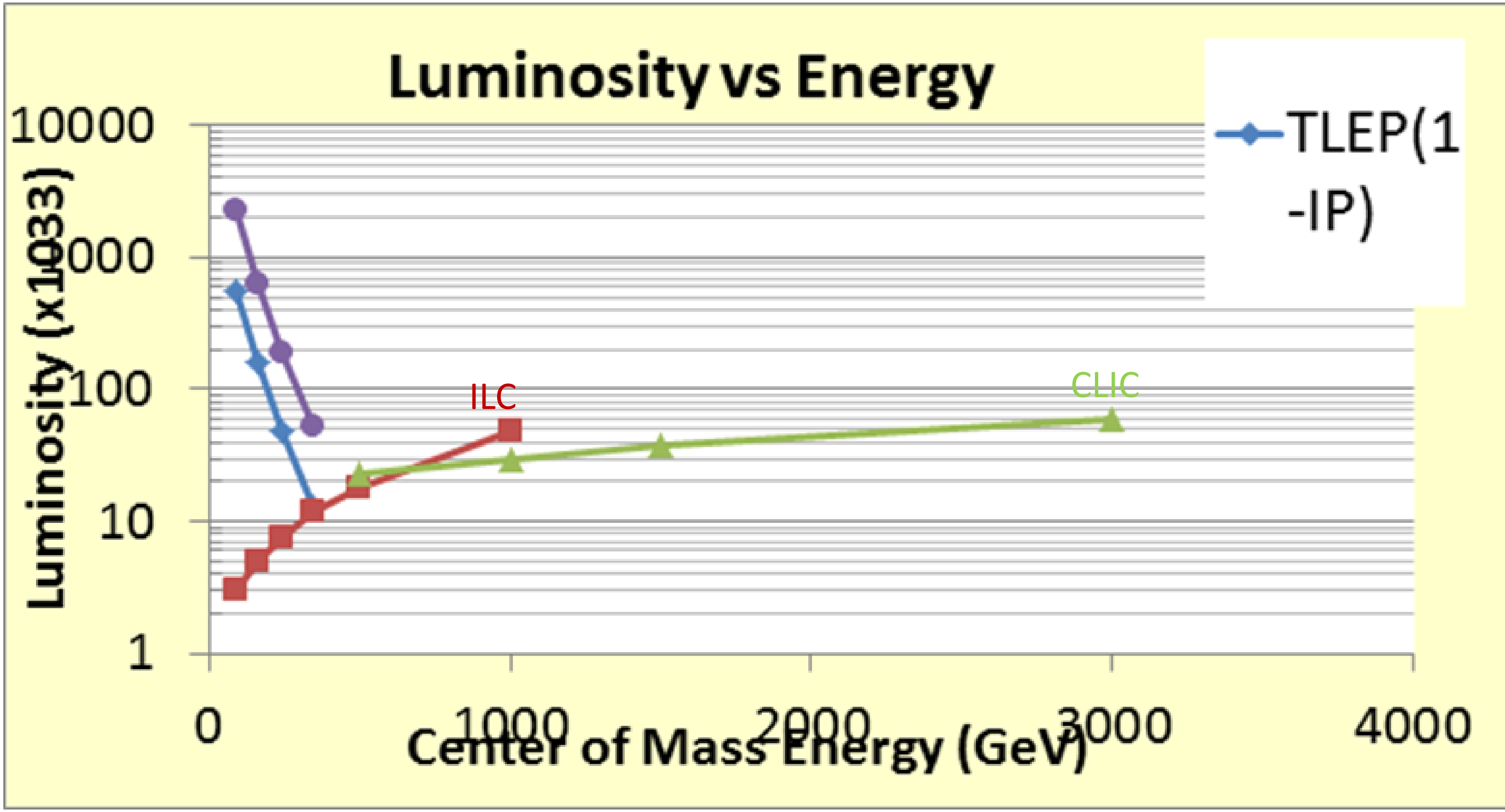
Effect of primary ions in a FCC-ee/TLep

Philippe Schwemling

Irfu
Institut de recherche sur les lois fondamentales de l'Univers

université PARIS DIDEROT PARIS 7

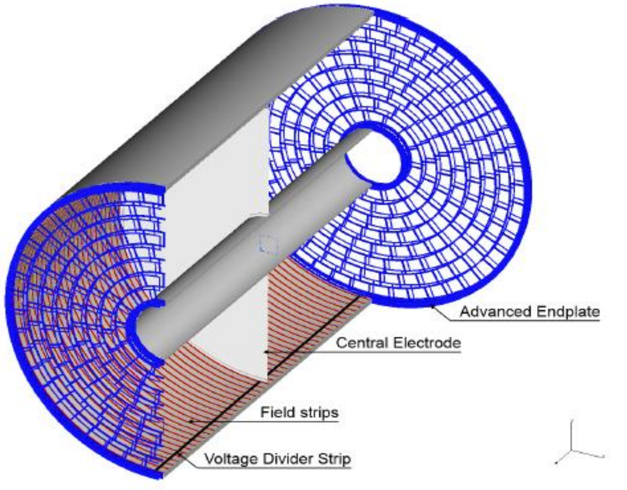


Most demanding : lowest energies (Z peak)

Rates : 16.8 kHZ hadronic Z decays (1 every 60 µs avg, or 1 every 270 BC)

33,6 kHz Bhabhas (1 every 120 µs avg, or 1 every 540 BC)

ILD/TLep TPC parameters



- R internal : 229 mm
- R out : 1808 mm
- Z length : 2×2350 mm
- Drift gas : Ar CF4(3%) isobutane (2%)
- B=4 T
- E = 350 V/cm (Arxiv 1006.3220v1)
- Other data extracted from ILC TDR

A TPC for FCC-ee/Tlep ?

- Assume $L=5.6\times10^{34}$ $cm^{-2}s^{-1}$, Nbunch=16700
- Average time between hadronic events : 60 μs
- Total drift time (electrons): 25 μs → on average, 0.4 hadronic event drifting in the TPC
- Probability of events mixing in z negligible : 2-hit r-z resolution is 8 mm, or 90 ns drift time, or 0.4 BC
- A ILD inspired TPC with Micromegas position measurement looks viable as a TLep detector.

Why consider a TPC at Tlep ?

- Large (continuous) tracking volume at reasonable price.
- Strong (and positive) past experience with TPCs (LEP)
- Very low material budget (typically 0.05 X0 in r, up to 0.25 X0 including endplates)
- Continuous tracking eases reconstruction of non-pointing tracks :
  - Physics signatures
  - PFA
- dE/dx measurement (5% resolution)

Distorsions estimation procedure

- Revisit ILC calculations on same topic
- Estimate total electric charge of ions stored in TPC volume
- Use Pythia to have an estimate of track length

per event (proportional to N electrons/ions, assume typical 40 e/ion pairs per cm)

- Estimate total electric charge of ions stored in TPC volume
- Scale ILC distortion to Tlep, assuming similar shape of charge distribution
- *My comments and additions on ILC slides are in italic*

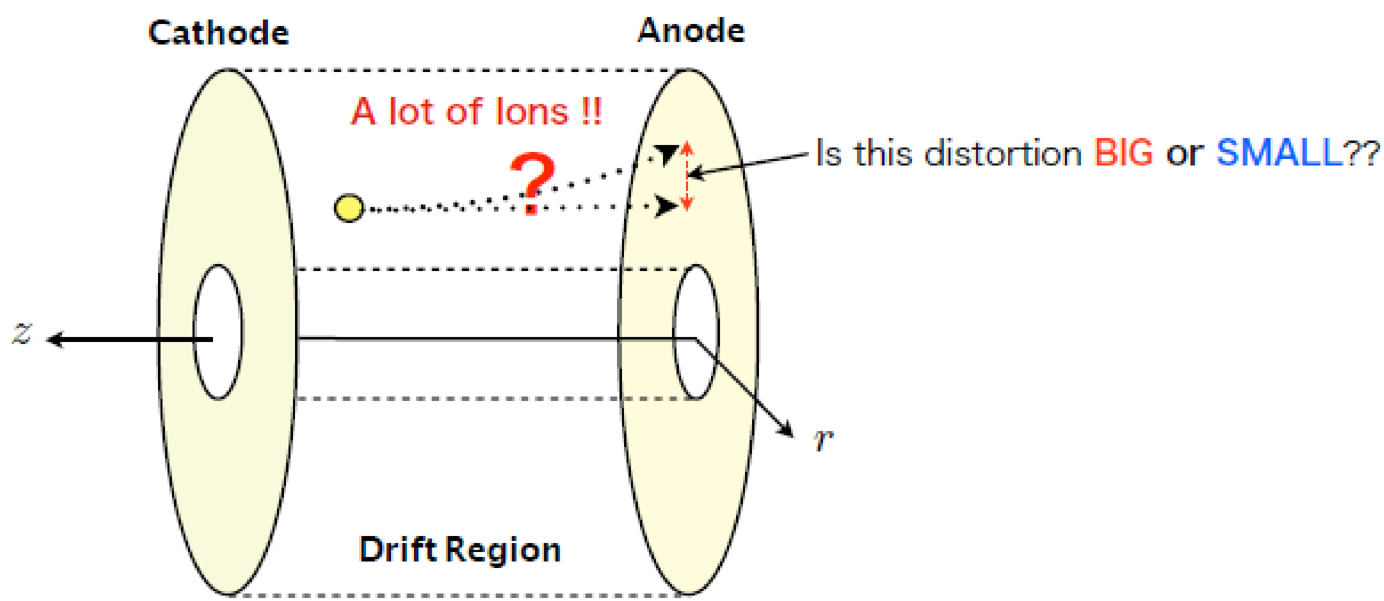
Motivation

Arai Daisuke
2012/February/23 @ WP meeting

* There are a lot of ions in TPC at the ILC experiment.
* These ions in the drift region make the distortion of electric field.
* The distortion of electric field disturb the drift electron path.
* **For the moment we don't know exactly how large the distortion is.**

⇩

I approximately calculate the distortion of the electron drift path.

