beam background studies with ILD

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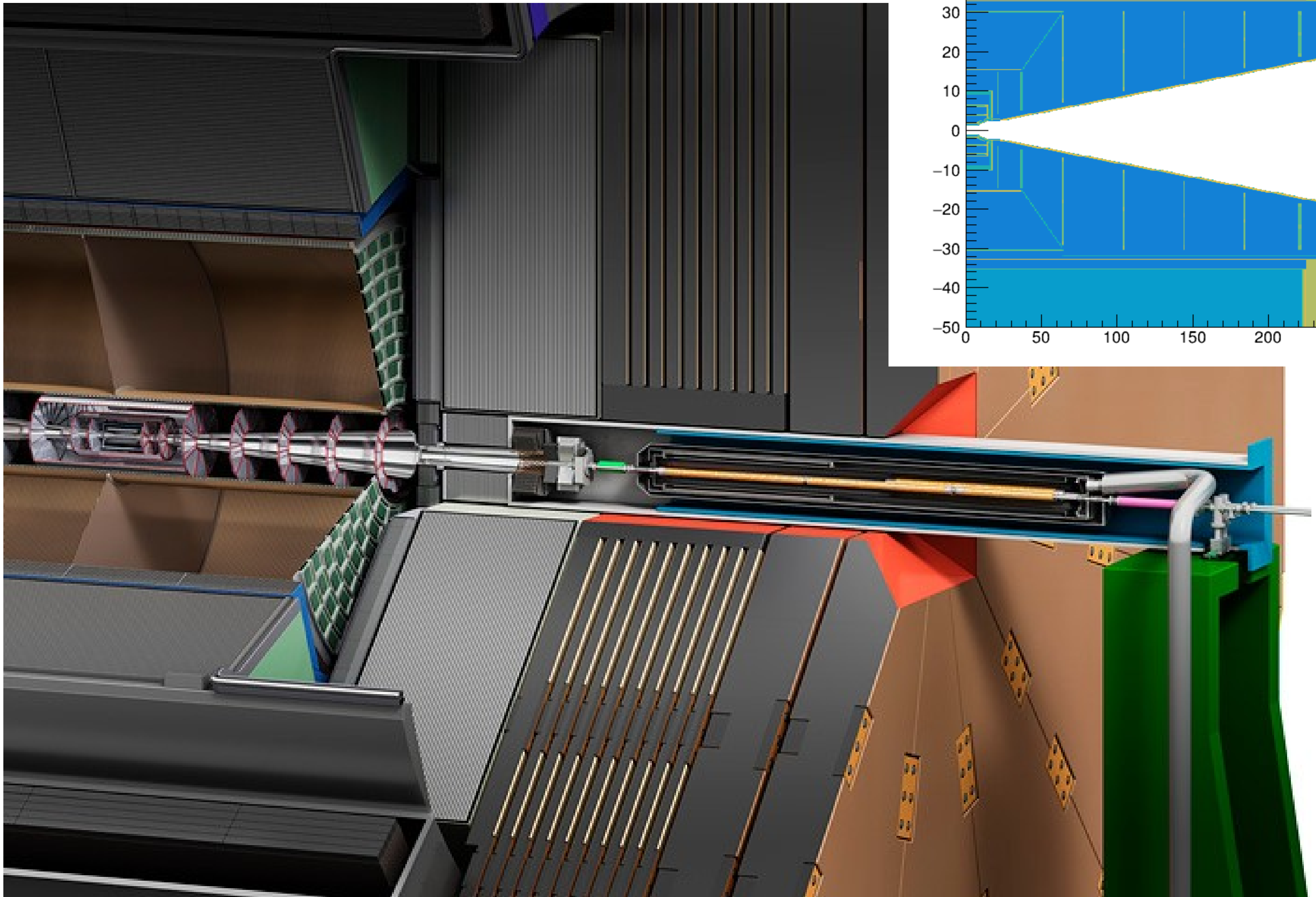
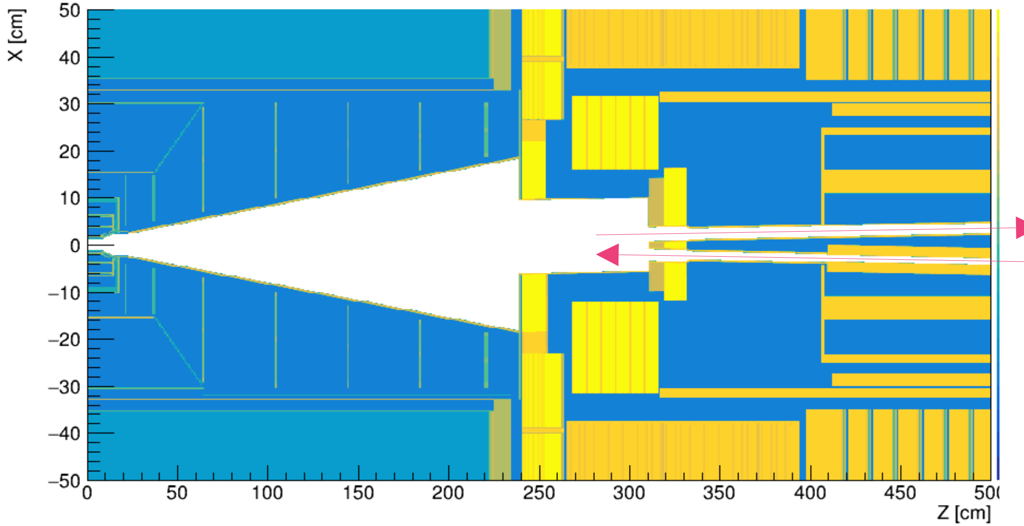
reminder of “recent” past studies of ILD @ ILC

