Charged particle yield evolution in particle multiplicity in pp, p–Pb and Pb–Pb

Beomkyu Kim
Sungkyunkwan University

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ATHIC2021, Inha University

- Study interplay between soft and hard QCD

AA collisions

- Direct relation to the initial ϵ of QGP
  $\epsilon = \frac{dE_T/dy}{\tau_0 \pi R^2} \approx \frac{3}{2}\langle m_T \rangle \frac{dN_{ch}/d\eta}{\tau_0 \pi R^2} > 1\mathrm{GeV/fm}^3$

pp collisions

- Reference data for nuclear effect
- Study MPI in high N_{ch} collisions

p–Pb collisions

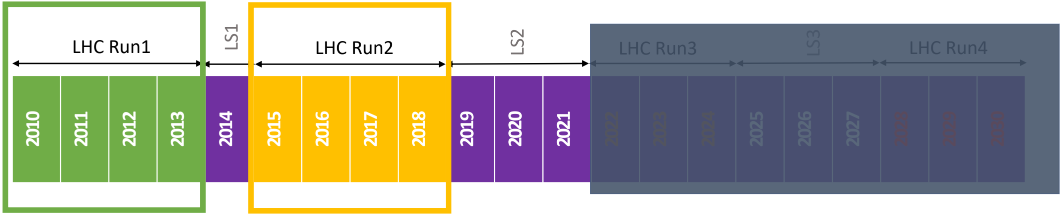
- Discriminate between FSR in AA and ISR of nuclei themselves

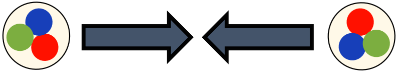
- QGP-like effects even in pp and p–Pb collisions at LHC energies

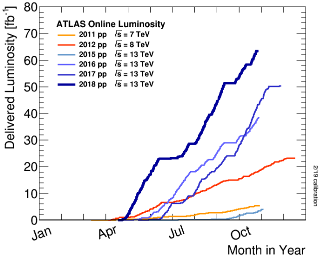
  proton (A=1) — p–Pb ——— Xe (A=129) ——— Pb (A=208)

- System size and $\langle dN_{ch}/d\eta \rangle \rightarrow$ starting of the story

proton-proton collisions in LHC Run1 and Run2







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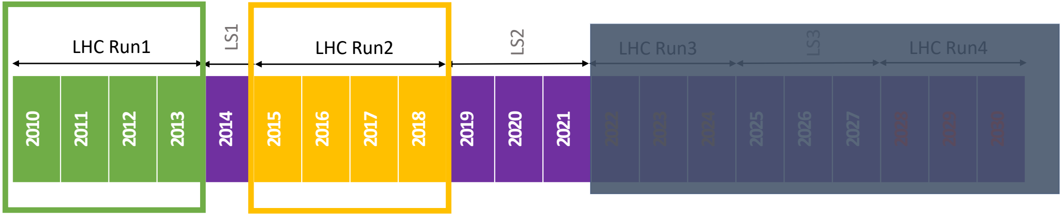
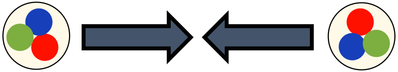
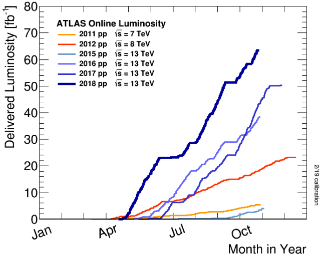
PROTON-PROTON COLLISIONS IN LHC RUN1 AND RUN2







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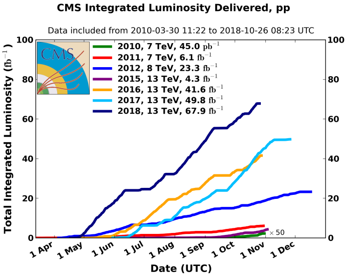

cmslumi.web.cern.ch

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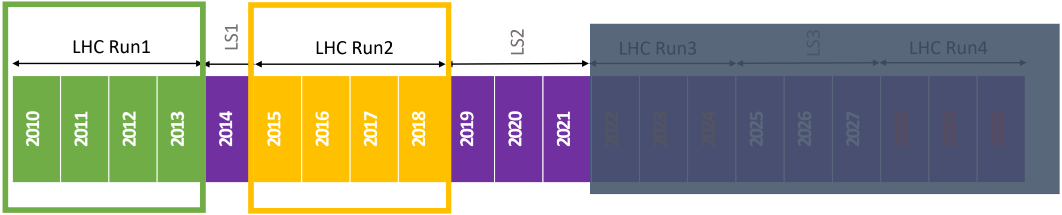

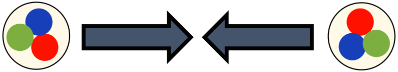

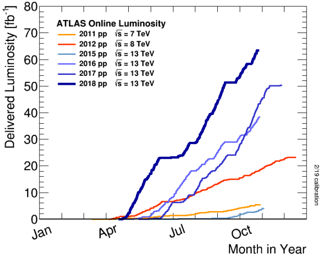

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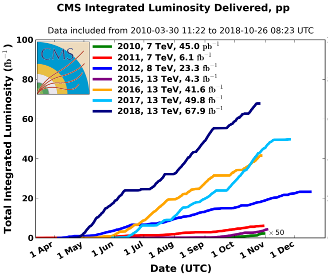

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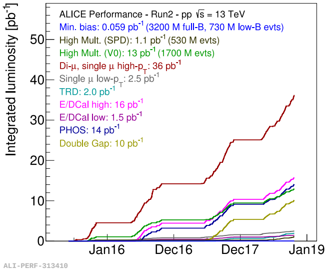


ALI-PERF-313410

At LHC energy → more contributions from hard-processes

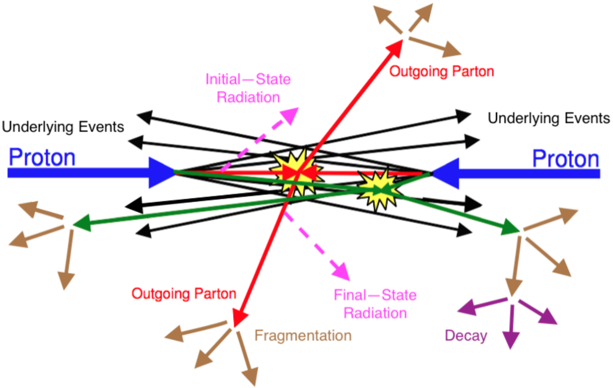
- Multi Parton Interactions (MPI) : more than one hard scattering

Still particle production dominated by Soft-QCD processes

- ISR + FSR (gluon-strahlung)
- colour-connected beam remnant
- infrared MPI (not primary)

