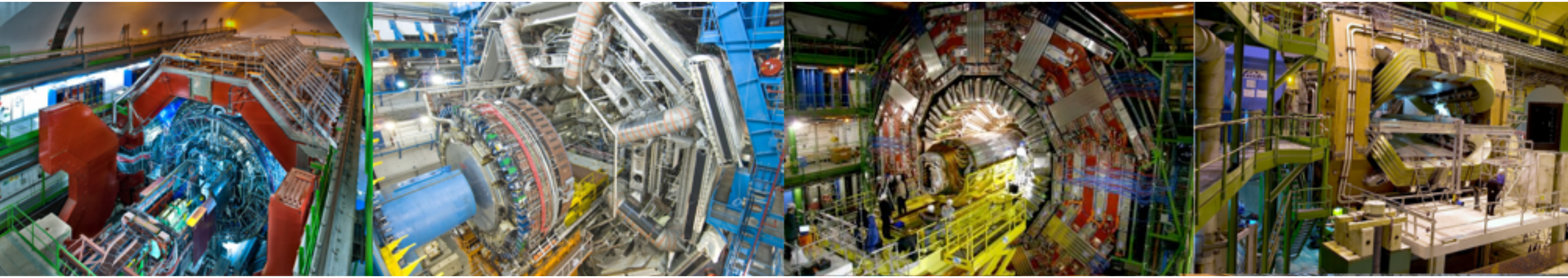
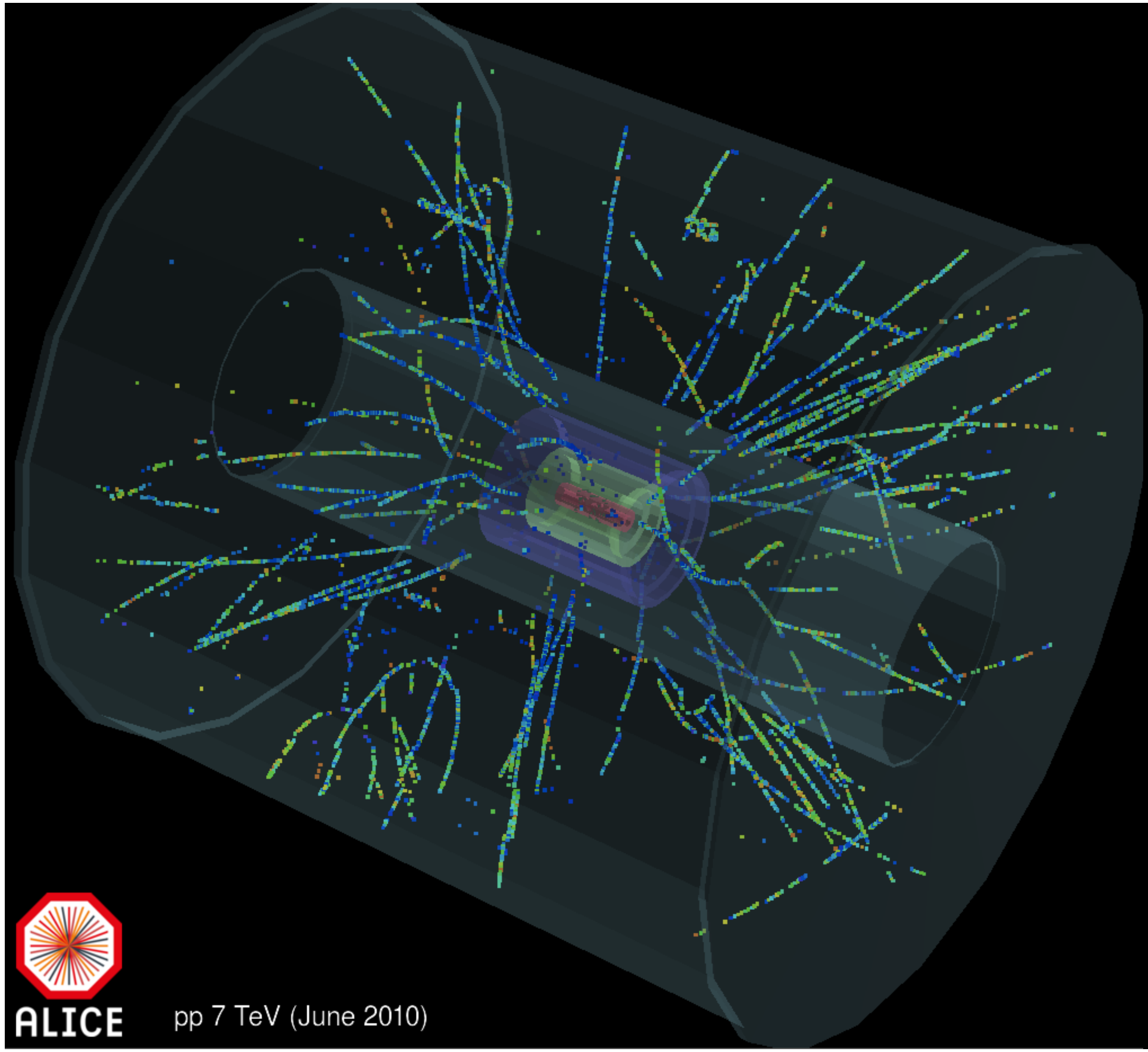
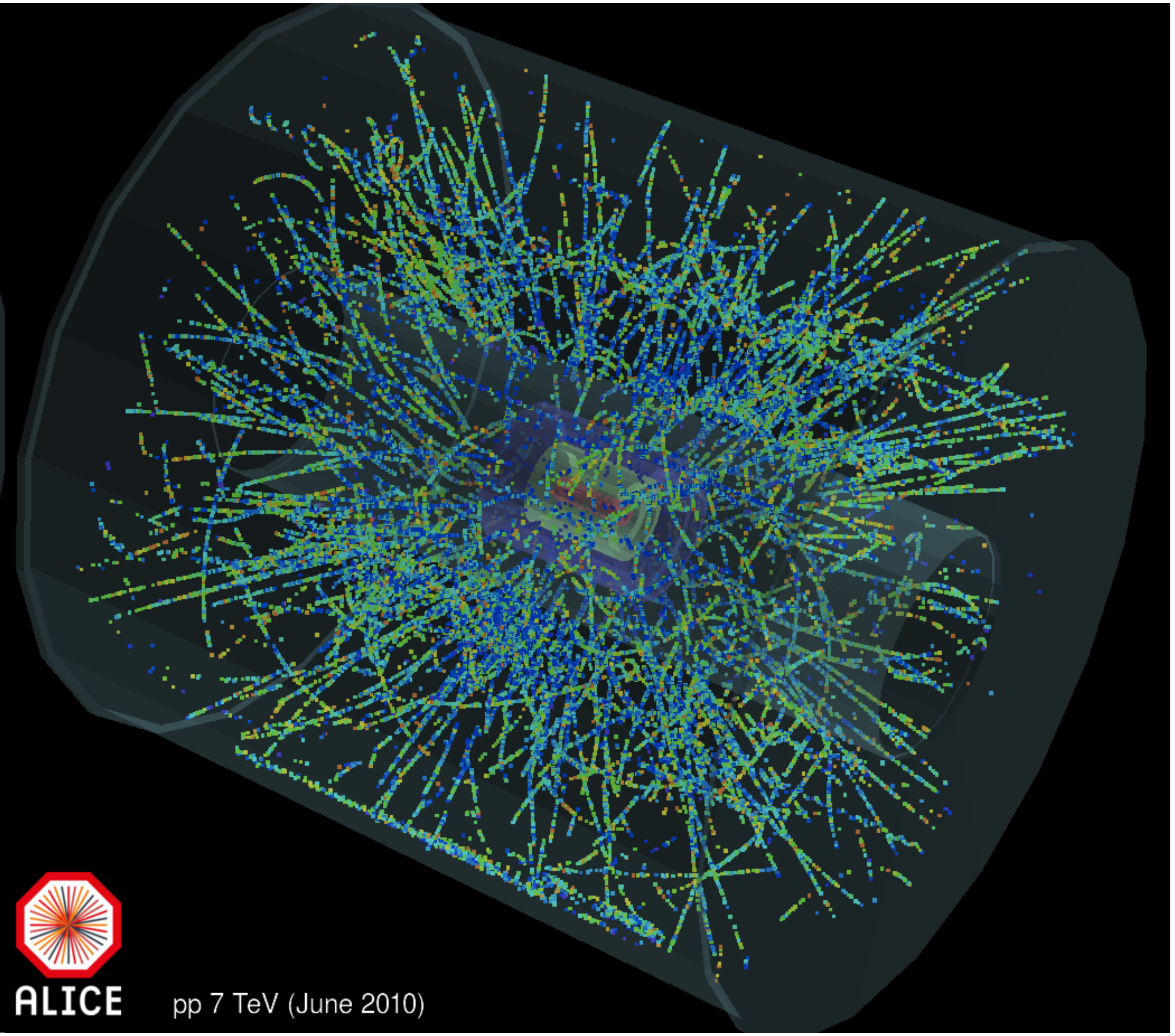
Small systems: discussion on high multiplicity pp and pA collisions in Run 3 & 4



