Using the SR info in full detector simulation and results

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Summary from past discussions in the EIC project IR background meetings

EIC: unique collider, Important of minimizing background

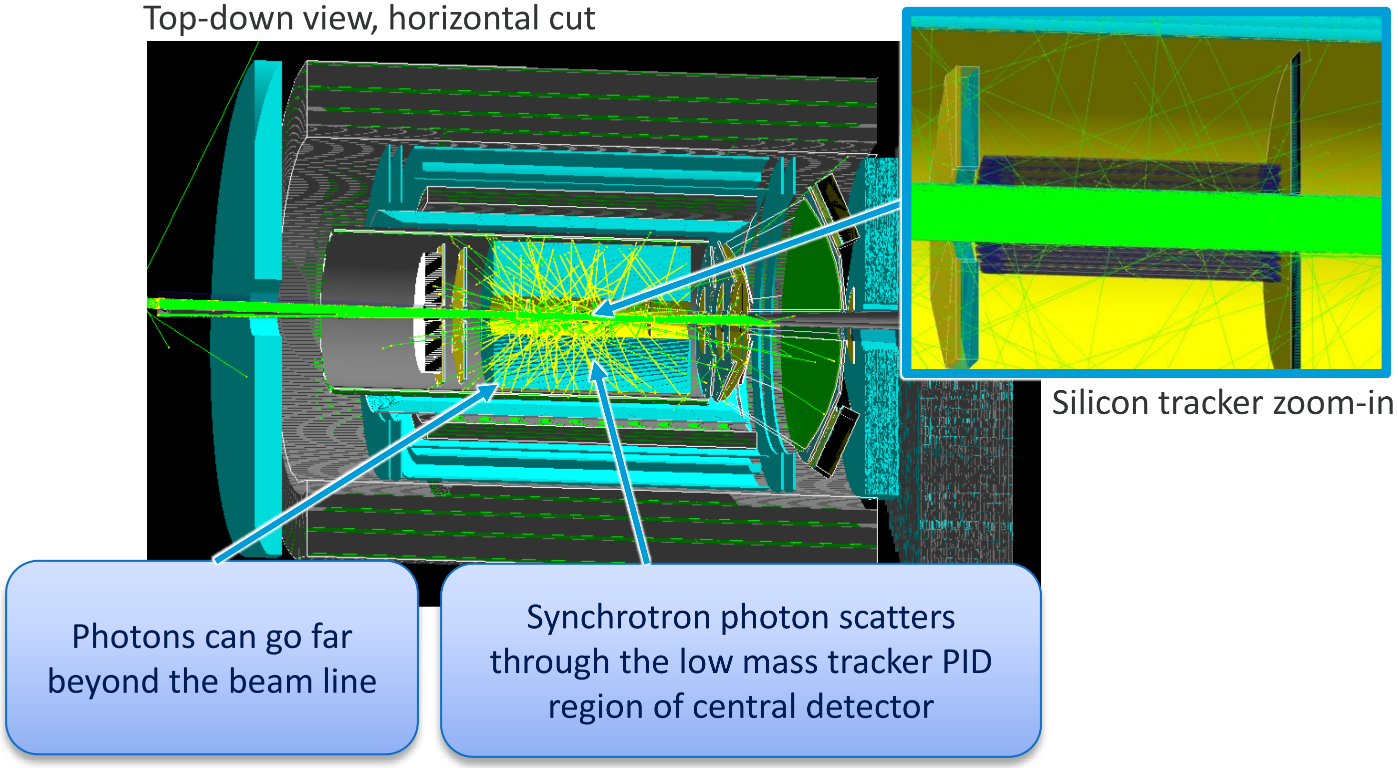
- EIC luminosity is high, but collision cross section is small ($\propto \alpha_{EM}^2$) → Important to control background for detector safety and minimizing systematic uncertainty
- Synchrotron background from the high intensity electron ring pose a unique challenge

	EIC	RHIC	LHC → HL-LHC
Collision species	$\vec{e}+\vec{p}, \vec{e}+A$	$\vec{p}+\vec{p}/A, A+A$	$p+p/A, A+A$
Top x-N C.M. energy	140 GeV	510 GeV	13 TeV
Bunch spacing	10 ns	100 ns	25 ns
Peak x-N luminosity	10^{34} cm^{-2} s^{-1}	10^{32} cm^{-2} s^{-1}	10^{34} → 10^{35} cm^{-2} s^{-1}
x-N cross section	**50 μb**	**40 mb**	**80 mb**
Top collision rate	500 kHz	10 MHz	1-6 GHz
$dN_{ch}/d\eta$ in p+p/e+p	0.1-Few	~3	~6
Charged particle rate	**4M N_{ch}/s**	**60M N_{ch}/s**	**30G+ N_{ch}/s**

Considerations for Synchrotron bgd.

- See also talk, E. C. Aschenauer
- Synchrotron background is major challenge for high energy collider with electron beams
- Many detectors at EIC could be venerable to Synchrotron background
  - E.g. challenging for readout design, background filtering tracking, and fake large DCA for HF
- Strong emphasize on co-design of collider, IR and experiment that is low in Synchrotron background from the start:
  - General EIC R&D eRD21
  - bi-weekly IR background meeting joining accelerator and detector physicists

- 100k SynRad synchrotron photon by M. Stutzman
- Reproduce this Geant4 simulation from GitHub: macros / SynRad->HepMC reader



SR full detector simulation workflow

In this talk, Fun4All-EIC simulation is used: https://eic.github.io/software/fun4all.html
Based on G4 description of an earlier detector concept: ePHENIX/arXiv:1402.1209

SynRad

- Well established Machine simulation tool for SR bgd: See talks C. Hetzel/M. Stutzman
- Taken care of far upstream simulation, SR photon generation/reflection/absorption

Geant4

- Import SynRad photons as weighted HepMC events [macros / SynRad->HepMC reader]
- Require full detector description, in particular beam chamber and near-beam structures
- Proper description of the x-ray photon interaction

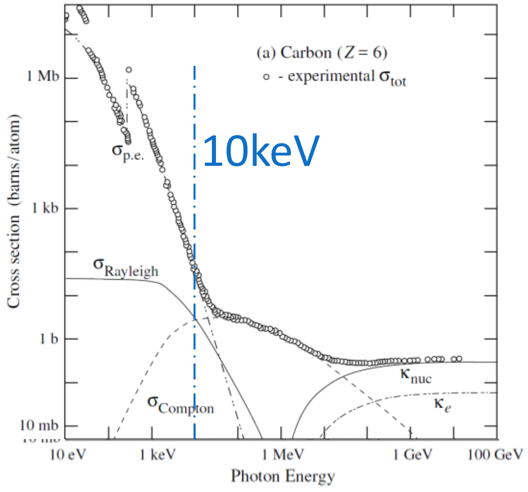
Digitization

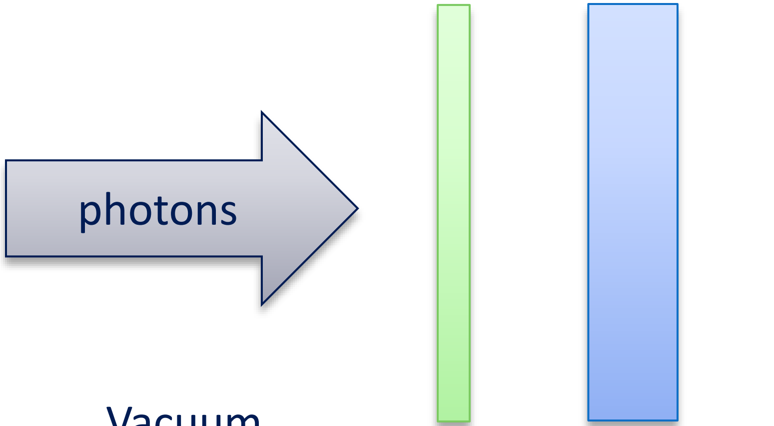
- Translate low energy photon interaction to visible detector response in data stream
- Offer hit rate for detector design req. and embedding for physics bgd. Study
- Result notebook archival: https://github.com/blackcathj/SynRad

Validation 1: G4 treatment of low energy X-ray γ

- Simplest setup for a Geant4 validation,
- A few keV photon energy threshold for leaving non-zero ionization energy in silicon
- Reproduce: https://github.com/blackcathj/macros/blob/synrad_valid_flatphoton/macros/g4simulations/PhotonConversion.ipynb

