DE LA RECHERCHE À L'INDUSTRIE

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EIC, the Ultimate Machine for Hadron Physics. A CEA's Perspective

CEA/Irfu activities on EIC

F. Bossù

CEA/Irfu (aka CEA-Saclay)

APCTP Workshop on the Physics of Electron Ion Collider
Nov 3rd 2022

DE LA RECHERCHE À L'INDUSTRIE

CEA/IRFU,

SHORT PRESENTATION

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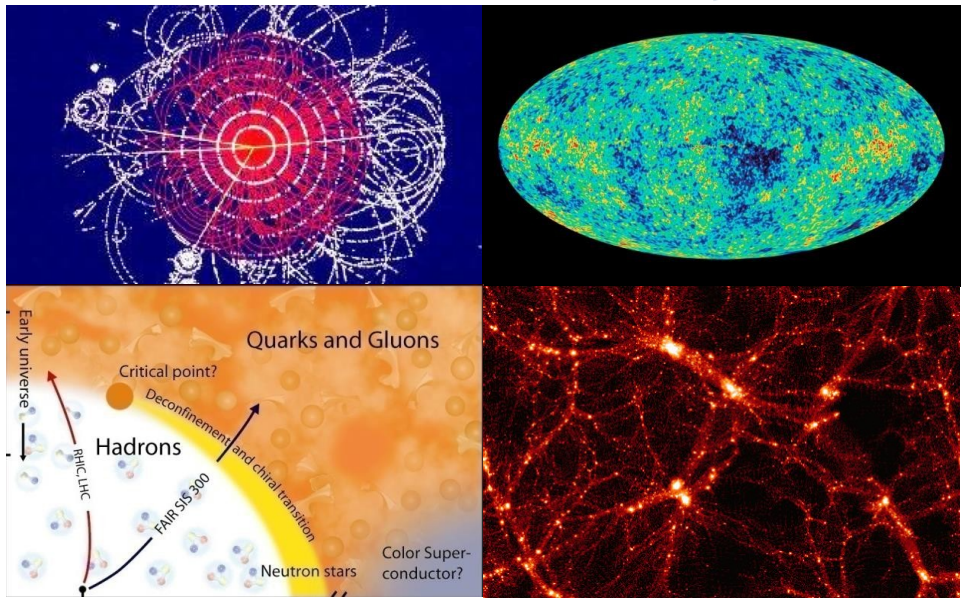
IRFU: Research Institute on the Fundamental laws of the Univers

What are the ultimate constituents of matter?
- LHC (ATLAS, CMS)
- Neutrinos (accelerator, reactor, source)

What is the energy content of the Universe ?
- Dark matter & energy (CTA, DESI, EUCLID))
- Antimatter (GBAR)

Infinitely small → *Infinitely large*

Elementary ↓ *Complex*



What are the origins of particles and nuclei ?
- Exotic nuclei (Riken, Ganil)
- QGP (ALICE, LHCb)
- Structure (Compass, CLAS12, EIC)

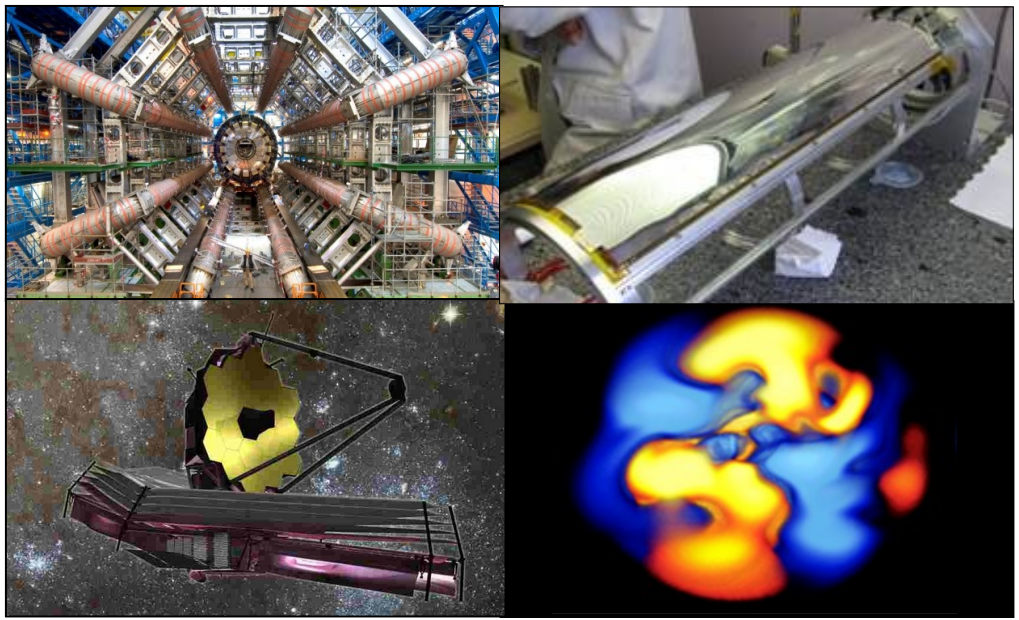
What are the origin and structure of the Universe ?
- Star and galaxies (Artemis, JWST, ELT))
- Planets (Solar Orbiter, Plato))
- Violent phenomena (SVOM, ATHENA))

Accelerator and superconducting magnets

- Intense ion sources, RFQ, Cryomodules:
- Superconducting magnets for accelerators and detectors
- Beam dynamics

Detecting

- Gaseous detectors (Micromegas)
- Solid detectors (bolometers)
- Electronics (ASICs)



Observing : space devices

- Camera, spectroimaging,..
  From X-ray to sub-mm
- cryomecanisms

Simulating

- HPC
- Grid

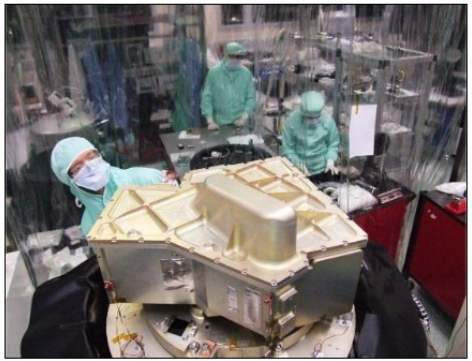
Irfu – facilities

DETECTORS

Large migromegas detectors integration and tests (LHC UPGRADES)

Clean room - 130m²

SPACE

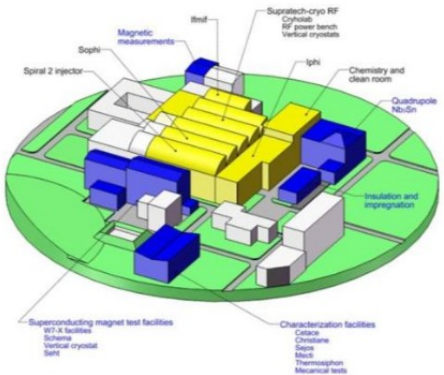


Clean rooms for space instruments integration and tests

Magnets and accelerators

Synergium - 25 000m²

Integration halls, clean rooms cryostats



Computing

HPC cluster

Node of Grid@LHC

Irfu structure

CEA
Alternative Energies & Atomic Energy Commission

Basic Research

Irfu
Institut de recherche sur les lois fondamentales de l'univers
Head: Franck Sabatié

- **DAp** Astrophysics
- **DPhN** Nuclear physics
- **DPhP** Particle physics
- **DACM** Accelerators, Magnets
- **DEDIP** Detectors, Electronics, Computing
- **DIS** Engineering
- **GANIL**

More than 1100 FTEs

DPhN:
Four research groups (laboratories):
LENA, LERN, LQGP, LSN.

LSN: Nucleon Structure Laboratory

(SOME) HIGHLIGHTS IN HADRON PHYSICS

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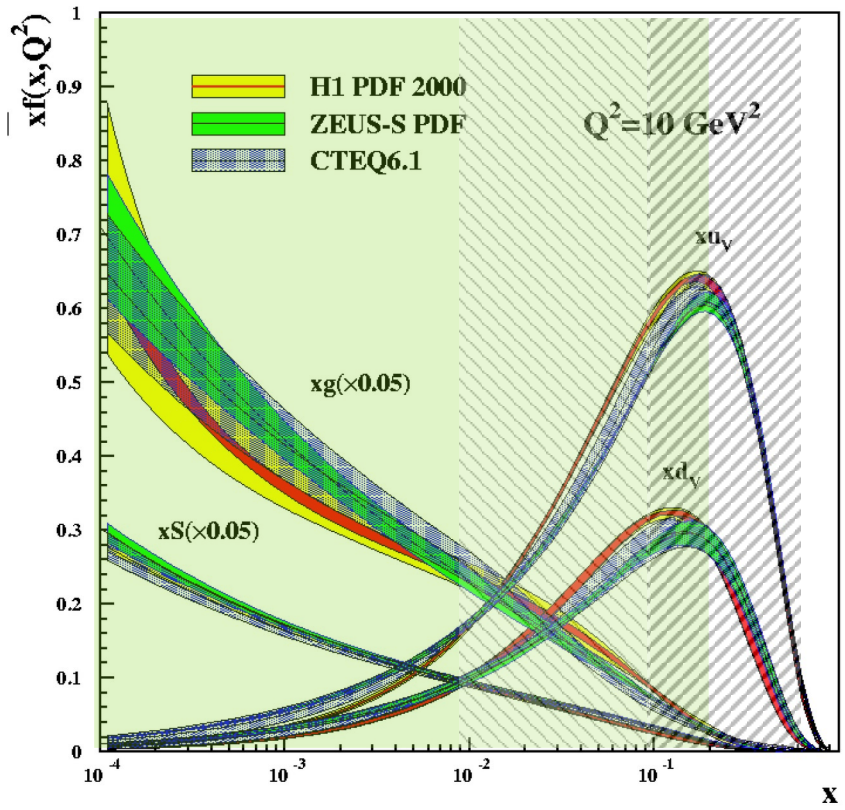
Nucleon at different scales



