A compact, high-field Solenoidal spectrometer for Jefferson Lab Hall C

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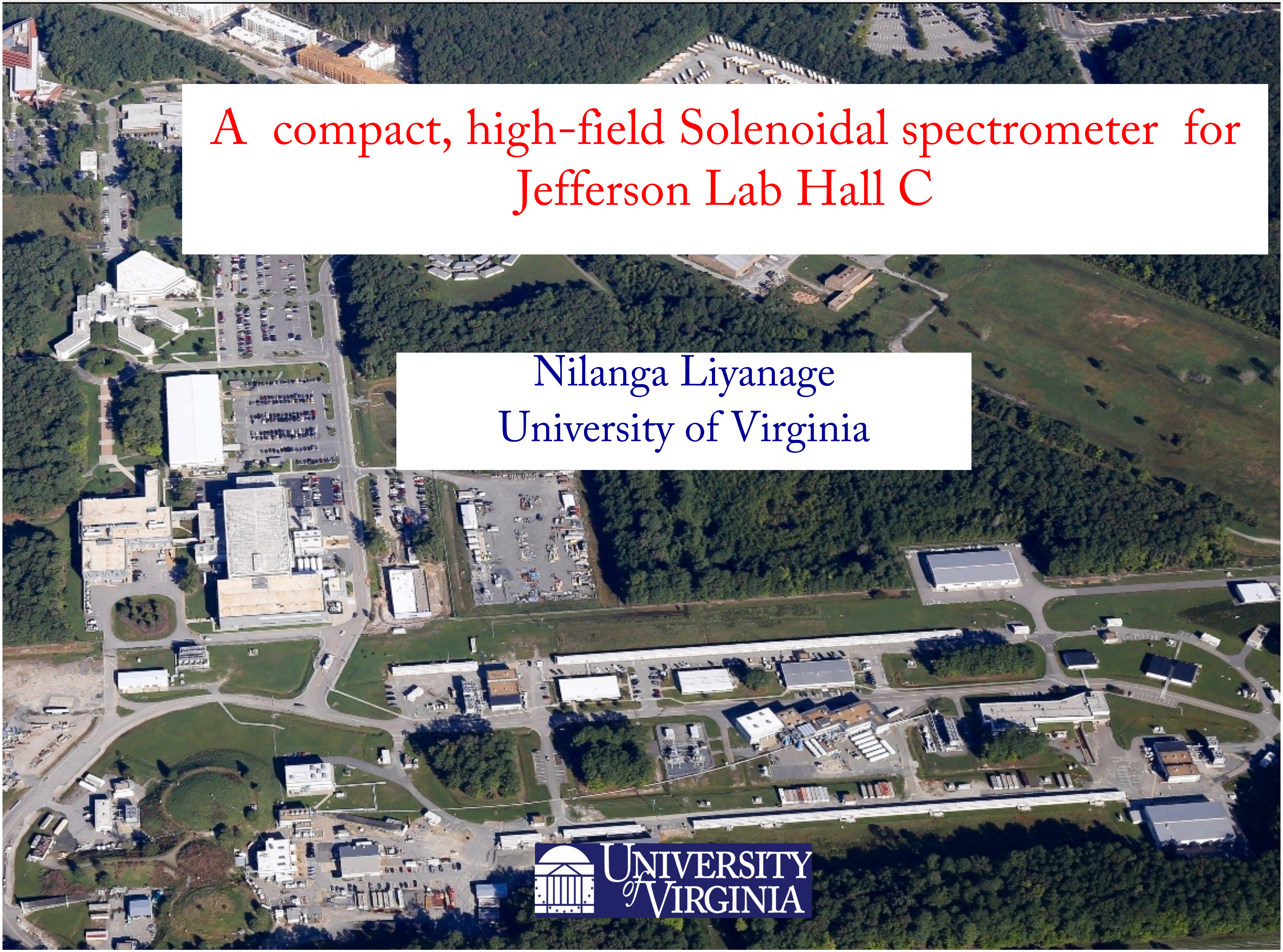
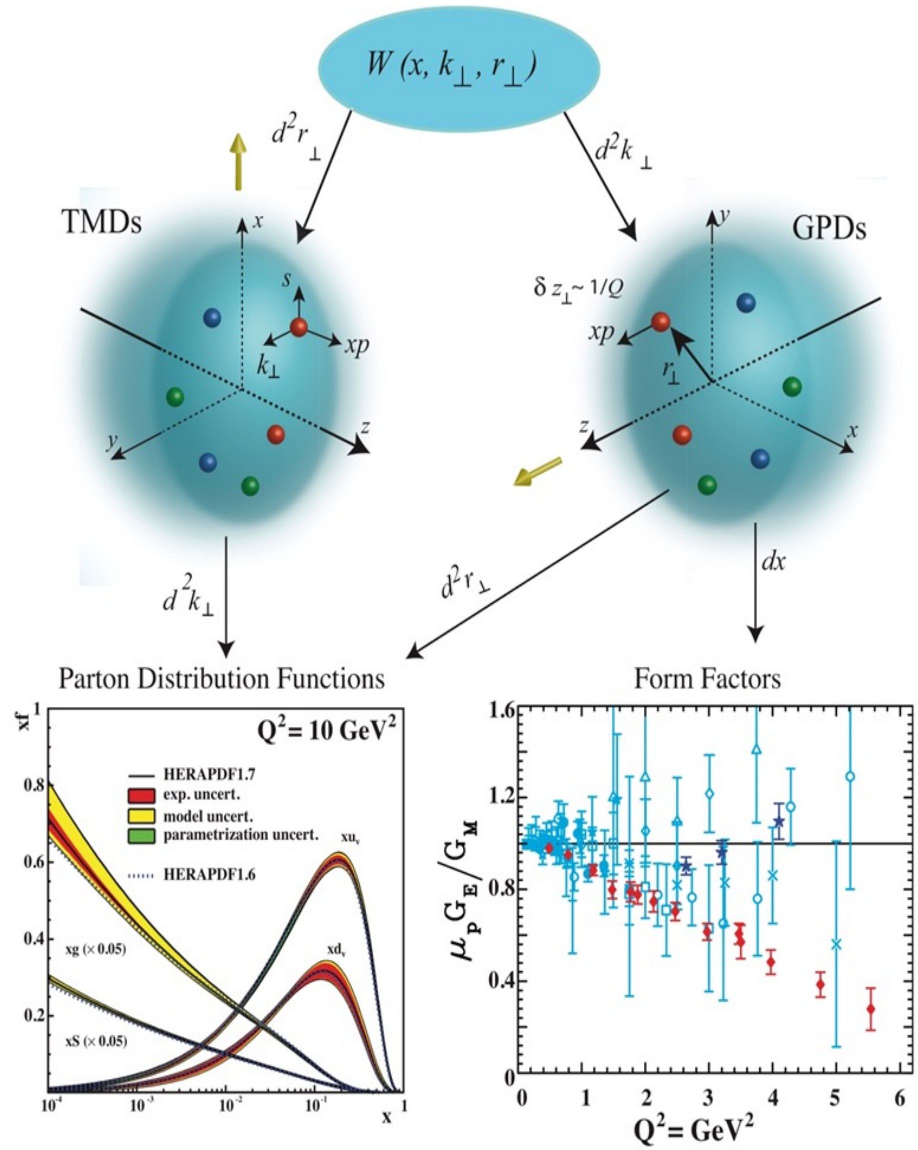


UNIVERSITY of VIRGINIA

The Hadron Structure: Generalized Parton Distributions (GPDs) and Transverse-Momentum Distribution Functions (TMDs)

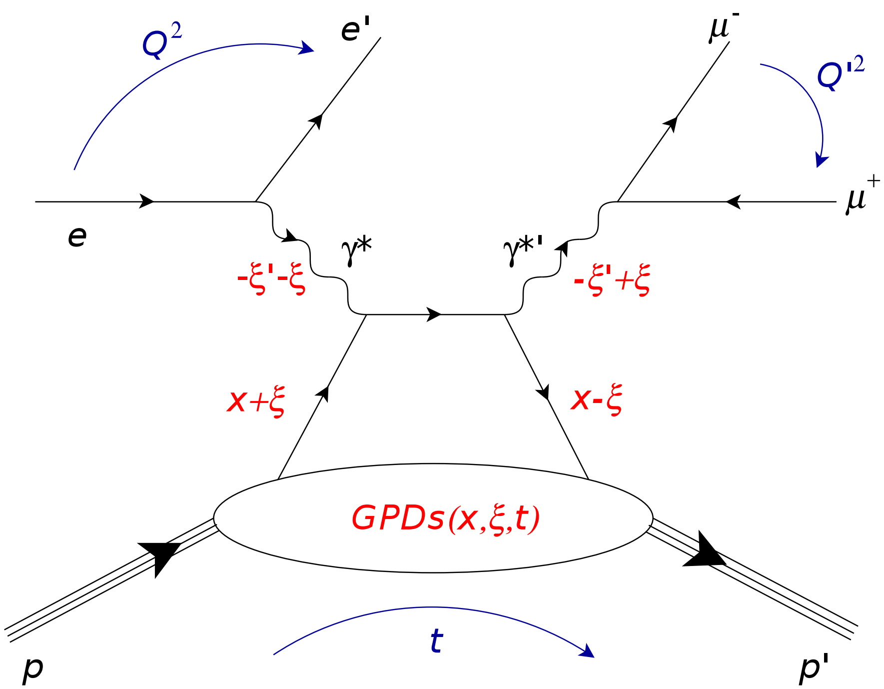
- Hadron 3D framework includes the correlation between momentum and spatial coordinates
  - Generalized Parton Distributions (GPDs) – describe distributions of partons w.r.t. their **transverse position** and longitudinal momenta.
  - Transverse-Momentum Distributions (TMDs) – describe distributions of partons w.r.t. their **transverse momentum** and longitudinal momenta.

TMDs & GPDs accessible via semi-inclusive DIS and deep exclusive processes

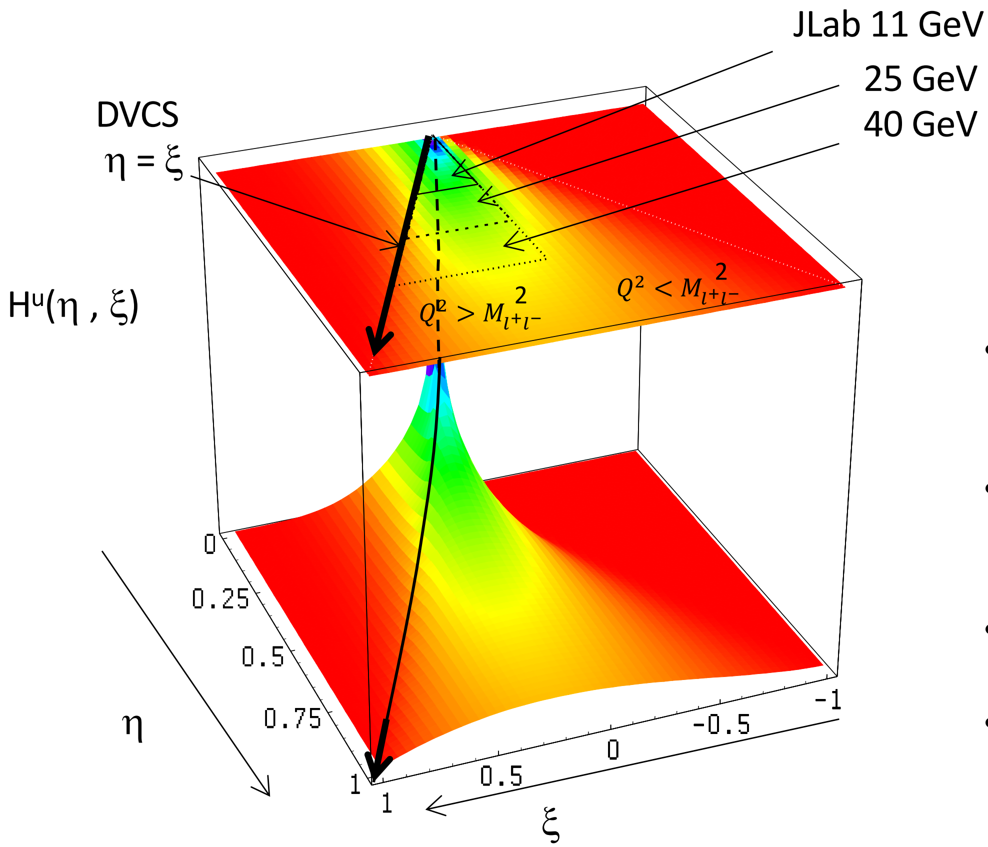


DDVCS

- Because of the virtuality of the final photon, **DDVCS** allows a direct access to GPDs at $x \neq \pm\xi$, of importance for their modeling and for the investigation of nuclear dynamics through sum rules.

