Prospects of Charged Kaon Mass Measurement via TOF at ILD

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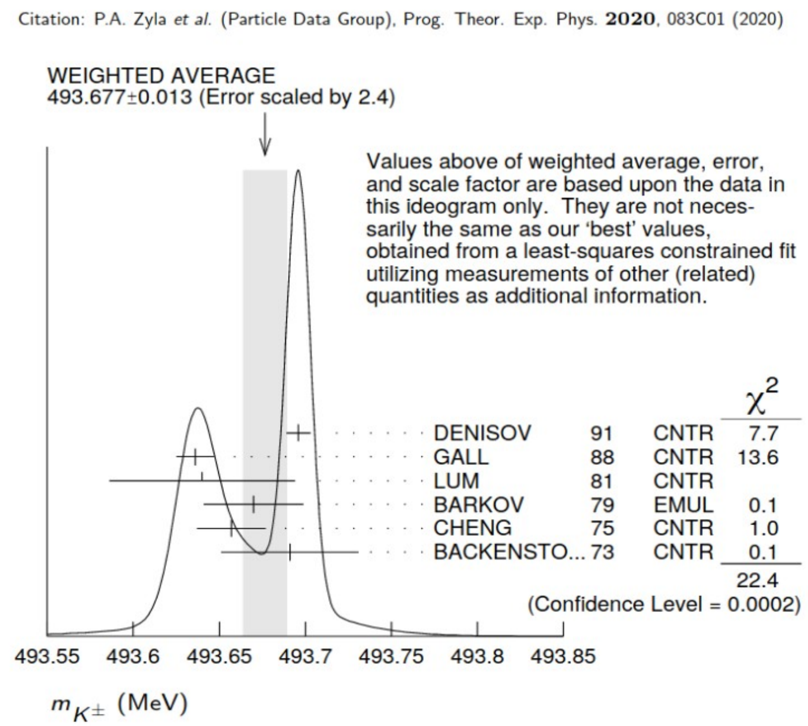
The Question

- Best estimate for charged kaon mass in PDG dominated (since early 90s) by two contributions from kaonic atom spectroscopy, at tension with each other ($\Delta \approx 0.060$ MeV)
- $m_K = 493.677 \pm 0.013$ MeV
- Mass necessary for reconstructing B and D decays, possible input for lattice QCD scale setting
- How can we get a high-purity kaon sample and measure the mass?



[Particle Data Group Booklet 2020]

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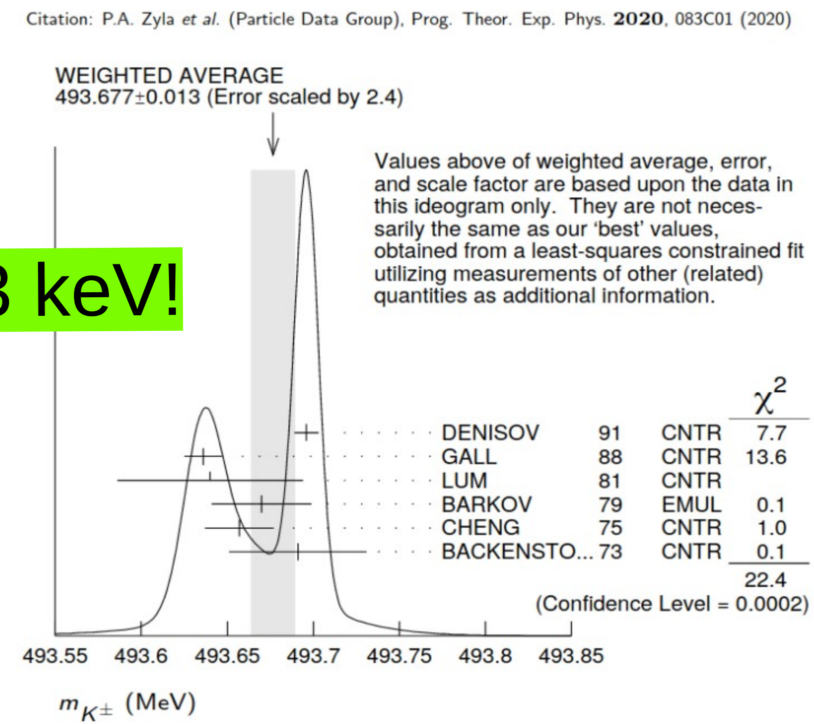
13 keV!



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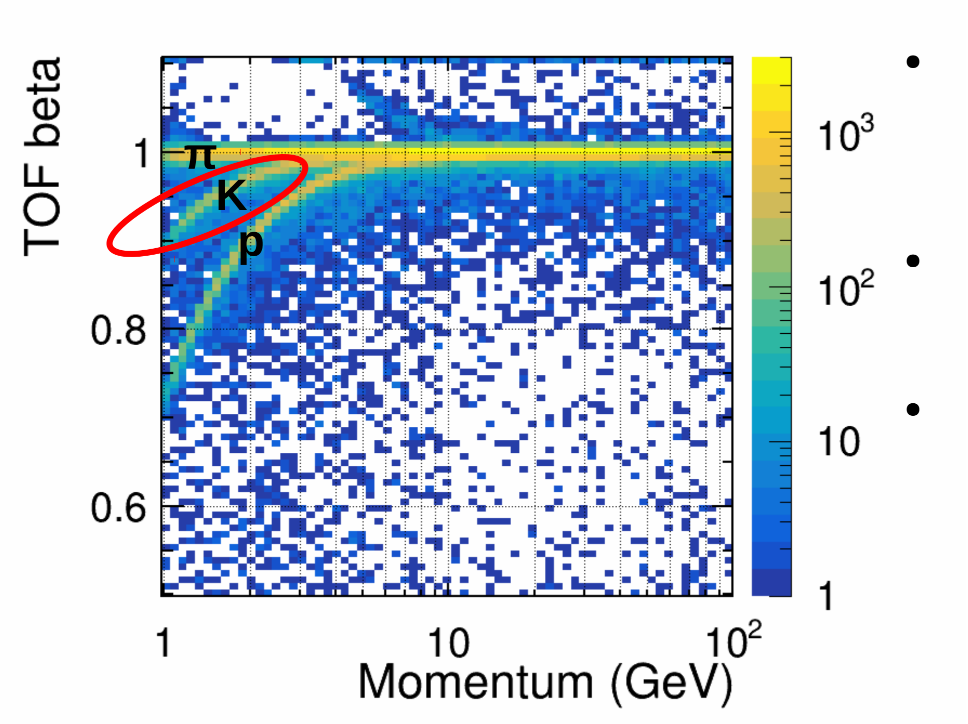
The Idea

