Recap from the FCC Week 2026

ILD - AnaSoft

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HELMHOLTZ

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DESY.

Improved Absolute Beam Energy Measurement over RDP

Introduction

- Feasibility study quotes 100 keV systematic uncertainty on m_Z from absolute beam energy scale compared to 4 keV statistical uncertainty
  - Probably conservative, but can we constrain and/or cross-check the absolute calibration by independent means?

Table 24: Current projected $\sqrt{s}$-related uncertainties on selected electroweak observables.

Uncertainty	m_Z (keV)	Γ_Z (keV)	$\sin^2\theta_W^{\text{eff}}$ ($\times 10^{-6}$)	$\frac{\Delta\alpha_{QED}(m_Z^2)}{\alpha_{QED}(m_Z^2)}$ ($\times 10^{-5}$)	m_W (keV)
	Observable				
Absolute	100	2.5	–	0.1	150
Point-to-point	14	11	1.2	0.5	50
Sample size	1	1	0.1	–	3
Energy spread	–	5	–	0.1	–
Total $\sqrt{s}$-related	101	12	1.2	0.5	158
FCC-ee statistical	4	4	1.2	3.9	180

arXiv:2505.00272

Muon Production at Threshold

- Beam energy threshold for muon pair production in fixed target e^+e^- collisions is $\sim$ 43.7 GeV $\longrightarrow$ not far away from $\frac{m_Z}{2}$
- Kinematics are very constrained at or just above threshold by construction

LEMMA proposal to use positron beams as low emittance source for muon colliders

Also proposal for $\mu^+\mu^-$ bound state production at threshold with positrons from FCC-ee booster

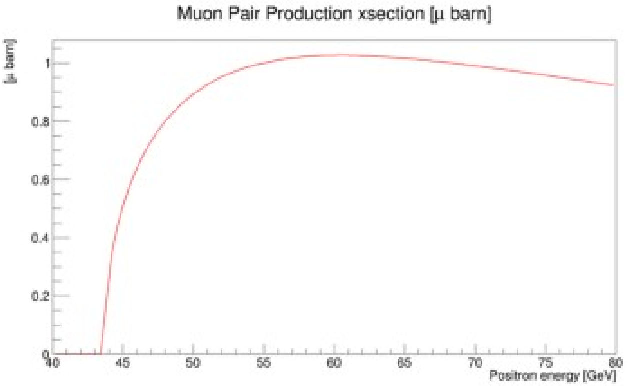
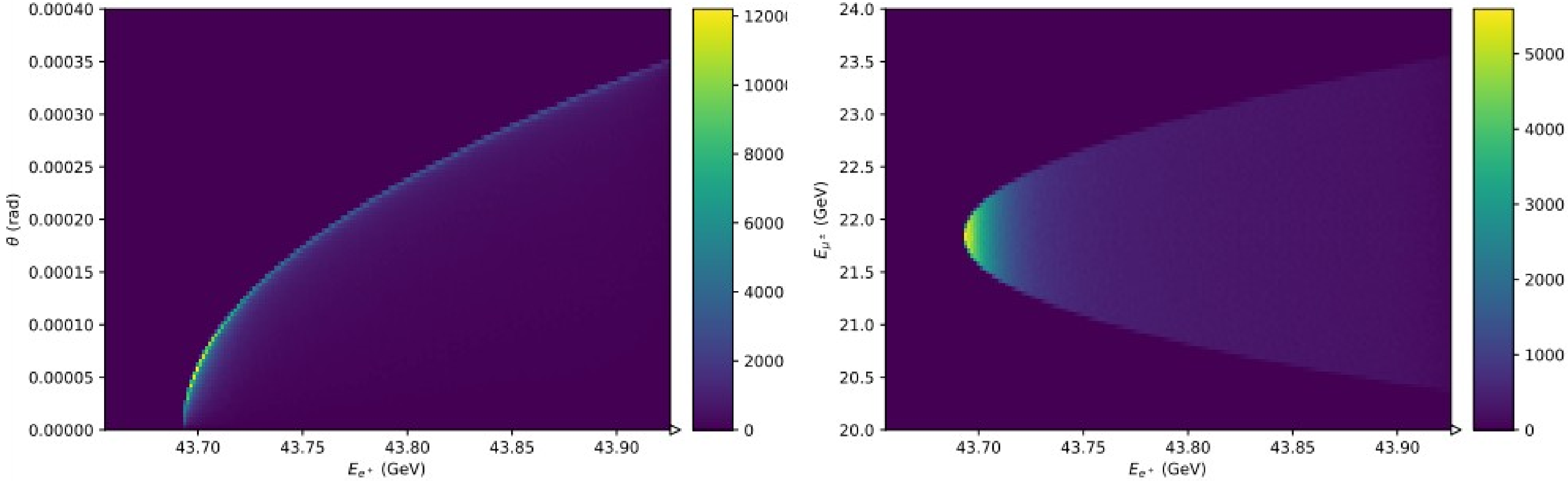


