Experiences from Background Simulation in sPHENIX & Fun4All-EIC

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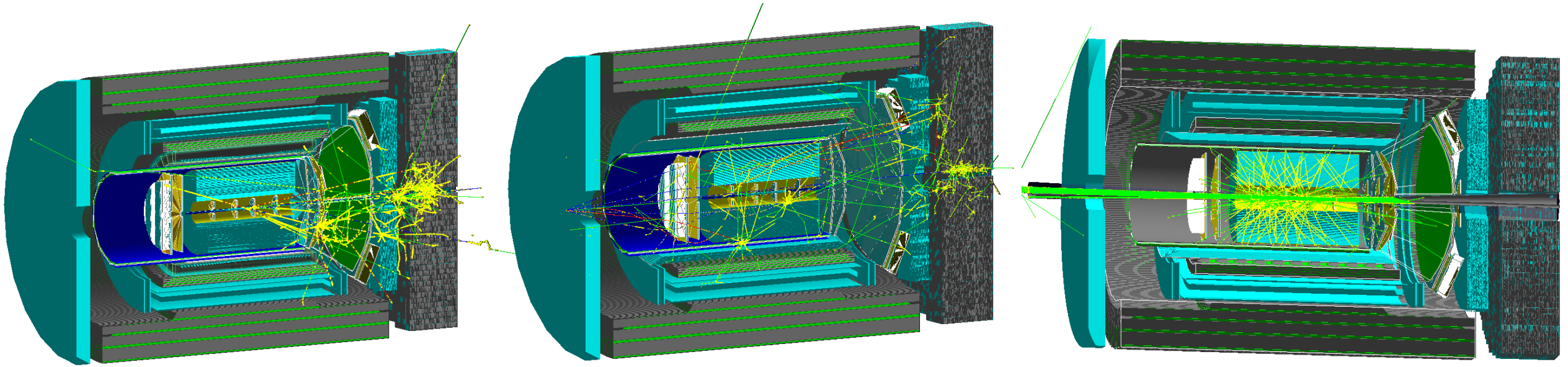
Background sources in Fun4All-EIC simulation

e+p DIS 18+275 GeV/c
(pile up)

Beam gas event
p + p(gas), 275 GeV/c
at z=-4 m

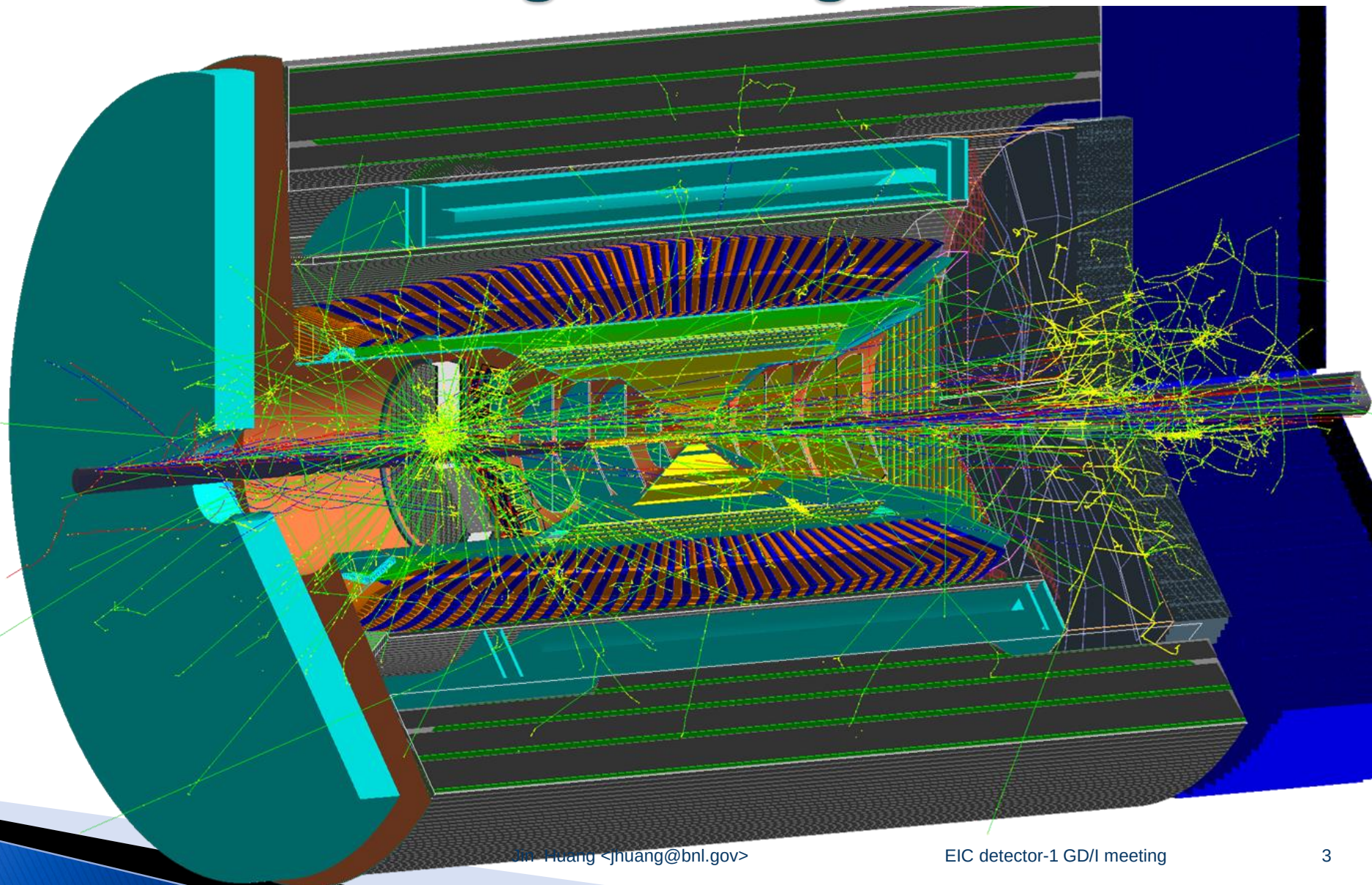
100k SynRad
synchrotron photon



Detector-1 event embedding in background

What is in this event:

- Config: Det-1 2022.1 production tag
- Signal: 18x275 GeV SIDIS, Q2~600, x=0.16
- Pile up: e+p M.B.
- p+p Beam gas: interaction at z=+4.5m
- 10^4 synchrotron photon: mostly absorbed in beam chamber Au coating, but much more stat. is needed



