Summary of the Tracking WG session

1st EIC Yellow Report Workshop @ Temple University

Domenico Elia

Leo Greiner

Kondo Gnanvo

Tracking WG – Technologies Summary

Thu 19/03

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14:00	Introduction to YR-Tracking WG and activities	*Online*	*Kondo Gnanvo*	14:00 - 14:15
	Survey of Silicon Detector Technologies	*Online*	*Laura Gonella*	14:15 - 14:30
	ITS3 Technology	*Online*	*Leo Greiner*	14:30 - 14:45
	Survey of Gaseous Detector Technologies	*Online*	*Kondo Gnanvo*	14:45 - 14:55
15:00	Report on eRD6 and eRD22 activities	*Online*	*Matt Posik*	14:55 - 15:15
	Cylindrical Micromegas for the Central Tracking	*Online*	*Francesco Bossu*	15:15 - 15:25
	Drift Chambers and Straw Tubes for Central Tracking	*Online*	*Franco Grancagnolo*	15:25 - 15:45
	sTGCs for the End Cap Tracking	*Online*	*Daniel Brandenburg*	15:45 - 16:00
16:00				

Si tracking summary (instrumentation)

Report from Laura Gonella on the technology survey for inner detector Si tracking

https://indico.bnl.gov/event/7449/contributions/35954/attachments/27180/41558/20200319-EIC-YR-SiTech-v2.pdf

- Technology assessment:
  - Hybrid pixels, strip and pad sensors – do not meet EIC requirements for pixel size and X/X0
  - LGAD – do not meet EIC requirements for pixel size, X/X0, power dissipation
  - DEPFET and other technologies – do not meet EIC requirements as they are (rolling shutter readout). Would need extensive development path.
  - DMAPS – Technology does meet EIC requirements. Has an existing development path for sensor that meets the EIC requirements.
  - Conclusion: "*the best path forward to arrive at an EIC Si vertex and tracking detector with the required performance is to join the ITS3 effort and contribute to integrating the EIC requirements into the ITS3 sensor design*"

Report from Leo Greiner on ITS3 sensor silicon consortium

https://indico.bnl.gov/event/7449/contributions/35955/attachments/27131/41358/2020_03_18_EIC_ITS3_tech.pdf

- The ITS3 effort is underway with work package (WP) meetings
- There is a schedule defined and WP responsibilities defined – BUT – this is all pre covid-19
- For EIC use we would need to add additional WP to develop discs/staves/infrastructure.
- Non ITS/ALICE/CERN groups are welcome by design so we are developing a EIC silicon sensor consortium and joining this effort with many EIC interested groups (see Laura's talk). Please contact Leo if any one wants to join.

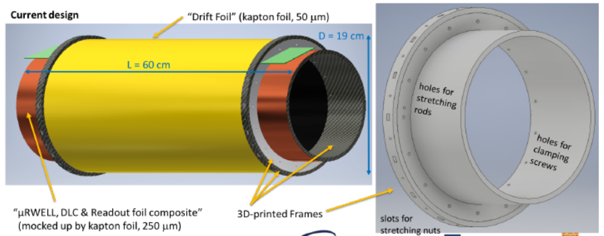
Overview of EIC R&D Gas Tracking Projects

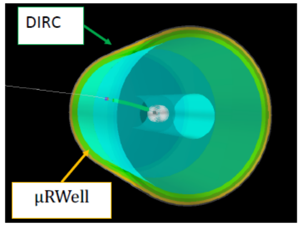
M. Posik, Temple U.

The eRD6 R&D Activities: Central Tracking (2)

- Cylindrical $\mu RWell$ prototype (FIT, TU, UVa)
  - Cylindrical fast tracking MPGD layers
    - can be used to provide seed tracks correlated to bunch crossings
    - Operating in μTPC mode can provide additional track direction information to DIRC via tracklets
  - Design of prototype (FIT)
  - Simulation of prototype (TU)
  - Characterization of small planar prototype with 2D readout strips (Uva)
  - Design and characterization of prototype operating in $\mu RWell$ (UVa, TU
  - Investigation of new tracking FE (VMM3-SRS) (UVa)

eRD6 Central Tracker: TPC + Cyl. Fast Signal µRWELL layer





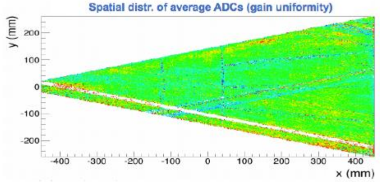
The eRD6 R&D Activities: End Cap Tracking

