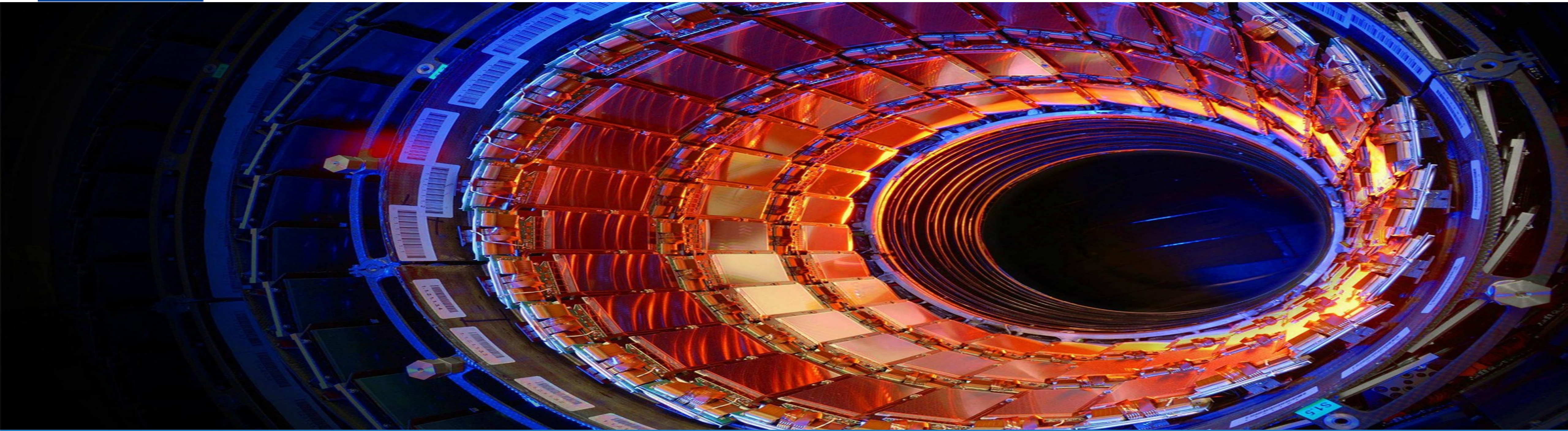


JRA6 - Challenges for next generation DIS facilities

Francesco Bossù
CEA Saclay, France

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

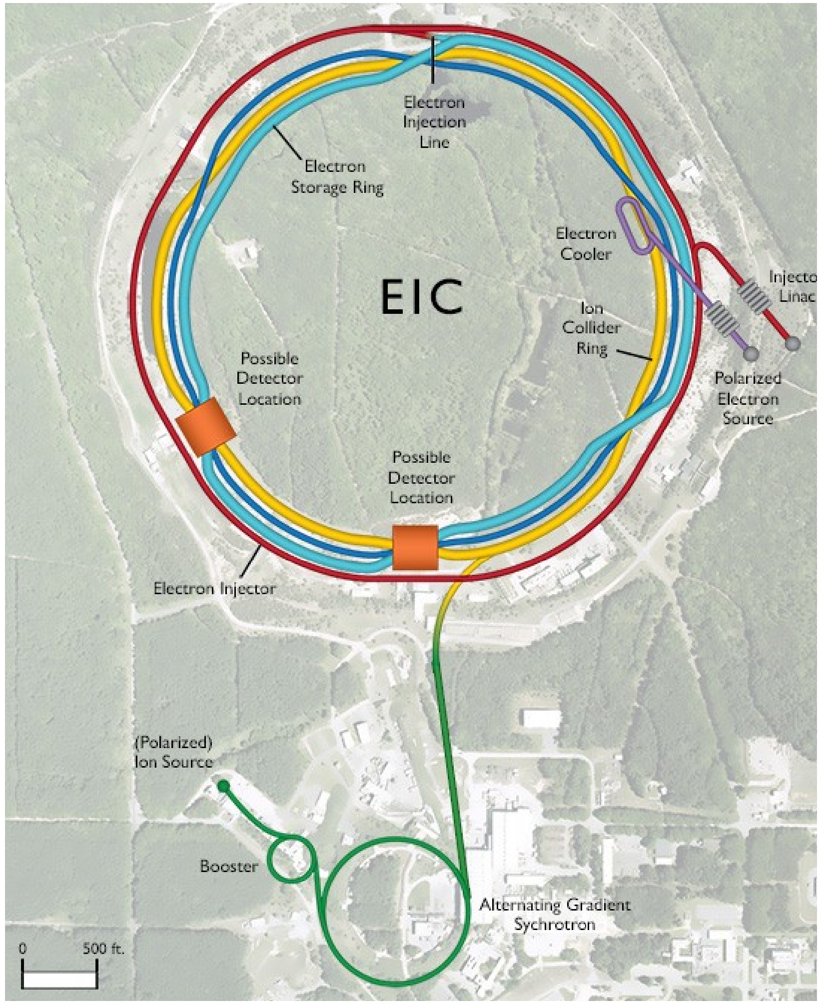
JRA6 - Challenges for next generation DIS facilities

Electron-Ion Collider: World's first polarised electron-proton/light ion and electron-nucleus collider → high luminosity and large CM energies for unprecedented access to the quark-gluon sea.

