Particle identification with fast timing detectors at future Higgs factories

DPG conference T 44.1

22 March 2022

Bohdan Dudar[1, 2], Jenny List[1], Ulrich Einhaus[1]

[1]Deutsches Elektronen-Synchrotron, [2]Universität Hamburg

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

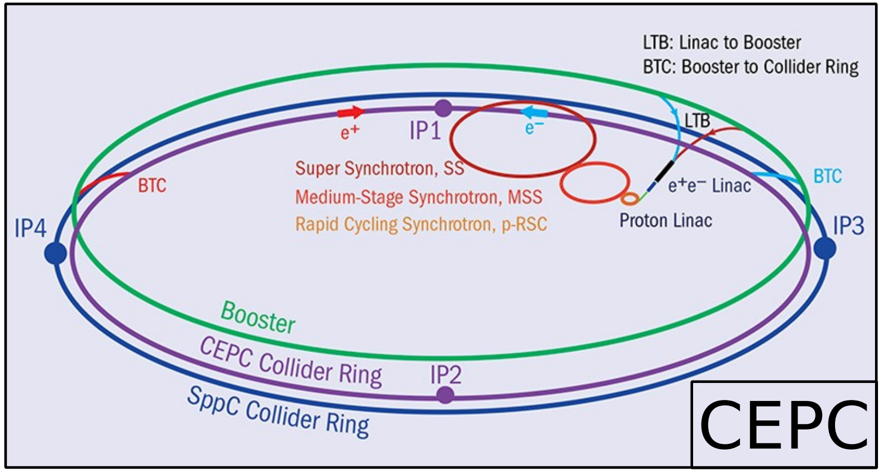
2020 Update of the European strategy for particle physics

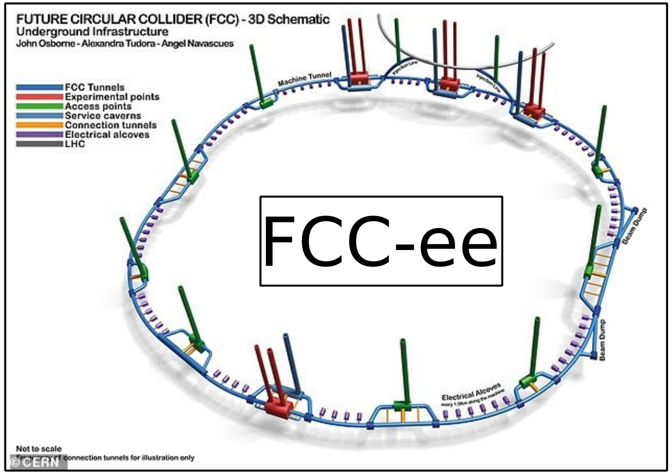
3

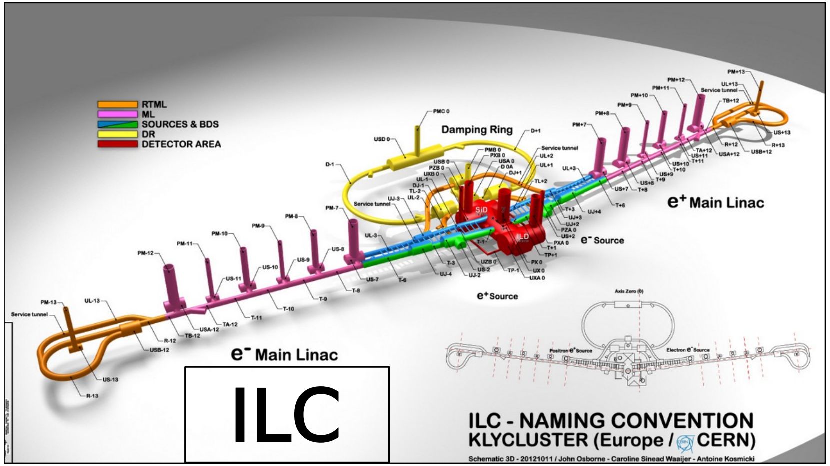
High-priority future initiatives

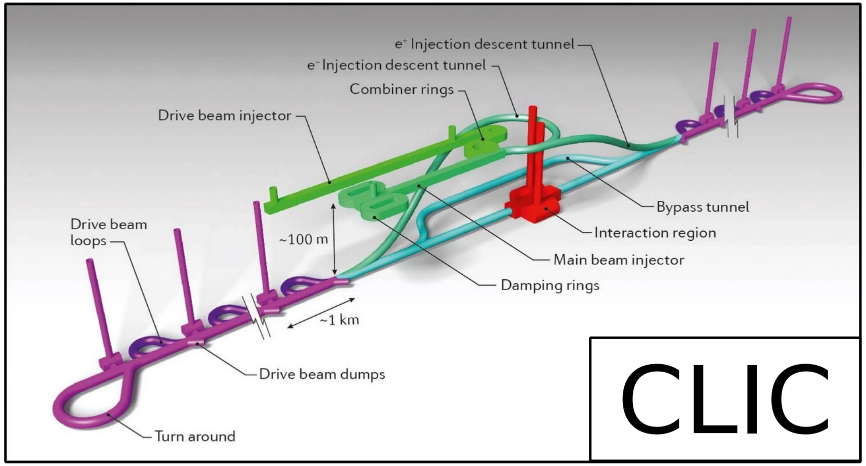
A. An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge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

