Pair-production background and event sizes at FCC-ee (Z)

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Introduction

Luminosity expected at the Z-peak : could read 2 10^{36} cm^{-2} s^{-1} (crab-waist scheme)
σ(ee -> had at Z peak) ≈ 30 nb
Hence a rate of O(100 kHz) of physics events to write to disk (+ Bhabha).
Feasible ? Depends on the event size.

	Trigger rate	Event size	Throughput to disk
ATLAS / CMS Phase 2	5 kHz	4 MB (PU = 140)	20 GB / s
LHCb upgrade	20 kHz - ?	100 kB	1 GB / s

Event size at of a multi-jet event in the TESLA detector, from the TESLA TDR (*) :

- Data due to the signal event only ≈ 200 kBytes
- However, adding the background, this increased to 5 MB !

100 kHz x 200 kB = 20 GB / s would be OK
but 100 kHz x 5 MB = 500 GB / s would be a lot !

(*) 15 yrs old… the more recent ILC TDR does not give the event size of a "signal" event, since ~ all the data volume comes from background; and give the volume of a bunch train, which is what is relevant.

Background sources in e+e-

At ILC : most of the data volume is coming from background

mostly pair-production background, largely induced by Beamstrahlung photons. Creation of e+e- pairs, low PT particles, enter (many times) in the vertex detector. Or can make showers in material in the fwd region (BeamCal, LumiCal, last focusing quadrupole), leading to secondaries that can backscatter into the main detector -> affect central tracker and calorimeters.

Detailed background studies at ILC and CLIC :

- ILC : PhD Thesis Adrian Vogel, DESY-THESIS-08-036
  http://www-library.desy.de/preparch/desy/thesis/desy-thesis-08-036.pdf
- CLIC : PhD Thesis André Sailer, CERN-THESIS-2012-223
  http://cds.cern.ch/record/1506163/files/CERN-THESIS-2012-223.pdf

At FCC-ee : expect a much lower beamstrahlung background. Still, negligible effect ? Especially with the different interaction region ?

Ongoing studies for CEPC as well (M. Ruan et al).

Kinematics of BS photons and e+/e- pairs at FCC, Z (c.w.)

Scenario considered : FCC at Z peak, crab-waist scheme, parameters shown by Frank Z at Washington for 4 IPs (see backup)

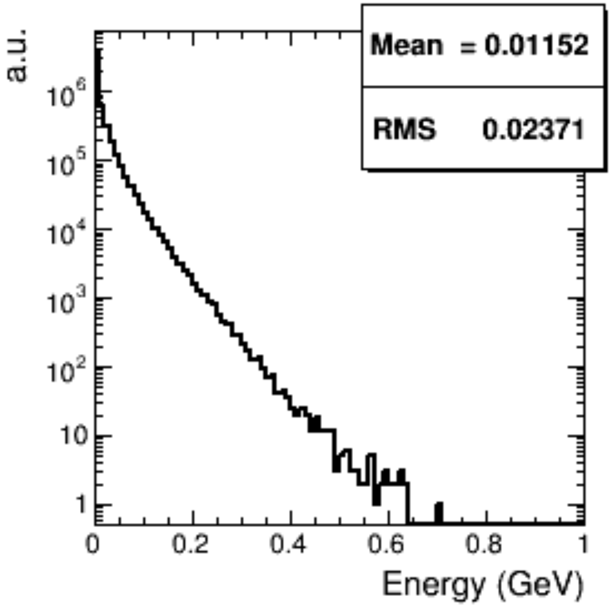
- Nbunches ~ 60000

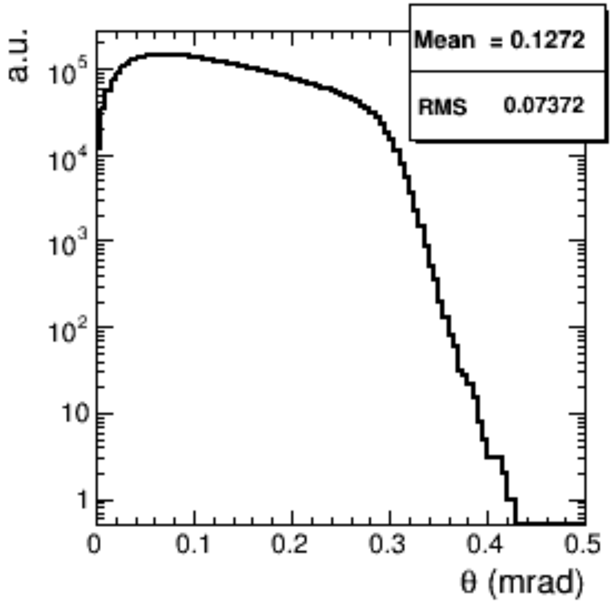
Use Guinea-Pig (Daniel Schulte) to generate the Beamstrahlung photons and the incoherent pair-production background (γγ -> e+ e-)

(kinematics in the center-of-mass frame)

Photons have a mean energy of 10 MeV and a polar angle below 0.5 mrad.

i.e. the photon beam escapes down the beam pipe

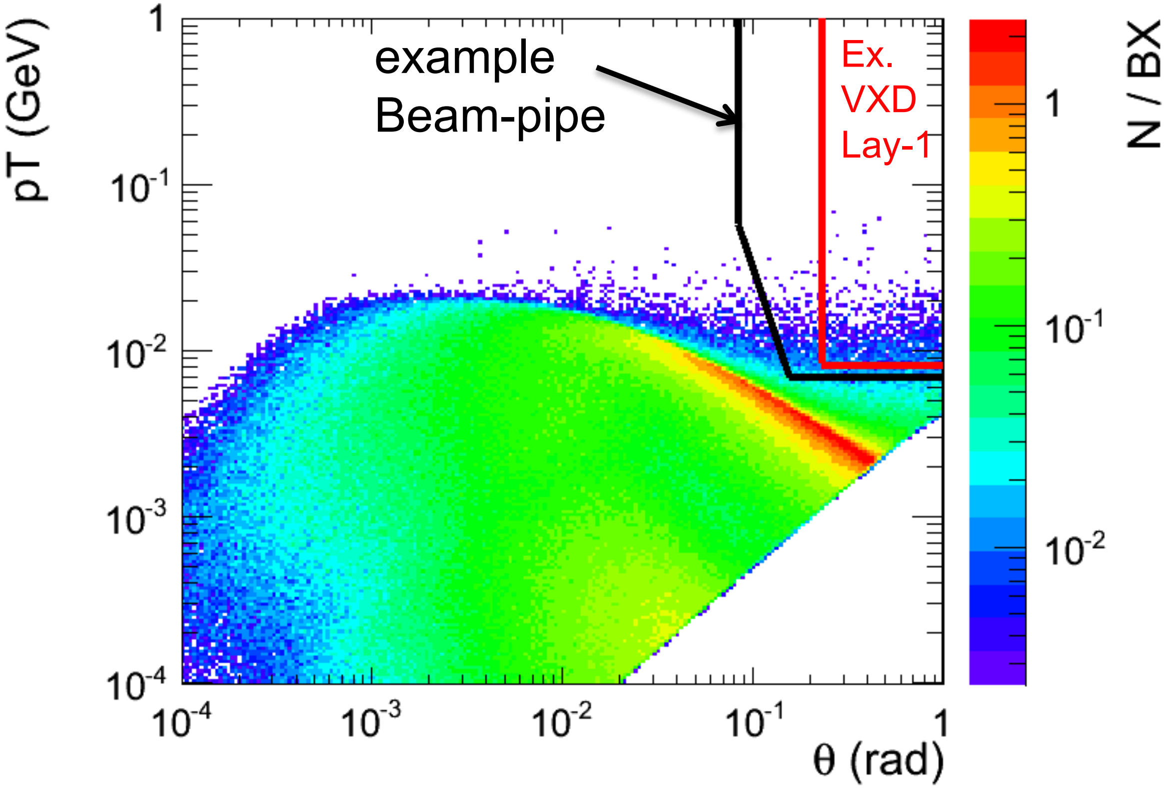


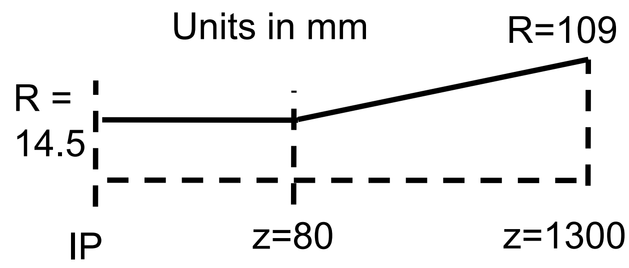


Pair-production background

On average : ~ 4000 pairs created per BX
carry an energy of ~ 1 TeV (400 x less that at ILC500)
largely dominated by the Landau-Lifschitz process ($\gamma^*\gamma^* \to ee$)

To reach a given R, the particle must bend with $2\rho > R$. With B = 3.5 T and a beam-pipe at R = 14.5 mm, this means pT > 8 MeV.





