LA THUILE 2024 - Les Rencontres de Physique de la Vallée d'Aoste

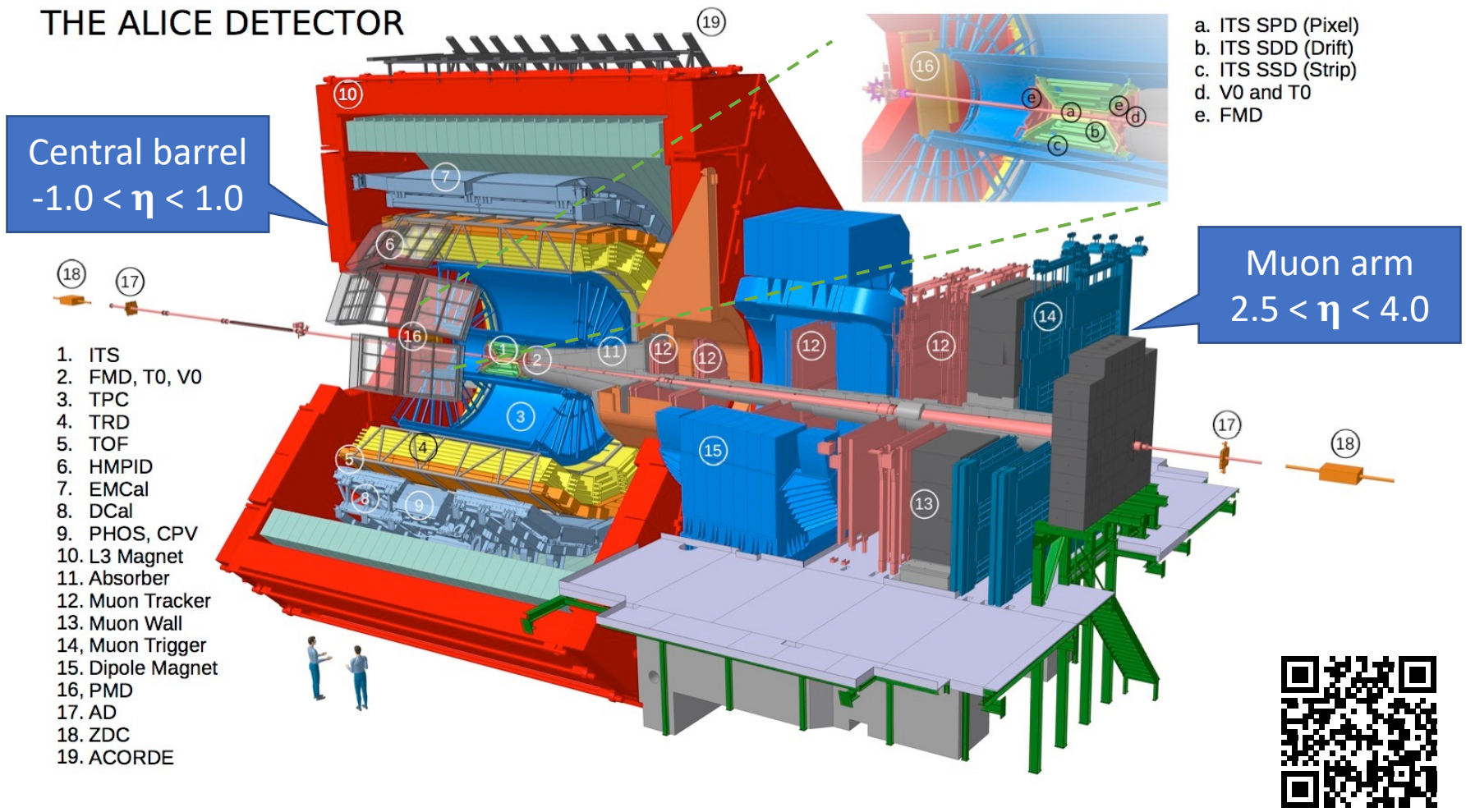
ALICE Overview

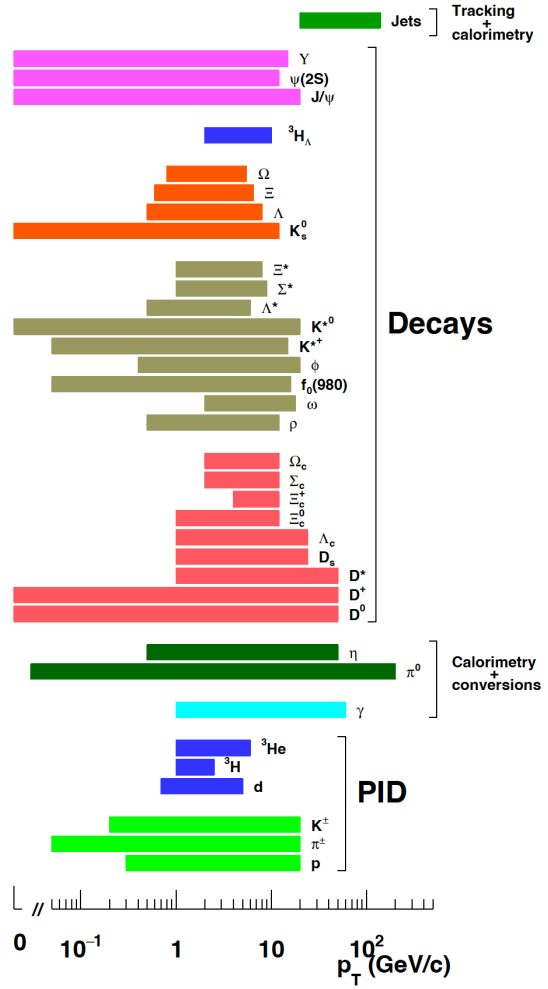
Jacek Otwinowski (IFJ PAN, Krakow)

(on behalf of the ALICE Collaboration)

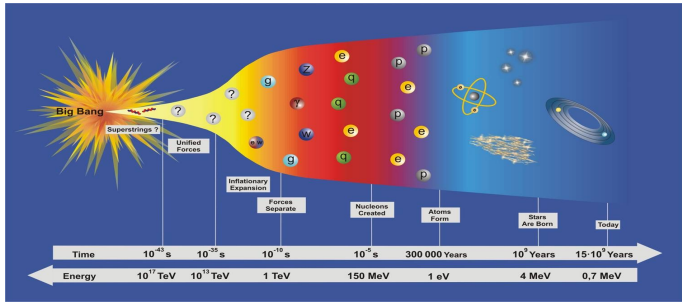
A Large Ion Collider Experiment (ALICE)

Excellent particle identification and good tracking in the broad momentum range!





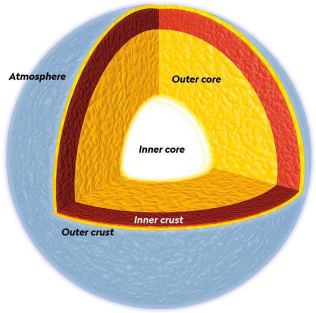
ALICE Purpose



- Properties of QCD matter at extreme conditions
- Characterization of Quark-Gluon Plasma (QGP)

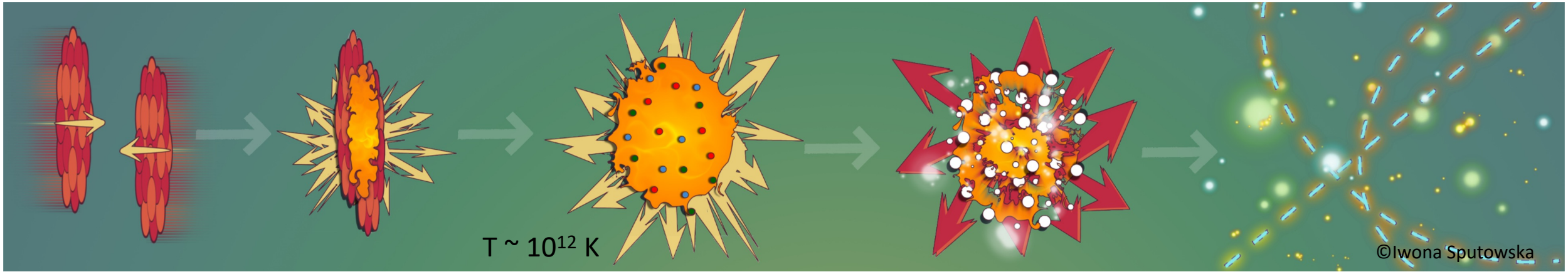
  N. Cabibbo & G. Parisi. Phys. Lett. B59 (1975) 67

  J. C. Collins and M. J. Perry. Phys. Rev. Lett. 34 (1975) 1353
- Influence of initial- and final-state effects on particle production



"Quark Stars"
D. D. Ivanenko & D. F. Kurdgelaidze
Astrofizika (1965) 479

Initial PDFs | Little Big Bang | Quark-Gluon Plasma | Collective expansion | Freeze-out

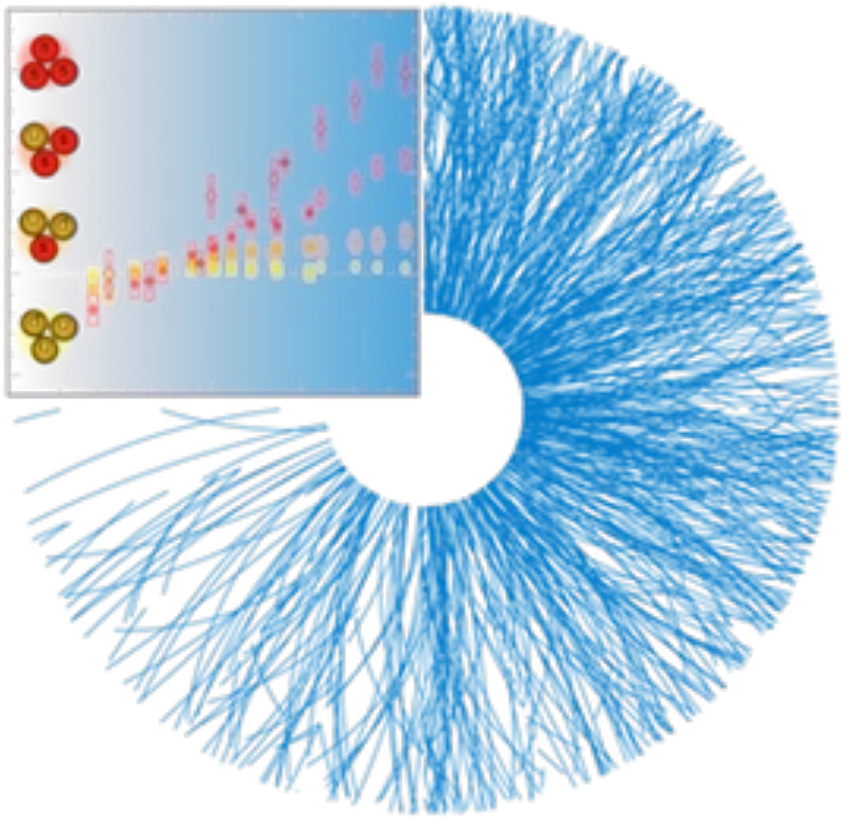


Time

Measurements in A-A and reference p-p and p-A collisions!

Outline

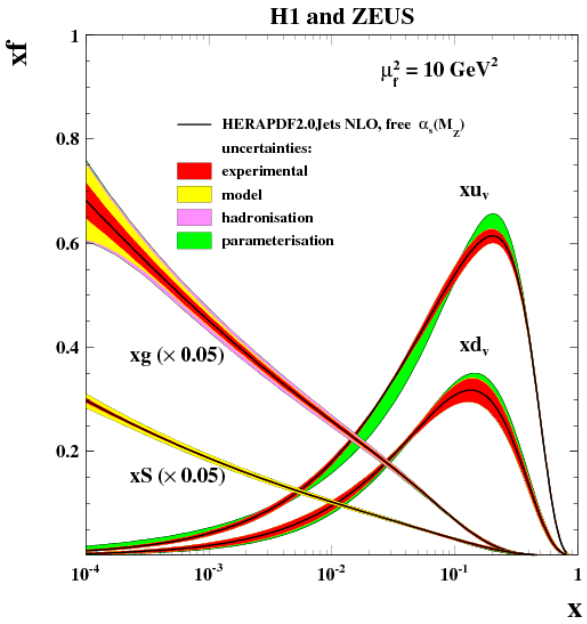
- Recent ALICE results
- ALICE Run 3 Performance
- ALICE Upgrades
- Summary



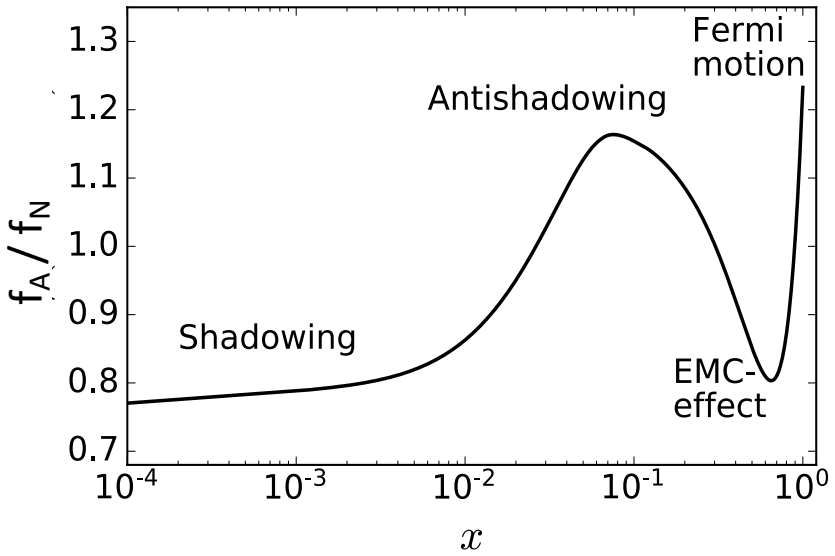
Probing parton distributions

- Hadron and nuclear PDFs at high energy
- Shadowing and gluon saturation at small Bjorken-x?
- Universal state of matter at high energy - Color Glass Condensate (CGC)?

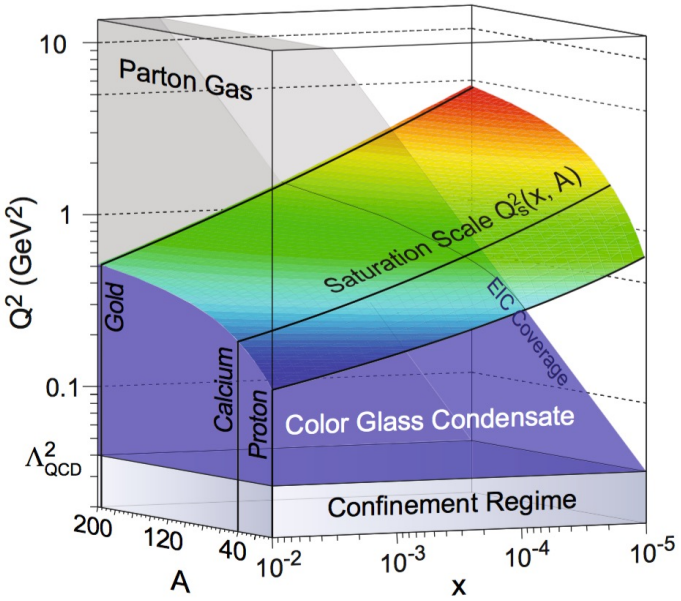
L. McLerran, R. Venugopalan, Phys. Rev. D 49 (1994) 2233



H1 and Zeus, EPCJ 75 (2015) 580

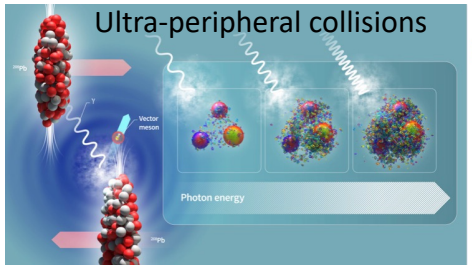


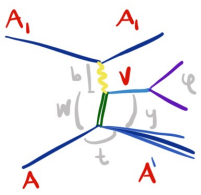
EMC, J.J. Aubert et al. Phys. Lett B123 (1983) 275



