A Detector for FCC-eh

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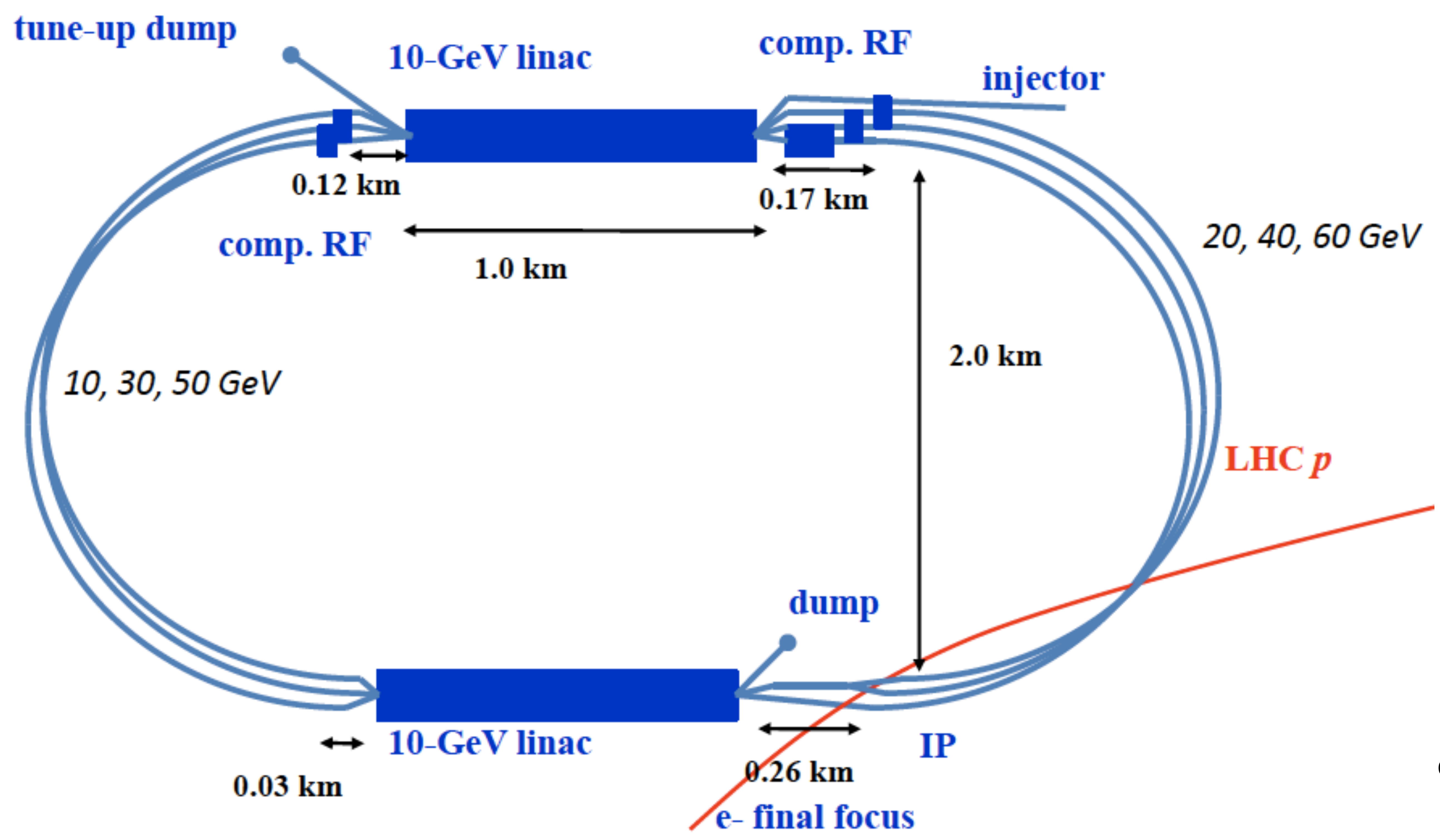
on behalf of the LHeC/FCC-eh Study Group

* currently dismissed from Uludag University, Turkey

Baseline Electron Beam Configuration*

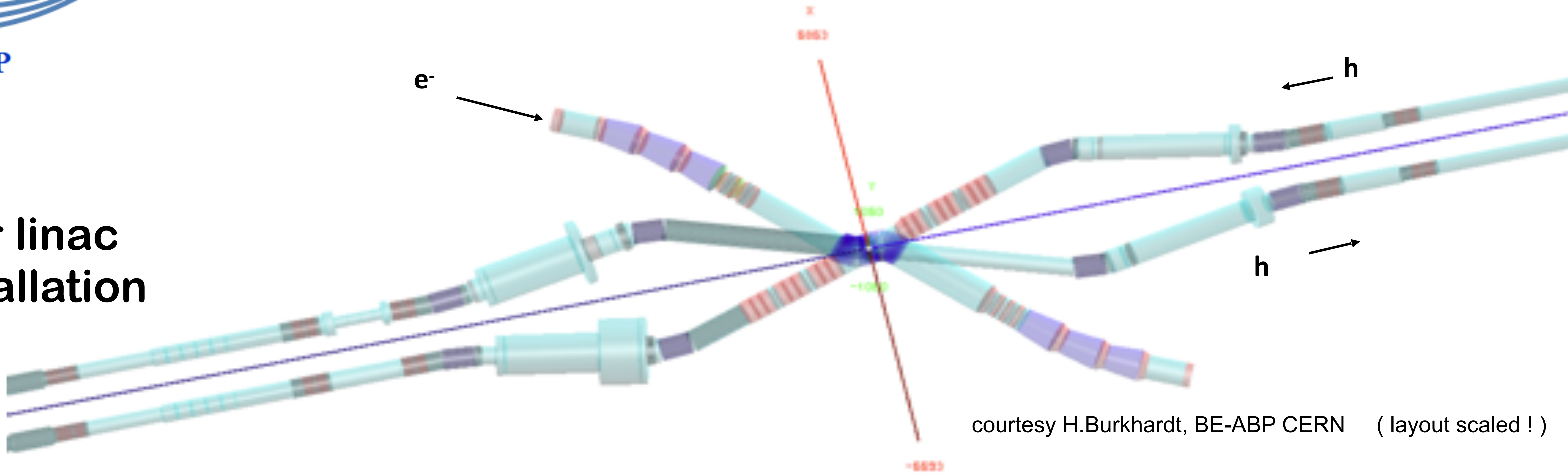
* LHeC CDR, arXiv:1206.2913



Operation in parallel with LHC/HE-LHC/FCC-eh

- 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} $cm^{-2}s^{-1}$

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



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

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

See talk:

LHeC & FCC-eh Machine Configuration and performance (Oliver Brüning)

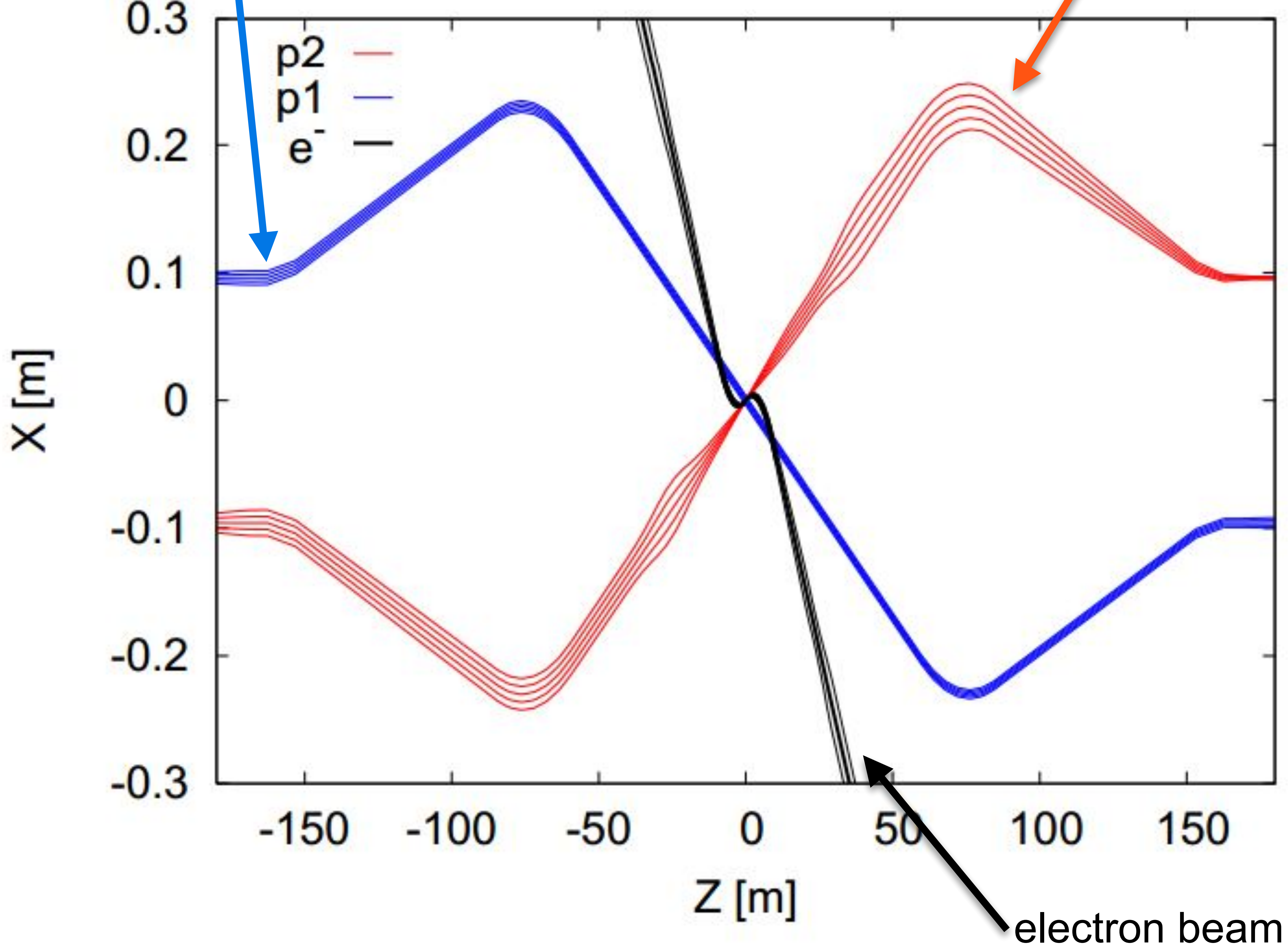
FCC-eh ERL configuration; goal: β^*=5 cm (for L > 10^{34} cm^2s^{-1})

IR configuration with head-on collisions ← in-experiment dipole system

LHeC/FCC-eh interaction region

non focused beam bypasses the interaction

focused interacting proton beam



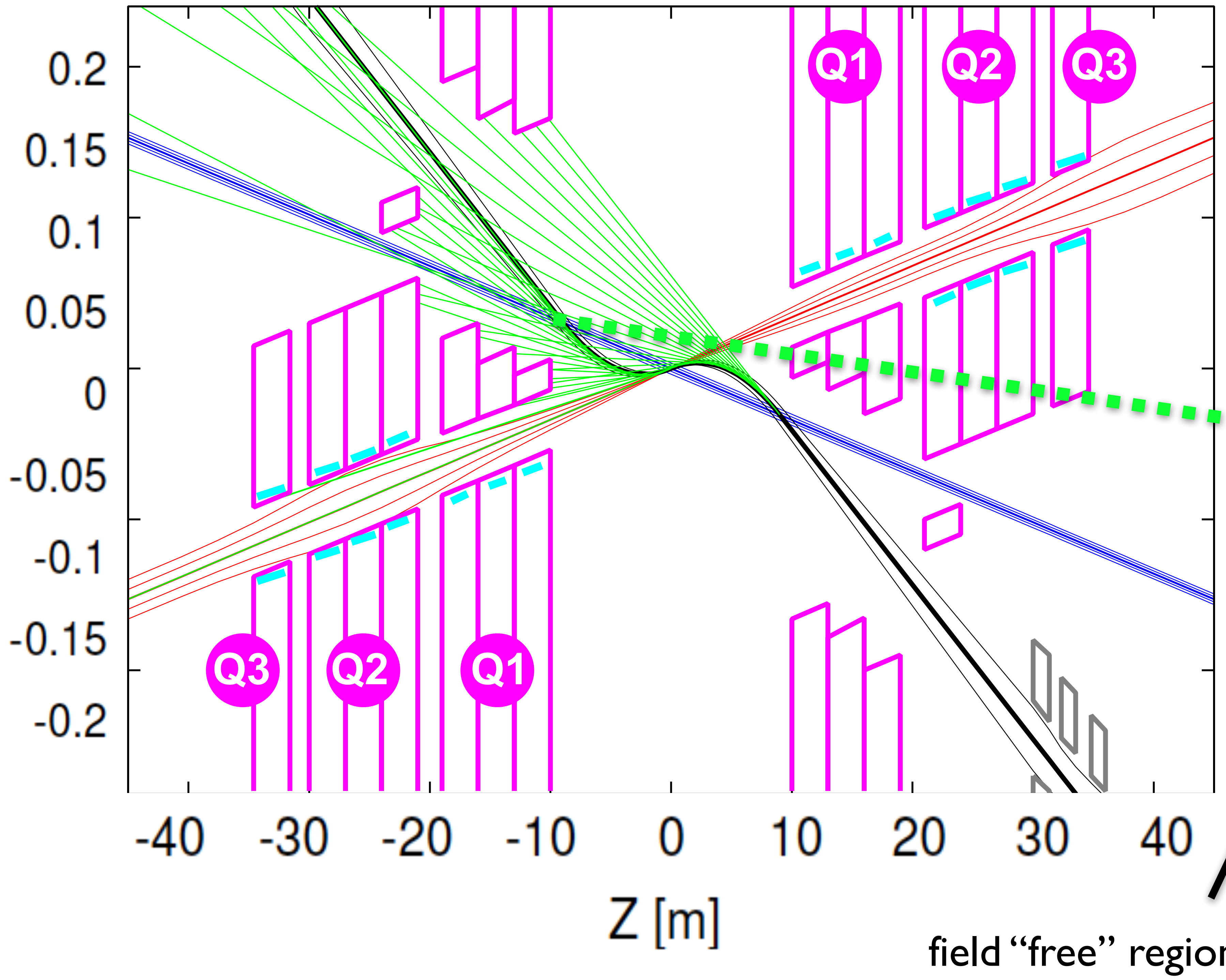
electron beam from ERL

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

Synchrotron Radiation and various beams

SR fan

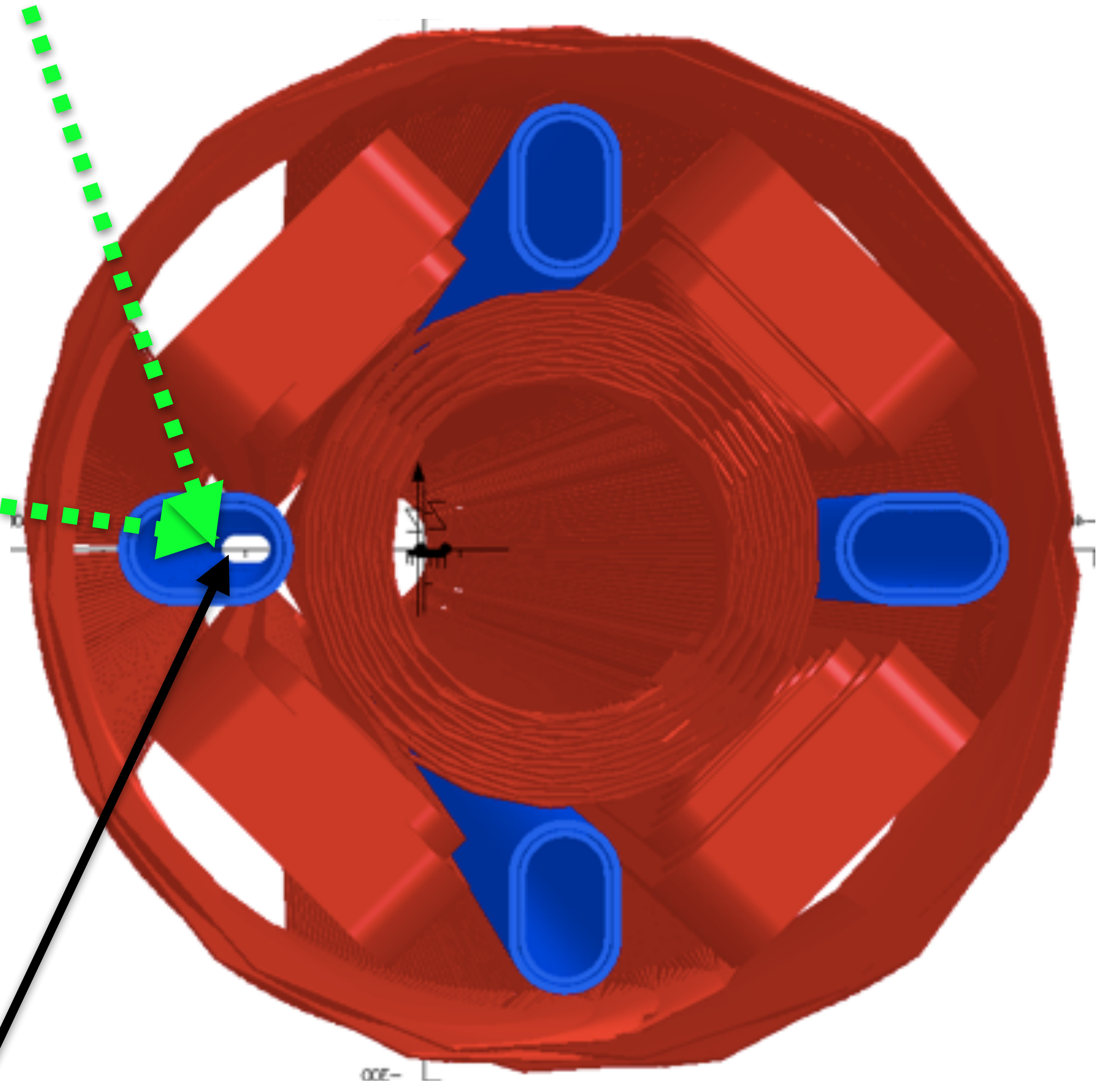
exit hole - electrons and non-colliding protons



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

electron proton beams well matched!

