TID and fluence in the detector and IR

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Introduction

Motivation

- at FCC-ee high luminosity and beam intensity
- challenging radiation environment
- input essential for machine and detector design

Objectives

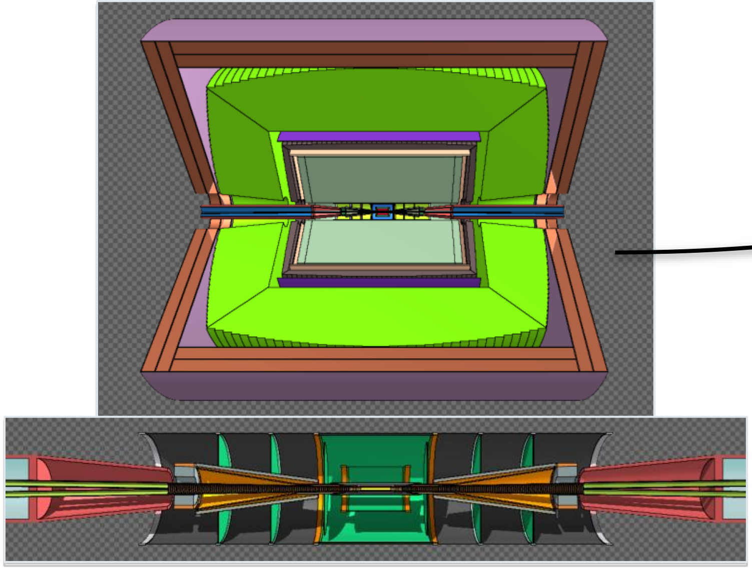
- FLUKA model of FCC-ee IR
- radiation levels of critical regions
- radiation load to critical components

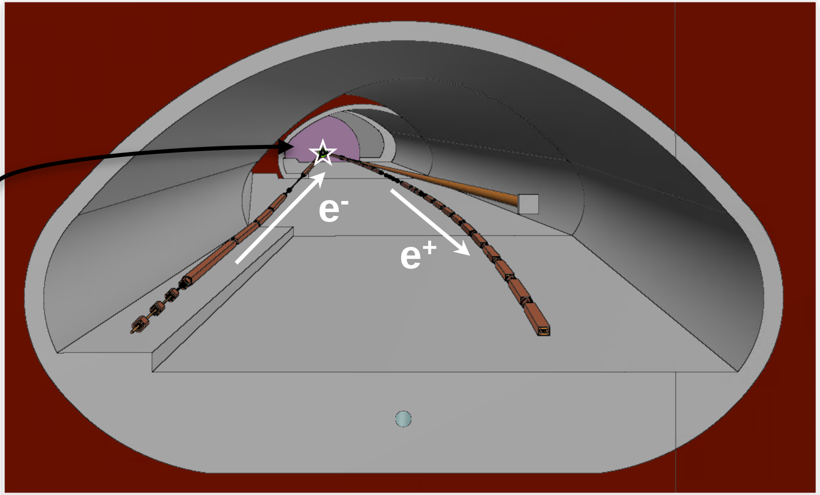
First results of total ionising dose (TID) and fluence in IDEA detector and update of tunnel radiation levels for Z pole operation

Outline

- FLUKA geometry
- collision-driven sources: incoherent pair creation and radiative Bhabha
- radiation load to detector
- beam-driven sources: beam-gas bremsstrahlung and beam-gas Coulomb scattering
- tunnel radiation levels
- radiation load to detector from beam-gas interactions
- conclusions

Geometry model





New IDEA baseline

- **crystal** DR ECAL (PWO)
- **iron** DR HCAL
- simplified vertex geometry with equivalent layers

IR up to 725 m from IP

- **e**$^{+}$ and **e**$^{-}$ beamlines (optics v24.4)
- tertiary and SR collimators
- SR masks

