ALICE Experiment: Present and Future

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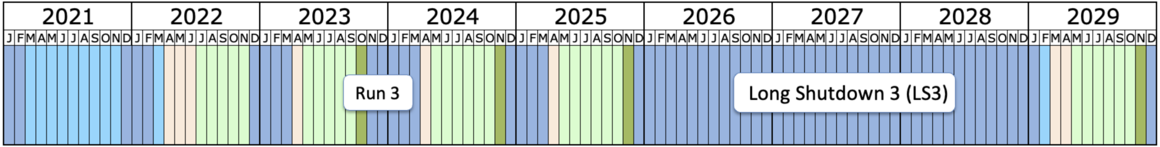
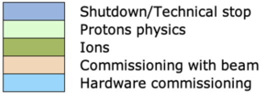
University of Jyväskylä, **Particle Physics Day 2023, Jyväskylä, Finland**

12.10.2023

ALICE present and near future

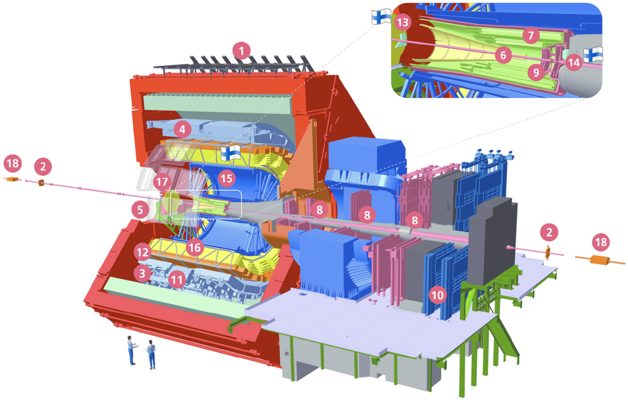


https://lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm



- ALICE strategy for Run 3
  - 50 kHz Pb–Pb interaction rate (Run 2 $<$ 10 kHz)
  - Experiment upgrades during LS2
  - Continue to collect pp with high multiplicity trigger and achieve Pb–Pb (x 3 more precise tracking and x 100 statistics increase)
- Physics goals : CERN Yellow Rep.Monogr. 7 (2019) 1159-1410
  - High-precision measurement($h^{\pm}$, PID..) $\rightarrow$ Viscosity and further QCD transport coefficients.
  - Heavy-flavours and jets $\rightarrow$ Investigating the quasi-particle structure of QCD matter.
  - Charmonium states $\rightarrow$ Testing colour screening and regeneration dynamics.
  - Dileptons and low-mass vector mesons $\rightarrow$ χ symmetry restoration, initial temperature and EoS.

Upgraded Experiment – ALICE 2

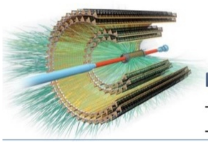


ALICE Collaboration:
40 countries, 170 institutes, 1972 members
360 papers.
ALICE Finland:
3 seniors, 3 post doc, 4+1 PhD-students

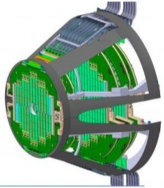
ALICE 2 is build on the great success of the past 10 years operation.
TPC(detector (15)), FIT((2) + (13) + (14) + (17)), ALICE Grid Tier-1 since 2007

Key elements of ALICE Upgrades for Run 3, installed in 2019–2021

6 to 7 layers, $|\eta| < 1.0 \rightarrow 1.5$, $1 \rightarrow 100$kHz(Pb–Pb)

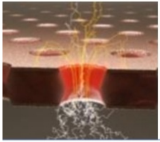


New Inner Tracking System (ITS)
- -CMOS pixel, MAPS technology
- -Improved resolution, less material, faster readout



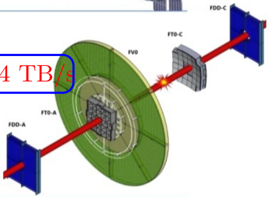
New Muon Forward Tracker (MFT)
- -CMOS Pixels, MAPS technology
- -Vertex tracker at forward rapidity

$\psi(2S)$ S/B x5



New TPC Readout Chambers (ROCs)
- -Gas Electron Multiplier (GEM) technology
- -New electronics (SAMPA), continuous readout