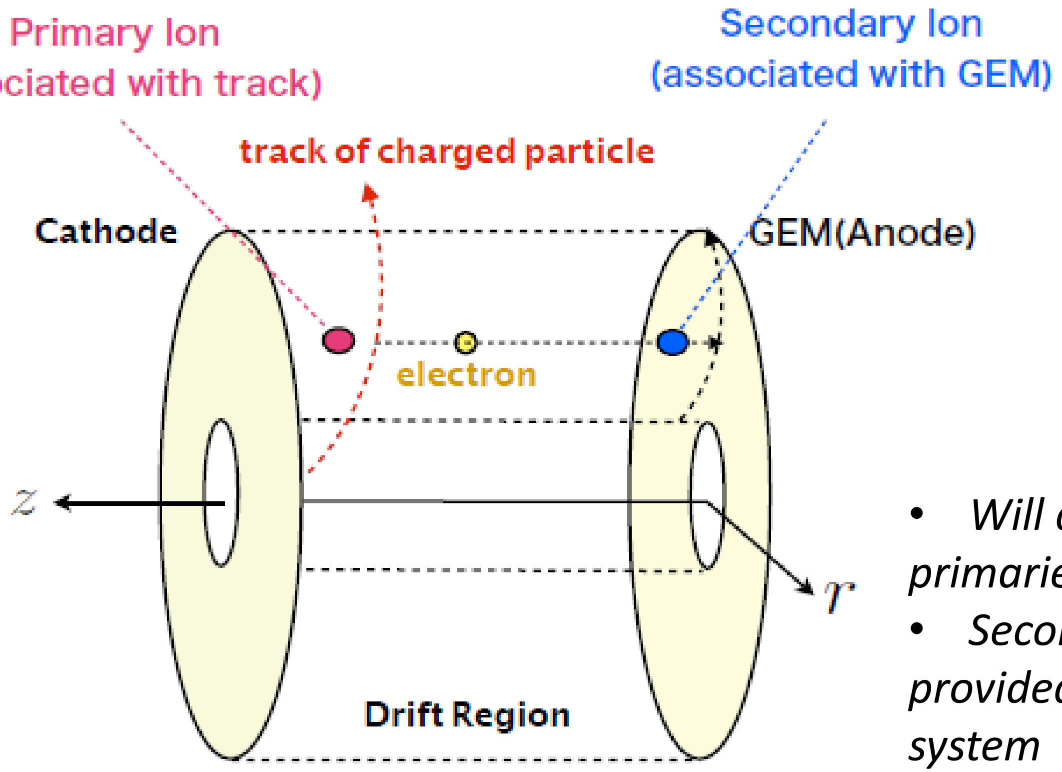


Primary Ion & Secondary Ion

Arai Daisuke
2012/February/23 @ WP meeting

The ions are made in TPC drift region.

We call the ions are made by ionization of charged particle is "Primary Ion" and by GEM amplification is "Secondary Ion".



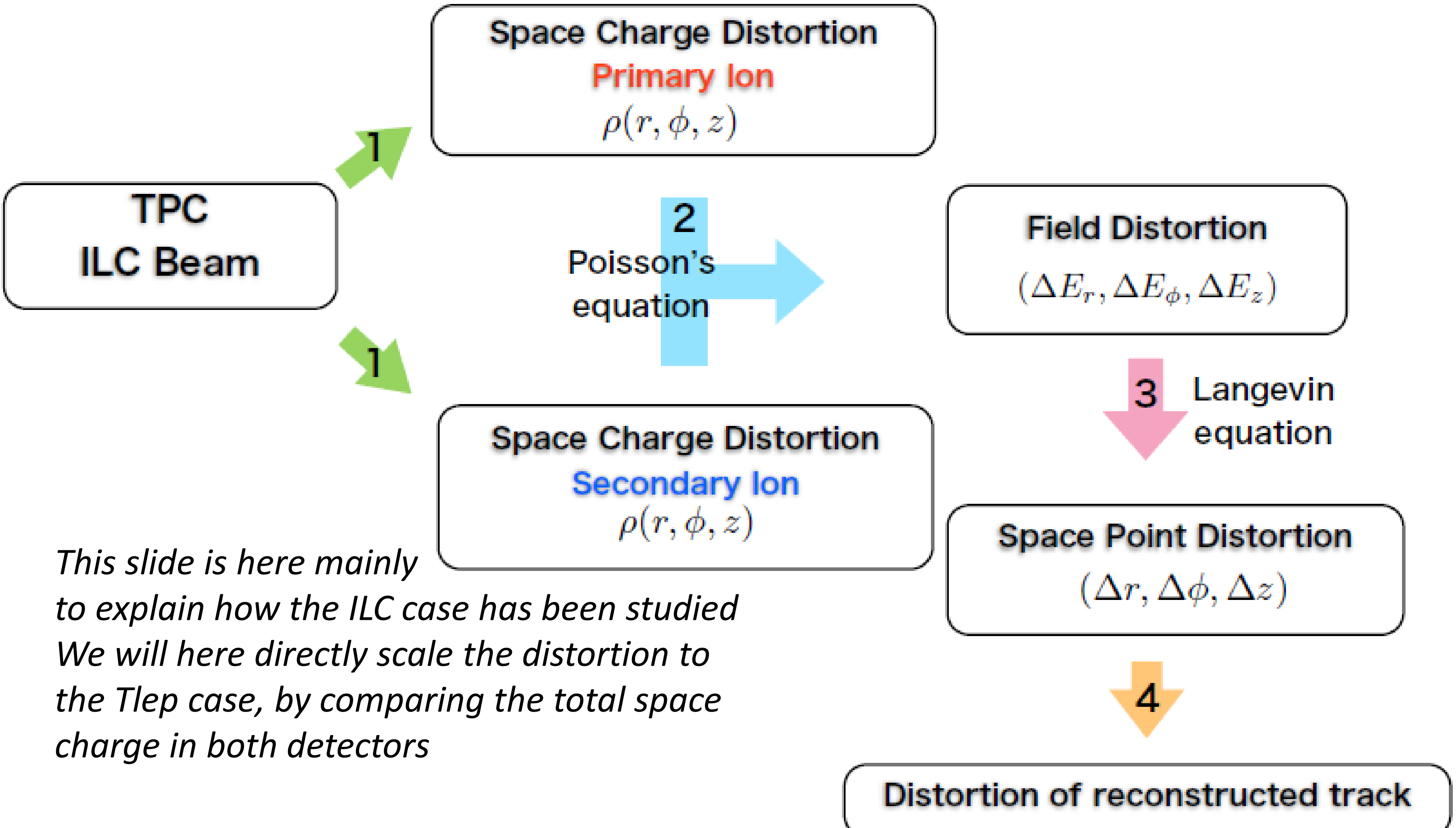
- *Will deal here only with primaries*
- *Secondaries under control, provided there is a gating system*

➡ There are Primary Ion and Secondary Ion in TPC.

Calculation Method

Arai Daisuke
2012/February/23 @ WP meeting

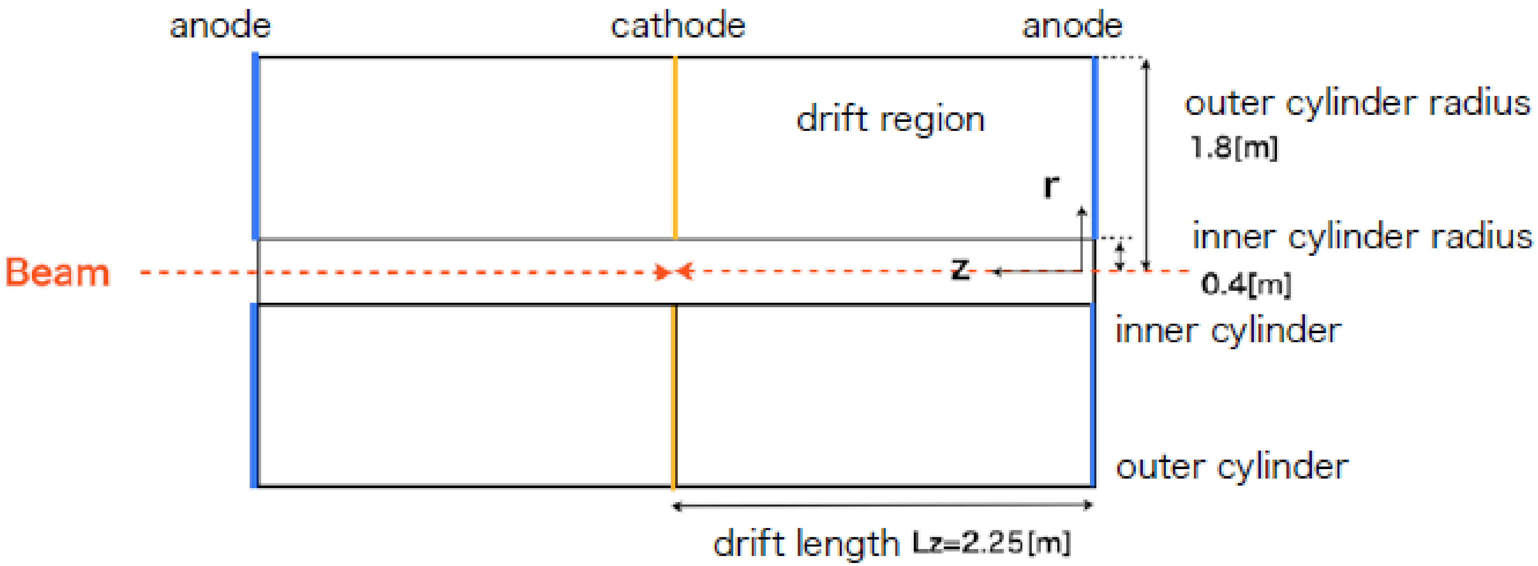
＊ How calculate the distortion of drift electron path ?



