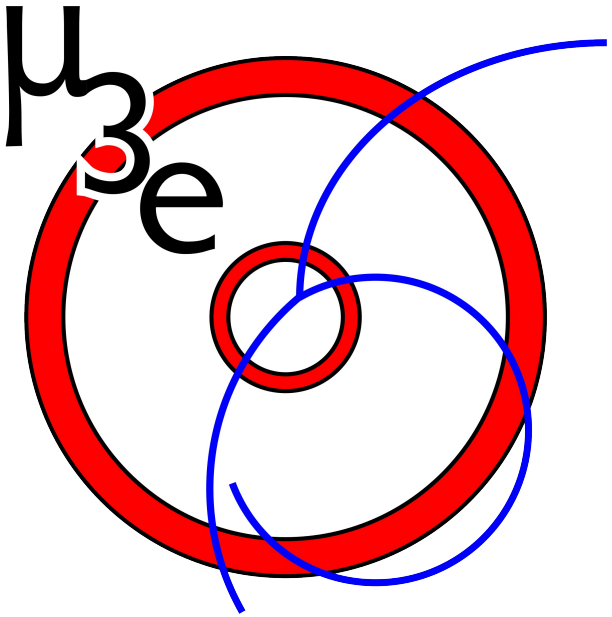
Track Fitting With Broken Lines for the MU3E Experiment



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Göttingen 2012

Overview

What?

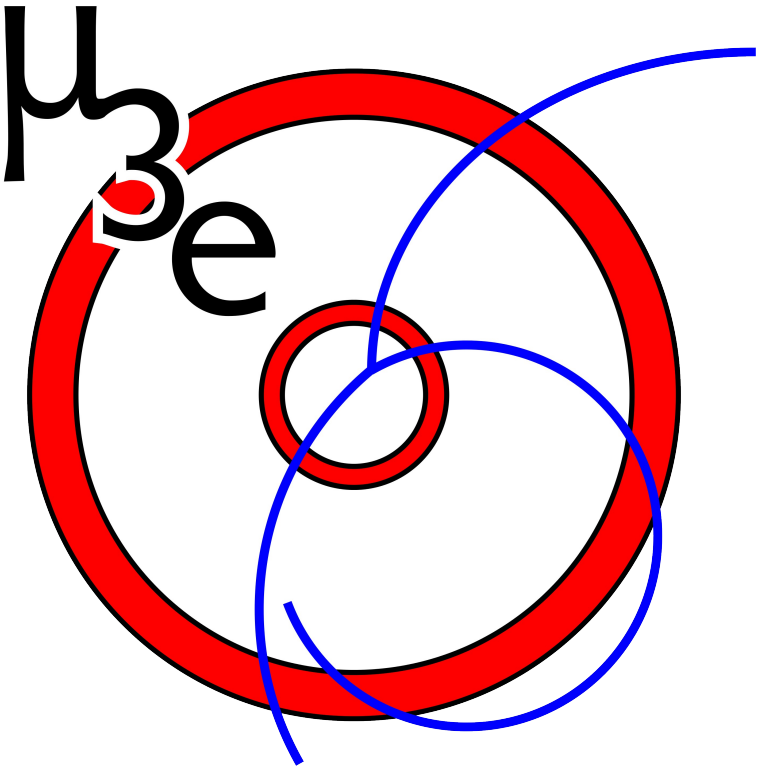
- a new experiment
- search for the decay μ→eee
- planned sensitivity
  BR(μ→eee) ~ 1×10^{-16}

Why?

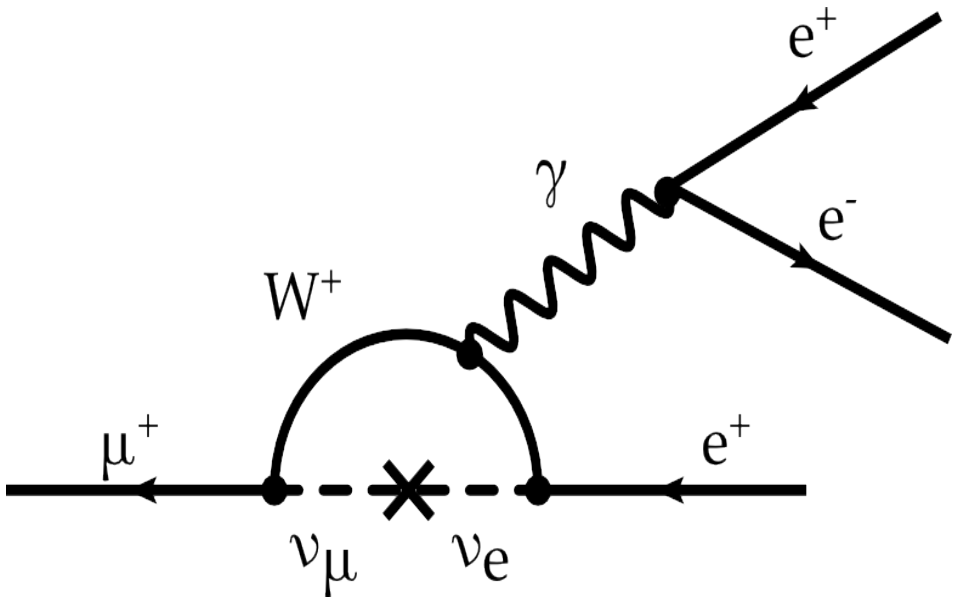
- new physics search
- complementary to other searches

Challenges

- high rates
- requires excellent resolution
  (momentum and vertex)



