FCC week, Berlin
30/05/2017

Experimental environment in the interaction region and luminosity measumerent

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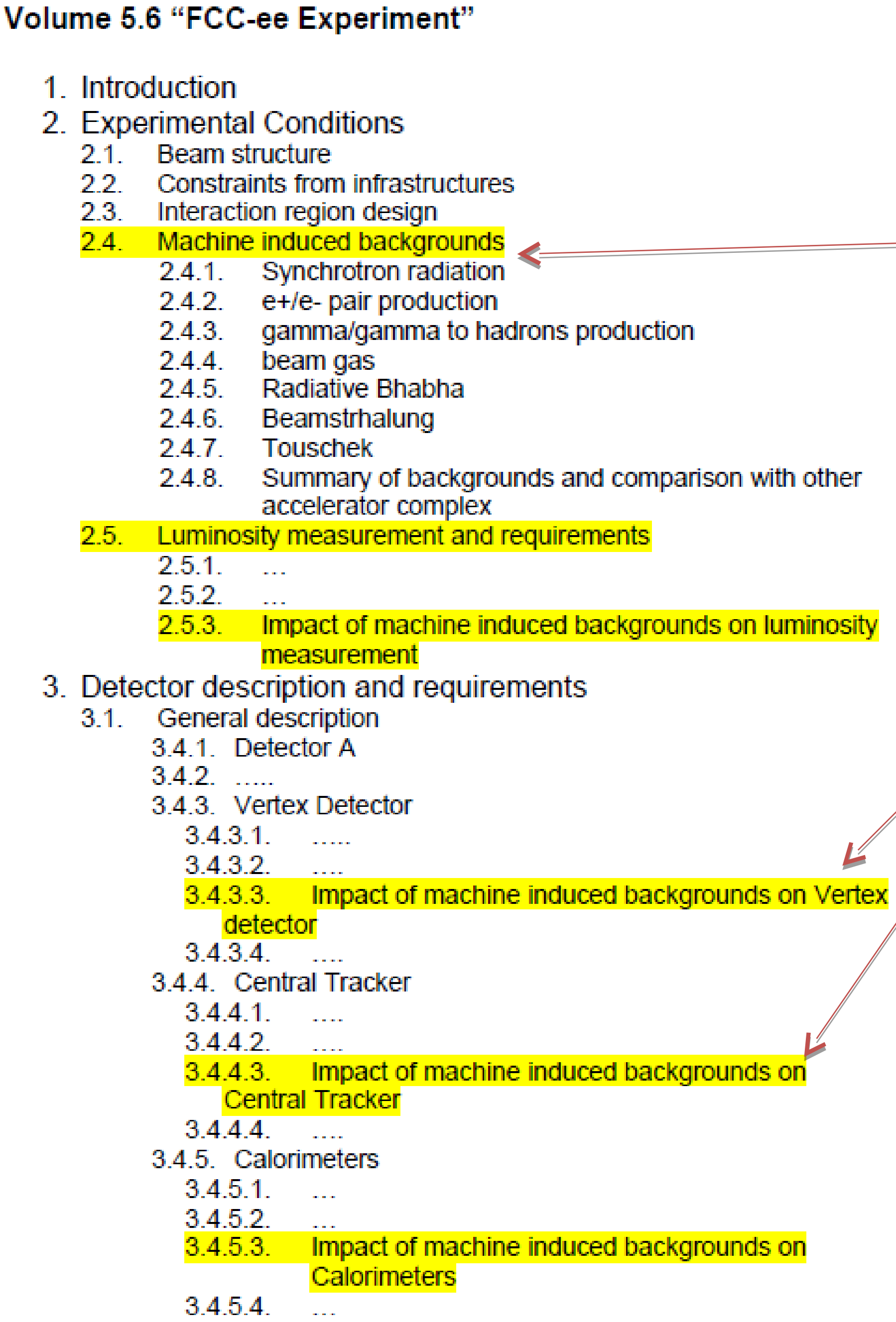
and many thanks to CLICdp group for the support

CDR Vol. 5
“Lepton Collider Comprehensive”



Volume 5.6 “FCC-ee Experiment”

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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.

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

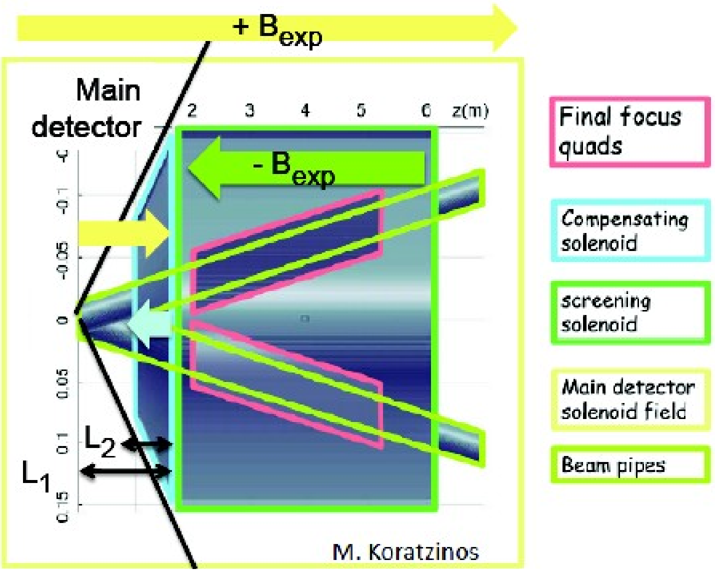
The IR design is meant to work for all FCC – ee energies: 45 GeV (Z), 80 GeV (W), 120 GeV (H) and 175 GeV (top)

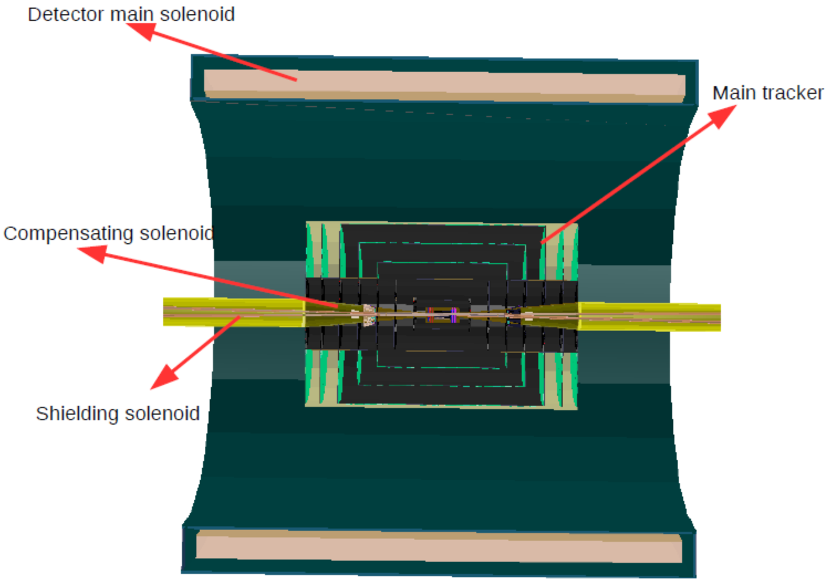
Please see Manuela's talk for more information on IR

