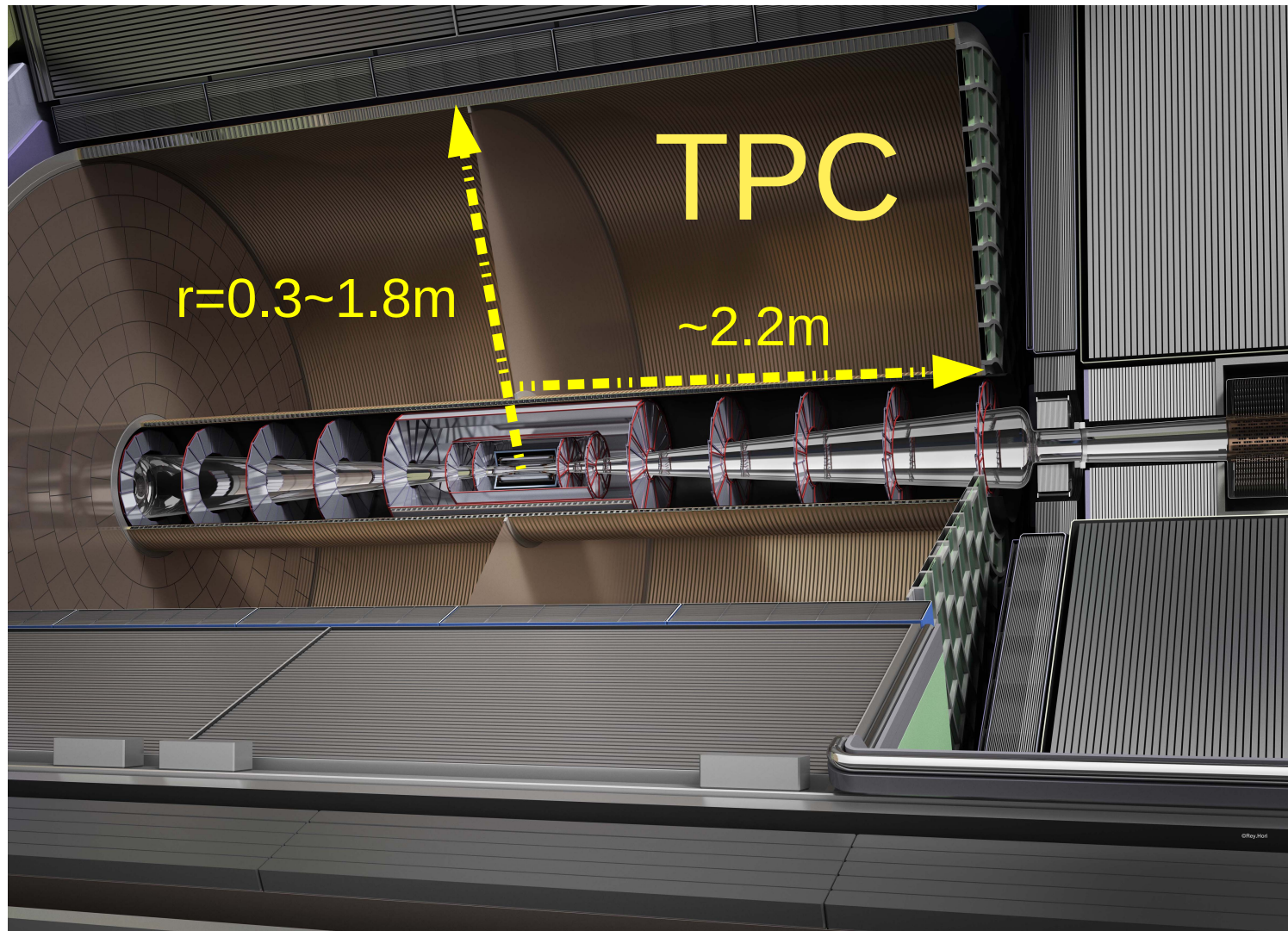
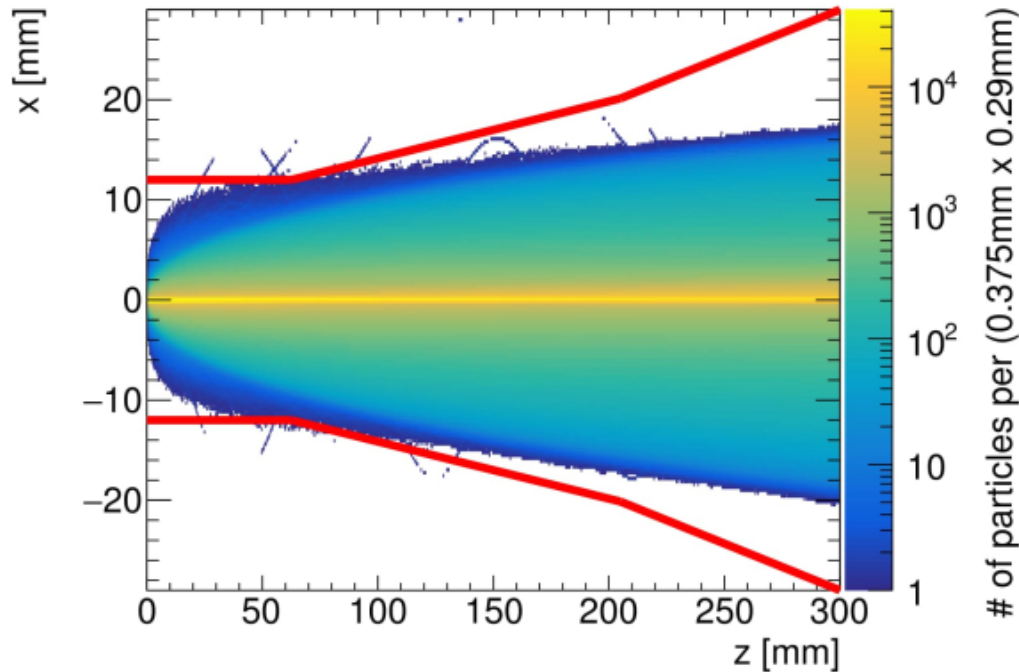