The Decay μ→eee



In the Standard Model

- lepton flavor violating
- via neutrino mixing
- suppressed by mass ratio

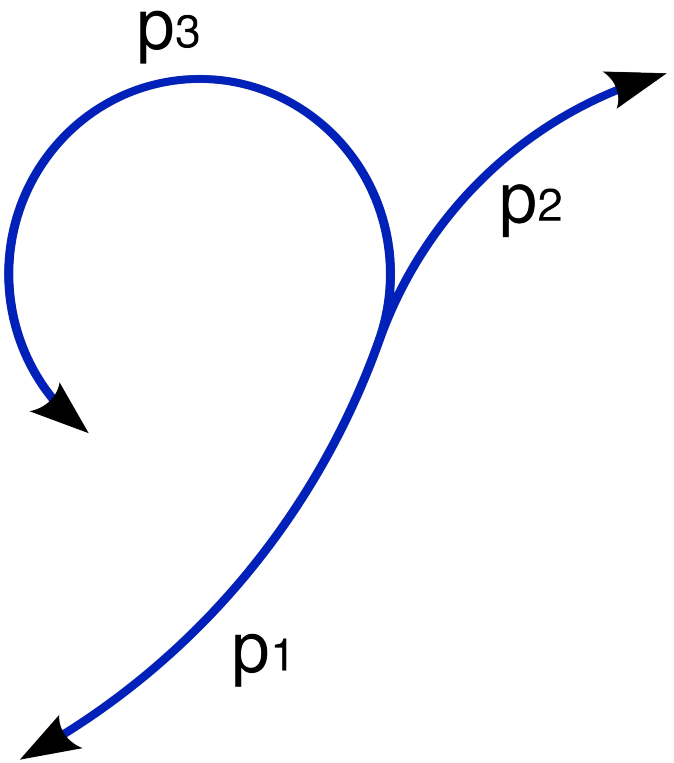
$$\sim \left(\frac{\Delta m_\nu^2}{m_W^2} \right)^2$$

- predicted BR < 1×10^{-50}
- current limit BR < 1×10^{-12}

In New Physics Models

- predicted by many theories
- BR up to the current limit

Signal Decay Topology



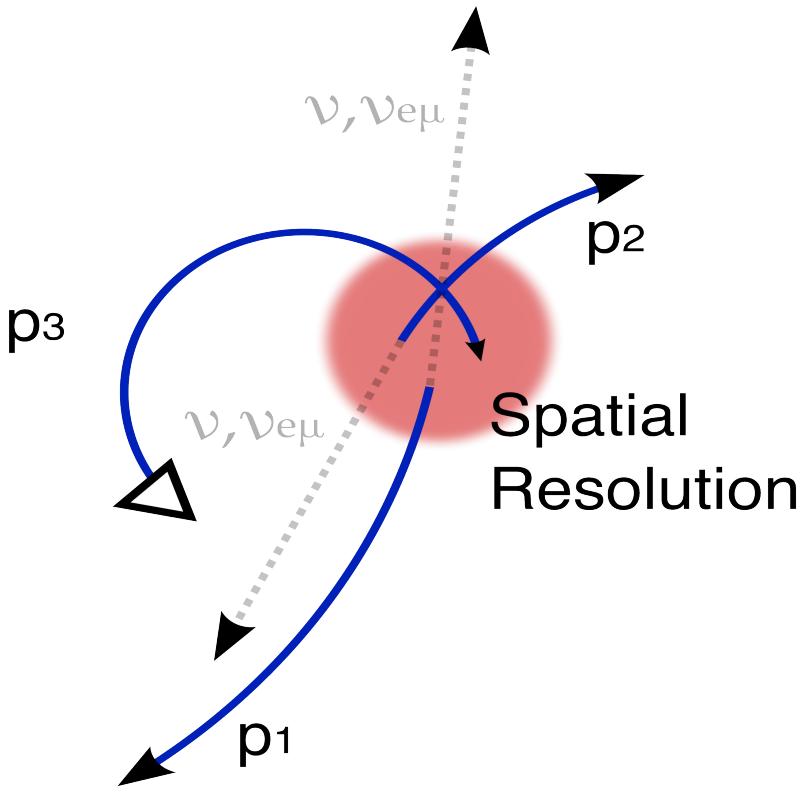
$\mu^+ \rightarrow e^+e^-e^+$

- 3 electrons
- common vertex
- coincident in time
- $\left(\sum P_i\right)^2 = m_\mu^2$
- momentum up to ~ 53 MeV

Challenges

- very low momentum tracks (measurable down to 10 MeV)
- high acceptance required

Accidental Background



Origin of Electron Tracks, e.g.

- 2x e^+ from $\mu^+ \rightarrow e^+ \nu_\mu \nu_e$

  and
- 1x e^- from Bhabha scattering, hard radiation (e^+e^-) or wrongly identified charge

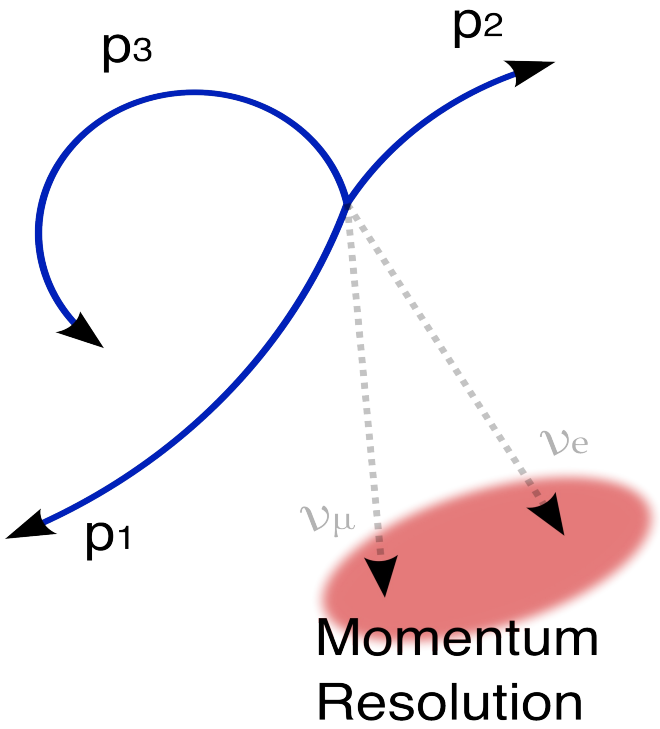
but ...