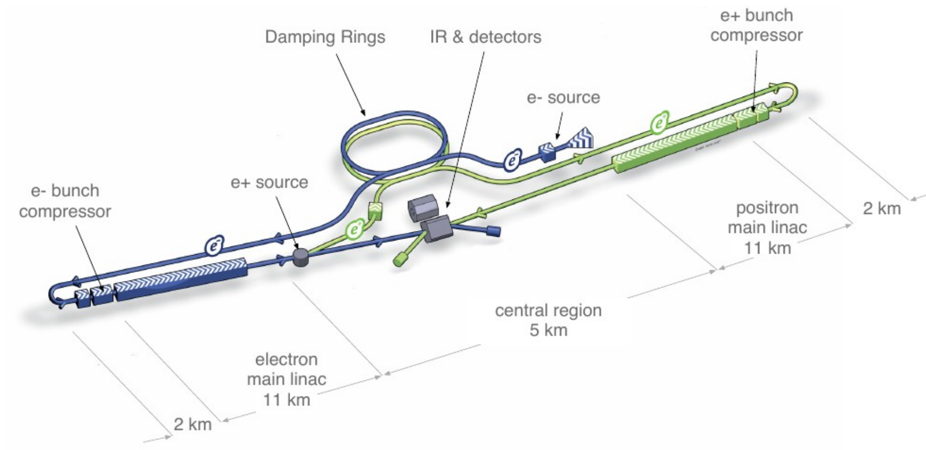


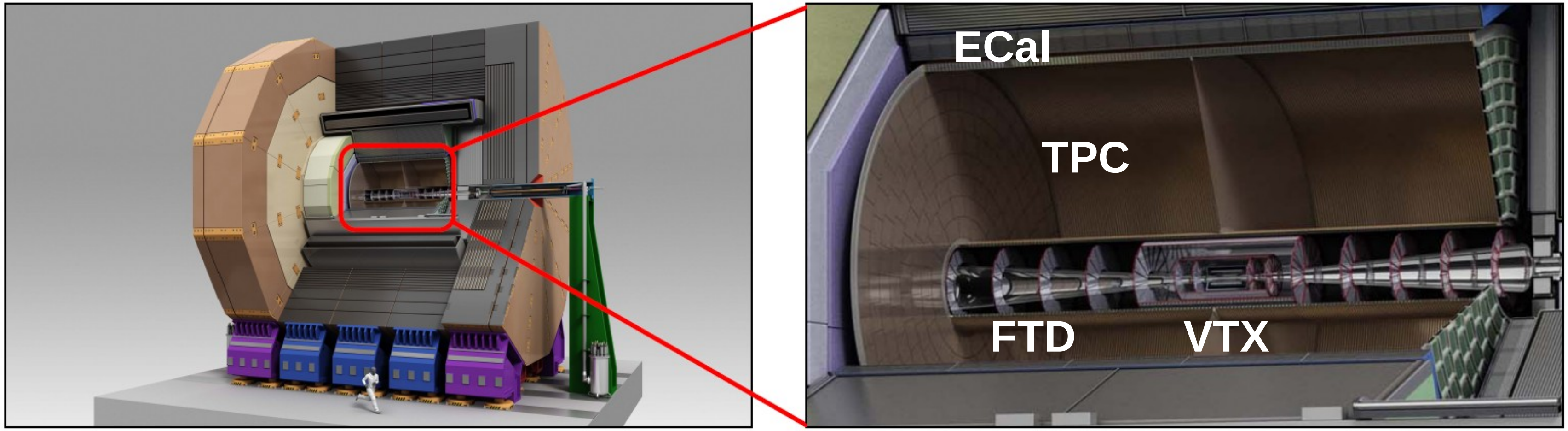
- Use time-of-flight separation to select low-momentum kaons from a random particle collection!
- Use these to extract their mass via β $m = p \cdot \sqrt{1/\beta^2 - 1}$ from a large sample!
- Needs large statistics at low momenta, a high timing resolution and an excellent calibration of the momentum scale

→ Could this be done at a future Higgs factory?

The Experiment

- Use the recent MC production of the International Large Detector ILD for the International Linear Collider ILC
- Use TOF measurement at first ECal layer at r = 1.8 m (barrel) or z = 2.4 m (endcap) with σ_t = {0, 10, **30**, 50, 100} ps





