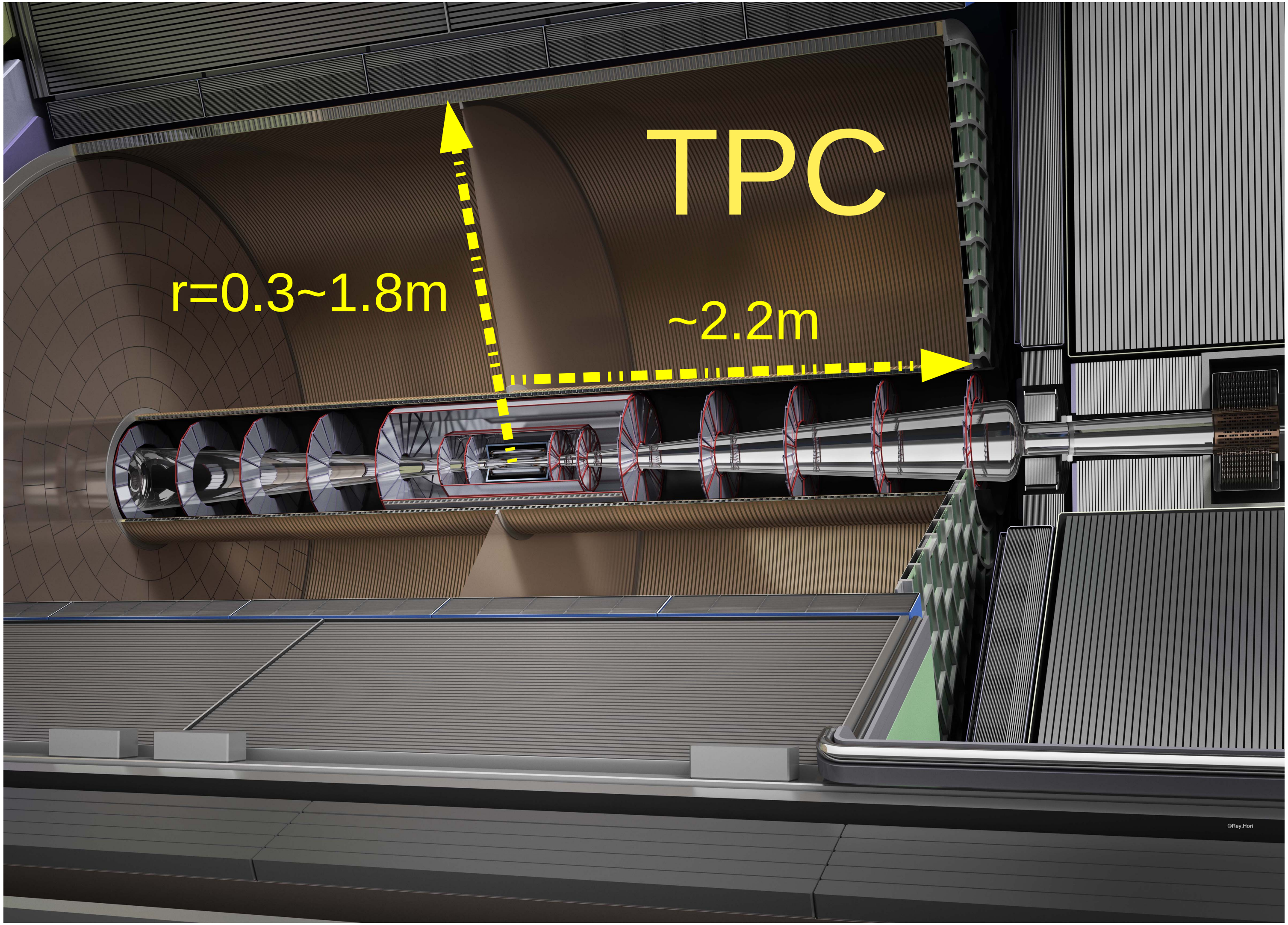
Beamstrahlung backgrounds in ILD at linear (ILC) and circular (FCCee) colliders

