

REPORT ON SYNCHROTRON RADIATION IN FCC-EE

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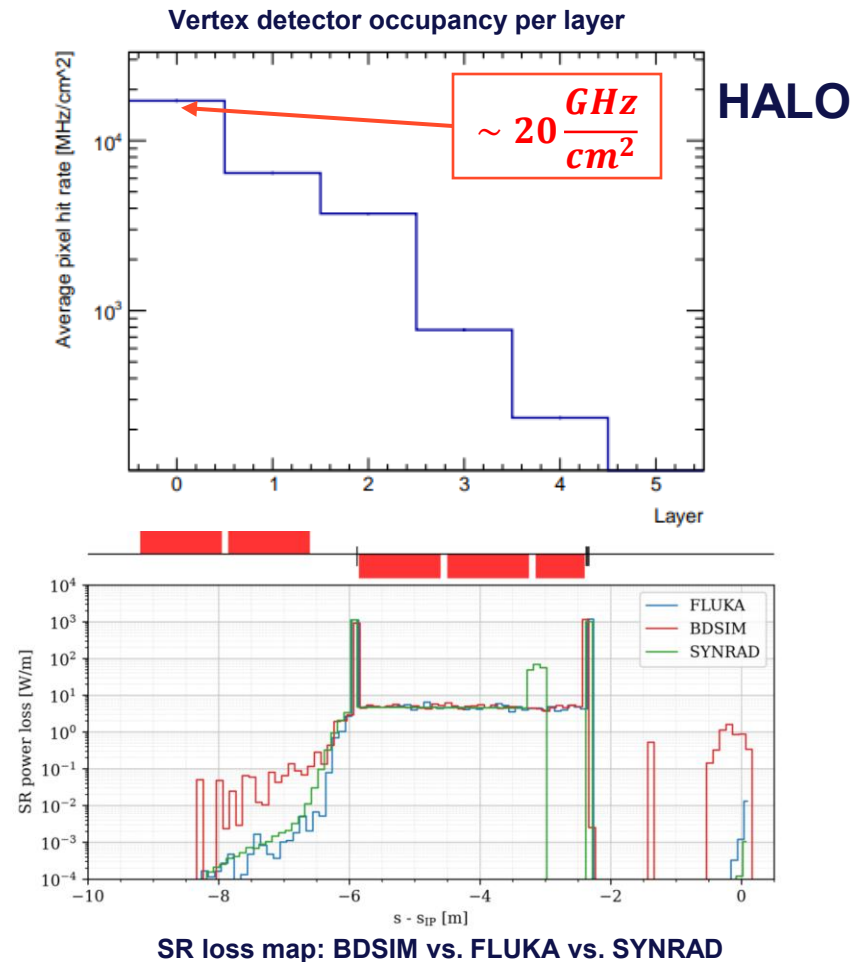
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Many thanks for the inputs and fruitful discussions to M. Ady, H. Bartosik, M. Boscolo, G. Broggi, R. Bruce, H. Burkhardt, D. Calzolari, C. Carli, G. De Gois Saretti, J. Eyearns, A. Frasca, C. Garion, A. Ilg, D. Jeans, M. Jebramcik, A. Lechner, G. Lerner, K. Oide, F. Palla, P. Raimondi, S. Redaelli, J. T. Seeman, M. Sullivan, F. Zimmermann.

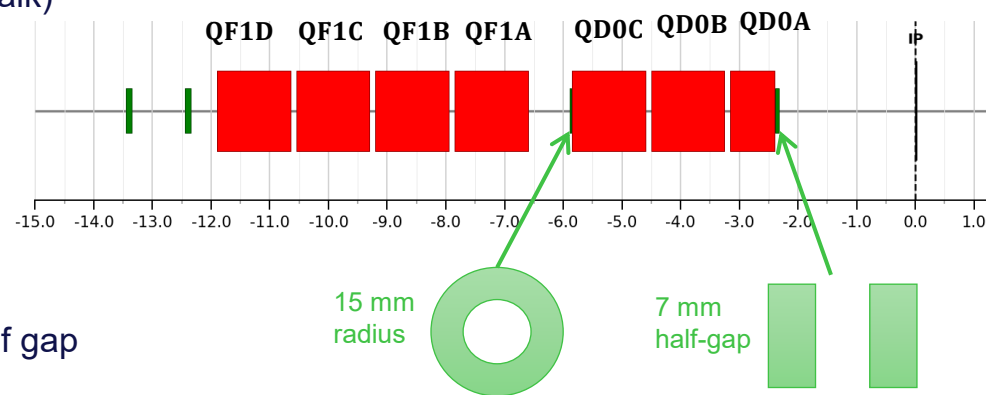
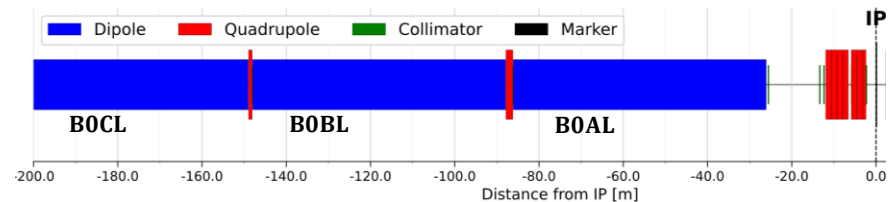
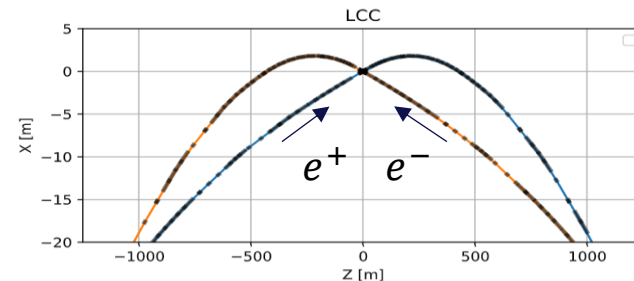
SR problem