Major candidates for the future Higgs factories

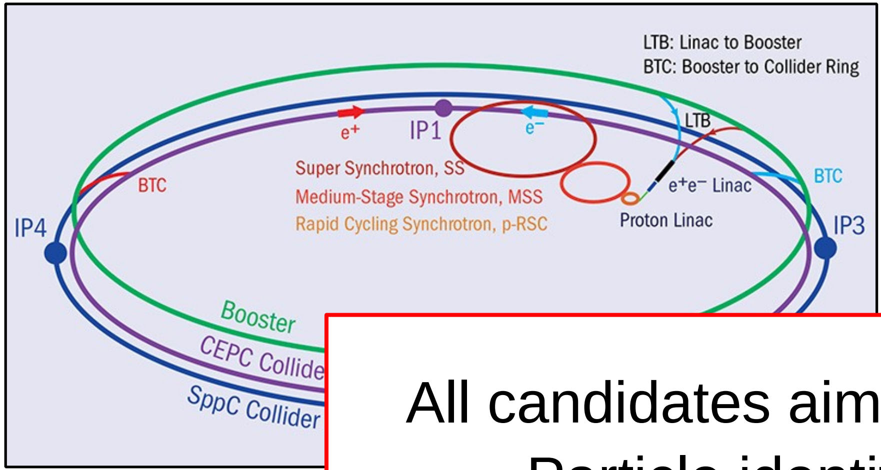


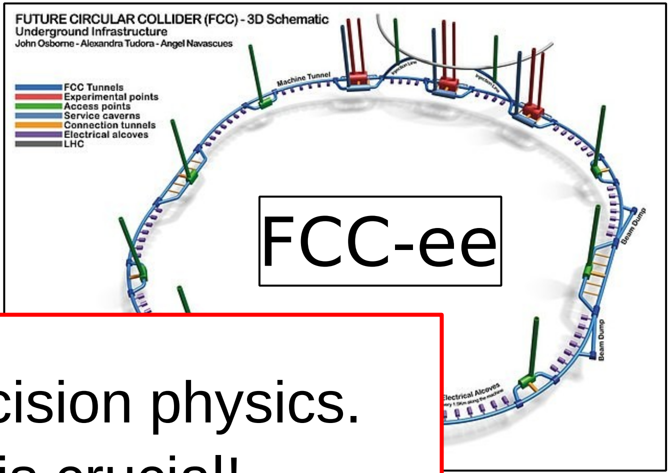






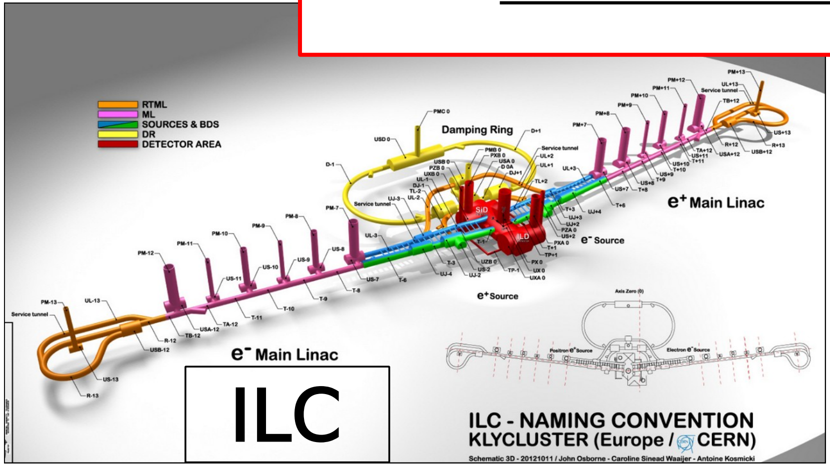
Major candidates for the future Higgs factories

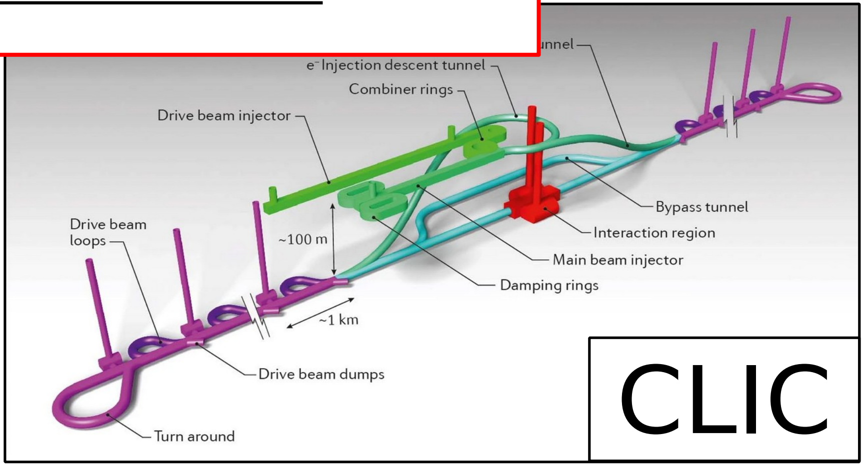




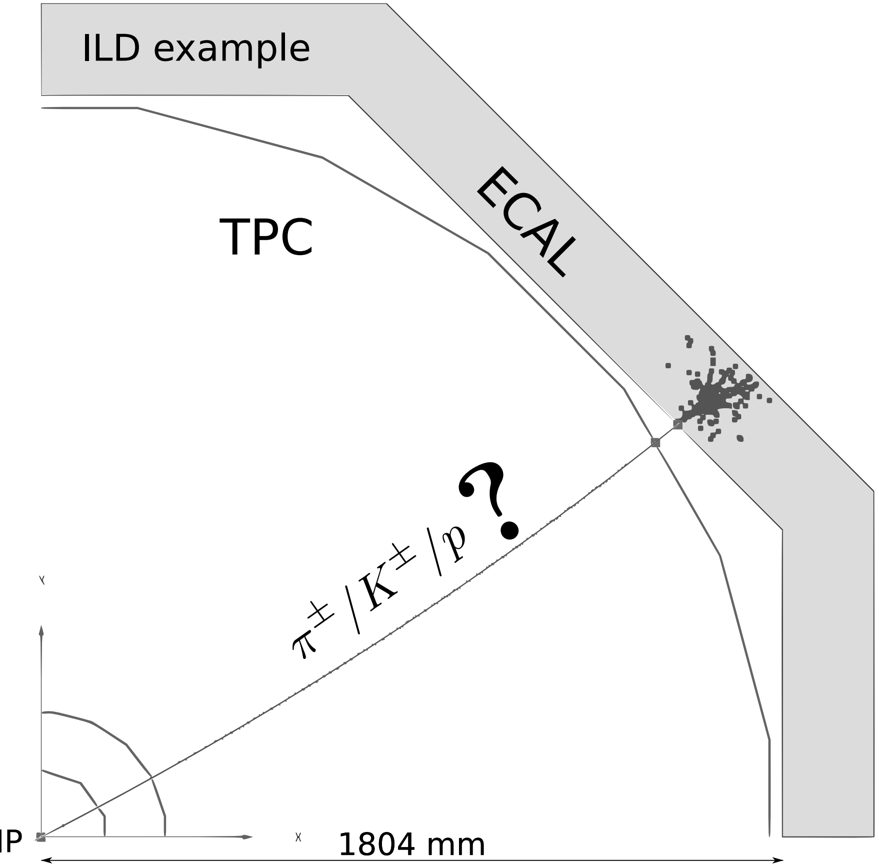
All candidates aim for precision physics.

<u>Particle identification is crucial</u>!

