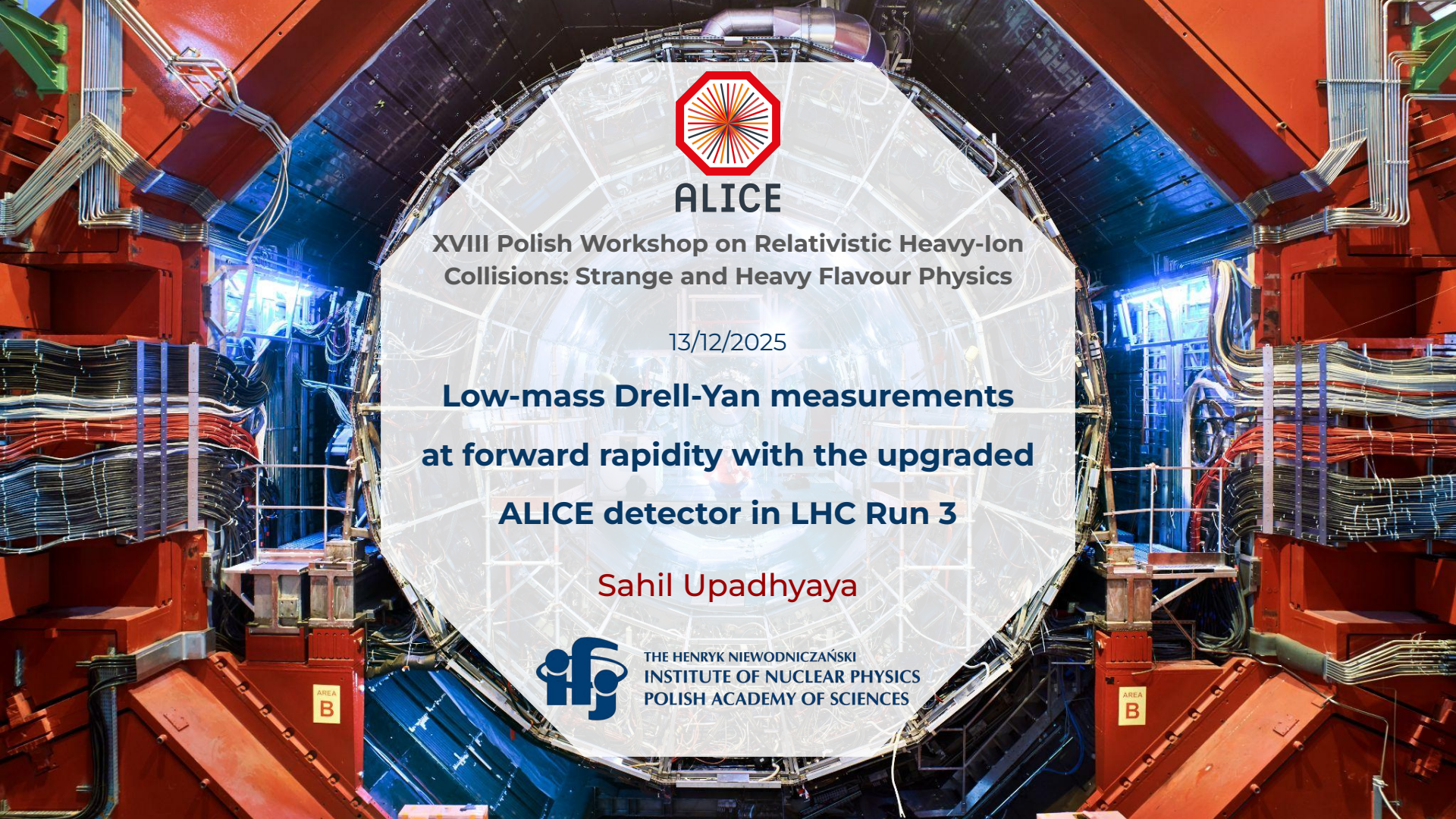


ALICE

XVIII Polish Workshop on Relativistic Heavy-Ion Collisions: Strange and Heavy Flavour Physics

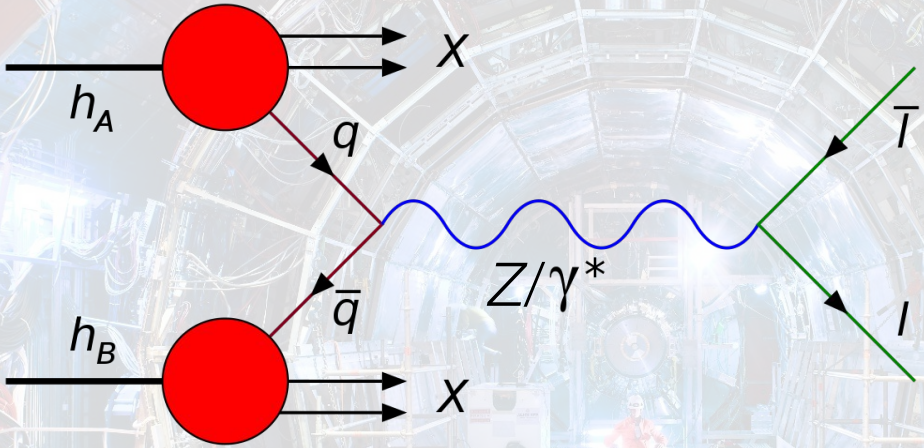
13/12/2025

Low-mass Drell-Yan measurements at forward rapidity with the upgraded ALICE detector in LHC Run 3

Sahil Upadhyaya

THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

Drell-Yan process



Phys. Rev. Lett. **25** 316 (1970)