Valence region: $0.1<x_B<0.7$

Fixed target electron scattering

See region: $0.01<x_B<0.1$

Fixed target muon scattering

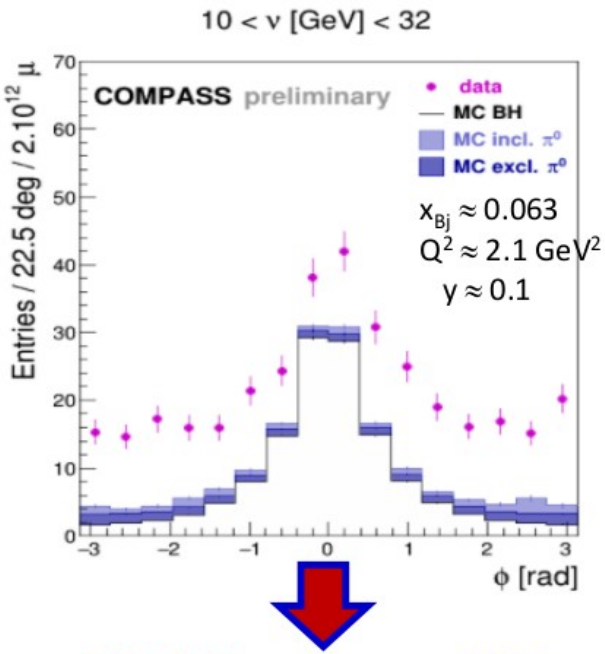
Gluons: $10^{-4}<x_B<0.2$

The EIC to explore the nucleon down to gluon saturation regime

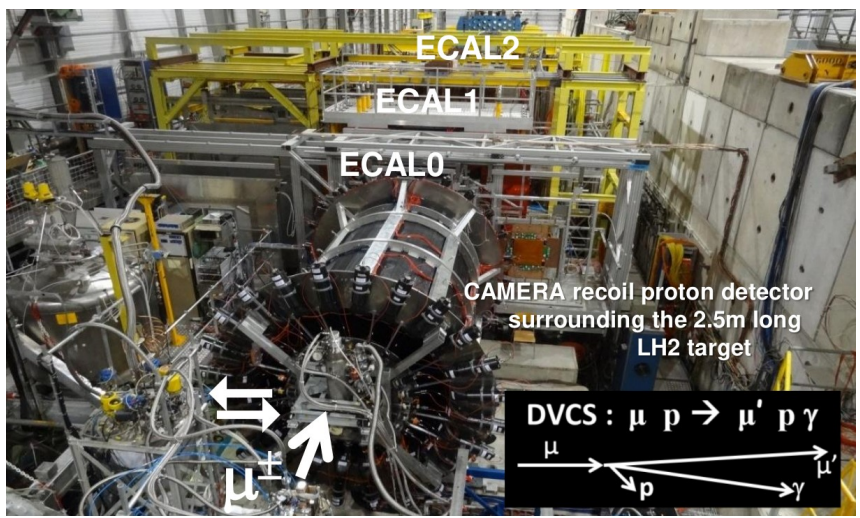
Luminosities 100 – 1000 times that of HERA

DVCS at COMPASS

N.d'Hose



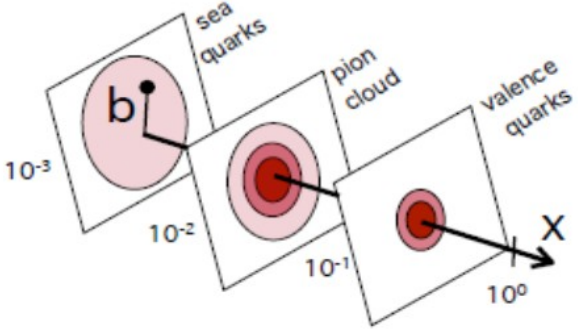
- A dedicated recoil proton detector (CAMERA)
- Leadership in the DVCS analysis
- Data taking: $\mu^{\pm}$ beams of E=160GeV on a LH2 target
  - Test run in 2012
  - 2016 and 2017, 2x6 months



DVCS at COMPASS

$$d\sigma^{DVCS}/dt = e^{-B|t|} = c_0^{DVCS} \propto (Im\mathcal{H})^2$$

$$\langle b_\perp^2(x)\rangle \approx 2B(\xi)$$



3σ difference between 2012 and 2016 data

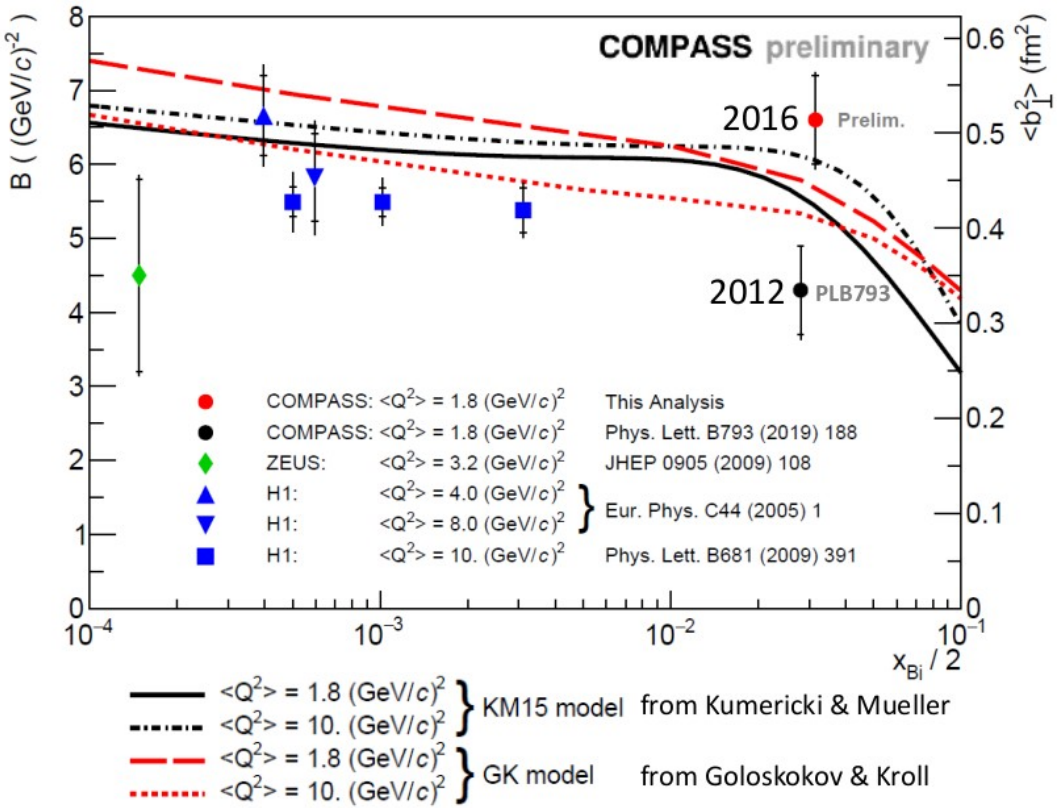
- more advanced analysis with 2016 data
- π^0 contamination with different thresholds
- binning with 3 variables (t,Q^2,ν) or 4 variables (t,ϕ,Q^2,ν)

2012 statistics = Ref

2016 analysed statistics = 2.3 × Ref

2016+2017 expected statistics = 10 × Ref

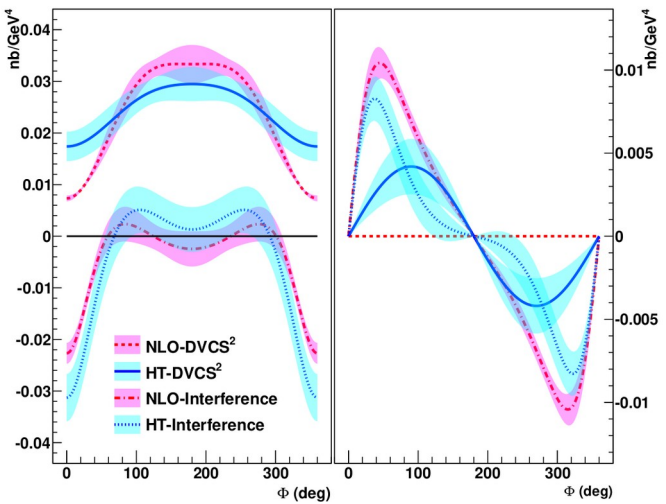
N.d'Hose



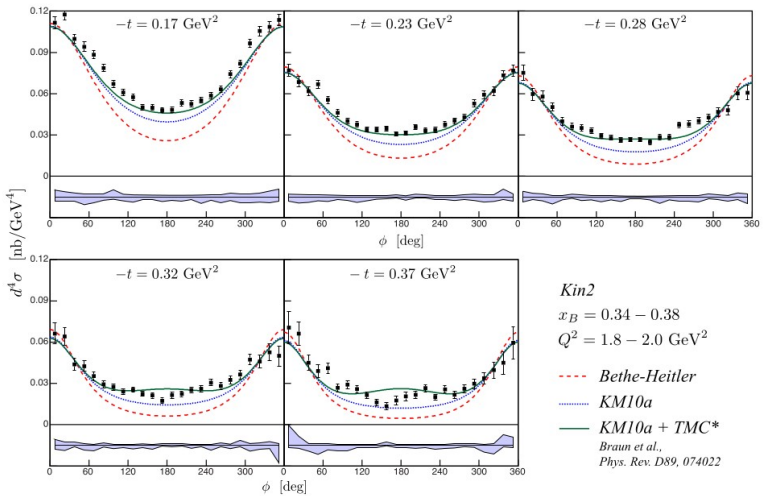
DVCS at JLab – 6GeV

At 6GeV:

- Hall A DVCS experiment for high statistics on unpolarized target
- Fixed kinematics but multiple beam energies



M. Defurne et al., Hall A collaboration, Nat. comms.8, 1408 (2017)



M. Defurne et al., Hall A collaboration, Phys.Rev. C92 (2015) no.5, 055202

- Separation of the DVCS² and the DVCS-BH interference
- Need for gluons to explain the data, NLO or higher twist contributions

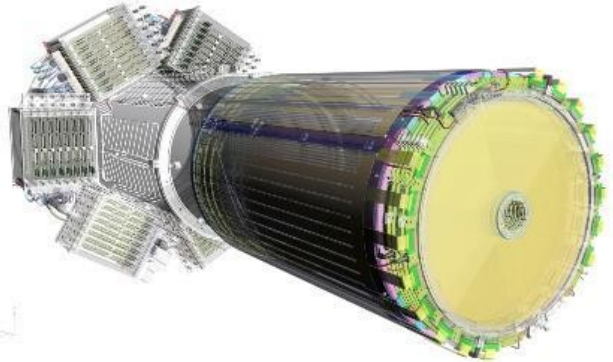
DVCS at JLab – 12GeV

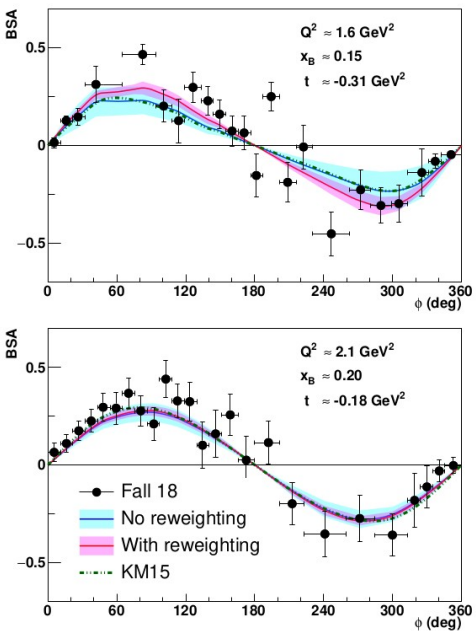
Involvement in CLAS12

- Run Group A proponent leadership
- Spokepersons of DVCS experiments

Contributions to CLAS12

- Micromegas Vertex Tracker
- Forward Tagger Tracker
- LH2 target upgrade



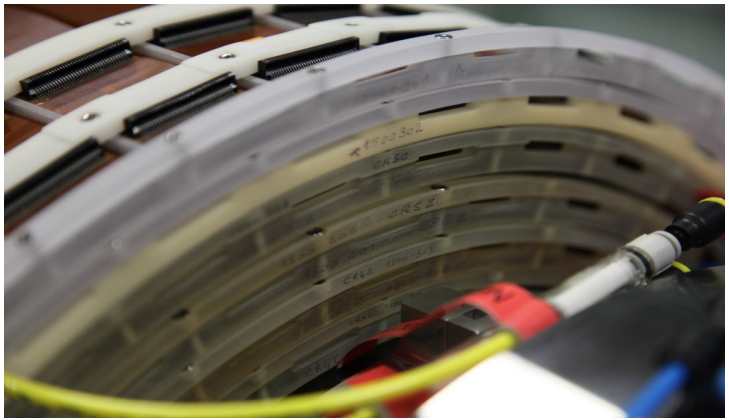


- DVCS Beam spin asymmetries from RGA experiment
- Results will be published soon (in collaboration review)
- Extend the kinematic reach at higher Q^2
- The large statistics allow the reduction of GPD extraction uncertainties

G. Christiaens et al., CLAS collaboration, soon on arXiv

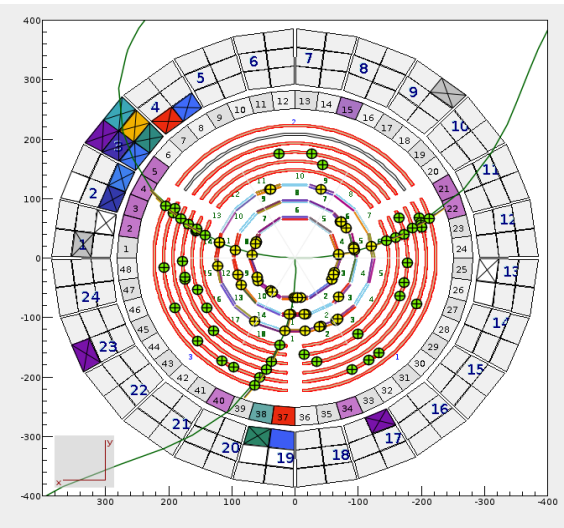
Cylindrical MicroMegas for CLAS12

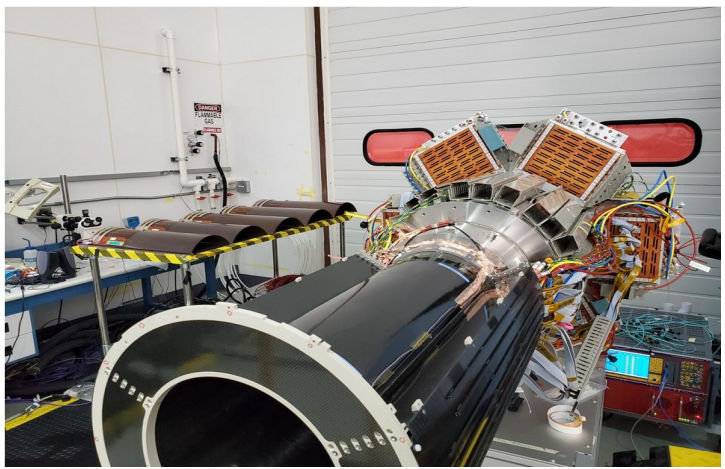
- 4 m² of curved Micromegas detectors
- DREAM based Front-End Electronics ~ 20k ch.
- Low momentum particles => Light Detectors ~0.4% of X0
- Limited space of ~10 cm for 6 layers (small radius ~12 cm)
- High magnetic field (5T)
- 6 Layers with different R (18 detectors total), 1D readout
- Up to 10 MHz of signal rate
- **Taking data since 2017**



Dedicated ASIC developped

Dream : Dead-timeless Read-out Electronics ASIC for Micromegas





Theory/Phenomenology

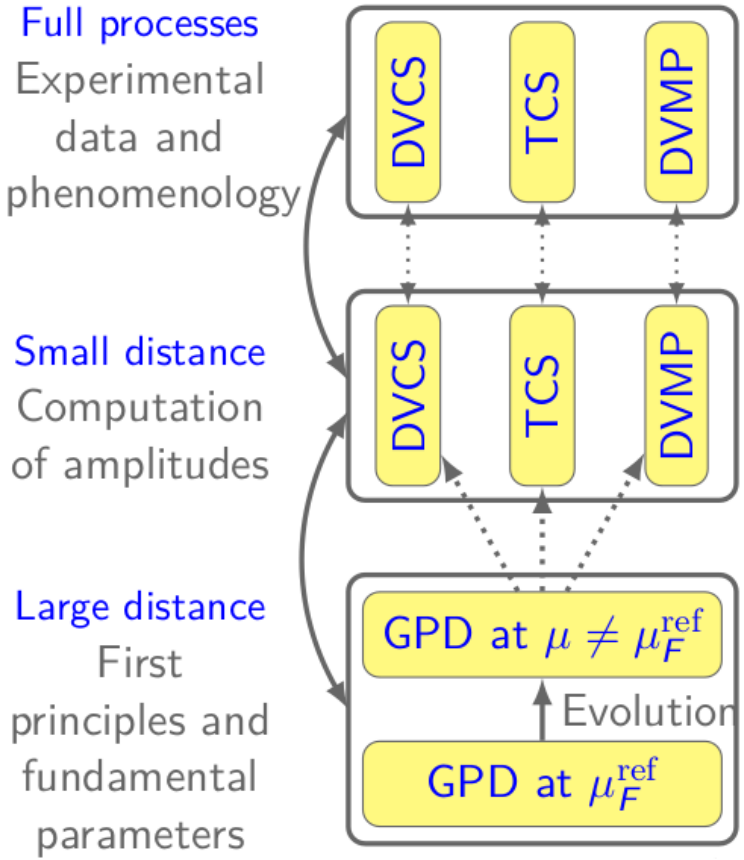
- **Framework** for the theory and phenomenology of GPDs and TMDs
- **Open source**

