Istituto Nazionale di Fisica Nucleare

WP2: MDI
Stato e piani futuri

M. Boscolo
for the RD_FA MDI group

RD_FA Collaboration Meeting
3-4 Luglio 2017, Bologna

Anagrafica MDI 2018

M. Boscolo (INFN-LNF), N. Bacchetta (INFN-Pd), E. Belli (Rm1),
O. G. Blanco (LNF), F. Collamati (Rm1), M. Migliorati (Rm1), M. Zobov (LNF)

MDI FCC-ee

M. Boscolo (convener), N. Bacchetta (co-convener), E. Belli, O. G. Blanco,
M. Migliorati, M. Zobov, F. Collamati

MDI FCC-hh

M. Boscolo, F. Collamati
Activity supported by EU-H2020, **EuroCirCol**

Anagrafica **2017**: M. Boscolo, N. Bacchetta, F. Collamati

Current Activity on MDI

FCC-ee

- great progress in the IR layout, now defined in many details, thanks to the combined effort of many people
- Two workshops since last collaboration meeting in November:
  - two-weeks workshop @CERN only on MDI (Jan.'17) http://indico.cern.ch/event/596695
  - FCC WEEK17

  in addition to monthly meetings and weekly meetings by CERN group on detector side
- dedicated talk by E. Belli later

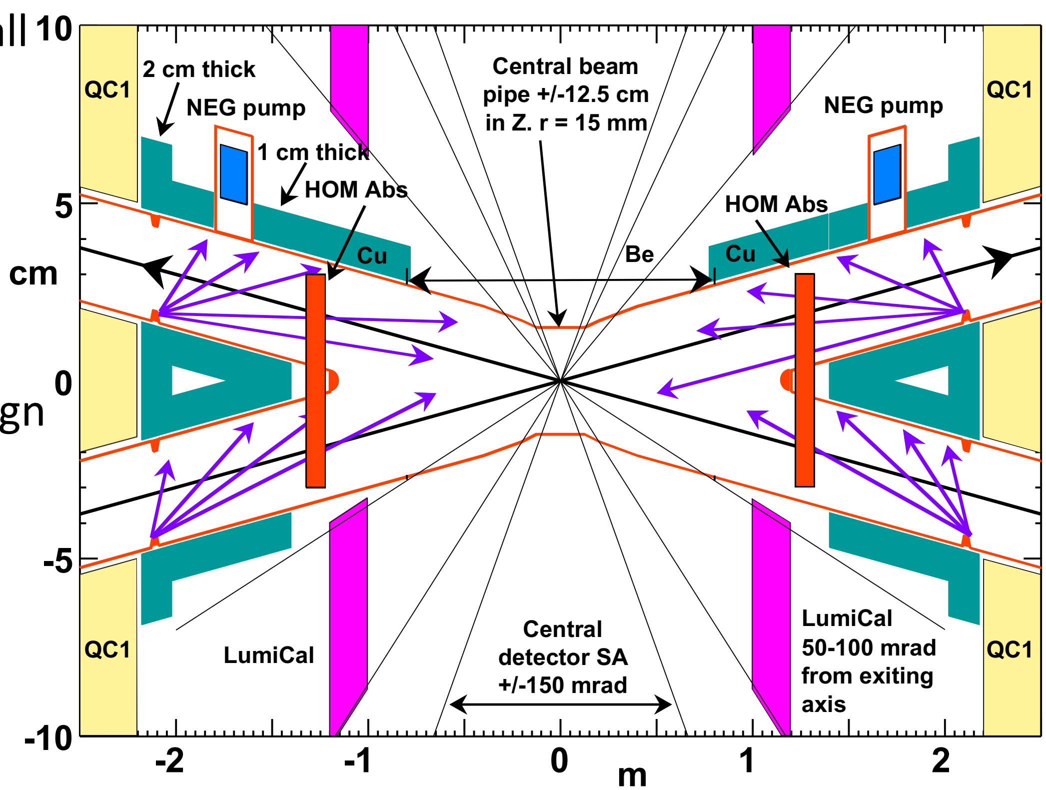
FCC-hh

- characterization of the SR into the IR together with software tools developments, SR power into the detector estimated
- dedicated talk by F. Collamati later

Future Plan: next year will be crucial: studies will be finalized in view of the CDR, to be ready for mid-2019, for the European Strategy Update

Some details on the Main Features of the **FCC-ee MDI** design

- Present baseline **optics** works well for all beam energies, **L*=2.2 m** fulfills the requirements.
- **Symmetric beam pipes** in the FF.
- Detector **Lumical** from 1.0 m to 1.2 m from the IP.
- **Compensating solenoid** in present design starts at 1.25 m.
- **Warm beam pipe, water cooled** .



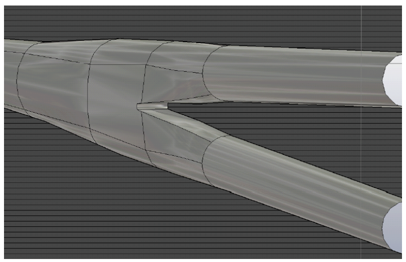
central beam pipe = 30 mm
beam pipe aperture **@QD0 =30 mm**
beam pipe aperture **masks tip**

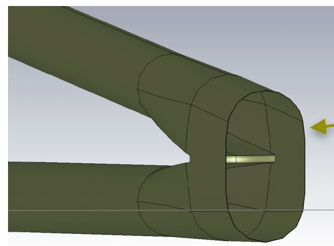
beam pipe aperture@**QF1** = **40 mm**
after QF1 = 60 mm

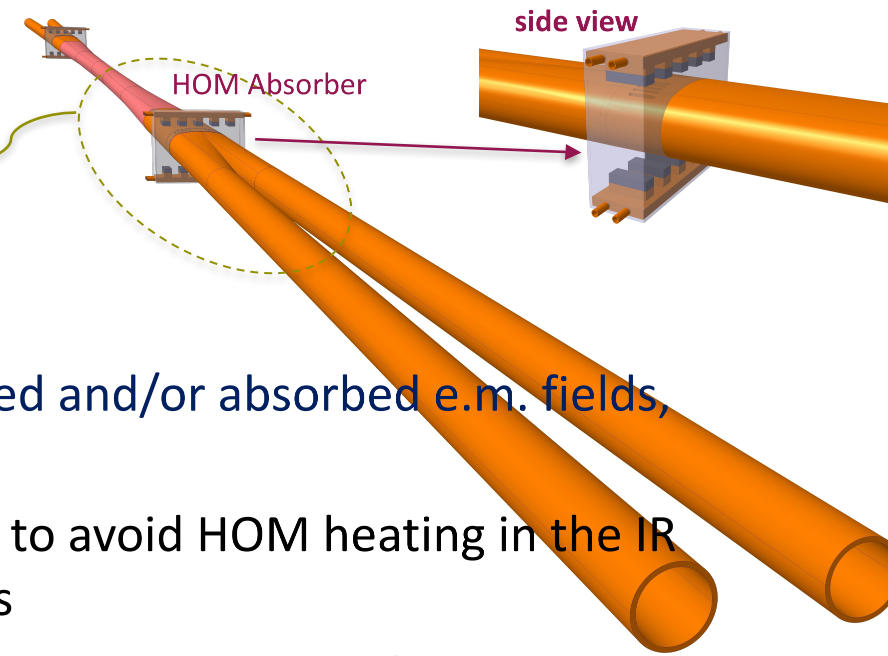
IR Beam pipe design for wake field calculations

Two beam pipes are merged into one central pipe in the IR

- **Professional CAD design** of the complicated **IR** geometry **done**,







essential for:

- **CST/HFSS numerical studies** for generated and/or absorbed e.m. fields, propagating or trapped in the IR
- **water cooling of the beam pipe needed** to avoid HOM heating in the IR chamber due to absorption of e.m. fields
- **HOM absorber** design in progress in the central chamber, following the PEP-II experience.

