can a TPC work at FCCee ?

or

beamstrahlung backgrounds in the TPC @ FCCee & ILC

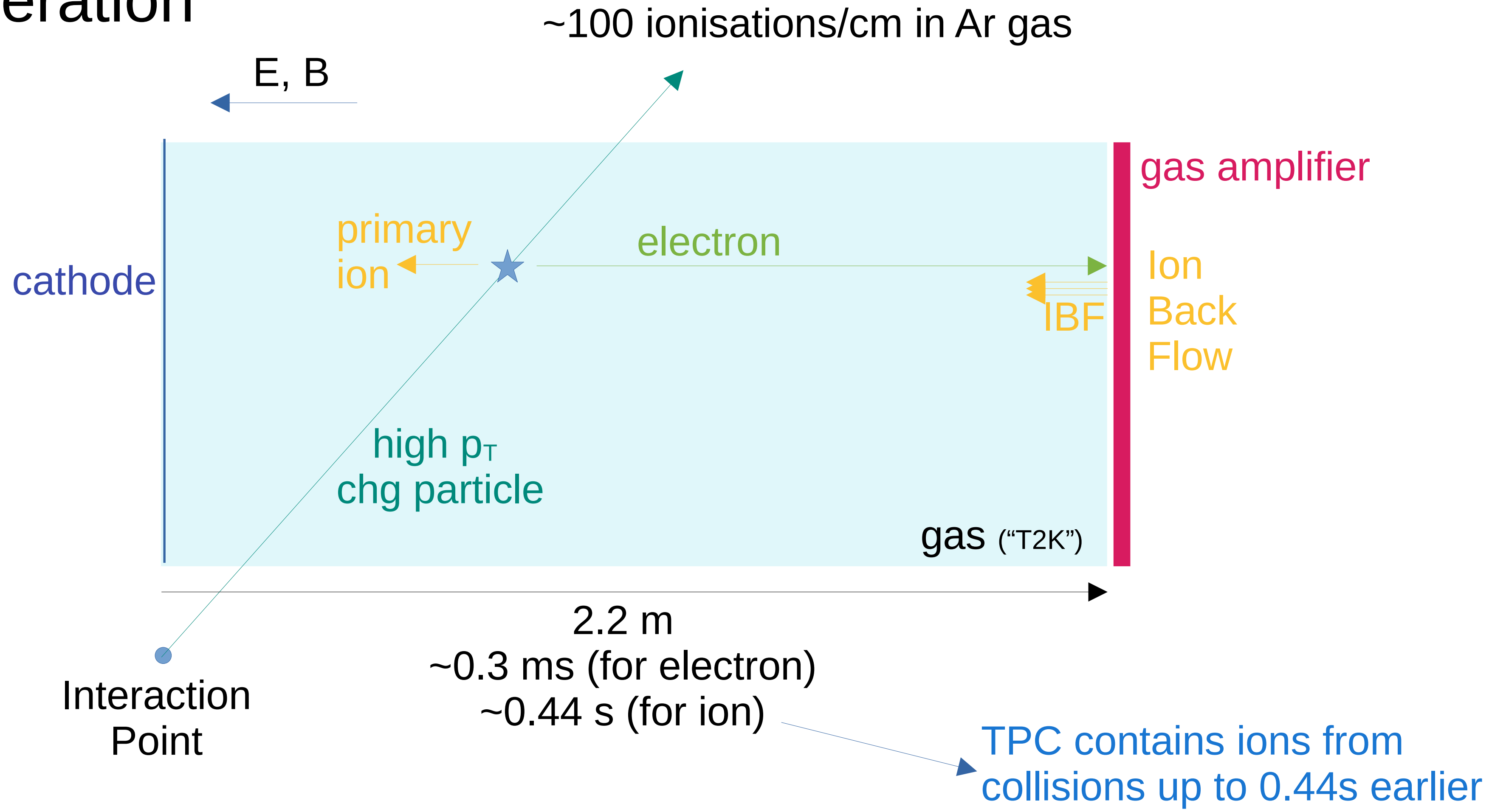
preliminary

Daniel Jeans / KEK

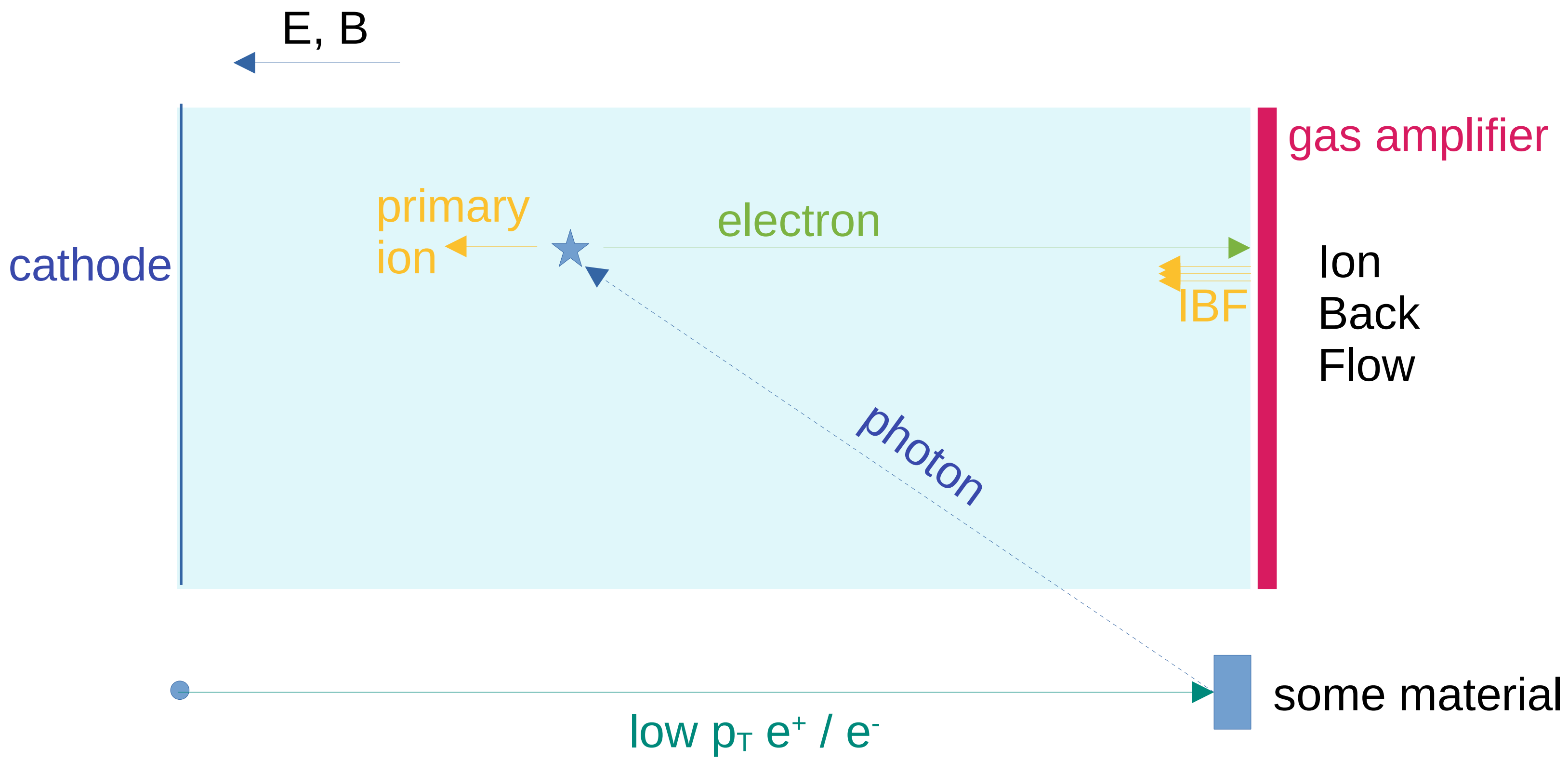
