FCC-ee Interaction Region Backgrounds

Yorgos Voutsinas, on behalf of the FCCee MDI group

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Outline

- FCCee MDI region challenges and design
- Interaction region bkgs and effect on the detectors
    - Focus on synchrotron radiation and $e^- e^+$ pairs
    - Backgrounds from beam–gas interaction and radiative Bhabhas will be also presented

Introduction

Double ring e^+e^- collider $\sim 100\ km$

- Share same footprint with FCChh

Flexible design: it will run in four E_{cm} : 91.2, 160, 240 and 365 GeV

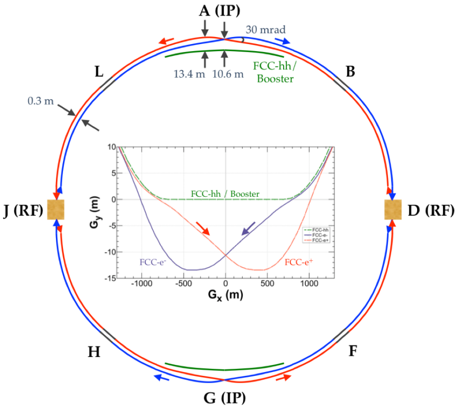
- With respective luminosities (in units of $10^{34} cm^2 s^{-1}$): 230, 28, 8.5, 1.55

Study started few years ago as TLEP
CDR concise summary volume was published end of 2018
Two Interaction Points

30mrad crossing angle along x-axis

Crab waist scheme used

Interaction Region (IR) design is driven mainly by luminosity requirements & mitigation of Synchrotron Radiation (SR)



Experimental constraints

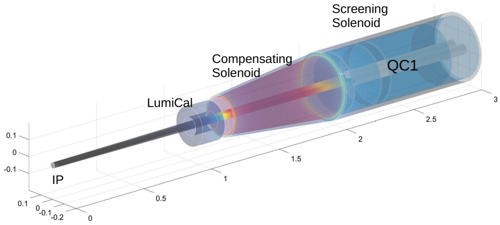
Experimental constraints defining the IR/detector design

- Synchrotron radiation (SR) mitigation: asymmetric IR optics and masking/shielding to protect the detector from SR hits
- SR defines beam pipe radius
- Luminosity requirements necessitate a compensating solenoid scheme and therefore define the detector's B field
- Higher order modes: beam pipe radius and split vacuum chamber design

Final Focus - Solenoid Compensation Scheme

Luminosity goals (Z peak) call for FF quads to be placed very close to the IP

- $\epsilon_y \sim pm \rightarrow L* \sim 2.2m \rightarrow$ the FF quadropole is inside the detector's solenoid field
    - A screening solenoid placed around FF quad to shield from detector's field
- 30mrad crossing angle
    - Could lead to an emittance blow up
    - Placement of a compensating solenoid of a high magnetic field,so that the field integral seen by the beam will be 0
    - Should be placed as close as possible to IP