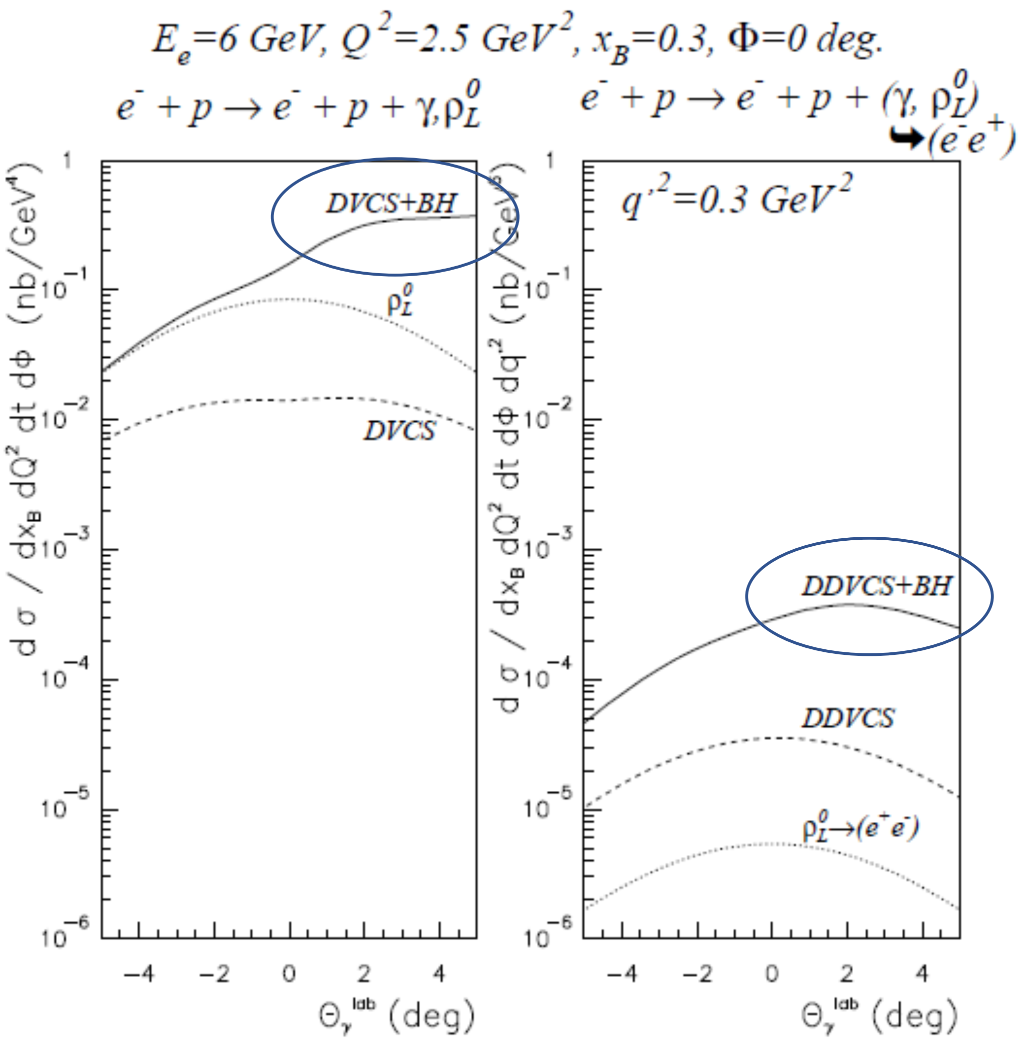


Kinematical coverage



- DVCS only probes η = ξ line
- Example with model of GPD H for up quark
- Jlab : $Q^2>0$
- Kinematical range increases with beam energy (larger dilepton mass)

DDVCS cross section



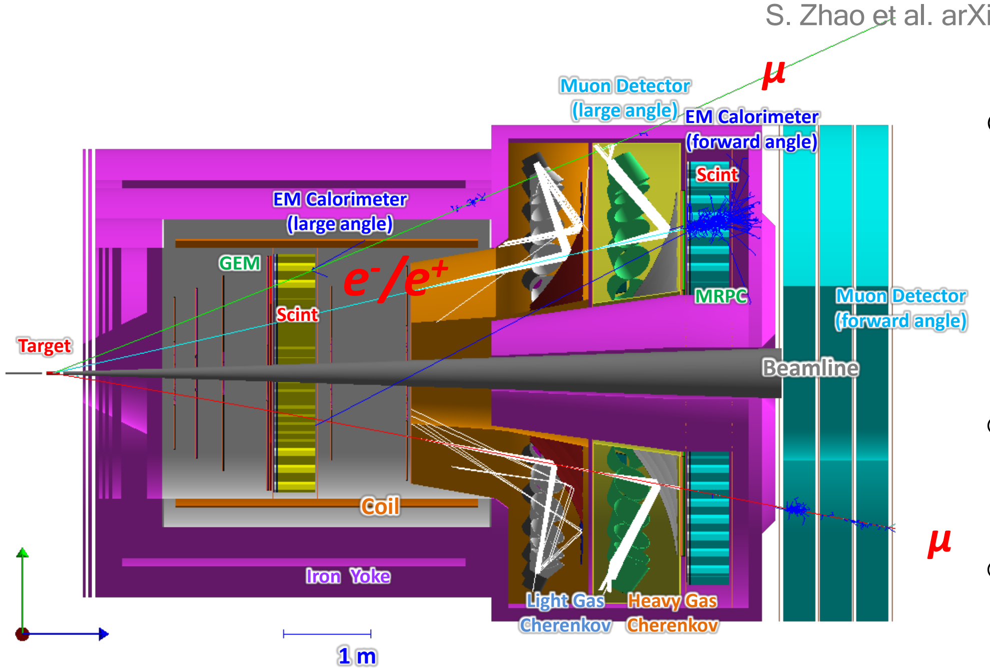
- VGG model
- Order of ~0.1 pb = 10^{-36}cm^2
- About 100 to 1000 smaller than DVCS
- Interference term enhanced by BH
- Contributions from mesons small when far from meson mass

Slide from Alexandre Camsonne

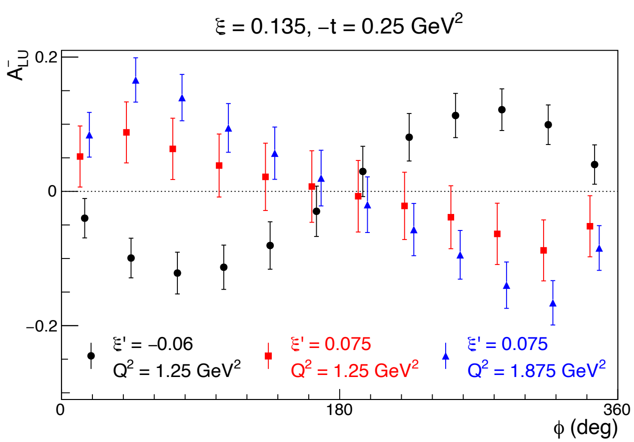
LoI12-15-005

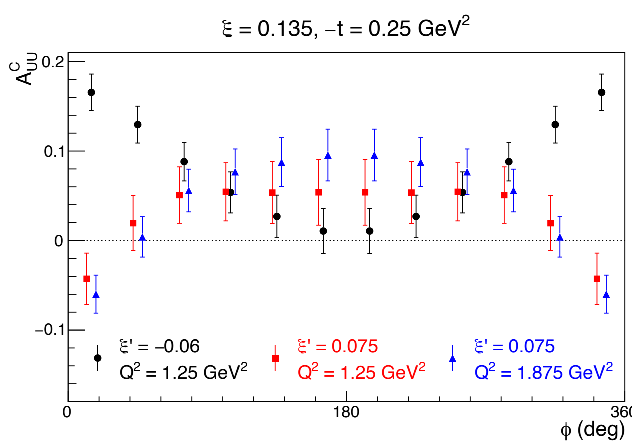
M. Boer, A. Camsonne, K. Gnanvo, E. Voutier, Z. Zhao et al.

S. Zhao et al. arXiv:2103.12773 (2021)



- The SoLID apparatus completed with muon detectors at large and forward angles, would allow DDVCS measurements with both polarized electron and polarized positron beams.
- The initial LoI discussed electron BSA measurements over a 50 days run parasitic to the J/Ψ approved experiment.
- Completing this program with a 50 days positron beam run would provide unpolarized BCA data.

