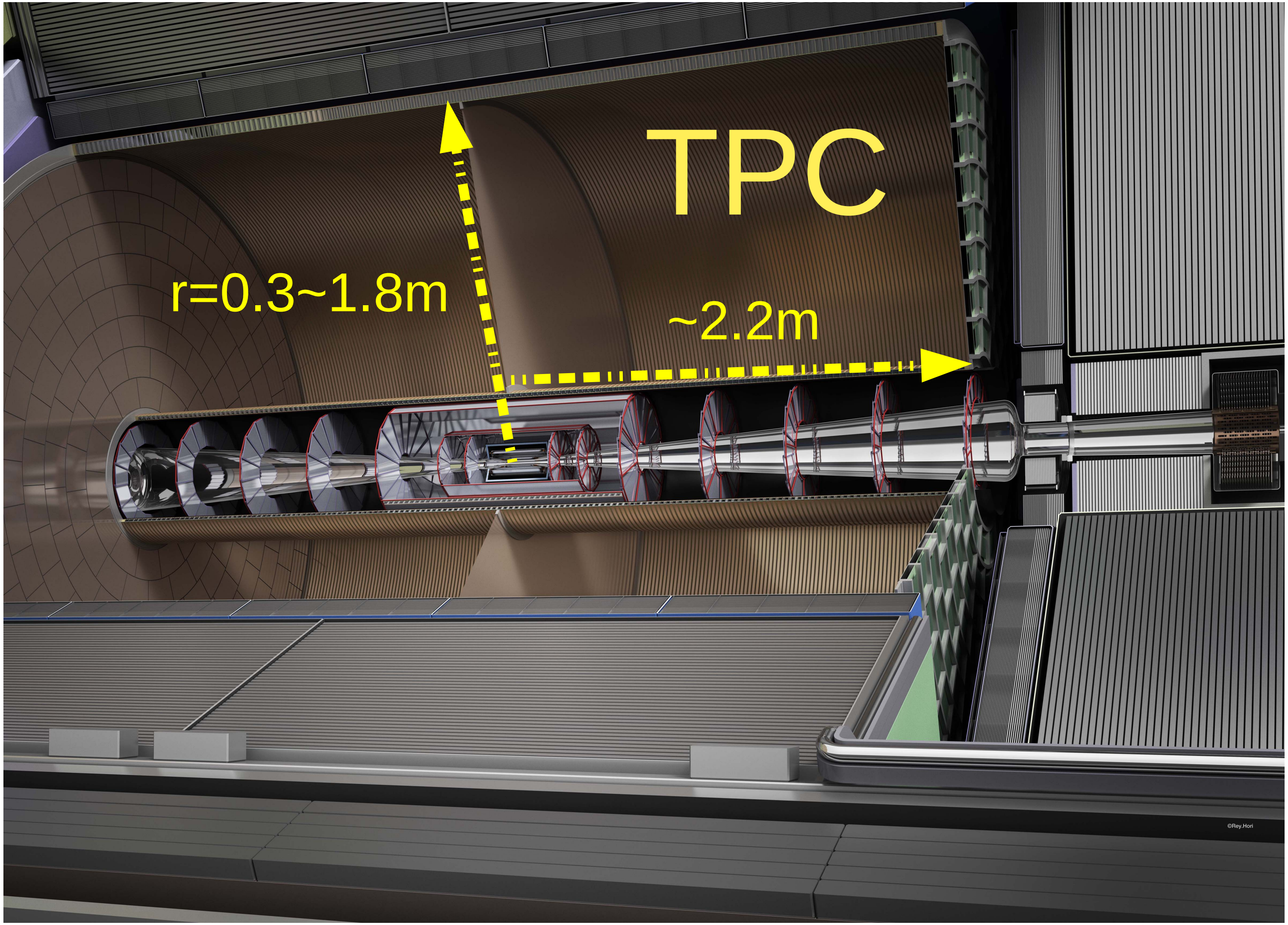
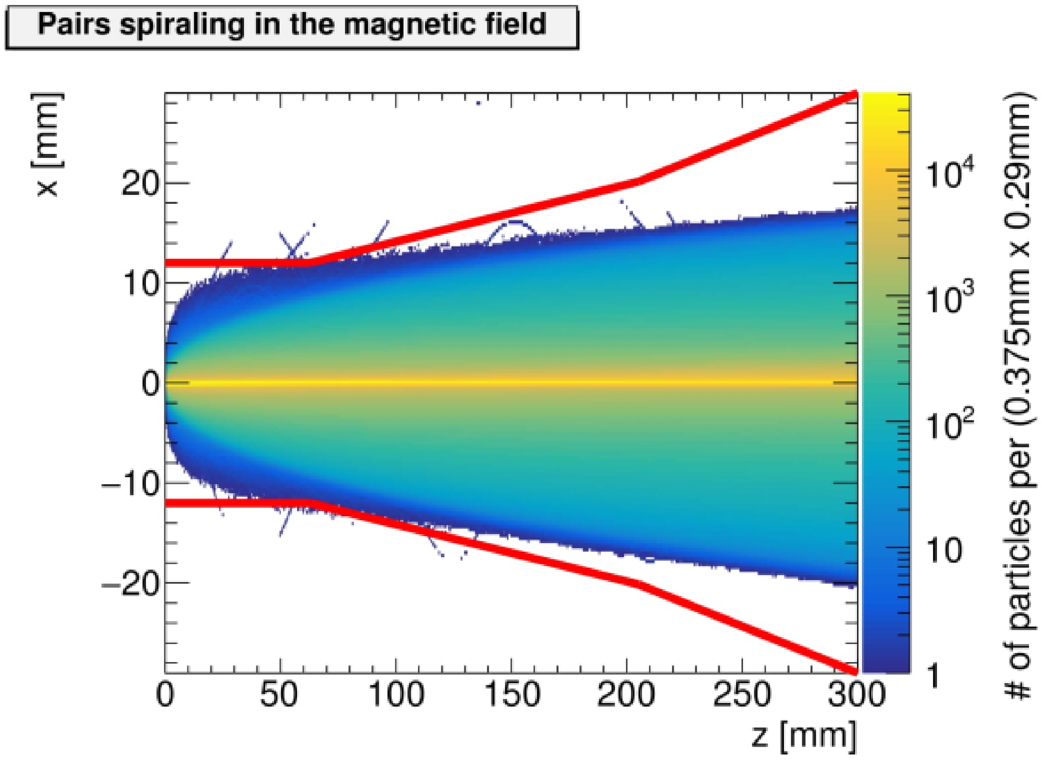
Beamstrahlung backgrounds in ILD at linear (ILC) and circular (FCCee) colliders