- Recent interface with Apfel++ for GPD evolution
- A PARTONS based event generator (EpIC) for DVCS and TCS developed during the EIC YR

A PDF evolution library in C++

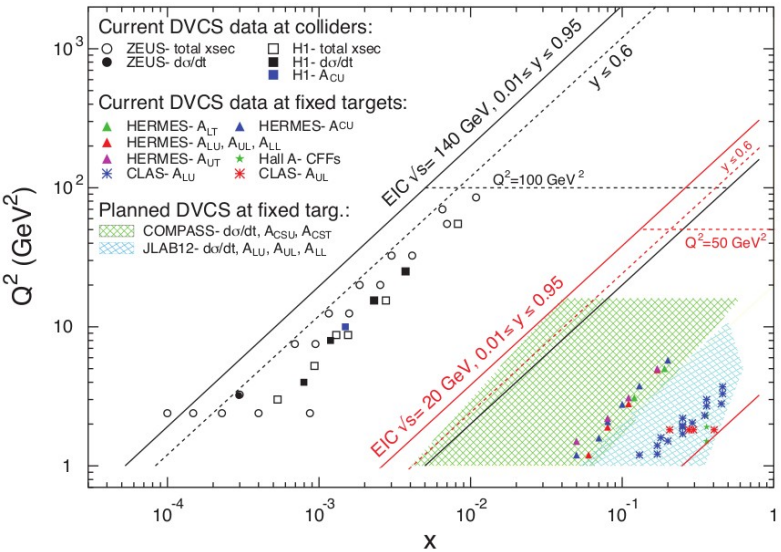
Eur.Phys.J.C 82 (2022) 10, 888

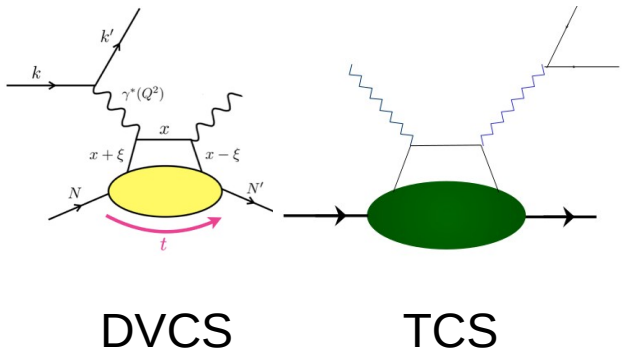
Eur.Phys.J.C 82 (2022) 9, 819



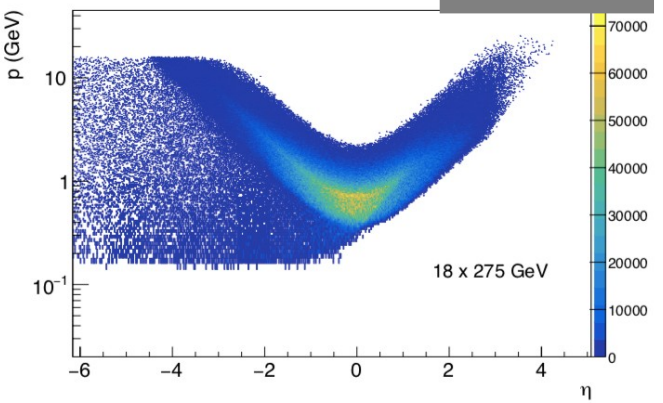
Eur.Phys.J.C 78 (2018) 6, 478

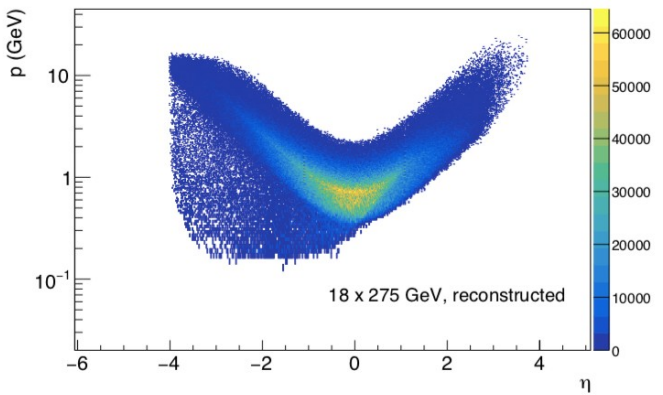
DVCS and TCS at EIC

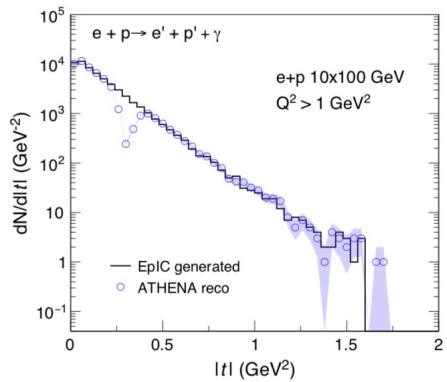




D.Sokhan





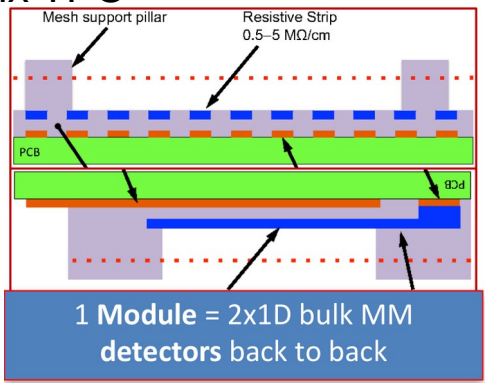


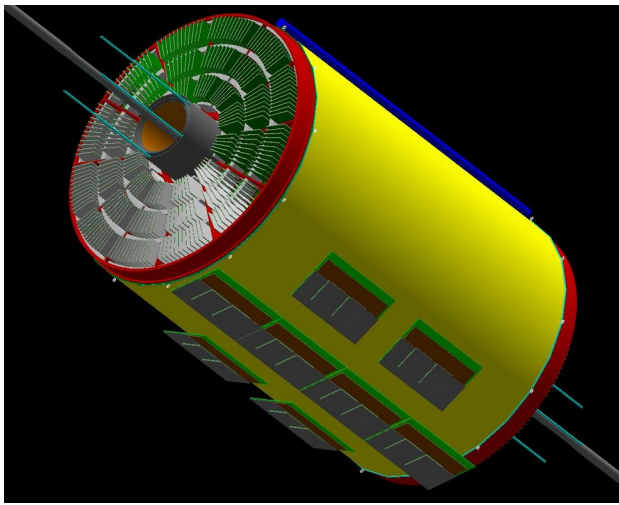
- EIC expands the kinematic range achievable at fix target
- EpIC used as event generator
- DVCS studies focusing on pi0 background
- TCS studies show promising results for BSA

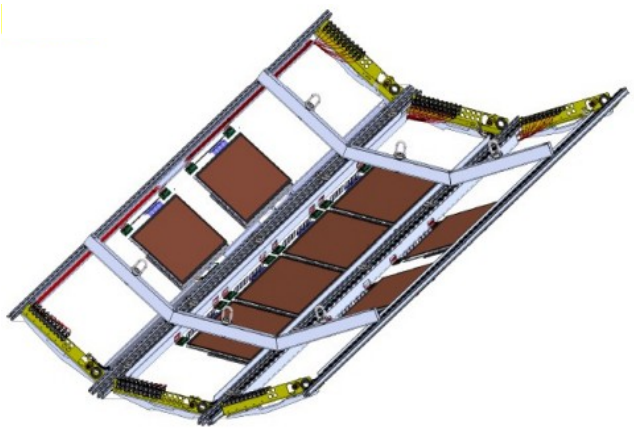
TPOT – sPhenix

TPOT: TPC Outer Tracker

- Provide a measurement point outside the sPhenix TPC
- Useful for space charge distortion corrections
- 10 modules: 2x1D MicroMegas per module
- Resistive technology for spark protection
- Readout same as TPC: SAMPA FEE
- Production started beginning 2022
- Installation at BNL in Sep 2022