ILD meeting

2023/11/7

TPC operation

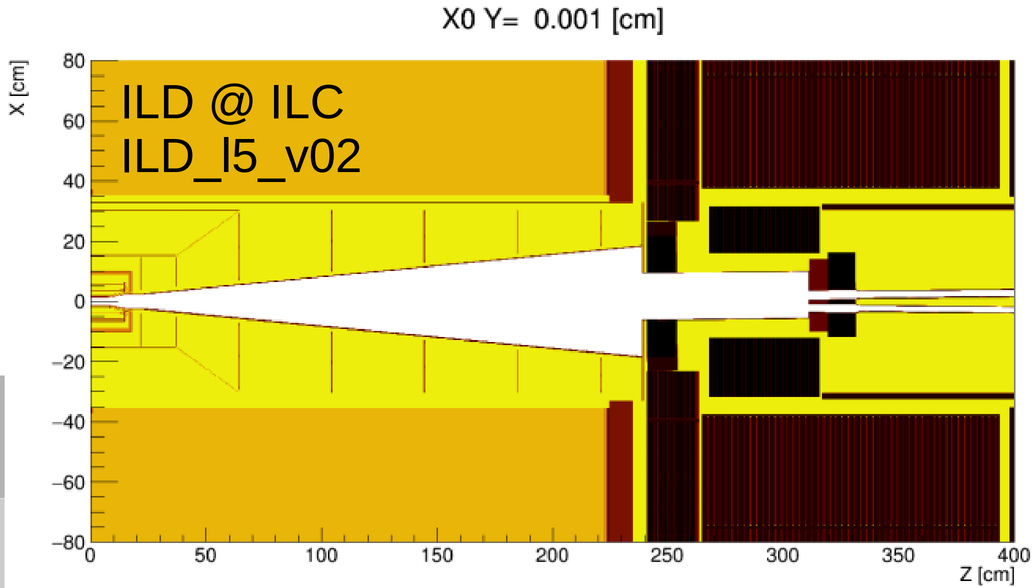


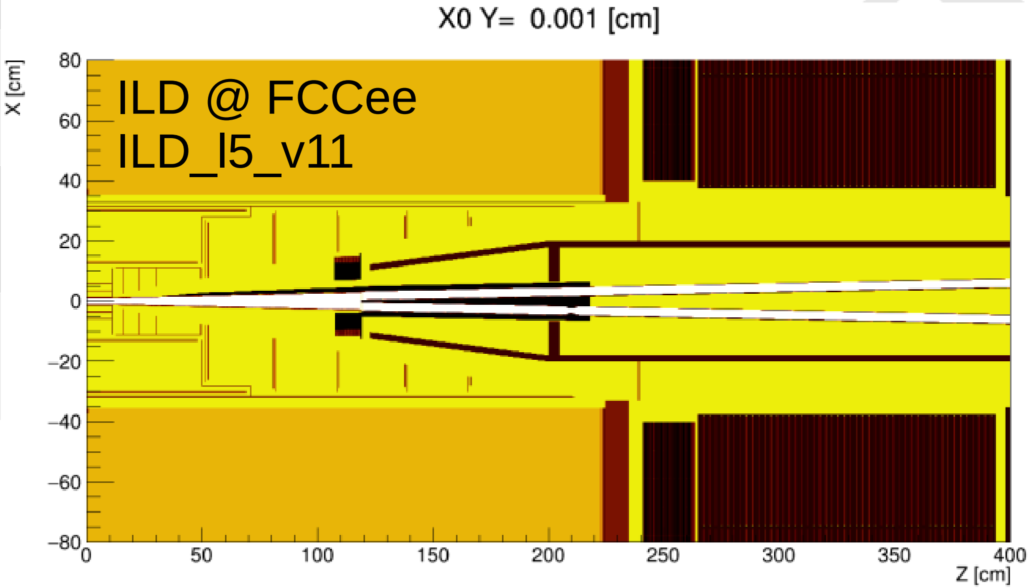
beam backgrounds : usually small p_T → particles do not reach TPC directly