But for small angle, the helicoidal trajectory will cross R at a | z | that is larger than the z-extend of the layer.

Conical BP allows a small R in the central part, while staying away from the bckgd particles.

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Simulation software

Pair-production events from Guinea-Pig are sent to the Mokka full simulation sw, developed by the ILC community.

Start from the ILD design, as used for the ILC TDR
model ILD_o1_v05
nominal solenoidal field : B = 3.5 T (most simple field model here)
But modify the forward region to be compliant with (some) FCC-ee constraints (lower L* = 2 m, instead of L* > 4 m in ILD design).
-> “FCCee_v01” model. See next slides.

GEANT uses the QGSP_BERT physics list.

Resulting LCIO file is converted in a Root tree via LCTuple. Contains GEANT hits in the sensitive detectors.

In the following: look at multiplicity of GEANT hits in the tracking detectors.

Results are obtained by averaging over O(500) BXs.

Forward region : ILD design

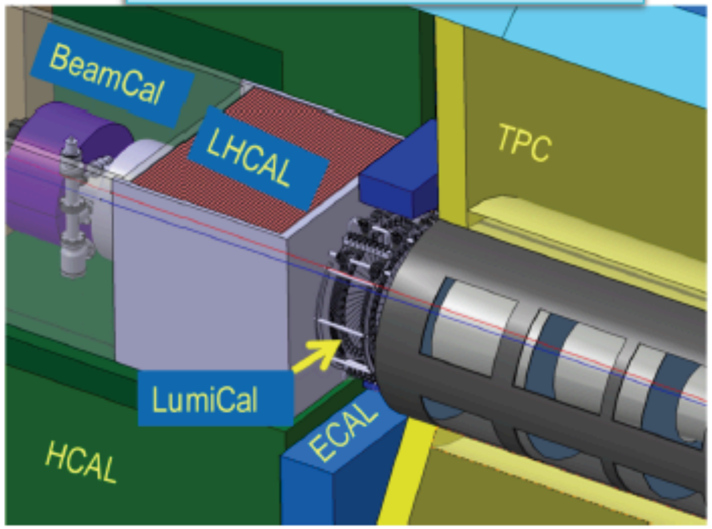
ILC detectors:

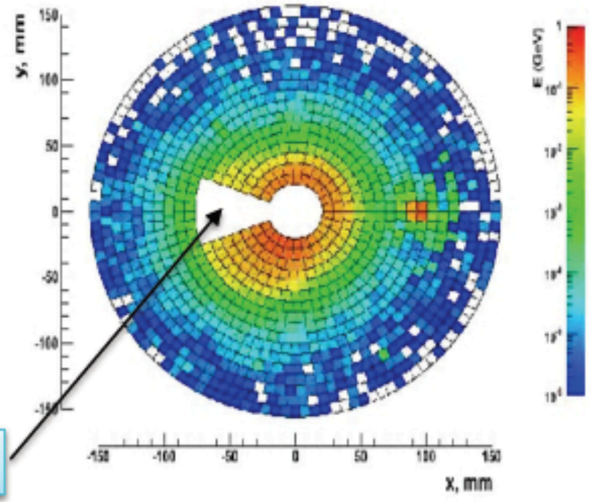
Three very forward detector systems:

- LumiCal: Precise luminosity monitoring z ~ 2.5 m
- BeamCal: z ~ 3.5 m
  - Closure of calorimetry down to 5 mrad. Mainly for tagging of 2-photon events as background to new physics searches with missing energy signature
  - Part of beam monitoring fast feedback system
- LHCAL: Extension of HCAL coverage to polar range of LumiCal

FCC-ee: Not clear whether we need all of this, and whether IR design allows for it.

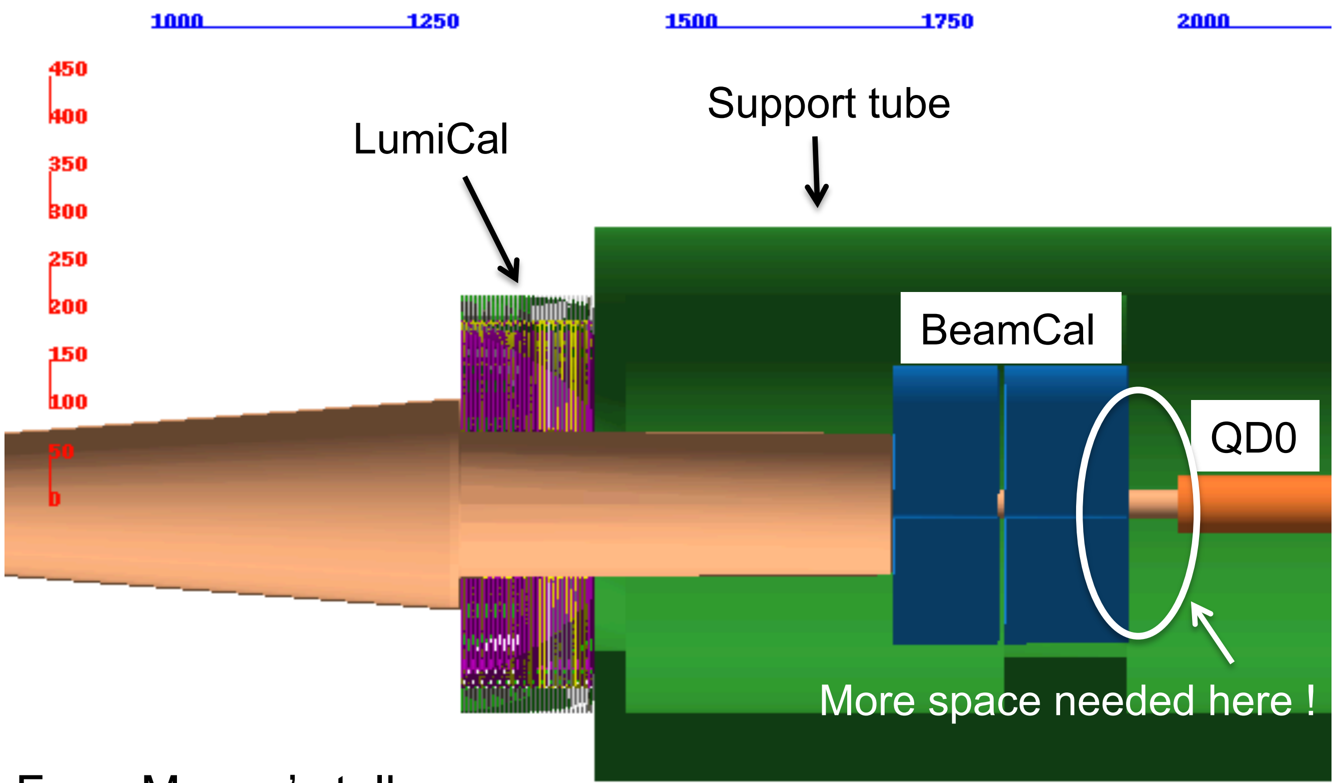
ILD Forward Calorimetry





Hole for entry beam pipe

Forward region in Mokka for L* = 2 m, based on ILD_o1_v05



In (y, z) plane

Removed LHcal.
For Lumical and Beamcal : kept dimensions of the ILD design.

Moved FTD disks (not shown) closer to the IP.

From Mogen's talk:

z_{front} [mm]	r_{min} [mm]	r_{max} [mm]	θ_{min} [mrad]	θ_{max} [mrad]
1000	80	115	80	115
1300	89	157	68	121
1500	95	185	63	123

QD0 at z = 2m
LumiCal starts at 1.3 m
(80 < R < 195 mm as in ILD)
BeamCal system a 1.72 m