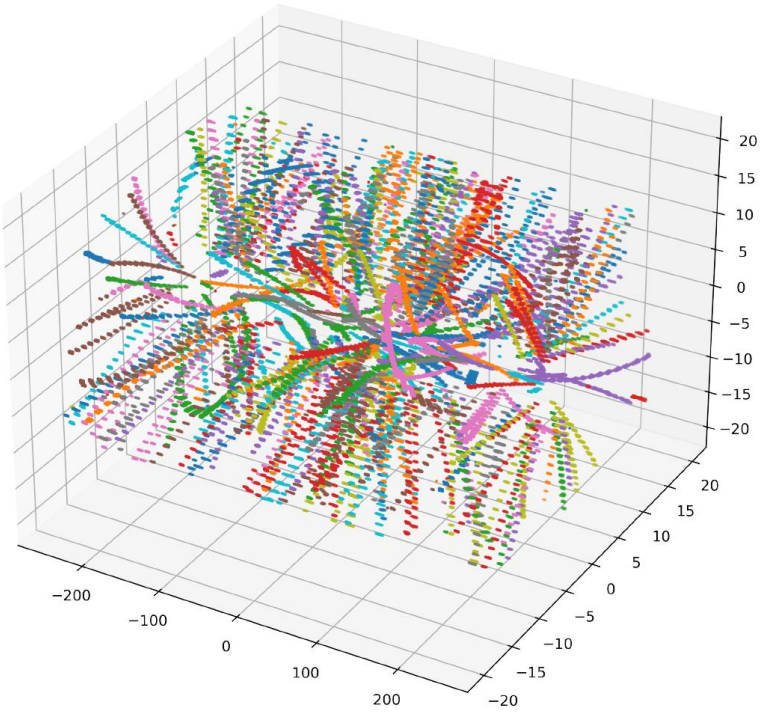
Framework support

- Many mature framework support background embedding, e.g. Fun4All
- Requirements:
  - Embedding of events and hits: merging multiple event generator records and/or G4-hits sources
  - Reproduce proper space-time offsets for embedded background (e.g. beam bunch spacing)
  - Reconstruction with truth recording supporting sub-event sources : e.g. evaluate how many hits on track are from background
- More specific thoughts on
  - pile up, beam gas, synchrotron, noises

Pile up background

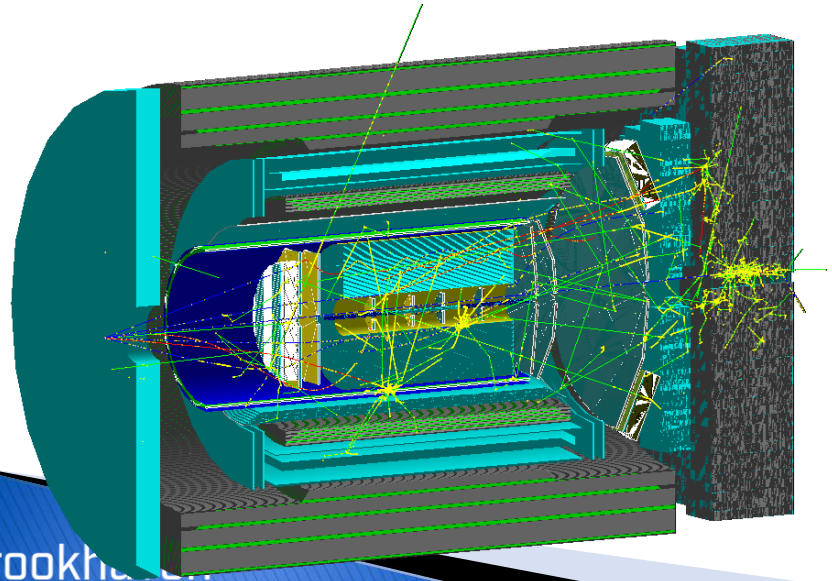
- Detector-1 simulation and reconstruction should be done in streaming time slices
  - Similar way for sPHENIX simulation as pp data are pile up dominant
- Minimal time slice length for simulation is longest detector integration window, e.g. ITS3-MAPS in 2us (may change with R&D)
- → In Detector-1, when we study a rare collision (e.g. SIDIS), there is likely 1 pile-up collision (Poission distributed) in the same tracking time window in MAPS main tracker, separated by ToF tracker
- Can consider embedding at event-gen sub-event or hit levels
  - Need large enough background pool to sample all phase spaces

sPHENIX TPC time-slice (1 drift window)
3MHz p+p collision (pileup~40)

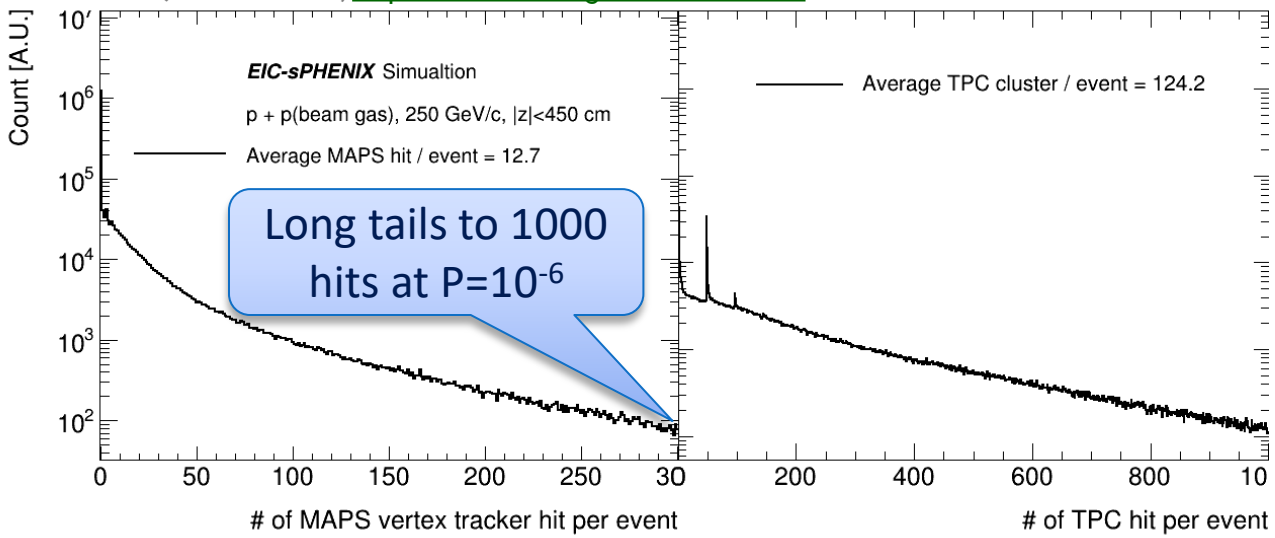


Beam gas background

- Treatment of beam gas is very similar to that of the pile up background
  - Note: beam effects to be applied to e+p/p+p beam gas generated events (beam crossing angle, divergence, gas density distributions), e.g. through after-burner
- A nasty feature is up-stream beam gas event can shower through detector stack producing high hit multiplicities
- Can consider embedding at event-gen sub-event or hit levels
  - Need large enough background pool to sample all phase spaces



