Multiplicity and centrality determination in pp, p-Pb and Pb-Pb collisions

D.D. Chinellato for the ALICE Collaboration

LHCP – 27th May 2020

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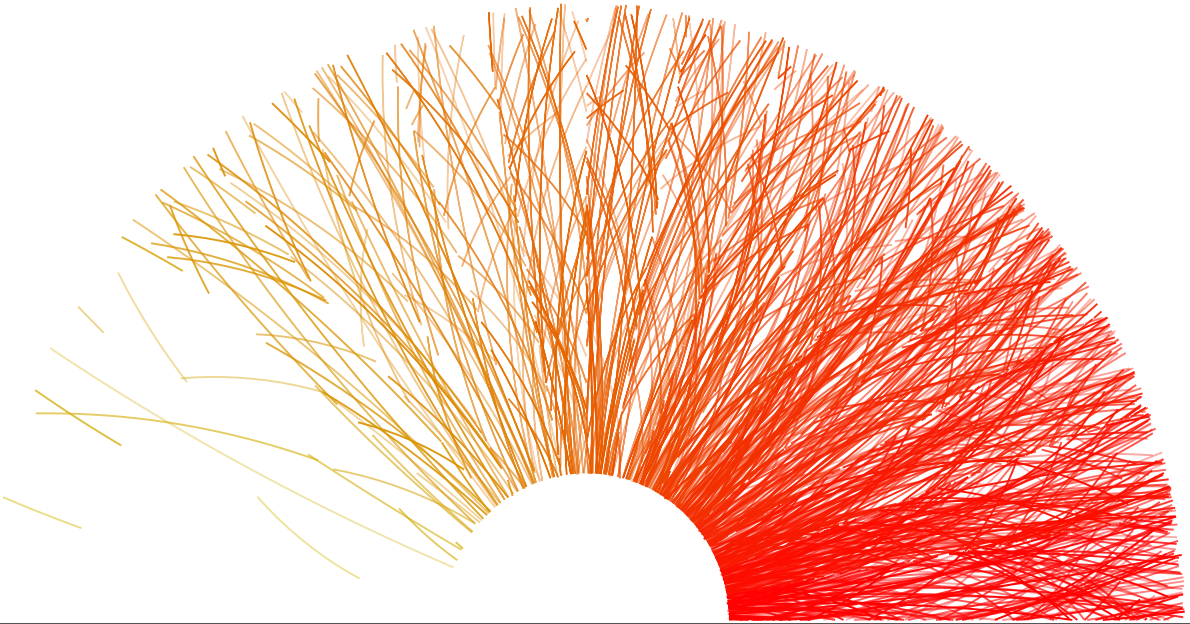
Physics across systems

proton-lead (p-Pb)
collisions

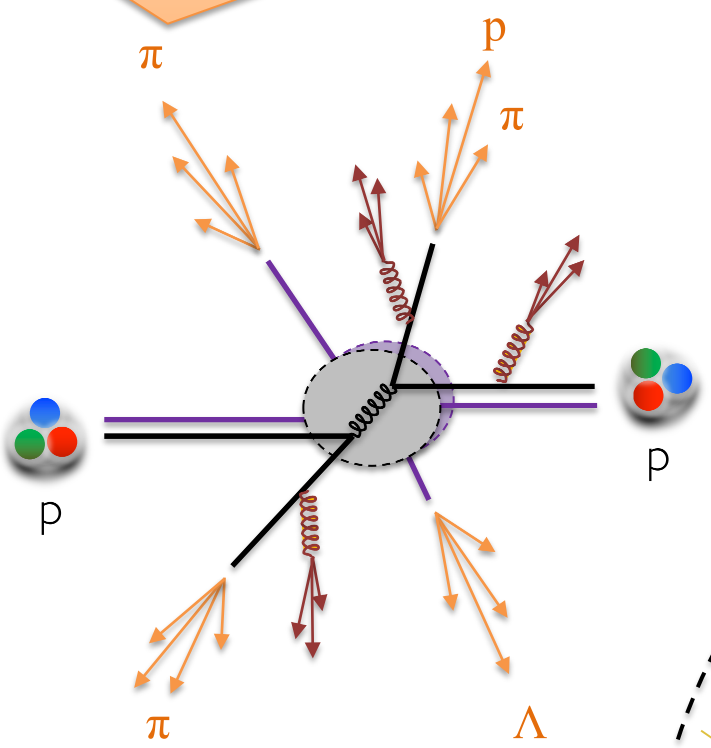


proton-proton (pp)
collisions

lead-lead (Pb-Pb)
collisions

Physics across systems

- 2 → 2 scatterings (LO)
- Soft physics: multi-parton interactions and initial and final state radiation
- MPI correlated via b, Q^2



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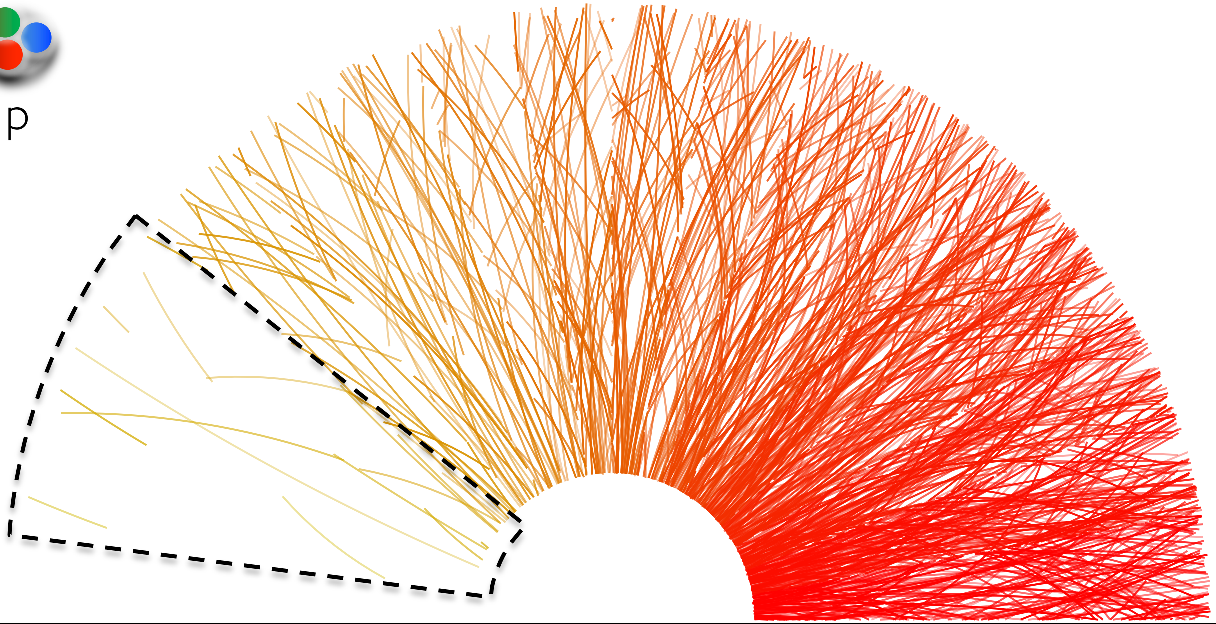
proton-lead (p-Pb) collisions



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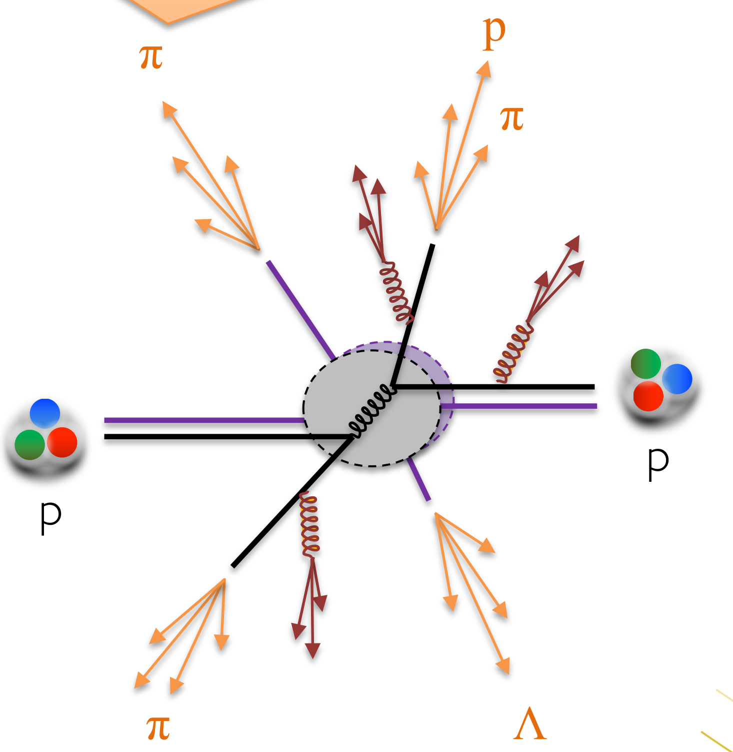
kinematically and chemically equilibrated system: hydrodynamics and statistical principles



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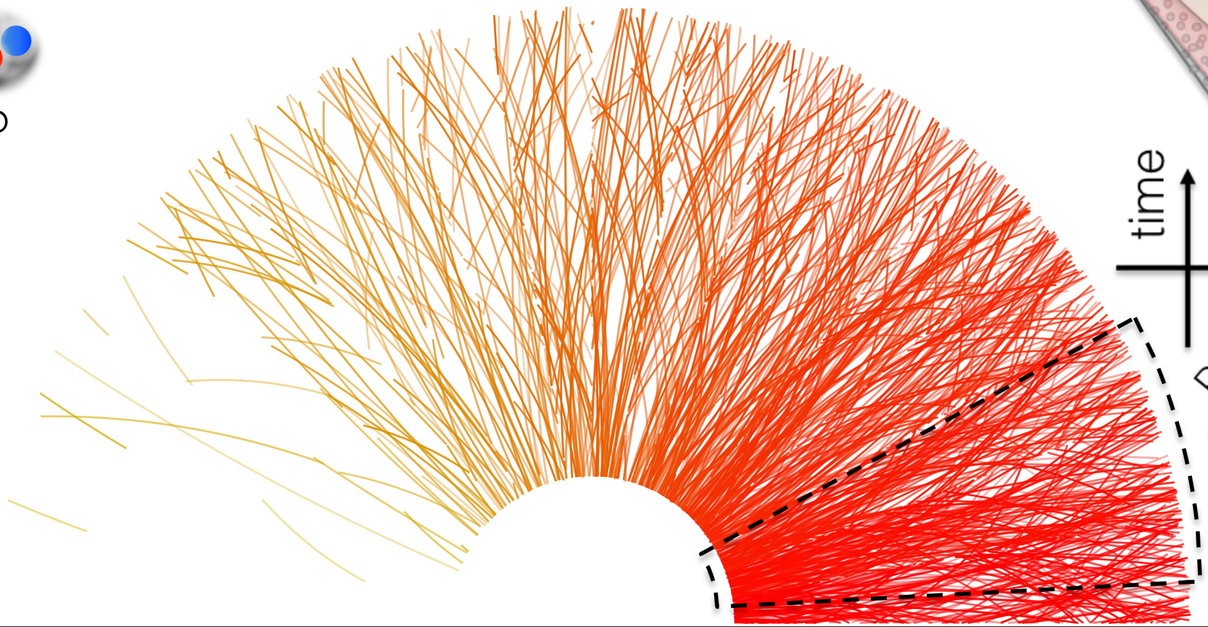

