Prospects of fast timing detectors for particle identification at future Higgs factories

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International Workshop on Future Linear Colliders, 16 March 2021
PD4/PD6: Software & Detector Performance / Calorimeters

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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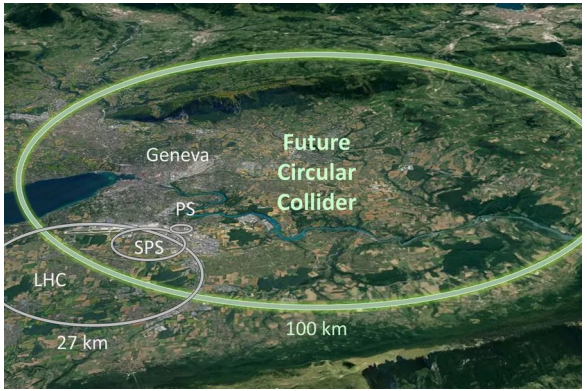
Prospects of fast timing detectors for particle identification at future Higgs factories



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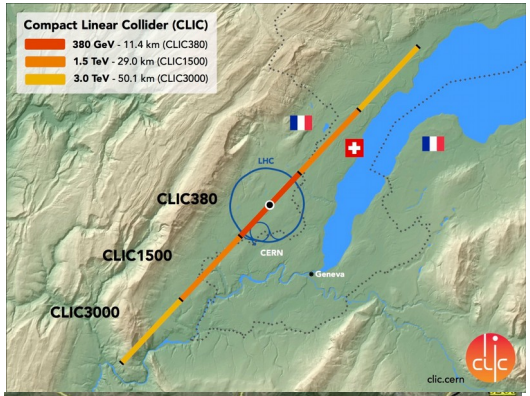

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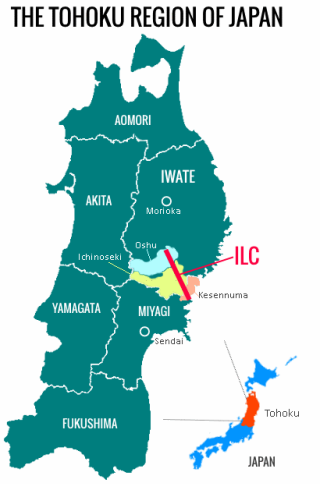


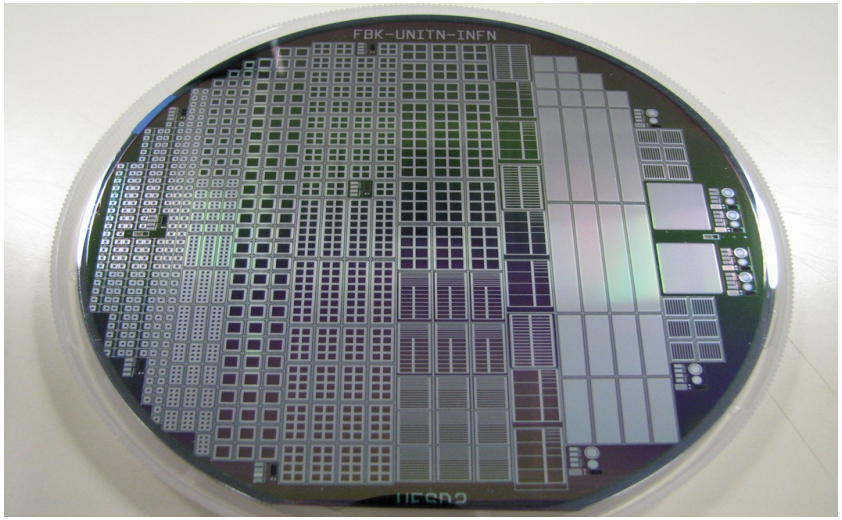
ILC

CEPC

Can we improve event reconstruction at future Higgs factories?

Prospects of **fast timing detectors** for particle identification at future Higgs factories

Low **G**ain **A**valanche **D**iode
LGAD



provided by Annika Vauth

Si sensor technology	Approximate hit time resolution
Conventional	10 ns
LGAD	10 – 100 ps

Open question:

Equip ECAL or Si external tracker (SET) with the **LGAD**?

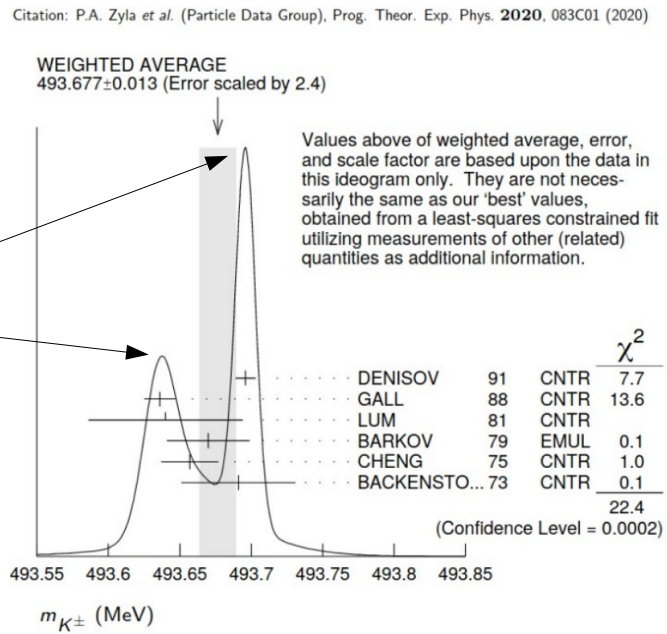
Allows to measure time of flight (TOF)