2 detector designs exist

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

- See Emilia's talk for this detector model





Sources of background

Sources of machine induced background

- Study of backgrounds on generation level
- Requirements imposed on FCC – ee IR design
- Will constitute section 2.4 of chapter 2 “Experimental Conditions “ of CDR Vol. 5

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

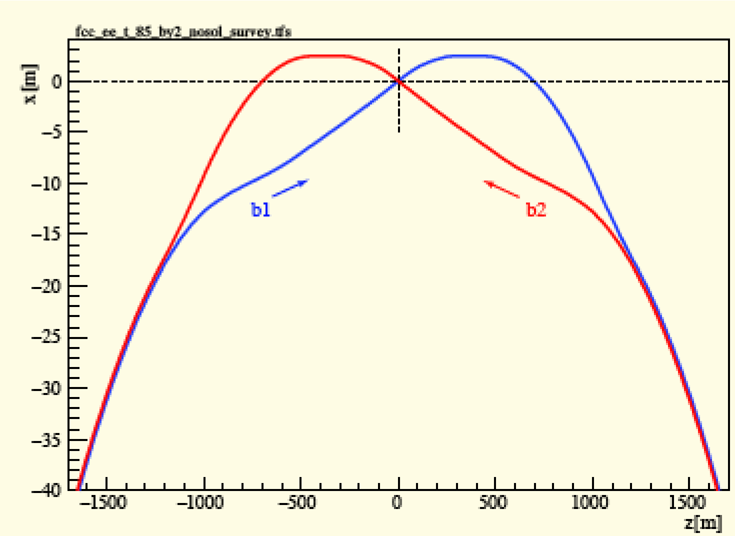
- Limits the amount of SR on the detector
- SR kept in LEP levels

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

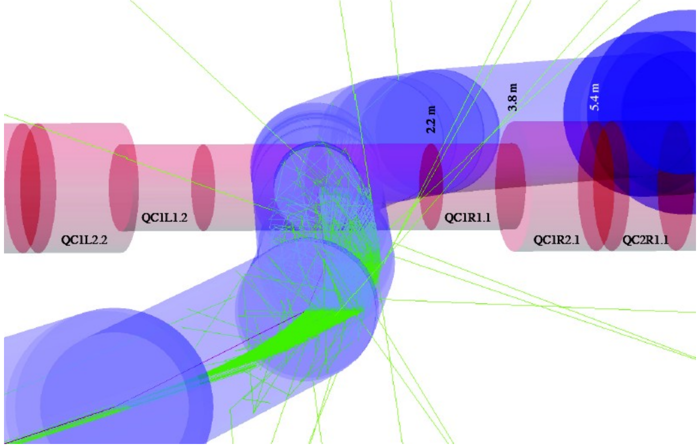
Proper masking and shielding required

- Simulations on going

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



From H. Burkhardt

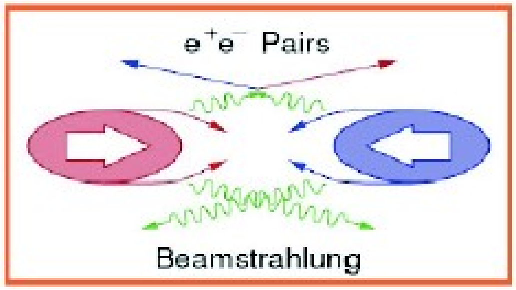


SR radiation obtained of G4 simulation of upstream beam line (H. Burkhardt)

e^+e^- pairs

Opposite bunches exert force to each other

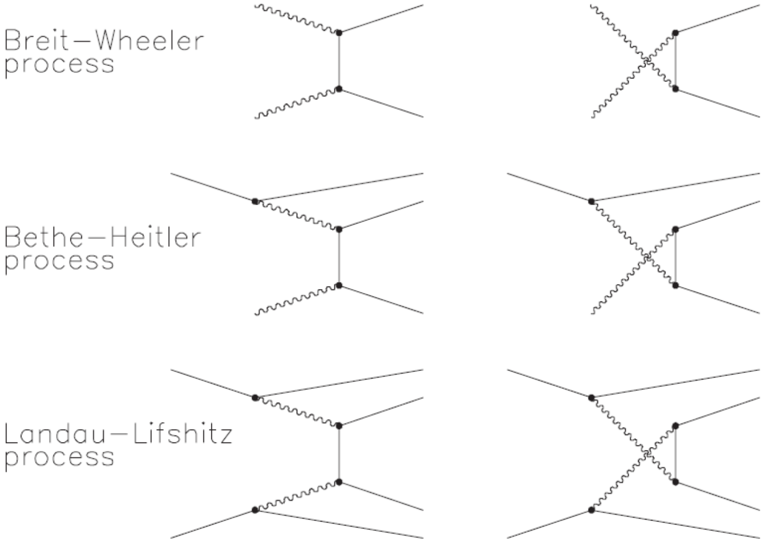
- production of hard bremstrahlung photons



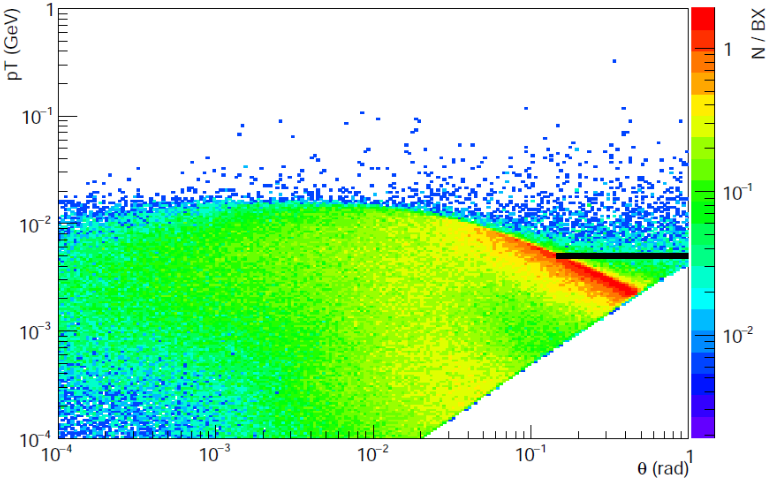
- Photon interaction with the collective field of the opposite bunch : Coherent Pairs Creation (CPC)
  - Strongly focused on the forward direction →negligible effect for FCCee
- Real or virtual photon scattering: Incoherent Pairs Creation (IPC)
  - Virtual γ scattering dominant

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 $\sqrt{\hat{s}}$ for E_{cm} = 350 GeV. The black line indicates the 1st VXD layer

