Beamstrahlung backgrounds in ILD at ILC and FCCee

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CEPC workshop

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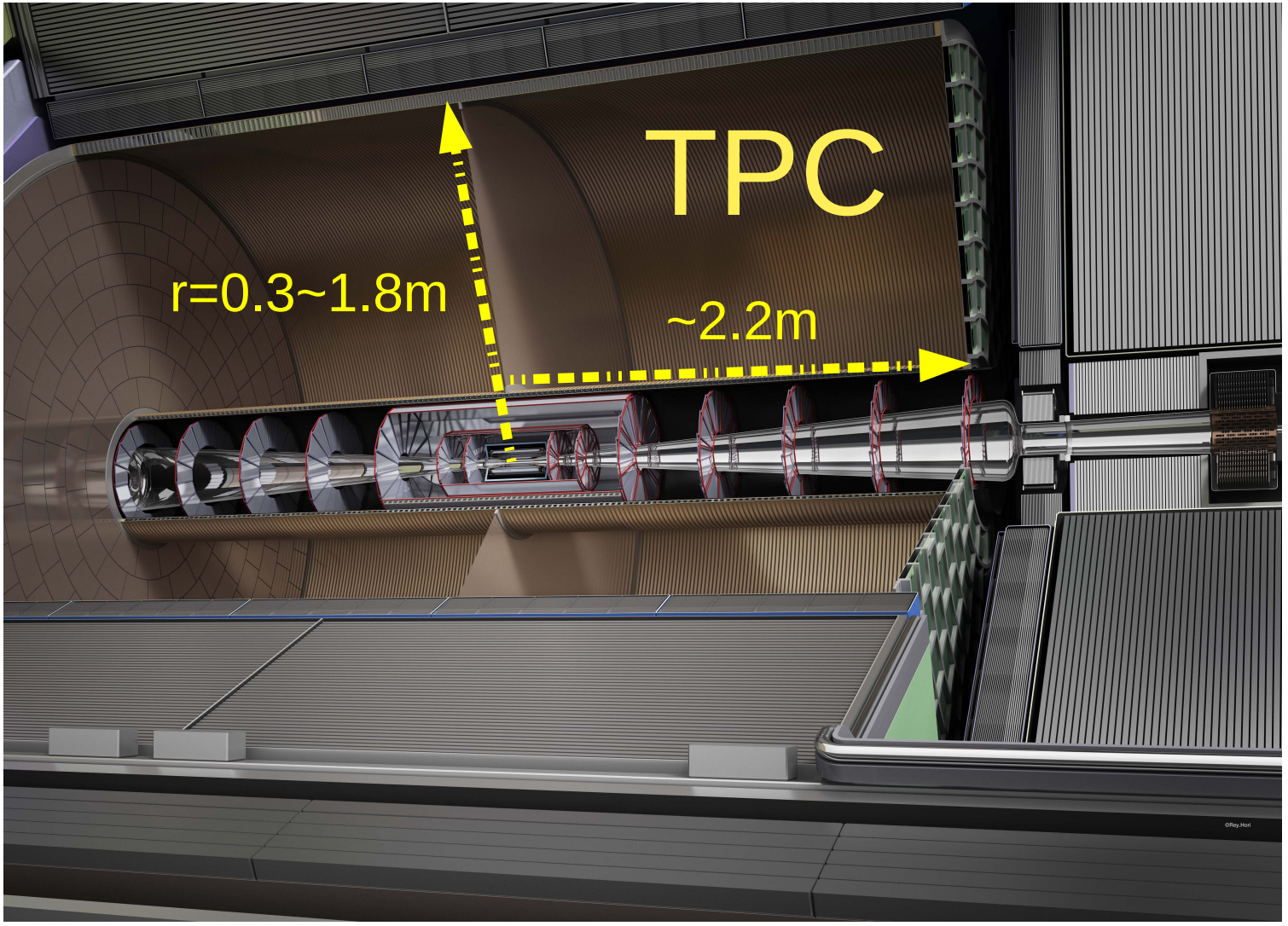
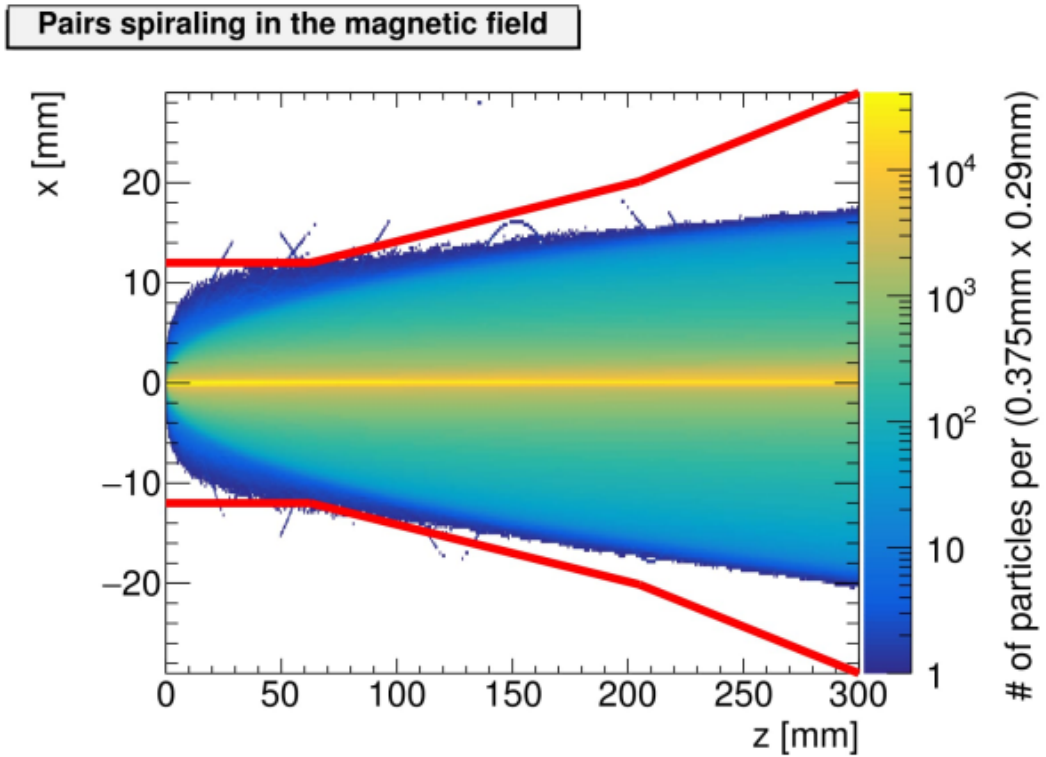