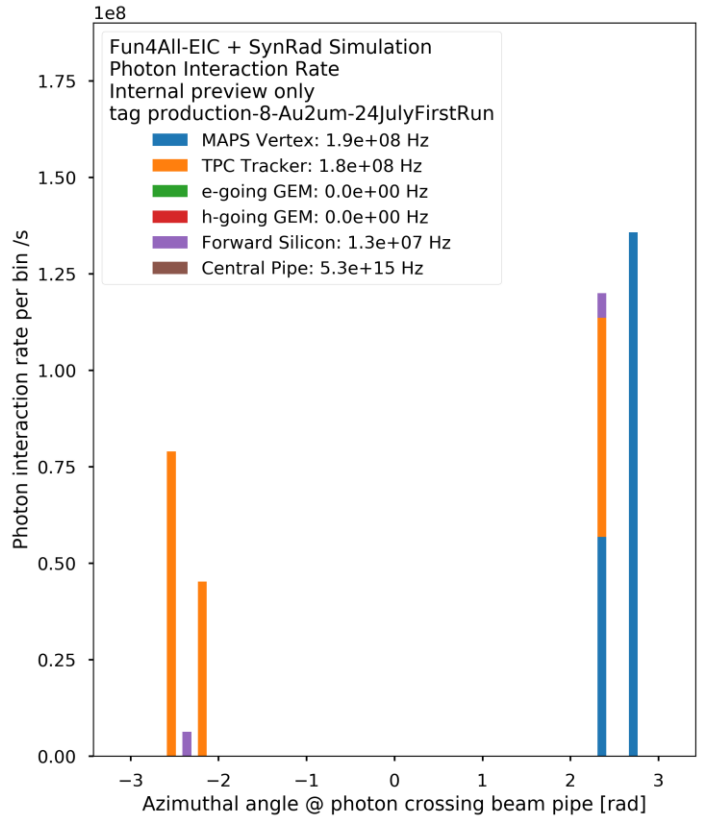
sPH-cQCD-2018-001, https://indico.bnl.gov/event/5283/



Synchrotron background

- Synchrotron require joint accelerator + detector simulations
- Could be the dominant background in EIC
- Nonetheless, probability of a photon interact with detector is very low with proper beam chamber shielding (10^-4 – 10^-7 depending on phase space)
- → likely it has to rely on G4-hit level of embedding
- Current datasets only produce a few hits in detector
- → likely require xO(1000) times more statistics to properly cover phase space and reduce duplications

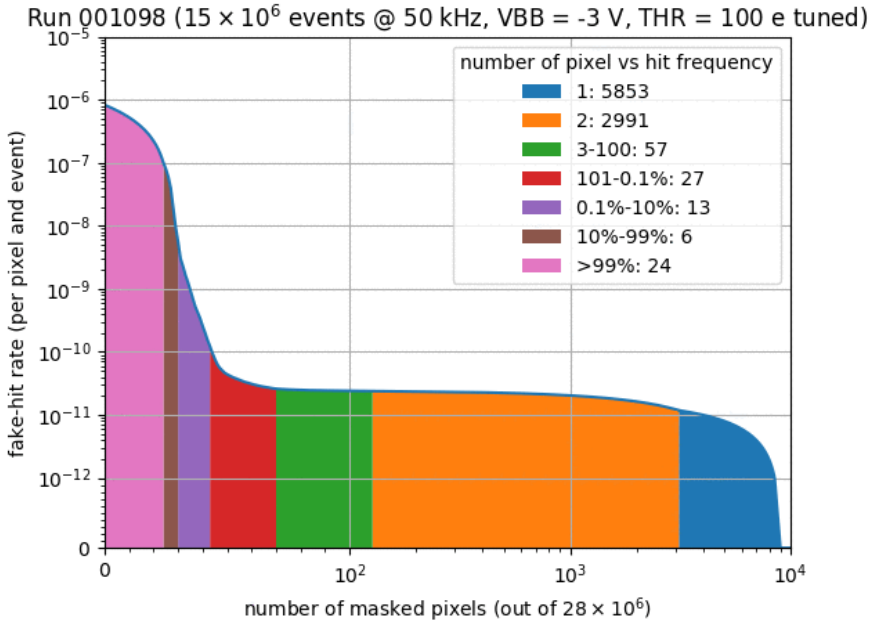
CDR SynRad simulation
2um Au on 760um Be chamber



