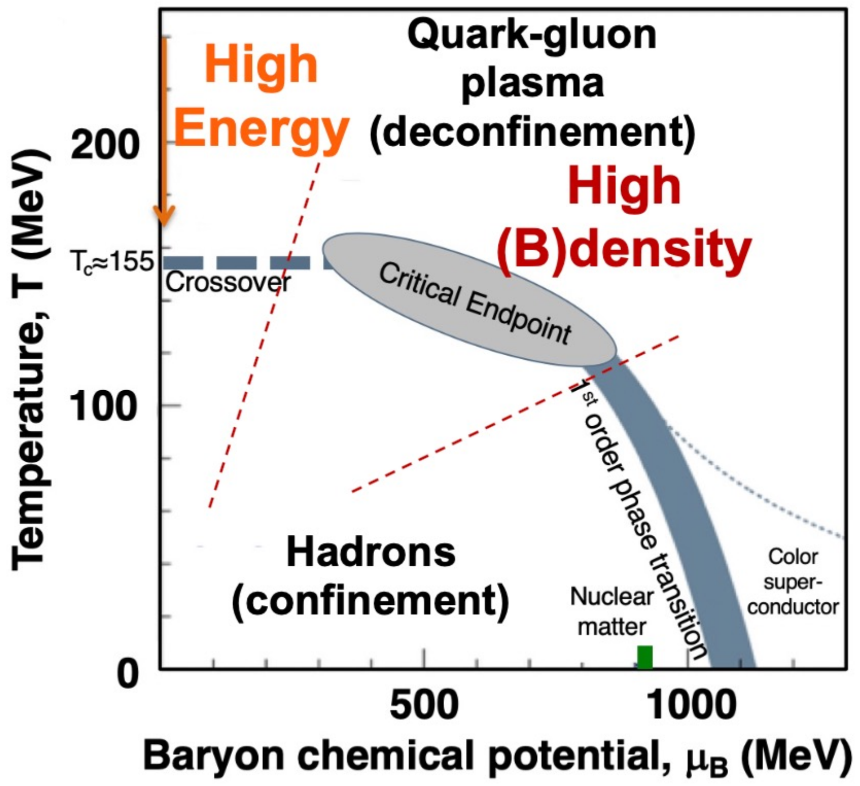
Workshop di Sezione sulla Strategia Europea per la Fisica delle Particelle Elementari

ALICE 3, ePIC@EIC and Heavy-ion physics at FCC-hh

21/11/2024

Giacomo Volpe

Quark-gluon plasma: future research directions



High energy collisions (LHC, FCC-hh):

- Quantify properties of QGP and relate them to its constituents
- How do collectivity and thermalization emerge in QCD?
- Can they be developed also in small systems (pp, pA)?

High baryon density collisions (SPS, FAIR, ...):

- Search for onset of deconfinement via energy scans
- Search for the Critical Endpoint (lQCD: $\mu_B > 300$ MeV, $T < 140$ MeV)
- QGP constituents at high μ_B → Neutron Star EoS

ALICE roadmap at LHC

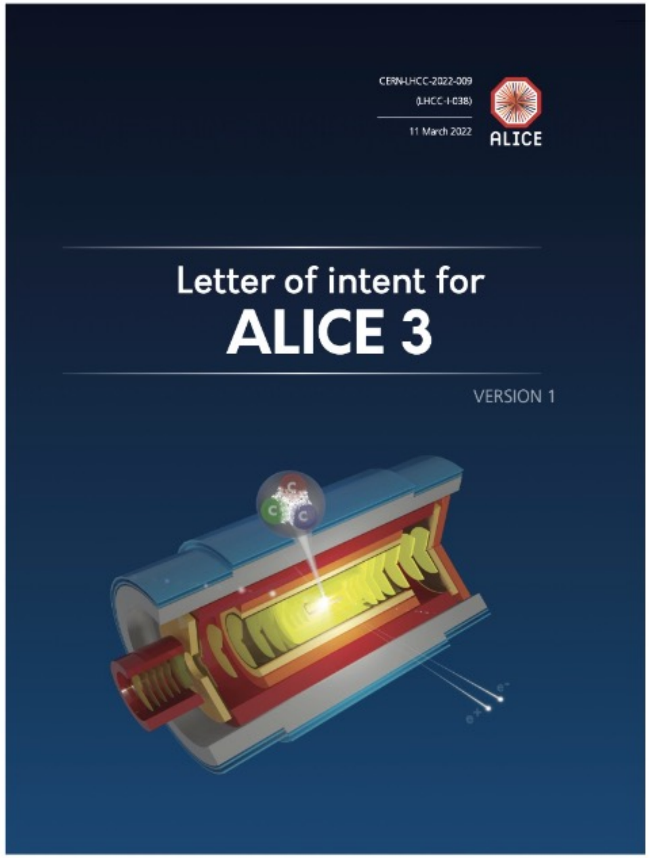
- Ideas for dedicated **heavy-ion programme for Run 5 and 6 at the LHC** developed within ALICE in the course of 2018/19

- First ideas at Heavy-Ion town meeting (2018)

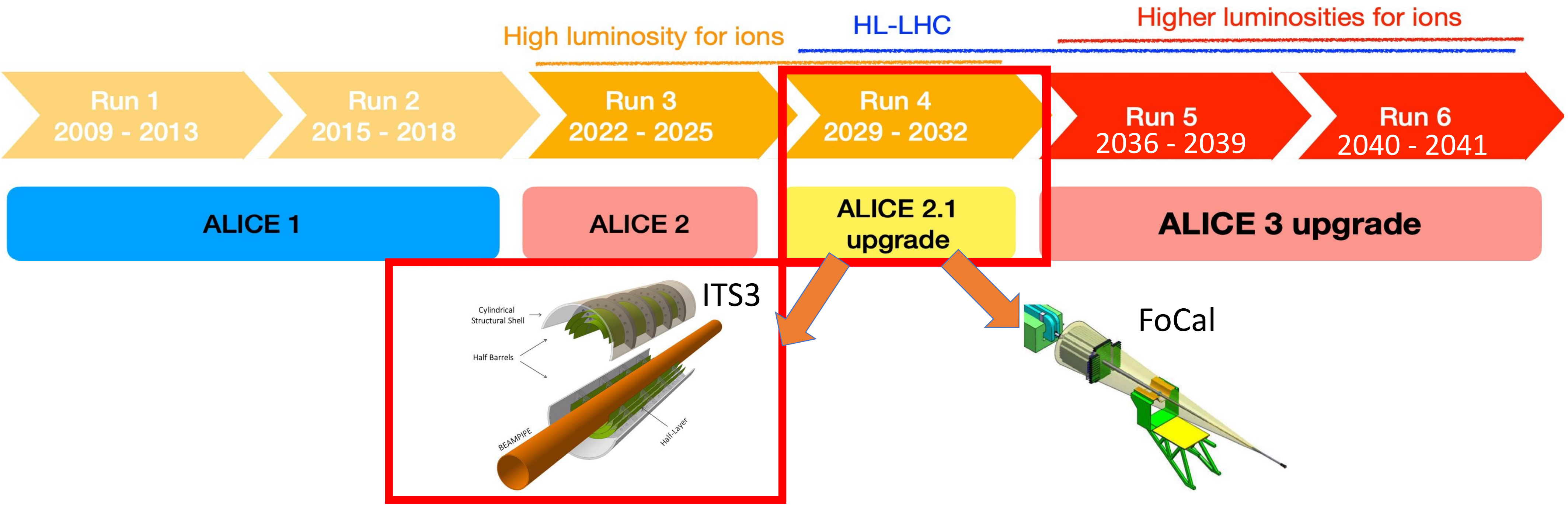
- **Expression of Interest** submitted as input to the **European Strategy for Particle Physics Update** (2019) arXiv:1902.01211

- **Letter of Intent for ALICE 3**: Review concluded with very positive feedback by the LHCC in March 2022 arXiv:2211.02491

- **Scoping Document** and resource planning now in preparation



ITS3 project: the seed of the future ALICE 3 inner tracker and the root of the SVTX detector of ePIC@EIC



- ***ALICE-ITS3 project is the main backbone of the R&D for the ALICE 3 tracker***
  - *Intense R&D since 2018 at INFN-BA, after the big commitment with construction of ITS2:*
    - *Prin_2017 - budget 1M€*
    - *CSN3 substantial funding*
  - *ITS3 MoU prepared*
  - *INFN-BA committed for ITS3 on CMOS sensor ASIC, mechanics and integration, physics performance and reconstruction*

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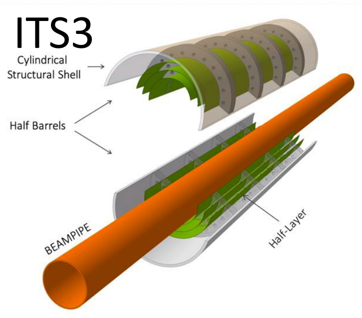
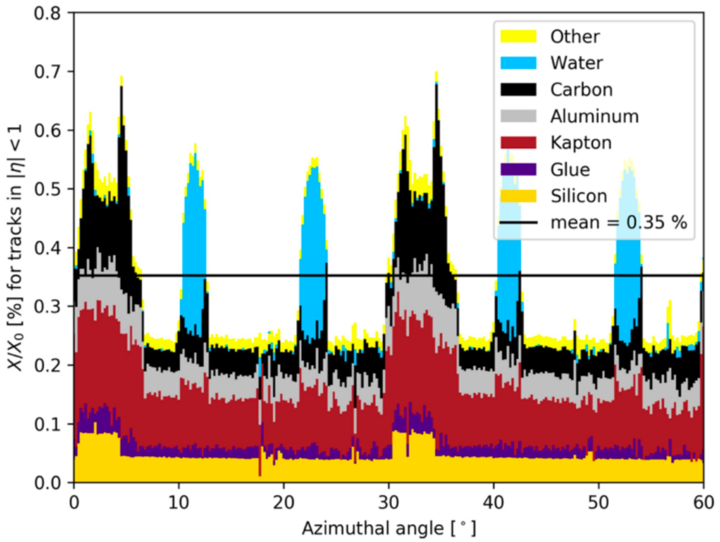
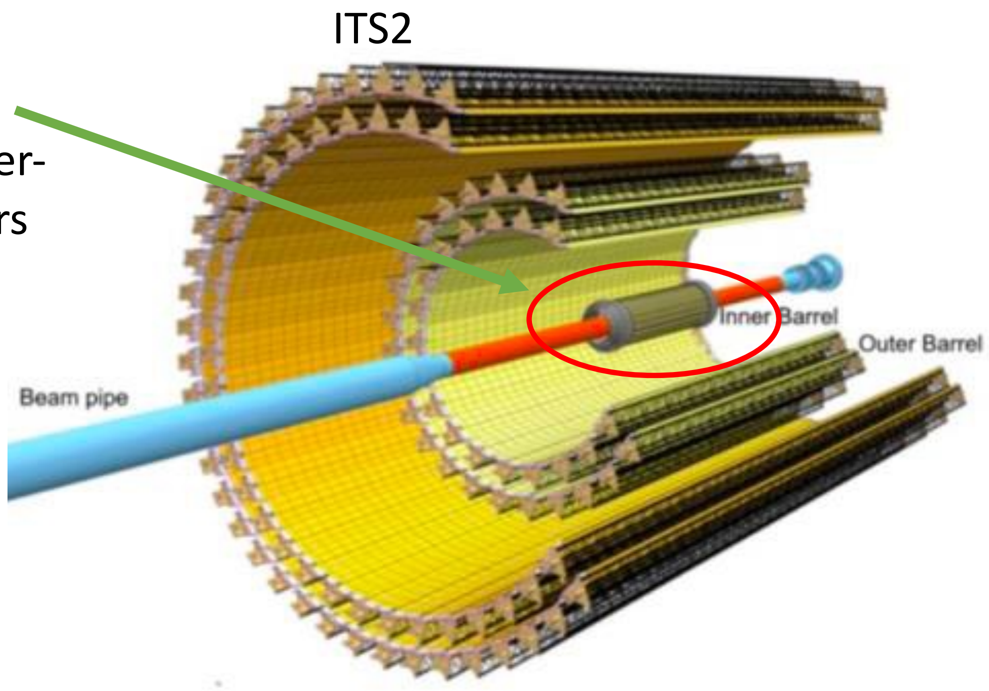


goal of ITS3 project: replacing inner barrel of ITS2 with **silicon-only** wafer-scale truly-cylindrical layers

in 65 nm CMOS technology





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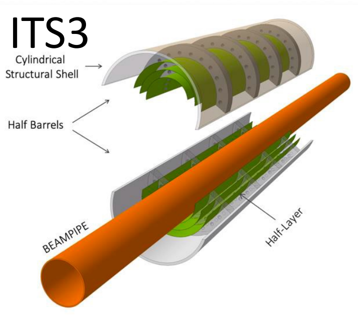

