Highlights from ALICE

Michael Weber for the ALICE Collaboration

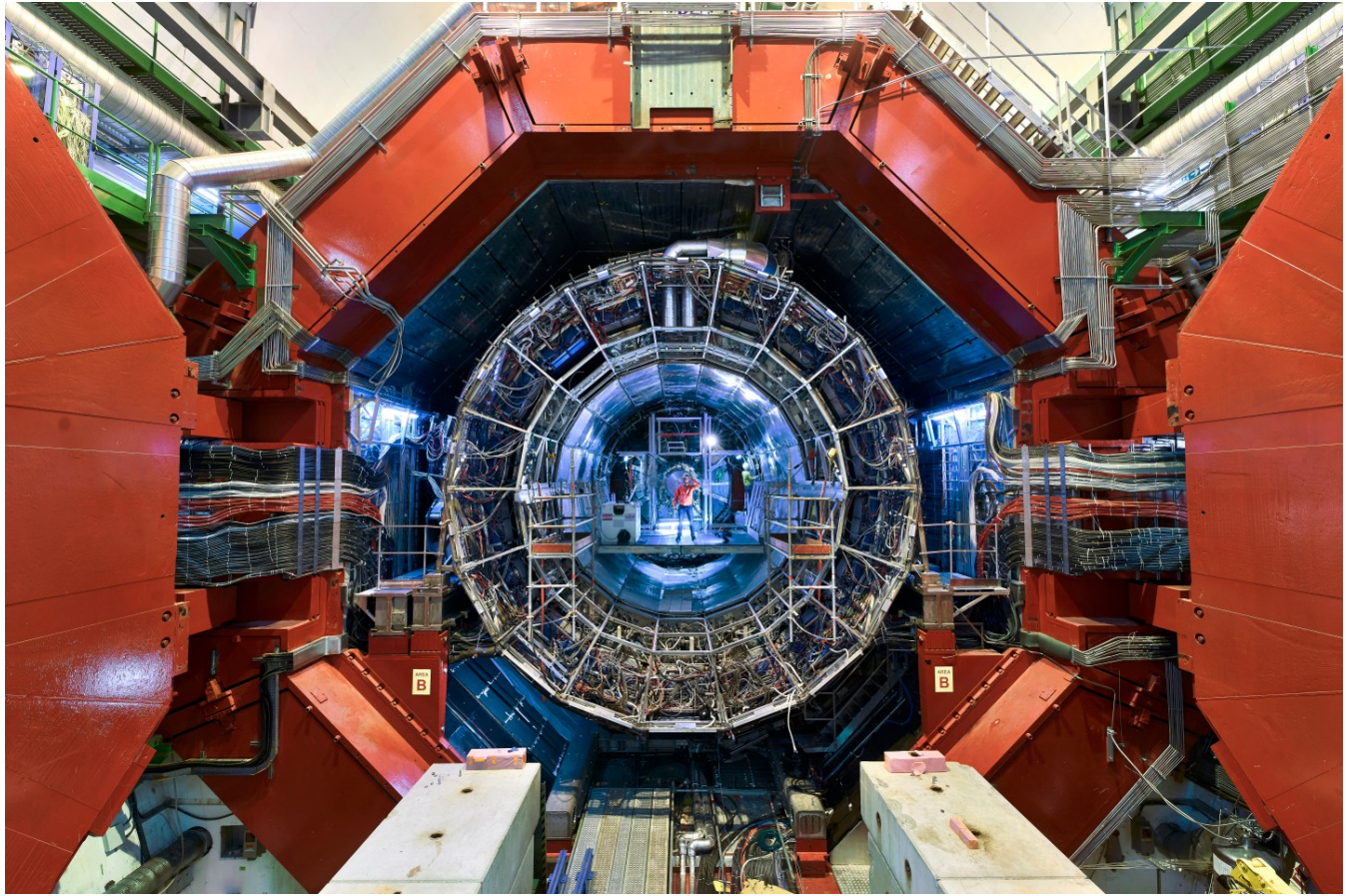
ÖAW FTE NATIONALSTIFTUNG FORSCHUNG | TECHNOLOGIE | ENTWICKLUNG

Opening the doors (December 2018)

CERN-PHOTO-201812-335

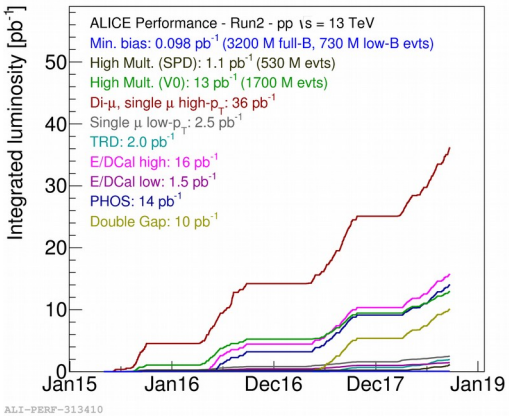
Soon after

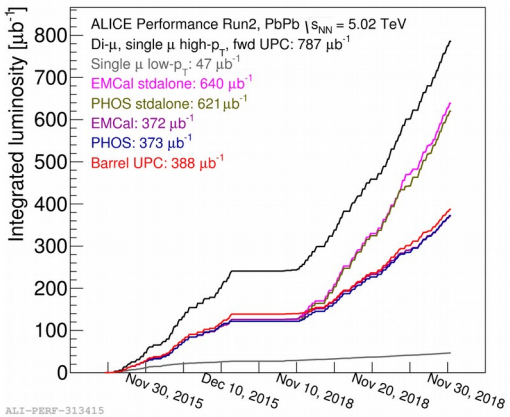
CERN-PHOTO-201903-053



Harvest of the past ten years

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	Recorded L_{int} (for muon triggers)
Pb–Pb	2010,2011	2.76	~75 μb^{-1}
	2015	5.02	~0.25 nb^{-1}
	2018	5.02	**~0.55 nb^{-1}**
Xe–Xe	2017	5.44	~0.3 μb^{-1}
p–Pb	2013	5.02	~15 nb^{-1}
	2016	5.02, 8.16	~3 nb^{-1}; ~25 nb^{-1}
pp	2009-2013	0.9,2.76,7,8	~200 μb^{-1}; ~100 nb^{-1}; ~1.5 pb^{-1}; ~2.5 pb^{-1}
	2015,2017	5.02	~1.3 pb^{-1}
	2015-2018	13	**~36 pb^{-1}**





New for QM 2019:

- Full 13 TeV pp data set with **high-multiplicity triggers**
- 2018 Pb-Pb with **central and semi-central triggers**
- **Selected results out of 26 parallel talks, 68 posters, and 18 new papers**

Labels used in this presentation:

New since last QM **New** *New preliminary for QM* **Final** *On arXiv for QM*

Outline

Initial state

→ **Hadronic structure and photoproduction**

QGP - Macroscopic properties

→ **Properties of QCD matter and the transition between phases**

QGP - Microscopic dynamics

→ **Degrees of freedom at each stage and their interactions**

Small systems

→ **Unified picture of QCD particle production from small to larger systems**

Hadron physics

→ **LHC as laboratory for hadron interaction studies**

Following the open questions in the HL-LHC WG5 yellow report

ALICE parallel talks

Initial state

- Low-mass dielectron measurements in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC — S. Scheid, 6 Nov 2019, 16:40

Macroscopic properties

- Anisotropic flow fluctuations of charged and identified hadrons in Pb-Pb collisions with the ALICE detector — Y. Zhu, 5 Nov 2019, 10:00
- Recent results on event-by-event fluctuations in ALICE — M. Arslandok, 5 Nov 2019, 11:00
- Search for the chiral magnetic effect and the chiral magnetic wave with the ALICE experiment — S. Aziz, 5 Nov 2019, 14:00
- Event shape dependence of anisotropic flow for inclusive and identified hadrons in Pb-Pb and Xe-Xe collisions with ALICE — M. Besoiu, 5 Nov 2019, 16:20
- Linear and non-linear flow modes of charged and identified particles in Pb-Pb collisions with ALICE — J. Parkkila, 6 Nov 2019, 09:20
- Spin alignment measurements of vector mesons with ALICE at the LHC — S. Kundu, 6 Nov 2019, 11:00

Microscopic properties

- First direct measurement of the dead-cone effect at colliders using iterative declustering techniques in the Lund plane — N. Zardoshti , 5 Nov 2019, 09:20
- Recent quarkonium measurements in small systems with the ALICE detector at the LHC — J. Ghosh, 5 Nov 2019, 10:00
- Latest results on Λc and D production in pp and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE at the LHC — G. Innocenti, 5 Nov 2019, 11:00
- Beauty production with ALICE at the LHC — D. Thomas, 5 Nov 2019, 12:00
- Quarkonium production in nucleus-nucleus collisions with ALICE — X. Bai, 5 Nov 2019, 14:20
- New results on light (anti-)(hyper-)nuclei production and hypertriton lifetime in Pb-Pb collisions at the LHC — E. Bartsch, 5 Nov 2019, 15:40
- Recent results on azimuthal anysotropies of open heavy-flavour particles with ALICE at the LHC — S. Tang, 5 Nov 2019, 16:40
- Light neutral meson production in heavy ion collisions with ALICE in the era of precision physics at the LHC — M. Sas, 5 Nov 2019, 18:00
- Exploring the phase space of jet splittings in Pb—Pb and pp collisions at $\sqrt{s_{NN}}$ =5.02 TeV in ALICE — L. Havener, 6 Nov 2019, 09:00
- Constraining the production mechanism of light (anti-)nuclei in small systems with ALICE at the LHC — L. Barioglio, 6 Nov 2019, 11:00
- Jet quenching and acoplanarity via hadron+jet measurements in pp and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE — Y. Mao, 6 Nov 2019, 11:40
- Heavy-flavour jet production and correlations with ALICE — J. Kvapil, 6 Nov 2019, 14:00

Small systems

- Search for jet quenching effects in high multiplicity proton-proton collisions at √s=13 TeV with ALICE — P. Jacobs, 5 Nov 2019, 11:00
- Latest results on the production of hadronic resonances in ALICE at the LHC — A. Khuntia, 5 Nov 2019, 16:40
- Light flavour hadron production vs. multiplicity in pp and in p-Pb collisions with ALICE — S. Pisano, 6 Nov 2019, 11:40
- Measurement of long-range two- and multi-particle correlations by ALICE — Y. Sekiguchi, 6 Nov 2019, 15:00

Hadron physics

- First experimental test of HAL QCD lattice calculations for the multi strange hyperon - nucleon interaction with ALICE — D.Mihaylov, 6 Nov 2019, 11:00
- Measurement of the anti-deuteron nuclear inelastic cross section with ALICE and implications for indirect Dark Matter searches — I. Vorobyev, 6 Nov 2019, 16:20

Upgrade

- Upgrading the Inner Tracking System and the Time Projection Chamber of ALICE — F. Reidt, 5 Nov 2019, 18:20

ALICE posters

A. Sharma	Event-by-Event measurement of charge separation in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
Q. Shou	Charge dependent flow and the search for the chiral magnetic wave at the LHC with A
L. Husova	Two-particle correlations with high-pT Λ baryons and $K0S$ mesons in pp collisions at Al
Z. Khabanova	Collective effects in pp collisions with the balance function of the identified particles
C. Mordasini	Multi-harmonic correlations in ALICE
C. Ristea	Using Event Shape Engineering to study anisotropic flow of inclusive and identified pa ALICE
A. Danu	Measurements of charge-dependent correlations in Xe-Xe collisions with ALICE
J. Adolfsson	Studying strangeness enhancement in small systems through Ξ−hadron correlations
R. Raniwala	Effect of longitudinal asymmetry on pseudorapidity distributions in PbPb collisions at
S. Khan	Net-charge fluctuations in pp, p-Pb, Pb-Pb and Xe-Xe collisions with ALICE Detector

D. Sekihata	Study of dielectron productions in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV with ALICE
E. Meninno	Machine learning approach for studying of dielectrons from open charm and beauty decays in p-Pb collisions with ALICE at the LHC
D. Thakur	J/ψ production as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV at forward rapidity with ALICE at the LHC
A. Bell	Mid-rapidity J/ψ production as a function of charged-particle multiplicity in proton-proton collisions at √s=13 TeV
S. Hayashi	J/ψ production at mid-rapidity in p-Pb collisions with the ALICE detector
L. Micheletti	J/psi polarization measurement in Pb-Pb collisions
A. Neagu	J/ψ elliptic flow at mid-rapidity in Pb--Pb collsions at $\sqrt{s_{NN}}$= 5.02 TeV with ALICE
X. Bai	Nuclear modification factor R_{AA} of inclusive J/ψ at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.
L. Viebach	Low-mass dielectron measurements in minimum-bias pp collisions at 5.02 TeV with ALICE
A. Capon	A multivariate approach to measuring low-mass dielectrons in p-Pb collisions at $\sqrt{s_{NN}}$= 5.02
H. Degenhardt	Study of the charm quark production mechanisms through angular correlation of dielectron

T. Herman	J/ψ production at forward rapidities in ultra-peripheral collisions in ALICE
O. Matonoha	Production of identified light flavour hadrons as a function of underlying event activity in pp collisions using the ALICE detector
Y. Minato	Performance evaluation of a Forward Calorimeter for ALICE upgrade
D. Andreou	Towards improved measurements with the upgrade of the ALICE Inner Tracking System in LS3
Y. Yamaguchi	Muon Forward Tracker: adding vertexing capability to the ALICE MUON Spectrometer
K. Kamano	Quantitative evaluation of muon track matching efficiency with Muon Forward Tracker and Muon Spectrometer at ALICE
T. Osako	Dimuon polarization measurement for detecting ultra-intense magnetic field in Pb-Pb collisions at the ALICE experiment
B.Nielsen	The ALICETPC: Upgrade and Physics Perspectives

E. Meninno	Charm production in pp and p-Pb collisions with ALICE at the LHC
M. Cai	Non-prompt D0-meson production in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV with
J. Zhu	https://alice-conferences.web.cern.ch/node/31810
S. Kar	Measurements of prompt D-meson production in p-Pb collisions with ALICE at the LHC
T. Cheng	Measurement of $\Xi 0_c$ baryon in pp collisions with ALICE at the LHC
Z. Zhang	Open heavy-flavour hadron decay muon ν2 in p--Pb collisions at $\sqrt{s_{NN}}$=8.16~TeV with
R. Singh	D + meson production as a function of charged particle multiplicity in pp at √s =13 Te
S. Sakai	Measurement of heavy flavour jets with electrons from heavy-flavour hadron decays i
R. Bala	D+ meson production in pp, p-pb and Pb-Pb collisions at √s= 5 TeV with ALICE
S. Rode	Measurement of electrons from heavy-flavour hadron decays in proton-proton collision
M. Faggin	Prospects for measuring Ξ+c and Σc baryons with ALICE
K. Tadokoro	Elliptic flow of electrons from heavy-flavour hadron decays in Pb-Pb collisions at $\sqrt{s_{NN}}$=
H. Zanoli	Azimuthal anisotropy of heavy-flavour electrons in p-Pb collisions with ALICE
J. Park	RAA of electrons from beauty-hadron decays in Pb-Pb collisions at 5.02 TeV with ALICE
M. Zhao	Study of W±--boson production in p--Pb and Pb--Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV with ALICE at the LHC
S. Trogolo	D mesons production in Pb-Pb collisions with ALICE at the LHC
D. Godoy	hapes of jets containing electrons from heavy-flavour hadron decays in pp collisions at √s= 13 TeV at ALICE

R. Sahoo	Event shape and multiplicity dependence of K*± and ϕ production in pp collisions
B. Lim	Charged-particle multiplicity dependence of Σ(1385)± and Ξ(1530)0 production in
R. Rath	Insight into $K*$(892)0 production in pp collisions as a function of collision energy,
D. Mallick	Hadronic resonance production in asymmetric collisions with ALICE at the LHC
P. Larionov	Production of pions, kaons and protons in p-Pb collisions
M. Sharma	K^0_S and Λ production in p-Pb collision system at 8.16 TeV
P. Huhn	Charged-particle production as function of event multipli
A. Khuntia	Insight into Multiplicity Dependence of Strangeness and
A. Nassirpour	Identified light flavor particle production in "jetty" and "is
D. Pistone	Charged-particle multiplicity dependence of K*(892)± res
J. Song	Recent Measurements of Hadronic Resonances in Small S

L. Havener	Machine Learning Based Jet p_T Reconstruction with Full Jets in ALICE
O. Saarimaki	Dijet invariant mass in pp and p--Pb collisions with ALICE
K, Lapidus	Substructure-based classification of medium-modified jets
Y. Dang	Semi-inclusive hadron-jet productions in pp collisions at 5.02 TeV with ALICE
Y. Hou	Multiplicity dependent charged jet production in pp collisions at √s= 13 TeV
Y. Wu	Production of J/ψ mesons in jets at mid-rapidity in pp collisions at √s = 13 TeV with ALICE
P. Cui	Study of (multi-)strange particle production in jets and two-particle correlations with high-p_T V0 particles in small collision systems with ALICE at the LHC
F. Acosta	Isolated Photon-Hadron Correlations in pp and p--Pb Collisions at $\sqrt{s_{NN}}$ = 5 TeV in ALICE
M. Takamura	The neutral meson measurement in jets in Pb--Pb collisions in ALICE
R. Xu	Isolated photon production in pp collisions at √s=13 TeV measured with ALICE
A. Liu	Photon identification in the ALICE EMCal using a neural network and template fit

Publications for QM

Production of charged pions, kaons and (anti-)protons in Pb-Pb and inelastic pp collisions at $\sqrt{s_{NN}}$ = 5.02 TeV	arXiv:1910.07678 [nucl-ex]
Measurement of electrons from semileptonic heavy-flavour hadron decays at midrapidity in pp and Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV	arXiv:1910.09110 [nucl-ex]
Measurement of the (anti-)3He elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV	arXiv:1910.09718 [nucl-ex]
Longitudinal and azimuthal evolution of two-particle transverse momentum correlations in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV	arXiv:1910.14393 [nucl-ex]
Investigation of the p-Σ0 interaction via femtoscopy in pp collisions	arXiv:1910.14407 [nucl-ex]
Global baryon number conservation encoded in net-proton fluctuations measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV	arXiv:1910.14396 [nucl-ex]
Measurement of spin-orbital angular momentum interactions in relativistic heavy-ion collisions	arXiv:1910.14408[nucl-ex]
Inclusive Υ production in p-Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV	arXiv:1910.14405 [nucl-ex]
Centrality and transverse momentum dependence of inclusive J/ψ production at midrapidity in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV	arXiv:1910.14404 [nucl-ex]
Azimuthal correlations of prompt D mesons with charged particles in pp and p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV	arXiv:1910.14403 [nucl-ex]
Probing the effects of strong electromagnetic fields with charge-dependent directed flow in Pb-Pb collisions at the LHC	arXiv:1910.14406 [nucl-ex]
Measurement of electrons from heavy-flavour hadron decays as a function of multiplicity in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV	arXiv:1910.14399 [nucl-ex]
Jet-hadron correlations measured relative to the second order event plane in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV	arXiv:1910.14398 [nucl-ex]
Evidence of rescattering effect in Pb-Pb collisions at the LHC through production of K*(892)0 and ϕ(1020) mesons	arXiv:1910.14419 [nucl-ex]
Multiplicity dependence of K*(892)0 and ϕ(1020) production in pp collisions at √s = 13 TeV"	arXiv:1910.14397 [nucl-ex]
Production of (anti-)3He and (anti-)3H in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV	arXiv:1910.14401 [nucl-ex]
K*(892)0 and ϕ(1020) production at midrapidity in pp collisions at $\sqrt{s}$ = 8 TeV	arXiv:1910.14408 [nucl-ex]
Study of underlying event properties in pp collision at 13 TeV with ALICE at the LHC	arXiv:1910.14400 [nucl-ex]

Initial state

→ **Hadronic structure and photoproduction**

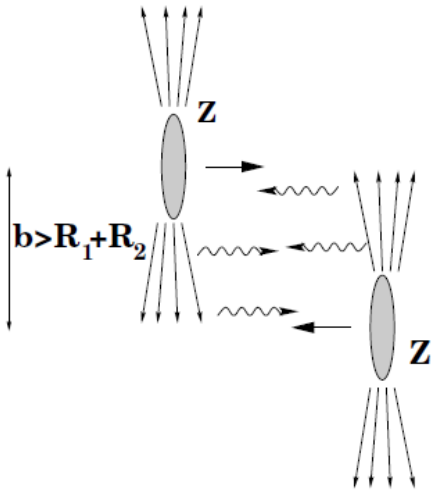
QGP - Macroscopic properties

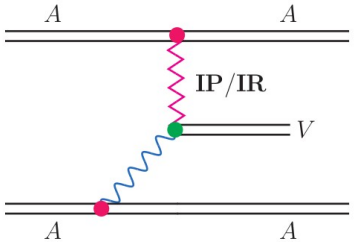
QGP - Microscopic dynamics

Small systems

Hadron physics

Probing nuclear Parton Distribution Functions

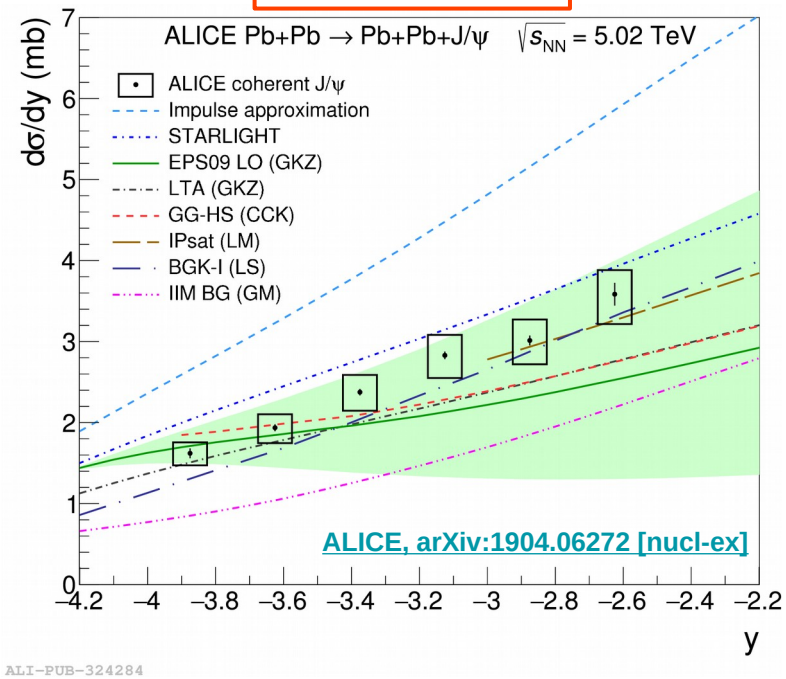




- Probe **nPDFs** with quasi-real photon in ultra-peripheral Pb-Pb collisions

Probing nuclear Parton Distribution Functions

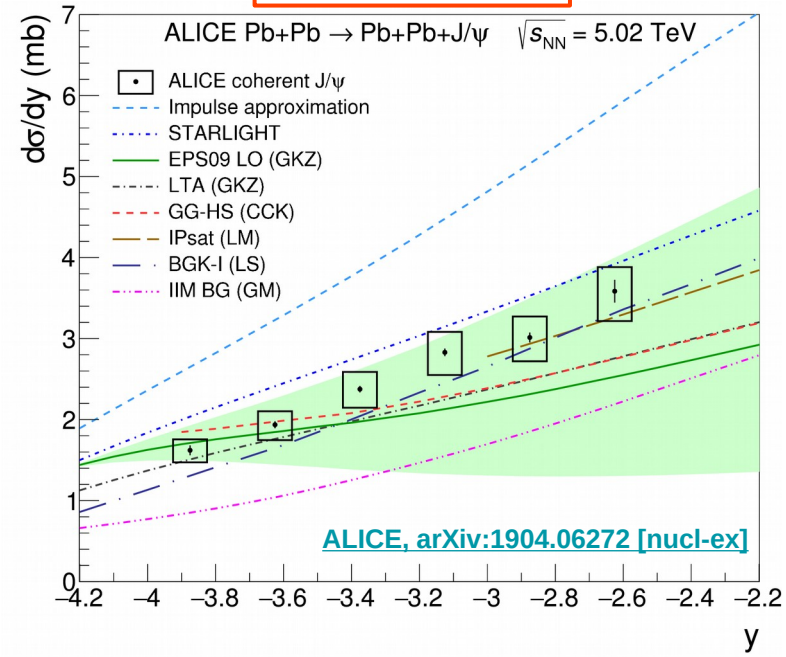
UPC J/ψ vs. *y*



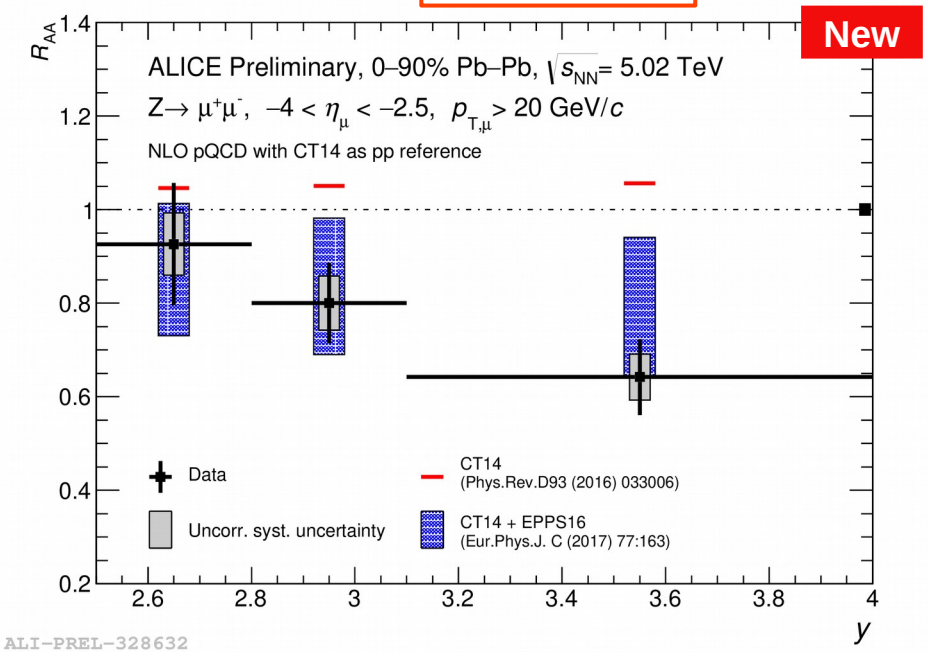
- Probe **nPDFs** with quasi-real photon in ultra-peripheral Pb-Pb collisions
  - **First ALICE paper from 2018 Pb-Pb run**

Probing nuclear Parton Distribution Functions

UPC J/ψ vs. *y*



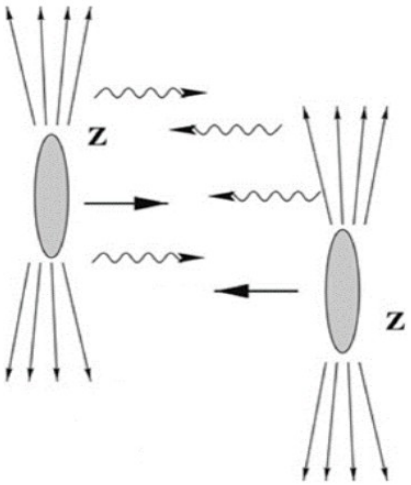
Pb-Pb Z vs. *y*

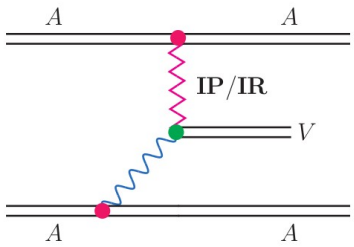


- Probe **nPDFs** with quasi-real photon in ultra-peripheral Pb-Pb collisions
  - **First ALICE paper from 2018 Pb-Pb run**
- Probe **nPDFs** with partons in initial state and colour neutral final state
  - **Improved stat. Precision**