Detector magnetic field map

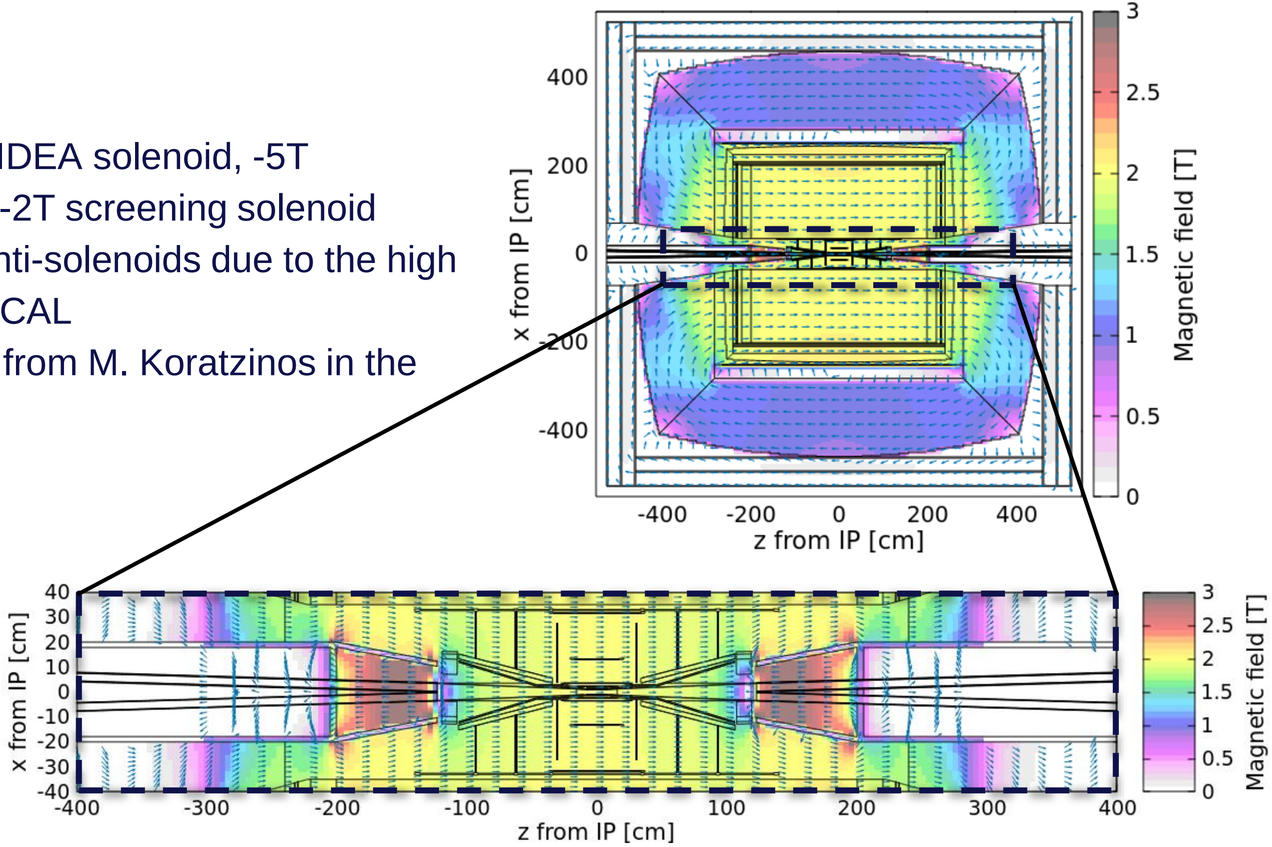
*courtesy of S. Mariotto

- full 3D field map integrated
- COMSOL simulation* of 2T IDEA solenoid, -5T compensation solenoid and -2T screening solenoid
  - required optimization of anti-solenoids due to the high field gradients from iron HCAL

→ hybrid map: combining map from M. Koratzinos in the central region

✓ -3T reached at the compensation solenoid

✓ field screened inside the cryostat



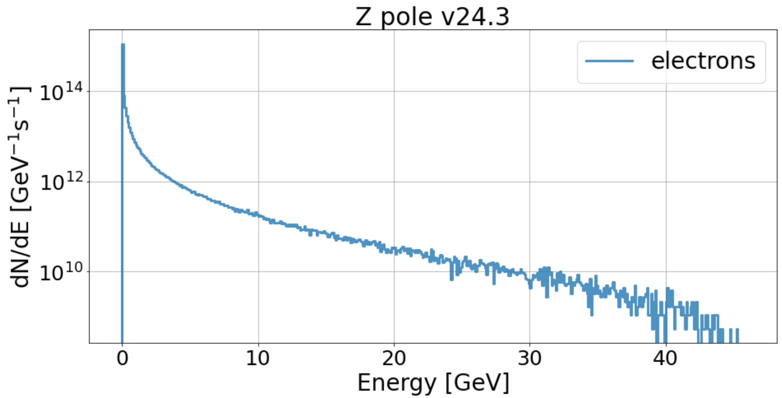
Radiation load to detector

Collision-driven radiation sources

*courtesy of A. Ciarma

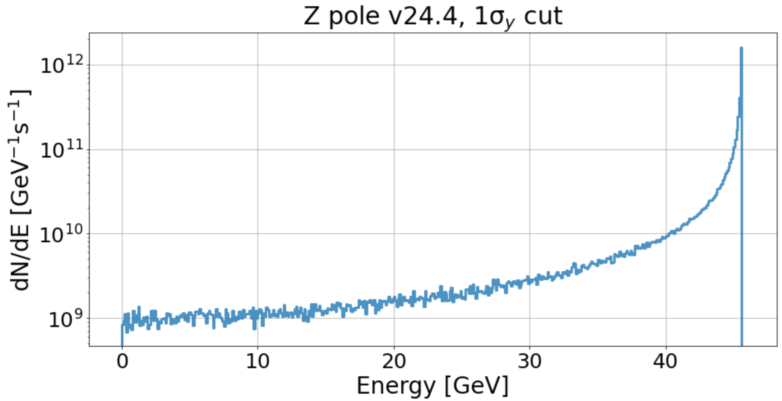
Incoherent pair creation (IPC)

- e^+e^- pairs from the interaction of both real and virtual photons from individual particles of two colliding bunches
- generated by GUINEA-PIG++*
- relevant for the the MDI and the detector



Radiative Bhabha (RB)

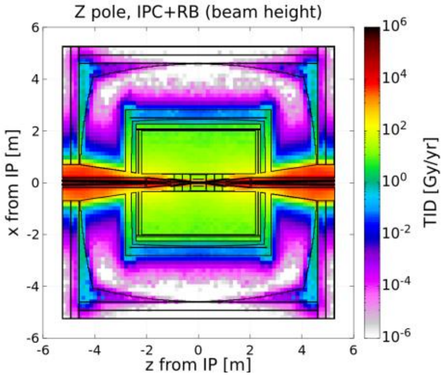
- e^+e^- scattering + emission of one or more photons
- BBBrem→RB events
  - cutoff in maximum interacting distance ($1\sigma_y$)
  - cutoff in minimum photon energy (50%, 7%)
- GUINEA-PIG++→smearing and beam-beam effects*
- relevant also for the forward tunnel region

