Synergy between CERN projects and EIC: physics and technology

QCD and heavy-ion community workshop on European Strategy for Particle Physics Update 2025

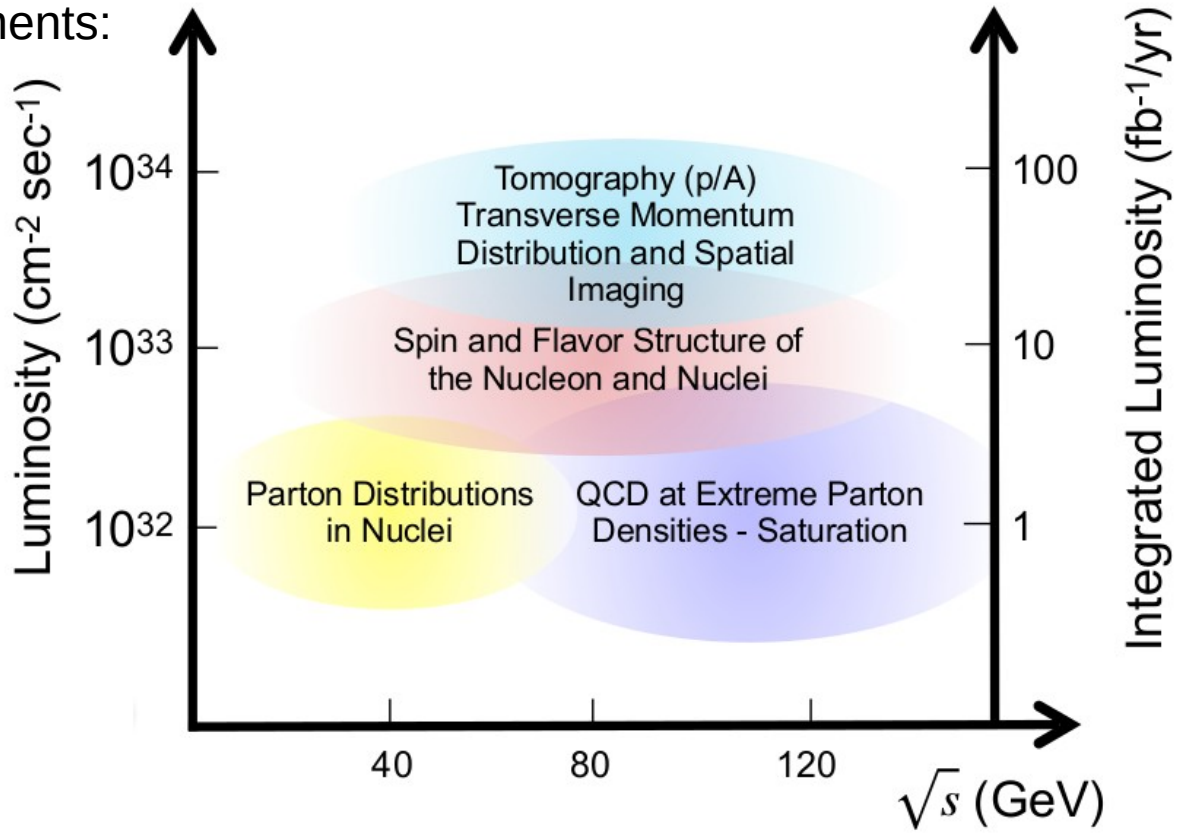
19 Septembre 2024

F. Bossù (CEA)

EIC progam and requirements

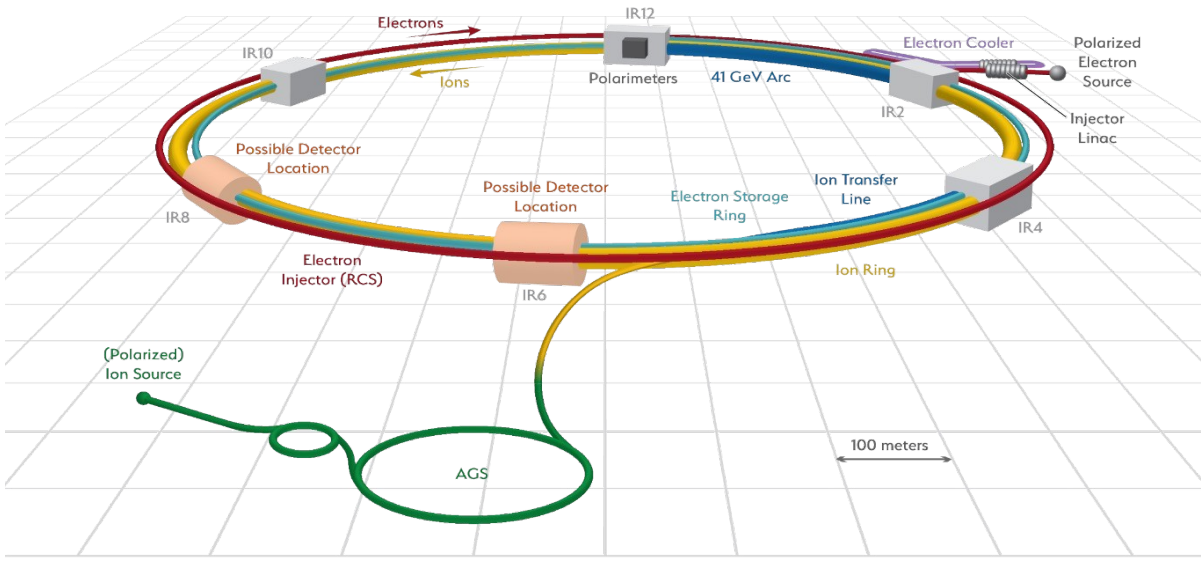
The EIC will meet the following requirements:

- high luminosities
- large centre of mass energy range
- highly polarized beams: P > 70%
- wide variety of ion species
- large detector acceptance

