Highlights from the ALICE experiment

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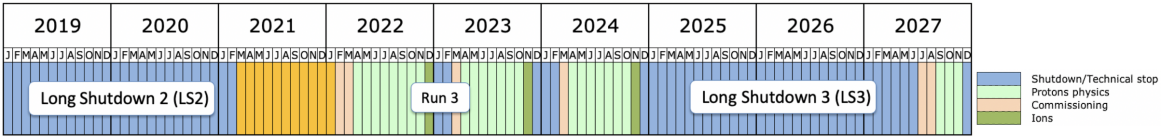
[1] University of Jyväskylä & Helsinki Institute of Physics, Finland

Nov, 5th, 2020

Particle Physics Days 2020

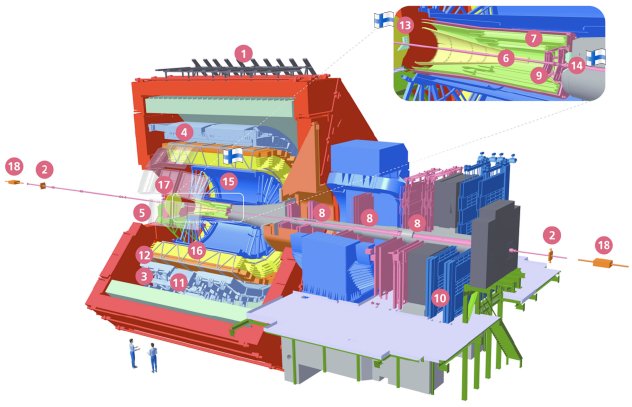
ALICE PRESENT AND NEAR FUTURE



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

- Start of the LHC Run 3
  - Extend Run 3 until end of 2024 (decided already pre-COVID)
  - LHC default scenario: cavern closes 1st February 2022
  - 4 months of ALICE Global Commissioning
- 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 PbPb (x 3 more precise tracking and x 100 statistics increase)
- Physics goals : CERN Yellow Report, arXiv:1812.06772
  - 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 $\rightarrow \chi$ symmetry restoration, initial temperature and EoS.

Upgraded Experiment – ALICE 2



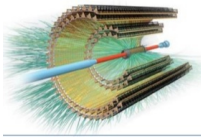
ALICE Collaboration:
39 countries, 175 institutes, 1927 members
311 papers.

ALICE Finland:
3 seniors, 1 post doc, 4 PhD-students
($\approx$ 0.5% of ALICE)

- Sami Räsänen (Team Leader, HIP project leader)
- Wladyslaw Trzaska (FIT project leader)
- DongJo Kim (Flow PWG convener)
- Maciej Slupecki (FIT software coordinator)
- Jasper Parkkila (PhD-student, flow, TPC)
- Heidi Rytkönen (PhD-student, flow, FIT)
- Oskari Saarimäki (PhD-student, jets, FIT)
- Anna Önnerstad (PhD-student, flow)

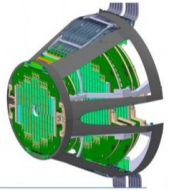
ALICE 2 is build on the great success of the past 10 years operation.
TPC(detector 15), FIT(2 + 13 + 14 + 17), ALICE Grid Tier-1 since 2007

Key elements of ALICE Upgrades for Run 3



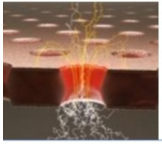
6 to 7 layers, $|\eta| < 1.0 \rightarrow 1.5, 1 \rightarrow 100$kHz(PbPb)

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



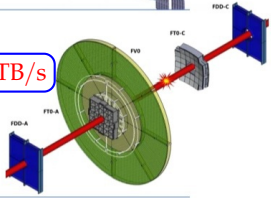
New Muon Forward Tracker (MFT)
-CMOS Pixels, MAPS technology
-Vertex tracker at forward rapidity

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



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

50kHz PbPb, $\approx$ 34 TB/s



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

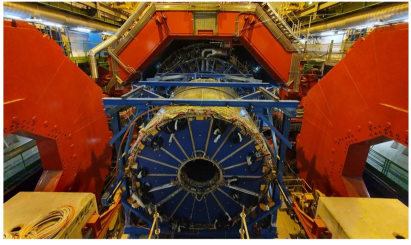
Readout upgrade
-TOF, TRD, MUON, ZDC, Calorimeters

