Prospects of Charged Kaon Mass Measurement via TOF at ILD

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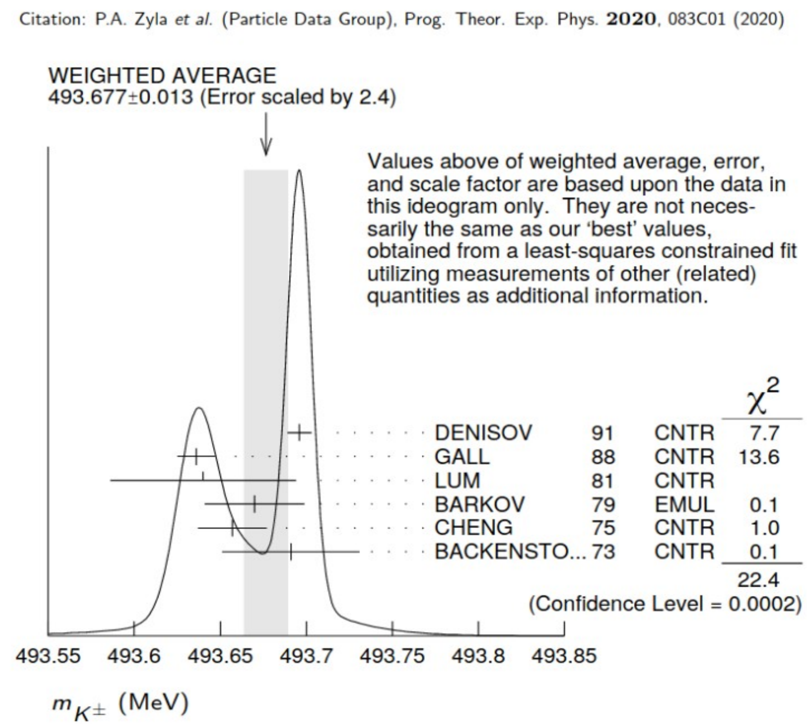
RESEARCH FOR GRAND CHALLENGES

The Question

- The best estimate for the charged kaon mass according to the PDG is dominated since the early 90s by two contributions from kaonic atom spectroscopy which are 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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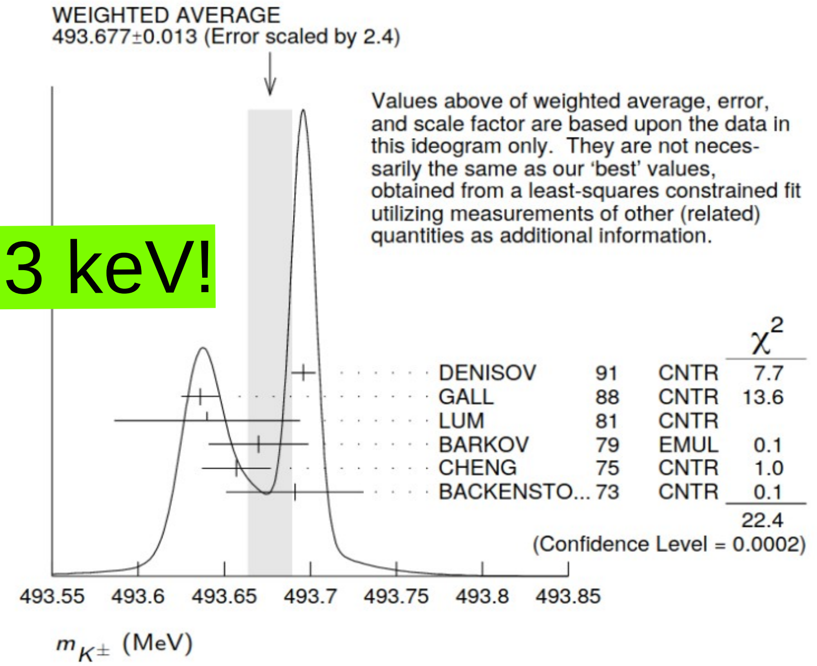
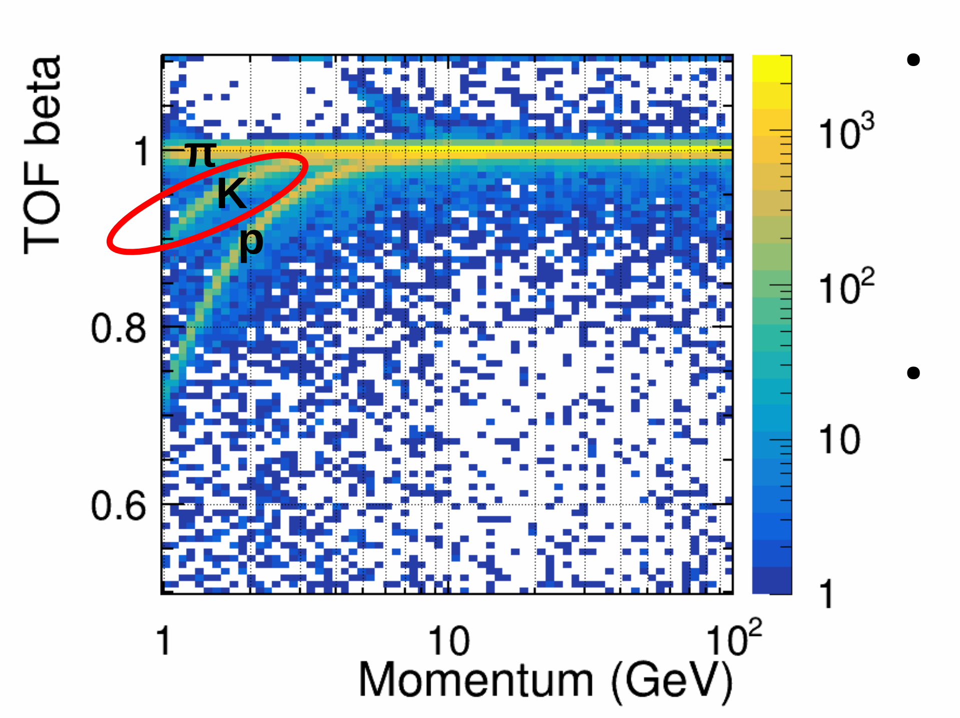
Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)