TPC
r=0.3~1.8m
~2.2m

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



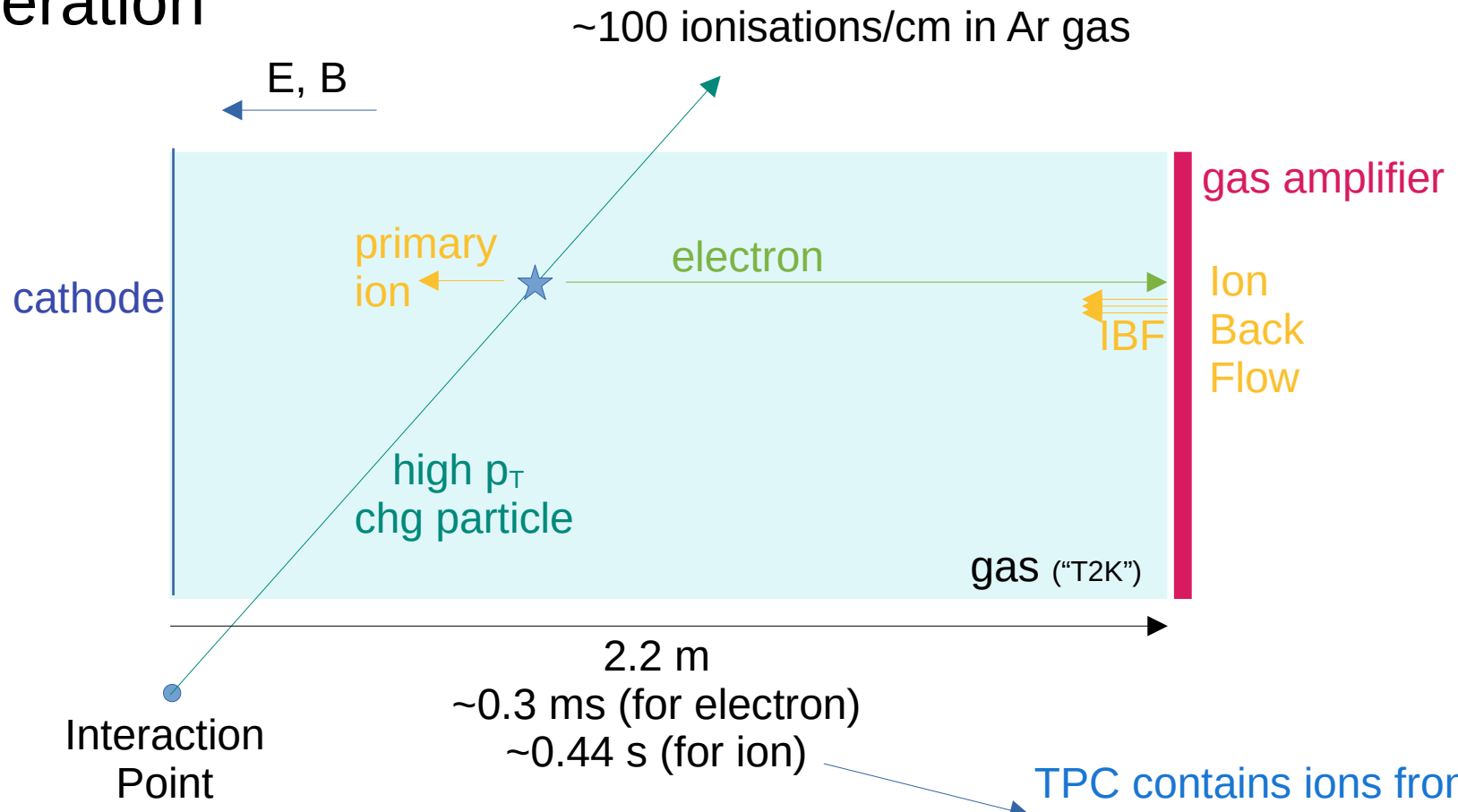
(b) *ILC250 set (A)*

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

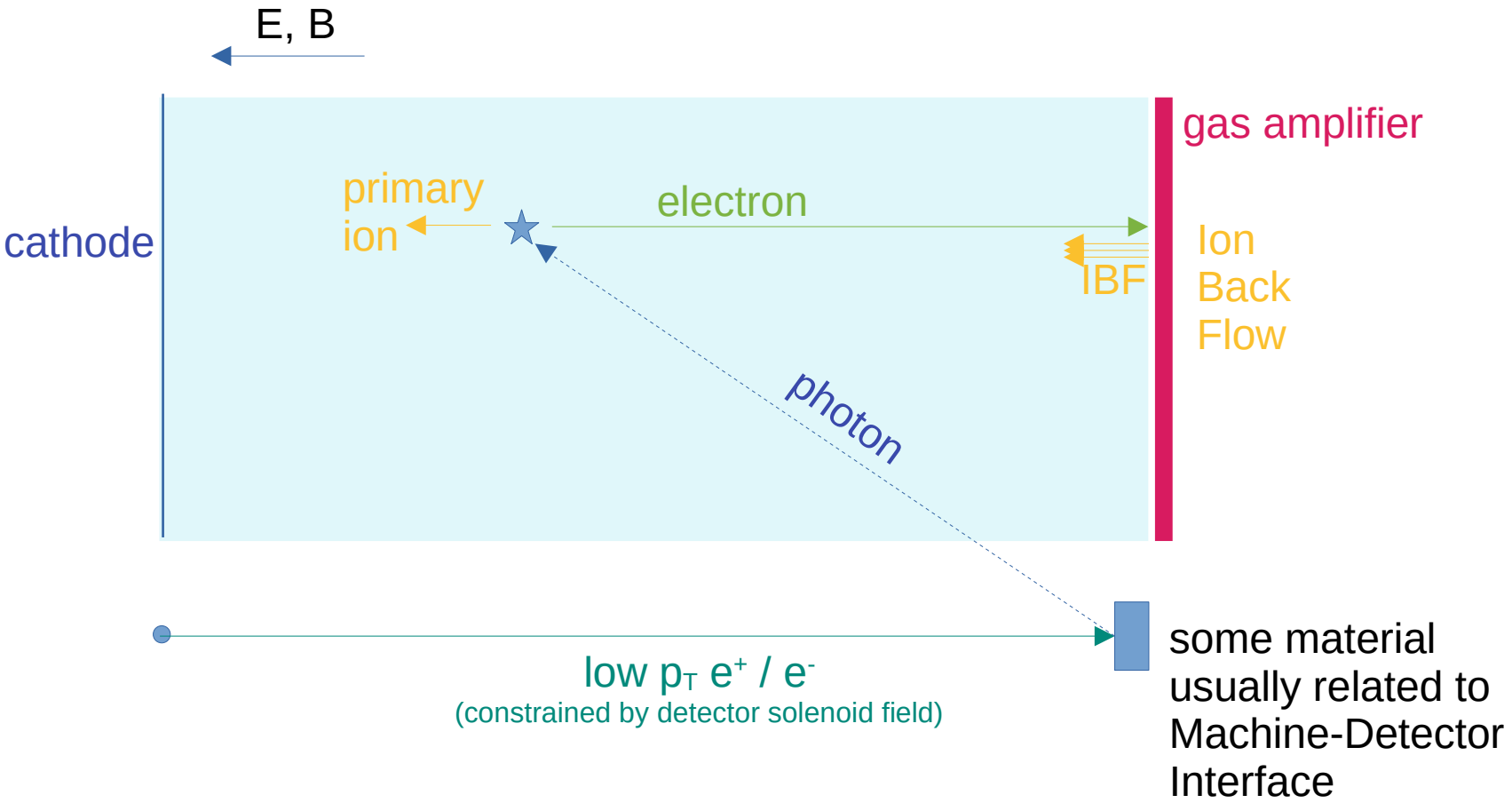
simulated by GuineaPig and/or CAIN

A. Schuetz
arXiv:1801.04156

TPC operation



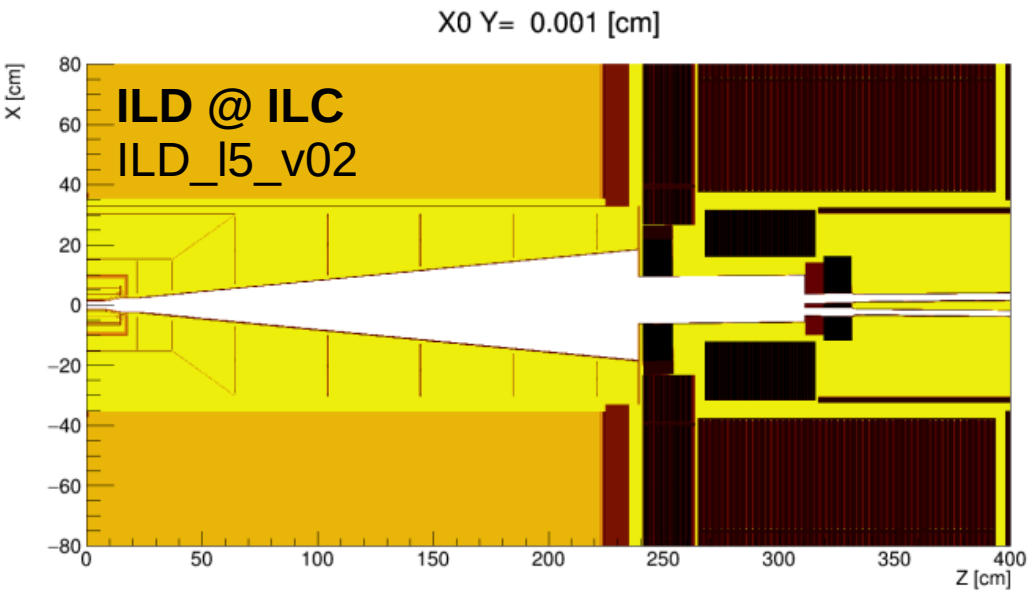
beam backgrounds : usually small p_T → particles do not reach TPC directly