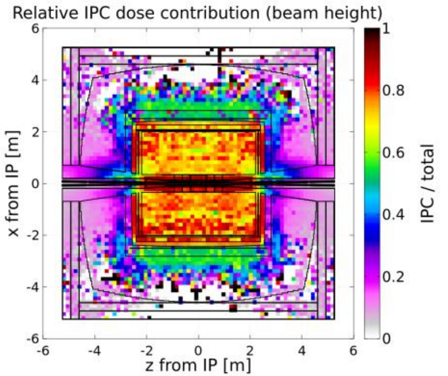


Radiation load to full detector (IPC + RB)

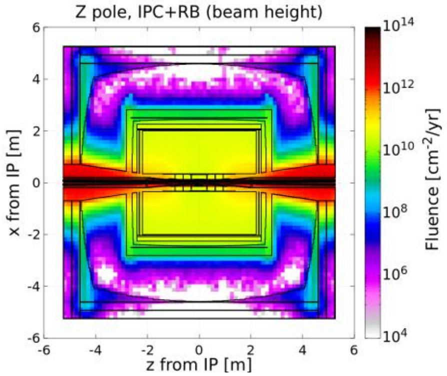
*1 operational year = 1e7 s
Luminosity = 145e34 cm^{-2}/s

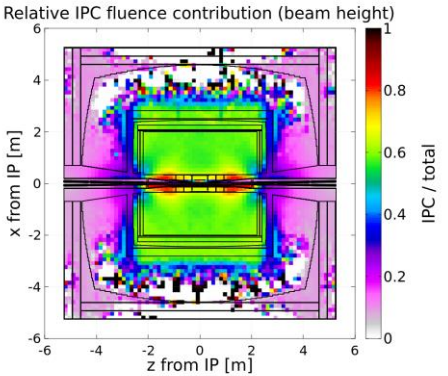
Dose





1-MeV n in Si eq. fluence





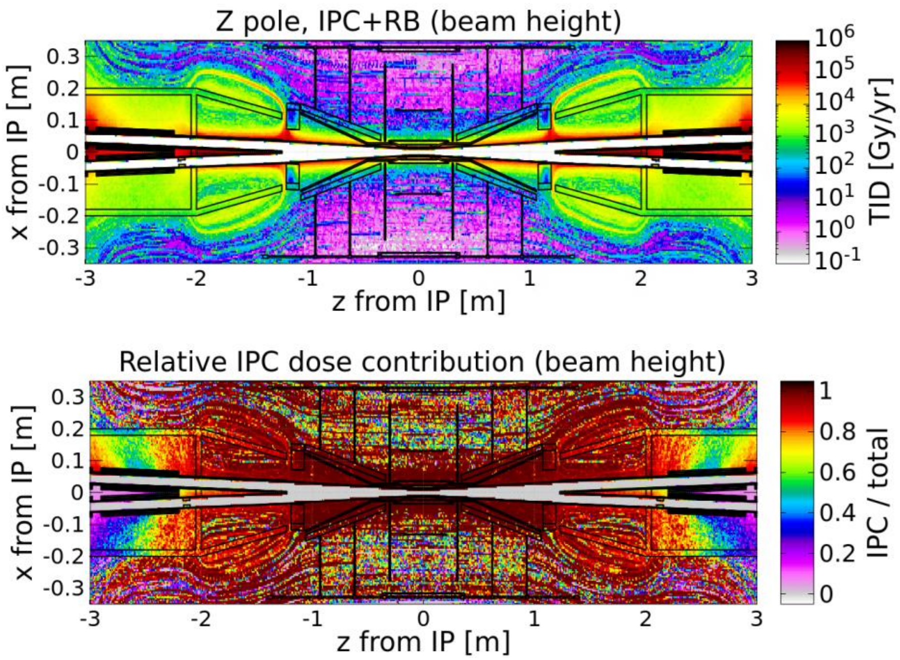
New results not covered in the FSR

	TID [Gy/yr*]	**Fluence** [cm^{-2}/yr]
drift chamber	~10	~10^{11}
crystal ECAL	~1	~10^{10}
iron HCAL	<1	<10^{10}

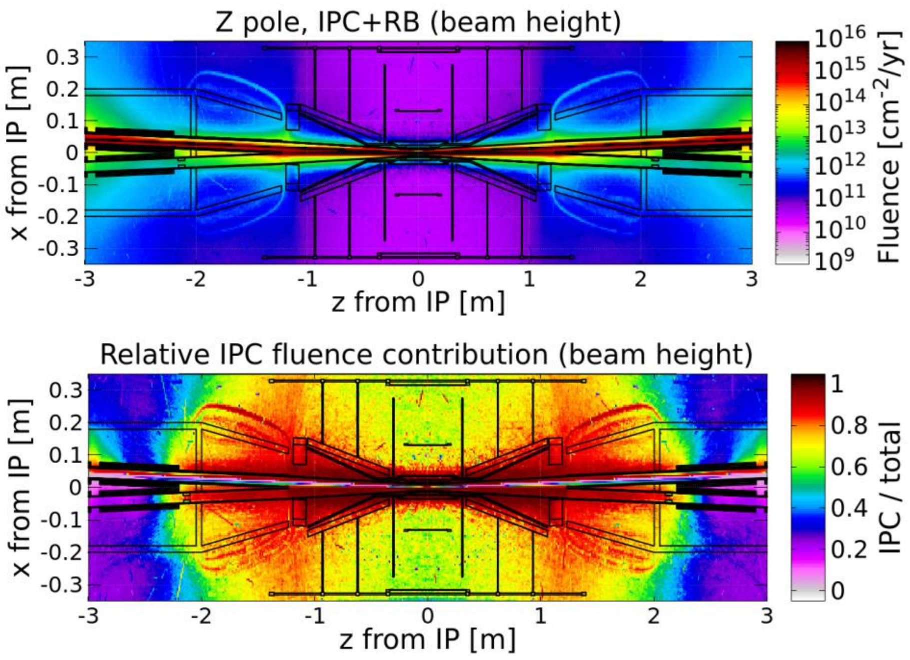
- IPC dominates up to the drift chamber
- RB dominant in the forward direction (HCAL endcaps)

