FCC week, Berlin
08/05/2017

Experimental environment in the interaction region and luminosity measumerent

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on behalf of FCC – ee detector MDI group

Outline

Current status

- Machine / luminosity induced backgrounds
- Interaction Region (IR) optimisation studies, w.r.t. backgrounds
- Effect of backgrounds on subdetectors
  - Comparison of the different sources
- Luminosity measurement

Towards the CDR

- To do list
- Contributors
- CDR chapter structure

Introduction & IR description

FCCee detector & Interaction Region

Very small β_y^* (~pm)

- 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 quadropole

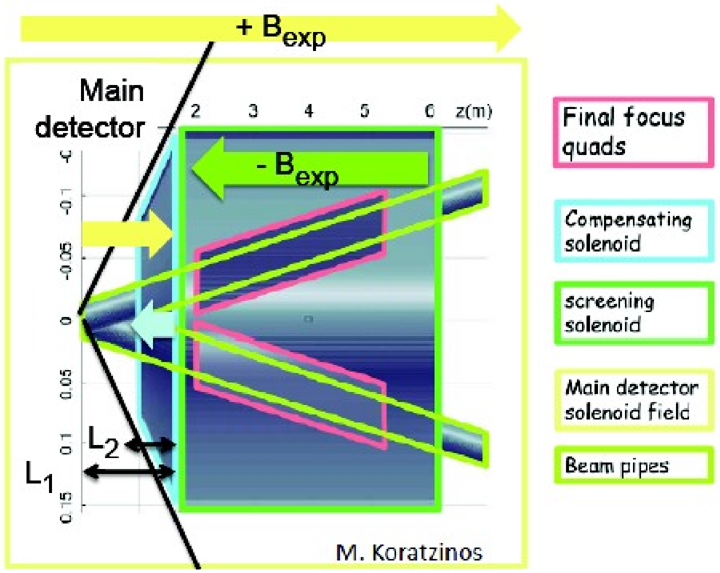
Very short bunch spacing

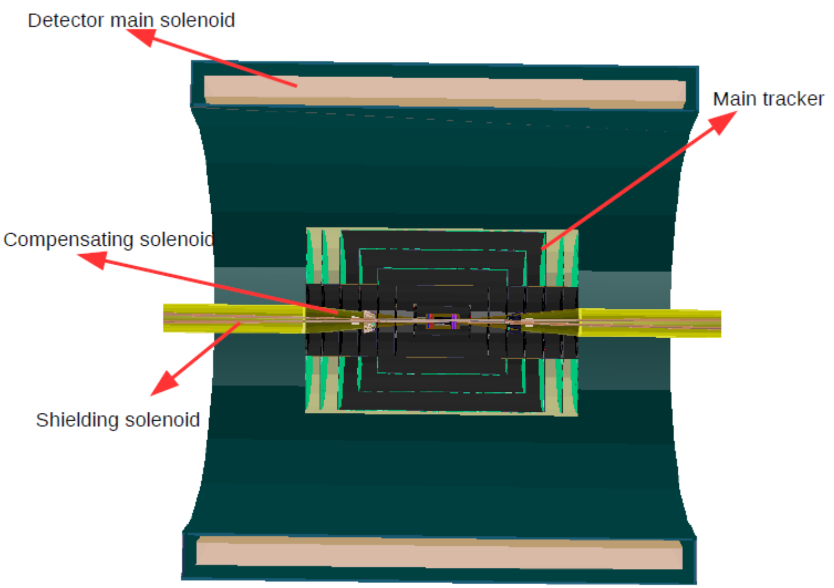
- Crossing angle required for bunch separation
  - Could lead to an emittance blow up during the final 2m before IP
  - Placement of a compensating solenoid of a high magnetic fild, so that the field integral seen by the beam will be zero
    - Restricted space for forward intsrumentation (LumiCal)

Please see Manuela's talk on MDI for more information on IR

Upon the FCC – ee interaction region is placed the CLIC detector model

- **B** field = 2T





Sources of background

Synchrotron radiation

Dictates the IR design and optics

Critical energy should be kept below 100kev

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

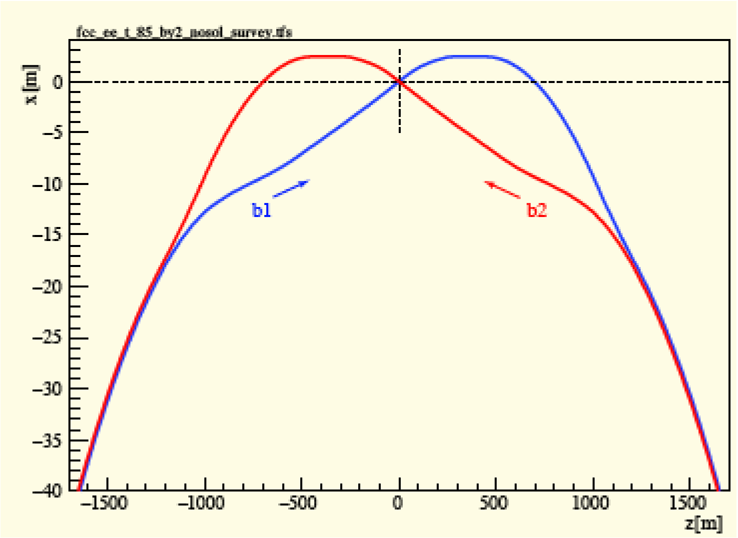
- Limits the amount of SR on the detector
- SR kept in LEP levels

For E_{cm} = 350 GeV, one expect ~$2x10^9$ photons per beam from last bend to fall on the tip of mask

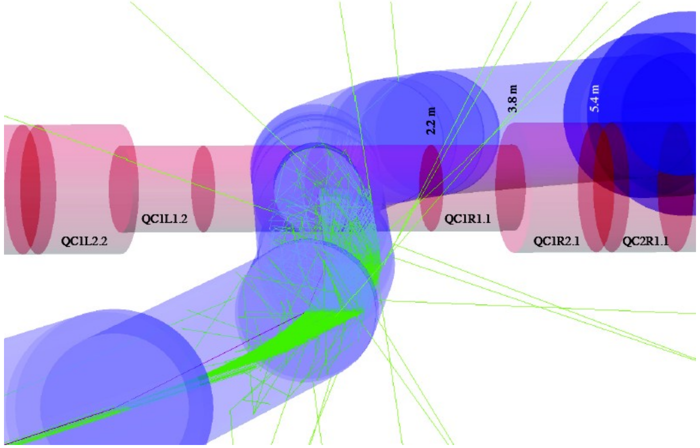
For lower energies (Z) seems not to be an issue