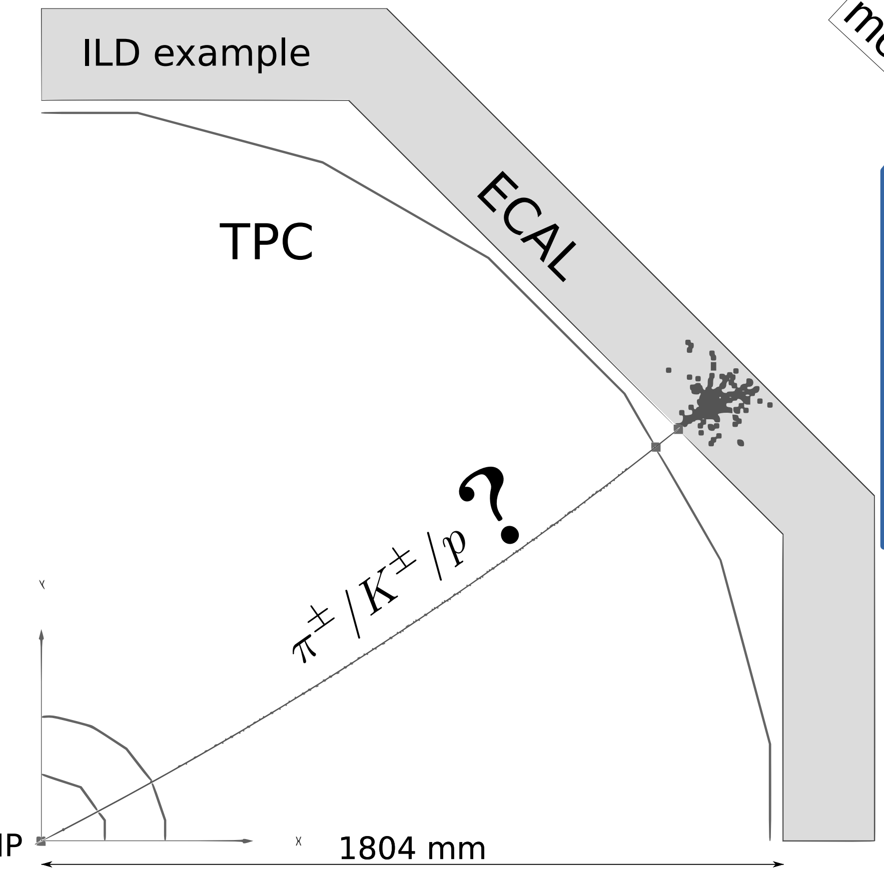


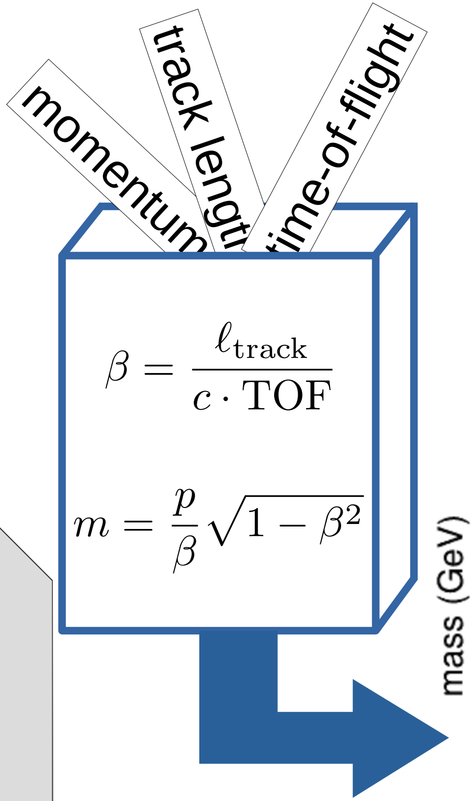


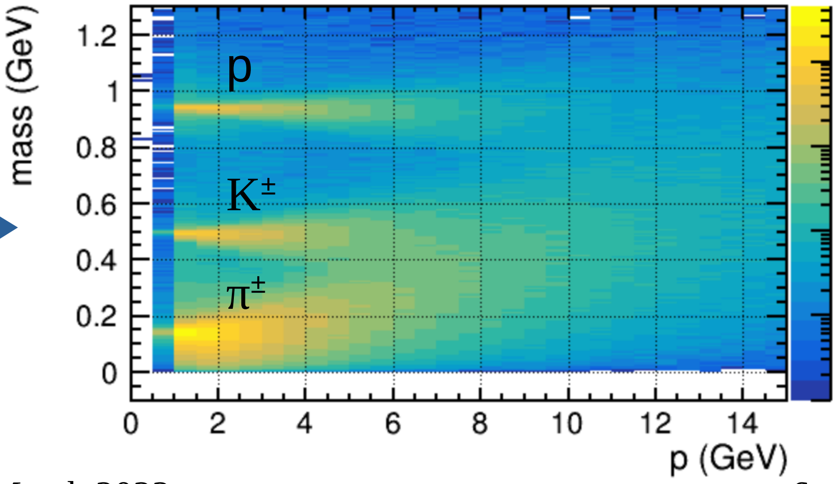
Particle identification with time-of-flight



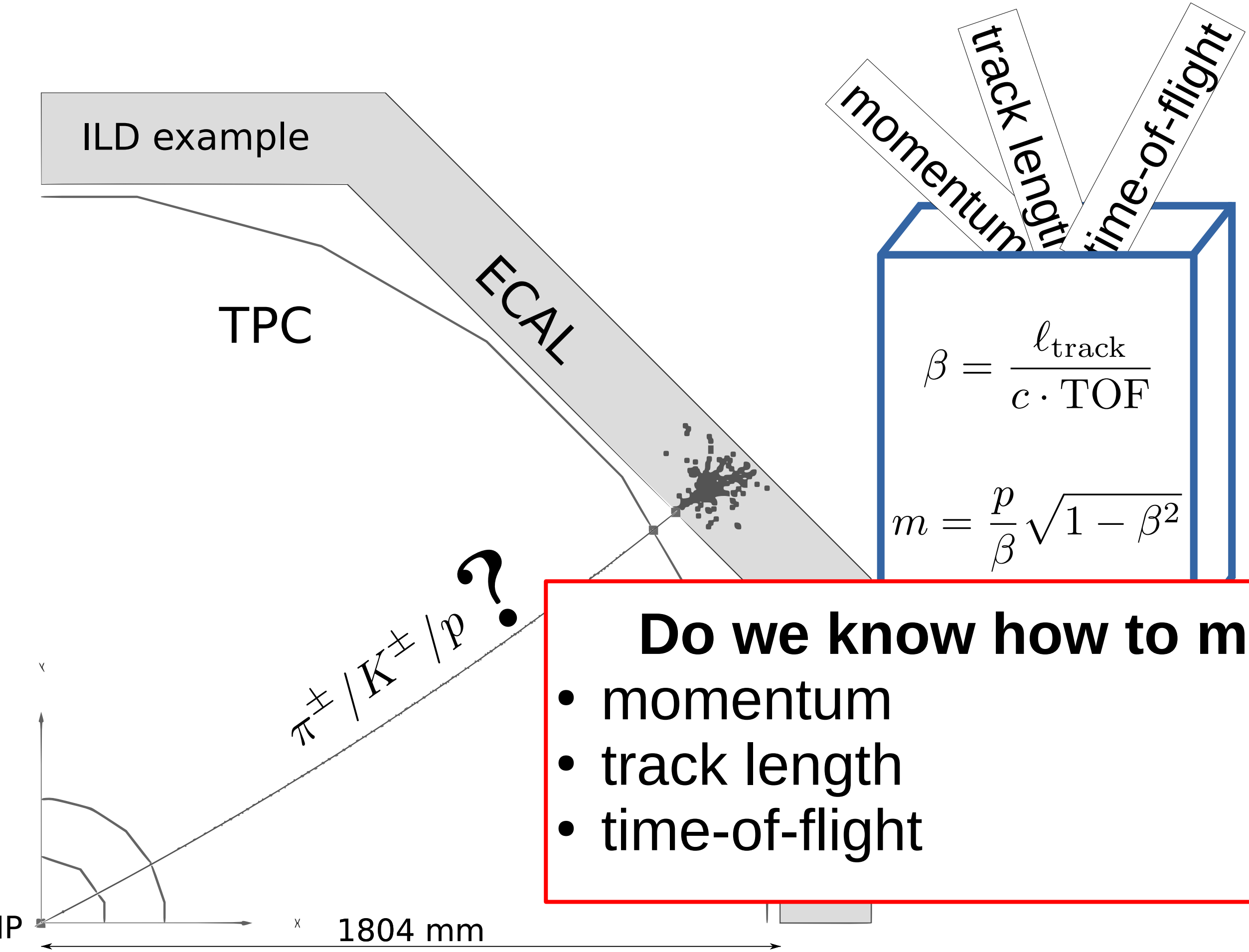
Particle identification with time-of-flight