Radiation load to vertex detector (RB + IPC)

Dose



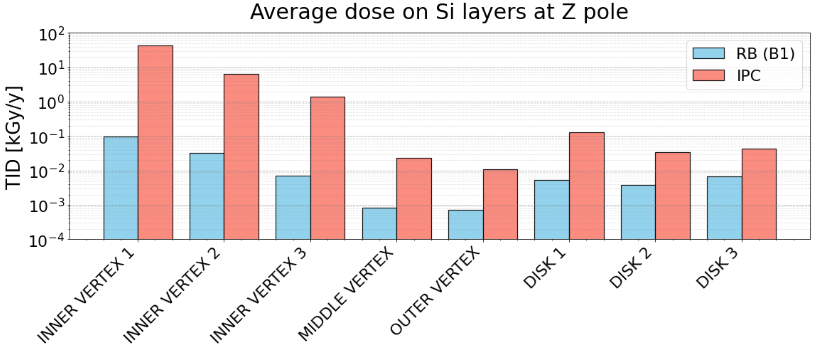
1-MeV n in Si eq. fluence

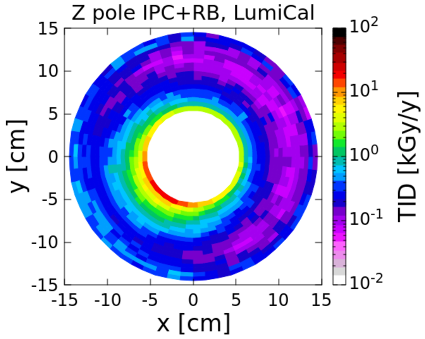


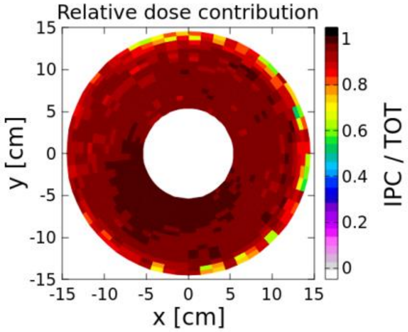
- IPC dominates the radiation levels on the VTX detector
- simulation extended to the full detector→important backscattering of neutrons from RB→increase in fluence

Vertex sub-detectors and LumiCal (RB+ IPC)

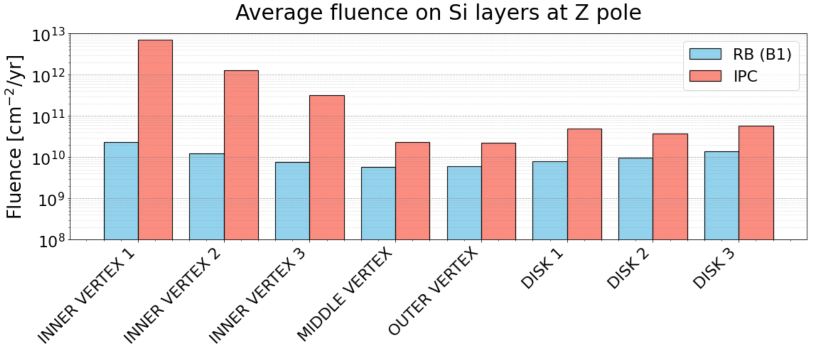
Dose

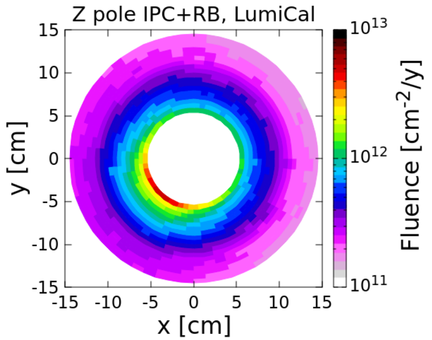


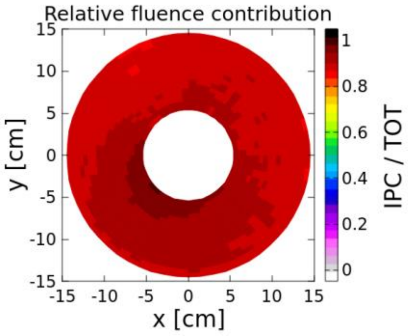




1-MeV n in Si eq. fluence





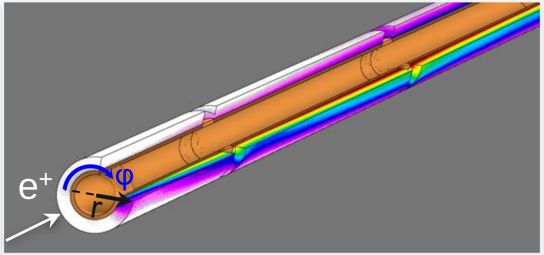


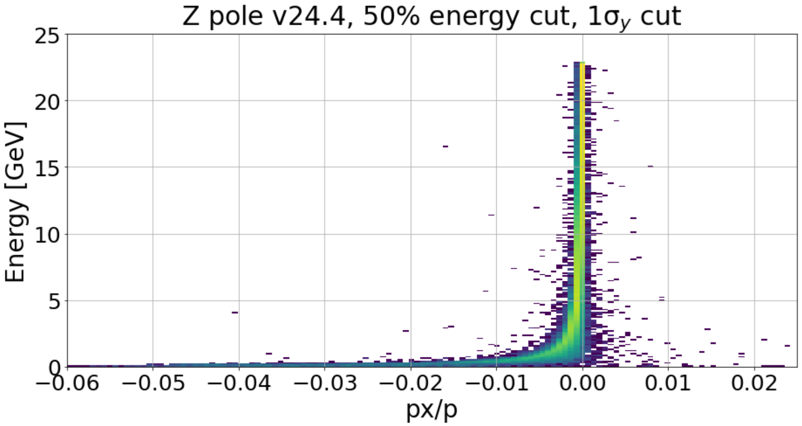
- IPC dominates the VTX radiation levels, with a larger relative fraction from RB in the disks