Accardi et al, EPJA 52 (2016) 268

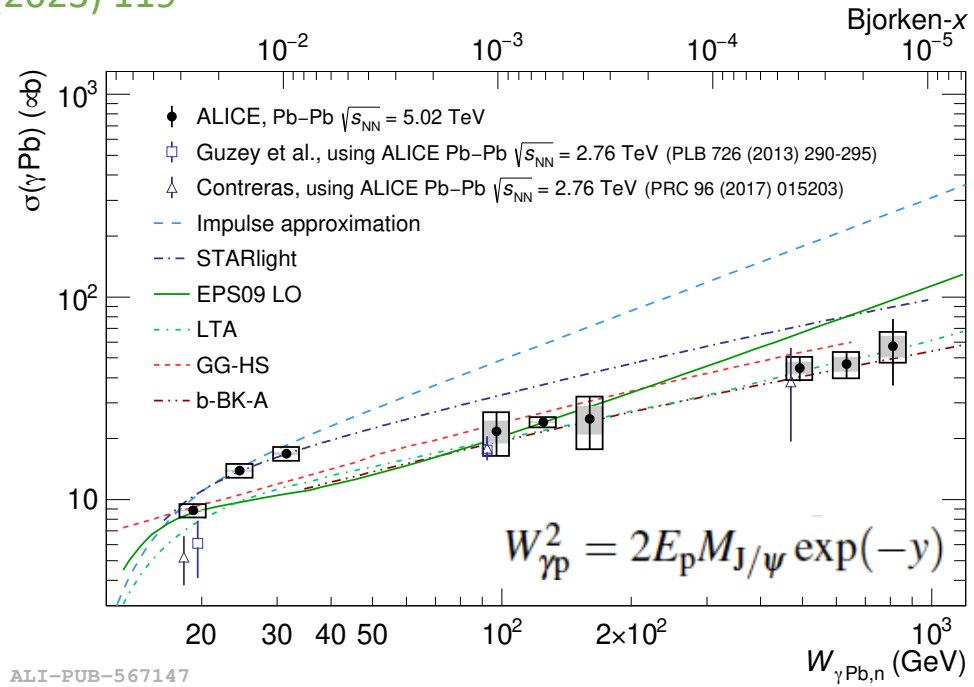
J/ψ photoproduction in Pb-Pb

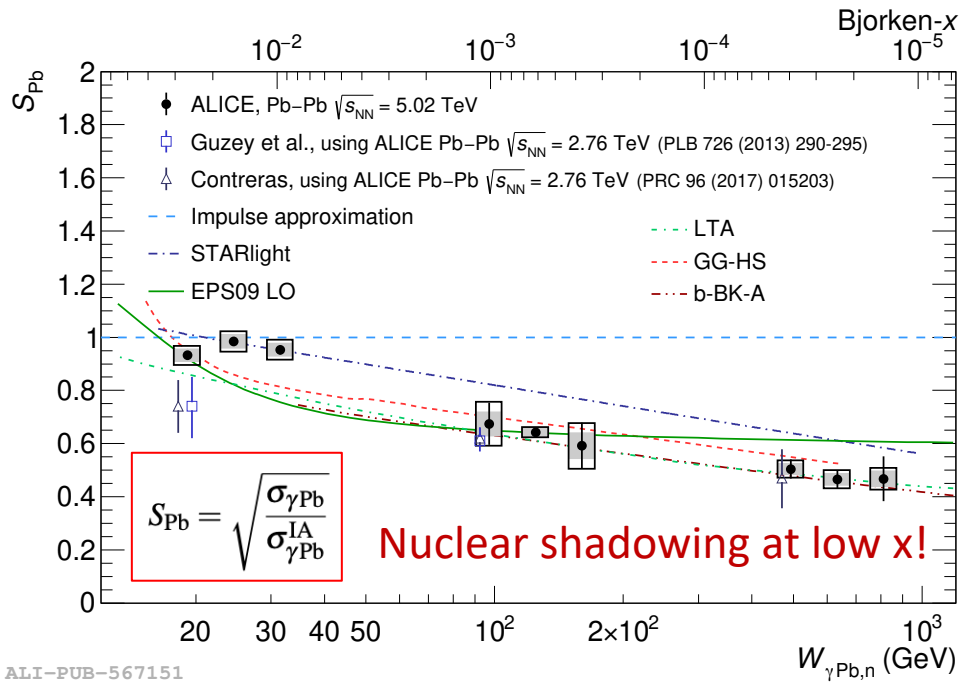




Probing parton distributions – nuclear shadowing and gluon saturation

JHEP 10 (2023) 119



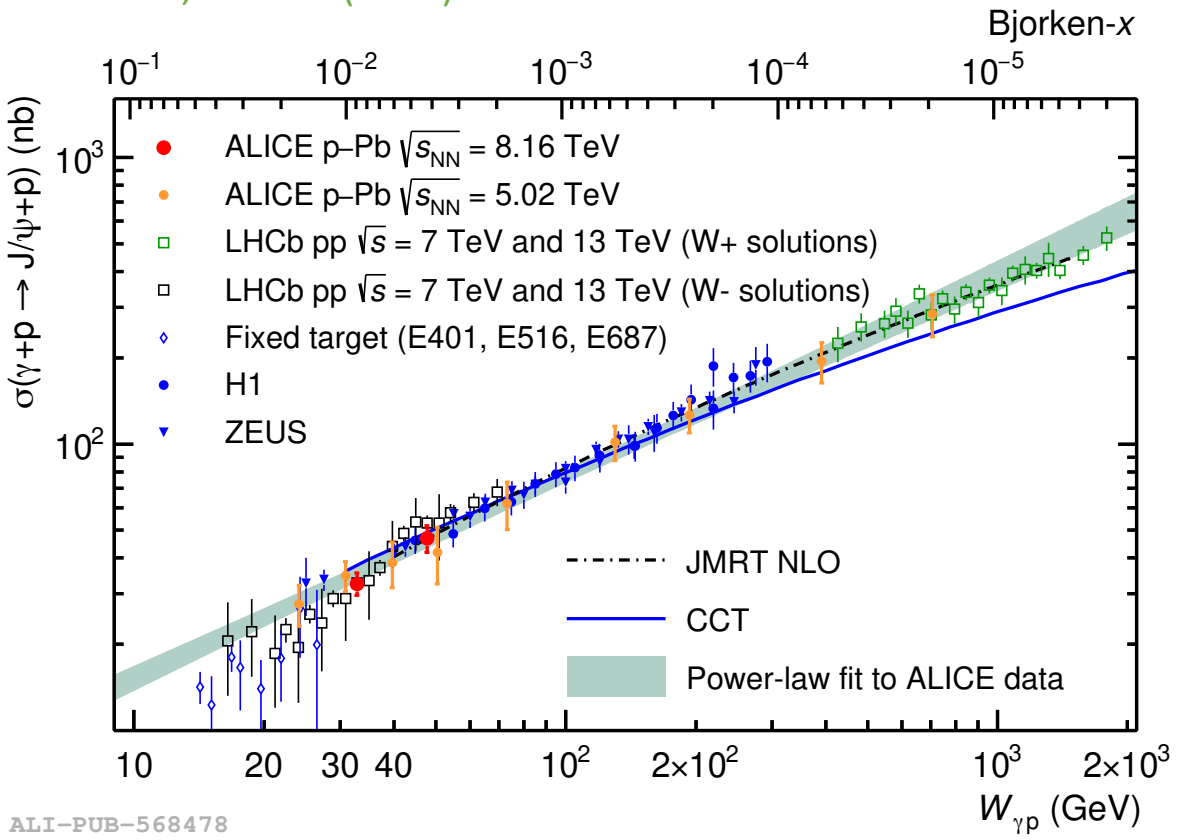


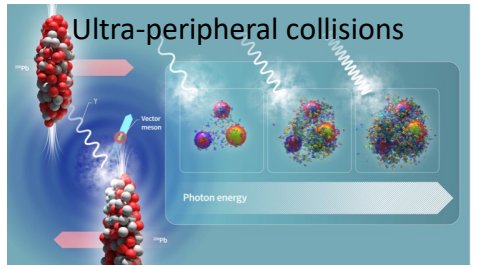
- Impulse approximation (no nuclear effects)
- EPS09 LO - parametrization of available nuclear shadowing data
- LTA (leading twist approximation) of nuclear shadowing using Gribov-Glauber theory
- GG-HS – color dipole model + gluon saturation (hot spot model for hadronic structure)
- b-BK-A – color dipole approach coupled to Balitsky-Kovchegov equation

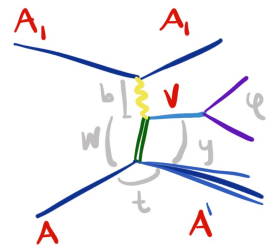
Energy dependence of J/ψ photoproduction

Probing parton distributions – nuclear shadowing and gluon saturation

Phys. Rev. D 108, 112004 (2023)



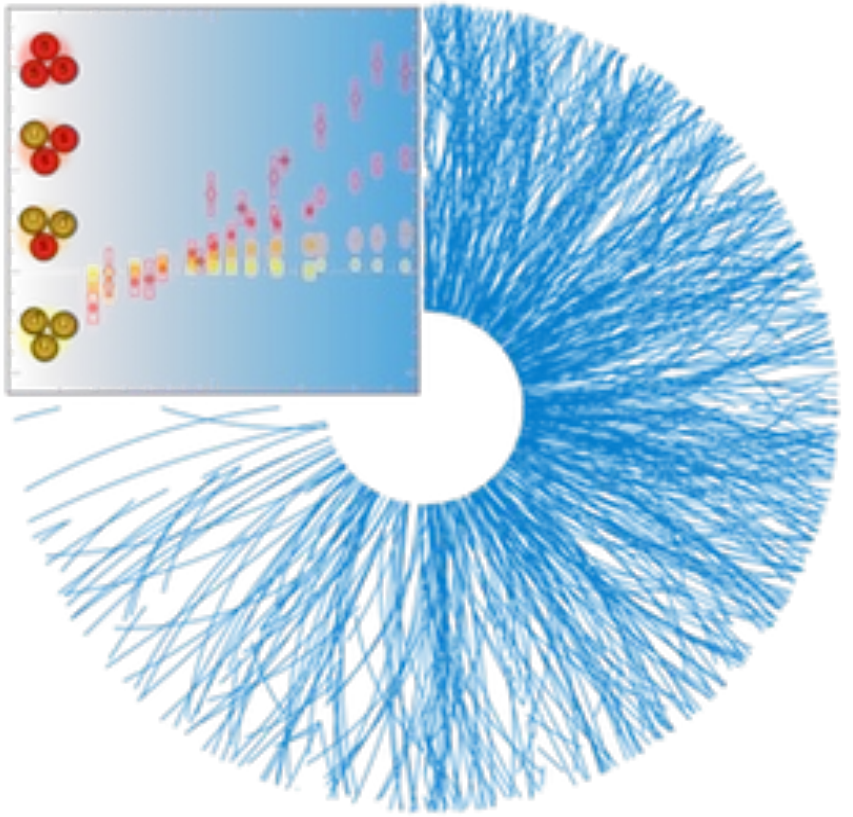




- Power-law dependence of $\sigma(\gamma+p \to J/\psi+p)$ on $W_{\gamma p}$ (power $\delta = 0.70 \pm 0.04$)
- ALICE results compatible with HERA

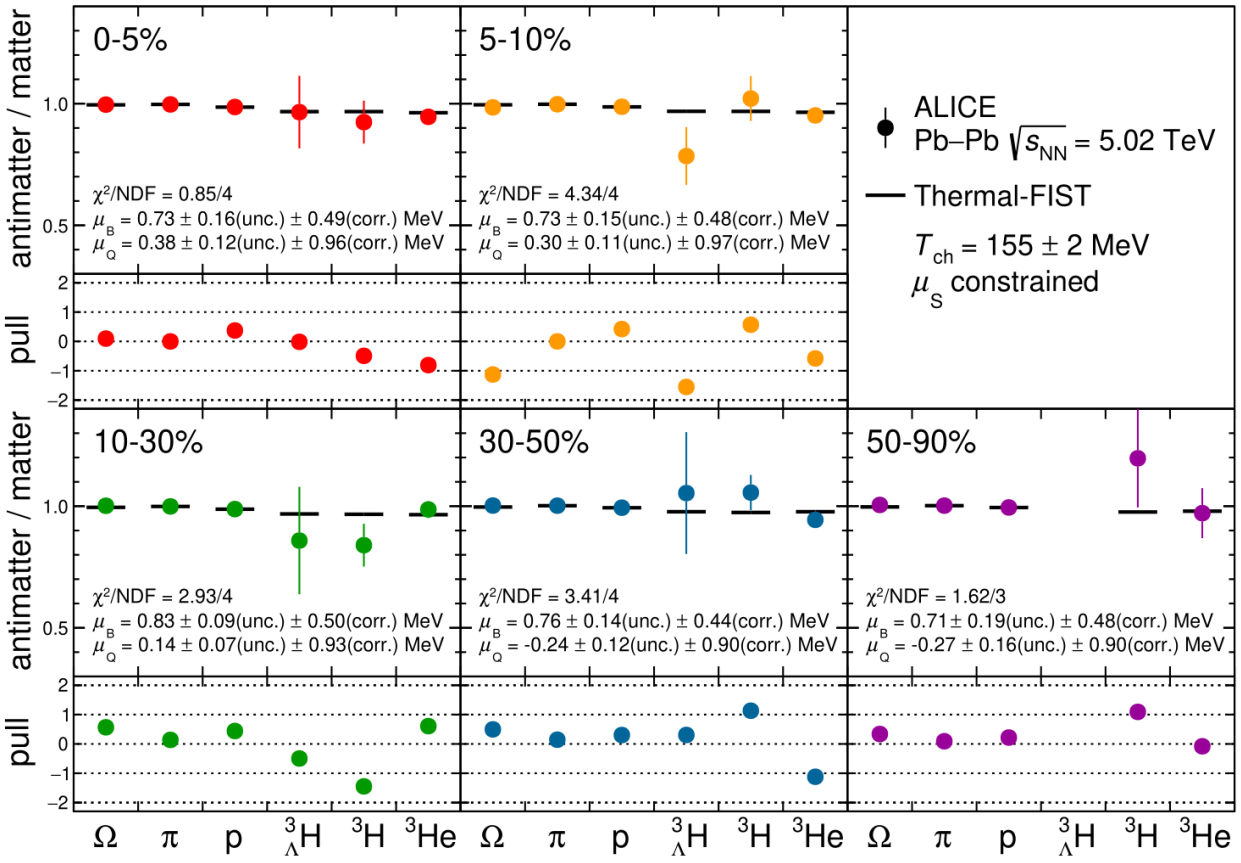
- Cepila–Contreras–Takaki (CCT) – color dipol approach + hot spot model for hadronic structure
- Jones–Martin–Ryskin–Teubner (JMRT) – NLO fit of HERA data

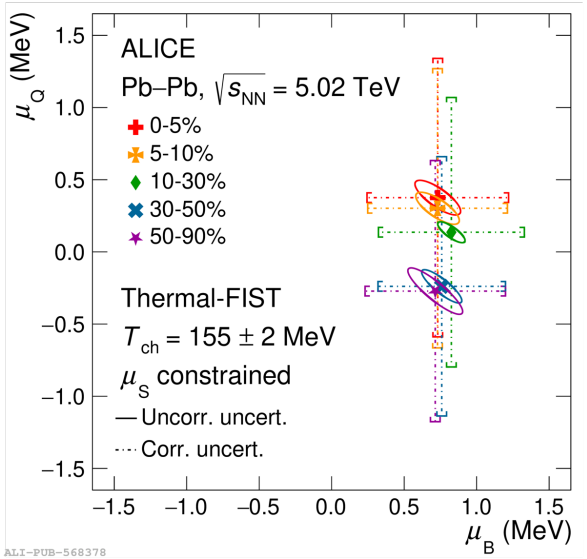
Light flavour

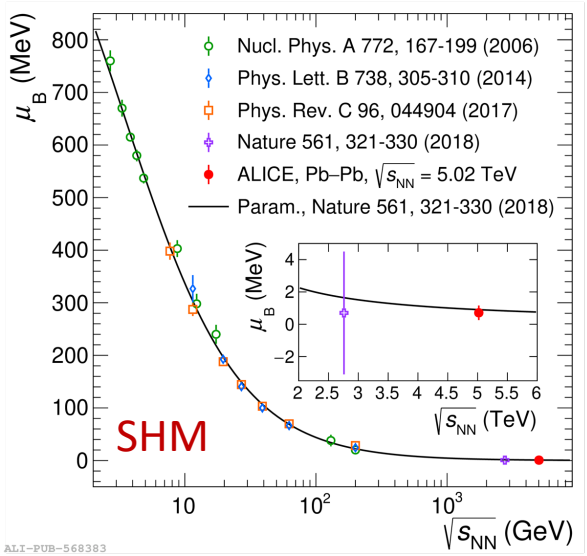


Antimatter/matter imbalance at the LHC

arXiv:2311.1333





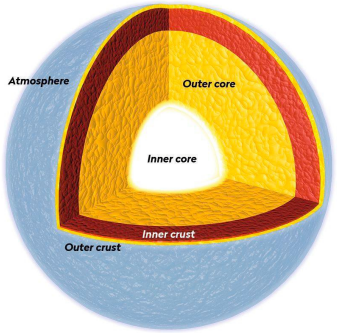


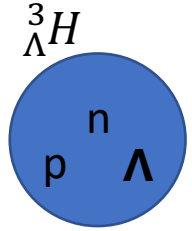
$$\frac{\bar{h}}{h} \propto e^{-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T}-2Q\frac{\mu_Q}{T}}$$