Alexander Kalweit, *CERN*

Introduction: not all pp collisions are the same





Introduction: key result and questions (1)

- Unique situation at the LHC:
  - Unlike the dedicated heavy-ion machine RHIC, large fraction of the LHC program consists of pp collisions.
  - In a *significant fraction* of the cross-section, particle multiplicities comparable to Cu-Cu collisions at RHIC are observed.
  - In a *small fraction* of the cross-section, particle multiplicities comparable to peripheral Pb-Pb at the LHC are observed.

- Key result (so far):
  - High multiplicity pp and pPb collisions show **collective behavior in the soft sector**.

Introduction: key result and questions (2)

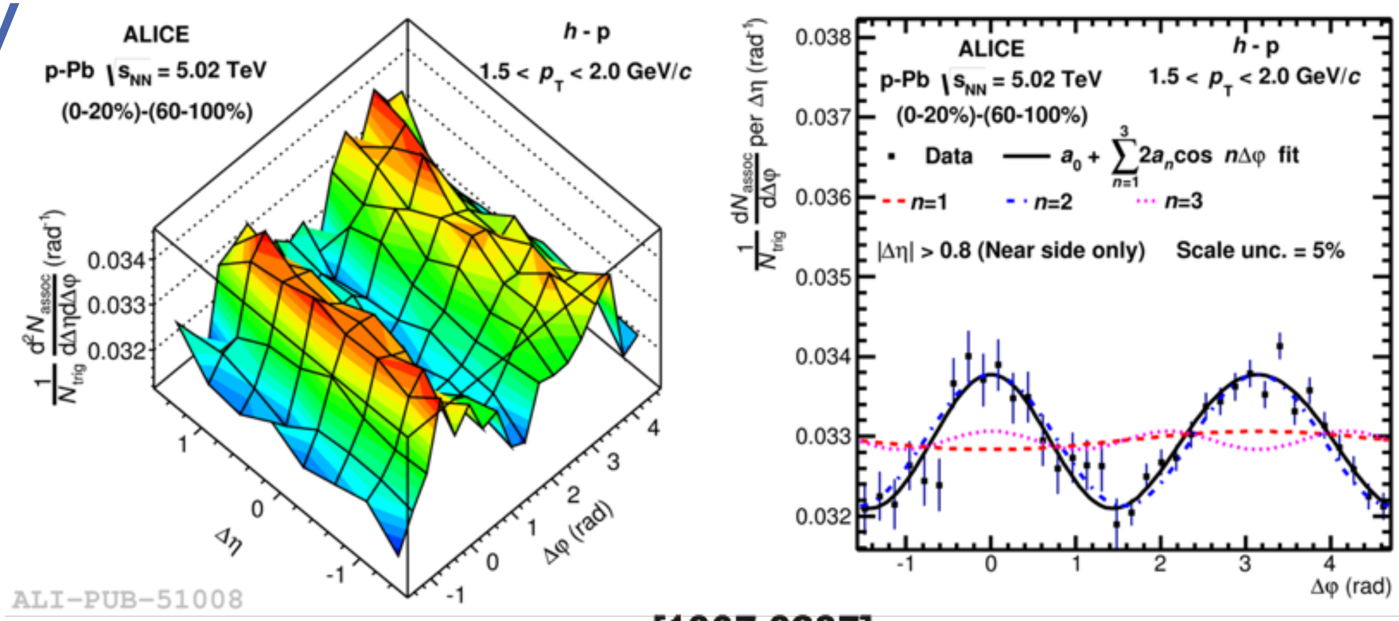
- Key questions:
  - Is the underlying physics of soft collectivity the same in Pb-Pb and pp collisions?
  - Does the collectivity extend to the **heavy-flavor and hard sector** as well as other QGP signatures?
    - Quarkonium suppression
    - Jet quenching
    - Thermal radiation
  - Are there explanations arising from QCD not related to the creation of a thermalized system explaining QGP signatures across different collision systems?
  - Is there a QGP in high multiplicity pp and pPb collisions? Do we see an onset or a smooth transition?

Introduction: collectivity

- Baseline model for soft light flavor particle production in heavy-ion collisions:
  fireball in local thermodynamic equilibrium
  - Success of hydrodynamics (spectral shape via radial flow, elliptic flow) → kinetic equilibrium.
  - Success of thermal-statistical model for hadronisation → chemical equilibrium.

→ **Works also in small collision systems!**

→ Ongoing discussion of utility/relevance of hydro without a strict (strong) assumption of local thermal equilibrium in the theory community.



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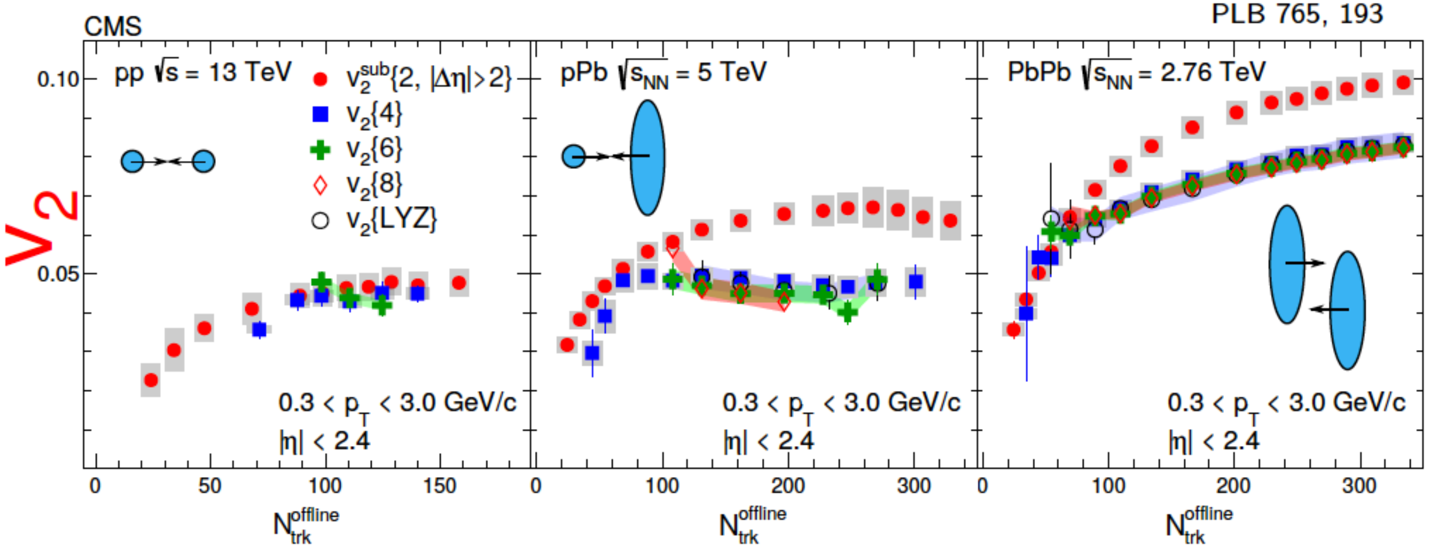