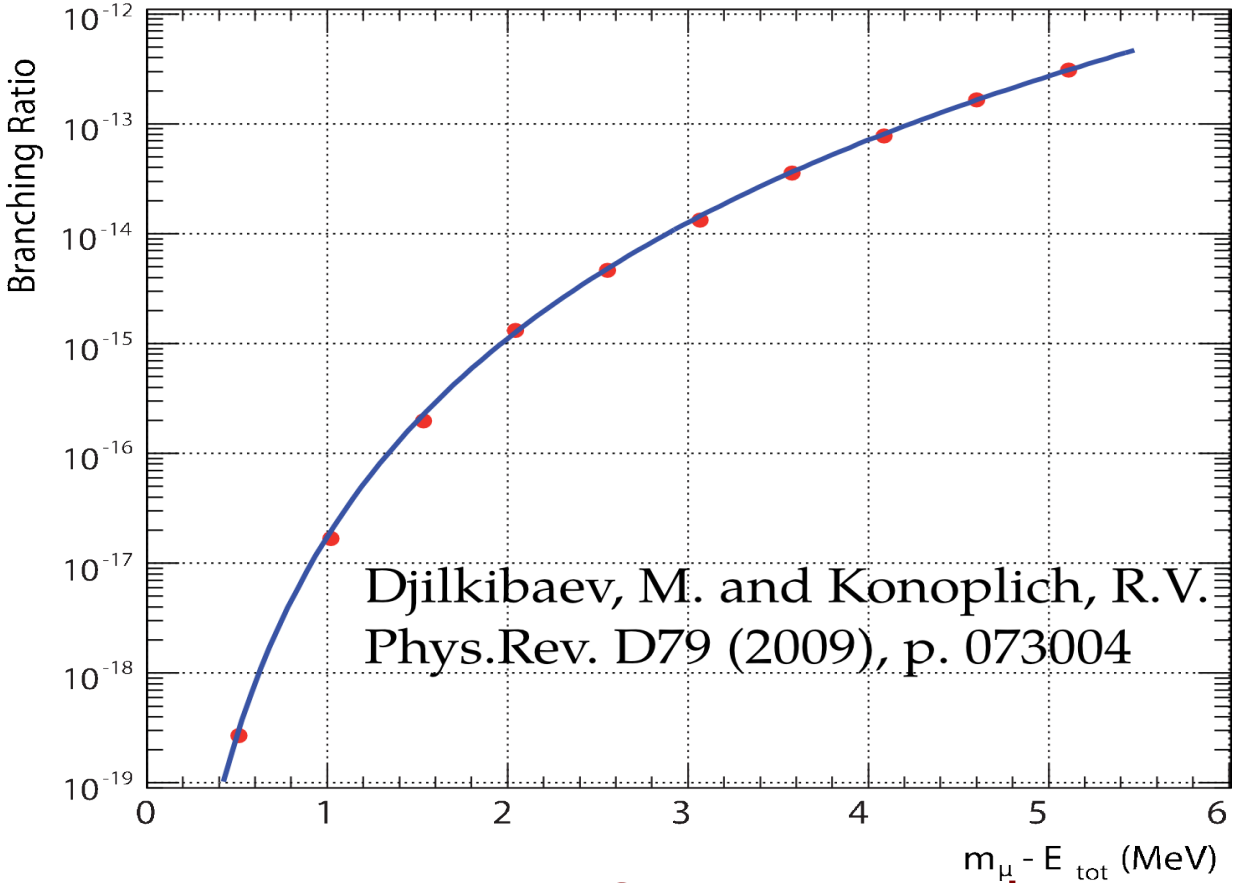
- *no* common vertex
- *not* coincident in time

Suppression by:

- high vertex resolution
- precise timing measurements

Internal Conversion Background





Origin of Electron Tracks

- $\mu^+ \rightarrow e^+ e^- e^+ \nu_\mu \nu_e$
- common vertex
- coincident in time

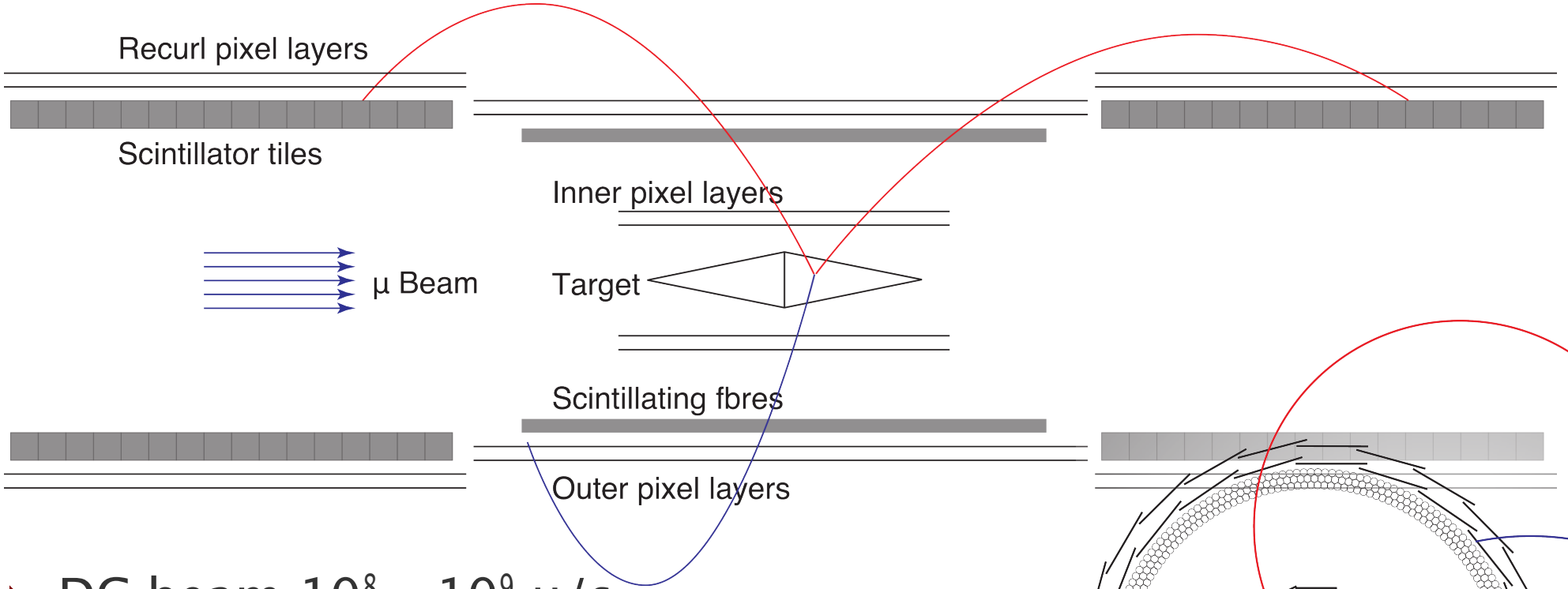
But:

$$\left(\sum P_i\right)^2 \neq m_\mu^2$$

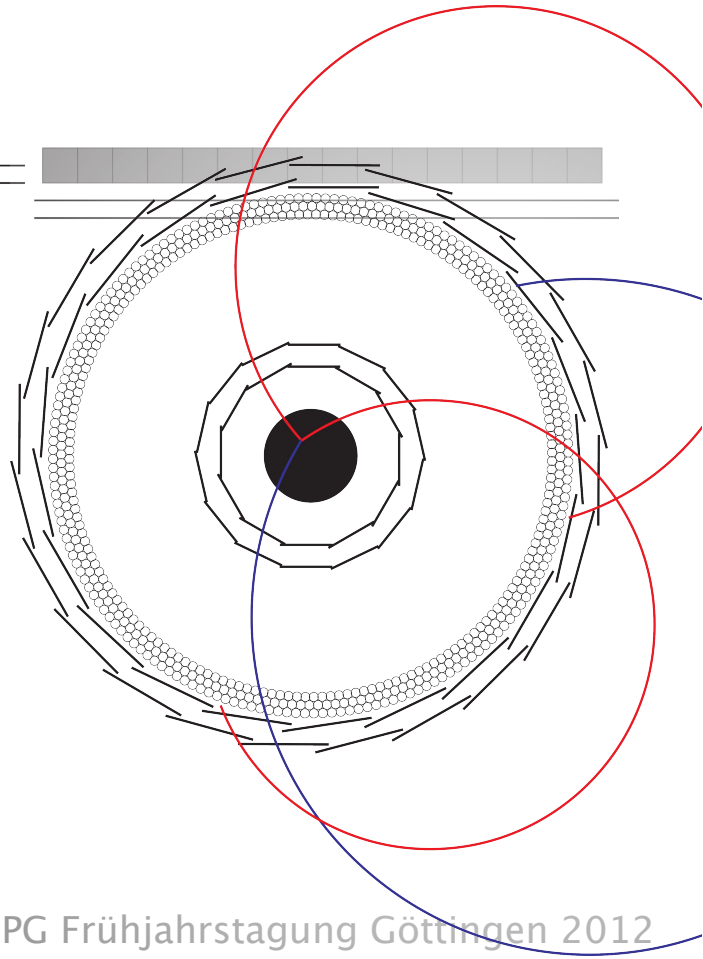
Suppression by:

- high momentum resolution

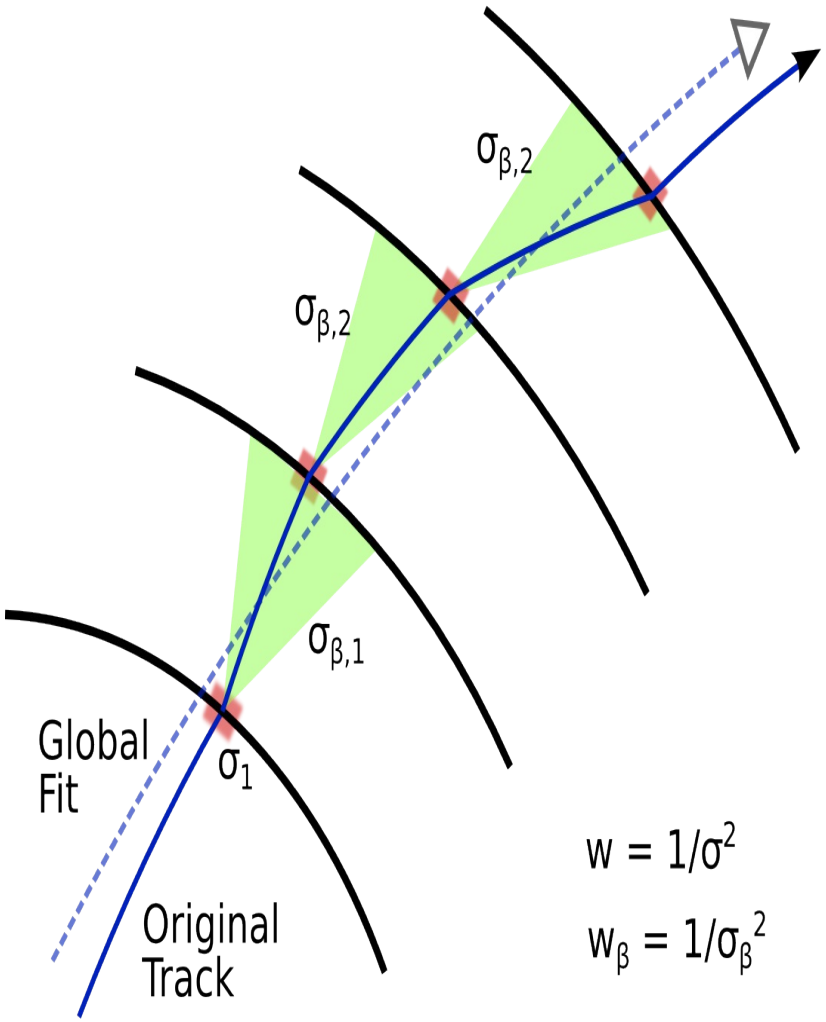
MU3E Baseline Design



- DC beam 10^8 – 10^9 μ/s
  (at Paul Scherrer Institute)
- Extended Target
- Solenoidal Field ~ 1T
- Thin Silicon Pixel Sensors (HV-Maps
- Low Material Budget x / X_0 < 10^{-3}



