Central Detector Integration / Magnet subgroup status, goals and future plans

*Conveners: William Brooks and **Alexander Kiselev***

EICUG Yellow Report subgroup Meeting   April 15 2020

The scope as shown at the "Temple" meeting

- **All the questions associated with the solenoid magnet:**
  - Options, overall design, geometry, GEANT model, field map(s)
  - Central field strength: photo-sensors, tracking resolution, acceptance for low Pt tracks, fringe field & gaseous RICH performance, etc

- **Detector components "co-existence" verification**
  - Geometry conflicts, fiducialization, realistic space for sub-detectors, etc
  - Combined sub-detector performance (?)

- **Dead material accounting**
- **Integration in the IR**
- **Backgrounds (?)**
- **Infrastructure, support, services**

“Temple” meeting: Solenoid field strength

- Photo-sensors in the magnetic field
  - Junqi Xie (Argonne)
    https://indico.bnl.gov/event/7449/contributions/36024/attachments/27216/41540/YR-Temple-Magnet.pdf

We are good for 1.5 T field; there are options even for 5T but then cost is an issue

- Tracking resolution
  - Nicholas Lukow (Temple)
    https://indico.bnl.gov/event/7449/contributions/36028/attachments/27226/41509/YellowReport_MagneticFieldStrengthTrackingResolution.pdf

A compromise between the two objectives needs to be found

-> a set of combined eic-smear parameterizations will be provided

- Acceptance for low Pt tracks
  - Yulia Furletova (JLab)
    https://indico.bnl.gov/event/7449/contributions/36027/attachments/27229/41512/TrackingField_Feb2020.pdf

- Fringe field & gaseous RICH performance
  - Jin Huang (BNL)
    https://indico.bnl.gov/event/7449/contributions/36025/attachments/27209/41610/sPHENIX_Magnet.pdf
  - AK (BNL) / also BeAST field map calculation summary /
    https://indico.bnl.gov/event/7449/contributions/36026/attachments/27242/41531/ayk-2020-03-20-beast-magnetic-field.pdf

If one has a freedom to optimize the fringe field on the design stage, high momentum RICH should work fine

PHOTO-SENSORS IN A STRONG MAGNETIC FIELD: OPTIONS FOR EIC

JUNQI XIE

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1st EIC Yellow Report Workshop at Temple University

19-21 March 2020
Temple University

TYPES OF SINGLE PHOTON DETECTORS

- **Vacuum Photon Detectors**
  - Photo Multiplier Tubes
  - Hybrid Tubes
  - MCP-PMT
- **Gas-based Photon Detectors**
  - Micro-pattern Detectors
- **Solid State Photon Detectors**
  - Silicon-based (MPPC, CCD)



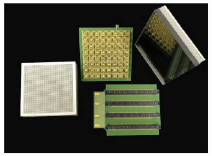
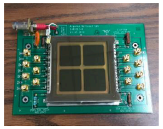
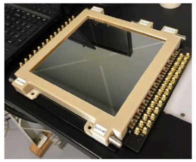
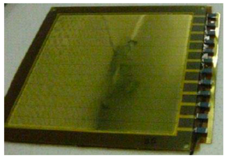
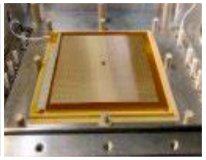
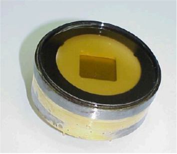
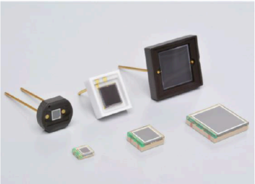








PHOTO SENSOR OPTIONS FOR EIC

Many photo sensors are available in market, but to EIC, the choices are limited.

Time resolution (σ)

- PMTs, MAPMTs >/~ 0.3 ns
- MCP-PMT <100 ps
- SiPM <100 ps
- MWPCs >/~ 20 - 400 ns
  - FE dependent, ballistic deficit implications (*)
- MPGDs ~ 7-10 ns (INTRINSIC)

(*) COMPASS – Gassiplex 400 ns, ballistic def. 50%
APV25 20ns, ballistic def. 25%

Effective QE range

- Vacuum-based devices:
  λ > 300, 250, 200 nm
  [also solar-blind]
- Gaseous devices (CsI):
  λ < 205 nm

Operation in magnetic field

- ~~PMTs, MAPMTs, HPMTs~~ NO
- MCP-PMT YES
- MWPCs, MPGDs YES
- SiPM YES

COSTS

- Gaseous (*) - $ (0.2-0.4 M / m²)
- MAPMTs - $$ (0.5-1 M / m²)
- SiPM - $$ (0.8-1 M / m²)
- MCP-PMT - $$$ (???)
  - LAPPD - $$ (0.8-1 M / m²)

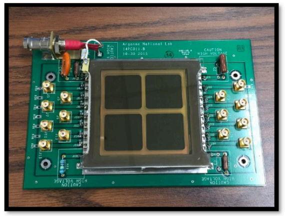
(*) gas system, mirrors more DEMANDING → expensive

S. Dalla Torre, this workshop

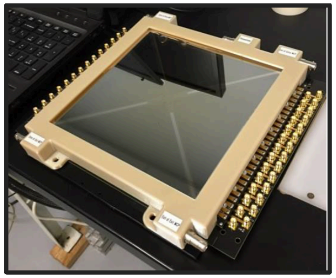
ARGONNE 6 CM MCP-PMT & COMMERCIAL LAPPD™

Small form factor LAPPD (Argonne 6 cm MCP-PMT) was produced for R&D. Knowledges, Design and Experiences were transferred to Incom to support commercialization of 20 cm LAPPD™

R&D test bed: 6x6 cm²



Commercialization: 20x20 cm²



- Close collaboration and communication (bi-weekly meeting, joint SBIR program), optimized configurations are directly transferred to Incom production line for mass production.

Magnetic Field Strength and Tracking Resolutions

Nick Lukow

March 20, 2020

1st Yellow Report Meeting

Temple University

College of Science and Technology

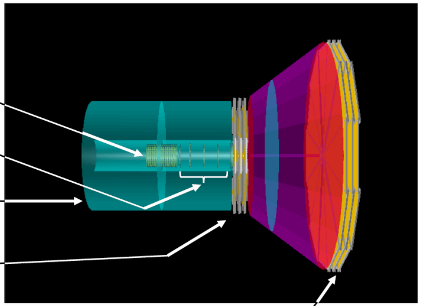
TEMPLE UNIVERSITY®

Detector - BeAST

All “naïve” default resolution parameters*

Detectors:

- **Silicon Vertex Tracker**
  - $5.8\ \mu m \times 5.8\ \mu m$ resolution
- **Forward Silicon Trackers**
  - $5.8\ \mu m \times 5.8\ \mu m$ resolution
- **TPC**
  - Intrinsic longitudinal resolution: $500\ \mu m$
  - Intrinsic transverse resolution: $200\ \mu m$
  - Longitudinal dispersion: $1\ \mu m/\sqrt{D[cm]}$
  - Transverse dispersion: $15\ \mu m/\sqrt{D[cm]}$
  - Vertical pad size: 0.5 cm
- **Forward Gem Trackers**
  - $50\ \mu m \times 50\ \mu m$ resolution
- **Far Forward Gem Trackers**
  - $100\ \mu m \times 100\ \mu m$ resolution

