can a TPC work at FCCee ?

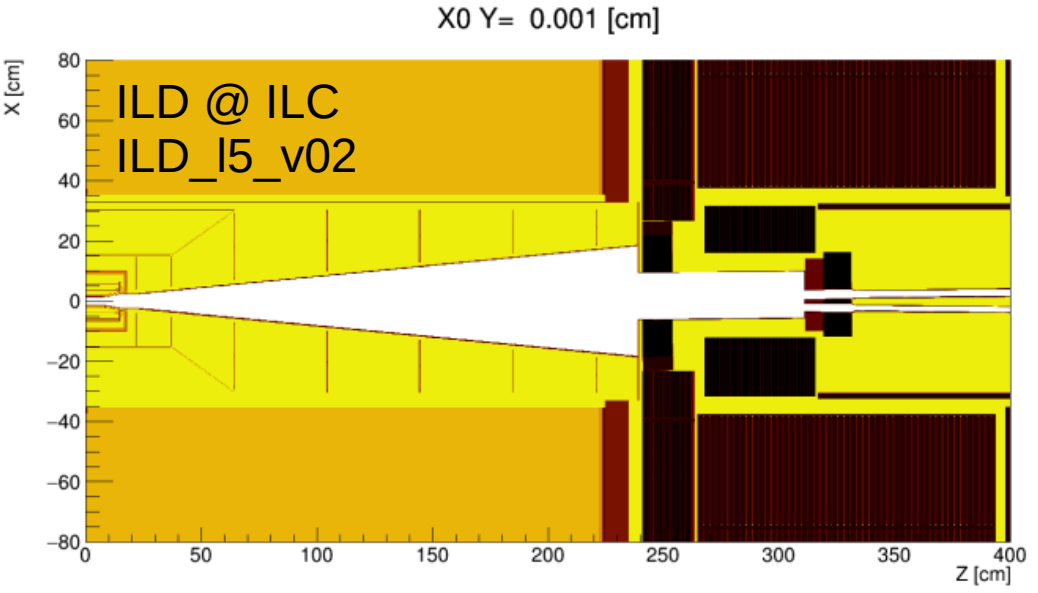
or

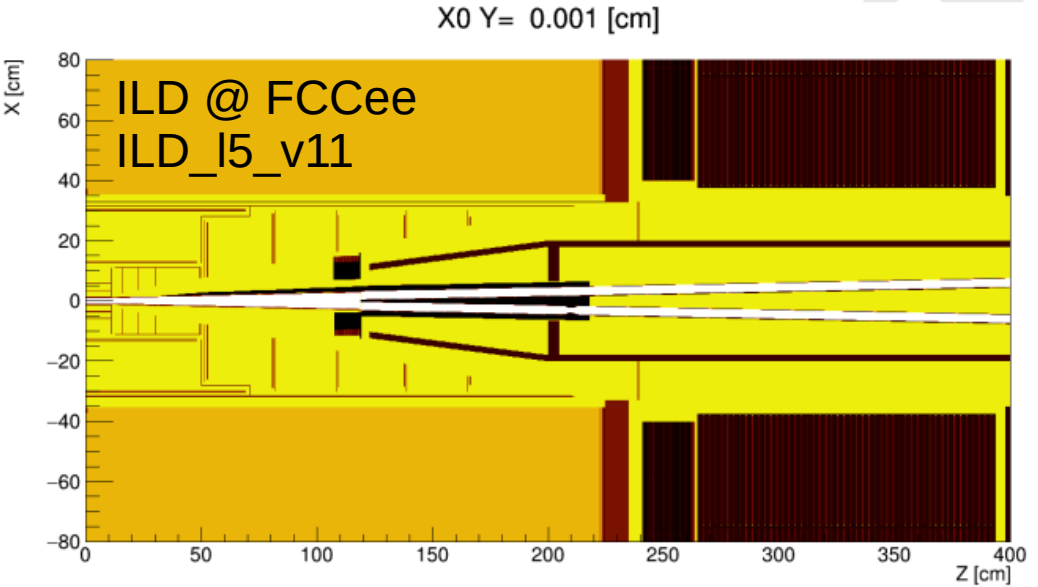
beamstrahlung backgrounds in the TPC @ FCCee & ILC