machine-detector interface

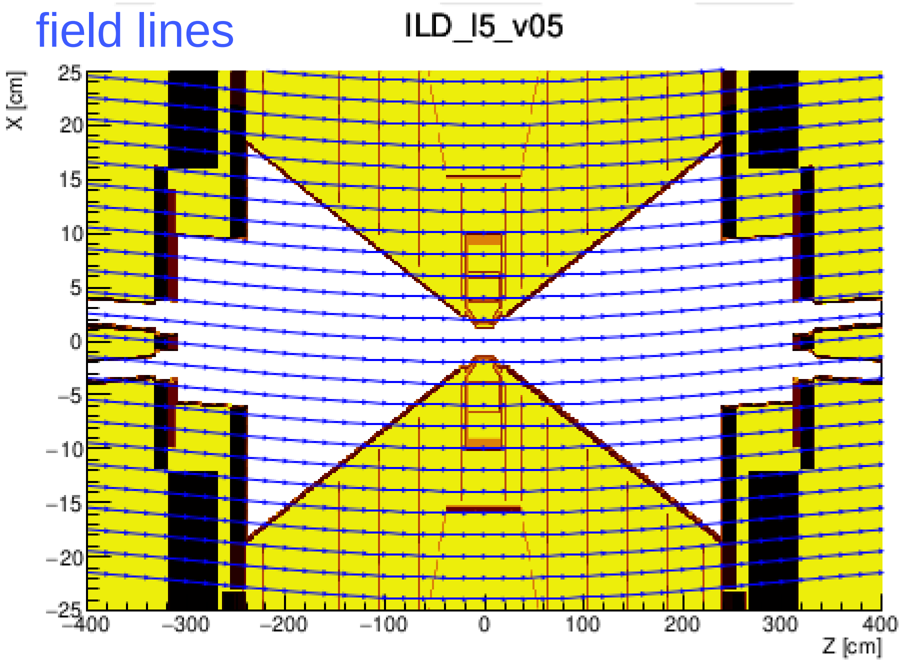
	ILC	FCCee
crossing angle	14 mrad	30 mrad
L* [distance from IP to last accel focusing quadupole magnet]	4.1 m	2.0 m
detector solenoid	3.5 T	2.0 T
additional B-fields	anti-DID (?)	- compensating - screening





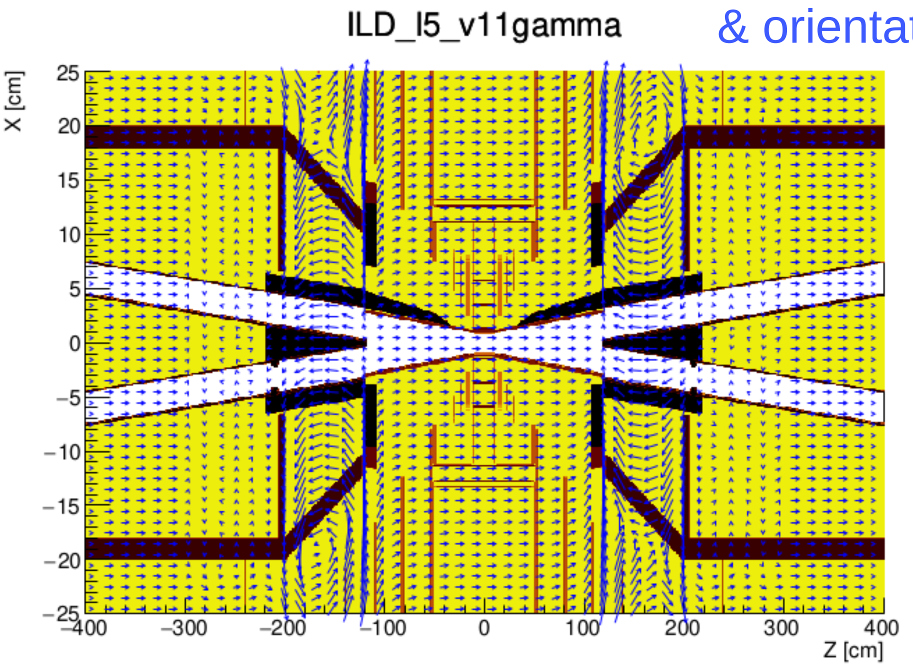
field maps

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:

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

ILD @ ILC :

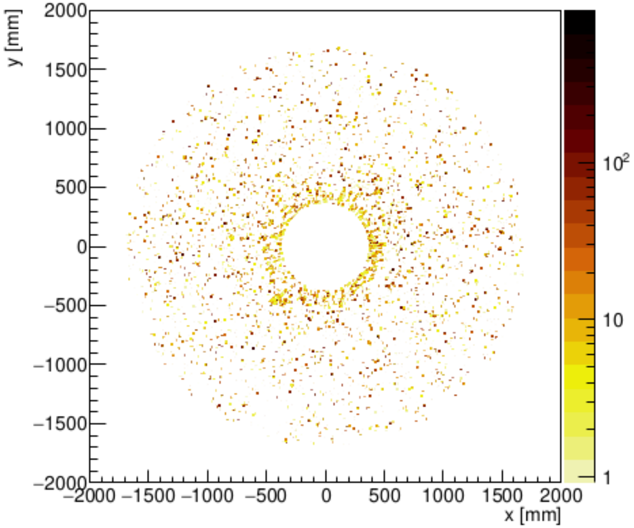
- uniform 3.5T
- uniform 2.0T
- field map with and without anti-DID

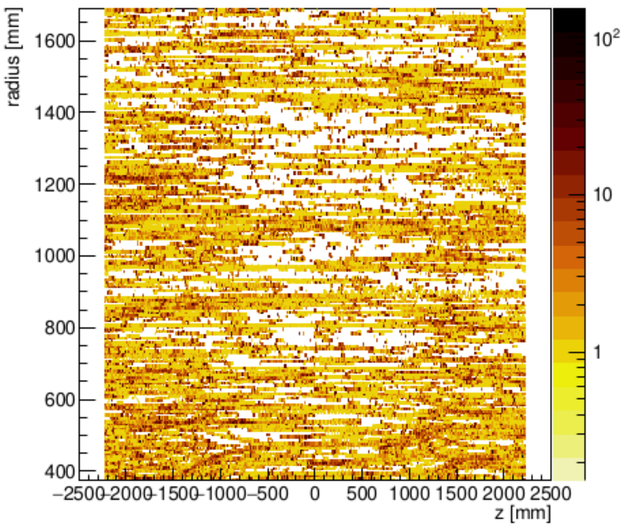
ILD @ FCCee :