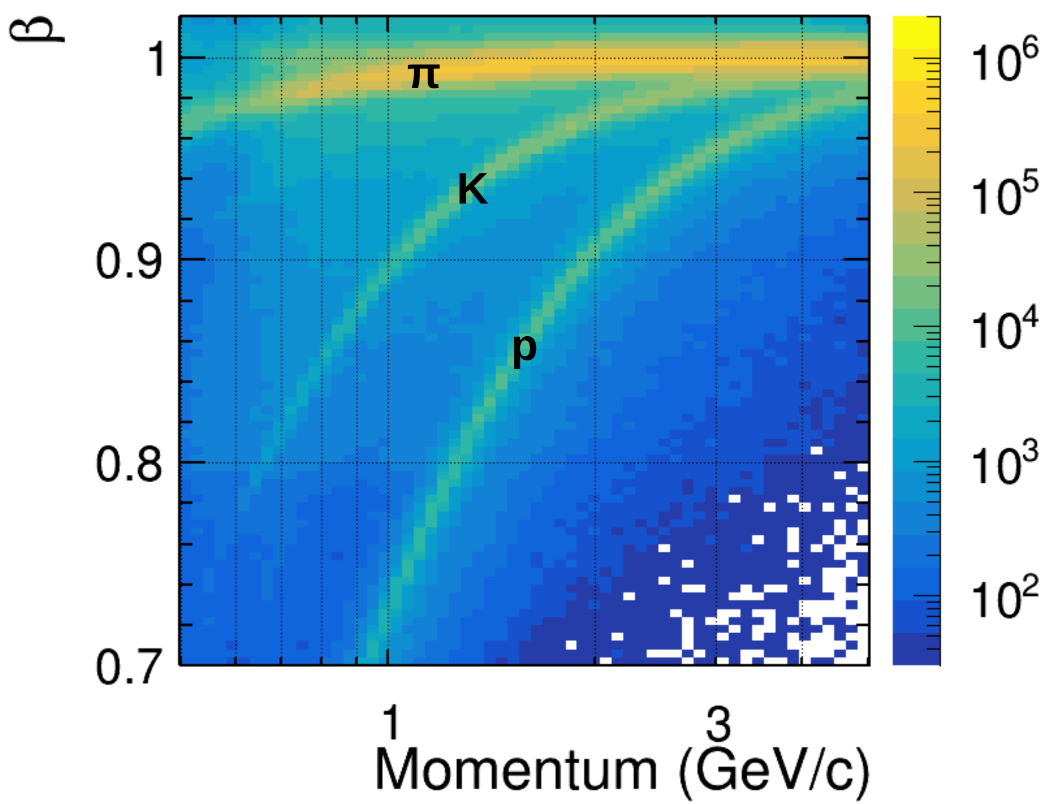
Data Sample

- $e^+ e^-$ collisions at E_{CM} = 500 GeV with polarised beams (± 80% e^-, ± 30% e^+)
- Two luminosity scenarios:
  - 400 fb^{-1} → ILC ~ before a luminosity upgrade
  - 4 ab^{-1} → full ILC 20-year: "H20" (missing here: 2 ab^{-1} of 250 GeV data)
- MC production povides full SM with about a tenth of the 4 ab^{-1} statistics
- For computational simplicity only leading processes to kaon production are used:
  - 2-fermion hadronic final state consistent with Z
  - 4-fermion hadronic and semi-leptonic final state consistent with ZZ
  - 4-fermion hadronic and semi-leptonic final state consistent with WW

The Procedure – Kaon Selection

- Big issue: various backgrounds from mismeasured particles and from large fraction of pions
- Cut on track properties to reduce mismeasured particles, making sure particles come from the IP:
  - $|d_0| < 10$ mm
  - $|z_0| < 20$ mm

here: σ_t = 30 ps



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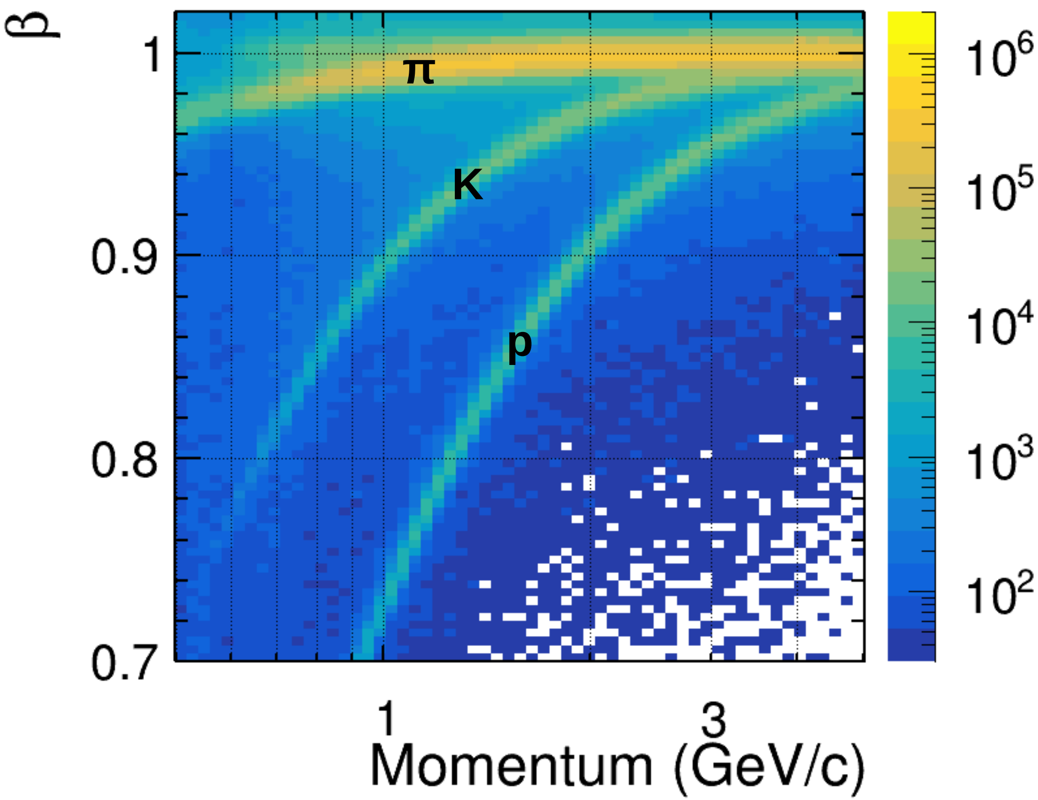
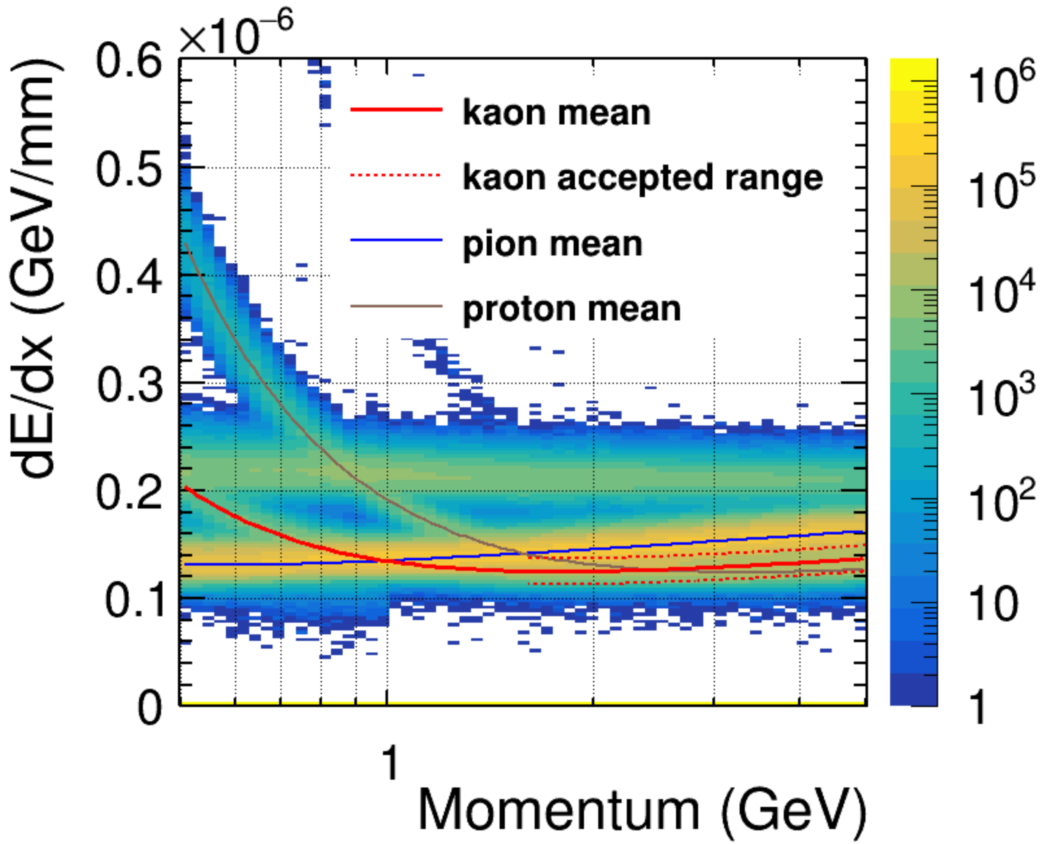