preliminary

machine-detector interface

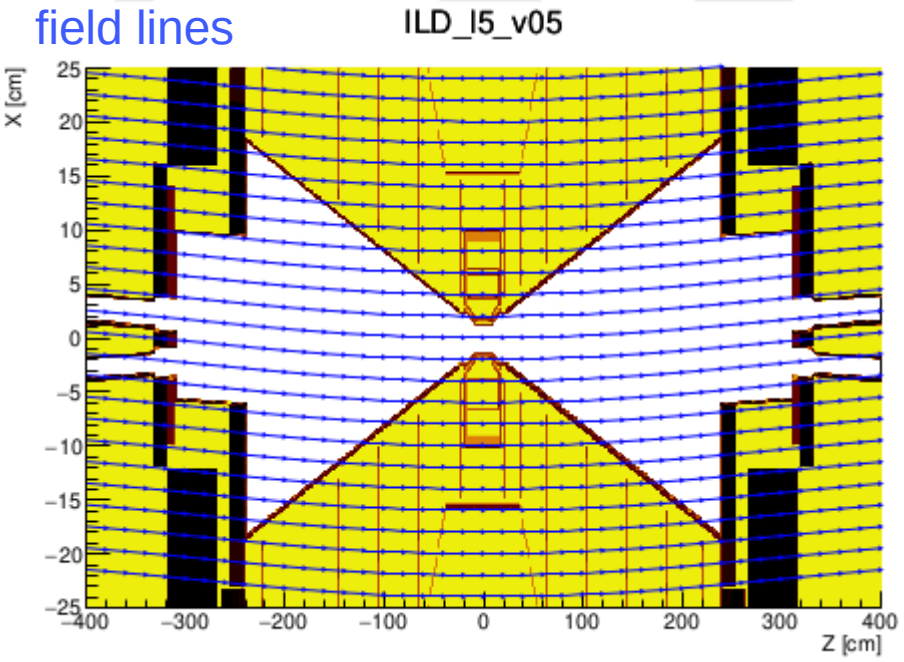
	ILC	FCCee
crossing angle	14 mrad	30 mrad
L*	4.1 m	2.0 m
detector solenoid	3.5 T	2.0 T
additional B- fields	anti-DID (?)	- compensating - screening





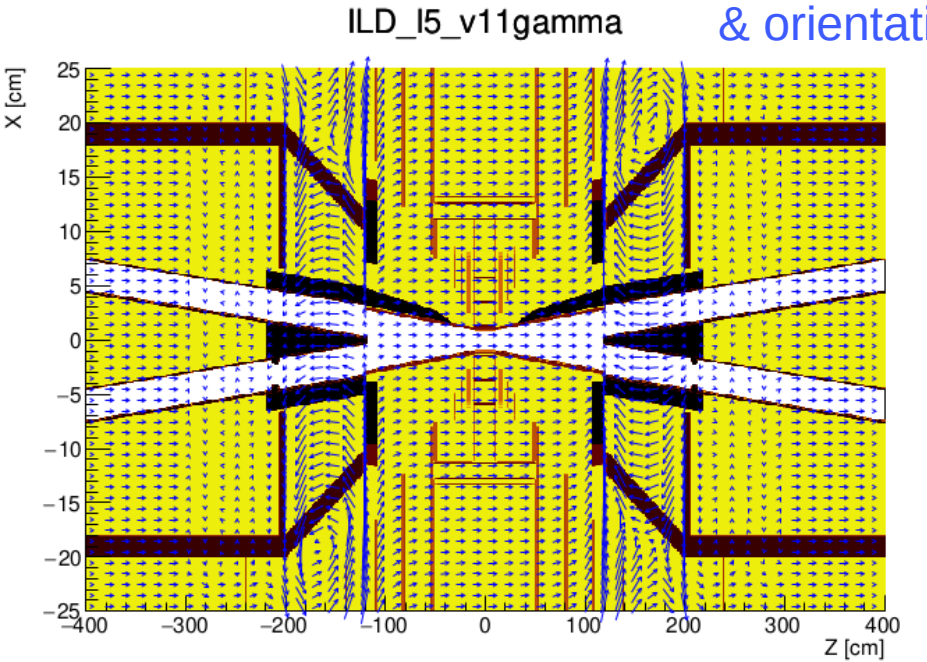
field maps

field lines



ILC with anti-DID

field magnitude & orientation



FCCee: screening and compensating coils

beamstrahlung: many very low energy e+e- created in bunch collisions

very different bunch structure, materials and fields in the forward region
→ major effect on beamstrahlung backgrounds ?