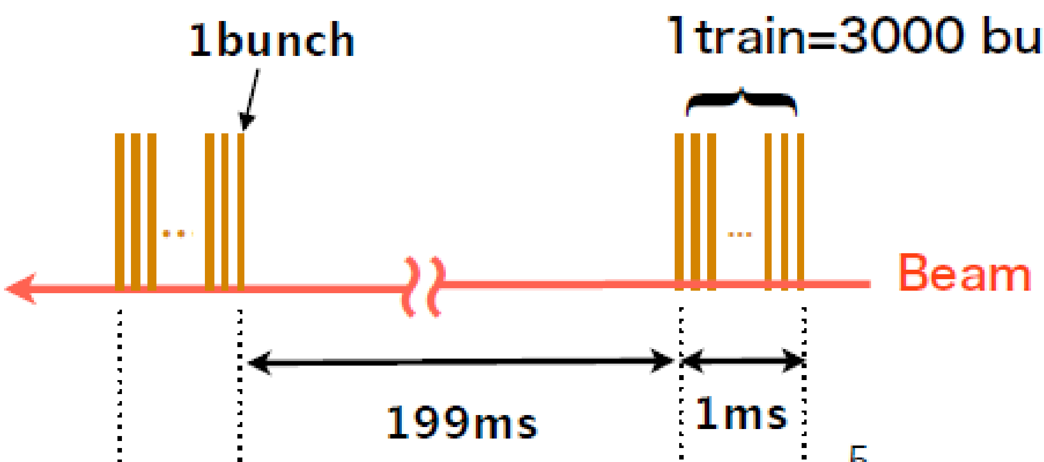
This slide is here mainly to explain how the ILC case has been studied We will here directly scale the distortion to the Tlep case, by comparing the total space charge in both detectors

TPC structure

Arai Daisuke
2012/February/23 @ WP meeting



ILC beam structure



1bunch

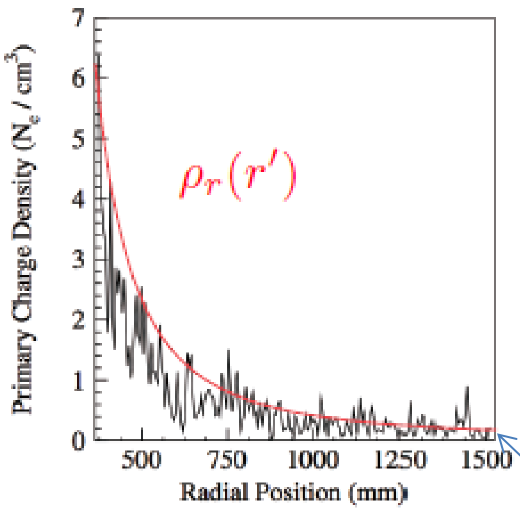
2×10^{10}

electron and positron

Charge Distribution (Primary Ion)

Arai Daisuke
2012/February/23 @ WP meeting

(1) r-direction



Charge Density (per 100 bunches)

We can get the charge density on r direction by fitting left graph. (A.Vogel's simulation results)

Charge distribution per 1train(3000 bunches)

$$\rho_r(r') = 1.6 \times \frac{1}{4(r'-0.2)^2} \times 30 \times 10^{-13} [\mathrm{C/m^3}]$$

r' in m

(average of z-direction)

$\rho_r(r')=1/4/(r'-0.2)^2$ Ne/cm^3 for 100 bunches, r' in m

(2) phi-direction

We assume ρ is symmetric in ϕ direction.

Integrate this function over
R_in=400 mm, R_out=1808 mm
Zmax=2350 mm, dV=2π r dr dz →

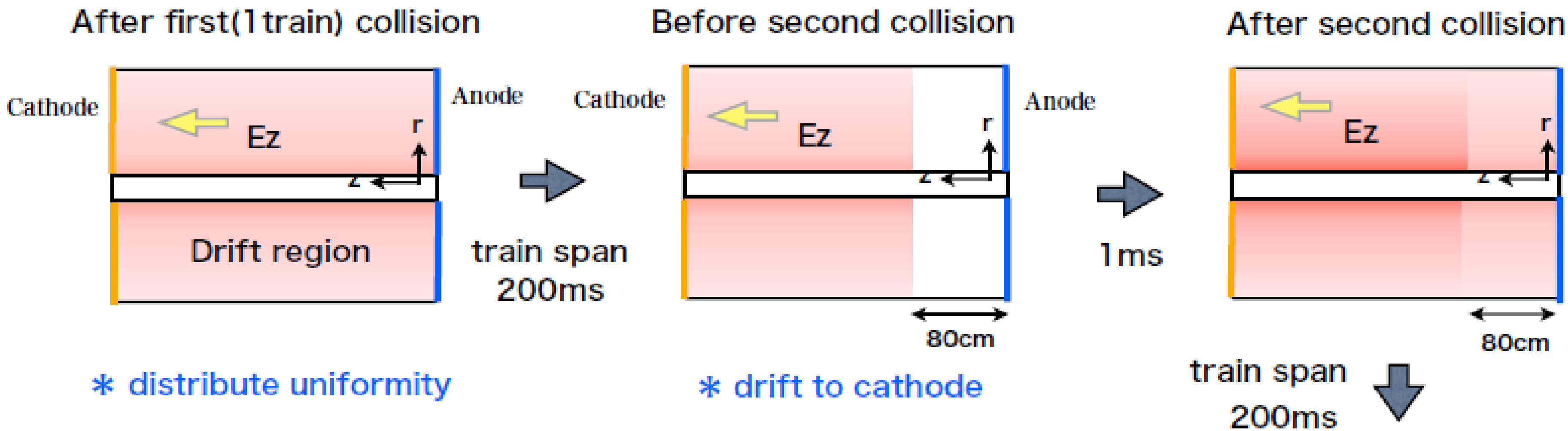
Nions=11*10^6 (100 bchs)

(3) z-direction

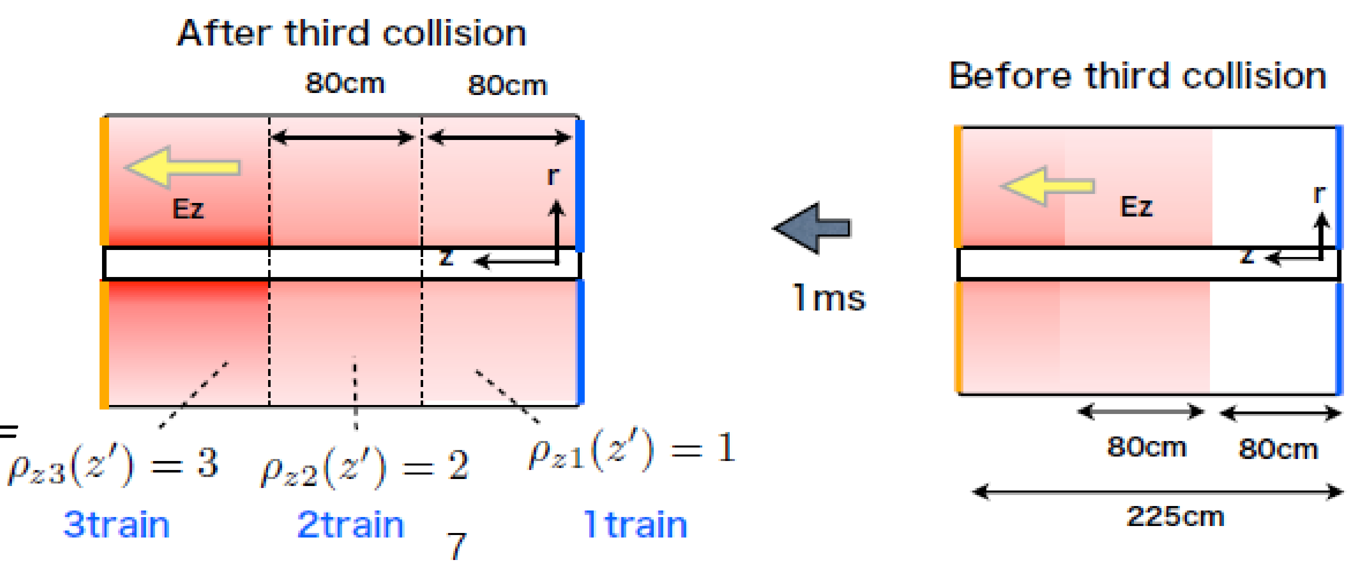
Rough approximation,
this is not quite true, but OK for
an order of magnitude estimate

Arai Daisuke
2012/February/23 @ WP meeting

We think charge distribution on z-direction is constant.



