LHeC Detector Design Status and Overview

P. Kostka , A. Polini ,
on behalf of the LHeC Study Group

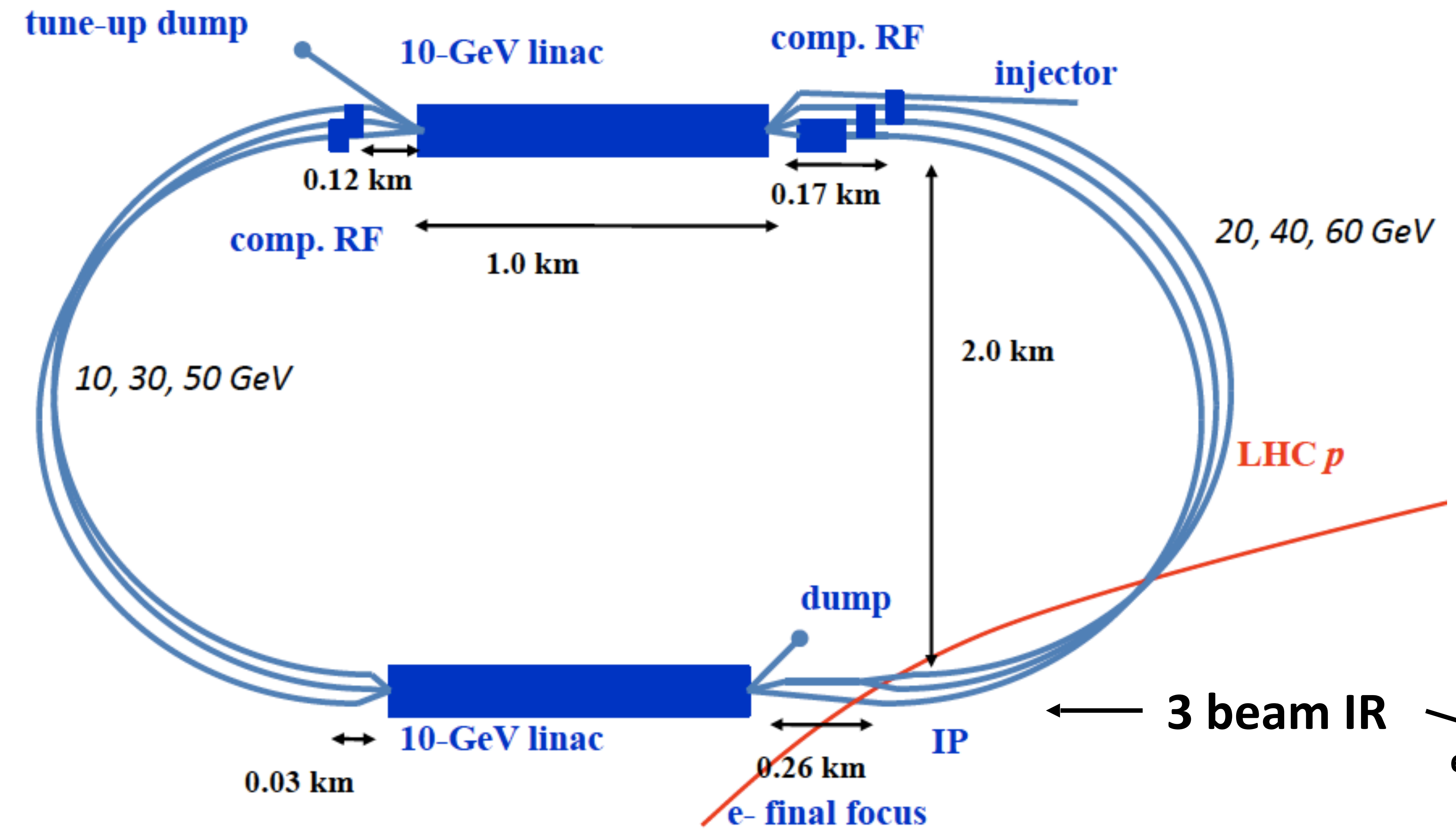
LHeC Workshop, CERN,
September 11-13

Outline

The ERL 60GeV Concept
LHeC Kinematics
IR
Kinematics
Detector Elements
Remarks, CDR Guideline

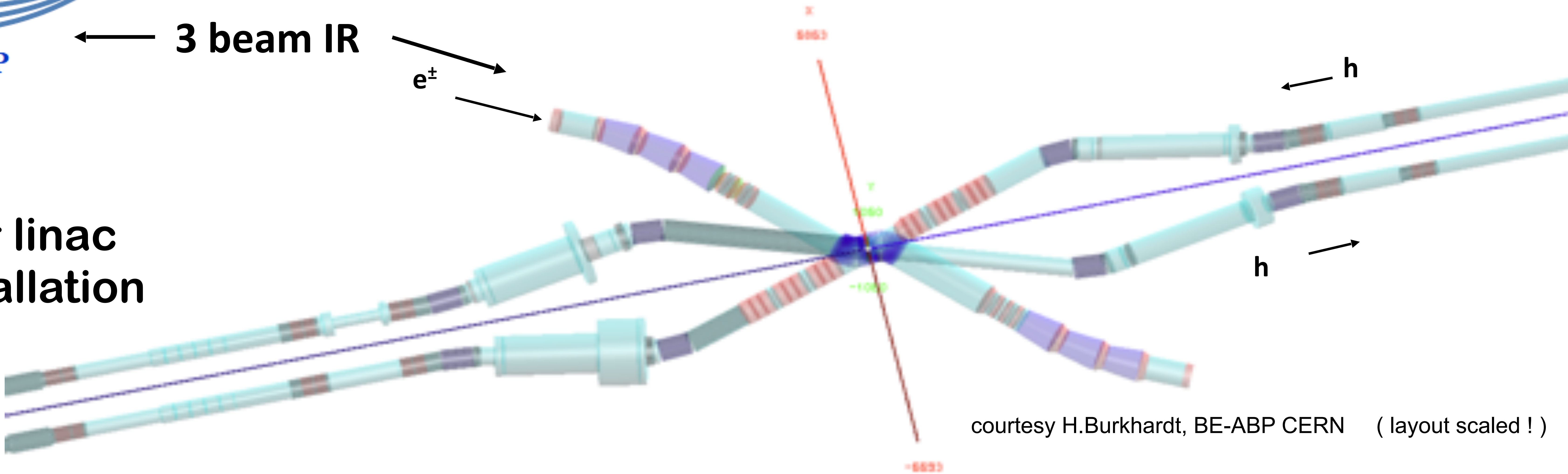
Baseline Electron Beam Configuration*

* LHeC CDR, arXiv:1206.2913



Operation in parallel with LHC/HE-LHC

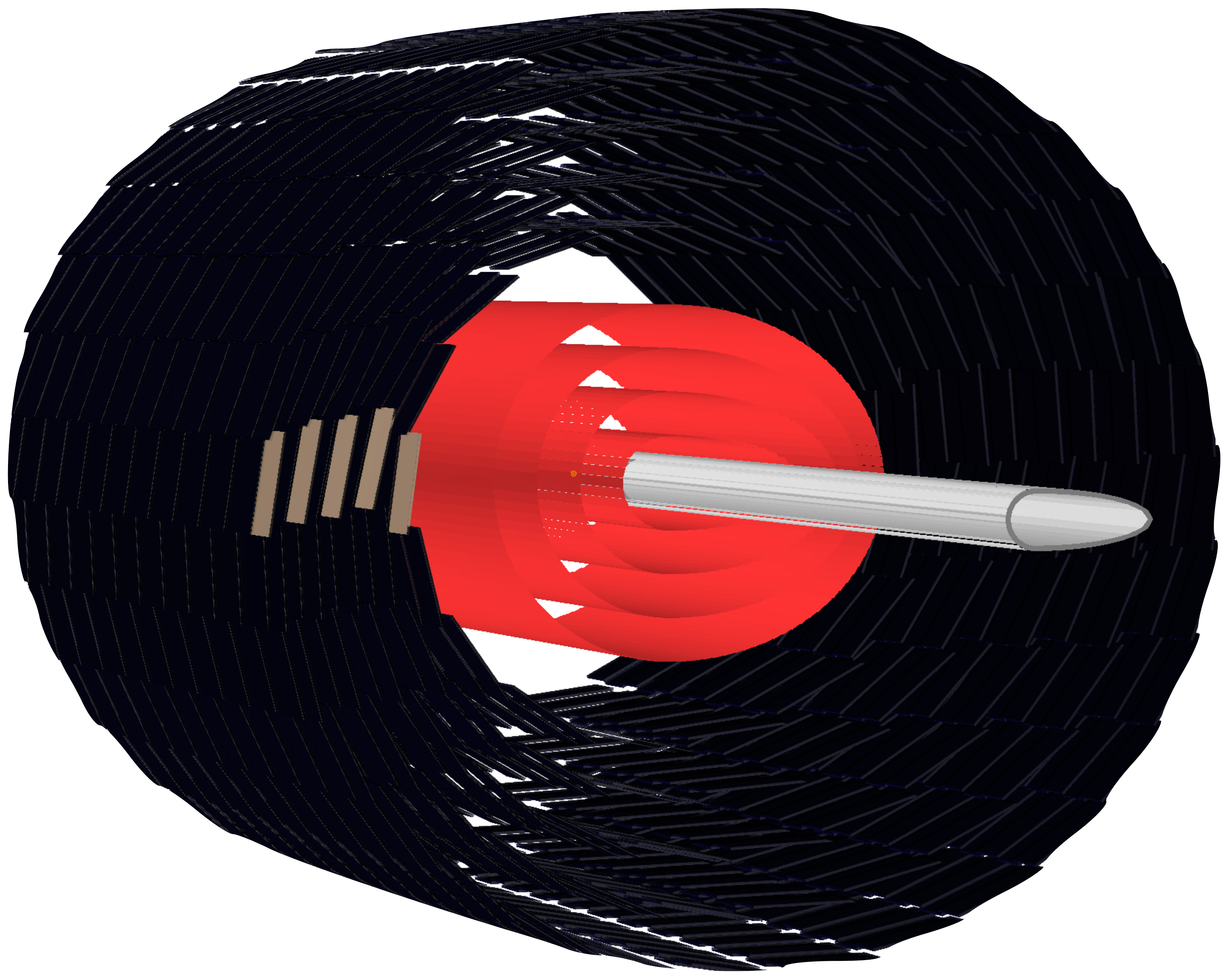
- TeV scale collision energy
  - ➔ 50-150 GeV beam energy
- power consumption < 100 MW
  - ➔ 60 GeV beam energy
- int. luminosity > 100 * HERA
- peak luminosity L > 10^{34} $cm^{-2}s^{-1}$



courtesy H.Burkhardt, BE-ABP CERN (layout scaled !)

➔ 944 cavities; 59 cryo modules per linac
➔ ca. 9 km underground tunnel installation
➔ more than 4500 magnets

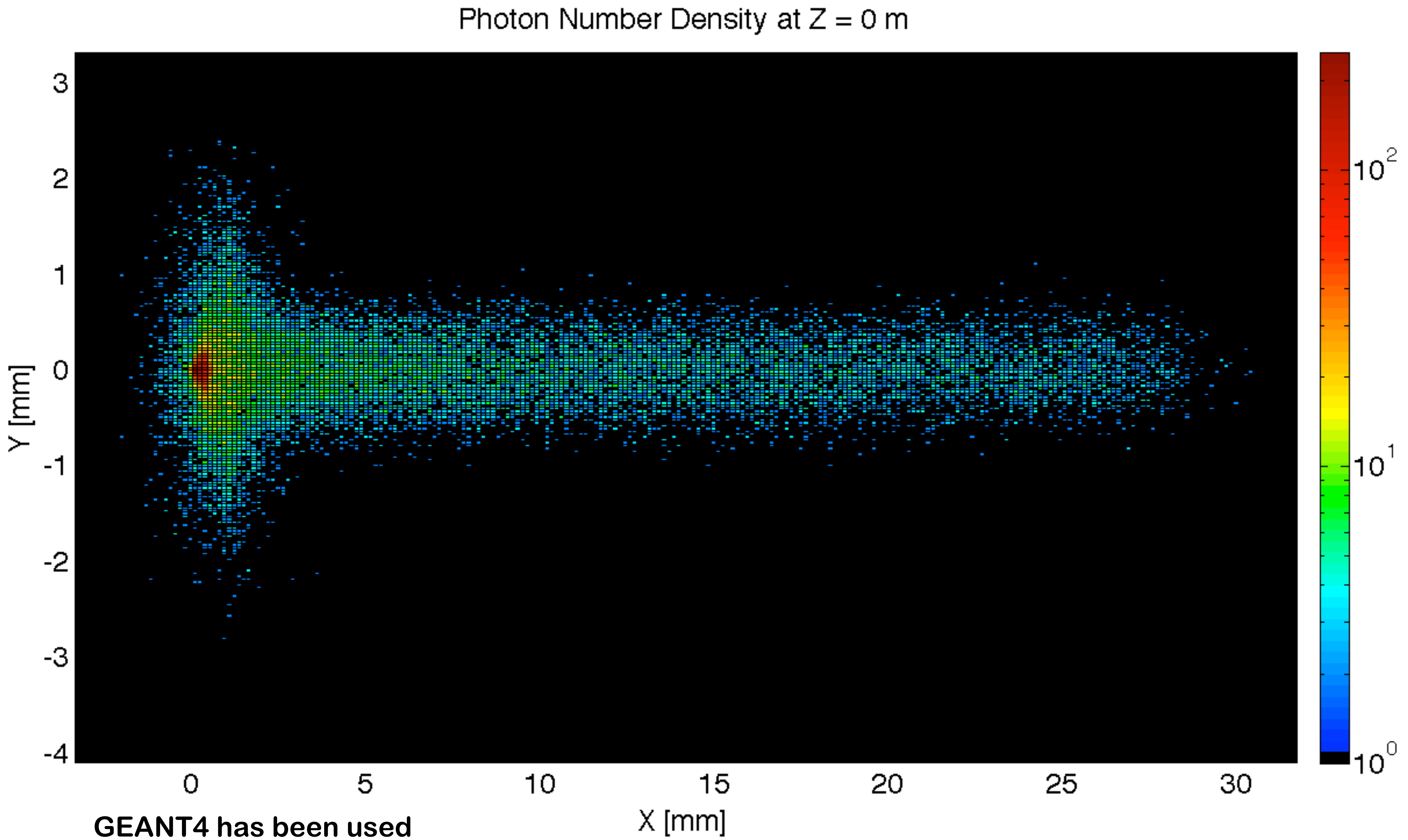
Detector Layout - Beampipe & Central Tracker



Central Tracker
circular-elliptical beam pipe
4 layers Si-pixel
5 layers Si-macro_pixel

(see Table of Detector Dimensions/Parameters)

Synchrotron Radiation Fan at IP

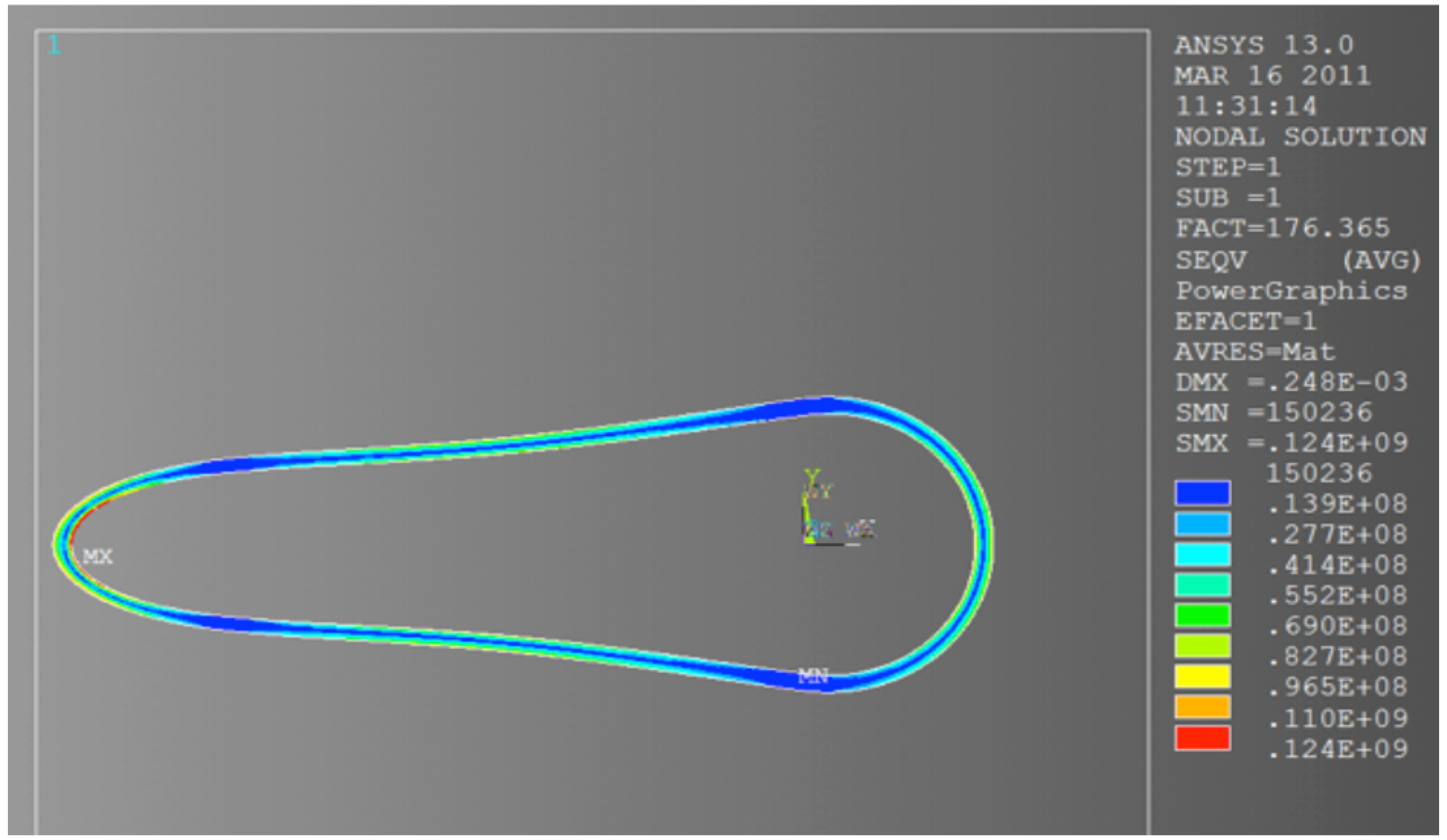


GEANT4 has been used

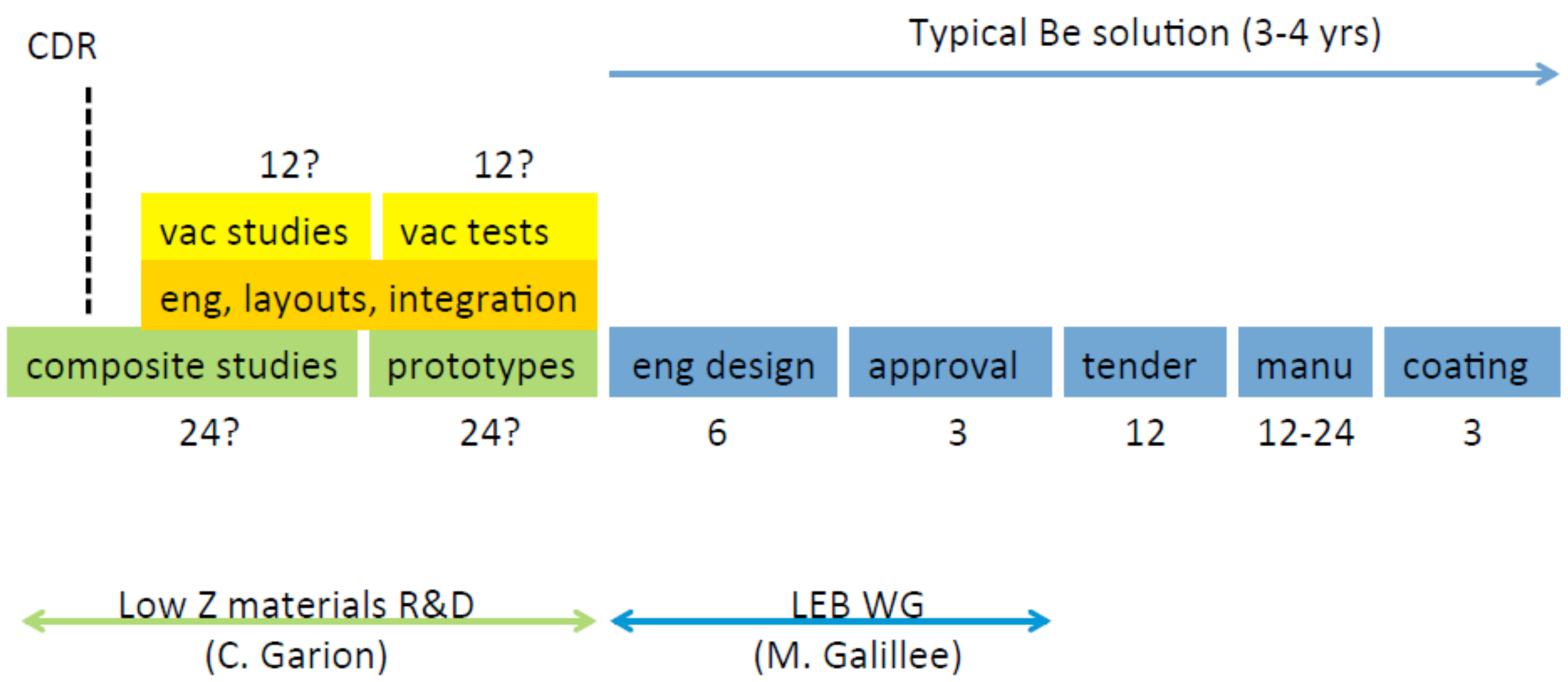
Beam Pipe Considerations

courtesy Paul Cruikshank, CERN

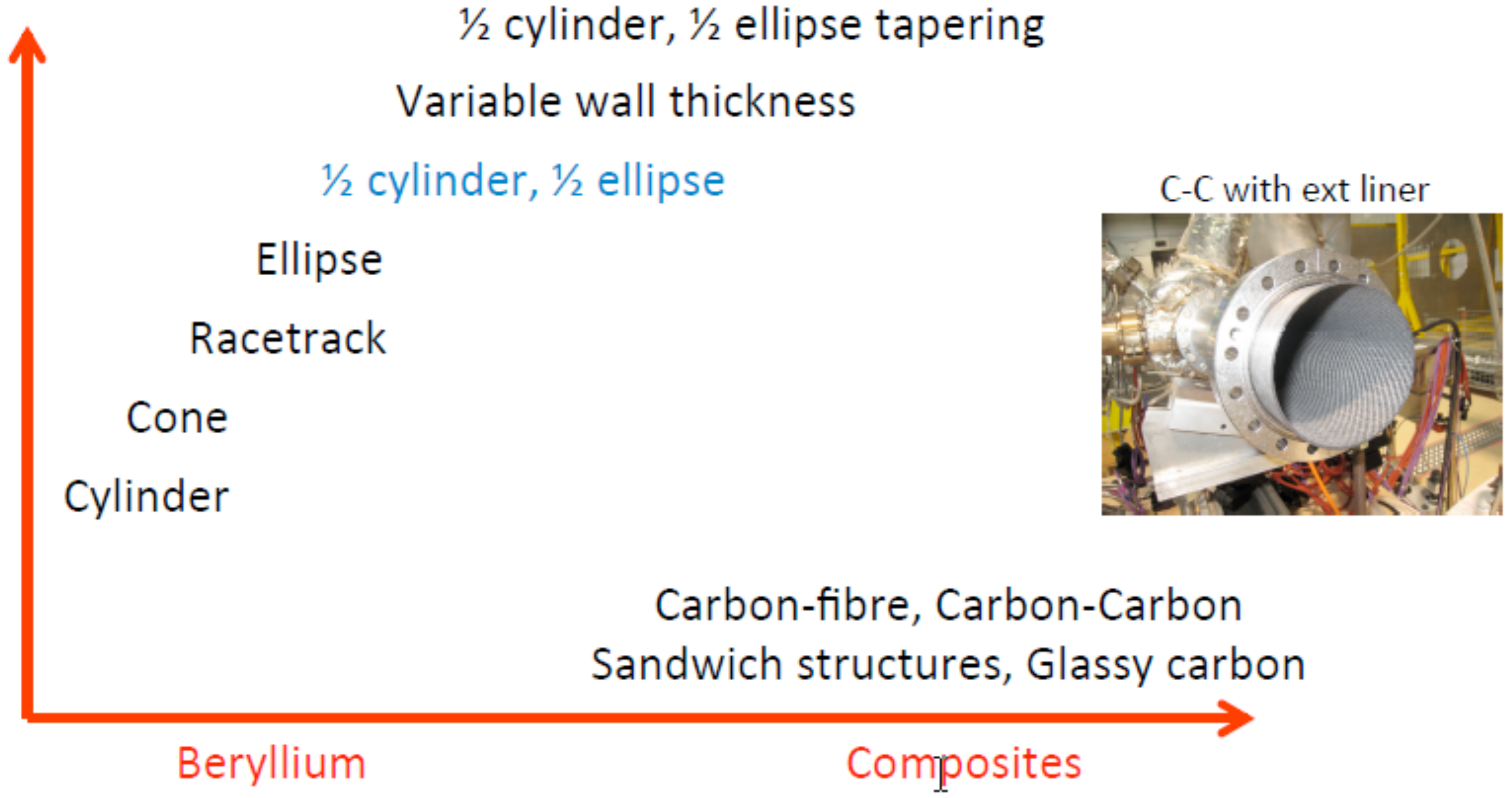
https://indico.cern.ch/event/183282/session/12/contribution/54/material/slides/1.pdf



A tentative timescale (months)...........



Additional manpower is necessary to advance on LHeC eng & vacuum physics issues



- Circular-Elliptical beam-pipe design
  - Beryllium 2.5-3.0 mm wall thickness
  - Central beam pipe ~ 6 meters
  - TiZrV NEG coated
  - Wall protected from primary SR (upstream masks)
  - Minimised end flanges, minimised supports
  - optimisation needed - R&D

Interaction-Region Design for ep/eA at LHC/HE-LHC/ FCC

Machine-detector interface
- dipoles inside detector volume (Rogelio Tomas talk)
- experiment-solenoid(s) (Herman Ten Kate's talk)

Final quadrupole magnets (Brett Parker's talk)

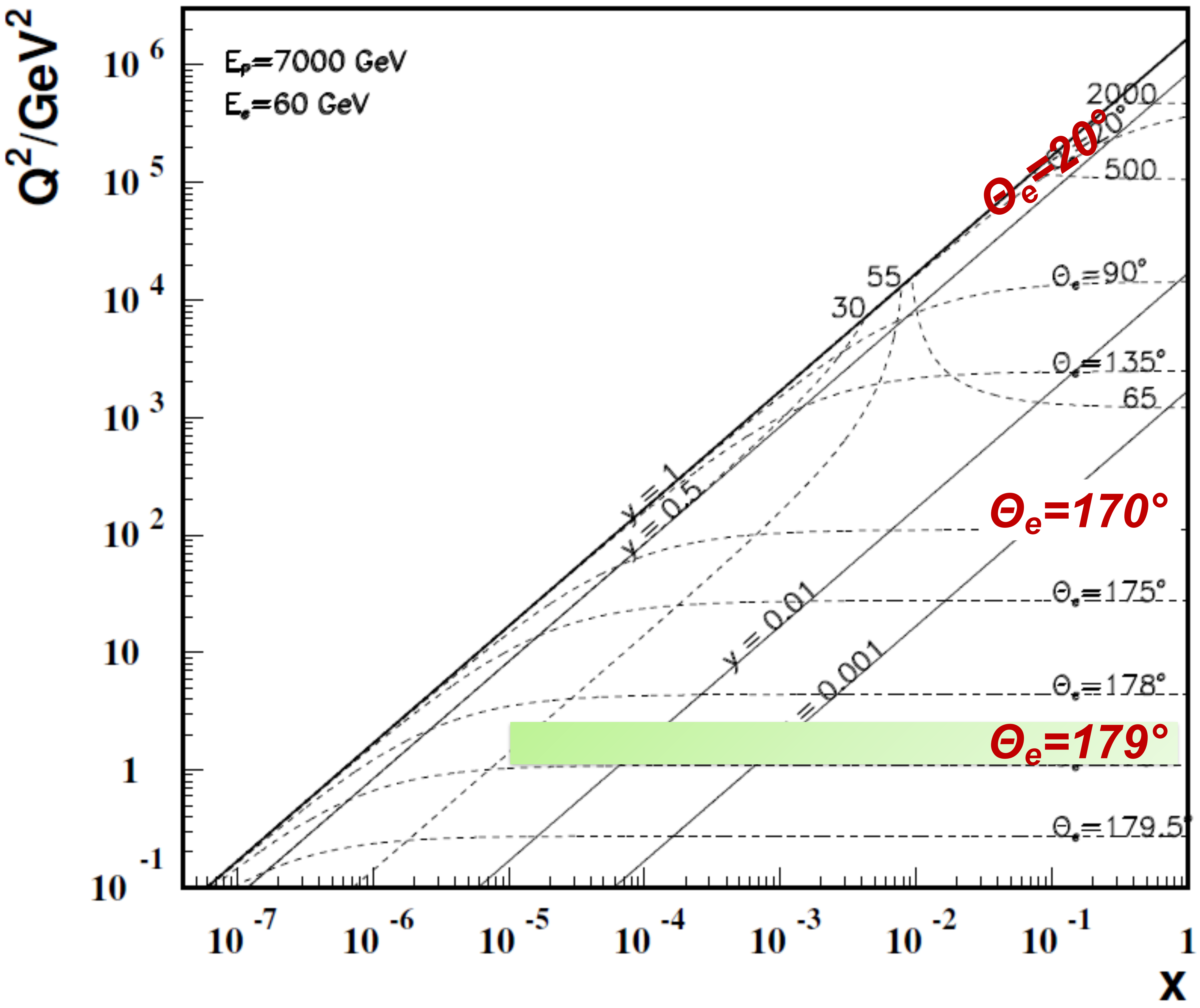
Synchrotron-Radiation / beam induced background inside detector
- avoid / mask (fixed/movable) / shield (Q1 - water cooled(?))