Considerations for tracker intrinsic noise

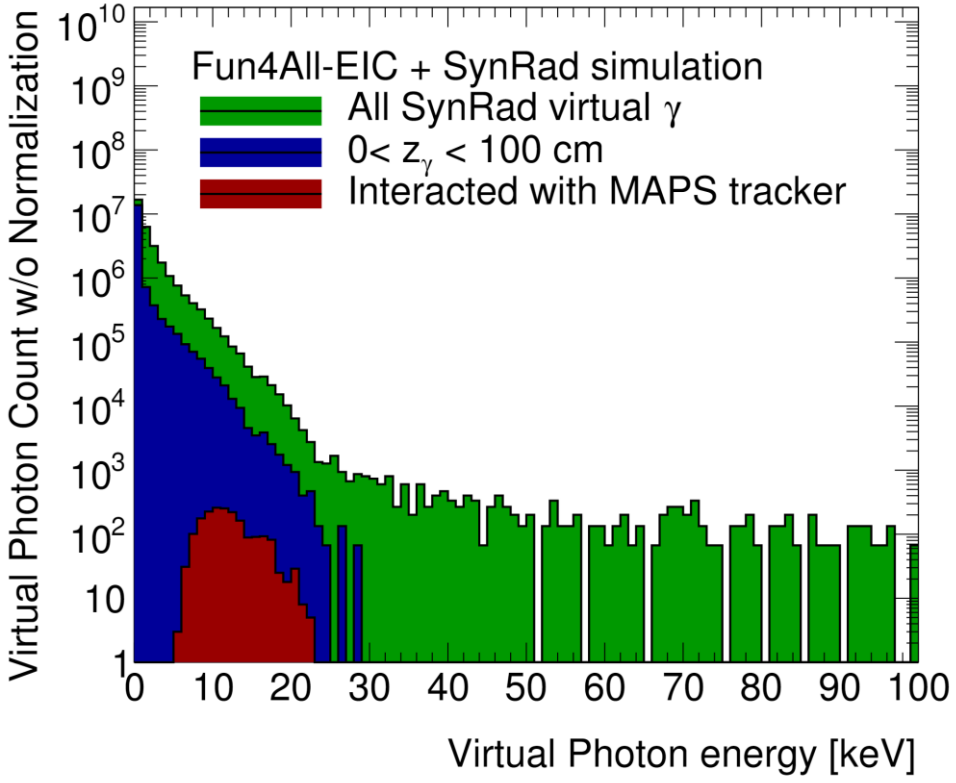
- Largest-channel-count detector: silicon pixel vertex tracker
  - Most recent MAPS (ALPIDE) in large applications:
    - ALICE ITS: 12.5B channels
    - sPHENIX-EIC vertex tracker: 200M chan
- Detector-1 MAPS tracker
  - 10-100B channels
  - 10^{-5} noise rate → O(1)M noise pixel per frame
  - 10^{-10} noise rate → O(10) noise pixel per frame
- What about LGADs?
- We need to pay attention to noise control in detector design

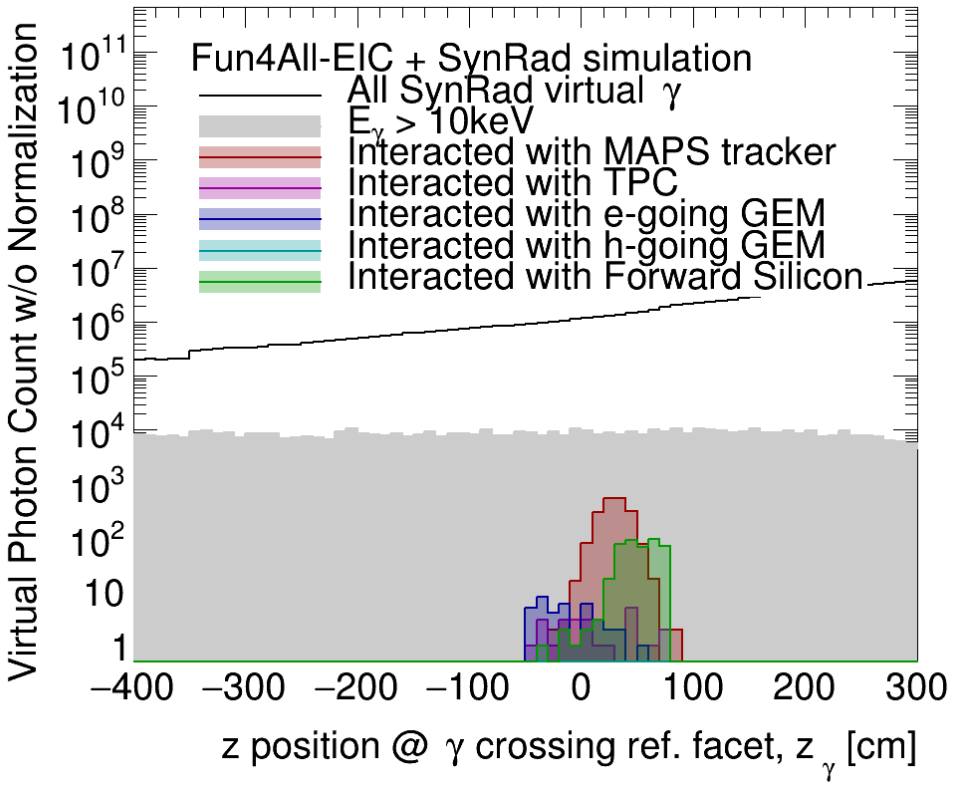
Ref: ALICE ITS commissioning run
Felix Reidt, QM2019



Synchrotron background: detector response

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





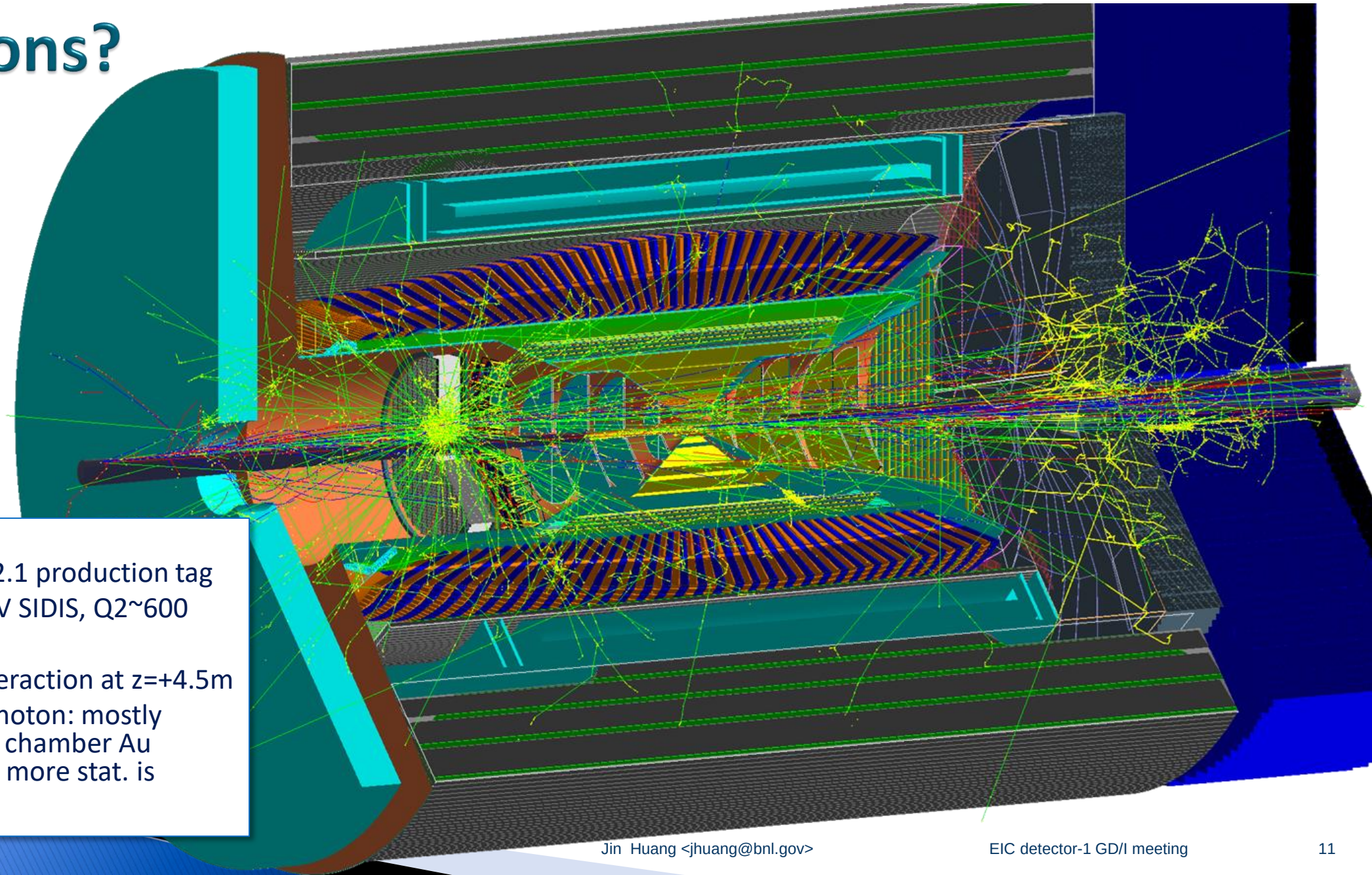
Energy dependence of MAPS vertex tracker to synchrotron