- uniform 2.0T
- field map for central region

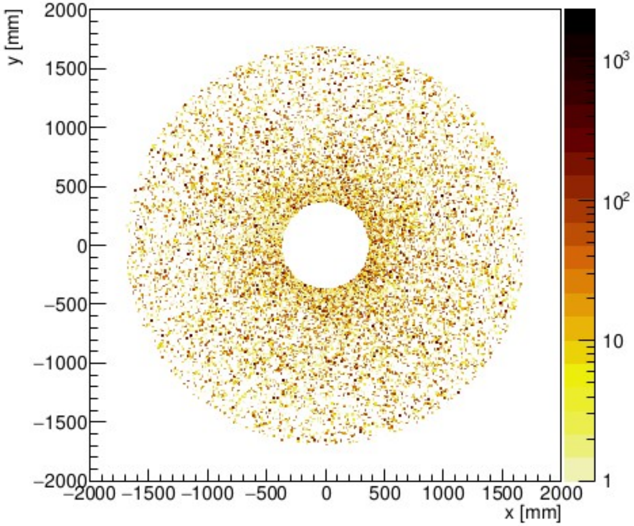
TPC hits
superimpose
100 bunch crossings

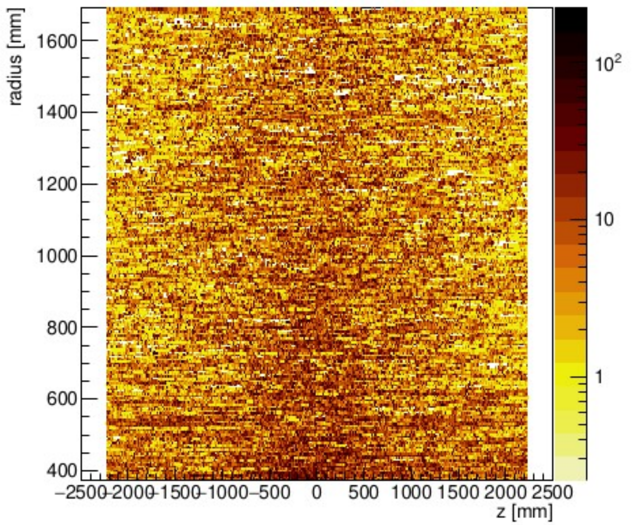
ILD_l5_v11y @ FCCee-91





ILD_l5_v03 @ ILC-250





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

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

model	B-field	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing		
ILD_15_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

model	B-field	MDI	FCCee-91	FCCee-240	ILC-250
			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 factor ~2 at ILC-250

4~10 at FCCee

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

model	B-field	MDI	FCCee-91	FCCee-240	ILC-250
			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 x ~50 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

model	B-field	MDI	FCCee-91	FCCee-240	ILC-250
			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 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 * 50% [ions already reached cathode]

Collider	FCCee-91	FCCee-240	ILC-250
Detector model	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05
BX frequency (average)	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**?

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

→ 2.5 x 10^{10} primary ions in TPC at any time

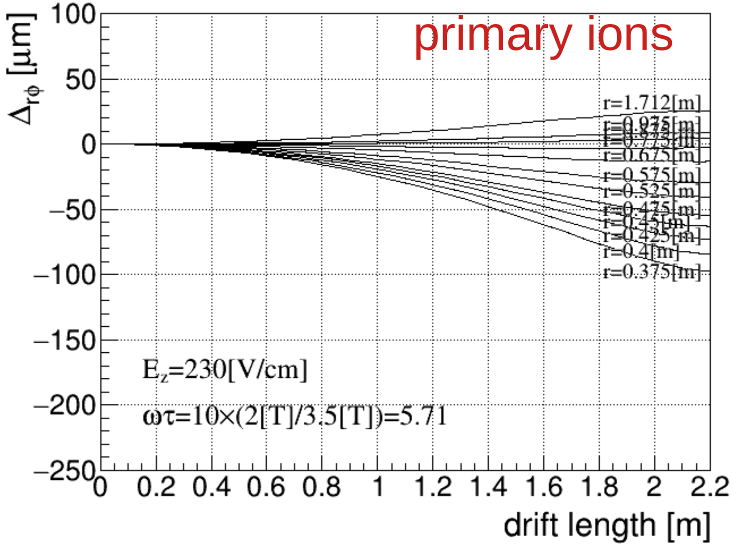
c.f. 4.1x10^{12} from beamstrahlung @ FCCee-91

$e^+ e^- \rightarrow q\,q$ @ 91 GeV :

primary ions give rise to

maximum drift distortions in R-phi of ~100 μm

seem stable @ few-micron level



beamstrahlung background seems

much more severe than $\mathbf{e^+ e^- \rightarrow q\,q}$

using naive scaling,

maximum distortions due to beamstrahlung (primary ions only) → 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
    "Ion Back Flow" IBF

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 ?

    distortions increased by factor 2x ~ 10x ?

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

compare to ALICE-TPC

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

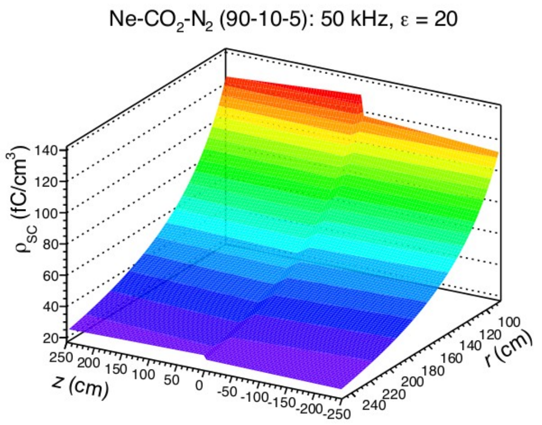
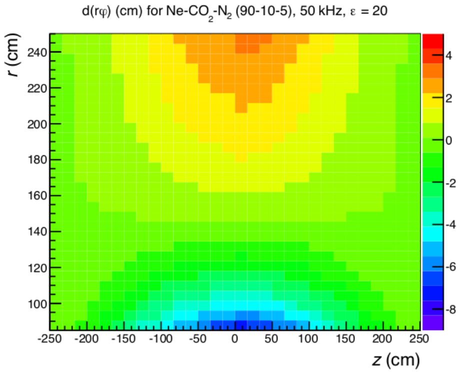


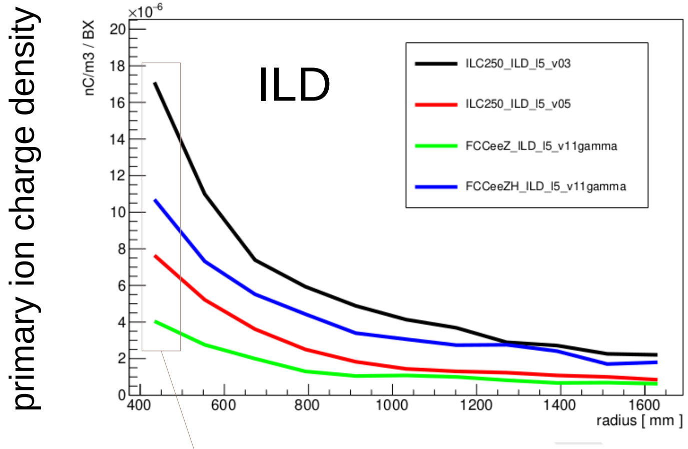
Figure 7.7: Average space charge density for Ne-CO$_2$-N$_2$ (90-10-5), R_{int} = 50 kHz and ε = 20.

