The 2nd Detector at the EIC

- Motivation
- Activities
- IP-8 & Detector
- Physics Examples
- Summary

Anselm Vossen

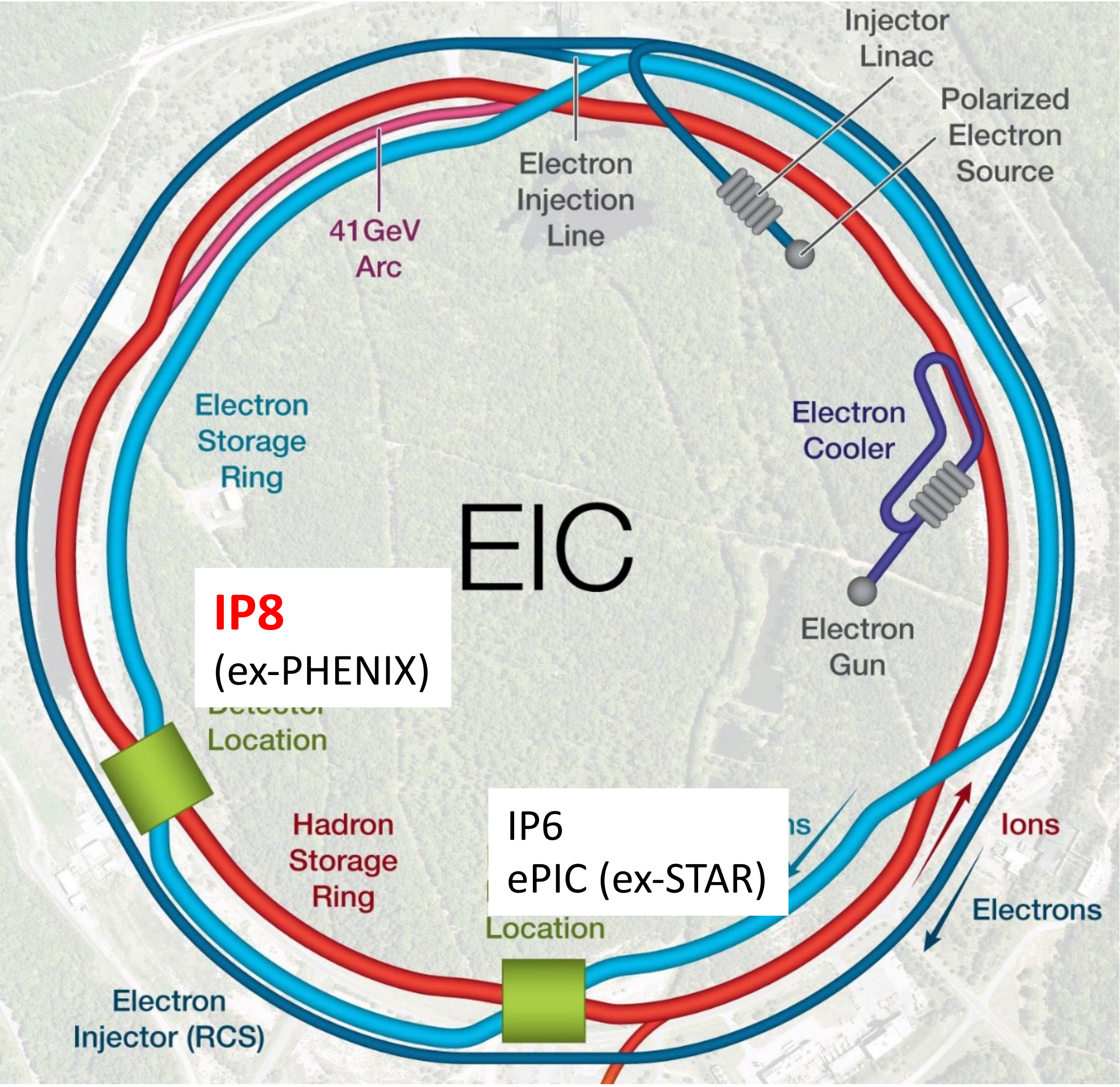
on behalf of the EICUG working group on the 2nd Detector

Duke UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

Jefferson Lab

A second detector at the EIC



- Two interaction regions that can house detectors
- IP6: Project detector ePIC
- **IP8: Detector 2**

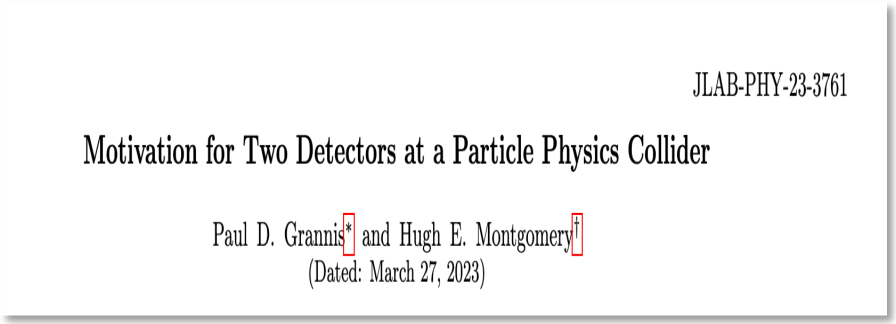
A **Strong** Motivation for a 2nd Detector

- EIC community recognized the need for two detectors early
  - Most facilities had two detectors for a reason:
  - Discoveries need independent verification
  - Two experiments have uncorrelated systematics: 1+1 > 2
  - Complementarity in technology
  - Complementarity in strength
- EIC community can support 2 detectors!
  - ≈ 1400 members, still growing→about 2x BNL, Tevatron experiments


THE ELECTRON-ION COLLIDER

The Benefits of Two Detectors

Brochure Spring 2022


JLAB-PHY-23-3761

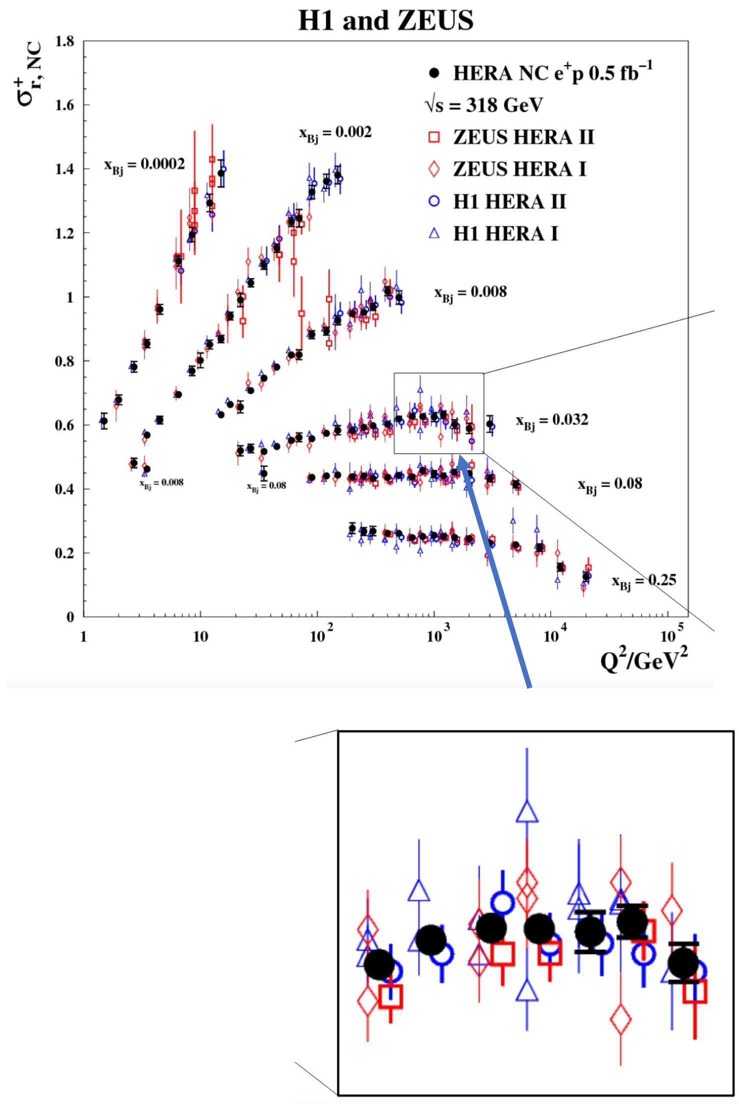
Motivation for Two Detectors at a Particle Physics Collider

Paul D. Grannis* and Hugh E. Montgomery†

(Dated: March 27, 2023)

Complementarity examples from HERA

- Importance of 2 detectors demonstrated by
  - Confirmation of precision measurements
  - Confirmation of unexpected effects (e.g. diffraction)
  - Resolution of spurious effects (pentaquarks)
  - Use of uncorrelated systematics (1+1 > 2)



Steps towards a 2^{nd} detector

- Strong support in the community with early NSAC/NAS documents assuming two detectors, discussions at EICUG meetings, 2nd detector brochure

➔DPAP panel endorsing 2^{nd} detector at IP8 with delayed start of project detector (3-5) years (Spring 2022)

  – Focus on complementarity, take advantage of technology progress
  – Take advantage of 2^{nd} focus

- DPAP report: "The DOE project includes significant funding for the construction of one EIC detector, […] and a conceptual design for a second interaction region."