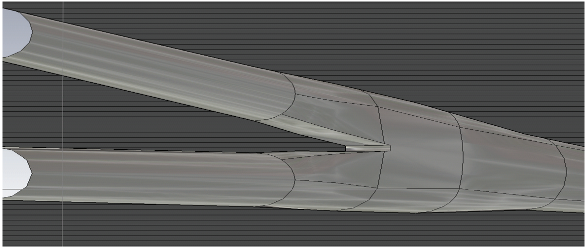
Limited space in IR

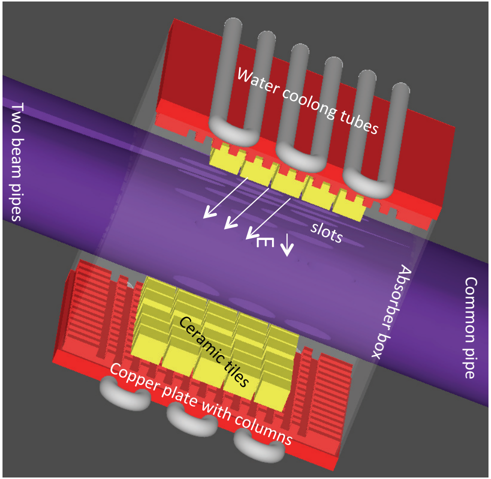
- Machine elements confined inside a cone of 100mrad
- Placed in 1.25m from the IP, so there is enough space for the LumiCal
- Compensating solenoid field cannot be too high $\rightarrow$ sets a limit on detector's main field

IR trapped modes and HOM absorbers

Smooth transition from 2 to 1 beam pipe

- Minimise IR impedance
- Still one (unavoidable) trapped mode remains at the IR
- Higher Order Mode (HOM) absorbers have been designed for FCCee IR, in order to cope with it





Backgrounds in FCCee IR

Synchrotron radiation

- Unlike in linear colliders, SR is expected to be a source of bkg on FCCee detectors
- Main source comes from the last bend, but contribution is expected also from FF quads

Beamstrahlung induced backgrounds: Incoherent Pairs Creation (IPC), Coherent Pairs Creation (CPC), and $\gamma\gamma \to$ hadrons

- Smaller space charge density for FCCee bunches compared to ILC/CLIC bunches
- These backgrounds are expected to be less severe in comparison with linear colliders

Beam–gas interactions

Radiative Bhabhas

Synchrotron Radiation

Total SR power is kept at 100MW

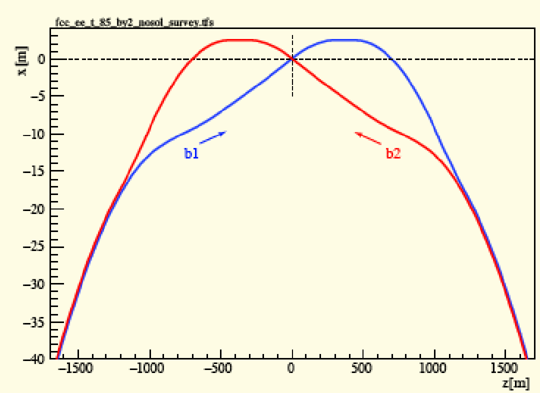
Effect of SR can be partially suppressed by bending the beams after the IP

- Final bend critical E $\leq 100 keV$ (Top)
- Billions of photons from the last bend (Top)
- Appropriate masking along the last 100 meters from the IP protects the detector from direct stream of SR photon

The IR and mask design has been optimised using SR estimates with SYNC_B

Further studies on−going

- Please see Marian's talk



Mitigation of Synchrotron Radiation

A fraction of the last bend and Quad produced SR scatters off the mask and showers into the detector area

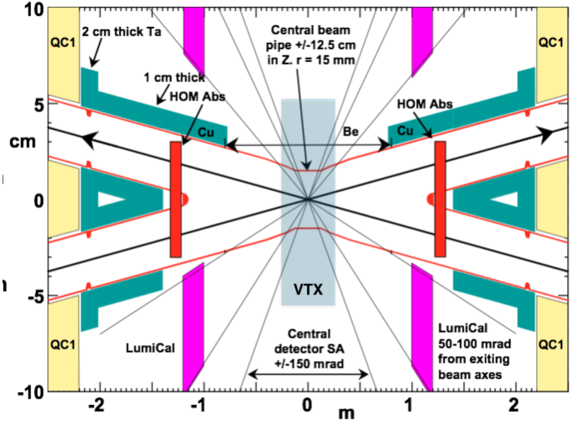
- Those surviving photons is the relevant sample for the full simulation studies

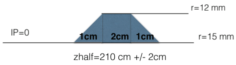
W shield used in order to limit the SR reaching the detector

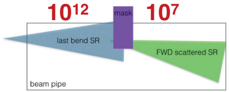
Window left in front of LumiCal in order not to degrade the energy resolution