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 * 50%

	max (single BX)	BX freq	max (steady state)
FCCee91	4e-6 nC/m^3	30M	60 nC/m^3
FCC240	1e-5 nC/m^3	800k	4 nC/m^3
ILC250 (v5)	8e-6 nC/m^3	6.6k	0.03 nC/m^3
ALICE		50k	120 nC/m^3 with IBF=20

primary ions only

TPC with IBF at FCCee91
→ at best, similar space-charge as at ALICE

guestimate: 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

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 add a multiplicative factor of 2~10 (?): gating/blocking of ions

FCCee-91 looks similar to ALICE-TPC environment

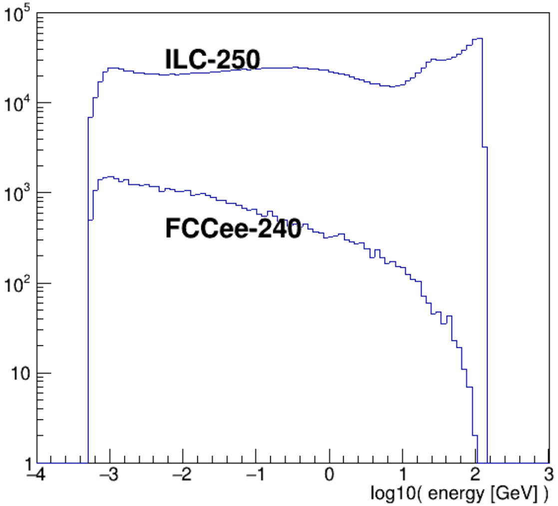
dominated by **MDI**: can it be redesigned to reduce back-scatter?

can a TPC work (with the required precision) at FCCee ?

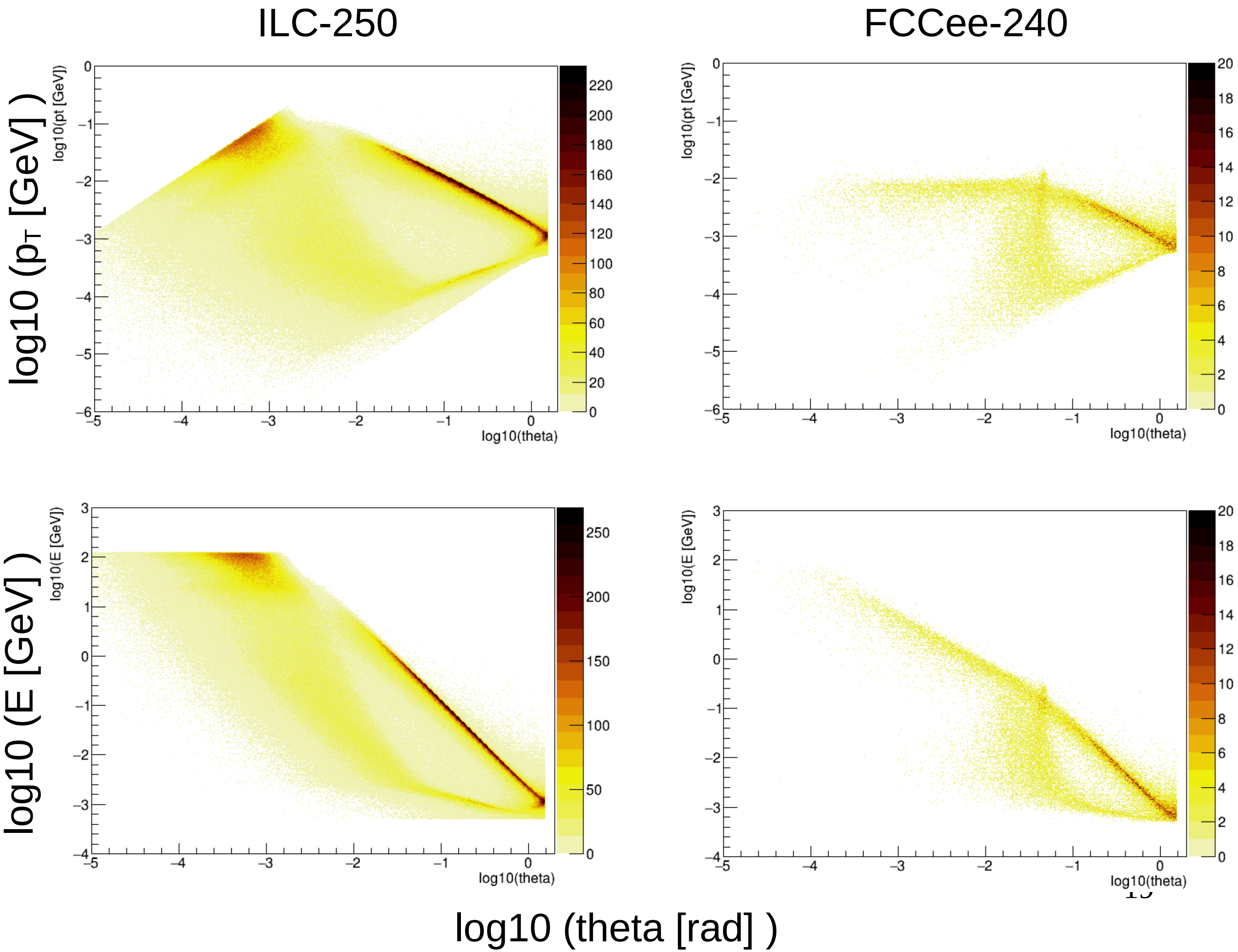
backup

GuineaPig output

(CM frame)