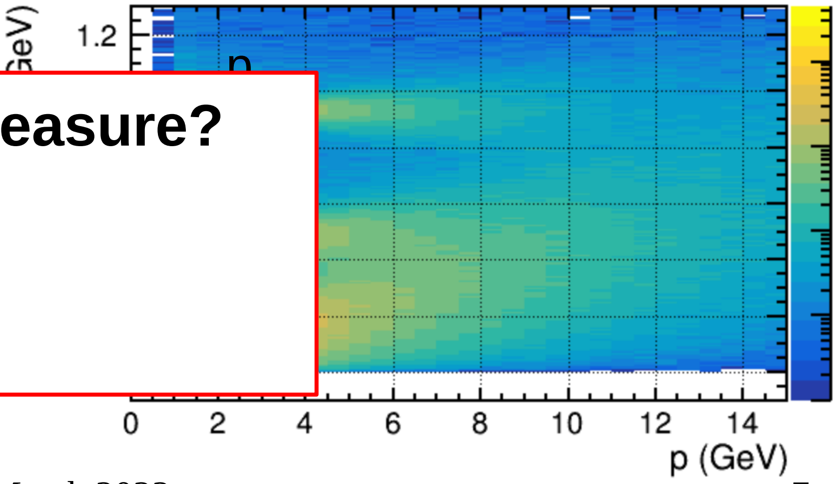






Particle identification with time-of-flight

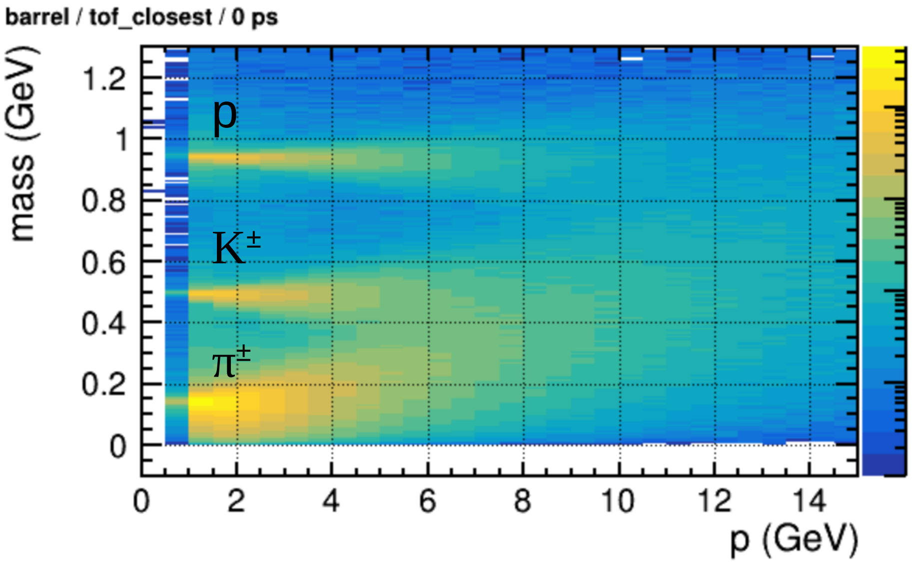




Do we know how to measure?

- momentum
- track length
- time-of-flight

Particle identification with time-of-flight



← requires <u>extremely precise</u> time-of-flight measurement (~10 ps)

e.g. with LGADs

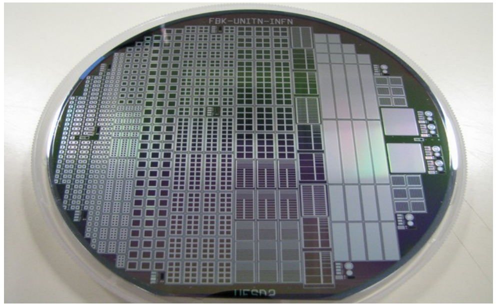


photo: Annika Vauth

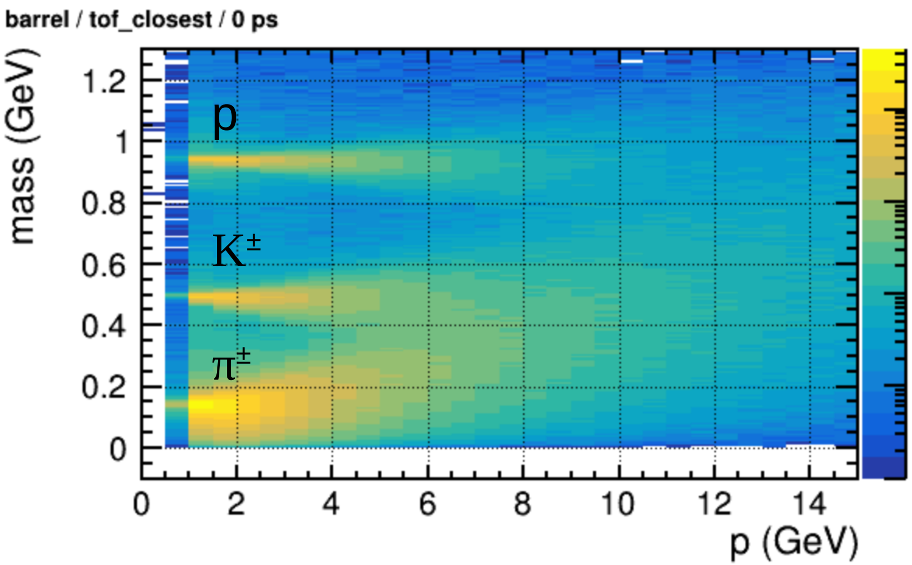
drawbacks:

→ expensive

→ require cooling

→ not radiation hard

Particle identification with time-of-flight



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

e.g. with LGADs

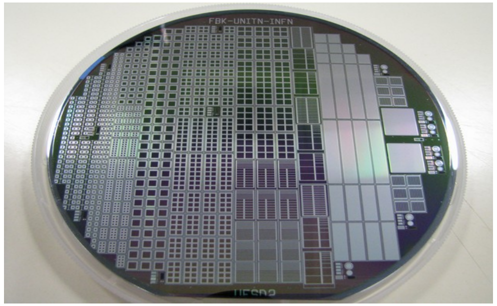


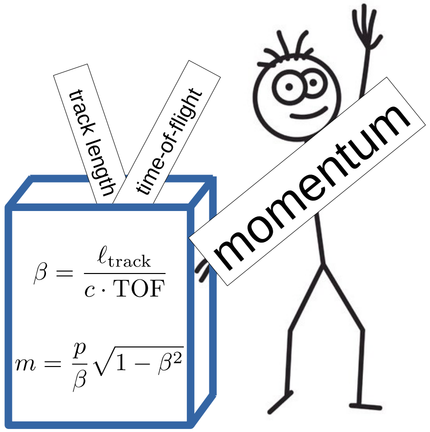
photo: Annika Vauth

drawbacks:

- expensive
- require cooling
- not radiation hard

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

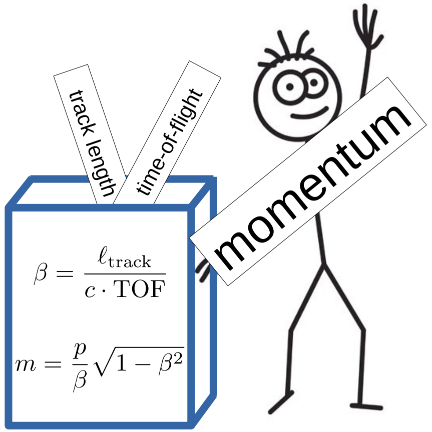
Momentum calculation



We calculate momentum from the curvature Ω:

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

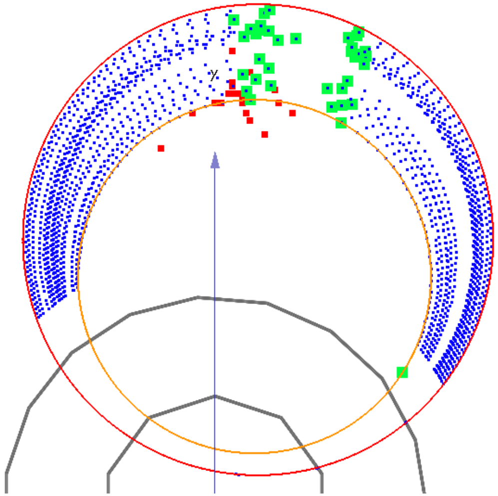
Momentum calculation



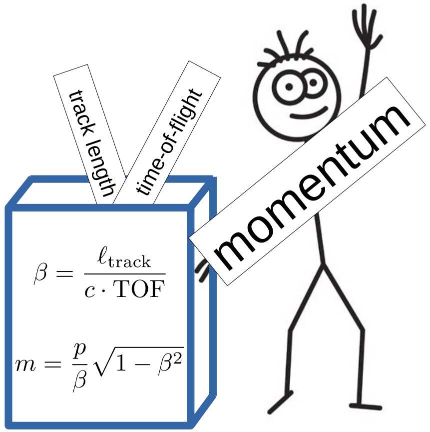
We calculate momentum from the curvature Ω:

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

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



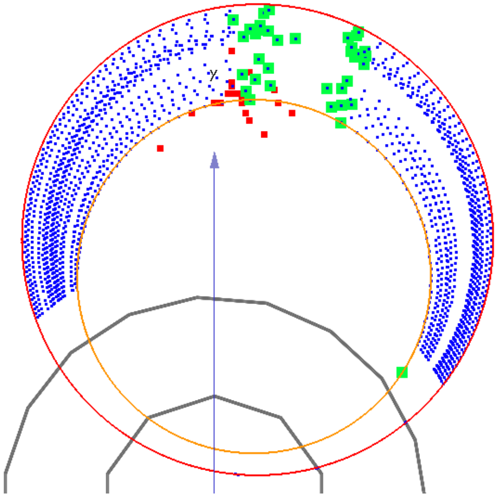
Momentum calculation



We calculate momentum from the curvature Ω:

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

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



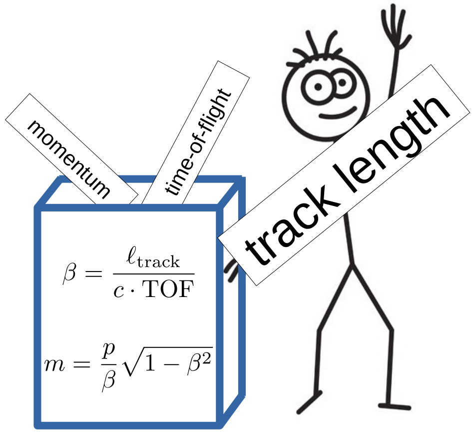
IMPROVED: calculate momentum at every tracker hit and use harmonic mean for particle ID

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

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

credit goes to Winfried A. Mitaroff
arXiv:2107.02031

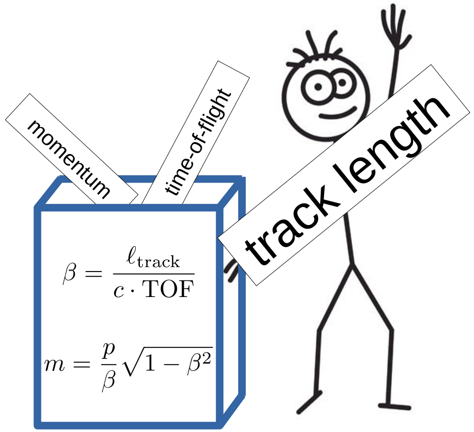
Track length calculation



Simple assumption: track is a helix

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

Track length calculation



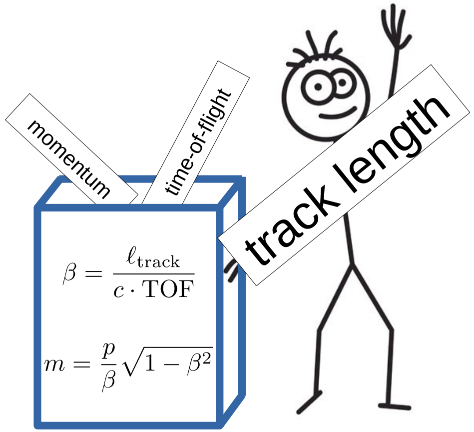
Simple assumption: track is a helix

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

BUT has similar limitations:

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

Track length calculation



Simple assumption: track is a helix

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

BUT has similar limitations:

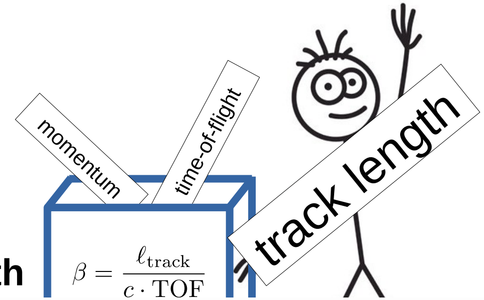
- Relies on constant momentum along the track
- Does not work for curly tracks

IMPROVED: iterate hit-by-hit and sum lengths between neighbor hits:

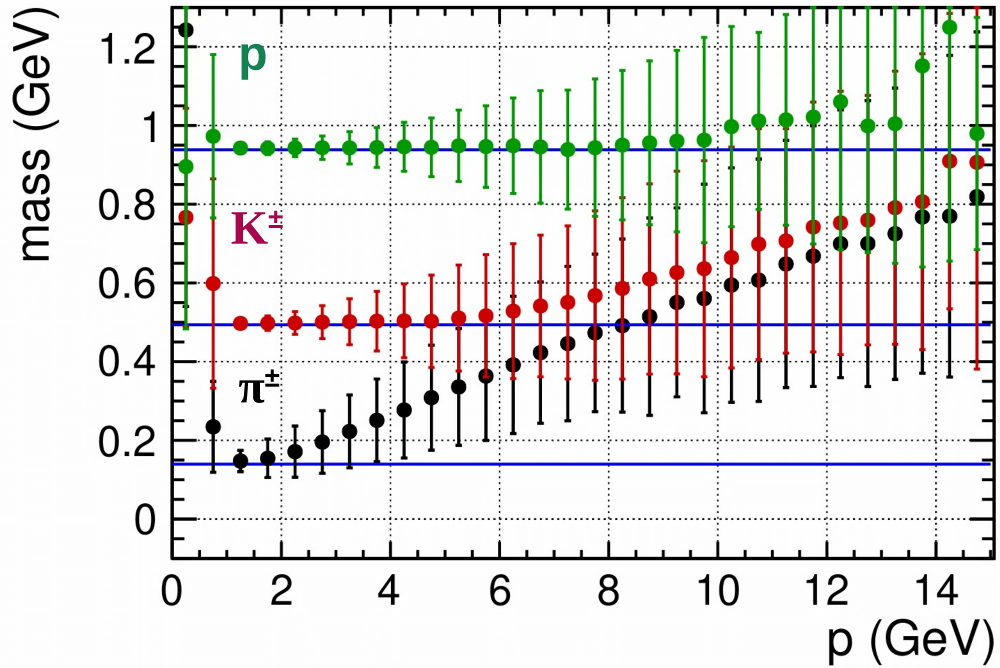
$$\ell_{\mathrm{track}} = \sum_{i=0}^{n} \ell_i = \sum_{i=0}^{n} \sqrt{\left(\frac{\varphi_{i+1} - \varphi_i}{\Omega_i}\right)^2 + (z_{i+1} - z_i)^2}$$