50kHz Pb–Pb, $\approx$ 34 TB/s



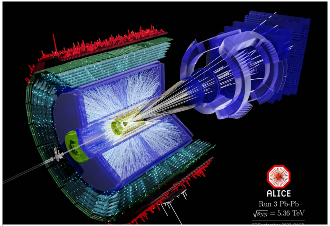
New Fast Interaction Trigger (FIT) Detector
- -Centrality, event plane, luminosity, interaction time

Readout upgrade
- -TOF, TRD, MUON, ZDC, Calorimeters

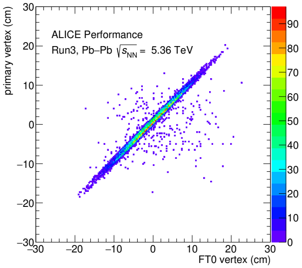
Integrated Online-Offline system (O²)
- -Record MB Pb-Pb data at 50 kHz

ALICE upgrades: arXiv:2302.01238
ITS: NIM 1032(2022)166632
TPC: JINST 16 P03022 (2021)
FIT: NIM 1039 (2022) 167021

- 05.07.2022: start of Run 3
- pp collisions at $\sqrt{s} = 0.9$ and 13.6 TeV ($\approx 30\ pb^{-1}$)
- 17-18.11.2022: Pb–Pb pilot run ($766 \cdot 10^9$, $2.6 \cdot 10^9$[Run2])
- 26.10.2023 : Pb–Pb
  - Pb–Pb: started with ≈ 15 kHz
  - 47 kHz on 9th Oct

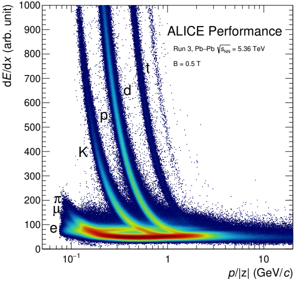


Vertex



ALI-PERF-529916

PID



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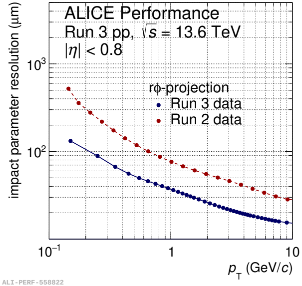
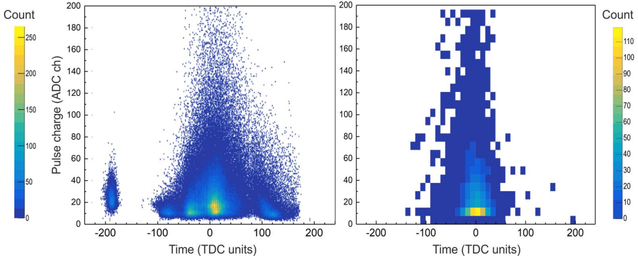


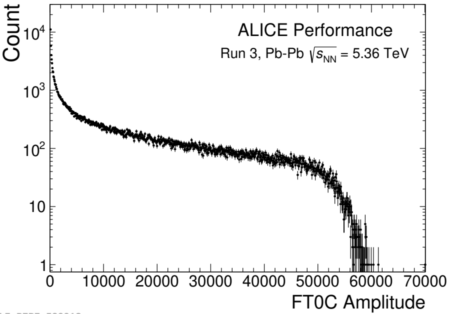
ALI-PERF-558822

- Following the 2022 YETS, pp collisions were back in April 2023
  - FIT operated well while being commissioned for the upcoming Pb–Pb
  - Successful van der Meer scans for luminosity calibrations
- Hardware and electronics updates:
  - FT0-C re-cabling to avoid signal reflections → cleaner or C trigger
  - FDD re-cabling to enable layer coincidence requirements in triggers → cleaner triggers
  - New mezzanine boards in the processing modules of FV0 and FDD → larger dynamic range, improved time measurement