System created in Pb-Pb collisions is baryon-free and electrically neutral at midrapidity

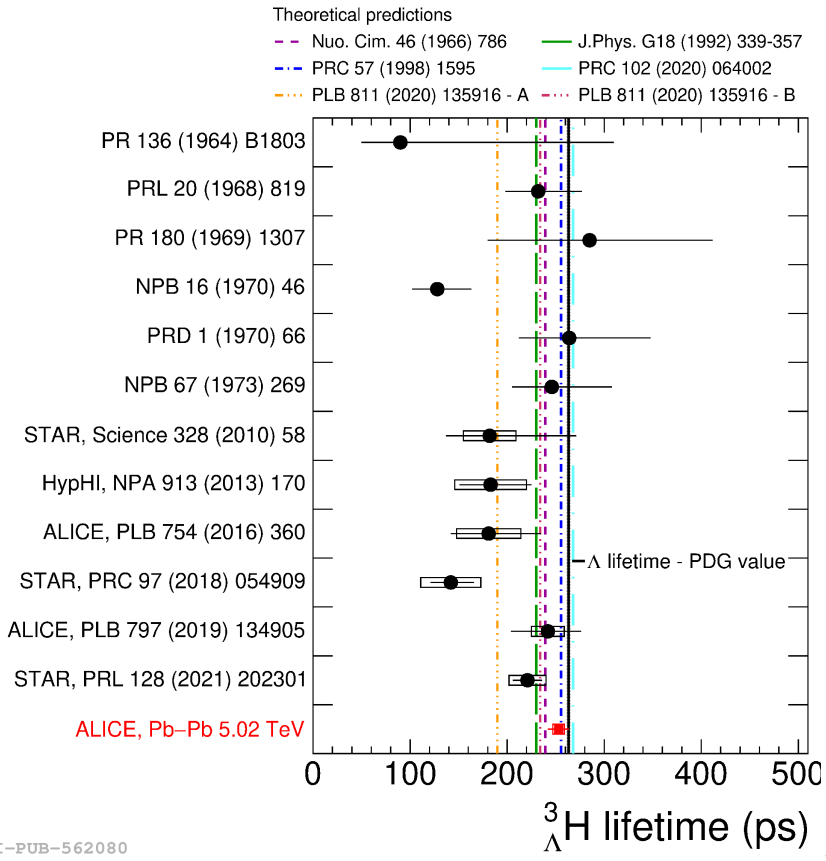
Thermal-Fist, V. Vovchenko et al. Comput. Phys. Commun. 244 (2019) 295
Statistical Hadronization Model (SHM) A. Andronic et al. Nature 561 (2018) 321

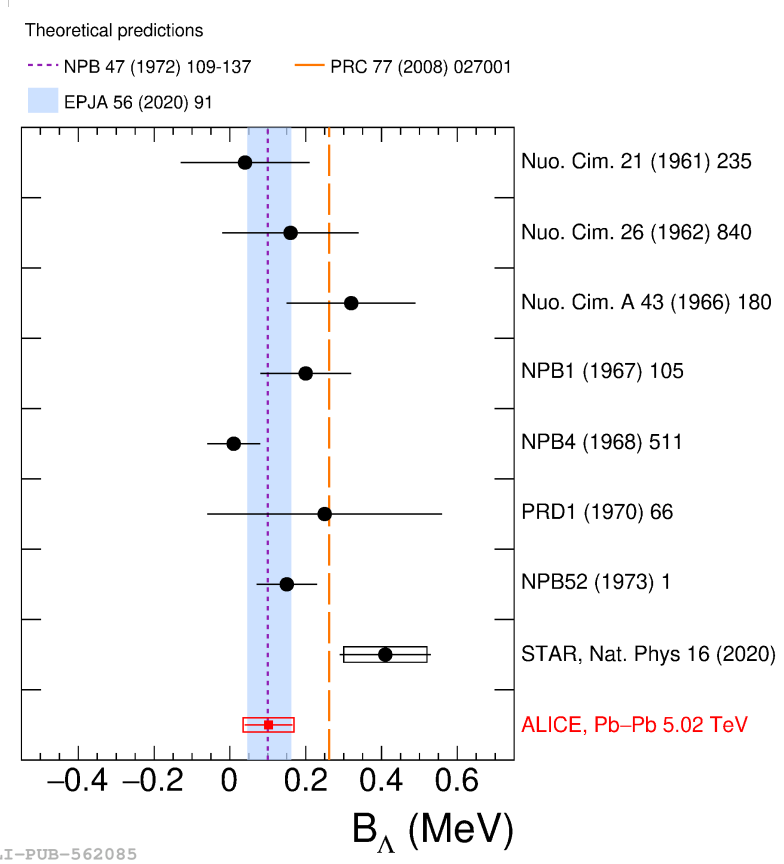
(Anti)hypertriton lifetime





Neutron Stars EoS - hyperon "puzzle" ($M_{NS} > 2\ M_{\odot}$)





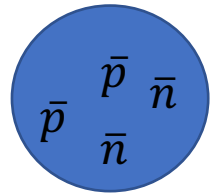
Phys. Rev. Lett. 131 (2023) 102302

$\tau = 253 \pm 11(\text{stat.}) \pm 6\ (\text{syst.})$ ps

$B_{\Lambda} = 72 \pm 63(\text{stat.}) \pm 36\ (\text{syst.})$ keV

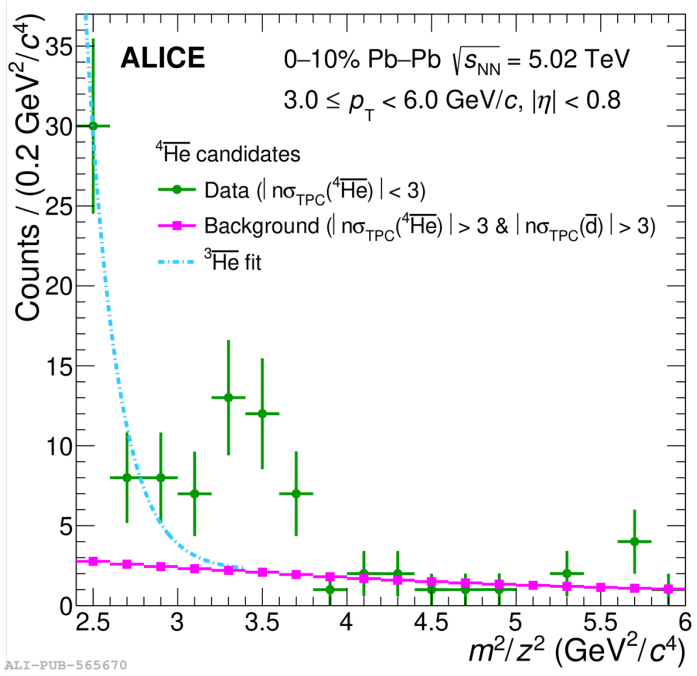
- Most precise measurement of hypertriton lifetime
- Models confirms that hypertriton is a weakly bound state

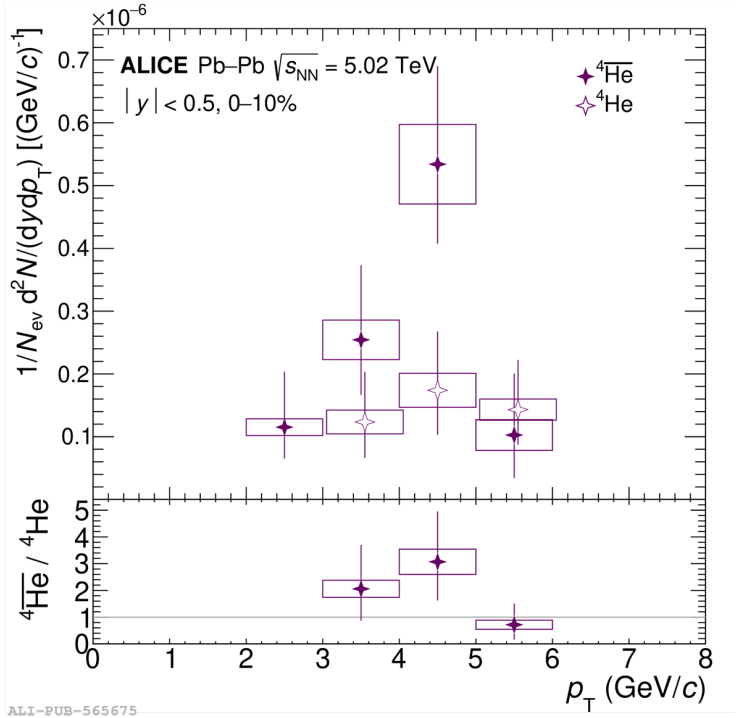
(Anti)alpha production at the LHC

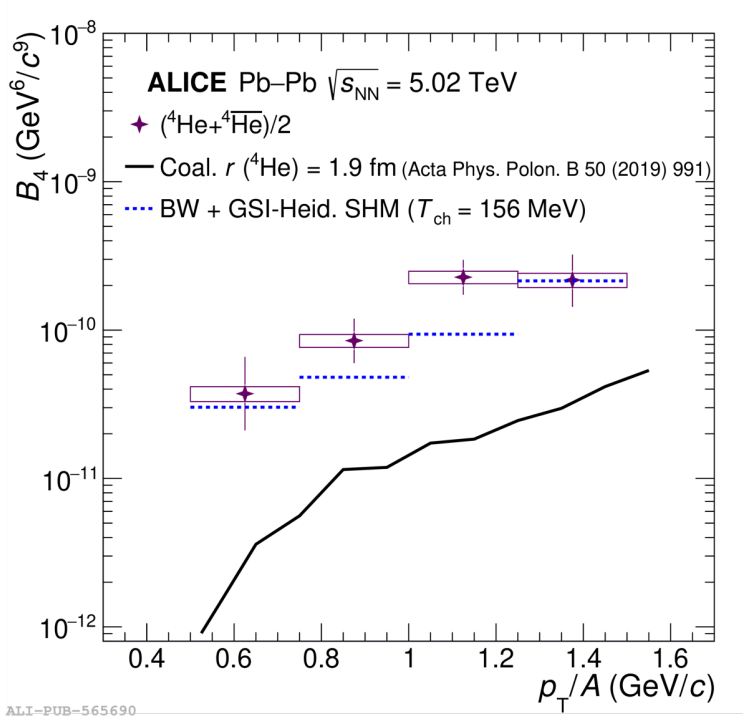


Test particle production mechanism with light nuclei

arXiv:2311.11758







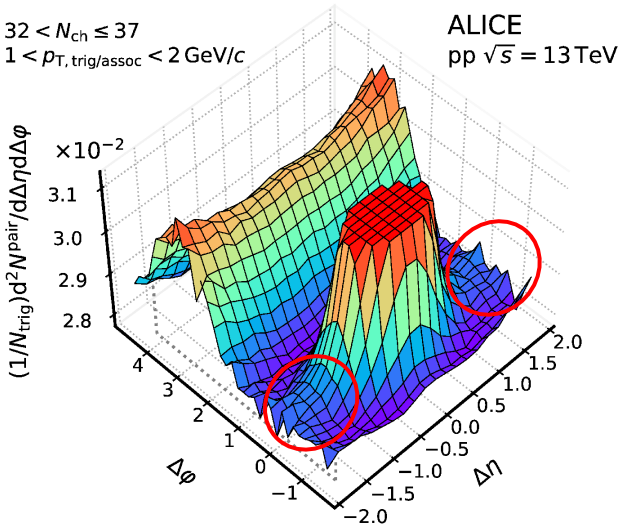
- Anti-alpha p_T differential distributions measured for the first time at the LHC
- (Anti)alpha production underestimated by the coalescence model (different picture than for the lighter nuclei)

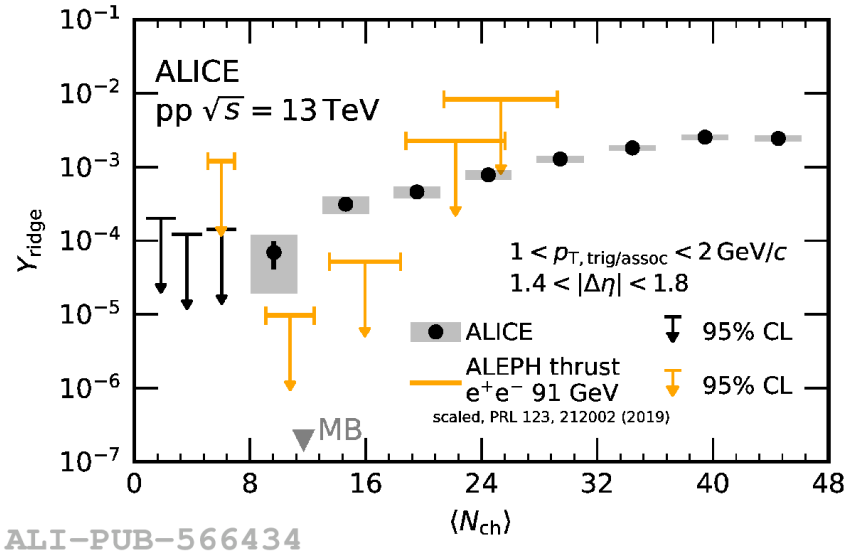
$$B_A = E_A \frac{\mathrm{d}^3 N_A}{\mathrm{d}p_A^3} \left(E_\mathrm{p} \frac{\mathrm{d}^3 N_\mathrm{p}}{\mathrm{d}p_\mathrm{p}^3} \right)^{-A}$$

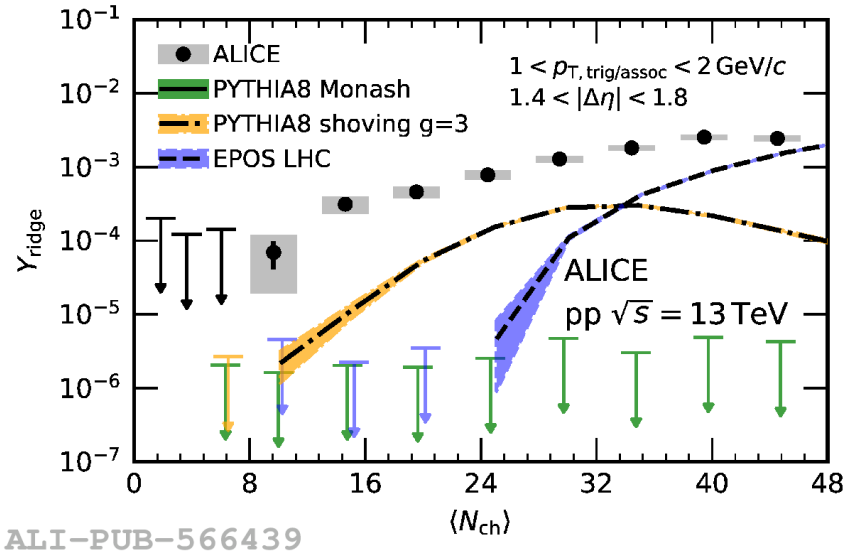
Emergence of long-range angular correlations (“ridge”) in low-multiplicity pp collisions

The “ridge” – sign of collective expansion of QGP in Pb-Pb collisions

arXiv:2311.14357

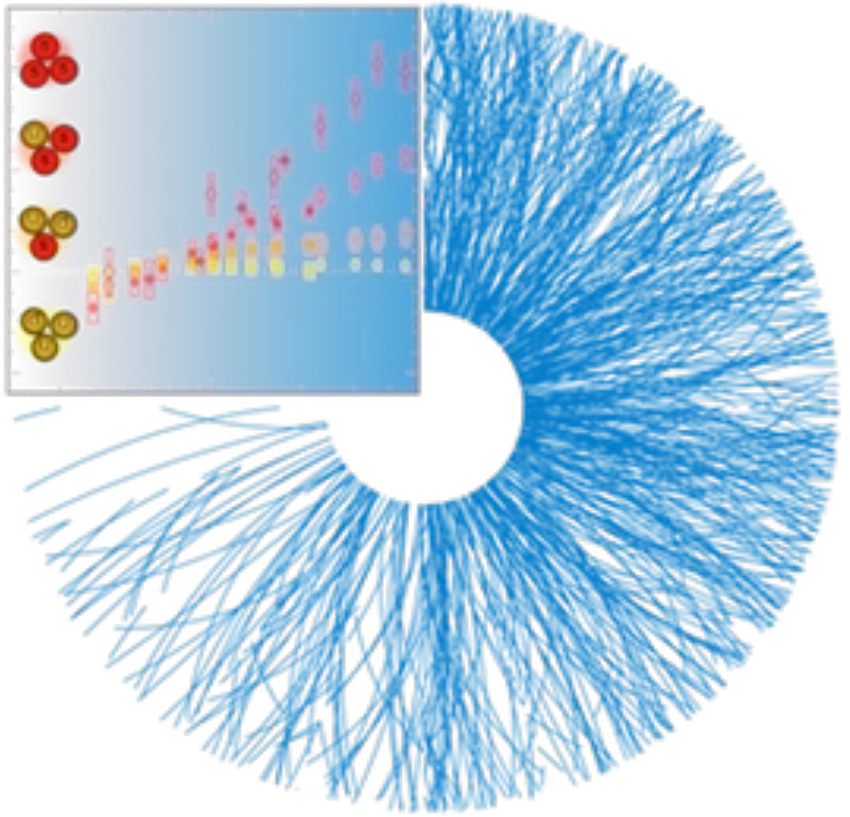






- The ridge is also visible in low multiplicity pp collisions
- Processes involved e$^+$e$^-$ annihilation (ALEPH) do not contribute to the ridge in pp collisions (also confirmed at higher energy Y.-Ch. Chen et al. arXiv:2312.0508)
- Pythia tunes underestimate the ridge

