FCCee detector design meeting,
CERN 19/06/2017

Experimental environment in the interaction region and luminosity measumerent

N. Bacchetta, M. Dams, K. Elsener, P. Janot, A. Kolano, E. Leogrande ,E.F. Perez, M. Sullivan, N.A. Tehrani, O. Viazlo, Y. Voutsinas

and many thanks to CLICdp group for the support

Outline

Introduction

Sources of Interaction Region (IR) background

Effect of background on vertex/tracking detectors

Luminosity measurement

- IR backgrounds on LumiCal

Outlook

Introduction & IR description

FCCee detector & Interaction Region

Very small ε_y^* (~pm), β_y 1mm, L* ~ 2.2m

- the final focus magnet elements are located inside the tracker's magnetic field
  - Need to be shielded
  - Shielding solenoid around the final quadrupole

Very short bunch spacing

- Crossing angle required for bunch separation
  - A compensating solenoid is placed in order to limit the emittance blow-up due to the crossing angle

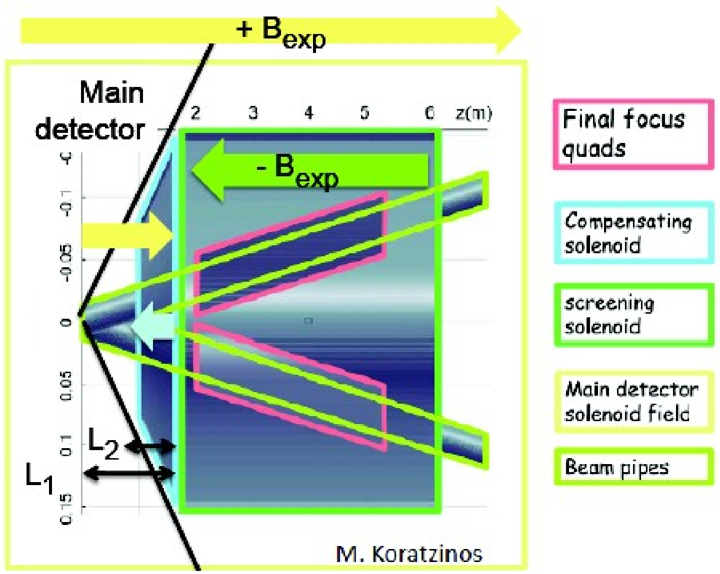
Rather limited space for forward instrumentation

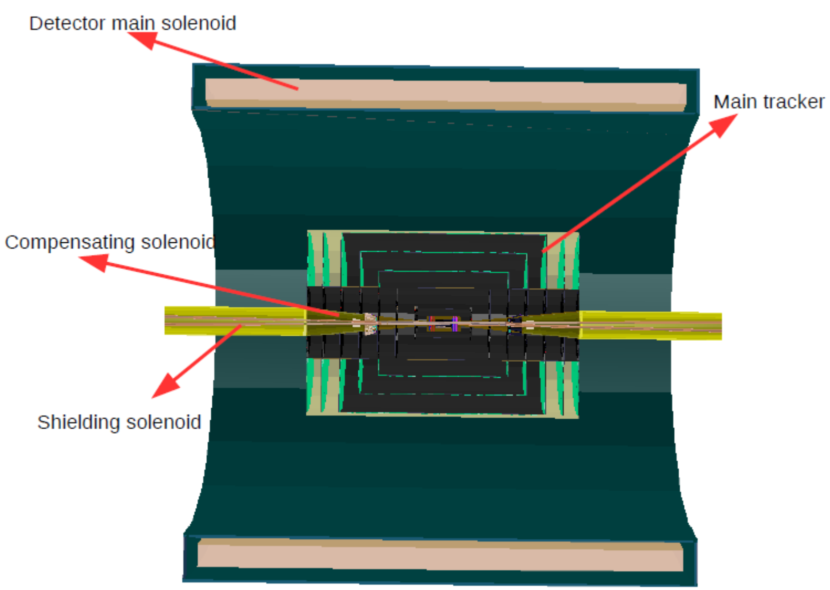
The IR design is meant to work for all FCC – ee energies: 45 GeV (Z), 80 GeV (W), 120 GeV (H) and 175 GeV (top)

2 detector designs exist

Results presented in these slides are obtained with a modified CLIC detector model placed around the FCC – ee IR and linear collider sw

- See Emilia's and Nilou's talks for the detector model





Sources of background

Sources of machine induced background

- Study of backgrounds on generation level

- Requirements imposed on FCC – ee IR design

Synchrotron radiation

Dictates the IR design and optics

Effect of SR can be partially suppressed by bending the beams after the IP & implementing proper masking / shielding

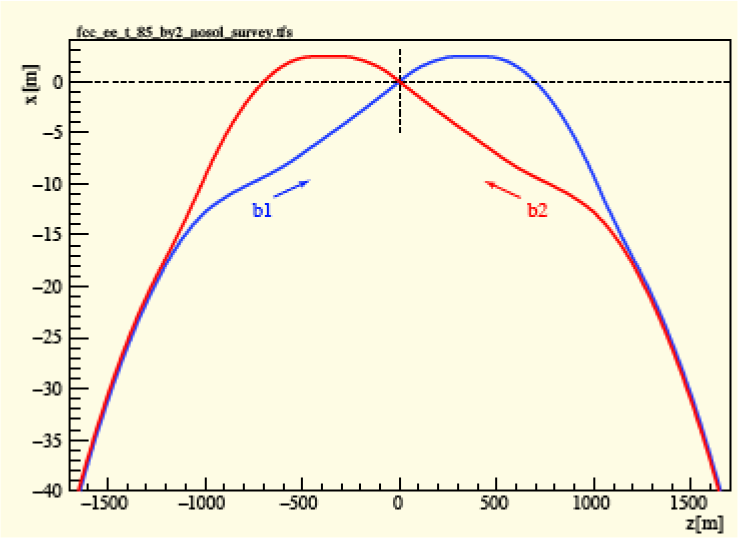
- Limits the amount of SR on the detector
- SR kept in LEP levels

For E_{cm} = 350 GeV, we expect billions of photons from the last bend

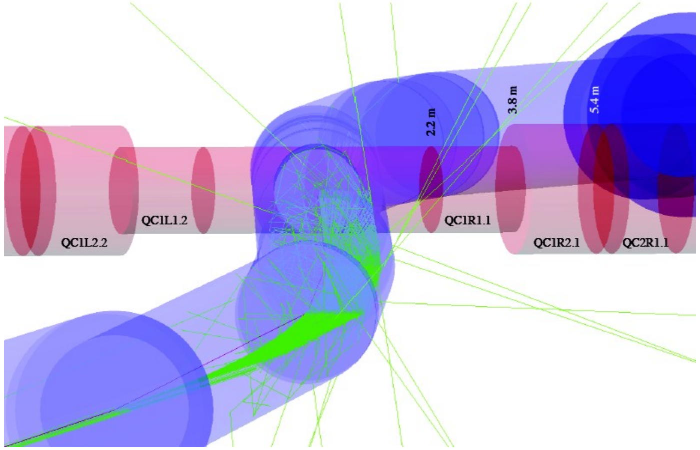
Proper masking and shielding required

- Simulations on going

For lower energies (Z) seems not to be an issue



From H. Burkhardt

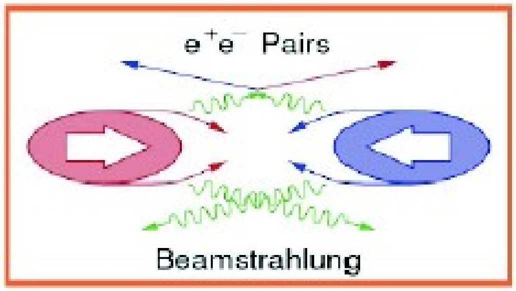


SR radiation obtained of G4 simulation of upstream beam line (H. Burkhardt)

e^+e^- pairs

Opposite bunches exert force to each other

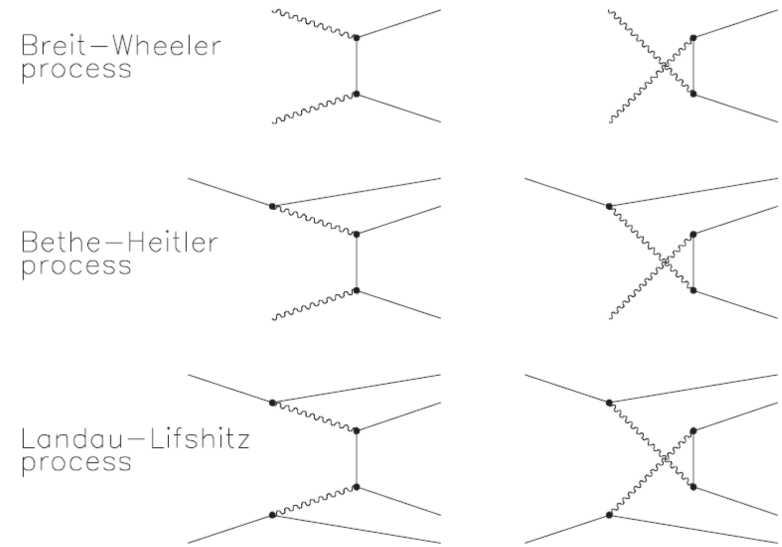
- production of hard bremstrahlung photons