  - $p_T \sim$ few GeV
  - non perturbative
  - phenomenology
  - modelling

EPJC 62 (2009) 237-242



A Large Ion Collider Experiment

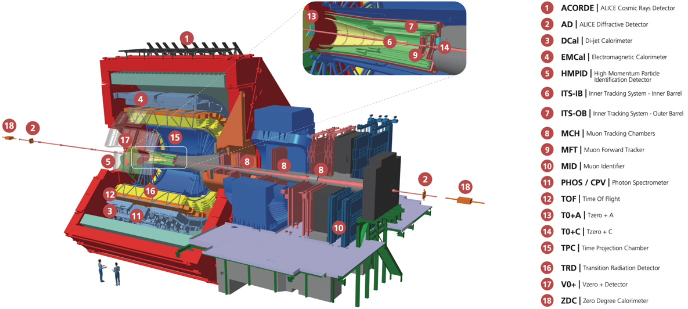
V0 (Scintillator hodoscopes)
- triggers forward activity
- multiplicity & centrality estimation

FMD (Forward Multiplicity Detector)
- Three sets of Si strip sensors
- close to V0 detectors

SPD (Silicon Pixel Detector)
- 6-layer silicon detector
- innermost tracking at mid rapidity

TPC (Time Projection Chamber)
- Large cylindrical detector
- designed upto $dN_{ch}/d\eta \sim 8000$

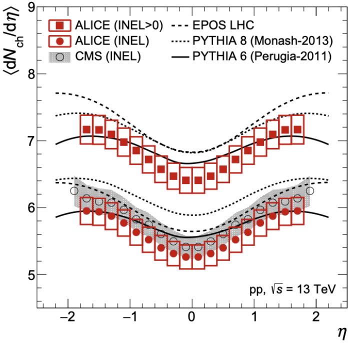
- 18 detectors, sensitivity at low p_T, excellent PID
- Optimized for soft QCD physics

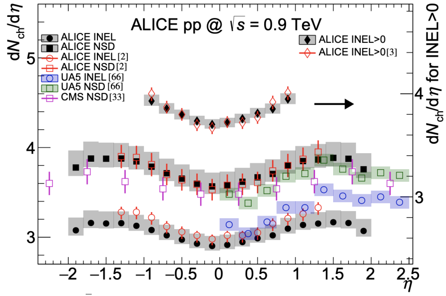


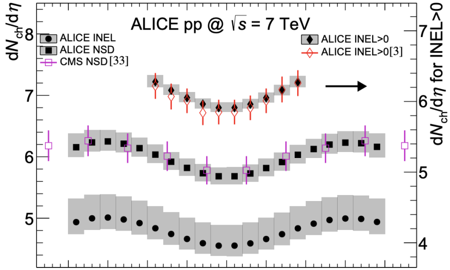
	η_{min}/η_{max}	
	A side	C side
V0	2.8/5.1	-3.7/-1.7
FMD	1.7/5.1	-3.4/-1.7
ITS	-1.4/1.4	
TPC	-0.9/0.9	

Summary of the results in pp collisions at LHC

Type	$\sqrt{s}$ (TeV)	paper
ALICE	0.9, 2.76, 7 and 8	Eur. Phys. J. C 77 (2017) 33
	0.9, 7 and 8	Eur. Phys. J. C 77 (2017)
	5.02, 7, 13	Eur. Phys. J. C 81 (2021) 630
	13	Phys. Lett. B 753 (2016) 319-329
CMS	7	Phys. Rev. Lett. 105, 022002
	0.9, 2.36 and 7	JHEP 1101 (2011) 079
	13	Phys. Lett. B 751, (2015) 143-163
	13	Eur. Phys. J. C 78 (2018) 697
ATLAS	8	Eur. Phys. J. C 76 (2016) 403
	13	Phys. Lett. B758 (2016) 67







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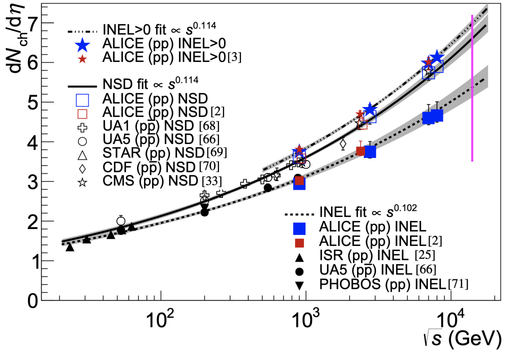

$$\langle dN_{ch}/d\eta \rangle = \int d\eta dN_{ch}/d\eta$$
$$\langle dN_{ch}/d\eta \rangle \propto s^{\Delta}$$

- A power law of s
- s: squared centre-of-mass energy
- Δ: Pomeron trajectory intercept parameter
- Above LHC energy: the power-law broken because of the unitarity

Summary of the results in pp collisions at LHC

Type	$\sqrt{s}$ (TeV)	paper
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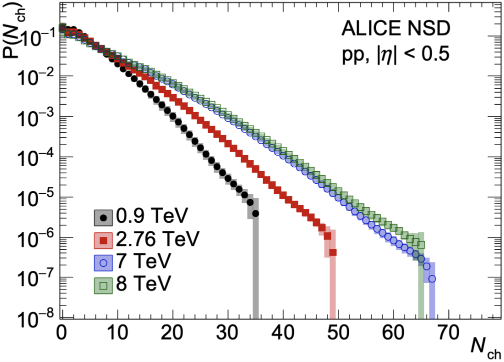
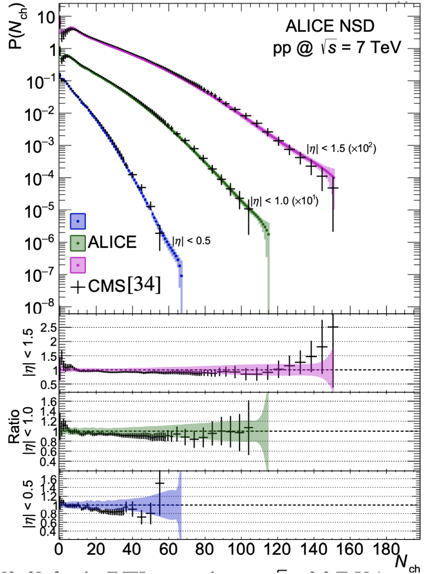




Single NBD fit

- Traditional parametrisation of particle multiplicity

$$P_{\mathrm{NBD}}(n, \langle n \rangle, k) = \frac{\Gamma(n+k)}{\Gamma(k)\Gamma(n+1)} \left[\frac{\langle n \rangle}{\langle n \rangle + k}\right]^n \times \left[\frac{k}{\langle n \rangle + k}\right]^k$$

- Single NBD fit overestimates the data at LHC

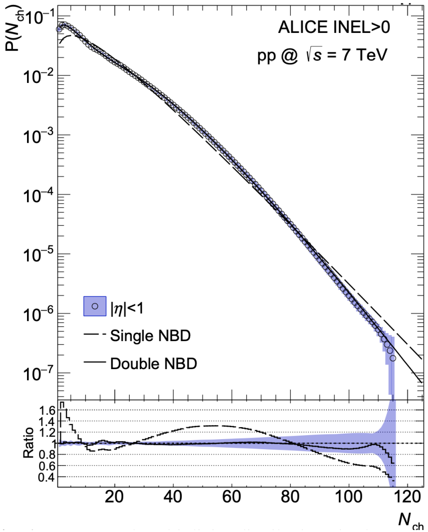
Double NBD fit

- Weighted sum of two NBD functions

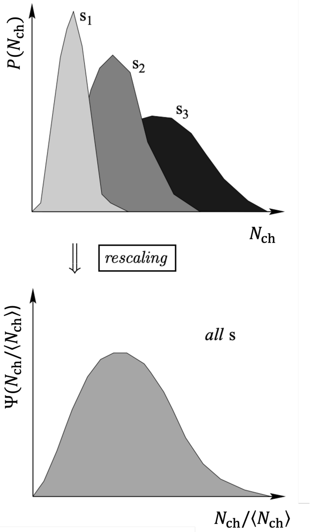
$$P(n) = \lambda\left[\alpha P_{\mathrm{NBD}}(n, \langle n_1 \rangle, k_1) + (1-\alpha) P_{\mathrm{NBD}}(n, \langle n_2 \rangle, k_2)\right]$$

