TPC in an FCC environment

results are all preliminary

study in the context of ILD

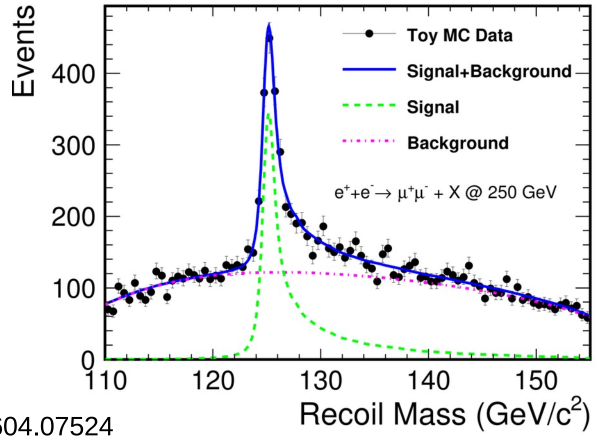
2003.01116

Time Projection Chamber 0.3m < r < 1.8m
|z| < 2.4 m

* highly-redundant pattern recognition

* d(EorN)/dx measurement → Particle ID

* with silicon (strip/pixel) wrapper:
→ p_T resolution for Higgs recoil



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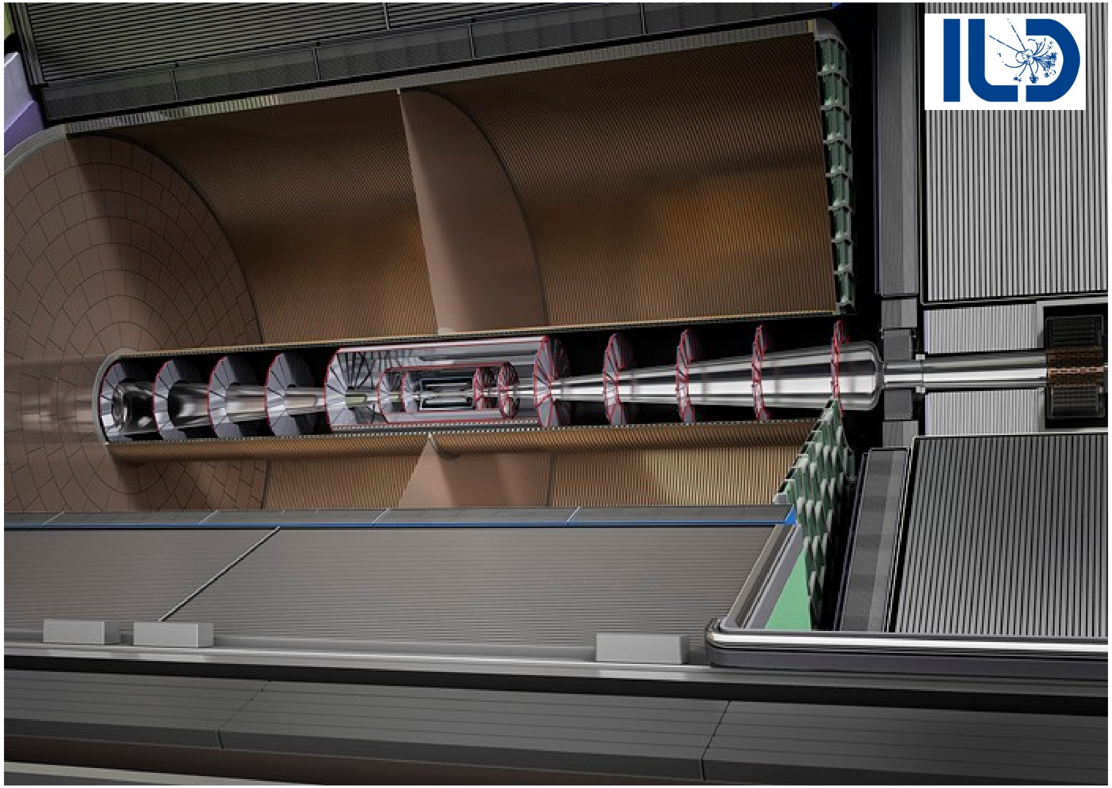
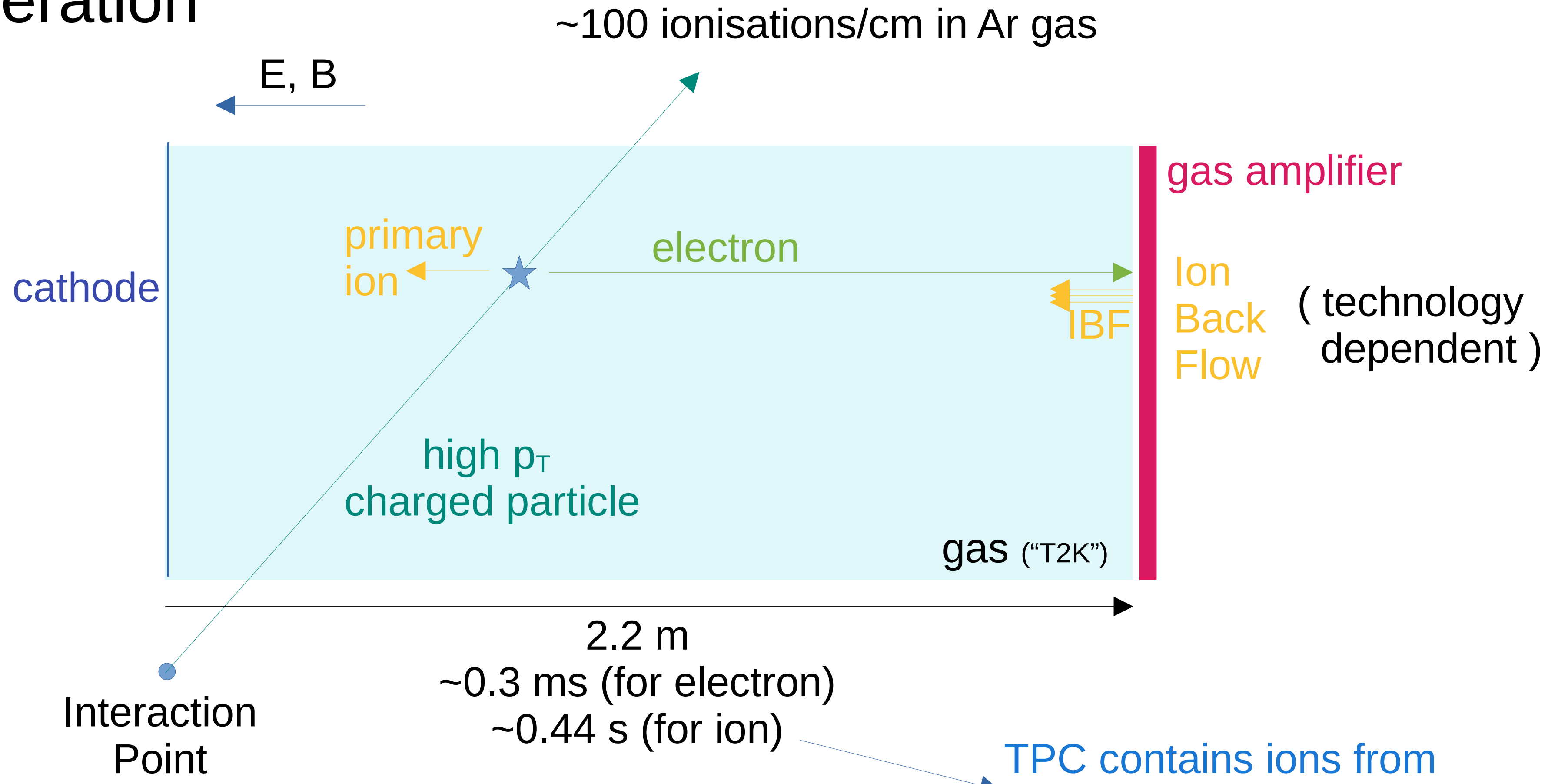


