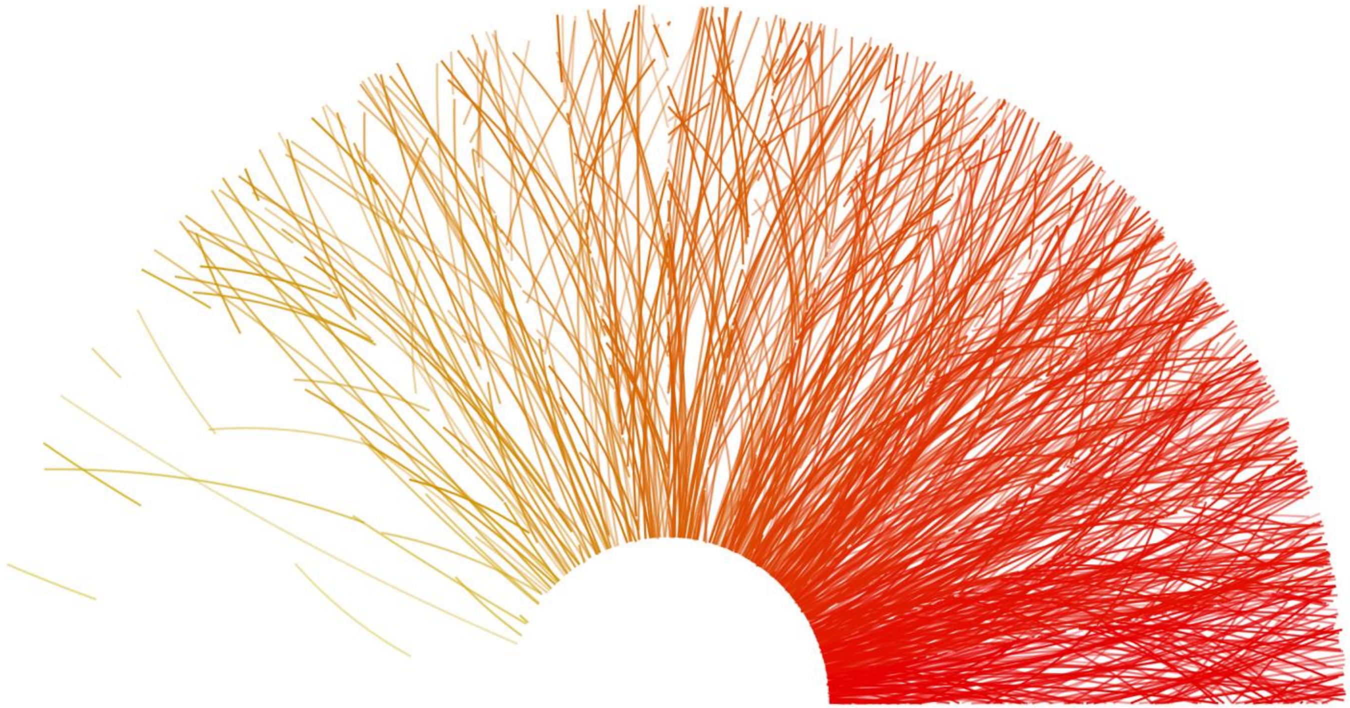
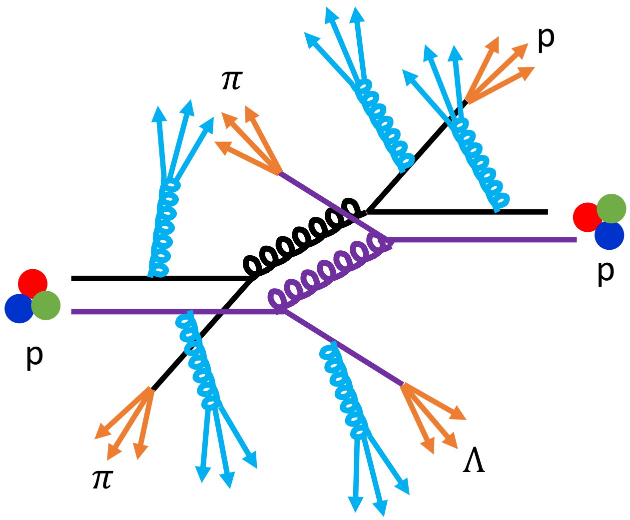
System-size dependence studies at ALICE



Heavy Ion Meeting, 24 May 2019

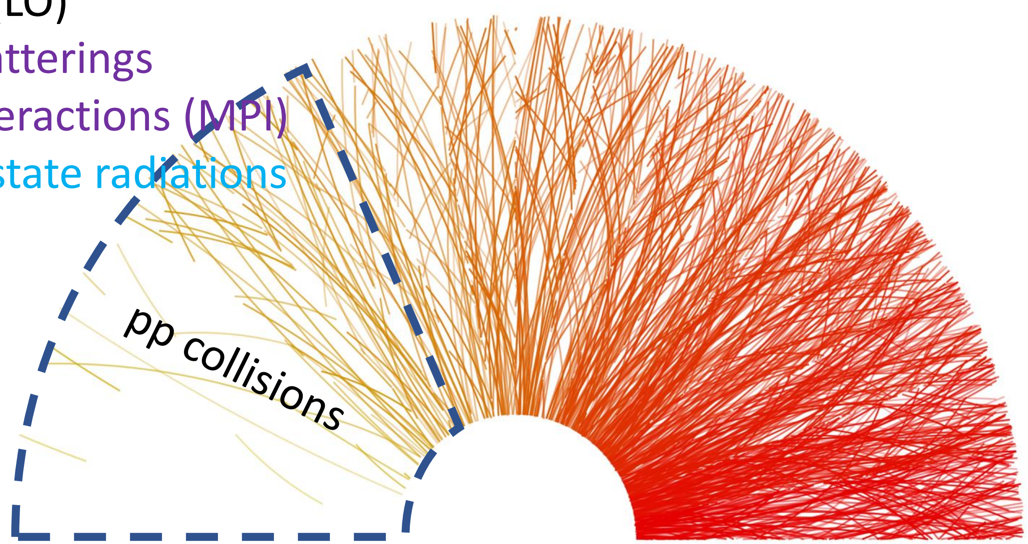
Beomkyu Kim
INHA Univ. & KoALICE

Multiplicity in different collision systems

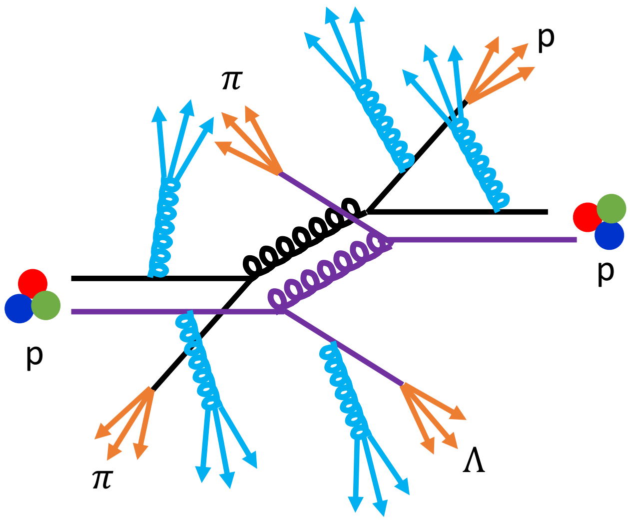


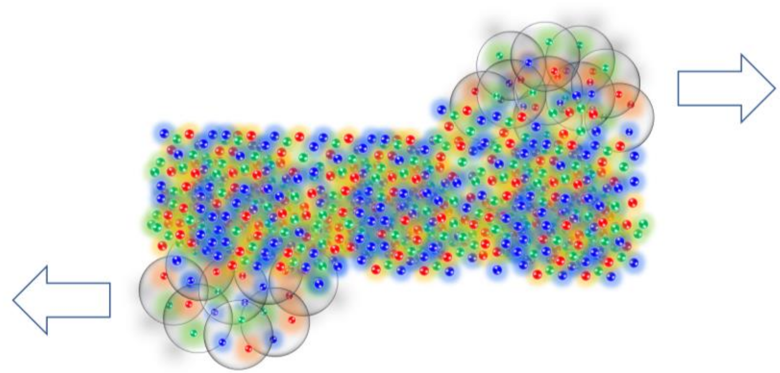
Particle production in pp collisions

- 2→2 scattering (LO)
- infrared 2->2 scatterings
  Multi Parton interactions (MPI)
- Initial and Final state radiations



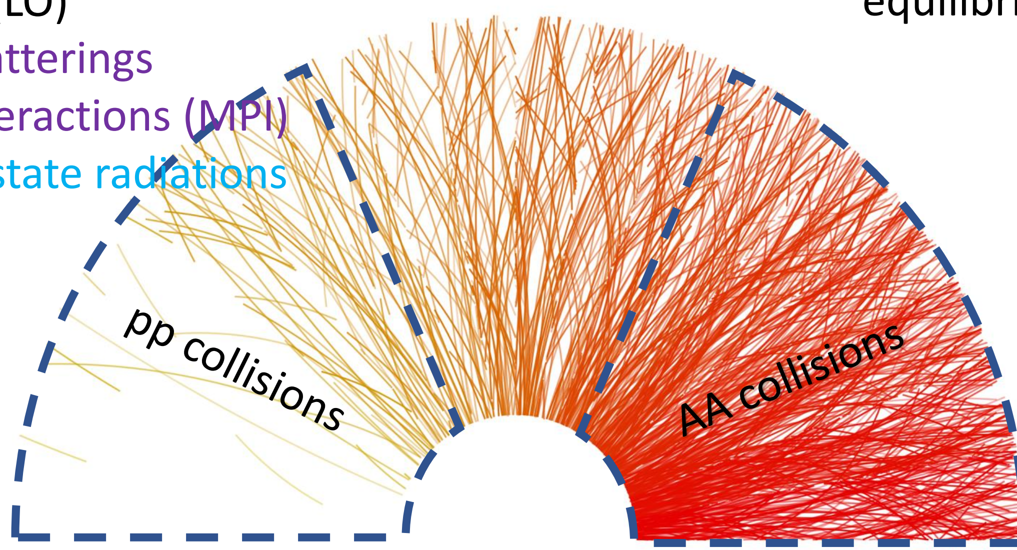
Multiplicity in different system sizes



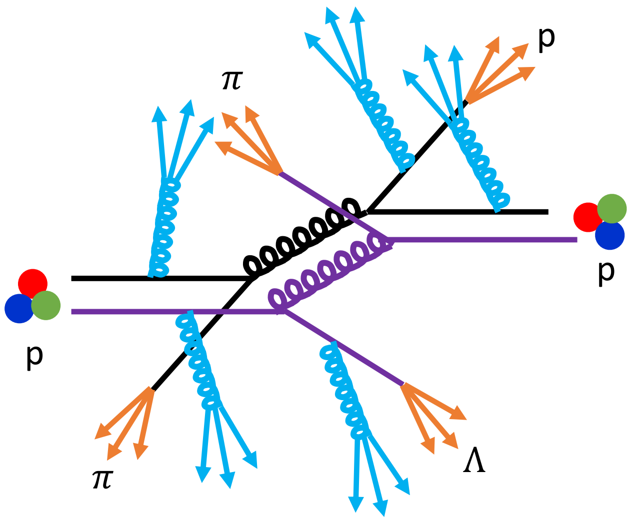


Particle production in pp collisions
- 2→2 scattering (LO)
- infrared 2->2 scatterings
  Multi Parton interactions (MPI)
- Initial and Final state radiations