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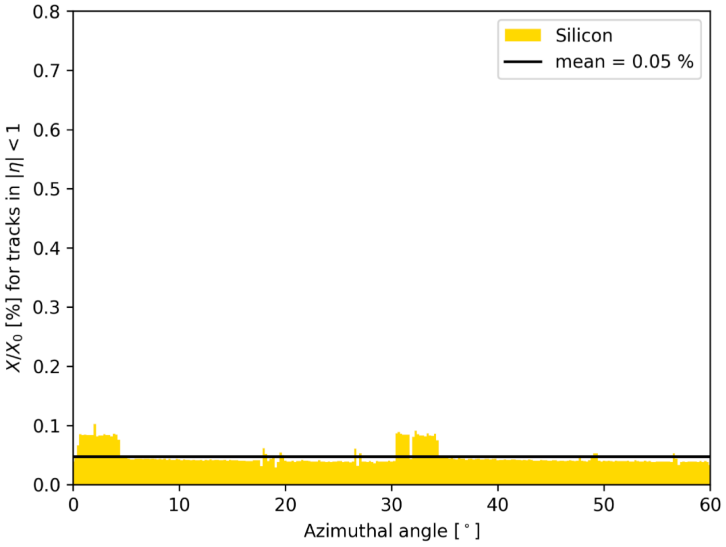

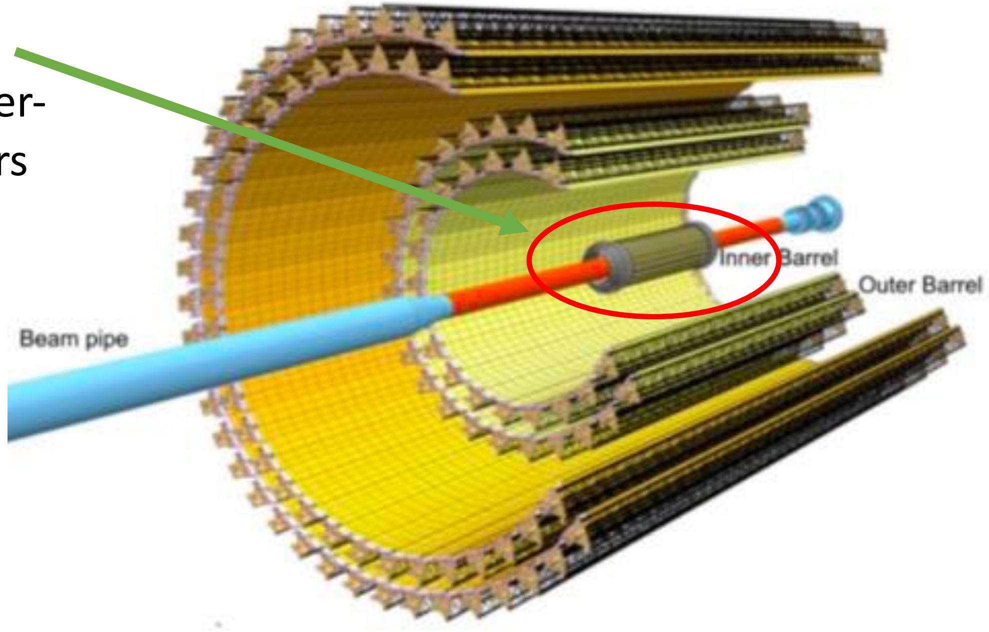

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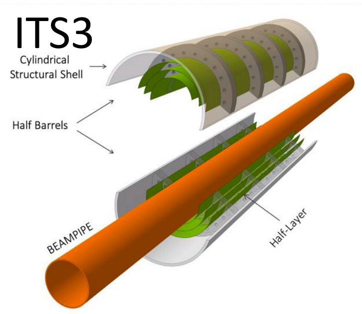

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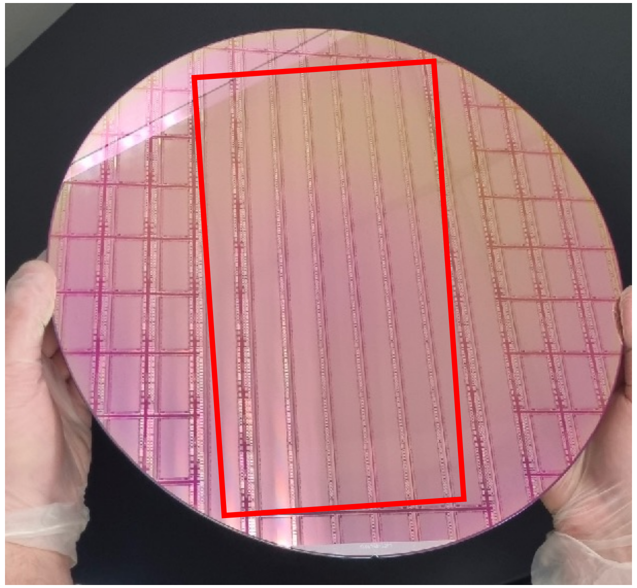
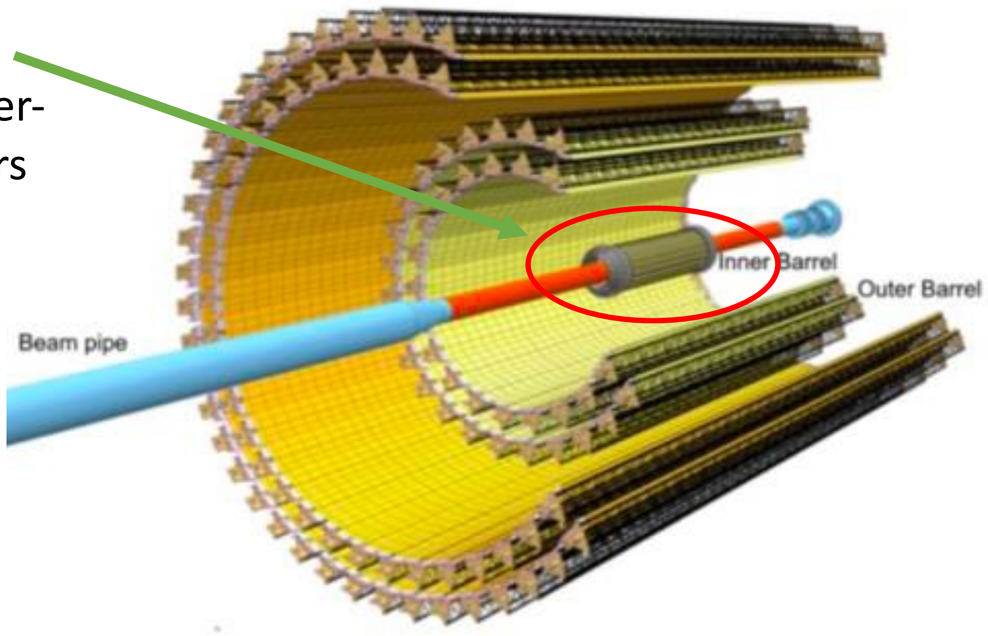


ITS2



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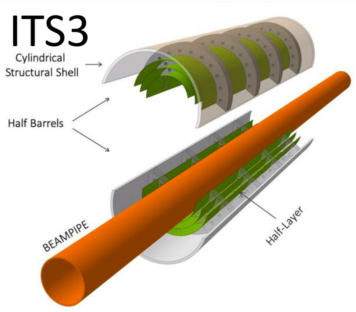

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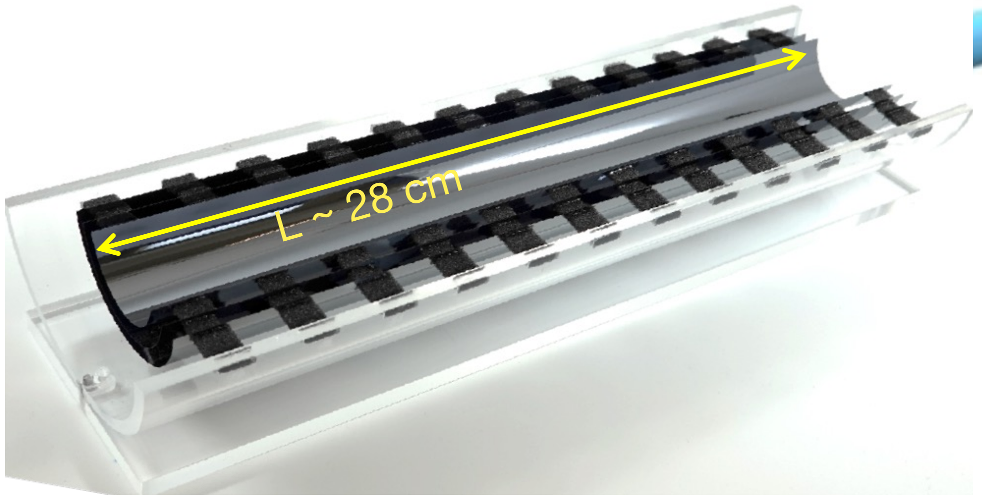

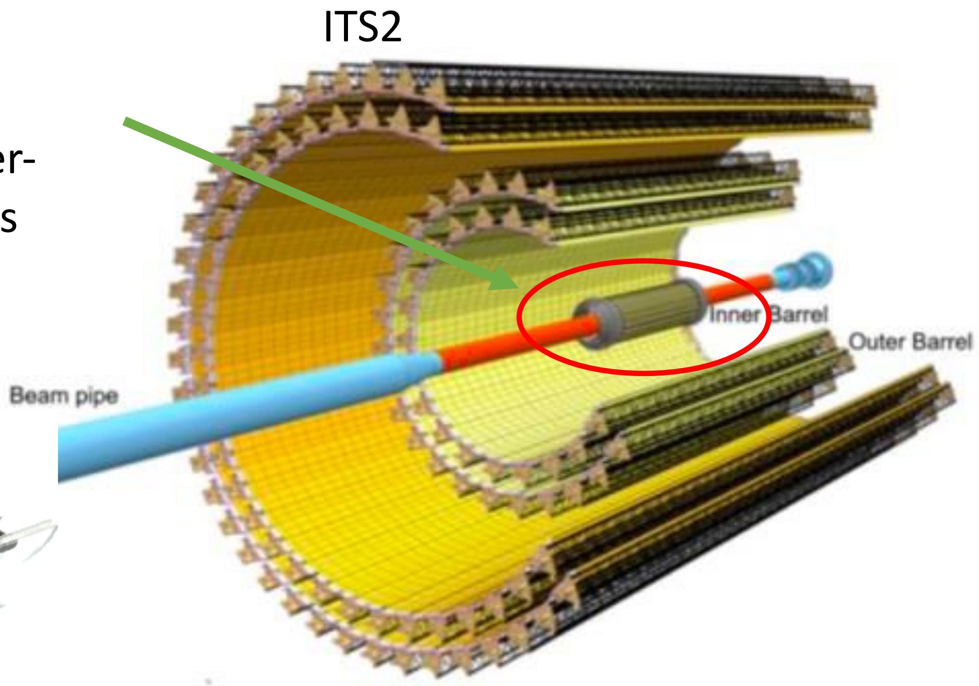

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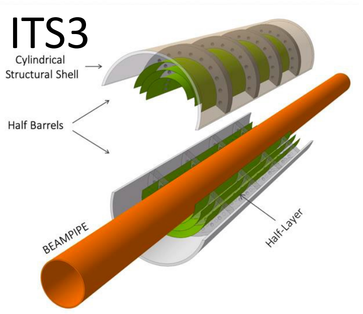