- Shield asymmetric in ϕ

We ended up with an optimised IR design wrt the mitigation of SR





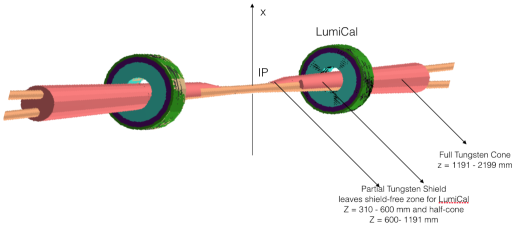


Study of IR backgrounds in full simulation

Full simulation studies of the impact of SR, IPC, and $\gamma\gamma \to$ hadrons backgrounds on FCCee detectors was performed

- The IR elements (beam pipe, W SR shield, LumiCal, HOM absorbers, solenoids) have been implemented in DD4hep
- Water cooled Be beam pipe (0.8mm Be, 0.4mm water) + 5μm Au layer $\to$ absorbs SR γ and reduces heat on BP
  - 0.5 $\% X_0$
- Use of a realistic field map (combines main solenoid & compensating scheme)

The 2 FCCee proposed detectors, CLD and IDEA, have been placed around this IR



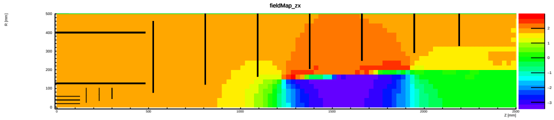
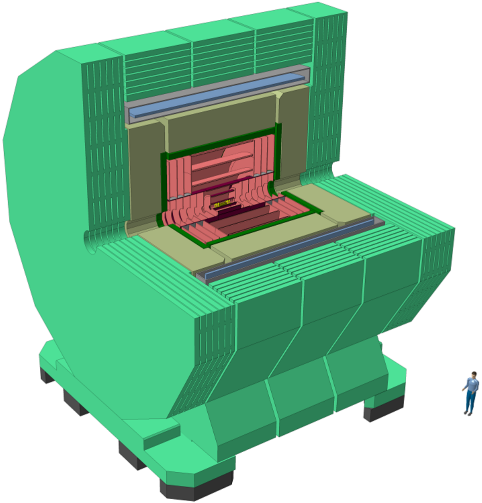


Figure: RZ slice of the B field map. The black lines correspond to VXD/tracker layers

CLD detector



Based on CLIC detector, tailored for FCCee needs

- 2T main field $\rightarrow$ increased tracker radius wrt to CLIC ($1.5m \rightarrow 2.1m$)

No power pulsing $\rightarrow$ increased demands on cooling

VXD

- 3 double layers (barrel) & 4 discs (endcaps)
- Rin = 17.5mm, Rout=59mm
- 0.6% X_0 per double layer

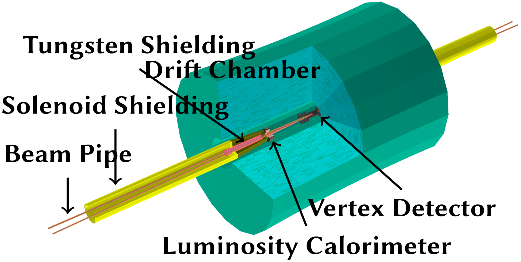
Tracker

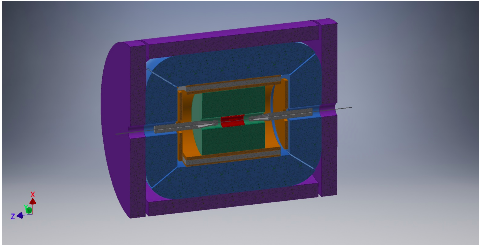
- Inner tracker: Rin = 127mm, Rout=670mm
- Outer trackrRin = 1000mm, Rout=2100mm,Length = 2x1264mm

