

Particle identification with fast timing detectors at future Higgs factories

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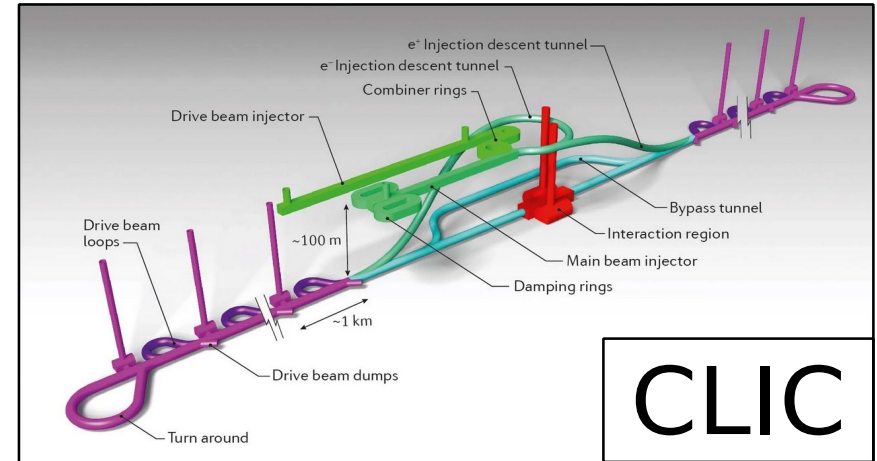
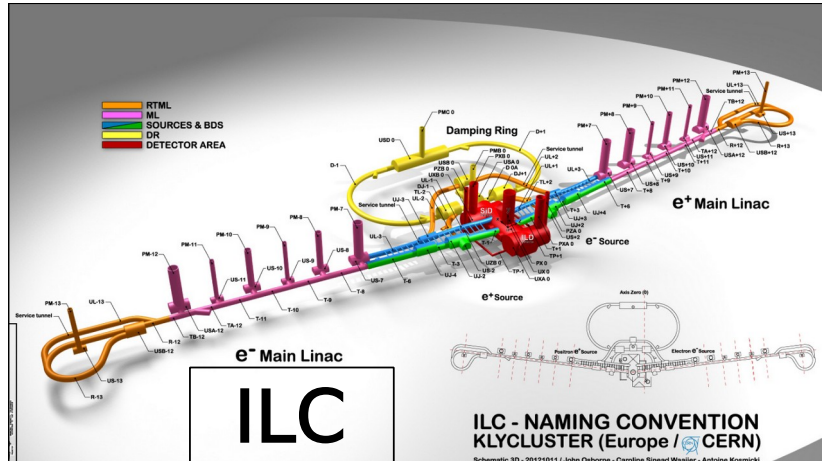
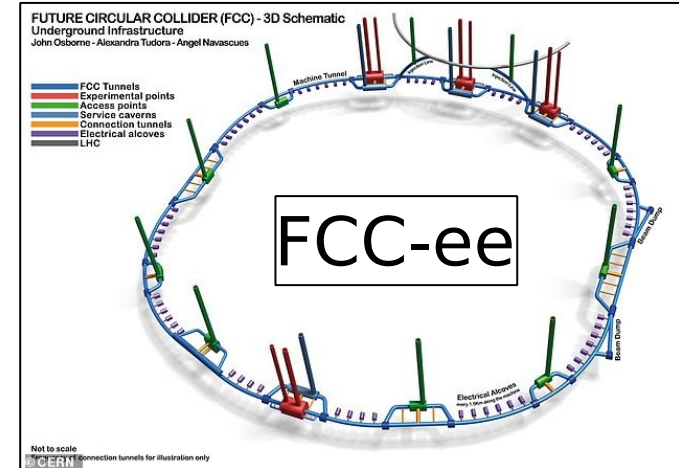
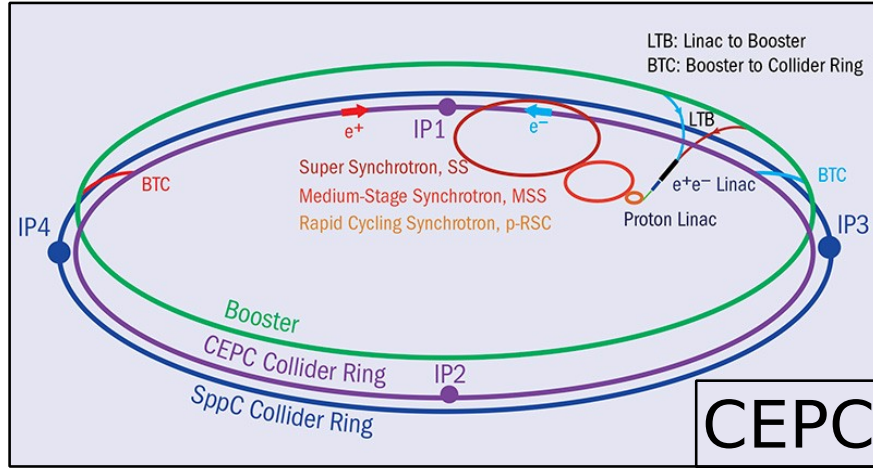
2020 Update of the European strategy for particle physics



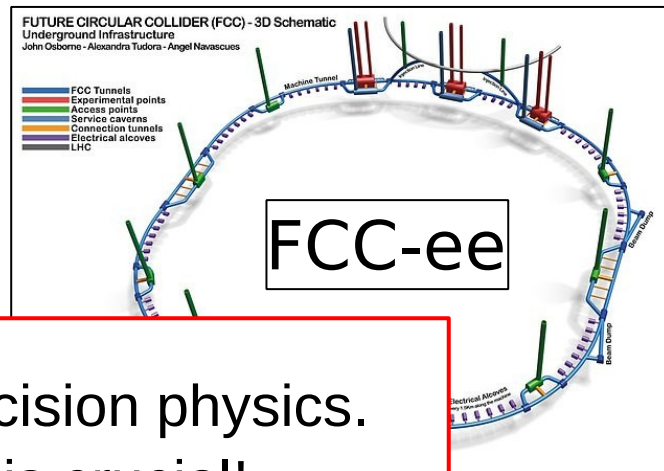
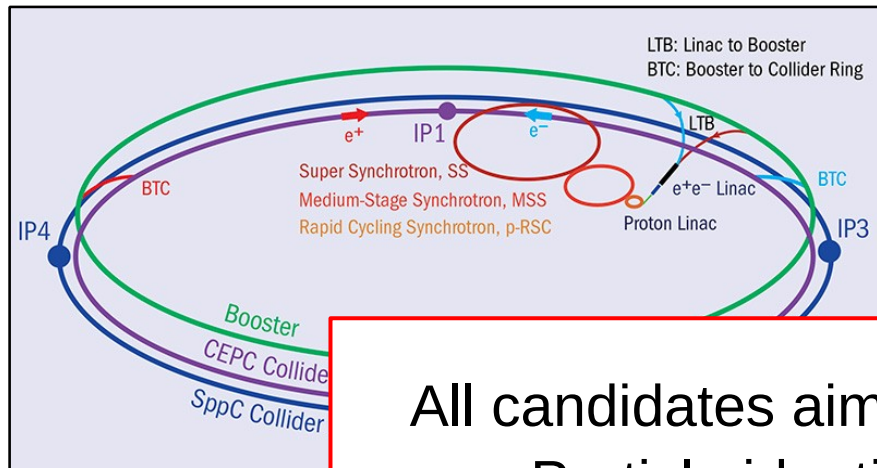
High-priority future initiatives

