TPC studies for FCC-ee

Philippe Schwemling

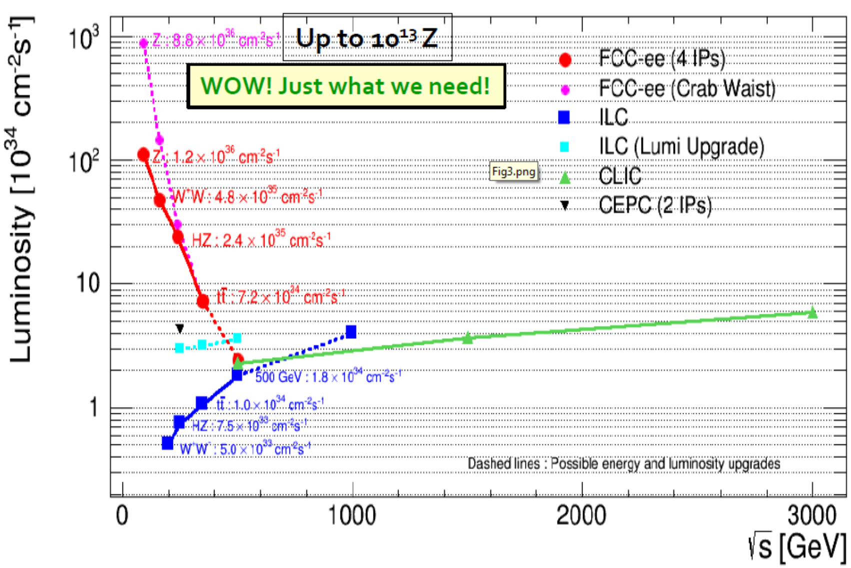
Outline

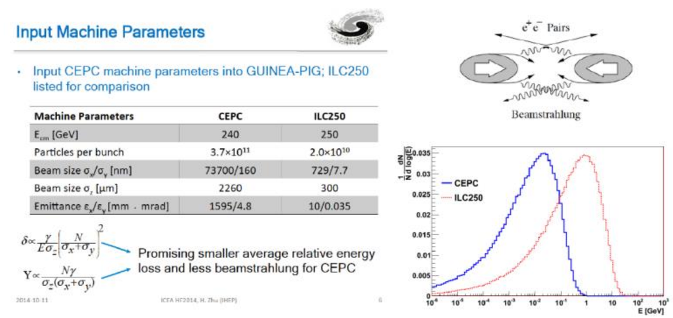
- Track distorsions due to charge stored in the TPC
- Performance estimation of tracking system (TPC+Si tracker)

Basic parameters

- Luminosity (at the Z peak) : 5.6 ($\times 10^{34}$)
  - Rates :
    - 16.8 kHZ hadronic Z decays (1 every 60 µs avg, or 1 every 270 BC)
    - 33,6 kHz Bhabhas (1 every 30 µs avg, or 1 every 135 BC)
    - Some γγ interactions from Beamstrahlung (maybe 100 times less ?)
- Numbers to be scaled up by

≈ 5 ?





Input Machine Parameters

- Input CEPC machine parameters into GUINEA-PIG; ILC250 listed for comparison

Machine Parameters	CEPC	ILC250
E_{cm} [GeV]	240	250
Particles per bunch	3.7×10^{11}	2.0×10^{10}
Beam size σ_x/σ_y [nm]	73700/160	729/7.7
Beam size σ_z [µm]	2260	300
Emittance $\varepsilon_x/\varepsilon_y$ [mm · mrad]	1595/4.8	10/0.035

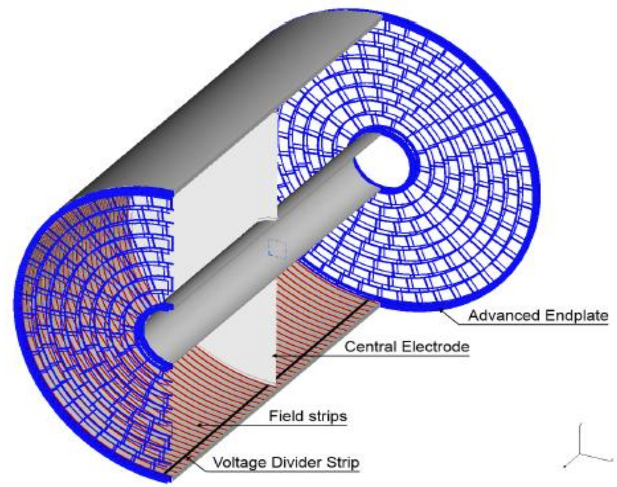
$\delta \propto \frac{\gamma}{E\sigma_z}\left(\frac{N}{\sigma_x+\sigma_y}\right)^2$

$\Upsilon \propto \frac{N\gamma}{\sigma_z(\sigma_x+\sigma_y)}$

Promising smaller average relative energy loss and less beamstrahlung for CEPC

M. Ruan, Paris Tlep workshop

ILD/TLep TPC parameters



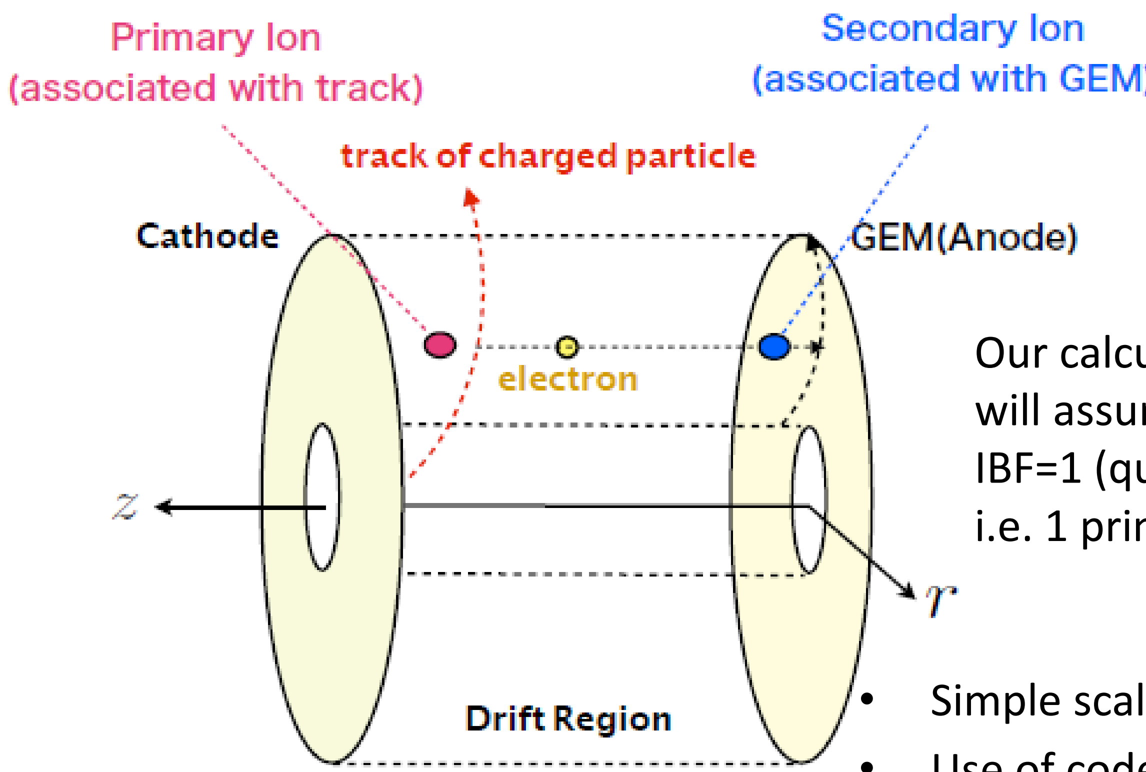
- R internal : 329 mm
- R out : 1808 mm
- Z length : 2×2350 mm
- Drift gas : Ar CF4(3%) isobutane (2%)
- B=4 T
- E = 350 V/cm (Arxiv 1006.3220v1)
- Inner cage at 400 mm (not 329)

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".



Our calculation will assume IBF=1 (quite aggressive), i.e. 1 primary ion ←→ 1 BF ion

- Simple scaling of studies done at IL
- Use of codes developed for ILC

➡ There are Primary Ion and Secondary Ion in TPC.

Distorsions estimation procedure

- Estimate charge distribution of ions stored in TPC volume (primaries and back-flow)
- Use Pythia to have an estimate of track length

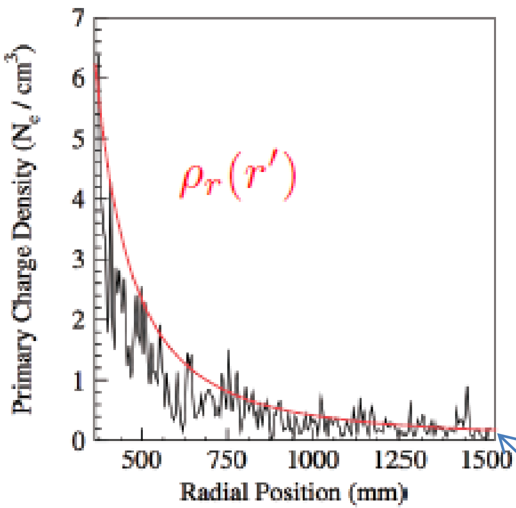
per event (proportional to N electrons/ions, assume typical 40 e/ion pairs per cm)

1) Do simple scaling with ILC results
2) Use ILC distorsion computation program (from Keisuke Fuji)
   - Produce analytical parameterization of $\rho(r,z)$
   - This code assumes that that $\rho(r,z)=\rho_r(r)\times\rho_z(z)$
   - This holds rigorously for backflow ions (created at zmax), not for primaries
   - No experimental validation of the code, but computations it does are in principle straightforward.

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.

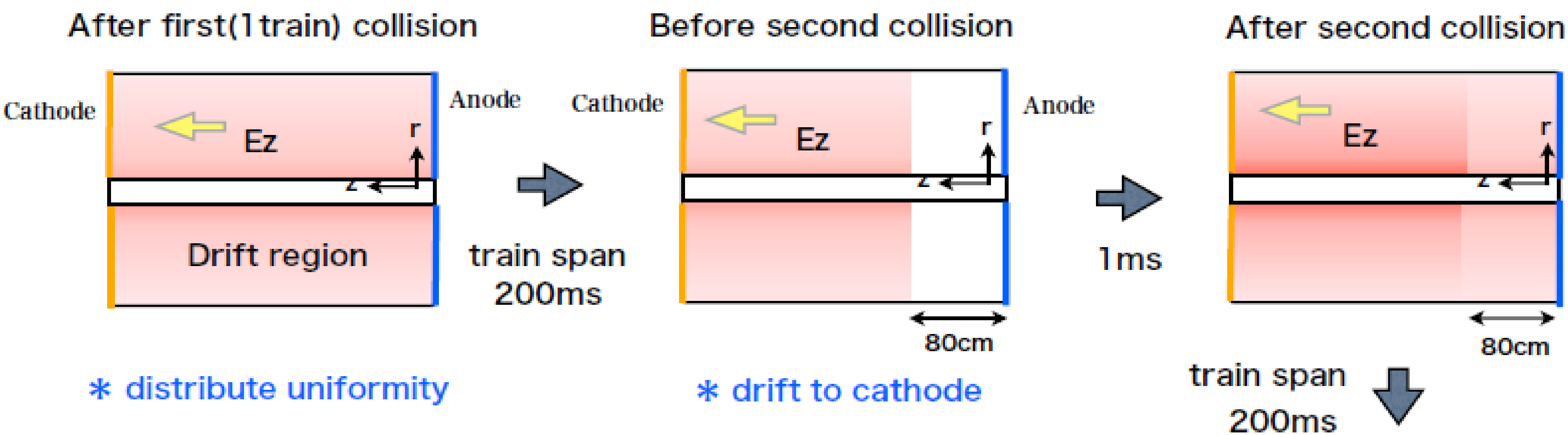
Integrate this function over
R_in=400 mm, R_out=1808 mm
Zmax=2350 mm, dV=2π r dr dz →
Nions=11*10^6 (100 bchs,Rin=400)