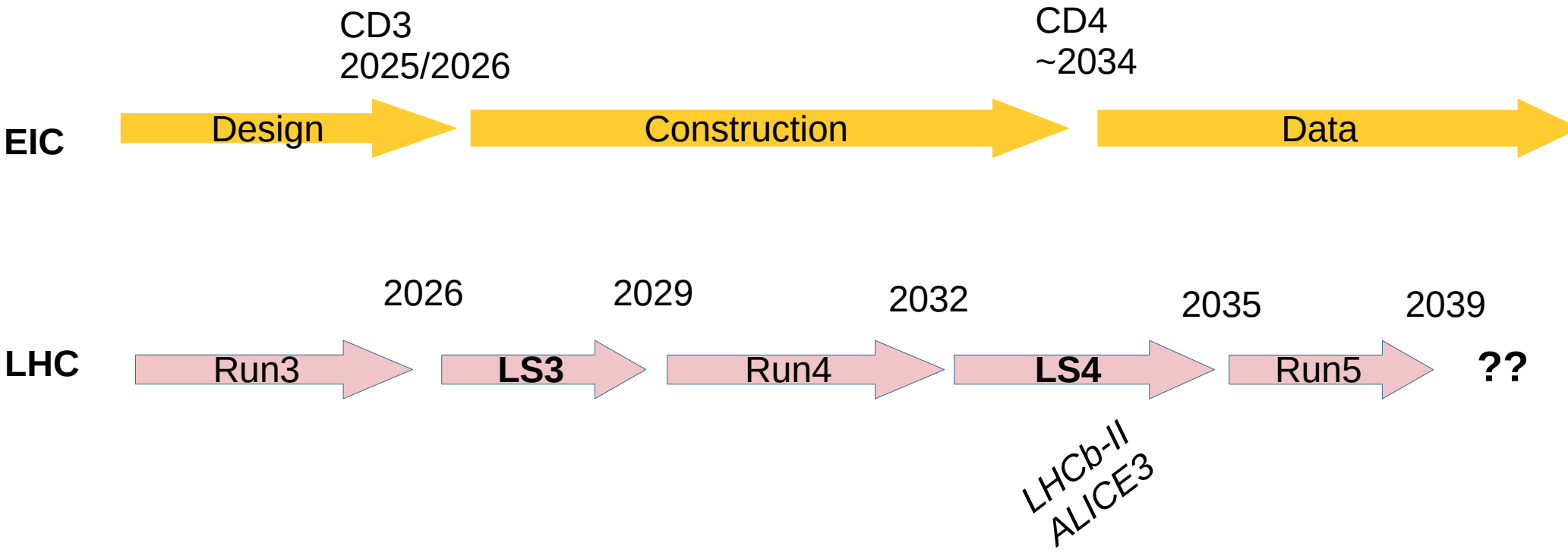


EIC in a nutshell

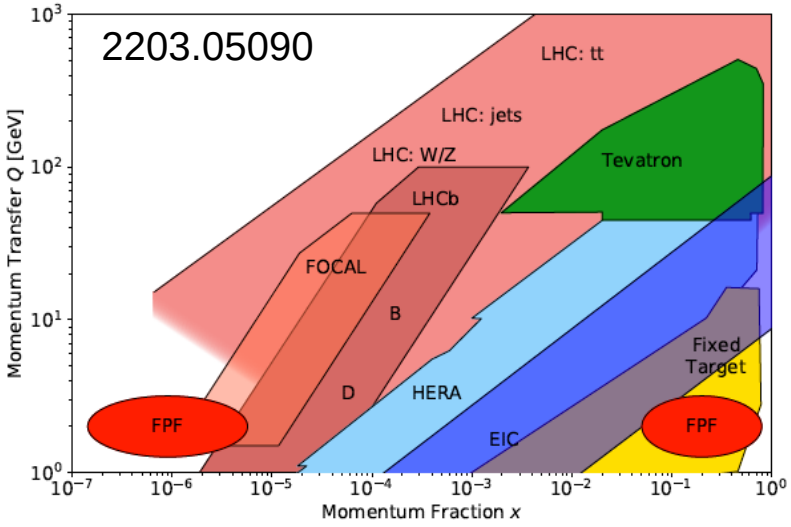
- Polarized beams: e, p, d/3He
- e beam 5-10 (18) GeV
- Luminosity $L_{ep} \sim 10^{33\text{-}34}$ $cm^{-2}sec^{-1}$ (100-1000 times HERA)
- 20-100 (140) GeV Variable CoM
- Nuclei from p to Uranium
- Two interaction regions
- One detector from day-0, strong wish for a second detector

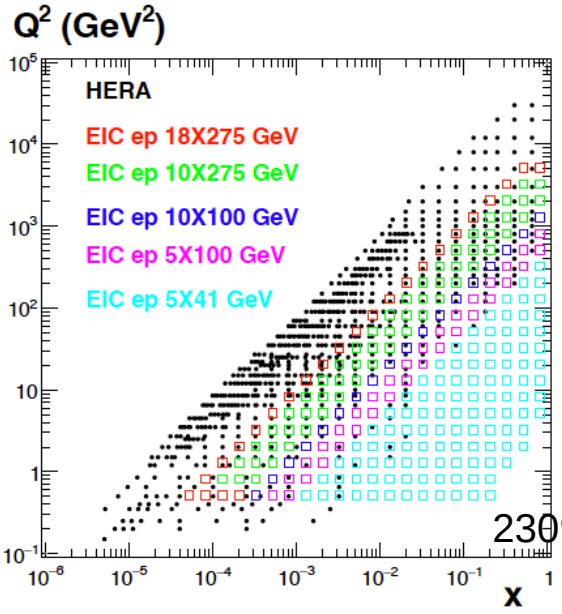


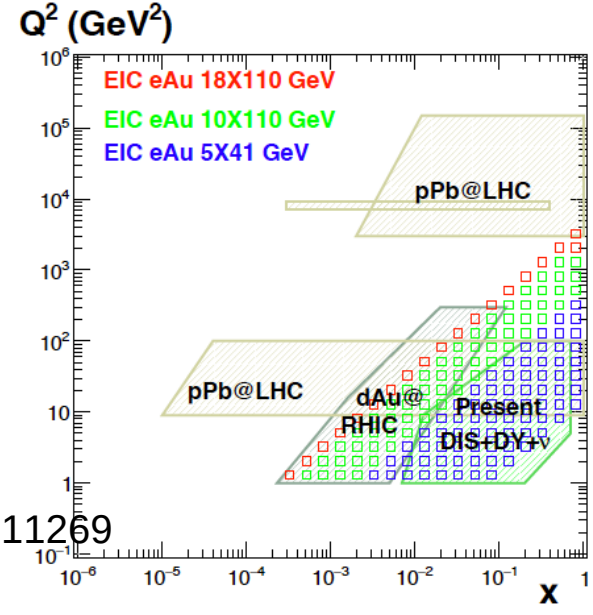
LHC and EIC timelines



Kinematics







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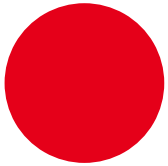
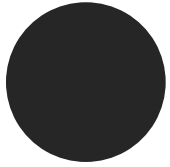
- LHC offers a much larger coverage at small-x and high Q2
- Complementarity EIC data at moderate Q2 and large-x
- DIS (theoretically and experimentally) cleaner than an hadron machine

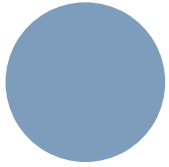
Selected synergy topics – Physics



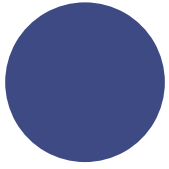
PROTON
Proton PDFs



IONS
- Nuclear PDFs
- “cold medium” effects



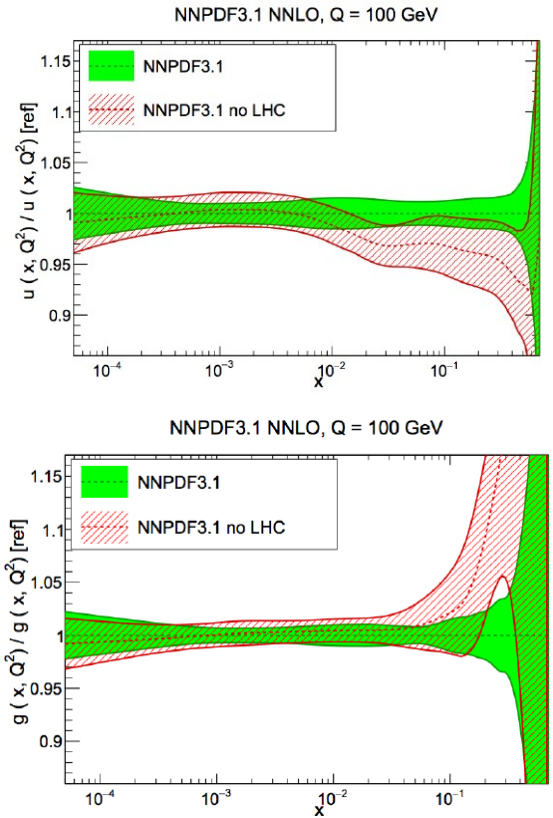
TOMOGRAPHY
Going beyond PDFs : TMDs, GPDs,...



