JLEIC forward detector design

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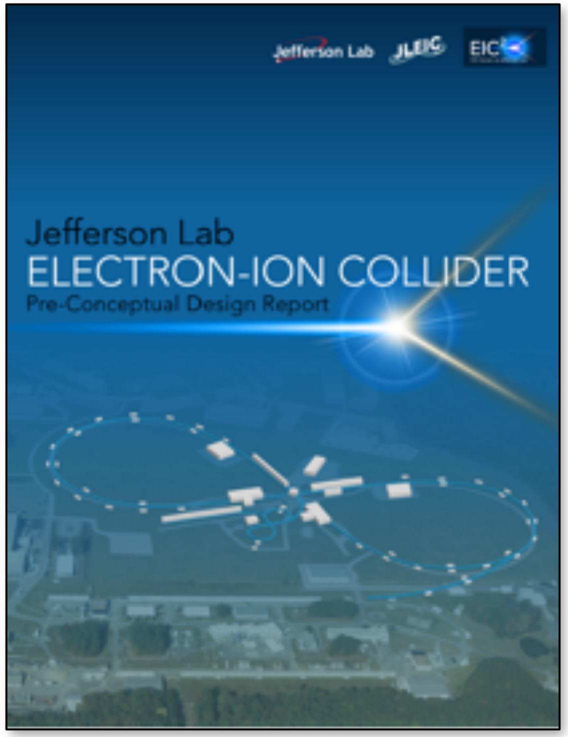
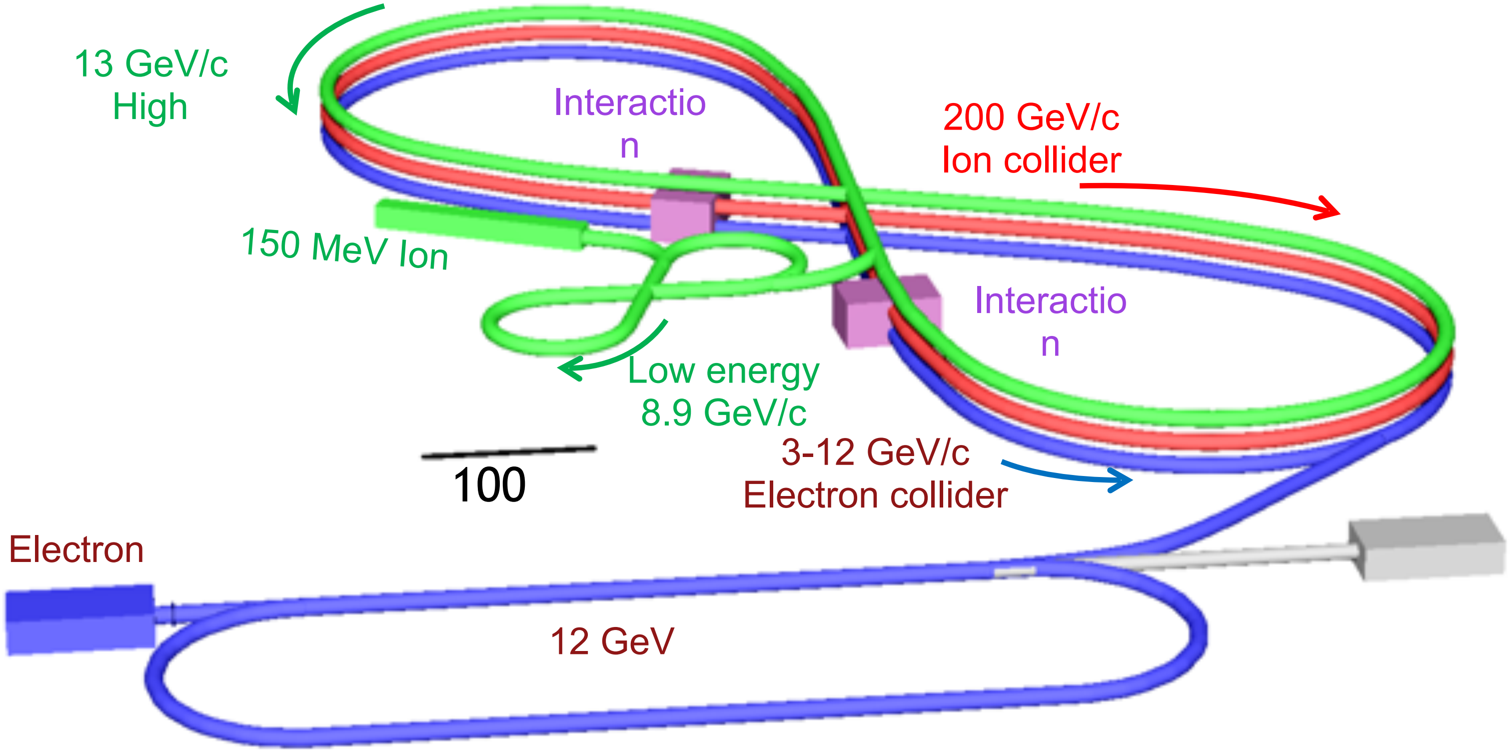
CFNS/RBRC Workshop Physics and Detector at Zero Degrees, Stony Brook, 24-26 Sep 2019

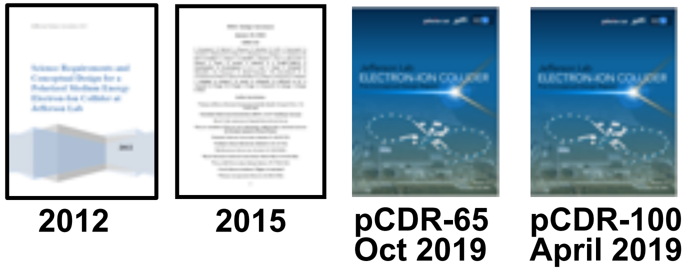
- JLEIC accelerator design 65/100 GeV
- Accelerator-detector integration
- Forward detector concept
  - Physics requirements
  - Three forward acceptance regions (dipoles + tracking detectors) integrated in IR design
  - Magnet and beam pipe design
  - Simulation tools



JLEIC: Layout

- Electron complex
  - CEBAF as full-energy injector
  - Electron collider ring: 3-12 GeV/c
- Ion complex
  - Ion source
  - SRF linac: 150 MeV for protons
  - Low Energy Booster: 8.9 GeV/c
  - High Energy Booster: 13 GeV/c
  - Ion collider ring: 200 GeV/c
- Up to two detectors at minimum background locations
- Upgradable to 140 GeV CM by doubling ion energy





JLEIC: Design concepts

- **High luminosity: High collision rate of modest-size low-emittance bunches**

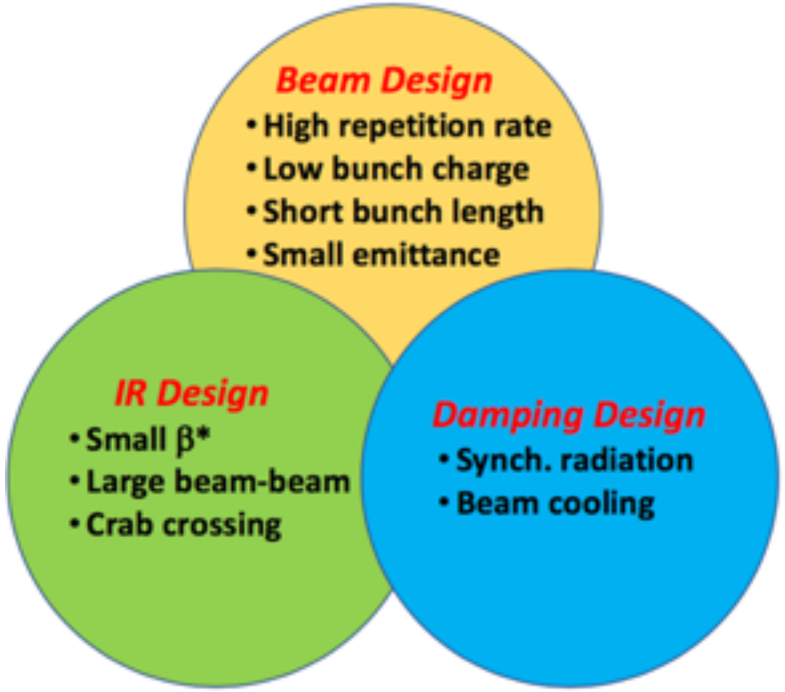
  Small beam size

  Short bunch length -> small β*

  Cooling -> small emittance

  Similar to lepton colliders such as KEK-B with L ~ 2×10^{34} cm^{-2} s^{-1}

$$L = f\frac{n_1 n_2}{4\pi\sigma_x^*\sigma_y^*} \sim f\frac{n_1 n_2}{\varepsilon\beta_y^*}$$