(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

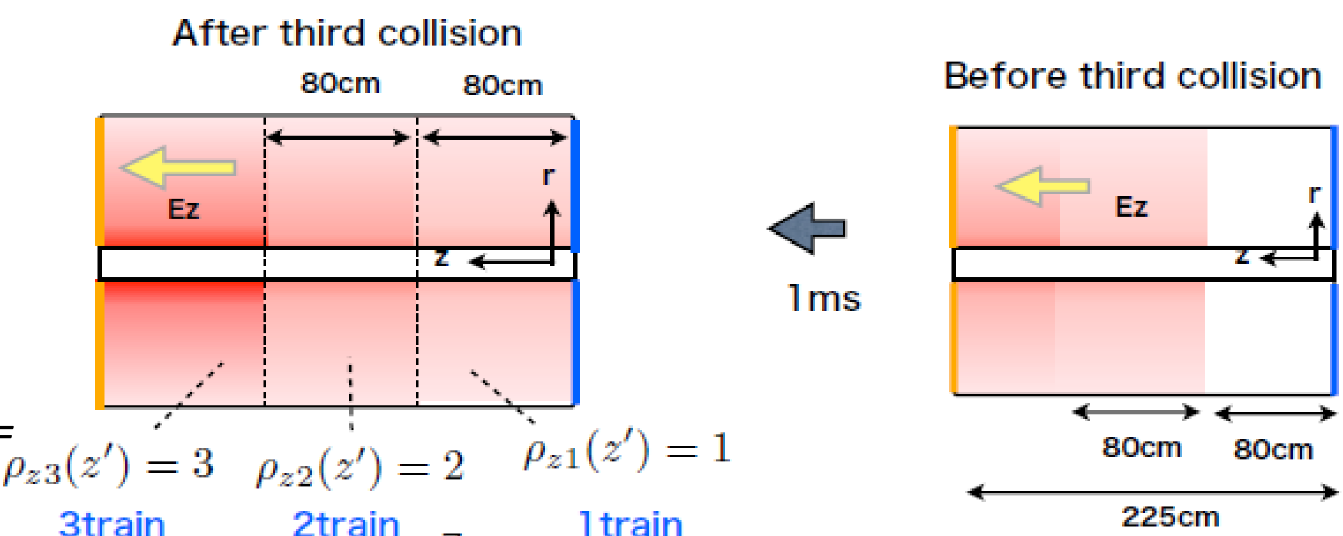
We think charge distribution on z-direction is constant.



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

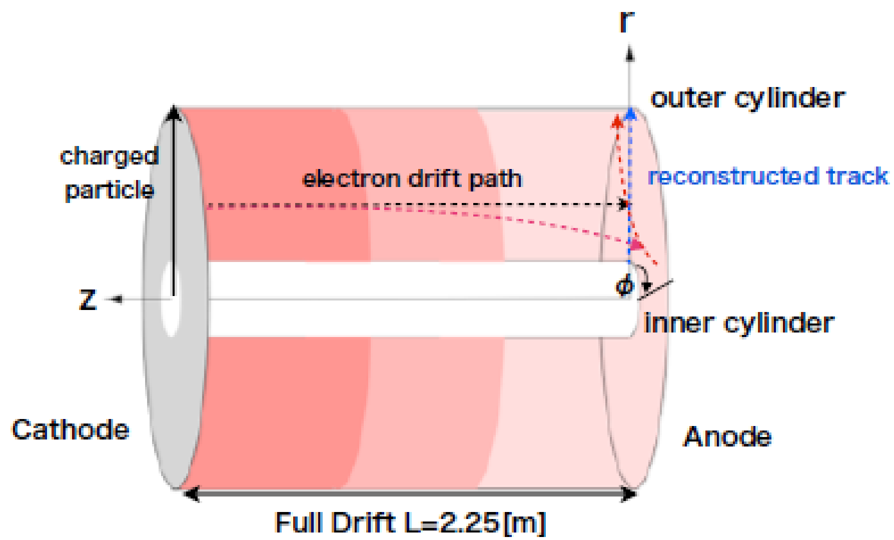
*Total charge in TPC is (3/3+2/3+1/3)ρ(1train)= 2ρ(1train)=0.66*3= 3000/100*2*ρ(100 bch)=*

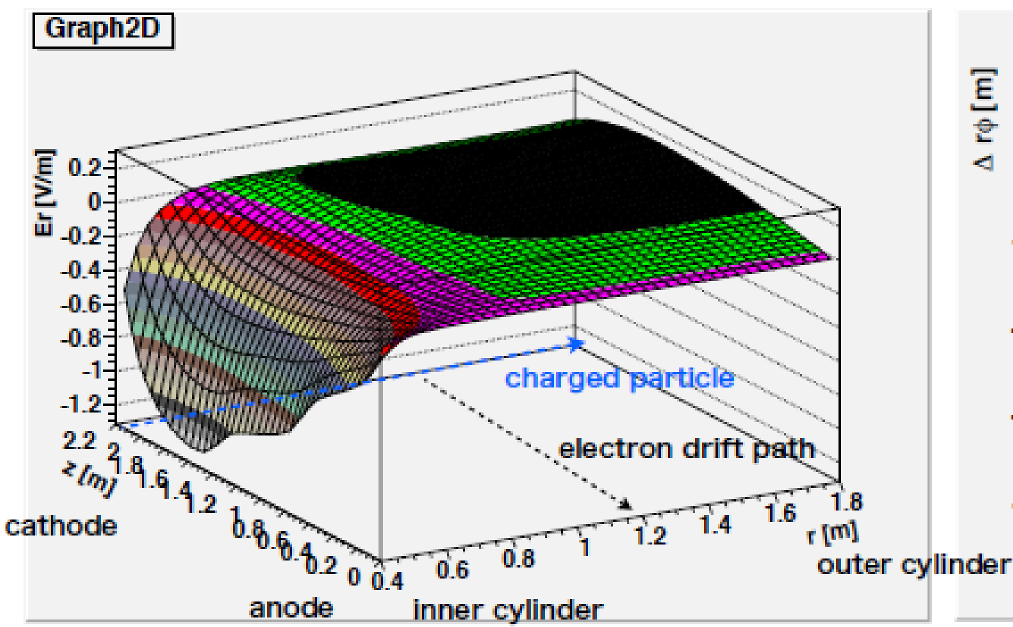
*0,66*10⁹ Nions*



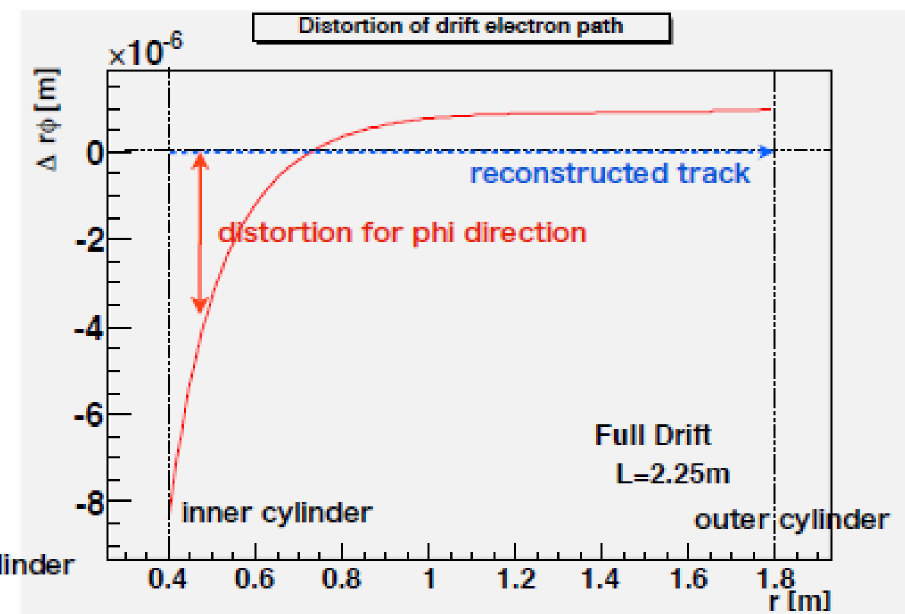
Result

Primary Ion





Efield map



Distortion of drift electron path (Full drift)

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

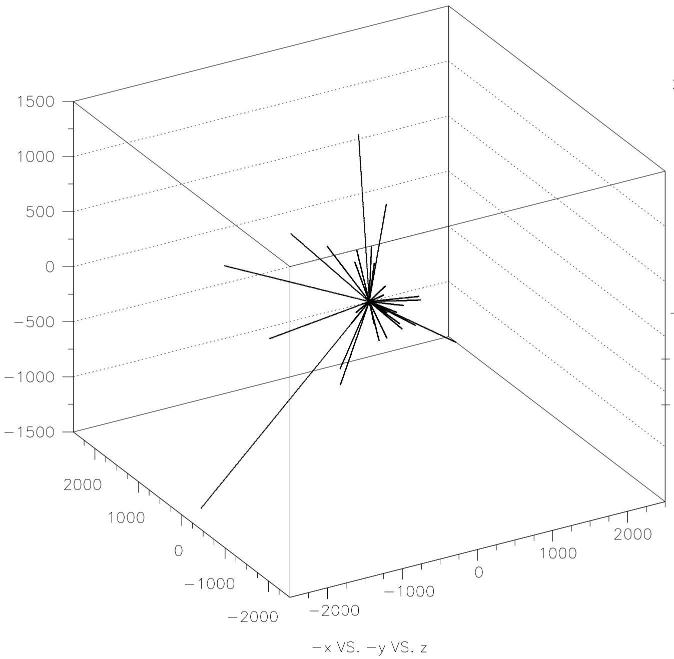
How much ion charge in FCC-ee/Tlep TPC ?