At the beginning of 2020, the EIC project passed the **CD-0:**

- **Brookhaven National Lab,** the selected site

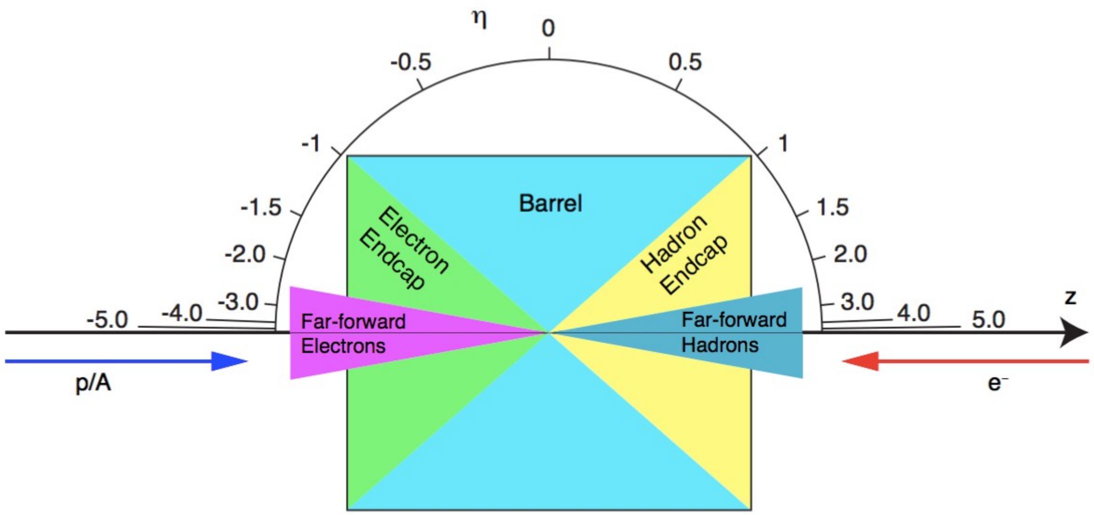
The **EIC Yellow Report:** promoted and organised by the EICUG, will better define detector requirements from physics. Expected to be published at the beginning of 2021.



JRA6 - Challenges for next generation DIS facilities

Detector concepts:

- Hermetic detector
- Excellent vertex resolution
- Very good PID (e/π, π/K, p/K) in a wide momentum and angular range
- Excellent tracking



Objectives of JRA:

Task 1 - Monte-Carlo simulations for detector requirement definition

Task 2 - Very low ion-back-flow detectors for tracking with TPC

Task 3 - PID with RICH

Task 4 - Depleted MAPS for vertex detector and tracking

Task 1: Monte Carlo Simulations

Carried out within the framework of the **Electron-Ion Collider Yellow Report activity**: a one-year (Jan 2020 – 21) intensive study of physics processes and detector constraints: http://www.eicug.org/web/content/yellow-report-initiative

Exclusive Reactions WG activities co-ordinated by D. Sokhan (U. of Glasgow) as co-convener.

Processes under study:

- Deeply virtual Compton scattering
- Hard exclusive meson production
- Timelike Compton scattering
- Charged current meson production
- Diffractive di-jet production

First draft of Yellow Report nearing completion: constraints are tightest on the reconstruction of low-angle scattered nucleons / nuclei and electrons and on photon acceptance.

Timepix-based detector for far-forward/backward regions

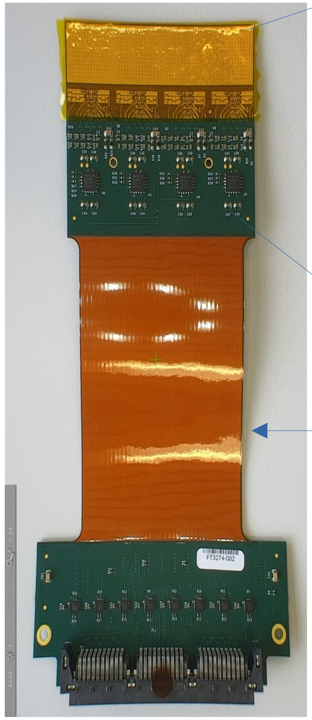
Stringent detector requirements for the detection of far-forward recoil and far-backward scattered electron (in quasi-real photoproduction): refocusing of part of U. of Glasgow effort on R&D into Timepix read-out chips for possible integration with the detectors.

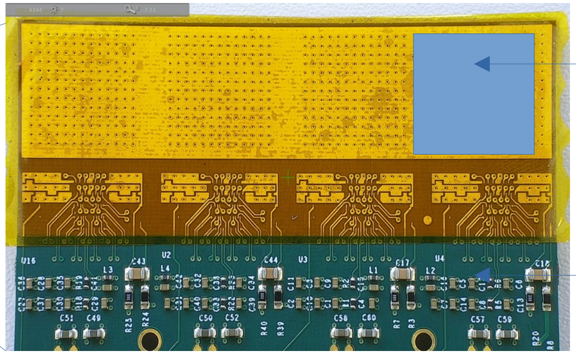
Timepix:

- Compact
- Radiation-hard
- Excellent spatial resolution < 50µm

Study is within the Yellow Report Far-Forward Detector WG and in synergy with the Glasgow group’s R&D on Timepix-based polarimeter for linearly-polarised photons and development of an RF-PMT for picosecond timing.

Current R&D on Timepix3 chip (in anticipation of release of Timepix4):