We study TOF effect on physics studies in the Monte-Carlo simulations

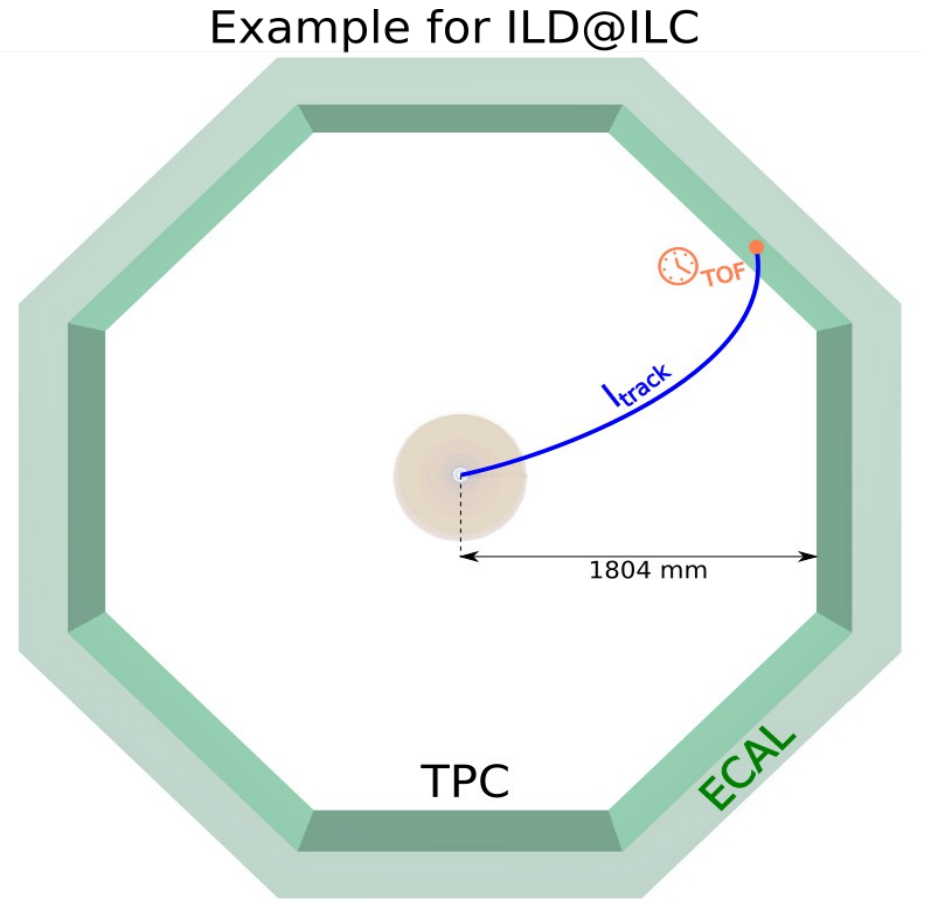
Prospects of fast timing detectors for particle identification at future Higgs factories

Particle identification (PID) is one of the applications of the **TOF**

TOF PID application	TOF PID motivation
Reconstruction of D, B mesons	Heavy-flavor physics
Jet charge discrimination	CP violation
bottom/charm jet discrimination	Higgs Yukawa couplings
$K^{\pm}$ mass measurement	PDG has two distinct measurements for $K^{\pm}$ mass Can we achieve ~10 keV precision to improve $K^{\pm}$ mass?