- EICUG Steering Committee forms working group to continue the Det2/IP8 effort at 2022 annual meeting
  – Engage broader community
  – Work with steering committee to recruit new institutions
  – Identify R&D opportunities
  – Facilitate the development of a unified concept for a general-purpose detector at IR8. In particular, the 2nd detector should be complementary to the project detector at IR6 and may capitalize on the possibility of a secondary focus at IR

- NSAC Facilities Subcommittee Report (4/2024) assesses the science case of Det2 as important

DPAP: Detector Proposal Advisory Board

Activities of the Working Group

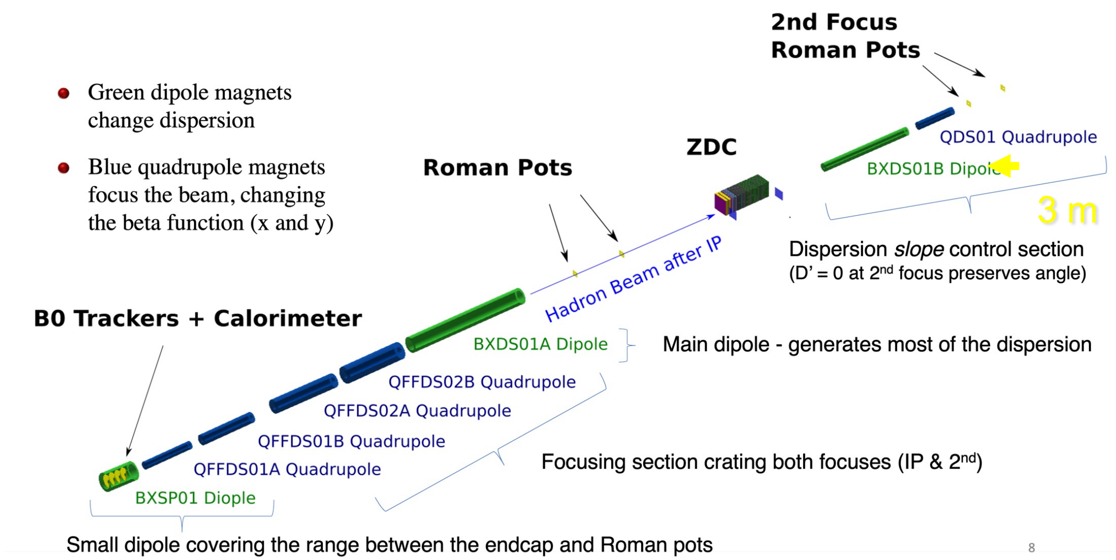
- Outreach
- Open Meetings to discuss science and detector options
- Organization of Workshops
  - 2nd Detector Incubator meeting Dec 2022@SBU

  →First discussion of required baseline measurements, opportunities and detector options
  - 1st Int. Workshop on a 2nd Detector for the EIC, May 2023@Temple

  →move towards concrete physics and detector options

- Renee Fatemi (ex-officio)
- Sangbaek Lee (ANL)
- Anselm Vossen (Duke/JLAB)
- Thomas Ullrich (BNL/Yale)
- Pawel Nadel-Turonski (CFNS/SBU)
- Simonetta Liuti (UVA)
- Detector WG
  - [Klaus Dehmelt (CFNS/SBU)]
  - Ernst Sichtermann (LBNL)
- Physics WG
  - Charles Hyde (ODU)
  - Bjoern Schenke (BNL)
- Software Custodians
  - Wenliang (Bill) Lee
  - Zhoudunming (Kong) Tu

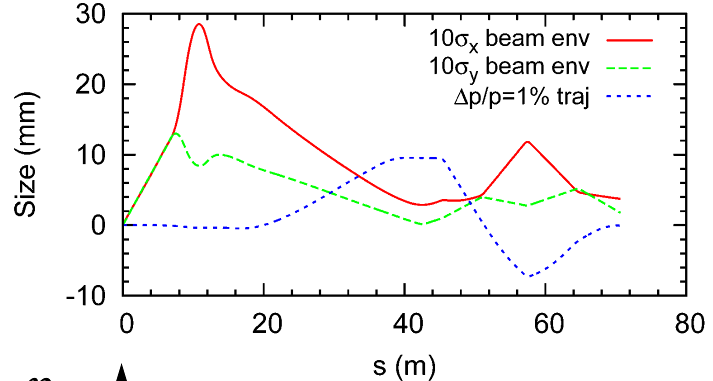
Beamline at 2nd IP with 2nd Focus



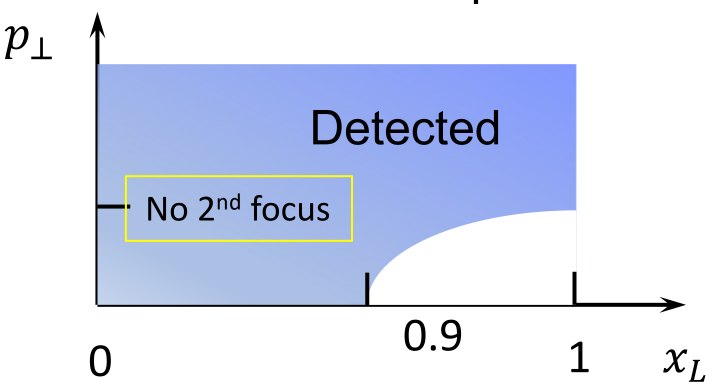
- Larger crossing angle (35 vs 25 mRad)
- Luminosity sharing (but only relevant at full luminosity)
- Far forward detectors could be optimized in a complimentary way
- 2nd Focus allows the detection of charged particles in Roman Pots for much lower p_T than for IP6

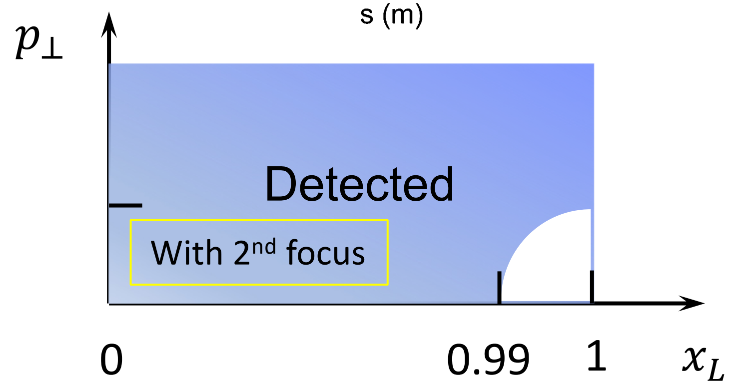
2nd Focus → order of magnitude improvement of far forward detection of (nuclear) remnants

- 2nd beam focus where dispersion is largest enables RPs close to beam



Exclusive protons





($x_L = p' / p_{beam} \sim 1 - x$)

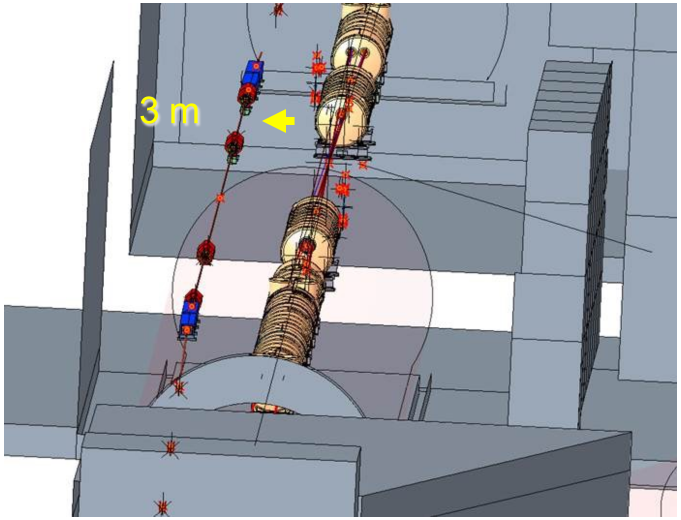
New physics opportunities

– Excellent low-p_T acceptance for protons and light nuclei from exclusive reactions → low t

– Detection of target fragments makes it possible to

- veto breakup to study coherent processes
- study the final state when breakup occurs (e.g. $A - 1$ etc)