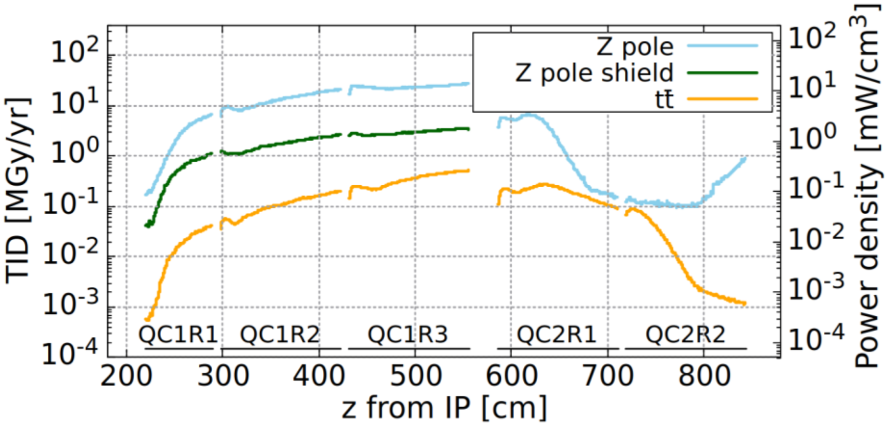
Radiative Bhabha impact on FFQs

Off-momentum e^+/e^- from RB cause localised losses in superconductive FFQs

- peak of TID and power density at $\varphi = \pi$
- risk of quench and radiation damage







- **peak values @Z pole:** 28 MGy/yr, 14 mW/cm^3, **ttbar:** 0.3 MGy/year, 0.2 mW/cm^3

→shielding needed, but **2 mm of W** likely enough (yields **3.6 MGy/y, 1.8 mW/cm^3** at Z pole)

Tunnel radiation levels

Beam-driven radiation sources at Z pole

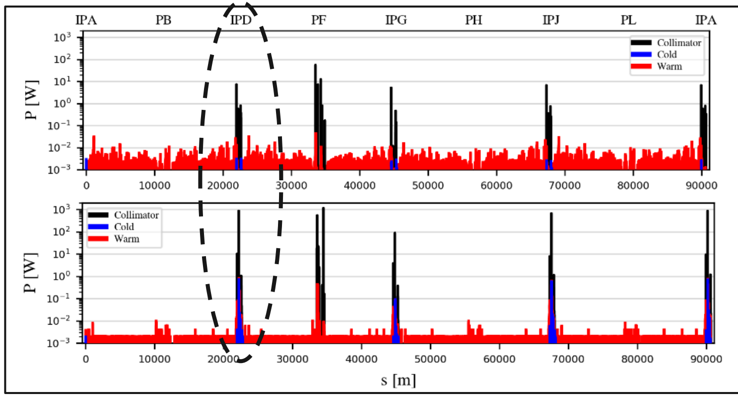
*SR is the dominant source at ttbar, see my talk at FCC week 2024

Synchrotron radiation (SR)

- soft photons (Ec=1-10 keV)→no impact on radiation levels*→neglected

Beam-gas interactions (BG)

- high beam current (1.29 A) @Z pole→more important than at the other modes
  - BG bremsstrahlung→photons and off-momentum beam particles
  - BG Coulomb scattering→small angular deflection, high cross section + limited DA



Beam-gas bremsstrahlung

- Estimated lifetime after only 1h of beam conditioning*: **274 min**
- Expected to increase to > 100 h in a fully conditioned machine

Beam-gas Coulomb scattering

- Estimated lifetime after only 1h of beam conditioning*: **41 min**
- Expected to increase to > 10 h in a fully conditioned machine

from talk by G. Broggi "Collimation studies for FCC-ee"

Other sources sources not discussed here (injection, Touschek..) see talks by G. Broggi and G. Nigrelli

Beam-gas source modeling in FLUKA

FLUKA sampling of BG bremsstrahlung

- photon emission + correction of particle momentum (target atom recoil neglected)
- position sampling
  - longitudinally: along beam orbit proportionally to gas pressure profile
  - transversely: matched beam
- normalization by integrated probability of interaction in the simulated s interval

↓

contribution from local BG events occurring in the FLUKA geometry

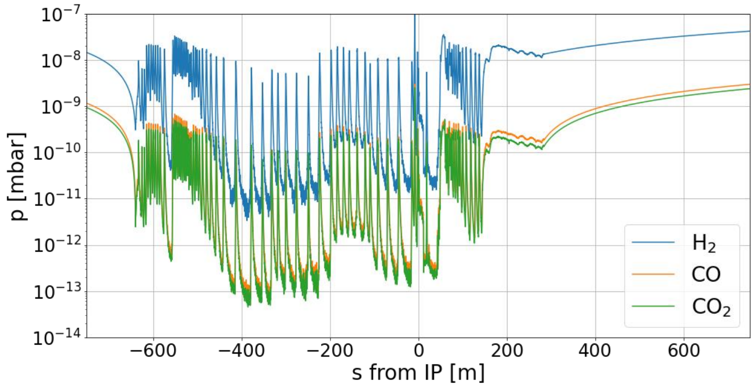
Loading collimator hit distribution

- loading into FLUKA particles impacting on collimator from multi-turn tracking
- normalization by collimator hit rate