→ in agreement with nuclear gluon shadowing

Photoproduction with nuclear overlap

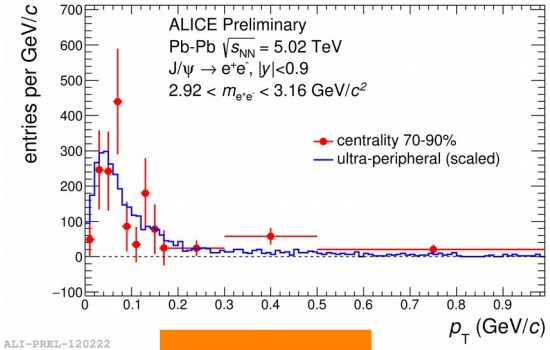




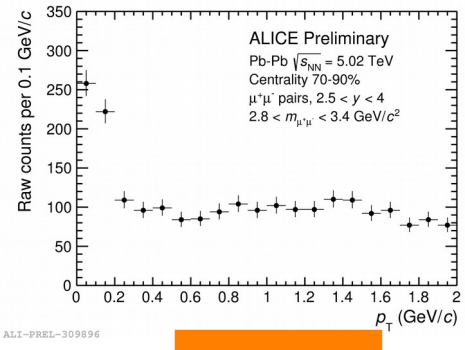
- Coherent photoproduction of J/ψ in peripheral Pb-Pb collisions

Photoproduction with nuclear overlap

J/ψ vs. p_T (Centrality 70-90%)

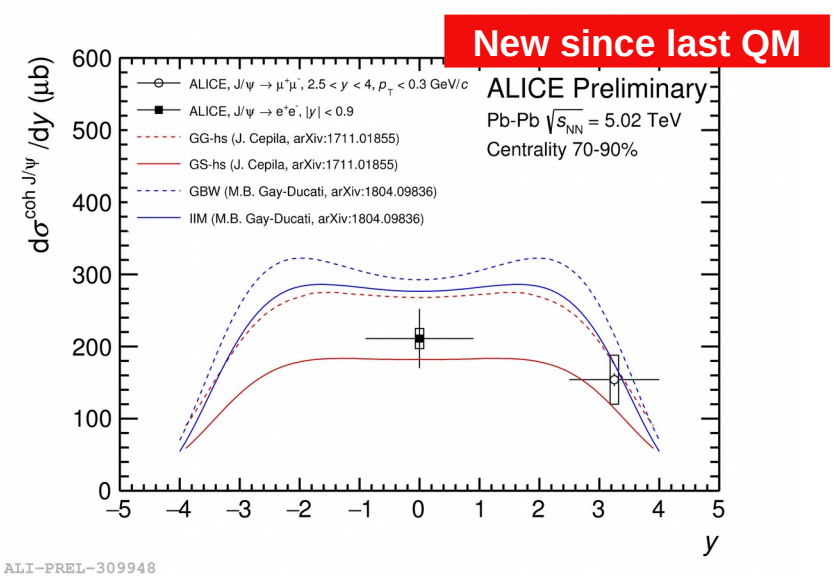


J/ψ → e⁺e⁻



J/ψ → μ⁺μ⁻

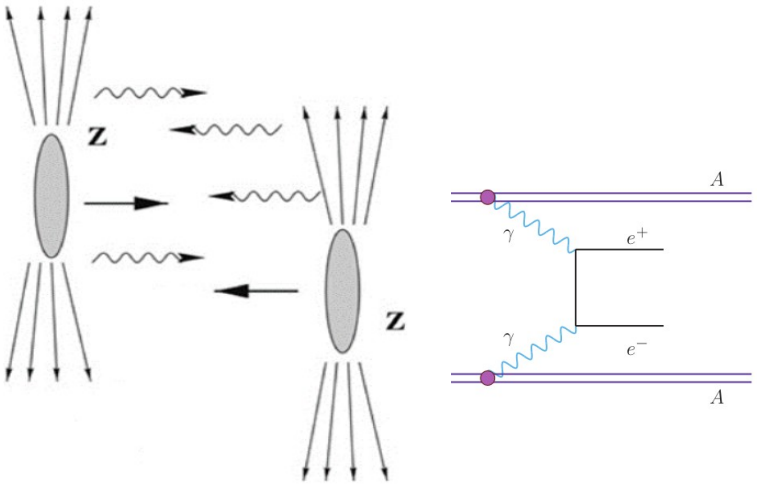
New since last QM



- Coherent photoproduction of J/ψ in peripheral Pb-Pb collisions
  - Significant signal in dielectron and dimuon channel
  - **Cross section extracted at mid- and forward rapidity**

Photoproduction with nuclear overlap

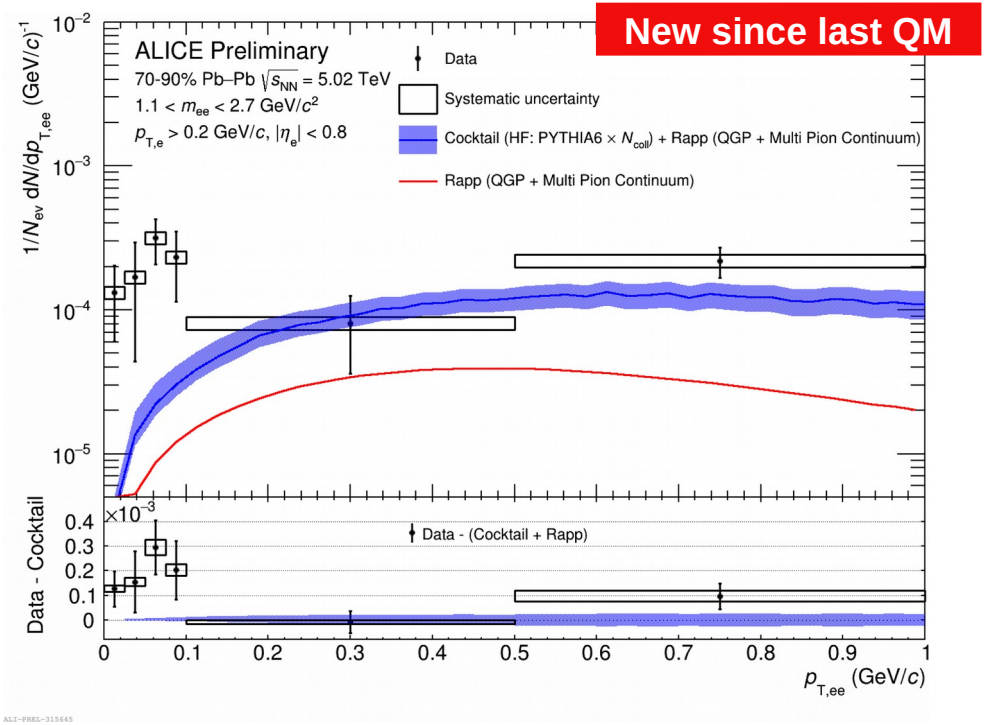
S. Scheid, 6 Nov 2019, 16:40



- Coherent photoproduction of J/ψ in peripheral Pb-Pb collisions
- Low transverse momentum dielectron excess in continuum region also below the J/ψ mass
  - **Excess > 3σ at LHC**

e^+e^- production vs. p_T (Centrality 70-90%)

New since last QM



→ Photoproduction also at LHC, baseline for more differential studies

Initial state

QGP - Macroscopic properties

→ Properties of QCD matter and the transition between phases

QGP - Microscopic dynamics

Small systems

Hadron physics

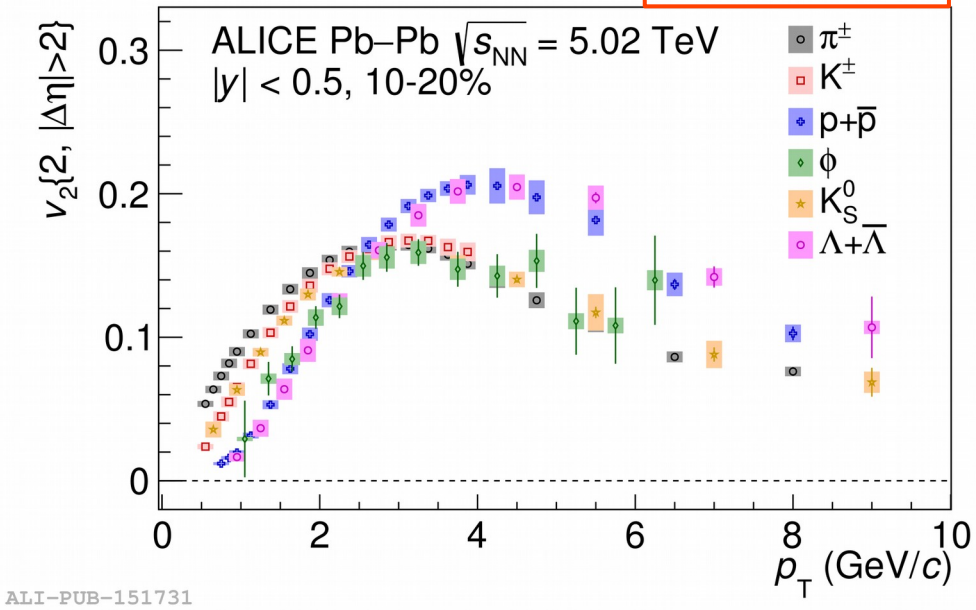
Flow: identified particles

Event shape engineering: M. Besoiu, 5 Nov 2019, 16:20
PID flow: Y. Zhu, 5 Nov 2019, 10:00

Going beyond measuring v_n

ALICE, JHEP 1809 (2018) 006

PID $v_2\{2\}$ vs. p_T

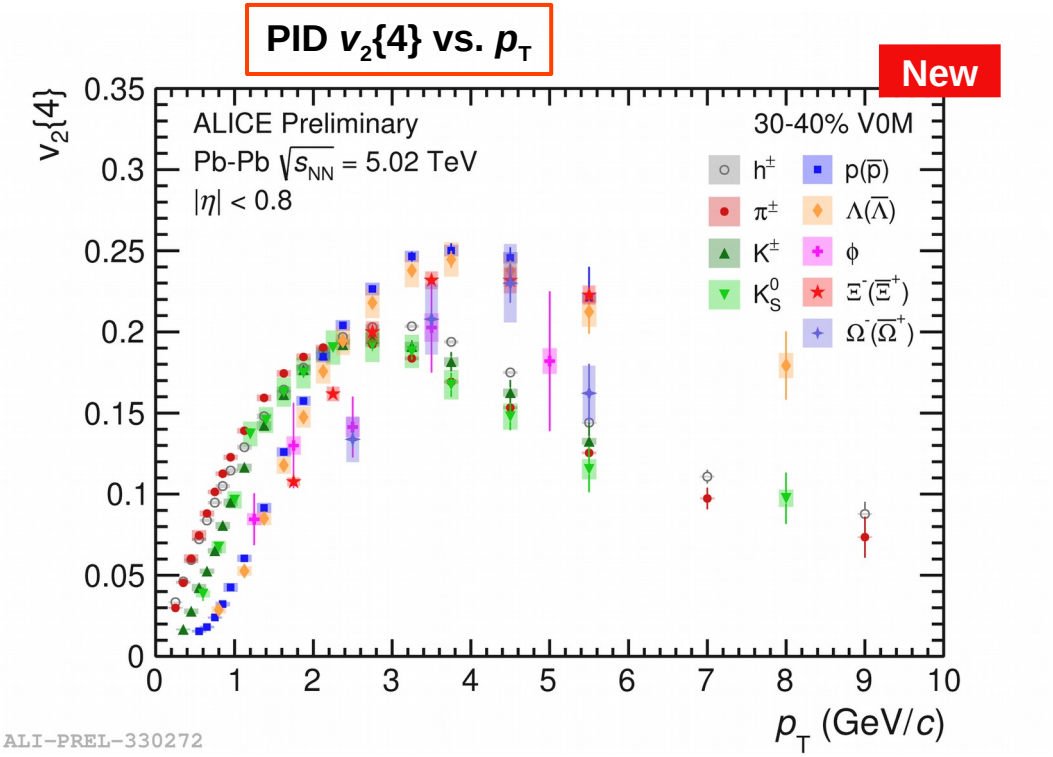


- Full set of particle species available
  - Mass ordering (low p_T)
  - Quark content grouping (high p_T)

Flow: identified particles

Y. Zhu, 5 Nov 2019, 10:00

Going beyond measuring v_n

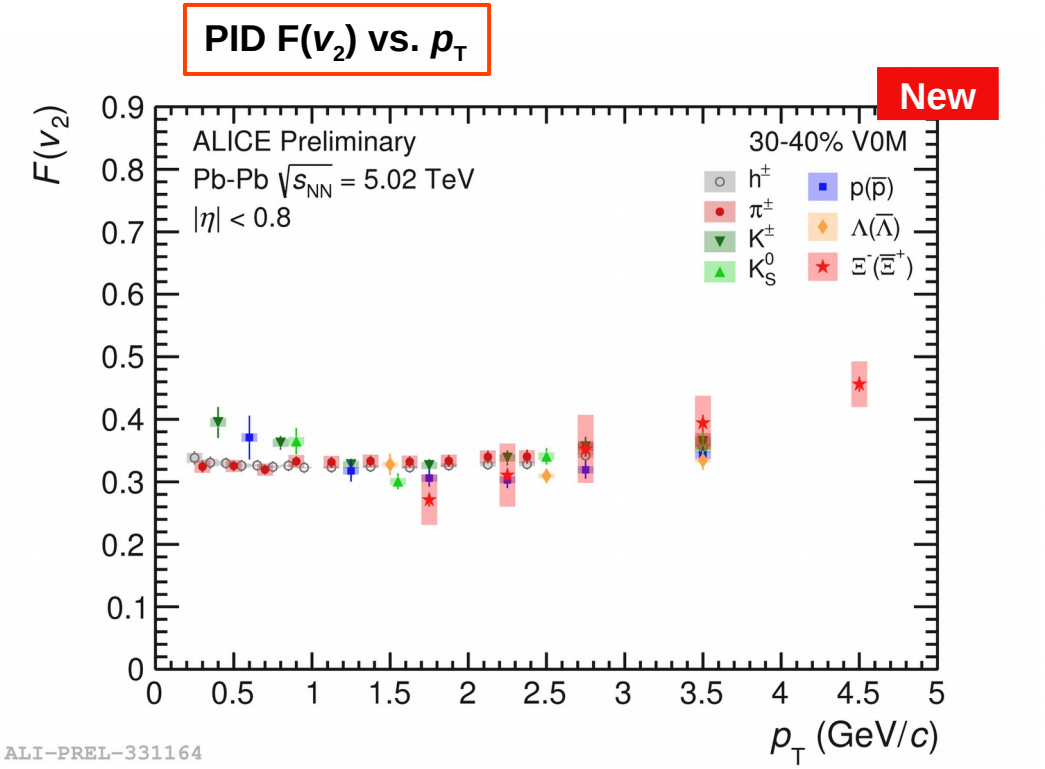


- Full set of particle species available
  - Mass ordering (low p_T)
  - Quark content grouping (high p_T)
- **First experimental PID $v_2\{4\}$**

Flow: identified particles

Y. Zhu, 5 Nov 2019, 10:00

Going beyond measuring v_n



- Full set of particle species available
  - Mass ordering (low p_T)
  - Quark content grouping (high p_T)
- First experimental PID $v_2\{4\}$

$$\sigma_{v_n} \approx ((v_n\{2\}^2 - v_n\{4\}^2)/2)^{1/2}$$

$$F(v_n) = \frac{\sigma_{v_n}}{\langle v_n \rangle}$$

- **First measurement of relative flow fluctuations for identified hadrons**

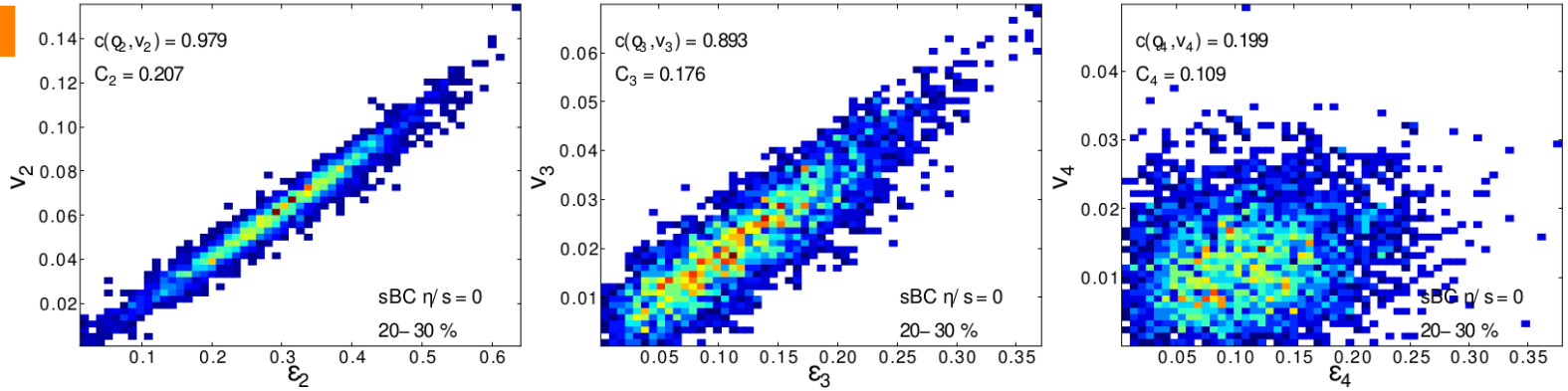
→ Characterising flow distribution (medium response) for full set of particle species

Flow: identified particles

J. Parkkila, 6 Nov 2019, 09:20

Going beyond measuring v_n

v_n

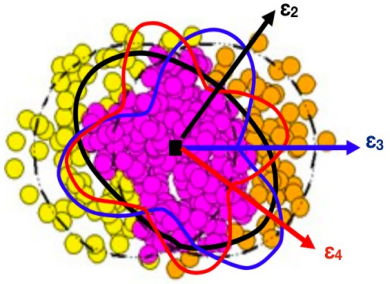


H. Niemi, G. S. Denicol, H. Holopainen, P. Huovinen, Phys.Rev.**C87** 054901 (2013)

Relation between v_n and ε_n

- Linear: e.g. $\varepsilon_3 \rightarrow v_3$
- Non-linear: e.g. ε_2 and $\varepsilon_3 \rightarrow v_5$ $\boxed{v_{5,32}}$

Initial spatial anisotropy ε_n

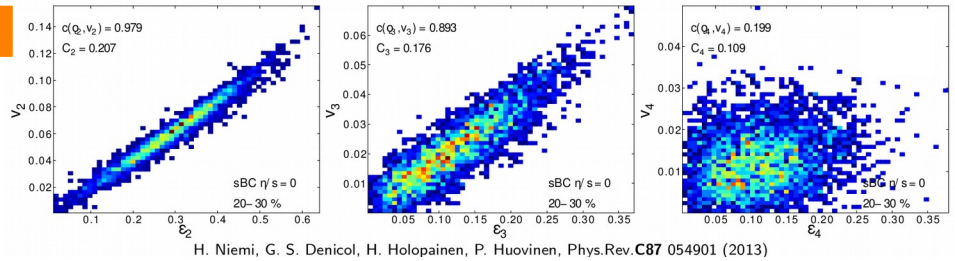


Flow: identified particles

J. Parkkila, 6 Nov 2019, 09:20

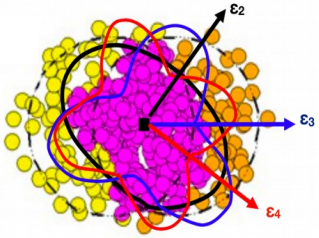
Going beyond measuring v_n

v_n



H. Niemi, G. S. Denicol, H. Holopainen, P. Huovinen, Phys.Rev.C87 054901 (2013)

Initial spatial anisotropy ε_n

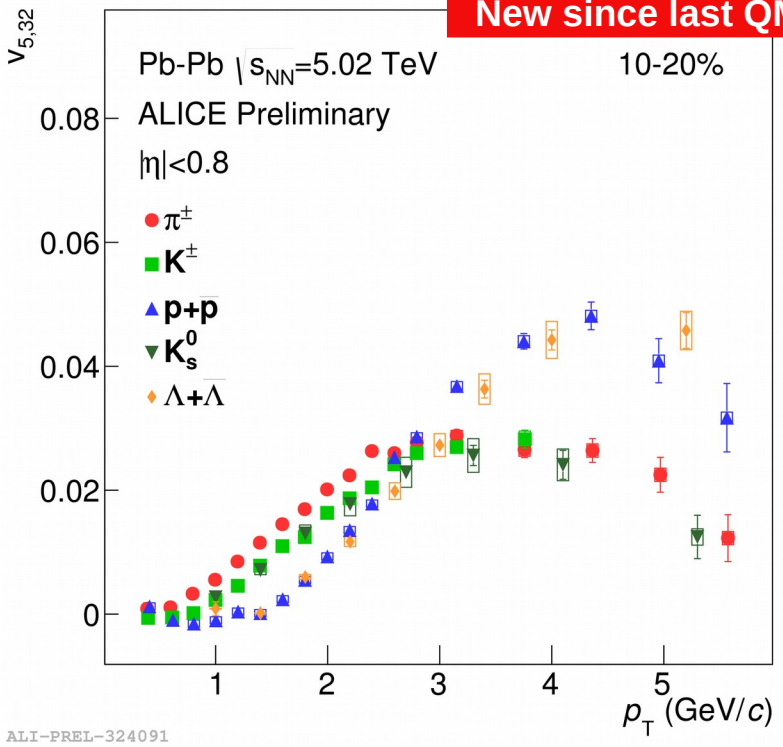


Relation between v_n and ε_n

- Linear: e.g. $\varepsilon_3 \rightarrow v_3$
- Non-linear: e.g. ε_2 and $\varepsilon_3 \rightarrow v_5$ $\boxed{v_{5,32}}$
  - Mass ordering (low p_T)
  - Quark content grouping (high p_T)

PID non-linear flow mode $v_{5,32}$

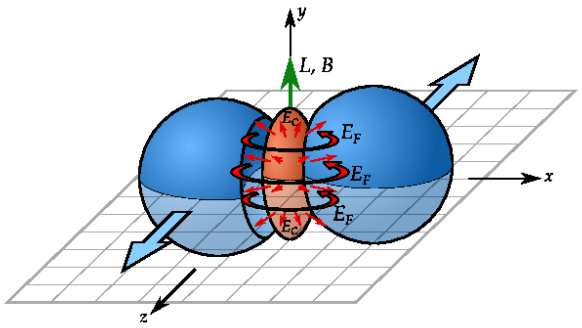
New since last QM



→ **Non-linear flow modes of identified particles follow same trend as v_n**

Angular momentum and magnetic field

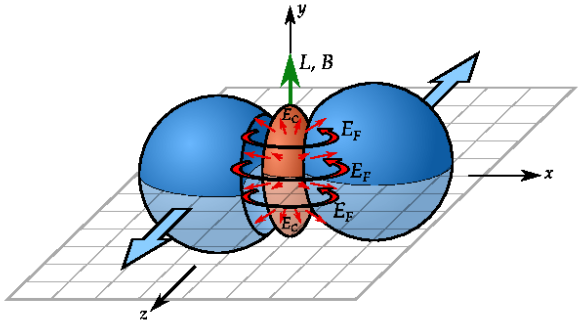
S. Kundu, 6 Nov 2019, 11:00



- Initial angular momentum *L*
- Spin-orbit coupling of vector mesons (spin 1):
  Polarization ρ_{00}

Angular momentum and magnetic field

S. Kundu, 6 Nov 2019, 11:00



- Initial angular momentum L
- Spin-orbit coupling of vector mesons (spin 1): **Polarization ρ_{00}**
- **At low momenta: deviation from 1/3 (maximum in semi-central collisions)**

→ **Larger effect than observed in Λ polarization**

ALICE, arXiv:1909.01281 [nucl-ex]

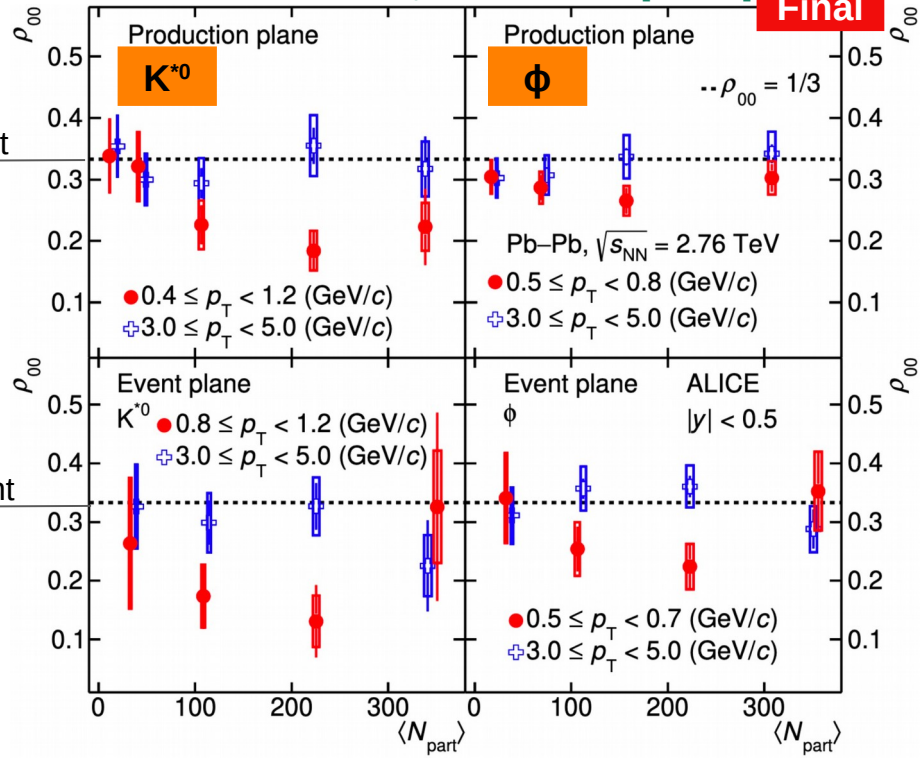
Spin polarization vs. N_{part}

ALICE, arXiv:1910.14408[nucl-ex]