- **High polarization: Figure-8 ring design**

  Complete cancellation of spin precession in left/right arcs, energy-independent

  Spin easily controlled by small magnetic field for any particle species

  Polarized deuteron beams

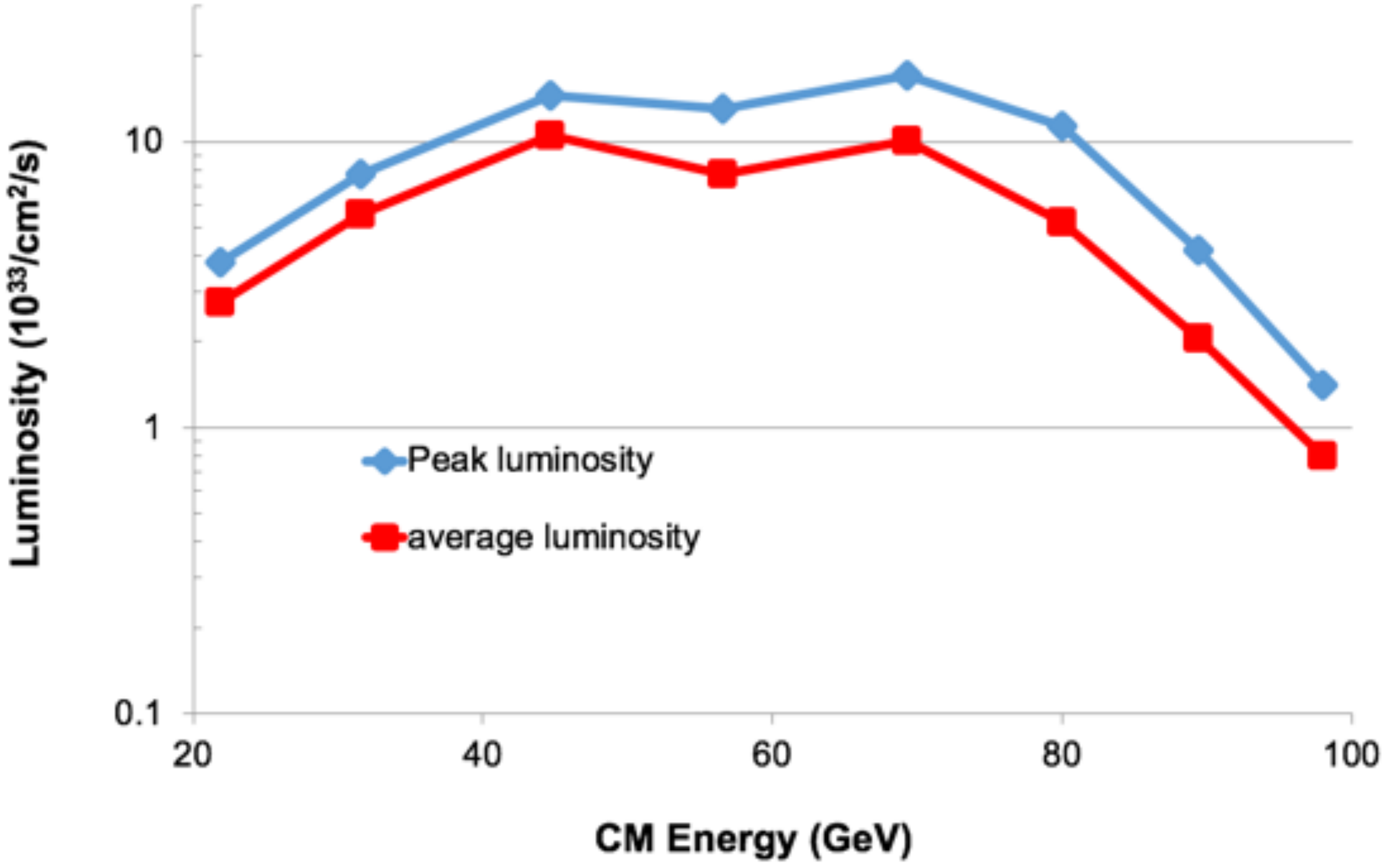
- **Full-acceptance primary detector including far-forward region**

JLEIC: Parameters and luminosity performance

CM energy	GeV	21.9		44.7		63.3		89.4		98	
		p	e	p	e	p	e	p	e	p	E
Beam energy	GeV	40	3	100	5	200	5	200	10	200	12
Collision	MHz	476		476		476/2=238		476/4=119		476/4=119	
Particles per	10^{10}	0.59	3.9	0.98	4.7	1.97	6.8	3.93	4.2	3.93	2.05
Beam current	A	0.45	3	0.75	3.5	0.75	2.58	0.75	0.8	0.75	0.39
Polarization		85%	>85%	85%	>80%	85%	>80%	85%	~80%	85%	~80%
RMS bunch length	cm	2.5	1	2.5	1	2.1	1	4	1	4	1
Norm. emitt, hori.	mm mrad	0.5	18	0.65	83	0.96	83	3.1	664	3.1	1145
Norm. emitt, vert.	mm mrad	0.2	3.6	0.13	16.6	0.25	16.6	1.5	133	1.5	229
Horizontal β*	cm	8	30	8	5.72	21	11.2	21	9.1	21	6.6
Vertical β*	cm	1.3	9.8	1.3	0.93	1.6	1.1	1.6	1.65	1.6	1.15
Beam-beam, hori.		0.015	0.12	0.015	0.045	0.015	0.09	0.003	0.02	0.0013	0.014
Beam-beam, vert.		0.01	0.15	0.013	0.041	0.008	0.065	0.001	0.02	0.0005	0.012
Laslett tune-shift		0.055	small	0.018	small	0.008	Small	0.0014	Small	0.0014	Small
Hour-glass (HG)		0.85		0.73		0.82		0.73		0.67	
Peak lumi., w/ HG	$10^{33}/cm^2s$	3.2		14.7		15.5		1.9		0.86	
Average lumi.*	$10^{33}/cm^2s$	2.3		10.6		9.3		1.6		0.71	

* Average luminosity was calculated assuming a one or two hour proton beam store without or with high energy bunched beam electron cooling plus 5 min beam formation time (mainly due to detector overhead), and a 75% duty factor of machine

JLEIC: Luminosity performance

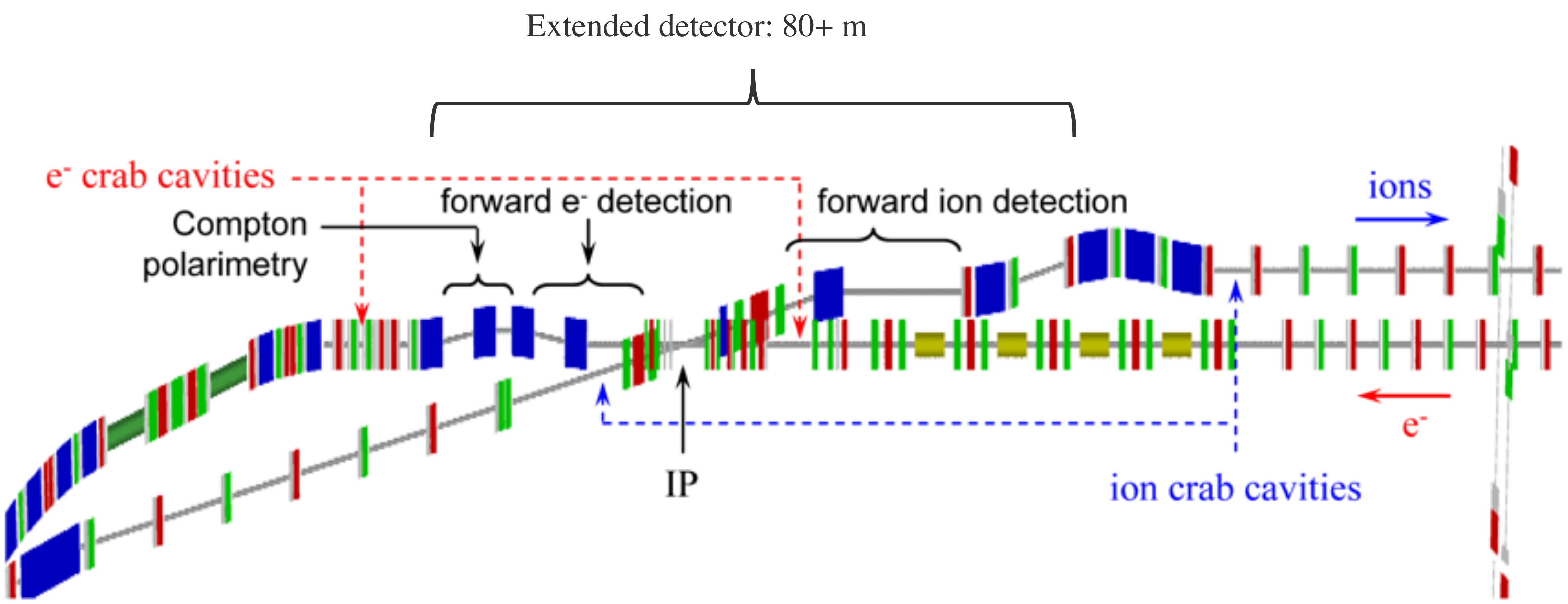


100 fb^{-1}/year

Reference: At HERA ~ 1 fb^{-1} after 10 years

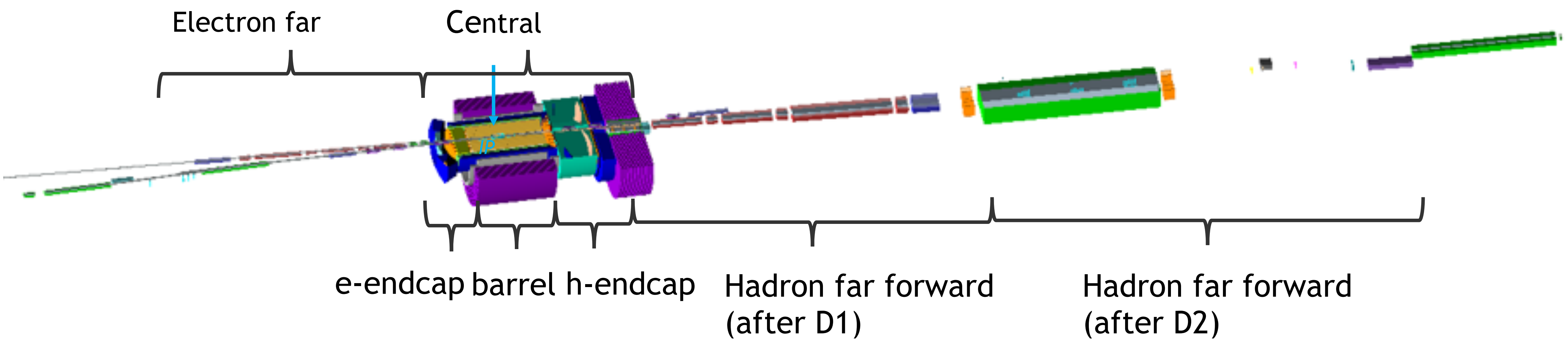
CM Energy	Main luminosity limitation in each scenario
low	space charge
medium	beam-beam
high	synchrotron radiation