- A. **An electron-positron Higgs factory is the highest-priority next collider.** For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

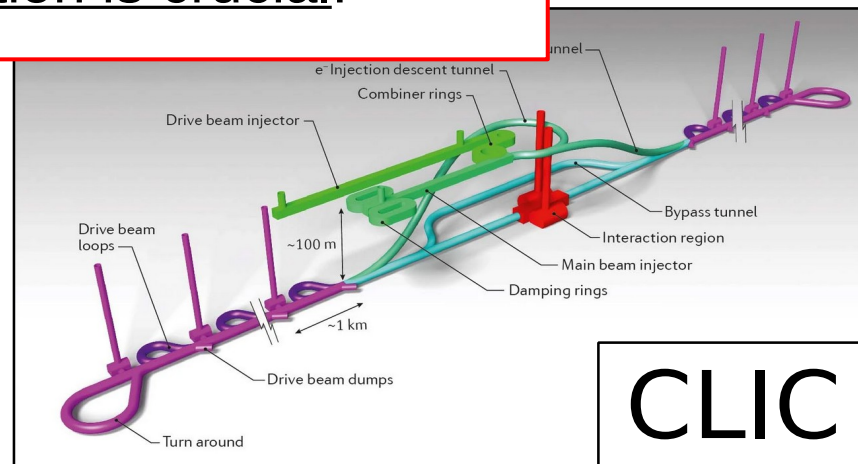
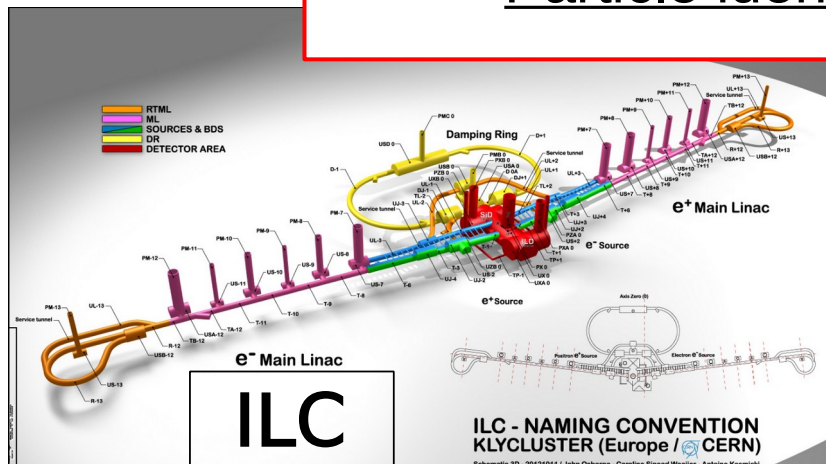
Major candidates for the future Higgs factories



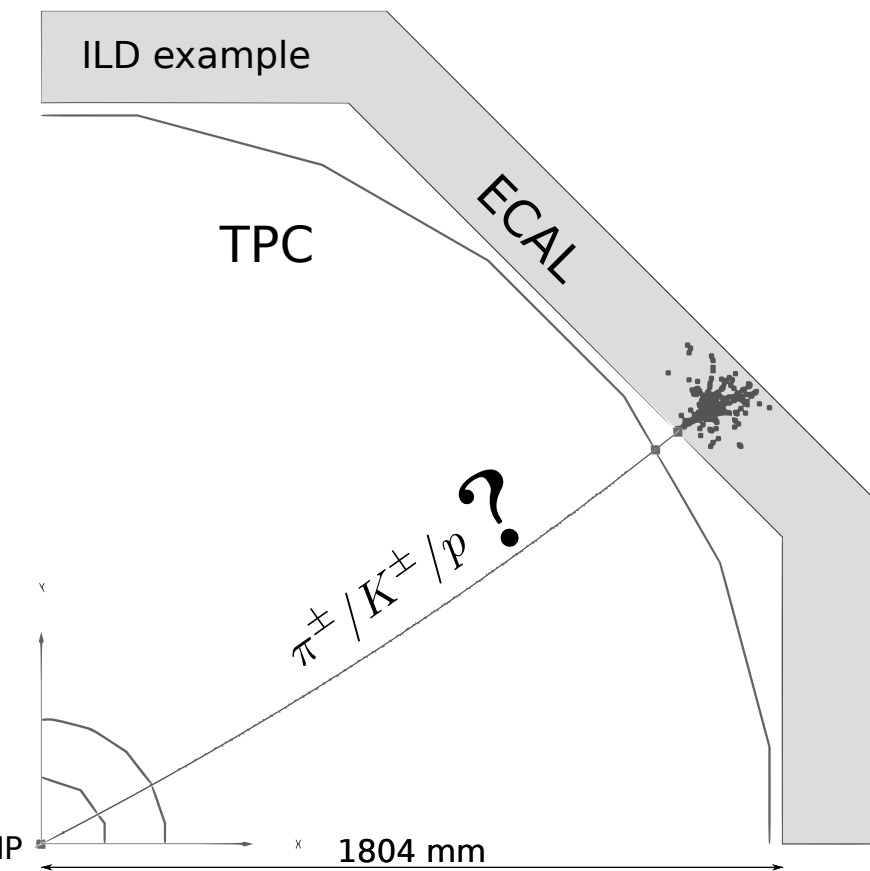
Major candidates for the future Higgs factories



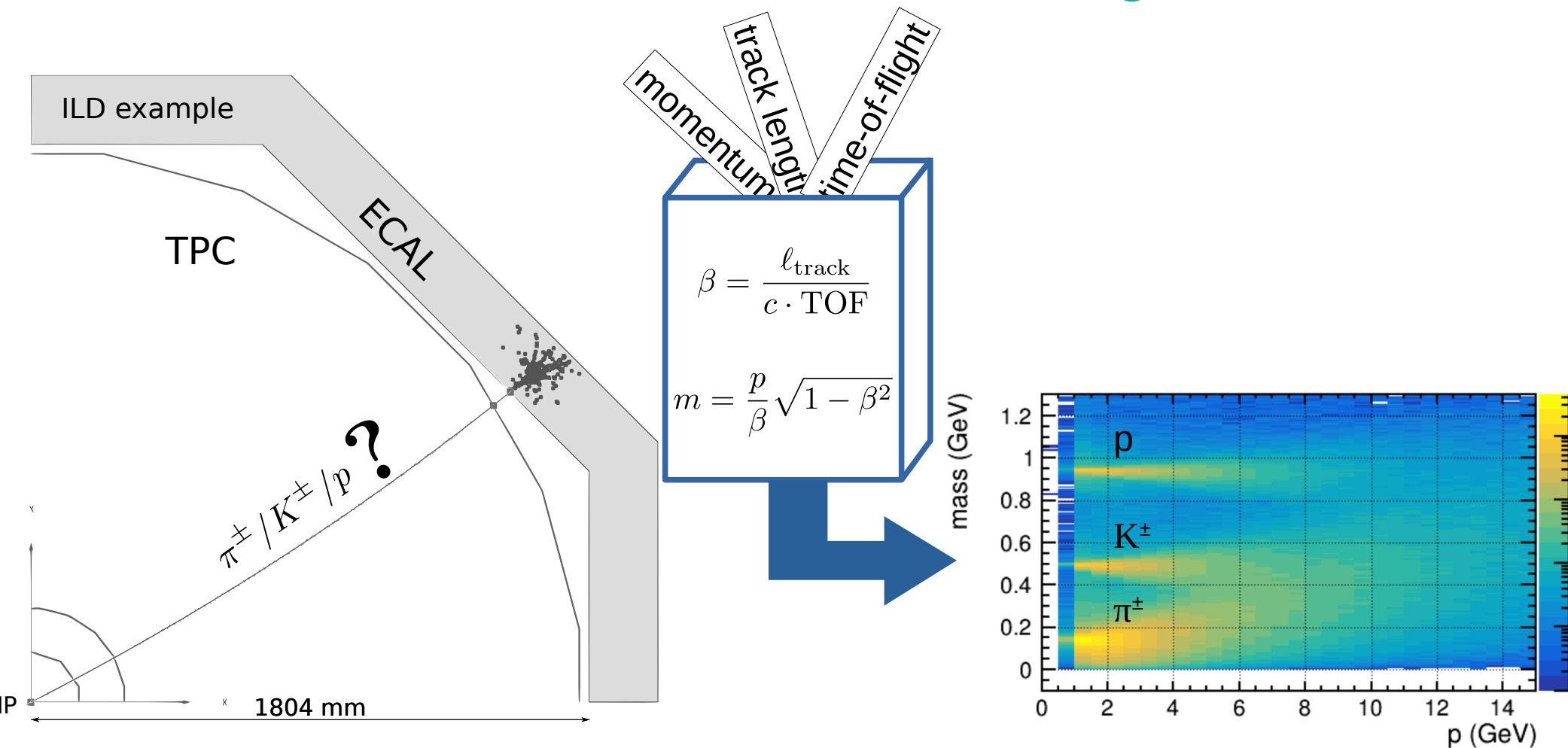
All candidates aim for precision physics.
Particle identification is crucial!