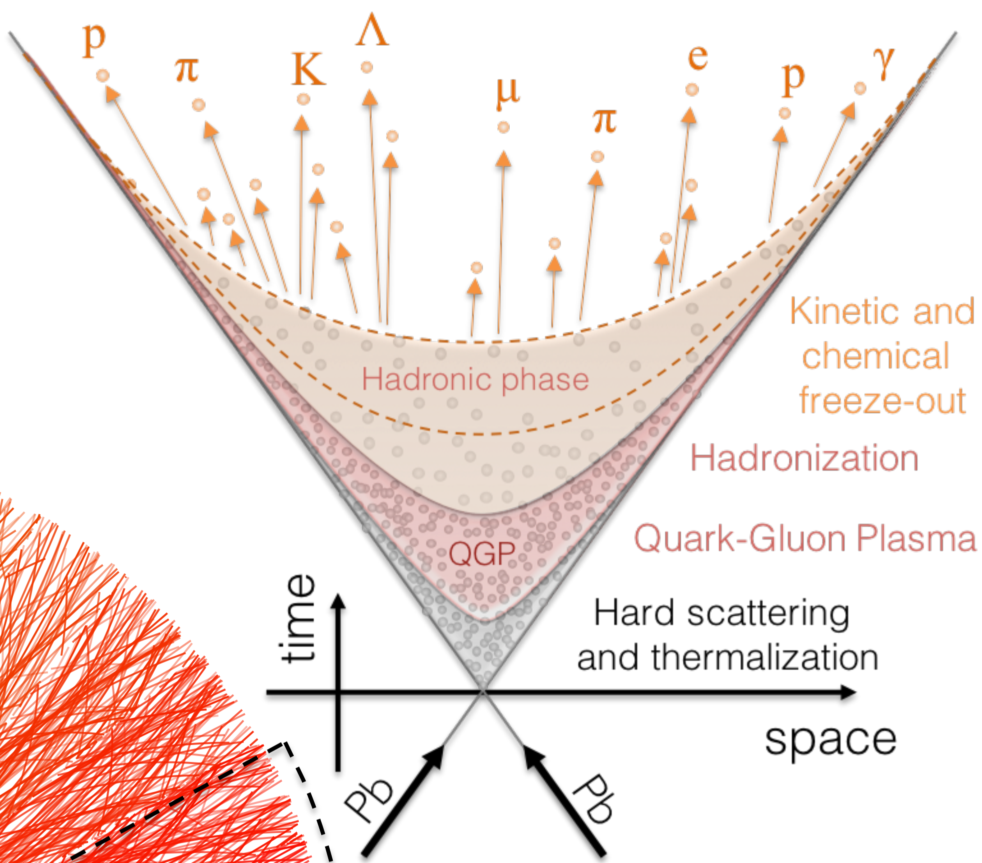

lead-lead (Pb-Pb) collisions

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- 2 → 2 scatterings (LO)
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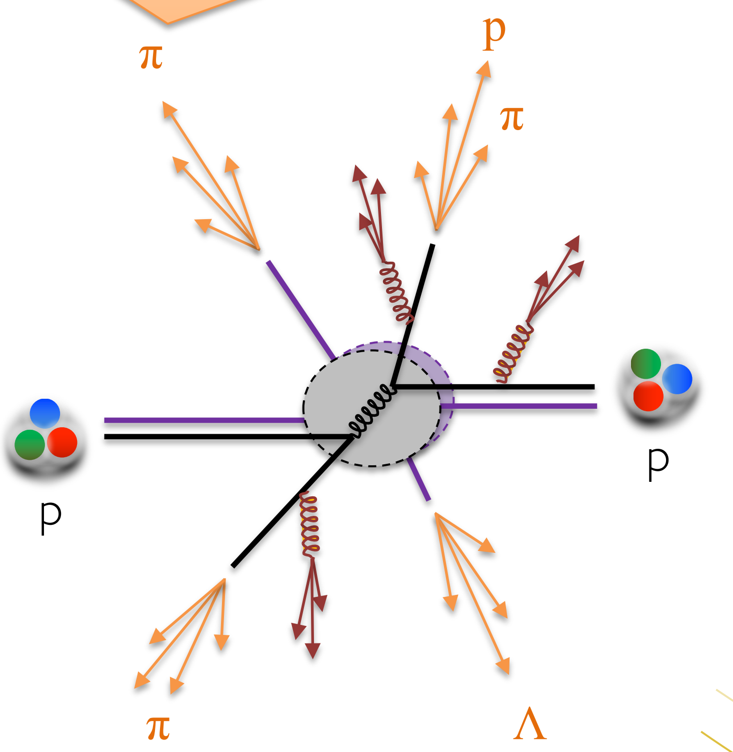
Physics across systems

kinematically and chemically equilibrated system: hydrodynamics and statistical principles

How can we connect the two regimes?



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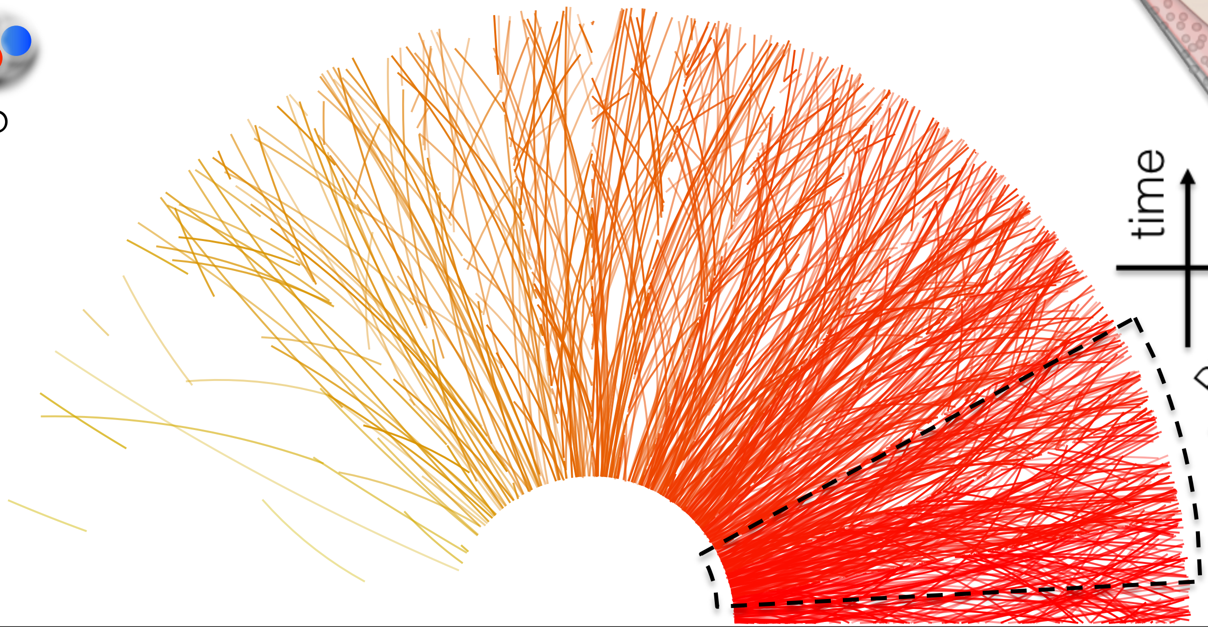
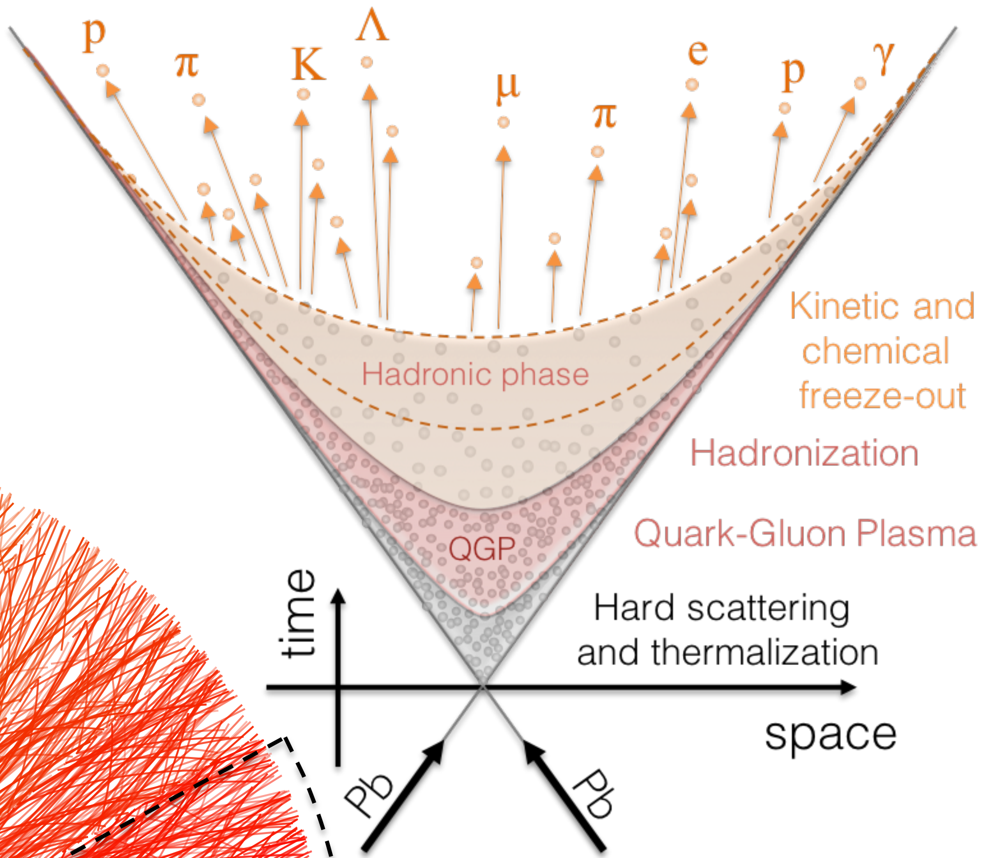
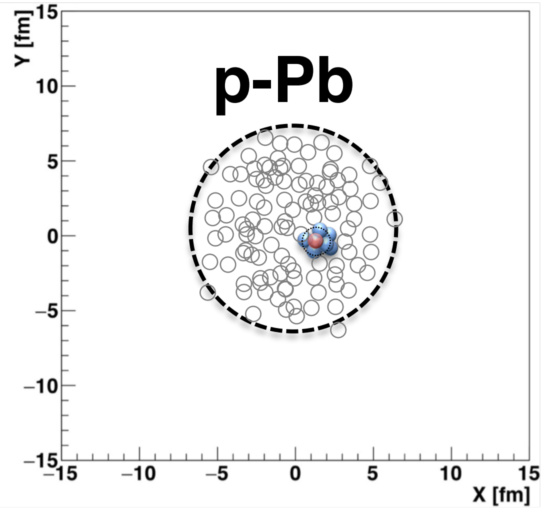
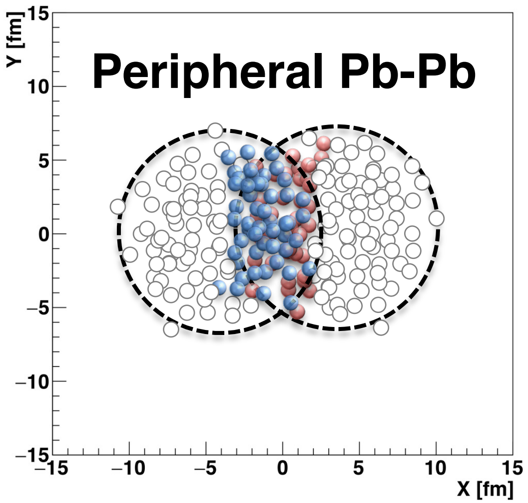


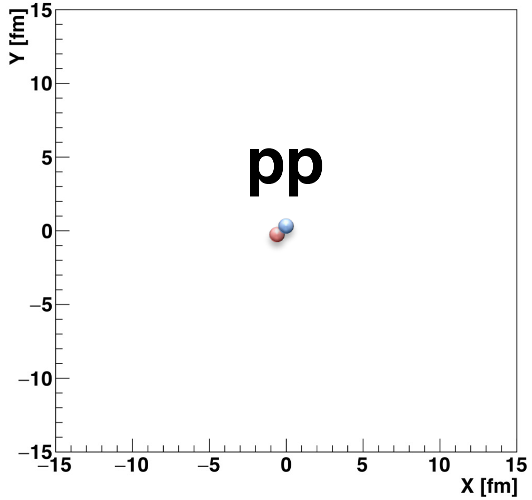


lead-lead (Pb-Pb) collisions

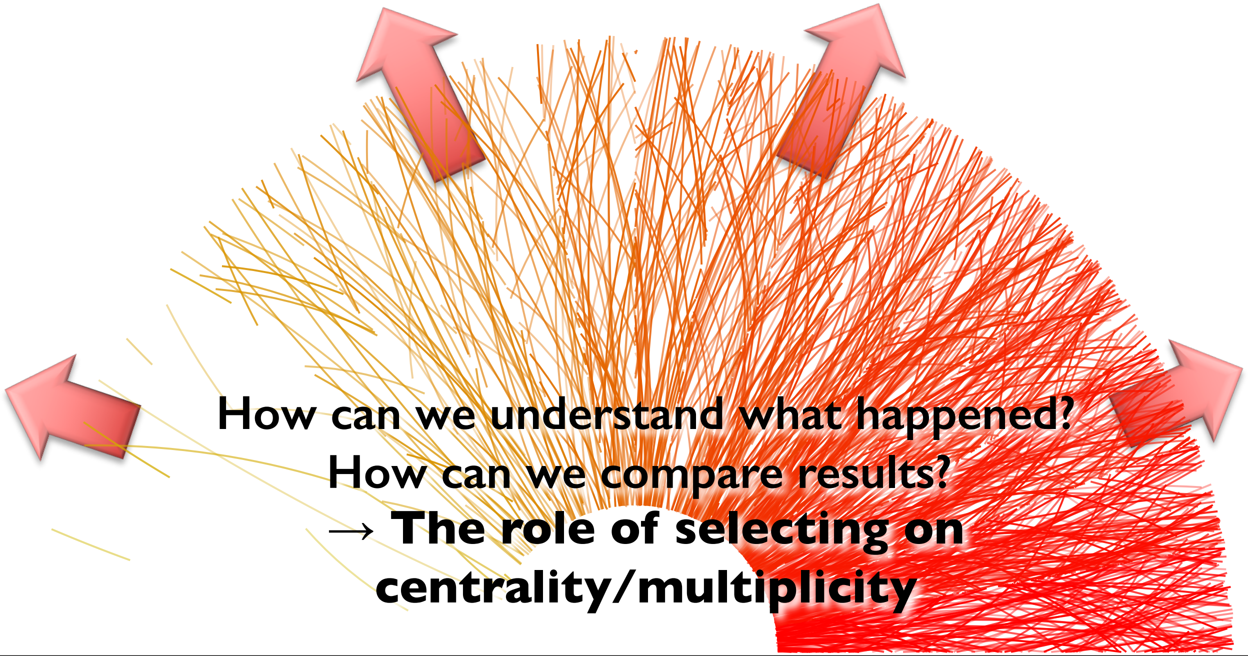
Towards a systematic comparison



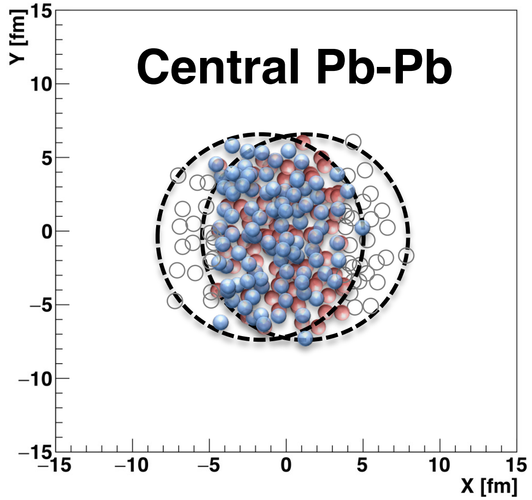




proton-proton (pp)
collisions



How can we understand what happened?
How can we compare results?
→ The role of selecting on centrality/multiplicity