Integrated Online-Offline system (O^2)
-Record MB Pb-Pb data at 50 kHz

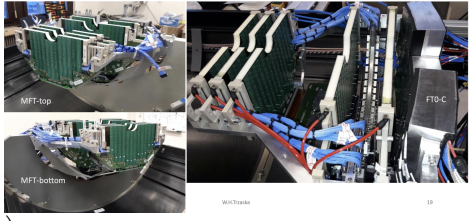
LS2 upgrade of ALICE experiment is nearing completion

Return of the upgraded TPC, 4 August 2020

Reinsertion of the TPC 6 August 2020

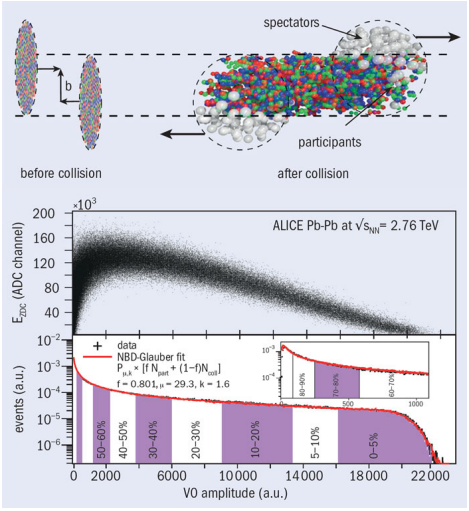


MFT and FT0-C ready for installation



W.H.Trzaska ALICE upgrade talk in NN2020 11-17 Oct.(Link)

Heavy-ion Collisions, Centrality and Particle productions



b=11.4-12.5fm

$N_{part} \sim 53$

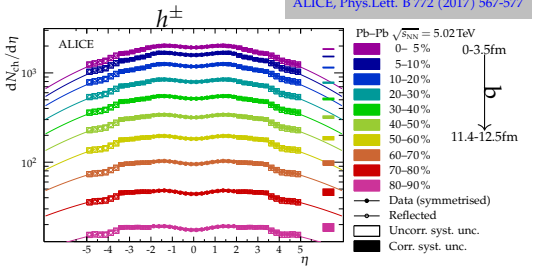
$N_{coll} \sim 100$

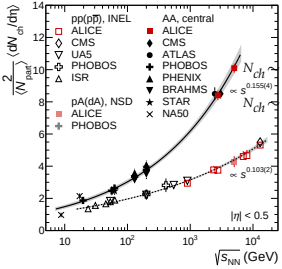
b=0-3.5fm

$N_{part} \sim 382$

$N_{coll} \sim 1685$

ALICE, Phys.Lett. B 772 (2017) 567-577

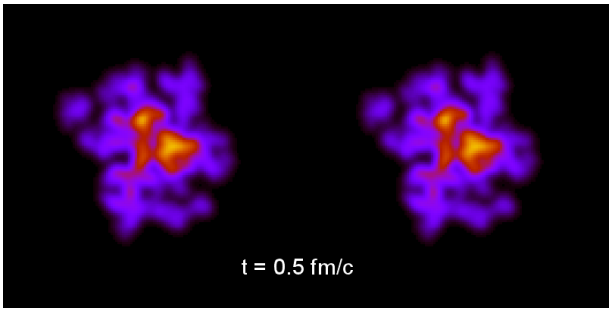




ALICE, Phys. Rev. Lett. 116 (2016) 222302

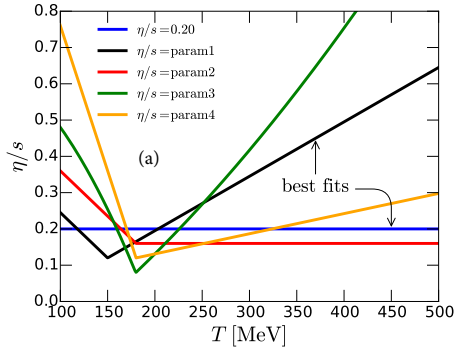
Space-time history of Heavy-Ion Collisions