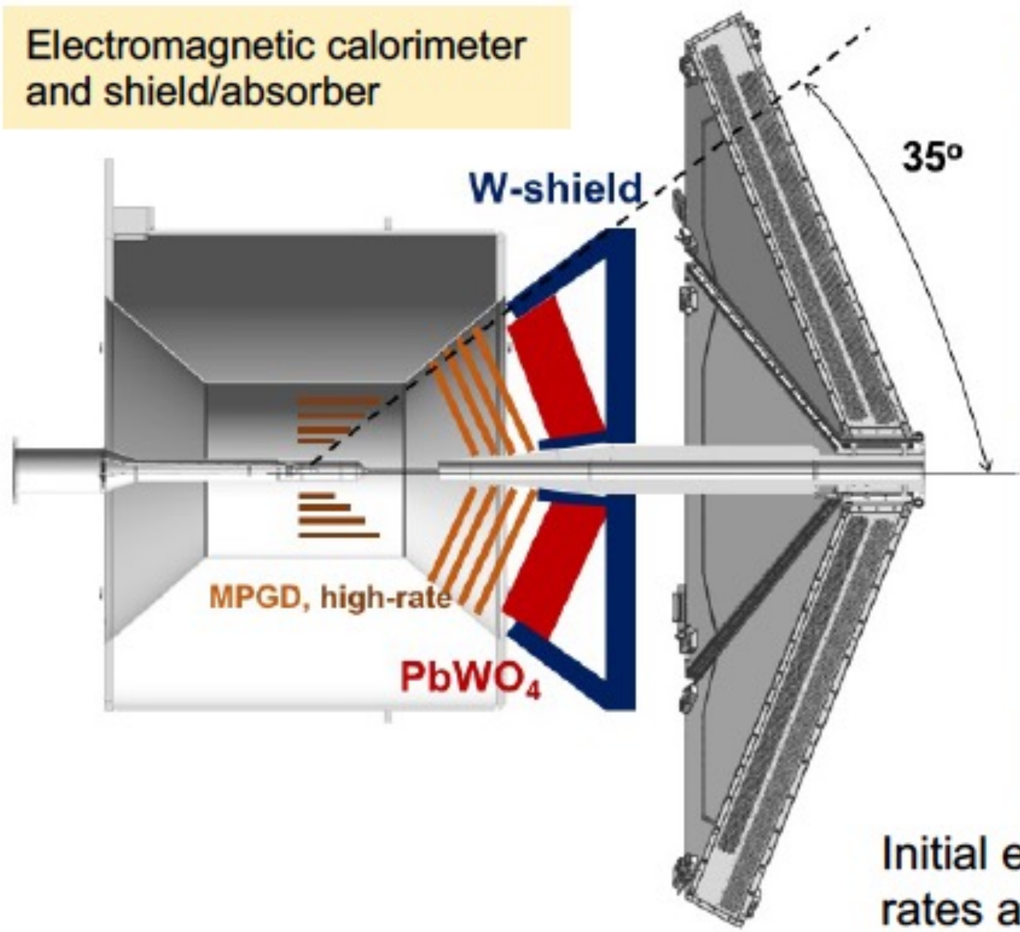




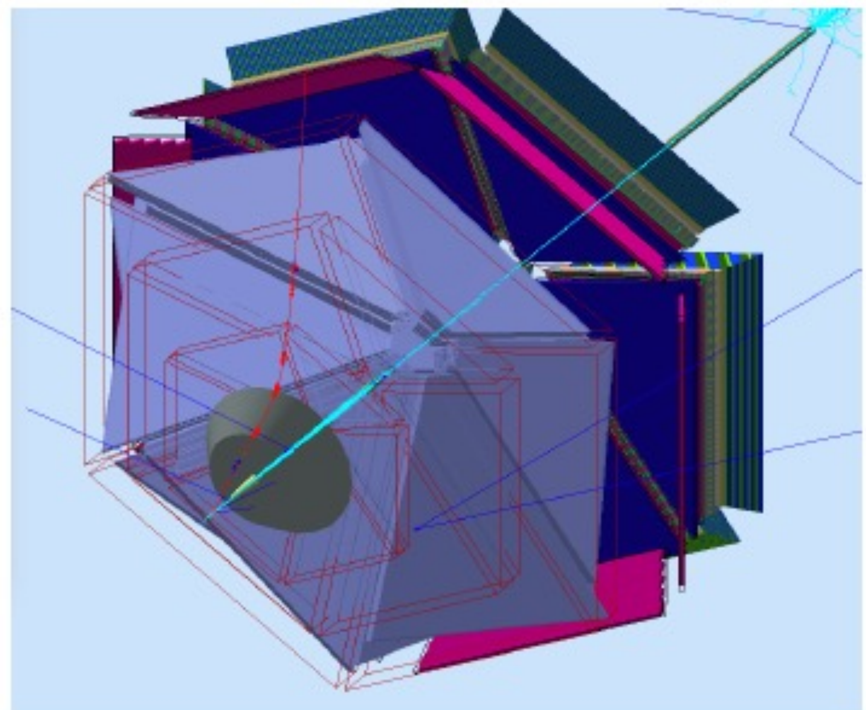
DDVCS with CLAS12 in Hall-B

$$ep \rightarrow e'p'\mu^+\mu^-$$

Luminosity ≈10^{37} cm^{-2} s^{-1}



GENT4 MC with the detector mockup.



Initial estimate of the detector occupancies and rates are reasonable. More studies are underway.

Issues with existing/proposed detectors

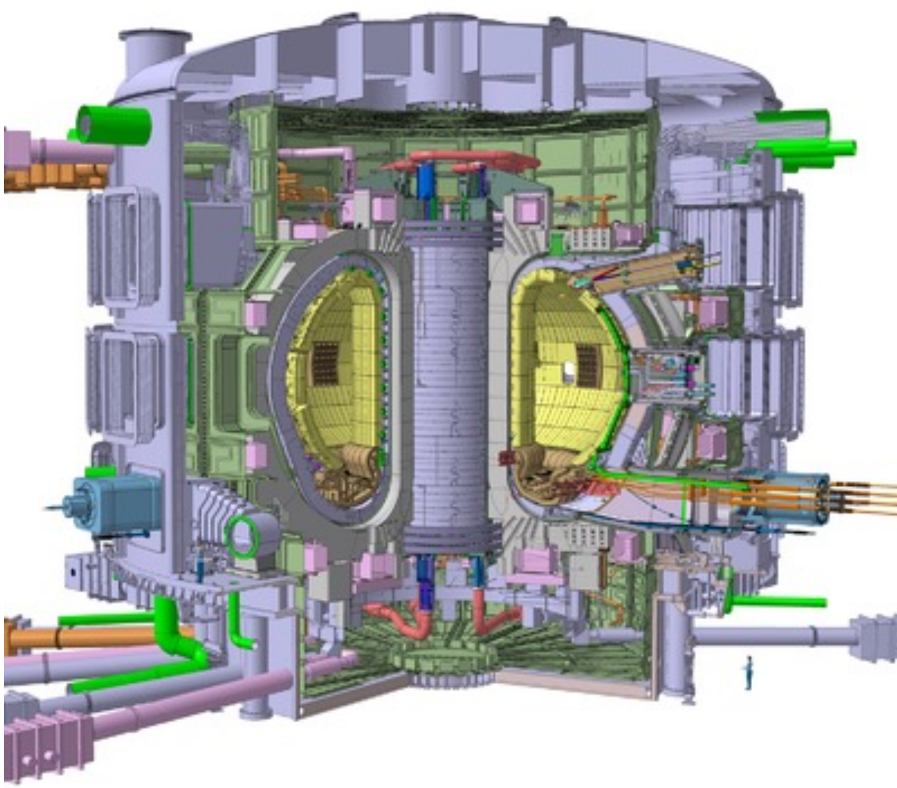
- CLAS: Luminosity limited to 10^{37}; not sufficient for a comprehensive mapping
- SoLID: Not sufficient vertex and missing mass resolution.
- Hall C: partial phase space coverage

- Also, large magnets are not optimum because:.
  - Expensive to instrument : large areas needed to be covered with detectors.
    - This is especially the case for muon chambers
  - Given the volume of detectors, not easy to re-configure or upgrade as needed with new tech.
  - With ~ 2-3 of meters or more from target to detectors, usually through air: multiple scattering leads to poor vertex resolution and momentum resolution, even with good detector resolutions.

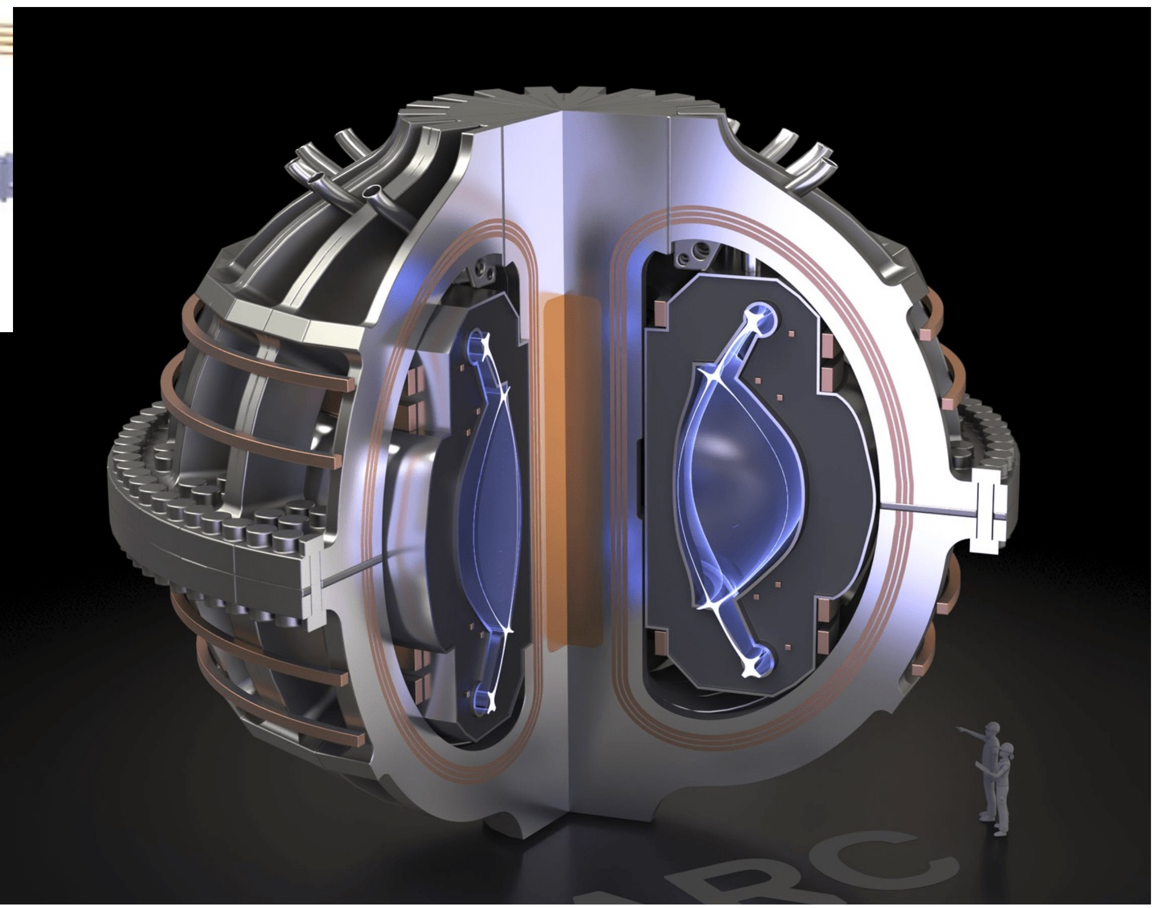
Solution: A compact, high field solenoid?

- A high field compact Solenoid (~ 7 T field, bore diameter and length ~100 cm) has a $\int b \cdot dl$ similar to a large solenoid like SoLID, but has some important advantages:
  - Mature technology: huge advances in technology for magnets of this size thanks to MRI industry.
  - Costs much less (estimate from manufacturer: ~ $ 4 M for the magnet)
  - Much easier to install, instrument and run
  - The area need to be covered by the detectors is much smaller: this allows for state of the art detectors such as $PbWO_4$ calorimeters, pixel GEMs, MAPS etc. with high granularity.
  - The path length from target to detectors is very short: much less multiple scattering – better resolution- clean missing mass identification

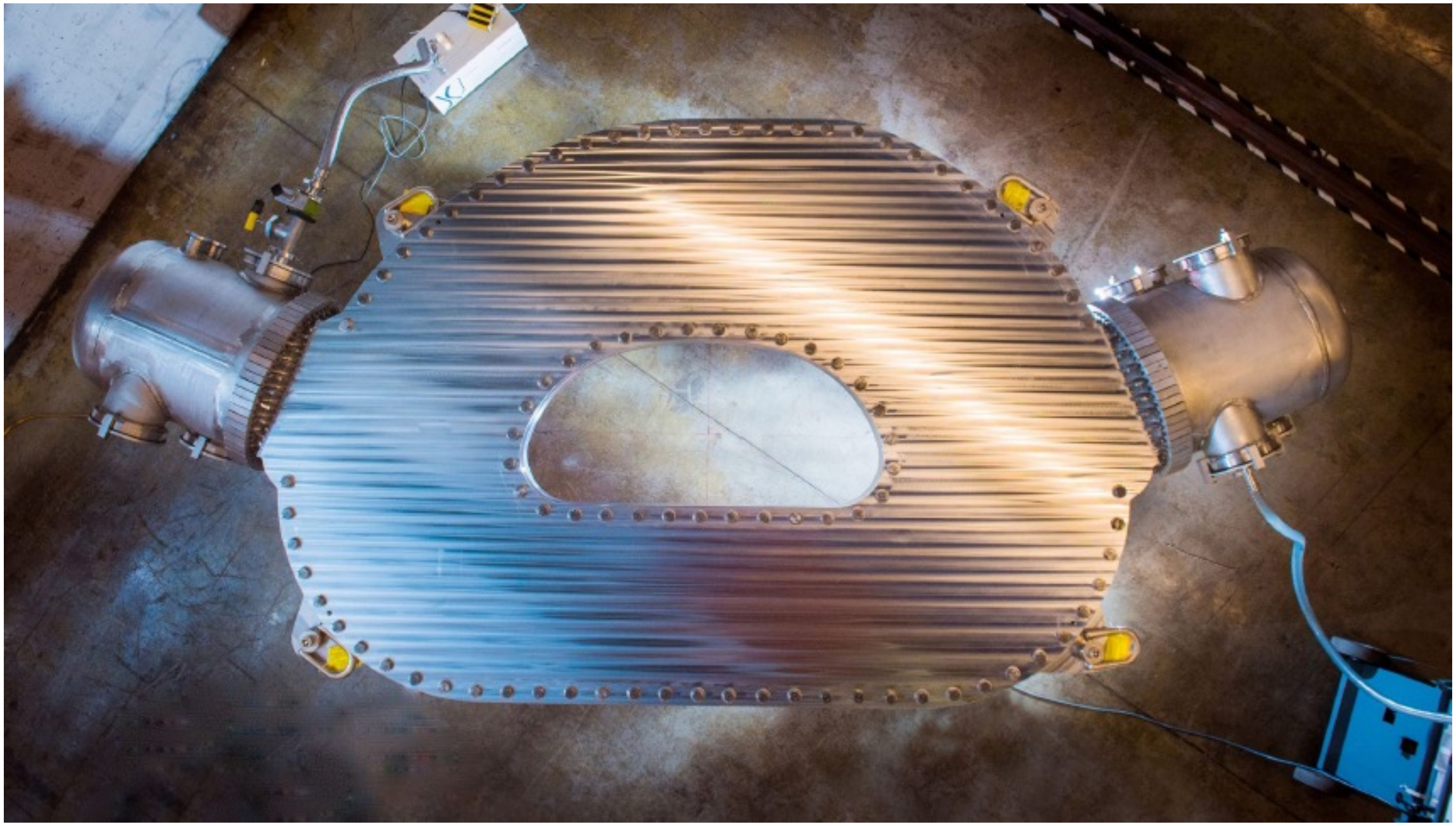
Other fields are using this idea too,



ITER: ~ 6 T cryogenic magnets



Commonwealth fusion systems proposed TOKAMAK : ~ 20 T HTS magnets
The torus volume reduced by ~ factor of 10

