2nd Detector and IR at the EIC Workshop Summary — Experiment

Ernst Sichtermann (LBNL)

2nd Detector and IR at the EIC Workshop
Faculty of Physics, University of Warsaw
Warsaw, Poland — July 31, 2023

Prior Detector 2 Workshops

- EICUG 2nd Detector (Kickoff) Meeting, December 6—8, 2022 at CFNS, Stony Brook University — https://indico.bnl.gov/event/17693/

  97 participants from 12 countries — 40 presentations

- 1st International Workshop on a 2nd Detector for the Electron-Ion Collider, May 17—19, 2023 at Temple University, c.f. https://indico.bnl.gov/event/18414/

  114 participants from 14 countries — 50 presentations

- Thank you to all who participated so far!

  162 unique participants from 14 countries

- In what follows, I have freely used your materials — errors are my own and apologies if I am not covering your favorite topic; selections needed to be made. In particular, I have omitted topics in direct overlap with those presented at this meeting, including e.g. on accelerator aspects and luminosity sharing.

Charge for Detector II/IP8 Working Group

1. Engage the broader community, ***including theorists, accelerator physicists and ePIC experimentalists***, to fully develop projections for the portfolio of measurements that are complementary to the ePIC physics program, including those that capitalize on the implementation of the secondary focus.

2. Work with the EICUG Steering Committee and Project to ***recruit new institutions*** and establish a diverse and vibrant 2nd Detector working group.

3. Utilize the extended design period for Detector 2 to identify groups that will focus on ***R&D for emerging technologies*** that could provide another aspect of complementarity to ePIC.

4. Facilitate the development of a ***unified concept*** for a general-purpose detector at IR8. In particular, the 2^{nd} detector should be complementary to the project detector at IR6 and may capitalize on the possibility of a secondary focus at IR8.

Renee Fatemi, EICUG

Perspective on 2nd Detector

- Project Design Goals
  - **Accommodate a Second Interaction Region (IR)**
- DOE, and BNL and JLab as the Host Labs, are establishing a governance structure intended to support the EIC. This includes the construction of a 2nd IR and detector.
  - EAB, RRB, DOE International Agreements
- Successful delivery of the EIC Project will be a major challenge, and the priority of the EIC project leadership team
- 2nd IR and Detector will be **installed after the EIC project** is complete
  - Science case must be compelling given resources required
  - IR and detector technologies should be state of the art
  - International engagement should be significant
- Organized effort needed now to prepare plans and build support for the 2nd IR and Detector

EIC Detector Proposal Advisory Panel Report on a 2nd Detector/IR

- "A strong case for ***two complementary general-purpose detectors*** has been made during the panel review"
- "…requires a ***well-chosen balance between optimization as general-purpose detector versus partial specialization*** and the ability to cross check the other detector for a broad range of measurements. The design of a second detector should be chosen with these criteria in mind."
- "The time required for its design and construction may offer ***opportunities for benefiting from technological progress***."
- "As laid out in the section 2.1 on physics performance, ***an IR with a secondary focus can significantly broaden the physics scope and output of the EIC***."
- A strong push for two detectors at this time ***would likely require additional person power and expertise to complete successfully***.

Abhay Deshpande, this meeting

Vision for the 2nd detector: C2C

- Complementary (IR, detector technologies & design)
  - Continue to explore complementary ready and not-yet-ready technologies
  - Generic detector R&D program – Run through Jlab
- Complementary (physics)
  - A significant list of physics topics exists (some-exclusive to 2nd IR, some-overlapping): drill down and see which of those can *develop into strong pillars of science for the 2nd detector.*
  - New physics developing around the world: we need to monitor constantly
- Complementary (people)
  - New non-US/outside groups who may bring new interests & funding in future
  - New US groups – other than those with significant responsibilities in ePIC

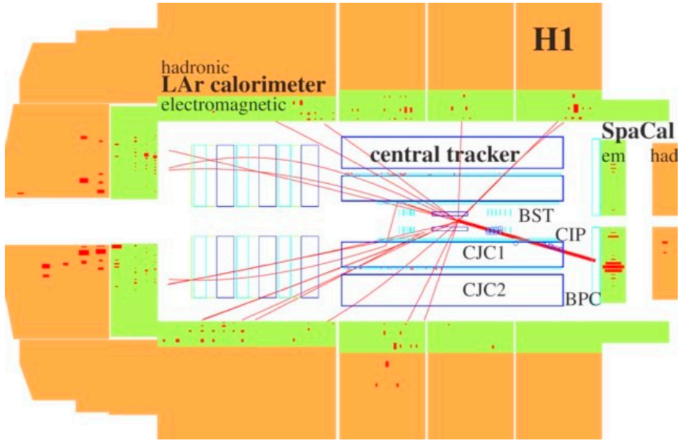
Complementarity, Cross-Checks, Data Combination

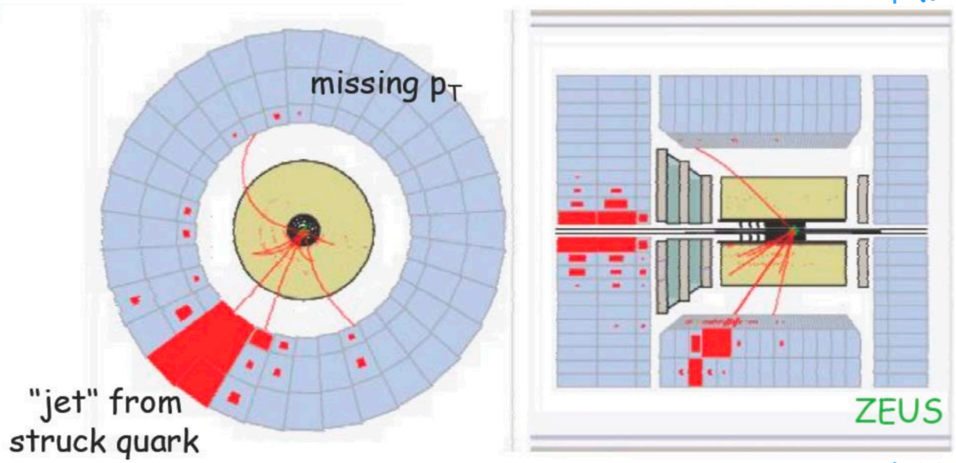
Detectors strengths

- Both detectors → almost fully hermetic multipurpose HEP detectors
- Design differences turned out to give complementarity – by chance

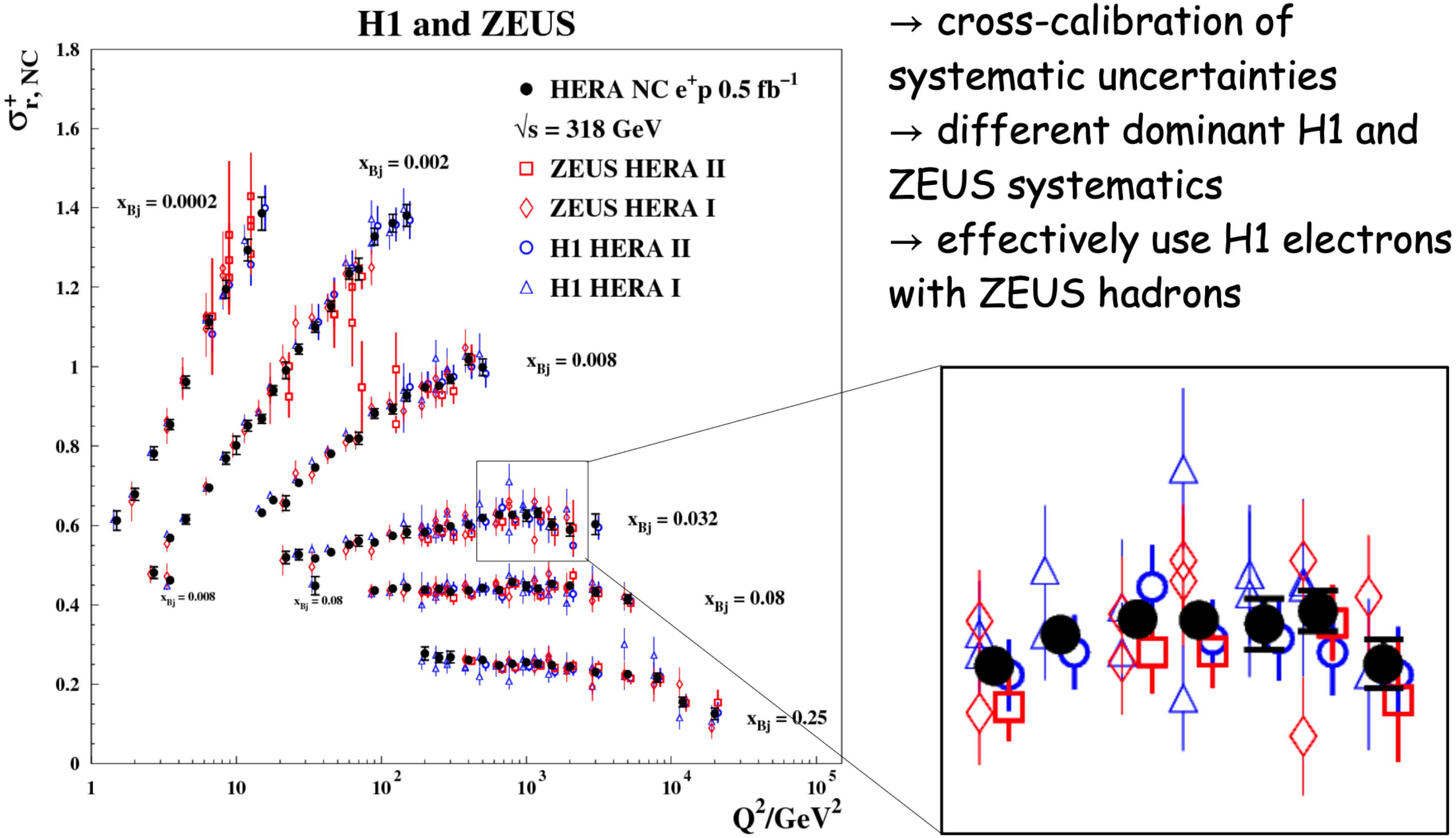
- H1 better at electron reconstruction due to EM calorimeter and detector design
- At HERAII → only forward detectors for diffraction