- Low Mass Large Area GEM Tracker Beam Test
  - UVa tested GEM tracker with FNAL proton beam
  - Detector radiation length = 0.41%
  - U-V readout strips with double-sided zebra connection
  - Excellent X-Y resolution measured
    - $\sigma_x = 426\ \mu m$
    - $\sigma_y = 115\ \mu m$

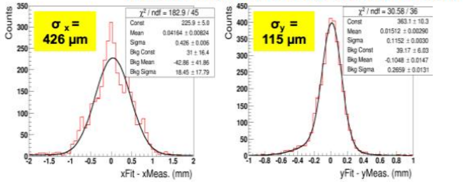
Large GEM Setup in MT6.2b Area at FTBF (June-July 2018)

eRD6 End Cap Tracking: MPGD (GEMs, µRWELL)

Spatial distr. of average ADCs (gain uniformity)



Spatial resolution with U-V strip readout (FNAL data)



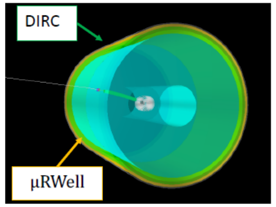
https://indico.bnl.gov/event/7449/contributions/35957/attachments/27141/41373/posik-eRD6-Summary.pdf

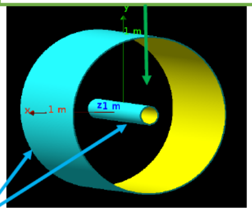
The eRD6 R&D Activities: Simulations

- Simulations (FIT, TU)
  - Actively involved in tracking performance studies of central and end cap regions
  - Fast $\mu RWell$ cylindrical trackers (TU)
    - Operate in μTPC mode
    - Provide information for DIRC as well as main central detector (e.g. TPC, Si) -> better PID
  - TPC in central region
  - GEM trackers in the forward region (FIT)
    - Outer forward GEMs would provide information to RICH -> better PID

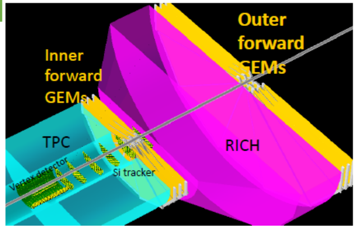
eRD6 Simulation Effort: Synergy with YR Tracking WG

Favorite central tracking detector TPC, Silicon, ...



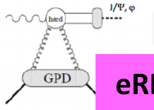


Fast $\mu RWell$ mini-drift trackers



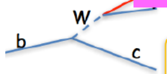
Electron Identification at EIC

- Particle Decays
  - J/ψ (spatial gluon distribution from photoproduction and DVCS, saturation)
  - Heavy quark (charm, beauty)
  - Spectroscopy
  - Beyond the Standard Model
- Environment (Hadron endcap)
  - Background: high multiplicity, large number of charged hadrons.
  - Large π^0 background
  - Electrons from particle delays will be boosted towards hadron endcap
- A GEM TRD/Tracker
  - TRD provides high e/h rejection for electrons in 1-100 GeV range.
  - GEM tracker functions as a μTPC (21 mm drift gap)
    - Provides high resolution tracking
    - Low mass
  - Located behind RICH detector would help with RICH ring reconstruction

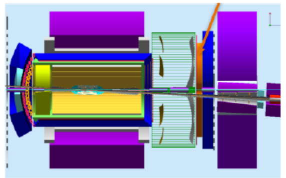


Br (J/ψ->e+e-) ~6%

eRD22 - Hadron End Cap Tracking & PID: (GEM-TRD/T)



Br (D+ -> e + X) ~16%
Br (D0 -> e + X) ~ 6.5%



Cylindrical Micromegas Tracker and More …

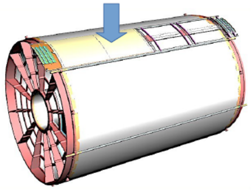
F. Bossu, CEA Saclay, France

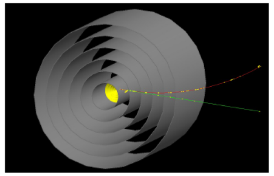
MPGD Cylindrical tracker

- Two options

- External/Internal layers to a TPC to help track matching with calorimetry and particle identification detectors
- Must fit in very narrow space
- Good spatial resolution
- Possibly, good timing resolution

- Full tracker, i.e. several concentric layers of MPGDs
- Layers can be cylindrical for a compact designs
- Must work in high particle rates and high magnetic fields





- For both solutions, low X/X0 is mandatory
- The technology must be affordable and reliable for large surfaces

