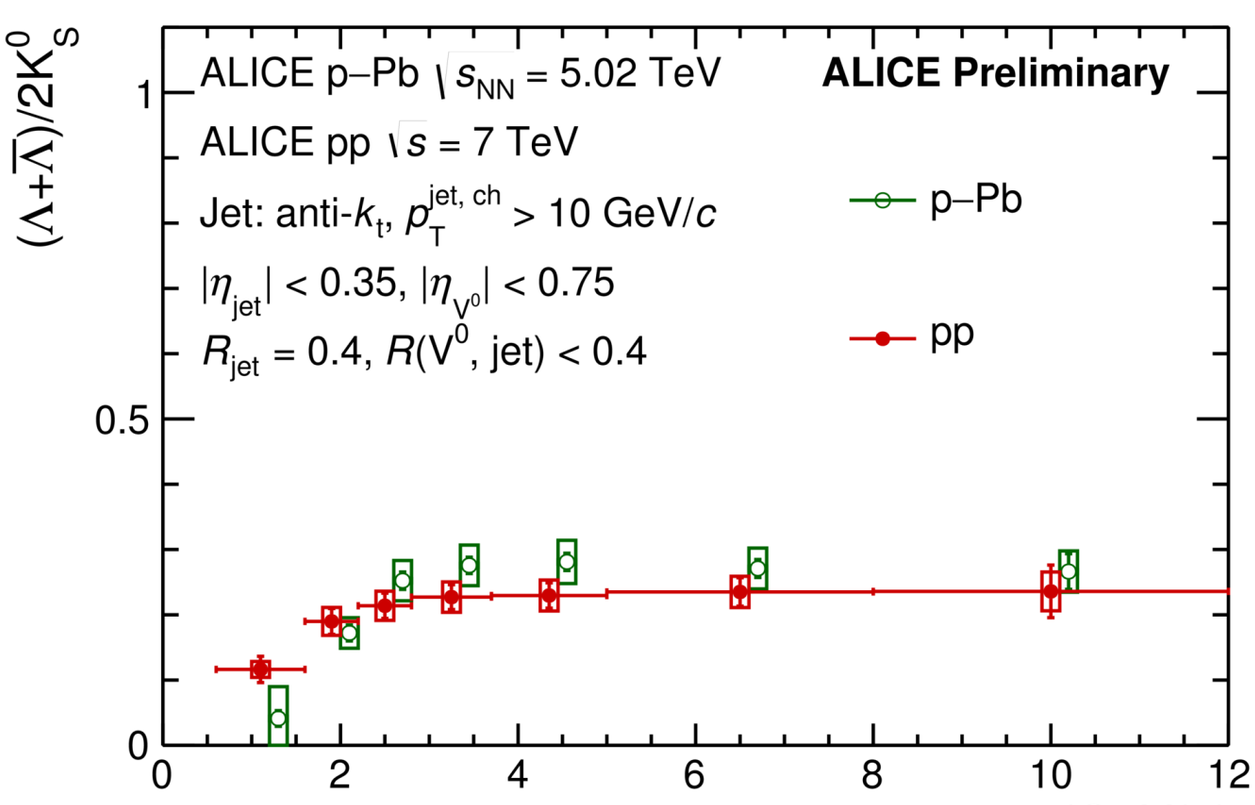


- Width in $\Delta\varphi$ in 50-80% is equal to pp
- Small increase at low p_T in $\Delta\varphi$ with centrality
- Very pronounced increase at low p_T in $\Delta\eta$