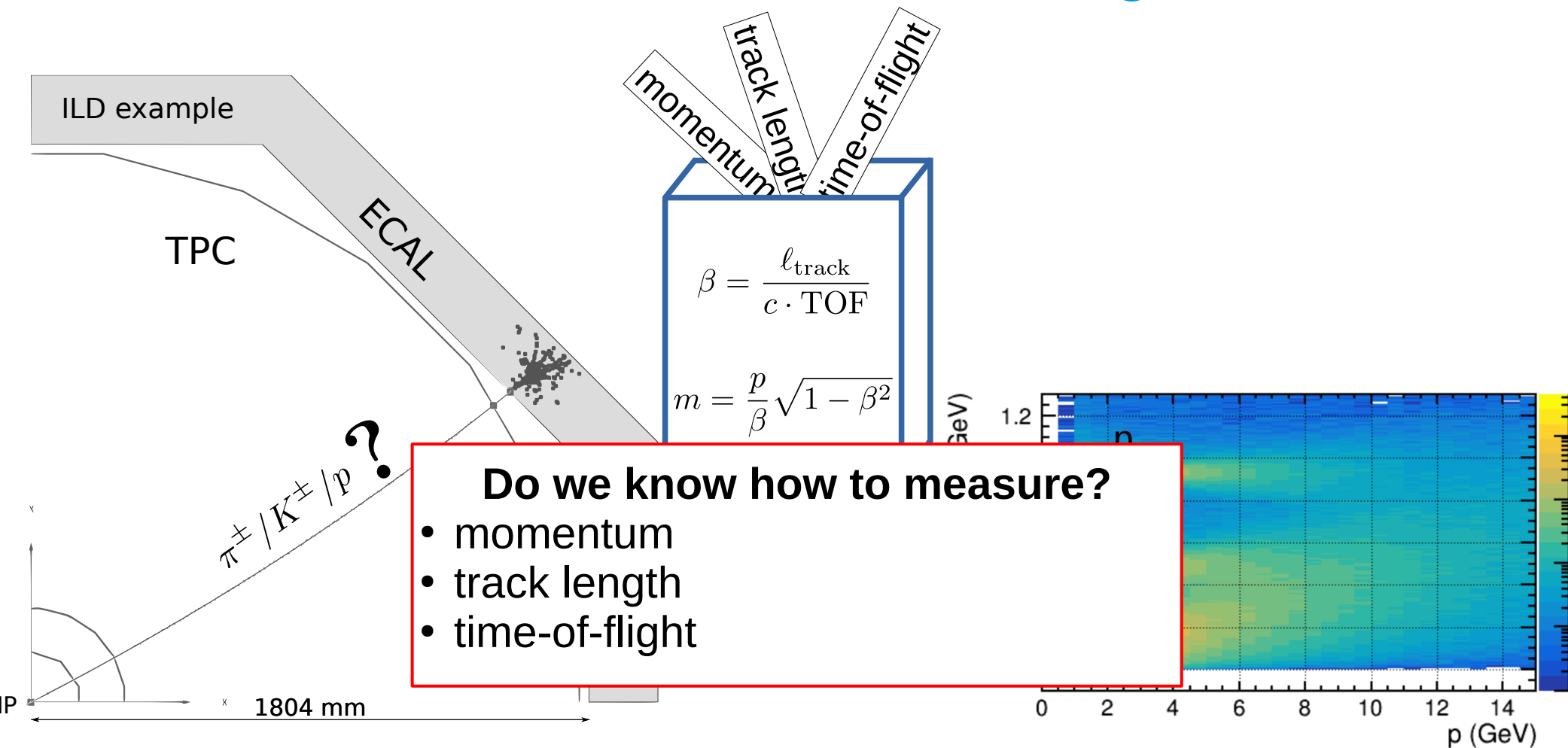
Particle identification with time-of-flight



Particle identification with time-of-flight



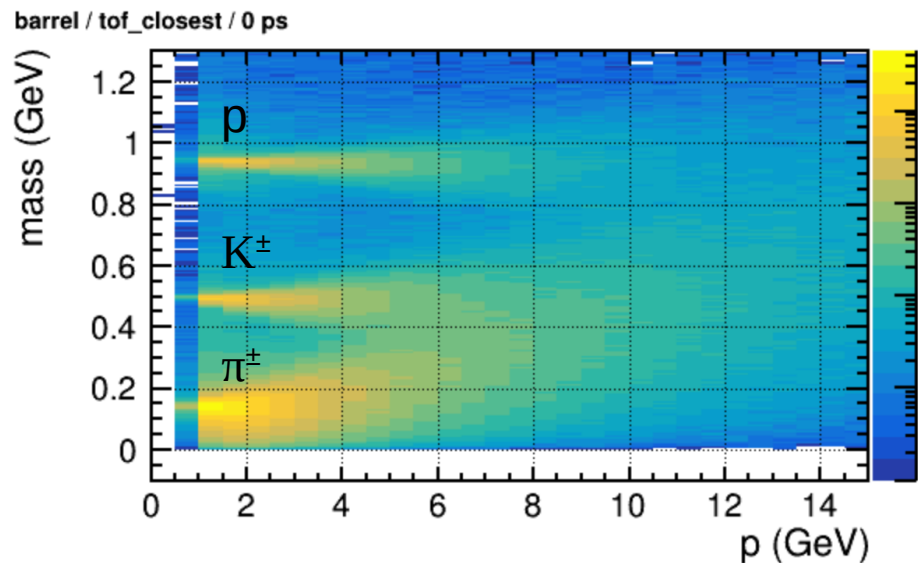
Particle identification with time-of-flight



Do we know how to measure?