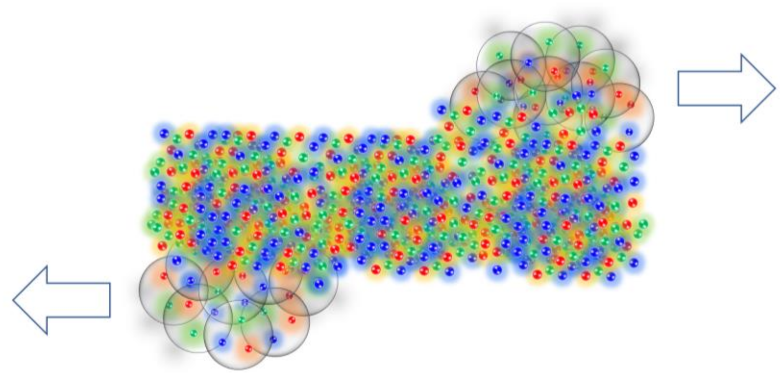
- Chemically and kinematically equilibrium state



Multiplicity in different system sizes

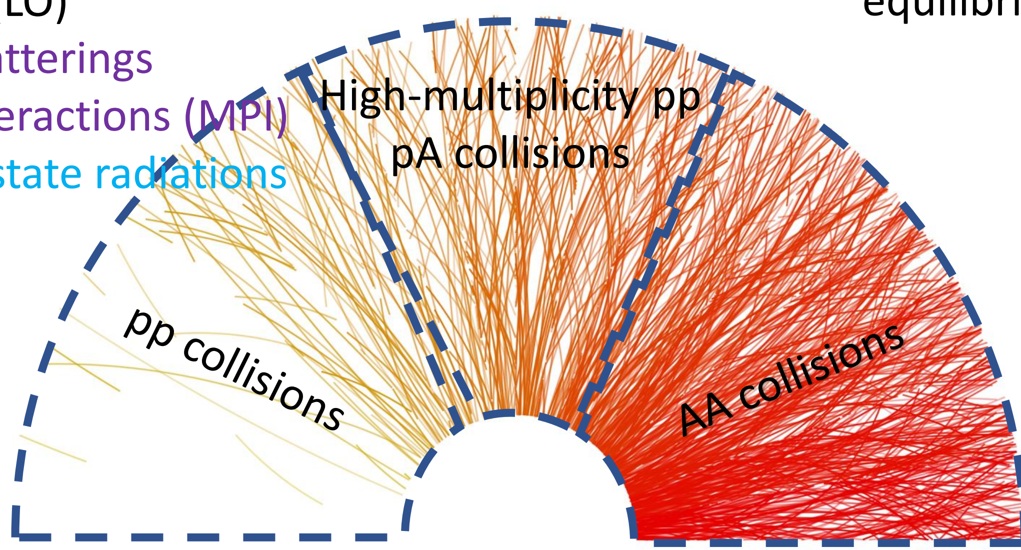


Some threshold? In-transition? in between the two collision systems?

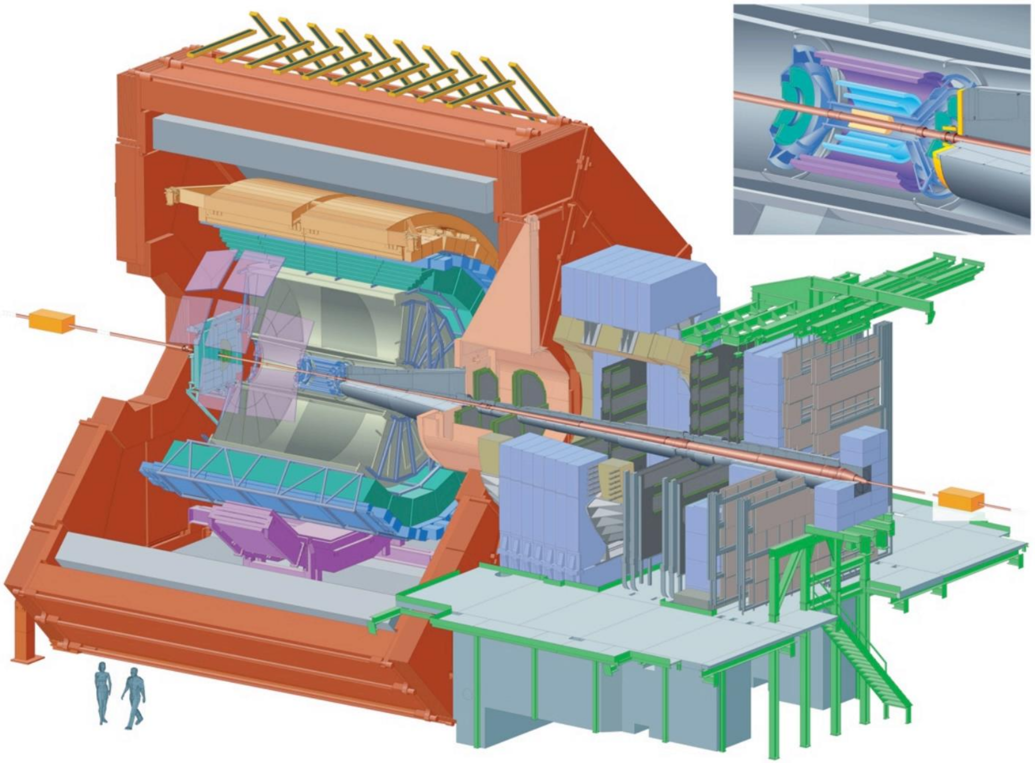


Particle production in pp collisions
- 2→2 scattering (LO)
- infrared 2->2 scatterings
  Multi Parton interactions (MPI)
- Initial and Final state radiations

- Chemically and kinematically equilibrium state

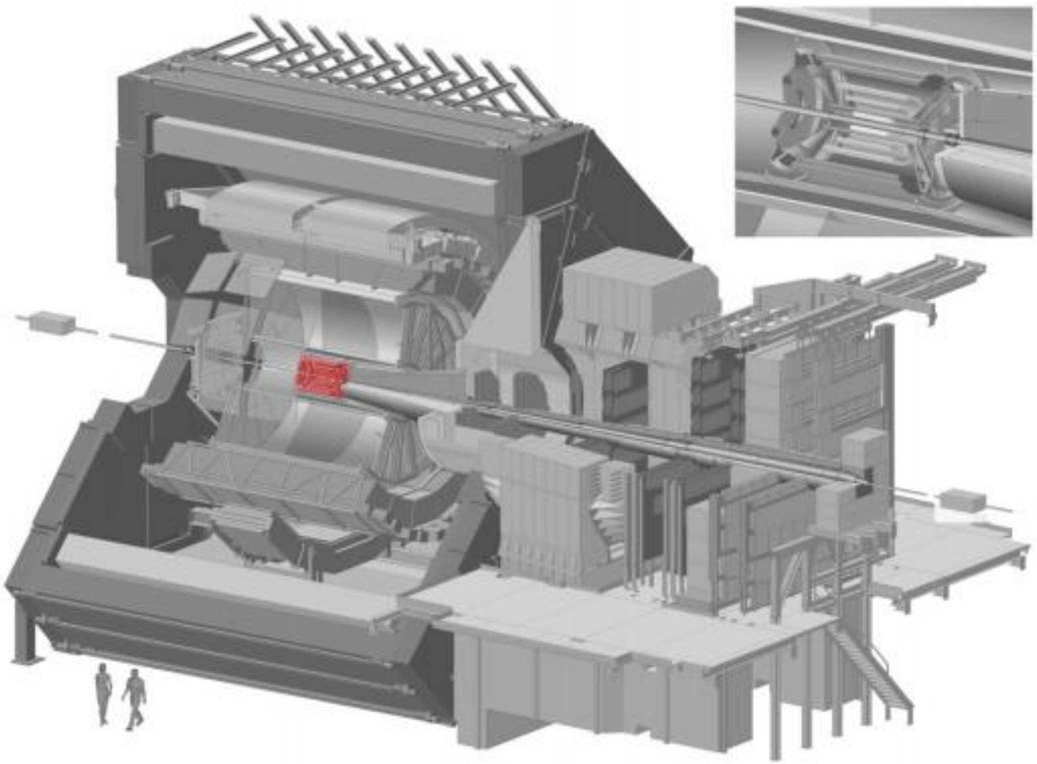


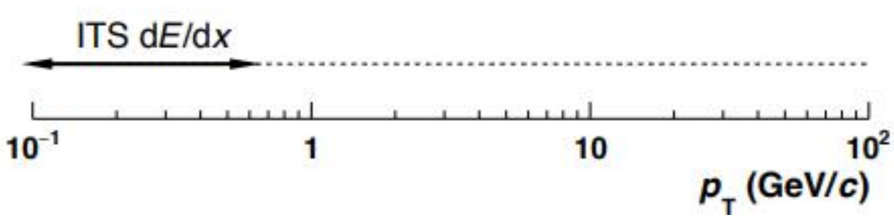
ALICE



Low-momentum tracking and **particle identification** in a **high multiplicity** environment