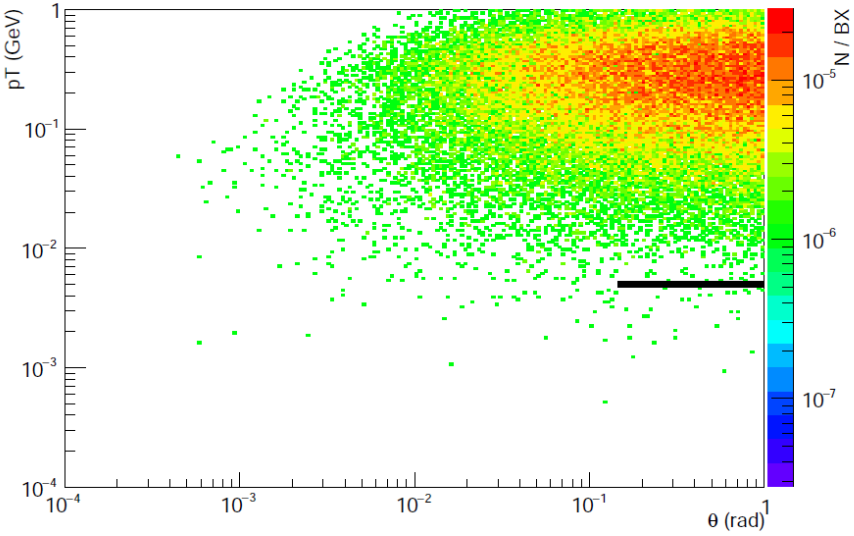
yy to hadrons

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

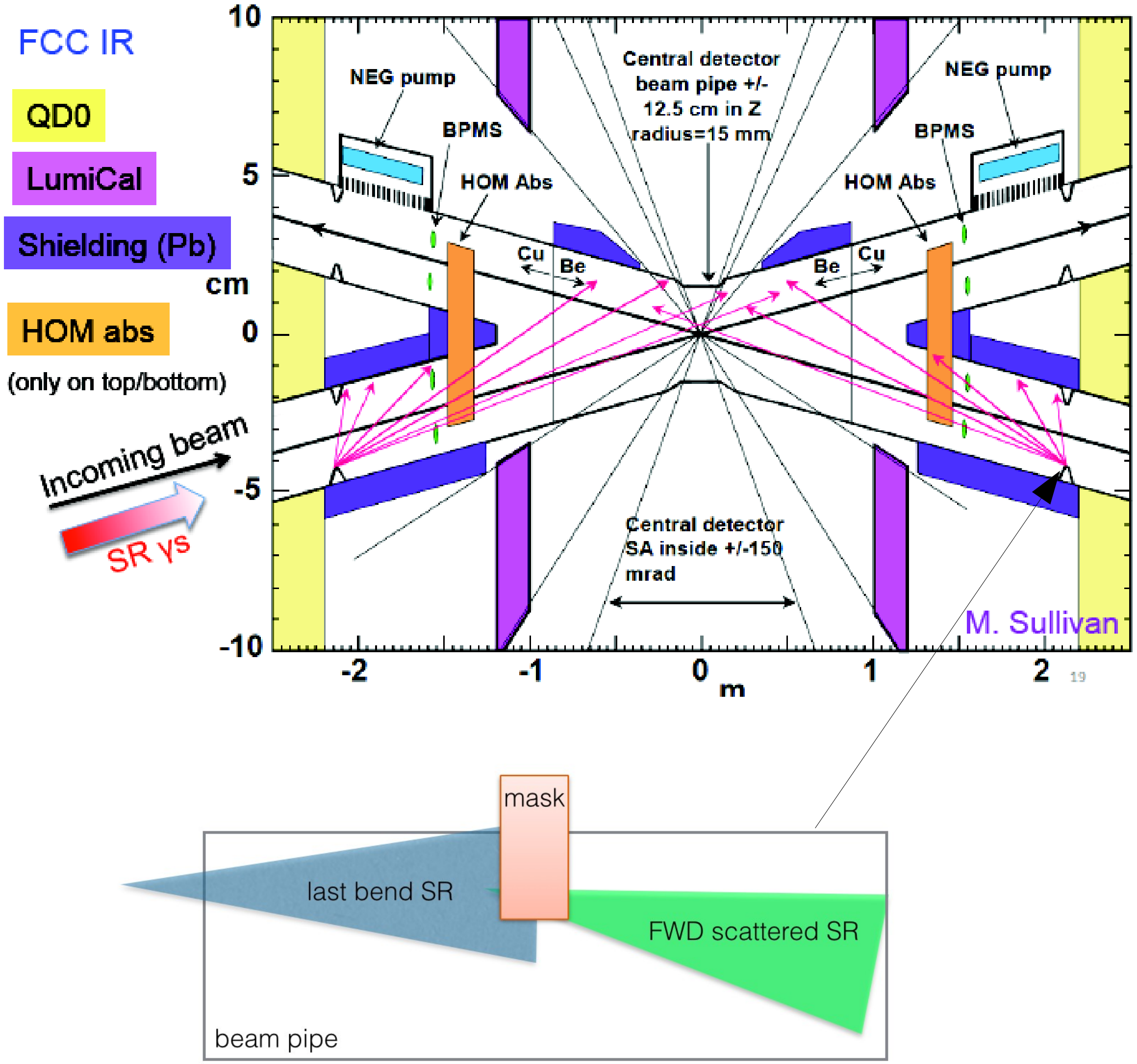
- Relevant surviving photons are those emerging from the tip of the mask

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	$P_T > 20$MeV‡ $\theta > 7.3^0$	total	$P_T > 5$MeV $\theta > 7.6^0$
IPC	$3x10^5$	60	2600	33
CPC	$6x10^8$	0	0	0
hadrons	102	54	0.05	~0.05
Syn. rad			$\sim5x10^6$ †	