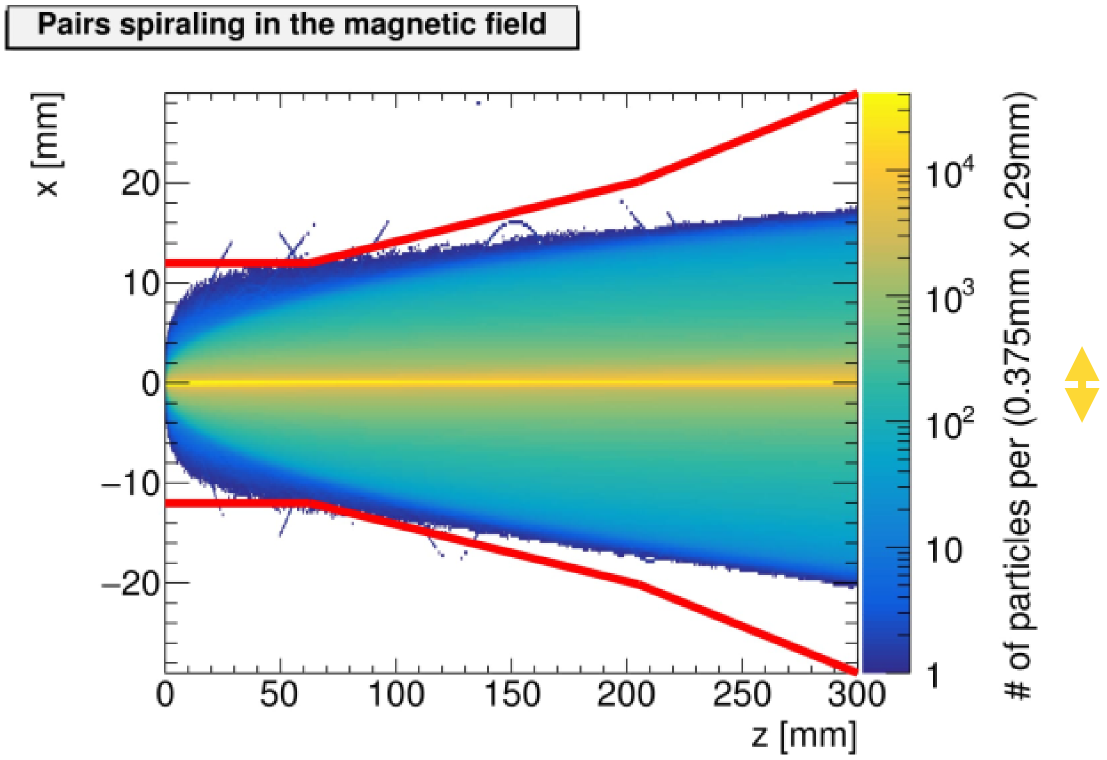
Daniel Jeans / KEK IPNS

ECFA mtg

October 2024


TPC
r=0.3~1.8m
~2.2m
©Rey.Hori

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

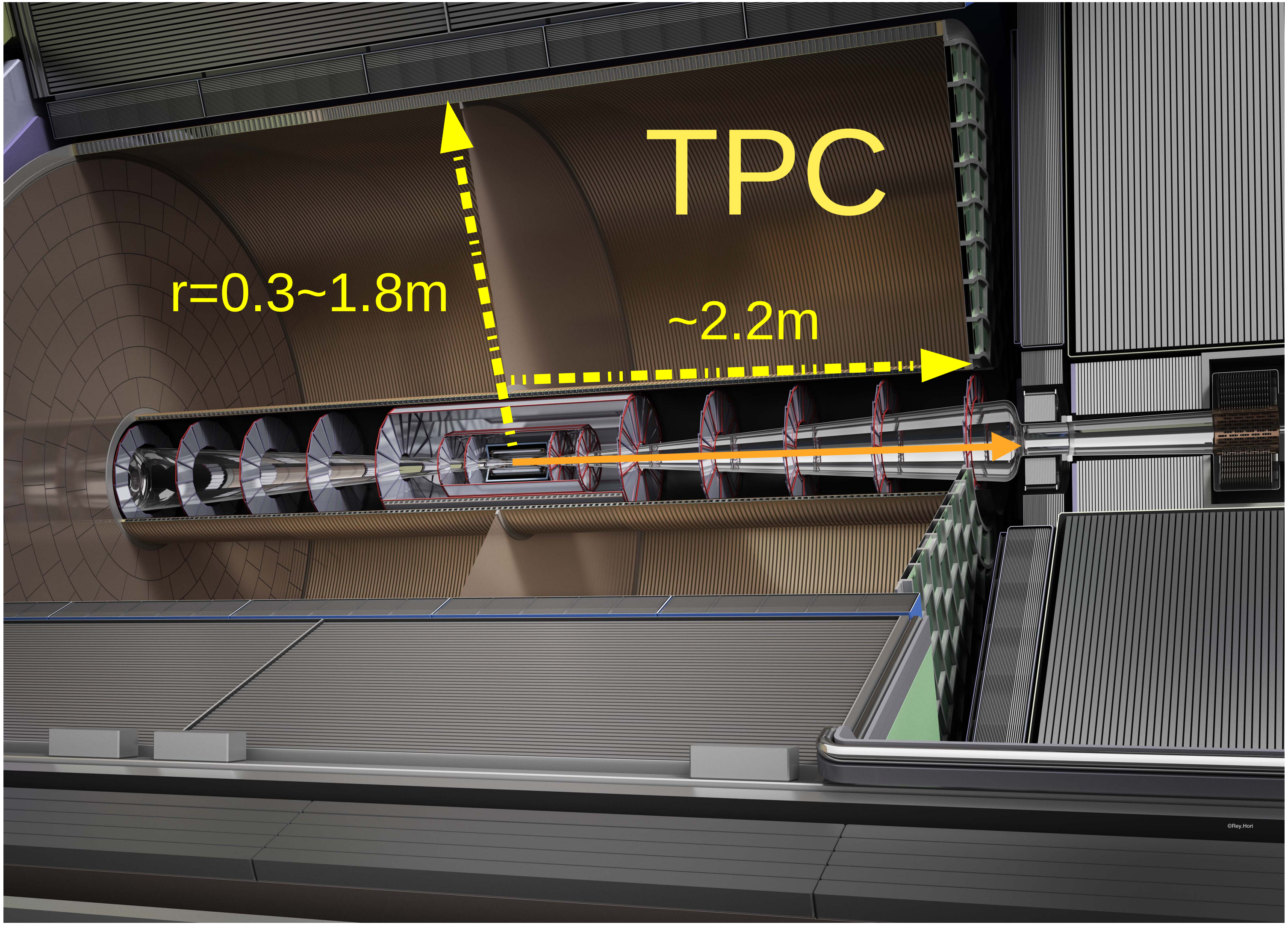


(b) *ILC250 set (A)*

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

simulated by GuineaPig and/or CAIN

A. Schuetz