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



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

H. Niemi, K.J. Eskola, R.Paatelainen:EKRT+Hydrodynamics
(Phys. Rev. C 93, 024907 (2016), arXiv:1505.02677)

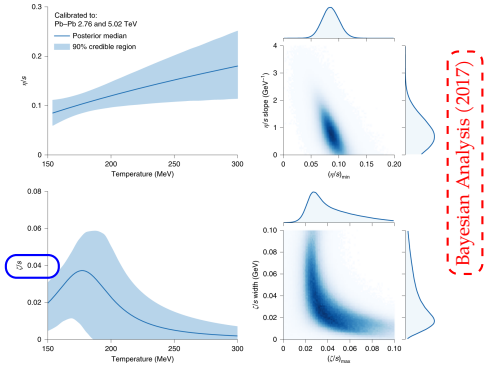


Quark-gluon plasma (QGP) is a nearly perfect guark-gluon fluid:
Best fit seems to indicate $\eta/s \approx 0.12$ around $T_c \approx 150$ MeV, very close to $1/4\pi$ (≈ 0.08) from string theory[a] (AdS/CFT correspondence).

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

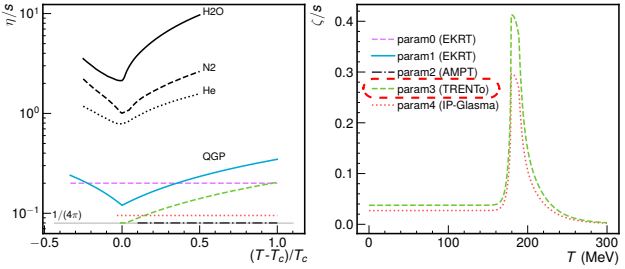
Current understanding of the medium properties

Steffen A. Bass *et. al*, Nature Physics (2019)



- ALICE data on multiplicity, spectra and flow are key inputs to estimate the properties of the QGP (including p–Pb data), i.e Global Bayesian Analysis and other theory groups.

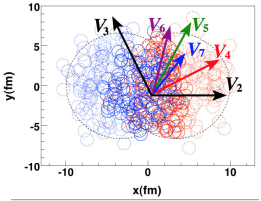
Various parameterizations used in latest hydrodynamic calculations

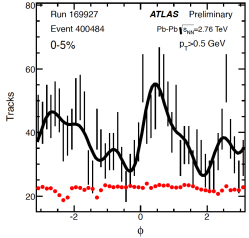


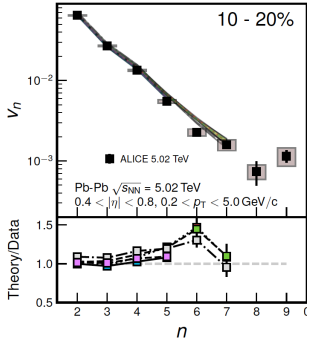
- Inclusion of $\zeta/s(T)$ [a] makes things complicated.
- Latest bayesian analysis gives very small $\zeta/s(T)$, 0.04 compared to 0.4 (x10).
- $\eta/s(T)$ and $\zeta/s(T)$ should be constrained further (larger uncertainties) by separating the effects from the initial conditions.

[a] Phys.Rev.Lett. 115 (2015) no.13, 132301

Higher Flow Harmonics Seen by All Experiments

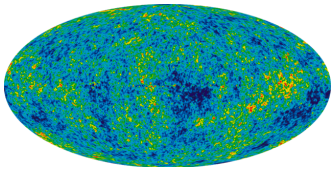


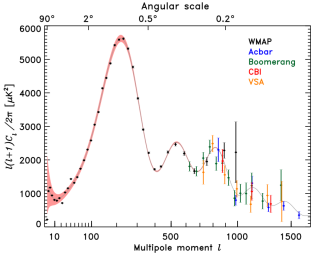




$$P(\varphi) \propto \frac{1}{2\pi} \sum_{n=-\infty}^{+\infty} V_n e^{-in\varphi}$$