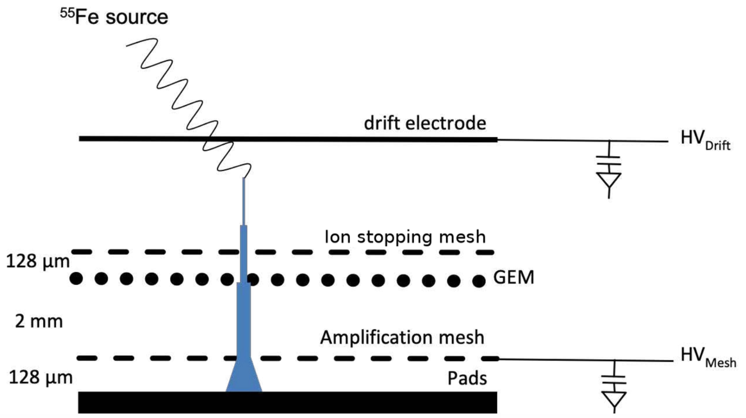


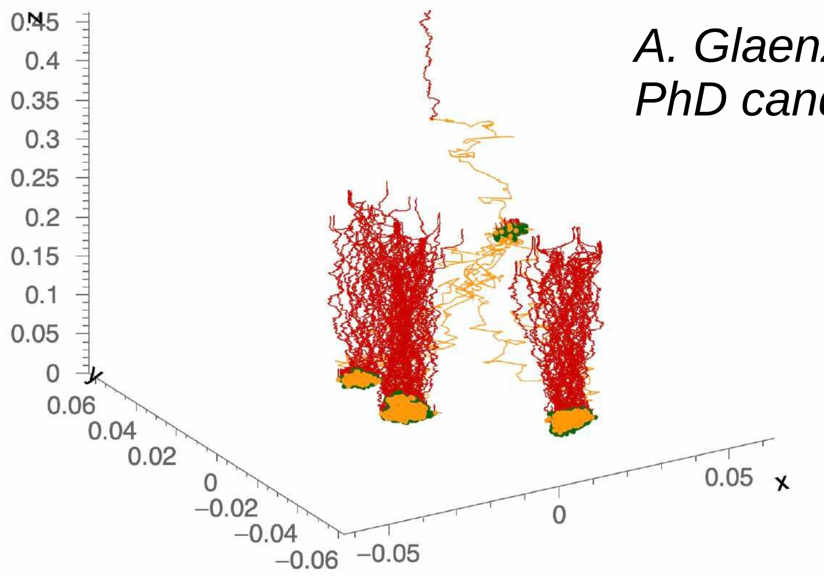


In collaboration with the UK’s Nuclear Physics Cross-Community Support Group at Daresbury Laboratory.

Task 2: Low IBF for TPC read out

- Requirements for a TPC at EIC
  - Gain ~2000
  - Good energy resolution: dE/dx < 12%
  - Lowest possible Ion Back Flow (IBF)
- During Covdi-19 lock-down, focus on exploring several hybrid combinations using GARFIELD++ (varying number of meshes and GEMs, their relative positions and E field configurations)
- Micromegas + (GEM + Micromesh), promising configuration
- Work also done in collaboration with Yale team

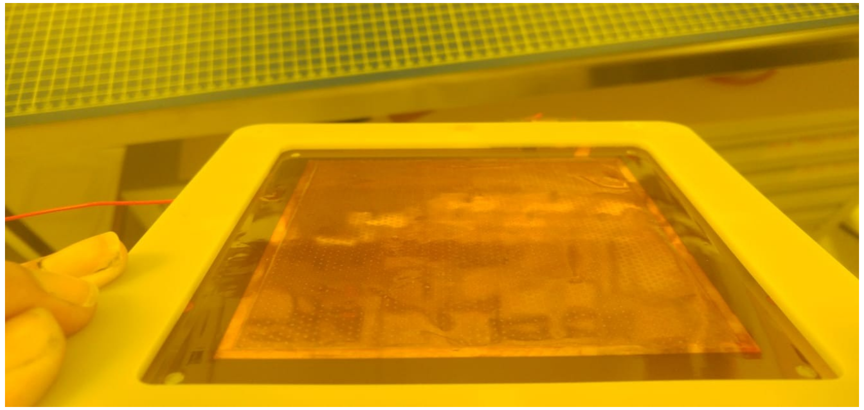


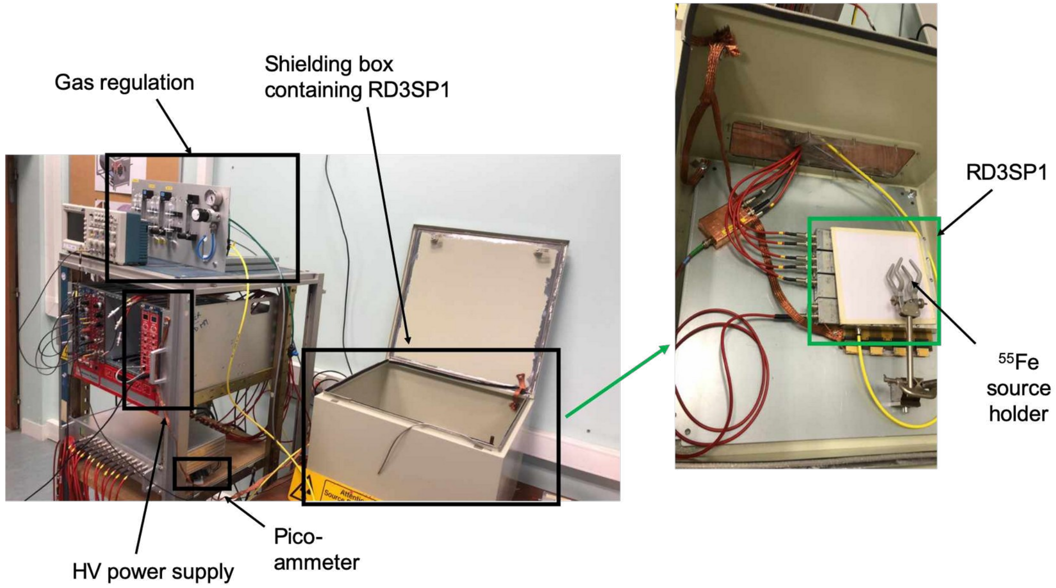


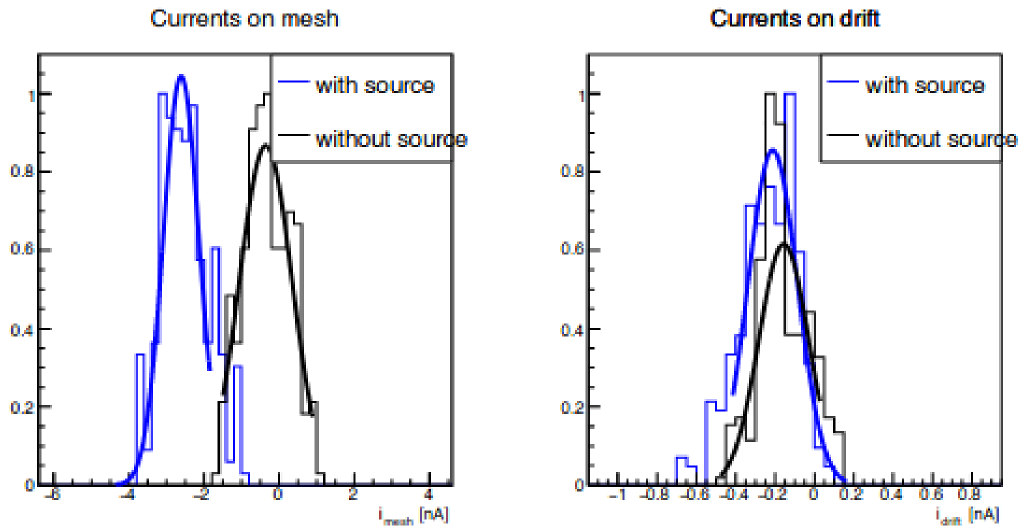
A. Glaenzer, PhD candidate

Low IBF prototype

- First milestone delayed due to Covid-19: now prototype production restarted
- First test of a MM + GEM + MM produced
- Ongoing preliminary characterization
- Expected delivery of fully functional prototype soon