Figure 1: $e^+e^- \to \mu^+\mu^-$ cross section as a function of the positron beam energy ($\sqrt{s}$ ~0.23 GeV = 53 GeV positron beam).

arXiv:1905.05747

Muon Kinematics: No BES or ISR



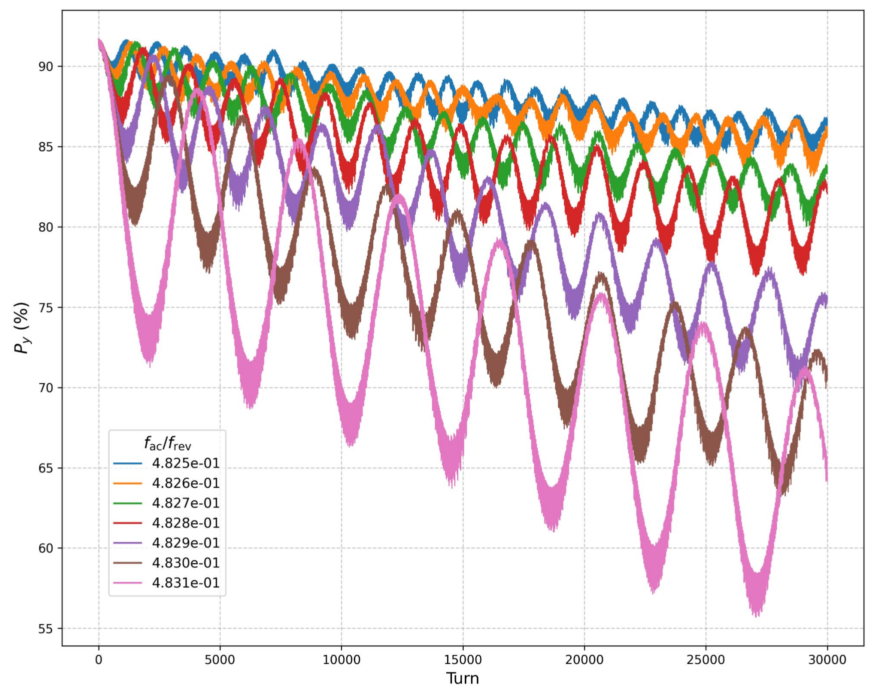
- Scattering angles of O(10^{-4}) rad and muon energy $\sim \frac{E_{e^+}}{2}$
- Sharp endpoints in both angular and energy distributions without BES

Conclusions

- New idea to use muon production at threshold as energy reference
  - Complementary to measurements from resonant depolarization and relative measurements from main detectors
- Basic target and detector configuration has been considered
- Prototype analysis in place with Monte Carlo + toy detector simulation including both muon rate and kinematics
  - Significant internal redundancy
- **Promising numbers suggest it is possible to at least approach the projected 4 keV statistical limit for the Z mass measurement**
- **Many practical issues to be further considered**

Near Resonance Polarization Modulation (NRPM)[1]

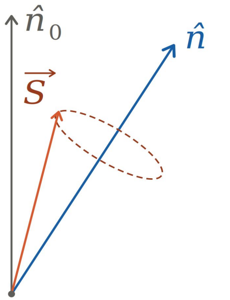
Polarization beating



AC dipole drives at a fixed frequency

$$\Omega = \sqrt{[2\pi(f_{\mathrm{ac}}/f_{\mathrm{rev}} - \nu_0)]^2 + \epsilon_k^2}$$

single resonance model[2]



- excite the beam using different f_{ac}/f_{rev}
- measure the Ω
- fit the relation between Ω and f_{ac}/f_{rev}

$\rightarrow \nu_0 \rightarrow$ **E**

[1] Y. Wu, IPAC 2026, https://indico.jacow.org/event/95/contributions/12371/editing/slides/46453/125260/WEO1T03_talk.pdf
[2] J. P. Devlin, G. H. Hoffstaetter, D. P. Barber, “A generalization of the Froissart-Stora formula to piecewise-linear spin-orbit resonance crossings”

Comparisons

	RDP	NRPM
Strengths	• High precision • Rapid localization of the spin tune over a wide range • Easily measurable signal	• Sub-keV precision achievable • Fast measurement • Reusable polarized beam • Frequency domain signal analysis
Limitations	• Based on curve fitting, easily affected by fit function and curve shape • Longer measurement time	• Polarimeter requirements: high resolution and fast acquisition rate

Hybrid RDP + NRPM: RDP for the scan, NRPM for finer measurement when needed

Background Studies

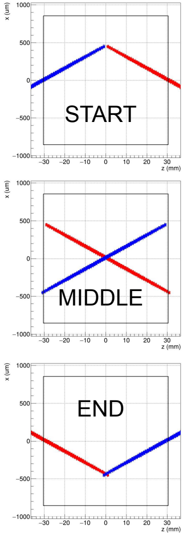
Overview of Guinea-Pig and recent implementations

