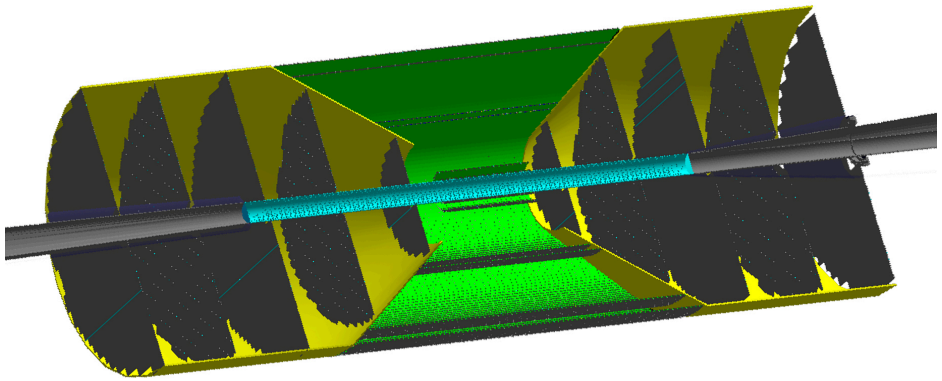
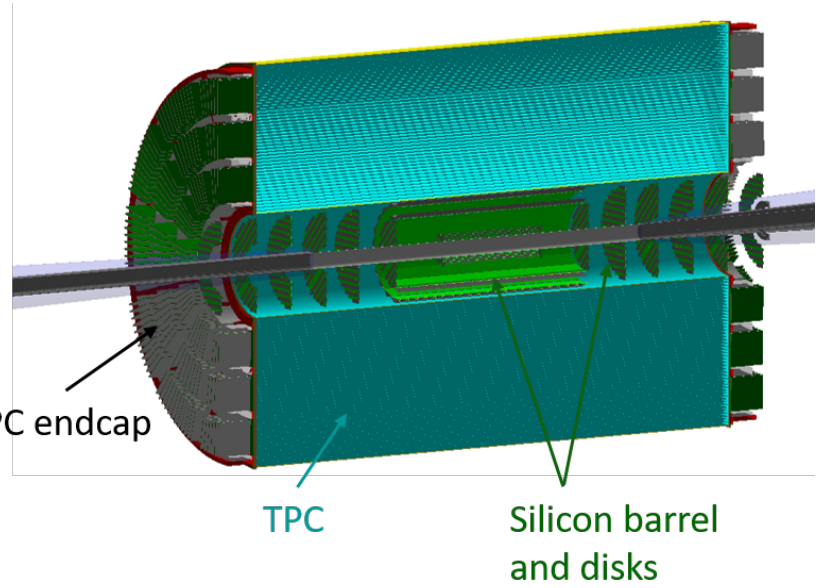
EIC@IP6 Tracking Discussion

EIC@IP6 bi-weekly meeting April 29, 2021

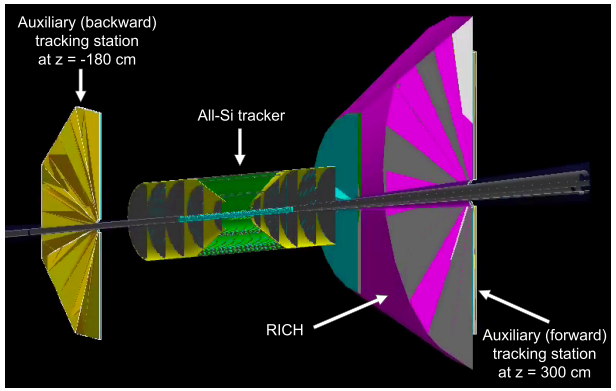
Yellow Report tracking concepts

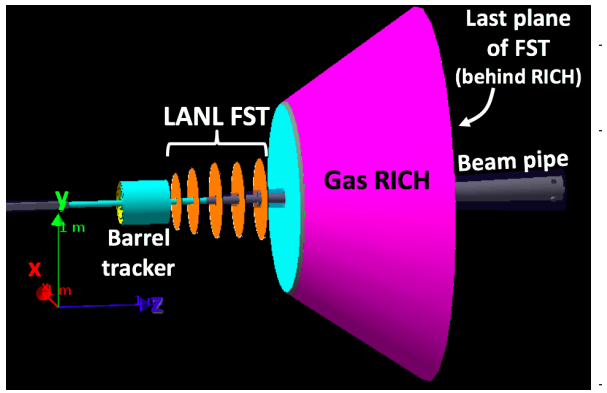
- Baseline concepts
  - All-silicon and hybrid (MAPS + TPC)

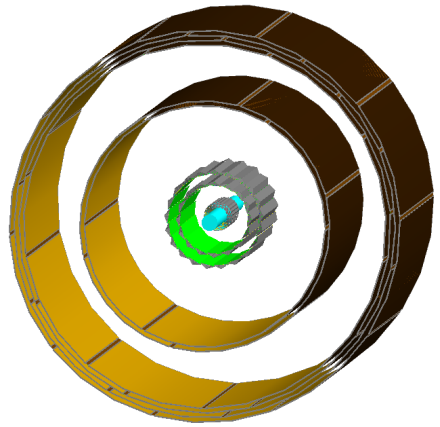




- Alternative tracking options considered for the endcaps
- MAPS + MPGD-based barrel







The outline of this session:

- Presentations from the groups
  - EIC Silicon consortium / Leo /
  - UK silicon groups / Laura /
  - Berkeley / Ernst /
  - INFN / Domenico /

  - Si+MPGD concept (SIMPLE @ IP6) / Matt for FIT, Temple, UVa/
  - Saclay contribution / Francesco /
  - LANL contribution / Xuan /

  - Czech institutions / Lukas /
  - GEM-TRD / Yulia /

- Discussion

In red: the conveners of our newly formed Tracking WG

EIC Silicon Consortium at IP6

(Taken from the April 15 meeting charge slide)
CHARGE, addressing these points:

- *which is the contributions you can bring to the tracking activity towards the proposal in the next months?*
- *what are the most relevant and urgent questions in the tracking sector?*
- *how do you see globally tracking for Detector 1?*

The goal of the EICSC is to develop a complete silicon tracking system solution for EIC detector collaborations based on the development of a new sensor derived from the CERN ALICE ITS-3 silicon project.
Thus, the effort that will be put into this task applies equally to all of the nascent EIC detector collaborations.

We will report on the full effort that is expected for the EICSC in the next months.

EIC Silicon Consortium at IP6

• which is the contributions you can bring to the tracking activity towards the proposal in the next months?

The EICSC membership currently LBNL, BNL instrumentation division, UK collaboration (currently University of Birmingham, RAL, Brunel University - London), JLAB, ORNL, CCNU – Wuhan, Groups from INFN (currently Bari, Trieste), Institute of Modern Physics (IMP, China), CTU Prague.

All institutions are or will be actively engaged in this development process and will be developing and detailing (at the current level of knowledge) the tracking detector parameters. These are the areas in which we can contribute well. This would include:

- Granularity and technical specifications of expected silicon performance.
- Parameters for the readout and estimates of hardware footprints.
- Research into services reductions based on DC-DC converter or serial powering and fiber multiplexing and estimates of the resulting improvements.
- Estimation of radiation length for the detector components, services and mechanics.
- Cost and schedule generation for the R&D, construction and deployment of detector concepts.
- Assessments of the viability of detector layouts.
- Participation at a high level in the simulation of detector concepts based on this technology.

EIC Silicon Consortium at IP6

- *what are the most relevant and urgent questions in the tracking sector?*
- *how do you see globally tracking for Detector 1?*

We see these questions as highly interrelated.
The most urgent task for the tracking sector is to implement the YR concepts (or variants thereof) into a full detector simulation with realistic services, mechanical supports magnetic fields, beam pipe models, etc. for all sub-systems and assess the physics performance.

- This can and will lead to optimizations on the tradeoffs inevitable associated with these type of exercises.
- The large feature silicon tracking detector components are already developed in the areas of vertexing, barrel staves and discs, but optimizations based on detector layout still need to be investigated.
- This will also allow for the identification of areas where new concepts may need to be developed and point out where new technology or techniques will need to be examined.
- The “problem” areas will need to be addressed to the point where viable solutions can be presented as part of an overall detector proposal.