- Software (O^2) and detector control system (DCS) updates:
  - Online calibration for time offsets and new features for online and offline data quality control (O^2)
  - New laser calibration procedure with dedicated quality control (QC) software to monitor aging of FT0 (DCS & O^2)
  - New procedures to backup hardware and trigger settings to be used in QC and anchored MC (DCS & O^2)
  - Automated laser scans to determine detector channel health and map out dead channels for QC and anchored MC (DCS & O^2)
  - Centrality and Event Plane calibration is prepared (O^2)

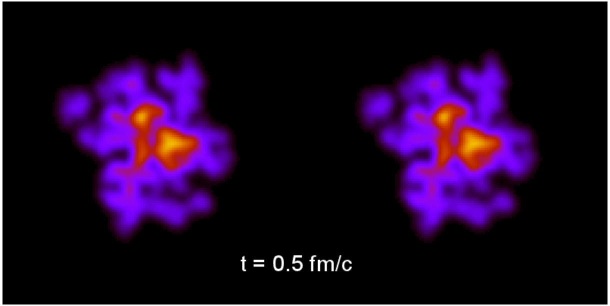
Collision Centrality



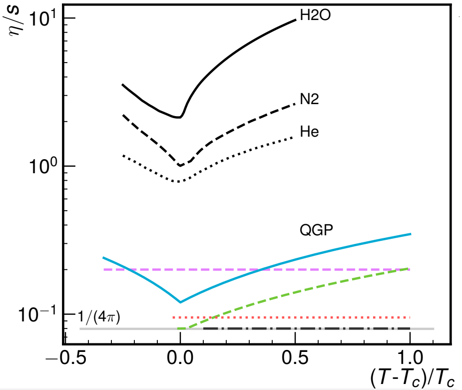
ALI-PERF-529913

FIT Video Link

Initial geometry fluctuations → Transport $\delta_\mu T^{\mu\nu} = 0$ (η/s) → final-state particles



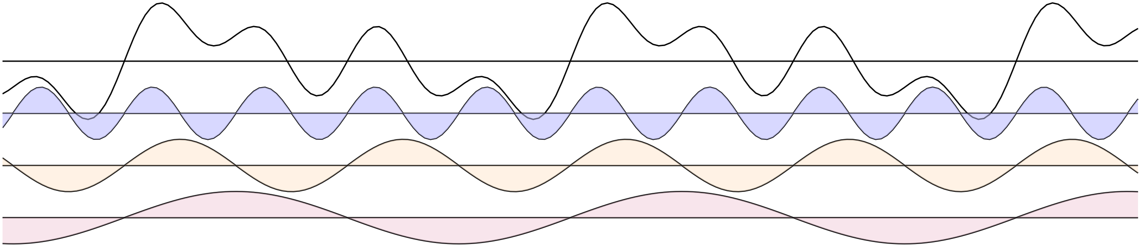
Ideal hydrodynamics vs Viscous hydrodynamics(η/s=0.16)



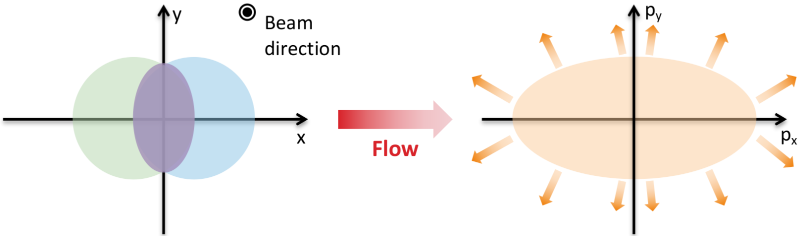
Quark-gluon plasma (QGP) is a nearly perfect guark-gluon fluid:
Best fit seems to indicate $\eta/s \approx 0.12$ around $T_c \approx 150$ MeV, very close to $1/4\pi$ (≈ 0.08) from string theory[a](AdS/CFT correspondence).