† scattered from the tip of the mask per beam

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

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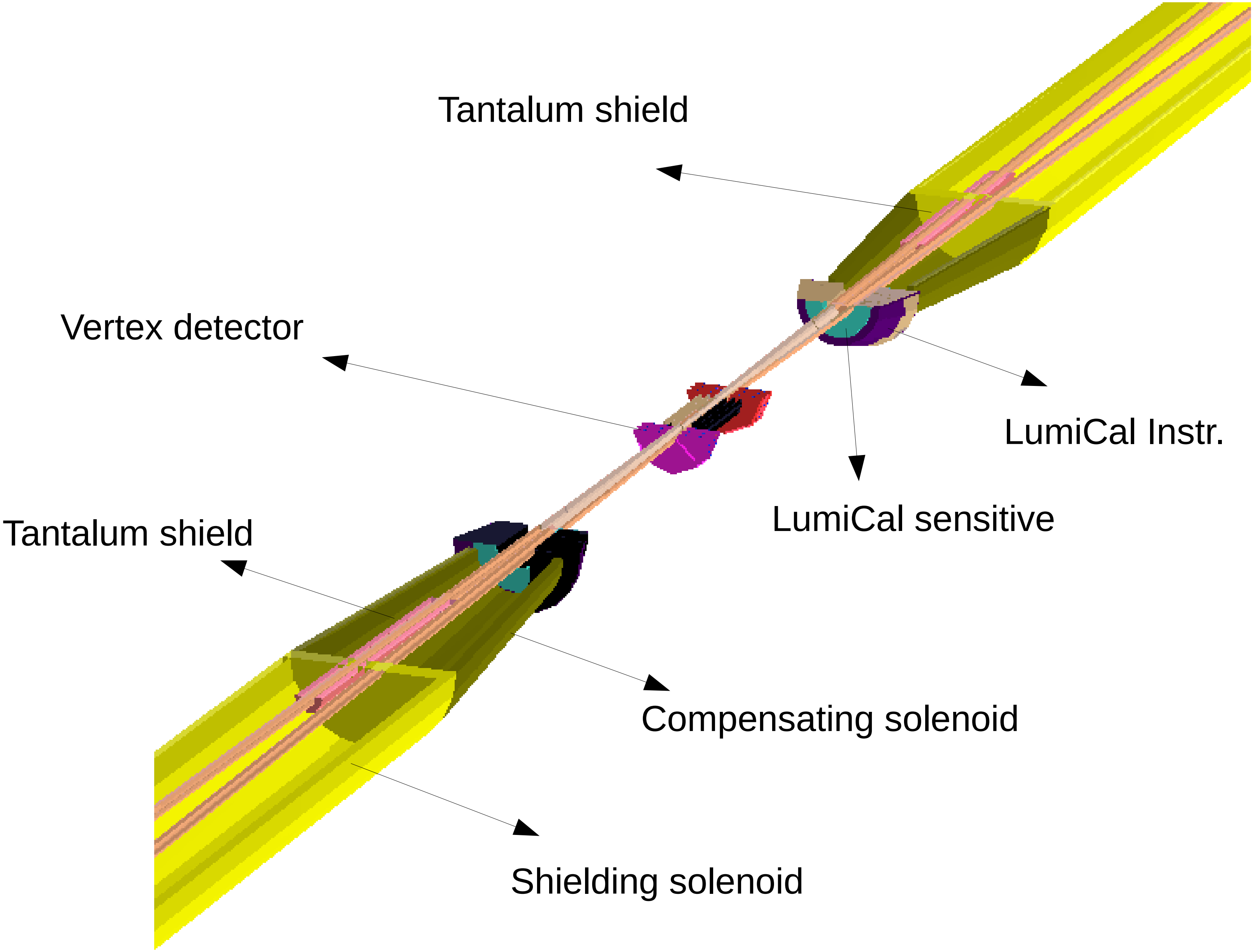
* From LCD-2011-021

Geant4 description of IR



Tantalum shield

Vertex detector

LumiCal Instr.

LumiCal sensitive

Tantalum shield

Compensating solenoid

Shielding solenoid

Impact of machine induced background on the detector

Full simulation studies of effect of various IR backgrounds on the FCC – ee subdetectors

- Estimation of hit density / occupancy / deposited energy on the subdetectors due to bkg hits
- Data rate considerations
- Evaluation of radiation damage on the sensors
- Will be included on chapter 3 “Detector Description and Requirements” of CDR Vol. 5

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

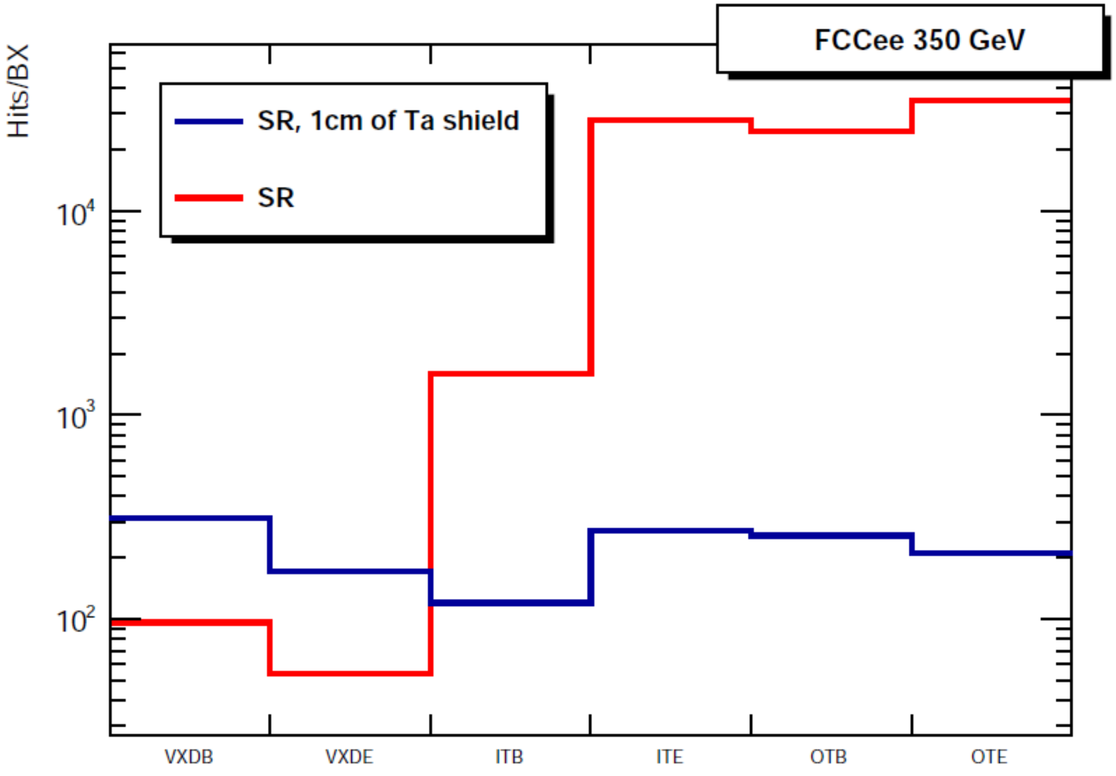
- Most unfavourable case in terms of bkg hits / BX
- However we should stress the very short bunch spacing at the Z working point