Proper masking and shielding required

- Simulations on going



From H. Burkhardt

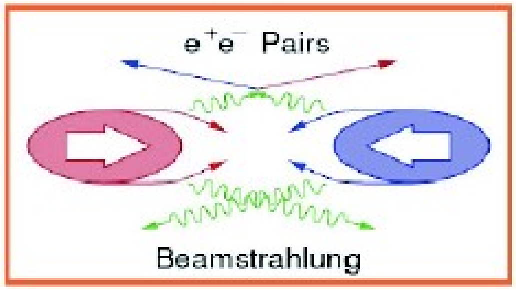


SR radiation obtained of G4 simulation of upstream beam line (H. Burkhardt)

e^+e^- pairs

Opposite bunches exert force to each other

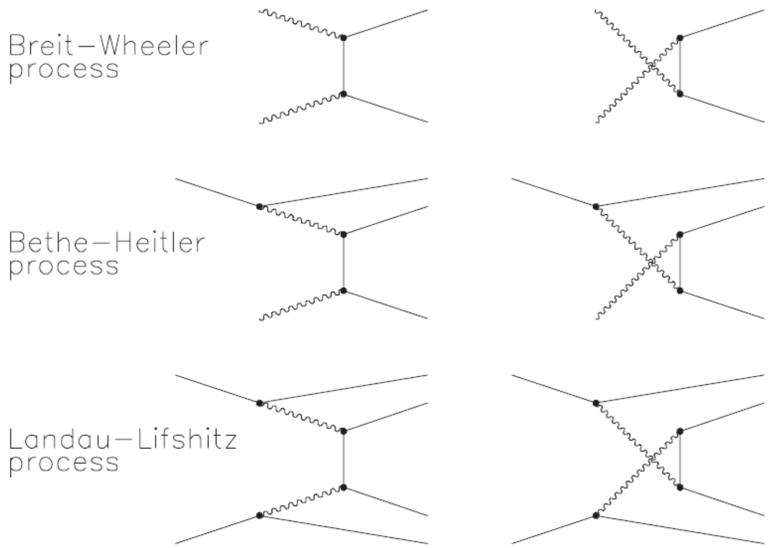
- production of hard bremstrahlung photons



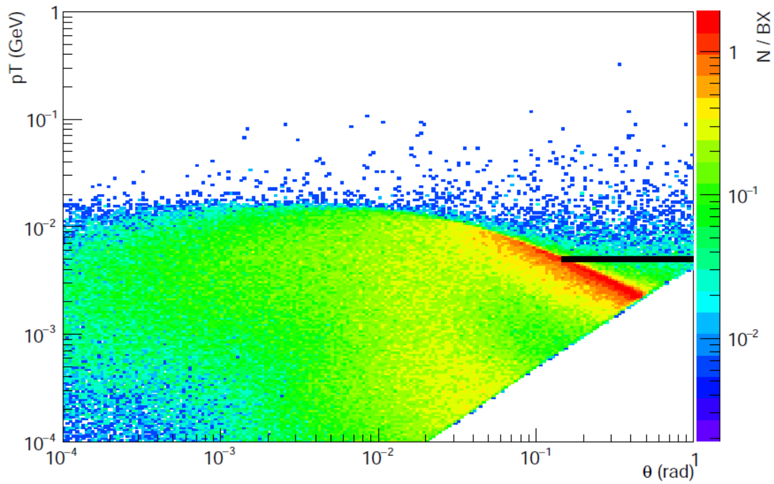
- Photon interaction with the collective field of the opposite bunch : Coherent Pairs Creation (CPC)
  - Strongly focused on the forward direction →negligible effect for FCCee
- Real or virtual photon scattering: Incoherent Pairs Creation (IPC)
  - Virtual γ scattering dominant

Generation of samples using Guinea Pig

Mean energy of produced pairs ~ 1GeV (tt)



IPC creation (from D. Schulte thesis)

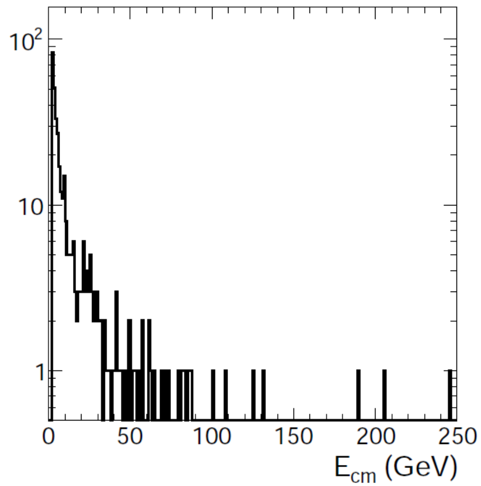


P_T vs θ for IPC in √ŝ for E_{cm} = 350 GeV. The black line indicates the 1st VXD layer

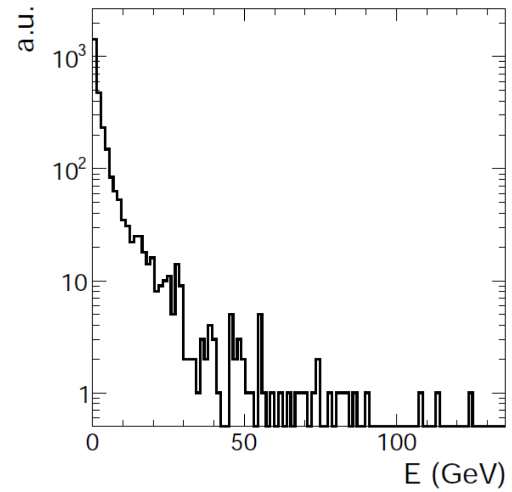
γγ to hadrons

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

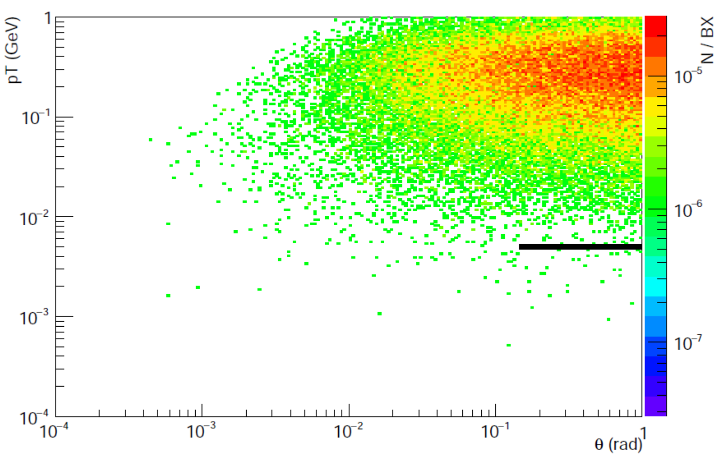
2 GeV threshold on E_{cm} of the 2 photons for hadron production applied in our simulation