Introduction: collectivity

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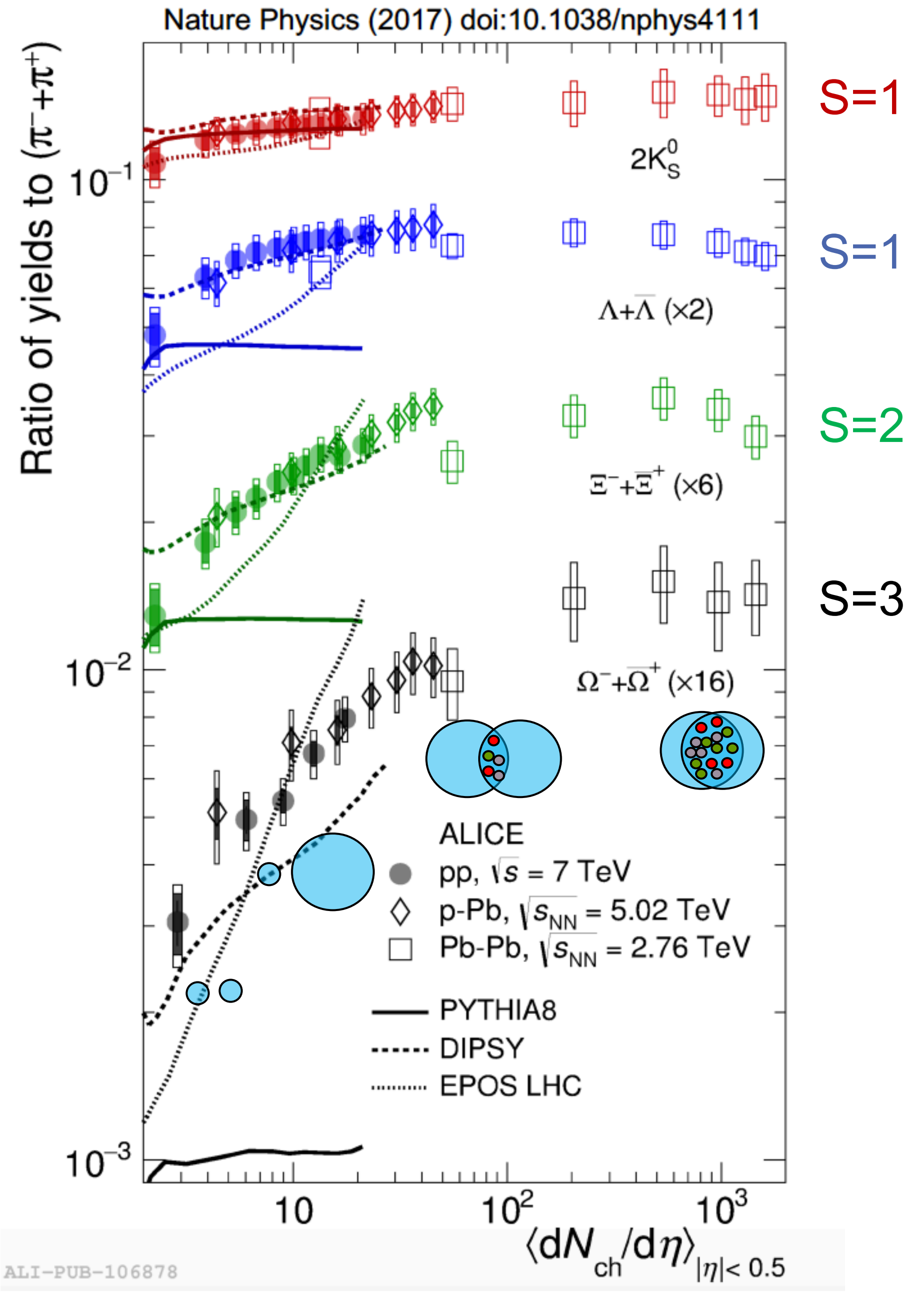
Fireball in local thermal equilibrium: QCD matter following the dynamics and conservation laws of the underlying theory (`macroscopic` modeling).

↔

QCD inspired event-by- event generators (`microscopic modeling).

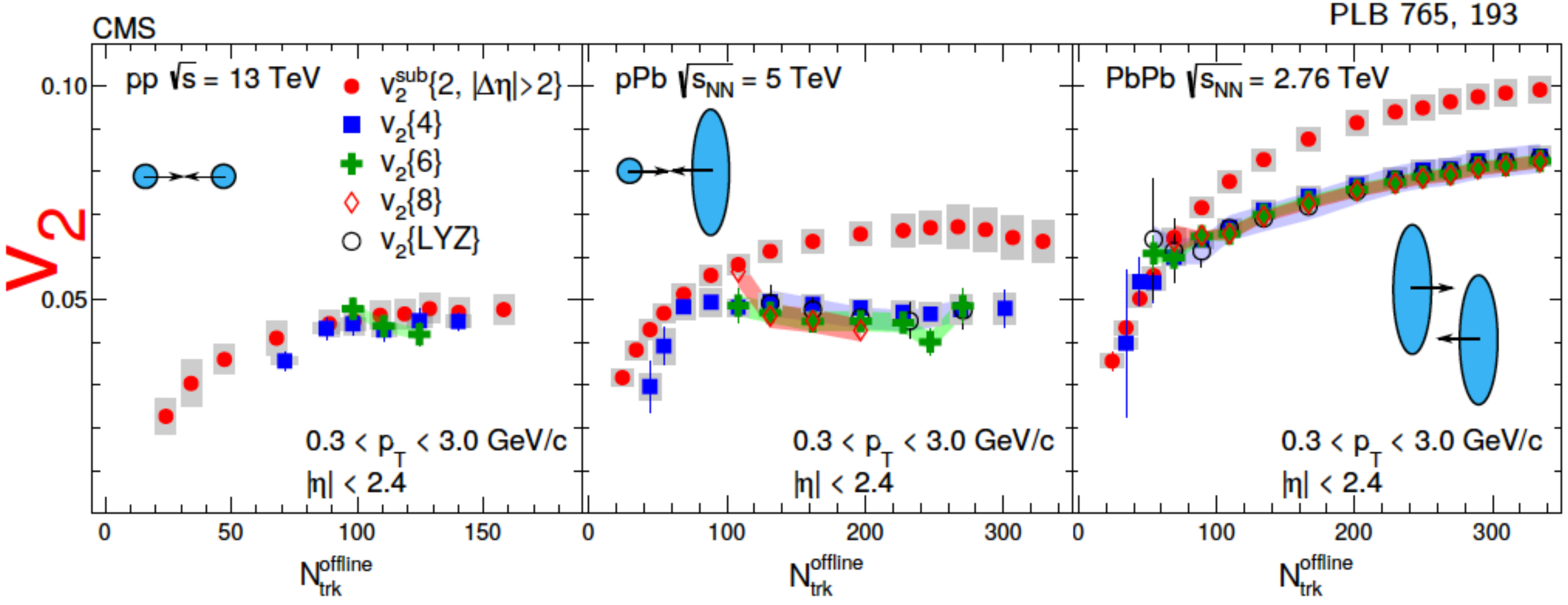


Flow without significant jet quenching (1)

If flow in small systems is due to final state interactions, then there should be jet quenching effects, even if they might small (see details in talk by U. Wiedemann).
→ careful and precise studies in the overlapping multiplicity range of high multiplicity pPb and Pb-Pb collisions.

→ non-flow contributions in small systems and how to address them (e.g. subevent cumulants,..)?