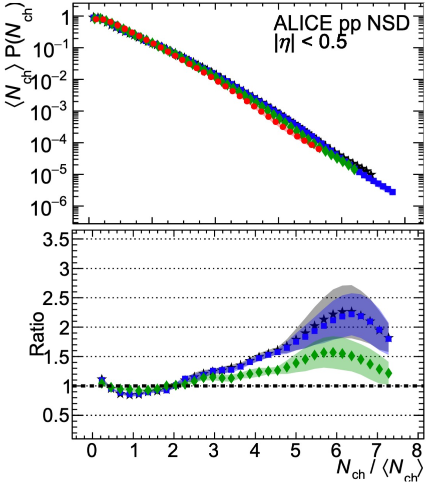
  - α : soft and MPI (not primary)
  - $1-\alpha$: hard scattering

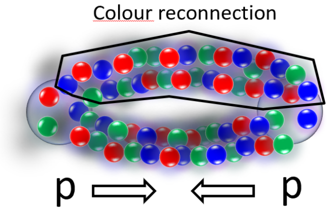
- Describes the data better $\rightarrow$ some hints of MPI

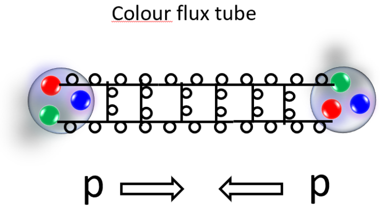


KNO (Koba-Nielsen-Olesen) scaling



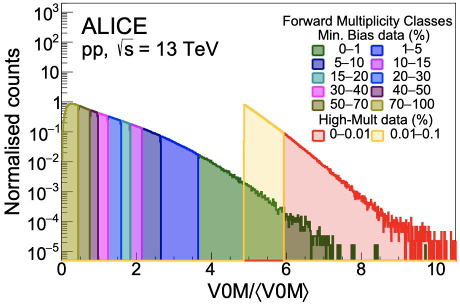




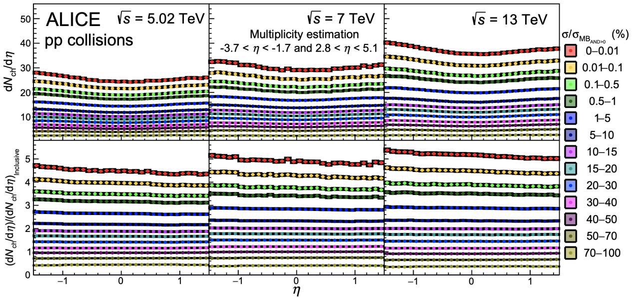


- Colour reconnection (PYTHIA 8 Monash)
  - clour strings from two hard scatterings are connected
  - two hard scatterings start to dependent in high mul pp collisions
  - the rise of $\langle p_{\mathrm{T}} \rangle$ with multiplicity like flow boost
- Core & corona (EPOS-LHC)
  - multiparton scattering froms a coulur-flux tube (Pomeron ladder)
  - Tube's high density region $\rightarrow$ thermalised as a flow-like(core)
  - Tube's edge region $\rightarrow$ hadronised as conventional

Multiplicity dependent $dN_{ch}/d\eta$



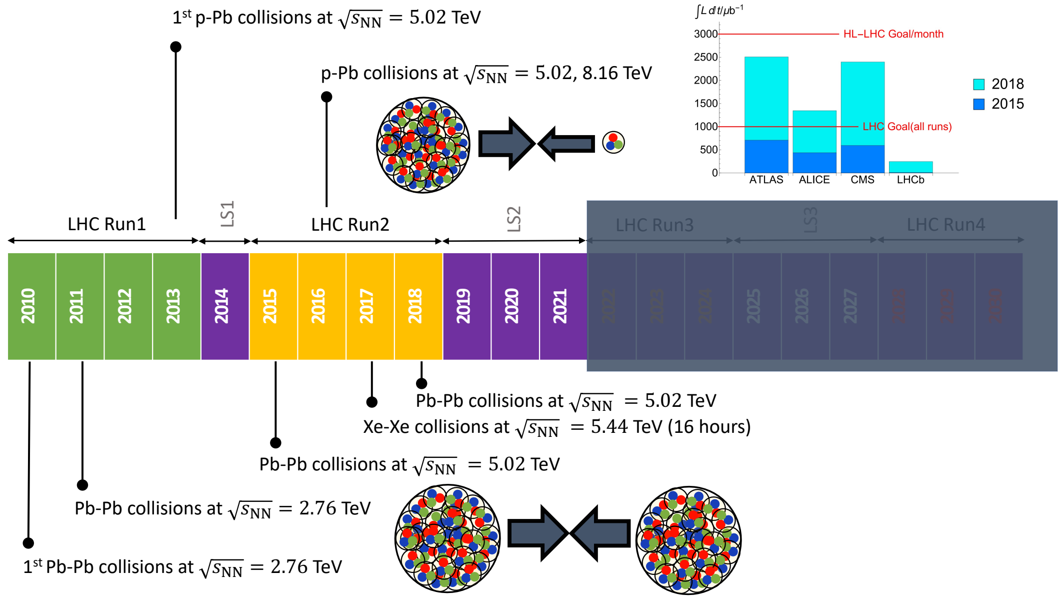
Eur. Phys. J. C 81 (2021) 630



Eur. Phys. J. C 81 (2021) 630

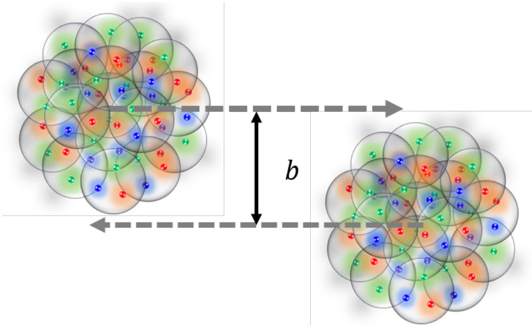
- Measurements provide input for the tuning of perturbative and soft QCD models
- Colour reconnection and core-corona models describe particle production in high-multiplicity within 10%
- Reference data for all multiplicity dependent studies in pp collisions