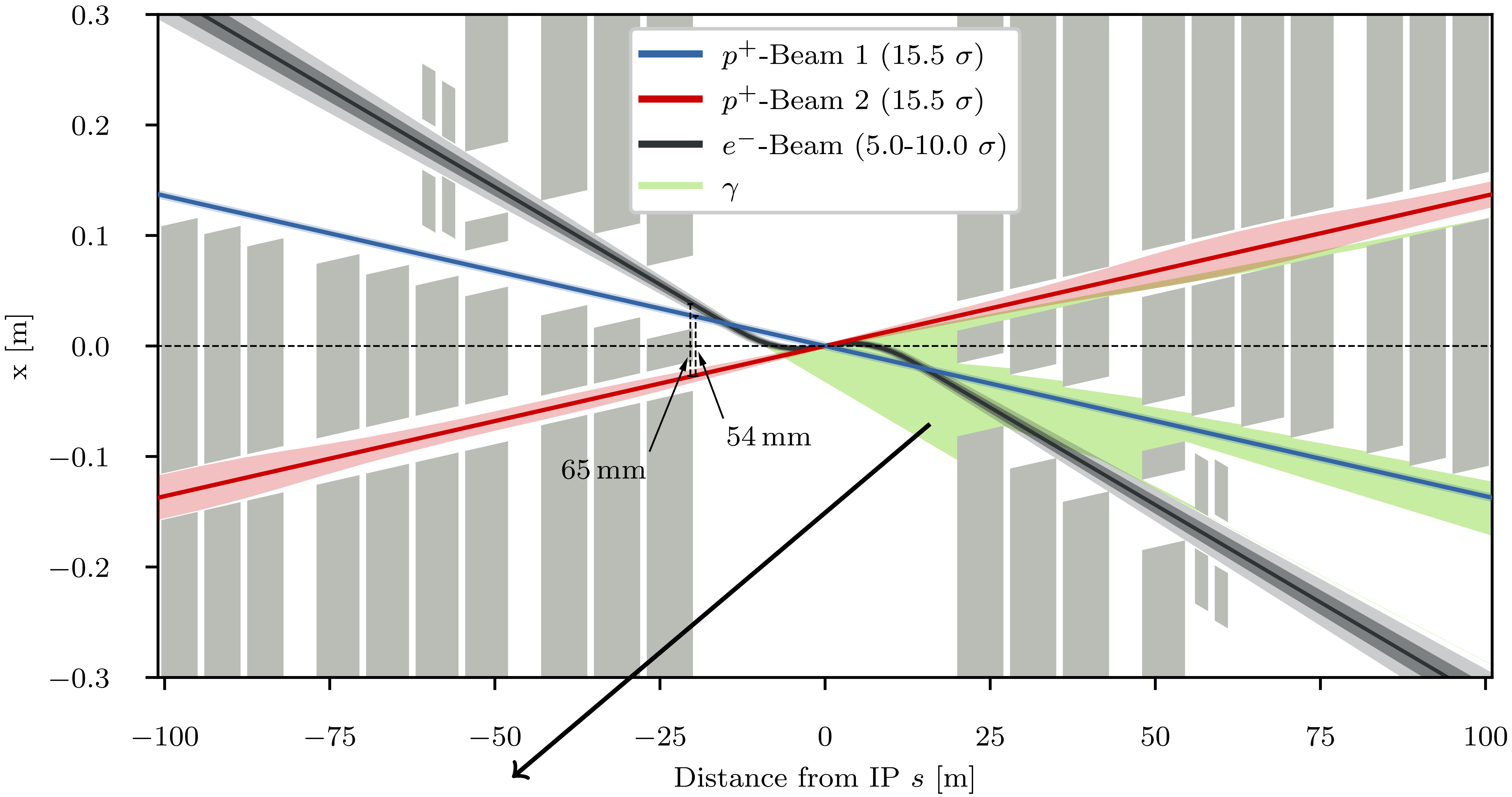
Final quadrupole magnet Q1 example design "sweet spot"



field "free" region

B. Parker, S. Russenschuck et al.

Interaction region layout for $\beta^* = 0.3\,\mathrm{m}$



New compared to 2017

$P_{\mathrm{synch}} = 13\,\mathrm{kW}$, $E_{\mathrm{crit}} = 176\,\mathrm{keV}$

Compare with LHeC: $P_{\mathrm{synch}} = 49\,\mathrm{kW}$, $E_{\mathrm{crit}} = 718\,\mathrm{keV}$

Interaction-Region Design for ep/eA at FCC - p-Optics

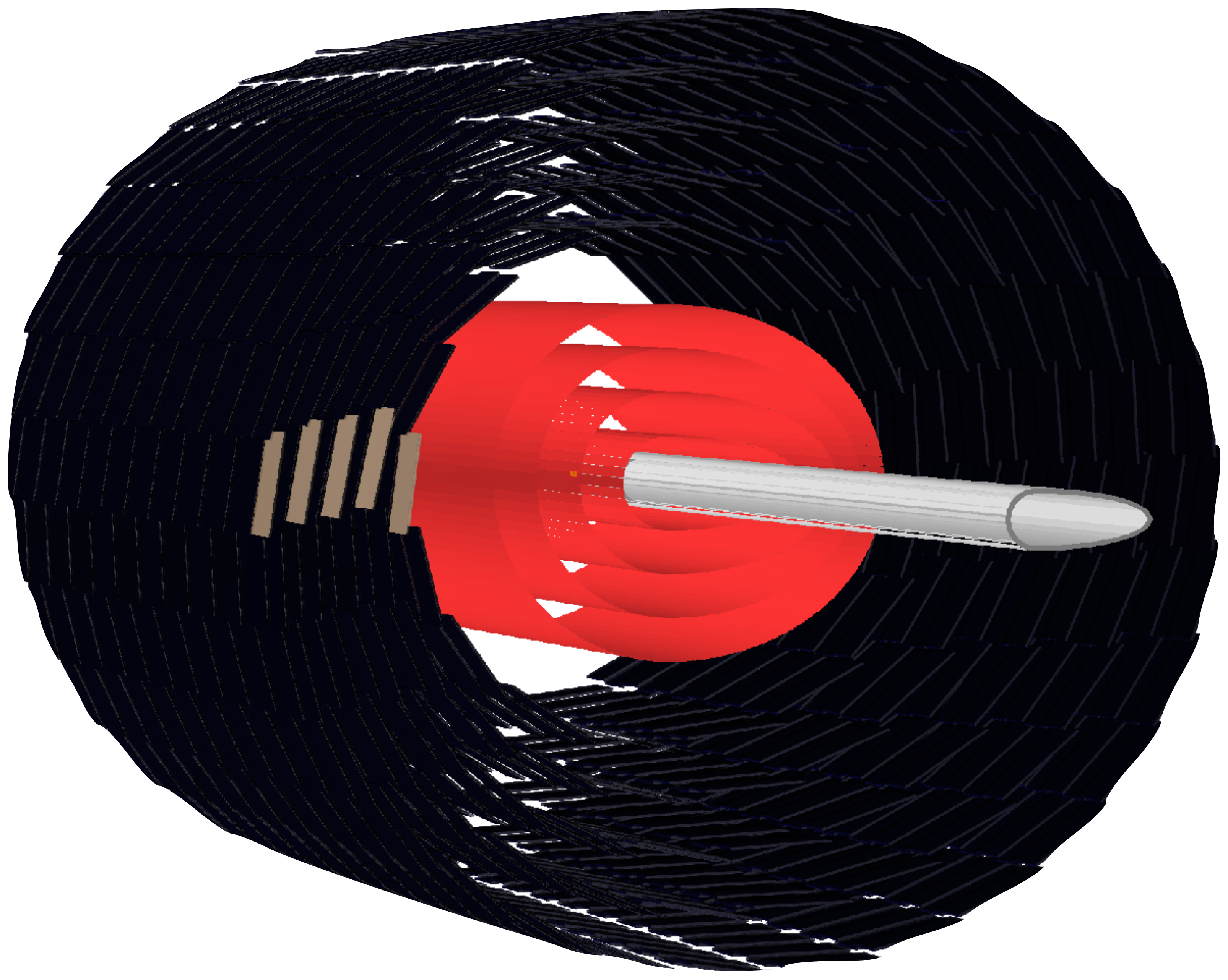
See in more detail:

Status of the interaction region layout for FCC-eh (Roman Martin)

FCC Point L for FCC-eh; current layout β^* =0.3m - ok - work in progress

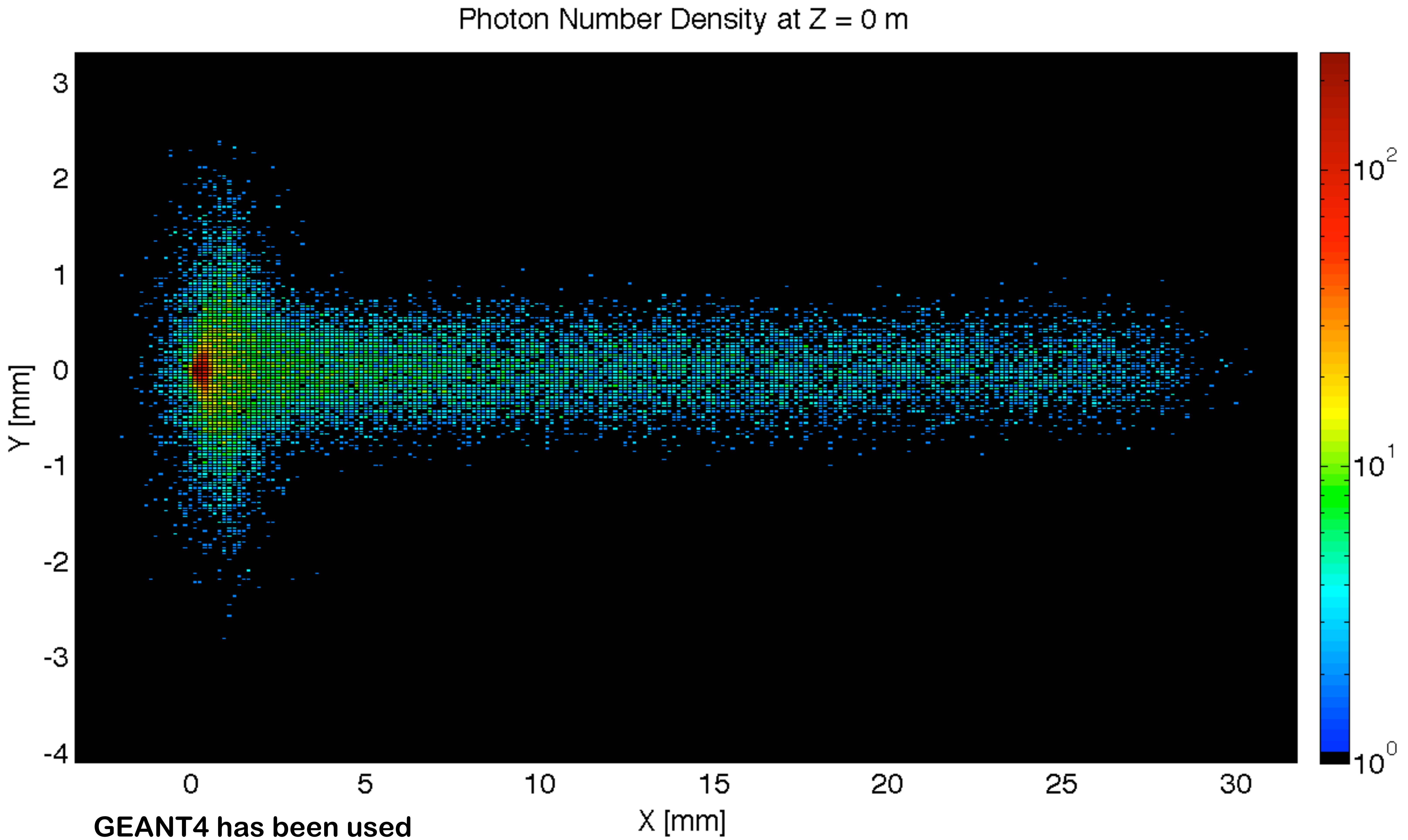
critical: Magnet apertures and gradients - β^*, Synchrotron Radiation
Magnet design currently under consideration

Beampipe & Central Tracker



Central Tracker Barrel
circular-elliptical beam pipe
4 layers Si-pixel → tilted partially
3 layers Si-macro_pixel → tilted partially

Synchrotron Radiation Fan at IP

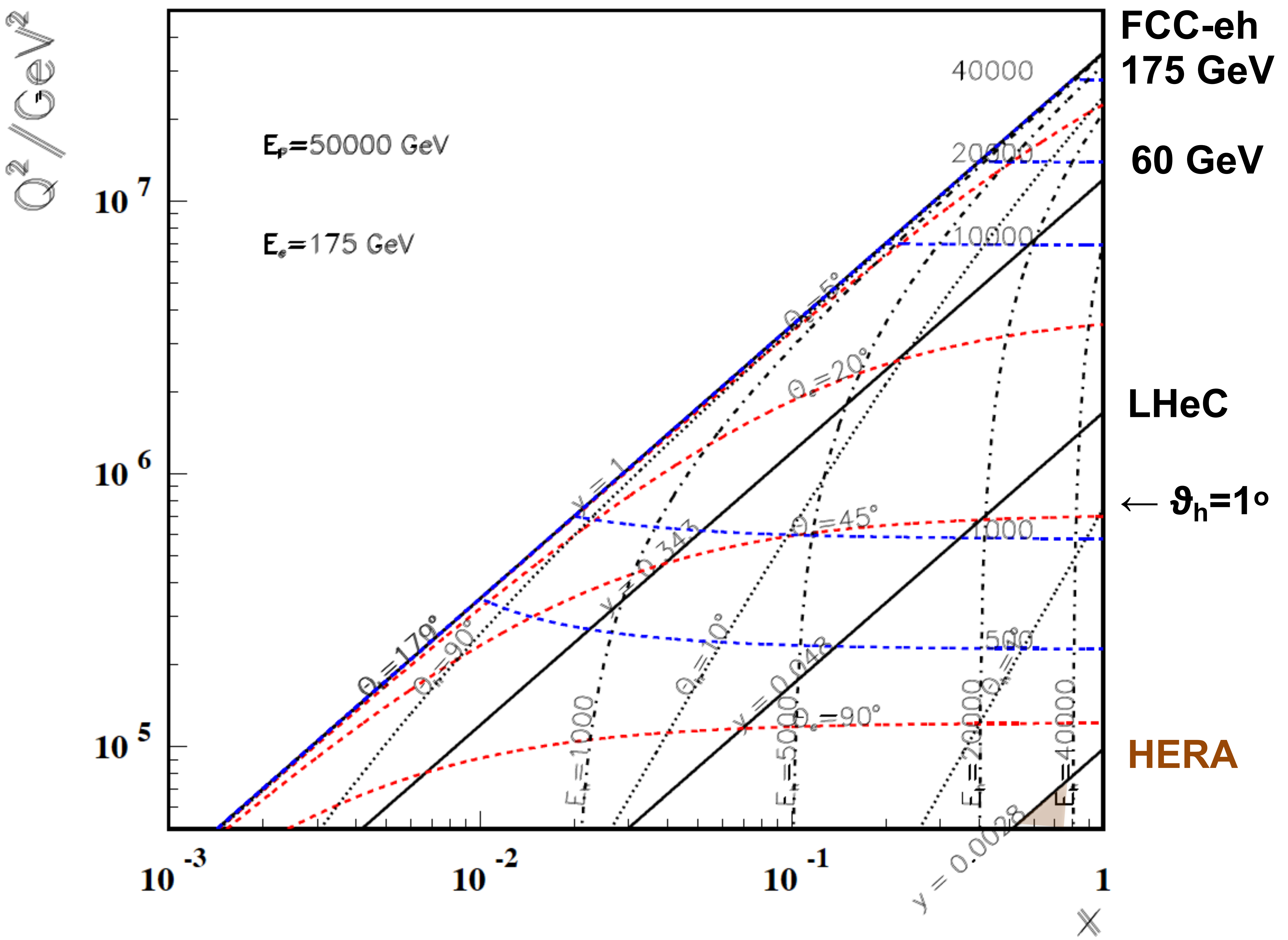


GEANT4 has been used

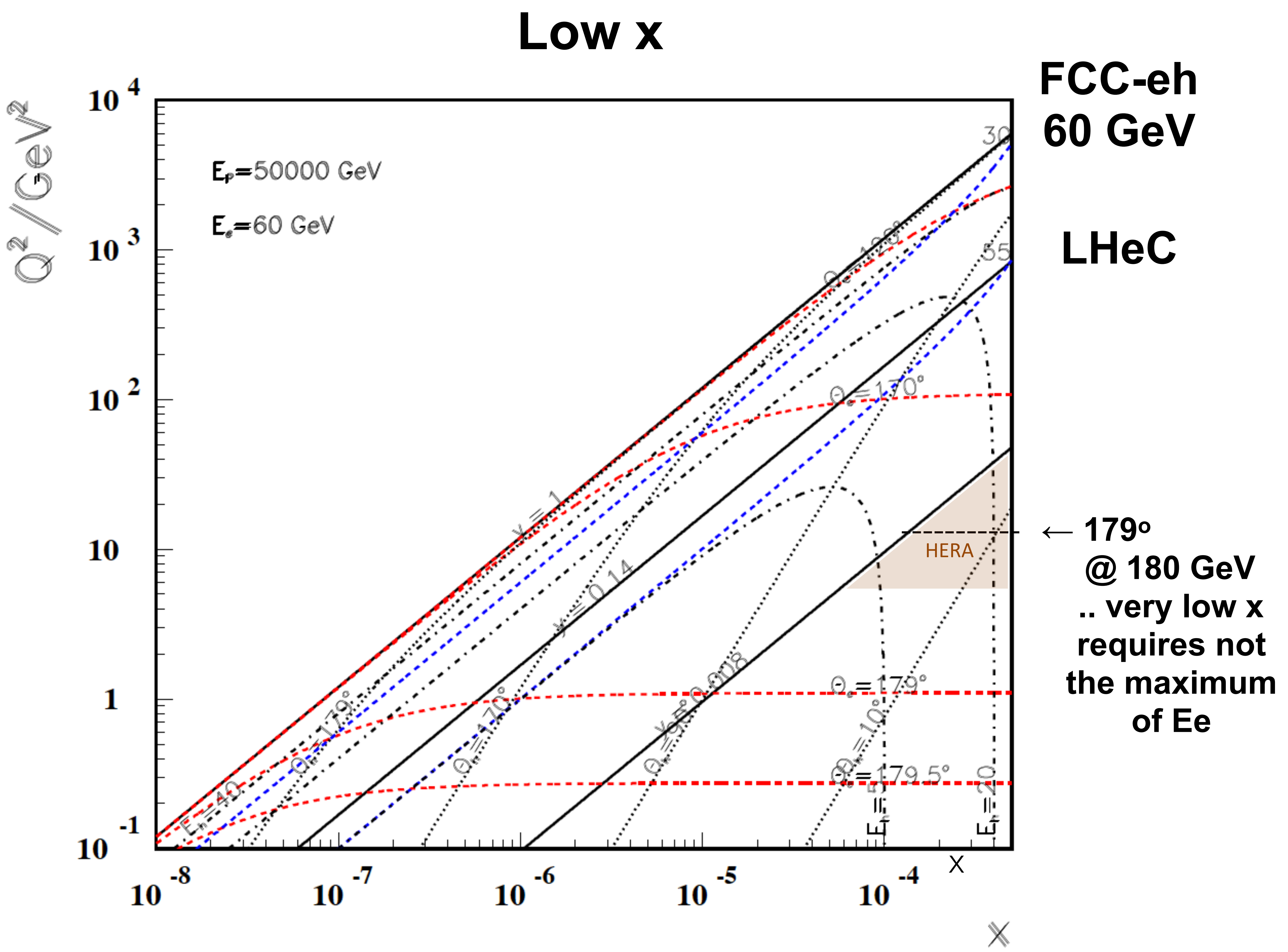
FCC-he Kinematic Range (low x; high Q^2)

courtesy Max Klein

Rutherford backscattering
of dozens of TeV e- energy



Low x



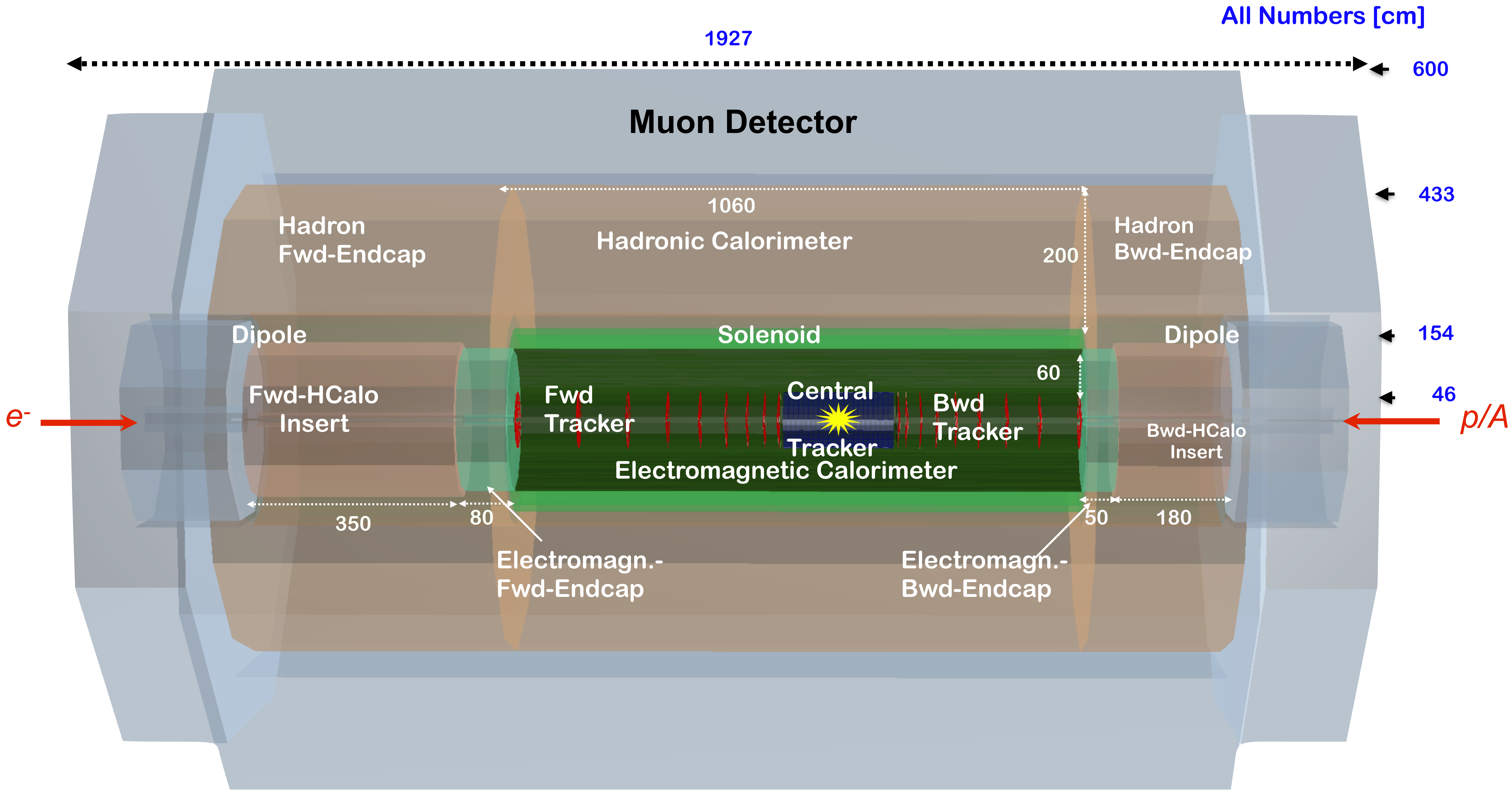
Large imbalance of e and p energies is surprisingly tolerable for the high Q^2, x kinematics,
LHeC to bridge from HERA to FCC