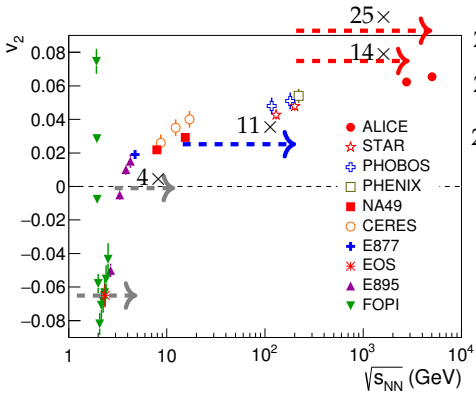
$$V_n \equiv v_n\{\psi_n\} e^{in(\psi_n - \phi)}$$





- Sensitive to initial state geometry and properties of the expanding QGP (viscosity(η/s), equation of state)
- Like measurements of early universe sound harmonics

v_2 VS $\sqrt{s_{NN}}$ AND FLOW POWER SPECTRUM



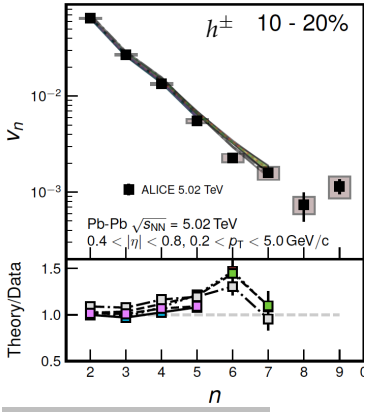
2015 LHC 5.02TeV CERN

2010 LHC 2.76TeV CERN

2000 RHIC 200GeV USA

90s SPS 17GeV CERN

80s AGS 4GeV USA



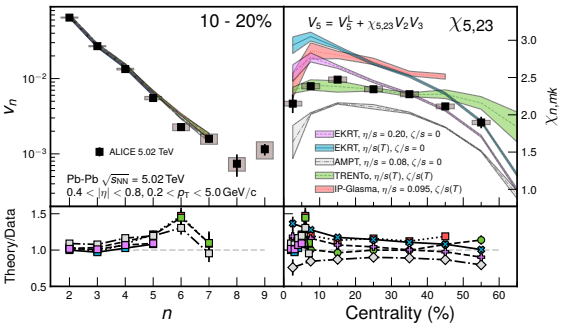
ALICE, PRL105 (2010) 252302

ALICE, JHEP05 (2020) 085, Jasper Parkkila

ALICE had measured the largest flow v_2 in 2010!
ALICE has measured the largest harmonic order flow(up to v_9) so far!

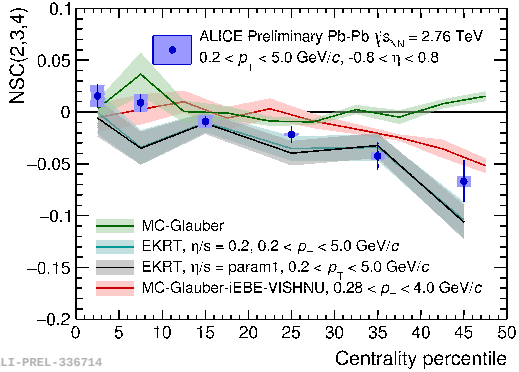
High precision flow results and New developments

Non-linear flow modes get dominant for $(n > 3)$



ALICE, JHEP05 (2020) 085, Jasper Parkkila

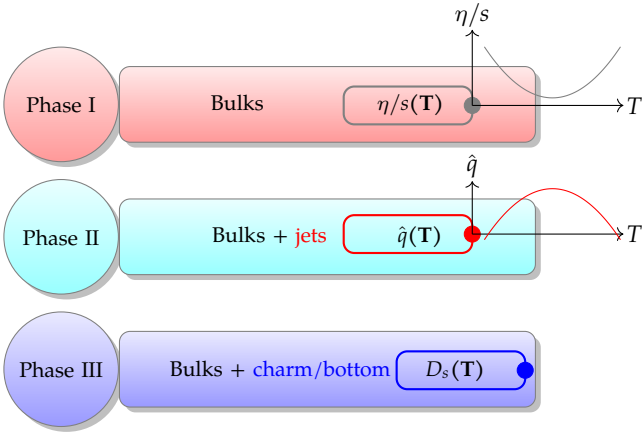
EbE three harmonic flow correlation, $\langle v_k v_l v_m \rangle$