Heavy flavour

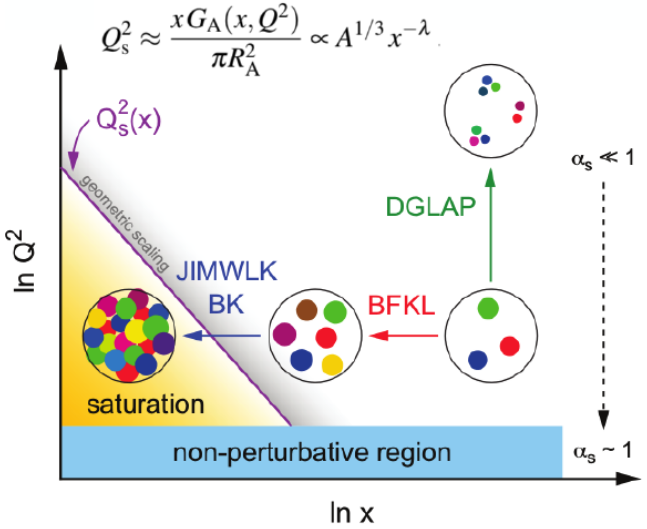


Heavy flavour (hard probes)

Ideal probes to study initial and final state effects on particle production

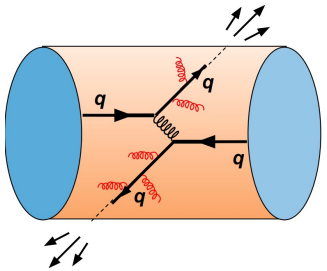
Initial state

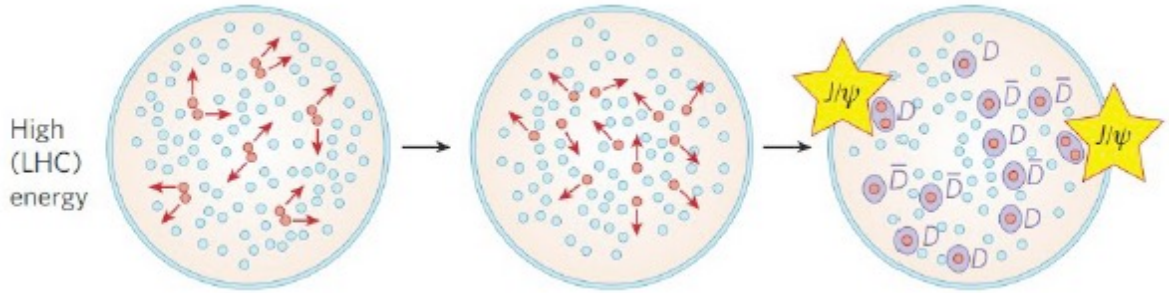
- Modification of Parton Distribution Functions
- Gluon saturation and Color-Glass Condensate (CGC)
  L. McLerran, R. Venugopalan, Phys. Rev. D 49 (1994) 2233



Final state

- Parton energy loss in QGP (collisional/radiative, $\Delta E_g > \Delta E_q > \Delta E_Q$)
  Yu. L. Dokshitzer et al., J. Phys. G: Nucl. Part. Phys. 17 (1991) 1602
- Hadronization mechanisms (fragmentation/recombination)
- Dissociation of charmonium states in hot medium
  T. Matsui & H. Satz, Phys. Lett. B178 (1986) 416
- Recombination of charm and anti-charm quarks
  P. Braun-Munzinger & J Stachel, Phys.Lett. B490 (2000) 196
  R Thews et al., Phys. Rev. C 63:054905

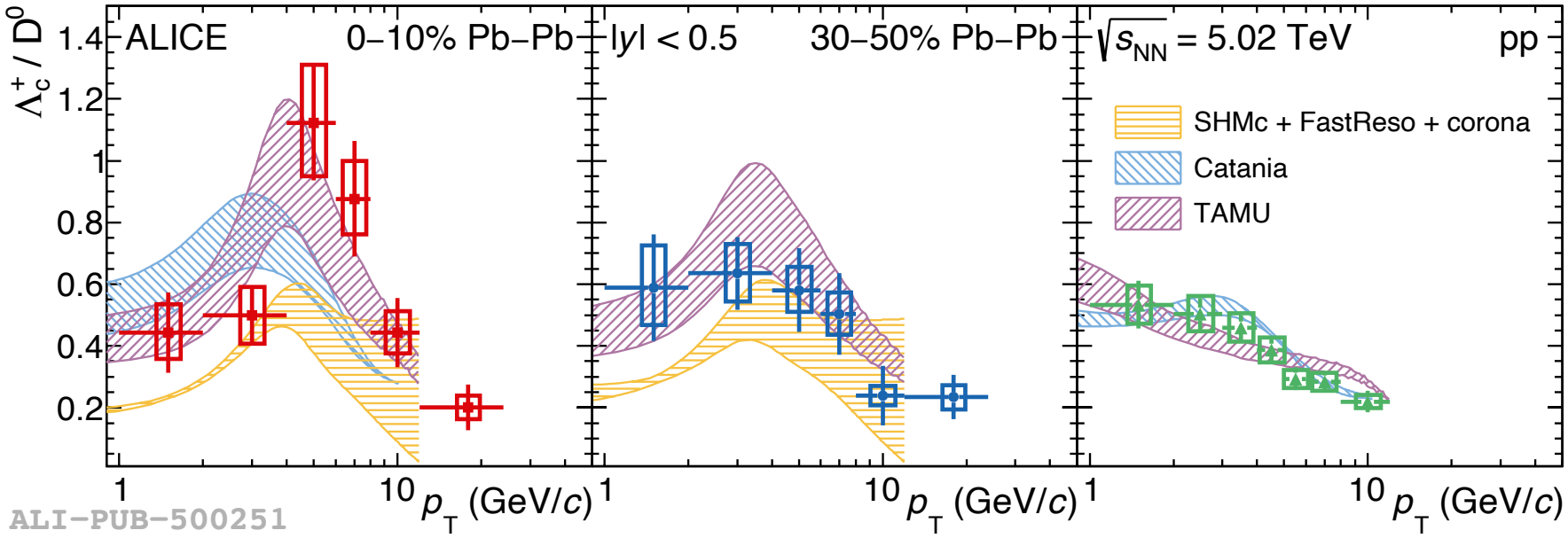


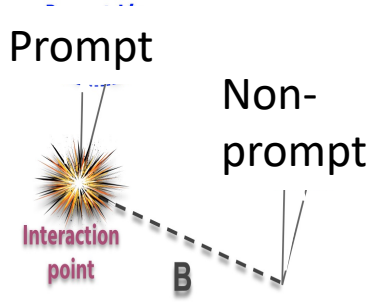


Prompt Λ_C baryon production in pp and Pb-Pb

Constraining hadronization mechanisms

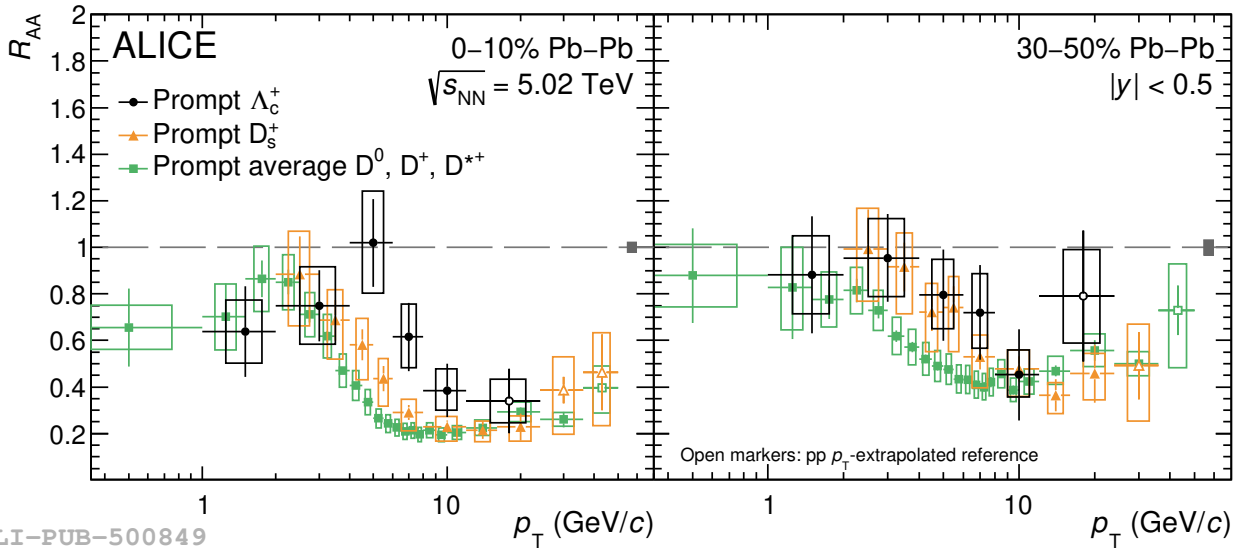
Phys. Lett. B 839 (2023) 137796

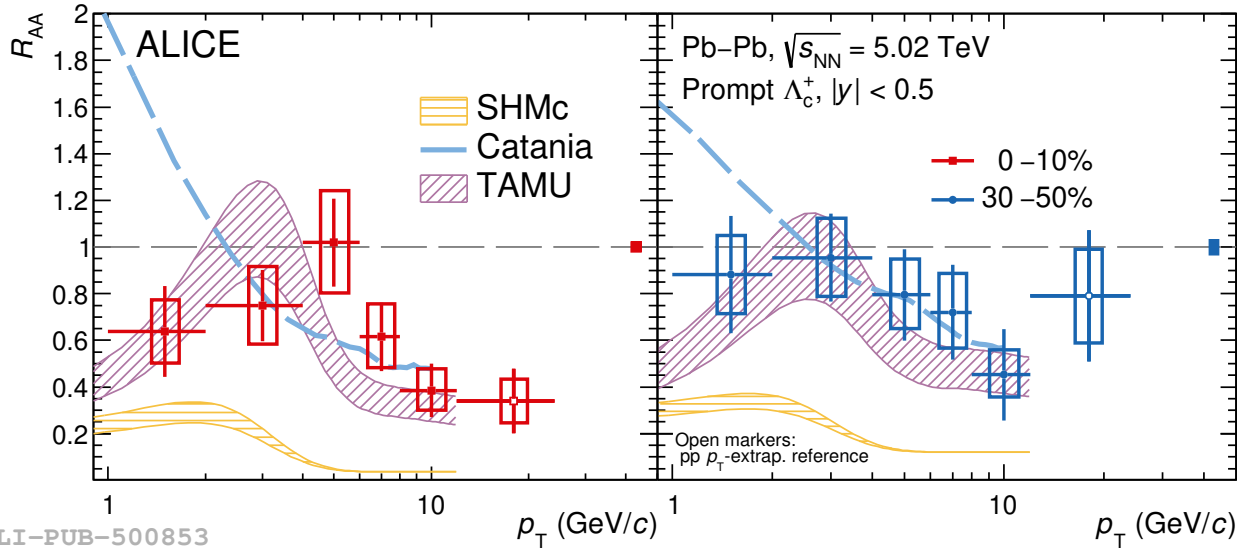




- Prompt Λ_C / D meson ratio in pp and Pb-Pb compared to model predictions
- Catania and TAMU models include hadronization mechanisms via coalescence and fragmentation
- Statistical hadronization model (SHMc) include only measured charmed mesons and baryons (p_T distributions modeled with core-corona approach)
- Λ_C / D ratio increases from pp to central Pb-Pb collisions at intermediate p_T → enhanced production via coalescence or/and feed-down from higher mass resonances

R_{AA} of prompt Λ_c baryon in Pb-Pb





Phys. Lett. B 839 (2023) 137796

$$R_{AA} = \frac{d^2N_{AA}}{dp_T dy} \Big/ \frac{d^2N_{pp}}{\langle N_{coll}\rangle dp_T dy}$$

- Hint of hierarchy in central collisions:
  $R_{AA}(\Lambda_c) > R_{AA}(D_s^+) > R(D^0)$

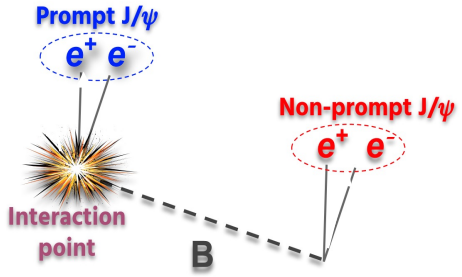
→ Hadronization via charm quark coalescence or/and feed-down from higher mass resonances

- Catania and TAMU models do not include charm-quark radiative energy loss
- TAMU model provides a good description of the R_{AA} over the whole p_T range in both centrality classes

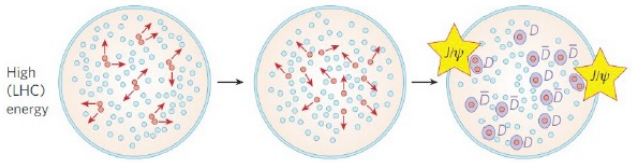
Prompt and non-prompt J/ψ production

Parton energy loss, dissociation vs regeneration

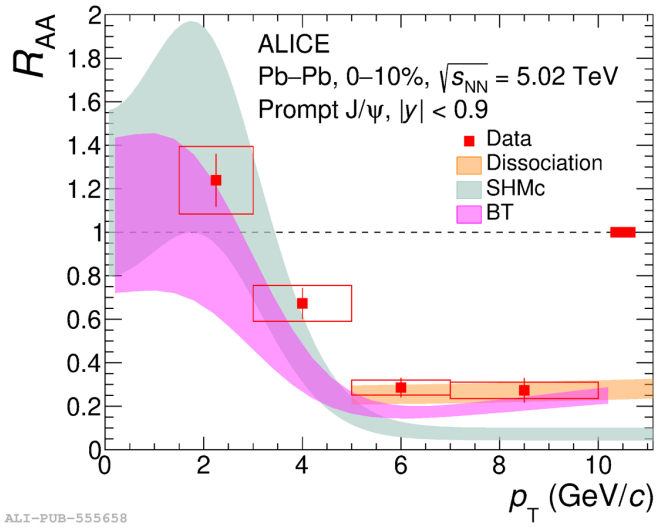
$$R_{AA} = \frac{d^2N_{AA}}{dp_T dy} \Big/ \frac{d^2N_{pp}}{<N_{coll}> dp_T dy}$$

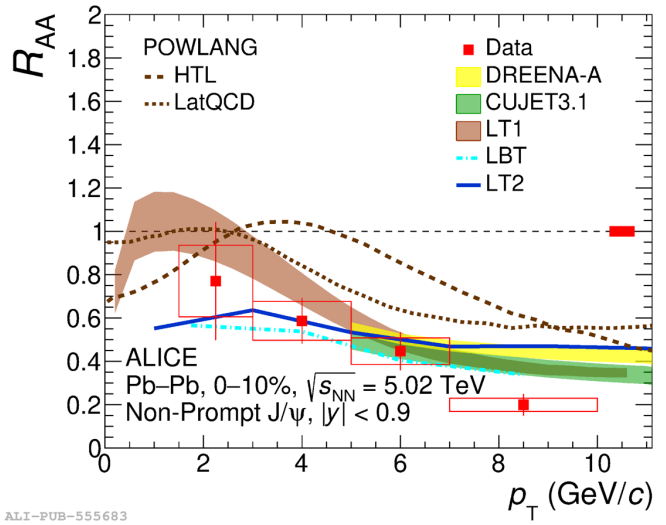


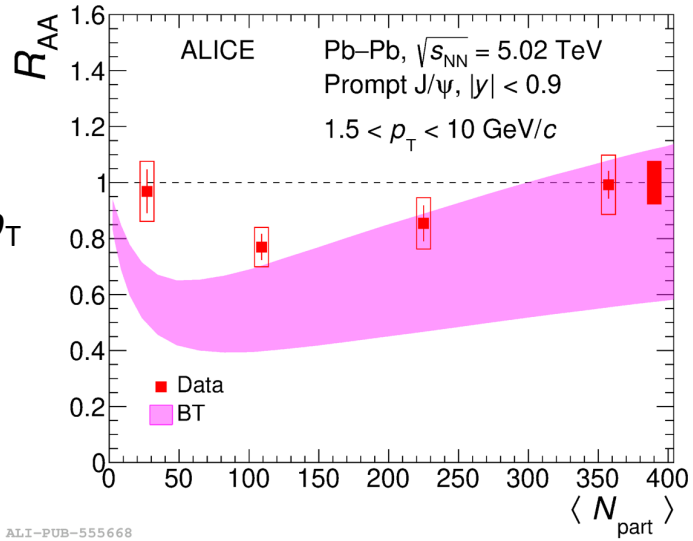
- Sign of prompt J/ψ (re)generation in central collisions
- Prompt J/ψ R_{AA} described by models including quarkonium dissociation (regeneration) at high (low) p_T
- Non-prompt J/ψ described by LT1 transport model