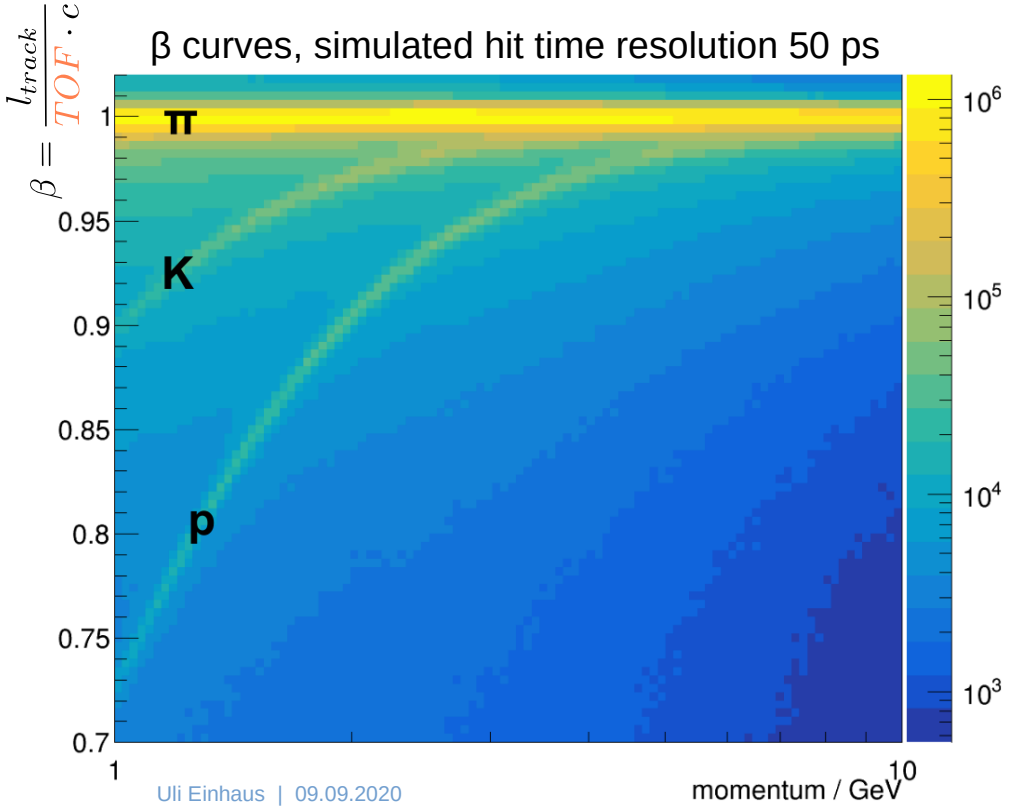
Basic principle of the TOF PID

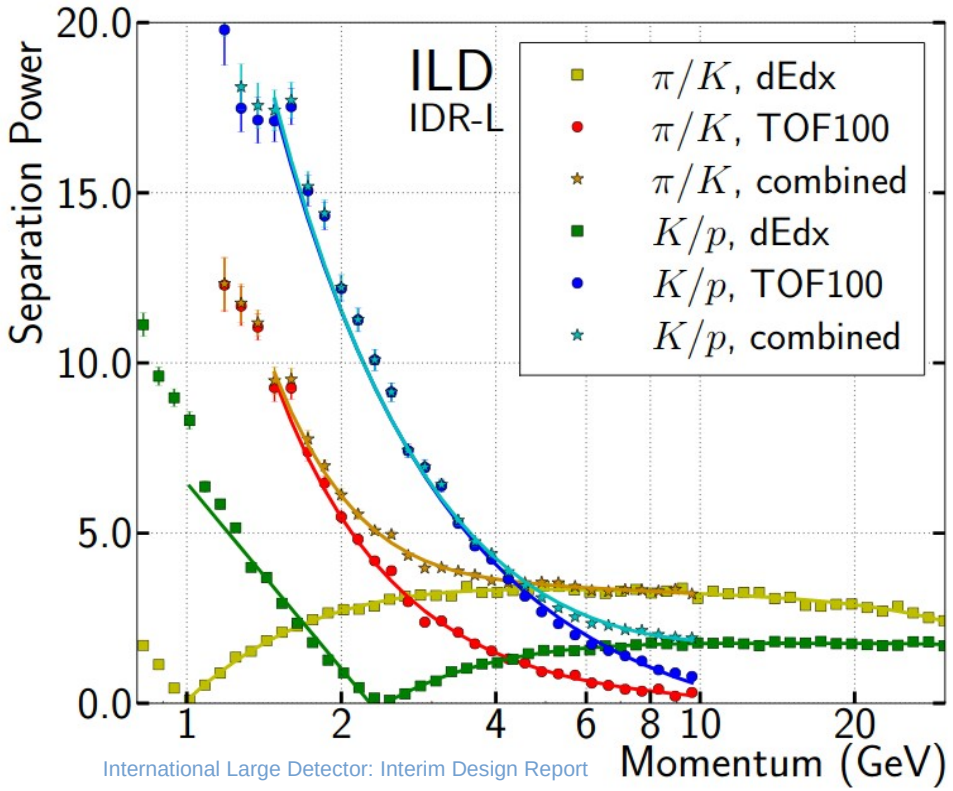


$$m = \frac{p}{\beta}\sqrt{1-\beta^2} \qquad \beta = \frac{l_{track}}{TOF \cdot c}$$

p	Momentum from the track fit
l_{track}	Track length from the track fit
TOF	Time of flight from the **LGAD** Si sensors in the ECAL
β	Velocity
m	Mass of the particle