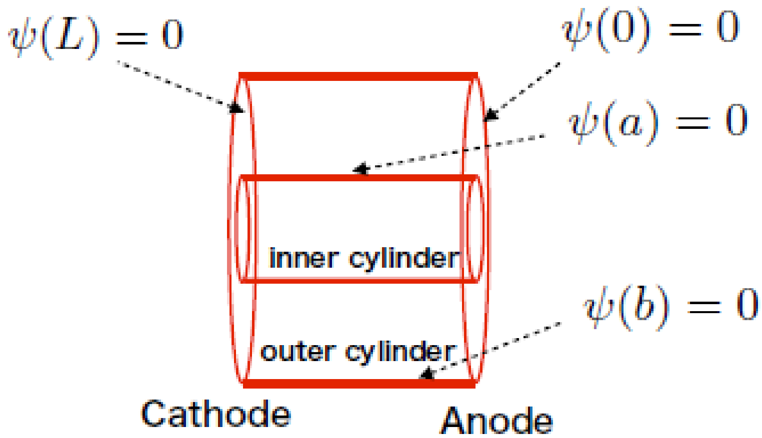
ILC assumes ion drift time is 600 ms → will do the same



Total charge in TPC is
(3/3+2/3+1/3)ρ(1train)=
*2ρ(1train)=0.66*3=*
*3000/100*2*ρ(100 bch)=*
*0,66*10⁹ Nions*

Electric Field

Arai Daisuke
2012/February/23 @ WP meeting



Here only for reference.

This is the EXACT expression for the radial electric field generated by a ϕ-symmetric charge distribution

We can get electric field with boundary conditions using Poisson's equation.
In this time we need only r-direction because E×B effect.

$$E_r = -\frac{2}{4\pi\varepsilon}\sum_{n=1}^{\infty}\frac{4\pi}{L}\frac{sin(\beta_n z)\int_0^L \rho(z')sin(\beta_n z')dz'}{I_0(\beta_n a)K_0(\beta_n b) - K_0(\beta_n a)I_0(\beta_n b)}$$

$$\Bigg[\{K_0(\beta_n b)I_1(\beta_n r) + I_0(\beta_n b)K_1(\beta_n r)\}\int_{r_{min}}^{r}\rho(r')\frac{K_0(\beta_n a)I_0(\beta_n r') - I_0(\beta_n a)K_0(\beta_n r')}{K_0(\beta_n r')I_1(\beta_n r') + I_0(\beta_n r')K_1(\beta_n r')}dr'$$

$$+\{K_0(\beta_n a)I_1(\beta_n r) + I_0(\beta_n a)K_1(\beta_n r)\}\int_{r}^{r_{max}}\rho(r')\frac{K_0(\beta_n b)I_0(\beta_n r') - I_0(\beta_n b)K_0(\beta_n r')}{K_0(\beta_n r')I_1(\beta_n r') + I_0(\beta_n r')K_1(\beta_n r')}dr'\Bigg] \text{[V/m]}$$

K(r) and I(r) is Bessel function.

Distortion of drift electron path

Arai Daisuke
2012/February/23 @ WP meeting

we can get the velocity of drift electron in TPC by Langevin equation.

$$\langle v \rangle = (v_r, v_\phi, v_z) = A\Big(E_r,\ -(\omega\tau)E_r,\ (1+\omega\tau)^2 E_z\Big)$$

$$A = \frac{e}{m}\Big(\frac{\tau}{1+(\omega\tau)^2}\Big)$$

T2K Gas (3.5T)
$\omega\tau = 10$

Drift velocity on z-direction is constant, so we get the drift time.
Use the velocity and drift time, we get the distortion of drift electron path.
We define the distortion of drift electron path is only phi-direction.

- *This is here also only for reference.*
- *This tells how to very simply go from field to position distorsion*

$$L_z = v_z \times t_{drift}$$

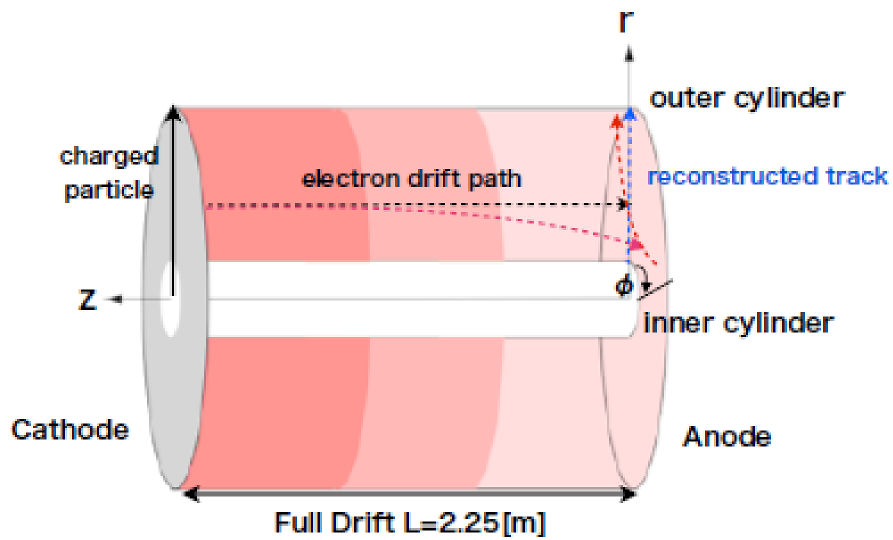
$$L_{dist} = v_\phi \times t_{dist} = \frac{v_\phi}{v_z} L_z$$

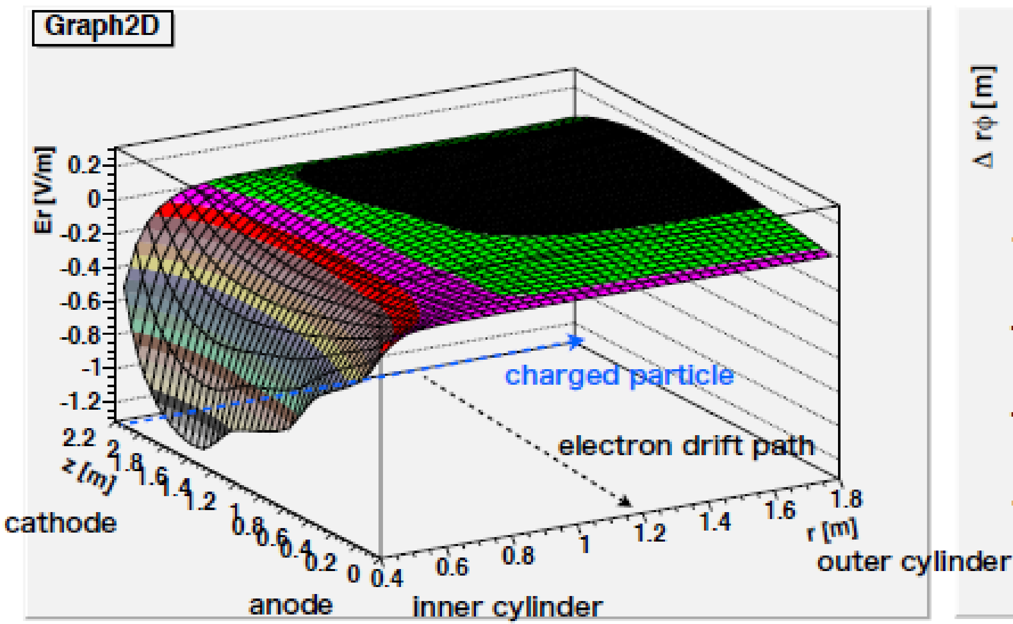
$$|L_{dist}| = \frac{\omega\tau}{1+(\omega\tau)^2}\frac{E_r}{E_z} L_z$$

L_z	Drift length $ILC : 2.2[m]$ $ALICE : 2.5[m]$
t_{drift}	Drift time
L_{dist}	Distortion of the track

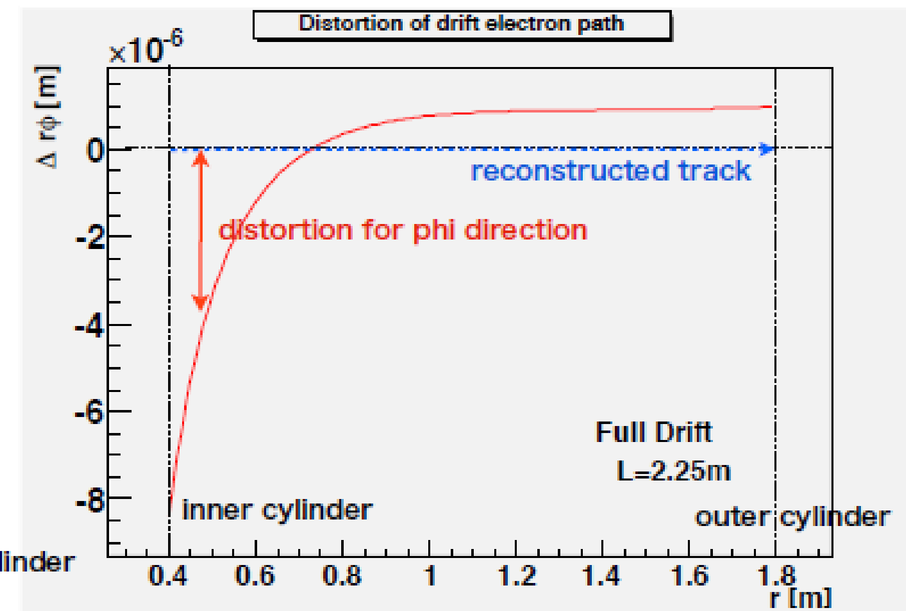
Result

Primary Ion





Efield map



Distortion of drift electron path (Full drift)

point resolution 100μm > Maximum distortion is 8.5μm. Small !!