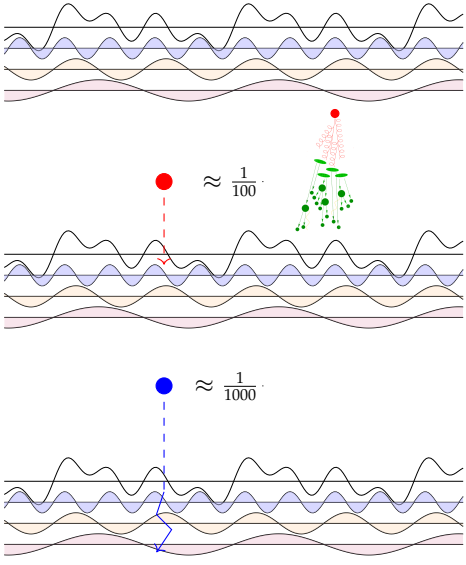


- Nonlinear components of high order harmonics are decomposed, showing better sensitivity for $\eta/s(T)$.
- Exponential decrease via viscosity damping, a hint that $v_9 > v_8$, acoustic peak?
- Three harmonic correlations might be more sensitive to $\zeta/s(\mathrm{T})$.
- Provide new and independent constraints for initial conditions and QGP properties.

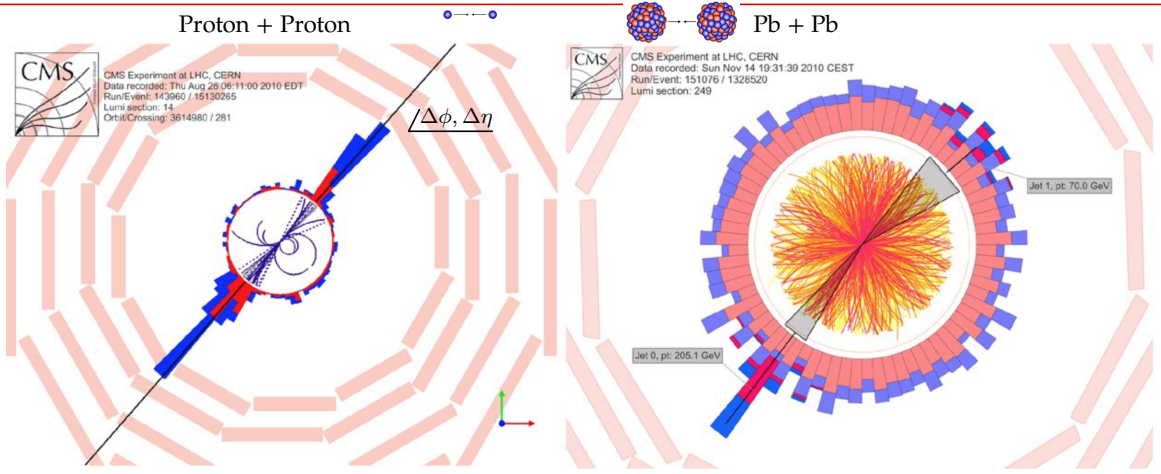
Two harmonic versions are published(PRL 117(2016)182301,PRC 97(2018) 024906).
Very challenging measurements because of their required high precisions (i.e 1e-6 SC(m,n), 1e-12 for SC(k,l,m))) and difficulties in correcting experimental biases.

Transport properties



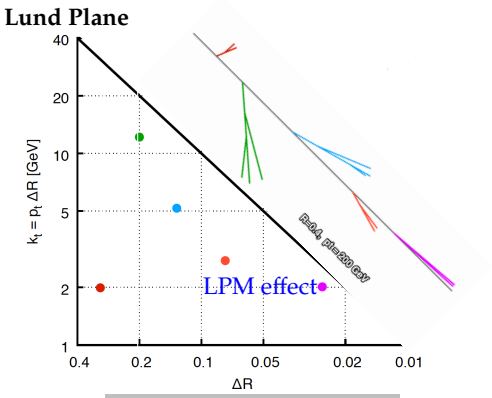


Di-Jet, Jet quenching can be seen visually



- We can see a clear away side jet suppression for this special PbPb event (Jet Quenching in QGP).