- For the first time SR samples were tracked in the detectors and first results presented at FCC WEEK 2026
- Very high occupancy in the vertex detector**: up to ~ 20 GHz/cm² (HALO) and ~ 1 GHz/cm² (CORE).
- "Impossible" occupancies extrapolated in the main tracker.**
- Discrepancies were also found across codes** (BDSIM/FLUKA/SYNRAD).
- A Task Force was formed to reduce the impact of SR.
- This talk presents the current status of this ongoing effort:
 - Discovered issues with the simulations
 - Mitigation of the SR background



SR in LCC IR

- Studies performed for lattice LCC 106 at Z pole.
- Most SR is collinear with the beam $\rightarrow$ stopped in the photon dump.
- Weak dipoles and strong quadrupoles** (upstream IP) are main SR source.
- Produced photons can reach the detector via:
 - Direct impacts** in beam pipe within detector region
 - Reflection** in the pipe walls (not treated in this talk)
- SR collimation system:**
 - 5 movable W-based collimators
 - 2 fixed W masks
 - QF1 exit -- 15mm radius circular mask
 - QD0 exit -- double horizontal jaws 7mm half gap

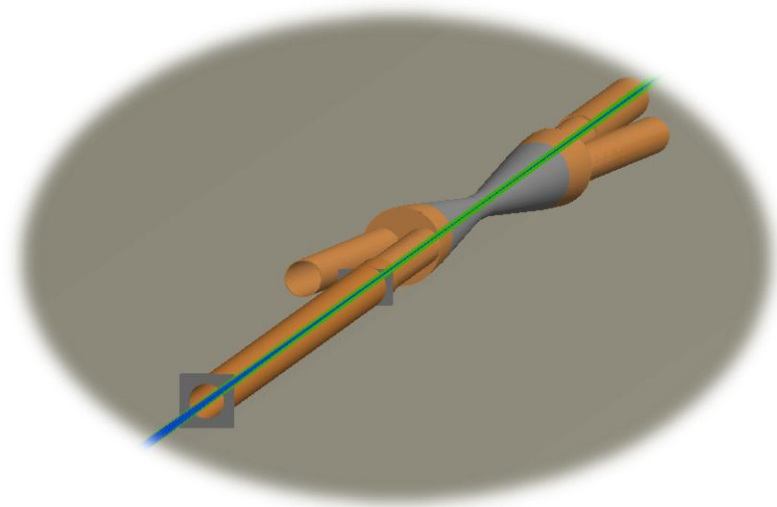


Simulation Setup

SR studies can be performed with Synrad+, FLUKA and **BDSIM**.

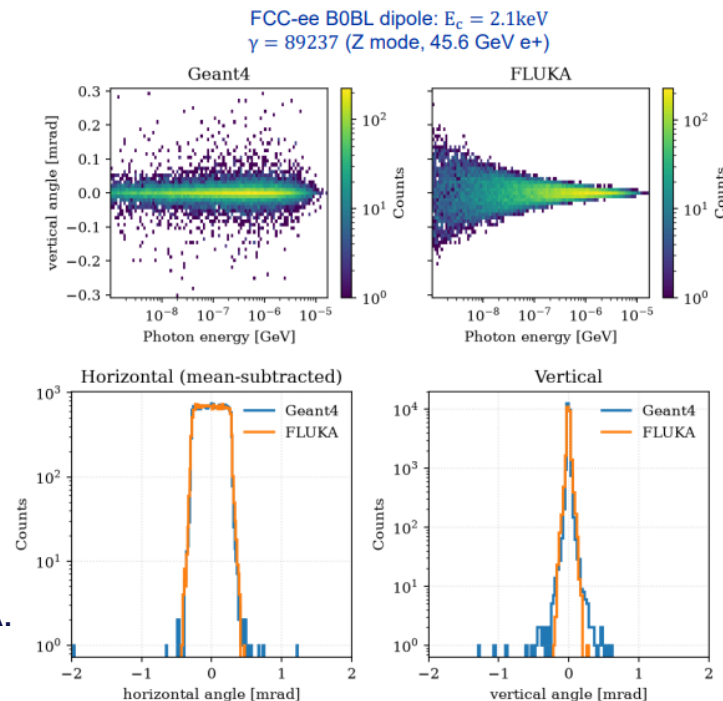
This talk focuses on studies with BDSIM:

- Accurate IR optics.
- **Model flexibility** → easily extendable.
- e^+ beam loaded at start of IR and propagated with SR photons generated.
- **Starting conditions:**
 - beam core,
 - beam halo.
- **X-ray reflection OFF** (work ongoing – currently presents discrepancies with the other codes)
- **Scattering ON – NO black absorbers**
- Single pass in ideal orbit, no beam-beam deflection.
- No real magnet geometry.
- Focus only on γ_{SR} produced within the beampipe, main source of background.