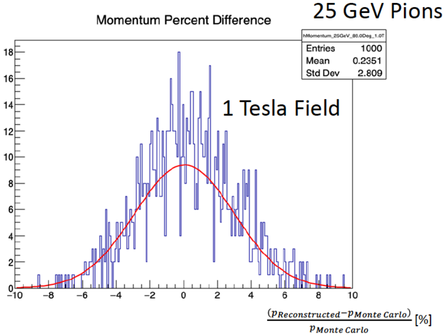


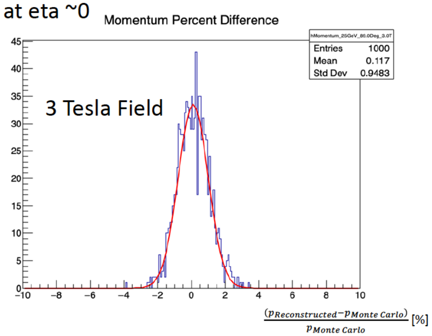
** Can be updated to more realistic parameters*

Details

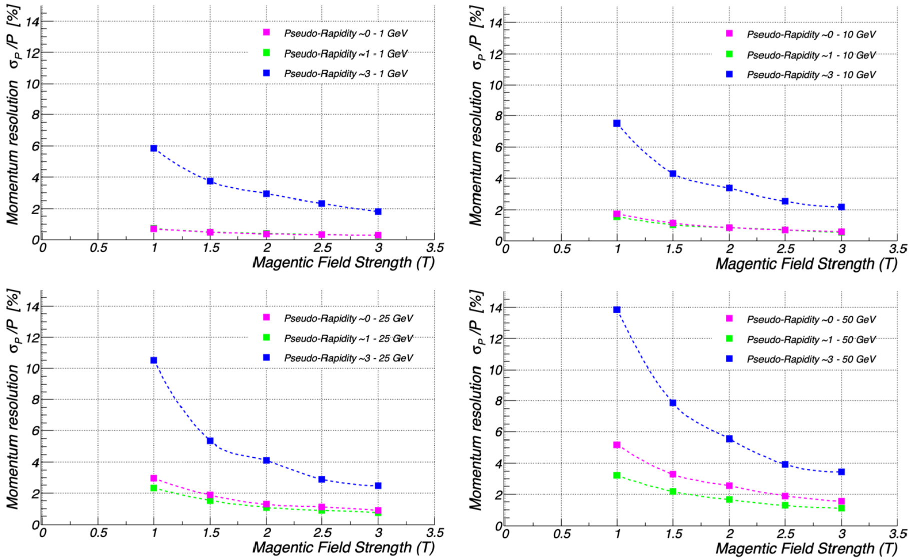
Simulations were performed in EICRoot.
1000 pions were thrown at $\eta = \{0, 1, 3\}$ and $p = \{1, 10, 25, 50\}\ GeV$
This was done for magnetic fields of {1.0, 1.5, 2.0, 2.5, 3.0} Tesla
The tracks were reconstructed, and the reconstructed momentum was compared to the actual momentum of the generated track.
Distributions of $\frac{(p_{Reconstructed} - p_{Monte\ Carlo})}{p_{Monte\ Carlo}}$ are made, and the standard deviation is taken as the momentum resolution.

25 GeV Pions at eta ~0





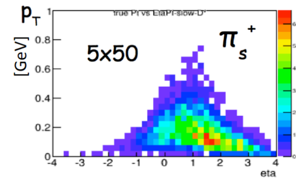
$\frac{\sigma_p}{p}$ vs B for Constant p



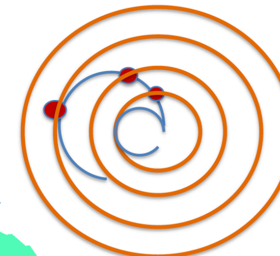
Low momentum particles

Problem of too high magnetic field:

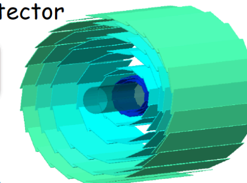
$$D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$$



- Layered structure of vertex detectors
- For track reconstruction slow particles have to pass at least 3 layers of tracking detector



Barrel part of vertex detector



p_T [GeV] = 0.3· B [T] · R [m]

Beampipe: 3.2cm
Inner layer of outer tracker: 20 cm

Minimum pT possible to detect for 3T (at 6cm): ~ 30MeV

Yulia Furletova 3

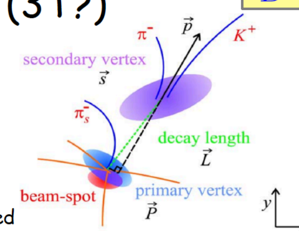
Magnetic field (3T?)

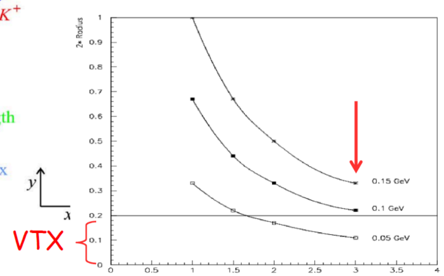
$$R(m) = \frac{P_T(GeV)}{0.3 \cdot B(T)}$$

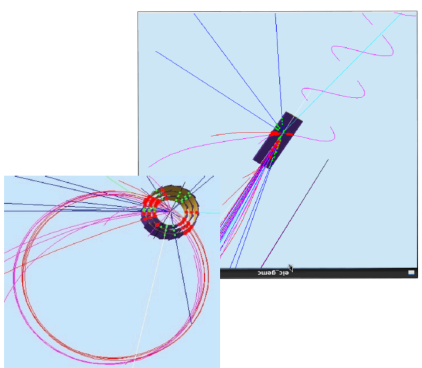
$2R > R_{out}$ (VTX)

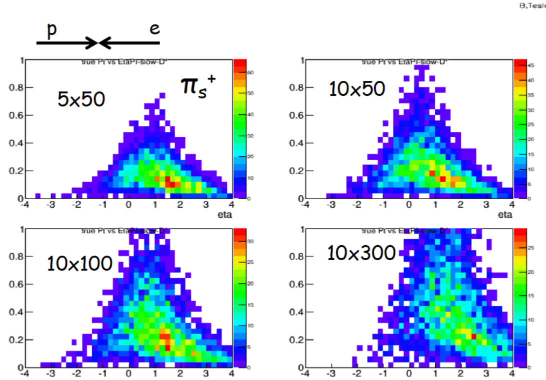
For Vertex- 20 cm in R - reserved

$D^{*+} \to D^o\pi_s^+$, $D^o \to K^-\pi^+$









Jefferson Lab
Thomas Jefferson National Accelerator Facility

Yuli...

Conclusion

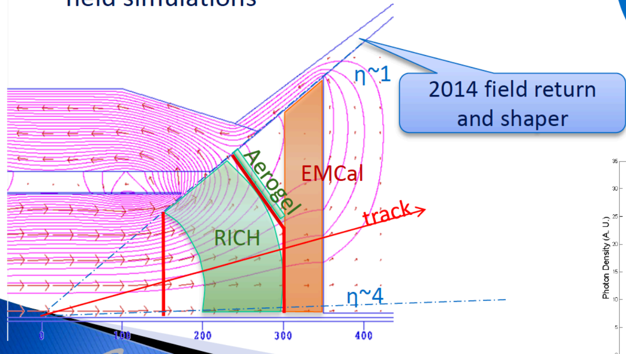
- For barrel, expected PT ~ 0-10(20) GeV. With too high magnetic field tracks start to curl..
- Too high field creates inefficiency for low-Pt tracks.
- A magnitude of the field should depends on a granularity of a central detector (for all-si tracker magnetic field could be higher)
- Problem for accelerator: magnetic field should be compensated.