Central lead-lead (Pb-Pb)
collisions

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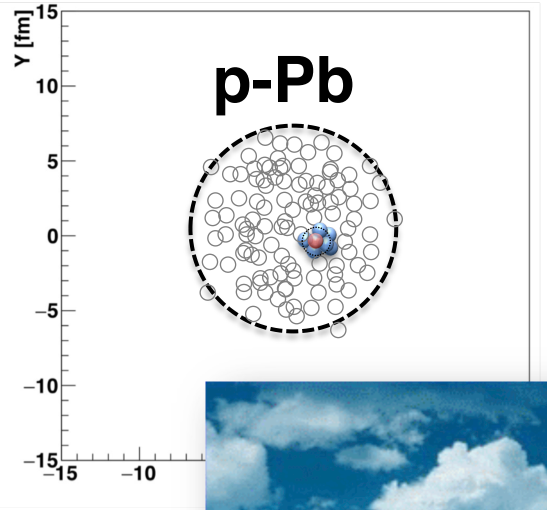
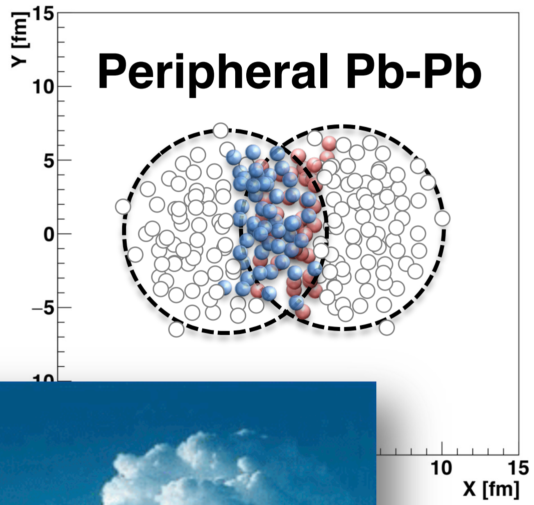
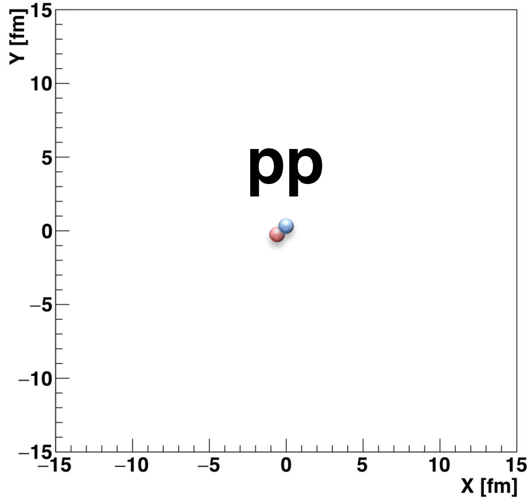
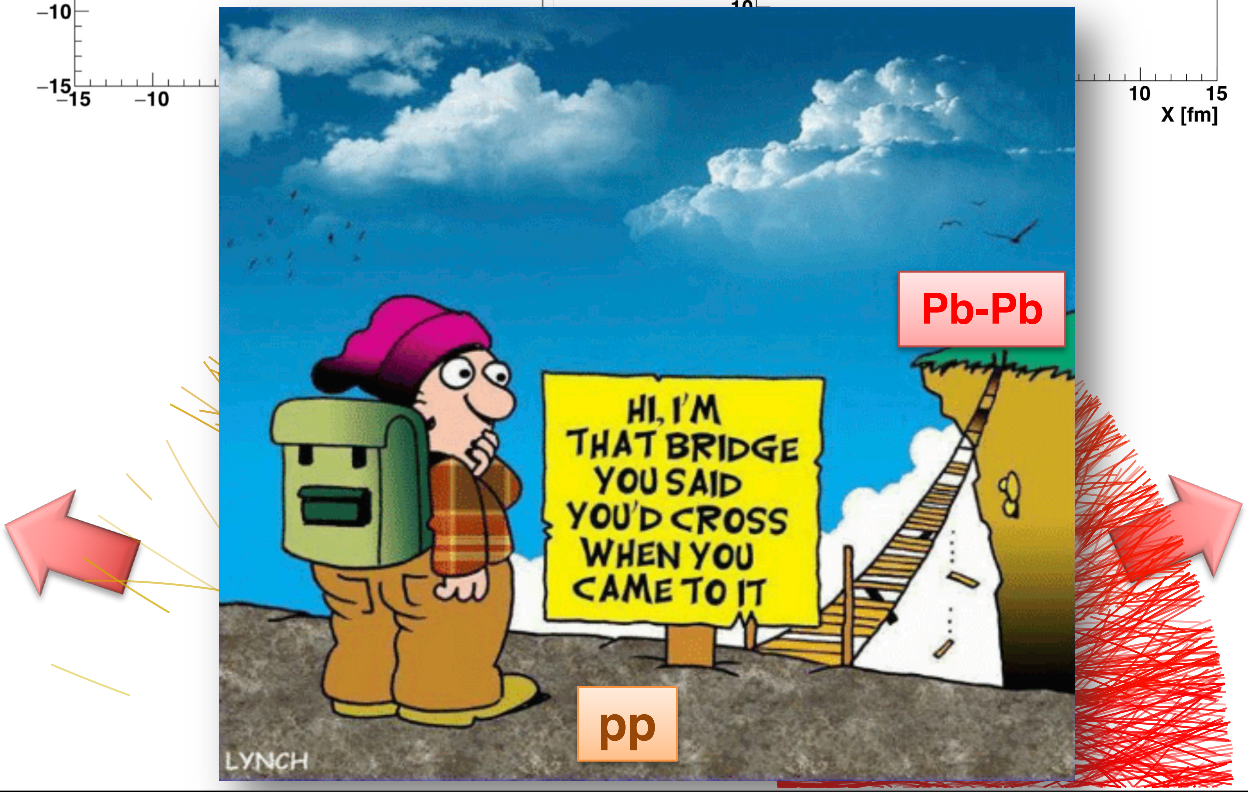
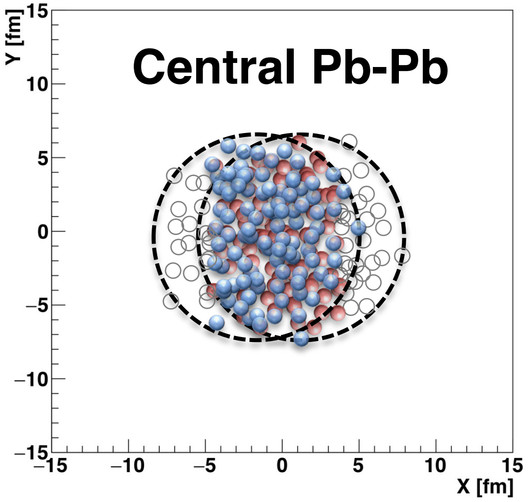
Towards a systematic comparison







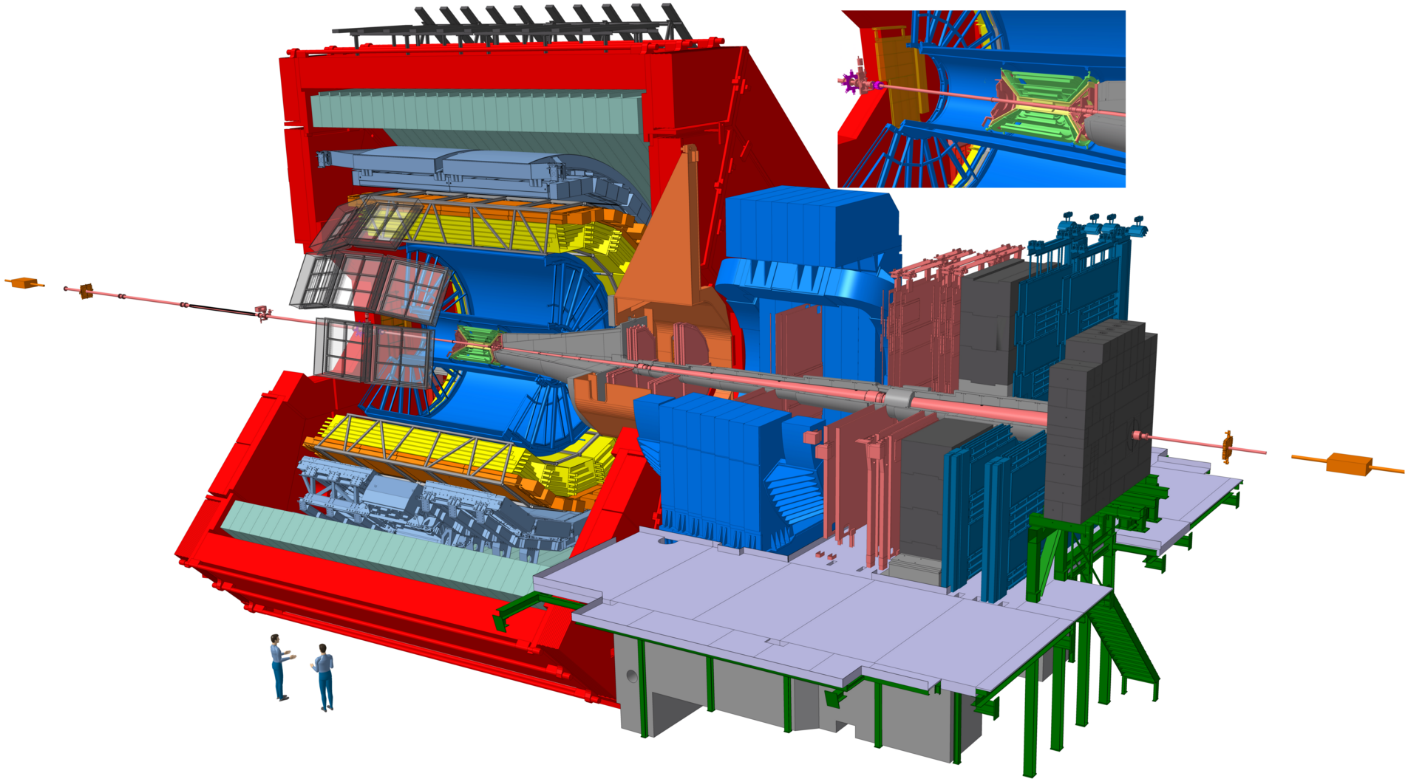




proton-proton (pp) collisions

Central lead-lead (Pb-Pb) collisions

The ALICE experiment at the LHC



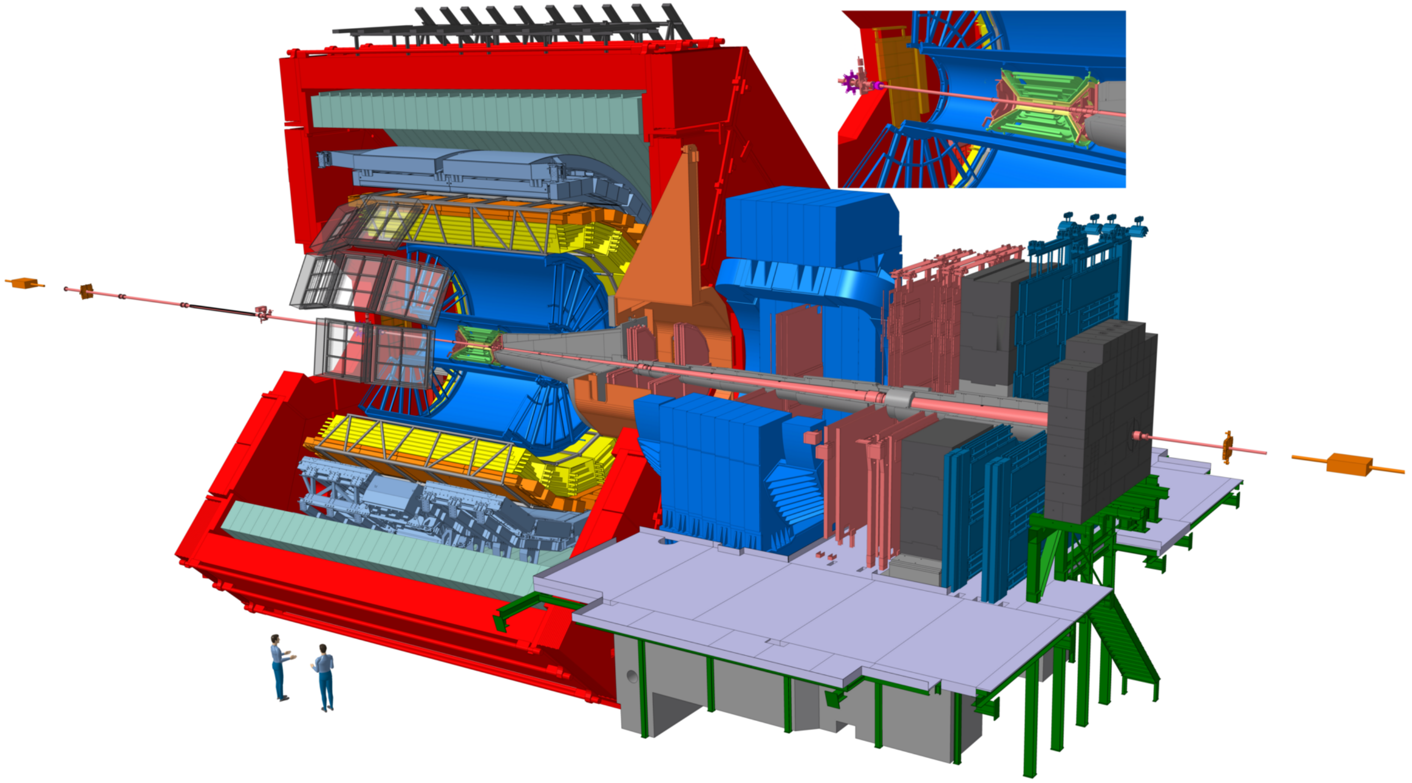
Central barrel tracking

ITS, TPC, TOF ($|\eta| < 0.9$)