Beamstrahlung backgrounds in ILD at linear (ILC) and circular (FCCee) colliders



Beamstrahlung : many low p_T $e^+ e^-$ pairs produced in each bunch crossing

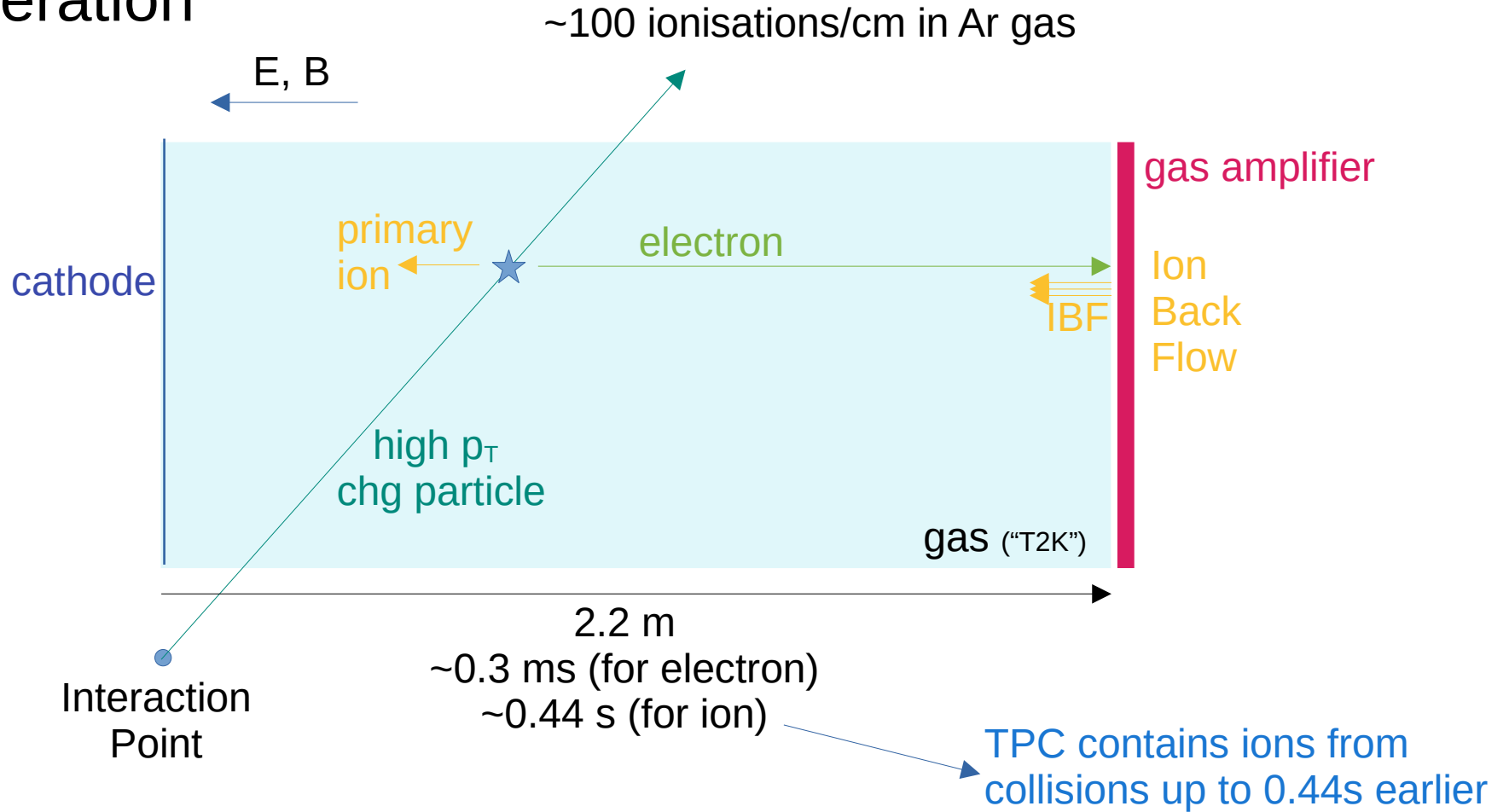
Pairs spiraling in the magnetic field



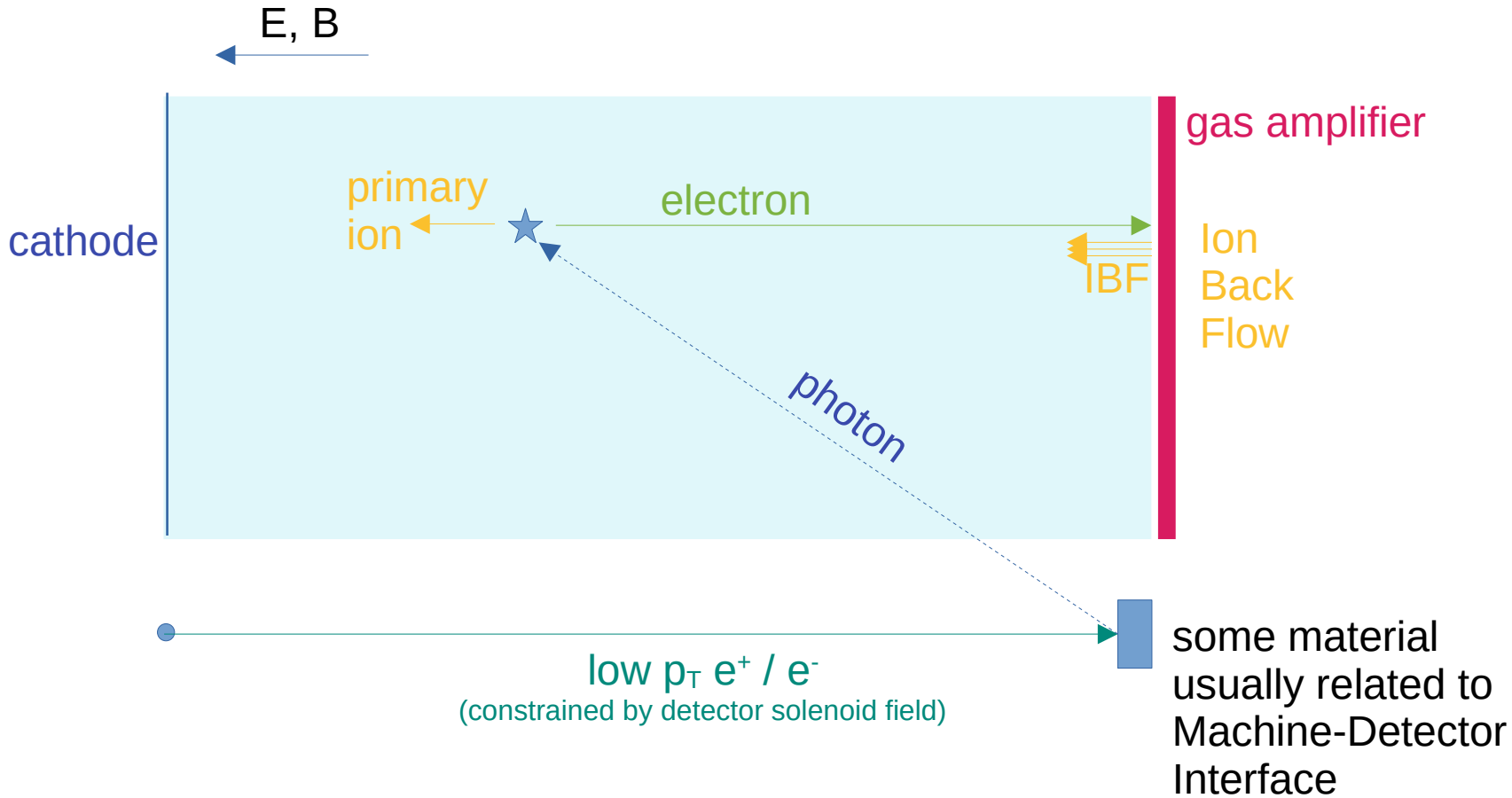
strongly constrained
to small radii by
detector's B-field