GuineaPig : program to simulate beamstrahlung

beamstrahlung pairs @

ILC-250	(from ILD/Mikael Berggren)
FCCee-91, FCCee-240	(from FCCee/Andrea Ciarma)

simulate in various DD4hep ILD detector models:

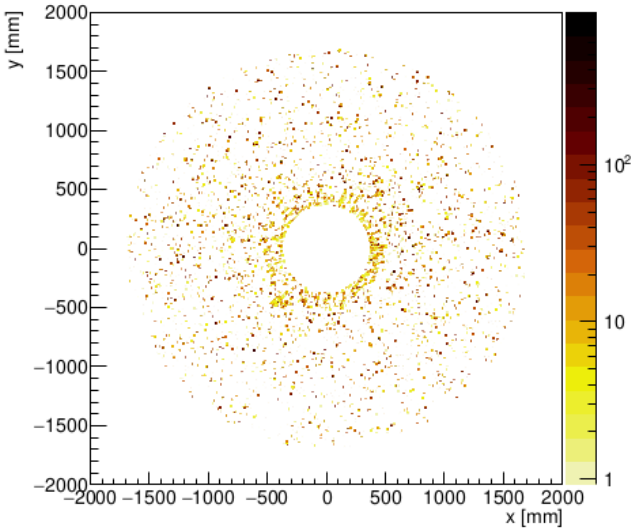
- ILD @ ILC :
  - uniform 3.5T
  - uniform 2.0T
  - field map with and without anti-DID
- ILD @ FCCee :
  - uniform 2.0T
  - field map for central region

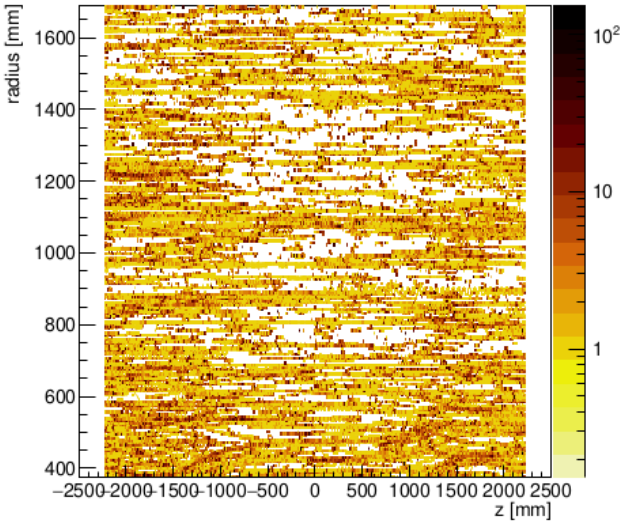
using ddsim ; some special parameters to correctly track low pT particles

TPC hits

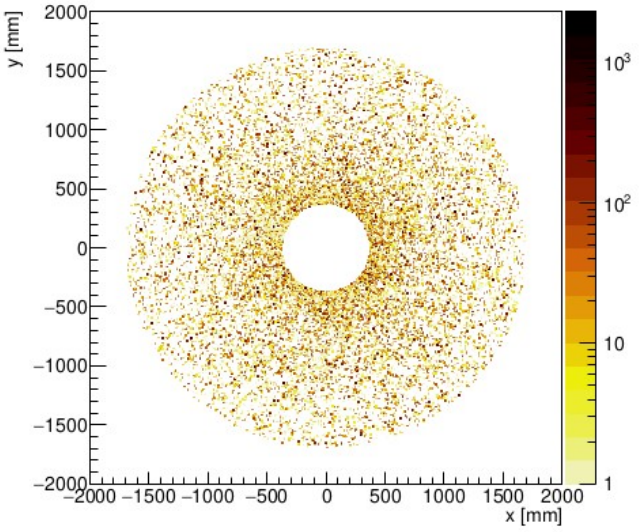
superimpose
100 bunch crossings

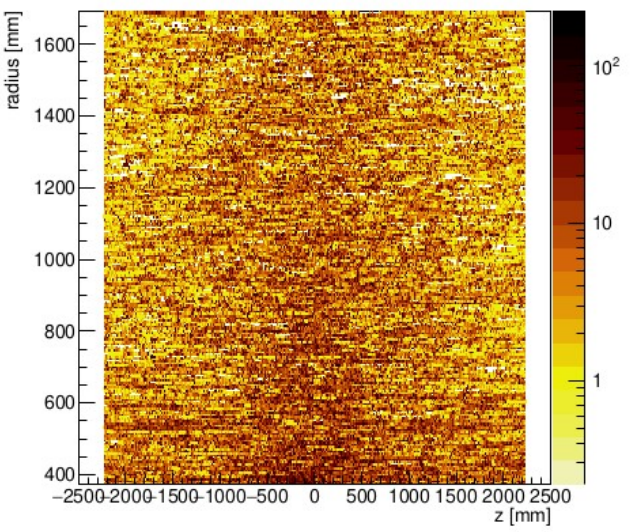
ILD_l5_v11y @ FCCee-91





ILD_l5_v03 @ ILC-250





estimate number of primary ions produced in the TPC per bunch crossing

			FCCee-91	FCCee-240	ILC-250
model	B-field	MDI	thousand ions / bunch crossing		
ILD_l5_v02	3.5 (uniform)	ILC	6.5	14	960