- momentum
- track length
- time-of-flight

Particle identification with time-of-flight



← requires extremely precise time-of-flight measurement (~ 10 ps)

e.g. with LGADs

drawbacks:

- expensive
- require cooling
- not radiation hard

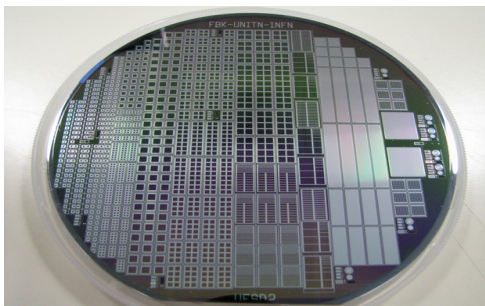
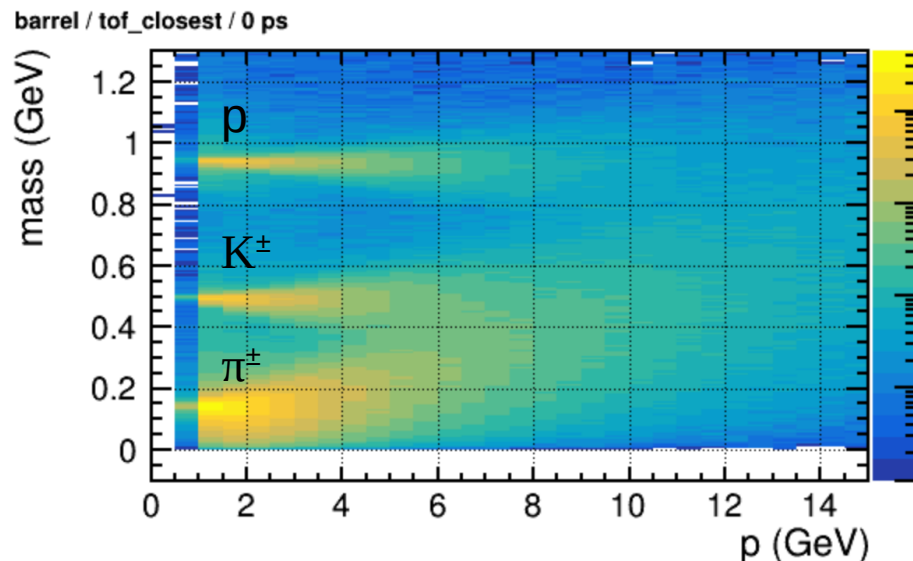


photo: Annika Vauth

Particle identification with time-of-flight



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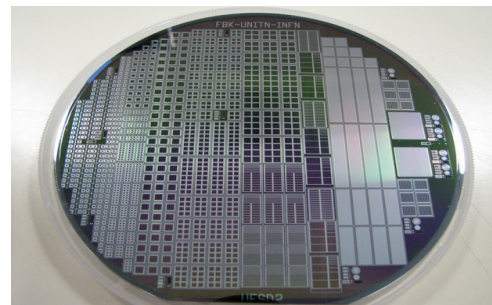


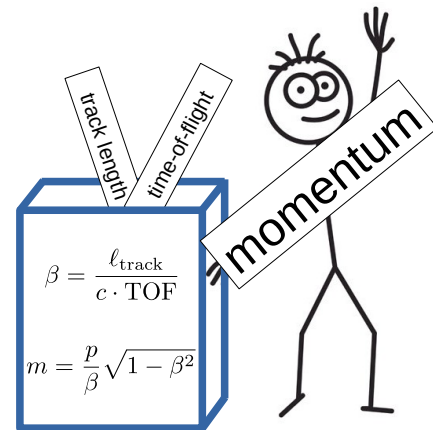
photo: Annika Vauth

Long-term goal is to understand:
How beneficial TOF pID would be?
Is it worth the investment?

Momentum calculation

We calculate momentum from the curvature Ω :

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

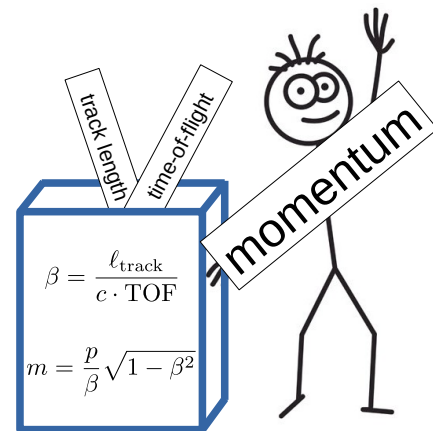
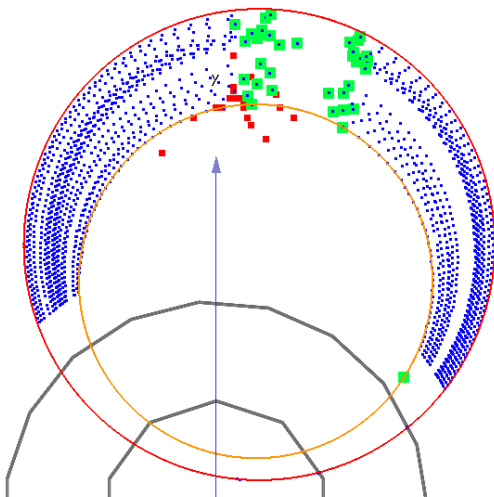


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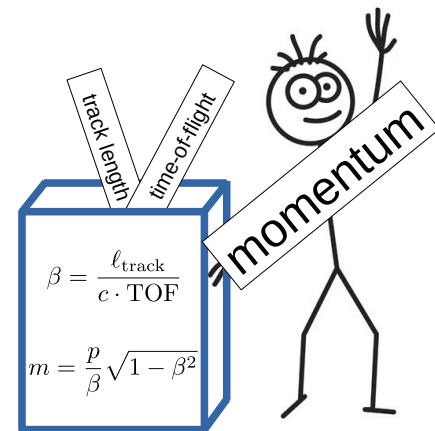
BUT curvature may significantly change
due to energy loss along the track!



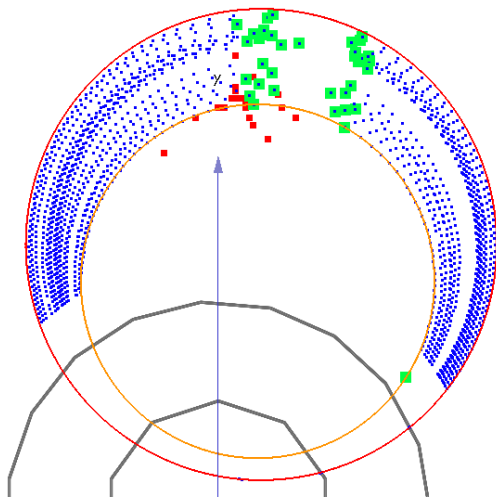
Momentum calculation

We calculate momentum from the curvature Ω :

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BUT curvature may significantly change due to energy loss along the track!