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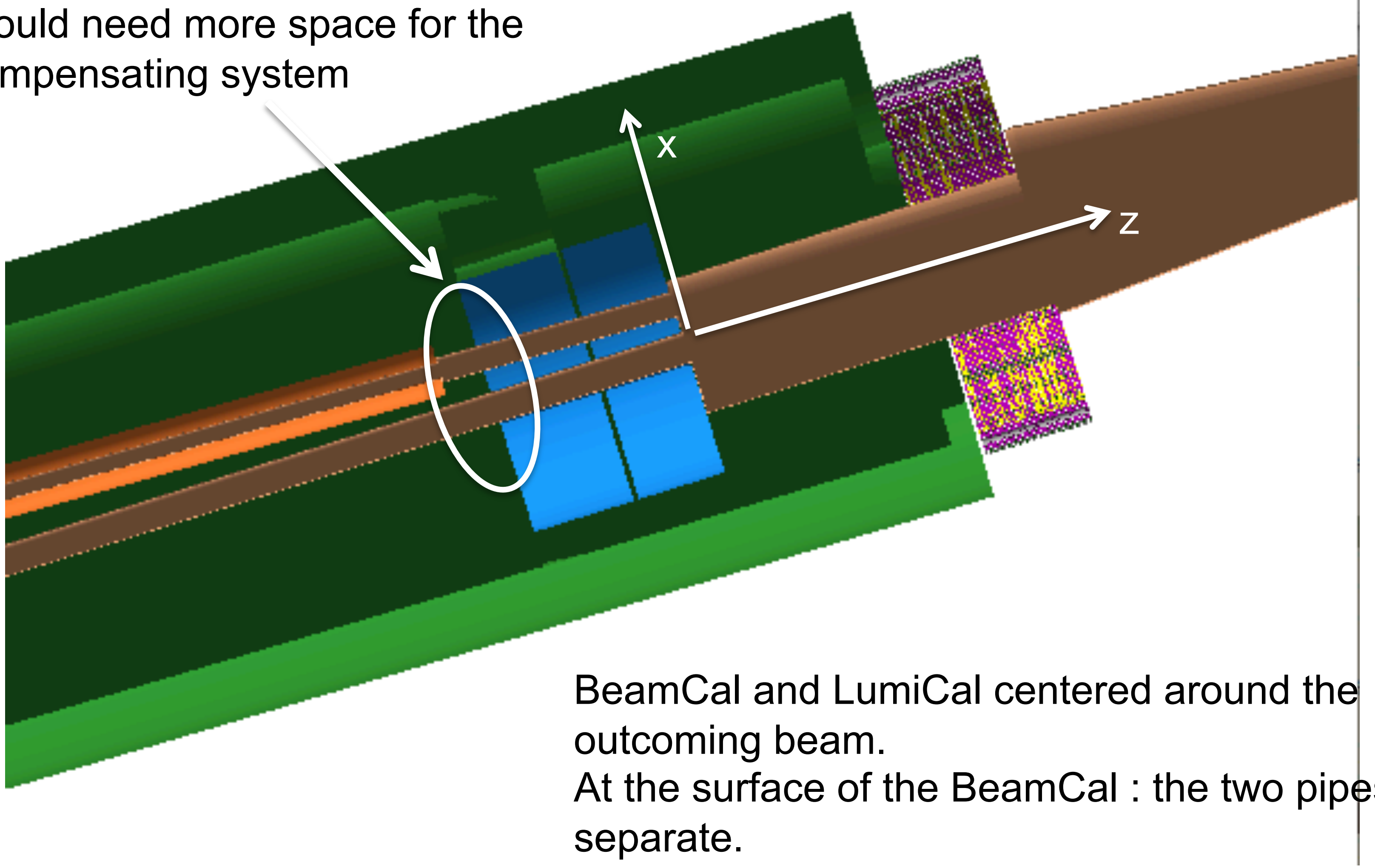
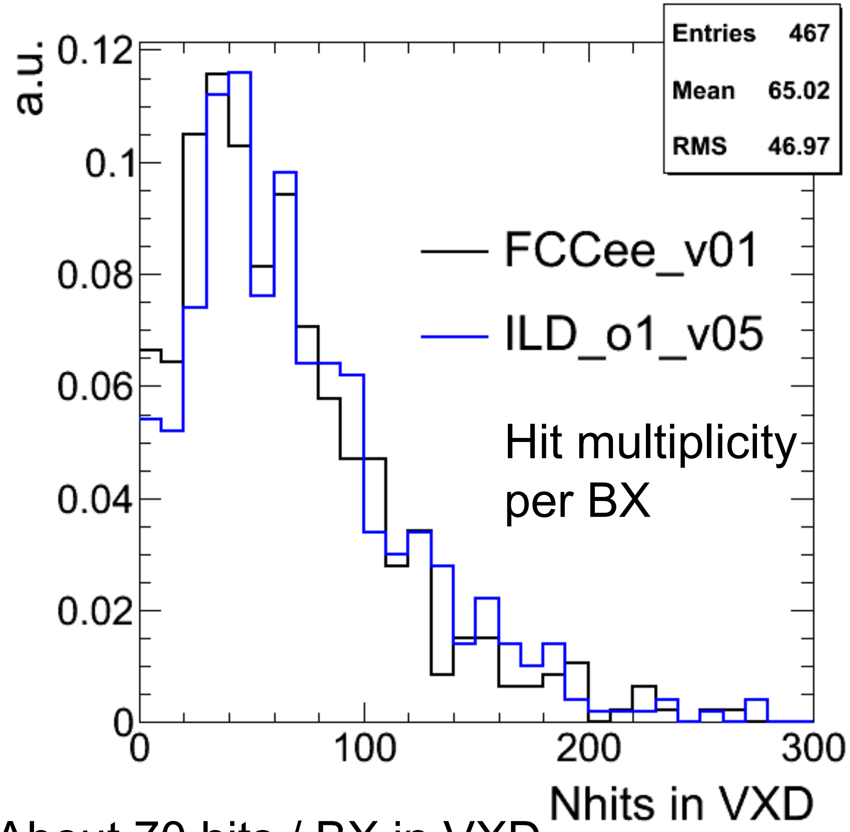
Forward region in Mokka for L* = 2 m, based on ILD_o1_v05

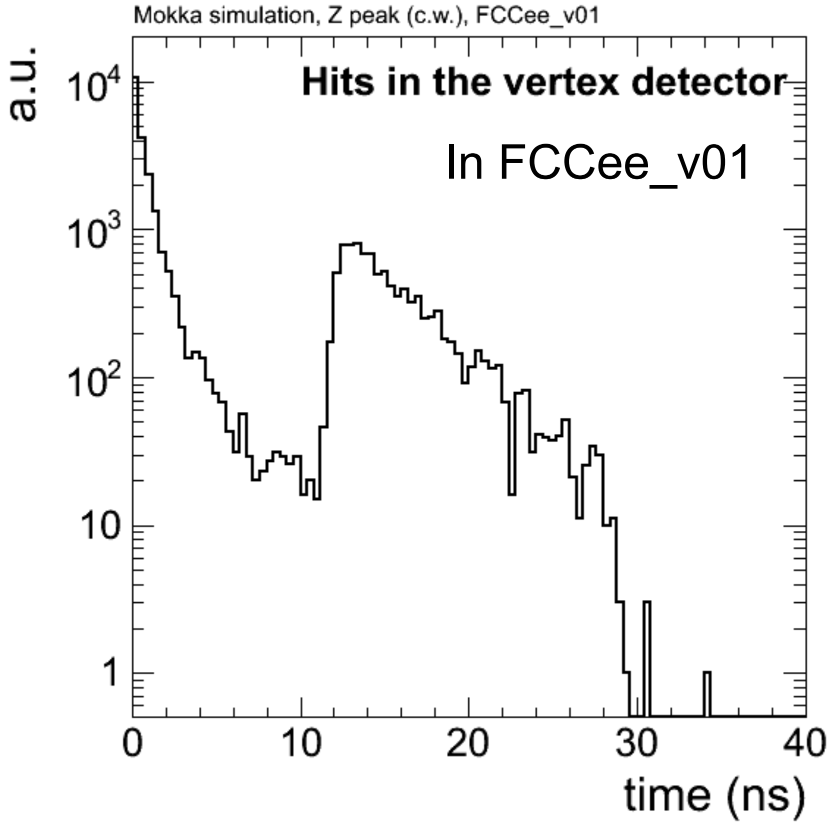


BeamCal and LumiCal centered around the outcoming beam.
At the surface of the BeamCal : the two pipes separate.
Use crossing angle of 30 mrad.

Hits in the vertex detector (ILD-like VXD, B = 3.5 T)

GEANT hits with deposited energy > 20% of that of a MIP in Si.





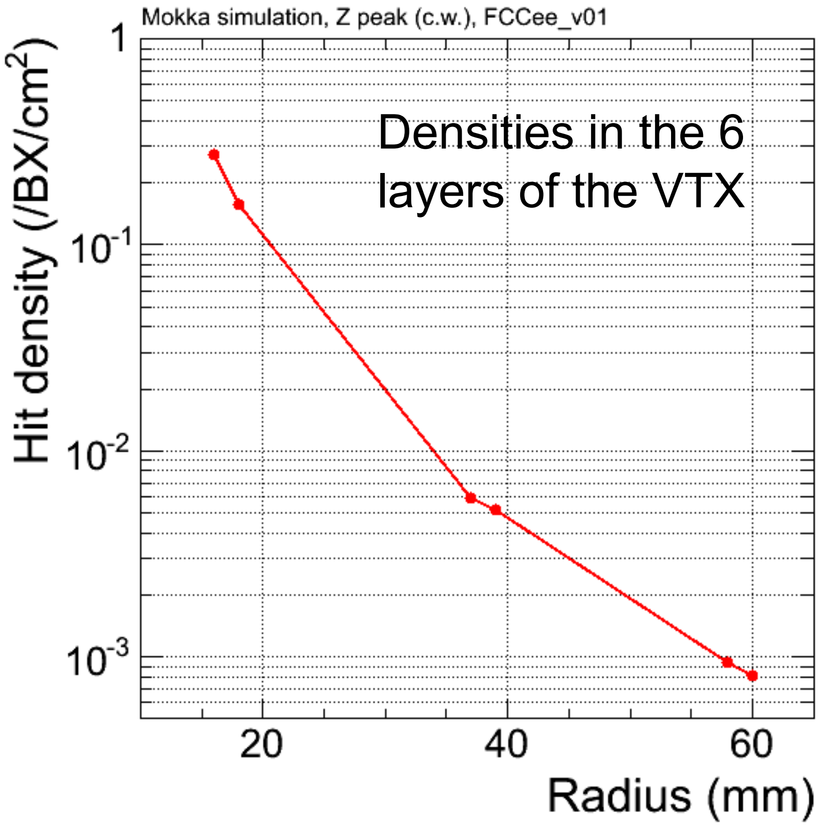
- About 70 hits / BX in VXD
- similar with both designs of the forward region.