PLB 765, 193



Flow without significant jet quenching (2)

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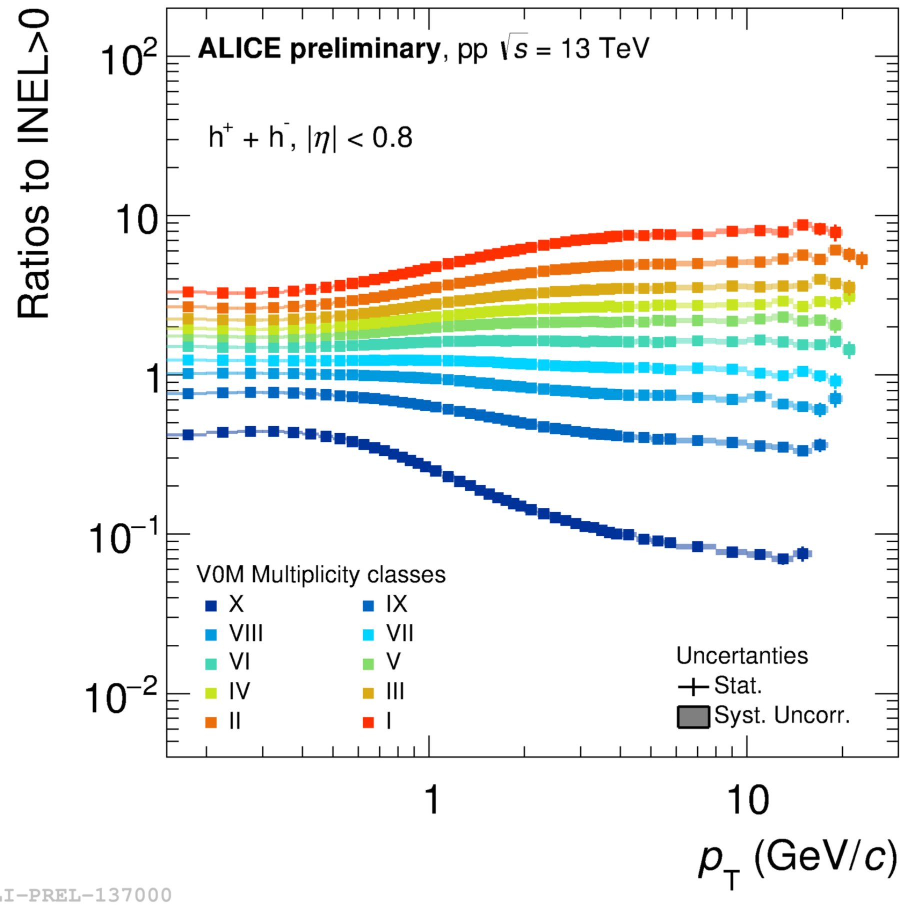
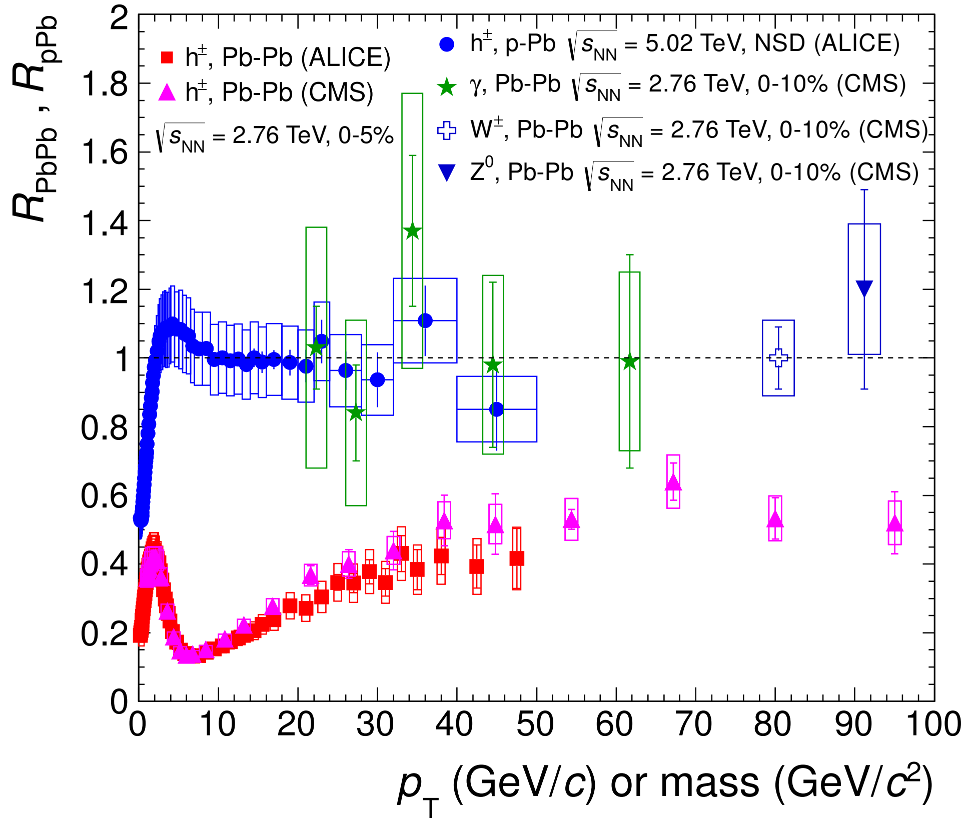
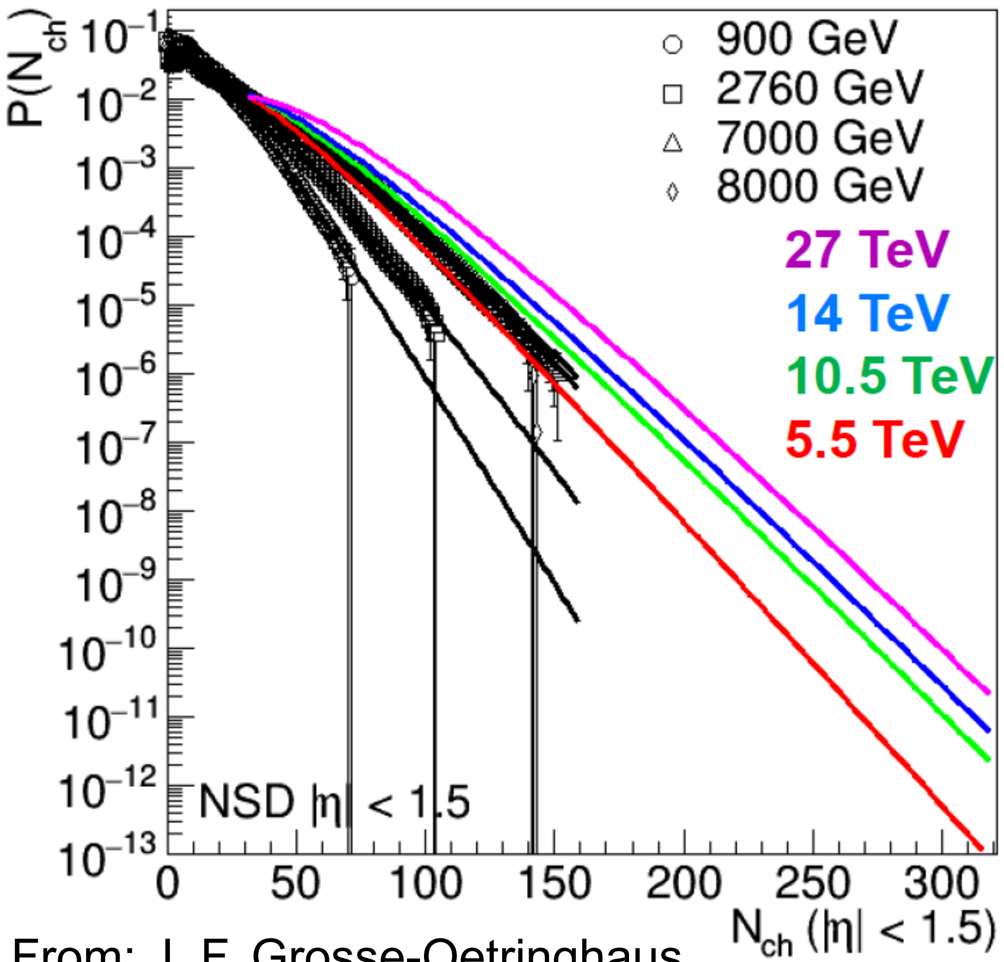