[a]D. T. Son et. al. Phys. Rev. Lett. 94 (2005) 111601

Flow measurements



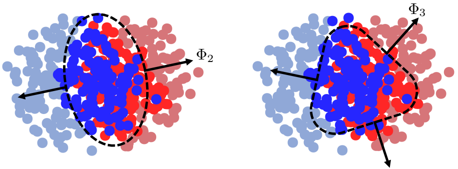
Anisotropic flow briefly



$\longrightarrow$ Anisotropic flow = medium response to the initial geometry

$$V_n \equiv v_n e^{in\Psi_n}$$

$$f(\varphi) = \frac{1}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\varphi - \Psi_n))\right)$$



Credits to M. Lesch

S. Voloshin *et al.*, Z. Phys. C **70**, 665–672 (1996)

Recent sensitivity studies of flow observables to model parameters

$\longrightarrow$ **Higher sensitivity of higher-order flow observables to QGP properties!**

Ongoing new developments

- Experimentally
  - symmetric to asymmetric cumulants: arXiv:2303.13414 accepted by PRC, C. Mordasini, A. Onnerstad **New**
- Phenomenology: Inclusion of RHIC data in Bayesian analyses, M. Virta **New**

"Why do we need independent observables to improve our understanding of the QCD matter properties; how?"

(See Maxim's talk)

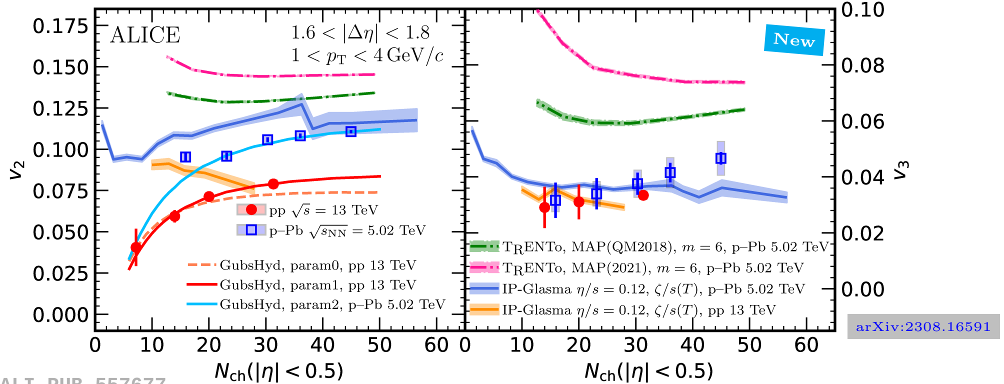
$S[x_j]$	$dN_{ch}/d\eta$	$dN_{p^\pm}/d\eta$	$\langle p_{T,\pi^\pm}\rangle$	$\langle p_{T,K^\pm}\rangle$	$\langle p_{T,p^\pm}\rangle$	$\rho_{4,22}$	$\rho_{5,23}$	$\rho_{6,222}$	$\rho_{6,33}$	NSC(3,2)	NSC(4,2)	NSC(4,3)	NSC(2,3,4)*	NSC(2,3,5)*	NSC(2,4,6)*
τ_{fs}	0.00	0.17	1.05	1.01	0.85	1.25	1.26	1.98	1.44	0.65	6.25	12	30	2.07	40
$(\eta/s)_{slope}$	0.00	0.14	0.19	0.19	0.18	1.74	1.37	3.03	1.36	0.70	7.02	1.70	34	30	1.06
T_c	0.00	0.25	0.03	0.03	0.04	0.80	0.40	0.45	0.61	0.41	3.53	1.44	4.46	7.15	0.21
$\eta/s(T_c)$	0.00	0.08	0.22	0.21	0.14	2.53	1.27	2.85	2.76	1.61	15	9.80	22	29	14
$(\eta/s)_{crv}$	0.00	0.17	0.05	0.05	0.05	0.40	0.40	0.73	0.75	0.13	1.81	4.72	2.20	8.41	6.17
$(\zeta/s)_{peak}$	0.01	0.44	1.16	1.01	0.73	0.34	1.59	1.04	1.15	1.49	1.49	2.57	3.74	2.04	15
$(\zeta/s)_{max}$	0.00	0.07	1.05	0.96	0.77	0.52	0.64	1.26	0.59	0.44	1.43	8.00	3.02	1.58	2.91
$(\zeta/s)_{width}$	0.00	0.01	0.20	0.15	0.07	0.39	1.66	1.55	1.35	0.38	1.41	1.21	1.77	23	19
T_{switch}	0.01	1.34	0.25	0.21	0.16	3.95	2.42	1.98	1.00	1.96	17	13	4.08	0.47	6.22