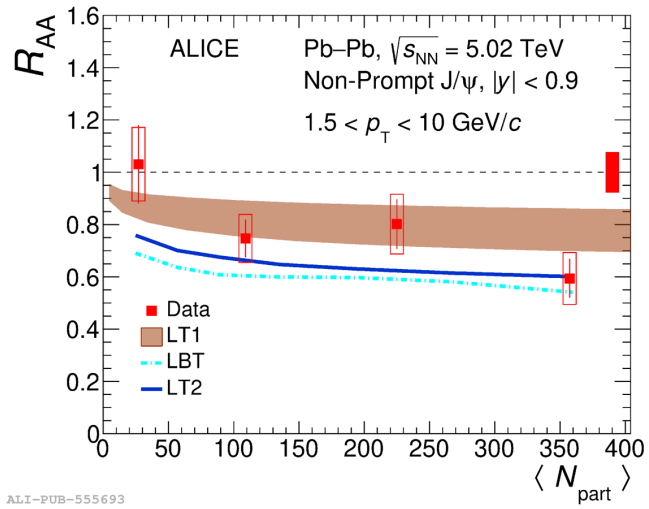


JHEP 02 (2024) 066

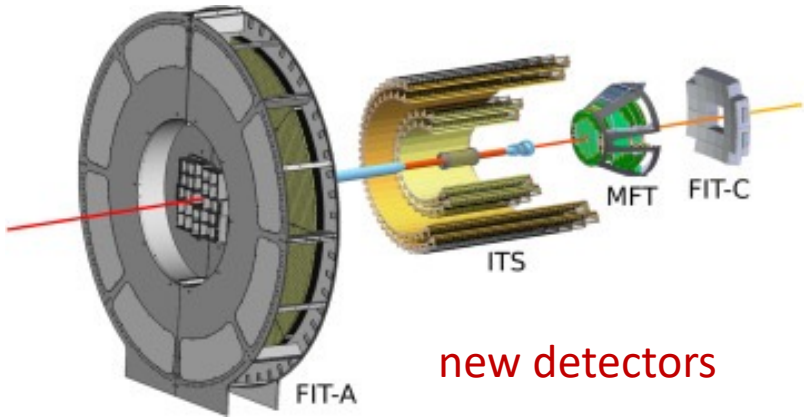




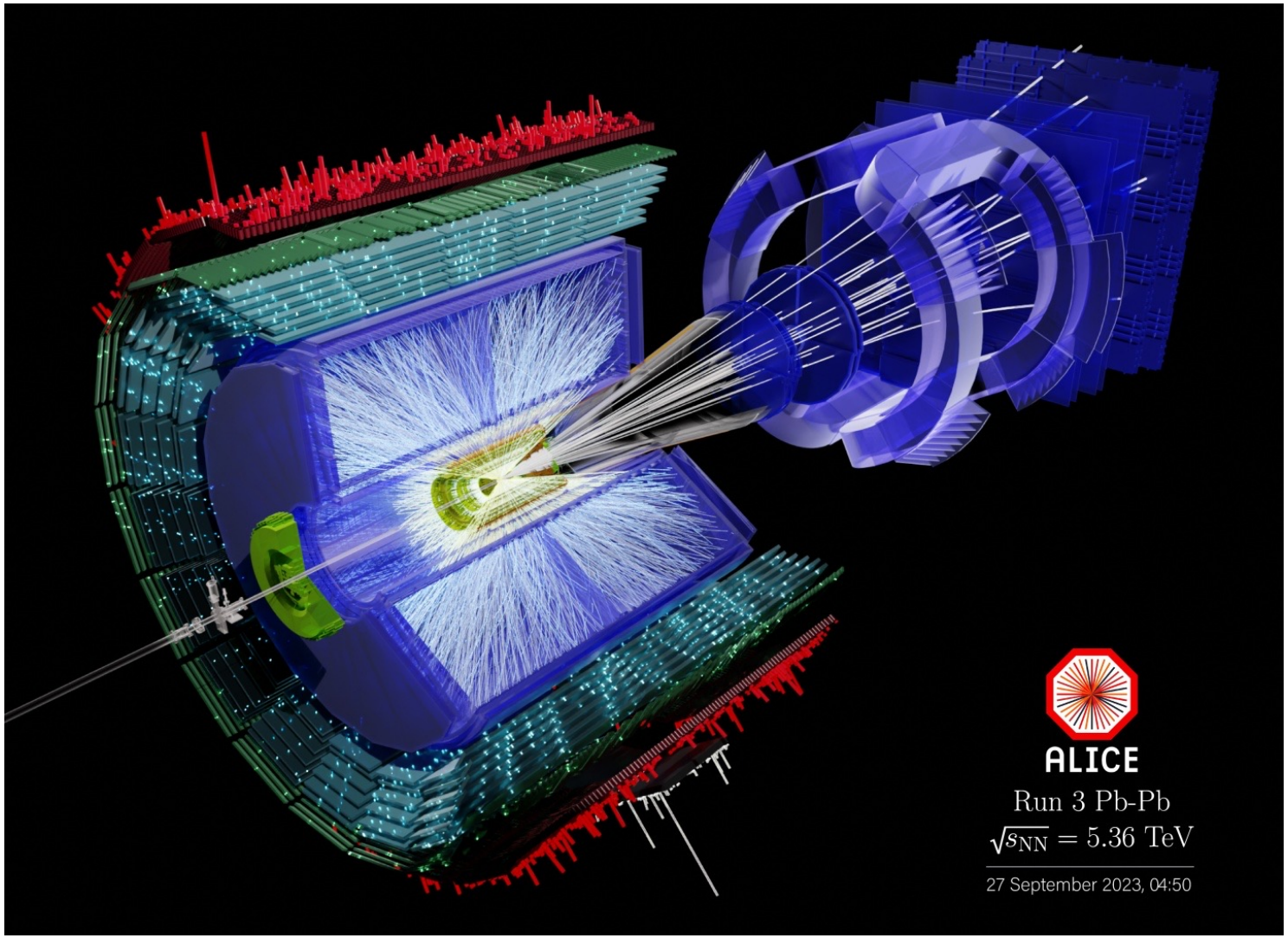




ALICE in Run 3

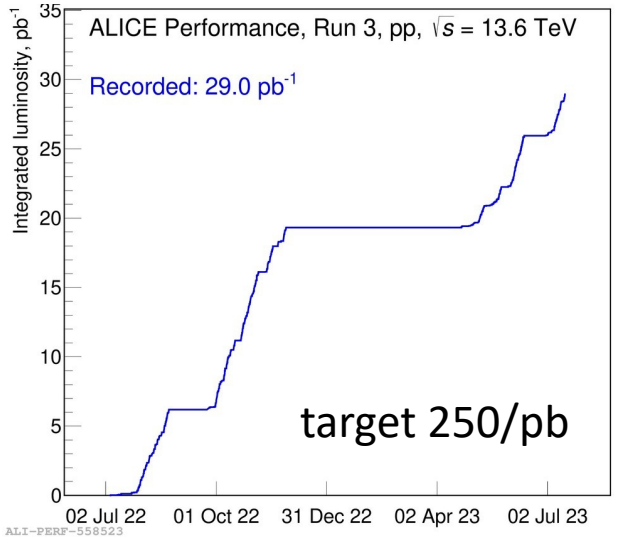


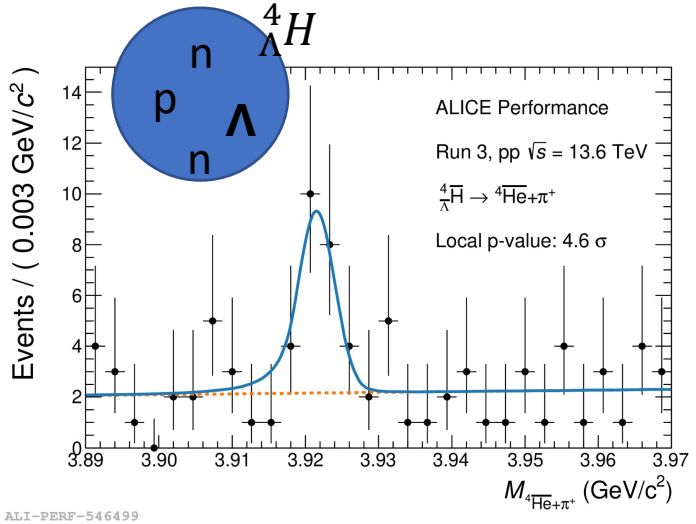
new detectors

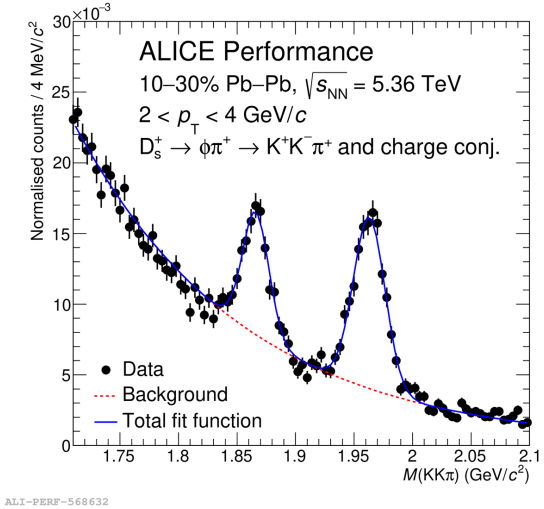


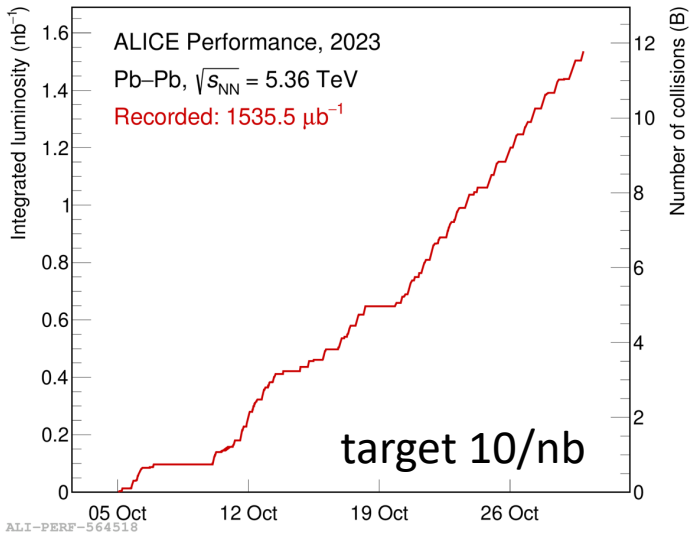
ALICE Run 3 Performance

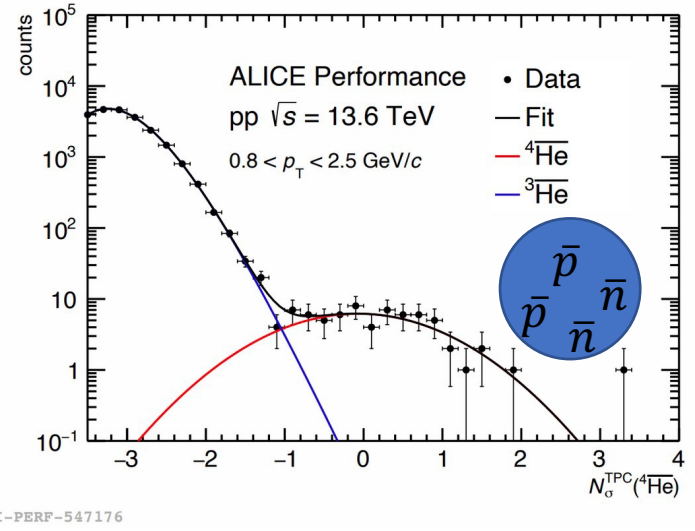
Work in progress!

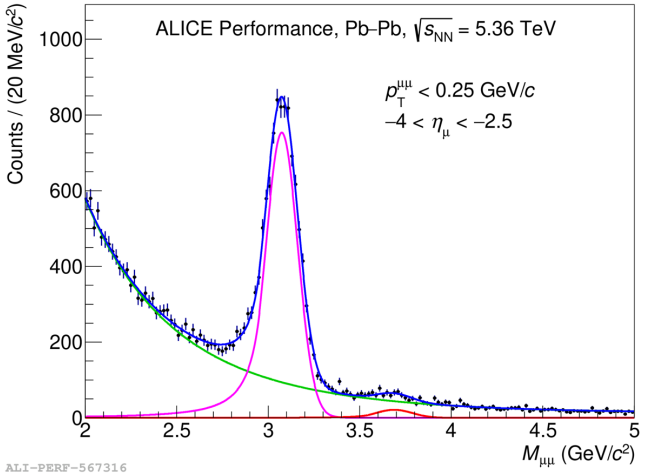




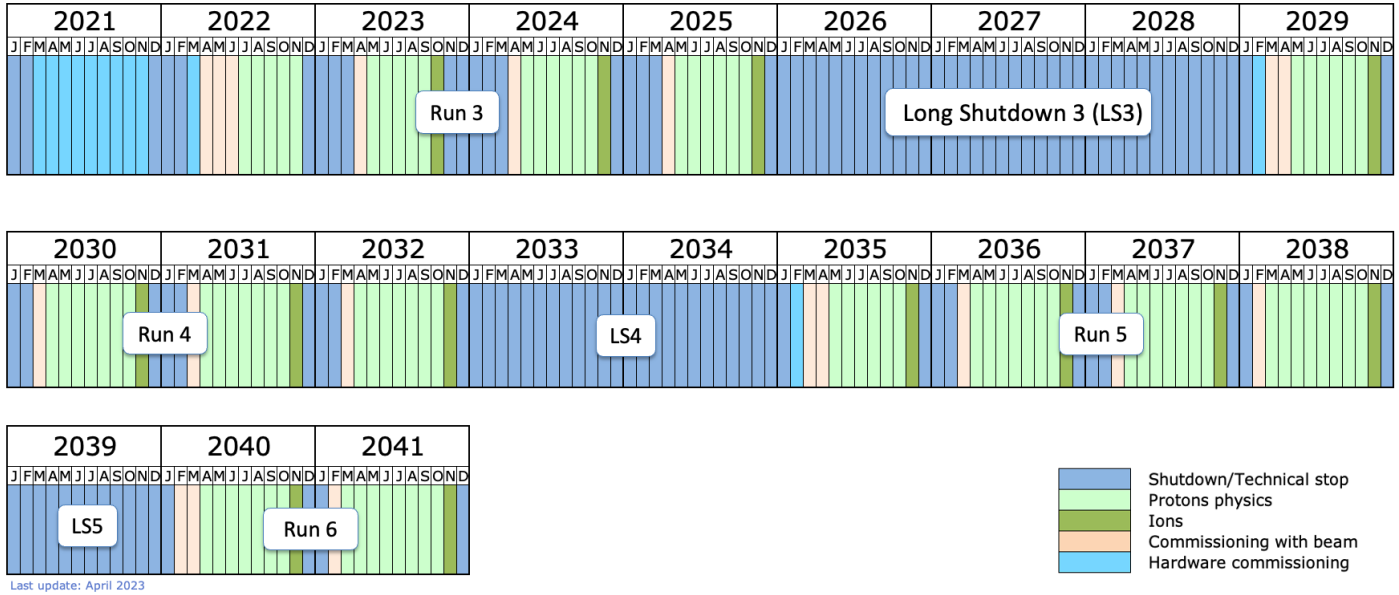




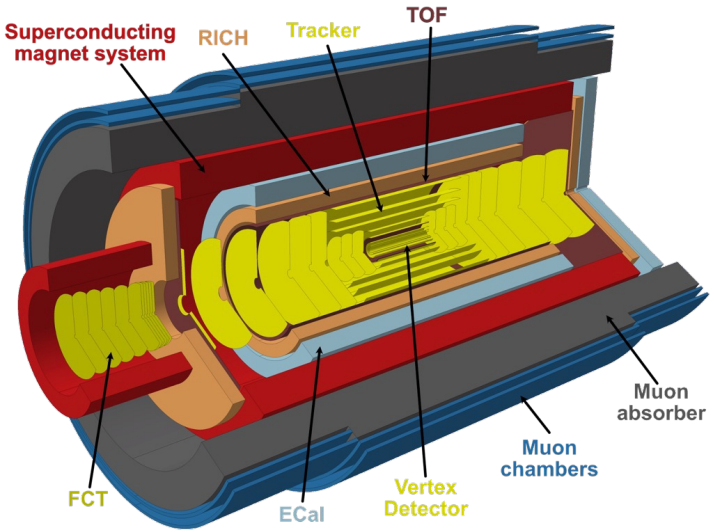




ALICE Upgrades

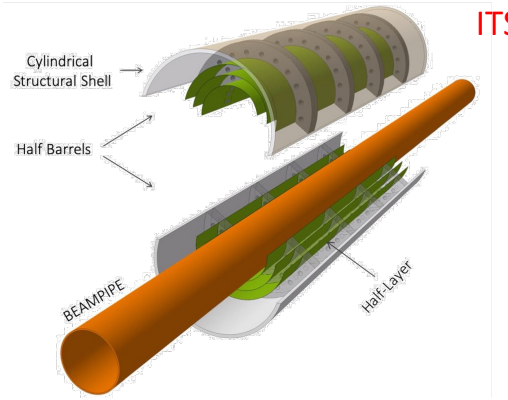


LS4: Future heavy-ion detector (ALICE 3)