original concept for International Linear Collider

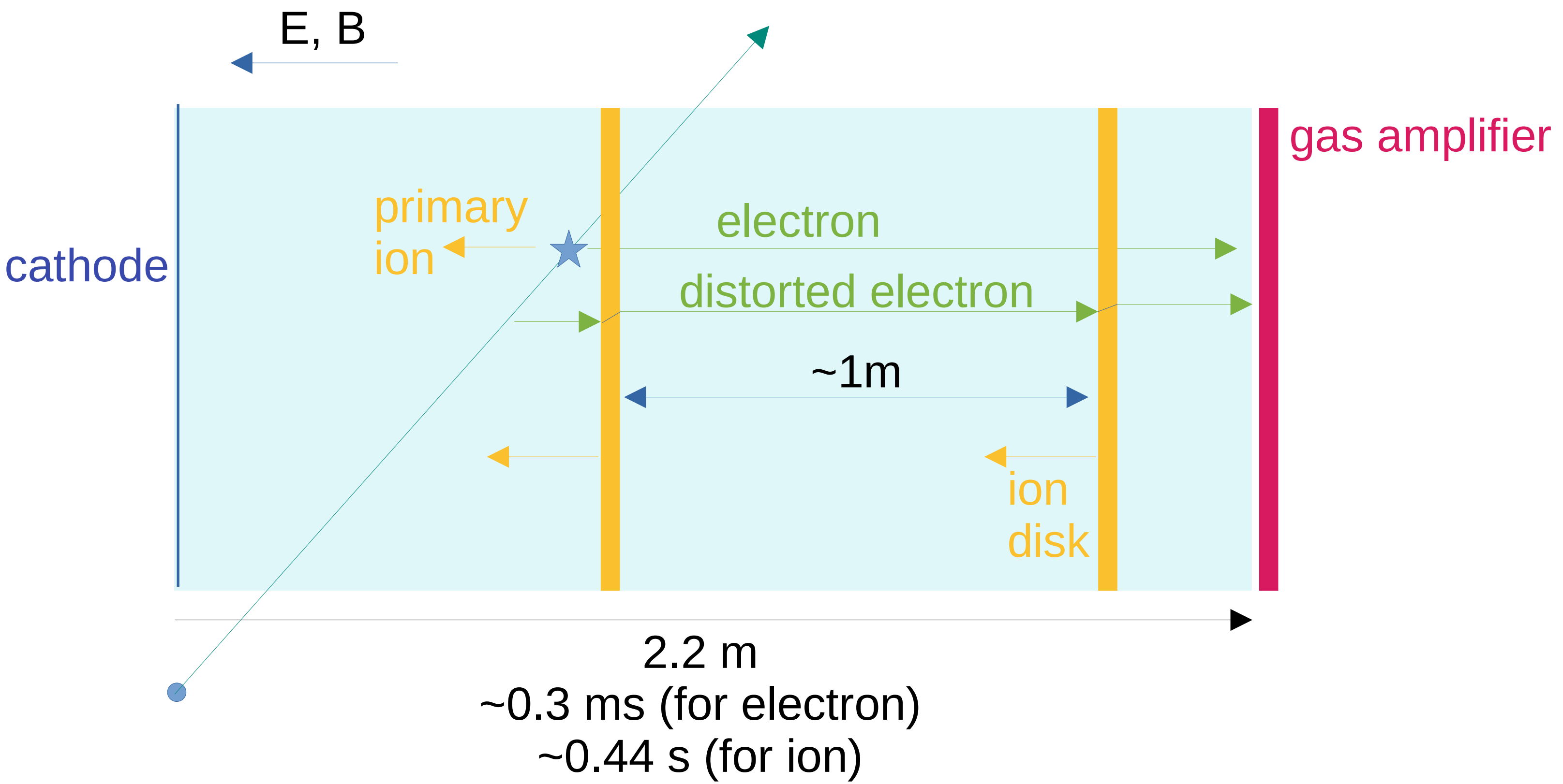
recently considering wider application
e.g. circular e+e- colliders

TPC operation



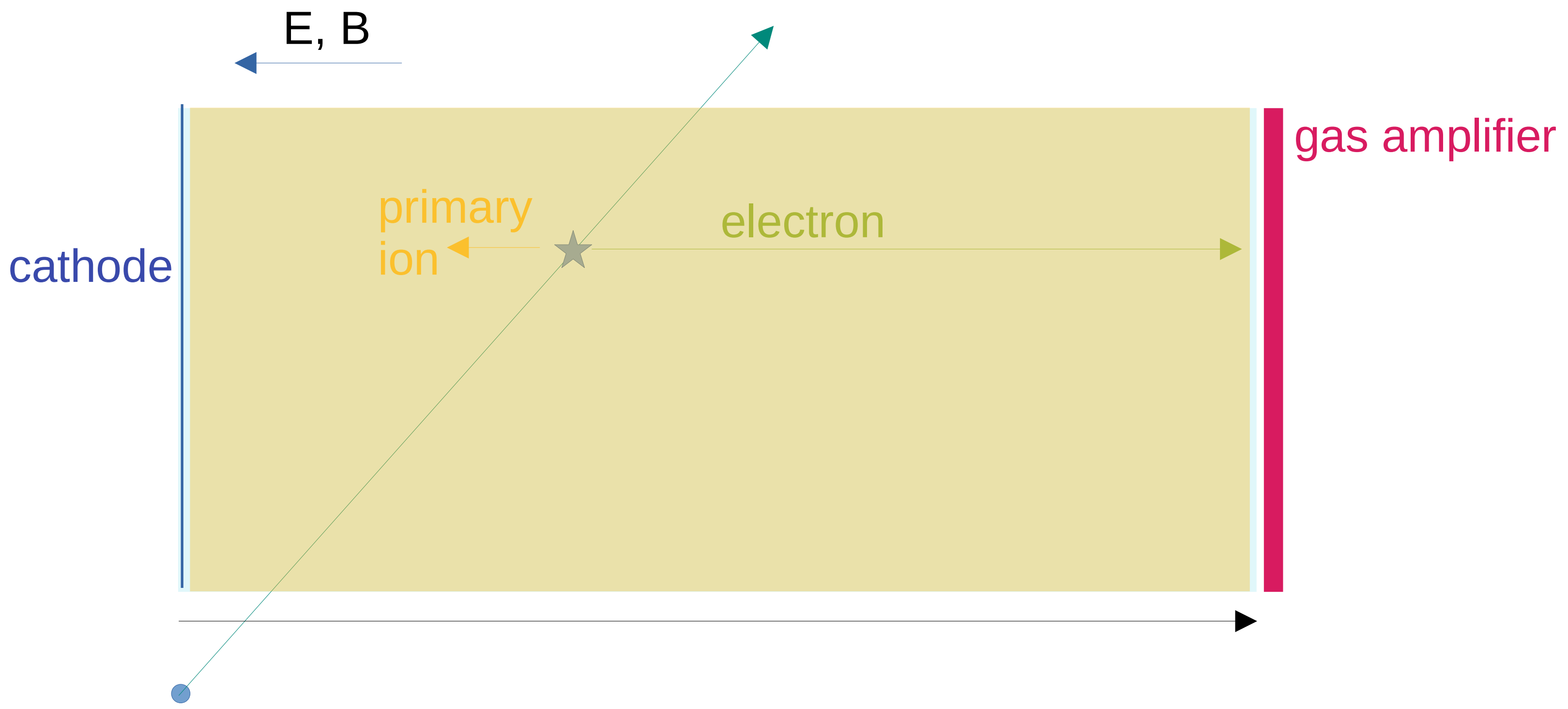
TPC contains ions from collisions up to 0.44s earlier