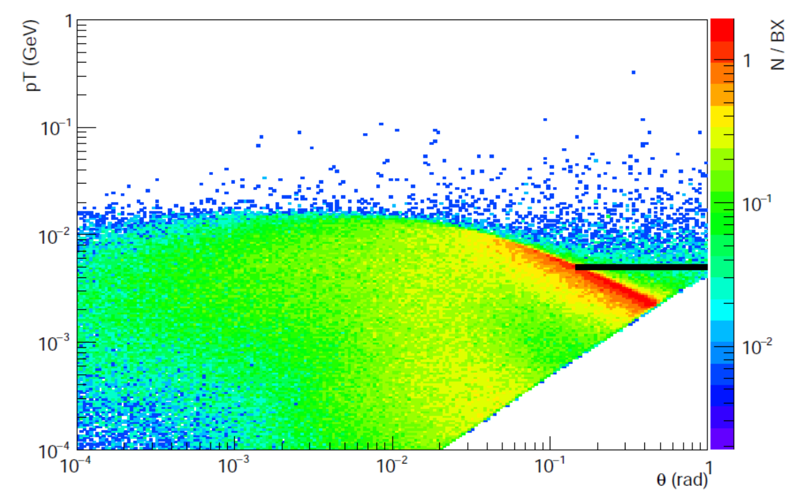
- Photon interaction with the collective field of the opposite bunch : Coherent Pairs Creation (CPC)
  - Strongly focused on the forward direction →negligible effect for FCCee
- Real or virtual photon scattering: Incoherent Pairs Creation (IPC)
  - Virtual γ scattering dominant

Mean energy of produced particles ~ 1GeV (tt)

Generation of samples using Guinea Pig



IPC creation (from D. Schulte thesis)



P_T vs θ for IPC in √ŝ for E_{cm} = 350 GeV. The black line indicates the 1st VXD layer

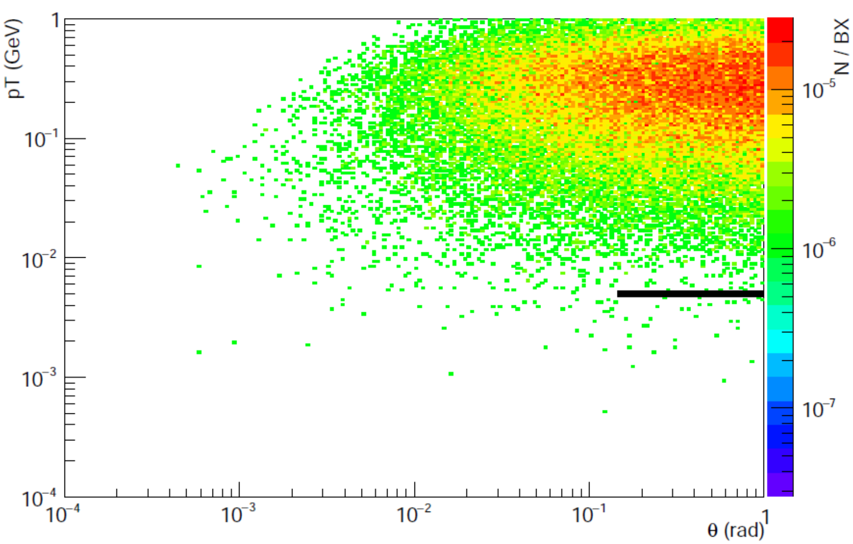
γγ to hadrons

Direct production of hadrons, or indirect, where one or both photons interact hadronically

Simulation with a combination of Guinea Pig and Pythia

- GP: energy spectrum of interacting photons
- Pythia: produces & fragments the partons

2 GeV threshold on E_{cm} of the 2 photons for hadron production applied in our simulation



P_T vs θ of hadrons after pythia fragmentation

Hadronic events per BX	
√ŝ (GeV) of interacting photons	Number of events
>2	0.004
>5	0.002
>10	0.001

The effect of this background is expected to be small

IR optimisation vs IR backgrounds

IR design driven by Synchrotron Radiation (SR) considerations

- SR in particular defines the beam pipe radius, position of masks and shields

Mask shields the detector from direct hits

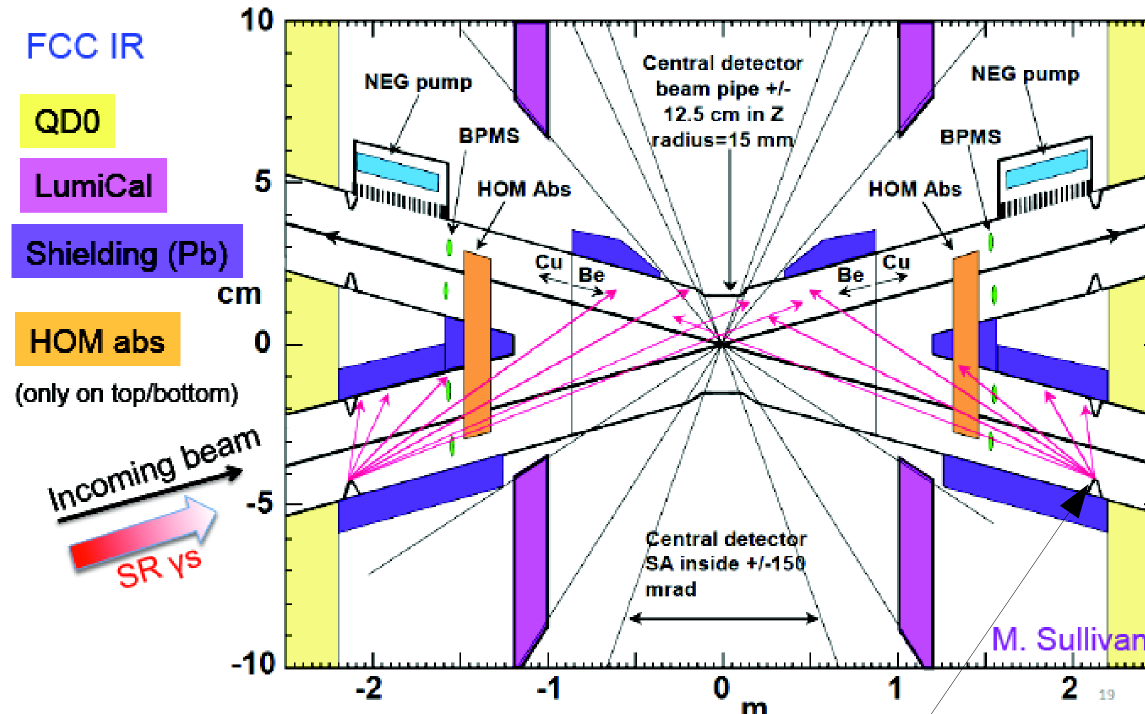
- Relevant surviving photons are those emerging from the tip of the mask

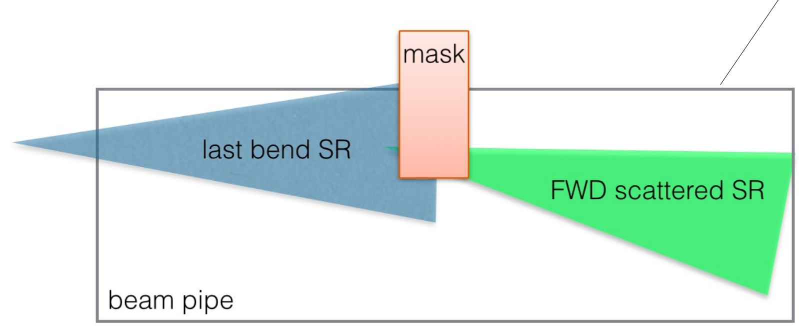
Pb (or Ta) limit the amount of SR reaching the IR

- Window left in front of LumiCal in order not to degrade the energy resolution

5 μm Au layer coating on the central section of the beam pipe

- Absorbs photon & reduces heat on BP
- Au sufficiently thin in order not to degrade the impact parameter resolution





SR from last bend intercepted by the mask
We study photons emerging from the mask

Comparison with 3 TeV CLIC

Comparing FCC E_{cm} 350 GeV with CLIC 3 TeV (worst cases for the 2 machines)