simulated by GuineaPig
and/or CAIN

TPC operation



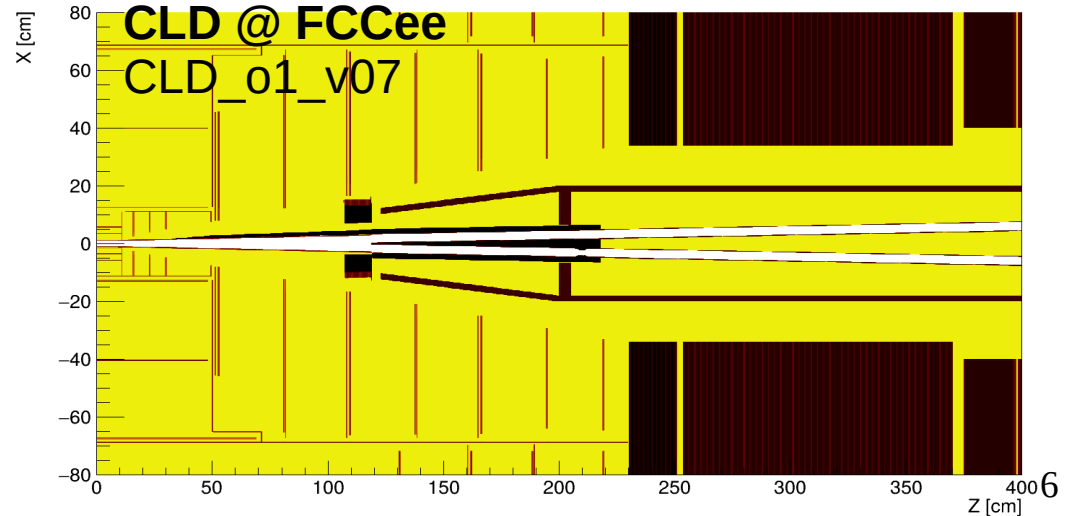
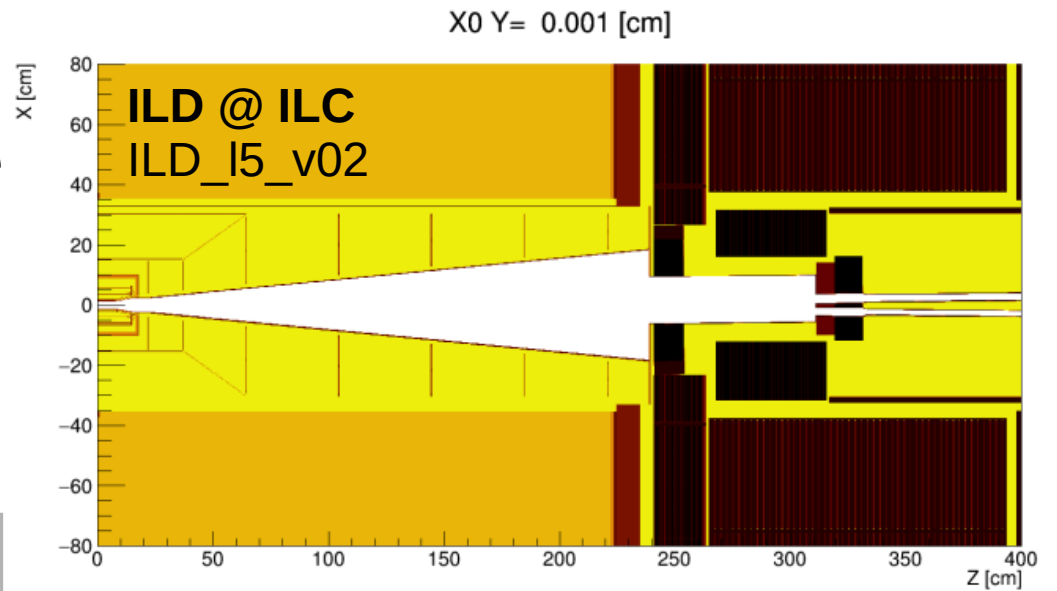
beam backgrounds : usually small $p_T \rightarrow$ particles do not reach TPC directly



Machine-Detector Interface

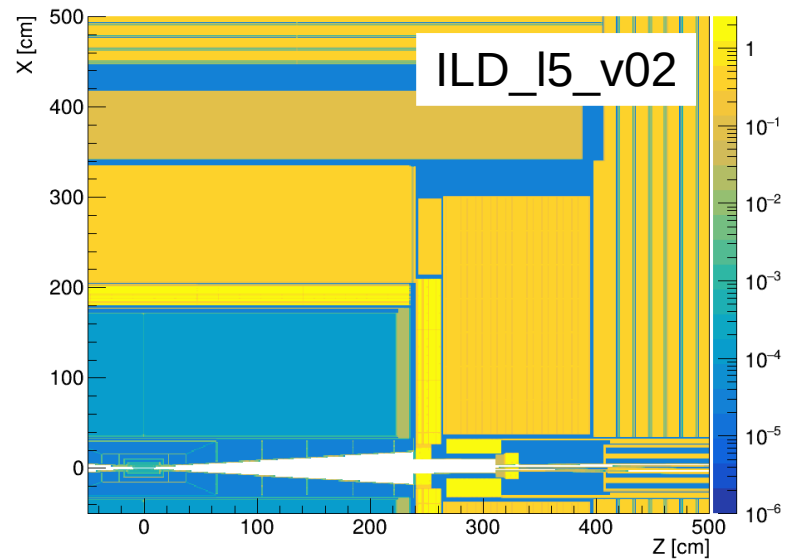
is significantly different @
ILC and FCCee

	ILC	FCCee
crossing angle	14 mrad	30 mrad
L^* [distance from IP to last accel focusing quadrupole magnet]	4.1 m	2.0 m
detector solenoid	3.5 T	2.0 T
additional B-fields	anti-DID (?)	- compensating - screening