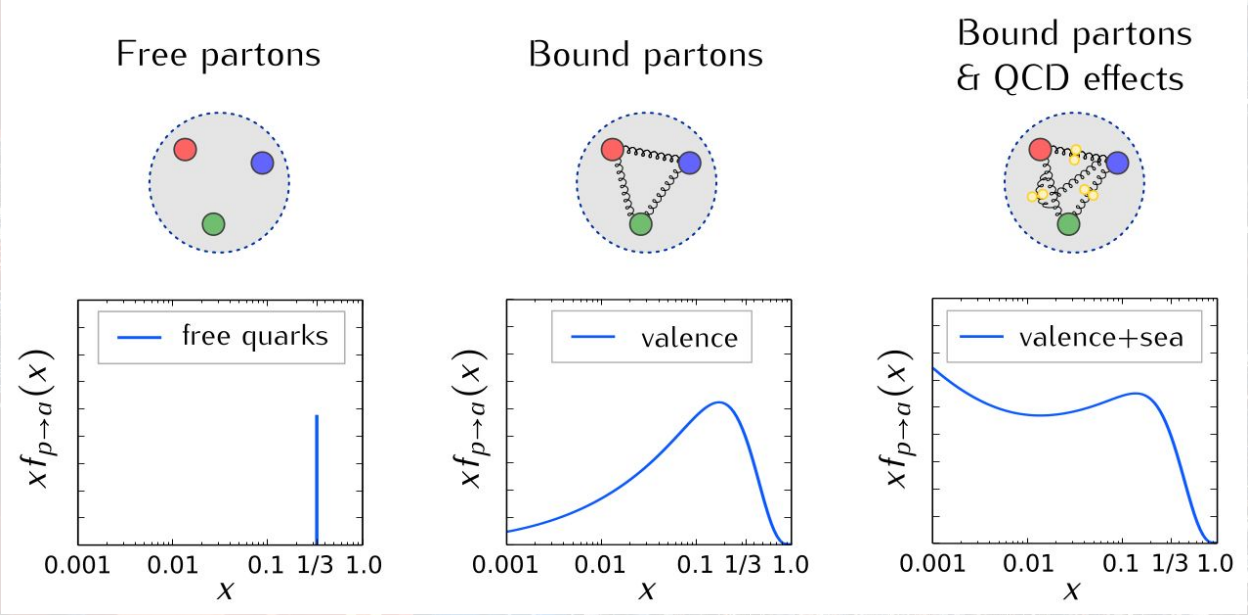
→ Production of a lepton pair from an electroweak interaction of a quark-antiquark pair (leading-order process):

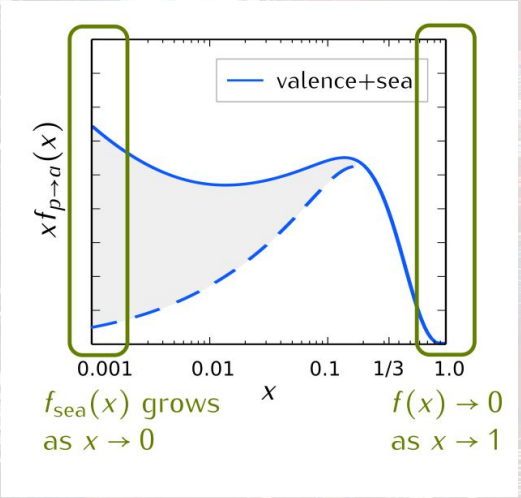
$$q + \bar{q} \rightarrow Z/\gamma^* \rightarrow l + \bar{l}$$

→ Clean probe for parton distribution functions (PDFs)
  – non-perturbative ; determined via experimental measurements

Parton Distribution Functions

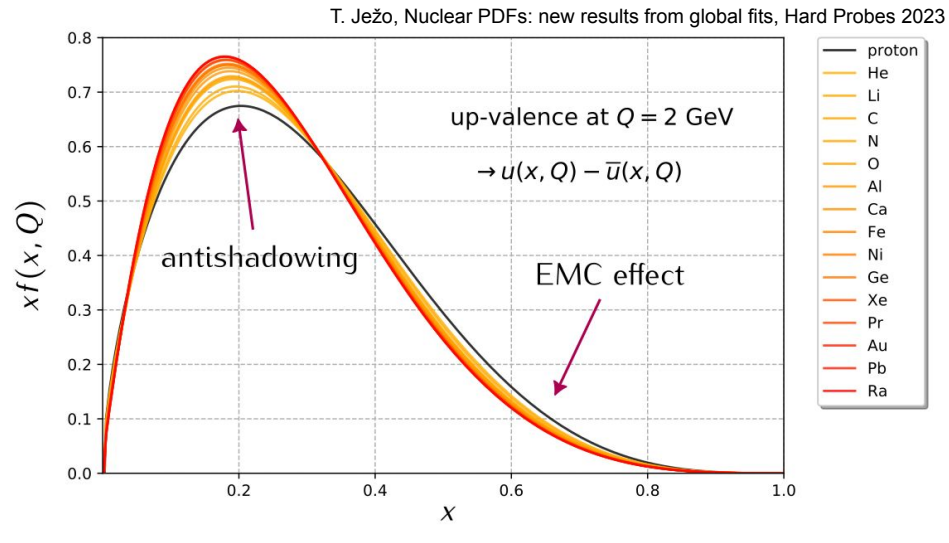
→ PDFs – probability to find partons (quarks and gluons) in a hadron as a function of the fraction (*x* / *Bjorken-x*) of the proton's momentum carried by the parton



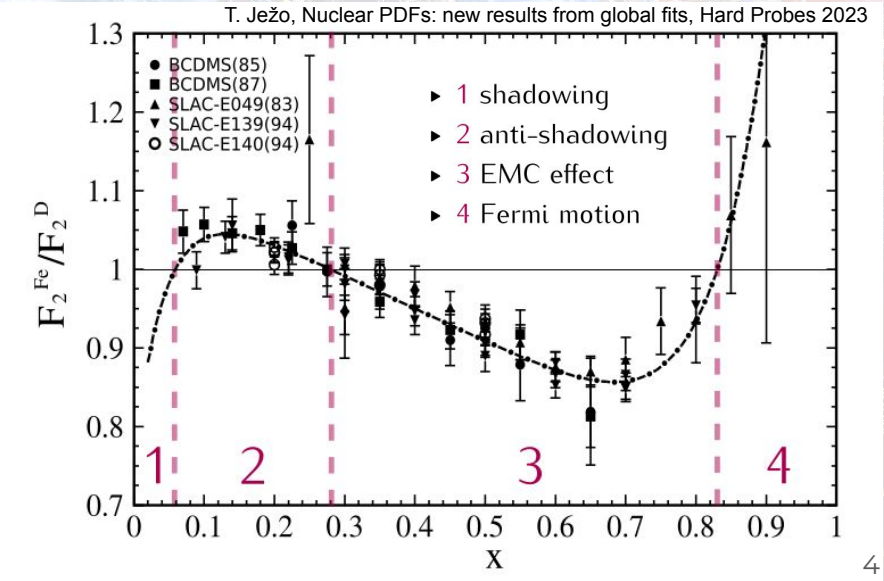


→ DY more sensitive to the sea quarks of the colliding hadrons

Parton Distribution Functions



→ PDFs are modified for bound partons in a nucleus [J. J. Aubert *et al.*, Phys. Lett. B **123** (1983) 275]