13 keV!

[Particle Data Group Booklet 2020]

The Idea

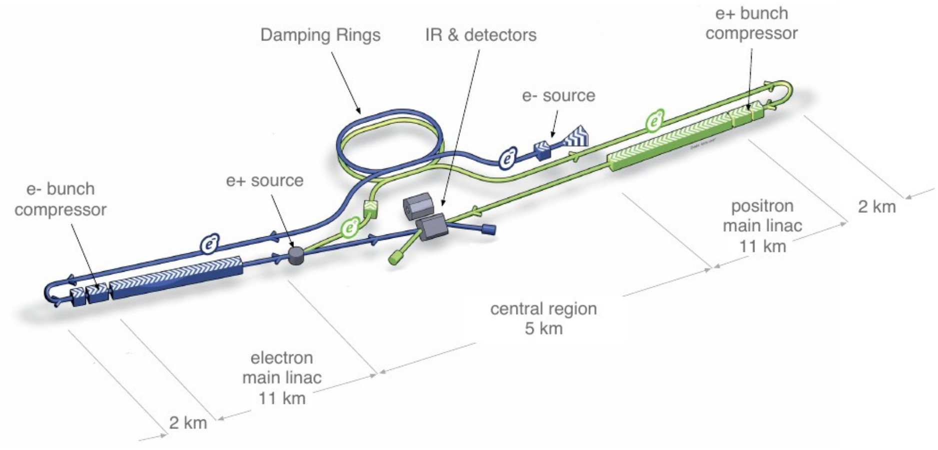


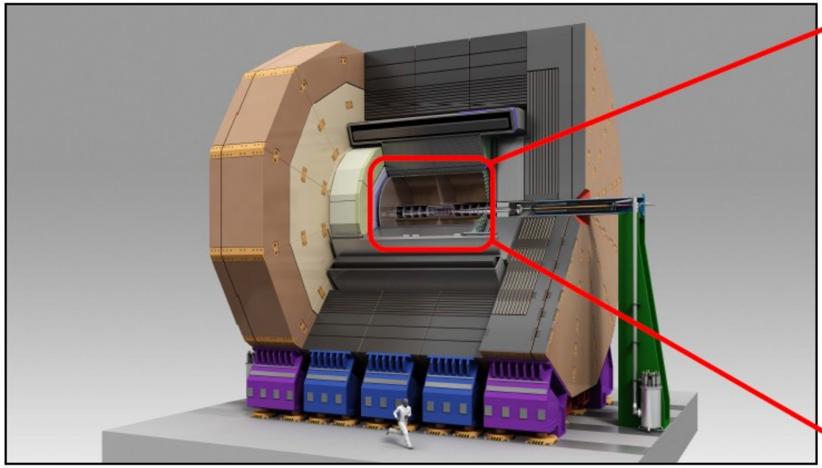
- Use time-of-flight separation to select low-momentum kaons from a random particle collection!
  Use these to extract their mass via β
  $m = p \cdot \sqrt{1/\beta^2 - 1}$ from a large sample!
- Needs large statistics at low momenta, a high timing resolution and an excellent calibration of the momentum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