beamstrahlung much weaker @ FCCee
→ bunches less focused

estimate number of primary ions produced in the TPC per bunch crossing

			FCCee-91	FCCee-240	ILC-250
model	B-field	MDI	thousand ions / bunch crossing		
ILD_l5_v02	3.5 (uniform)	ILC	6.5	14	960
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9	15	4700

reducing field to 2T has
modest effect at FCCee,
large effect at ILC

estimate number of primary ions produced in the TPC per bunch crossing

			FCCee-91	FCCee-240	ILC-250
model	B-field	MDI	thousand ions / bunch crossing		
ILD_l5_v02	3.5 (uniform)	ILC	6.5	14	960
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9	15	4700
ILD_l5_v03	3.5 (map)	ILC	5.7	14	1100
ILD_l5_v05	3.5 (map, anti-DID)	ILC	0.6	3.7	450

anti-DID reduces TPC background by ~2

estimate number of primary ions produced in the TPC per bunch crossing

			FCCee-91	FCCee-240	ILC-250
model	B-field	MDI	thousand ions / bunch crossing		
ILD_l5_v02	3.5 (uniform)	ILC	6.5	14	960
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9	15	4700
ILD_l5_v03	3.5 (map)	ILC	5.7	14	1100
ILD_l5_v05	3.5 (map, anti-DID)	ILC	0.6	3.7	450
ILD_l5_v11	2.0 (uniform)	FCCee	390	1000	110000
ILD_l5_v11γ	2.0 (map)	FCCee	270	800	100000

FCCee MDI system induces enormous increase in TPC background compared to ILC

detailed description of field has modest effect with FCCee MDI

estimate number of primary ions produced in the TPC per bunch crossing

			FCCee-91	FCCee-240	ILC-250
model	B-field	MDI	thousand ions / bunch crossing		
ILD_l5_v02	3.5 (uniform)	ILC	6.5	14	960
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9	15	4700
ILD_l5_v03	3.5 (map)	ILC	5.7	14	1100
ILD_l5_v05	3.5 (map, anti-DID)	ILC	0.6	3.7	450
ILD_l5_v11	2.0 (uniform)	FCCee	390	1000	110000
ILD_l5_v11γ	2.0 (map)	FCCee	270	800	100000

“realistic” situations : a few 100s → 1000 TPC hits / BX

TPC integrates over many collisions; maximum ion drift time ~ 0.44 s

roughly estimate the number of primary ions in the TPC volume (42 m^3) at any time, taking account of the different collision rates

BX freq * primary ions/BX * 50% ions already reached cathode

Collider	FCCee-91	FCCee-240	ILC-250
Detector model (average)	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05
BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	270 k	800 k	450 k
primary ions in TPC at any time	4.1×10^{12}	3.2×10^{11}	1.5×10^{9}
average primary ion charge density nC/m^3	15	1.2	0.006

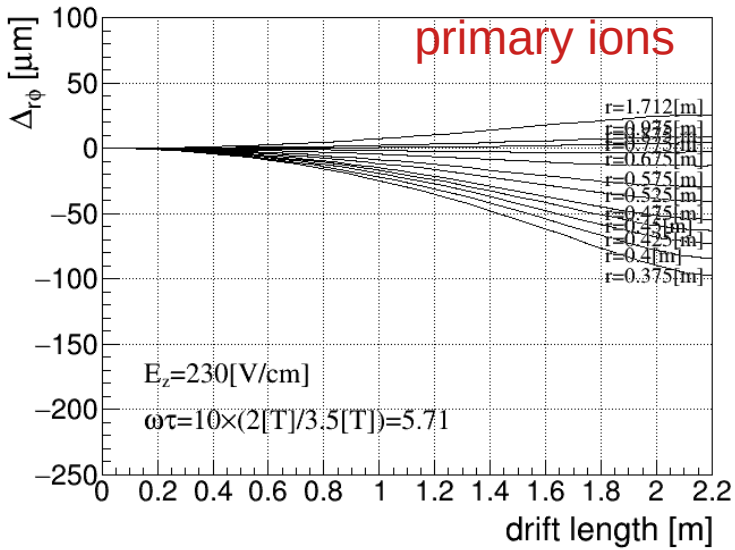
primary ion density in TPC: 2500 times higher at FCCee-91 than ILC-250
200 times higher at FCCee-240 than ILC-250

how does this compare to other sources of primary ionisation?