The Procedure – dE/dx Refinement

- Big issue: various backgrounds from mismeasured particles and from large fraction of pions
- Cut on TPC dE/dx to suppress pions:
  - Track dE/dx must be within 2.5 σ of kaon dE/dx for p > 1.6 GeV



The Procedure – Kaon Selection

- Use momentum window from 0.5 GeV to a variable maximum between 1.6 GeV and 3.6 GeV

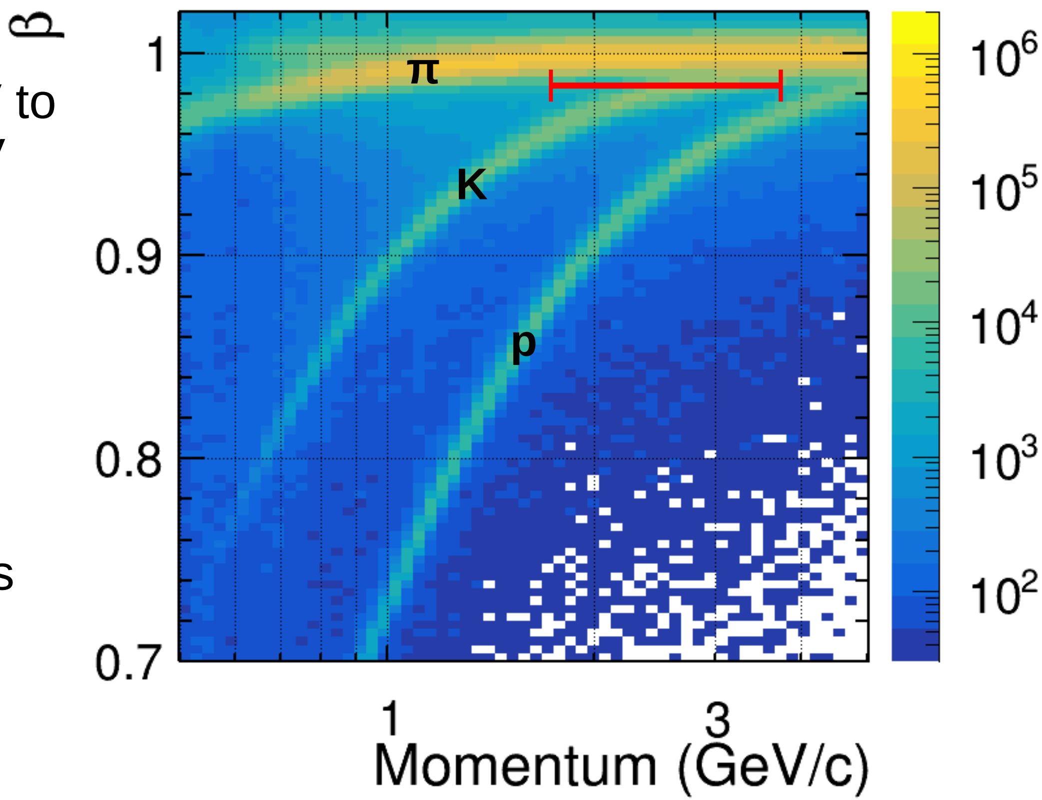
  → optimise separation from pions

- Reconstruct mass of each PFO:

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

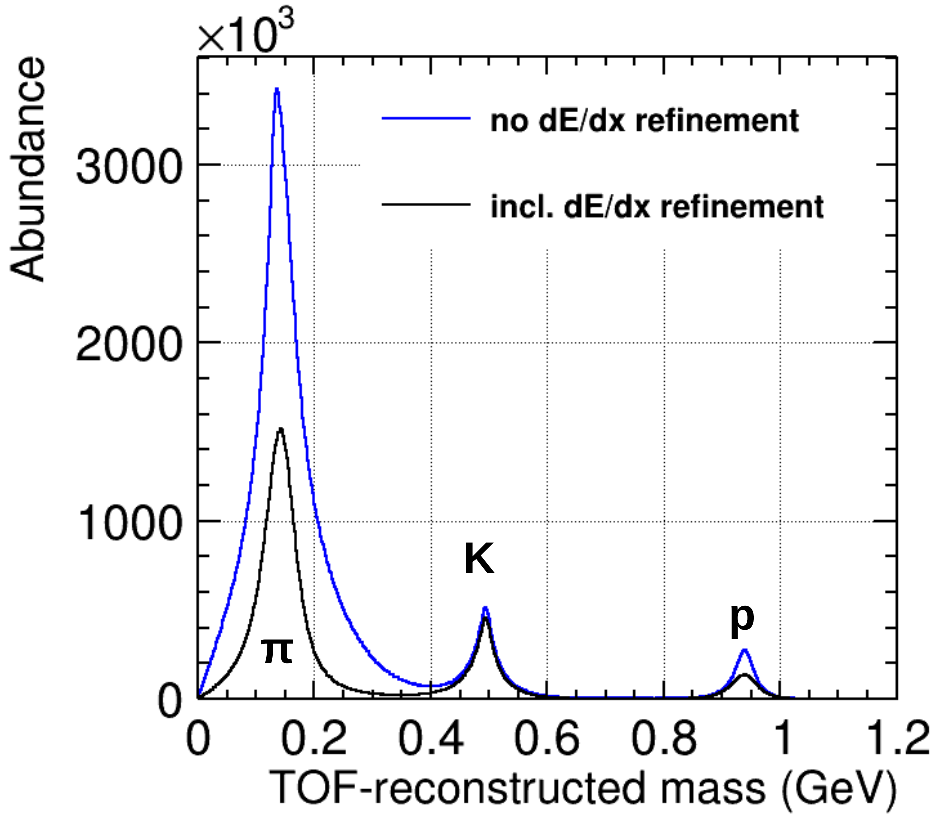
→ equals projection along TOF-bands

here: σ_t = 30 ps



The Procedure – Mass Fit

- Select kaons by requiring
  0.36 GeV < m < 0.7 GeV
- Fit kaon mass peak with Breit-Wigner + Exponential (to cover background)
- Fit mean of Breit-Wigner is estimate for reconstructed mass, uncertainty of mean is the achievable statistical error



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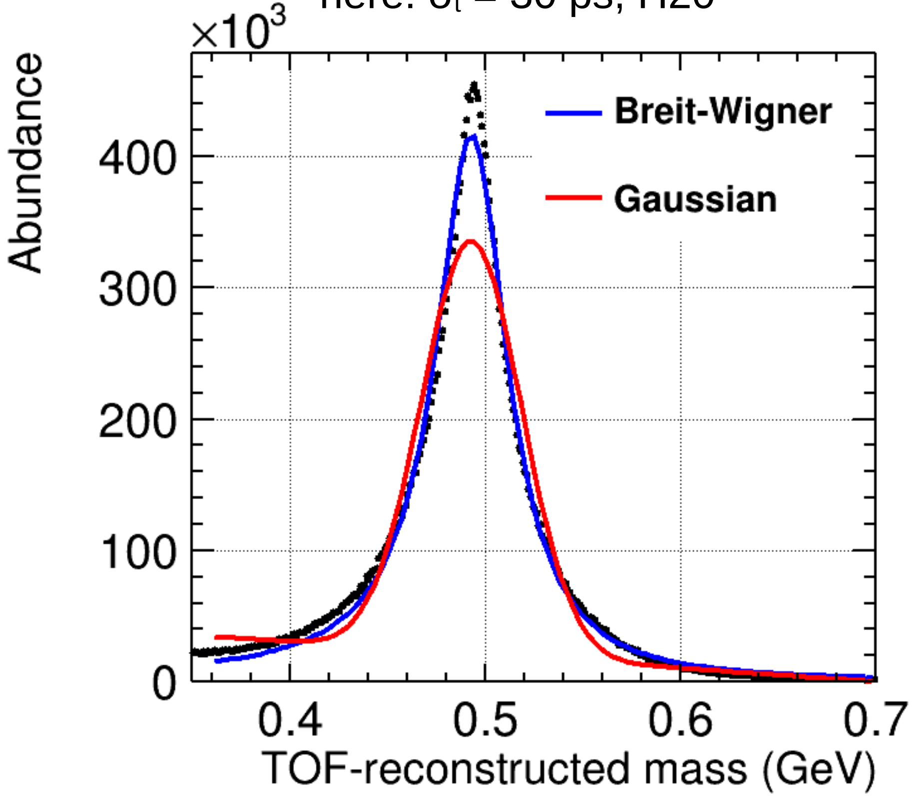
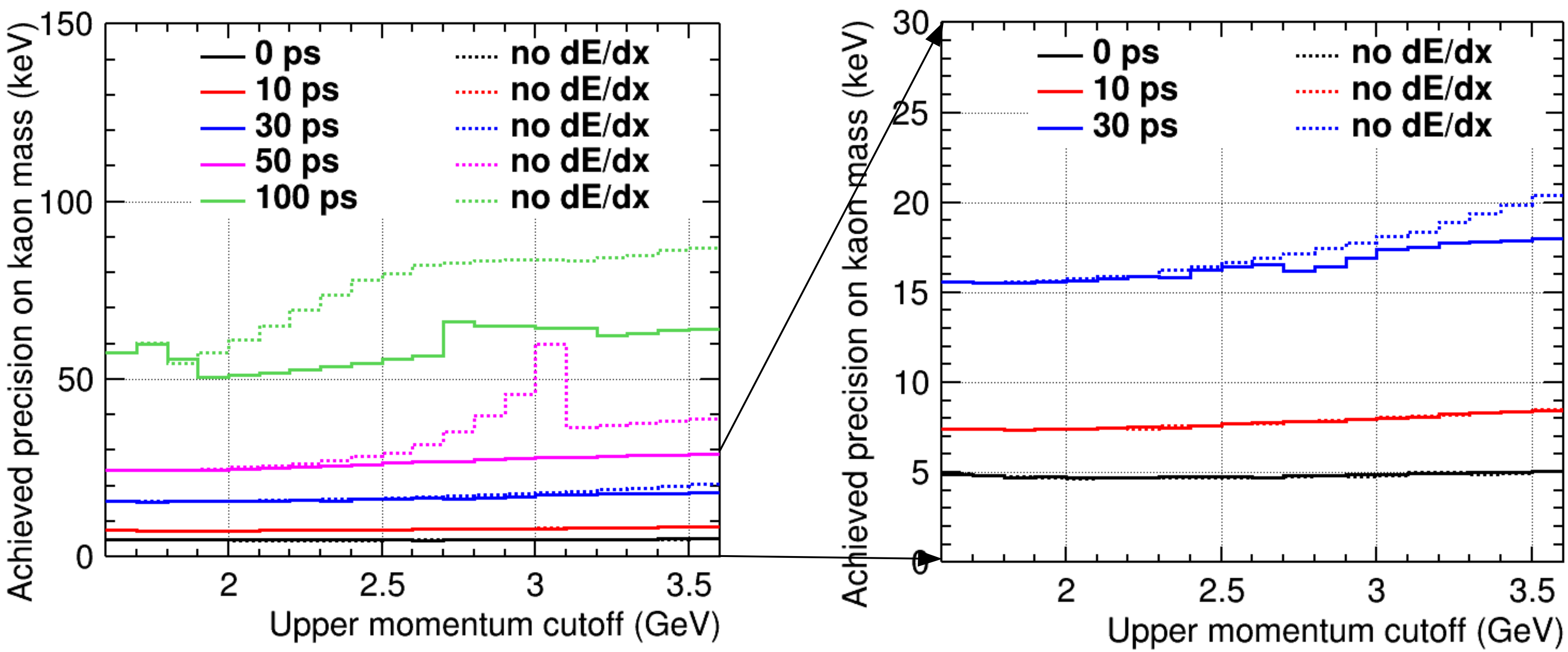
- Here: $m_{K,Fit}$ = (493.101 ± 0.0058) MeV
- But: $m_{K,MC}$ = 493.677 MeV