$e^{\pm}$ energy



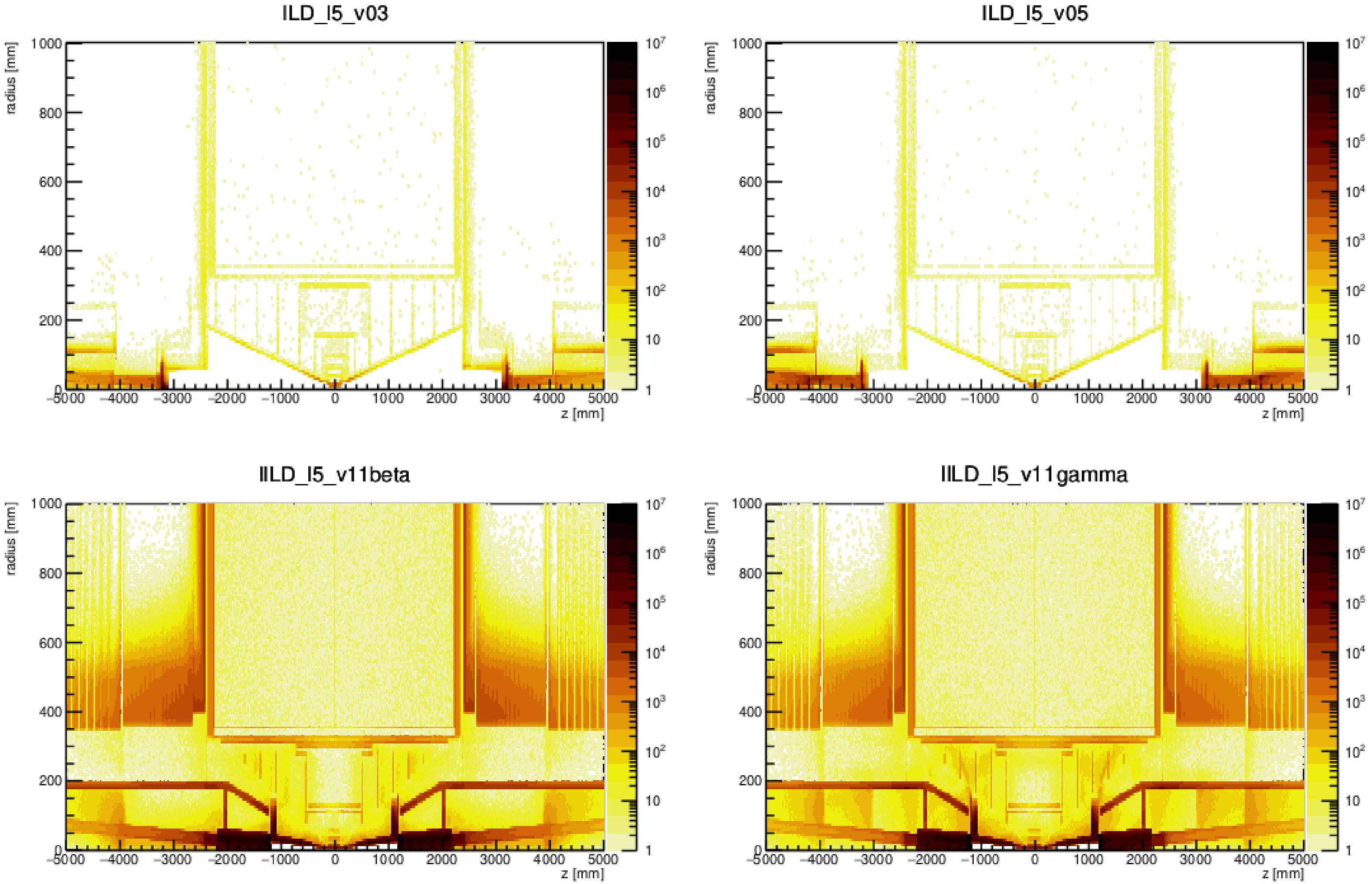


Figure 6: Pair background at FCCee-91 in different models: distribution in radius and z of the endpoint of all MC particles.

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	$[10^{34}/\text{cm}^2\text{s}]$	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

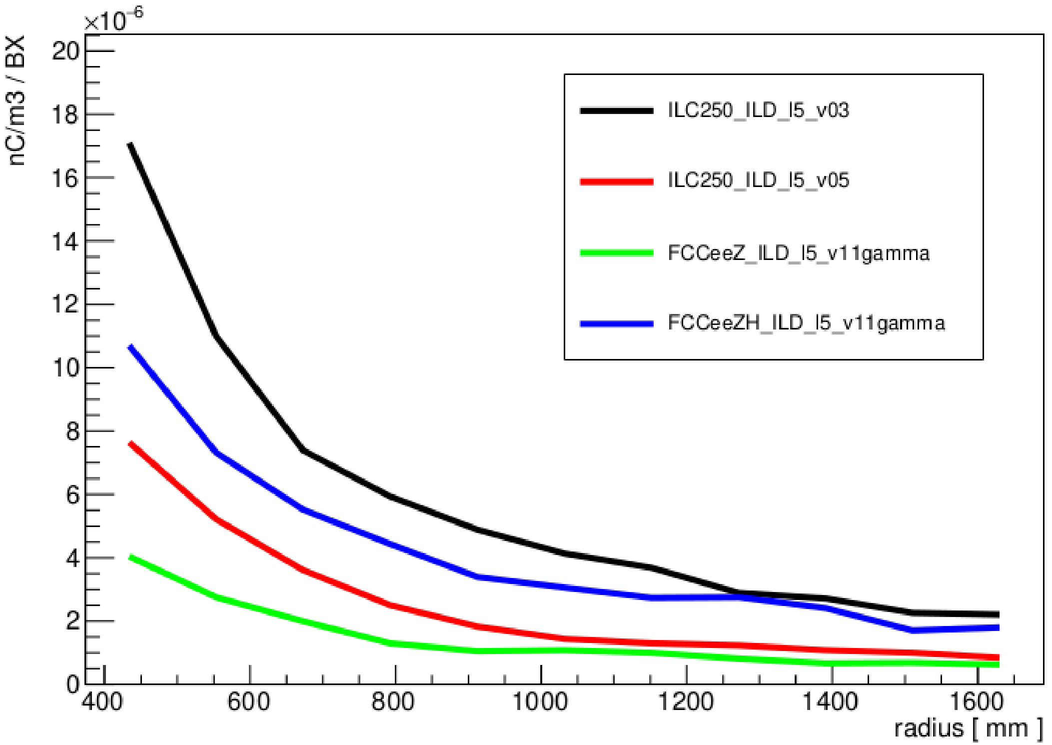


Figure 8: Radial dependence of the primary ion charge density induced by beamstrahlung in a single BX in the realistic collider/detector combinations.