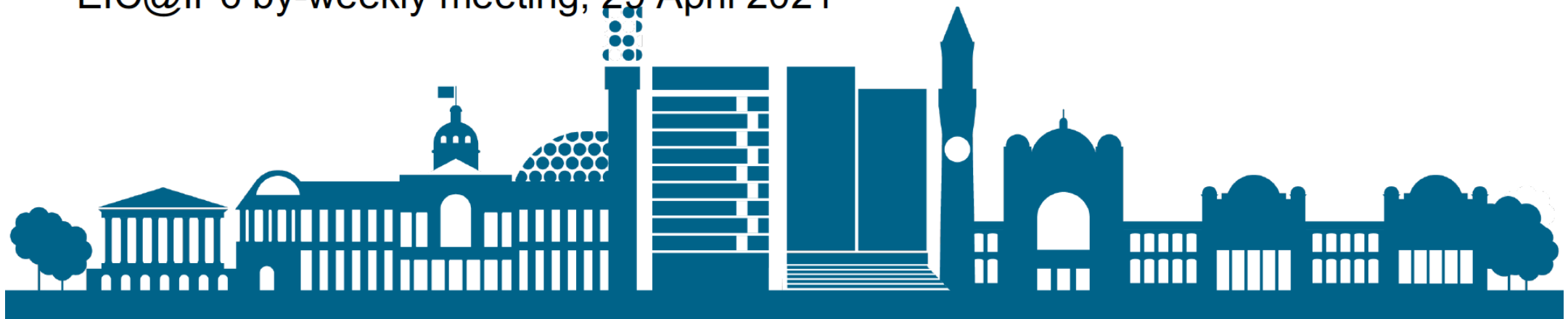
UNIVERSITY OF BIRMINGHAM

UK groups contribution to EIC@IP6 tracking (silicon)

L. Gonella, University of Birmingham

on behalf of Brunel University, Daresbury Laboratory, RAL CMOS Sensor Design Group (CSDG), RAL Particle Physics Division (PPD), University of Lancaster, University of Liverpool

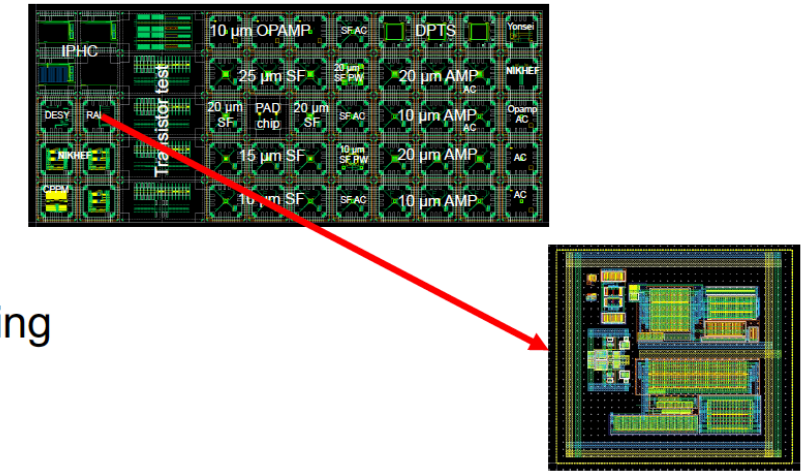
EIC@IP6 by-weekly meeting, 29 April 2021



1- Which contributions you can bring for work on tracking, aiming to develop the proposal over the coming months

Note: Available effort over the proposal timescale depends on funding.
Awaiting response on proposal submitted to UKRI.

- Detector simulations
  - Continuation of YR activities on detector performance parametrisation and physics performance simulations (Birmingham, Lancaster)
- Sensor design
  - RAL CSDG already full involved in 65nm sensor development with ITS3, IP block contribution for the MLR1 (Dec 2020)
  - RAL CSDG and Brunel currently defining details of contribution to the ITS3 Engineering Run 1 (submission Q4 2021)

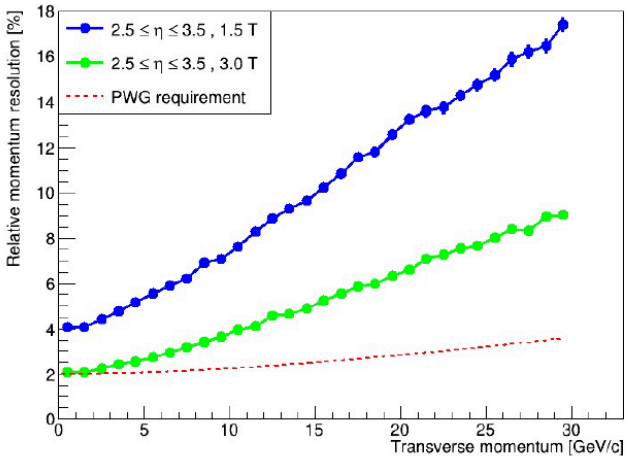


- Sensor prototype characterisation
  - Wire bonding of prototypes on test cards, lab and beam tests, irradiations, data analysis, device simulations, DAQ development (Birmingham, Daresbury, Lancaster, Liverpool, RAL PPD)
- Carbon fibre mechanics design and manufacture (Daresbury, Lancaster, Liverpool)

2- What are the most relevant and urgent questions in the tracking sector?

Detector performance to be studied in simulations

- Starting point: YR baseline configurations
  - Transverse pointing resolution: requirements satisfied at both 1.5T and 3T at all pseudo-rapidity
  - Relative momentum resolution: requirements better satisfied for the higher field value and in the central pseudo-rapidity region



- Simulations to run with realistic B-field map, 25 milliradians crossing-angle
- Implement realistic services outside active area
  - Impact performance in forward and backward regions, and other detector systems
  - Feedback to services design and integration
- Continue studies of tracking stations at large z to improve momentum resolutions in forward/backward regions (with improved B-field and services description)
- Integration of silicon with MPDG tracker
- Tracker integration in the full detector

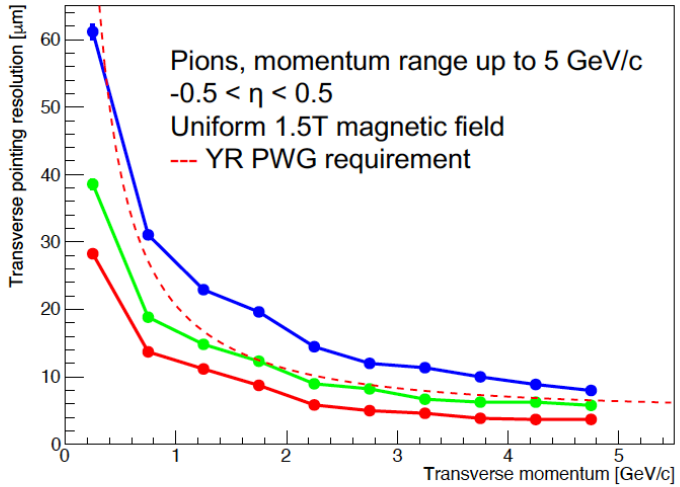
2- What are the most relevant and urgent questions in the tracking sector?

Technology selection

- Starting from the YR selection, identify baseline technology with fallback option(s)
- Trade-off between physics performance, cost, development timeline
- Exercise well underway for the central silicon tracker
  - Strategy document, estimate of R&D costs, timeline of development up to CD4 already available

3- How do you see the global tracking system for Detector 1

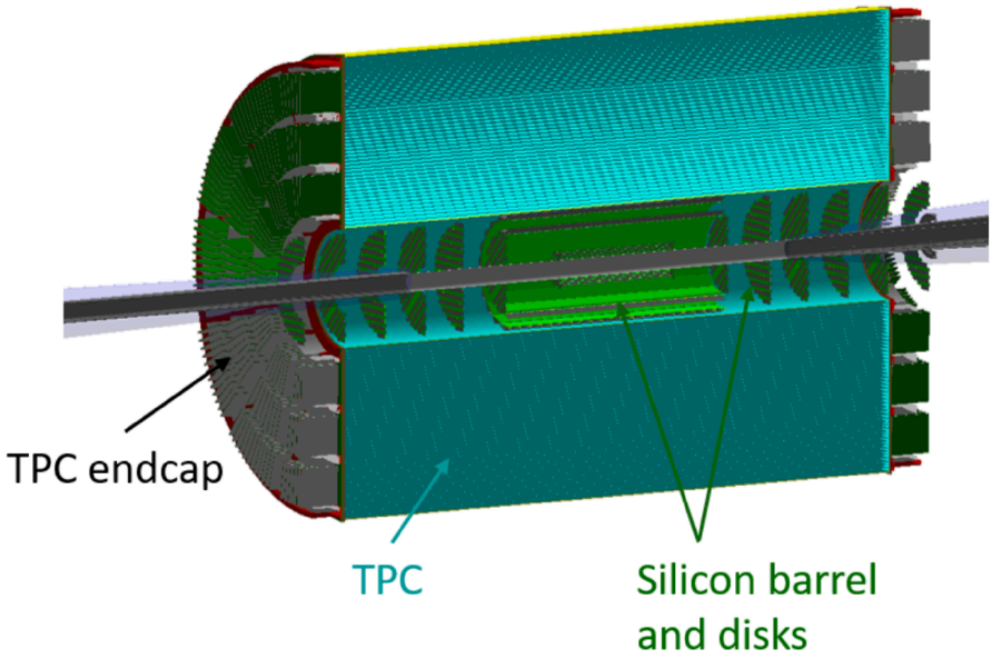
- Very high granularity, very low mass silicon vertex and tracking detector …
  - Need clearly highlighted in YR work

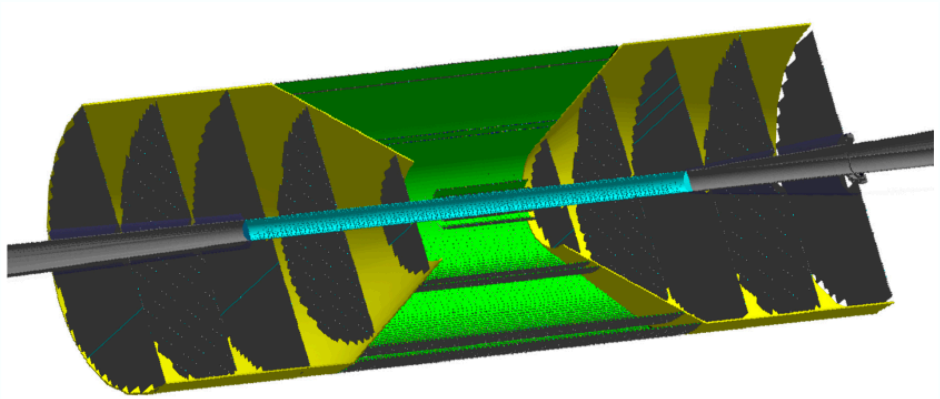


	Green	Blue	Red (ITS3-derived EIC SVT)
Beam pipe radius [mm]	18	31	31
x/X0 vertex	0.3%	0.3%	0.05%
x/X0 tracking layers	0.8%	0.8%	0.8%
Pixel pitch [um]	20	20	10

- … either in a compact all-silicon configuration or complemented by a larger gas tracking system…
- … possibly with tracking stations further away from the IP

Towards MAPS-based tracking solutions for EIC@IP6





Ernst Sichtermann (LBNL)

Based on effort by many - thank you, errors are mine.