new models of ILD for FCCee

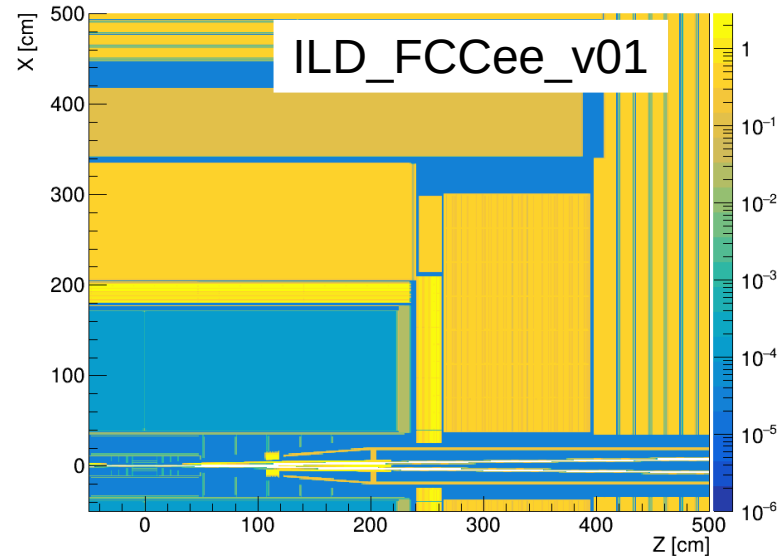
Work In Progress
with V. Schwan



common MDI: MDI_o1_v00

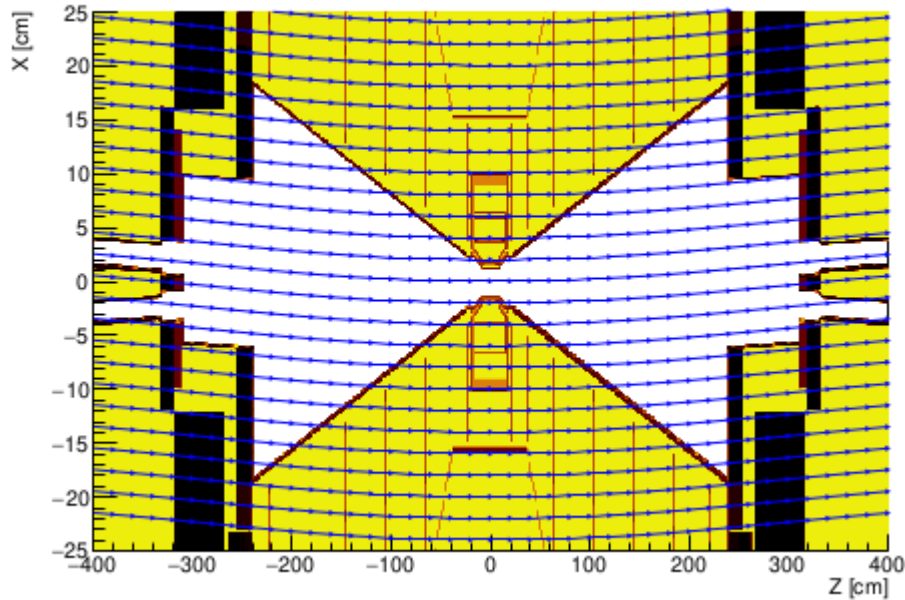
vertex, inner tracker
adapted from CLD_o1_v07

remainder from ILD



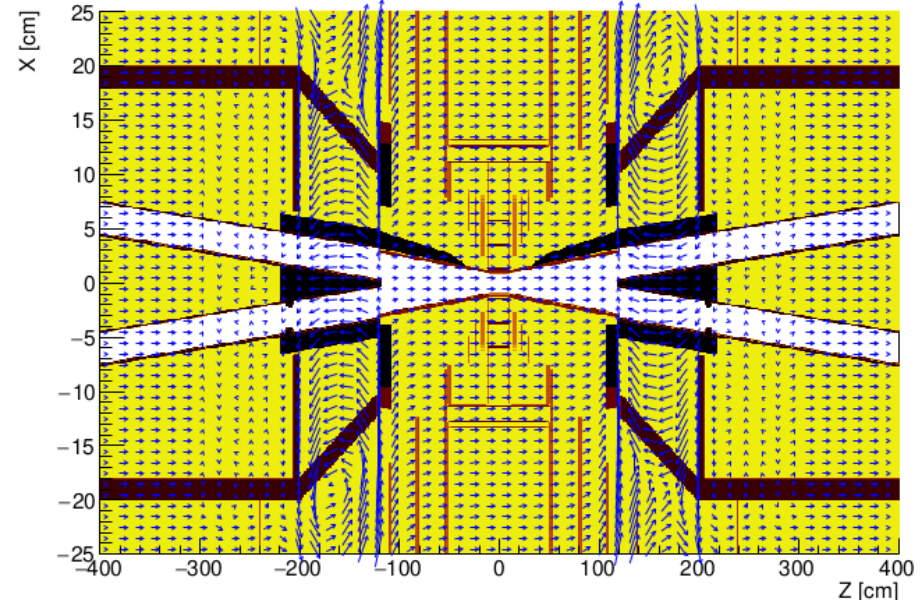
field maps

field lines



ILC with anti-DID

field magnitude
& orientation



FCCee: screening and compensating coils

beamstrahlung: many very low p_T 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:

using ddsim/DD4hep/Geant4

some special parameters to correctly track low p_T particles

ILD @ ILC :

uniform 3.5T

uniform 2.0T

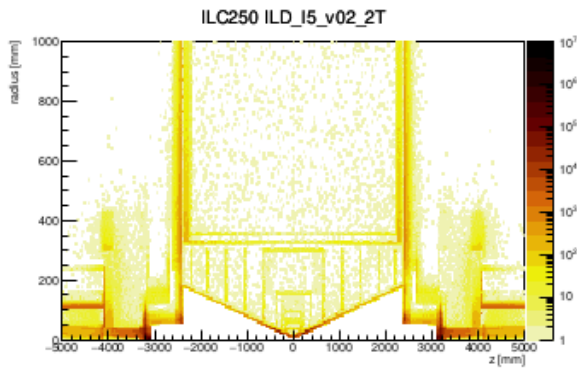
field map with and without anti-DID

ILD @ FCCee :