→ Various effects seen in nuclear modification as a function of *x*

Nuclear modification factor

→ Modified nuclear PDFs (nPDFs) can be studied using the Nuclear modification factor (***R***)

→ Nuclear modification factor for proton-nucleus (pA) collisions,

$$R_{\mathrm{pA}}(y, p_{\mathrm{T}}) = \frac{1}{\mathrm{A}} \frac{\mathrm{d}^2\sigma_{\mathrm{pA}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}^2\sigma_{\mathrm{pp}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}$$

Eur. Phys. J. C **78** 466 (2018)

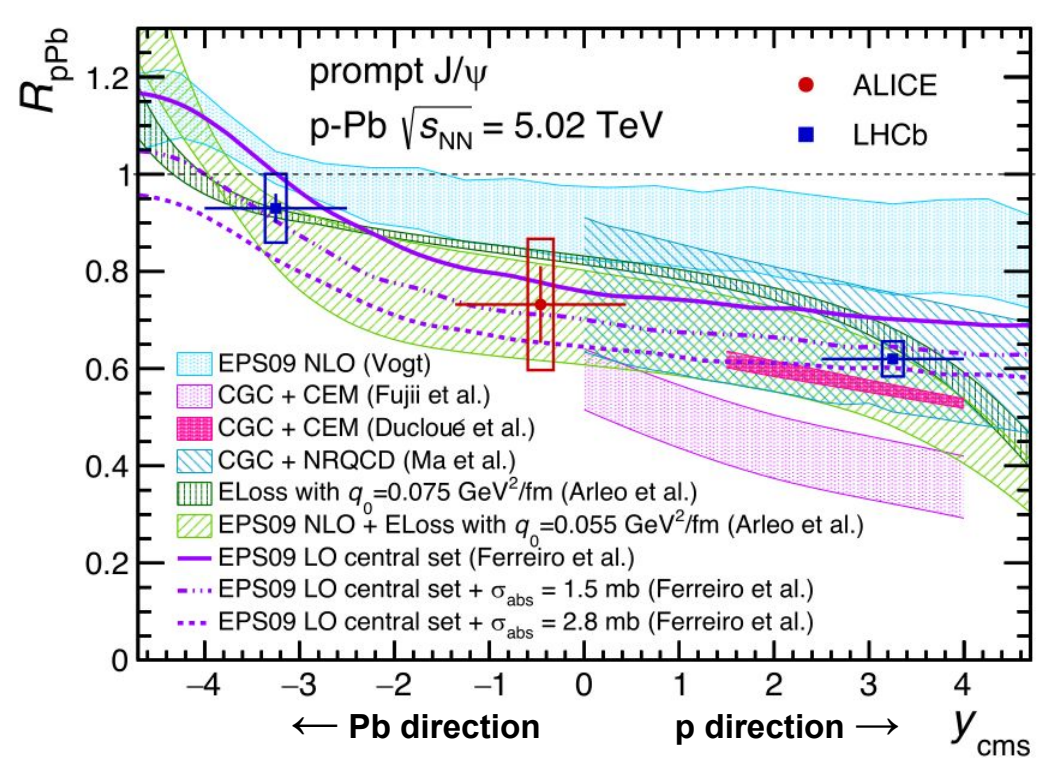
σ_{pA}, σ_{pp} – production cross-section in pA and pp collisions scaled by A

y is the rapidity of the measured hadron in the nucleon-nucleon centre-of-mass frame

p_{T} its transverse momentum

→ R_{pA} can help us to constrain the nPDFs

Charmonia production in p-Pb



Eur. Phys. J. C **78** 466 (2018)

→ Promt J/ψ Nuclear Modification Factor (R_{pPb}^{ψ}) as a function of y

→ Larger suppression at forward rapidity in p direction

→ initial- or final- state effects ?

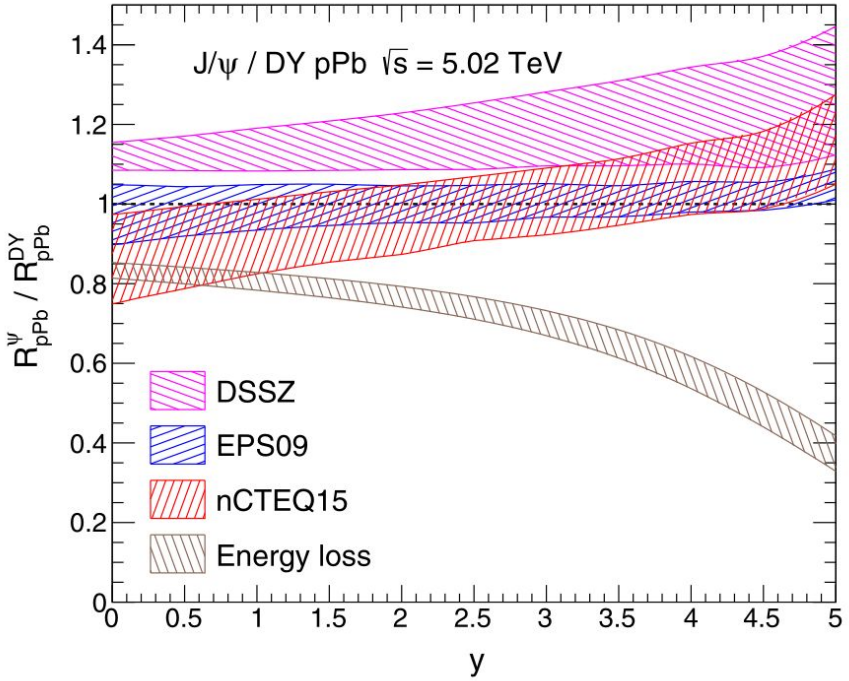
Drell-Yan predictions in p-Pb

- “Shadowing” effect – J/ψ ~ DY
- Coherent energy loss affects J/ψ and DY

$$\textbf{nPDF} \quad R^{\psi} \simeq R^{\mathrm{DY}} \rightarrow \mathcal{R}^{\psi/\mathrm{DY}} \simeq 1,$$
$$\textbf{E. loss} \quad R^{\psi} < 1; \quad R^{\mathrm{DY}} \gtrsim 1 \rightarrow \mathcal{R}^{\psi/\mathrm{DY}} < 1.$$

- Double ratio: $\mathcal{R}^{\psi/\mathrm{DY}}_{p\mathrm{A}}(y) \equiv R^{\psi}_{p\mathrm{A}}(y) / R^{\mathrm{DY}}_{p\mathrm{A}}(y)$
- Cancellation of nPDF effects
- Sensitive to coherent energy loss
- Preferable low-mass region (< 20 GeV/c^2)
  - good cancellation of nPDF effects
  - reasonable statistics at LHC