Studies performed with ILCSoft

IDEA detector

- Vertex detector: MAPS
- Ultra-light drift chamber with PID (DCH)
- Dual read-out calorimetry
- Additional disk layers to be placed in the space between DCH and DR
- 2 T solenoidal magnetic field



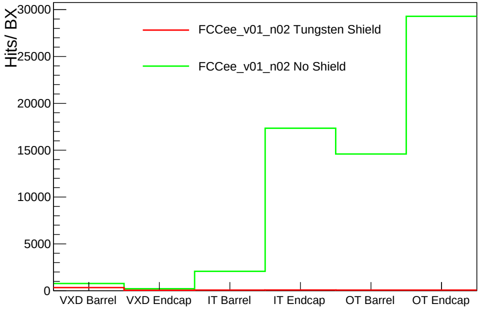


IDEA DCH

- Material budget $\sim 1.6\% X_0$
- Resolution $\sigma_{xy} < 100\mu m$, $\sigma_z < 1$mm
- ~ 100 *ns* integration time
- dE/dX $\sim 4\%$, dN/dX $\sim 2\%$
- Implemented in DD4hep
  - Analysis performed with FCC software

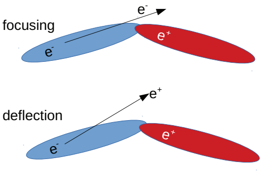
SR full simulation studies – effect of shielding

Full simulation studies of SR effect on FCCee detectors showed that proper shielding around the BP can reduce it to almost negligible levels



Beamstrahlung induced backgrounds–e^+e^- pairs

Background generation was performed with Guinea Pig

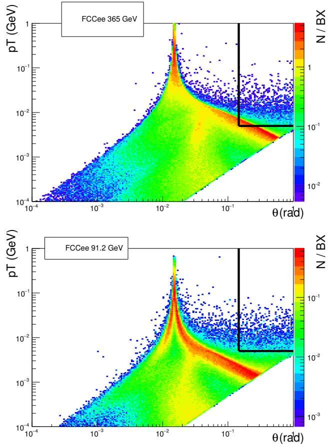


e^+e^- $pairs(IPC)$		
$\sqrt{s}$ [GeV]	91.2	365
Total particles	$\sim$ 800	$\sim$ 6200
Total E (GeV)	$\sim$ 500	$\sim$ 9250
$p_T \geq 5\,MeV$ and $\theta \geq 8^\circ$	$\sim$ 6	$\sim$ 292

CPC strongly focused on fwd direction

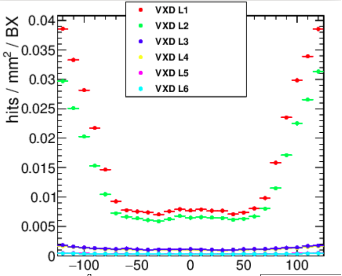
- negligible effect for FCCee

IPC is a main source of bkg for FCCee detectors

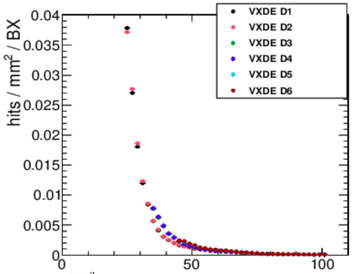


Only the particles within the top right corner will reach a typical VXD in a 2T field

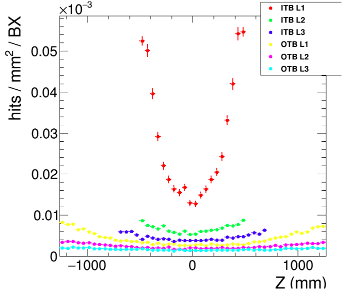
Hit densities from IPC at CLD VXD/Tracker at 365 GeV