here: σ_t = 30 ps, H20

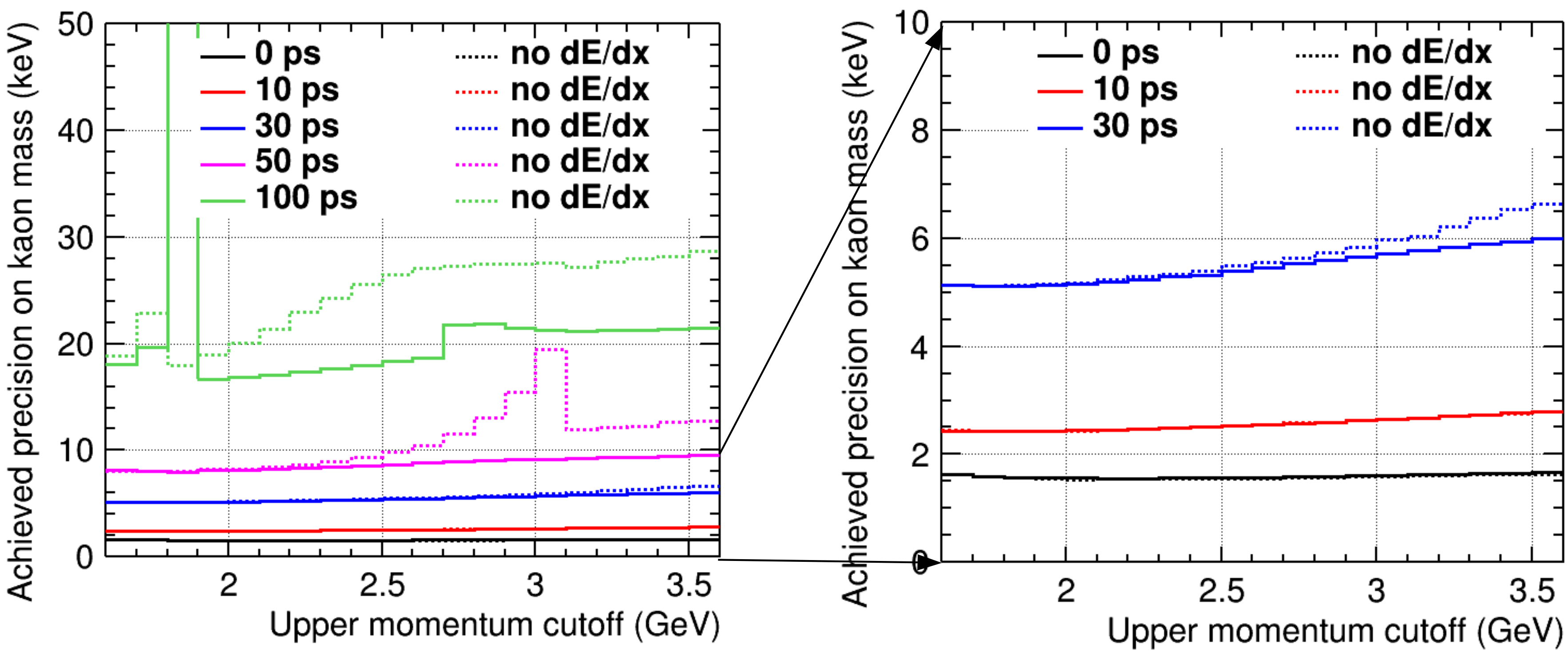


Results - 400 fb^{-1} Scenario



16 keV resolution (stat.) achievable, would be significant contribution.