Basic principle of the TOF PID

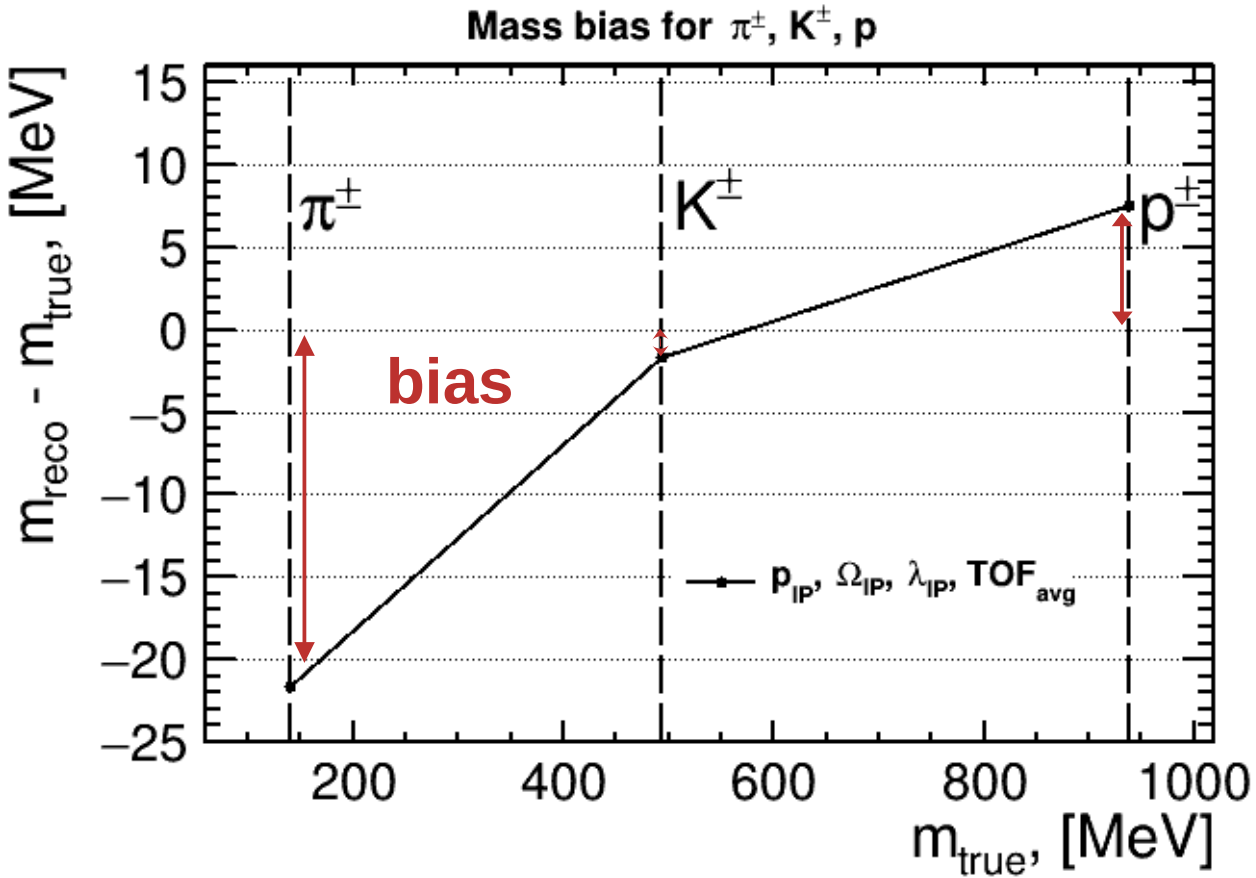




$\pi^{\pm}$, $K^{\pm}$, p bands are separate for p ≤ 4 GeV

TOF complements existing dE/dx PID

Challenges of the TOF particle ID



First attempts using **TOF** show **significant bias** for the particle mass

$$m = \frac{p}{\beta}\sqrt{1-\beta^2} \qquad \beta = \frac{l_{track}}{TOF \cdot c}$$

How **precisely** do we measure?

- Momentum
- l_{track}
- **TOF**

Estimating **momentum**

Momentum is calculated from:

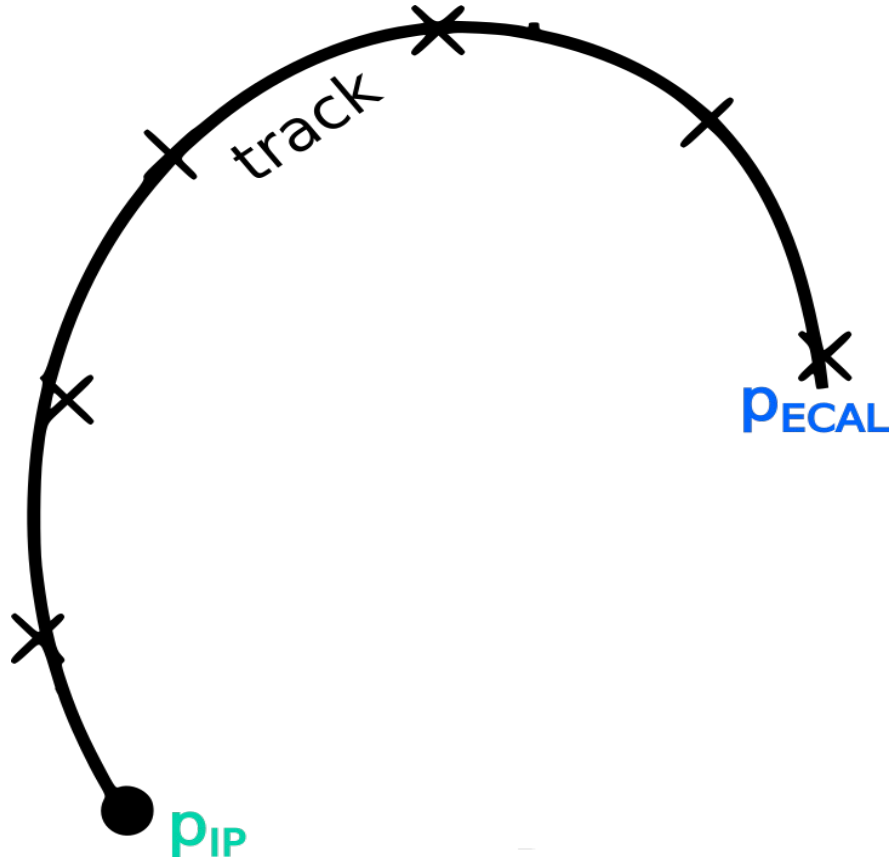
- Track curvature (Ω)
- Track slope in z direction (tan λ)
- Magnetic field (B_z)

$$p \sim |\frac{B_z}{\Omega}|\sqrt{1+tan^2\lambda}$$

Issue:

Momentum **changes** along the track due to the energy loss! $p_{IP} \neq p_{ECAL}$