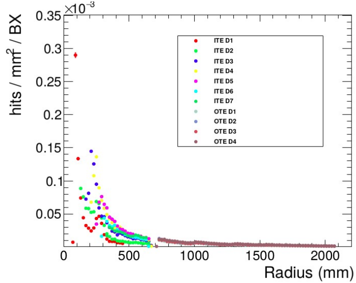
VXD B



VXD EC



ITB



ITE

IPC bkg impact on FCCee detector tracker/VXD

Assumptions to calculate occupancy

Cluster multiplicity = 5 for pixels and = 2.5 for strips
Pixel pitch $25 \times 25\ \mu m^2$ for VXD, $1 \times 0.05\ mm^2$ for strips
Safety factor 3 (SF=1 for DCH)
We present occupancy/BX
Term Max. occupancy refers to the occupancy on the hottest area of the subdetector

DCH average occupancy

Background	$\sqrt{s}$ [GeV] 91.2	$\sqrt{s}$ [GeV] 365
IPC	$\sim 1.1\%$	$\sim 2.9\%$
SR	0	$\sim 0.2\%$

CLD max. occ. / subdetector, IPC & SR

$\sqrt{s}$ [GeV]	91.2	365
VXDB	$\sim 10^{-5}$	$\sim 4 \times 10^{-4}$
VXDE	$\sim 4.7 \times 10^{-6}$	$\sim 4 \times 10^{-4}$
TE	$\sim 1.8 \times 10^{-5}$	$\sim 3 \times 10^{-4}$

The presented occupancy / BX is rather low for VXD and Si tracker

However bunch spacing at the Z peak is 20ns

- Might be that we have to integrate over several Bxs
- Still with a time resolution of $1\mu s \to$ occupancy stays $\leq 6 \times 10^{-4}$

DCH: Based on experience from the MEG2 drift chamber, this occupancy is believed to be at a managable level

Beamstrahlung induced backgrounds–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 and fragments the partons

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

hadrons		
$\sqrt{\hat{s}_{\min}}$ [GeV]	evts Z	evts Top
2	0.00063	0.0078
5	0.00029	0.0043
10	0.00015	0.0027

The effect of this background is expected to be small

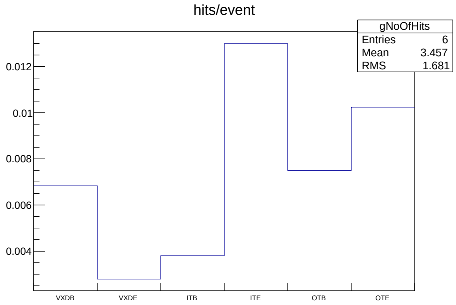
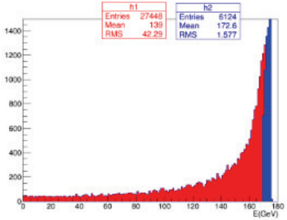


Figure: Avg number of hits per event, after full simulation

Radiative Bhabhas bkg in IR

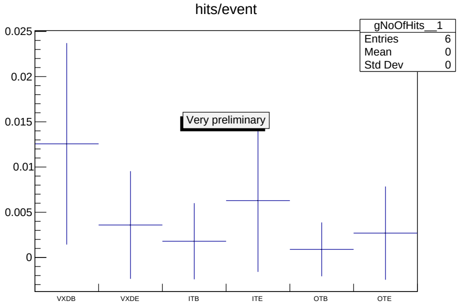
Radiative Bhabhas will be lost from the beam downstream the IP
Can reach the next IP and therefore is a source of bkg

- The Bhabhas are generated with GP and then tracked with SAD (half ring, full ring and several turns)
- For $E_{cm} = 45.6 GeV$ all Bhabhas are lost 70m downstream the IP
- For $E_{cm} = 182.5 GeV$ the Bhabhas are lost all over the ring
    - 20% of the particles reach the 2nd IP $\rightarrow$ possible source of bkg



Bhabhas lost before 2.18 m upstream of IP2
Survived Bhabhas at 2.18 m upstreamof IP2

