# Gaseous Main Tracker for Higgs Factory

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# FCC-*ee* Detector Requirements (from [2505.06781](2505.06781))

Table 2: Schematic overview of FCC-ee Detector Requirements.

| Physics programme | Detector Requirements |
|---|---|
| **Higgs Factory**<br>- At $\sqrt{s} = 240$ GeV and 365 GeV, collect 2.6M HZ and 150k WW $\rightarrow$ H events<br><br>- Higgs properties: mass and width, couplings to fermions and bosons, self-coupling measurement via loop diagrams | - Momentum resolution $\delta(p_T)/p_T \simeq 10^{-3}$ at $p_T \simeq 50$ GeV<br><br>- Jet energy resol $\delta(E)/E \simeq$ 3–4 % for Z/W/H classification<br><br>- Superior impact parameter resolution for b, c tagging<br><br>- Charged hadron PID for s tagging |
| **Precision electroweak**<br>- Collect $6 \times 10^{12}$ Z and $2.4 \times 10^{8}$ WW events:<br><br>Factor $\sim$ 500 improvement of statistical precision on EWPOs<br>$m_Z, \Gamma_Z, \Gamma_{inv}, \sin^2\theta_W, R_\ell, R_b, m_W, \Gamma_W, \ldots$<br><br>- Collect $2 \times 10^{6}$ $t\bar{t}$ events: $m_{top}, \Gamma_{top}$, EW and Higgs couplings<br><br>- Indirect sensitivity to new physics up to several tens of TeV | - Absolute normalisation to $10^{-4}$ or better<br><br>- Relative normalisation between channels and between energy-scan points to $10^{-5}$<br><br>- Track angular resolution to 0.1 mrad<br><br>- Stability of B field (momentum scale) to $10^{-6}$ |
| **Flavour**<br>- From Z decays: $10^{12}$ $b\bar{b}$, $c\bar{c}$, $2 \times 10^{11}$ $\tau^+\tau^-$, clean and boosted | - Superior impact parameter resolution<br><br>- Precise identification and measurement of sec- |

# Transverse Momentum Resolution

Typically parameterized as

$$\frac{\sigma(p_T)}{p_T} = (a \times p_T) \oplus b$$

where the first term $a$, which dominates at asymptotic momentum, is driven by measurement precision and the second term $b$ represents the contribution from multiple scattering.

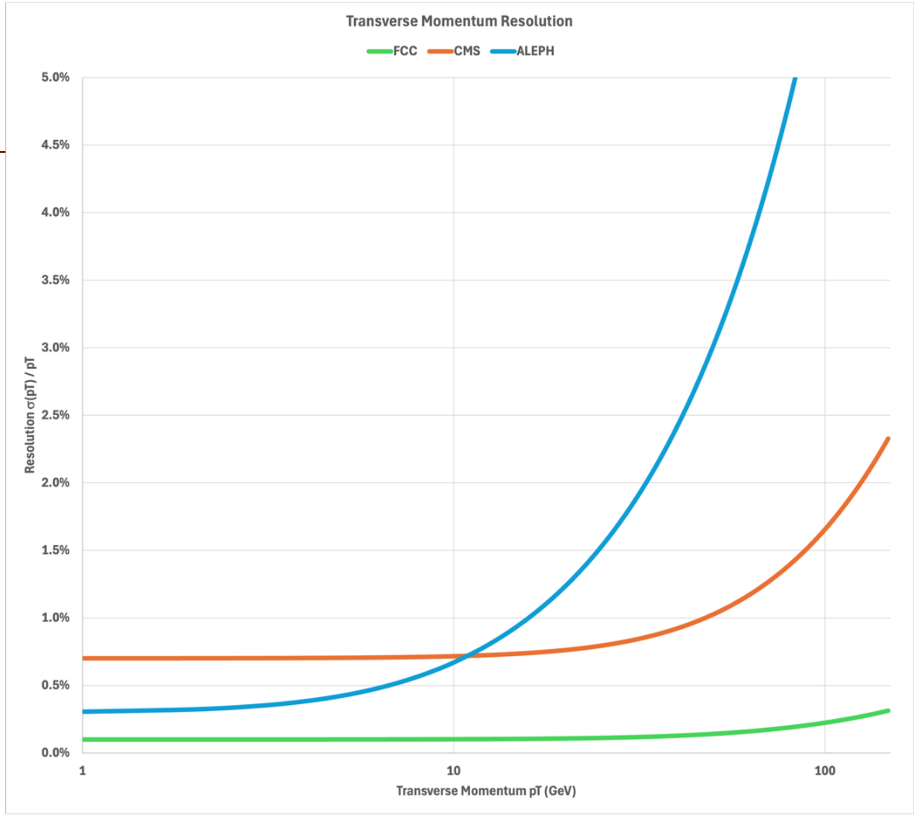
To achieve $\frac{\sigma(p_T)}{p_T} \approx 10^{-3}$ at $p_T \approx 50\ GeV$, each term must not exceed $10^{-3}$, i.e.