With 32 bits per channel :
< 300 bytes per BX. Small ☺
Even after multiplying by a typical cluster size of say O(3).

- Direct hits at low values of t
- Second population (30% of hits) at t > 12 ns corresponding to particles backscattering from z ~ ½ c t = 1.8 m (BeamCal).

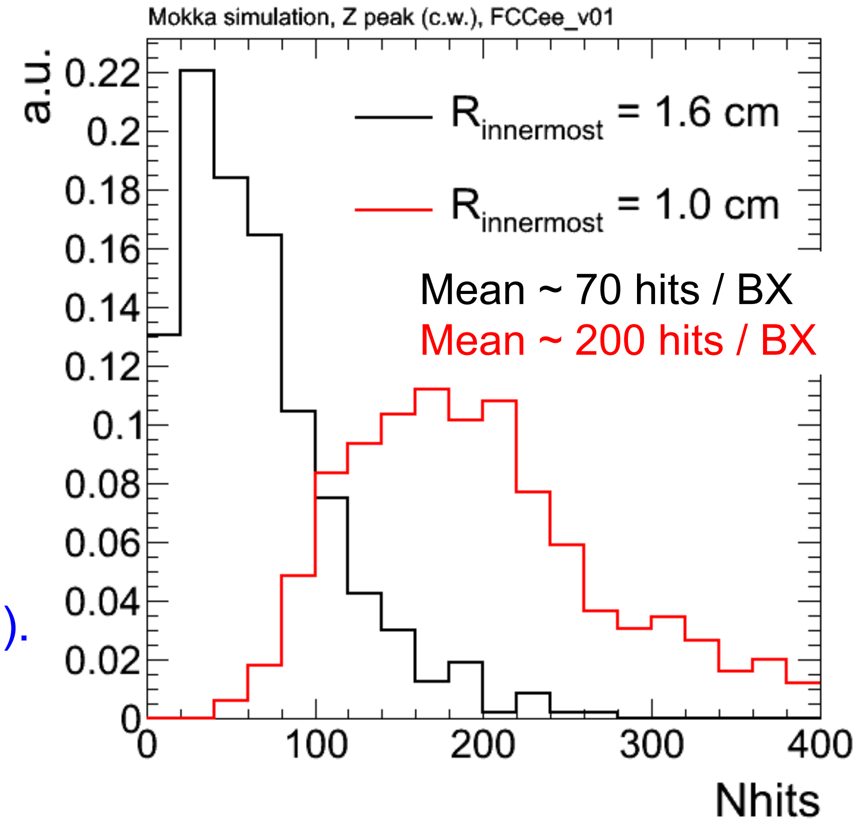
More later on backscattering.

Hits in the vertex detector: dependence with R



At R = 1.6 cm : density ~ 0.3 hit / BX / cm^2. Typically 25x less than at ILC.

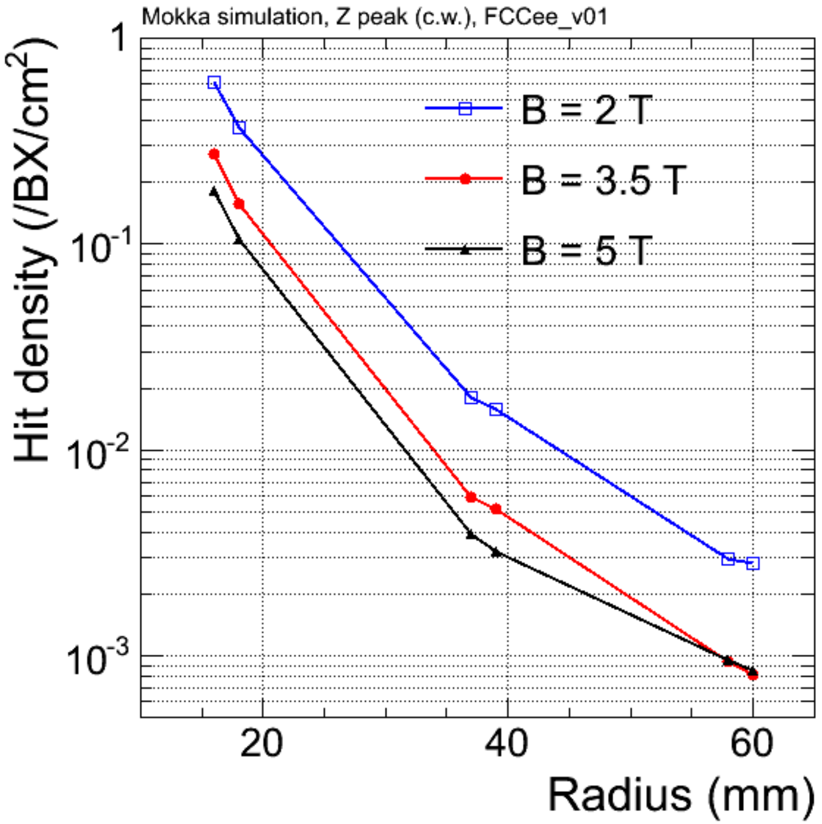
At R = 1cm (BP shrinked) : density is ~ 1.5 hit / BX / cm^2 i.e. 5.5x larger.



The right plot shows the hit multiplicity in VXD when the two innermost layers are brought closer to the IP (10 and 12 mm).

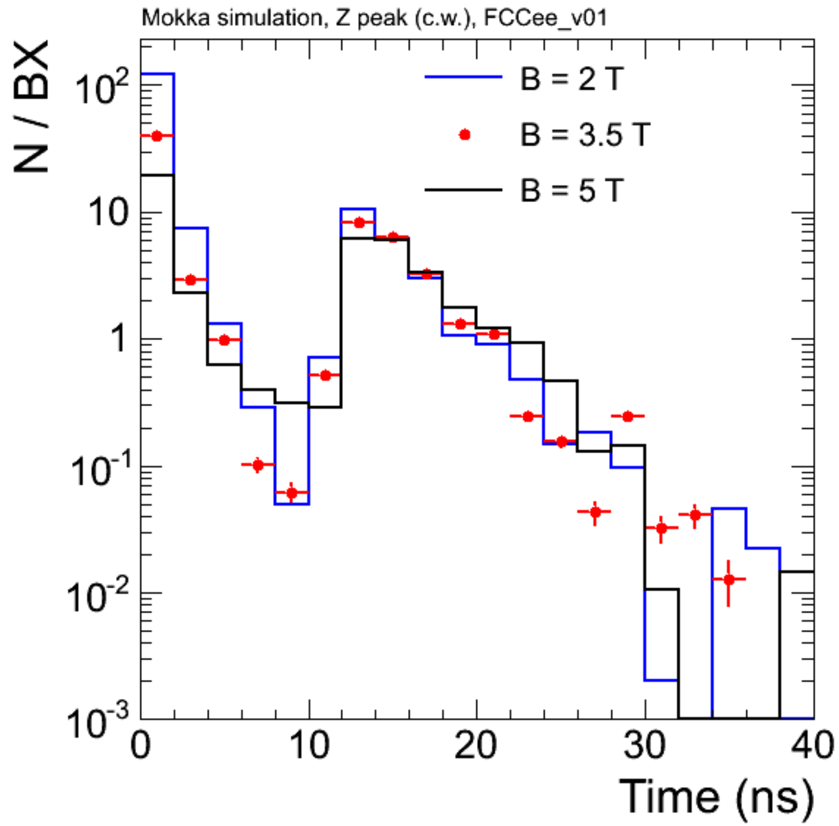
VXD multiplicity would remain low, with O(1 kB) of data per BX.

Hits in the vertex detector: dependence with B



Going from 3.5 T to 2 T : density in layer-1 increases by a factor of 2.2.