G4 angular sampling

- **Problem:** loss maps disagreed between BDSIM (Geant4), FLUKA, and SYNRAD
- **Root cause:** approximated Geant4 angular sampling
 - SR photon emission angle independent of the photon's energy
 - **unphysical multi-mrad photons emission angles**
- **Solution:** Implemented exact angular sampling in G4SynchrotronRadiation module (patch).
 - Validated against analytic theory and against FLUKA.
 - **Loss maps now agree well between BDSIM/FLUKA/SYNRAD.**

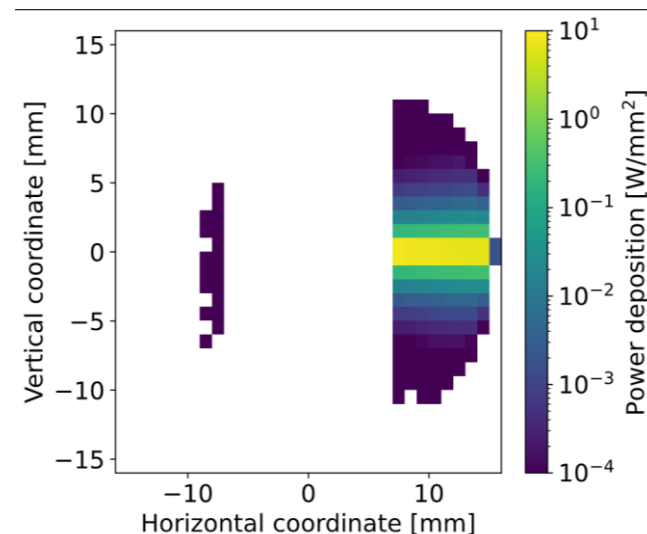
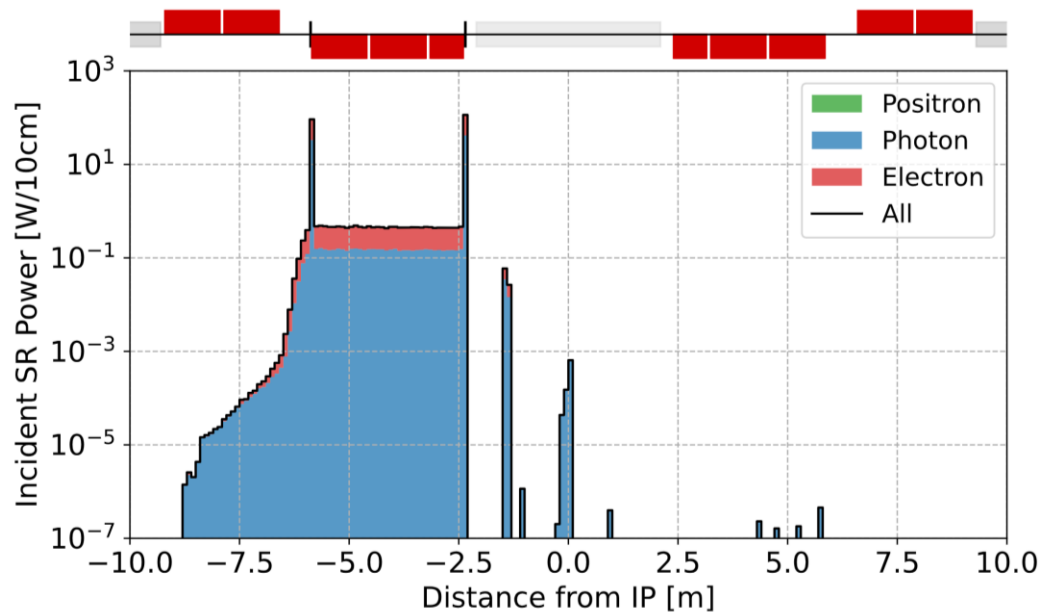


Detailed description on implementation in [Giacomo's talk at the last SR Task Force Meeting](#).

SR from beam core

Disclaimer
results obtained
without reflection

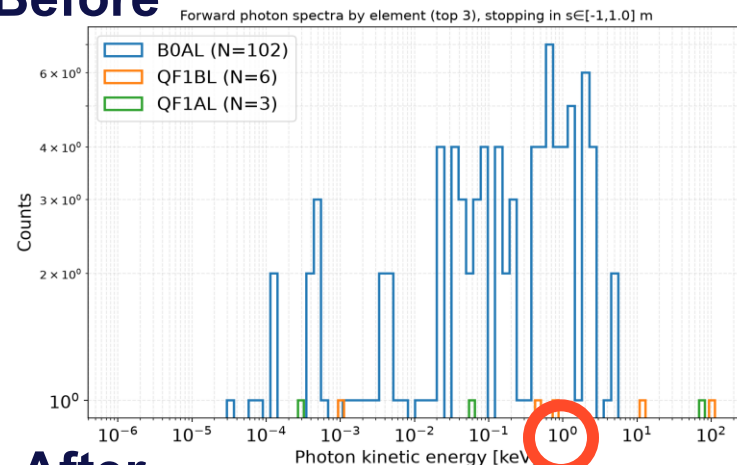
- No changes in the overall power deposited with the new sampling.
- Energy and pattern at the masks **have not changed**: **~100 W in QD0 mask** focused on one jaw.
- **2 orders of magnitude reduction at IP** with the new angular sampling $\leftrightarrow$ **recovered agreement with other codes.**



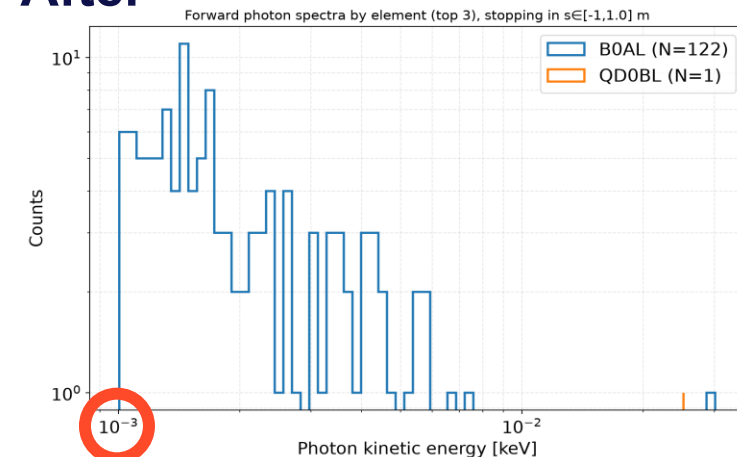
Background implication

- SR background from core should be significantly **suppressed**
 - **~2 orders of magnitude reduction in power** → lower hit rate in the detector
- **Energy spectrum of SR photons at IP is significantly different**
 - shifted by about **3 orders of magnitude** to lower energies
- With energy dependent sampling, **majority of photons with energies $\mathcal{O}(eV)$**
 - None of this will make it to the detector → **SR background from core expected to be fully suppressed!**