➡ Similar measurements can be pursued with jet axis

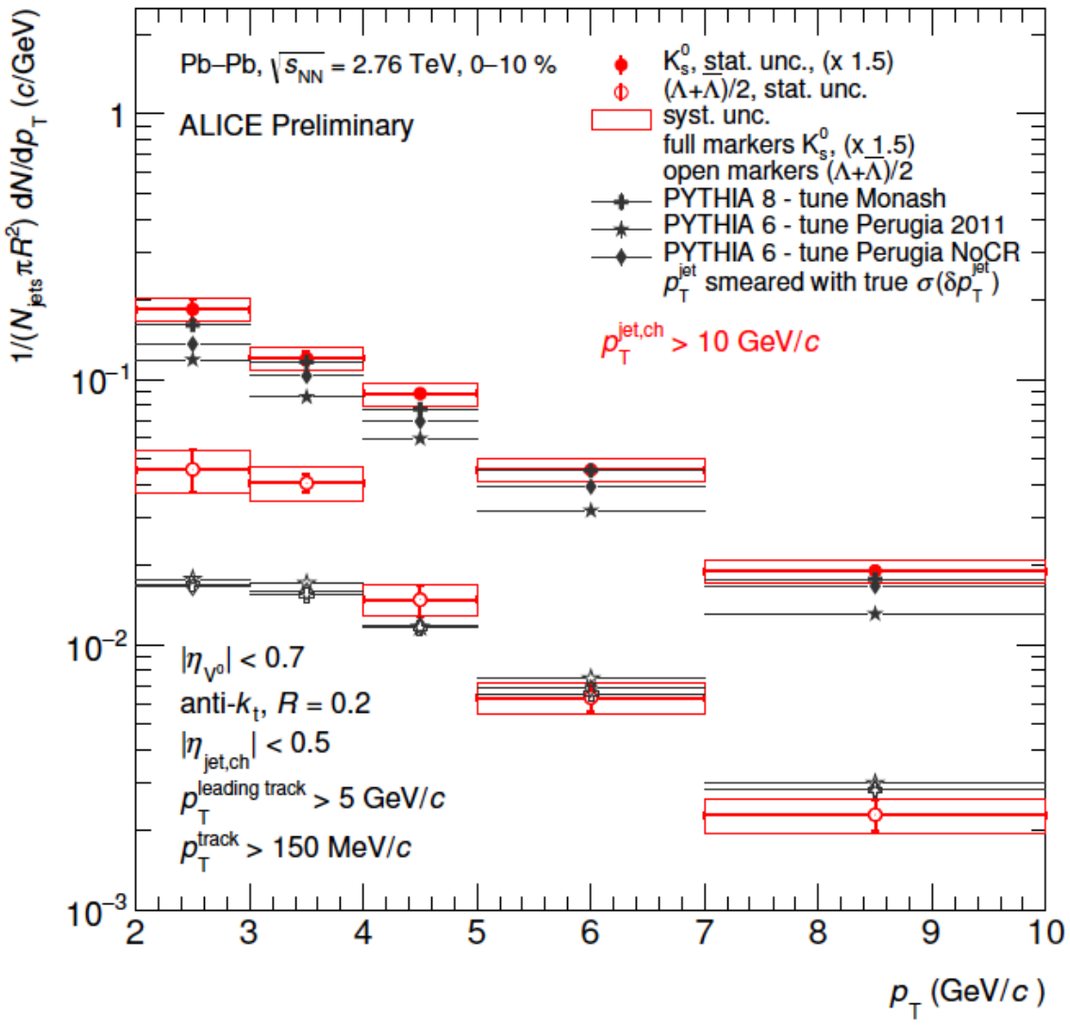
V^0 production in jet





- K_s^0 and Λ in the UE region - consistent with inclusive measurements
- Λ/K_s^0 ratio in jets is unambiguously different from the UE (and inclusive)
- Slightly decrease of the ratio with decreasing R(V_0, jet)
- The ratio is flat with $p_{T,V0}$ > 3 GeV/c, and consistent with inclusive V_0s at high pT
- pp consistent with p-Pb within uncertainties in jet R = 0.4