Very low x reaches direct range of UHE neutrino physics

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

Backward region, low x is governed solely by E_e

FCC-he Detector Basic Layout



Based on the LHeC design; Solenoid&Dipoles between Electromagnetic Calorimeter and Hadronic Calorimeter. Length of Solenoid ~11m. detector setup in DD4hep.

https://dd4hep.web.cern.ch/dd4hep/

FCC-he Detector Layout - Inner Dipoles and Solenoid

3 beams:

e$^-$ + proton1 + proton2
(or heavy ions A)

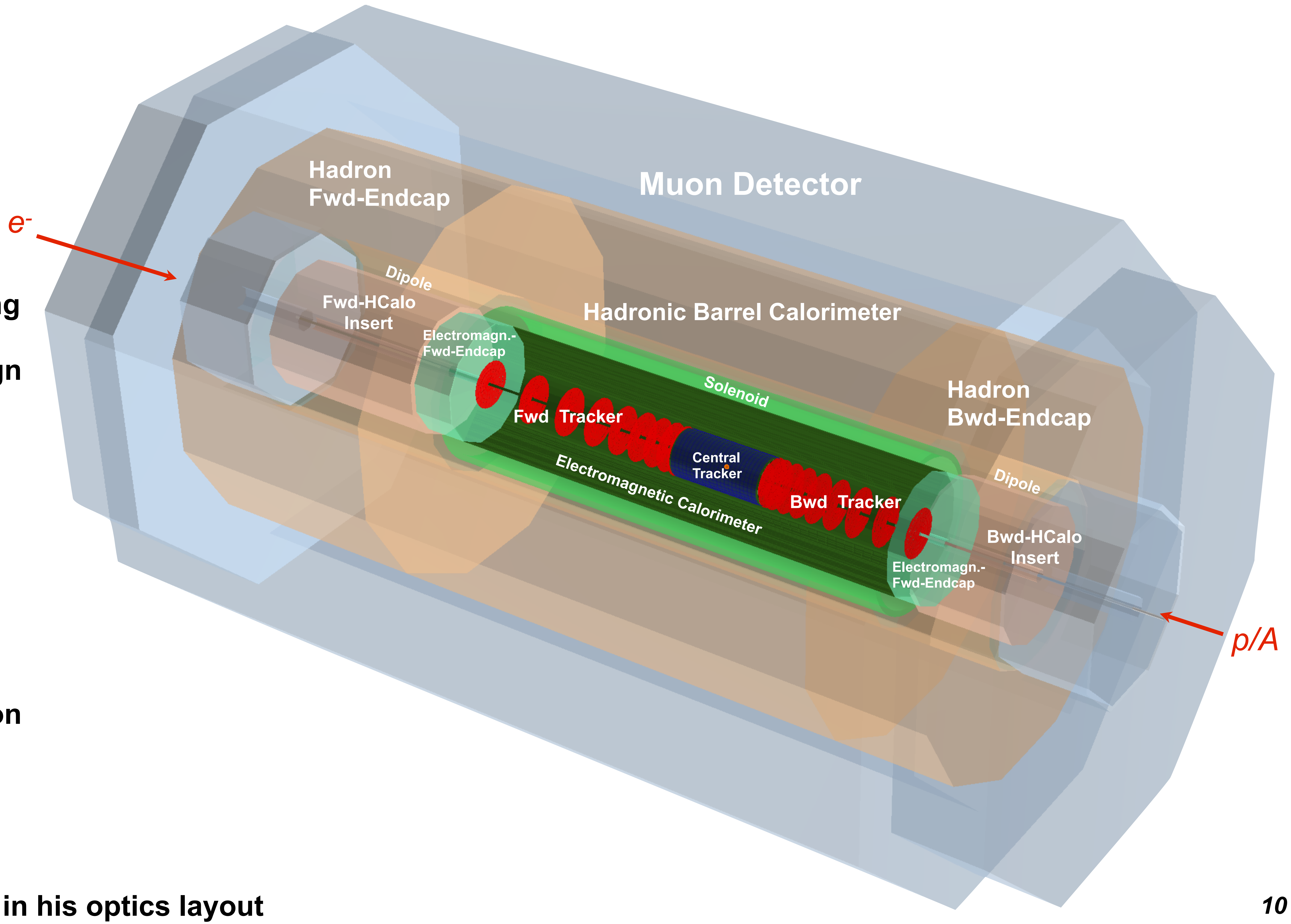
Dipole magnets to guide
the e-beam in and out,
for making electrons to collide head-on
with p-beam1;

±0.073 T dipoles* (transverse) field along
2 x ~9 m (?) (internal shown only)
- field & layout to be defined ← IR design

Length of Solenoid ~11m,
Solenoid required very light-weighted -
material budget !

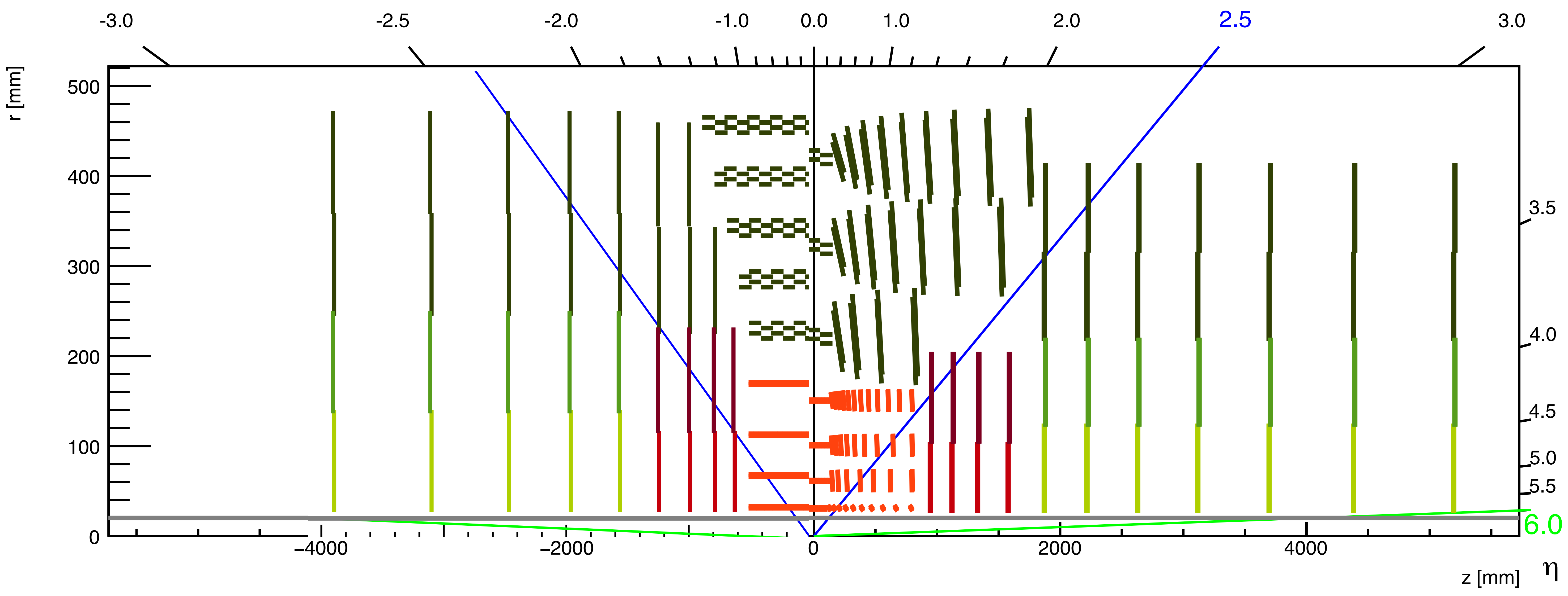
From LHeC → FCC-eh

Longitudinal FCC_eh calorimeter
dimensions roughly scale proportional
to the logarithm of the ratio of the proton
beam energies in forward direction
(ln(50/7) = 2) and of the electron beam
energies in backward direction (~1.3)



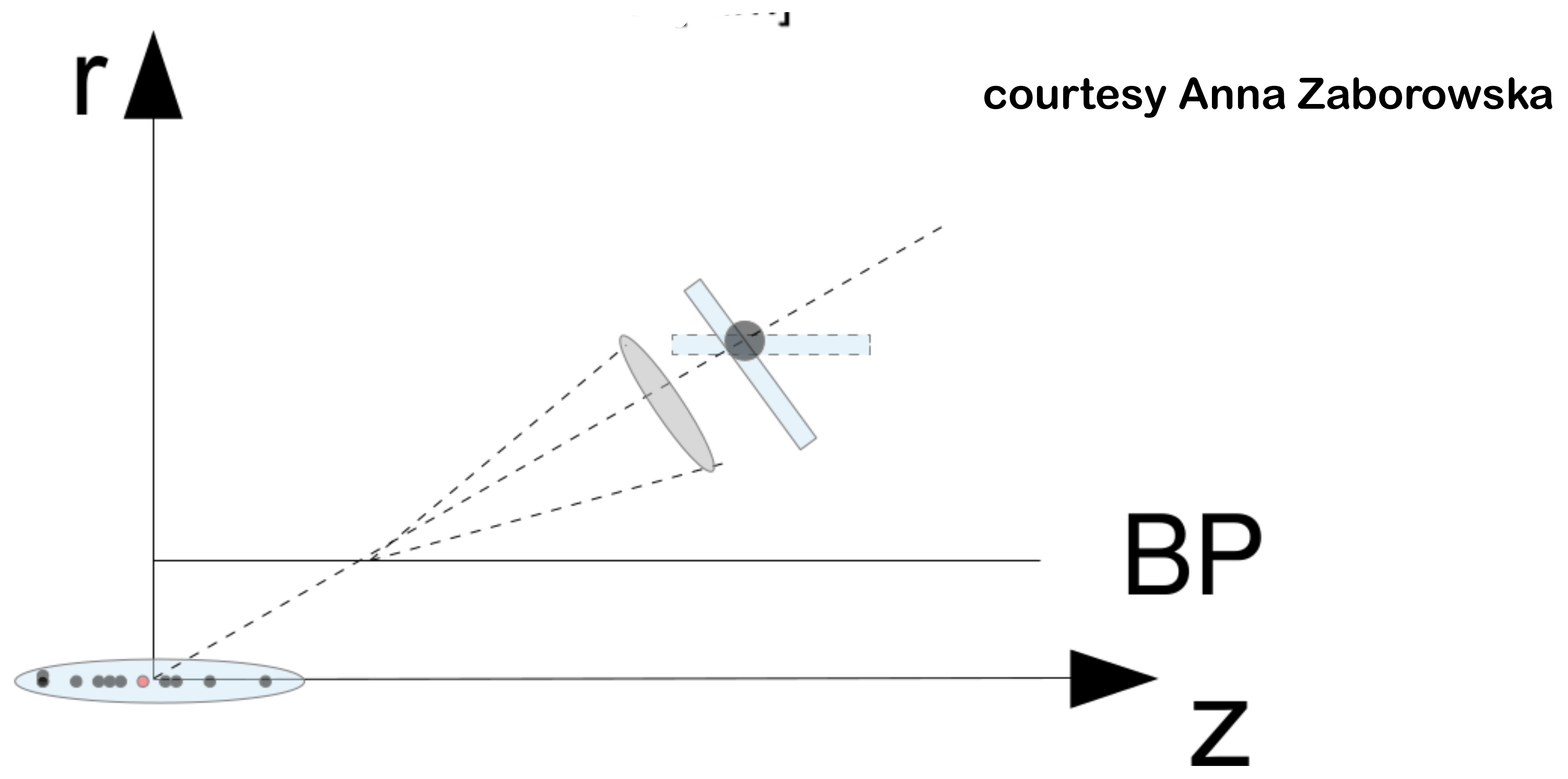
* used by Roman Martin in his optics layout

FCC-eh Tracker Layout



bwd - planar design **fwd - tilted design**

Going from planar design to Inclined inner tracker modules minimizing material budget



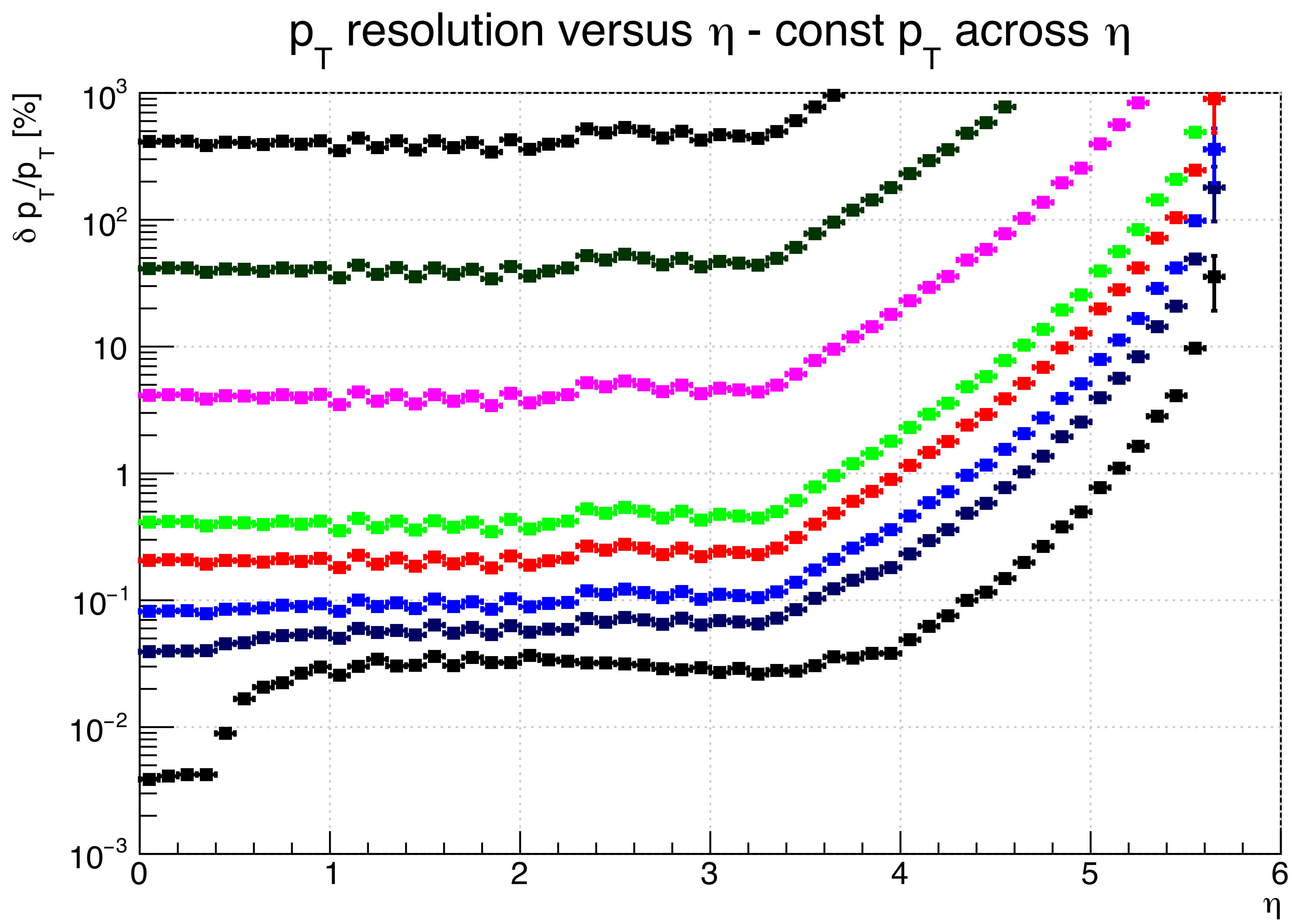
Very compact layout
Forward/backward boosted jet-/particle-flow
The physics requirements dictates final dimensions
Higher accuracy/ larger lever arms (radius, z-extension) needed … No problem

Number of R/O channels [M]:
pixel: 3849.015
macro-pixel: 1321.89

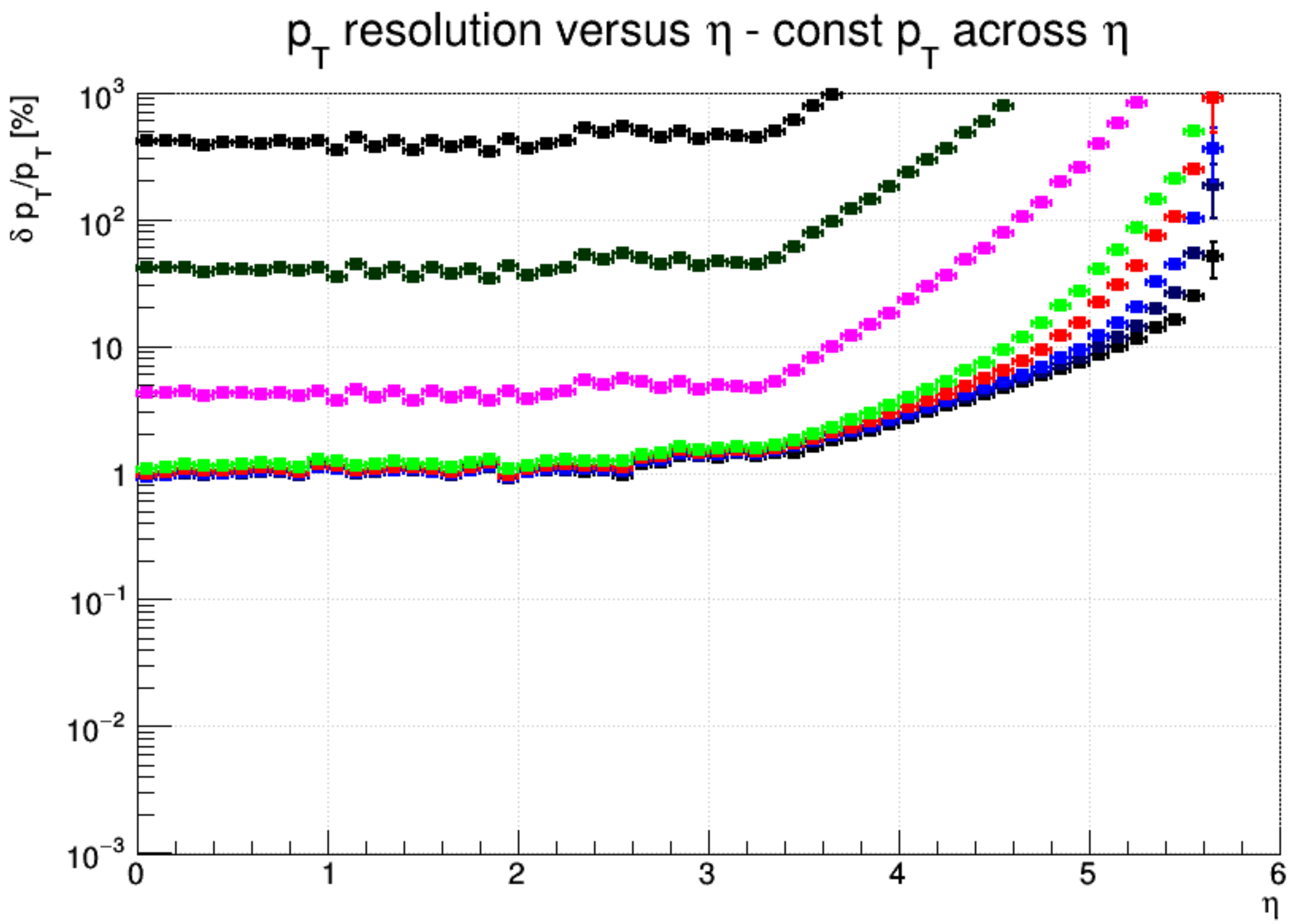
Optimised by pattern recognition and vertexing
3.5mm beam pipe thickness
3.5T solenoidal field
NO pile-up from FCC-eh