taken from note ILD-TECH-PUB-2019-001
https://confluence.desy.de/download/attachments/42357928/machine_backgrounds_final.pdf?version=1&modificationDate=1585012405260&api=v2

only beamstrahlung today

some recent work in progress on ILD @ FCCee





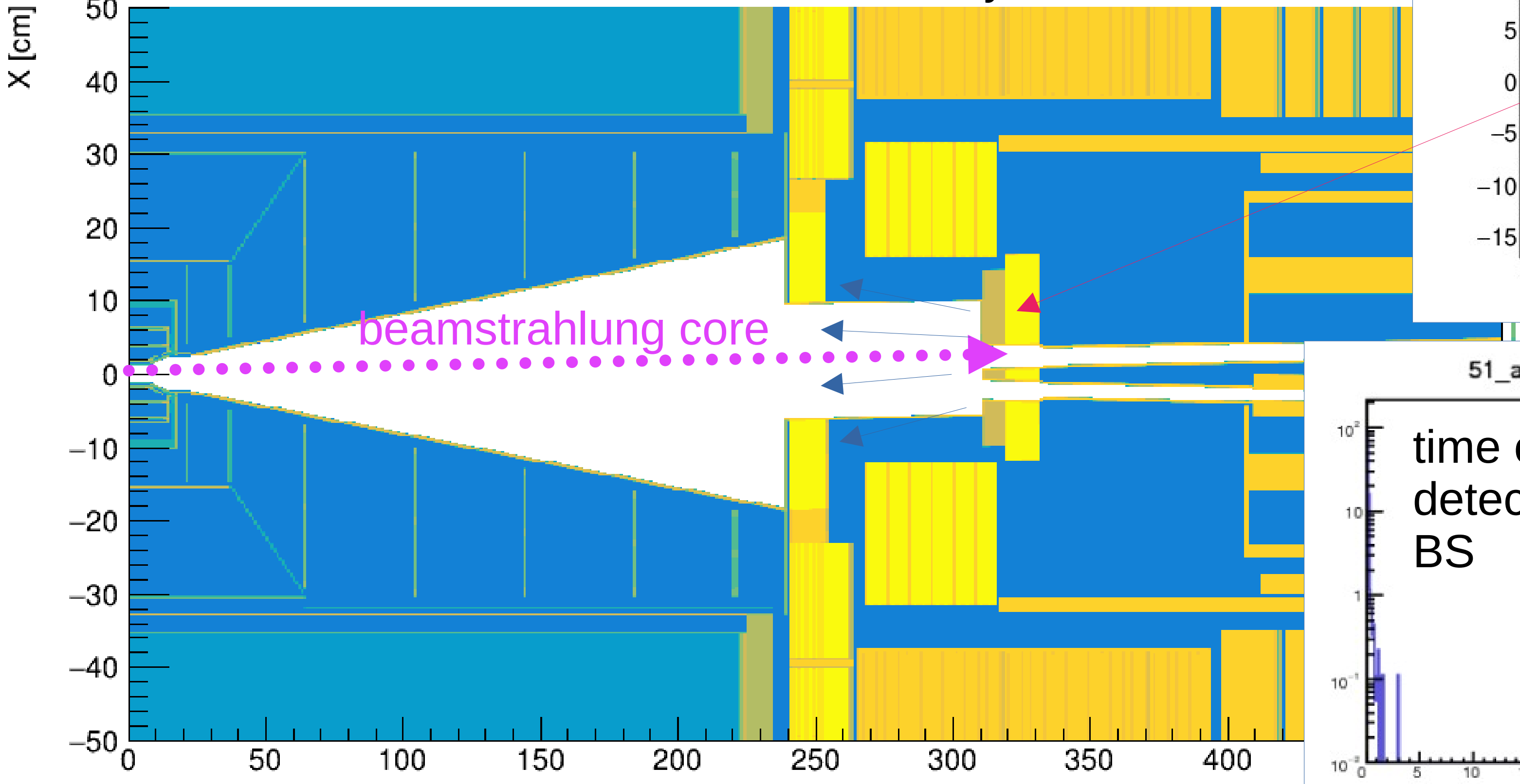
DD4hep detector
model of ILD

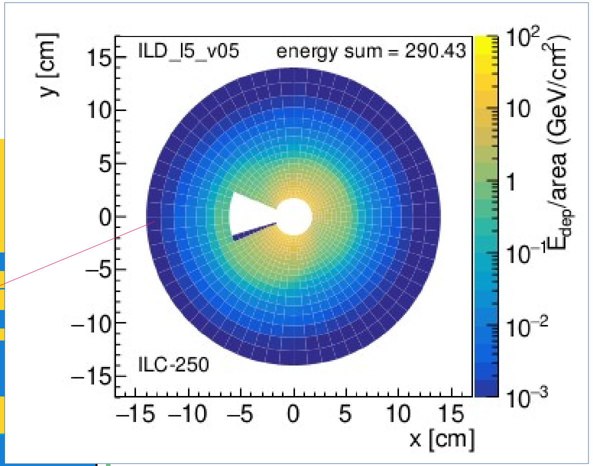
GuineaPig simulation
of beamstrahlung
at ILC-250