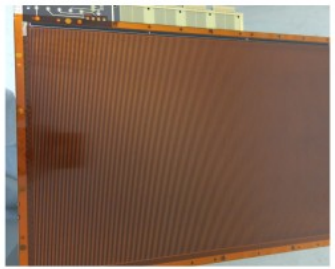




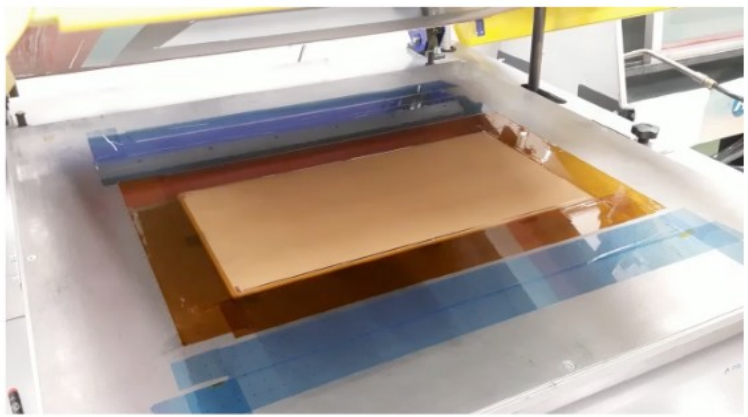
TPOT – sPhenix

Production in Saclay

PCB at Saclay

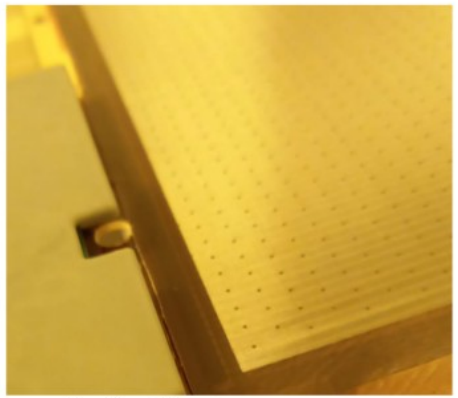


Resistive foil pressed on PCB



Printing resistive strips at Saclay

First test process



"Bulked" micromegas

3D printed frame

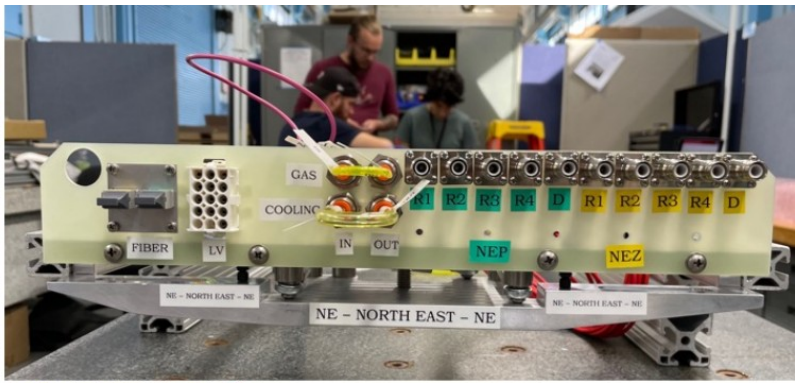
Frist carbon drift

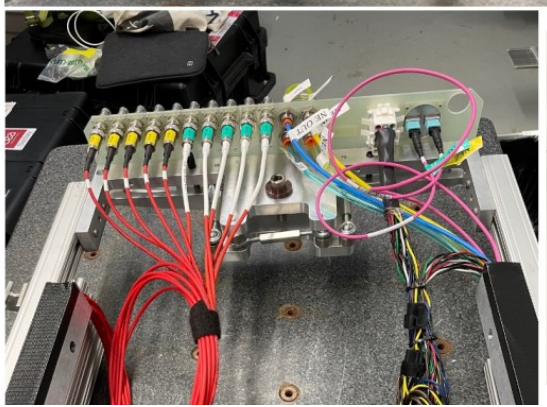
Frist carbon drift

TPOT – sPhenix

Sep 2022

- Four people from CEA
- Tests after shipping at SBU
- Assembly of the modules on the support mechanics in BNL





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CURRENT ACTIVITIES IN EIC AND ASPIRATIONS

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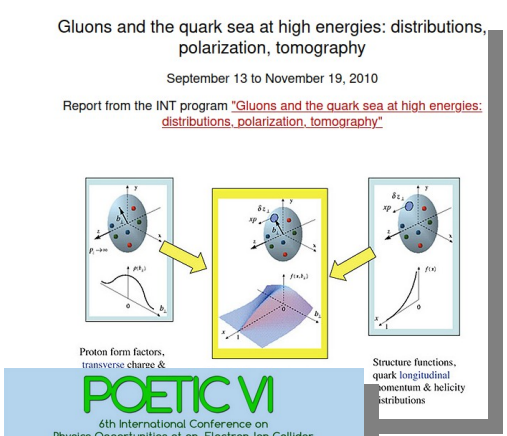
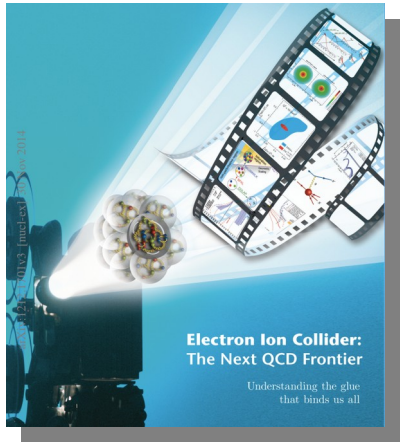
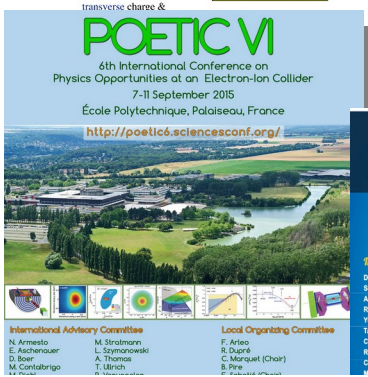
Road to EIC

Pre-Yellow Report

- 2010: INT report on the joint BNL/INT/Jlab program on the science case for an EIC
- 2012: EIC White Paper, F. Sabatié as writing committee member
- 2015: Organization (with CPhT Ecole Polytechnique) of POETIC VI in Palaiseau
- 2019: Co-organization (with IJCLab-Orsay) of EICUG meeting in Paris
- 2020: Expression of Interest submission







CEA-Saclay/Irfu (France) - Expression of Interest (EOI)

Please indicate the name of the contact person for this submission:

Primary contact: Francesco Bossù (francesco.bossu@cea.fr, +33 1 69 08 86 23)
On detectors: Maxence Vandenbroucke (maxence.vandenbroucke@cea.fr)
On electronics: Irakli Mandjavidze(irakli.mandjavidze@cea.fr), Damien Neyret (damien.neyret@cea.fr)
On software: Hervé Moutarde (herve.moutarde@cea.fr)

Road to EIC

Yellow Report:

- Co-convener of the DAQ/Electronics WG (D.Neyret)
- Active contributions in the exclusive and SIDIS physics WG
- Development of an event generator for DVCS/DVMP studies
- Participation in the Tracking WG studies on hybrid trackers

Detector proposal:

- Contribution to the ATHENA proposal.
- F. Sabatié as member of ATHENA Executive Board
- ATHENA Tracking WG co-convener (F.Bossù)
- ATHENA Exclusive physics co-convener (D. Sokhan)

EIC: current involvement

EIC User Group:

- F. Sabatié – co-chair of the Charter Committee
- D. Sokhan – EU representative on the Steering Committee
- Currently, 18 registered users

ePIC Detector:

- Design of a new superconducting solenoid magnet in collaboration with JLab
- F. Sabatié – co-chair of the IB and member of the Charter Committee
- F. Bossù – co-convener of the Tracking WG
- D. Sokhan – co-convener of the Exclusive Processes WG

EIC R&D program:

- Participation in eRD108 on cylindrical MPGD tracking detectors and eRD109 on FEE
- Submission on two proposals for the generic R&D call: 1) development of a PLL IP block for FEE ASICs; 2) Development of DMAPS for ToF applications

Design of a solenoid for ePIC

New solenoidal magnet @ 1.5 T (minimum), possibly 2.0 T

Design collaboration between CEA/Irfu and Jlab

Requirements:

Geometric
- Must fit into BaBar's volume

Transparency
- Thickness / interaction length < 1

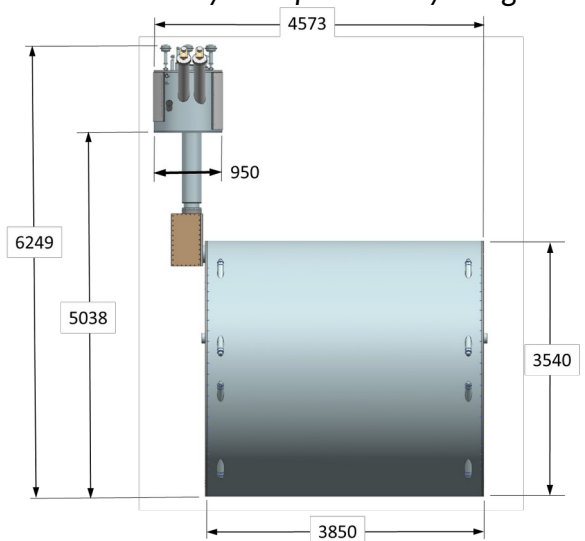
Stray field
- B < 10 G in the focalizing magnets zone

Magnetic
- B @ IP = 1.5 T to 2.0 T
- Field Uniformity < 12.5%
- Projectivity < 10 T/Amm^{-2}

MARCO

***MA**gnet with **R**enewed **CO**ils*

MARCO Cryostat preliminary design

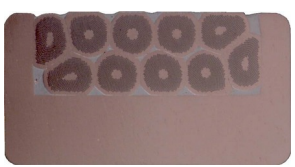


Design of a solenoid for ePIC

About the cable:

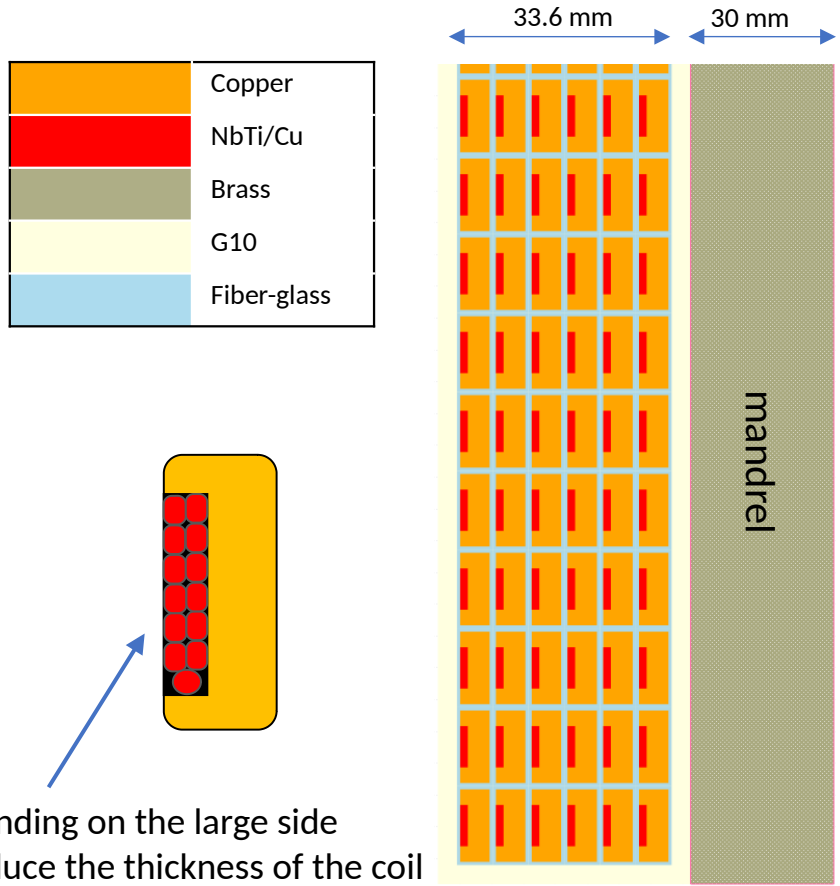
- Aluminum would be the best option to minimize the interaction length
- No existing extrusion line in the world
- Workshop on Superconducting Detector Magnets @ CERN, 12/14 Sept 2022 : **Aluminum stabilized conductors won't be available for a long time**
- Copper must be used instead

***RIC**: **R**utherford cable **I**n **C**opper Channel*



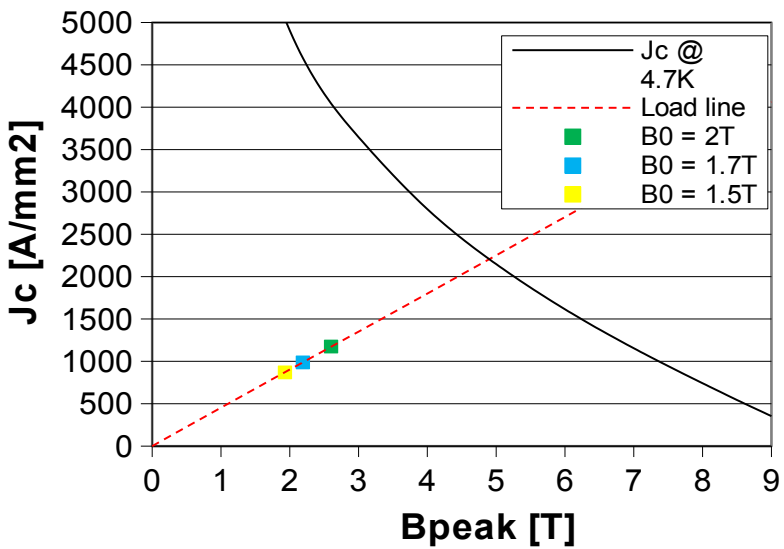
RIC conductor for ***Iseult*** **(MRI magnet)**

- Designed at CEA Saclay
- Cable insertion by Luvata at Waterbury still exist



Design of a solenoid for ePIC

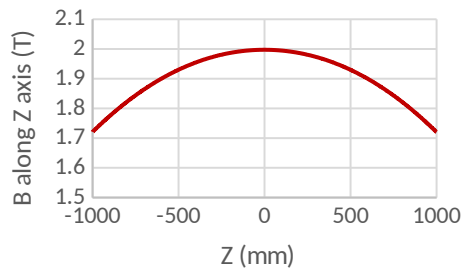
MARCO designed with large safety margins to ensure long time operations



Value	1.5 T	1.7 T	2.0 T	Units	Criterion
Current	2900	3296	3924	A	
B_0	1.500	1.704	2.023	T	2.0
Uniformity	12.3	12.3	12.3	%	< 12.5%
Projectivity	1.806	2.047	2.408	T/Amm²	< 10

MARCO respects the criteria on

- **The magnetic field at center**
- **The uniformity**
- **The projectivity**



MARCO is mature to start the detailed phase design, to be achieved by the end of 2023.

Cylindrical MicroMegas R&D

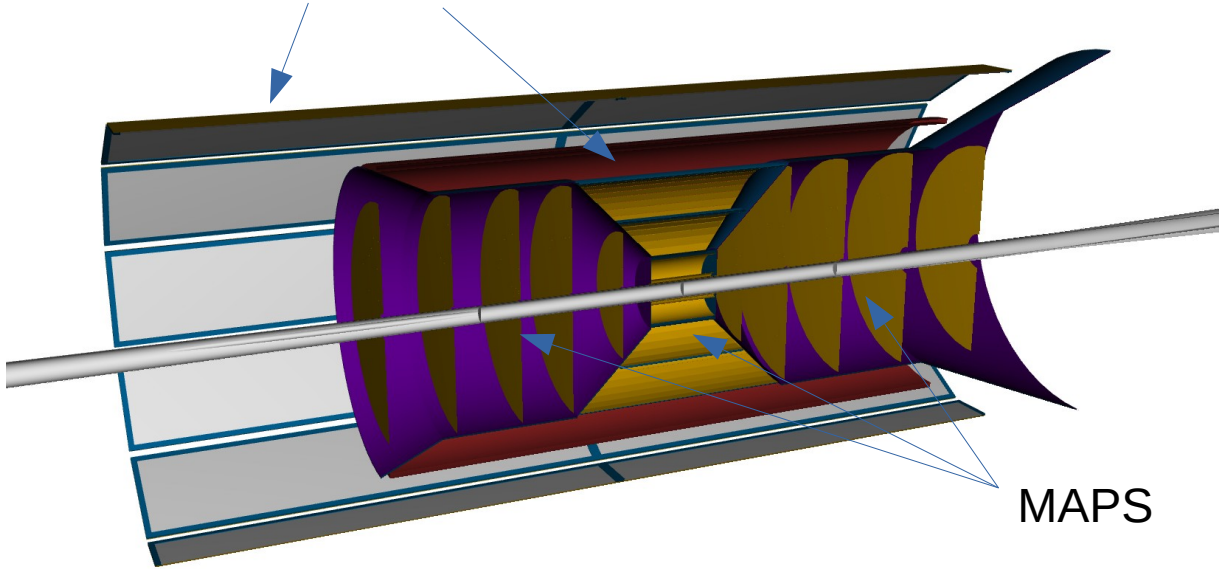
MicroPattern Gaseous Detectors (MPGDs) are a cost effective solution for large area tracking detectors

Two MPGD applications in ePIC:

- Barrel tracking:
  - Cylindrical layer(s) to complement the silicon tracker
  - Required to be low mass
  - Spatial resolution ~100µm
- Support for PID detectors:
  - Complement hpDIRC
  - Space point after the PID detector to constrain the track direction determination
  - Spatial resolution ~100µm

MicroMegas and/or µRWELL can fulfill these requirements

MPGD layers in ePIC



Current ePIC tracking system

MPGDs for ePIC is the focus of eRD108

Cylindrical MicroMegas R&D

Motivation

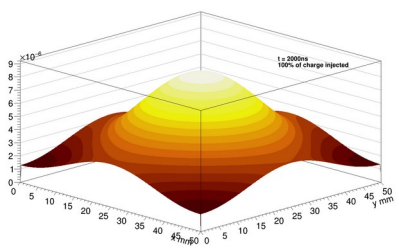
- Build a full (no acceptance gaps) light-weight modular Micromegas barrel tracker to complement the silicon vertex detector
- Take the existing 1D MM technology from CLAS12 and upgrade it to be **2D readout**

Objectives

- Optimization of the 2D readout to reach resolutions of ~100–150 µm with the fewest possible number of channels
- Full size prototype module in 2023 50x70cm^2
- Find industrial partner for 50x100cm^2 (or bigger)