credit goes to Winfried A. Mitaroff
arXiv:2107.02031

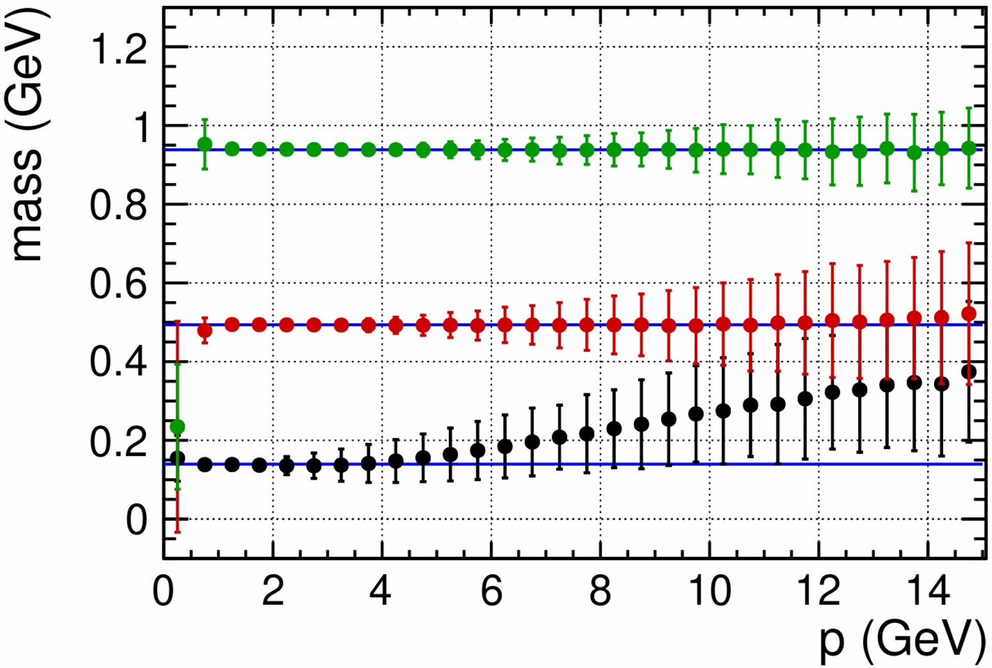
Mass reconstruction in the endcap



conventional track length

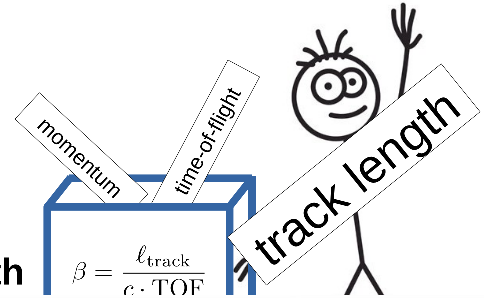


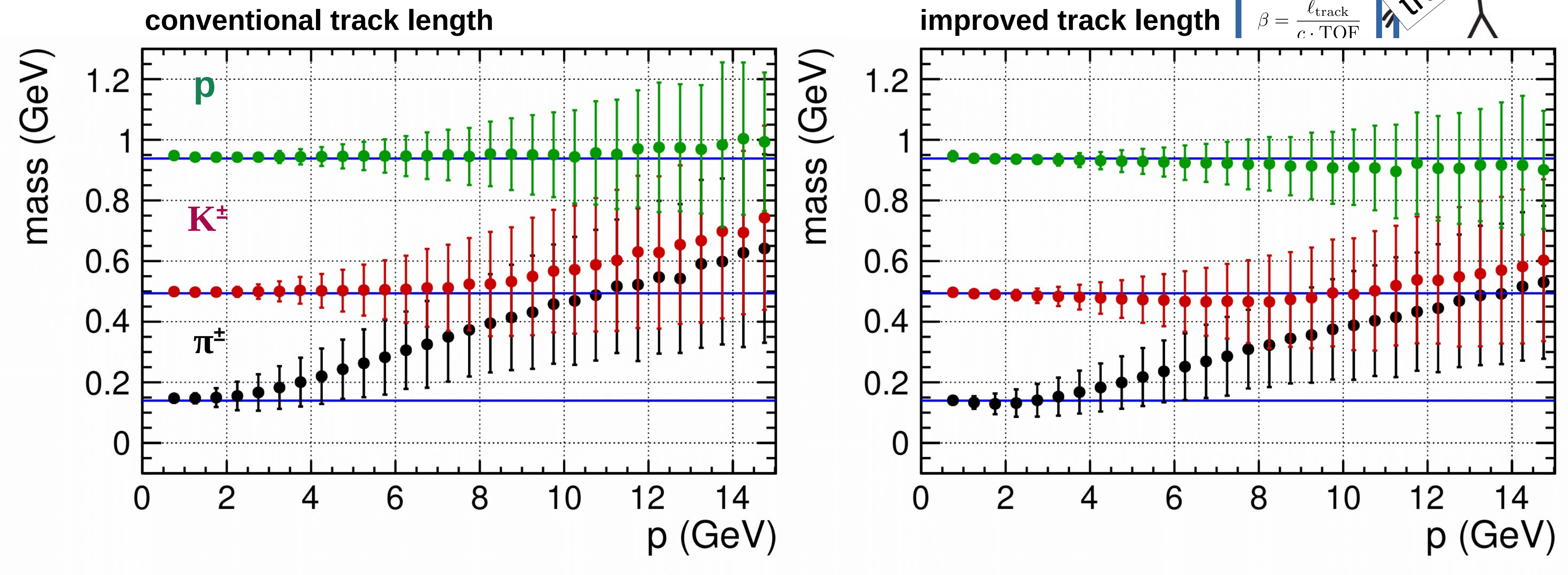
improved track length



*plots assume perfect time resolution in the first ECAL layer

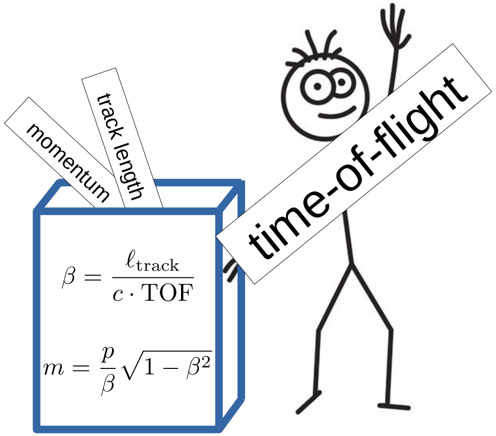
Mass reconstruction in the barrel





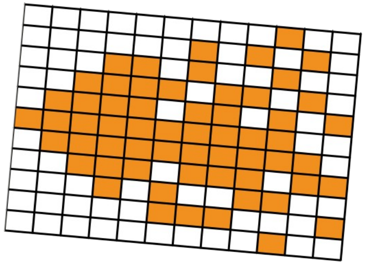
*plots assume perfect time resolution in the first ECAL layer

Time-of-flight measurement



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

ECAL shower

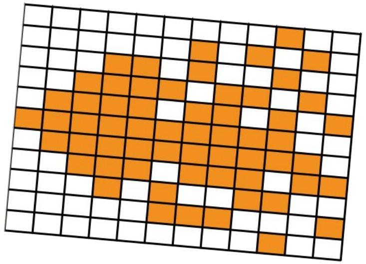


Very smart algorithm ( ) = time-of-flight

Time-of-flight measurement

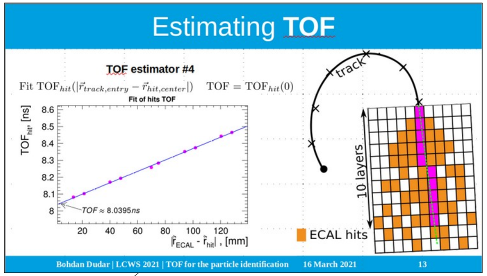
Each hit has:
x, y, z, t, E

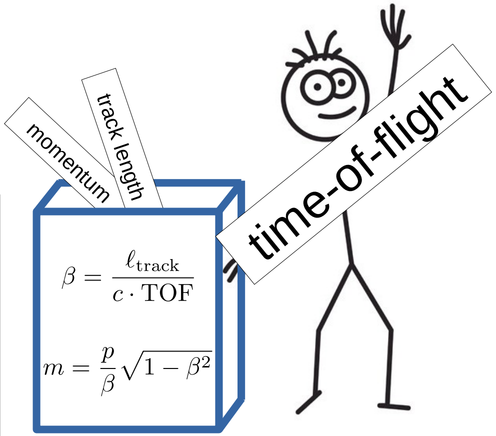
ECAL shower



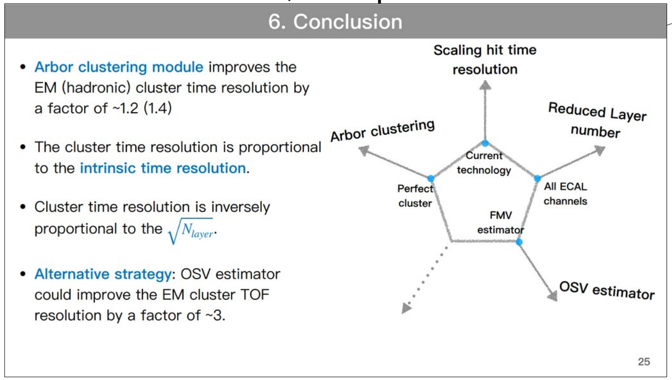
$$\text{Very smart algorithm}\ (\quad\quad) = \text{time-of-flight}$$

Bohdan Dudar, Ulrich Einhaus



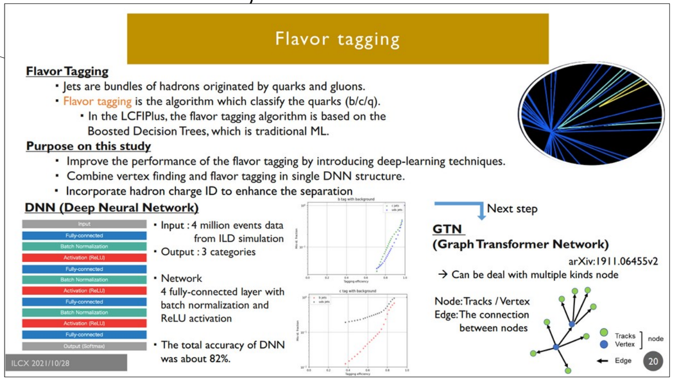


Yuzhi Che, Manqi Ruan



<u>Many</u> analyses are ongoing...

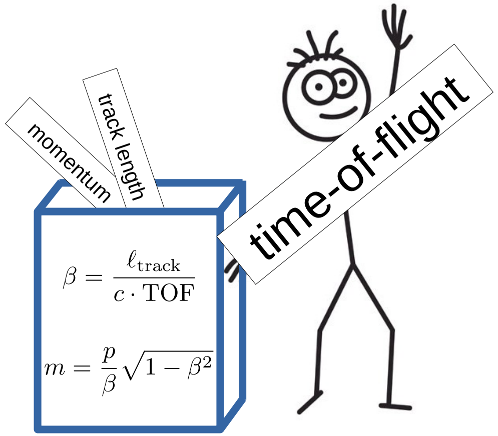
Mami Kuhara, Taikan Suehara



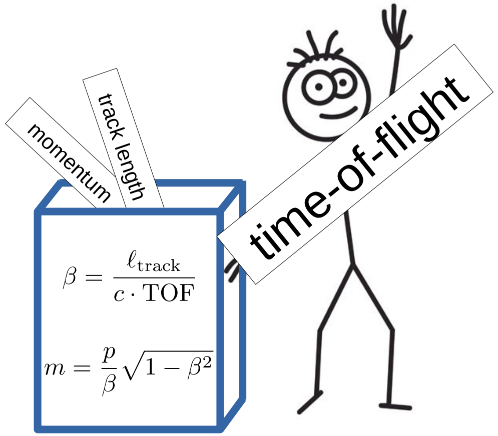
Time-of-flight measurement

BUT we have very simplified simulation of time measurement.