- Trigger, tracking, vertex, particle identification

Specificity: low-momentum tracking and particle identification in a high-multiplicity environment

The ALICE experiment at the LHC



Specificity: low-momentum tracking and particle identification in a high-multiplicity environment

Central barrel tracking

ITS, TPC, TOF ($|\eta| < 0.9$)

- Trigger, tracking, vertex, particle identification

Centrality/multiplicity selection

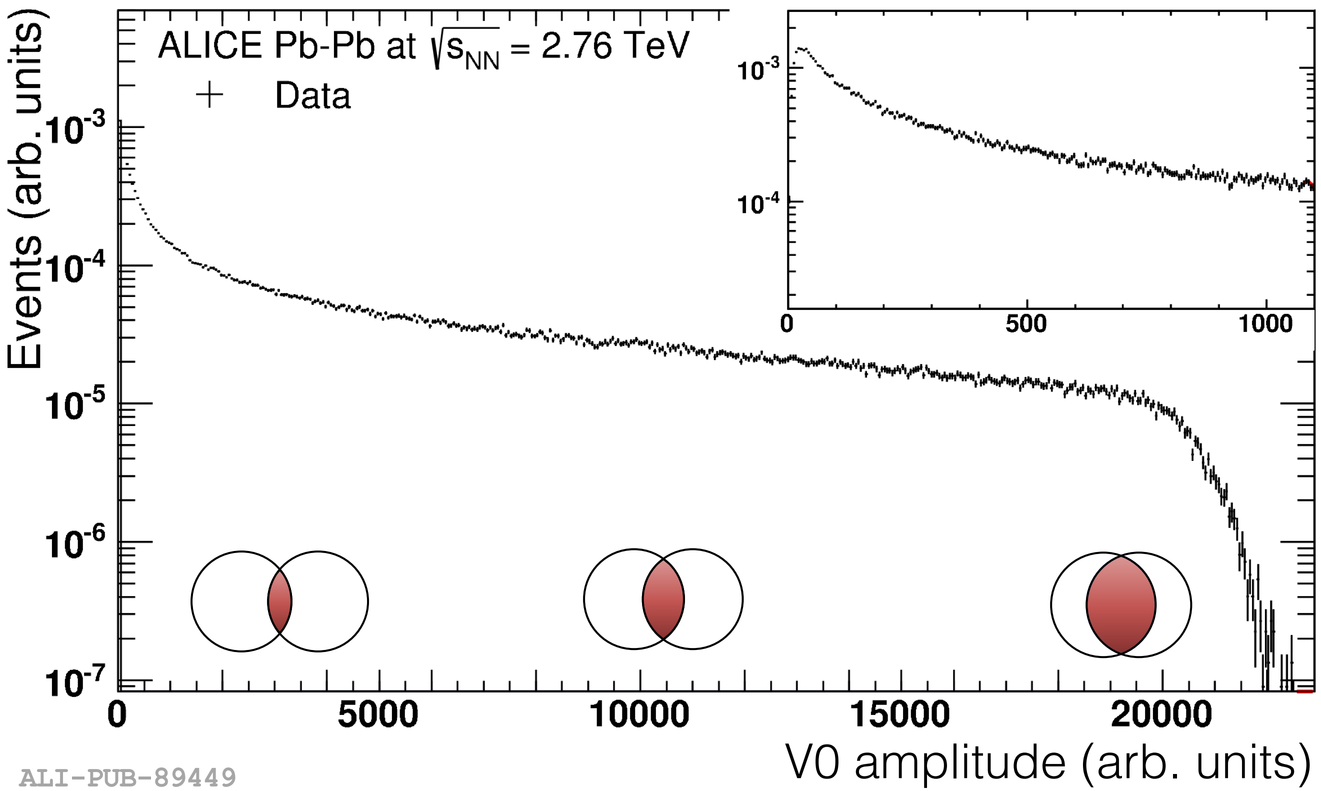
V0 [V0A ($2.8<\eta<5.1$) & V0C ($-3.7<\eta<-1.7$)]

- Forward arrays of scintillators
- Trigger, beam gas rejection
- Multiplicity/centrality selection

ZDC

- Very forward (zero-degree) calorimeters
- Located 112.5m away from interaction point
- Centrality selection

Centrality determination in Pb-Pb



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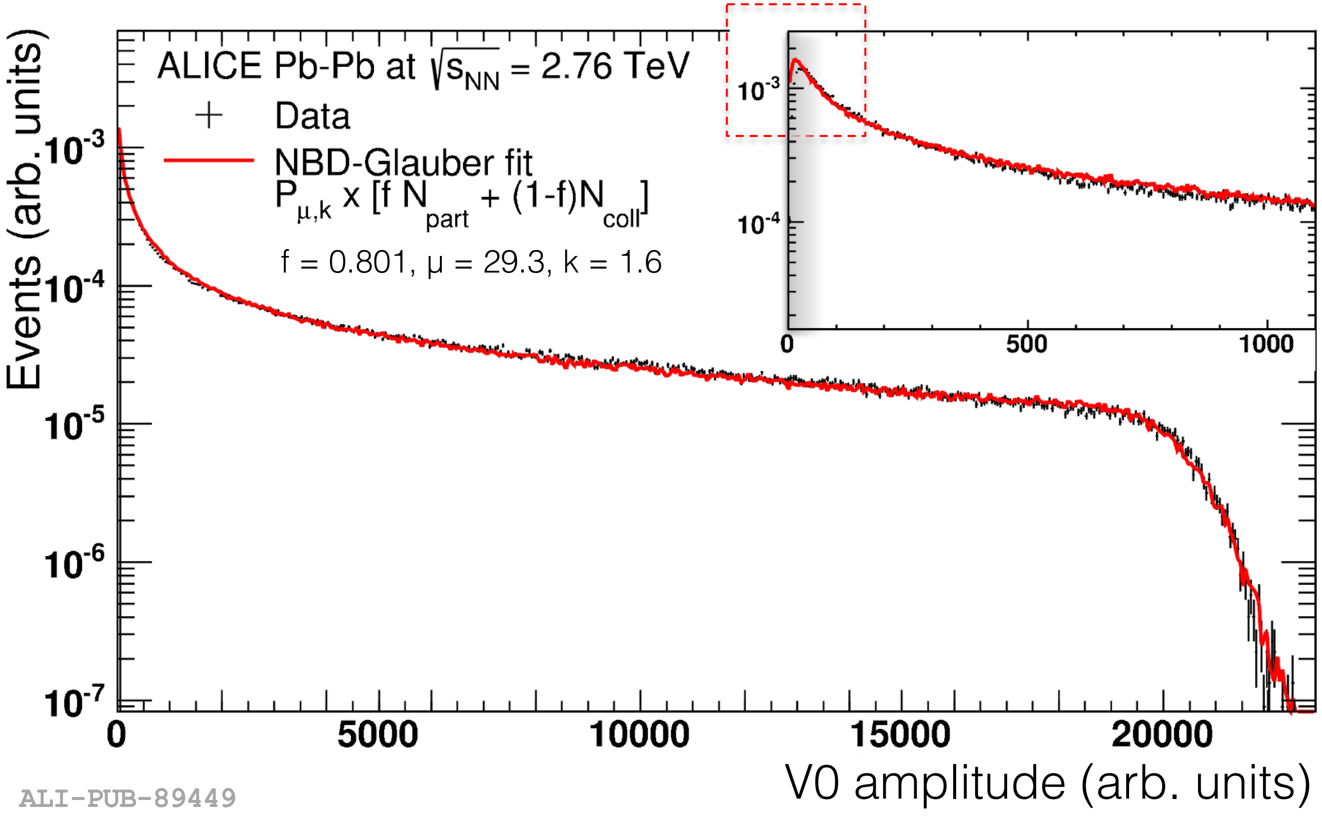
Phys. Rev. C 88 (2013) 044909

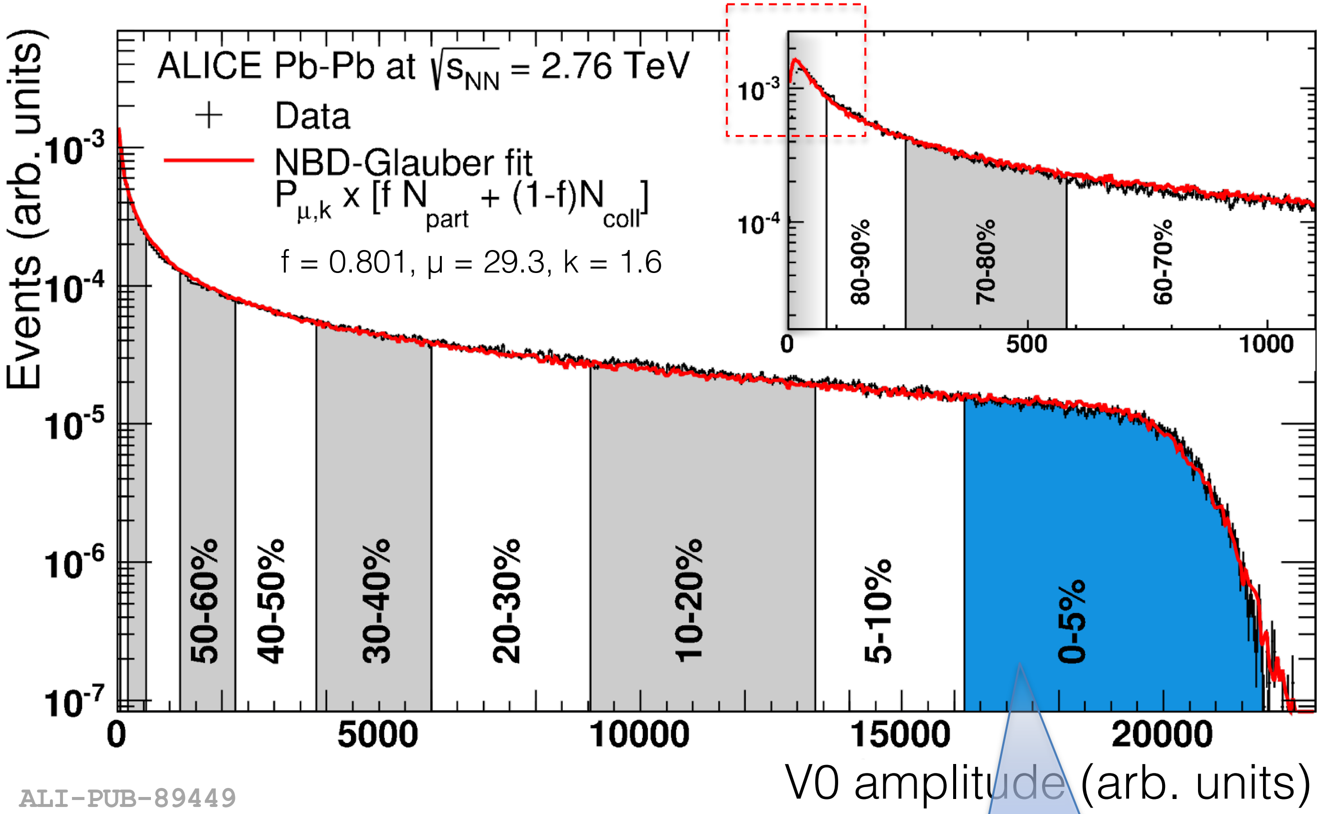
Centrality determination in Pb-Pb



Phys. Rev. C 88 (2013) 044909

- Description of V0 signal distribution:
  - Glauber $N_{ancestors}$: combination of N_{part}, N_{coll}
    - N_{part}: number of participant nucleons
    - N_{coll}: number of NN interactions
  - Convoluted with Neg. Bin. Distribution

Centrality determination in Pb-Pb



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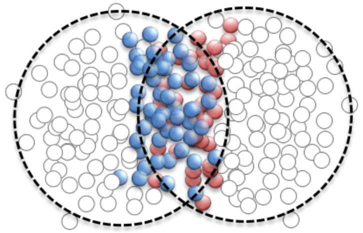
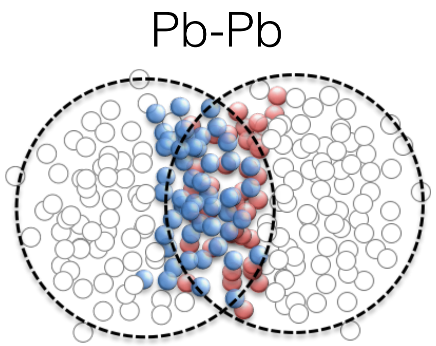
$\langle N_{part} \rangle$ = 381.6
$\langle N_{coll} \rangle$ = 1619

- Description of V0 signal distribution:
  - Glauber $N_{ancestors}$: combination of N_{part}, N_{coll}
    - N_{part}: number of participant nucleons
    - N_{coll}: number of NN interactions
  - Convoluted with Neg. Bin. Distribution
- Lowest multiplicity range discarded
- 90% of hadronic cross section analysed