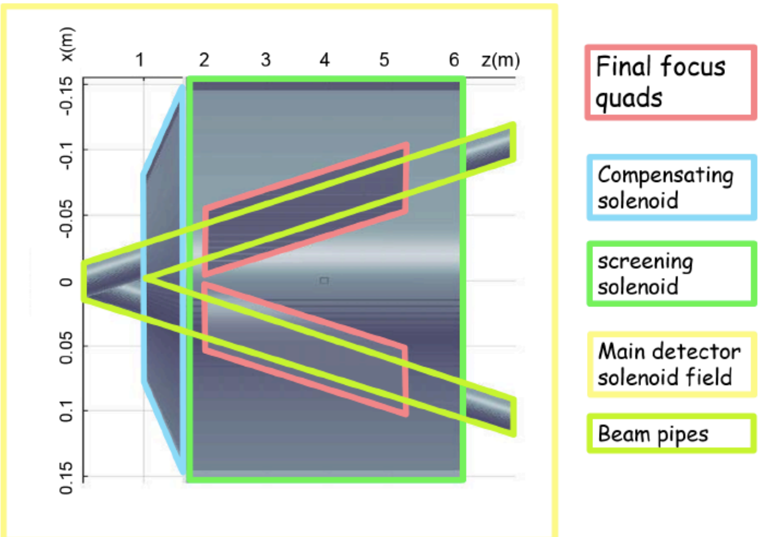
Solenoid Compensation Scheme

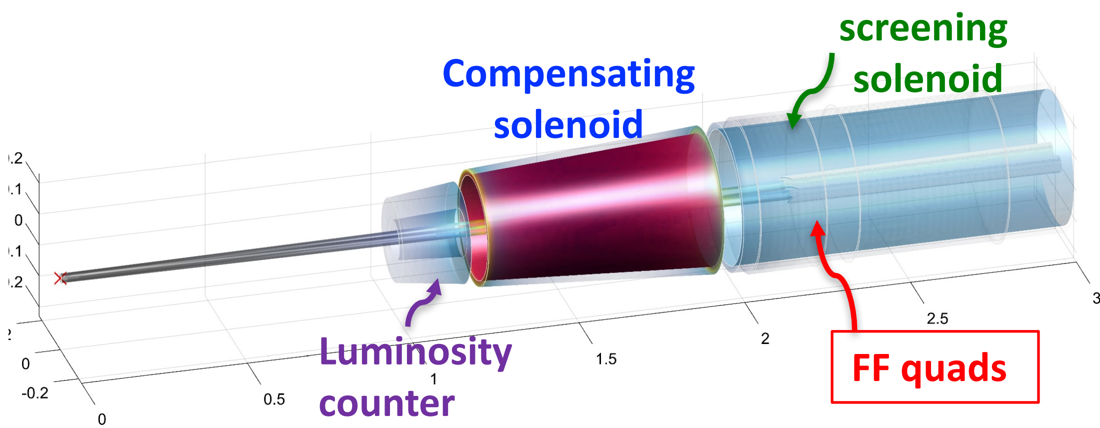
Constraints:

- **2T** detector field
- **L*=2.2m**
- Space (i.e. only 6.6 cm distance at the tip closest to IP for QD0)
- must be inside the lumical acceptance ~**140-170 mrad**
- final focus quads inside the detector (low βy^* and large crossing angle)
- leave space for **luminosity detector** at small angle
- field quality at each end and all along the FF quads $\lesssim 10^{-4}$ for all multipoles
- emittance blow-up much smaller than 1 pm

Particles on the beam axis are not on the detector axis, so they will experience vertical dispersion, that brings vertical emittance blow-up. Due to the low nominal ε_y~1 pm, this effect needs to be cured. A compensating and screening **solenoid scheme** has been designed.

Solenoid Compensation Scheme





Two solenoids are introduced in the IR:

- **screening solenoid** that shields the detector field inside the quads (in the quad net solenoidal field=0)
- **compensating solenoid** in front of the first quad, as close as possible, to reduce the ε_y blow-up (integral BL~0)

0.3 pm is the overall ε_y blow-up for 2IPs @Z with this compensation design

- A few design choices have been proposed.
- Prototyping for a double aperture quadrupole has been going on at BINP.

Background considerations for the IR design

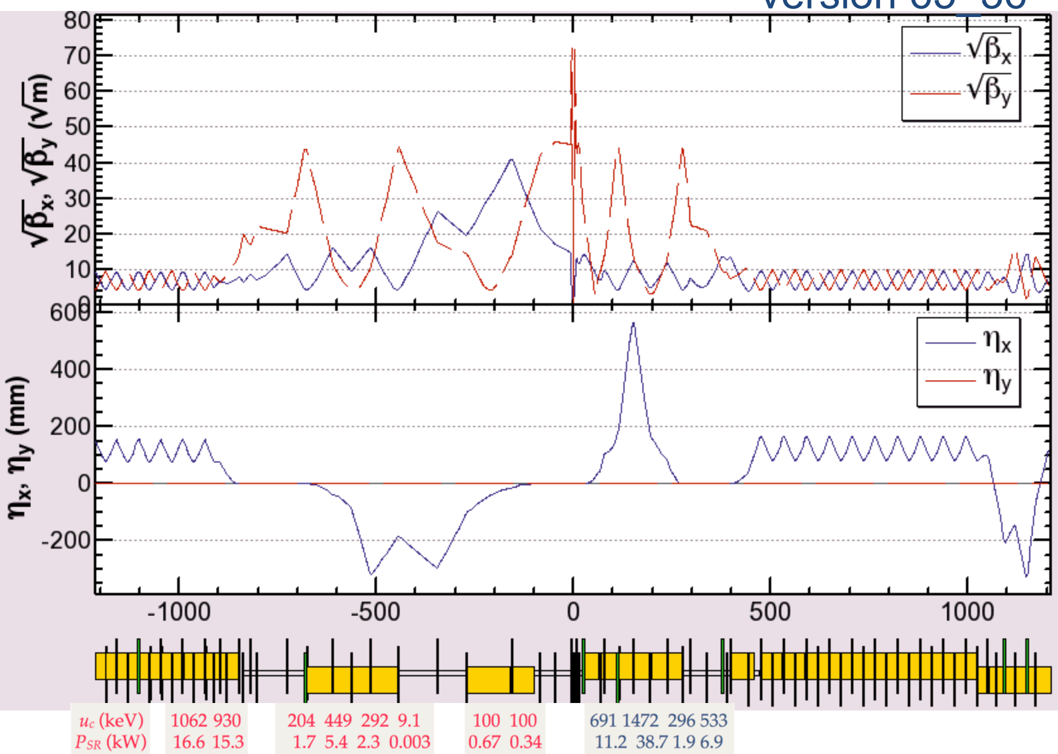
- Minimization of the effects of SR has been a fundamental driver for the design of the interaction region (and optics)
- SR simulation obtained with MDISIM (*H.Burkhardt, M.Boscolo*) and dedicated software (*M.Sullivan*)