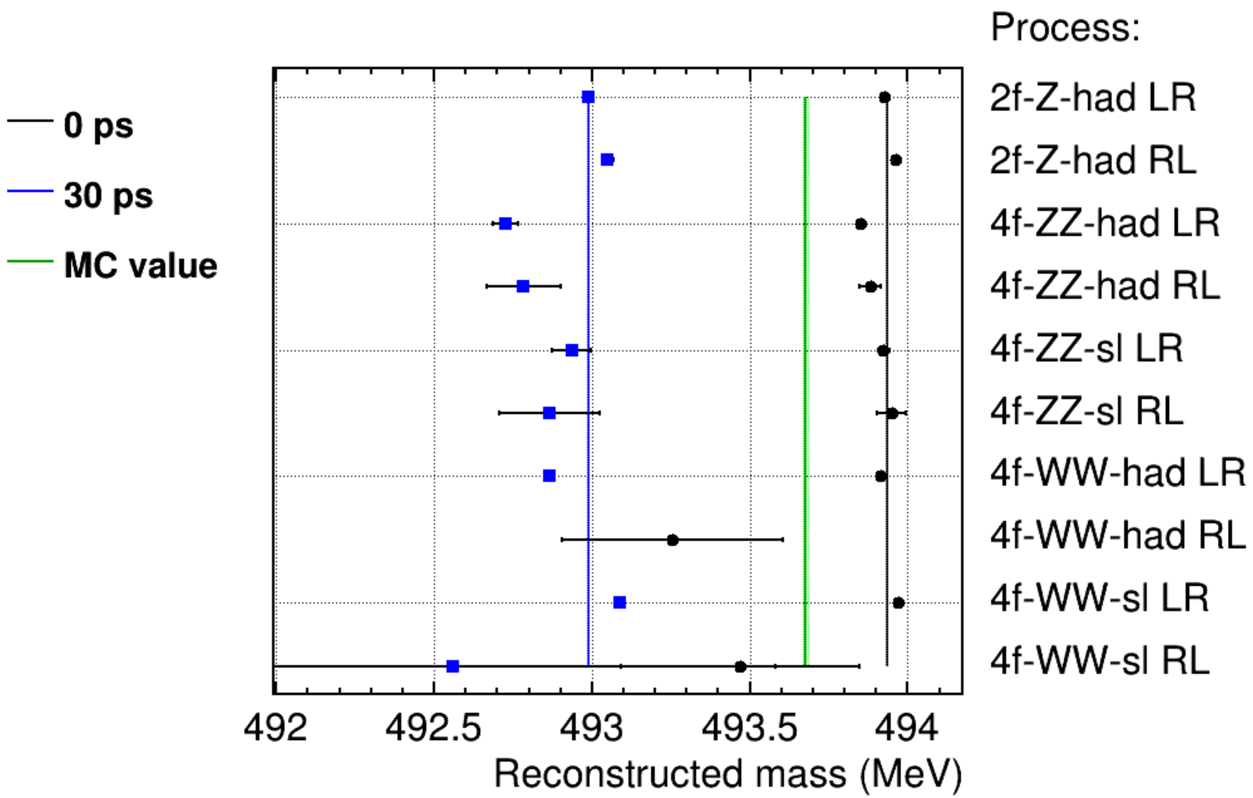
Results - 4 ab^{-1} Scenario



5 keV resolution (stat.) achievable, would be decisive on kaon mass question!

Open Questions

- Systematic error needs investigation
- Large offset O(100s keV) between reconstructed mass and PDG/MC value
- Consistent fluctuations between processes due to phase space distribution of kaons, large differences between timing resolutions



Systematics

- Need more study to calibrate biases in the TOF algorithm, depending on the process, i.e. the phase space distribution of the particles; can use calibration with pions and protons

- $m \propto p \propto B$ $\rightarrow$ crucial to determine momentum scale and magnetic field
  - Desired precision: 5 keV / 500 MeV = 10^{-5}
  - CMS: calibration in 2012 to level of 10^{-4}
  - ILD aims to measure the magnetic field map to 10^{-4},
    determination of the momentum scale via K^0_s and J/Ψ decays to 10^{-6} $\rightarrow$ G. Wilson [**https://agenda.linearcollider.org/event/9071/**] doable with full H20 ILC or , 1 year at Z-pole

Conclusion

- Future Higgs Factory, like ILD, can tackle kaon mass question

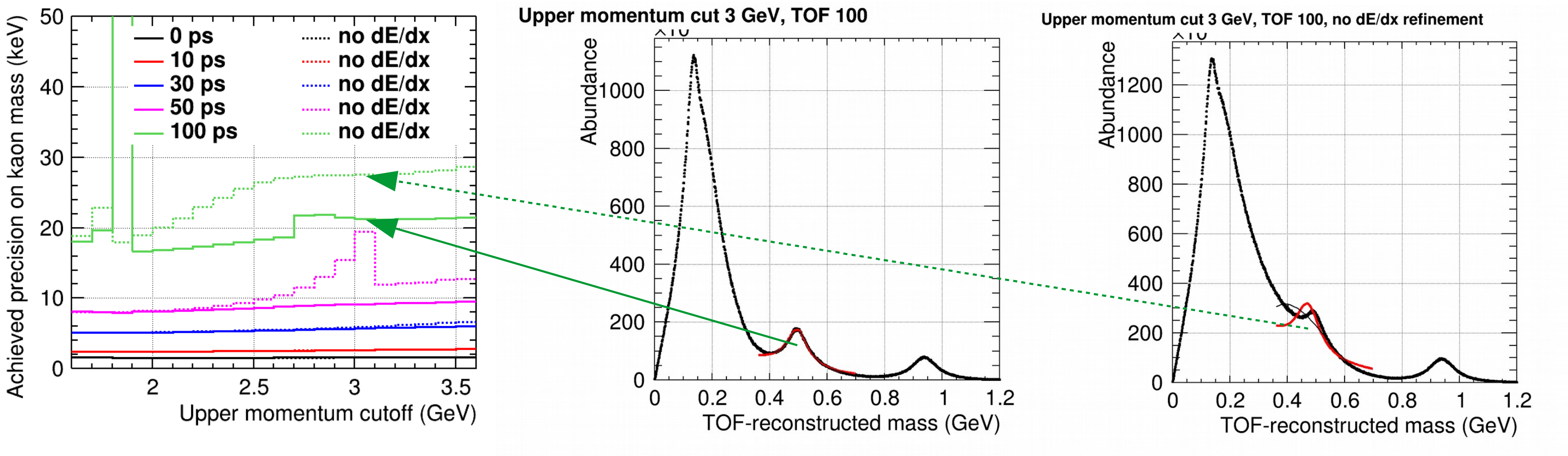
  timing resolution 30 ps, 400 fb^{-1}: 16 keV stat. precision → significant impact
  timing resolution 30 ps, 4 ab^{-1}: 5 keV stat. precision → resolution of mass question