TPC operation



at ILC: bunch trains at 5 Hz → IBF ions disks separated by ~1m
→ small distortions of ionisation electron trajectories

TPC operation



at FCCee-91 : quasi-continuous collisions at 30 MHz

→ continuous ion cloud

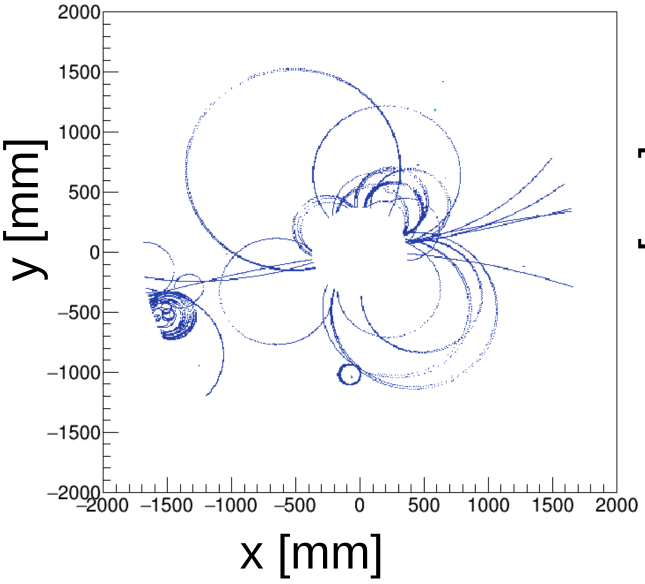
how thick is the cloud ? how big are the distortions?

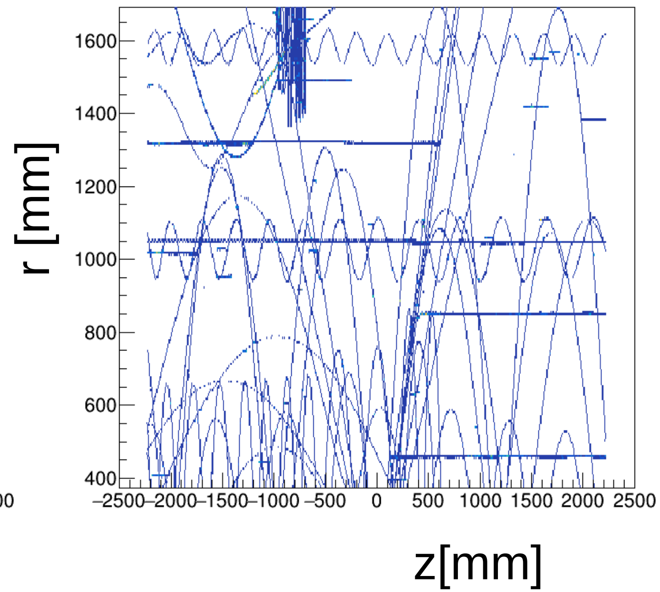
$e^+ e^- \rightarrow$ hadrons

at FCCee-91, very large lumi and x-sec

most track multiplicity (TPC activity) from
e+ e- → hadrons (@ ~50 kHz)