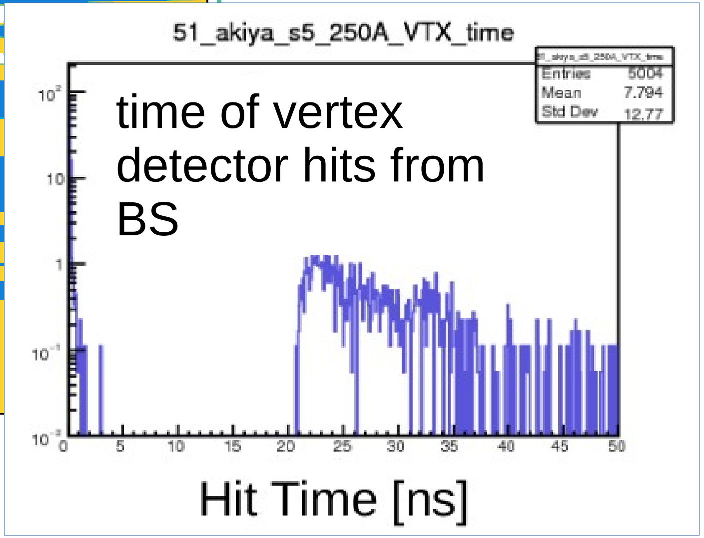
simulated in ILD
ddsim/Geant4

simulation model of ILD @ ILC

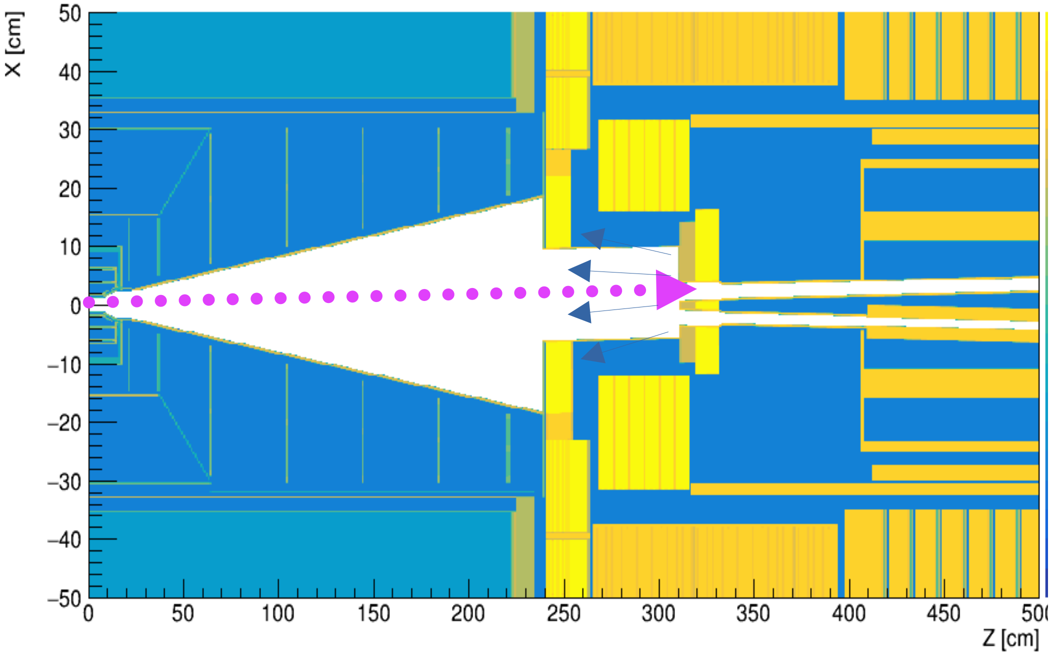
nominally 3.5 T field

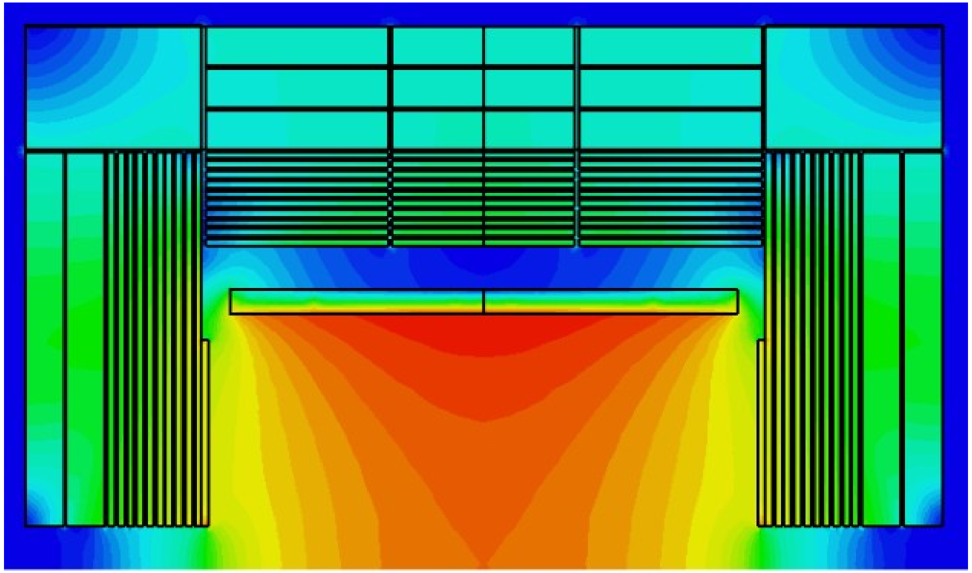






Beamstrahlung hitting BeamCal@z=3m is a source of particles coming back into the detector
anti-DID field tries to minimise this by steering beamstrahlung core into outgoing beampipe