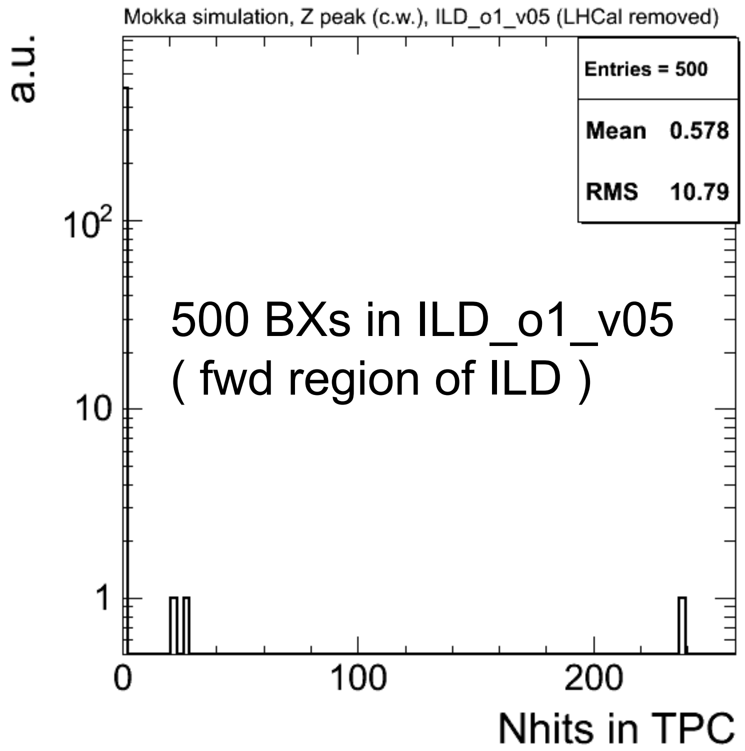
Going from 3.5 T to 5 T : it decreases by a factor of 1.5.

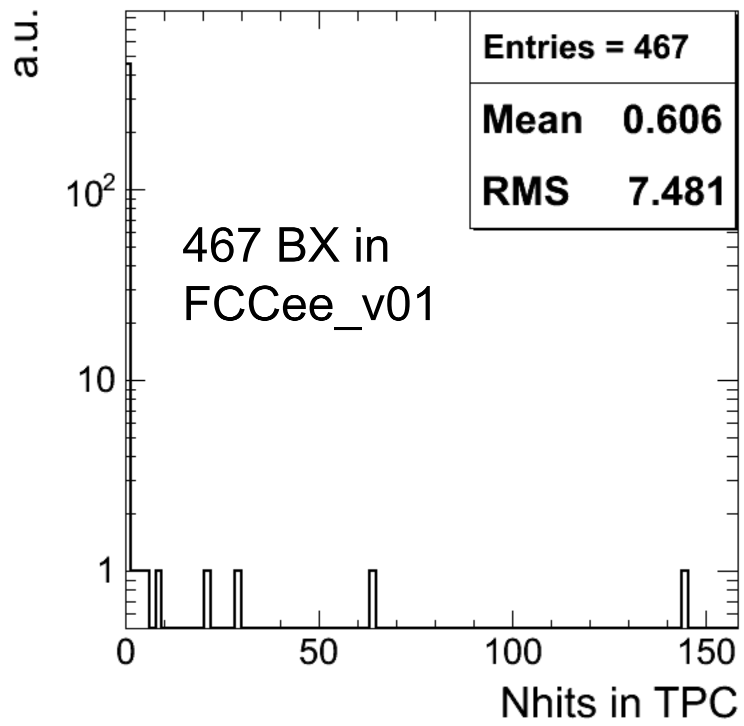


The value of the solenoidal field mostly affects the direct hits.
Hits from backscattering are less affected.

Hits in the TPC

These are GEANT hits. Simulation done with a max step length of 5 mm, ~ radial size of TPC readout strips. Hence a reasonable proxy for TPC “digis”…

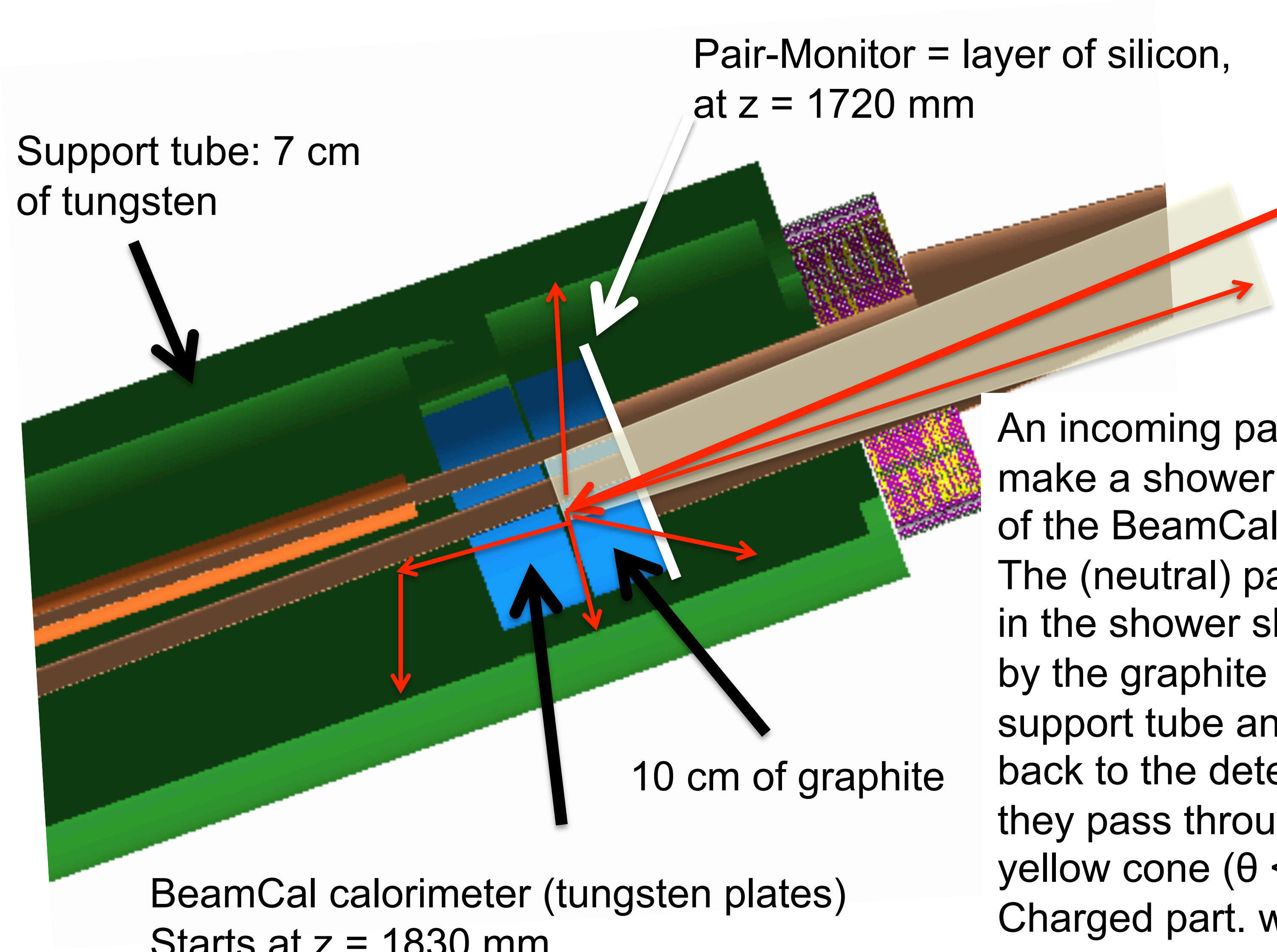




Would need a much larger statistics to get a reliable value for the mean multiplicity. Remember that the readout time of the TPC is O (50 μs) i.e. would integrate signals over 10000 BXs with Δt = 5 ns between consecutive bunches !

But the background does not seem to be much larger in FCCee_v01 (fwd region with QD0 at 2m) than in ILD_o1_v05 (fwd region with QD0 at 4m).