simulated TPC hits in one e+ e- → hadrons event

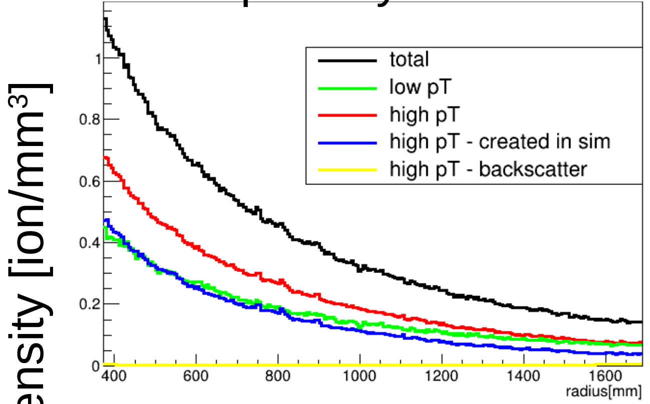




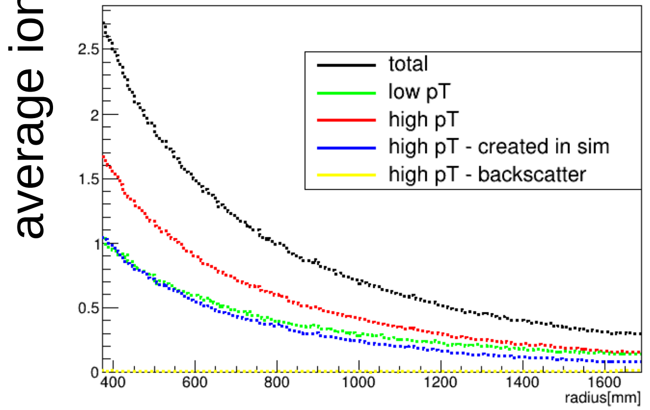
around 1M primary ions per event

estimate steady state ion density

primary ions

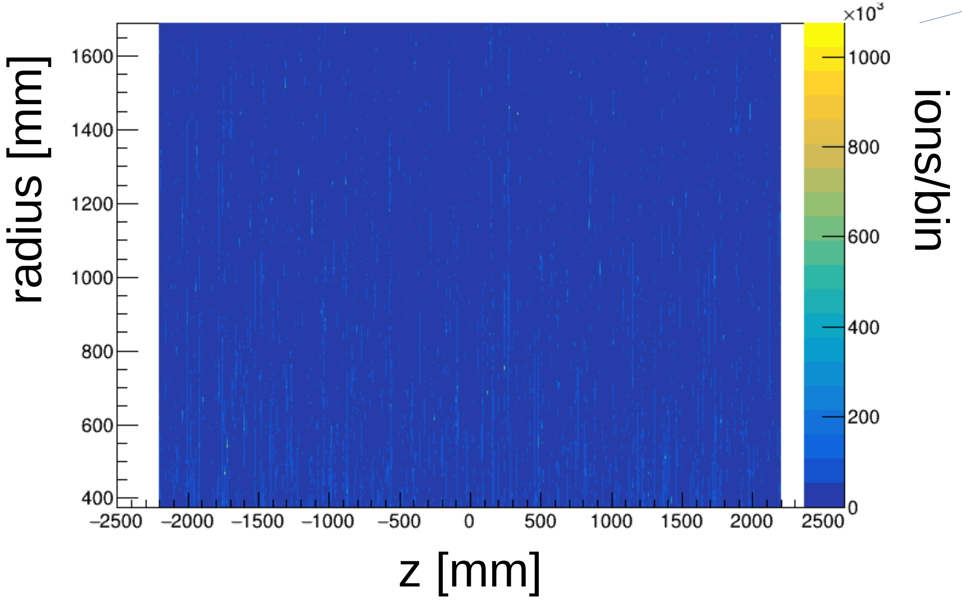


ion back flow (@IBF=1)

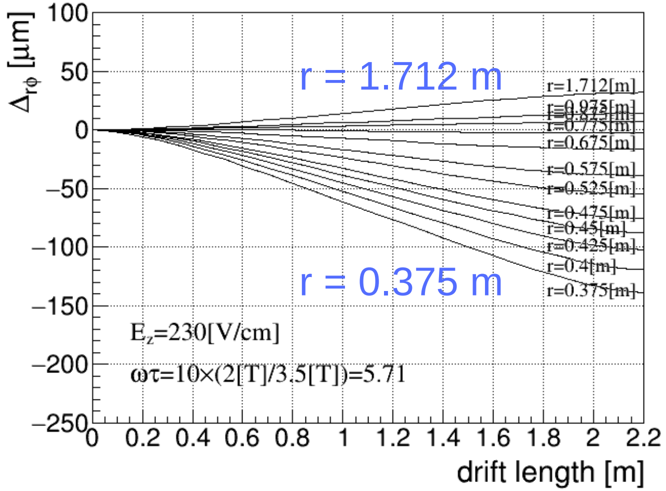


model the 2d (z-r) ion distribution

calculate electron trajectory distortion
(code by K. Fujii)



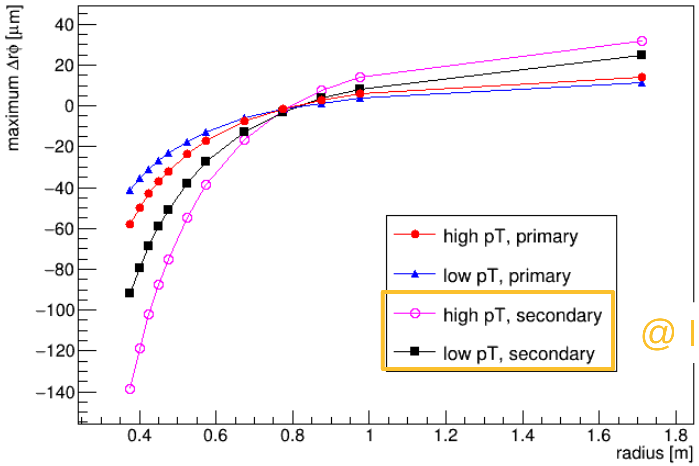
r-φ distortion as function of radius and drift length