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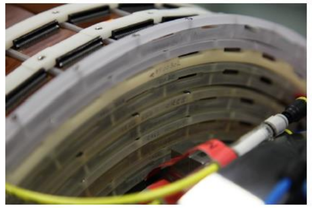
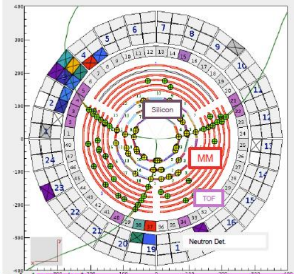
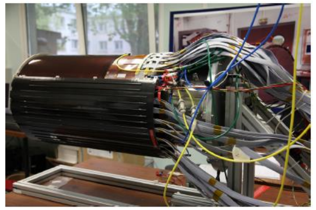
CEA Saclay: Exploring Cylindrical Micromegas
- Full multiple cylindrical Outer Tracker
- Fast signal tracking layer with TPC

CLAS12 Micromegas Vertex Tracker

- 4 m² of curved Micromegas detectors
- DREAM based Front-End Electronics ~ 20k ch.
- Low momentum particles => Light Detectors ~0.3% 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)
- Up to 30 MHz of particle rate





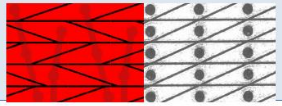


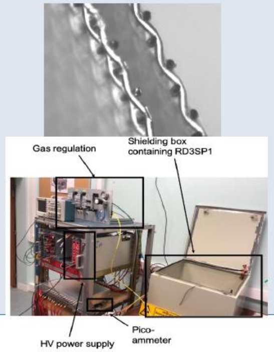
F.Bossù (CEA/Irfu)

Experience with CLAS12 @ Jlab
Cylindrical Micromegas Vertex Tracker (MVT)

2D READOUT AND LOW-IBF

ZigZag 2D read out	Low-IBF for TPC
• R&D on laser etching for read out of MPGD detector • 1D ZigZag: better then 100um res with 2mm strips • MM, GEM and uRWELL read by the DREAM electronics • 2D read-out with better than 200um resolution • Development within an LDRD • M. Revolle's PhD subject	• Micromegas based solutions for low-IBF read-out planes for TPC • A. Glaenzer's PhD subject





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DREAM Front-End Electronics

Versatile FE readout electronics developed at Saclay primarily for CLAS12, and widely used by various experiments

Sustains trigger rates of 50 kHz and beyond; Low dead time operation with concurrent sampling and readout

Off-detector architecture with up to ~2m micro-coaxial cables and tolerant to 1.5 T magnetic field

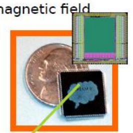
Based on an in-house developed 64-channel Dream ASIC

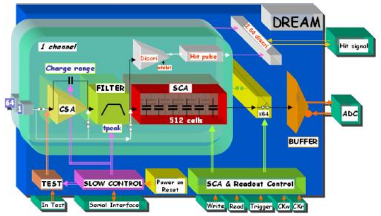
High input capacitance friendly: O(100pF) level

Sampling frequency up to 50 MHz

Adjustable peaking time from 70 ns to 1 µs

Adjustable gain/dynamic range from 50 fC to 600 f





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Experience with FE readout: DREAM Electronics for CLAS12 MVT

Ongoing R&D:
- Development of 2D strip readout structure
- Minimization of IBF

https://indico.bnl.gov/event/7449/contributions/35958/attachments/27181/41436/CEASacaly_EICYR_Tracking_TempleMeeting.pdf

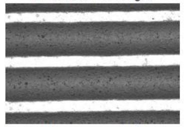
MPGD WORKSHOP AT SACLAY

120 m² of clean room for Micromegas bulk and resistive layer manufacturing.

Bulk process: addition of a mesh on PCB by photolithography
- Maximum detector size: 600 x 700 mm².
- Amplification gap from 50 to 292 µm
- Mesh woven (18 µm wires) or thin mesh (down to 5 µm)
- PCB with strip, XY strip, pixel,…
- Production : ~ 150 bulk in 2019
- R&D : thins mesh, curved bulk, segmented mesh, double mesh….