arXiv:1801.04156


TPC
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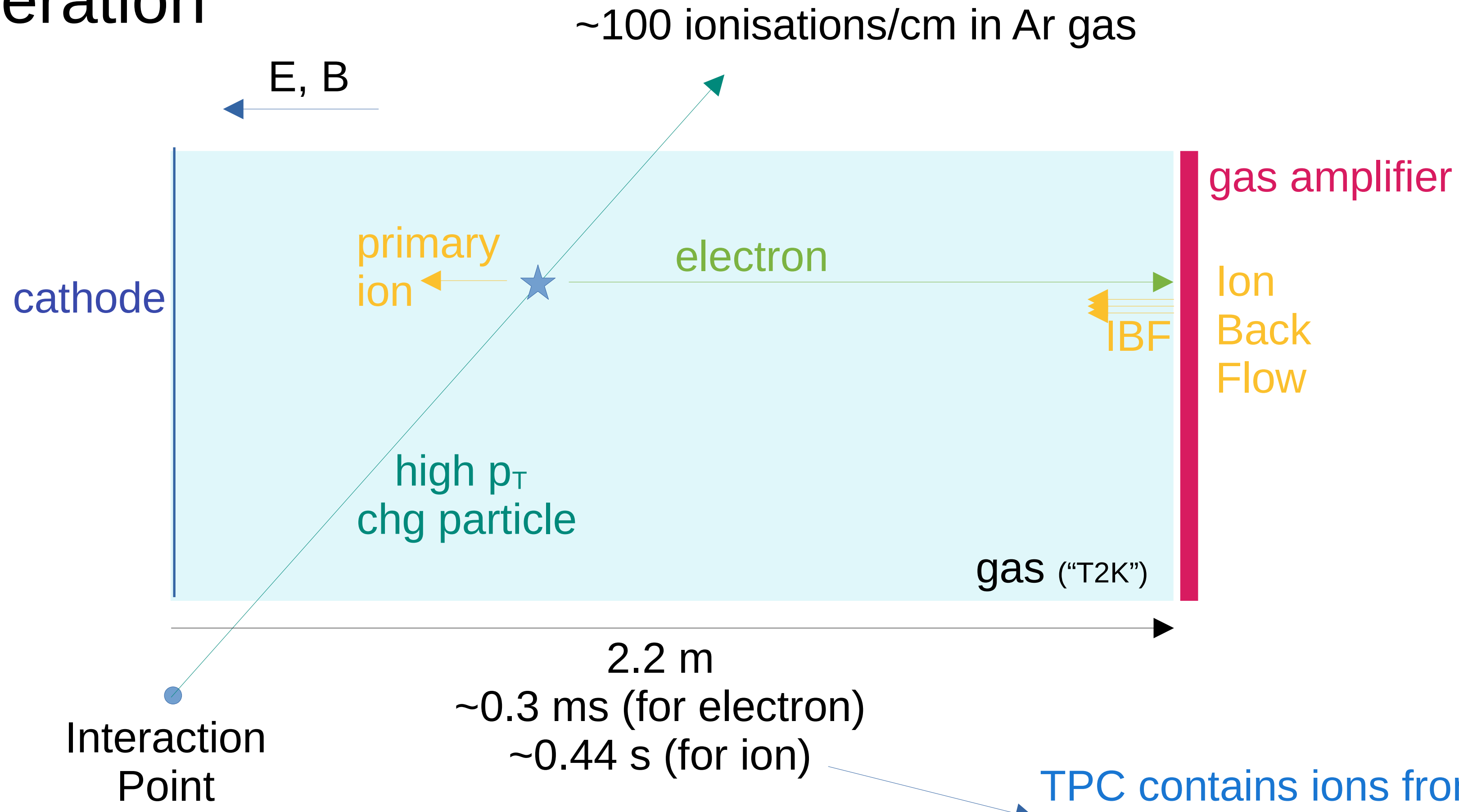
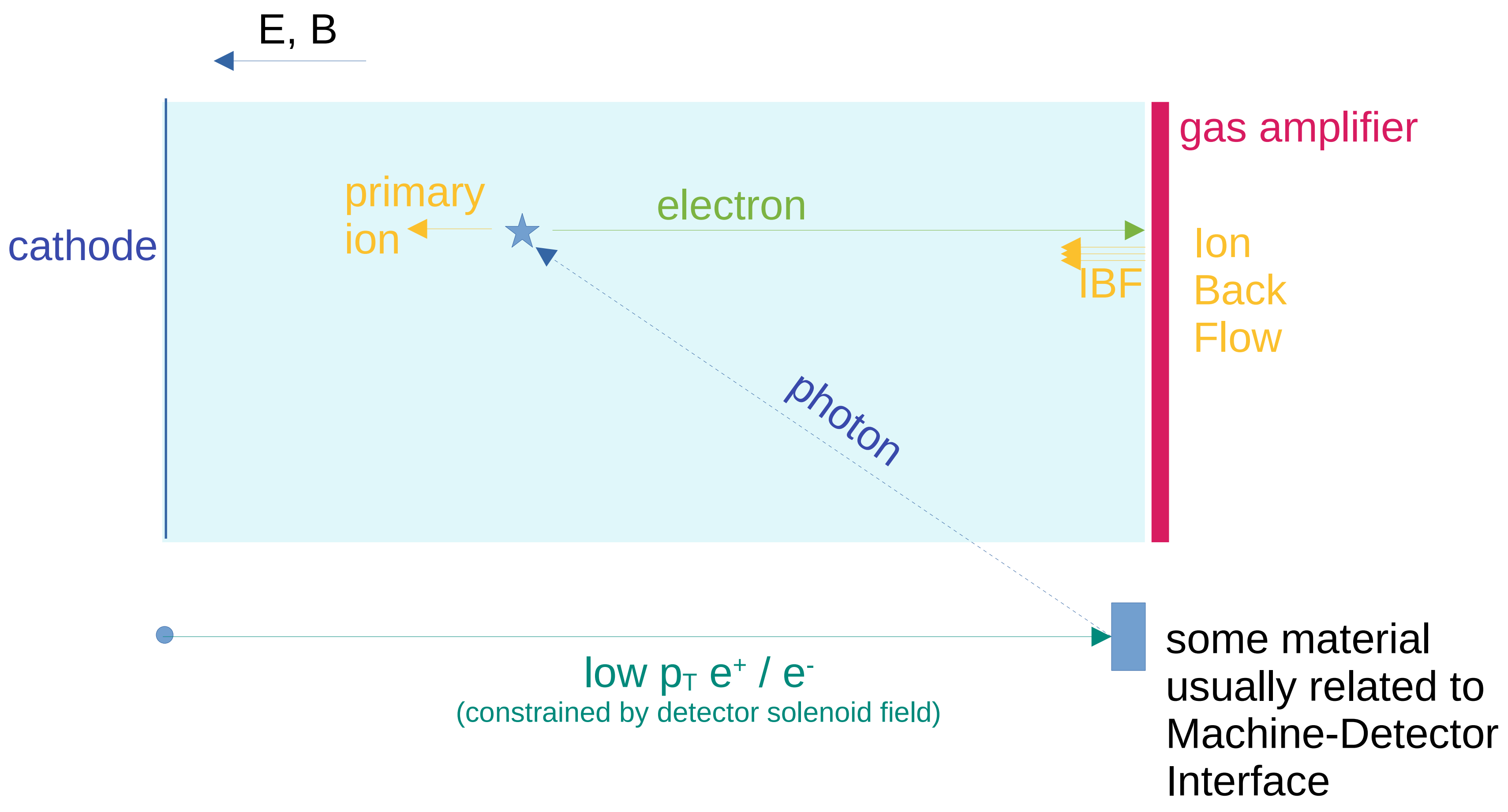
TPC operation



TPC contains ions from collisions up to 0.44s earlier

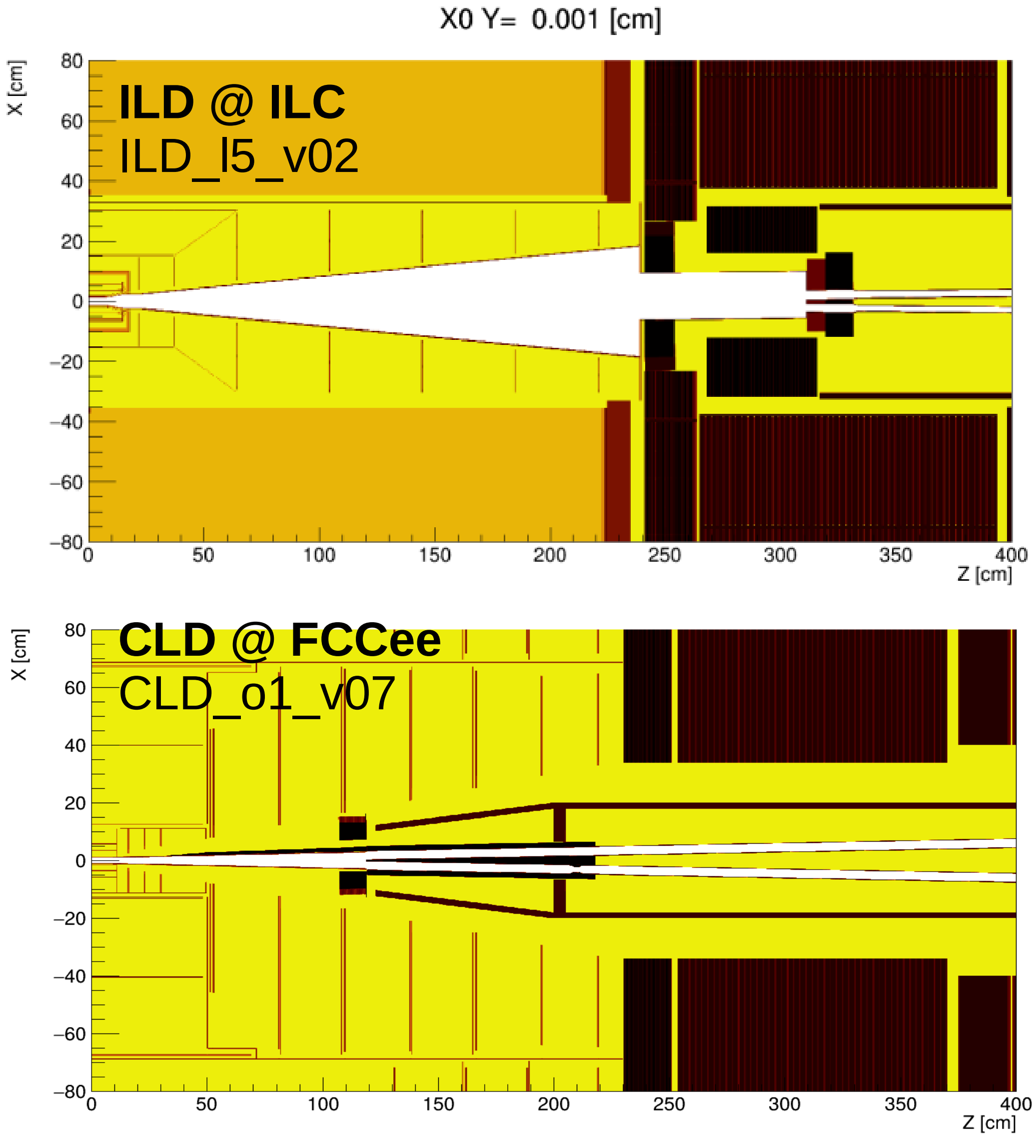
beam backgrounds : usually small p_T → particles do not reach TPC directly