- Z hadronic decays : 16.8 k Hz. Corresponds to

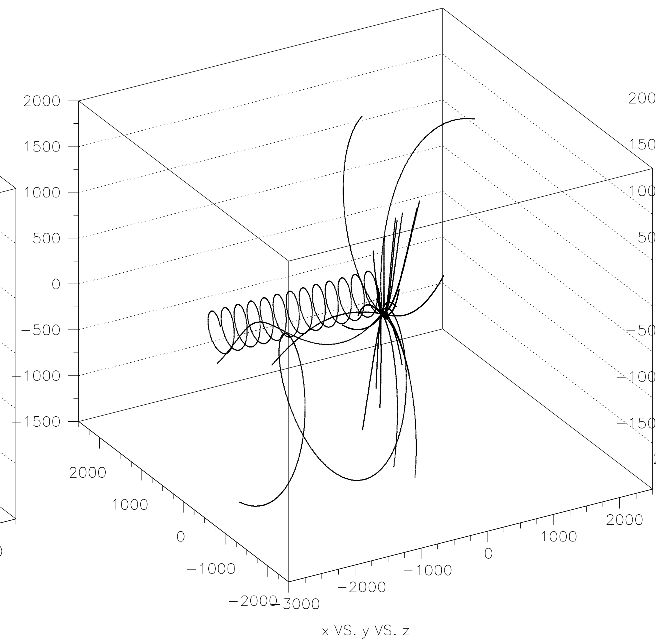
19.22 visible (lept+had) Z decays

- 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

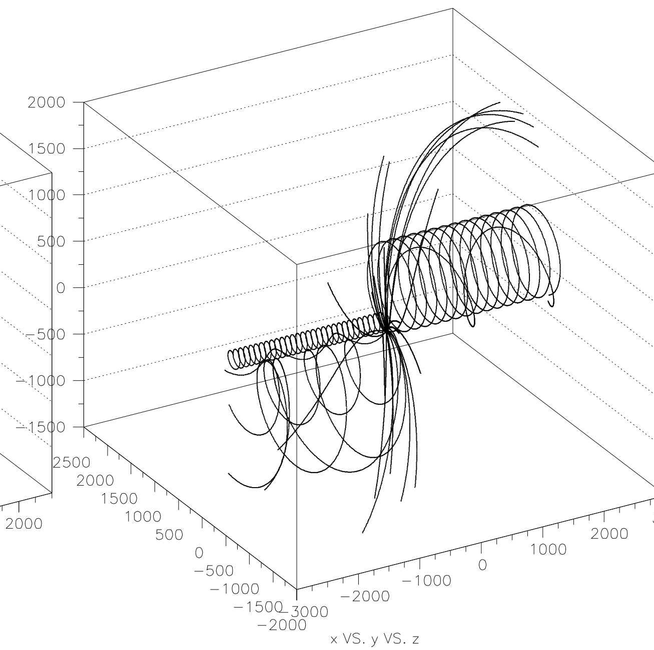
Hadronic Z decays



B=0



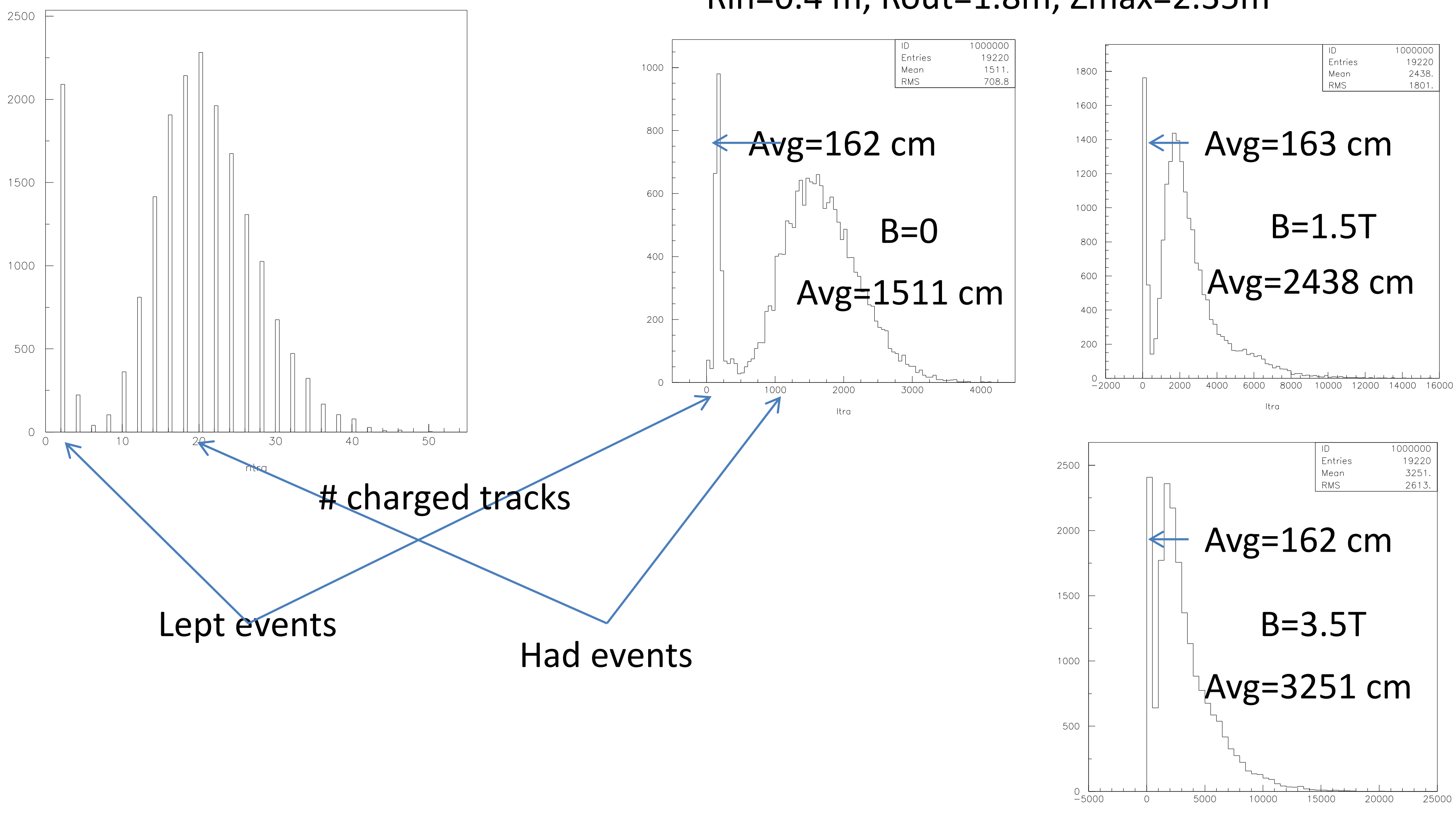
B=1.5 T



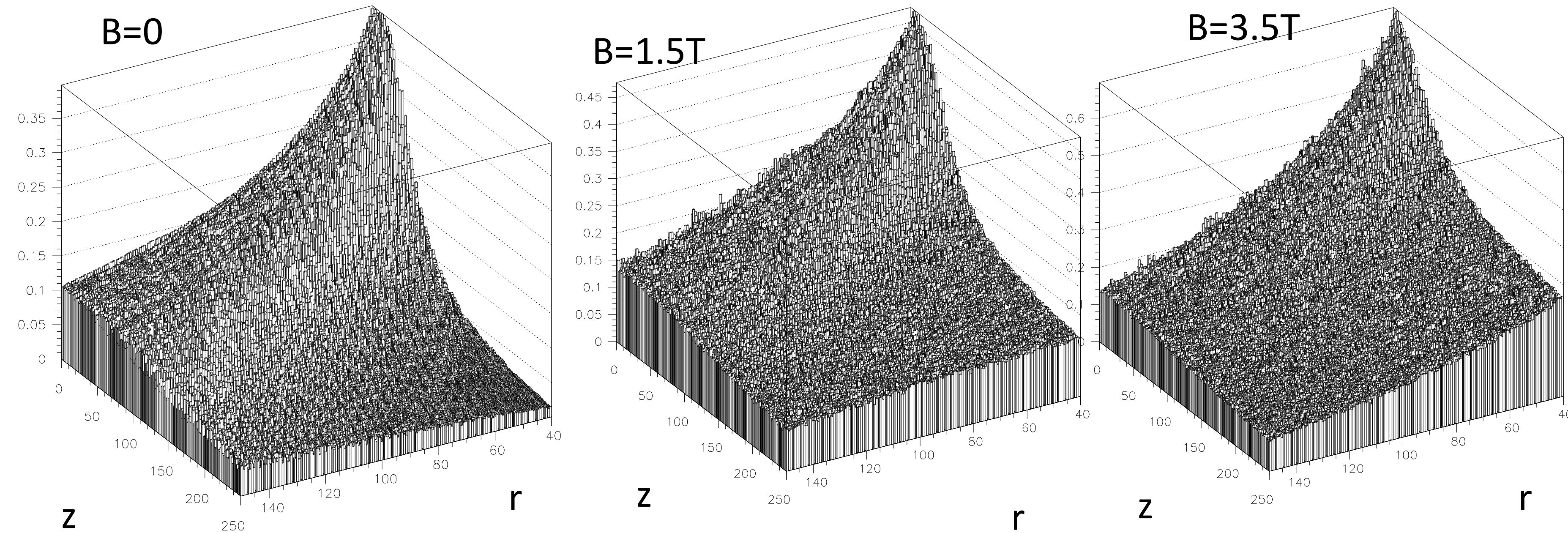
B=3.5 T

Number of tracks and track length

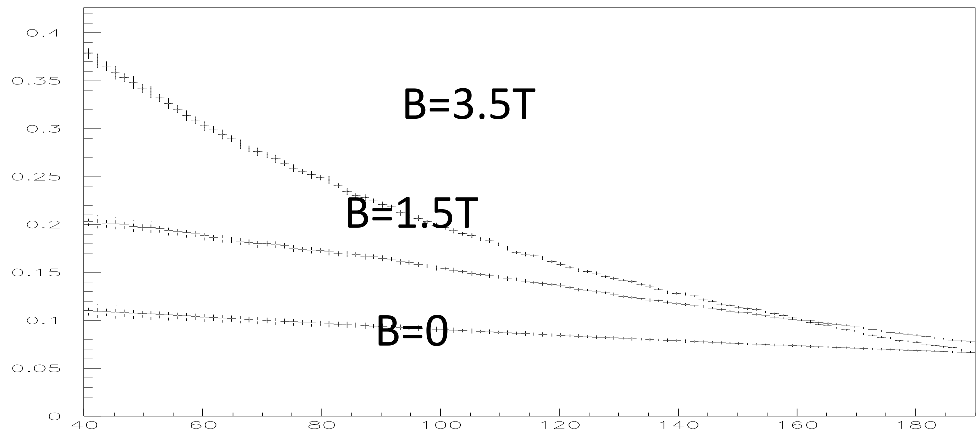
Gas length traversed/ionised per event (cm)
Rin=0.4 m, Rout=1.8m, Zmax=2.35m

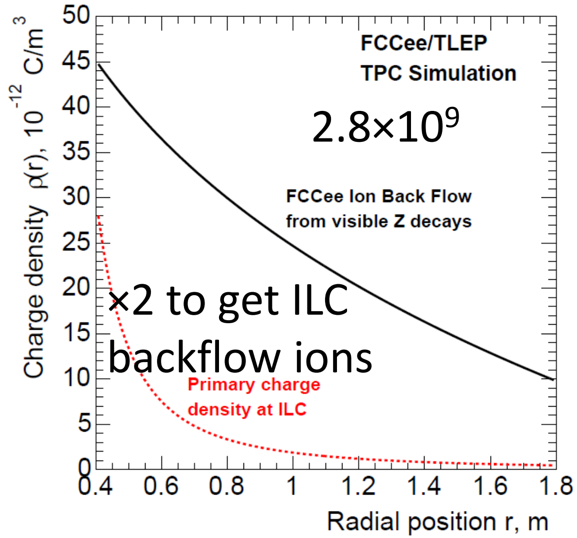


Charge distribution (one event)