Double face micromegas

Resistive screen printing on various surface
- Maximum size: 600 x 600 mm²
- Resistive value: from 10 KOhm/sq, to 10 Gohm/sq
- Possibility of neutral on conductive paste
- Substrate: Kapton, glass, FR4
- Production: ~ 100 resistive substrate in 2019
- R&D : mixture for ad hoc resistive value, segmented resistive,…



Resist strip of 500 µm

contact stephan.aune@cea.fr

Bulk lab

Resist lab

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An Ultra Low-Mass Drift Chambers with Particle Identification for EIC

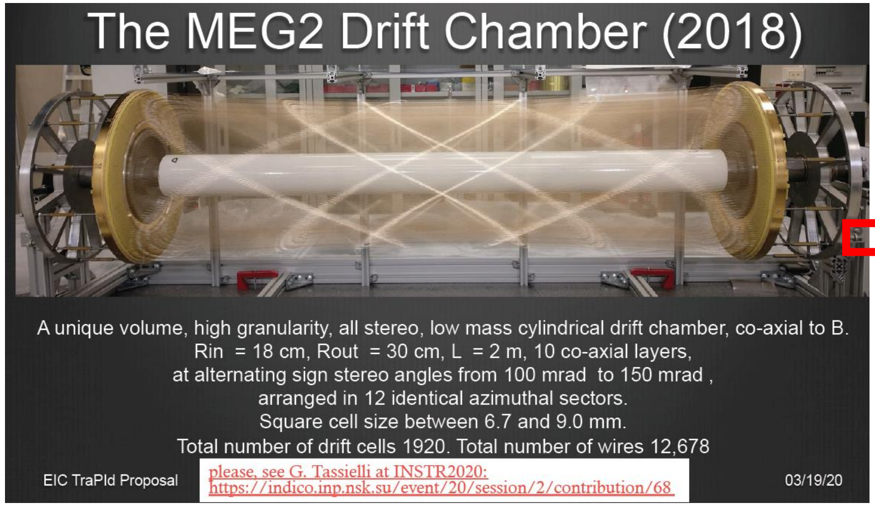
F. Grancagnolo, INFN Lecce, Italy

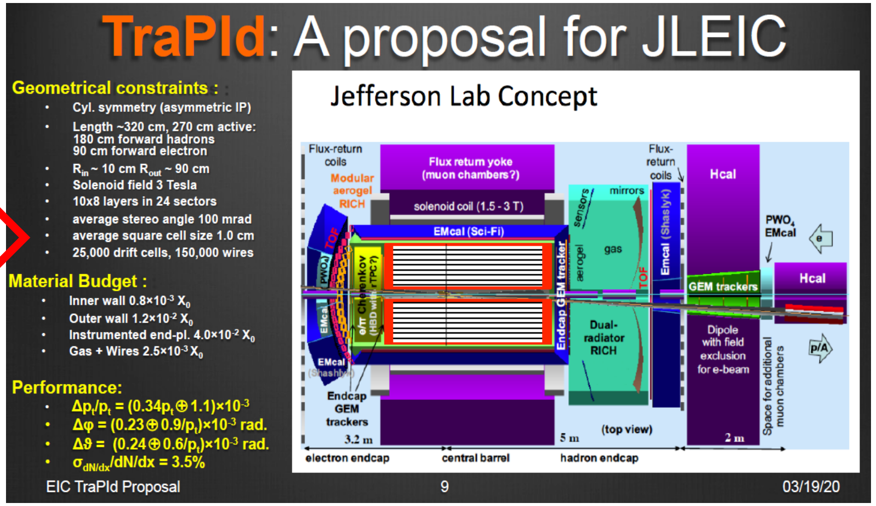
Innovation for Cyl. Low Mass Drift Chambers

- Separation of gas containment from wire support
- No feed through wiring
- Large number of thinner wires (low mass)
- **Cluster timing for improved spatial resolution**
- **Cluster counting (dN/dx) improved PID**
- **TraPId: A proposal for JLEIC Detector**
  - New ideas worth exploring