K_s^0 and Λ production in jets



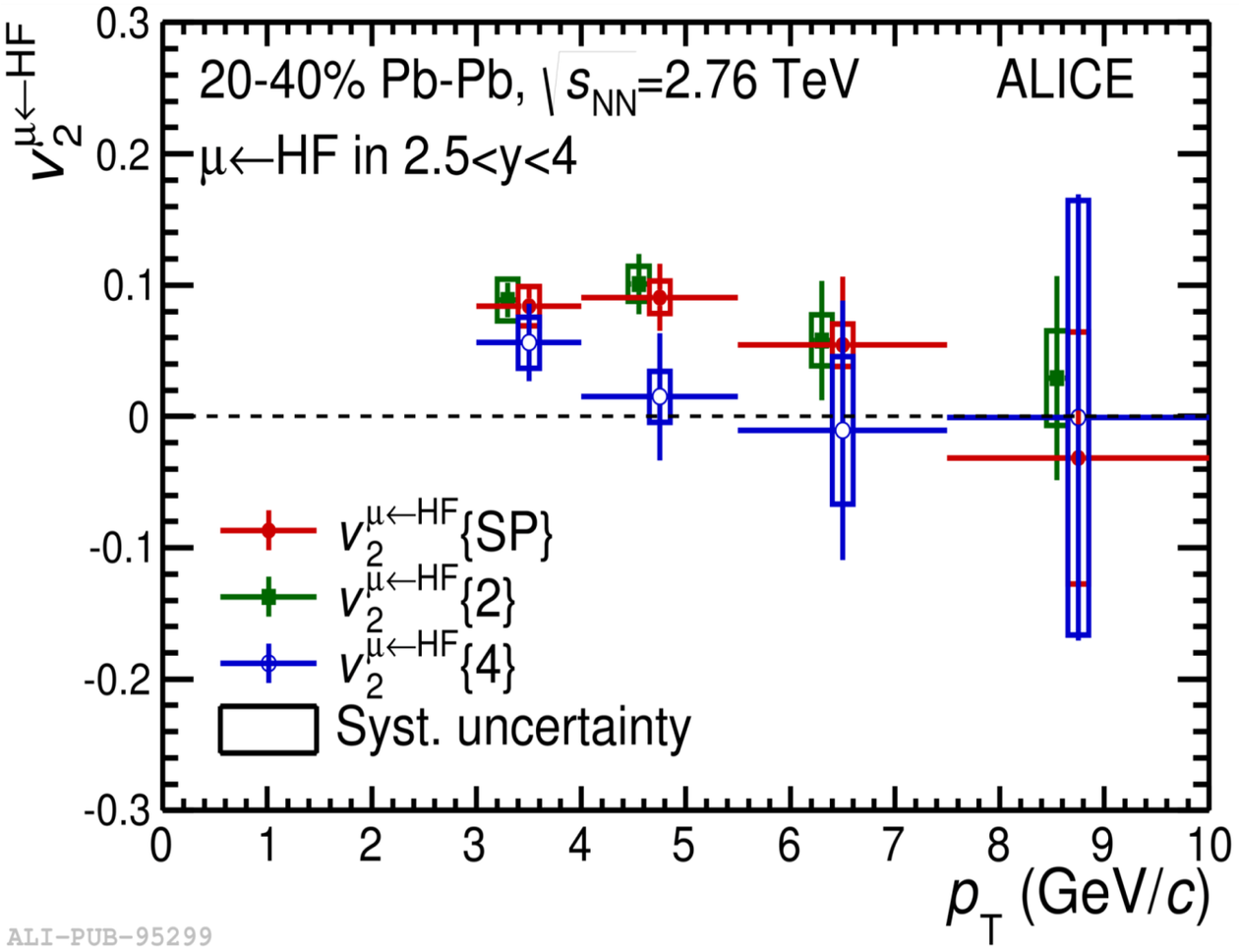
ALI-PREL-112798

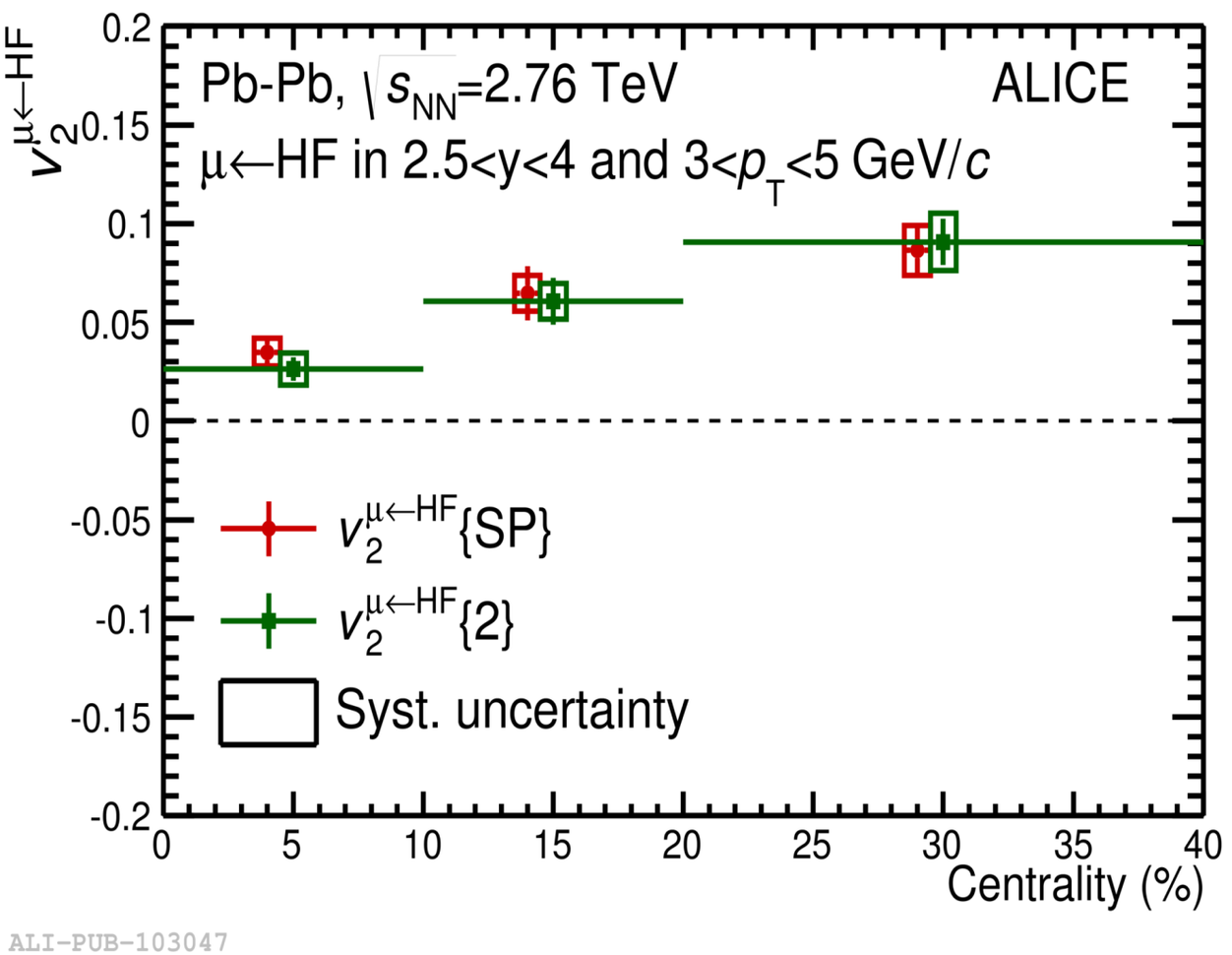
- K_S^0 and Λ production in charged-particle jets in Pb–Pb collisions
- Reference PYTHIA smeared with background fluctuations
- K_S^0 data consistent with PYTHIA
- within errors - hint of low-p_T enhancement in data
- Λ: data significantly higher than PYTHIA at low p_T

- Investigating medium modified fragmentation, effect seems to differ between baryons and mesons — further constraints on reference from data needed

Azimuthal anisotropy

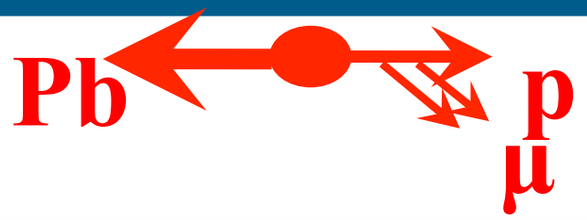
- Elliptic flow (v2): spatial anisotropy -pressure gradients lead to momentum anisotropy —hydrodynamics $v_n = < \cos n(\varphi - \Psi_{\mathrm{RP}}) >$