Before



After



Background implication

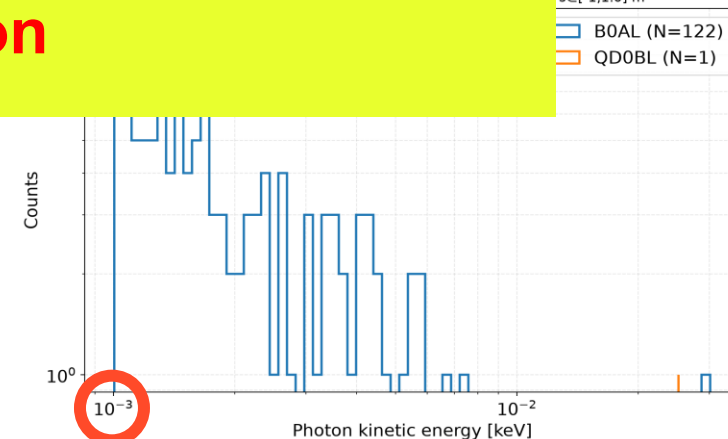
- SR background from core should be significantly **suppressed**
 - ~ 2 orders of magnitude reduction in power $\rightarrow$ lower hit rate in the detector
- Energy spectrum of SR photons at IP is significantly different
 - shift to lower energy of photons
 - or $\rightarrow$ SR background fully suppressed
- With energy dependent sampling, majority of photons with energies $\mathcal{O}(eV)$
 - None of this will make it to the detector $\rightarrow$ SR background from core expected to be fully suppressed!

Before

- SR background from core should be significantly **suppressed**
 - ~ 2 orders of magnitude reduction in power $\rightarrow$ lower hit rate in the detector
- Energy spectrum of SR photons at IP is significantly different

Good news for the background!

BUT results still need to be checked including xray-reflection

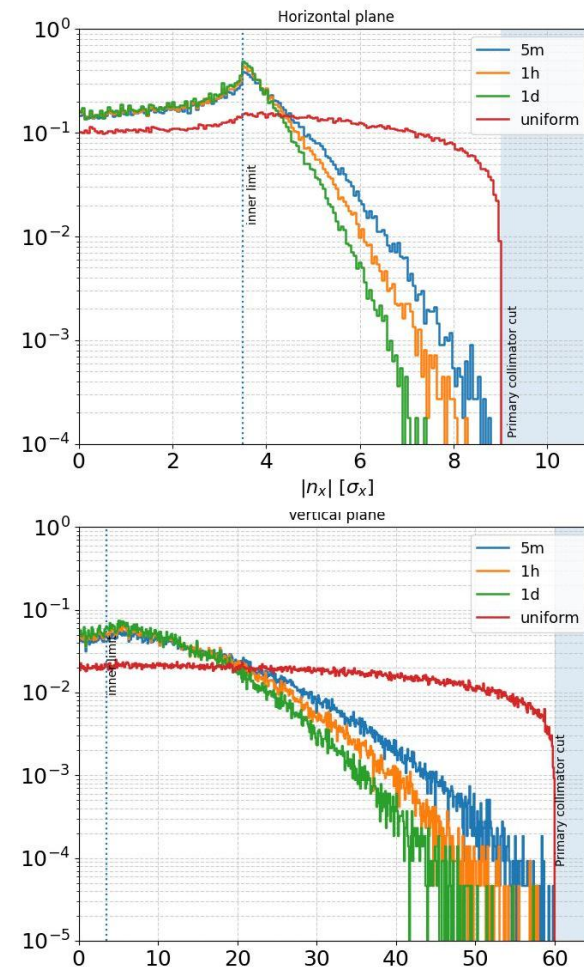




WHAT ABOUT THE HALO?

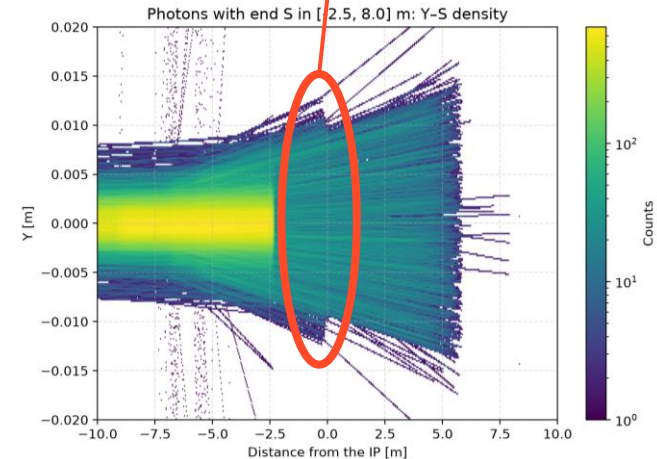
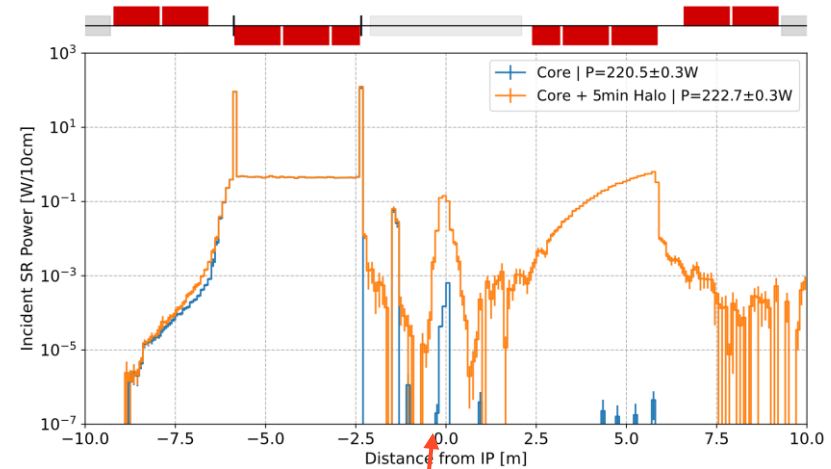
Halo modeling