Forward gaseous RICH performance in the EIC-sPHENIX solenoid fringe field

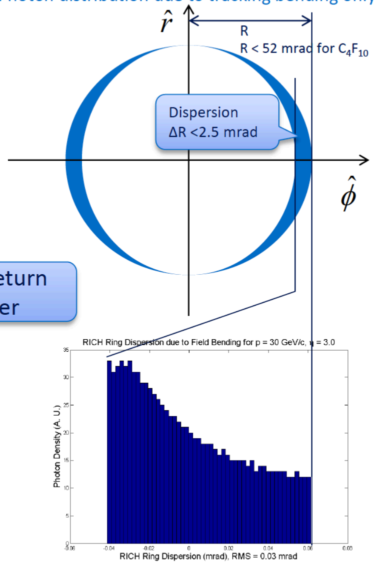
Jin Huang (BNL)

Field effect - distortion for RICH

- Field calculated numerically with field return
- Field lines mostly parallel to tracks in the RICH volume with the yoke
- We can estimate the effect through field simulations

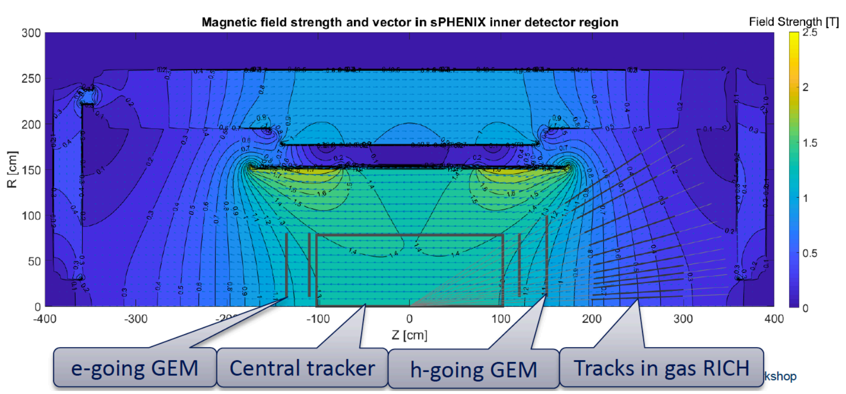


A RICH Ring : Photon distribution due to tracking bending only

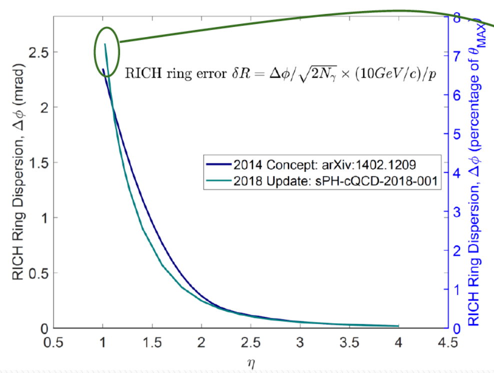


Now: new field return for sPHENIX and sPHENIX-EIC concept

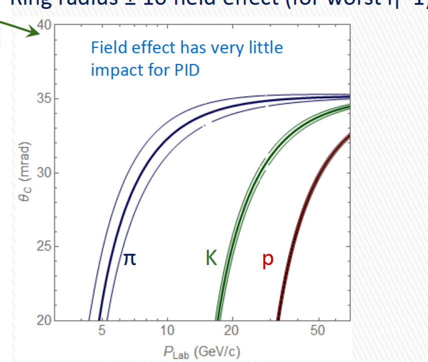
- After arXiv:1402.1209, field return and HCal design for sPHENIX was updated
  - [sPHENIX CDR]: https://indico.bnl.gov/event/6145/
- Updated field map and conceptual EIC layout: sPH-cQCD-2018-001
  - Using Hcal to return field at the same location as the sPHENIX field return door
  - Field map : https://github.com/sPHENIX-Collaboration/calibrations/tree/master/Field/Map



Quantitative bending



Ring radius ± 1σ field effect (for worst η~1)



2014 & 2018 field maps

In the respect of PID: minor effect

BeAST solenoid magnetic field calculation and accompanying studies

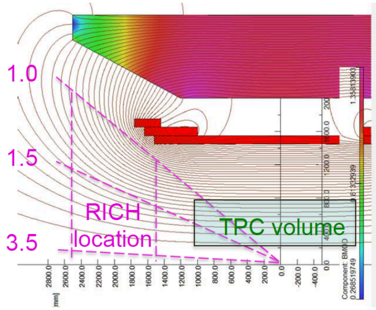
Alexander Kiselev

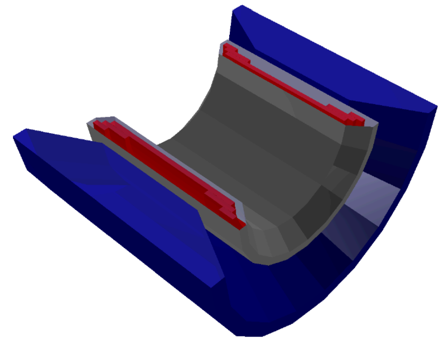
Remote “Temple” EICUG YR Meeting Mar,20 2020

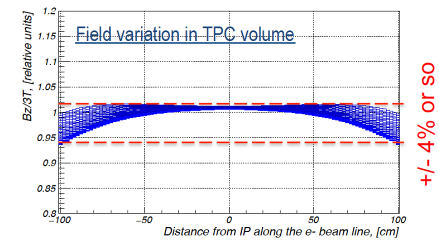
BeAST magnetic field

Goal:

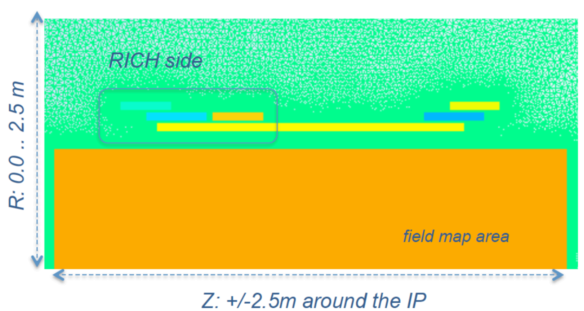
- Implement in the same compact design:
  - homogeneous ~3T field in the TPC
  - hadron-track-aligned field in the RICH
- Keep it simple (no dual solenoid configuration; no reversed current coils; no flux return through HCal; no warm coils between RICH and EmCal)







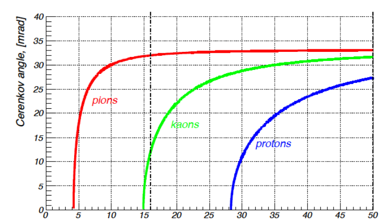
Coil configuration (optimized for RICH)



- RICH side (hadron-going direction) gets tuned
- The other side stays almost the same as before

R_{min}, [mm]	R_{max}, [mm]	Length, [mm]	Z-offset, [mm]	Current, [A/mm^2]
1610	1700	500	1600	-20
1510	1600	500	700	12
1510	1600	600	1300	40
1400	1500	3000	0	24
1510	1600	600	-1400	34
1610	1700	500	-1600	12

Will gas radiator RICH work in this field?