e+ e- → q q @ 91 GeV : ~1 M primary ions @ ~50 kHz
→ 2.5 x 10^{10} primary ions in TPC at any time c.f. 4.1x10^{12} from beamstrahlung @ FCCee-91

e+ e- → q q @ 91 GeV :
primary ions give rise to
maximum drift distortions in R-phi of ~100 μm

using naive scaling,
maximum distortions due to
beamstrahlung → 15 mm



must also consider **secondary ions**, produced in the gas amplification device

O(1000) ions produced in the device for each incoming ionisation electron

without any mitigation, significant fraction flow back into the main TPC volume

ILC bunch structure → gating device can stop most of these
- open gate only during bunch train
- a few per-mille of secondary ions may leak : 1~5~10 per initial electron ?

with quasi continuous collisions @ FCCee, cannot apply the same gating trick
- multi-layer GEM , micromegas+GEM , ….
- nano-material through which ions cannot pass ? e.g. graphene

Summary

TPC background from beamstrahlung:
same order per BX at ILC250 and FCCee

average BX frequency: 4.5k times higher at FCCee

TPC ions from beamstrahlung dominate those from ee→qq @ FCCee-91

guestimate: maximum distortions up to 15mm in R-phi from primary ions only

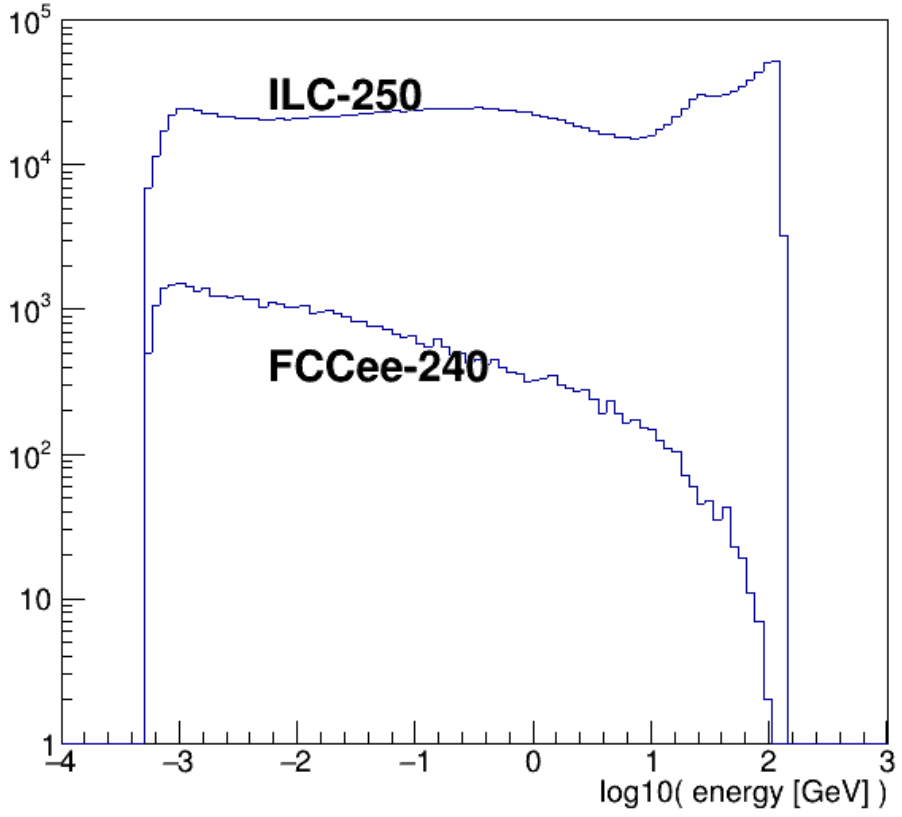
secondary ions: gating/blocking of ions

can a TPC work at FCCee ?