Detector Hall



RCS line (left) in IR8

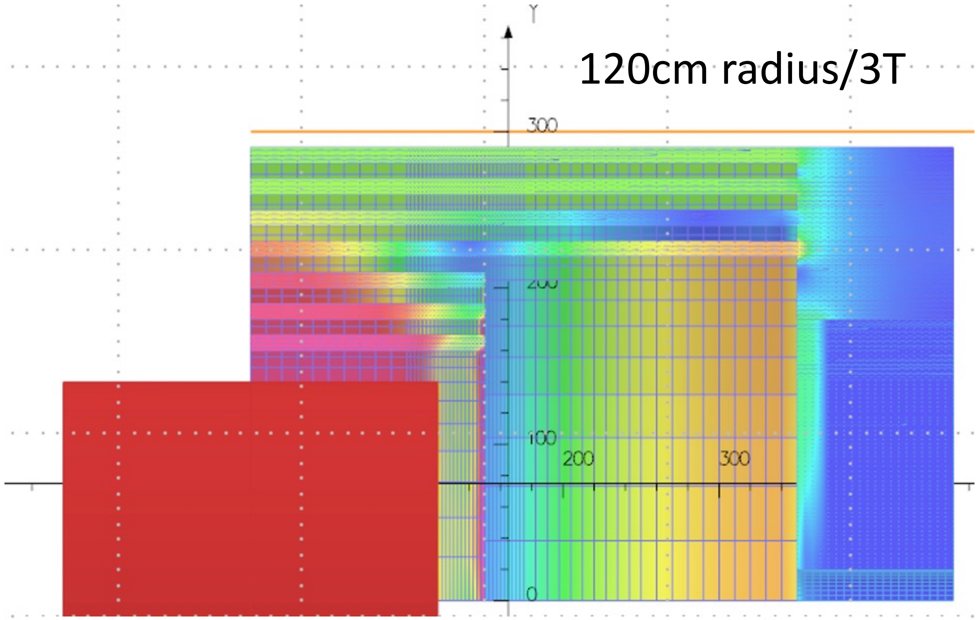
- Constraints on IR
  - Electron line passes at 3m → constrains on fringe B field (< 10 Gauss) (and detector radius)
  - Size of experimental hall comparable to IP-6 (a bit wider), assembly area more constraint

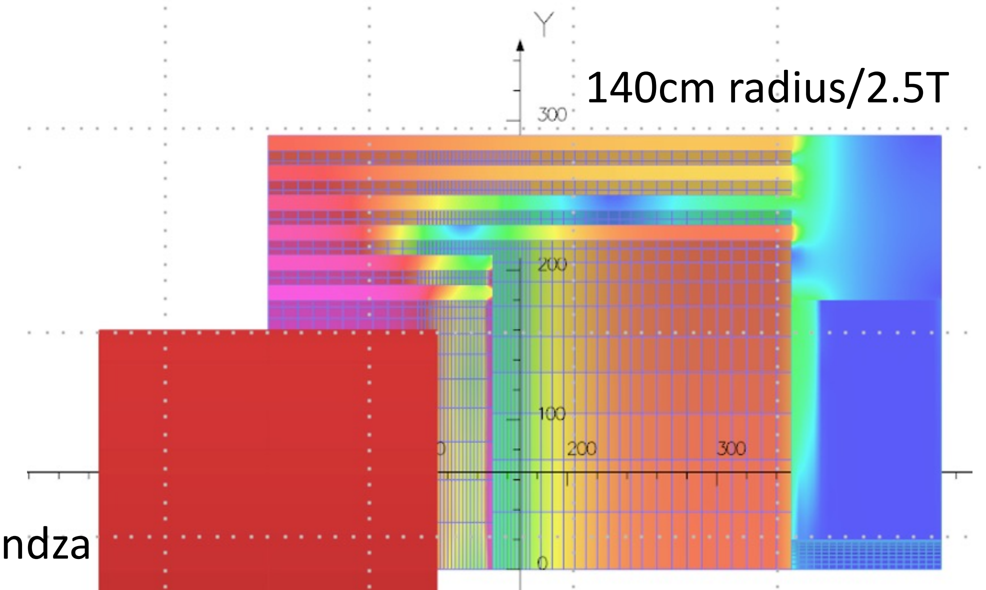
What kind of detector do you want to have?

- Magnet design is central, other choices flow from there
- Complementarity but also capable of doing the full physics program for mutual cross-check
  - → **Solenoid**

- Would like to have higher B field for tracking performance
- Space constraint
  - Large bore magnet: No instrumented flux return for $B \geq 2.5\ T$
  - Smaller bore magnet can have $3T$ and instrumented flux return

- Points of complementarity
  - 2nd focus
  - MuonId
  - ECal
  - Low Q2?
  - …





Paul Brindza

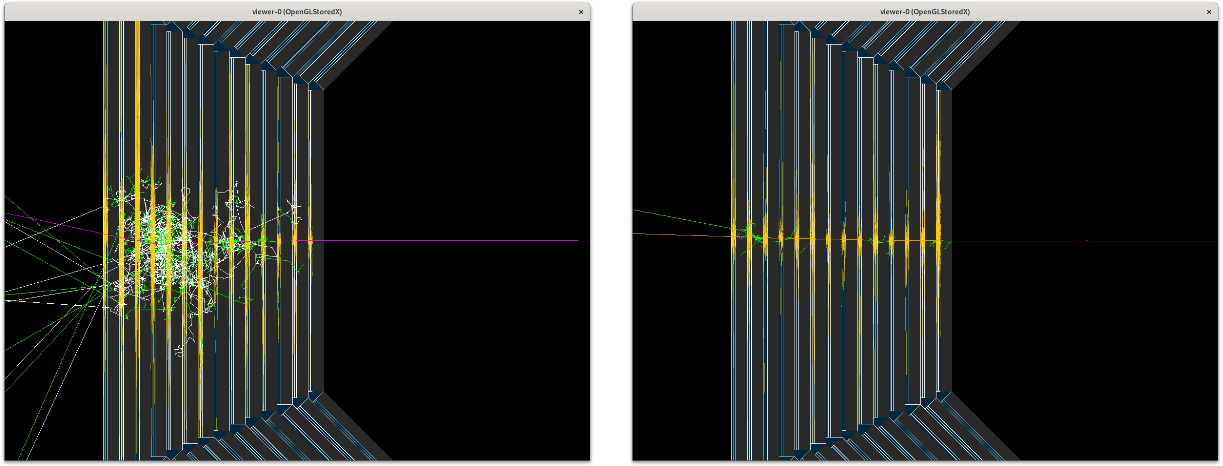
Complementarity of Technologies

- Generic R&D program central
- Funding ≈ $\$2M$/year
- Aimed at Detector 2, or upgrades of Detector 1

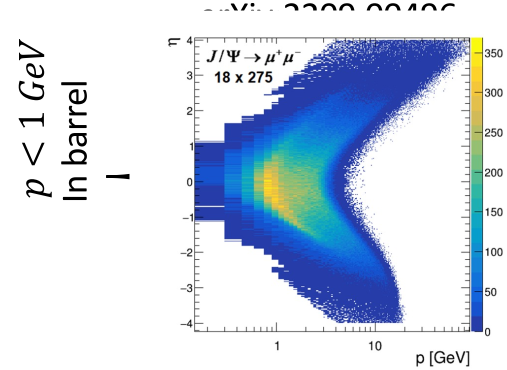
Topic	# of proposals before filtering	# of proposals after filtering
Calorimetry	5	5
PID (non-TOF)	3	3
Gaseous Precision Timing and/or Tracking	3	3
Front End Electronics	3	3
Silicon Detectors	6	5
Software Supporting Electronics/Detector Design or Physics Program	4	4
"Other New Detectors"	3	1
Studies to Support or Expand the Physics Program	3	1

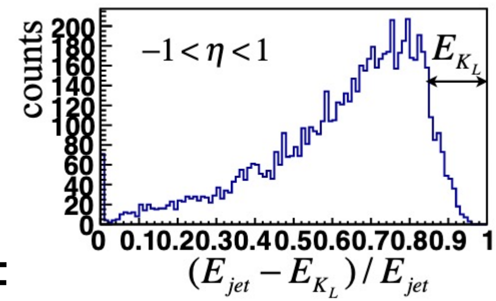
Table by D. Mack at 2nd detector workshop at Temple
See also T. Ullrich overview of technologies at same meeting