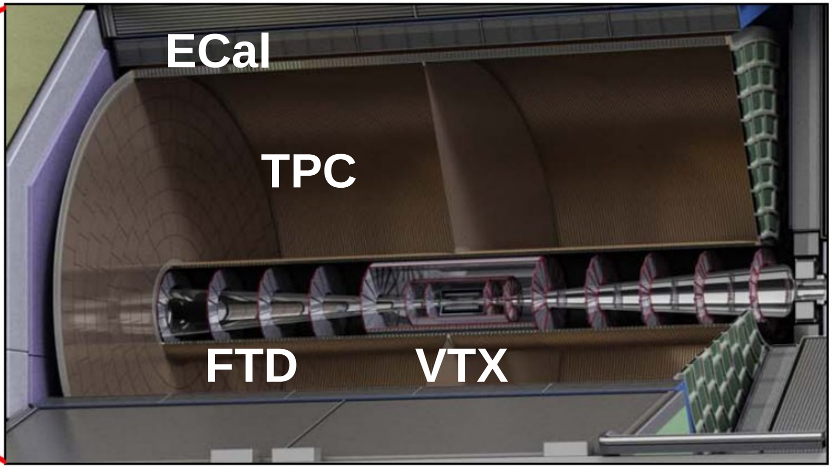
→ Could this be done at a future Higgs factory?

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







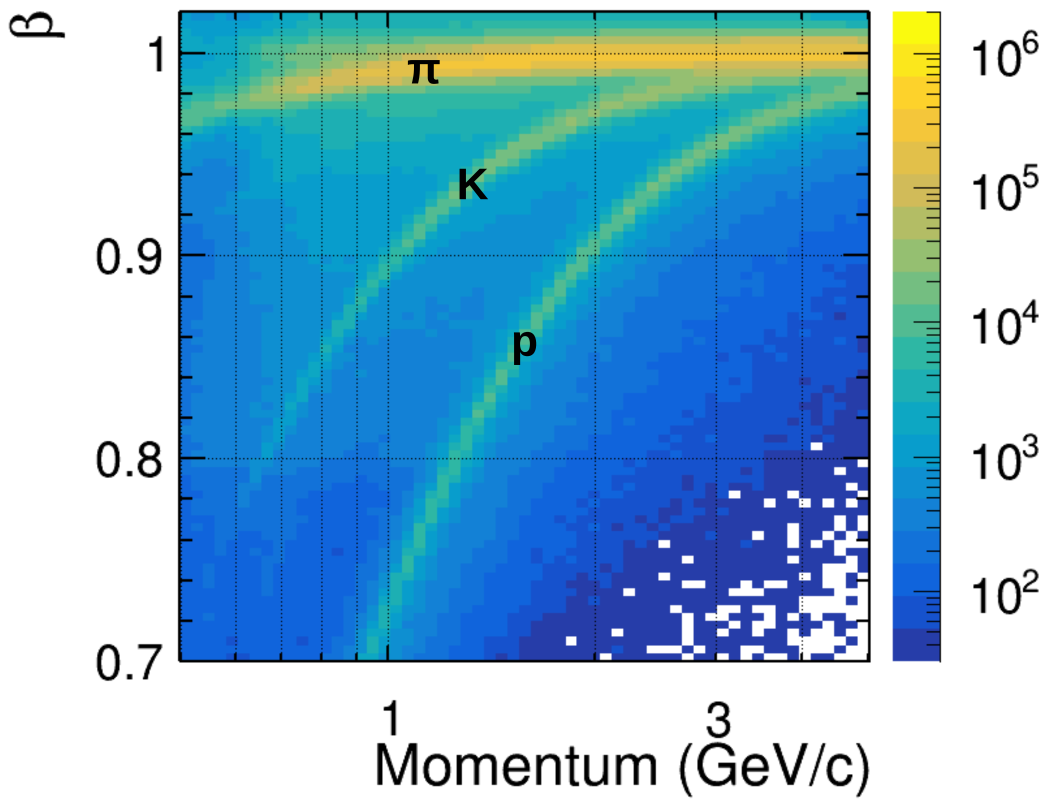
Data Sample

- $e^+ e^-$ collisions at E_{CM} = 500 GeV with polarised beams (± 80% e^-, ± 30% e^+)
- Two luminosity scenarios:
  - 200 fb^{-1} (-,+), 200 fb^{-1} (+,-) → ILC ~ before a luminosity upgrade
  - 1800 fb^{-1} (-,+), 1800 fb^{-1} (+,-), 200 fb^{-1} (-,-), 200 fb^{-1} (+,+) → full ILC 20-year: “H20”
- 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
  - ~~6-fermion final state consistent with ttbar~~