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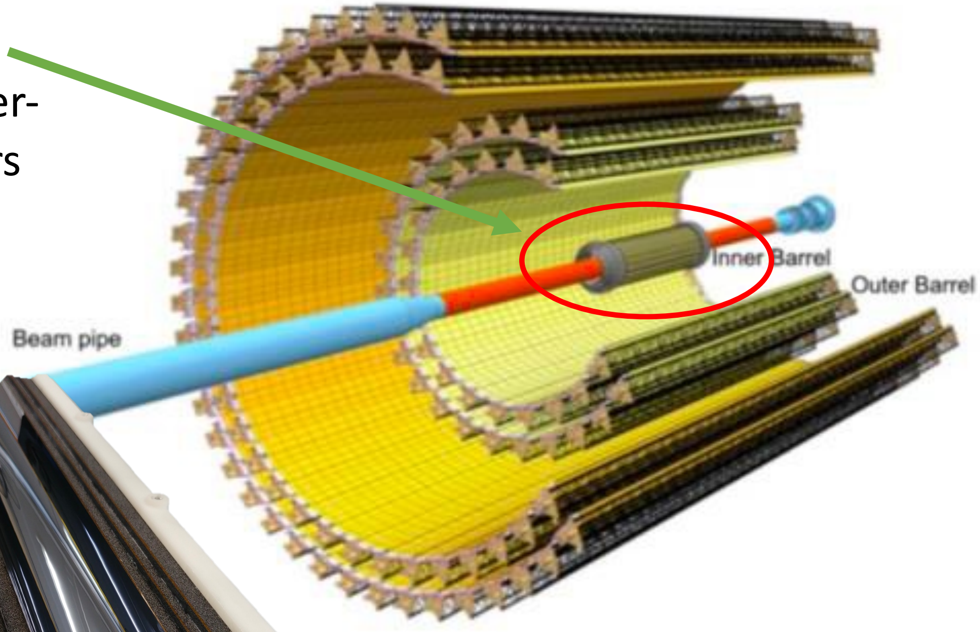
ITS2



LHC heavy-ion physics beyond Runs 3-4

Early stages: temperature, chiral symmetry restoration
- Dilepton and photon production, elliptic flow

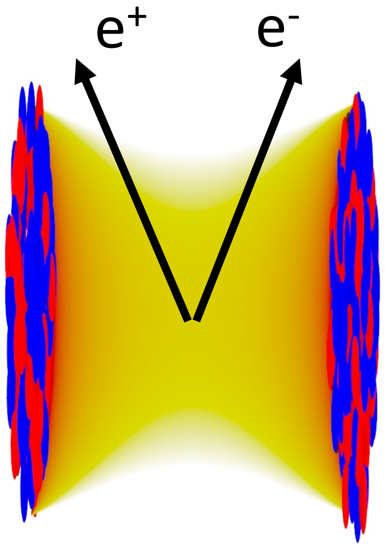
Heavy flavour diffusion and thermalization in the QGP
- Beauty and charm flow, charm hadron correlation

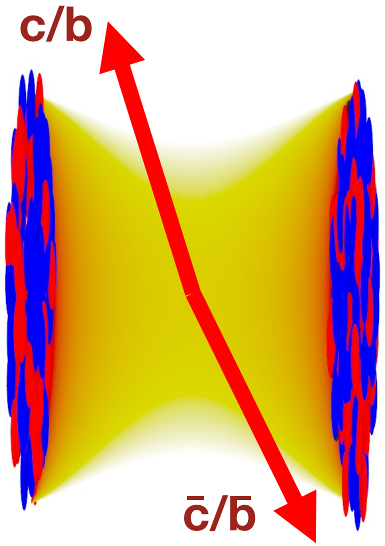
Hadronization in heavy-ion collisions
- Multi-charm baryon production: quark recombination
- Quarkonia, exotic mesons: dissociation and regeneration

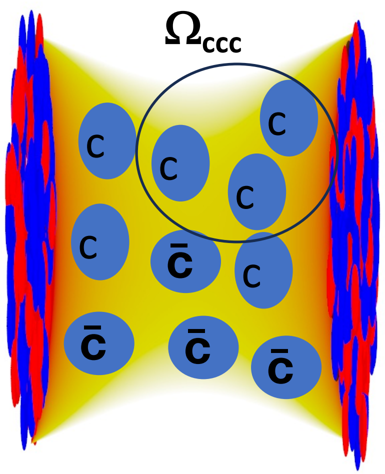
Understanding fluctuations of conserved charges
- Hadron correlation and fluctuation measurements

Nature of exotic hadrons
- Momentum correlations, production yields and dacays

Beyond QGP physics
- Ultra-soft photon production: test of Low's theorem
- Search for axion-like particles in ultra-peripheral Pb-Pb
- Search for super-nuclei (c-deuteron, c-triton)



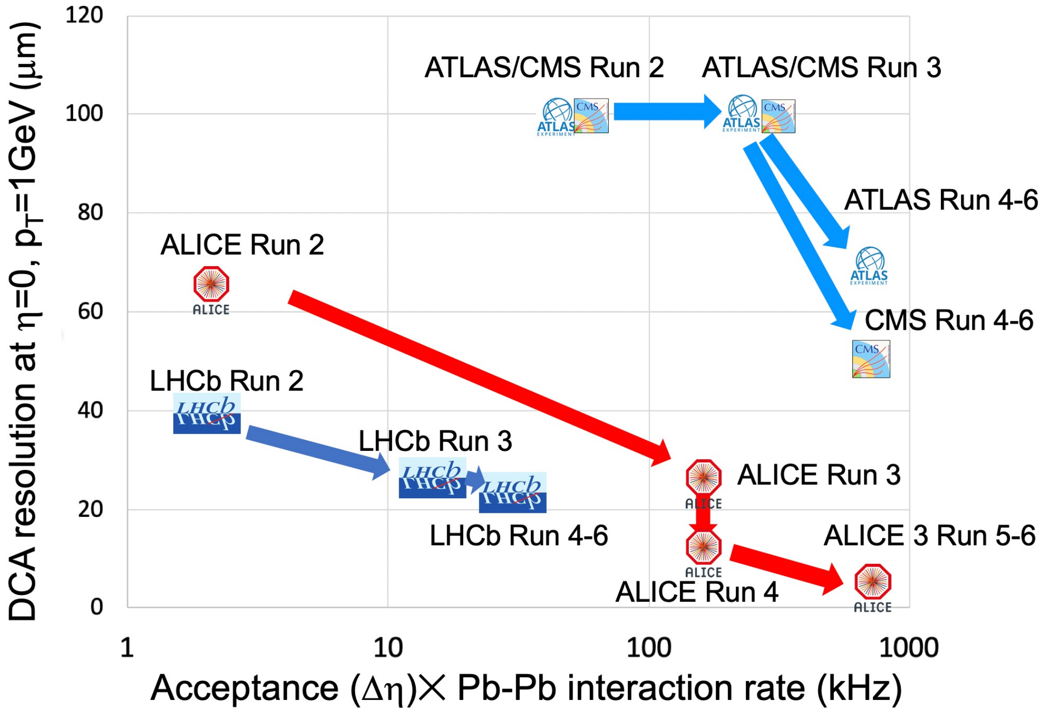


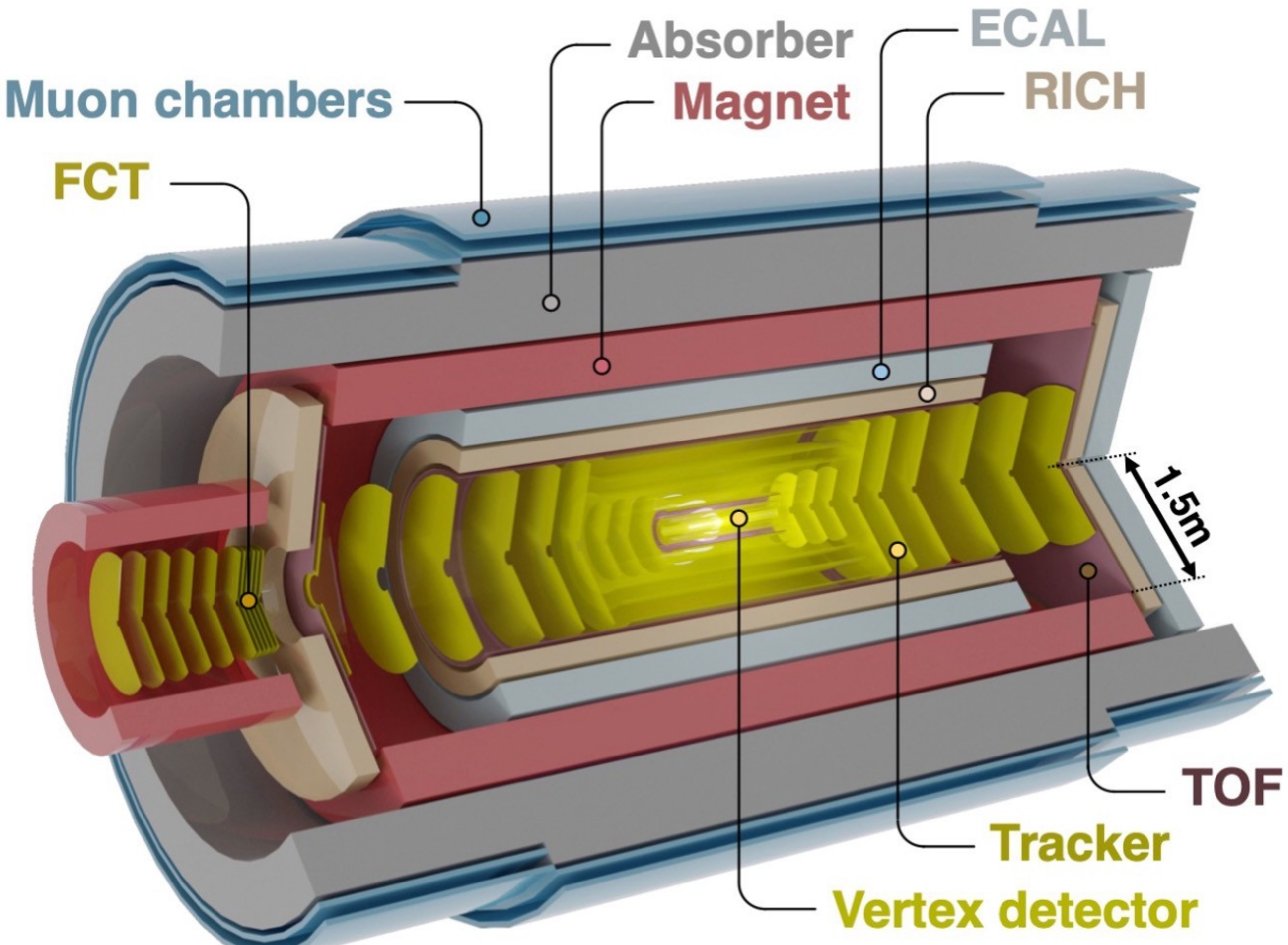


ALICE 3 detector concept

Novel and innovative detector concept

- Compact and lightweight all-silicon tracker
- Retractable vertex detector
- Superconducting magnet system
- Extensive particle identification
- Large acceptance: $|\eta| < 4$
- Continuous readout + online processing