$$a \leq 2 \times 10^{-5}\ GeV^{-1}$$
$$b \leq 10^{-3}$$

# Transverse Momentum Resolution

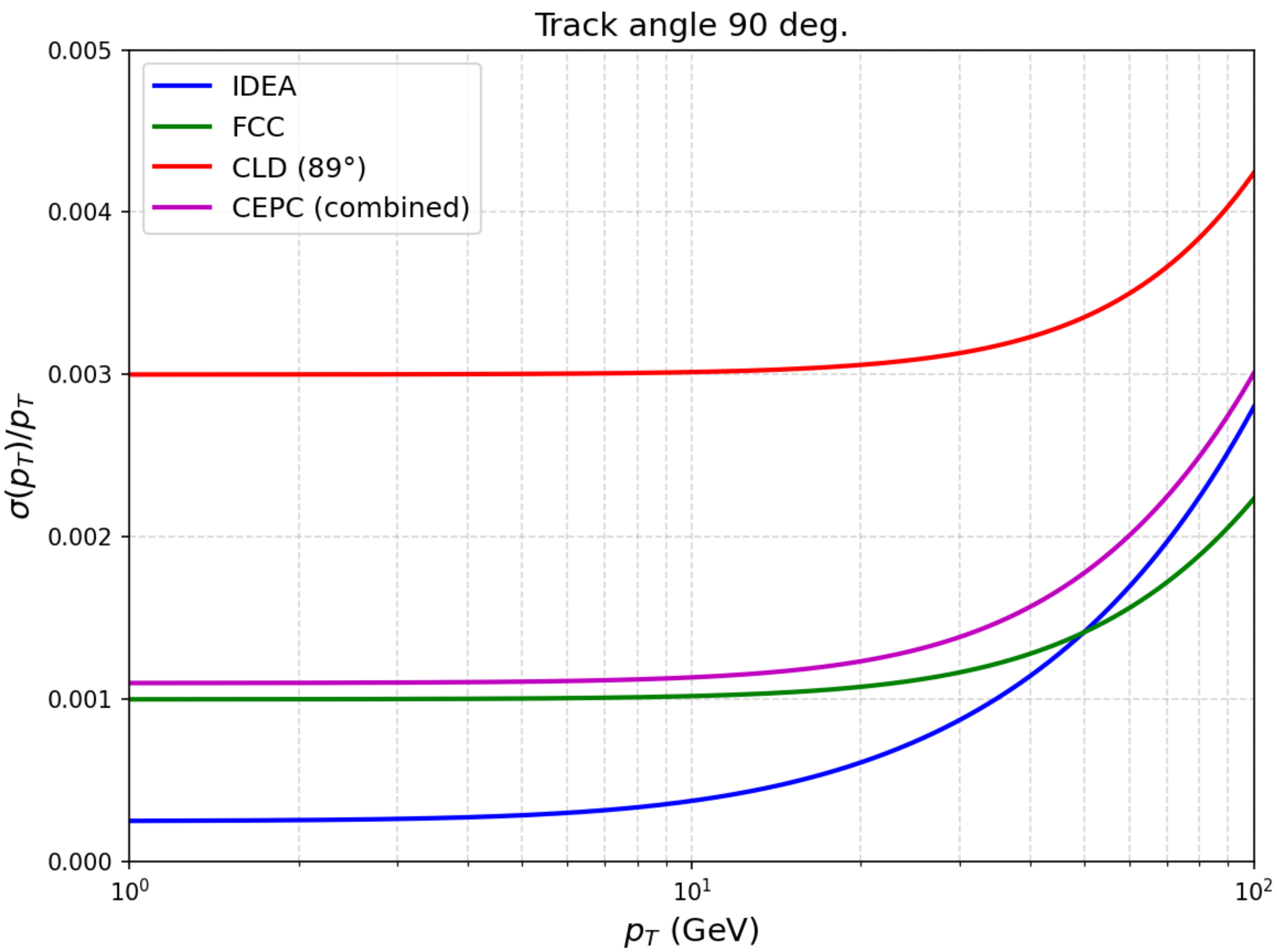
$$\frac{\sigma_{pT}}{pT} \approx (a \times pT) \oplus b$$

| | *a* (GeV$^{-1}$) | *b* |
|---|---|---|
| FCC-*ee* | 2 $10^{-5}$ | 0.001 |
| CMS | 1.5 $10^{-4}$ | 0.007 |
| ALEPH | 6 $10^{-4}$ | 0.003 |




- Multiple scattering contribution term "*b*" dominates over measurement precision term "*a*" for virtually the entire momentum range in FCC-*ee*.
- Preference for low-mass tracker to minimize multiple scattering

# *Approximate* Resolutions for IDEA, CLD and CEPC




**CLD**:
**silicon** main tracker
adapted by Claude from slides

**CEPC**:
**TPC** main tracker
adapted by Claude from TDR

**IDEA**:
**drift chamber** main tracker
adapted by Claude from slides

# Low-Momentum $p_T$ Resolution in TPC vs Drift Chamber

## TPC worse because of Argon

Argon (in CEPC TPC)

- Z = 18
- A = 40
- Density ~ 1.66 x $10^{-3}$ g/cm$^2$
- $X_0$ = 1.17 x $10^4$ cm

Helium (in IDEA drift chamber)

- Z = 2
- A = 4
- Density ~ 1.66 x $10^{-4}$ g/cm$^2$
- $X_0$ = 5.67 x $10^5$ cm

~ 50x larger than Argon

## Replace Argon with Helium?

Reduced multiple scattering

- "*b*" goes down
- What about "*a*"?