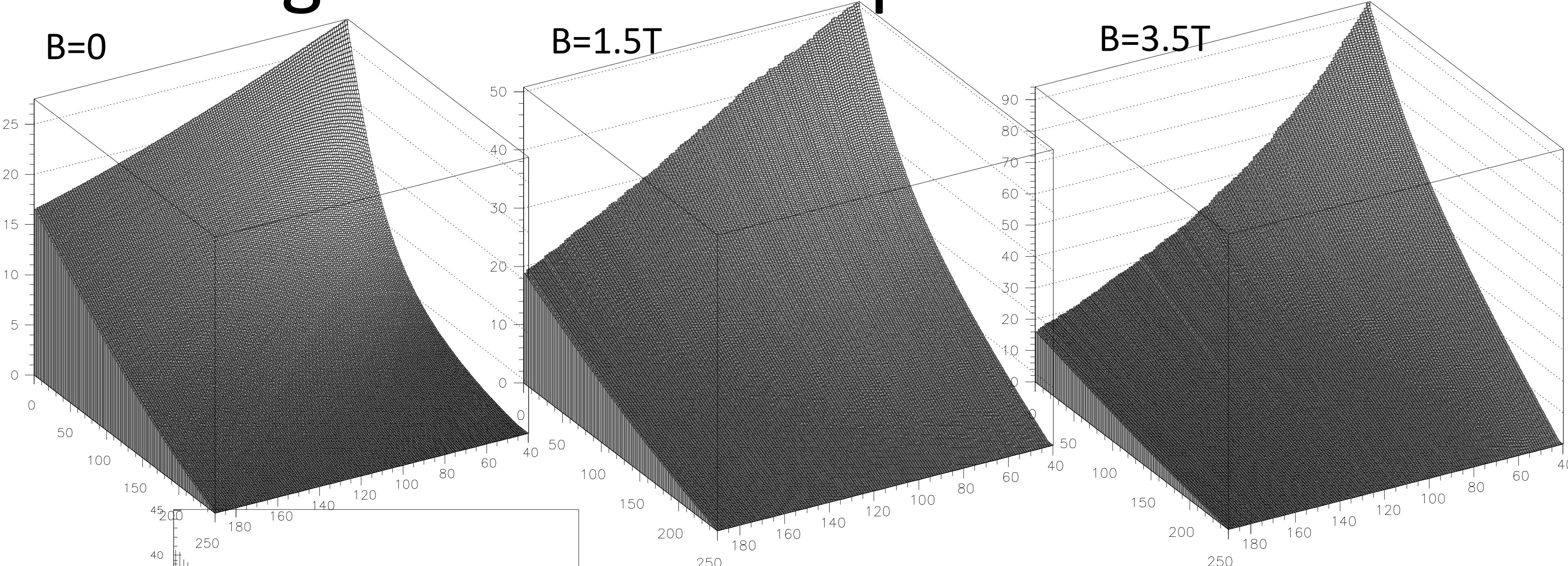


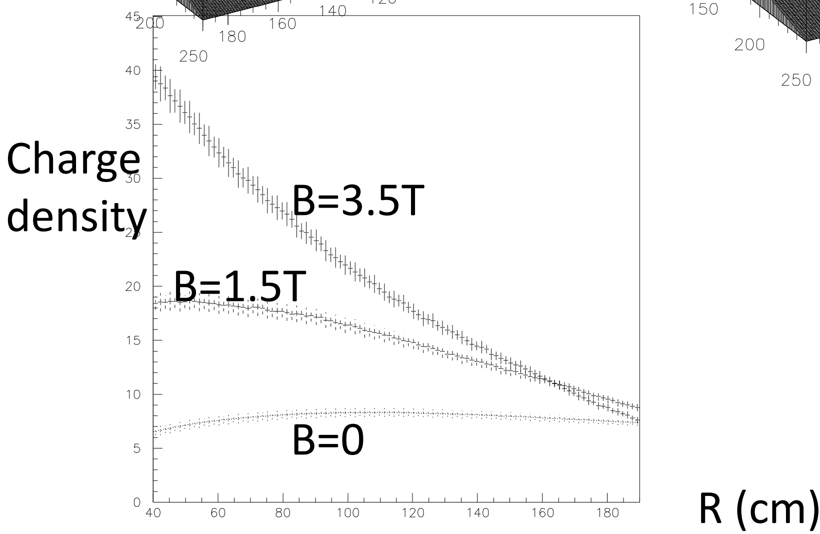
Charge density from one event





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
ILC : 0.66

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

- 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)

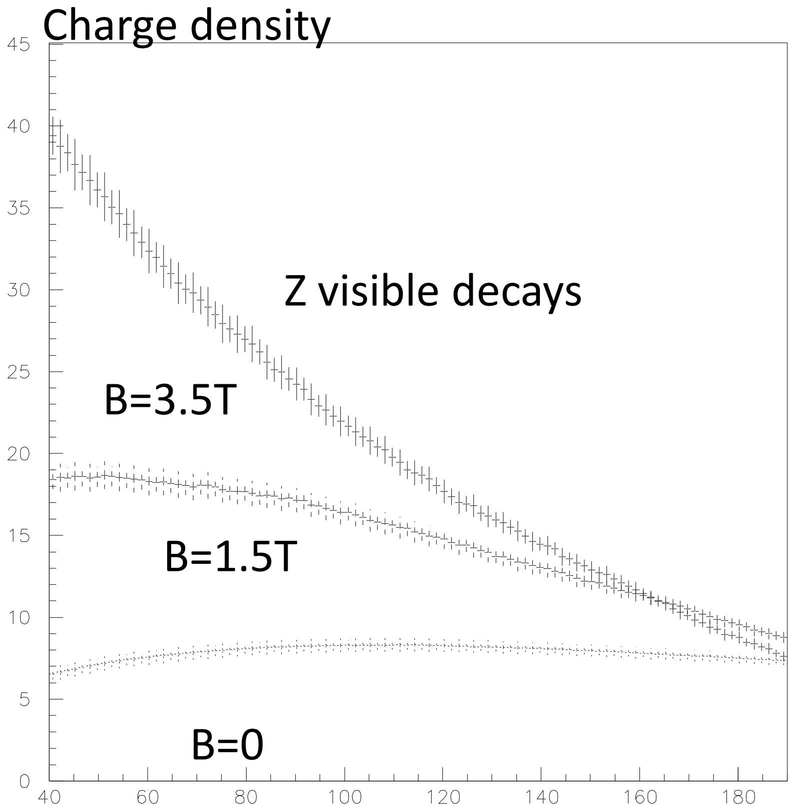
  $0.70*10^9$ Ions (B=3.5 T), $2.8*10^9$ Ions backflow

→ Expect 35 μ max distorsion from primaries

- From Bhabhas : 162*33600*0.37*0.6*40=

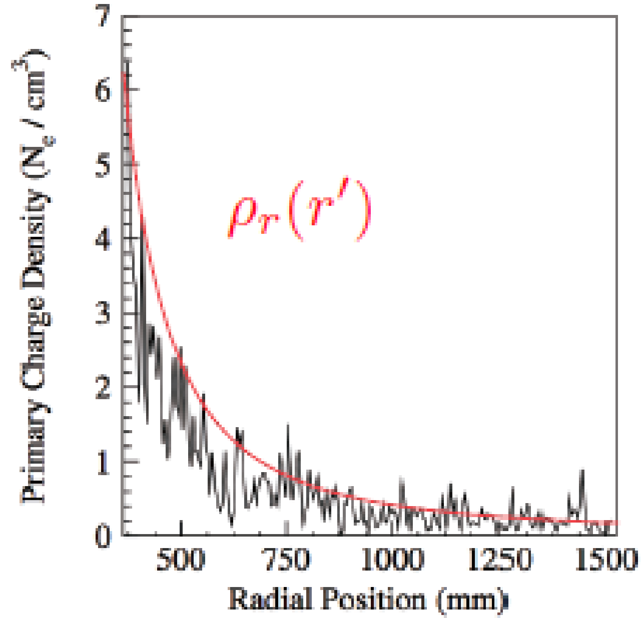
  $0.04*10^9$ Ions

Qualitative comparison Tlep/ILC



r

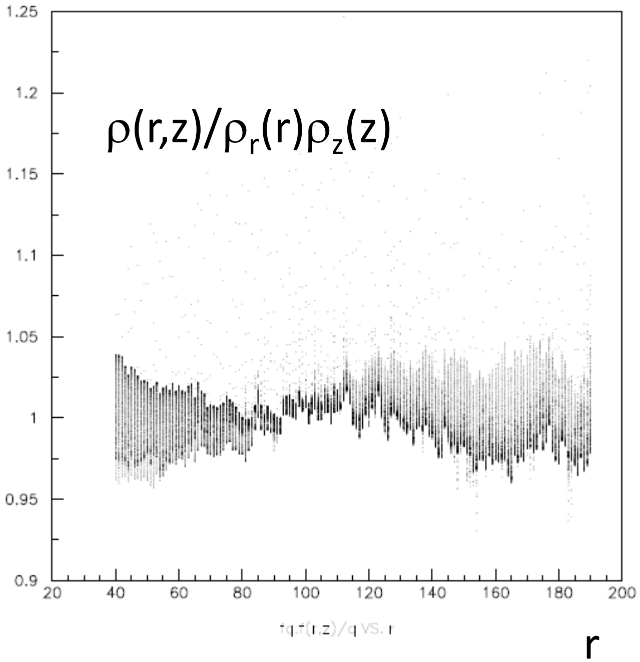
ILC simulations



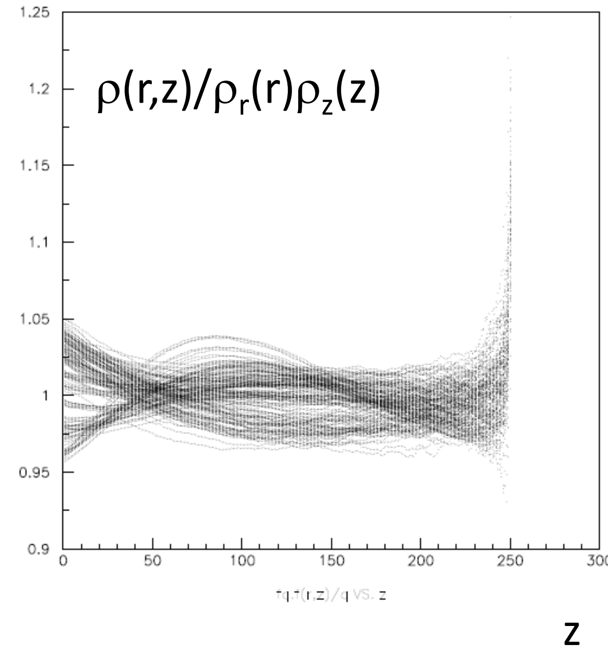
Charge Density (per 100 bunches

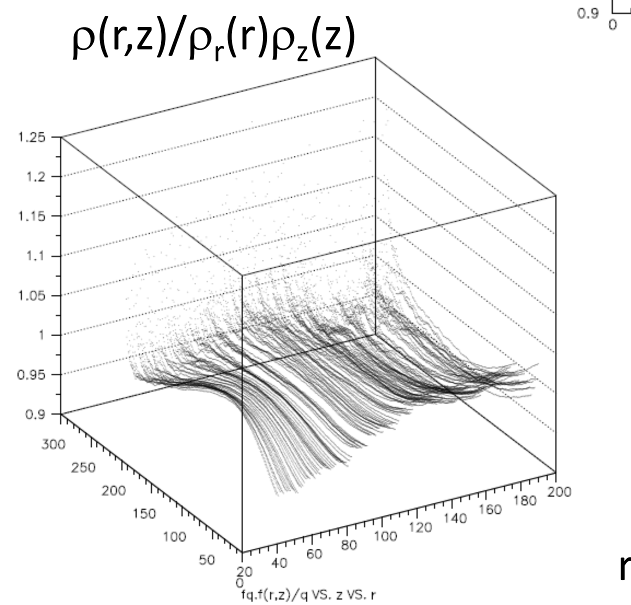
Charge distributions quite different,
ILC simulation more peaked at low radius : Inclusion of low Pt backgd ?