- ZEUS better at hadron calorimetry → compensating uranium calorimeter → the only so far and one of the best calorimeters ever built





Combined data accuracy reaches ~1%



Improvement well beyond statistical factor of sqrt(2)
→ cross-calibration of systematic uncertainties
→ different dominant H1 and ZEUS systematics
→ effectively use H1 electrons with ZEUS hadrons

Complementarity - the detectors

H1 and ZEUS detectors complementary
→ by chance …

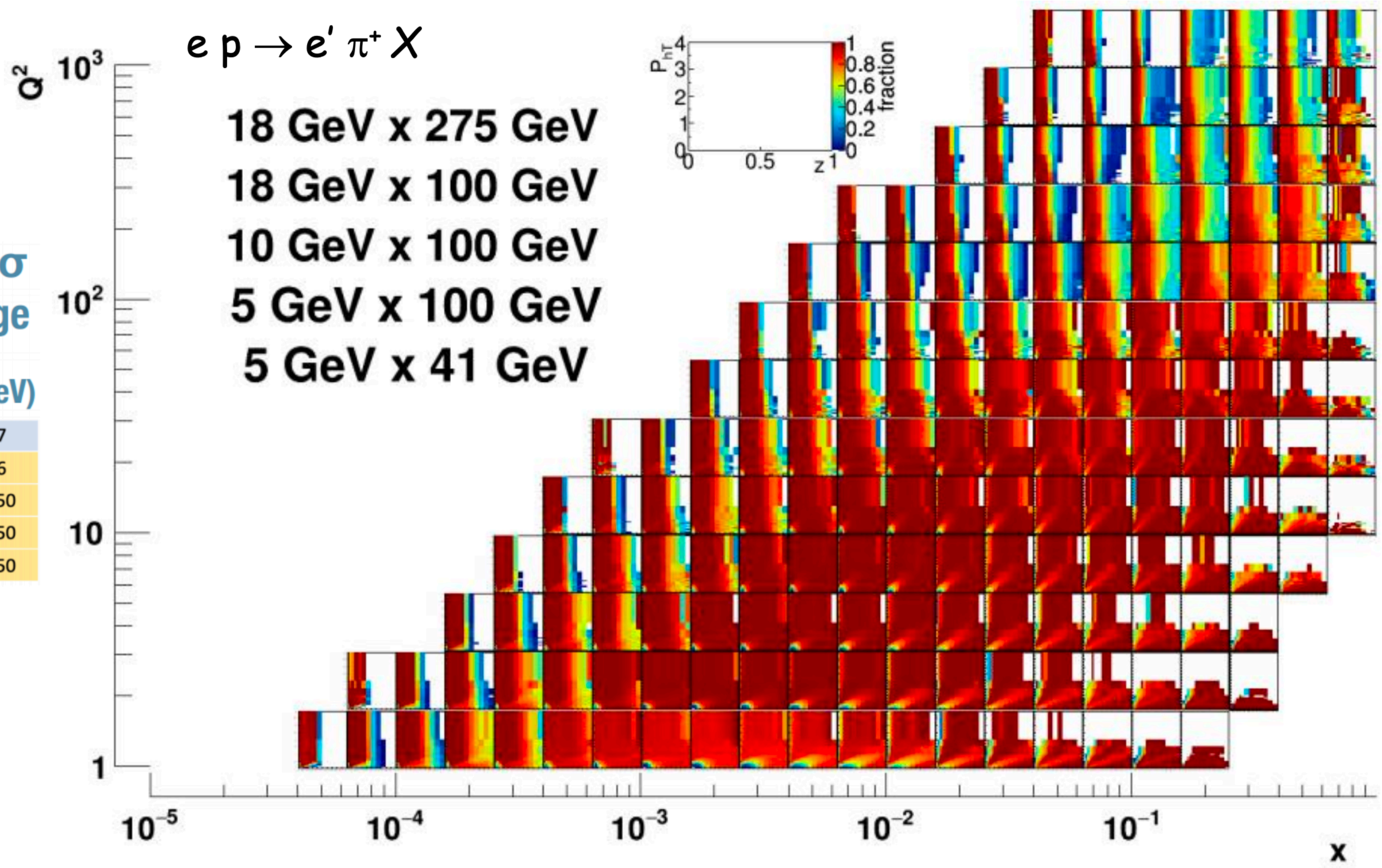
EIC has a chance to do it on purpose :)

Arguably, this is a *must do* in view of the 10^{2-3} increase in lumi,
an operations duration and hence cost consideration,
not straightforward to accomplish.

WG 2 - Semi-inclusive reactions: Hadron PID

Assumed 3σ PID coverage

η	p (GeV)
-3.5 - -1.0	0.2 - 7
-1.0 - 1.0	0.2 - 6
1.0 - 2.0	0.2 – 50
2.0 - 3.0	0.5 – 50
3.0 - 3.5	0.5 – 50

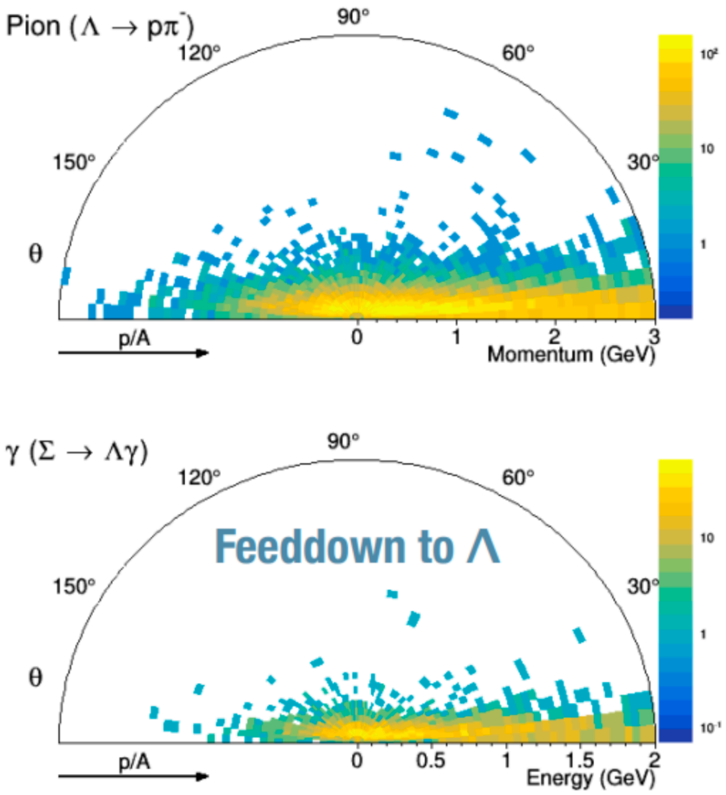


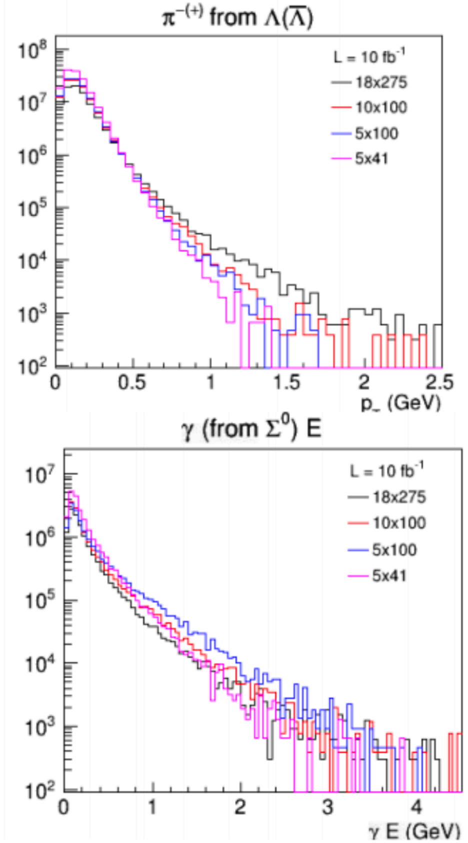
- High z/p_T limited in some cases by barrel PID p<6 GeV
- Impact at intermediate x-Q2 compensated by different beam energies, when using existing models for TMD extraction