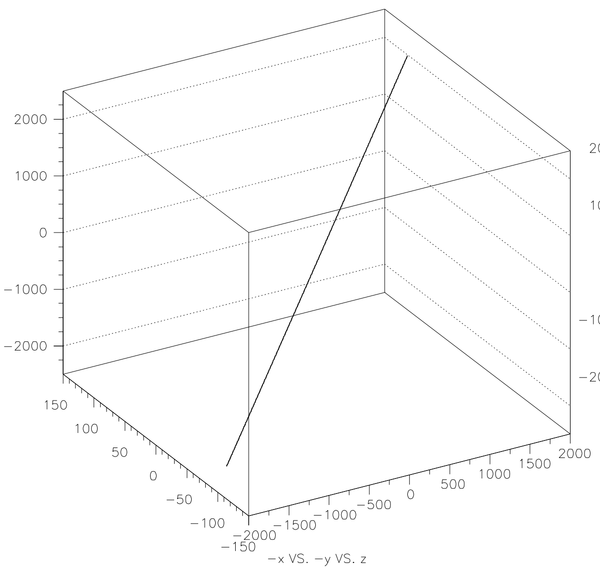
How much ion charge in FCC-ee/Tlep TPC ?

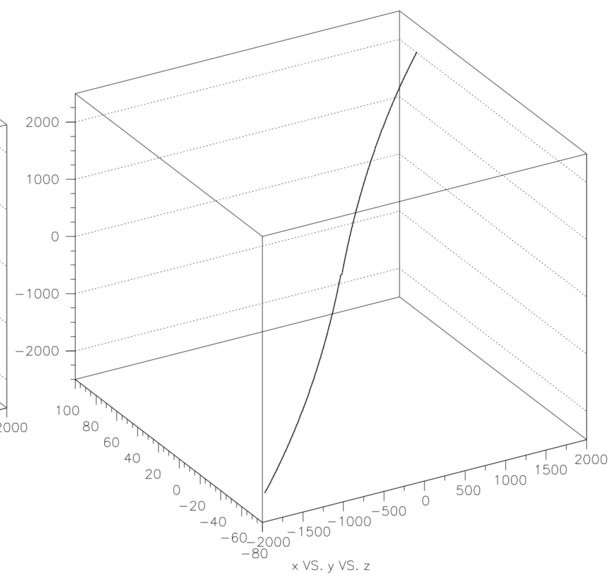
- Z hadronic decays : 16.8 k Hz. Corresponds to

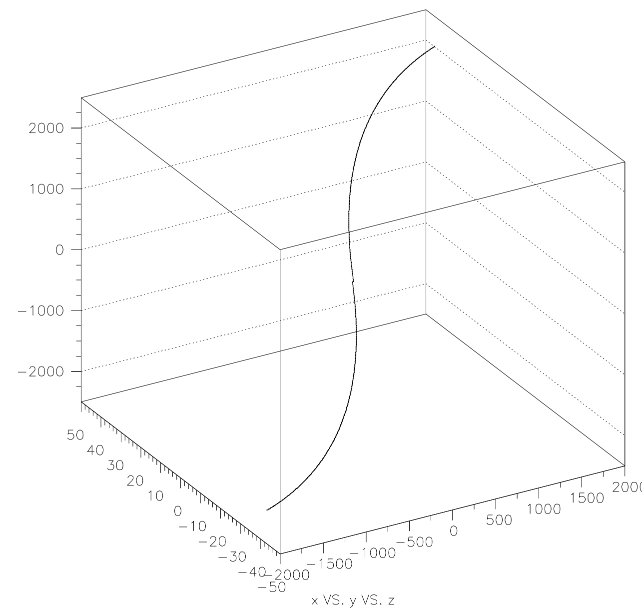
19.22 visible (lept+had) Z decays

- Bhabhas : 33.6 k Hz
- Use Pythia to simulate number of charged « tracks » (stable final particles, in Pythia terminology) and length traversed through the TPC
- Different mag field values studied : 0, 1.5 T, 3.5 T