Effect of SR

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

Focus on E_{cm} = 350 GeV

- ~5x10^6 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



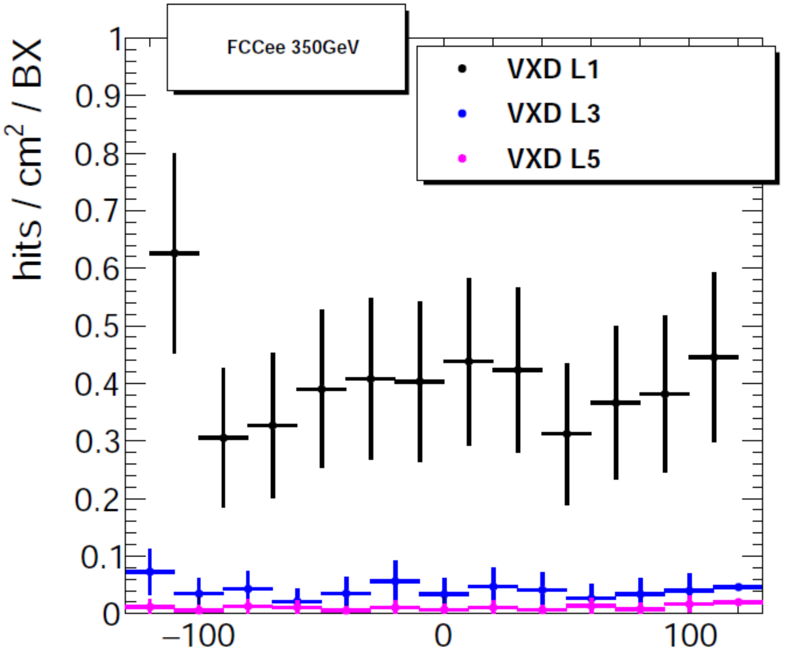
Effect of e^+e^- pairs on detector

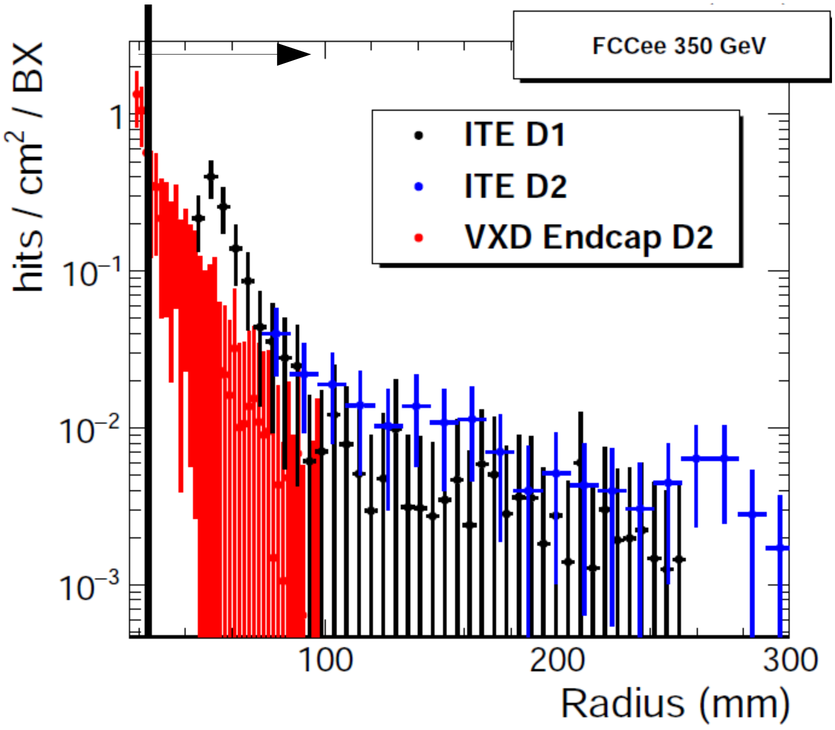
Pairs generation with Guinea Pig

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

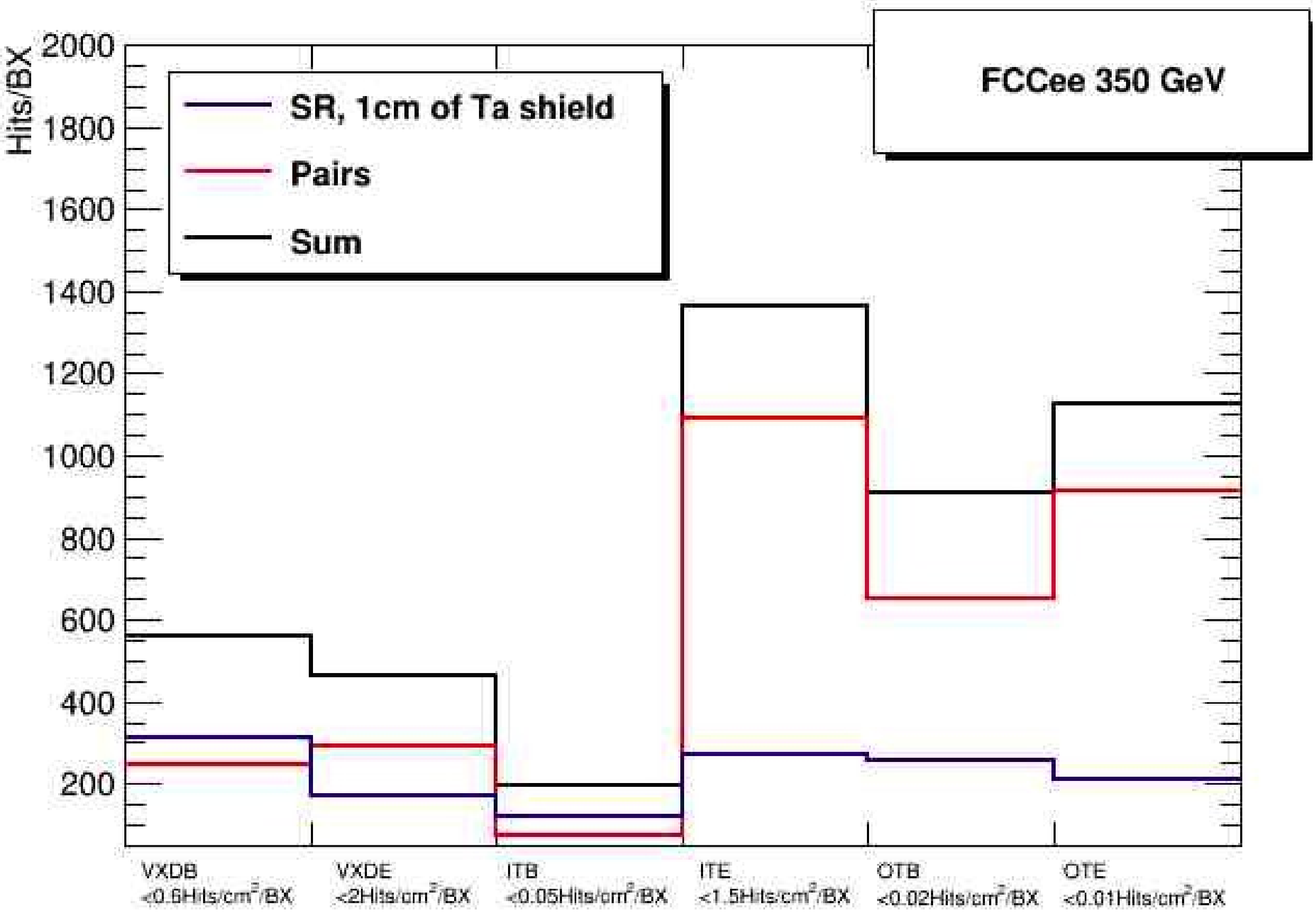
Assuming a pixel pitch of 20µm and an average cluster size of 5

- 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

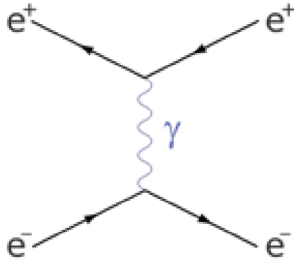
Impact of machine-induced backgrounds on luminosity measurement

- Will constitute section 2.5 of chapter 2 “Experimental Conditions “ of CDR Vol. 5