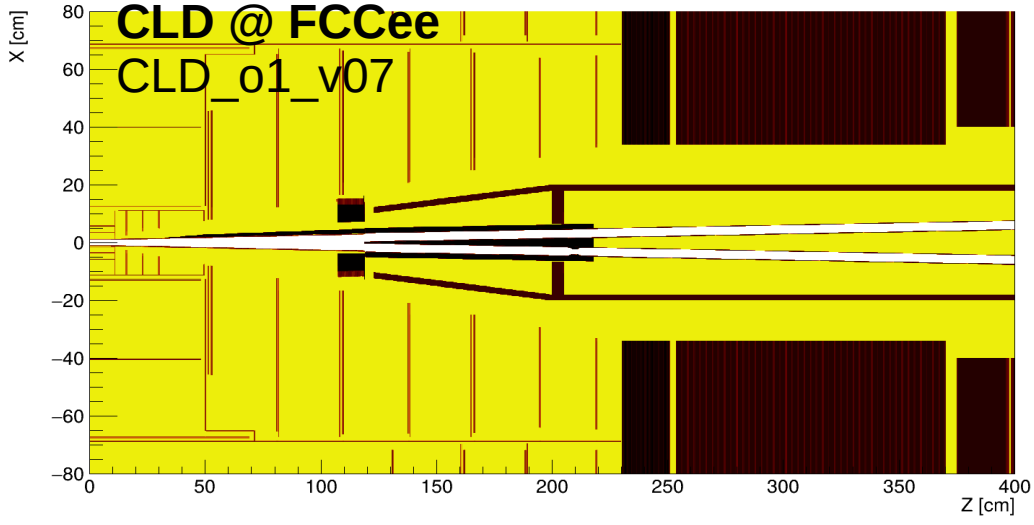


Machine-Detector Interface

is significantly different @ ILC and FCCee

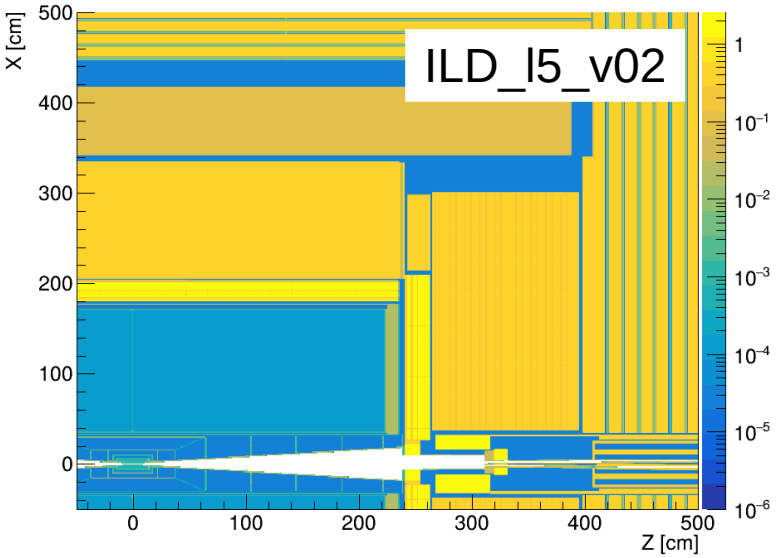
	ILC	FCCee
crossing angle	14 mrad	30 mrad
L* [distance from IP to last accel focusing quadupole magnet]	4.1 m	2.0 m
detector solenoid	3.5 T	2.0 T
additional B-fields	anti-DID (?)	- compensating - screening