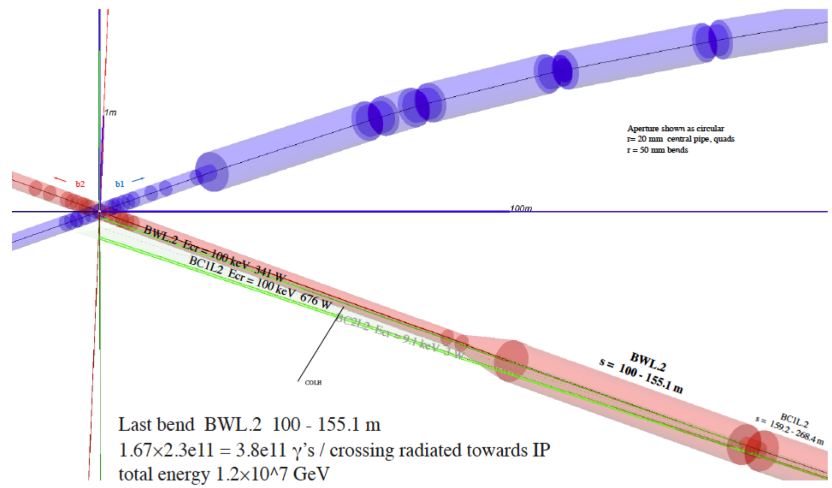
Optics main requirements

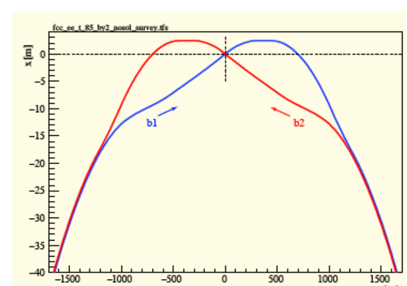
- Crab waist scheme
- 2 IPs
- β*x/y = 0.5m/1mm (1m/2mm)
- Vertical emittance 1 pm (@Z energy)
- Horizontal emittance ~1 nm (@t energy)
- Energy acceptance +/- 2%
- Eγ,c < 100 KeV within ±250m from IP
- As close as possible to the FCC-hh beam line

K.Oide

version 65_36







H.Burkhardt

Some details on the Main Features of the **FCC-ee Synchrotron Radiation in the IR**

Synchrotron Radiation is the main constraint for IR design and it drives the IR optics and layout

General requirement for the optics based on LEP experience:

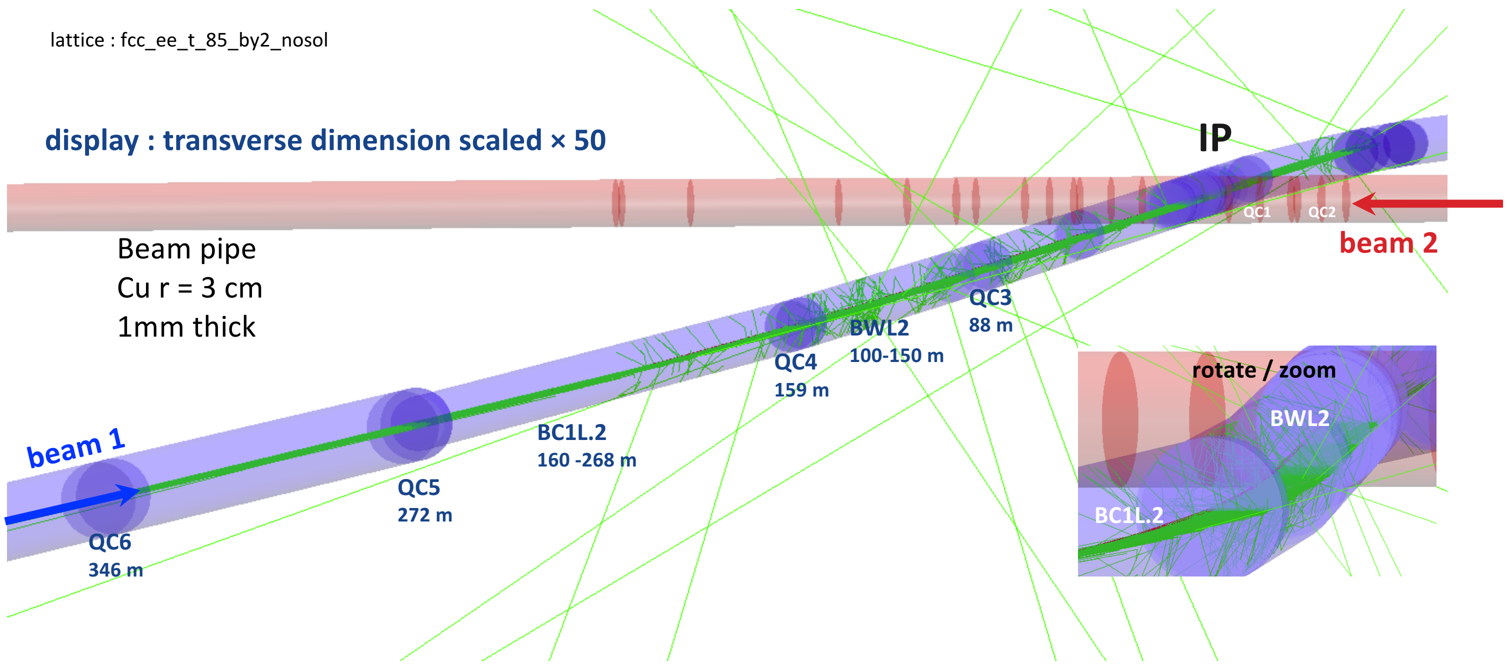
1. Weak bends $E_{critical}$ < 100 keV (LEP2 was 72 keV)
2. Weak bends far from IP (LEP2 was 260 m from IP)
3. Keep Ecr $\lesssim$ 1 MeV in whole ring, to minimize n-production (LEP2 0.72 MeV)

Various lattice options have been studied in detail with different approaches*

- **MDISim** (flexible software toolkit developed by H. Burkhardt et al.)
  - ROOT based machine detector interface toolbox described by MAD-X sequence
  - particle interactions in the IR/detector regions using GEANT4
- SYNC_BKG (modified version by M. Sullivan)
- SYNRAD+ (R. Kersevan)

[* studies for FCC WEEK2016: M. Boscolo *et al.,* Phys.Rev. AB 19 (2017) 20, 011008]