Luminosity monitoring with Bhabha scattering

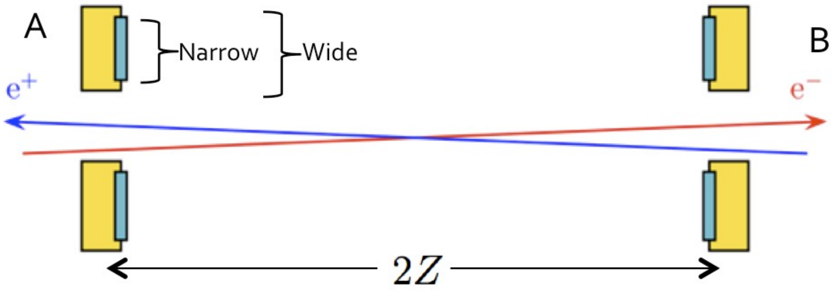
Luminosity monitoring:

- **Absolute** – target precision **10^{-4}**
  - May be best achieved through the process $e^+e^- \rightarrow \gamma\gamma$
- **Point to point** for Z lineshape measurement – need a relative precision of **$2\text{-}5 \times 10^{-5}$**
  - Need cross section comparable to Z production:, i.e. ≥ 15 nb
  - Can be achieved via **small angle Bhabha scattering $e^+e^- \rightarrow e^+e^-$**
    - 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



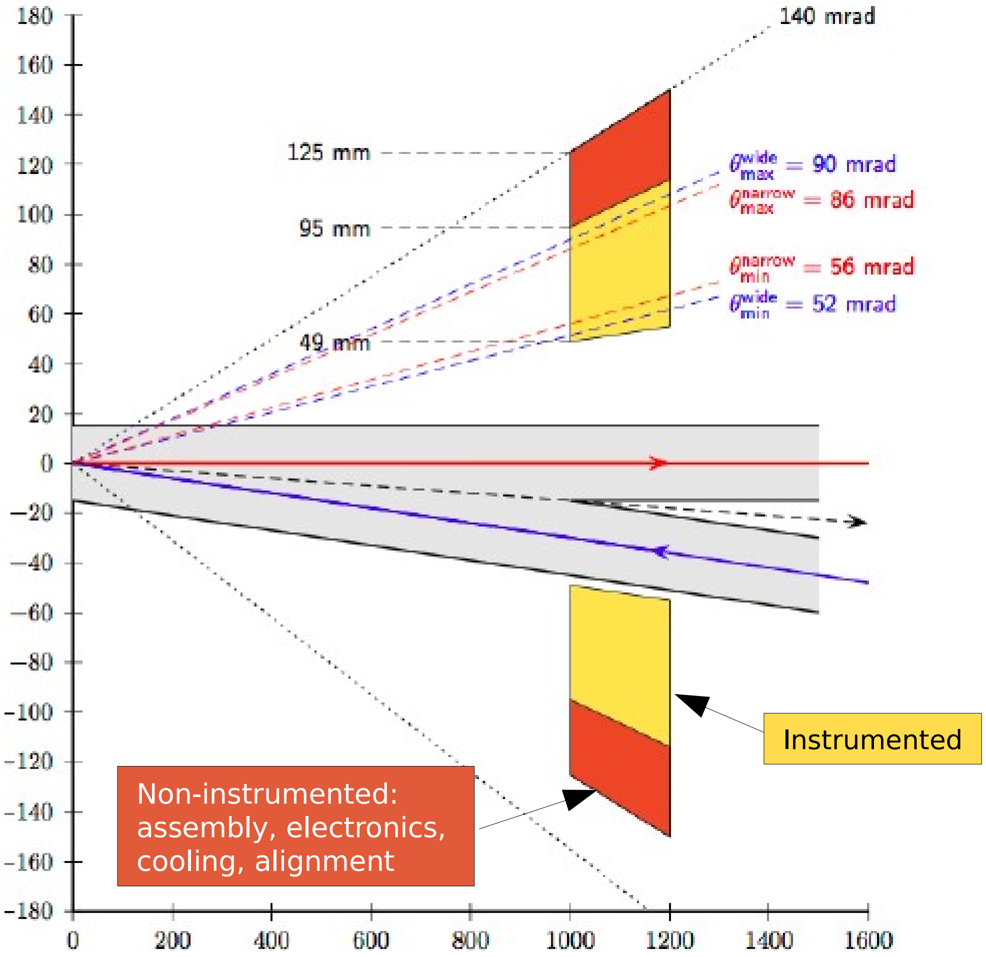
Two counting rates:
- SideA = NarrowA + WideB
- SideB = NarrowB + WideA

    - 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

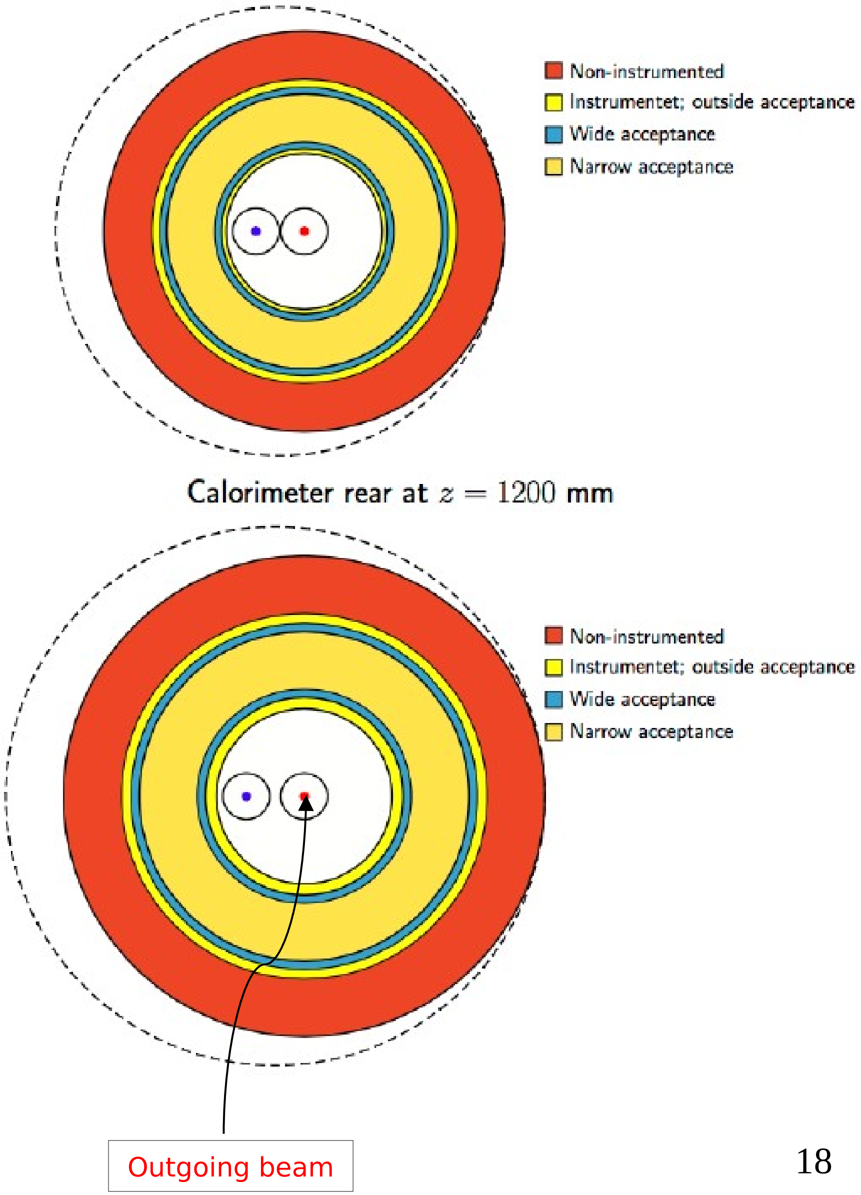
Side view



Instrumented

Non-instrumented: assembly, electronics, cooling, alignment

End view



Outgoing beam

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

- $\delta z = 50\ \mu m$
- $\delta r_{min} = 1.6\ \mu m$
- $\delta r_{max} = 5.8\ \mu m$