Zbyněk Drásal:
https://github.com/drasal/tkLayout/tree/masterLite

FCC-eh Tracker - p_t Resolution



No Material & No Services



BeamPipe (3.5mm) & Active Material

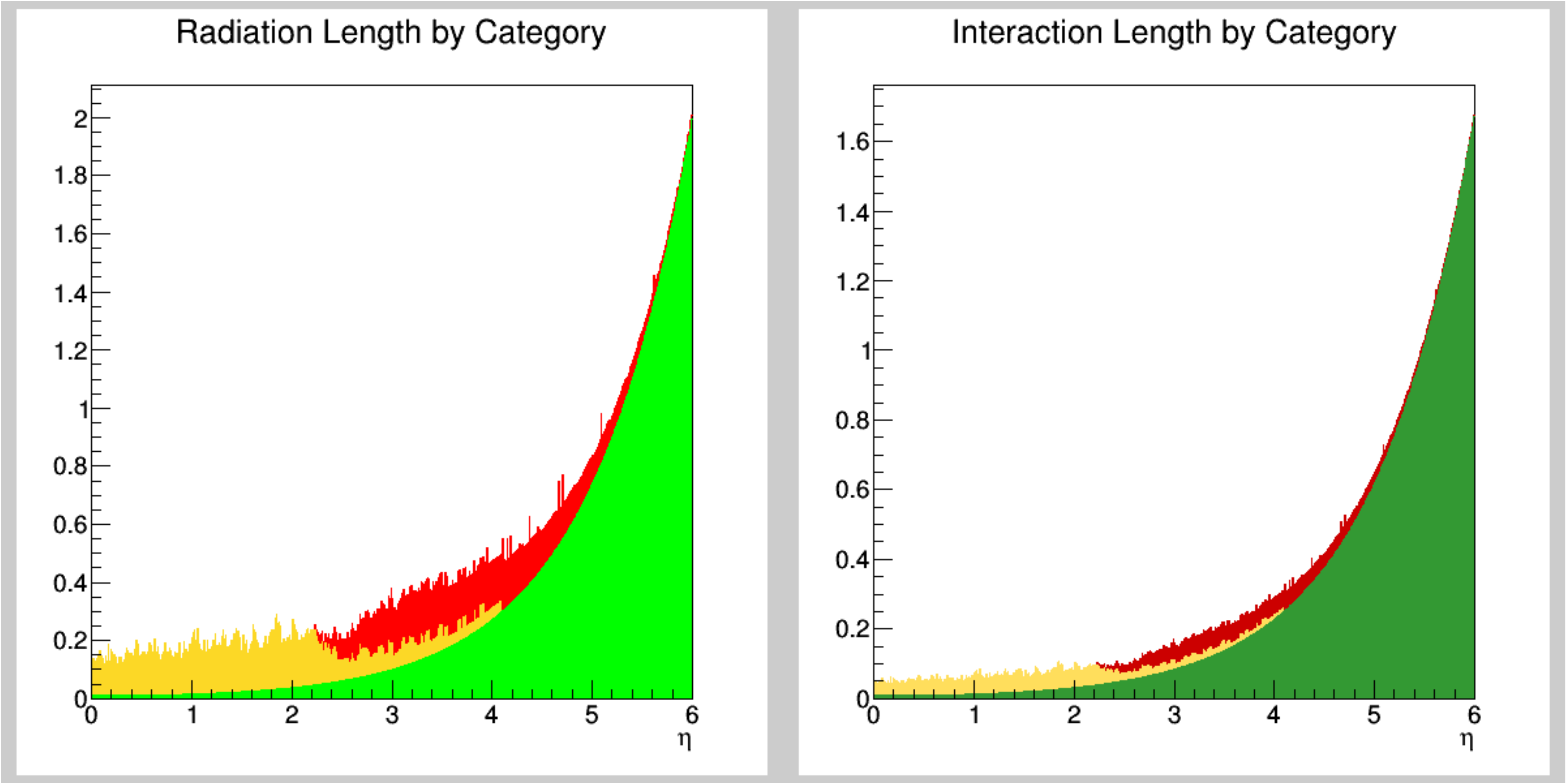
Particle momenta in GeV: 0.2 (Black), 1 (DarkBlue), 2 (Blue), 5 (Red), 10 (Green), 100 (Magenta), 1000 (DarkGreen), 10000 (Black).

preliminary

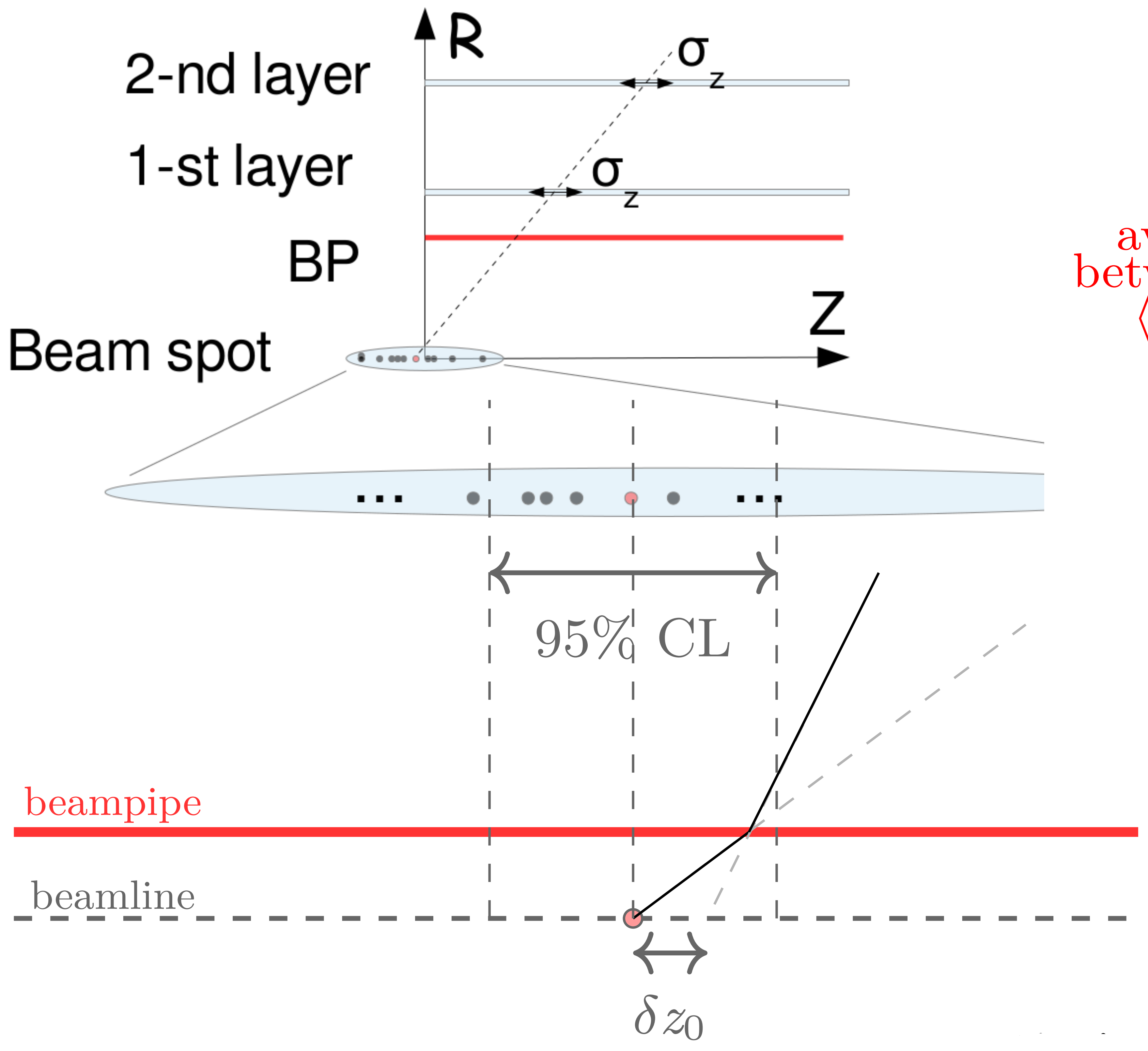
FCC-eh Track-Detector - Material Allocation

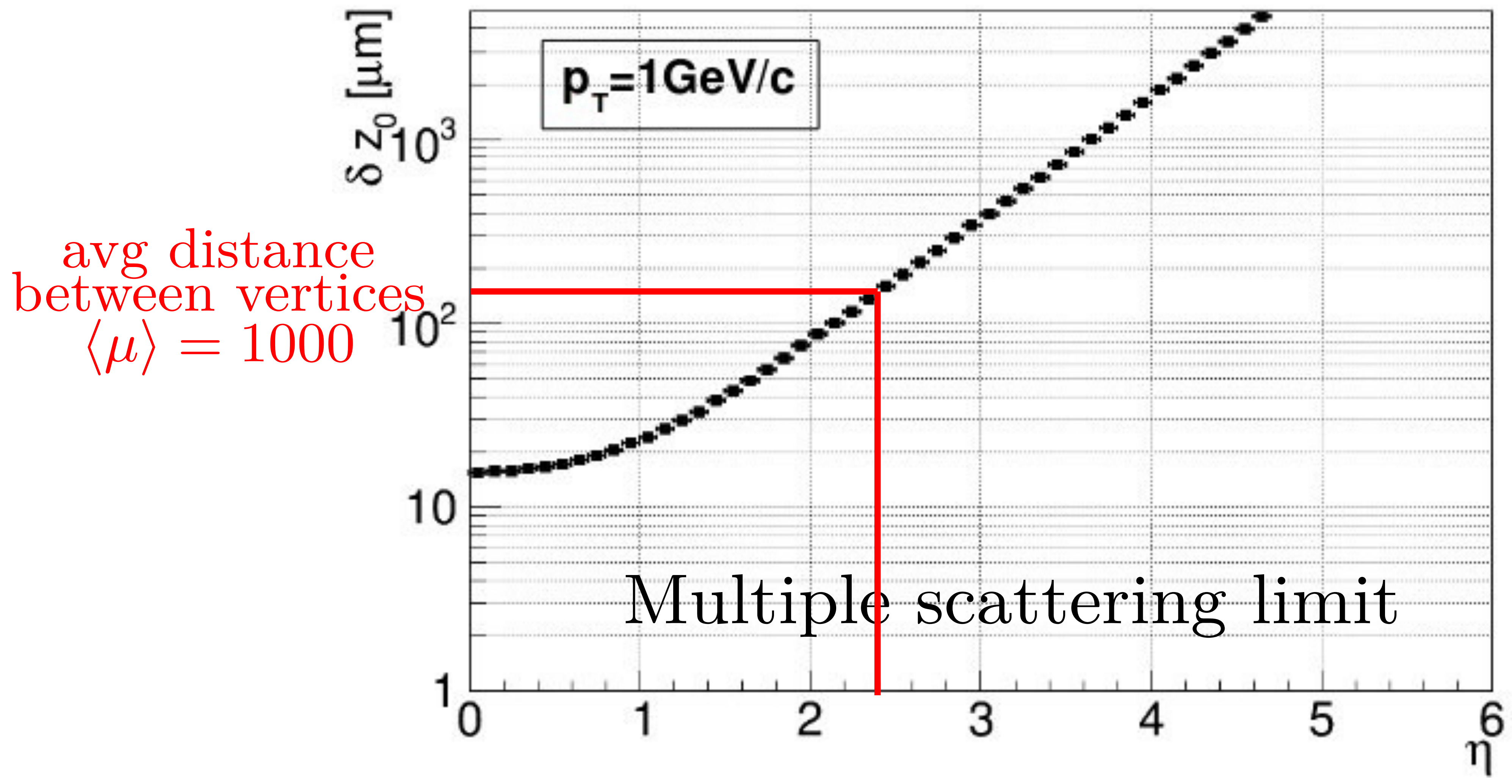
Material overview by category

Average	Radiation length [%]	Interaction length [%]
Beam pipe (green)	33.35	27.95
Barrel modules (yellow)	7.47	2.32
Endcap modules (red)	7.35	2.28
Total	48.17	32.54



FCC-eh Track-Detector - Vertex Resolution





FCC-hh picture

courtesy Anna Zaborowska

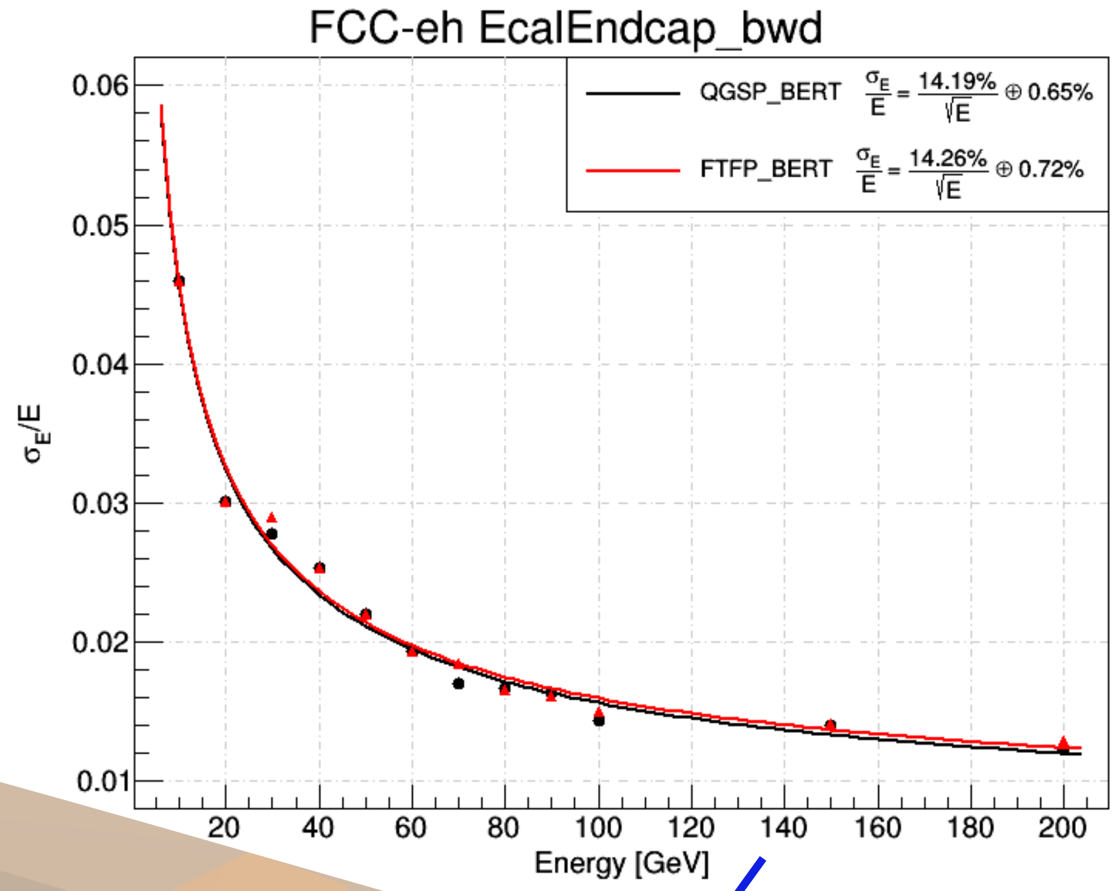
NO pileup for FCC-eh BUT
- effects of thicker BP to be investigated in detail
- resolution of displaced vertices, secondary vertices, boosted daughters

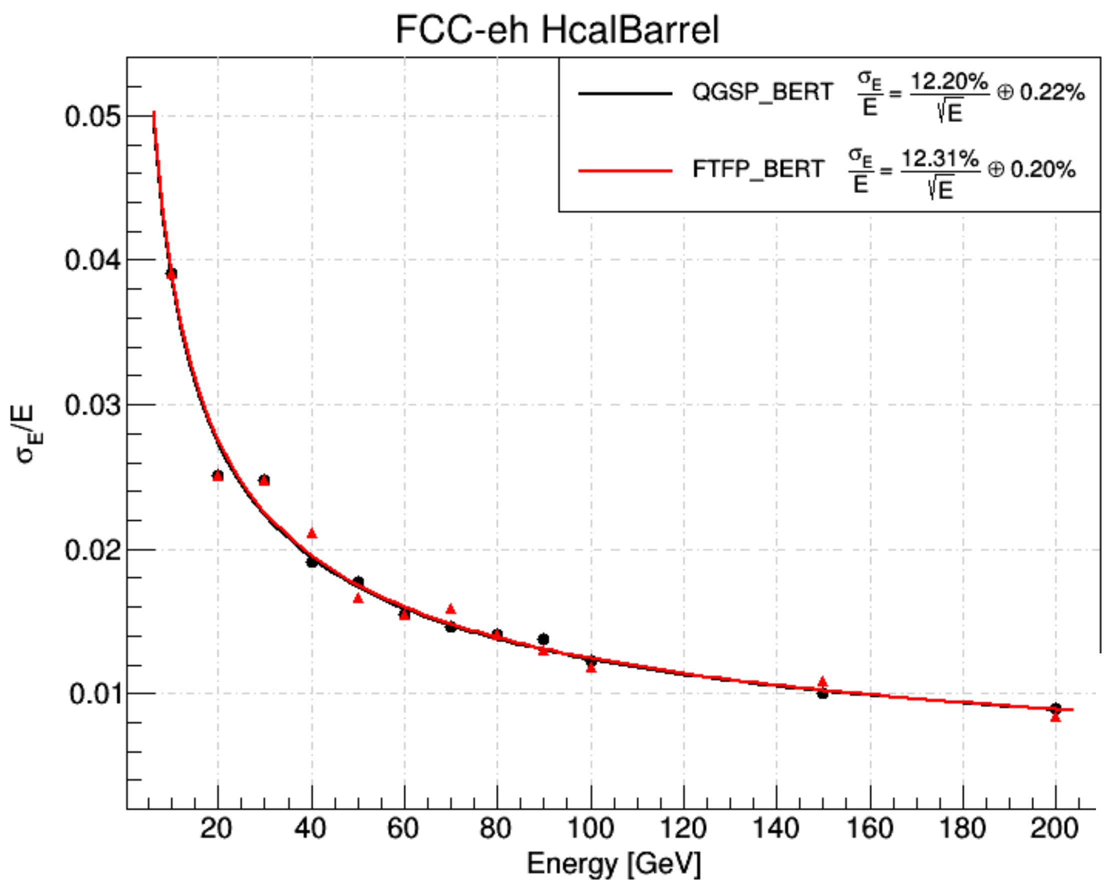
Calorimeter (all warm) FCC-eh Energy Resolutions