Beamstrahlung mostly defined from space charge density

- Linear colliders: need for very small bunches in order to maximise luminosity
  - Enhanced beamstrahlung effect

Synchrotron radiation not an issue for linear colliders

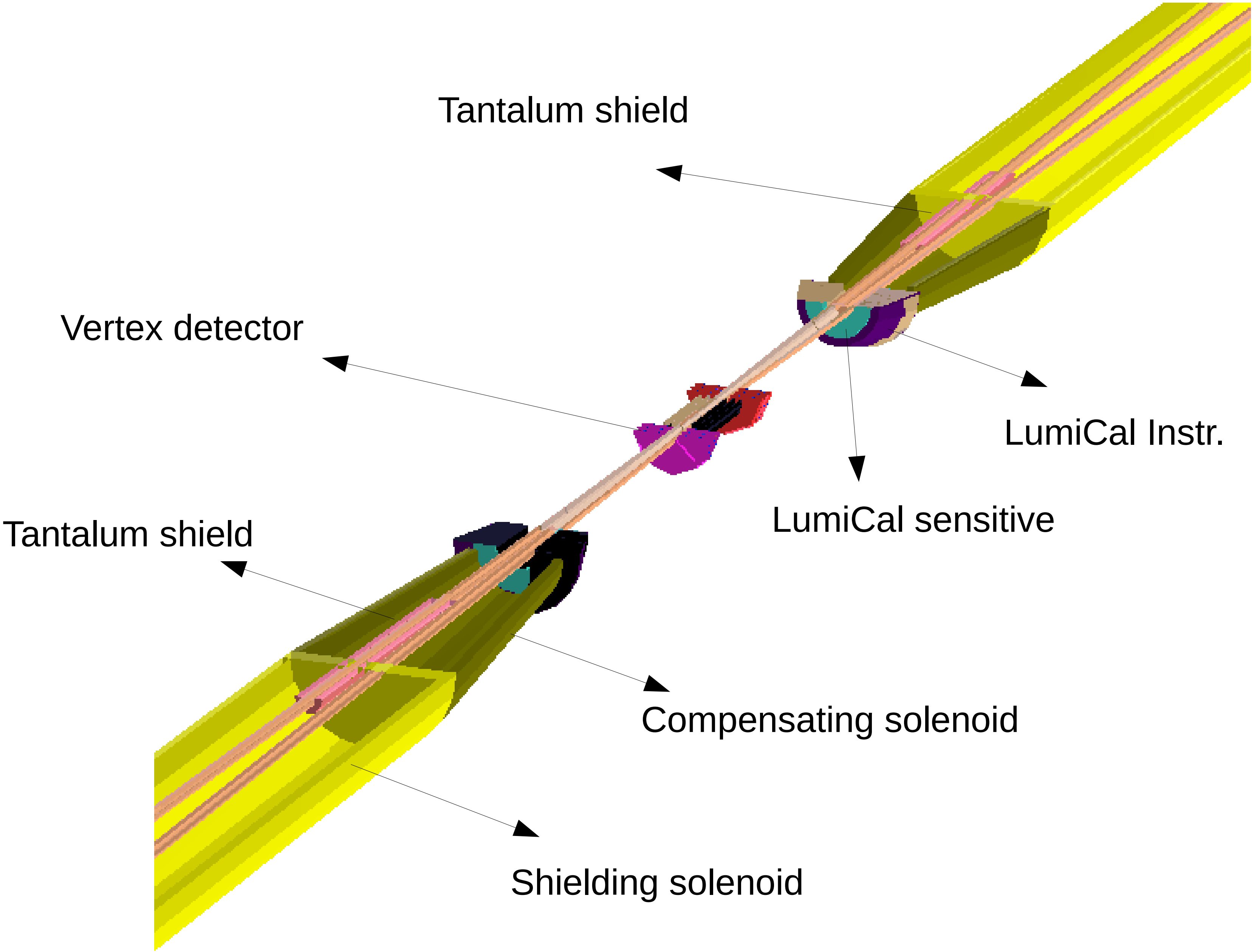
Source	CLIC 3 TeV*		FCC 350 GeV	
	particles / BX			
	total	P_T > 20MeV‡ θ > 7.3^0	total	P_T > 5MeV θ > 7.6^0
IPC	$3x10^5$	60	2600	33
CPC	$6x10^8$	0	0	0
hadrons	102	54	0.05	~0.05
Syn. rad			~$5x10^6$ †	

† scattered from the tip of the mask per beam

‡The minimum required for a particle to reach the innermost VXD layer

* From LCD-2011-021

Geant4 description of IR



Impact of machine induced background on the detector

Full simulation studies of effect of various IR backgrounds on the FCC – ee subdetectors (CLIC-based det. model, ILCSoft)

- Estimation of hit density / occupancy / deposited energy on the subdetectors due to bkg hits
- Data rate considerations
- Evaluation of radiation damage on the sensors

In the following slides we focus on E_{cm} = 350 GeV

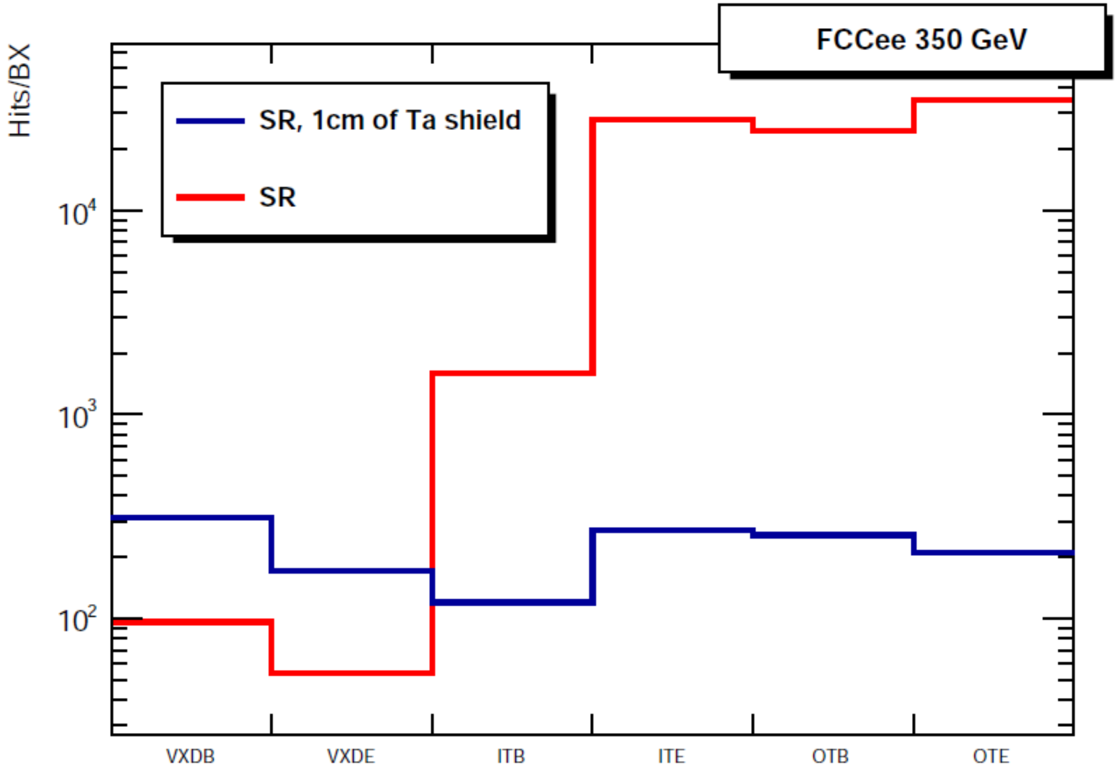
- Most unfavourable case in terms of bkg hits / BX
- However we should stress the very short bunch spacing at the Z working point

Effect of SR

Full simulation study of the last bend photons scattered from the tip of the mask

Focus on E_{cm} = 350 GeV

- ~5x10⁶ scattered photons per beam expected
- SR is the dominant source of background on the detector
- However proper shielding could substantially suppress the effect on detector