↓

contribution from non-local BG events occurring all along the ring

- simulations based on **realistic pressure** and gas **composition** profile provided as input by vacuum group
- **pessimistic conditions**→1h beam conditioning, pressure is expected to condition down further (up to a factor ~100)



Local beam-gas bremsstrahlung FLUKA

*only electron hits on the collimators are plotted

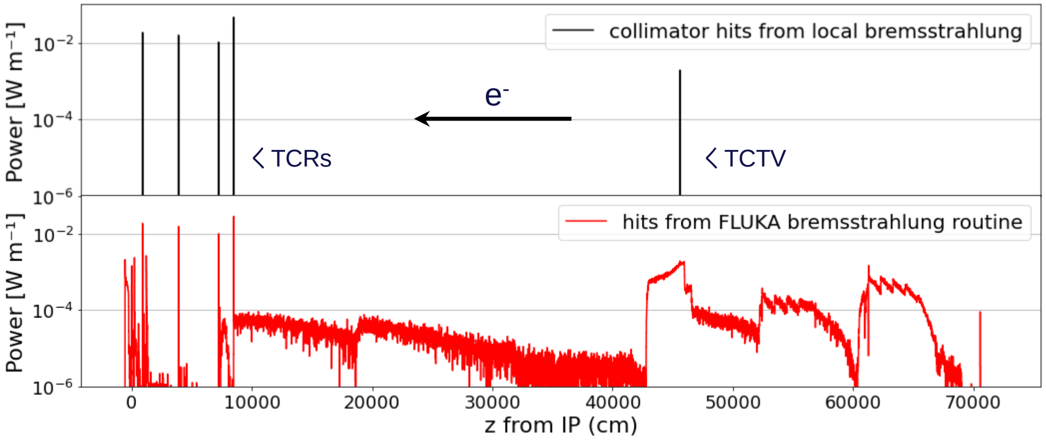
- hits from FLUKA routine match the hits on the collimators from local BG bremsstrahlung*

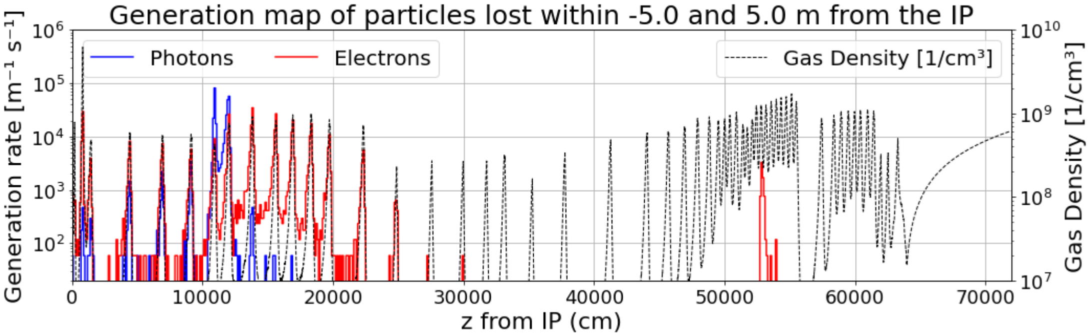
→ excellent agreement between the two models

- hits in the MDI (±5 m from IP) do not come from events further than ~250m upstream

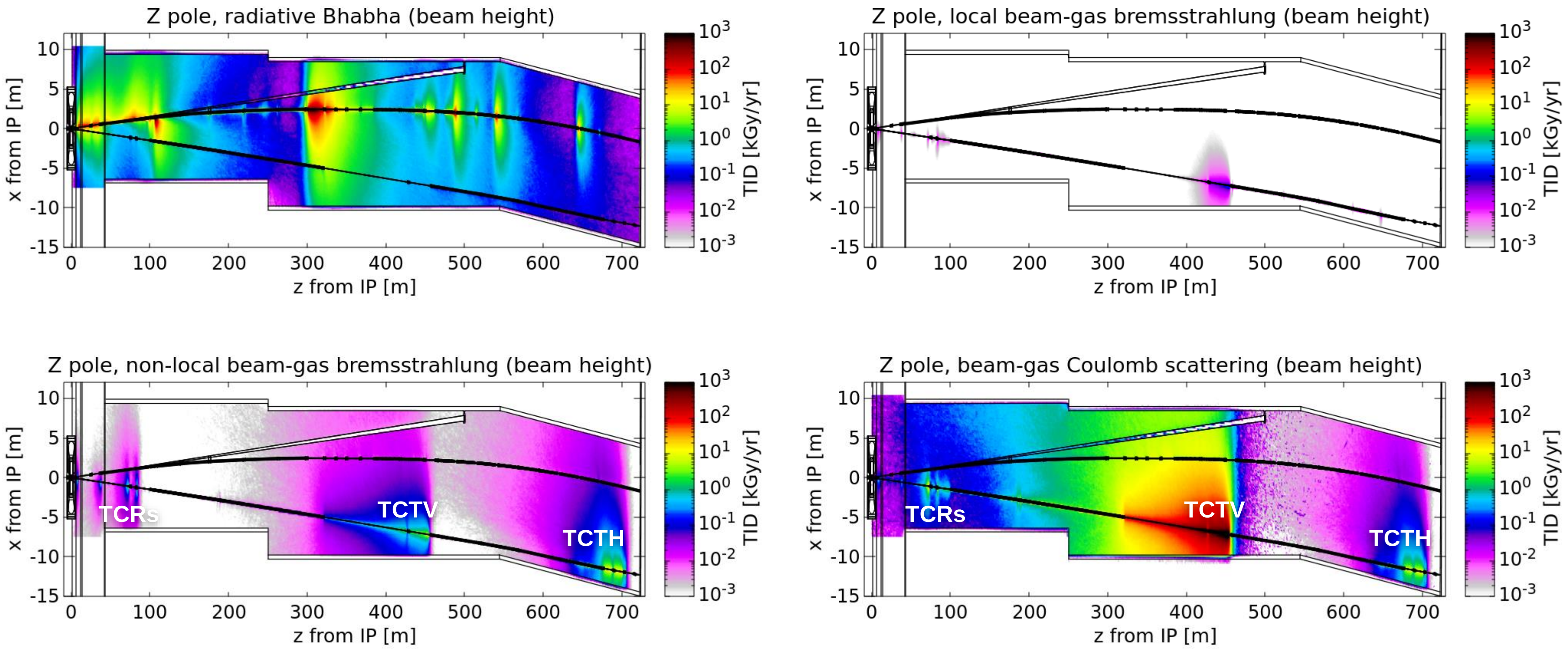
→ non-local BG bremsstrahlung contributes mainly with losses on the collimators