ALICE 3 at INFN BA

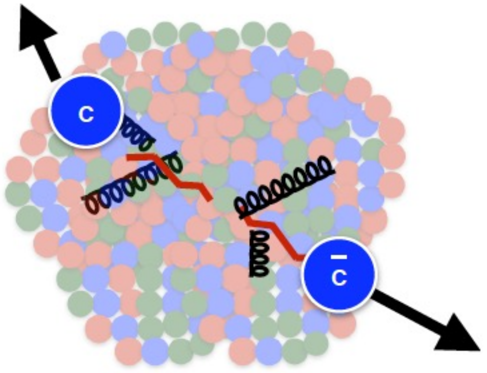
- Physics performance studies
- Detector R&D
  - Inner tracker
  - RICH
  - R&D for ALICE upgrade covers a significant part of the long-term strategic R&D lines defined by ECFA → ***the way for future HEP experiments***

ALICE 3 at INFN BA

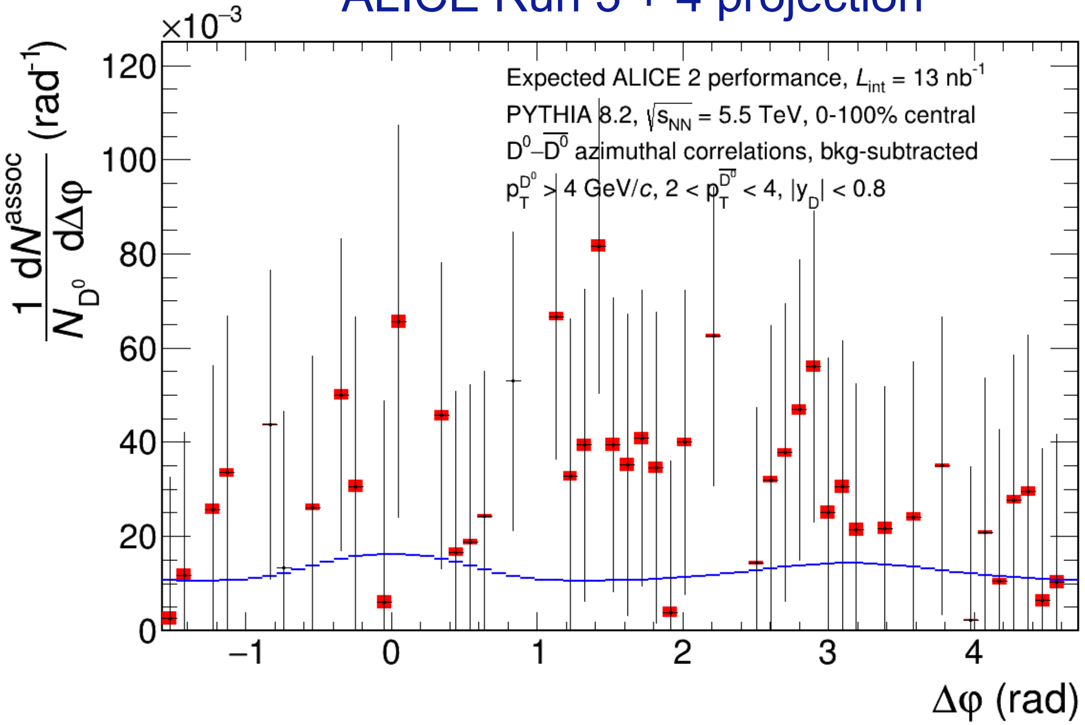
- Physics performance studies

Heavy-flavour correlations (e.g. D-Dbar Δη-Δφ)

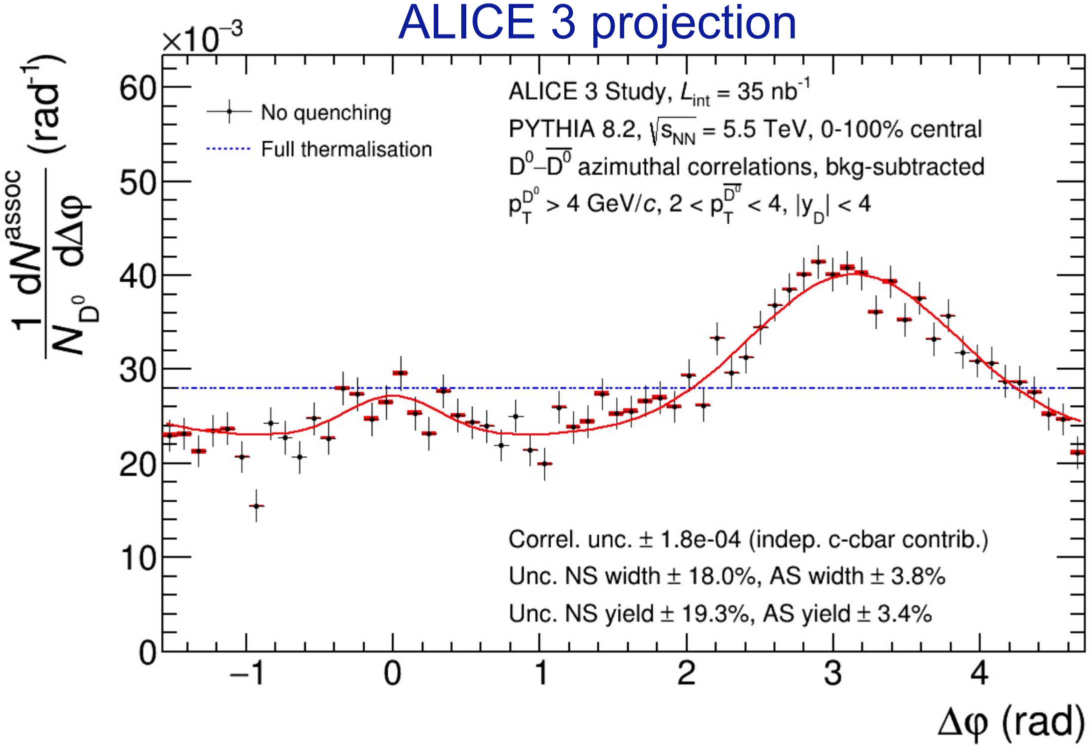
- Elastic scatterings of charm quarks → diffusion regime
- Direct constraints on heavy-quark "equilibration"



ALICE Run 3 + 4 projection



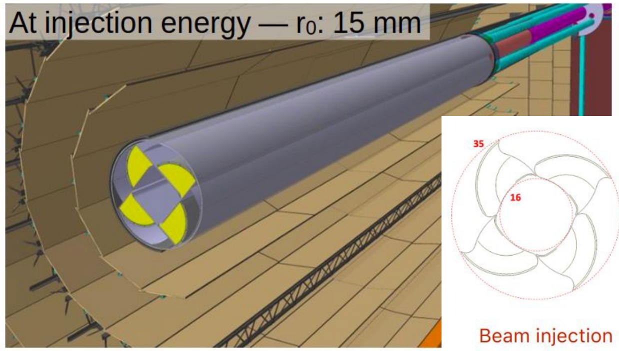
ALICE 3 projection

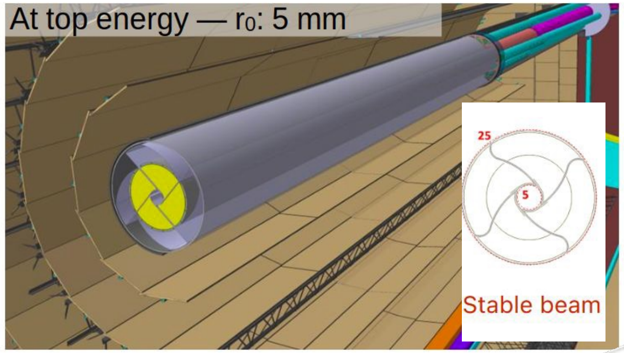


ALICE 3 R&D at INFN BA unit: inner tracker

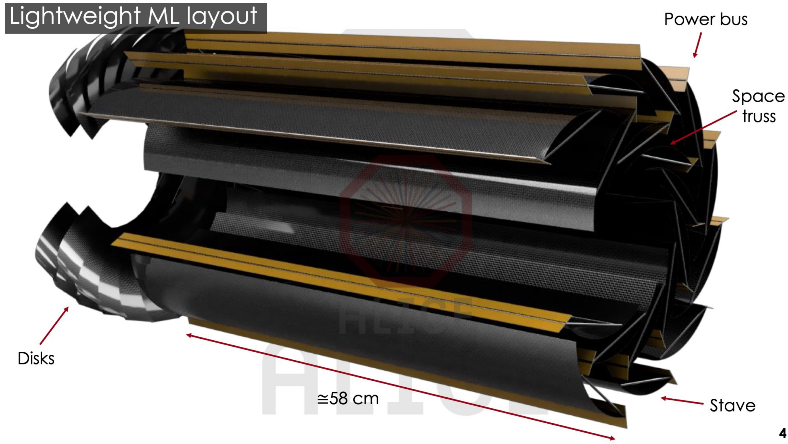
- For the ALICE 3 Inner tracker furher R&D beyond ITS3 is required
- At INFN-Ba dedicated R&D is ongoing since 2023 on studies in the vacuum
  - Outgassing properties of components and materials
  - Interconnection under vacuum

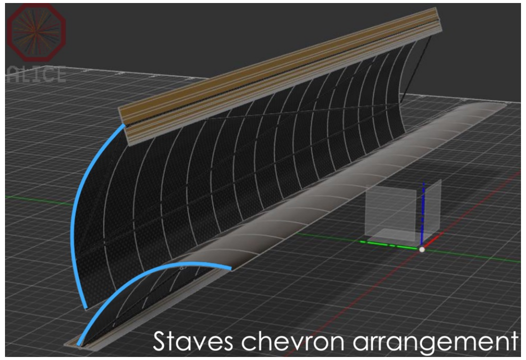
IRIS detector





Middle Layers





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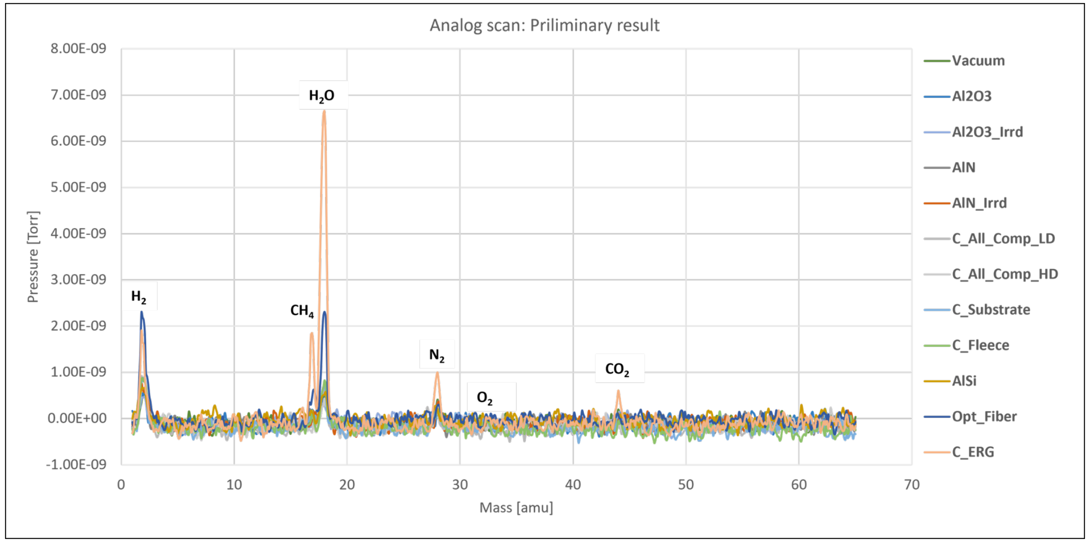