Primary ions : parametrization as $\rho(r,z)=\rho_r(r)\rho_z(z)$



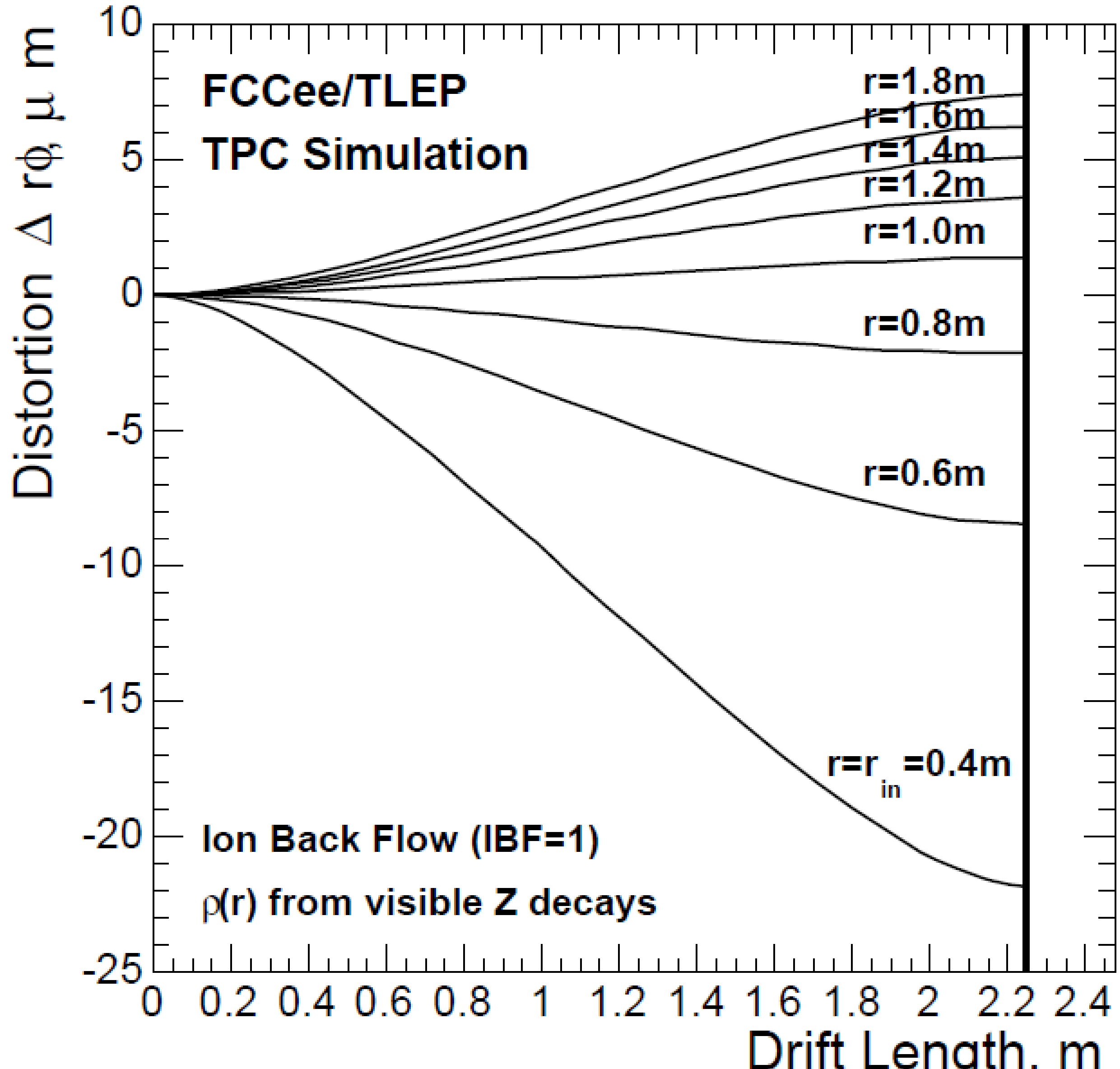
Factorization
holds at 10-20% level



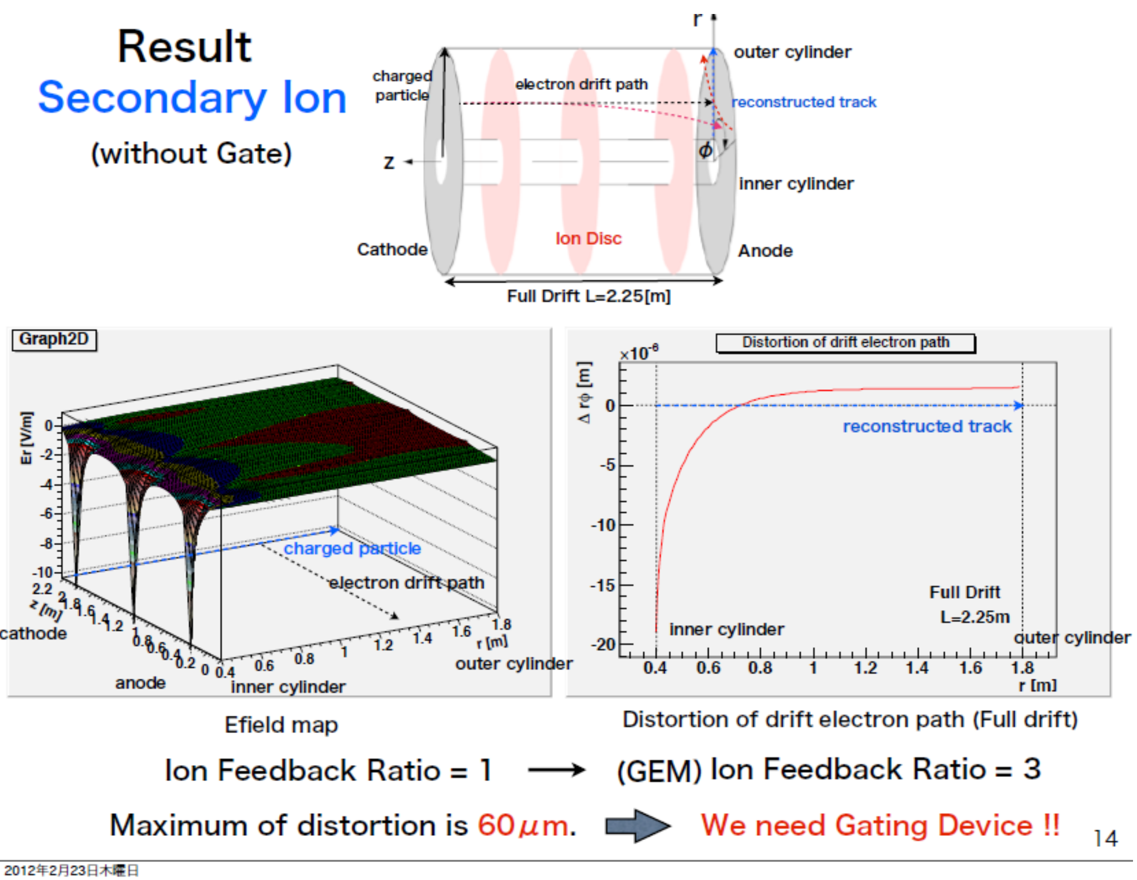


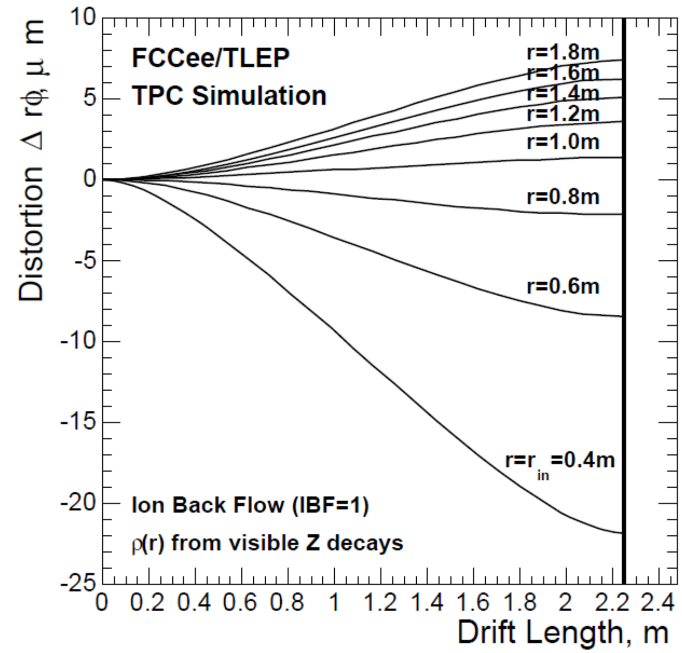
Effect on distorsion of
non-factorization to
be evaluated

Electron trajectories



Comparison with ILC

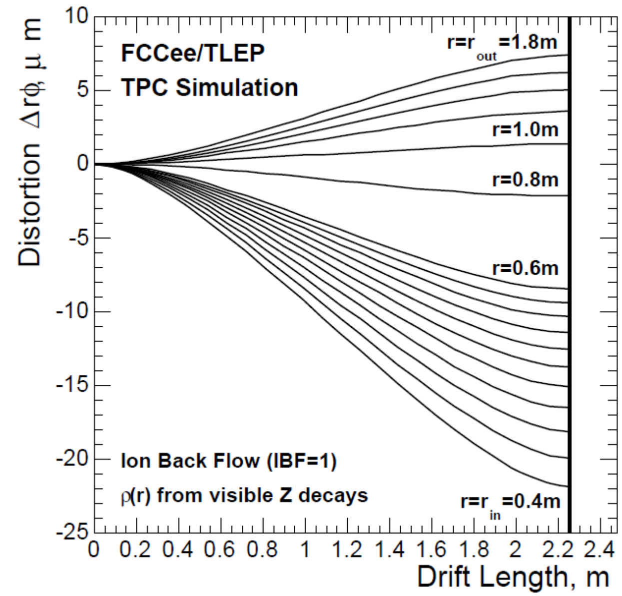




Same order of magnitude

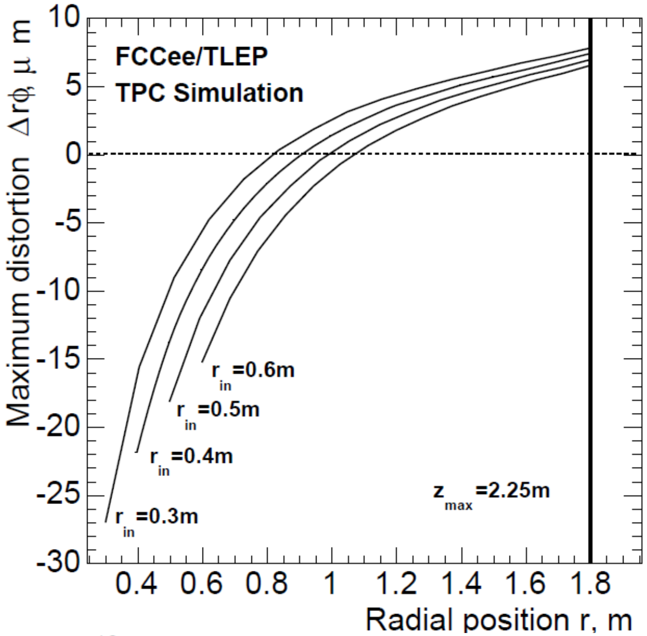
Comments

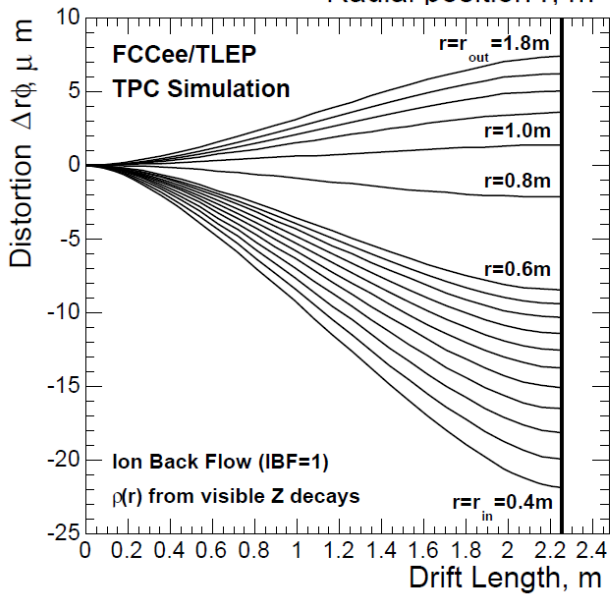
- Distorsion comparable with ILC results
- Not much margin to stay below 100 µm
  - IBF=1 quite aggressive
  - Luminosity at Z peak up to $10^{36}cm^{-2}s^{-1}$
- Possible handles
  - Increase TPC minimum radius ?
  - Decrease somewhat B field ?