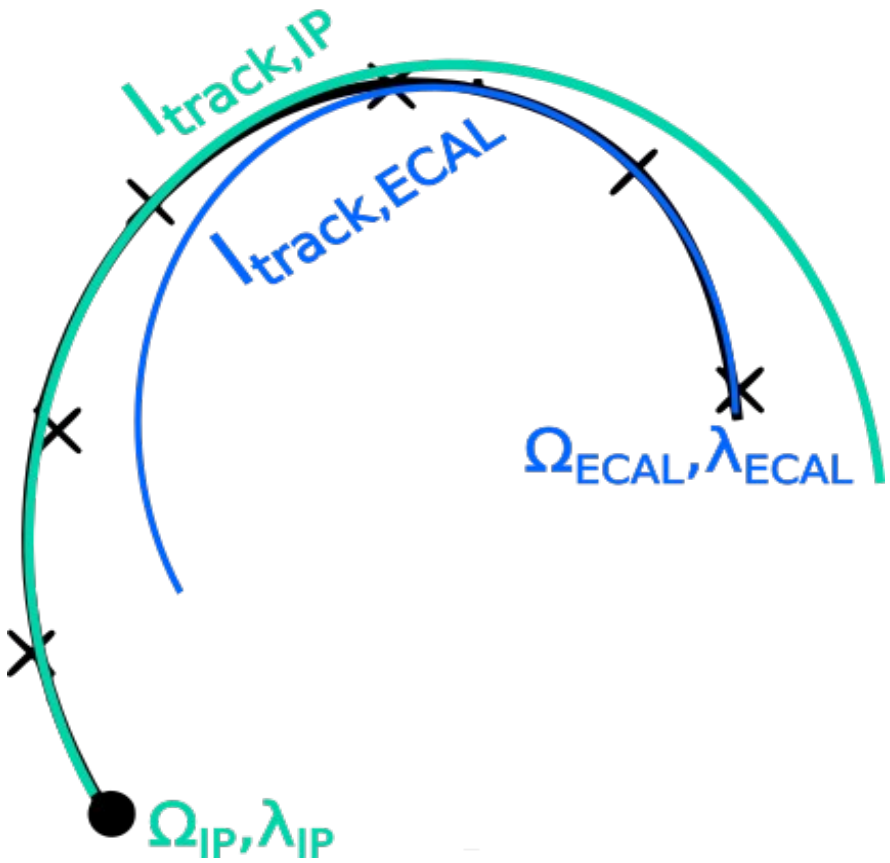
How does it effect PID and mass reconstruction?



Estimating **track length**

Track length is calculated **assuming constant** curvature (Ω) and slope (tan λ)!

$$l_{track} = |\frac{\varphi_{ECAL} - \varphi_{IP}}{\Omega}|\sqrt{1 + tan^2\lambda}$$



Issue:

Curvature of the track **is not constant** due to the energy loss. $l_{track,IP} \neq l_{track,ECAL} \neq l_{track,true}$

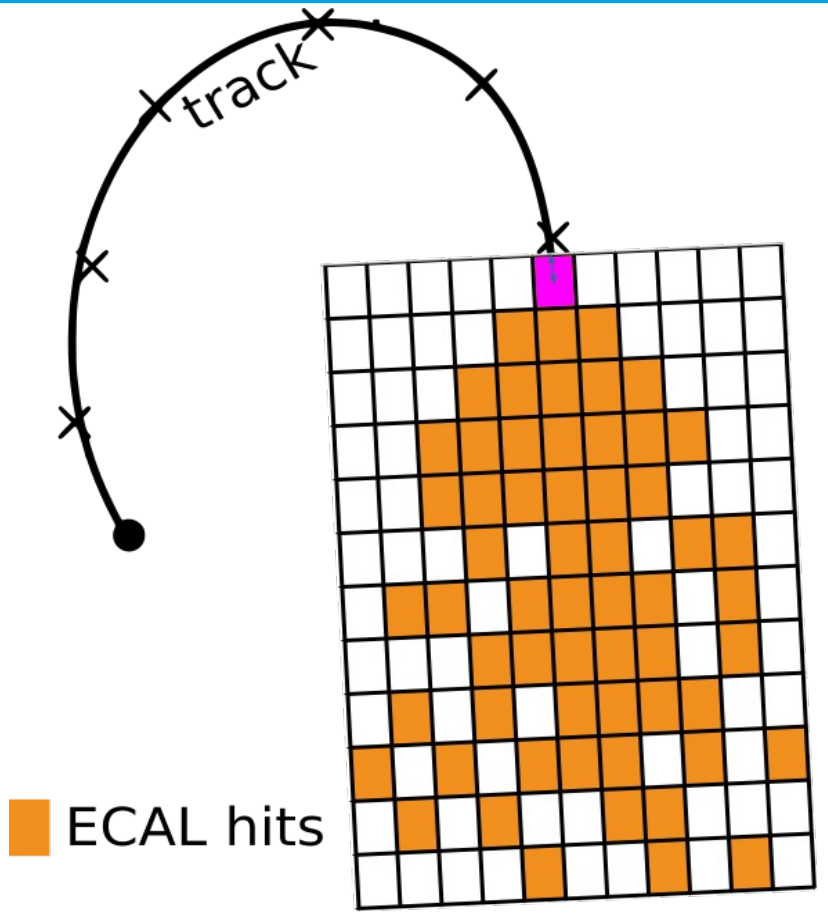
It is tricky to calculate the track length precisely

Estimating **TOF**

TOF estimator #1

$$TOF = t_{hit,closest} - \frac{|\vec{r}_{track,entry} - \vec{r}_{hit,center}|}{c}$$

- Consider time only of the closest ECAL hit to the track entry point
- Correct for the **distance** from the track entry point to the **ECAL hit** center
- Sensitive to the **single hit** time resolution
- Assumes speed of light in the ECAL