Daniel Jeans / KEK IPNS

September 2024


TPC
r=0.3~1.8m
~2.2m
©Rey.Hori

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

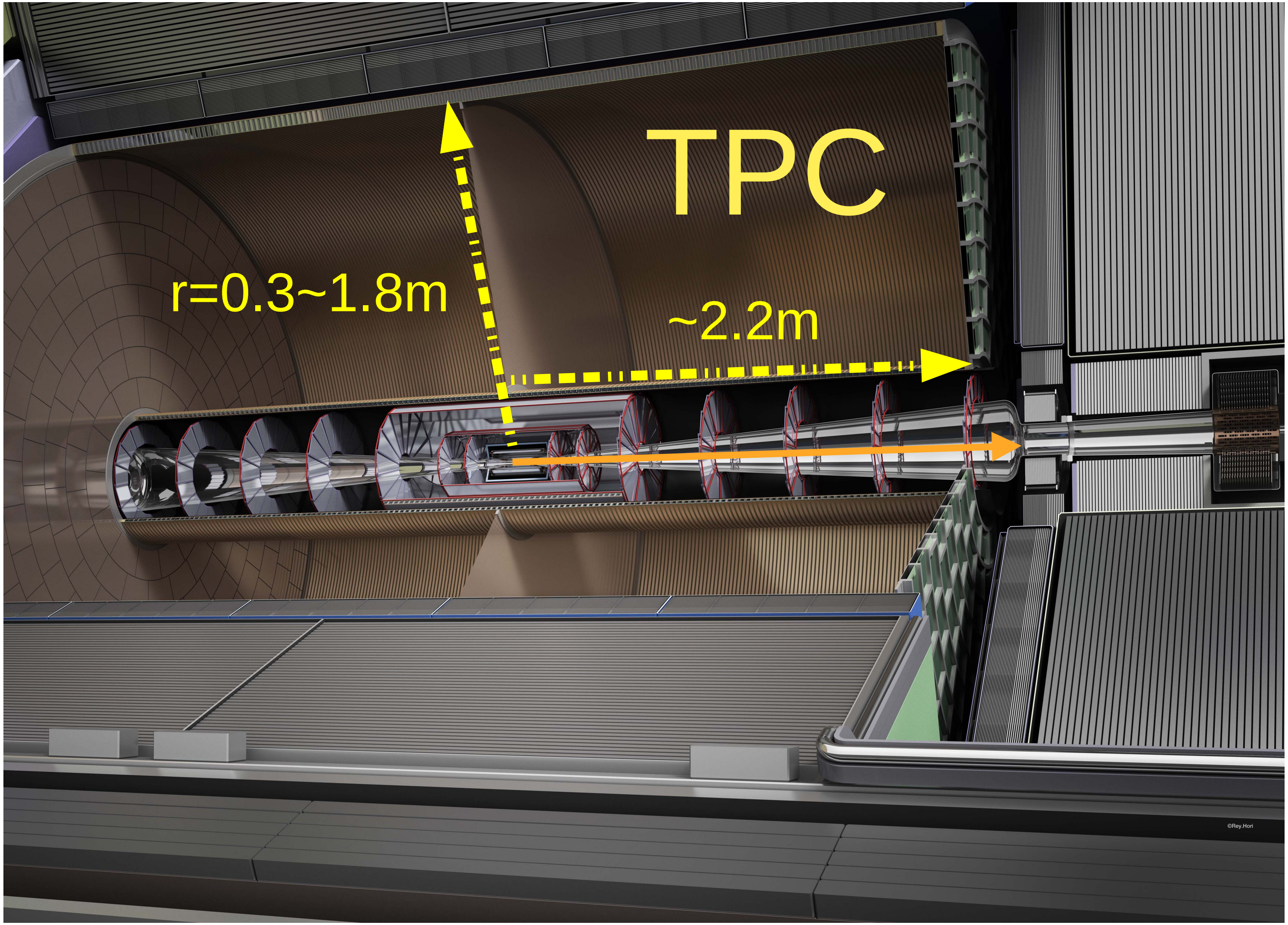


(b) *ILC250 set (A)*

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

simulated by GuineaPig and/or CAIN

A. Schuetz
arXiv:1801.04156


TPC
r=0.3~1.8m
~2.2m
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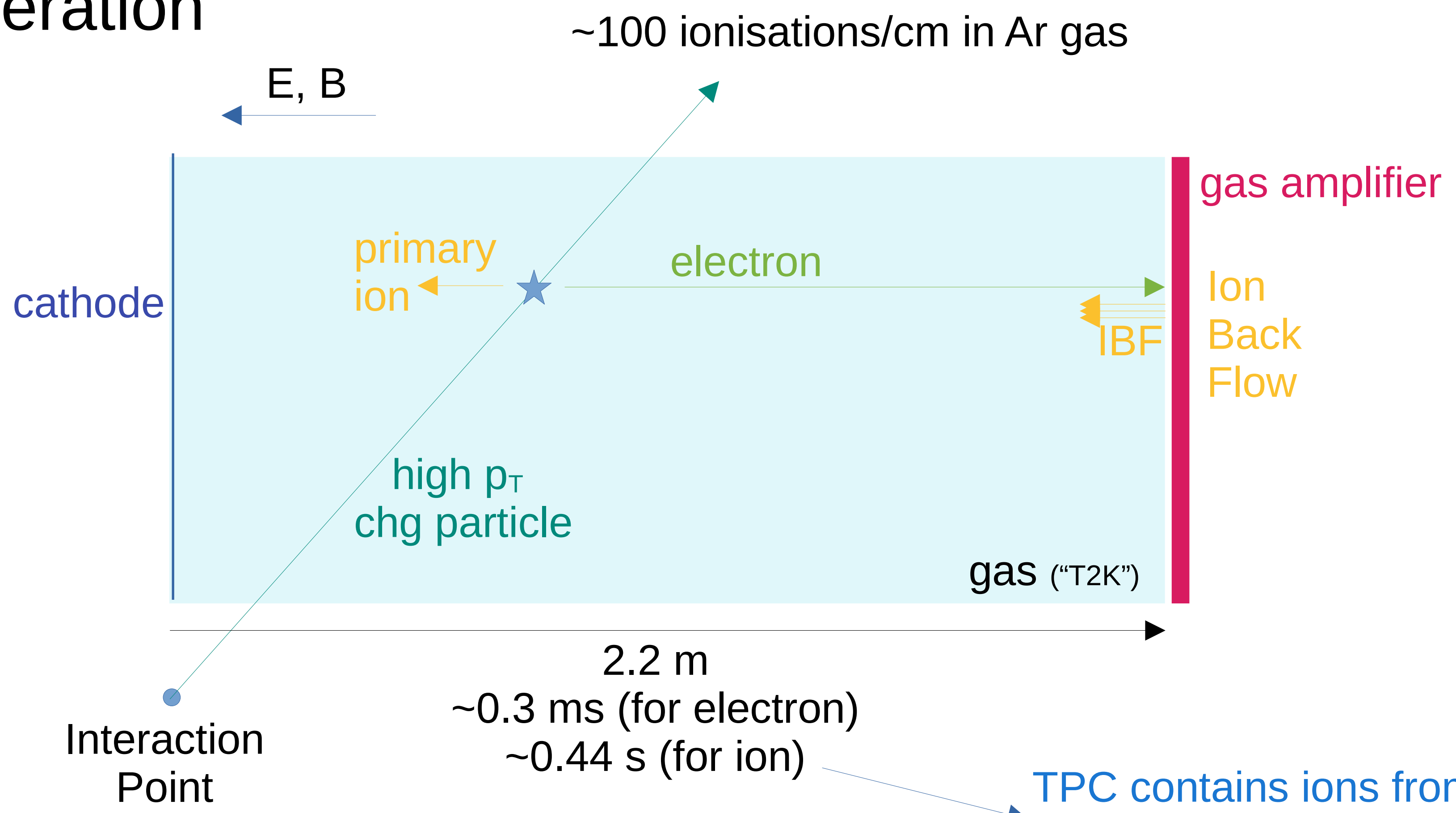
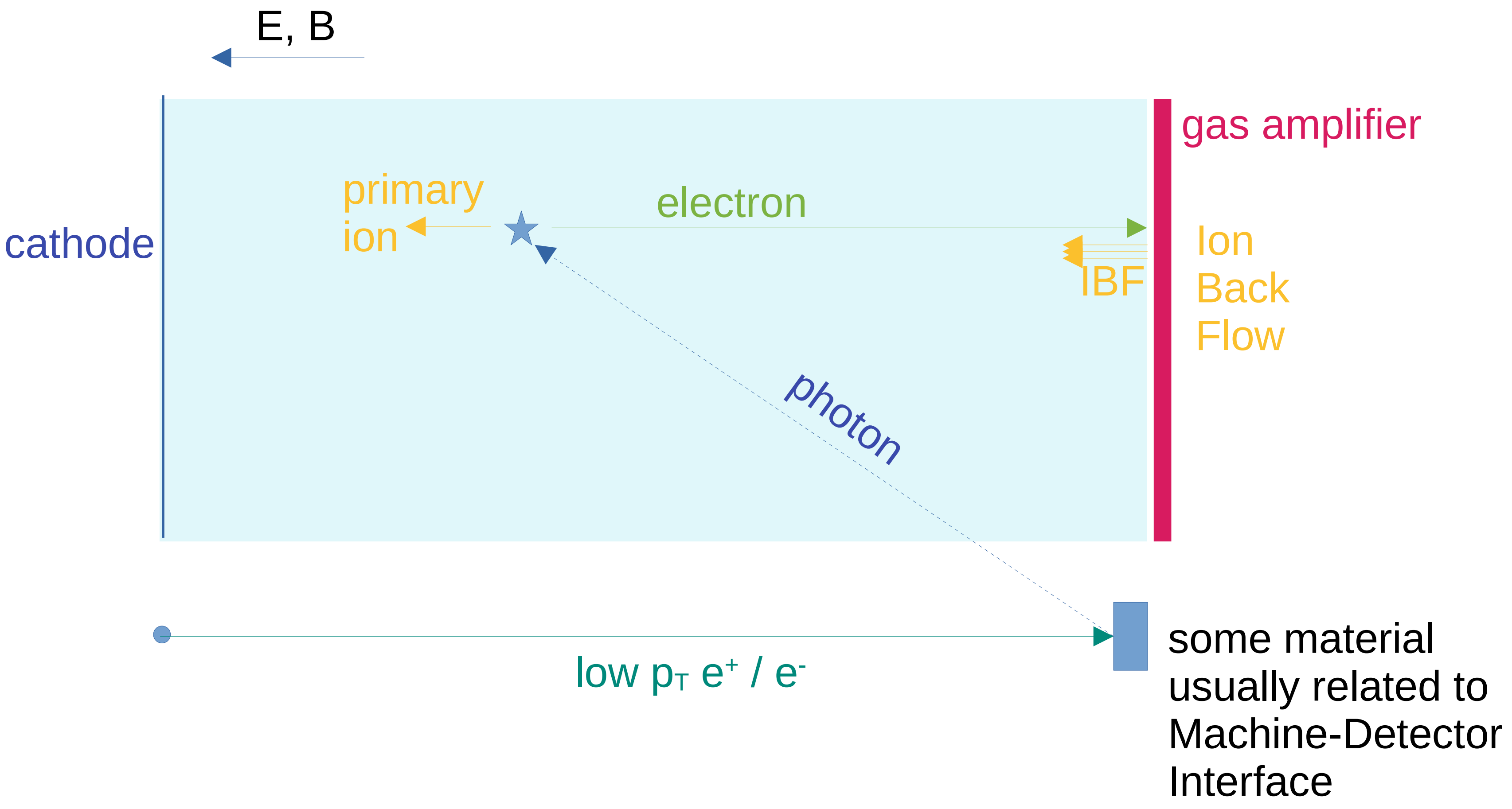
TPC operation