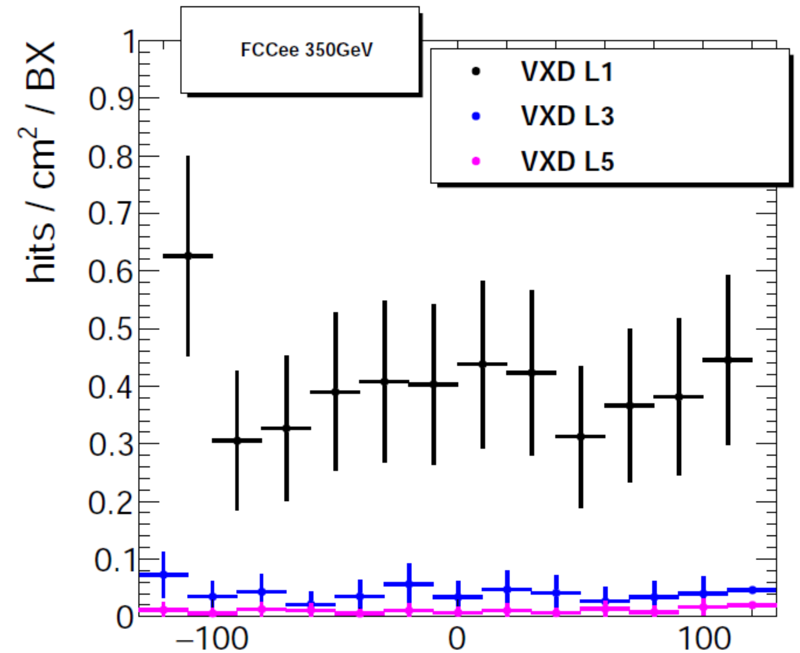
Effect of e^+e^- pairs on detector

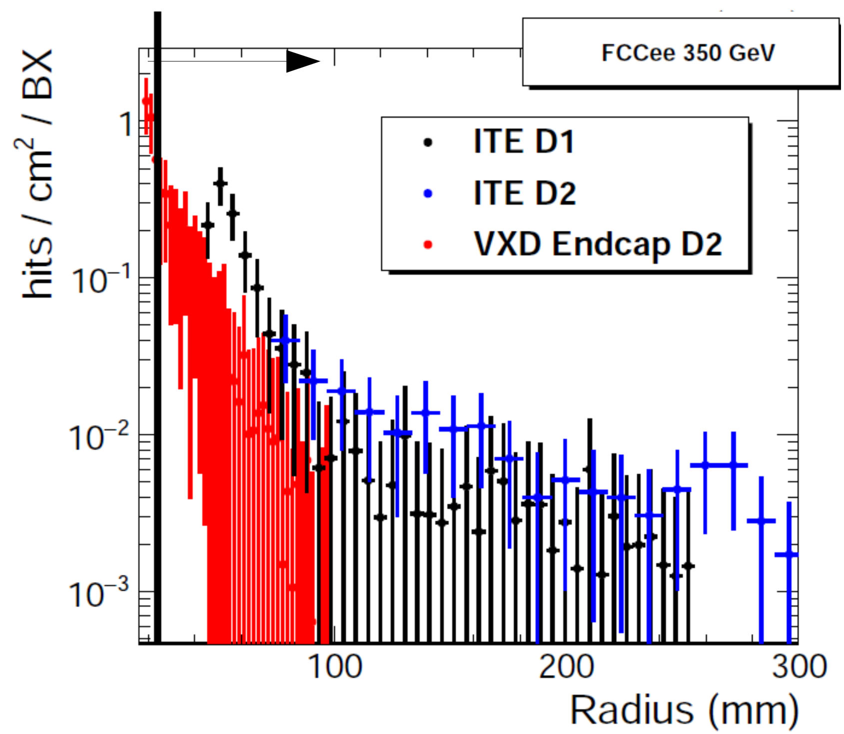
Pairs generation with Guinea Pig

Full simulation studies using DD4hep ILCSoft (geant4 based simulation) / ILCSoft

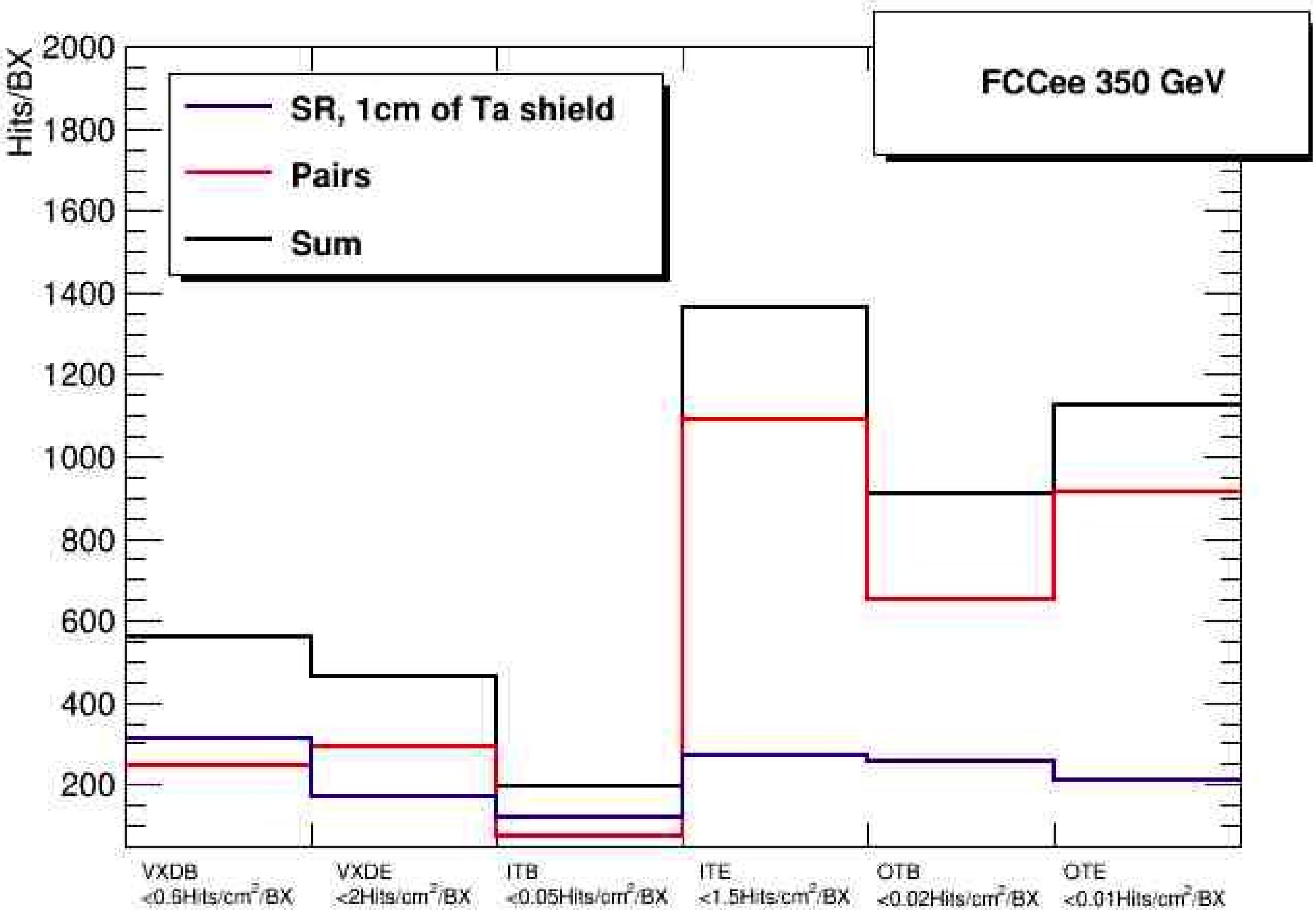
Assuming a pixel pitch of 20μm and an average cluster size of 5

- Occupancy/BX ~ 10^{-5} for the hottest areas
- For E_{cm} 91.2 GeV
  - Maximum occupancy ~ $2x10^{-6}$ observed in VXD Endcaps
  - However note the very short bunch spacing of ~ 3ns
  - For example: a sensor with readout time of 3μs would integrate over 1000 BX
  - Occupancy / r.o. time ~ $2x10^{-3}$





Combined effect of SR and pairs



The maximum hit density obtained in the hottest area of each subdetector is noted in the plot

Luminosity measurement

Luminosity measurement & requirements

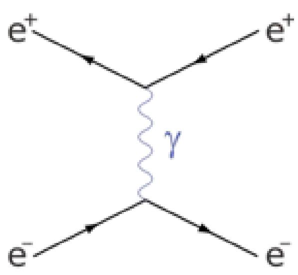
Impact of machine-induced backgrounds on luminosity measurement

- On going study - preliminary

Luminosity monitoring with Bhabha scattering

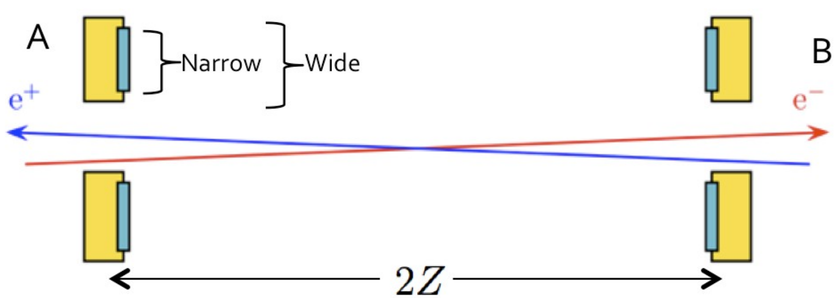
Luminosity monitoring:

- **Absolute** – target precision $\mathbf{10^{-4}}$
  - May be best achieved through the process $e^+e^- \to \gamma\gamma$
- **Point to point** for Z lineshape measurement – need a relative precision of **2-5 x $\mathbf{10^{-5}}$**
  - Need cross section comparable to Z production:, i.e. ≥ 15 nb
  - Can be achieved via **small angle Bhabha scattering $e^+e^- \to e^+e^-$**
    - Very strongly forward peaked – control of angular acceptance very important



$$\sigma^{\text{Bhabha}} = \frac{1040 \text{ nb GeV}^2}{s}\left(\frac{1}{\theta^2_{\text{min}}} - \frac{1}{\theta^2_{\text{max}}}\right)$$

    - Measured with set of two calorimeters; one at each side of the IP



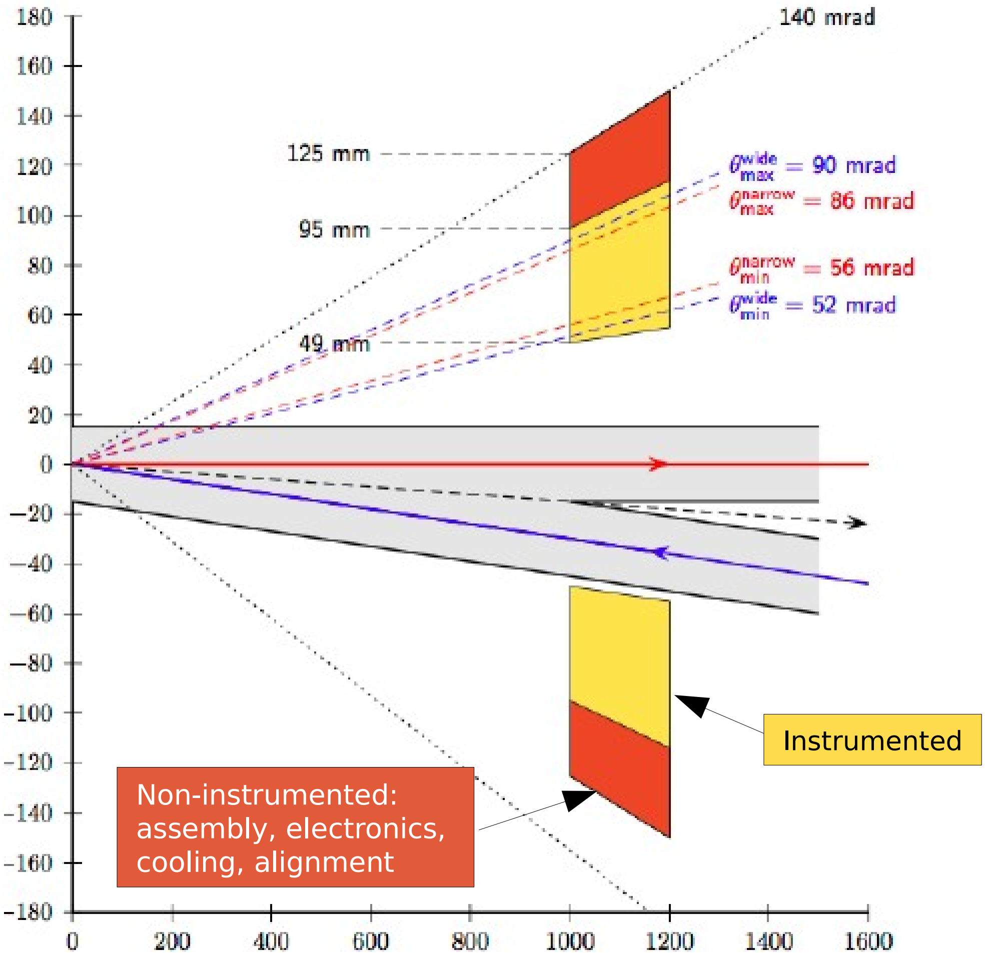
Two counting rates:
- SideA = NarrowA + WideB
- SideB = NarrowB + WideA

    - Average over SideA and SideB rates: Only dependent to second order on beam parameters:

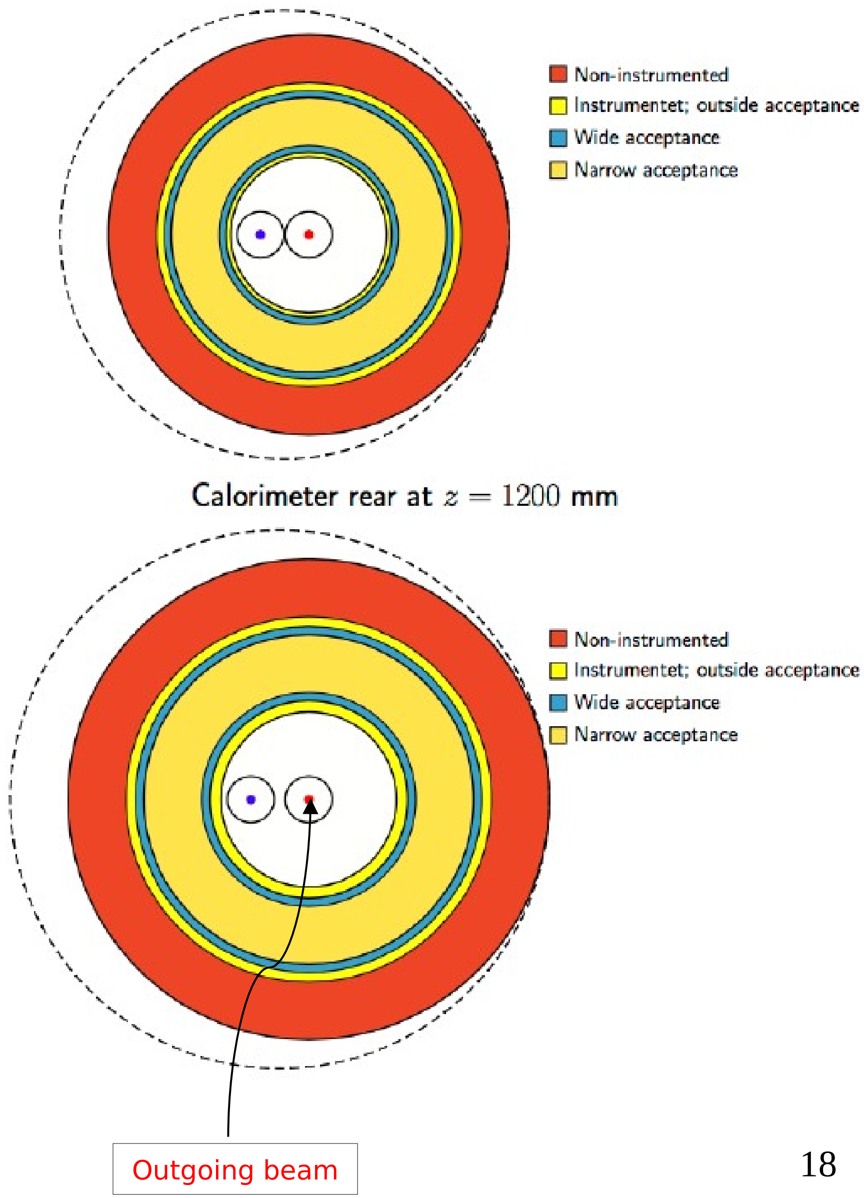
$$\frac{\delta \bar{R}}{\bar{R}} = 3\left(\frac{\delta z}{Z}\right)^2 \qquad \frac{\delta \bar{R}}{\bar{R}} = 2\left(\frac{\delta x}{r_{\text{min}}}\right)^2$$

LumiCal geometry

Side view



End view



Cross section: σ = 23 nb
Geometric precision needed for absolute normalization to 10^{-4}

- δz = 50 µm
- δr_{min} = 1.6 µm
- δr_{max} = 5.8 µm

Challenges

Readout electronics

- Few ns beam crossing time:
  - To maintain backgrounds (off-momentum particles, etc) at a tolerable level, need **very fast readout** (one or few crossings)
  - Continous beam:
    - No power pulsing possible: heat dissipation, how to maintain mechanical stability

Control of geometry to few µm

- For increased acceptance in tight geometry suggest **conical layout** of monitors
  - Need detailed plan for mechanical assembly
- Heat dissipation:
  - Need detailed plan for cooling

High integrated rate particularly at low radii

- Possible need for radiation tolerant sensors and electronics

FCC-ee group (Copenhagen) invited to join ILC FCAL Collaboration for discussion of forward instrumentation issues