uniform 2.0T

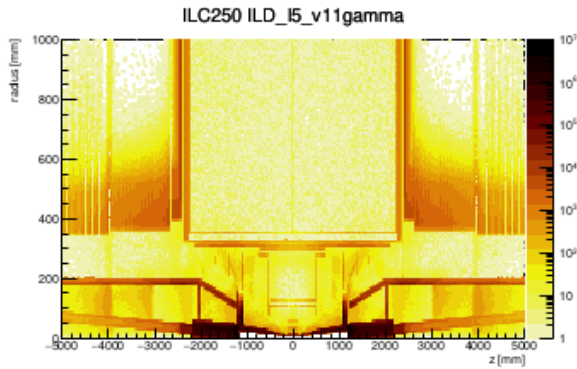
field map for central region

MC particle endpoints in 100 BX



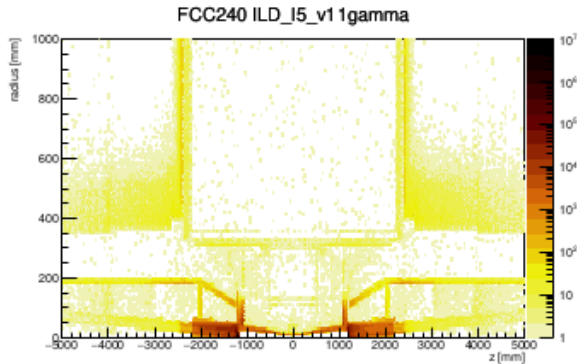
ILC250 beamstrahlung

ILC-like detector



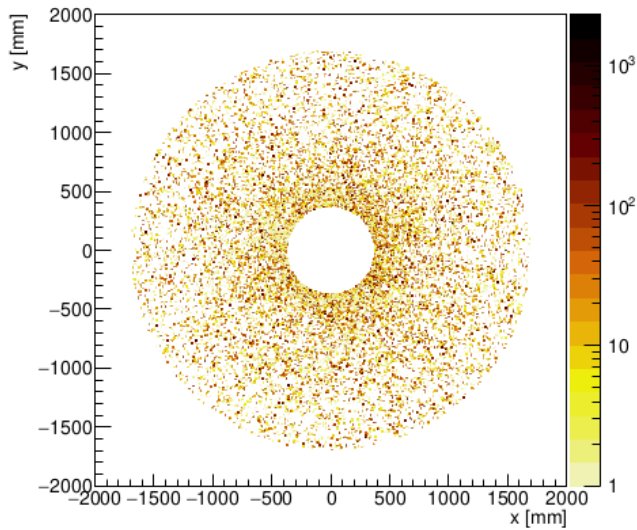
ILC250 beamstrahlung

FCC-like detector



FCC-240 beamstrahlung

FCC-like detector



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

→ geant4 energy deposit /
effective ionisation potential of Ar [26 eV]

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean \pm RMS		
ILD_15_v02	3.5 (uniform)	ILC	6.5 \pm 19.9	14 \pm 14	960 \pm 150

large variations between bunch crossings

beamstrahlung much weaker @ FCCee

→ bunches less focused

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

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean \pm RMS		
ILD_15_v02	3.5 (uniform)	ILC	6.5 ± 19.9	14 ± 14	960 ± 150
ILD_15_v02_2T	2.0 (uniform)	ILC	6.9 ± 11.1	15 ± 11	4700 ± 300

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

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean \pm RMS		
ILD_15_v02	3.5 (uniform)	ILC	6.5 ± 19.9	14 ± 14	960 ± 150
ILD_15_v02_2T	2.0 (uniform)	ILC	6.9 ± 11.1	15 ± 11	4700 ± 300
ILD_15_v03	3.5 (map)	ILC	5.7 ± 7.9	14 ± 11	1100 ± 200
ILD_15_v05	3.5 (map, anti-DID)	ILC	0.6 ± 1.5	3.7 ± 9.7	450 ± 110

anti-DID reduces TPC background by factor ~ 2 at ILC-250
4~10 at FCCee

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

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean \pm RMS		
ILD_15_v02	3.5 (uniform)	ILC	6.5 \pm 19.9	14 \pm 14	960 \pm 150
ILD_15_v02_2T	2.0 (uniform)	ILC	6.9 \pm 11.1	15 \pm 11	4700 \pm 300
ILD_15_v03	3.5 (map)	ILC	5.7 \pm 7.9	14 \pm 11	1100 \pm 200
ILD_15_v05	3.5 (map, anti-DID)	ILC	0.6 \pm 1.5	3.7 \pm 9.7	450 \pm 110
new FCCee models					
ILD_FCCee_v01	2.0 (uniform)	FCC-ee	351 \pm 115	987 \pm 155	111000 \pm 2100
ILD_FCCee_v01	2.0 (map)	FCC-ee	261 \pm 86	823 \pm 180	100000 \pm 2100

FCCee MDI system induces ~50x increase in TPC activity compared to ILC

detailed description of field has relatively modest effect with FCCee MDI

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

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean \pm RMS		
ILD_15_v02	3.5 (uniform)	ILC	6.5 ± 19.9	14 ± 14	960 ± 150
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new FCCee models					
ILD_FCCee_v01	2.0 (uniform)	FCC-ee	351 ± 115	987 ± 155	111000 ± 2100
ILD_FCCee_v01	2.0 (map)	FCC-ee	261 ± 86	823 ± 180	100000 ± 2100

“realistic” situations : a few 100k \rightarrow 1M primary ions / BX

ILC and FCCee are similar

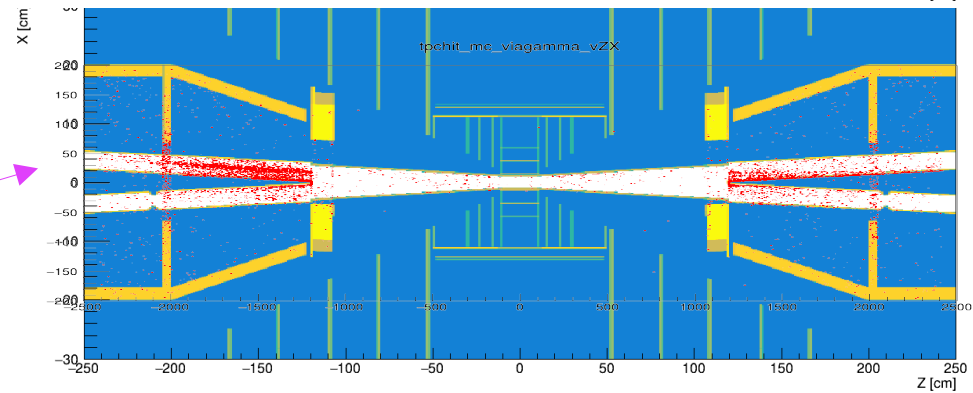
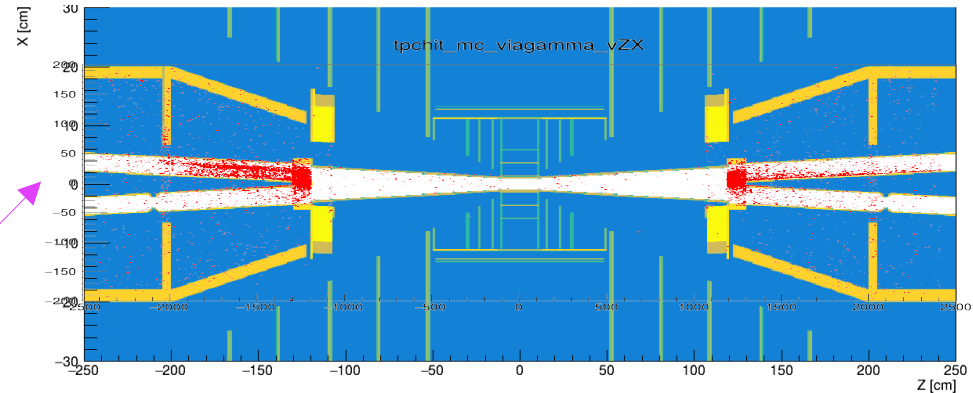
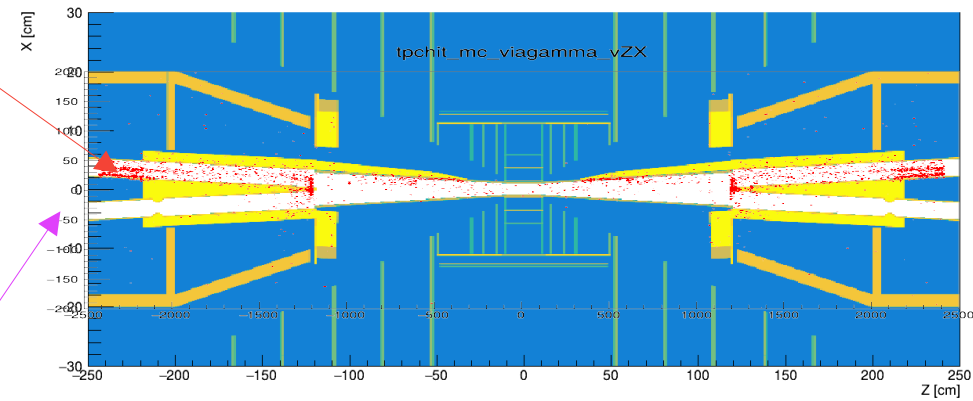
look at **first interaction**
of initial MC particles
which later induce TPC hits