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

Towards the CDR

To do list

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

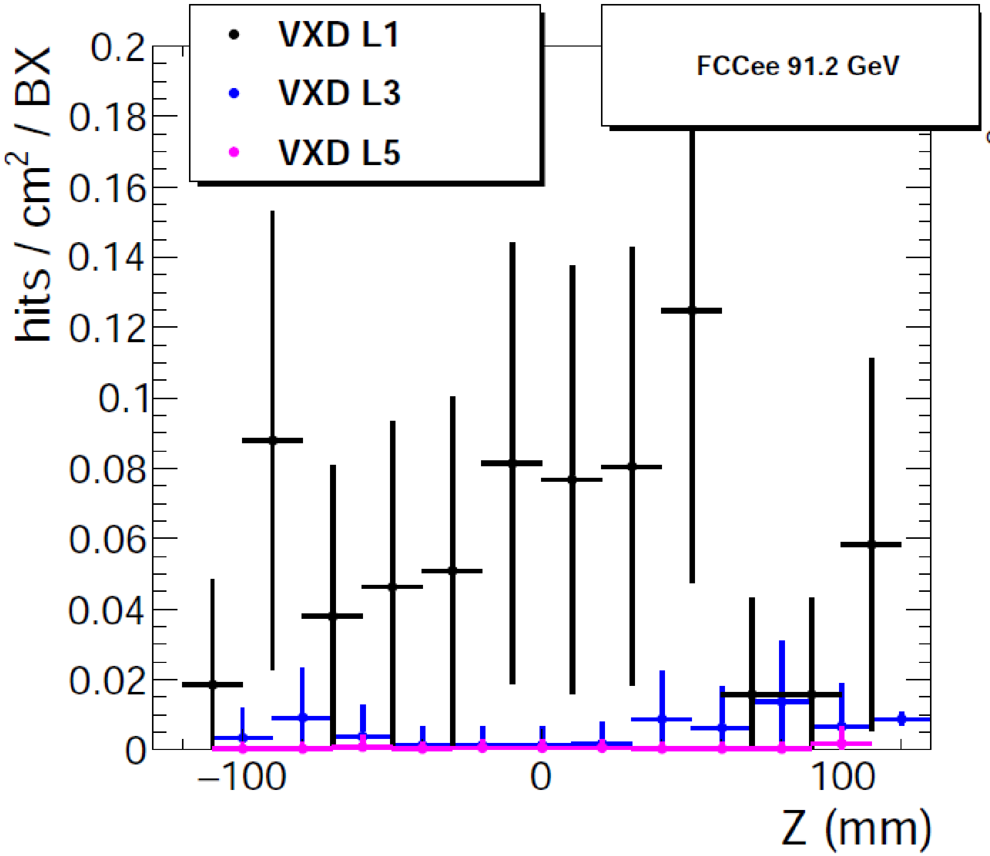
- On going study on beam – gas interactions
- On going study of radiative Bhabhas
- Complete $\gamma\gamma \rightarrow$ hadrons study by extending it to lower energies

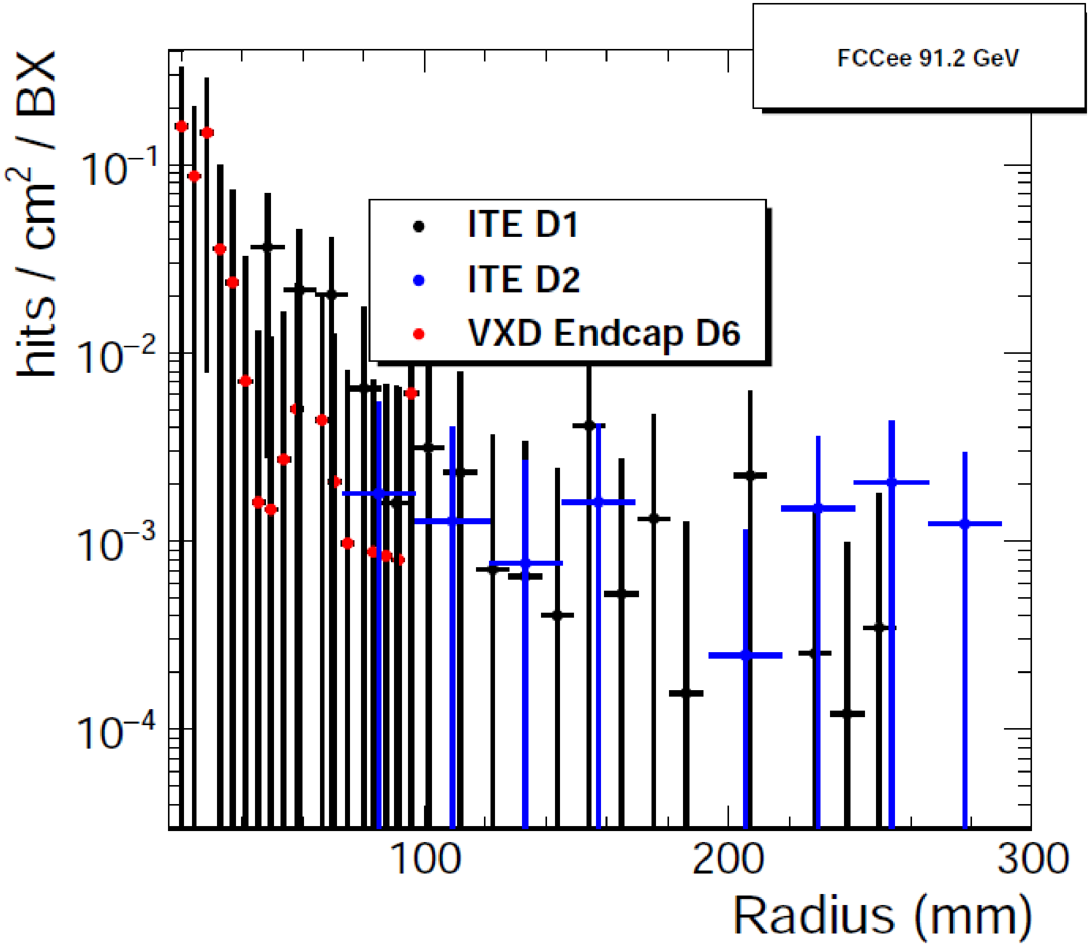
Radiation damage to sensors

Impact of IR backgrounds on sensor's readout payload

backup

Hit densities for Z working point





Summary of LumiCal Geometry

- Z position of calorimeter face: **z_{face} = 1000 mm**
- Effective minimum scattering angle: **θ_{min} = 55 mrad**
- Effective maximum scattering angle: **θ_{max} = 115 mrad**
- Bhabha cross section: **30 nb**