Deeper understanding of jet quenching is not an option

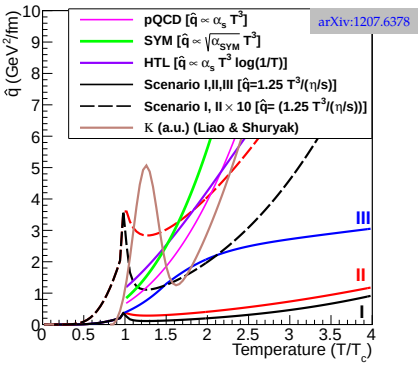


Gavin P. Salam, Dreyer, Soyez, GPS, in progress

$$< p_\perp{}^2 >= \hat{q} L,$$

$$\Delta E \sim \alpha_s \, C_F \, \hat{q} \, L^2.$$

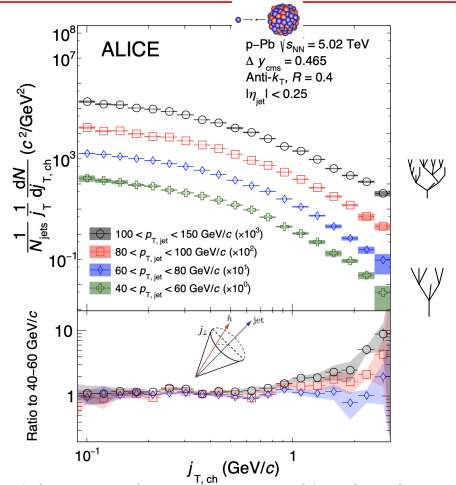
$C_F = 3$(gluon) and 4/3(quark)

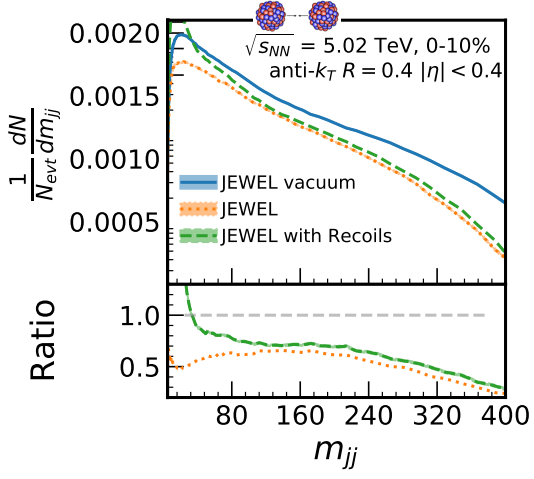


- How do T or scale dependent features translate to final state?
- An unambiguous determination of both sides of [the equation] from experimental data ? (Phys. Rev. Lett., 99:192301, 2007)

$$\frac{\eta}{s} \left\{ \begin{array}{c} \approx \\ \gg \end{array} \right\} 1.25 \, \frac{T^3}{\hat{q}} \qquad \left\{ \begin{array}{l} \text{for weak coupling,} \\ \text{for strong coupling.} \end{array} \right.$$

Further constraining Jet quenching model with j_T and m_{jj}, Jet virtuality evolution

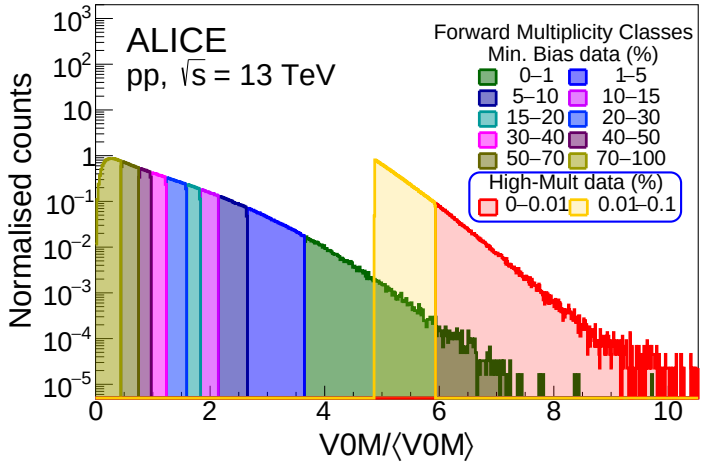




- Modification of transverse profile of jet fragmentation - about to be submitted to JHEP.
- Proving medium path length via di-jets[1]-[Oskari Saarimaki, p-Pb(being done), PbPb(from 2021)]