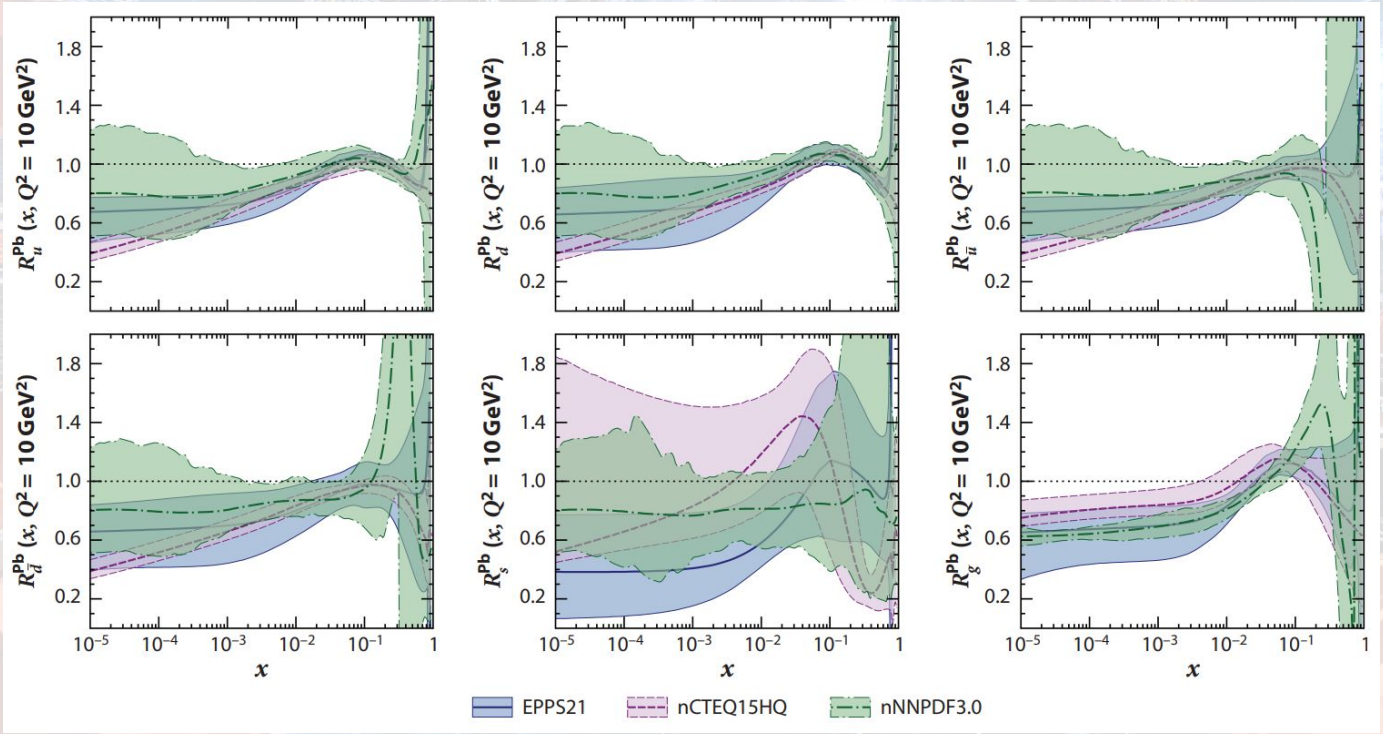
F. Arleo, S. Peigné, Phys. Rev. D **95** 011502(R) (2017)



nPDFs and low-x

→ Quark and gluon nPDFs are not well known at low-x ($< 10^{-3}$)

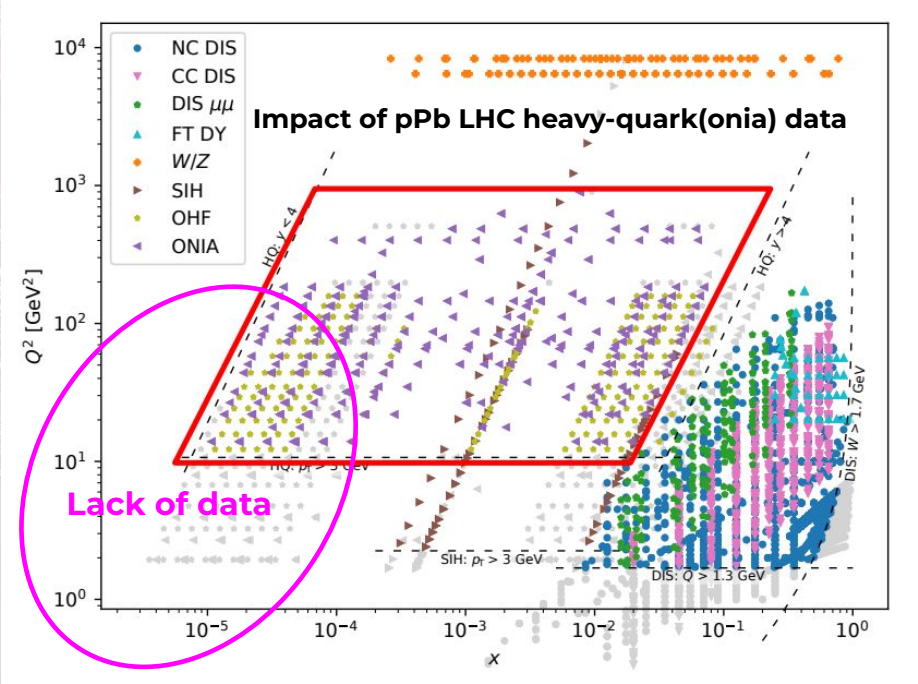
→ Need for improved precision → need for experimental data!!