IMPROVED: calculate momentum at every tracker hit and use harmonic mean for particle ID

$$p_i = e \frac{|B_z|}{|\Omega_i|} \sqrt{1 + \tan^2 \lambda_i}$$

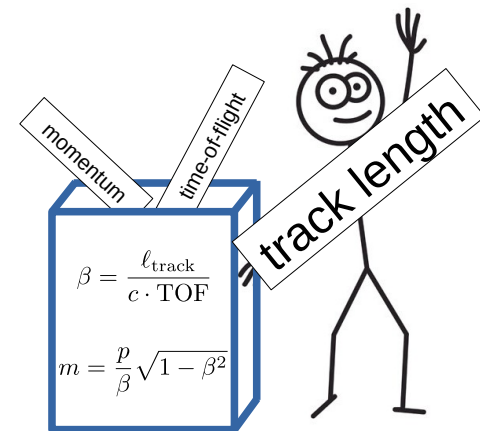
$$p = \sqrt{\langle p^2 \rangle_{HM}} = \sqrt{\sum_{i=0}^n \ell_i / \sum_{i=0}^n \frac{\ell_i}{p_i^2}}$$

credit goes to Winfried A. Mitaroff
arXiv:2107.02031

Track length calculation

Simple assumption: track is a helix

$$\ell_{\text{track}} = \frac{|\varphi_{\text{end}} - \varphi_{\text{start}}|}{|\Omega|} \sqrt{1 + \tan^2 \lambda}$$



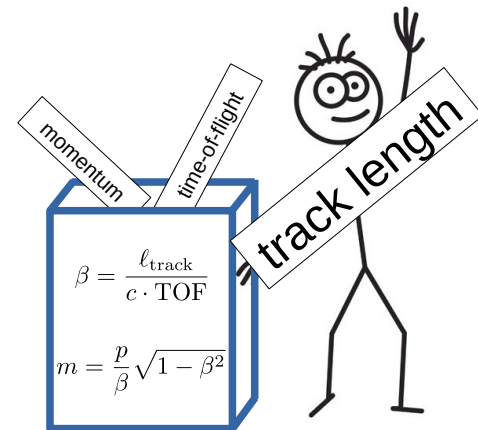
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BUT has similar limitations:

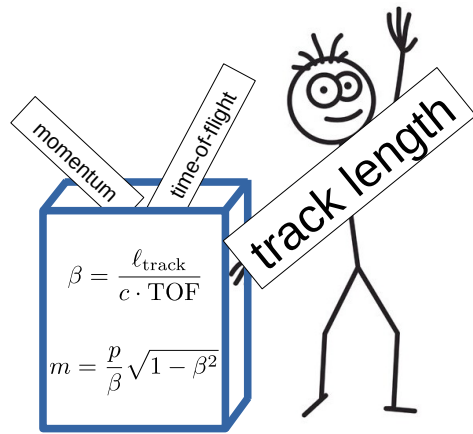
- Relies on constant momentum along the track
- Does not work for curly tracks



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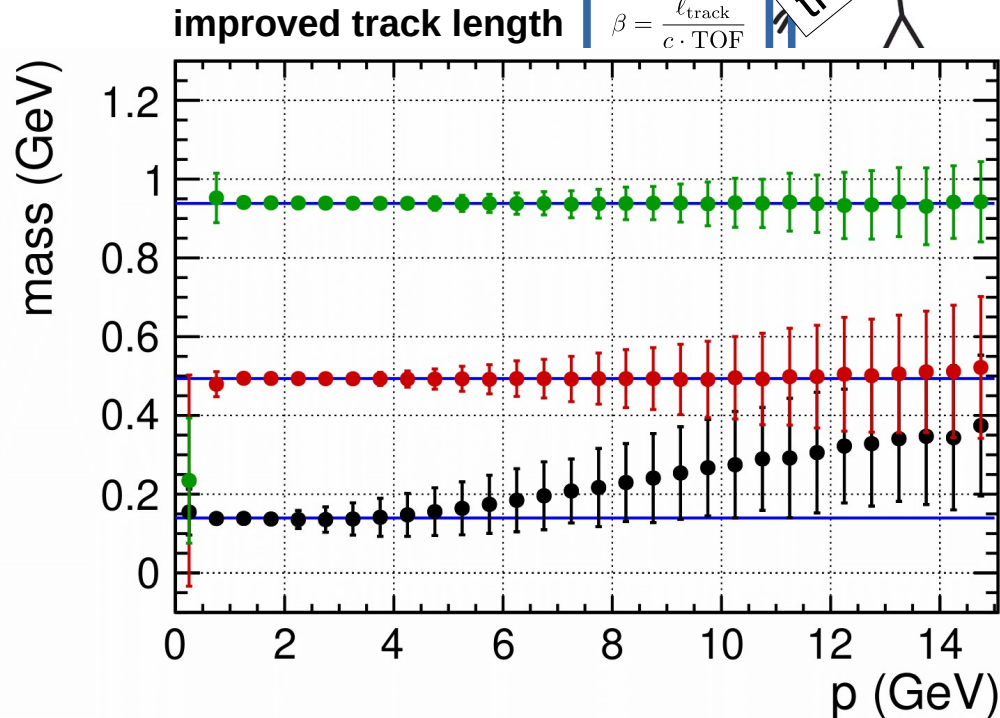
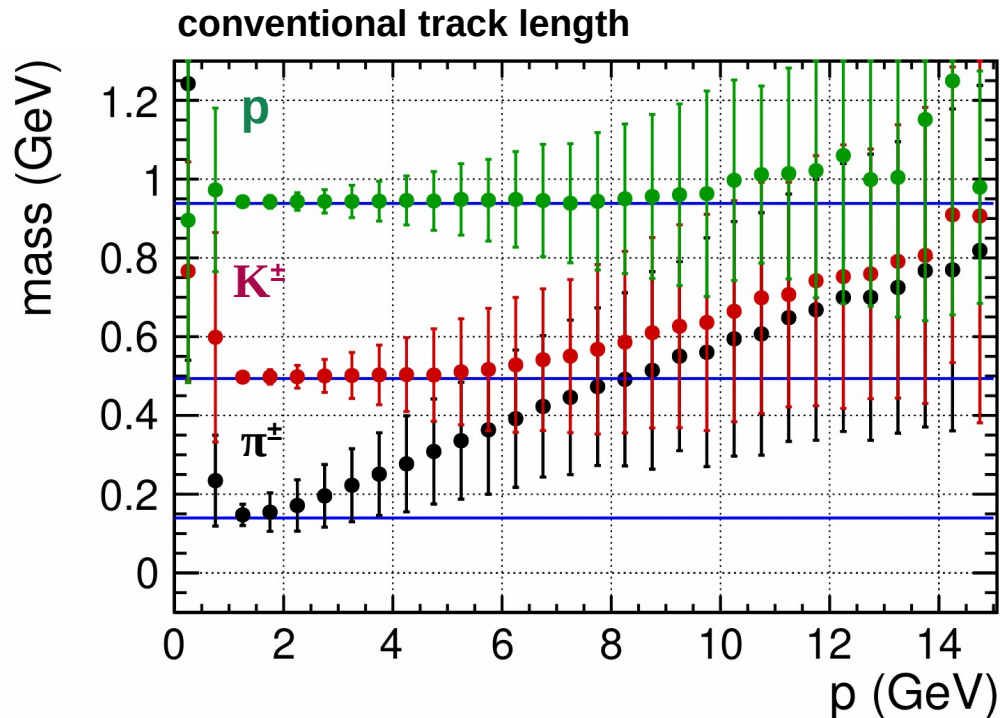
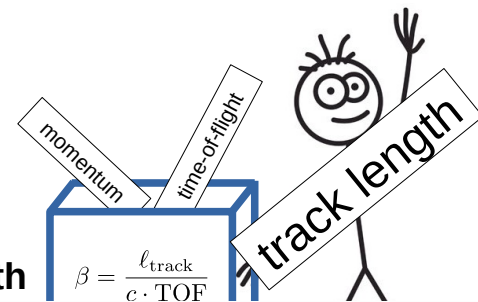
- Relies on constant momentum along the track
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IMPROVED: iterate hit-by-hit and
sum lengths between neighbor hits:

$$\ell_{\text{track}} = \sum_{i=0}^n \ell_i = \sum_{i=0}^n \sqrt{\left(\frac{\varphi_{i+1} - \varphi_i}{\Omega_i} \right)^2 + (z_{i+1} - z_i)^2}$$