new models of ILD for FCCee

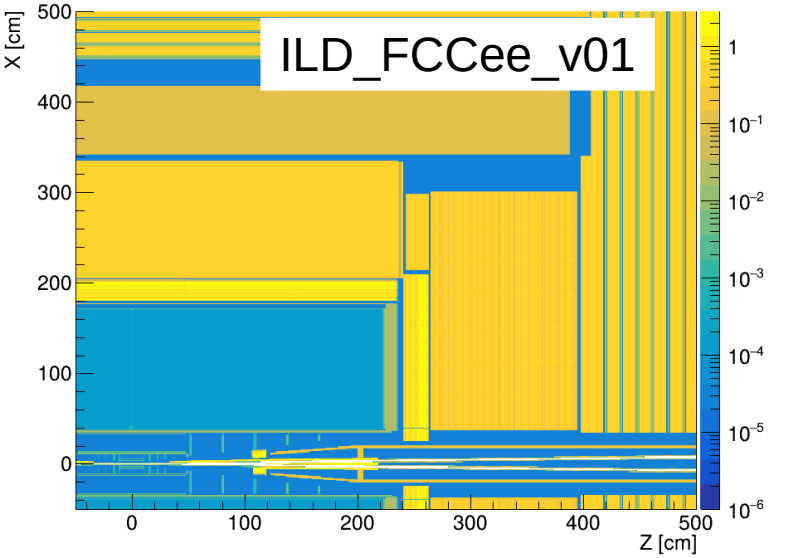
Work In Progress
with V. Schwan



common MDI: MDI_o1_v00

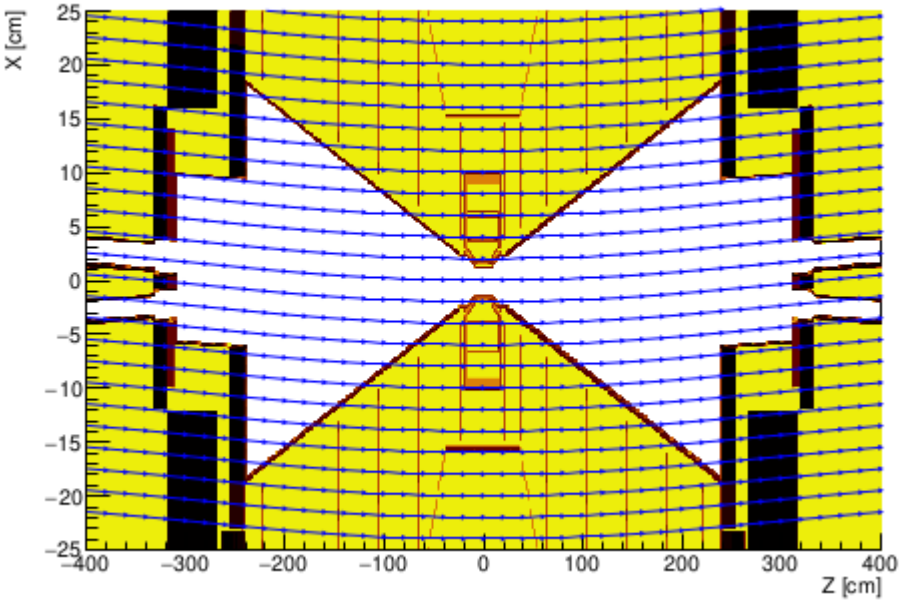
vertex, inner tracker
adapted from CLD_o1_v07

remainder from ILD



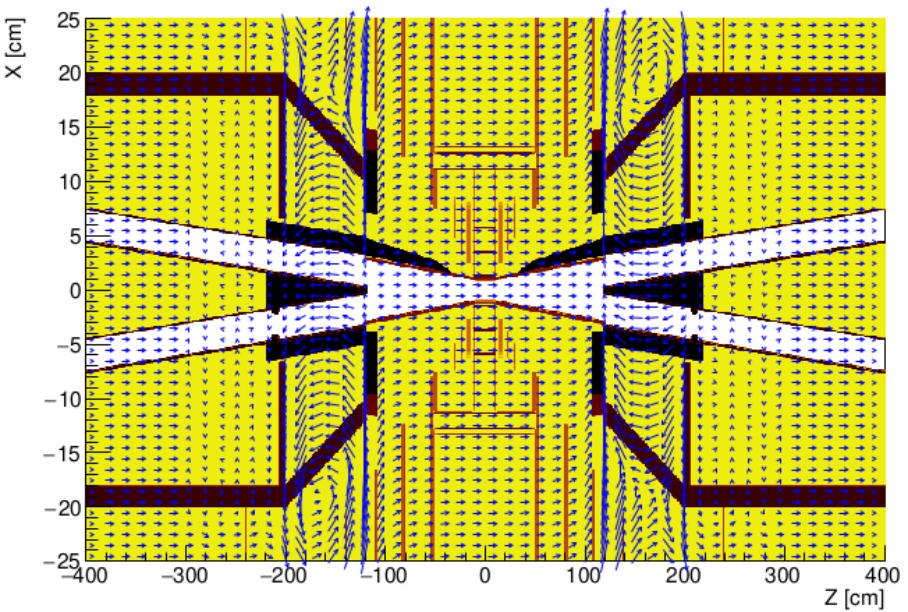
magnetic field maps

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)