effect of MDI variations

default
(with masks)

remove masks

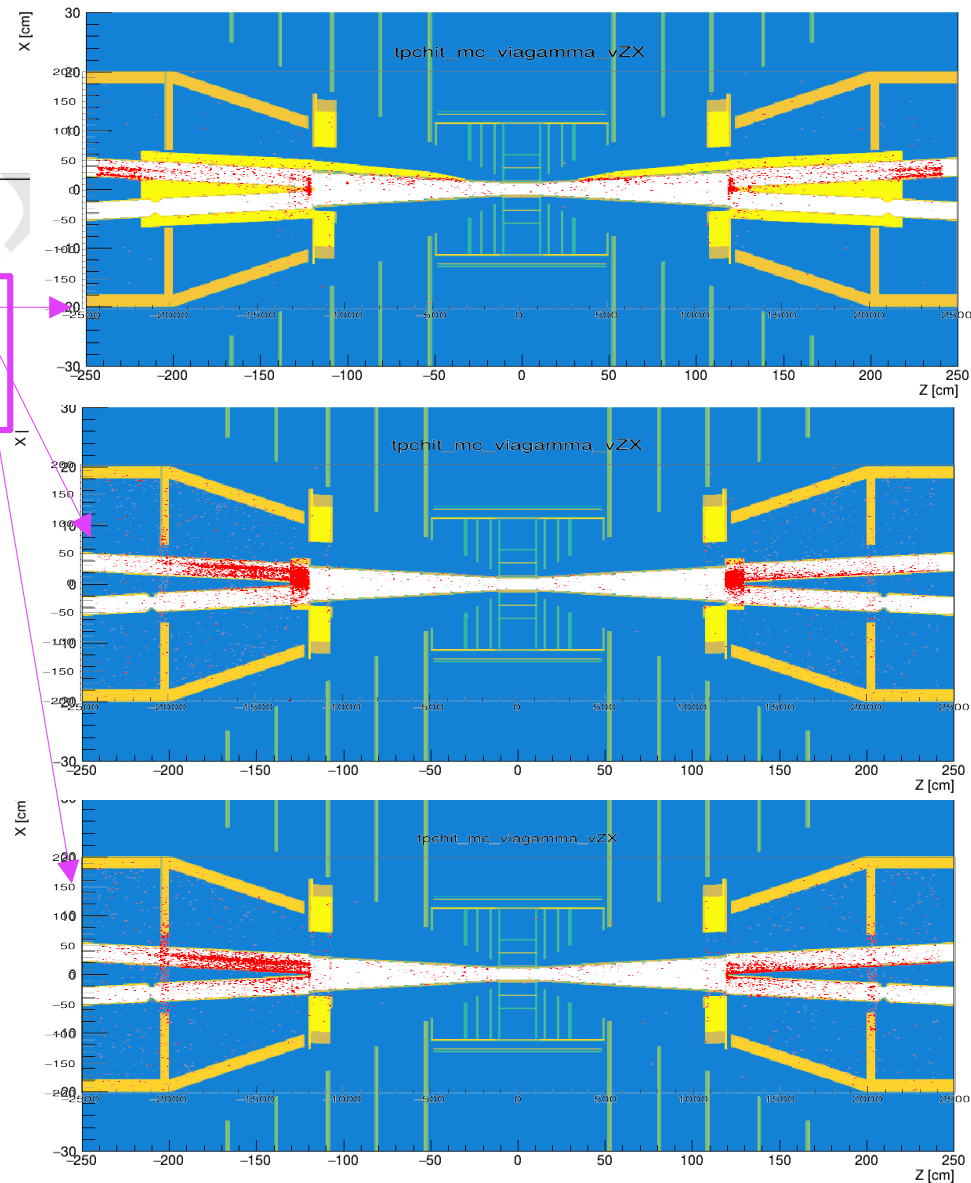
remove masks and HOM



new FCCee models

ILD_FCCee_v01	2.0 (uniform)	FCC-ee	351 ± 115
ILD_FCCee_v01	2.0 (map)	FCC-ee	261 ± 86
ILD_FCCee_v01	2.0 (map), no mask	FCC-ee	707 ± 116
ILD_FCCee_v01	2.0 (map), no mask HOM	FCC-ee	536 ± 114

- many TPC hits induced by beamstrahlung interactions with shielding
- if we remove the shielding, they just interact elsewhere: actually *increases* TPC backgrounds
- can we consider applying an additional B_x field to steer pairs into outgoing beampipe ? (*a la* "anti-DID")
- a stronger detector solenoid and/or larger exit beampipe may also help



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

roughly estimate number of primary ions in the TPC volume (~ 42 m³) at any time,
taking account of different collision rates

number of ions \sim primary ions/BX * BX freq * max drift time * 50% [some ions already reached cathode]

Collider	FCC-91	FCC-240	ILC-250
Detector model	ILD_FCCee_v01	ILD_FCCee_v01	ILD_15_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	260 k	820 k	450 k
primary ions in TPC at any time	1.7×10^{12}	1.4×10^{11}	6.5×10^8
average primary ion charge density nC/m ³	6.4	0.54	0.0025

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**?