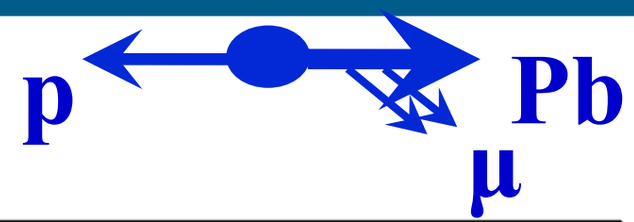


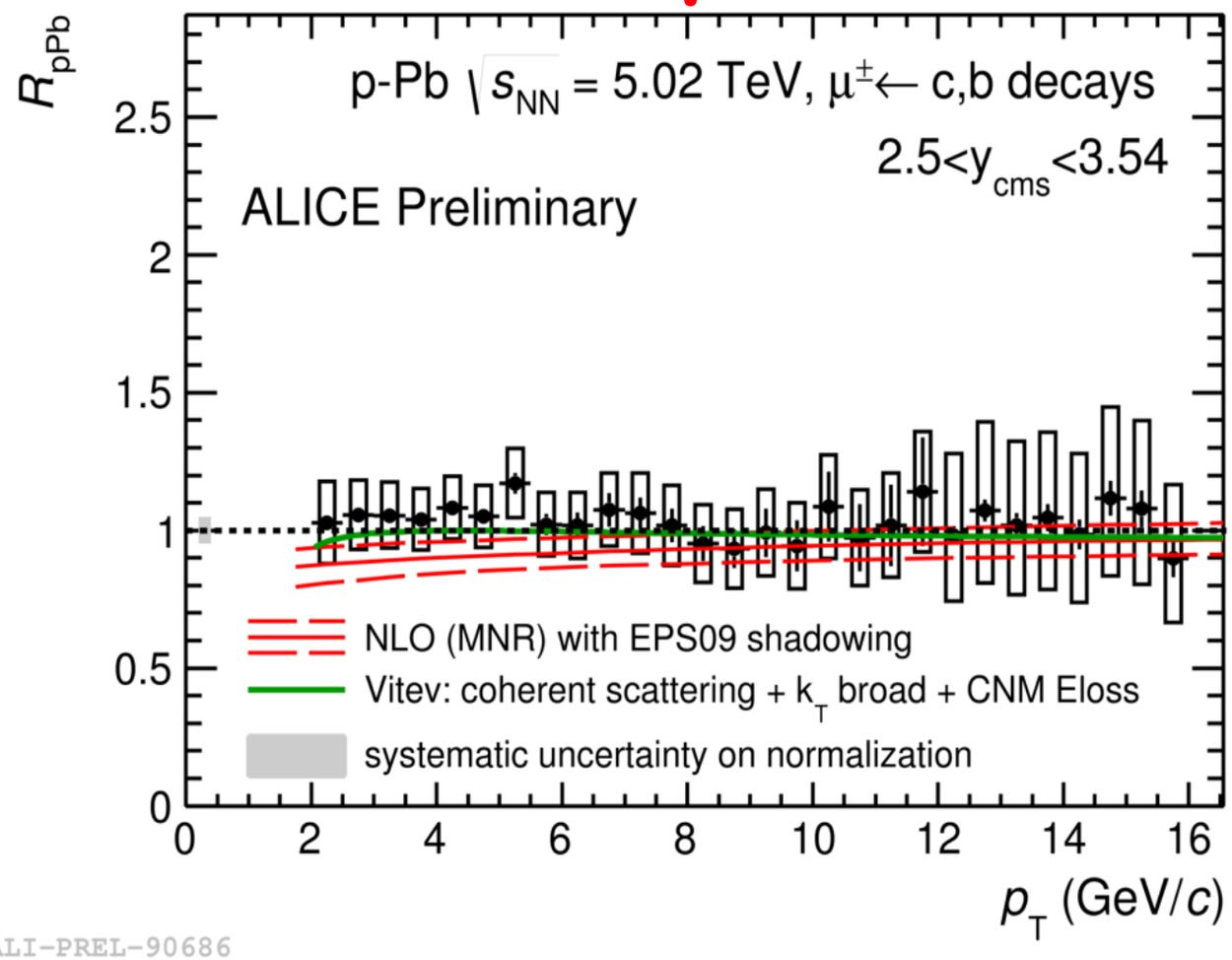
- Increase of v_2 from central to semi-central collisions in centrality range 0-40%
- Observed a positive v_2 in semi-central collisions at intermediate p_T
- Indication of strong interaction of heavy flavors with the hot and dense medium

Heavy-flavour decay muons R_{pA}



QM2015





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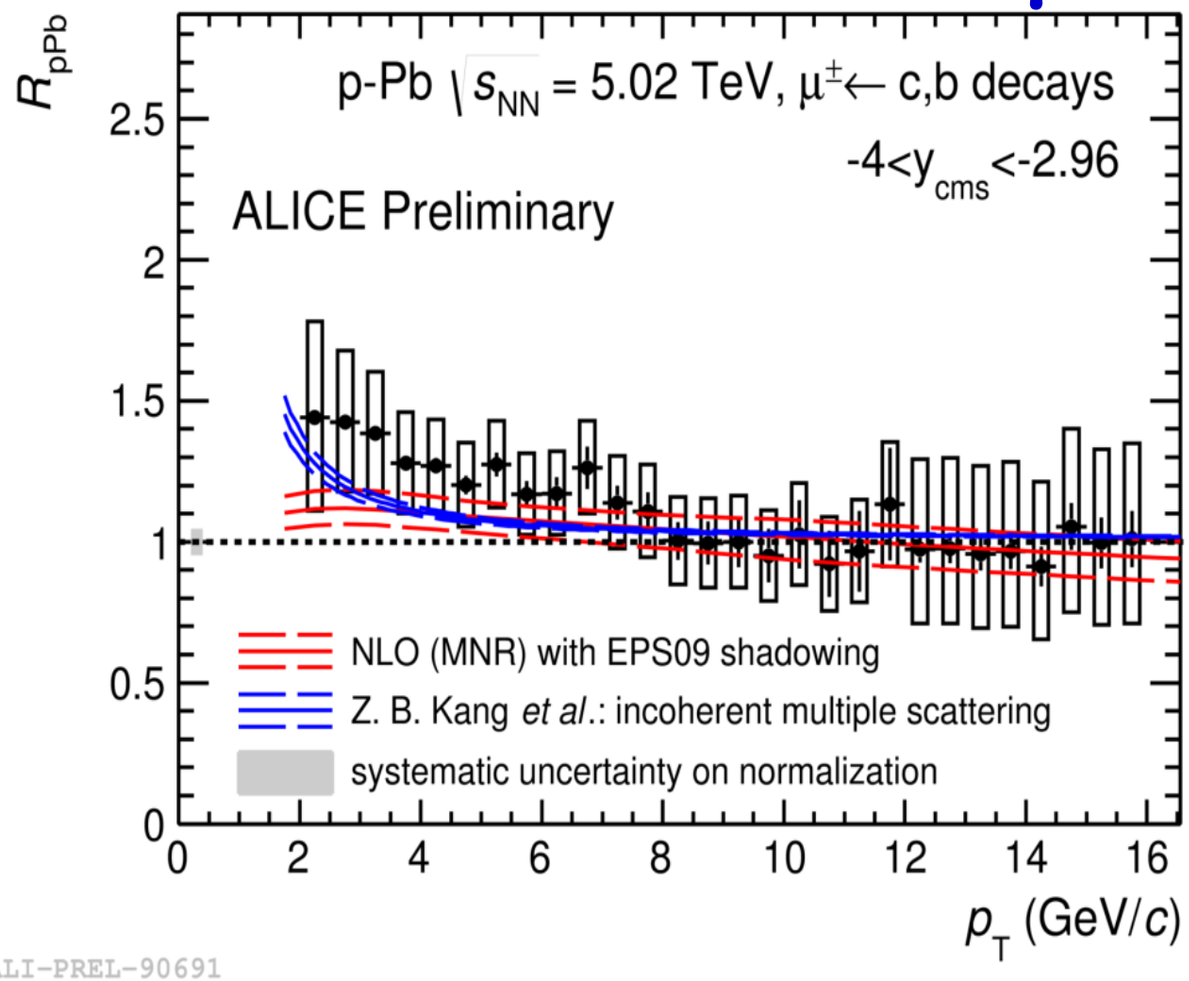