Final

no spin alignment

ρ_{00} = 1/3

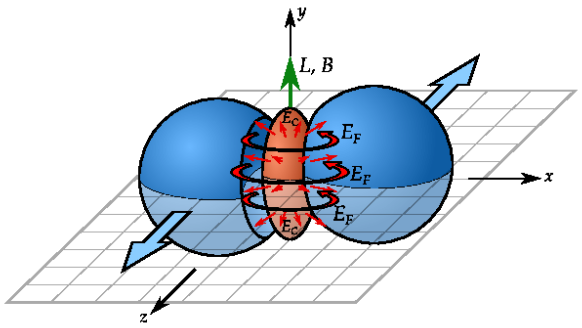


no spin alignment

ρ_{00} = 1/3

Angular momentum and magnetic field

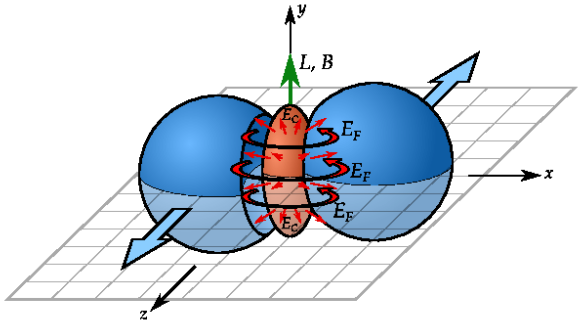
S. Tang, 5 Nov 2019, 16:40



- Strong magnetic field *B*
- **Charge-dependent flow v_1** of heavy- and light quark particles
  - **sensitive to early / late times**

Angular momentum and magnetic field

S. Tang, 5 Nov 2019, 16:40

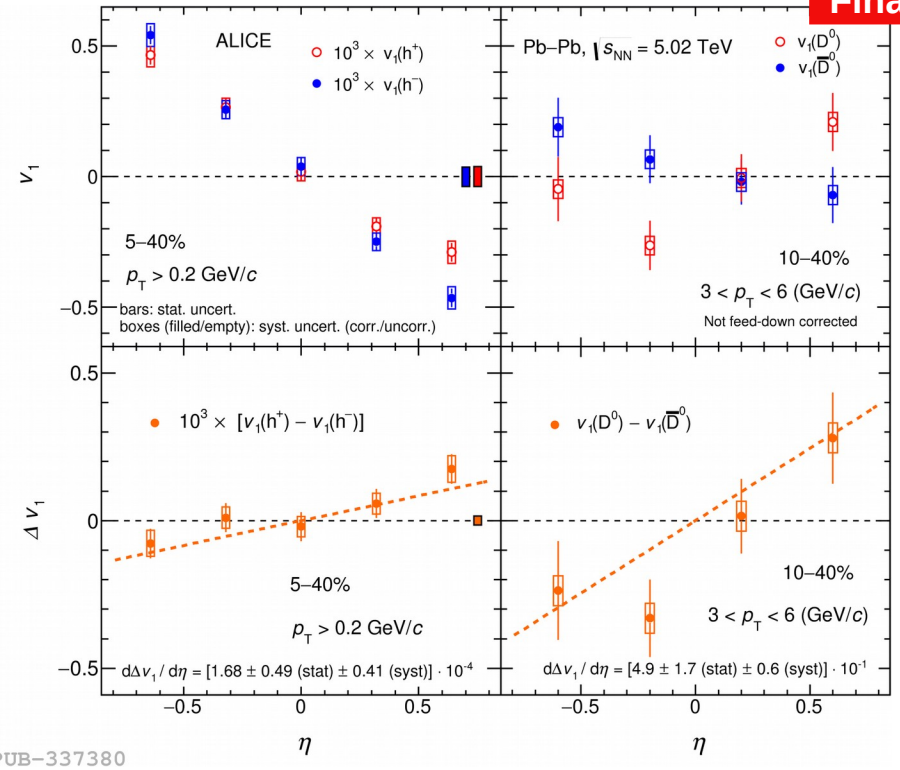


- Strong magnetic field *B*
- **Charge-dependent flow v_1** of heavy- and light quark particles
  - **sensitive to early / late times**
- **Effect for D mesons about three orders of magnitude larger than that of charged hadrons**

→ Significance ~2.5 σ; to be confirmed with higher statistics data in future (Run 3-4)

D meson Δv_1 vs. η

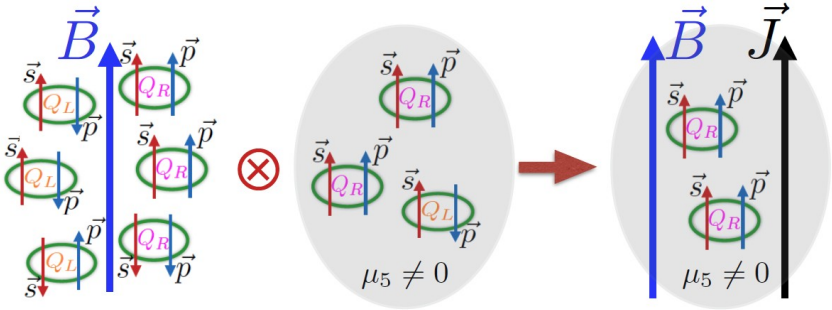
Final



ALICE, arXiv:1910.14406 [nucl-ex]

Chiral Magnetic effect

S. Aziz, 5 Nov 2019, 14:00



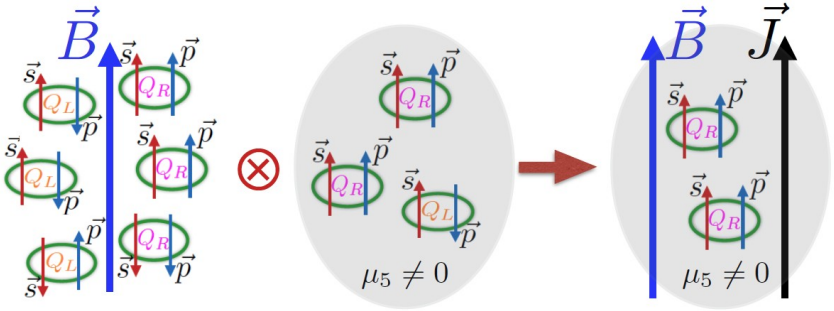
Local parity violation + strong magnetic field

- Splitting of same and opp. sign correlators
  - Main question: background?

- **First measurement in Xe-Xe collisions**
  - **Expect weaker magnetic field**
    → Smaller splitting

Chiral Magnetic effect

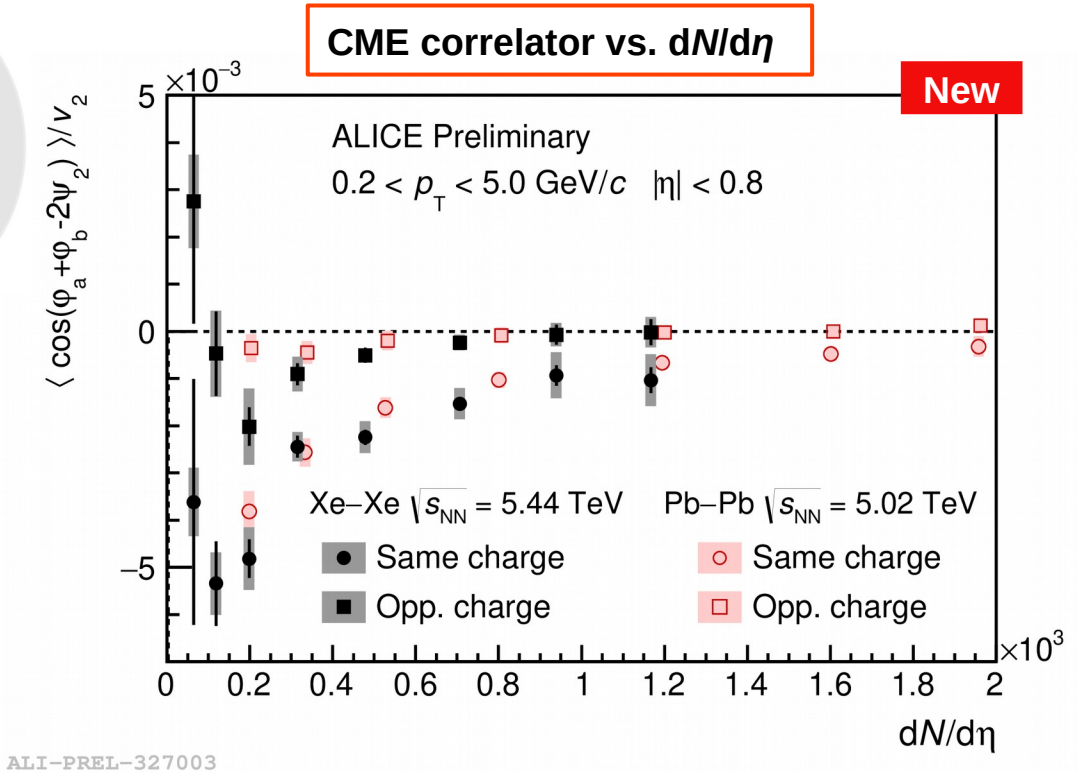
S. Aziz, 5 Nov 2019, 14:00



Local parity violation + strong magnetic field

- Splitting of same and opp. sign correlators
  - Main question: background?

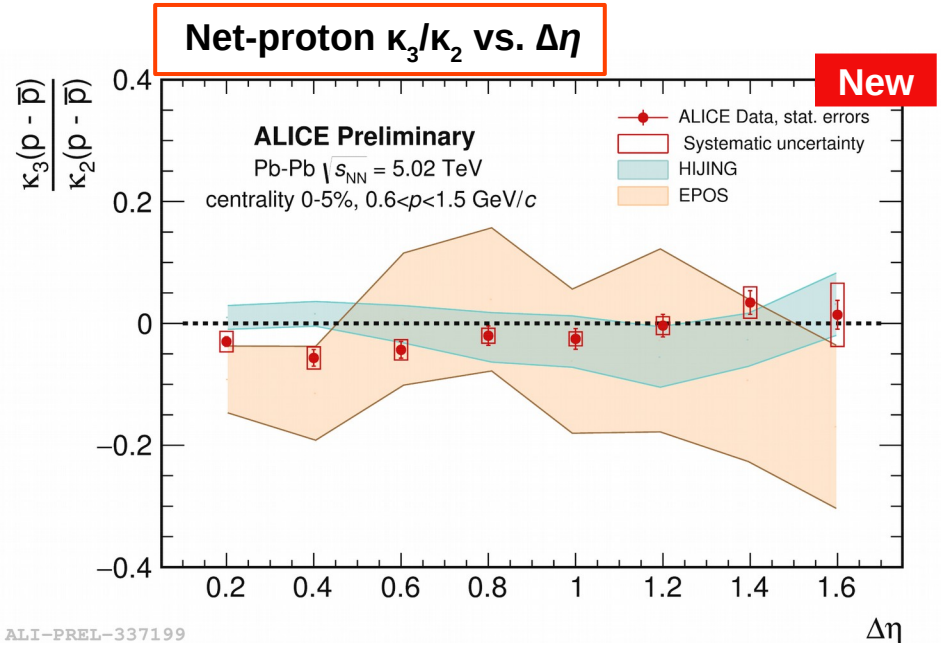
- **First measurement in Xe-Xe collisions**
  - **Expect weaker magnetic field**
    → Smaller splitting



→ **Splitting in Xe-Xe and Pb-Pb similar**
→ **Indicates large background contribution (coupled to v_2)**

Event-by-event fluctuations

M. Arslandok, 5 Nov 2019, 11:00



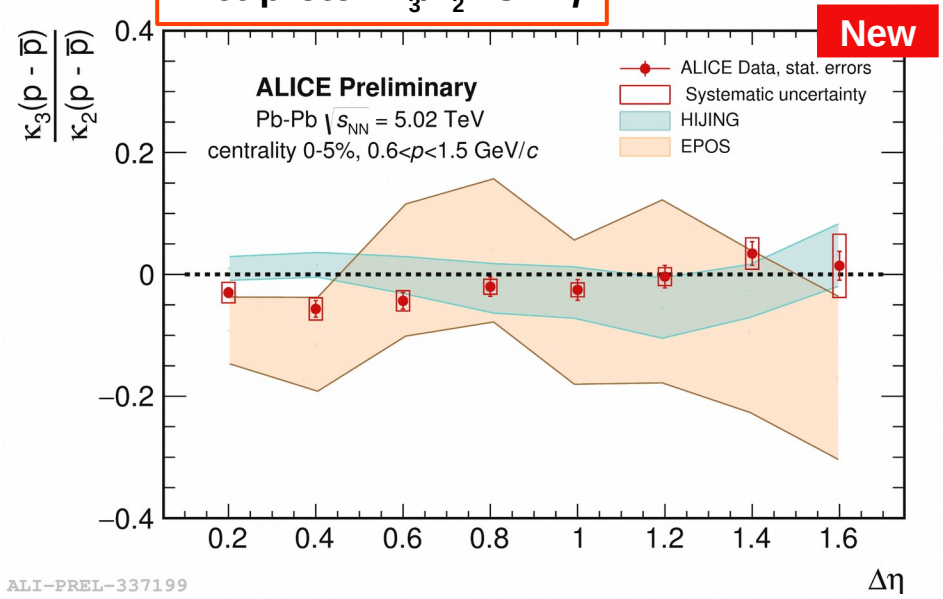
- Measure net-baryon fluctuations: sensitive to phase transitions
  - **Third moments with precision of ~5%**
  - Lattice QCD expectation $\kappa_3/\kappa_2 \sim 0$

→ **Baseline set for higher moments in Run 3-4 aiming at κ_6**

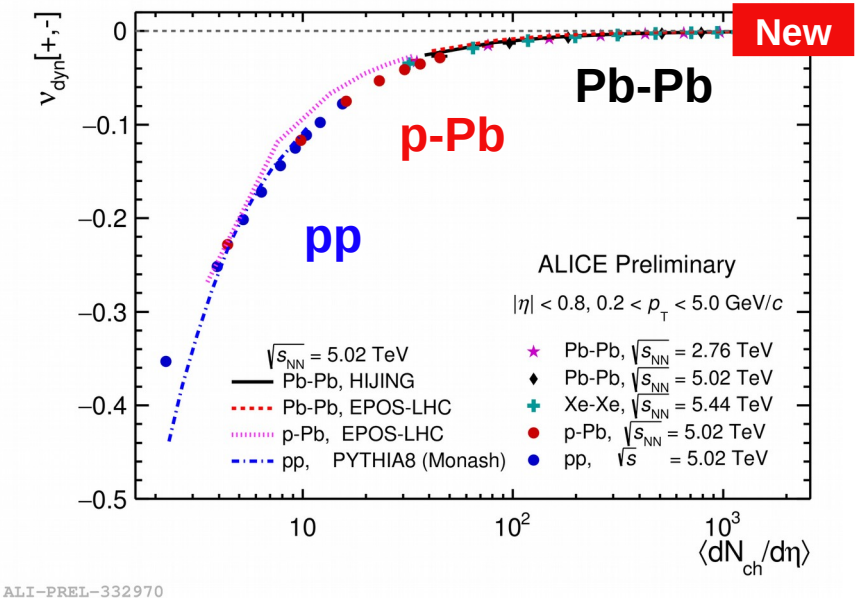
Event-by-event fluctuations

M. Arslandok, 5 Nov 2019, 11:00

Net-proton κ_3/κ_2 vs. $\Delta\eta$



Net-charge ν_{Dyn} vs. $dN/d\eta$



- Measure net-baryon fluctuations: sensitive to phase transitions
  - **Third moments with precision of ~5%**
  - Lattice QCD expectation $\kappa_3/\kappa_2 \sim 0$

→ **Baseline set for higher moments in Run 3-4 aiming at κ_6**

- Net-charge fluctuations:
  - "Trivial" multiplicity scaling not removed yet

→ **Smooth behaviour as a function of system size**

Initial state

QGP - Macroscopic properties

QGP - Microscopic dynamics

→ Degrees of freedom at each stage and their interactions

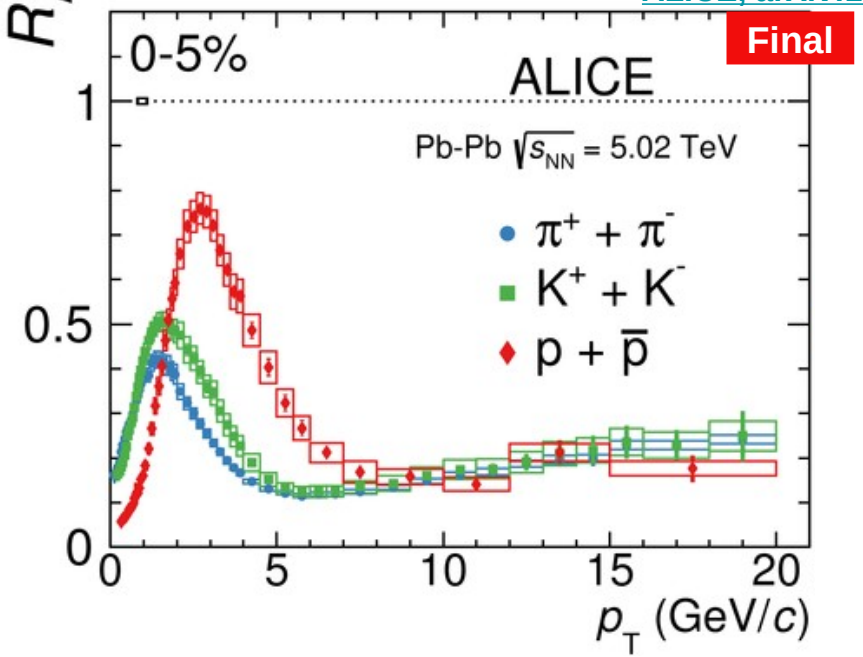
Small systems

Hadron physics

Nuclear modification factor - light flavour

R_{AA} vs. p_T

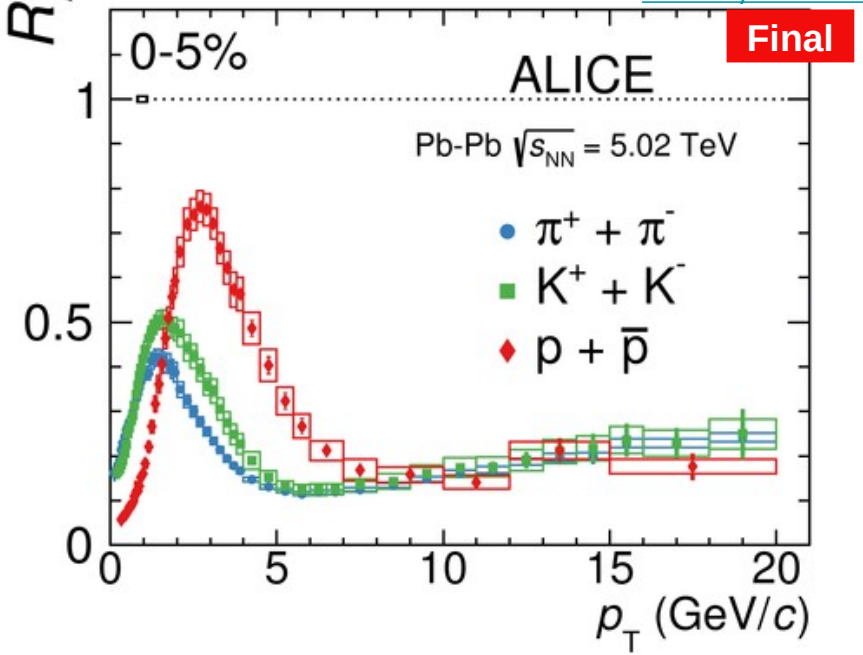
ALICE, arXiv:1910.07678 [nucl-ex]

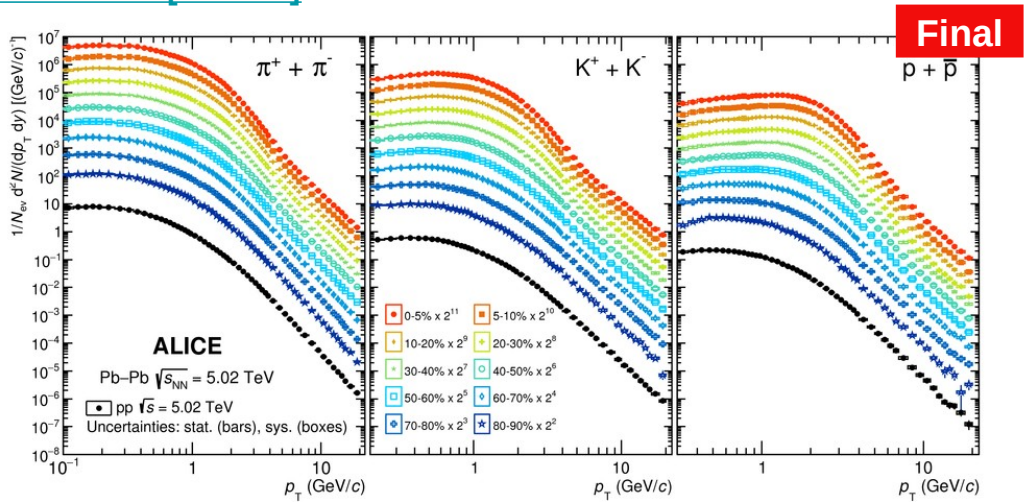


Nuclear modification factor - light flavour

R_{AA} vs. p_T

ALICE, arXiv:1910.07678 [nucl-ex]

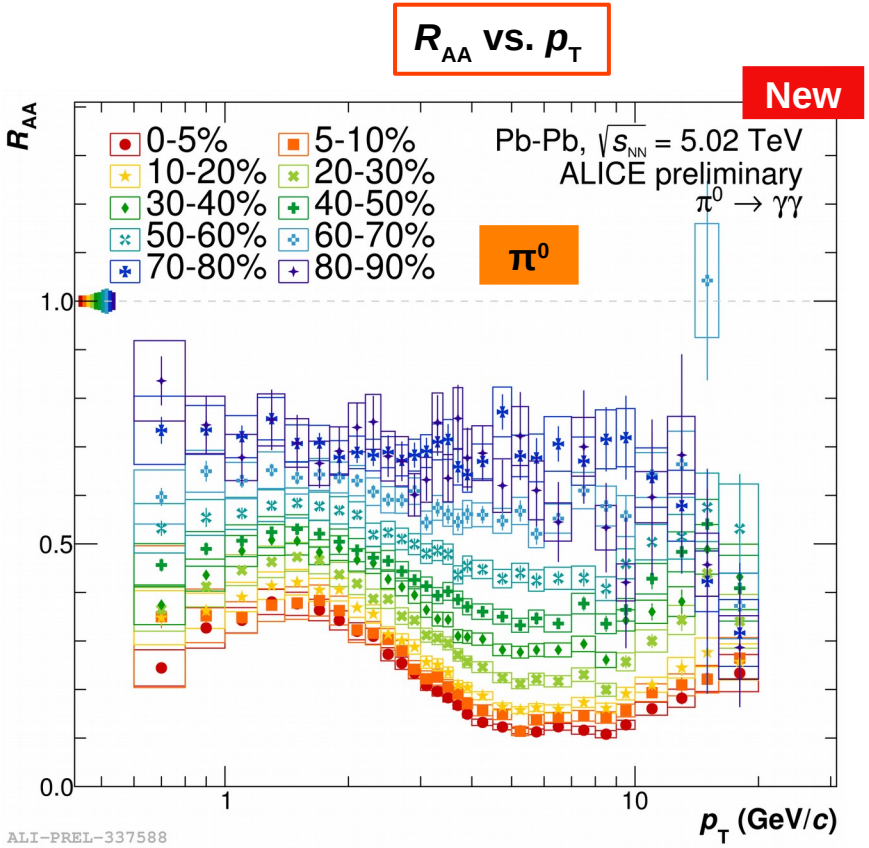




→ **High quality data for pions, kaons, protons**

Nuclear modification factor - light flavour

M. Sas, 5 Nov 2019, 18:00

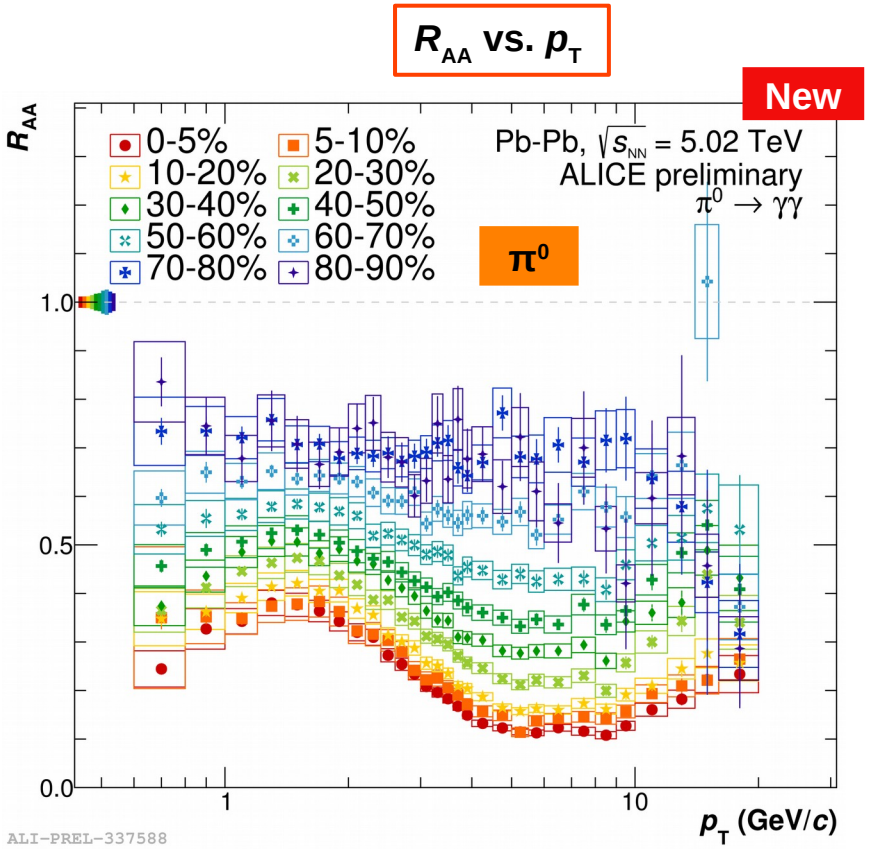


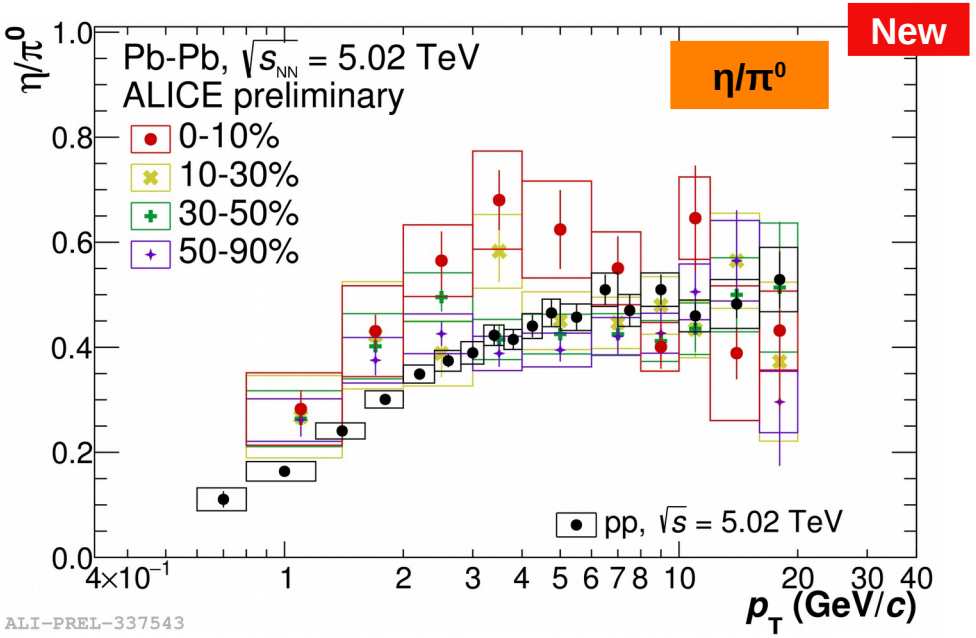
Also neutral particles enter high quality era

- π^0 down to 0.4 GeV/c

Nuclear modification factor - light flavour

M. Sas, 5 Nov 2019, 18:00





Also neutral particles enter high quality era

- π^0 down to 0.4 GeV/c
- η down to 0.8 GeV/c

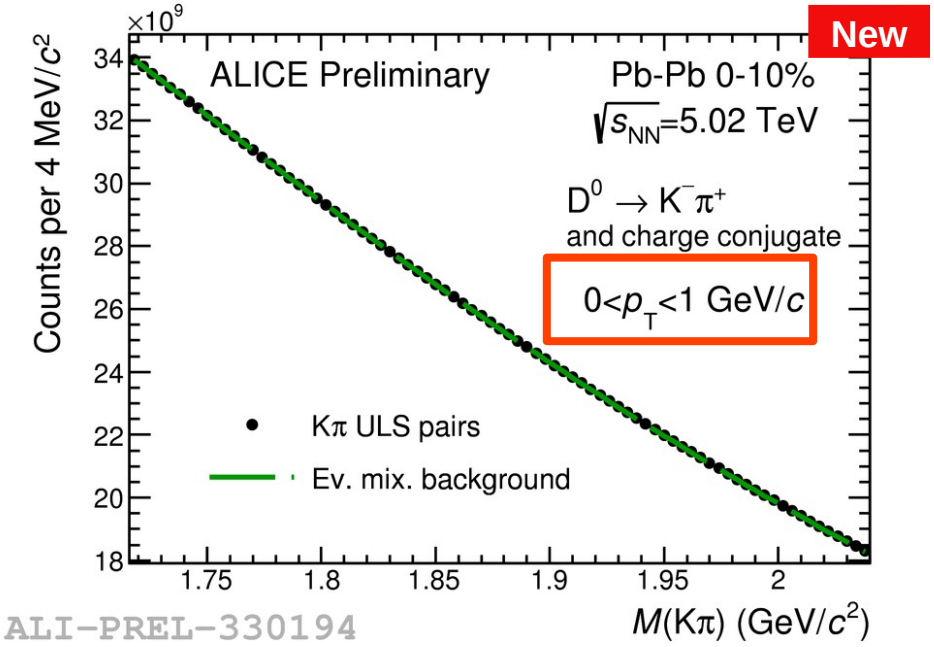
in Pb-Pb collisions!