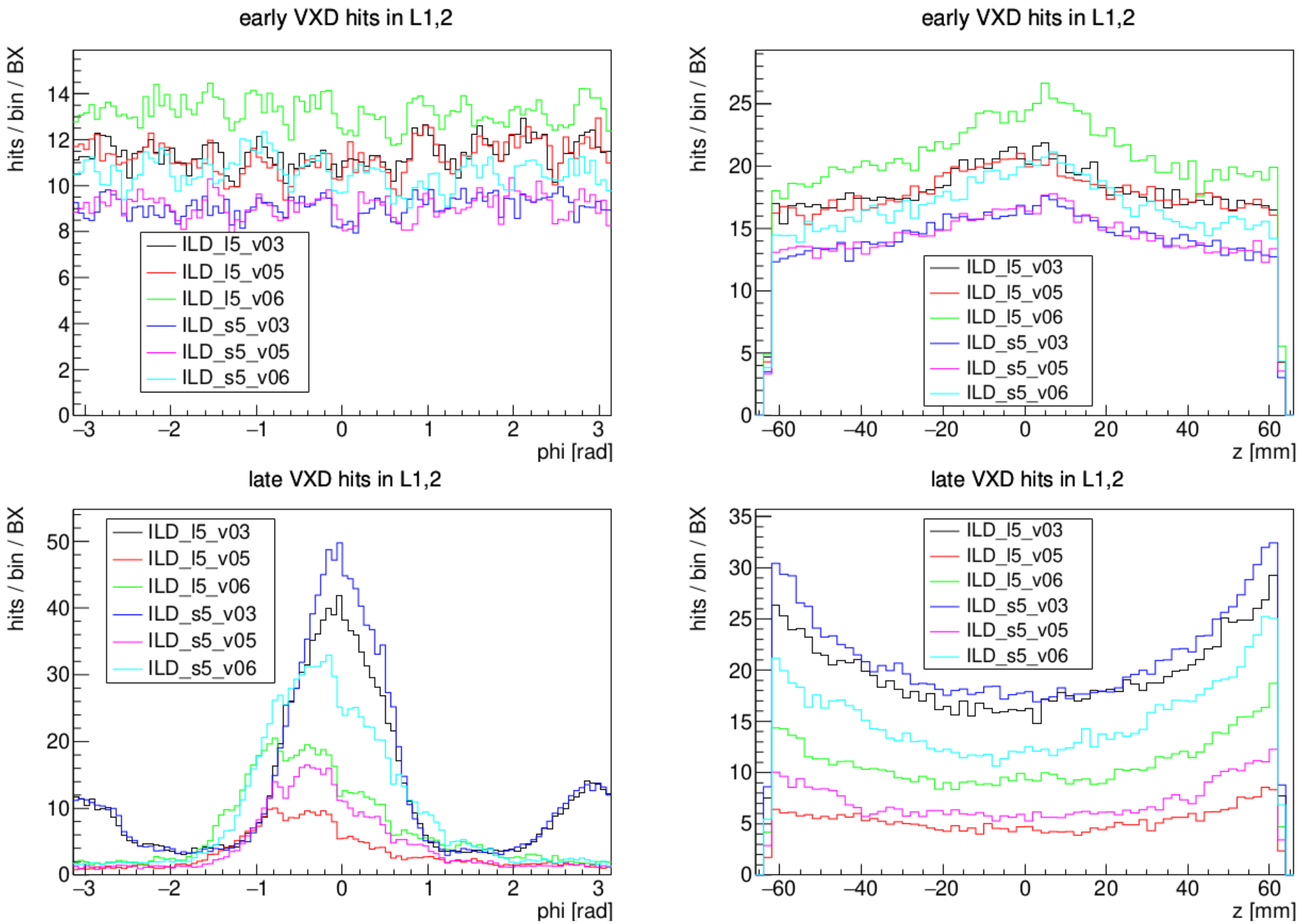


most beamstrahlung e+e- are very low pT
→ tend to “follow” the magnetic field lines

B-field rather non-uniform in forward region

accurate description of reflected beamstrahlung probably requires
a somewhat realistic map of the B-field

n.b. proper tracking of low-p_T particles in non-uniform field with ddsim was non-trivial: required special settings



ILC-250

3.5 T, anti-DID
3.5 T, no anti-DID

early hits (direct) do not depend on anti-DID

late hits (reflected)

strong reduction with anti-DID

strong phi dependence

ILD model	ECOM [GeV]	aDID	nom. field [T]	VXD hits per BX Layers 1, 2 Early	Layers 1, 2 Late	Layer 3, 4 Early	Layer 3, 4 Late	Layer 5, 6 Early	Layer 5, 6 Late
ILD_l5_v03	250	no	3.5	1139	1234	213	48	64	19
ILD_l5_v05	250	yes	3.5	1125	334	222	14	69	6
ILD_l5_v06	500	yes	3.5	1321	691	258	29	70	13
ILD_s5_v03	250	no	4.0	909	1343	176	60	54	21
ILD_s5_v05	250	yes	4.0	910	453	177	22	52	7
ILD_s5_v06	500	yes	4.0	1057	963	206	38	63	18