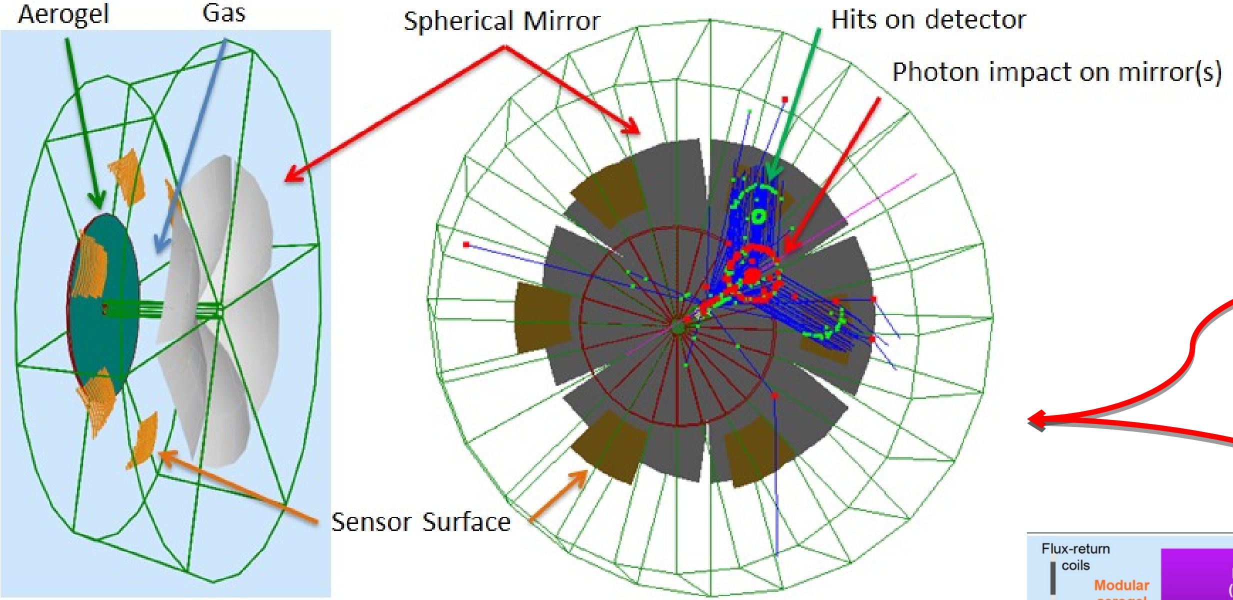


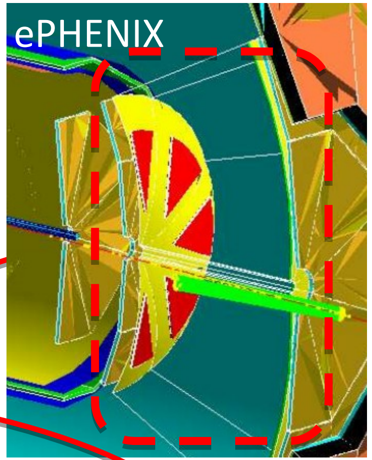


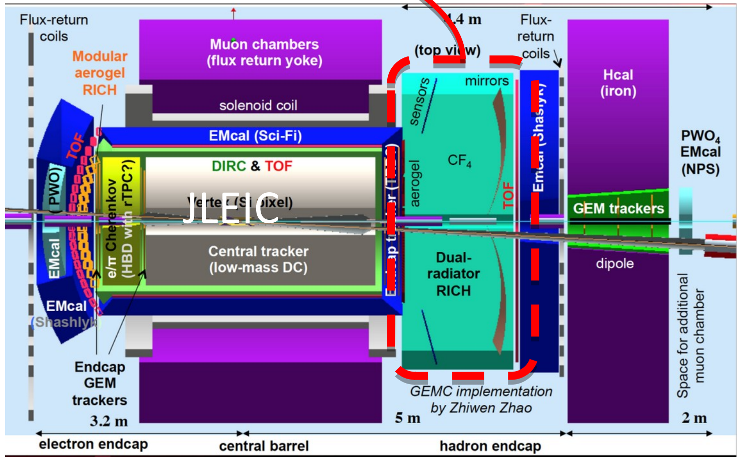


Task 3: Dual Radiator RICH in EIC Hadron-endcap

Phase Space:
- Polar angle: 5-25 deg
- Momentum: 3-60 GeV/c







dRICH: flexible configuration (JLEIC, ePHENIX)

Radiators: Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6} ~ 1.0008)