question

distribution of $e^{\pm}$ energy

GuineaPig output

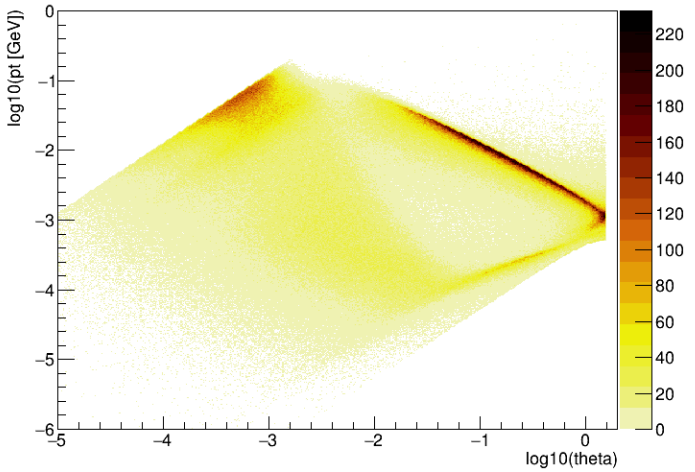


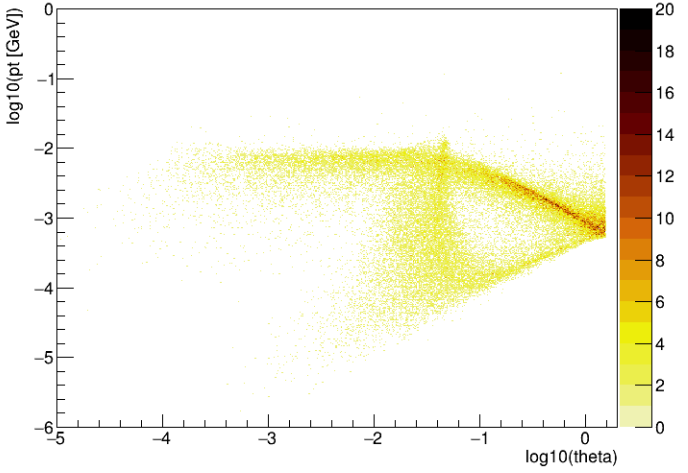
Q. does this look reasonable ?

ILC-250

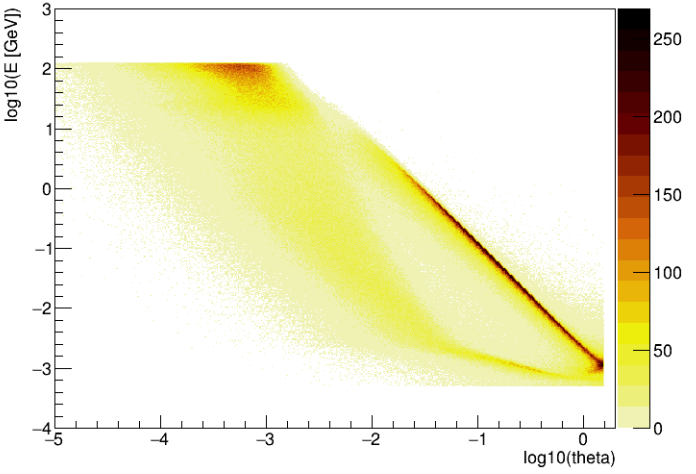
FCCee-240

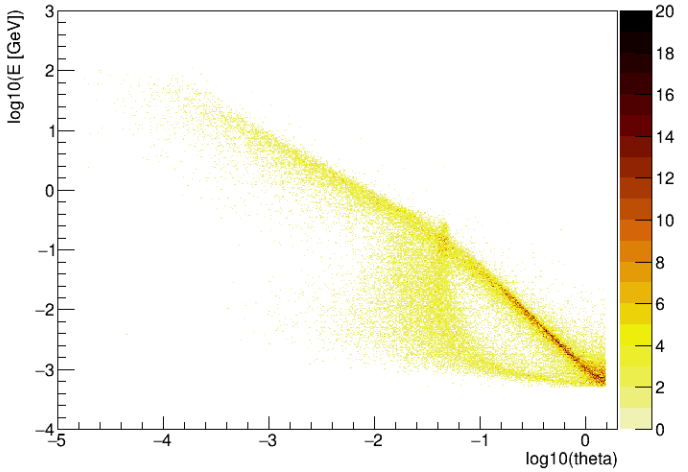
log10 (p_T [GeV])





log10 (E [GeV])





log10 (theta [rad])

