Progress on “Online” studies

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Introduction

LEP or planned experiments for the ILC : triggering is not an issue.

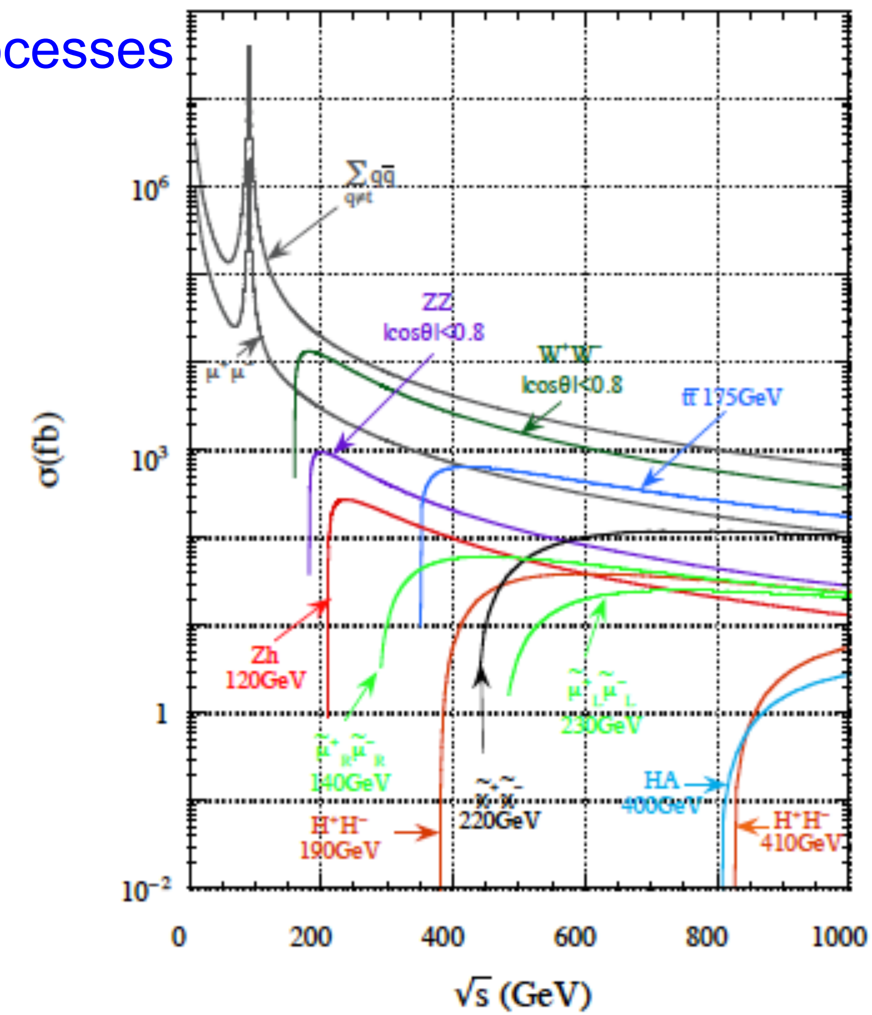
FCC ee, Z peak, crab-waist scheme :

- lumi about 2 10^{36} $cm^{-2}s^{-1}$
- many bunches, Δt = 10 ns between two BXs (i.e. 100 MHz)
- detector: probably many channels. Use ILC detectors as an example
  - VTX : 1000 M channels (CMS phase-1: 80M, LHCb upgrade: 40M)
  - ECAL : 100 M channels (CMS : 100 000)

The Z-peak running, esp. in the high luminosity option (crab waist), may pose online issues not encountered earlier in high energy e+e- collisions.

Expected rates at FCC-ee from physics processes

	Z	Z (c.w.)	WW
Lumi (10^{34} $cm^{-2}s^{-1}$)	28	212	12
Rate qq (kHz)	8.5	65	0.005
Rate Bhabha (*) (kHz)	35	265	4.5



(*) down to θmin = 30 mrad
10x smaller for θmin = 70 mrad

Putting aside the Bhabha events for the while :
At the Z peak, crab-waist scheme : need to write to disk O(100 kHz) of “physics” events.