Detector: 0.5 m^2/sector , 3x3 mm^2 pixel

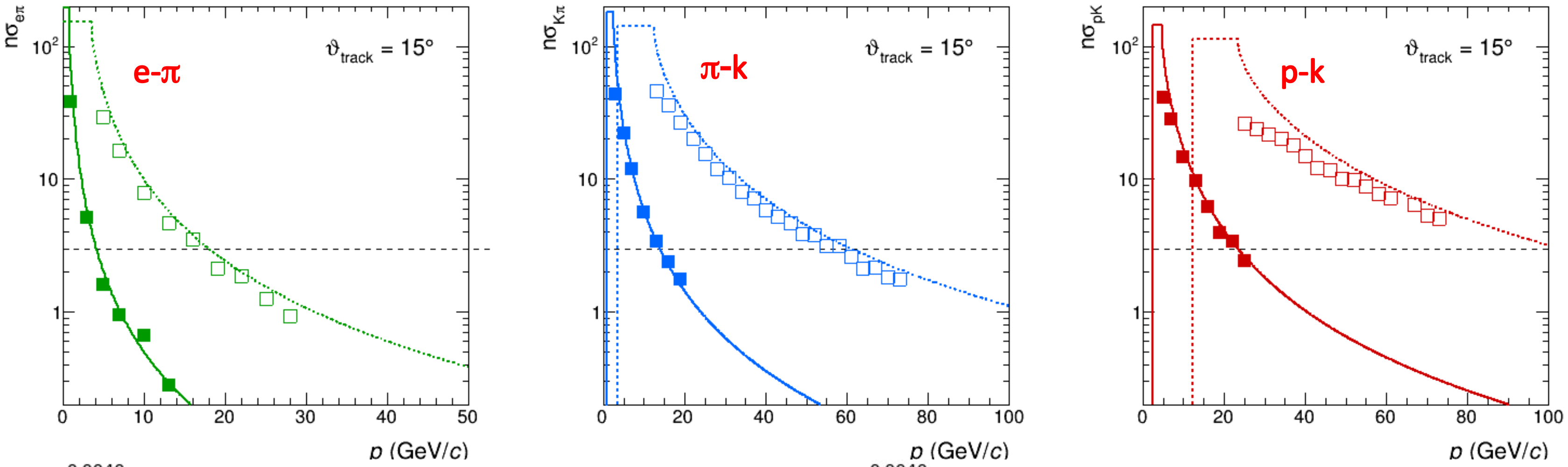
Single-photon detection in ~1T magnetic field

Outside acceptance, reduced constraints

best candidate for SiPM option

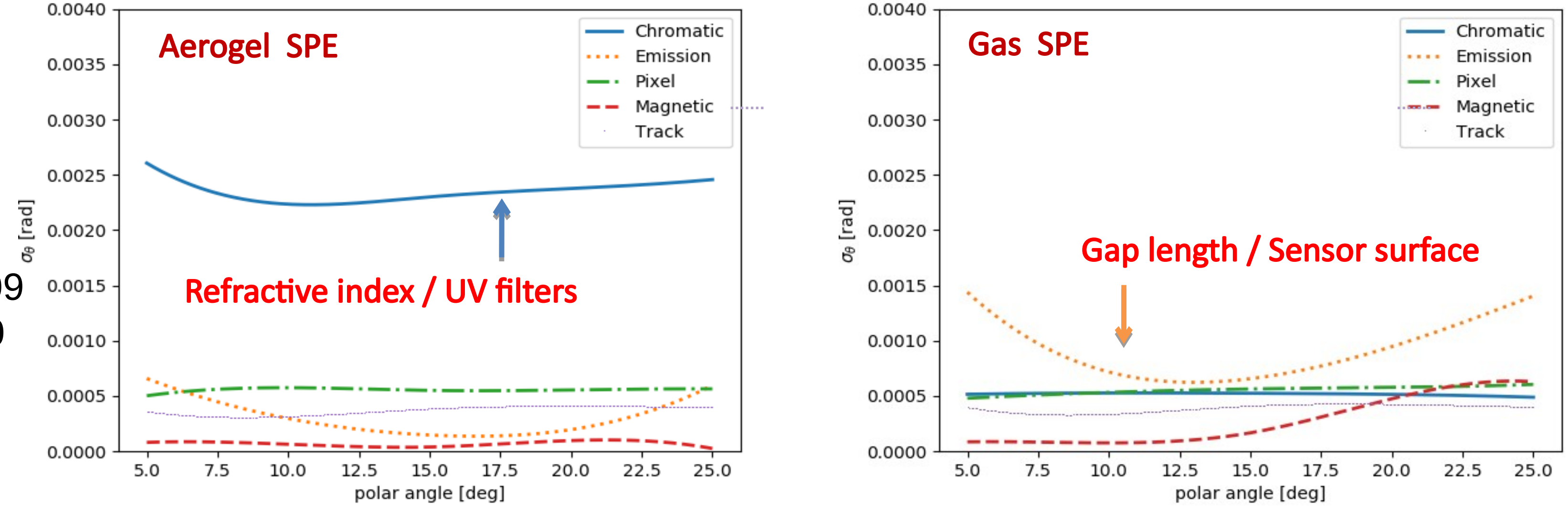
dRICH Feasibility Study

Compact and cost-effective solution for continuous momentum coverage (3-60 GeV/c)
Strong interest in the dRICH electron-pion separation capability



Studied with full Geant4 simulation, with Bayesian optimization and analytic parameterizations

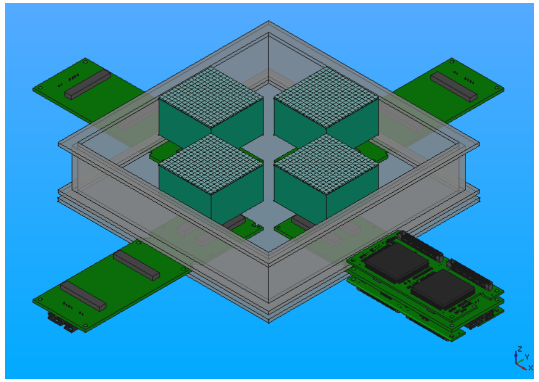
E. Cisbani et al., JINST 15 (2020) 05, P05009
L. Barion et al., JINST 15 (2020) 02, C02040