The Procedure – Kaon Selection

- Big issue: various backgrounds from mis-measured particles and from large fraction of pions
- Cut on track properties to reduce mis-measured particles:
  - $|d_0| < 10$ mm
  - $|z_0| < 20$ mm
- Cut on dE/dx to suppress pions:
  - Track dE/dx must be within 2.5 σ of kaon dE/dx for p > 1.6 GeV

here: $\sigma_t = 30$ ps



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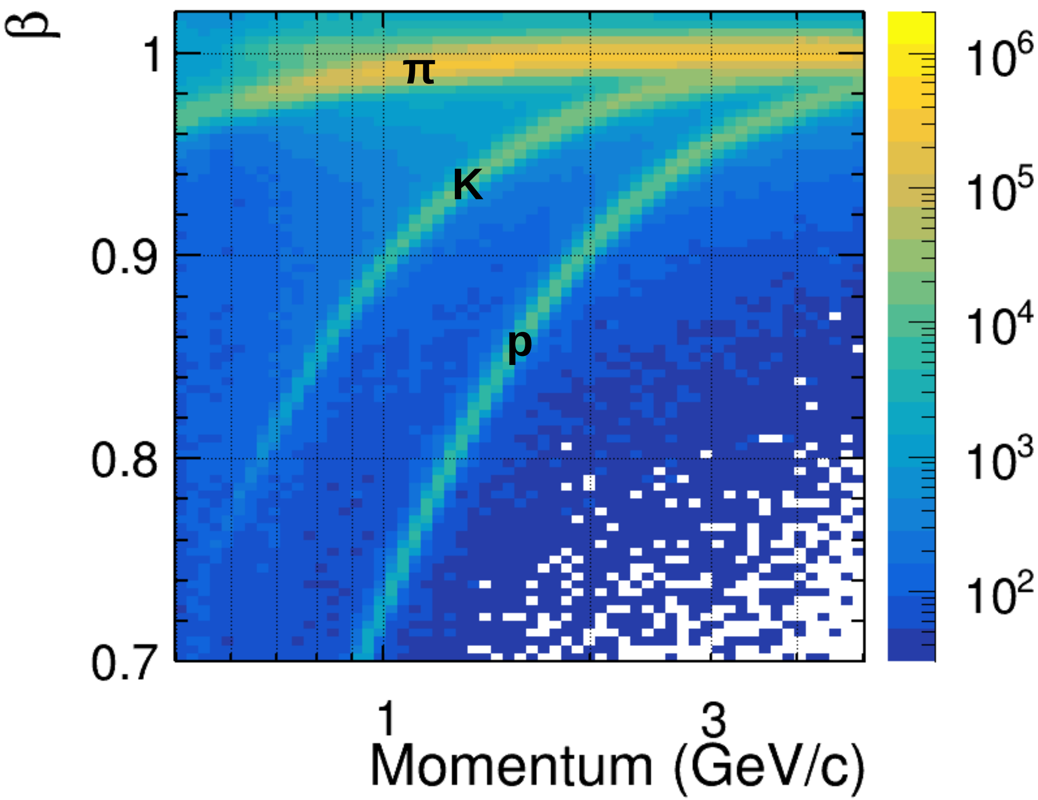