Examples of R&D project for 2nd Det:KLM



Simon Schneider, Rowan Kelleher, Nilanga Wikaramachchi



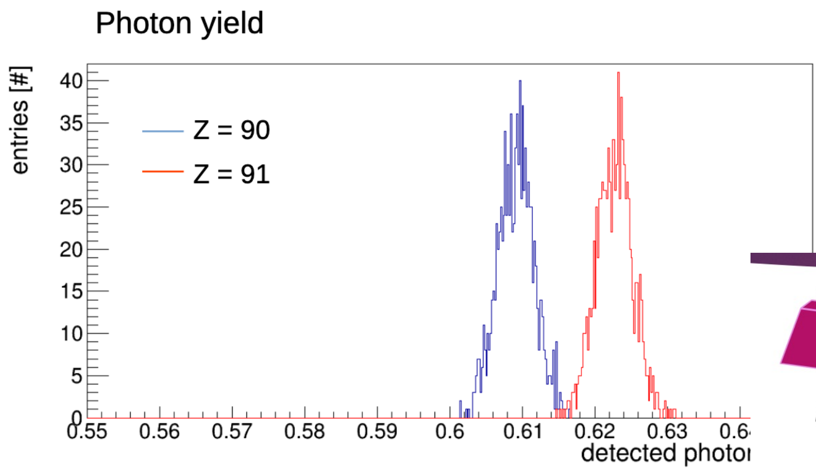


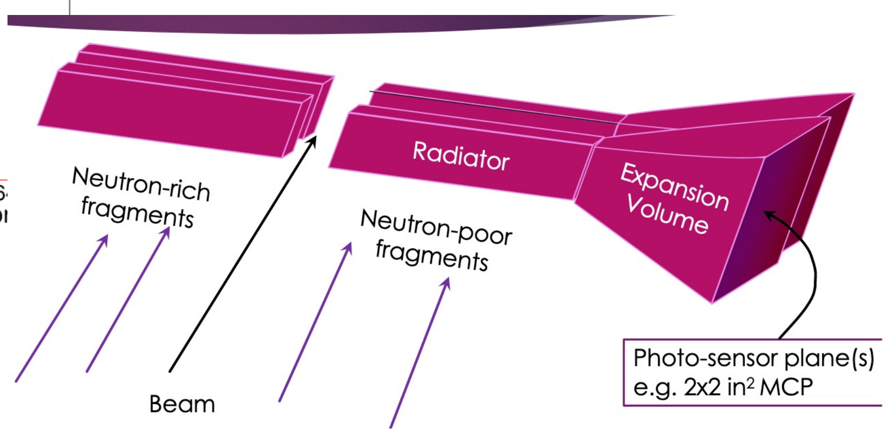
- Iron/Scintillator sandwich integrated in flux return
- μId at low ($\approx 1\ GeV$) momenta
- R&D on fast scintillator (readout) ($\mathcal{O}(50ps)$) for ToF
- Longitudinal segmentation for better h/μ ID , energy reconstruction
- Possible solution for endcap HCAL
- Physics Motivation: Muon channels (J/Psi DDVCS), cost effective HCAL

AV, Yordanka Illeva, Will Jacobs,

Example II: Z-tagging Mini DIRC for 2nd Focus

C.Hyde et al.

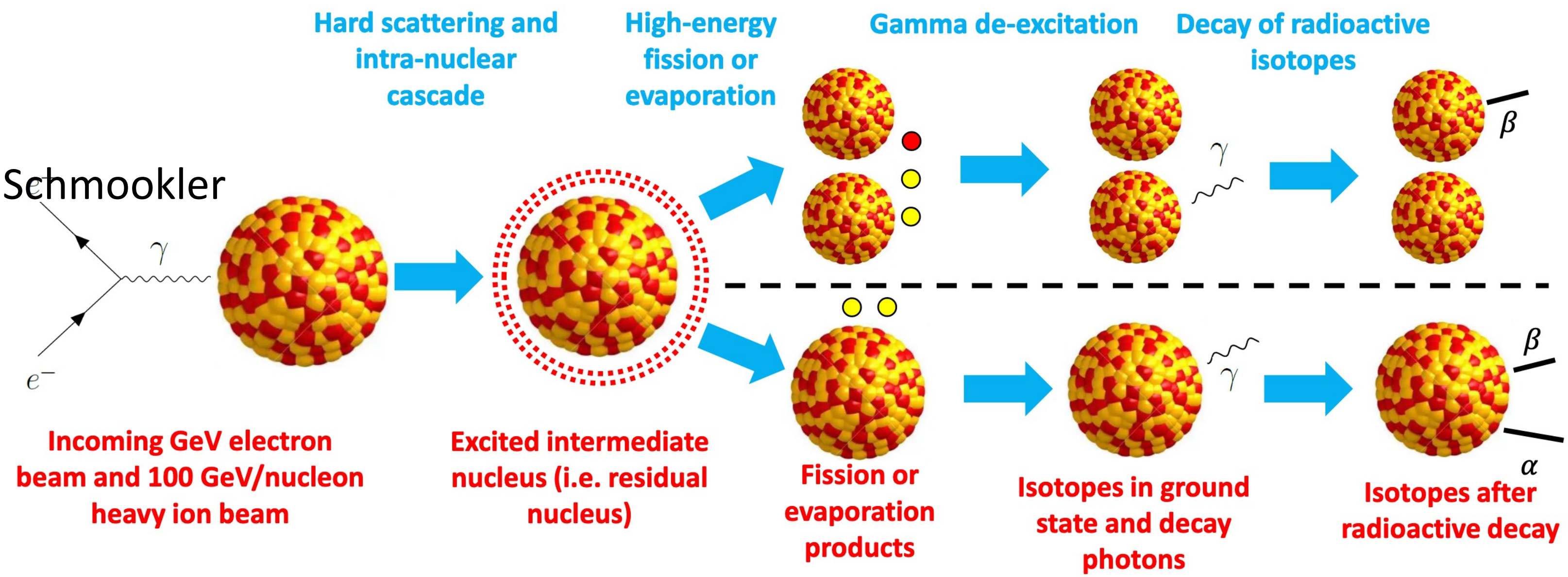




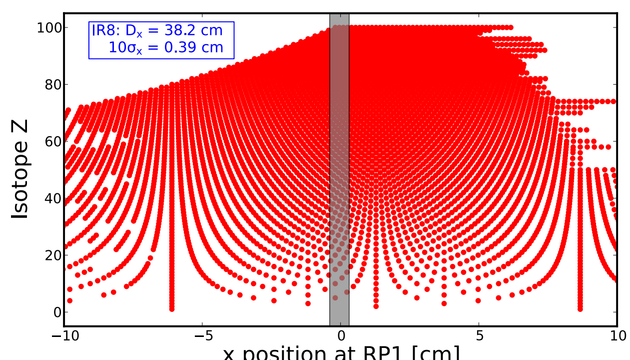
- Z information on fragments (in addition to A/Z)
- E.g. tagging of specific incoherent channels (1n, 1p, 2p, 1n1p…)

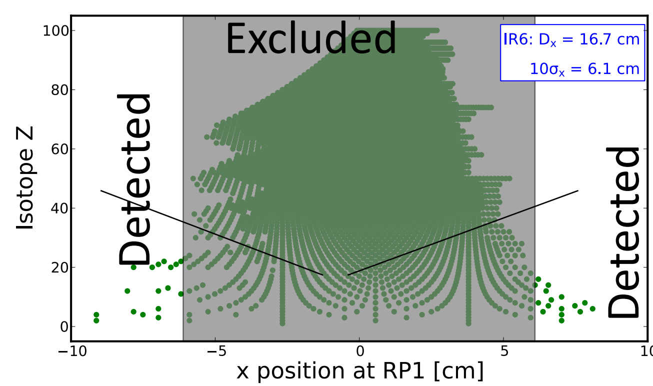
Example Physics: Isotope production at EIC

B. Schmookler



t = 0 | t = 10^{-22} s | t = 10^{-20} - 10^{-17} s | t = 10^{-14} s | t = ? – never (stable)



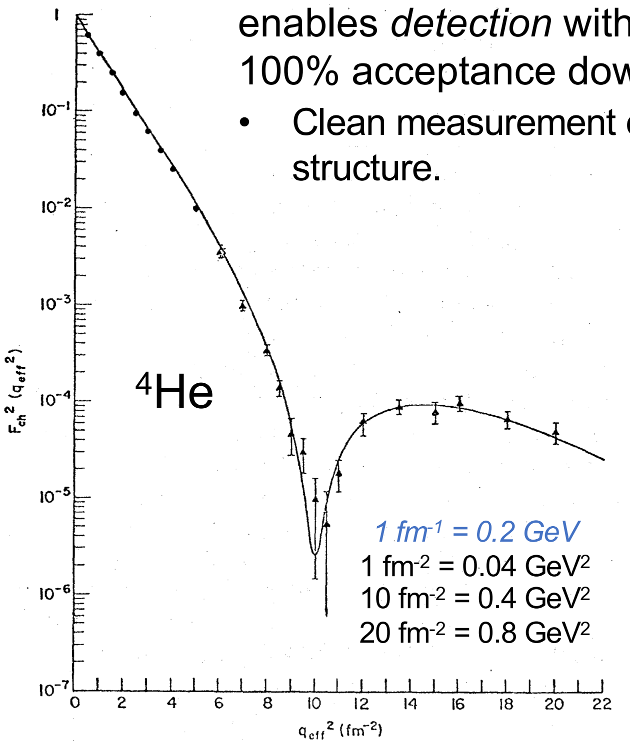


x position ~ A/Z

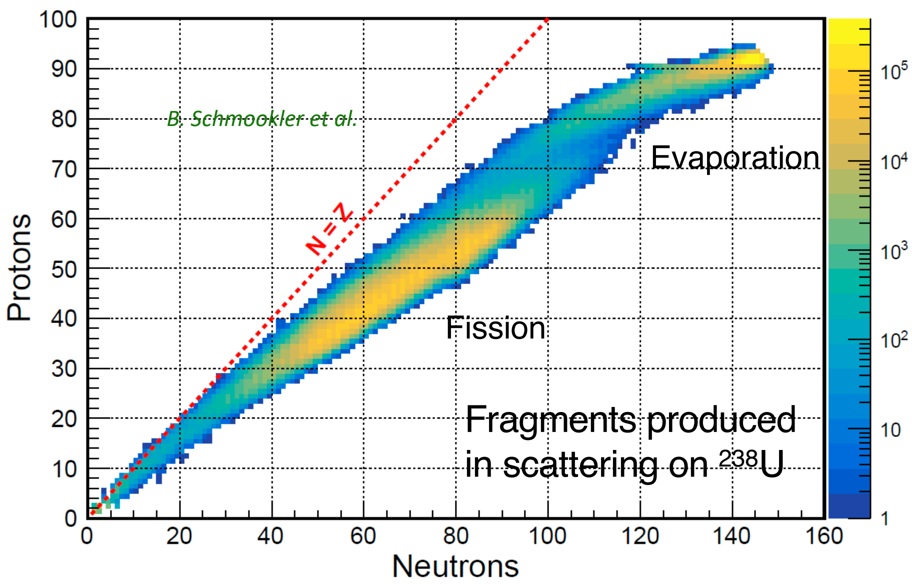
Ion fragments from ^{238}U

Example Physics: exclusive coherent scattering on nuclei

- For light nuclei, the 2nd focus enables *detection* with close to 100% acceptance down to $p_T = 0$.
  - Clean measurement of 3D structure.