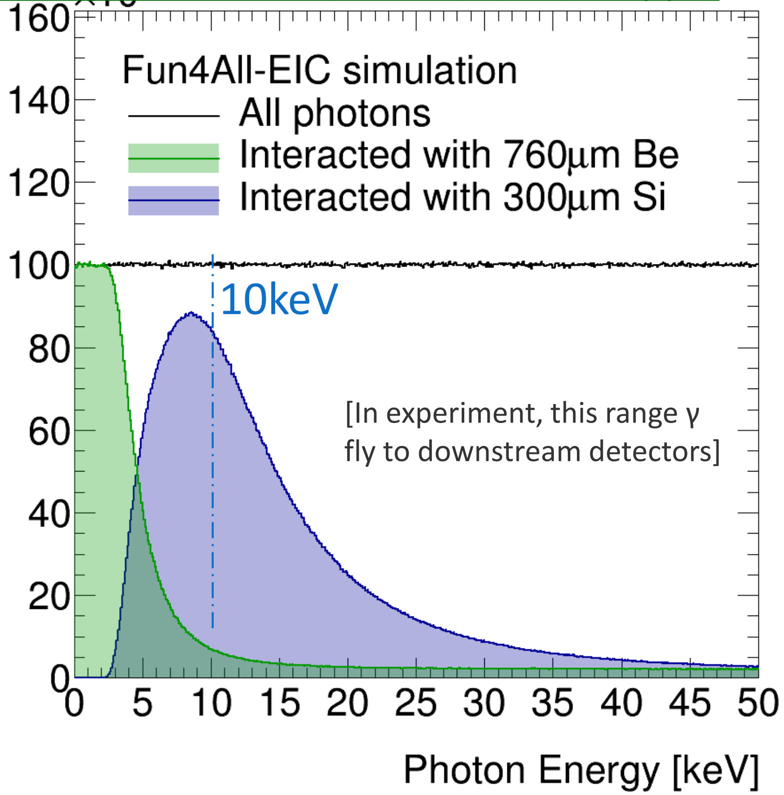
PDG, Phys. Rev. D 98, 030001 (2018)





Vacuum No B-field	30mil Be	300μm Si
0.99 keV	1.8keV	5.9 keV

(Geant4 γ-propagation threshold)



High-z Coating validation

Note: normal indenting angle
Further reduction if shallow indenting

- https://nbviewer.jupyter.org/github/blackcathj/macros/blob/synrad_valid_flatphoton_AuCoating/macros/g4simulations/PhotonConversion.ipynb

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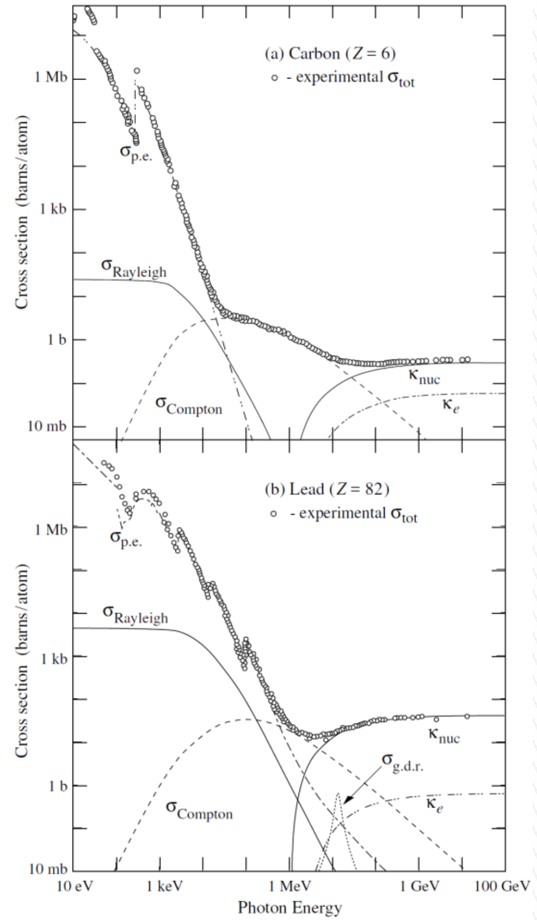
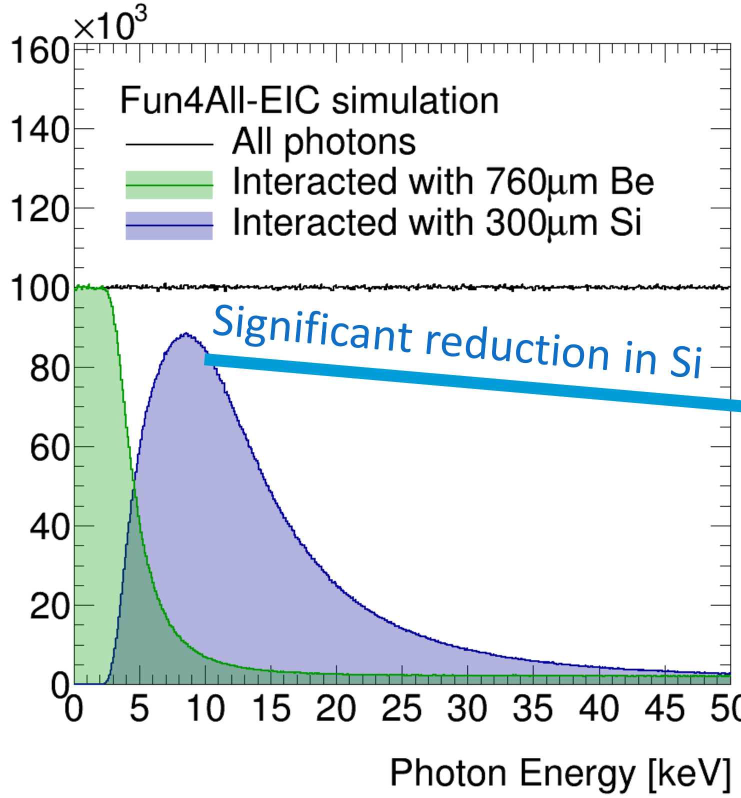
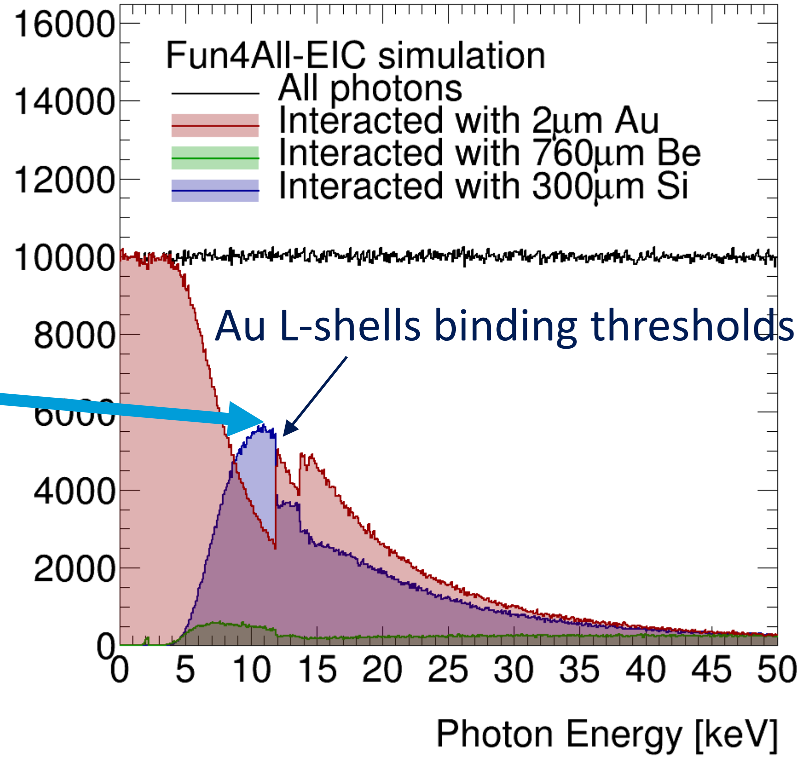






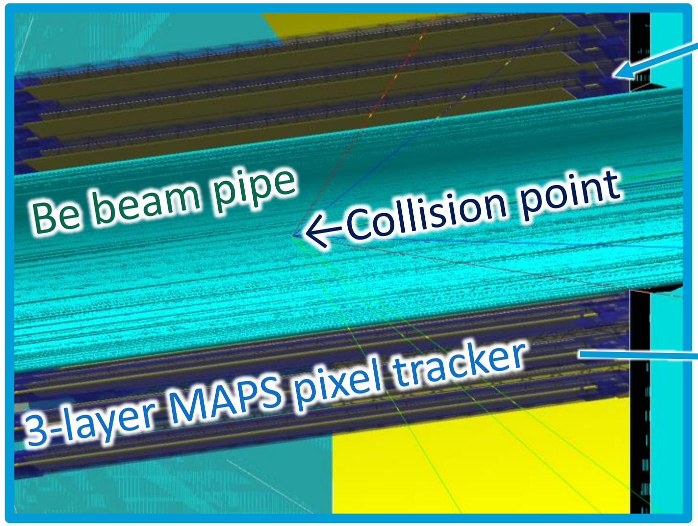
Photon on 30mil-Be and 300um silicon

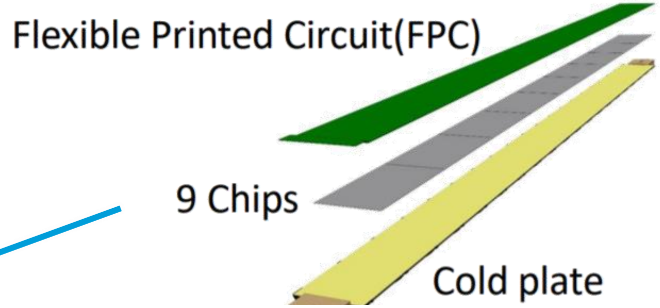
+2μm Au coating on be pipe 0.06% X0 (30mil Be = 0.2% X0)