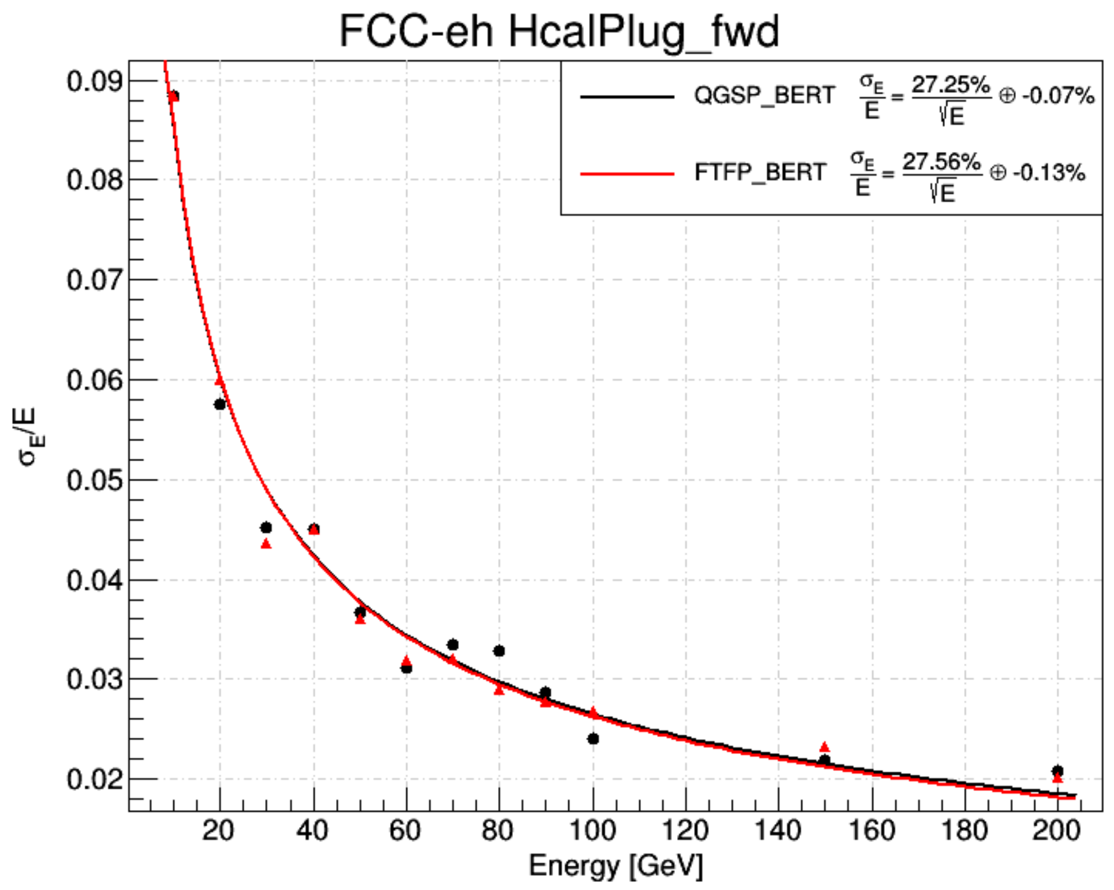
DDG4 * Simulation
done by Ercan Pilicer

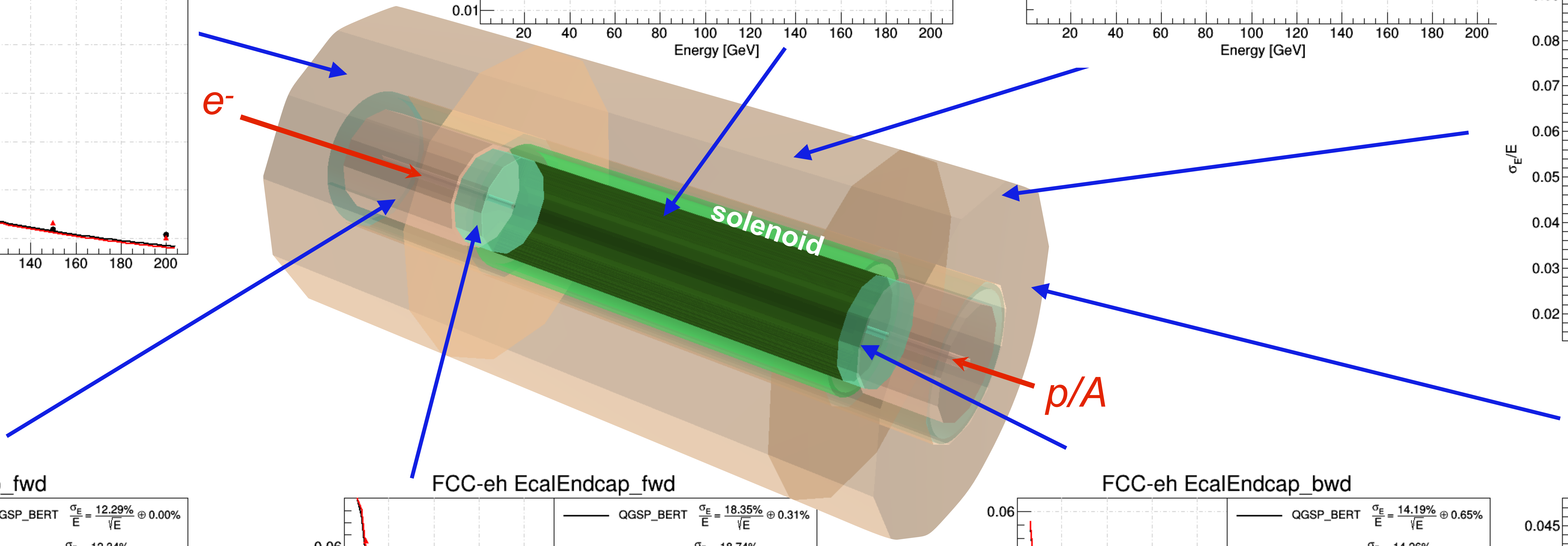
* https://dd4hep.web.cern.ch/dd4hep/

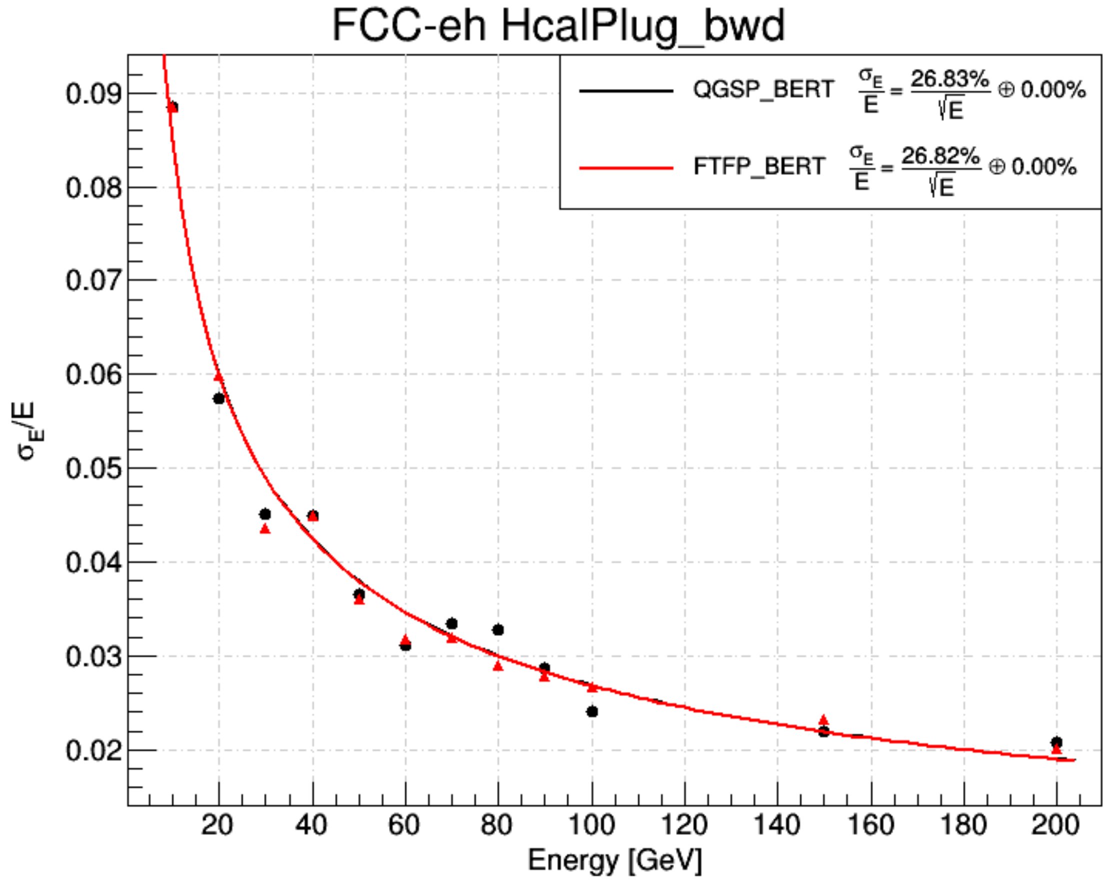
Good performance
constant terms small

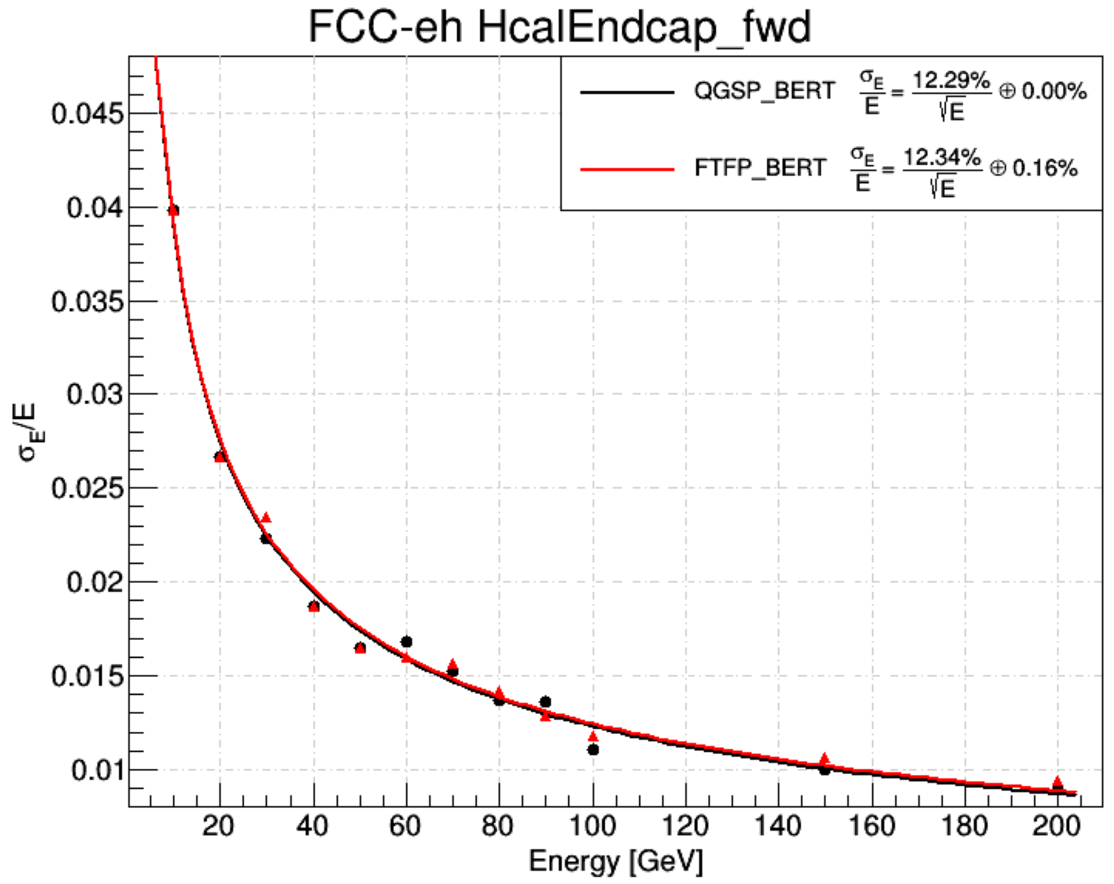


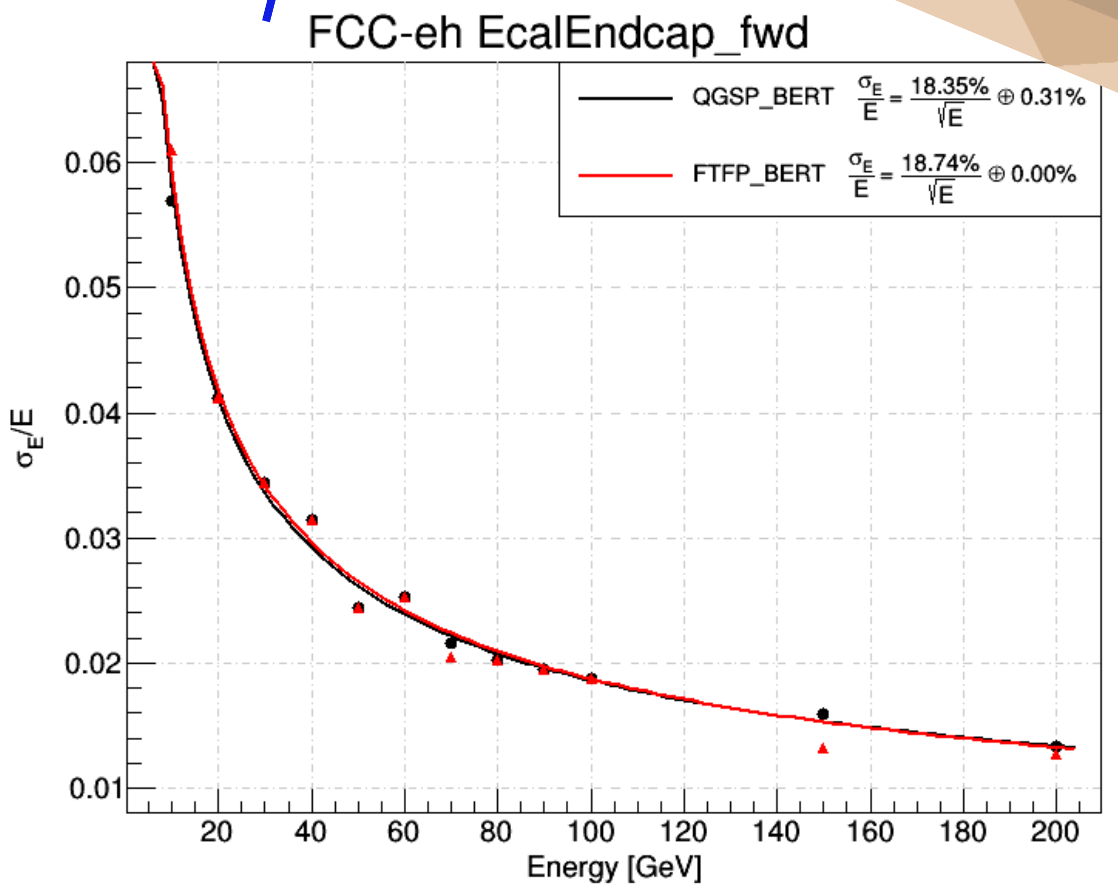


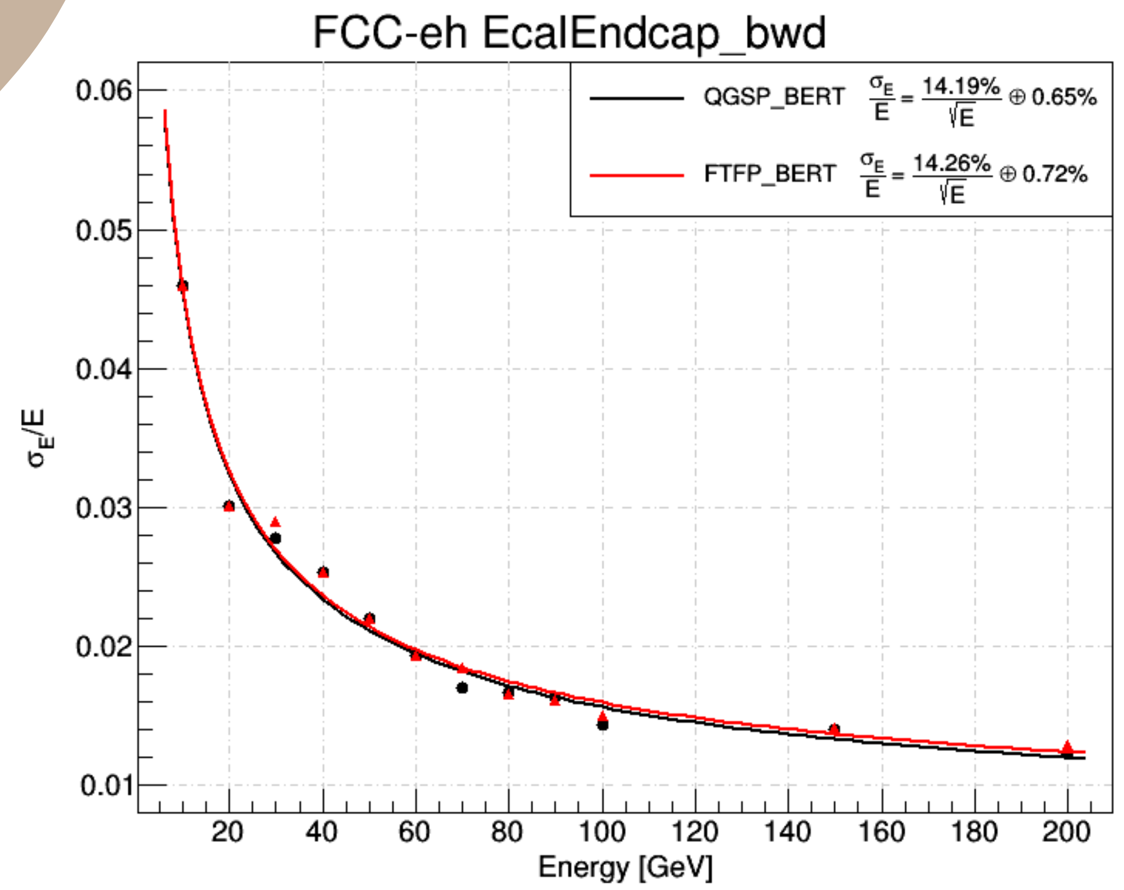


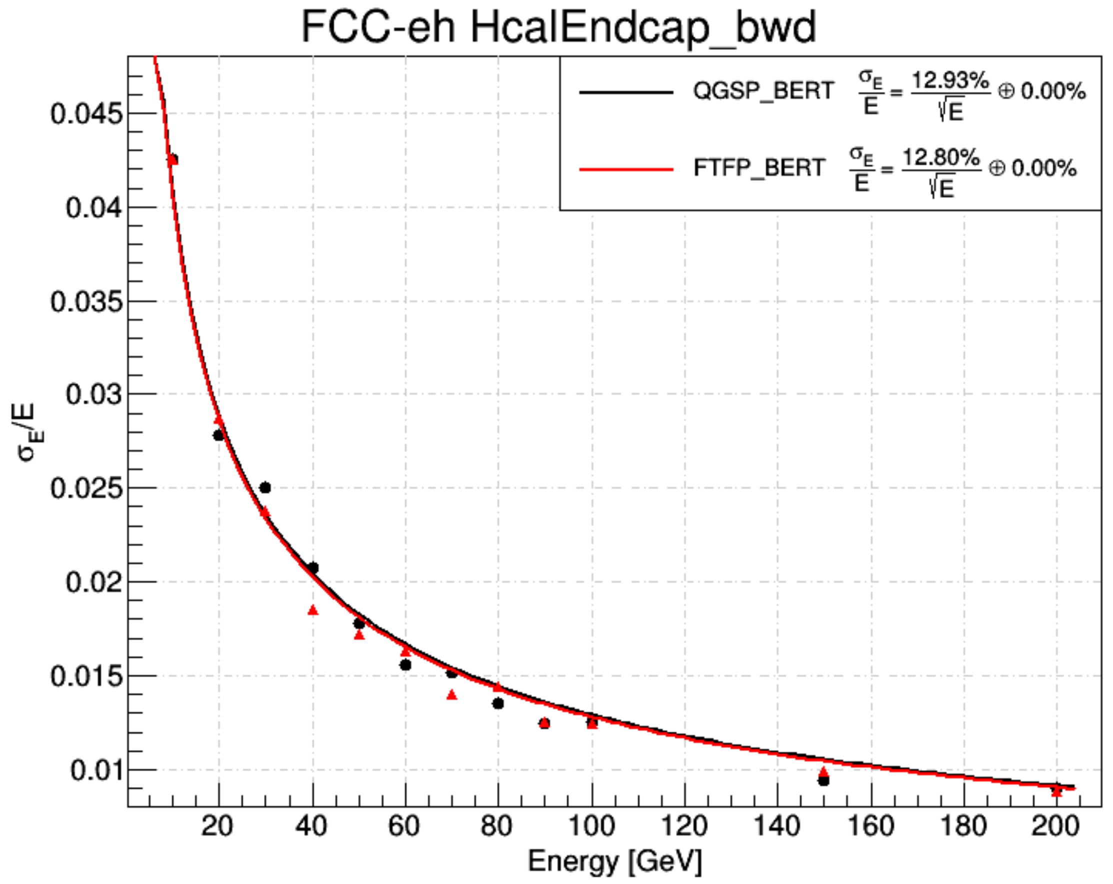












FCC-eh Technology Choice 1

Barrel ECAL	SciPb	⟷	LAr	~28-30 X_0
Barrel HCAL	SciFe	⟷	LAr	~10-12 λ_I
EndPlugs HCAL	SciFe	⟷	LAr	~10-12 λ_I
Fwd Endcap HCAL / ECAL	SiW / SiW	⟷	LAr	~12 λ_I / ~30 X_0
Bwd Endcap HCAL / ECAL	SiFe / SiPb	⟷	LAr	~9-10 λ_I / ~25-28 X_0

Si-based technology rely on last developments of reconfigurable, radiation hard CMOS MAPS devices

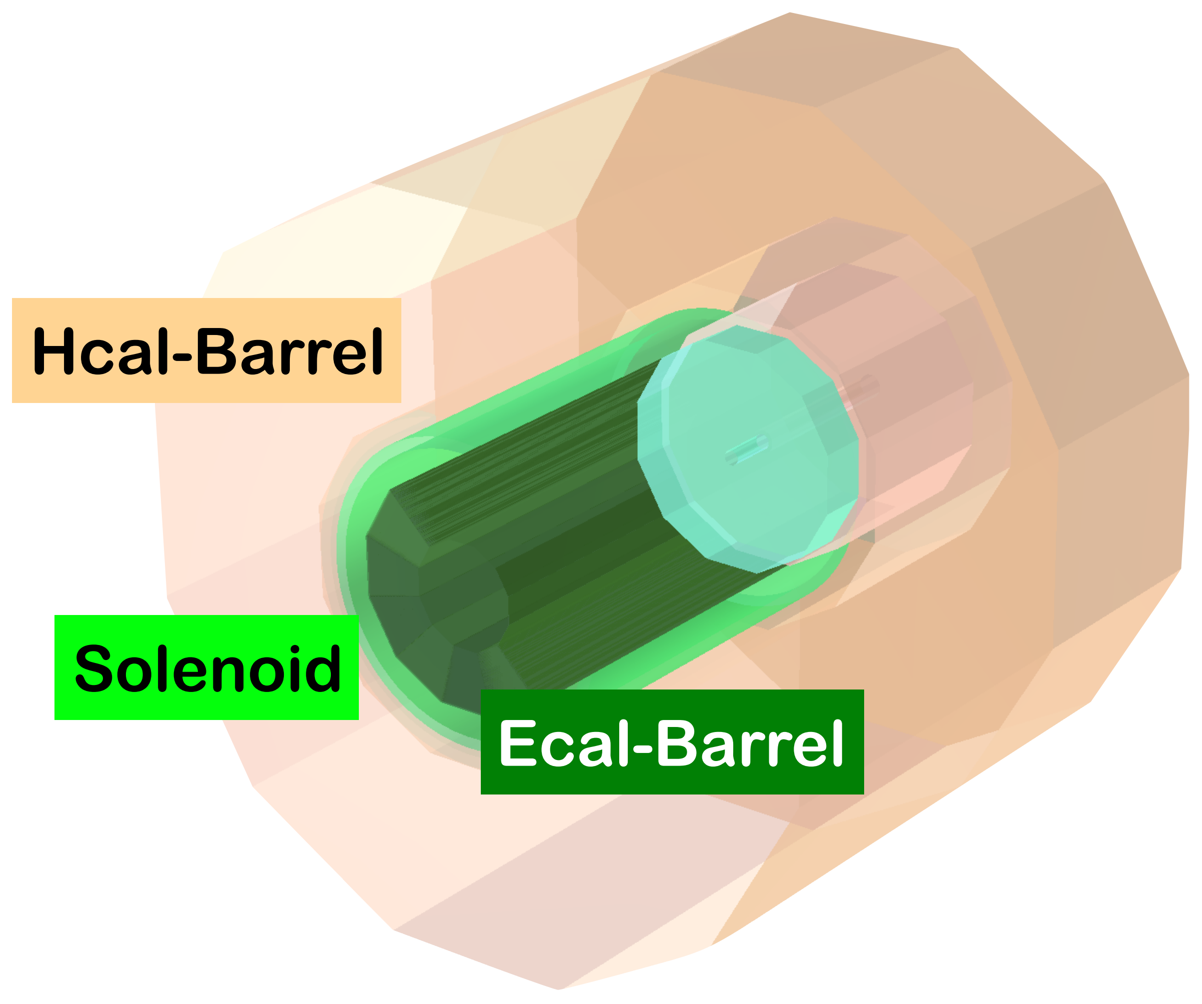
Silicon tracker	pixel, macro-pixel
Muon tracker	various detector technologies (RPC, MDT, TGC, CSC, MM etc.), not discussed here