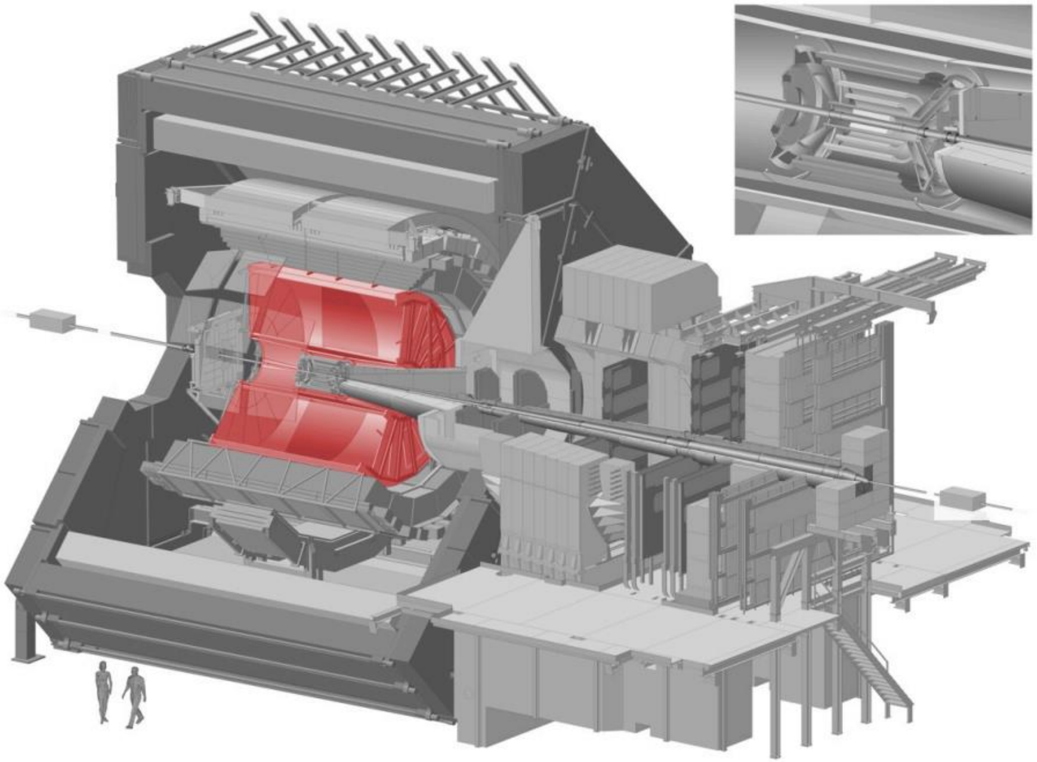
ALICE





ITS $(|\eta| < 0.9)$
- 6 layers of Si detector
- Trigger, tracking, vertex, PID

ALICE

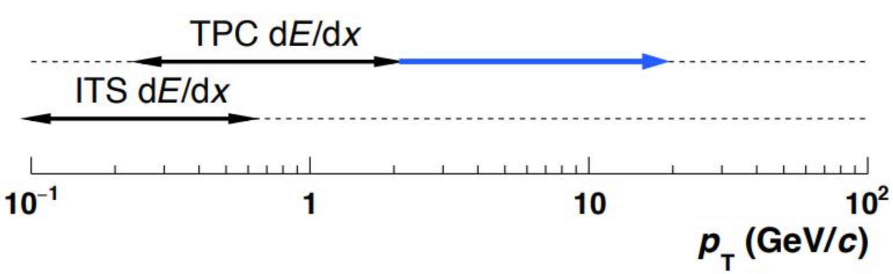


ITS ($|\eta| < 0.9$)

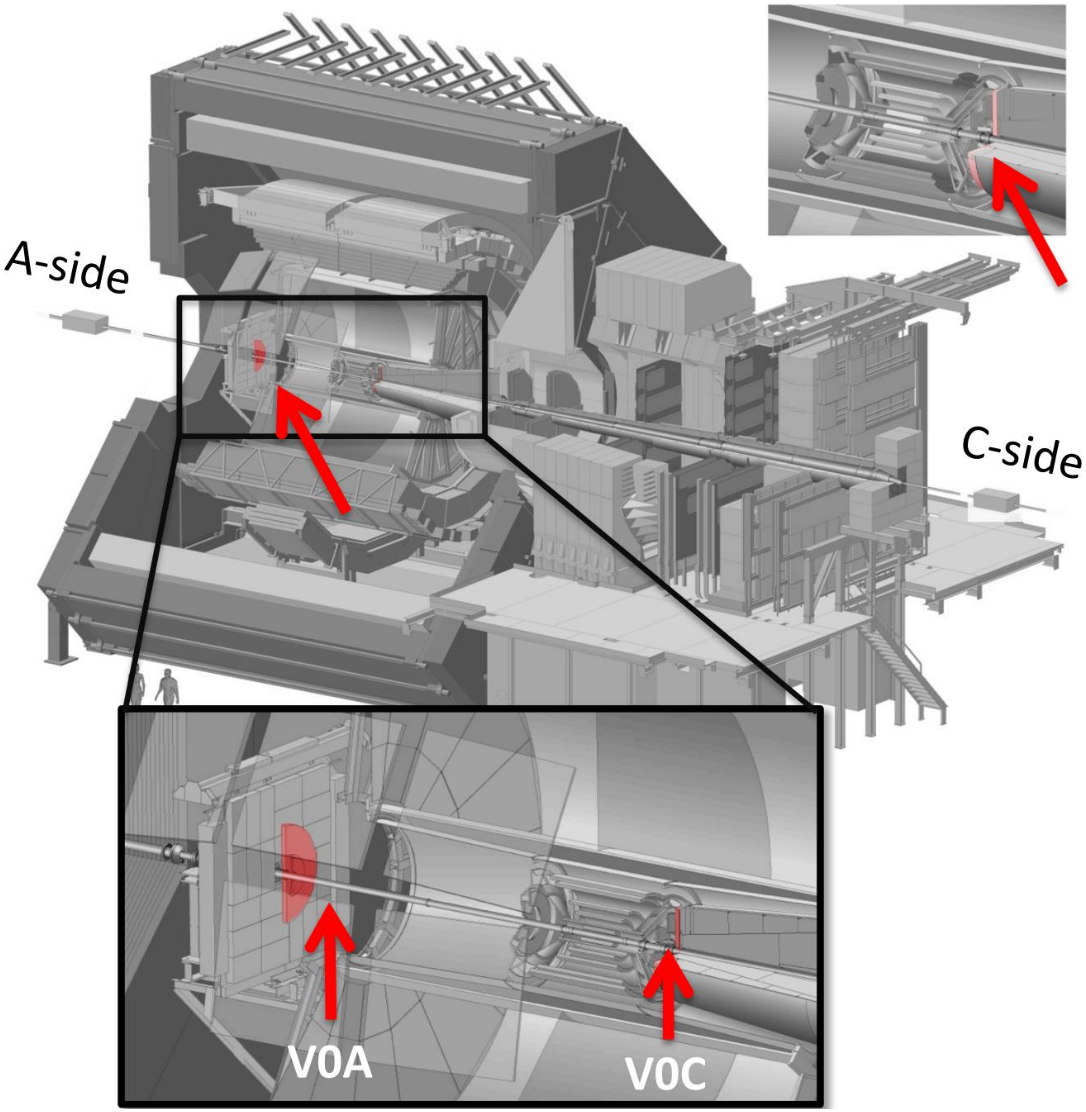
- 6 layers of Si detector
- Trigger, tracking, vertex, PID

TPC ($|\eta| < 0.9$)

- Gas detector
- Tracking, vertex, PID



ALICE



ITS $(|\eta| < 0.9)$

- 6 layers of Si detector
- Trigger, tracking, vertex, PID

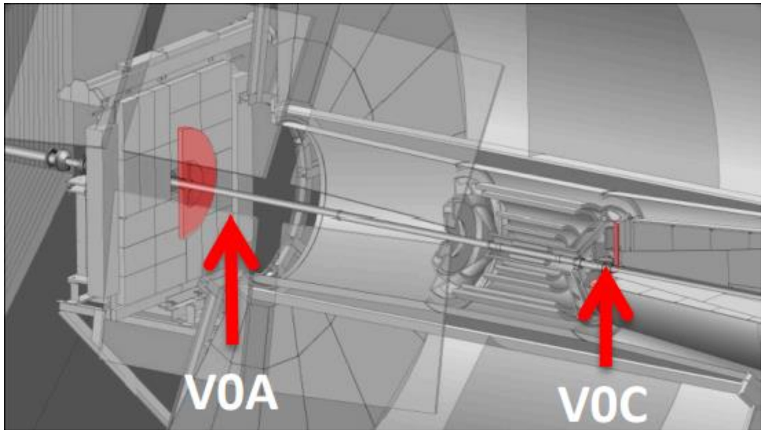
TPC $(|\eta| < 0.9)$

- Gas detector
- Tracking, vertex, PID

V0 $(2.8 < \eta < 5.1, -3.7 < \eta < -1.7)$

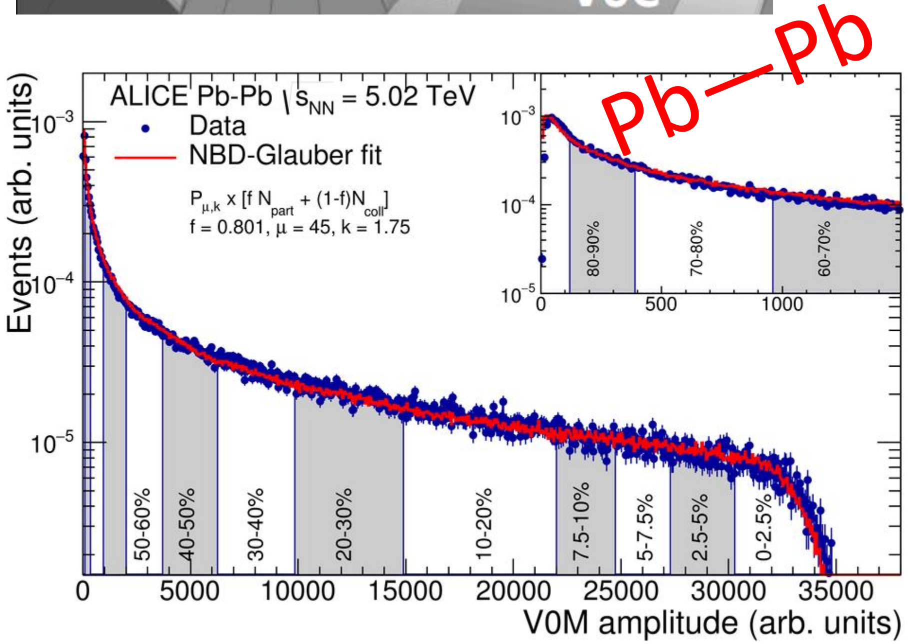
- Forward arrays of Scintillator
- Trigger, beam gas rejection
- Multiplicity estimator