Consider configuration inspired by the RD6 test run:

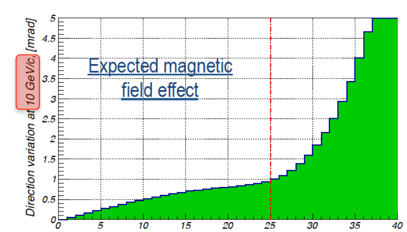
- 1m long CF_4 gas volume [1.5 .. 2.5]m from the IP
- 1m focal length; ~33mm ring radius at β ~ 1
- GEM readout; effective 2.5mm hexagonal pads
- Assume on average 12 photons per ring at β ~ 1
- Additional 300 μrad instrumental resolution

EIC R&D project

“Back-of-the-envelope” Monte-Carlo study:

- Realistic solenoid magnetic field
- Realistic tracker momentum resolution
- Cerenkov angle smearing in the field
- CsI quantum efficiency $\varepsilon(\lambda)$ dependence
- Refractive index $n(\lambda)$ variation
- Finite readout board “pixel” size

- ROOT TMVA-based output evaluation



NB: this spread is in principle noticeable compared to the intrinsic single-photon angular resolution of ~1 mrad

"Temple" meeting: Infrastructure

- Adding services to the EIC Monte-Carlo simulations
  - Leo Greiner (Berkeley)
    https://indico.bnl.gov/event/7449/contributions/36038/attachments/27241/41530/2020_03_20_EIC_Si_services_parametrization_for_sim.pdf

A very practical approach; should be used by all groups

-> requests to the detector and the software WGs will follow

- EIC detector infrastructure
  - Mark Breitfeller (BNL)
    https://indico.bnl.gov/event/7449/contributions/36039/attachments/27201/41474/EIC_Detector_Infrastructure_-_Breitfeller.pdf

You may have missed this: quite a lot was considered already -> see the slides

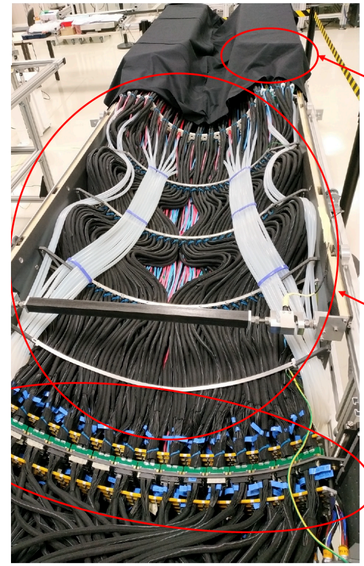
- IR vacuum chamber design
  - Charles Hetzel (BNL)
    https://indico.bnl.gov/event/7449/contributions/36037/attachments/27245/41538/Yellow_book_workshop_3-20-20.pdf

We do have a CAD model for 25mrad crossing angle (central area), but more work needed for the far forward region

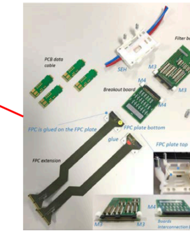
-> a request to the software WG will follow

A possible method for adding services load to the EIC simulations

- Services (power, signal, configuration, cooling, etc.) are expected to be a dominant part of the material in the large acceptance of the EIC central detector region.
- Unlike the support pieces, which need to change according to the detector configuration and would be difficult to parametrize, the services load can be scaled with reasonable accuracy to the silicon surface area.
- The parameters of this then method can then be adjusted to different sensor technologies showing performance differences from the services load standpoint.
- The physical volumes required at the end of staves/discs can also be added to the simulation models to allow for more realistic geometries.



Example: Services for existing technology (ALPIDE sensor) in ALICE ITS upgrade services for outer half-barrel layers

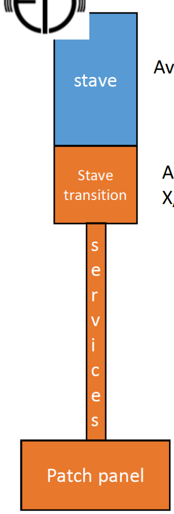


Material at end of each stave

Power, signal, cooling

Patch panel
(usually required for all detectors)

Approach to separate pieces of parameterized services



If we use ALPIDE (existing technology) we can estimate services as below

Average of 0.7-0.8 % X/X0 in simulation

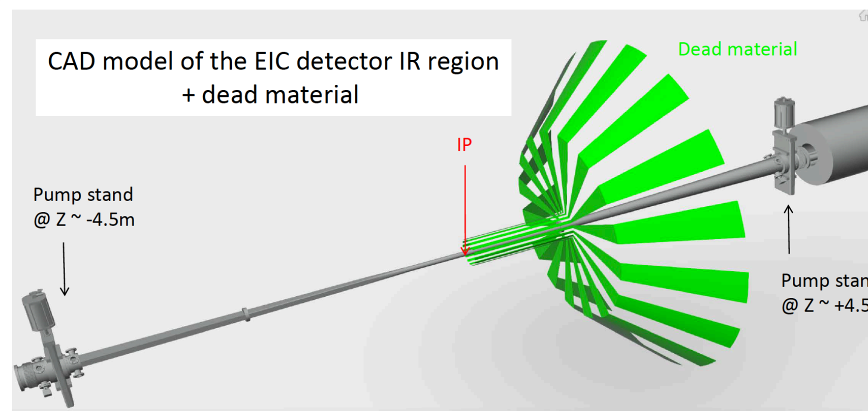
Area of (63 cm^2) of sensor requires 3 cm^3 material with an X/X0 of 0.0383 per traversed cm.

This should also worl

Area of (63 cm^2) of sensor requires a cross section of 1 cm^2 with a X/X0 of 0.007861 per traversed cm of length.

Area of (63 cm^2) of sensor requires a block of 2cm x 1 cm x 1 cm with 0.03423 X/X0 per traversed cm.

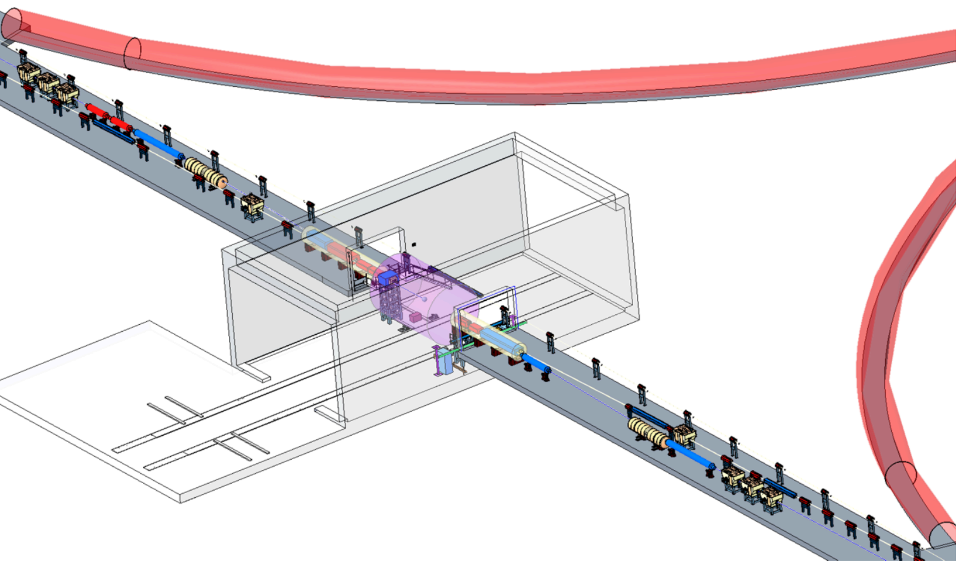
A possible software implementation (by Alexander)