→ detector backgrounds should be estimated from secondary showers produced by <u>collimator hits from non-local bremsstrahlung</u> + <u>locally simulated bremsstrahlung in FLUKA</u>



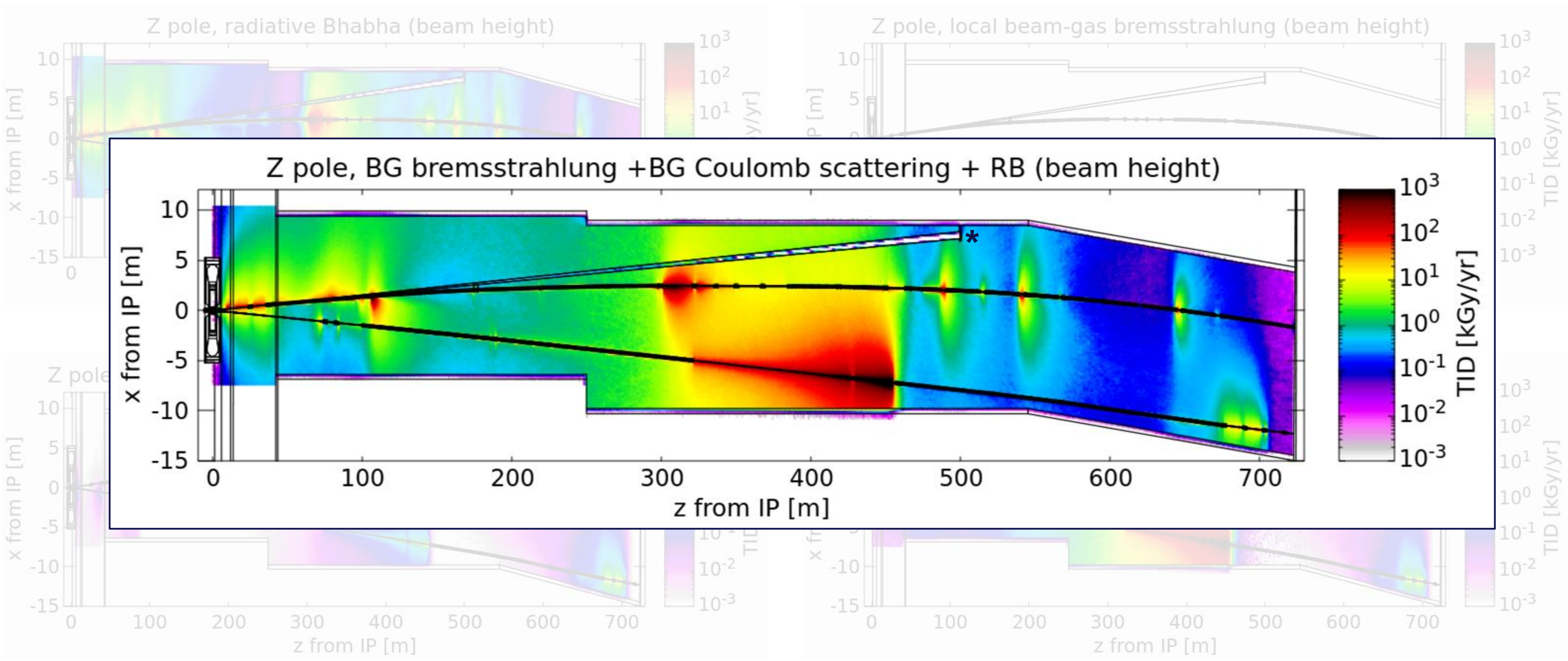


Tunnel TID levels (IPD)



Tunnel TID levels (IPD)

*beamstrahlung radiation neglected (shielding design under study by RP)



Beam-gas interaction contribution to detector

- beam loss mechanisms depend on many parameters with significant uncertainties at this design stage