WG 2 – Semi-inclusive reactions: Minimum p_T

$$ep \rightarrow e'\Lambda X$$

18x275 GeV





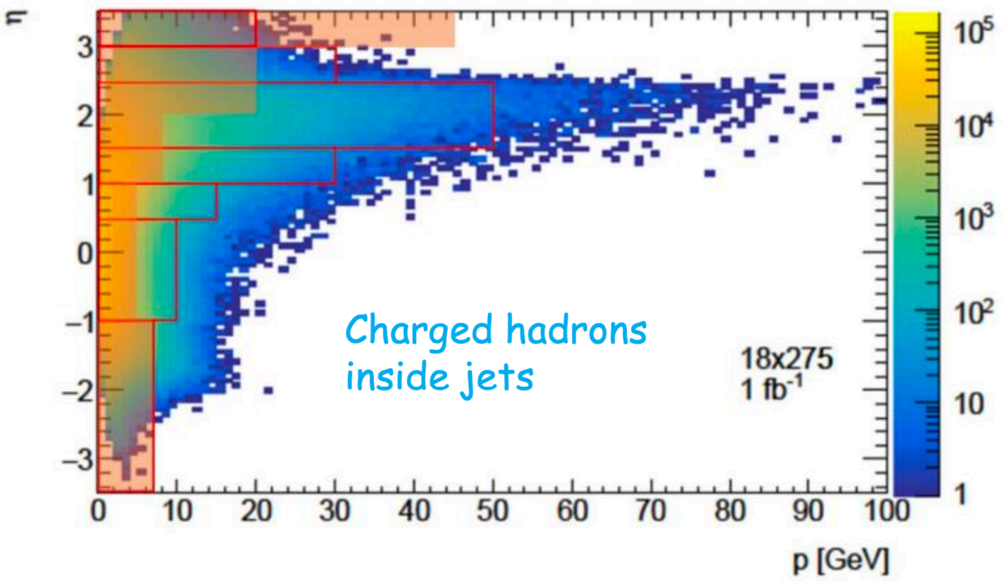
- ➢ 100 MeV p_T detection required for efficient Λ detection
- ➢ Σ feeddown rejection requires Eγ>200 MeV for η<3 and Eγ>400 MeV for η>3

WG 3 - Jets and Heavy Quarks: PID

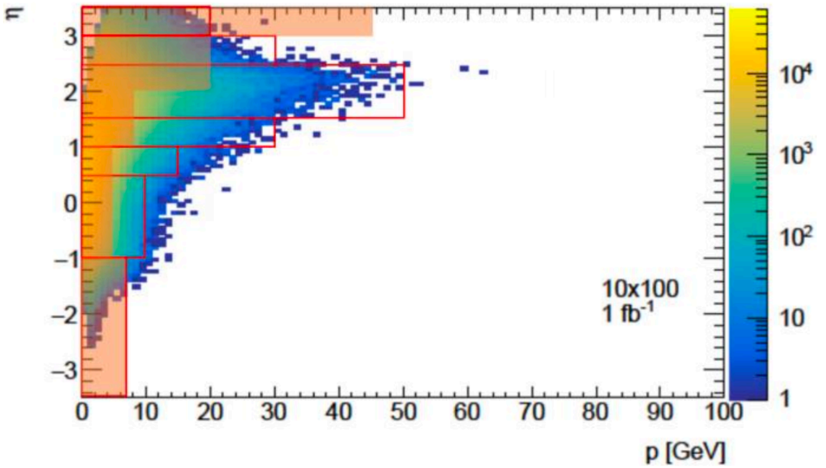
PID Momentum Coverage

Eta Range	Default Momentum Coverage	Requested Momentum Coverage
-3.5 < η < -1.0	≤ 7 GeV	Same
-1.0 < η < 0.0	≤ 5 GeV	≤ 10 GeV
0.0 < η < 0.5		
0.5 < η < 1.0		≤ 15 GeV
1.0 < η < 1.5	≤ 8 GeV	≤ 30 GeV
1.5 < η < 2.0		≤ 50 GeV
2.0 < η < 2.5	≤ 20 GeV	
2.5 < η < 3.0		≤ 30 GeV
3.0 < η < 3.5	≤ 45 GeV	Can tolerate ≤ ~20 GeV

18x275



10x100

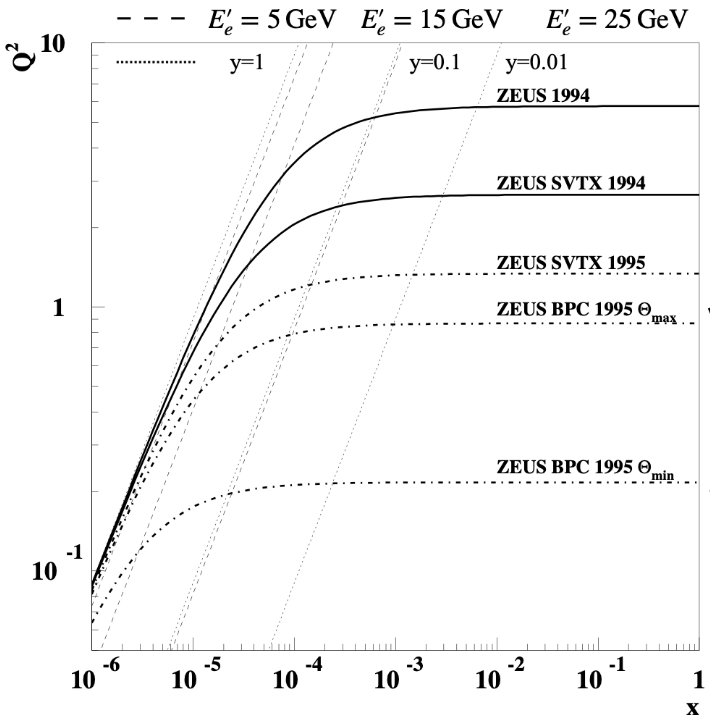


Reduction of particle momenta at highest (and lowest) eta are due to jet radius

Hadron PID required up to large values of momenta

HERA data

- Kinematic coverage

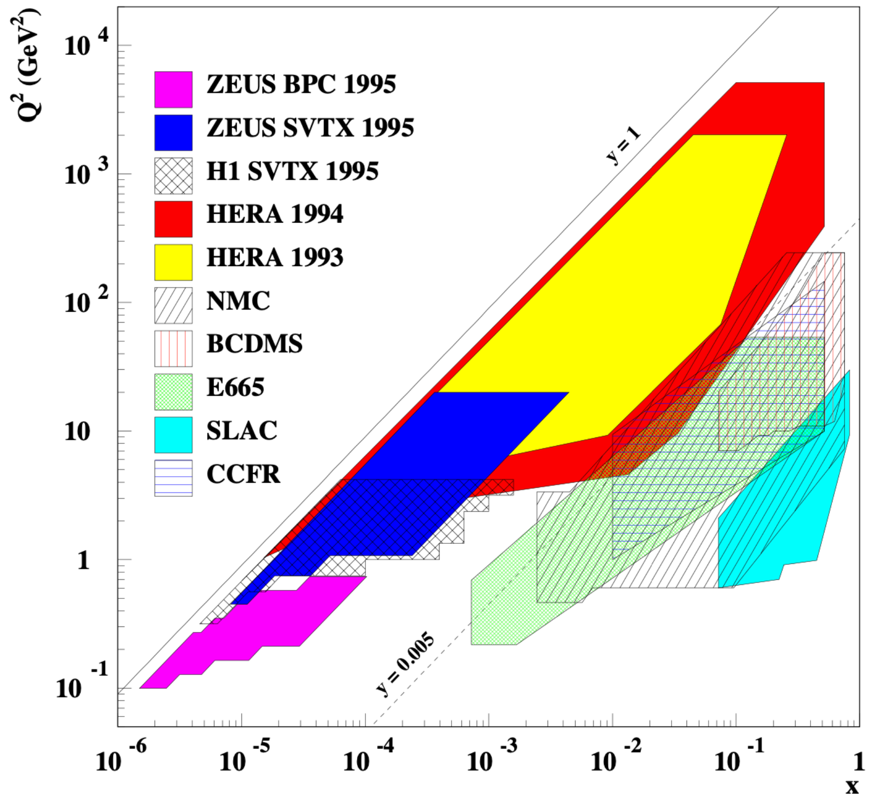


$$Q^2 = 4E_eE_e^{'}\sin^2\left(\frac{\vartheta_e^{'}}{2}\right) \simeq E_eE_e^{'}\vartheta_e^{'2}$$

$$\vartheta_e^{'} = \pi - \theta_e^{'}$$

~35mrad

~17mrad



Interest in lepton-proton scattering does not start or stop at 1 GeV² — see also Miguel Arratia's talk at this meeting.

Diffraction, Exclusive Reactions

Marie Boër, EICUG 2nd Detector (Kickoff) Meeting

SUMMARY: for discussion

Physics conclusion: we need to study these channels with muons

- for exclusive physics (GPDs…)
- likely for semi-inclusive physics (TMDs…) but we haven't explore it yet

Experimental side:

- is it possible to add muon detectors?
- what kind of detector or trigger?
- cost?
- significant improvement in PID?
- what can be achieved without dedicated muon detectors?

Open questions:
- How not having muon or fine resolution affects GPD extraction?
- Other physics, with/without muons?
- Quarkonia + charmed/beauty meson?
- TMDs and other nucleon's imaging approach in the low -t region?
- certainly many more questions!

Spencer Klein, EICUG 2nd Detector (Kickoff) Meeting

Conclusions

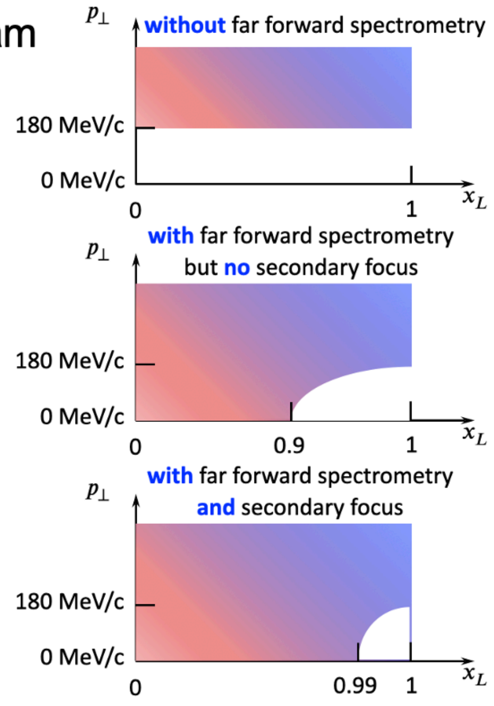
- Very wide pseudorapidity coverage is required to study vector meson production over the full range of Bjorken-x.
- Near-threshold production & Reggeon-exchange production, including exotica requires good forward acceptance
    - Running at a reduced ion beam energy will shift this production toward mid-rapidity.
- These requirements challenge EPIC in some places.
- Excellent far-forward ion-going detectors are required to separate coherent and incoherent photoproduction.
- Backward production reactions lead to mid-rapidity baryons and far-forward mesons. The later are a detector challenge, requiring more study.
- A second detector could emphasize forward coverage, at the expense of the central barrel.