TPC contains ions from collisions up to 0.44s earlier

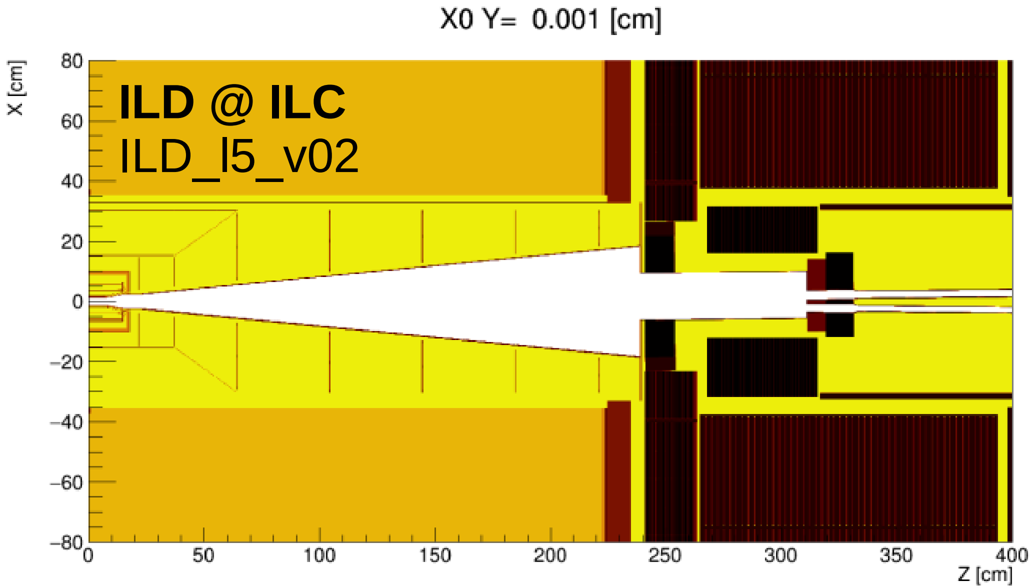
beam backgrounds : usually small p_T → particles do not reach TPC directly

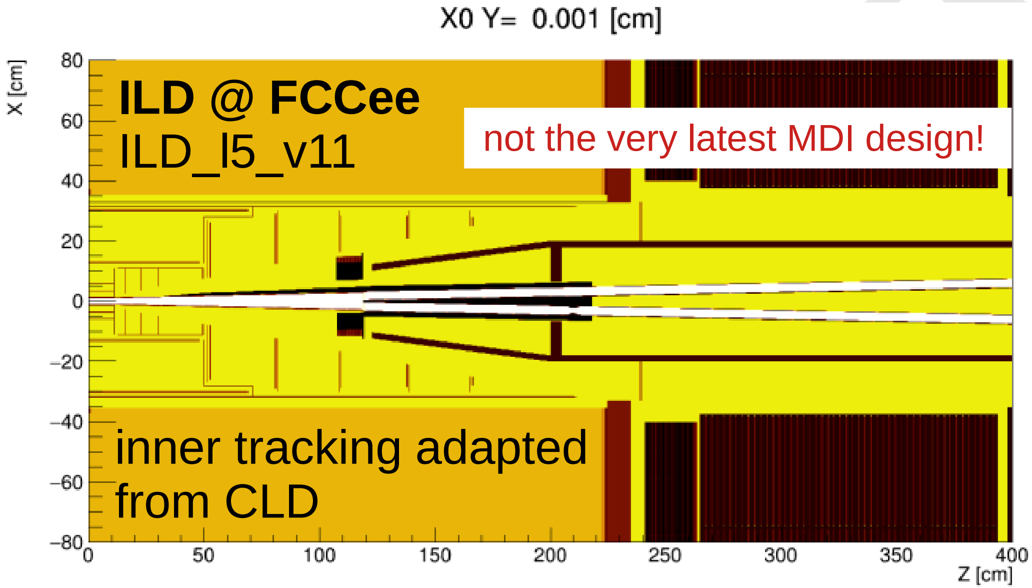


Machine-Detector Interface

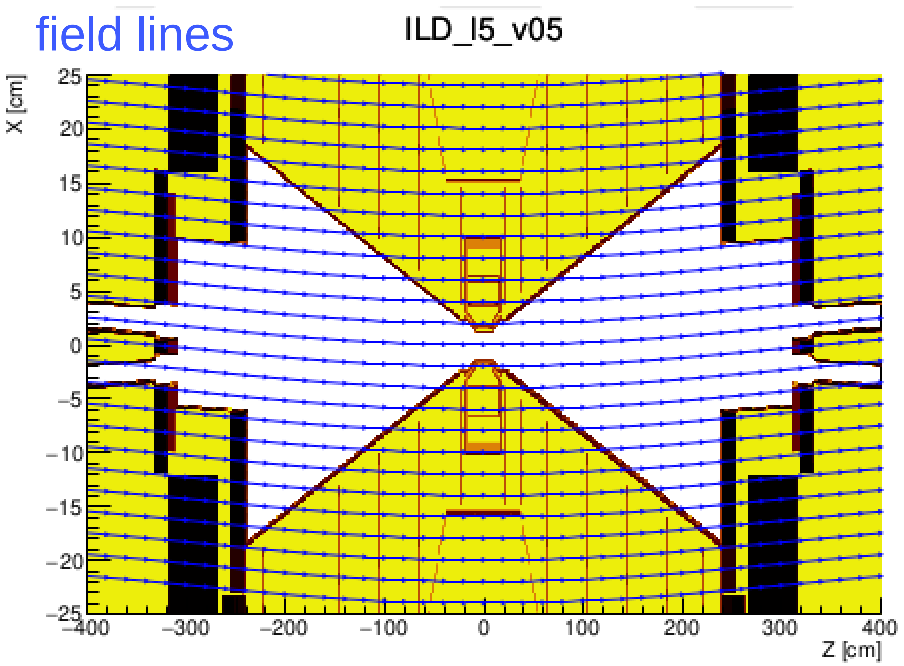
is significantly different @ ILC and FCCee