- **Halo model crucial to estimate backgrounds.**
 - Work in progress to compare results between assumptions with Mike Sullivan.
- **Lifetime can be extrapolated from the halo distribution** ([Sands, 5.7](#)) → different lifetime will give different halo population.
- **Halo beam extends up to the primary collimator cut** and the **population exponentially decays** based on the chosen quantum lifetime (>1h at Z mode).
- **5 minutes lifetime is a pessimistic approximation** → gives an upper limit to the background levels.
- **Not a realistic model** as it does not include effects from beam-beam or beam-gas interactions – work in progress.
- **No significant changes expected with the new angular sampling**
 - SR is already primarily produced at large angles.



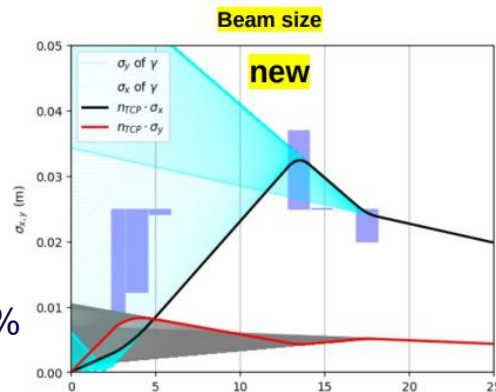
SR from beam halo

- As expected, no significant changes:
 - Power at IP about a factor 2 smaller than before
 - SR from dipole is now negligible.
- SR at IP increased by 2 orders of magnitude** by halo-5min lifetime wrt core
- Previous findings still valid:
 - Most of halo SR is **produced at the FFQ**
 - Fan diverging in vertical plane causes losses at IP
 - Main source of background – **still very problematic**
- **Mitigation strategy needed!**

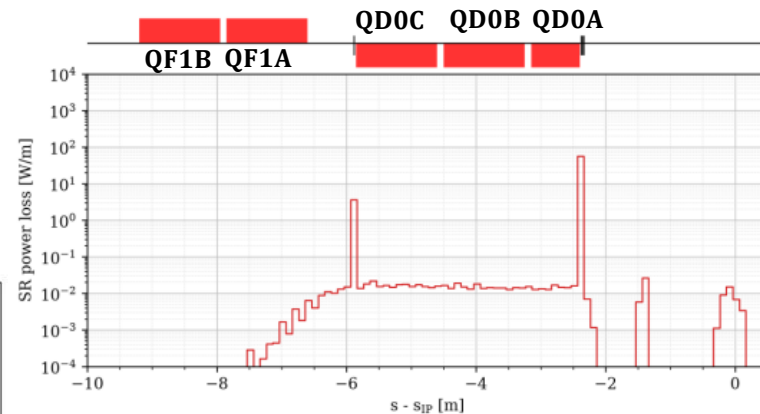


Alternative Final Doublet

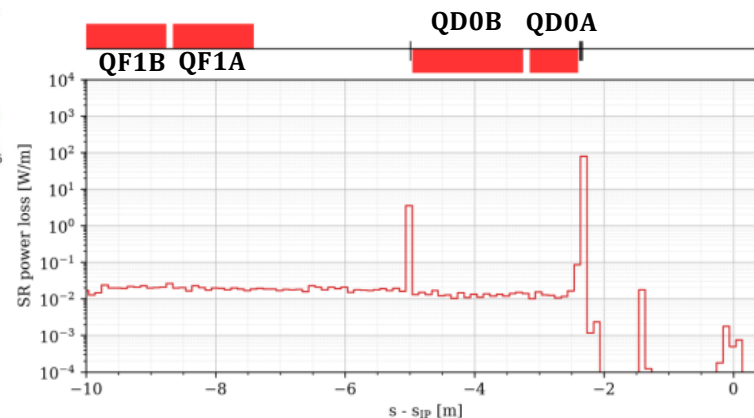
- Increasing QF1-QD0 separation can reduce the amount of direct hits at the IP
 - More info on the optics in [Marc's talk at the Task Force meeting](#).
- Layout:
 - QF1abcd repositioned
 - QD0b shortened, QD0c removed, QD0a +10% stronger
 - Hor. beam size at FD +10%
- Factor 10 reduction of SR from halo can be achieved for direct hits in the central chamber!**
- Almost no effects on SR from core.
- More info in [Giacomo's talk at the Task Force meeting](#).