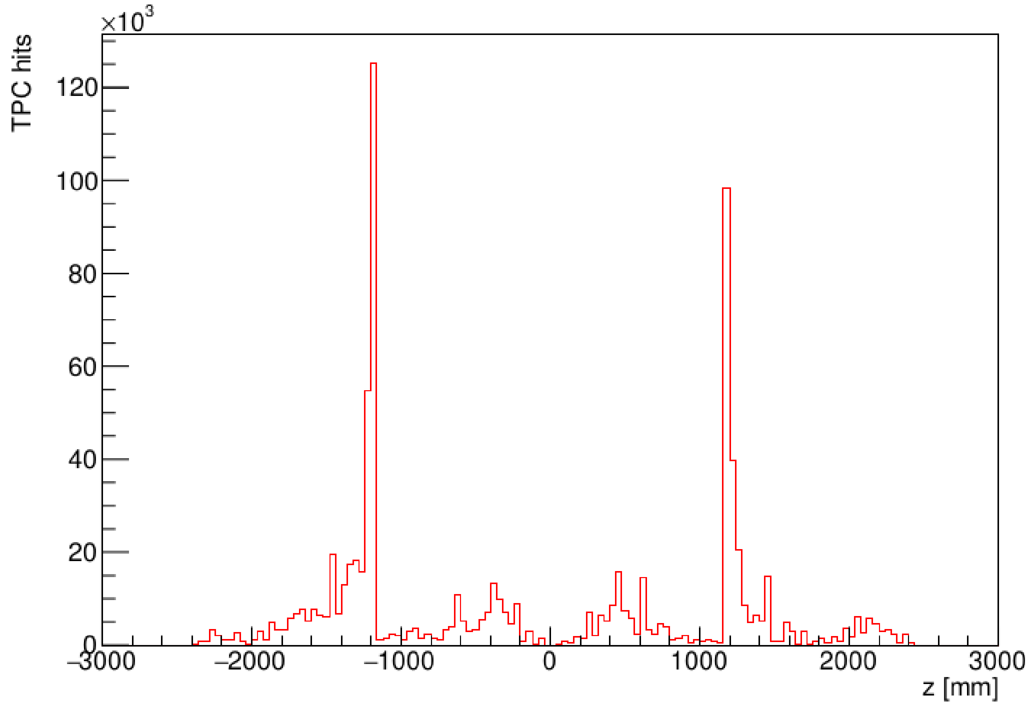


Figure 9: Distribution in z of the position of the first simulated interaction which gave rise to a TPC hit. ILD_l5_v11γ detector model, 100 BX of pair background at FCCee-91.

			FCCee-91	FCCee-240	ILC-250
model	B-field [T]	MDI	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

compare to ALICE-TPC

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

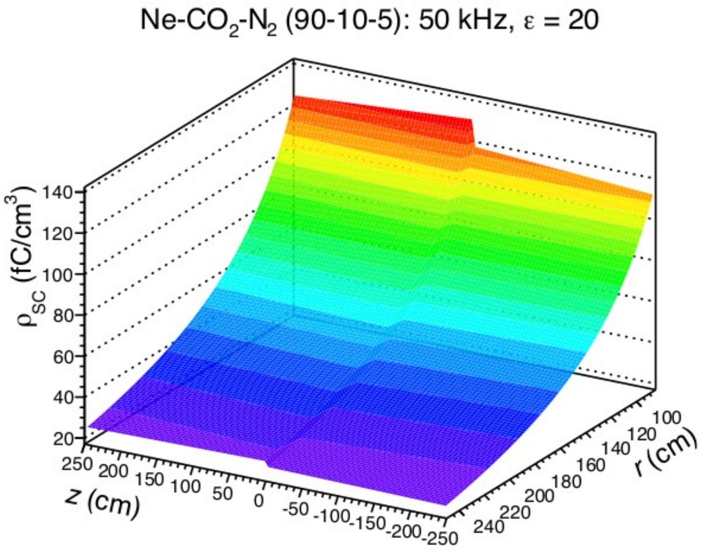
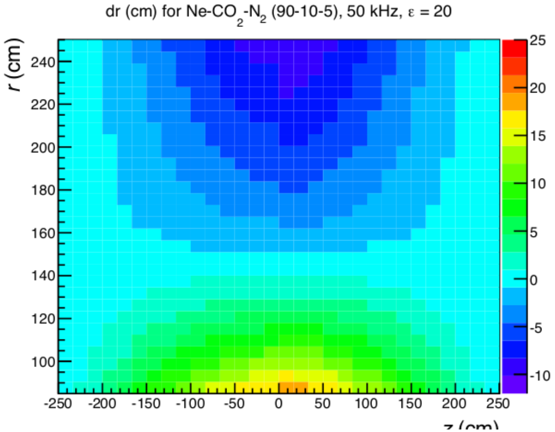
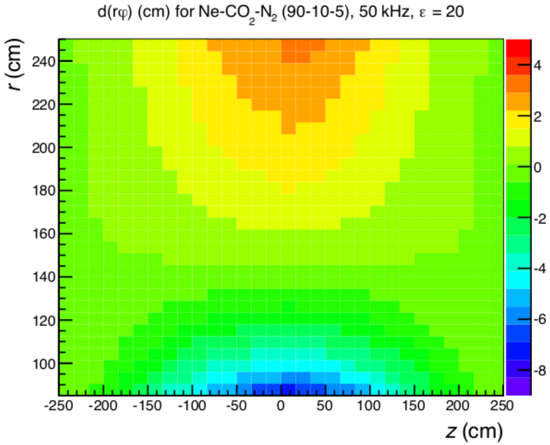
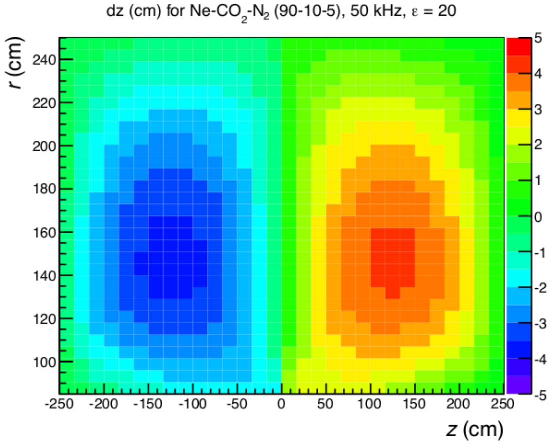


Figure 7.7: Average space charge density for Ne-CO_2-N_2 (90-10-5), $R_{\mathrm{int}} = 50$ kHz and $\varepsilon = 20$.