Dileptons





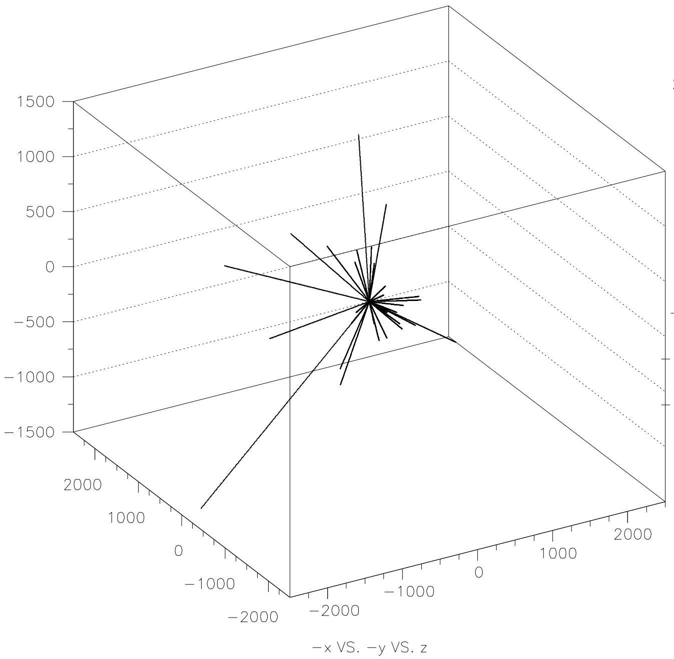


B=0

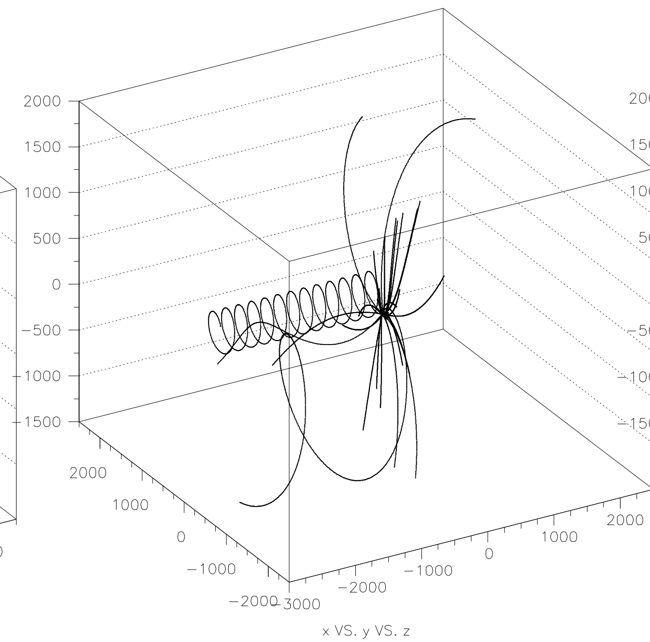
B=1.5 T

B=3.5 T

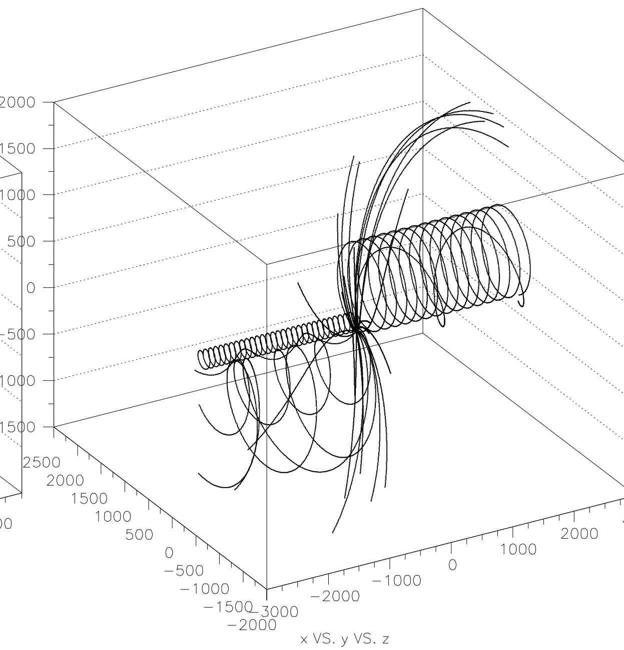
Hadronic Z decays



B=0



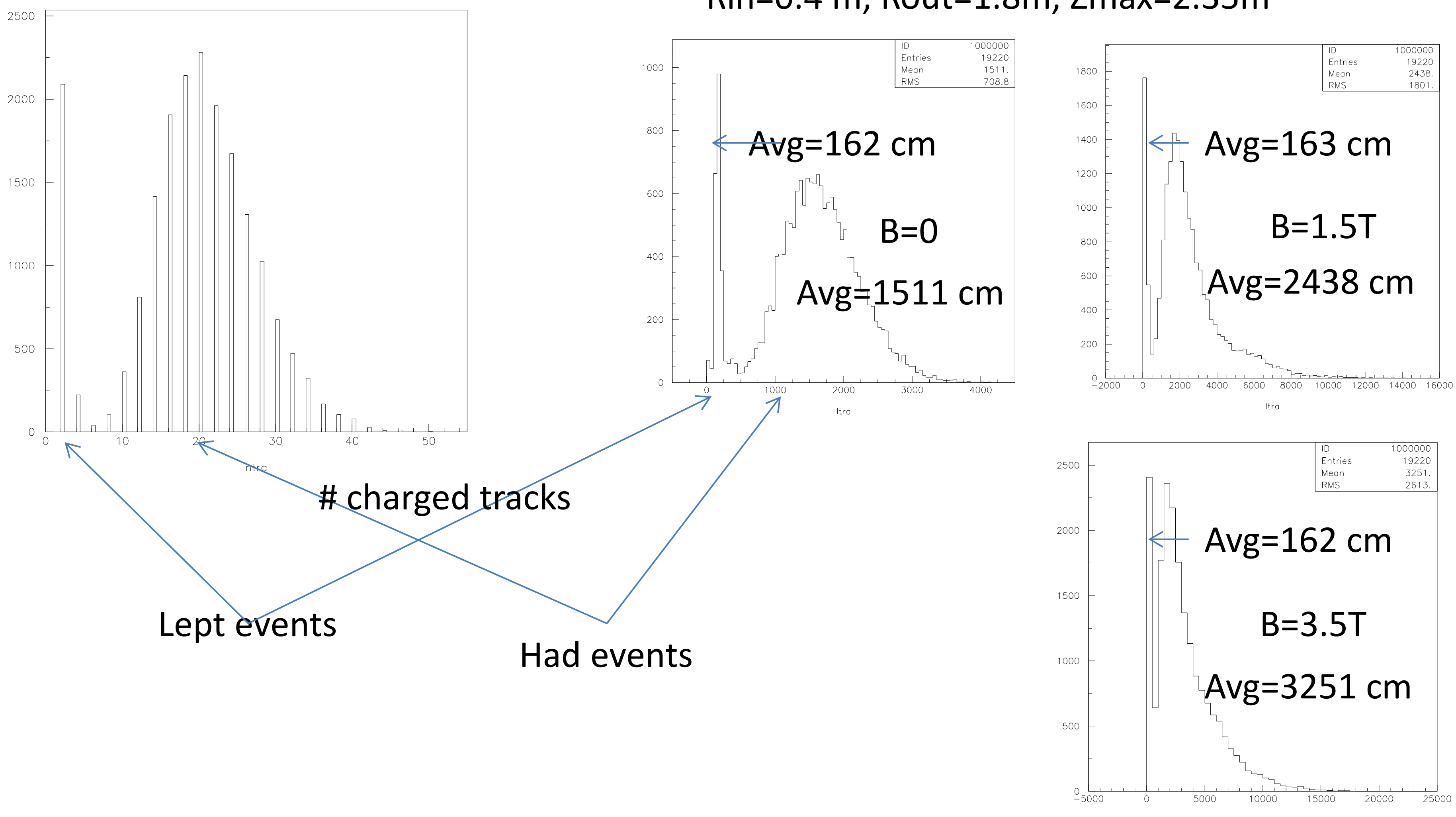
B=1.5 T



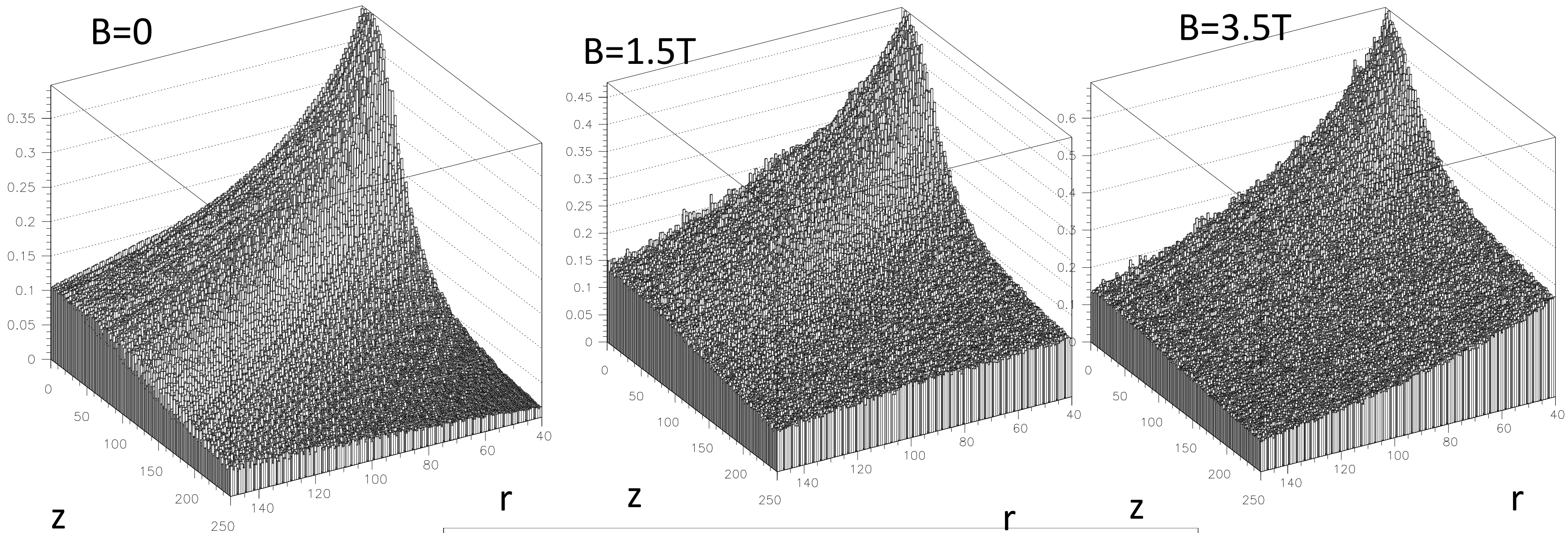
B=3.5 T

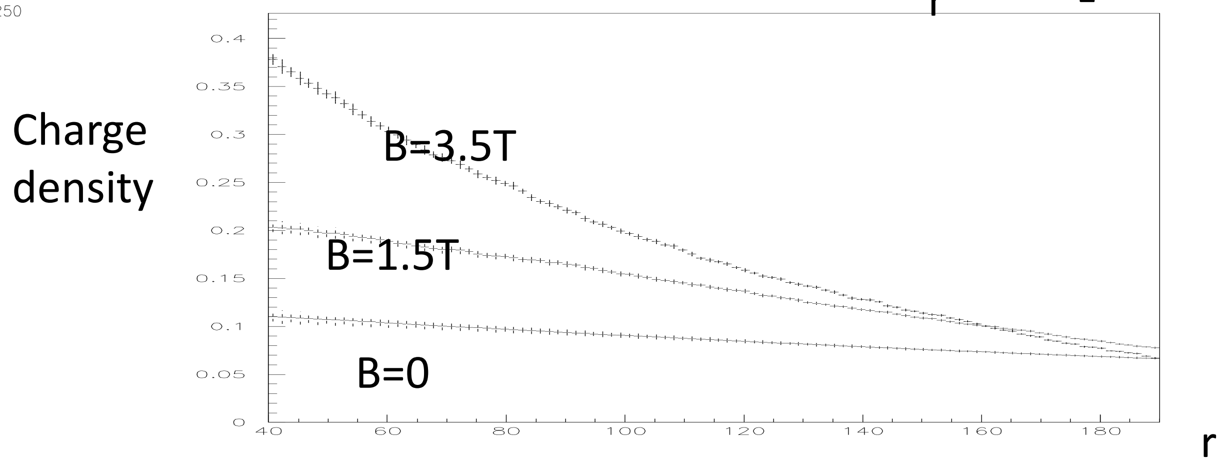
Number of tracks and track length

Gas length traversed/ionised per event (cm)
Rin=0.4 m, Rout=1.8m, Zmax=2.35m



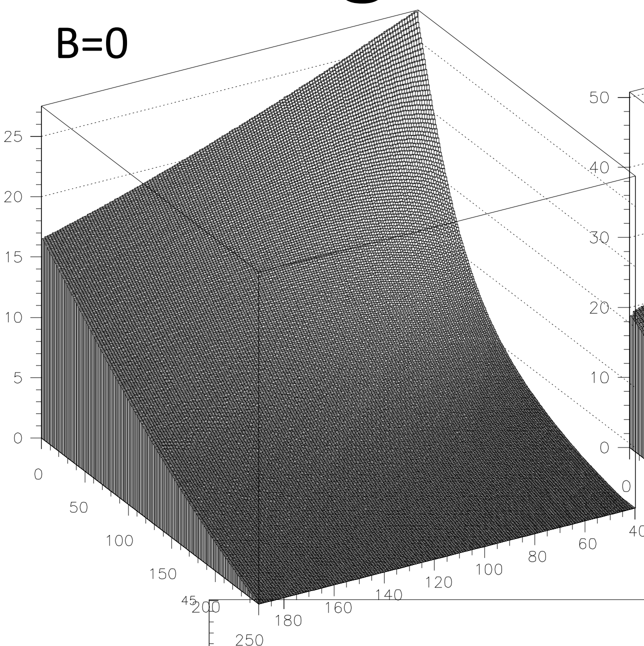
Charge distribution (one event)