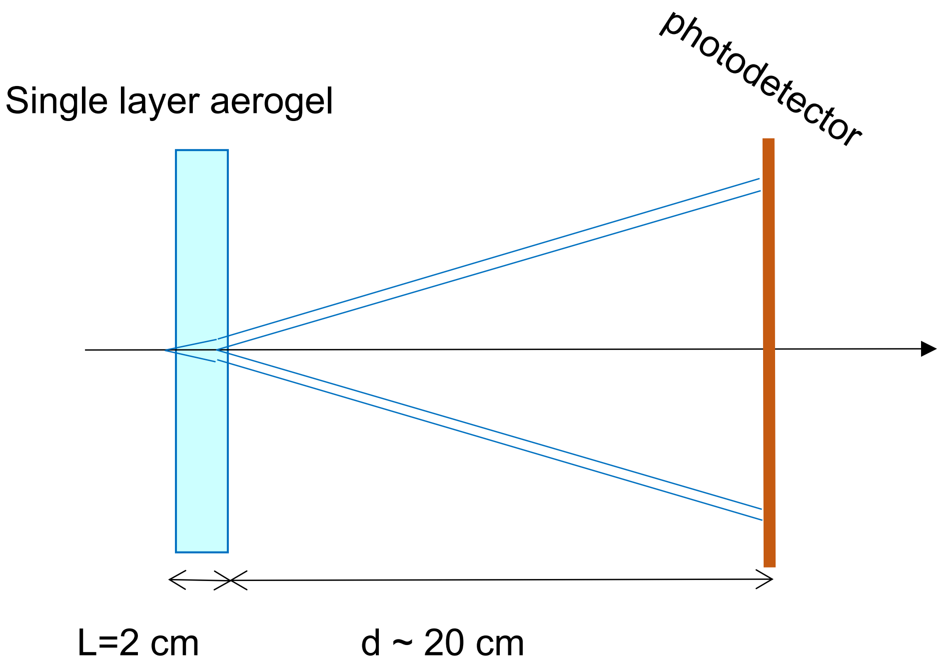
ALICE 3 R&D at INFN BA unit: RICH detector

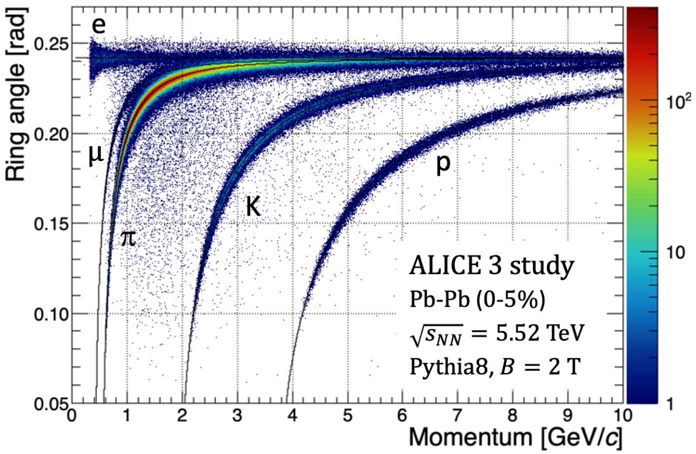
Requirements

- Extend charged PID beyond TOF limits
  - e/π up to ≈ 2GeV/c
  - π/K up to ≈ 10GeV/c
  - K/p up to ≈ 16GeV/c

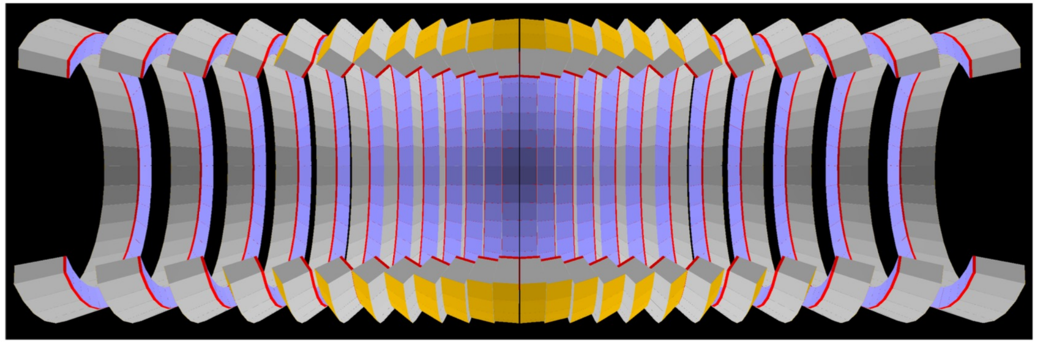
- Cherenkov threshold: $p \geq m/(n-1)^{1/2}$
  - n = 1.03 (barrel), n = 1.006 (forward)
  - Aerogel radiator
  - SiPM for photon detection (2x2 mm^2 pixel size)

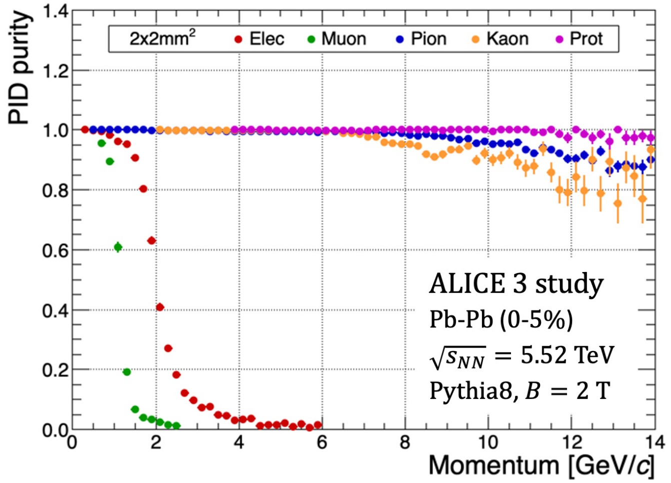
- Angular resolution: $\sigma_{\text{ring}} \approx 1.5$ mrad





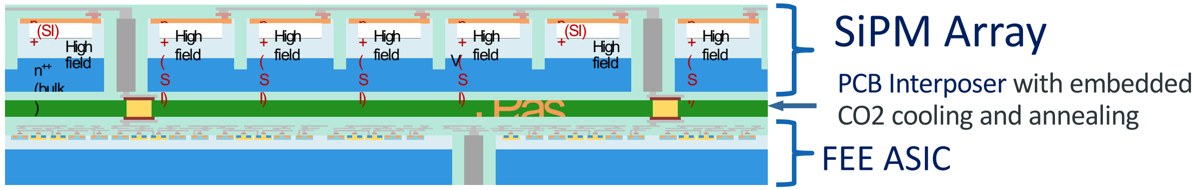
Projective bRICH to improve coverage at large $|\eta|$ while saving on overall photosensitive area

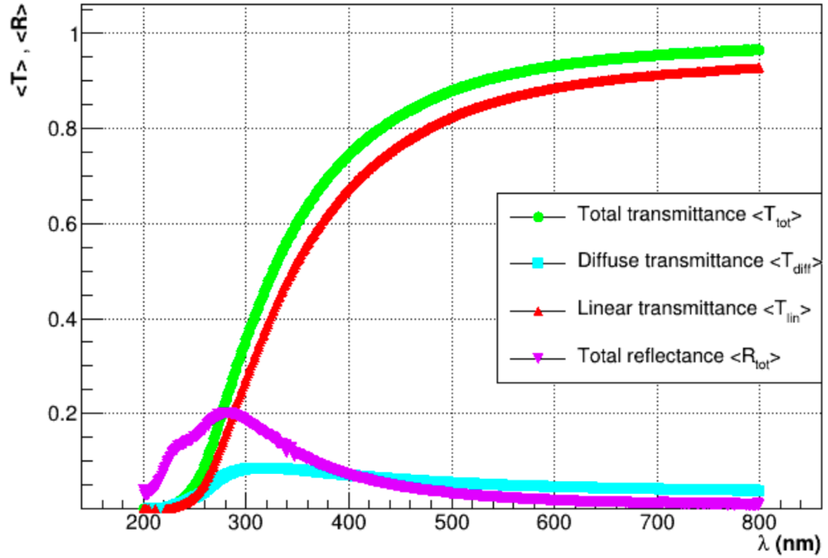


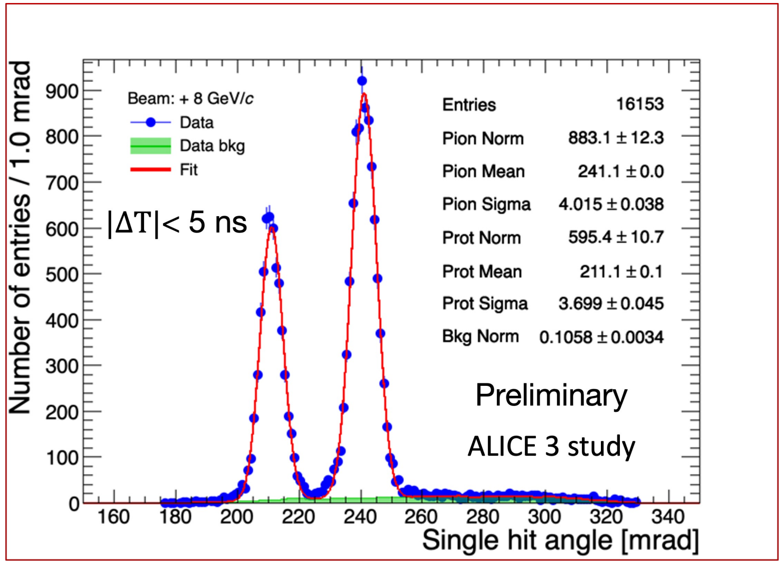


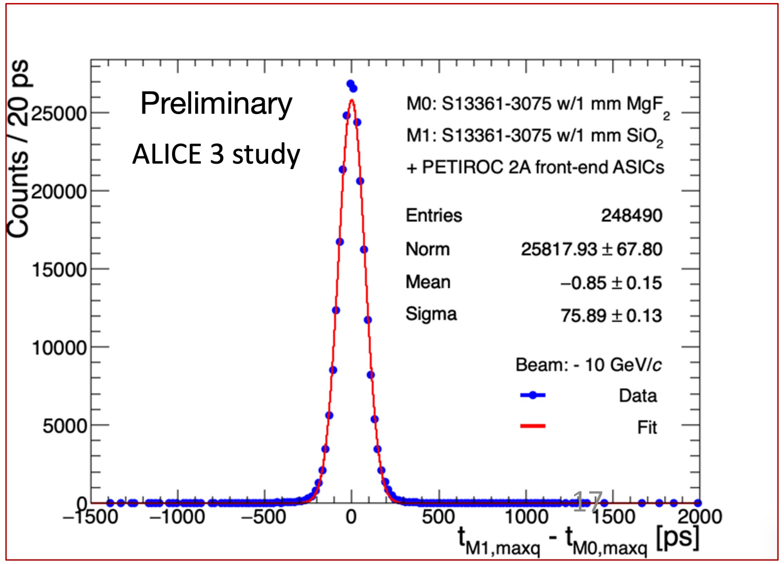
ALICE 3 R&D at INFN BA units: RICH

- Bari group interested/involved in RICH detector:
  - Project coordination
  - Simulation studies
  - Aerogel Characterization (synergical to ePIC)
  - SiPM studies (in collaboration with astro-particle group)
  - Beam testing (PS at CERN) of prototypes
  - Tests performed in 2022, 2023 and October 2024