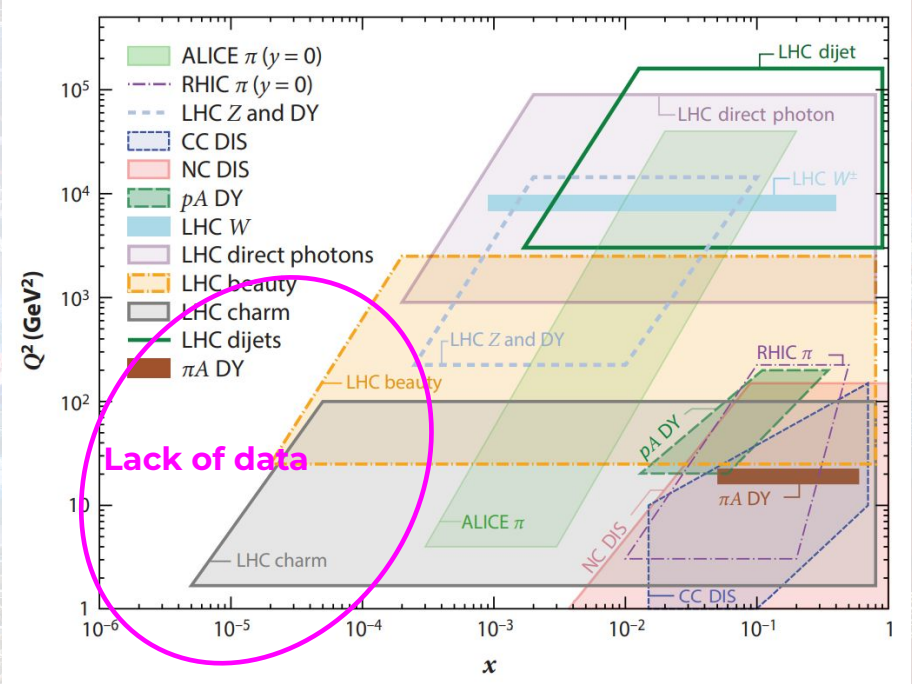


Annu. Rev. Nucl. Part. Sci. **74** (2024), 49–87

Need for experimental data

Before LHC Run 3





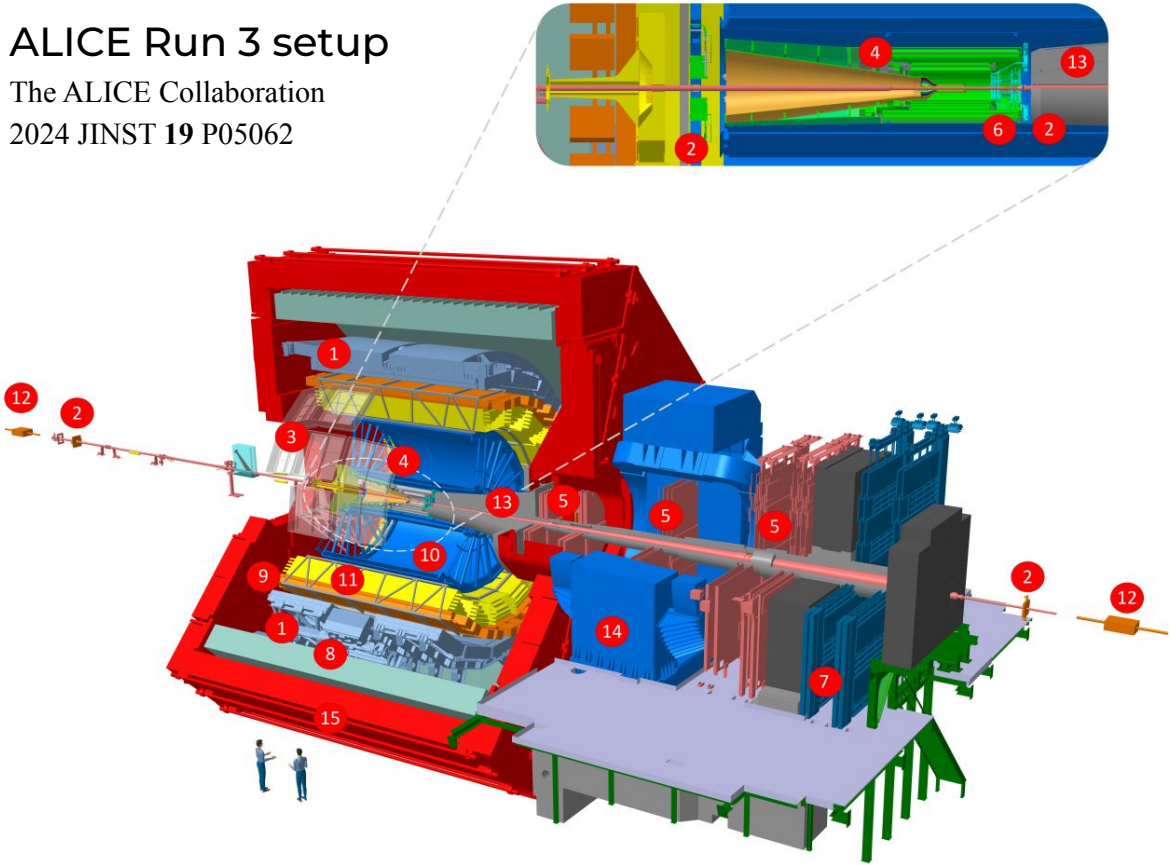
A. Kusina, Pinning down nuclear PDFs with the LHC data
Joint ECFA-NuPECC-APPEC Workshop Synergies between the EIC and the LHC 2025

Annu. Rev. Nucl. Part. Sci. **74** (2024), 49–87

The ALICE experiment in LHC Run 3

ALICE Run 3 setup

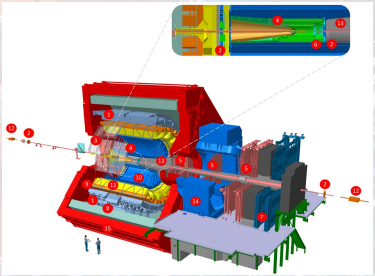
The ALICE Collaboration
2024 JINST **19** P05062



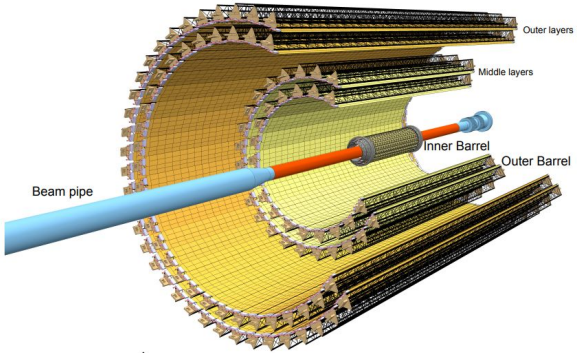
1. **EMCAL |** Electromagnetic Calorimeter
2. **FIT |** Fast Interaction Trigger
3. **HMPID|** High Momentum Particle Identification Detector
4. **ITS|** Inner Tracking System
5. **MCH|** Muon Tracking Chambers
6. **MFT|** Muon Forward Tracker
7. **MID|** Muon Identifier
8. **PHOS/CPV|** Photon Spectrometer
9. **TOF|** Time Of Flight
10. **TPC|** Time Projection Chamber
11. **TRD|** Transition Radiation Detector
12. **ZDC|** Zero Degree Calorimeter
13. **Absorber**
14. **Dipole Magnet**
15. **L3 Magnet**