	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

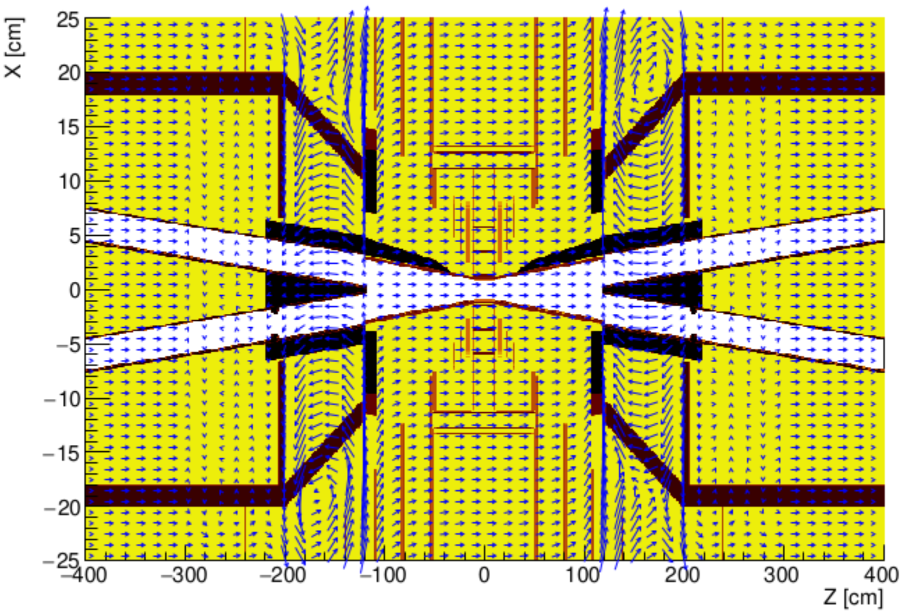




field maps



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

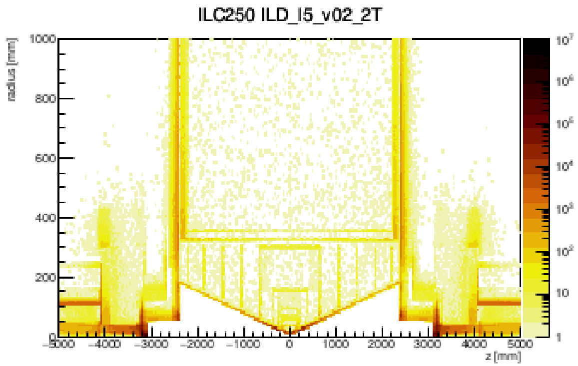
ILD @ ILC :

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

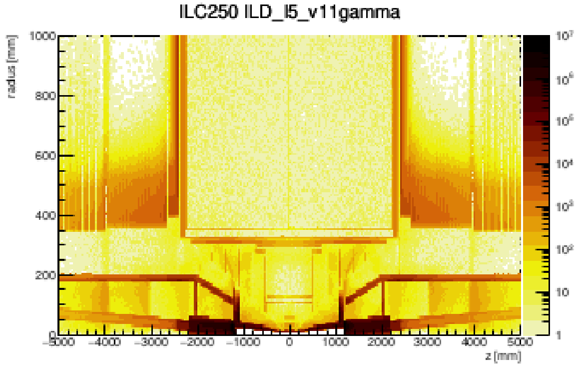
ILD @ FCCee :