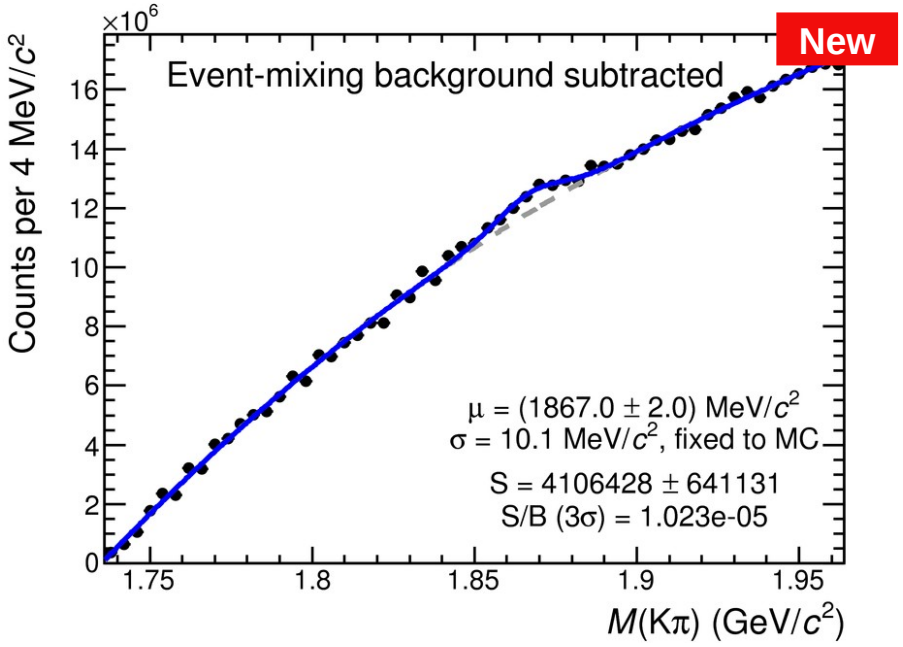
→ Good prospects for direct photon measurements

Heavy flavour: D^0 down to p_T = 0 GeV/c

G. Innocenti, 5 Nov 2019, 11:00

Mass spectrum: $D^0 \rightarrow K\pi$



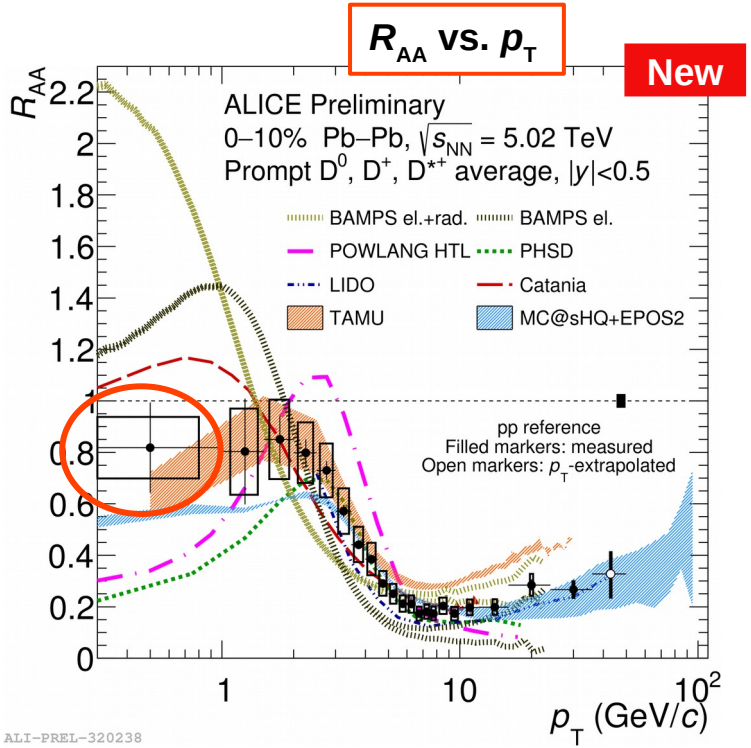


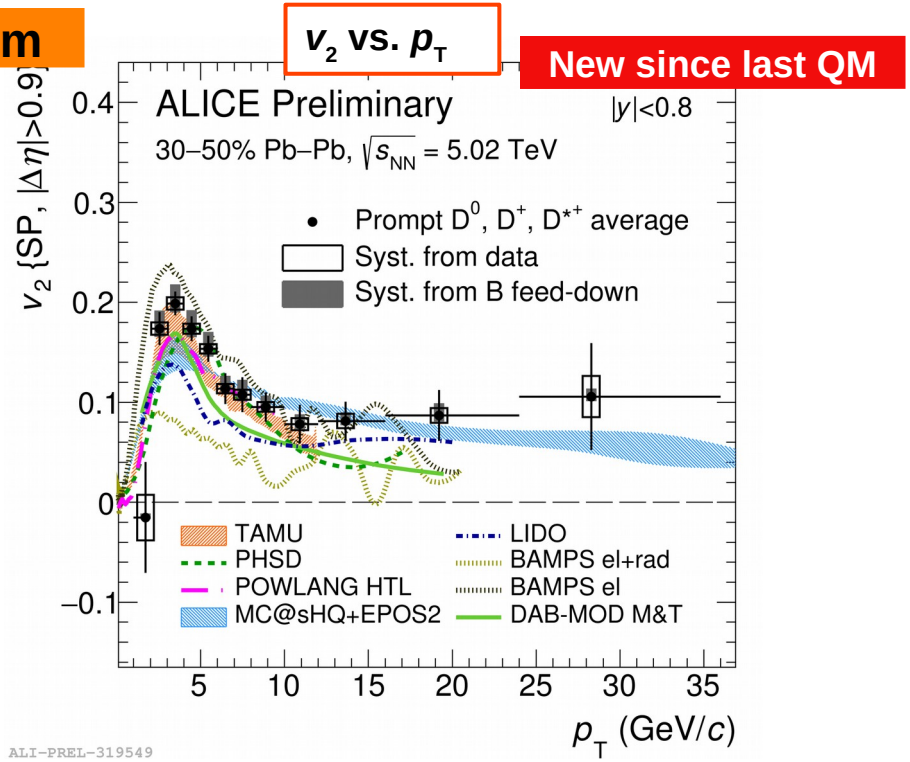
→ First measurement of HF production in heavy-ion collisions at LHC down to 0 GeV/c

Charm quark energy loss

S. Tang, 5 Nov 2019, 16:40
G. Innocenti, 5 Nov 2019, 11:00

Charm





Prompt D mesons

- Compare data and models for R_{AA} and v_2 simultaneously

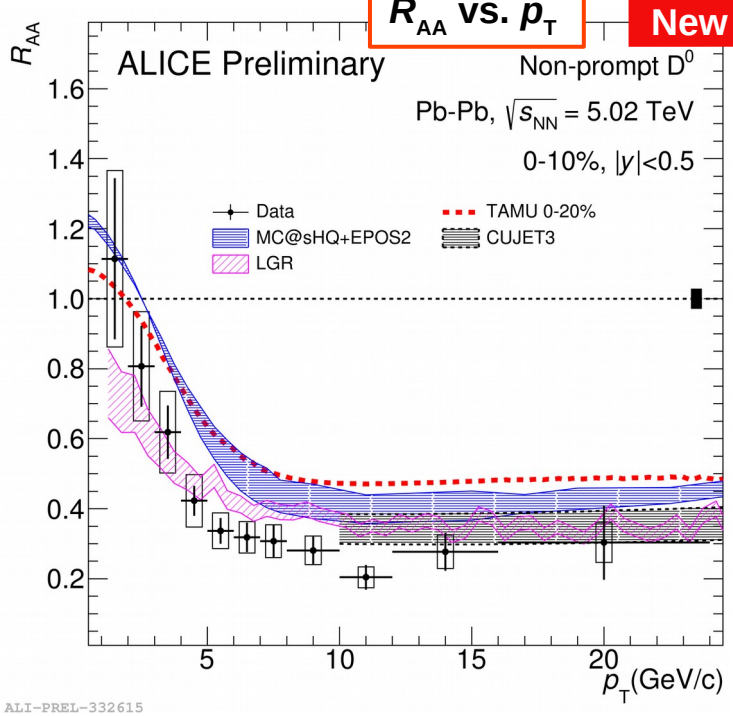
→ **first step to really distinguish different geometry and energy loss models**

Beauty quark energy loss

D. Thomas, 5 Nov 2019, 12:00

R_{AA} vs. p_T

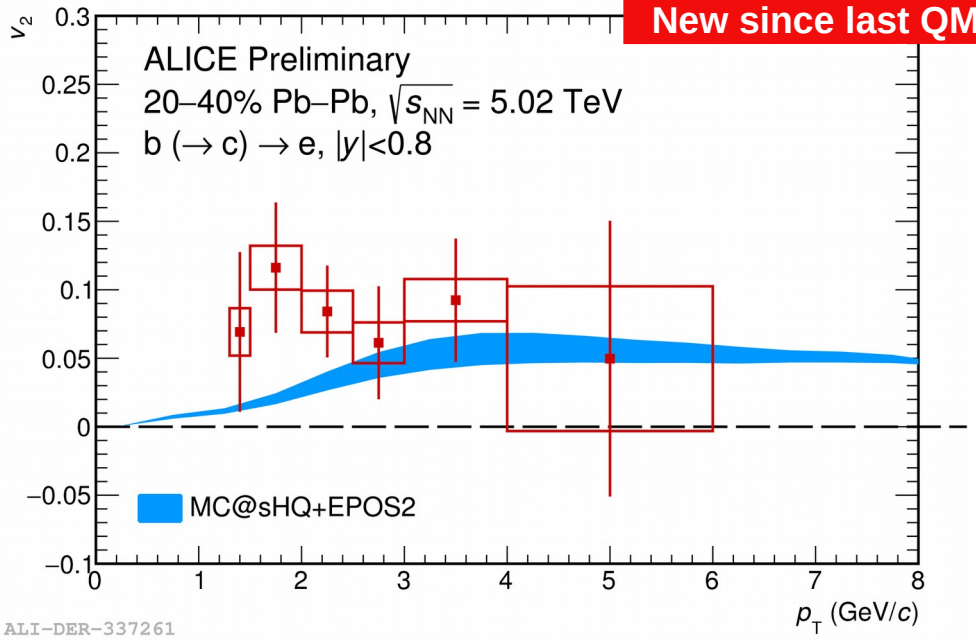
New



Beauty

v_2 vs. p_T

New since last QM



Non-Prompt D mesons and electrons from beauty decays

- Compare data and models for R_{AA} and v_2 simultaneously

→ **first step to really distinguish different geometry and energy loss models**

The heavy flavour family picture

QM 2019 edition

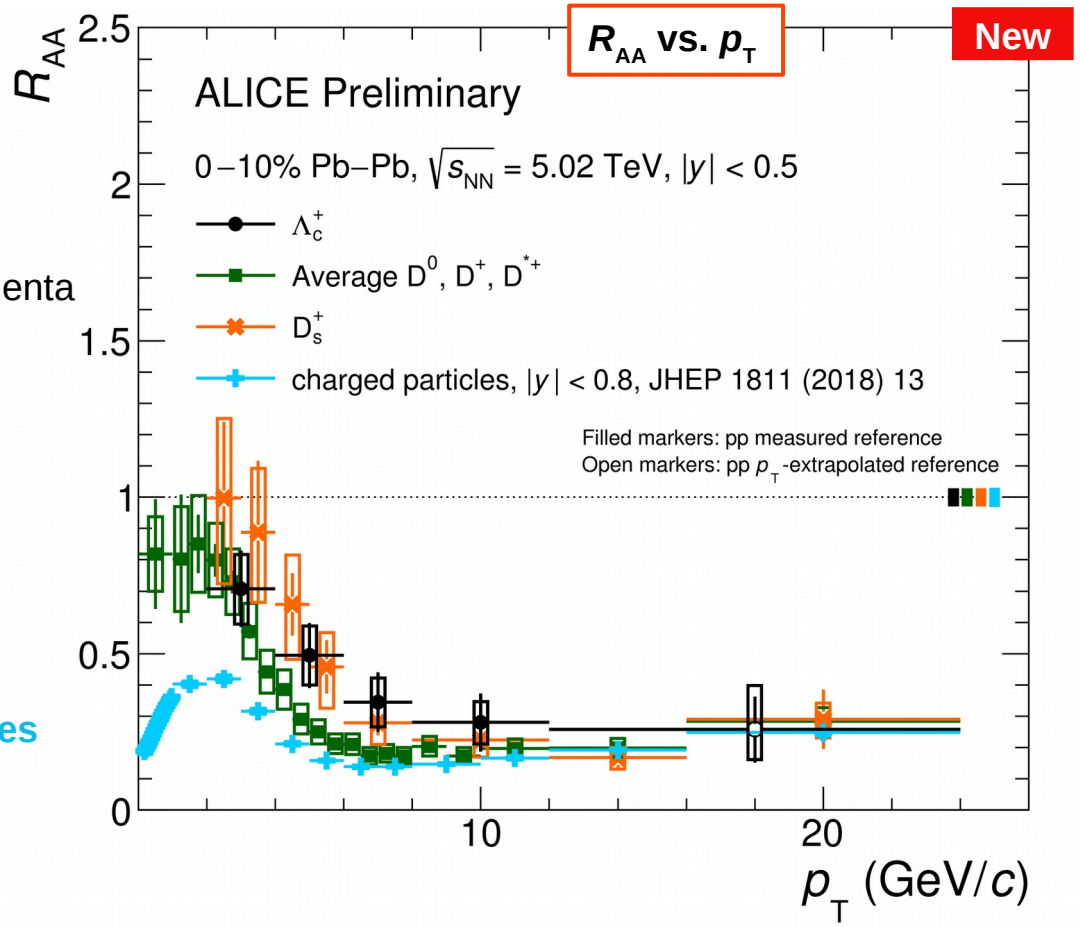
Adding new information

- Strange D mesons with low momenta
- Charm baryons

enhancement { D_s, Λ_c }

Prompt D

Charged particles



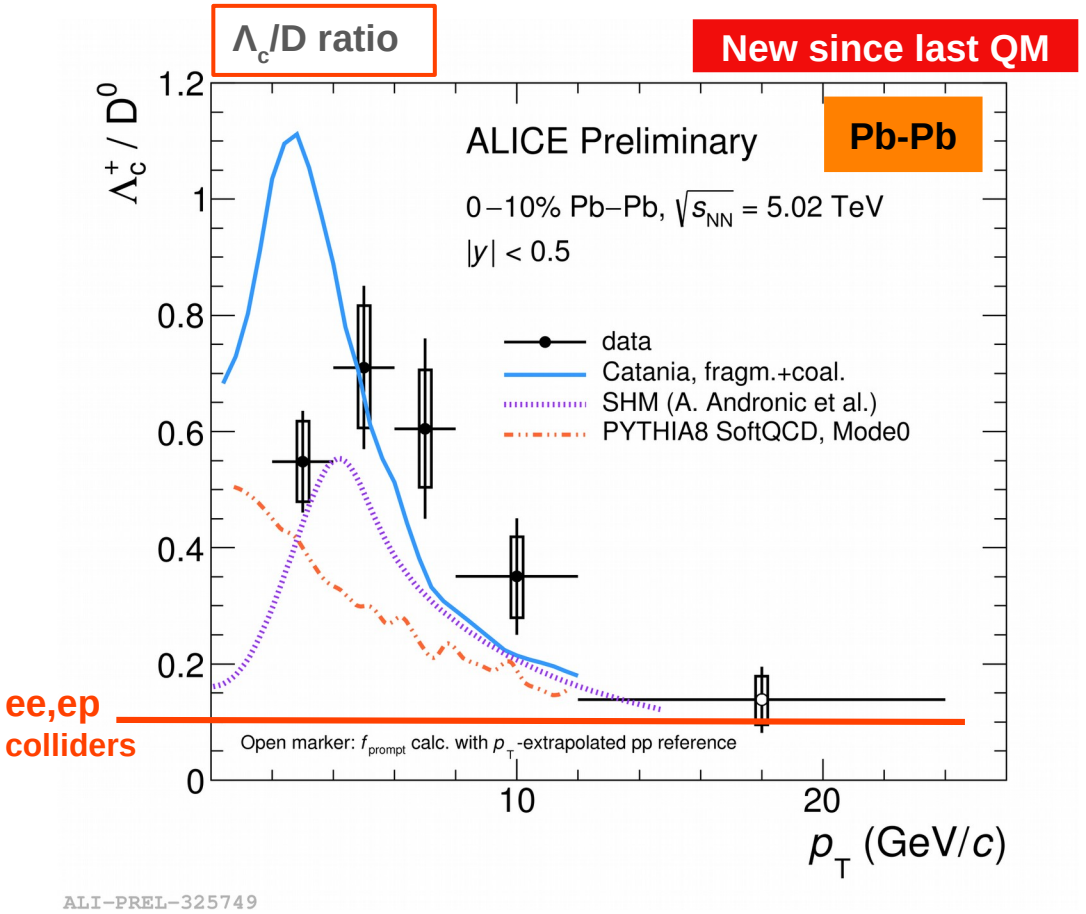
ALI-PREL-330734

Heavy quark hadronisation

G. Innocenti, 5 Nov 2019, 11:00

Λ_c/D ratio

- Sensitive to hadronisation mechanism
  - Recombination → enhancement



Heavy quark hadronisation

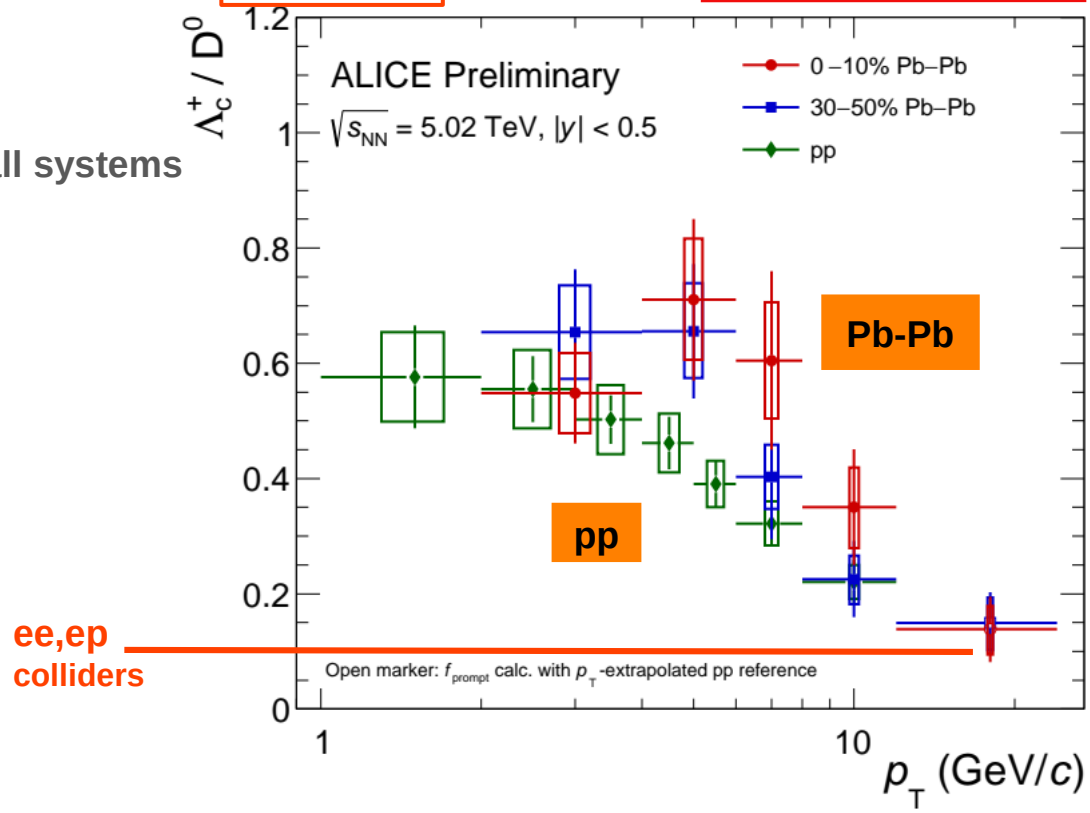
G. Innocenti, 5 Nov 2019, 11:00

Λ_c/D ratio

- Sensitive to hadronisation mechanism
  - Recombination → enhancement
  - **Already an enhancement in small systems**

Λ_c/D ratio

New since last QM



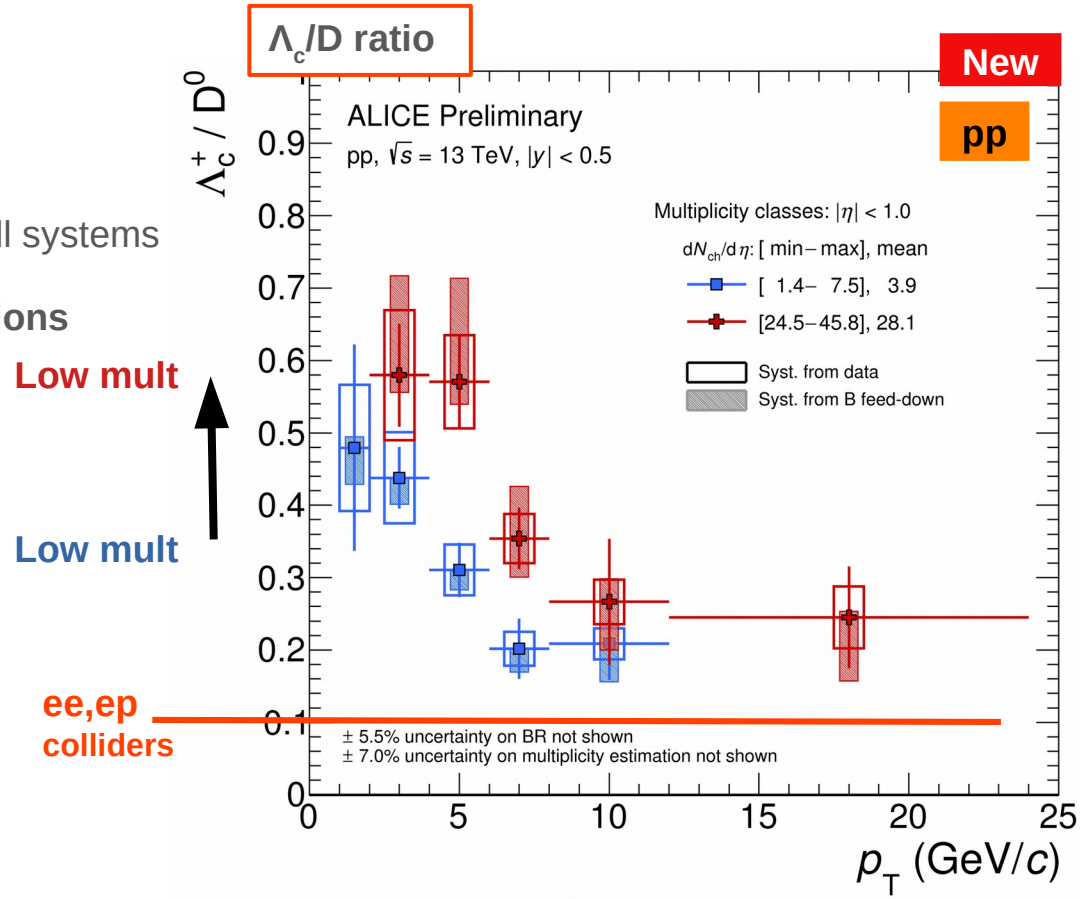
ee,ep colliders

Heavy quark hadronisation

G. Innocenti, 5 Nov 2019, 11:00

Λ_c/D ratio

- Sensitive to hadronisation mechanism
  - Recombination → enhancement
  - Already an enhancement in small systems
- **Multiplicity dependence in pp collisions**