with no anti-DID, similar number of direct & reflected hits in VXD inner layers

anti-DID reduces reflected hits by factor ~4

ILD at a circular collider

especially the TPC

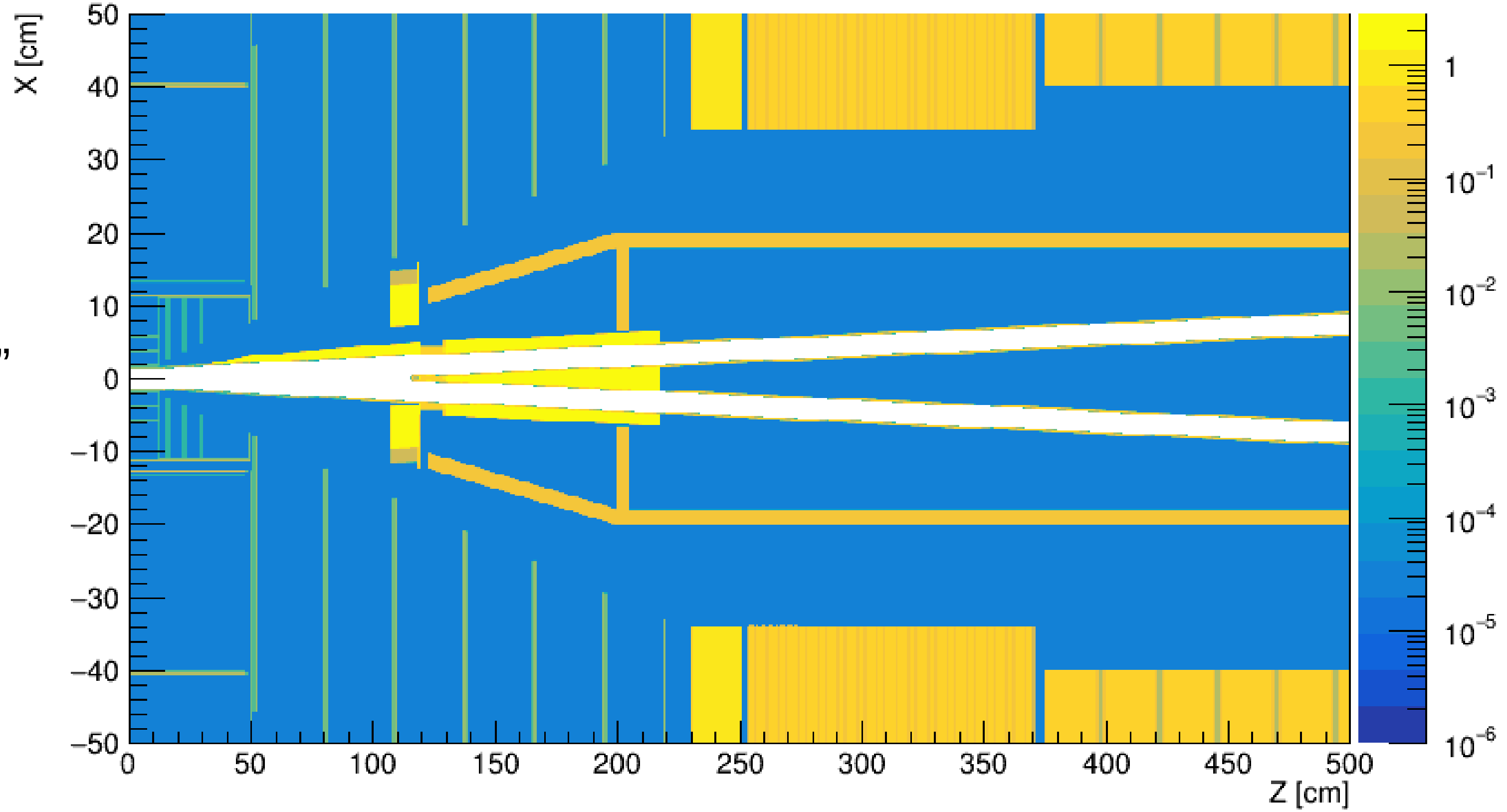
now let's look at ILD at a circular collider

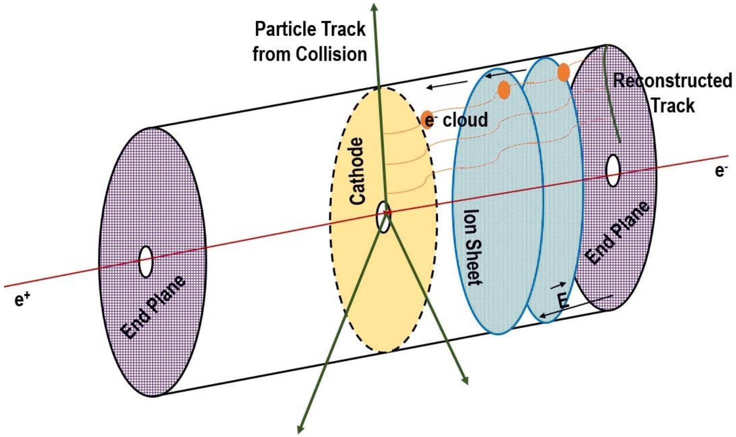
MDI region is very different

FCCee/CLD

lumical & masks
inside "tracking region"

field limited to 2T





bunch structure is very different:
continuous bunch crossings at ~33 MHz @ Z-pole

we looked at what this implies for the TPC

the ions produced in the TPC gas amplification
drift through the gas volume for ~0.44 s

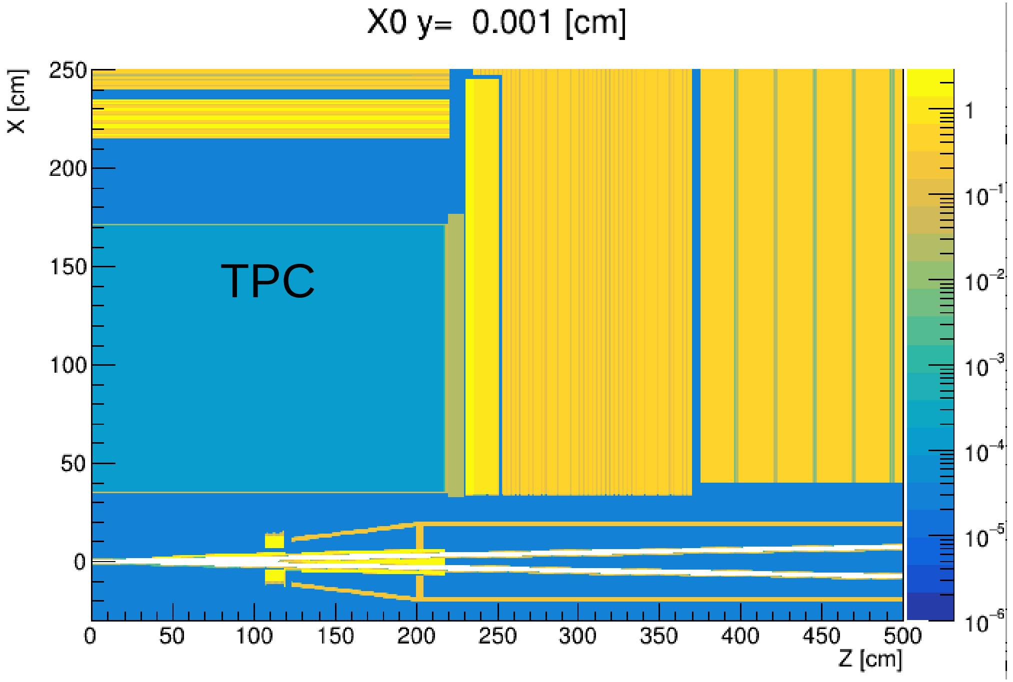
at ILC, there are up to 3 localised disks of ions drifting though the TPC,
each with ions from ~1k bunch crossings of 1 train
resulting distortions on electron trajectories don't destroy the momentum resolution