maximum r-φ distortion

40µm

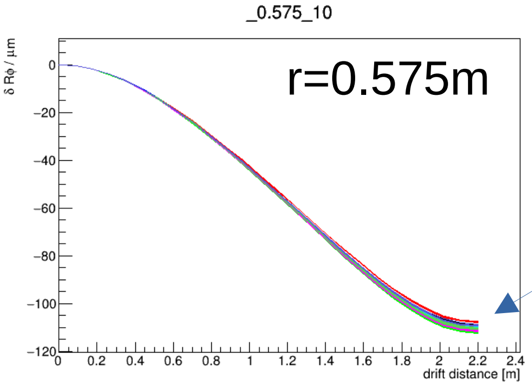
-140µm



@ IBF=1

stability of distortions

→ if distortions are static, should be easy to correct



r-φ distortion [μm]

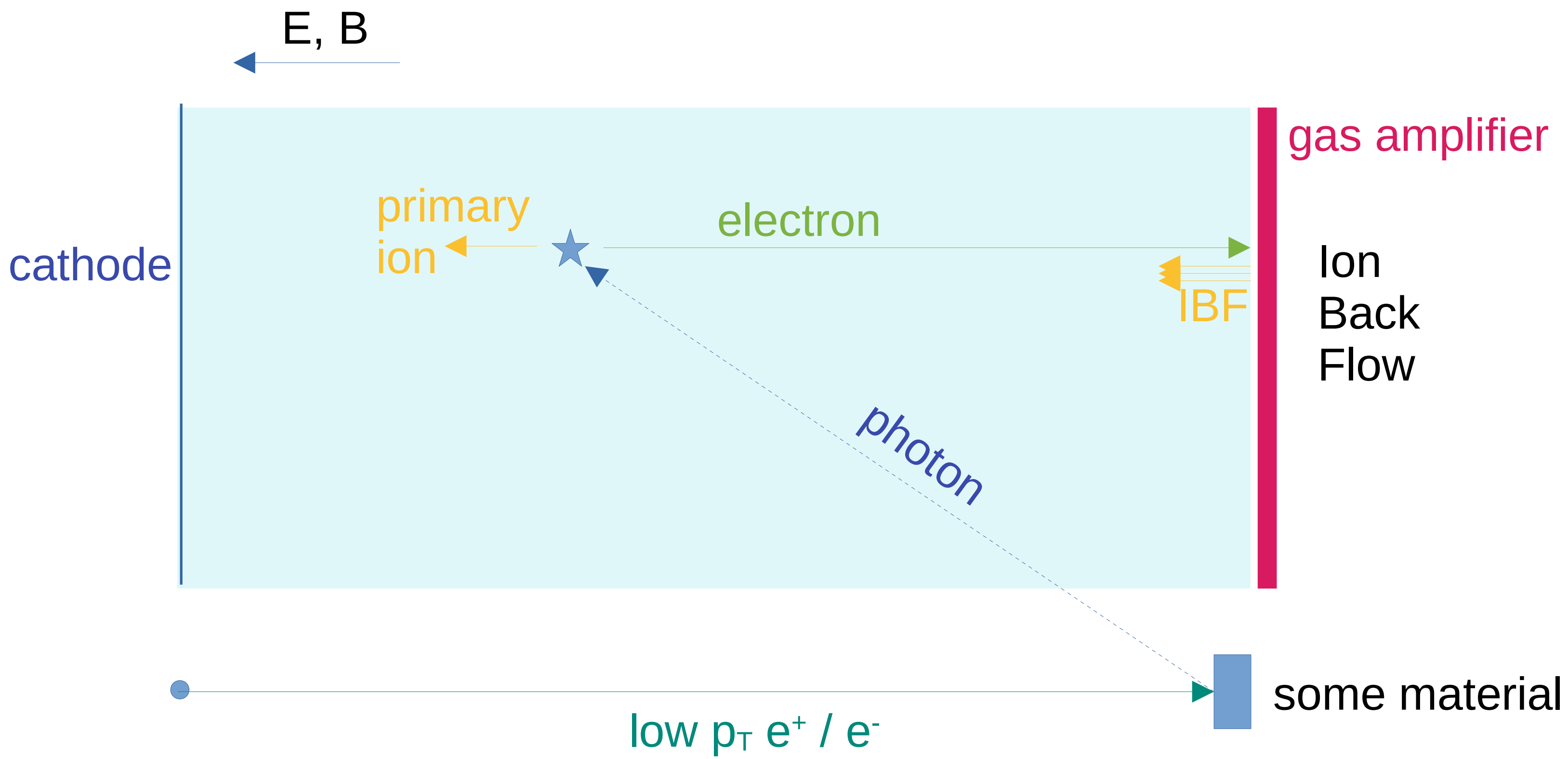
drift distance [m]

different mixes of events

in general, r-φ distortions of trajectories in the TPC
due to e+e- → hadrons seem stable within a few μm at FCCee-91

beam induced backgrounds
→ beamstrahlung

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



beamstrahlung: many very low energy e+e- created in bunch collisions

very different bunch structure, MDI at ILC and FCCee
→ 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 :