J.E. Parkkila *et al.*, PLB **835**, 137485 (2022)

These flow observables and our Baysian analysis were highlighted in ALICE White paper, arXiv:2211.04384 $\leftarrow$ synergy with the local theory group

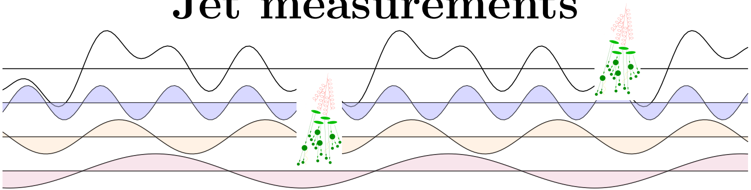
Flow or QGP in small systems

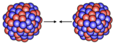
- Strong collective behaviour associated with the QGP formation in large systems
- In recent years, collectivity also observed in small systems (eg. ALICE, JHEP 05 (2021) 290, Phys. Lett. B 719 (2013) 29-41)
  $\longrightarrow$ **Presence of strongly interacting medium in small systems?**
- **Problems**: Flow measurements strongly biased by non-flow effects, jets and resonance decay
- **Solutions**:
  - latest development is published
    in hep-ph, PRC **108**, 034909 (18.09.2023), T. Kallio, M. Virta **New**
    $\rightarrow$ gives a definitive suggestion on how to extract flow signals in small systems
  - experimental verifications of the non-flow subtraction and hydro limits
    in ALICE, arXiv:2308.16591 (31.08.2023, submitted to JHEP) A. Onnerstad **New**



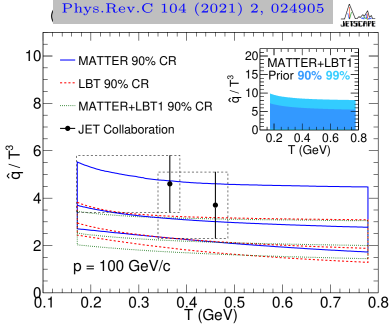
- Verified the validity of the non-flow subtraction in small systems
- Testing the limit of the multiplicity in the flow signal
- Comparison to the state-of-the-art model, pointing to the shortage of the models and discussing the hydro limits in small systems.
- Excellent inputs to developments of the models for small systems, including MC-based models.