Before

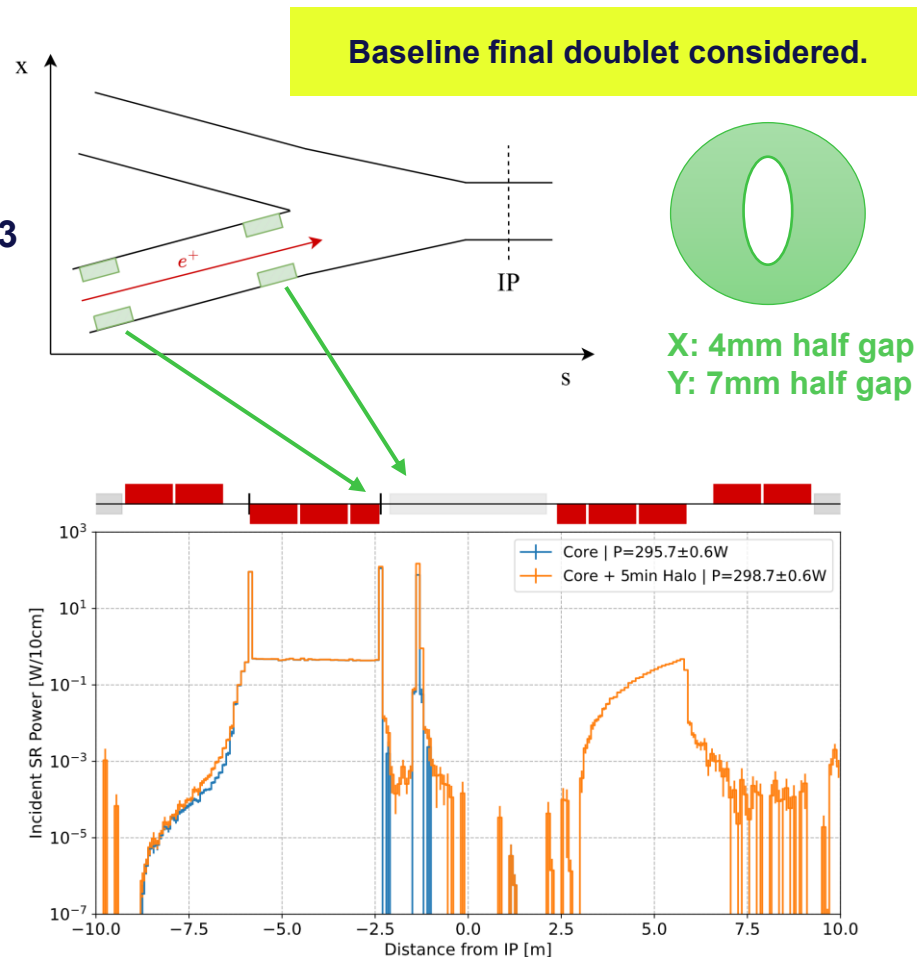


After



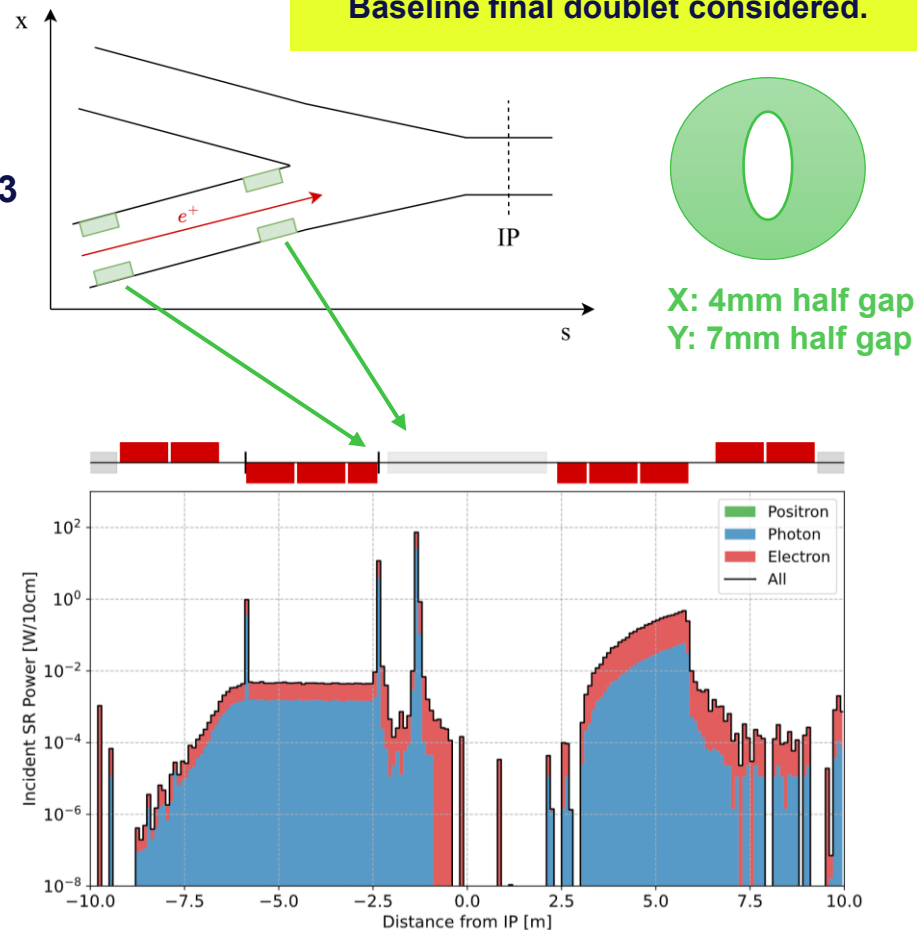
Additional masking

- As initially proposed by Pantaleo and investigated by Mike Sullivan, **a mask could be placed at ~ -1.3 m from the IP** to reduce direct SR hits.
 - More info in [Mike's talk at the Task Force meeting](#).
- SR at the IP mostly intercepted by the mask!**
 - No residual SR at IP from the core.
 - Massively reduced for the halo** by at least a factor of 100
- Not many shower generated at mask**
 - Photons mostly with $E < 100$ keV
 - Only photoelectric effect, with e^- immediately reabsorbed
- Next step: estimate detector occupancy.**