E_{cm} of the 2 γ system for hadron production



Energy of produced hadrons



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

IR optimisation vs IR backgrounds

Synchrotron radiation mainly dictates the IR design

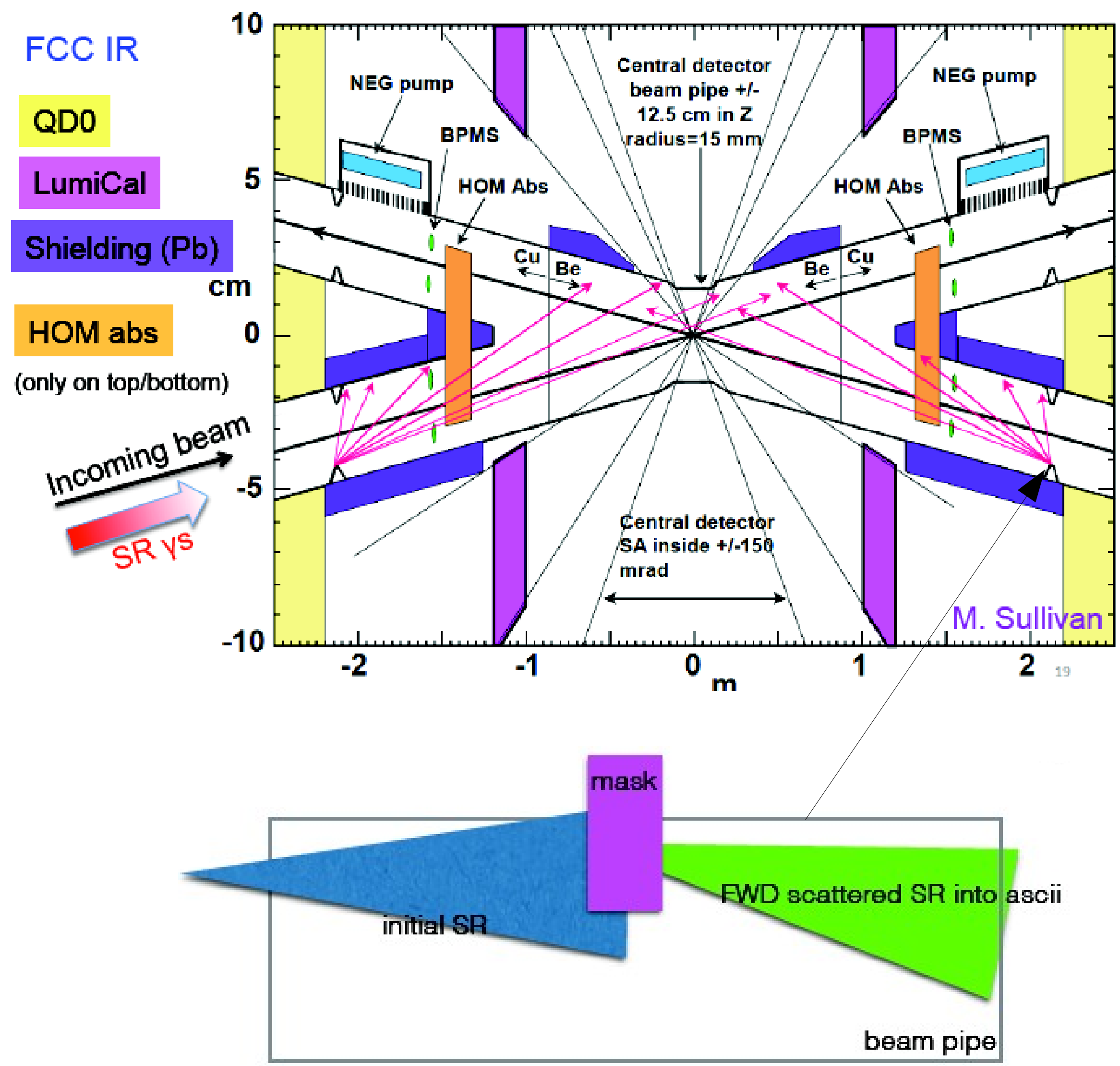
- Defines the beam pipe radius

Mask shields the detector from direct hits

- Some photons are scattered from the tips 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 inside the central 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