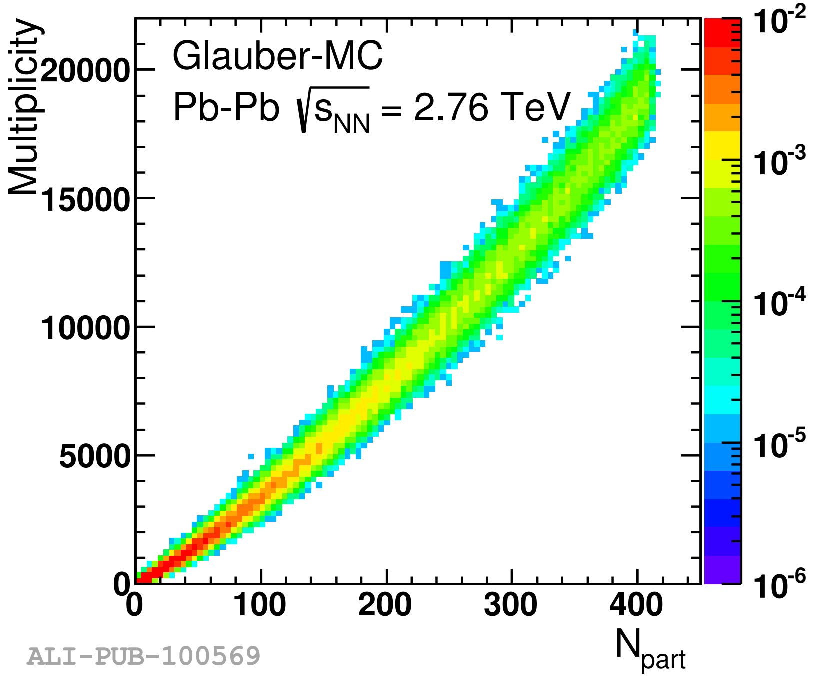


No strong ambiguity in parameters!
$\langle N_{part} \rangle$, $\langle N_{coll} \rangle$ used to interpret Pb-Pb results

Going towards p-Pb



Phys. Rev. C 91 (2015) 064905



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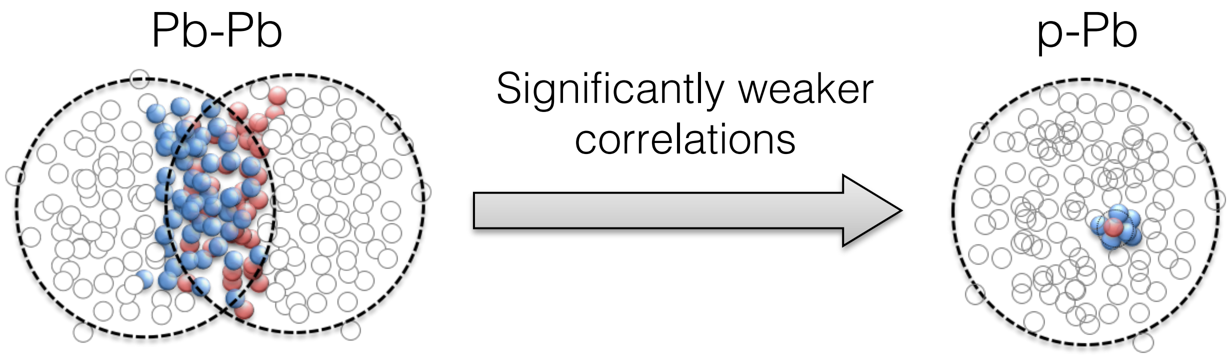

The challenge:

- Multiplicity and Glauber quantities are weakly correlated
- A.k.a.: multiplicity “fluctuates”
- How can we relate variables?

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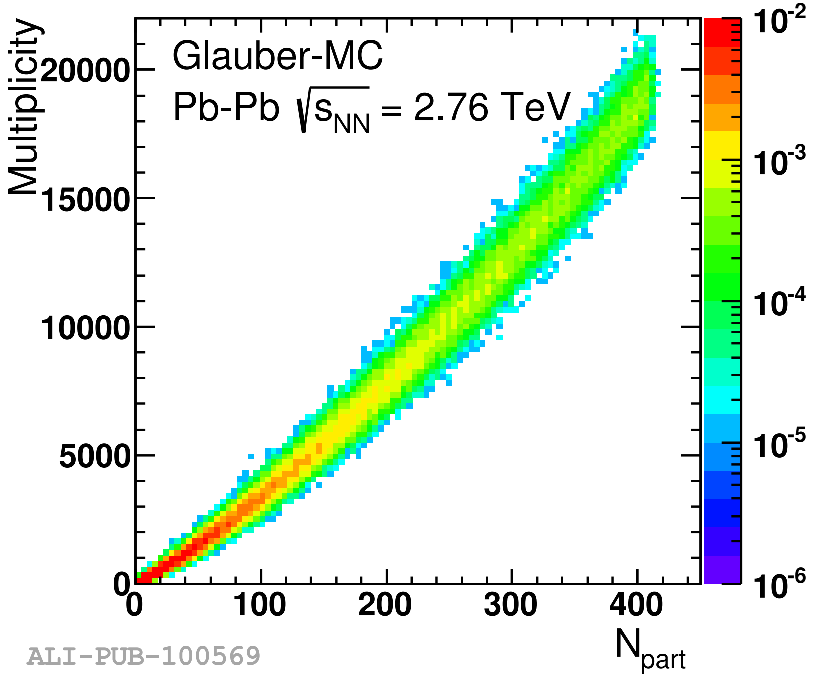
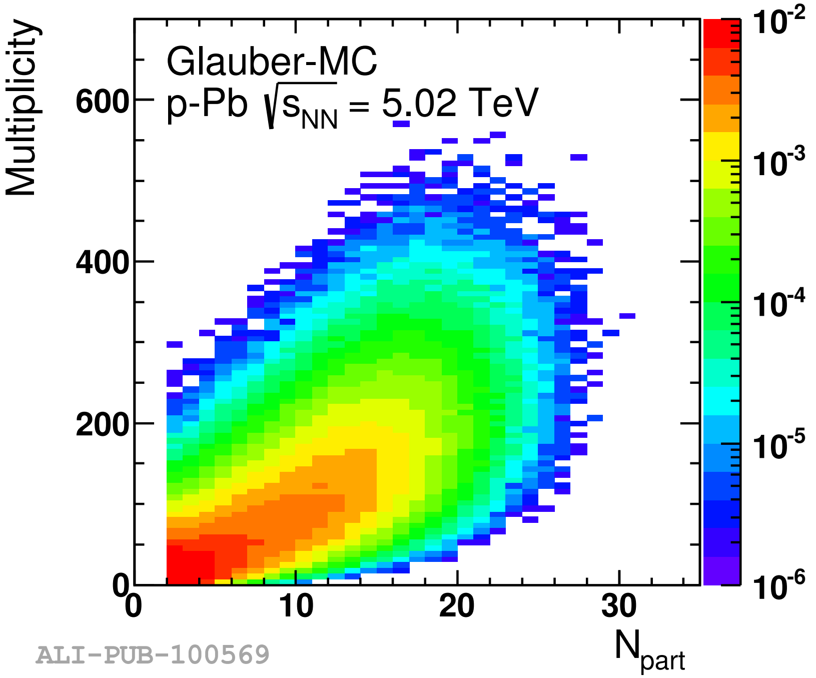
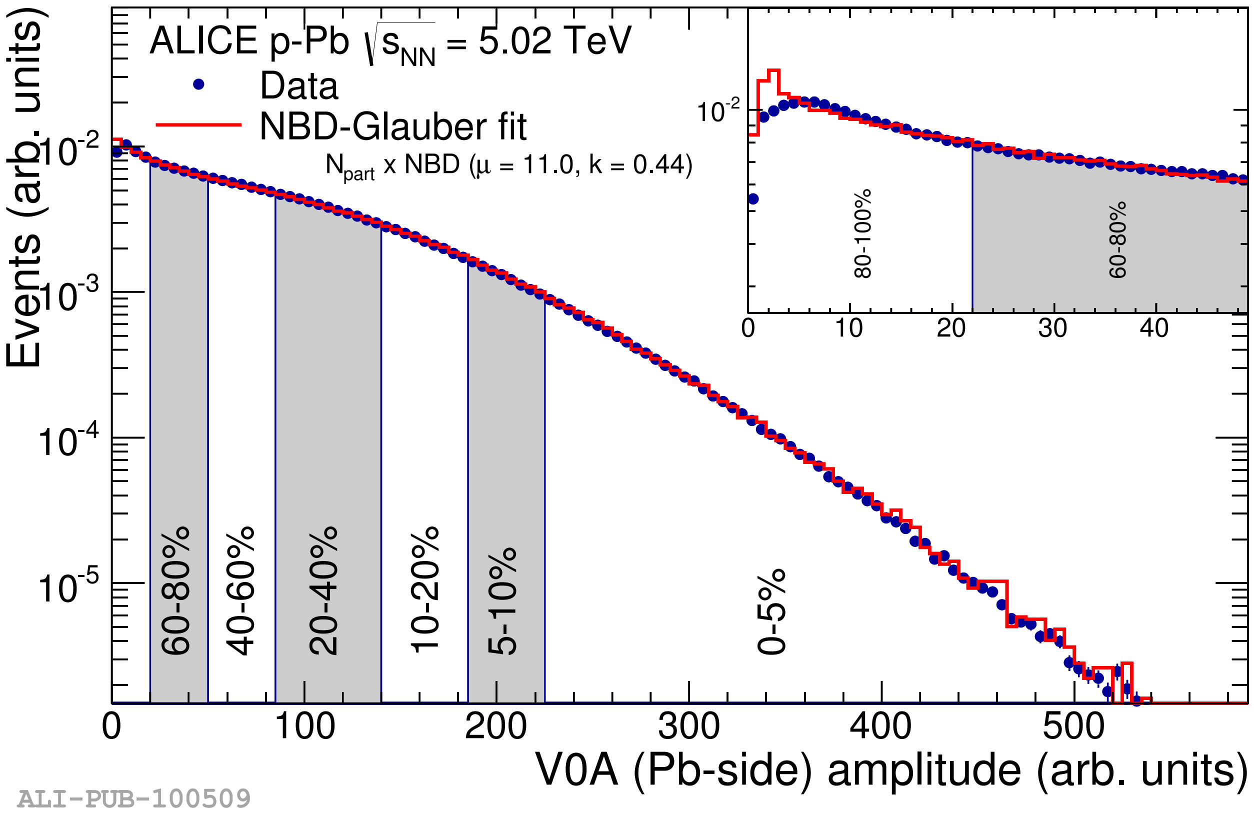




Could we try the same strategy?

Glauber model meets p-Pb: describing the signal



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- V0A: in the Pb-going side → expect scaling closer to N_{part} for multiplicity
- Description reasonable except for lowest multiplicity
- N_{part}, N_{coll} obtained slicing the model curve are very broadly distributed
  - $\langle N_{part}\rangle$, $\langle N_{coll}\rangle$ can still be determined
  - Can we check if these are reasonable?

Resort to Pb-Pb experience:
The nuclear modification factor

$$R_{AA} = \frac{\text{Yield in AA}}{\langle N_{coll}\rangle \times \text{Yield in pp}}$$

Is unity if (Pb-Pb) = $\langle N_{coll}\rangle$ × (pp)
"N_{coll} Scaling"

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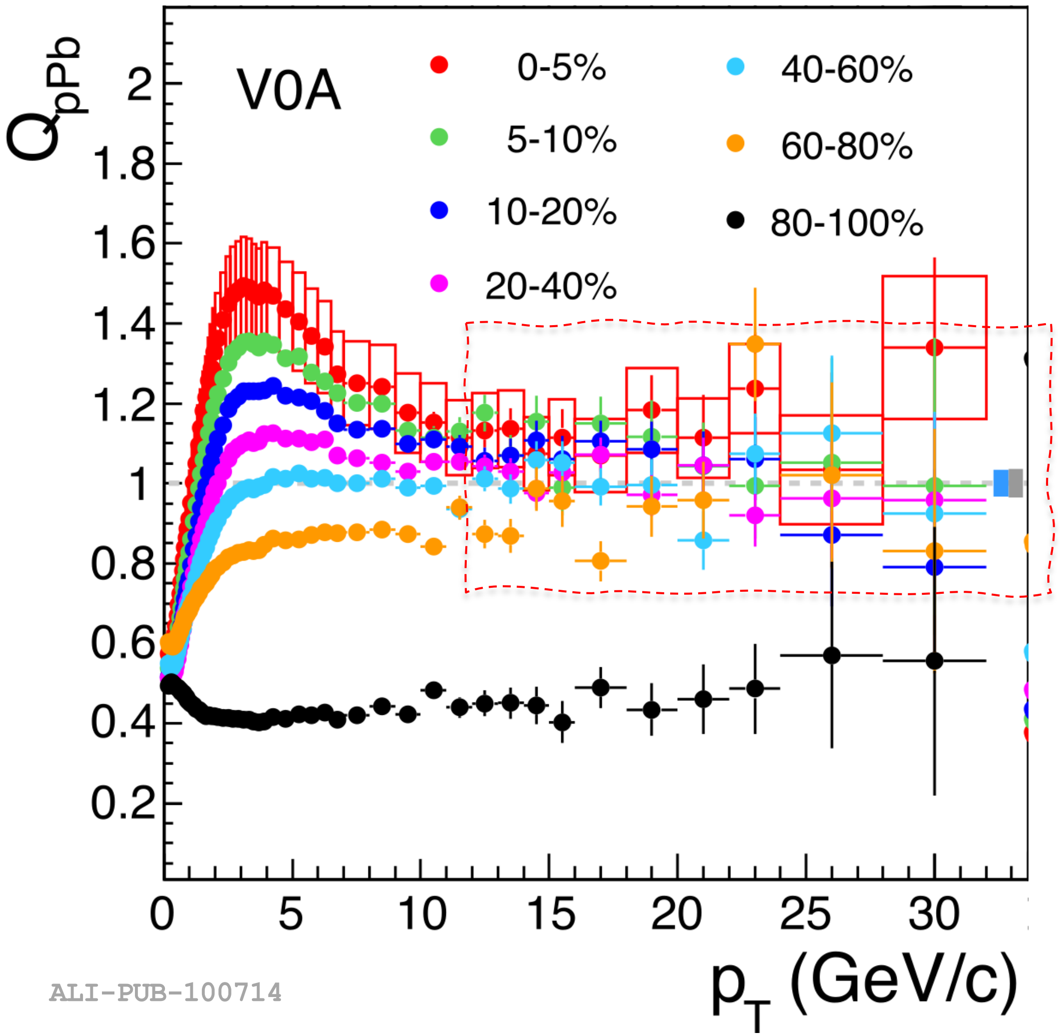
The nuclear modification factor in p-Pb