Eur. Phys. J. C 74 (2014) 3054



The challenge

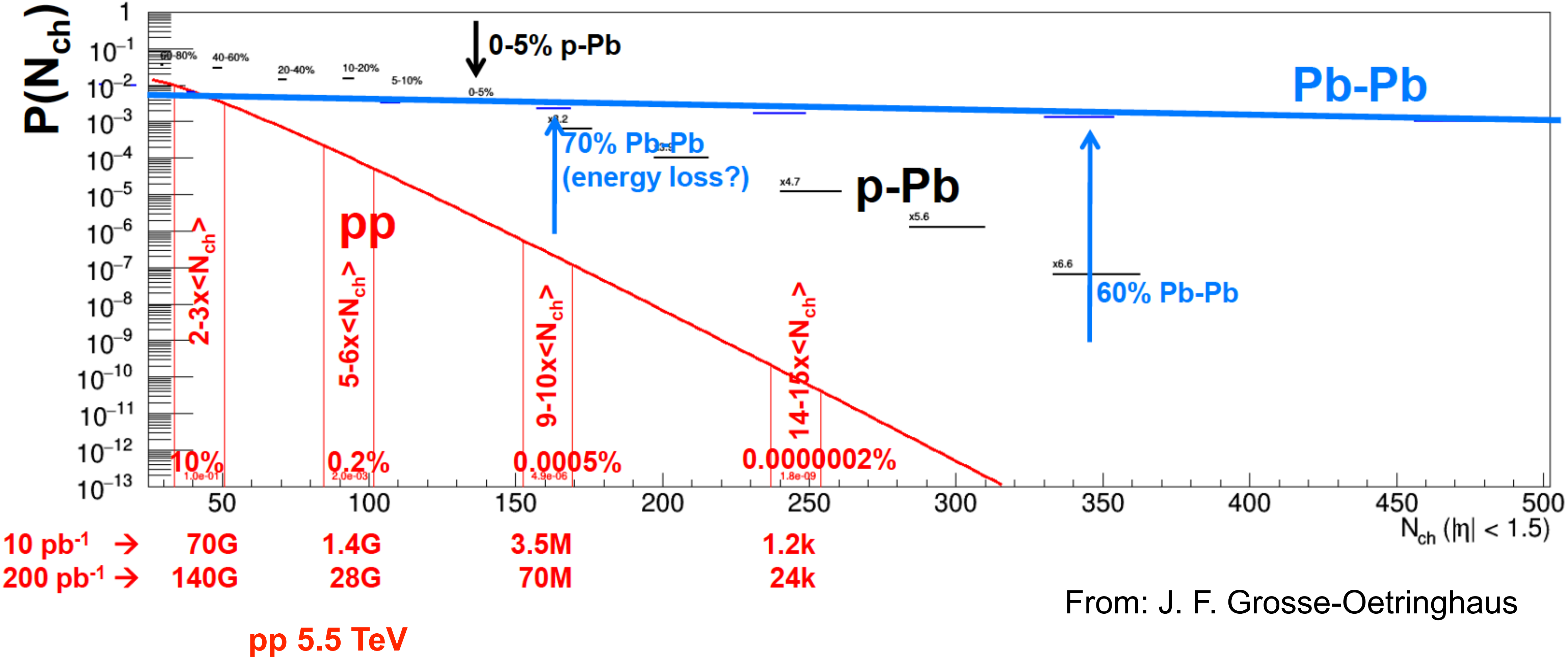
- The multiplicity distribution in pp collisions is steeply falling → any further increase in multiplicity reach requires sampling very large integrated luminosity L_{INT}.
- Extrapolations can be based on available input distributions from 0.9 to 8 TeV
  - Negative Binomial fit to tail (above 12-20 tracks such that it contains 40% of total cross-section)
  - Inter- (5.5 TeV) and extrapolation of NBD parameters.
- Collision energy:
  - Reference energy (allowing for dedicated beam configurations) and nominal energy with higher average multiplicity.



From: J. F. Grosse-Oetringhaus

Expected multiplicity is not well constrained by data
→ common baseline for extrapolations should be agreed across experiments.

Multiplicity reach



From: J. F. Grosse-Oetringhaus

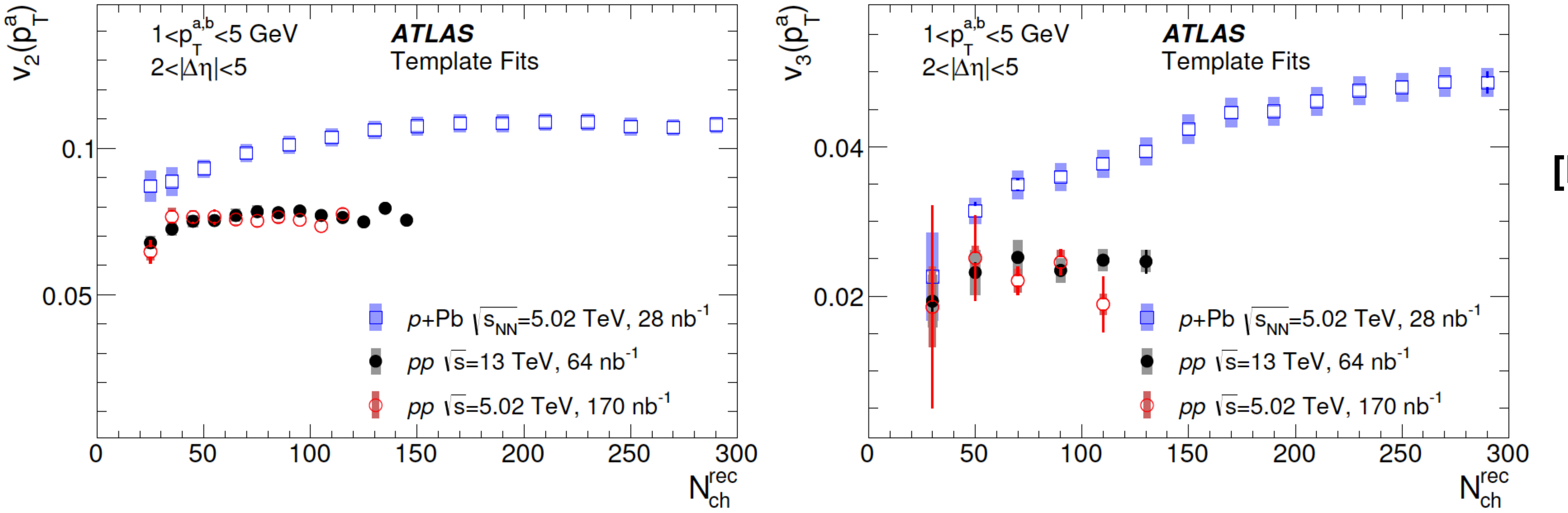
ATLAS: summary

- Overarching goal is to form **a coherent physics picture from pp to pA to AA**.

- pp collisions
  - Observed flow most striking result
  - How can data be optimally used?
- pA collisions
  - Should/must be bridge between pp and AA
  - Key for understanding low-x and other initial nuclear state studies
- AA collisions
  - Centrality dependent analyses should extend as peripherally as possible
  - Forward detectors (e.g. upgraded ZDC) will help to suppress EM-induced backgrounds
  - Can smaller nuclei (e.g. Ar) fill gaps changing collision geometry for a given system size?