- uniform 2.0T
- field map for central region

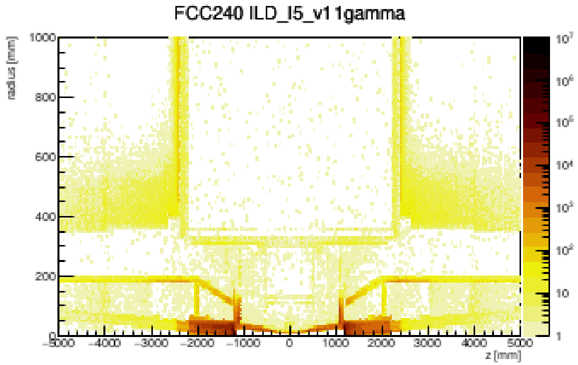
MC particle endpoints in 100 BX



ILC250 beamstrahlung ILC-like detector



ILC250 beamstrahlung FCC-like detector

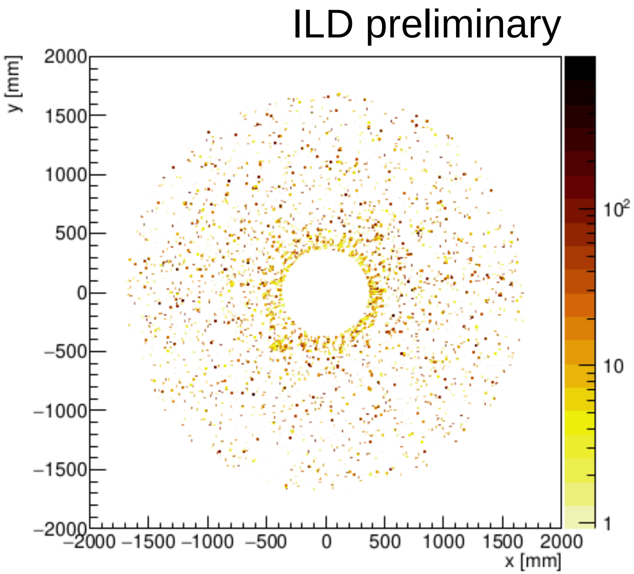


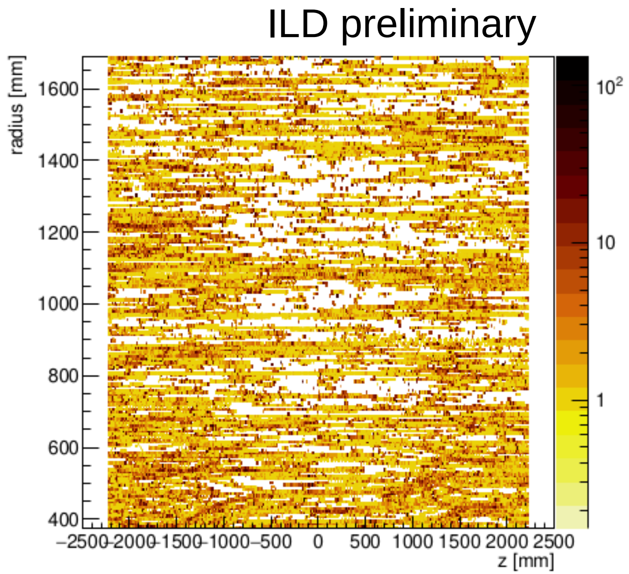
FCC-240 beamstrahlung FCC-like detector

TPC hits

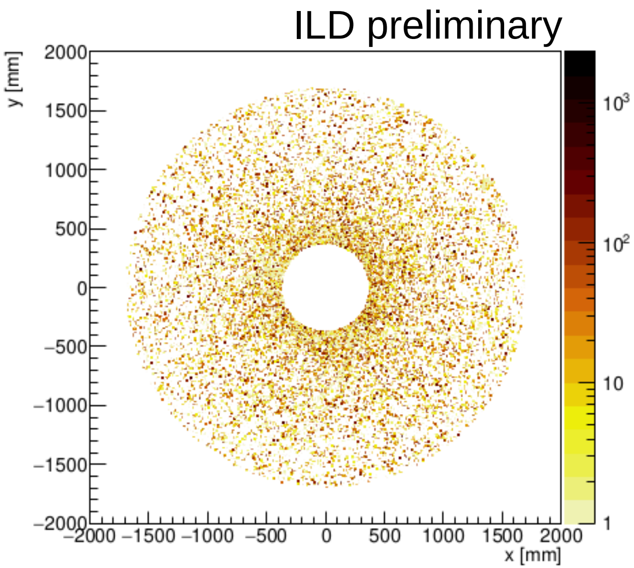
superimpose
100 bunch crossings

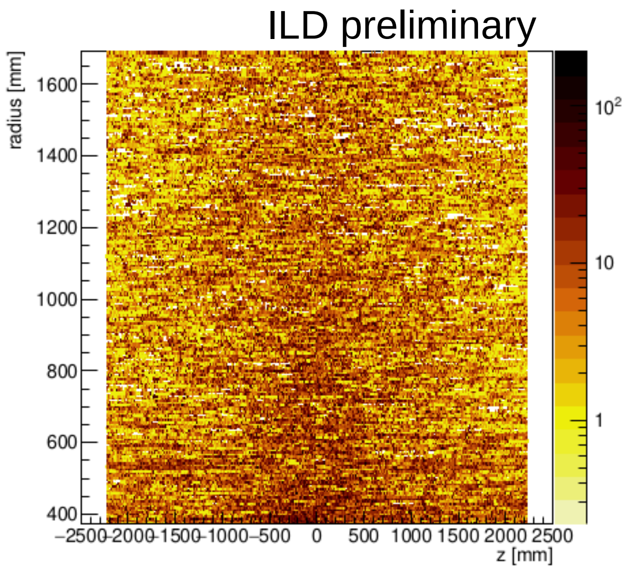
ILD_l5_v11y @ FCCee-91





ILD_l5_v03 @ ILC-250





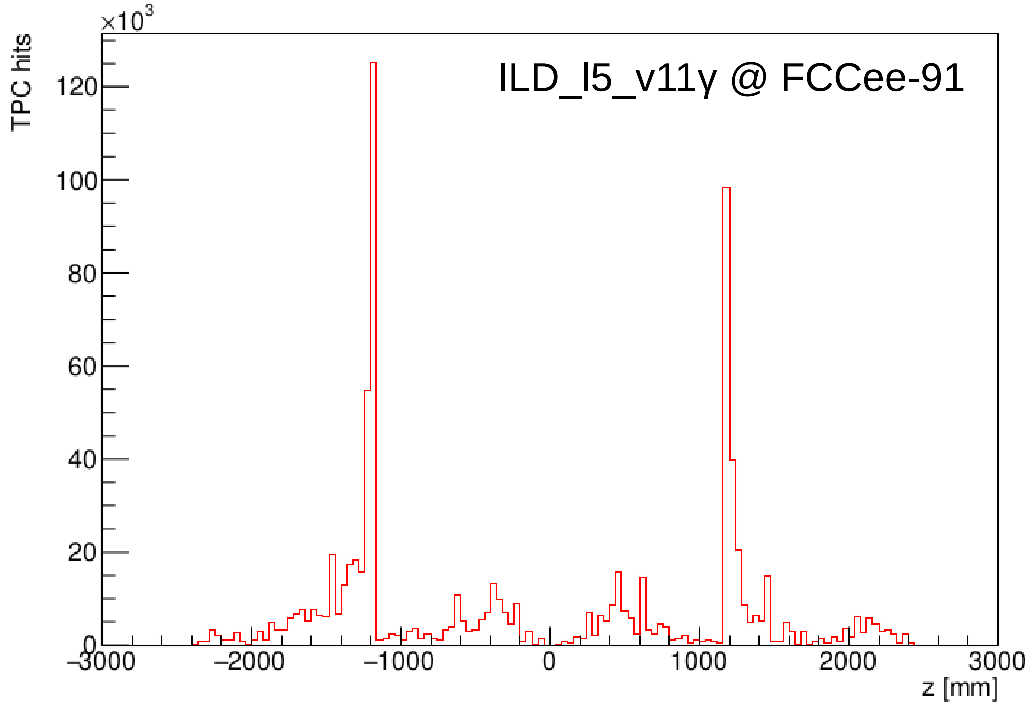


Figure 9: Distribution in z of the position of the first simulated interaction which gave rise to a TPC hit. ILD_l5_v11γ detector model, 100 BX of pair background at FCCee-91.

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 $\pm$ 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

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

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ILD_l5_v02	3.5 (uniform)	ILC	6.5 ± 19.9	14 ± 14	960 ± 150
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

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

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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

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

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ILD_l5_v11β	2.0 (uniform)	FCCee	390 ± 120	1000 ± 170	110000 ± 2400
ILD_l5_v11γ	2.0 (map)	FCCee	270 ± 100	800 ± 140	100000 ± 1900

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

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean $\pm$ RMS		
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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	FCCee-91	FCCee-240	ILC-250
Detector model	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05
average 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	1.8×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.8	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

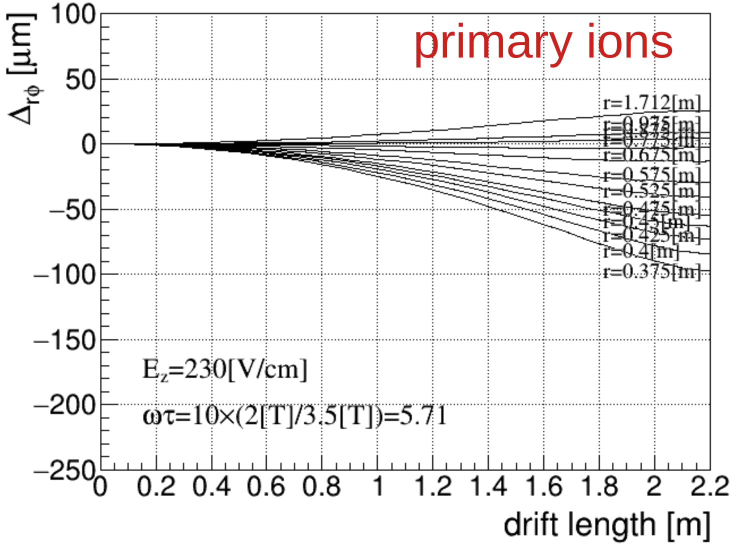
cf. 2×10^{12} from beamstrahlung @ FCCee-91

$e^+ e^- \rightarrow q\, q$ @ 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 $\mathbf{e^+ e^- \rightarrow q\, q}$

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

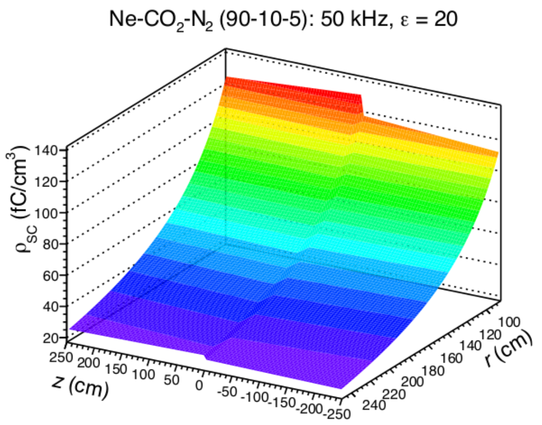
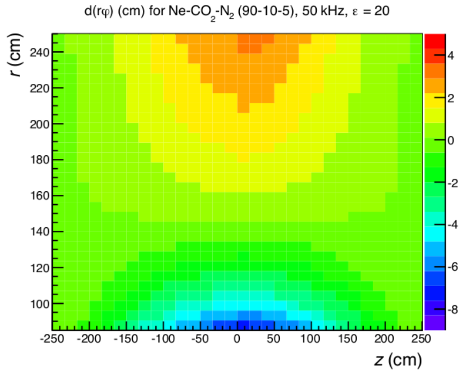


Figure 7.7: Average space charge density for Ne-CO_2-N_2 (90-10-5), R_{int} = 50 kHz and ε = 20.