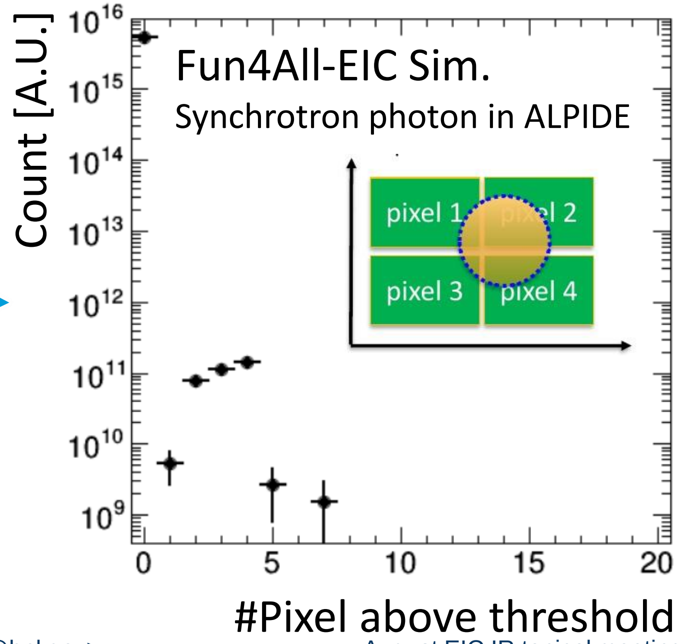
Validation 2: SVT detector response

- Synchrotron photon interaction are digitized to detector data rate with sPHENIX ALPIDE model
- Calibrated with 2019 sPHENIX test-beam

sPHENIX/ALICE ALPIDE ASIC model:
Geant4 transport
(1.8 keV photon threshold for Be pipe)
-> Ionization energy loss in active silicon
-> produce ionization trail
-> ionization diffusion
-> map to readout pixels
-> electronics threshold (~1keV)
-> Pixel hit -> ALPIDE data format
-> Data rate

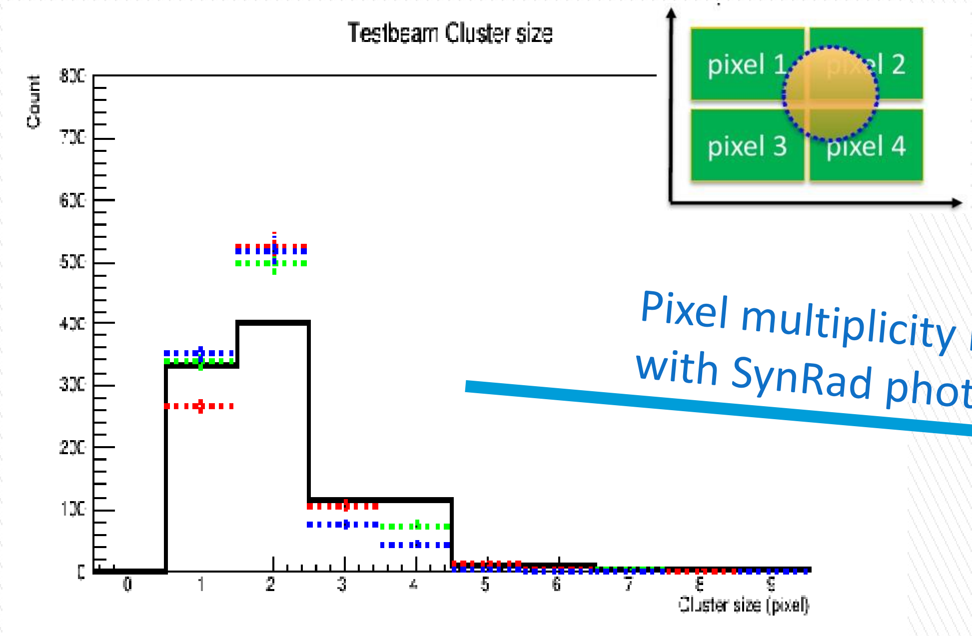




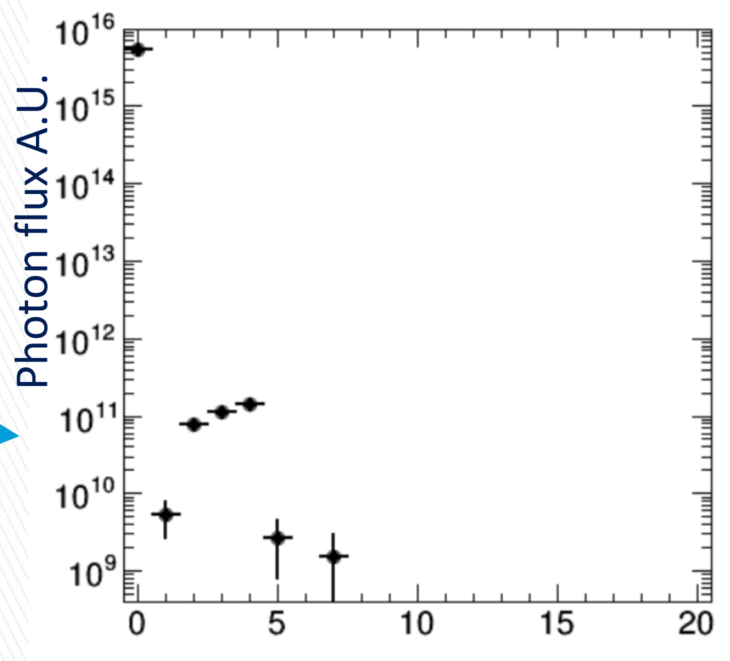


MAPS pixel hit multiplicity per interaction

MAPS (ALPIDE) diffusion-digitization model:



Pixel multiplicity higher with SynRad photon



#Pixel above threshold

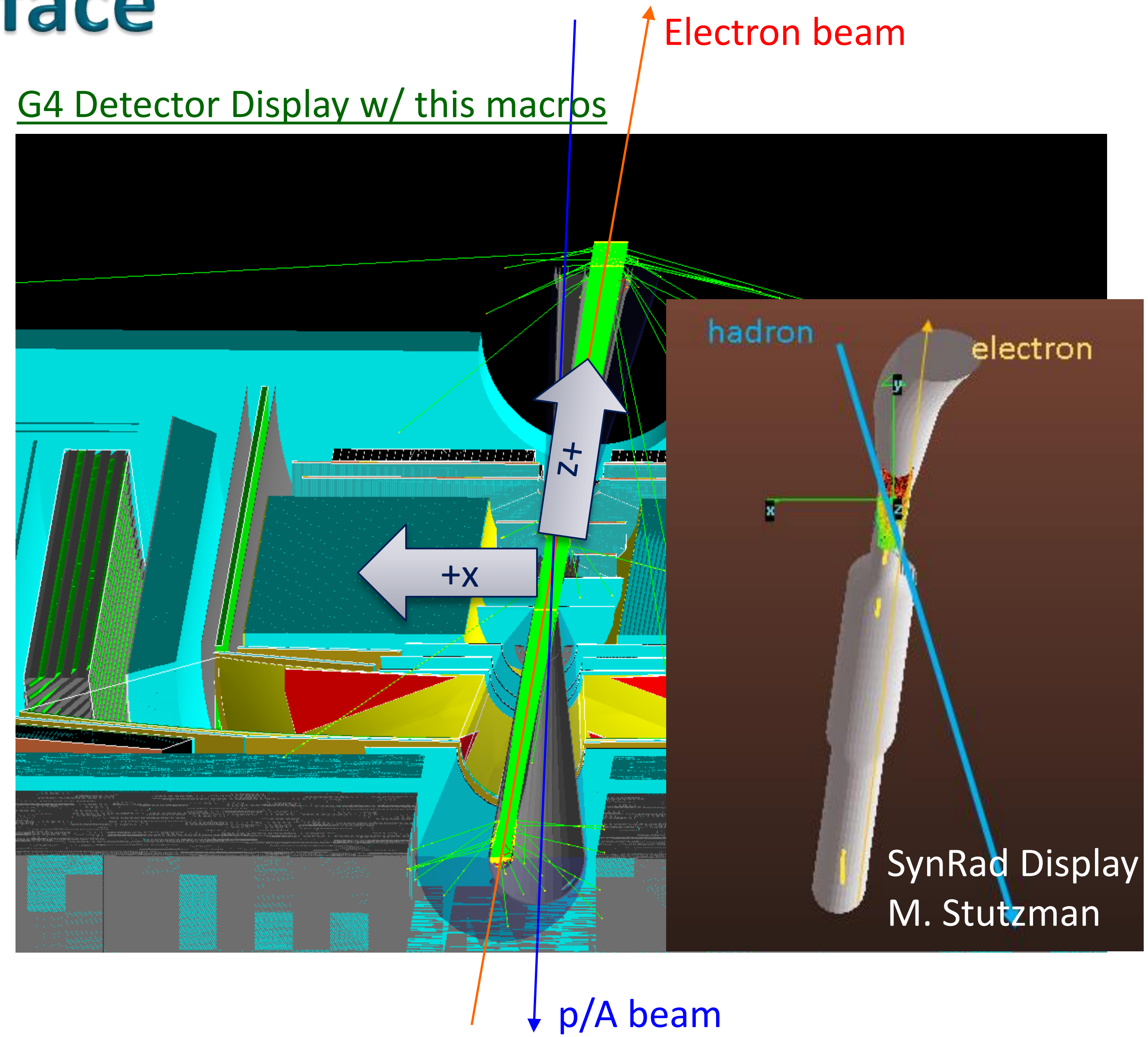
Line: test beam data (normal indenting)
Point: simulation with various tunes

sPHENIX MVTX test beam 120 GeV proton @ FTBF	SynRad photon SynRad photon interacted