3d display - **FCC-ee** SR MDISim – Geant4 simulation



(Gaussian) beam 1, 5000 e+ 175 GeV

tracked 510 m to IP **(just after BC3 to Q2)**

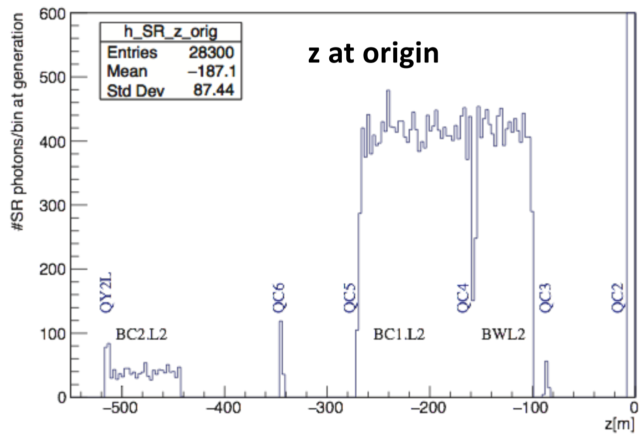
with SR and standard G4 em processes eloni, eBrem, annihil, phot, compt, conv, Rayl

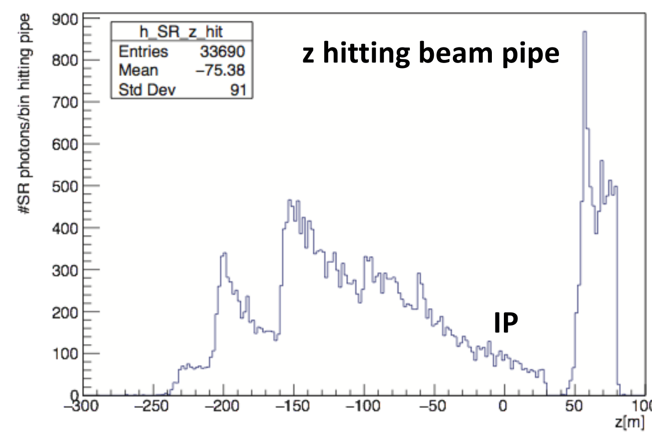
28300 SR γ's generated, **first 1000 γ's shown here**

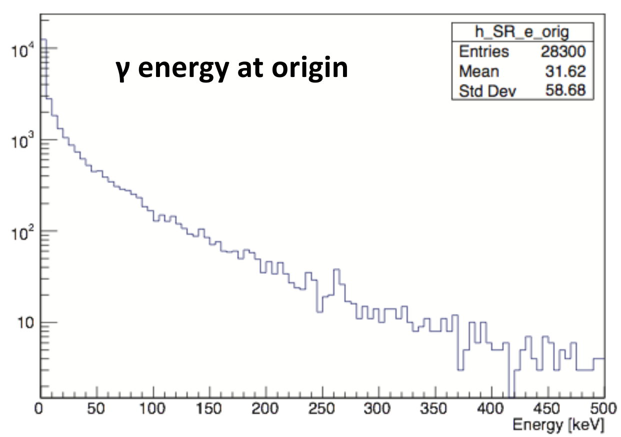
rather fast, < 1 min (MacMini i7)

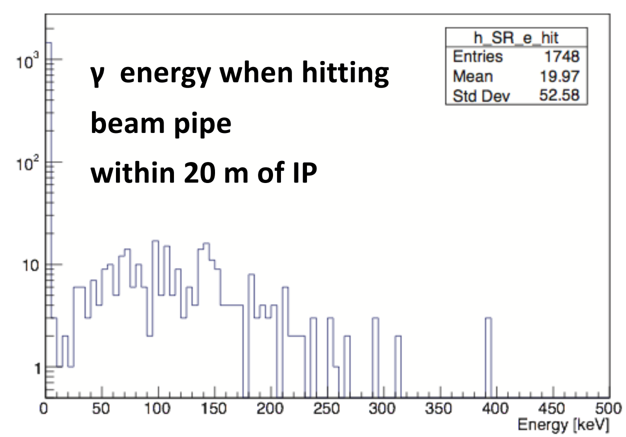
multiply with
2.3e+11/5000 = 4.6e7
to get statistics of 1 bunch
1.3e12 SR γ's

distributions of these photons





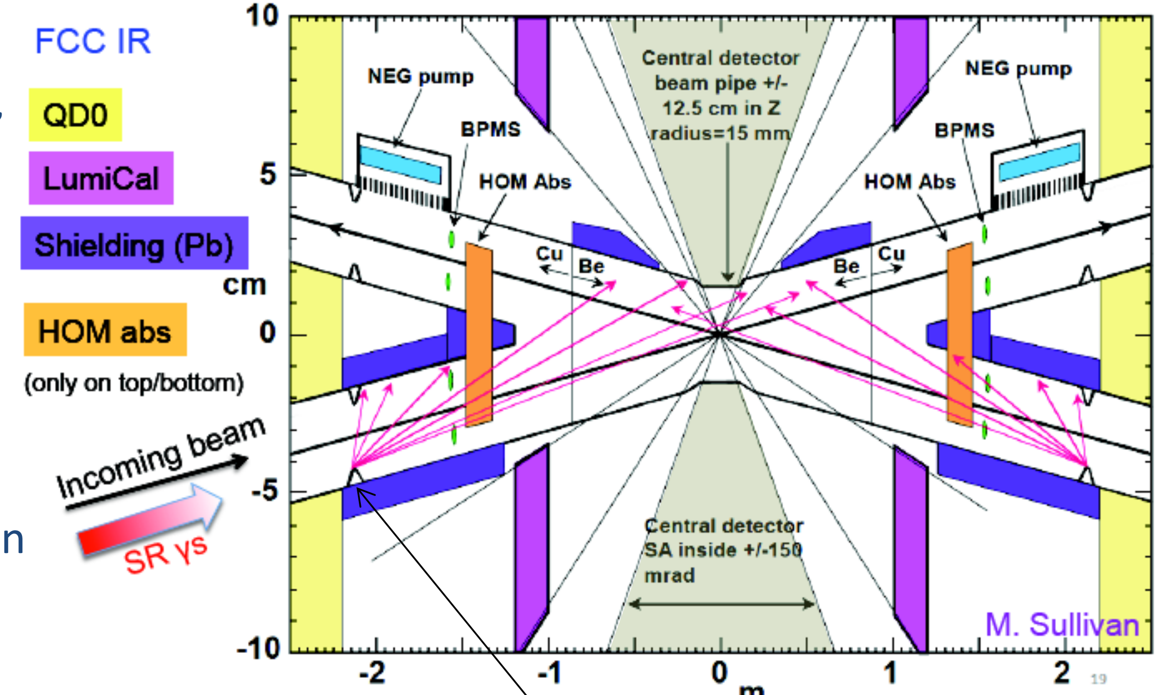




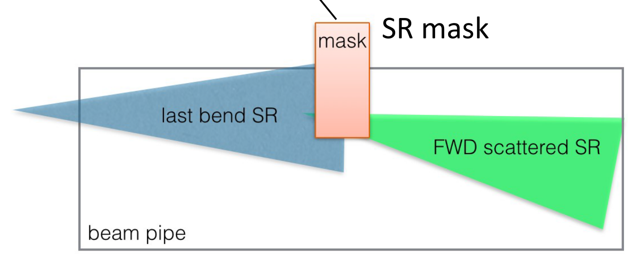
Background considerations for the IR design