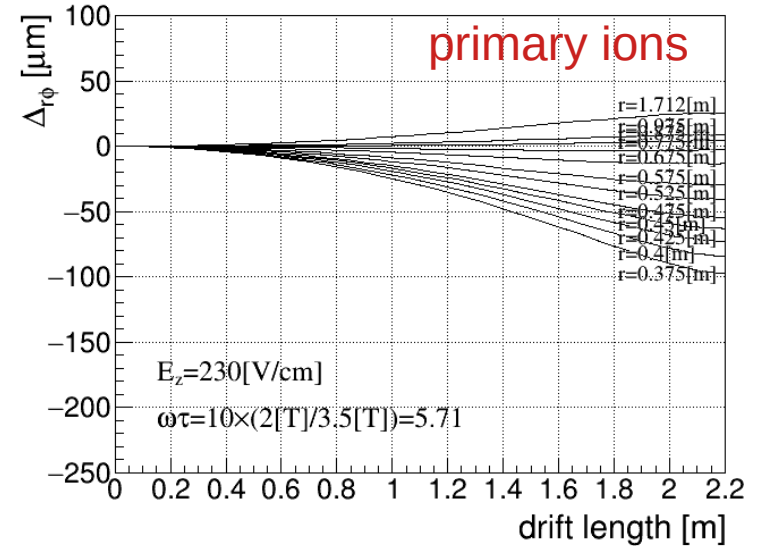
$e^+ e^- \rightarrow q q$ @ 91 GeV : ~1 M primary ions per event @ ~50 kHz [FCCee]
→ 10^{10} primary ions in TPC at any time
cf. 2×10^{12} from beamstrahlung @ FCCee-91

$e^+ e^- \rightarrow q q$ @ 91 GeV :
primary ions give rise to
maximum drift distortions in R-phi of ~100 μm
seem stable @ few-micron level

beamstrahlung background seems
~200 times more severe than $e^+ e^- \rightarrow q q$

using naive scaling,
maximum distortions due to beamstrahlung (primary ions only) → 20 mm

n.b. only primary ions considered → no ion backflow



compare to ALICE-TPC

ALICE TPC upgrade TDR: CERN-LHCC-2013-020

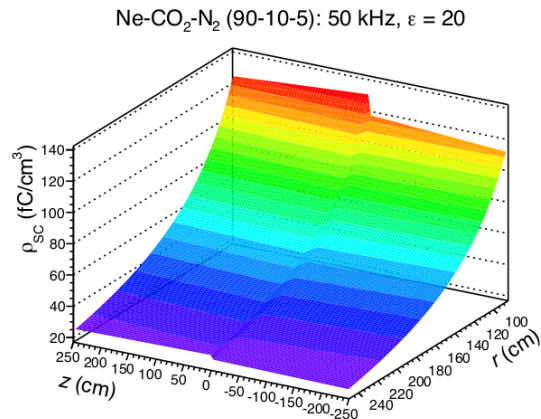
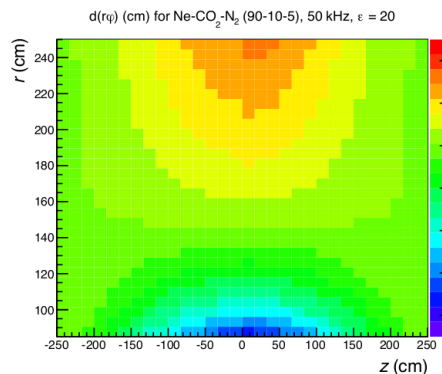


Figure 7.7: Average space charge density for Ne-CO₂-N₂ (90-10-5), $R_{int} = 50$ kHz and $\epsilon = 20$.

assumed ion back flow factor ϵ : 20 secondary ions / primary

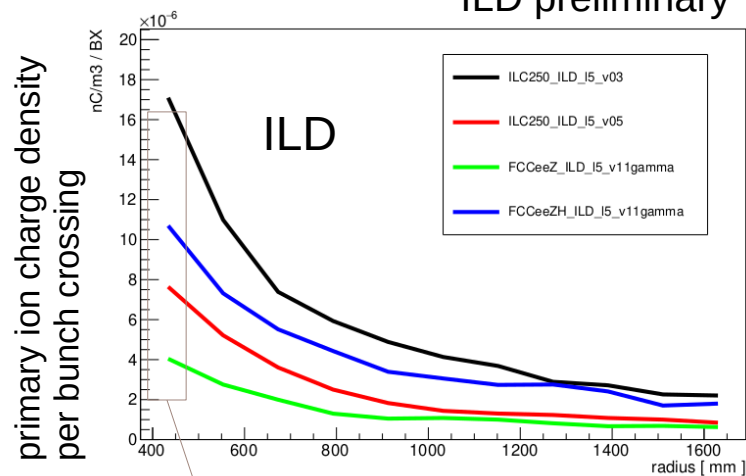
20~120 fC/cm³ → cm-level distortions



r-phi distortion [cm]

ALICE

ILD preliminary



maximum steady state space-charge ~
max space-charge/BX * BX freq * max drift time * 50%

	max (single BX)	BX freq	max (steady state)	
FCCee91	4e-6 nC/m ³	30M	26 nC/m ³	primary ions only: IBF=0
FCC240	1e-5 nC/m ³	800k	2 nC/m ³	
ILC250 (v5)	8e-6 nC/m ³	6.6k	0.01 nC/m ³	
ALICE		50k	120 nC/m ³ with IBF=20	

TPC at FCCee91 with IBF of 3~5
→ similar space-charge as at ALICE
O(1~10) cm max distortions
consistent with our "first-principles" estimate

Summary

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

interplay between stronger beamstrahlung @ ILC
more intrusive MDI @ FCCee

average BX frequency: **4.5k times higher at FCCee**
→ TPC integrates over many more BX

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

distortions in a TPC at FCCee-91 with
Ion Back Flow (gas gain * back flow probability) ~ 4 looks similar to ALICE-TPC

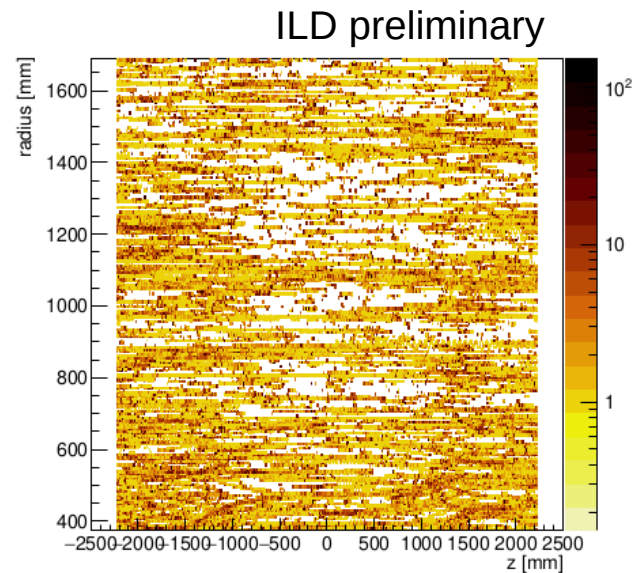
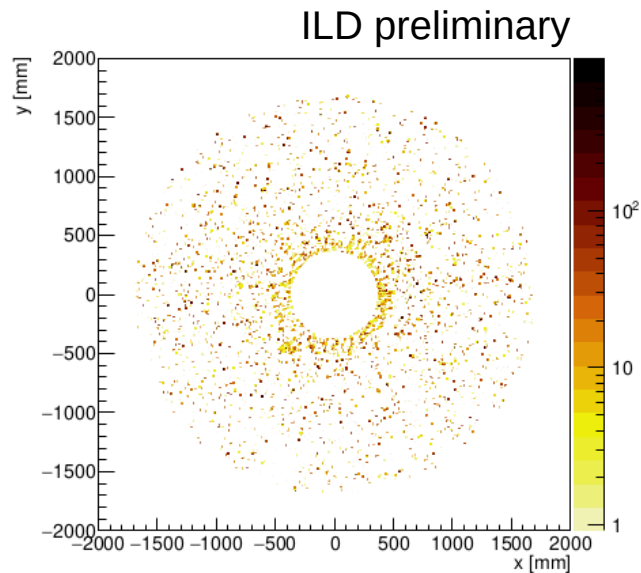
→ will need distortion corrections, constrained by silicon hits