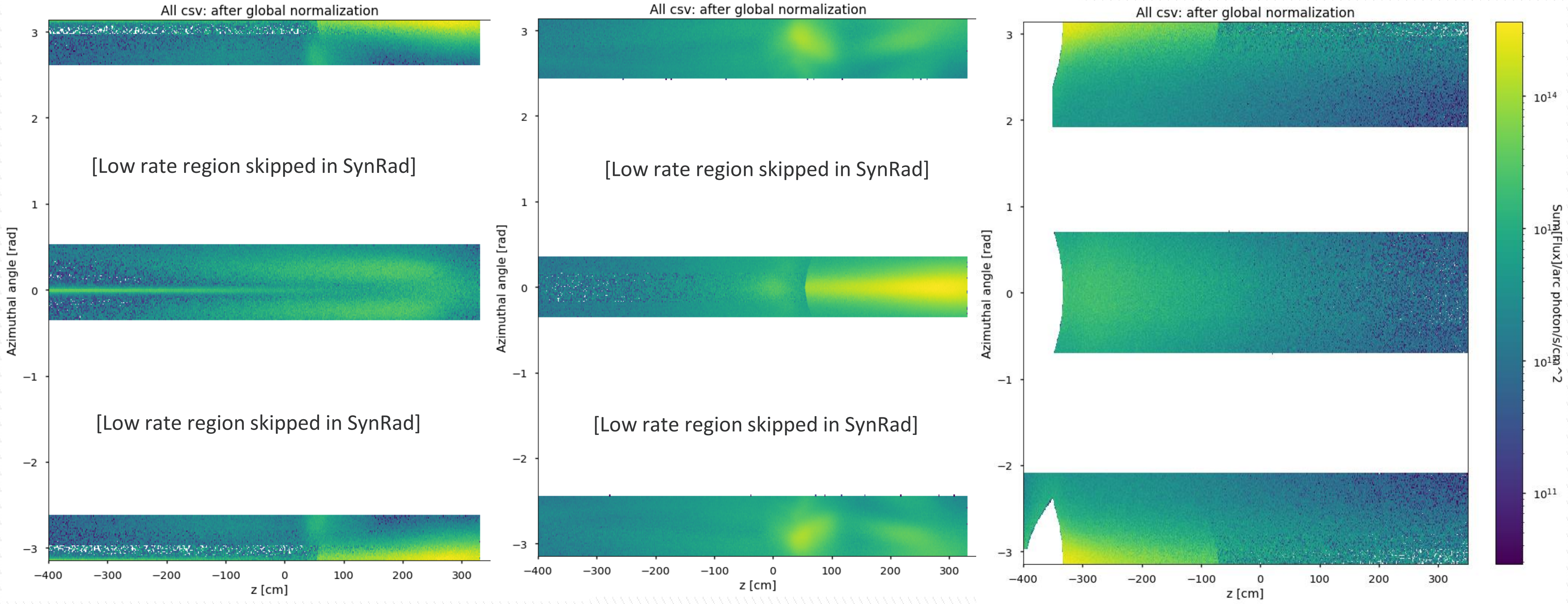
SynRad→Detector interface

- We use a cylindrical surface near inner surface of beam pipe to interface SynRad and G4, segmented in facets
- SynRad output
  - total SR flux on each facets
  - VIRTUAL photon of full kinematics and weight
  - Reuse virtual photon O(10) times in G4 simulation to improve stat (and avoid causing too much deviation from Poisson stat.)
- Normalization is obtained bia ***scale factor (per facet)*** * sum of virtual photon weight on each facet → flux on facet [link to example notebook]
- Cautious of coordinate definition

G4 Detector Display w/ this macros



Normalized photon flux (without energy cuts)



0 ⟷ π flip with dipole B-field

0 ⟷ π, +z ⟷ -z flip in coord. choice

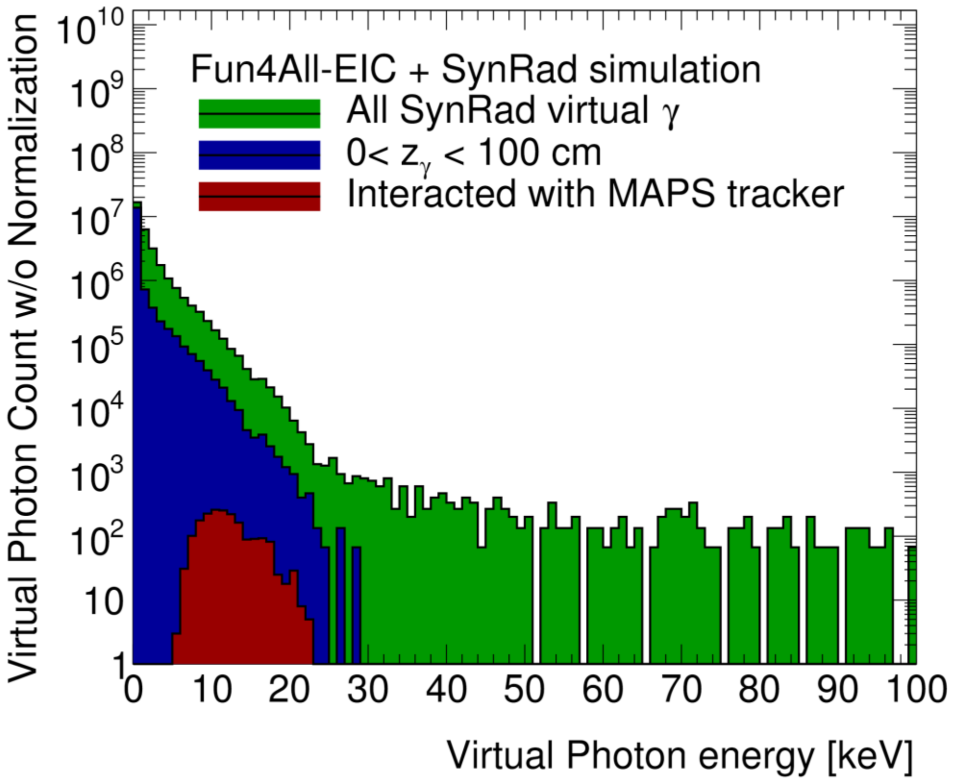
SharePoint: **March2020**Lattice/Full beam & magnets

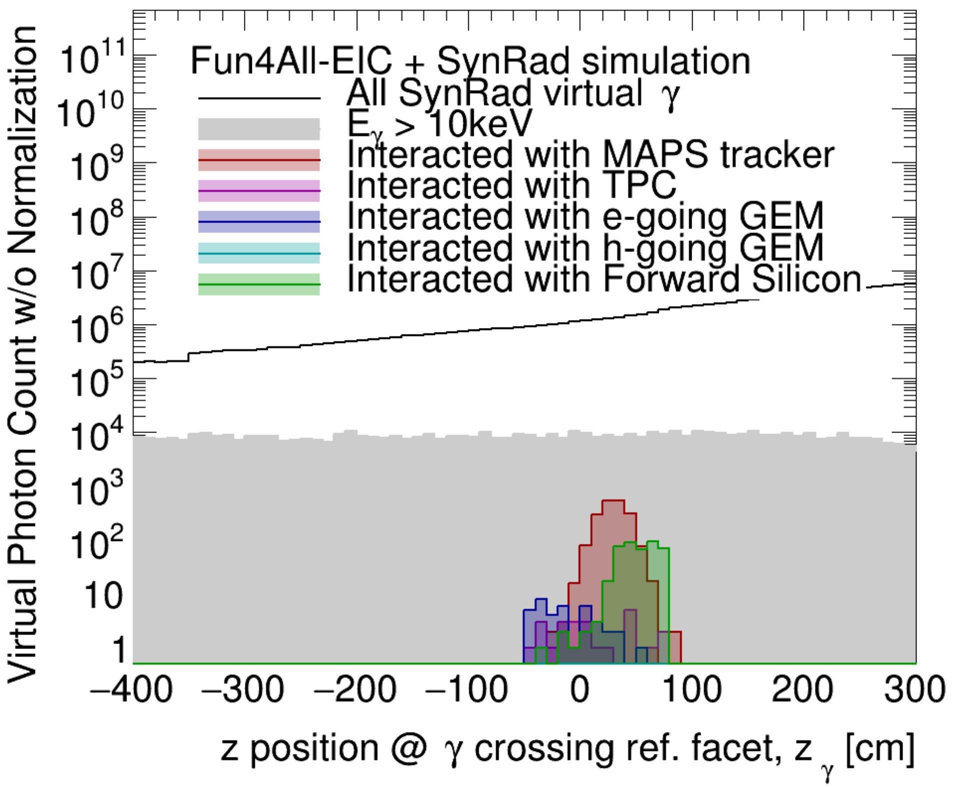
SharePoint: **May2020**Lattice/CharlieGoemetry