Additional masking

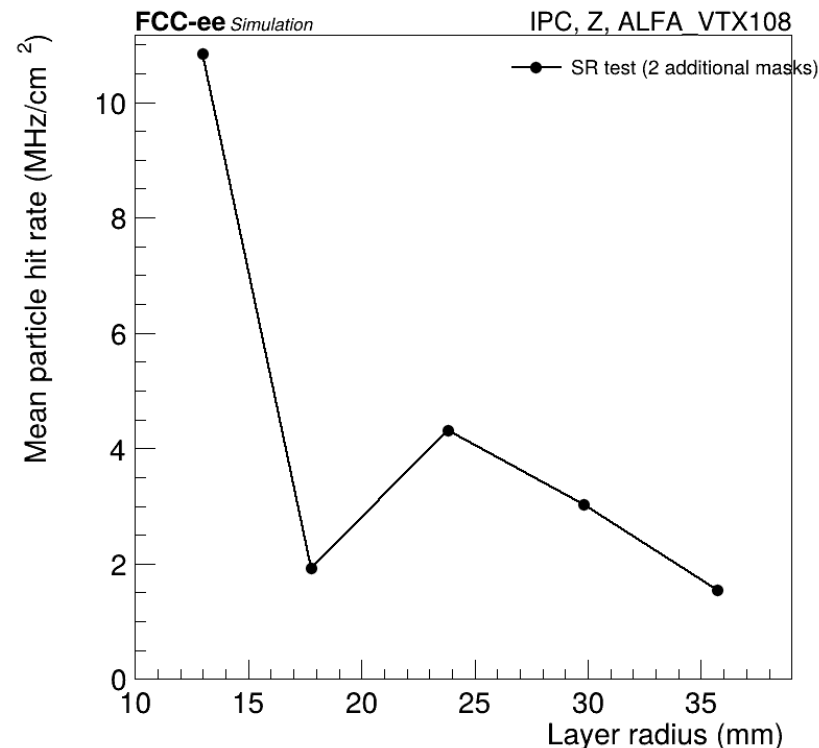
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Preliminary background results

Baseline final doublet considered.

- Halo samples produced for FCC week were processed again using the **shape-based MDI geometry** with the new mask at ~ 1.3 m
- ALFA vertex (thanks to J. Eysermans):
 - As expected, rate decreased by a factor ~ 100 !
 - SR is now at the level of the IPC.
- IDEA/ALLEGRO (thanks to A. Ilg):
 - Vertex $\mathcal{O}(1-10)$ MHz/cm² pixel hit rate
 - Silicon wrapper $\mathcal{O}(0.05)$ MHz/cm² pixel hit rate
 - Very promising results – **to be validated with higher statistics**
- Very effective for vertex detectors!
- Still to be investigated in the main trackers

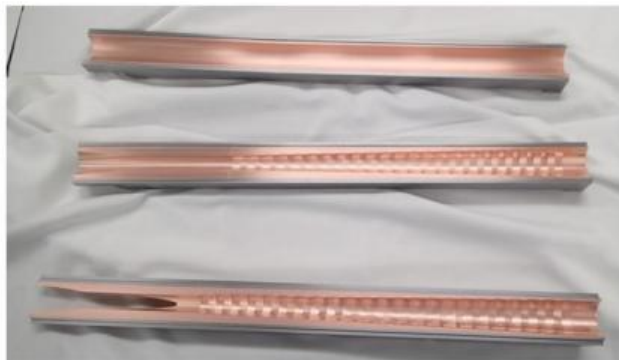
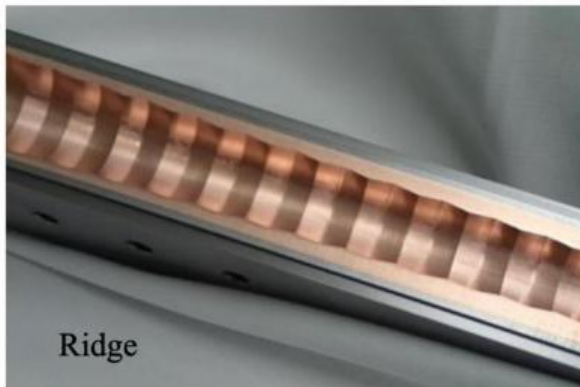


Courtesy of J. Eysermans

Corrugated beam pipe

- Undergoing studies within the vacuum group on efficiency of a **corrugated beam pipe à la SuperKEKB**
 - **Could help with the reflected component of the SR**
- The additional mask could also be integrated in the corrugated design.
- Synrad+ better suited for this study

IP chamber (Ta part manufacturing)



Conclusions

- Identified Geant4's SR angular sampling as source of discrepancies
 - **BDSIM SR loss maps now agree with FLUKA and SYNRAD**
- **Beam halo at the FFQs confirmed as the dominant source of SR background at the IP**
 - Halo SR at IP **~ 2 orders of magnitude above core** contribution
- Possible mitigation strategies:
 - **Alternative Final Doublet** (increased QF1-QD0 separation): **factor 10 reduction of SR from halo for direct hits in the central chamber**, with no effect on SR from the core
 - **Additional masking near the IP**: SR at IP mostly intercepted; **halo contribution reduced by at least a factor 100**
- **SR background at the IP can be significantly reduced with the proposed mitigations**
 - **Very promising results for the vertex detectors!**