Multiplicity (and centrality) estimation

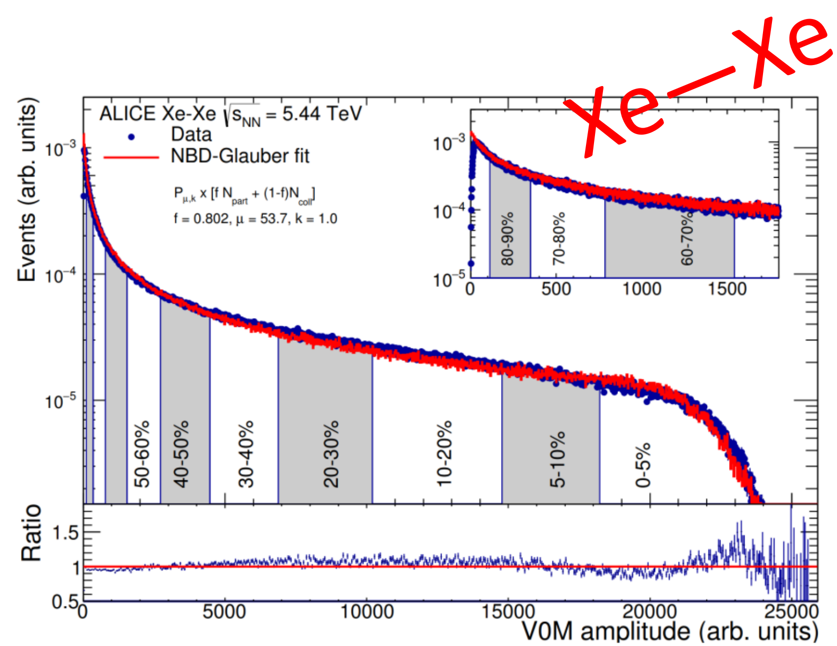


V0 detector

- **Centrality estimation in AA collisions**
  - **V0M is the energy deposited in V0A & V0C**
  - V0M multiplicity fitted with MC-Glauber

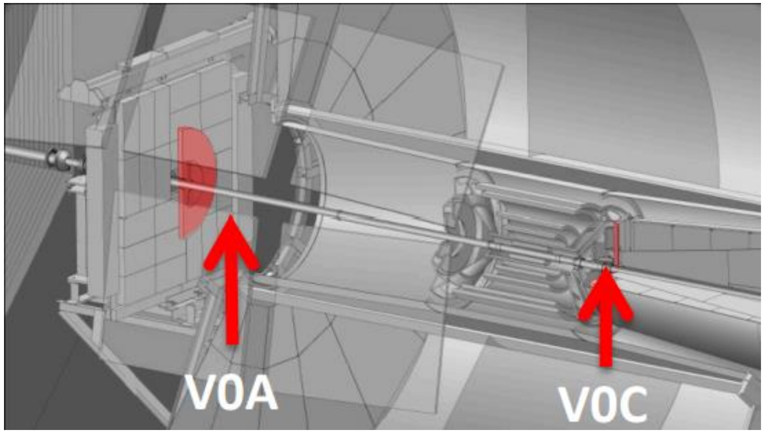


ALICE-PUBLIC-2018-003



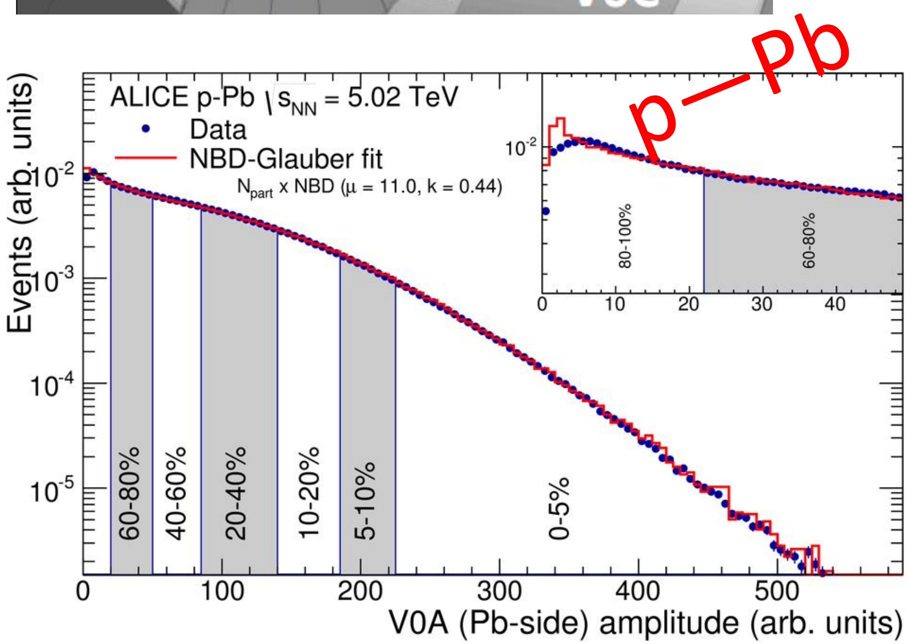
ALICE-PUBLIC-2018-003

Multiplicity (and centrality) estimation



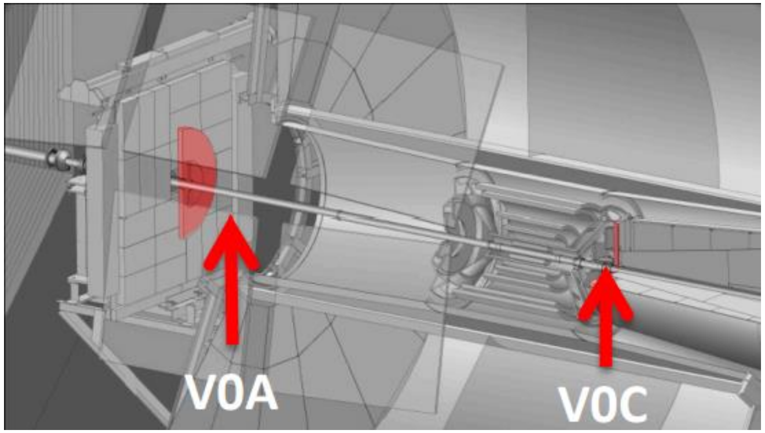
V0 detector

- Centrality estimation in AA collisions
  - V0M amplitude fitted with MC-Glauber
- Centrality estimation in p—Pb collisions
  - Pb-outgoing side V0 (V0A) amplitude fitted with MC Glauber



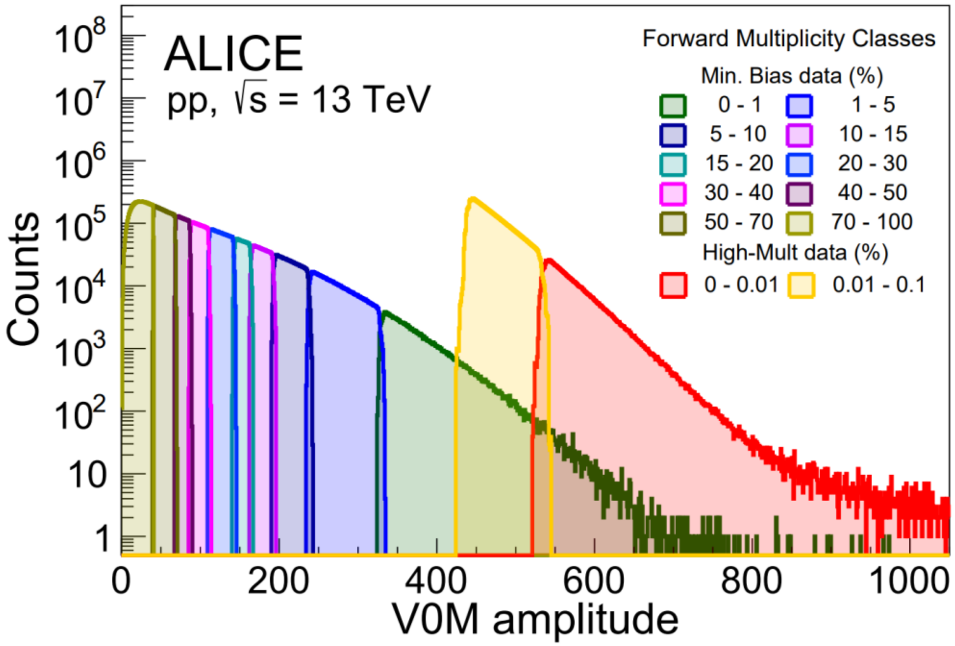
[Phys. Rev. C 91 (2015) 064905]

Multiplicity (and centrality) estimation

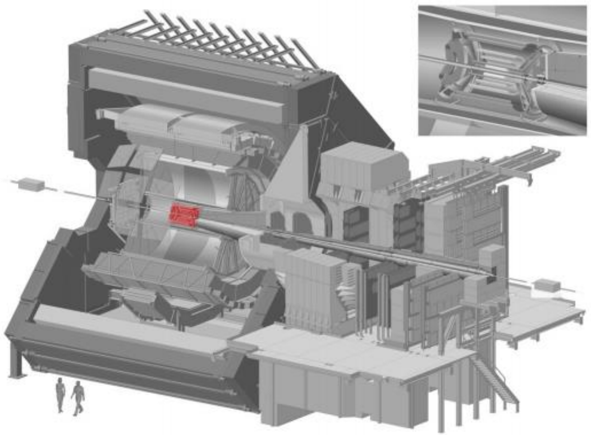


V0 detector

- Centrality estimation in AA collisions
  - V0M amplitude fitted with MC-Glauber
- Centrality estimation in p—Pb collisions
  - Pb-outgoing side V0 (V0A) amplitude fitted with MC Glauber
- Multiplicity percentile estimation in pp collisions
  - Raw V0M amplitude is used

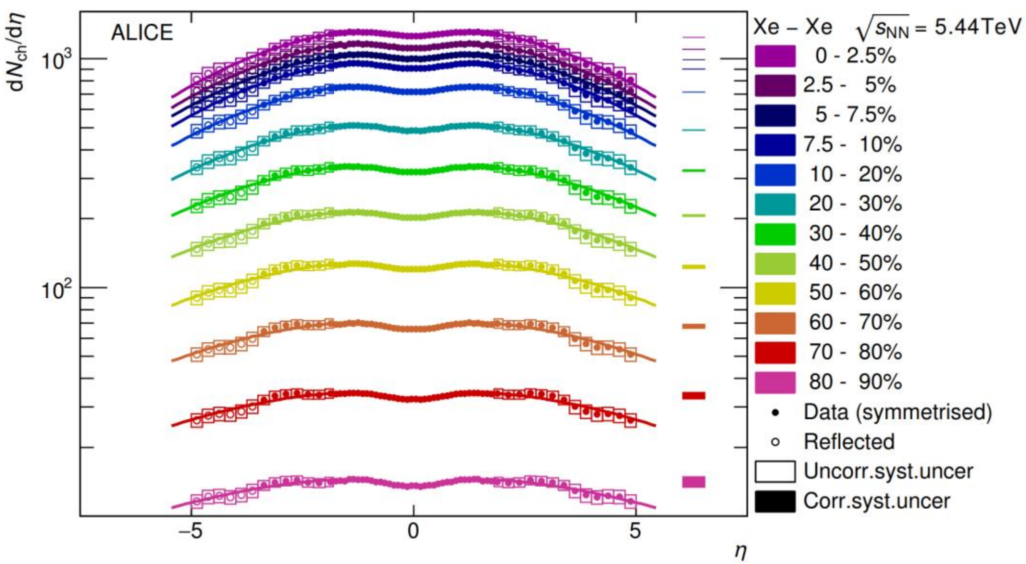


Multiplicity density measurement



Multiplicity density in all systems

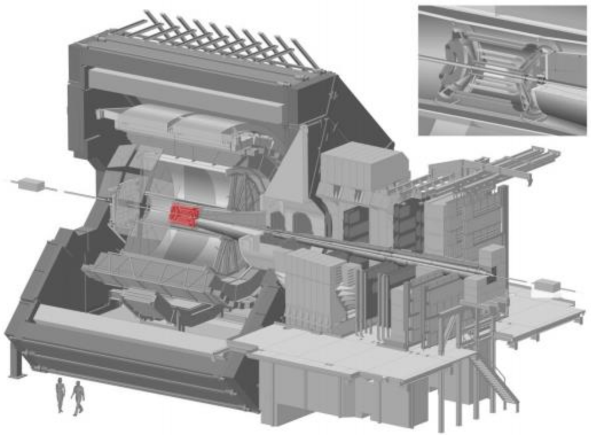
- SPD : innermost two silicon layers of ITS
- Track counting : A short track segment reconstructed with two hits on the SPD that can be extendable to the primary vertex