Machine-Detector Interface

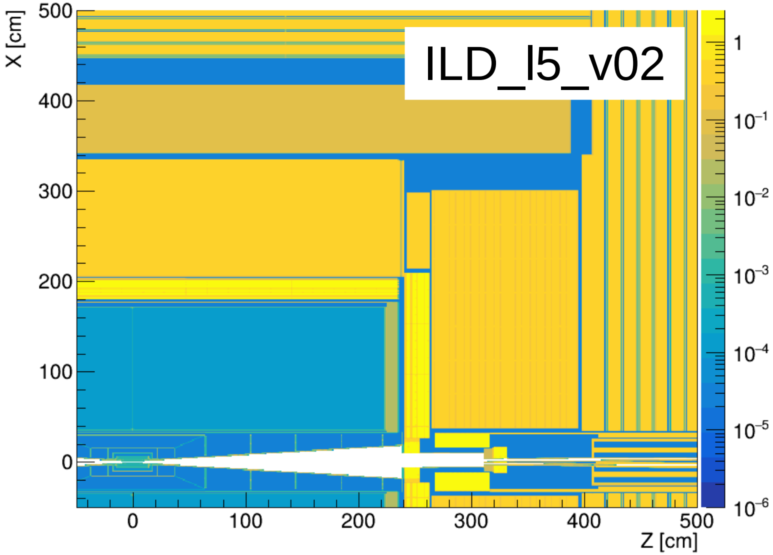
is significantly different @ ILC and FCCee