Jet measurements

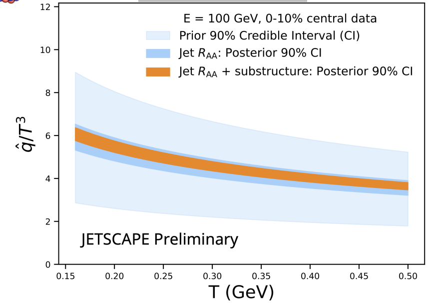


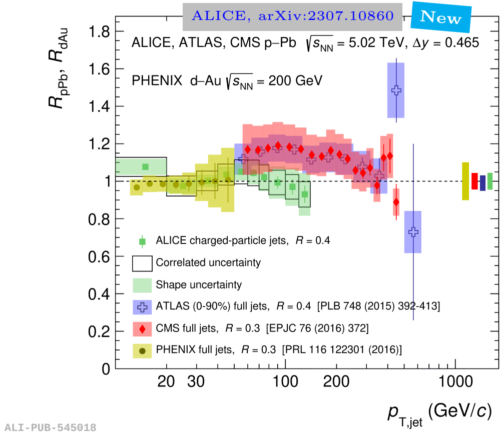


Phys.Rev.C 104 (2021) 2, 024905

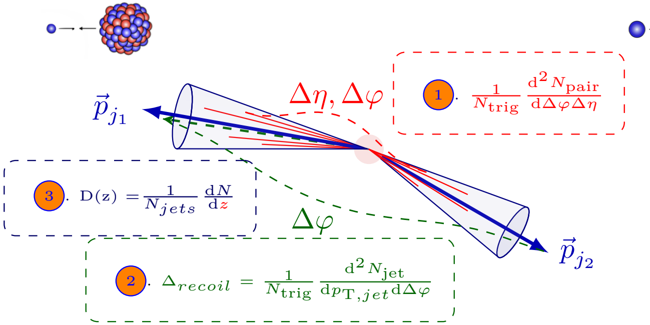


Quark Matter 2023



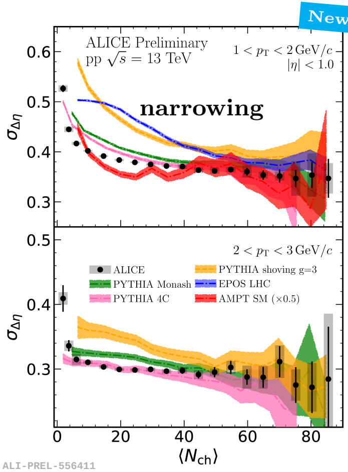


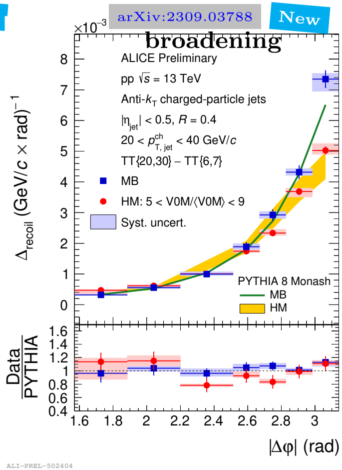
- Even though flow signatures are observed
- No sign of jet quenching in small systems



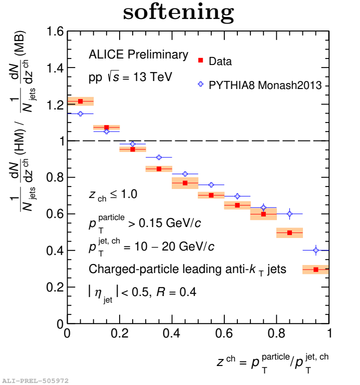
What about pp collisions at $\sqrt{s} = 13$ TeV?

1. hadron-hadron correlations?
2. hadron-jet correlations?
3. intra-jet correlations?



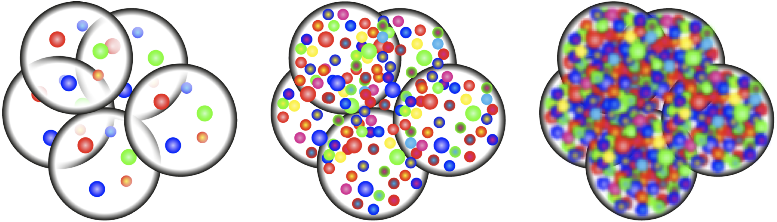


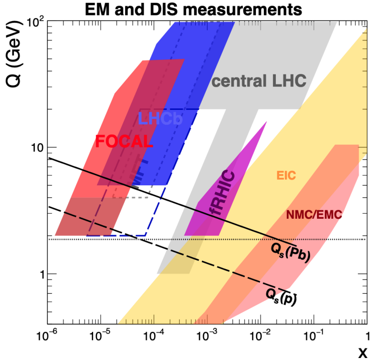
QM2023



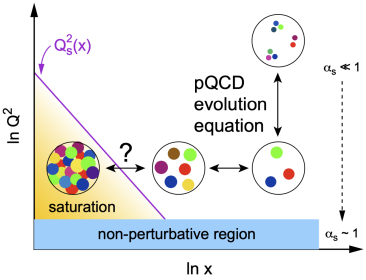
- **The similar modifications are also seen in the PYTHIA8 model.**
- To identify jet quenching, first disentangle these observed effects.

A Forward Calorimeter (FoCal) in ALICE

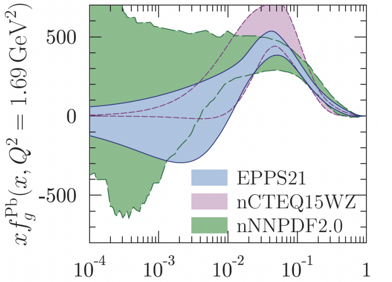




T. Lappi, H. Mantysaari et al.



K.J. Eskola, H. Paukkunen et al.