Phys. Lett. B 790 (2019) 35-48

Centrality	$\langle N_{part}\rangle$	$\langle dN_{ch}/d\eta\rangle$	$\frac{2}{\langle N_{part}\rangle}\langle dN_{ch}/d\eta\rangle$
0–1%	246 ± 2	1302 ± 17	10.6 ± 0.2
1–2%	241 ± 2	1223 ± 25	10.1 ± 0.2
2–3%	236 ± 3	1166 ± 23	9.88 ± 0.23
3–4%	231 ± 2	1113 ± 20	9.64 ± 0.19
4–5%	225 ± 3	1069 ± 20	9.50 ± 0.22
0–2.5%	242 ± 2	1238 ± 25	10.2 ± 0.2
2.5–5.0%	229 ± 2	1096 ± 27	9.57 ± 0.25
5.0–7.5%	214 ± 3	986 ± 25	9.21 ± 0.27
7.5–10%	199 ± 2	891 ± 24	8.95 ± 0.26
0–5%	236 ± 2	1167 ± 26	9.89 ± 0.24
5–10%	207 ± 3	939 ± 24	9.07 ± 0.27
10–20%	165 ± 3	706 ± 17	8.56 ± 0.26
20–30%	118 ± 4	478 ± 11	8.10 ± 0.33
30–40%	82.2 ± 3.9	315 ± 8	7.66 ± 0.41
40–50%	54.6 ± 3.6	198 ± 5	7.25 ± 0.51
50–60%	34.1 ± 3.0	118 ± 3	6.92 ± 0.63
60–70%	19.7 ± 2.1	64.7 ± 2.0	6.57 ± 0.73
70–80%	10.5 ± 1.1	32.0 ± 1.3	6.10 ± 0.68
80–90%	5.13 ± 0.46	13.3 ± 0.9	5.19 ± 0.58

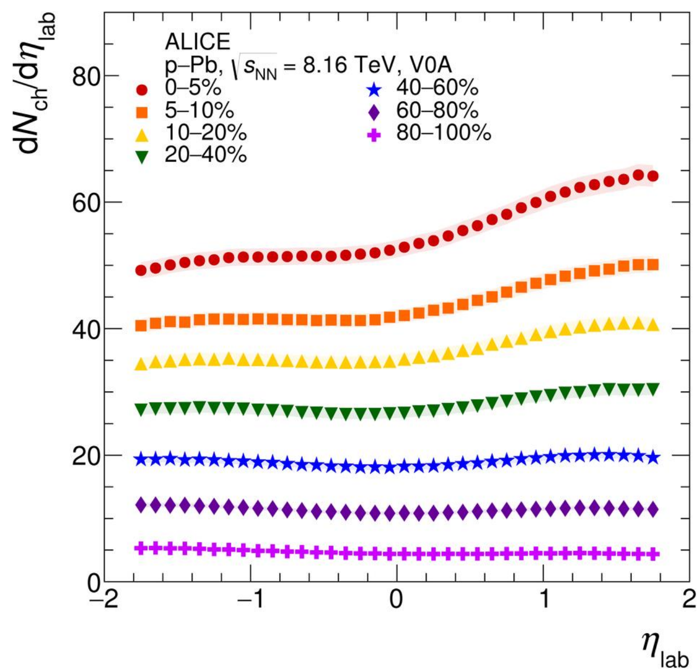
Multiplicity density measurement



Multiplicity density in all systems

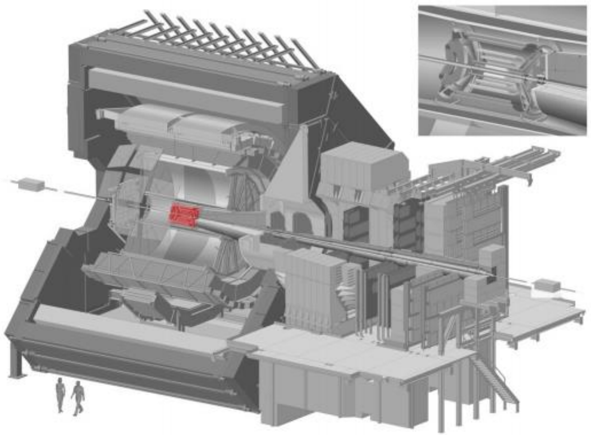
- SPD : innermost two silicon layers of ITS
- Track counting : A short track segment reconstructed with two hits on the SPD that can be extendable to the primary vertex

Cent (%)	Class	η_{lab}	$dN_{ch}/d\eta$	sys
0 - 5	NSD	$\|\eta_{lab}\|<0.5$	53.22	± 1.38
5 - 10			42.40	± 1.10
10 - 15			37.30	± 0.97
15 - 20			33.64	± 0.87
20 - 30			29.30	± 0.76
30 - 40			24.49	± 0.66
40 - 50			20.34	± 0.53
50 - 60			16.46	± 0.43
10 - 20			35.49	± 0.92
20 - 40			26.89	± 0.70
40 - 60			18.39	± 0.48
60 - 80			10.97	± 029
80 - 100			4.47	± 0.14
5 - 15			39.86	± 1.04
15 - 30			30.77	± 0.80
30 - 60			20.42	± 0.53
60 - 100			7.63	± 0.24



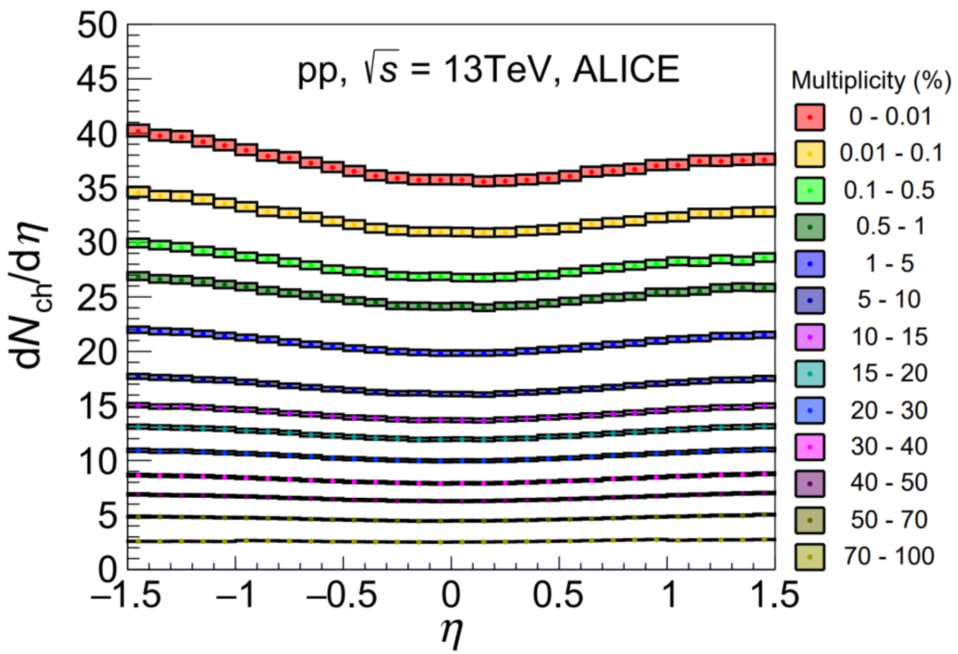
Eur. Phys. J. C (2019) 79: 307

Multiplicity density measurement



Multiplicity density in all systems

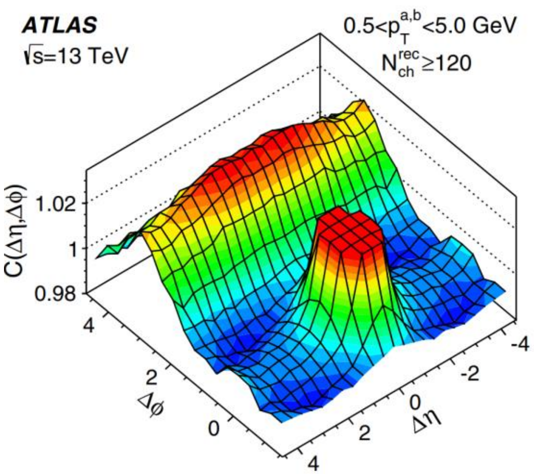
- SPD : innermost two silicon layers of ITS
- Track counting : A short track segment reconstructed with two hits on the SPD that can be extendable to the primary vertex



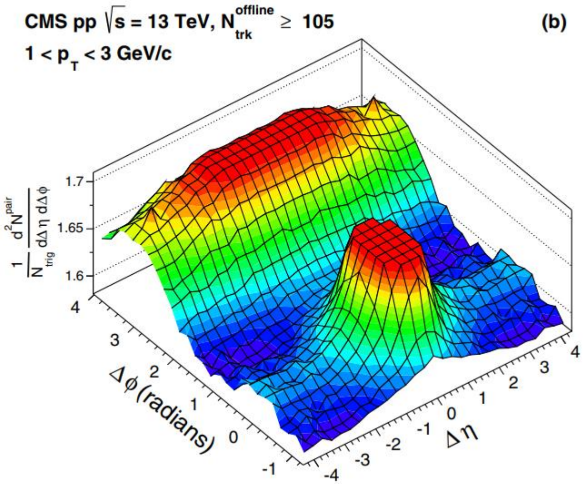
	Forward Multiplicity Estimator		
	$\sqrt{s}$ (TeV)		
	5.02	7	13
Multiplicity Class	$\langle dN_{ch}/d\eta \rangle$		
0–0.01%	24.43±0.37	27.82±0.39	35.84±0.45
0.01–0.1%	21.62±0.30	24.05±0.27	31.06±0.39
0.1–0.5%	19.02±0.24	21.25±0.21	26.93±0.33
0.5–1%	17.29±0.21	19.36±0.20	24.24±0.30
0–1%	18.44±0.23	20.60±0.23	26.01±0.32
1–5%	14.47±0.18	16.23±0.16	19.98±0.24
0–5%	15.26±0.19	17.11±0.17	21.17±0.25
5–10%	11.91±0.15	13.34±0.13	16.18±0.19
10–15%	10.29±0.13	11.50±0.12	13.77±0.17
15–20%	9.10±0.11	10.24±0.10	12.01±0.15
20–30%	7.75±0.10	8.90±0.09	10.03±0.13
30–40%	6.33±0.08	7.21±0.07	7.95±0.10
40–50%	5.21±0.07	5.84±0.06	6.32±0.08
50–70%	3.93±0.05	4.30±0.05	4.49±0.06
70–100%	2.42±0.03	2.33±0.03	2.54±0.04
0–100%	5.48±0.07	5.91±0.06	6.92±0.09