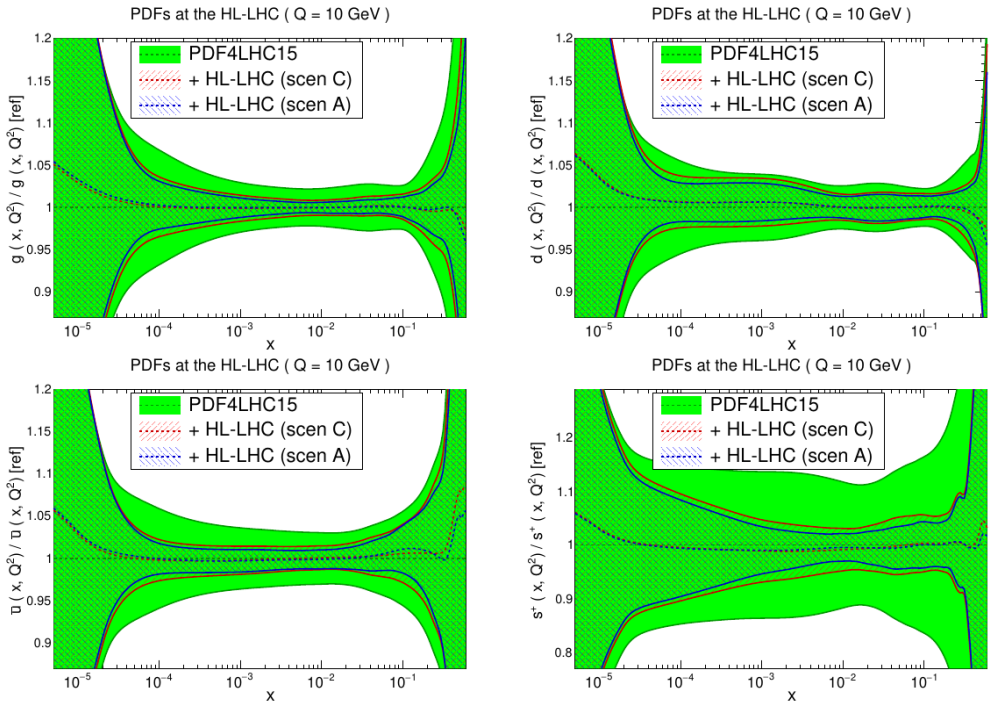
SMALL-X
The quest for gluon saturation

Proton PDFs – LHC

LHC data are playing already an important role



HL-LHC data will considerably help in reducing PDF uncertainties even further



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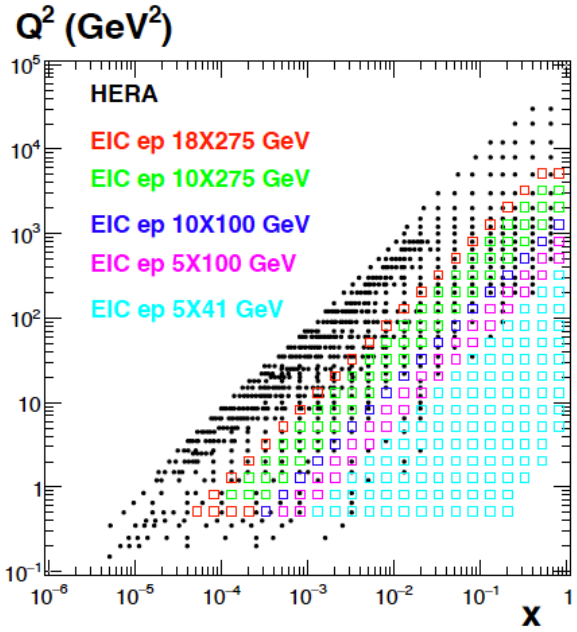
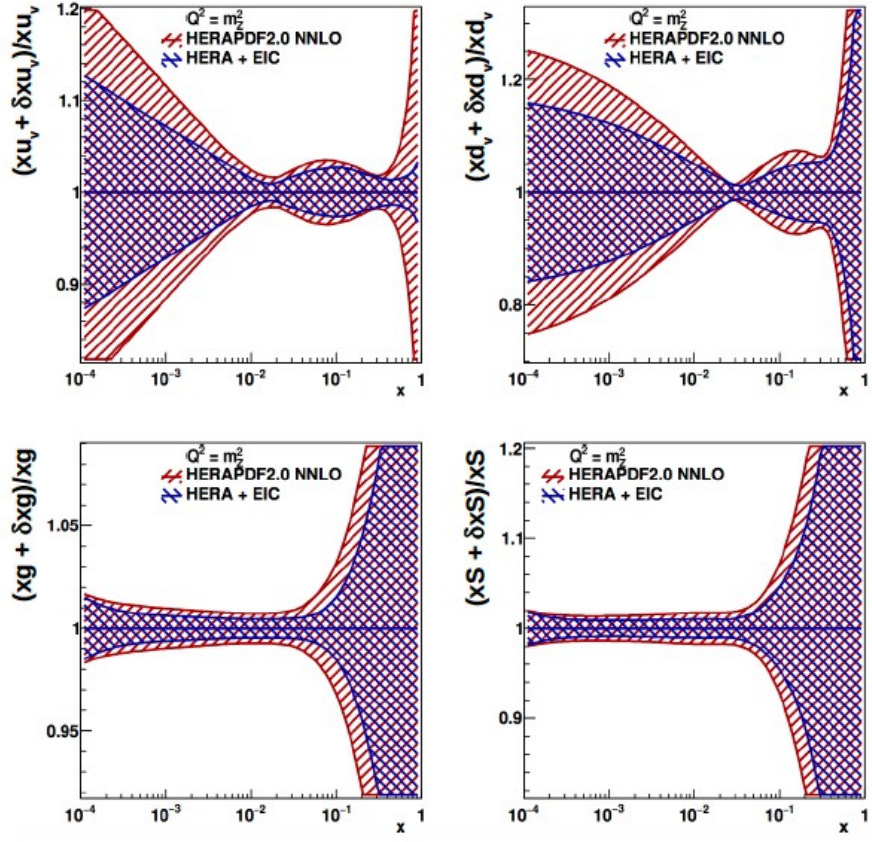
Proton PDFs – EIC





- EIC will impact high x glue and valence
- (HL-)LHC (will) compete with it.
- Comparable impact on observables: tests of factorization

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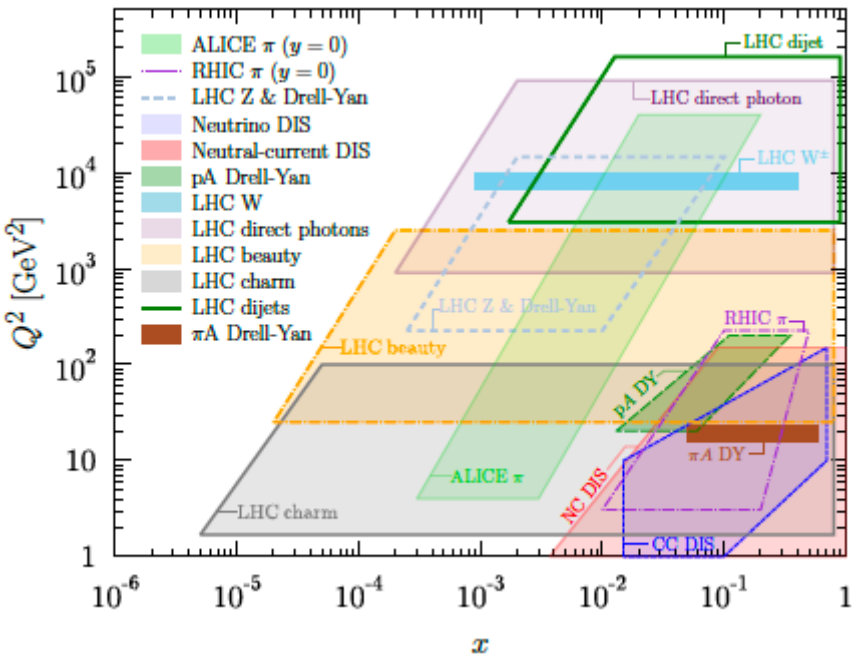
Ions – Nuclear PDFs – LHC