The ALICE experiment in LHC Run 3

New detector systems

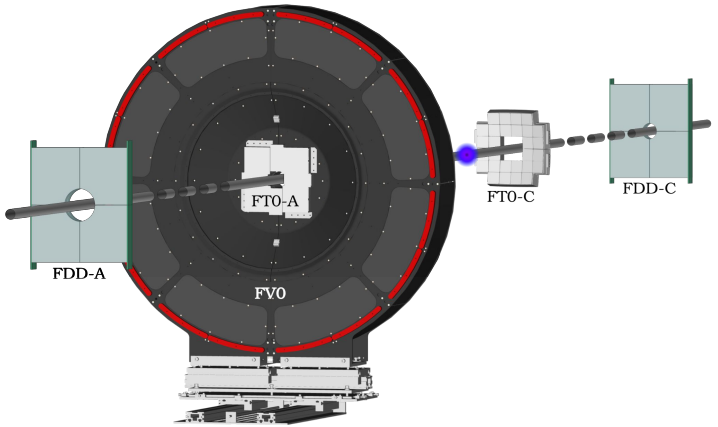


Inner Tracker System (ITS)



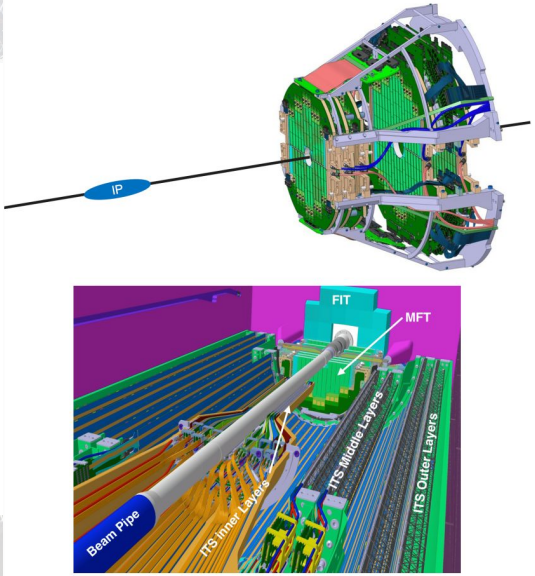
ITS2 Technical Design Report:
J. Phys. G: Nucl. Part. Phys. **41** 087002 2014

Fast Interaction Trigger (FIT)



New Fast Interaction Trigger for ALICE
Nucl. Instrum. Meth. A **845** (2017) 463

Muon Forward Tracker (MFT)

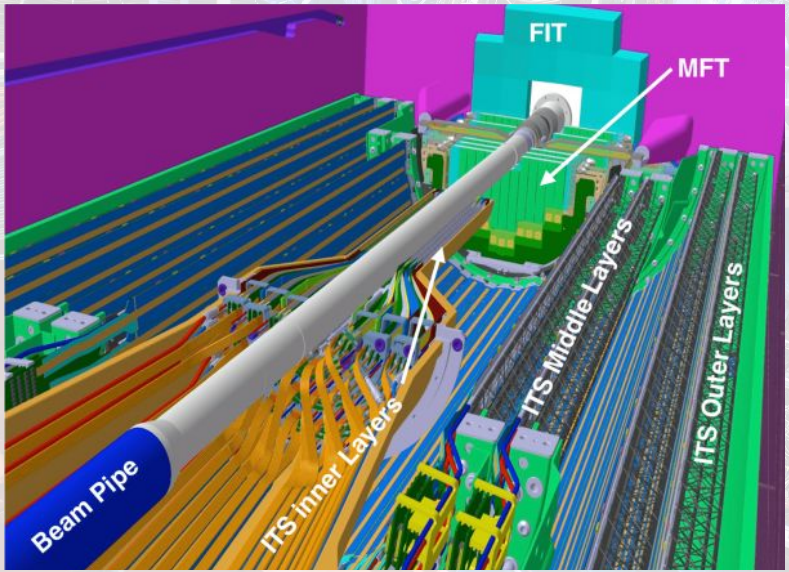


MFT Technical Design Report:
CERN-LHCC-2015-001 ; ALICE-TDR-018

ALICE Muon Forward Tracker

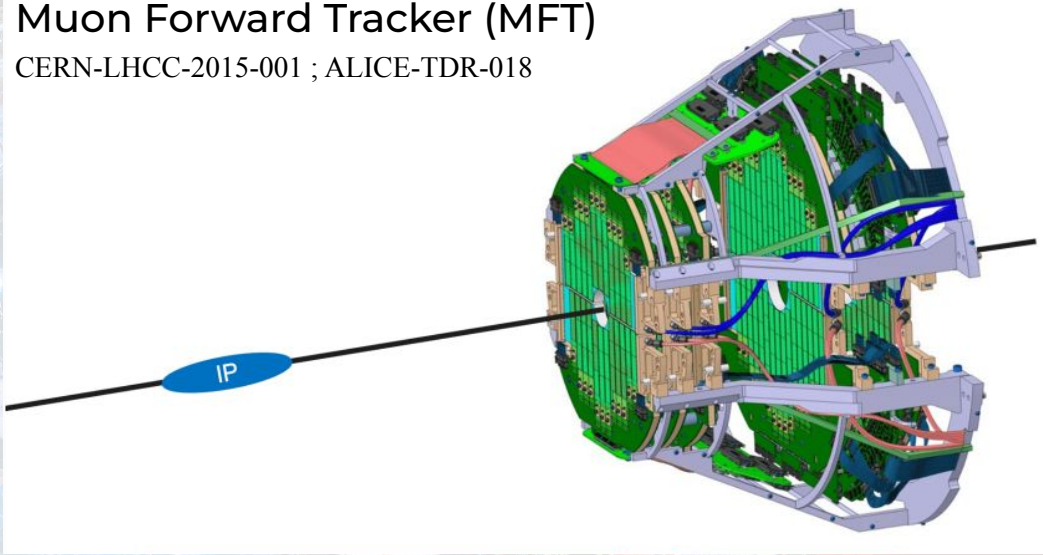
→ 2 halves (top and bottom) total 936 ALPIDE sensors

→ Spatial resolution per pixel sensor ~ 5 μm



Muon Forward Tracker (MFT)