BERKELEY LAB

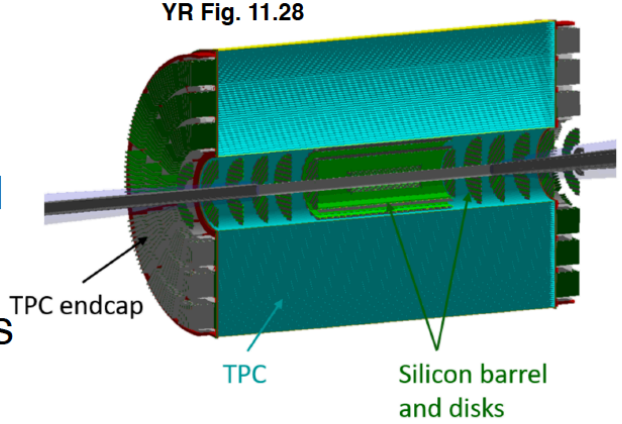
Berkeley
UNIVERSITY OF CALIFORNIA

eMAPS-based tracking R&D for EIC since 2016
(eRD16, in partnership with eRD18, now eRD25),

Two baseline options put forward in the recently released EIC YR: TPC+inner-Si, All-Si,

ArXiv:2102.08337 contains (further) science opportunities

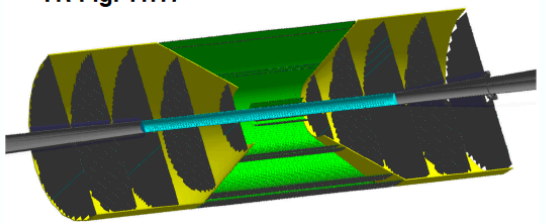
YR Fig. 11.28



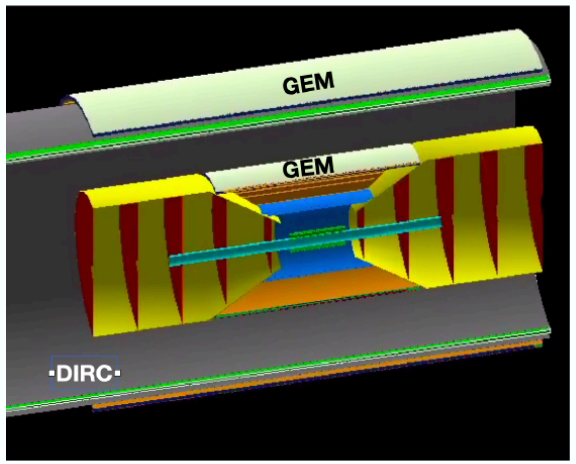
Very productive UCB, LBNL, Birmingham partnership,

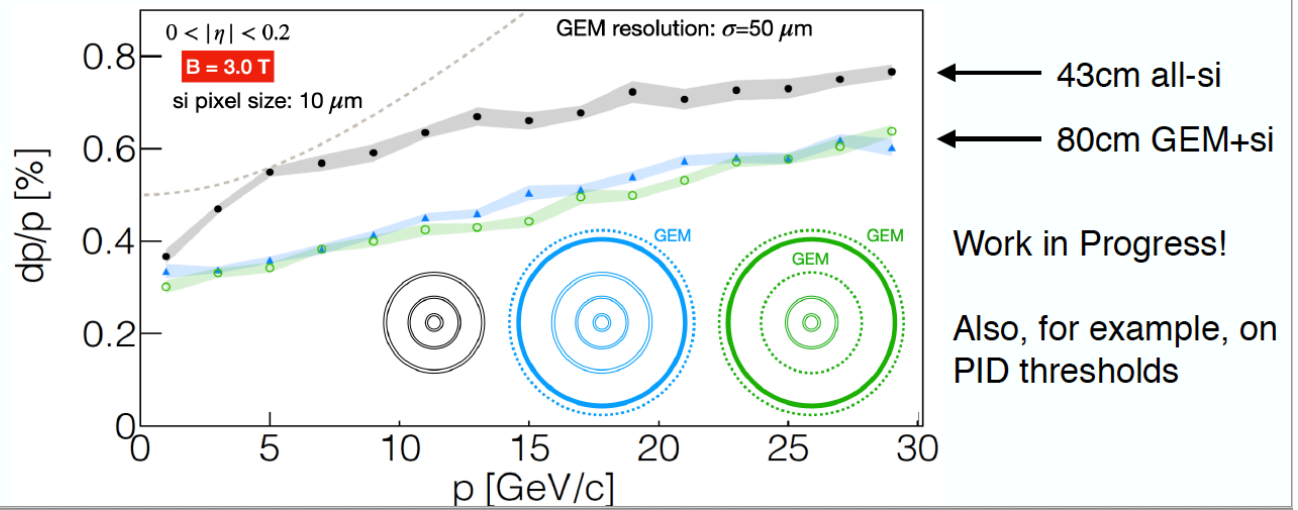
- dp/p, vertex resolutions, … *and*
- early considerations of all-important integration of supports and services,
- effects of crossing angle, angular resolutions at PID,
- complement with (GEM) tracking downstream of forward RICH,
- path(s) towards realization: talks by Leo Greiner, Laura Gonella,

YR Fig. 11.17



We see EIC@IP6 as a logical step and made a start towards alternative hybrid option(s):





Work in Progress!

Also, for example, on PID thresholds

To the questions posed by the organizers for today:

- *Which contributions you can bring for work on tracking*

We see the development of the EIC@IP6 proposal as a logical follow-up to the YR and anticipate to continue our contributions at a similar level of effort as for the YR with a continued focus on the realization of MAPS-based tracking and vertexing.

- *What are the most relevant and urgent questions in the tracking sector*

Magnetic field,
z_{min} and z_{max} ,
EIC sensor development,
services and supports (integration),
timely convergence on overall detector concept,

- *How do you see the global tracking system for Detector 1,*

Highly granular, low-mass, well-integrated MAPS-based inner barrels and forward/backward disks for tracking and vertexing, leveraging sensor development initiated by ALICE-ITS3,

Very likely complemented with one or more forward GEM planes,

TPC+Si seems less probable (to me), however, promising developments towards alternative hybrid solutions e.g. with MPGDs

INFN interest in collaborating to Tracking/Vertexing for EIC@IP6

Currently involved divisions: **BA** and **TS**

Preliminary feedback on the suggested points:

- **which contributions you can bring for work on tracking, aiming to develop the proposal over the coming months:**
  - ✓ study of the vertex detector performance with Monte Carlo simulations:
    - starting from the experience for the YR (mainly with EICROOT), need to move to Fun4All

    estimate of man power needed / involved: ~ 2 people from INFN (0.5-1 FTE)
  - ✓ development of techniques and tools for bending and interconnecting wafer-scale chips:
    - scale techniques developed for ALICE ITS3 to size / modularity needed by EIC geometry and constrains
  - ✓ characterization of 65 nm test structure and study of the effect of curvature on the performance:
    - use the knowledge of the test system currently under development for the first 65 nm chip submission
    - participate in the laboratory and beam facility tests, exploiting the experience in characterization gained for ALICE ITS2 and ITS3, which the 65 nm MAPS is the direct evolution of

    estimate of man power needed / involved: ~ 3-4 people from INFN (1-1.5 FTE)

INFN interest in collaborating to Tracking/Vertexing for EIC@IP6

Currently involved divisions: **BA** and **TS**

Preliminary feedback on the suggested points (cont'd):