Rate to disk in other experiments (approx. numbers…)

	Trigger rate	Event size	Throughput to disk
ATLAS / CMS 2012	0.5 kHz	0.8 MB	500 MB / s System could go to 2 GB / s. Limited by storage
ATLAS / CMS Phase 2	5 kHz	4 MB (PU = 140)	20 GB / s
LHCb upgrade	10-20 kHz	100 kB	1 GB / s

Event size at FCCee ?
TESLA TDR (*): A multijet event in the TESLA detector = about 200 kBytes.

100 kHz x 200 kBytes = 20 GB / s OK

However, adding the background, this increased to 5 MBytes !

100 kHz x 5 MB = 500 GB / s 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.

Questions on event size

- 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 ECAL

- Pair-production background at FCC ?
  - lower Beamstrahlung than at ILC
  - still, is it a negligible effect on data volume ?

- Event size of a physics event in a FCC detector ?

} New since TLEP8

Pair-production background at FCC

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

	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

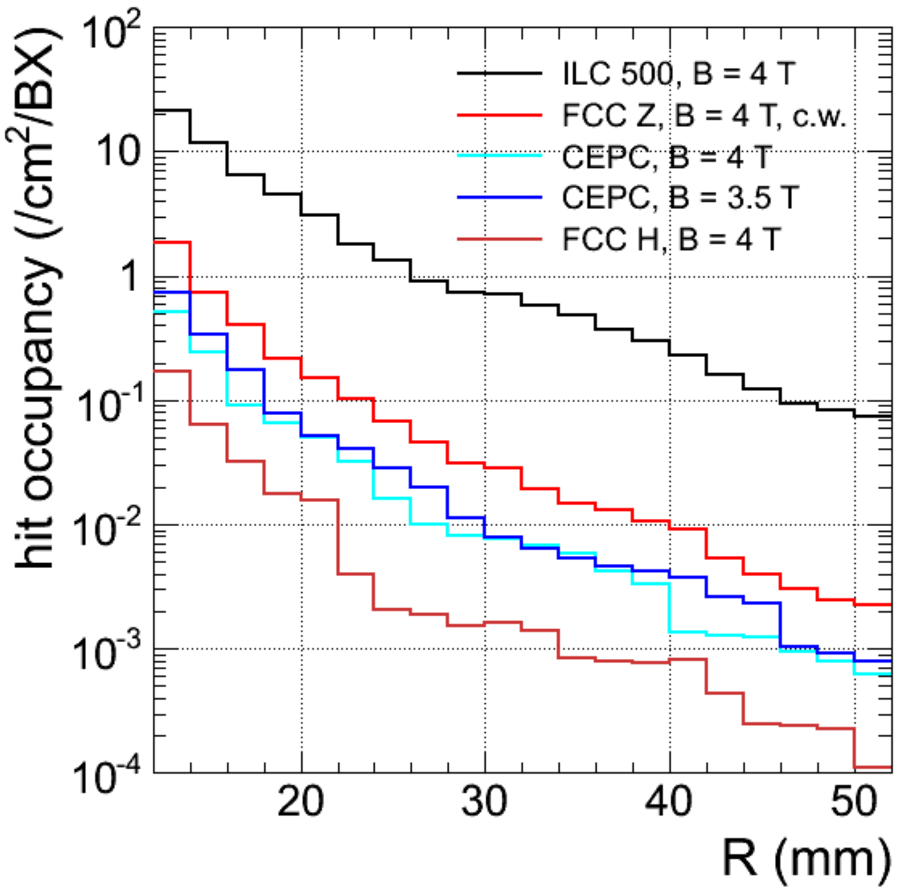
FCC Z, c.w. : 15x less pairs than at ILC500
and these pairs carry a 135x lower energy