Detectors: Accelerator-detector integration



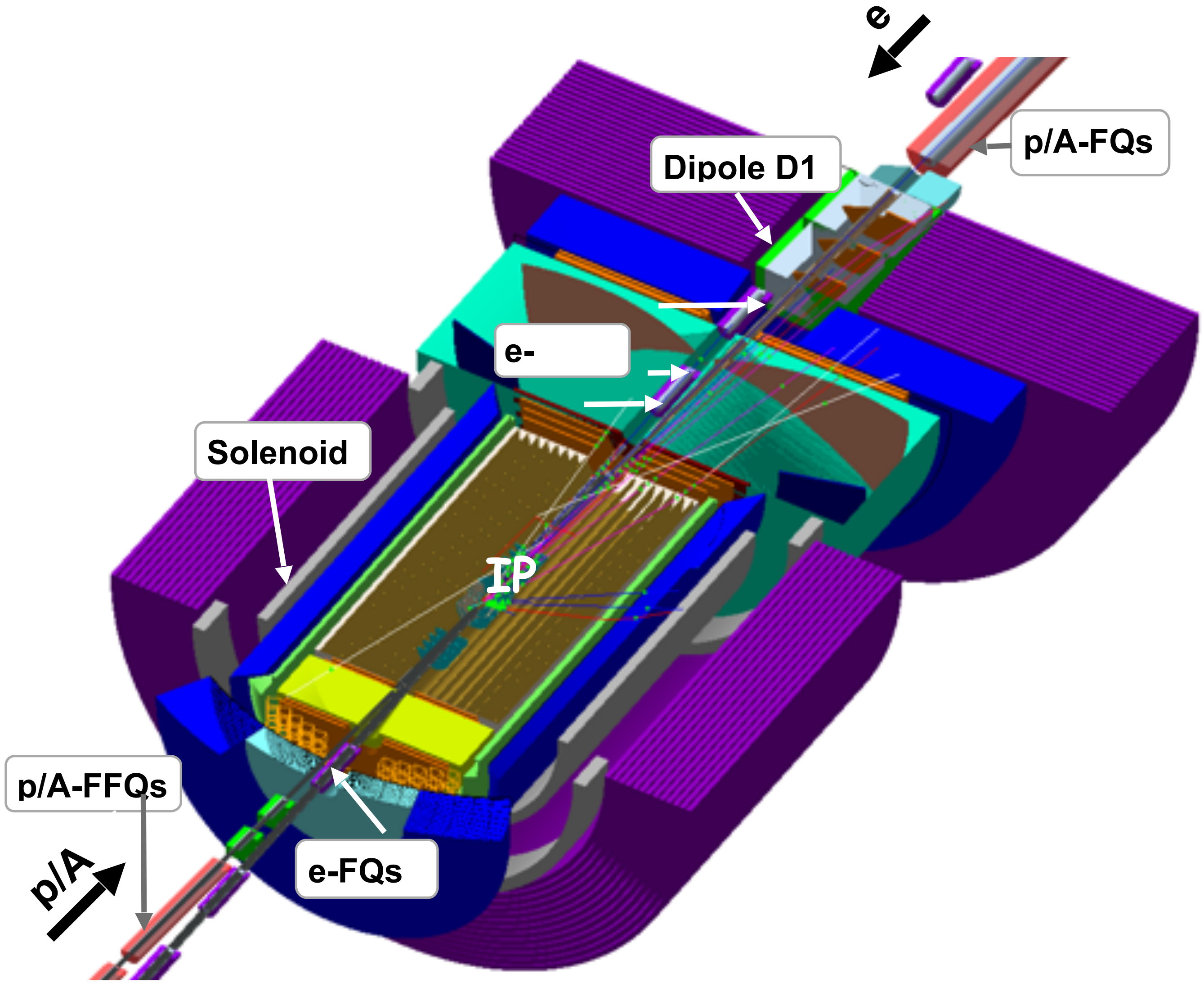
- IR and detector design: Schematic

Detectors: Accelerator-detector integration



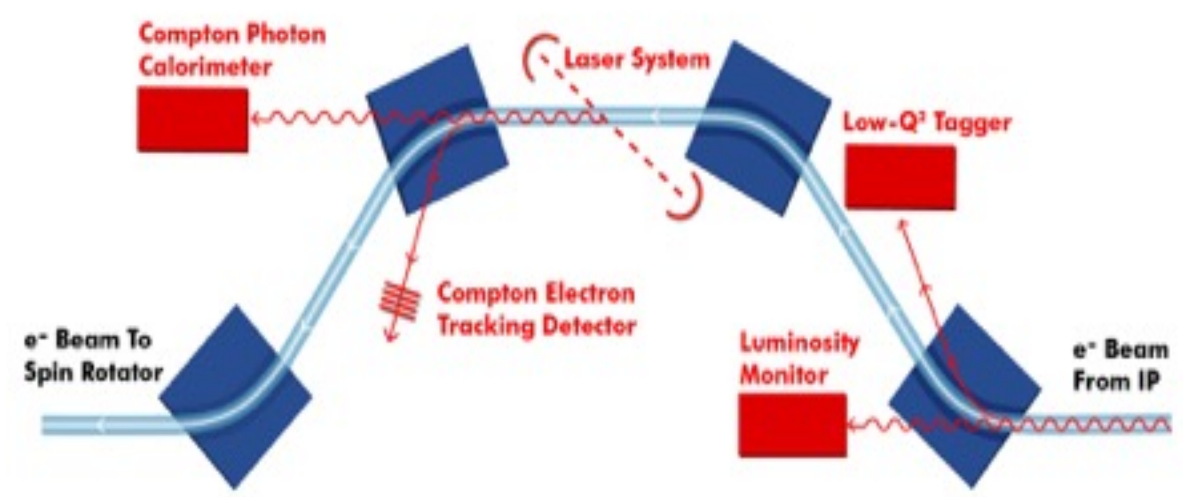
- IR and detector design: Physical layout (GEANT4)

Detectors: Central detector



- **General-purpose detector**
  - Asymmetric design due to beam energies
  - Solenoid 2 T, length ~4 m, radius ~1.6 m
  - IP shift 40 cm
  - Coverage ~4π, barrel $-1.3 < \eta < 1.5$ (or $150 < \theta < 25$), endcap $\eta < 3.5$
- **Central tracking**
  - Several options: Straw tubes, drift chambers, all Si
  - Momentum resolution below ~few% required
- **Vertex detection**
  - Resolution < 25 μm
- **EM calorimetry**
  - High performance needed in electron endcap, small energy loss of scattered electron
  - High granularity in forward p/A direction
- **Particle identification e, μ, π, K, p**
  - mRICH, DIRC, dualRICH

Detectors: Far-forward electron

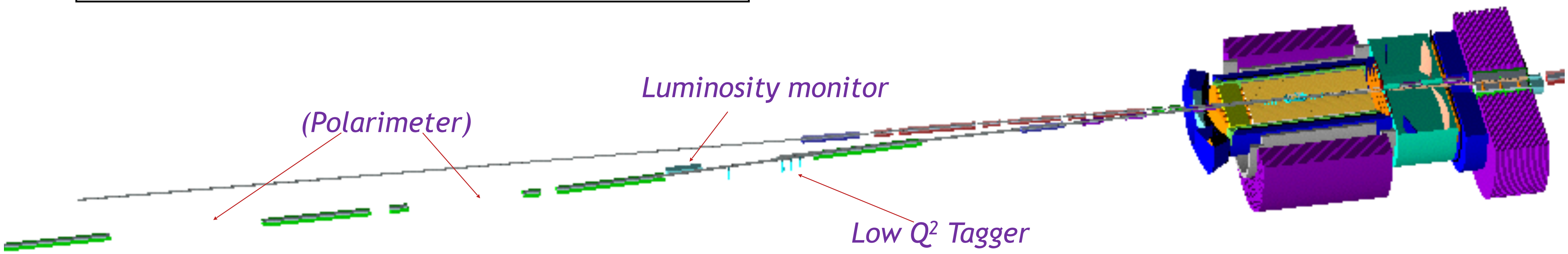


Forward electron chicane
First two dipoles compensate each other
Measurement of both Compton photons and electrons
Minimum background location, ample space

- **Luminosity monitor**
- **Low-Q^2 tagger for photo production**
- **Electron polarization measurement**

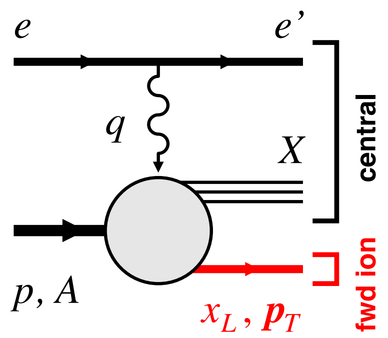
Setup similar to JLab Hall A/C chicane, achieves ~1% electron polarization measurement

EIC simulations ongoing [D. Gaskell, J. Hoskins]
Collaboration with EICUG Polarimetry WG



Forward ion: Physics requirements

Processes	Beam -> Fwd	Rigidity Fwd/	Coverage	Resolution (Charged)	Neutrals	Comments
Exclusive & diffractive scattering on proton	p -> p, n	1	pT = [0, ~2 GeV] xL = [~0.5, ~0.999] 1-xL = [~1E-3, ~0.3]	ΔpT ~ 50 MeV ΔxL/xL << 0.1 Δ(1-xL)/(1-xL) < 0.1	n Λ, Σ0	Inelastic diffraction physics & background
Coherent scattering on light nuclei	A -> A (A = D, He)	1	pT = [0, ~200 MeV] 1-xL = [~1E-3, ~1E-1]	ΔpT ~ 10-20 MeV Δ(1-xL)/(1-xL) < 0.1	none	Momentum spread in ion beam significant
Spectator tagging in deuteron	D -> p (n)	1/2	pT = [0, ~500 MeV] xL = [~0.25, ~0.75]	ΔpT ~ 10-20 MeV ΔxL/xL << 0.1	(n)	Momentum spread in ion beam significant
Breakup of light and heavy nuclei	A -> p, n, A-1	various	pT = [0, ~500 MeV] xL various	?	multiple n	Veto detection for heavy nuclei