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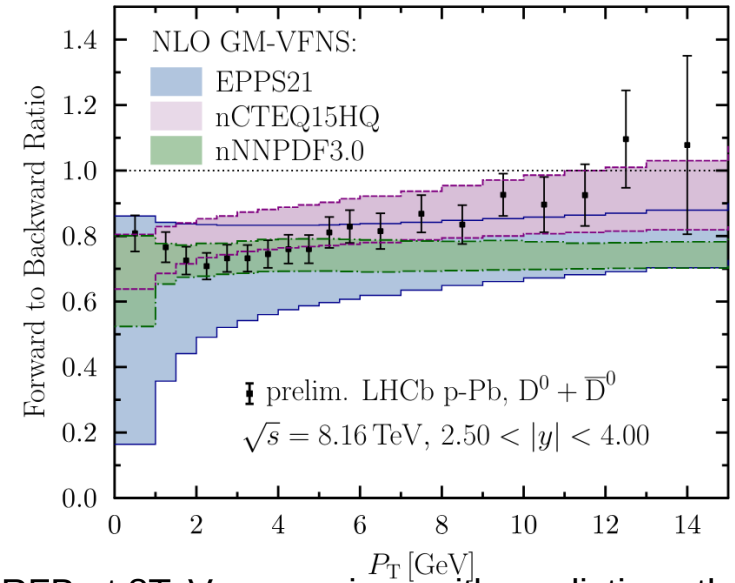
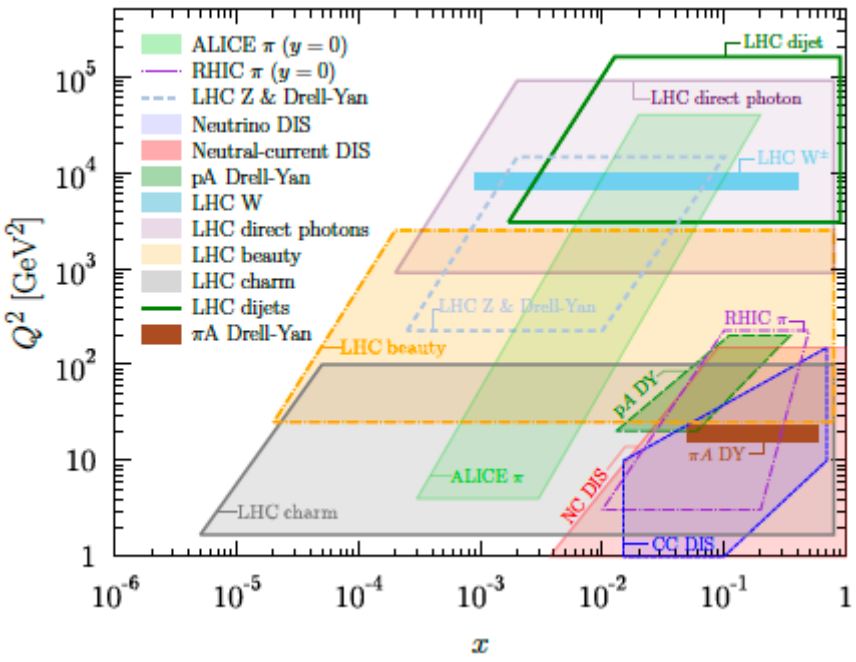
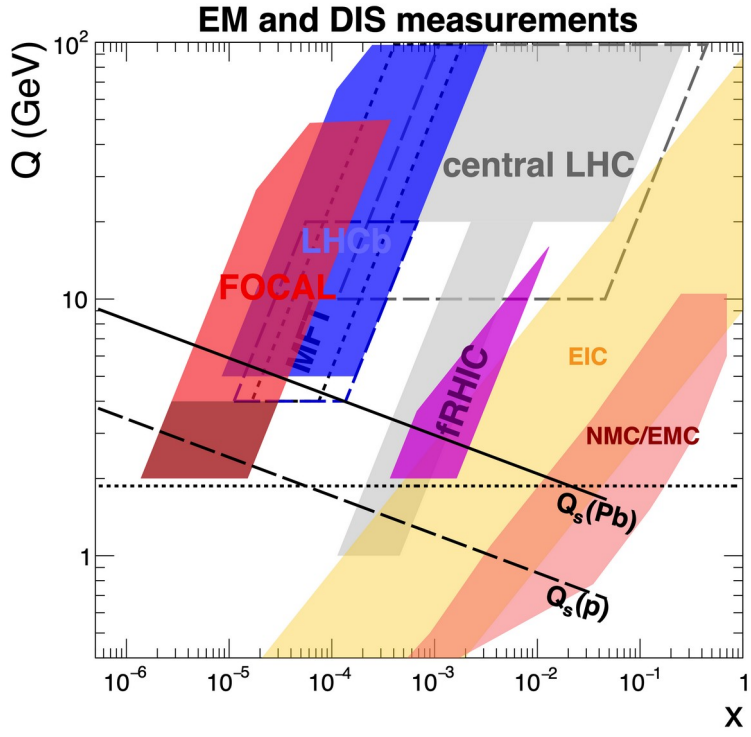
- Data from **different nuclei and observables**
- LHC data now cover large-Q2 and small-x
- Still important uncertainties when compared with new data



D0 RFB at 8TeV comparison with predictions that contains the 5TeV data

Ions – Nuclear PDFs – LHC





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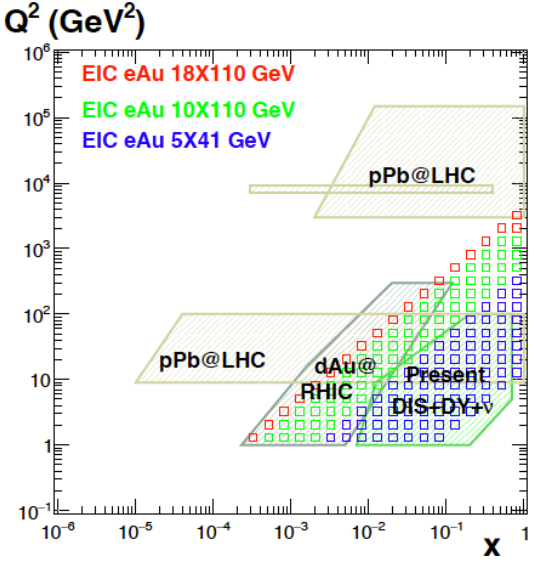
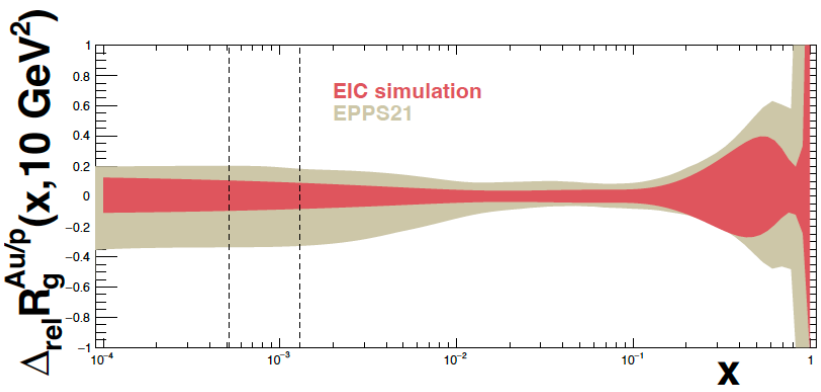
Near future possible improvements at LHC: EM data from FOCAL and vector meson in UPC data

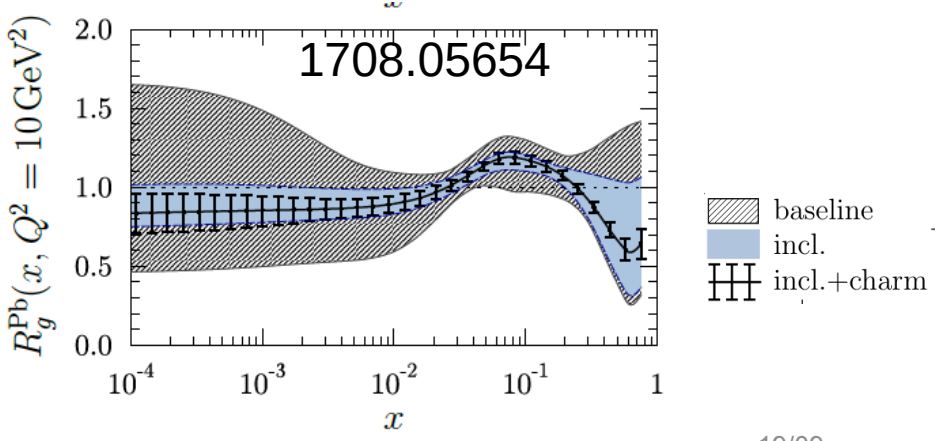
Ions – Nuclear PDFs – EIC



At EIC:

- Extensive DIS data from **single nucleus**
- Data from different nuclei too
- Impact both at low and high x
- Not only inclusive data, but also multiple probes
- Charm particularly sensitive at gluons at high-x

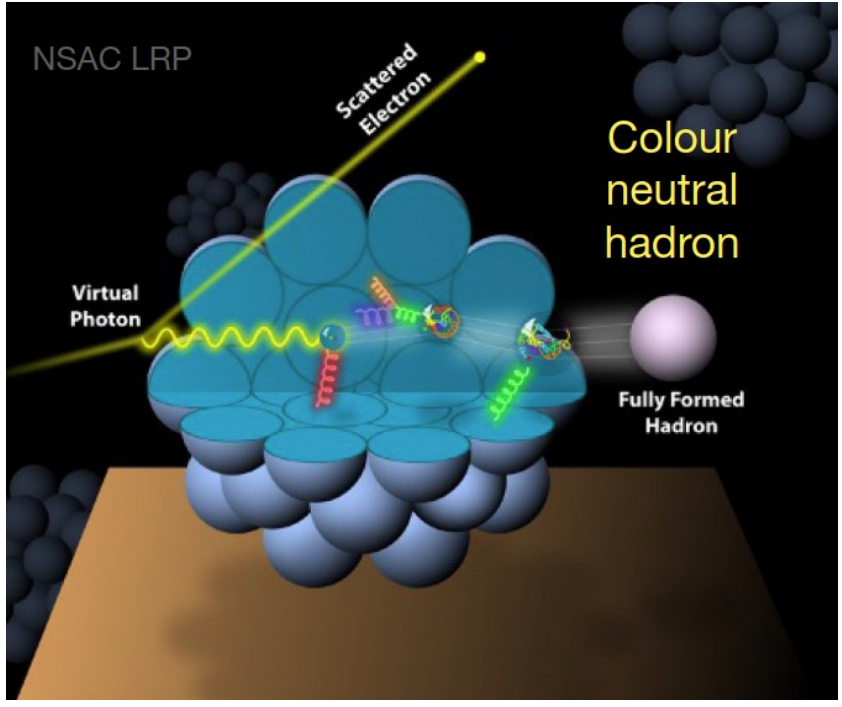




Ions – “cold”

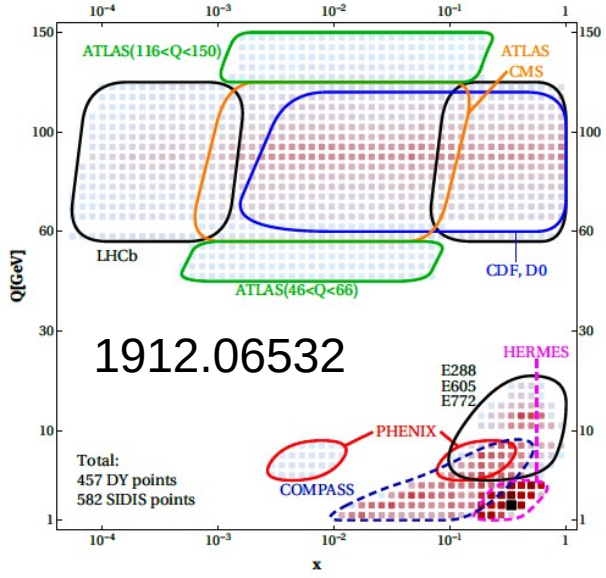
Open question:

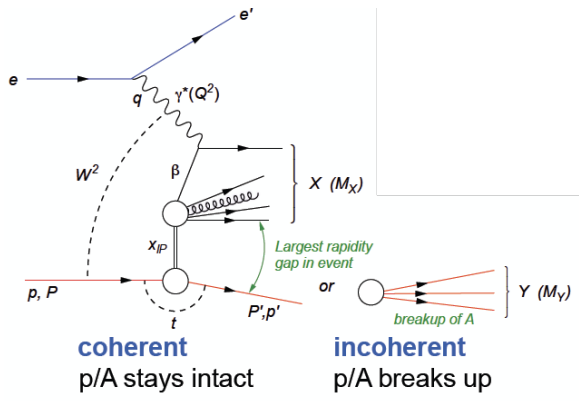
- How partons and hadrons interact with the “cold” nuclear medium
- Instrumental for understanding better QGP signatures
- Measurements in pPb at LHC not unambiguous
- EIC provides a cleaner environment in e-A
  - Light and Heavy flavours
  - Jets
  - ….
  - Varying A



Tomography – LHC

- Unpolarized quark TMDs with DY
- Gluon TMDs with double quarkonium
- Also in fixed (polarized) targets (LHC-Spin)
- **Small-x** connections with CGC
- Gluon GPDs in exclusive vector meson production in UPC
- Double (multiple) parton scatterings
- Shape fluctuations in incoherent UPC
- …

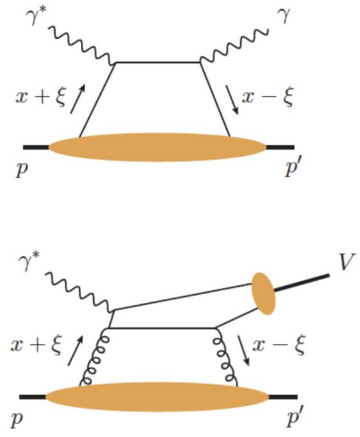


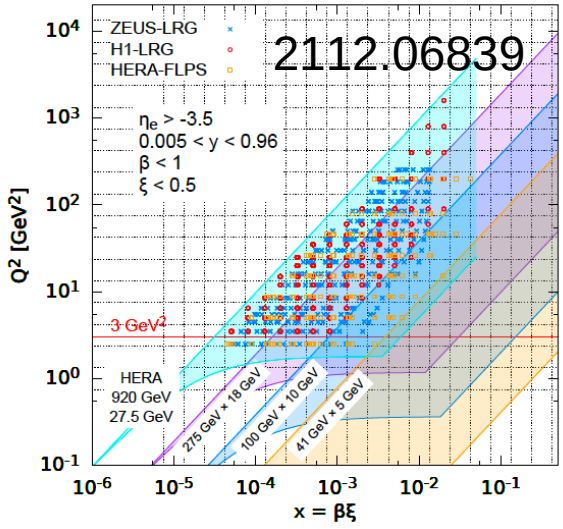


Tomography – EIC

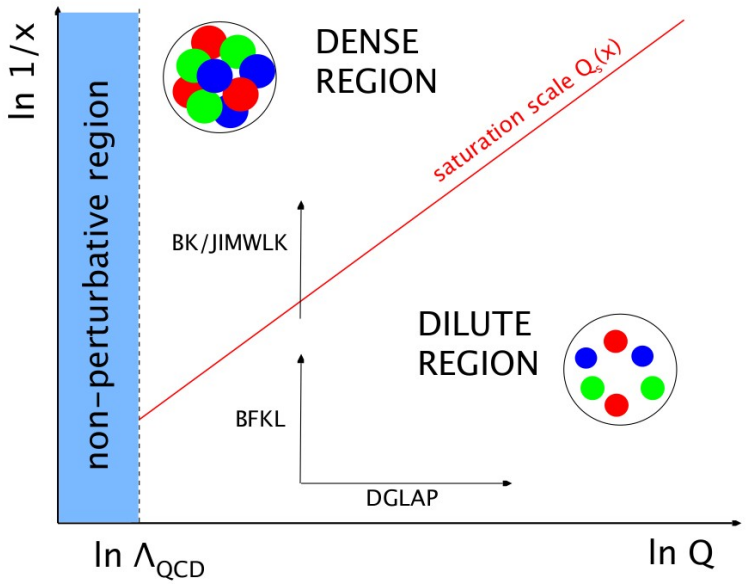
Domain where EIC features shine:

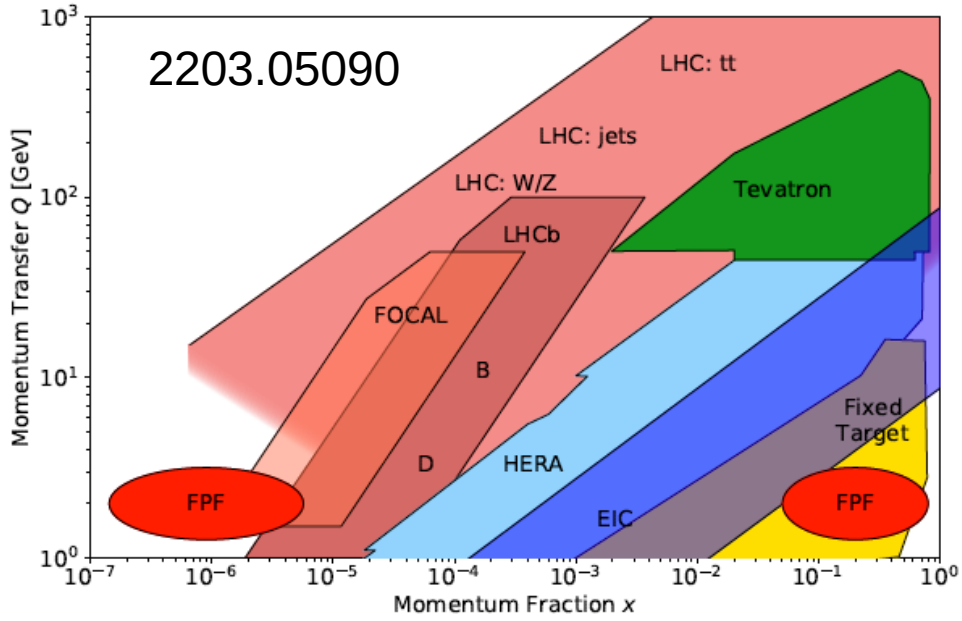
- **Highly polarized beams**
- Unpolarized and polarized TMDs on protons with SIDIS
- Quarks and gluons GPDs with exclusive processes (DVCS and DVMP)
- **Q2 dependence**, but limited in low-x (wrt LHC)
- Diffraction: “DIS” on the colorless exchange





Small-x





- At small x, linear evolution must fail, but present data cannot really tell us how
- we need
  - Differential observables: correlations, diffraction,…
  - Lever arm in $Q^2 > Q_s > \Lambda_{QCD}$ at small x

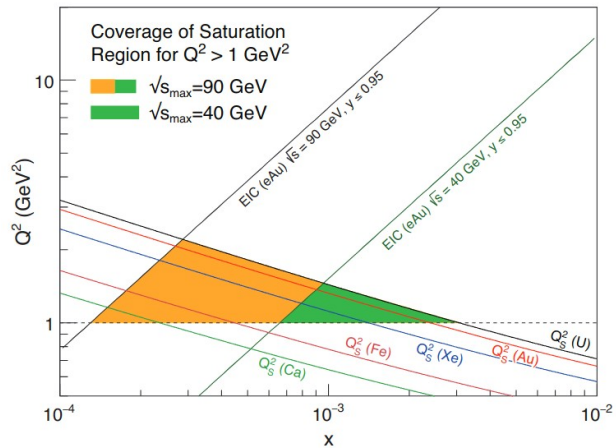
Small-x

LHC

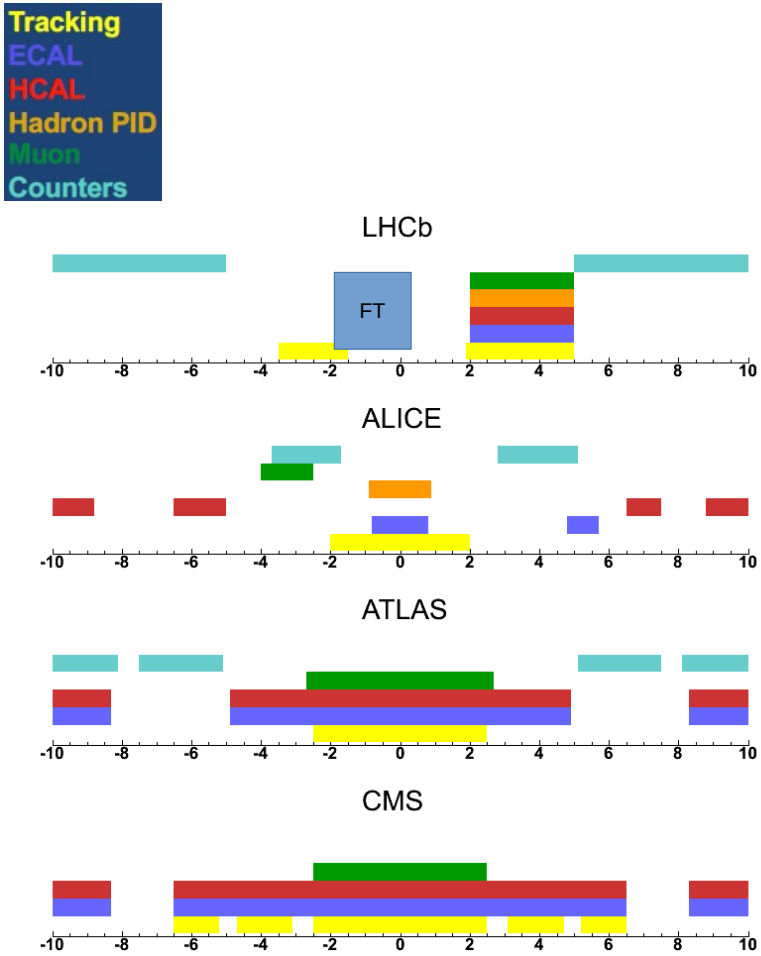
- Access to very small-x, down to 10^{-6}
- Single particle and di-jets in p-Pb
- Exclusive process, diffractive di-jets… in UPC
- Sizable theory uncertainties and experimental ambiguities difficult to resolve completely

EIC

- Limited a x ~10^{-4}
- Need ions to get to the saturation region in perturbative regime: $Q_s \sim A^{1/3} x^{-0.3}$
- Focus on inclusive measurements, but DIS provides more control on the reaction



Detectors



ATLAS and CMS:

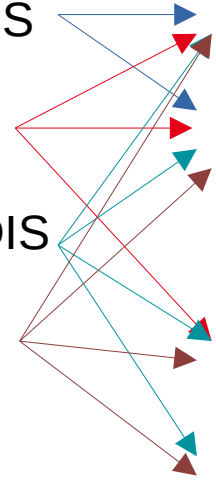
- Tracking, calorimetry, large acceptance

Particle ID only for ALICE(3) and LHCb

EIC detector

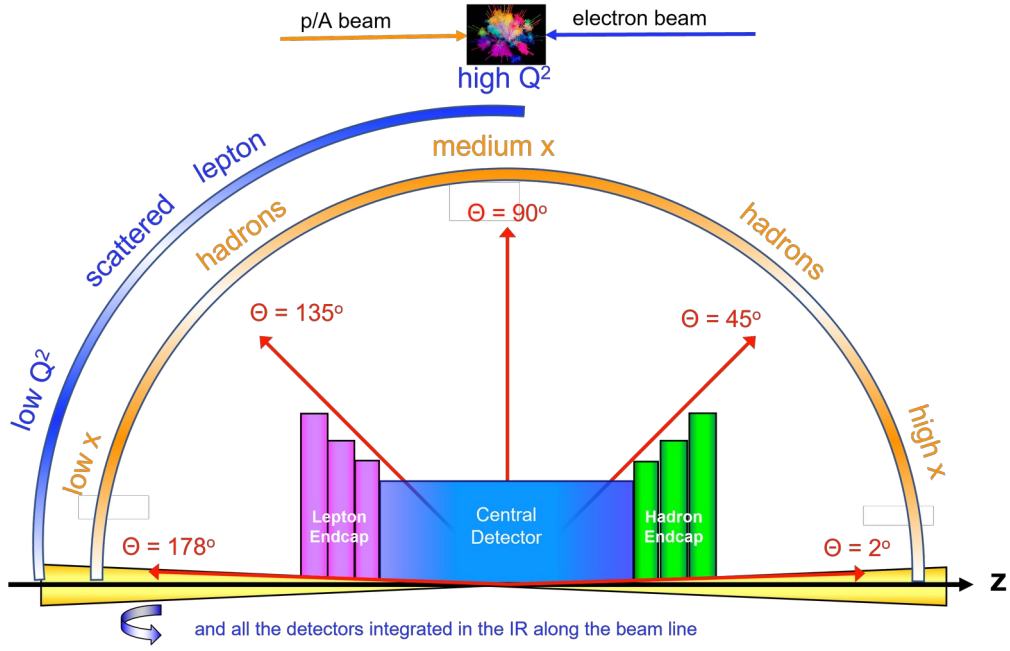
Key measurements:

- Inclusive DIS
- SIDIS
- Exclusive DIS
- Diffraction



Features:

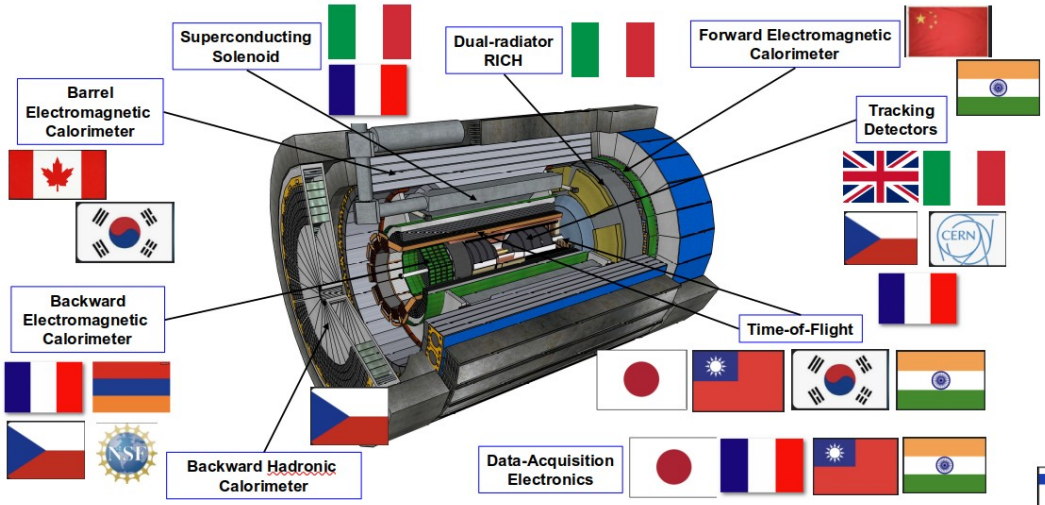
- e-ID
- Tracking res:
  - Momentum
  - Angular
  - Pointing
- PID, calorimetry
- Hermetic, t-res



η < -4.6
Low-Q2 tagging
Polarimetry

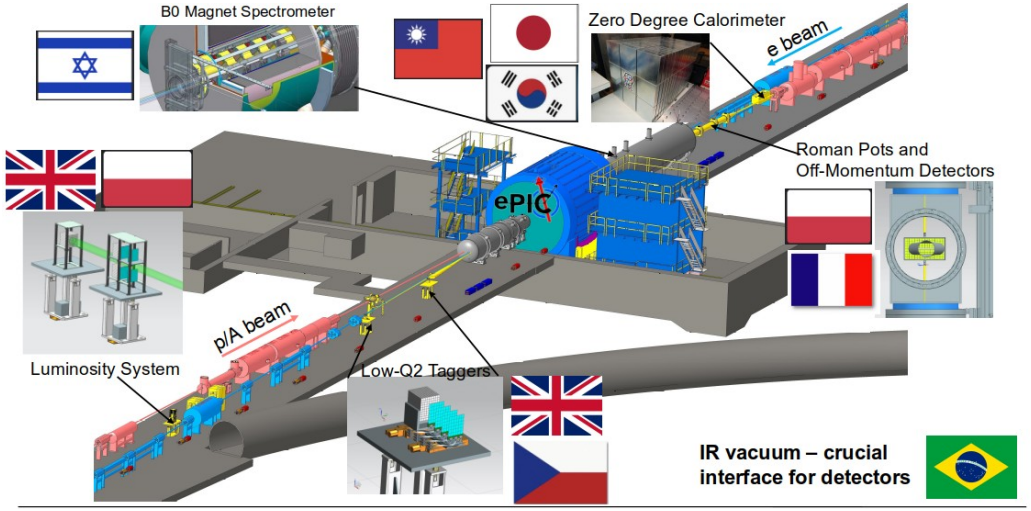
η > 4.6
Tracking and calorimetry

EIC detector 1 : ePIC



Central detector

Forward/backward detectors



Selected synergy topics – Detector

TRACKING
MAPS
MPGDs
AC-LGAD

CALORIMETRY

DATA PROCESSING
Streaming readout
Reconstruction

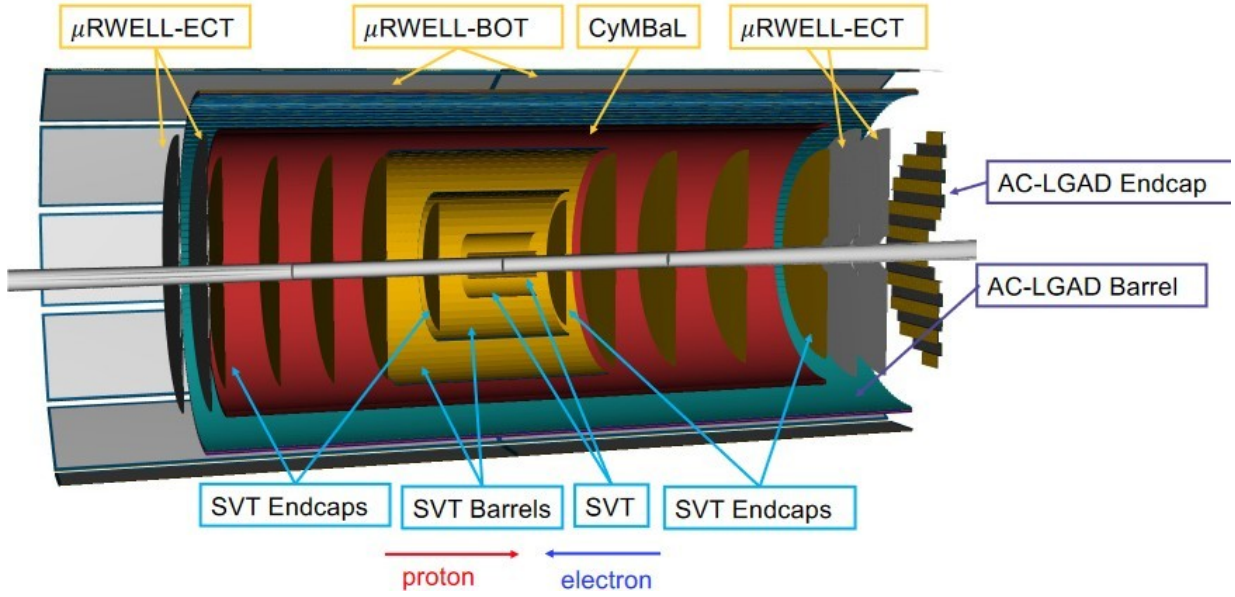
MAGNETS
Big experimental solenoid
Accelerator components

With a French bias

Tracking

µ-vertex and barrel tracker

- Excellent momentum 0.05%pT⊕0.5%
- and spatial resolution 20mm/pT⊕ 5mm
- Monolithic Active Pixel Sensor: ALICE ITS3 MOSAIX sensor (65 nm)
- small pixels (~18 mm) and power consumption (<20 mW/cm2)
- Barrel: EIC Large Area Sensor (LAS), modification of ITS3 sensor with 5 or 6 RSU forming staves



MPGDs (Micromegas and µRWELL)