Ridges / v_n / cumulants: ATLAS (1)

- Many results measuring harmonic modes in pp already exist:



ATLAS EXPERIMENT

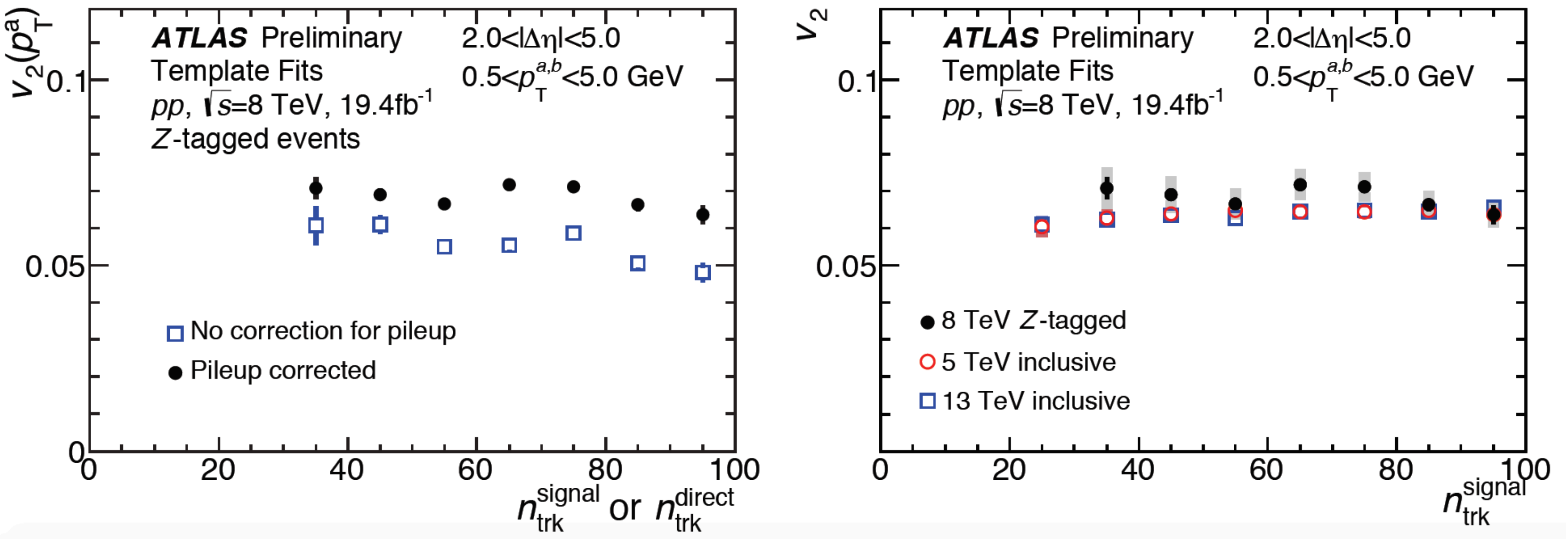
[PRC 96, 024908]

- Upgrades to tracking (Itk) will allow for improved measurements of the same quantities.

Ridges / v_n / cumulants: ATLAS (2)

- Strategy for use of high luminosity/pile-up data is essential.
- New analysis approaches and new observables (flow and other)
  - First high pile-up ($\mu \sim 20$) flow analysis uses Z boson events. Z allows primary vertex definition, pile-up is then subtracted and N_{trk} distribution is unfolded for event classification. Results are similar to the min bias selection (in events which are tagged as what should be small-b events with a very hard process).
  - Approach can be applied to other hard processes and bulk observations.