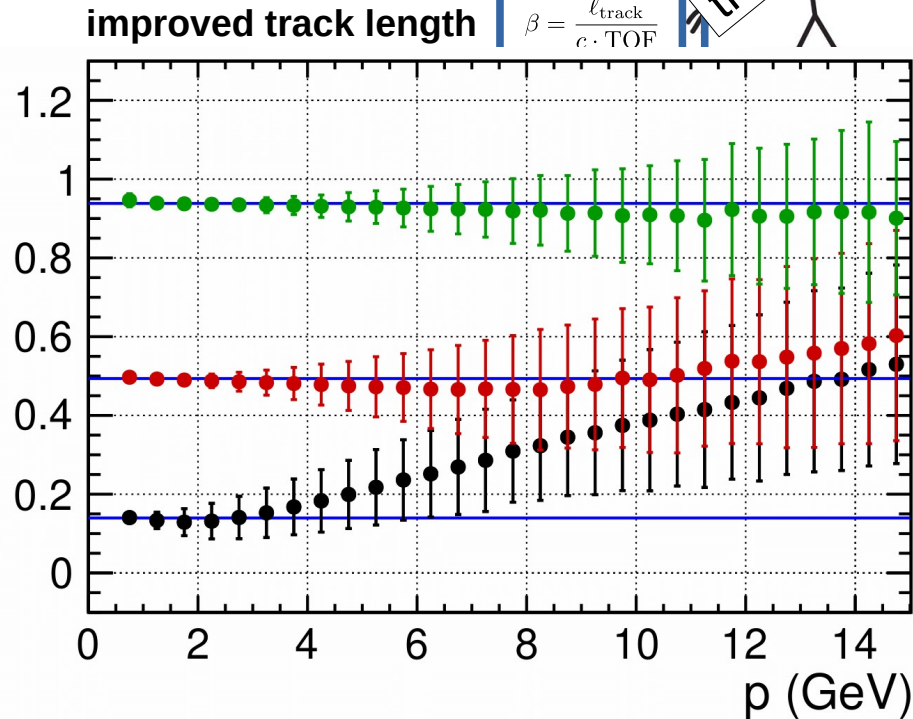
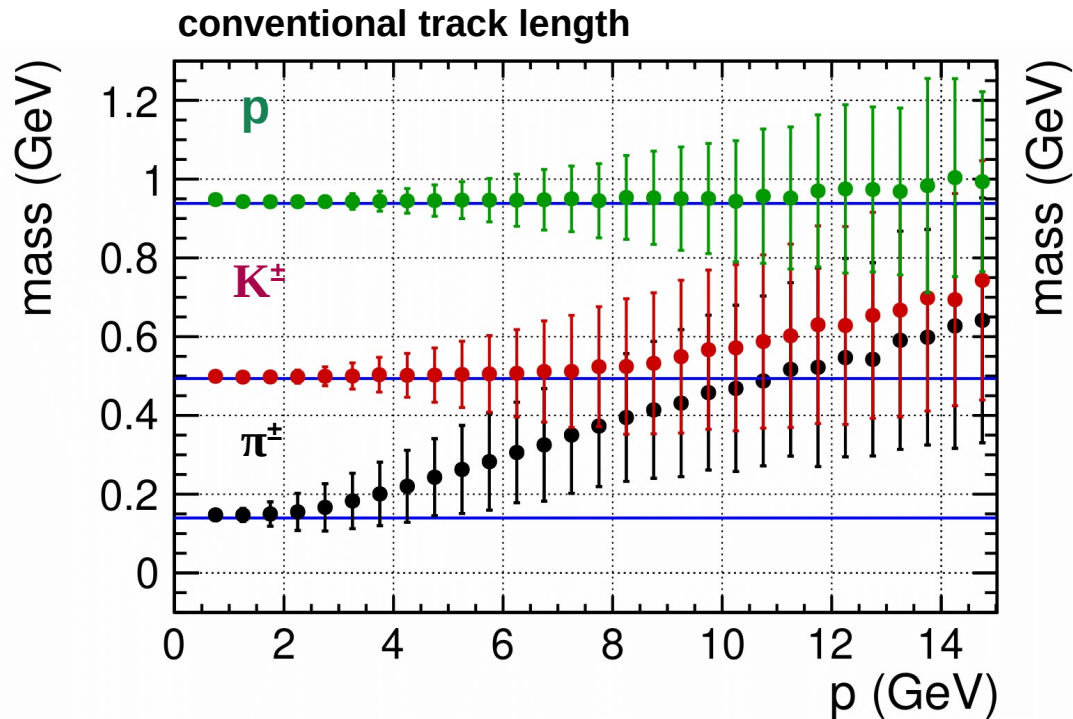
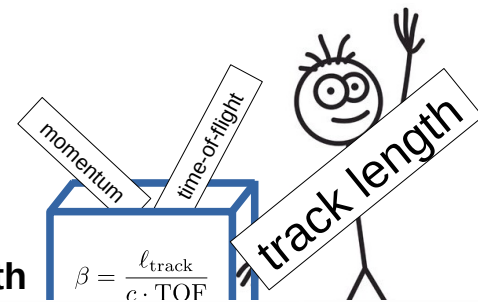
credit goes to Winfried A. Mitaroff
arXiv:2107.02031

Mass reconstruction in the endcap



*plots assume perfect time resolution
in the first ECAL layer

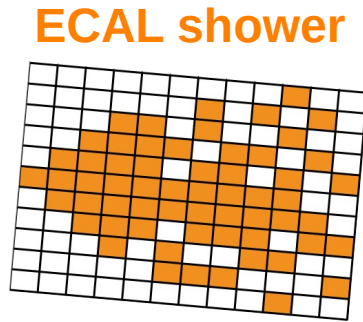
Mass reconstruction in the barrel



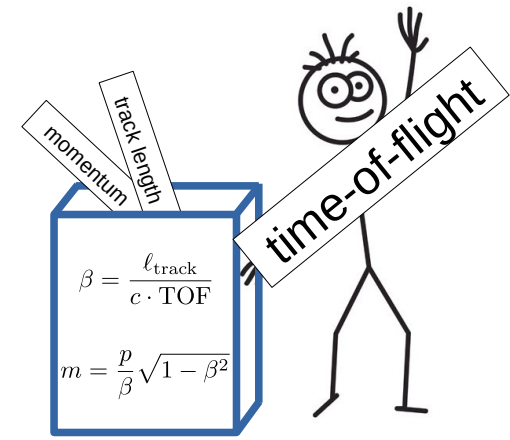
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Time-of-flight measurement