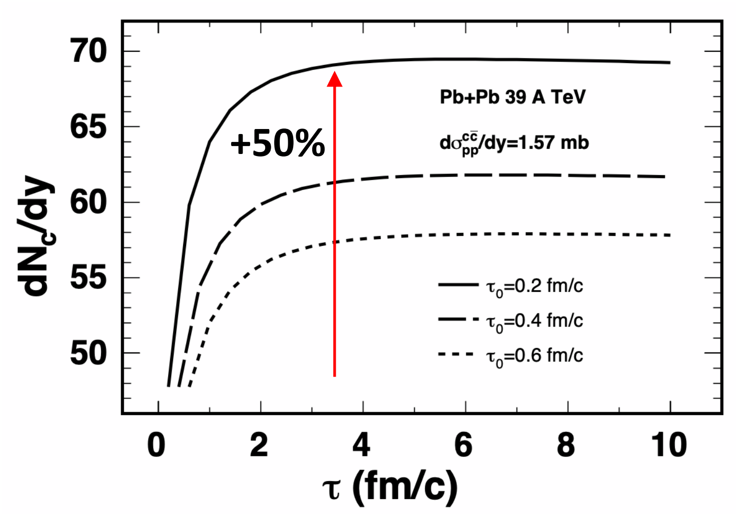




Far future: heavy ions at FCC-hh

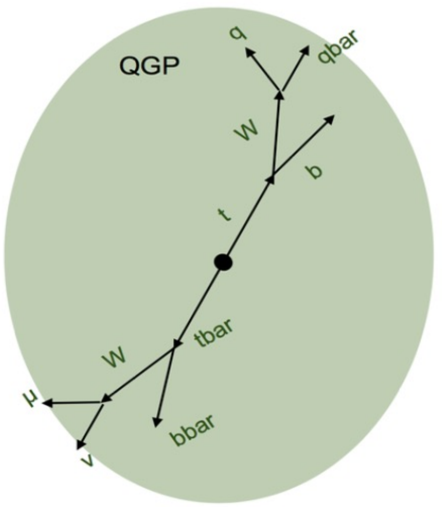
- FCC-hh HI performance: Pb-Pb $\sqrt{s_{NN}}$ = 39 TeV about 7 x LHC $\sqrt{s_{NN}}$
- Integrated luminosity larger than 100 nb^{-1}/month in "ultimate" luminosity scenario: **~ 20-30 x LHC L_{int}**
- QGP from LHC to FCC: volume x2, energy density x3, initial temperature ~1 GeV.

Thermal charm-anticharm from QGP gluons



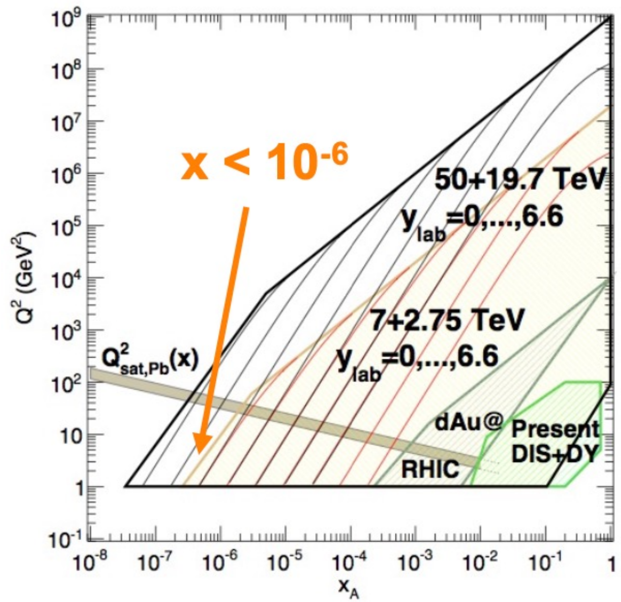
Ko, Liu, JPG43 (2016) 12, 125108
Zhou et al., PLB758 (2016) 434

New hard probes of QGP



Apolinario et al., PRL120 (2018) 23, 232301

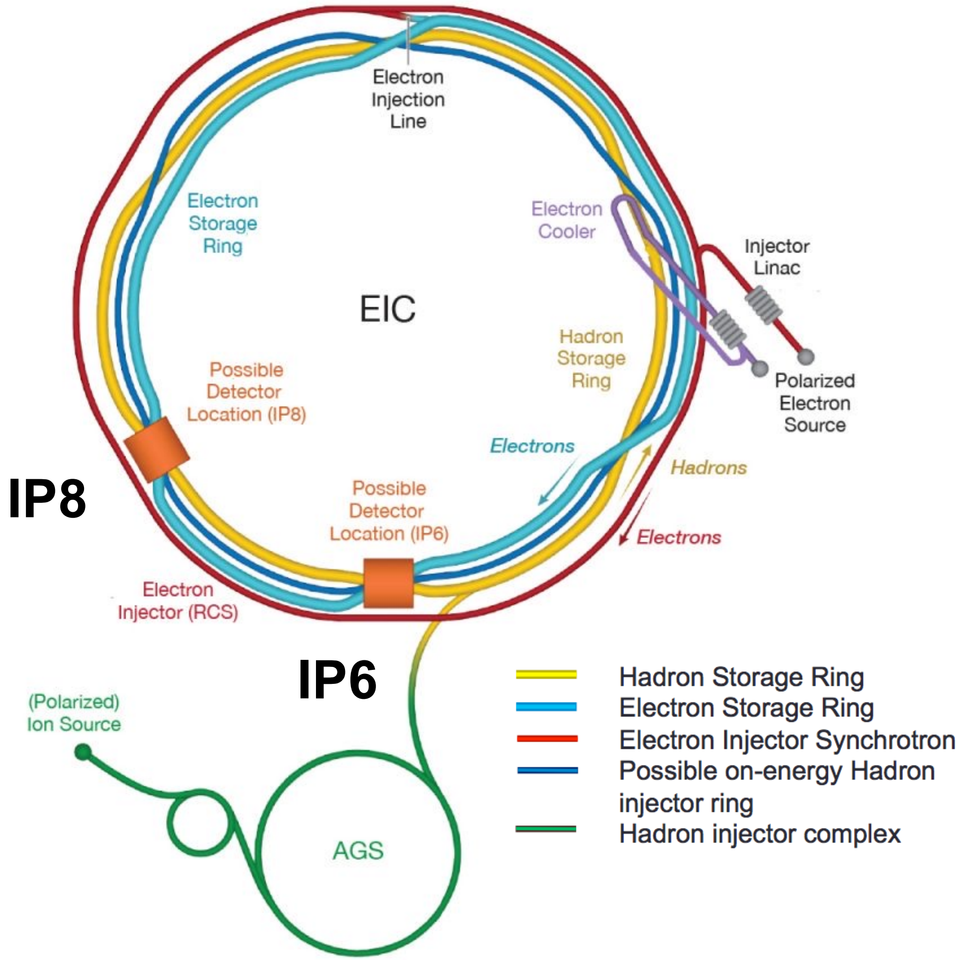
Smallest Bjorken-x ever for gluons in nuclei



Dainese et al., arXiv:1605.01389

ePIC@EIC

Electron-Ion Collider @BNL



EPPS 2020

CERN/SPC/1239/Rev.2
Update of the European Strategy for Particle Physics:
Remit of the European Strategy Group

The ESG should take into consideration:

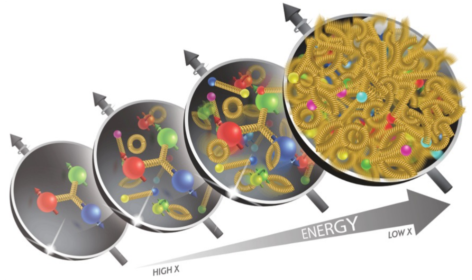
- the input of the particle physics community;
- the status of implementation of the 2020 Strategy update;
- the accomplishments over recent years, including the results from the LHC and other experiments and facilities worldwide, the progress in the construction of the High-Luminosity LHC, the outcome of the Future Circular Collider Feasibility Study, and recent technological developments in accelerator, detector and computing;
- the international landscape of the field.

- $\mathcal{L}_{ep}$ ~10^{34} cm^{-2} s^{-1} (>100 × HERA)
  - *crab crossing*, CEC, small β^*, crossing rate 100 MHz
- $E_e \times E_h$ = 5-18 × 41-275 (A) GeV → $\sqrt{s}$= 20-141 GeV
- Polarization e/(p-^{3}He) ~ 70% (for the first time!)
- Hadronic beams: from H up U, at different $\sqrt{s}$
- ***The only new large accelerator to start within the next ~10 years***
- ***Start of construction: end of next year/beginning of 2026!***
- ***DOE: project approved and financed***

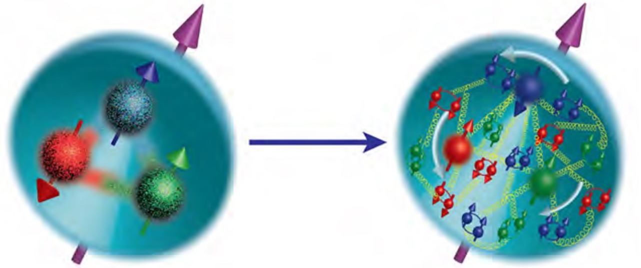
ePIC@EIC

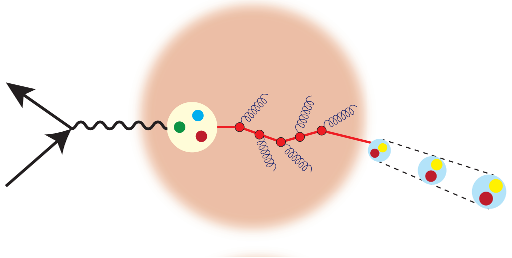
Physics at the EIC

3D imaging of the nucleon, study of the nucleon “glue”



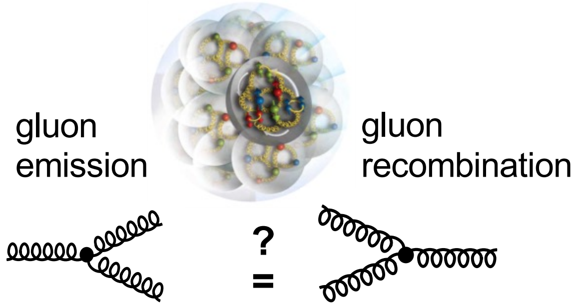
How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?