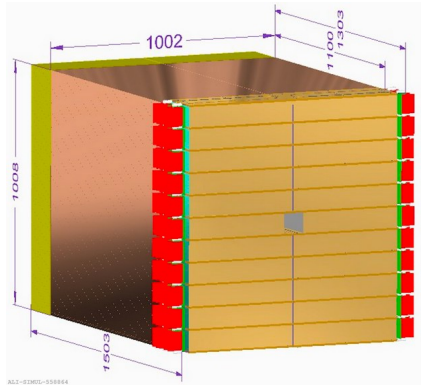


LS3: ITS3 and FoCal

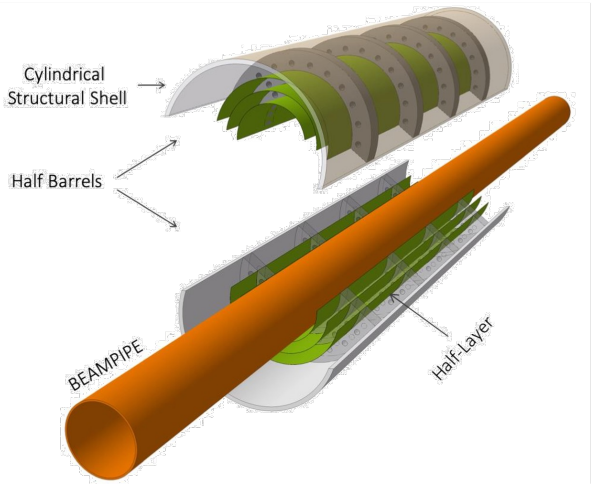
ITS3

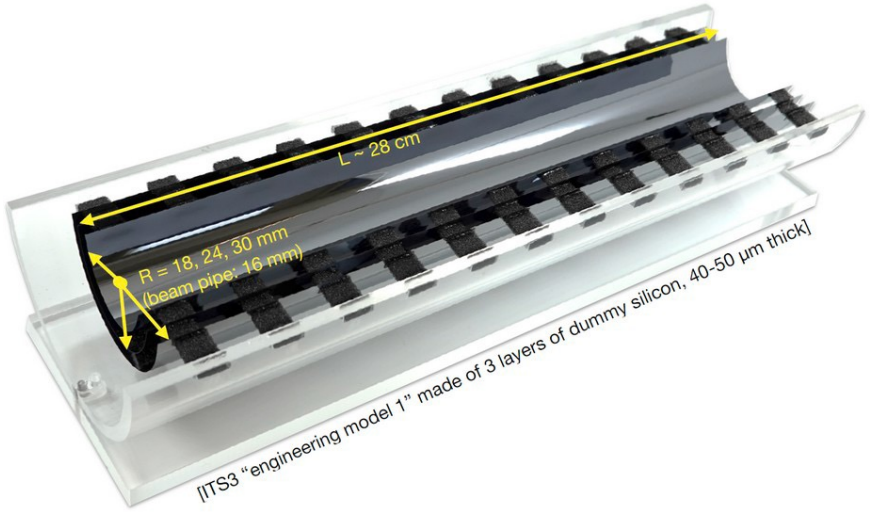


FoCal



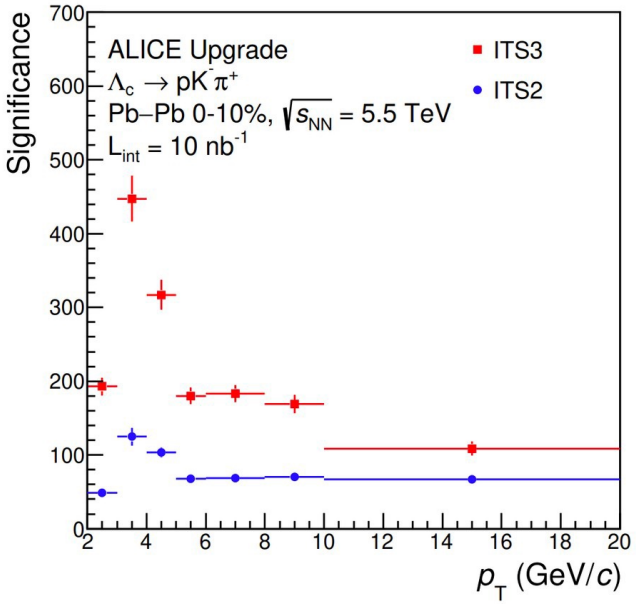
Inner Tracking System 3 (ITS 3)

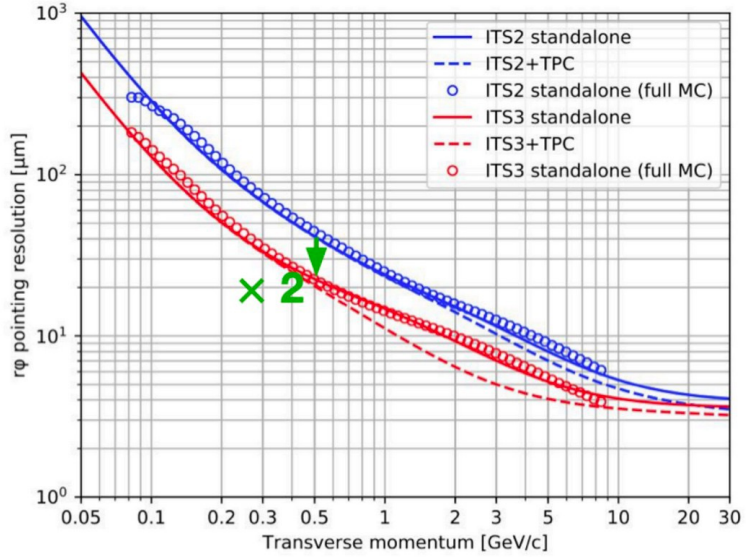




- Truly cylindrical (silicon sensor bending)
- 65 nm MAPS sensors
- Sensor stitching (30 cm wafers)

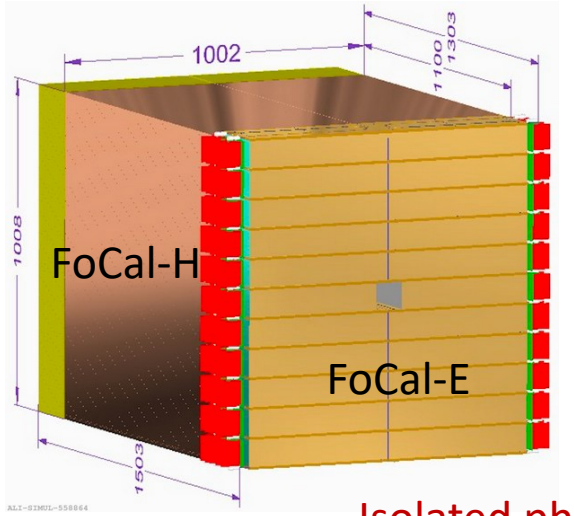
- Main physics motivation
  - Improve performance for heavy flavour and dielectron measurements





LoI: CERN-LHCC-2019-018
Physics performance: ALICE-PUBLIC-2023-002

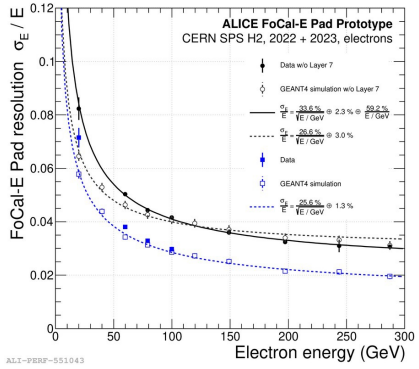
Forward Calorimeter (FoCal)

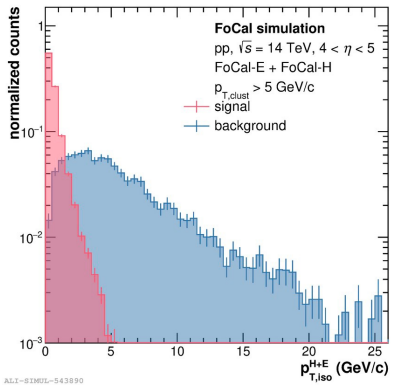


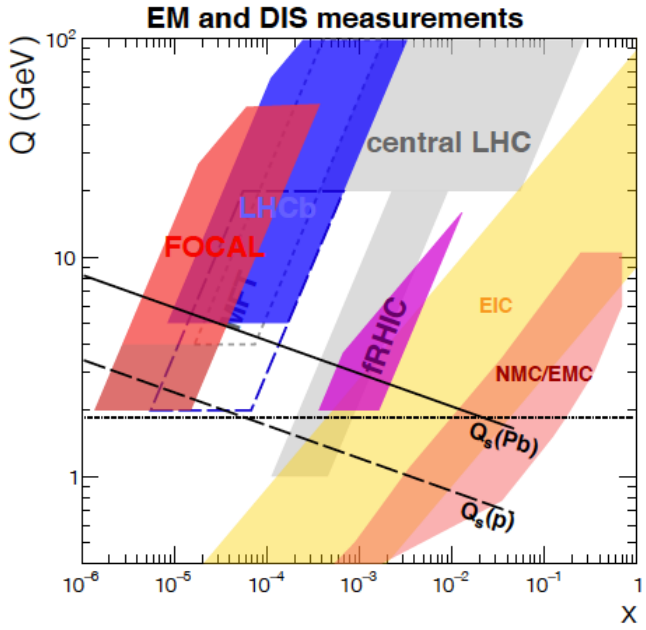
- Electromagnetic (FoCal-E) and hadronic (FoCal-H) calorimeter
- Acceptance: $3.2 < \eta < 5.8$

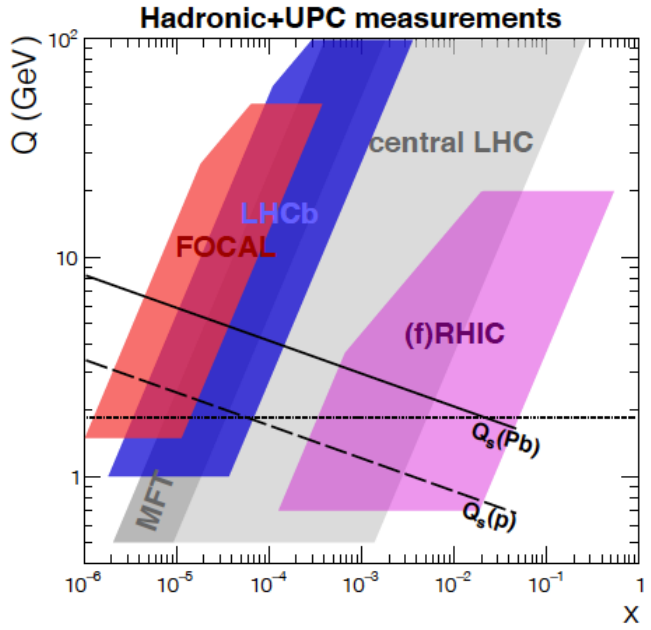
- Main physics motivation
  - Explore non-linear QCD evolution at small-x
  - Measurements of isolated-γ, DY, open charm and UPC

Isolated photons



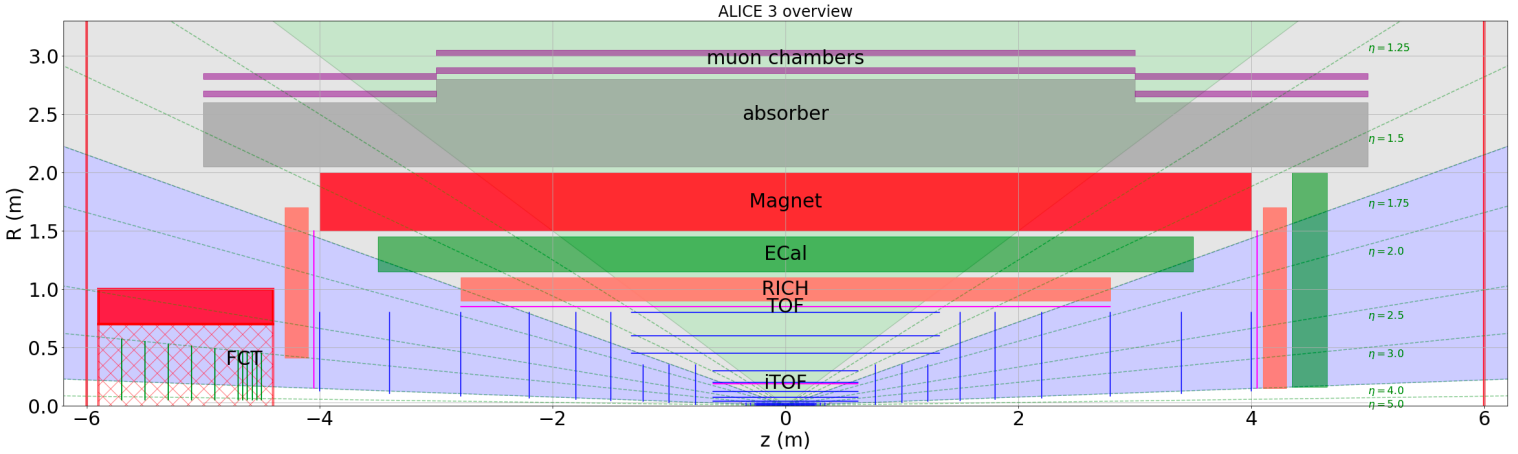






LoI: ALICE, LHCC-I-036 (2020)
Physics case: ALICE-PUBLIC-2023-001
Physics performance: ALICE-PUBLIC-2023-004

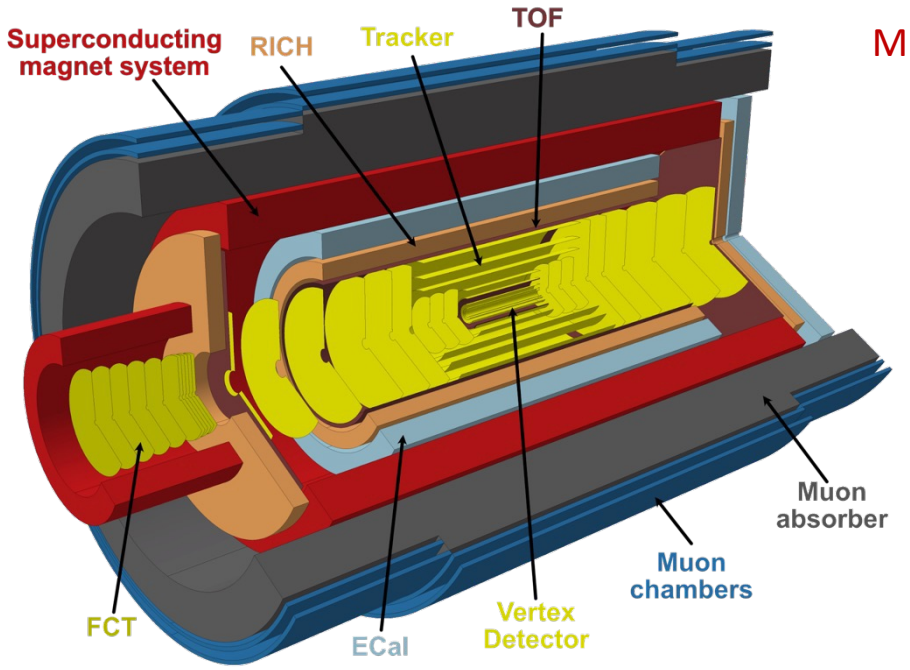
ALICE 3



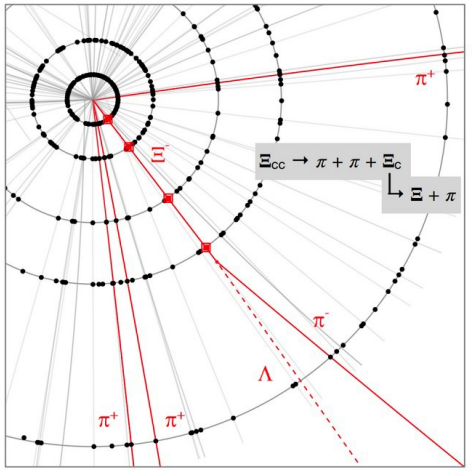
Main physics motivation

- QGP transport properties
- Hadronization mechanisms of charm and beauty hadrons, and nuclei
- Chiral symmetry restoration (photon and dileptons)
- BSM searches
- …