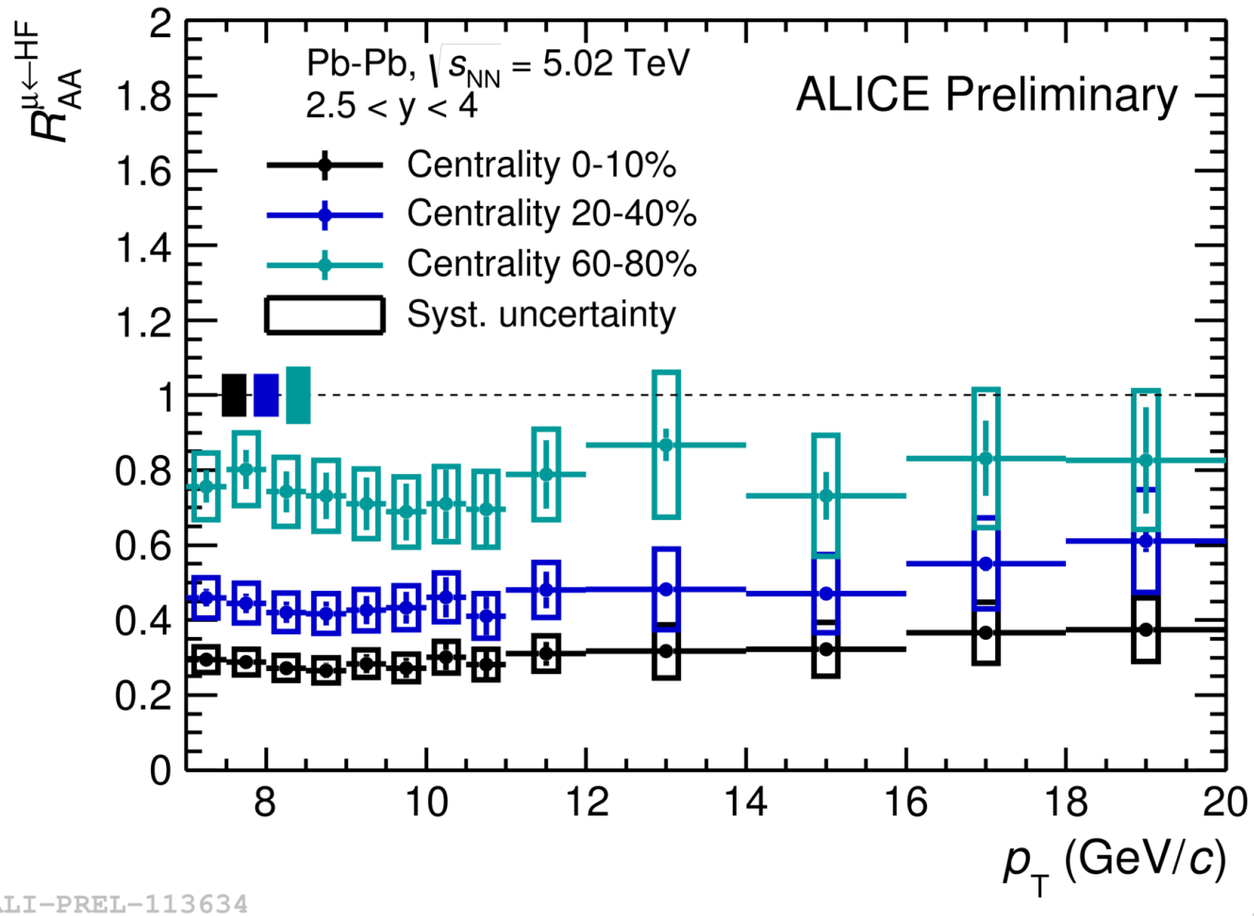
ALI-PREL-90691

- Consistent with unity at backward (Pb-going, left) and forward (p-going, right) rapidity at high pT
  → Backward rapidity: slightly larger than unity in 2 < pT < 4 GeV/c
- Data described within uncertainties by model calculations that include cold nuclear matter effects

pQCD NLO (MNR): Nucl. Phys. B 373 (1992) 295; EPS09: JHEP 04 (2009) 065 ;
Z. B. Kang et al.: PLB 740 (2015) 23 ; I.Vitev: PRC 75 (2007) 064906