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

Pair-production background: occupancies in the central VTX

Simple model to estimate the occupancies in a vertex detector :

track the charged particles through the magnetic field of the main solenoid;
intersections of the trajectories (helixes assumed) with the VTX layers
take into account loopers and simple geometric effects

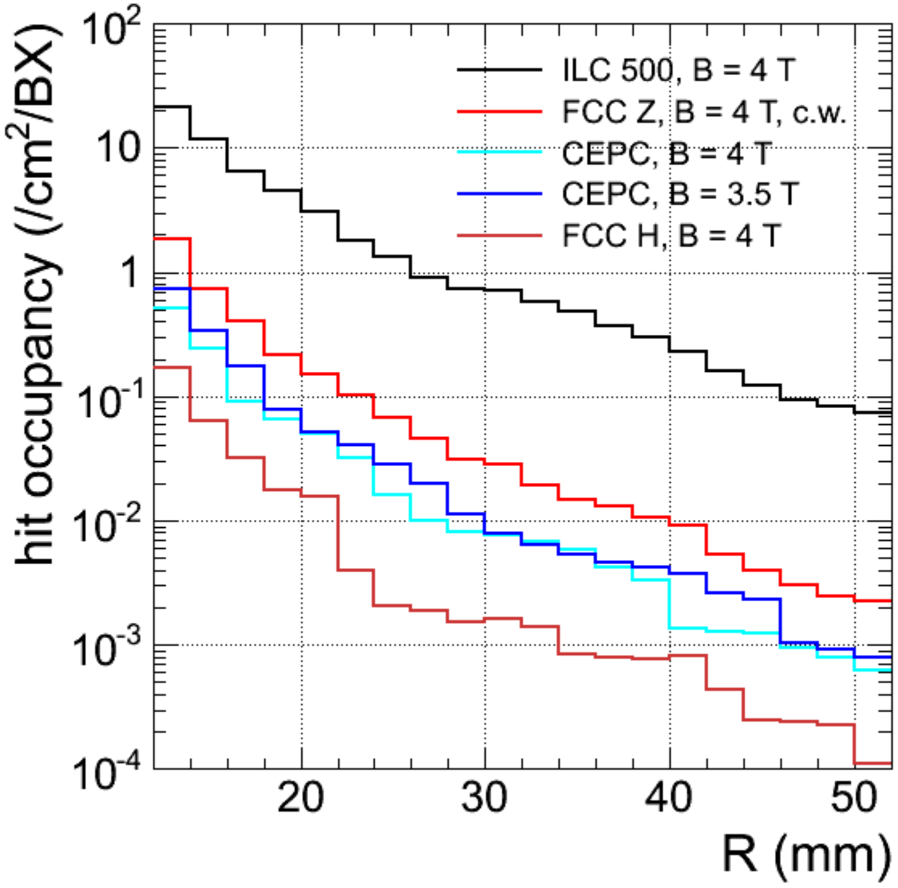


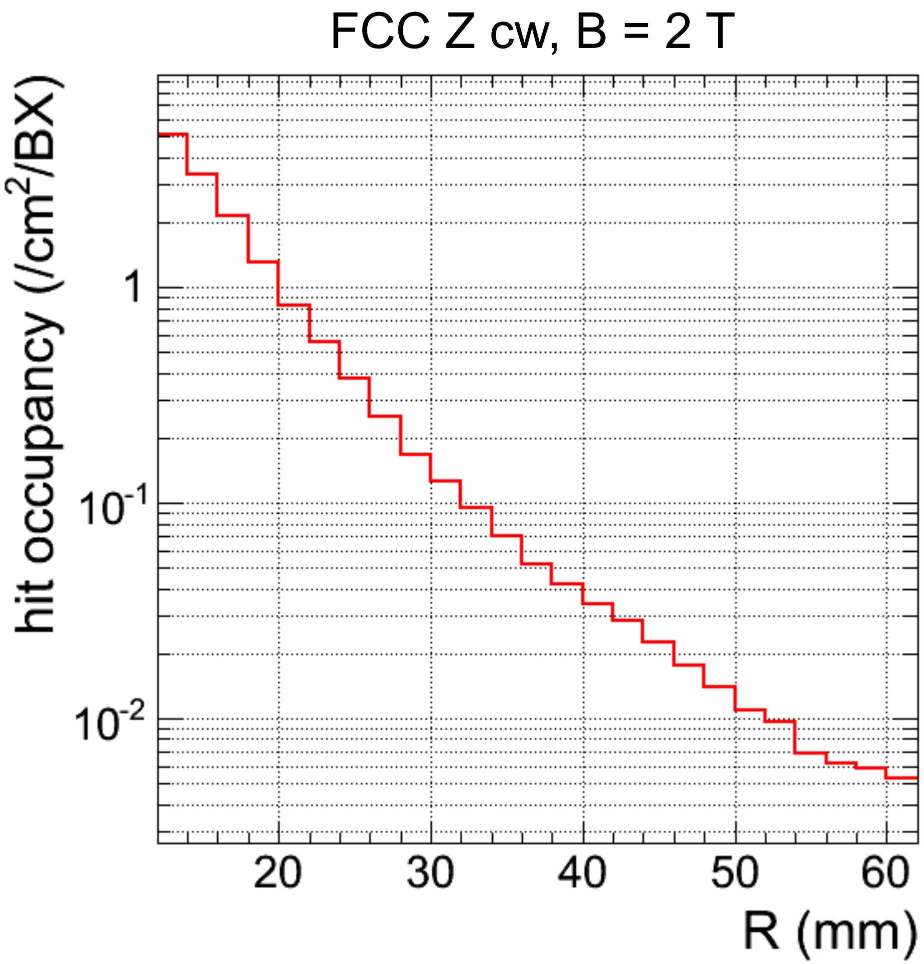
Use cylindrical layers with
Zmax = 65 cm for R < 3 cm
Zmax = 120 cm for R > 3cm
(cf ILD design)

Count the number of hits in a layer at a given R, and divide by its area

Occupancies in VTX at FCC Z c-w are O(10) lower than at ILC500.

Effect of the magnetic field





Typically 2.5x – 3x larger with B = 2 T instead of 4 T

Pair-production background: occupancies in the VTX

Nhits / BX in 1st layer, taken at R = 12 mm, from the simple model (B = 4 T) :

	Nhits Per BX	**Size Per BX (*)**	**Number of BXs in 20 μs (**)**	**Size per event If readout time = 20 μs**
FCC Z c.w.	260	1 kB	2000	2 MB
ILC500	2600	10 kB	35	350 kB

(*) using 32 bits per channel
(**) for most pixel detectors foreseen at ILC, timestamp is O(few 10 μs)