18

Acceptance, Muon capability

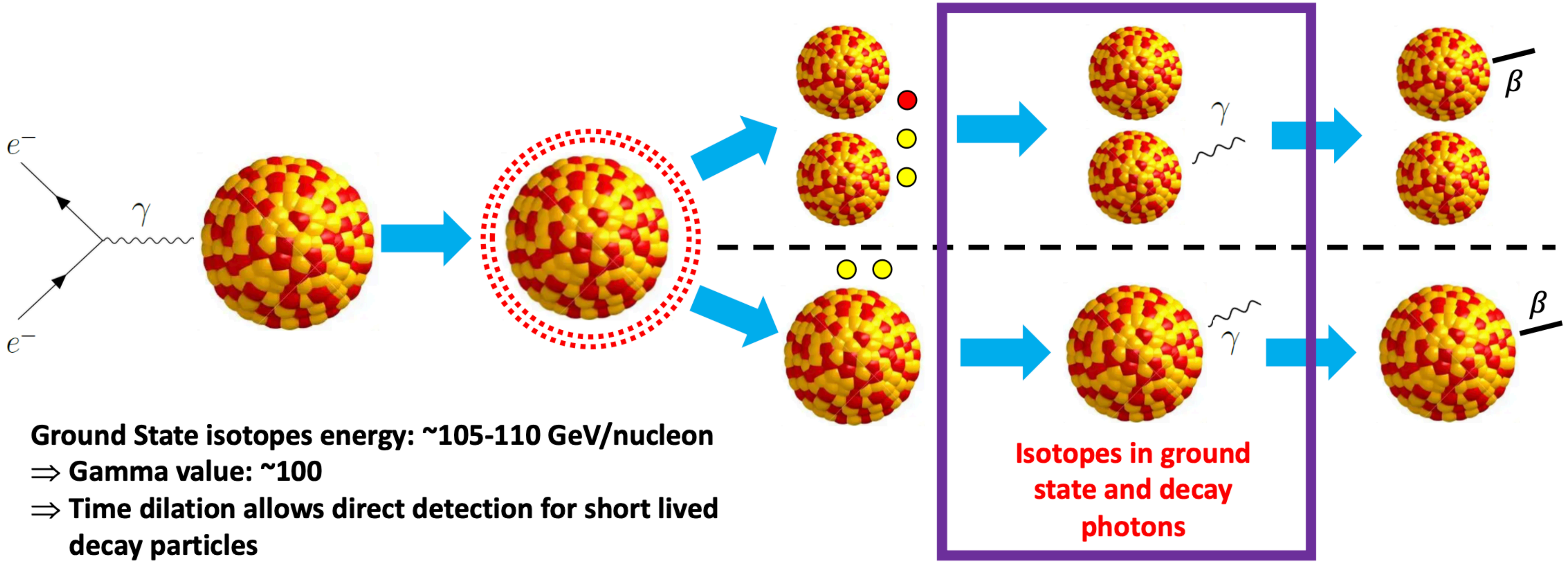
Acceptance as Function of x_L and p_T

- x_L - fraction of longitudinal momentum relative to ion beam
- p_T - fraction of transverse momentum relative to ion beam
- p_T acceptance at $x_L = 0$
  - $p_T^{min} > 10 p_0 \theta_{IP} = 10 p_0 \sqrt{\frac{\epsilon}{\beta^*}}$
- x_L acceptance at $p_T = 0$
  - $x_L < 1 - 10\frac{\sigma_x}{D} = 1 - 10\frac{\sqrt{\beta_x^{2nd}\epsilon_x + D_x^2\sigma_\delta^2}}{D}$
- Secondary focus allows for $|D\sigma_\delta| \gg \sqrt{\beta\epsilon}$
- Can reach the limit
  - $x_L < 1 - 10\sigma_\delta$
- Increase of β^* which in turn increase the β_x^{2nd} may result in a smaller x_L acceptance.



See, in particular, also Pawel Nadel-Turonski’s talk at this meeting.

Isotope production at the EIC

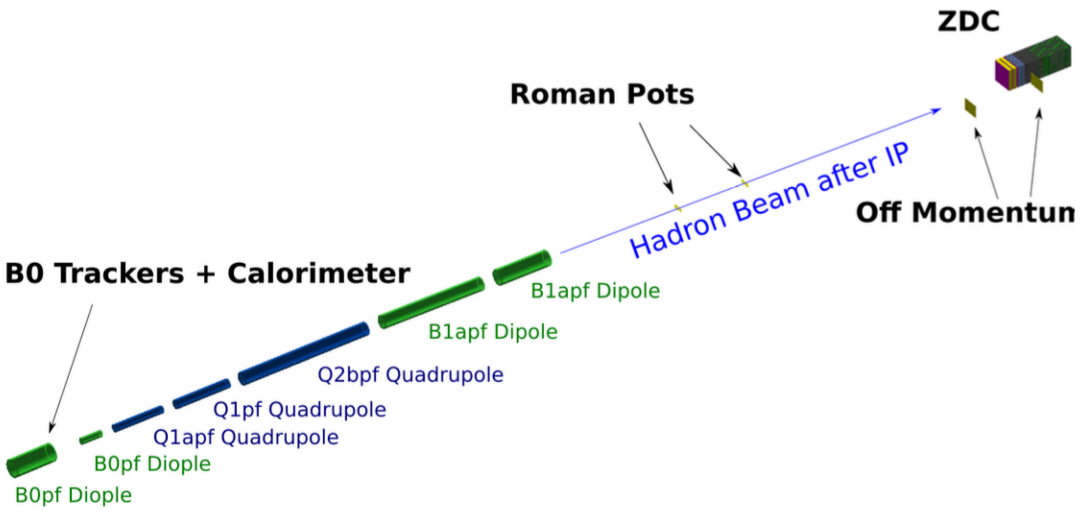


Ground State isotopes energy: ~105-110 GeV/nucleon
⇒ Gamma value: ~100
⇒ Time dilation allows direct detection for short lived decay particles

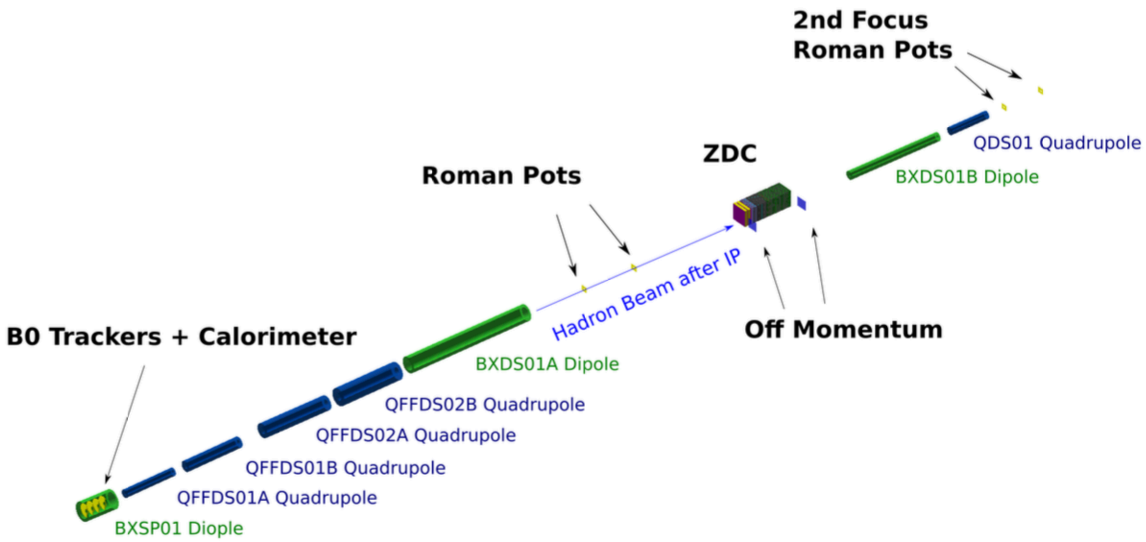
This is primarily where the EIC could potentially contribute