[1] PRC 75 (2007) 054910, JEWEL(JHEP 1707 (2017) 141)

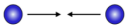
13TeV pp high multiplicity trigger

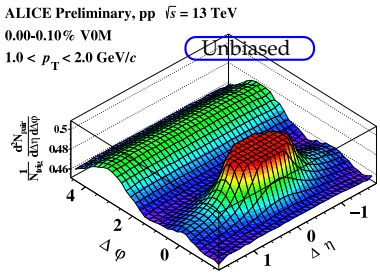


- Full 13TeV pp data sets including high multiplicity triggered events.
- The studies on different multiplicity selection biases - submitted to EPJC (arXiv:2009.09434)

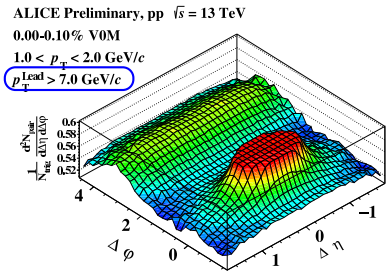
Event scale dependent ridge/flow studies in pp collisions

Top 0.1% high multiplicity events



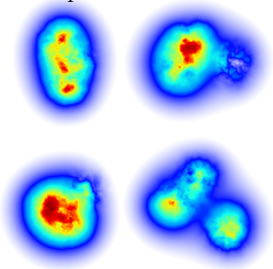


ALI-PREL-319153



ALI-PREL-319168

Fluctuating gluon density in a proton



Heikki Mantysaari et al., PRL 117, 052301

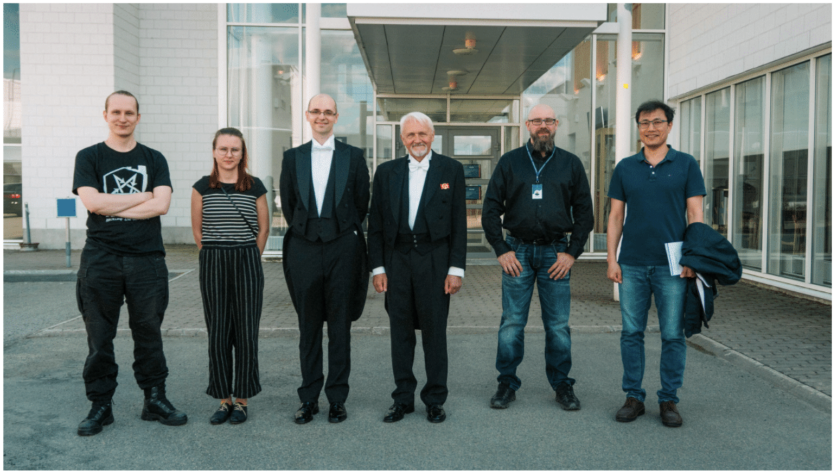
- The ridge/flow is observed clearly for hard events for the first time.
- Additional information on initial states via jet or multi-jet events, the impact parameter dependence.
- Initial state or final state effects?
  - importance of detailed fluctuating gluon density in a proton.
- The analysis can be improved significantly with high luminosity pp running during Run 3 and 4.

Summary

- Precision measurements on soft observables
  - Higher precision data on $\langle dN_{ch}/d\eta \rangle$, spectra and v_n become "Run"-ly routine.
  - $\langle v_m v_n \rangle$ correlations and the nonlinear response of v_n(n>3) $\rightarrow$ Strong constraint on the η/s(T).
  - ζ/s(T) should be better constrained with new observables, i.e $\langle v_k v_l v_m \rangle$.
  - Significant role in the ALICE review paper in preparation.

- No one thought that temperature dependence of the medium properties would be accessible with the experimental data (K.J. Eskola, Jyväskylä colloquium, March 2015).
- Significant pioneering contributions from Jyväskylä Univ.(Thanks to the collaborative efforts).
- A lot more to learn from Run 3 and 4 data including jets and heavy flavours.