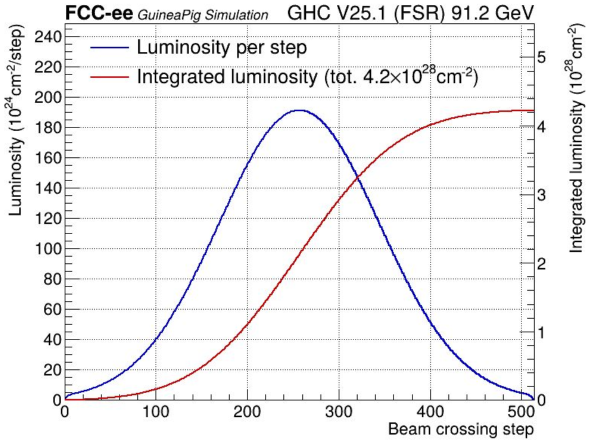
IPCs are a luminous background

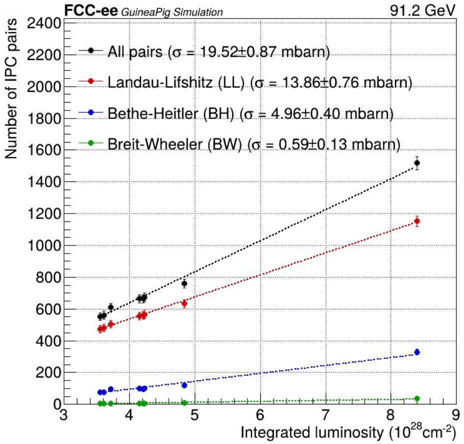
- Production cross-section estimated to be ~20 mbarn
- Important and validated that Guinea-Pig is able to reproduce tabulated luminosities within 5-10%

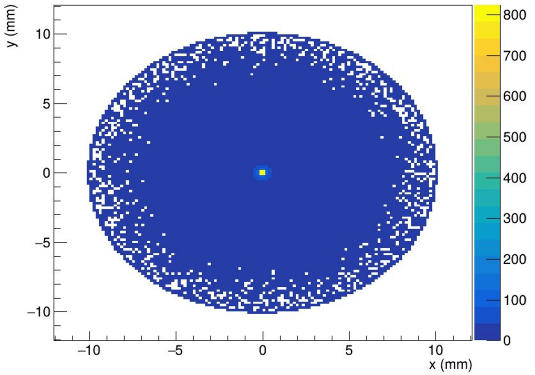
Recent implementations

- OLD: Constrain the particles at the beam pipe as interface to Geant4 for MDI/detector studies
- OLD: Implementation of detector magnetic field (2T) that acts on the propagation of the IPCs
- NEW: timing information of the IPCs
- NEW: handling of output data and meta information









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Updates Guinea-Pig: handling output data

Up to now, the pairs were stored in ASCII files (.pairs)

- Very specific and not so modern format
- Does not allow to merge several files
- Dedicated ddsim reader for .pair files

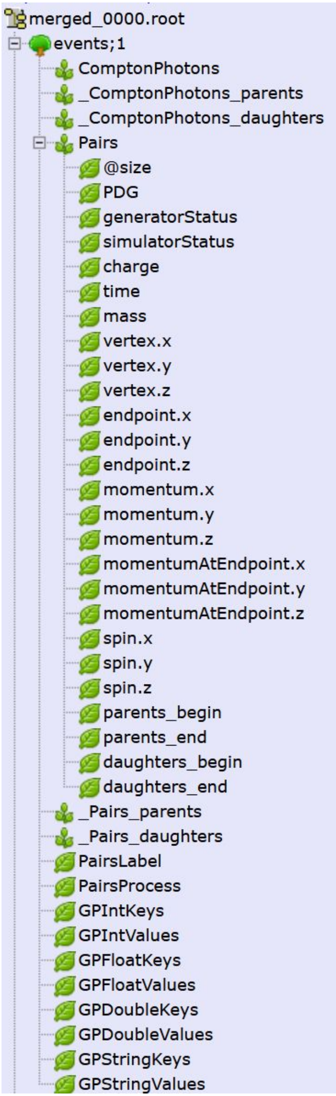
Re-implemented the EDM4hep ROOT output

- Originally done by in 2024 by K. Stoimenova (summer student 2024, report)
- Code had to be revised because of updated EDM4hep handlers and data formats
- IPCs are stored as a MCParticle collection under branch name “Pairs”
- Original particles at production level also stored with mother-daughter relationships
- All meta info available as well (input parameters, luminosity/BS parameters, …)
- Documentation will be updated on how to access all these

Validation

- Per-particle level between ROOT and pairs files
- Using ddsim by specifying the MCParticle collection

```
--inputFiles input.root --edm4hep.mcParticleCollectionName Pairs
```