SharePoint: **July2020**Chamber/24JulyFirstRun

Synchrotron background: detector response

- Iterating with accelerator design to avoid 10keV photon that exits -50 to +100cm from beam pipe





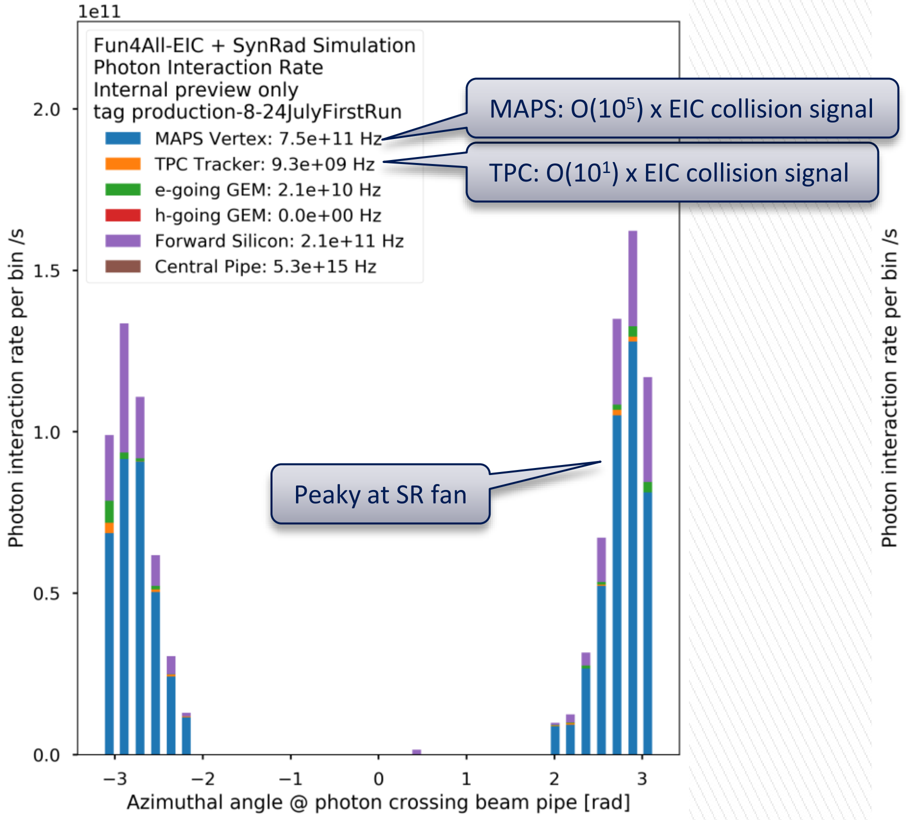
Energy dependence of MAPS vertex tracker to synchrotron

Beam-pipe exit-location

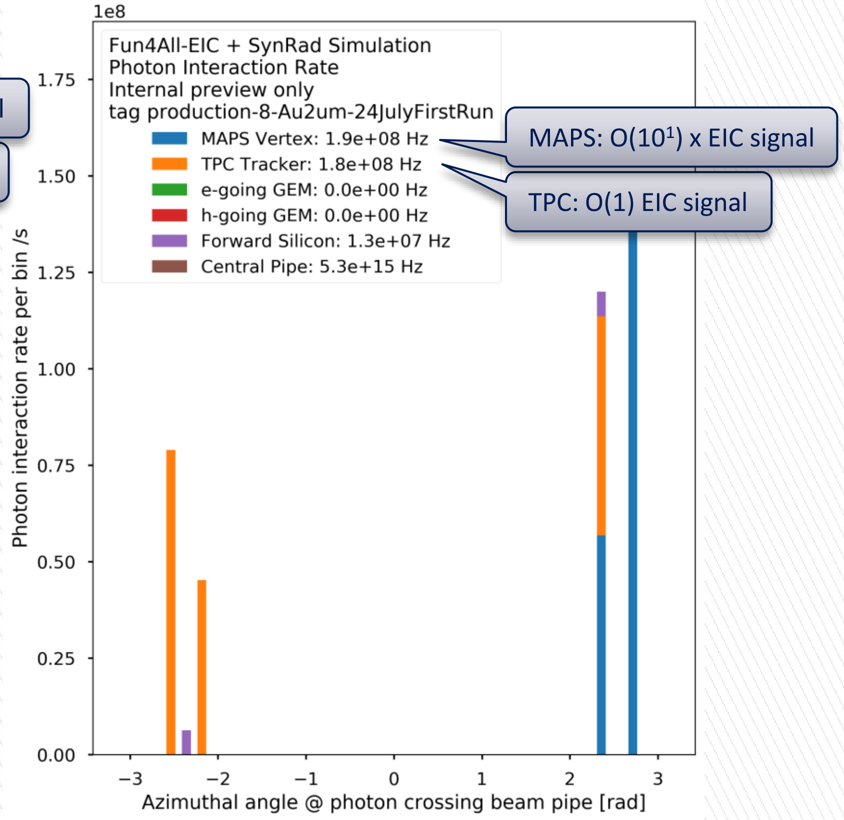
Note: all photons simulated for detector interaction, without cuts on z or energy. July-2020 lattice/chamber