…

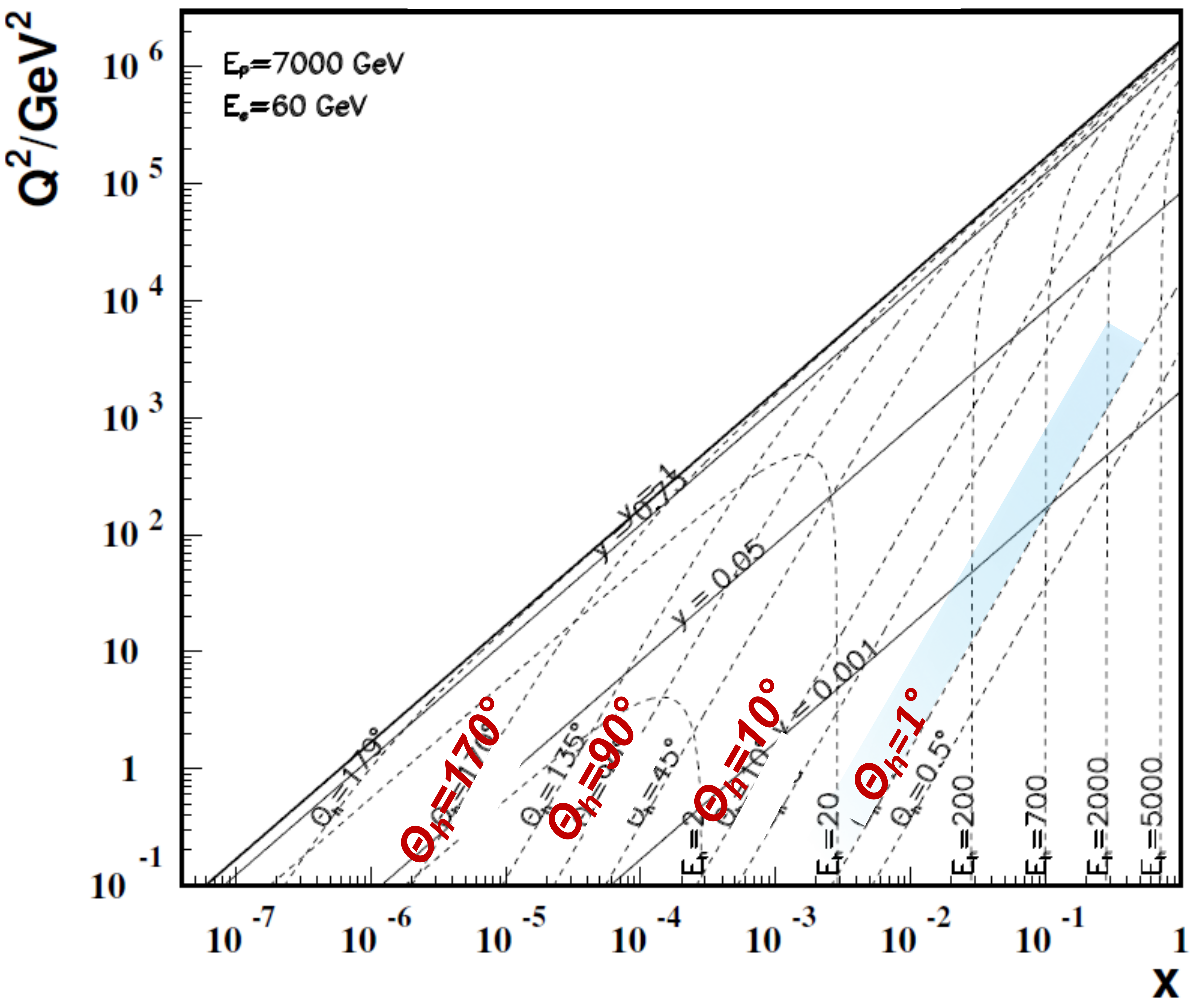
LHeC Kinematic Range (low x; high Q^2)

courtesy Max Klein

LHeC – electron kinematics



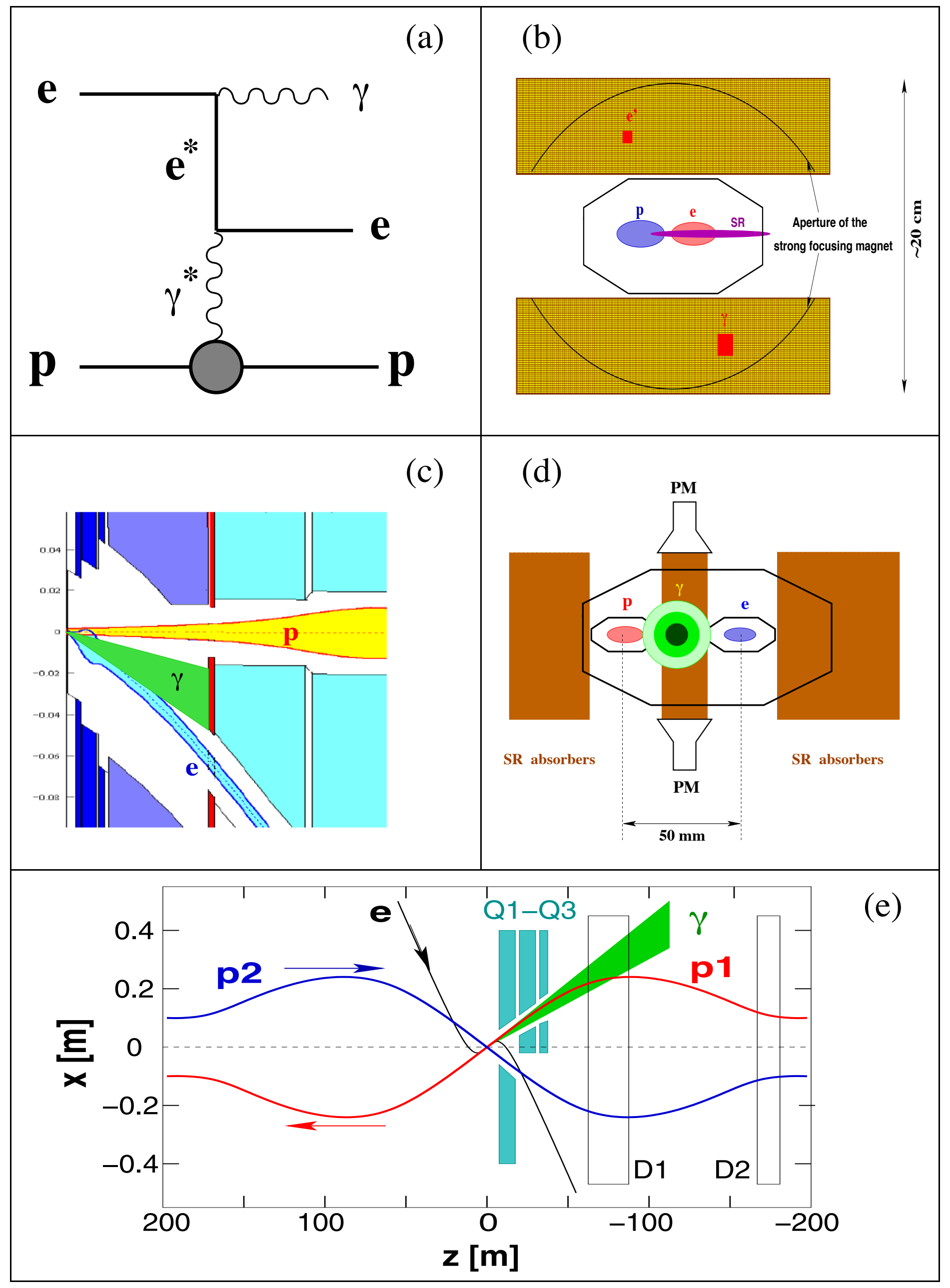
LHeC – jet kinematics



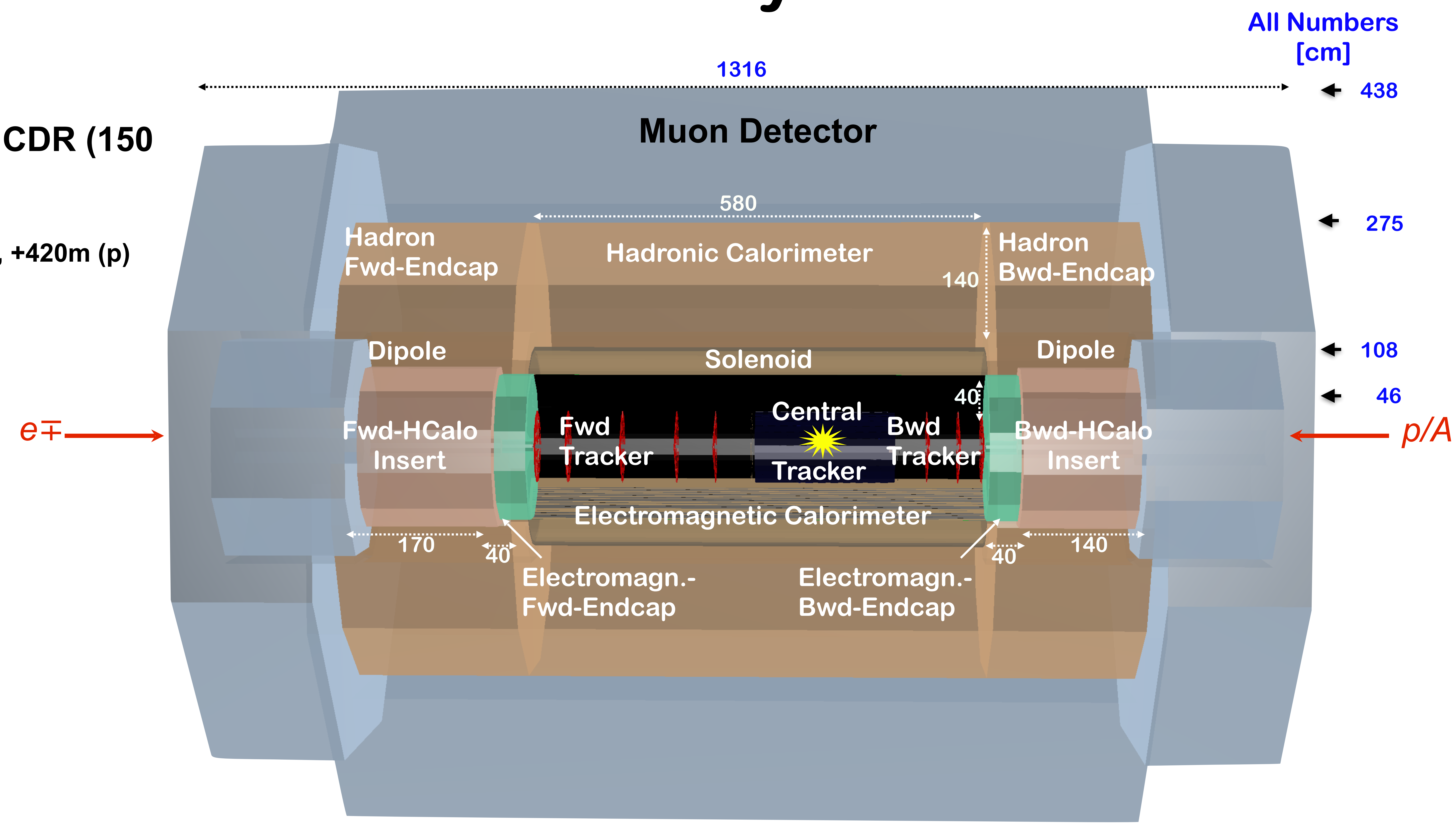
- High x and high Q^2: few TeV HFS scattered forward: Need forward calorimeter of few TeV energy range down to 1^0
  - Mandatory for charged currents where the outgoing electron is missing
- Scattered electron: Need very bwd angle acceptance for accessing the low Q^2 and high y region

LHeC Detector Basic Layout

Detailed report and study in LHeC CDR (150 pages).
Includes fwd/bwd taggers at
~62m (e), 100m (γ,LR), -22.4 (γ,RR), +100m (n), +420m (p)



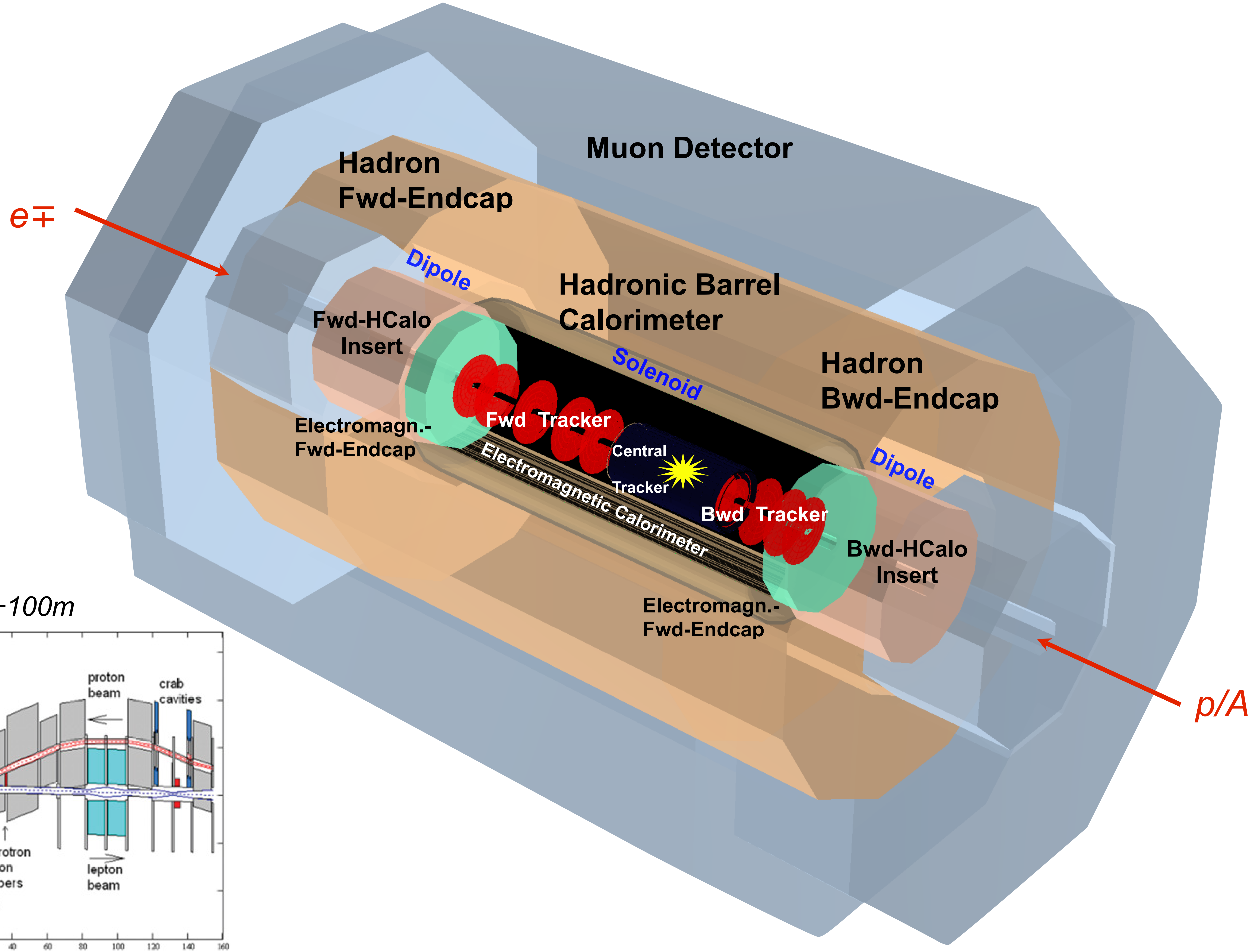
Options for the luminosity monitoring at the LHeC



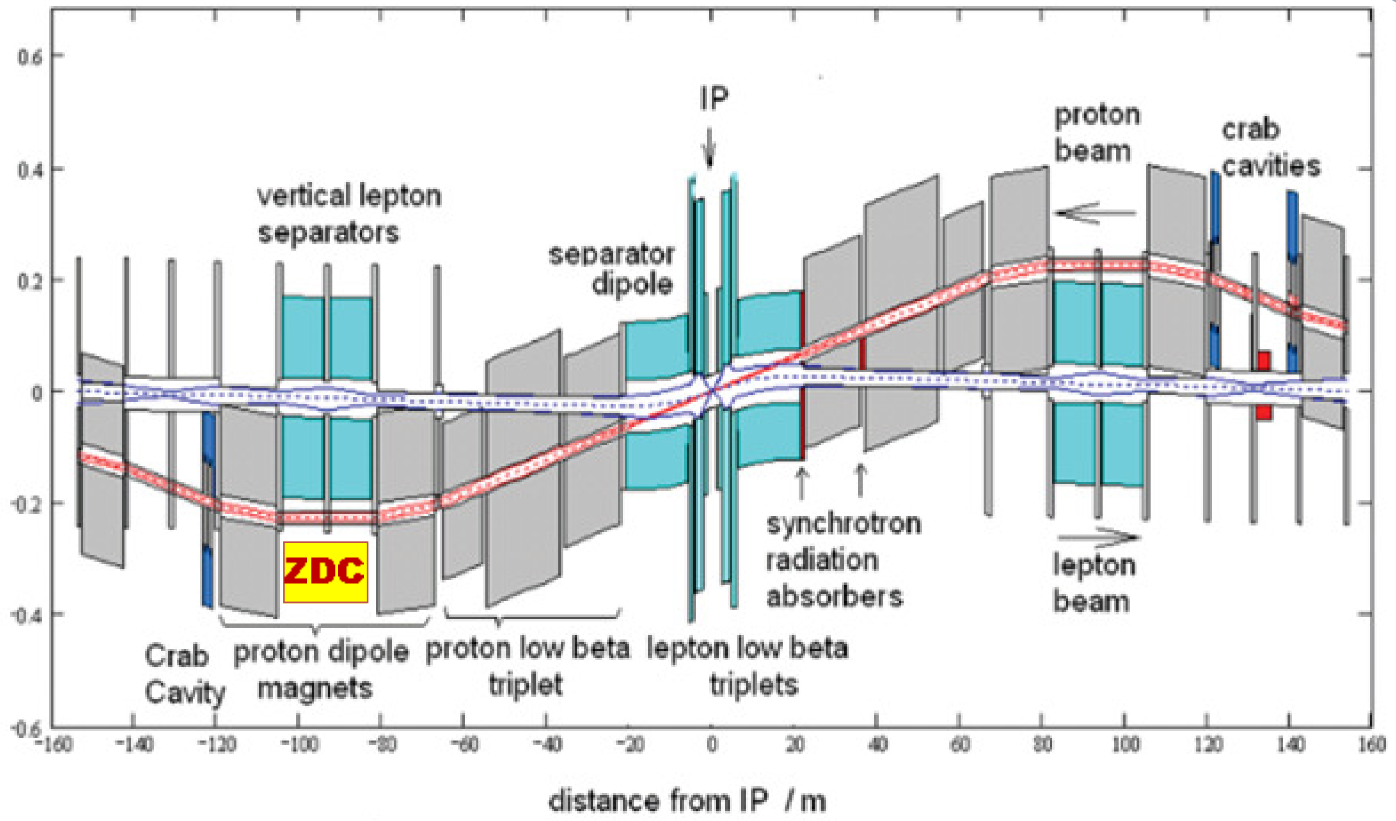
http://cern.ch/lhec
CDR: "A Large Hadron Electron Collider at CERN" ,
LHeC Study Group, [arXiv:1206.2913],
J. Phys. G: Nucl. Part. Phys. 39 (2012) 075001

"On the Relation of the LHeC and the LHC" [arXiv:1211.5102]

LHeC Detector Basic Layout



Zero Degree Calorimeter -
Neutron calorimeter at +100m



Does it fit into cavern P2?
L3 Magnet inner bore - 11.5m)
- YES

Installation in time slot?
- YES (Andrea Gaddi's talk)

LHeC:
detector installation with removal of current detector on IP2 can be done within 2 years, which is compatible with typical LHC shutdowns.

For FCC-eh (and HE-LHC) that constraint is lifted.

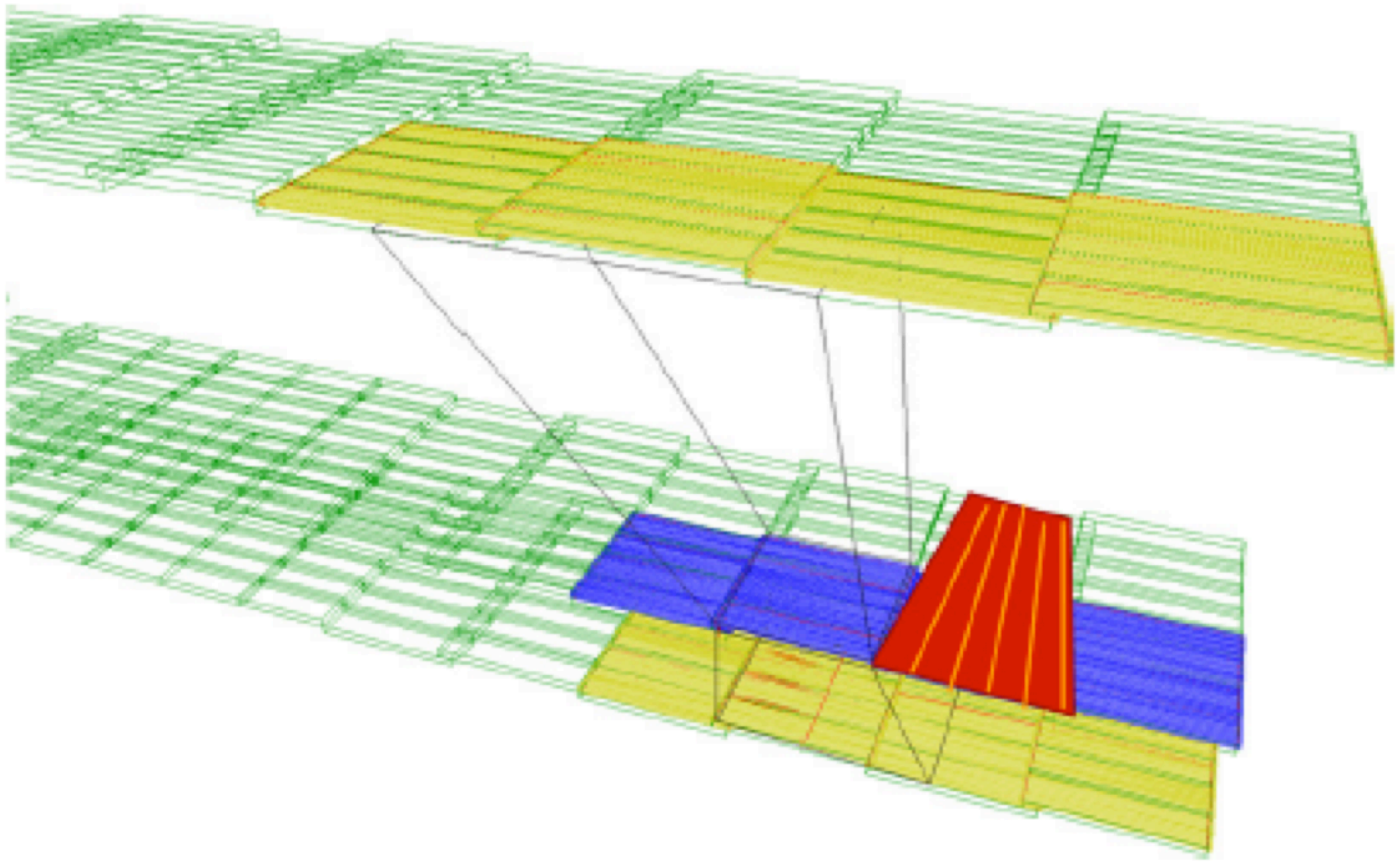
Forward/backward asymmetry in energy deposited and thus in geometry and technology

Present dimensions: LxD = 14x9m^2 [CMS 21x15m^2 , ATLAS 45x25m^2]

Muon Tagging/Measurement

Detector Solenoid System defines
whether or not the Muon System provides tagging OR (AND) independent momentum measurement when inside B-field
Momentum measurement done in combination with inner tracking

Present technologies in use in LHC experiments & their upgrades sufficient (RPC, TGC, MDT …)



Detector Concepts for the CDR upgrade

Barrel ECAL	SciPb ⟷ LAr	~27-30 X_0	
Barrel HCAL	SciFe	~7-12 λ_I	
Endcap HCAL	SciFe	~7-12 λ_I	
Forward Plug HCAL / ECAL	SiW / SiW	~12 λ_I	/ ~30 X_0
Backward HCAL / ECAL	SiFe / SiPb	~7-10 λ_I	/ ~25-28 X_0

Silicon tracker pixel, macro_pixel
Muon tracker RPC's …

3.5T inner Solenoid ~580cm (LHeC); ~720cm (HE-LHeC)
0.3T Dipoles ~985cm (LHeC); ~1220cm (HE-LHeC) + fwd/bwd dipoles
bore " ~260cm (LHeC); ~300cm (HE-LHeC)