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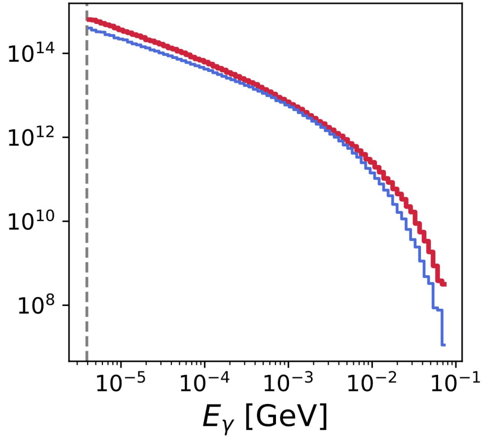
WarpX benchmarking and performance

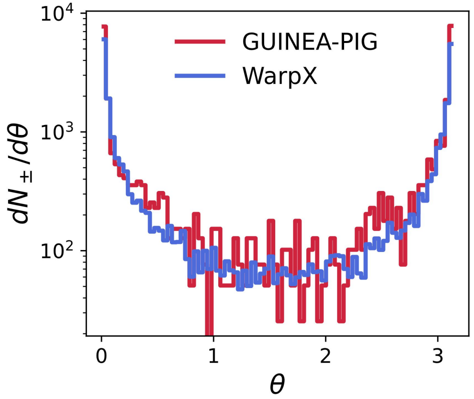
Continuous extensive benchmarking against GuineaPig

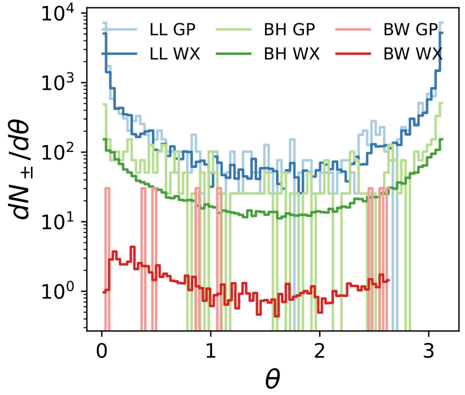
- Beamstrahlung photon spectra reproduced
- IPC kinematics and dynamics validated for all three processes (LL, BH, BW)
- Excellent agreement observed across key observables



Performance

- Example at FCC-ee Z pole with comparable discretization
    - Guinea Pig: 38h (1 CPU)
    - WarpX: 3.45m (8 GPUs)
- More than two order-of-magnitude reduction in runtime
- GPU acceleration enables large-scale parameter scans and background studies





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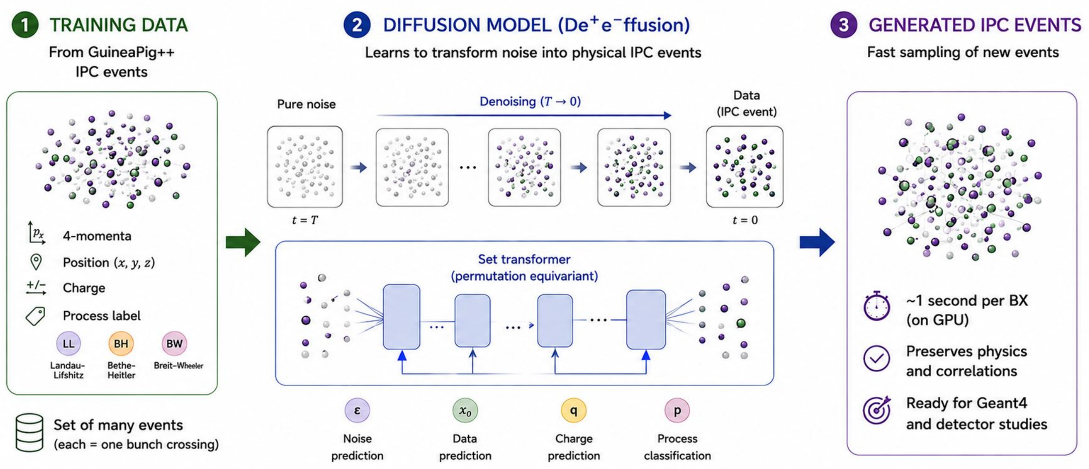
De$^+$e$^-$ffusion: ML-based fast simulation IPC

Current situation

- IPC backgrounds are a key input to MDI and detector design studies
- Occupancy and radiation studies require very large background samples
- Large statistics are also needed to overlay beam backgrounds with physics events
- Full IPC simulation with Guinea Pig is computationally expensive (less with WarpX)

Scope and goal

- Develop a fast ML surrogate for IPC event generation
- Preserve the detector-relevant physics and correlations
- Enable large-scale datasets



Trained on FSR lattice based on 50k GP events

- Fixed lattice, will be extended to take into account first-order lattice perturbations ($\sigma_{x,y,z}$, $\beta_{x,y}$)
- IPC processes taken into account due to different kinematics