QGP-like effects in small systems

High-Multiplicity (HM) pp collisions

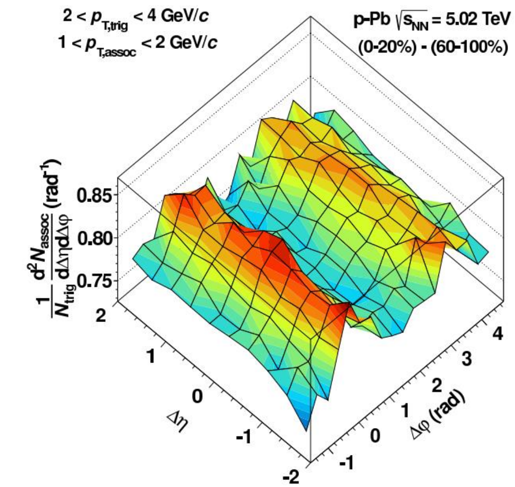


ATLAS, $\sqrt{s} = 13$ TeV
PRL 116, 172301 (2016)



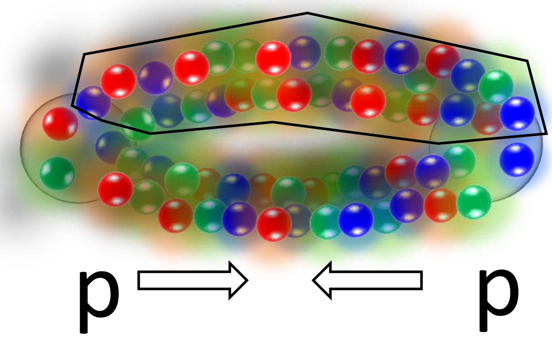
CMS, $\sqrt{s} = 13$ TeV
PRL 116, 172302 (2016)

p—Pb collisions

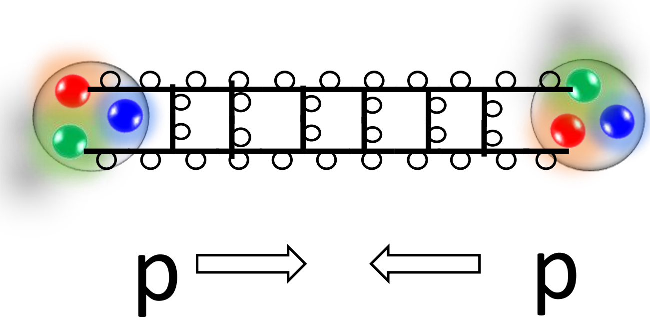


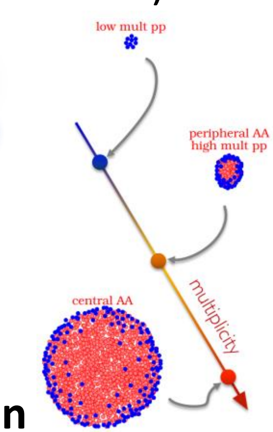
ALICE, $\sqrt{s_{NN}} = 5.02$ TeV
PRL 116, 172302 (2016)

Color Reconnection



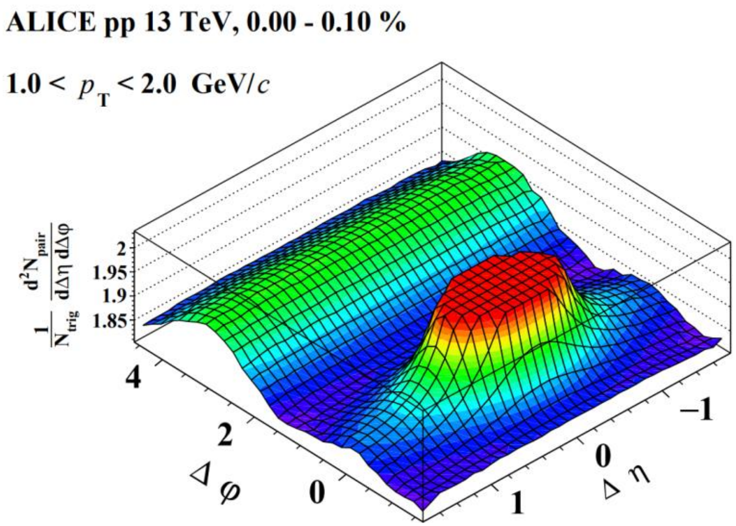
EPOS LHC, Color flux tube (Core & Corona)

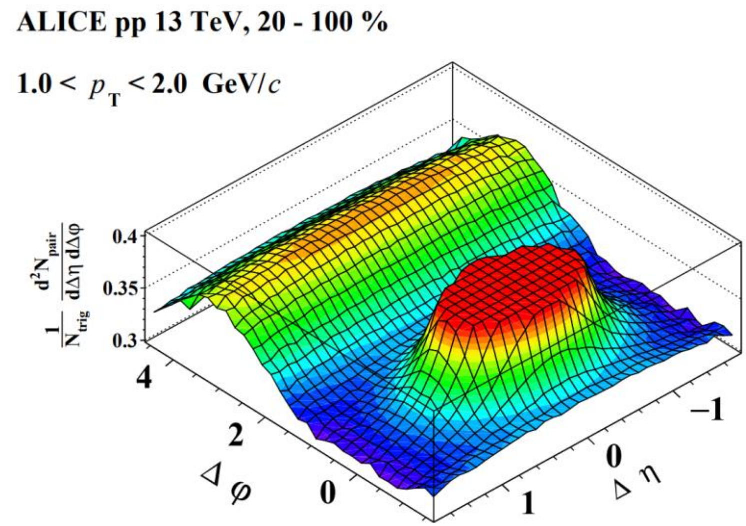


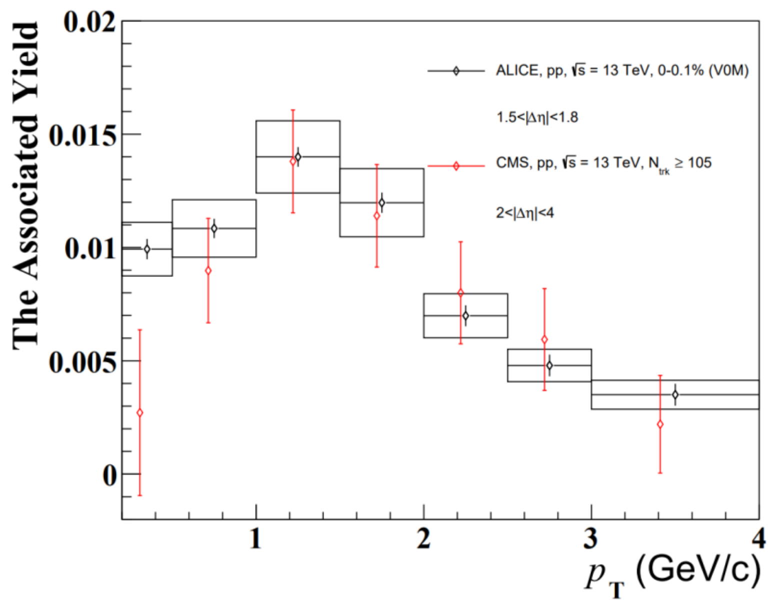


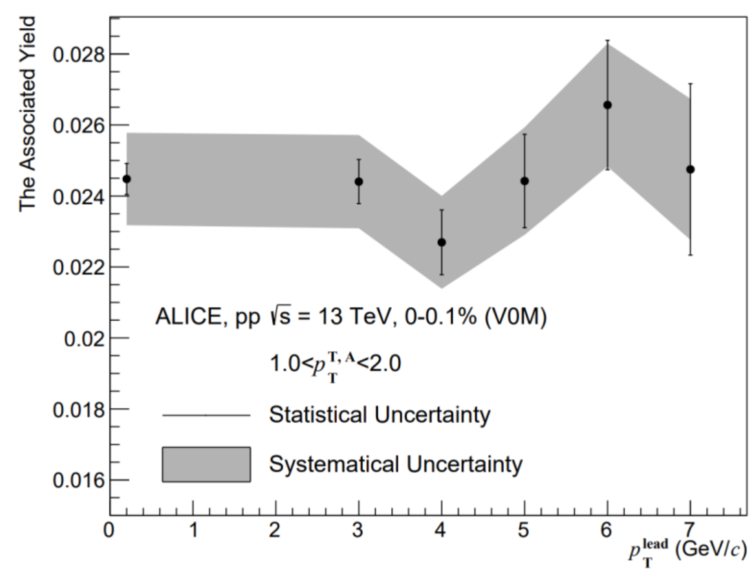
Two models introduced recently for the long range correlations in high multiplicity pp collisions by constraining the increased MPI !