- Describe the dead material distribution according to the proposed scheme
- Describe the way you ”route the material away”
- Export as a STEP file -> can overlay with the IR/detector engineering drawings

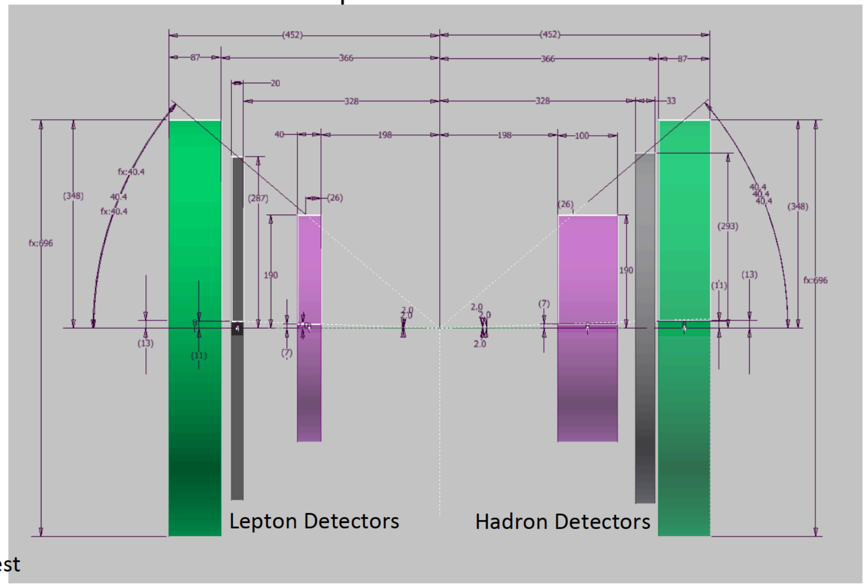
EIC Detector Infrastructure

e-Rhic Magnet Components – Limiting Available Space



EIC Detector Infrastructure

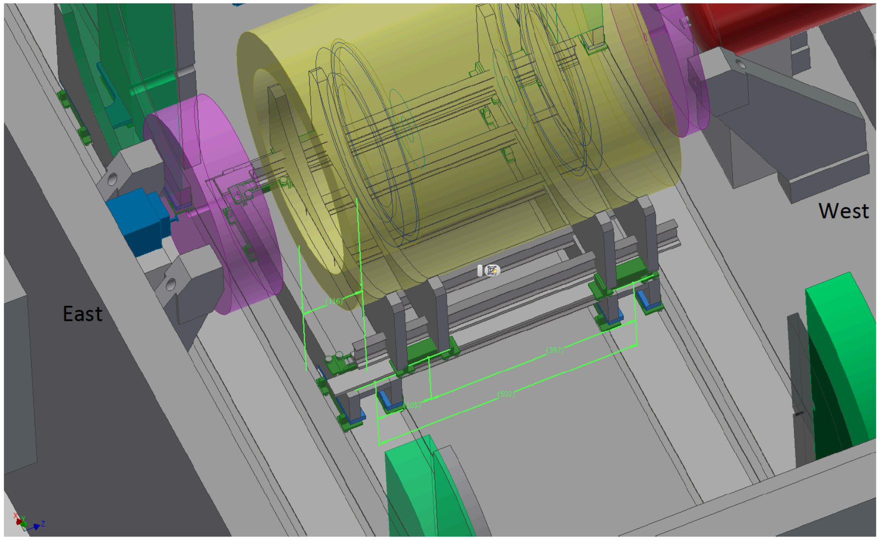
End-Cap Detectors Positioned



Pink = PID/RICH, Grey = ECAL, Green = HCAL

EIC Detector Infrastructure

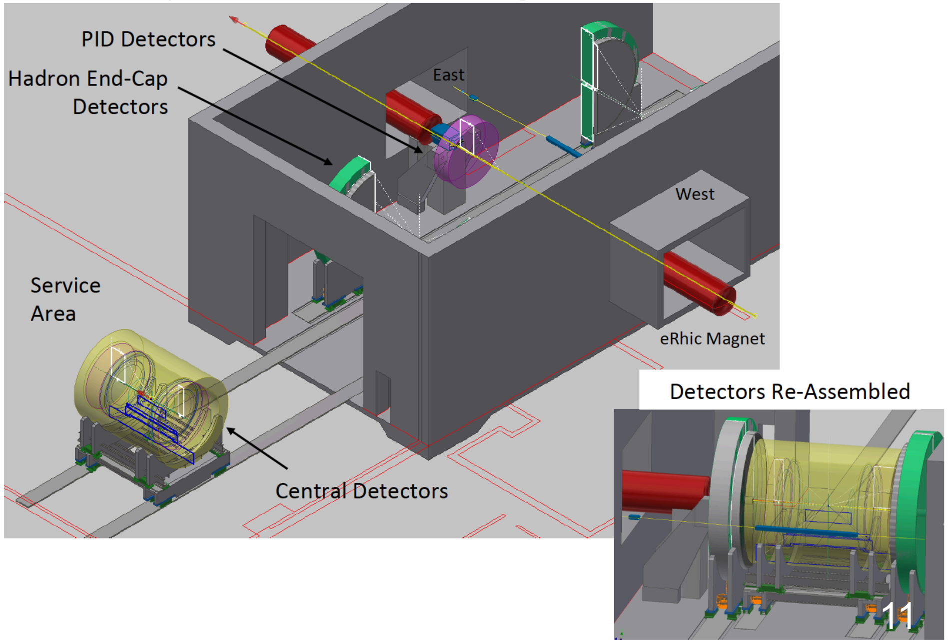
3D Model Access to Central Detectors



View shows Central Barrel traveled 58 cm along Electron Beam Axis, to access detectors inside barrel - gives approximately 116 cm (46”) clearance opening.

EIC Detector Infrastructure – BLDG 1006

Detectors separated and moved on carriage frames for service



EIC Yellow Report Workshop

Detector vacuum chamber and SR studies

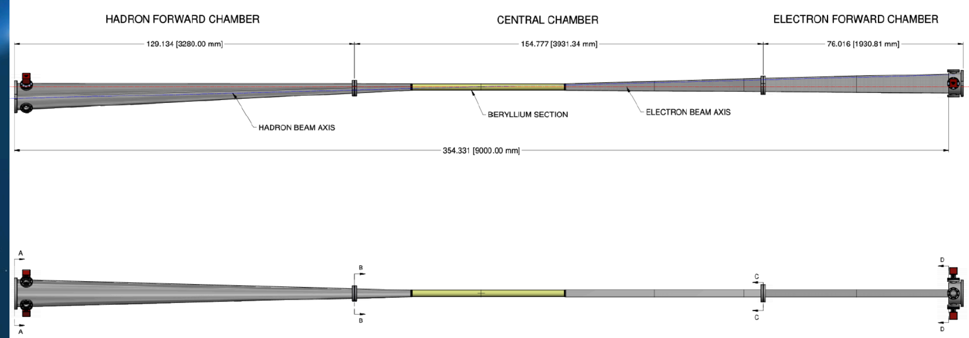
Charles Hetzel

March 20, 2020

Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY | U.S. DEPARTMENT OF ENERGY | Office of Science