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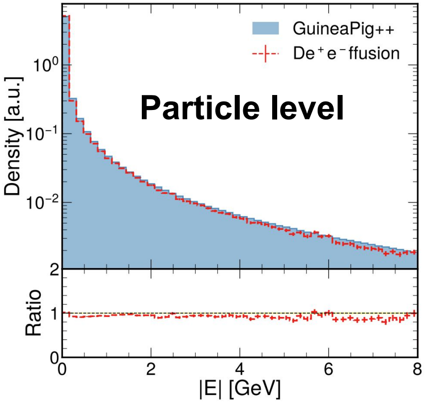
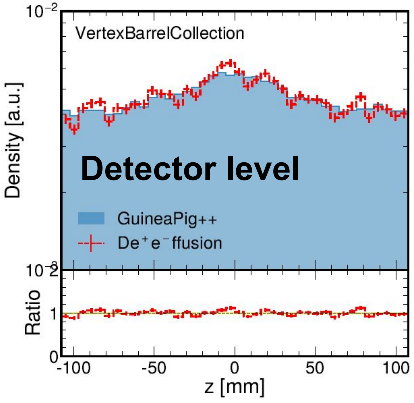
De^{+}e^{-}ffusion: validation and performance

Extensive validation

- **Particle level**
  - Energy, momentum and spatial distributions reproduced
  - All IPC processes reproduced consistently
- **Detector level**
  - Full Geant4 simulation of generated events
  - Vertex detector hit distributions reproduced
  - Occupancy patterns preserved

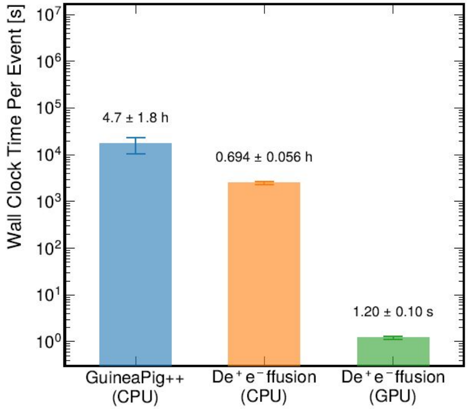




Detector response from generated events is very similar to the reference simulation at the % level

Performance

- Order of magnitude improvement w.r.t. Guinea Pig on CPU
- 4 orders of magnitude faster when running on GPU
- Allows for large and fast generation of beam background samples



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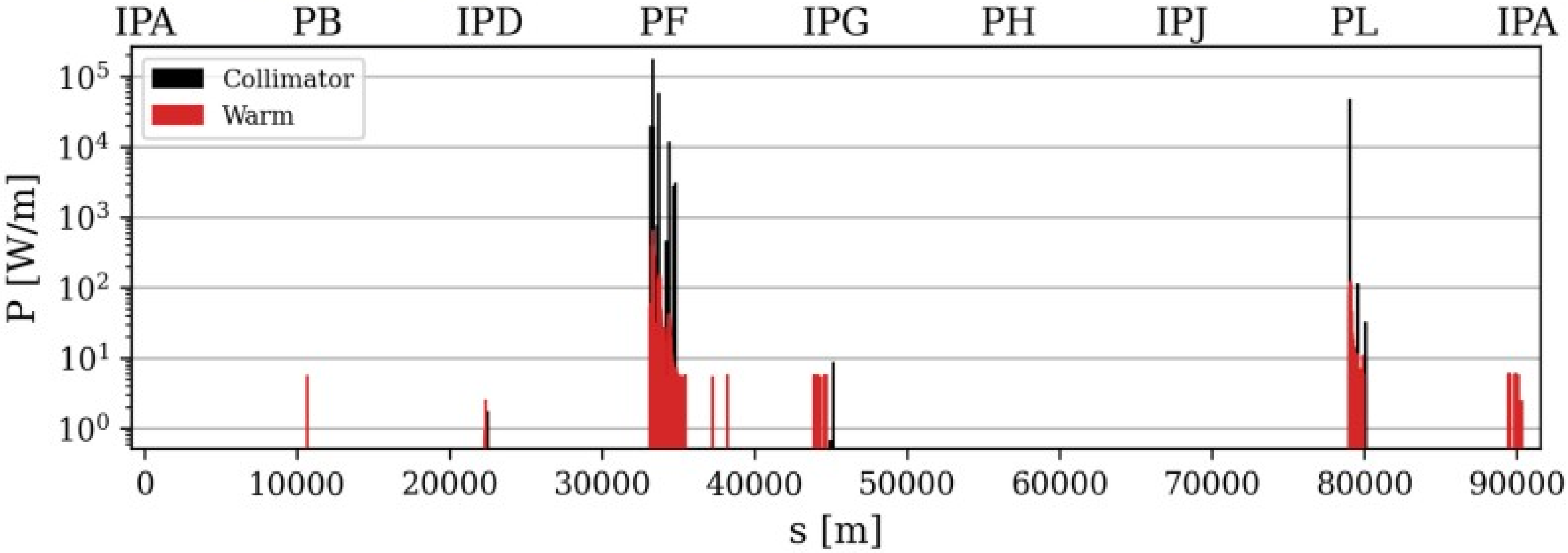
LCC Injection performance