Beam-pipe exit-location

Summary

- In Detector-1 current simulation setup, Fun4All would already support background embedding of various sources
- Detector-1 framework should implement full functionality of embedding on pile up, beam gas, synchrotron, noises; + truth record keeping
- Main challenge on background sources:
  - Stat. for synchrotron photon, probably need x1000 more stat.
  - In both pile up and beam gas events, need large enough background pool to sample all phase spaces
  - We may need to proceed in CD2 with some considerable uncertainty (e.g. at synrad source) → we need to address both most-likely and worst-case scenarios
- Main challenge for reconstruction:
  - Tracking pattern recognition and tuning with background
  - Reco with 4D space-time pattern recognition in streaming time slices, in particular with ToF separating out-of-time collisions/backgrounds
    - sPHENIX 4D reco: Joe Osborn talk in HSF/Reco WG

Questions?



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Extra Information

EIC and HL-EIC: unique collider → unique real-time system challenges

Collision signal rate at HL-EIC looks like that from RHIC

- EIC luminosity is high, but collision cross section is small ($\propto \alpha_{EM}^2$) → low collision rate
- But events are precious and have diverse topology → hard to trigger on all process
- Background and systematic control is crucial → avoiding a trigger bias

	EIC	→ HL-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^{35} 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	5 MHz	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**	**40M N_{ch}/s**	**60M N_{ch}/s**	**30G+ N_{ch}/s**

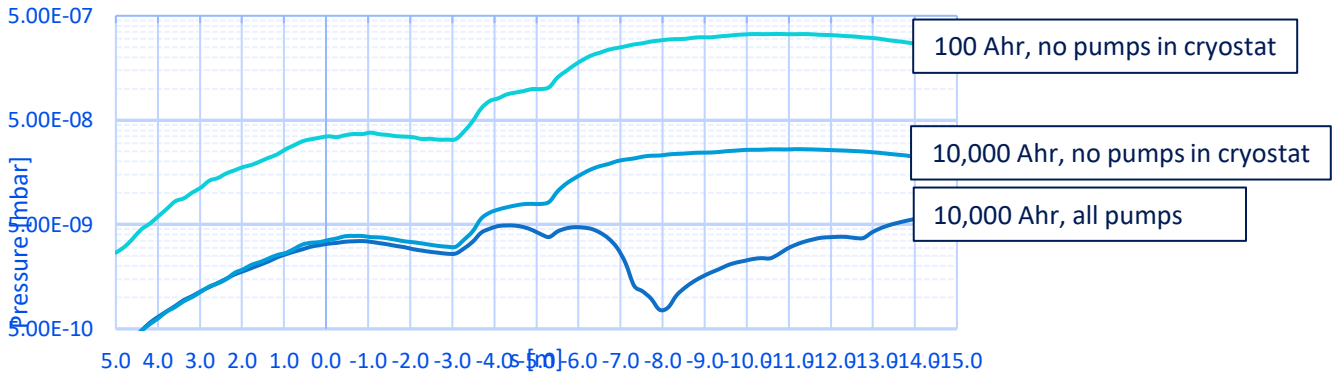
EIC x-sec : further quantification [Courtesy E. Aschenauer]

- Inelastic e+p scattering x-sec:
  - For a luminosity of 10^{35} $cm^{-2}s^{-1}$ 50ub corresponds to **5 MHz**
- Elastic e+p cross-section:
  - For EIC central barrel, elastic cross section is **small** comparing to the inclusive QCD processes
- Beam gas interaction:
  - Beam proton – beam gas fix target inelastic interactions. The pp elastic cross section is smaller (~7 mb)
  - For a vacuum of 10^{-8} to 10^{-9} mbar in the detector volume (10m) this gives a rate of **10-100 kHz**

Beam [GeV]	HERA	5 x 50	10 x 100	18 x 275
$Q^2>10^{-9}$ GeV	65.6	**29.9**	**41.4**	**54.3 ub**
$Q^2>1$ GeV	1.29	0.45	0.65	0.94 ub

Beam [GeV]	HERA	5 x 50	10 x 100	18 x 275
σ [y_{Exp} >-4]	5 pb	**5 ub**	**0.7 ub**	**0.06 ub**
σ [y_{Exp} >-6]	11 ub	420 ub	100 ub	29 ub