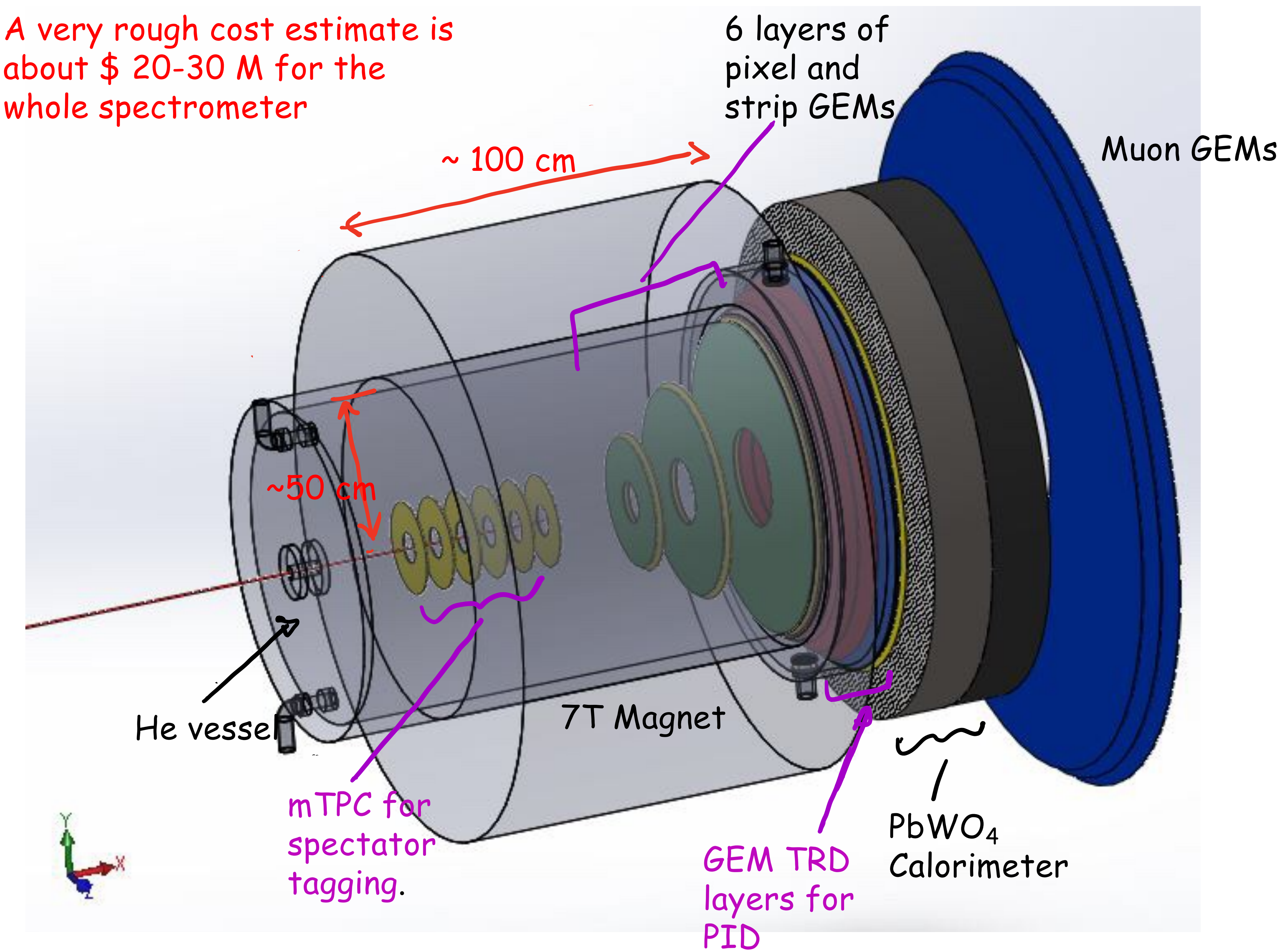


Cambridge, Mass. - September 8, 2021– Commonwealth Fusion Systems (CFS) and MIT's Plasma Science and Fusion Center (PSFC) today announced the successful test of the world's strongest high temperature superconducting (HTS) magnet, the

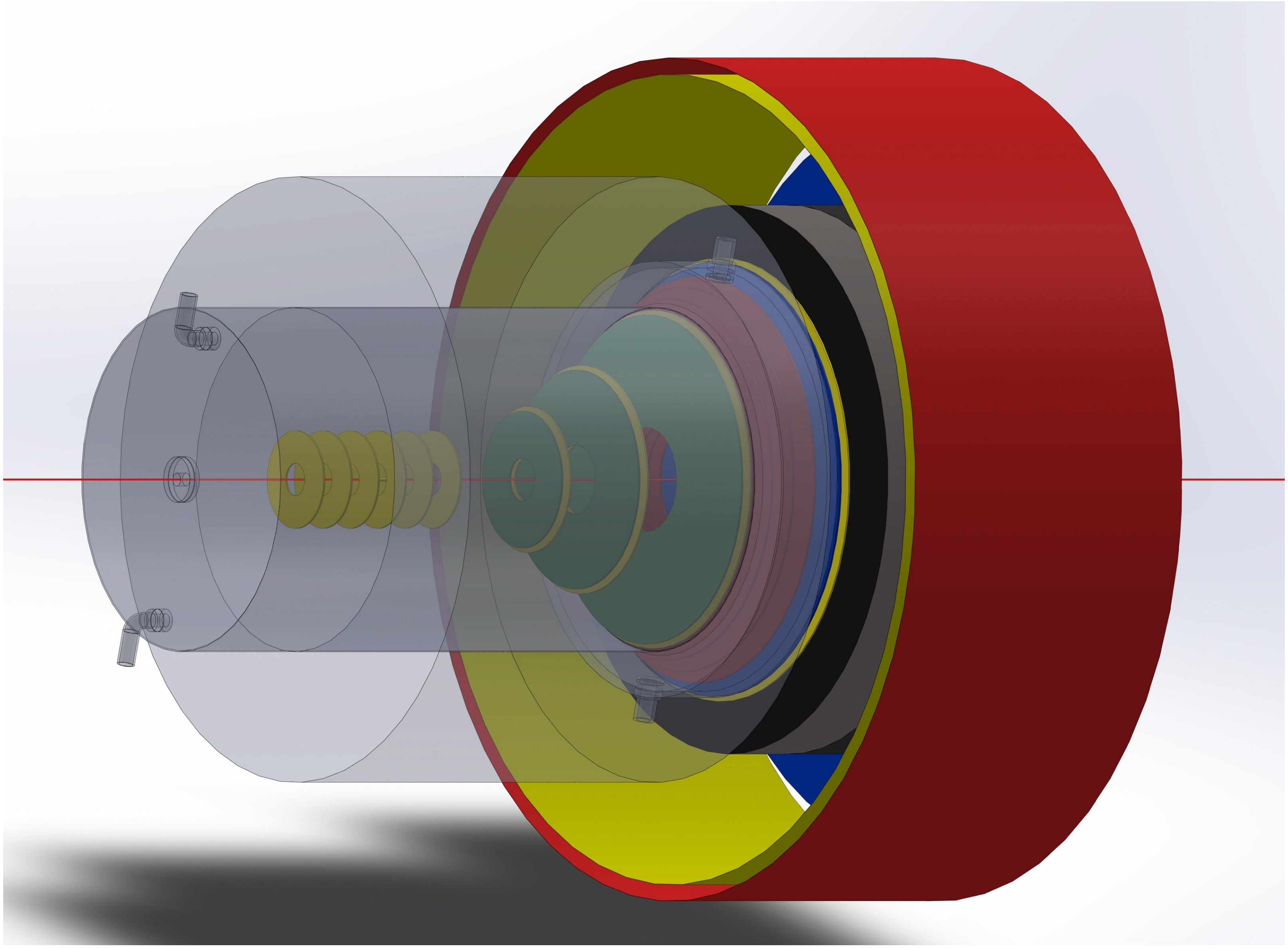
The milestone test, conducted at MIT's Plasma Science and Fusion Center, proved that the magnet built at scale can reach a sustained magnetic field of more than 20 tesla, enough to enable CFS's compact tokamak device, called SPARC, to achieve net energy from fusion, a historic first.