(in case HE-LHeC to be build → HE-LHeC magnet system on first place for LHeC)

dual dipoles ±0.3 T - steering the e-beam for head-on collisions

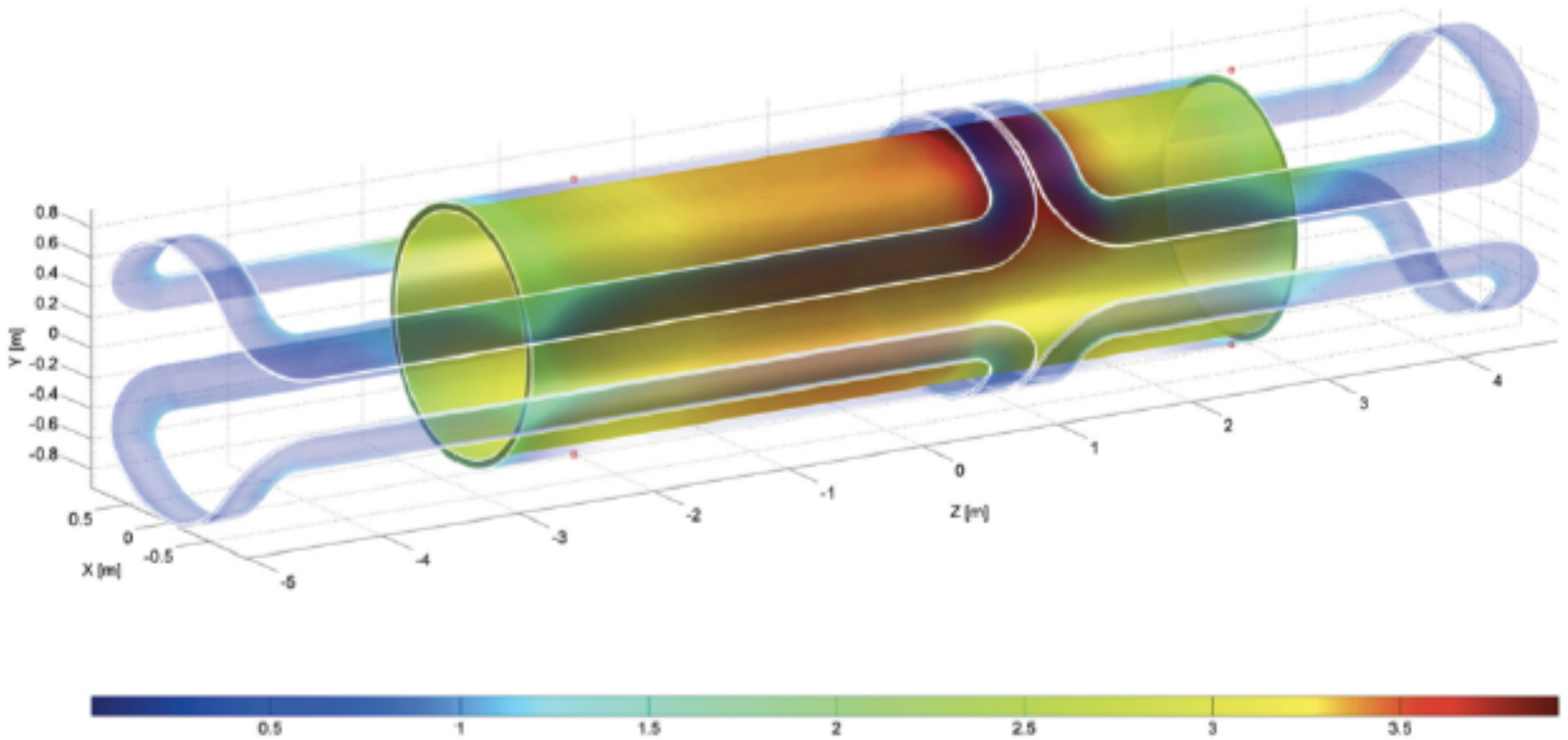
Detector Magnets: Solenoid and Dipoles

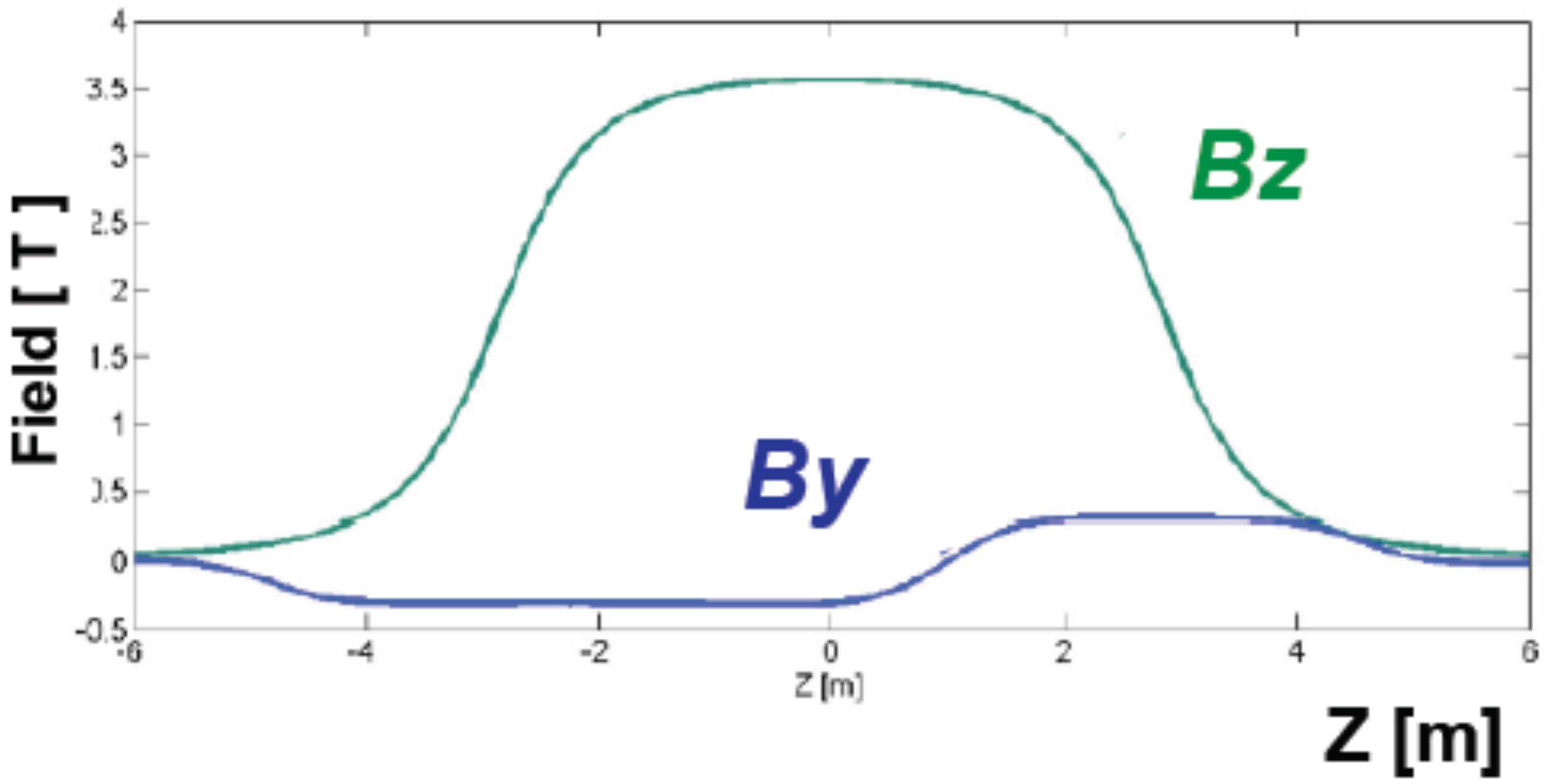
courtesy Herman ten Kate and Alexey Dudarev

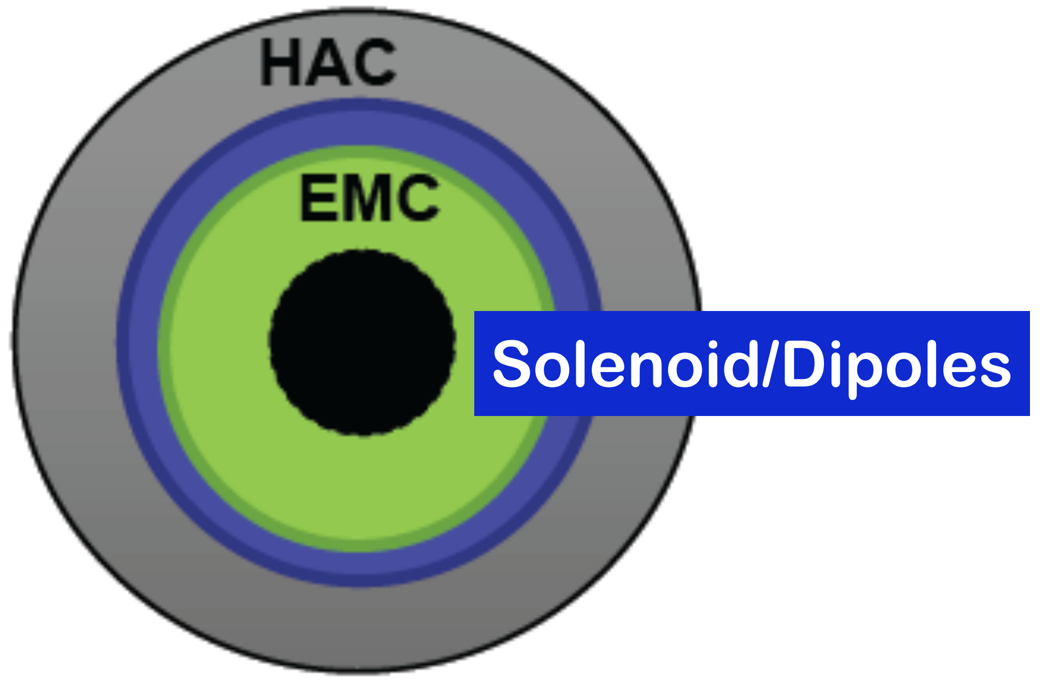
Baseline: Solenoid (3.5 T) + dual dipole 0.3 T (Linac-Ring Option)
Inner solenoid: containing full Tracker; ECAL/HCAL calorimeter & MuonDet outside

Small coil: Cheaper & less iron for return flux, solenoid and dipoles (& ECAL-LAr?) conveniently within the same cold vacuum vessel, but no muon measurement

OR: new solenoid system - FCC-hh style (H.T.Kate's talk)

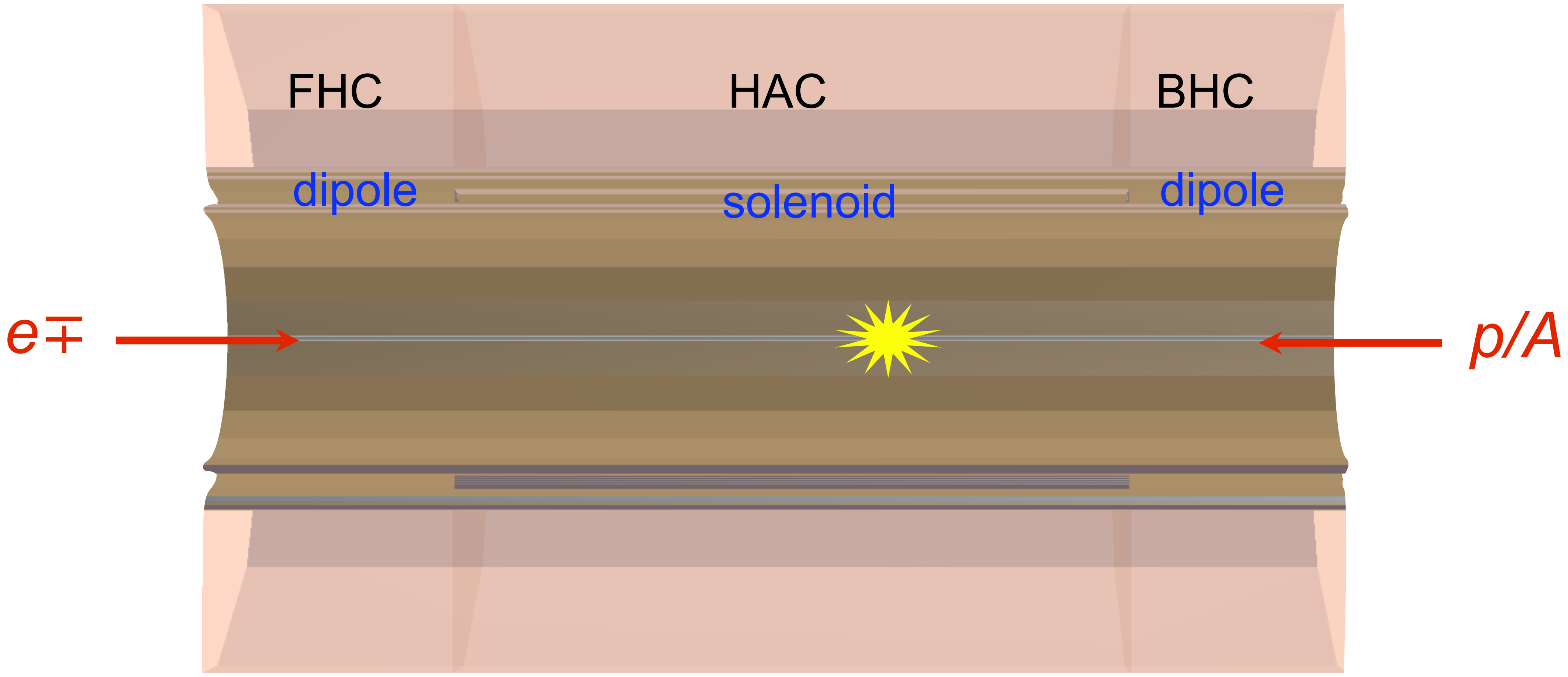






LHeC Detector Magnet system, Herman ten Kate
LHeC Workshop Chavannes, Jan 21, 2014

HCAL-Scintillator-Iron Barrel

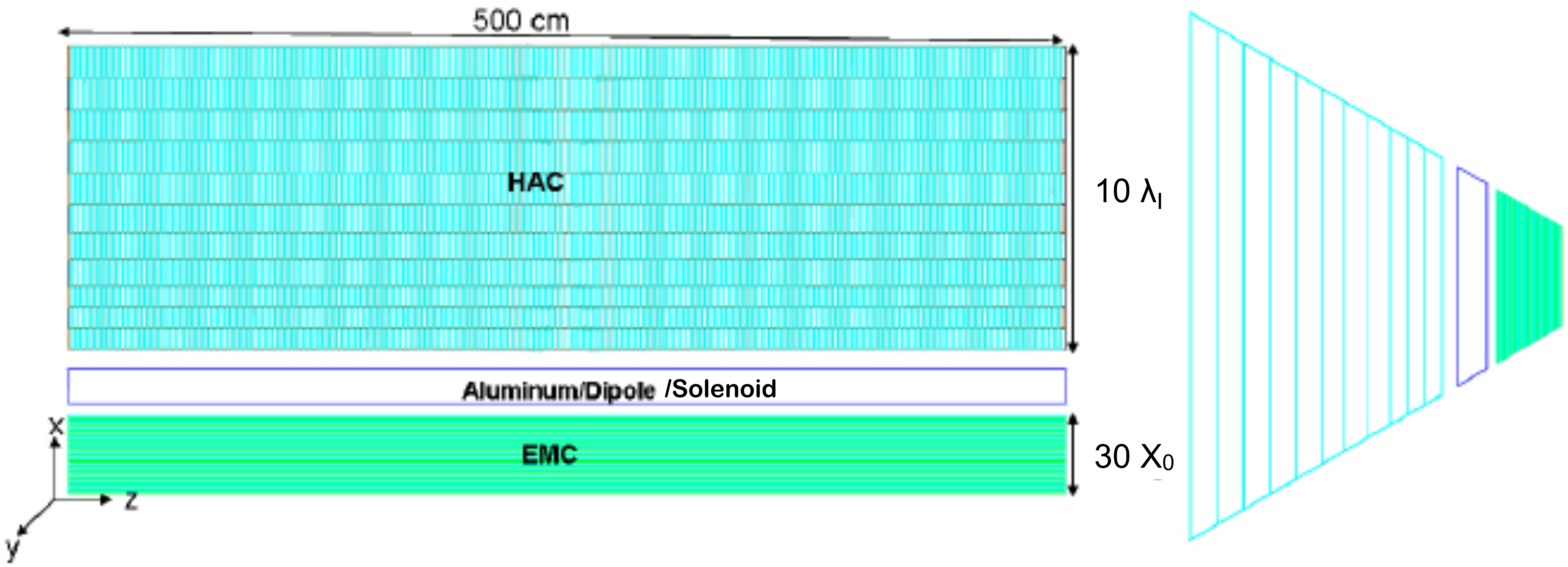


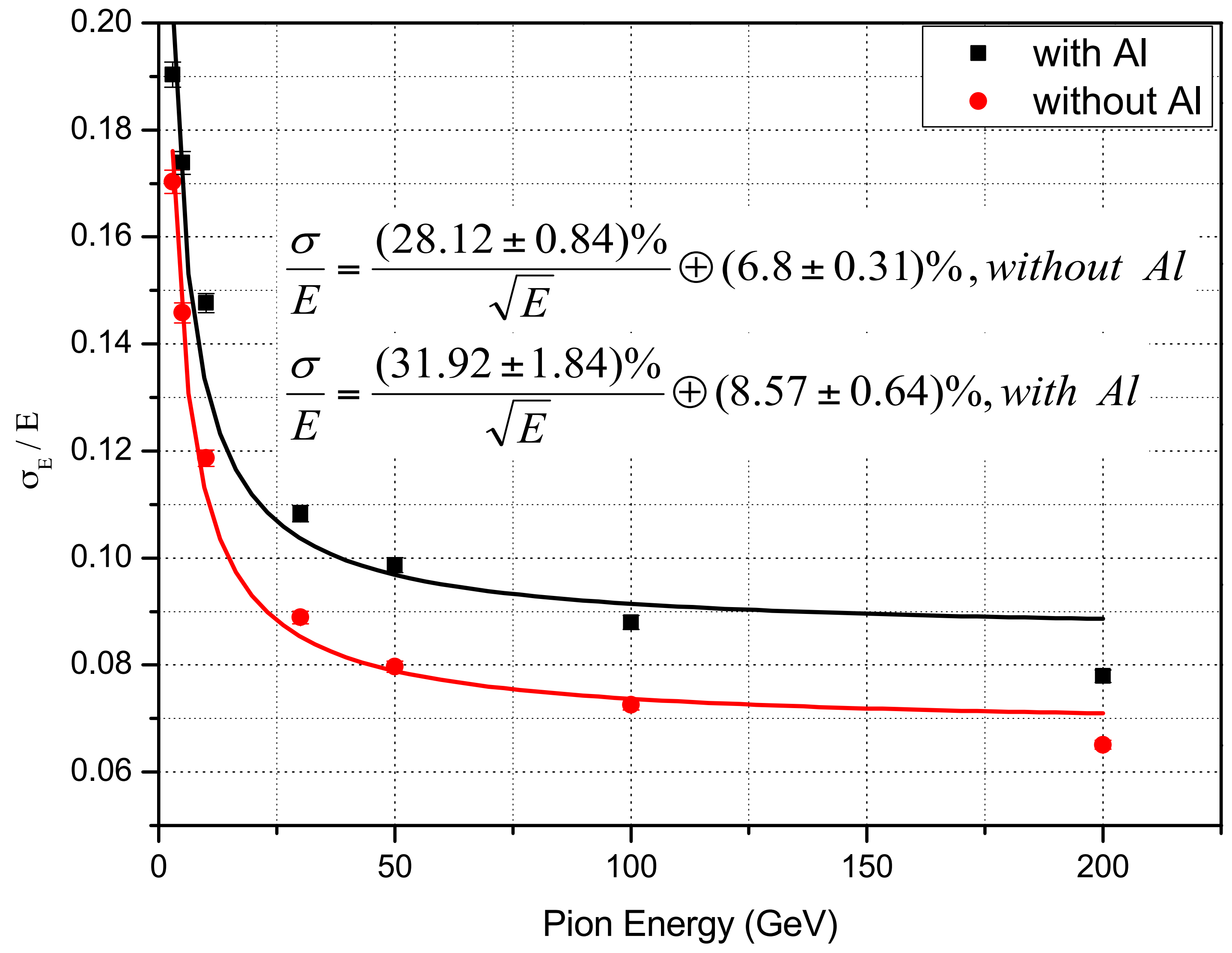
HAC iron absorber (magnet return flux)

Scintillating plates (similar to ATLAS TILE CAL)

Interaction Length: ~8-12 λ_I

Geant4 Simulation done with structure:





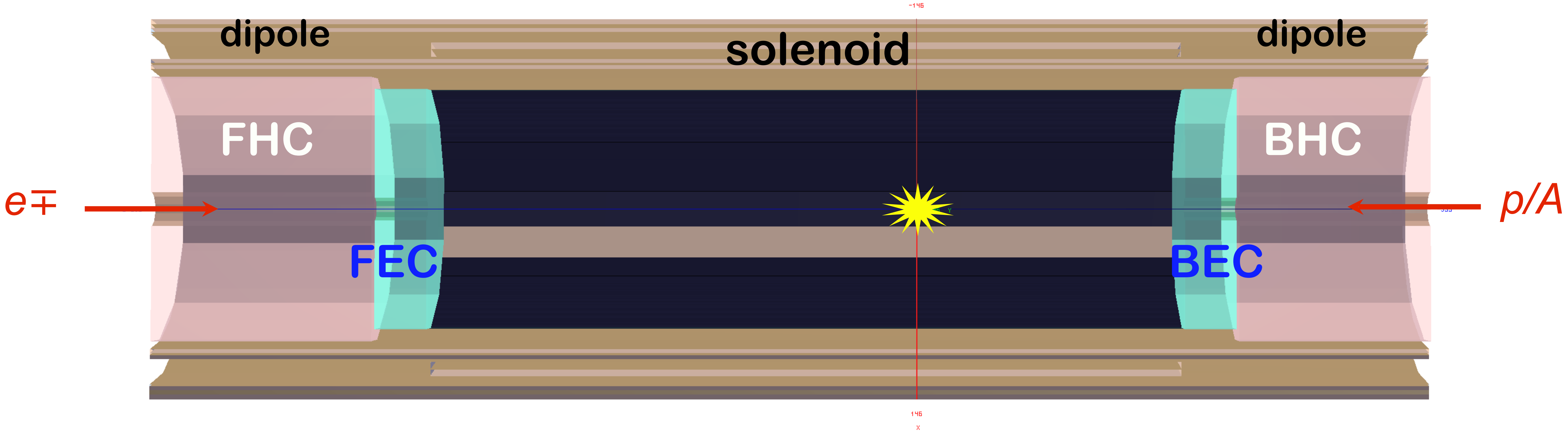
HCAL/ECAL fwd/bwd Calorimeters

Forward FEC + FHC:

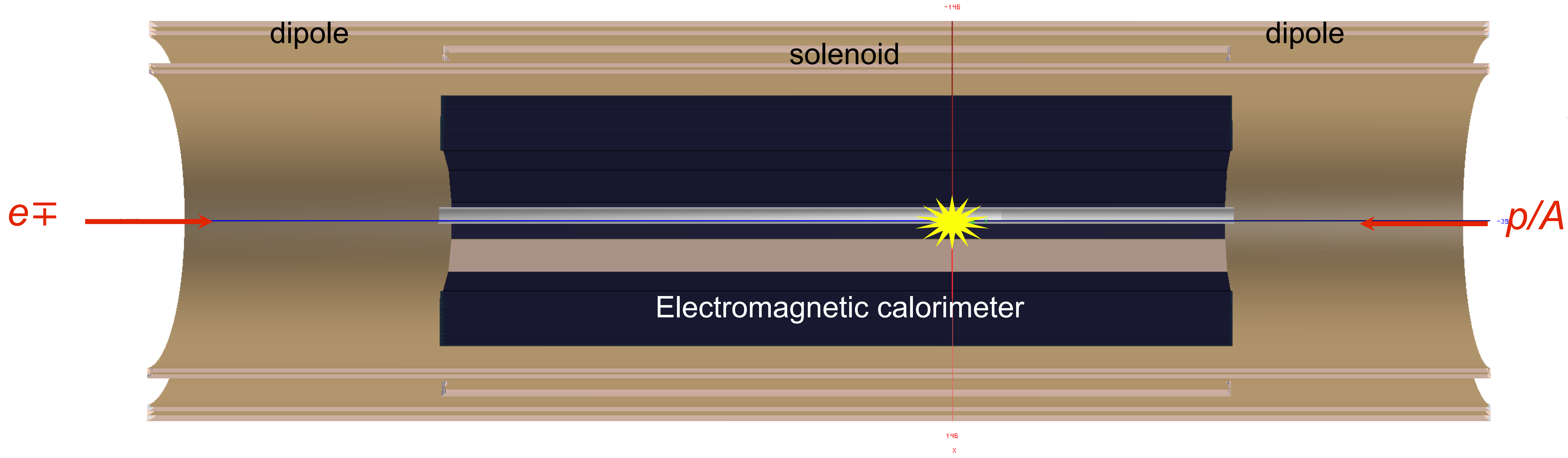
- tungsten high granularity
- Si (rad-hard)
- high energy jet resolution
- FEC: ~30X_0; FHC: ~8-12 λ_I

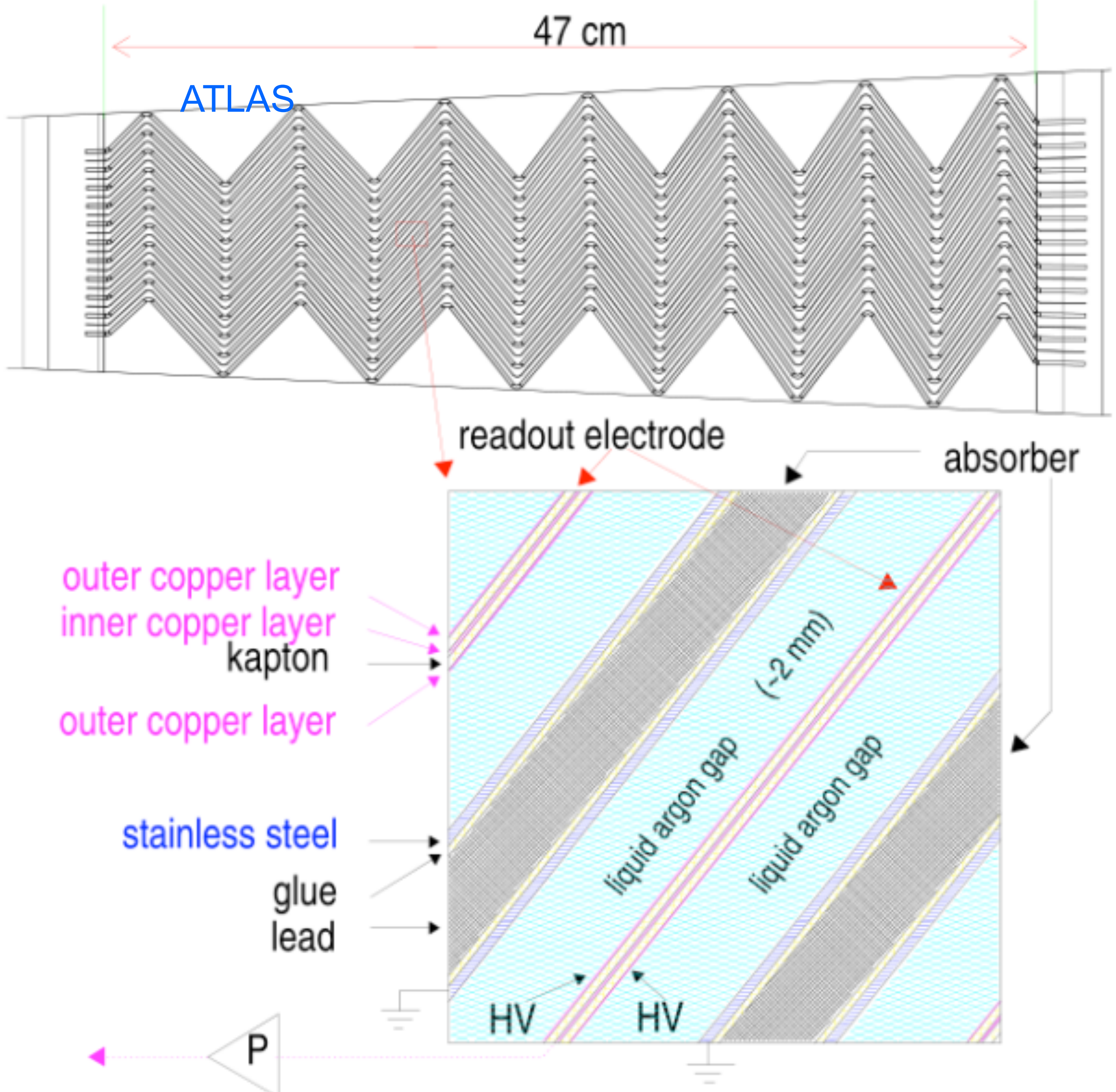
Backward BEC + BHC:

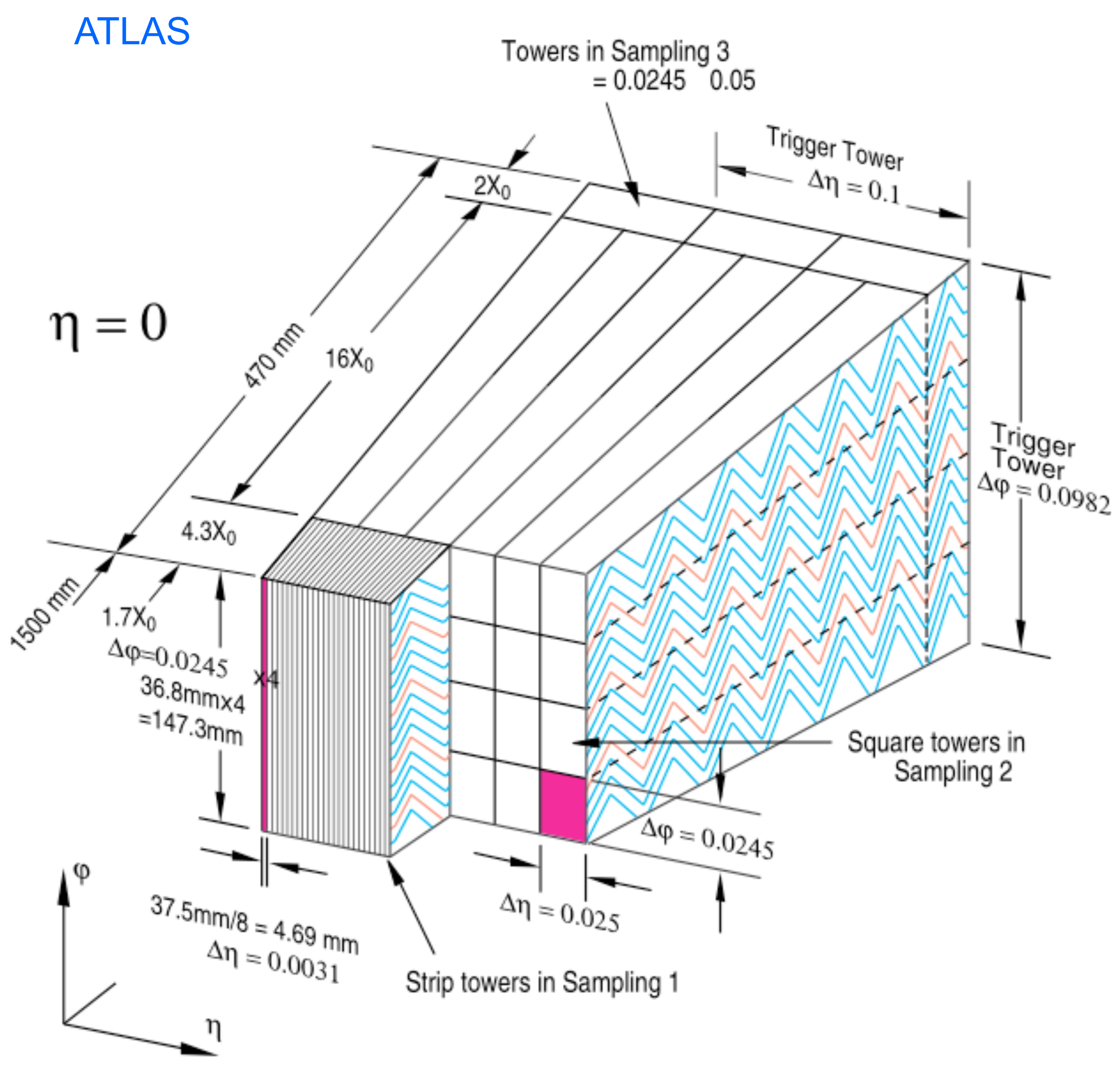
- need precise electron tagging
- Si-Pb, Si-Fe (~25X_0, 6-9 λ_I)