	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

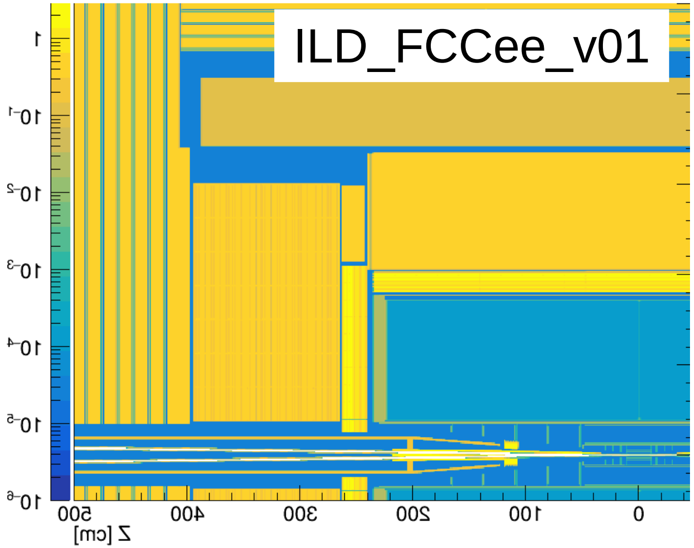


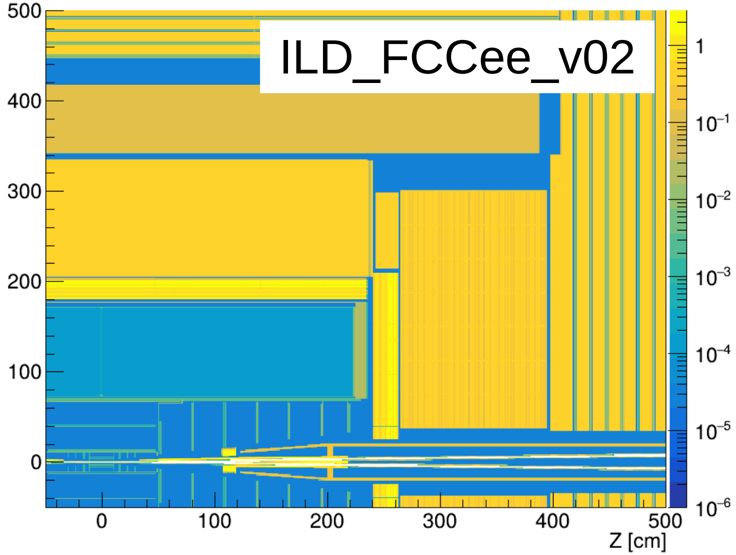
MDI_o1_v00

vertex, inner tracker
adapted from CLD_o1_v07

remainder from ILD

2 options:
inner TPC radius

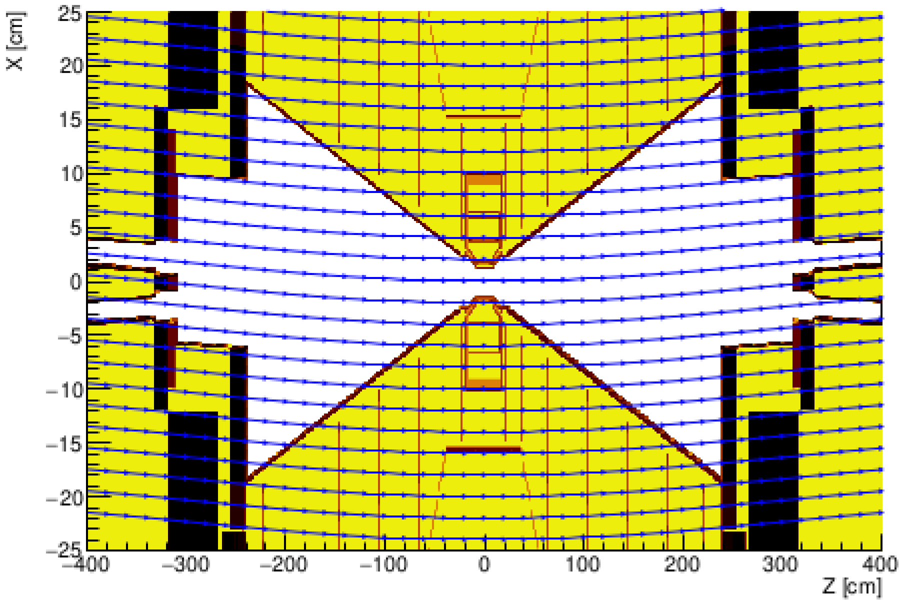




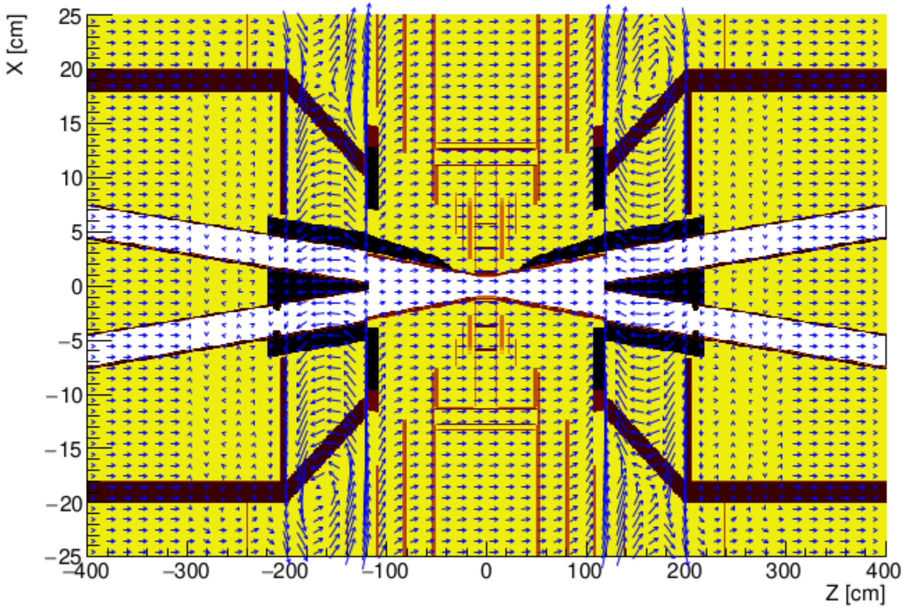
field maps

field magnitude & orientation

field lines



ILC with anti-DID



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)

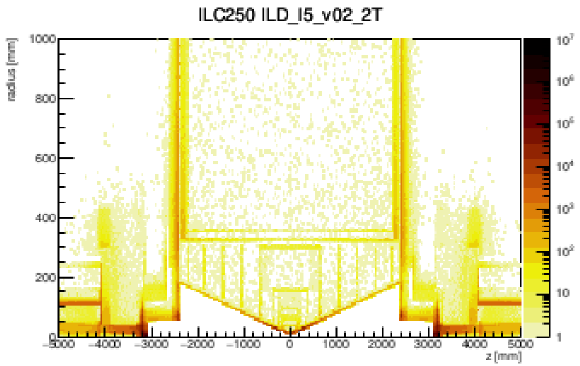
simulate in various DD4hep ILD detector models:

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

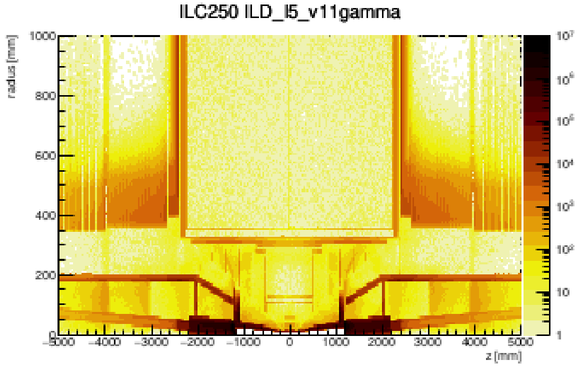
- ILD @ ILC :
  - uniform 3.5T
  - uniform 2.0T
  - field map with and without anti-DID