IR features driven by background considerations:

- SR defines the beam pipe radius, position of masks and shields
- Masks 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
- Extra 5 µm Au layer coating on the central section of the beam pipe:
  - Absorbs photon & reduces heat on beam pipe
  - Still sufficiently thin not to degrade impact resolution

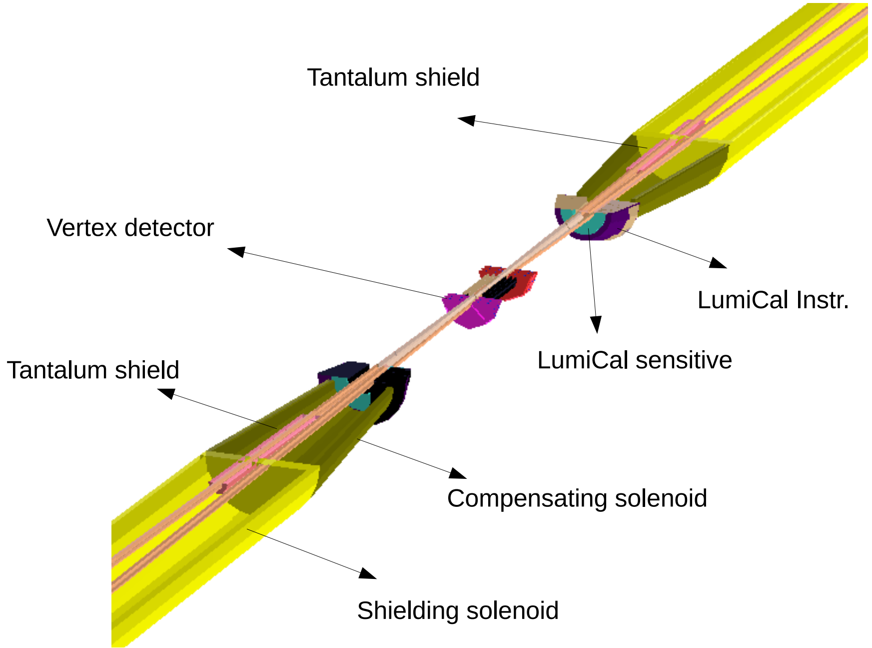


Detector to stay in region limited to +/- 150mrad



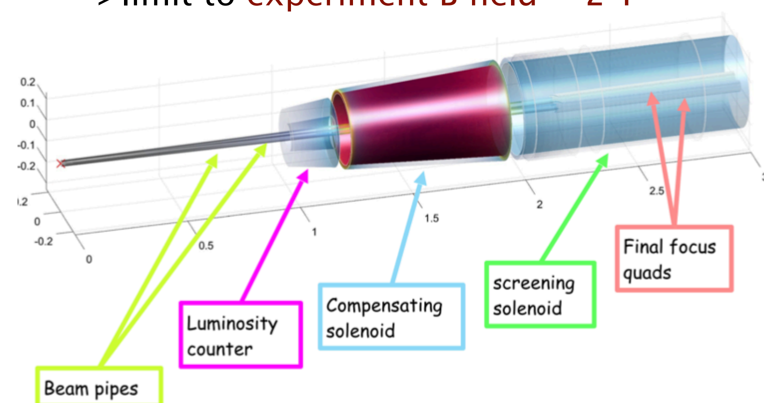
For SR, we study the impact on detector elements of the photons emerging from the mask

Geant4 description of the interaction region & detector



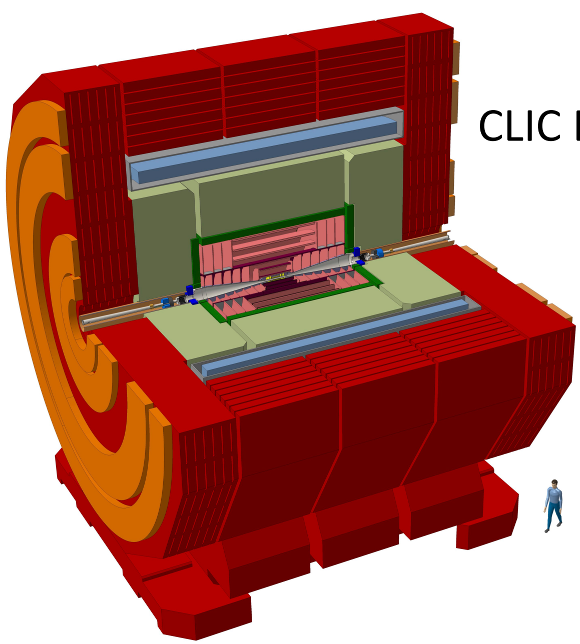
- Last focusing quadrupole close to IP (L*=2.2m)
- Compensating solenoid to prevent emittance blow-up due to non-zero crossing angle

=>limit to experiment B field = 2 T



energy/beam [GeV]	45	120	175
bunches/beam	70760	770	78
Bunch spacing [ns]	3.0	400	4000

- Large number of bunches —> crossing angle 30mrad to avoid parasitic collisions



Original CLIC design adapted mainly to cope with FCC-ee IR and 2T magnet:

1. Vertex layers closer to beam line
2. Extended Tracker to compensate for lower B
3. HCAL shrunk to 5.5 interaction lengths
4. Yoke shrunk for smaller B

Backgrounds

- We have performed full simulation studies of effects of various backgrounds mostly on the Vertex and Tracker (more recently also on the luminosity monitor) part of the modified CLIC detector, estimating hit density/ occupancy/ deposited energy.

- Focus on Ecm = 350 GeV (tt) as worse case scenario for most of the considered backgrounds.

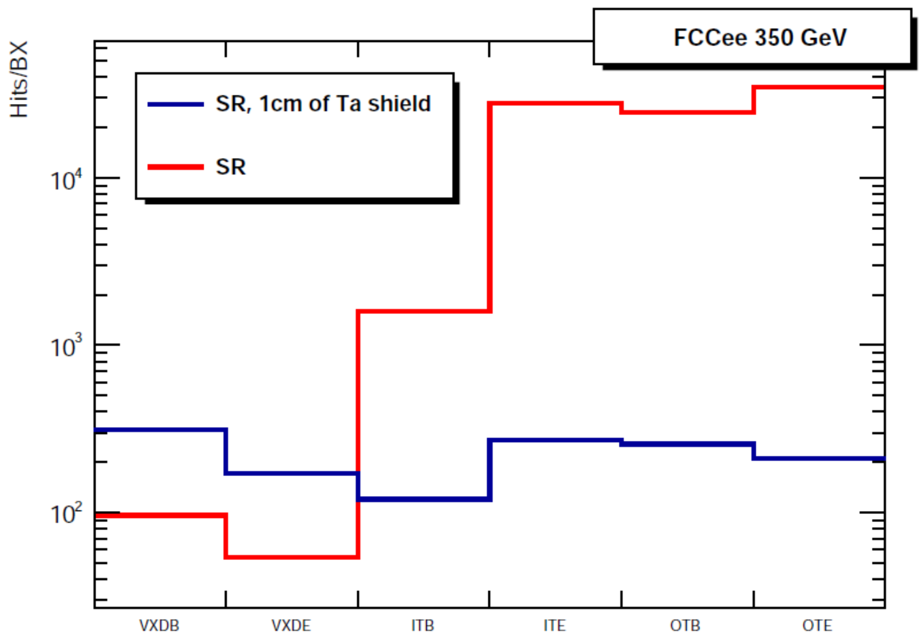
- Studied:
  - Synchrotron radiation
  - e^+e^- pair production
  - γγ to hadrons