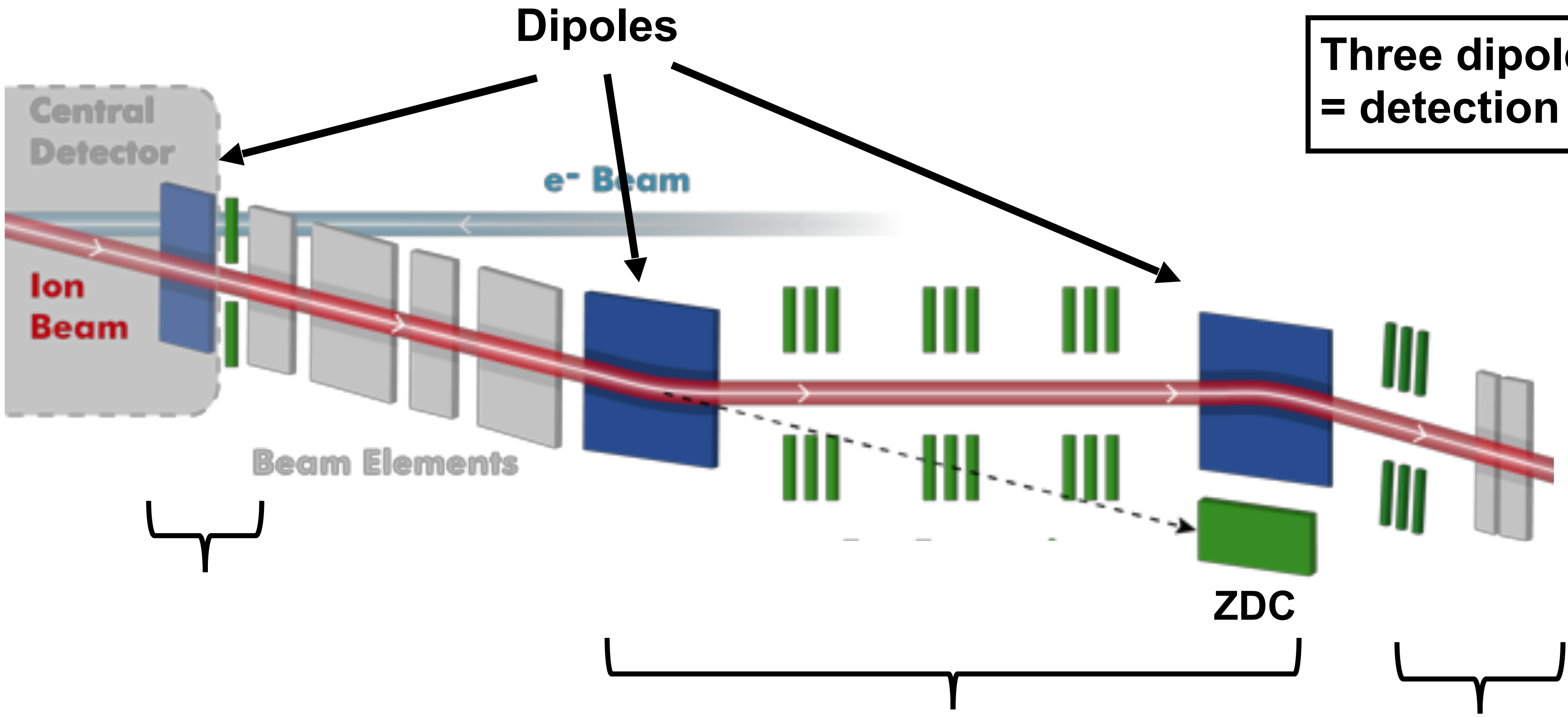


xL — longitudinal momentum fraction with respect to proton/ion beam

pT — transverse momentum -> angle θ

[Related to physics variables in photon-ion collinear frame]

Forward ion: Concept and regions



Three dipoles + instruments = detection regions

P. Nadel-Turonski, Ch. Hyde et al.

Region 1
High-θ, high-pT fragments, e.g. nucleon fragmentation

Small dipole instrumented in hadron endcap, covering angles up to 3 deg

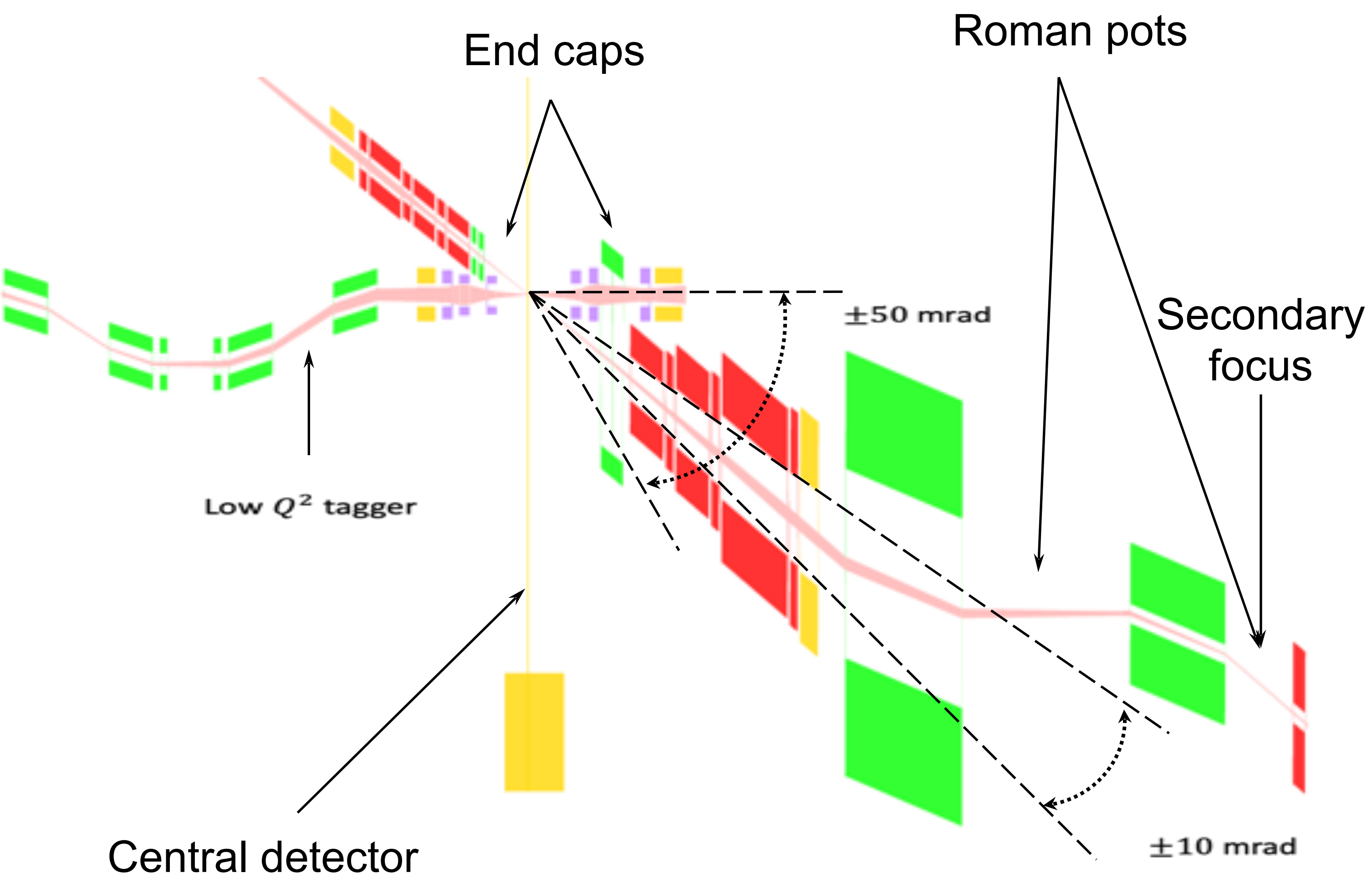
Region 2
Decay products of Λ, Σ
High-pT diffractive protons
Spectator protons in D

Neutrons: 10 mrad cone for neutrons passing through FFQ

Region 3
Low-pT diffractive protons
D, He in coherent processes

Roman Pots
Secondary focus of ion beam

Forward ion: Physical design



Multi-dimensional optimization

- Different beam energies
- Various physics processes
- Crossing angle
- Geometric size of magnets and infrastructure
- Bore radius of FFQs
- Space for detectors

⬇

- Crossing angle 50 mrad
- Large bore 10 mrad
- Dipole 1 opening 50 mrad

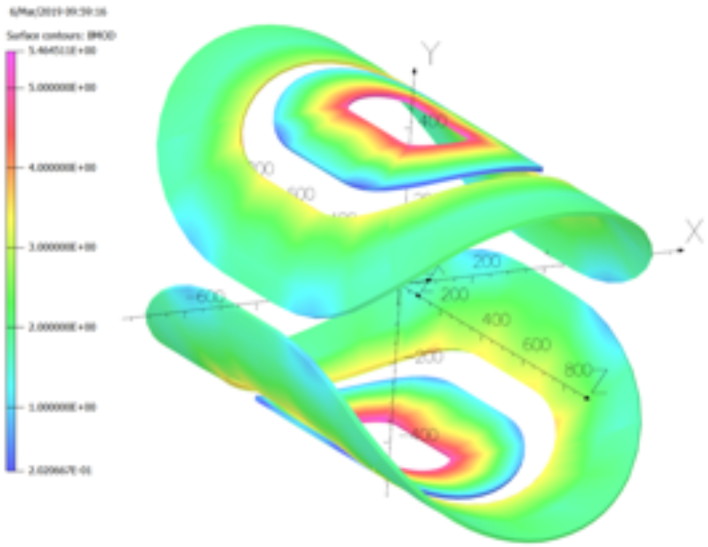
Forward ion: Dipole 1 and tracking elements

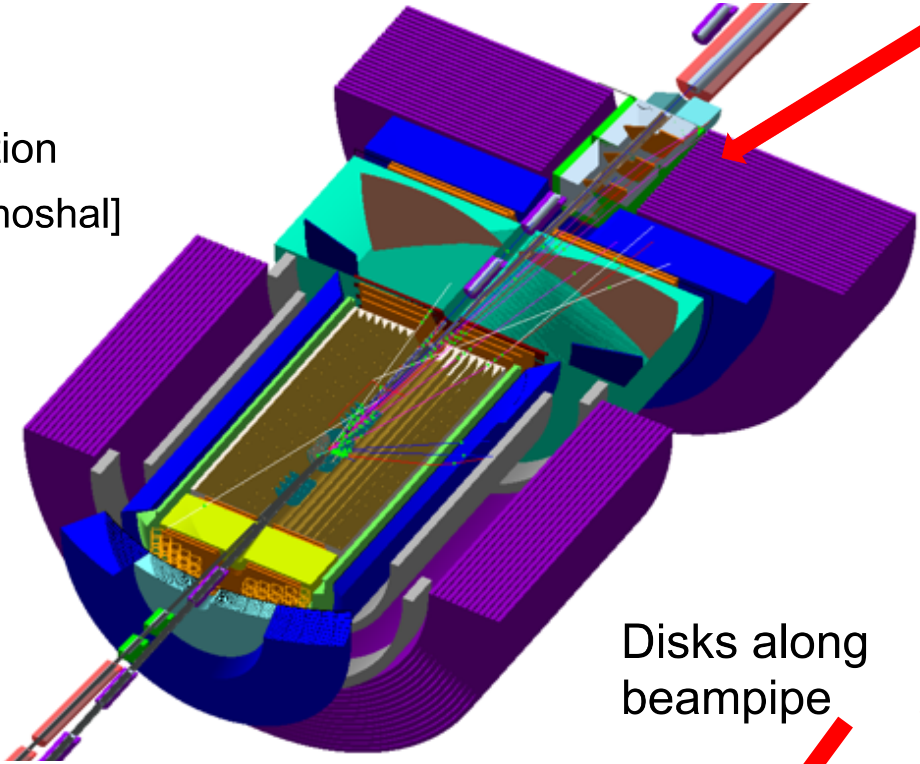
- Integrated in central detector, covers ~3 deg
- Si discs along beam pipe for tracking resolution
- Preliminary magnet design [Renuka Rajput Ghoshal]