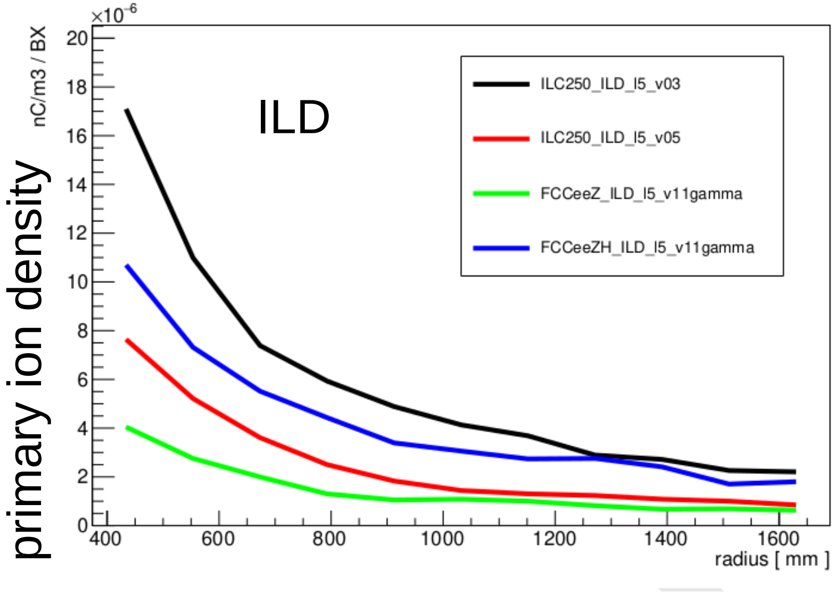


ion back flow factor ε: 20 secondary ions / primary

100 fC/cm^3 = 100 nC/m^3

→ cm-level distortions

compare to ALICE-TPC



primary ions only

	max (single BX)	BX freq	max (steady state)
FCCee91	4e-6 nC/m³	30M	60 nC/m³
FCC240	1e-5 nC/m³	800k	4 nC/m³
ILC250 (v5)	8e-6 nC/m³	6.6k	0.03 nC/m³

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

cf. ALICE : ~100 nC/m³
(including Ion Back Flow IBF of 20)

TPC with IBF at FCCee91 → at best similar or probably larger space-charge that at ALICE

my guestimate: O(1~10) cm maximum distortions depending on IBF
(consistent with our “first-principles” estimate)

imagine we could use ILC-MDI at FCCee-91

(completely unrealistic…?)

Collider	FCCee-91	FCCee-240	ILC-250	“best case” FCCee-91
Detector model	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05	ILD_l5_v05
BX frequency (average)	30 MHz	800 kHz	6.6 kHz	30 MHz
primary ions / BX	270 k	800 k	450 k	0.6 k
primary ions in TPC at any time	4.1×10^{12}	3.2×10^{11}	1.5×10^{9}	9×10^{9}
average primary ion charge density $\mathrm{nC/m^3}$	15	1.2	0.006	0.04

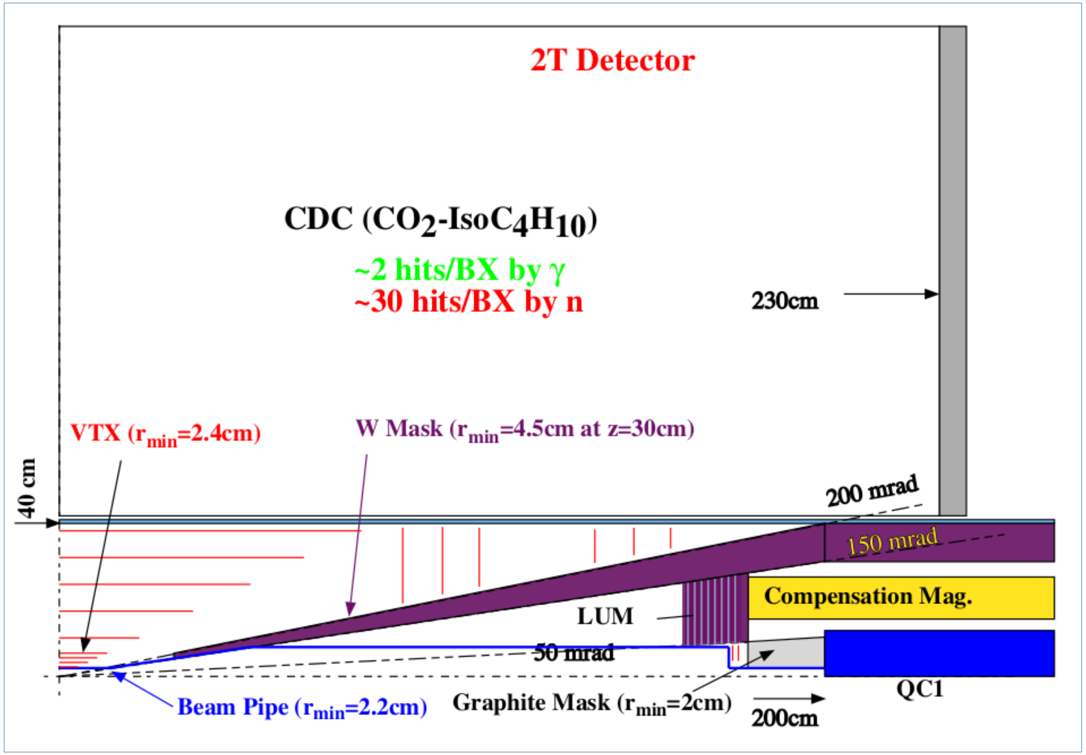
https://www-jlc.kek.jp/~sugimoto/jlc/ir/lcws2k.pdf

New JLC Mask System at B=3T

Y. Sugimoto
KEK
@LCWS2000

Contents:

- Pair background hits in JLC detector models
  --- 2T, 3T(l^*=2m), 3T(l^*=4.3m)
- Beam background from disrupt beam
  --- Preliminary design of the beam extraction line



include a “W mask” ?