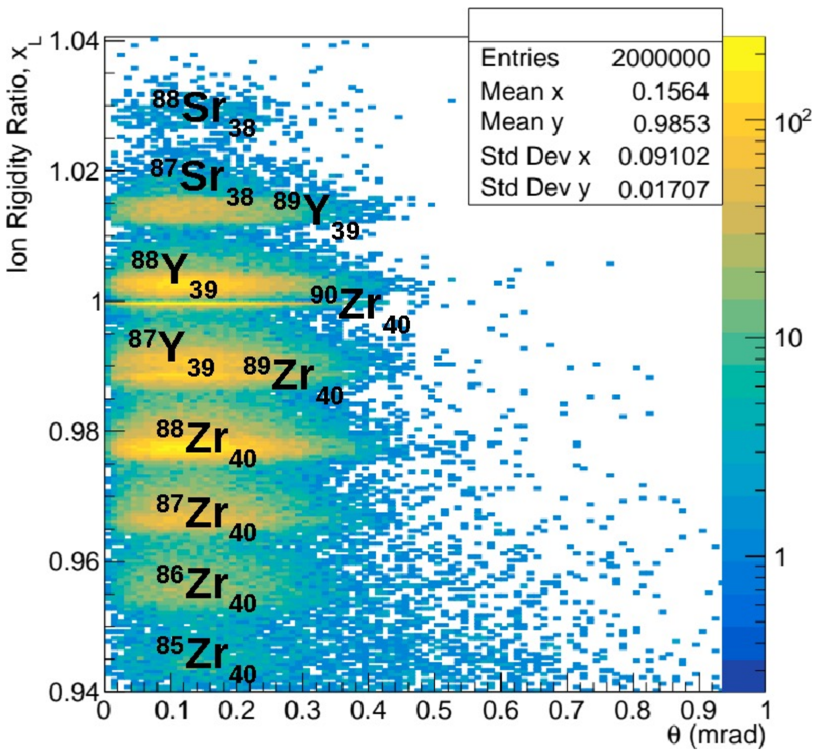


- For heavier nuclei, incoherent events can be suppressed with a high efficiency by detecting the fragments (including neutrons and photons) from the breakup.

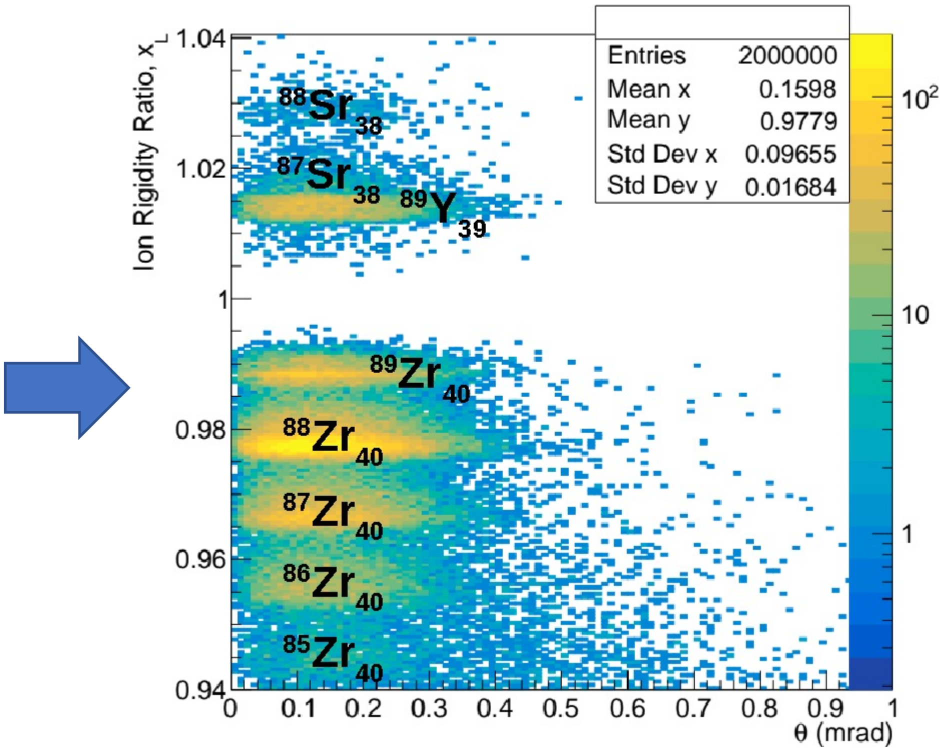


Example: A-1 tagging with a 2nd focus using a 90Zr beam

arxiv:2208.14575



generated (BeAGLE)

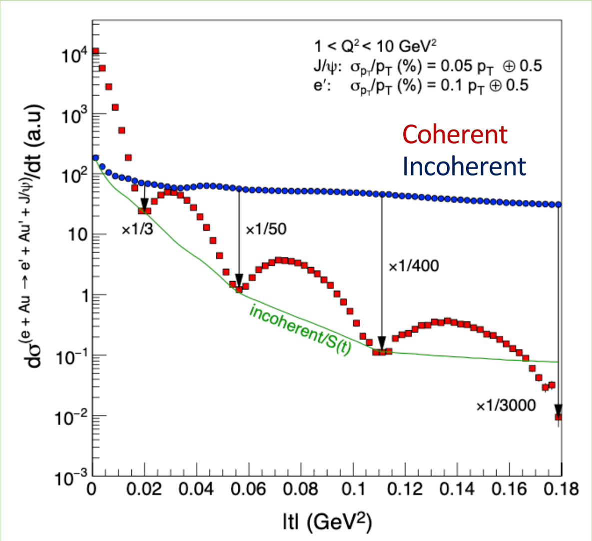


detected (Geant)