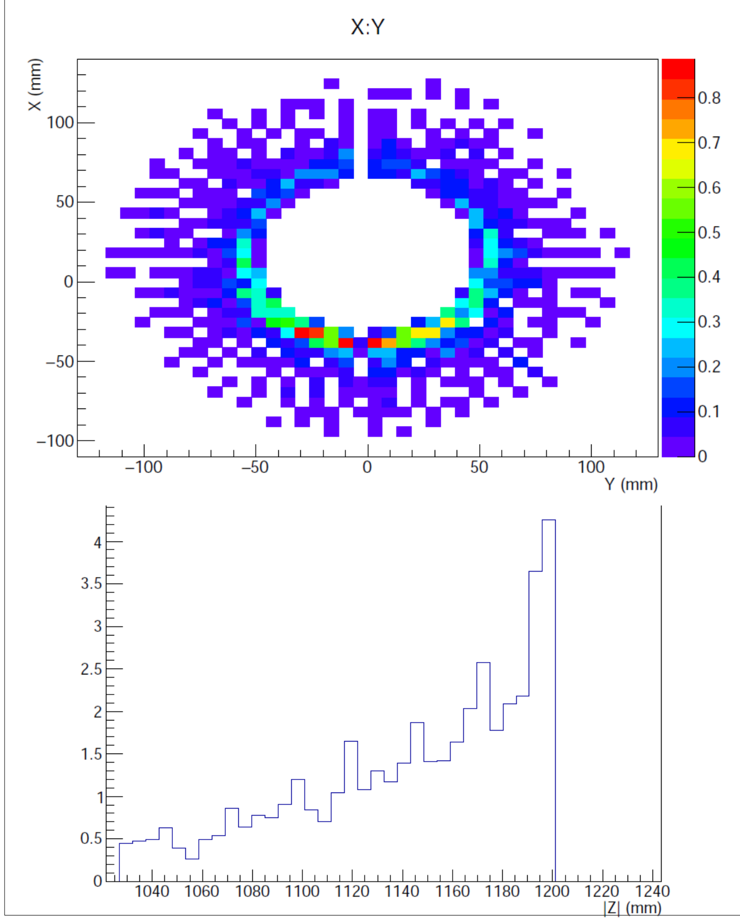
Impact of IR bkg on LumiCal

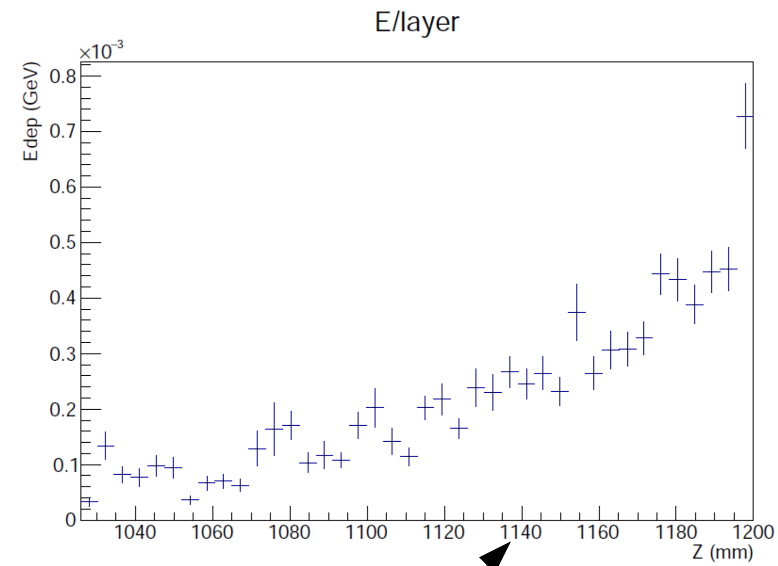
LC - like LumiCal, 40 layers SiW calorimeter, 48/64 Azimuthal/radial divisions

Studying E_{cm} = 91.2 GeV

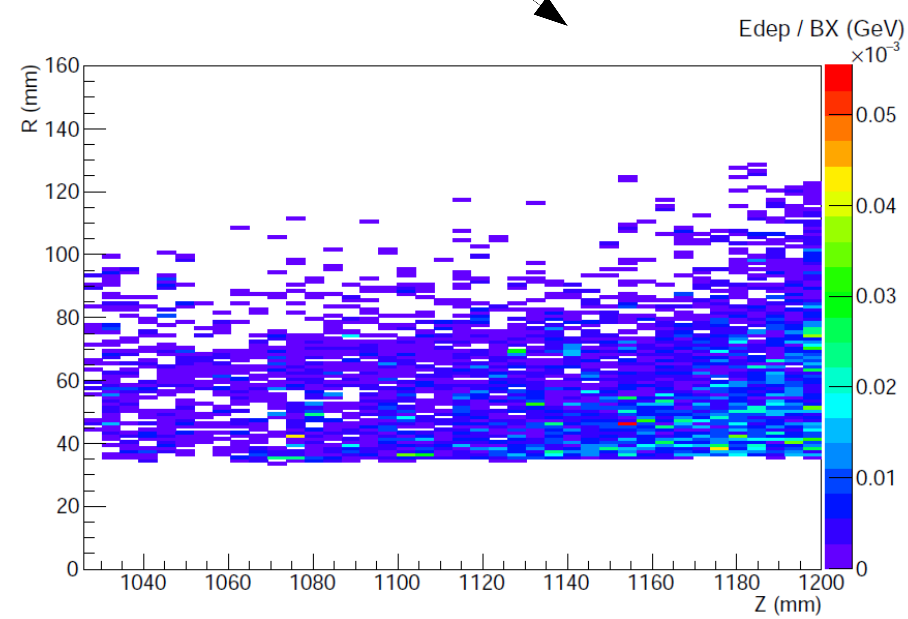
- SR seems not to be in issue in that energy
- Focusing on pairs