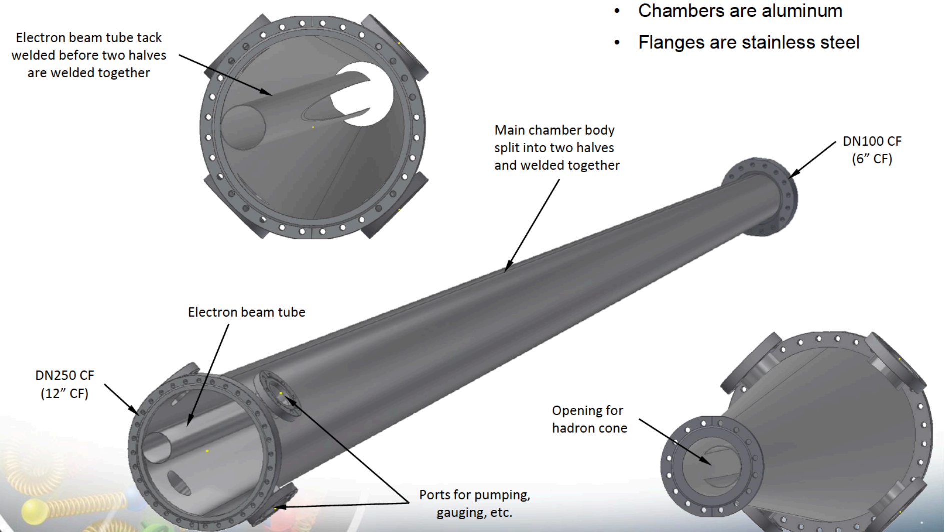
Chamber Geometry



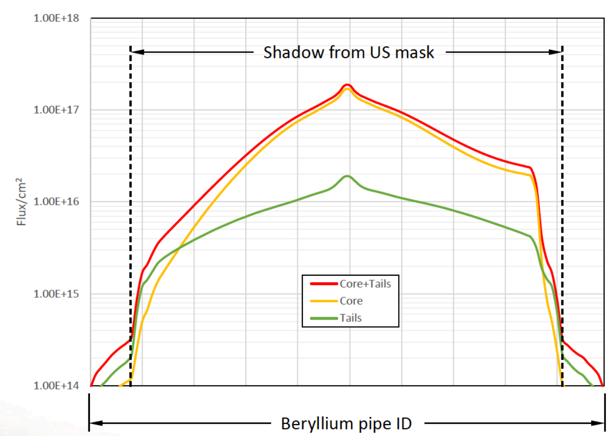
Hadron Forward Chamber

Note:

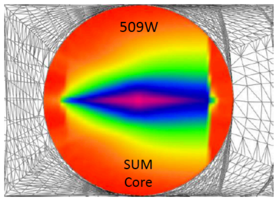
- Chambers are aluminum
- Flanges are stainless steel

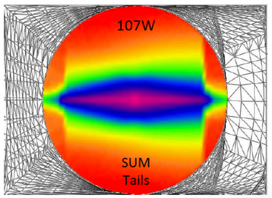


SynRad Results



Flux from core and tails





“Temple” meeting: Backgrounds

- Synchrotron radiation studies with the current IR design
  - Charles Hetzel (BNL) / the same talk /
    https://indico.bnl.gov/event/7449/contributions/36037/attachments/27245/41538/Yellow_book_workshop_3-20-20.pdf

This is a problem, but we can seemingly manage it

- Background sources and studies at the EIC
  - Latifa Elouardhiri (JLab)
    https://indico.bnl.gov/event/7449/contributions/36034/attachments/27260/41566/BGS-03202020-LE.pdf

A set of comprehensive studies for JLEIC configuration

- Beam-gas induced background, neutron flux, radiation dose at the EIC
  - Jin Huang (BNL)
    https://indico.bnl.gov/event/7449/contributions/36036/attachments/27210/41611/EIC_BeamGas_background.pdf

Several studies for EIC-sPHENIX and BeAST configuration

The amount and the quality of all the studies performed so far *in principle suffices for the YR*; they need to be adopted to the current EIC IR geometry though

EIC Background Sources and Studies and the Impact on the IR and Detector Design

Latifa Elouadrhiri
Jefferson Lab

Background Sources

Study background generated by machine operation in simulation:

- **Synchrotron radiation**
- **Beam-gas interactions**

Focus of this talk

- Beam halo effects and beam losses
- Neutron flux
- Others

➢ **Quantify background rates and radiation doses in order to assess the impact on**

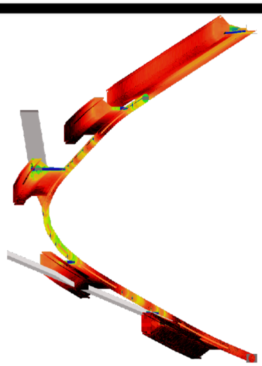
- **Detectors' operation, electronics, beamline components, etc.**

➢ **Provide input**

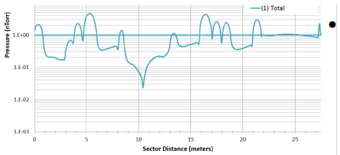
- **Machine lattice, IR design: beam pipe, magnets, vacuum/pumping**
- **Detector design, technology choices & Support structures, etc.**

It is critical to perform a thorough study of the type/dose and distribution of machine induced background **NOW** that the IR is being designed

Vacuum Modeling Tools



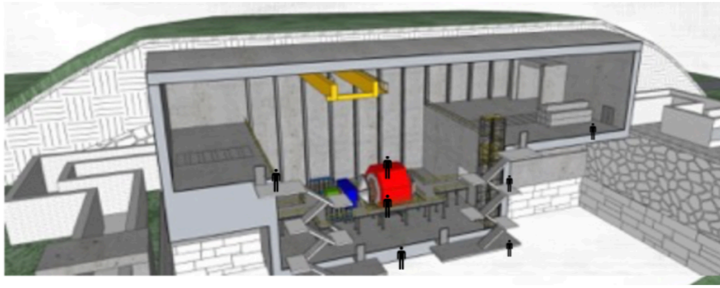
- Molflow+ and Synrad modeling software developed by Roberto Kersevan & Marton Ady
  - **Molflow+**: static vacuum modeling
  - **SynRad:** model of vacuum events due to beam
- Jason Carter, ANL, used Molflow+/Synrad to model static and dynamic vacuum for APS upgrade
- Jason Carter, ANL, and Marton Ady, CERN, used Molflow+/Synrad for SuperKEKB interaction region



- CAD designs of beamline are combined with pumping speeds and outgassing rates of elements yield expected pressure becomes input to our GEANT simulations.