Hybrid scheme $\delta_{off} = -1.02\%$

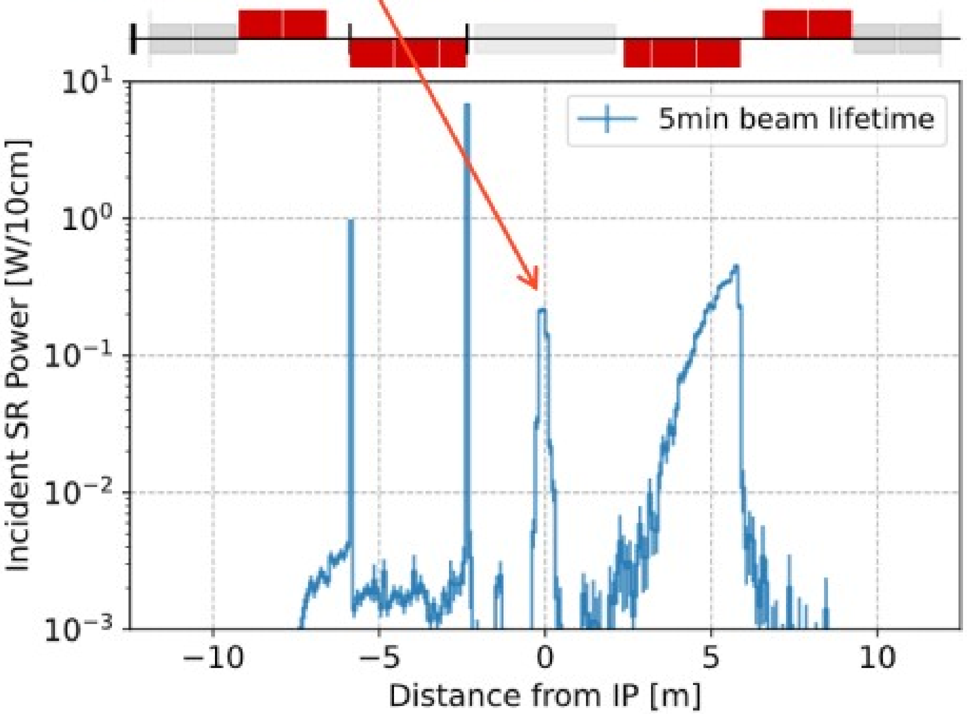
- **Injection efficiency ~86%**, includes collimation, SR, and beam-beam, like GHC.
- **Losses localized in collimation insertions**, both betatron and momentum.
- Negligible leakage to IR → **injection background significantly suppressed**.
  - Step 2 and 3 not performed for LCC.
- **Overall, very good performance w.r.t. GHC**!

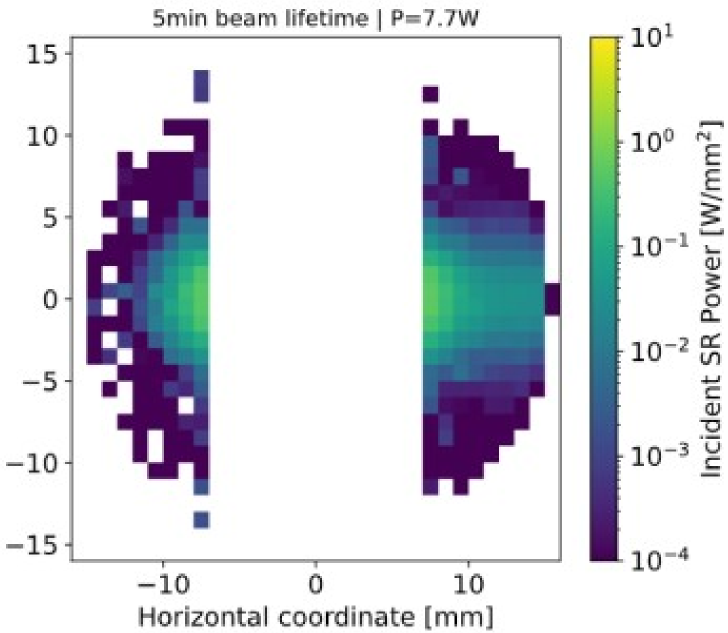


SR from beam halo

Background estimate details in the next talk.