Proposed compact solenoid spectrometer

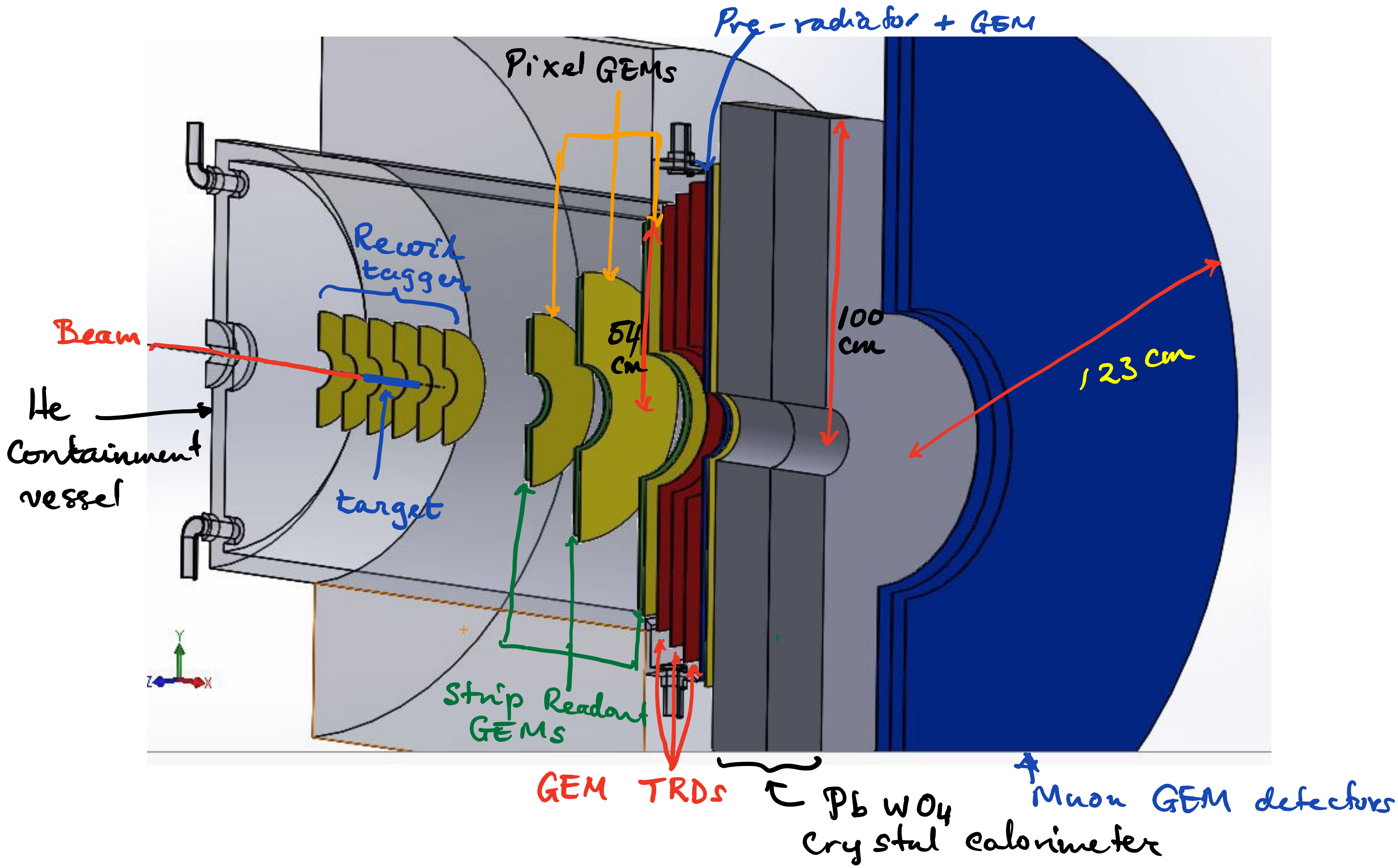
- Luminosity up to 10^{38}.
- 2π azimuthal acceptance; 5^o to 35^o polar angle coverage.
- High pressure gas targets, cryo targets and polarized targets.
- Optimized for exclusive reactions: DVCS, DVMP, DDVCS etc.
- Spectator tagging with recoil detector: access to neutron DVCS, DVMP etc.
- A rich Tagged DIS (TIDS) program possible with spectator tagging for pion and Kaon structure functions.
- Could be configured for a SDIS measurements.


A very rough cost estimate is about $ 20-30 M for the whole spectrometer
6 layers of pixel and strip GEMs
Muon GEMs
~ 100 cm
~50 cm
He vessel
7T Magnet
mTPC for spectator tagging.
GEM TRD layers for PID
$PbWO_4$ Calorimeter
Y
X

Wrap the forward end with muon GEMs



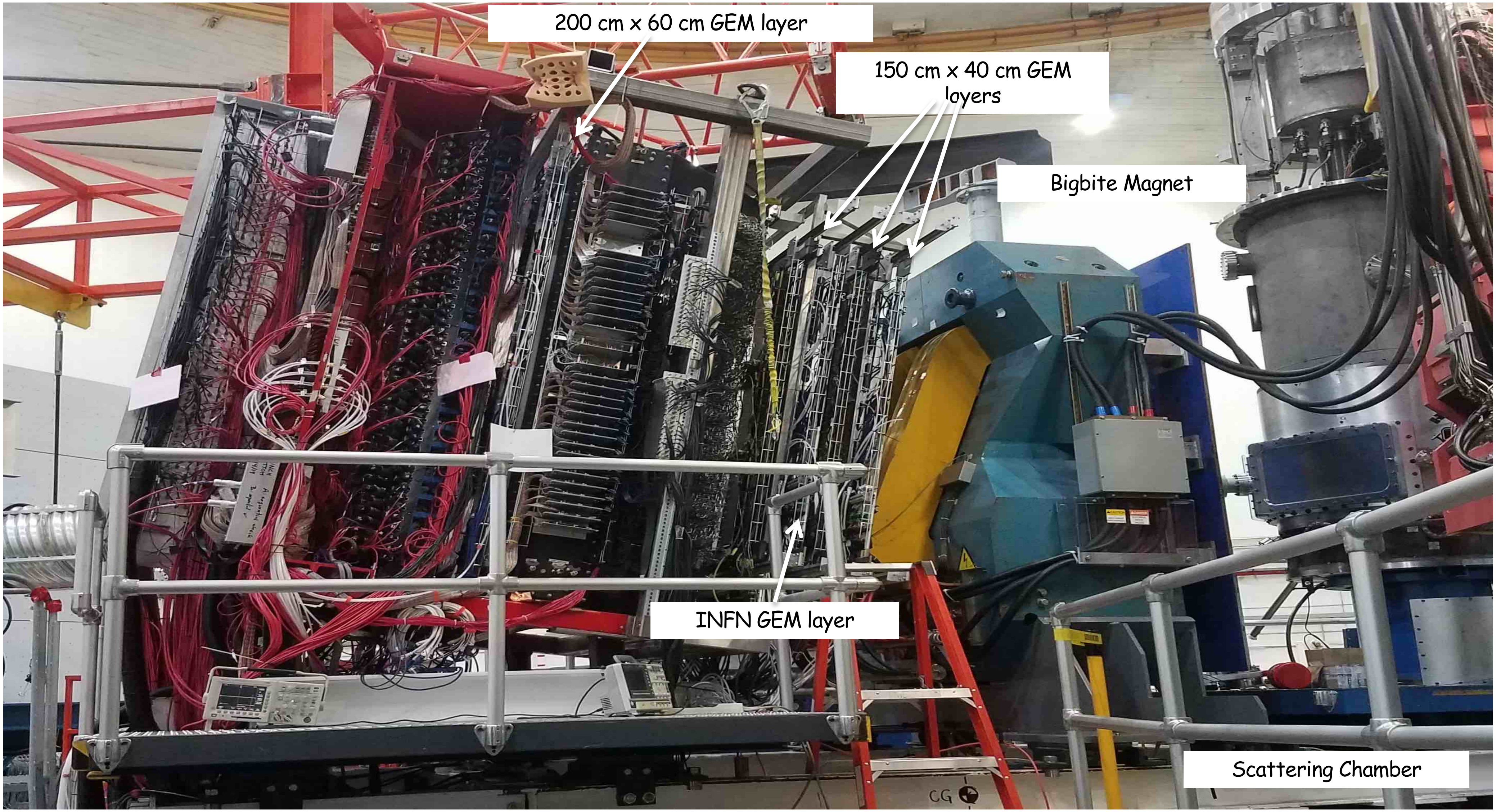
Two layers of R ~ 125 and short cylindrical GEMs: very doable, currently under development for EIC.



- Charged particle coverage from 12° to 36°.
- E/M calorimeter coverage from 10° to 36°
- HV MAPS and/or pixel GEMs for first few tracking layers; strip readout GEMs for back layers
- High time res. electronics to match the hits from the two layers: VMM is a good candidaes

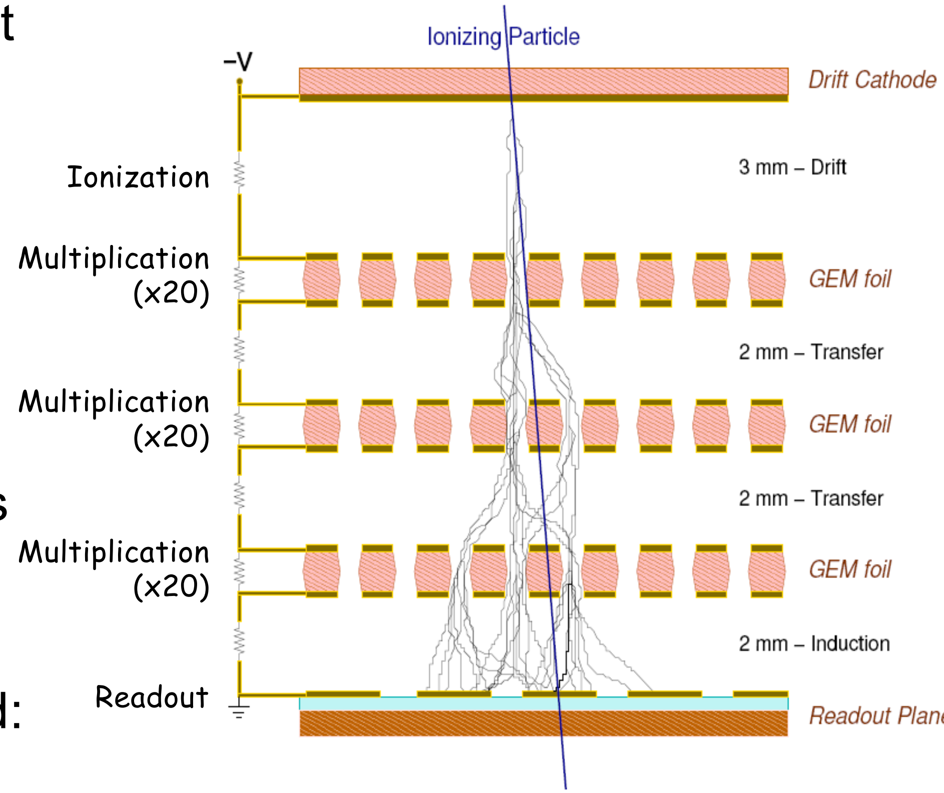
SBS project: high luminosity in open configuration

- Data taking up to luminosity of 10^{38} so far
- Expect to go higher

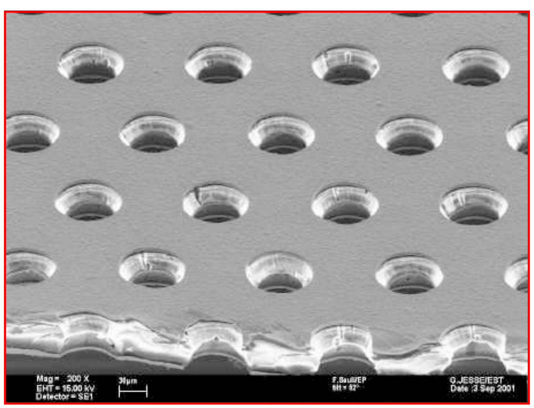


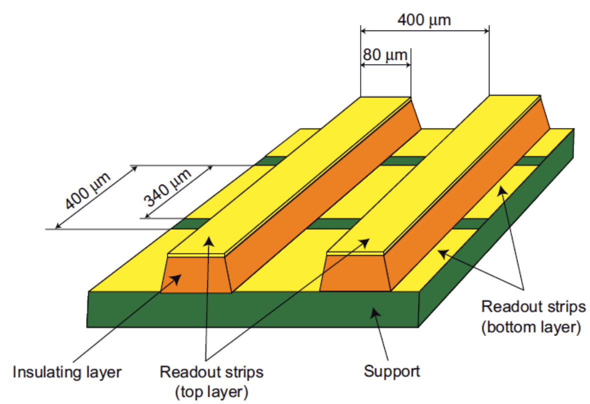
Detectors for high rates: GEM Technology

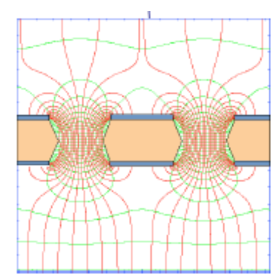
- Gas Electron Multiplier (GEM) detectors: cost effective solution for high resolution tracking under high rates over large areas.
- Rate capabilities higher than many 100s of MHz/cm^2
- High position resolution (< 70 μm)
- Highly radiation hard
- Ability to cover very large areas (10s – 100s of m^2) at modest cost.
- Low thickness (~ 0.5% radiation length)
- Used for many experiments around the world: PRad, CMS upgrade, SBS, COMPASS etc.



GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch



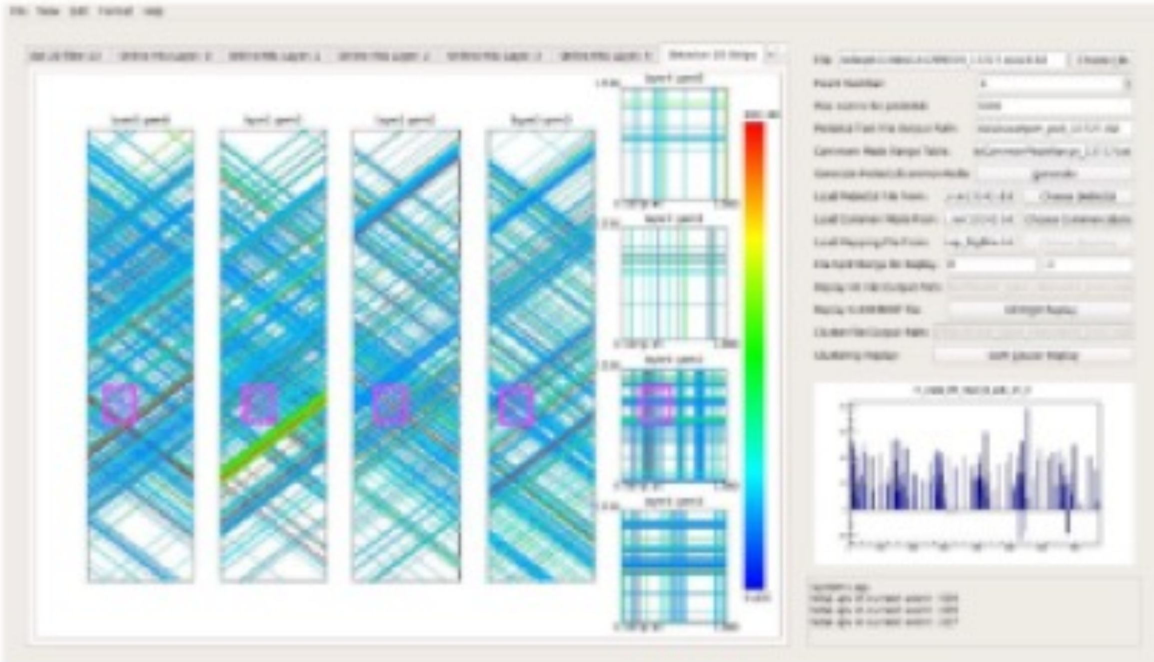


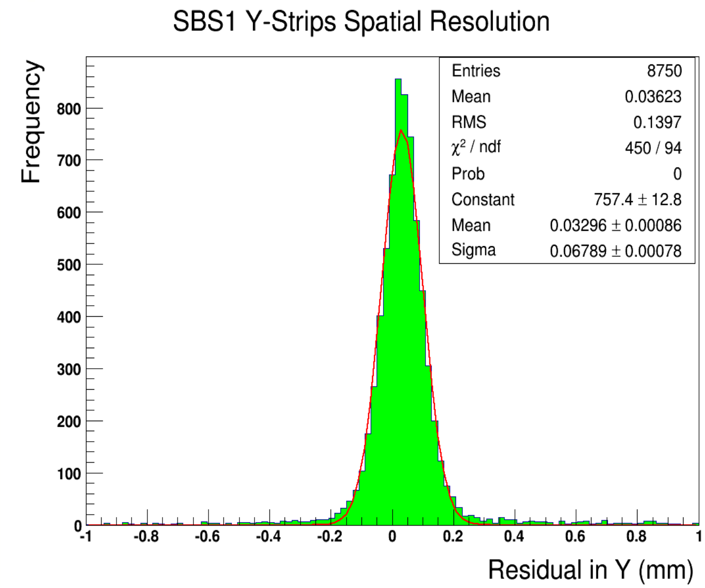


Strong electrostatic field in the GEM holes

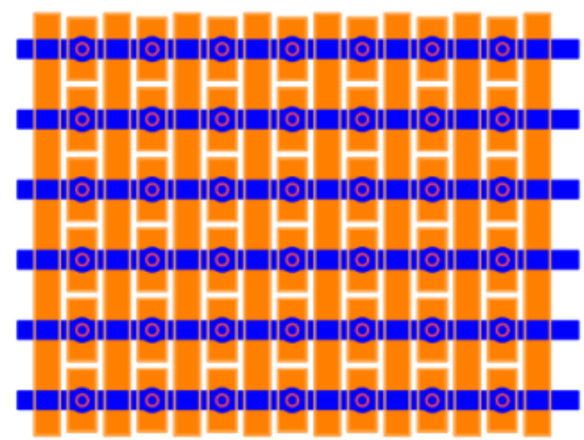
SBS tracking

What we're up against, II (run 13727, 12 uA LD2, $Q^2 = 4.5\ GeV^2, E = 4\ GeV$)





- With SBS GEMs we can handle up to ~ 0.5 MHz/cm^2
- Limitation comes from the readout strip length ~ 50 cm
- In compact solenoid rates could be ~ 10 MHz/cm^2
- Solution: segment readout strips down to about 2 cm:
    - Occupancy low enough for reliable tracking
    - Still get very good resolution

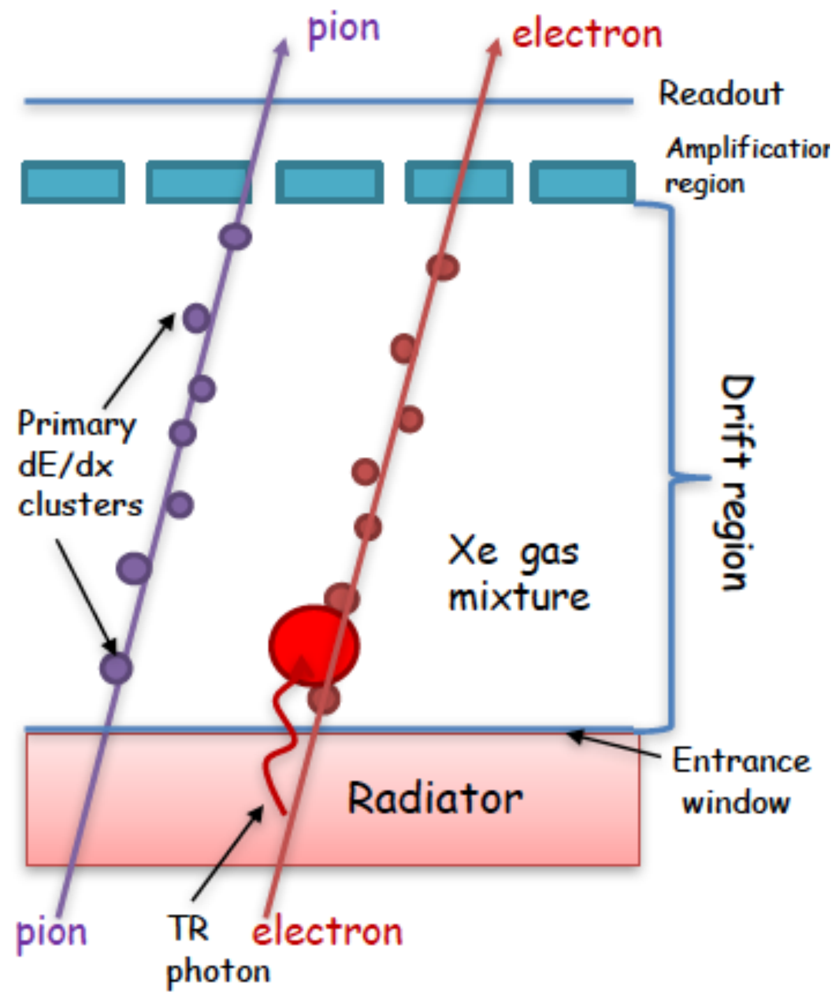


GEM-TRD for eπ rejection

GEM as Transition Radiation detector and tracker for EIC

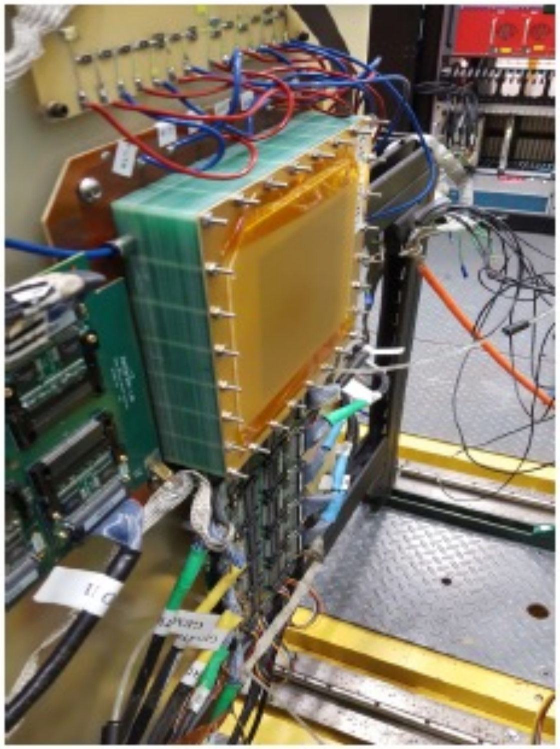
eRD22
EIC R&D
program

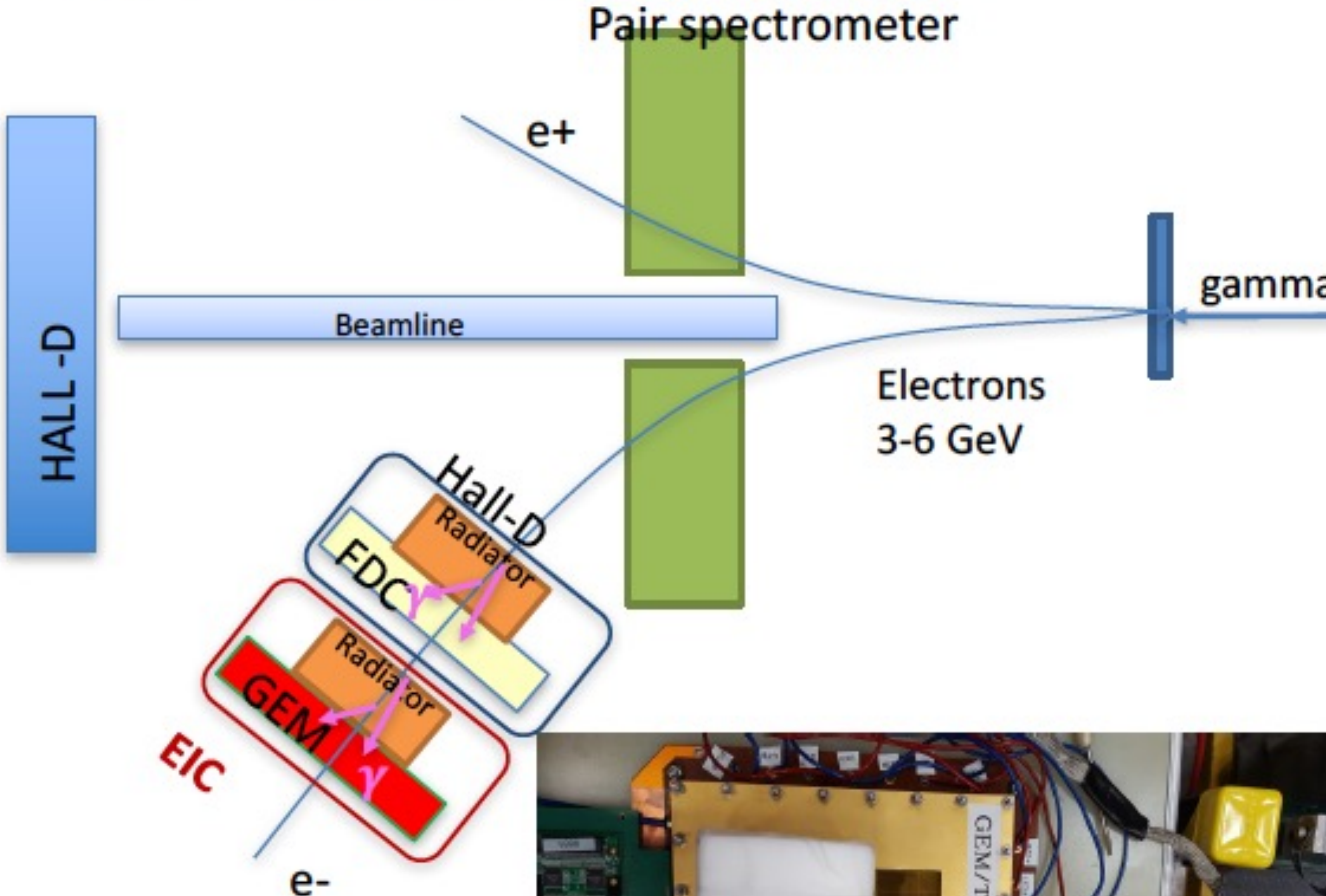
- High resolution tracker.
- Low material budget detector
- How to convert GEM tracker to TRD:
  - ✓ Change gas mixture from Argon to Xenon (TRD uses a heavy gas for efficient absorption of X-rays)
  - ✓ Add a radiator in the front of each chamber (radiator thickness ~5-10cm)
  - ✓ Increase drift region up to 2-3 cm (for the same reason).
  - ✓ Number of layers depends on needs: Single layer could provide e/pi rejection at level of 10 with a reasonable electron efficiency.