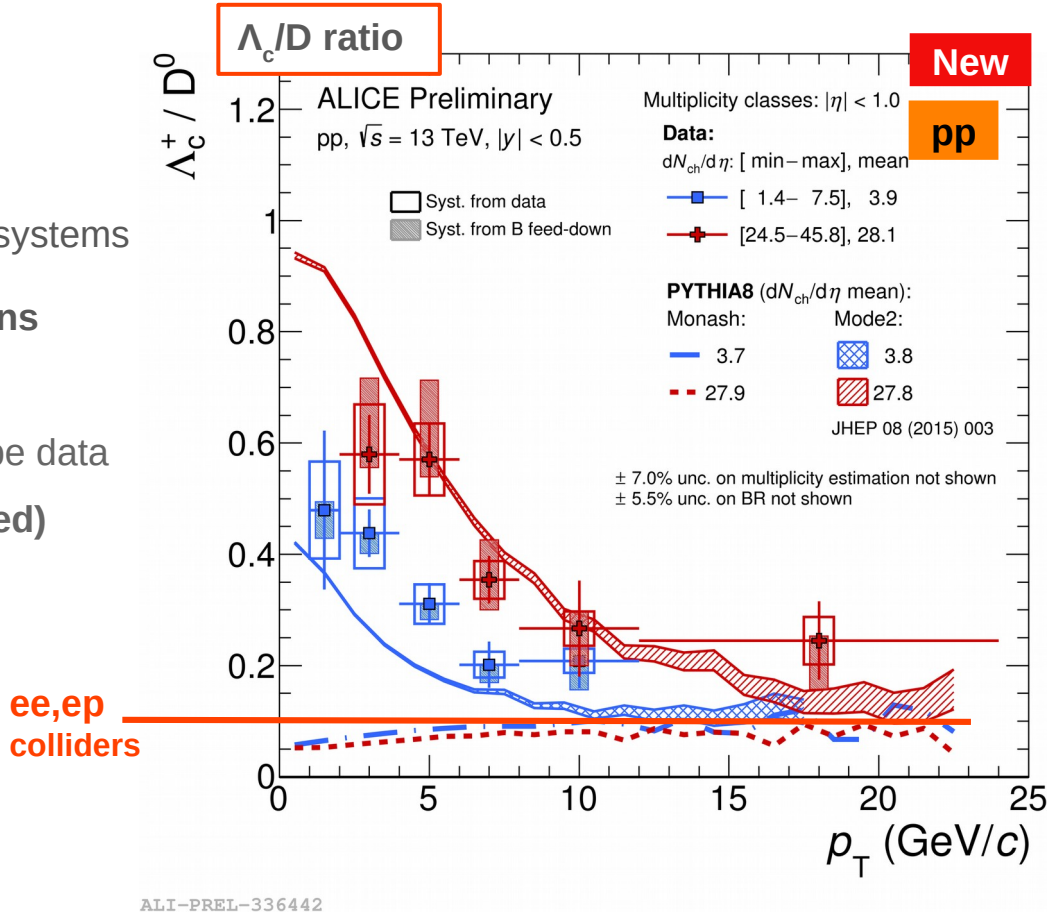
Heavy quark hadronisation

G. Innocenti, 5 Nov 2019, 11:00

Λ_c/D ratio

- Sensitive to hadronisation mechanism
  - Recombination → enhancement
  - Already an enhancement in small systems
- **Multiplicity dependence in pp collisions**
  - Enhancement over default Pythia
  - Color reconnection models describe data

    (but cross section not reproduced)



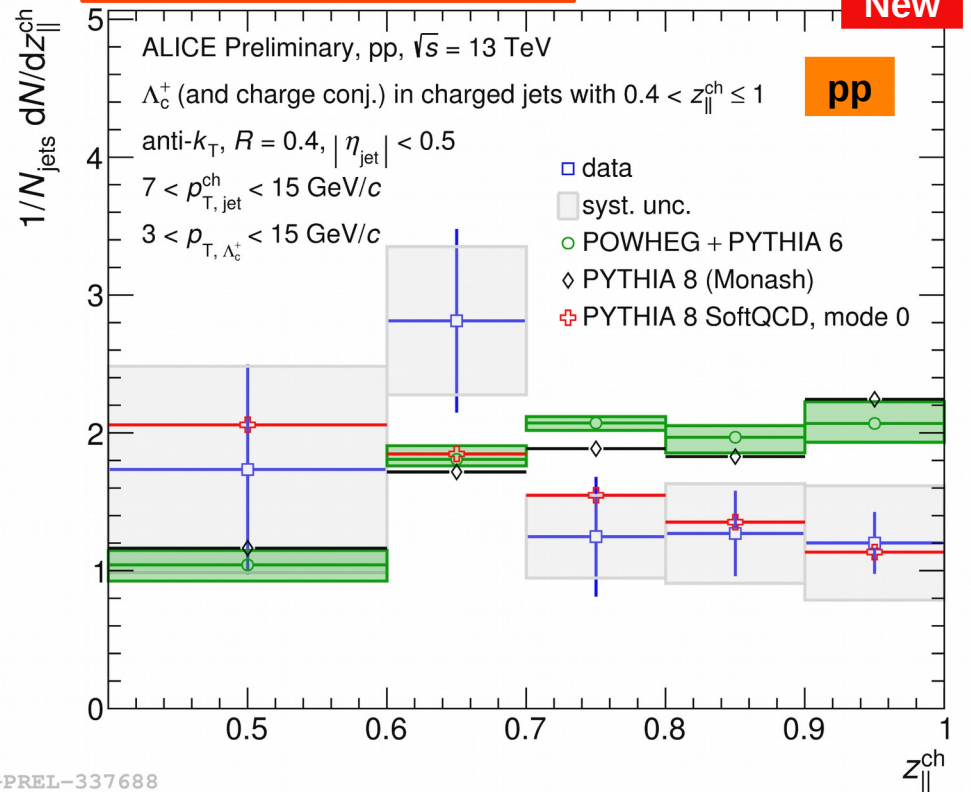
Heavy quark hadronisation

HF jets: J. Kvapil, 6 Nov 2019, 14:00
Lc and D: G. Innocenti, 5 Nov 2019, 11:00

Λ_c/D ratio

- Sensitive to hadronisation mechanism
  - Recombination → enhancement
  - Already an enhancement in small systems
- **Multiplicity dependence in pp collisions**
  - Enhancement over default Pythia
  - Color reconnection models describe data
- **Fragmentation function of Λ_c**
  - Shape similar to Pythia

Λ_c fragmentation function



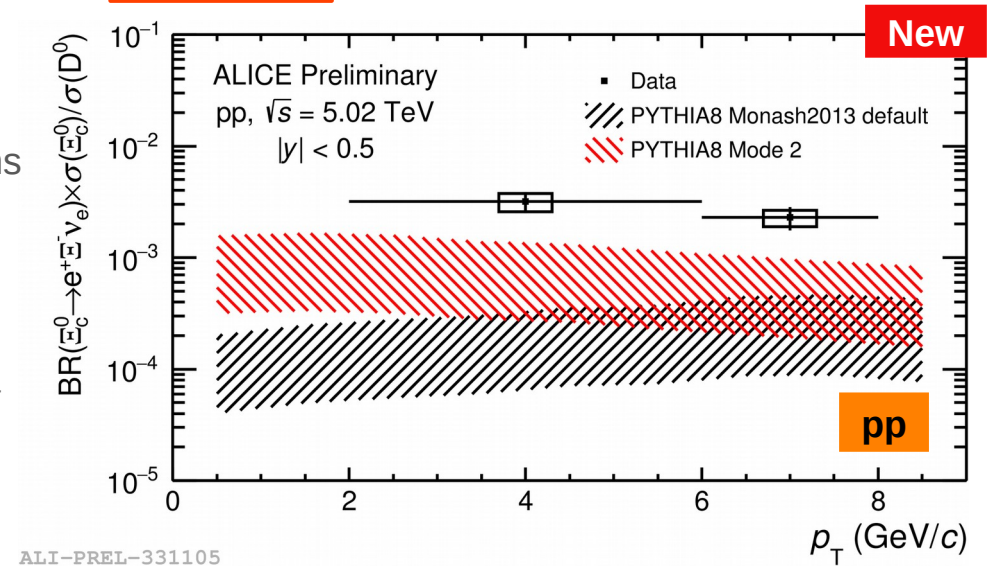
Heavy quark hadronisation

G. Innocenti, 5 Nov 2019, 11:00

Λ_c/D ratio

- Sensitive to hadronisation mechanism
  - Recombination → enhancement
  - Already an enhancement in small systems
- **Multiplicity dependence in pp collisions**
  - Enhancement over default Pythia
  - Color reconnection models describe data
- **Fragmentation function of Λ_c**
  - Shape similar to Pythia

Ξ_c/D ratio



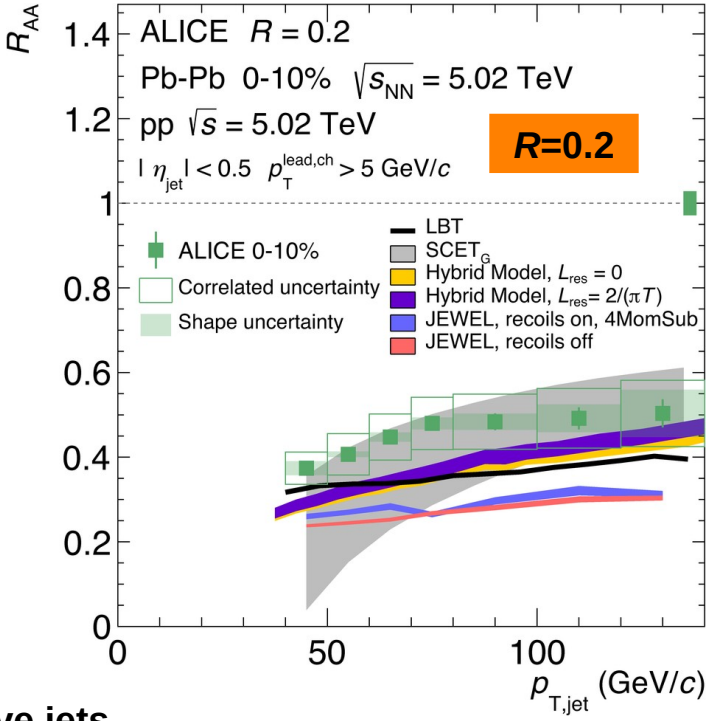
- **Another player in this game: Ξ_c/D^0**
  that is also higher than Pythia expectations

→ **Global charmed baryon-to-meson enhancement p_T-dependent over lepton collider expectations**

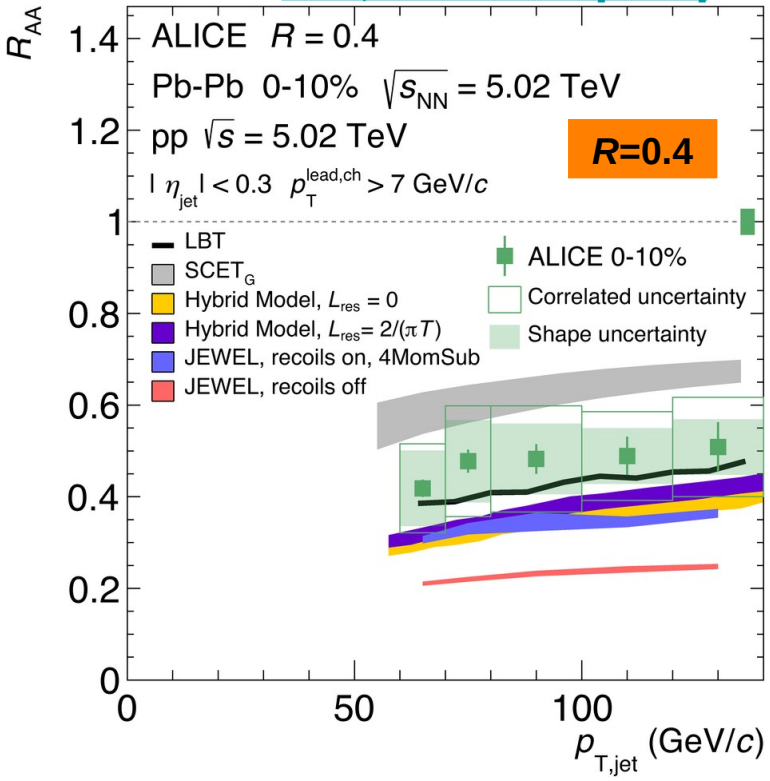
Jet energy loss

Y. Mao, 6 Nov 2019, 11:40

Jet R_{AA} vs. p_T



ALICE, arXiv:1909.09718 [nucl-ex]



R_{AA} for inclusive jets

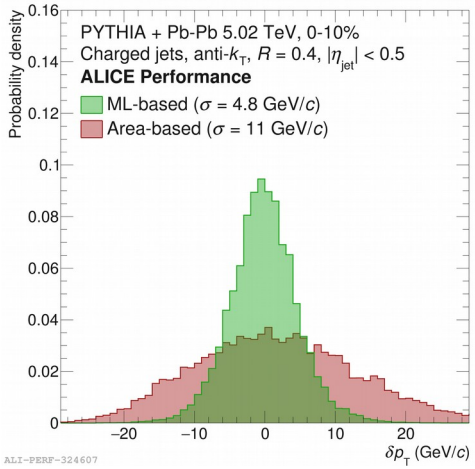
- Significant quenching in central Pb-Pb collisions
  → **Pushing down in p_T and to larger jet R**
  - Challenging of inclusive jet measurements in HI is the huge background

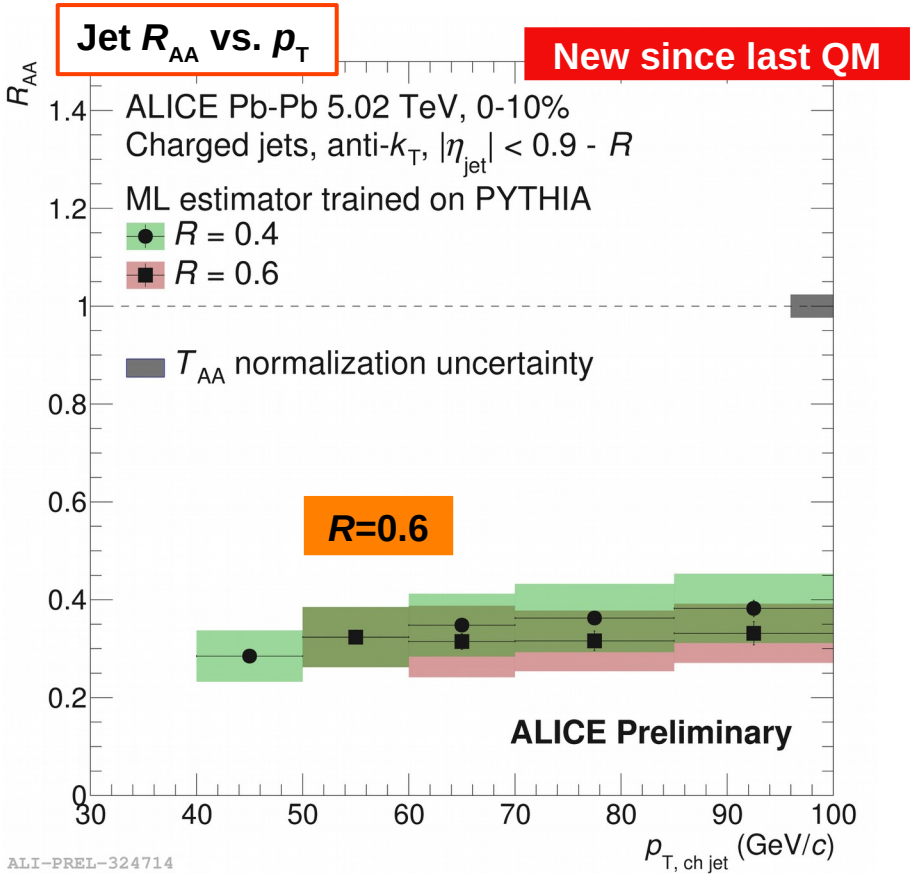
Jet energy loss

Option 1) Using Machine Learning for background estimation

- Improve resolution compared to the standard area-based method
- But purely based on Pythia (fragmentation)

  → ***R_{AA}* for independent of jet *R* also at low *p_T***



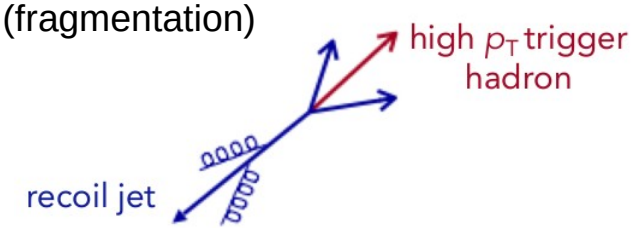


Jet energy loss

Small systems: P. Jacobs, 5 Nov 2019, 11:00
Pb-Pb: Y. Mao, 6 Nov 2019, 11:40

Option 1) Using Machine Learning for background estimation

- Improve resolution compared to the standard area-based method
- But purely based on Pythia (fragmentation)

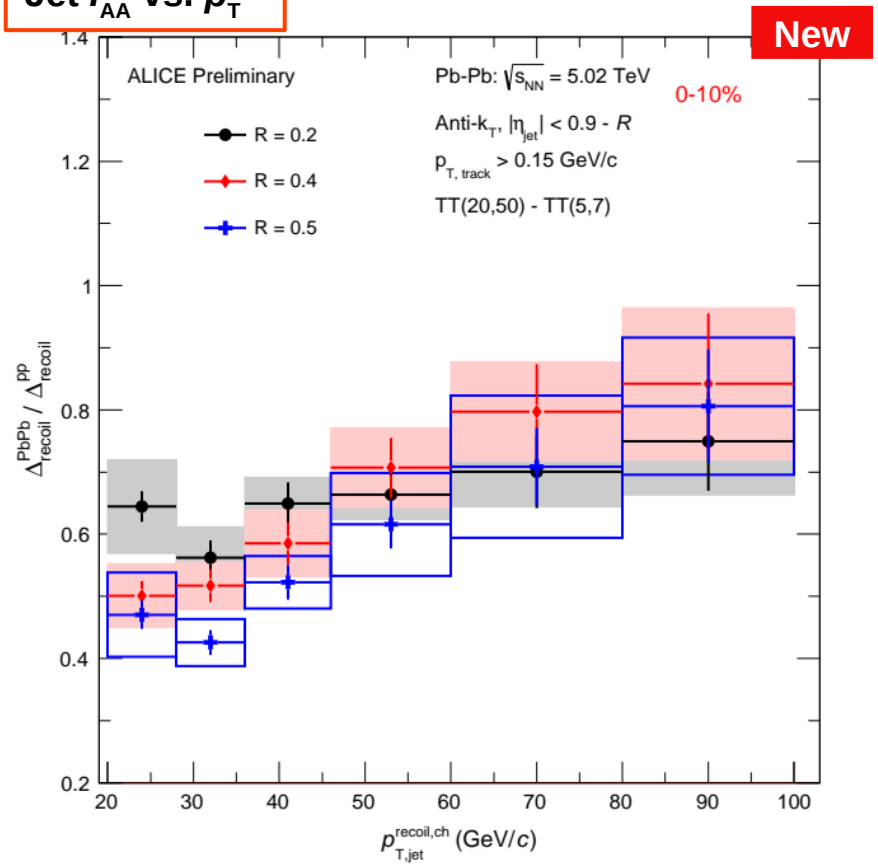


Option 2) Semi-inclusive recoil jet measurements

- suppress the uncorrelated background in HI collisions
- Data-driven method to extract I_{AA}

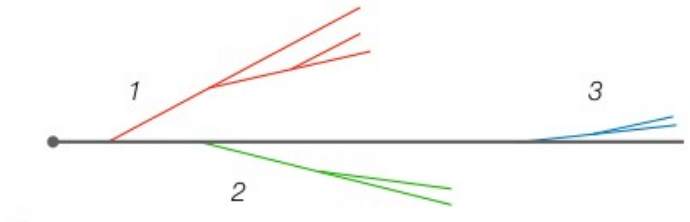
→ **Down to 20 GeV/*c***

Jet I_{AA} vs. p_T



Jet substructure

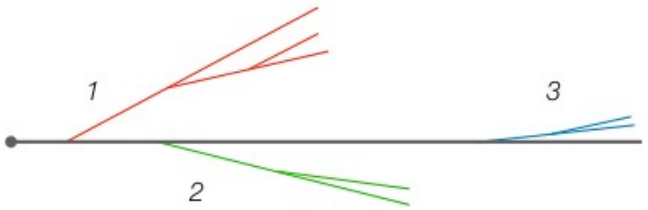
L. Havener, 6 Nov 2019, 09:00



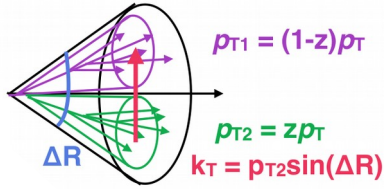
Constrain parton (in-medium) radiation by declustering reconstructed jets

Jet substructure

L. Havener, 6 Nov 2019, 09:00

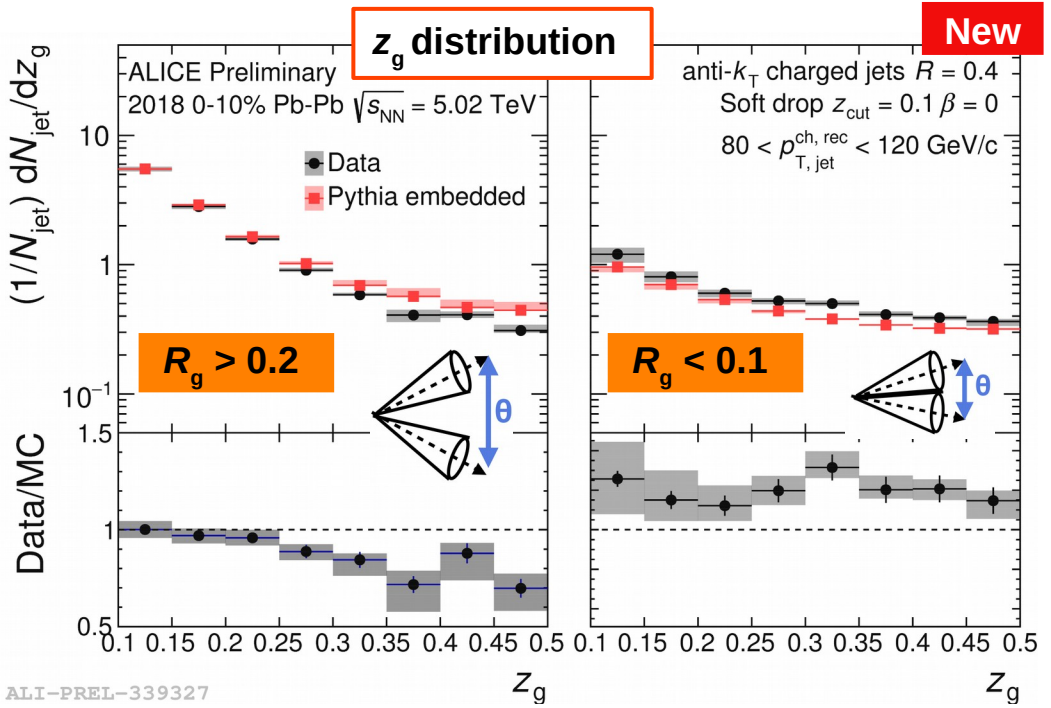


Constrain parton (in-medium) radiation by declustering reconstructed jets



$$z_g = \frac{\min(p_{Ti}, p_{Tj})}{p_{Ti} + p_{Tj}}$$

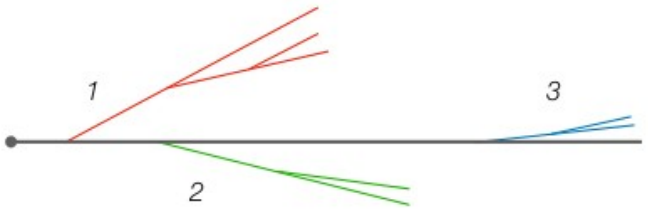
Shared momentum fraction between two subjets in parton shower



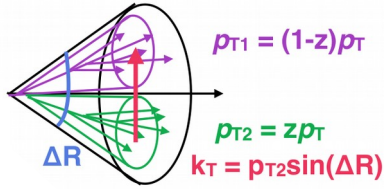
Study momentum fraction z_g for small and large angles of first hard splitting

Jet substructure

L. Havener, 6 Nov 2019, 09:00

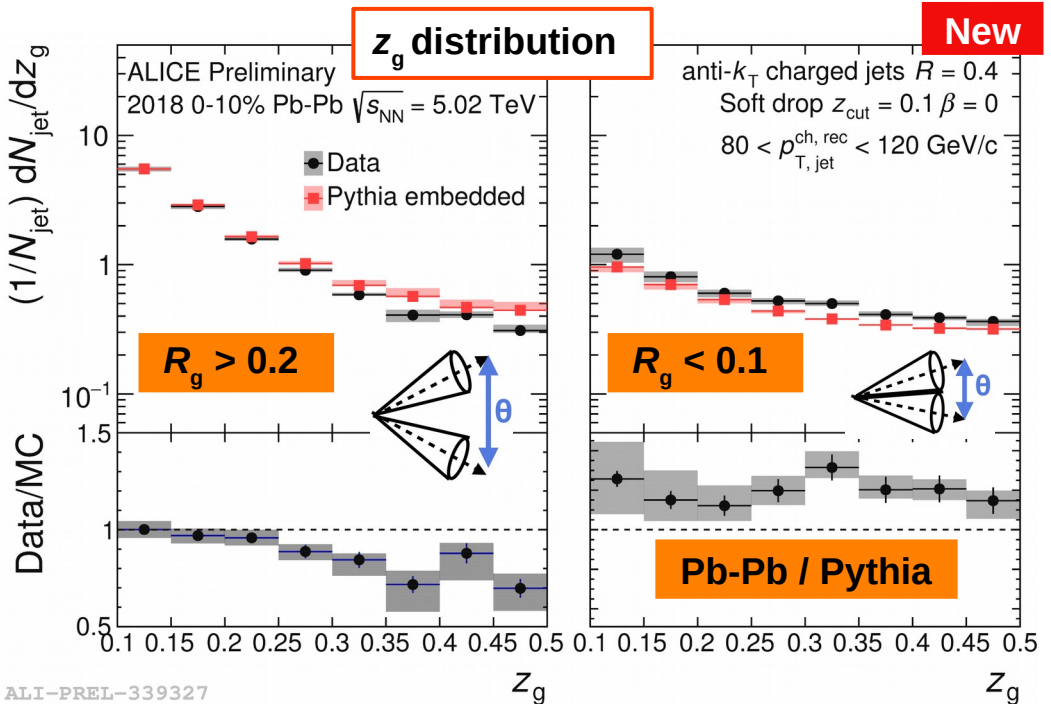


Constrain parton (in-medium) radiation by declustering reconstructed jets



$$z_g = \frac{\min(p_{Ti}, p_{Tj})}{p_{Ti} + p_{Tj}}$$

Shared momentum fraction between two subjets in parton shower



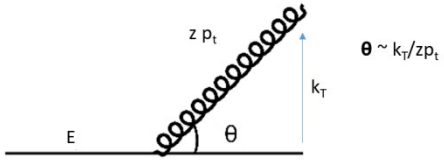
Study momentum fraction z_g for small and large angles of first hard splitting

- **Enhancement for small angles**
- **Suppression for large angles**

The dead cone

N. Zardoshti , 5 Nov 2019, 09:20

- Coherence effect of QCD
- Suppression of emissions from a radiator (quark) within $\theta < m_q/E_q$

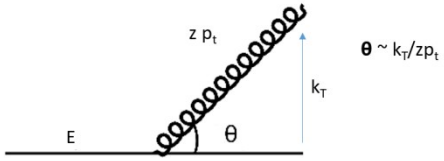


- Deconvolute the jet via iterative declustering **until small-angle splittings are probed**
- Study **angle of splittings for charm and inclusive (light-flavour) jets**