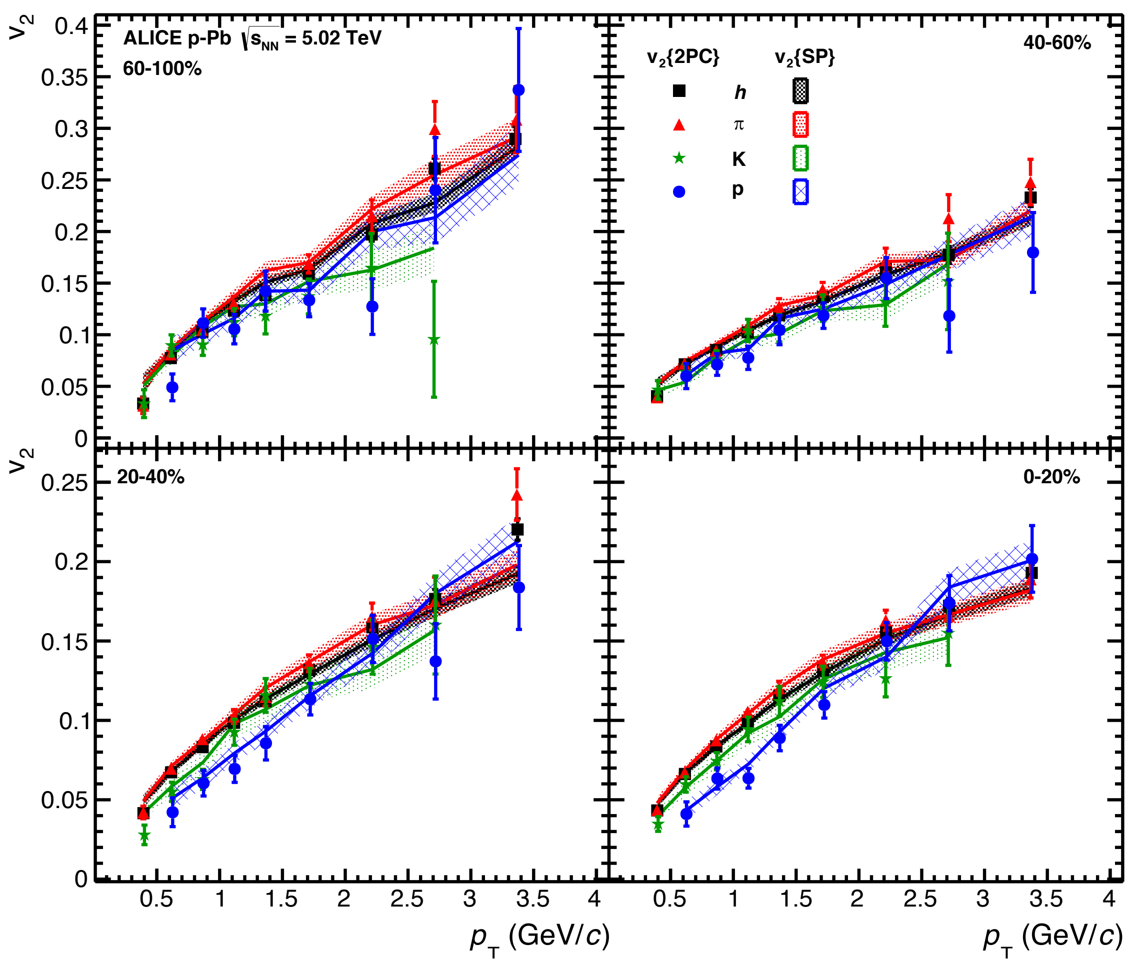
ATLAS-CONF-2017-068



Ridges / v_n / cumulants: ALICE

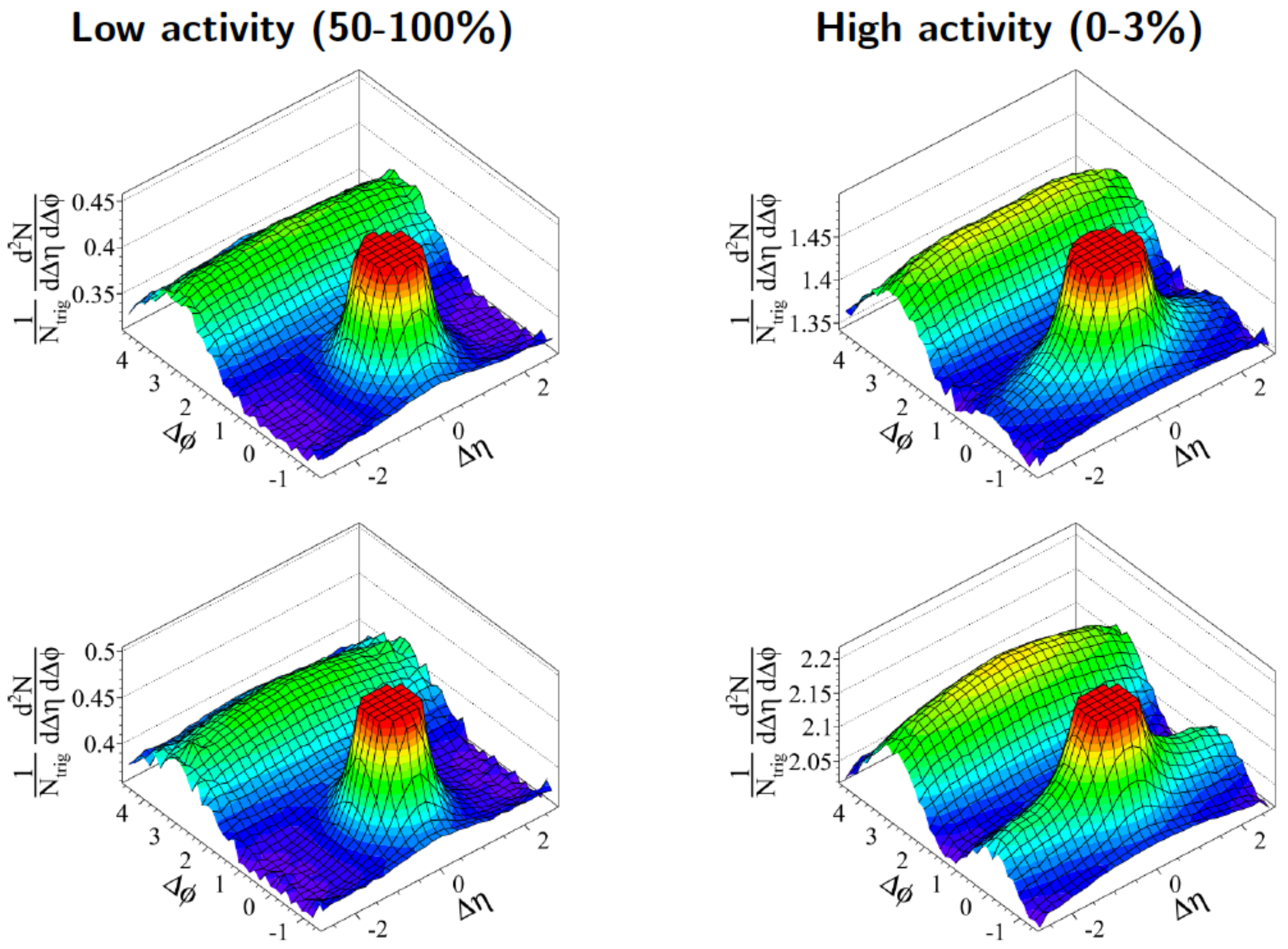
- Increase in statistics will allow to measure mass ordering in pp collisions as in 0-20% (V0A) pPb multiplicity bin.
- Explore possibilities with high multiplicity triggers from Run 2 and then elaborate physics case and reach for Run 3 & 4.
- Focus on observables which require particle identification.

[Phys. Lett. B 726 (2013) 164–177]



Ridges / v_n / cumulants: LHCb

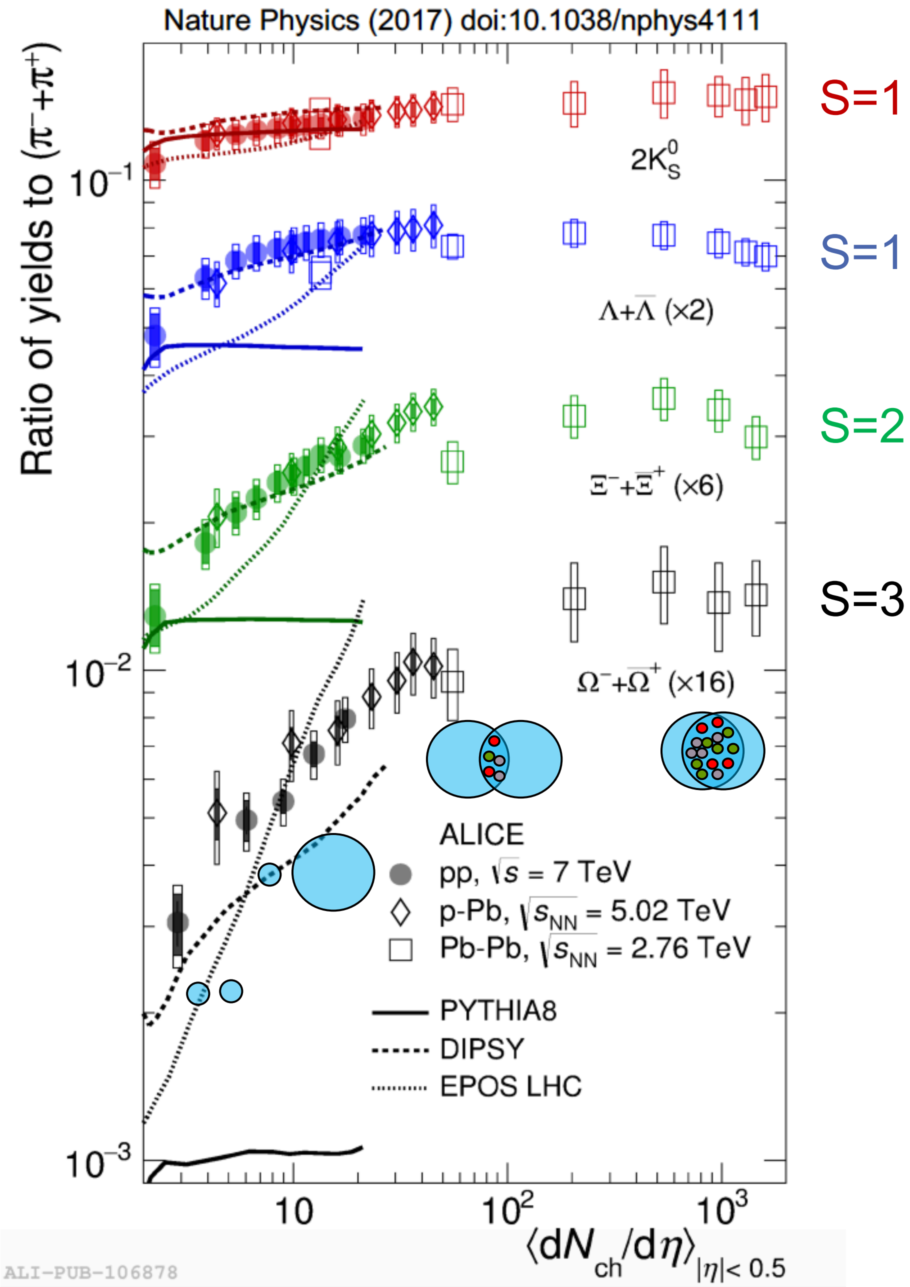
- LHCb: double ridge measured in pPb collisions.
- Unique possibility to extend correlation studies in small systems to the heavy flavour (charm sector): D^0-hadron, D^0-D^0 correlations,…



In high activity events, near side ridge ($\Delta\phi = 0$) visible

[1512.00439]

Hadrochemistry and strangeness enhancement (1)