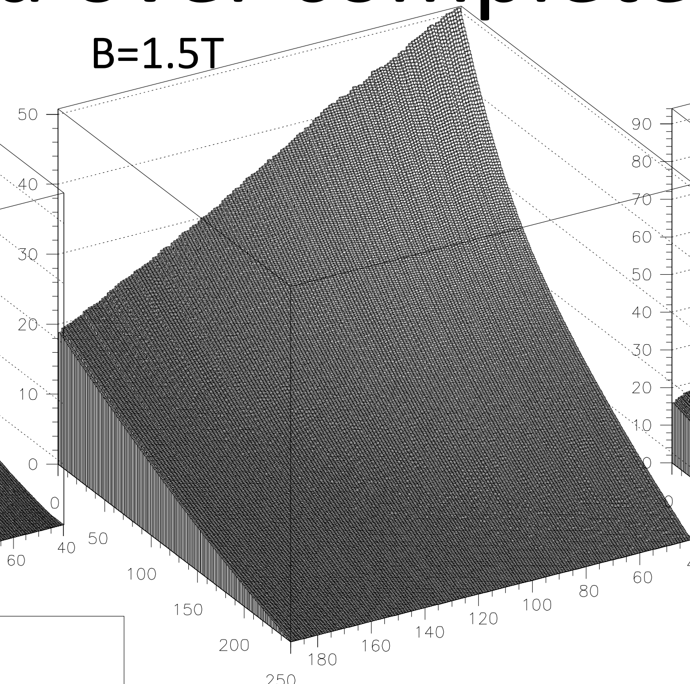


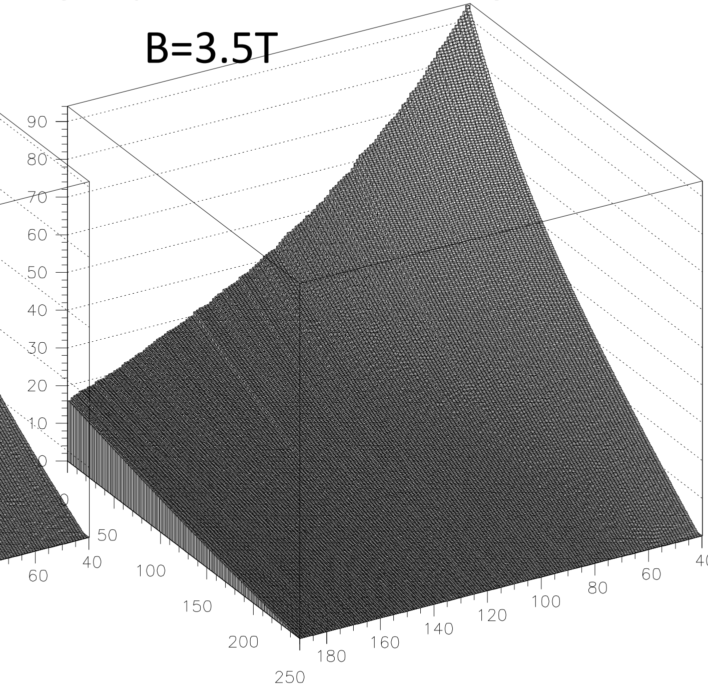


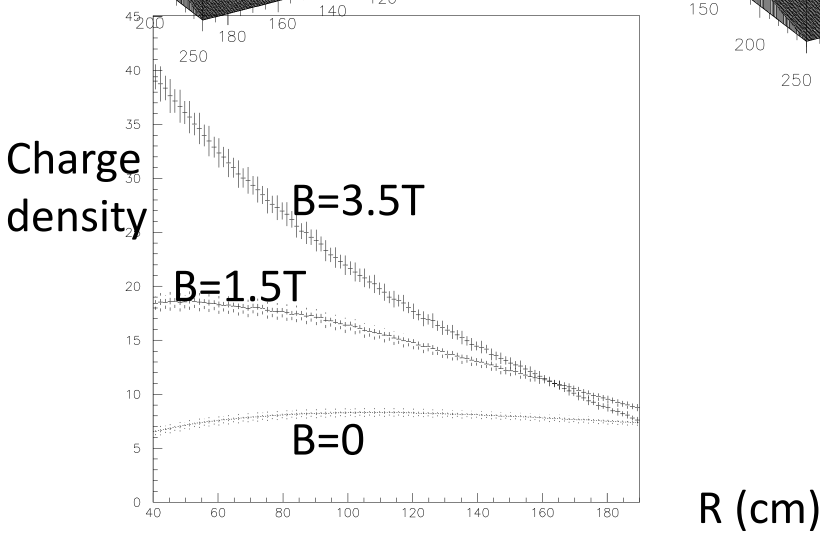
Charge vs r vs z distribution is complicated. The more B, the more charge at low R.
Plan to study effects by tracking electrons through such charge distribution

Charge distribution integrated over complete drift time



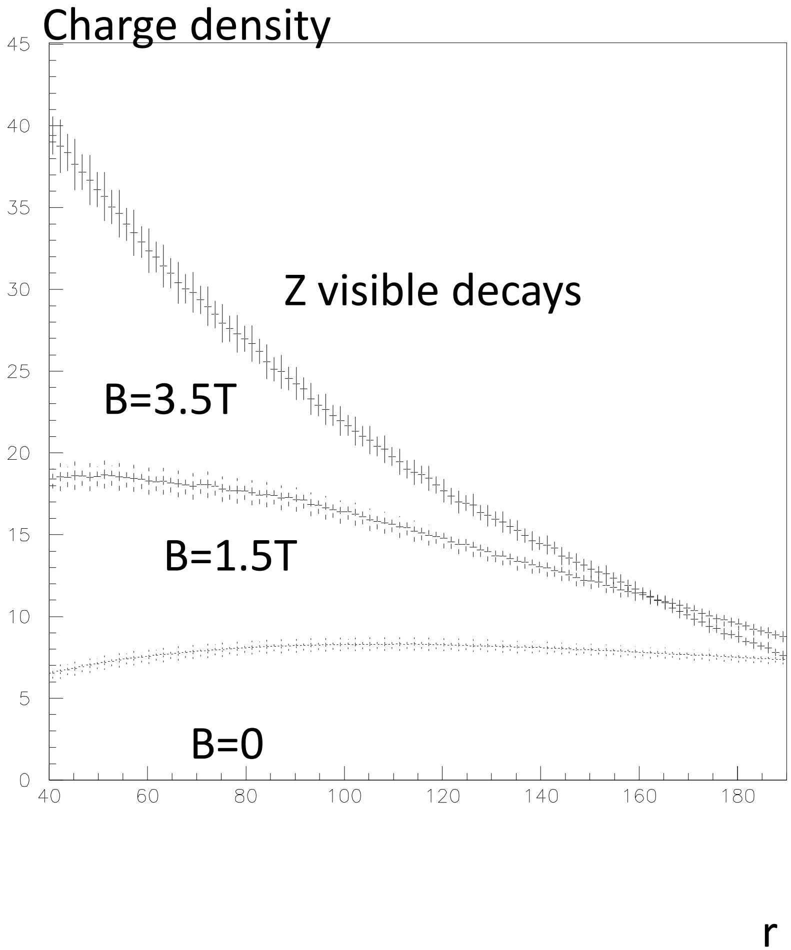




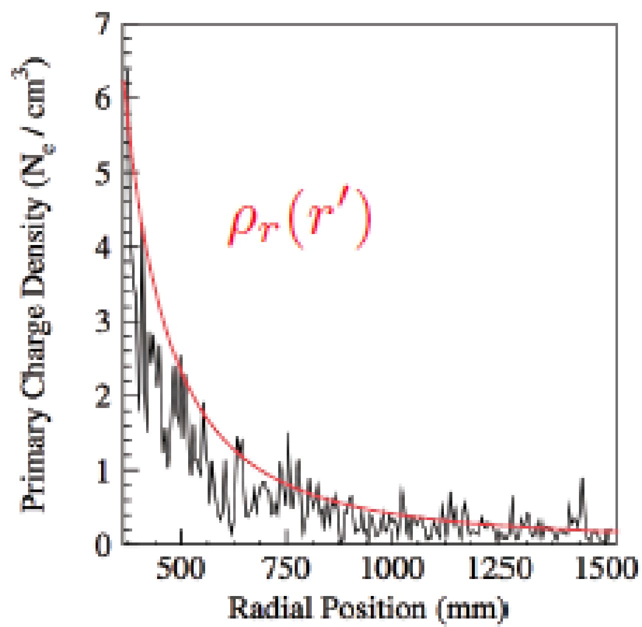


Charge reduction factor due to drift
B=0 : 0.37
B=1.5 : 0.43
B=3.5 : 0.47

Qualitative comparison Tlep/ILC



ILC simulations



Charge Density (per 100 bunches

Charge distributions quite different,
ILC simulation more peaked at low radius : Inclusion of low Pt backgd ?

How much charge in a FCC-ee/Tlep TPC ?

- Remember ILC : $0.66*10^9$ Ions
- From visible Z decays : average track length*trigger rate*drift time*charge reduction factor*Nion/cm=1511*19220*0.37*0.6*40=

  $0.26*10^9$ Ions (B=0)

  $0.48*10^9$ Ions (B=1.5T)

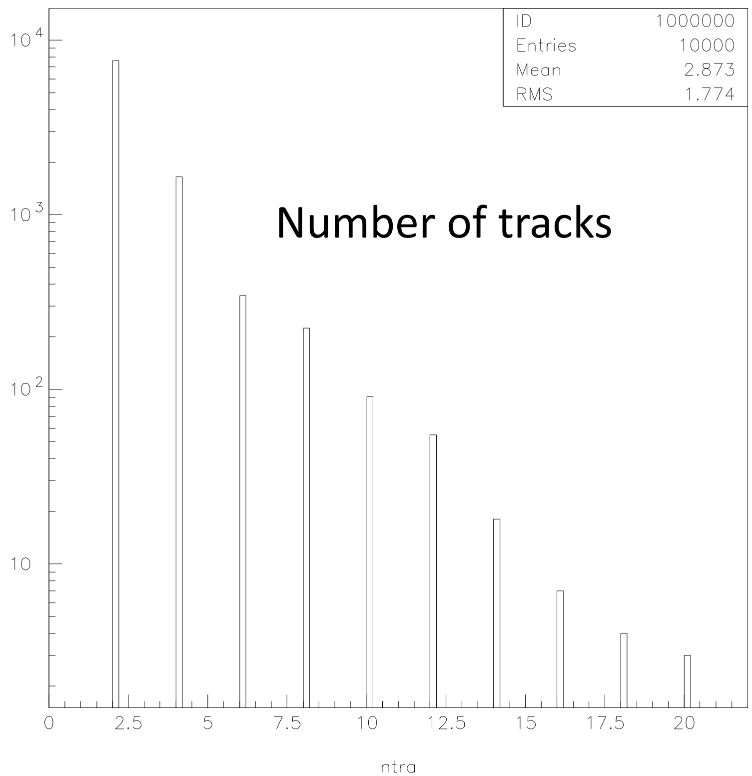
  $0.70*10^9$ Ions (B=3.5 T)
- From Bhabhas : 162*33600*0.37*0.6*40=