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- The Q_{pPb}: the nuclear modification factor in multiplicity classes in p-Pb

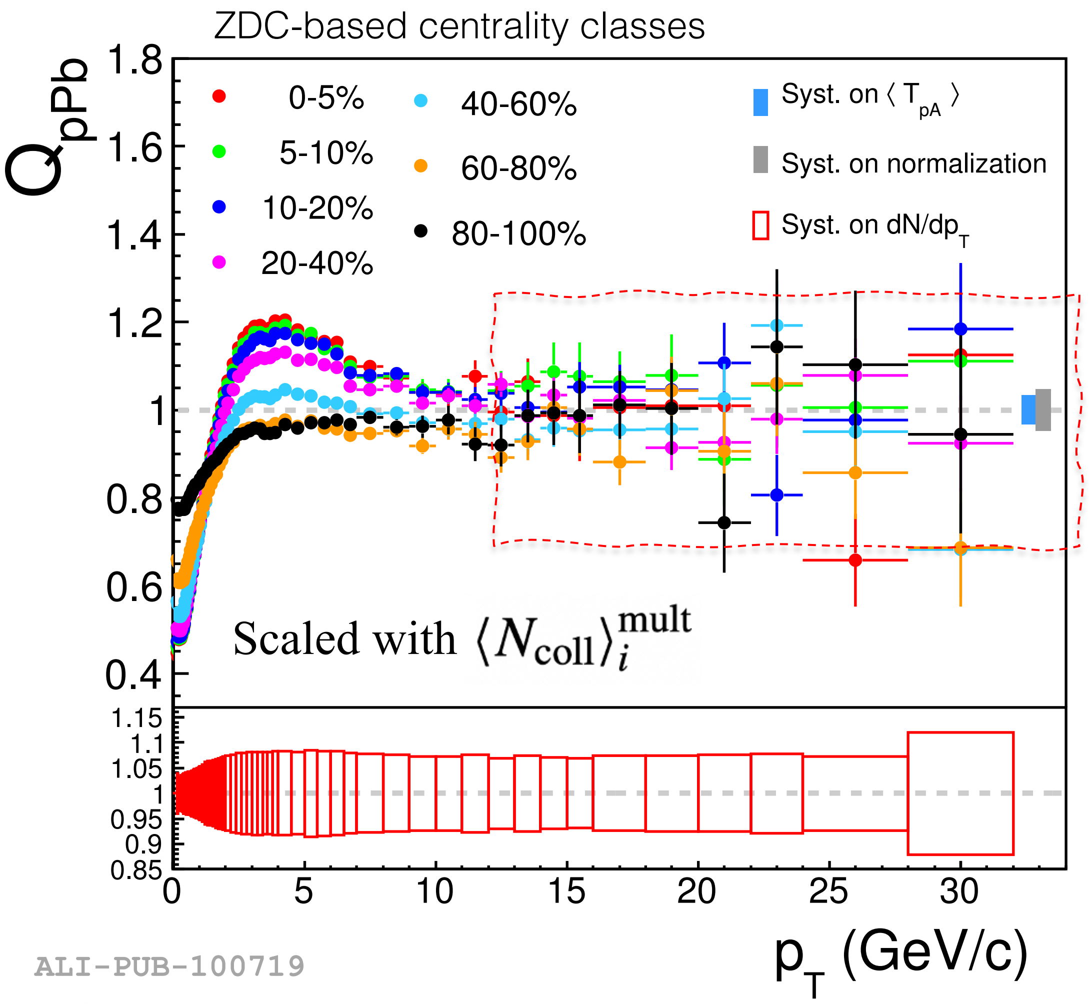
$$Q_{\mathrm{pPb}}\left(p_{\mathrm{T}}; cent\right) = \frac{\mathrm{d}N^{\mathrm{pPb}}_{\mathrm{cent}}/dp_{\mathrm{T}}}{\left\langle N^{\mathrm{Glauber}}_{\mathrm{coll}}\right\rangle \mathrm{d}N^{\mathrm{pp}}/dp_{\mathrm{T}}}$$

- N.B.: Not called R_{pPb} because multiplicity fluctuation biases may cause unexpected behaviour

- Should be unity in the absence of nuclear modification or biases
- High p_{T}: no modification?
  - Fails for low multiplicity
  - Works reasonably for higher multiplicity

…Can we do better?

The Q_{pPb} using the ZDC and a 'hybrid' approach



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- ZDC: Zero Degree Calorimeter
  - Very forward in rapidity
  - Geometry biased with minimal impact on hadronisation
- The hybrid approach:
  - Assume $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ at mid-rapidity (in CMS) scales with N_{part}
  - Motivated by wounded nucleon model
  - N_{coll} in a given centrality i selected with the ZDC:

$$\langle N_{\mathrm{part}}\rangle_i^{\mathrm{mult}} = \langle N_{\mathrm{part}}\rangle_{\mathrm{MB}} \left(\frac{\langle dN/d\eta\rangle_i}{\langle dN/d\eta\rangle_{\mathrm{MB}}} \right)_{-1<\eta<0}$$

$$\langle N_{\mathrm{coll}}\rangle_i^{\mathrm{mult}} = \langle N_{\mathrm{part}}\rangle_i^{\mathrm{mult}} - 1.$$

Least biased: N_{coll} scaling recovered at high momentum!

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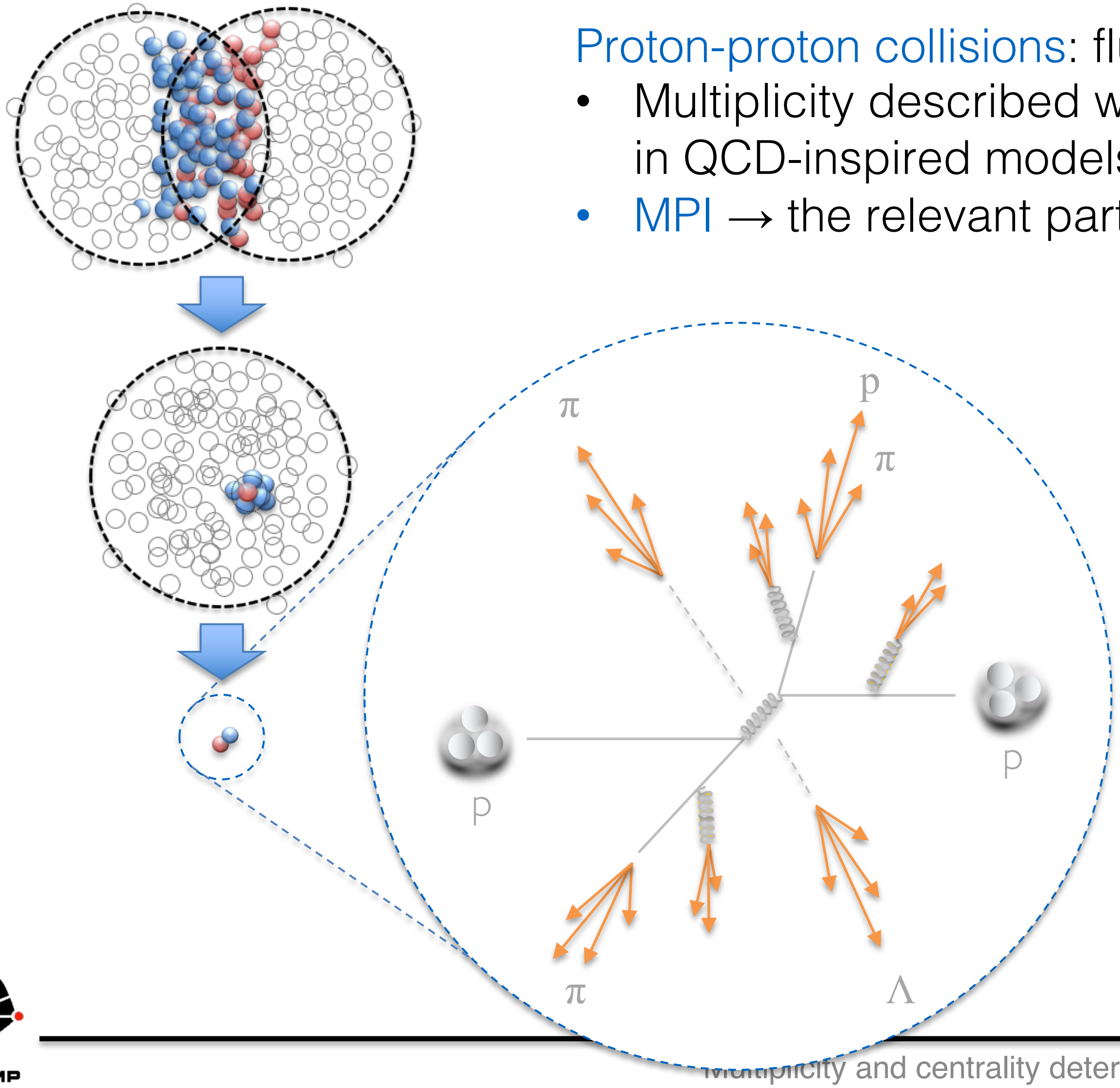
The pp limit: going towards low multiplicity



Proton-proton collisions: fluctuations even more significant

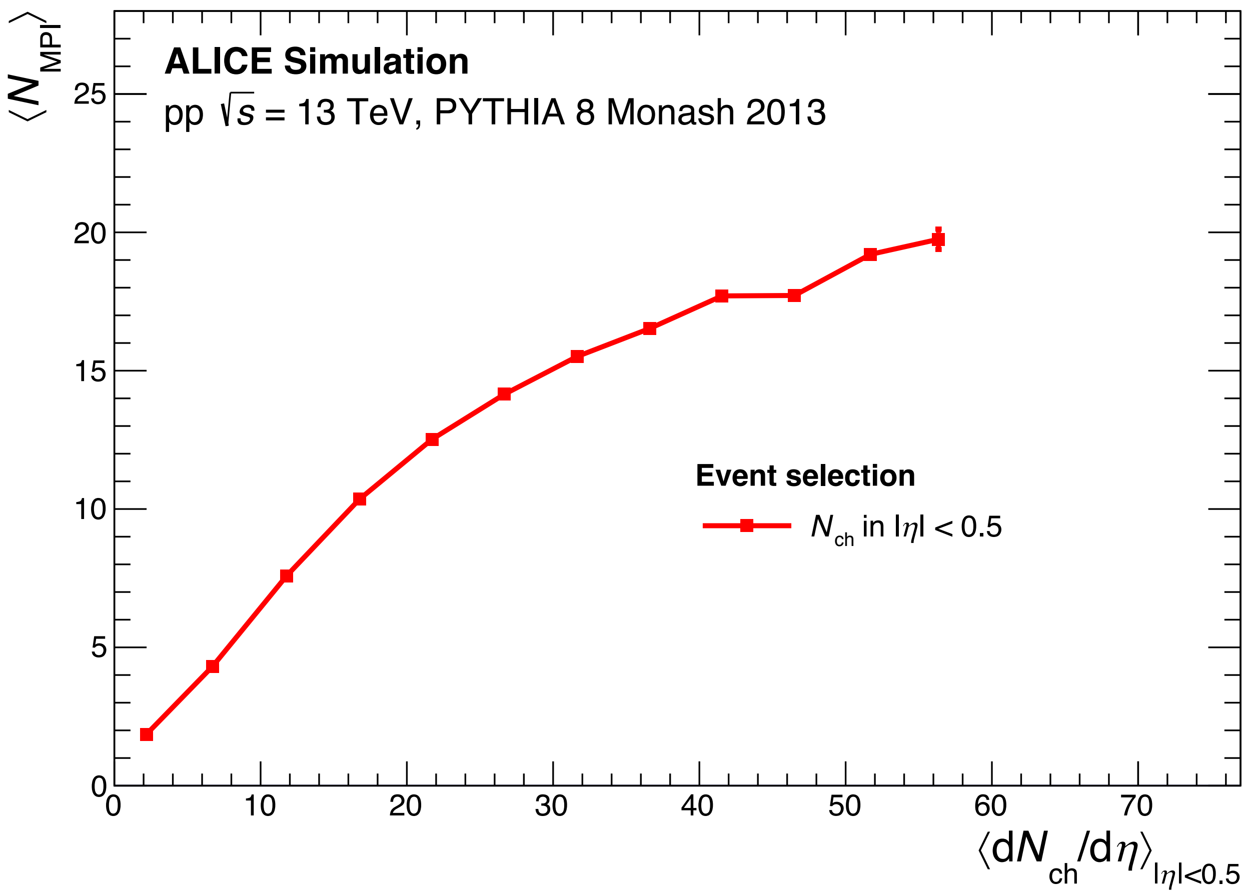
- Multiplicity described well via multi-parton interactions (MPI) in QCD-inspired models such as PYTHIA
- MPI → the relevant particle-emitting source

The ideal scenario would be to select on number of partonic interactions (“N_{MPI}”)

…which is of course impossible!