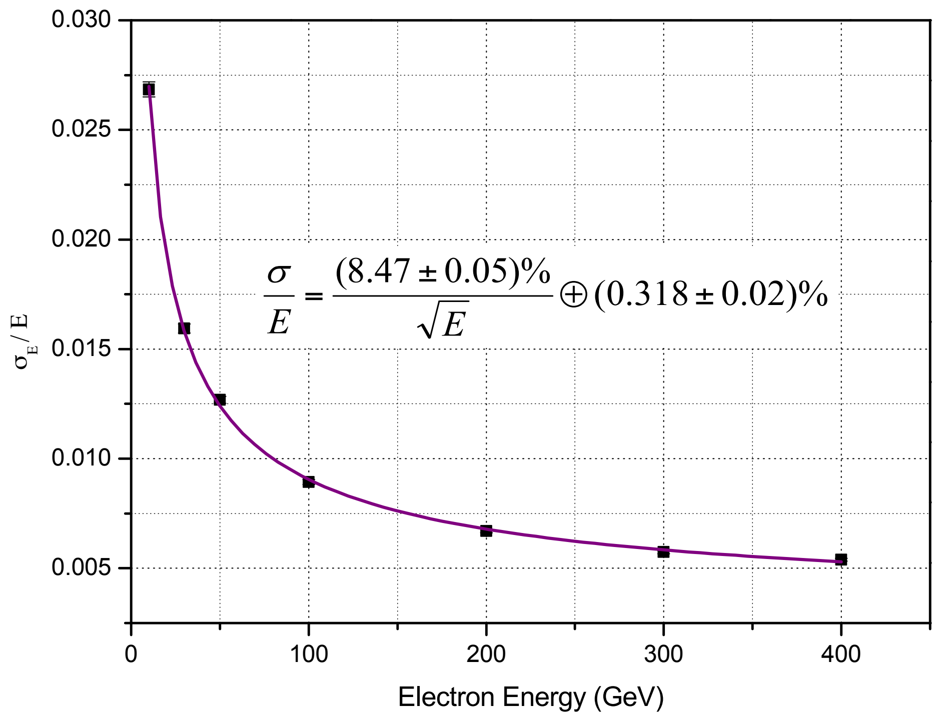
ECAL-LAr Barrel

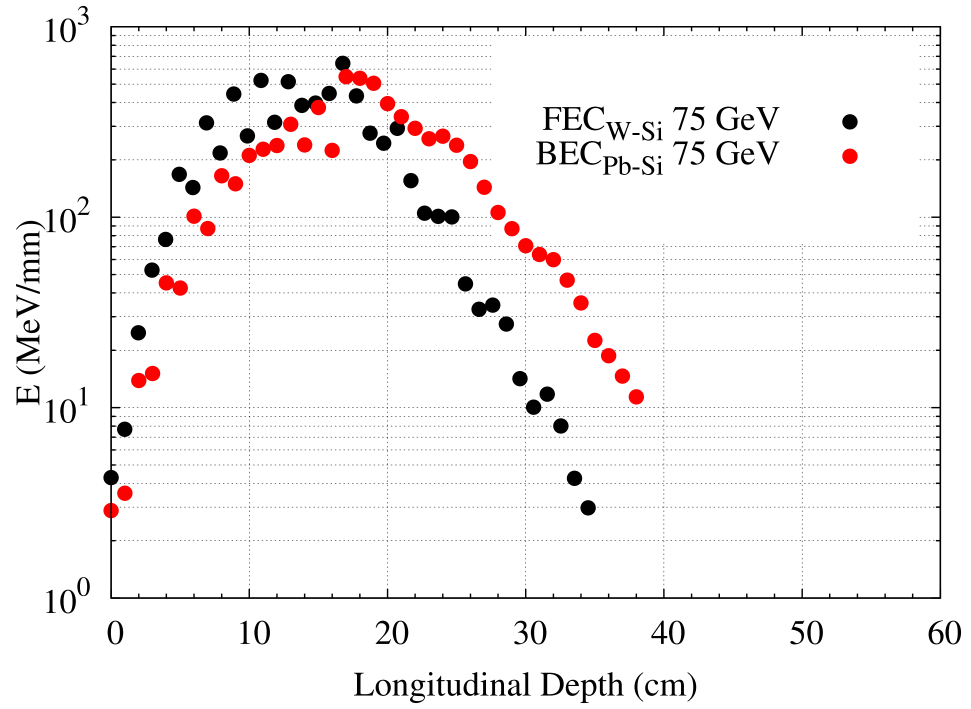




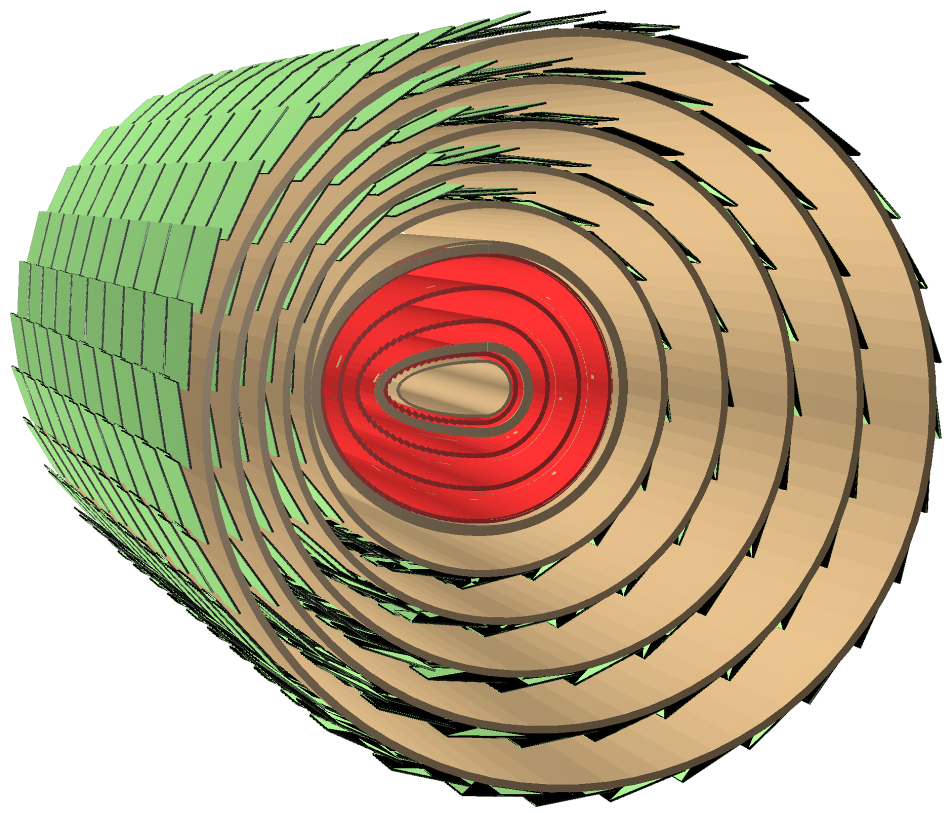


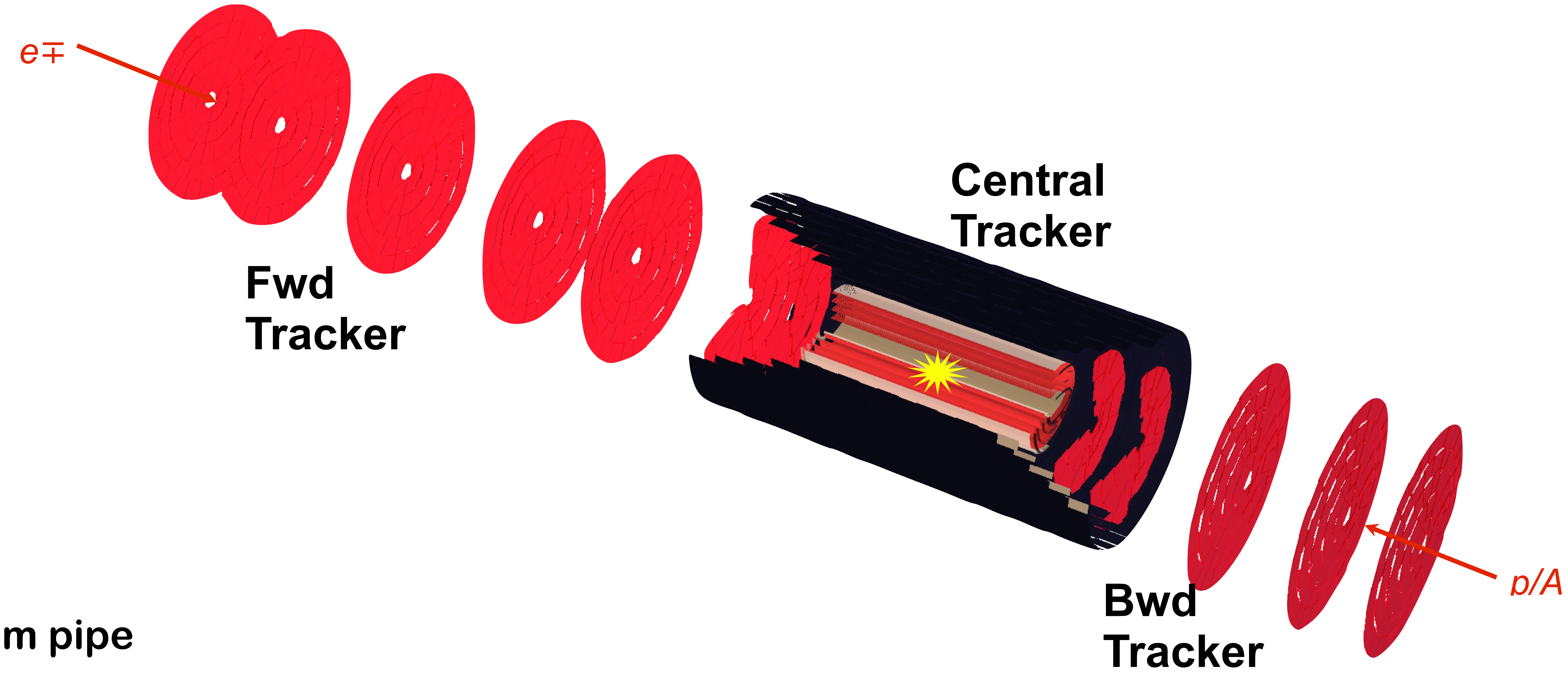
- LAr for barrel EMCal – ATLAS (28-30 X_0)
- Same cryostat used for inner solenoid and dipoles
- Simulation results compatible with ATLAS
- 3 different granularity sections longitudinally
- Warm (Pb/Sci) option also investigated $30X_0$ (X_0(Pb)=0.56 cm; 20 layers)





LHeC Track-Detector CDR Layout





Central Tracker
circular-elliptical beam pipe
4 layers Si-pixel
5 layers Si-macro_pixel

(see Table of Detector Dimensions/Parameters - a bit outdated

LHeC Detector Basic Element Layout- prel.

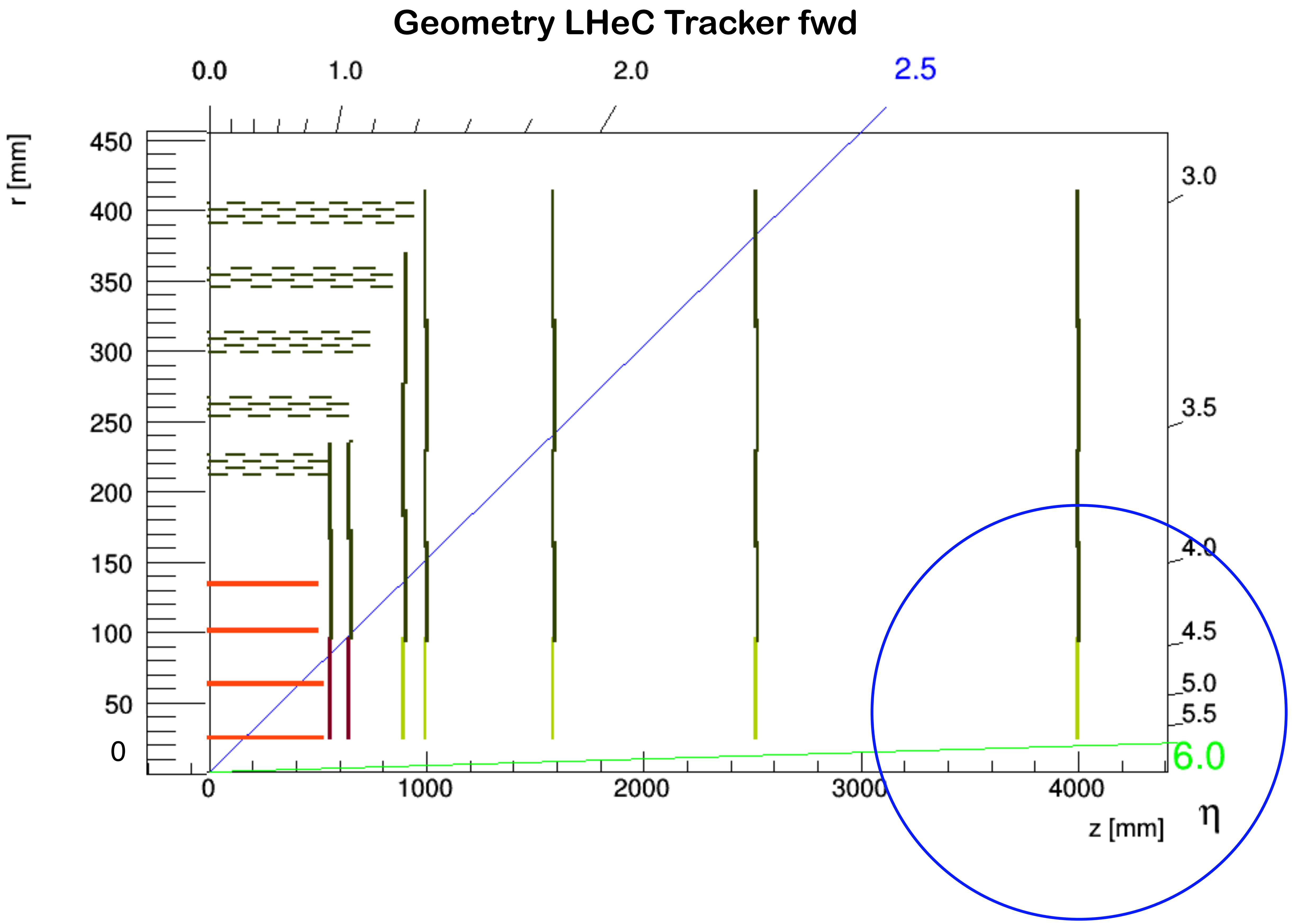
LHeC

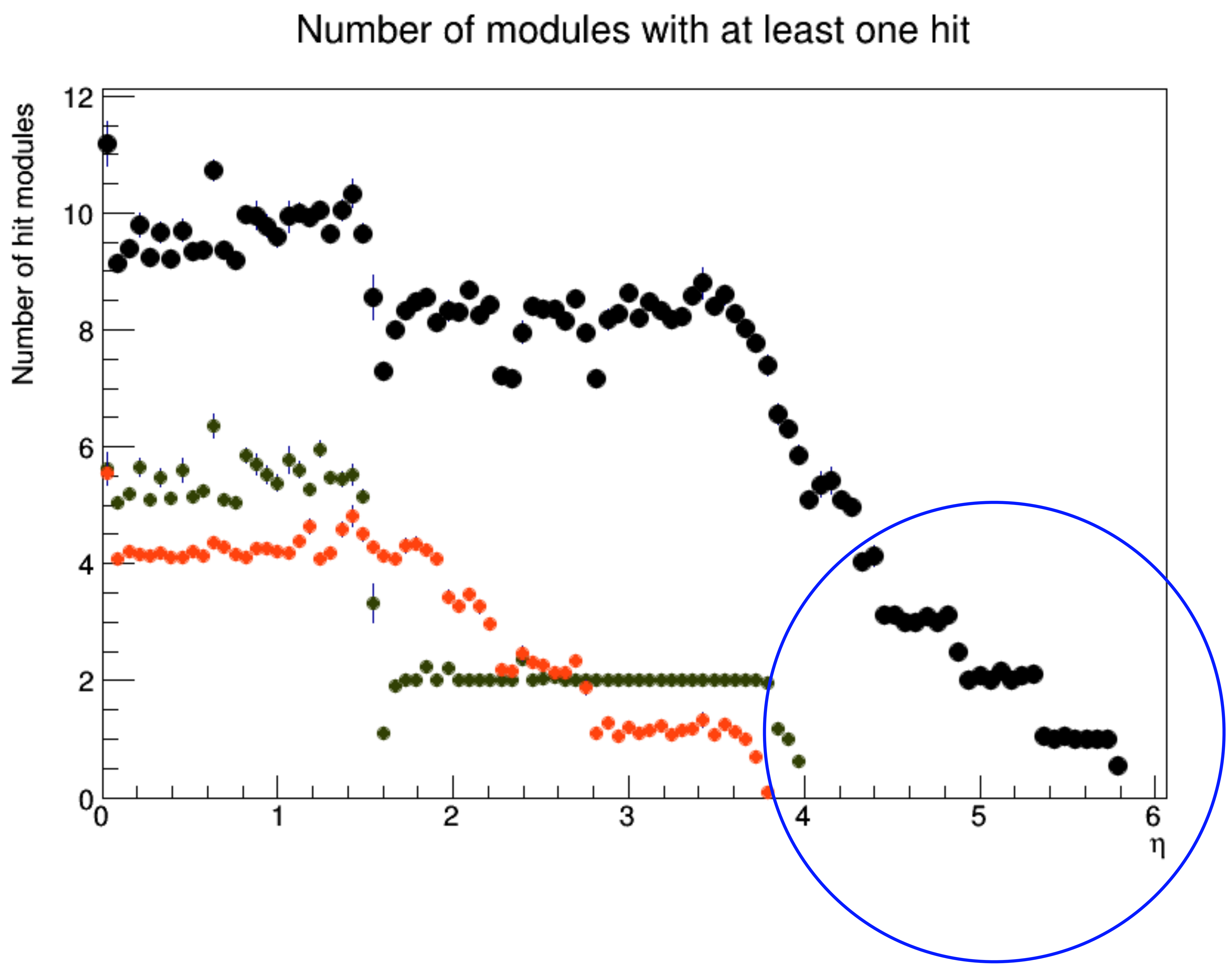
Tracker	FST_{pix}	FST_{strix}	CFT_{pix}	CPT_{pix}	CST_{strix}	CBT_{pix}	BST_{strix}	BST_{pix}
#Wheels	5		2	–	–	2	3	
#Rings/Wheel	2_{inner}	3_{outer}	3/4	–	–	3/4	3_{outer}	2_{inner}
#Layers	–	–	–	4	5	–	–	–
$\theta_{min/max}$ $[^0]$	0.7	3.8	3.0	5.1	24/155	177.8	173.1	178.7
$\eta_{max/min}$	5.1	3.4	3.6	±3.1	±1.4	-3.6	-2.8	-4.5
$Si_{pix/strix}$ $[m^2]$	6.9	9.5	2.8	5.4	33.7	2.8	5.7	4.1
Sum-Si $[m^2]$	70.9 double layers taken into account							

Calo	FHC_{SiW}	FEC_{SiW}	$EMC_{SciPb/LAr}$	HAC_{SciFe}	BEC_{SiPb}	BHC_{SiFe}
$\theta_{min/max}$ $[^0]$	0.61	0.68	8/166	14.2/160	178.7	178.9
$\eta_{max/min}$	5.2	5.1	2.7/-2.1	2.1/-1.7	-4.5	-4.7
Volume $[m^3]$	6.7	1.6	15.1	165	1.6	5.8
Sum-Si $[m^2]$	197.4					

being updated

LHeC Track-Detector CDR Layout - Using tklayout*





Average Radiation Length [%] 22.16
Average Interaction Length [%] 10.89

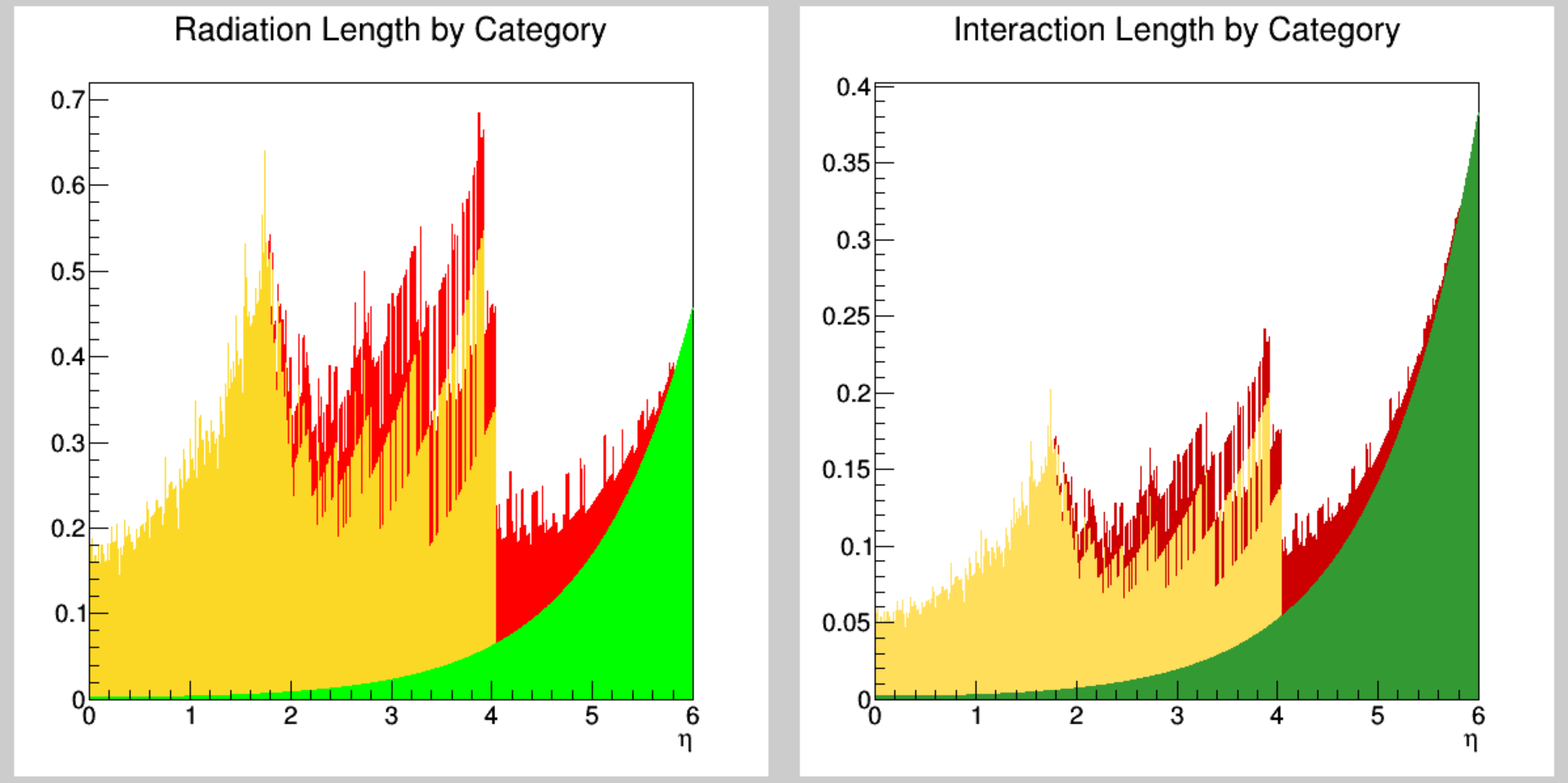
FCC-hh pixel, macro_pixel wafers / dimensions materials used; Be-beam-pipe 3.5mm thickness Solenoidal field 3.5T

*) Zbynek Drasal https://github.com/drasal/tkLayout/tree/masterLite

LHeC Track-Detector - Material Allocation

Material overview by category

Average	Radiation length [%]	Interaction length [%]
Beam pipe (green)	7.63	6.39
Barrel modules (yellow)	15.88	4.92
Endcap modules (red)	5.88	1.82
Total	29.40	13.14

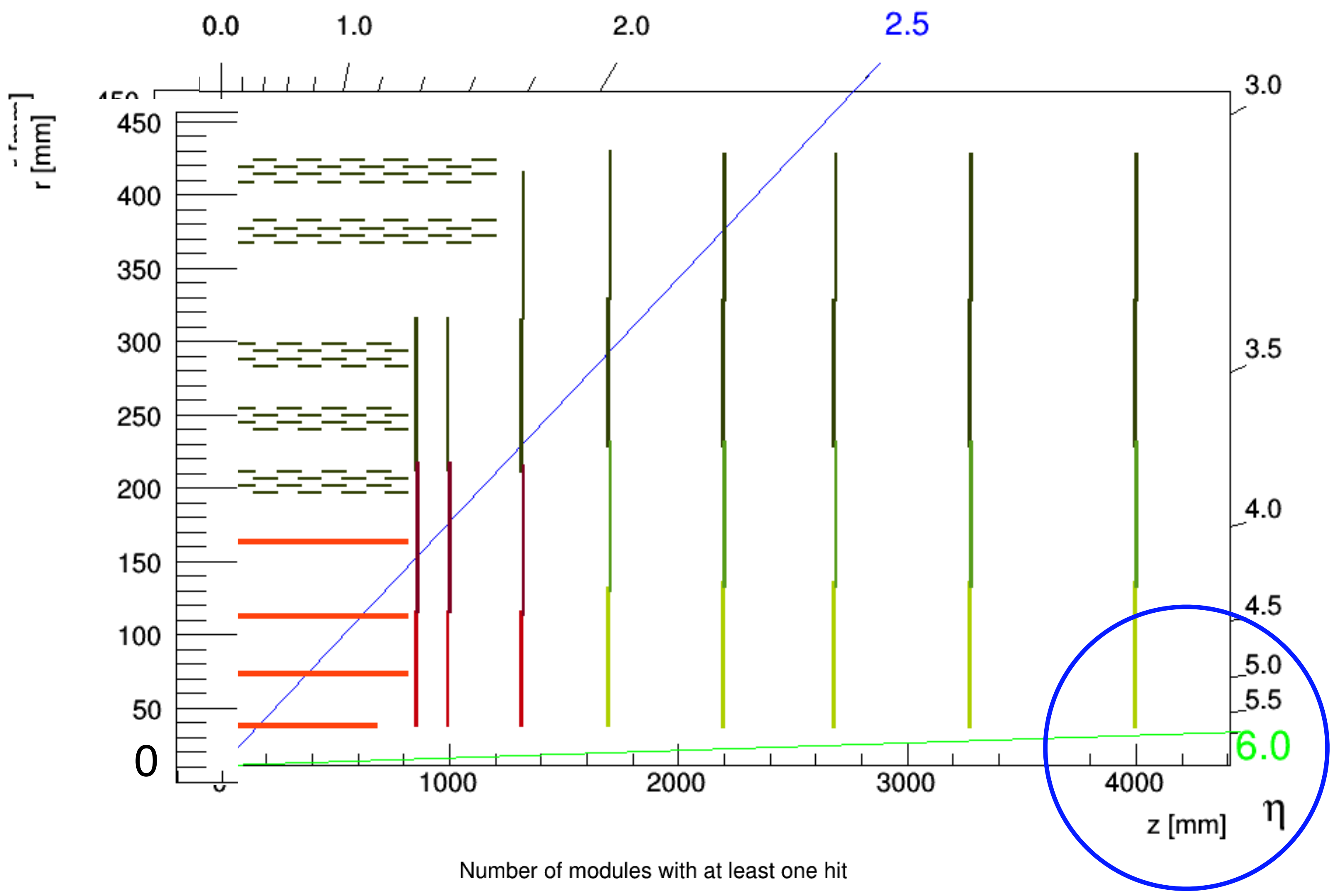


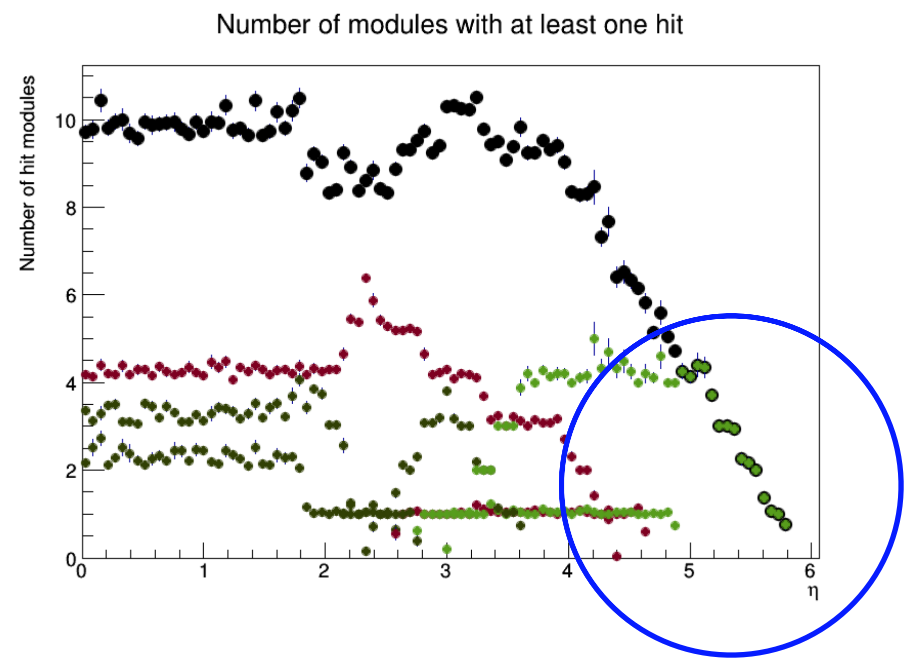
*) Zbynek Drasal https://github.com/drasal/tkLayout/tree/masterLite