# Measurement Term in TPC vs Drift Chamber

Electrons drift in z direction vs in r-phi for drift chamber

Long drift distance compared with drift chambers: 1-2 m vs 1-2 cm

- Diffusion scales as sqrt(distance) => ~10x worse for TPC
- Point resolution in bend plane expected to degrade by this factor
- “*a*” term expected to be worse

Why is “*a*” in TPC comparable to (and may even be slightly better) than in drift chamber?

# Transverse Diffusion Suppression

## Magnetic field *B* parallel to electric field *E* as in TPC

Longitudinal diffusion largely unaffected by *B* field

Transverse diffusion is suppressed due to cyclotron motion of electrons

$$D_T(B) = \frac{D_T(0)}{1 + \omega^2\tau^2}$$

where $\omega = \frac{eB}{m}$ is the cyclotron frequency

and $\tau$ is mean time between collisions with gas molecules

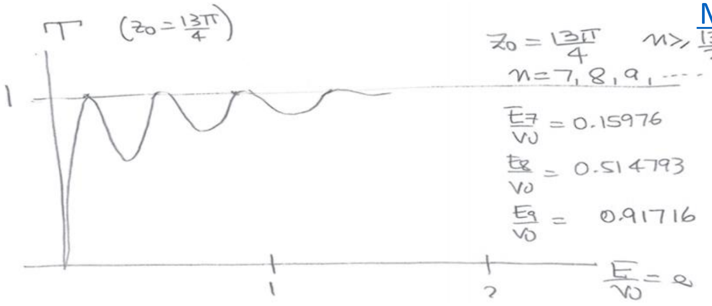
Typical values of $\omega\tau$: ~2 for ALEPH and DELPHI, >10 for ILD

# Ramsauer-Townsend Effect

## Quantum mechanical resonant transmission of low-energy electron in noble gas

Heavier noble gases (A, Kr and Xe)

- Polarization of electron cloud
- Resulting in potential well
- Resonant transmission for specific energies
- Practically transparent to ~1 eV drift electrons

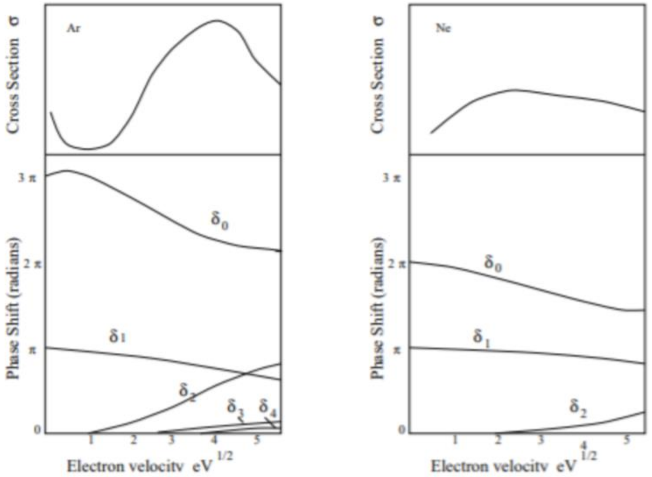



MIT online course

Figure 3: The transmission coefficient $T$ as a function of $e$ for a square well with $z_0 = \frac{13\pi}{4}$. At the energies for which $T = 1$ we have resonant scattering. The values of $E_7, E_8, \ldots$ are indicated in the figure. There are three cases of resonant transmission for $0 < E < V_0$. Note that the spacing between the points where $T = 1$ grows as $e$ grows.

Lighter noble gases (Ne and He)

- Low polarizability
- No R-T effect




LibreTexts Physics

Figure 14.6.1: Minimum in scattering cross section in Ar due to $\delta_0 = 3\pi$; No such effect in Ne due to weaker polarization.

# Recap

TPC prefers Argon gas for reduced transverse diffusion and hence better point measurement precision.

Argon is ~50x more $X_0$ than Helium, resulting in larger multiple scattering contribution to momentum resolution.

Switching to Helium reduces multiple scattering but degrades point measurement resolution.

No good options to achieve good momentum resolution in the entire momentum range.

***But a reminder:***

We should be careful and avoid making decisions based on one single metric, such as ruling out TPC as main tracker here as well as elsewhere.

Detector design is a compromise of many competing priorities, and proponents rarely tell us all the challenges.

# Comments on Claude Interaction

Claude knows lots of things

- Drift chambers used broadly, proposed for FCC
- TPCs used in LEP, proposed for FCC and CEPC
- Their typical performance numbers
- Ramsauer-Townsend effect – it is in many university physics courses

What Claude did not know (until I pointed it out)

- Role of R-T in TPC