How do color-charged partons and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

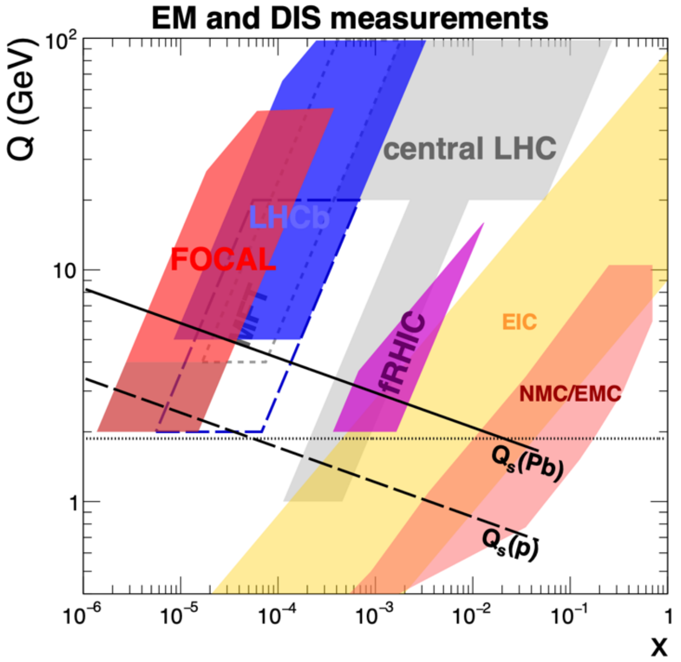
How does a dense nuclear environment affect the quarks and gluons distribution & interactions? Do gluons saturate at high energy in nucleons and nuclei? Properties of the novel gluonic matter?



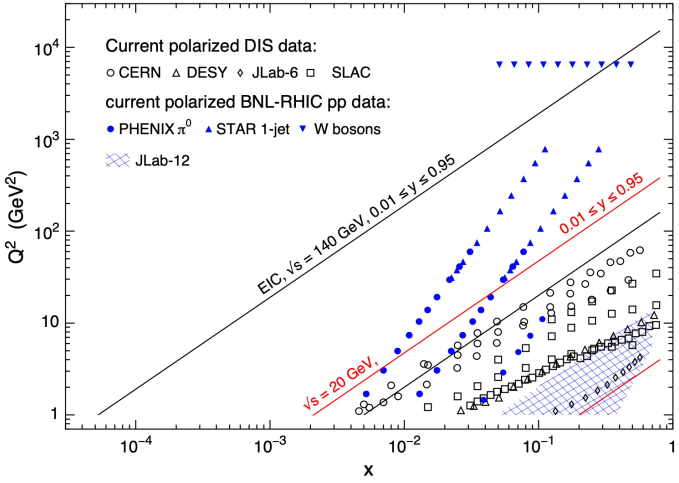
ePIC@EIC

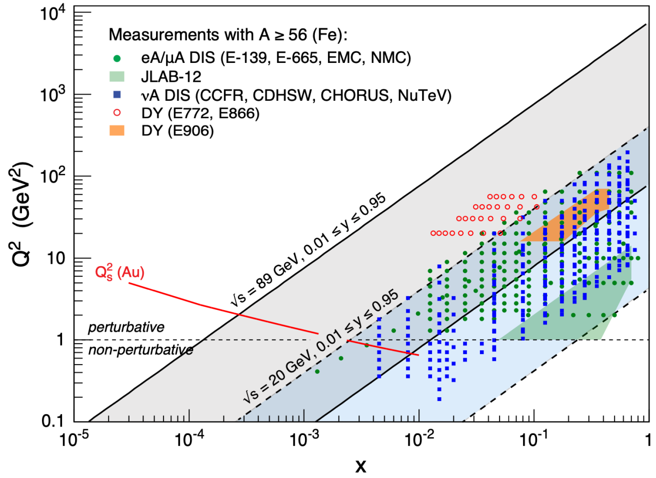
EIC-LHC synergies on scientific topics:

- COMPASS/AMBER
  - wide range of measurements, from nucleon spin to DVCS measurements,
  - chirality from PDF pion/kaon, TMD from SIDIS, etc.
- FOCAL (@ALICE)
  - ALICE Forward Calorimeter (e.m.+ hadronic)
  - Saturation, gluon pdf via prompt foton, γ-jet, γ-hadron, vector mesons



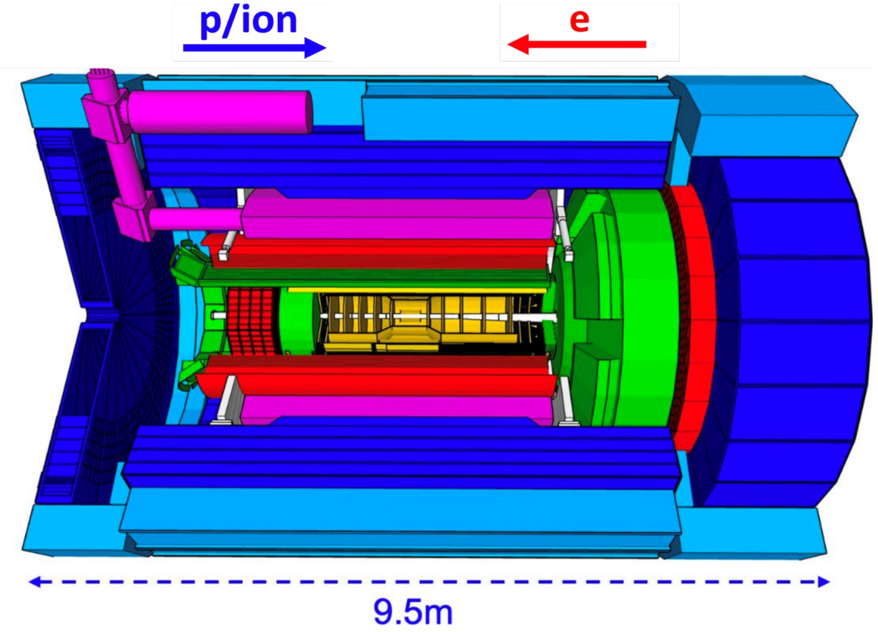
- LHCspin (@LHCb)
  - polarized target
  - gluon/quark TMD's via HF mesons
- Very high impact on PDFs see workshop JENAA "Synergies between the EIC and the LHC" https://indico.desy.de/event/41404/





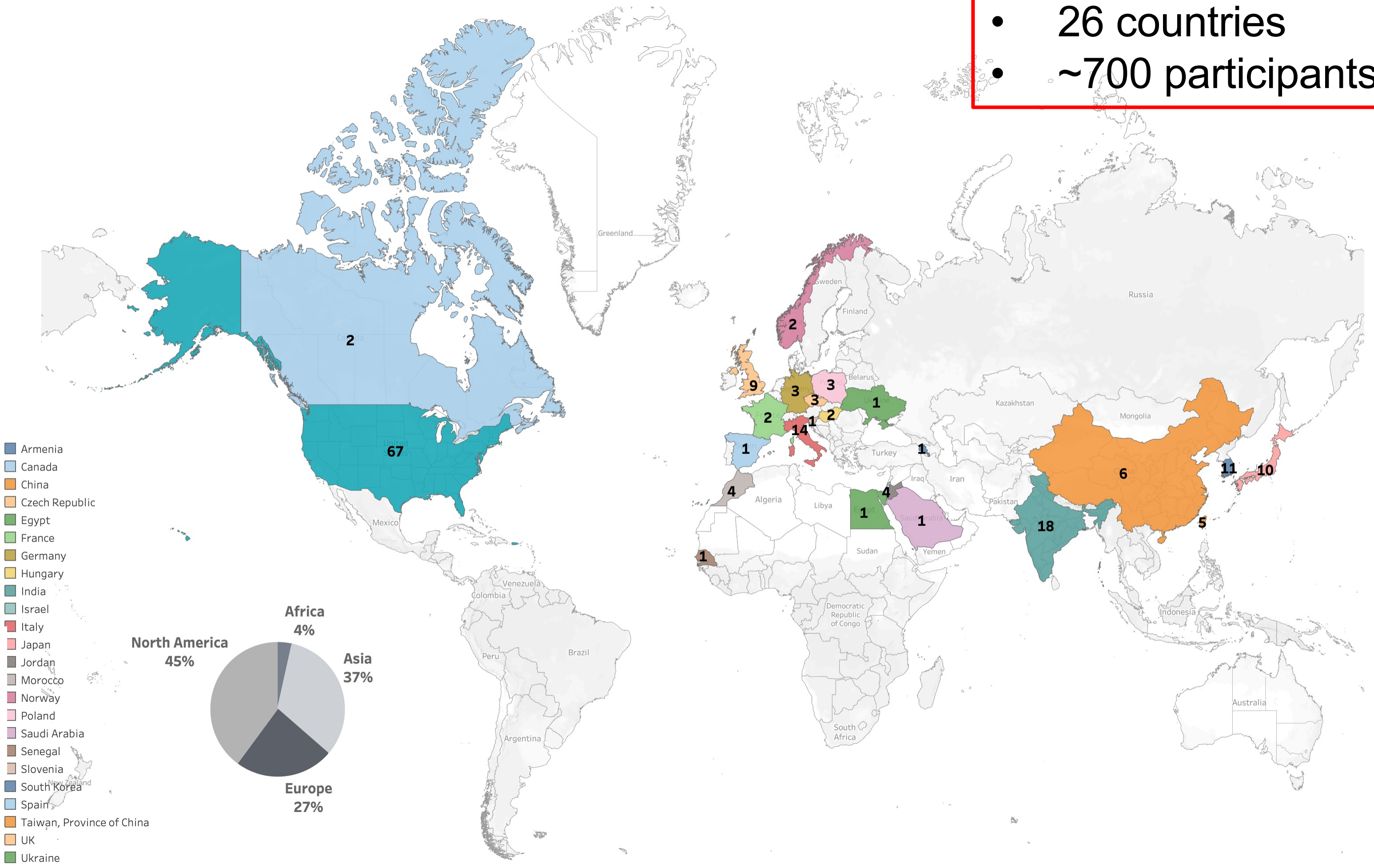
ePIC: electron-proton/ion collider Collaboration

- 177 institutes
- 26 countries
- ~700 participants



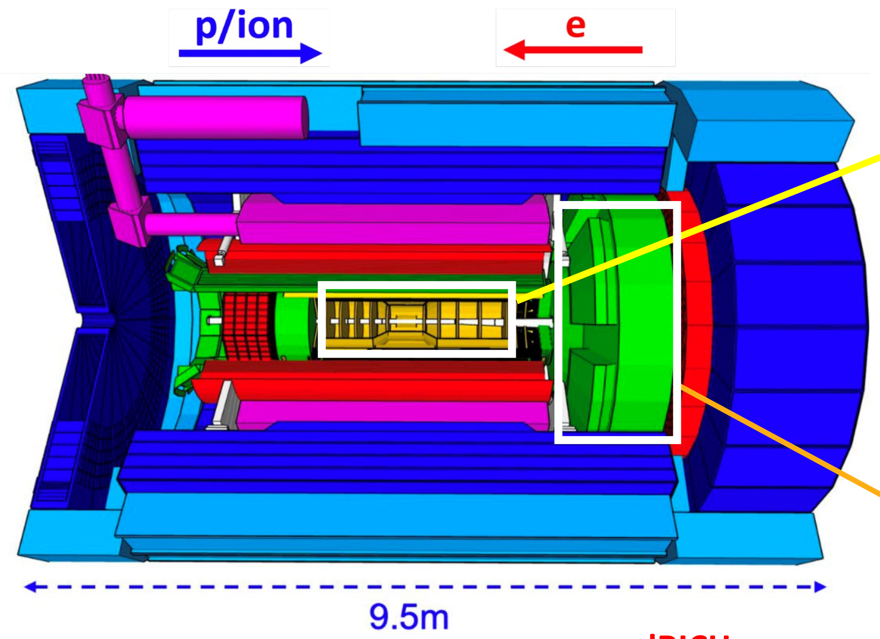
calorimetri adronici
solenoide
calorimetri e.m.