CERN-LHCC-2015-001 ; ALICE-TDR-018

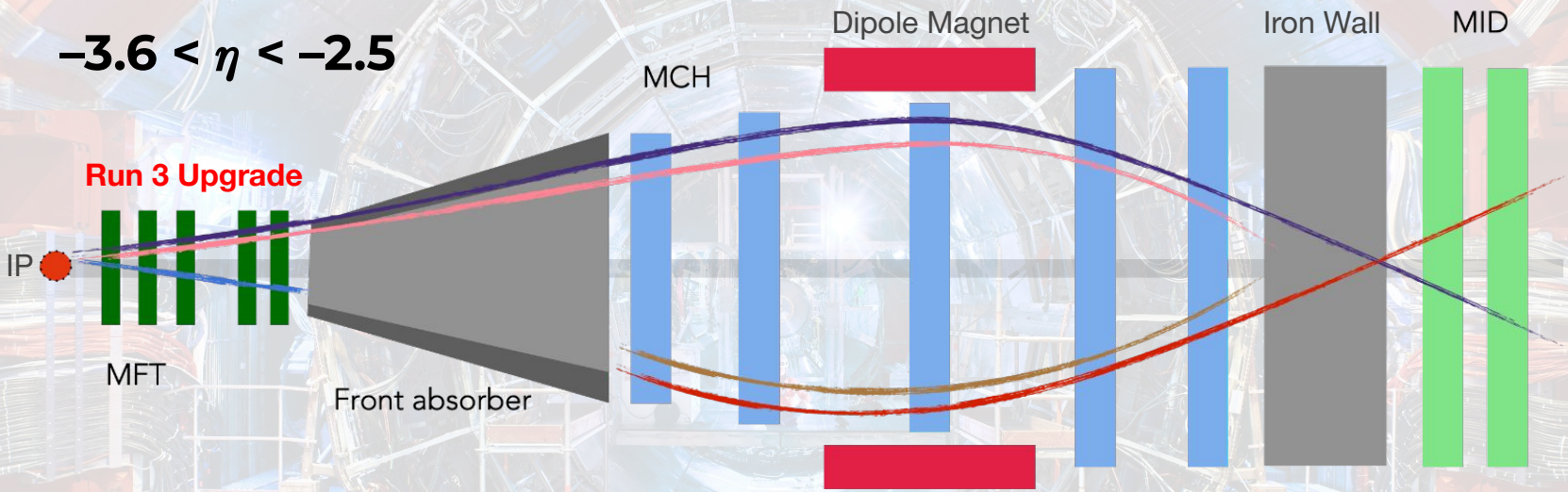


→ MFT in Run 3 → better tracking precision for muons

→ Allows the removal of multiple scattering effects in the hadron absorber

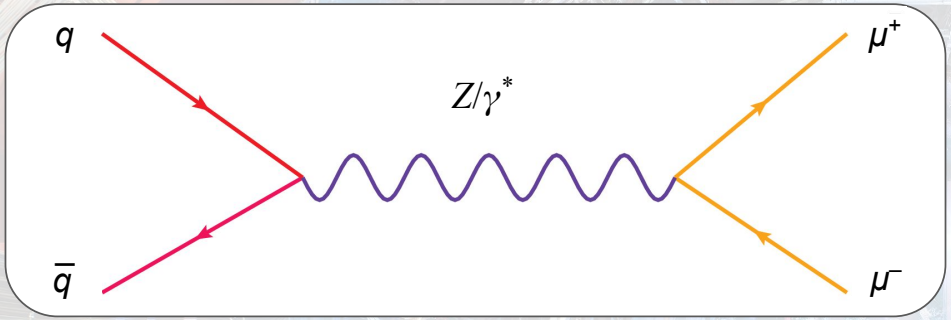
– muon track pointing resolution of about 100 μm

Muon Spectrometer in Run 3



- MFT+MCH+MID = track reconstruction with higher precision
- Previously, heavy quarks decays could not be distinguished from pion and kaon decays
- MFT helps to introduce isolation cuts to remove leptons from semileptonic HF decays

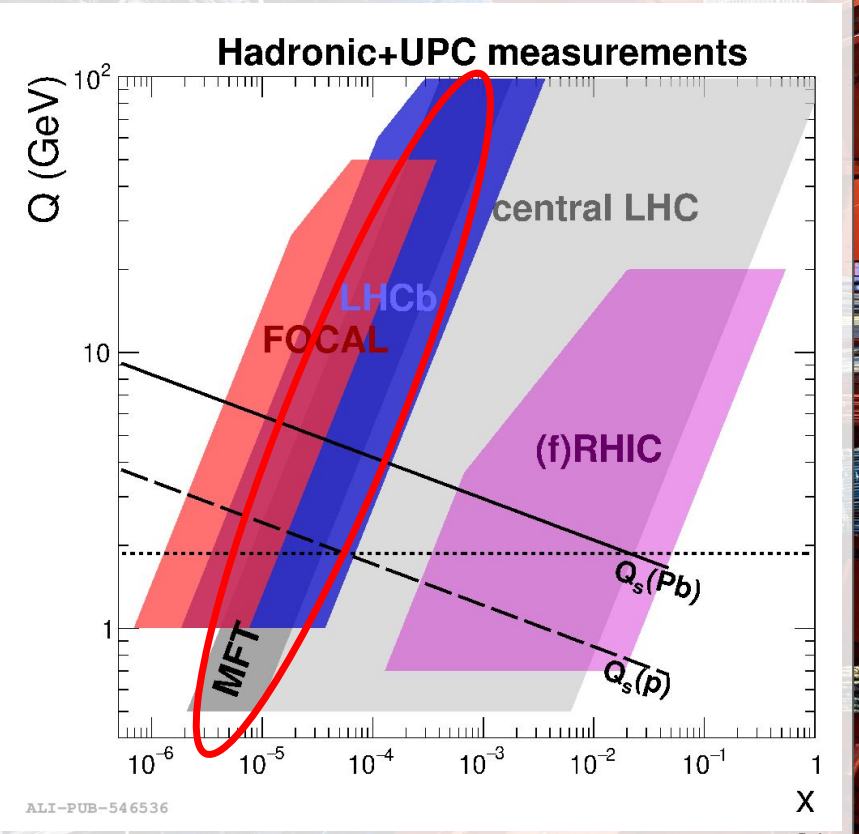
Measuring DY process with ALICE



DY with muonic decay channel

→ $\mu^+\mu^-$ detection and tracking in forward rapidity ($-3.6 < \eta < -2.5$)

→ Possible to access **low-*x* region**!