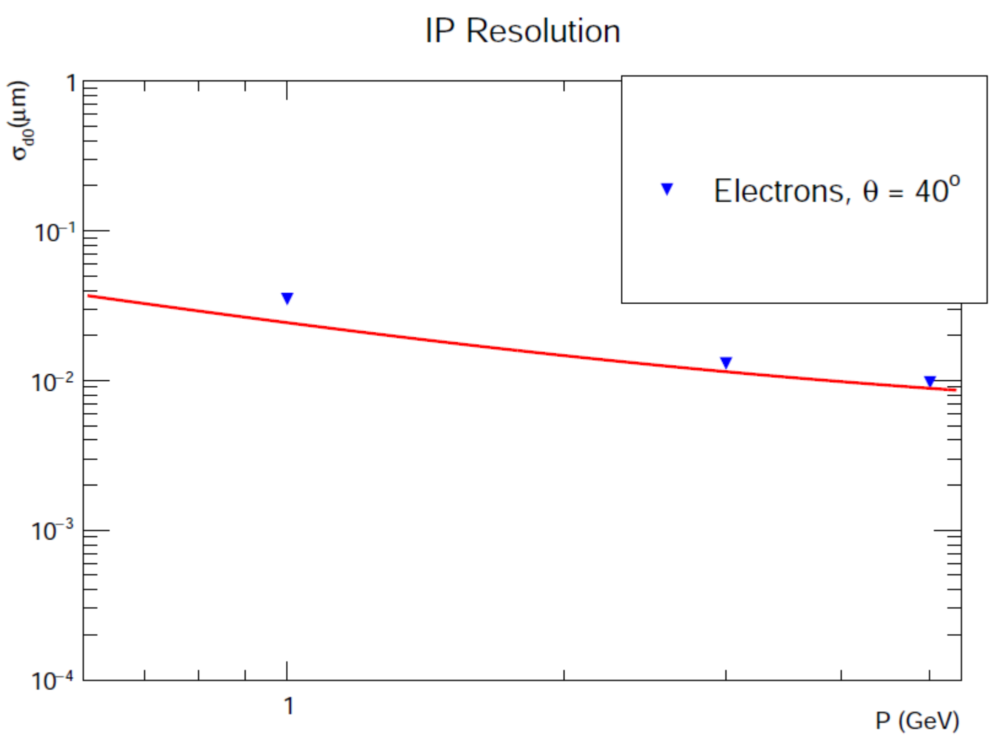
IR optimisation vs physics performance

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



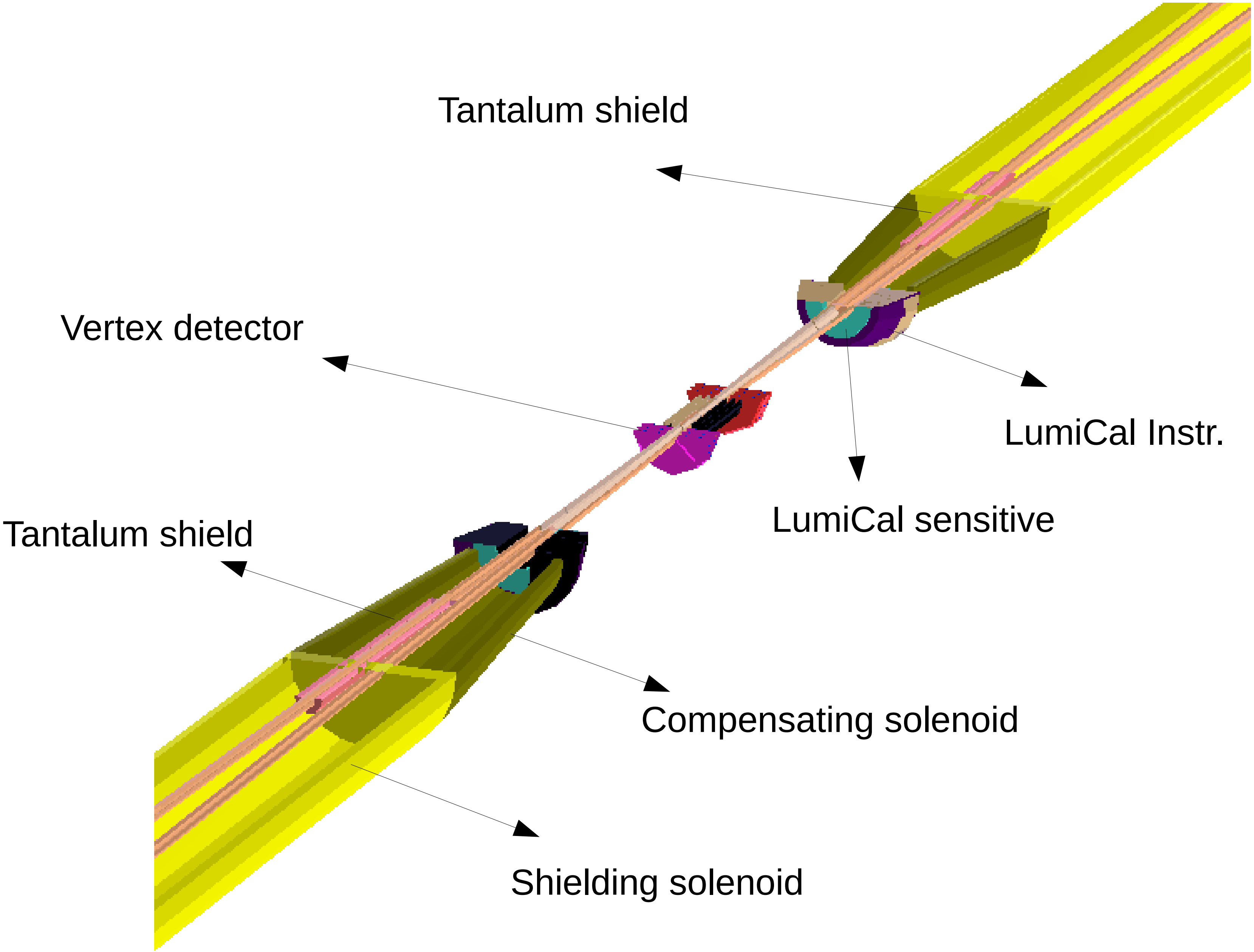
Red line corresponds to the desired impact parameter resolution allowing efficient and pure b- and c-tagging (as was estimated in ILC)

$$\sigma_{IP} = a \oplus b/p\sin^{3/2}\theta$$

$$a \leq 5\mu m,\ b \leq 10\mu m\ GeV$$

Flavour tagging is very sensitive on changes of IP resolution
We are already on the limit
Care should be taken not to further increase the material budget
- Dedicated FT studies are needed

Geant4 description of IR



Comparison with other future colliders

Focus on FCC E_{cm} 350 GeV

- Most unfavourable case for both synchrotron radiation and beamstrahlung

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	
	N / BX			
	total	P_T > 20MeV	total	P_T > 5MeV
IPC	$3x10^5$	60	4000	14
CPC	$6x10^8$	0	0	0
hadrons	102	54	0.05	~0.05
Syn. rad			$\sim 5x10^6$ †	