Tracker Design (fwd) Optimisation 1 - Using tklayout*

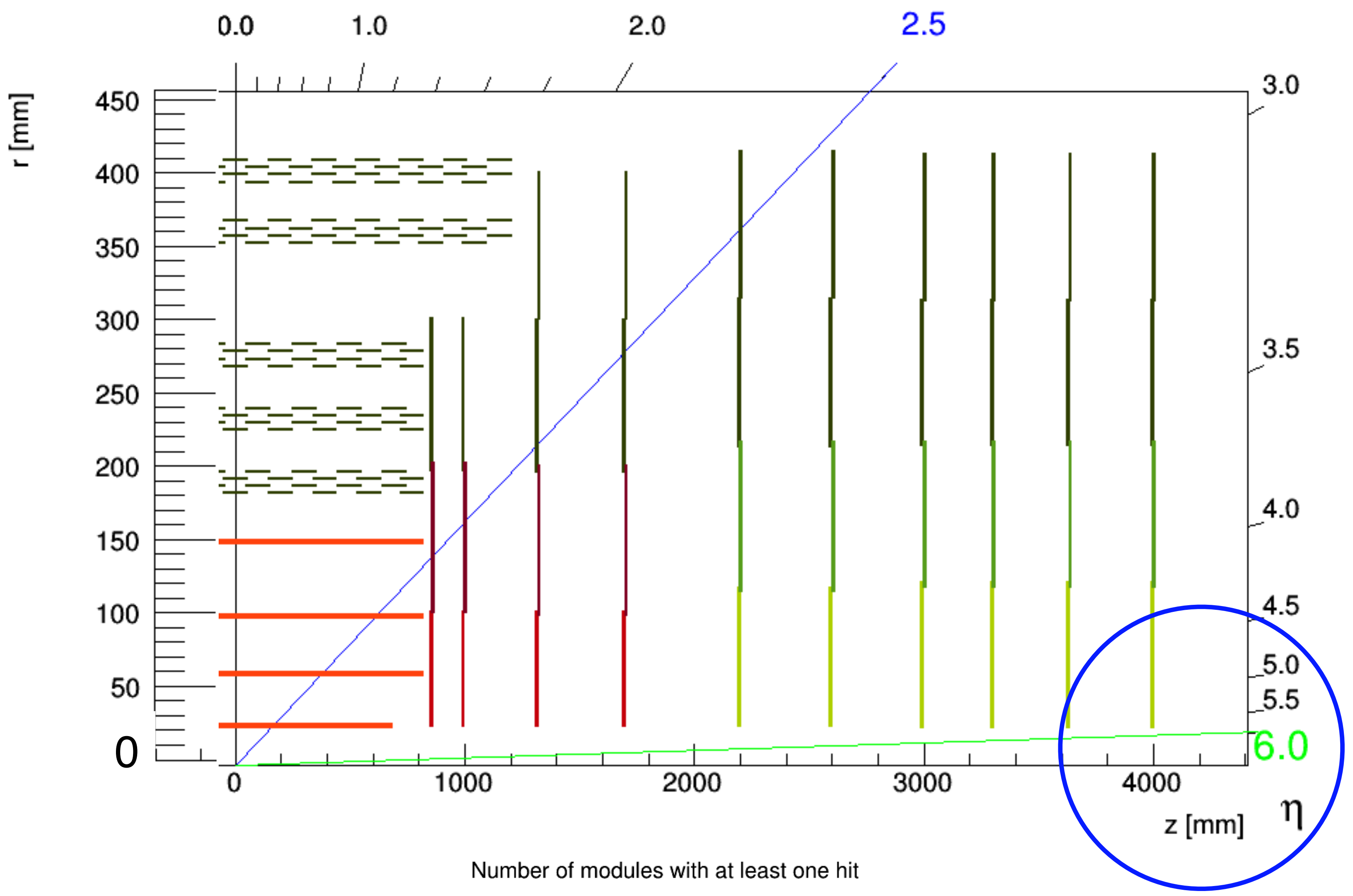
Planar Ring Version - prel.

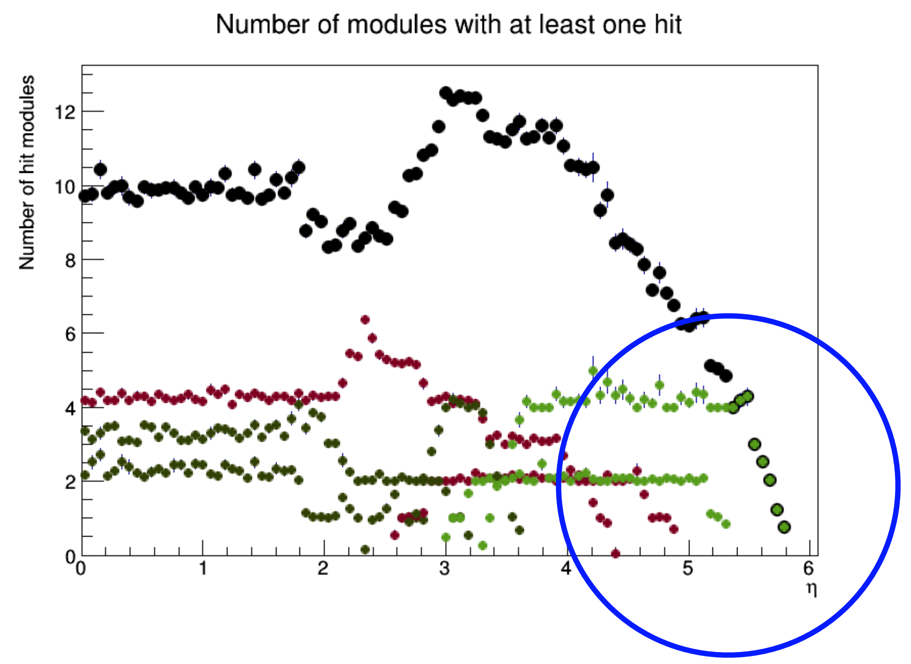
LHeC (fwd) Tracker



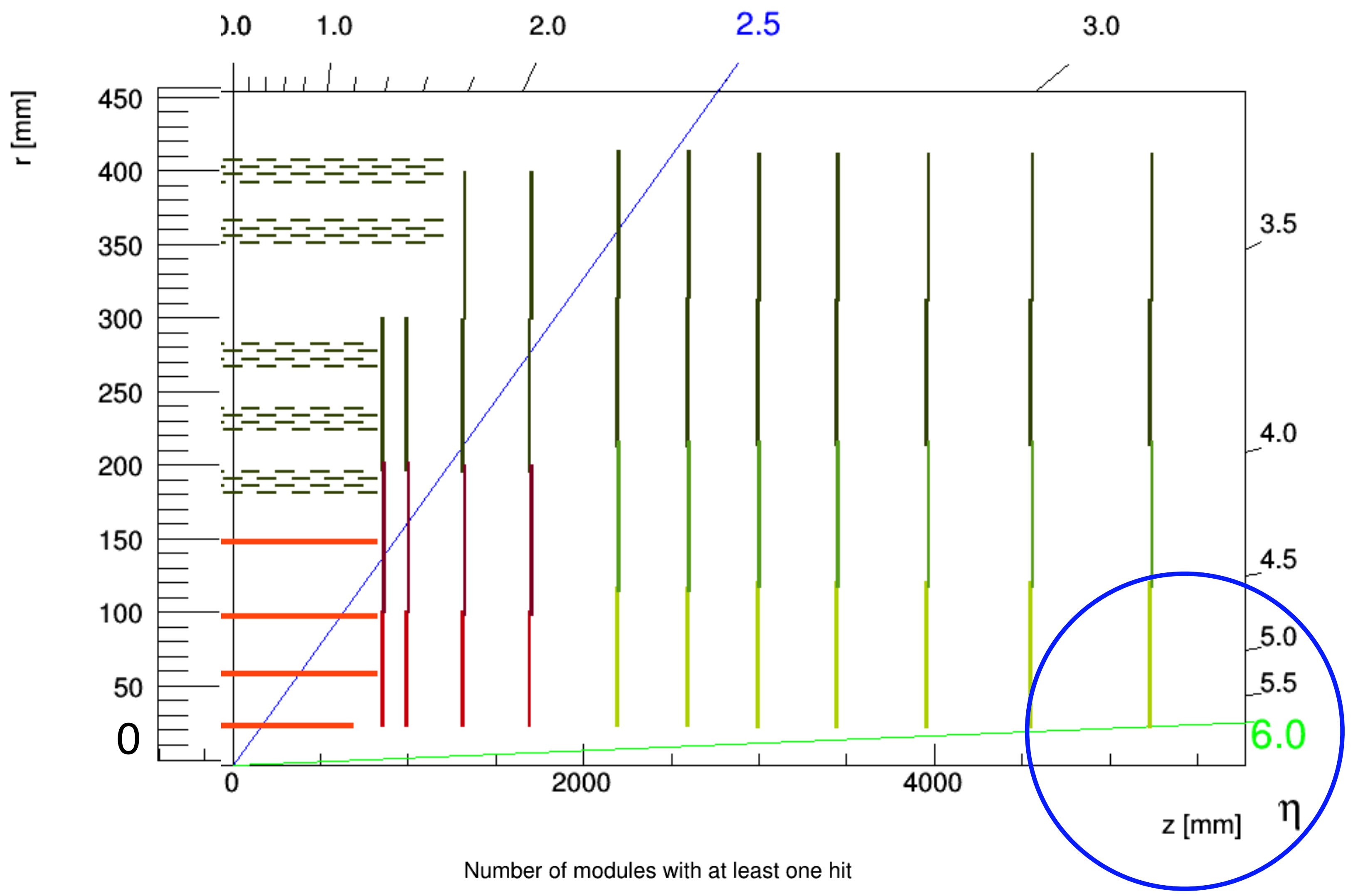


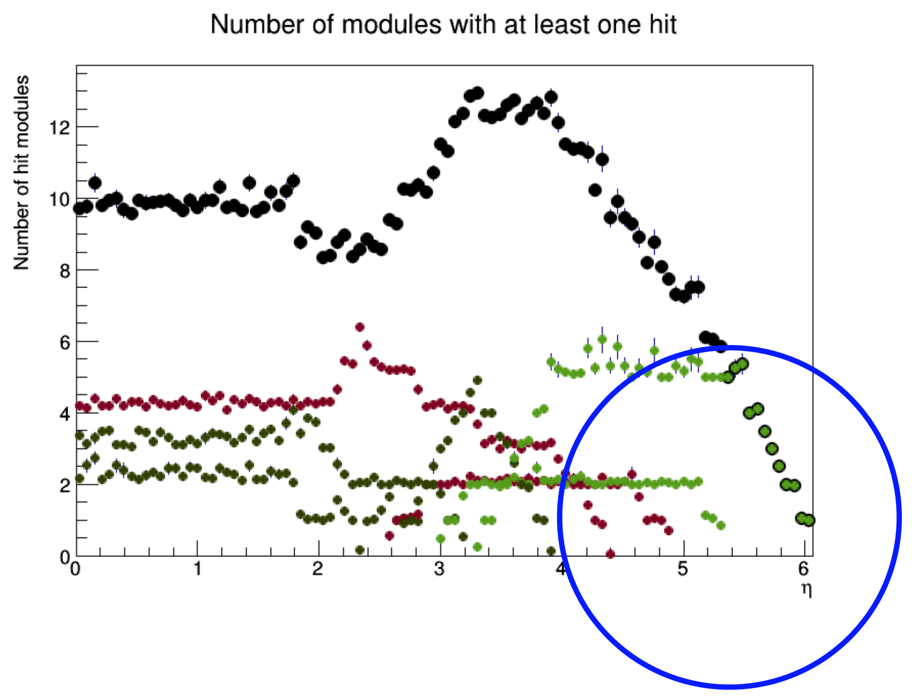
HE-LHeC (fwd) Tracker





FCC-eh (fwd) Tracker





Average Radiation Length [%]

	LHeC	HE-LHeC	FCC-eh
Average Radiation Length [%]	Planar 29.40	Planar 30.91	Planar 31.66
Average Interaction Length [%]	Planar 13.14	Planar 13.61	Planar 13.84

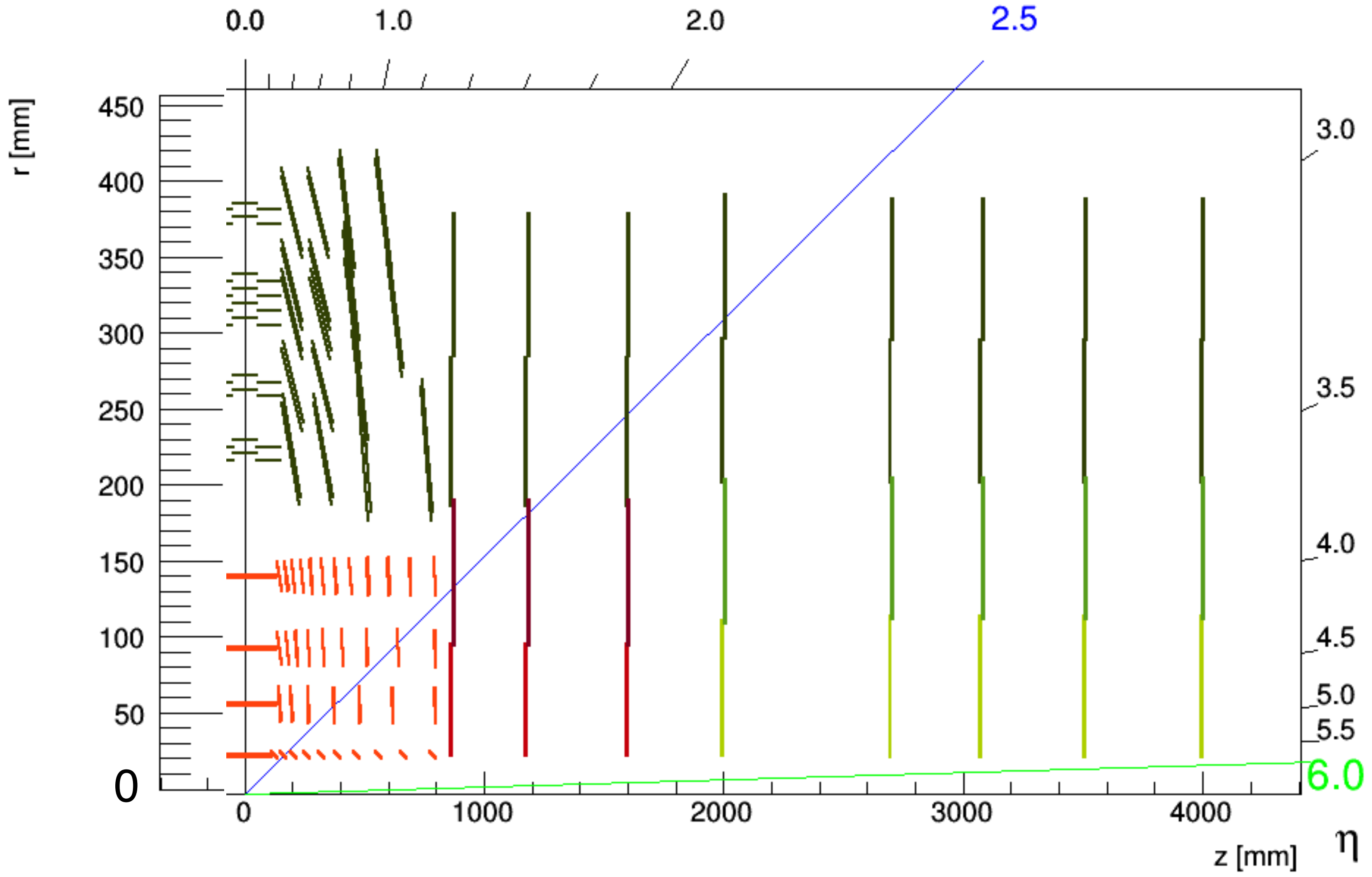
Average Interaction Length [%]

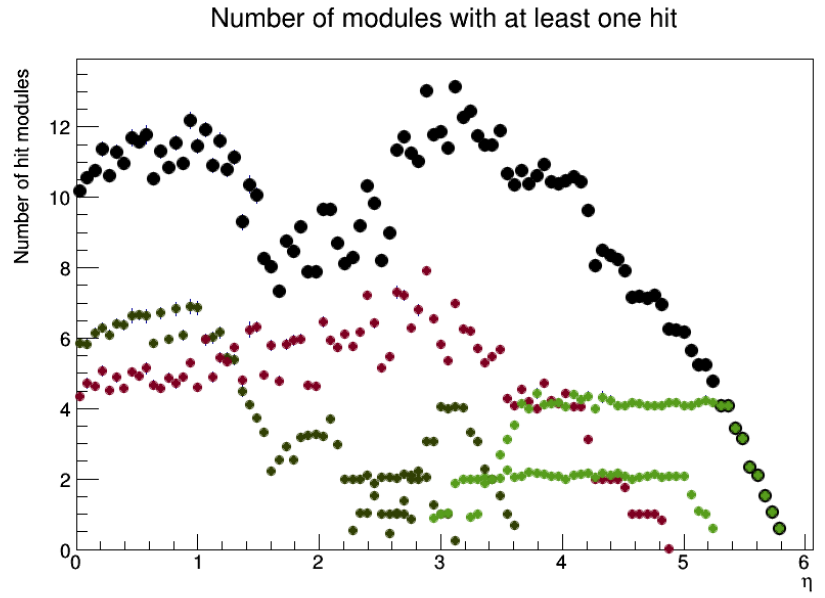
*) Zbynek Drasal https://github.com/drasal/tkLayout/tree/masterLite

Tracker Design (fwd) Optimisation 2 - Using tklayout*

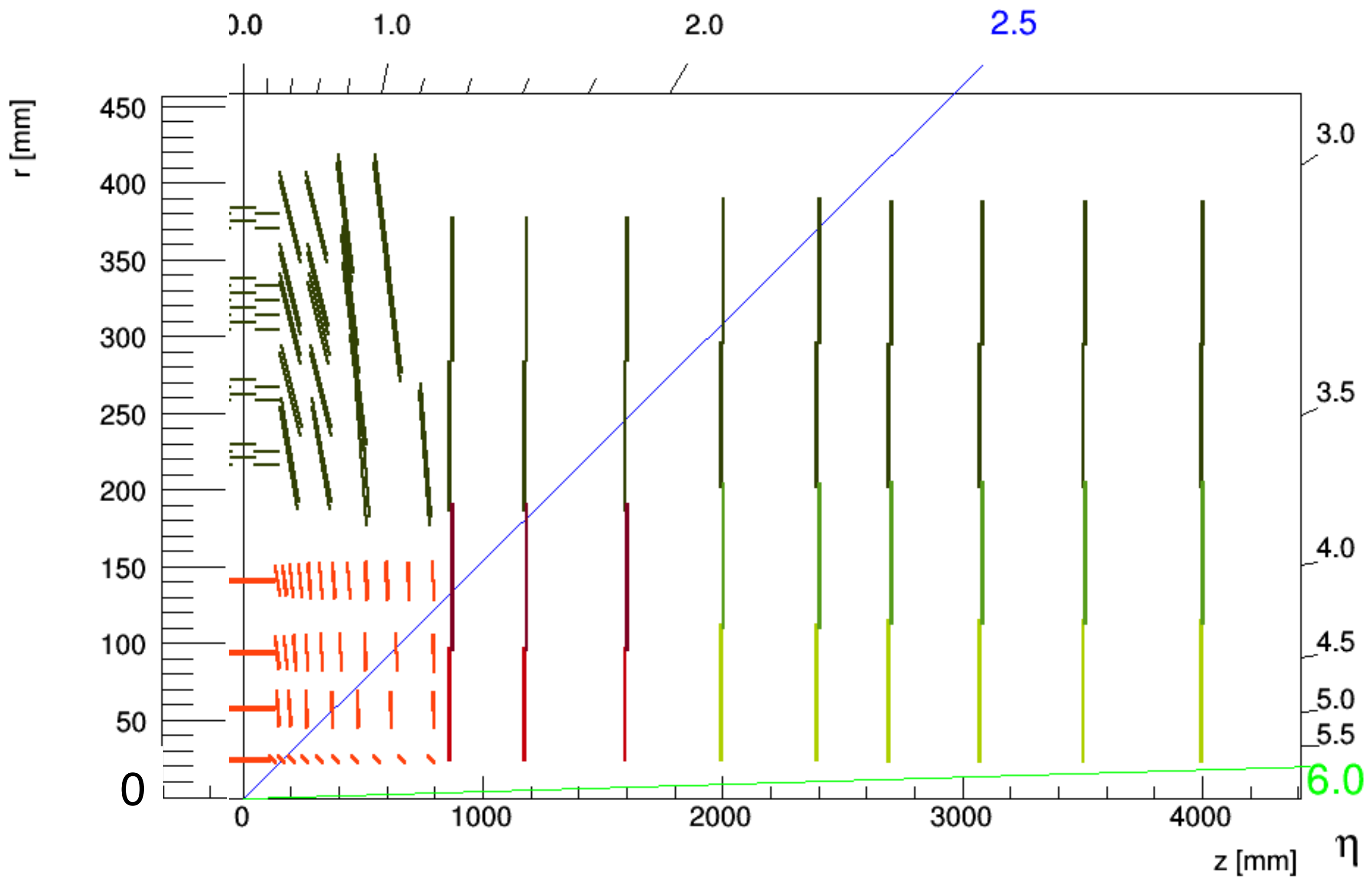
Inclined Ring Version - prel.

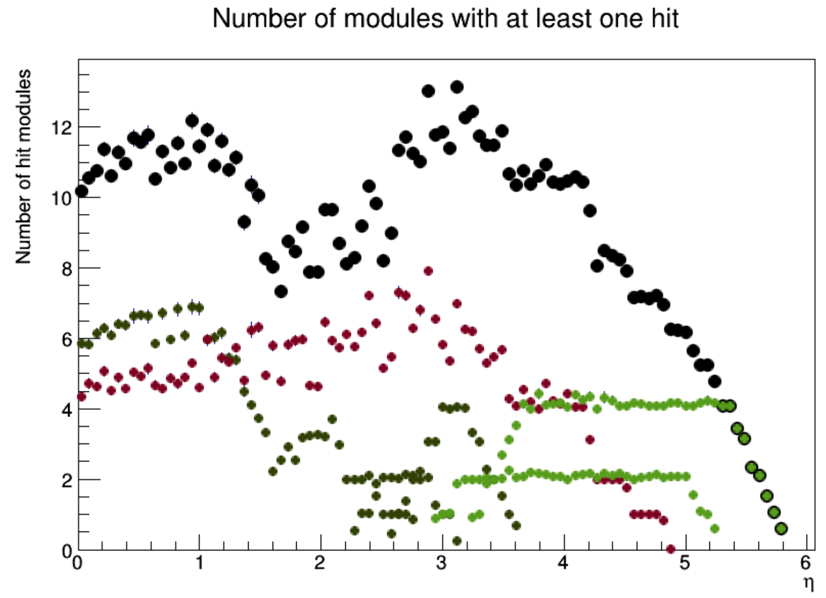
LHeC (fwd) Tracker



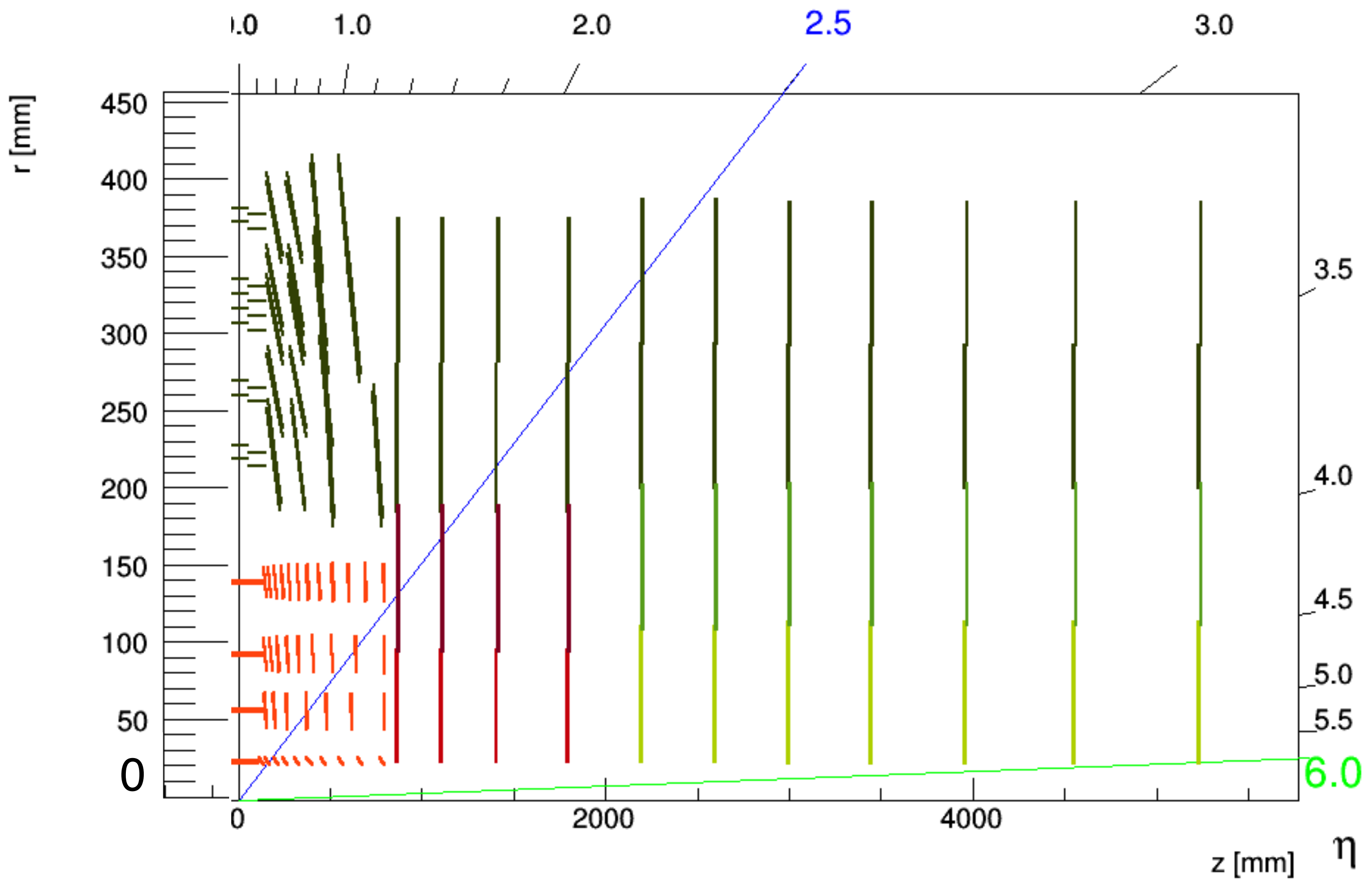


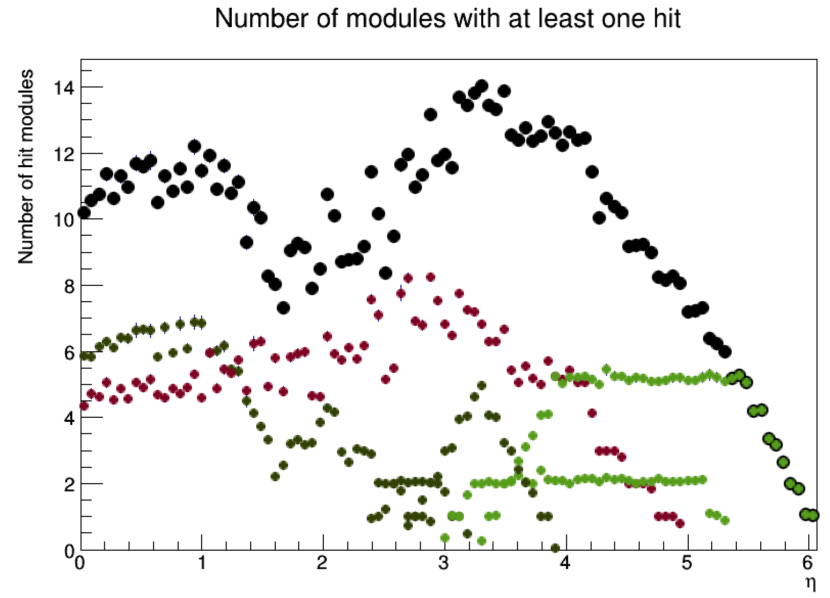
HE-LHeC (fwd) Tracker





FCC-eh (fwd) Tracker





Reduction Average Radiation Length [%]