TOF, DIRC,RICH
tracker MPGD
tracker MAPS

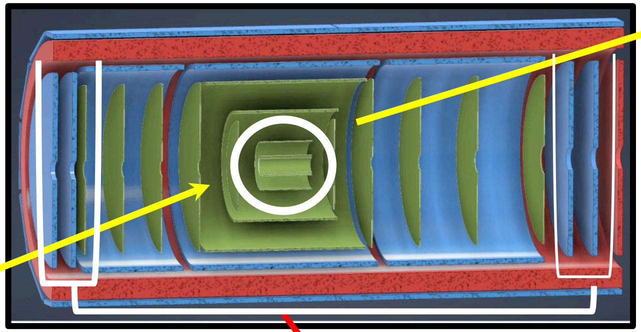


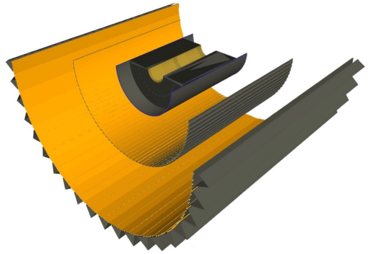
ePIC@EIC at INFN BA

INFN involvement in ePIC



ePIC@INFN-CSN3
- “sigla” starting from 2025
- 14 INFN units involved
- 122 Ric/Tec, 34 FTE





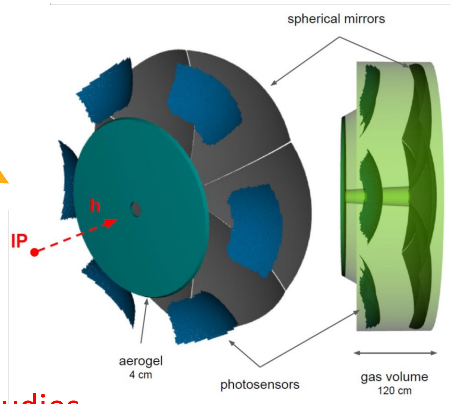
SVT (Silicon Vertex Tracker) barrel

SVT IB (Inner Barrel):
- 3 layers (L0, L1 and L2)
- INFN: L0-L1 + global mechanics
- Bari: L0-L1 half-barrel assembly

MAPS development of ALICE/ITS3
→ sinergies with **ALICE and NA60+**

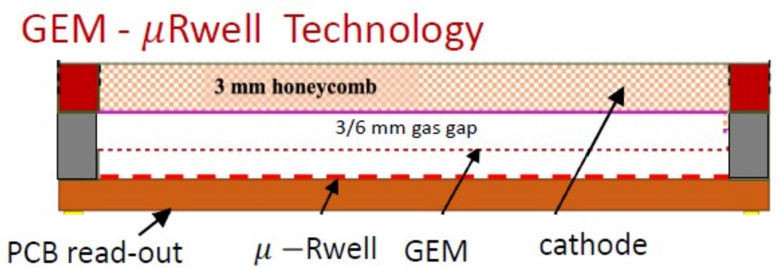
dRICH (dual-radiator RICH)

dRICH
- INFN project
- Bari: aerogel characterisation studies



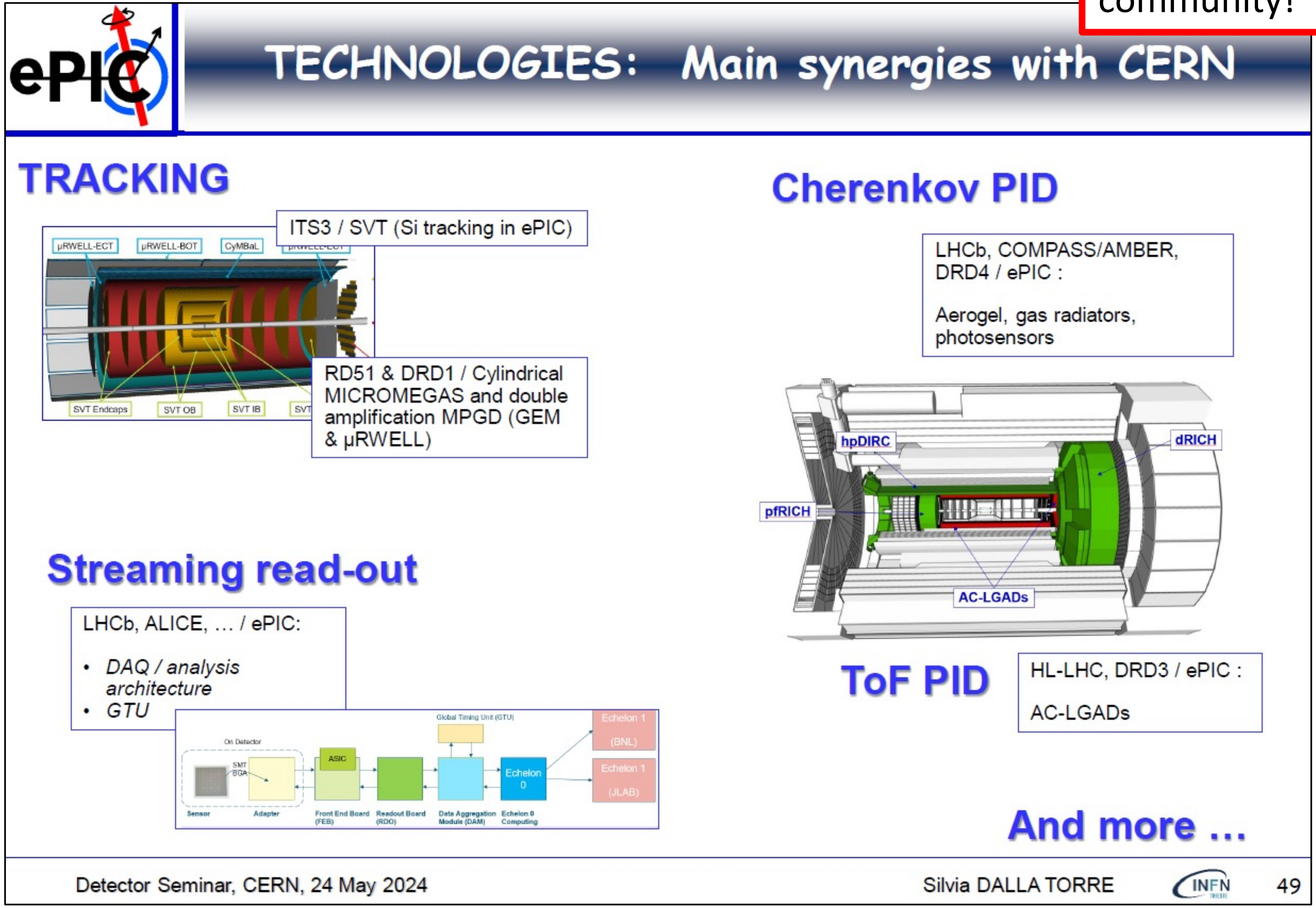
Aerogel and SiPM
→ sinergies with **ALICE 3**

microRWELL ECT (End-Cap Tracker)

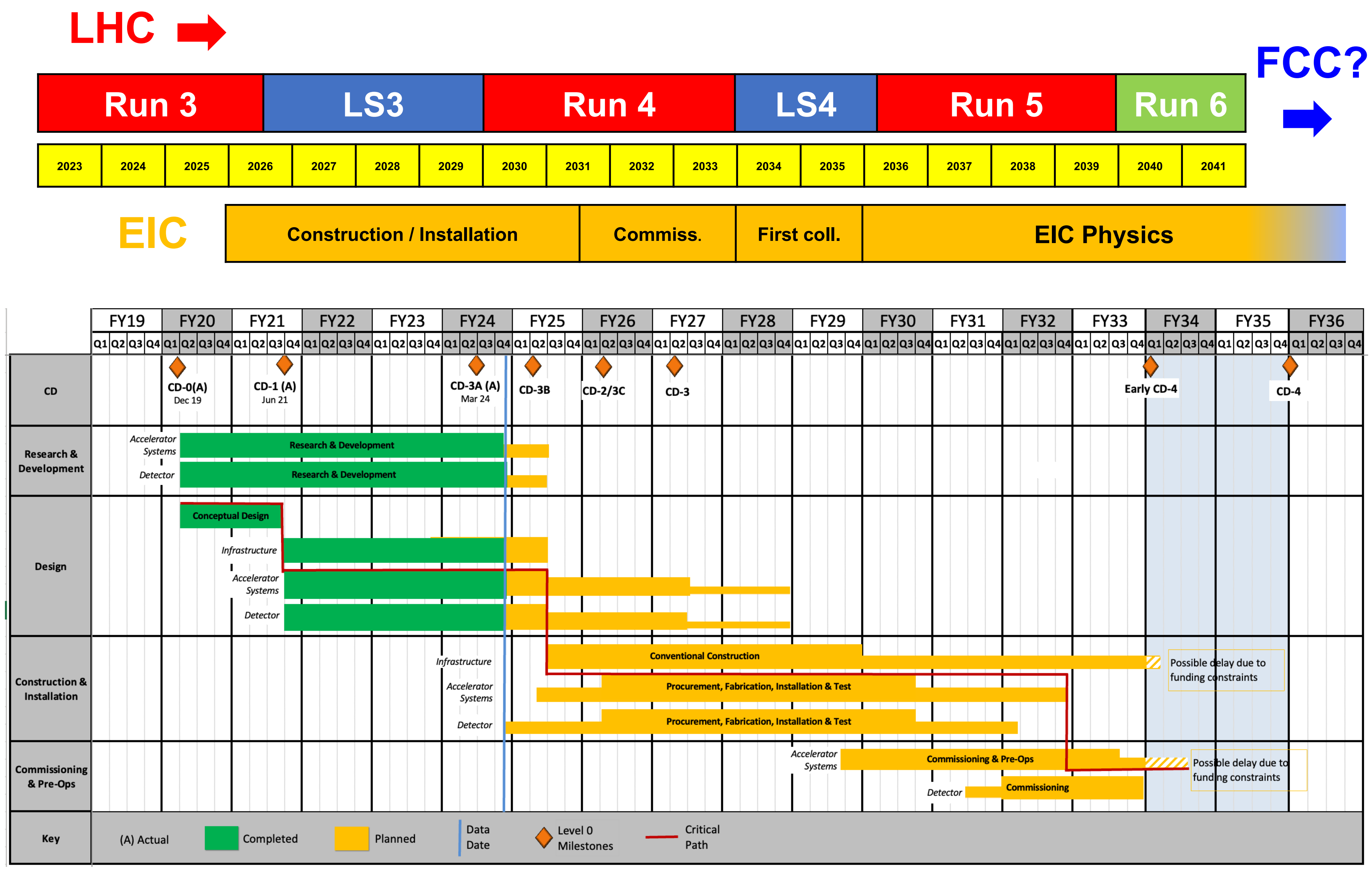


R&D for ePIC@EIC

Many developments cited in the ECFA report as of interest for the whole community!



ePIC@EIC timeline



Final remarks

- Europe and CERN should support the continuation of heavy-ion programmes to pursue the exploration of the emergent properties of hot QCD matter and the measurement of its fundamental physics parameters
  - New detectors at LHC (ALICE 3) can address the open fundamental questions, while ensuring a full exploitation of these accelerators, and a rich and diverse scientific environment

- LHC and EIC: complementary programs, with great mutual impact
  - Detector technologies: many opportunities for synergy
  - EIC timelines: life cycle ~20 years, between HL-LHC and FCC

- New detectors for the LHC and EIC also open paths for advancing full-scale frontier detectors, laying the groundwork for sensor technology in future high-energy physics experiments.