Track Fitting with Multiple Scattering



Multiple Scattering

$$\sigma_\beta \sim \frac{1}{p}\sqrt{\frac{x}{X_0}}$$

- dominates due to low momentum

Possible Tracking Algorithms

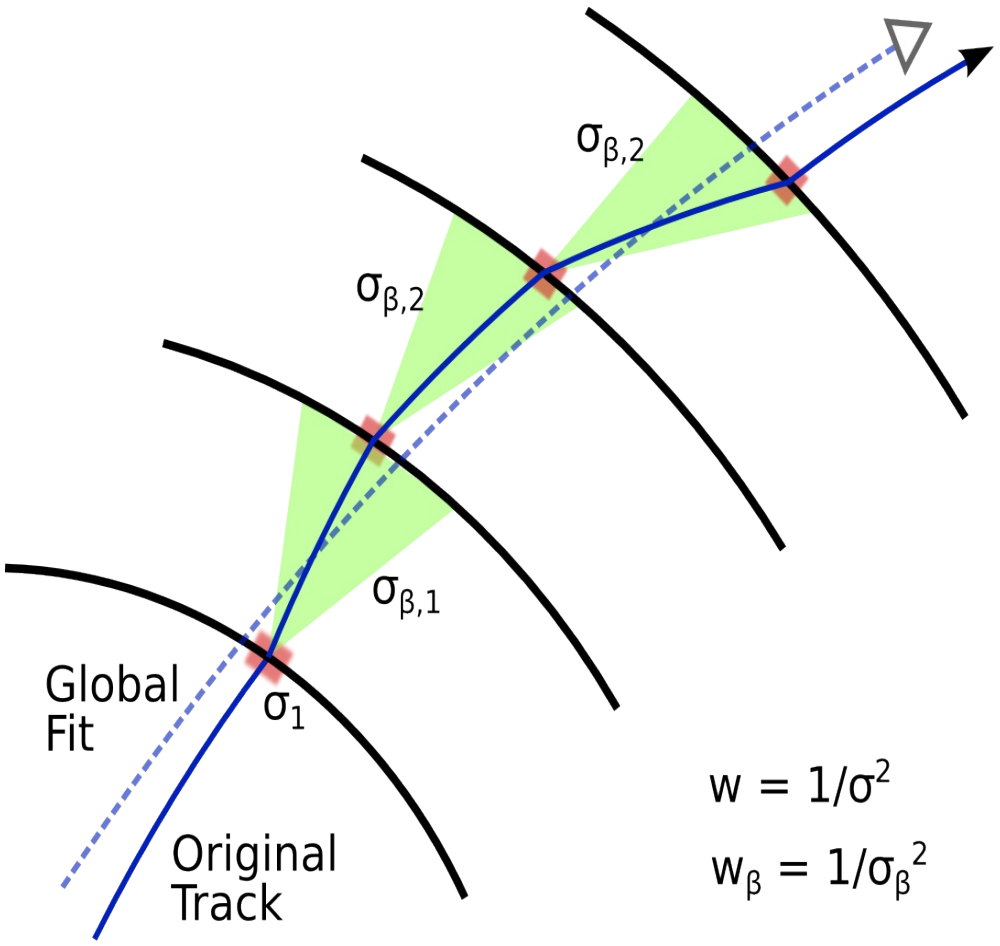
- Global Helix Fits
  fast, but no multiple scattering
- Kalman Filter
  iterative, with multiple scattering

New Algorithm based on Broken Lines

- non-iterative
- treats multiple scattering

The Broken Lines Track Fit

An Idea from Volker Blobel:
NIM A 566 (2006), pp. 14-17



Detailed Refit of Residuals

(here: transverse plane)