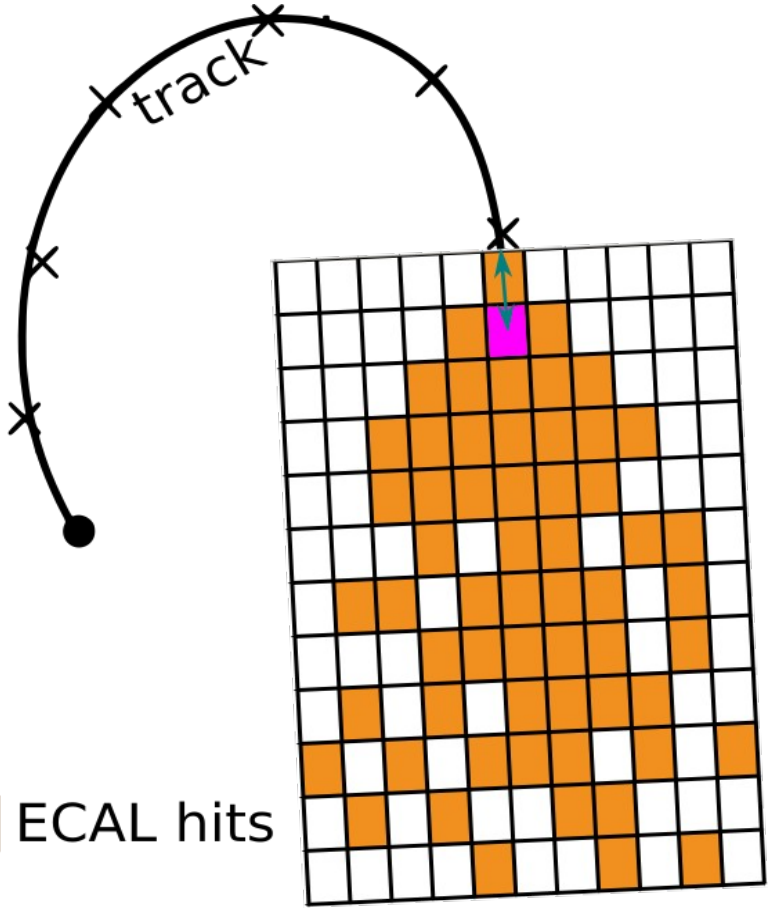


Estimating **TOF**

TOF estimator #2

$$TOF = t_{hit,fastest} - \frac{|\vec{r}_{track,entry} - \vec{r}_{hit,center}|}{c}$$

- Consider time only of the fastest ECAL hit to the track entry point
- Correct for the **distance** from the track entry point to the **ECAL hit** center
- Sensitive to the **single hit** time resolution
- Assumes speed of light in the ECAL

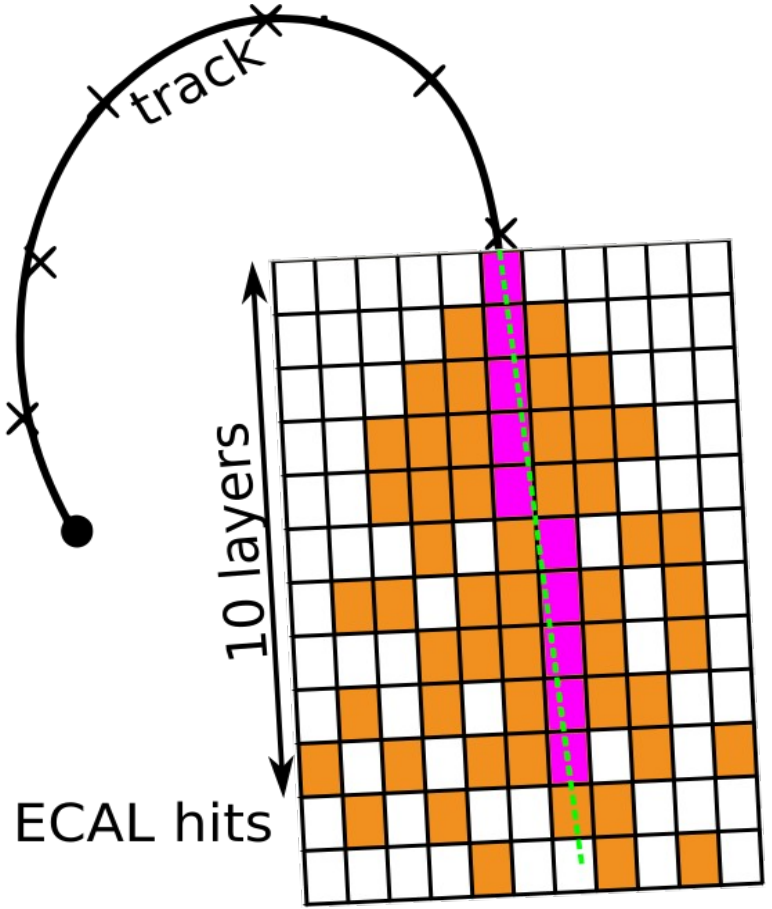


Estimating **TOF**

TOF estimator #3

$$TOF_{hit} = t_{hit} - \frac{|\vec{r}_{track,entry} - \vec{r}_{hit,center}|}{c} \qquad \mathrm{TOF} = \sum_{hits} \frac{TOF_i}{N_{hits}}$$