at FCCee,
quasi-continuous ion cloud from ~14M bunch crossings

100 BX of GuineaPig simulation for FCCee-91 courtesy of A. Ciarma (CERN)
full geant4 simulation in "ILD" models

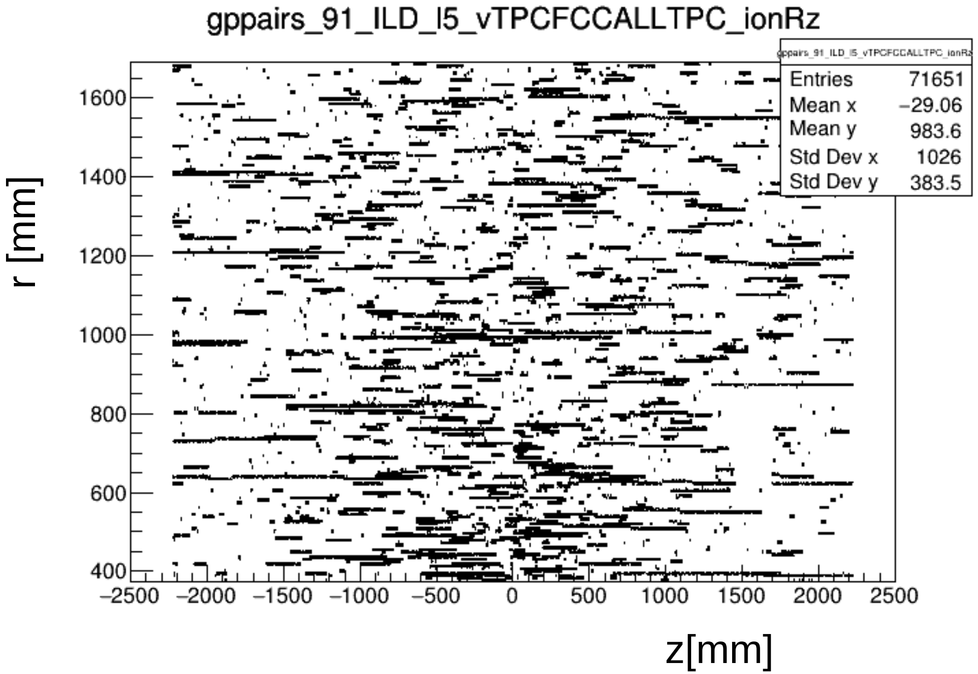
To study this made a FCCee/CLD model with TPC

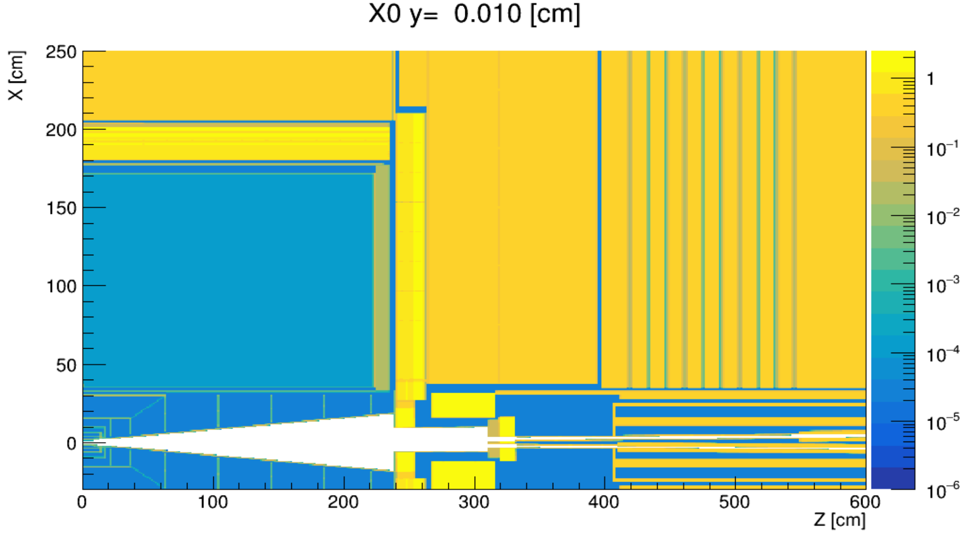
remove silicon tracking from CLD
squeeze in ILD's TPC
reduce B-field to 2 T [n.b. uniform field for now...]