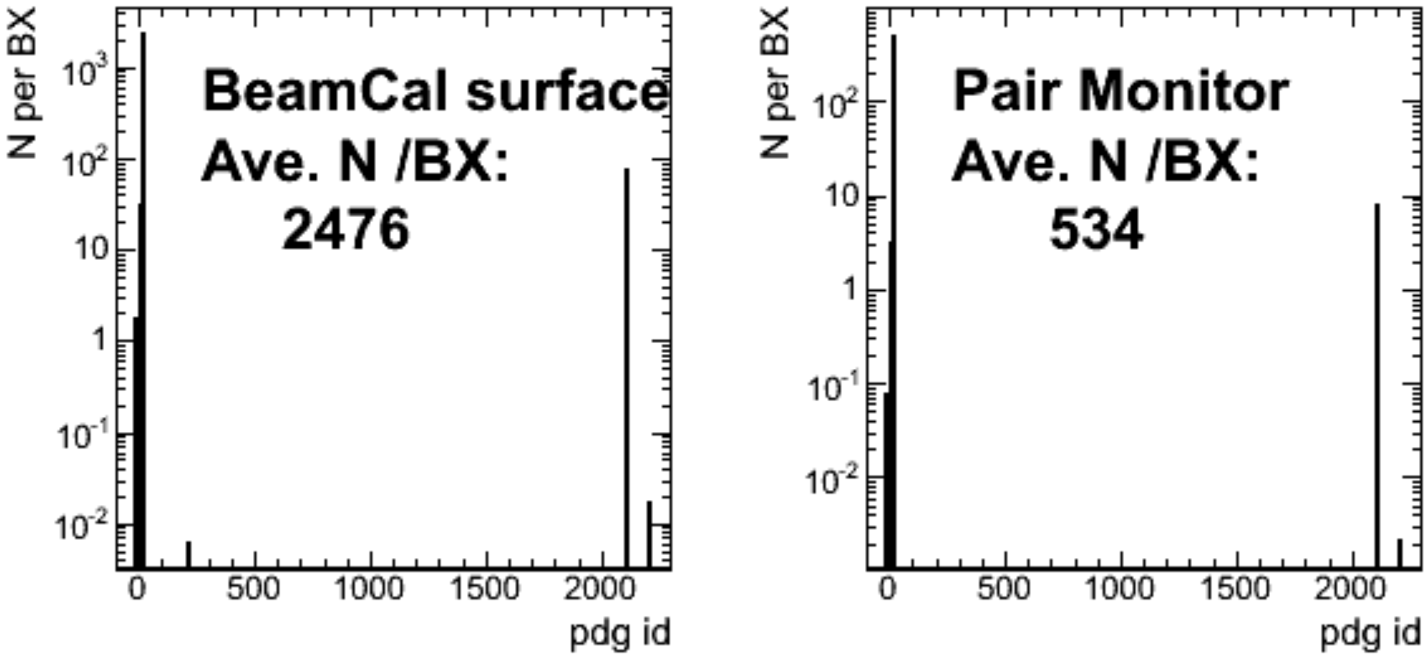
More detailed view of the BeamCal as implemented



An incoming particle can make a shower at the surface of the BeamCal.
The (neutral) particles created in the shower should be stopped by the graphite layer or the support tube and not come back to the detector, unless they pass through the light yellow cone ($\theta < 8$ deg).
Charged part. would be trapped in B and won't reach
R = 350 mm (TPC volume).

Backscattering on the BeamCal surface

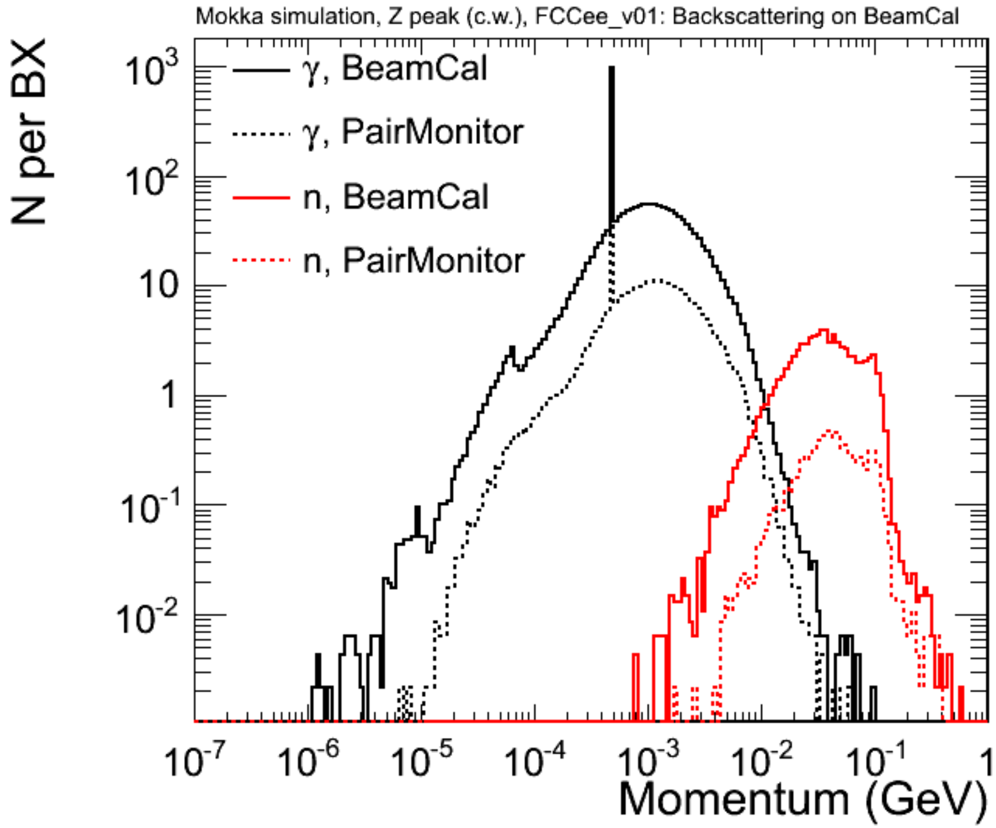
PdgId of particules that cross scoring planes (*) in front of BeamCal and of the Pair Monitor, and that go backwards, i.e. z * pz < 0 :



- Mostly photons, then neutrons
- after the graphite layer : the number of backscatters is reduced by a factor of 5

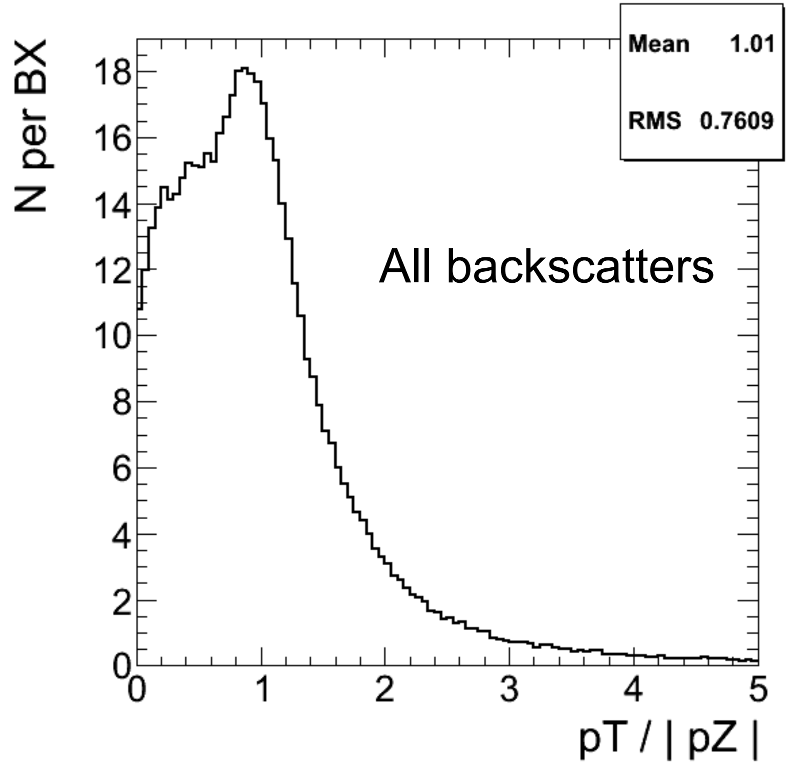
(*) Thanks to André Sailer for providing me with the Mokka drivers for the "scoring" surfaces !

Momentum of particles backscattering on BeamCal



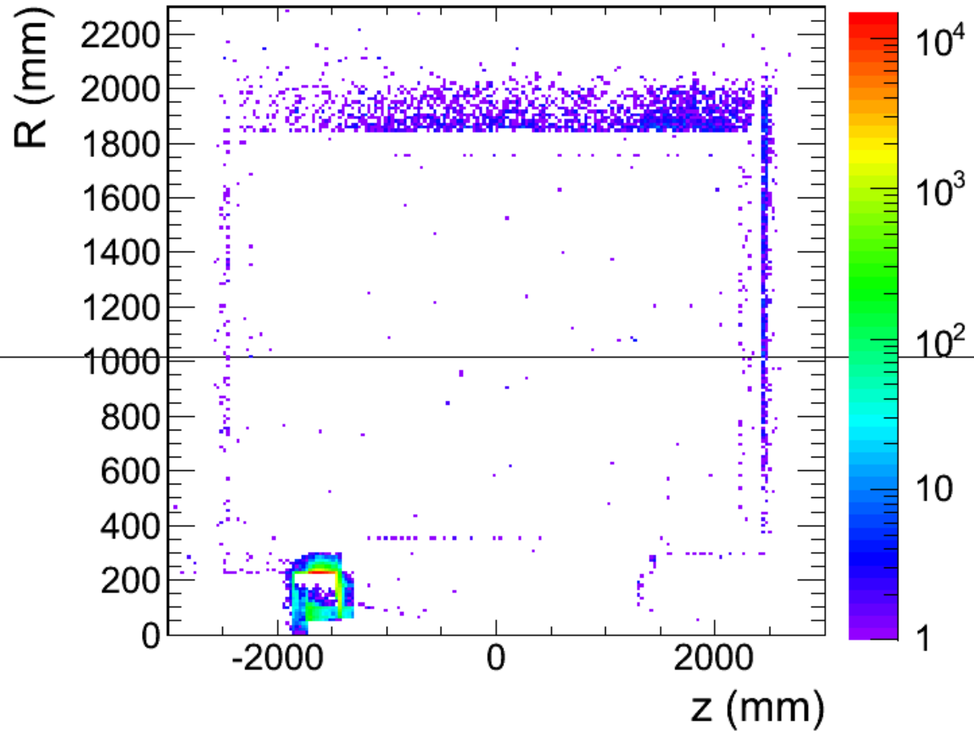
Very low momentum.