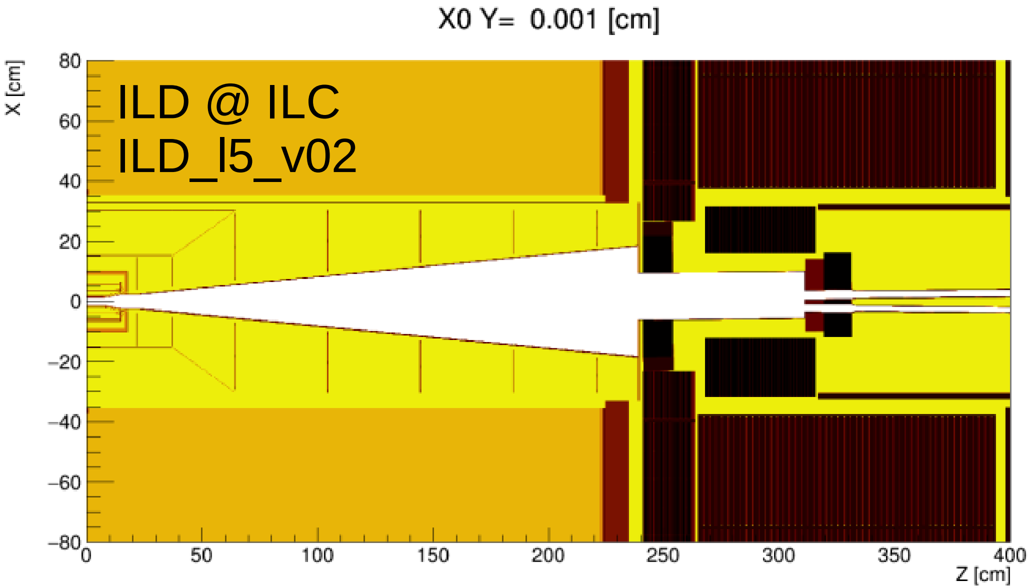
- uniform 3.5T
- uniform 2.0T
- field map with and without anti-DID

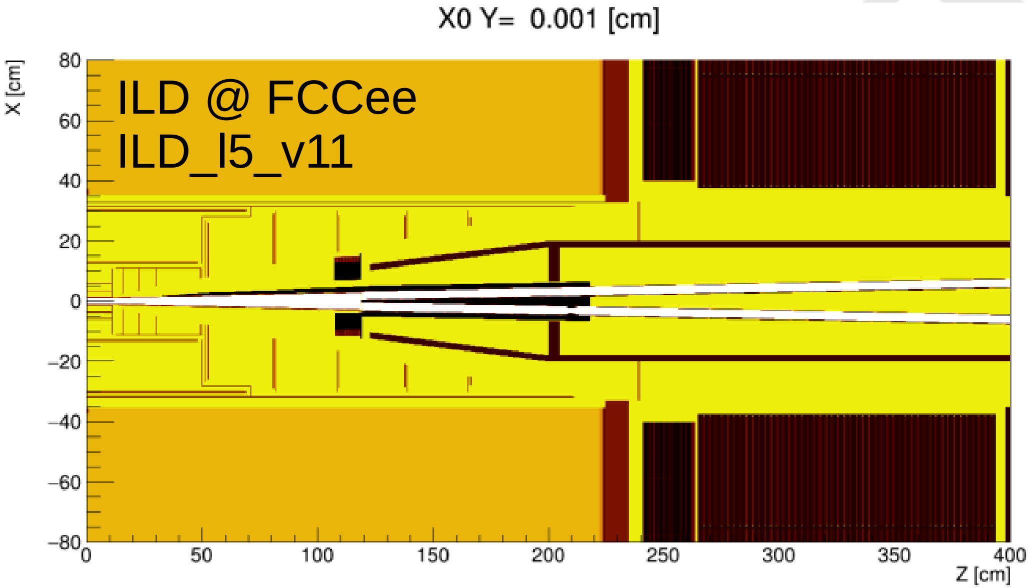
ILD @ FCCee :