  Length ~ 1.5 m

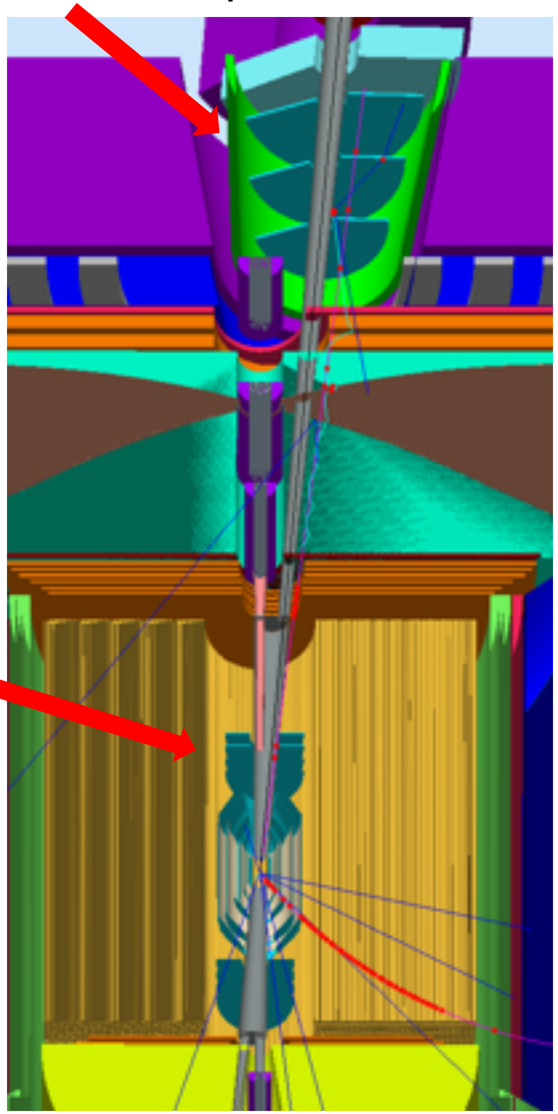
  By ~ 2 T x 0.75 m

  Bx ~ 0.22 T x 0.75 m

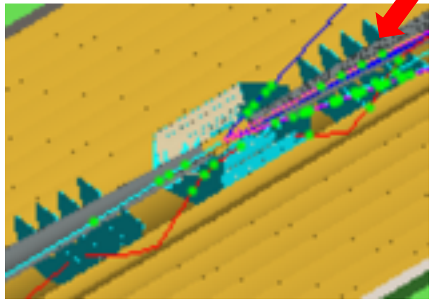




Forward Dipole 1



Disks along beampipe



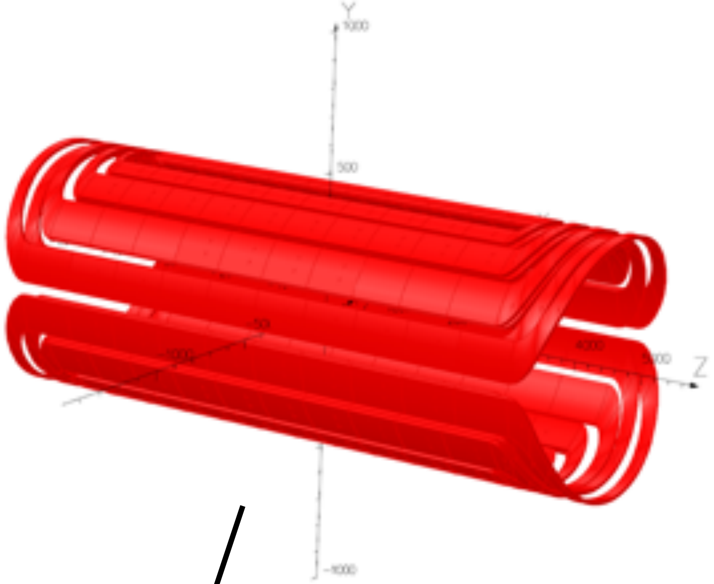
Forward ion: Dipole 2 and tracking elements

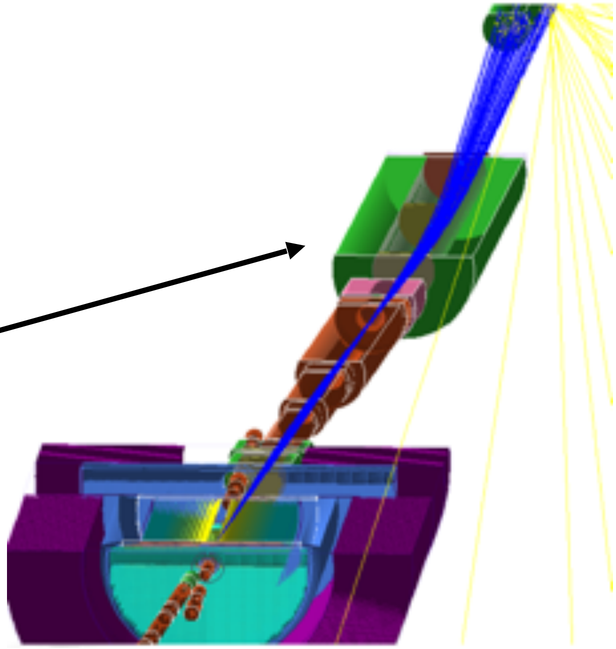
- Detection of high pT diffractive protons, rigidity < 1 spectators
- Defines acceptance for neutral particles
- Iron-free core ~10 mrad
- Preliminary magnet design

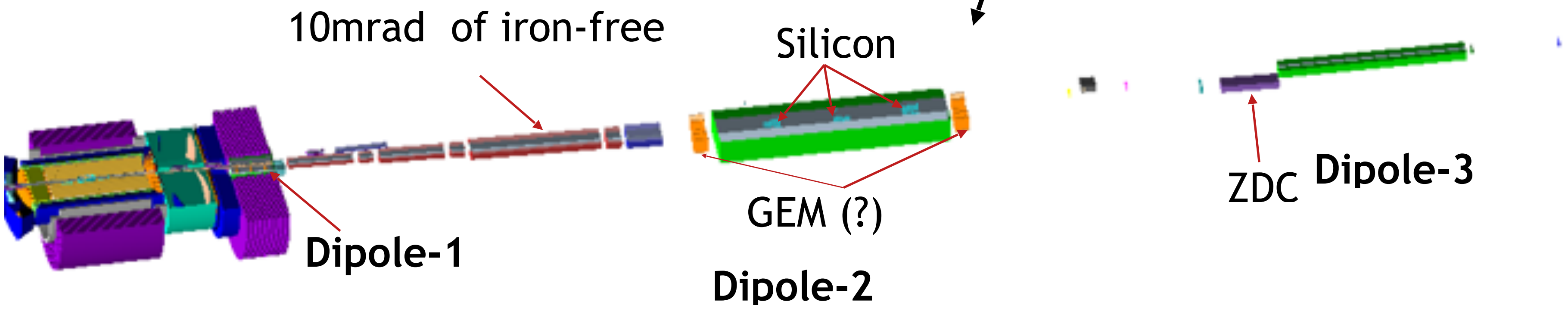
  Length ~ 8 m, field ~ 4 T

  Cold magnet, detectors inside

- Simulations in progress: Transport through all beam elements (g4beamline), beam pipe







Forward ion: Neutron detection

- Example: Neutron produced in high-pT diffractive process on deuteron (BeAGLE)

- Various proposals for ZDC technology. High-granularity (fast silicon) calorimeter concept developed by Argonne group. Advantages: Particle flow calorimeter, charge/neutral rejection