Normalized γ-detector interaction rate

SynRad data tag: July2020Chamber/24JulyFirstRun



Default beam pipe
760um Be chamber

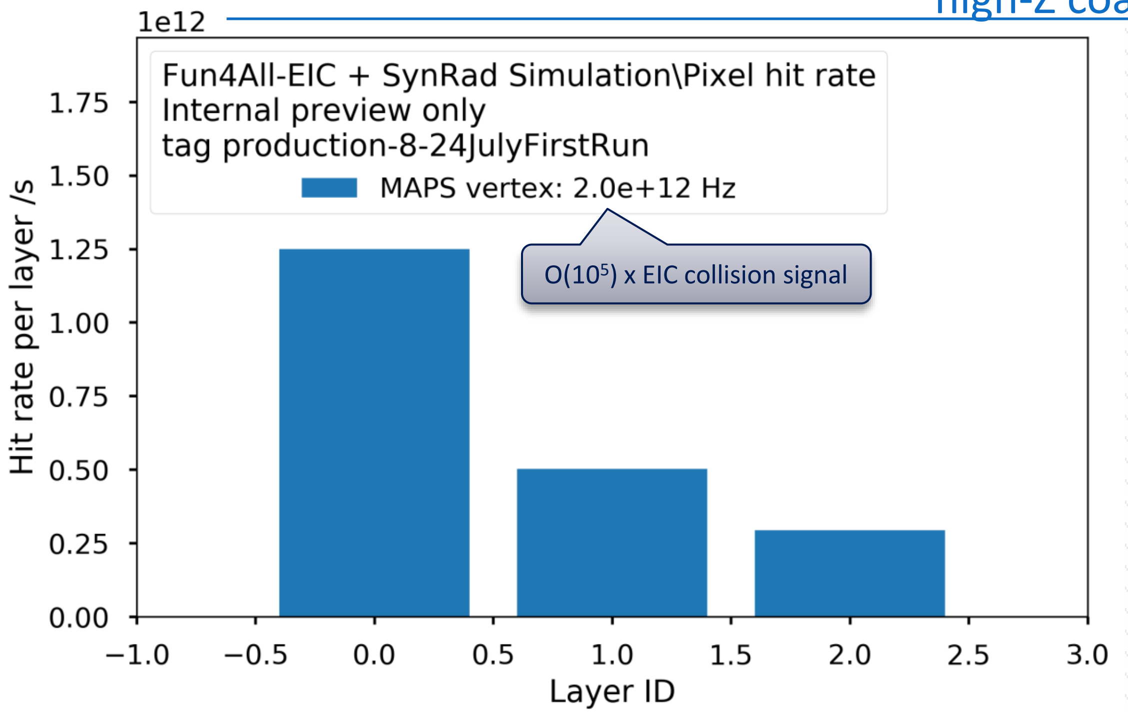


High-Z-coated beam pipe
2um Au on 760um Be chamber

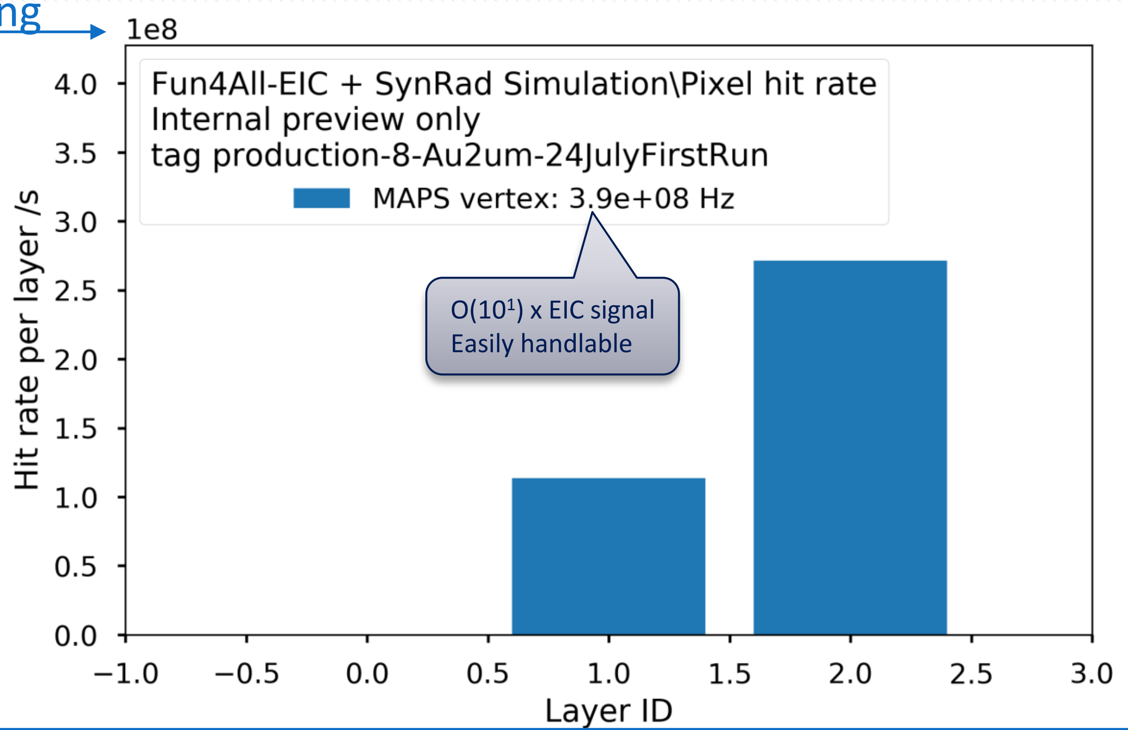
Synchrotron background: detector response

- SR background can be overwhelming, orders of magnitude higher than signal rate
- high-Z coating on chamber, e.g. 2-µm Au coating (0.06 X_0) on Be pipe significantly reduces the synchrotron rate
- Absolute hit rate is likely to change by orders of magnitude with changing beam parameter and shielding

high-Z coating



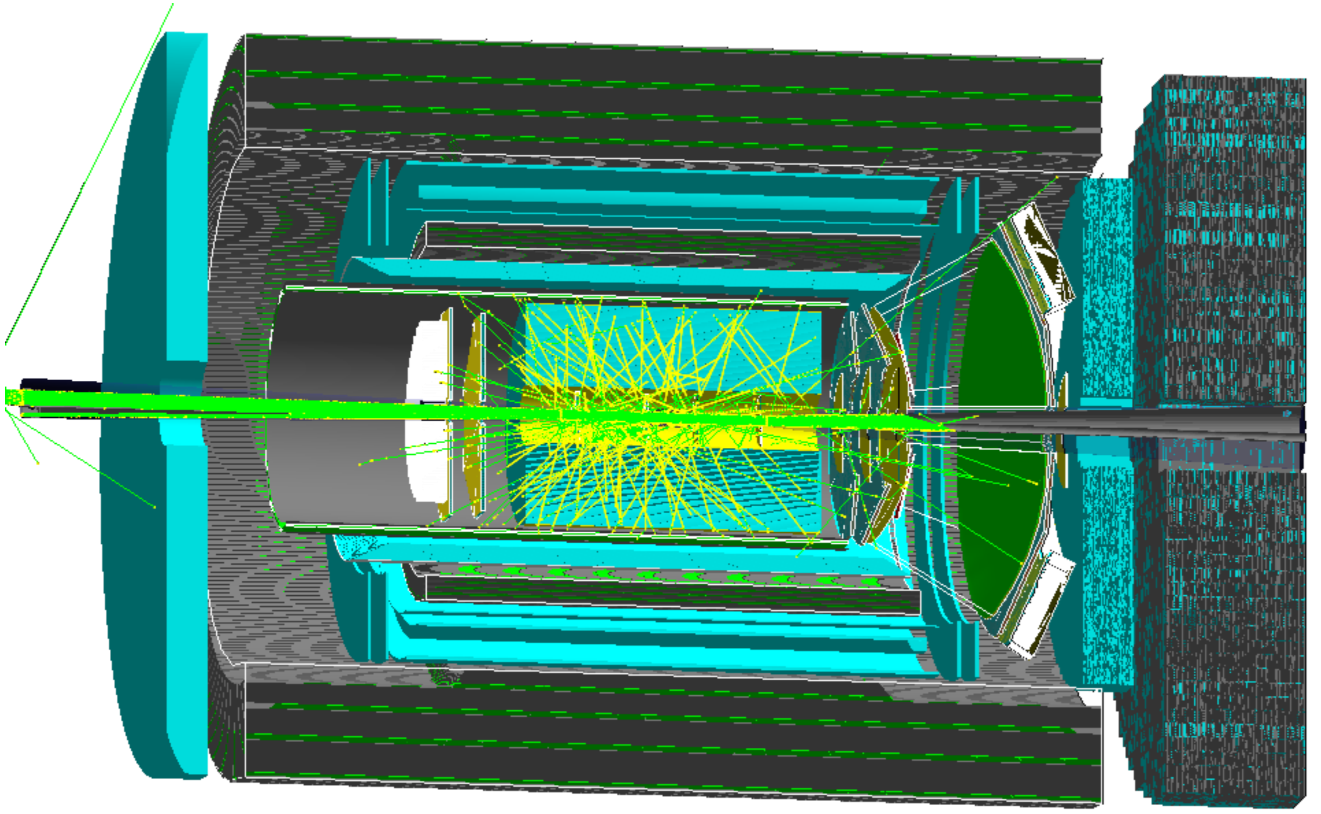
Default 760µm-Be beam pipe



High-Z-coated beam pipe (+2µm Au)

Summary

- SR background can be overwhelming, orders of magnitude higher than signal rate
- Tuning on-going with +0.5m IR shift and improving SR photon shielding: See talk C. Hetzel. M. Stutzman
- Absolute hit rate is likely to change by orders of magnitude with changing beam parameter and shielding
- High-z shield on beam pipe (e.g. few-µm Au) is very effective in reducing inner detector hits



Code sharing: G4 macros / SynRad->HepMC reader / Plot notebook & Results @ github.com/blackcathj/SynRad

Extra information

Coating validation

Note: normal indenting.
Further reduction if shallow indenting

- https://github.com/blackcathj/macros/blob/synrad_valid_flatphoton_NEG/macros/g4simulations/PhotonConversion.ipynb
- https://github.com/blackcathj/macros/blob/synrad_valid_flatphoton_AuCoating/macros/g4simulations/PhotonConversion.ipynb