- uniform 2.0T
- field map for central region

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

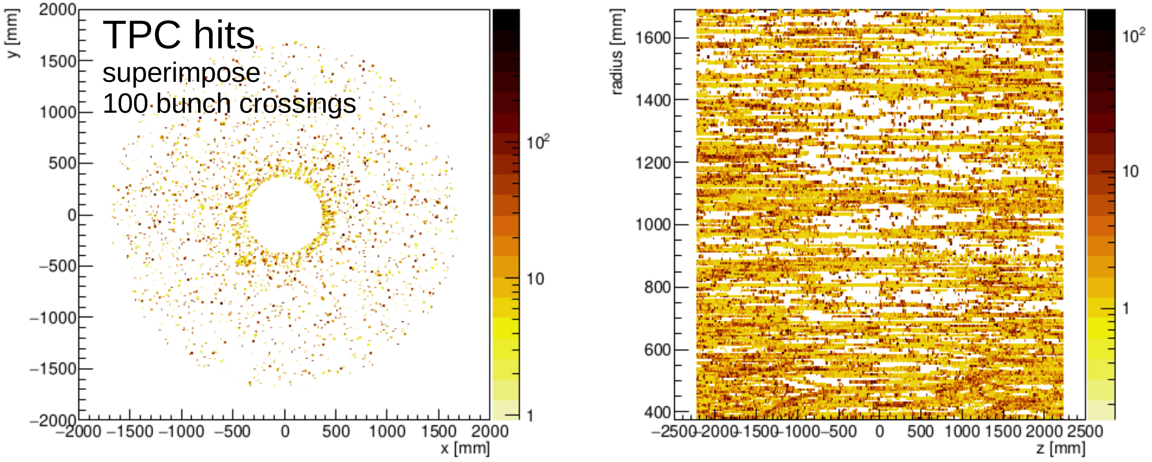




estimate number of **primary ions** produced in the TPC per bunch crossing
→ geant4 energy deposit / effective ionisation potential of Ar [26 eV]

			FCCee-91	FCCee-240	ILC-250
model	B-field	MDI	thousand ions / bunch crossing		
ILD_l5_v02	3.5 (uniform)	ILC	6.5	14	960

bunches less focused @ FCCee
→ beamstrahlung much weaker



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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

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

ions / BX at ILC and FCCee are similar

(reminder e+e- → hadrons ~ 1M primary ions in TPC)

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

c.f. e+e- → hadrons @ FCCee-91 : ~1M primary ions @ 50 kHz
beamstrahlung dominates by 2~3 orders of magnitude

compare to ALICE-TPC

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

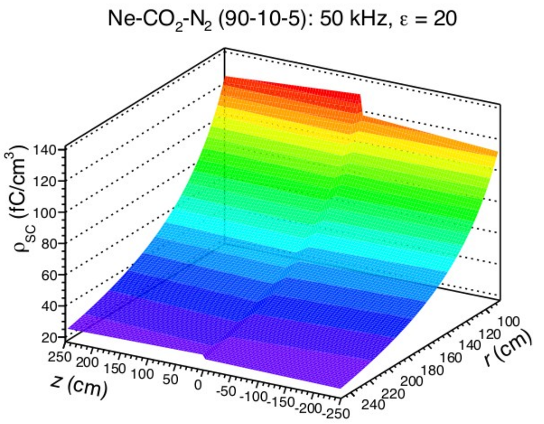
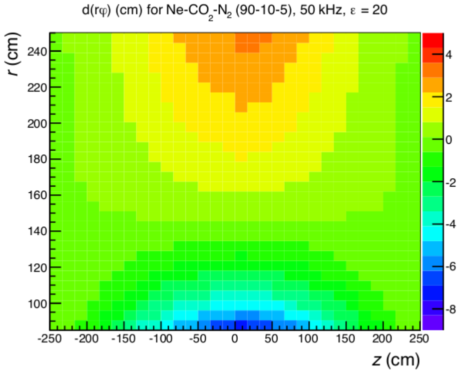


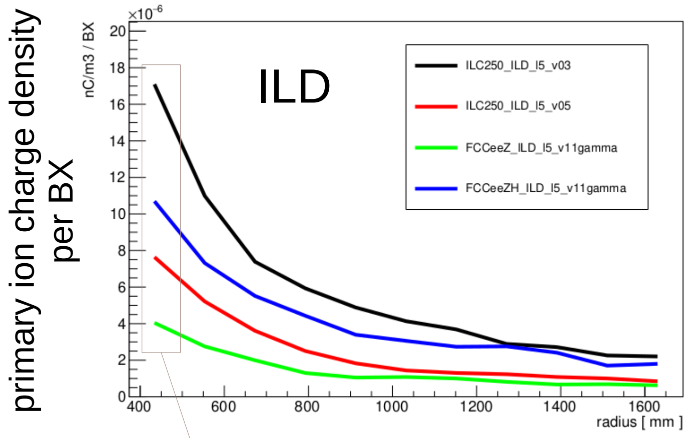
Figure 7.7: Average space charge density for Ne-CO$_2$-N$_2$ (90-10-5), R_{int} = 50 kHz and ε = 20.

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

20~120 fC/cm^3 → cm-level distortions



r-phi distortion [cm]



ILD
FCCee91
FCCeeZH

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

	max (single BX)	BX freq	max (steady state)
ILC250 (v5)	8e-6 nC/m^3	6.6k	0.03 nC/m^3
FCCee240	1e-5 nC/m^3	800k	4 nC/m^3
FCCee91	4e-6 nC/m^3	30M	60 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

with what stability ?

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

FCCee-91 **ion cloud density** looks similar to ALICE-TPC
→expect similar level of distortions O(cm)
→distortion **fluctuations** at FCCee not known

what TPC/**momentum precision** is needed at Z-pole ?
→ requirement at ZH is driven by negligible Higgs width & beam energy spread

ion cloud fluctuations can in principle be measured and **corrected**
→ machine learning ?