E_p:	50 GeV	100 GeV	275 GeV	920 GeV
	38.4 mb	**38.4 mb**	**39.4 mb**	41.8 mb

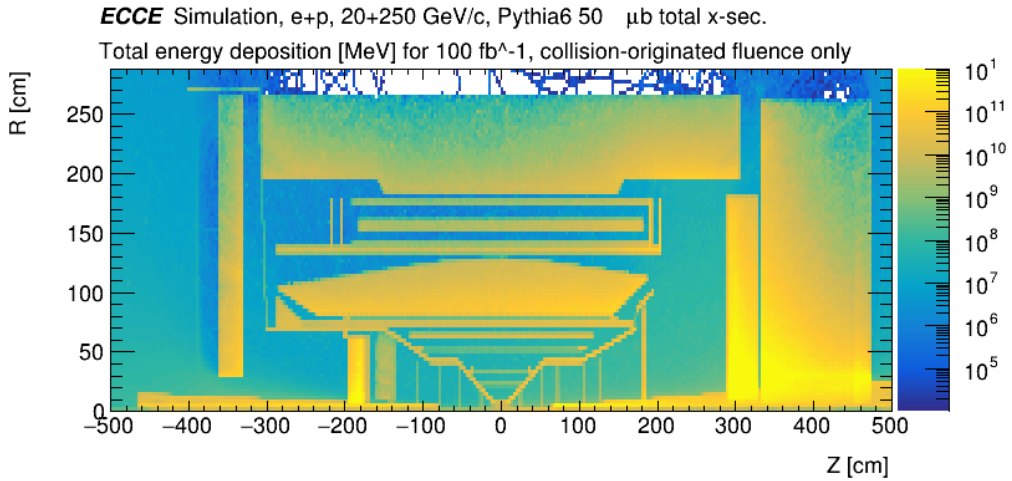


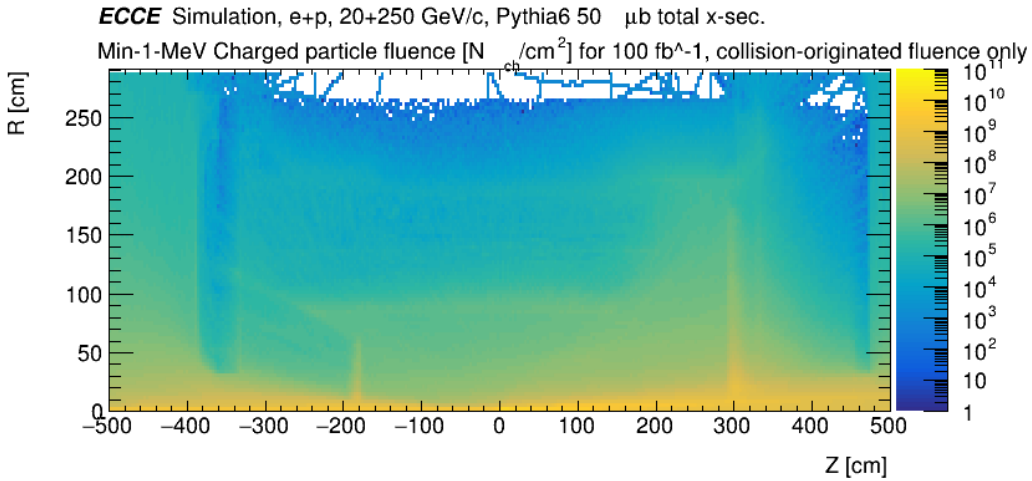
T-6 : ECCE approaches to Radiation Estimation

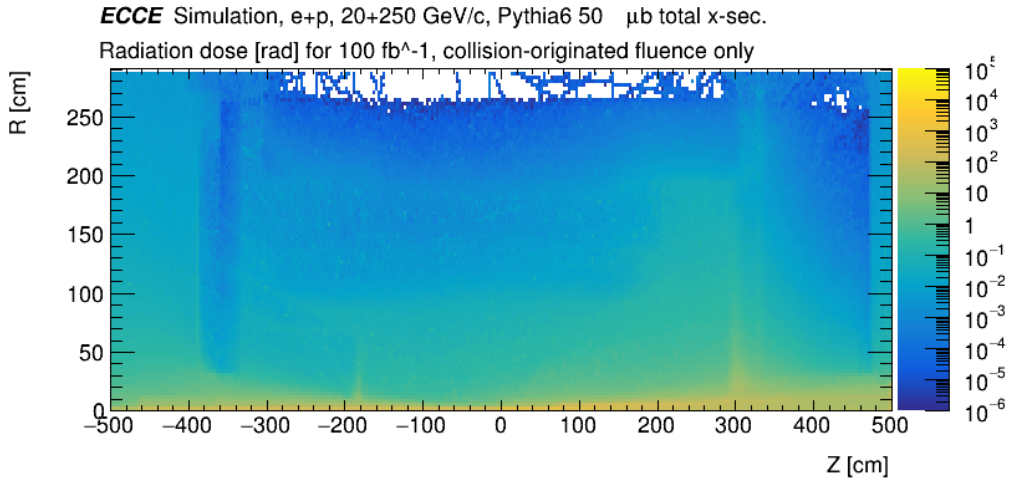
- For central detector, radiation field is quantified specifically for ECCE
  - Radiation estimation is built into ECCE software based on G4 simulation [technote].
  - Tool stack calibrated using PHENIX Run14 data (TID on silicon tracker with ionization radiation dose and MeV-equivalent neutron-fluence.)
  - Updated study for ECCE with EIC beam crossing, beam divergence, vertex distribution, crabbing effect, vacuum vol. geometry [Aug-2021 version from EIC project] and z-dependent beam gas density [Oct-2021 version from EIC project]
  - In later slides: quantitative estimation for primary collision and beam gas, qualitative estimation on Synchrotron radiation
- The far forward and backward
  - Common instrumentation layout shared between collaborations
  - Radiation map included in EIC CDR [link]
  - Updated and detailly examined for the far-forward spectrometer [ecce-note-det-2021-06]
- We caution that in this conceptual design stage, the current radiation maps carry large uncertainty, in particular for machine background radiation
  - ECCE has been taking an active approach in designing a detector to be low in background and radiation damage (e.g. included Au-coating on beam pipe for Synchrotron radiation shield) and actively participating the biweekly EIC project IR background meeting