p–Pb and Pb–Pb collisions in LHC Run1 and Run2



Summary of the results in p–Pb, Xe–Xe, and Pb–Pb at LHC

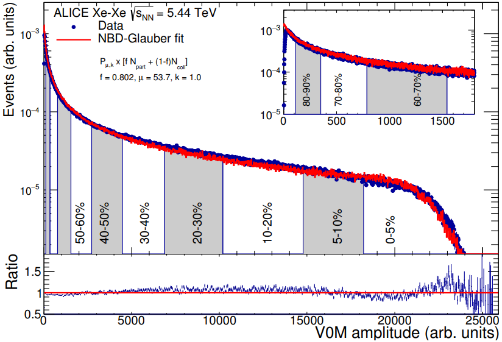
Type	$\sqrt{s_{\mathrm{NN}}}$ (TeV)	paper
ALICE	Pb–Pb 2.76	Phys. Rev. Lett. 106, 032301
	Pb–Pb 2.76	Phys. Lett. B 726, (2013) 610-622
	Pb–Pb 5.02	Phys. Rev. Lett. 116 (2016)
	Xe–Xe 5.44	Phys.Lett.B 790 (2019) 35-48
	p–Pb 5.02	Phys. Rev. Lett. 110 (2013)
	p–Pb 8.16	Eur. Phys. J. C (2019) 79: 307
CMS	Pb–Pb 2.76	JHEP 08 (2011) 141
	Xe–Xe 5.44	Phys. Lett. B 799 (2019) 135049
	p–Pb 5.02 and 8.16	JHEP01 (2018) 045
ATLAS	Pb–Pb 2.76	Phys. Lett. B 710 (2012) 363–382
	p–Pb 5.02	Eur. Phys. J. C (2016) 76:199



Impact parameter (b)

- The degree of geometrical overlap
- Centrality : fraction of geometrical cross-section
- N_{part}, N_{coll}

ALICE-PUBLIC-2018-003

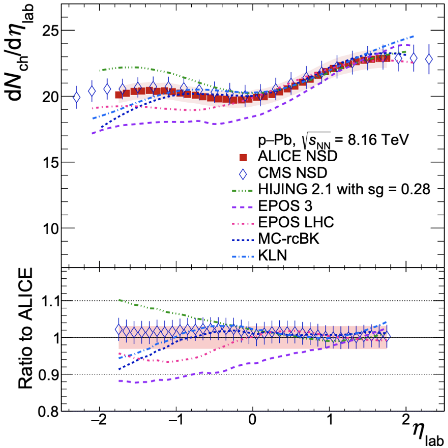


Centrality estimation for Xe–Xe

- Deformation of the nuclear density considered
- Multiplicity with the V0 detector
- NBD Glauber fit coupled to a two component model

$\langle dN_{ch}/d\eta \rangle$ in p − Pb collisions

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



All models lie within 15% of data

HIJING (Phys. Rev. C86 (2012) 051901)

- strong b dependence of parton shadowing
- combines pQCD and soft QCD
- reproduces magnitude and shape for Pb-going side

EPOS LHC (Phys. Rev. C92 (2015) 034906)

- collective effects like flow included
- reproduces Pb-going side

EPOS 3 (Phys. Rev. C89 (2014) 064903)

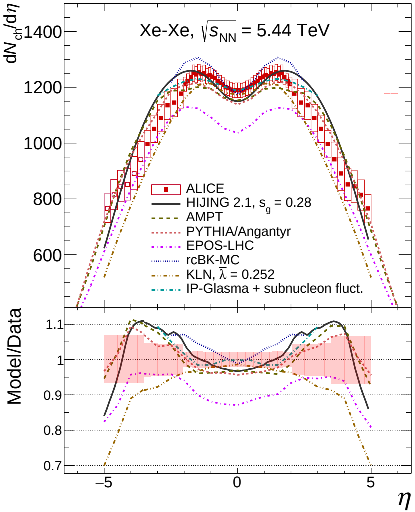
- includes a full viscous hydrodynamical simulation
- only the most forward part in the Pb-going side

rc-BK (Nucl. Phys. A897 (2013) 1-27)
KLN (Phys. Rev. C85 (2012) 044920)

- saturation based models
- perform better in $\eta_{lab} > -1.3$

$dN_{ch}/d\eta$ vs η and models for 0–5% central Xe–Xe colllisions

arXiv:1805.04432



HIJING

Good match in mid, overestimate at forward η (due to large value of s_g)

AMPT and PYTHIA/Angantyr

fairly good, slight overestimate at forward η

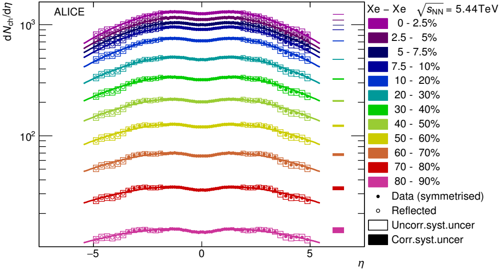
EPOS LHC

underestimate data overall

rcBK-MC: overall overestimation
KLN: matches in mid η, not true for forward η
IP-Glasma: wider than data

$\langle dN_{ch}/d\eta \rangle$ AND N_{ch}^{tot} IN Pb – Pb AND Xe – Xe COLLISIONS

arXiv:1805.04432



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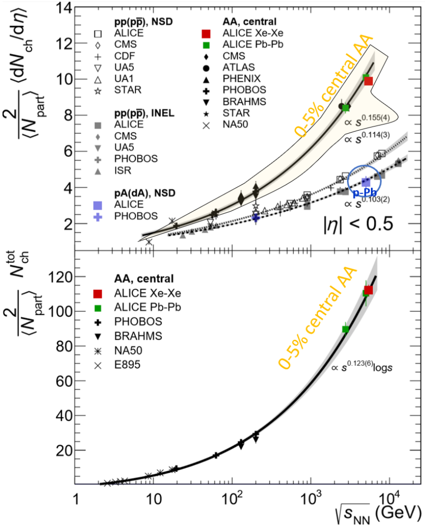
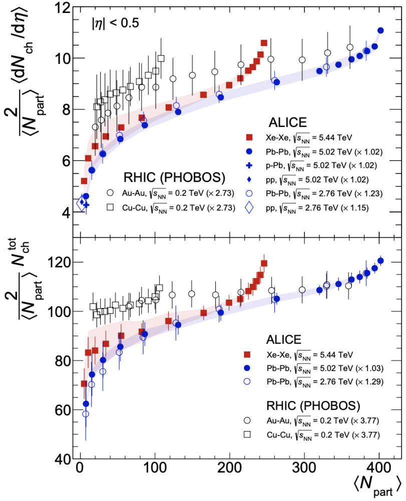


$\frac{2}{\langle N_{part} \rangle} \langle dN_{ch}/d\eta \rangle$ and $\frac{2}{\langle N_{part} \rangle} N_{ch}^{tot}$

- for the most 5% central collisions
- Xe–Xe result is in agreement with the trend
- A stronger rise w.r.t $\sqrt{s_{NN}}$ than for pp
- At $|\eta| < 0.5$ p–Pb fits with INEL pp points