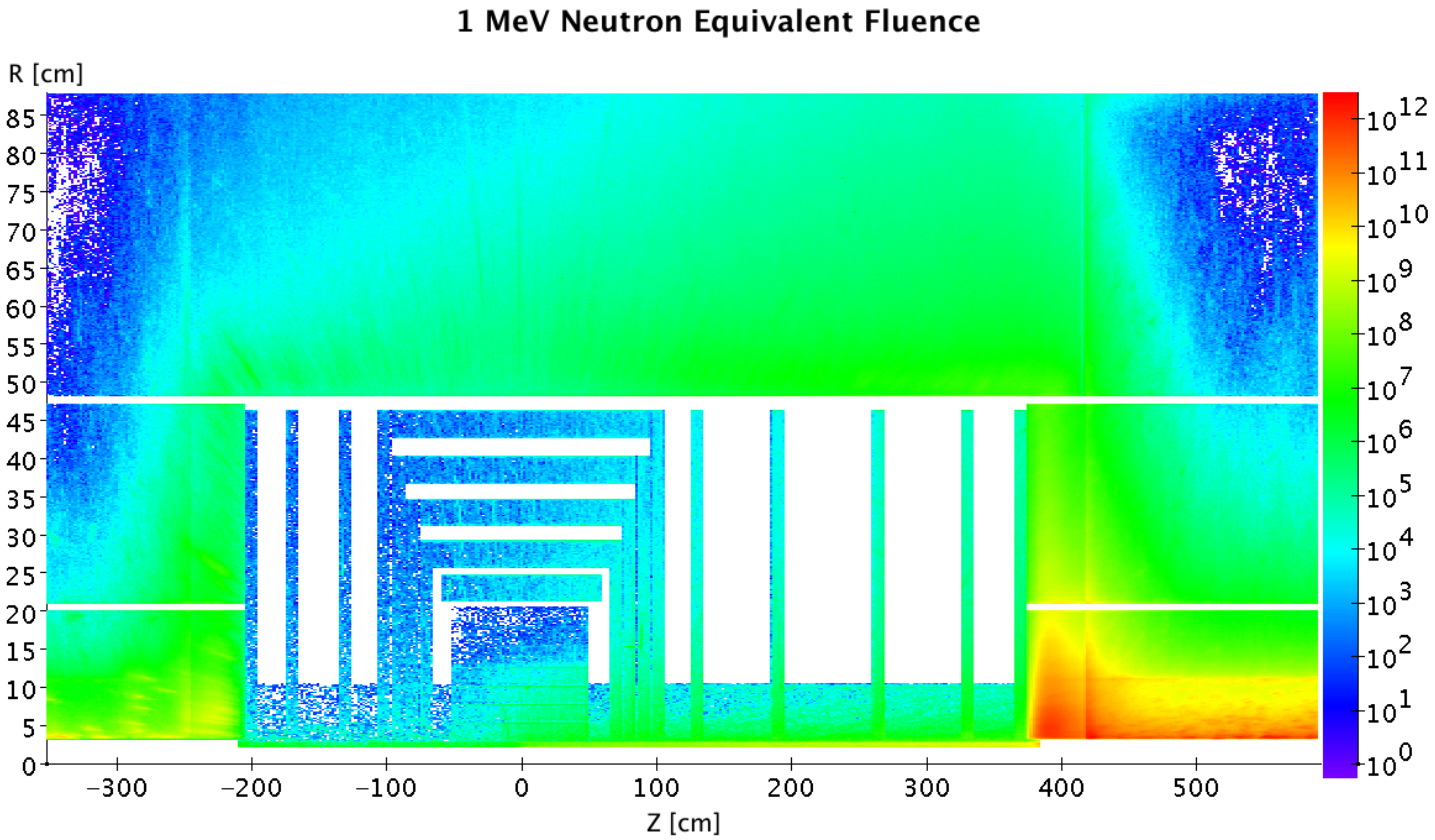
	LHeC	HE-LHeC	FCC-eh
Radiation Length	Planar 29.40 → Inclined 21.93	Planar 30.91 → Inclined 22.75	Planar 31.66 → Inclined 24.24

Reduction Average Interaction Length [%]

	LHeC	HE-LHeC	FCC-eh
Interaction Length	Planar 13.14 → Inclined 10.82	Planar 13.61 → Inclined 11.08	Planar 13.84→ Inclined 11.54

*) Zbynek Drasal https://github.com/drasal/tkLayout/tree/masterLite

LHeC - Radiation Load - Tracker (CDR design)



Central Barrel			
Region	$\Delta Z[cm]$	R_{min} [cm]	Fluence [$\frac{N}{cm^2 yr}$]
CPT1	100	3.1	1.38×10^{10}
CPT2	100	5.6	9.99×10^9
CPT3	100	8.1	8.26×10^9
CPT4	100	10.6	7.25×10^9
CST1	116	21.2	6×10^9
CST2	128	25.6	5.66×10^9
CST3	148	31.2	5.38×10^9
CST4	168	36.7	5.25×10^9
CST5	188	42.7	5.16×10^9
Central Endcaps			
Region	Z [cm]	ΔR [cm]	Fluence [$\frac{N}{cm^2 yr}$]
CFT1	70	26	8×10^9
CFT2	80	31.6	7.42×10^9
CFT3	90	37.1	7.08×10^9
CFT4	101	43.1	6.93×10^9
CBT1	-70	26	2.77×10^9
CBT2	-80	31.6	2.48×10^9
CBT3	-90	37.1	2.26×10^9
CBT4	-101	43.1	2.09×10^9
Fwd/Bwd Planes			
Region	Z [cm]	ΔR [cm]	Fluence [$\frac{N}{cm^2 yr}$]
FST1	130	43.1	8.2×10^9
FST2	190	43.1	1.14×10^{10}
FST3	265	43.1	1.63×10^{10}
FST4	330	43.1	2.29×10^{10}
FST5	370	43.1	2.75×10^{10}
BST1	-130	43.1	1.96×10^9
BST2	-170	43.1	1.91×10^9
BST3	-200	43.1	1.99×10^9

Expected radiation load defined/influenced by:
interaction rate, luminosity, particle rate per angle interval, fluence n_{eq} and ionisation dose.

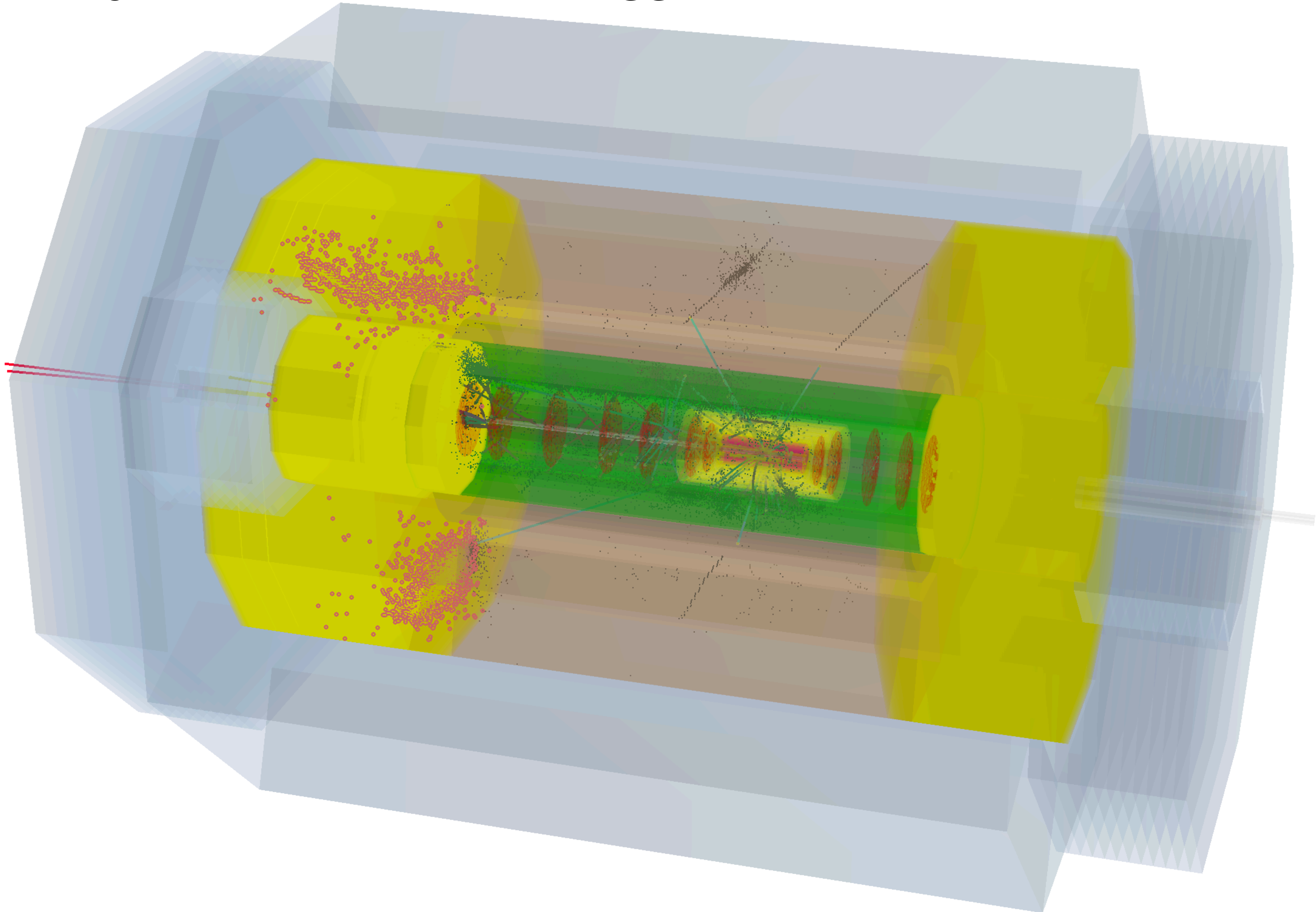
Impact of radiation on
tracker wheels, calorimeter inserts and the inner tracker-barrel layer.

prel. Geant4-Event-Simulations (Pythia6):
→ no indication for extremely high radiation load in the detectors adjacent to the beam pipe.
The expected levels are far below what the LHC experiments have to withstand.

Higgs in LHeC

courtesy U. Klein - Generator input files for simulation

Pythia-event → LHeC-Higgs-bƀ→ DDG4 →LHeC-DDEve



Software DD4Hep/DDG4 based Detector Design / Simulation / Reconstruction Environment
Software for LHeC and HE-LHeC, FCC-eh detectors - DD4hep xml-description adopted only
All calorimeters here set to "warm" option.

Remarks

Based on HERA, LHC, ILC R&D there exist a clear concepts for eh-detectors

Experimental demands are lighter than for pp - reduced radiation level,
no pileup concern and a cleaner final state

Redundant DIS kinematics allows cross calibration & very high precision, such as 0.1% electron energy scale calibration.

Modern technology → high precision tracking and high energy, O(10) TeV, fwd particle and jet reconstruction in ep. R&D for even higher energies ongoing.

Specific eh demands are the 3-beam IR for synchronous ep/eA and pp/pA operation and the need to bend the e-beam for head-on collision with the p/A beam.

The Higgs and top studies → higher demand on the fwd acceptance and spatial and energy jet resolutions lead to current developments beyond the 2012 LHeC CDR.

After the Higgs discovery, LHeC + HE-LHC (FCC-eh) designs upgraded to O(10^{34}) luminosity
→ ep precision Higgs facilities! (see talks yesterday)

Summary and Outlook

Status

- With the CDR an LHeC baseline detector concept had been worked out
- The design depends heavily on the constraints from the machine and interaction region
- As a baseline many improvements available now. A more precise design will follow from more detailed simulations, engineering and the knowledge of the machine constraints
- The HE-LHeC/FCC-he extends the physics reach and the phase space of the investigation.

- Nonetheless it brings along also questions and design aspects which need to be sorted out:
  - Interaction region (input from Accelerator Group required)
  - LHeC 3 beams, dipole along the interaction region
  - Timeline: HL-LHC / HE-LHC and FCC-hh concurrent operation

The Future

- Aim for a full LHeC / HE-LHeC / FCC-he detector / physics simulation framework
  Switch from DD4hep+DDG4 to FCCSW framework (access to FLUKA for eA, especially)
  Closing the loop: Detector design → Simulation → Analysis → Design optimisation ↩

- Much more work needed:
  - Synergy with other R&D and running experiments required
  - Manpower needed and budget for these projects allocated; Join the effort, please!

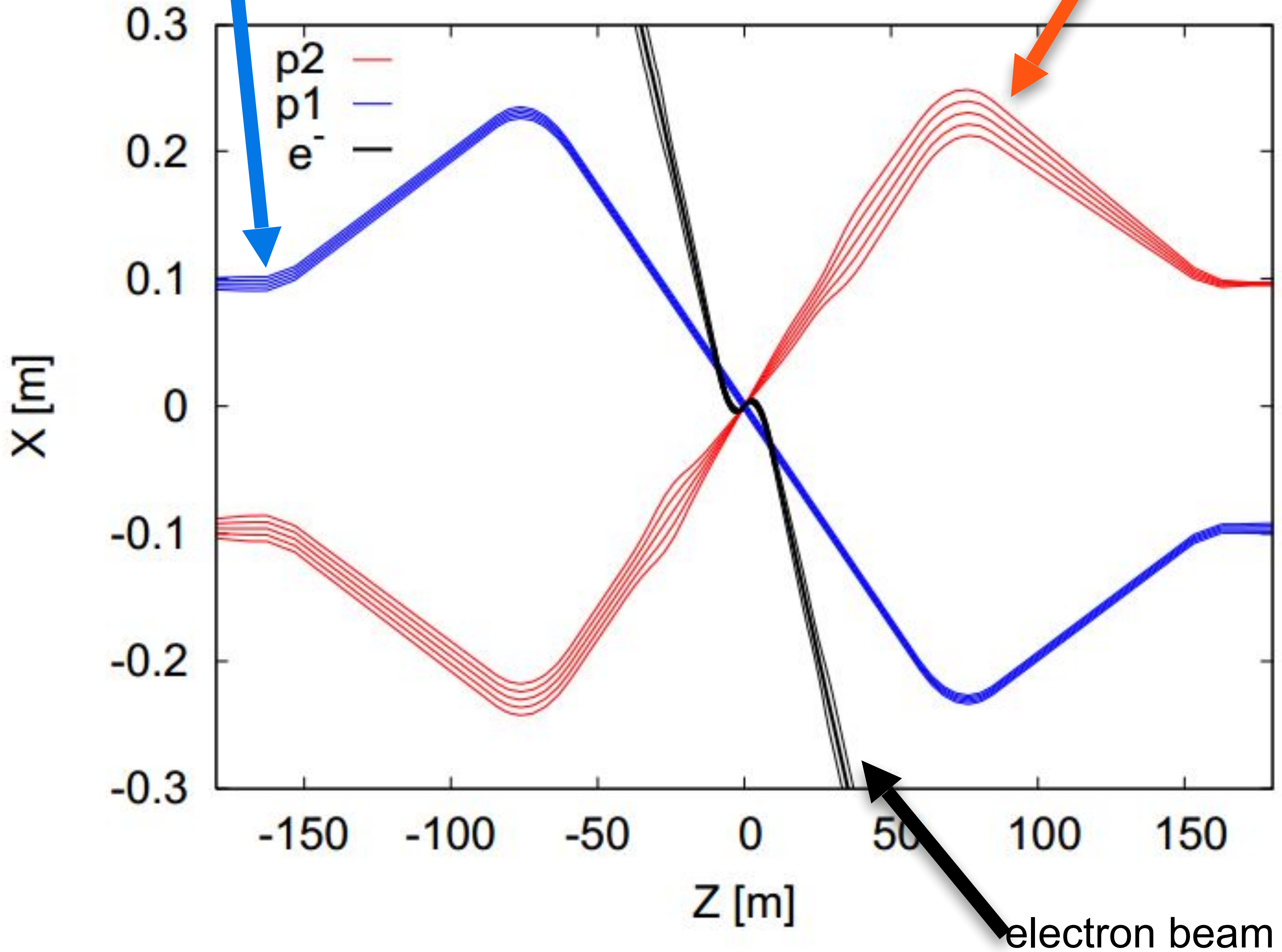
- Updated LHeC/FCC-he CDR by 2018

Backup

LHeC/FCC-eh Interaction Region

non focused
beam
bypasses
the interaction

focused interacting
proton beam



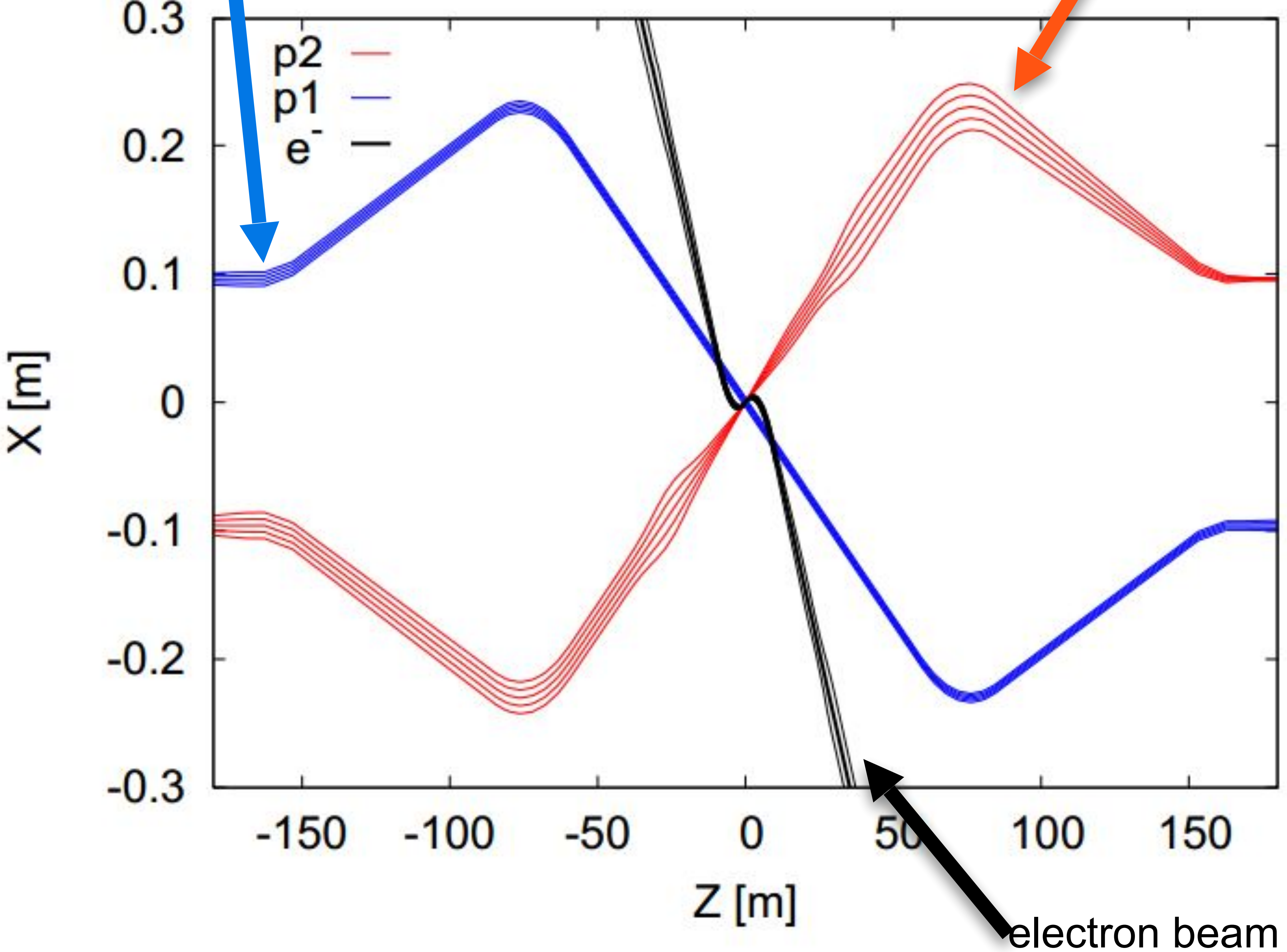
electron beam
from ERL

E. Cruz, R. Tomas, F. Zimmermann et al.

LHeC/FCC-eh Interaction Region

non focused beam bypasses the interaction

focused interacting proton beam

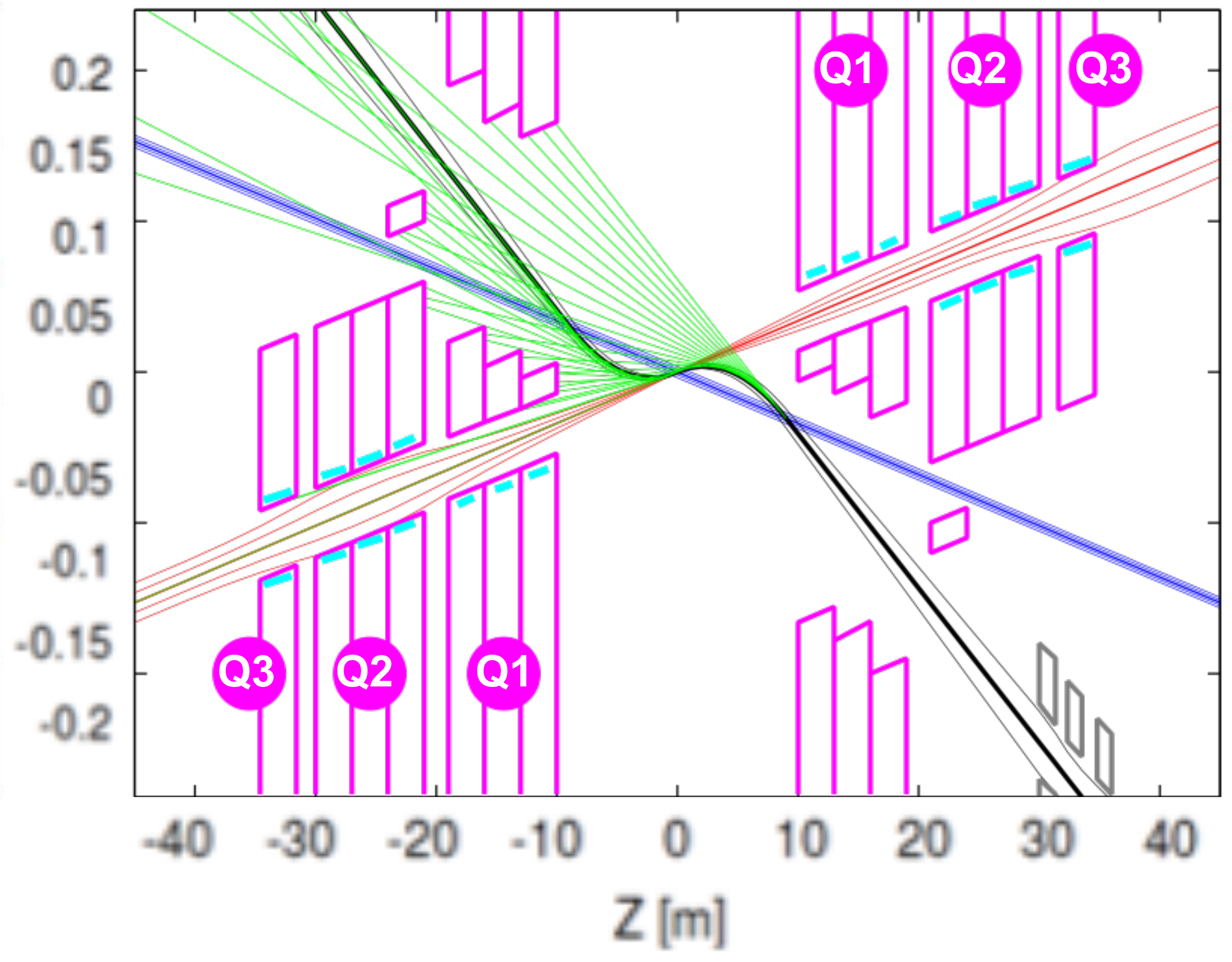


electron beam from ERL

E. Cruz, R. Tomas, F. Zimmermann et al.

Synchrotron Radiation and various beams

SR fan



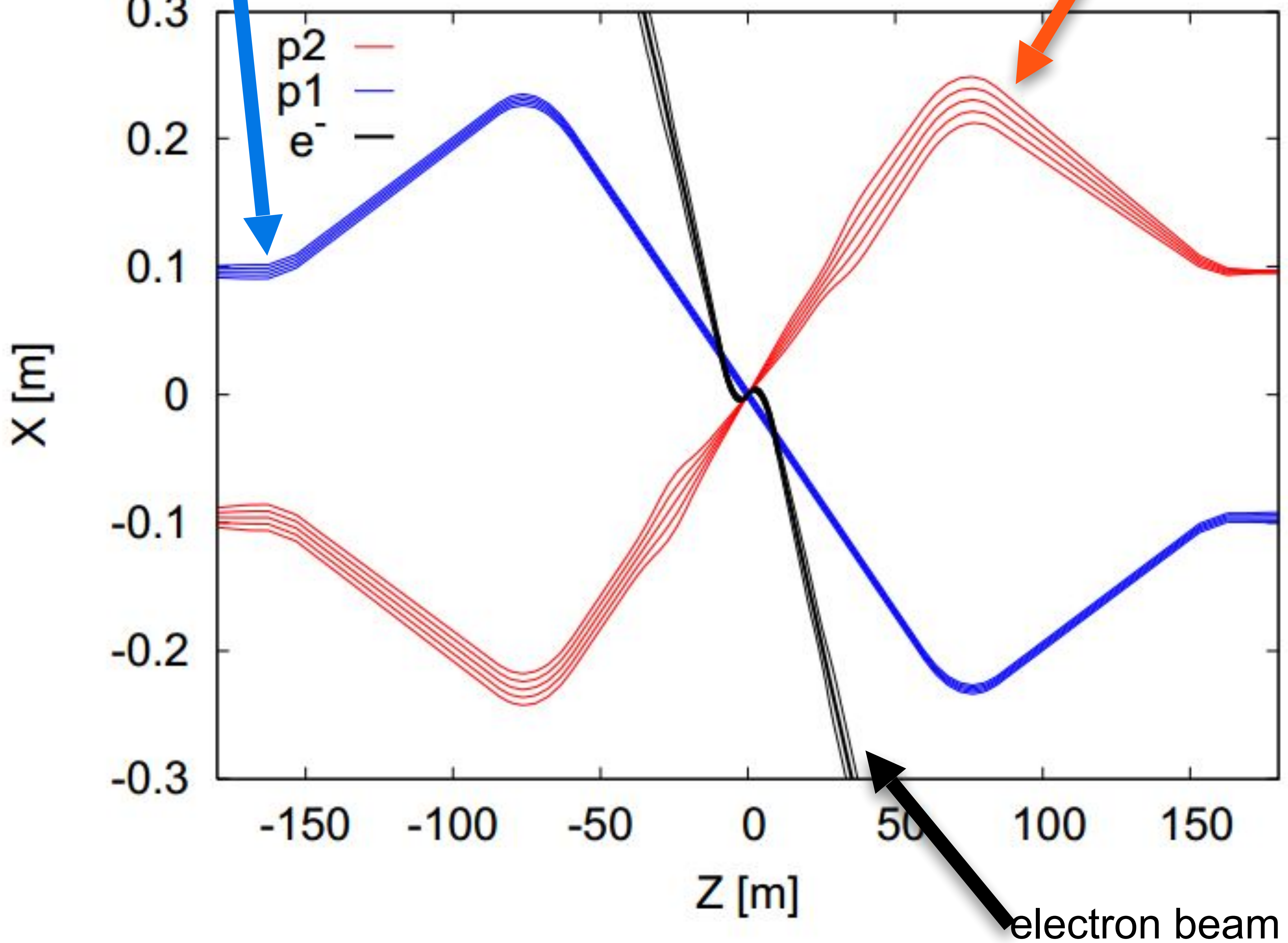
Tentative: ε_p=2µm, β*=20cm → σ_p=3µm ≈σ_e matched! ε_e=5µm ..

electron proton beams well matched!