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

† scattered from the tip of the mask per beam

* From LCD-2011-021

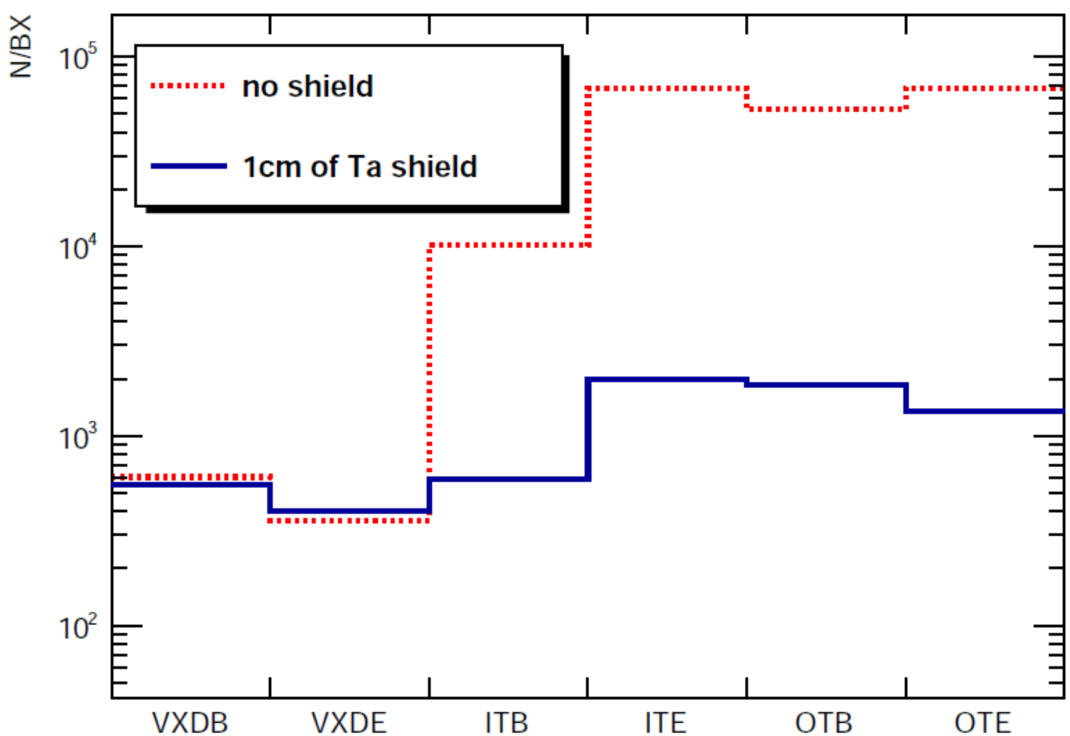
Full simulation studies of effect of various IR backgrounds on the FCC-ee detector

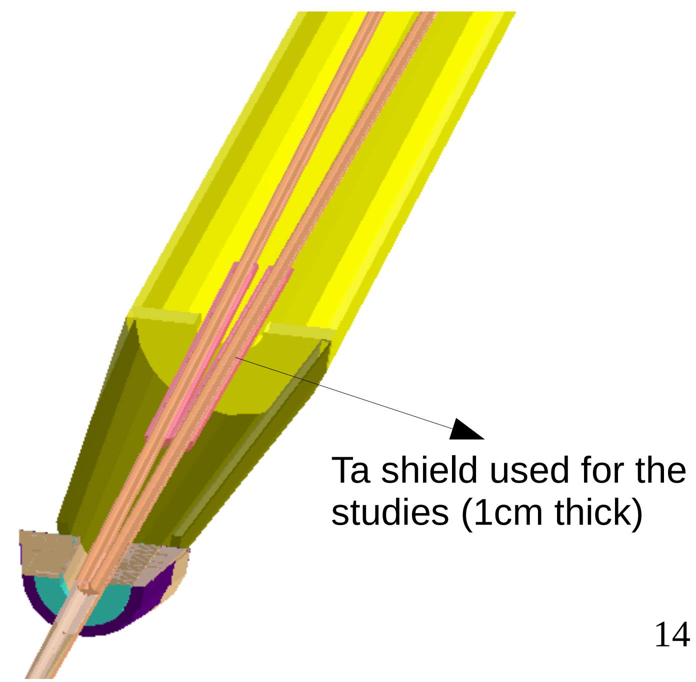
Effect of SR background

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



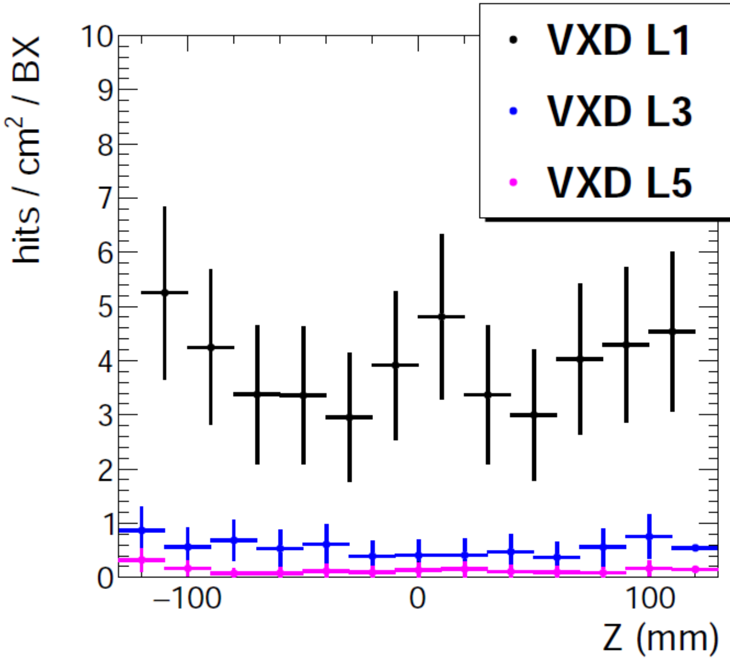


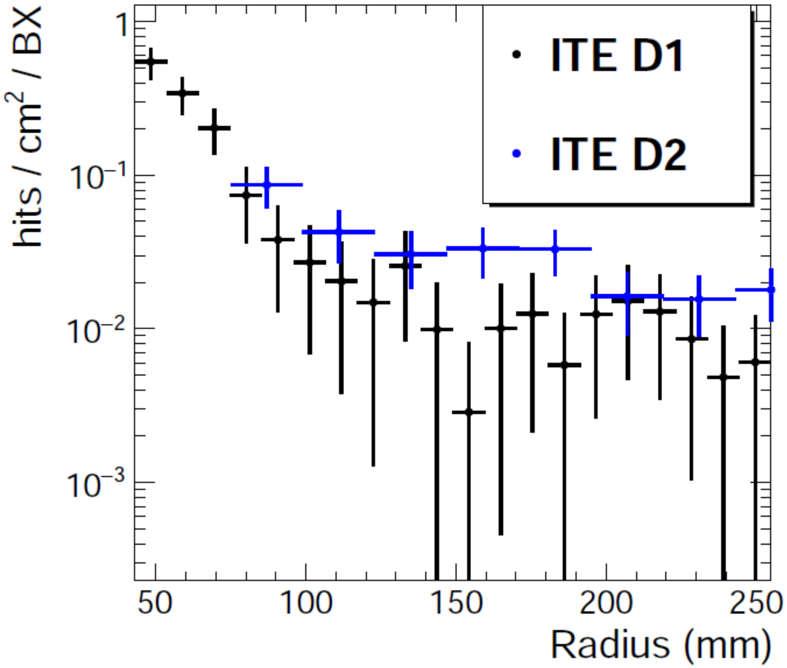
Effect of luminosity induced backgrounds