R_{AA} of muons from heavy-flavor decay

PLB 753 (2016) 41



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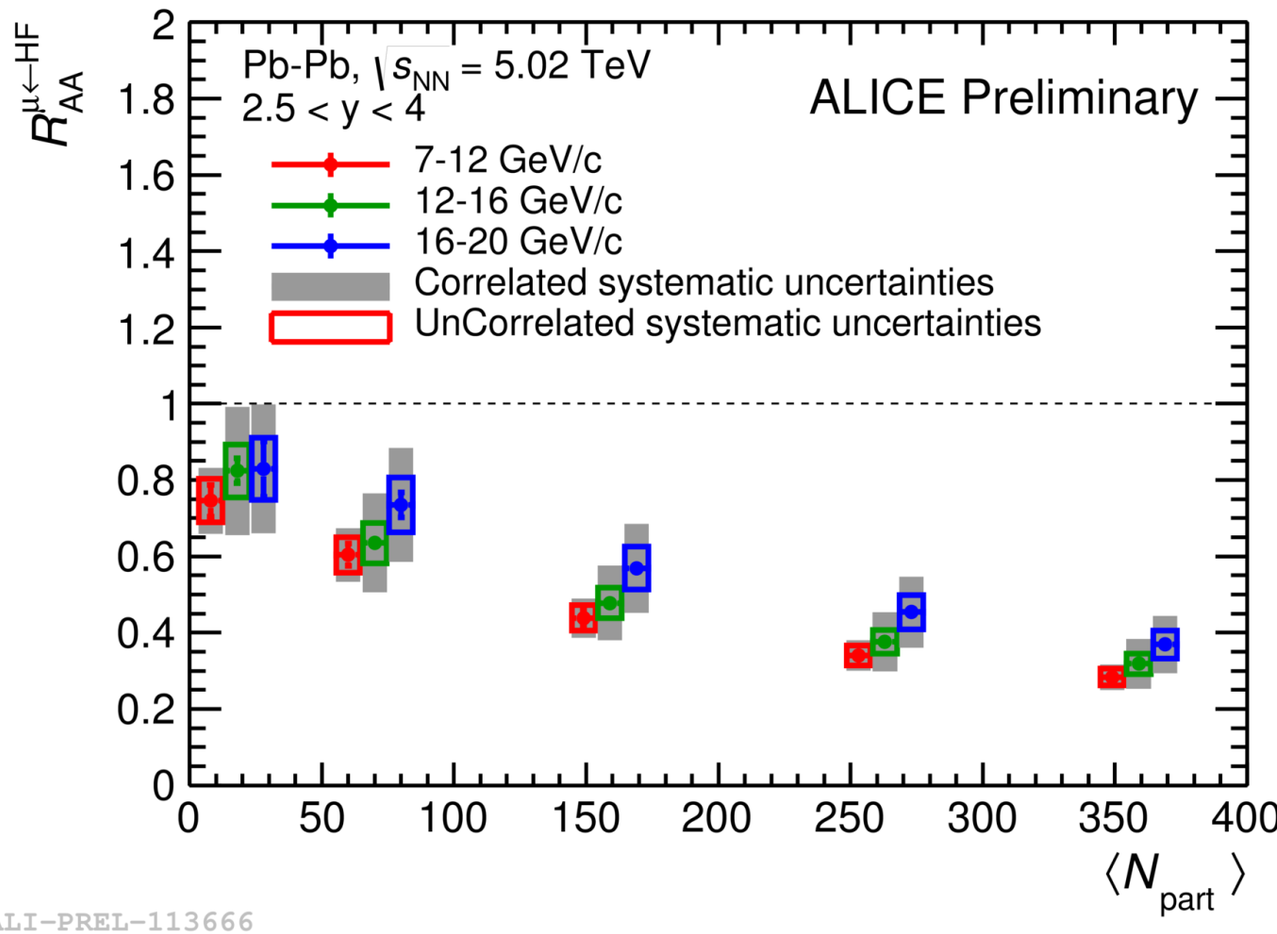
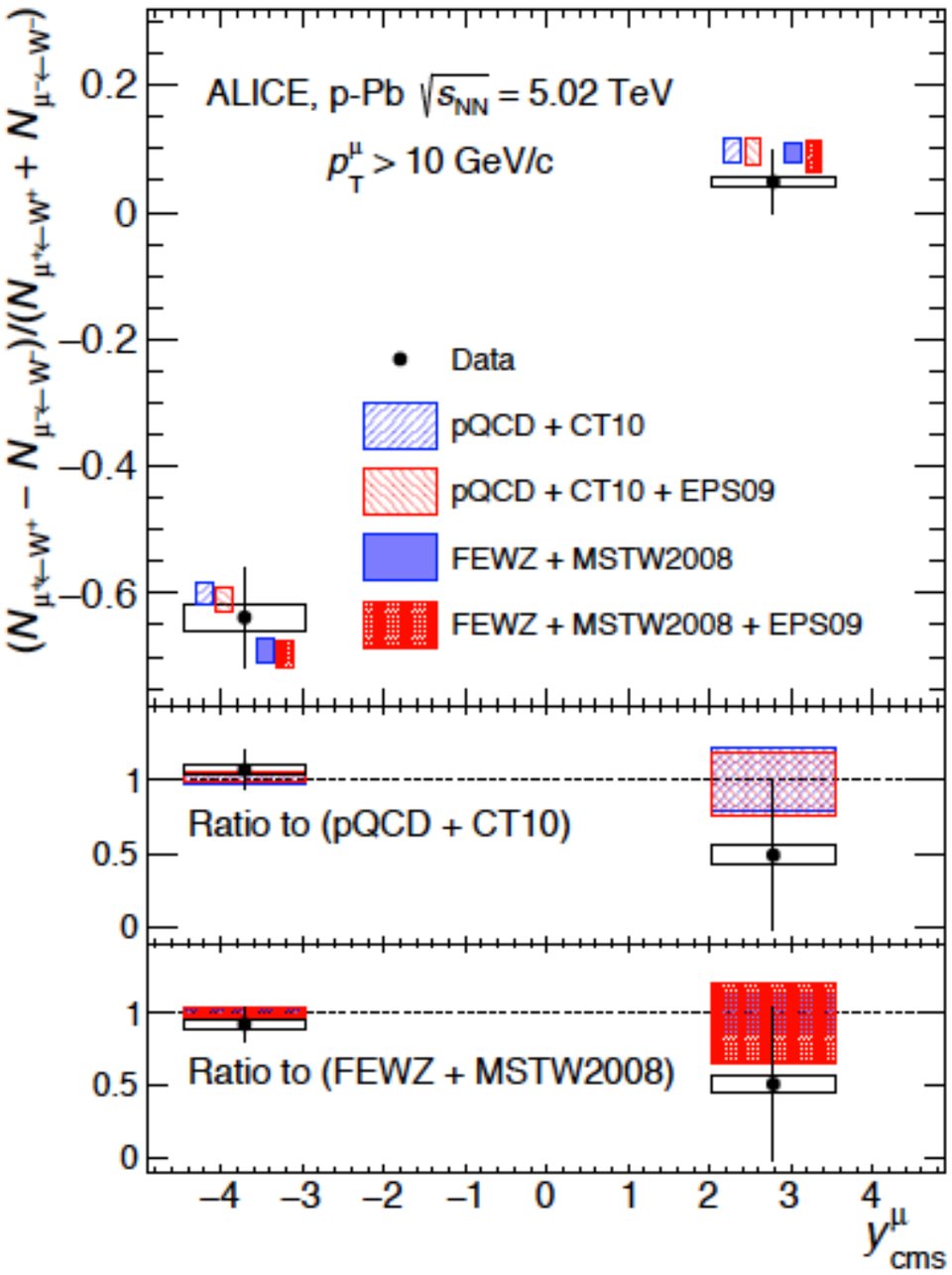
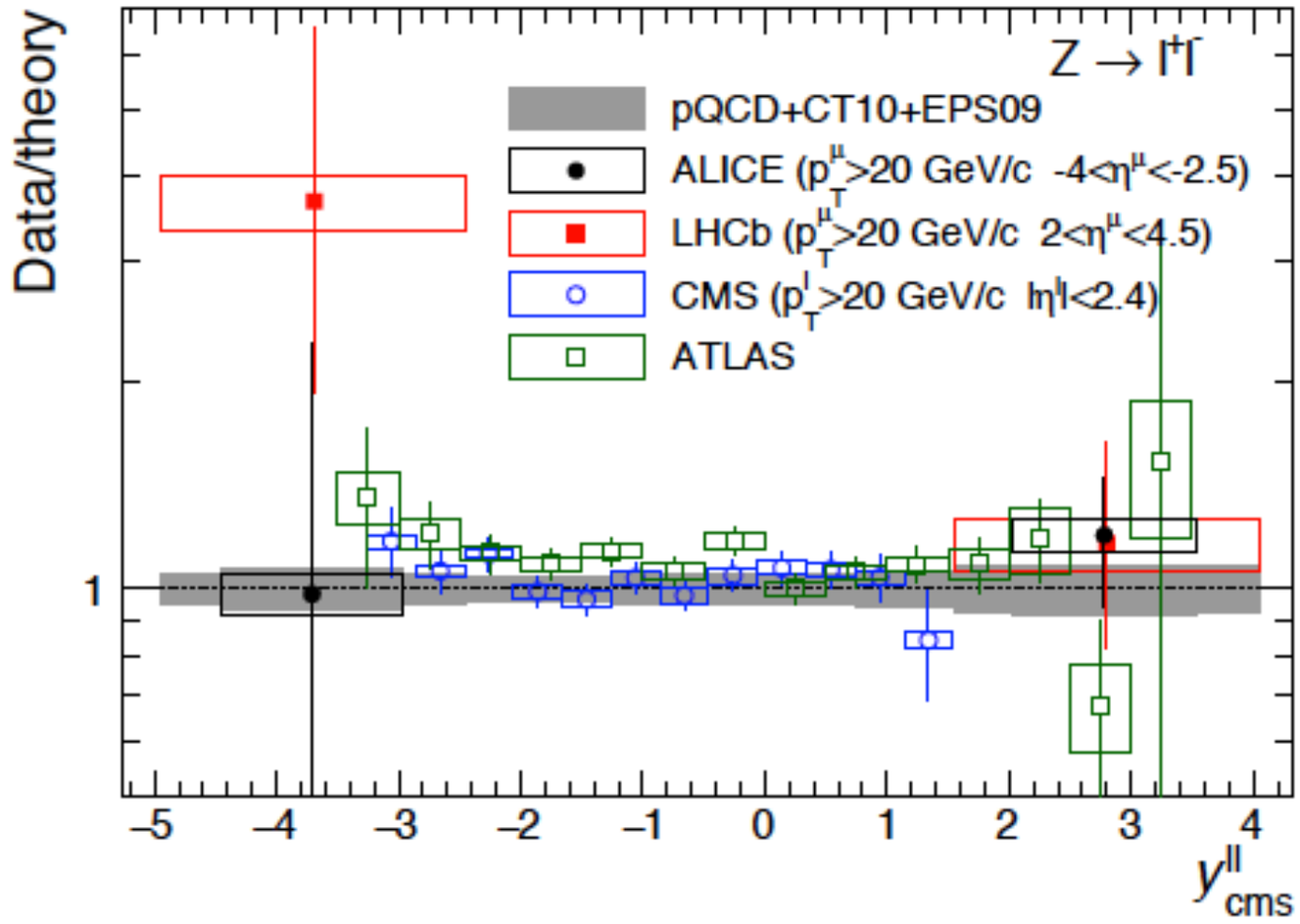