The dead cone

N. Zardoshti , 5 Nov 2019, 09:20

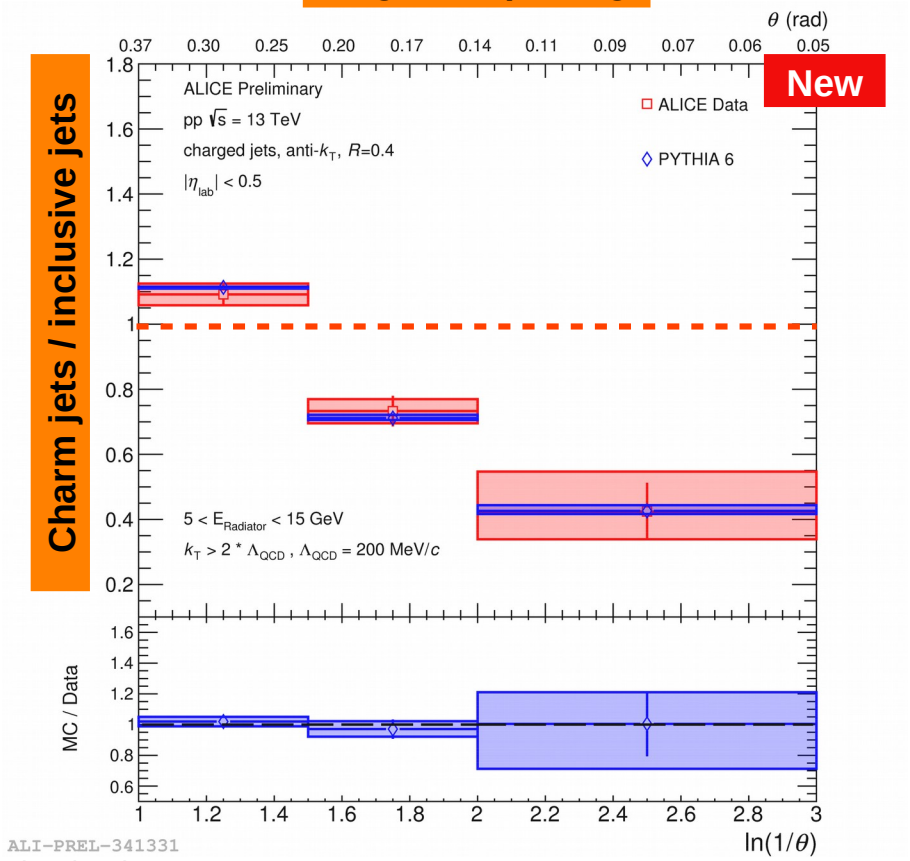
- Coherence effect of QCD
- Suppression of emissions from a radiator (quark) within $\theta < m_q/E_q$



- Deconvolute the jet via iterative declustering **until small-angle splittings are probed**
- Study **angle of splittings for charm and inclusive (light-flavour) jets**
  - **Charm: larger angles**

→ **First direct measurement of the dead cone**

Angle of splitting

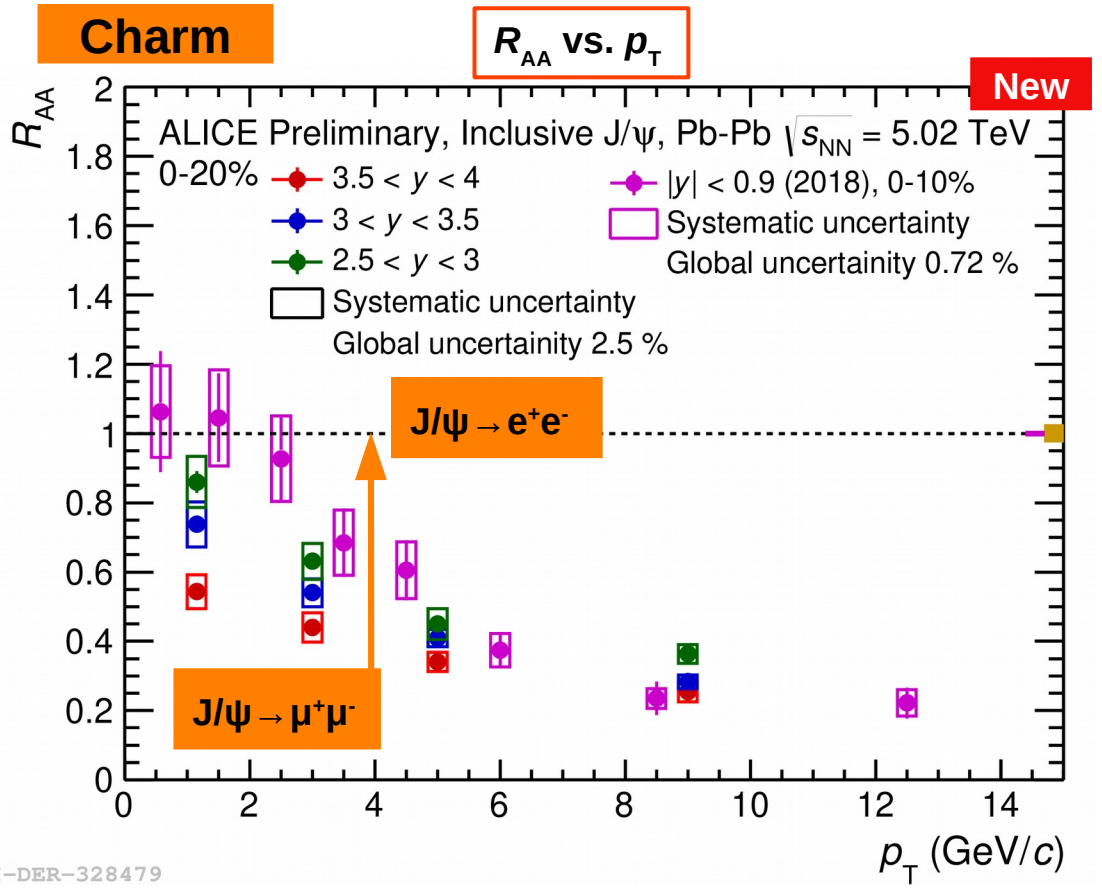


Quarkonia

Small systems: J. Ghosh, 5 Nov 2019, 10:00
Pb-Pb: X. Bai, 5 Nov 2019, 14:20

Quarkonia R_{AA}

- Clear rapidity dependence of J/ψ R_{AA} at low p_T
  - **Consistent with regeneration models**



Quarkonia

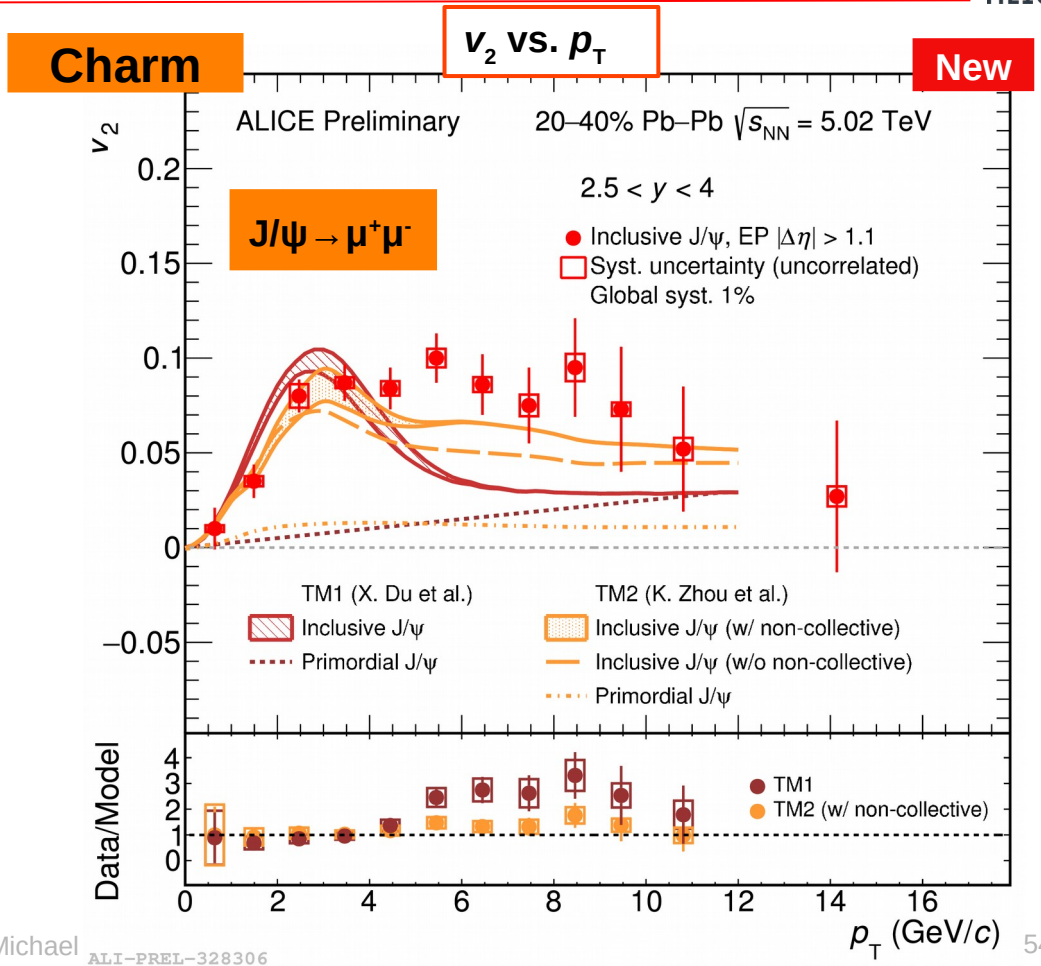
X. Bai, 5 Nov 2019, 14:20

Quarkonia R_{AA}

- Clear rapidity dependence of J/ψ R_{AA} at low p_T
  - **Consistent with regeneration models**

Quarkonia v_2

- Large J/ψ v_2 in large p_T range
  - Regeneration: J/ψ inherits elliptic flow of charm quarks)
  - **Additional mechanisms at work?**



Quarkonia

X. Bai, 5 Nov 2019, 14:20

Quarkonia R_{AA}

- Clear rapidity dependence of J/ψ R_{AA} at low p_T
  - **Consistent with regeneration models**

Quarkonia v_2

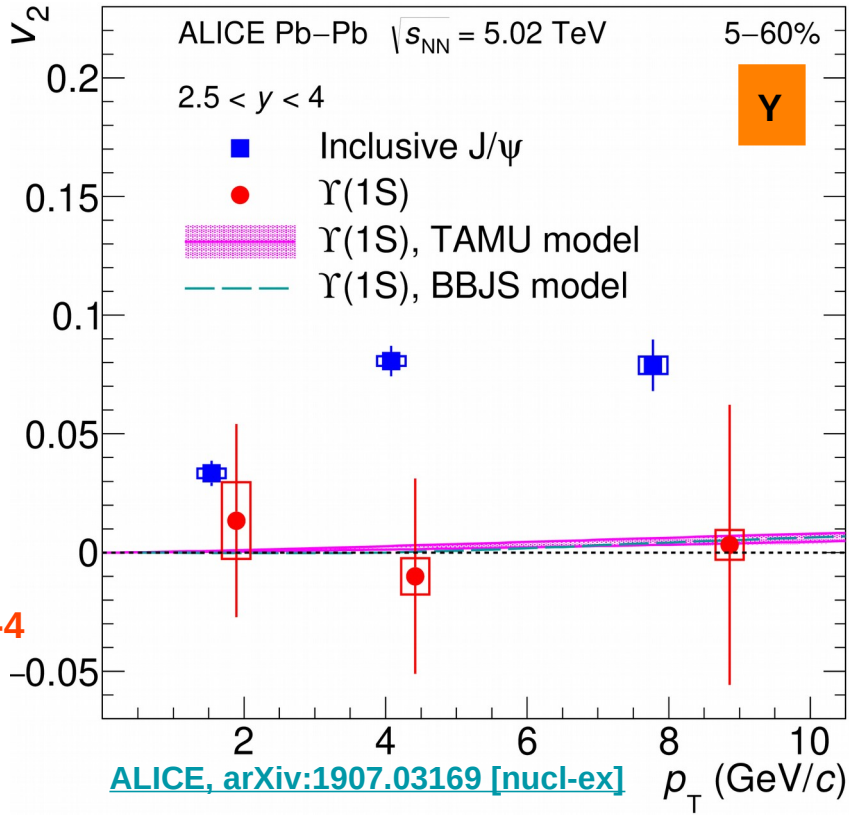
- Large J/ψ v_2 in large p_T range
  - Regeneration: J/ψ inherits elliptic flow of charm quarks)
  - **Additional mechanisms at work?**

- **First measurement of Υ (bottomonium) flow**
  - $v_2 \sim 0$

→ Not yet sensitive to distinguish models → Run 3-4

Bottom

v_2 vs. p_T

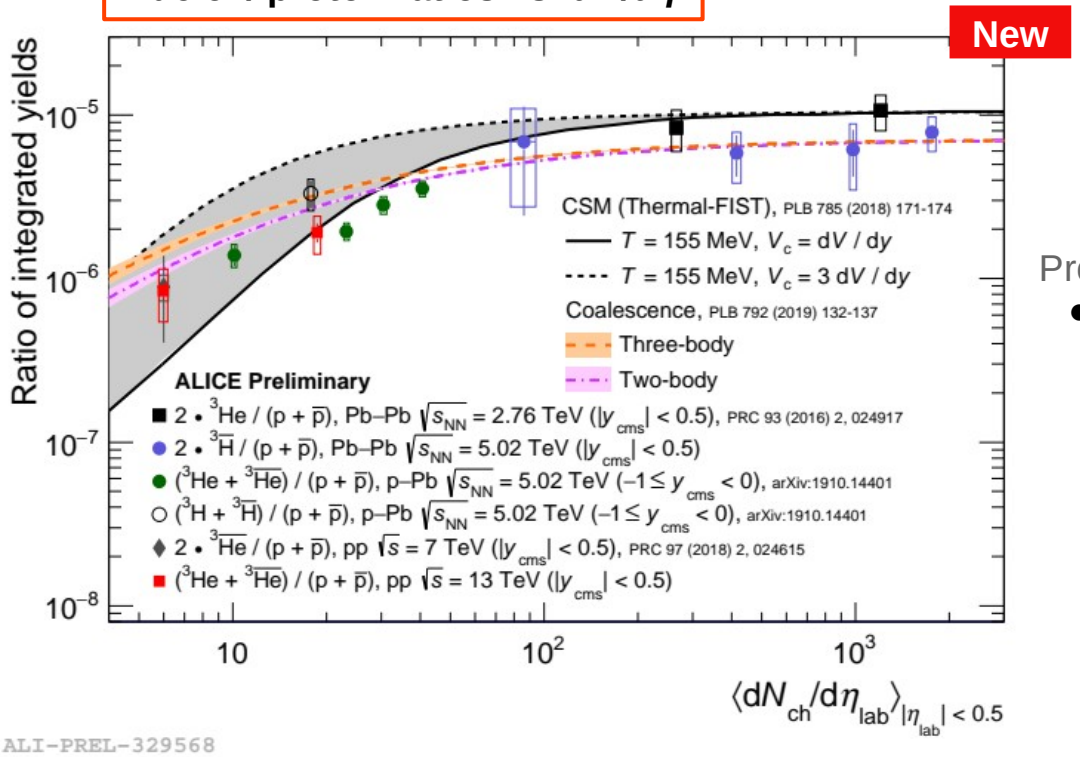


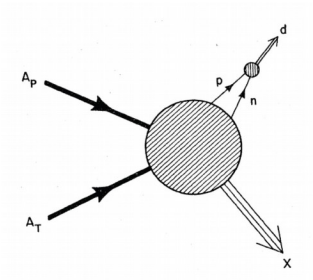
ALICE, arXiv:1907.03169 [nucl-ex]

Formation of light nuclei

Small systems: L. Barioglio, 6 Nov 2019, 11:00
Pb-Pb: E. Bartsch, 5 Nov 2019, 15:40

Nuclei / proton ratios vs. d*N*/d*η*





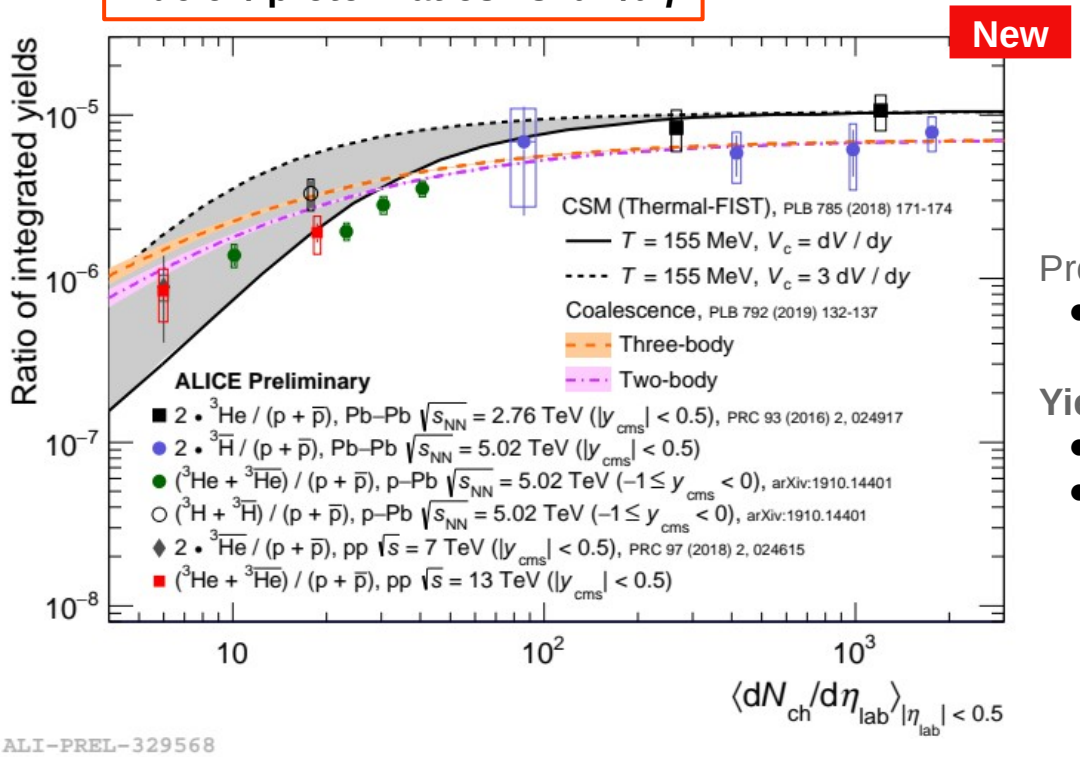
Production mechanism of A=3 nuclei

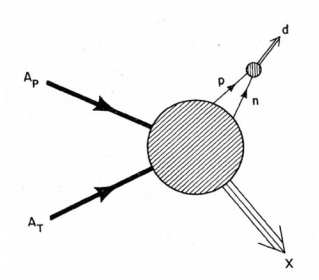
- **Thermal**, **coalescence**, …?

Formation of light nuclei

Small systems: L. Barioglio, 6 Nov 2019, 11:00
Pb-Pb: E. Bartsch, 5 Nov 2019, 15:40

Nuclei / proton ratios vs. d*N*/d*η*





Production mechanism of A=3 nuclei

- **Thermal**, **coalescence**, …?

Yields and ratios

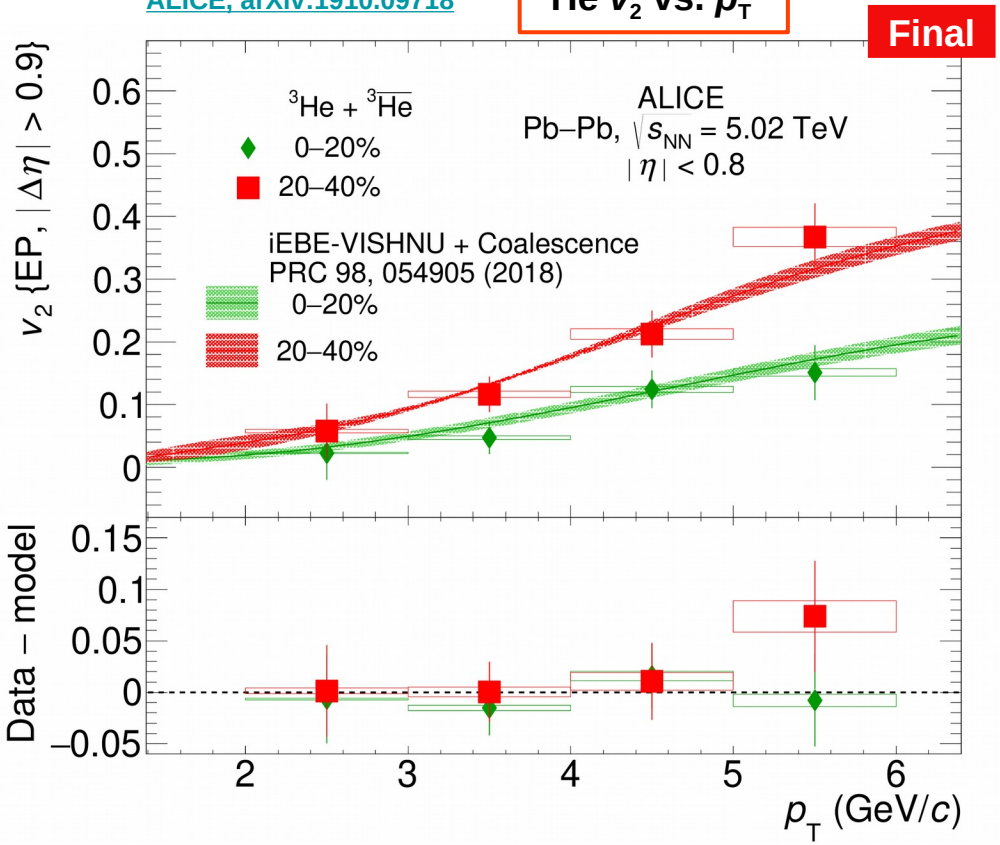
- First **(anti-)triton** spectra in Pb-Pb collisions
- **^{3}He/p** increases by one order of magnitude

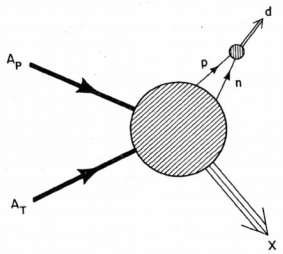
Formation of light nuclei

E. Bartsch, 5 Nov 2019, 15:40

ALICE, arXiv:1910.09718

^{3}He v_2 vs. p_T





Production mechanism of A=3 nuclei

- Thermal, coalescence, …?

Yields and ratios

- First (anti-)triton spectra in Pb-Pb collisions
- ^{3}He/p increases by one order of magnitude

Light nuclei flow

- ^{3}He described by hydro + coalescence

→ Not sensitive enough with compact nuclei
→ Need wider nuclei (hypernuclei) → Run 3-4

Initial state

QGP - Macroscopic properties

QGP - Microscopic dynamics

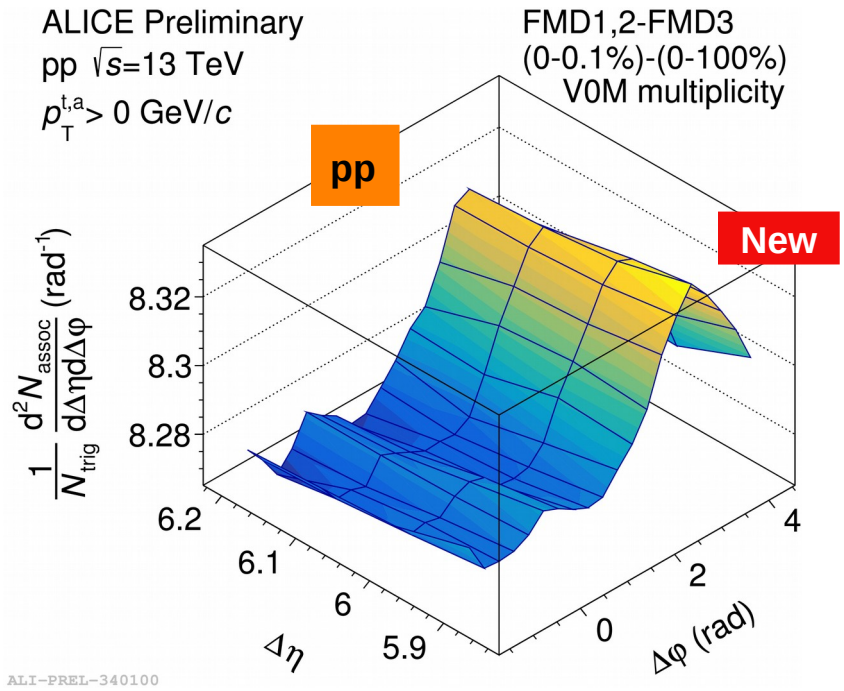
Small systems

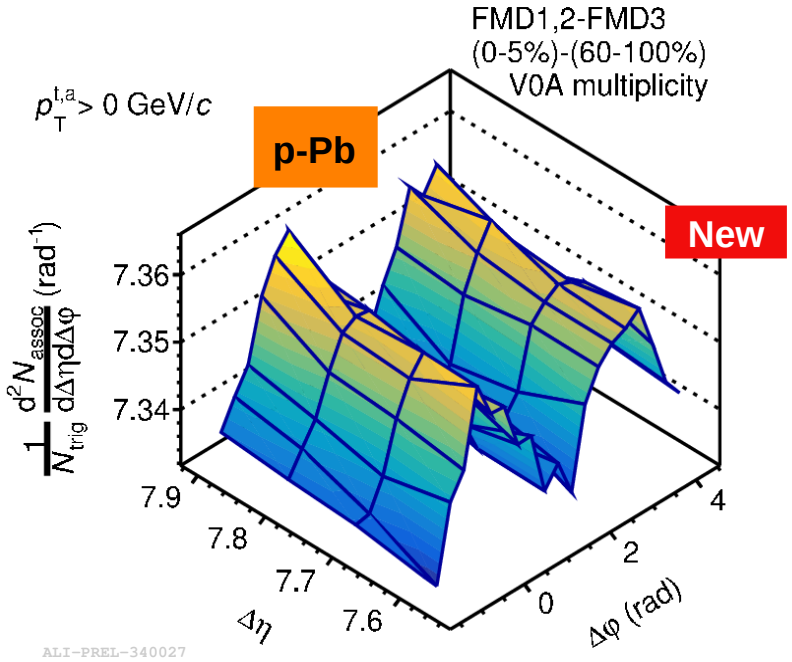
→ unified picture of QCD particle production from small to larger systems