FCC-he Experiment Solenoid

3.5T inner Solenoid ~11m length
containing full Tracker and ECAL-barrel; HCAL-barrel calorimeter outside

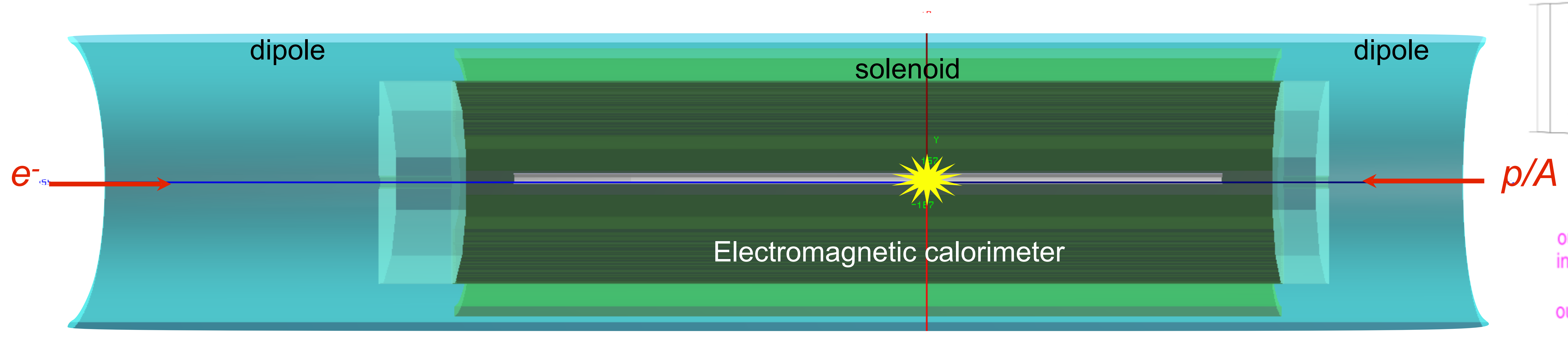
±0.073 T inner Dipoles 952cm fwd dipole; 629cm bwd dipole (currently)
after IR-magnet design fixed
conductor radius between Ecal-Barrel, Hcal-Barrel - 157cm

Barrel HCAL Fe-absorber (magnet return flux)
OR
open solenoidal field like for FCC-hh

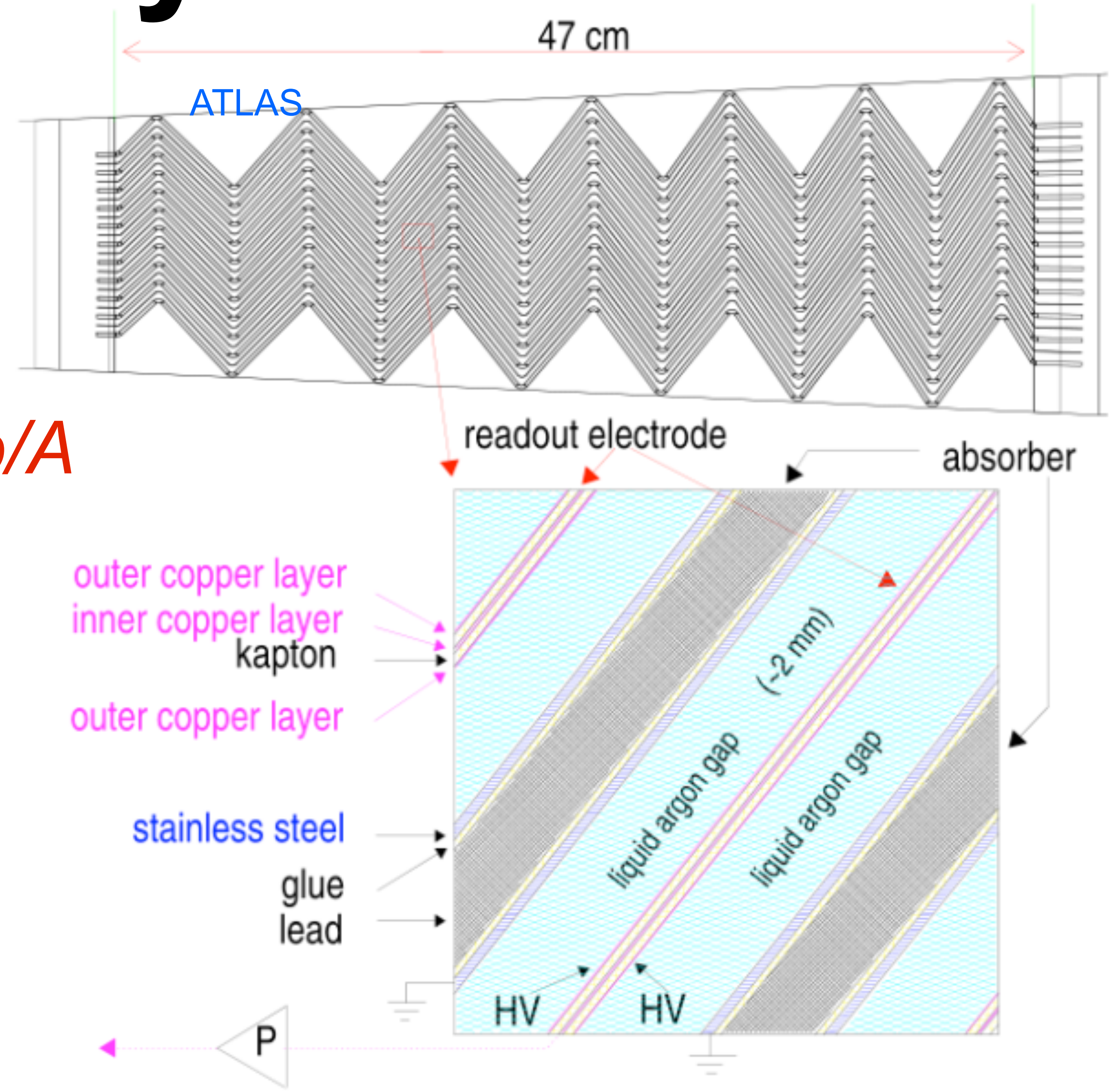


cutted view

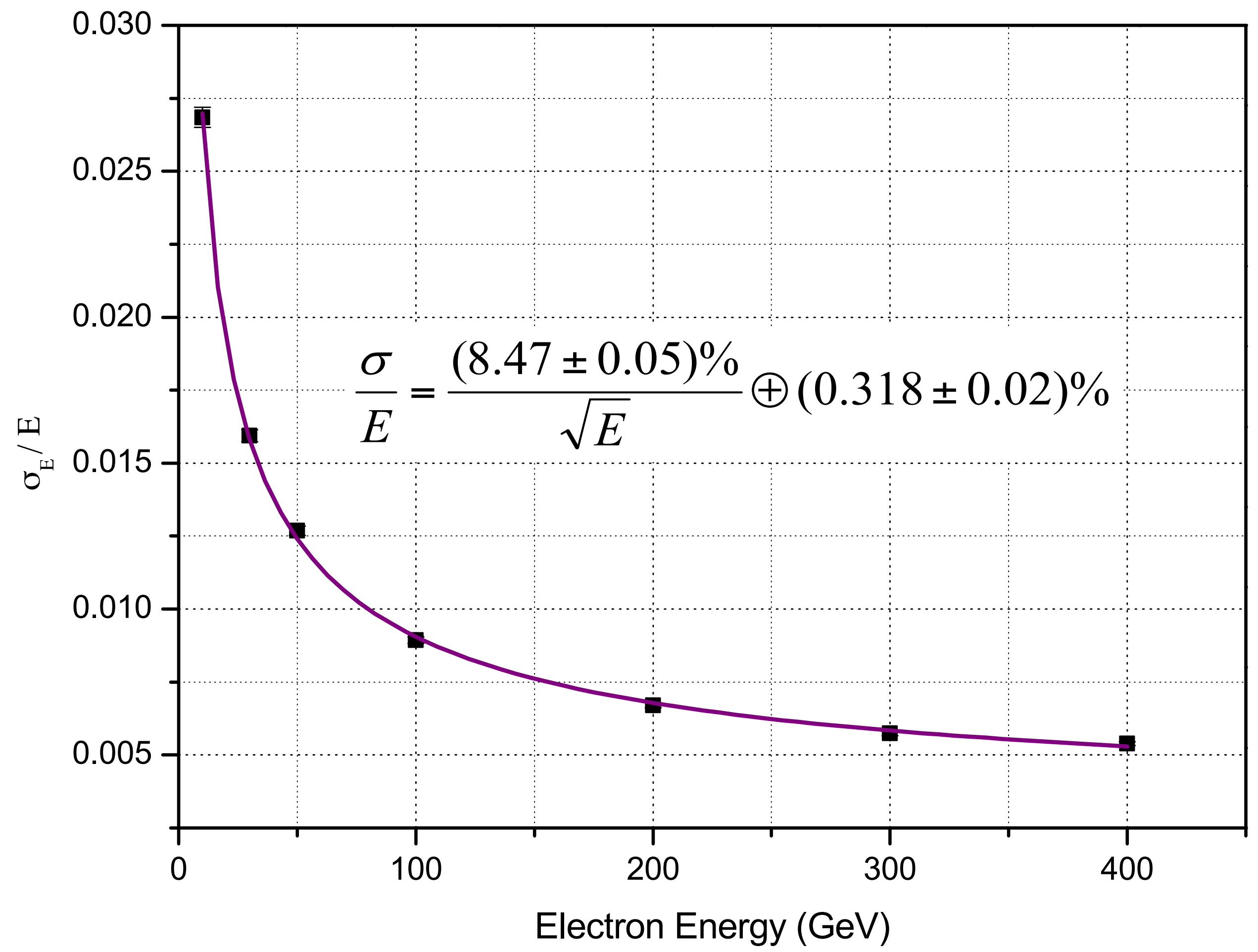
ECAL-LAr Barrel - LHeC Study

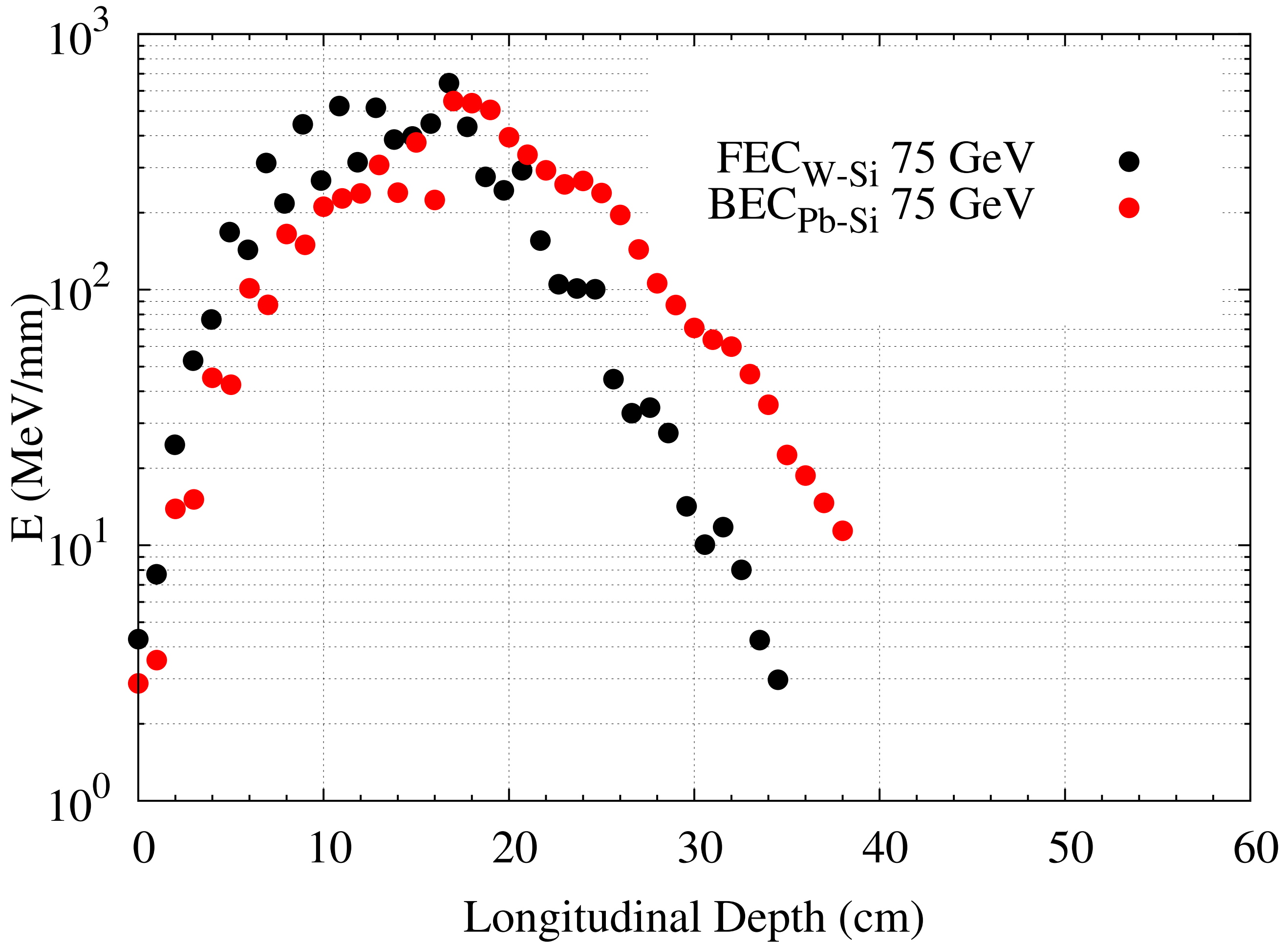


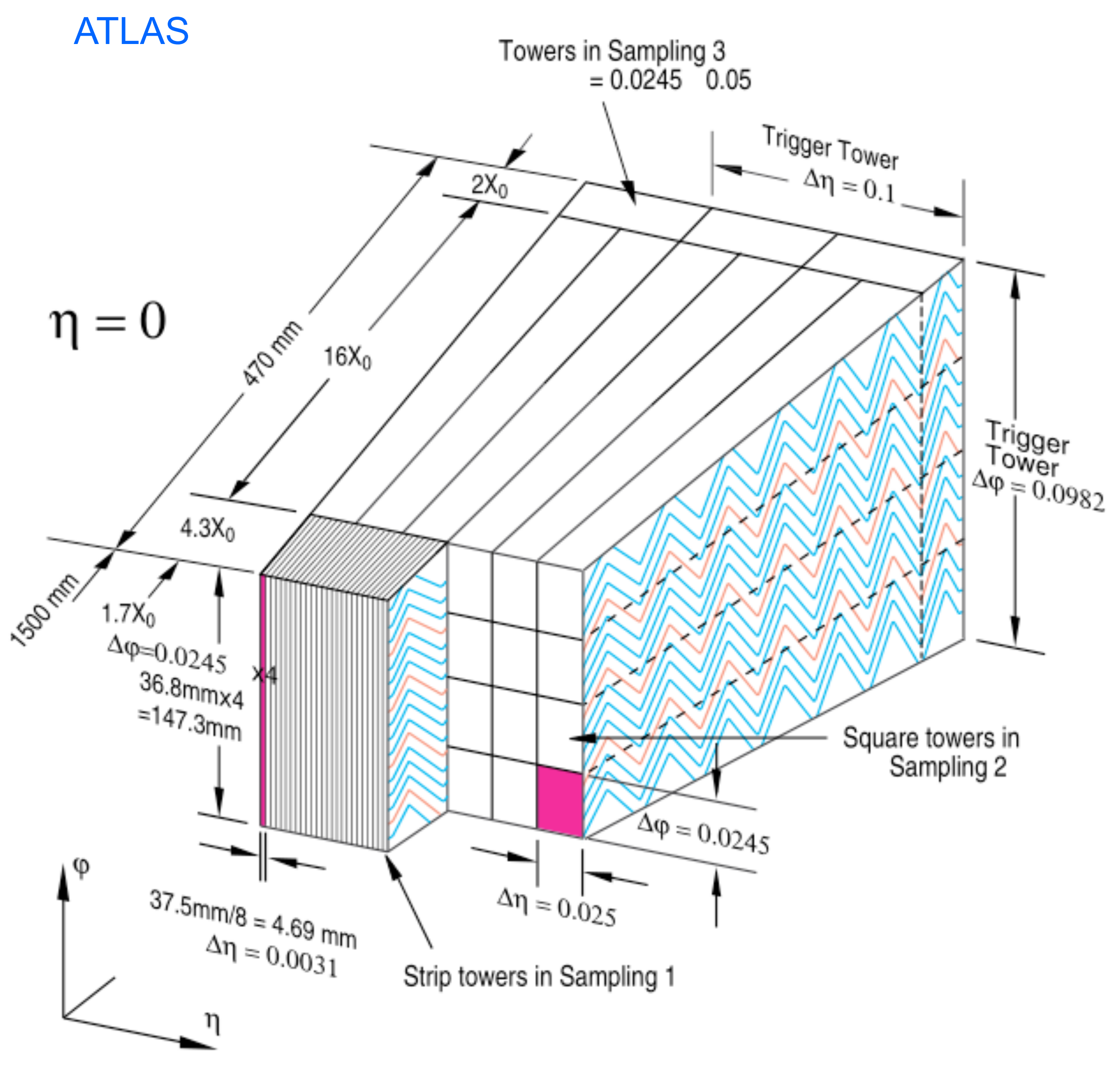
FCC-eh - Ecal-Barrel inside the Solenoid



- LAr for barrel EMCal – ATLAS Type (28-30 X_0)
- Same cryostat used for inner solenoid and dipoles
- Simulation results compatible with ATLAS
- 3 different granularity sections longitudinally







FCC-he Detector Dimensions/Parameters

Very high energy ≥ 10 TeV in forward direction: resolution terms less relevant vs constant term

e-p allows stringent cross calibration of calorimeters (HERA)

see
On the cross calibration of calorimeters at e-p colliders
J. Blumlein, M. Klein
(DESY, Zeuthen). Nov 1992. 9 pp.
Published in Nucl.Instrum.Meth. A329 (1993) 112-116
DESY-92-148

Tracker	FST_{pix}	FST_{strix}	CFT_{pix}	CPT_{pix}	CST_{strix}	CBT_{pix}	BST_{strix}	BST_{pix}
#Wheels	7		2	–	–	2	5	
#Rings/Wheel	2_{inner}	3_{outer}	3/4	–	–	3/4	3_{outer}	2_{inner}
#Layers	–	–	–	4	5	–	–	–
$\theta_{min/max}$ [^{0}]	0.5	3.8	3.6	5.1	24/155	176.4	173.1	179.3
$\eta_{max/min}$	5.4	3.4	3.5	±3.1	±1.4	-3.5	-2.8	-5.2
Pitch [μm]	30 x 30	37.5 x 1750	30 x 30	30 x 30	37.5 x 1750	30 x 30	37.5 x 1750	30 x 30
ReadOut-Pitch [μm]	30	75	30	30	75	30	75	30
pix-σ^{point} [μm]	≤14		≤14	≤14		≤14		≤14
strix-$\sigma^{r-\phi}$ [μm]		~5			~5		~5	
strix-σ^{z} [mm]		~5			~5		~5	
Vertexing-σ	$5\mu m \times 20\mu m/(p \times \sin^{3/2}\theta)$ solenoid and dipole field							
Tracking-σ [μm]	$\Delta(p_T/p_T{}^2) = 5 \times 10^{-5}$							
X_0 per layer [%]	0.3	0.8	0.3	0.3	0.8	0.3	0.8	0.3
$Si_{pix/strix}$ [m^2]	9.7	13.3	2.8	5.4	33.7	2.8	9.7	6.9
Sum-Si [m^2]	84.3 double layers taken into account							

Calo	FHC_{SiW}	FEC_{SiW}	$EMC_{SciPb/LAr}$	HAC_{SciFe}	BEC_{SiPb}	BHC_{SiFe}
$\theta_{min/max}$ [^{0}]	0.3	0.4	5.6/173.4	8.6/167	179.4	179.6
$\eta_{max/min}$	6.0	5.6	3.0/-2.7	2.5/-2.2	-5.3	-5.6
R/O-Pitch [mm]	20 x 20	10 x 10			20 x 20	20 x 20
$\sigma_E/E \approx$	$0.4/\sqrt{E}+0.02$	$0.1/\sqrt{E}+0.01$	$0.09/\sqrt{E}+0.02$	$0.4/\sqrt{E}+0.02$	$0.1/\sqrt{E}+0.01$	$0.4/\sqrt{E}+0.04$
E-Flow	$\sigma_{E_{jet}}/E_{jet} = 0.03$ (at lower energies $25\%/\sqrt{E}$; sampling ~55 ; $\sigma_{jet} \sim 3\%$)					
Λ_I / X_0	$\Lambda_I \geq 12$	$X_0 \geq 28$	$X_0 \geq 28$	$\Lambda_I \geq 12$	$X_0 \geq 25$	$\Lambda_I \geq 10$
Volume [m^3]	13.2	3.1	28.8	407	1.98	7.0
Sum-Si [m^2]	461					

Attention being updated!! Not consistent any more

FCC-eh Physics Benchmarks e.g.