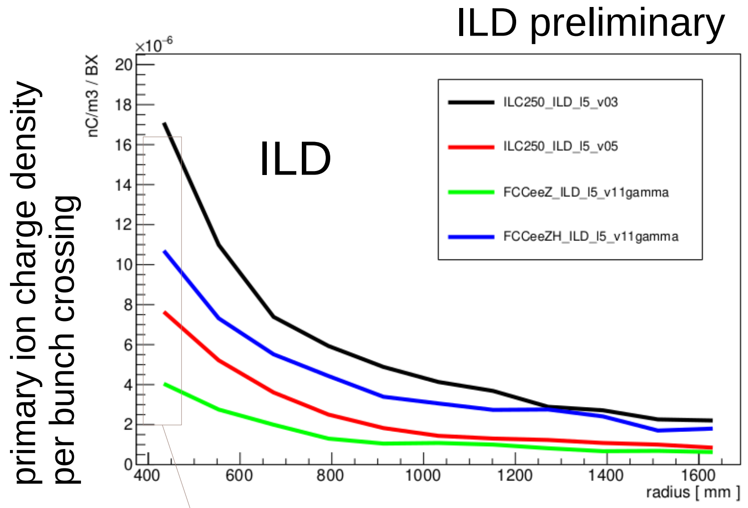
assumed ion back flow factor ε: 20 secondary ions / primary

20~120 fC/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

TPC at FCCee-91 with IBF~4 looks similar to ALICE-TPC

Current work/plans/suggestions:

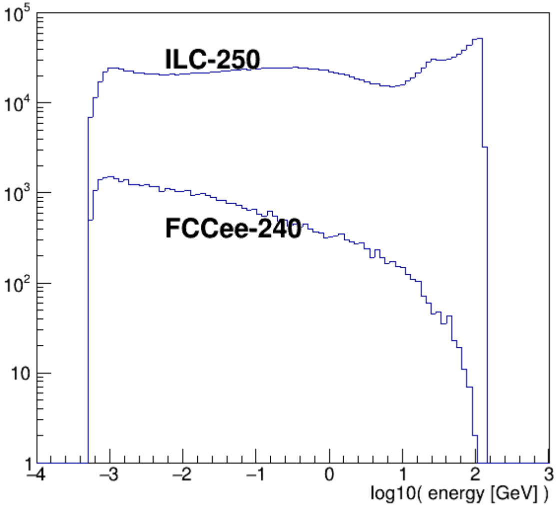
repeat study with CAD-level MDI design

how much possibility for shielding redesign/reduction?

backup

GuineaPig output

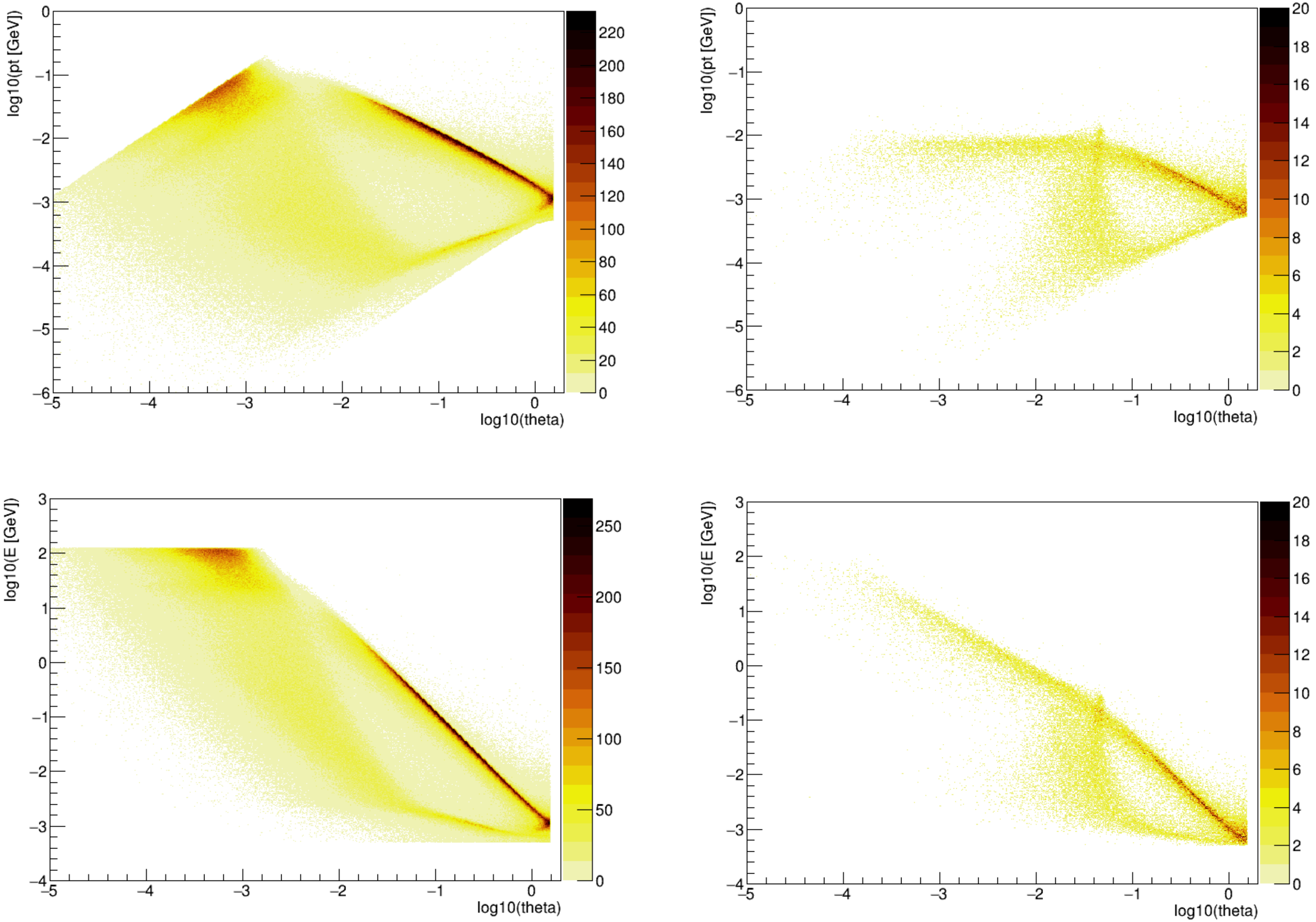
(CM frame)