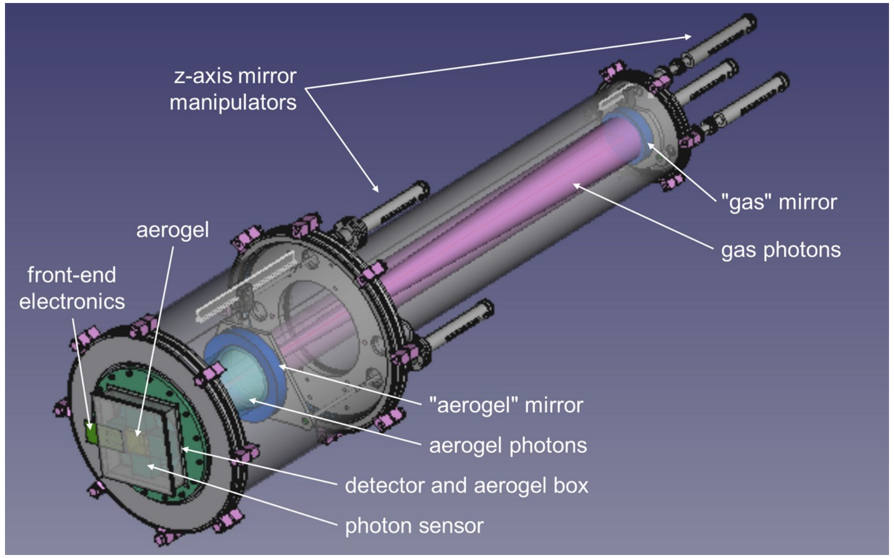


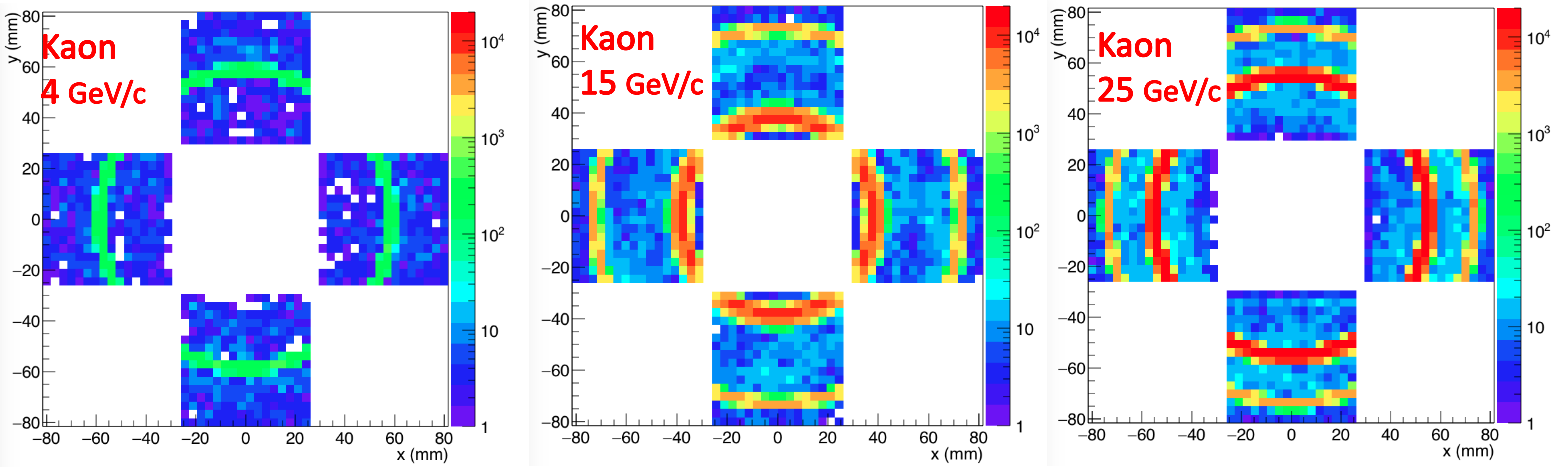
dRICH Prototype

Dual radiator imaging
Pressure vessel for gas & n tune
Sensor & readout friendly

4 x H13700







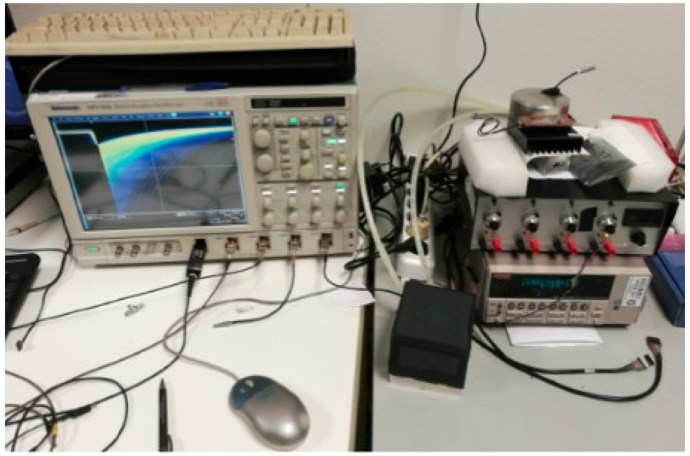
SiPM Program

SiPM: sampled for vendor, type and dose (at groups of 4) organized in 8 x 4 matrices for imaging to be irradiated up to 10^{11} n_{eq}/cm^2

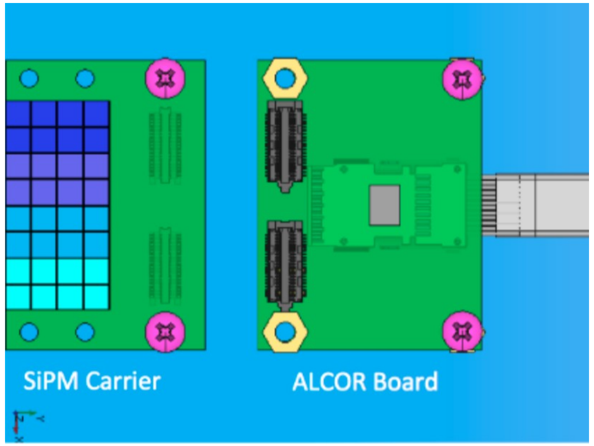
ALCOR: ASICS under development at INFN: ToT architecture for cryogenic application 32 channels, 50 ps TDC, >500 kHz/channel

Readout: bias distributors and signal pre-conditioning compatible with temperature treatments, laboratory characterization, and firefly high-data rate DAQ