Hits / BX in LumiCal





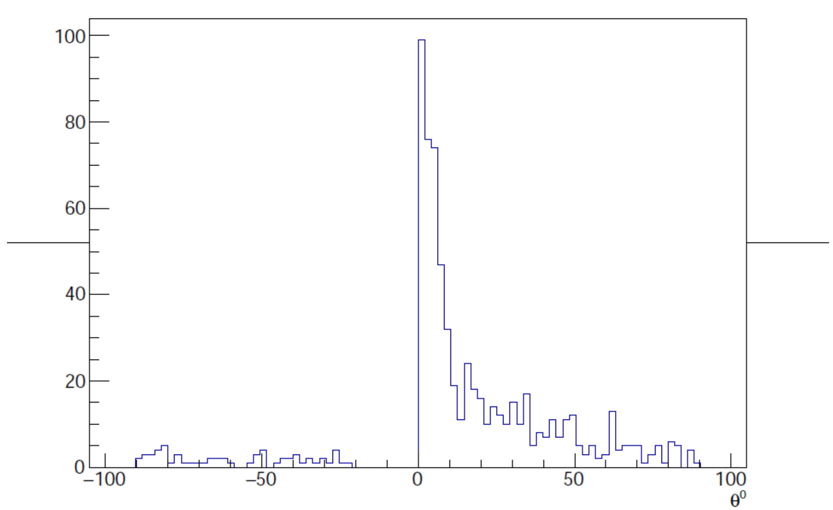
E deposited in Si / BX

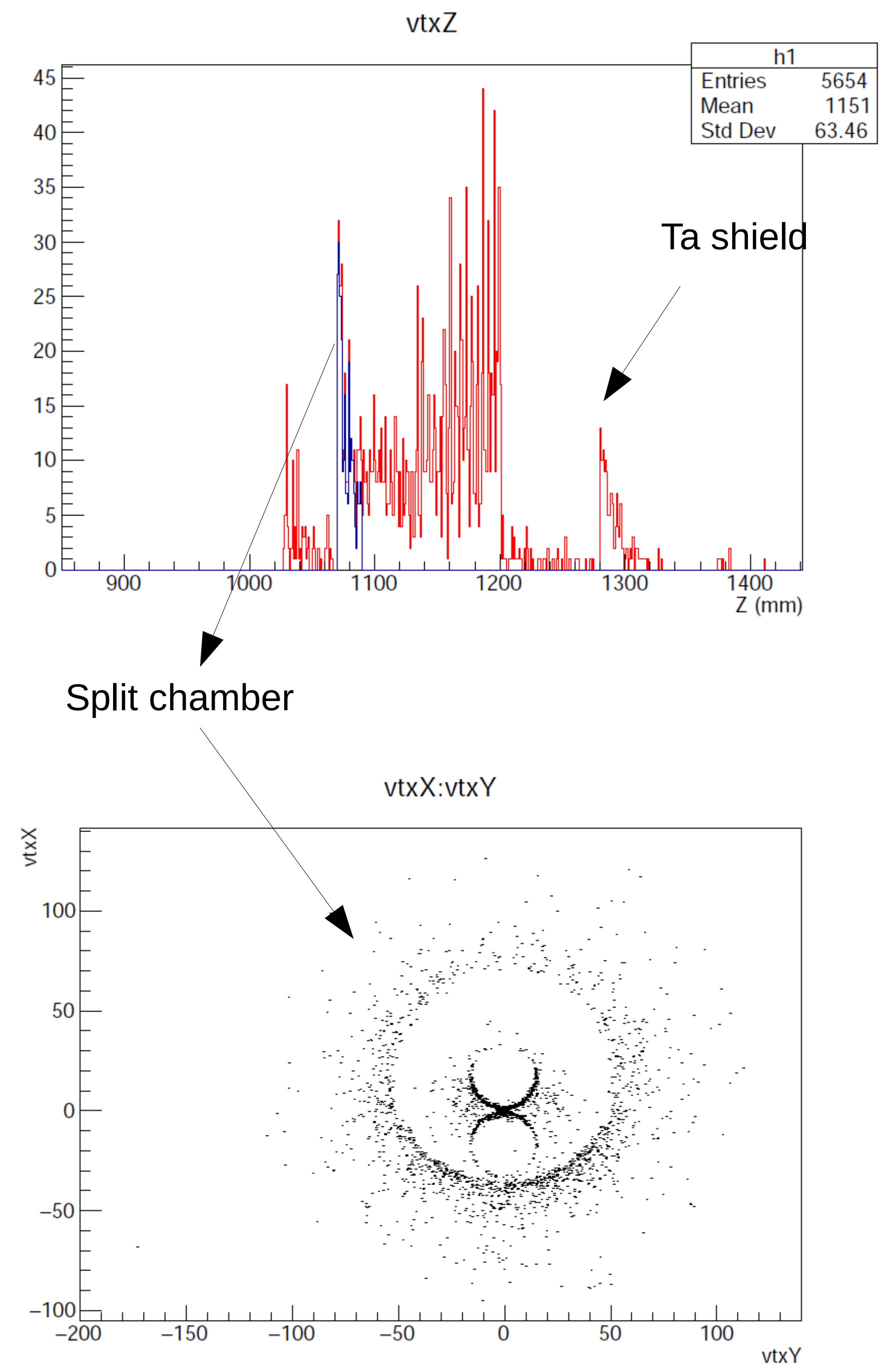


Origin of hits

Pairs deposit energy mostly on the back of the LumiCal

- Potential sources are the Ta shield behind the LumiCal
  - This source might be more easily shielded
  - Very first results show that ~10%-15% of the deposited energy comes from backscattered from Ta shield
- The split vacuum chamber (engulfed by the LumiCal)
  - Secondaries produced there have rather small angles





Outlook on IR backgrounds

Updated beam parameters → regenerate the bkgs

New CLIC_FCCee detector model

- Effect on occupancy in trackers, possibly also in LumiCal

Update IR elements G4 description

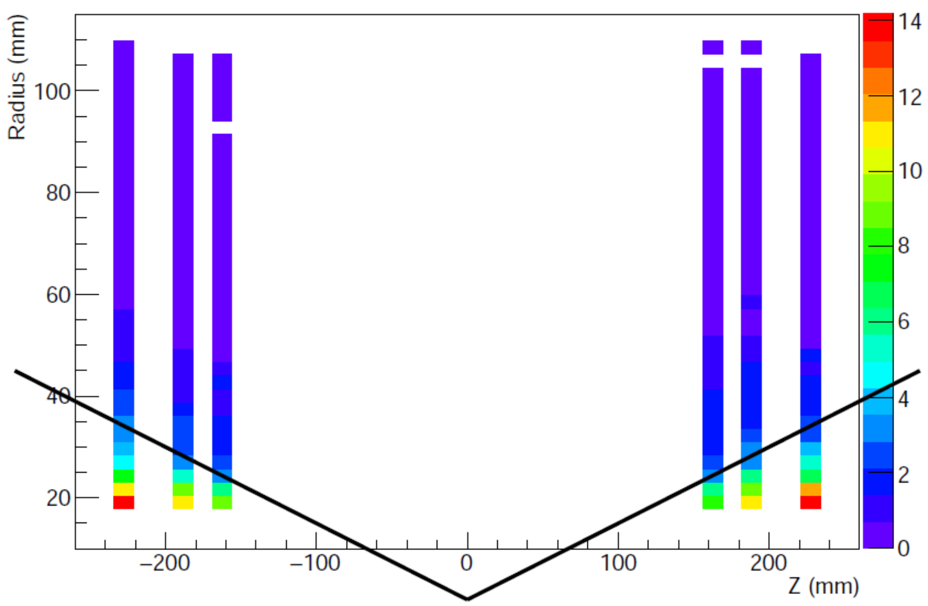
- e.g. beam pipe, see

https://indico.cern.ch/event/556692/contributions/2590396/attachments/1468161/2270594/Novokhatski_FCC_IR_HOMs_05_31_17.pdf

Study of beam – gas interactions

Overlay bkg in LumiCal on a Bhabha sample – study the effect on luminosity measurement

VXD Endcaps



150mrad angle

To do list common to the MDI group

Synchrotron radiation studies

- Optimisation of the SR mask and shielding with full simulation studies
  - Evaluation and minimisation of the material budget
- Study of the heating of the beam pipe due to SR
- Examine the efficiency on SR absorption of various beam pipe shapes
- On going effort on integrating Geant4 simulation of the detector with the upstream beam line

Impact of IR backgrounds on LumiCal

Study of other IR backgrounds

- On going study on beam – gas interactions
- On going study of radiative Bhabhas
- Complete $\gamma\gamma \rightarrow$ hadrons study by extending it to lower energies

Radiation damage to sensors

Impact of IR backgrounds on sensor's readout payload

CDR Vol. 5
"Lepton Collider Comprehensive"

Volume 5.6 "FCC-ee Experiment"

1. Introduction
2. Experimental Conditions
   - 2.1. Beam structure
   - 2.2. Constraints from infrastructures
   - 2.3. Interaction region design
   - 2.4. Machine induced backgrounds
     - 2.4.1. Synchrotron radiation
     - 2.4.2. e+/e- pair production
     - 2.4.3. gamma/gamma to hadrons production
     - 2.4.4. beam gas
     - 2.4.5. Radiative Bhabha
     - 2.4.6. Beamstrhalung
     - 2.4.7. Touschek
     - 2.4.8. Summary of backgrounds and comparison with other accelerator complex
   - 2.5. Luminosity measurement and requirements
     - 2.5.1. …
     - 2.5.2. …
     - 2.5.3. Impact of machine induced backgrounds on luminosity measurement
3. Detector description and requirements
   - 3.1. General description
     - 3.4.1. Detector A
     - 3.4.2. …..
     - 3.4.3. Vertex Detector
       - 3.4.3.1. …..
       - 3.4.3.2. ….
       - 3.4.3.3. Impact of machine induced backgrounds on Vertex detector
       - 3.4.3.4. ….
     - 3.4.4. Central Tracker
       - 3.4.4.1. ….
       - 3.4.4.2. ….
       - 3.4.4.3. Impact of machine induced backgrounds on Central Tracker
       - 3.4.4.4. ….
     - 3.4.5. Calorimeters
       - 3.4.5.1. …
       - 3.4.5.2. …
       - 3.4.5.3. Impact of machine induced backgrounds on Calorimeters
       - 3.4.5.4. …

Chapter "Experiment"

List of all backgrounds.
Background description:
- Simulation used
- General impact on FCC IR
- Optimization of FCC IR

Summary, mitigation, comparison.

Background impact on sub-detectors:
Occupancy, readout, radiation damage, etc.
Summary/mitigations.

Chapter "Accelerator"

IR Description.
MDI issues.