- Strong R&D on innovative sensors ongoing (large-area MAPS, Si time-of-flight and SiPM RICH)



Multi-charm hadron production

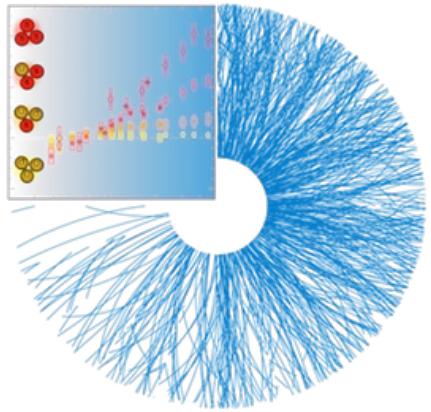


LoI: CERN-LHCC-2022-009

Summary

Initial stages

- Nuclear shadowing observed in UPC at the LHC
- Power-law dependence of $\sigma(\gamma$+p→J/ψ+p) on $W_{\gamma p}$ in agreement with HERA results



Light flavour

- System created in Pb-Pb collisions is baryon-free and electrically neutral at midrapidity
- Most precise measurement of hypertriton lifetime (hypertriton is a weakly bound state)
- Anti-alpha p_T differential distributions measured for the first time at the LHC
- The “ridge” is also observed in low multiplicity pp collisions

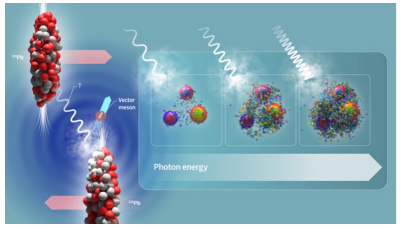
Heavy flavour

- Λ_C / D ratio increases from pp to central Pb-Pb collisions at intermediate p_T → enhanced production via coalescence
- Sign of prompt J/ψ (re)generation in central collisions

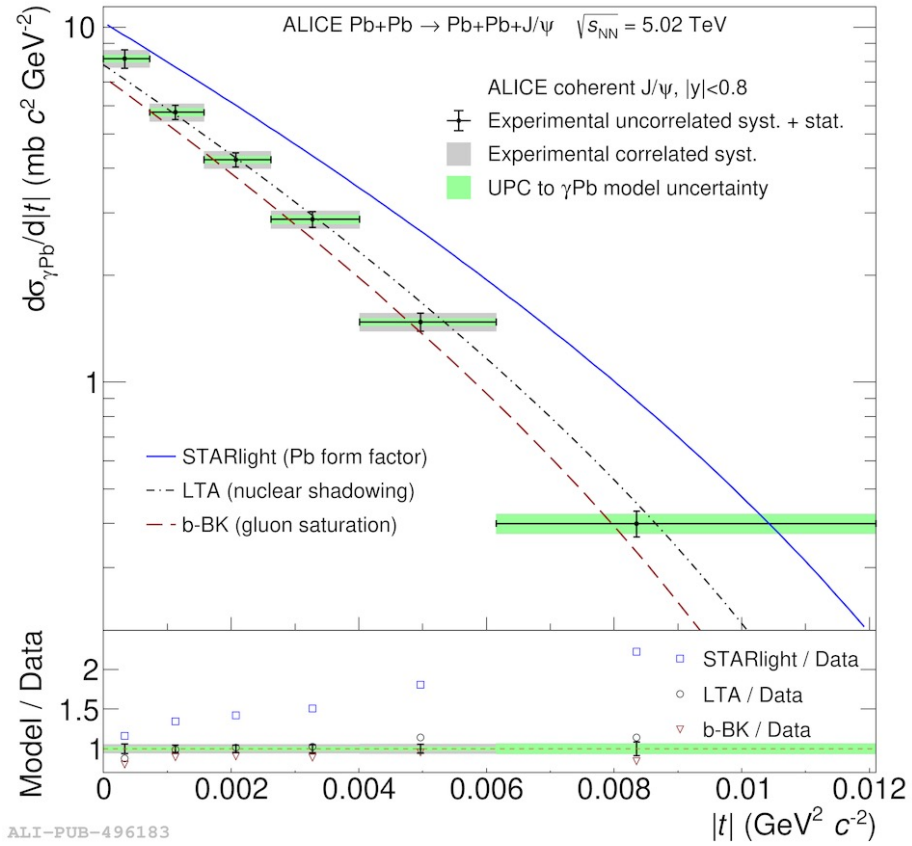
- ALICE has ambitious upgrade plans: ITS 3, FoCal (Run 4) and ALICE 3 (beyond Run 4)

backup

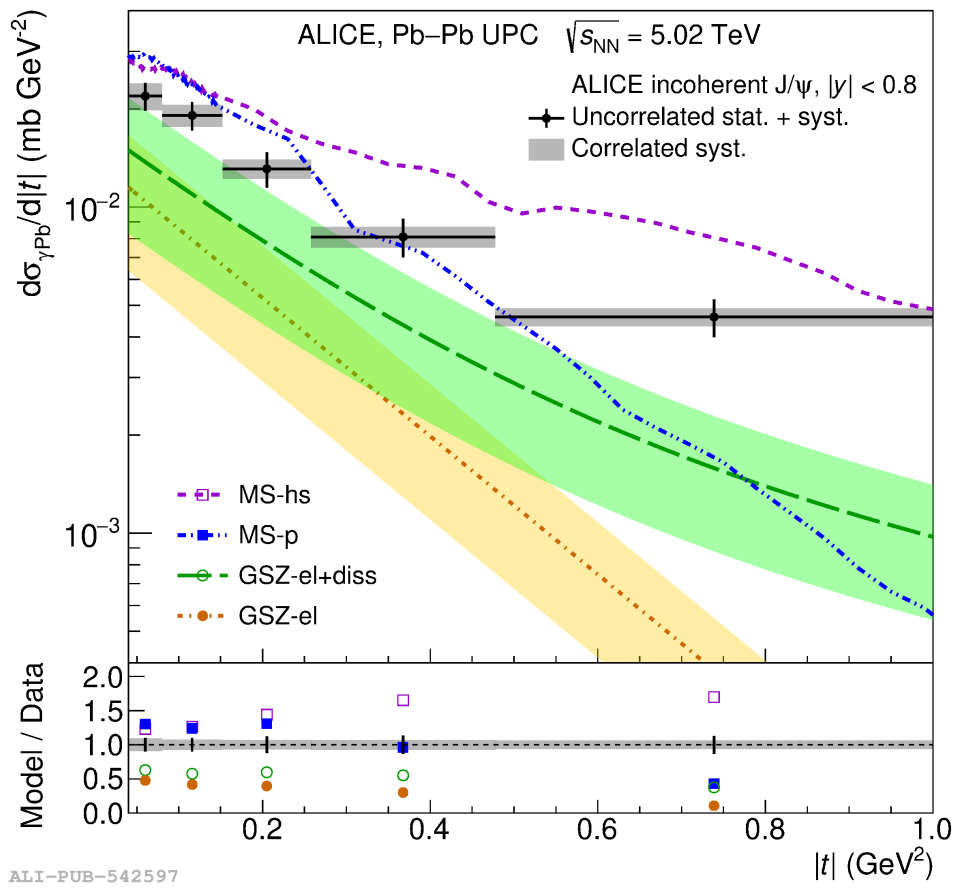
Mandelstam |t| dependence of J/ψ photoproduction