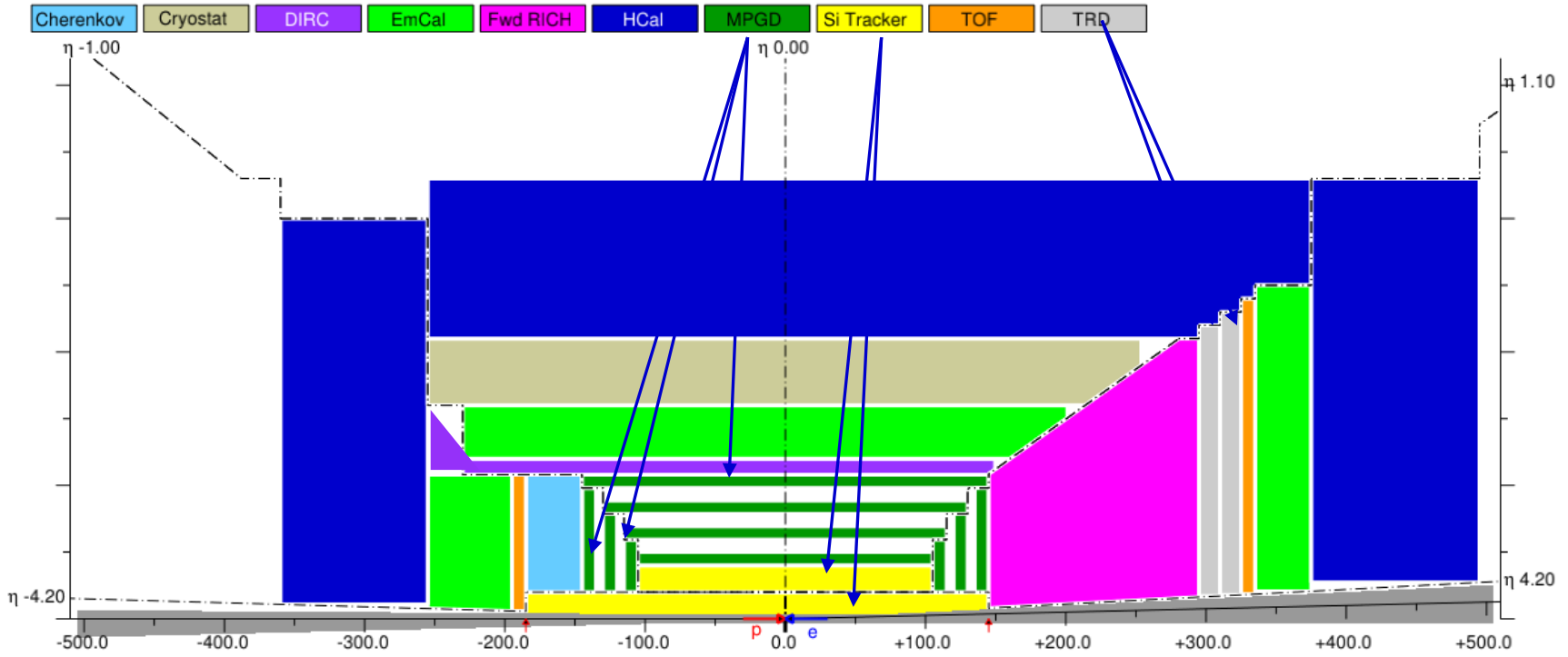
- **what are the most relevant and urgent questions in the tracking sector:**
  - ✓ need to clarify how to proceed with MC simulation strategy:
    - continue/extend developments and implementations in Fun4All, preserving compatibility with other frameworks
    - implement geometry directly in Fun4All bypassing present link with EICROOT (vertex) implementations
    - consider to reduce the level of details for the vertex staves, include what is still missing (eg services material)
    - study of vertex performance with physics events (benchmark physics signals)
  - ✓ define the reference tracking detector:
    - clarify main implications of the all-silicon detector (cost, compacteness, missing PID vs space left to other detectors)
    - finalize selection of the gaseous detector options for the hybrid tracker (TPC vs various MPGDs)

- **how do you see the global tracking system for Detector 1:**
  - ✓ EIC@IP6 to asses all implications of the hybrid vs all-silicon tracking solutions
  - ✓ need to proceed in close connection with PID and Calorimetry WGs

SiMPLE @ IP6: Silicon and Micro Pattern Gaseous Detector for Large Experiment

- SiMPLE at this point is a starting point derived from a ToyModel cartoon describing what the idea we try to coalesce around
- Not a frozen configuration, the hybrid (MAPS layers + MPGDs) is still open nothing is frozen yet
- France, UK and China institutions and universities as major players
  - Open to and expect new members
- Several US institutions

SiMPLE @ IP6: a Si+MPGD tracker concept



SiMPLE @ IP6: Participating groups

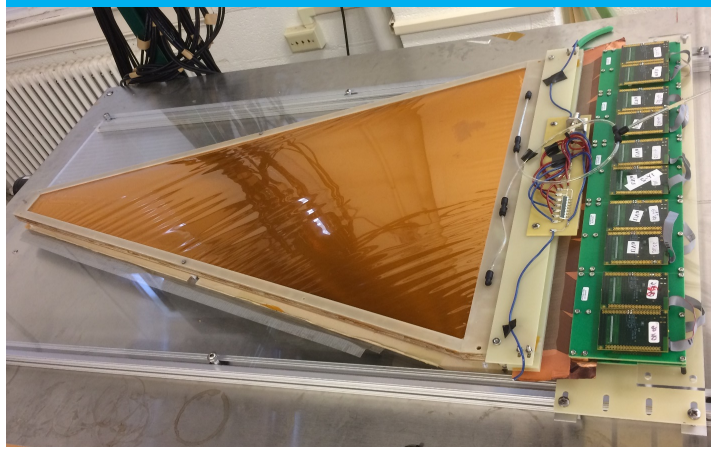
Groups	Contacts	expertise
Florida Tech Temple U. Univ. of Virginia	**Marcus Hohlmann** **Matt Posik** **Kondo Gnanvo**	**MPGDs:** GEM & µRWELL Barrel, forward & backward trackers GEM-TRD in forward region
CEA Saclay	**Francesco Bossu** **Maxence Vandenbroucke**	**MPGDs:** Micromegas Barrel, forward & backward trackers, **Readout electronics** for MPGDs
BNL + Yale University	**Bob Azmoun,** **Alexander Kiselev,** **Nikolai Smirnov**	**MPGDs:** anode readout, hybrid MPGD structures (GEM + Micromegas)
eRD25 – University of Birmingham & other institutions	**Laura Gonella …**	**MAPS:** Vertex detector, Barrel, forward & backward trackers,
eRD25 – UC Berkeley – LBNL	**Leo Greiner** **Ernst Sichtermann**	**MAPS:** Vertex detector, Barrel, forward & backward trackers,
LANL	**Li Xuan…**	**MAPS + other Si technologies**
Chinese Collaborators: USTC, IMPCAS …	**Yuxiang Zhao…**	**MPGDs & MAPS** **Readout electronics?**
Jefferson Lab, Vanderbilt University	**Yulia Furletova,** **Sourav Tarafdar**	**TRD** in forward region (GEM / µRWELL)

Tracking Detectors: Florida Tech – Temple U. – Univ. of Virginia

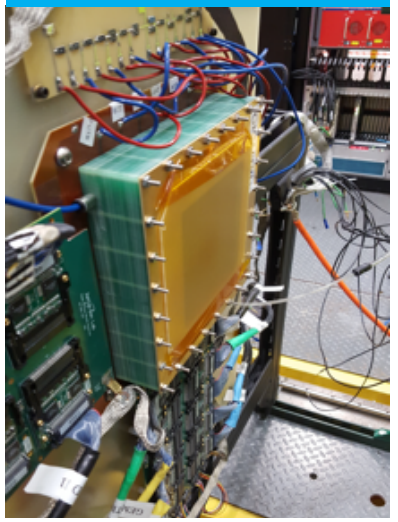
Hardware R&D Work within eRD6 & eRD22

- Large area GEM for forward / backward trackers
  - Large area (1 m × 0.5m) & Low mass GEMs (~0.5% X/X0)
- High performance & low channels count anode readout for MPGD
  - Zigzag strips, Capacitive-sharing readout
- Resistive Micro-Well (μRWELL) technology
  - Develop large area μRWELL with capacitive-sharing readout
- Large Cylindrical μRWELL for EIC Barrel tracker
  - Fast tracking & precision layer for DIRC & TPC
  - Layers for the main barrel Cylindrical MPGD Trackers
- GEM-based transition radiation detector (GEM-TRD)
  - Prototyping and Gas system
  - Provide e/π discrimination and tracking