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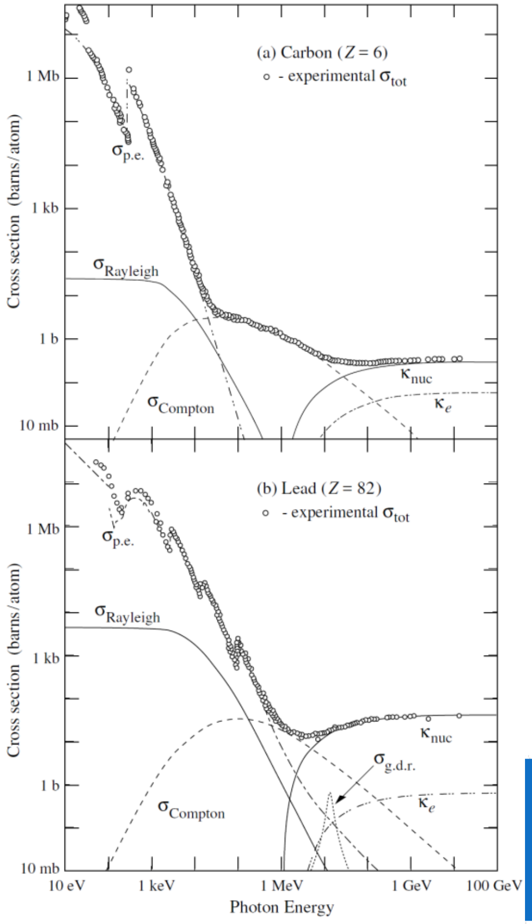
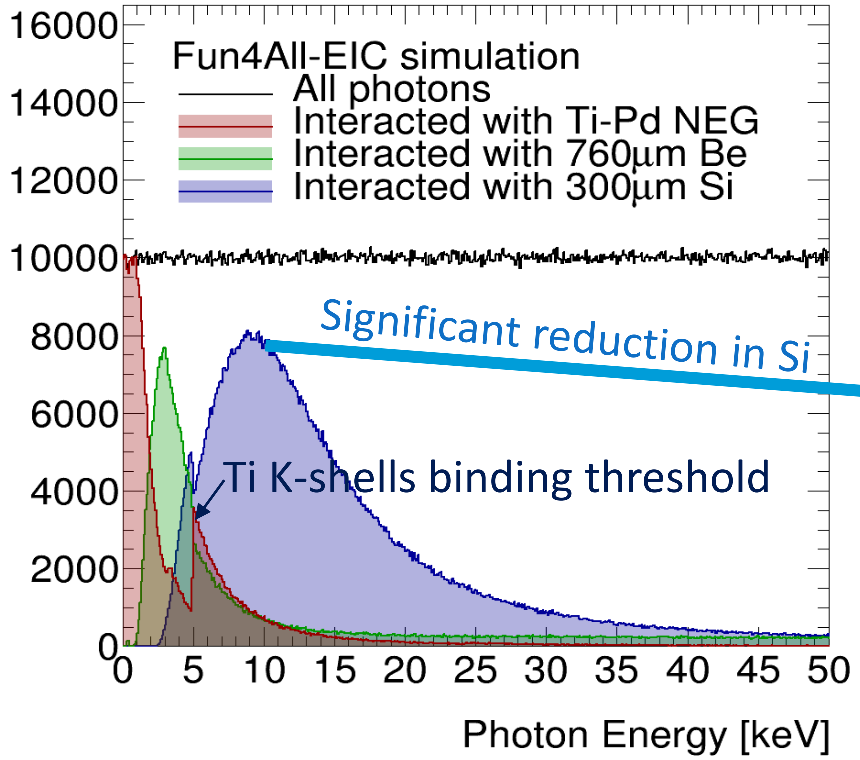
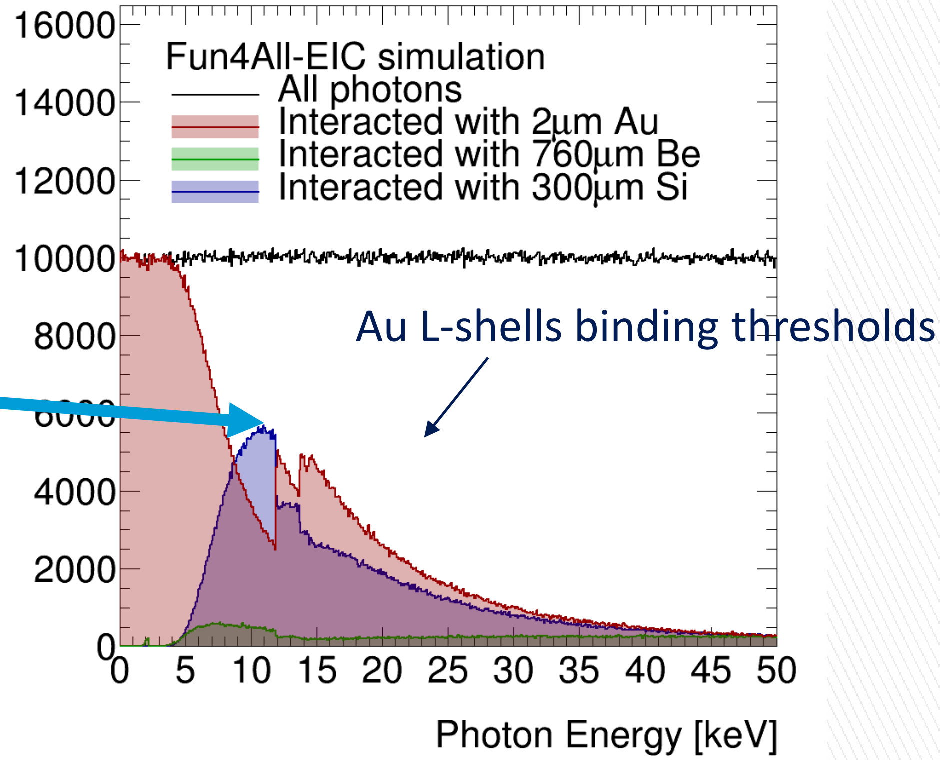




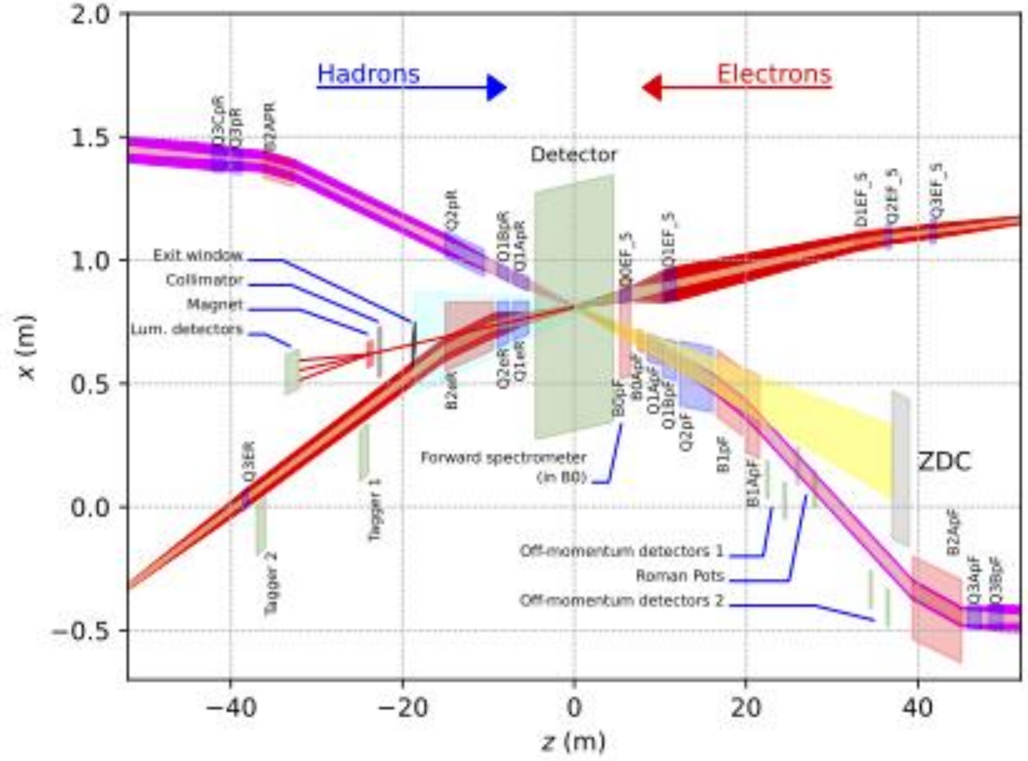


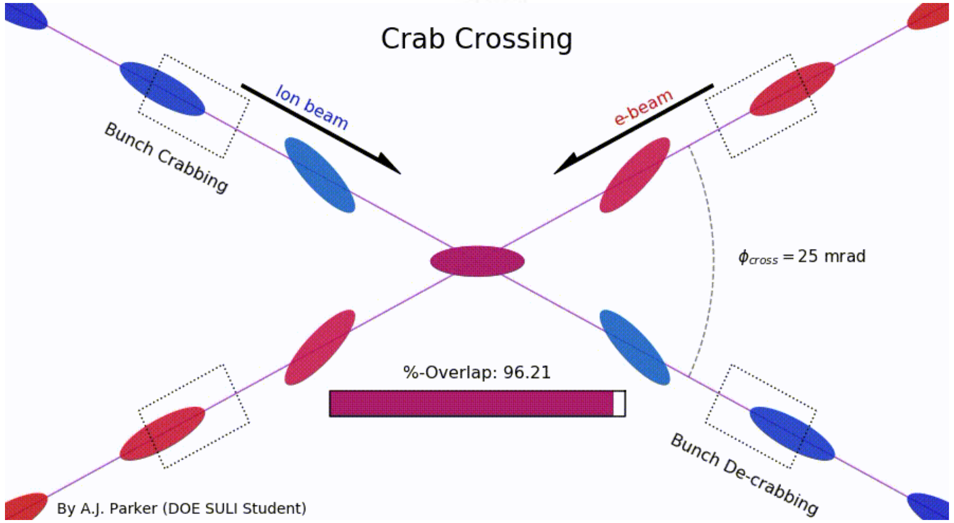
1.3μm Ti-Pd NEG coating
https://doi.org/10.1116/1.5037023

2μm Au coating
0.06% X0 (30mil Be = 0.2% X0)

Leading EIC beam effects

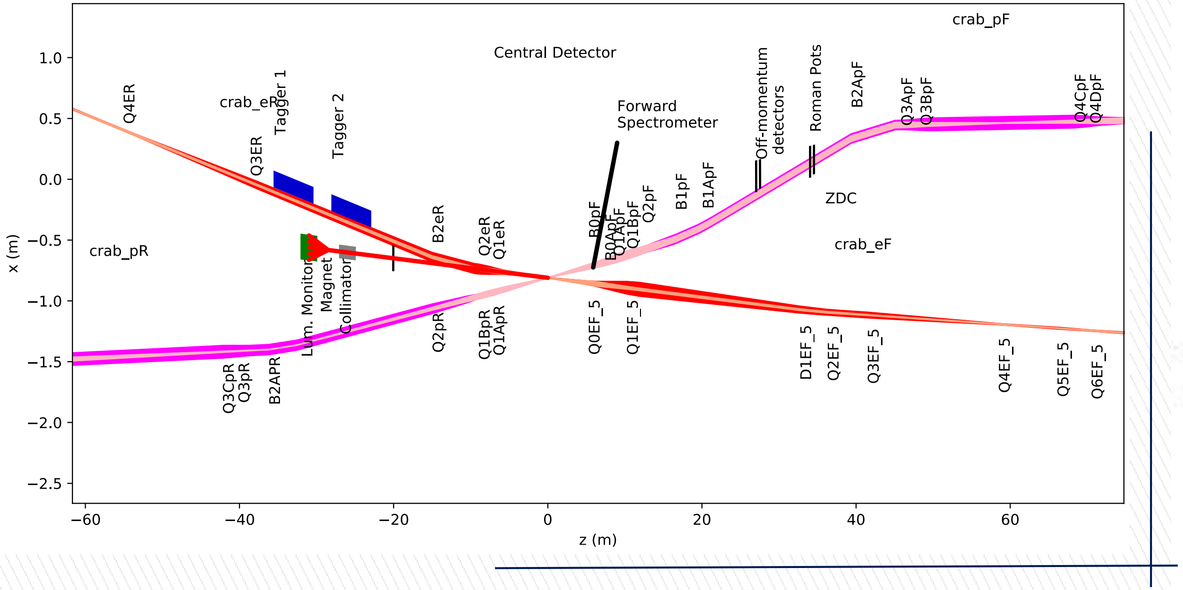
- Unique accelerator with diverse beam effect direct impact exp.
  - Beam parameter in CDR section 3.1 and tables 3.3 to 3.5 and section 3.2
- 25-35 mrad beam crossing angle
- Angular beam divergence: O(100urad)
- Crab crossing (bunch-z dependent angle smear): O(<100urad)
- Beam energy spread O(10^{-4})
- Beam vertex spread from 10cm h-bunch collider with 1-cm e-bunch at finite crossing angle