- circle fit
- calculate residuals
- define local offsets & angles

$$u_i \qquad \beta_i\left(u_{i-1}, u_i, u_{i+1}, \Delta\kappa\right)$$

- new residual expressions

$$S^2 = \sum w\left(r_i - u_i\right)^2 + \sum w_\beta \beta_i^2$$

- minimize S^2

Full Correlations
Linear Complexity

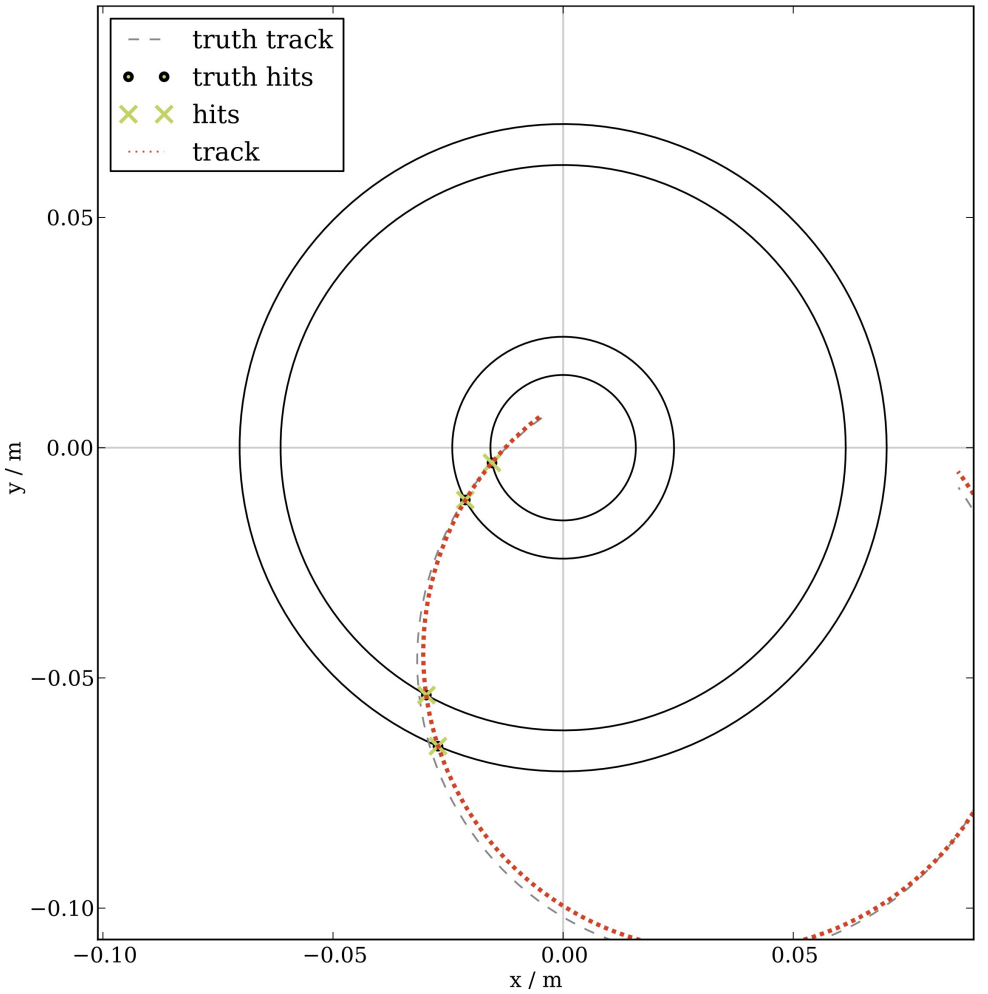
Simulation Setup

Simulation

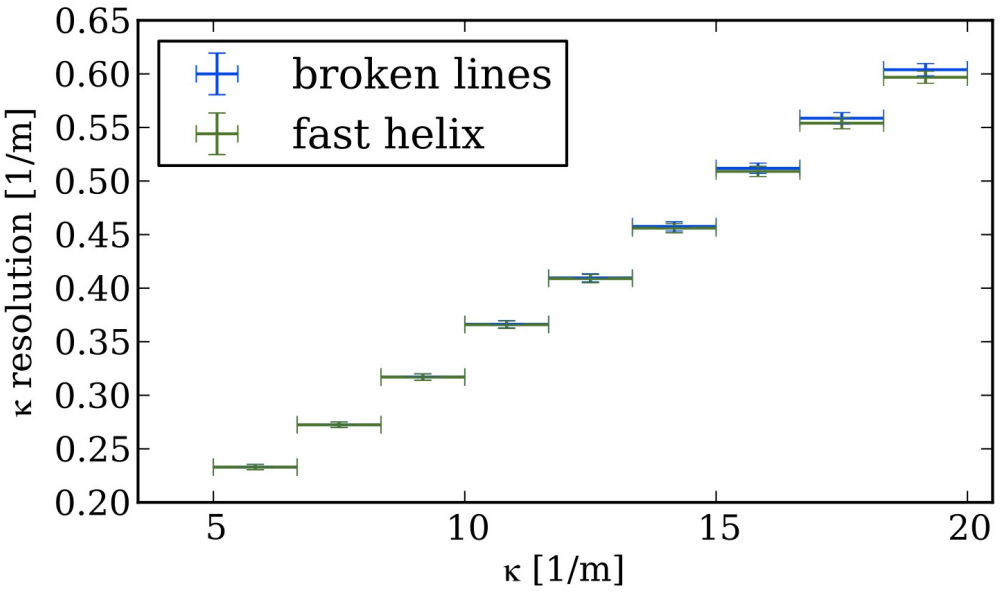
- four cylindrical layers
- pixel size 100µm
- layer thickness 0.001 X_0
- tracks in the transverse plane
- pixel resolution + multiple scattering