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

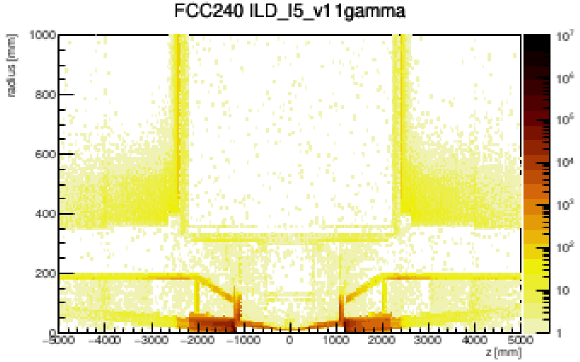
MC particle endpoints in 100 BX



ILC250 beamstrahlung | ILC-like detector



ILC250 beamstrahlung | FCC-like detector

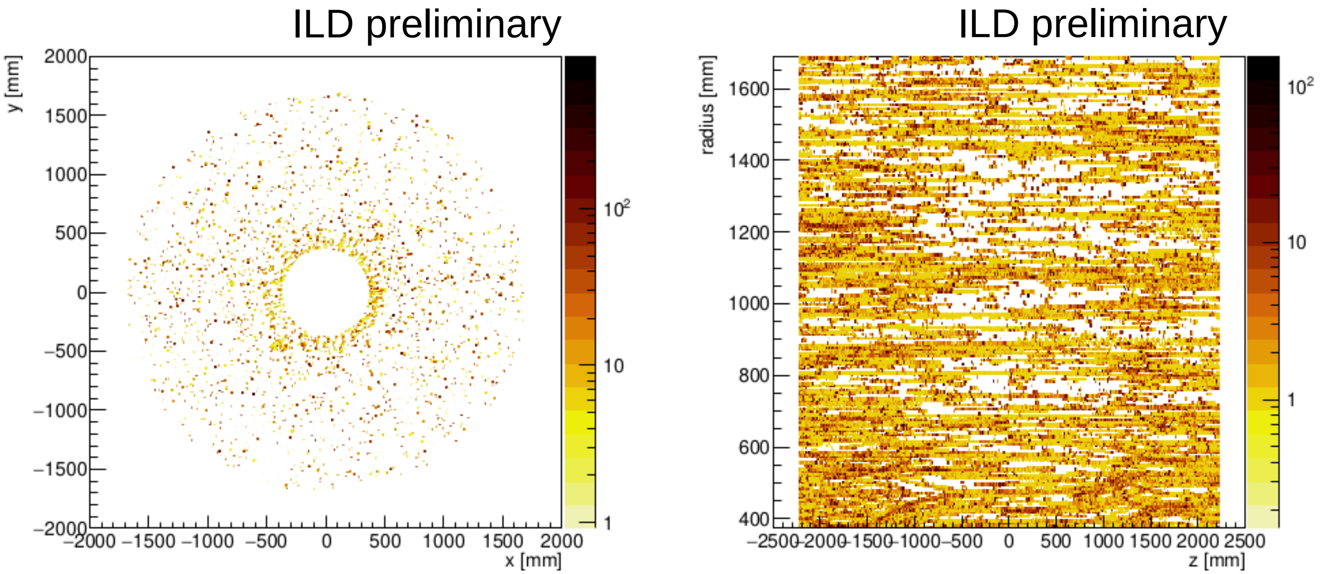


FCC-240 beamstrahlung | FCC-like detector

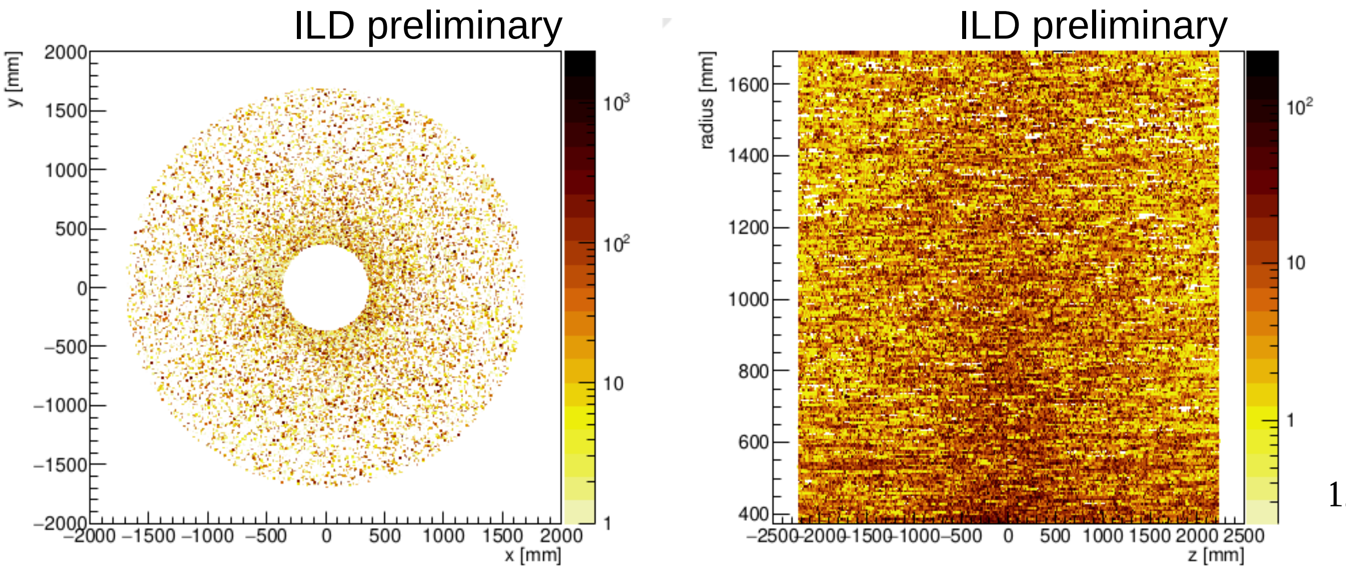
TPC hits

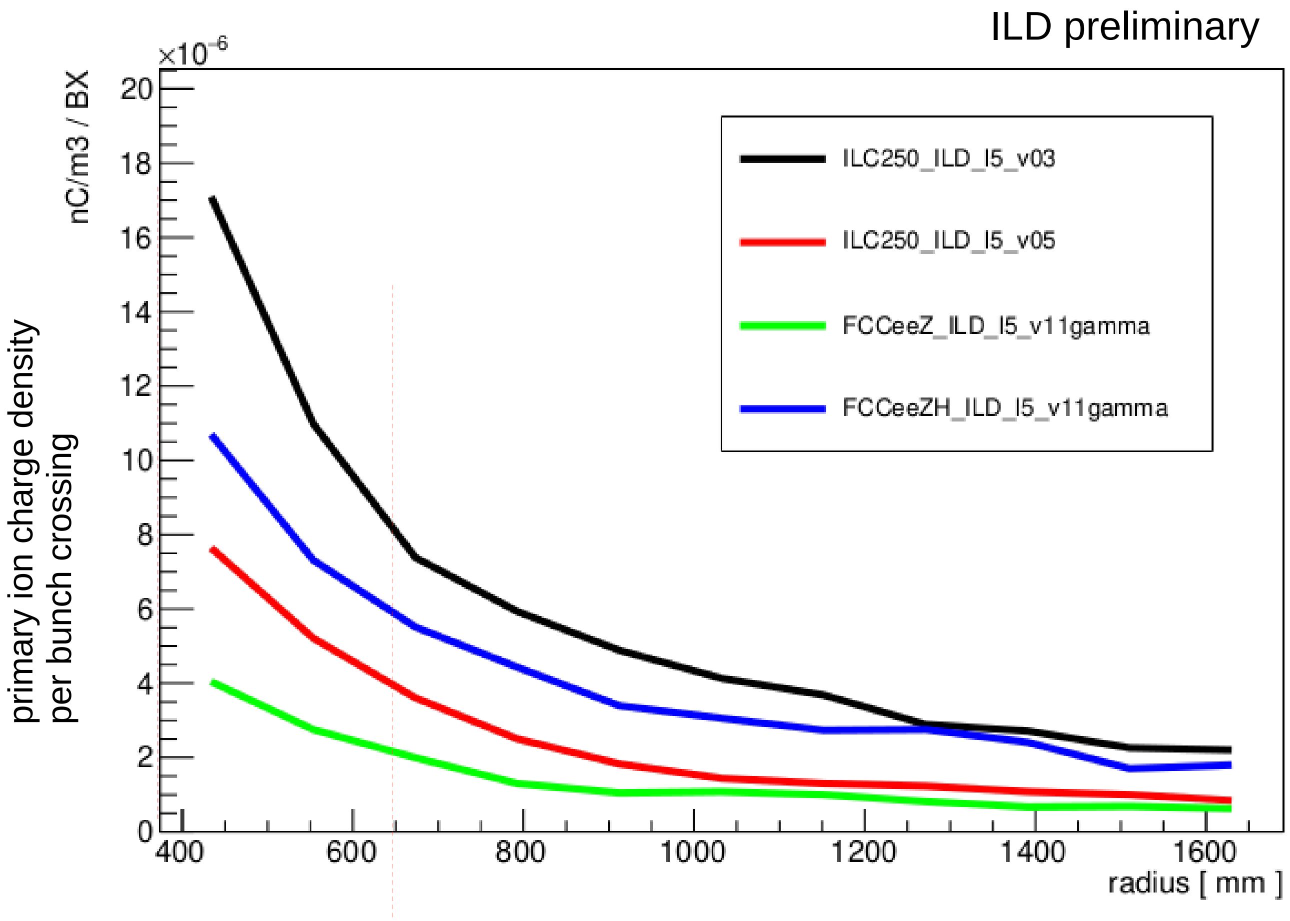
superimpose
100 bunch crossings

ILD_l5_v11y @ FCCee-91



ILD_l5_v03 @ ILC-250





lower TPC edge
in “small TPC” option

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_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 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