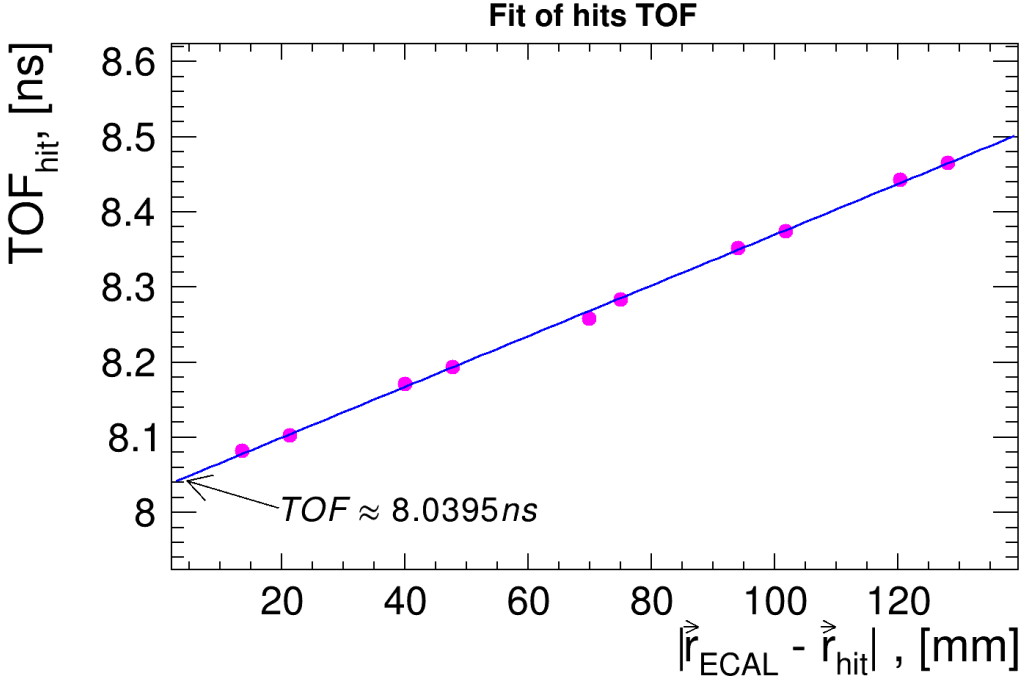
- Consider time of **closest hits** to the **extrapolated track** in the first ten ECAL layers
- Correct for the **distance** from the track entry point to the each **ECAL hit** center
- Average the result between all **selected hits**
- Assumes speed of light in the ECAL

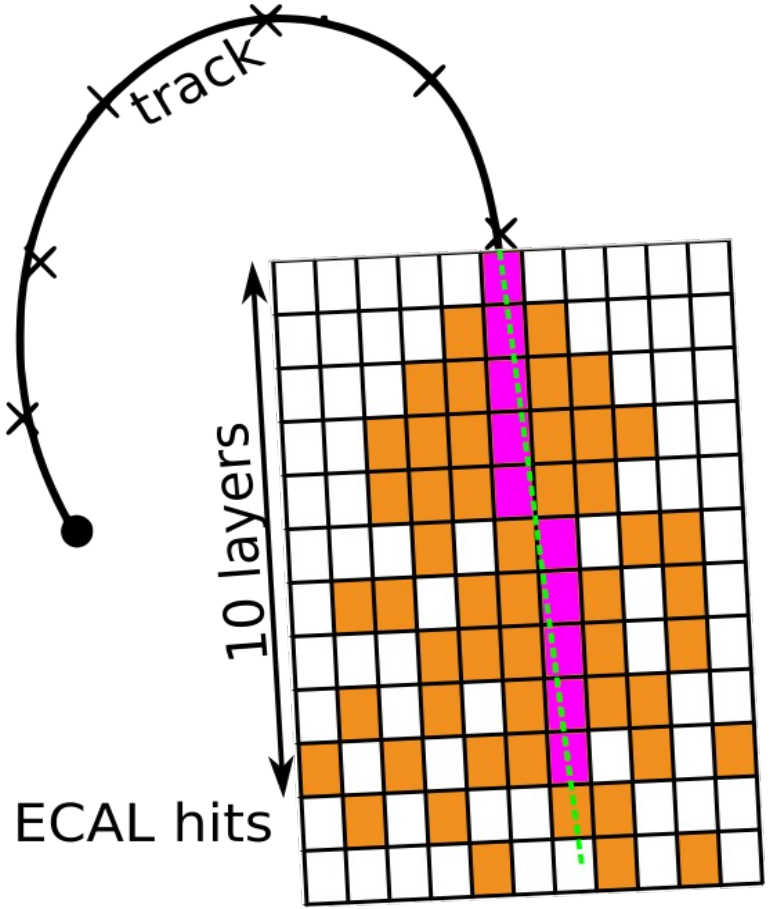


Estimating **TOF**

TOF estimator #4

$$\text{Fit TOF}_{hit}(|\vec{r}_{track,entry} - \vec{r}_{hit,center}|) \quad \text{TOF} = \text{TOF}_{hit}(0)$$





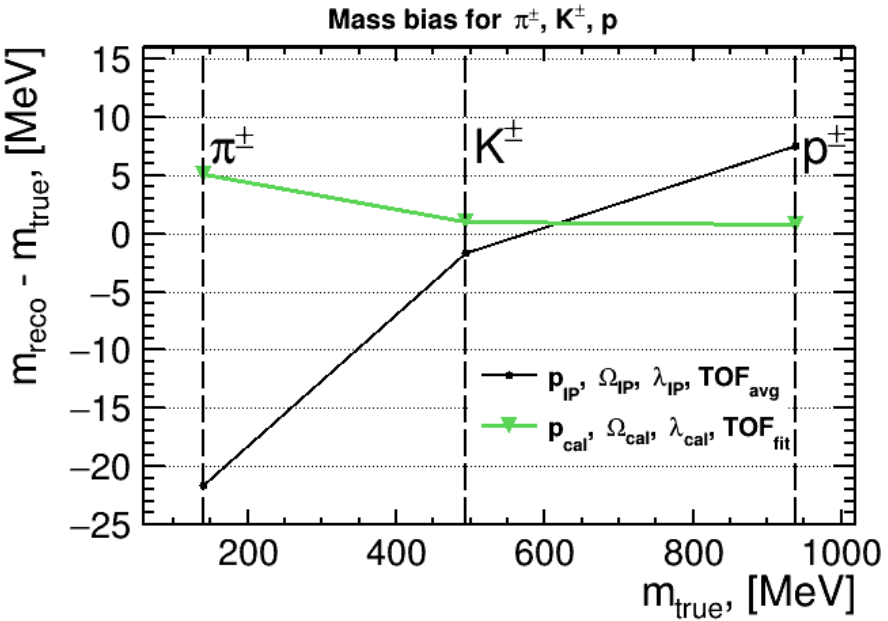
Improving TOF particle ID

First attempt:

- $p = p_{IP}$
- $l_{track} = l_{track}(\Omega_{IP}, \lambda_{IP})$
- TOF = 10 layers average

Improved method:

- $p = p_{calo}$
- $l_{track} = l_{track}(\Omega_{calo}, \lambda_{calo})$
- TOF = 10 layers **fit**



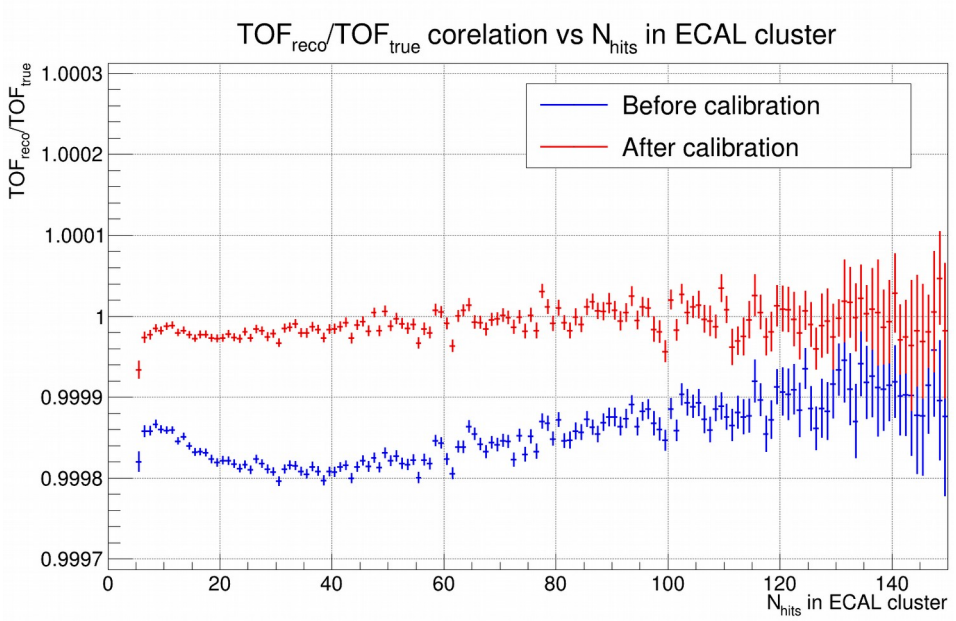
Bias is significantly reduced! But still some bias remains!

Not crucial for particle ID, but ~100 off (1MeV vs 10keV) to precisely measure K mass

Calibrating TOF with photons

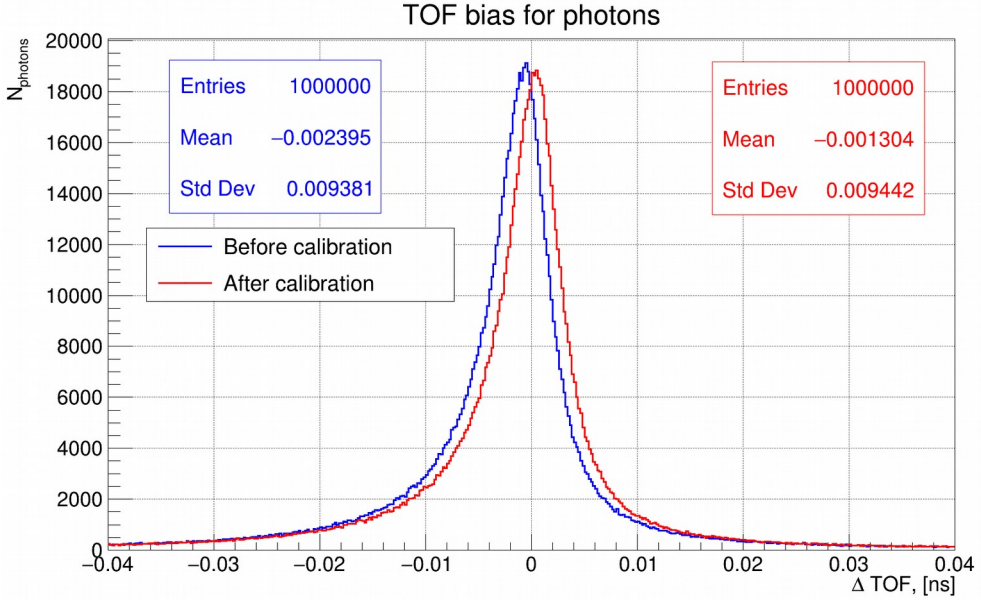
Check TOF estimation on photons:

- track is a straight line
- speed is c
- We know $\mathbf{l_{track,\ true}}$ and **p is constant**



TOF estimators show bias correlated with the $N_{ECAL\ hits}$ and E_{photon}

We are investigating **calibration factors** to **correct** for this bias



Summary

- Particle identification is an important tool for future Higgs factories
- TOF can complement existing dE/dx particle ID tool
- Future Higgs factories with TOF particle ID can potentially improve PDG $K^{\pm}$ mass. But still need to understand absolute mass scale ~100 better

Future plans:

- Tune and calibrate TOF estimators to avoid biases and improve particle ID
- Derive required LGAD hit time resolution for physics analyses
- Study more realistic implementation of the electronics in the simulation
- (smearing, digitization)
- Assess systematic uncertainties

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