Example: vetoing breakup in coherent using a 2nd focus

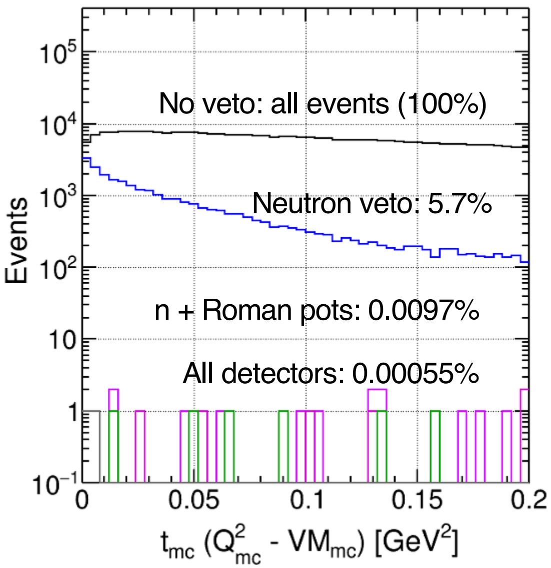
Jihee Kim

Reference from EIC YR p.352



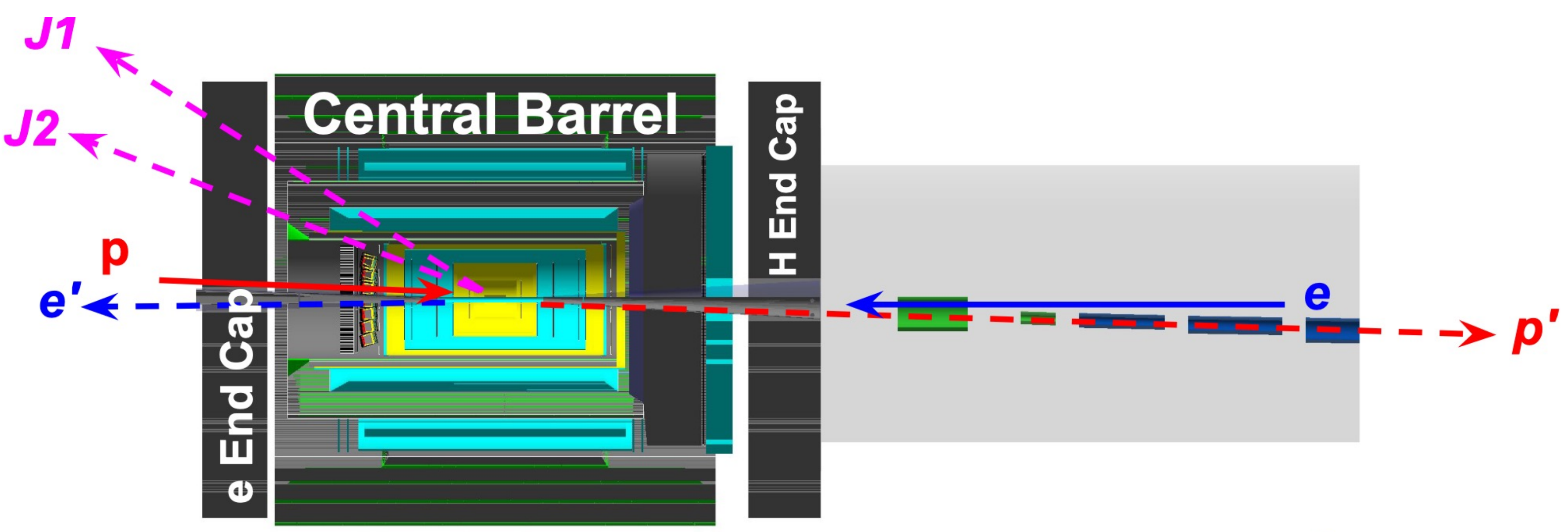
At the third diffractive minimum, a rejection factor for incoherent event better than 400:1 (0.0025% inefficiency) must be achieved

Veto inefficiency for incoherent events



Fragment detection using the Roman pots at the 2nd focus provides a stronger veto at larger values of t.

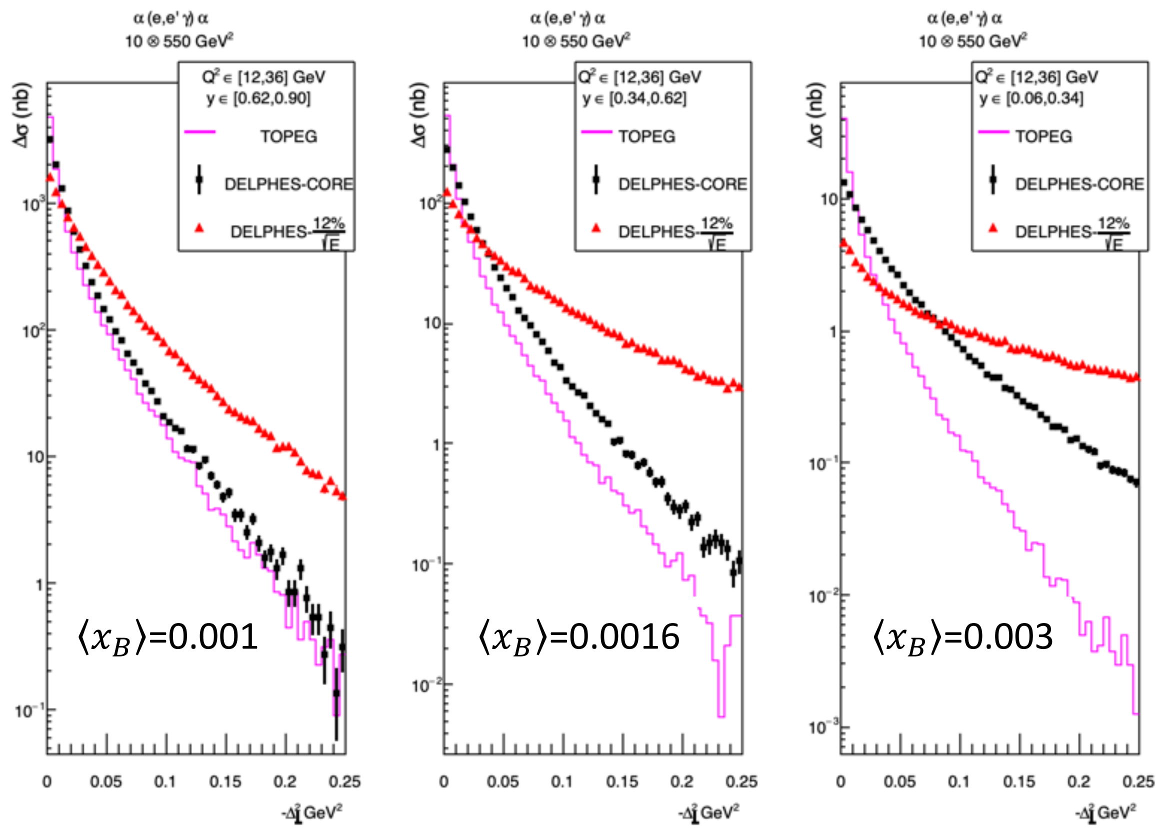
Example: Diffractive dijects to access gluon GTMDs



- Second focus important for proton acceptance

High Resolution ECAL could help DVCS →Complimentarity

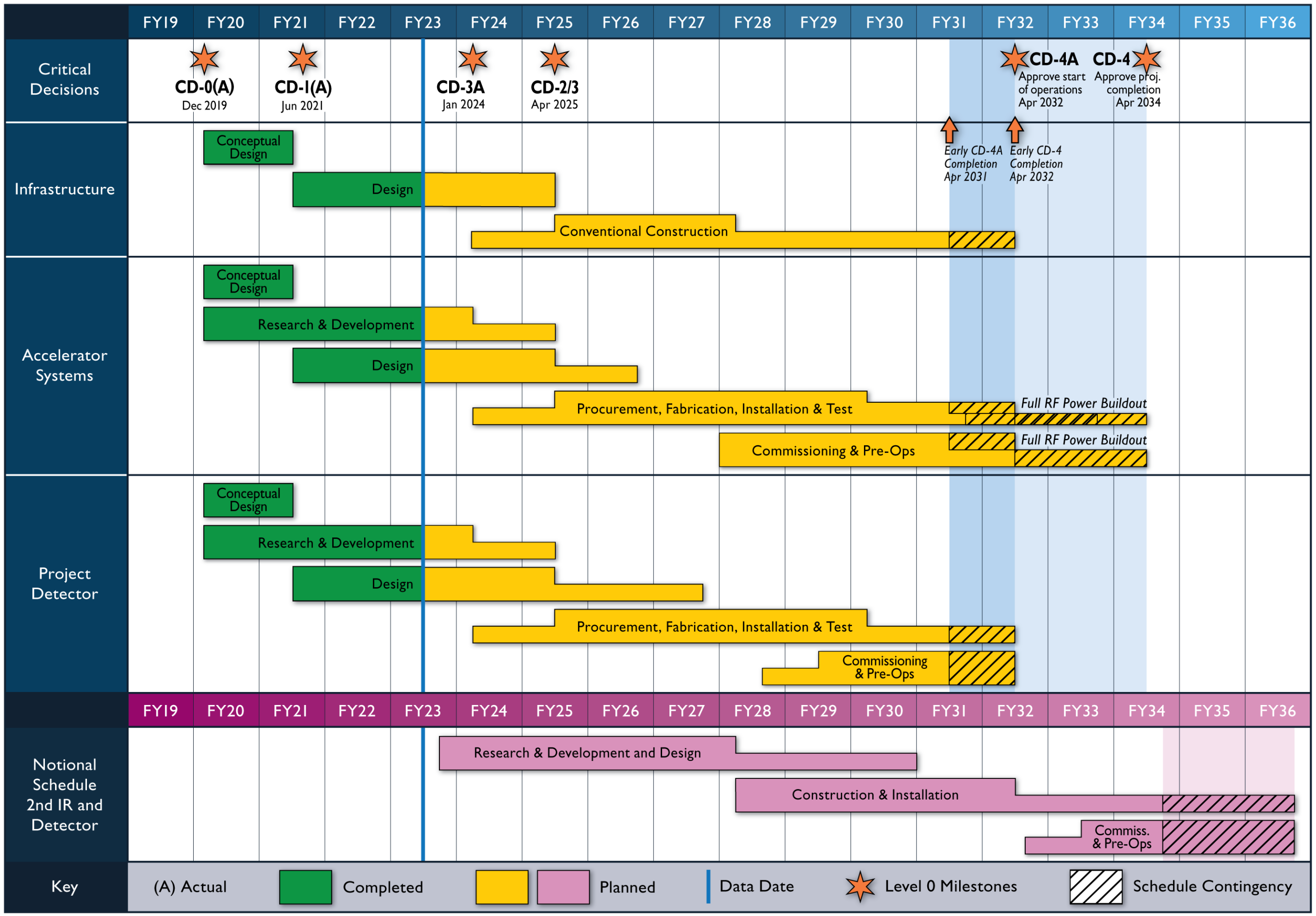
- α(e,e'γ)α:
  - (10 GeV)x(137.5 GeV/u)
  - $Q^2 \in [12,36]$ GeV^2
  - Orsay-Perugia (TOPEG) Generator
  - $PbWO_4$: $1\% \oplus \frac{2\%}{\sqrt{E}} \oplus \frac{1\%}{E}$
  - EMCal: $\frac{12\%}{\sqrt{E}}$
- Bin Migration grows with x_B and strongly depends on EMCal resolution.