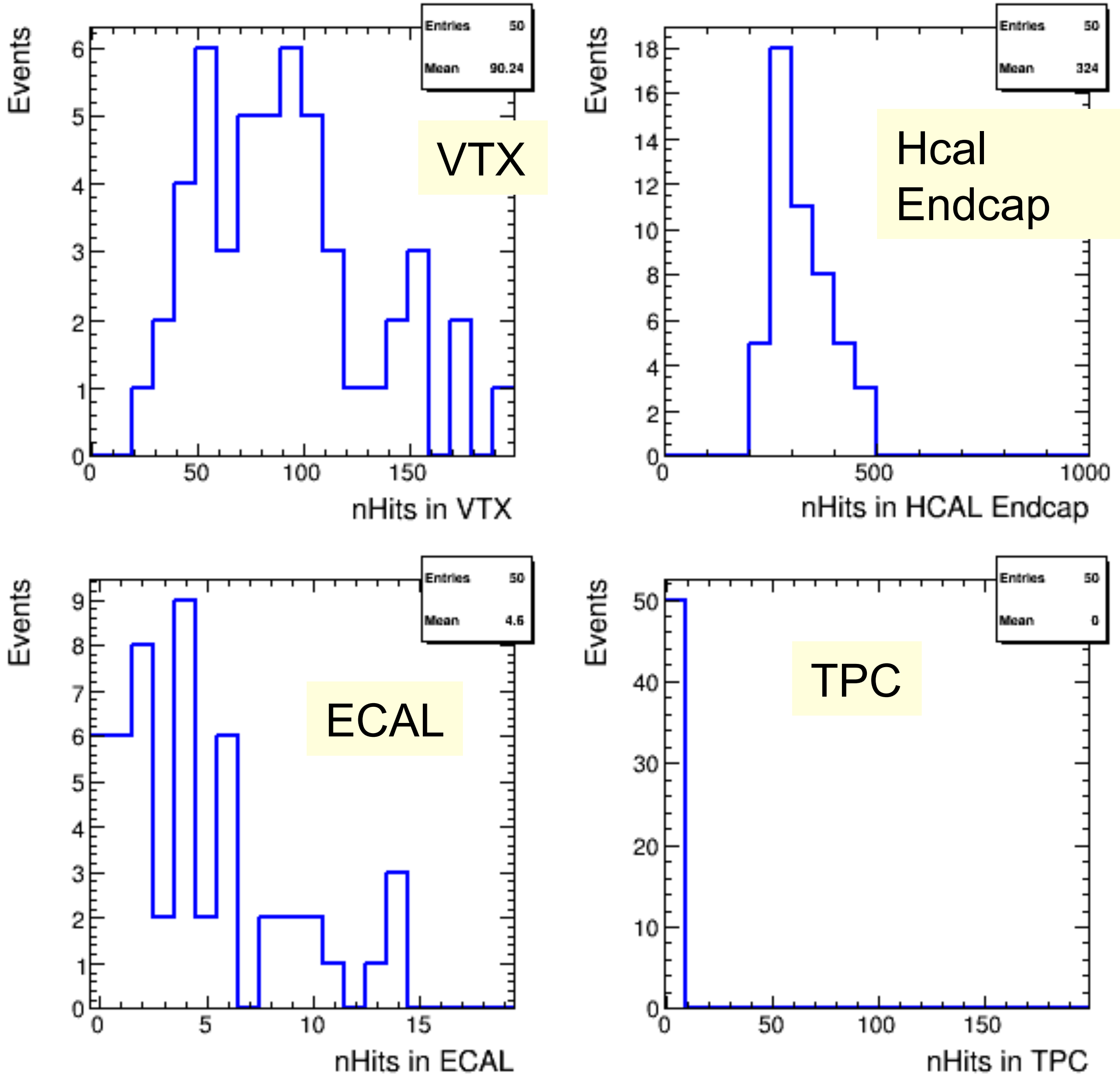
ILC numbers : consistent with Table on slide 4:
- a full train at ILC1000 = 2500 bunches
- all layers & safety factor of 5

-> O (100 MB) for a full train

Assuming that one uses pixels "a la LHC", i.e. with a timestamp resolution close to the Δt between two bunches:
the data volume due to the pair background, in the VTX, will only be of a few kBytes -> negligible - assuming also that backscattering is subleading (with the ILC design for the forward region, it is).

Pair-background using a full simulation – ILD detector (inc. fwd region)

Full simulation of the ILD detector as implemented in Mokka (ILC software, ILD design).
50 BXs simulated with GuineaPig for FCCee-Zcw



VTX : $R_{1,2}$ = 16 & 18 mm
< Nhits > = 90 consistent with simple model

<Nhits> = 350 in HcalEndcap

No hit in TPC : good news…
r/o time of TPC =
50 μs = 5000 BXs !
Important to limit the backscattering in the TPC.

Backscattering depends a lot on the fwd region, ILC used here !