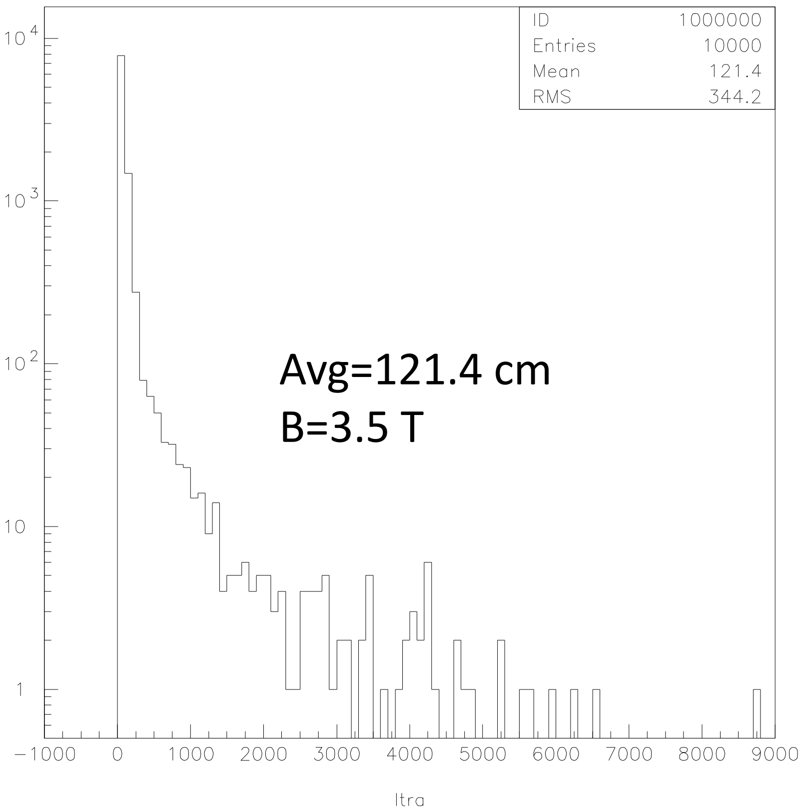
  $0.04*10^9$ Ions

How much charge in a FCC-ee/Tlep TPC (cont'd)?

- $\gamma\gamma$ events

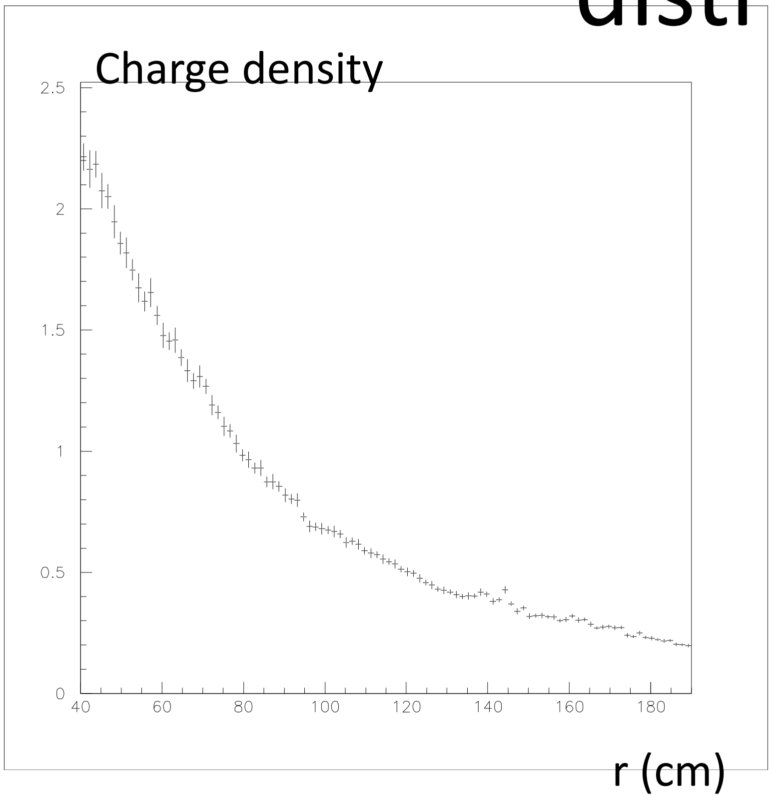
Gas length traversed/ionised per event (cm)
Rin=0.4 m, Rout=1.8m, Zmax=2.35m

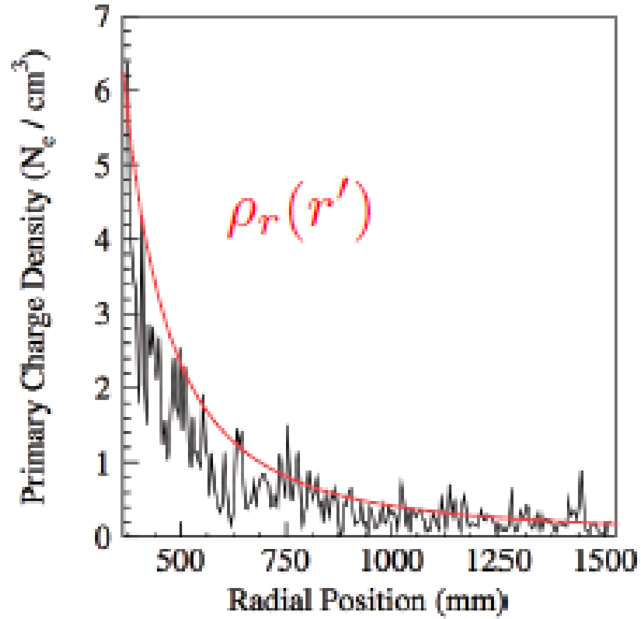




$\gamma\gamma$ Resulting charge/Z resulting charge=121.4/3251*$\sigma_{\gamma\gamma}/\sigma_Z$=0.4% →negligible

Comparison ILC and FCC-ee γγ charge distributions



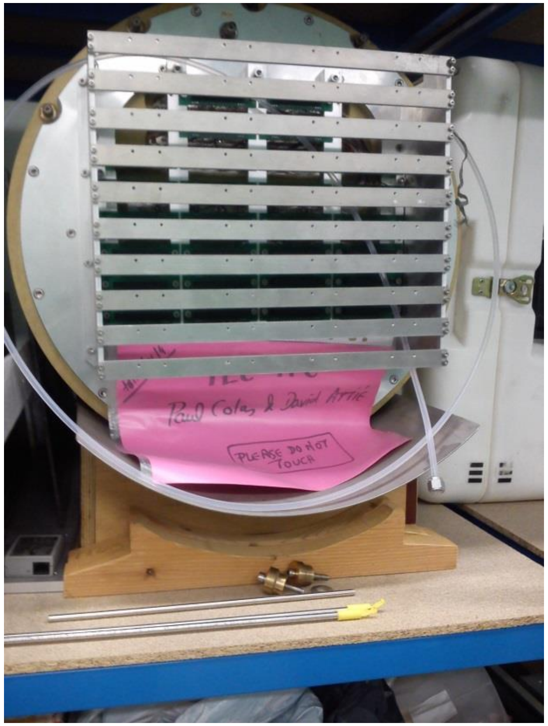


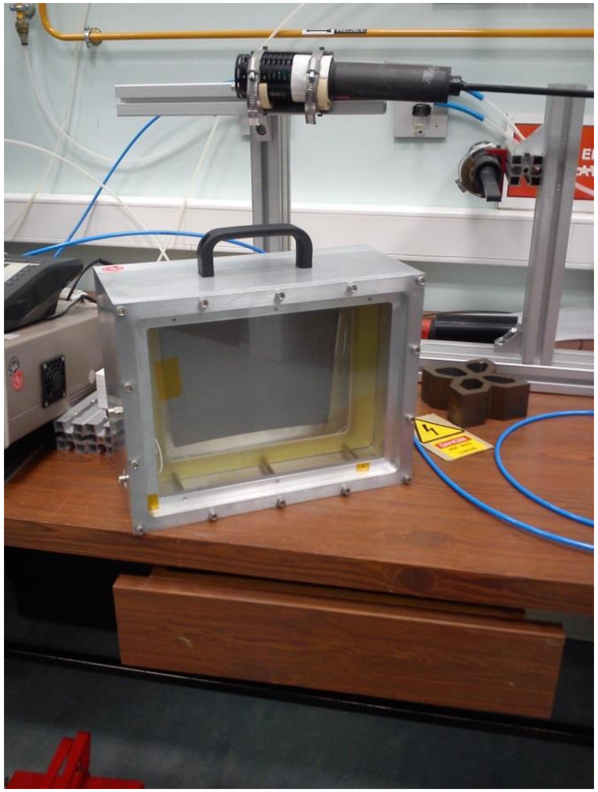
Charge Density (per 100 bunches

Distributions look similar
ILC charge density dominated by beamsstrahlung

R&D plans

- Use a small TPC in the lab, with cosmics
- Inject controlled amount of charge, using UV flashes
- Longer term : join ILC test-beam at DESY





Conclusions

- Z visible decays should induce a distortion of the same order of magnitude as for ILC case.
- Distorsion to be studied in more detail experimentally, and also numerically
- Understanding of beamsstrahlung necessary
- There is some margin to accomodate beamsstrahlung, even more if L=2.8 instead of 5.6 ($\times 10^{34}$)