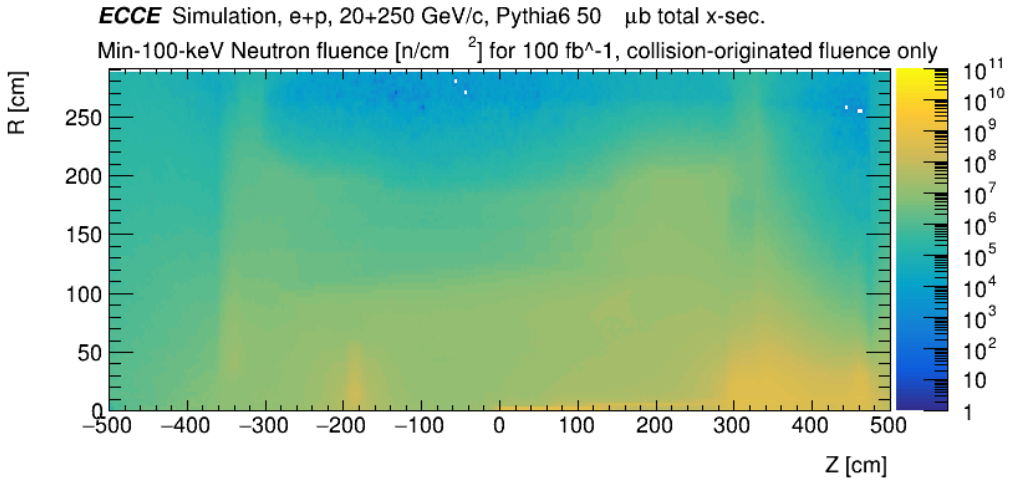
T-6 : ECCE centra detector radiation map 1/3

- Beam collision radiation: based on Pythia6 50ub total inelastic x-section tuned for EIC



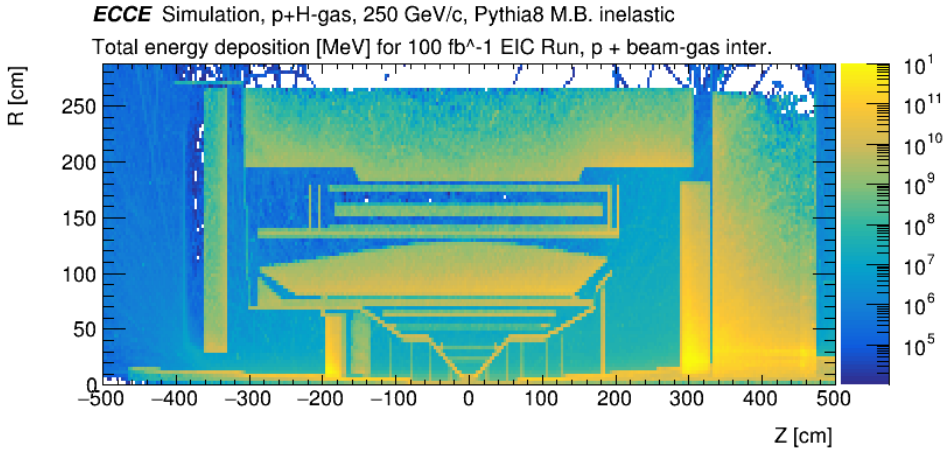


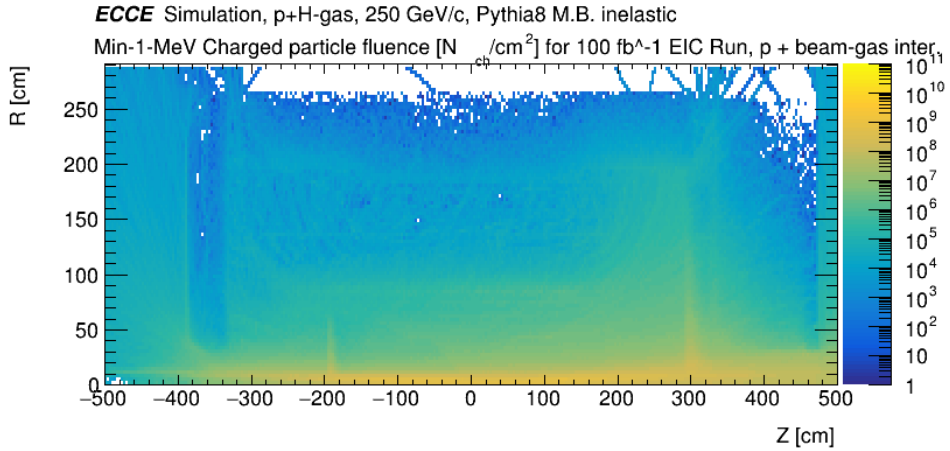


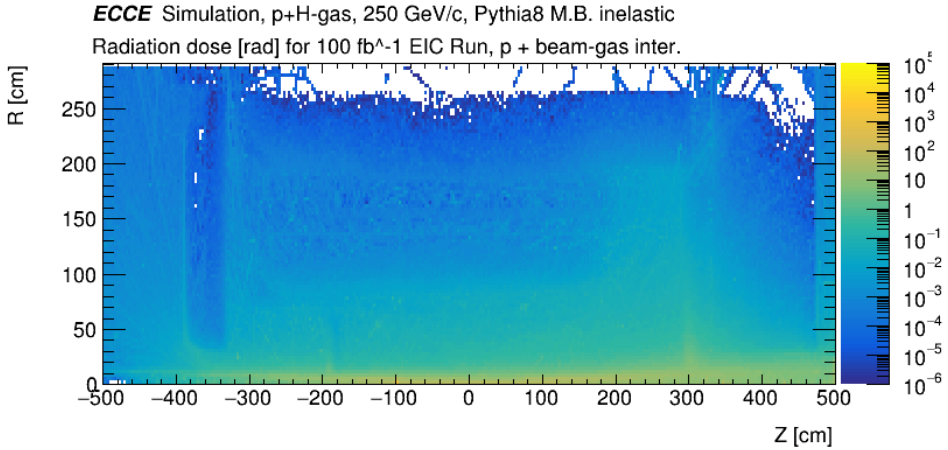


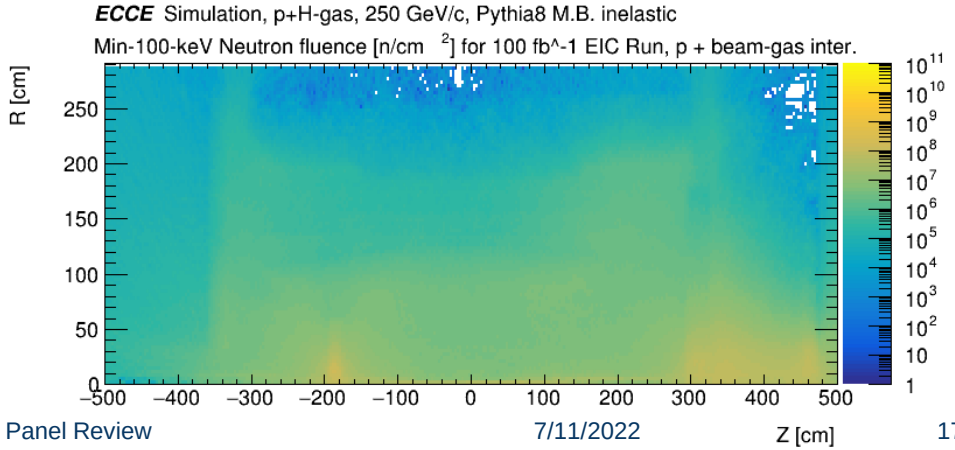
T-6 : ECCE centra detector radiation map 2/3