E.Perez

Typical event sizes from full simulation (Mokka, ILD design)

Average Nhits from simulation of the ILD detector, over 500 events for the signal processes.
NB: conversion from GEANT Nhits in TPC to number of “digis” is approximative.

< Nhits >	Pair bckgd (c.w.)	Z to μμ	Z to jj	Bhabha	ZH to jjbb at 350 GeV
VTX 32 bits / ch	90	15	160	7	350
TPC 50 bits / ch	< 0.06	90	1400	50	3000
Ecal 40 bits / ch	5	70	1400	20	9000
HcalBarrel id	-		2000	5	9000
HcalEndcap id	340	90	1000	15	
Muons 32 bits	-	50	30	6	50
BeamCal 32				60	
LumiCal 32				800	
LHCal 32				75	
Approx size	2 - 4 kB	1.6 kB	30 kB	2.5 kB	110 kB

Typical event sizes from full simulation (in the ILD design)

Comments on the table :

- Pair production background is not an issue

- TPC occupancies : ee -> qq rate = 65 kHz i.e. one qq event every 15 μs
  i.e. within the readout time of 50 μs of the TPC, pile-up of ~ 3 - 4 had events in the TPC.
  would be ~ 5000 hits i.e. 30 kBytes of TPC data with 50 bits / channel.

- hence, with a TPC, an "offset" of 30 kBytes to add to the raw data corresponding to any triggered event written to disk.
  - a Zmumu event would be 30 kBytes
  - a Bhabha event would be 30 kBytes…

- the guess / estimate of O (100 kB) per hadronic event looks reasonable
  - volume gets dominated by the calorimeter as soon as there is a lot of jet activity

Typical event sizes from full simulation

With the present estimates (caveats, approximations), based on

- simulation of ILD detector including fwd region
- pair-production background only

the volume of data to write to disk at the Z peak, c.w. scheme is about :

65 kHz x 100 kB of had. events = 6.5 GB / s
265 kHz x 30 kB of Bhabha events = 8 GB / s (with TPC)
- that's for θmin = 30 mrad, 10x lower if LumiCal down to θ = 70 mrad

Even in the extreme case (TPC and write full raw data, low angle LumiCal), it does not look challenging compared to LHC phase-2.

Still, several other sources of potential background that we need to estimate :

- backscattering of Beamstrahlung photons
- γγ -> hadrons

} Use GuineaPig. Need geometry of fwd region for backscattering.

- synchrotron radiation
- beam halo, beam gas
- from injection ?

see with MDI how we can simulate that

Trigger architecture : L1 or software only ?

ILC and LHCb upgrade : no L1 hardware trigger

- ILC : because of the bunch structure : can readout everything in the long time (199 ms) between two trains
- LHCb : because they need a very pure selection at the trigger level

	Event size	L1 rate	FE to Event Builder
ATLAS / CMS Run 1	0.5 MB	100 kHz	50 GB/s
ATLAS / CMS Phase 2	4 MB	O(500 kHz)	2 TB/ s
LHCb upgrade	100 kB	40 MHz	4 TB / s
FCC ee (Z c.w.)	2 kB	100 MHz	200 GB / s

From the bckgd from pair-production only, the data volume to be transferred to the event builder should not be a showstopper for a software-only trigger.

Need to review the pros and cons, and understand the constraints that a software-only trigger may put on the detector.

Physics analysis requirements

To which level do we need to know the trigger efficiencies ?

a fraction of a per-mil …

a goal could be to have an uncertainty that is not larger than that on the measured luminosity – i.e. below 0.01% ?

What is the precision expected from tag-and-probe techniques ?