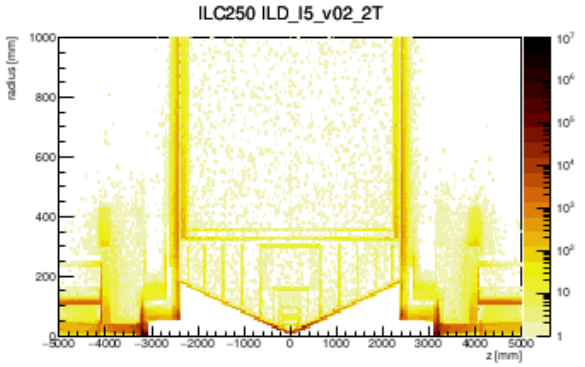
simulate in various DD4hep ILD detector models:

- using ddsim/DD4hep/Geant4
  - some special parameters to correctly track low p_T particles

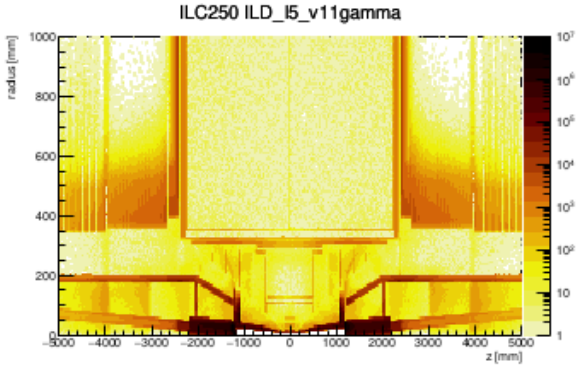
- ILD @ ILC :
  - uniform 3.5T
  - uniform 2.0T
  - field map with and without anti-DID

- ILD @ FCCee :
  - uniform 2.0T
  - field map for central region

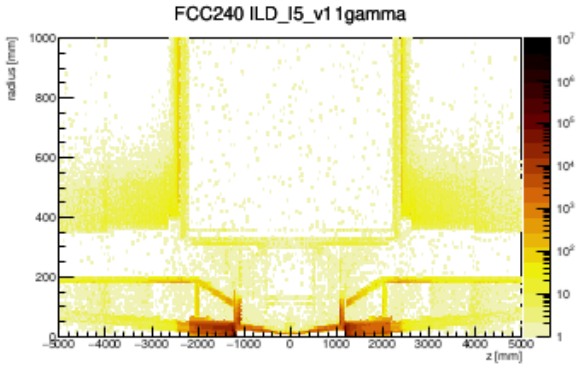
MC particle endpoints in 100 BX



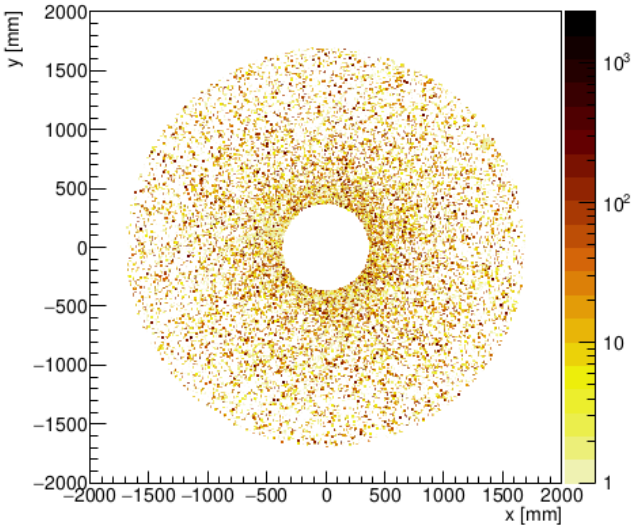
ILC250 beamstrahlung ILC-like detector



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]

			FCCee-91	FCCee-240	ILC-250
model	B-field [T]	MDI	thousand ions / bunch crossing mean ± RMS		
ILD_l5_v02	3.5 (uniform)	ILC	6.5 ± 19.9	14 ± 14	960 ± 150

large variations between bunch crossings

beamstrahlung much weaker @ FCCee
→ bunches less focused

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ILD_l5_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

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ILD_l5_v03	3.5 (map)	ILC	5.7 ± 7.9	14 ± 11	1100 ± 200
ILD_l5_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

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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

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

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

ILC and FCCee are similar

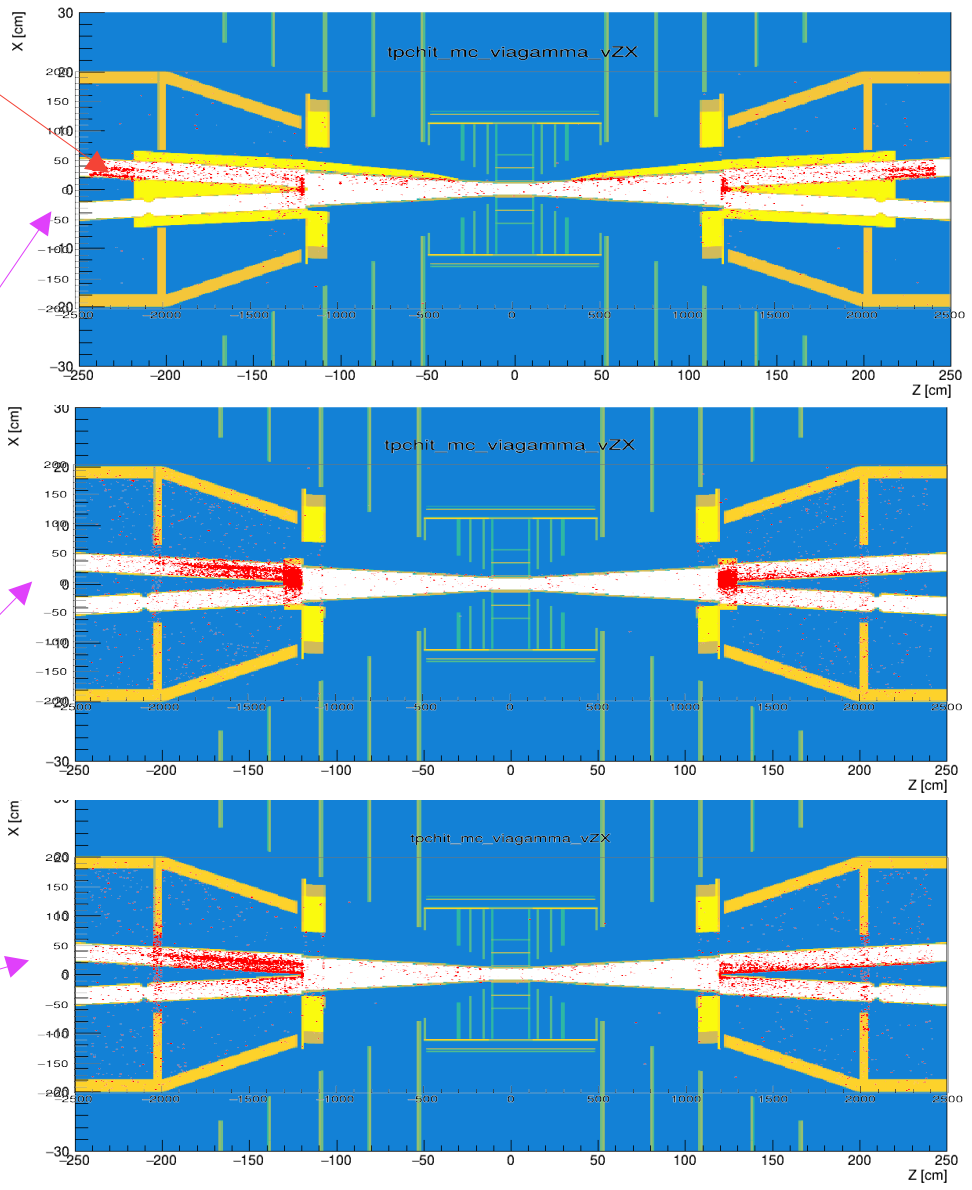
look at first interaction
of initial MC particles
which later induce TPC hits