Pair & hadrons generation with Guinea Pig

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

For the less favourable conditions (E_{cm} 350 GeV)





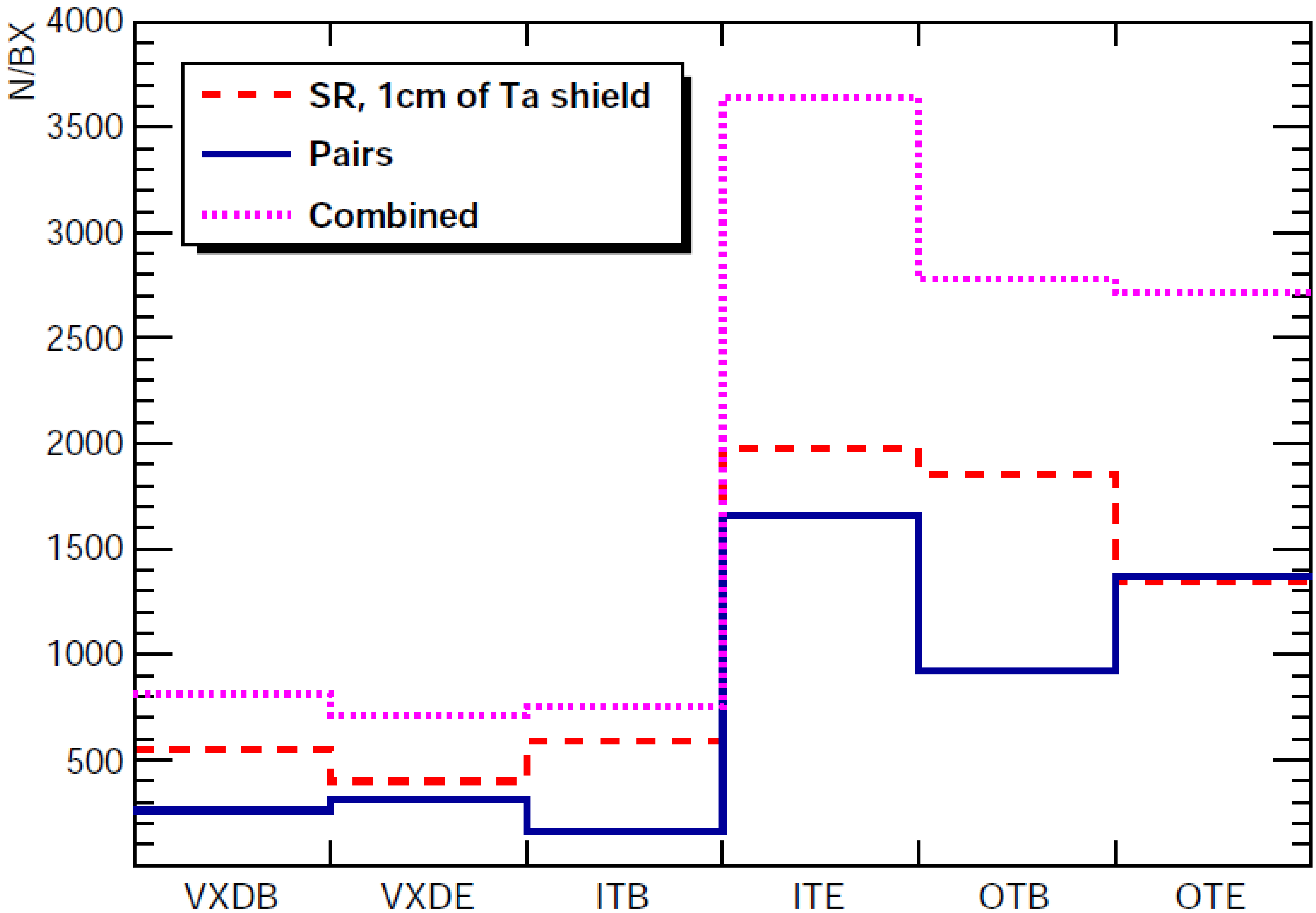
Assuming a pixel pitch of 20µm and an average cluster size of 5

- Occupancy < 10^{-5} for innermost VXD layer
- For E_{cm} 91.2 GeV, occupancy stays ~ 10^{-7}
  - However note the very short bunch spacing of ~ 2.5 – 7.5 ns
  - Fast readout sensors required

Combined effect of all examined sources

E_{cm} 350 GeV

Main contributors are SR & e^+e^- pairs

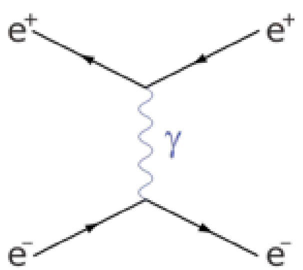


Luminosity measurement

Luminosity monitoring with Bhabha scattering

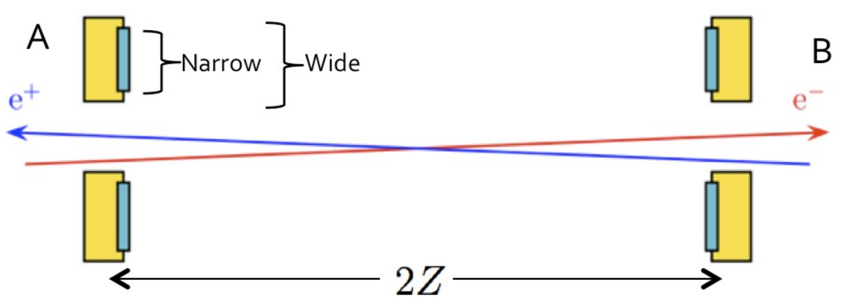
Luminosity monitoring:

- **Absolute** – target precision **10^{-4}**
  - May be best achieved through the process $e^+e^- \rightarrow \gamma\gamma$
- **Relative** for Z lineshape measurement – need a relative precision of **2-5 x 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



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

    - 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:

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

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

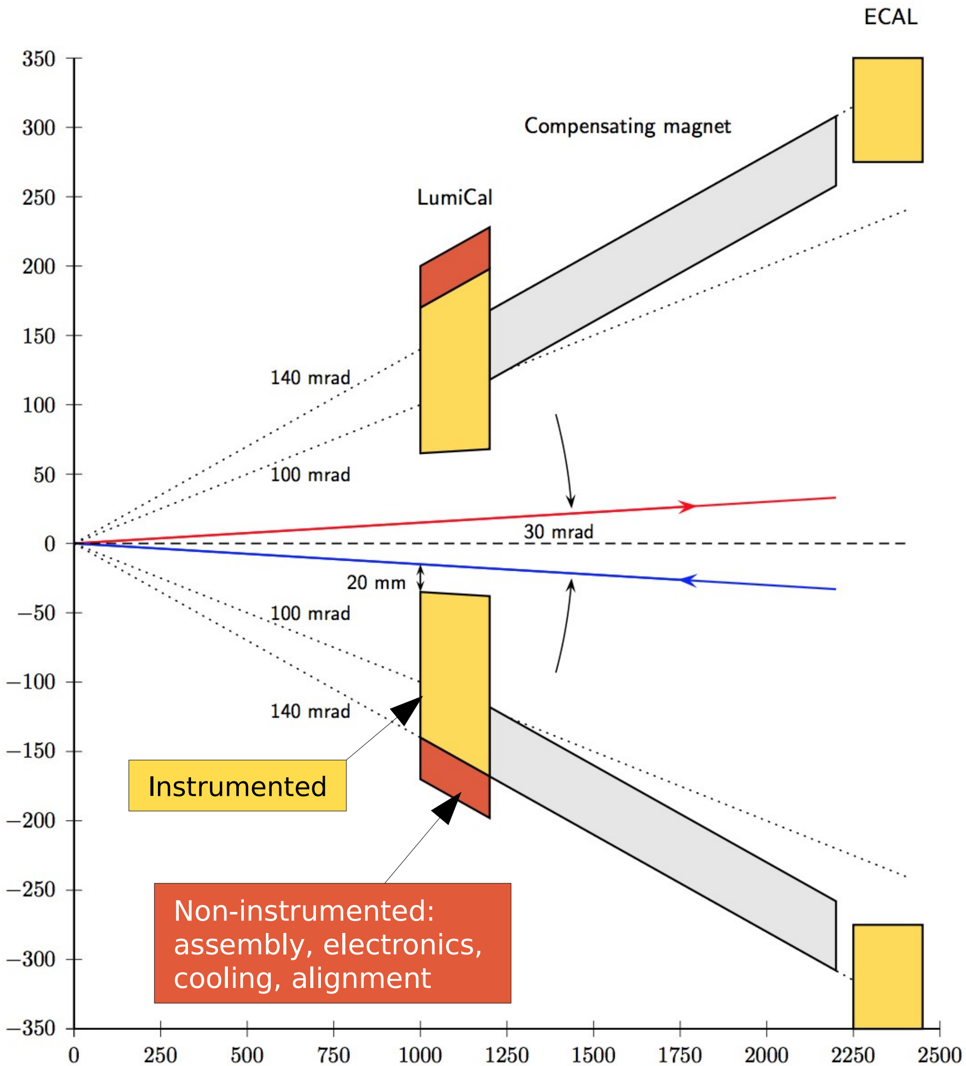
High integrated rate particilarly ar low radii

- Possible need for radiation tolerant sensors and electronics

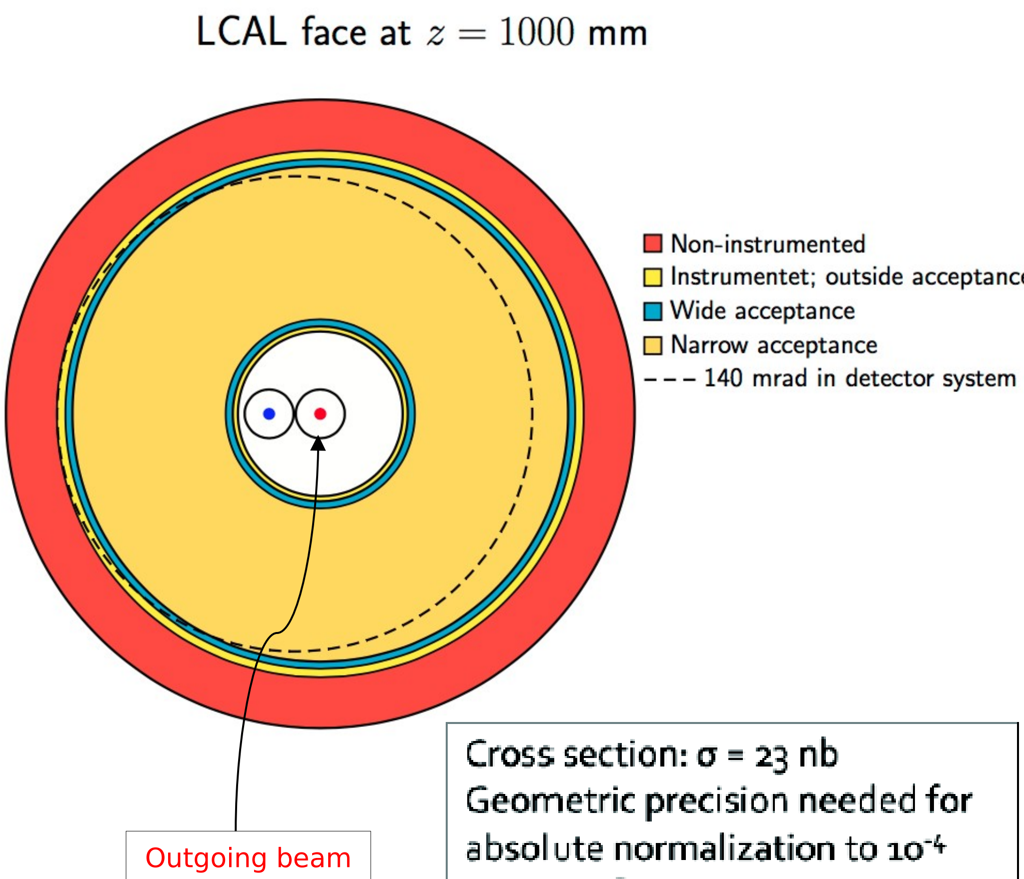
FCC-ee group (Copenhagen) invited to join ILC FCAL Collaboration for discussion of forward instrumentation issues