Straw Tubes approach vs. Open cells DC

- Low mass straw tubes i.e. PANDA or GLUEX





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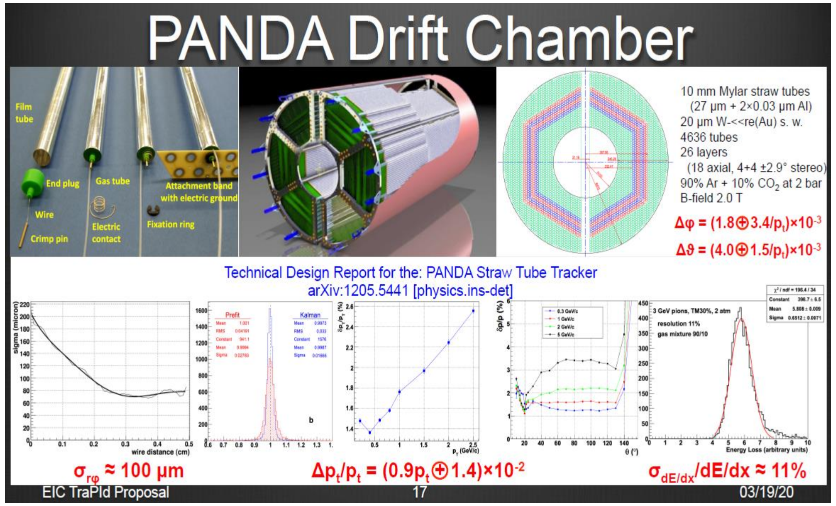
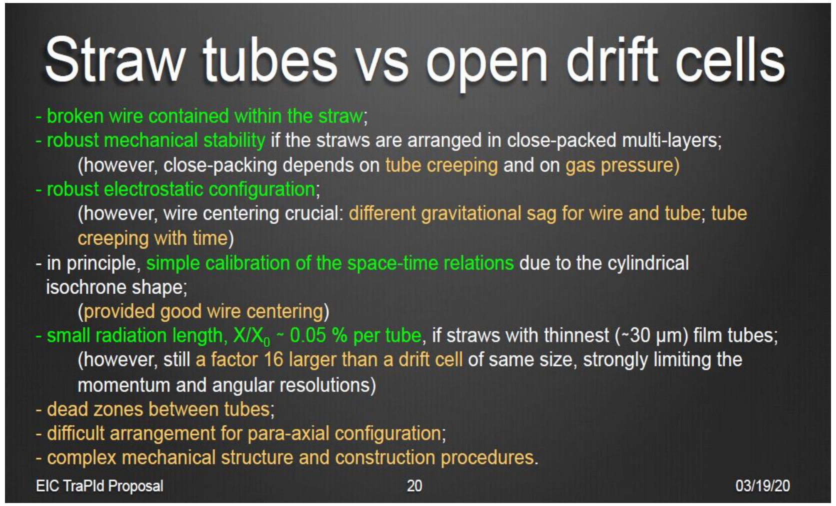
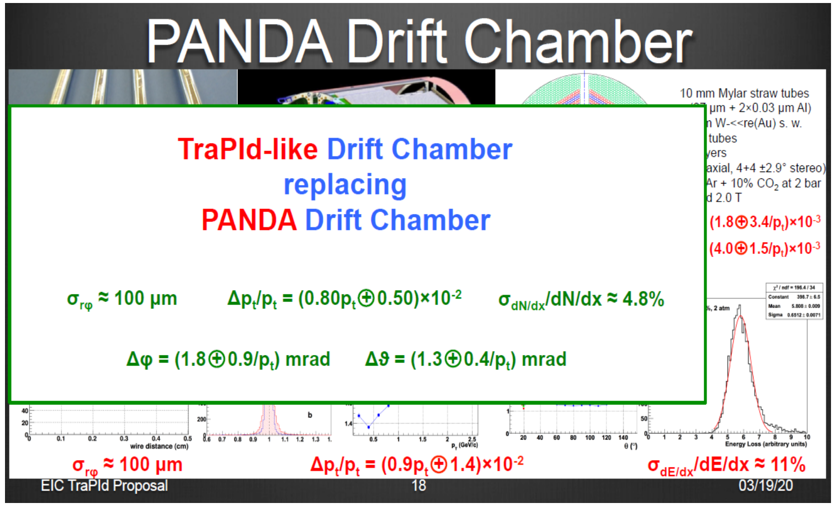






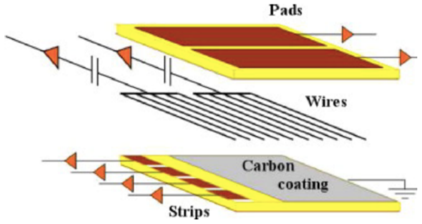
End Cap Tracking with Small-Strip Thin Gap Chambers (sTGCs)

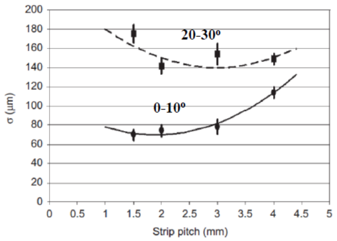
Daniel Brandenburg, BNL-CFNS

Overview: Small-Strip Thin Gap Chambers

<u>sTGC Detector Specification</u>

- Double-sided:
  - X & Y strips provided by one layer
  - Diagonal strips on other layer
- Pentagonal shape:
  - Rotational symmetry
  - One "disk" = 4 identical modules
- 22,000 readout channels in total
- STAR sTGCs are much smaller than ATLAS sTGCs
- **Expected Position Resolution: < 100 μm**
  - Resolution depends on perpendicular angle of incidence