→ still some work to demonstrate feasibility of TPC to reach performance goals
for the full tera-Z phase of a circular collider such as FCCee

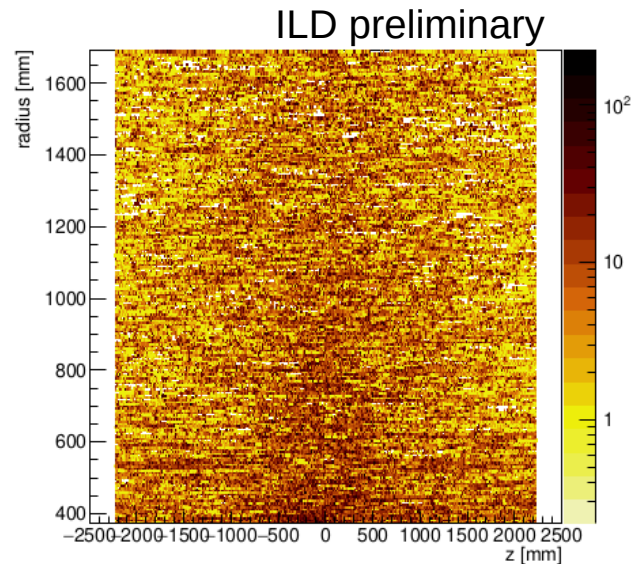
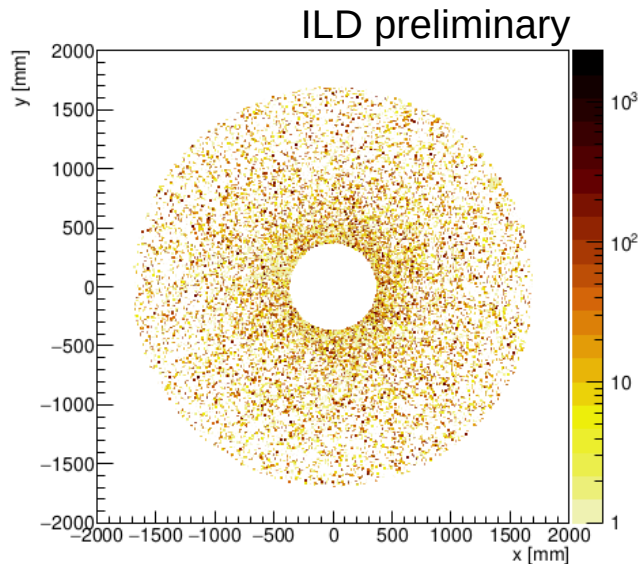
backup

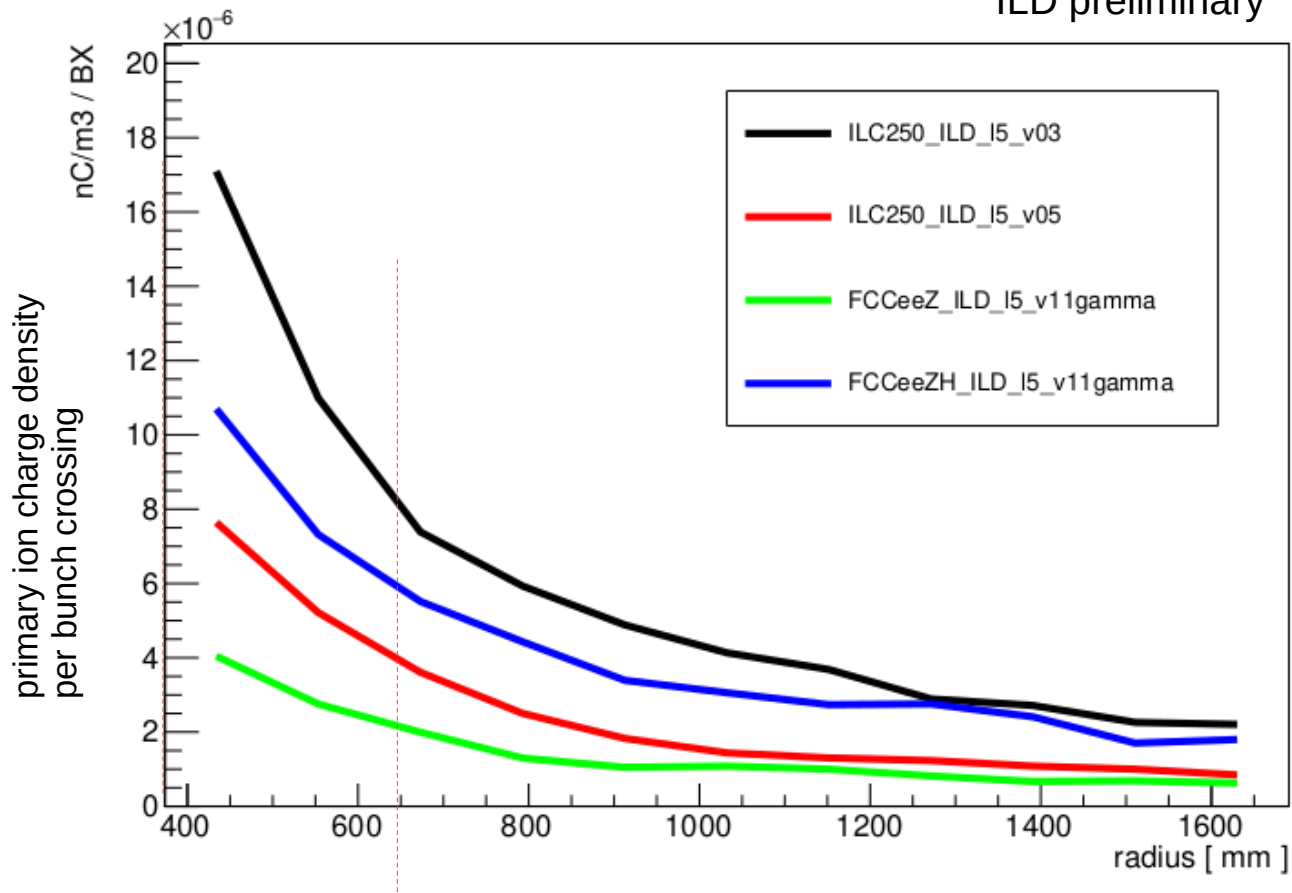
TPC hits
superimpose
100 bunch crossings

ILD_I5_v11y @ FCCee-91



ILD_I5_v03 @ ILC-250





lower TPC edge
in "small TPC" option