Charles Hyde

Reference schedule for a 2nd IR and Detector

Jim Yeck, EIC 2nd detector WS, May 2023



Second detector

Summary and Outlook

- A second detector at the EIC has broad community support
- Complementarity and cross-check with first detector
- New physics opportunities enabled by high-dispersion 2nd focus
  - Exclusive processes
  - Isotopes
  - …
- Areas of complementarity with 1st detector based on instrumentation choices
  - Muon Detection
  - ECAL
  - medium-low Q^2 acceptance
  - ..
- Strawman detector design based on solenoid with $2-3\,T$ field and KLM in flux return
- Existing fast simulations and evolving DD4HEP (IP8+FF, KLM,..) simulations basis for upcoming physics studies and concretization of detector concept
- All interested are welcome to join!

General support

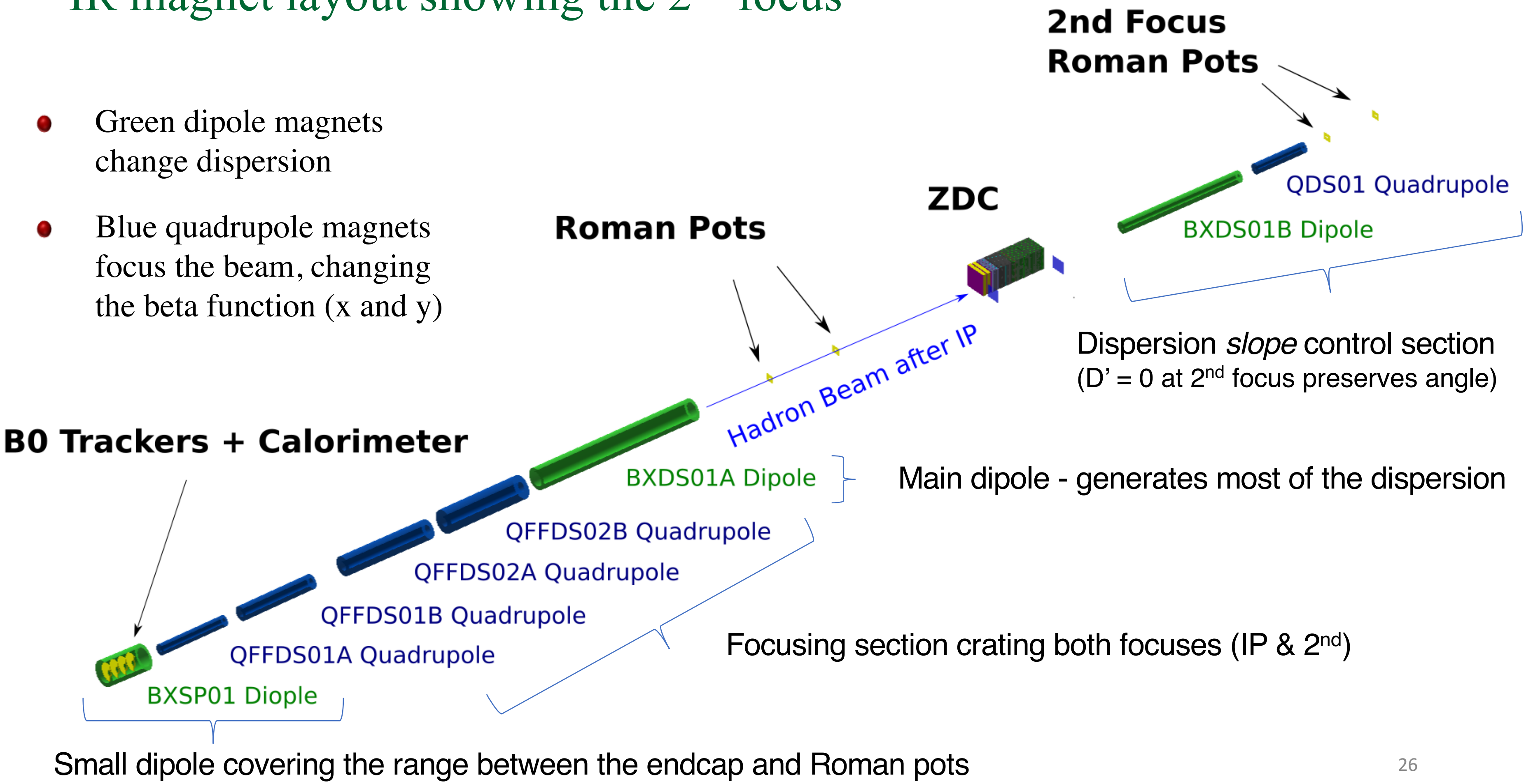
- EICUG can support 2 dets
- Complimentarity
- Cross-check
- Technologies

EICUG structure/procedure

DOE long range plan, activities

IR magnet layout showing the 2^{nd} focus

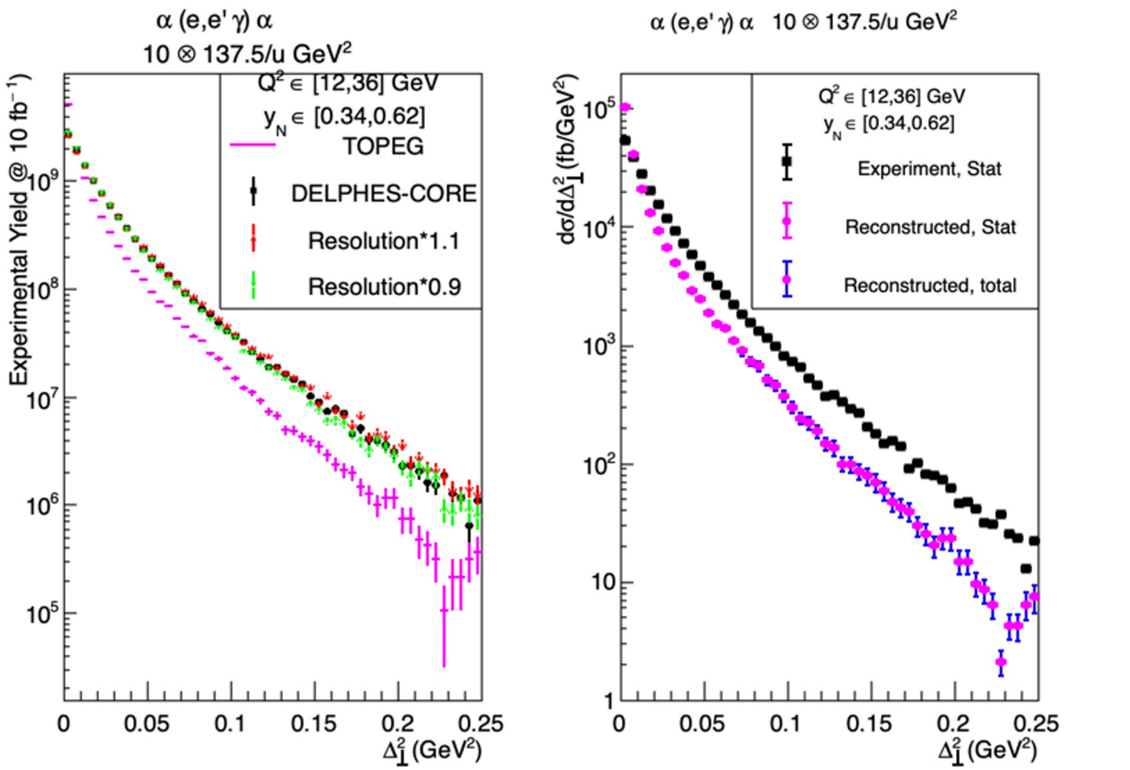
- Green dipole magnets change dispersion
- Blue quadrupole magnets focus the beam, changing the beta function (x and y)



Coherent DVCS on light nuclei. Unfolding the Bin Migration

TOPEG event generator
DELPHES FastMC

- Systematic uncertainty in reconstructed cross section estimated by varying $PbWO_4$ resolution event-by-event ±10%
- Error bars from uncertainty of bin-migration remain small.