effect of MDI variations

default
(with masks)

remove masks

remove masks and HOM



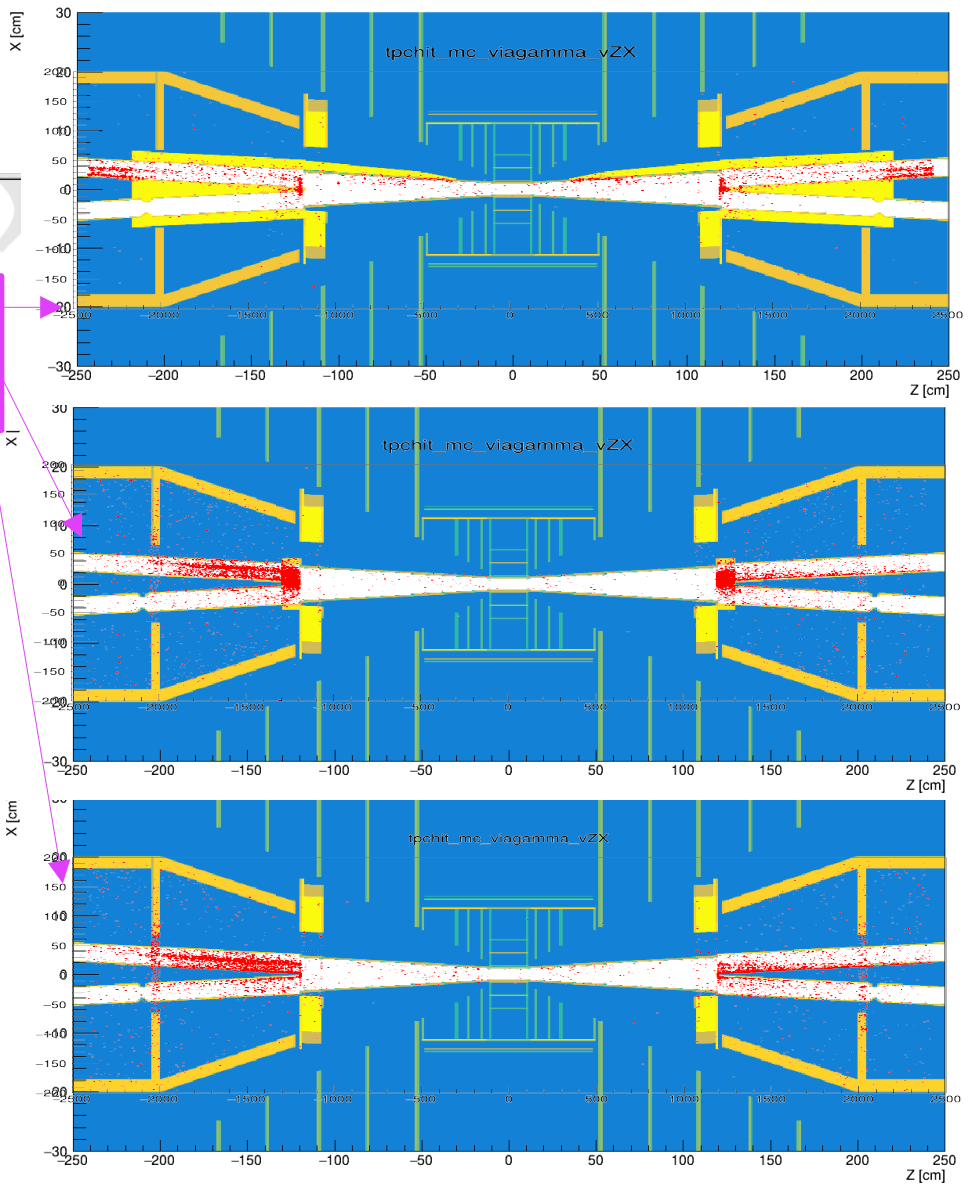
		new FCCee models	
ILD_FCCee_v01	2.0 (uniform)	FCC-ee	351 ± 115
ILD_FCCee_v01	2.0 (map)	FCC-ee	261 ± 86
ILD_FCCee_v01	2.0 (map), no mask	FCC-ee	707 ± 116
ILD_FCCee_v01	2.0 (map), no mask HOM	FCC-ee	536 ± 114

- 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 m^3) at any time,
taking account of different collision rates