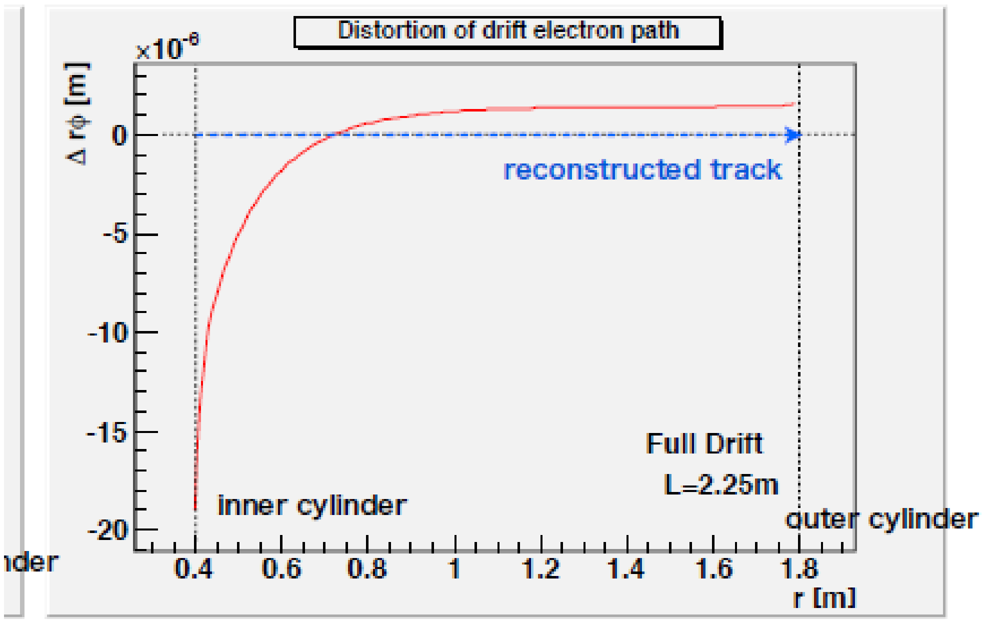
- A trade-off has to be found between tracker resolution and risk of loosing low momentum tracks…

Effect of inner radius increase





ILC (Backflow)



Distortion of drift electron path (Full drift)

Idres (pointed to me by Sergei)

The ATLAS Experiment

High Luminosity Upgrade

The program idres calculates the error matrix of the track-fit parameters for magnetic tracking spectrometers. Tracks are described by five helix parameters at the origin. The resolution for these parameters depends on the magnetic field B, the initial track transverse momentum Pt, the track angle eta, as well as on the geometry, radiation length and resolution of the detectors that do the tracking.

The program is based on the mathematics given in the note "Parameterisation of the Inner Detector Performance" by E-J Buis, R Dankers, A Reichold, S Haywood, 21 Jan 1998 - ATLAS Inner Detector note 97-195 . Idres can now handle both perfect solenoidal fields and imperfect ones, given as a table of values of (B_r, B_z) on an (r, z) grid, carrying out the double B-integrals in the Buis et al. document.

Input

All the parameters needed by idres are supplied in an external file (a simple text file). The file contains a list of B-fields, transverse-momenta, and eta angles followed by a description of the detector layout as cylinders or discs, each with the radiation length and resolutions (precision and second coordinates) given. The data is "free-format" - items are separated by white space or end-of-lines. You can spread the input out over as many or few lines as you want. Best is to get an example file and amend it; the exact input definition is given below:

Units: magnetic field in T; lengths in m (including resolutions); momenta in GeV/c; angles as pseudo-rapidity except for B-field integration angles, which are given in radians

Key:

```
() groups things together (e.g. before a ...), but leave out of your file

<> Replace angle-brackets and contents with desired value

... Repeat the preceding item as often as needed

[ |   | ...] Select one of the items

Any other characters should be given literally (as keywords) (probably case-sensitive).
```

Input definition:

```
[B <b-field | files <Brfilename> <Bzfilename>  >... end |
 bIntegral <nStepsR> <rMin> <rMax> <nStepstheta> <thetaMin> <thetaMax>  |
 eta <eta>... end |
 pt <Pt>... end |
 cylinder
     (<radius> <zstart> <zend> <%X0> <sigma-rphi> <sigma-z>)...
 end |
 disc
     (<inner-radius> <outer-radius> <z> <%X0> <sigma-rphi> <sigma-r>)...
 end |
 cone
```

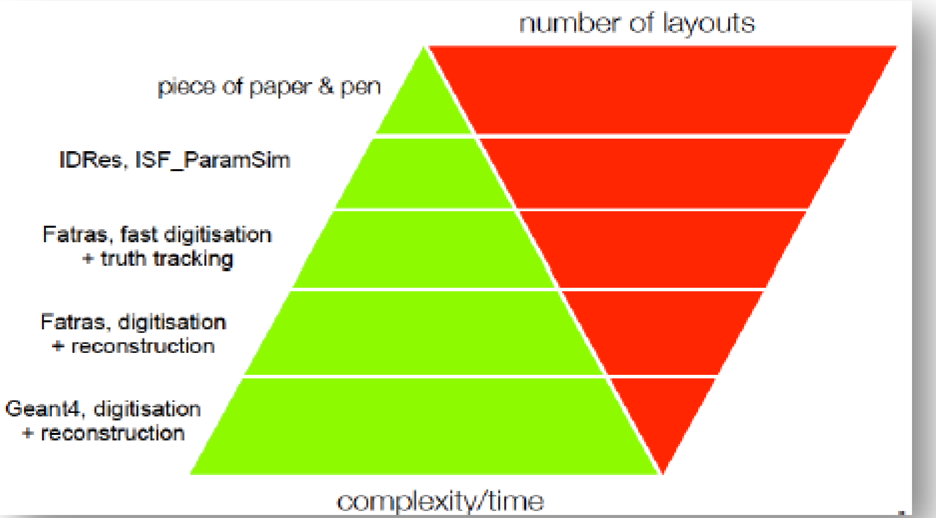
Idres advantages

- Code is easy to use
- Encoding of geometry very simple
- Can be used also for fcc-hh
- Can work with complicated B topology : accepts B-maps

ITK week, 23/02/2015

How to choose the best layout

- The main scope of the ILTF is to identify the best layout, with a shared and agreed choice in the community.
- There is no way to fully evaluate the performance of all the ones around.

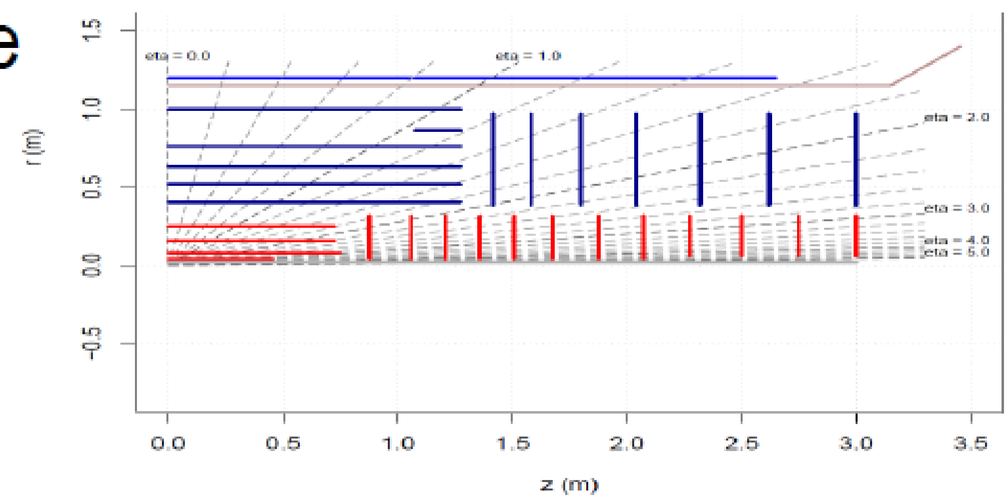


A.Salzburger
https://indico.cern.ch/event/355826/

- The consideration to reduce the number of layouts as the evaluation of the performances increases in complexity is pretty obvious.
- But how to do it? We do not want any *a priori* cut - including not enough manpower to support and evaluate the project if valuable.

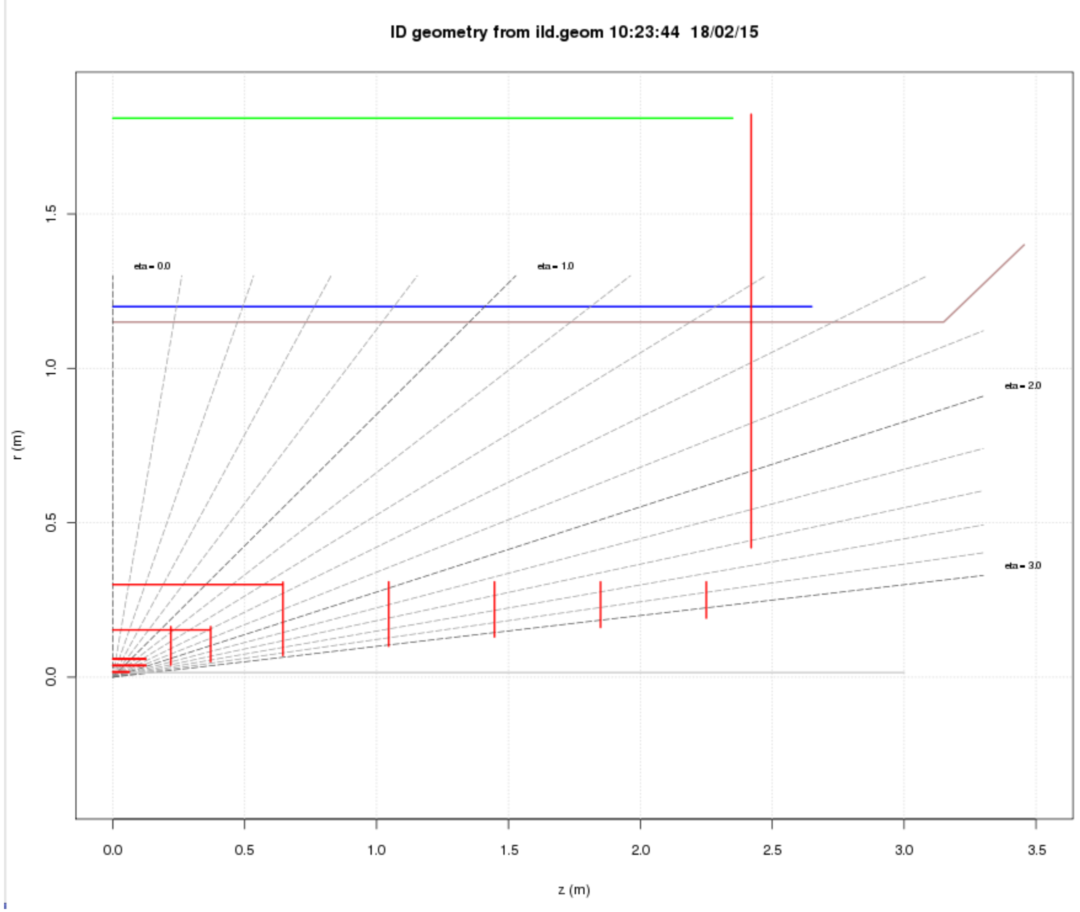
Tools: IDRes

- For fast initial layout studies
- Traces muon like particles through thin measurement layers with a specified resolution
- Can provide:
resolutions, some material effects, hit coverage, hermeticity
- Some extensions possible



Status

- ILD geometry fully encoded



ILD layout as encoded

The current layout of the proposed vertex detector is summarised in Table III-2.1. It is based extensive simulation and technical studies. The parameters are considered conservative.