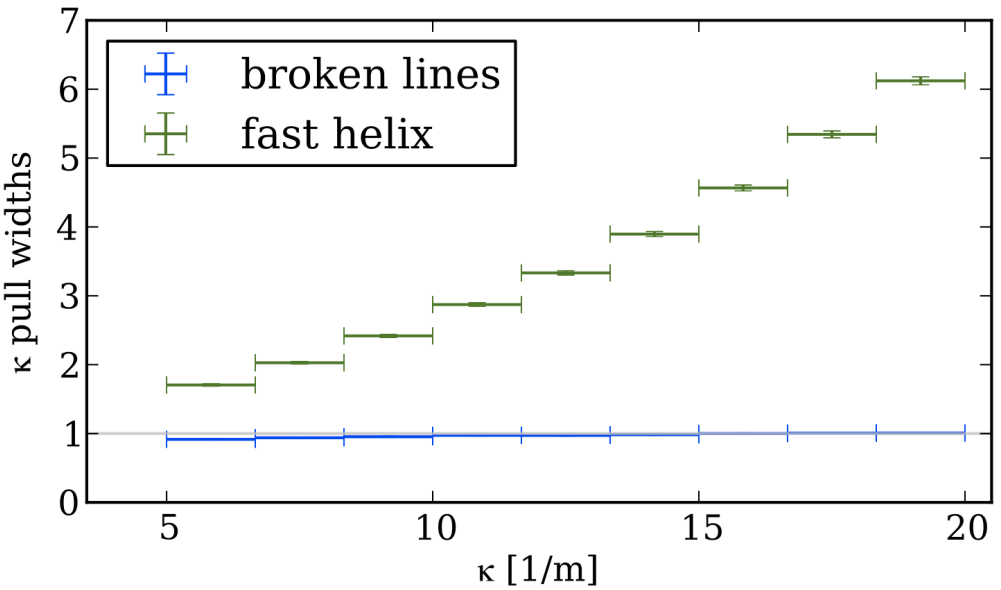
Reconstruction

- Broken Lines
- Global Helix Fit
- Parameters at 1st Hit



Track Curvature κ

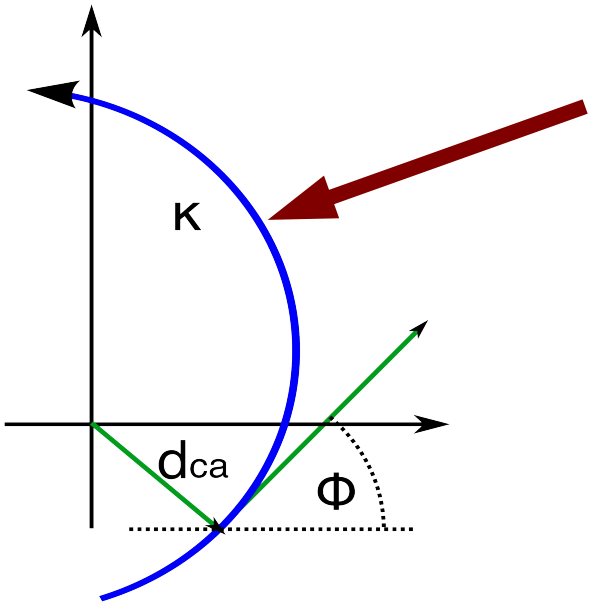




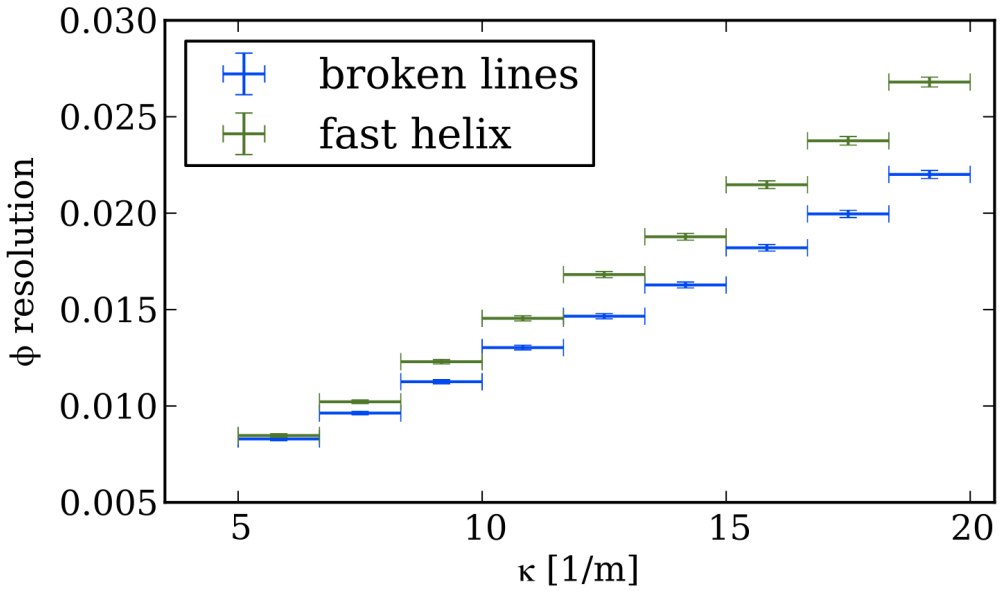
- no resolution increase
- correct errors

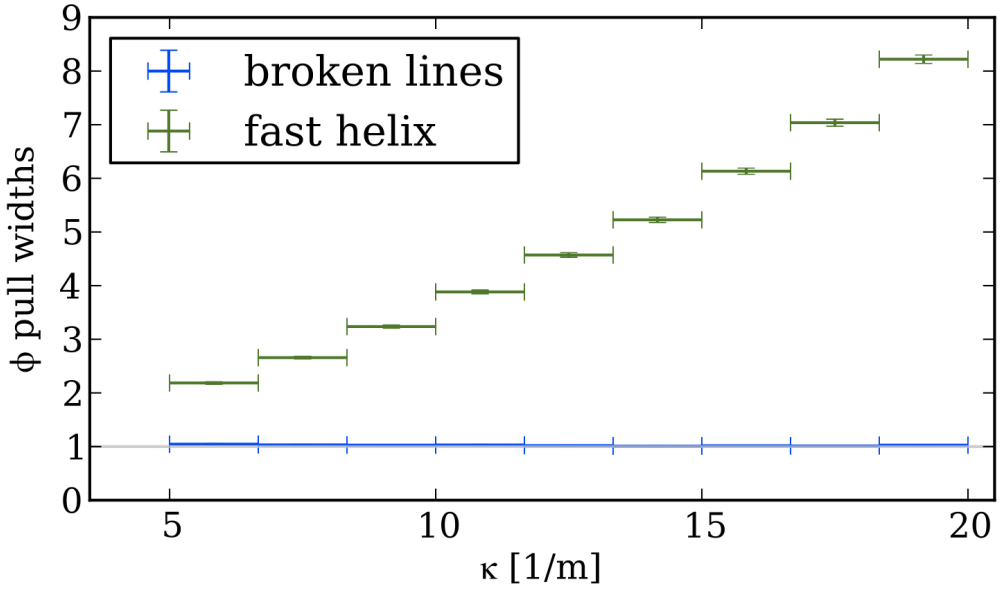
Why?