Let’s check our possibilities using **PYTHIA 8** as a diagnostic tool

Progressing in number of partonic interactions



- Selection at mid-rapidity ($|\eta| < 0.5$)
  - X axis biased: You get what you asked for
  - Privileges fluctuations: N_{ch}/N_{MPI} larger

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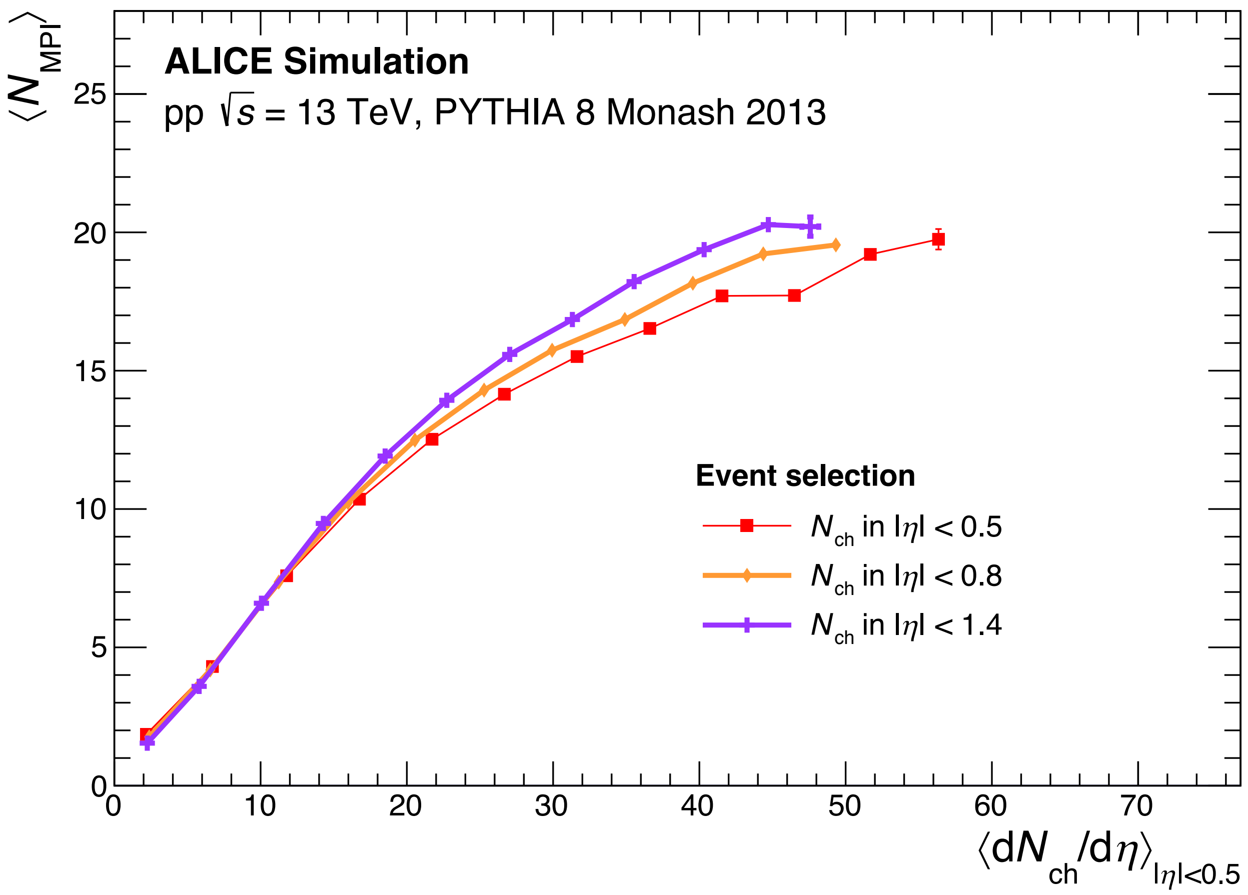

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  - X axis biased: You get what you asked for
  - Privileges fluctuations: N_{ch}/N_{MPI} larger
- Wider selection at mid-rapidity ($|\eta| < 0.8$)
  - Smaller bias, smaller N_{ch}/N_{MPI}
- ALICE acceptance at mid-rapidity ($|\eta| < 1.4$)
  - Further reduced N_{ch}/N_{MPI}
  - …but still far from linear

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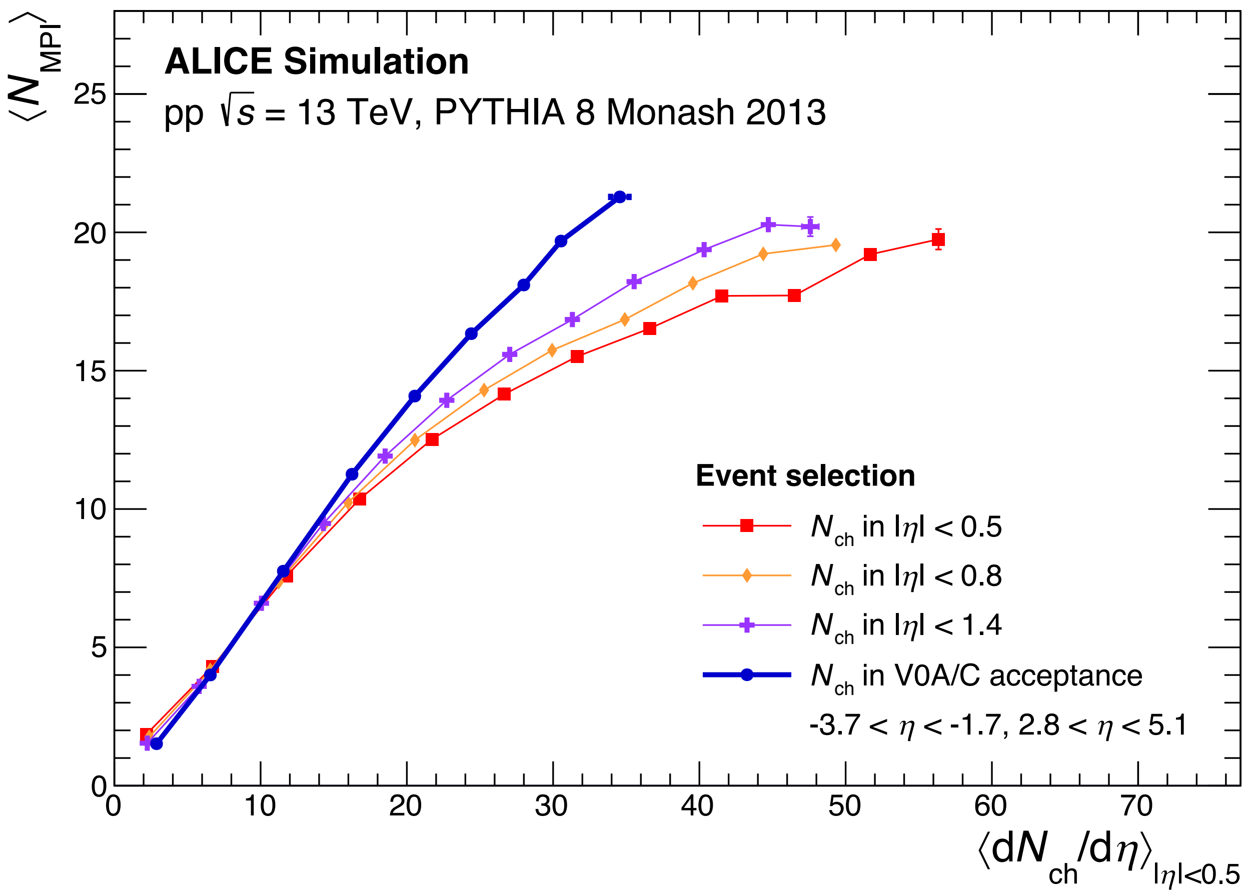

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  - Significant reduction of N_{ch}/N_{MPI}

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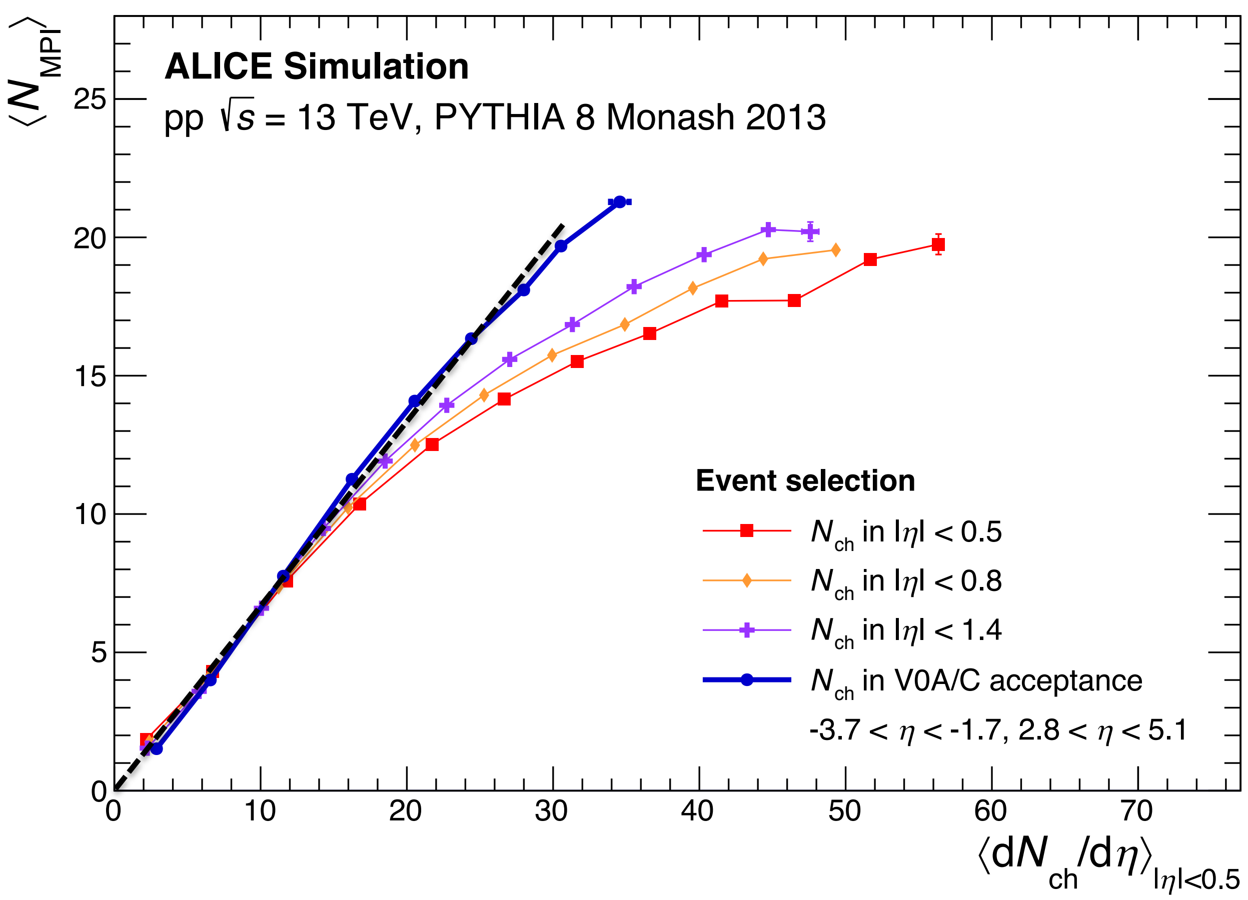

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Most importantly:
~linear behaviour between N_{MPI} and N_{ch}!
→ similar notion as before: mid-rapidity multiplicity scales with number of emitting sources

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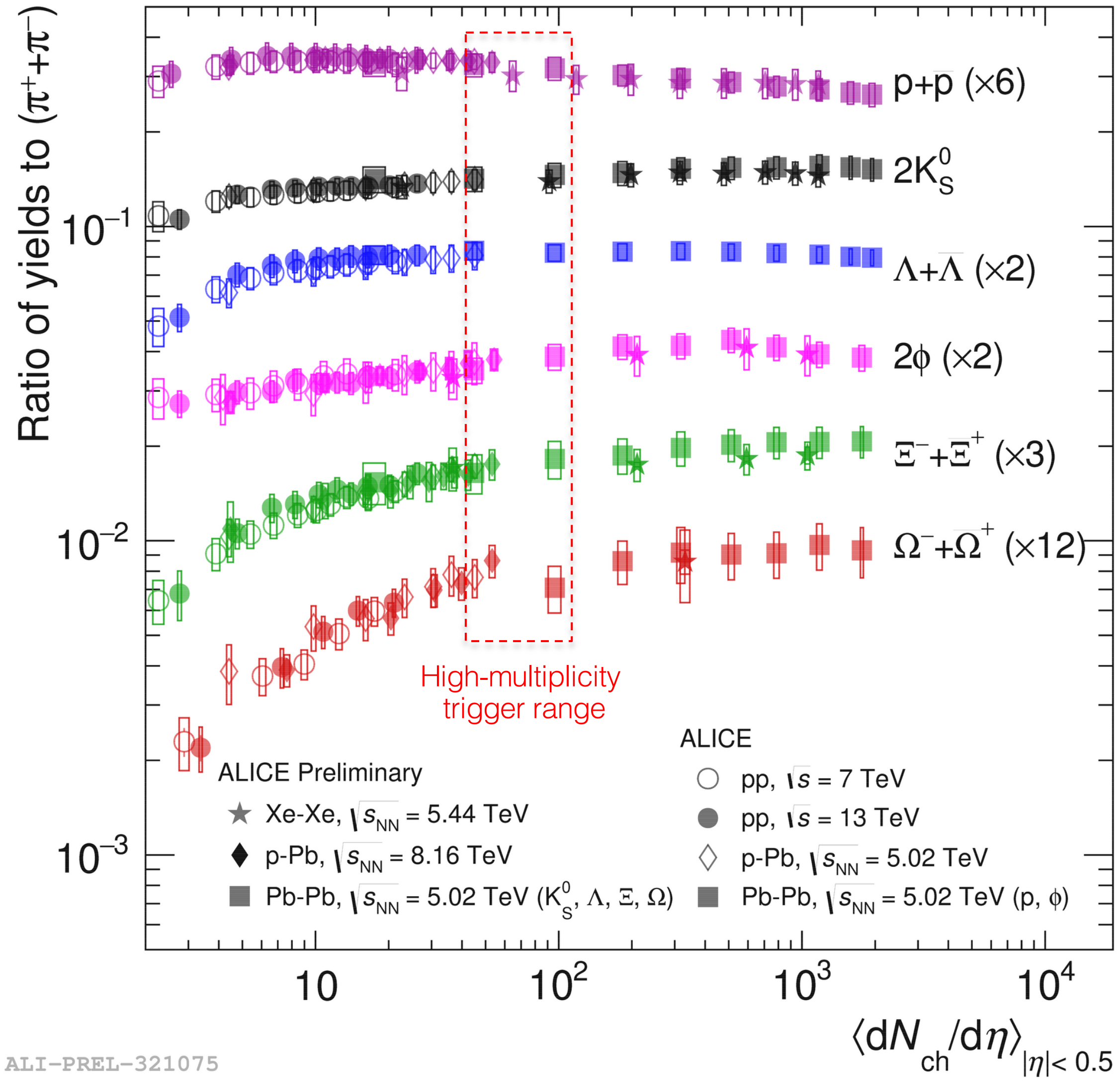
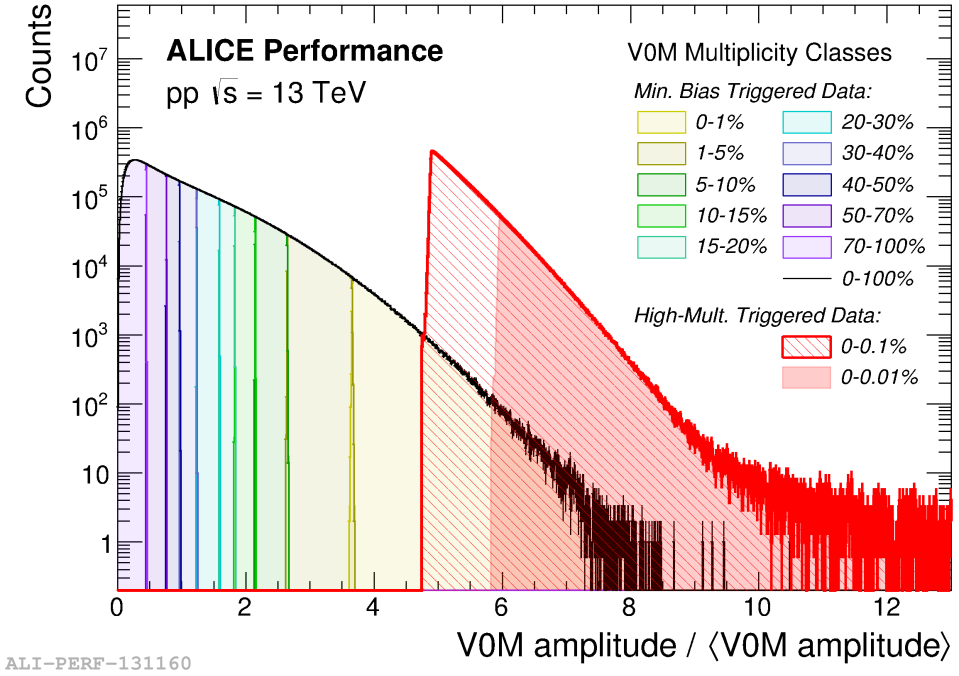
The outcome: a complete picture