Detection and identification of the nuclear isotopes

IR6



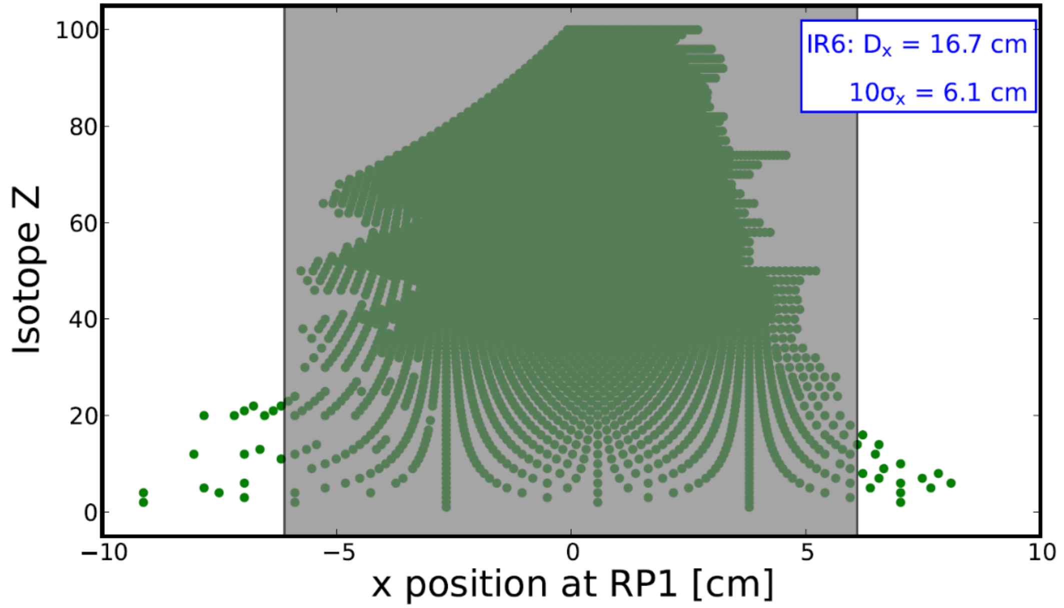
IR8



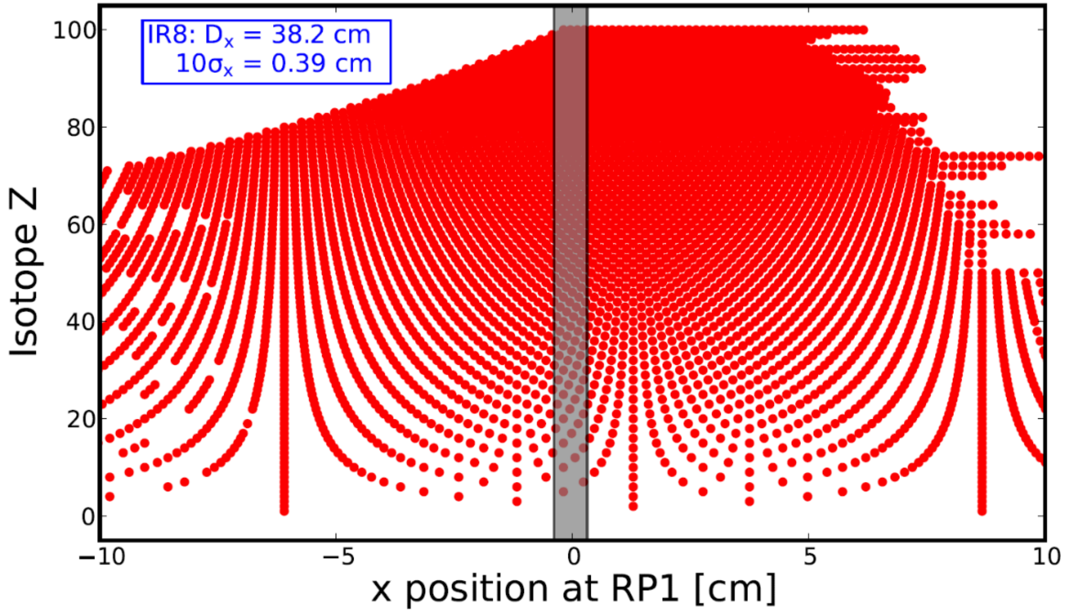
Far forward magnets and detectors in the *Fun4All* simulation framework

Roman Pot Acceptance

IR6



IR8



Isotope hit positions at the first RP vs. isotope Z
Includes all isotopes known/potential (NNDC and LISE++ database)
RP Positon Resolution of 10—100 microns

arXiv:2209.00496

Technology

Technology Inventory
or
The Quest For Complementarity

Thomas Ullrich
Detector-II Workshop
Temple University, Philadelphia
May 17-19, 2023

Much material taken shamelessly from too many people to be mentioned here.

A wealth of information in 56 slides!

Note: Dave Mack discussed the EIC-related generic detector R&D program at this meeting.

Si Tracker

Reality check:

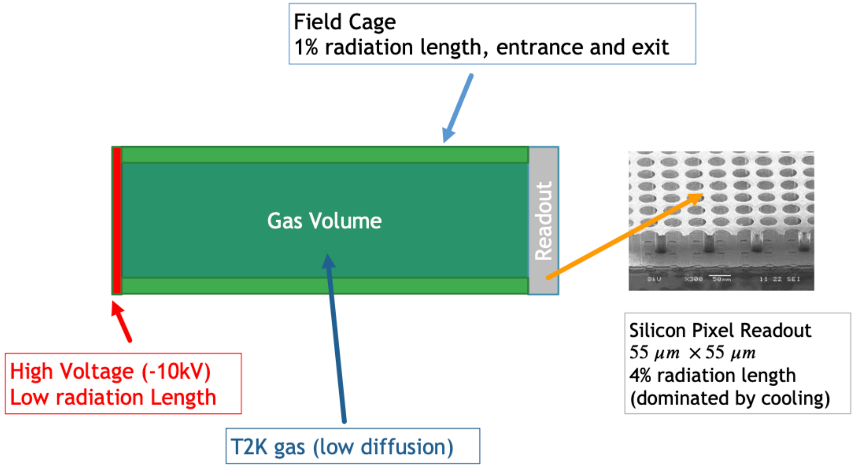
- MAPS/CMOS pixel sensors are the future for EIC detectors
  ➡ No other technology maps to EIC requirements like MAPS
- Experience in the community (STAR, ALICE, Si Consortium)
- HEP interest due to good match with FCC-ee might turn out beneficial
- Unclear if a next generation ITS3/EIC can be developed for D2 in time unless we start very soon (requirements)
- Independent: Stitching techniques must be developed to keep mass low
- Key is (as we leaned the hard way) to keep $(X/X_0)_{\mathrm{layer}} \leq 0.1\ \%$

Of high interest (also R&D needed):

- MAPS with reduced granularity, very low power consumption for large area detectors
- MAPS with reduced granularity and excellent timing (EIC generic R&D)

GridPIX aka miniTPC

- Basic idea: Small ΔR TPC with Si Pixel readout on one endcap
  - PID ($\pi - K - p$) from 100 MeV/c to 800 MeV/c
  - Tracking with large number of hits (pattern recognition)
  - Works only in barrel (field!)
- GridPIX
  - Avalanche grid in front of 55 x 55 μm^2 pixels.
  - >90% efficiency for single electrons.
  - Small area is not particularly expensive: 1800 chips (order/produce/test 3600) = $716k
  - Careful: 1.2-5.4 kW of power
  - Services bulky: Gas, power, cooling
  - Realistic X/X_0?

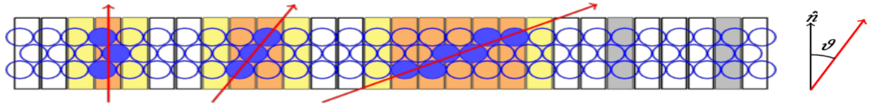


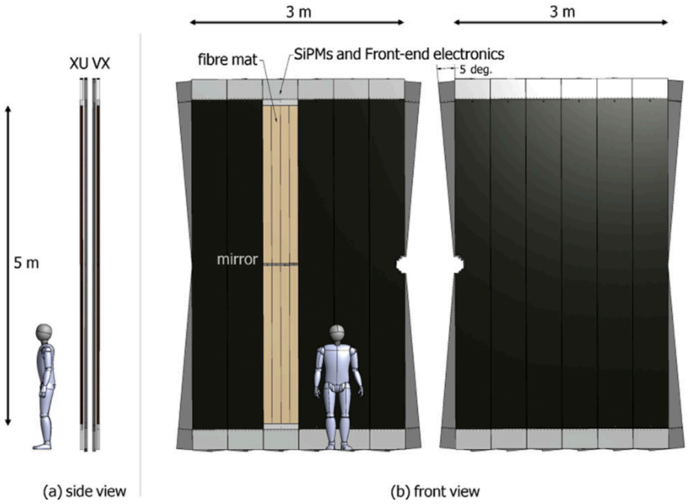
Reality check:
- Very compelling for D2
- Provided tracking an dE/dx (compare with ToF/AC-LGAD)
- Excellent Pattern recognition
- Less sensitive to backgrounds
- Generic R&D ongoing
- Need to see concrete prototype

Scintillating Fiber (SciFi) Tracker

Source: LHCb

- Deployed by LHCb upgrade, PERDaix, Mu3E
- 4-6 layers of 250 μm fibers (stereo angles or xy)
- Read out by SiPM
- Achieve 100 μm resolution at overall low mass $X/X_0 < 1\,\%$
- Provides vector ⇒ improve pattern recognition





Reality check:
- Definitely something to look into benefiting from long time efforts and experience at LHCb (e.g. winding machine)
- Solid alternative to miniTPC

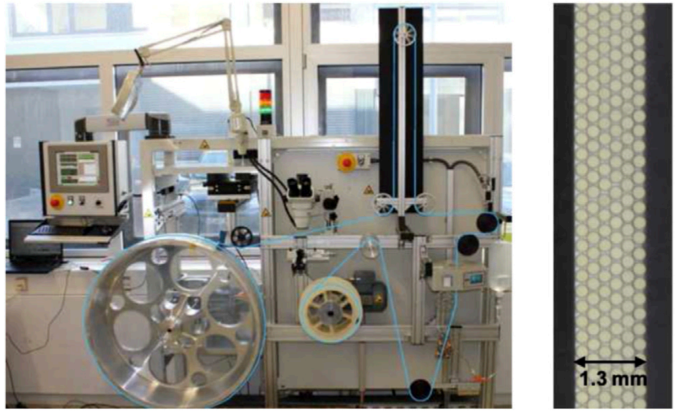


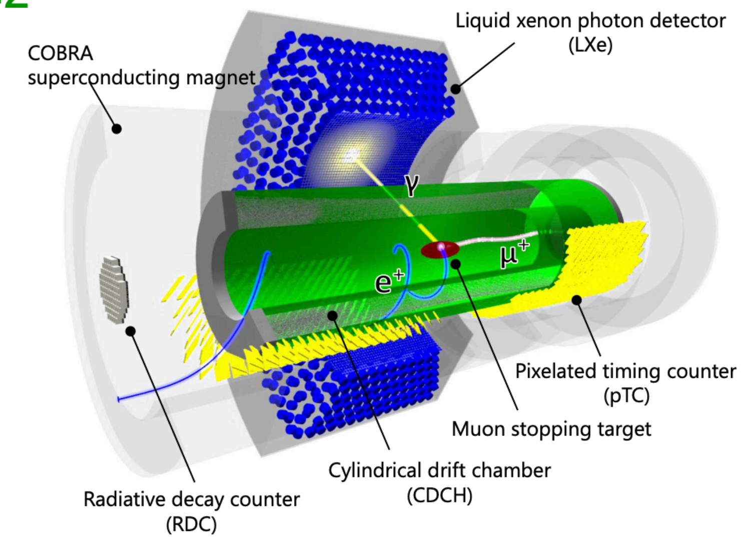
Fig. 3. Left: picture of the custom designed mat winding machine. Right: cross section of a fibre mat.