Large & low mass GEM

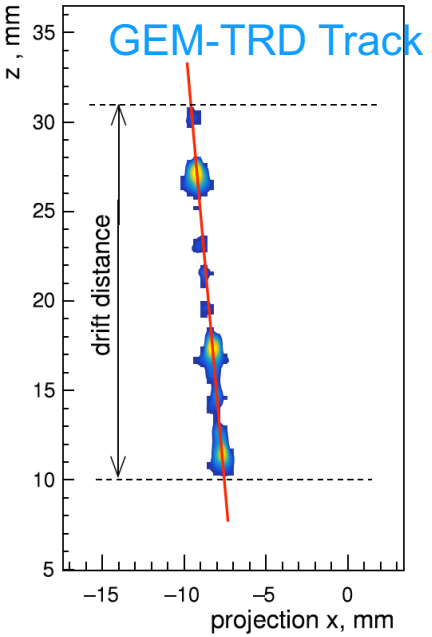


GEM-TRD Prototype



Cyl. uRWELL: Mockup

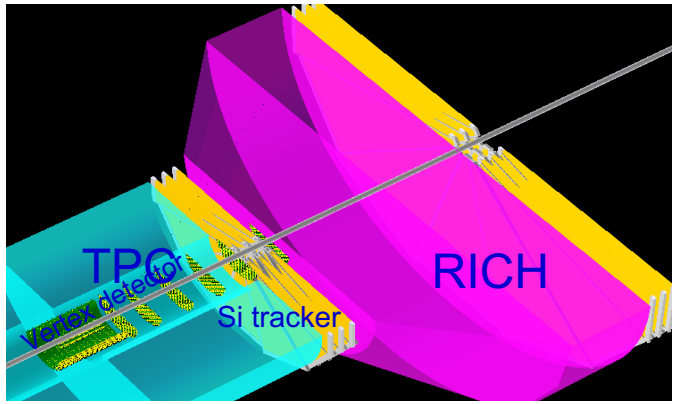
GEM-TRD Track



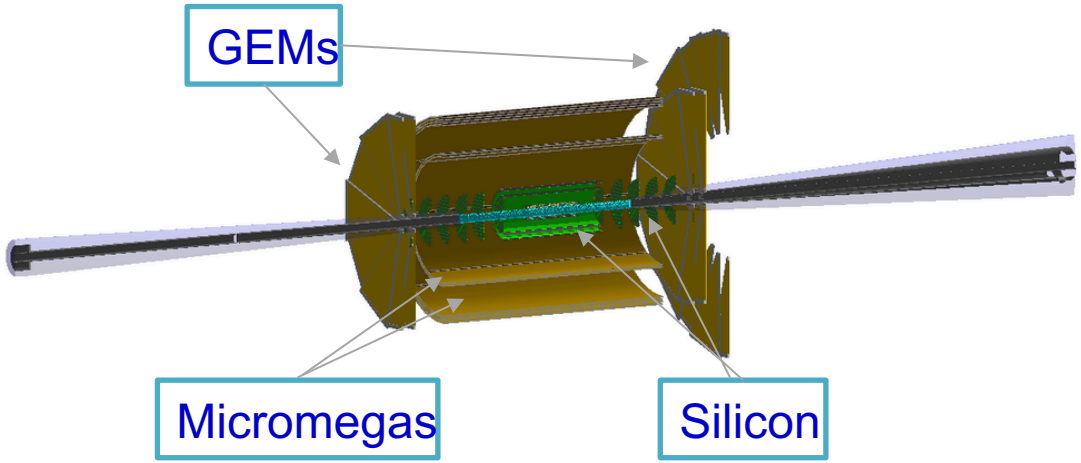
Tracking Detectors: Florida Tech – Temple U. – Univ. of Virginia

Simulation Work within eRD6

- Simulation with Fun4All
  - Optimize Si-MPGD design for tracking and material allocation
  - Implement μTPC mode for cyl. μRWELLs to allow reconstruction of tracklets
  - Study the impact of μRWELL tracking on DIRC PID
  - Implement large area GEM trackers for end cap regions

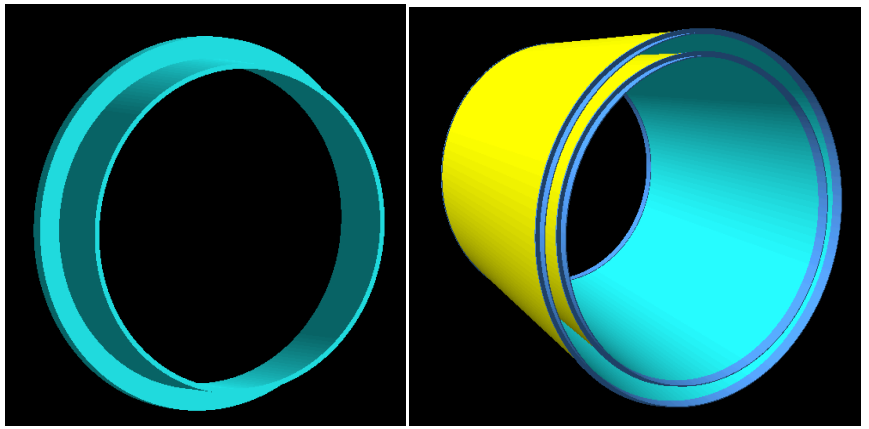


- Contributions to the Proposal
  - Collaborate with Si and other MPGD groups in simulation work for Si-MPGD hybrid detector
  - Continue R&D on $\mu RWELL$ and GEM trackers
  - Detector integration effort



FIT mock prototype

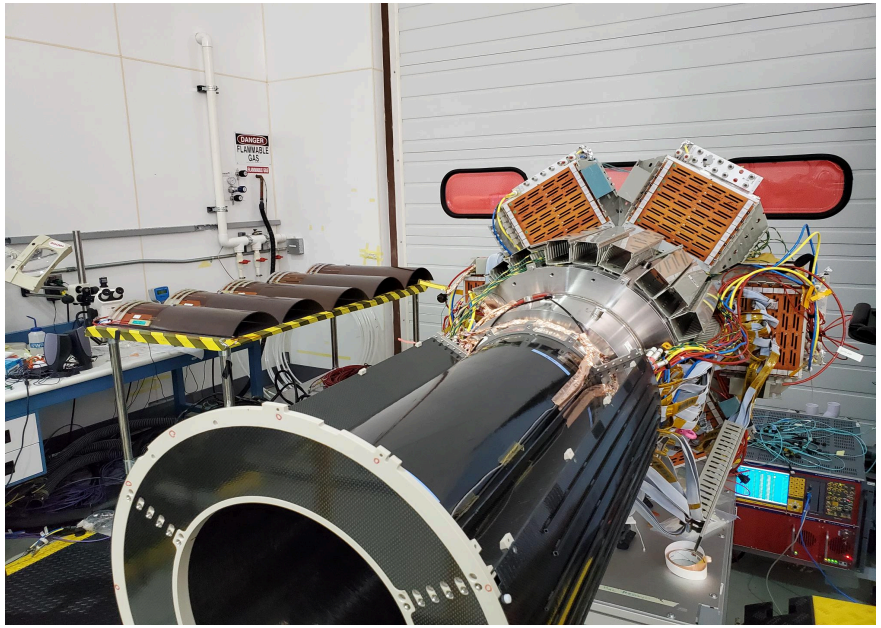
Simulation implementation

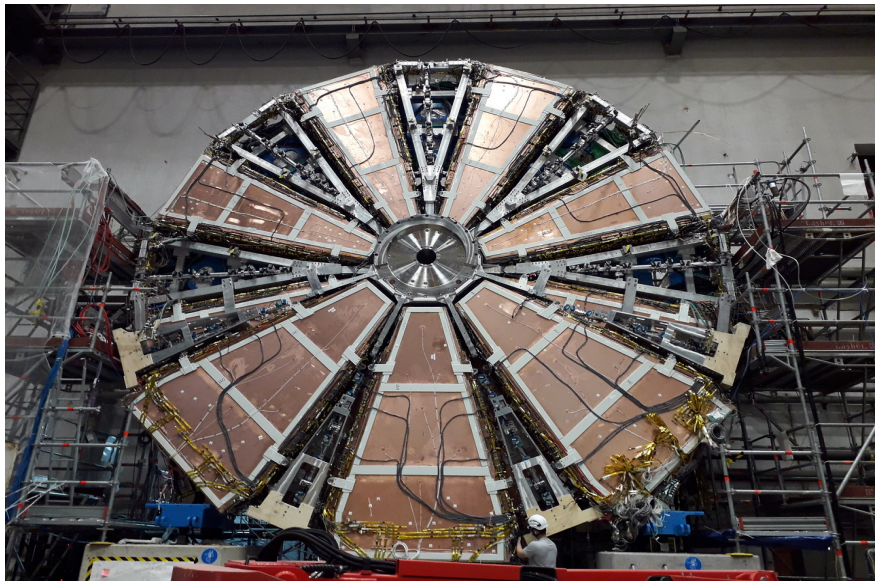


CEA Saclay – Tracking detectors

Expertise on large Micromegas detectors

- **CLAS12**
  - Compact and light cylindrical tracker in B=5T
  - About 0.4%X_0 per tile
  - Total area : ~4 m^2 (including spares)
  - It's taking data since 11/2017
  - "Easy" accessibility: being re-mounted by JLab team with Saclay team in remote
- **ATLAS NSW**
  - 392m^2 out of 1200m^2 resistive MM done in Saclay
  - 100µm mechanical precision
  - Max rate 15kHz/cm^2
  - ~2M channels
- **TPC readouts** (ILC, FCC, T2K, Minos…)





Ongoing R&Ds:

- Ultra-light MM (aiming at 0.05%X_0 per detector)
- Low IBF for TPC readout

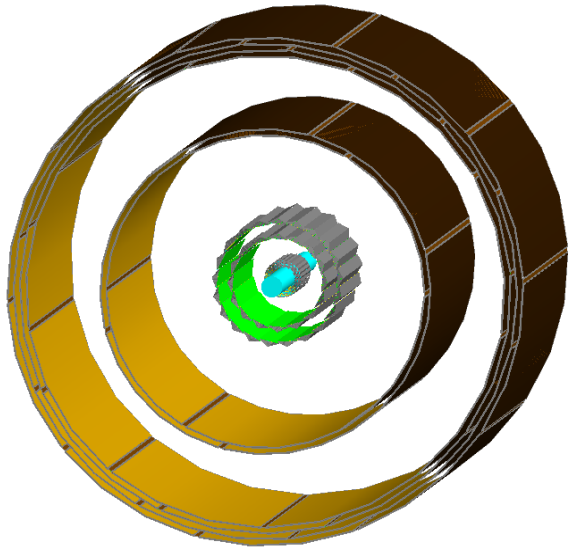
Strong interest in a new ASIC for MPGD readout

- Long experience in FEE (AGET, DREAM, …)
- Ongoing discussions with the Sa Paulo group for a common development
- Discussion started with eRD6 to collect the desired specifications