Eur.Phys.J.C 82 (2022) 5, 413, EPPS21

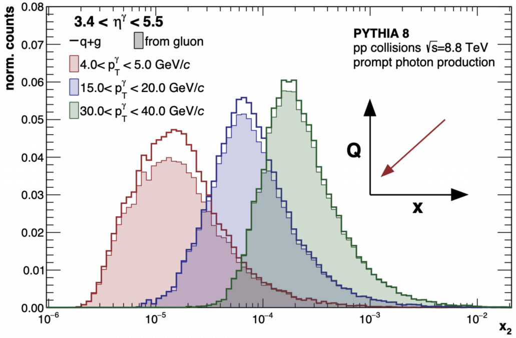
- FoCal acceptance, located ≈ 7 m from IP of ALICE , $3.4 < \eta < 5.8$
- Non-linear QCD evolution to study saturated state of gluonic matter at small and moderate Q^2
- Nuclear modification of the gluon density at small$-x$:
  global analyses (DIS, p+A) EPPS21, nCTEQ15, nNNPDF3.0
- Synergy with the local theory group

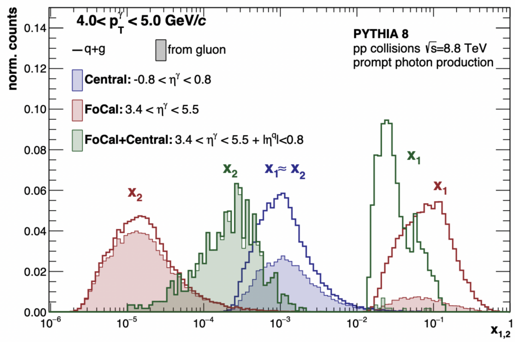
- Isolated photons, azimuthal correlations: $(\pi^0, \gamma^{iso}, \text{jet})_{trigg}$ x $(\pi^0, \text{jet})_{assoc}$.
- Vector meson photoproduction in ultra-peripheral collisions (UPC)
- Long-range flow correlations
- Jet quenching at forward rapidities
- ...

Physics of the ALICE Forward Calorimeter upgrade: ALICE-PUBLIC-2023-001

Photons

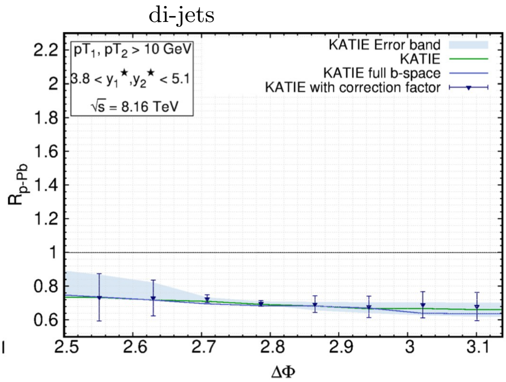
$$x_{1,2} \approx \frac{2p_{\mathrm{T}}\ exp(\pm y)}{\sqrt{s}}$$

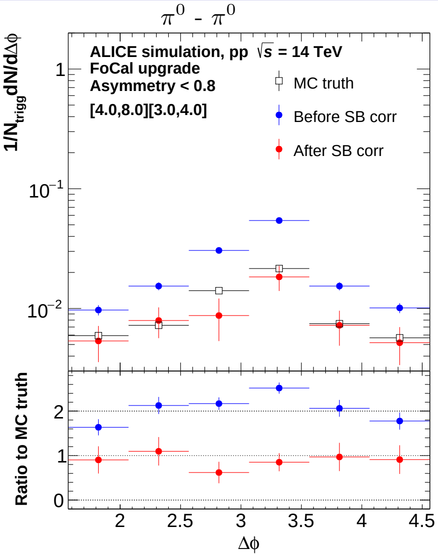




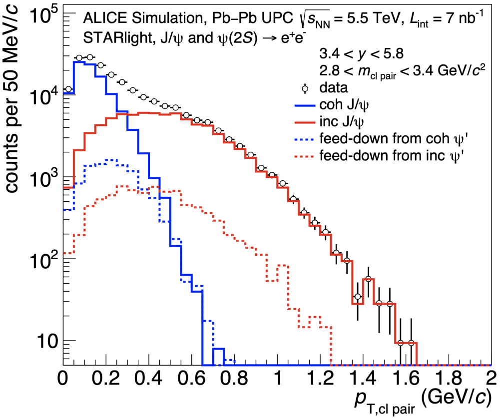
- Isolated photons
- Azimuthal correlations: $(\pi^0,\ \gamma^{iso},\ \text{jet})_{trigg}$ x $(\pi^0,\ \text{jet})_{assoc}$.
- Combining measurements in FoCal with central detectors probes the full phase space of x_2