ALI-PREL-113666

- Clear increase of the suppression for more central events: about a factor 3 in 0-10% at p_T (7< pT< 12 GeV/c)
- No clear p_T dependence within uncertainties

W/Z boson productions in p-Pb collisions





ALICE (朱剑辉，周代翠等): arXiv:1611.03002, JHEP in prep

- 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

Conclusions

- ALICE has collected a wealth of data through LHC run1 and is now enriching its data sample in run2
- From the study of the hottest lump of matter created up to now at particle accelerators
  - Confirm effects seen at SPS/RHIC extending them to a new energy scale
  - Bring new discoveries, and among them
    - ➡ Jets are strongly affected by the medium
    - ➡ Mass-dependence of heavy quark energy loss
- No qualitatively different effects are expected moving from $\sqrt{s_{NN}}$=2.76 to 5.02 TeV, but the quality of the results is improved, thanks to higher luminosities and better understanding of the apparatus
- Many more to come…stay tuned!
- Physics program extending into run 3 and run 4 thanks to the substantial upgrades foreseen for LS2

ALICE upgrade program (for Run3)

New Inner Tracking System (ITS)

- improved pointing precision
- less material → thinnest tracker at the LHC

Muon Forward Tracker (MFT)

- new Si tracker
- Improved μ pointing precision

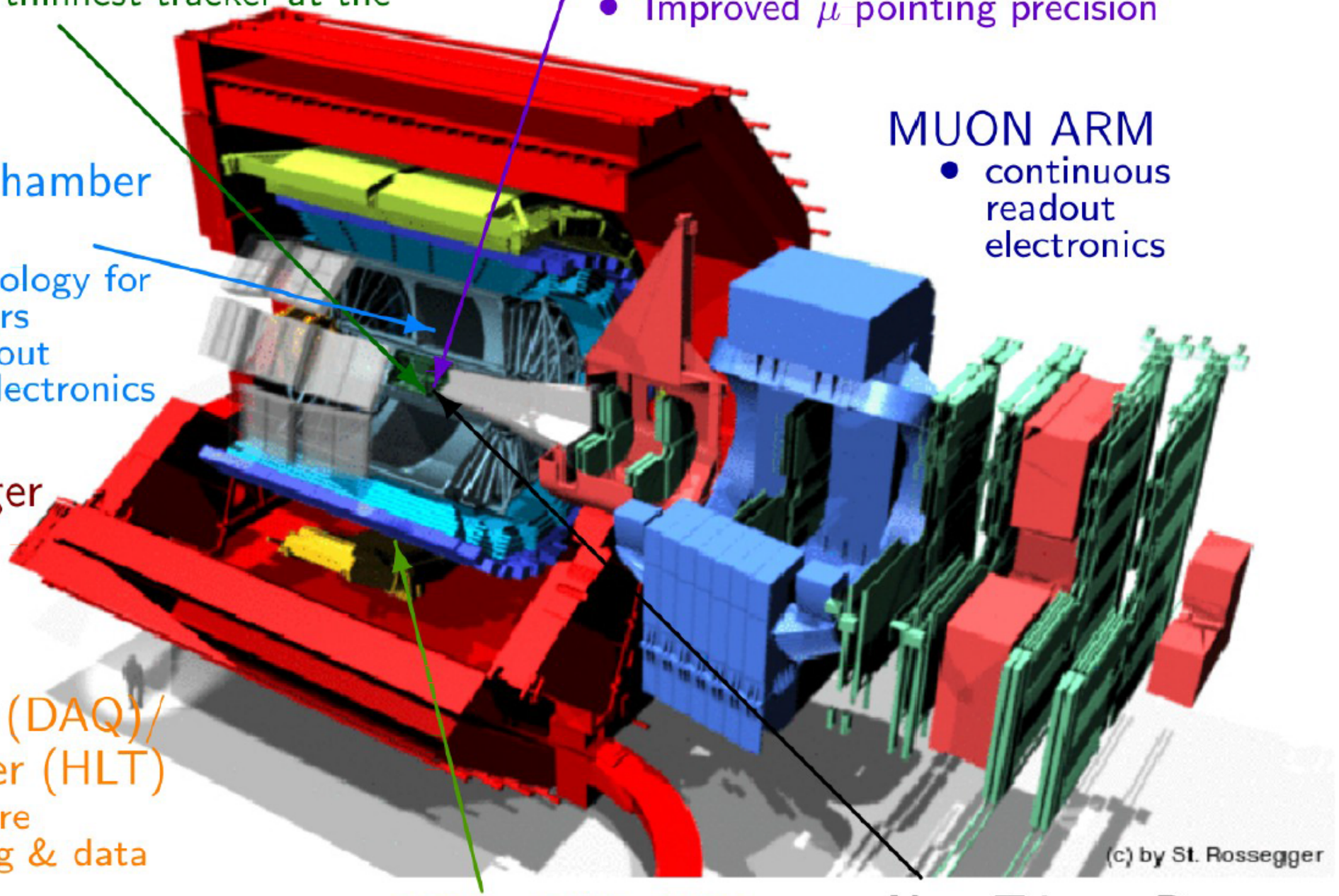
MUON ARM

- continuous readout electronics

Time Projection Chamber (TPC)

- new GEM technology for readout chambers
- continuous readout
- faster readout electronics

New Central Trigger Processor (CTP)



Data Acquisition (DAQ)/ High Level Trigger (HLT)

- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate

TOF, TRD, ZDC

- Faster readout

New Trigger Detectors (FIT)

→ technical design reports in CDS

Thank you for your attention!

Please stay tuned...

backup