- still a global parameter
- only 4 layers
- not enough constraints



Track Angle φ

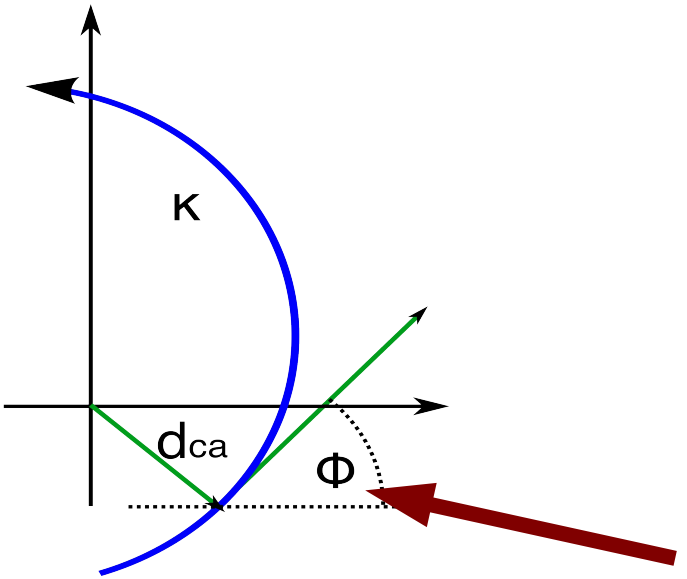




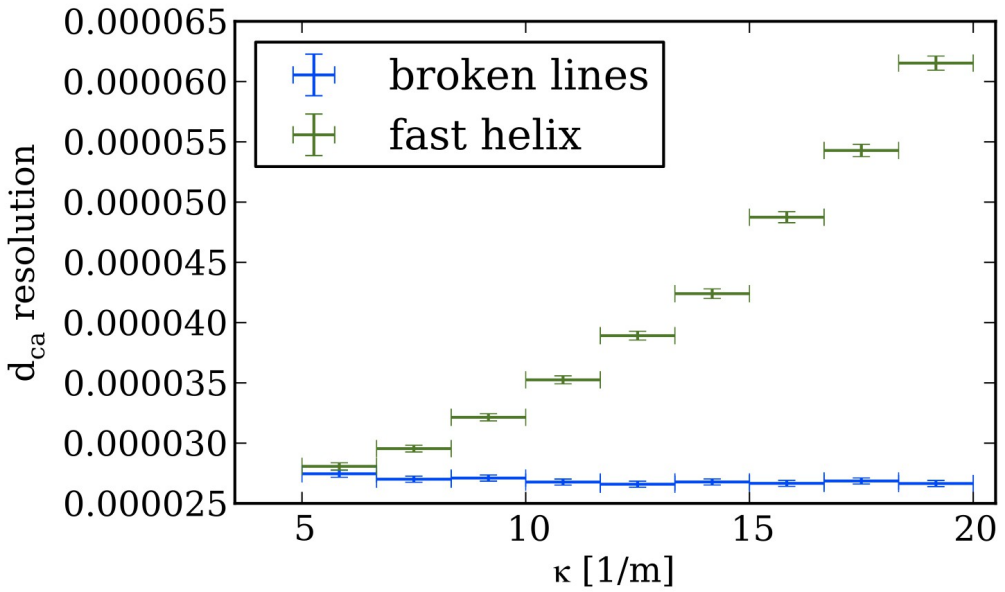
- increase in resolution
- correct errors

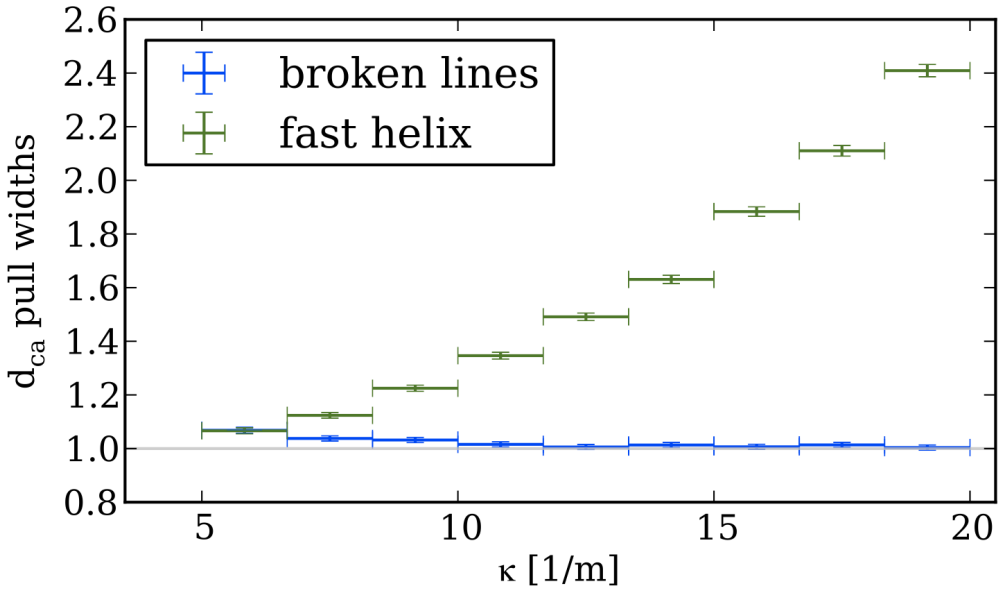
Why?

- local parameter
- only 4 layers
- not enough constraints



Distance of Closest Approach d_{ca}

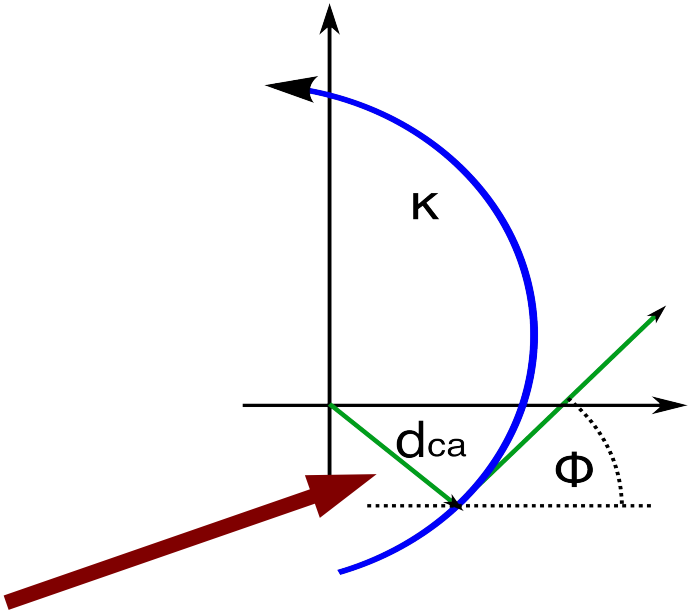




- increases resolution
- correct errors

Why?

- fully local parameter



Summary and Outlook

Summary

- new experiment to search for μ→eee
- requires fast and precise tracking
- new track fit based on Broken Lines w/ encouraging results

Open Questions

- complexity and speed
- comparison to Kalman Filter
- full 3d fit (w/ or w/o Broken Lines)