Simulations with FLUKA

- Full inclusion of 70 m upstream beamline
- Magnets
- Tunnel walls, ceiling, floor
- Calculate Neutron flux with different simulation tools and compare to mesurments



Calculate Neutron flux with different simulation tools and compare to measurments

Studies of beam-gas background, neutron flux, radiation dose at an EIC

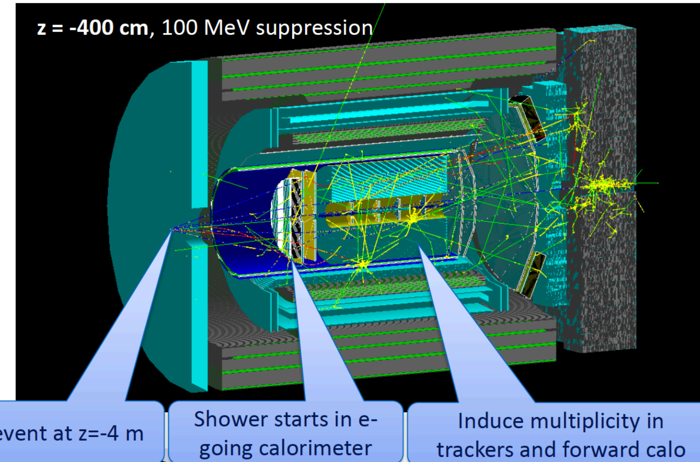
Jin Huang (BNL)

BROOKHAVEN NATIONAL LABORATORY

Thanks to the inputs from many of our colleagues!

Beam gas event in a detector

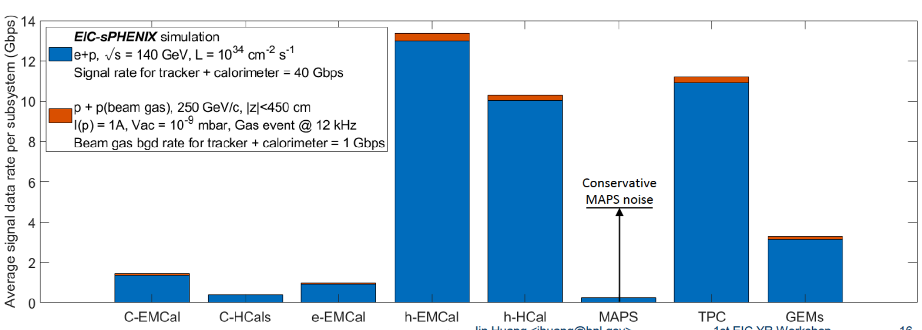
- 250 GeV proton beam on proton beam gas, sqrt[s] ~ 22 GeV
- For this illustration, use pythia-8 very-hard interaction event (q^hat > 5 GeV/c)



Signal data rate -> DAQ strategy

Note sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/ , Simulation: https://eic-detector.github.io/

- Beam gas of overall ~ 1 Gbps @ 12kHz beam gas << EIC collision signal data rate at ~100 Gbps (details in backup)
- Collision and background rate is critical for detector and DAQ design (see my parallel talk in DAQ session this AM)
- Looking forward to working with the group in integrating other important source of background, e.g. synchrotron radiation (see talk Charles Hetzel, Latifa Elouardhiri) and far forward detectors.

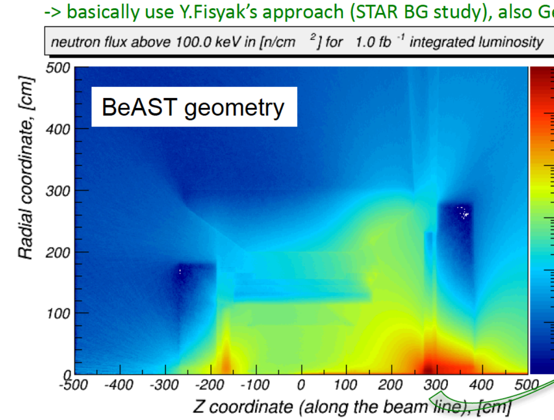


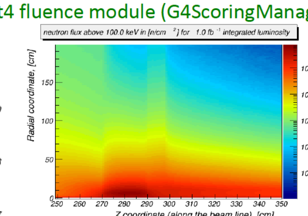
Neutron fluence

Study performed by Alexander Kiselev

<u>The quantity</u>: Fluence = "a sum of neutron path lengths"/"cell volume" for N events

-> basically use Y.Fisyak's approach (STAR BG study), also Geant4 fluence module (G4ScoringManager)





-> forward EmCal: up to ~5*10^9 n/cm^2 per fb^-1 (*inside the towers*); perhaps ~5 less at the SiPM location;

NB: "standard" EIC run at ~10^{33} cm^{-2}s^{-1} luminosity is 10 fb^{-1}

- Assume azimuthally-symmetric setup -> so build {R,Z} map
- Close to beam line: ~10^{34} cm^{-2}s^{-1} over ~10 years would exceed ~10^{11} n/cm^2

The first EIC Solenoid Magnet Designer meeting

- **Took place as a BJ meeting on April 8**
  - Attendees: WB, AK, R.Fair (JLAB), V.Morozov (JLAB), A.Morreale (LANL), B.Parker (BNL), R. Rajput-Ghoshal (JLAB), H.Witte (BNL)
  - The Indico page: https://indico.bnl.gov/event/8291/

- **Was a very useful initial exchange of opinions**

- **Once the list of specs is defined, it should take a couple of months to converge on a particular e/m design, from which point on the work on the subsystems can be distributed**

- **Need to think how to establish an efficient cooperation between the groups, but also an efficient work cycle between the designers and EIC physicists who should be able to validate the "released" configurations**

The solenoid requirement considerations

- **Generic input:**
  - Bore diameter ~3.0m, main coil length a la BaBar & BeAST designs
  - Max field 3T
  - Open, half-open (a la Hall D) or clamped solenoid design?
  - If clamped: will be strongly asymmetric, or? Clamp locations? Forces?
  - If open: a “clear conical opening” up to which polar angles, on both sides?
  - Polarity switch, a possibility to work at much smaller field as an option?

  - Yoke outer diameter limitations?
  - Any limitations imposed by an optional barrel HCal? Part of the yoke?

  - Can we agree that field homogeneity in the “TPC” region is not needed?

  - How many substantially different configurations should be considered?

The solenoid requirement considerations

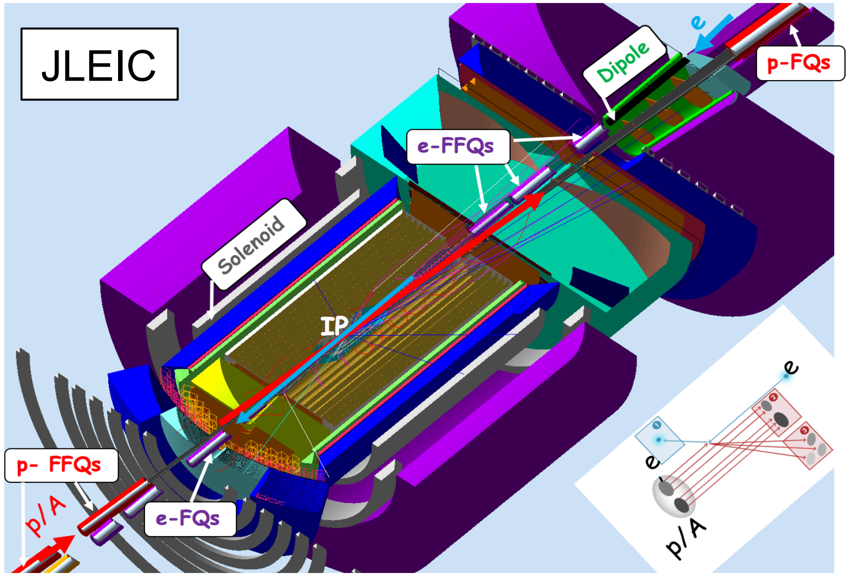
- **Fringe field affecting a gaseous RICH performance:**
  - Gas volume location and length with respect to the solenoid center
  - Maximum polar angle, which RICH is supposed to cover
  - IP shift zero or non-zero with respect to the solenoid center
  - Which level of distortions is acceptable? How to define this number?