Each **hit** has:
x, y, z, t, E



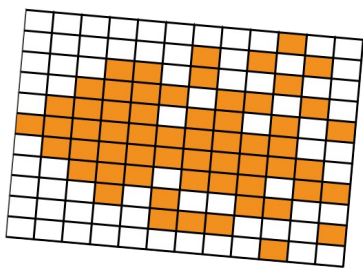
Very smart algorithm () = time-of-flight



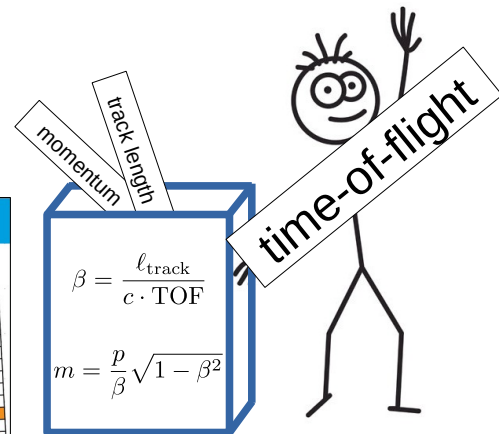
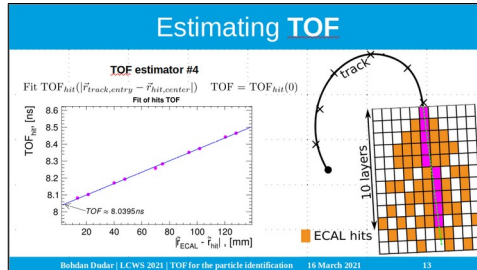
Time-of-flight measurement

Each **hit** has:
x, y, z, t, E

ECAL shower



Bohdan Dudar, Ulrich Einhaus



$$\beta = \frac{\ell_{\text{track}}}{c \cdot \text{TOF}}$$

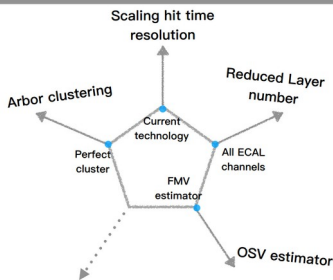
$$m = \frac{p}{\beta} \sqrt{1 - \beta^2}$$

Very smart algorithm () = time-of-flight

Yuzhi Che, Manqi Ruan

6. Conclusion

- **Arbor clustering module** improves the EM (hadronic) cluster time resolution by a factor of ~1.2 (1.4)
- The cluster time resolution is proportional to the **intrinsic time resolution**.
- Cluster time resolution is inversely proportional to the $\sqrt{N_{\text{layer}}}$.
- **Alternative strategy**: OSV estimator could improve the EM cluster TOF resolution by a factor of ~3.



Many analyses are ongoing...

Mami Kuhara, Taikan Suehara

Flavor tagging

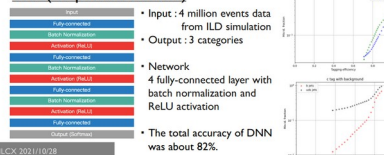
Flavor Tagging

- Jets are bundles of hadrons originated by quarks and gluons.
- **Flavor tagging** is the algorithm which classify the quarks (b/c/q).
- In the LCFIPlus, the flavor tagging algorithm is based on the Boosted Decision Trees, which is traditional ML.

Purpose on this study

- Improve the performance of the flavor tagging by introducing deep-learning techniques.
- Combine vertex finding and flavor tagging in single DNN structure.
- Incorporate hadron charge ID to enhance the separation

DNN (Deep Neural Network)

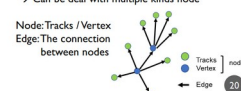


Next step

GTN (Graph Transformer Network)

arXiv:1911.06455v2

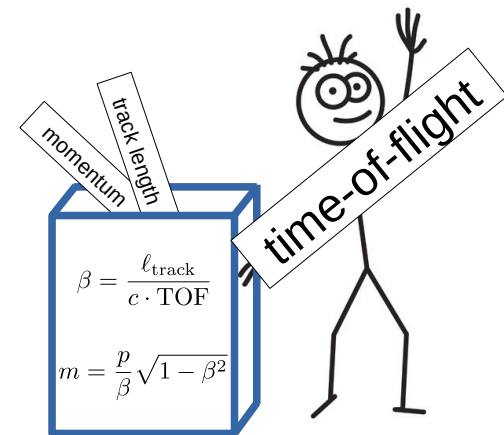
→ Can be deal with multiple kinds node



Time-of-flight measurement

BUT we have very simplified simulation of time measurement.

- no digitization
- $t_0 = 0$
- Only earliest MC contribution is considered



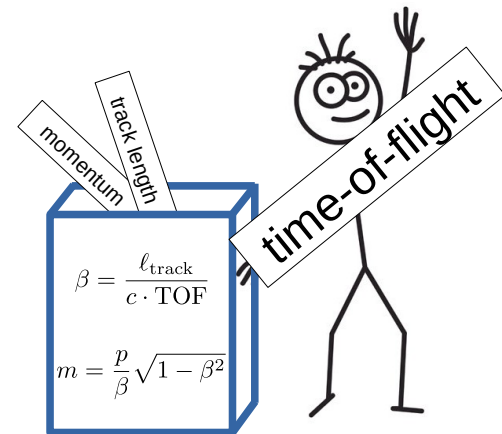
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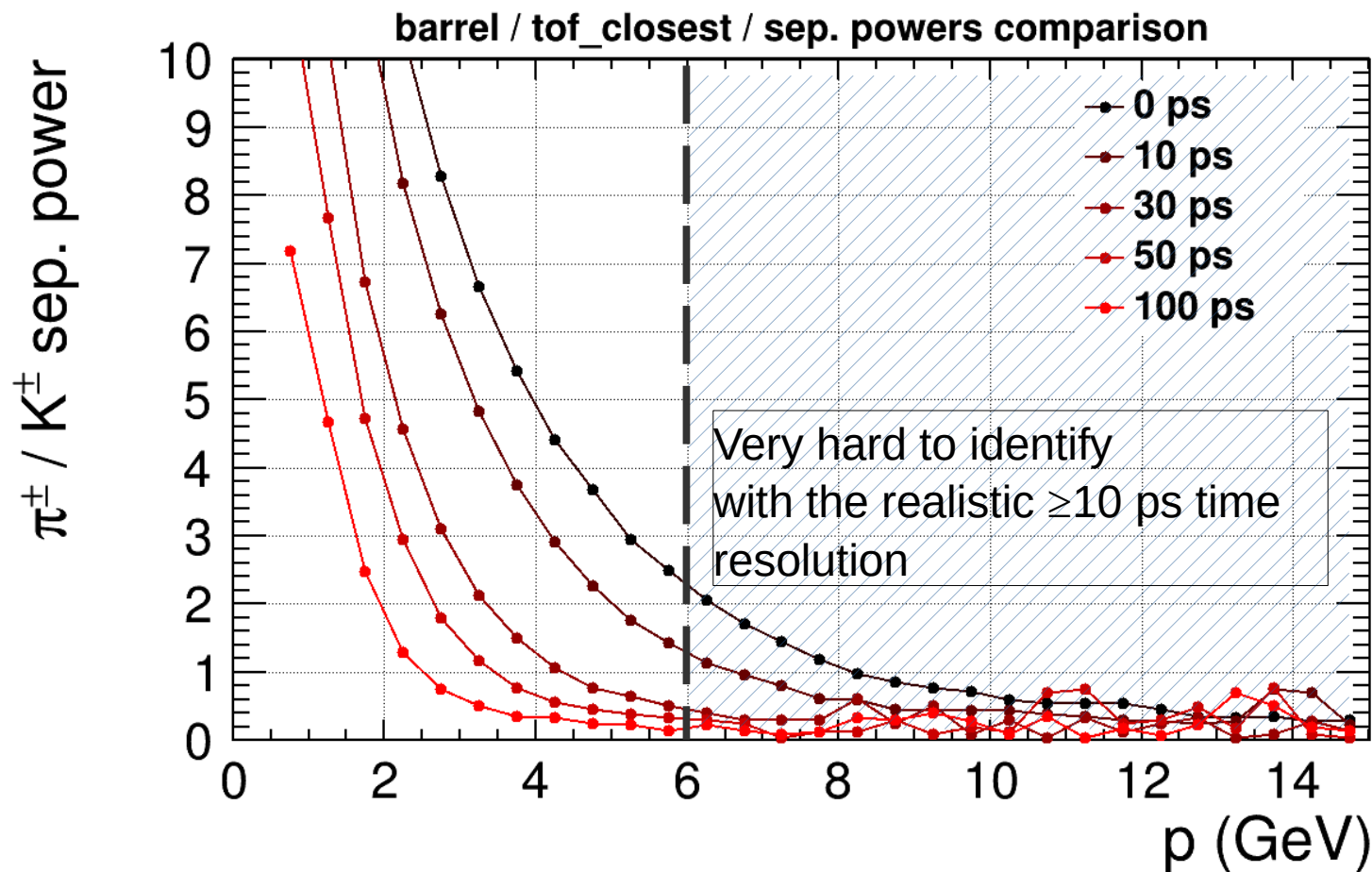
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FOR NOW use effective time-of-flight resolution:

- Take only closest ECAL hit to the track
- smear its time with a Gaussian

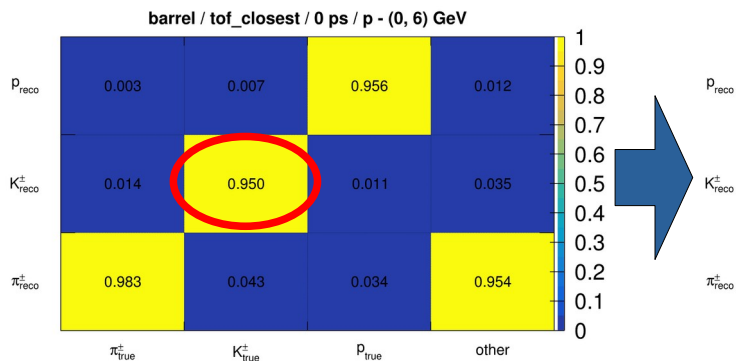


Particle identification: separation power

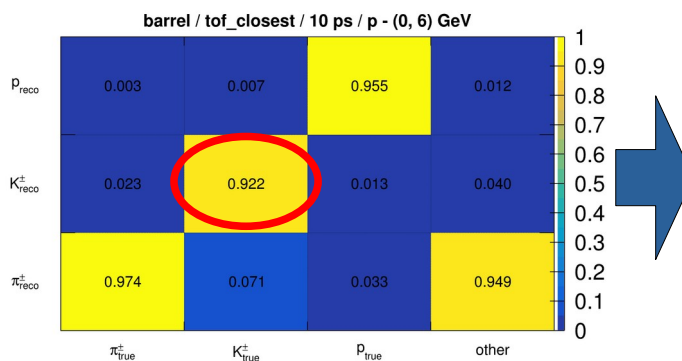


Particle identification: efficiency & purity

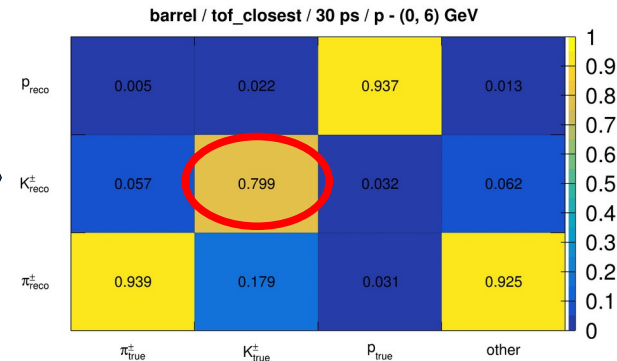
0 ps



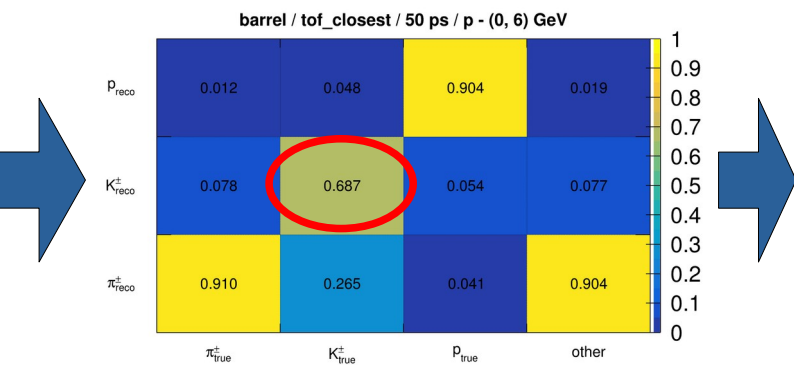
10 ps



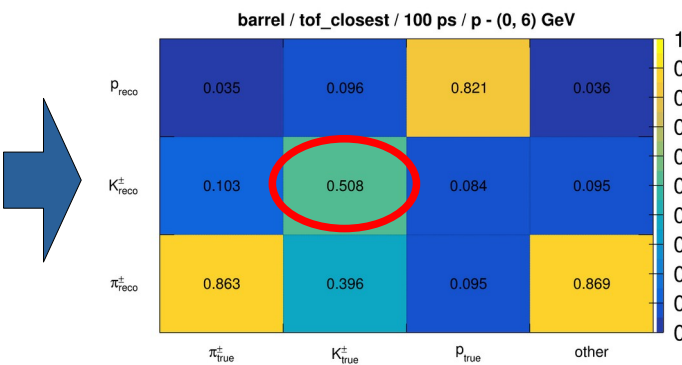
30 ps



50 ps



100 ps



Kaon ID efficiency degrades from 95% to 51% with worsening TOF resolution

Summary

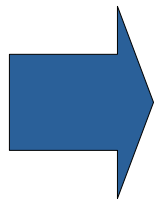
- We have improved momentum and track length estimations that are crucial for particle identification with the time-of-flight
- We can achieve K^\pm ID efficiency $> 92\%$ and mis-tag rate $< 8\%$ up to 6 GeV momentum using only single ECAL hit with 10 ps hit time resolution
- Take away for the hardware: get below 30 ps TOF resolution (as close to 10 ps as possible)

Summary

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- We can achieve K^\pm ID efficiency $> 92\%$ and mis-tag rate $< 8\%$ up to 6 GeV momentum using only single ECAL hit with 10 ps hit time resolution
- Take away for the hardware: get below 30 ps TOF resolution (as close to 10 ps as possible)

TODOs

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Is it worth the investment?



Flavour tag
Higgs couplings
 A_{FB}
Kaon mass (next talk by U. Einhaus)
Vertex position
Track refitting