The particles reaching the 2nd IP have been fully simulated (ILCSoft/DD4hep)
Preliminary results show that this bkg is expected to be small



Beam–gas interaction

Focus on Z peak

O(1000) off-momentum particles leave the beampipe within $|Z| \leq 2.1m$

- The loss rate in this z range corresponds to 2.05 MHz ($10^{-9}mbar$, N_2, $300K$)
- Probability to have such a particle per BX = 2 MHz / 50 MHz = 0.04

Full simulation study of their effect in LumiCal (see next slides) and in VXD/Tracker

- VXD
  - About 50-100x smaller than pair-production background for the barrel.
  - About 10x smaller than pair-production background for the endcap.
- Tracker
  - Barrel Layer1 : max is O(3-4x) smaller than pair-bkg
  - Other layers: O(50) smaller
  - Forward disks: factor O(10) smaller than pair-production bkg

Very small bkg in VXD/Tracker

IR backgrounds on LumiCal

IR bkgs effect on LumiCal have been studied in full sim. Main focus on $\sqrt{s}\,91.2\ GeV$

Synchrotron radiation is effectively stopped by beam-pipe shielding to a negligible level

- No hits at all $\sqrt{s}\,91.2\ GeV$

Main source of bkg is the IPC

- $\sim 300\ MeV$ energy deposited on LumiCal
- Energy mainly concentrated at inner radius at rear of calorimeter
- Mostly outside the fiducial volume

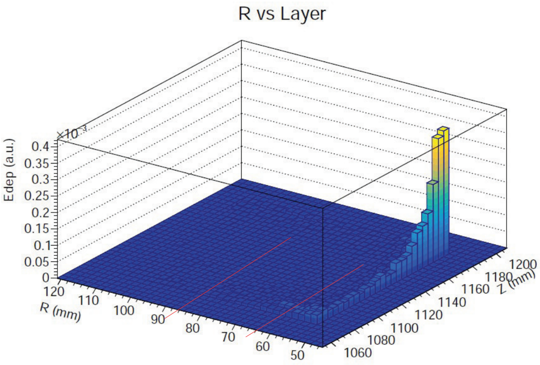
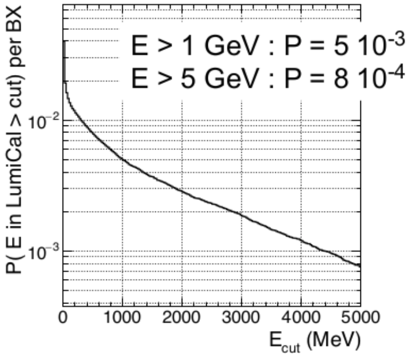


Figure: The 2 red lines are roughly indicating the fiducial volume.

Beam-gas interaction bkg on LumiCal

- The probability that an off–momentum particle leaves $\geq 5\, GeV$ at the fiducial volume of the LumiCal: 3×10^{-4}
- Probability of false coincidence = 0.9×10^{-7}
- 7000 times smaller than Bhabha rate
- Knowledge of this bkg with a presicion $\sim 7\,\%$ leads to an induced uncertainty to the luminosity measurement: $\leq 10^{-5}$



Impact of background on reconstruction (CLD)

Full simulation

Reconstruction framework Marlin

Tracking pattern recognition with conformal tracking

Particle-flow reconstruction with Pandora

Background events (IPC & SR) overlaid to physics events. The number of overlaid bckgd events corresponds to:

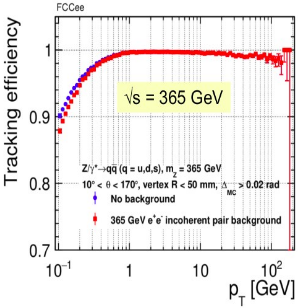
- 1 or 3 BXs for $E_{cm} = 365\ GeV$ - the latter corresponds to a (conservative) assumption of 10 s for the readout window of the electronics
- 1BX overlaid for calorimeter studies
- 3BXs overlaid for tracking studies