backup

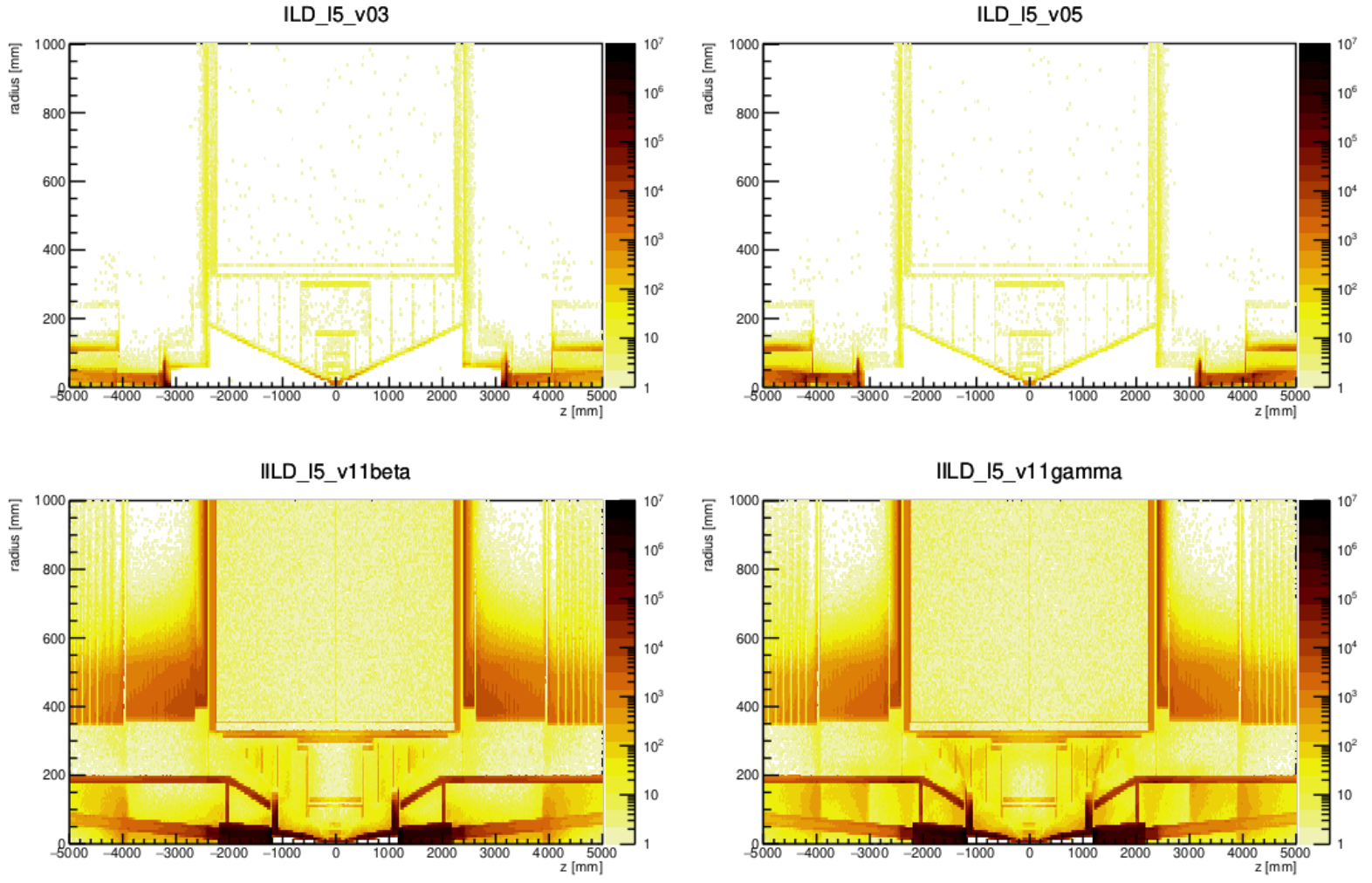


Figure 6: Pair background at FCCee-91 in different models: distribution in radius and z of the endpoint of all MC particles.