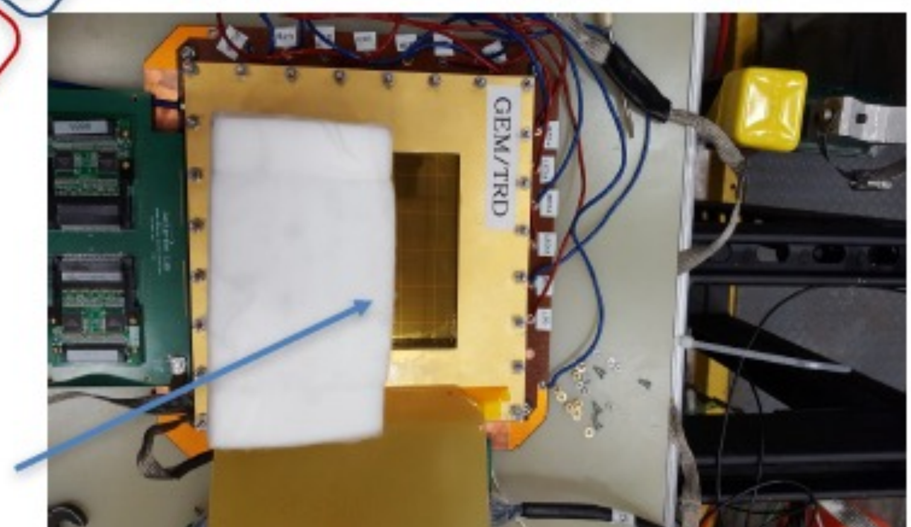


Slide from Yulia Ferletova

Test Setup at JLAB HALL-D







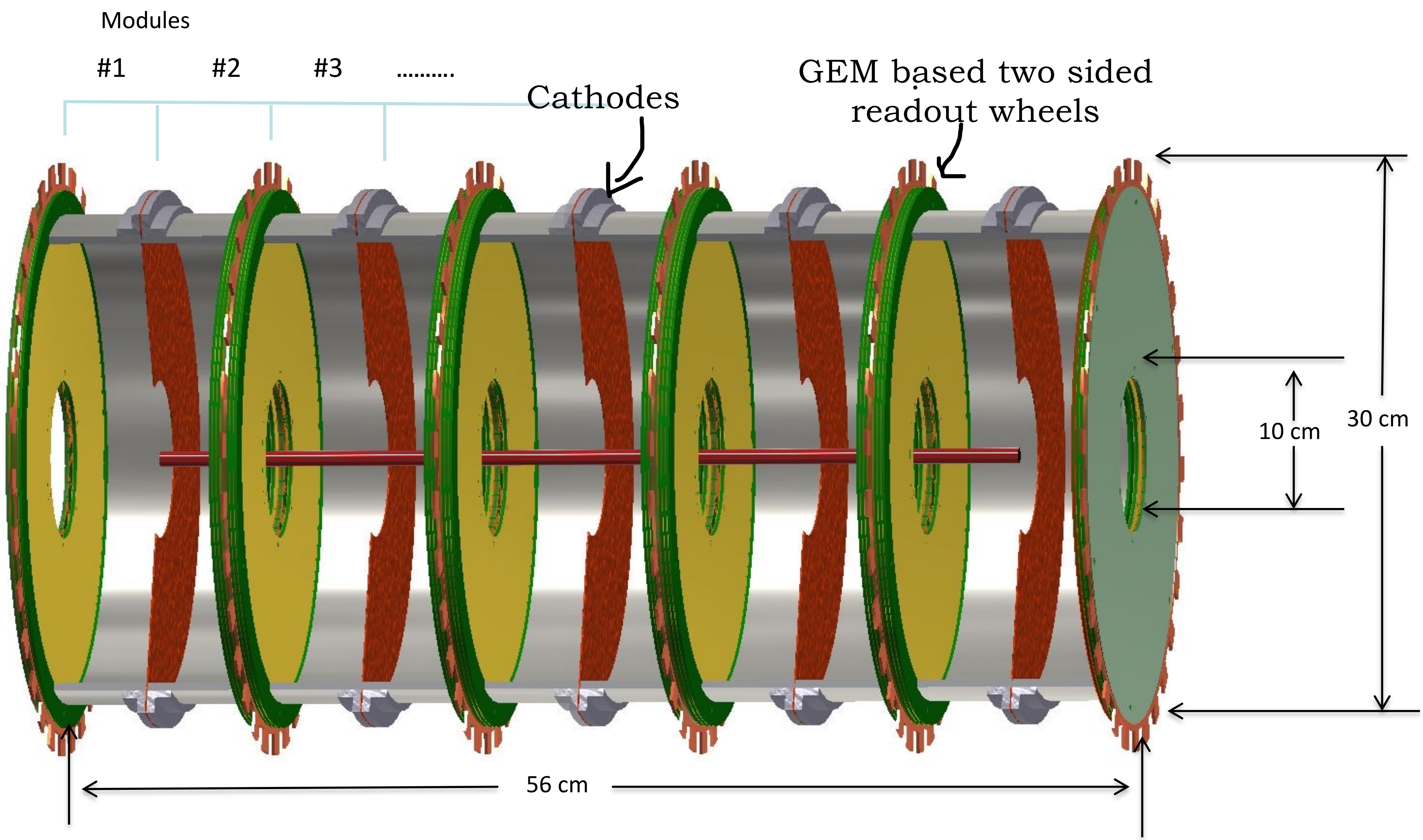
- 3-6 GeV electrons in Hall-D from pair spectrometer
- In parallel with Hall-D MW-TRD (FDC) system
- covered ½ of the sensitive area with radiator

Yulia Furletova

Now we are building a 70 cm x 54 cm GEM-TRD prototype for Hall D

Spectator tagging with mTPC recoil detector

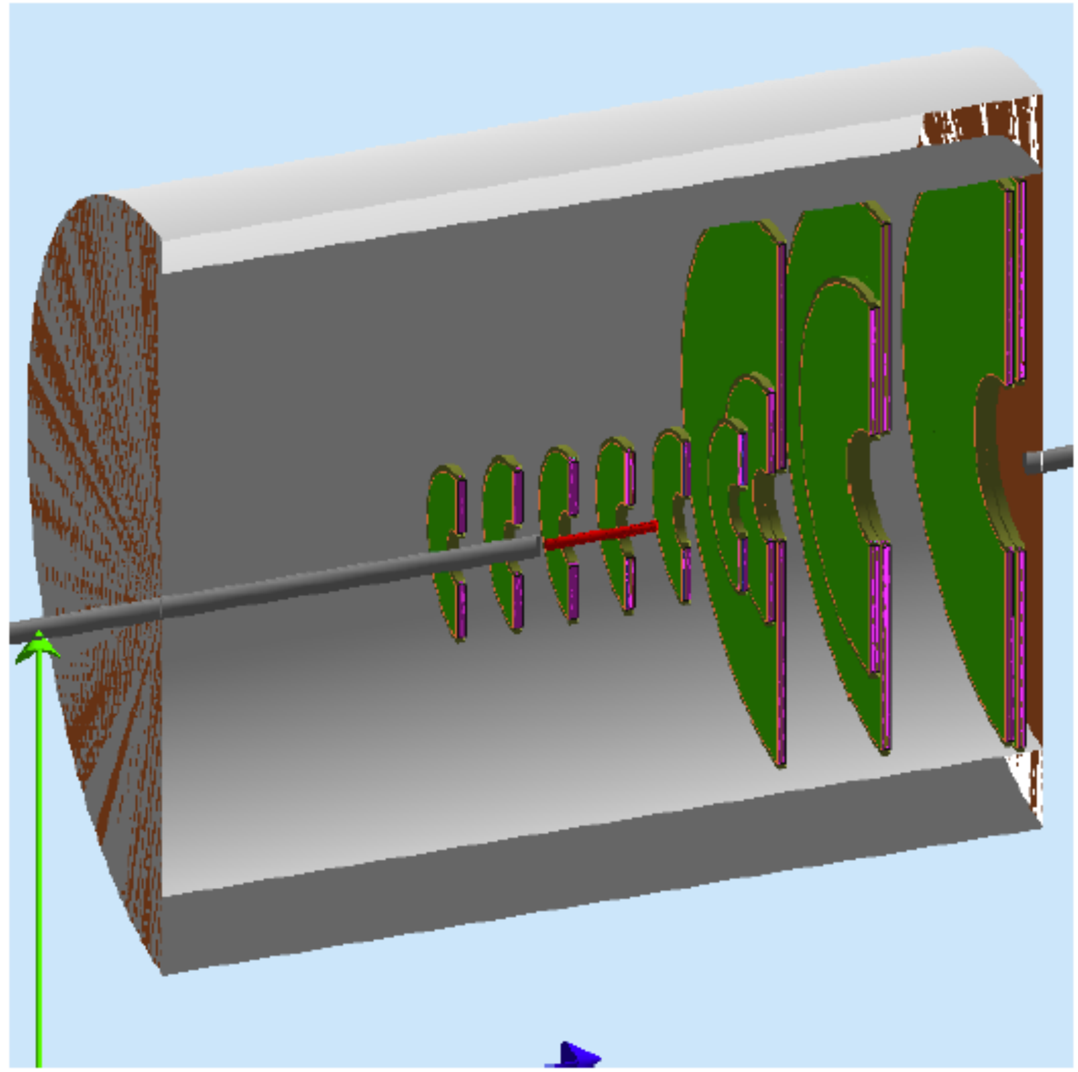
- mTPC recoil detector currently under development for Jlab TDIS program.
- It really nicely into the compact solenoid.
- No extra magnets needed; field provided by the solenoid: no clash between fields.
- Would enable pion and kaon structure functions, neutron DVCS, neutron DVMP etc. etc.