$e^{\pm}$ energy

ILC-250 FCCee-240

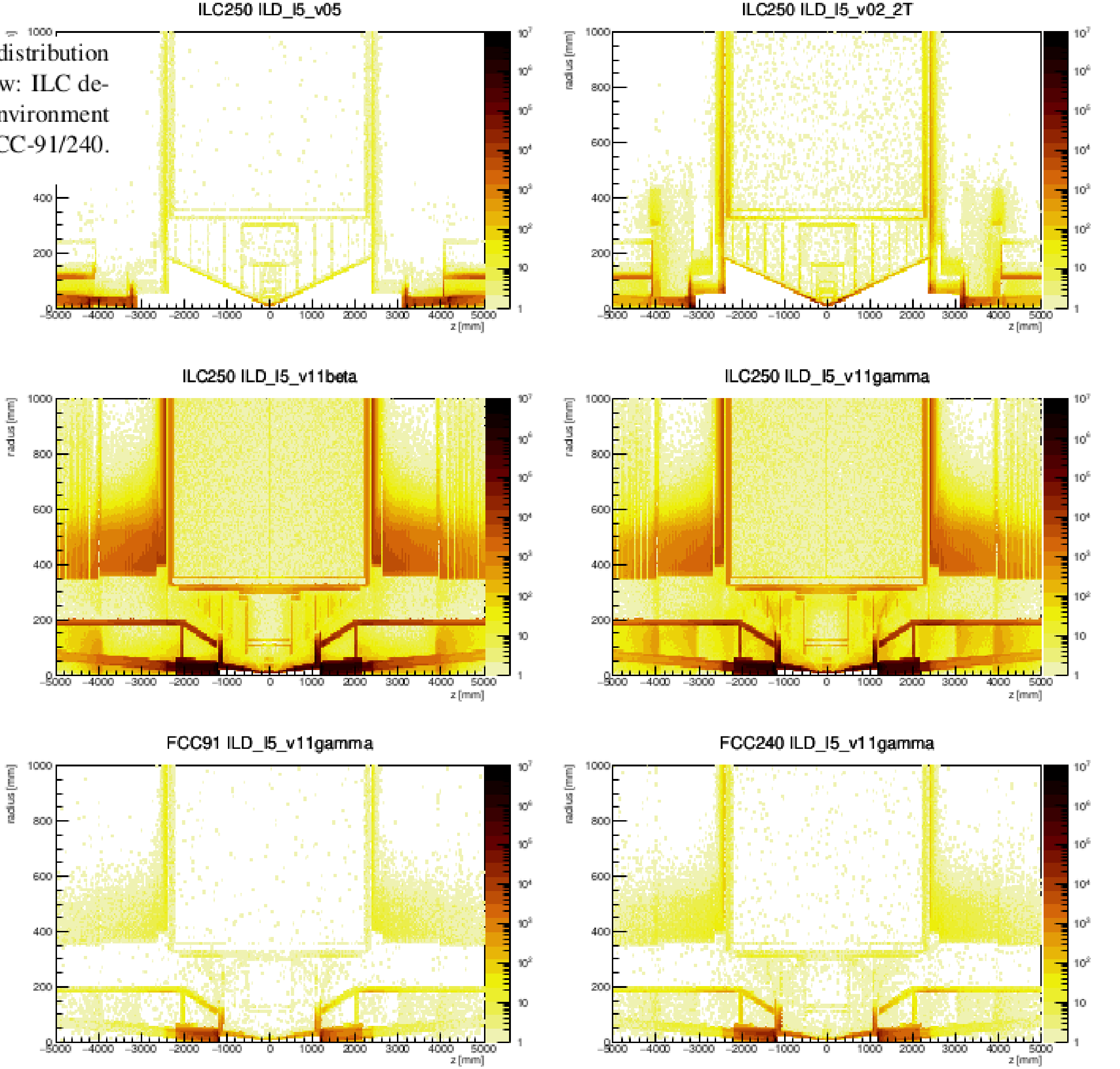
log10 (p_T [GeV])



log10 (E [GeV])

log10 (theta [rad])

5: Pair backgrounds at ILC-250, FCC-91 and FCC-240 in different detector models: distribution in radius and z of the endpoint of all MC particles, integrated over 100 BX. Top row: ILC detector variants at ILC-250; middle row: FCC-ee detector variants in the ILC-250 environment (unrealistic, shown for comparison only); bottom row: FCC-ee detector variant at FCC-91/240.



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

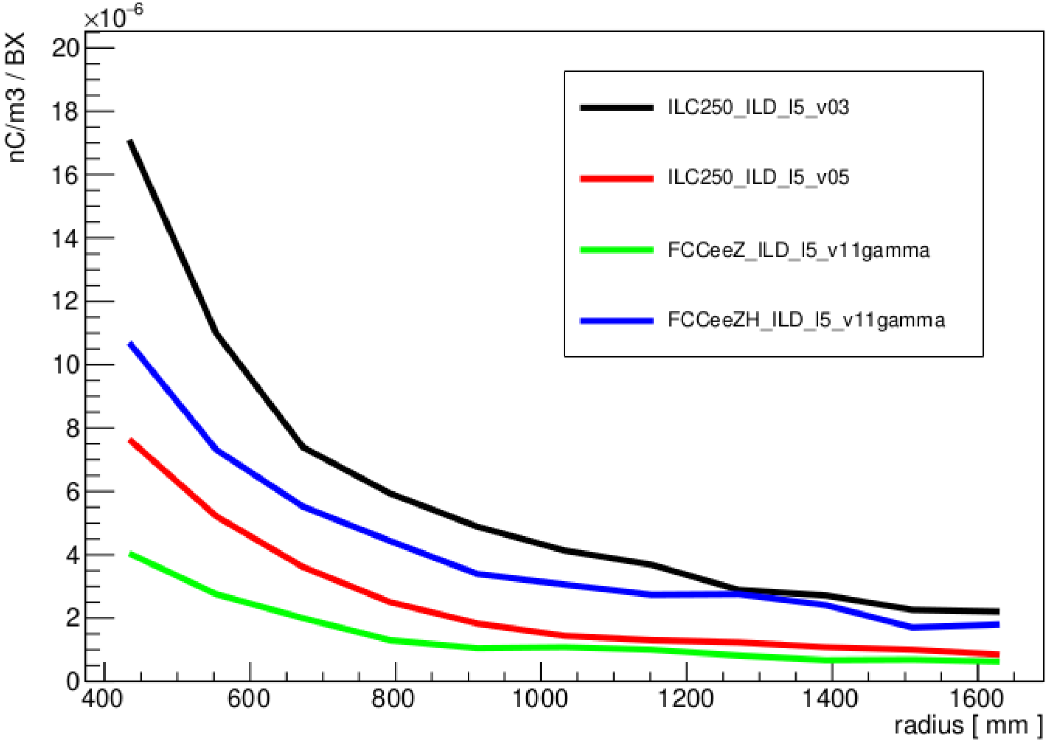


Figure 8: Radial dependence of the primary ion charge density induced by beamstrahlung in a single BX in the realistic collider/detector combinations.

			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
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9 ± 11.1	15 ± 11	4700 ± 300
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
ILD_l5_v11β	2.0 (uniform)	FCCee	390 ± 120	1000 ± 170	110000 ± 2400
ILD_l5_v11γ	2.0 (map)	FCCee	270 ± 100	800 ± 140	100000 ± 1900
removing BeamCal's graphite layer					
ILD_l5_v03	3.5 (map)	ILC			1300 ± 170
ILD_l5_v05	3.5 (map, anti-DID)	ILC			590 ± 120
			bunch crossing frequency		
			30 MHz	800 kHz	6.6 kHz