Golden Channels Strawman from 1st meeting

CHANNEL	PHYSICS	DETECTOR II OPPORTUNITY
Diffractive dijet	Wigner Distribution	detection of forward scattered proton/nucleus + detection of low p_T particles
DVCS on nuclei	Nuclear GPDs	High resolution photon + detection of forward scattered proton/nucleus
Baryon/Charge Stopping	Origin of Baryon # in QCD	PID and detection for low p_T pi/K/p
F_2 at low x and Q^2	Probes transition from partonic to color dipole regime	Maximize Q^2 tagger down to 0.1 GeV and integrate into IR.
Coherent VM Production	Nuclear shadowing and saturation	High resolution tracking for precision t reconstruction

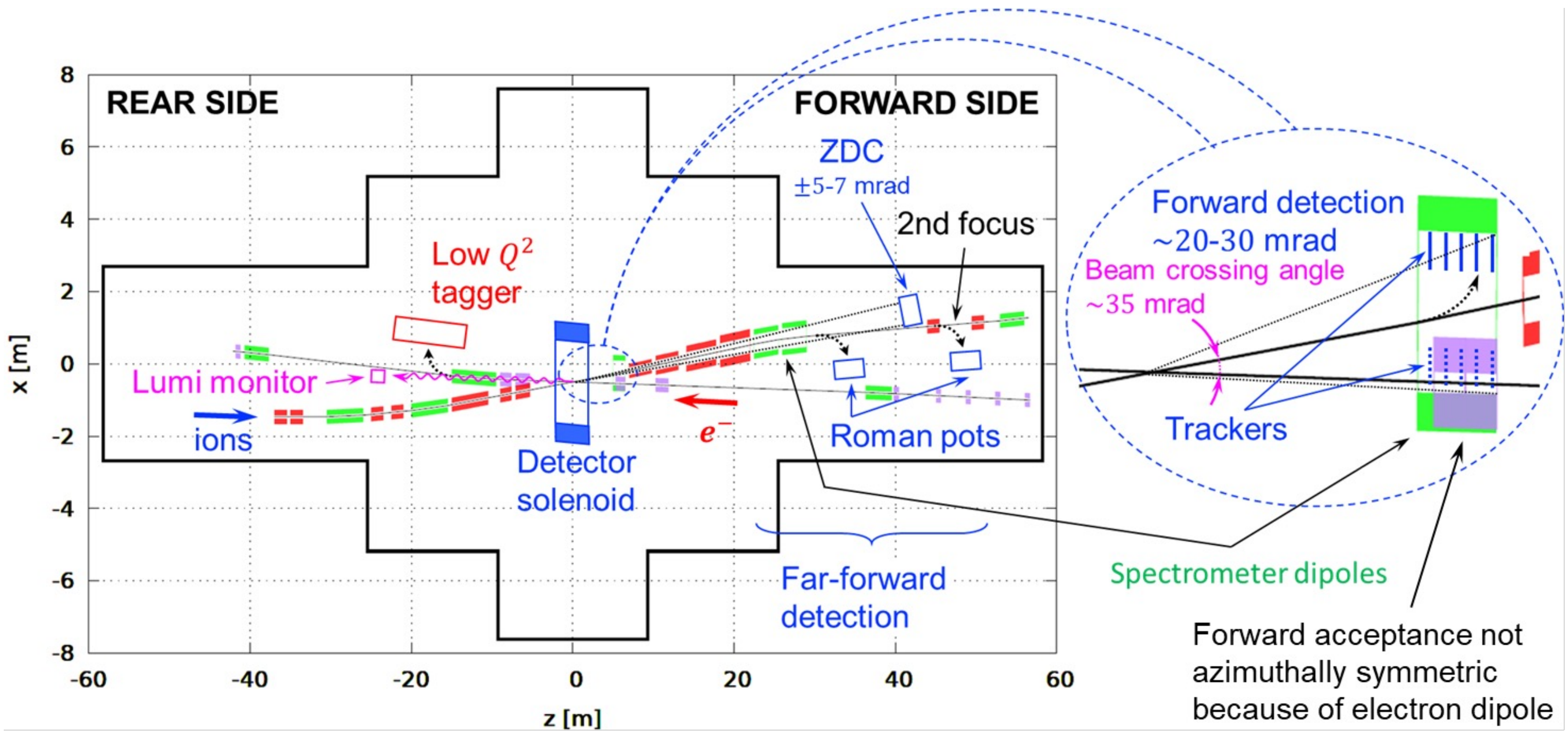
R Fatemi

Some measurements at a 2nd Detector

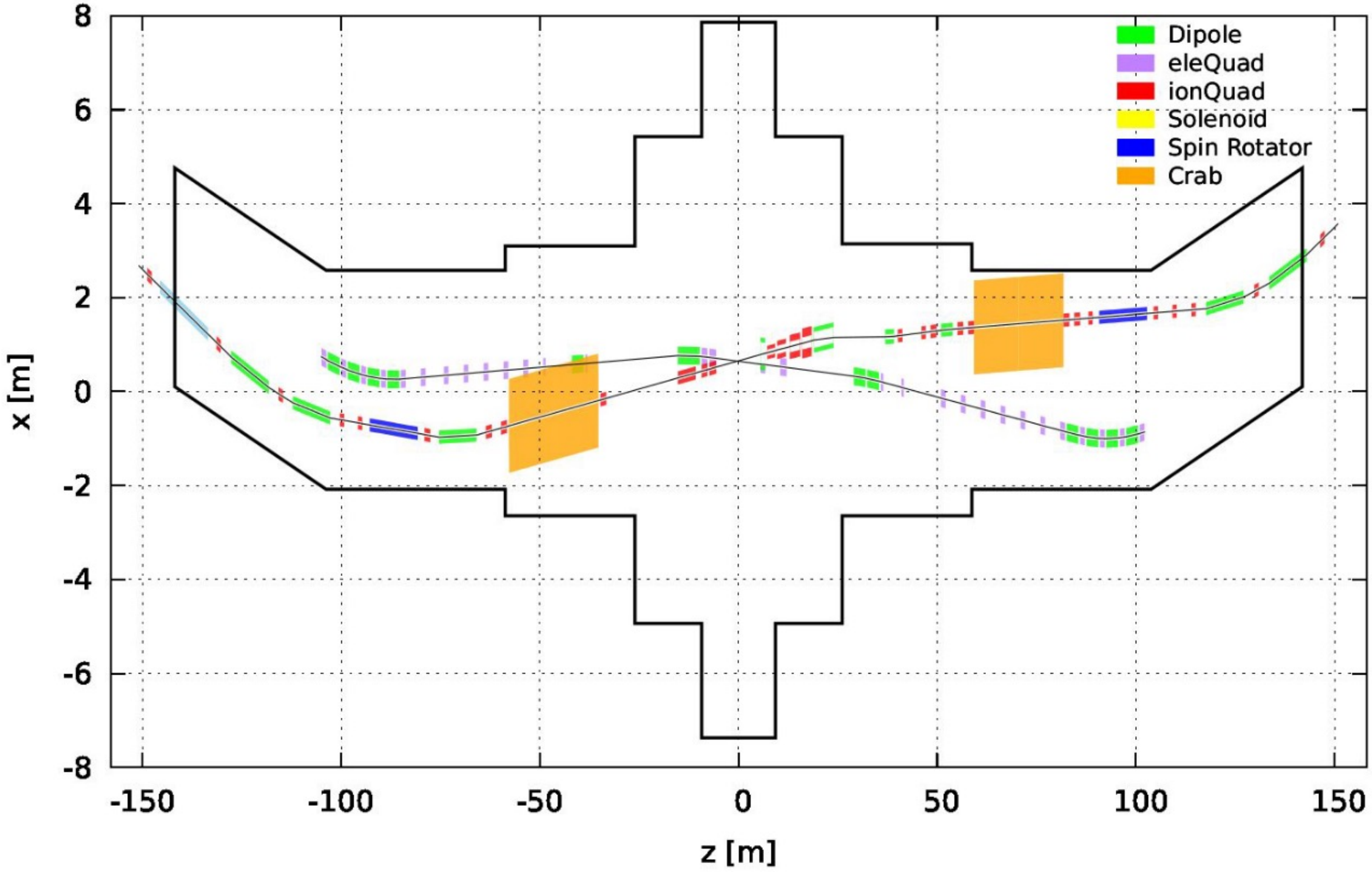
- Dijets with forward tagging
- Nucleon stuff
- Low Q2 tagger
- Incoherent diffraction
- Exotic isotopes

- EXTENDED COVERAGE for precision electromagnetic calorimetry - important
- for DVCS on nuclei
- BACKWARD HADRONIC CALO - Low-x physics, reconstruction of current jets
- in the approach to saturation
- Exclusive reactions on nuclei with tagging leftover nucleus
- https://indico.bnl.gov/event/17693/contributions/70919/attachments/44924/75857/ExclusiveNuclei_2022-03-6_CHyde.pdf

- Strawman for golden measurements from 1st meeting


REAR SIDE
FORWARD SIDE
ZDC
±5-7 mrad
2nd focus
Low Q^2 tagger
Lumi monitor
ions
Detector solenoid
e^-
Roman pots
Far-forward detection
Forward detection
~20-30 mrad
Beam crossing angle
~35 mrad
Trackers
Spectrometer dipoles
Forward acceptance not azimuthally symmetric because of electron dipole
x [m]
z [m]
8
6
4
2
0
-2
-4
-6
-8
-60
-40
-20
0
20
40
60

Complementarity, IP



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- Shorter space for detector
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