$\frac{2}{\langle N_{\rm part}\rangle}\langle {\rm d}N_{\rm ch}/{\rm d}\eta\rangle$ AND $\frac{2}{\langle N_{\rm part}\rangle}N_{\rm ch}^{\rm tot}$ AS A FUNCTION OF $\langle N_{\rm part}\rangle$

arXiv:1805.04432

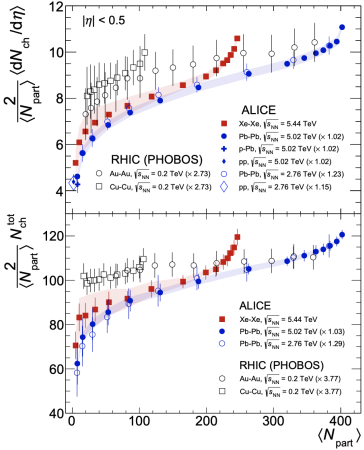


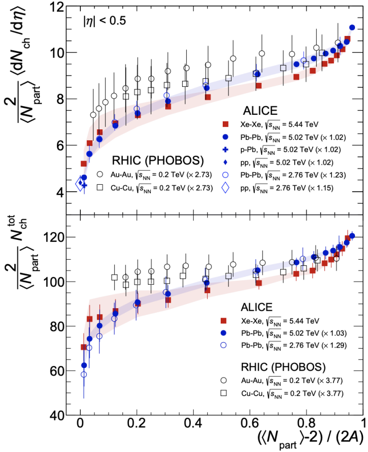
Data are scaled to $\sqrt{s}$, $\sqrt{s_{\rm NN}} = 5.44$ TeV (prev.) to match with Xe–Xe results.

- ALICE data decreasing by 2 from the most central to the peripheral
- smoothly connect to pp and p–Pb
- Xe–Xe shapes exceed Pb–Pb at similar $\langle N{\rm part}\rangle$ for the top 10 % central collisions
  - RHIC data show hint of same behaviour

Scaling of $\frac{2}{\langle N_{\mathrm{part}} \rangle} \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$

$\frac{2}{\langle N_{\mathrm{part}} \rangle} \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ as functions of $\langle N_{\mathrm{part}} \rangle$ and $(\langle N_{\mathrm{part}} \rangle - 2)/(2A)$.

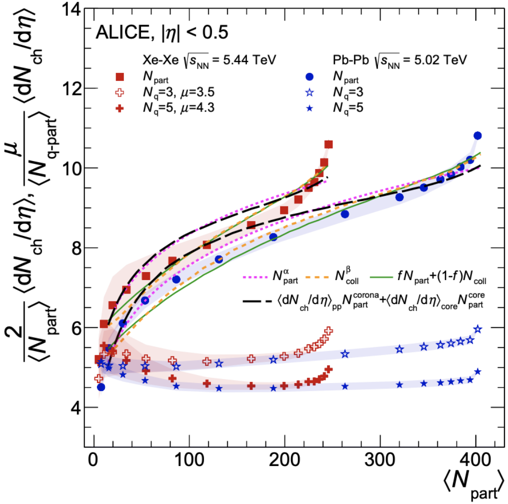




$\frac{2}{\langle N_{\mathrm{part}} \rangle} \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ depends on centrality rather than on the size of collision systems

Scaling of $\frac{2}{\langle N_{\rm part}\rangle}\langle dN_{\rm ch}/d\eta\rangle$

arXiv:1805.04432

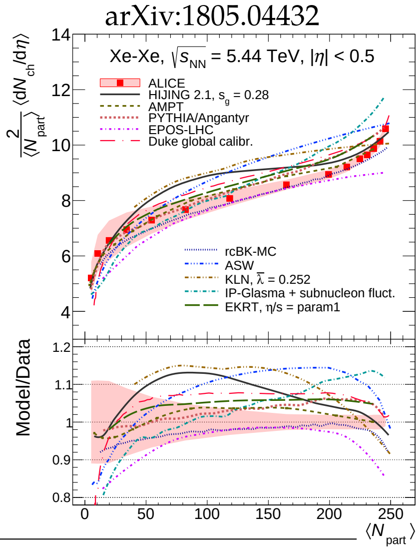


Different scalings for particle production

1. Power law function
2. Two component model
3. Core and corona model (Phys. Rev. Lett. 98 (2007) 152301))
4. Quark-Glauber parametrisation (Phys. Rev. C67 (2003) 064905 , Phys.Rev. C94 no. 2, (2016) 024914)

- using wounded constituent quarks
- $N_q = 3$ and 5
- A scaling violation for the 0–5% centrality range in Xe–Xe collisions (0-1-2-3-4-5% binning)

$\frac{2}{\langle N_{part} \rangle} \langle dN_{ch}/d\eta \rangle$ and models in Xe − Xe collisions



AMPT (Phys. Rev. C72 (2005) 064901)

– initial state by HIJING
– and then hydrodynamical evolution

PYTHIA/Angantyr (JHEP 10 (2016) 139)

– performing each nucleon-pair (parton level)
– Lund strings hadronised as an ensemble

Duke global (Phys. Rev. C92 no. 1, (2015) 011901

– viscous hydrodynamics coupled to a hadronic cascade model

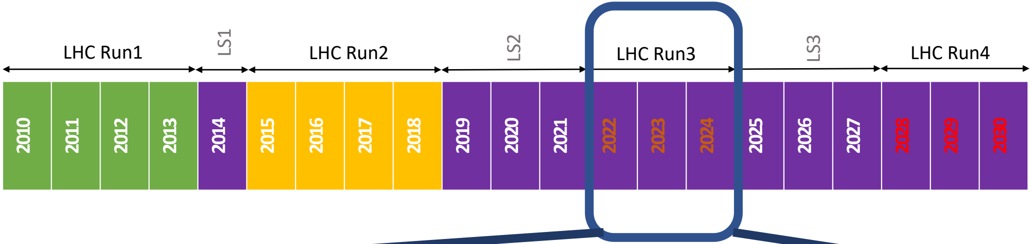
rc-BK, KLN, ASW[1], IP-Glasma[2] and EKRT[3]

– saturation-inspired models to limit N_{parton}

All models describe data within ±20%

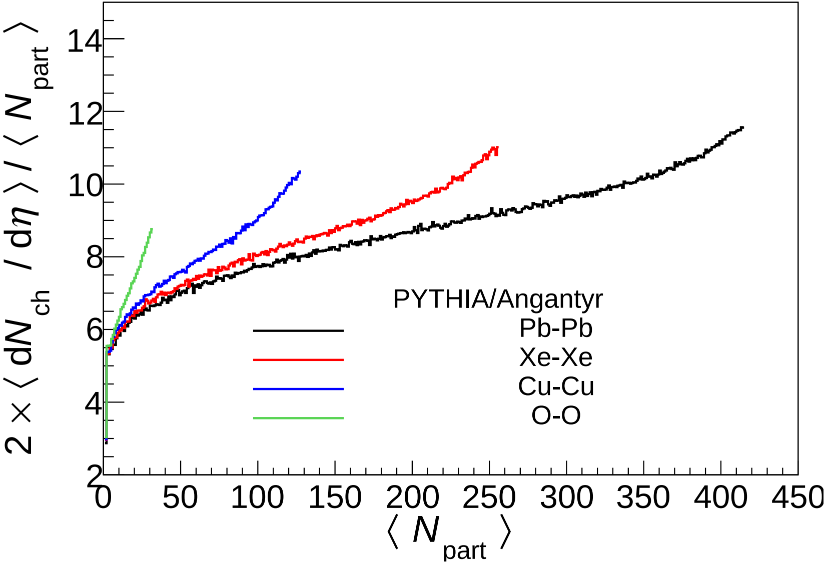
[0] 1. Phys. Rev. Lett. 94 (2005) 022002, 2. Phys. Rev. Lett. 108 (2012) 252301, 3. Phys. Rev. C97 no. 3, (2018) 034911