Uta & Max Klein, Contribution to FCC Workshop, 16.1.2018, preliminary

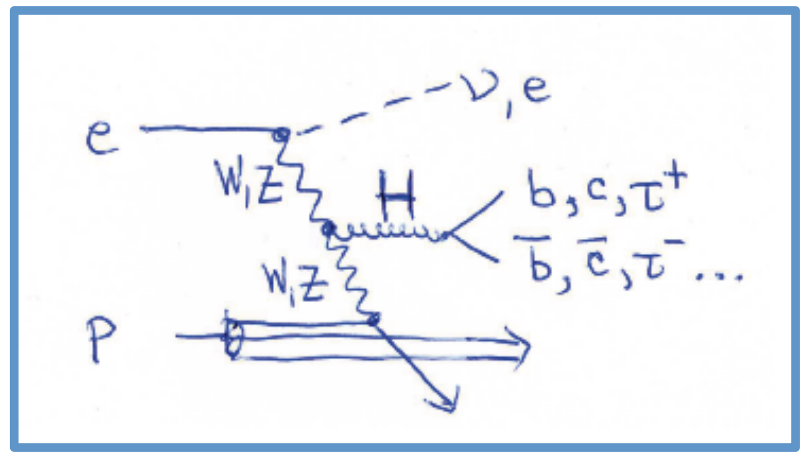
CC DIS WWH → H

FCC-he L=2 ab^{-1}

	bb	WW	gg	ττ	cc	ZZ	γγ
BR	**0.577**	**0.215**	**0.086**	**0.0632**	**0.0291**	**0.0264**	**0.00228**
δBR_{theory}	3.2%	4.2%	10.1%	5.7%	12.2%	4.2%	5.0%
N	**$1.15\ 10^6$**	**$4.3\ 10^5$**	**$1.72\ 10^5$**	**$1.26\ 10^5$**	**$5.8\ 10^4$**	**$5.2\ 10^4$**	**4600**
f	2.86_{BDT}	16	7.4	5.9	5.6_{BDT}	8.9	3.23
δμ/μ [%]	**0.27**	**2.45**	**1.78**	**1.65**	**2.36**	**3.94**	**3.23**
$\delta\kappa = \frac{1}{2}\frac{\delta\mu}{\mu}$	0.14	0.61*	0.89	0.83	1.18	1.97	2.37

bb/cc

both vertex tagging demanding somewhere between 5-10μm resolution required; accompanied by excellent calorimeter measurement



→ Sum of first 6 branching fractions that could be measured

LHeC : 0.9964 +- 0.02

FCChe: 0.9964 +- 0.01

pp: < 0.99 → cc? gg?

Further coupling constraints to be explored:

$$\sigma(WW \to H \to WW) \propto \kappa^4(HWW)$$
$$\sigma(WW \to H \to bb) \propto \kappa^2(HWW) \bullet \kappa^2(Hbb)$$
$$\sigma(WW \to H \to \tau\tau) \propto \kappa^2(HWW) \bullet \kappa^2(H\tau\tau)$$
$$\sigma(WW \to H \to gg) \propto \kappa^2(HWW) \bullet \kappa^2(Hgg)$$
$$\sigma(WW \to H \to cc) \propto \kappa^2(HWW) \bullet \kappa^2(Hcc)$$
$$\sigma(WW \to H \to ZZ) \propto \kappa^2(HWW) \bullet \kappa^2(HZZ)$$
$$Note: \sigma(ZZ \to H \to WW) \propto \kappa^2(HZZ) \bullet \kappa^2(HWW)$$

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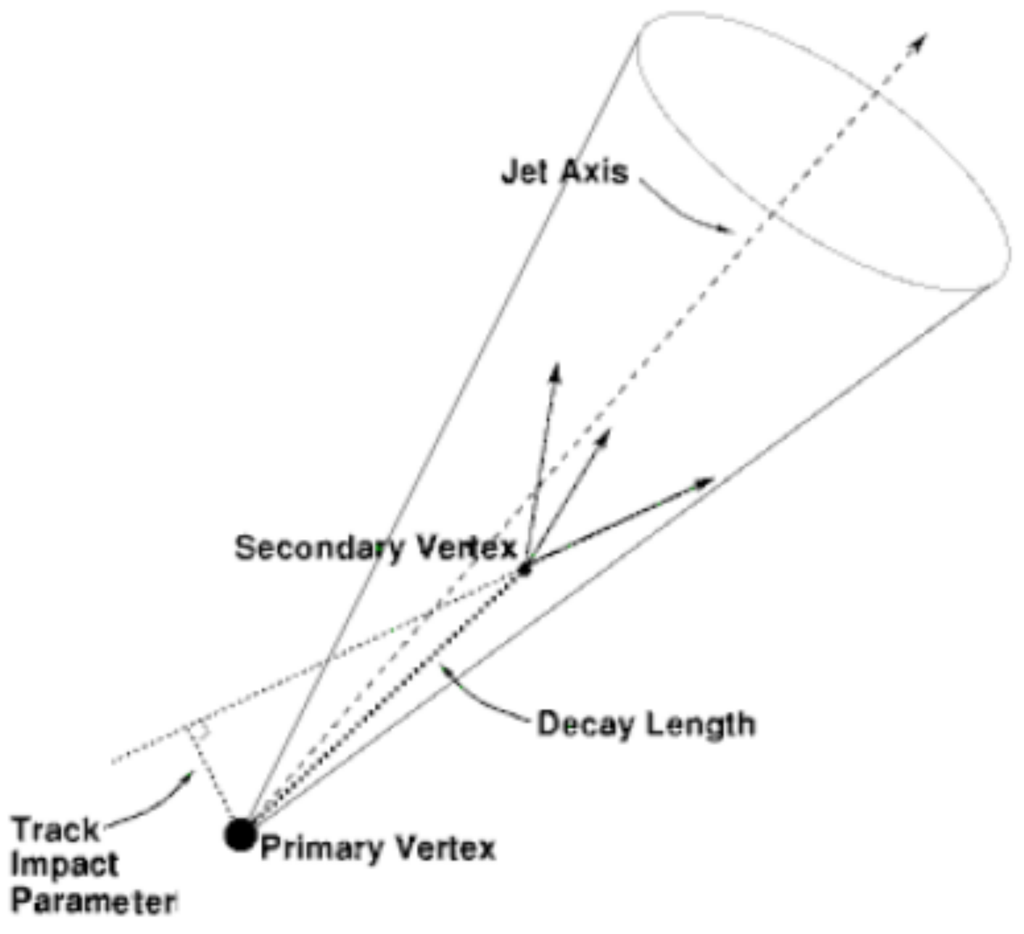
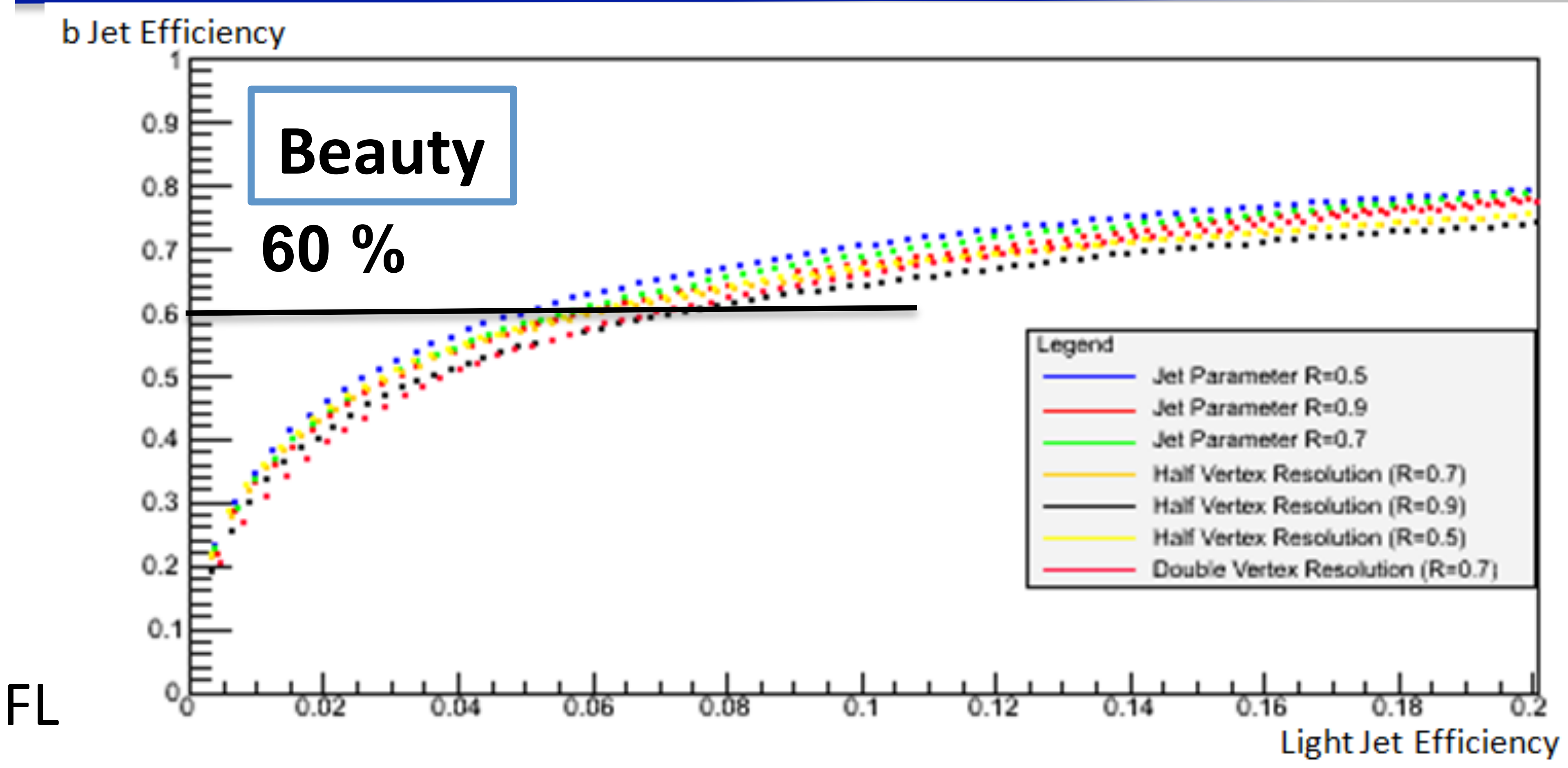
FCC-eh Secondary Vertex Tagging

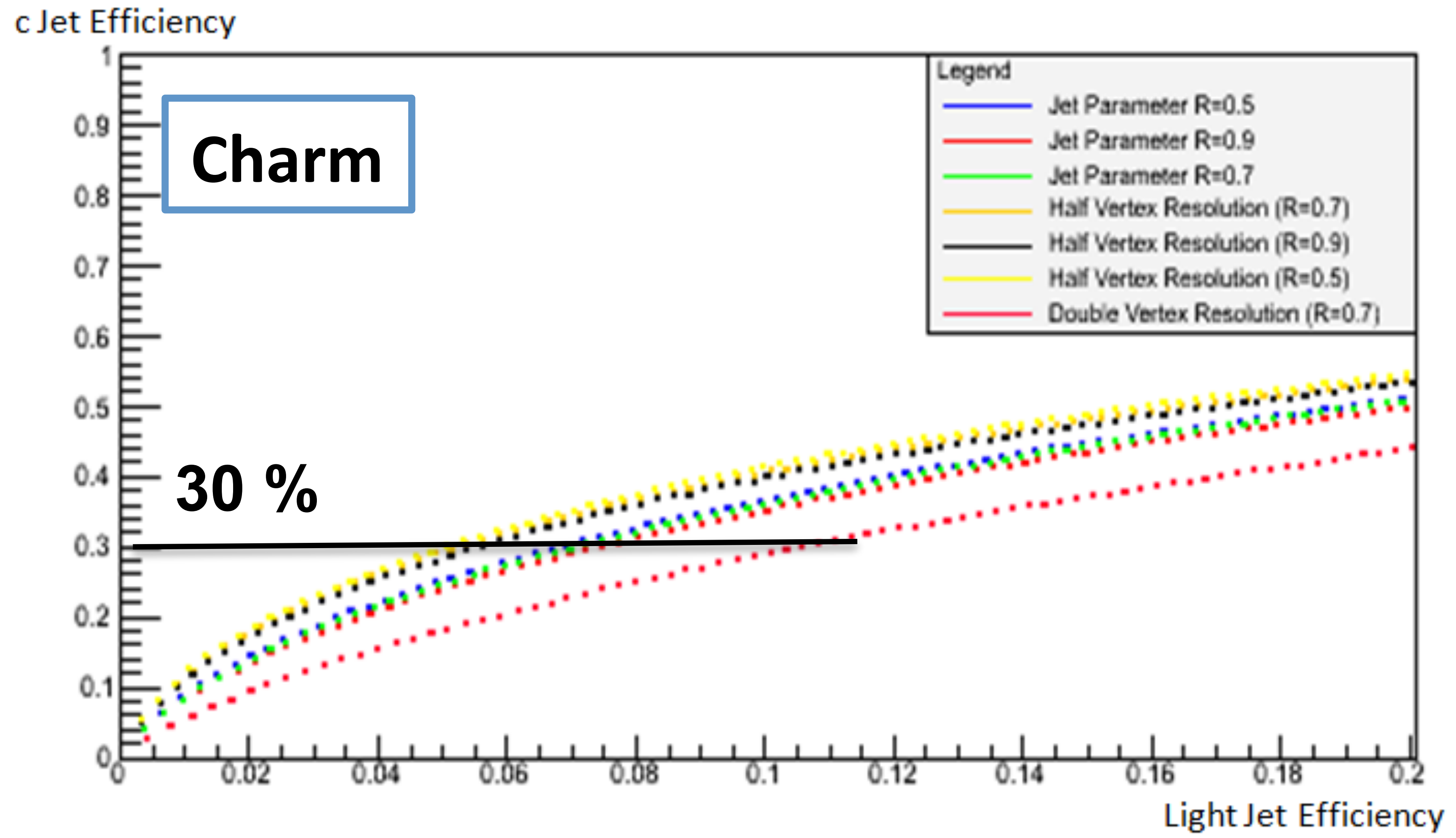
HFL Tagging

Uta Klein &
Daniel Hampson



- → Realistic and conservative HFL tagging within Delphes realised, and dependence on vertex resolution (nominal 10 µm) and anti-kt jet radius studied
- → Light jet rejection very conservative, i.e. factor 10 worse than ATLAS
- → **used in full LHeC analysis and for FCC-eh extrapolations**





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Summary 1

A ERL-based FCC-eh is taking shape

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 detector has to tolerate the additional dipole magnet system inside the IR

The IR region design passed the first corner stone - p optics with β^* =0.3m - ok
The goal is a design with β^* =0.15m, work on IR-magnet design needed
Synchrotron radiation load seems to be tolerable -
detailed investigation (MDISim, Geant4) to be done

Detector serving for the rich physics program -
different options, e.g. calorimeter warm ↔ cold (LAr based),
detector magnet design, some dimensions of detector parts
Modern technology → high precision tracking,
high energy forward particle & jet reconstruction in ep
Porting the FCC-eh detector description into FCCSW - ongoing
Benchmark channel test results being worked on

Some examples of detector performance given - in DD4hep/DDG4 environment still

Summary 2

Based on HERA, LHC, ILC R&D there exist a concept for a detector at FCC-eh, which is applicable. The technology choices investigated in parallel - the detector layout is evolving. Crucial: IR layout

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.

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

CDR - work in progress

FCC-eh Machine/Physics Presentations

Bruce Melado, FCC-eh and LHeC Overview	✓
Jorge de Blas, Higgs in hh-eh-ee	✓
Christian Schwanenberger, Top in hh-eh-ee	✓
Max Klein, QCD measurements at FCC	✓
Oliver Bruening, Overview on FCC-eh design	✓
John Osborne, Civil engineering	✓
Roman Martin, Interaction region	✓
Walid Kaabi, PERLE facility	✓
Uta Klein, FCC-eh as a Higgs Facility	✓
Monica D'Onofrio, BSM Physics in eh	✓
Orhan Cakir, Top Quark Physics in eh	✓
Uta Klein, FCC-eh Summary	Don't miss


Future Circular Collider Conference
fcc.web.cern.ch
FCCWEEK2018
EuroCirCol
EASITrain
ARIES
IEEE CSC
UNIVERSITY OF TWENTE.
Nikhef

Thank you

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

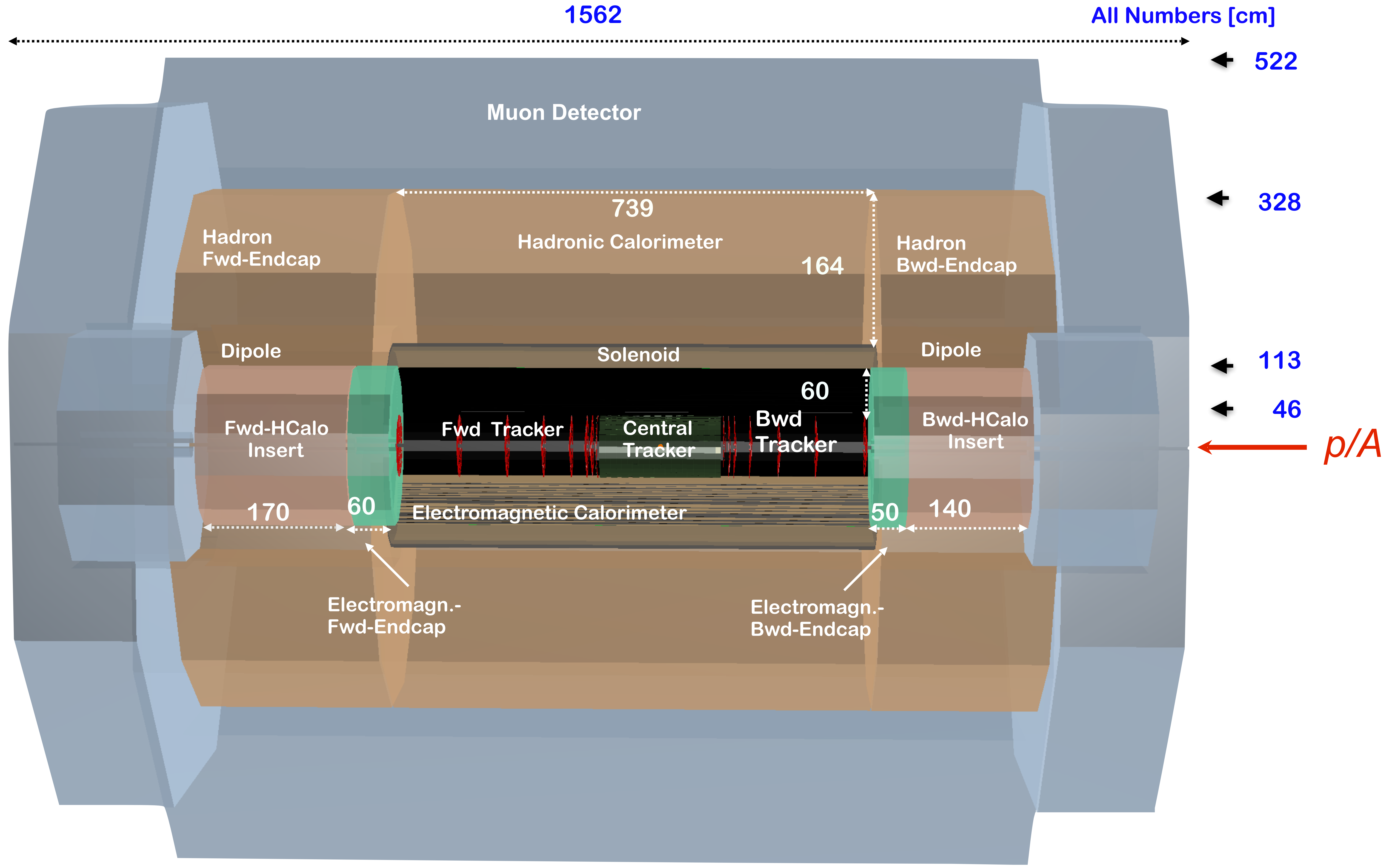
The Higgs discovery has raised the L(ep) goal to 10^{34}. The pile-up is O(1) at FCC-eh

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/

LHeC → HE-LHeC Detector Design

Basic change for HE-LHeC: extension of (spec.) calorimeter dimensions by factors log(12.5/7), backward extended by 1. …1.3



Synchrotron Radiation in FCC-ee Interaction Region

Marian Lückhof
CERN and Universität Hamburg

The FCC-ee

FCC-ee is one of the future circular collider options with 80 km to 100 km circumference, designed for e^+e^- collisions. It is supposed to run at several collision energies from 90 GeV to 350 GeV. [ea14]
Synchrotron radiation can be a serious source for backgrounds in case of circular lepton colliders. It scales as follows with particle energy E_0, bending radius ρ and circumference L:

$$U_0 = \frac{4\pi r_e}{3\,(m_0c^2)^3}\frac{E_0^4}{\rho}$$

$$\langle P_{SR}\rangle = \frac{U_0}{T_0} = \frac{4\pi c r_e}{3\,(m_0c^2)^3}\frac{E_0^4}{\rho L}$$

A significant level of synchrotron radiation can be expected, possibly limiting machine performance and detection conditions in the **interaction region (IR)**, where accelerator and detector are combined to produce and observe collisions in the **interaction point (IP)**. For FCC-ee, the maximum energy loss from synchrotron radiation was limited to 50 MW per beam which is one of the driving limits for the design.