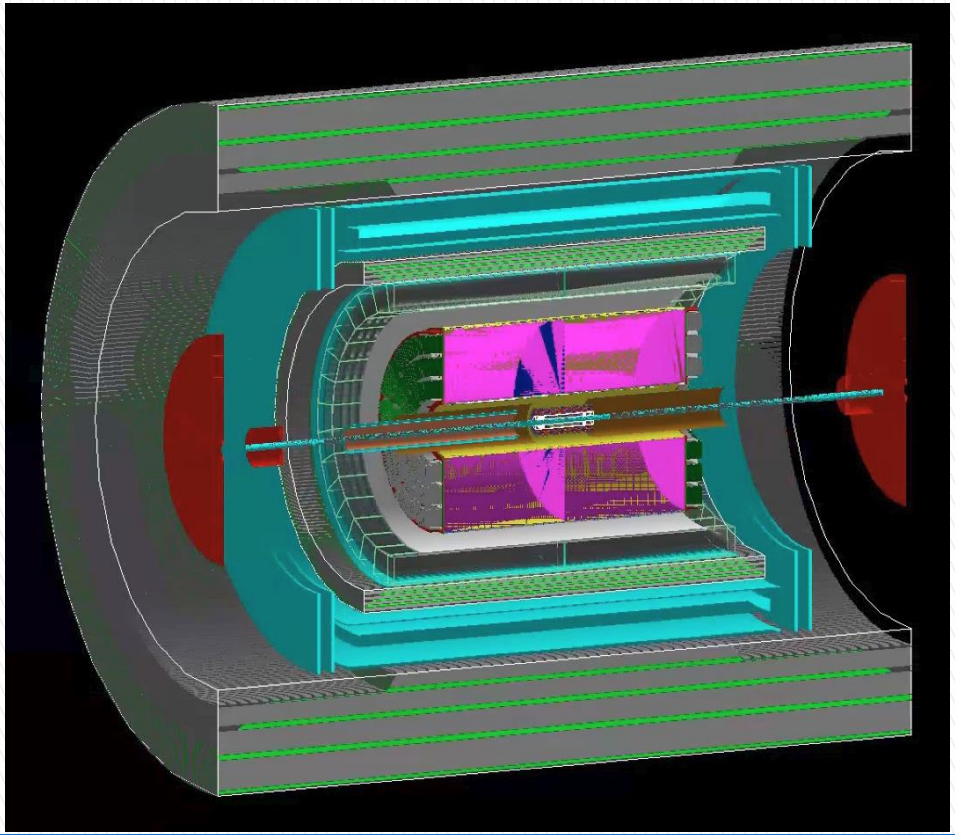
- Beam gas is dominated by proton-beam gas interaction, estimated below
- Based on Oct-2021 z-dependent beam gas profile from EIC project (w/ “worst beam tail” assumption)



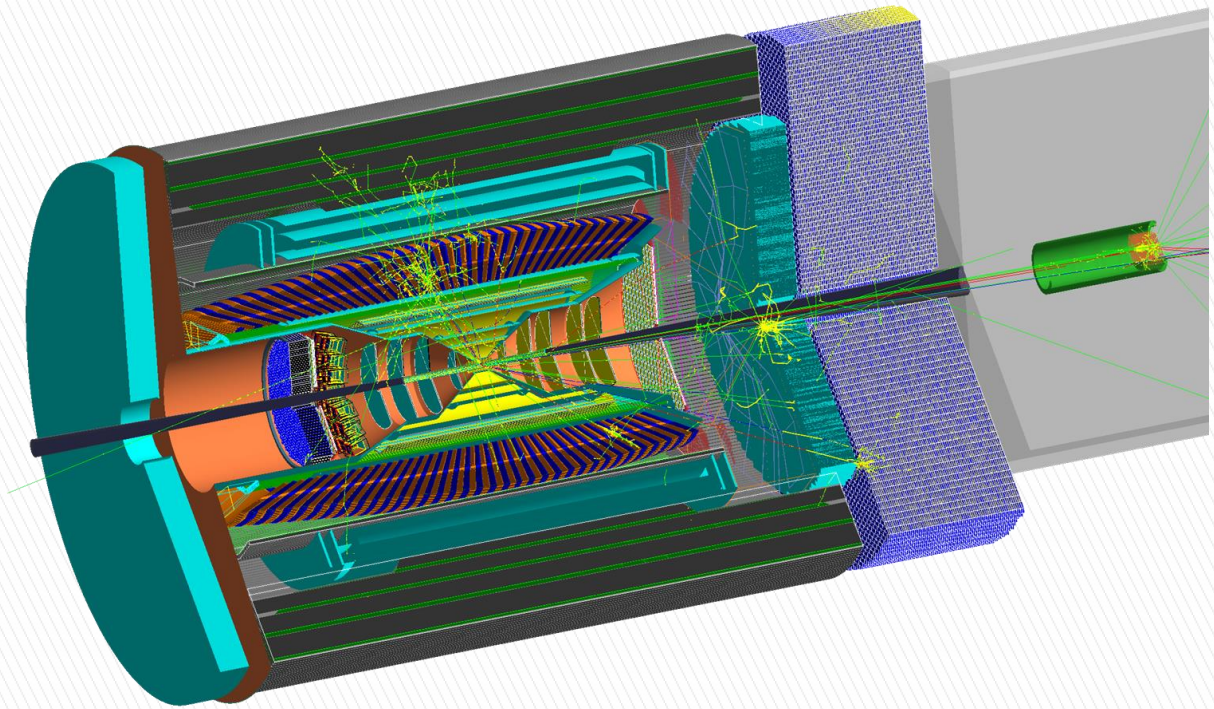








sPHENIX Central Barrel
https://github.com/sPHENIX-Collaboration/macros



Proposal ECCE simulation
https://github.com/ECCE-EIC/macros