Geometrical precision needed for **$\delta L/L = 10^{-4}$**:

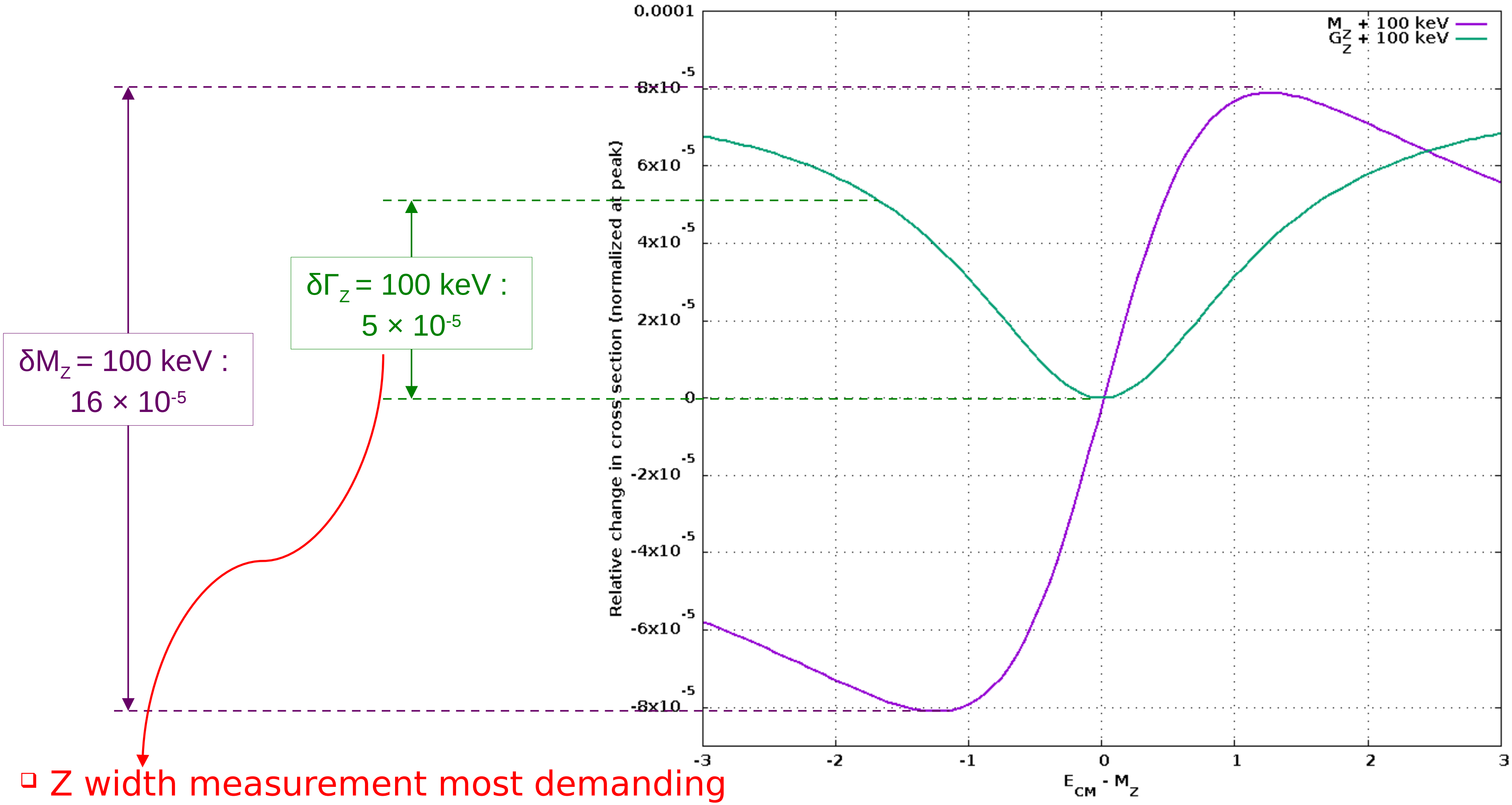
- Distance between face of two calorimeters: **$2\delta z_{face}$ = 100 µm**
- Inner radius of acceptance: **δr_{min} = 2 µm**
- Outer radius of acceptance: **δr_{max} = 18 µm**

Tera-Z Relative Normalisation (i)

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

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

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



$\delta\Gamma_Z = 100$ keV : 5×10^{-5}

$\delta M_Z = 100$ keV : 16×10^{-5}

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

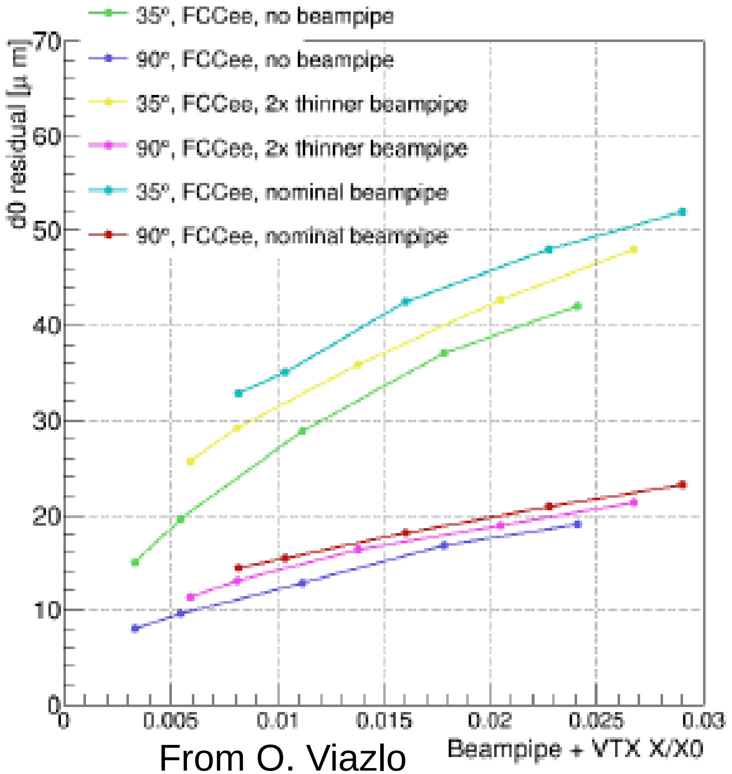
IR optimisation vs physics performance

Impact of beam pipe material budget on physics

Perpendicularly impinging particles will see

- 5µm (~0.15% X_0) of Au
- 0.8mm (~0.22% X_0) of Be
- 0.4mm (~0.11% X_0) of Water

Polar angle θ^0	BP Material Budget X_0 %	
	CLIC-like (0.5mm Be)	FCCee
85	0.15	0.5
40	0.23	0.77
20	0.42	1.4
10	0.84	2.9



From O. Viazlo

Flavour tagging is very sensitive on changes of IP resolution

Care should be taken with the material budget

- Dedicated FT studies are needed