LHC Run3



Year	Systems, $\sqrt{s_{NN}}$	Time	L_{int}
2022	Pb–Pb 5.5 TeV	3 weeks	2.3 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2023	Pb–Pb 5.5 TeV	5 weeks	3.9 nb^{-1}
	O–O, p–O	1 week	500 μb^{-1} and 200 μb^{-1}
2024	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)

$\frac{2}{\langle N_{part} \rangle} \langle dN_{ch}/d\eta \rangle$ OF MODELS FOR LIGHT IONS



- Charged particle production mechanism at LHC has greatly been studied for the last 10 years in various collision systems and at center-of-mass energies
  - pp collisions at $\sqrt{s} = 0.9, 2.76, 7, 8$ and 13 TeV
  - p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02, 8.16$ TeV
  - Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ and 5.02 TeV
  - Xe-Xe collisions at $\sqrt{s_{\mathrm{NN}}} = 5.44$ TeV
- $\sqrt{s}$ behaviour of $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ established
- Evidence for MPI from various measurements in pp collisions and some mechanisms introduced to regulate particle production and explain some collective effects in high-multiplicity events
- Medium-sized Xe-ion acts like a heavy ion $\rightarrow$ lighter ions? (OO, p-O) in LHC Run3
- Models have been tuned but still need more constraints

Backup

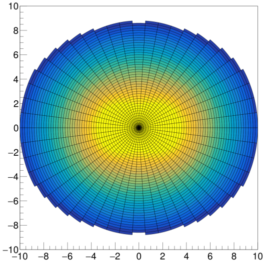
Woods-Saxon distributions

Go back to "Centrality Estimation

- Xe ion (deformed)

$$\rho(r,\vartheta) = \rho_0 \frac{1}{1+\exp\left(\frac{r-R(\vartheta)}{a}\right)}$$

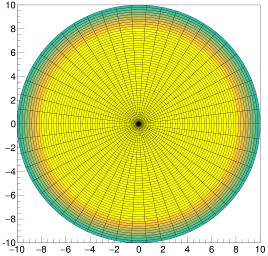
  - ρ_0 : the nucleon density
  - The nuclear skin thickness $a = 0.59 \pm 0.07$ fm [1]
  - Nuclear radius $R(\vartheta) = R_0[1+\beta_2 Y_{20}(\vartheta)]$



- Pb ion (spherical)

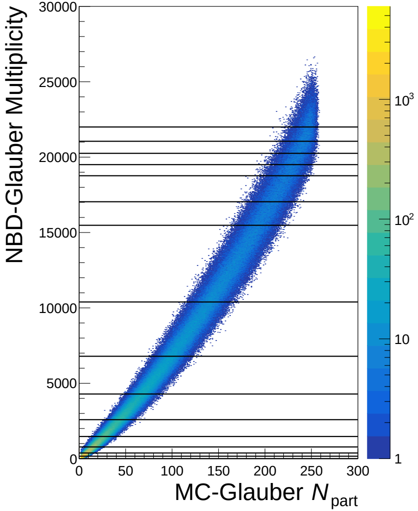
$$\rho(r,\vartheta) = \rho_0 \frac{1}{1+\exp\left(\frac{r-R}{a}\right)}$$

  - ρ_0 : the nucleon density
  - The nuclear skin thickness $a = 0.546 \pm 0.01$ fm
  - Nuclear radius $R = 6.62 \pm 0.06$ fm



[1] Phys. Rev. Lett. 118 no. 26, (2017) 262501

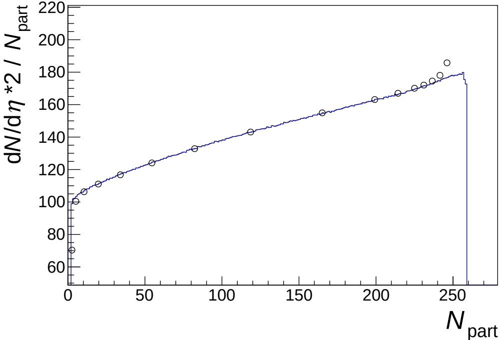
Multiplicity fluctuation?



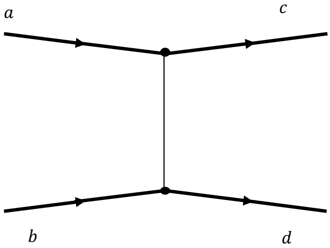
Xe–Xe case

NBD-Glauber Multiplicity (fitted to V0M) and MC-Glauber $\langle N_{part} \rangle$ filled on left

1. When sliced by centrality (0-1-2-3-4-5-7.5-10-20-...) and measured $\frac{2}{\langle N_{part} \rangle}\langle dN_{ch}/d\eta \rangle$ vs $\langle N_{part} \rangle$. (open circle)
2. When projected on $\langle N_{part} \rangle$-axis then measured $\frac{2}{\langle N_{part} \rangle}\langle dN_{ch}/d\eta \rangle$ vs $\langle N_{part} \rangle$(blue line)



When the squared momentum transfer is much less than $\sqrt{s}$



$$t = (p_{\text{a}} - p_{\text{c}})^2 \ll \sqrt{s}$$

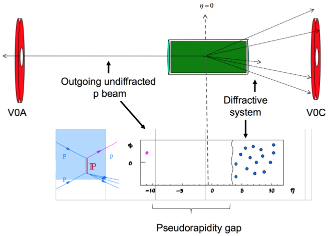
- Help us understand QCD in the non-perturbative regime ($t \sim 0$ or $q^2 < \Lambda^2_{\text{QCD}}$)
- By Regge theory [1] [2] [3], diffraction proceeds via the exchange of Pomerons ($gg_{\text{leading order}} + ggg_{\text{next leading order}} + \cdots$)

[1] P.D.B.Collins,An Introduction to Regge Theory and High Energy Physics, Cambridge, 1977

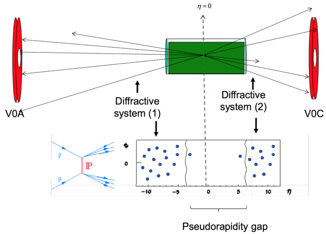
[2] A.B.Kaidalov,Phys.Rep.50,157,1979

[3] V. Barone, E. Predazzi, High-Energy Particle Diffraction ,Springer, Berlin, 200