Ridge in pp collisions at ALICE



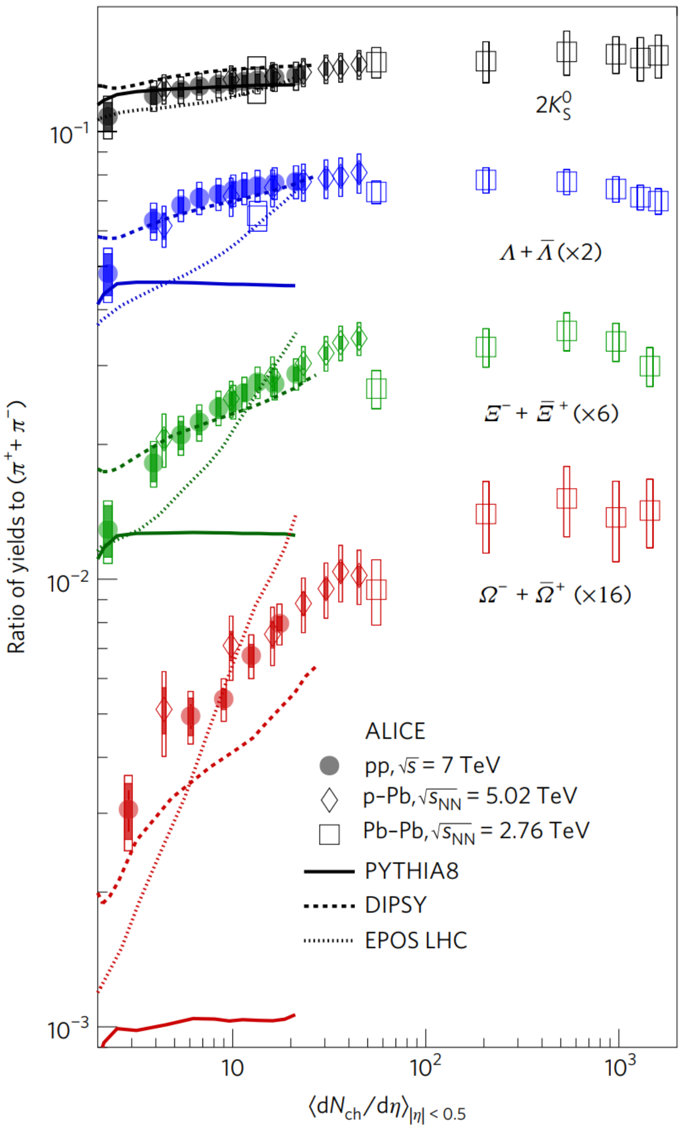






Junlee Kim, Chonbuk National Univ.

Strangeness enhancement



Nat. Phys. 13 (2017) 535-539

One of the original traces of the QGP
- Thermal production via gluon fusion in a QGP medium

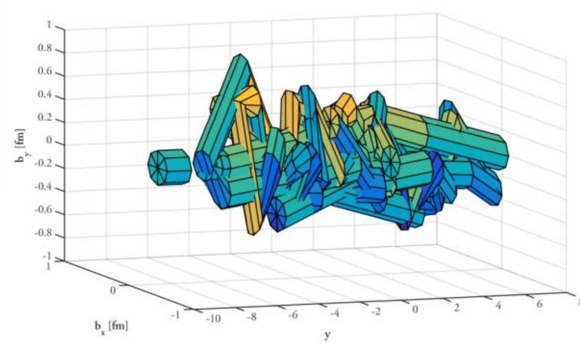
K_S^0, Λ, Ξ and Ω in Pb-Pb at 5.02 TeV
- Production w.r.t to π enhanced

Also studied in p—Pb and pp
- Strangeness increases with multiplicity following the universal trend

PYTHIA default
- Not describe the enhancement

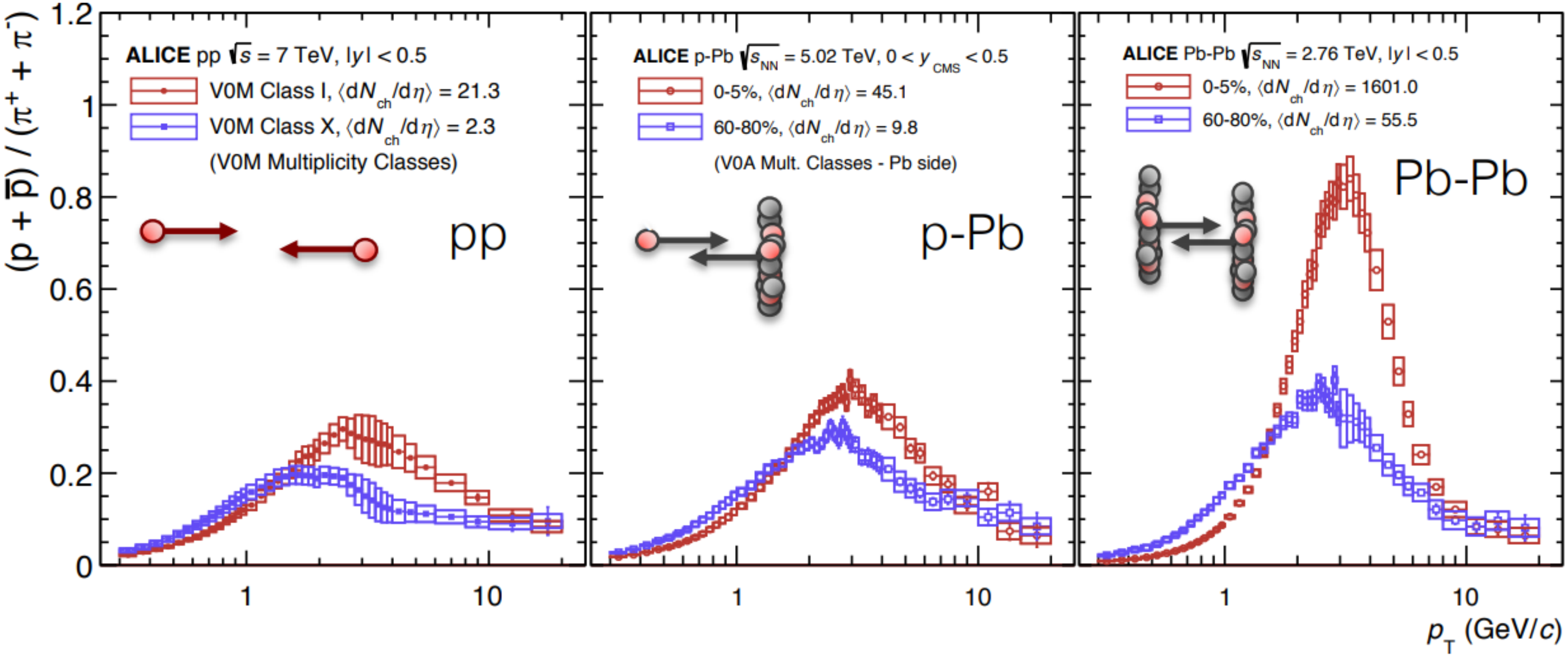
EPOS LHC
- Hydrodynamic treatment

DIPSY (PYTHIA8 + ROPE)
- Like the Color Reconnection
- strings may overlap to form color ropes
- Increased tension → increase strangeness



p/π

ALICE, Phys. Rev. C 99, 024906



Behavior known from Pb-Pb collisions

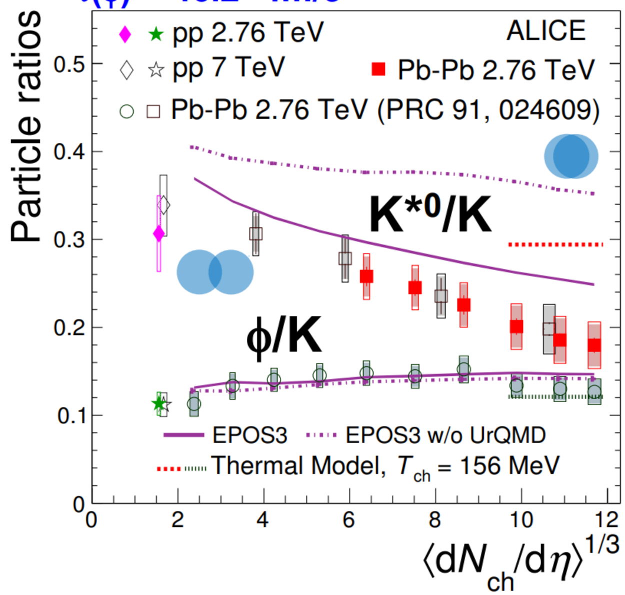
- Interpreted as radial flow:

  p are pushed to higher momenta by a common velocity field

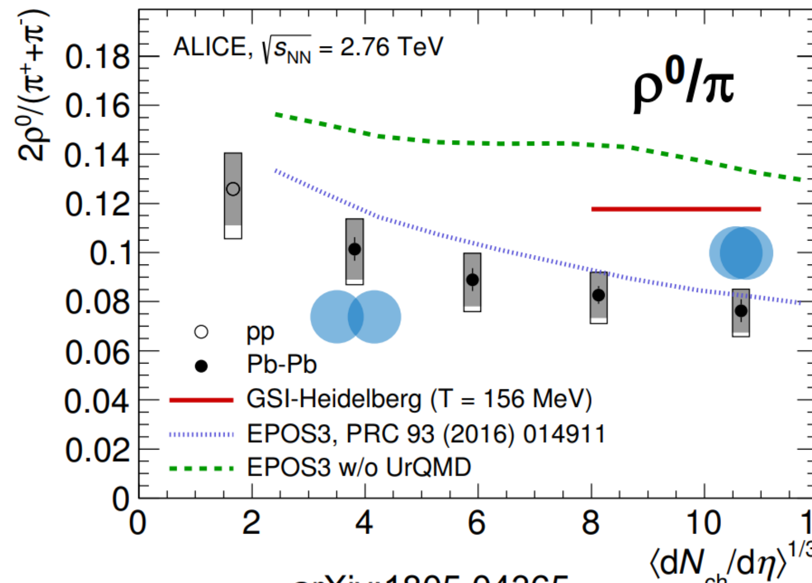
Same behaviors in pp and pA collisions with respect to system size