FCC-ee Interaction Region & Geometry

The interaction region requires careful design to provide **high luminosity at tolerable (or better minimized) background rates** and at the same time reliability at different collision energies [BBS17]. The IR design includes a crossing angle of 30 mrad (figure (a)). A practical implementation from MDISim is shown in figure (b), considering the two beam pipes of b1 and b2, meeting in the central interaction point.

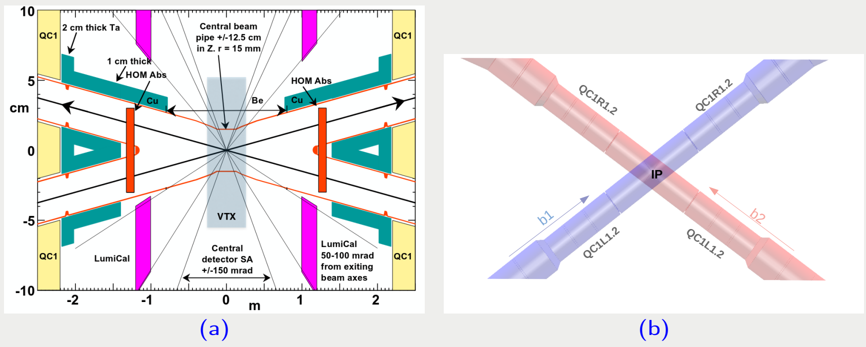


Figure: (a) schematic view on the interaction region of FCC-ee [Sul18]. (b) realization in MDISim. Note the enhanced scaling in x and y compared to z.

The Tool-Set - MDISim

Designing the interaction region requires a set of simulation tools, as not only geometry but also beam parameters and particle physics have to be combined in a flexible way. Therefore, the development of MDISim, Machine Detector Interface Simulations was initiated [BB15].
This top-level interface combines different codes in three steps :

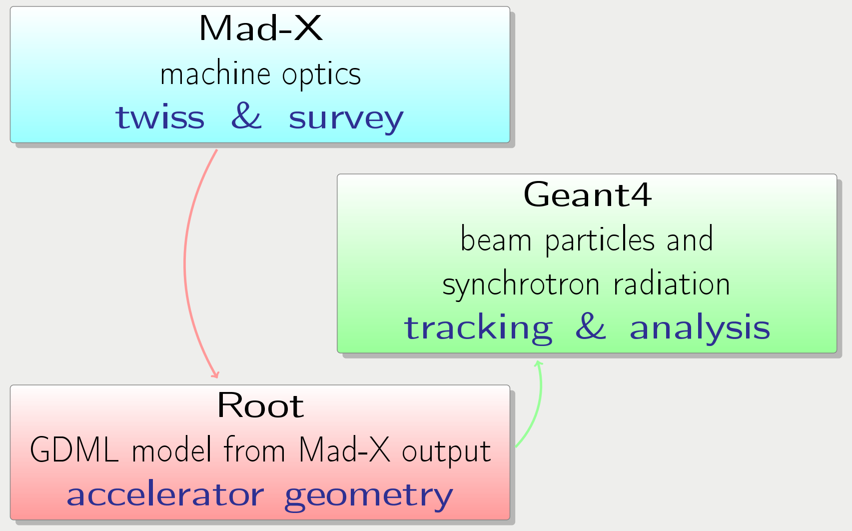


Figure: The three blocks that are combined with MDISim to study synchrotron radiation backgrounds in the machine-detector interface.

Synchrotron Radiation - Tracking in Geant4

To study synchrotron radiation in detail, Geant4 reads beam energy and beam size as input to generate and track the beam through the lattice. The resulting tracks of synchrotron radiation photons can be displayed using Root and the TEve display manager.
Full tracking information allows detailed analysis of several issues during or after the simulation run.
To start off the study, only b1 is considered, assuming a completely symmetric layout:

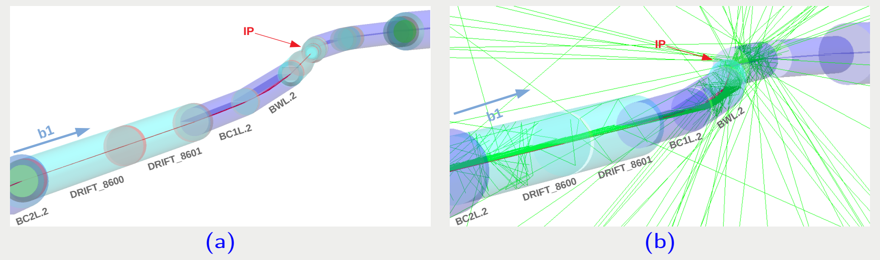


Figure: (a) tracking only beam particles upstream of the IP. (b) tracks of synchrotron radiation photons.

Analytic Estimates

How many photons per bunch crossing? What are average power and energy?
Estimating amount and nature of synchrotron radiation is an important step of the study and also possible with MDISim. The table below summarizes key parameters for upstream dipoles and final-focus quadrupoles.

Magnet	S [m]	L [m]	Angle [mrad]	E_c[keV]	$n_\gamma/e^\pm$	ρ[m]	B [T]	Power [kW]	$\geq$ 10 MeV	n_{tot}	$<E_\gamma>$ [keV]
BWL.2	214.2	114	-0.7879	93.2	2.96	1.45×10^5	-0.00421	0.456	5.6×10^{-49}	8.30×10^{11}	28.7
BC1L.2	293.1	74.83	-0.4935	88.9	1.86	1.52×10^5	-0.00401	0.273	3.27×10^{-51}	5.20×10^{11}	27.4
BC2L.2	549.2	61.99	1.038	226	3.91	5.97×10^4	0.0102	1.46	2.11×10^{-21}	1.09×10^{12}	69.5

Magnet	S [m]	L [m]	E_c[keV]	$n_\gamma/e^\pm$	B_x[T]	B_y[T]	Angle [mrad]	Power [kW]
QC1L1.2	3.4	1.2	368	0.1232	-0.00819	-0.0145	0.0749	0.0328
QC1L2.2	4.48	1	517.7	0.1444	-0.00869	-0.0217	0.124	0.0384
QC1L3.2	5.56	1	776.9	0.2167	-0.0081	-0.0341	0.278	0.0576
QC2L1.2	7.11	1.25	553.1	0.1929	0.0029	0.0248	0.176	0.0513
QC2L2.2	8.44	1.25	1013	0.3534	0.00426	0.0455	0.592	0.0939

Table: Estimates on synchrotron radiation from different types of magnets. Upper table: last three bending magnets. Lower table: final focus quadrupoles.

Contributions from Single Elements

How many photons are generated in a magnet, where are they produced and where do they hit the beam pipe?
Designing the interaction region also means to know which elements contribute most to the photon background and specific characteristics of these elements. Tracking the beam upstream allows not only to count all hits from photons on the beam pipe (figure (b)), but also the point of origin (figure (a)).
Further we can decompose these distributions into single elements (figure (c)).

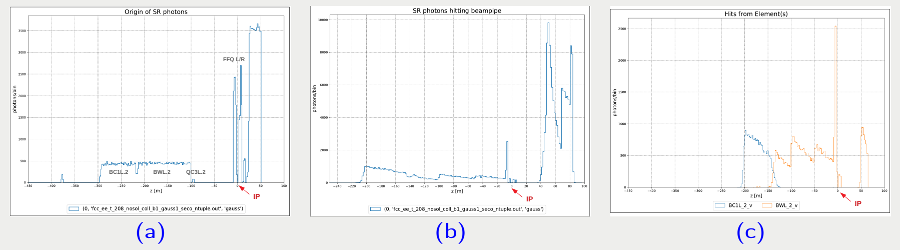


Figure: (a) origin of photons upstream. (b) full spectrum of hits on the beam pipe. (c) decomposed spectrum, only showing contributions from last two bending magnets.

Collimation

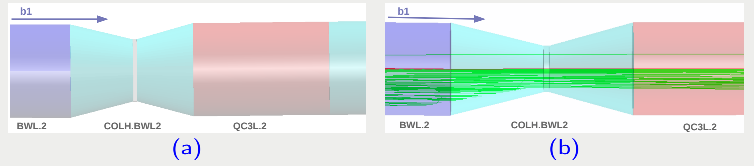


Figure: (a) collimator right after the last bending magnet upstream of b1. (b) tracks of photons, partially blocked by the collimator.

One possible measure to protect the interaction region from synchrotron radiation is to place **collimators** at certain locations. By using movable jaws, these elements allow to restrict the physical aperture and block a significant amount of photons already a long distance upstream, far from the interaction point to further suppress additional backgrounds.
MDISim allows to directly study the effect of these elements on synchrotron radiation background (also in terms of reflections and secondary backgrounds).

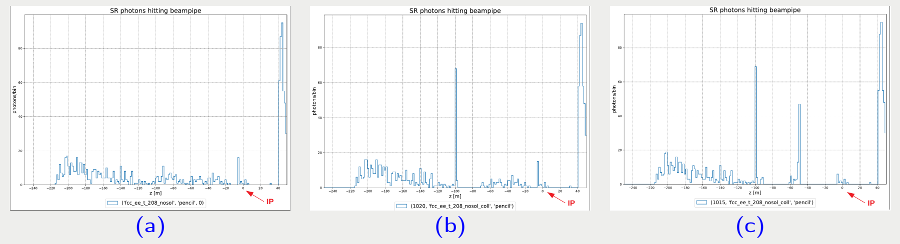


Figure: (a) unperturbed distribution of hits on the beam pipe. (b) although clearly shadowing a certain region upstream, a single COLH cannot effectively reduce the background at the interaction point. (c) a combination of several collimators might be required. **Note: Data-set different from above.**

Status and Outlook

- MDISim allows flexible combination of different powerful codes
- collimators: positions, combinations, apertures and secondary backgrounds
- collimators and masks: clean interaction point and detector conditions, machine protection
- increase statistics in Geant4 to allow more realistic estimates

References

[BB15] Helmut Burkhardt and Manuela Boscolo, *Tools for Flexible Optimisation of IR Designs with Application to FCC*, no. CERN-ACC-2015-279, TUPTY031. 3 p.
[BBS17] M. Boscolo, H. Burkhardt, and M. Sullivan, *MDI Studies: Layout and Synchrotron Radiation Estimate in the FCC Interaction Region*, Physical Review Accelerators and Beams **20** (2017), no. 1 (en).
[ea14] F. Zimmermann et al., *FCC-ee Overview*, Proceedings of HF2014, Beijing, China (2014).
[Sul18] M. Sullivan, *IR Layout with SR Masks and Shielding - Workshop on Mechanical Optimisation of the FCC-ee MDI*, January 2018.

Marian Luckhoff for FCC-ee - MDISim/Geant4 Analysis for identifying SR impact - to be done for new ep-optics at FCC-eh IR

Would fit to the compact tracker layout

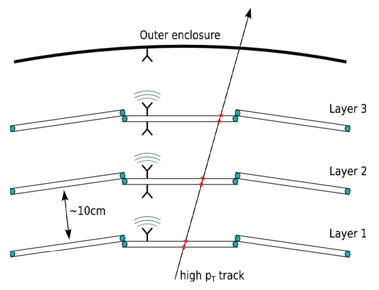
Multi-Gigabit Wireless Data Transfer
for High-Energy Physics Applications

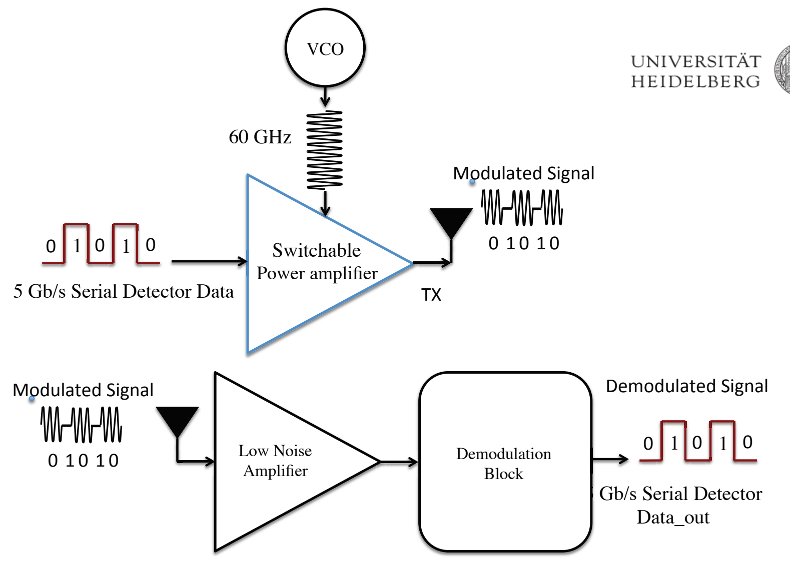
LoI, CERN-LHCC-2017-002 ; LHCC-I-028. – 2017

Elizabeth Locci (CEA/DRF/IRFU/DphP, Ecole Doctorale Paris Saclay) for the WADAPT Consortium

Motivation:
- **Large bandwidth (9 GHz at 60 GHz, 15-16 GHz at 240 GHz)**
- **Fast signal transfer (5 Gbps** typically over 20-30cm up to 1m at 60 GHz, up to 100 Gbps at 240 GHz possible)
- **Efficient detector partition in topological regions of interest**
- **Fast track trigger decisions, for physics requiring "triggerless" data**
  (e.g. low mass processes, exotic Higgs decays, long-lived charged particles…)
- **Reduced impact of massive cable plants** (e.g. radiation length, dead zones)
- **Steering & control of complex detector systems**

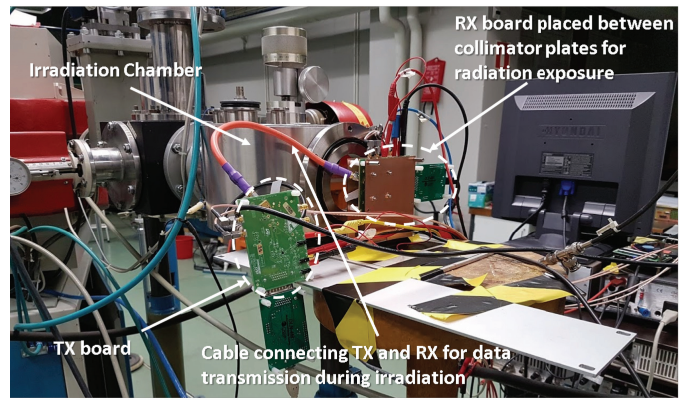
Example:





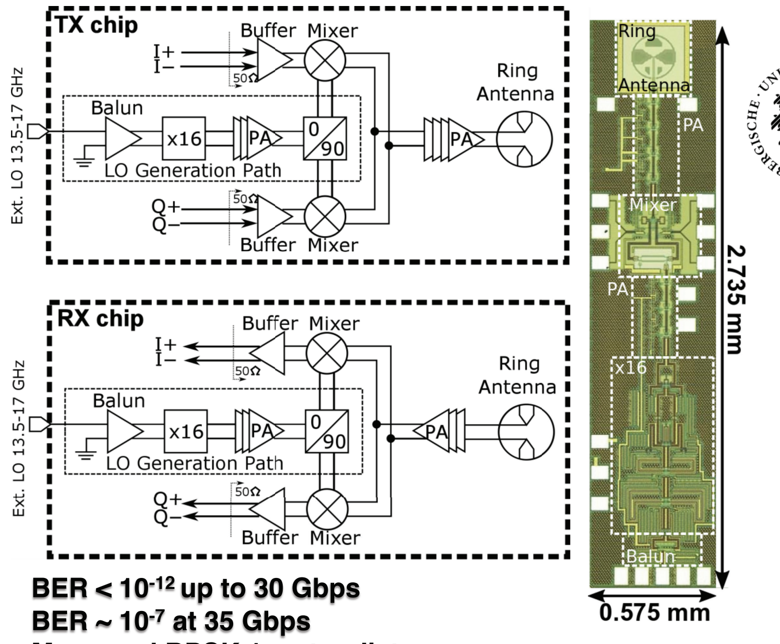
- **Building a 60 GHz demonstrator**
- **130nm SiGe Bi-CMOS technology**
- **Low power on-off keying modulation**
  (present power consumption ~ 90 mW)

10 years experience in the field
30 -300 GHz carrier frequency
60 GHz ASK Transceiver in 65 nm CMOS (power consumption ~ 35 mW)
Data rate up to 5.8 Gbps
Irradiation hardness tested at Turku, Finland



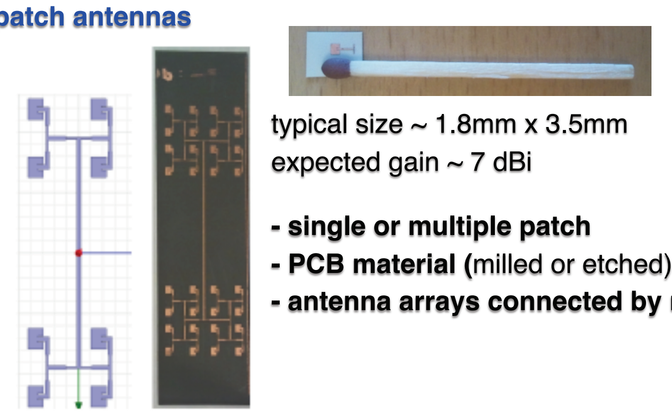
RX TID (prel): 0.788 kGy Fluence: 1.38 10^{14} Neq/cm^2
TX TID (prel): 0.369 kGy Fluence: 0.78 10^{14} Neq/cm^2
Transceivers have been found as functional over the air @5Gbps after irradiation

240 GHz transceiver in SiGe HBT technology ,30 GHz bandwidth



BER < 10^{-12} up to 30 Gbps
BER ~ 10^{-7} at 35 Gbps
Measured BPSK 1 meter distance (up to 100 Gbps with 16-QAM)
Expected power consumption ~ 1 W

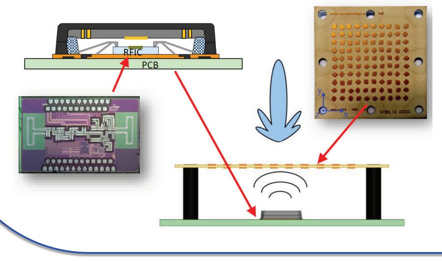
Antenna design
patch antennas



typical size ~ 1.8mm x 3.5mm
expected gain ~ 7 dBi

- **single or multiple patch**
- **PCB material** (milled or etched)
- **antenna arrays connected by microstrips**

Other possible designs



In package coupled antenna & focusing lens
gain ~ 16 dBi, range x 6

Several tests performed: - signal confinement - cross-talk - coexistence with detector (noise) - radiation hardness

Aim at: - data throughput up to 10 Gbps - BER < 10^{-12} - low latency - low mass - low power consumption - radiation hardness - high directivity antennas - low cost

Technical Proposal in preparation