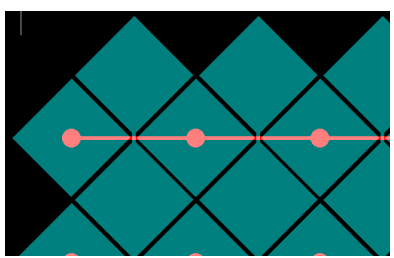
Activities

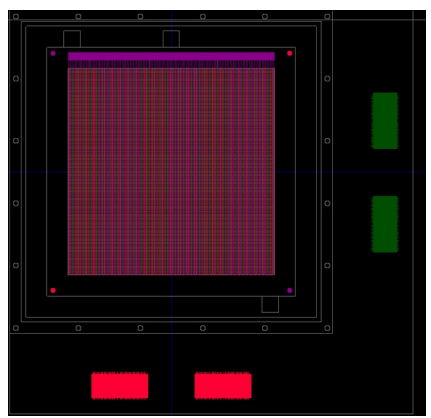
- **Finite difference element simulation of the resistive layer** coupled with Garfield++ output
- This tool will be calibrated with prototype results



Example of the charge density on the resistive surface 2µs after injection

Readout pattern design:
Several design 2D patterns:
- Orthogonal strips
- ASACUSA like readout



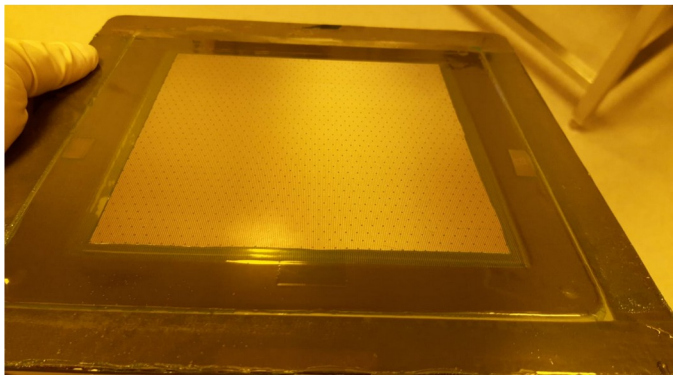


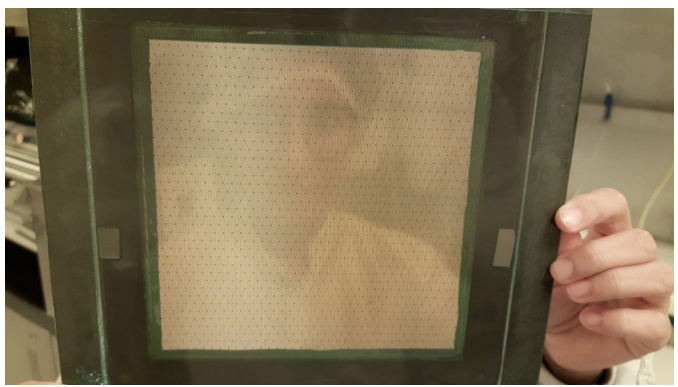
Cylindrical MicroMegas R&D

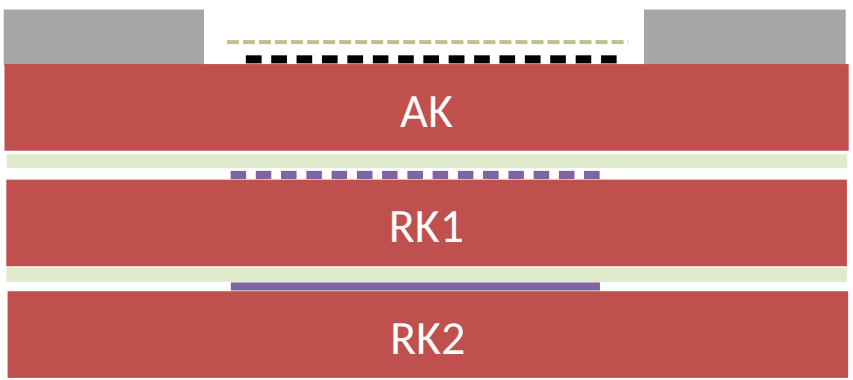
Prototype design and R&D

Amplification Kapton (AK): a Kapton foil with resistive paste stretched on a carbon fiber frame and then bulk with a micromesh

- AKs with different resistivity will be glued together with Kapton foils with 2D readout patterns
- First tests of assembly of AK are promising: holding up to 900V between the resistive layer and the mesh in air.

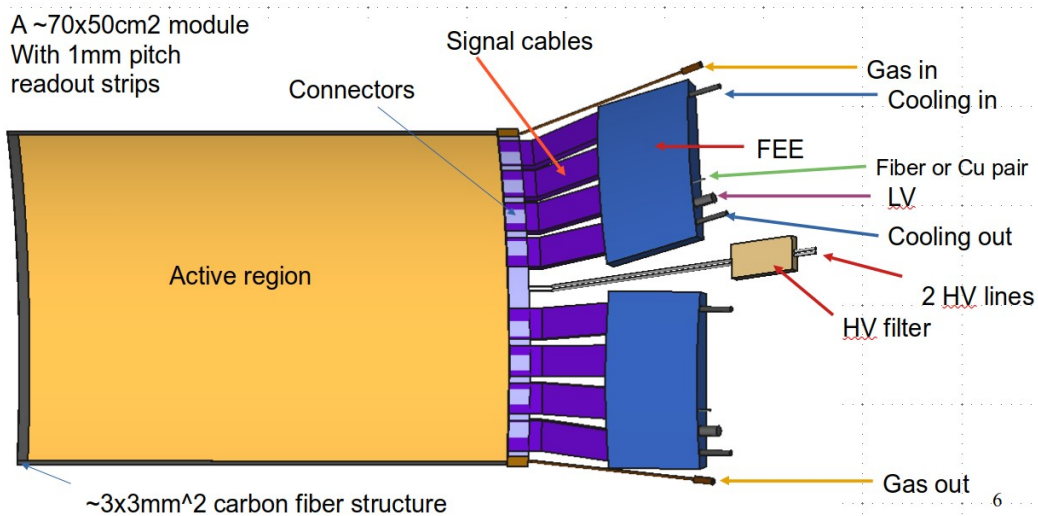


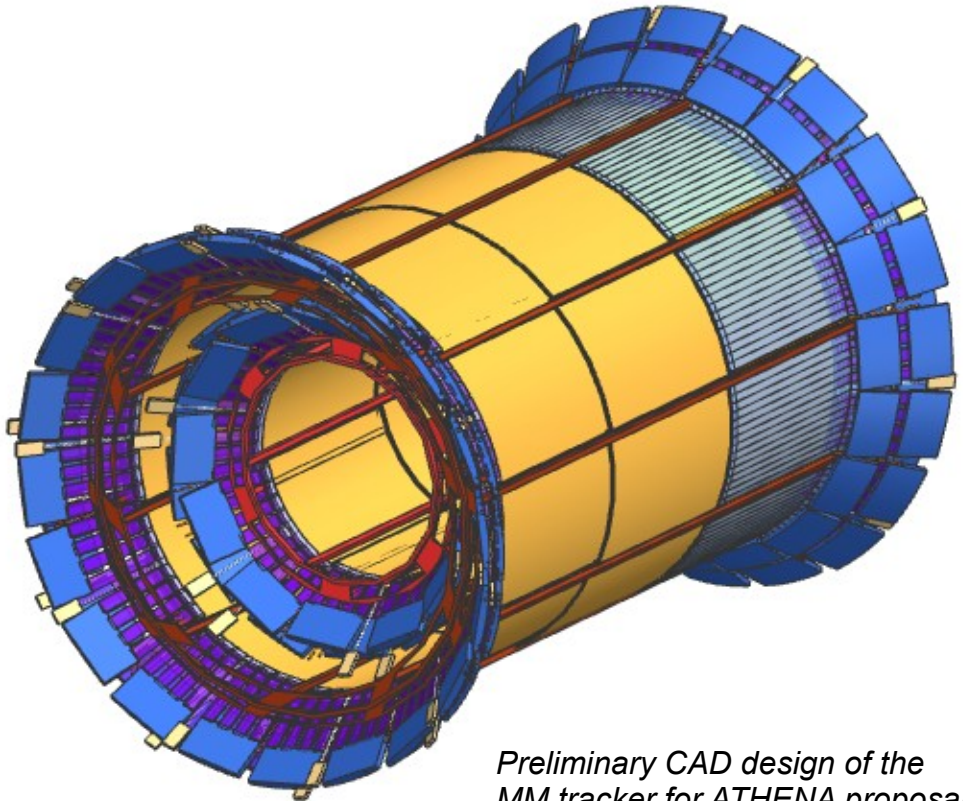




Cylindrical MicroMegas R&D

- First **CAD design** of the whole Micromegas tracker for the ATHENA proposal
- Being used also as starting point for ePIC