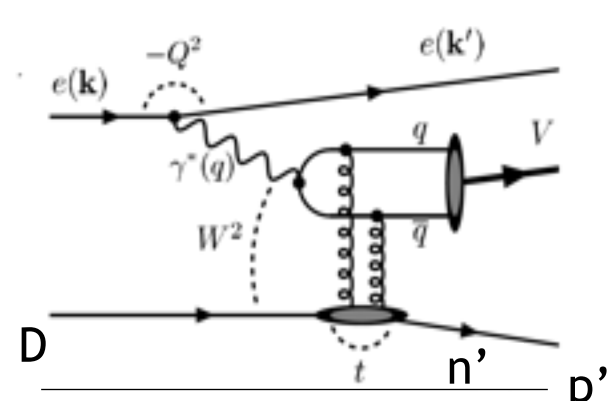
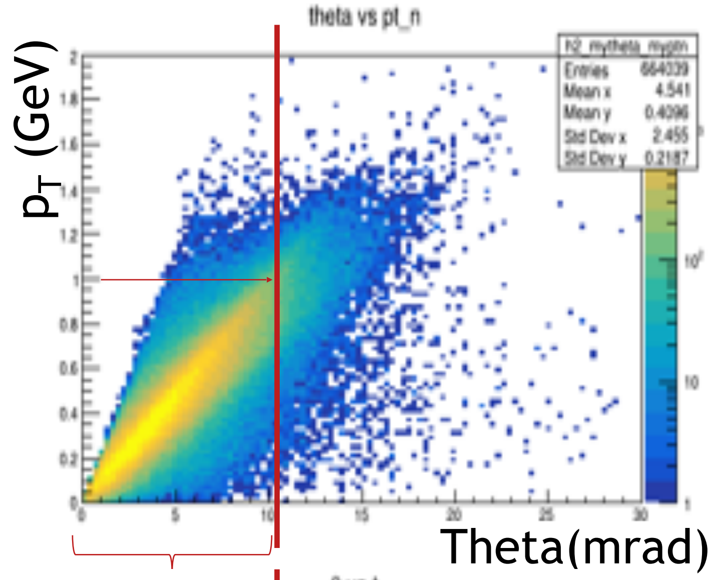
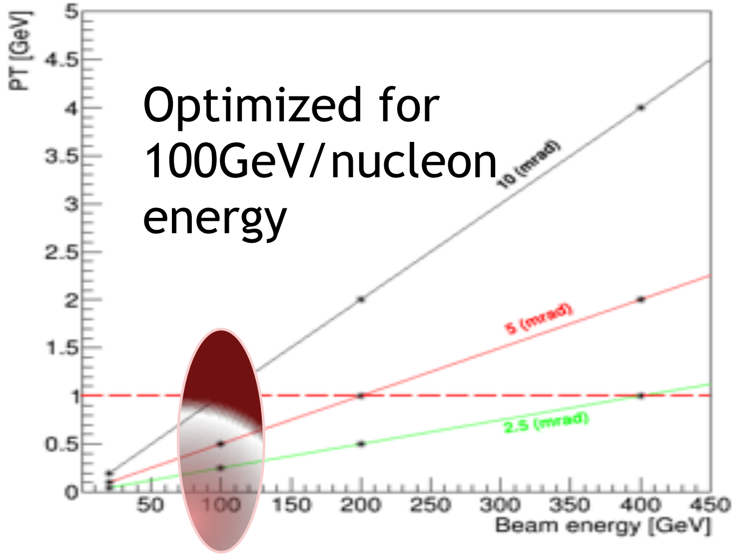
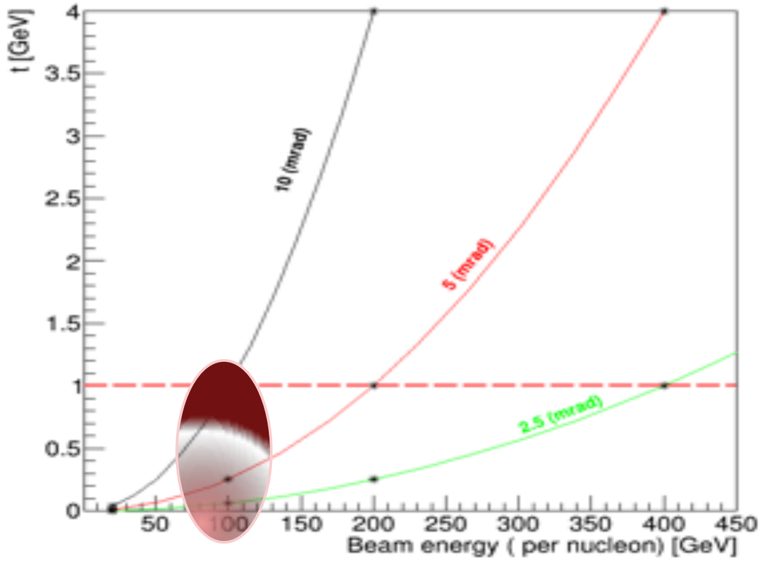
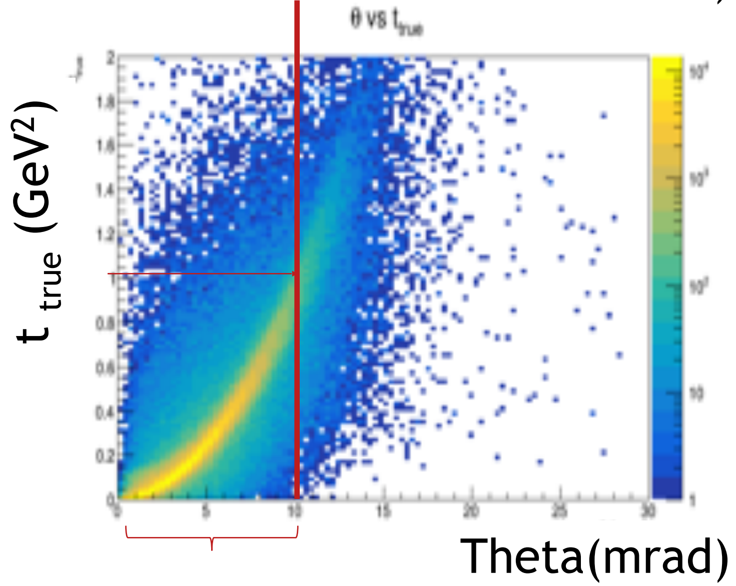


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.



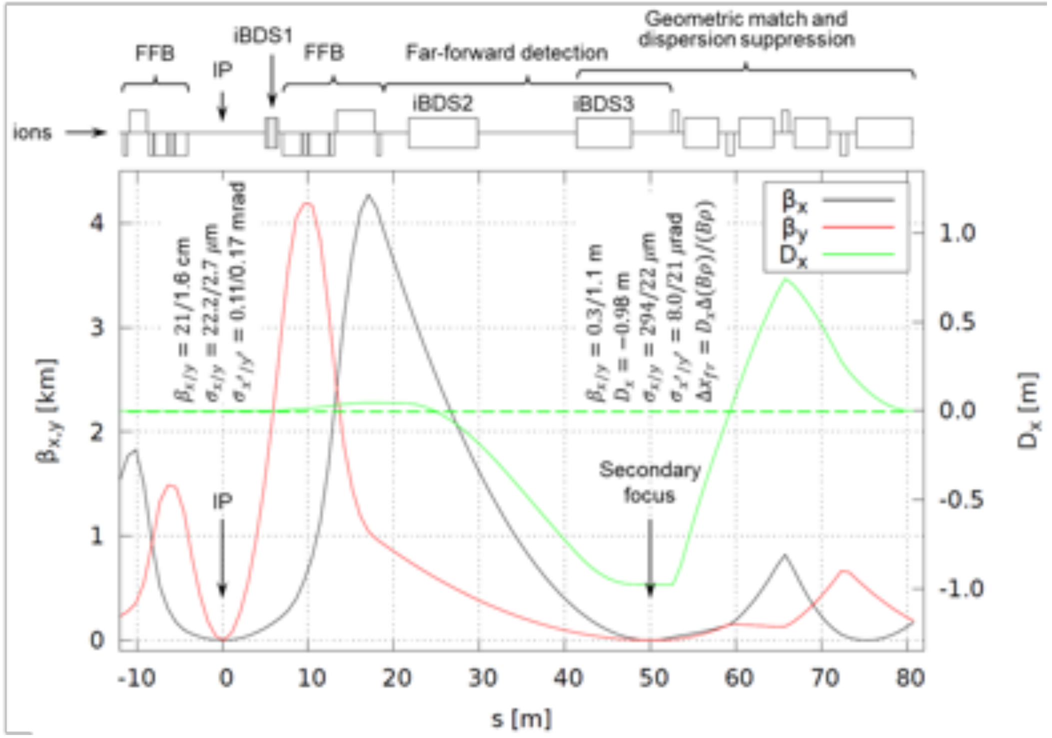


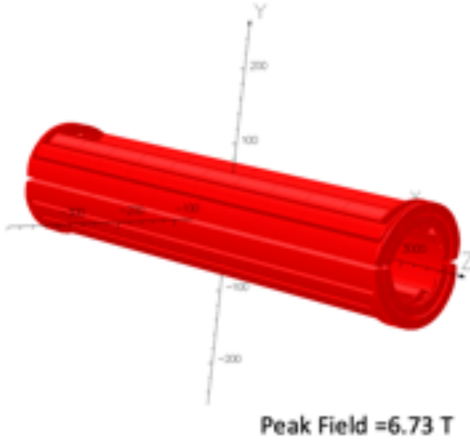


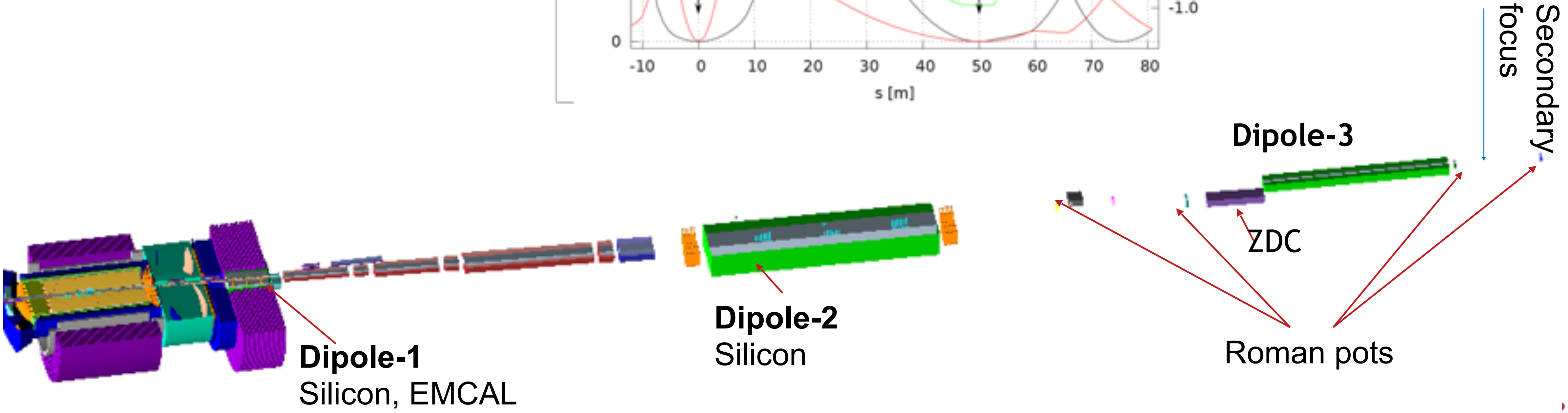


Forward ion: Dipole 3 and Roman Pots

- Detection of rigidity 1 forward protons/ ions with low pT
- Secondary focus β ~ 0
- Large dispersion ~ 1 m
- Location of Roman Pots
- Preliminary magnet design