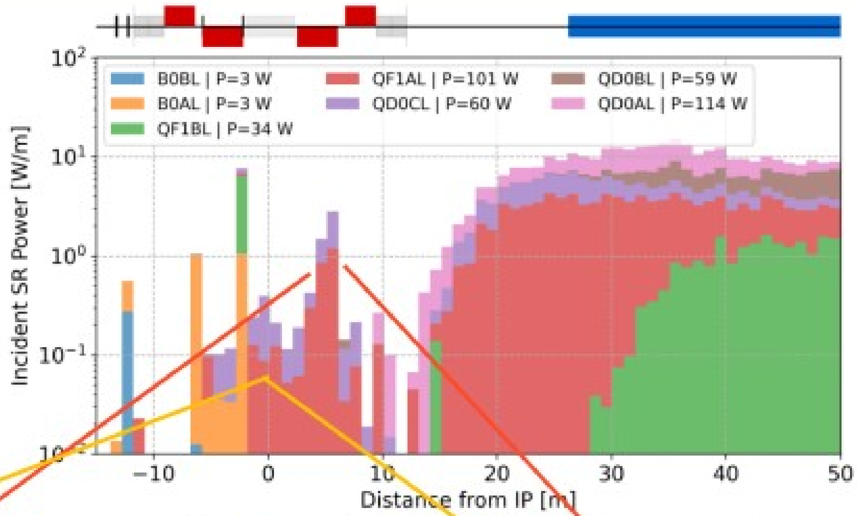
- **Most of the SR is produces at the FFQ** → only the fixed masks downstream can protect the detector!
- Total contribution about 2 kW, mostly downstream IP.
- **SR at IP increased by factor 3 with a 5min lifetime → occupancies study show too high values!**

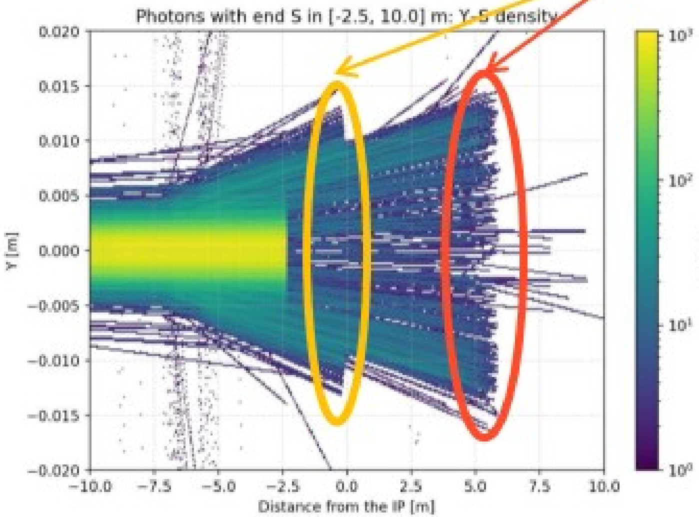


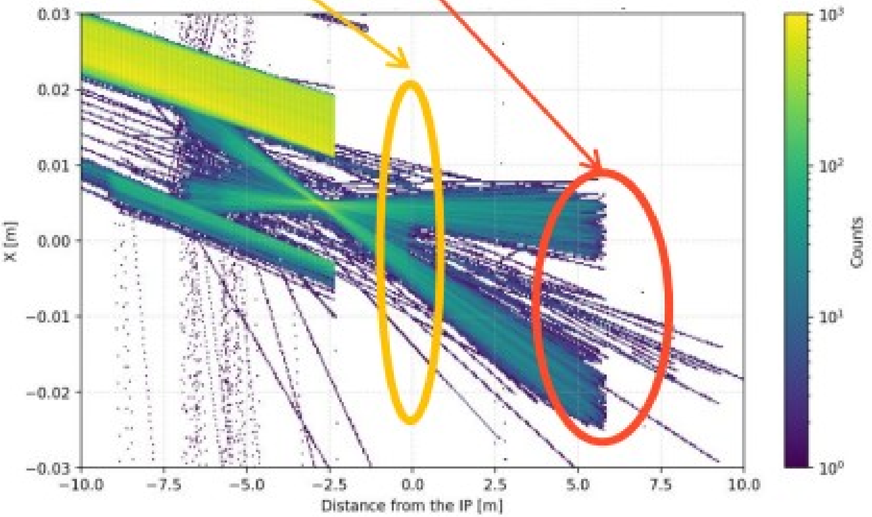


SR at the IP

- Halo-SR produced at QF1 → **mask not very effective.**
- **SR fan horizontally focused from QF1 →** through mask center.
- Vertical fan diverging → chamber impact **unavoidable!**
- QDO produce horizontal divergent fan.







take-home message

@ 91 GeV	Silicon Tracker pixel rate @ 3 pix/hit	Drift Chamber occupancy	TPC typical distortion
IPC	10 kHz / cm^2	~7% *	few mm
SR my back-of-envelope	~GHz / cm^2	>1000%	few m

IPC [comfortable → challenging]
SR [extremely challenging → impossible]