LHeC/FCC-eh Interaction Region

non focused beam bypasses the interaction

focused interacting proton beam



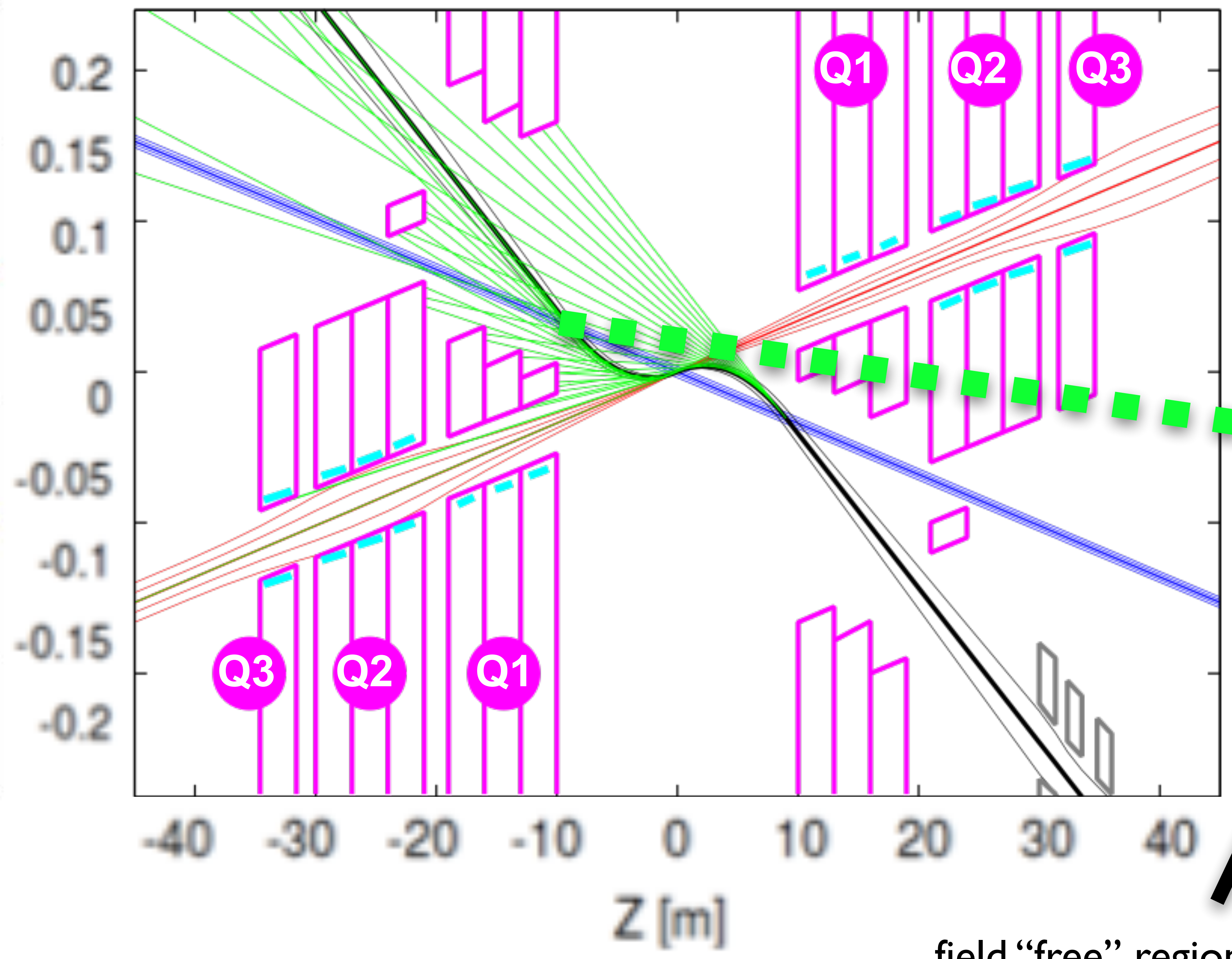
electron beam from ERL

E. Cruz, R. Tomas, F. Zimmermann et al.

Synchrotron Radiation and various beams

SR fan

exit hole - electrons and non-colliding protons

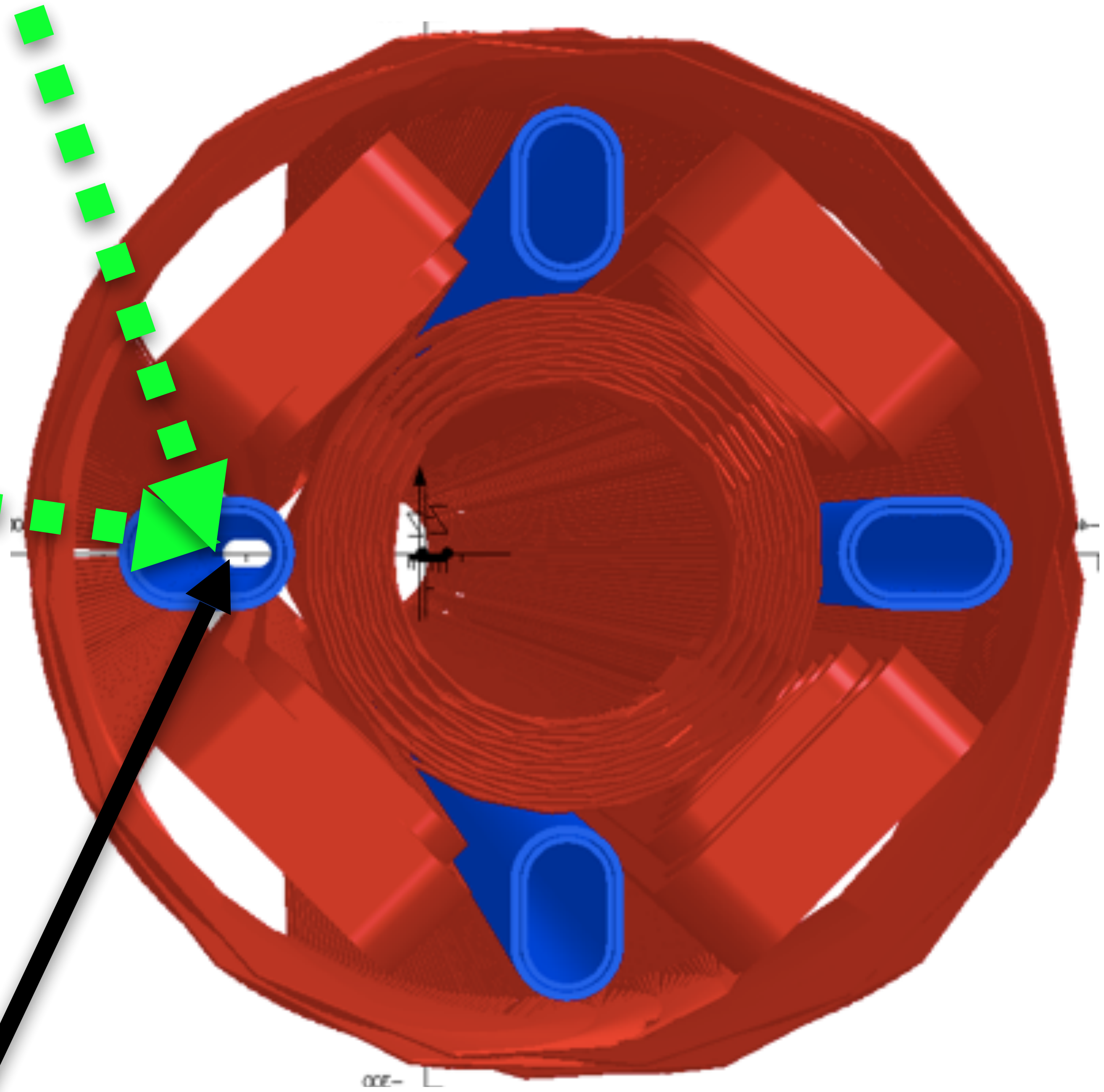


Tentative: ε_p=2µm, β*=20cm → σ_p=3µm ≈σ_e matched! ε_e=5µm ..

electron proton beams well matched!

Final quadrupole magnet Q1 example design

"sweet spot"



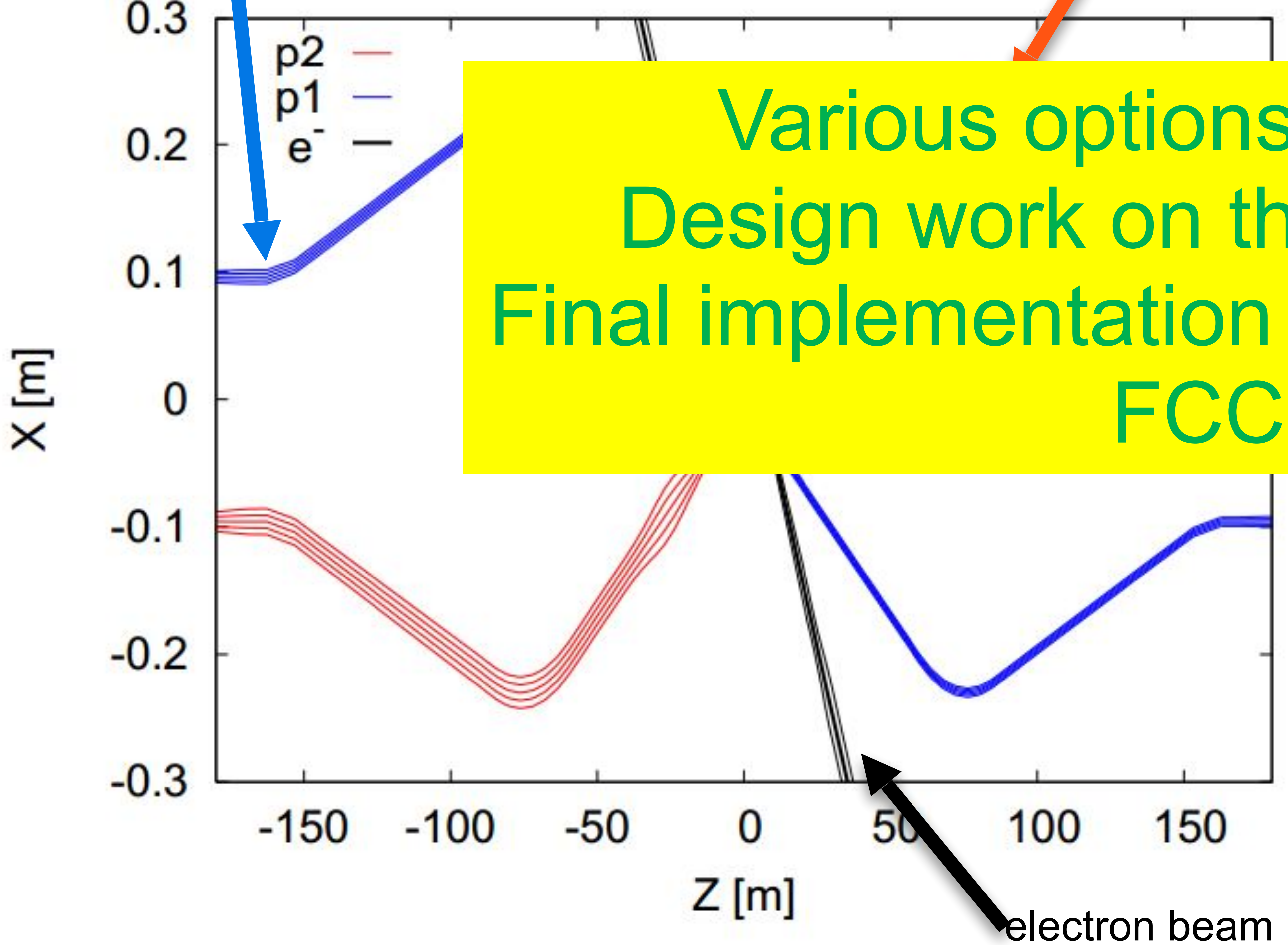
field "free" region

B. Parker, S. Russenschuck et al.

LHeC/FCC-eh Interaction Region

non focused beam bypasses the interaction

focused interacting proton beam



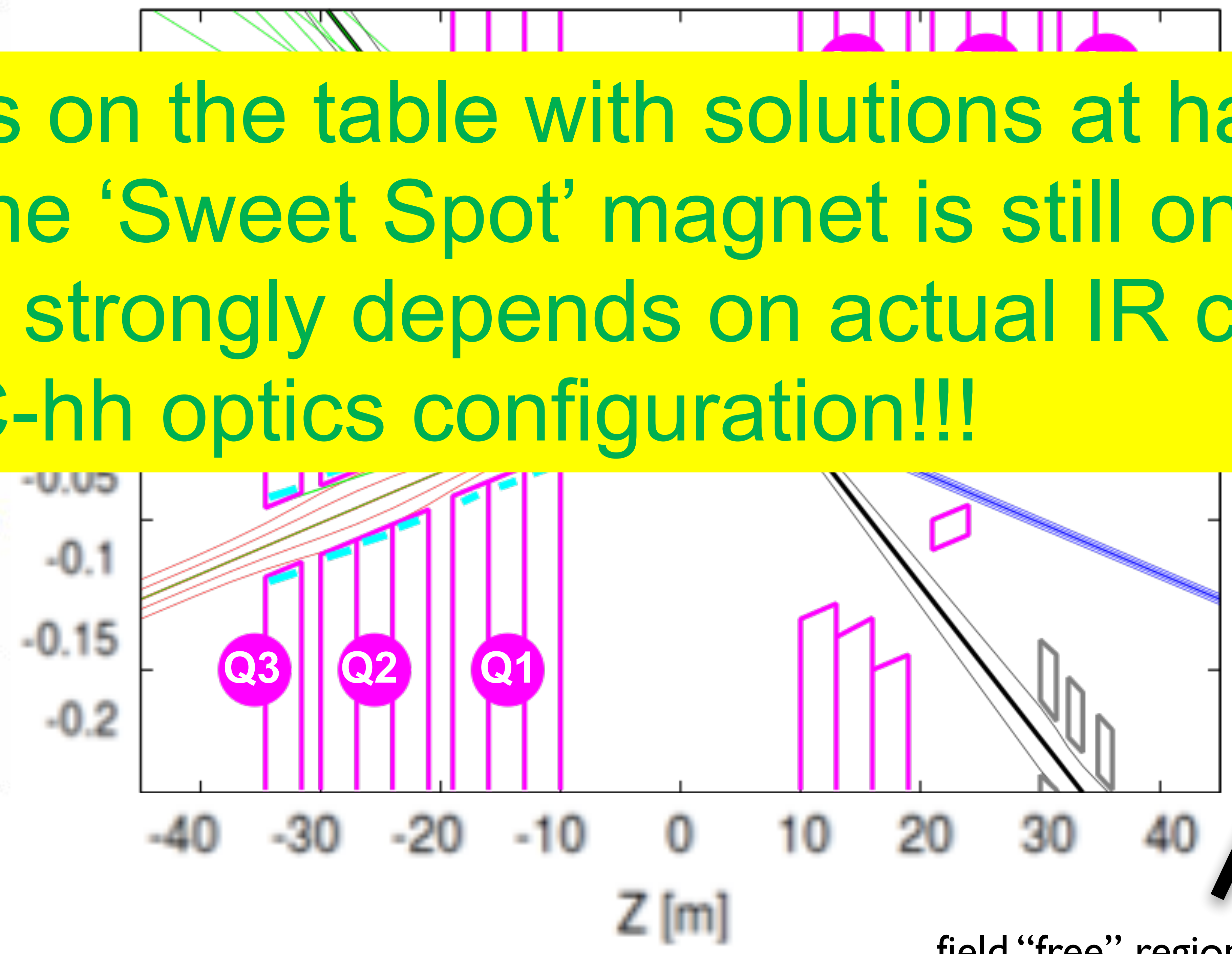
electron beam from ERL

E. Cruz, R. Tomas, F. Zimmermann et al.

Synchrotron Radiation and various beams

SR fan

exit hole - electrons and non-colliding protons



Tentative: ε_p=2μm, β*=20cm → σ_p=3μm ≈σ_e matched! ε_e=5μm ..

electron proton beams well matched!

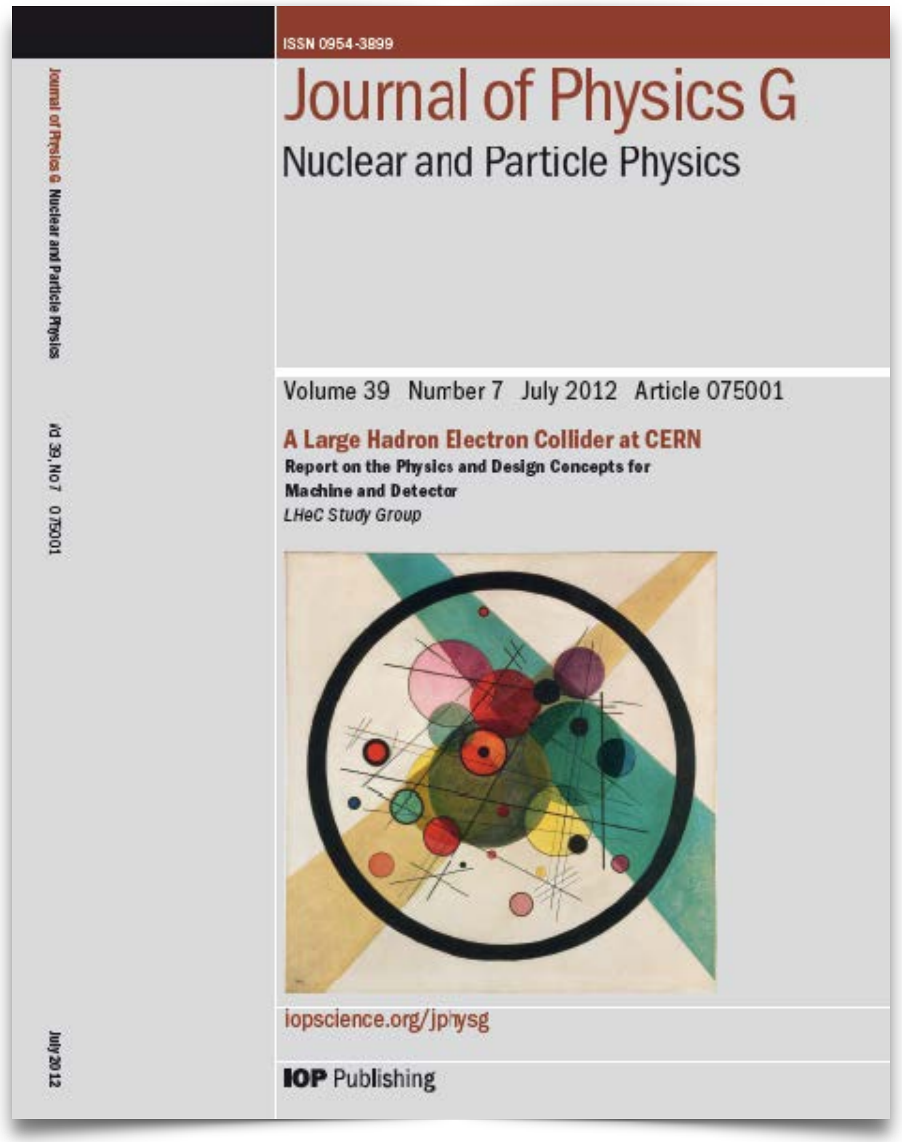
Final quadrupole magnet Q1 example design "sweet spot"

field "free" region

B. Parker, S. Russenschuck et al.

Various options on the table with solutions at hand!
Design work on the 'Sweet Spot' magnet is still ongoing!
Final implementation strongly depends on actual IR choice and FCC-hh optics configuration!!!

The LHeC CDR



Arguments, boundary conditions:
CDR written - physics program - not served experimentally elsewhere
- before Higgs discovery

The LHeC
- full featured, alternative device also for Higgs related measurements, high quality / sensitivity, with special strength for forward boosted Higgs production.
- characteristic: asymmetric eh (eA) kinematic

The eh-detector will be a 'general' purpose detector with large η acceptance and high granularity, build for increments of LHC:
HL-LHC (LHeC detector) and HE-LHC (HE-LHeC detector) (decision pending)

Does it fit into cavern P2 (ALICE experiment)? (L3 Magnet inner bore - 11.5m)
Installation within given time slots (large LHC shutdown) (M. Stuart, A. Gaddi's talk's)

Is it possible to build a detector serving the rich physics program (see talks yesterday)?

Future of eh-physics at FCC?; Detector layout for HE-LHeC FCC-eh (Alessandro Polini's talk)

LHeC(HE-LHeC) / FCC-he Detector CDR - Guideline

- **FCC-eh/HE-LHeC:** utilize the LHeC design study to describe baseline ep/A option.
- emphasis: multi TeV physics; IR and detector; synchronous ep-pp operation.
- open to other configurations and new physics developments
- caveats:
  - interaction region not yet well defined
    - need specifications/simulations allowing final detector layout
    - optics, beam-pipe, B Fields, masks, synchrotron radiation estimations …

- practical approach
  - start from LHeC CDR design
  - adapt existing detector (structures, resolutions) to larger beam energies (larger c.m.s. energy, larger forward boost, wider kinematic space) and the physics reach and scope
  - final choice of technology considered for CDR, consultations with FCC-hh (and ECFA detector panel)

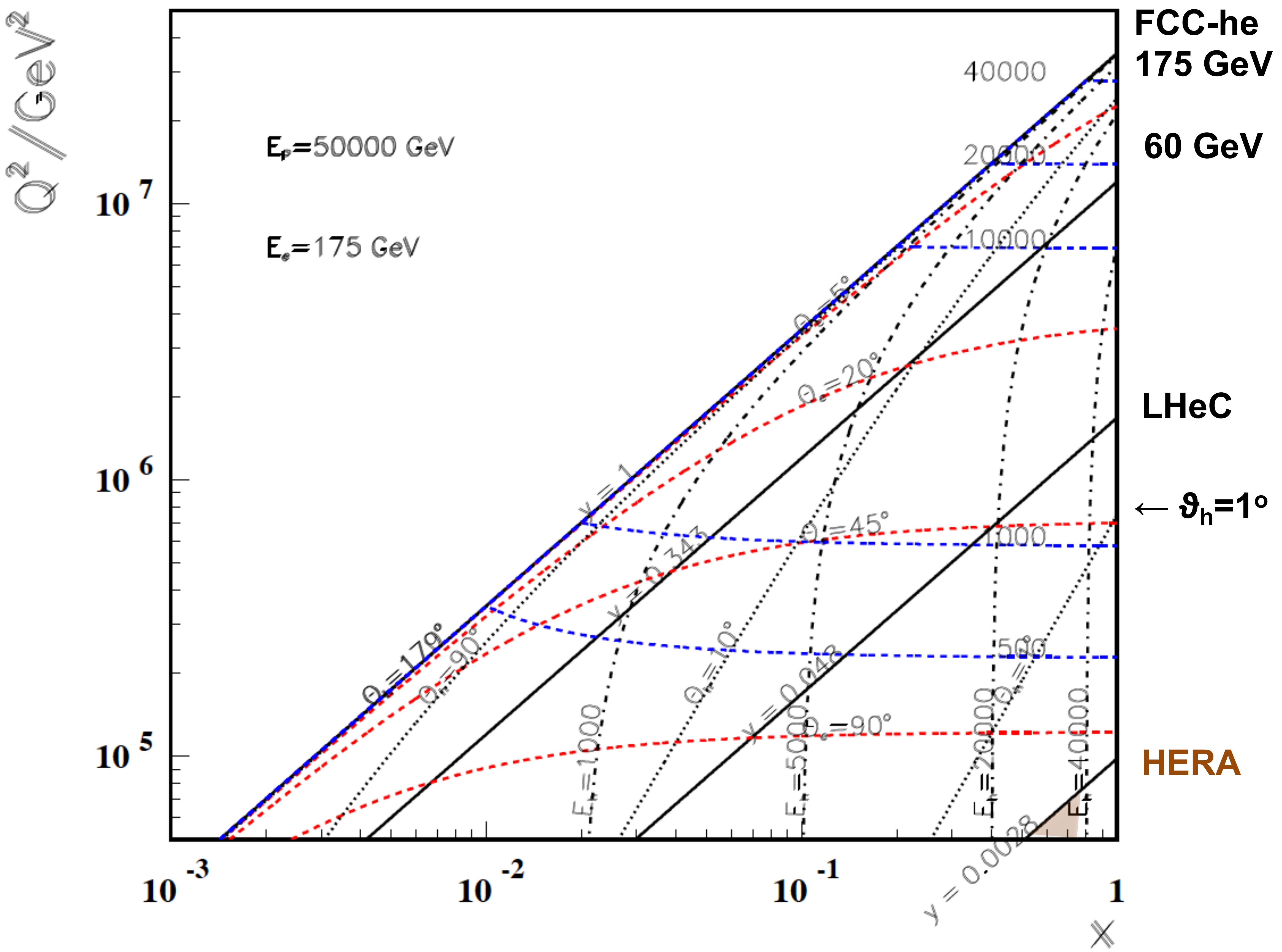
- aim at an update of the CDR (LHeC+ FCC-he) by 2018
  - establish interaction region/ machine detector interface
  - focus on detector simulations
  - key aspect: enlarge person power base and synergy with hh+ee detector studies!