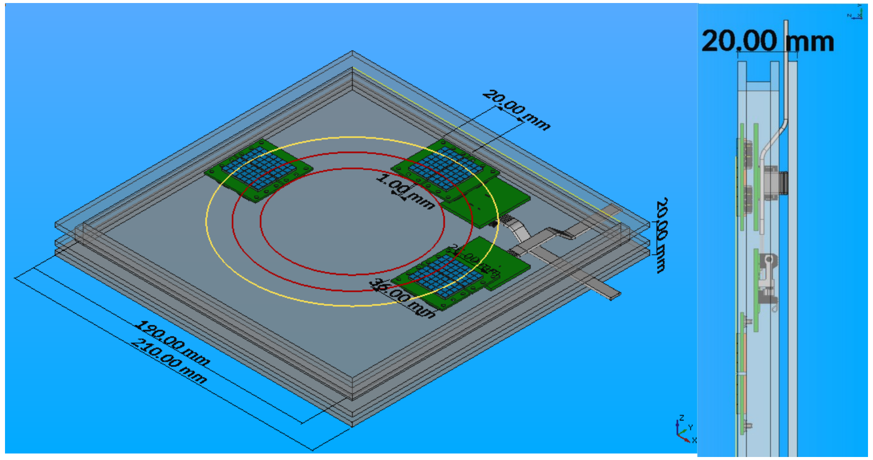
Laboratory characterization



Readout test with ALCOR chip



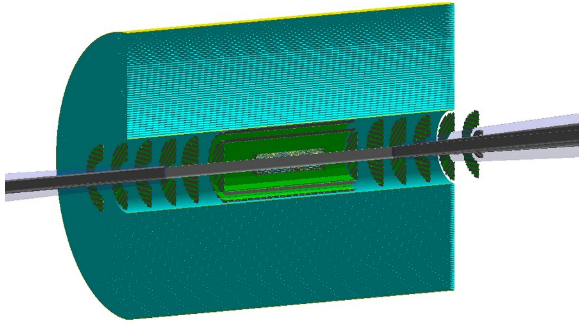
Imaging test with dRICH prototype



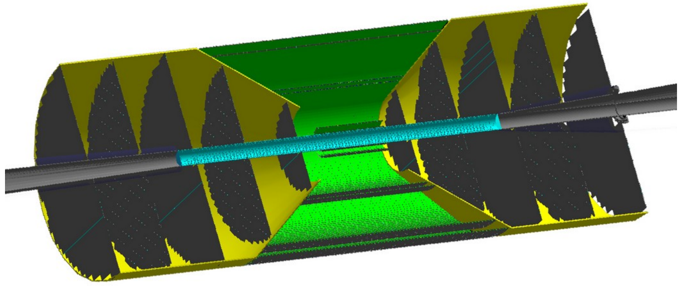
Task 4: EIC Silicon Vertex and Tracking (SVT) detector

- A **well integrated, large acceptance** silicon vertex and tracking (SVT) detector with **high granularity and low material budget** is needed to enable high precision measurements that are key to the EIC science programme
- Two baseline SVT concepts simulated: Hybrid with gas outer tracker and end-caps, all-silicon SVT compact tracker
- The detector technology identified to meet requirements is Monolithic Active Pixel Sensors (**MAPS**) in 65 nm CMOS technology

SVT requirements derived from simulations
- spatial resolution: < 5 μm in tracking layers and disks, < 2 μm in the vertex layers;
- material budget: < 1% X/X_0 in the vertex layers, <0.8% X/X_0 in the tracking layers, <0.3% X/X_0 in disks



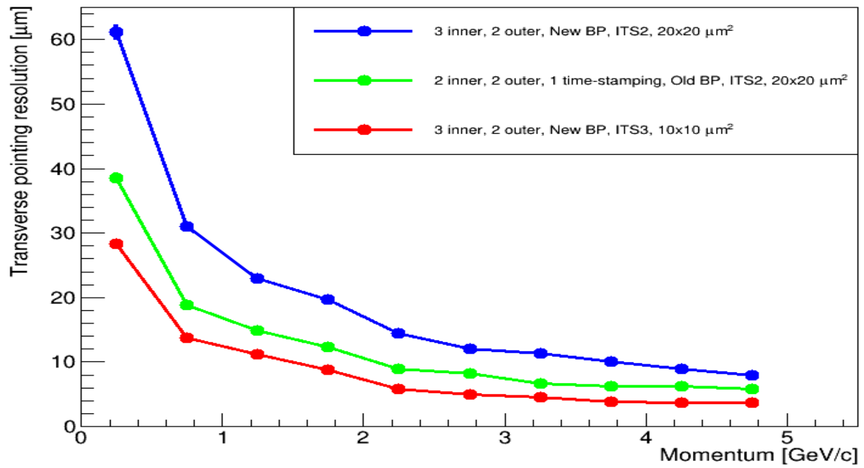
Baseline SVT parameters based on chosen sensor technology
10 μm pixel pitch, 0.05% X/X_0 vertex layers, 0.55% X/X_0 tracking layers, 0.24% X/X_0 disks



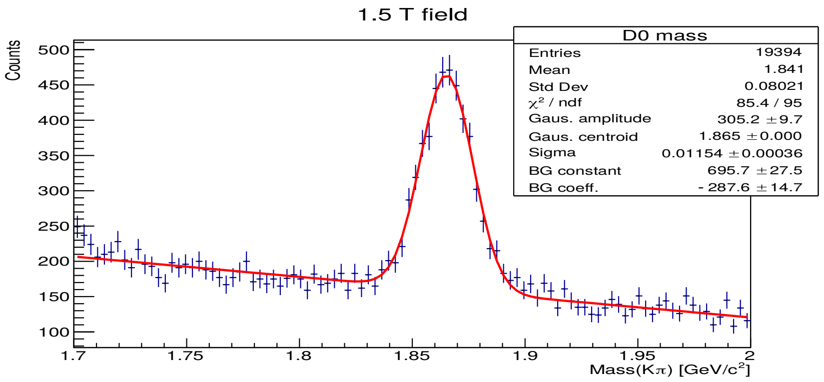
See also https://www.jlab.org/indico/event/400/contribution/9 and https://wiki.bnl.gov/conferences/images/1/1c/ERD25-proposal-Jul20.pdf