FCC

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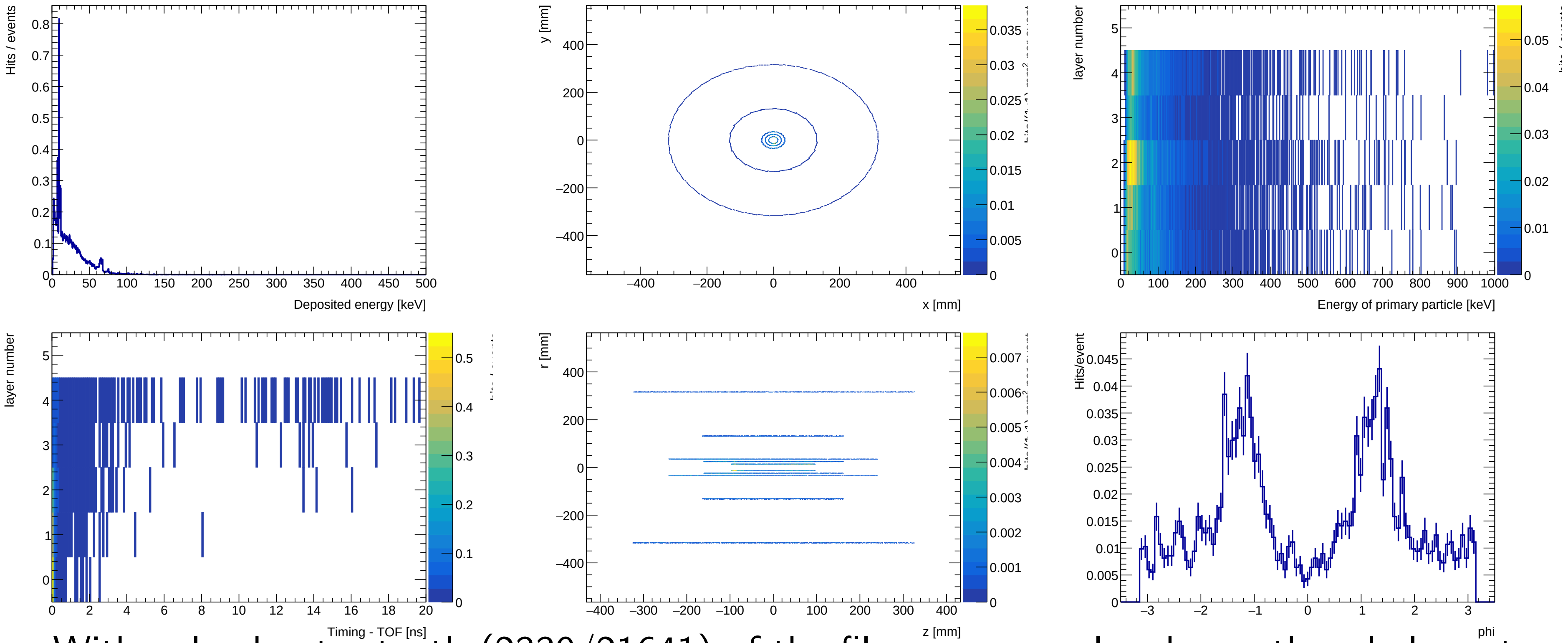
(*) https://indico.cern.ch/event/1583755/contributions/6727405/

More details on SR halo in VXD barrel



- With only about a tenth (2339/21641) of the files, one can already see the whole vertex barrel light up...
- Higher threshold would not really help

Conclusions and discussion

Knowledge of hit rates in the VXD important for sensor R&D and TDAQ. VXD barrel first layer could define whether streaming readout is possible

- IPC background in VXD first layer reduced compared to previous study (old v23 lattice) $\rightarrow$ $< 100\,\mathrm{MHz\,cm^{-2}}$ (even lower with realistic digitiser)
- First layer closer to beam pipe increases hit rate by ~ 2
- IPC greatly reduced in VXD disks and SiWr

Larger SR samples for the first time allow to properly evaluate this background

- SR background looks very scary in both VXD and SiWr, esp. SR halo in VXD barrel

$\rightarrow$ Need to revisit lattice and MDI design. Unclear if older lattice designs had same magnitude of SR issue $\rightarrow$ to be checked

- Difference of ~ 3 between different VXD sensor assumptions. Relevant but not game changer

Next steps:

- Run over more SR samples to reduce stat. errors
- Evaluate BIBs in FCC-SEED vertex detector $\rightarrow$ No reason this should be very different to the ultra-light design, but should be checked
- How well does a thicker beam pipe Au coating help? How much is needed to suppress SR enough?
- Look at SR cluster size with LUT-based digitiser

Miscellaneous

- PR in `HEP-FCC/FCC-config` with links to ILD resources
  - ILD software conveners should check that
- Next FCC Week: 12th-16th April 2027 in Madrid, Spain
- Question on Taikan's ILD Overview Talk:
  - Does ILD plan to integrate its samples into the FCC production/storage framework? (Juraj Smiesko)
- Big push for Gaudi-native code: e.g. new tracking validation tool even though `ILDPerformance` and Gaelle's framework already exist...