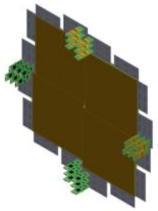


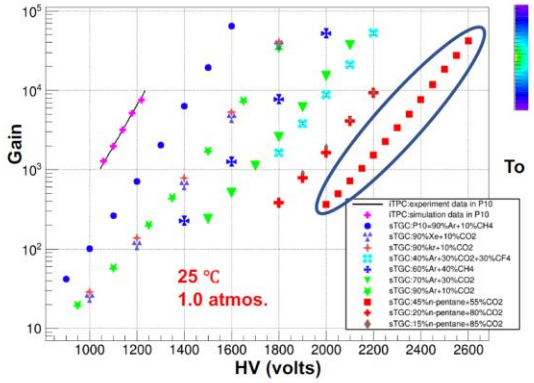
sTGCs for End cap Tracking:

- Shandong University with a lot experience with developing sTGCs for HEP/NP Experience
- ATLAS Small Wheel sTGCs
- STAR Forward Tracker

Prototype Tests III : @ SDU

Full size (60x60 cm) prototype built at Shandong University using 30x30cm square module design





Performance Test @ SDU

- Gas : 45% n-Pentane + 55% CO_2
- HV: 2700V

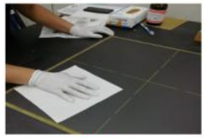
Optimal gas for sTGC: n-Pentane + CO_2

Efficiency > 98%

sTGC Production Procedure

- Shandong University has developed significant expertise
  - Production of ATLAS and STAR sTGC detectors

Carbon Coating ⇩ Wire Winding ⇩ Two Halfs Combination ⇩ X-ray Scan ⇩ Two Chambers Combination ⇩ Performance Test

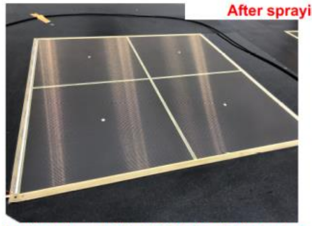


Polishing

Measuring

Carbon Coating

After spraying



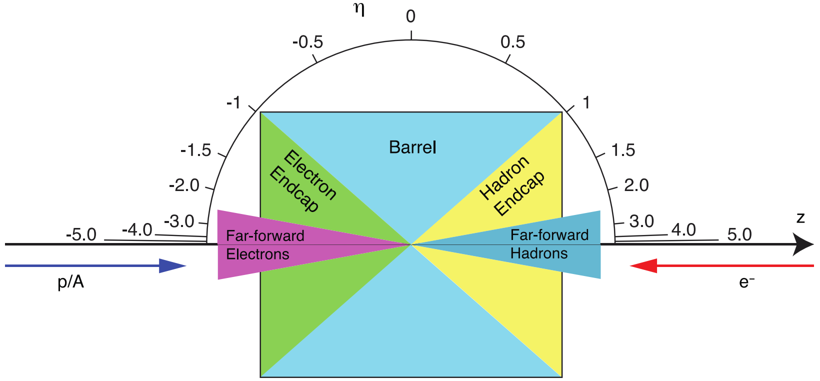
Ready to be bonded to the PPPCB half to build a chamber

- sTGC Production and QA Procedures in place

Summary and Conclusions

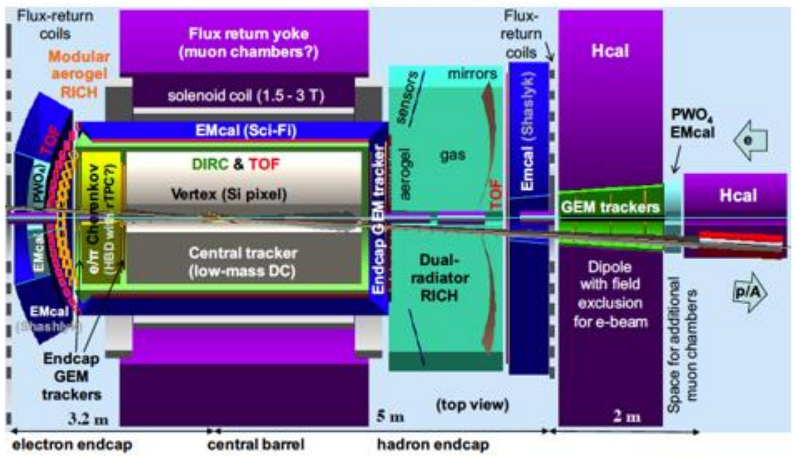
- Small-Strip Thin Gap Chambers detector technology:
  - <u>Cost effective</u> technology for large area tracking detector
  - Provide <u>good space point resolution</u> of $\sim 100\mu m$
  - High rate (100 kHz/cm^2)
- The STAR Forward tracking system (including silicon and sTGCs)
  - Meet or surpass requirements for physics goals in p+p, p+A, A+A
  - Momentum resolution better than 30% (for p_T < ~5 GeV/c)
  - Will be commissioned and run in STAR Fall 2021+
- Use of sTGC technology for EIC endcap detectors
  - Potential to benefit from significant developments from ATLAS & STAR
  - Design & Production expertise at Shandong University
  - Reuse of integration expertise & gas system design for n-Pentane