CEA Saclay – Tracking detectors

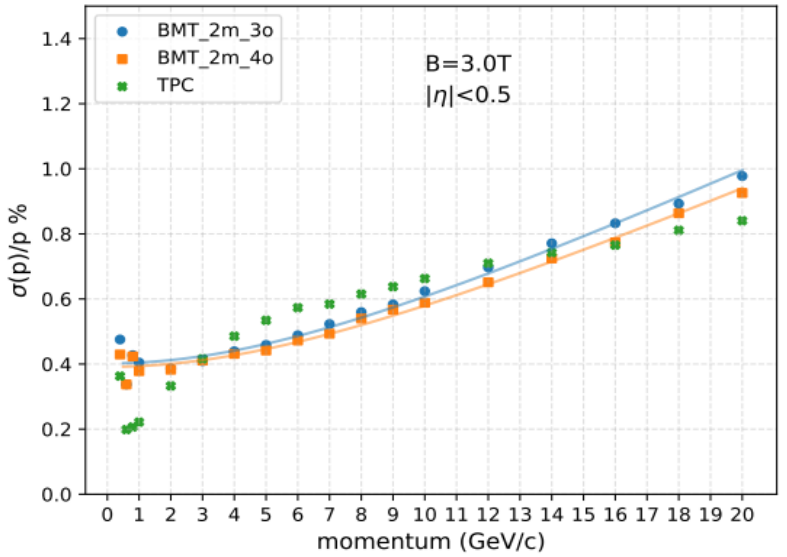
Contributions to the proposal:

- Continuation of the simulation work done for the YR
- In collaboration with other eRD6 groups
- Si + Micromegas hybrid configuration meet the requirements for material budget and momentum resolution
- Optimization of layers and tiles geometry
- Implementation of a light support structure in simulation
- Synergy with detector integration effort



Most relevant and urgent questions:

- Close discussion with the PID group to define available space and tracking performance requirements
- Timing requirements
- Technology cost estimates and total budget must be at the top of the problem boundary conditions
- Risk assessment of technology R&Ds and backup solutions
- Synergy with the software group



How do we see the global tracking system:

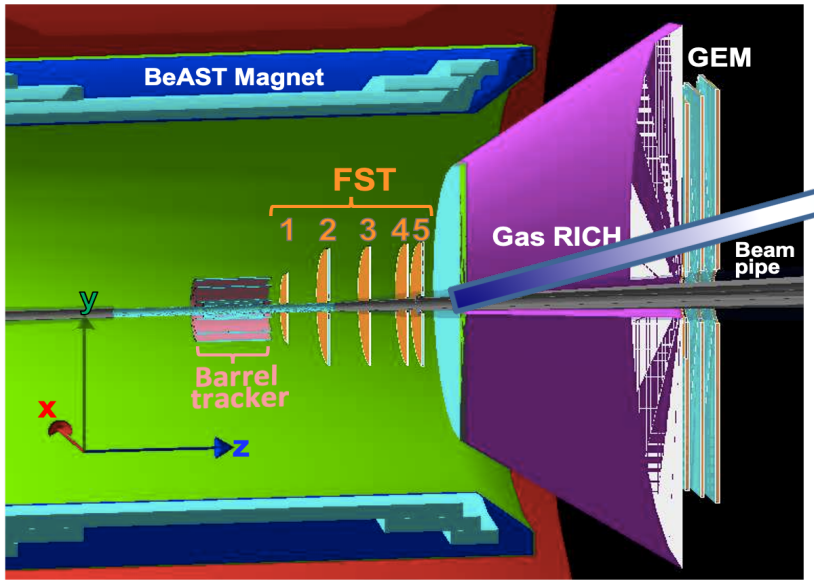
- Hybrid Si + MPDGs
- Performance driven by physics requirements
- Keeping an eye on costs and technology readiness

EIC Detector focus: a forward silicon vertex/tracking detector (FST)

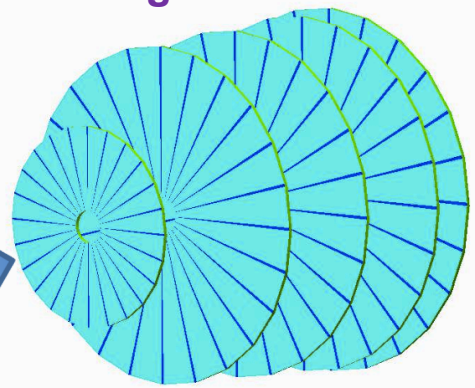
- Interested institutions/consortia: **LANL, BNL, JLab, Univ. of Michigan, UC Santa Cruz, FNAL, KIT, Univ. of Heidelberg, UC consortium, LGAD consortium…**
- Initial detector conceptual designs have been carried out in GEANT4 simulation with both Beast and Babar magnets, which is part of the EIC yellow report efforts.

Different geometries have been explored

See more details in arXiv:2009.02888



Finer segments for the FST

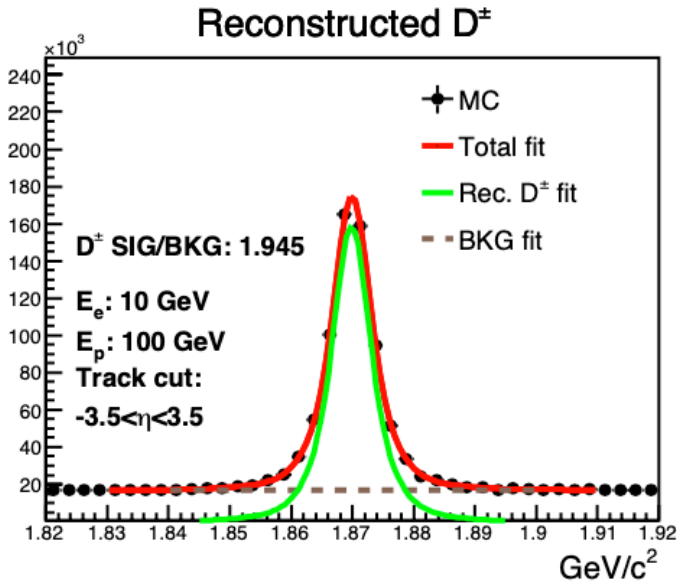


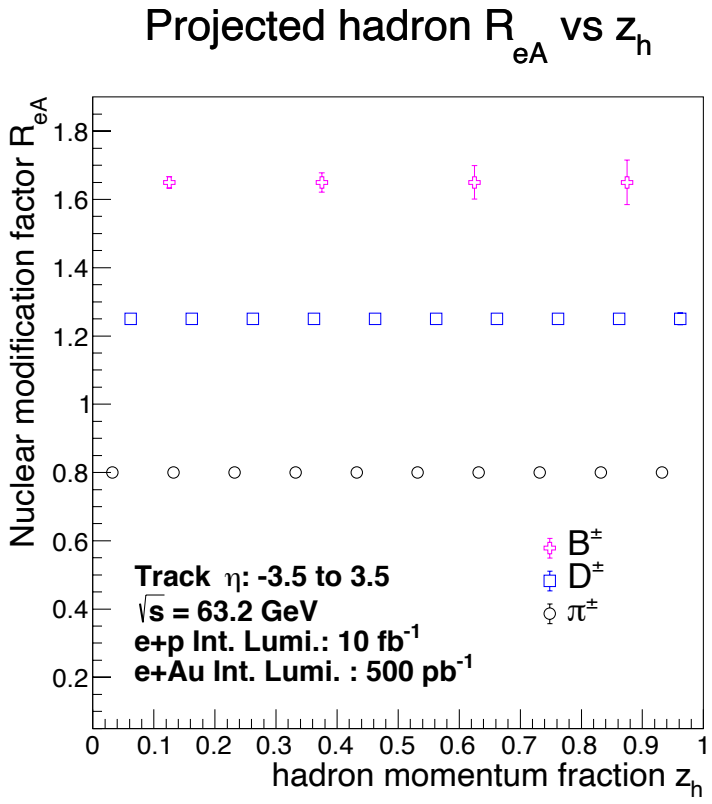
- Updates on the detector geometries and designs based on EIC overall detector requirements (e.g., integration needs) can be made.

Heavy flavor and jet physics studies associated with the proposed FST

- Explore the hadronization in medium via heavy flavor hadron nuclear modification studies, which is part of the EIC Yellow report.
- These studies can be updated with any new detector configurations and performance.

W/ Beast magnet
Barrel, forward and rear silicon vertex/tracking detector.





The most relevant and urgent questions in the tracking sector

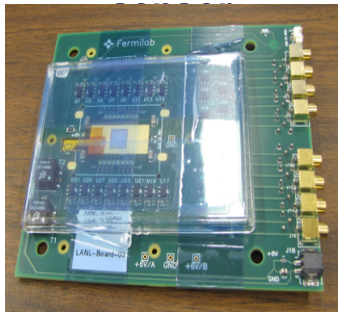
- Physics requirements: heavy flavor, jets, SIDIS, the other topics?
  - Better to merge into a table of the specific tracking requirements.
- Integration between gas and silicon detectors:
  - e.g., integrations in the barrel, forward and rear regions.
- Joint mechanical design for the barrel, forward and rear tracking detectors?
- Costs and risks:
  - Complementary options to mitigate the costs and risks?
  - Any risks for the proposed detector technologies to be able to fit in the EIC timeline?

Potential contributions depend on availability

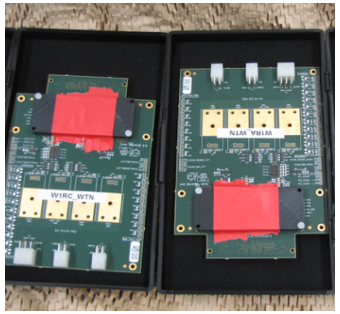
- Engineering design of the FST is underway with the supports from the LANL LDRD 20200022DR project.