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



Time-of-flight measurement



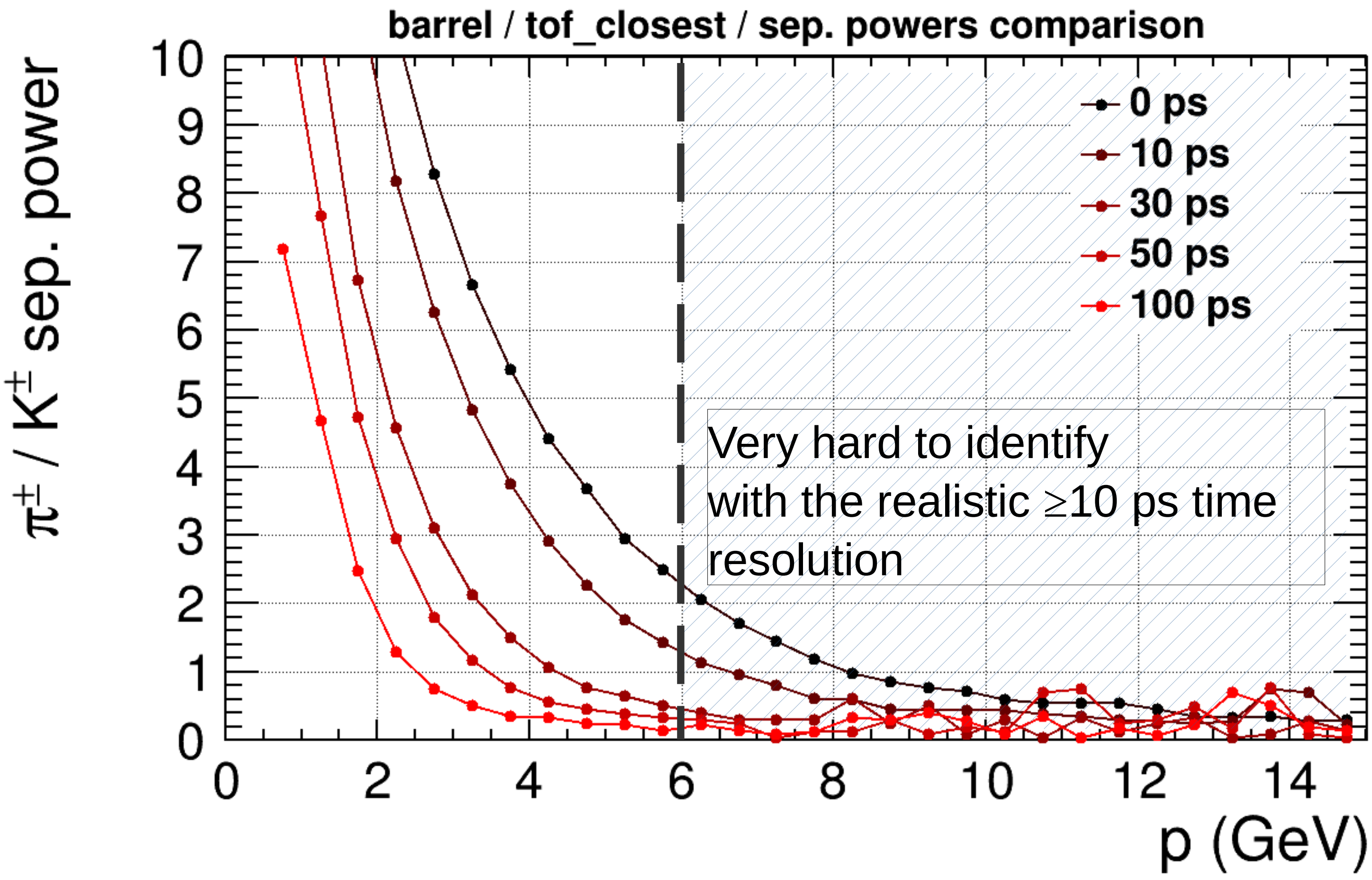
BUT we have very simplified simulation of time measurement.

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

FOR NOW use effective time-of-flight resolution:

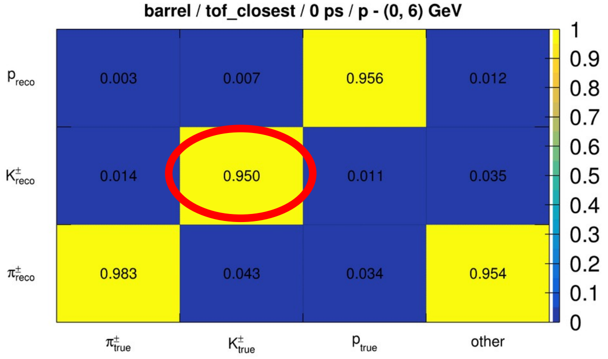
- Take only closest ECAL hit to the track
- smear its time with a Gaussian

Particle identification: separation power

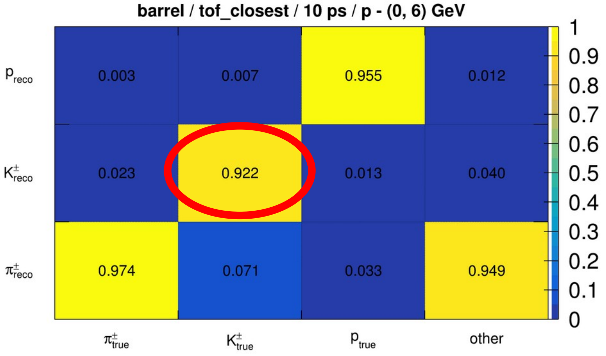


Particle identification: efficiency & purity

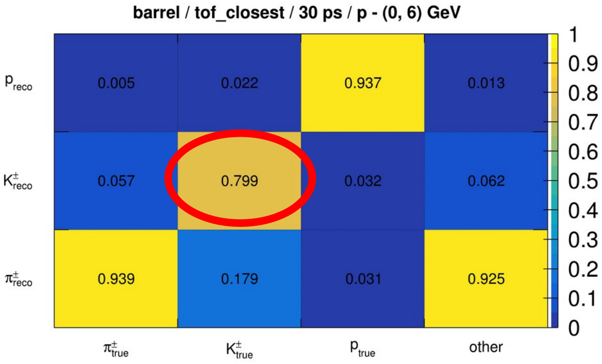
0 ps



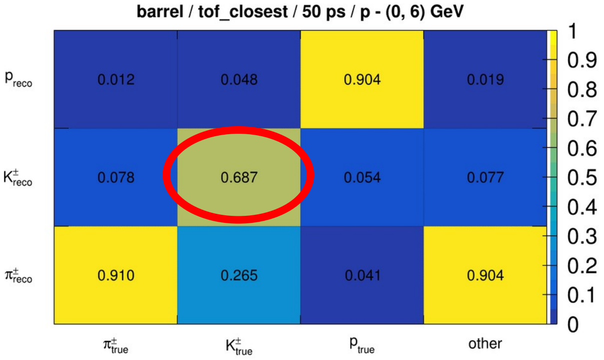
10 ps



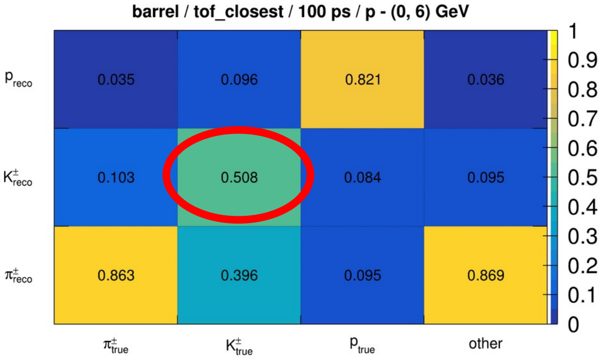
30 ps



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

- 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)

TODOs

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

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