Hadron physics

Collective flow

Y. Sekiguchi, 6 Nov 2019, 15:00

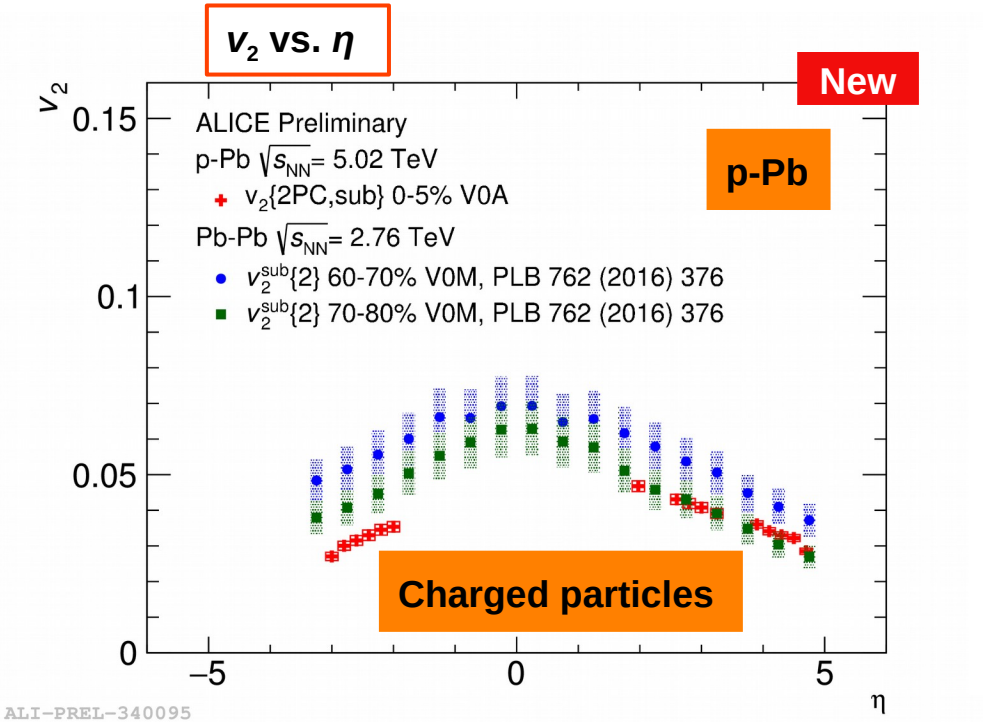


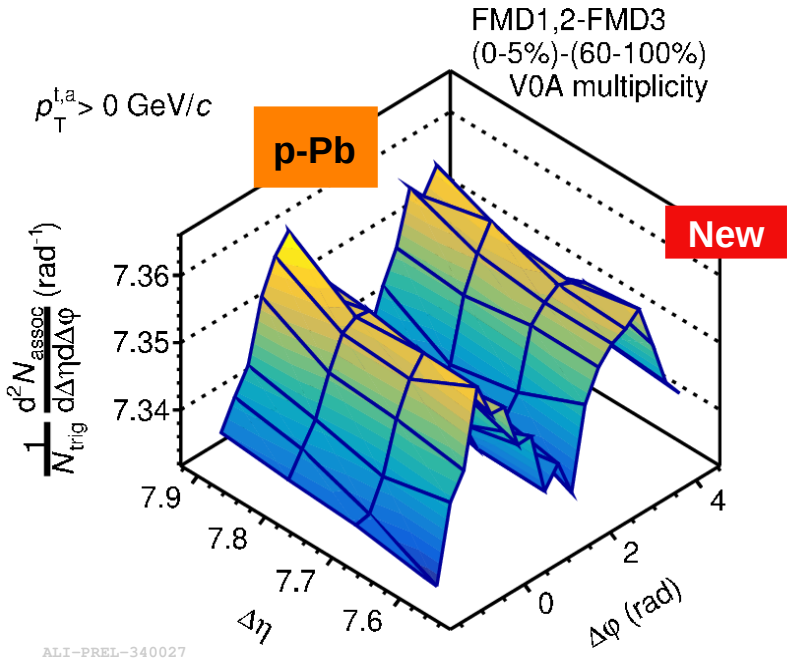


- Largest eta range studied at LHC in pp/p-Pb collisions
- **Correlations in small systems extend to large pseudorapidities**
  → Ridge up to Δη ~ 8

Collective flow

Y. Sekiguchi, 6 Nov 2019, 15:00

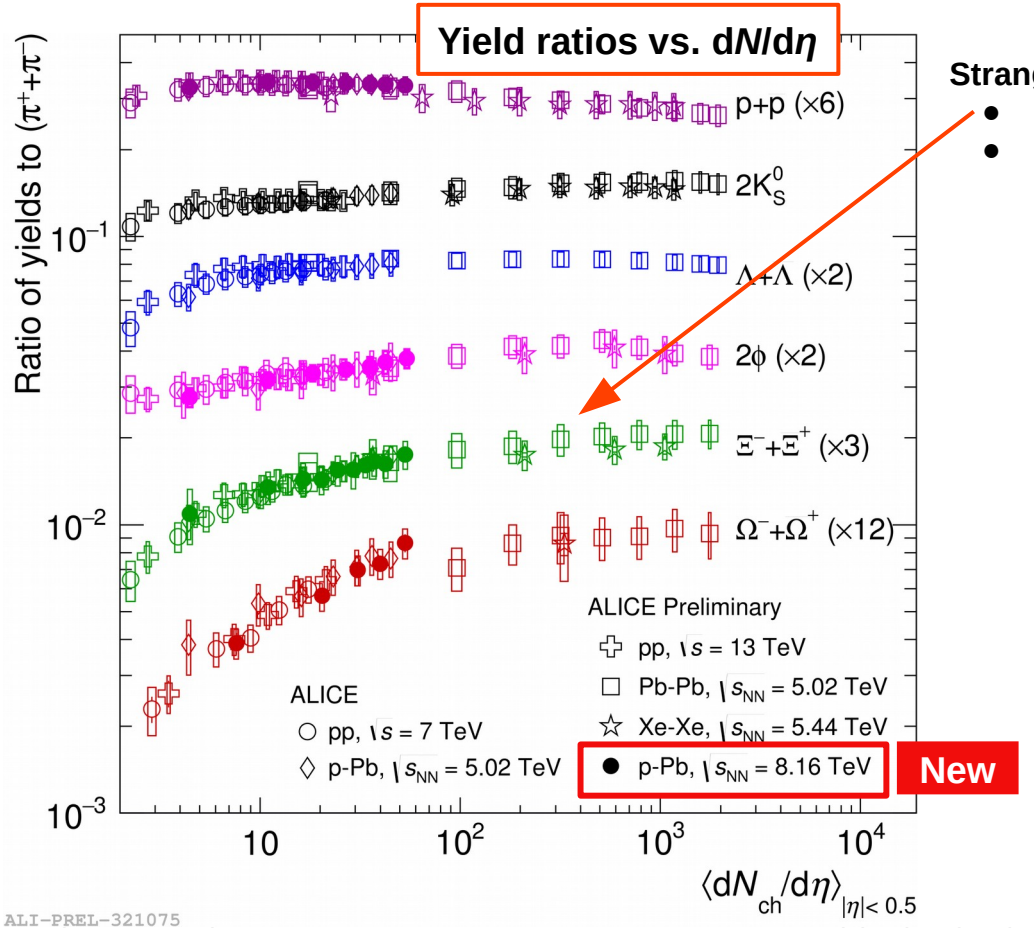




- Largest eta range studied at LHC in pp/p-Pb collisions
- **Correlations in small systems extend to large pseudorapidities**

  → Ridge up to Δη ~ 8 (v_2 in high-multiplicity p-Pb comparable with peripheral Pb-Pb)

Particle production vs multiplicity



Strangeness enhancement/suppression

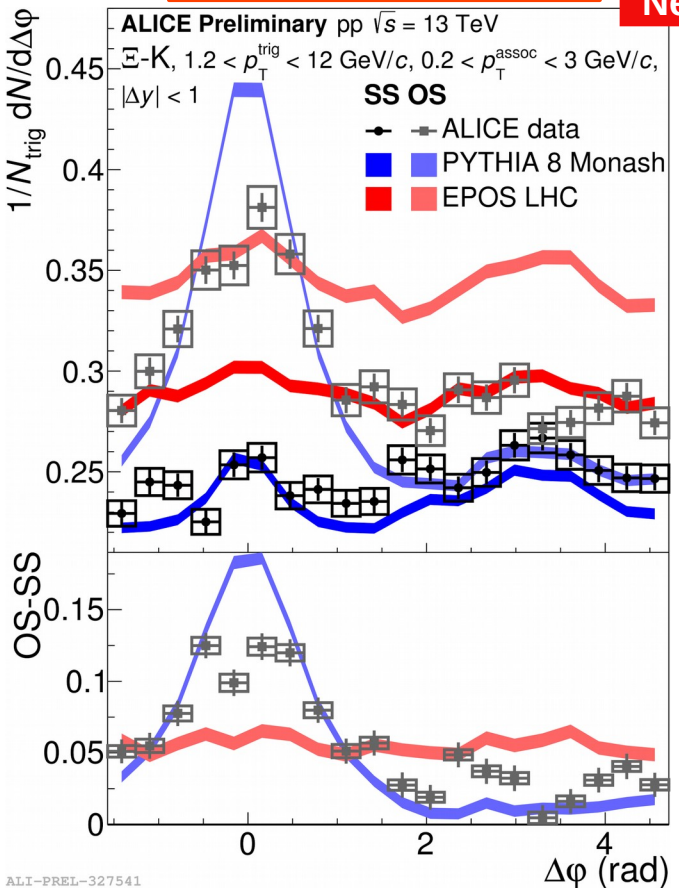
- Focus on multi-strange particles, e.g. Ξ
- Strongly suppressed in small systems

Particle production vs multiplicity

S. Pisano, 6 Nov 2019, 11:40

Ξ-K correlation function

New



Strangeness enhancement/suppression

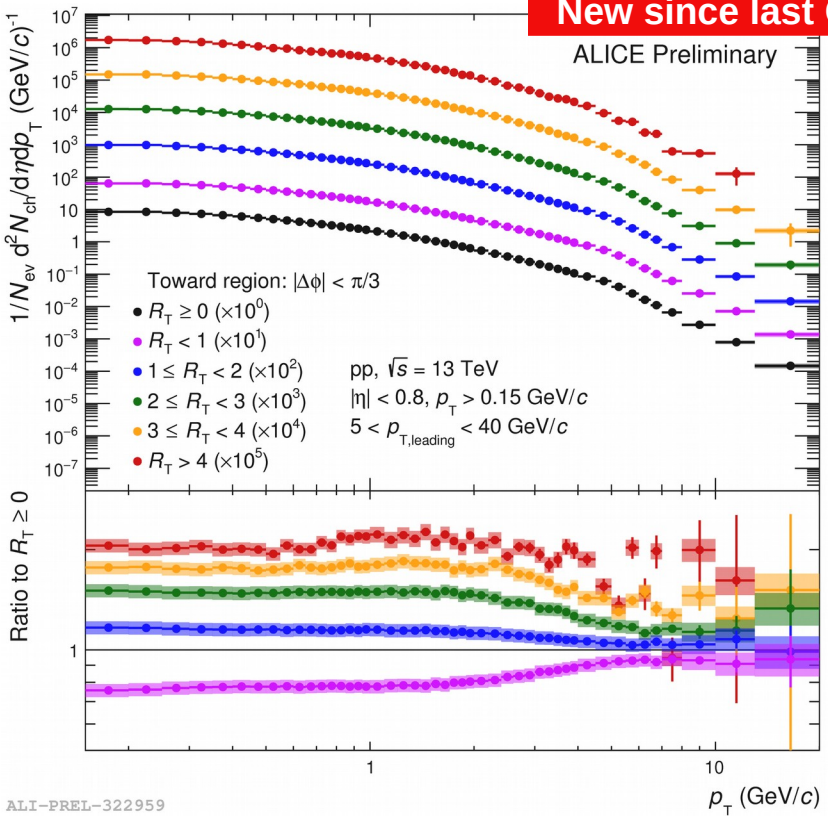
- Focus on multi-strange particles, e.g. Ξ
- Strongly suppressed in small systems
- Correlations between s-$\bar{s}$?
  - Study Ξ-K correlations
    → **Not well described by models**

Particle production vs multiplicity

S. Pisano, 6 Nov 2019, 11:40

Yield (ratios) vs. p_T (R_T classes)

New since last QM

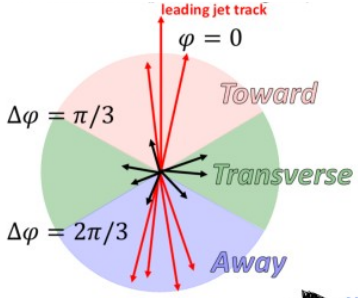


Strangeness enhancement/suppression

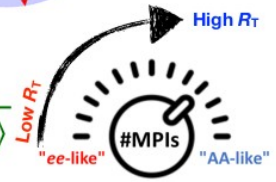
- Focus on multi-strange particles, e.g. Ξ
- Strongly suppressed in small systems
- Correlations between s-$\bar{s}$?
  - Study Ξ-K correlations

Jet-bias

- Can be disentangled/reduced with transverse activity R_T



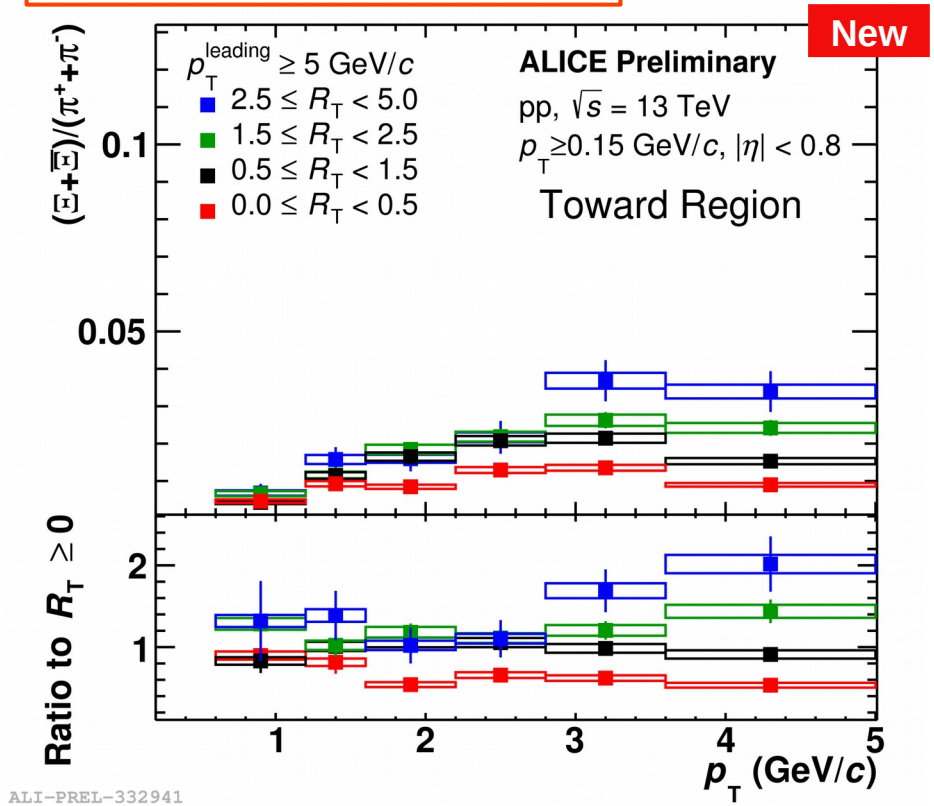
$$R_T = \frac{N_{ch}^{transverse}}{\langle N_{ch}^{transverse} \rangle}$$



Particle production vs multiplicity

S. Pisano, 6 Nov 2019, 11:40

Ξ/π ratio vs. p_T (R_T classes)



Strangeness enhancement/suppression

- Focus on multi-strange particles, e.g. Ξ
- Strongly suppressed in small systems
- Correlations between s-$\bar{s}$?
  - Study Ξ-K correlations

Jet-bias

- Can be disentangled/reduced with transverse activity R_T
- vary underlying event and jet contributions

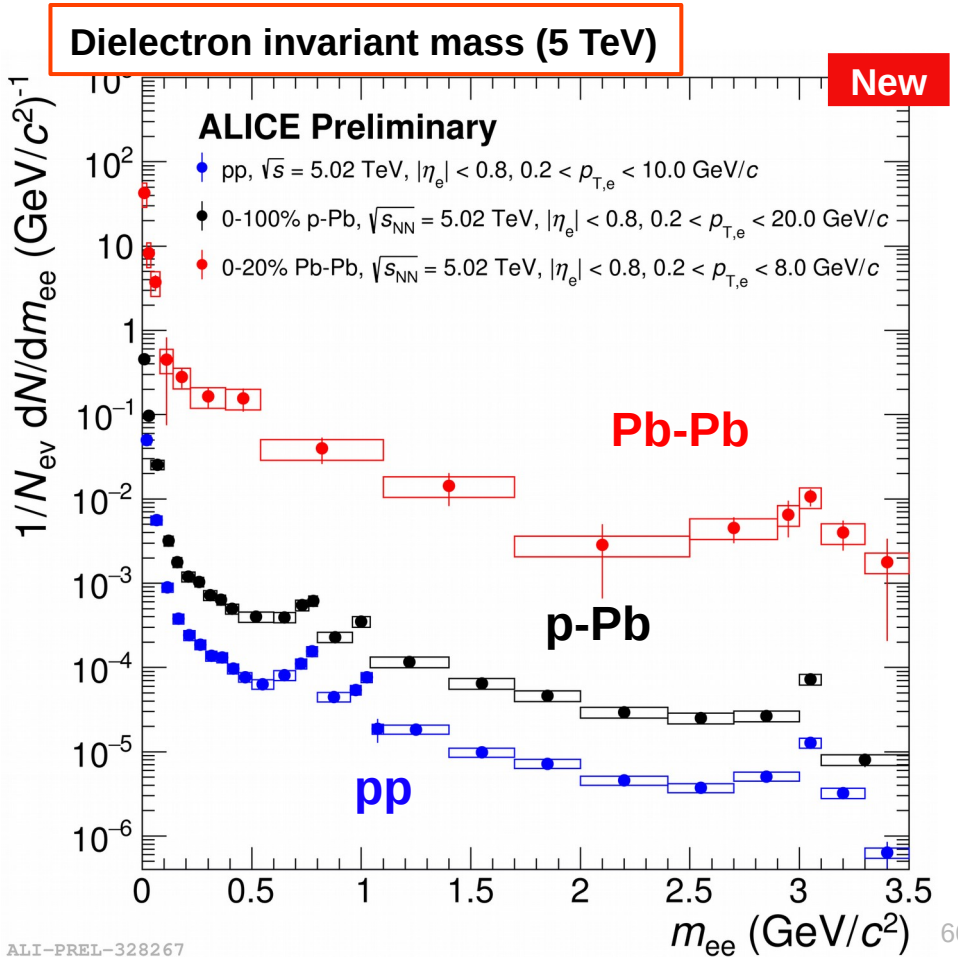
→ **hard component (low R_T): smaller particle ratios**

→ **soft component (high R_T): larger particle ratios**

Low mass dileptons

S. Scheid, 6 Nov 2019, 16:40

- Collision system scan at same energy
  → **Dielectron R_{AA}, R_{pPb}**



Low mass dileptons

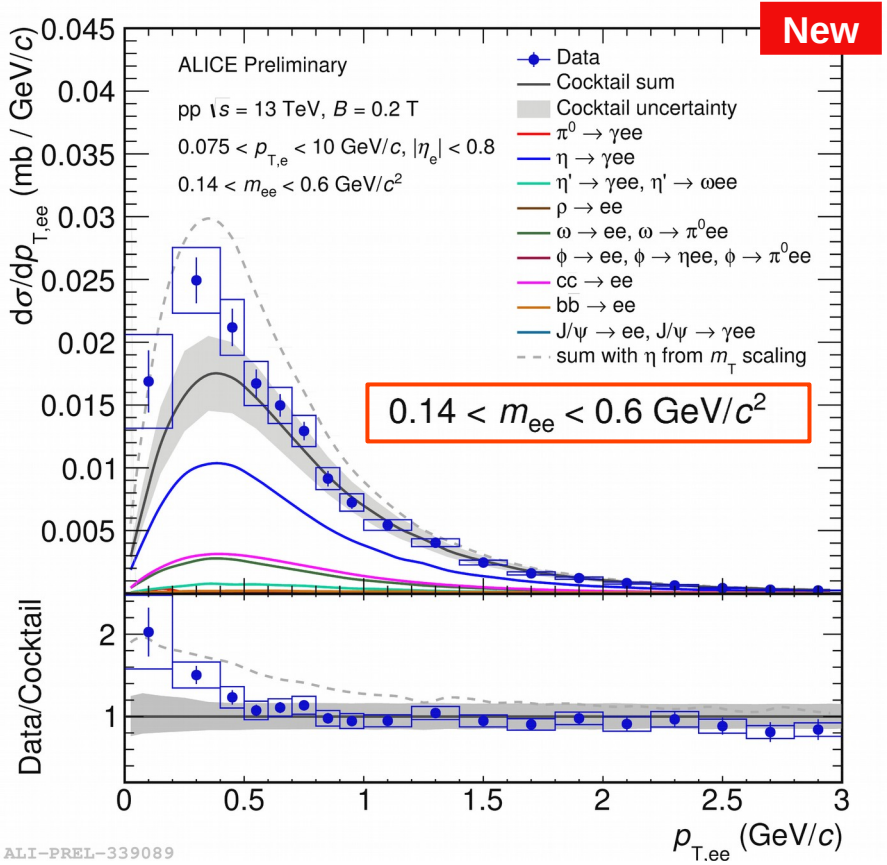
S. Scheid, 6 Nov 2019, 16:40

- Collision system scan at same energy
  → **Dielectron R_{AA}, R_{pPb}**

- Soft dielectron enhancement at low masses
  - **75 MeV/*c* single lepton p_T** cut
    (running ALICE with low field B = 0.2 T)
  - **Confirming AFS@ISR**

  - Study multiplicity dependence
    → **Insights on source**

Soft dielectron enhancement vs. p_T



Initial state

QGP - Macroscopic properties

QGP - Microscopic dynamics

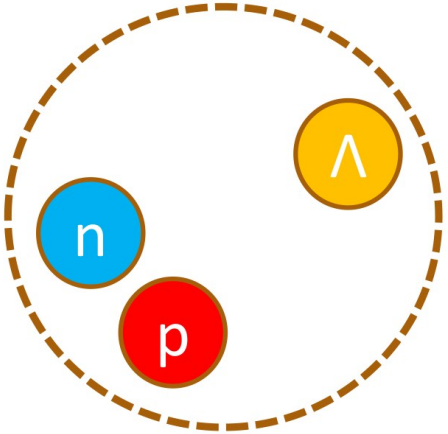
Small systems

Hadron physics

→ LHC as laboratory for hadron interaction studies

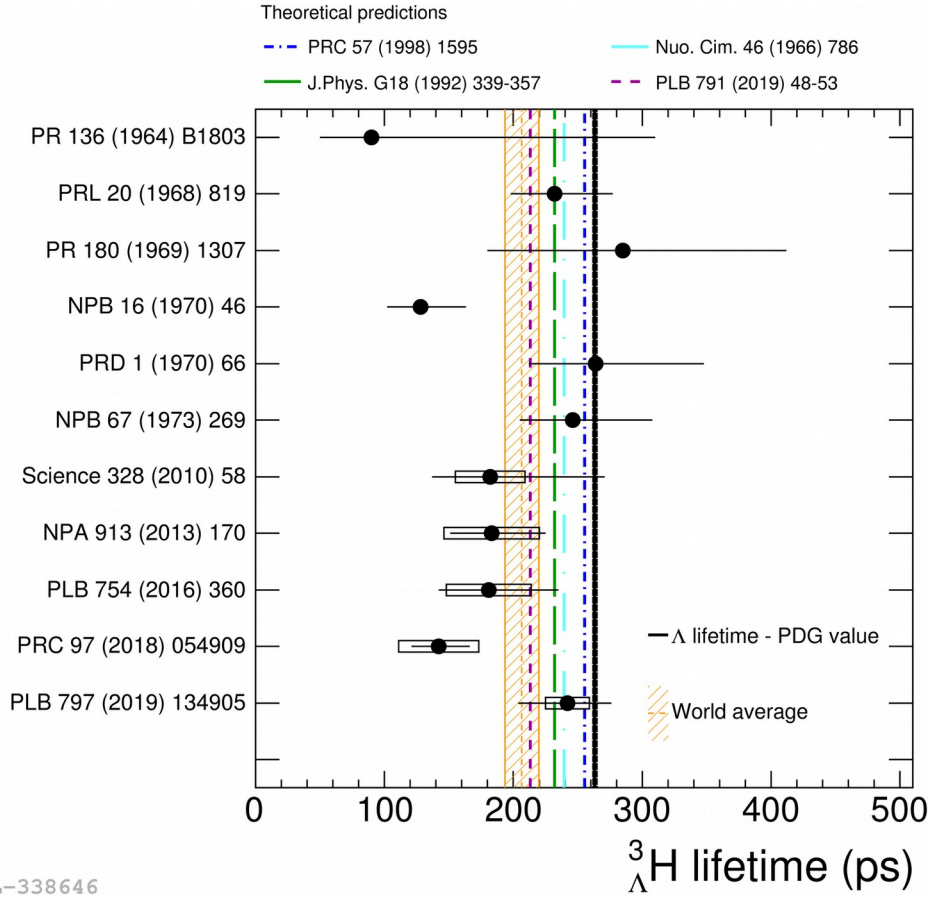
Hypertriton lifetime

E. Bartsch, 5 Nov 2019, 15:40



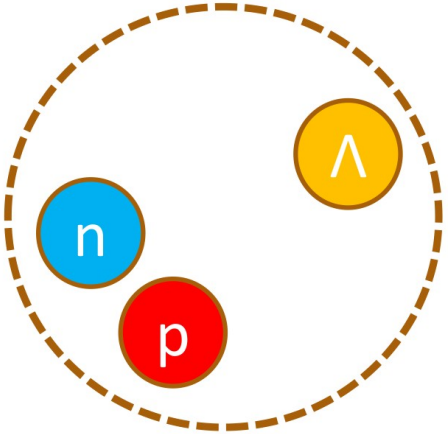
- Bound state of Λ, p and n
- m = 2.991 GeV/c^2, B_Λ = 130 keV
  →rms-radius = 10.3 fm

- ALICE measurement setting new standards
  S. Acharya et al., Phys. Lett. B 797 (2019) 134905

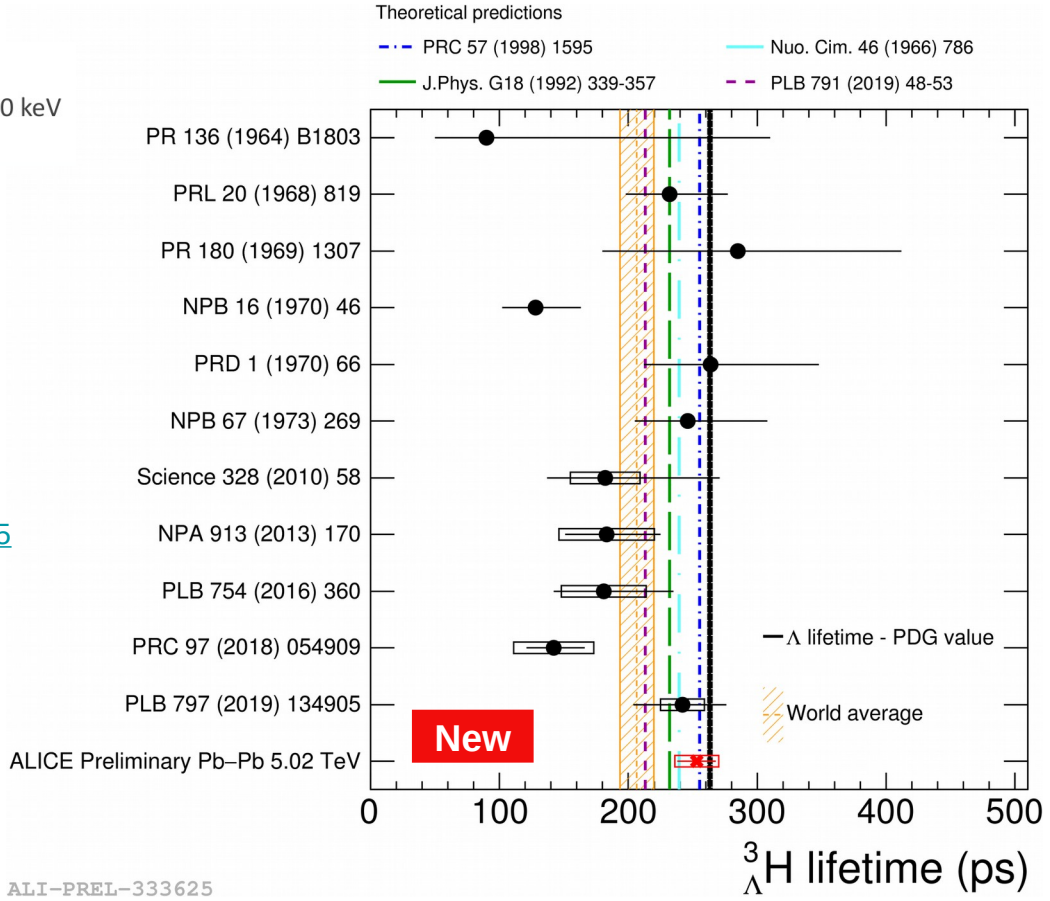


Hypertriton lifetime

E. Bartsch, 5 Nov 2019, 15:40



- Bound state of Λ, p and n
- m = 2.991 GeV/c^2, B_Λ = 130 keV
  → rms-radius = 10.3 fm