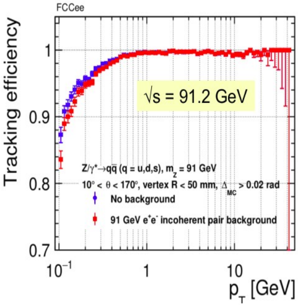
20 BXs = 400 ns for $E_{cm} = 91.2\ GeV$

- on the lowish side (but not so much)
- Imposed by current limitation from software/computing

Effect of beam bkg on tracking: efficiency

Tracking performance in complex events : qq events (q = u,d,s)



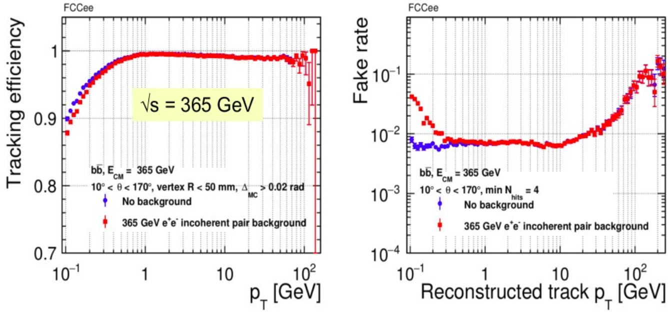


- Fully efficient for $P_T \geq 500\ MeV$
- $\sim 90\%$ efficiency in the range $100\ MeV \geq P_T \leq 500\ MeV$
- Robust against background both for $E_{cm} = 365$ and $E_{cm} = 91.2$

Effect of beam bkg on tracking efficiency / fake track's rate

Tracking performance in complex events : bb events

- Fake track rate: ratio of tracks that are either legitimate tracks coming from IPC particles or ghosts
- Ghosts: reconstructeded tracks for which $\leq 75\%$ of the hits belong to the same Monte-Carlo particle

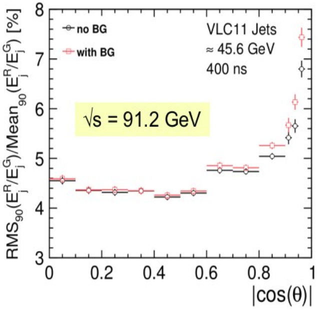


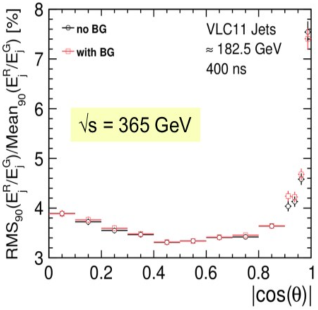
- Very high efficiency maintained, with % level fake rate except at low and high P_T
- Effect of background visible only at low P_T - increases the fake rate

Effect of beam bkg on jet energy resolution

jet energy resolution in qq events (q = u,d,s)

- Reconstructed PFO matched to MC jet and their energies are compared





- Impact of bkg is negligible, except in forward region at 91.2 GeV

Summary / Outlook

The FCCee interaction region has been designed in order to deliver the required luminosity and suppress SR

- A solenoid compensation scheme that can keep $\epsilon_y \sim pm$ has been designed and is confined in a 100mrad cone

IPC is the main source of beam–induced bkg on FCCee detectors

- The obtained occupancies in VXD and Si tracker are small and have a very little effect in reconstruction
    - SR is not an issue for Z,W,H working points
    - It is a source of bkg for Top, but the SR masking/shielding effectively suppresses the impact on the detector
- For DCH, occupancy due to IR bkg is expected to be manageable $\rightarrow$ further studies needed

Backgrounds from beam–gas interaction and radiative Bhabhas seem to be small

The MDI studies have been documented in the FCCee-CDR