Redundancies to ensure an in-situ control of the inefficiencies :

- e.g. for an electron trigger : trigger on a track / trigger on calo cluster

WG10 organization

- Twiki has been set-up, which summarizes where we stand in our brain-storming

- Good contacts with people working on these questions for CEPC

- Start to organize the WG and will call for a WG meeting shortly after Pisa.
  - connections with the software group (full simulation within the FCC data model)
  - with the MDI group (machine induced background, description of the IR, compensating field)
  - with the detector group (description of the fwd region, main detector)
  - with physics studies

Backup

Machine parameters used for Guinea-Pig

```
$ACCELERATOR:: CEPC
{
energy=120.0;
particles=37;
offset_x=0.;
offset_y=0.;
sigma_x=73700.;
sigma_y=160.;
sigma_z=2260.;
emitt_x=1595.;
emitt_y=4.8 ;
charge_sign=-1;
}
```

```
$ACCELERATOR:: FCCH
{
energy=120.0;
particles=4.6;
beta_x=500;
beta_y=1;
offset_x=0.;
offset_y=0.;
sigma_x=21600.;
sigma_y=44;
sigma_z=810.;
charge_sign=-1;
}
```

```
$ACCELERATOR:: FCCZcw
{
energy=45.0;
particles=10;
beta_x=500;
beta_y=1;
offset_x=0.;
offset_y=0.;
sigma_x=8400.;
sigma_y=32;
sigma_z=2700.;
charge_sign=-1;
}
```

```
$ACCELERATOR:: ILC500
{
energy=250.0;
particles=2;
beta_x=11;
beta_y=0.48;
offset_x=0.;
offset_y=0.;
sigma_x=474;
sigma_y=5.9;
sigma_z=300.;
charge_sign=-1;
}
```

Background at the ILC (ILC TDR)

Example for the SID detector at $\sqrt{s}$ = 1 TeV, from the ILC TDR
Occupancies and data volume for a full train (1 ms)

Will use this #bits / hit in the following

Table II-9.2 Overview of read-out details for the various subdetectors. Occupancies and data volumes are for a full bunch train at 1 TeV and include beam-induced background as well as charge sharing between pixels/strips. Safety factors of five and two have been applied to the rates of incoherent pairs and $\gamma\gamma \rightarrow$ hadrons respectively. BeamCal and Lumical are expected to be using the Bean chip with a buffer depth of 2820.

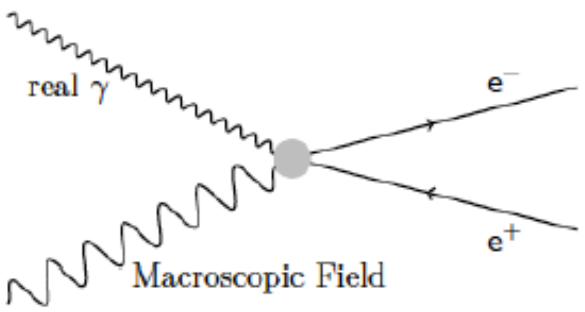
	cell size (mm^2)	number of channels (10^6)	av. to max. occ. (%)	approx. # bits per hit (bit)	data volume (Mbyte)
VXD barrel	0.02×0.02	408	8 - 60	32	130
VXD disks inner	0.02×0.02	295	4 - 70	32	50
VXD disks outer	0.05×0.05	980	0.5 - 20	32	20
Main tracker barrel	0.05×100	16	33 - 300	32	20
Main tracker disks	0.05×100	11	4 - 500	32	2
ECAL barrel	3.5×3.5	72	2 - 45	40	7
ECAL endcap	3.5×3.5	22	33 - 2300	40	36
HCAL barrel	10×10	30	0.07 - 200	40	0.1
HCAL endcap	10×10	5	96 - 3600	40	24
LumiCal	2.5×var.	0.061	≫100	16	(*) 340
BeamCal	2.5(5.0)×var.	0.076	≫100	16	430

(*) raw I think. After online treatment would be 5% of it (ILD)