Table III-2.1
Vertex detector parameters. The spatial resolution and read-out times are for the CMOS option described in section 2.1.2.1.

	R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ (μm)	Readout time (μs)
Layer 1	16	62.5	0.97	2.8	50
Layer 2	18	62.5	0.96	6	10
Layer 3	37	125	0.96	4	100
Layer 4	39	125	0.95	4	100
Layer 5	58	125	0.91	4	100
Layer 6	60	125	0.9	4	100

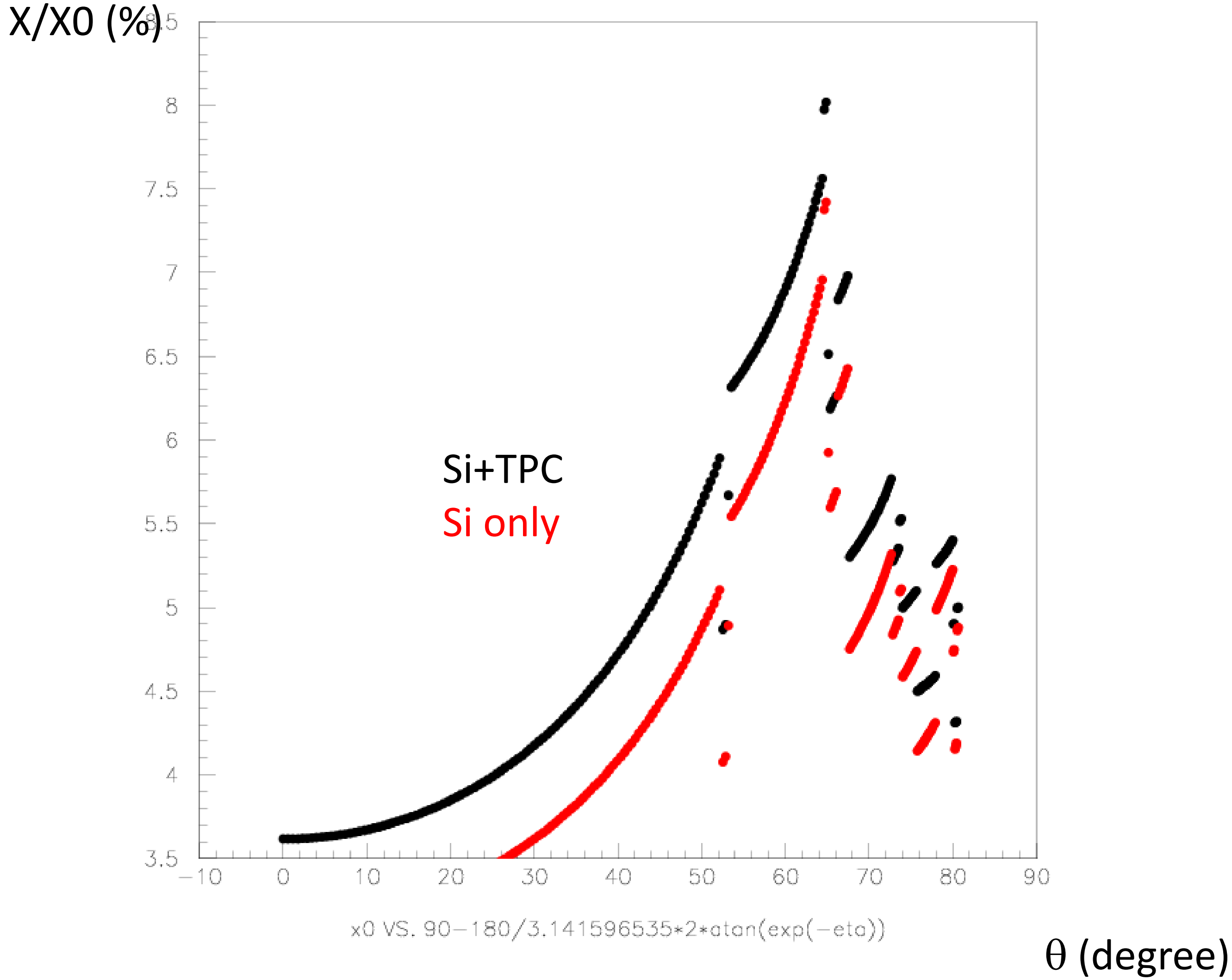
Table III-2.2
Main parameters of the central silicon systems SIT, SET, and ETD.

SIT (baseline = false double-sided Si microstrips)					
Geometry			Characteristics		Material
R [mm]	Z [mm]	cos θ	Resolution R-ϕ [μm]	Time [ns]	X_0 [%]
153	368	0.910	R: σ=7.0	307.7 (153.8)	0.65
300	644	0.902	z: σ=50.0	σ=80.0	0.65
SET (baseline = false double-sided Si microstrips)					
Geometry			Characteristics		Material
R [mm]	Z [mm]	cos θ	Resolution R-ϕ [μm]	Time [ns]	X_0 [%]
1811	2350	0.789	R: σ=7.0	307.7 (153.8)	0.65
ETD (baseline = single-sided Si micro-strips)					
Geometry			Characteristics		Material
R [mm]	Z [mm]	cos θ	Resolution R-ϕ [μm]		X_0 [%]
419.3-1822.7	2420	0.985-0.799	x: σ=7.0		0.65

Table III-2.3
Layout of the Forward Tracking Disks. The quoted single hit resolution for the pixel disk depends on its technological implementation which has also an effect on the material budget.

FTD (baseline: pixels for two inner disks, microstrips for the rest)				
Geometry			Characteristics	Material
R [mm]	Z [mm]	cos θ	Resolution R-ϕ [μm]	RL [%]
39-164	220	0.985-0.802		0.25-0.5
49.6-164	371.3	0.991-0.914	σ=3-6	0.25-0.5
70.1-308	644.9	0.994-0.902		0.65
100.3-309	1046.1	0.994-0.959		0.65
130.4-309	1447.3	0.995-0.998	σ=7.0	0.65
160.5-309	1848.5	0.996-0.986		0.65
190.5-309	2250	0.996-0.990		0.65