Summary of Gaseous Detectors Technologies

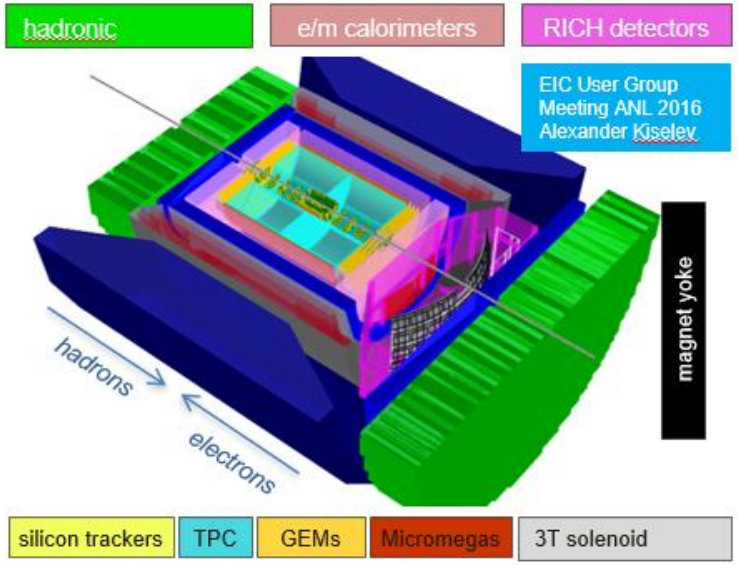


- Many baseline EIC detector designs involved various gaseous detectors technologies for tracking in the central as well as end cap region
- A few technologies are mature for EIC Detectors and would require only limited R&D
- Some of these technologies seems more natural options for some subdetectors
- There is still a need for small level of R&D to fully satisfy the EIC requirements
- The anticipated simulation work within Tracking WG will help select the best technologies for EIC

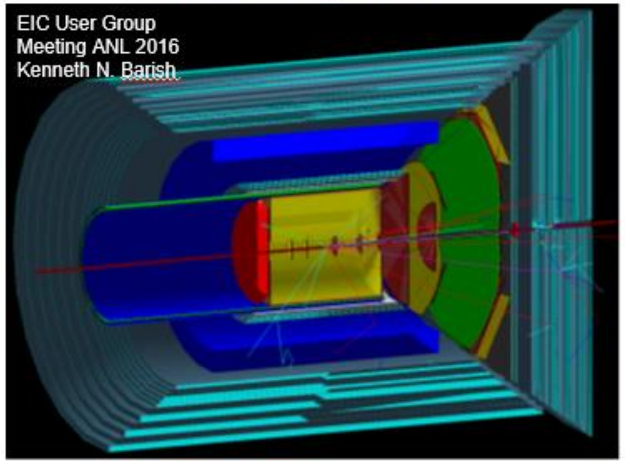
JLEIC Design



BeAST @ eRHIC



ePHENIX @ eRHIC



Tracking WG – Simulation summary

Simulation session agenda:

Introduction to YR-Tracking WG Simulation	*Domenico Elia*	
Online		16:30 - 16:45
Overview of Tracking Simulation needs and Plans	*Barbara Jacak*	
Online		16:45 - 17:15
Including detector services in simulations	*Leo Greiner*	
Online		17:15 - 17:30
Open Discussion	*All*	
Online		17:30 - 18:00

Tracking WG – Simulation summary

Tracking WG meetings:

- weekly held (on Thursday), started on 13/2
- collected interest from participating groups (next slide)
- recently dedicated to simulation issues

  27/2: https://indico.bnl.gov/event/7689/
  - ✓ presentation on framework simulation tools (fast and full) by the SWG (Markus)
  - ✓ detailed presentations on G4E/eJANA (Dmitry, Yulia, Nathan) and Fun4All (Chris)

  12/3: https://indico.bnl.gov/event/7885/
  - ✓ question / answer session on Fun4All with Chris (and participating groups)
- plan to have next meeting with q/a session on G4E/eJANA
- follow up developments and steer direction

Tracking WG – Simulation summary

Tracking WG meetings:

- weekly held (on Thursday), started on 13/2
- collected interest from participating groups:

Participating Institutes	Software oriented interest
eRD6: BNL, INFN Trieste, Florida Tech. Stony Brook U., Temple U., UVa, Yale U.	Central and forward tracking (gaseous)
eRD22: Jlab, Temple U., UVa	Central and forward tracking (gaseous)
CEA Saclay (France)	Central tracking
eRD18: University of Birmingham (UK)	Central tracking
LANL	Central and forward tracking
UC Berkeley / LBNL	Central and forward tracking
INFN Bari	Central tracking (silicon)

Tracking WG – Simulation summary

Simulation session agenda

Barbara Jacak – Overview of Tracking simulation needs and plans

https://indico.bnl.gov/event/7449/contributions/35962/attachments/27187/41446/tracking_simul_sum_Jacak.pdf

- all-silicon tracker studies:
  - ✓ Bari, Birmingham (eRD18), LBNL + UC Berkeley (eRD16)
    - barrel only, barrel & endcaps, ALPIDE-like sensors
    - 1.5 / 3 T solenoidal field, different nr. of layers / pixel size / outer radius / layer thickness
    - using fast simulation, transition to full (Fun4All, G4E/eJANA) ongoing/aimed to
  - ✓ LANL (fast simulation, mid-rapidity + forward MAPS, preliminary performance vs EIC handbook)
- hybrid / gas tracking studies:
  - ✓ BNL/sPHENIX (full chain simulation and reconstruction in Fun4All, early EIC detector concept)
  - ✓ eRD6 (EicRoot + BeAST configuration, investigate use of forward GEMs behind the RICH)
  - ✓ CEA-Saclay (Fun4All, focus on curved Micromegas, first momentum resolution estimates)

Tracking WG – Simulation summary

Simulation session agenda

Barbara Jacak – Overview of Tracking simulation needs and plans

https://indico.bnl.gov/event/7449/contributions/35962/attachments/27187/41446/tracking_simul_sum_Jacak.pdf

- main conclusions and next steps:

We now know

- There are complementary ways to address general tracking
  - But we do need silicon for vertexing
- All-silicon tracker can match or exceed performance of hybrid silicon/gas tracking system
- Some fast tracking layers may be important to best utilize DIRCs
  - Needs some work to specify
- For silicon tracker
  - 20 micron x 20 micron pixels will do the job
  - All-silicon barrel must extend to R ≥ 45 cm, needs 5 or 6 layers
  - Endcaps need more optimization & hardware specification

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Questions driving next steps

- Magnetic field? How to get sufficient forward Bdl?
- Optimum technology mix for tracking?
- Effect of thinner silicon (0.05% vs. 0.3% X/X_0)?
- What is the impact of more realistic mechanical infrastructure?
- Finish optimizing Si tracker layer placement (barrel & endcap both)
- Symmetric endcap trackers?
- How to optimize forward tracker?
  - Higher Bdl vs higher spatial resolution?
  - What will be affordable?
- Interaction between tracking and PID?
- What are the requirements for fast tracking layers?

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Tracking WG – Simulation summary

Simulation session agenda

Barbara Jacak – Overview of Tracking simulation needs and plans

Leo Grainer – Adding services load to the EIC simulations

https://indico.bnl.gov/event/7449/contributions/35963/attachments/27118/41332/2020_03_16_EIC_Si_services_parametrization_for_sim.pdf

- services are likely to be a major part of material in the large acceptance and can be reasonably parameterized as a function of silicon surface area
- the service volumes can be similarly parameterized
- examples are given for the sensor most often used in the simulations (ALPIDE)
- there are options to reduce services (better sensor, targeted R&D)
- recommended for all detector defining groups to provide this with their implementation

Tracking WG – Simulation summary

Preliminary workplan:

- optimize detector layout via fast simulation, eg:
  - ✓ checks with more realistic material sensor and services (Bari, Berkeley)
  - ✓ optimize silicon barrel layout (Bari, Birmingham)
  - ✓ optimize silicon endcap layout (LANL, Berkeley)
- besides optimizations, proceed with integration in full simulation:
  - ✓ define baseline detector concept (BeAST or ePHENIX? 1.5/3 T magnet?)
  - ✓ keep working on both frameworks Fun4All and G4E
  - ✓ implement realistic material and services, connection to integration issues
  - ✓ define (1-2?) strawman silicon vertex barrel to allow optimization of outer barrel?
- study gas tracker options (eRD6, Saclay)
- move to non-ideal track finding algorithms (BNL, Berkeley)
- study jet efficiency & resolution, jet substructure (Berkeley, LANL, BNL)
- further connections to physics benchmarks