Ongoing bench tests of the LGAD sensors

LGAD/AC-LGAD

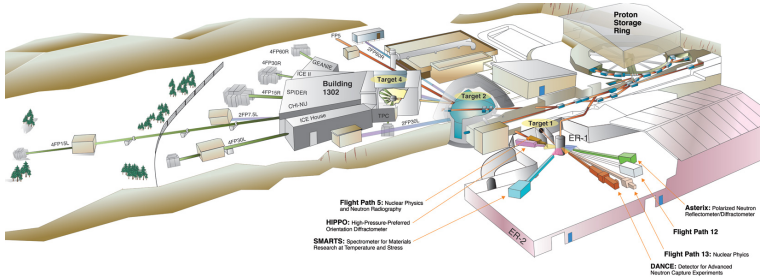


MALTA sensor



- Candidate silicon technology: LGAD (AC-LAG) and MALTA prototype sensors are under testing at LANL. These studies will provide feedback on the detector design, assembly and integration.

LANL LANSCE facility



- Request to carry out the irradiation tests for these silicon sensors with the LANL LANSCE facility has been submitted, expect to achieve results later this year.

Czech Interest in EIC@IP6 Tracking

Czech Technical University in Prague,
Faculty of Nuclear Physics and Physical Engineering (FNSPE CTU)
&
Nuclear Physics Institute, Czech Academy of Sciences (NPI CAS)

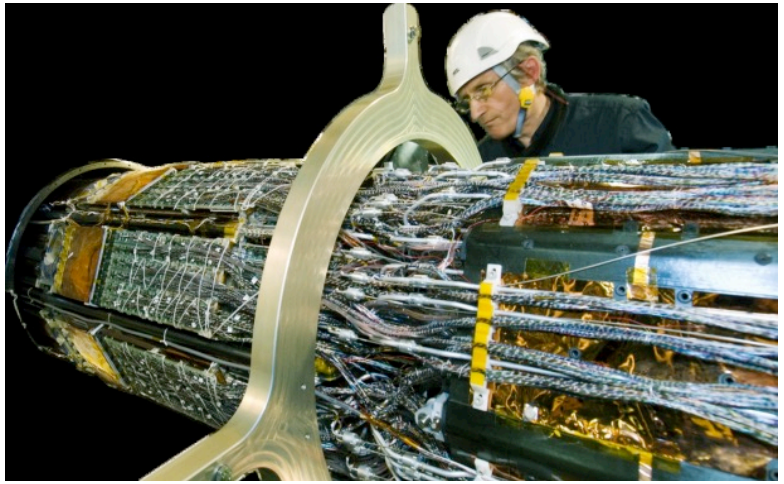
- Experiences from STAR, PHENIX, ATLAS and ALICE collaborations.

Possible contribution:

- Development and testing of detector simulations (Jaroslav Bielcik, Jana Bielcikova)
  0.5 FTE postdoc will be hired from summer 2021 EIC
- Participation in detector R&D and hardware preparation (Lukas Tomasek et al.)
- Radiation hardness tests (Filip Krizek)

contact email: Jaroslav.Bielcik@fjfi.cvut.cz

Detector R&D – CAPADS group @FNSPE CTU



Main focus of our detector group in general is mostly **R&D of silicon based detectors and related activities** (readout hw and sw, testing...).
We have designed strip and pixel silicon sensors and readout ASICs and also Monolithic Active Pixel Sensors (MAPS) for applications in dosimetry, imaging and tracking.
Our group collaborated for example on **CERN ATLAS Pixel** and Medipix projects.

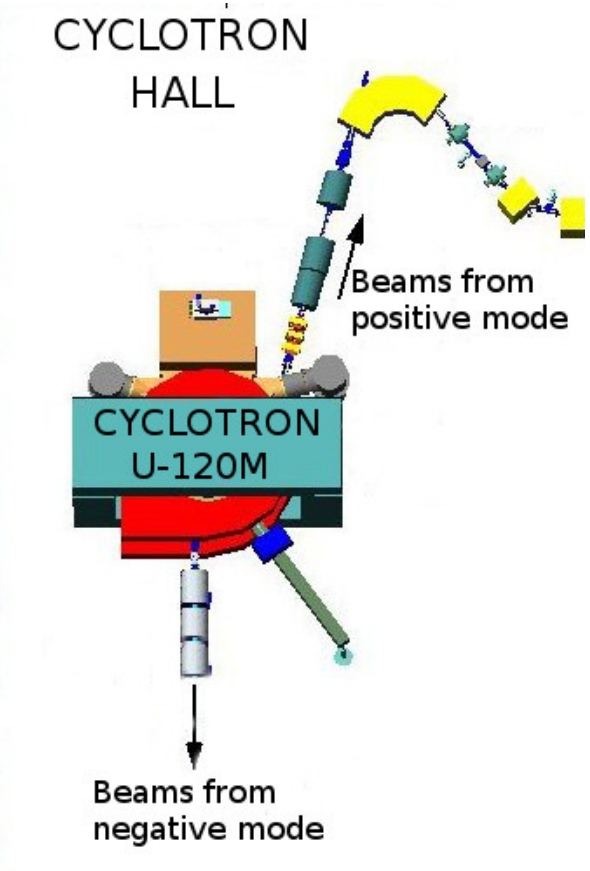
Areas of interest of our group include these topics:

- R&D and evaluation of modern semiconductor technologies for use in high energy physics;
- Investigation of possibilities to optimize MAPS fabrication process to achieve optimal detector performance using ASIC design simulation tools and TCAD;
- Design of silicon sensors and ASICs, fabrication and evaluation of its performance in terms of detector response to high energy particles, radiation tolerance and electrical characteristics.
- Characterization, testing, quality assurance of silicon detectors and ASICs on an automatic probe station;
- Radiation tests of developed detectors using 60 Co source, reactor neutrons and 23 MeV proton beam;
- In addition, work on the development of associated readout electronics, software and firmware and later to help with commissioning and operation.

We have just joined EIC Silicon Consortium@IP6 activities.

capads.fjfi.cvut.cz, contact email: Lukas.Tomasek@fjfi.cvut.cz

Tests of radiation hardness at the NPI cyclotron

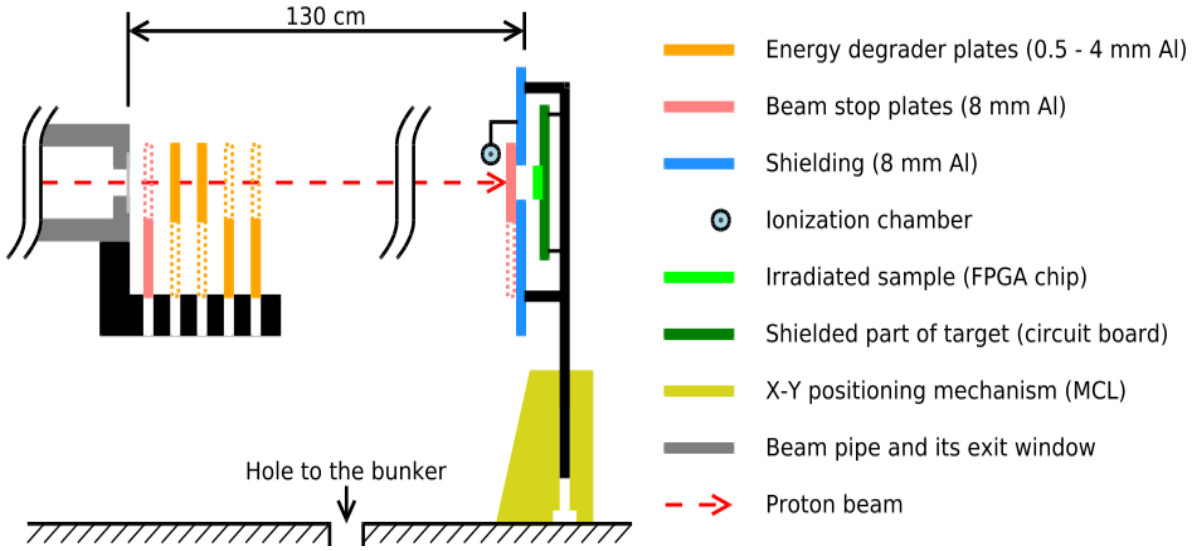


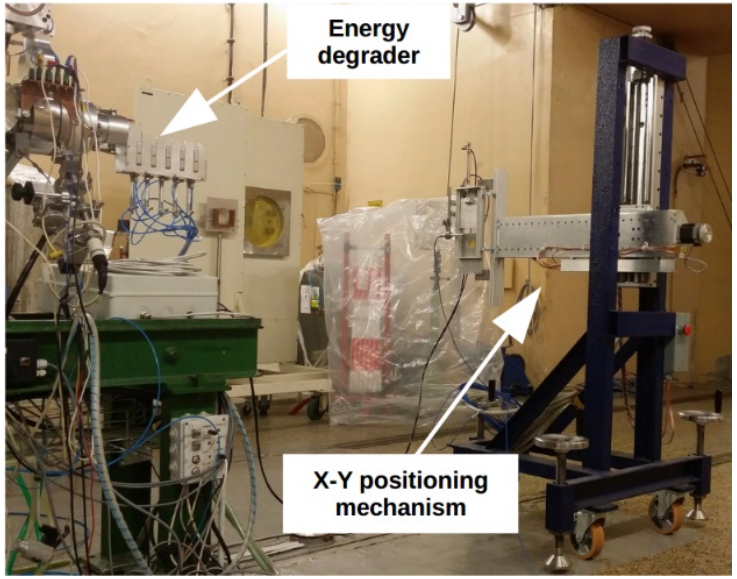
- 30 MeV protons
- Currents ~ 100 fA – 50 μA
- Beam 2D Gaussian $\sigma_x = \sigma_y \sim 2$ cm
- Time structure 26 MHz modulated with 150 Hz macro-pulse
  Duty cycle 4 - 65%