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

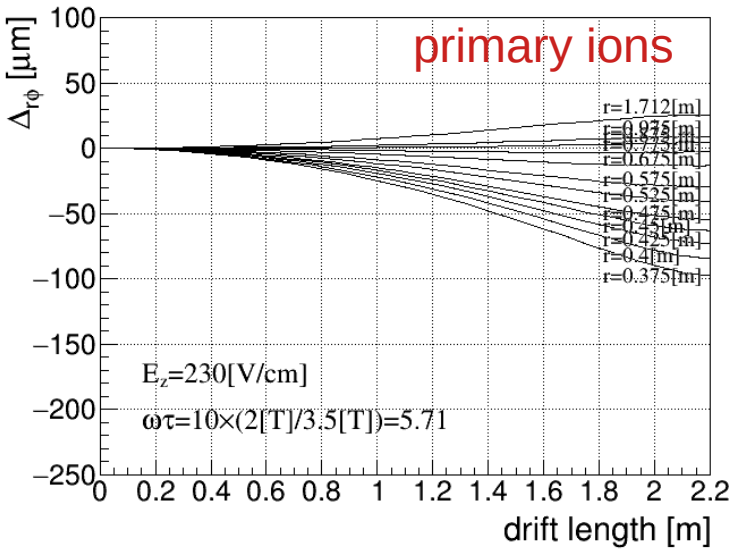
Collider	FCC-91	FCC-240	ILC-250
Detector model	ILD_FCCee_v01	ILD_FCCee_v01	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	260 k	820 k	450 k
primary ions in TPC at any time	1.7×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.4	0.54	0.0025

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

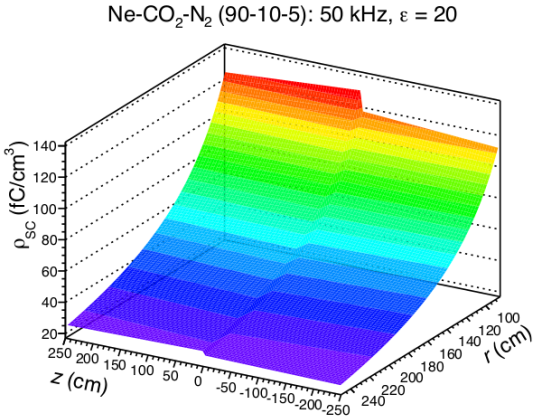
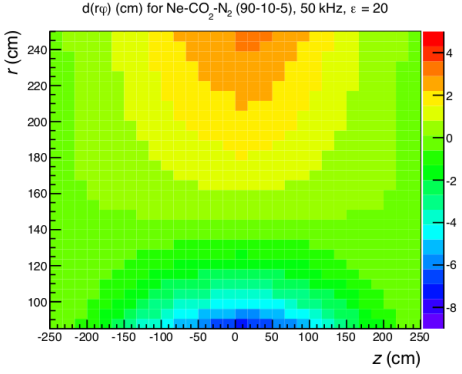


Figure 7.7: Average space charge density for Ne-CO_2-N_2 (90-10-5), $R_{int} = 50$ kHz and $\varepsilon = 20$.

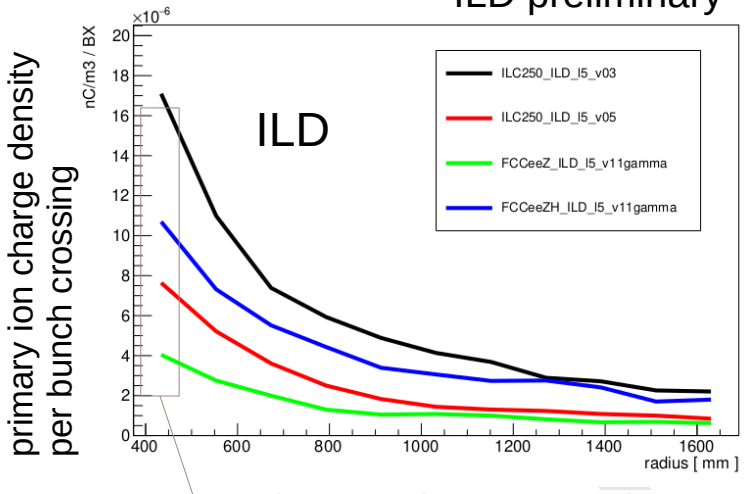
assumed ion back flow factor ε: 20 secondary ions / primary

20~120 fC/cm³ → cm-level distortions



r-phi distortion [cm]

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/m³	30M	26	nC/m³
FCC240	1e-5 nC/m³	800k	2	nC/m³
ILC250 (v5)	8e-6 nC/m³	6.6k	0.01	nC/m³
ALICE		50k	120	nC/m³ with IBF=20