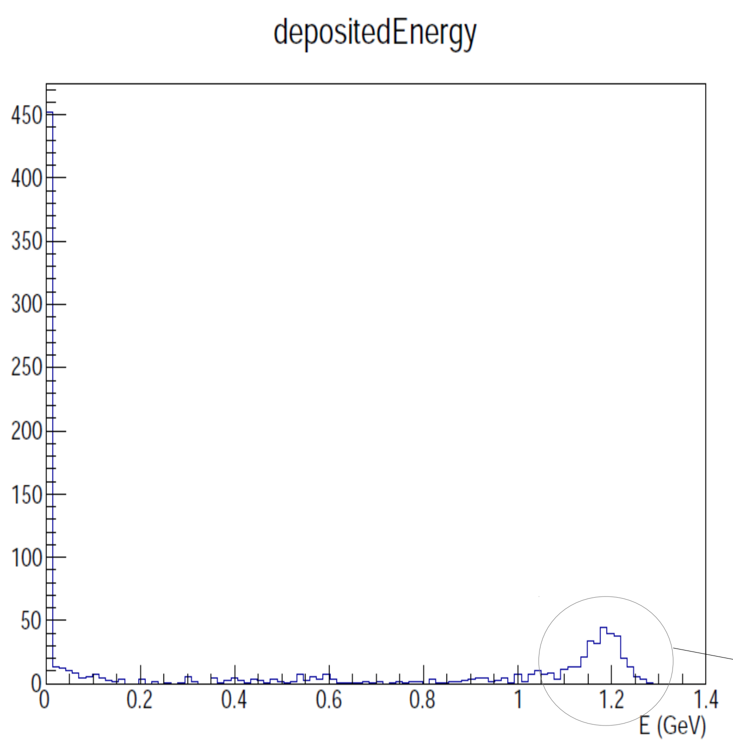
backup

Bhabhas generation with BHWIDE

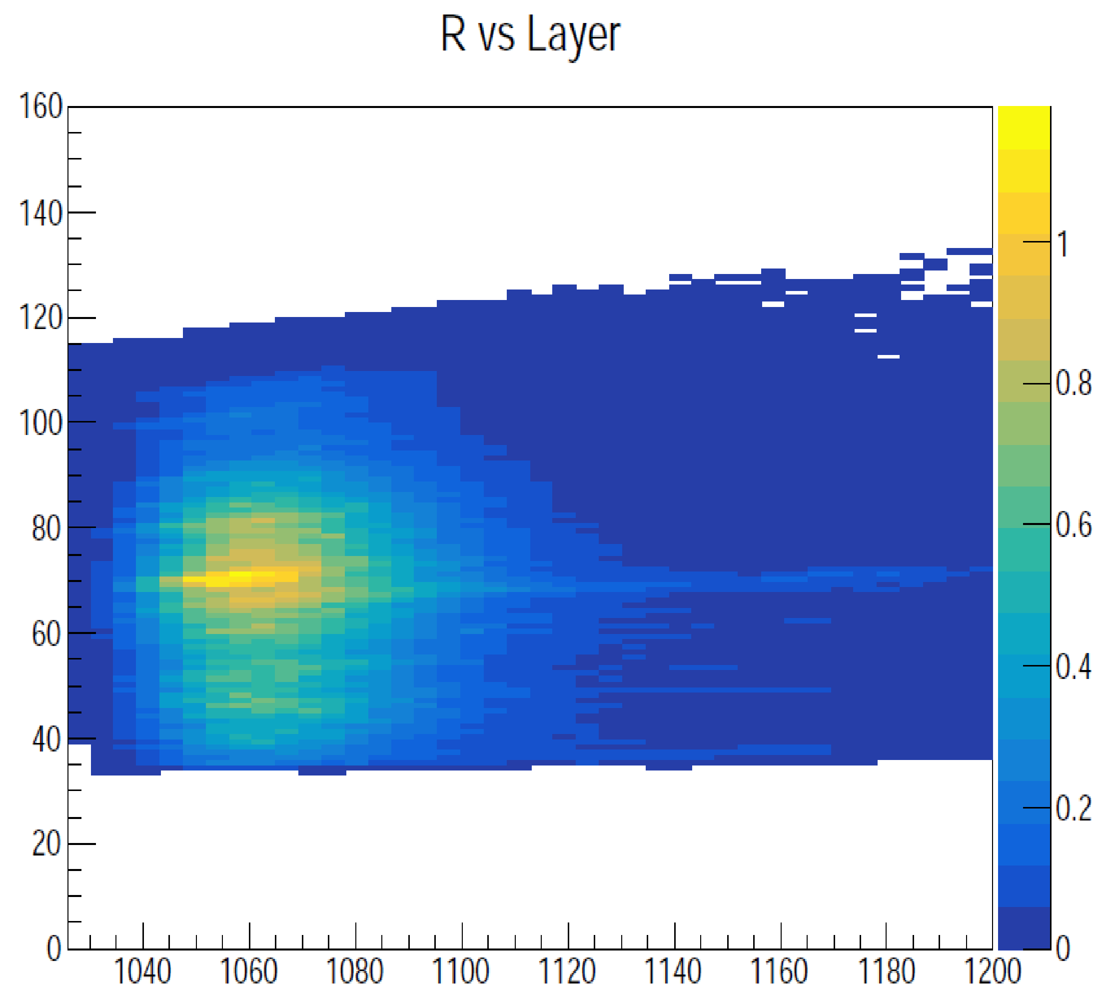
Using demo program

- Ecms 91.2 GeV
- Θ angle > 35mrad

Simulation with FCCee_o4_v01



Some first info about calibration can be inferred



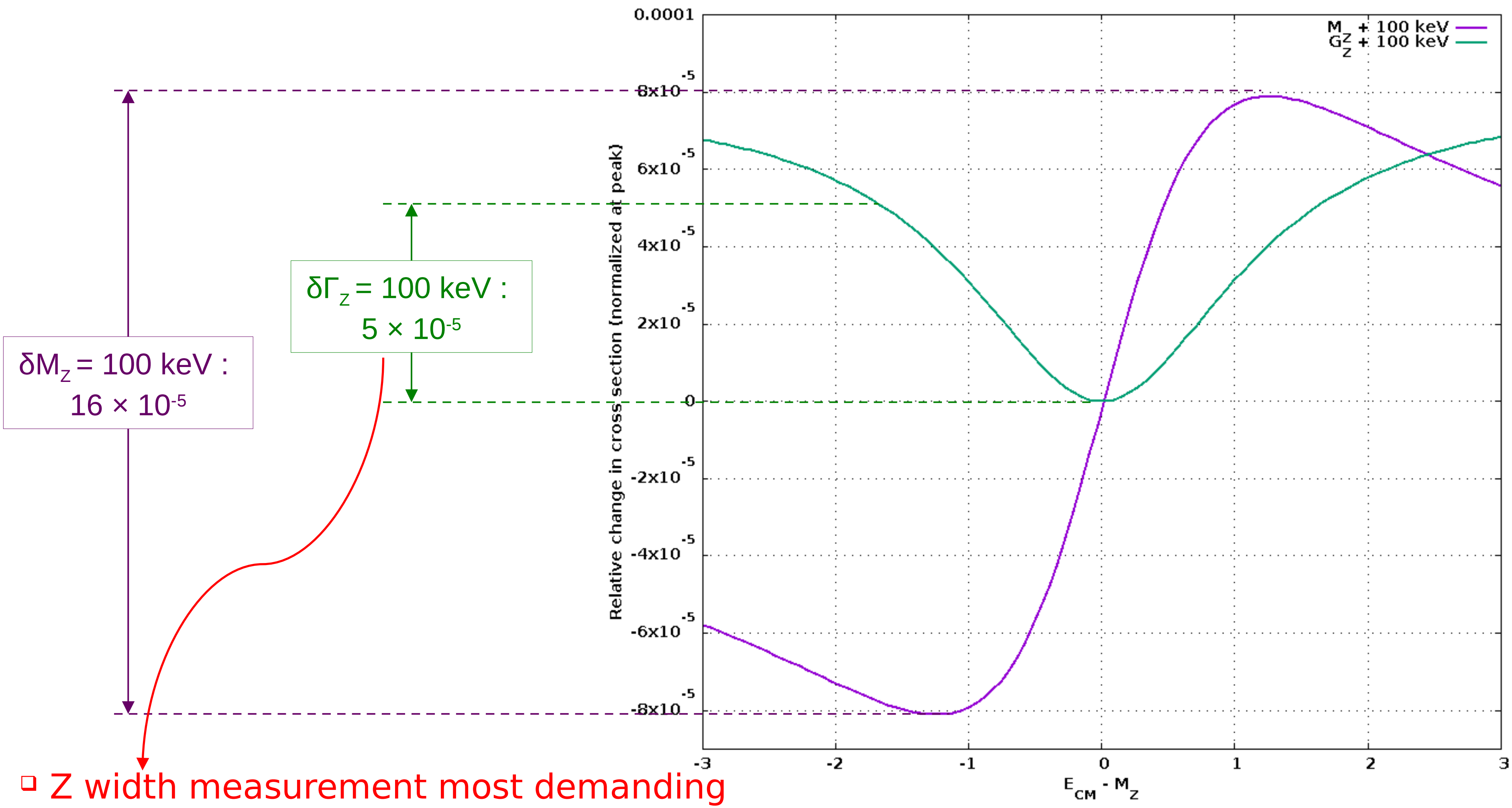
Several events piled up

Tera-Z Relative Normalisation (i)

- FCC-ee goal: Determine Z parameters to precisions:

  δM_Z = 100 keV ; $\delta\Gamma_Z$ = 100 keV

  - Plot shows relative change in cross section across Z resonance for variation of this size in these parameters



  - Z width measurement most demanding
    - Need **relative** normalisation to about **2×10^{-5}**