The Procedure – Kaon Selection

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

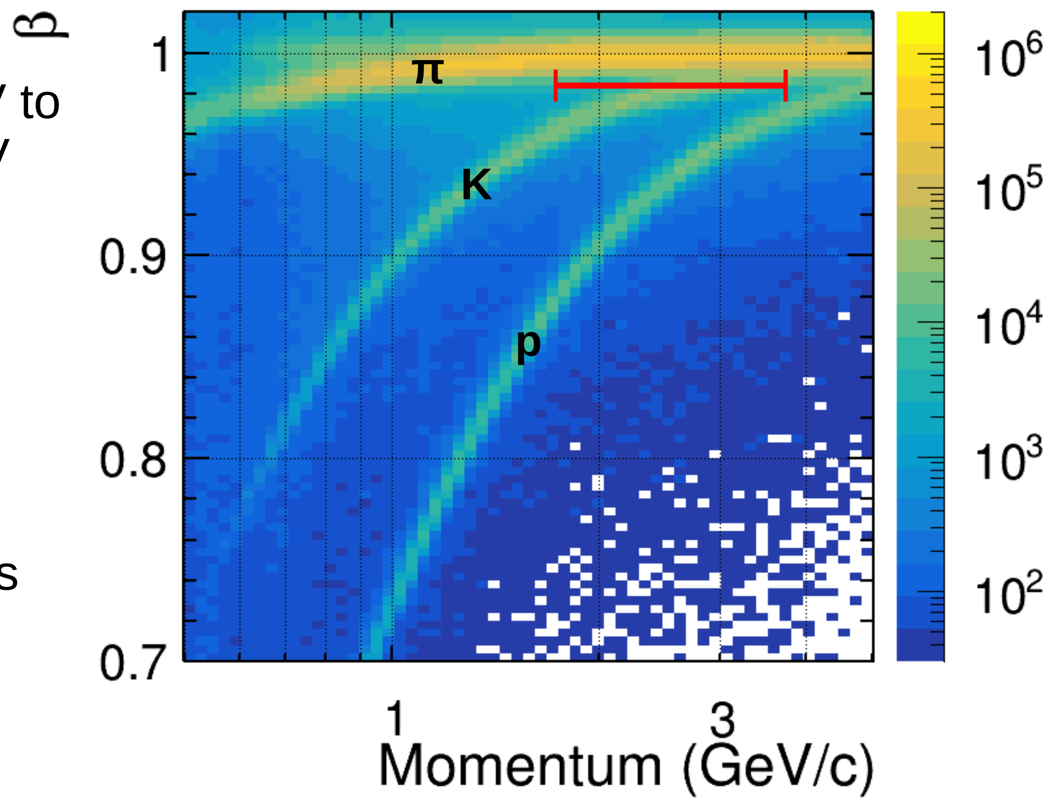
  → optimise separation from pions

- Reconstruct mass of each PFO:

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

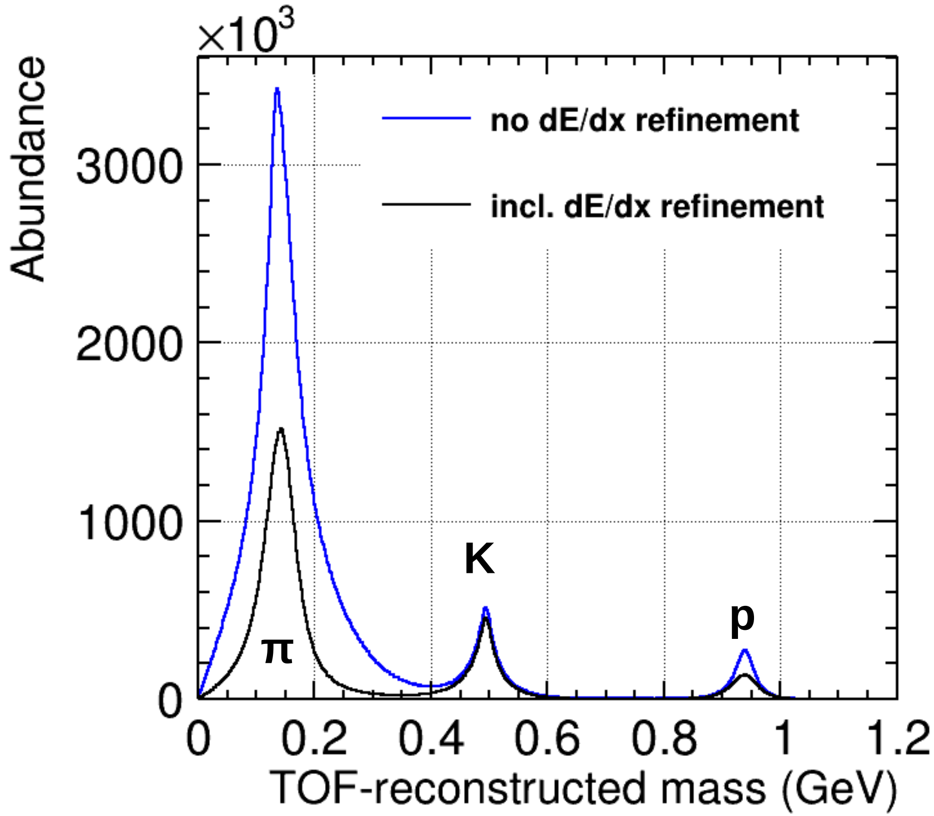
→ equals projection along TOF-bands

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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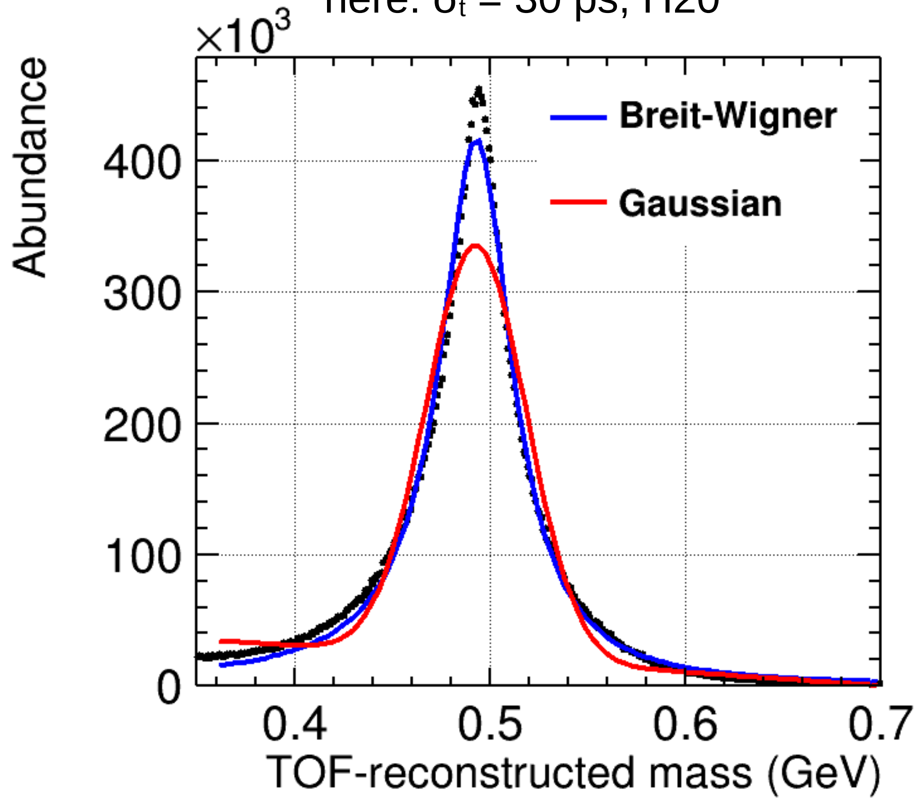
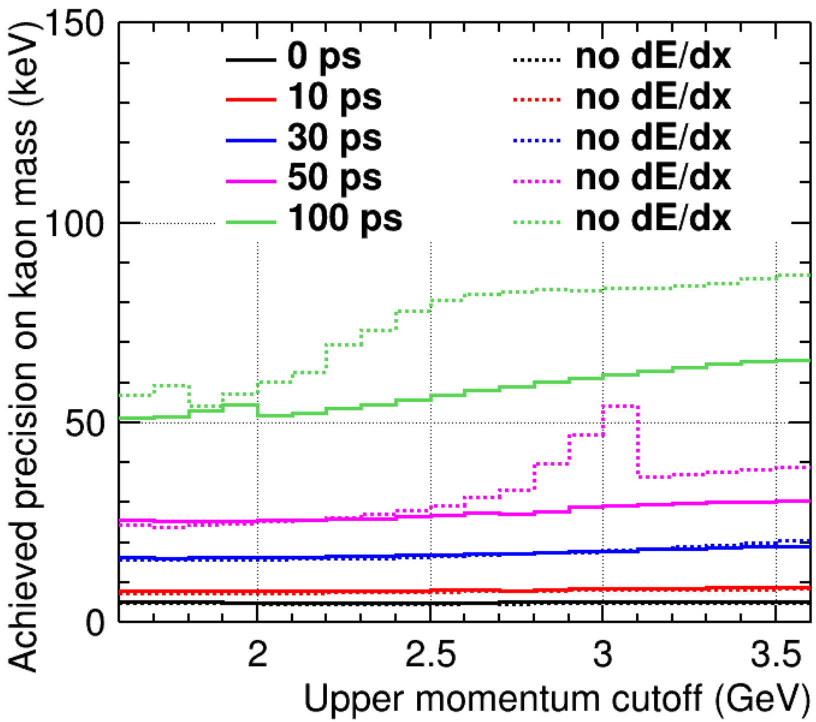
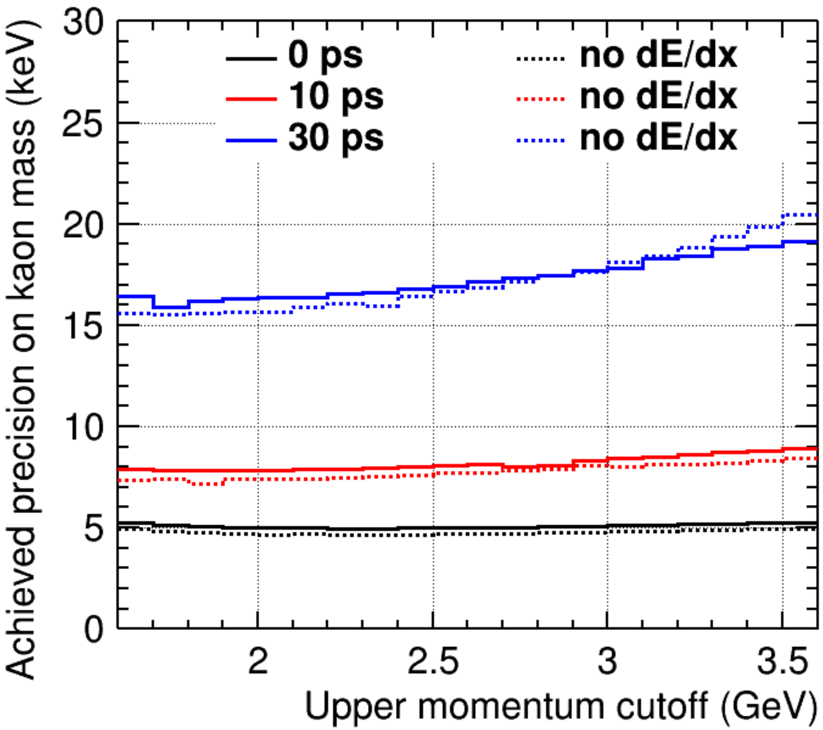
- Fit kaon mass peak with Breit-Wigner + Exponential (to cover background)
- Fit mean of Breit-Wigner is estimate for reconstructed mass, uncertainty of mean is the achievable statistical error
- Here: m_K = (494.739 ± 0.0057) MeV
- But: $m_{K,MC}$ = 493.677 MeV