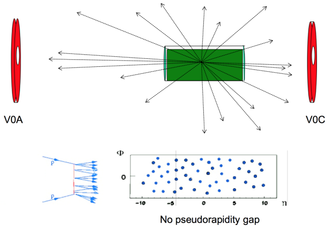
SD, DD and ND



SD

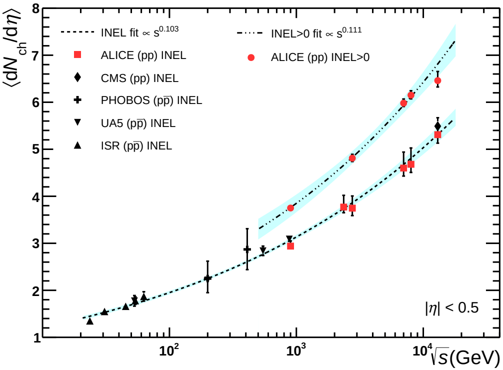


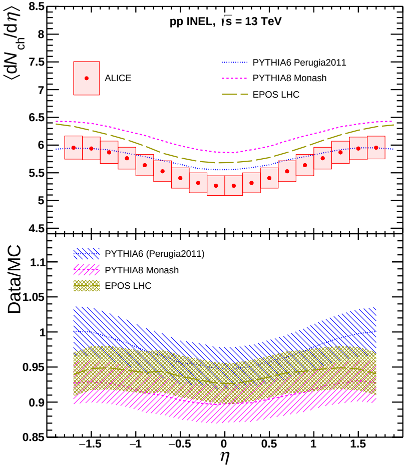
DD



ND

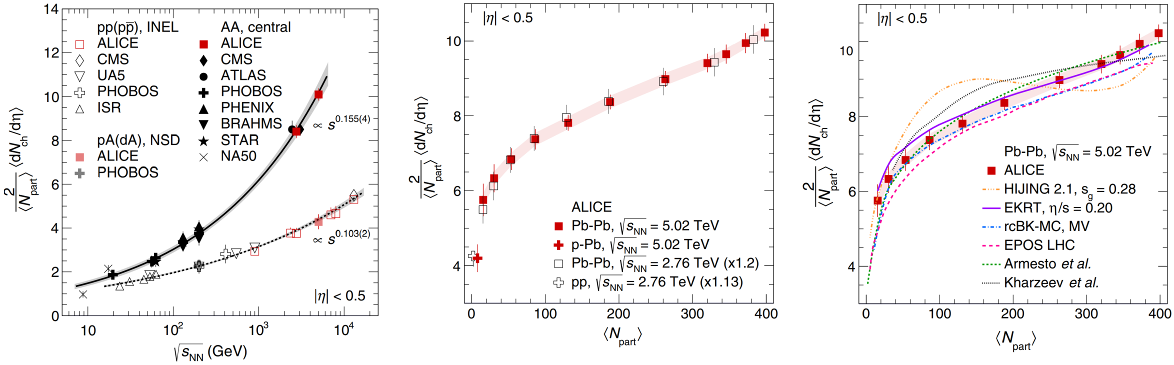
N_{ch} IN pp COLLISIONS





$$\text{INEL} \propto s^{0.103}$$
$$\text{INEL}_{>0} \propto s^{0.111}$$

N_{ch} in Xe – Xe collisions



- HIJING using gluon shadowing parameter $s_g = 0.28$
- EPOS based on Gribov-Regge theory incorporated with collected effect
- Saturation-inspired models : rcBK-MC, Armesto, Kharzeev and EKRT

- Published multiplicity papers

Type	$\sqrt{s}$ (TeV)	paper
pp	0.9, 2.76, 7 and 8	Eur. Phys. J. C 77 (2017) 33
	13	Phys. Lett. B 753 (2016) 319-329

- Reference data to study nuclear effect
  - in nucleus–nucleus
  - in proton–nucleus collisions
- Big contribution from non-perturbative QCD processes
  - INEL[1] : ND + SD + DD + CD ...
  - NSD : ND + DD (to ignore large uncertainty from SD)
  - $\text{INEL}_{>0}$: INEL + at least one activity in $|\eta| = 1$ (effective filter for SD and DD events)

[1] INEL = ND(~ 70 %) + SD (~ 20 %) + DD (~ 10 %) + CD (< 1 %) arXiv:1208.4968

N_{ch} in $\text{p}-\text{Pb}$ collisions

- Published (ongoing) multiplicity papers

Type	$\sqrt{s_{\text{NN}}}$ (TeV)	paper
p-Pb	5.02	PRL 110 (2013) 032301
	8.16	preliminary

- Valuable tool to discriminate between
  - final state effects in nucleus–nucleus
  - initial state effect of nuclei themselves
- N_{ch}
  - Discriminate the initial and final state effects
  - A tool to study the various models of gluon saturation[1]
  - Providing constraints to the initial state and small Bjorken-x modeling

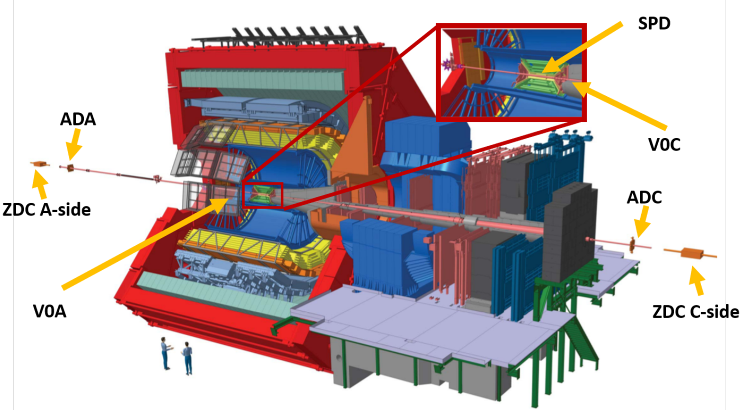
[1] Different descriptions of the upper limit in growth of the parton density

- Published (and ongoing) multiplicity papers

Type	$\sqrt{s_{NN}}$ (TeV)	paper
Pb-Pb	2.76	Phys. Rev. Lett. 106, (2011) 032301
	5.02	Phys. Rev. Lett. 116 (2016) 222302
Xe-Xe	5.44	

- N_{ch} : A key observable in the QGP (initial energy density)
- Impact parameter (b): The degree of geometrical overlap
- Centrality : Experimental proxy of b
- N_{part} : the number of nucleons participating in the collision
- N_{coll} : the number of binary nucleon-nucleon collisions among the participant nucleons

- 17 different detectors, Low p_T sensitivity, excellent PID



Trigger detectors

	η_{min}/η_{max} A side	C side
SPD	-2/2	
V0	2.8/5.1	-3.7/-1.7
AD	4.8/6.3	-7/-4.9
ZDC	$\sim \pm 10$	

SPD (Silicon Pixel Detector)

- Innermost two-layer silicon detector
- r = 3.9, 7.6 cm
- Triggers central activity

V0 (Scintillator hodoscopes)

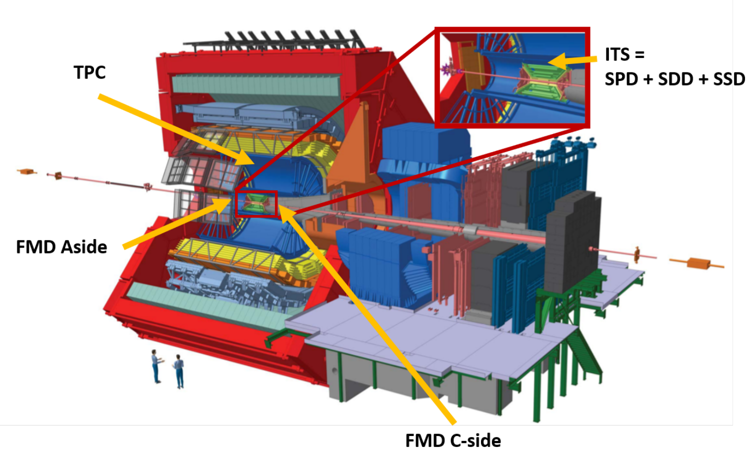
- Triggers forward activity
- z = -0.9, 3.3 m