primary ions only: IBF=0

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

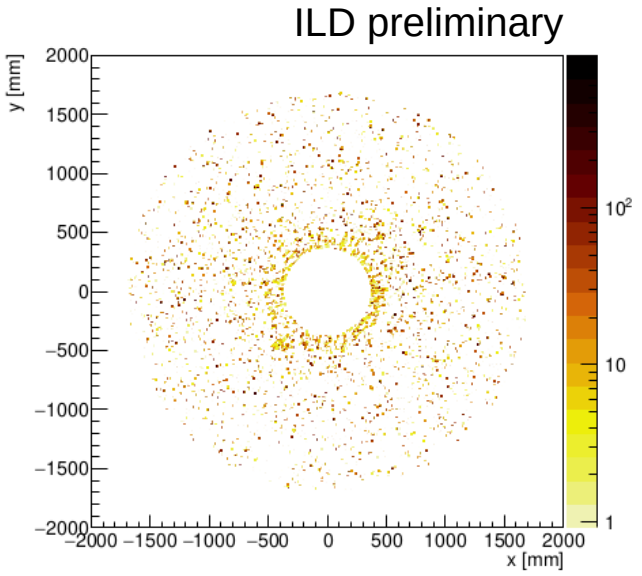
backup

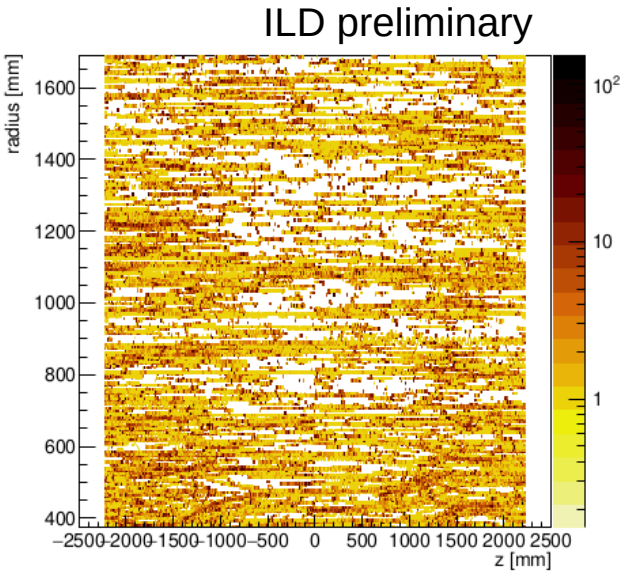
TPC hits

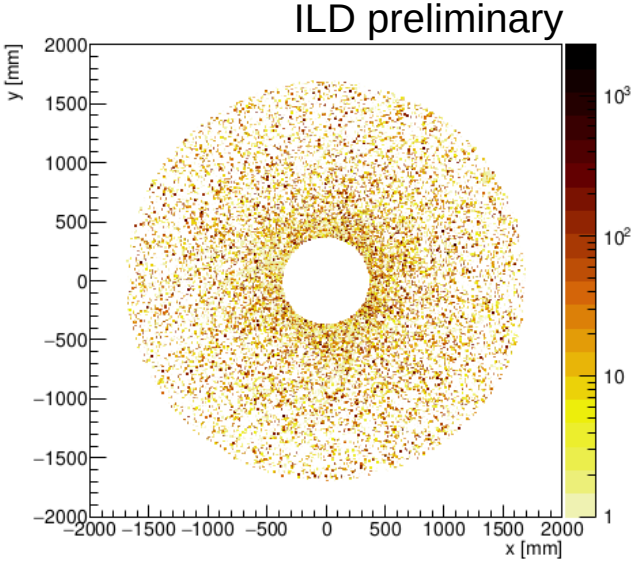
superimpose
100 bunch crossings

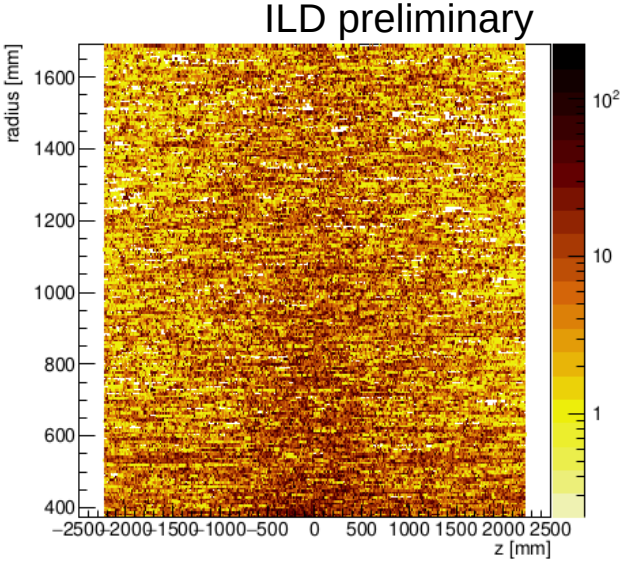
ILD_l5_v11y @ FCCee-91

ILD_l5_v03 @ ILC-250

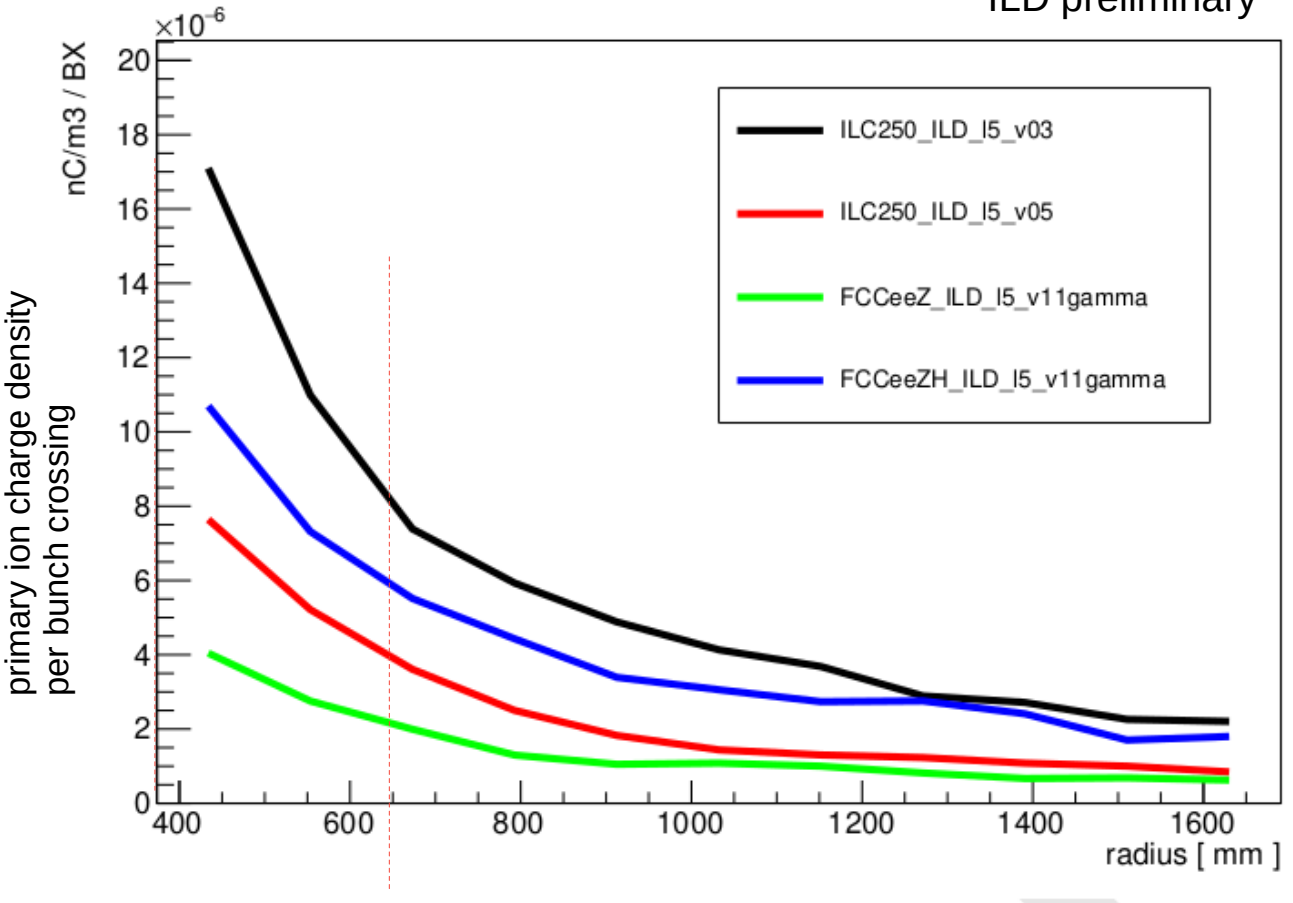








ILD preliminary



lower TPC edge
in “small TPC” option