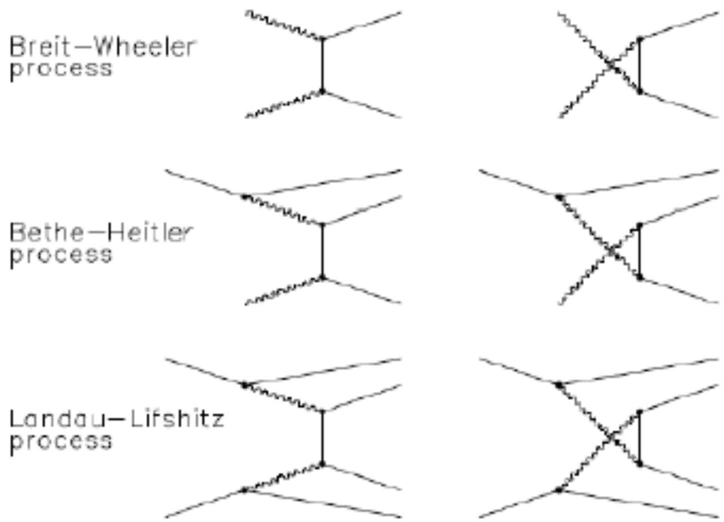
Beam induced background: pair production (γγ→ee)

Slide from Manqi Ruan
October workshop

- Coherent and incoherent electron-positron pair production; the most important background for detectors
  - **Coherent**: real photons (e.g. beamstrahlung) interaction with the coherent field of the out-coming bunch → in small angle
  - **Incoherent**: real/virtual photon interactions, including the Breit-Wheeler, Bether-Heitler and Landau-Lifschitz processes.



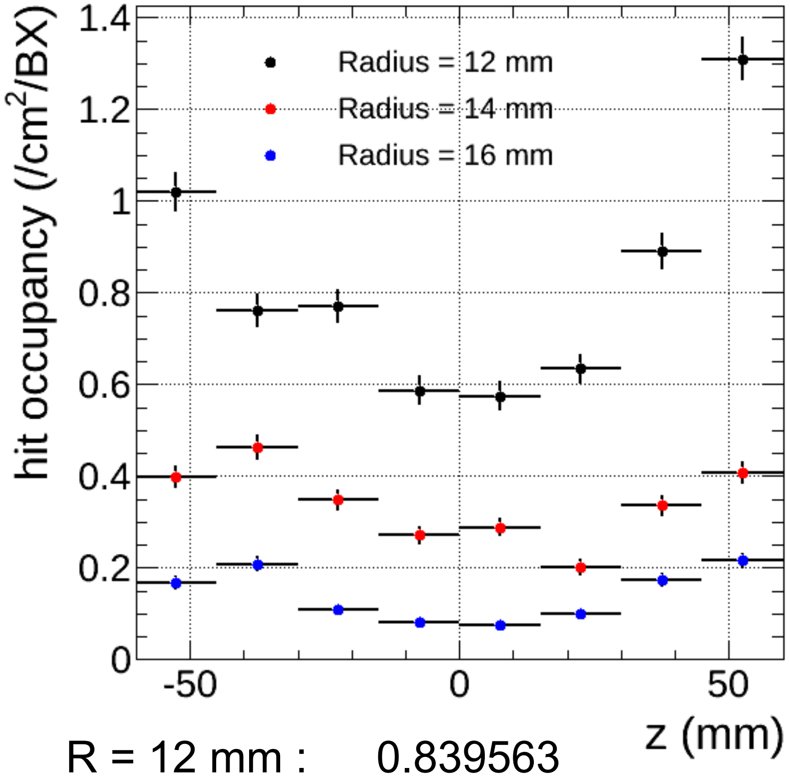
Coherent pair production



Incoherent pair production

VTX occupancies for CEPC : simple model vs GEANT simulation

CEPC, my model (B = 4 T) :



R = 12 mm : 0.839563
R = 14 mm : 0.341326
R = 16 mm : 0.143117
R = 38 mm : 0.0034693
R = 60 mm : 0.000278521

hit density in the 1st layer