Resonance suppression

$\tau(K^{*0})$ = 4.16 fm/c
$\tau(\phi)$ = 46.2 fm/c

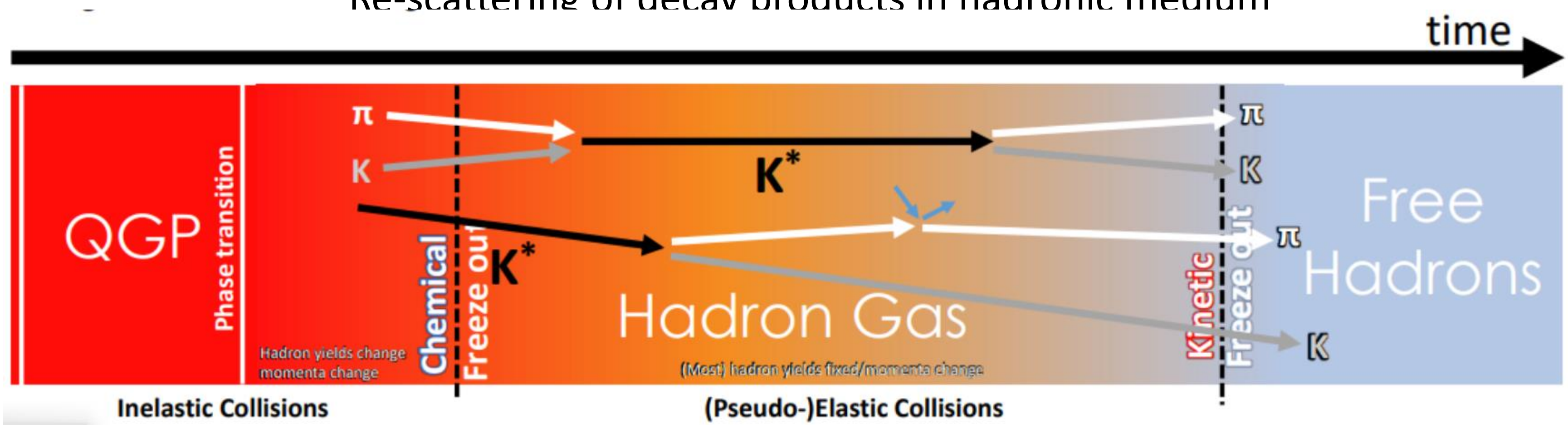


$\tau(\rho^0)$ = 1.3 fm/c



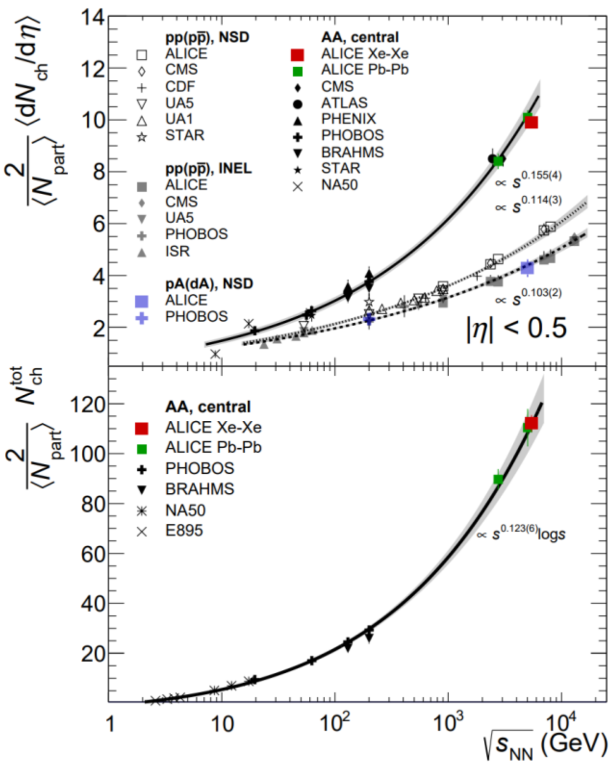
arXiv:1805.04365

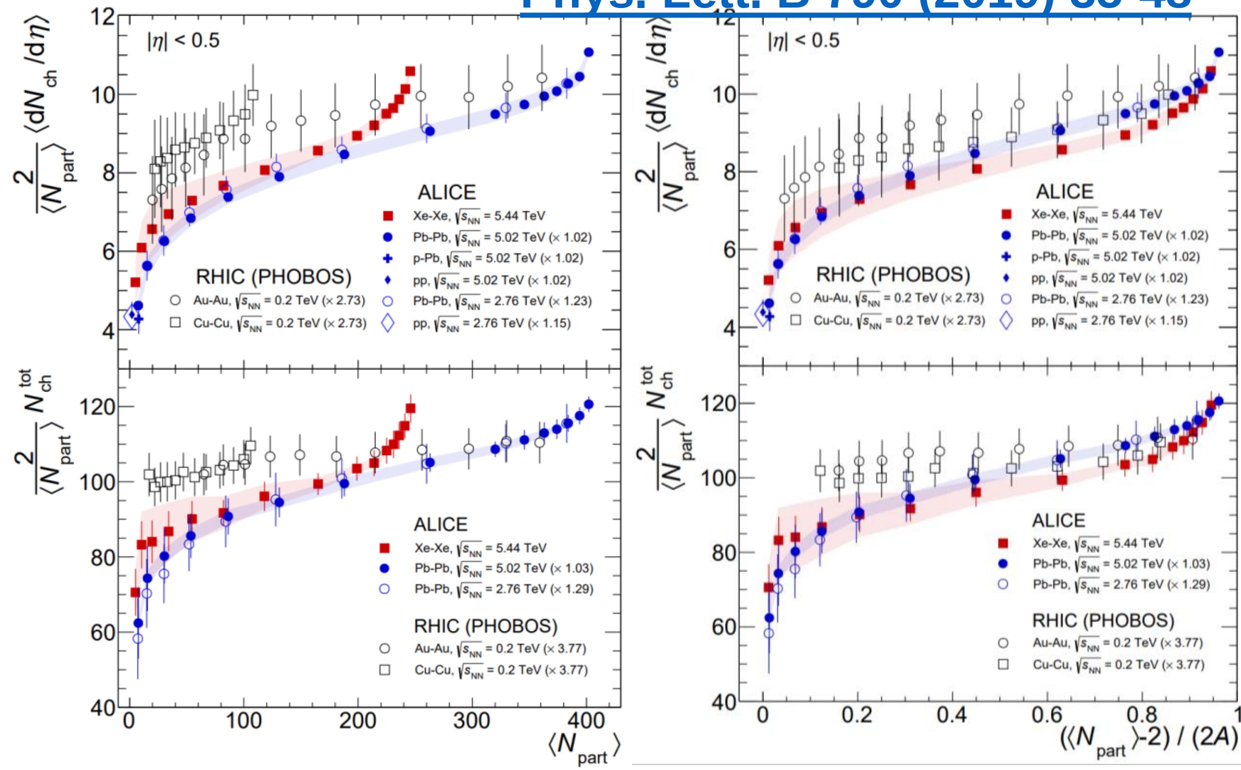
Re-scattering of decay products in hadronic medium

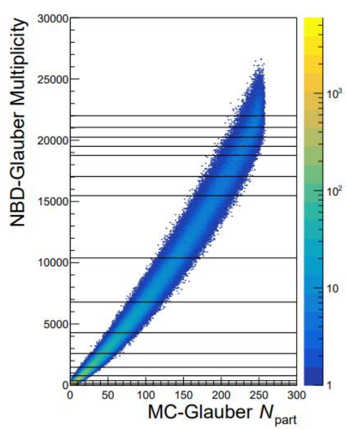


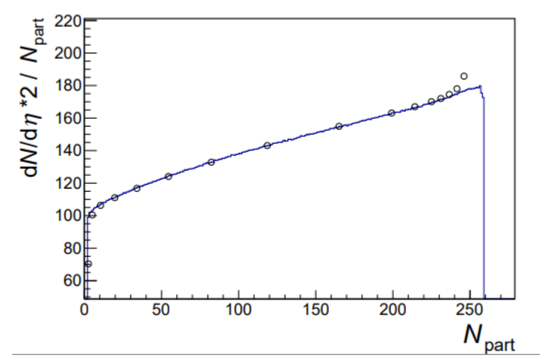
Medium-sized system (Xe—Xe)

Phys. Lett. B 790 (2019) 35-48

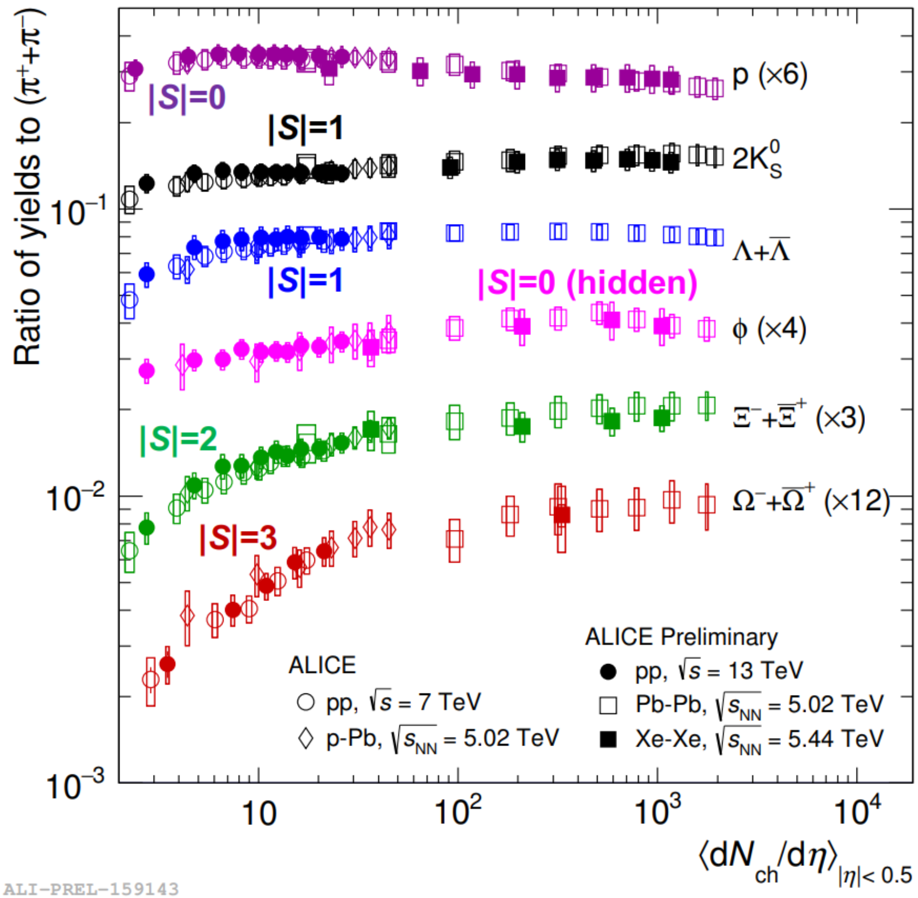






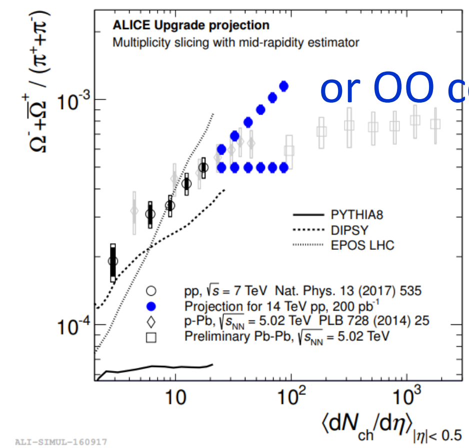


Medium-sized system (Xe—Xe)



Results from Xe—Xe confirm that multiplicity is the key observable for relative particle abundances

- No energy dependence
- Hadron chemistry is driven by the multiplicity (system size)



or OO collisions in RUN3+4

Summary

Multiplicity

- Key variable to connect pp to Pb—Pb collisions via high-multiplicity pp and medium sized AA collisions
- Fundamental constraints to theory
  - PYTHIA Rope, EPOS LHC and Color Reconnection
- Re-establishment of observables as a function of system size in Heavy-ion Physics
- Providing system-size information to ALICE and involved in various system-size dependent studies