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

Towards the CDR

To do list

Contributors

As conclusion, we present the structure of the relevant CDR chapters

- We are following the CLIC CDR outline

To do list

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

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

Contributors

Strong team working on MDI from accelerator perspective

From detector point of view:

- Senior : 4-6
- Fellows : 5
- PhD : 1

The above listing includes CLIC collaborators

In addition to that we receive a lot of help from the other members of CLICdp

FCCee CDR
"Physics and Detectors"

1. Introduction
2. Physics Potential
3. Experimental Conditions
   - 3.1. Beam structure
   - 3.2. Constraints from infrastructures
   - 3.3. Interaction region design
   - 3.4. Machine induced backgrounds
     - 3.4.1. Synchrotron radiation
     - 3.4.2. e+/e- pair production
     - 3.4.3. gamma/gamma to hadrons production
     - 3.4.4. beam gas
     - 3.4.5. Radiative Bhabha
     - 3.4.6. Beamstrhalung
     - 3.4.7. Touschek
     - 3.4.8. Summary of backgrounds and comparison with other accelerator complex
   - 3.1. Luminosity measurement and requirements
   - 3.5. …
   - 3.6. …
   - 3.7. Impact of machine induced backgrounds on luminosity measurement
4. Detector description and requirements
   - 4.1. General description
     - 4.4.1. Detector A
     - 4.4.2. …..
     - 4.4.3. Vertex Detector
       - 4.4.3.1. …..
       - 4.4.3.2. ….
       - 4.4.3.3. Impact of machine induced backgrounds on Vertex detector
       - 4.4.3.4. ….
     - 4.4.4. Central Tracker
       - 4.4.4.1. ….
       - 4.4.4.2. ….
       - 4.4.4.3. Impact of machine induced backgrounds on Central Tracker
       - 4.4.4.4. ….
     - 4.4.5. Calorimeters
       - 4.4.5.1. …
       - 4.4.5.2. …
       - 4.4.5.3. Impact of machine induced backgrounds on Calorimeters
       - 4.4.5.4. …

FCC-ee "Physics & Detectors" Book 7

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.

FCC-ee "Accelerator Complex" Book 5

IR Description.
MDI issues.

backup

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 **$\delta L/L = 10^{-4}$**:

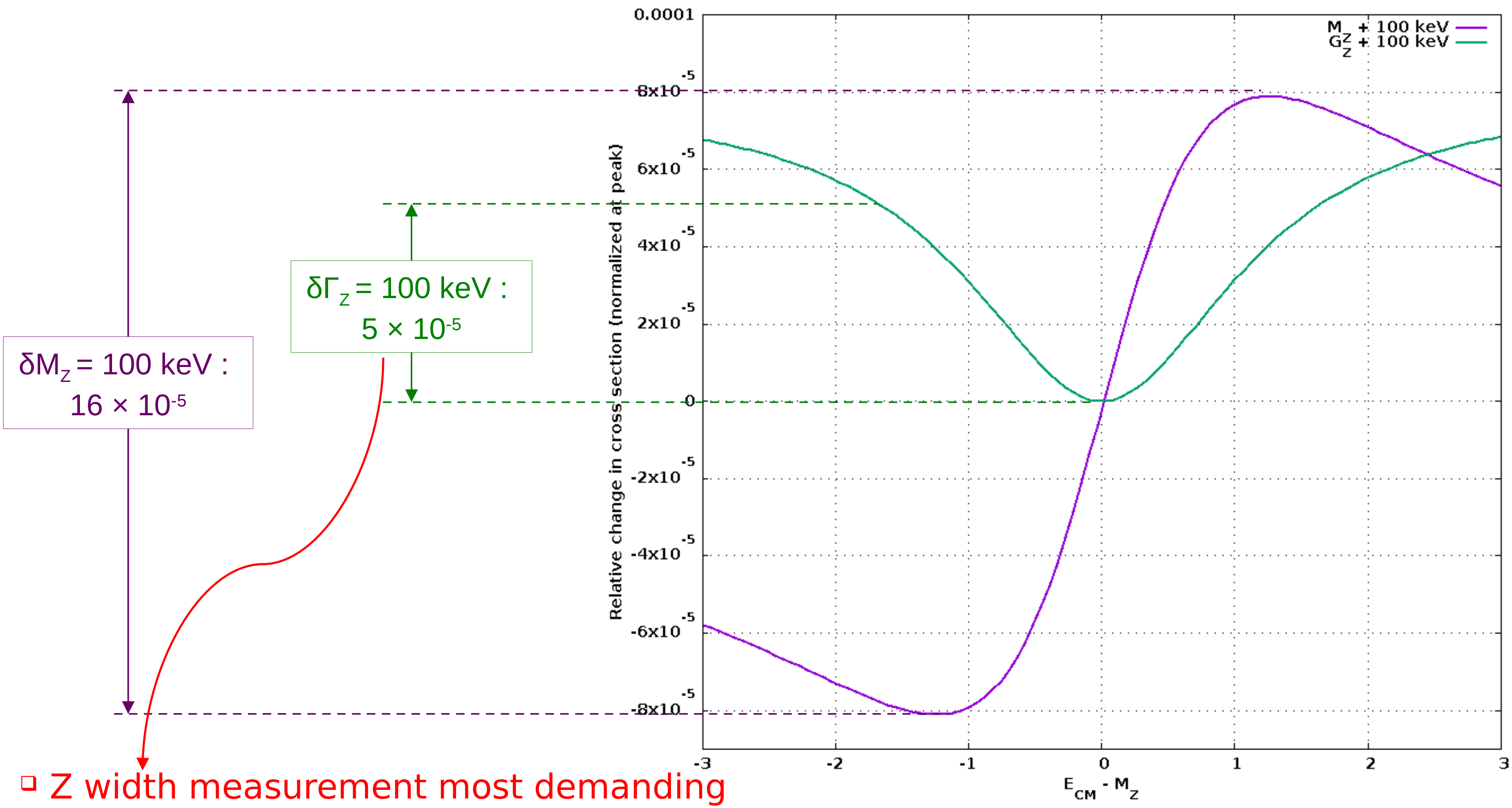
- Distance between face of two calorimeters: **$2\delta z_{face}$ = 100 μm**
- Inner radius of acceptance: **δr_{min} = 2 μm**
- Outer radius of acceptance: **δr_{max} = 18 μm**

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



  - Z width measurement most demanding
    - Need **relative** normalisation to about $\mathbf{2 \times 10^{-5}}$