FCC-he Kinematic Range (low x; high Q^2)

courtesy Max Klein

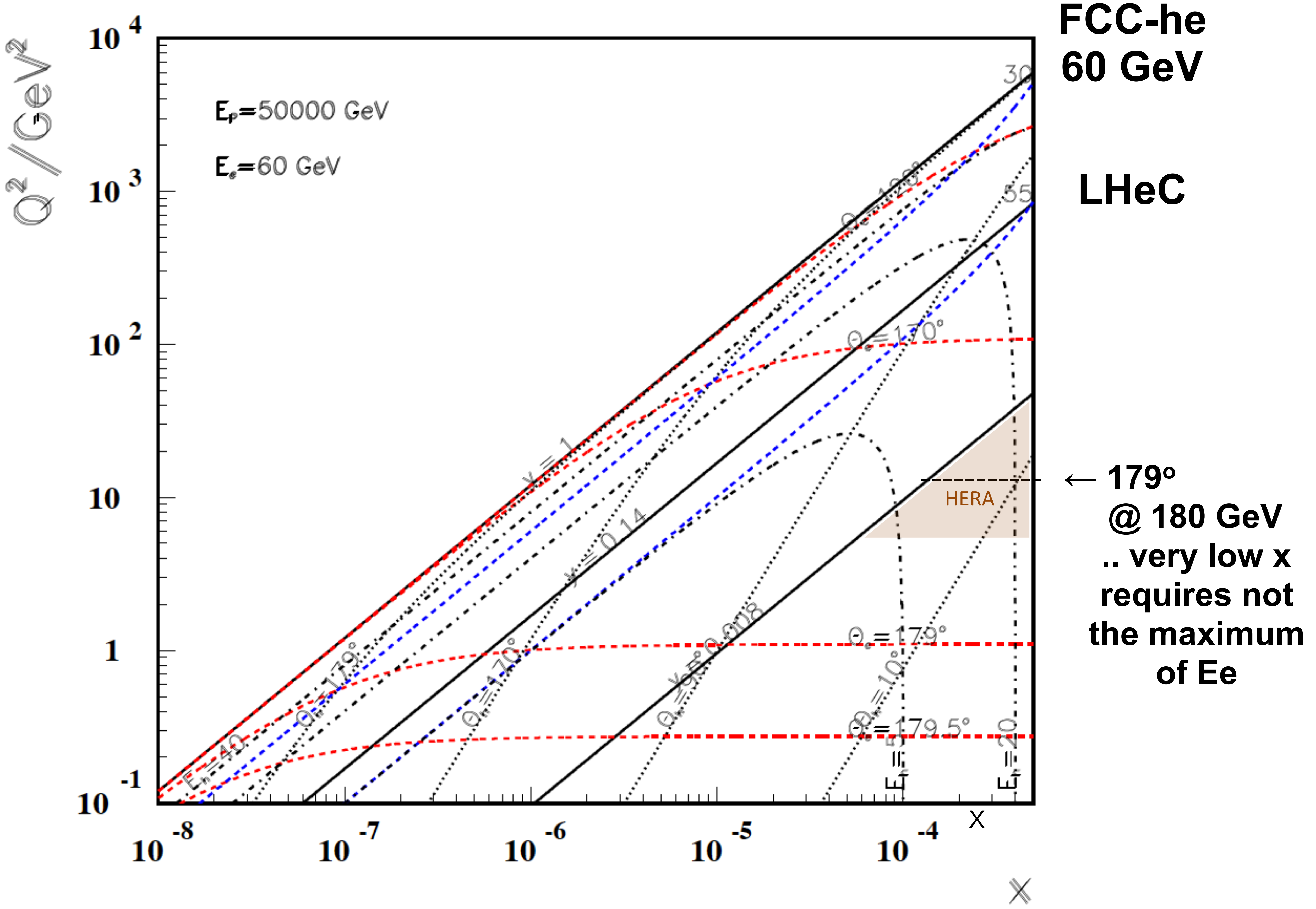
High Q^2

Rutherford backscattering of dozens of TeV e- energy



Large imbalance of e and p energies is surprisingly tolerable for the high Q^2, x kinematics, LHeC to bridge from HERA to FCC

Low x



Very low x reaches direct range of UHE neutrino physics

Forward calorimeter containment up to few 10th TeV down to 1^0 θ ~doubling the calorimeter depth compared to LHeC

Baseline Parameters of ep at LHC, HE-LHC and FCC

Baseline parameters of future electron-positron collider configurations based on the ERL electron linac

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	12.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.5	1
$\gamma\epsilon_p$ [μm]	3.7	2	2.5	2.2
electrons per bunch [10^9]	1	2.3	3.0	3.0
electron current [mA]	6.4	15	20	20
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor H_{geom}	0.9	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3	1.3
proton filling H_{coll}	0.8	0.8	0.8	0.8
luminosity [10^{33}cm^{-2}s^{-1}]	1	8	12	15

The Higgs discovery has raised the L(ep) goal to 10^{34}. The pile-up is O(1) at FCC-eh

EDMS 17979910 FCC-ACC-RPT-0012 V1.0, 6 April, 2017, "A Baseline for the FCC-eh"

Oliver Brüning, John Jowett, Max Klein, Dario Pellegrini, Daniel Schulte, Frank Zimmermann
see talk F. Zimmermann: https://indico.cern.ch/event/556692/contributions/2483407/

Baseline Parameters of ep at LHC, HE-LHC and FCC

Baseline parameters of future electron-positron collider configurations based on the ERL electron linac

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	12.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
bunch spacing [ns]	25	25	25	25
IP beta function β_p [cm]	10	[illegible]	10	15
hourglass factor H_{geom}	0.9	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3	1.3
proton filling H_{coll}	0.8	0.8	0.8	0.8
luminosity [10^{33}cm^{-2}s^{-1}]	1	8	12	15

LHeC-ERL added to LHC, HL-LHC, HE-LHC, FCC-eh,…

➔ high-energy high luminosity *ep* and *eA* collisions

The Higgs discovery has raised the L(ep) goal to 10^{34}. The pile-up is O(1) at FCC-eh

EDMS 17979910 FCC-ACC-RPT-0012 V1.0, 6 April, 2017,
“A Baseline for the FCC-eh”

Oliver Brüning, John Jowett, Max Klein, Dario Pellegrini,
Daniel Schulte, Frank Zimmermann
see talk F. Zimmermann: https://indico.cern.ch/event/556692/contributions/2483407/

Baseline Parameters of ep at LHC, HE-LHC and FCC

Baseline parameters of future electron-positron collider configurations based on the ERL electron linac

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	12.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.5	1
$\gamma\epsilon_p$ [μm]	3.7	2	2.5	2.2
electrons per bunch [10^9]	1	2.3	3.0	3.0
electron current [mA]	6.4	15	20	20
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor H_{geom}	0.9	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3	1.3
proton filling H_{coll}	0.8	0.8	0.8	0.8
luminosity [10^{33}cm^{-2}s^{-1}]	1	8	12	15

The Higgs discovery has raised the L(ep) goal to 10^{34}. The pile-up is O(1) at FCC-eh

EDMS 17979910 FCC-ACC-RPT-0012 V1.0, 6 April, 2017,
"A Baseline for the FCC-eh"

Oliver Brüning, John Jowett, Max Klein, Dario Pellegrini,
Daniel Schulte, Frank Zimmermann
see talk F. Zimmermann: https://indico.cern.ch/event/556692/contributions/2483407/

Baseline Parameters of ep at LHC, HE-LHC and FCC

Baseline parameters of future electron-positron collider configurations based on the ERL electron linac

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	12.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
luminosity [10^{33}cm^{-2}s^{-1}]	1	8	12	15

With the Higgs discovery and measured cross section σ ~ 200fb there is a striking option to make the LHeC a clean Higgs factory with maximum luminosity and even more the HE-LHeC (FCC-eh)

The Higgs discovery has raised the L(ep) goal to 10^{34}. The pile-up is O(1) at FCC-eh

EDMS 17979910 FCC-ACC-RPT-0012 V1.0, 6 April, 2017, "A Baseline for the FCC-eh"

Oliver Brüning, John Jowett, Klein Max, Dario Pellegrini, Daniel Schulte, Frank Zimmermann

see talk F. Zimmermann: https://indico.cern.ch/event/556692/contributions/2483407/

ep/eA Luminosities

Nominal case: 60 GeV ERL electron beam against the hadron beams.

- **e-p (as of March 2016):**

- **LHeC e-Pb:**
  $N_{Pb}=7\times10^{7}$/bunch (2012 values)
  ⇒ ~0.1 fb^{-1}/month
  - **L_{eN} = 9×10^{31} cm^{-2} s^{-1} (Nominal Pb)**
    (Pb numbers ~ 3 times higher with updated Pb parameters)
  - **L_{eN} = 1.6×10^{32} cm^{-2} s^{-1} (Ultimate Pb)**
  - L_{eD} = 3×10^{31} cm^{-2} s^{-1} (eD)

parameter [unit]	LHeC (HL-LHC)	eA at HE-LHC	FCC-he
E_{Pb} [PeV]	0.574	1.03	4.1
E_e [GeV]	60	60	60
$\sqrt{s_{eN}}$ electron-nucleon [TeV]	0.8	1.1	2.2
bunch spacing [ns]	50	50	100
no. of bunches	1200	1200	2072
ions per bunch [10^8]	1.8	1.8	1.8
$\gamma\epsilon_A$ [μm]	1.5	1.0	0.9
electrons per bunch [10^9]	4.67	6.2	12.5
electron current [mA]	15	20	20
IP beta function β^*_A [cm]	7	10	15
hourglass factor H_{geom}	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3
bunch filling H_{coll}	0.8	0.8	0.8
luminosity [$10^{32}cm^{-2}s^{-1}$]	7	18	54

- **FCC-he:**
  Crude estimates: ($N_{Pb}=2\times10^{8}$/bunch - 2016 values) and rescaling hadron parameters only ➔ $L_{eN}=3\times10^{33}$ $cm^{-2}s^{-1}$ ~4 fb^{-1} /month (J. Jowett).

EDMS 17979910 FCC-ACC-RPT-0012 V1.0, 6 April, 2017,
"A Baseline for the FCC-he"; Oliver Brüning, John Jowett, Max Klein, Dario Pellegrini, Daniel Schulte, Frank Zimmermann

ep/eA Luminosities

Nominal case: 60 GeV ERL electron beam against the hadron beams.

- **e-p (as of March 2016):**
- **LHeC e-Pb:**
  N_{Pb}=7×10^{7}/bunch (2012 values)
  ⇒ ~0.1 fb^{-1}/month
  – L_{eN} = 9 x 10^{31} cm^{-2} s^{-1} (Nominal Pb)

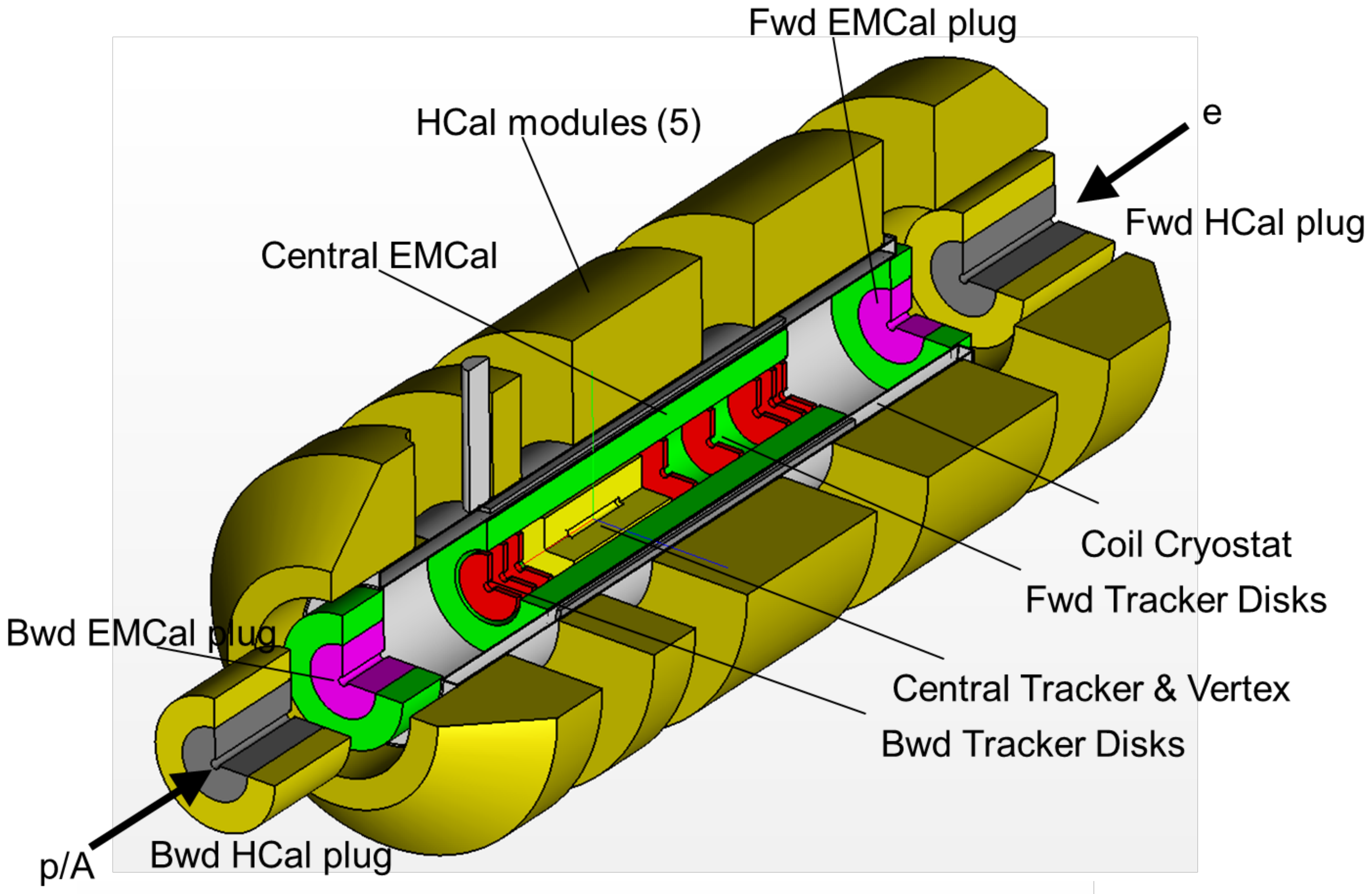
parameter [unit]	LHeC (HL-LHC)	eA at HE-LHC	FCC-he
E_{Pb} [PeV]	0.574	1.03	4.1
E_e [GeV]	60	60	60
$\sqrt{s_{eN}}$ electron-nucleon [TeV]	0.8	1.1	2.2
bunch spacing [ns]	50	50	100
no. of bunches	1200	1200	2072
ions per bunch [10^8]	1.8	1.8	1.8
$\gamma\epsilon_A$ [μm]	1.5	1.0	0.9

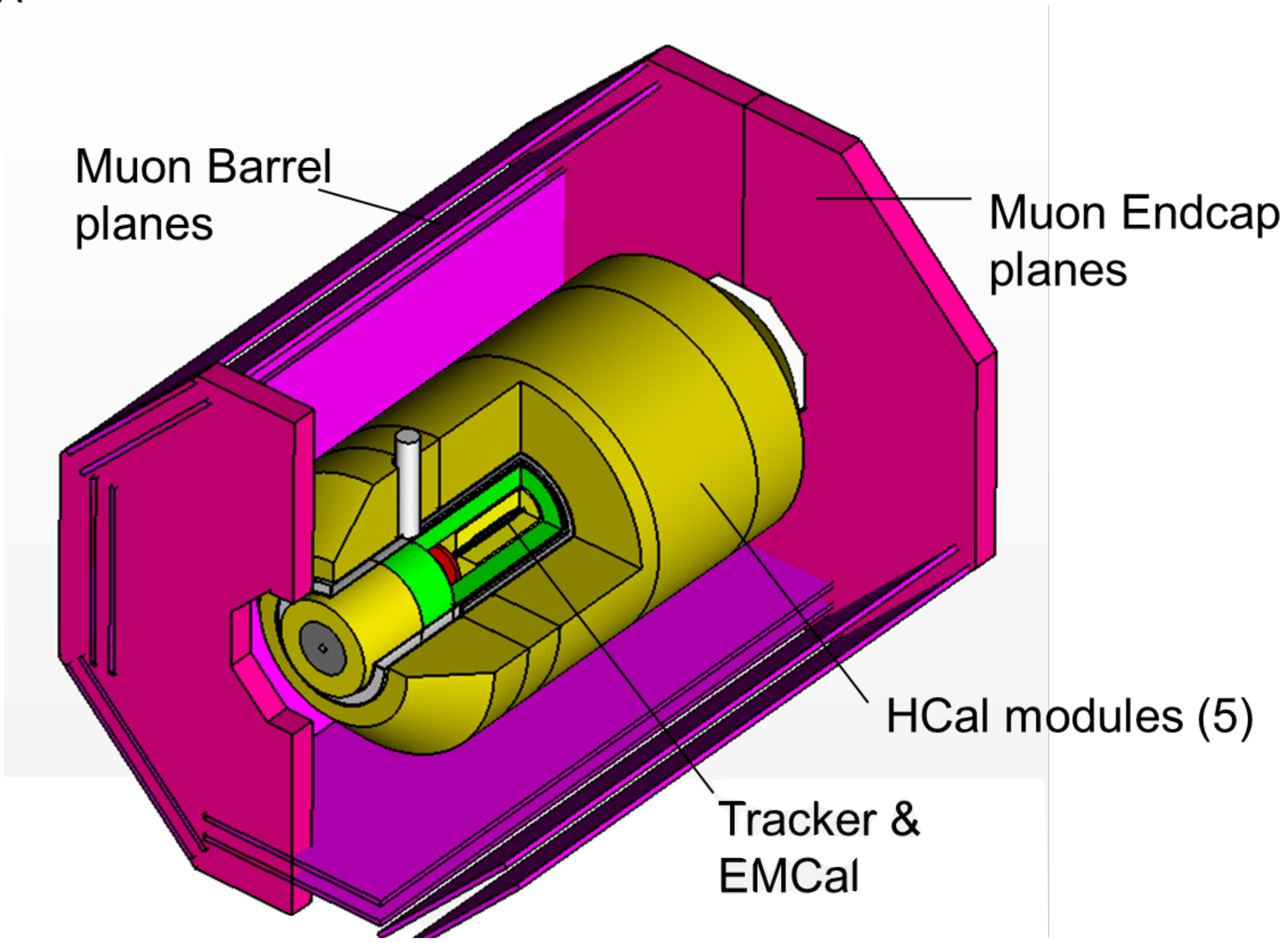
A novel opportunity for exploration of eA physics

- **Crude estimates: (N_{Pb}=2×10^{8}/bunch - 2016 values) and rescaling hadron parameters only ➔ L_{eN}=3×10^{33} $cm^{-2}s^{-1}$ ~4 fb^{-1} /month (J. Jowett).**

EDMS 17979910 FCC-ACC-RPT-0012 V1.0, 6 April, 2017,
"A Baseline for the FCC-he"; Oliver Brüning, John Jowett, Max Klein, Dario Pellegrini, Daniel Schulte, Frank Zimmermann

FCC-he Detector Segmenting/CMS-like-Install

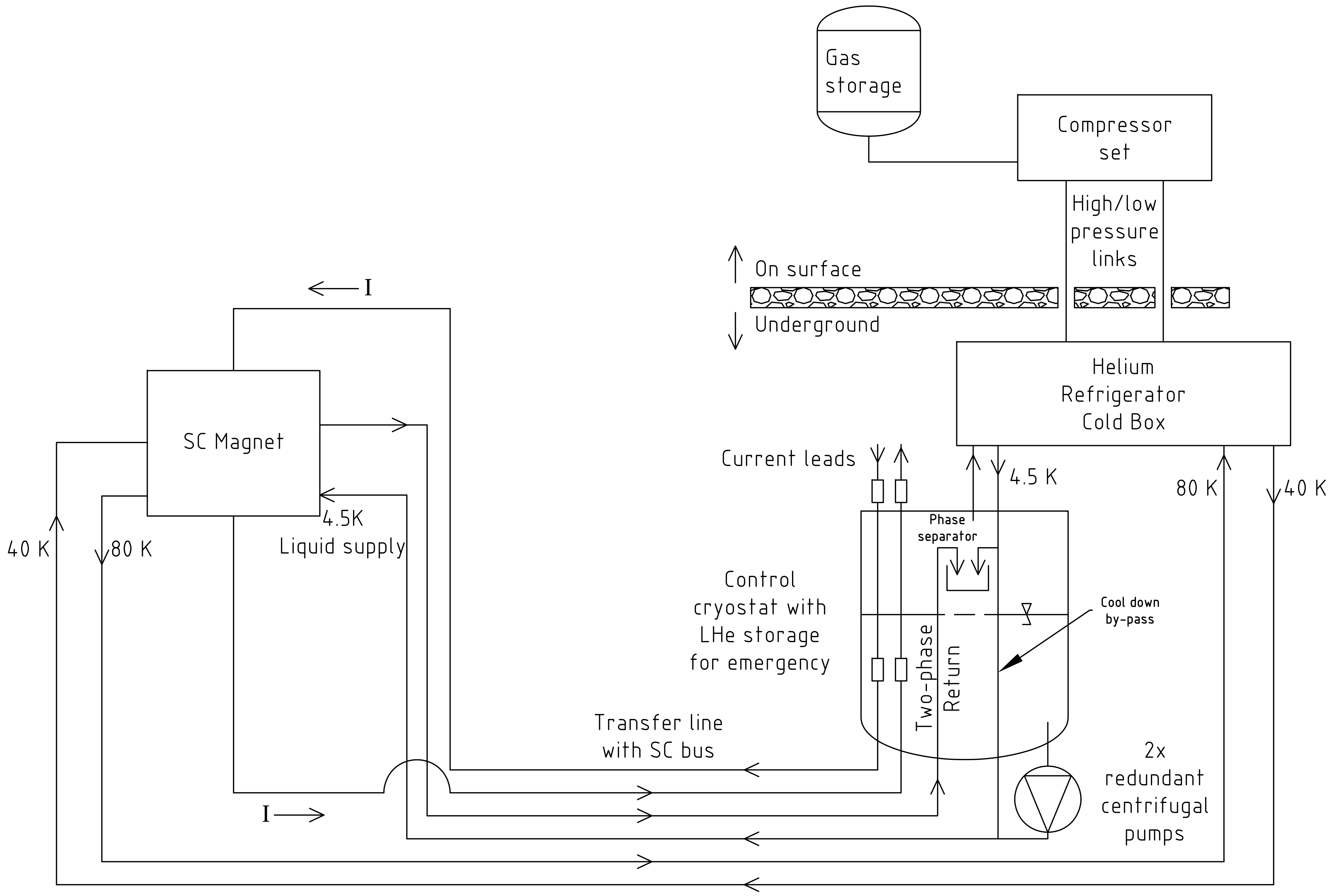


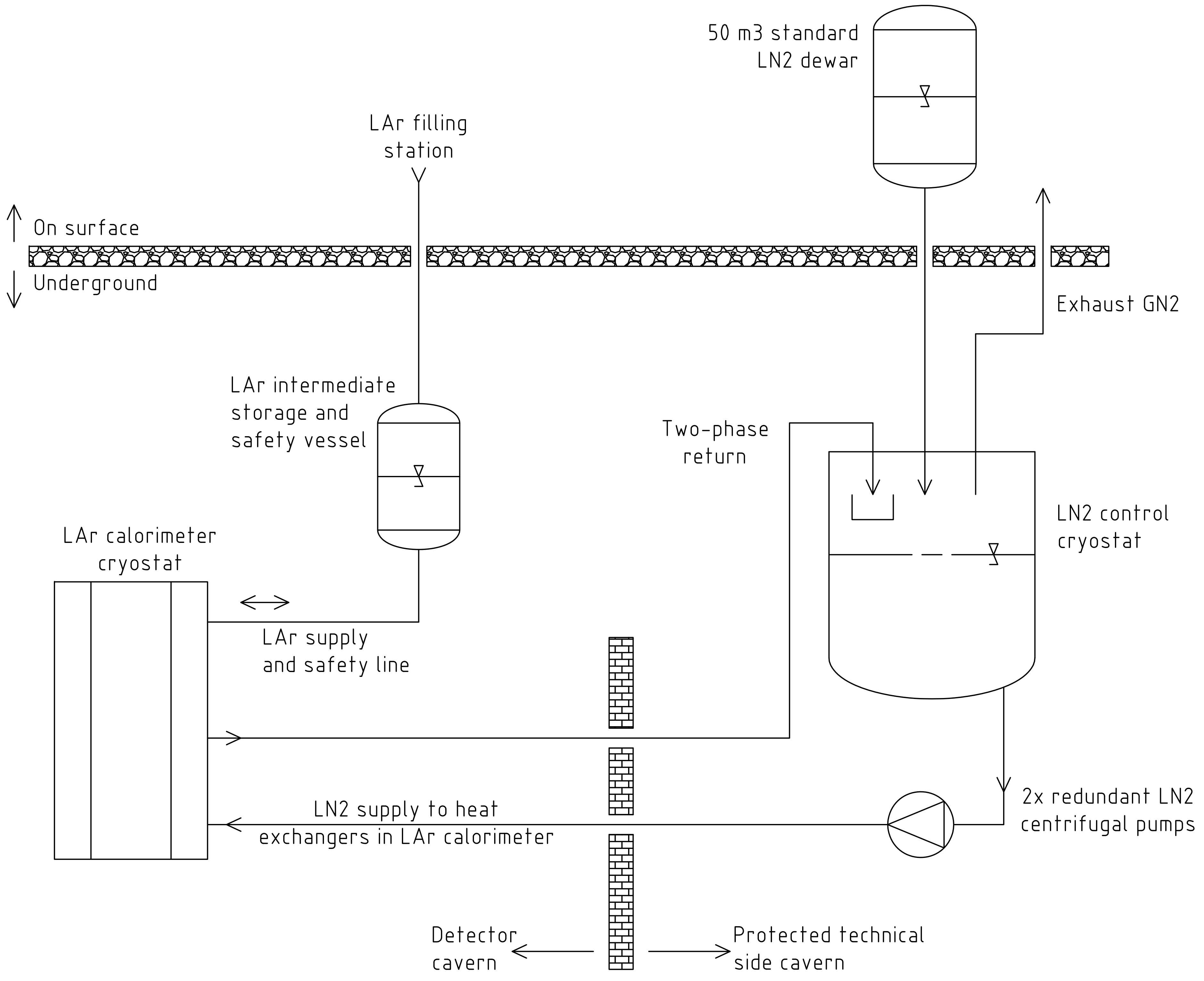


- First studies for the realization of the LHeC detector and perform its installation during a LHC Long Shutdown
- Preliminary installation and maintenance scenarios using LHC P2 interaction region
- Pre-mounting of detector and commissioning of the coil system on surface, lowering and commissioning of the detector underground. At IP2
- mount detector inside L3 magnet support structure.
- Time for field map of solenoid and beam-pipe bake out & vacuum pumping.
- Estimated total time is about compliant with LHC shutdown durations.

see talk A. Gaddi
https://indico.cern.ch/event/356714/contributions/844883/attachments/709255/973648/LHeC-Workshop-2015_ag_v6.pdf

Cooling Plant - On Surface / Under Ground - CDR

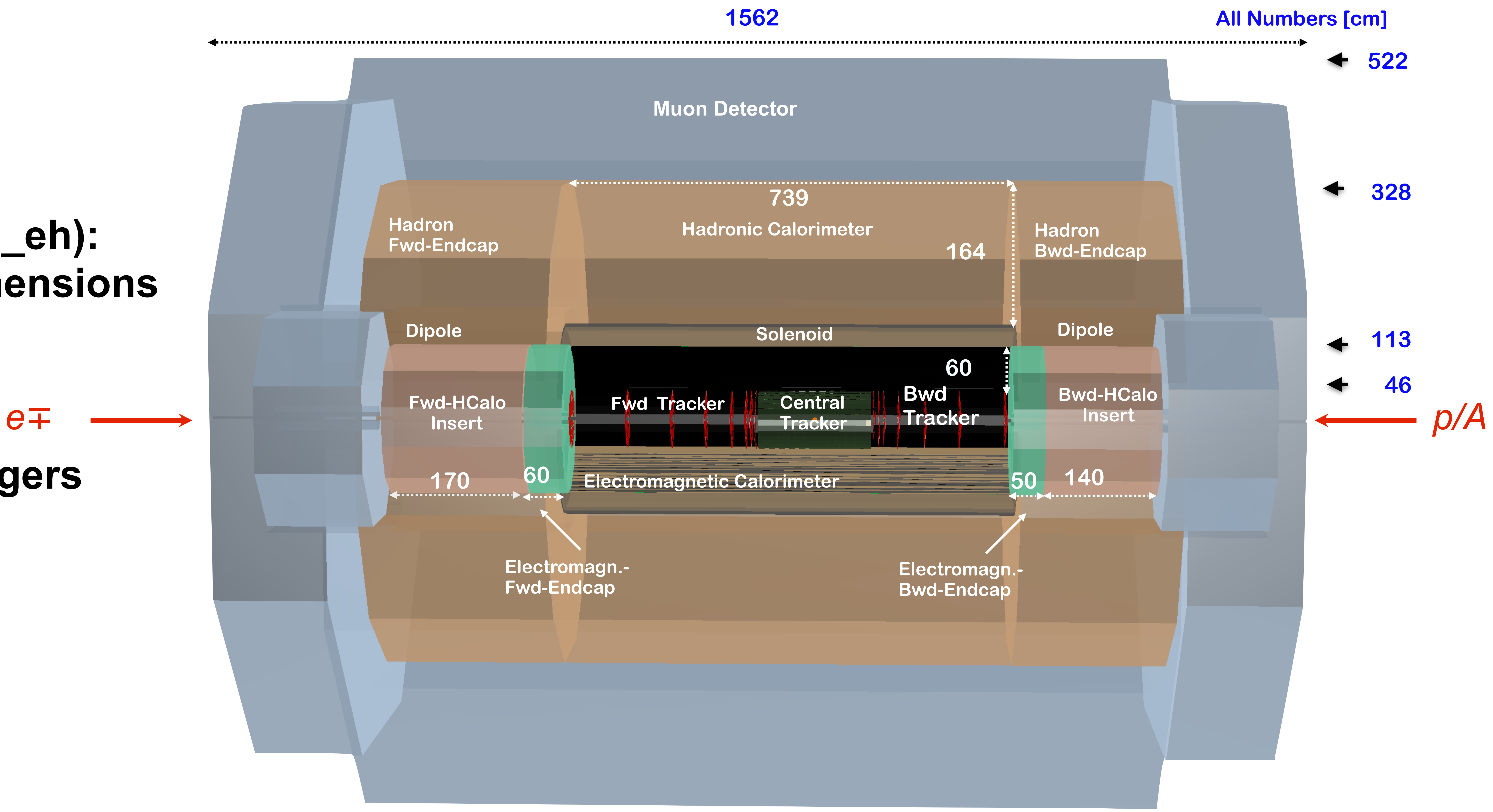




LHeC → HE-LHeC Detector Design

Basic change for HE-LHeC (FCC_eh): extension of (spec.) forward dimensions by factors log(12.5/7) (log(50/7)), backward extended

No studies of very fwd, bwd Taggers for HE-LHeC, FCC-he yet



SW Transfer DD4hep/DDG4 to FCCSW

DD4hep/DDG4 - driven by ILC/CLIC based developers - pre-release software

- LCIO event data model (EDM)
- LCIO - connecting all modules in DD4hep/DDG4
- Generator data import into the framework - root, stdhep- and hepmc2-file formats
- Python, C++ int./ext.
  - LHeC/FCC detector geometry (being optimised), material description, R/O description as needed, segmentations and surfaces - ingredients for reconstruction
  - DDEve - event display tool for quality judgment and control …

Switch into FCCSW framework - hope: closing the loop:

Detector design → Simulation → Analysis → Design optimisation

In progress: xml-descriptions - naming conventions; factory module rewriting

- Common efforts to be organised, e.g. forward region calorimetry - dense jets of very high energy
- template: ALICE^{+} tracker-lightweight, faster R/O (but low power) - cooling, ….
- Collaboration with other experiments
- Hardware optimisation according to latest R&D (HL-LHC, FCC-hh, CLIC …)

Challenges

- The ep configuration uniquely selects the WW-H and ZZ-H vertices for production
  - ep → νH(bb)X: O(1)% precision on H-bb couplings with matching theoretical uncertainty
- FCC-he reaches the H→μμ decay, with O(1000) events
  - μ measurement essential - magnet design - with return B-field yoke; "open" solenoid + balancing solenoids
- Very demanding and being studied in detail e.g.:
  - ep → νHHX ep produces the Higgs from WW → double Higgs
- FCC-he will be a Higgs factory and the consequences to be studied
  - desire to measure also rare decays,
  - maximum coverage for all kinds of decays
- Extrapolation from LHeC:
  the FCC-eh / HE-LHeC detectors are feasible, the design will benefit from coming technology progress (sensors, magnets, low power consumption, cooling, mechanical systems, electronics …)