Redundancy and fast hits for pattern recognition

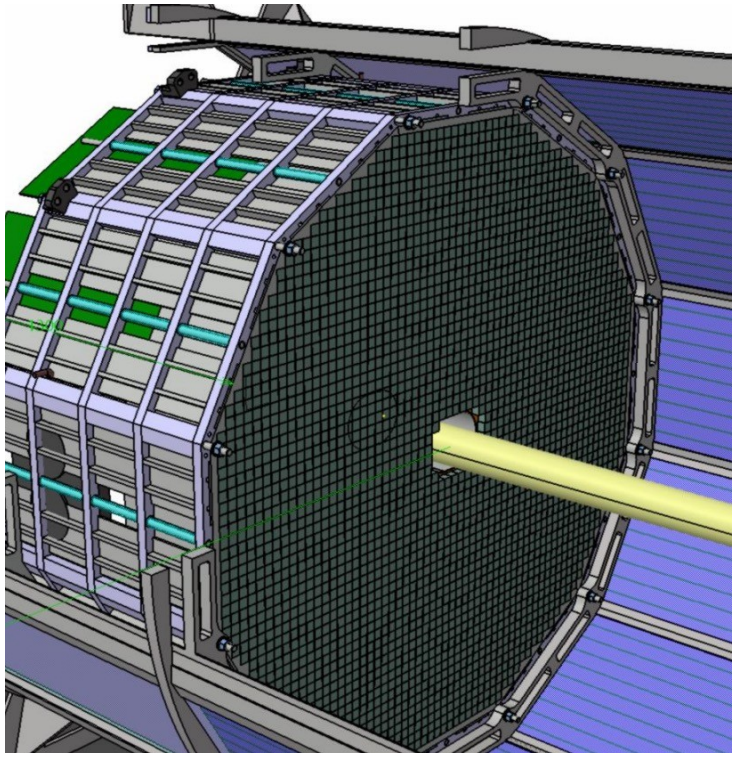
Large area, low material budget, 2D detectors

Novel readout ASIC development (*CEA*)

AC-LGAD

- Time of flight ~30ps
- Precise space point ~30µm
- Also used in Roman pots
- Readout ASIC development (IJCLab-CEA-Omega)

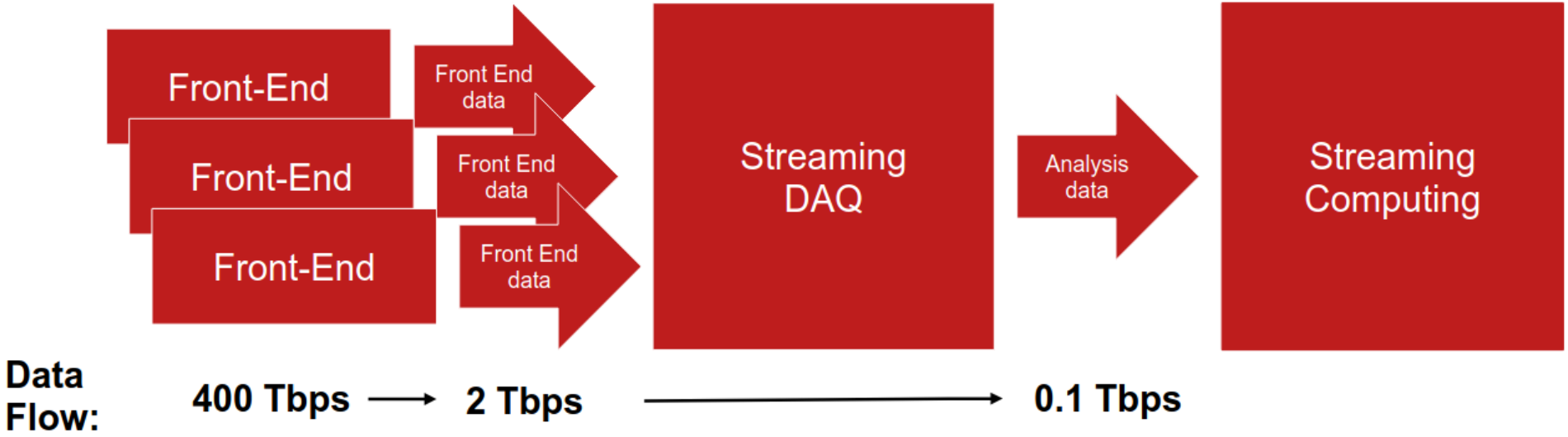
Calorimetry



Backward EM calorimeter

- Scattered lepton detection → very high-precision
- PbWO4
- SiPM as Photonsensors
- Readout ASIC: synergy with CMS electronics

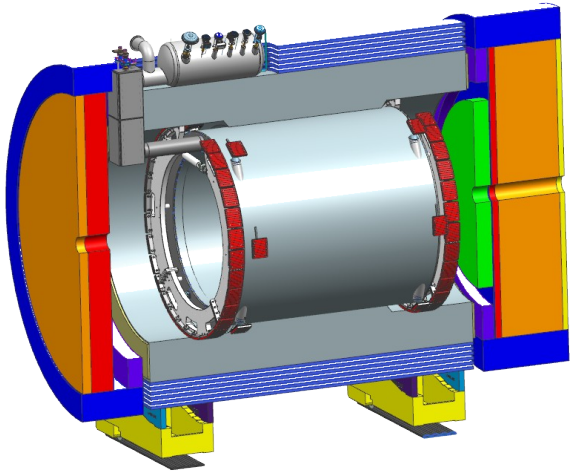
DAQ and software



- No trigger
- Processing every bunch crossing (spacing at ~10ns)
- Aim at holistic reconstruction

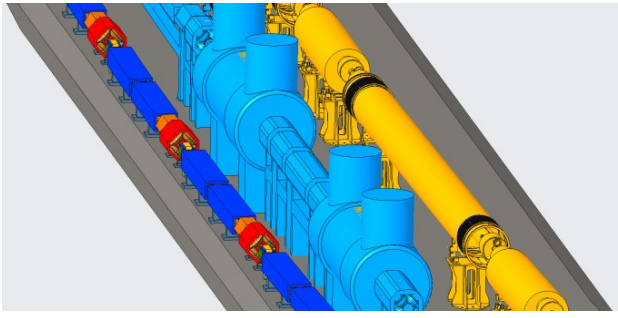
- Software :
  - Use and contribute to HEP packages
  - Example :
    - DD4Hep
    - ACTS for charger particle tracking

Magnets

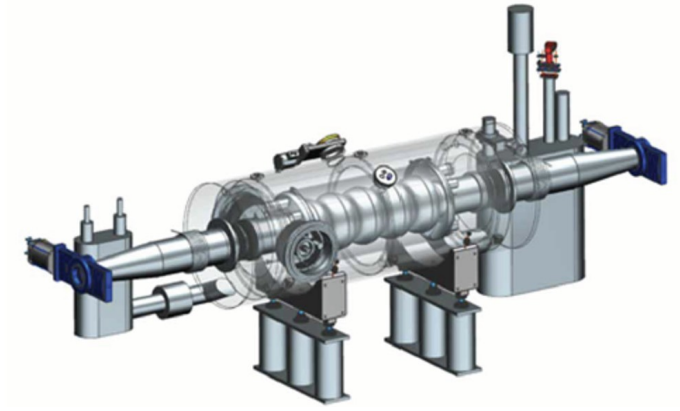


- MARCO (CEA)
  - New detector solenoid
  - 2 T, Babar magnet form factor, different conductor, but same transparency

Spin rotators (CEA)



Cryomodules for ERL (IJCLab)



Summary

	EIC	LHC	
PDFs	Large-x	Low-x and high-Q^2	Impact in SM parameter determination and BSM searches
Nuclear PDFs and 3D structure	Cleaner probes Polarized beams	Extension at Low-x	Initial conditions of HIC
Tomography: TMDs and GPDs	High precision	Evolution at low-x	Global analyses
Small-x	Smaller phase space Higher precision Several observables	Lever arm for “discovery”	Pin point gluon saturation dynamics

- Inputs for this talk :
  - Joint ECFA-NuPECC-APPEC Activity Workshop "Synergies between the EIC and the LHC"
  - In particular : Nestor Armesto Perez’s Talk