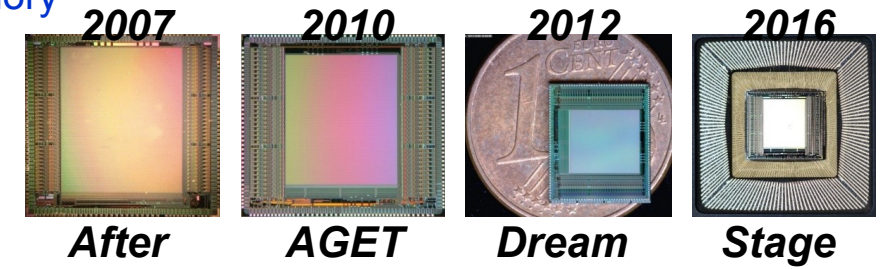




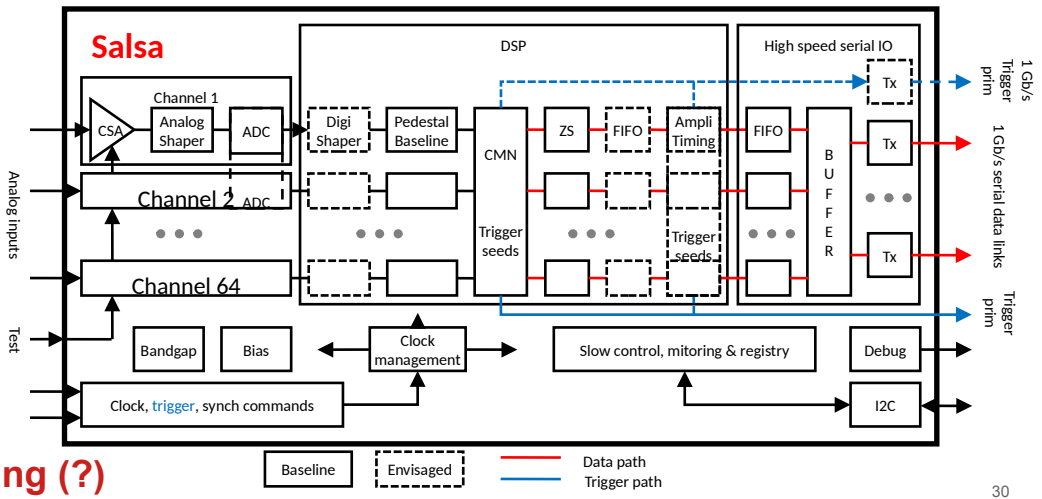
Preliminary CAD design of the MM tracker for ATHENA proposal

SALSA: ASIC for MPGDs

- Success story of 64-channel ASICs based on CSA and SCA memory
  - → Flexible Charge Sensitive Amplifier
    - Programmable dynamic ranges and shaping times
  - → 512-cell deep Switched Capacitor Array analog memory
  - → Long drift length TPC and high rate tracker research applications
  - → Applications in archeology, medicine, security
  - → ASICs, frontends and turn-key systems in experiments and R&D projects in Africa, Americas, Asia, Europe
    - *e.g.* T2K (Japan), Clas12 (Jefferson Lab, USA), ScanPyramids (Egypt), PandaX-III (China), etc...



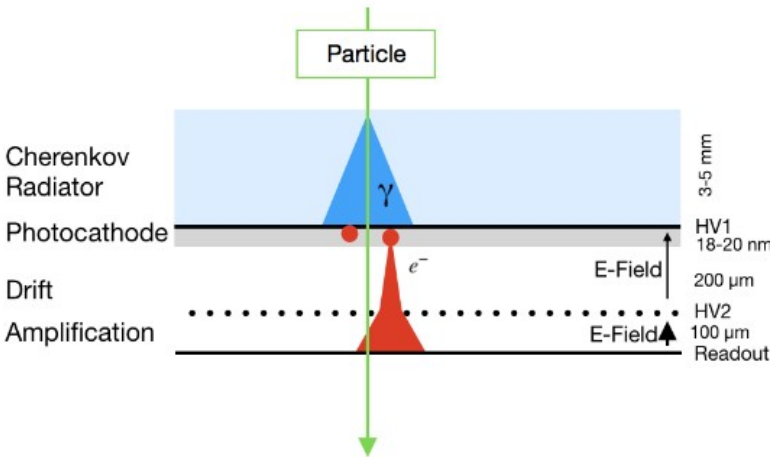
- 2022: **Development of future SALSA chip**
  - → **With** Sao-Paolo University consortium ~~**– Sampa !**~~
  - → 64-channel versatile ASIC
  - → Streaming and triggered readout
  - → Flexible programmable **front-end**
    - 50-500 ns peaking times
    - 0-50 fC to 0-5 pC dynamic range
    - 50-200 pF input cap but still efficient up to 1 nF
  - → 12-bit 50 (100) MHz **ADC** per channel
  - → DSP: pedestals, common mode noise, ZS, **peak finding (?)**
  - → Radiation hard design in **65 nm technology**



NewChip_RD51workshop_20210617.pdf

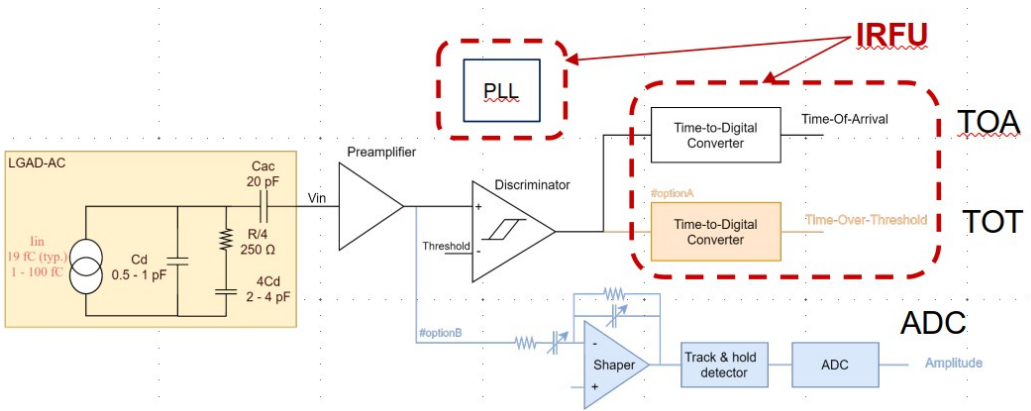
Picosec: MicroMegas for timing detectors

- Use light (Cerenkov radiation) instead of ionization: fast detectors
- Cheap and modular design
- Time resolution ~25 ps for MIPs



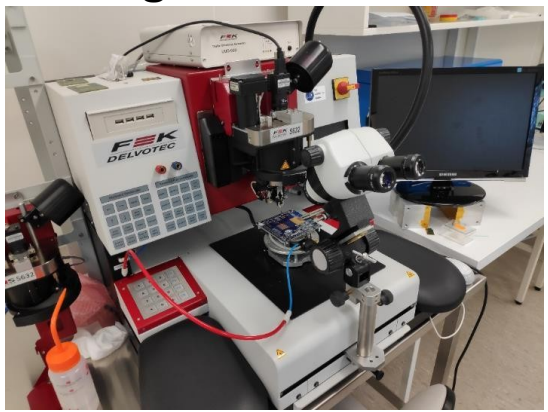
ASIC for AC-LGAD

- Consortium: IJCLab, Omega, Irfu
- Goal: 4D tracking with ultrafast silicon detectors
- Irfu contribution on high performance TDC

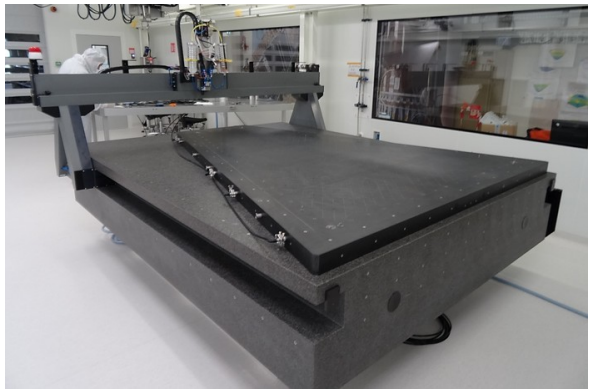


(SOME OF THE) ELECTRONICS AND DETECTOR FACILITIES

Wire-bonding machines

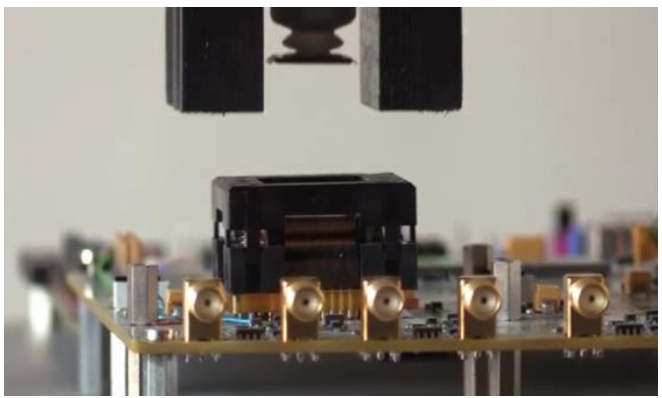


Large area clean rooms



CICLAD clean room: ~150 m2

Robotized test bench for ASIC



MPGD workshop

Summary

- Overview of CEA/Irfu structure and activities on hadron and EIC physics
- Irfu is strongly involved in ePIC
- Irfu is leading the design of the new magnet for ePIC
- Active R&D on 2D low-mass cylindrical MircoMegas for tracking
- A new ASIC for MPGD readout is being developed
- Participating in the development of the ASIC for AC-LGAD readout
- R&D ongoing on MicroMegas based timing detectors