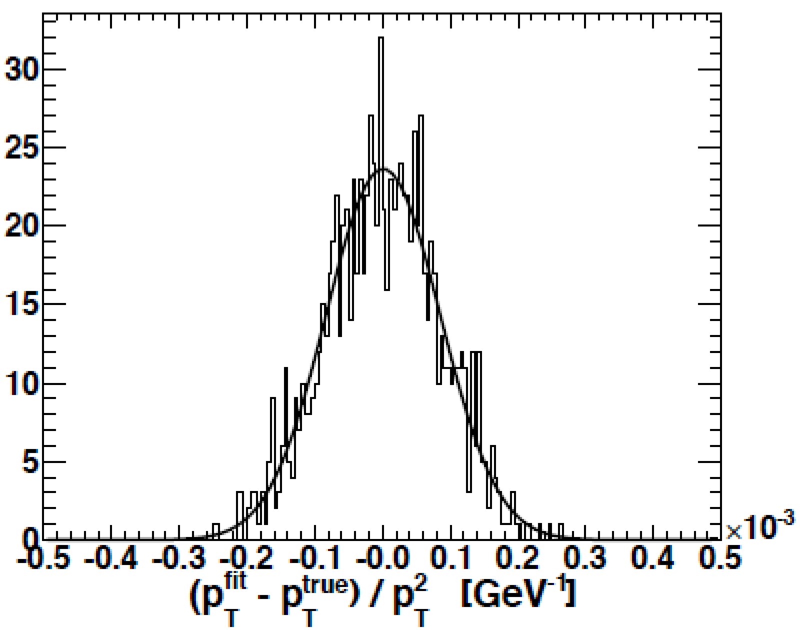
Material budget estimates



Validation plots

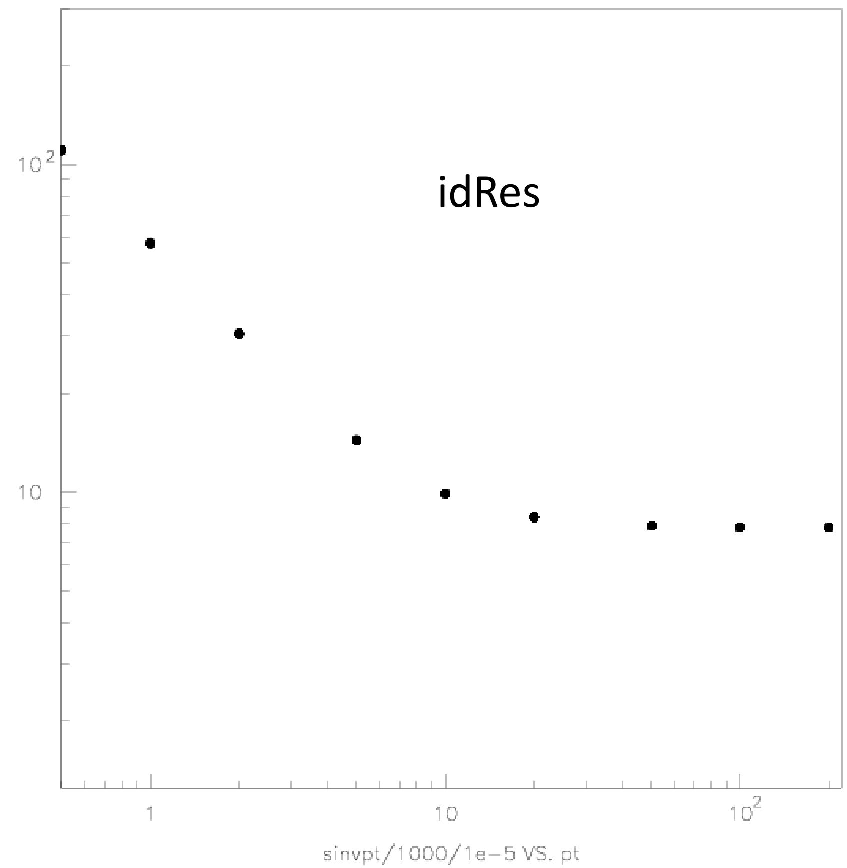
Plot F. Couderc TPC only

$\sigma_{r\varphi} = 100\mu m$



$\Rightarrow \sigma(1/pT) = 8.5 \times 10^{-5}$ / GeV

$\sigma(1/Pt)\times10^{-5}$

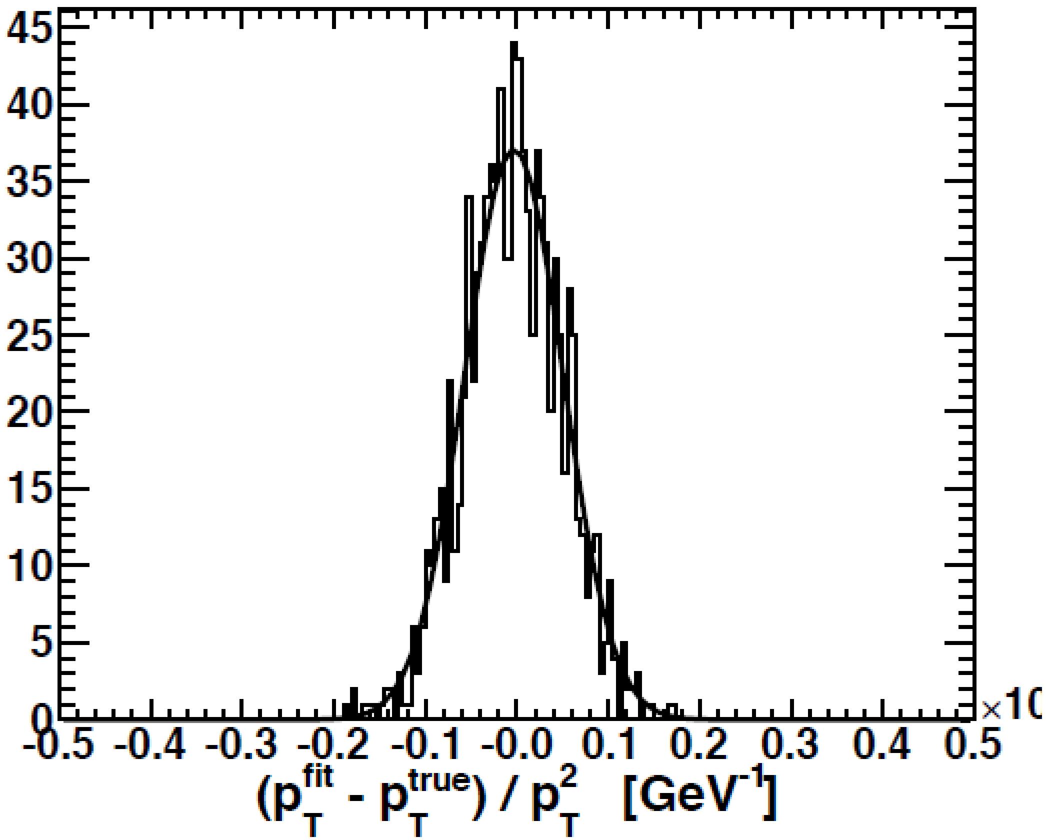


Pt

Validation plots

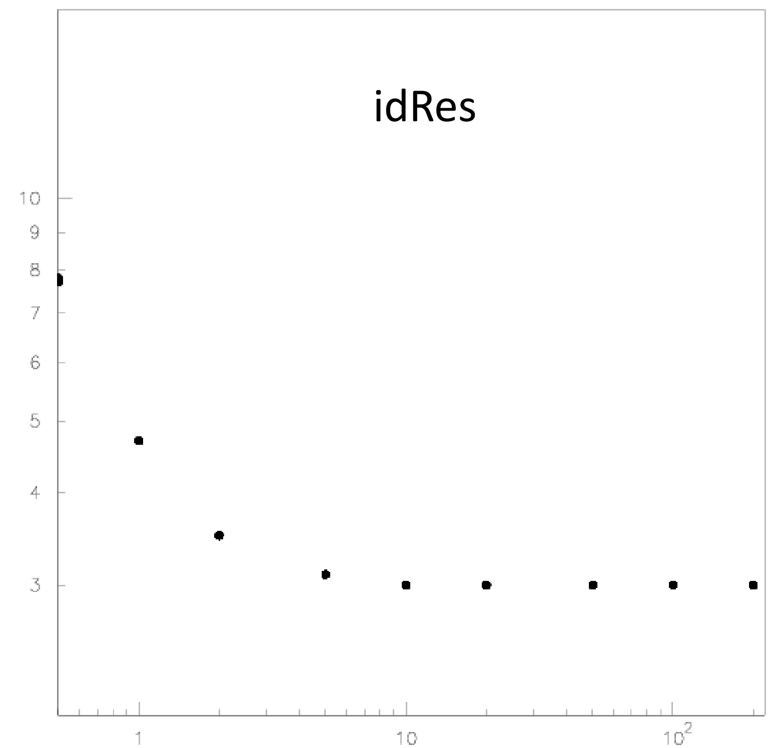
Plot F. Couderc

Only Si tracker



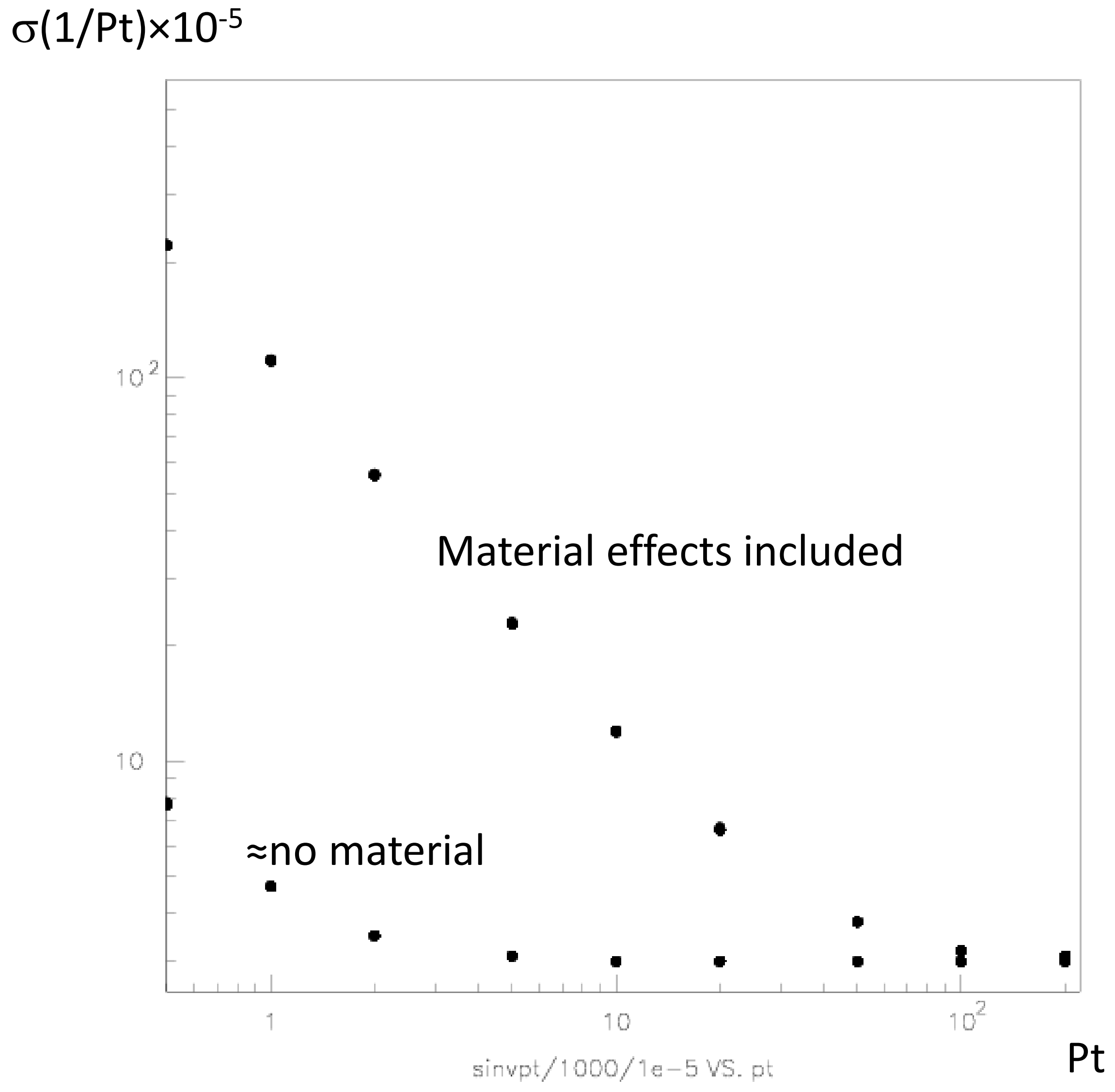
$\Rightarrow \sigma(1/pT) = 5.4 \times 10^{-5}$ / GeV

$\sigma(1/Pt) \times 10^{-5}$

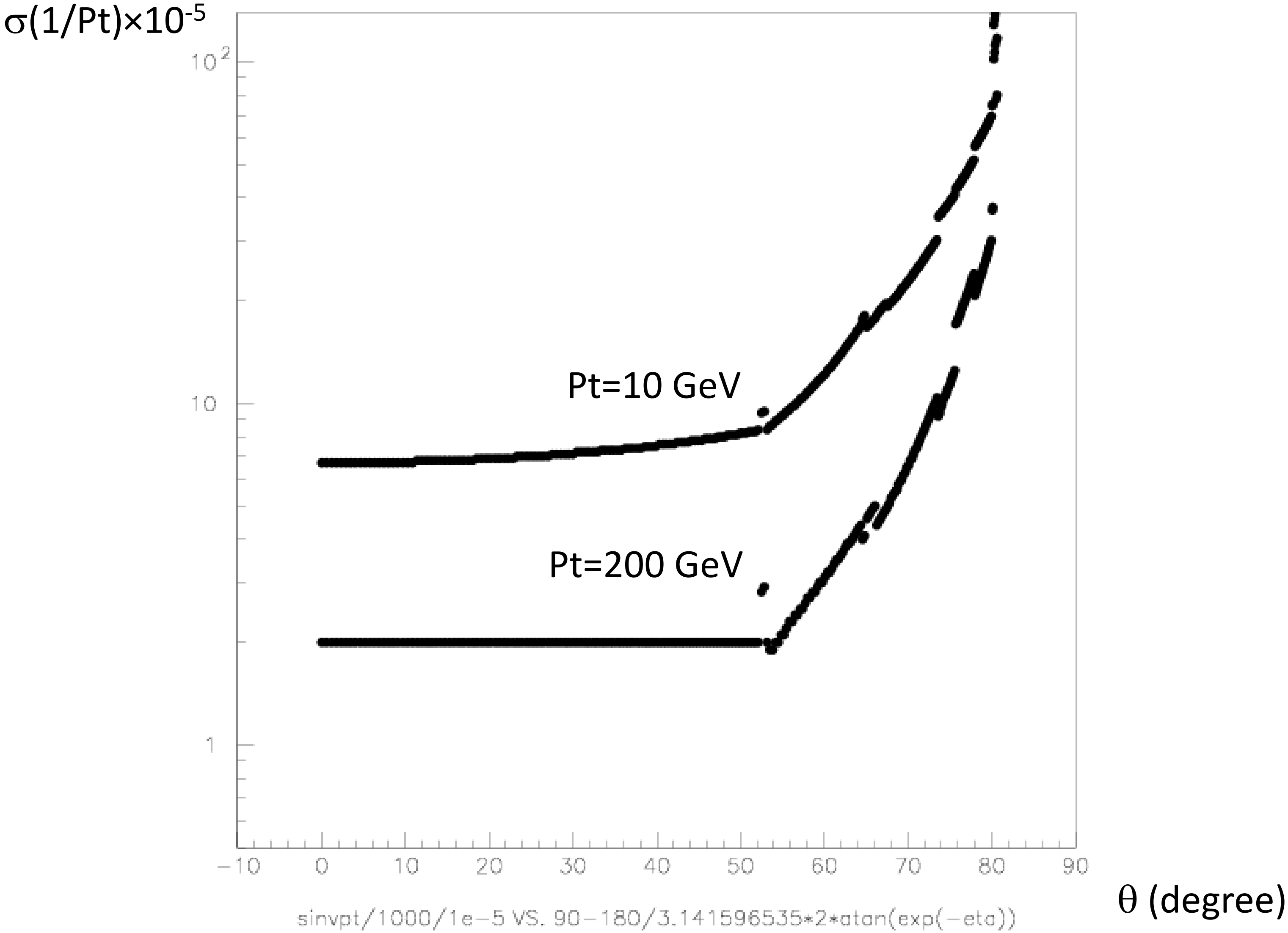


Pt

Material effects, Si only



Angular dependance (Si+TPC)



Conclusions

- Z visible decays should induce a distortion of the same order of magnitude as for ILC case.
- There is no margin in the design if L goes up to $10^{36}cm^{-2}s^{-1}$
- Correct distorsion event by event ?
- Assess what the tracker resolution has realistically to be at the Z peak (probably less than at ZH production)

Points to be studied

- Distorsion evaluation to be confronted to experimental studies
- Define what is the resolution target at the Z peak → benchmark channels to be defined and studied
- Do combined optimization of TPC+Si tracking system

Backup