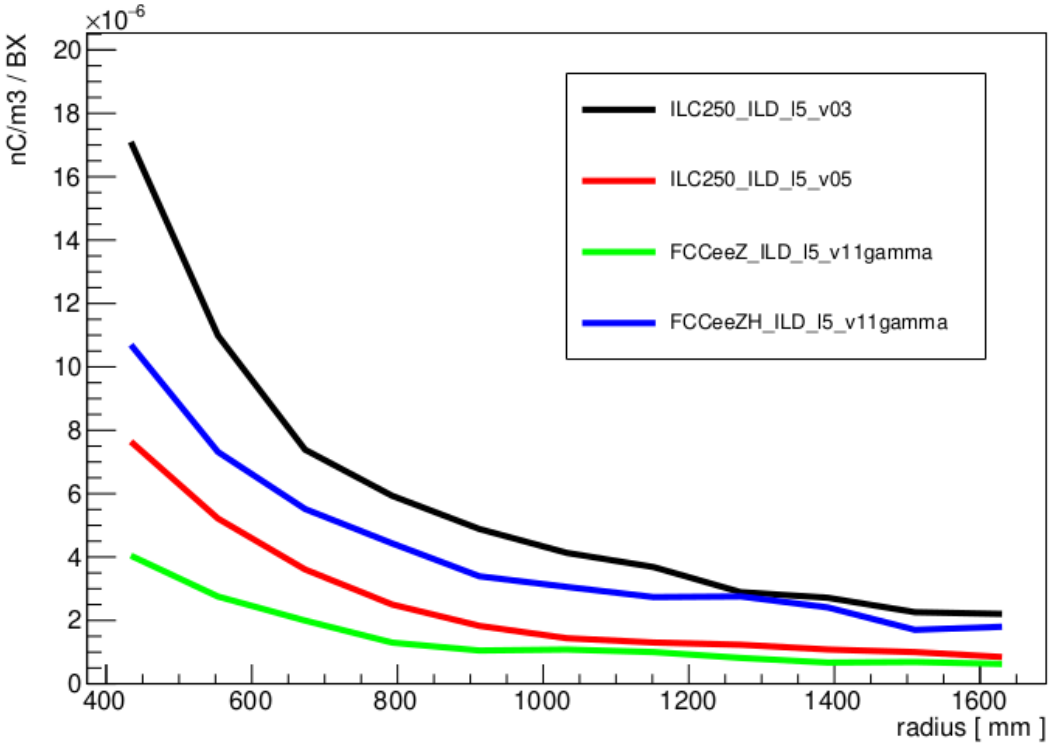


Figure 8: Radial dependence of the primary ion charge density induced by beamstrahlung in a single BX in the realistic collider/detector combinations.

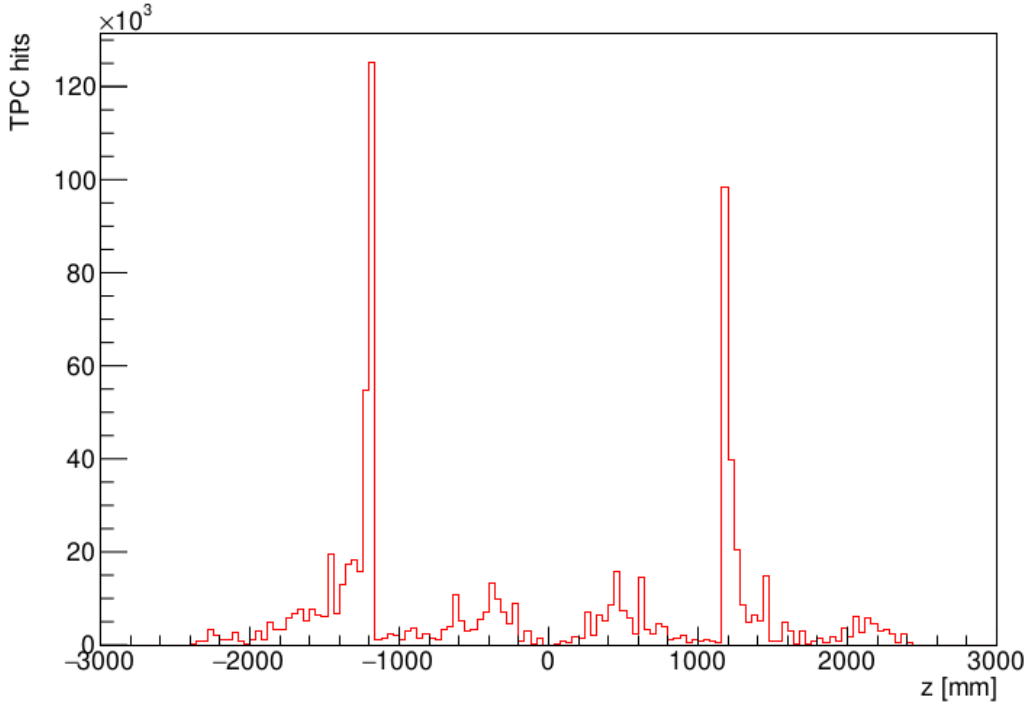


Figure 9: Distribution in z of the position of the first simulated interaction which gave rise to a TPC hit. ILD_l5_v11γ detector model, 100 BX of pair background at FCCee-91.

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing		
ILD_l5_v11β	2.0 (uniform)	FCCee	390	1000	110000
ILD_l5_v11γ	2.0 (map)	FCCee	270	800	100000
ILD_l5_v02	3.5 (uniform)	ILC	6.5	14	960
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9	15	4700
ILD_l5_v03	3.5 (map)	ILC	5.7	14	1100
ILD_l5_v05	3.5 (map, anti-DID)	ILC	0.6	3.7	450
removing BeamCal's graphite layer					
ILD_l5_v03	3.5 (map)	ILC			1300
ILD_l5_v05	3.5 (map, anti-DID)	ILC			590

~20% effect

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

ave collision freq:

1 / (90.8 km/# bunch/c)

33 MHz @ 91 GeV
2.9 MHz @ 160
810 kHz @ 240
130 kHz @ 365