usual ILD model, except B = 2T
(n.b. uniform field)

distribution of hits in the TPC,
overlaying 100 BX @ 91 GeV



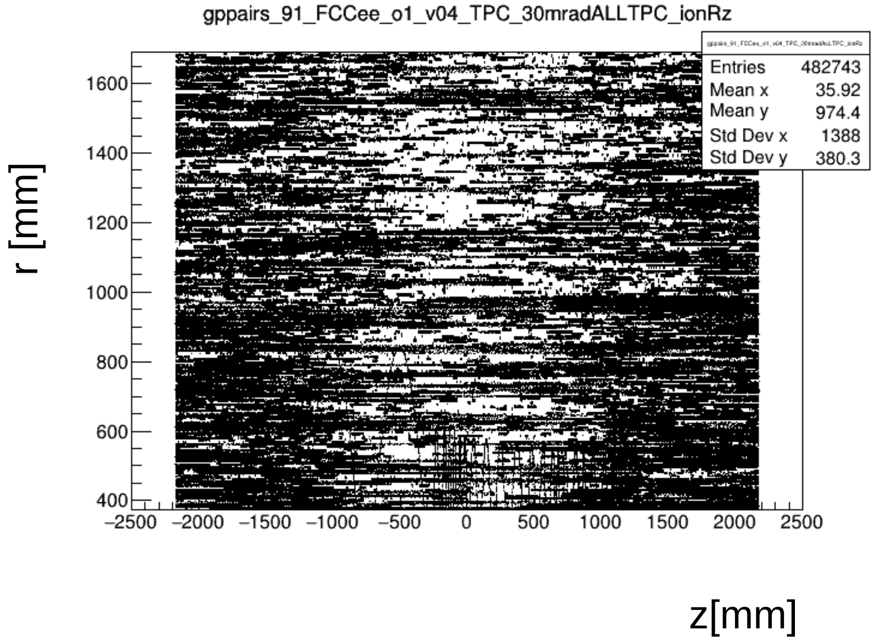


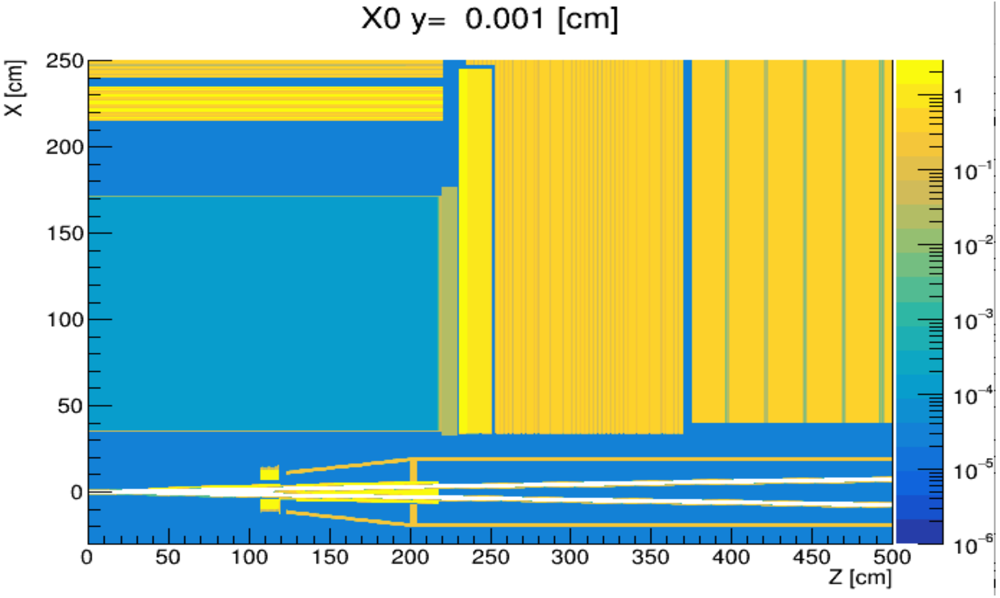
this corresponds to
~71k primary ions / BX

each primary ionisation also
induces 1~5 ? ions
flowing back from the gas
amplifier, depending on
gating efficiency
“Ion Back Flow” IBF

now CLD with TPC
(n.b. uniform field)

distribution of hits in the TPC,
overlaying same 100 BX @ 91 GeV





this corresponds to
~ 430k primary ions / BX

increase by factor ~6

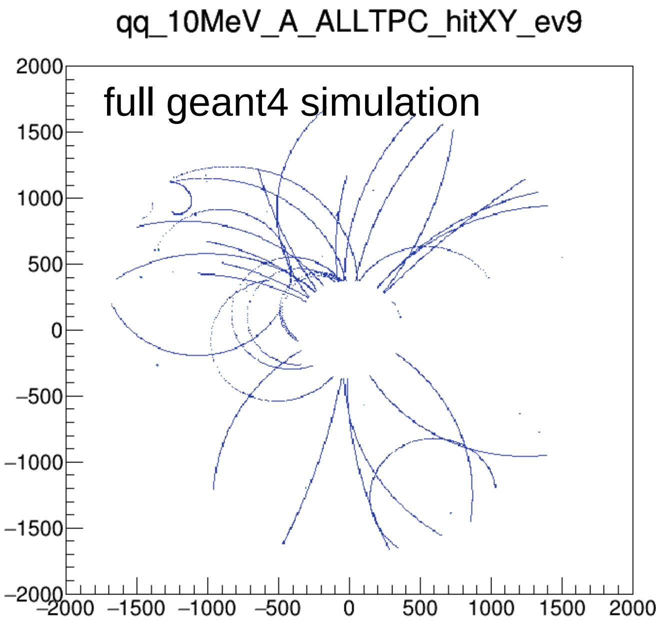
how about physics events ?

z → qq has high cross-section and multiplicity

~ 22k hadronic Z decays in the 0.44 s “TPC clearing time”