G4 simulation for compact solenoid

Geometry

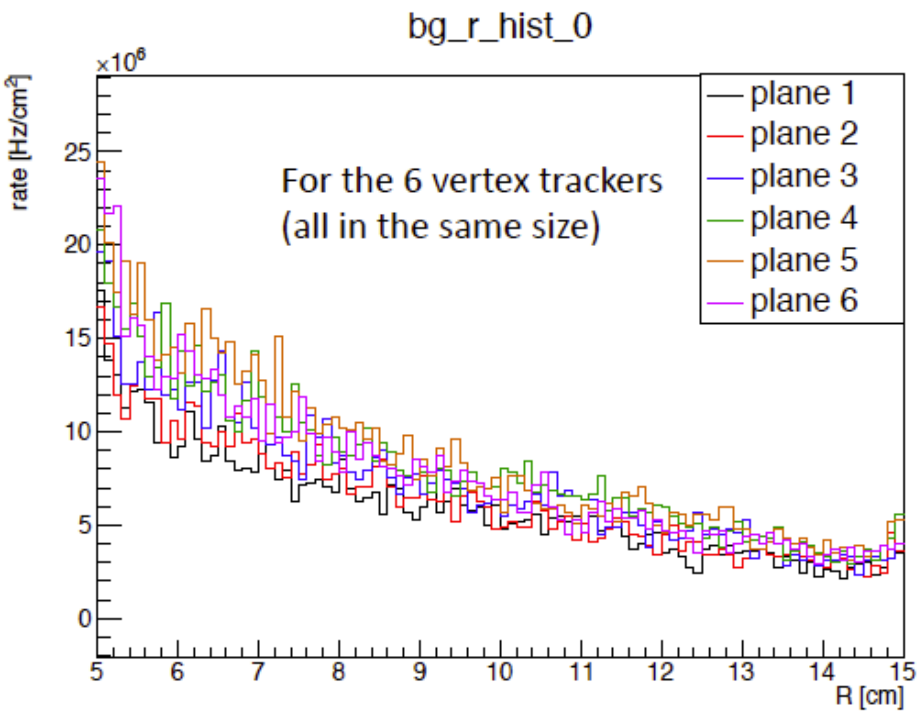
- Target cell:
  - 20 cm target cell made of 12 um Kapton file for both the windows and the wall
  - Fill with He3 gas at 10 atm
  - Located at the center of the magnet bore

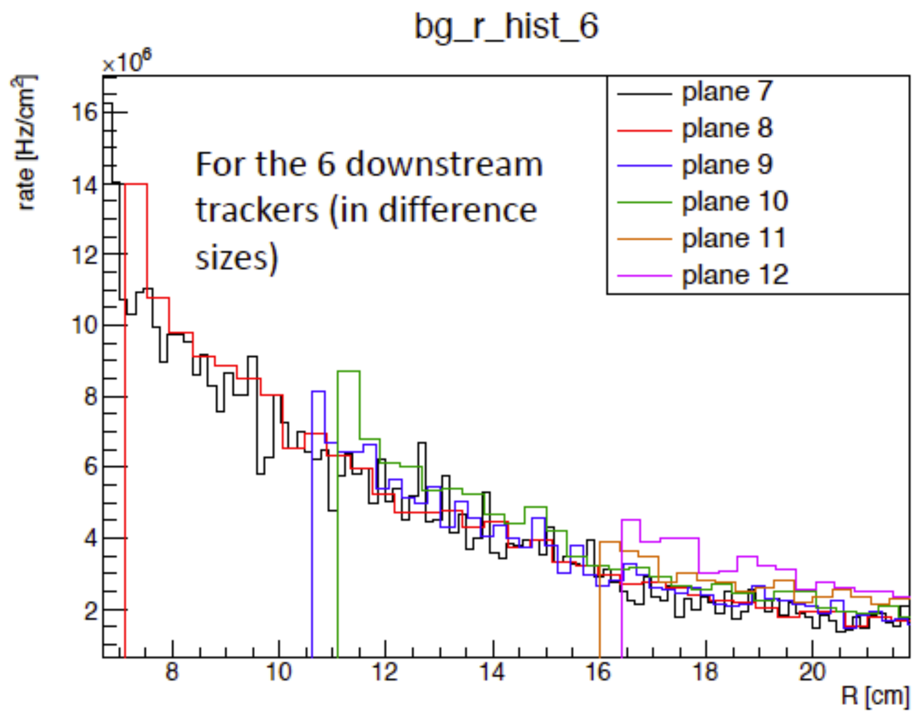


High rate considerations

Background rate

- Rates for particles deposit energy in the primary ionization layer of GEM (not the rate for bg particles entering the chamber)
- Assumes 50 uA beam current

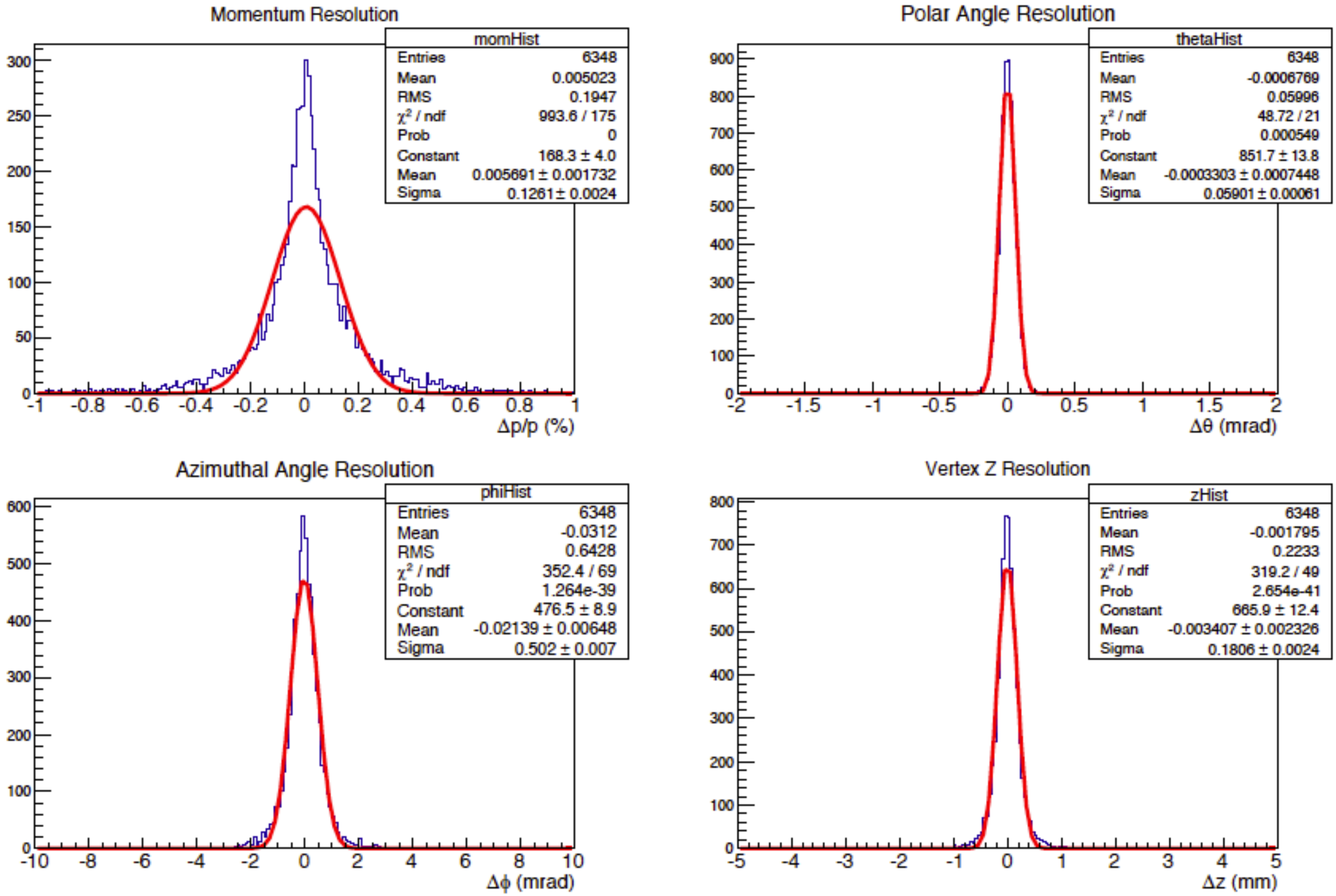




- Rates about factor of 30-40 higher than in SBS.
- Not a problem: with pixel GEMs and fast electronics we can easily handle this rate.
- Simulations and estimates show that this setup can handle luminosities up to 10^{38}

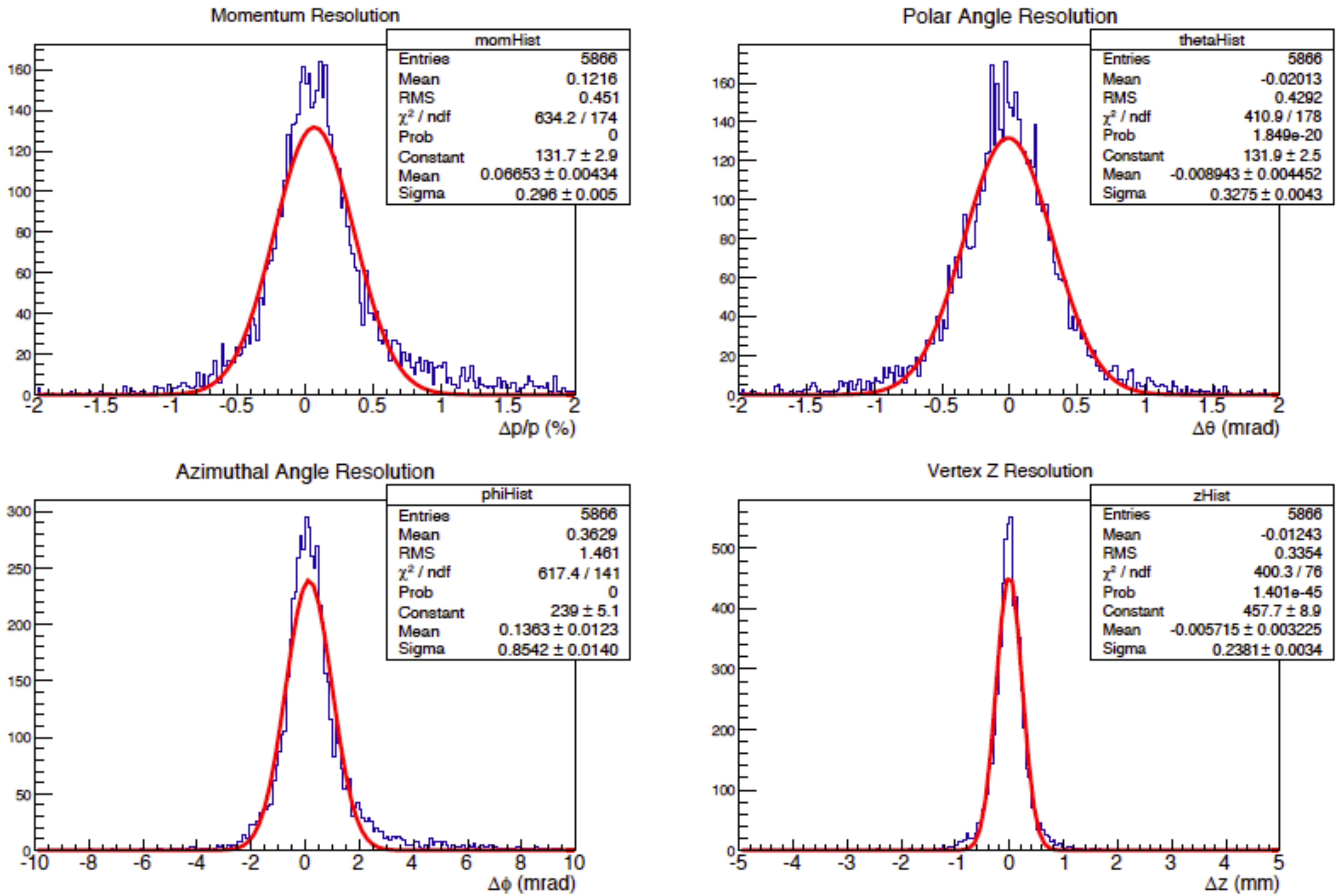
Very good vertex, angular and momentum resolution

Only detector resolution included, no material in the simulation



Very good vertex, angular and momentum resolution

Detector resolution and material included



Summary

- A high field compact Solenoid based spectrometer would allow us a comprehensive exclusive program and more
- Benefit from magnet development for MRI
- Recent advances in technology and experience with SoLID and SBS allows us to handle high luminosity conditions.
- Would allow a very rich physics program
  - mapping GPDs over the valence quark region using DVCS, DVMP, DDVCS etc.
  - unpolarized and polarized targets
  - proton and tagged neutron targets
  - TDIS for pions and kaons.
  - SRC
  - and more.
- We have already done preliminary simulations:
  - Excellent resolutions
  - Do not see any show stoppers
- This solenoid and associated detector development would provide an ideal test-bed for EIC detectors.