- Applicable to any future Higgs factory with precise timing and an excellent control of systematics
- Contributions by B. Dudar (previous talk) improved these number by a factor of 3
- Further improvements can be made by including all processes, adding 250 GeV and optimising the analysis, possibly leading to factor 1.5-2 better final resolution

Backup

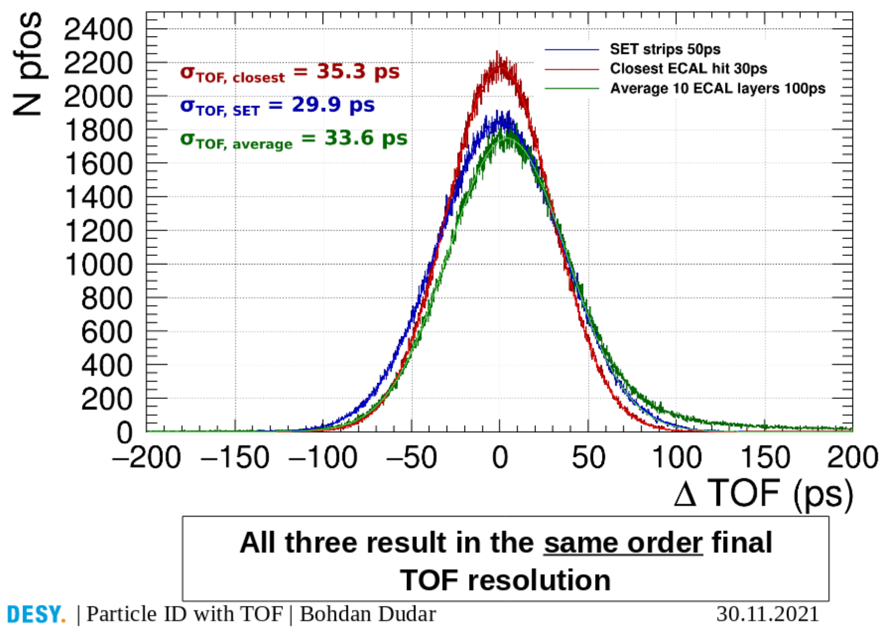
Fitting Issues

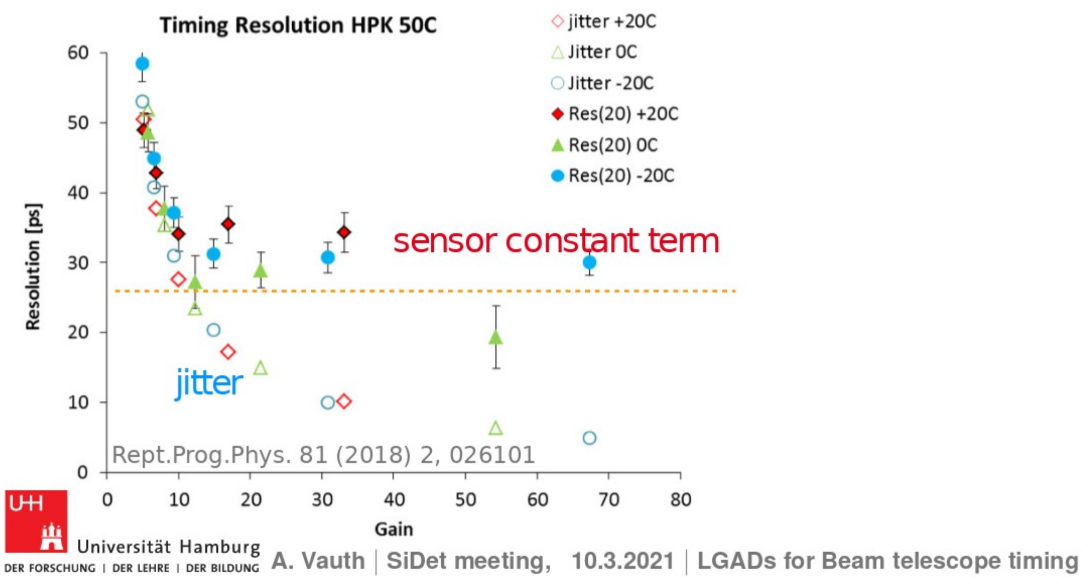
- At large values of timing resolutions and large upper momentum cuts, the pion ‘contamination’ becomes a problem for the fit routine
- Largely compensated by dE/dx refinement at this parameter conditions



30 ps Working Point

- 1 measurement with 30 ps → dedicated timing layer
- 2 measurements with 50 ps → Si strips layer
- 10 measurements with 100 ps → 10 Ecal layers





B. Dudar: https://indico.desy.de/event/29100/contributions/113642/

A. Vauth: https://indico.desy.de/event/29330/