Drift Chambers

Source: MEG2, Snowmass, ECFA

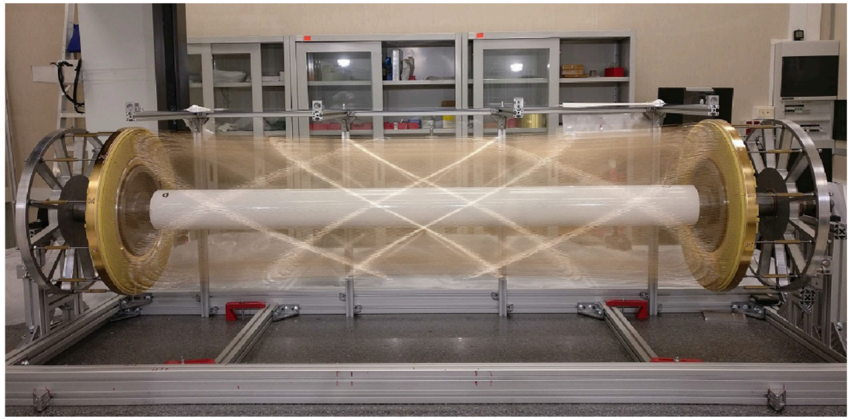
- Think twice if you consider this being old technology
- Huge progress thanks to KLOE and MEG2 drift chambers
  - Low radiation length thanks to novel approach for wiring and assembly procedures.
  - Total amount of material in radial direction, towards the barrel calorimeter is of the order of 0.016 X_0.
  - ~0.05 X_0 in the forward and backward directions, including the end-plates instrumented with front-end electronics.
    - obtained thanks to an innovative system of tie-rods, which redirects the wire tension stress to the outer end-plate rim
  - High granularity, all stereo, cylindrical drift chamber filled with helium based gas mixture. Resolution ~ 100 μm
- FCC-ee/IDEA: inspired by MEG2 a large-volume extremely-light drift chamber surrounded by a layer of silicon detector

MEG2



Reality check:

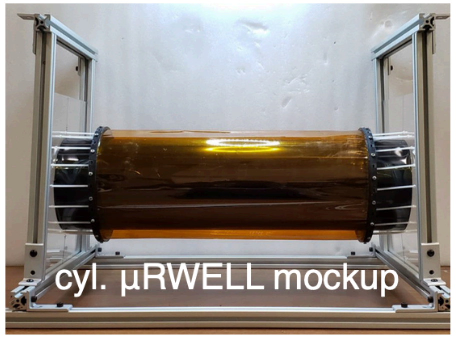
- Compelling but w/o expertise in community and R&D it is hard to see this as a viable alternative. X/X_0 might still be too much.



Eur. Phys. J. C (2018) 78:380

MPGDs

- MPGDs provide a flexible go-to solution whenever particle detection with large area coverage, fine segmentation, and good timing is required.
- R&D needed for curved/cylindrical applications and large area solutions (homogeneity, stability)



Reality check:

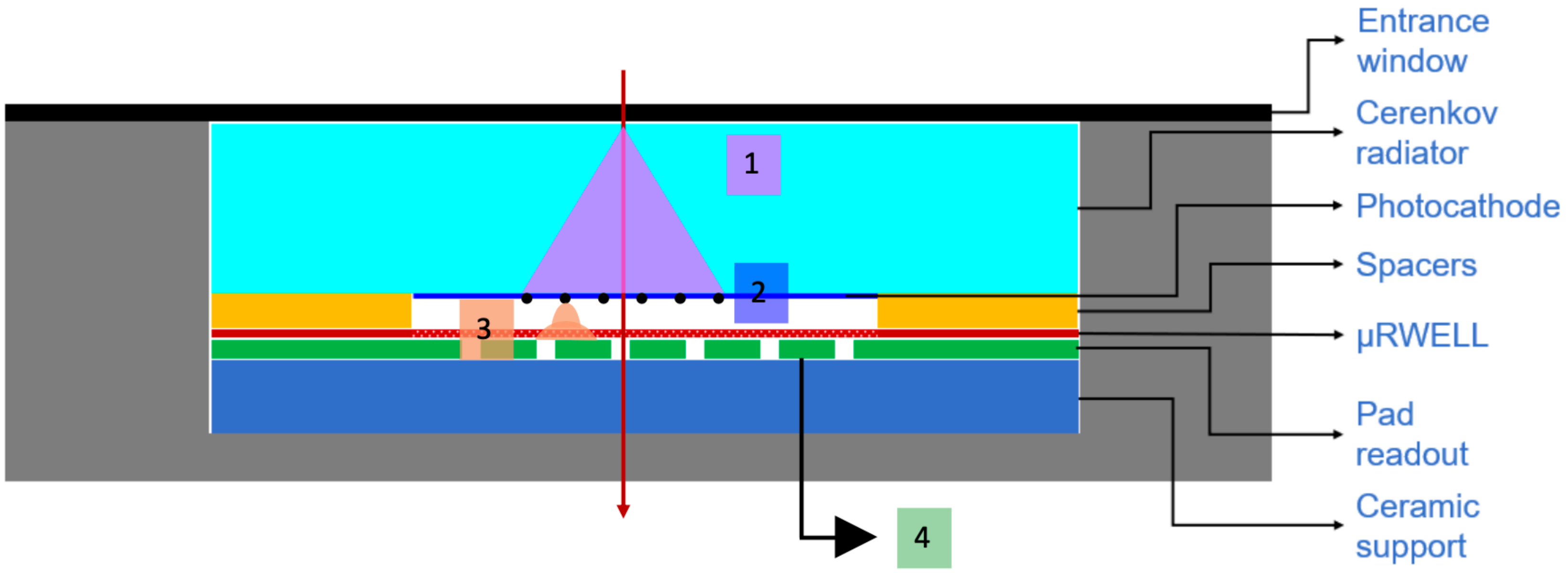
- MPGDs are here to stay. Many potential application (tracking, muon, …)
- Benefit from MPGD expertise in EIC community
- MMG and µRWELL increasingly favored over GEM
- Experience from ePIC (R&D prototypes) invaluable for D2

μRWELL-PICOSEC detector concept

Concept of μRWELL-PICOSEC: Develop fast timing gaseous detector using μRWELL amplification ➔ timing resolution of tens of ps

1. Cherenkov photons: relativistic charged particle creates Cerenkov photons ➔ prompt photons i.e., timing resolution.
2. Photoelectrons: convert the Cerenkov photons into electrons, all electrons created at the same z position ➔ timing resolution
3. Pre-amplification: First amplification of electrons 100 to 200 μm gas in high drift field region (~20 kV/cm)
4. Amplification : Final electron amplification in μRWELL gain structure ➔ high electric field (>40 kV/cm)
5. Electronic Signal: Arrival of the amplified electrons to the anode creates a signal.

1. Cerenkov photons in radiator
2. Photoelectrons in photocathode
3. Pre-amplification in 200 μm gas
3. uRWELL amplification
4. Collection of electronic signal



Yellow Report: DIS Physics with ECals

Inclusive DIS:

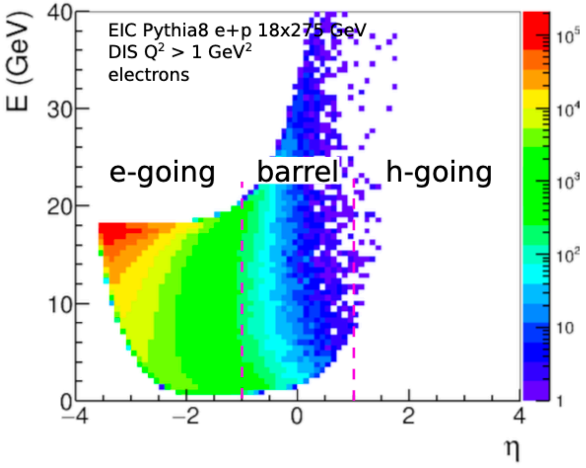
- scattered **electron** mostly backwards and in barrel
- electron energy ranges up to beam energy in backward and even higher in barrel
- electrons in barrel correspond to high Q^2 events
- electron **PID needed** due to γ and $\pi^{\pm}$ BG at low energies

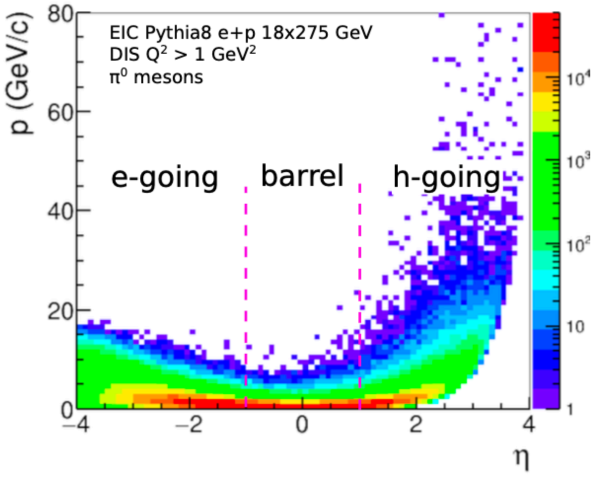
Semi-inclusive DIS:

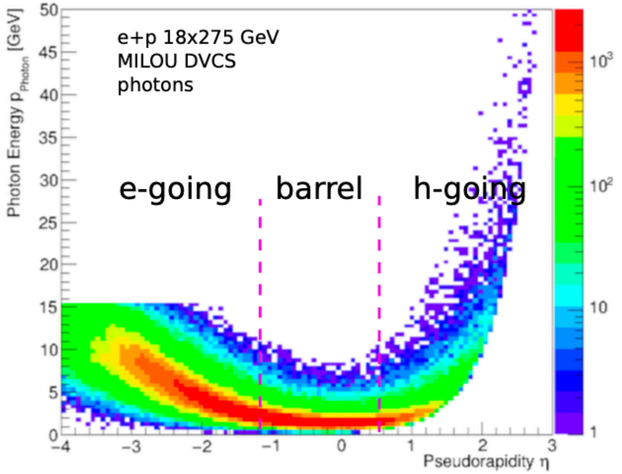
- $\pi^0 \rightarrow \gamma\gamma$ reconstruction needed
- momenta up to 10 GeV/c in barrel (higher in forward)
- **granularity requirement** to prevent merging of photon showers

Exclusive DIS:

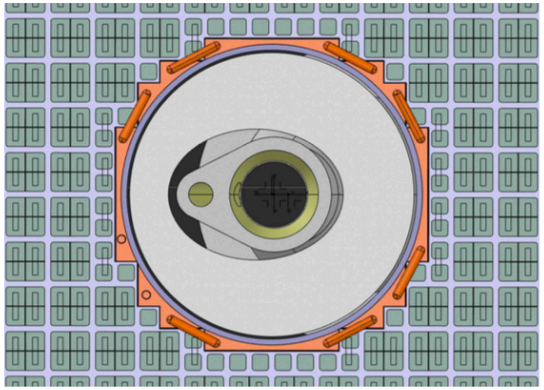
- measurement of **DVCS photons**, J/Ψ →ee, and more
- signal over wide rapidity range
- **hermetic coverage** necessary

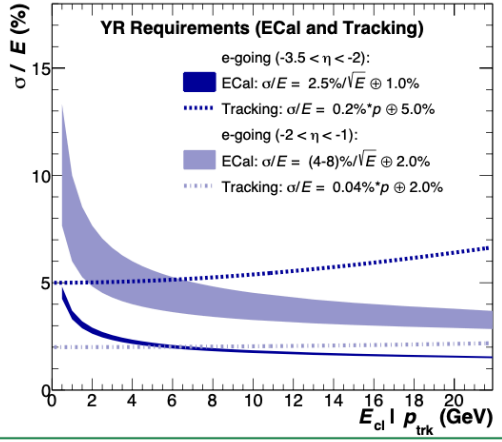


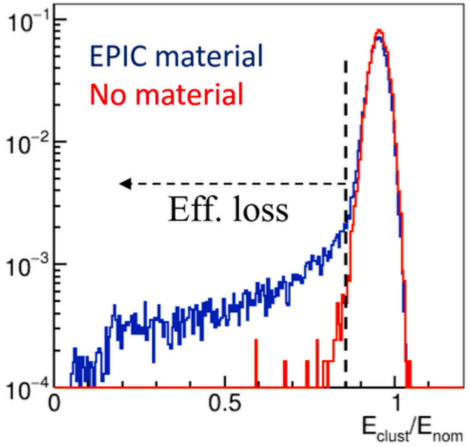




e-going direction - considerations



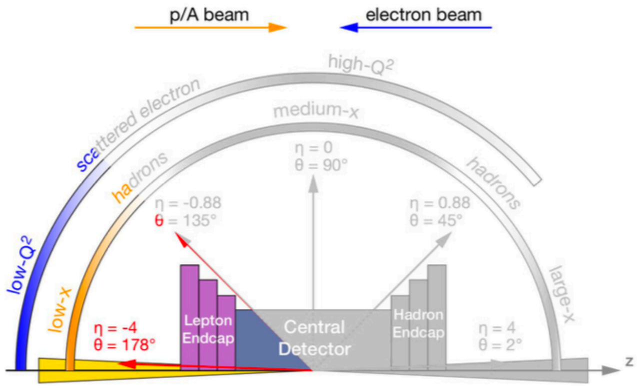


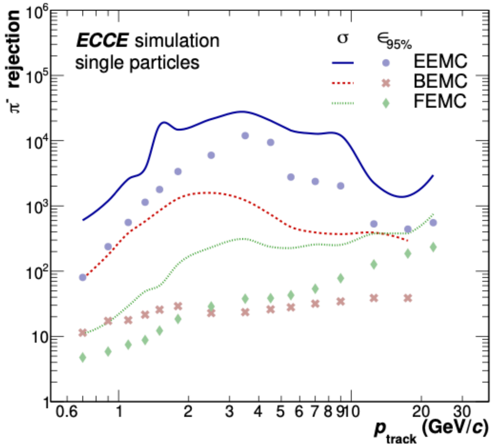


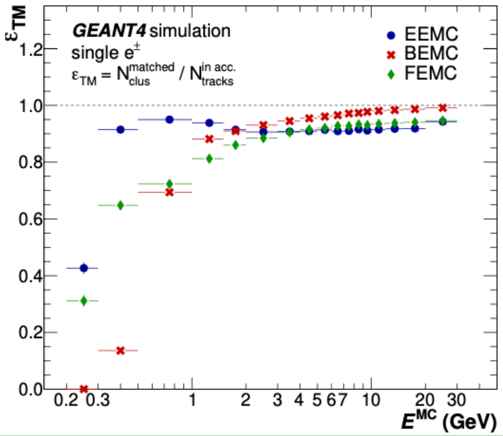
acceptance beyond $\eta < -3.5$ difficult

e$^-$ energy reco. largely based on tracking

Energy losses from detector material







Electron PID crucial

High track matching efficiency needed

Magnet from Various Perspectives

Magnet User/Physicist:

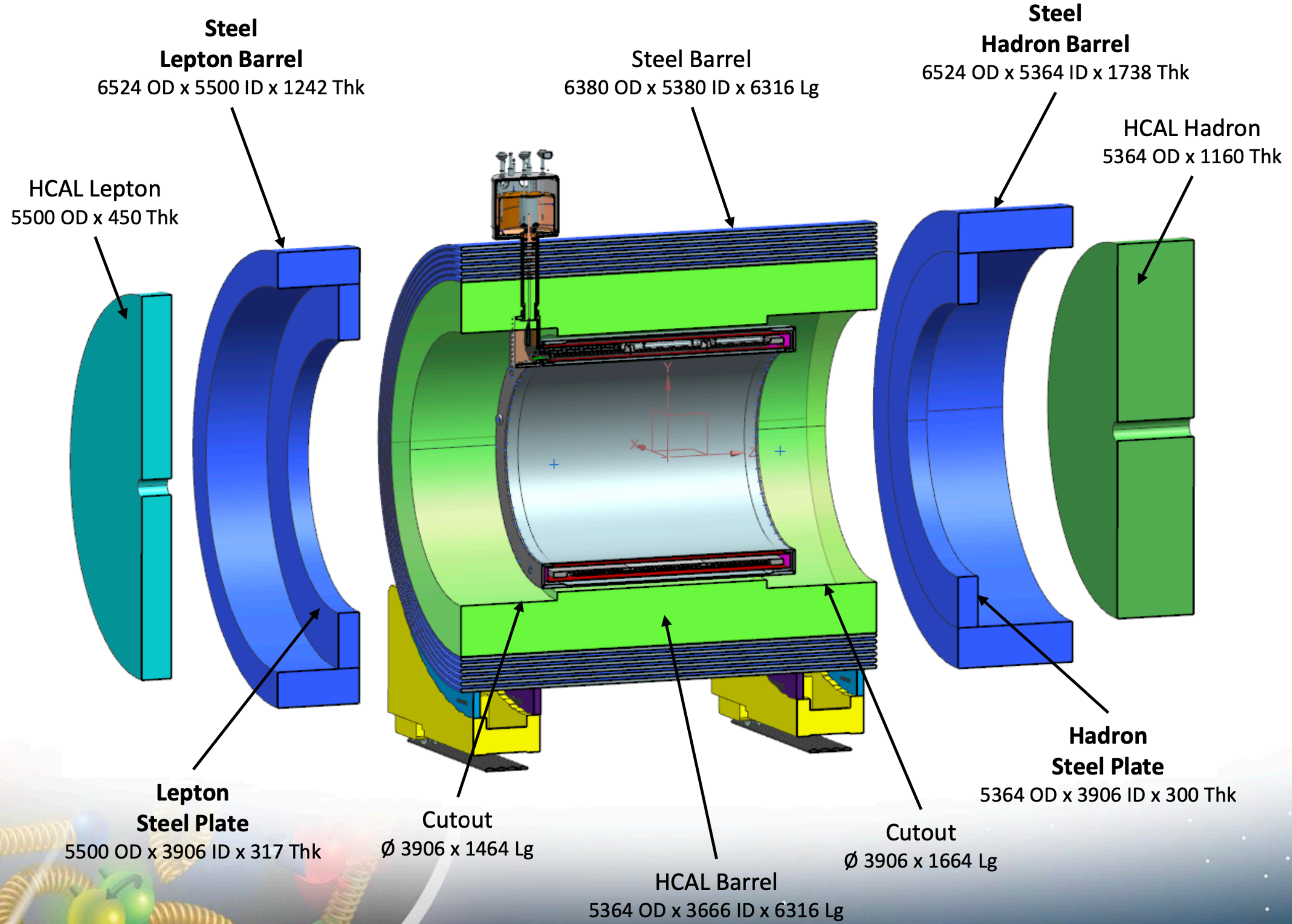
- •Maximum field strength,
- •Very high field homogeneity over a larger volume
- •No-to-minimum space,
- •fastest ramping, no quenching,
- •Absolute transparent (least amount of material)
- •No fringe/stray field
- • reuse of existing old magnet
- •…