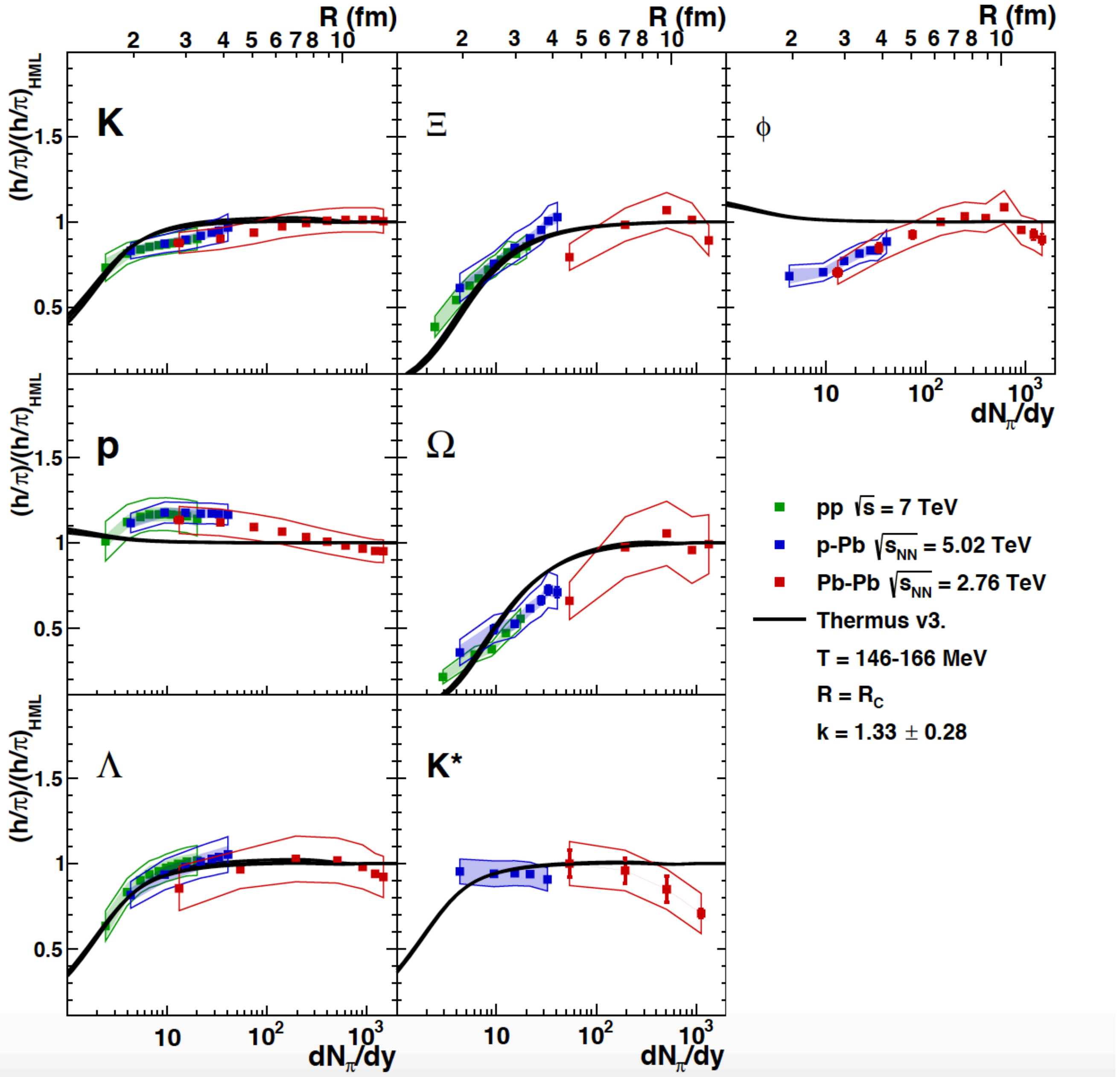


- Smooth evolution of hadrochemistry observed from pp to pPb to Pb-Pb collisions as a function of charged particle multiplicity.
- Significant enhancement of strange to non-strange particle production observed in pp collisions.
- pp collision data allows to compare to a plethora of QCD inspired event generators:
  - **PYTHIA8** completely **misses** the behavior of the data (independent of switching ON/OFF color reconnection)
  - **DIPSY** (color ropes) describes the increase in strangeness production qualitatively but fails to predict protons correctly in its original version..
  - **EPOS-LHC** (core-corona) only qualitatively describes the trend.

Hadrochemistry (2)

- Heavy-ion view: the thermal-statistical hadronisation picture can be extended to smaller collision systems (strangeness canonical suppression).

- Does strangeness canonical enhancement explain everything? Is there any need for a microscopic modeling?



[V. Vislavicius, AK, arXiv:1610.03001]

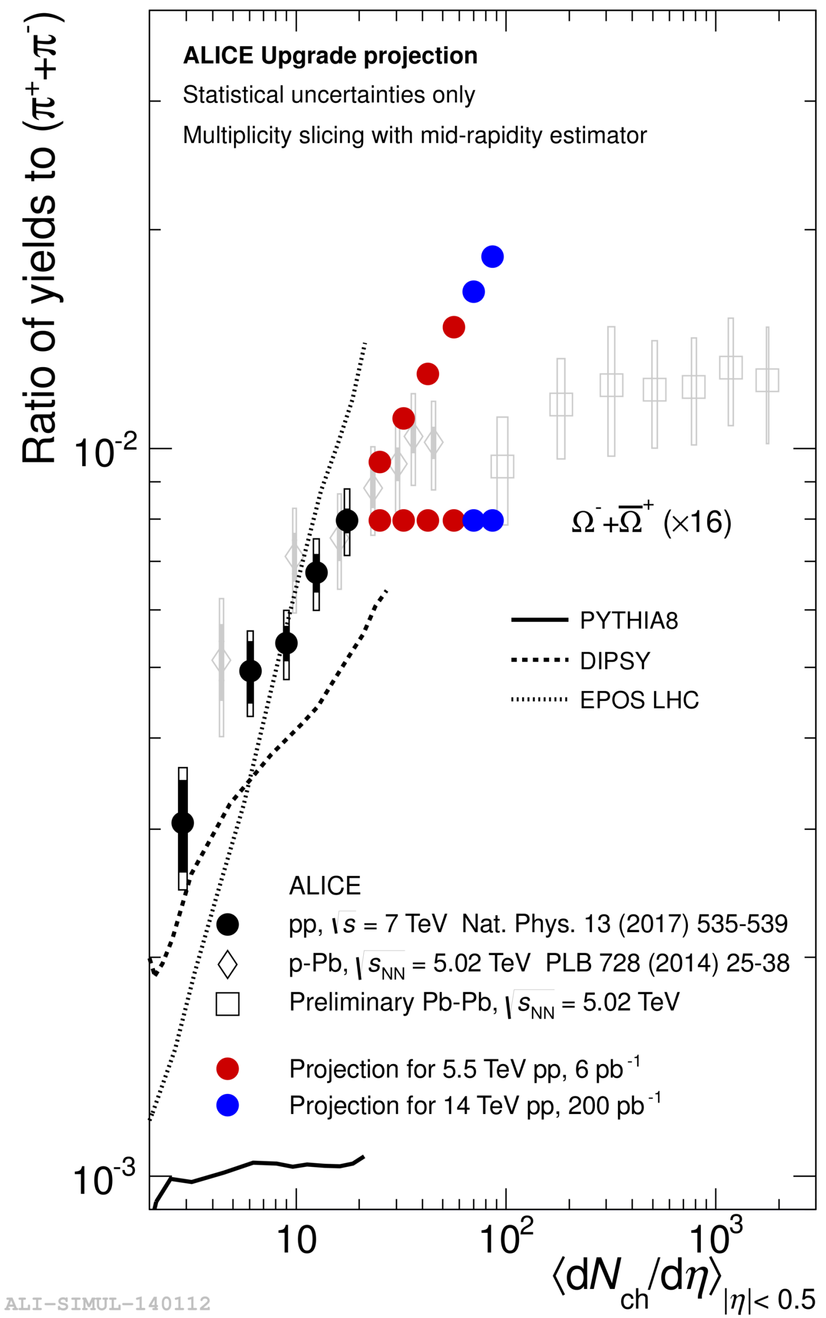
Hadrochemistry (3)

- Run 3 and 4 will provide crucial tests:

  Is the grand-canonical limit for particle production universally respected or is it violated in very high multiplicity pp collisions?

- Caveats:
  - Multiplicity estimators and selection biases.
  - Particle production in jets versus bulk
  - …

- N.B.: many observables in the soft sector need a large amount of integrated luminosity (multi-strange, anti-nuclei,..).



Homework for the experiments

- Small systems should become an integral part of the run 3 & 4 planning (computing and manpower resources, pile-up,..).

- Elaborate further on physics case:

  - Are there other interesting observables?

  - Define boundaries with the other heavy-ion topics (i.e. the small systems program of heavy-flavour or for light anti-nuclei):
    - Heavy flavour → See talk by E. Bruna.
    - Quarkonia → See talk by E. Chapon.
    - Thermal radiation → See talk by M. Weber.

  - Identify overlaps and synergies with the core pp program (in ATLAS, CMS, LHCb).