- LHC/ALICE is being prepared for the future.
  - LS2 upgrade of ALICE experiment is nearing completion to fully exploit the higher rate and to improve the physics performance.
    - x 3 more precise tracking
    - x 100 statistics increase for Run 3 and Run 4



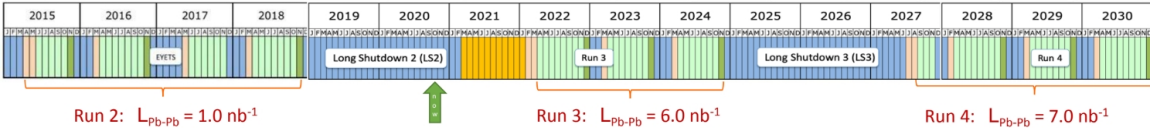
Oskari, Heidi, Maciej, Wladek, Sami, DongJo

Celebrating Maciej's defence on 12th Jun 2020

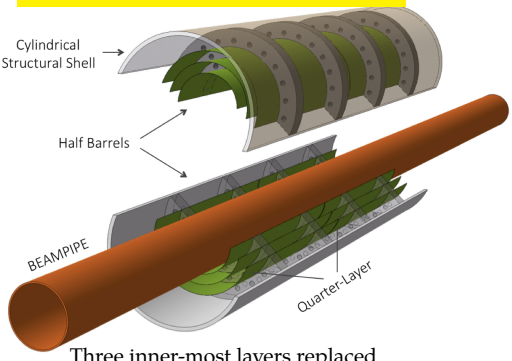
Jasper missing from Figure, Anna started 1st Sep 2020

Thank You!

ALICE Upgrades for Run 4



Ultra-light Inner Tracking System 3

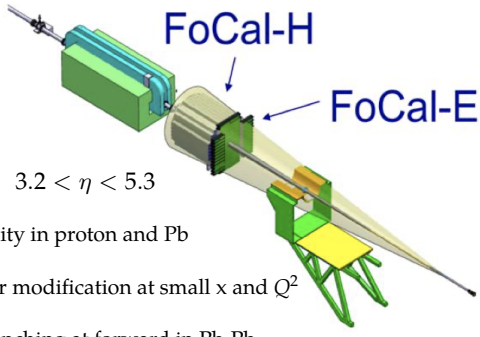


Three inner-most layers replaced

ALICE-PUBLIC-2018-013

Forward Calorimeter

LoI CERN-LHCC-2020-009



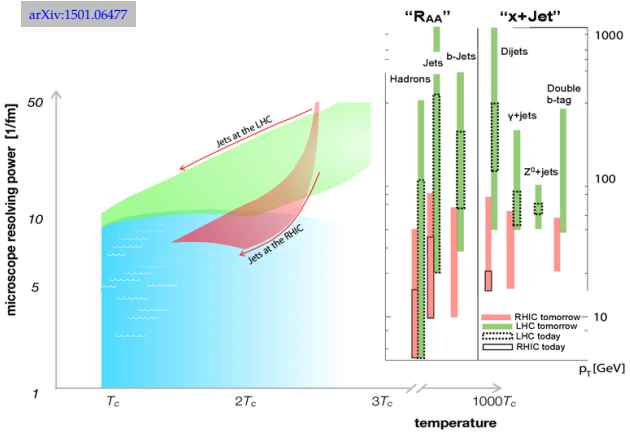
$3.2 < \eta < 5.3$

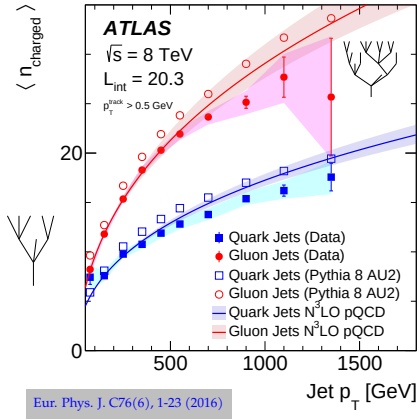
g-density in proton and Pb

nuclear modification at small x and Q^2

Jet quenching at forward in Pb-Pb

Jet virtuality evolution matters with medium temperature





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- Jet virtuality evolution paths simultaneous with the QGP temperature evolution for central Au+Au and Pb+Pb collisions at RHIC and the LHC
- Jet tomography in medium gets complicated with p_{T} or flavor dependent shower evolution.