Photons:
Peak at 5 10^{-4} GeV = photons from e^+e^- annihilation
Usually below 10 MeV, i.e. won't convert.

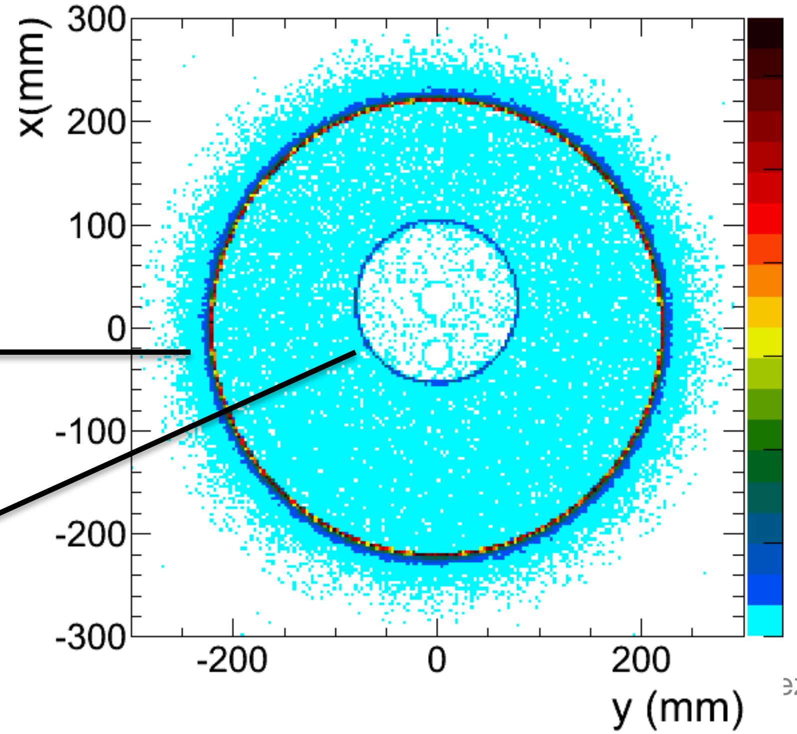


Fraction of backscatters emitted at Θ < 8 deg (yellow cone in slide 15) is small.

Backscatters in front of Pair Monitor (z < 0)



Look at the point where the particle is absorbed.

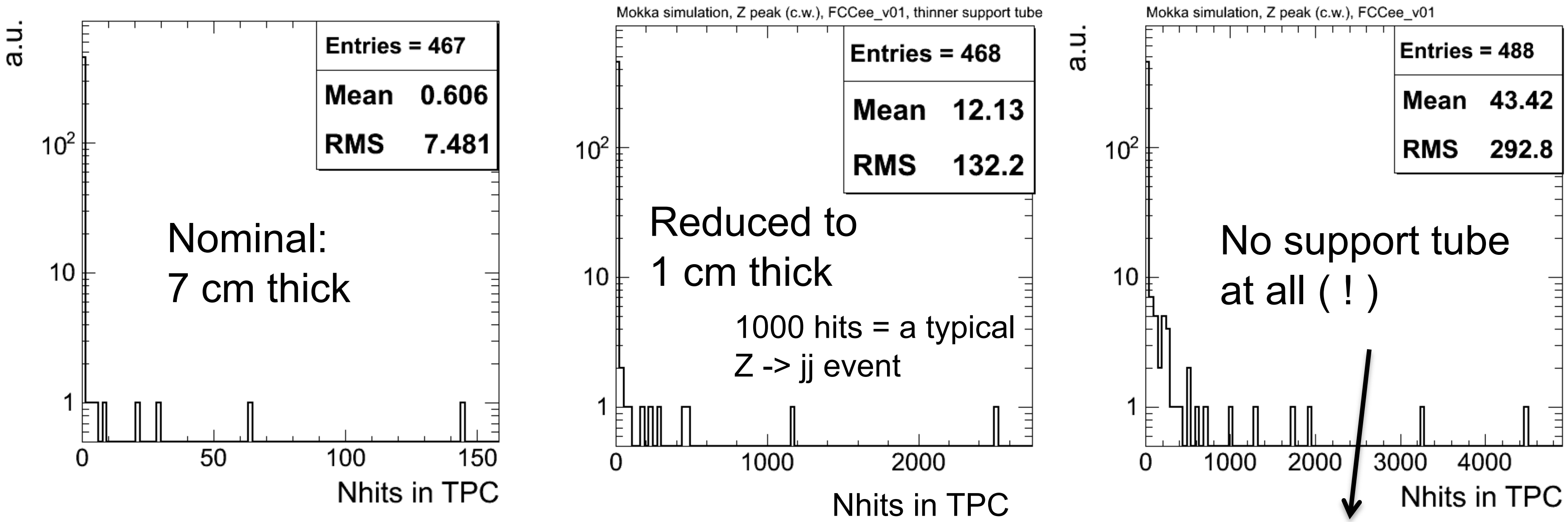


Support tube : R_{in} – 220 mm
(7 cm of tungsten)

Iron beam-pipe between LumiCal and BeamCal

Backscattering on the BeamCal

Reducing the thickness of the support tube – e.g. to limit the acceptance loss in θ : one sees the background increasing.

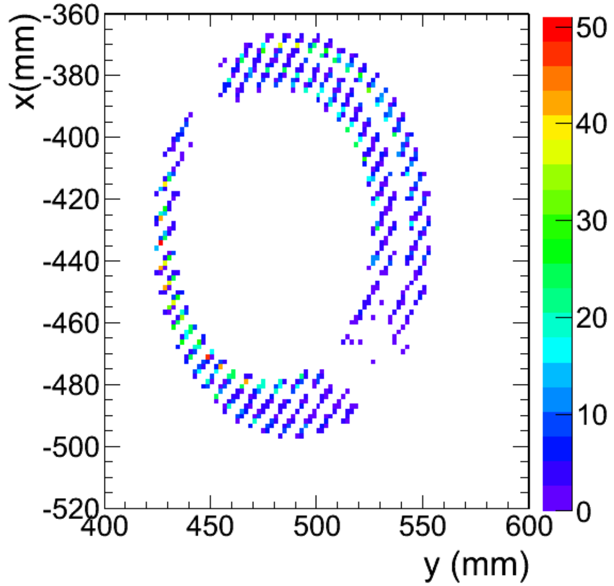


With an average of 40 hits / BX :
Integrating over the r/o of 50 μs = 10000 BXs : 400 k hits.
With 40 bits (*) / channel : one gets 2 MB !

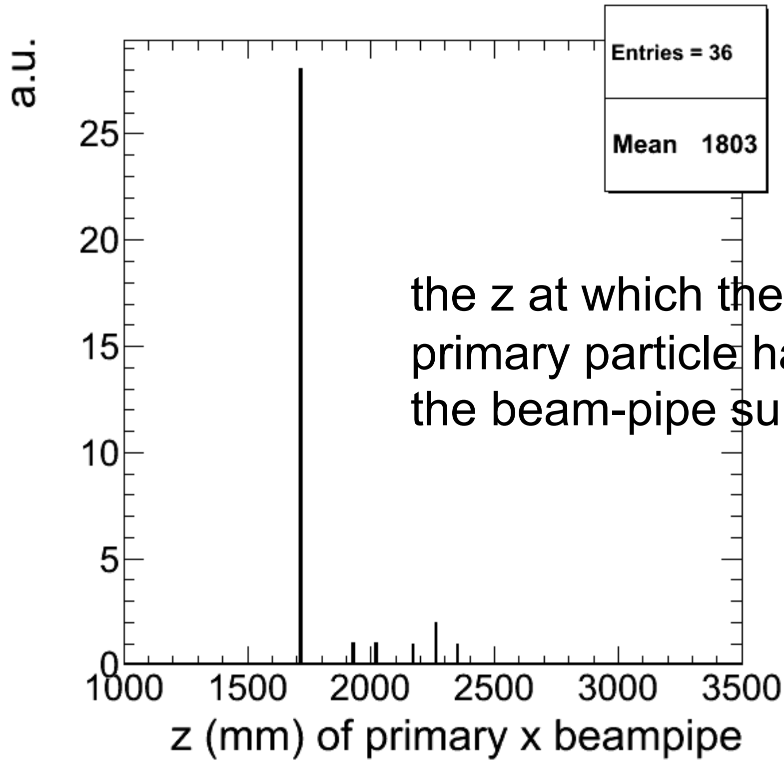
i.e. a LumiCal down to 10 mrad would lead to bckgd in TPC