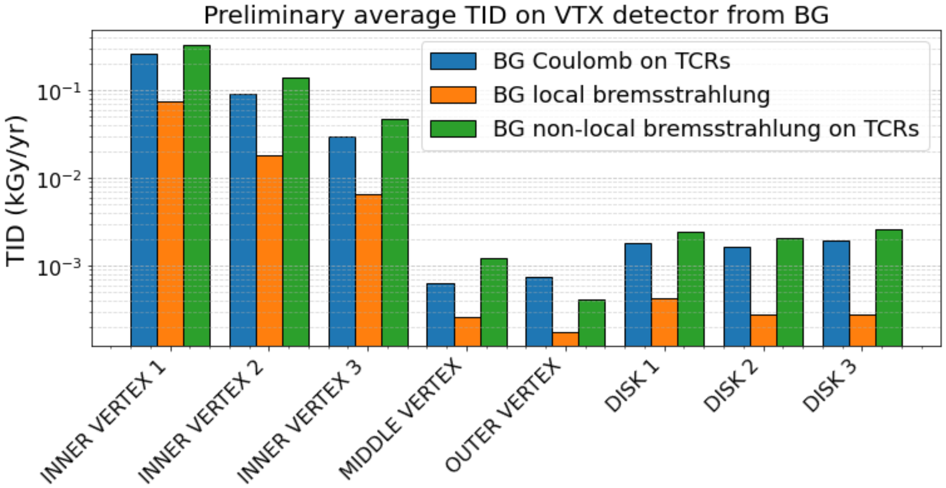
→ radiation estimates from beam losses carry higher uncertainties than those from collisional debris

Beam-gas bremsstrahlung

- contribution from TCTs negligible
- contribution from hits on TCRs (non-local) higher than local BG bremsstrahlung

Beam-gas Coulomb scattering

- contribution from TCTH negligible
- contribution from hits on TCRs comparable to BG bremsstrahlung hits
- contribution from TCTV difficult to estimate



Detector backgrounds

- workflow established to evaluate detector background from FLUKA simulations (see G. Nigrelli talk)

Conclusions

- developed FLUKA model of FCC-ee IR extending up to 725 m from the IP
  - IDEA detector geometry and its magnetic field map
  - B1 and B2 beamlines including TCTs, TCRs and SR masks
- first estimate of radiation load to detector from IPC and RB at Z mode
  - IPC dominates in the VTX detector (1 to few 10s kGy/yr and 10^{11}–10^{13} cm^{-2}/yr at inner VTX)
- studied a shielding to mitigate radiation load from RB to FFQs→2 mm tungsten around beam pipe
- setup a workflow to simulate collimator hits from multi-turn tracking simulations in the FLUKA IR model
- assessed the impact of local and non-local BG bremsstrahlung and Coulomb scattering in the IR for pessimistic operation conditions
  - updated tunnel radiation levels at Z mode
    - RB and BG Coulomb scattering hits on TCTV dominate with hotspots of 100 kGy/yr
  - first estimate of radiation load to vertex detector
    - ~ 1 kGy/yr on first inner vertex layer
- other beam losses to be studied (e.g. injection, multi-turn beam-beam, Touschek effect)
- the FLUKA model is ready to produce secondary dump files to be used for detector background studies

FCC

Backup

Radiative Bhabha power deposition in FFQ layers

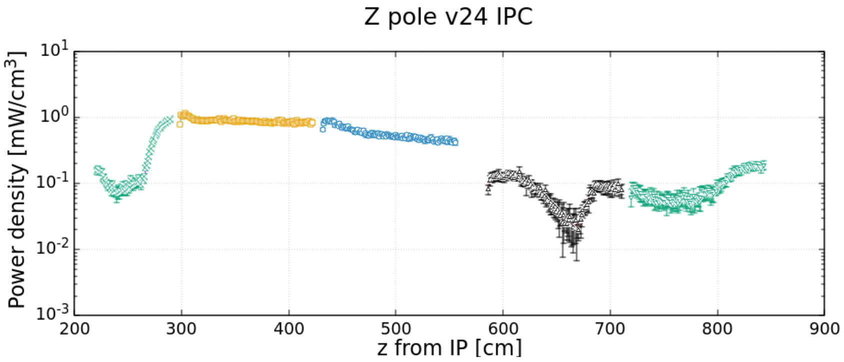
Magnet	QC1R1		QC1R2		QC1R3		QC2R1		QC2R2	
	Z pole	$t\bar{t}$	Z pole	$t\bar{t}$	Z pole	$t\bar{t}$	Z pole	$t\bar{t}$	Z pole	$t\bar{t}$
Gradient [T/m]	-40.8	-97.3	-29.5	-82.7	-19.4	-94.3	39.4	14.8	-0.00632	76.5
Al (I)	14 (3.7)	0.051	130 (26)	0.72	280 (52)	2.7	60	2.4	5.3	0.53
Coils (I)	33 (9.8)	0.15	300 (69)	1.9	650 (140)	6.6	150	5.8	12	1.3
Al (II)	5.7 (1.9)	0.029	52 (14)	0.36	110 (28)	1.1	30	1.0	2.1	0.26
Coils (II)	14 (5.4)	0.073	130 (39)	0.86	270 (81)	2.7	81	2.6	5.2	0.69
Total	66 (21)	0.30	610 (150)	3.8	1300 (300)	13	320	13	25	2.8

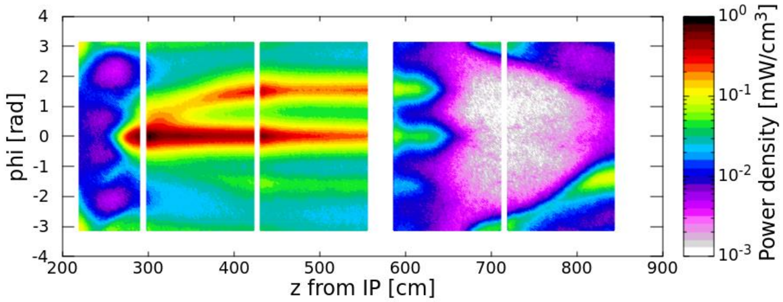
Power deposition in FFQ layers (mW) due to RB scattering at Z pole and ttbar simulated with FLUKA

- for QC1 segments at Z pole, values in parentheses represent power deposition with 2 mm-thick W shielding in place

IPC impact on FFQs

Power deposition density





Dose