AD (Alice Diffraction)

- Scintillation counters
- z = -19.5, 17 m

ZDC :

- 17 different detectors, Low p_T sensitivity, excellent PID



Data taking detectors

	η_{min}/η_{max} A side	C side
ITS	-1.4/1.4	
TPC	-0.9/0.9	
FMD	1.7/5.1	-3.4/-1.7

ITS (Inner Tracking System)

- 6 layers of Si detectors
- Containing SPD

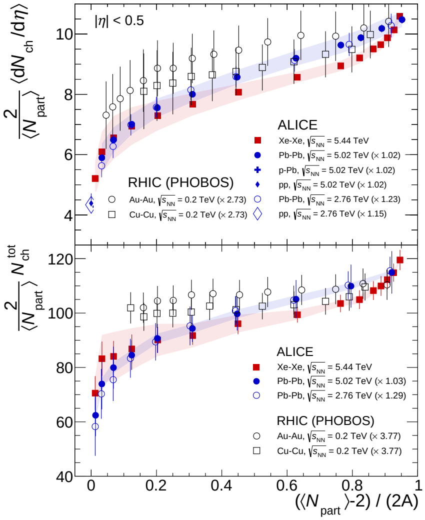
TPC (Time Projection Chamber)

- Large cylindrical detector
- -250< z <250 cm
- 86< r <250 cm
- 558 k readout channels

FMD (Forward Multiplicity Detector)

- Two sets of Si strip sensors
- close to V0 detectors

$\frac{2}{\langle N_{part} \rangle} \langle dN_{ch}/d\eta \rangle$ AND $\frac{2}{\langle N_{part} \rangle} N_{ch}^{tot}$ AS A FUNCTION OF CENTRALITY



Data are scaled to $\sqrt{s}$, $\sqrt{s_{NN}} = 5.44$ TeV (prev.) to match with Xe–Xe results.

- ALICE data decreasing by 2 from the most central to the peripheral
- smoothly connect to pp and p–Pb

A Large Ion Collider Experiment

V0 (Scintillator hodoscopes)

- triggers forward activity
- -3.7< η <-1.7, 2.8< η <5.1

SPD (Silicon Pixel Detector)

- Two-layer silicon detector
- counting tracklets at mid rapidity
- -2< η <2

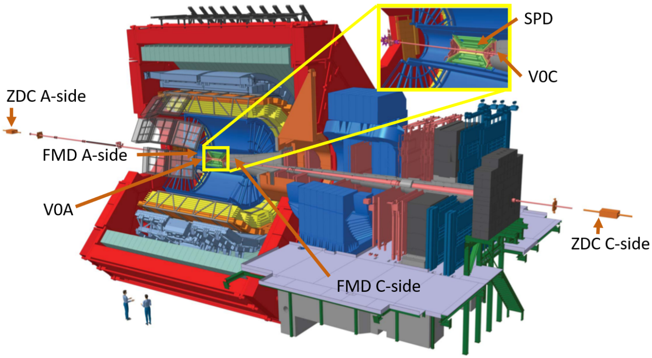
FMD (Forward Mult. Detector)

- three sets of Si strip sensors
- counting N_{ch} at forward rapidity
- -3.7< η <-1.7, 1.7< η <5.1

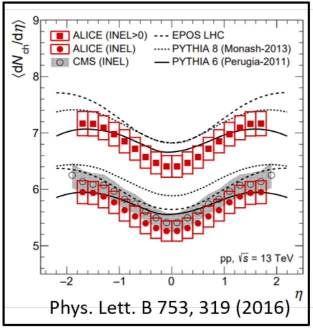
ZDC (Zero Degree Calorimeter)

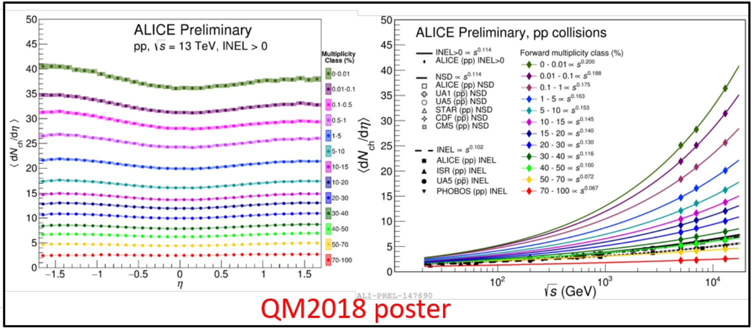
- measuring E of spectator nucleons
- $\eta \sim \pm 10$

- 18 detectors, sensitivity at low p_{T}, excellent PID



$\langle dN_{ch}/d\eta \rangle$ in pp collisions





- Inclusive study : INEL $\propto s^{0.102}$, NSD $\propto s^{0.114}$ and $\mathrm{INEL}_{>0}$[1] $\propto s^{0.114}$
- Multiplicity dependence study[2]
  - $\langle dN_{ch}/d\eta \rangle$ for different multiplicity classes
  - The evolution of $\langle dN_{ch}/d\eta \rangle$ with $\sqrt{s}$: steeper for higher multiplicity class (MPI)

[1] INEL requiring at least one charged particle in $|\eta| = 1$

[2] "Multiplicity dependence study of the η-density distribution of charged particles in pp collisions with ALICE" by Prabhakar Palni

Charged-particle multiplicity density studies on various collision systems and energies in centre of mass

pp and p–Pb collisions

- Compared to various theoretical models: for p-Pb better agreement with saturation based models
- $|\eta| < 0.5$ $\langle dN_{ch}/d\eta \rangle$ ($|\eta| < 0.5$) in p–Pb fits with INEL pp points

Pb–Pb and Xe–Xe collisions

- The high statistics distributions are useful to constrain the available models
- $\frac{2}{\langle N_{part} \rangle} \langle dN_{ch}/d\eta \rangle$ and $\frac{2}{\langle N_{part} \rangle} N_{ch}^{tot}$ for the top 5% central Xe–Xe collisions in agreement with the previous AA power-law trend
- steep rise of $\frac{2}{\langle N_{part} \rangle} \langle dN_{ch}/d\eta \rangle$ and $\frac{2}{\langle N_{part} \rangle} N_{ch}^{tot}$, and N_{part}-scaling violation for the 0–5% central Xe-Xe

- Update of the Xe–Xe paper done by reflecting all comments
  - New binning Pb–Pb results updated
  - Particle production model fitting redone for the new results
  - all answers for the referee prepared
- Uptick study on $\frac{2}{\langle N_{\text{part}} \rangle} \langle \mathrm{d}N_{\text{ch}}/\mathrm{d}\eta \rangle$ in Pb–Pb and Xe–Xe data
  - The whole effect is global in η, not local.
  - The effect is not relevant to σ_{NN} fluctuation.
  - Multiplicity fluctuation for a given $\langle N_{\text{part}} \rangle$ and partly artificial effect of the centrality slicing.
  - Contribution from the multiplicity bias (but expected to be small) could be related partially.