here: σ_t = 30 ps, H20



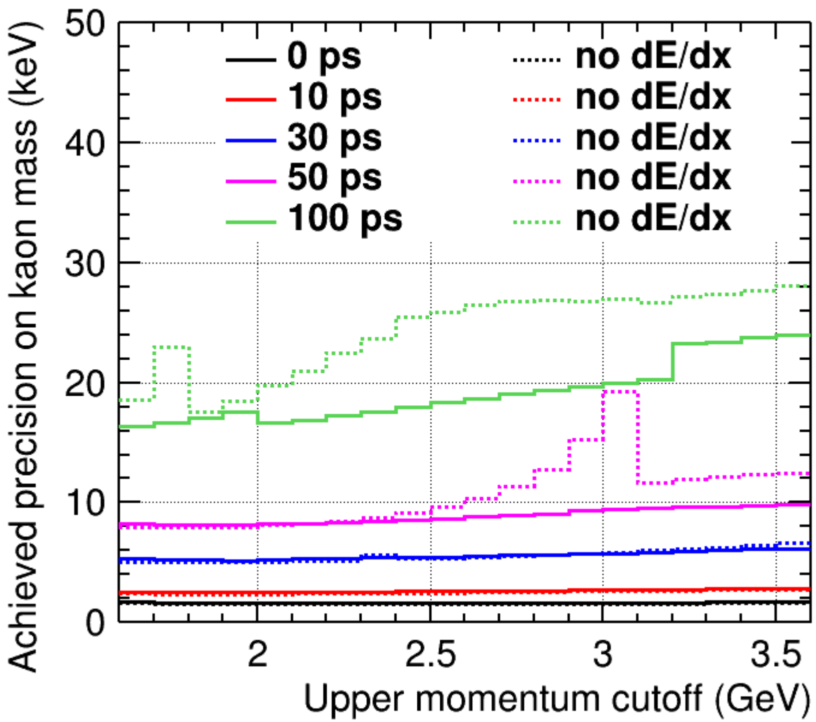
Results - 2x200 Scenario

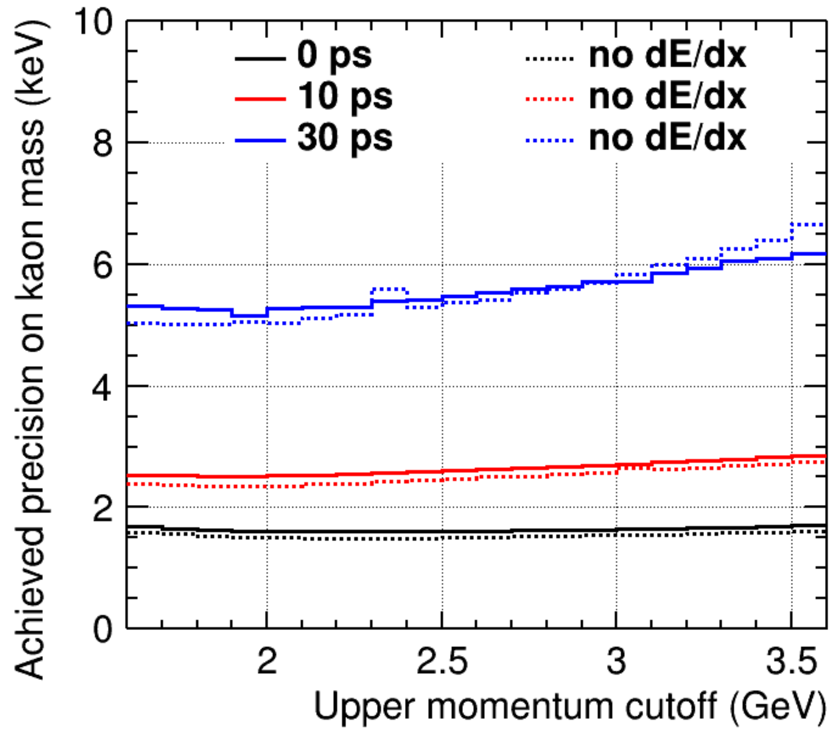




16 keV resolution (stat.) achievable, would be significant contribution.