Synchrotron Radiation

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



1:

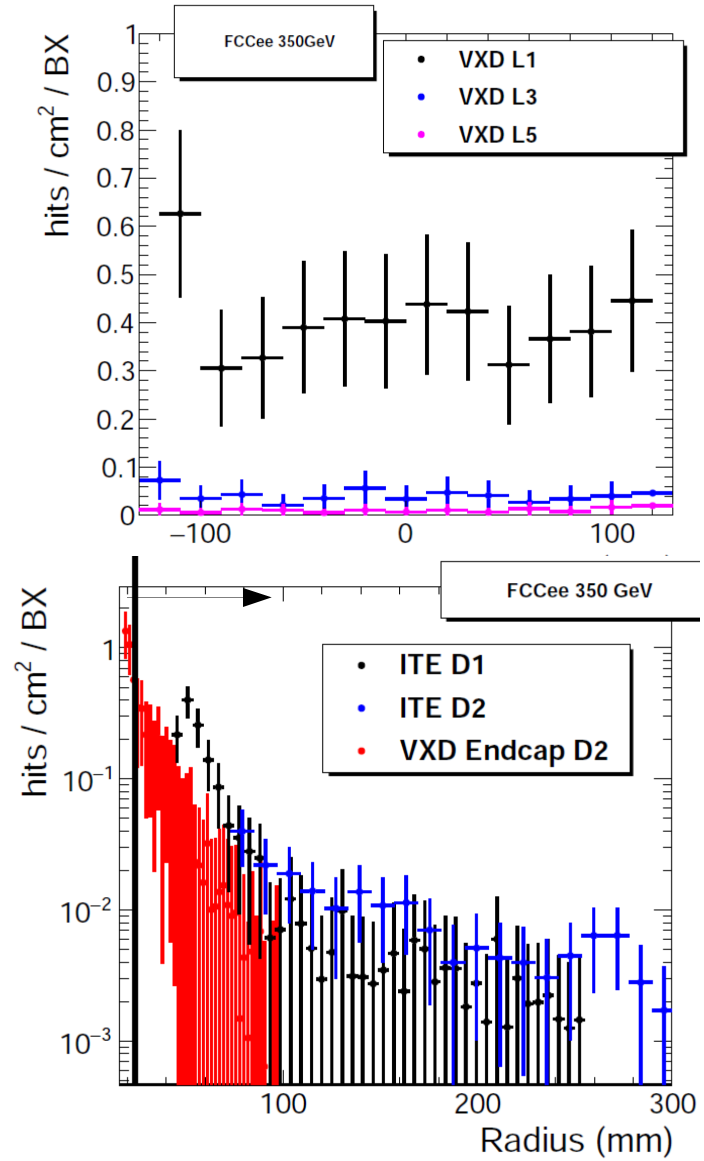
Pair Production

Pairs generation with Guinea Pig

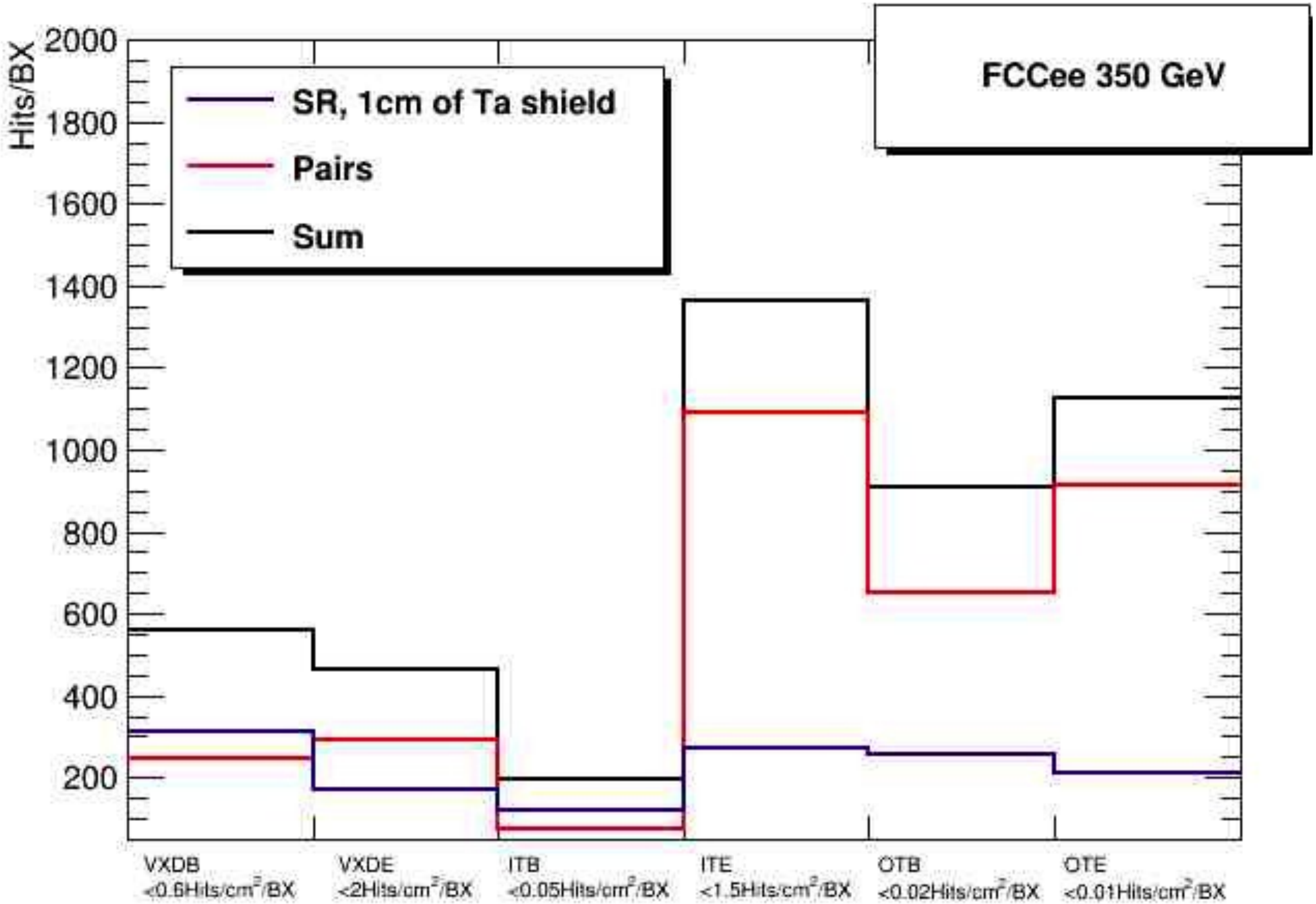
Full simulation studies using DD4hep ILCSoft (geant4 based simulation) / ILCSoft