- It is because of these considerations that we understand how to best compare systems!
- Going to even higher multiplicity will enable us to fully connect to Pb-Pb: triggered data



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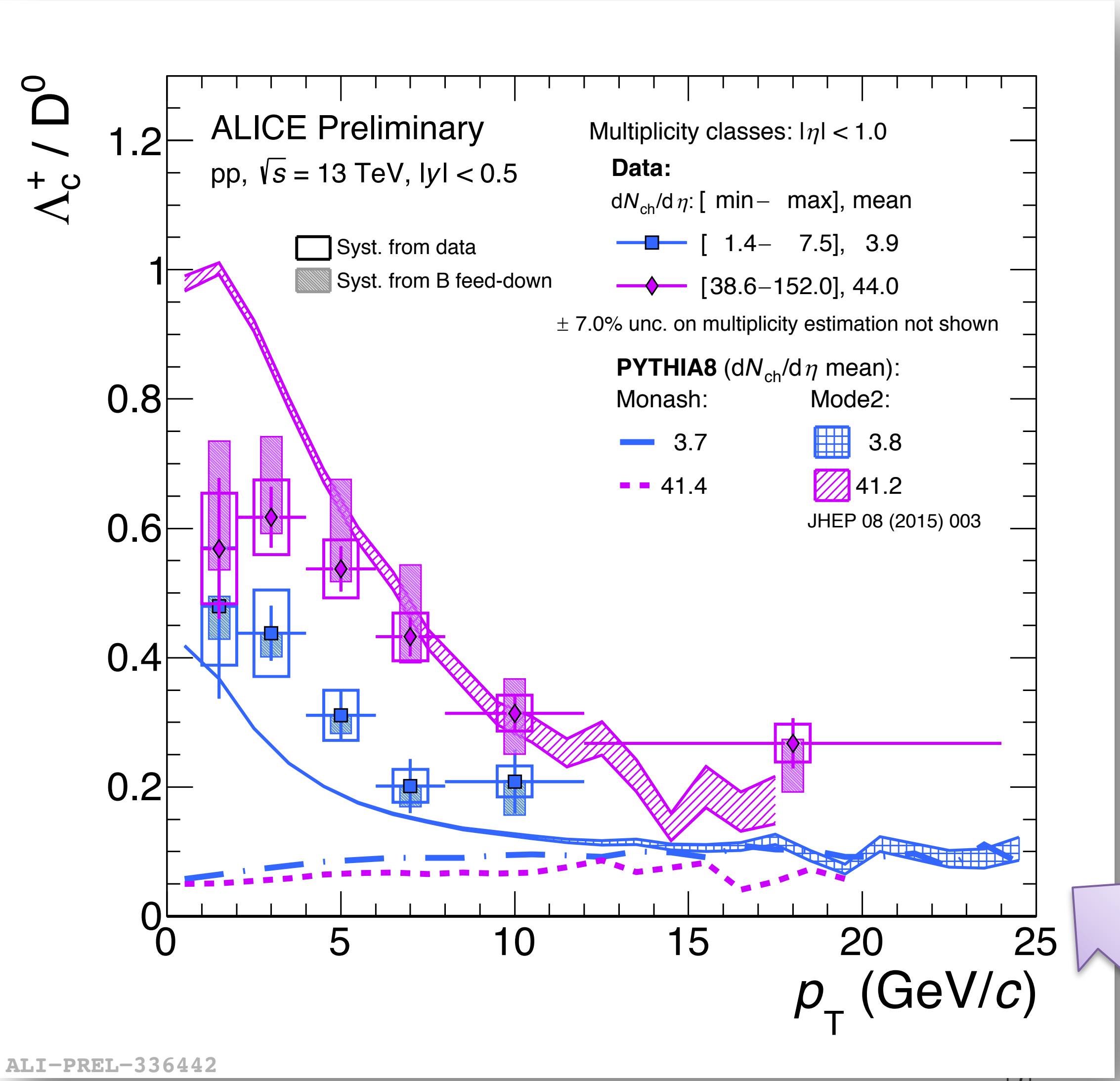

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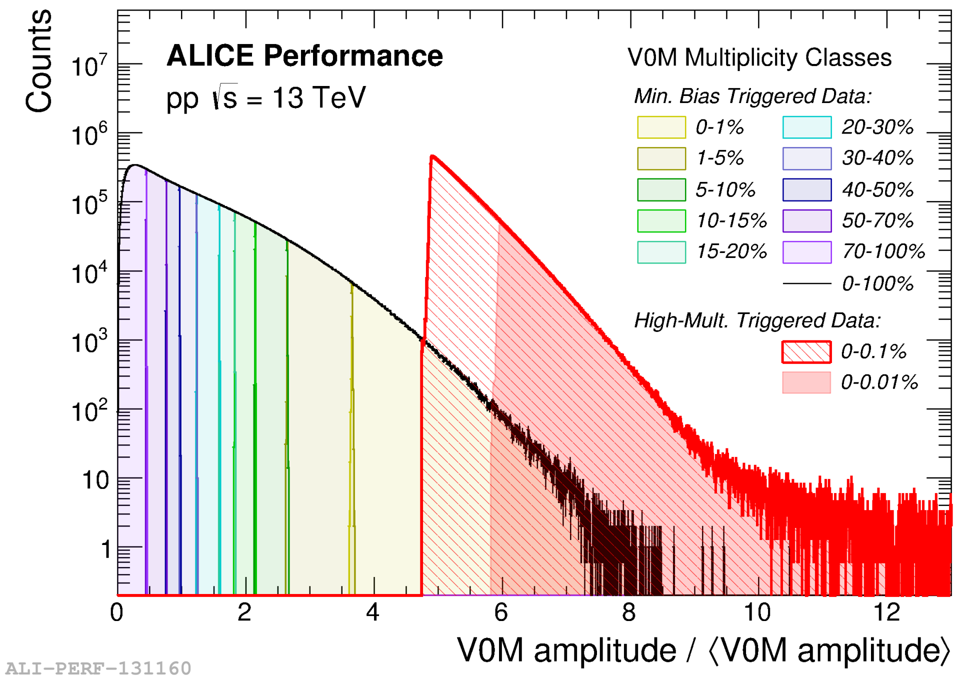

C. Terrevoli, [29/05/2020, 14:33]
A. Harlenderova, [25/05/2020, 15:36]

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Conclusion

- Studying selection biases very relevant for interpretation!
    - Note: biases aren't 'evil'!
    - The first approach: minimise $N_{\mathrm{ch}}/N_{\mathrm{source}}$ biases
    - Applied to choices in pp, p-Pb selections
    - Basic principle: phase space (η) gap ('jet veto')

- **Why is this relevant?**
    - By analogy: learning about the operation of dice will be more intuitive if we minimize biasing individual die rolls
    - In our work, dice → hadronization and other phenomena
    - Note: the more directly biased condition can also be useful!

- **Is this all?**
    - This is just the beginning: conditional measurements are on the rise!
    - Variants: phase space (φ) gap (R_{T} / transverse activity), many more!

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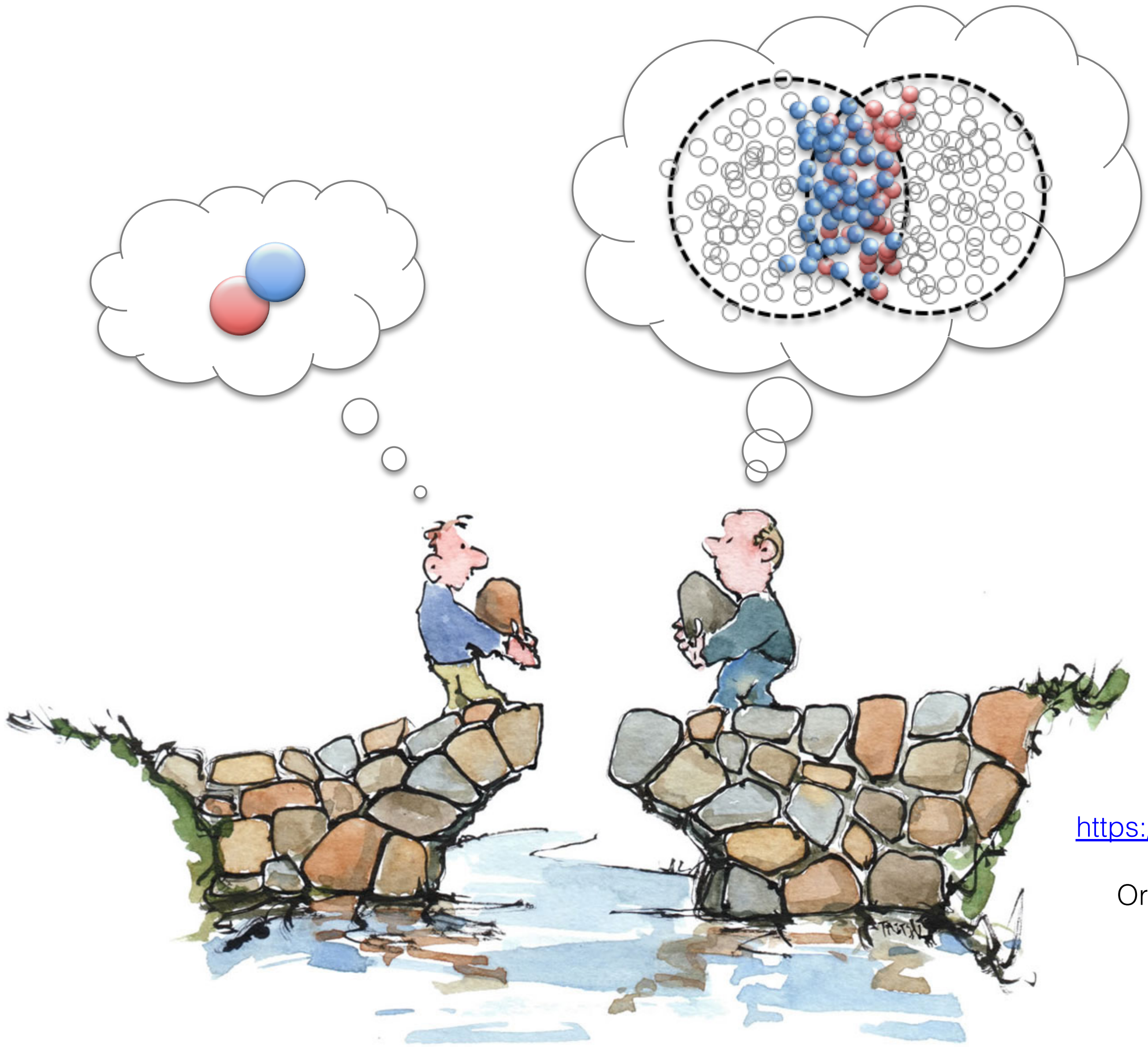

By Frits Ahlefeldt

My vidyo Room
For further discussions:
https://vidyoportal.cern.ch/join/alm47vMvP1fJ

Or: david.dobrigkeit.chinellato@cern.ch

Thank you!