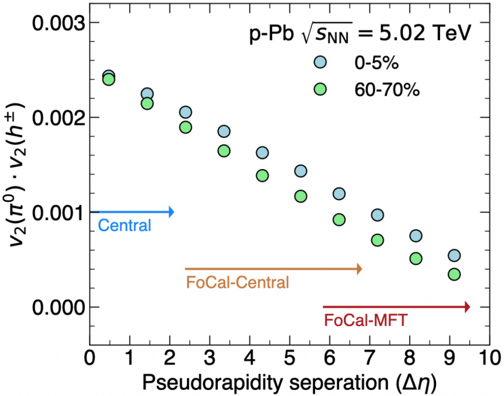
Foward di-jets and di-hadrons





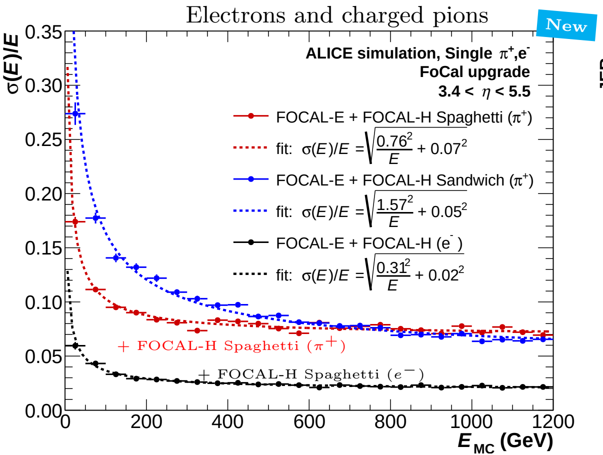
- di-jet acoplanarity in forward rapidity
- π^0's in the FoCal-E.
- Better side band subtraction method for both hemisphere than previous measurements.

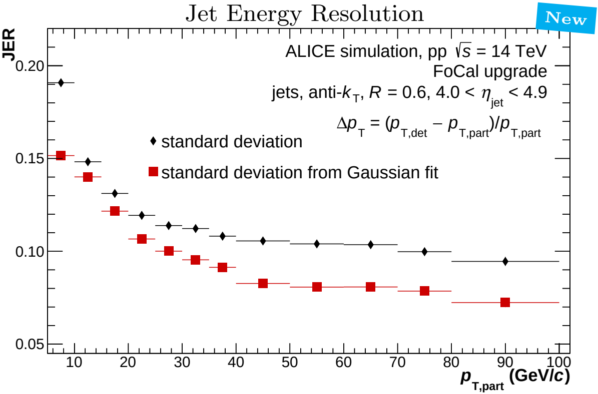




- Spatial distribution of small-x gluons and
- Sensitive to event-by-event fluctuations
- Provide valuable inputs to constraints for initial conditions

FoCal performance: Detector resolution





- Good energy resolution, can be improved by better clusterization?
- Details are in FoCal performance public note: ALICE-PUBLIC-2023-004

Summary and outlook

- LHC/ALICE is prepared for the future.
  - LS2 upgrade of ALICE is completion to exploit the higher rate and to improve the physics performance.
  - Running and development of FIT
- Sensitive and precise flow measurements improve understanding of the QCD matter properties from large to small system collisions.
  - Zeroing the uncertainties of the transport properties.
  - Deeper understanding of the initial conditions.
- Progress in measuring flow and jet in small systems, with remaining challenges in physics and measurements.
- Active work on FoCal technical design report
  $\Rightarrow$ FoCal performance public note: ALICE-PUBLIC-2023-004

- Significant pioneering contributions from Jyväskylä Univ.(Thanks to the collaborative efforts).
- A lot more to learn from Run 3 data.

Thank you for your attention!