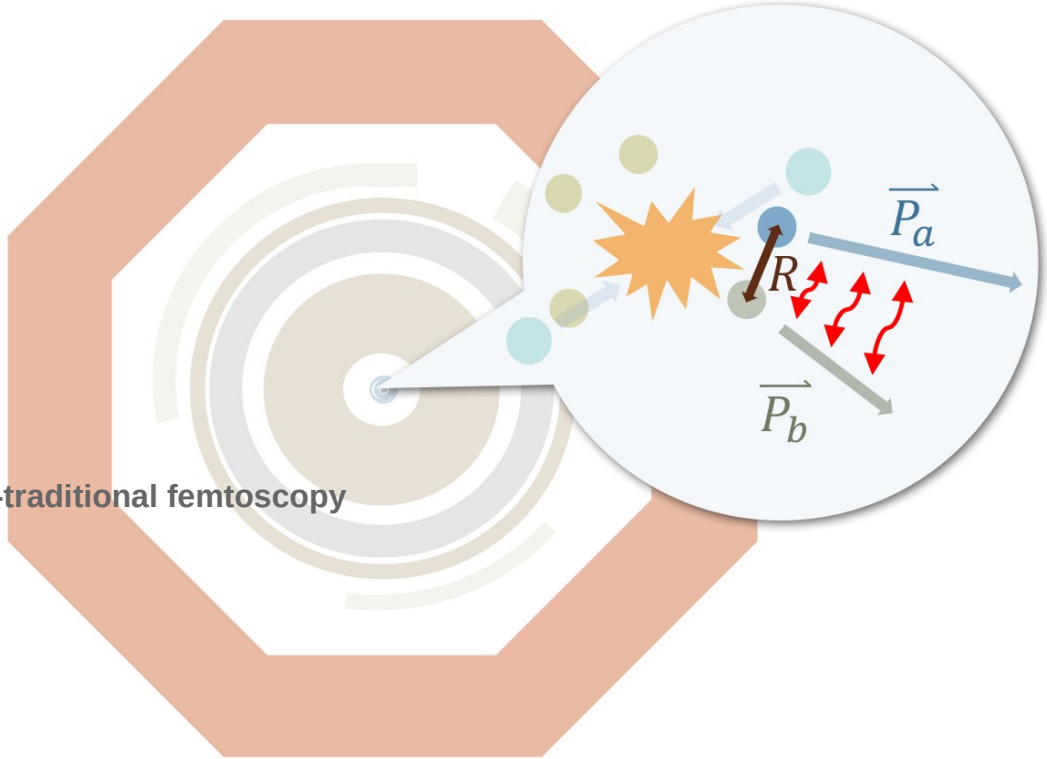


- ALICE measurement setting new standards
  S. Acharya et al., Phys. Lett. B 797 (2019) 134905
- Adding 2018 data + Machine Learning methods
  - single measurement same error bars as world average

  → **Exclude large deviations from free Λ life time**

Hadron interactions

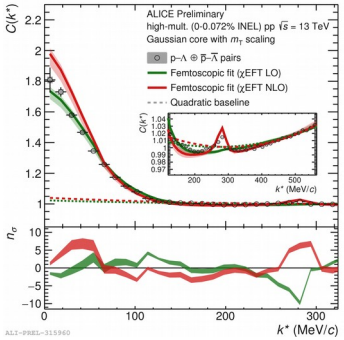
D.Mihaylov, 6 Nov 2019, 11:00



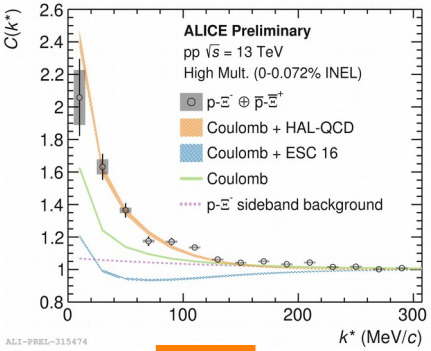
- **Constrain interaction parameters with non-traditional femtoscopy**
  - Revert logic: source size → interaction

Hadron interactions

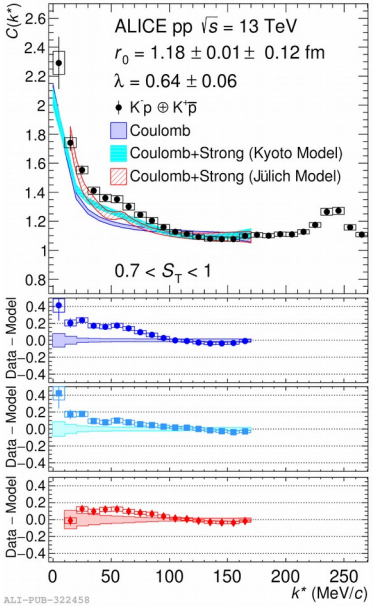
D.Mihaylov, 6 Nov 2019, 11:00



p-Λ



p-Ξ⁻

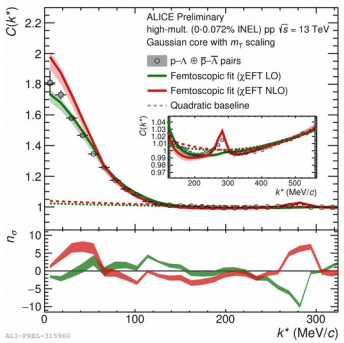


p-K⁻

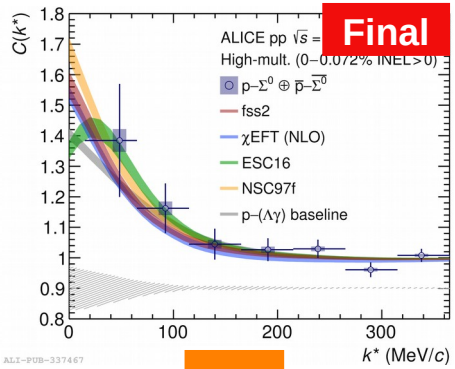
- **Constrain interaction parameters with non-traditional femtoscopy**
  - Revert logic: source size → interaction
- Large set of particle pairs studied in ALICE in **small collisions systems**, pp and p-Pb collisions
  ALICE, Phys.Rev.Lett. 123 (2019) no.11, 112002, p-Ξ⁻
  ALICE, Phys. Lett. B 797 (2019) 134822, Λ-Λ
  ALICE, arXiv:1905.13470 [nucl-ex], p-K⁻

Hadron interactions

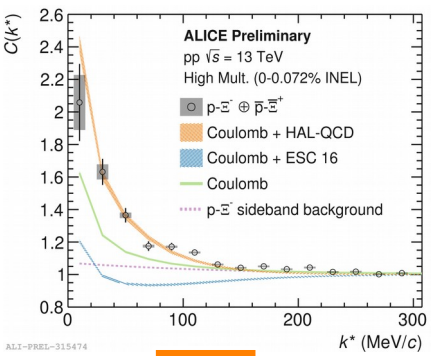
D.Mihaylov, 6 Nov 2019, 11:00



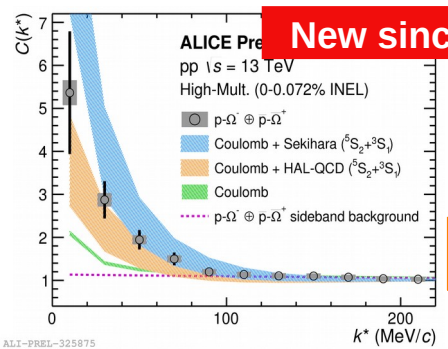
p-Λ



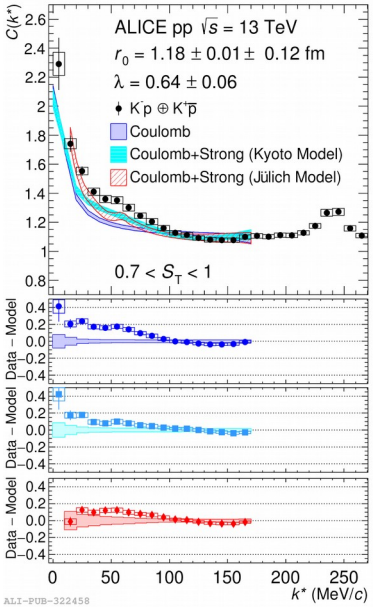
p-Σ⁰



p-Ξ⁻



p-Ω⁻



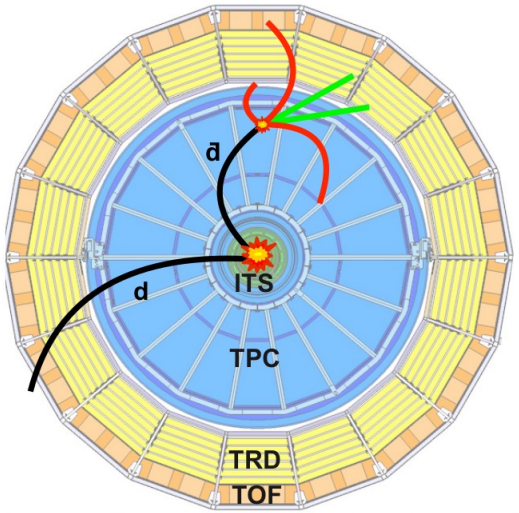
p-K⁻

- **Constrain interaction parameters with non-traditional femtoscopy**
  - Revert logic: source size → interaction
- Large set of particle pairs studied in ALICE in **small collisions systems**, pp and p-Pb collisions
  ALICE, Phys.Rev.Lett. 123 (2019) no.11, 112002, p-Ξ⁻
  ALICE, Phys. Lett. B 797 (2019) 134822, Λ-Λ
  ALICE, arXiv:1905.13470 [nucl-ex], p-K⁻
  ALICE, arXiv:1910.14407 [nucl-ex], p-Σ⁰

→ Large masses: bridging the gap to Lattice QCD

Anti-deuteron inelastic cross section

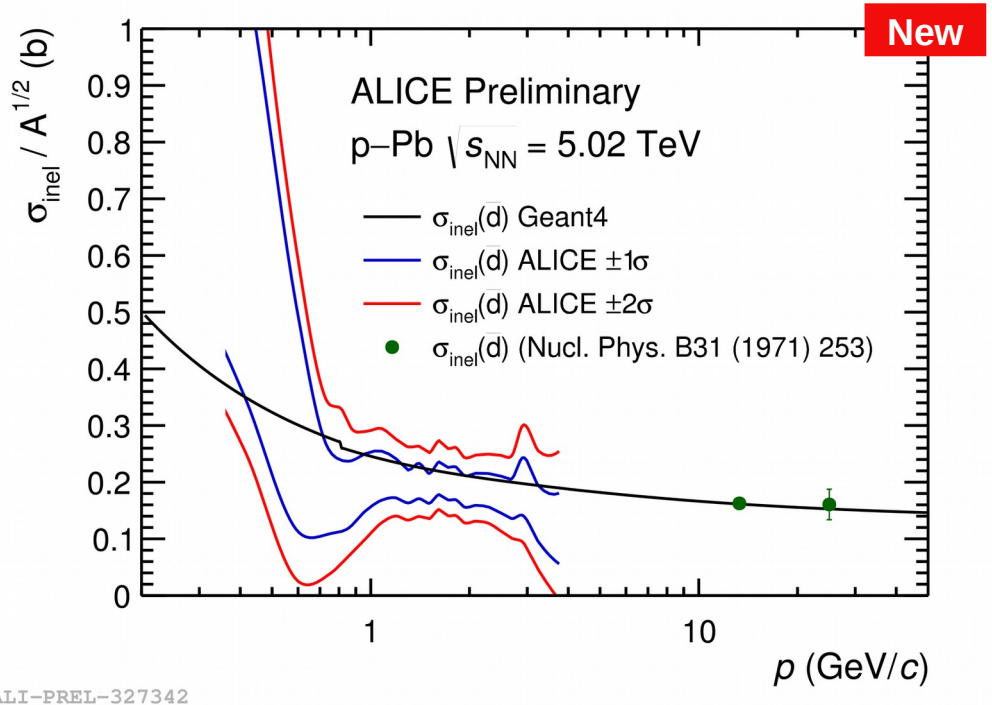
I. Vorobyev, 6 Nov 2019, 16:20

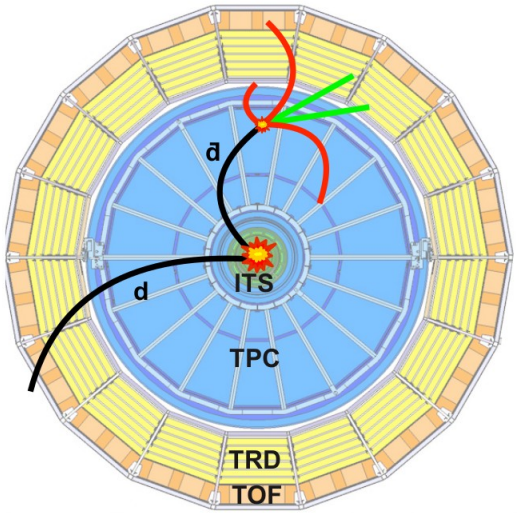


- **Use ALICE as target**
- anti-deuteron inelastic cross section from raw $\bar{d}$ / d ratio at low momenta

Anti-deuteron inelastic cross section

I. Vorobyev, 6 Nov 2019, 16:20



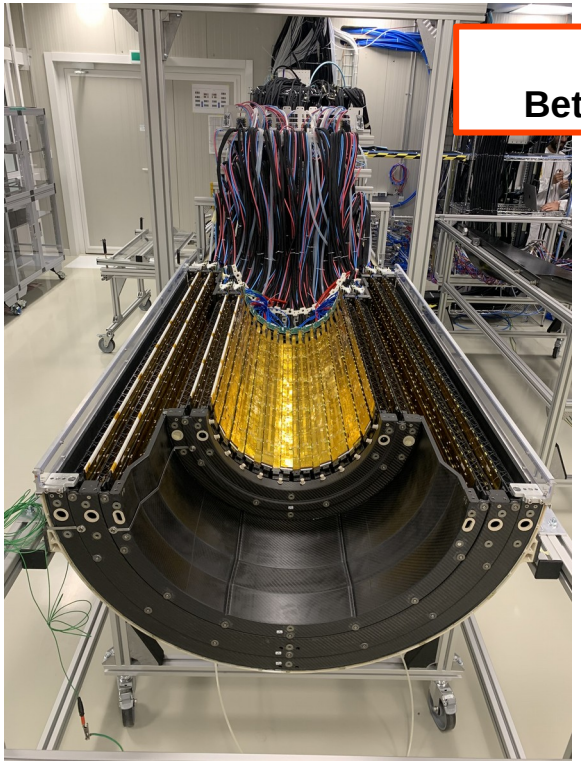


- **Use ALICE as target**
- anti-deuteron inelastic cross section from raw $\bar{d}$ / d ratio at low momenta
  - So far unconstrained

→ setting new limits is relevant for astrophysics (dark matter searches)

ALICE Upgrade

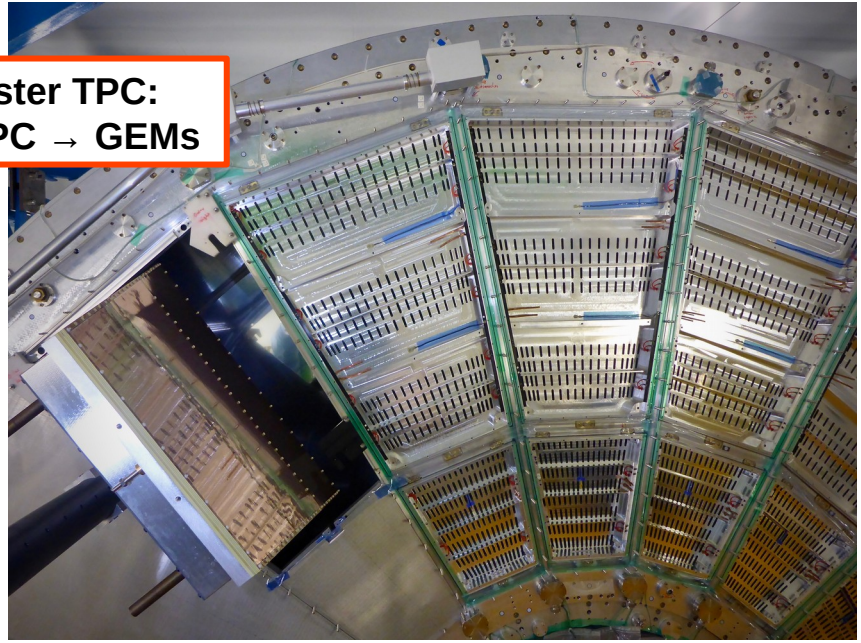
F. Reidt, 5 Nov 2019, 18:20



New ITS:
Better vertexing

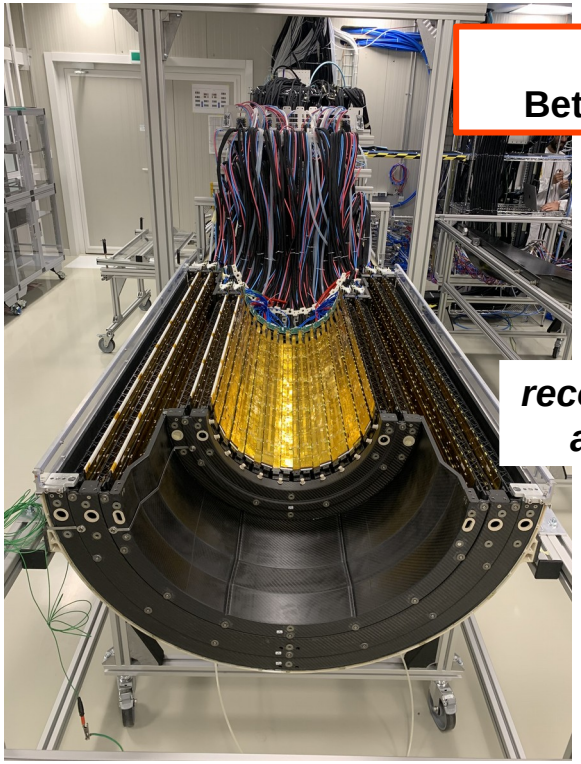
Faster TPC:
MWPC → GEMs

And many more detector upgrades and detectors (MFT, FIT, ...)



ALICE Upgrade

F. Reidt, 5 Nov 2019, 18:20



New ITS:
Better vertexing

Faster TPC:
MWPC → GEMs

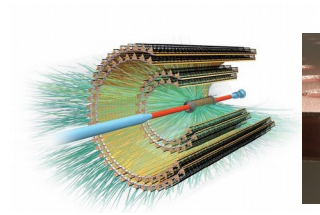
And many more detector upgrades and detectors (MFT, FIT, ...)

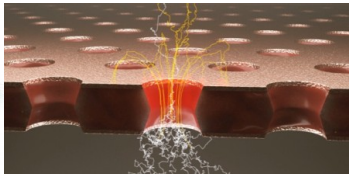
record minimum-bias Pb-Pb data at 50 kHz (currently <1 kHz)

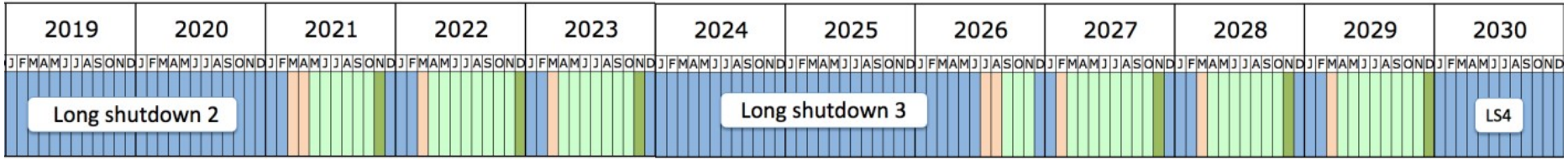
"triggerless operation" requiring data center for processing at Point-2

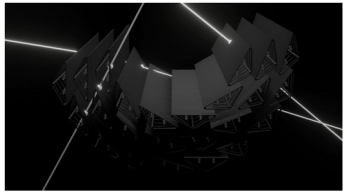
… and the next ten years

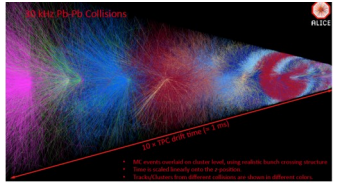
LS2: ALICE upgrade and installation







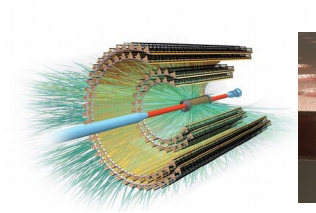


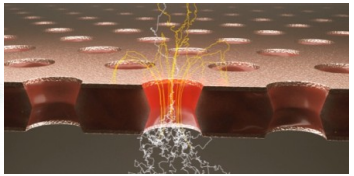


Restart operations
in 2020/21

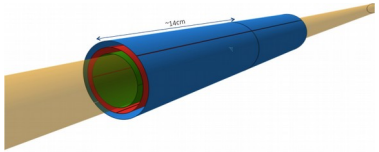
… and the next ten years

LS2: ALICE upgrade and installation



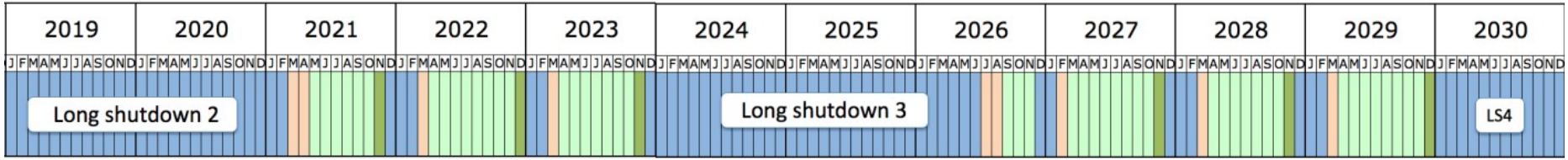


LS3: possible ALICE upgrades



ITS3
ALICE-PUBLIC-2018-013

FoCal
ALICE-PUBLIC-2019-005



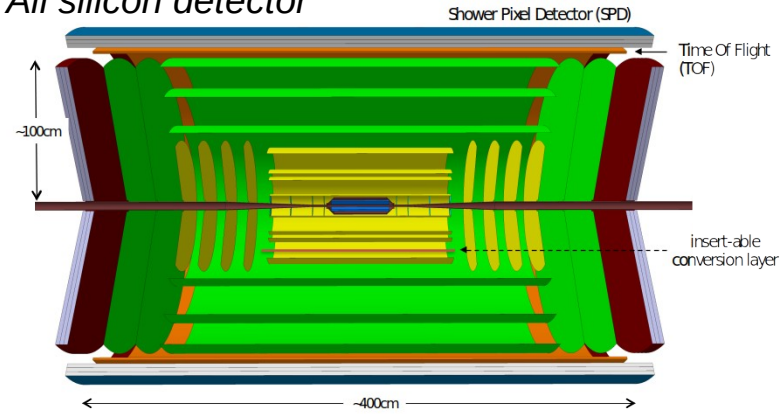
experimentally established, studies of heavy-ion collisions at the LHC (by the dedicated experiment ALICE, as well as the other experiments) and at RHIC (Brookhaven) have been a constant source of surprises, driving the theory developments. The observation of collective effects in pp collisions came as another surprise and opened a new area of studies for the heavy-ion community. A high-energy $AA/pA/pp$ research programme at present and future colliders would be unique to Europe and would lead to a profound understanding of hot and dense QCD matter.

Continue Heavy Ion physics at LHC beyond 2030

from European Particle Physics Strategy update
arXiv:1910.11775 [hep-ex]
(Physics Briefing Book)

Future heavy-ion detector

All silicon detector



Design guidelines

- high rate capability: L_{NN} up to 10^{34}/cm^2/s (~ 20 to 50 × Run 3,4)
- improve vertexing
  - ultra-thin waver-scale sensors, truly cylindrical shape, inside beam pipe
  - spatial resolution ~ 1 µm
  - material thickness < 0.05% X_0/layer
- improve tracking precision and efficiency
  - ~ 10 layers, out to 1 m radius
  - space resolution ~ 5 µm out to 1 m
  - whole tracker, less than 6% X_0
- tracking over wide range of p_T (down to tens of MeV/c) and rapidity ($|\eta| \leq 4$)
- B < 0.5 T would be sufficient, 1 T or higher also considered

Physics potential (just few examples)

- heavy flavours, quarkonia
  - multi-heavy flavoured hadrons (Ξ_{cc}, Ω_{cc}, Ω_{ccc})
  - χ_c states
  - B mesons at low p_T
  - X, Y, Z states
- low-mass dielectrons
  - chiral symmetry restoration
  - thermal continuum (virtual photons)
- soft hadronic and electromagnetic radiation
  - hadrons down to a few 10's of MeV/c
  - photons down to ~ 50 MeV/c
  - ultra-soft photons down to MeV scale with dedicated forward spectrometer
- BSM
  - dark photons searches
  - …?

EoI document signed by ~400 physicists (Dec 2018) submitted to European Strategy for Particle Physics Preparatory Group arXiv:1902.01211

Summary

Full Run 1 and 2 data set available

- Central and semi-central triggers
- Low B field data

→ **Larger precision, extending to low p_T, more differential, new analyses**

New insights

- **Initial state:** nPDFs and photoproduction
- **Macroscopic properties:** spin, magnetic field, CME, medium response, phase transition
- **Microscopic properties:** parton energy loss, jet substructure, dead cone, heavy quark hadronisation, charmonia, light nuclei formation
- **System evolution:** Flow, strangeness, dielectrons
- **Hadron physics:** hypertriton, hadron-hadron interactions, connection to astrophysics

Open questions:

- **ALICE upgrade:** order(s) of magnitude more events, better detectors, pushing the limits even further (event-by-event fluctuations, HF baryons, low mass dileptons, hypernuclei, etc.)
- **And thinking forward:** heavy ion physics at LHC after 2030

→ **welcome input from new groups**