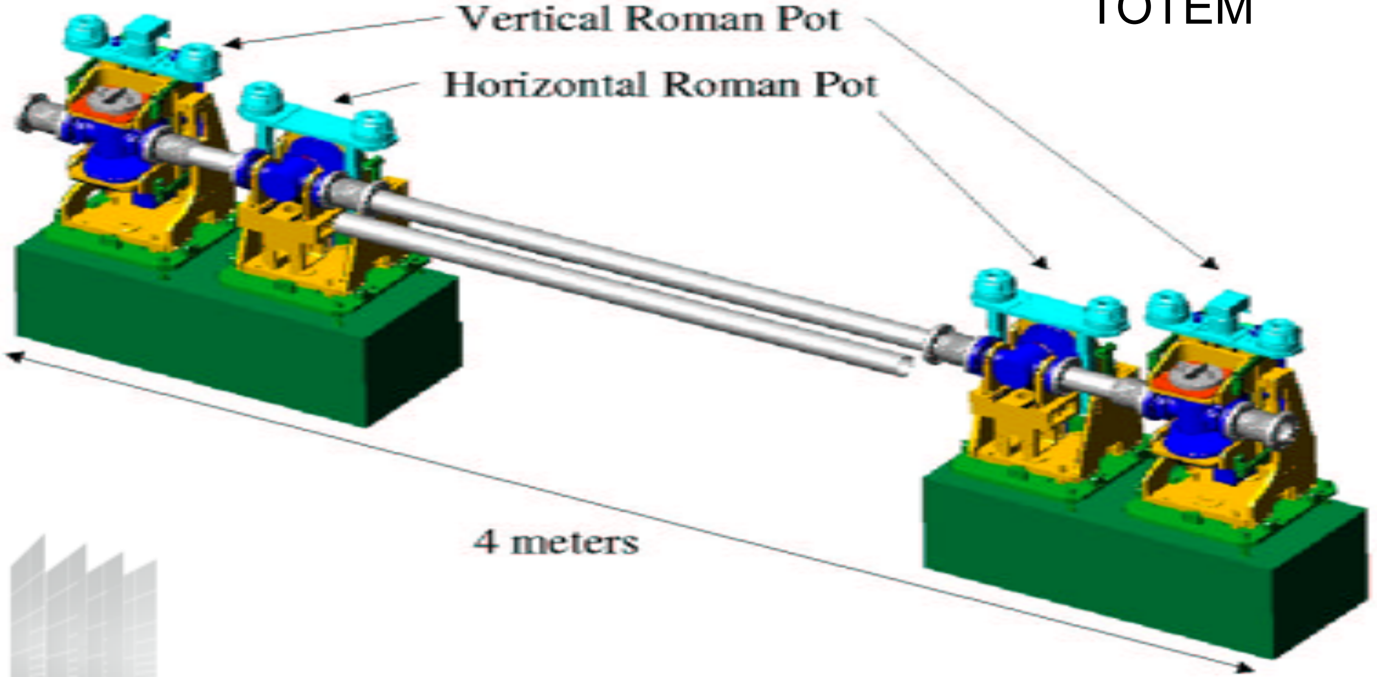


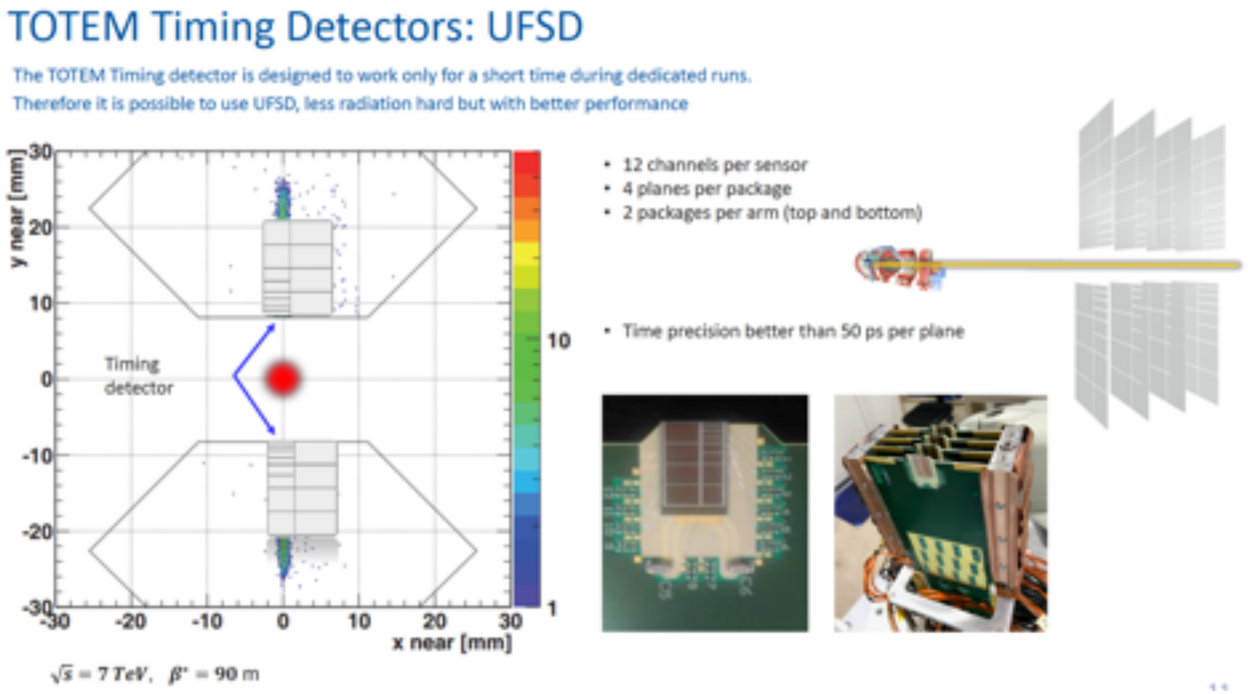


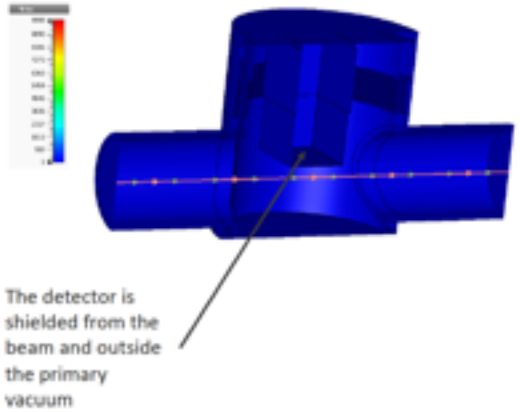
Forward ion: Roman Pots

TOTEM

- Needs to be optimized
- Joint meeting with TOTEM group last year
- Looking forward to collaboration with BNL!



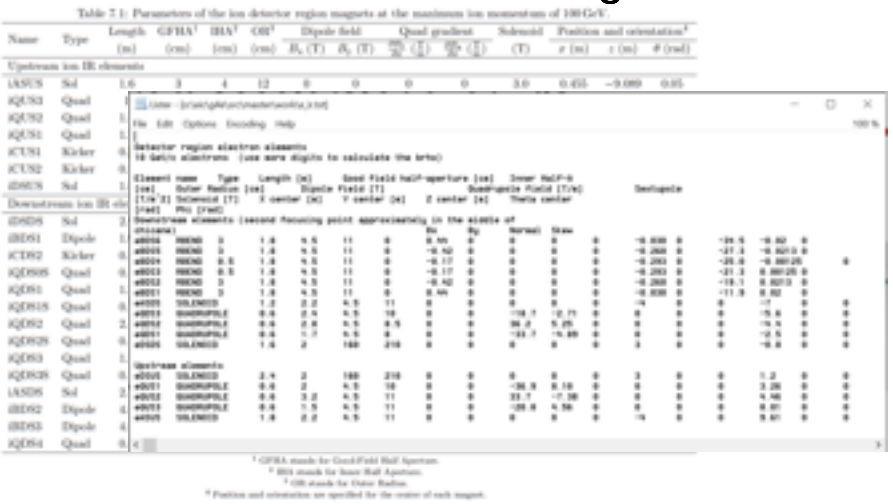




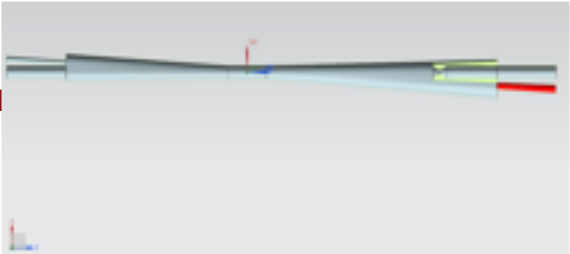
Jefferson Lab

Integration: Simulations for accelerator-detector integration

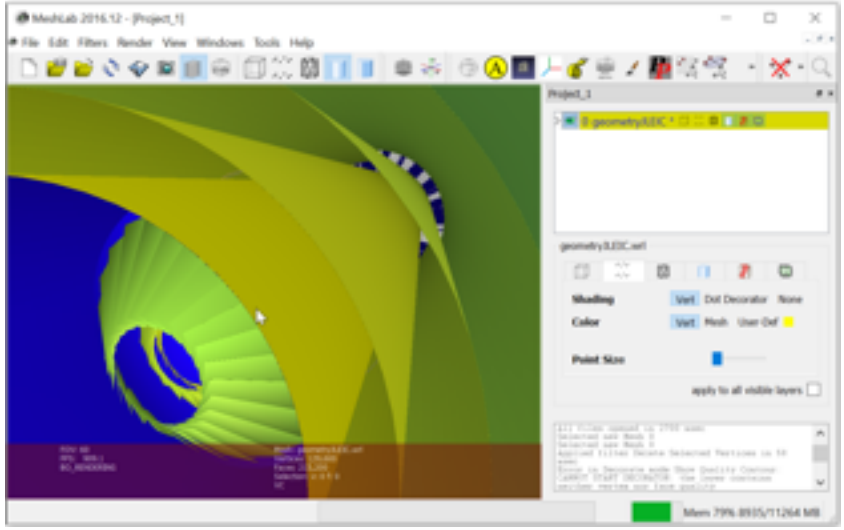
Beam elements design



Engineering Design CAD (M. Wiseman)