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

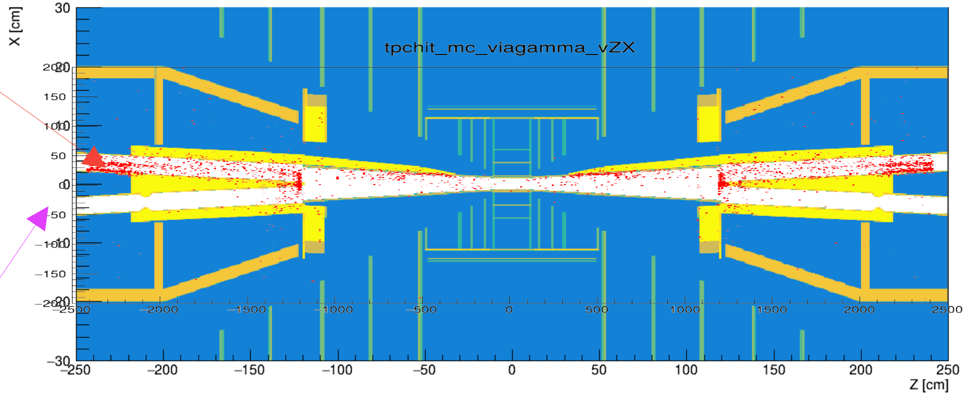
look at first interaction
of initial MC particles
which later induce TPC hits

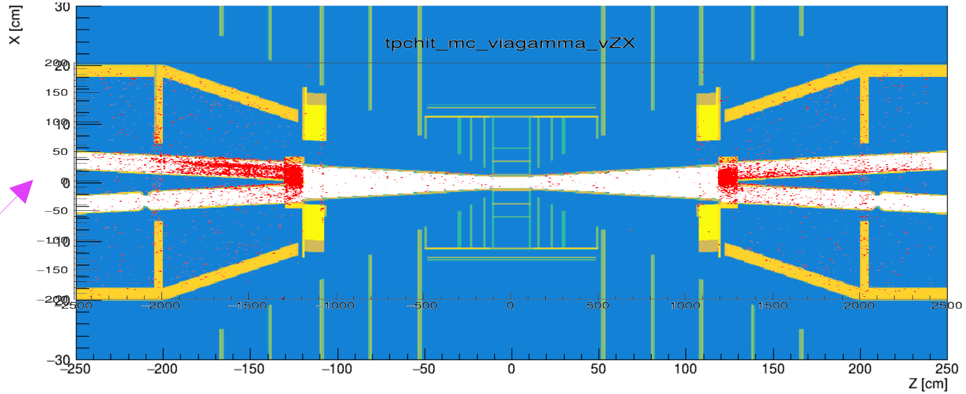
MDI variations

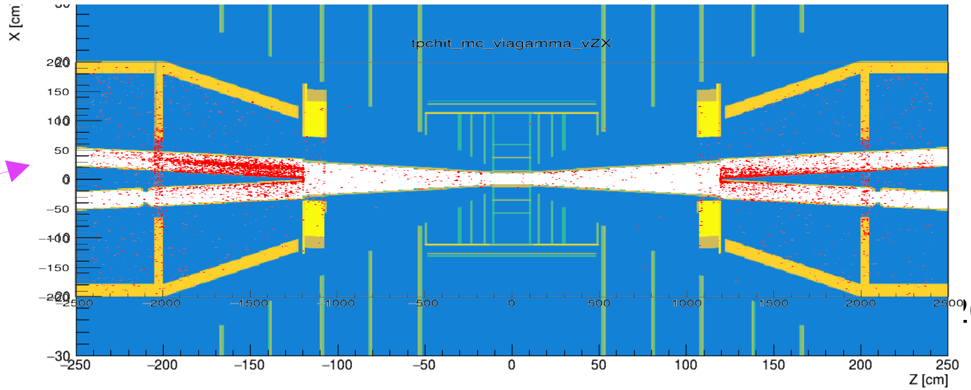
default
(with masks)