•Magnet Manufacturer/Industry:

- •Maximum margin (low field),
- •Low Homogeneity/ no stringent requirement
- •No space Constraint
- •Maximize probability of success on 1st ramp (90% of nominal is "Good Enough")
- •Minimum cost to build with maximum profit
- •No restriction on material usage
- •Other nearby things like detectors are not so important

- Magnet Engineer-3rd perspective:
  - Somewhere between these 2 perspectives!
  - The most rational agent in the equation that can bring together both sides,
  - Come-up with a practical solution and reasonable agreement between the above 2 perspectives

Cross-sectional view-Exploded view

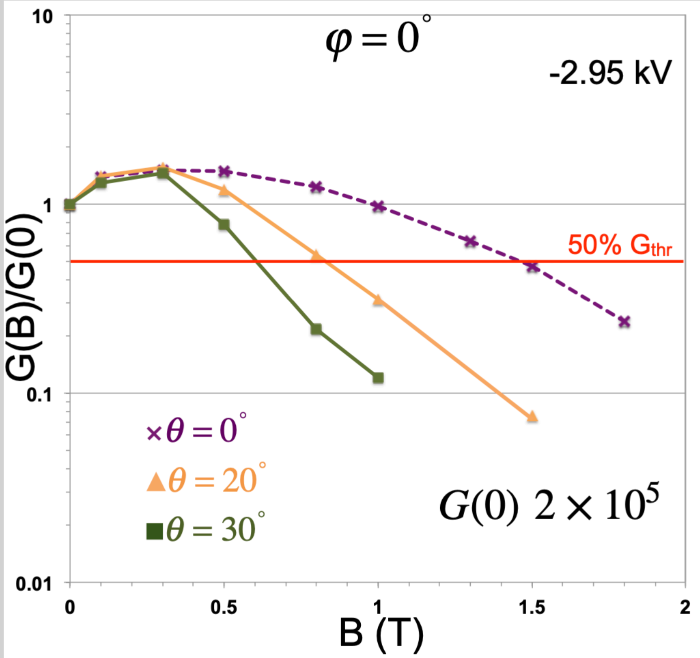


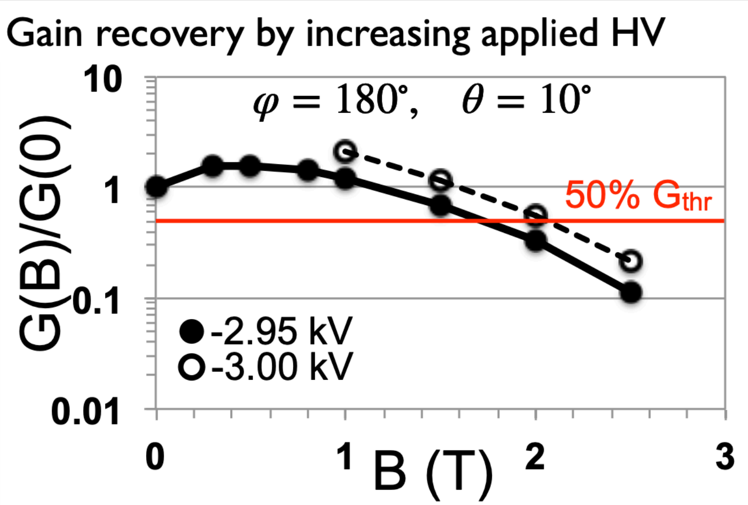
Summary

- Specifications
  - Should be clear and concise
  - Understand the implications of not meeting one or more specifications
  - Importance of various design parameters
  - Do not over constrain the magnet design
- Discussions with Magnet Engineers from the beginning of the project
- Discussions with Vendors at various stages of design (if possible)
- Design the magnet in collaborations with detectors design
- Detailed information about the environment that the magnet is required to operate in (Materials: support structure, equipment, target, etc.)
- Do not limit the magnet design by predetermining the type of conductor
- Magnet Design for ePIC detector magnet is very mature, 90% design review is scheduled for October.
- Sample conductor order placed.

EIC R&D: High-B Performance

Photek MAPMT253 Gain Scan (single channel)





@θ=10°:
G(1 T)/G(0 T) ~ 1
G(1 T)/G(2 T) ~ 3.6

@θ=0°:
G(1 T)/G(0 T) ~ 1
G(1 T)/G(1.8 T) ~ 4

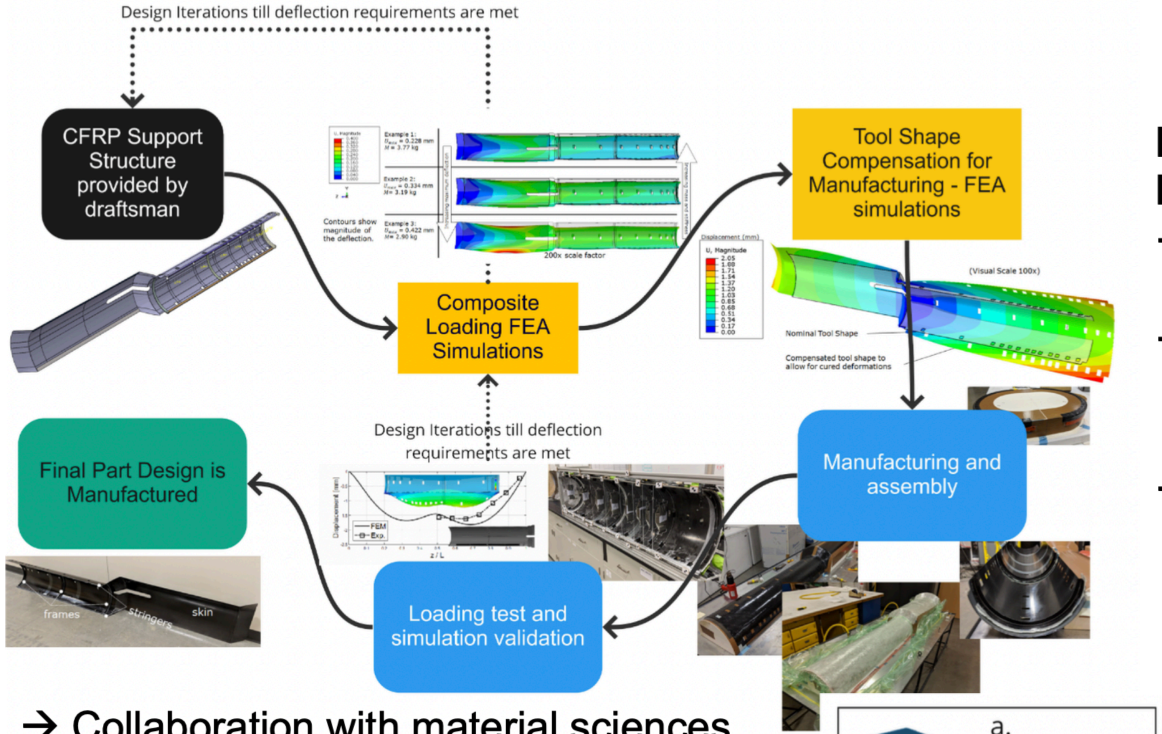
Some φ dependence

It is *not* a given that the all-important photosensors for PID will work (well) in the field one may dream of…

Composites Manufacturing & Simulation Center

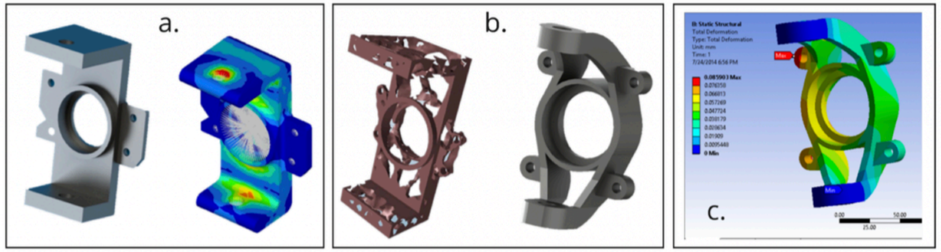
Going into the future of mechanics

→ Scalable mechanics structures: multi-functional & mass optimized
→ Ease integration, applies also to calorimetry, TOF, etc.



Full cycle of Process & Performance simulation:
→ FEA, prototypes, iterative process.
→ Consistent approach to better controlled manufacturing process, eases assembly.
→ Especially true the larger the structures become, integration is a "challenge"

→ Collaboration with material sciences, companies for novel materials, and latest techniques.
→ Example: ML for optimization with HEP inputs, **excites future generation**



Closing comments

- Thank you again to all who have participated so far!
- Many good arguments have been put forward for a complementary effort starting ~now,
- 6 days in 30 minutes — I hope to have done it some justice,

- A few comments for discussion:
    - AI/ML has thus far been a qualified experience in this arena,
    - Restart of the EIC-related generic R&D program is *excellent / essential;* yet, I have concerns if it can be as impactful as the prior program at the current funding and overhead levels
    - Magnet is an all-important experiment decision — consensus seems to point to a higher field than 1.7 T; opinions on the geometry (radius) differ.

- Thank you!