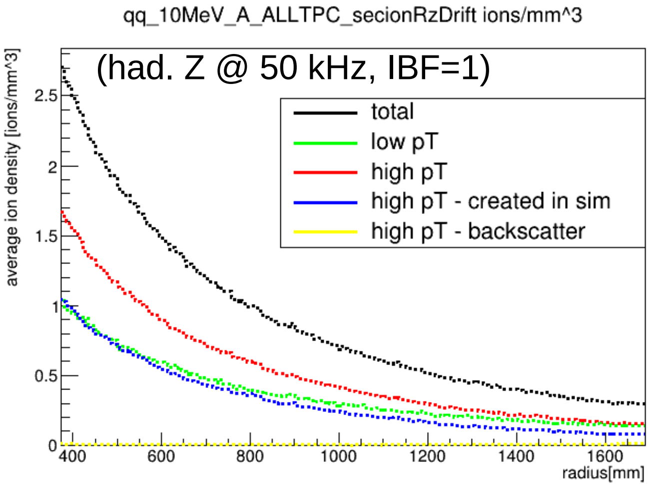
estimate ion distribution → extract expected distortions of electron trajectories

(with K. Fujii)

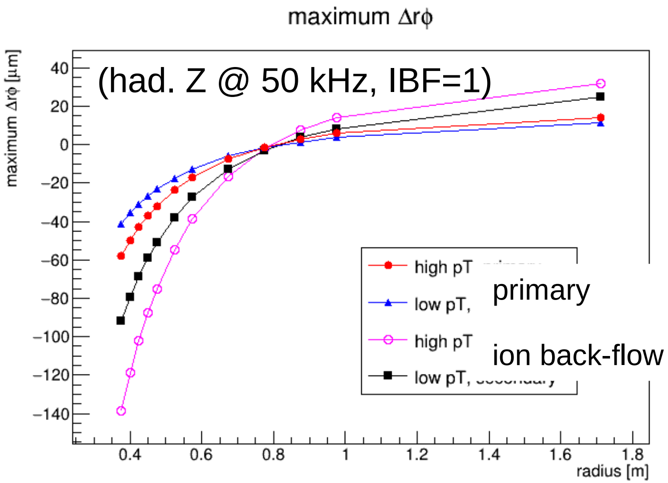


~1.3 M primary ions / event

average radial distribution of back-flow ion density



max. distortion in r-φ direction



maximum distortion

~ (100 + 230*IBF) μm

seem stable to ~μm

work in progress!

	primary ions / "event"	ave. rate	primary ions / 0.44 s "TPC frame"
Z→qq @ 91 GeV ILD_l5_v02 @ 2T	1.3M	54 kHz	30 $\times 10^9$
pairs@91GeV ILD_l5_v02 @ 2T	71 k	33 MHz	1000 $\times 10^9$
pairs@91GeV FCCee w/ TPC	0.43 M	33 MHz	6200 $\times 10^9$

max. distortions: 300 μm ~ mm
for IBF = 1 ~ 5

discussing with TPC colleagues...

summary

- beamstrahlung-induced backgrounds strongly influenced by
  Machine Detector Interface

- at ILC, MDI is ~2.5m from the IP

- at FCCee, MDI extends to ~1m from IP
  → 6 times more beamstrahlung background hits in TPC

- Tera-Z envisages very high bunch-crossing rate
  → can TPC cope with the resulting ion cloud from beamstrahlung ?
  → are large but rather stable distortions OK ?
  → mitigation? extra shielding ?

- various cross-checks needed
  → simulation or prcesses in TPC
  → effect of realistic B-field
  ...

https://indico.cern.ch/event/1203316/timetable/#5-fcc-accelerator-status-and-r

FCC-ee Parameters

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	90.836848			
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		10000	880	248	40
Bunch population	[10^{11}]	2.43	2.91	2.04	2.37
Horizontal emittance ε_x	[nm]	0.71	2.16	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.32	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	100 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.563 / 53.600		100.565 / 98.595	
Energy spread (SR/BS) σ_δ	[%]	0.038 / 0.132	0.069 / 0.154	0.103 / 0.185	0.157 / 0.221
Bunch length (SR/BS) σ_z	[mm]	4.38 / 15.4	3.55 / 8.01	3.34 / 6.00	1.94 / 2.74
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	2.1 / 9.2
Harmonic number for 400 MHz		121648			
RF freuqeuncy (400 MHz)	MHz	400.793257			
Synchrotron tune Q_s		0.0370	0.0801	0.0328	0.0826
Long. damping time	[turns]	1168	217	64.5	18.5
RF acceptance	[%]	1.6	3.4	1.9	3.0
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y[a]		0.0023 / 0.135	0.011 / 0.125	0.014 / 0.131	0.093 / 0.140
Luminosity / IP	[10^{34}/cm^{2}s]	182	19.4	7.26	1.25
Lifetime (q + BS + lattice)	[sec]	840	–	< 1065	< 4062
Lifetime (lum)	[sec]	1129	1070	596	741

[a] incl. hourglass.

K. Oide, Nov. 2022

https://indico.cern.ch/event/1209598/timetable/#9-overview-of-bi-studies-for-f

Beam Size Measurement

Parameter [4 IPs, 91.2 km]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
horizontal beta* [m]	0.1	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	8	21	14	39
vertical rms IP spot size [nm]	34	66	36	69

parameter (4 IPs, $t_{rev} = 304\ \mu s$)	value
circumference [km]	91.18
max. beam energy [GeV]	182.5
max. beam current [mA]	1280
max. # of bunches/beam	10000
min. bunch spacing [ns]	25
max. bunch intensity [10^{11}]	2.43
min. H geometric emittance [nm]	0.71
min. V geometric emittance [pm]	1.42
min. H rms IP spot size [μm]	8
min. V rms IP spot size [nm]	34
min. rms bunch length SR / BS [mm]	1.95 / 2.75

stability of distortions due to hadronic events @ Z-pole