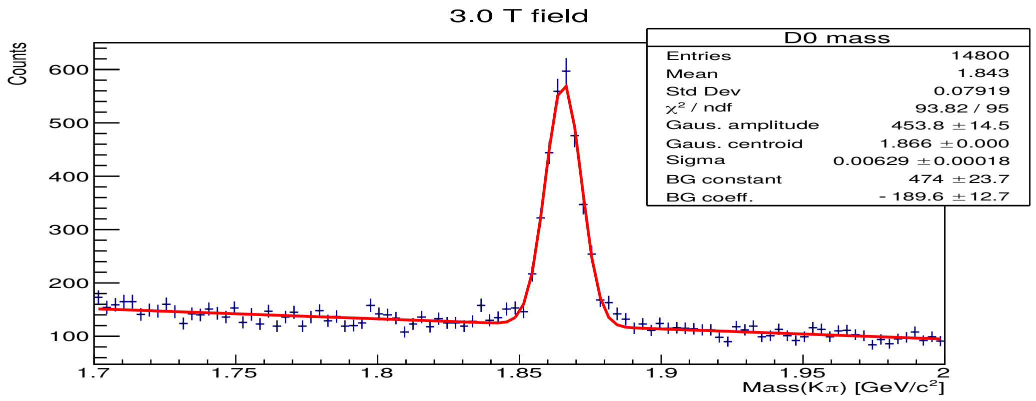
SVT simulations

- Baseline detector optimisation to meet physics requirements
  - Single particle studies of momentum and vertex resolution
  - Pre-CD0: ALICE ITS2-derived detector parameters satisfy requirements (full report at http://cern.ch/go/xKk6)
  - Post-CD0: **increased beam pipe radius requires higher granularity and lower material to achieve required vertex resolution**



- New baseline SVT layouts currently studied in physics performance simulations
  - Example: study of D^0 reconstructed mass, from hadronic decay to pion-kaon pair for different magnetic fields





SVT sensor development

- Preliminary EIC MAPS specifications defined
- Pre-CD0: technology evaluation and feasibility study for MAPS in 180 nm TowerJazz CMOS imaging technology completed
- Post-CD0: **65 nm MAPS** identified to satisfy updated requirements
  - **Improved performance** for precision measurements at the EIC and process availability on the EIC project timescale
  - **Collaborative development with the ALICE ITS3 project**, largely compatible sensor requirements and timescale
  - **EIC Silicon Consortium** involved already in first ITS3 65 nm submission planned for November 2020 in the TJ 65 nm CMOS imaging process
  - TJ 180 nm process kept as backup

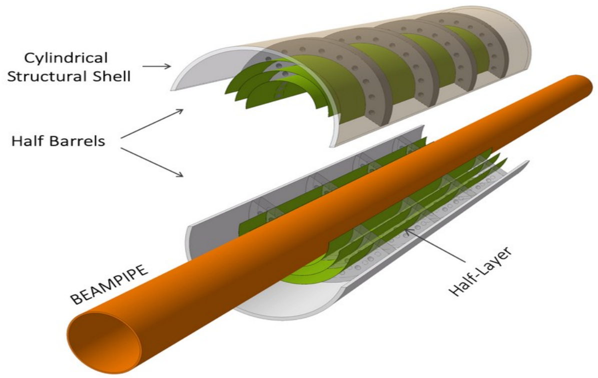
Parameter	EIC Vertex and Tracking MAPS
Technology	TJ ISC 65 nm (Backup: TJ CIS 180 nm)
Substrate Resistivity [kohm cm]	1 or higher
Collection Electrode	Small
Detector Capacitance [fF]	<5
Chip size [cm x cm]	Full reticule or stitched
Pixel size [μm x μm]	20 x 20
Integration Time [μs]	2
Timing Resolution [ns]	< 9 (optional)
Particle Rate [kHz/mm²]	**TBD**
Readout Architecture	Asynchronous
Power [mW/cm²]	< 20
NIEL [1MeV neq/cm²]	10^{10}
TID [Mrad]	< 10
Noise [electrons]	< 50
Fake Hit Rate [hits/s]	$< 10^{-5}$/evt/pix
Interface Requirements	**TBD**

Specifications

ALICE

Parameter	ALPIDE (existing)	Wafer-scale sensor (this proposal)
Technology node	180 nm	65 nm
Silicon thickness	50 μm	20-40 μm
Pixel size	27 x 29 μm	O(10 x 10 μm)
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	~ 5 μs	~ 200 ns
Time resolution	~ 1 μs	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm²	100 MHz/cm²
Max particle readout rate	10 MHz/cm²	100 MHz/cm²
Power Consumption	40 mW/cm²	< 20 mW/cm² (pixel matrix)
Detection efficiency	> 99%	> 99%
Fake hit rate	$< 10^{-7}$ event/pixel	$< 10^{-7}$ event/pixel
NIEL radiation tolerance	$\sim 3 \times 10^{13}$ 1 MeV n_{eq}/cm^2	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	3 MRad	10 MRad

M. Mager | ITS3 kickoff | 04.12.2019 |



ALICE-PUBLIC-2018-013 https://cds.cern.ch/record/2644611

Milestones

Milestones due for Reporting Period 1

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS48	EIC PID and tracking design	U GLASGOW	18	Report available
MS49	IBF-stopping device prototypes constructed	CEA SACLAY	15	Up and running

Deviations from expected delivery:

- MS48: the report will be part of the Yellow Report book that will be published in January 2021
- MS49: the production of a low IBF prototype was due for month 15, but due to the Covid-19, few months of delay has been accounted for.

JRA6 Participants

Brookhaven National Lab (BNL)
Centre National de la Recherche Scientifique (CNRS) *Institut de Physique Nucleaire d'Orsay*
Istituto Nazionale di Fisica Nucleare (INFN) *INFN Laboratori Nazionali di Frascati*
Istituto Nazionale di Fisica Nucleare (INFN) *INFN Sezione di Pavia*
Istituto Nazionale di Fisica Nucleare (INFN) *INFN Sezione di Roma 1*
Jefferson Lab (JLab)
University of Antwerpen (UAntwerp)
University of Edinburgh (UEdinburgh)
Universié Libre de Bruxelles (ULBrussels)
University of the Basque Country (UPV-EHU Bilbao)
University of Santiago de Compostela (USC)

Summary

All tasks of JR6 well advanced

- Simulations of physics processes for the EIC YR have defined tight constraints on the EIC detector
- A promising configuration of an low IBF device has been studied in simulation and the prototype is under construction
- Optimization of dRICH design in simulation and ongoing work on SiPM sensor studies
- A new 65 nm CMOS technology has been chosen for the EIC SVT design.

Major participation of JRA6 members to the EIC Yellow Report: significant impact on the EIC detector design and technologies