Future steps

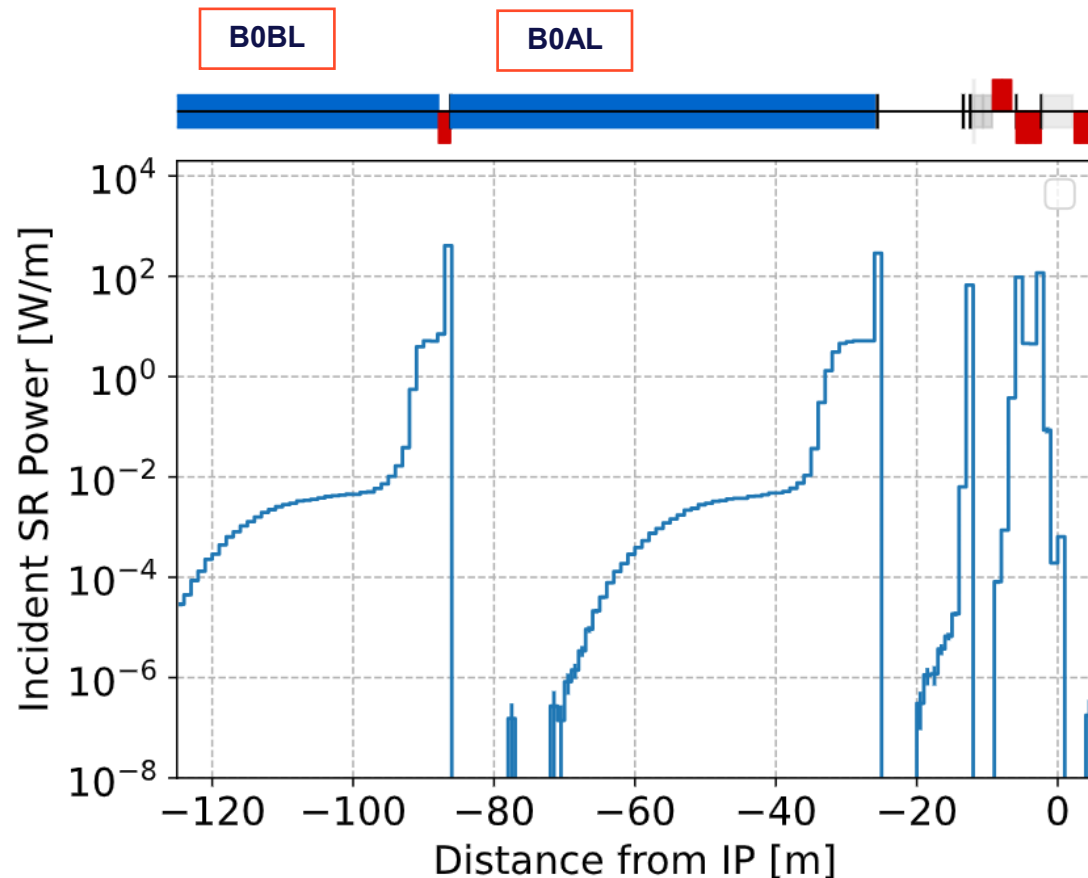
- Validate mitigation strategies in the detectors
 - New occupancies level can indicate the direction to follow
- **Investigate effect of reflection on these results**
 - **Possible mitigation under investigation already** – corrugated beam pipe, similar to SuperKEKB
- Investigate effect of the crotch
- Investigate mechanical and impedance implications of the mitigation strategies
- Explore combined Alternative Final Doublet + Additional masking for maximum SR background reduction
- Explore **Ultimate Final Doublet optics proposed by Pantaleo** ([see next talk!](#))
- Study SR at other energies to verify effectiveness of the strategy at all energies -- ongoing



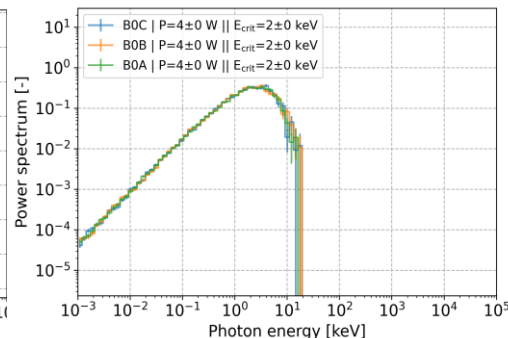
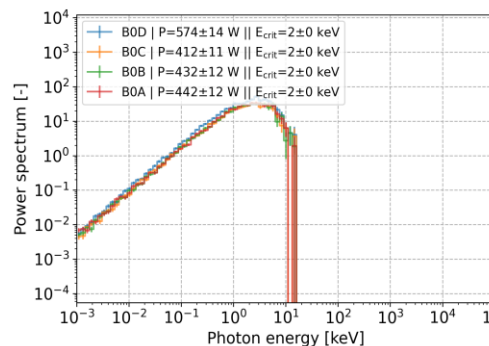
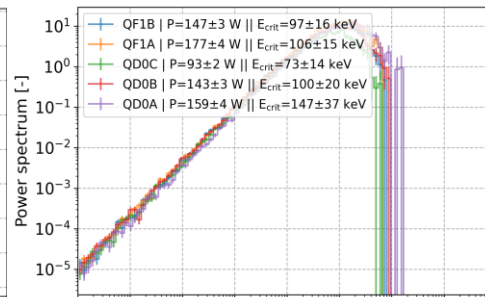
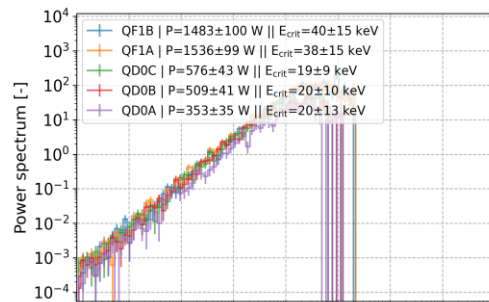
Thank you for
your attention!

SR from beam core

- Adopted parameters used by Synrad+ and FLUKA
 - $\varepsilon_x = 0.72 \text{ nm}$, $\varepsilon_y = 1.4 \text{ pm}$
 - Collimators aperture adjusted
- **SR that reach the IR is coming from the last dipoles (B0AL, B0BL for LCC) as expected.**
- **No changes in the overall power deposited.**
- **Loss pattern is different, mostly due to the new winglets.**



Spectra



core

halo