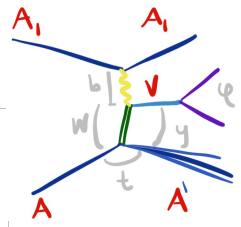


Phys. Lett. B 817 (2021) 136280



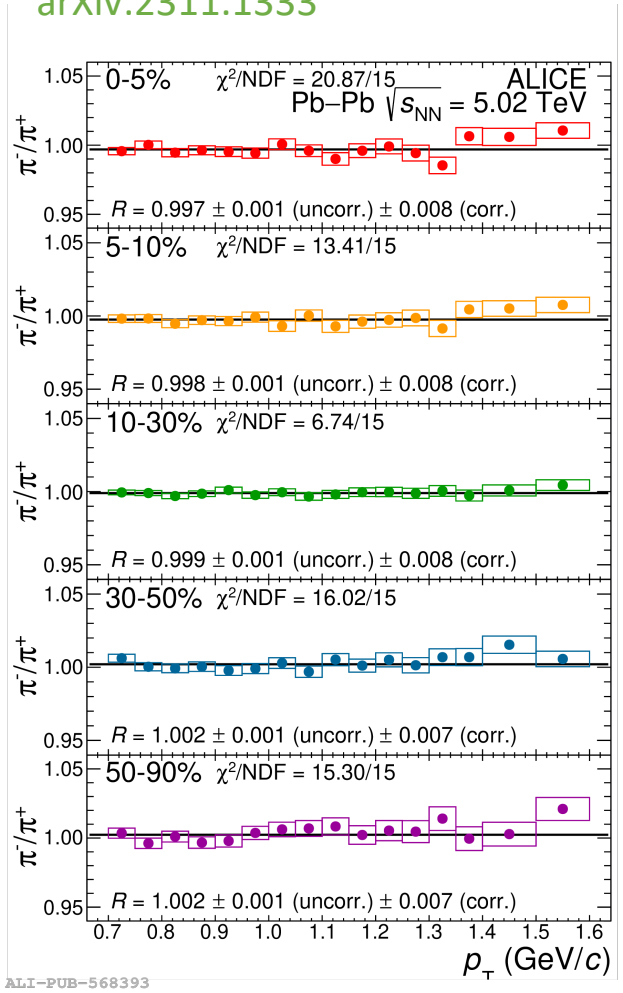
arXiv:2305.06169

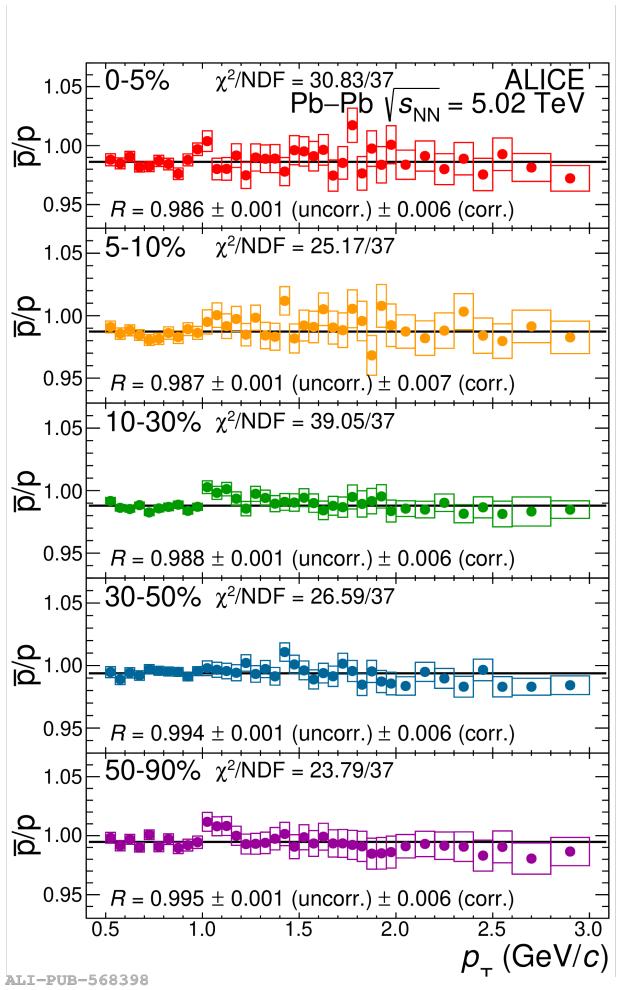


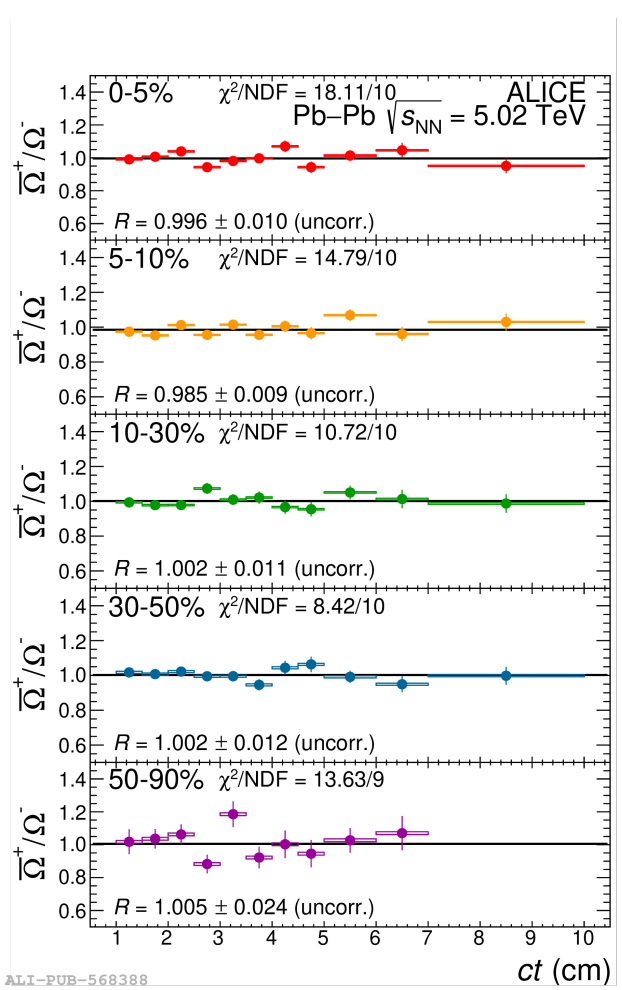


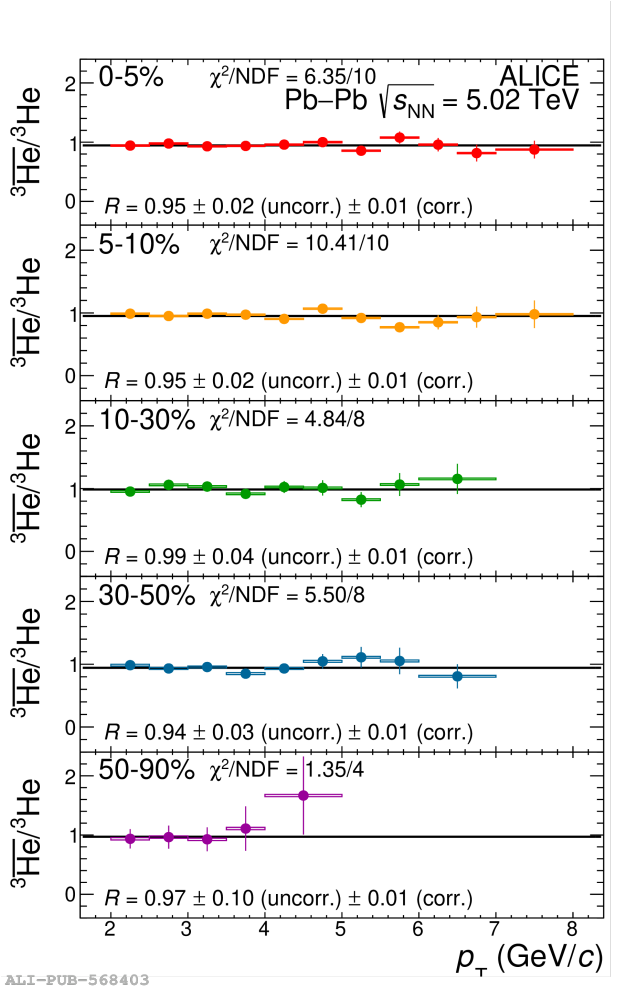
Antimatter/matter imbalance at the LHC

arXiv:2311.1333



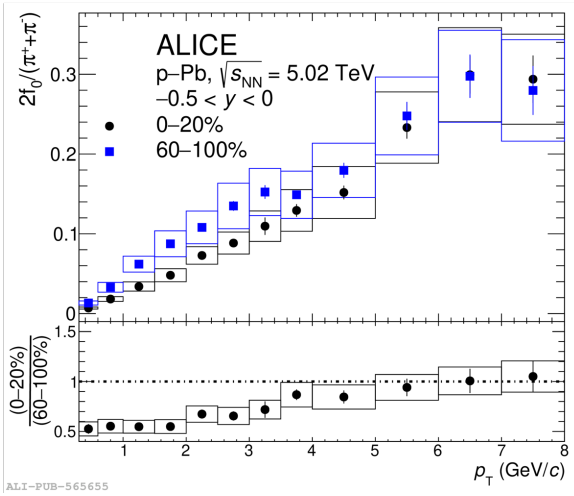


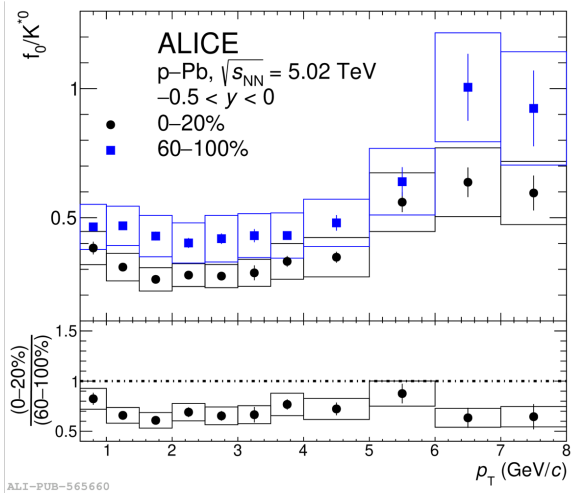


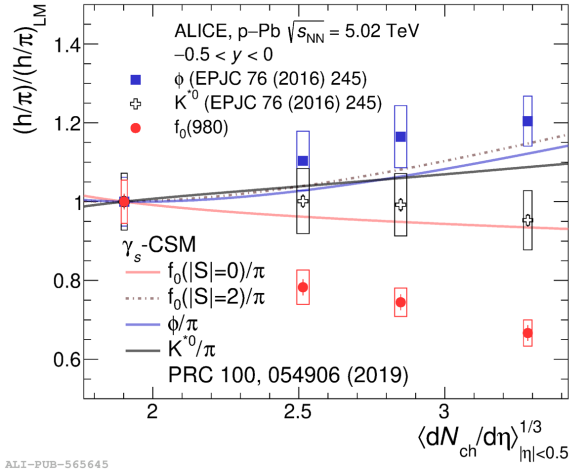


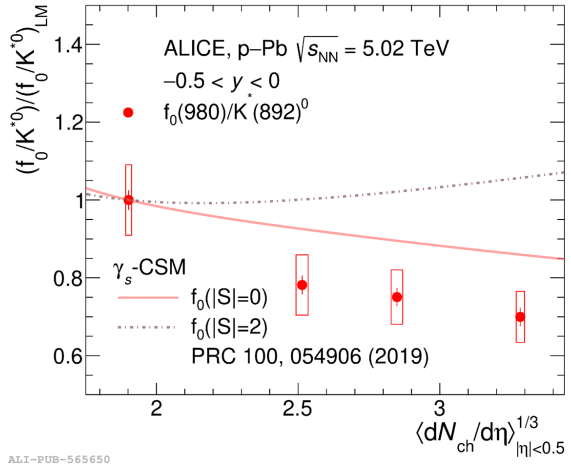
Abnormal $f_0(980)$ suppression in p–Pb collisions

Unknown internal structure of $f_0(980)$ – meson, tetraquark or $K\bar{K}$?







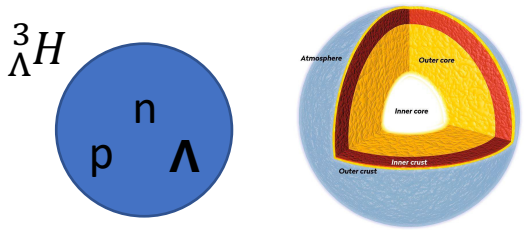


arXiv:2311.11786

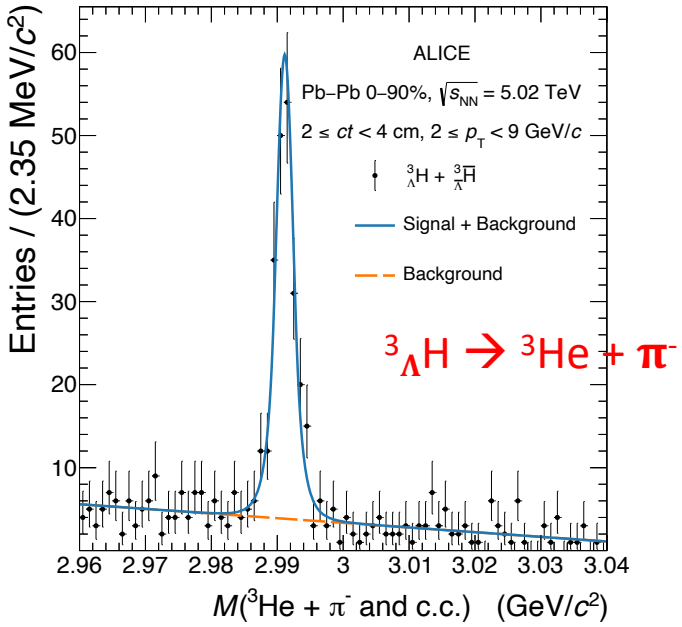
- $f_0(980)$ p_T spectrum harder than for π (radial flow)
- $f_0(980)/\pi$ and $f_0(980)/K^*(892)^0$ indicate that f_0 does not contain strange quarks (no strangeness enhancement in QGP)
- $f_0(980)/K^*(892)^0$ indicates that f_0 behaves like meson (no enhancement at intermediate p_T as for baryon-to-meson ratios)
- CSM predicts different suppression of $f_0(980)$ independent of number of strange quarks

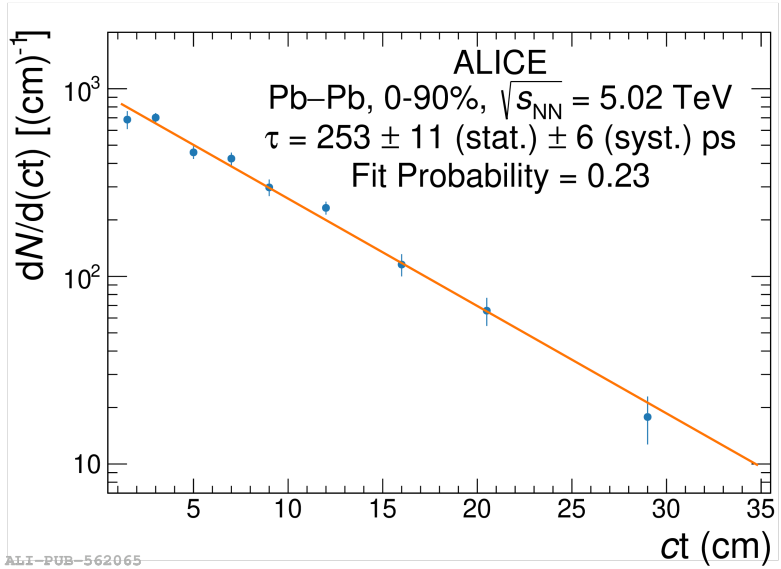
Canonical Statistical Model (CSM), V. Vovchenko et al., Phys. Rev. C 100 (2019) 054906

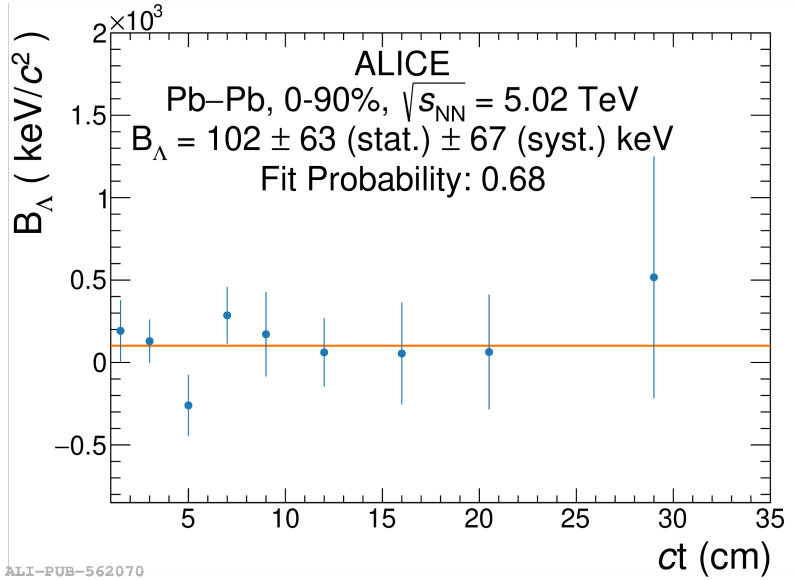
(Anti)hypertriton lifetime



Phys. Rev. Lett. 131 (2023) 102302







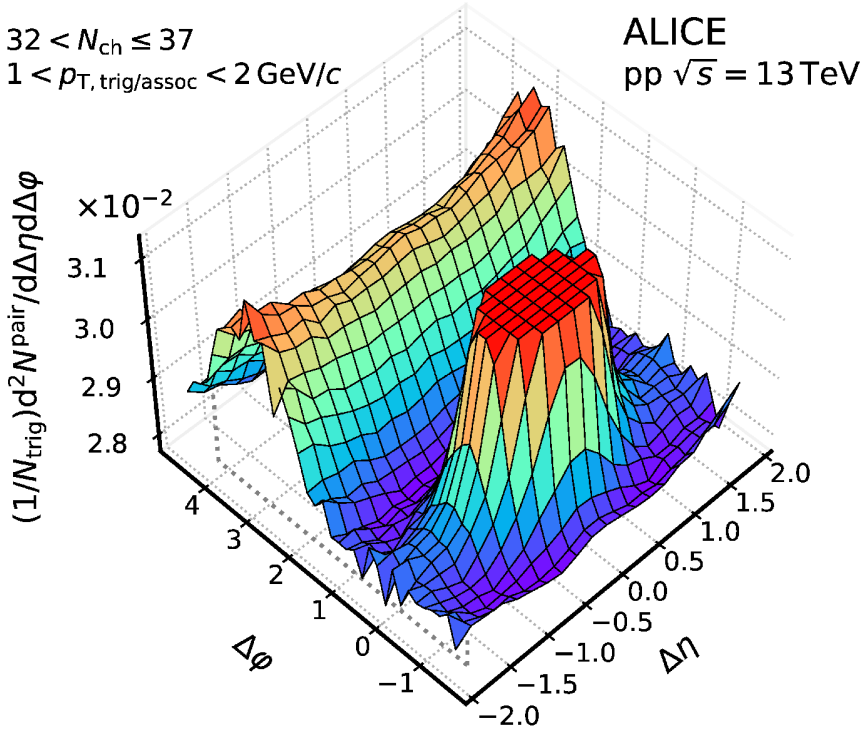
$c \cdot t = M \cdot L \cdot c/p$

L - decay length

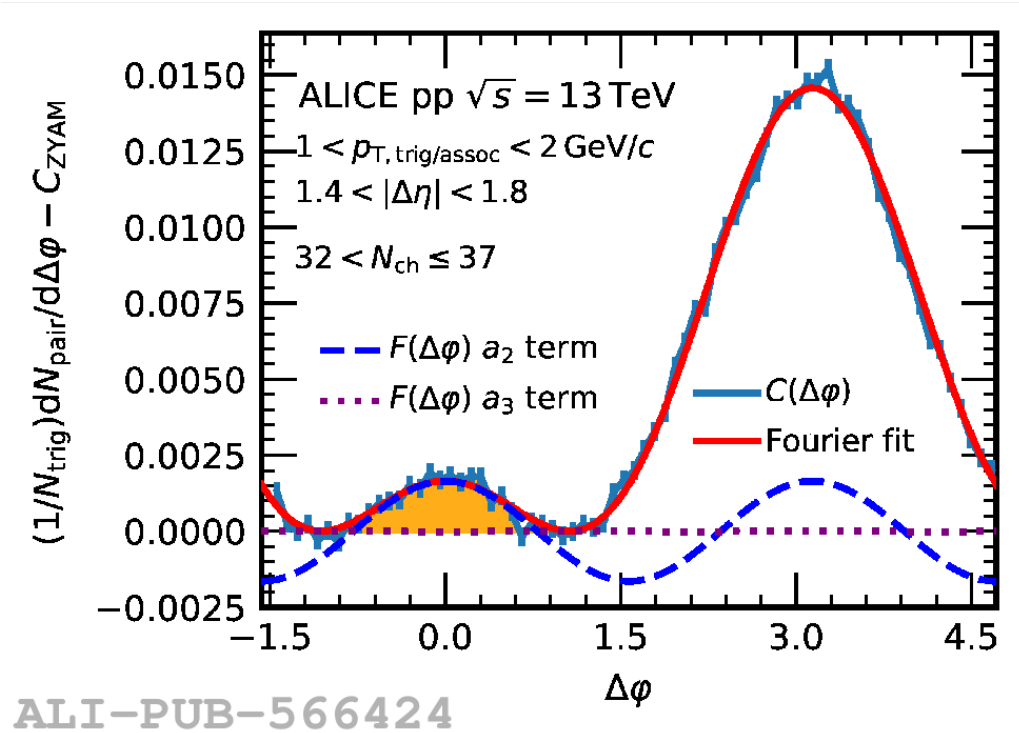
p - hypertriton momentum

Emergence of long-range angular correlations in low-multiplicity proton-proton collisions

arXiv:2311.14357

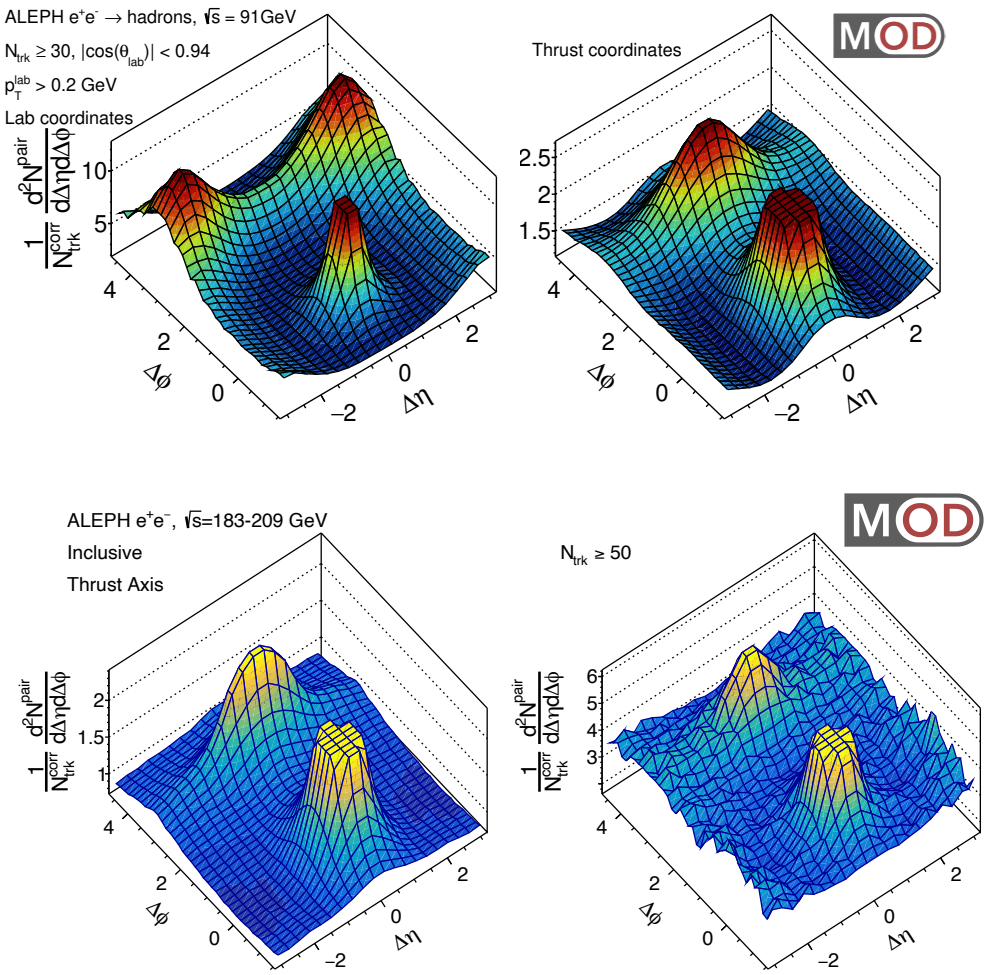


ALI-PUB-566419



ALI-PUB-566424

Long-range near-side correlation in e^+e^- Collisions at 91 GeV and 183-209 GeV with ALEPH



A. Badea et al. Phys. Rev. Lett. 123, 212002 (2019)
Yu-Chen Chen et al. arXiv:2312.0508