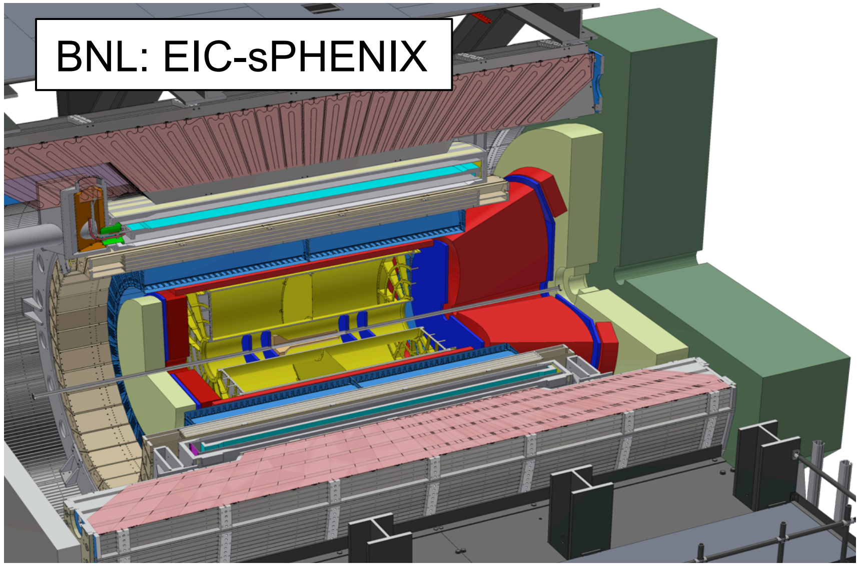
  - How to formulate these requirements in a way the magnet designers can work with them? Ranges of the parameter variation? Few configurations?

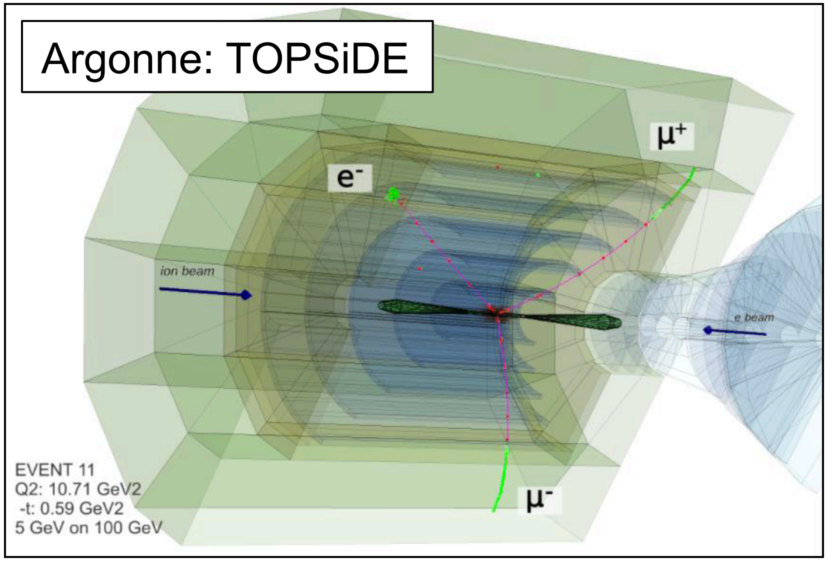
- **Interference with the calorimetry:**
  - If correction coils (inbetween EmCal & HCal) are needed, what are the additional requirements on field homogeneity and space?
  - Flux return through the endcap HCal encouraged/discouraged/optional?
  - Field strength limitations at the readout location?

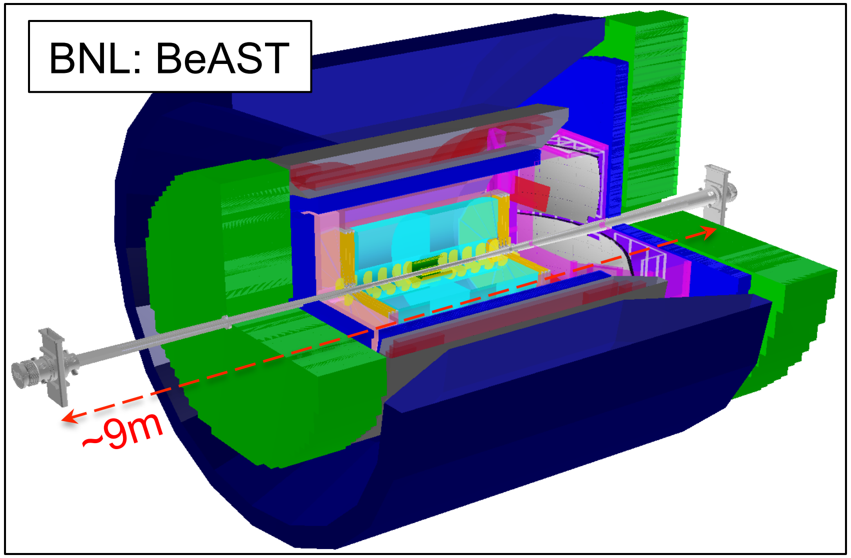
-> sounds like a poll for the WG opinions may still be needed

EIC detector concepts









What comes into an EIC YR detector model?

- **The concept driven by a set of physics goals**
- **The boundary conditions**
  - Accelerator-driven ones (available space, vacuum system, *other*)
  - A particular solenoid model (geometry, field map & strength)
- **A particular set of ancillary detector models in the IR region**
- **Individual sub-detector studies in GEANT (and/or beam tests)**
- **A particular set of the central detector components (or placeholders)**
  - Tracker, Calorimetry, PID: GEANT4 geometry and codes, test beam data
- **Fast smearing parameterizations**
  - eic-smear, *other*
- **Physics studies *for this particular model***
  - using fast smearing tools (most likely)
  - using full GEANT simulations (less likely, unless for the backgrounds)
- **Other ingredients**
  - DAQ concept, dead material description, …
- **Engineering model (to some level of detail)**

The task(s) of our subgroup

- **Become a central place where the detector concepts "materialize"**
- **Work in close contact with the other subgroups, DWGs in particular**
  - Agree on the responsibilities, deliverables & realistic timelines
- It is *desirable* that the other WG conveners (or their representatives) attend the meetings of this group on a regular basis (and the Complementarity group - where the conceptual part of the detector models is discussed - too)

- **Participate in working out the input formats & interfaces** …
- … **as well as in maintaining the detector model "database"**
  - Modular components (support a potential diversity of concepts) …
  - … but well-defined *releases* (facilitate the convergence at the end)

  -> come up with a first "release" NOW; work on the interface details in parallel

- **Provide the group's "native" deliverables: the straw man solenoid magnet design & engineering models of the selected setups**

The next steps

- **Define the “second option” solenoid requirements**

- **Come up with the first (even if incomplete) detector configuration** …
- … **and assist the SWG in developing the “database” layout**

- **Try to establish the missing responsibilities, also within the other WGs, and develop a list of expected deliverables and milestones**
  - This apparently requires a well-defined “set of formats”