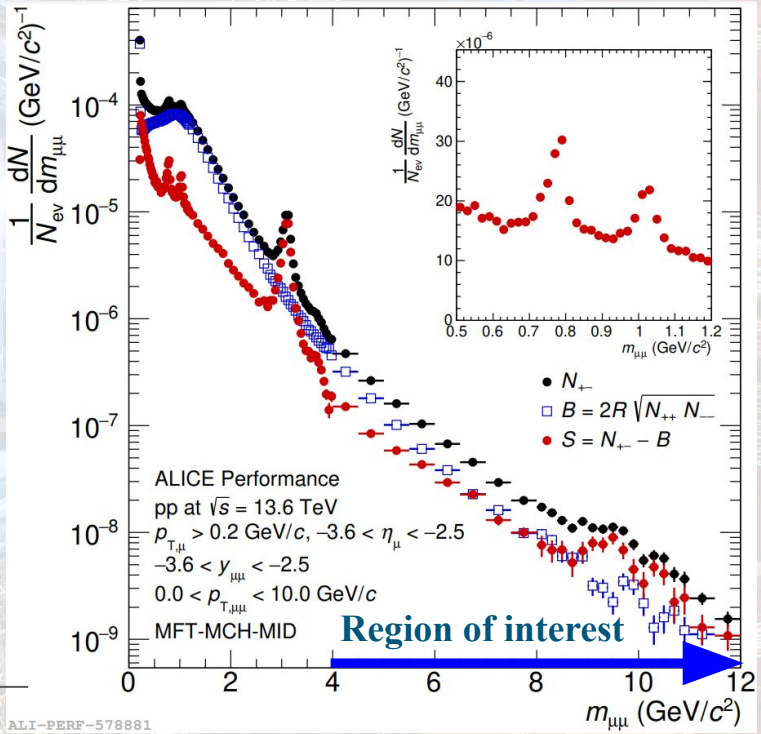
Measuring DY process with ALICE

Possibilities with ALICE in Run 3

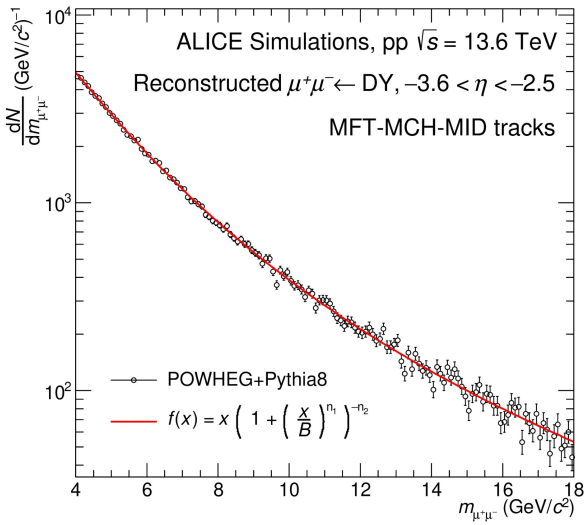
→ Access low-x via forward y measurements
→ Low-mass measurement to remove nPDF effects

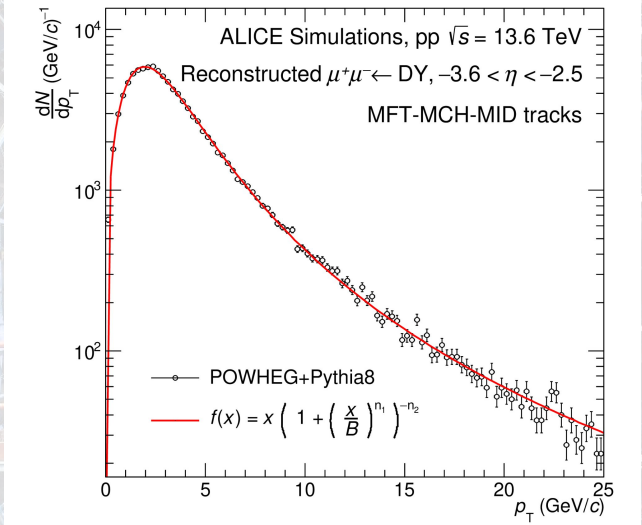
GOAL:
Measurement of low-mass DY lepton pairs
($m_{\mu^+\mu^-}^{DY}$ down to 4 GeV/c^2)
in pp, pO, p-Pb collisions to constrain nPDFs
at low-Q^2 and small-x ($<10^{-4}$)

Recent ALICE performance in pp @ 13.6 TeV ←



Current status





→ POWHEG+Pythia8 simulations available for pp $\sqrt{s}$ = 13.6 TeV

→ POWHEG box – DY signal input for standard Pythia8 simulation

→ Roughly calculations based on LHCb data

~10^4 DY pairs in 200 pb^{-1} in pp (now at 132.3 pb^{-1})

$$f(x) = \frac{x}{\left[1+\left(\frac{x}{B}\right)^{n_1}\right]^{n_2}}$$

x → observable (m or p_T)

B, n_1, n_2 → Fit parameters

Next steps

→ Extracted DY pdf shapes

→ Add semi-leptonic decay channels and extract yields

→ Compare with data and obtain DY cross-sections

Prospects with DY measurements

→ pp DY measurements will serve as a reference for the pO and future p-Pb data

→ Gluon density in hadrons grows with decreasing Bjorken-*x*, up to a point where it is controlled by non-linear QCD effects (gluon saturation)

– at very small-*x*, the ratio can also provide important constraints on gluon densities in the saturation regime

→ The double-ratio of R^{ψ}/R^{DY} may describe the rapidity dependence of J/ψ production at the LHC by distinguishing between initial- and final- state effects (eg, comovers, QGP, etc.)

Summary

→ Drell-Yan lepton pair measurements - probe for understanding Parton Distribution Functions in hadrons and ions at low-x , where there is lack of experimental data

→ The ratios of nuclear modification factors of DY and charmonia in forward rapidity would help to distinguish initial- or final-state effects related to charmonia production in p-A collisions

→ ALICE setup in Run 3 can help to measure DY dimuons in forward rapidity ($-3.6<\eta<-2.5$)

→ Goal is to measure low-mass DY dimuons in pp, pO and p-Pb collisions at forward rapidity using the upgraded ALICE detector to constrain nPDFs at small Q^2 and low-x

→ DY measurements would also help to study coherent energy loss, charmonia production at LHC energies as well as put constraints on gluon densities in the gluon saturation regime.

→ Work is in progress to include all background channels in simulations and extract DY cross-sections

→ Low-mass DY production at forward y in pO and p-Pb collisions has not been addressed yet at LHC

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ALICE
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