Full detector export to CAD



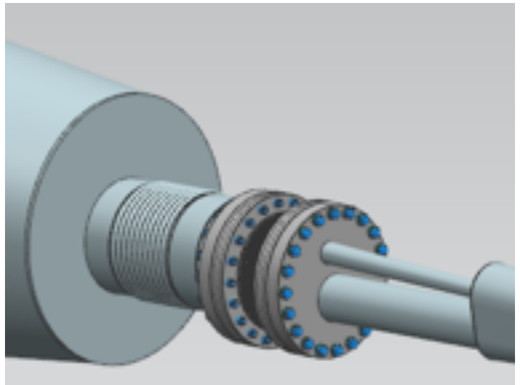
Detector simulation (Geant 4)

Tune

Optimization of elements (V. Morozov)

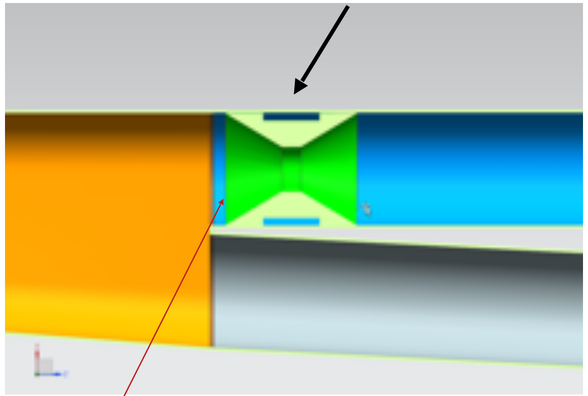
Integration: Beam pipe

Starting design of cryo volumes for FFQs



Mark Wiseman

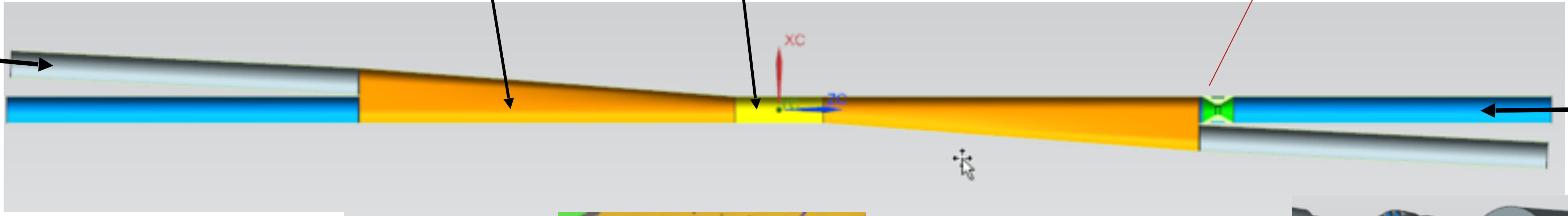
Synchrotron Radiation Mask
(Unchanged) Mike Sullivan



Central chamber:
- 6.0 cm internal diameter,
- 20 cm long (straight)
- Be

Shared volume

ion



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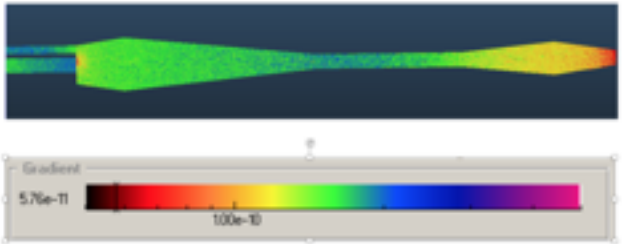
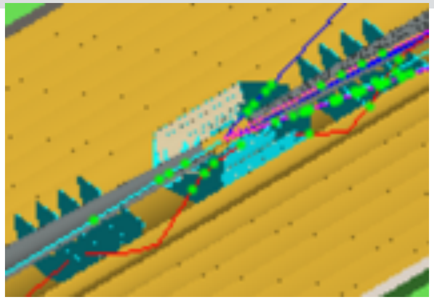
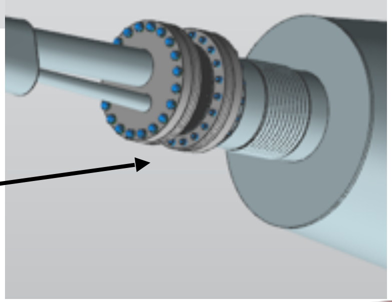


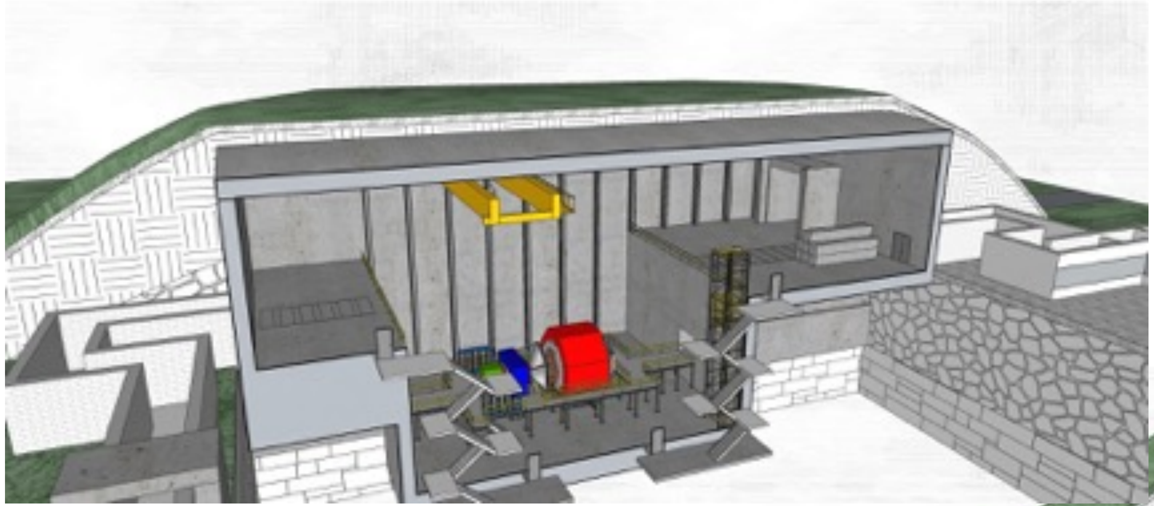
Molflow + tools (vacuum)



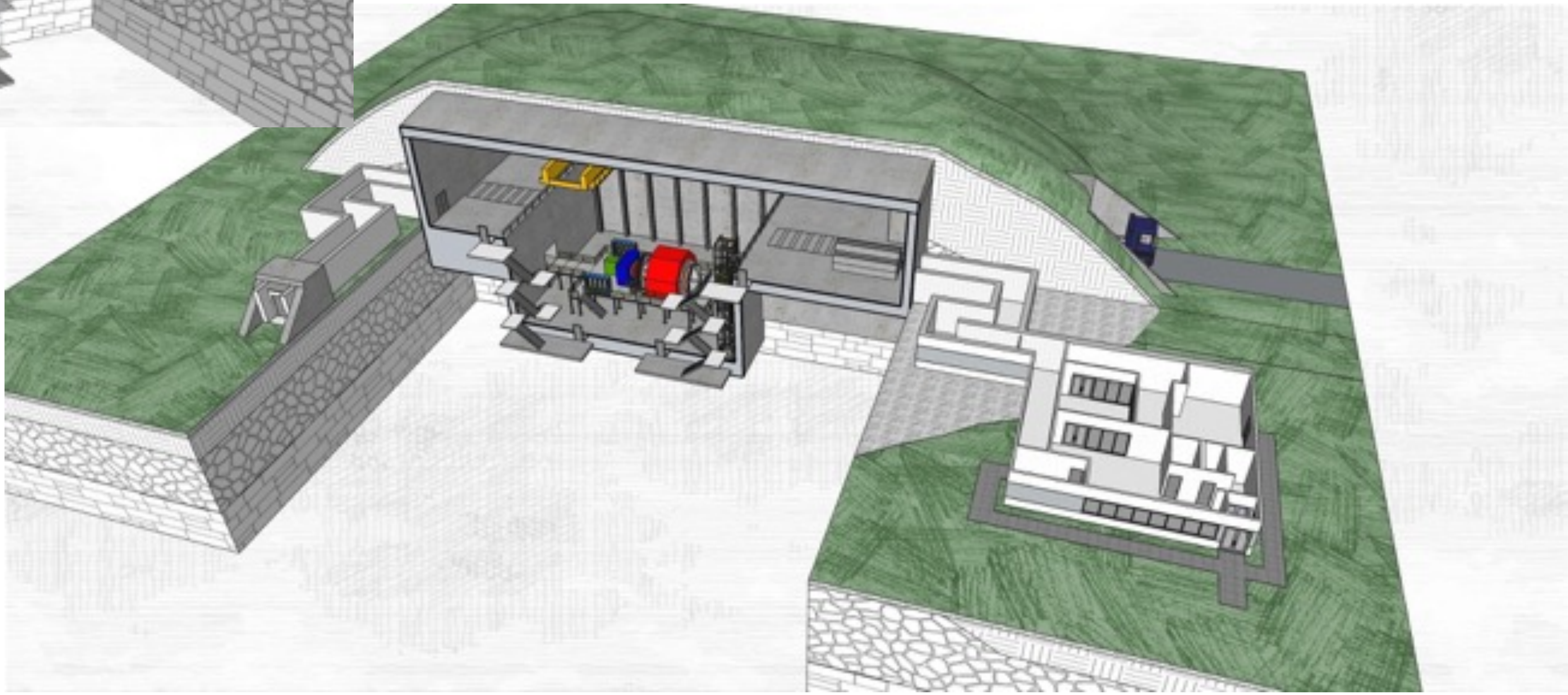
Cryo volumes and beampipe at ion outgoing side still under construction



Integration: Hall infrastructure



Walt Alkers



Summary

- Conceptual design of forward detector and IR for JLEIC with 65 and 100 GeV CM
- Three acceptance regions defined by dipole magnets and tracking detectors
- Performed first engineering design of dipole magnets
- Developed GEANT4-based simulation framework including accelerator and engineering elements
- Acceptance and resolution simulations on-going
- Collaboration within EIC User Group, EIC detector R&D program, international partners