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 ~ 2×10^{-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 ~ 2×10^{-3}



Combined effect of SR and Pairs



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

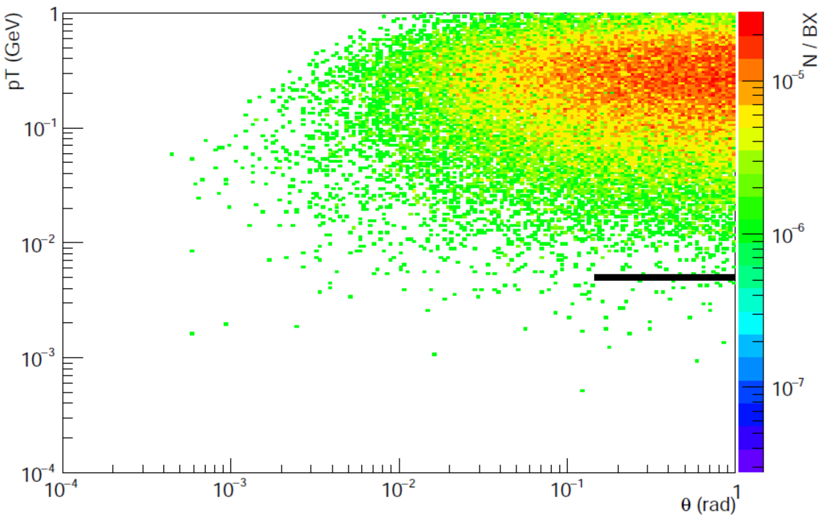
Gamma-gamma to Hadrons

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

8

Next

Synchrotron Radiation studies:

- Continue optimization of the SR masks and shielding
- Beam pipe heating due to SR
- Examine efficiency of SR absorption of various beam pipe shapes (masks)
- Ongoing effort on integrating Geant4 simulation of the detector with upstream beamline

Impact of IR backgrounds on Luminosity Calorimeter

Study of other backgrounds:

- Ongoing study on beam-gas interactions
- Ongoing study of radiative bhabhas
- Evaluate touschek backgrounds

Radiation damage to detectors

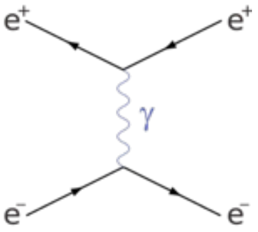
Impact of backgrounds on sensors readout payload

Repeat these studies for IDEA detector.

Luminosity Detector (I)

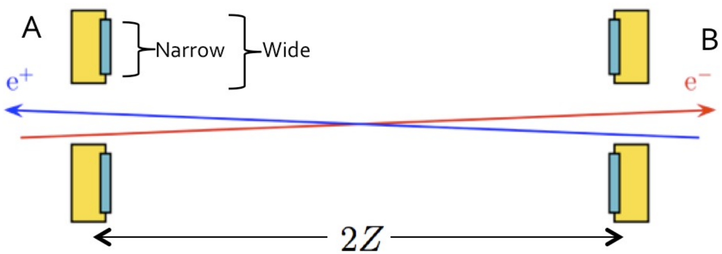
Luminosity monitoring:

- **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 $\mathbf{2\text{-}5 \times 10^{-5}}$
  - Need cross section comparable to Z production:, i.e. ≥ 15 nb
  - Can be achieved via **small angle Bhabha scattering** $\mathbf{e^+e^- \to e^+e^-}$
    - 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

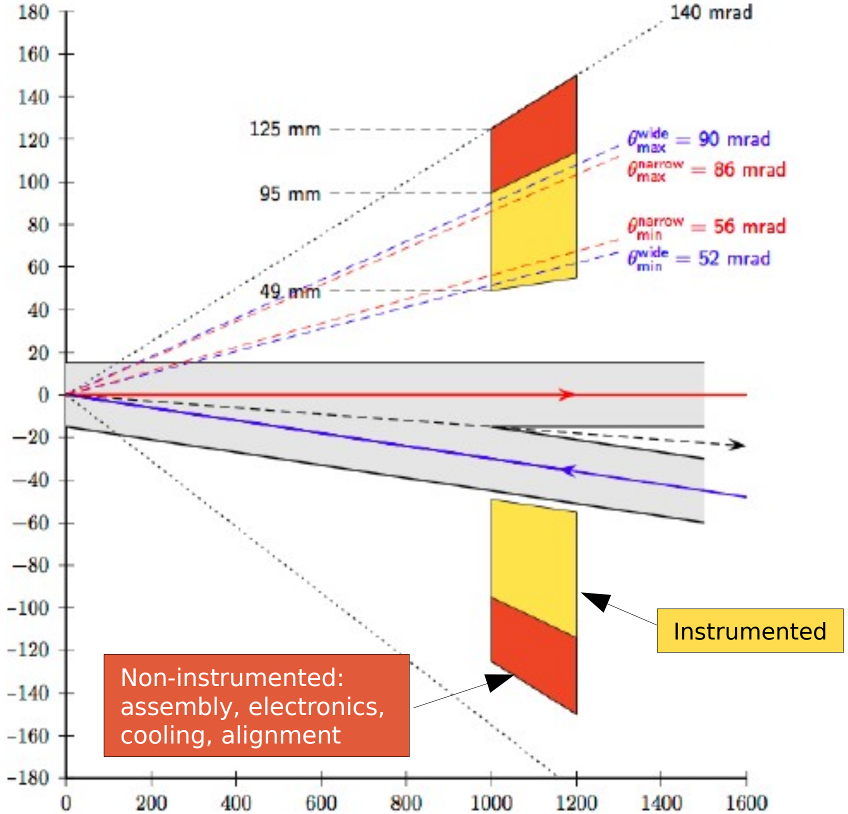
- Average over SideA and SideB rates: Only dependent to second order on beam parameters:

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

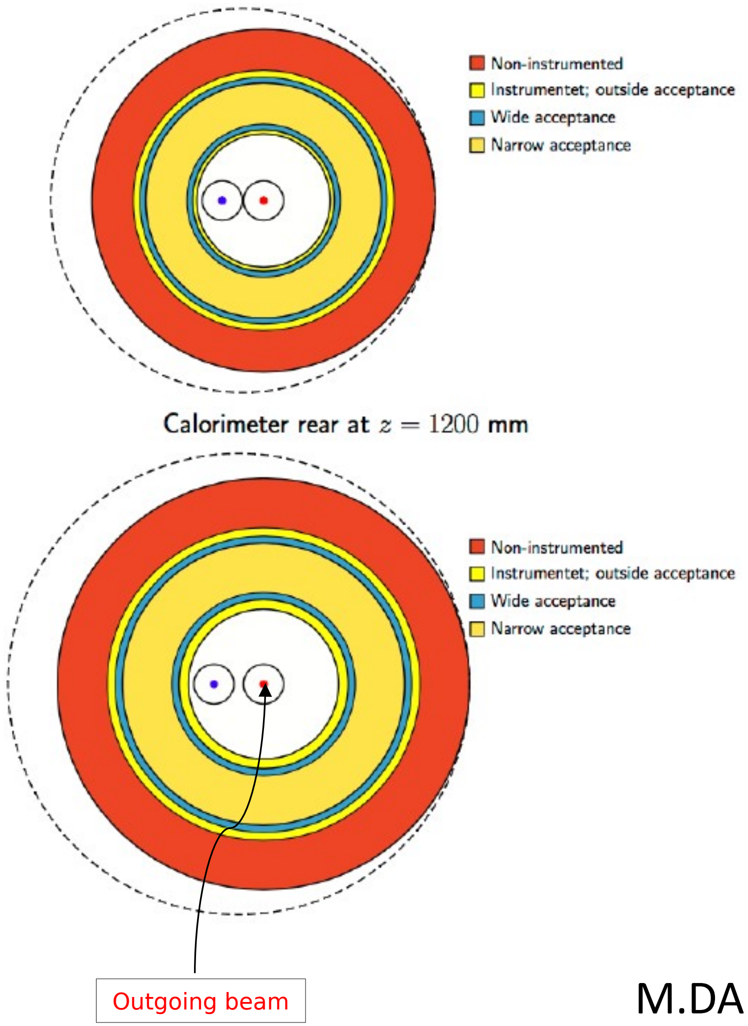
M.DAM

Luminosity Detector (II)

Side view



End view



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

- δz = 50 µm
- $\boxed{\delta r_{min} = 1.6\ \mu m}$
- δr_{max} = 5.8 µm

Still a big challenge given the available space in the IR

M.DAM

Luminosity Detector (III)

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

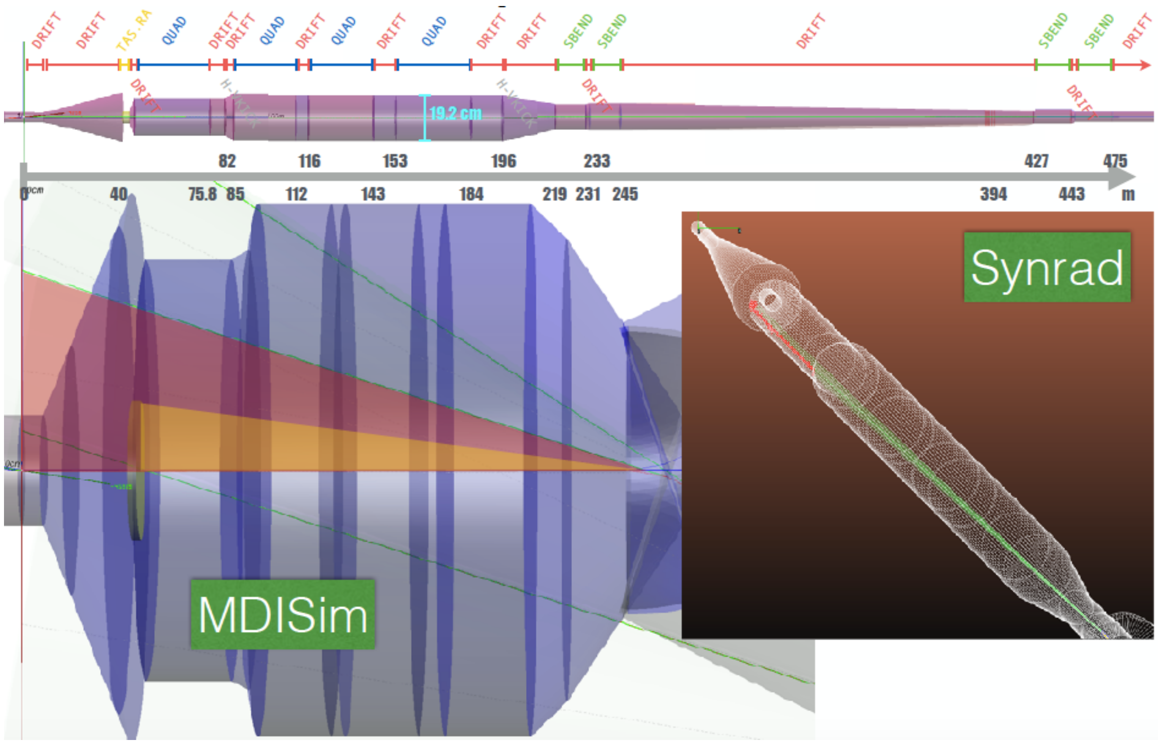
FCC-ee group (Copenhagen) invited to join ILC FCAL Collaboration for discussion of forward instrumentation issues

FCC-ee: Conclusion and Future Steps

- **Wake fields** calculations in IR in progress, also different chamber geometries under investigation
- **HOM absorber** in the central chamber needs further optimization
- **Vacuum Chamber heating** estimate and **water cooling** system
- Optimization of **SR masks, shielding, collimators, absorbers** also with full simulation
- **Solenoid Field maps** for more realistic studies (like SR from fringe solenoid fields, ..)
- Study of other **IR backgrounds** (off-momentum beam particles, beam-gas, radiative bhabha, complete $\gamma\gamma$-> hadrons)
- Full **G4 detector simulation** combined with the detailed IR geometry
- **QD0 design**: different proposals and design in progress
- **Injection backgrounds**
- Electron Cloud studies in the IR in progress, SEY<1.1 needed to avoid build-up
- More work will be needed for a more realistic and engineered design of the IR

FCC-hh MDI

- LNF-INFN is part of WP3-EuroCirCol, with the study on the impact of SR in the Experiments
- See next talk by F. Collamati for details



Summary of SR study in EIR for FCC-hh

See next talk by F. Collamati for details

- Synchrotron Radiation emitted in the last bends (500m from the IP) is not an issue:
  - The emitted Power is IN TOTAL ~100 W (=upper limit in all beam conditions)
  - The fraction of this power entering the TAS is ~10 W with/without crossing angle
  - Orbit correctors contribute for ~ W (~10x lower than bends)
  - The emitted photons, even if numerous (~1E10 per bunch), have a critical energy of 1keV
  - They are safely stopped within the pipe (no full simulation needed!)
- even in a non-collision scheme (beam separation at IP) we can use as a reference (extreme) value the 100 W limit -> safe limit

- Further studies:
  - Quantify why 10W is low (where these photons shine to and what needs to be cooled)
  - Study the effect of spectrometer bends (even though this is alternative detector model now)
  - Evaluate the effect of the high energy photons (tail of the distribution)

Conclusioni & Preventivi

- Next year will be crucial: studies will be finalized in view of the CDR, to be ready for mid-2019, for the European Strategy Update

- Richieste: spese missione
- LNF: 6 kEuro
- Roma-1: 4 kE