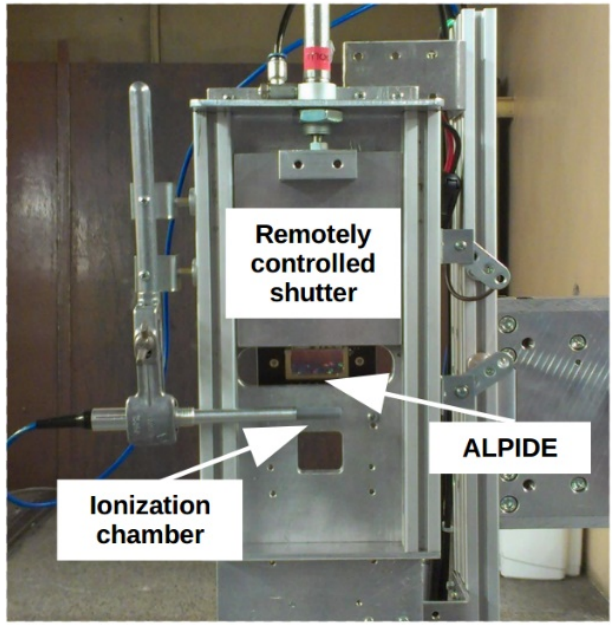
- Experimental setup is placed in the NPI's cyclotron hall

www.ujf.cas.cz, contact email: krizek@ujf.cas.cz

Setup for tests of radiation hardness







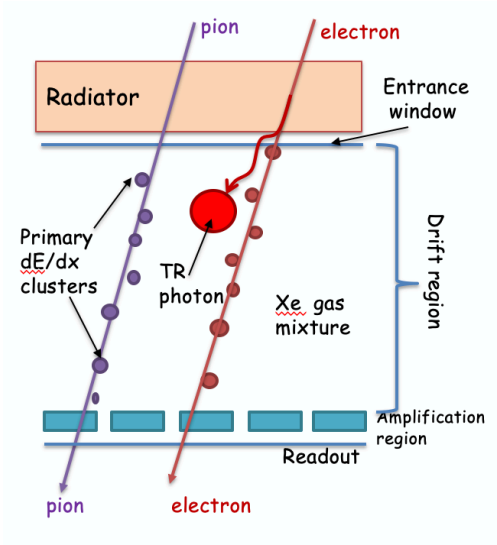
- Online measurement of total ionization dose (15% precision)
- Beam intensity monitored with an ionization chamber
  (linear up to 10^9 proton cm^{-2} s^{-1})
- Remotely controlled system of beam stops and energy degrader plates
  (allows tuning parameters of the beam without irradiating tested sample)

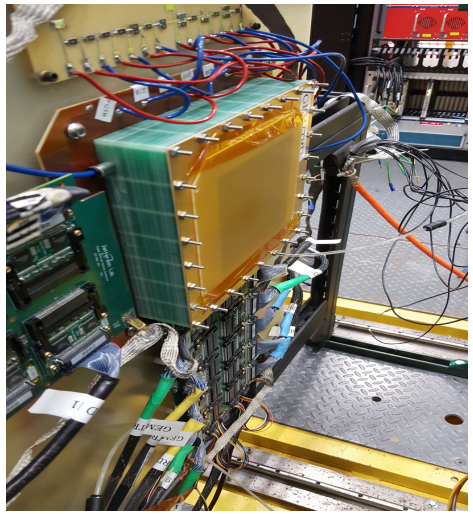
F. Krizek et al., Irradiation setup at the U-120M cyclotron facility, NIM A 894 (2018) 87

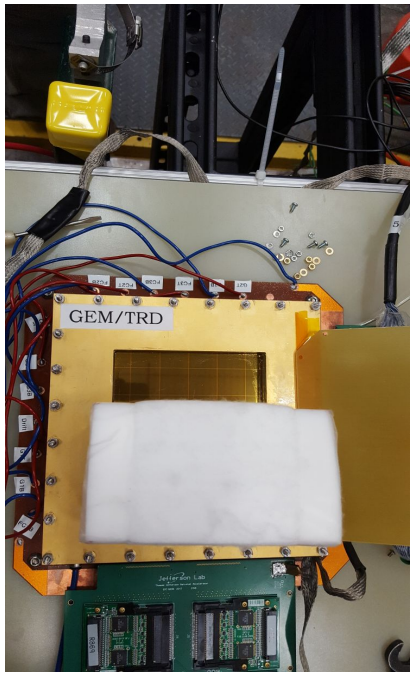
Tests: silicon sensors for ALICE@CERN, FPGA, electronics

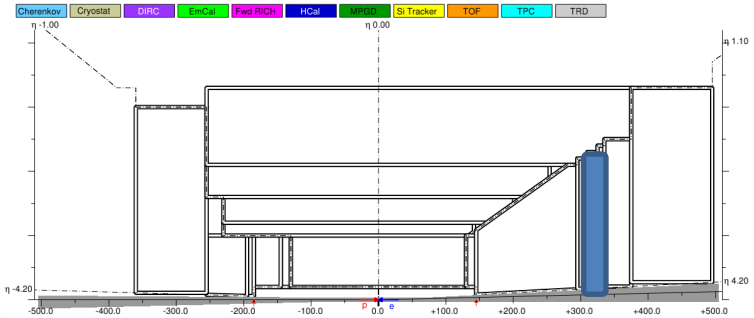
GEM-TRD: a tracker & additional e- ID

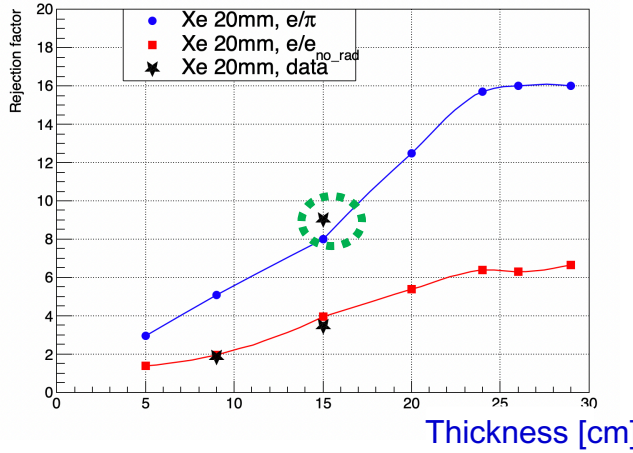
- To improve e-identification for leptonic/semi-leptonic decays.
- In addition to Calorimeters and Cherenkov detectors in the hadron-endcap considering TRD.
- GEM -TRD/Tracker :
  - e/π rejection factor ~10 for momenta between 2-100 GeV/c from a single ~15cm thick module.



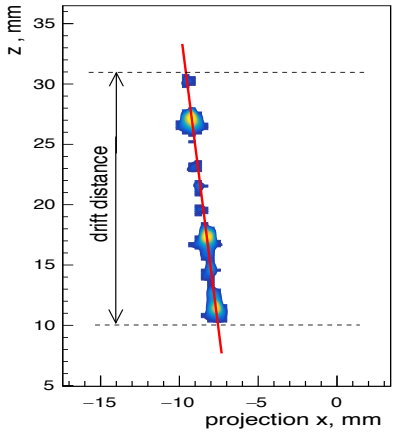


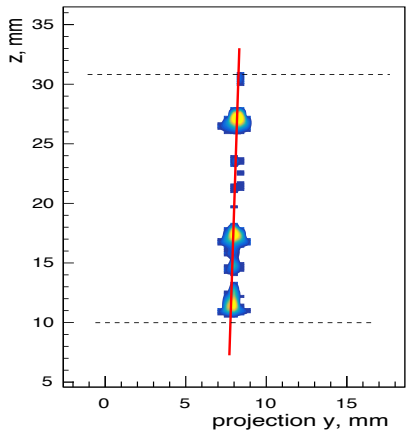






- Very precise Tracking segment behind dRICH:





Yulia Furletova

GEM-TRD: a tracker & additional e^- ID

1. which contributions you can bring for work on tracking, aiming to develop the proposal over the coming months;
   GEM based Transition Radiation Detector which serves as one-unit for tracking and additional e/pi rejection.
2. what are the most relevant and urgent questions in the tracking sector;

- VTX (Z-vertex) defemination (for long-lived particles)
- Material budget in the electron-endcap and barrel where particle energies are low.
- For software WG: track-finding algorithms (extrapolation vs interpolation)
- For physics and detector WGs- what are the required e/pi rejection and what we could achieve (taking into account all-minbias events) ?
- Read-out electronics and cost.

3. how do you see the global tracking system for Detector 1.
As a combination of Si and large-size gas-based detectors.