(*) Need at least 10000 time slices -> 14 bits; 2M channels in (x,y) -> 21 bits; say 5 bits to encode the charge for better position measurement. Need to run the TPC digitization for a better estimate…

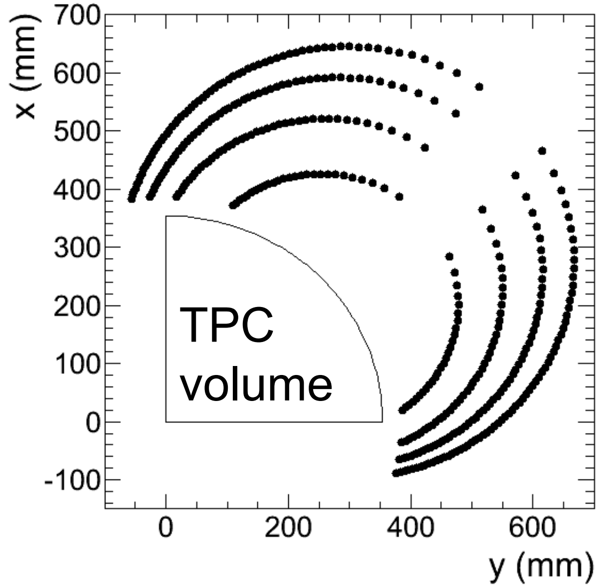
Hits in TPC – examples of a background particle making many hits



Particle of pT = 0.1 GeV that curls and makes many ionisation clusters.



the z at which the corresponding primary particle has crossed the beam-pipe surface



Trajectory of a particle of pT = 0.4 GeV. Enters the TPC volume on the z > 0 side, goes out, looses energy, goes in again, etc.

Conclusions

Used the hit multiplicity in VXD and in the TPC to assess the potential increase of the pair-production background when the LumiCal and BeamCal are brought closer to the IP, with QD0 at z = 2m.
No large bckgd is observed in the example considered.

Other aspects of the IR, as discussed yesterday, may have an important effect.

Set up to modify the Mokka model used for the simulation – at least for easy changes.

Data volume induced by the pair-production bkgd in the VXD is limited, of O(kB) per BX. Margin to put the VXD closer to the beam pipe, and for a lower value of the magnetic field.

Backup and old slides

Parameters used to steer GuineaPig

parameter	
	Z
E_{beam} [GeV]	**45**
current [mA]	1450
$P_{SR,tot}$ [MW]	**100**
no. bunches	59581
N_b [10^{11}]	0.5
ε_x [nm]	**0.13**
ε_y [pm]	**1.0**
β^*_x [m]	0.5
β^*_y [mm]	**1**
σ^*_y [nm]	32
σ^*_x [µm]	8

Changed compared to what I showed in Pisa

- Use updated machine parameters for Z peak, crab-waist scheme
    - with 2x more bunches
    - hence O (2x) lower beamstrahlung and pair-bakground

- Fixed some issues that I had at the time of Pisa…
    - in particular the e+e- files from GuineaPig were not read with the right format; as a result, about half of the e+/- particles for a given BX were ignored

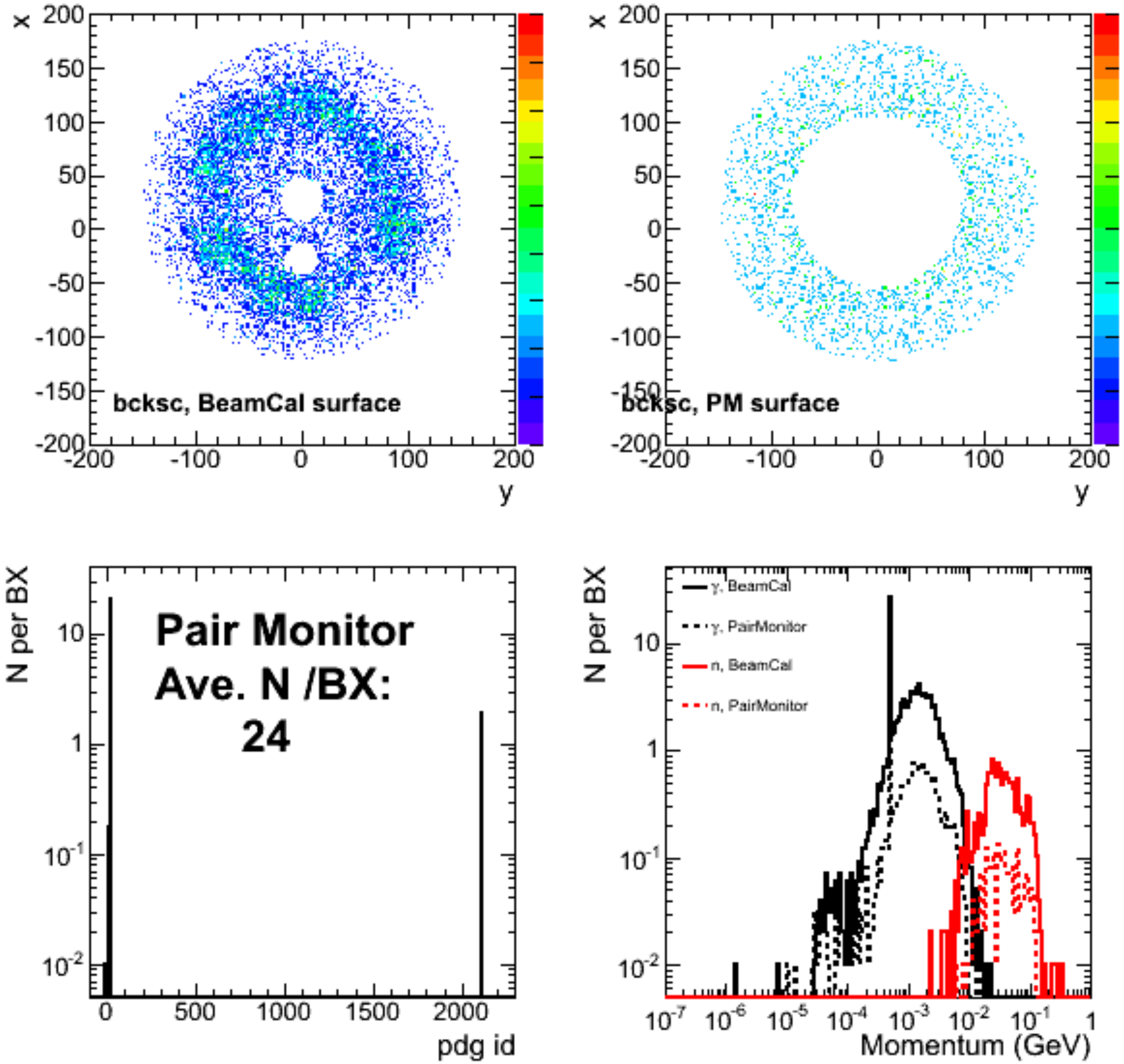
- Much more statistics (500 BXs here, used 50 BXs in Pisa)

- Changed the detector model
    - from ILD_o1_v05 to FCCee_v01
    - differs from ILD_o1_v01 by the crossing angle (30 mrad instead of 14 mrad) and the layout of the forward region (L* = 2m instead of > 4m)

- All simulation results shown here are based on the full simulation (Mokka)

Backscattering on BeamCal from Bhabha events

Very crude look… used Pythia ee -> ee events, t-channel photon, down to 40 mrad.



(40 mrad = the higher density region in the top-left plot)

Backscatters are still mostly photons and neutrons.

A bit harder than those from γ*γ* -> ee evts, but still in the MeV range for the photons.

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Pair-production background at FCC

Use Guinea-Pig (Daniel Schulte) to generate the pair-production background (parameters in back-up slides)

(older parameters, with ~ 30k bunches))

	FCCZ	FCCZ, c.w	CEPC	FCC ZH	ILC500
Npairs / BX	200	9900	3260	640	165000
Leading process	96% LL	65% LL	80% LL	90% LL	60% BH
Epairs / BX (GeV)	86	2940	2600	570	400000
Leading process	100% LL	100% LL	98% LL	96% LL	70% BH

Landau-Lifschitz (LL) : $\gamma^*\gamma^*$ -> ee
Bethe-Heitler (BH) : $\gamma^*\gamma_{BS}$ -> ee

FCC Z, c.w. : 15x less pairs than at ILC500
and these pairs carry a 135x lower energy

$\gamma^*\gamma^*$ largely dominates; processes induced by Beamstrahlung photon(s) are subleading, in contrast to ILC