remove masks

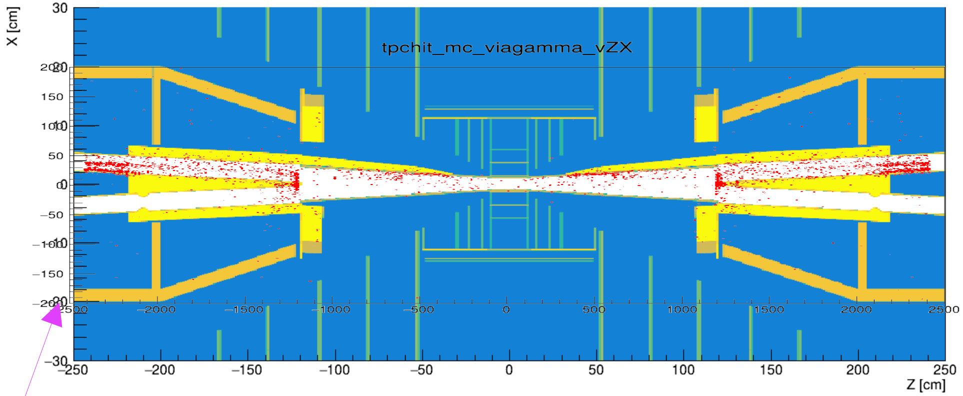
remove masks and HOM

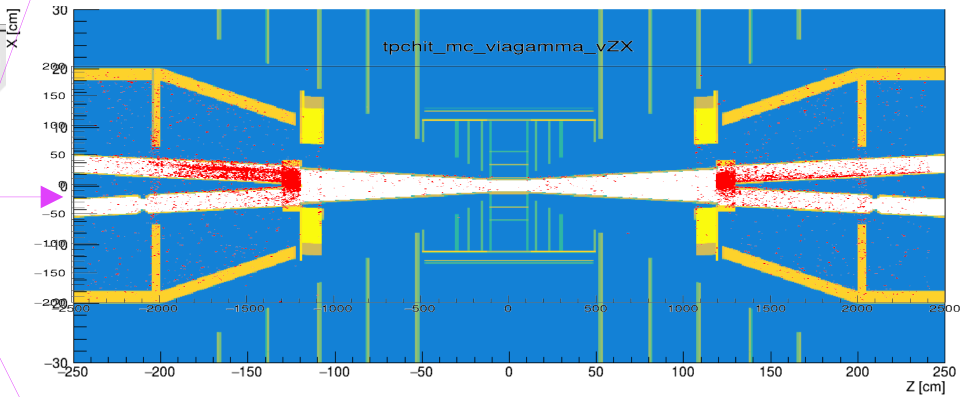


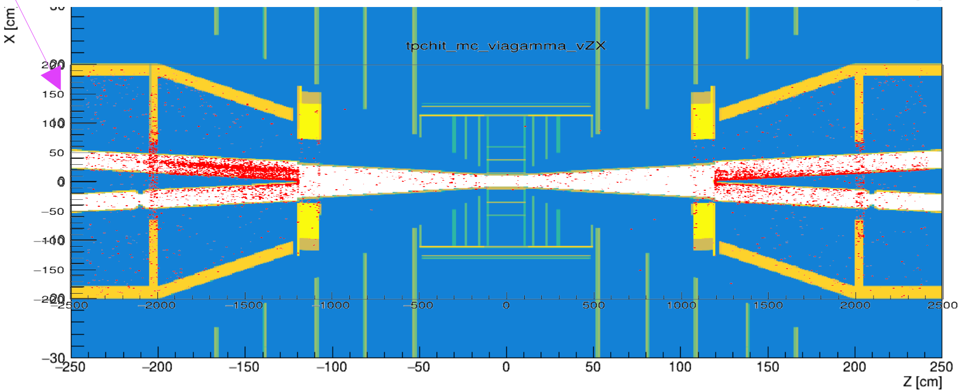




	new FCCee models		
ILD_FCCee_v01	2.0 (uniform)	FCC-ee	351 ± 115
ILD_FCCee_v01	2.0 (map)	FCC-ee	261 ± 86
ILD_FCCee_v01	2.0 (map), no mask	FCC-ee	707 ± 116
ILD_FCCee_v01	2.0 (map), no mask HOM	FCC-ee	536 ± 114







- many TPC hits induced by beamstrahlung interactions with shielding

- if we remove the shielding, they just interact elsewhere: actually *increases* TPC backgrounds

- z-symmetry... ?

how does this compare to **other sources of primary ionisation**?

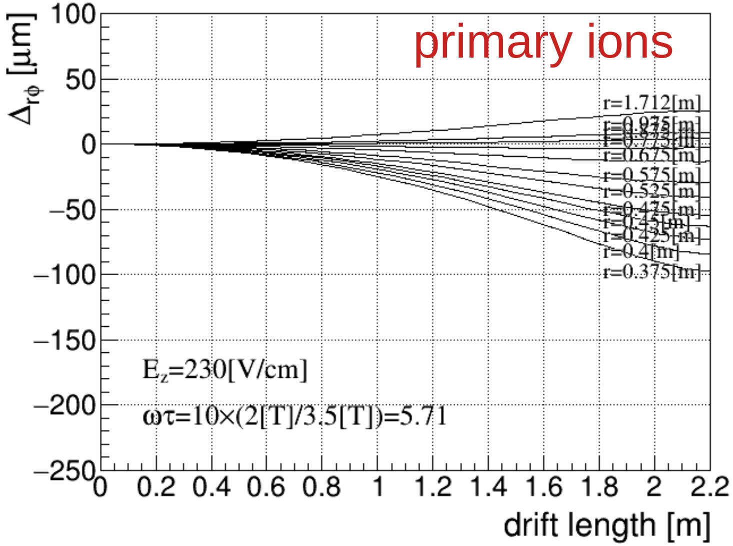
$e^+ e^- \rightarrow q\,q$ @ 91 GeV : ~1 M primary ions per event @ ~50 kHz [FCCee]

→ 10^{10} primary ions in TPC at any time

cf. $2\text{x}10^{12}$ 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 $\mathbf{e^+ e^- \rightarrow q\,q}$

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

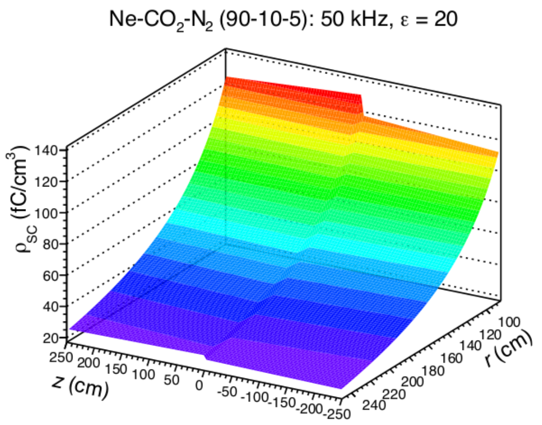
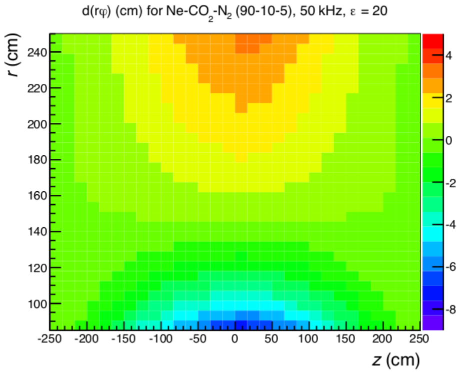


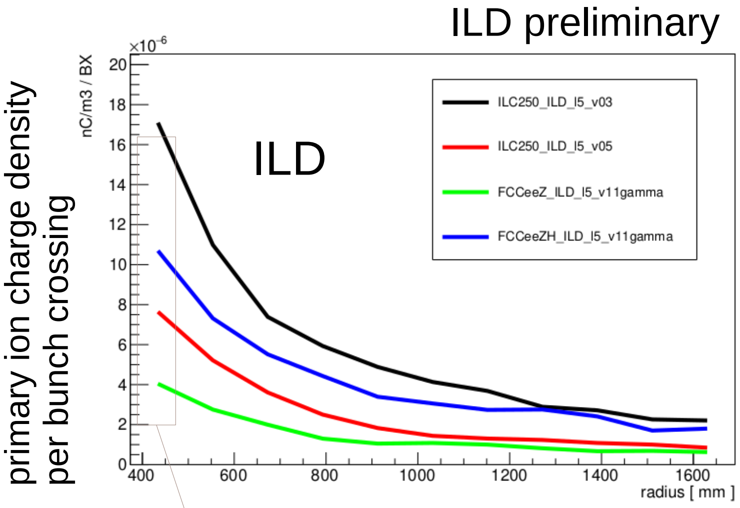
Figure 7.7: Average space charge density for Ne-CO_2-N_2 (90-10-5), R_{int} = 50 kHz and ε = 20.

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

20~120 fC/cm^3 → cm-level distortions



r-phi distortion [cm]



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
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

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 IBF~4 looks similar to ALICE-TPC
→ still some work to demonstrate feasibility of TPC
for the full tera-Z phase of a circular collider such as FCCee