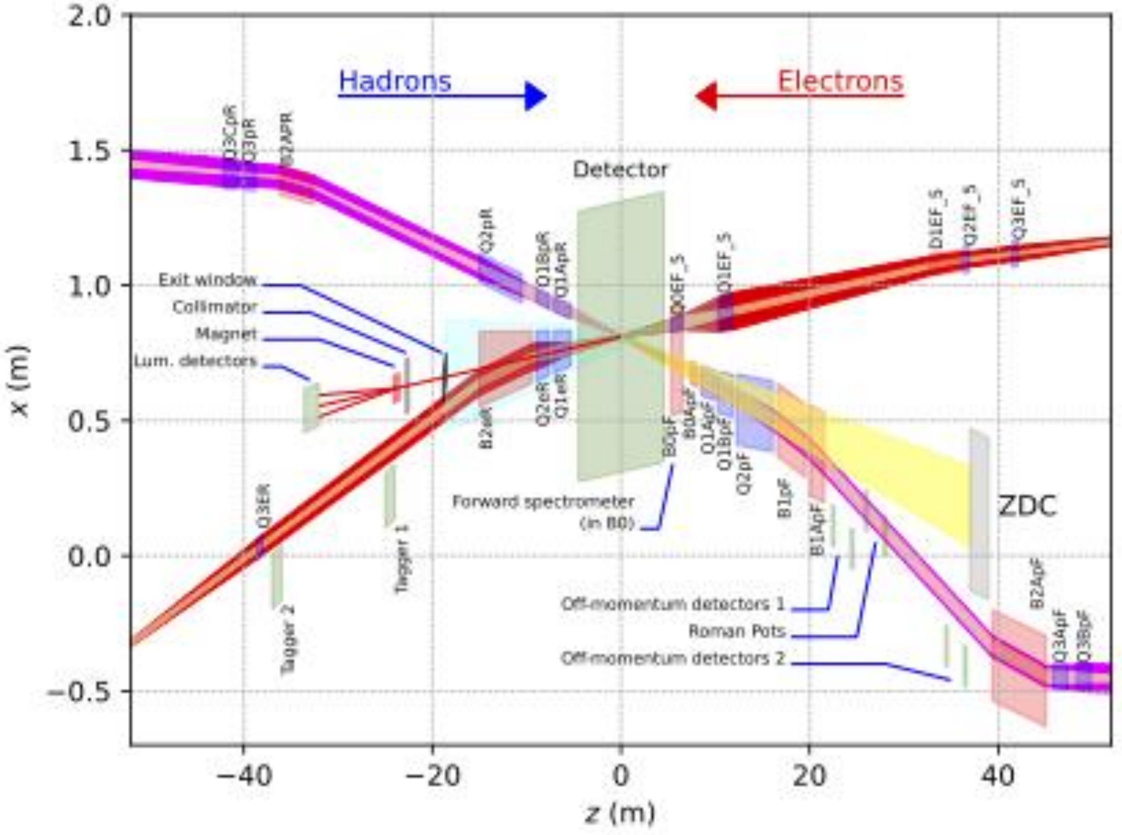


New IP6 crossing sign convention, now default in ECCE sim-reco!

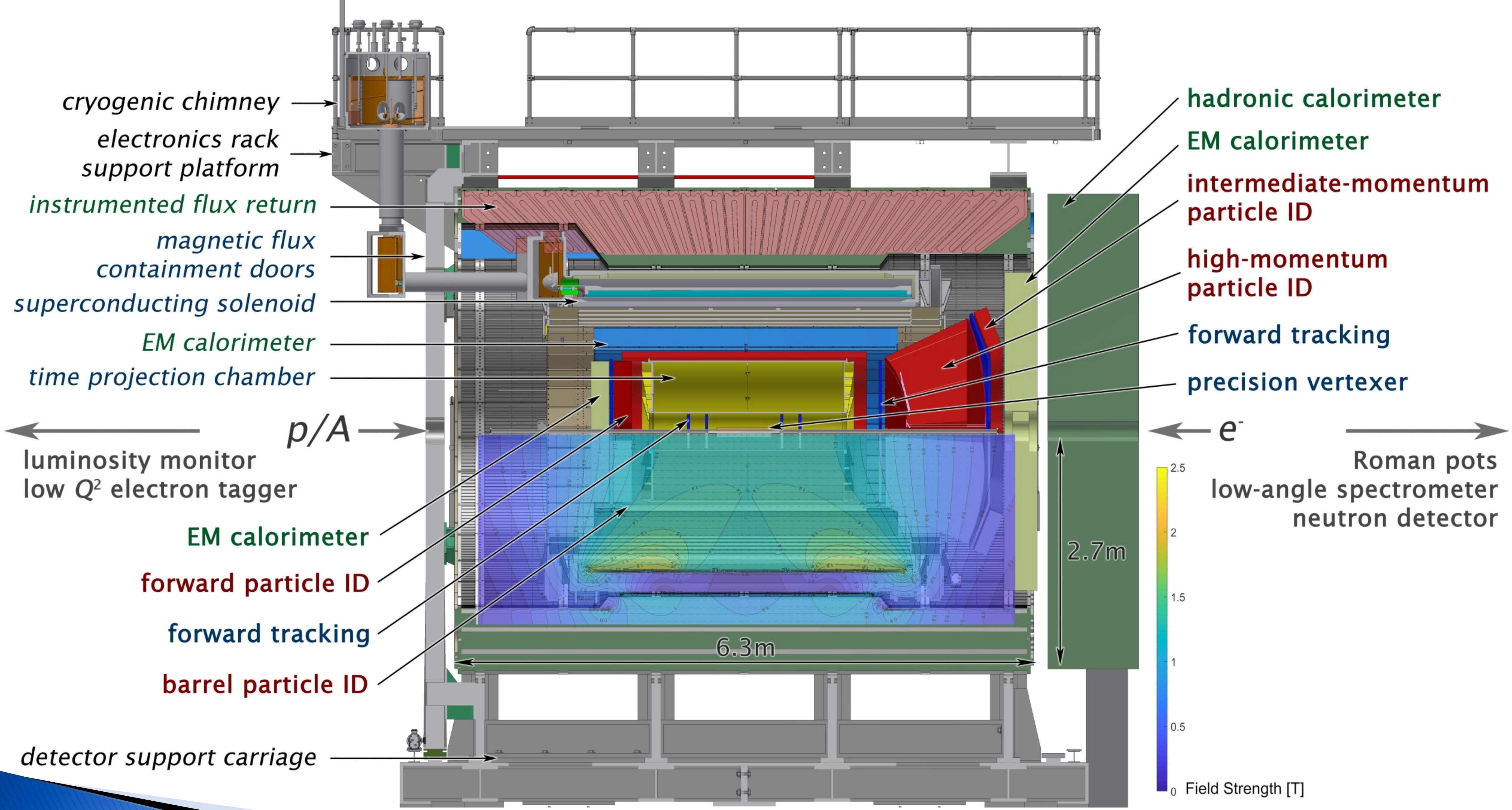
EIC CDR / YR (bottom-up view of IP6)



New convention (top-down view)



- New convention of IP6 has y-axis towards up and x-axis towards inside the ring
- Hadron beam cross towards **–x** direction
- Default of ECCE sim-reco this week(!) at PR26 [link]



cryogenic chimney
electronics rack support platform
instrumented flux return
magnetic flux containment doors
superconducting solenoid
EM calorimeter
time projection chamber
p/A
luminosity monitor
low Q^2 electron tagger
EM calorimeter
forward particle ID
forward tracking
barrel particle ID
detector support carriage
hadronic calorimeter
EM calorimeter
intermediate-momentum particle ID
high-momentum particle ID
forward tracking
precision vertexer
e^-
Roman pots
low-angle spectrometer
neutron detector
2.7m
6.3m
2.5
2
1.5
1
0.5
0
Field Strength [T]