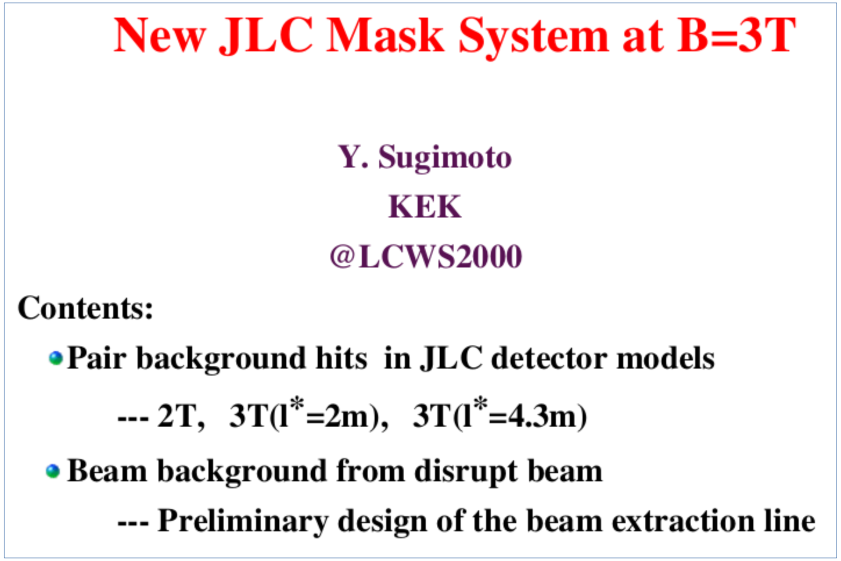
~20% effect

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
average BX frequency	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	1.8×10^{12}	1.4×10^{11}	6.5×10^{8}	4×10^{9}
average primary ion charge density nC/m^3	6.8	0.54	0.0025	0.015

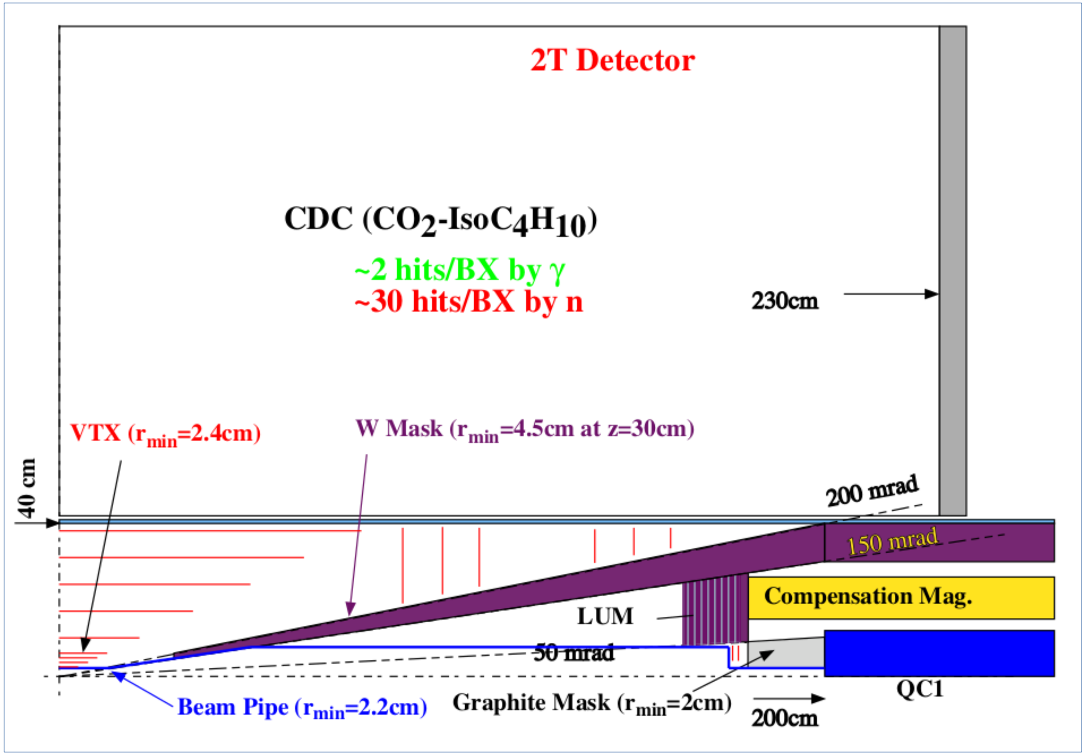
https://www-jlc.kek.jp/~sugimoto/jlc/ir/lcws2k.pdf


New JLC Mask System at B=3T

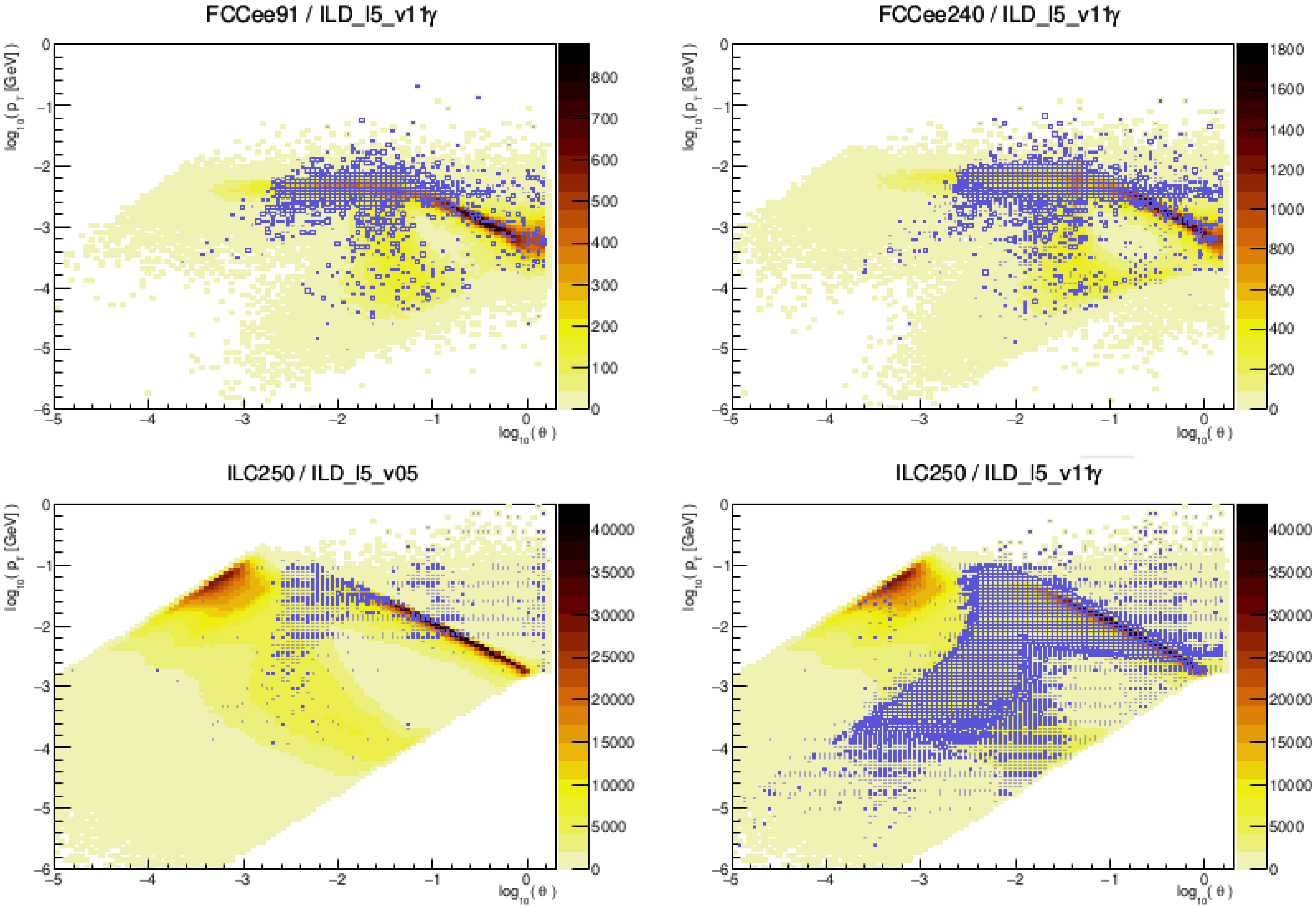
Y. Sugimoto
KEK
@LCWS2000

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” ?


FCCee91 / ILD_l5_v11γ
FCCee240 / ILD_l5_v11γ
ILC250 / ILD_l5_v05
ILC250 / ILD_l5_v11γ
log10(pT [GeV])
log10(θ)