Results - H20 Scenario

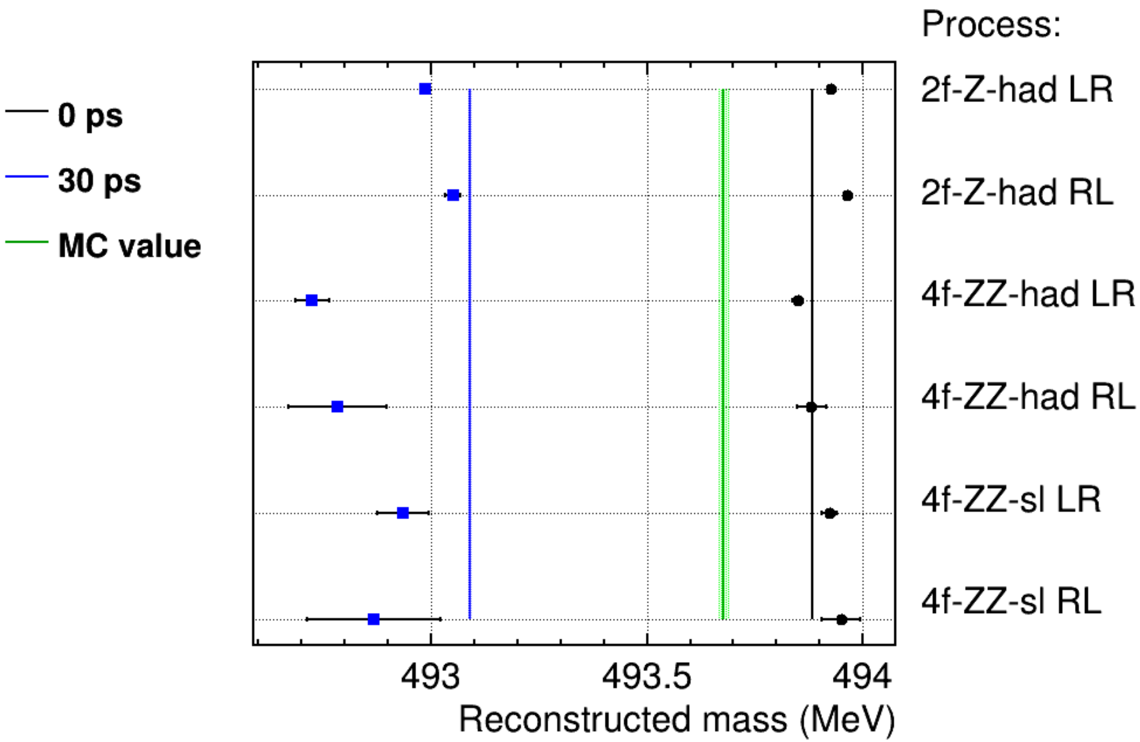




5 keV resolution (stat.) achievable, would be decisive on kaon mass question!

Open Questions

- Systematic error needs investigation
- Large offset O(100s keV) between reconstructed mass and PDG/MC value
- Consistent between processes, but different between timing resolutions



Systematics

- Biases in the TOF algorithm, depending on the process, i.e. the phase space distribution of the particles

  → Needs more study to calibrate this, can use calibration with pions and kaons

- $m \propto p \propto B$ → 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} → G. Wilson [**https://agenda.linearcollider.org/event/9071/**] doable with full H20 ILC or , 1 year at Z-pole

Conclusion

- With a TOF timing resolution of 30 ps per reconstructed particle, ILD can make a significant impact on the kaon mass measurement statistical resolution:
  Before the luminosity upgrade up to 15 keV, which would be a significant contribution.
  In the full H20 scenario up to 5 keV, which would be decisive on the problem.

  This is applicable to any future Higgs factory with precise timing and an excellent control of systematics.

- Contributions by B. Dudar presented in the previous talk lead to an improvement of these number by a factor of 3.

- Improvements can be made by including all processes, adding 250 GeV and optimising the analysis, possibly leading to factor 1.5 better final resolution.