Developing and evaluating kink finding method with BSM models in ILD

Work in progress

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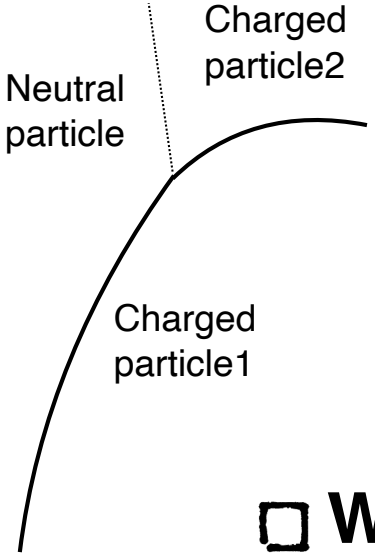
The motivation and aim of my study

Many models of new physics predict **charged long-lived particles** (LLP).



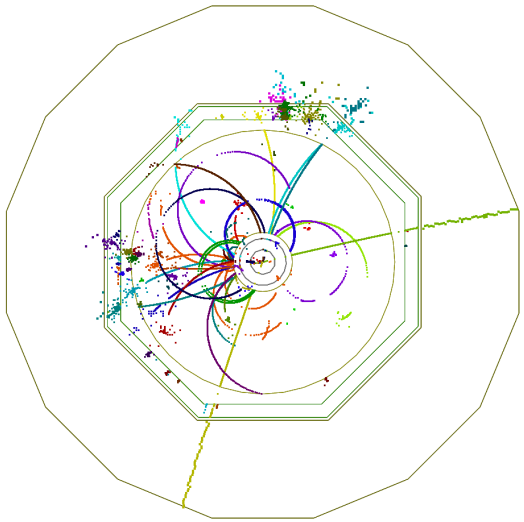
What is kink?

Charged LLPs decay to another charged particle, producing a characteristic track. It is called "**kink**".

e.g. Chargino decays into a SM charged particle and a neutralino (Lightest SUSY Particle) etc…

Why do I focus on kinks?

Time Projection Chamber (TPC) of ILD can measure more than 200 position.
→ kink comig from LLPs can be measured with **high sensitivity**.



A TPC is therefore very powerful tool for kink.
This study focuses on the reconstruction of kink inside ILD's TPC.

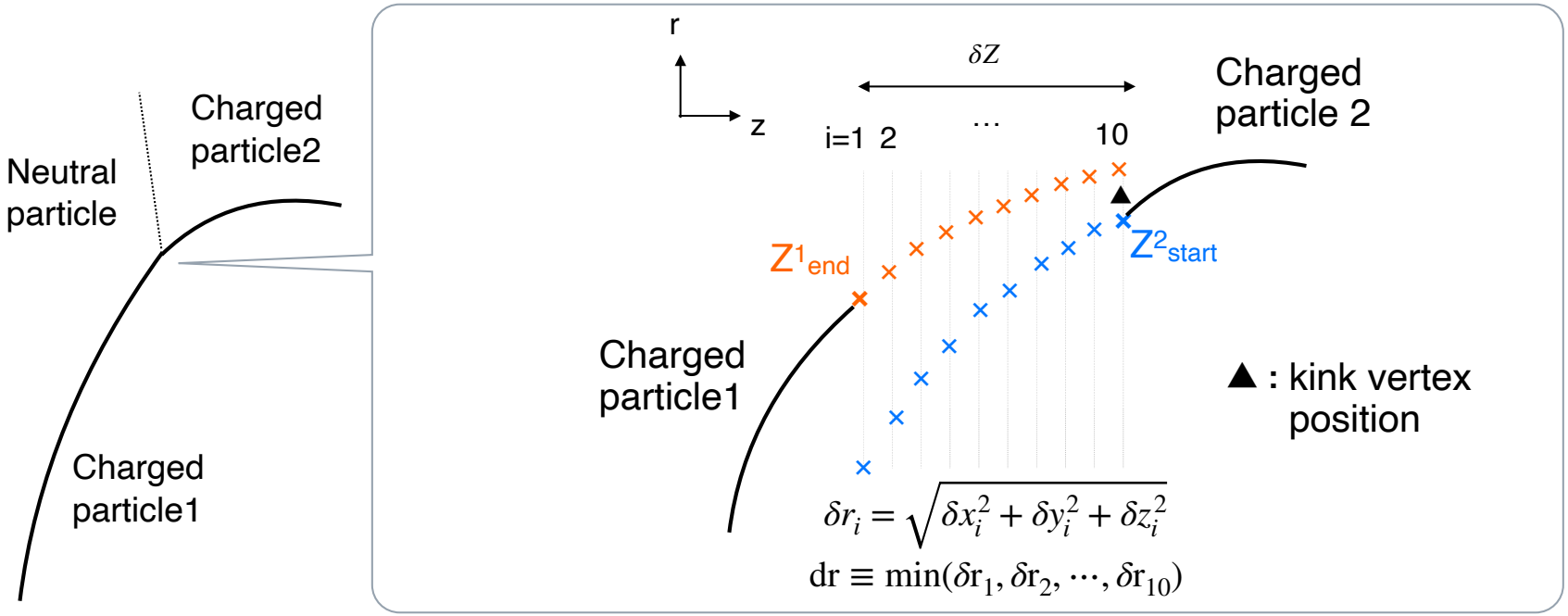
How do I identify kinks? - KinkFinder

in MarlinReco/Tracking/KinkFinder

I want to study kinks from LLPs but firstly I try to check "standard kinks" from **SM particles (eg. Kaon…)** → "Background study"

KinkFinder:
- a processor in ILD reconstruction chain
- Input reconstructed tracks

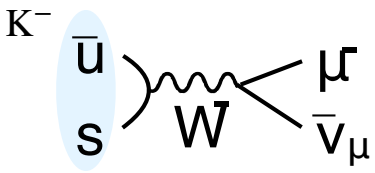
A pair of tracks with
- Same sign
- Dissimilar momenta
- The distance between Z^1_{end} and Z^2_{start} is resonably small



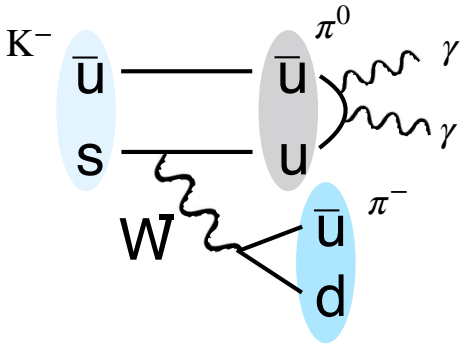
Kaon

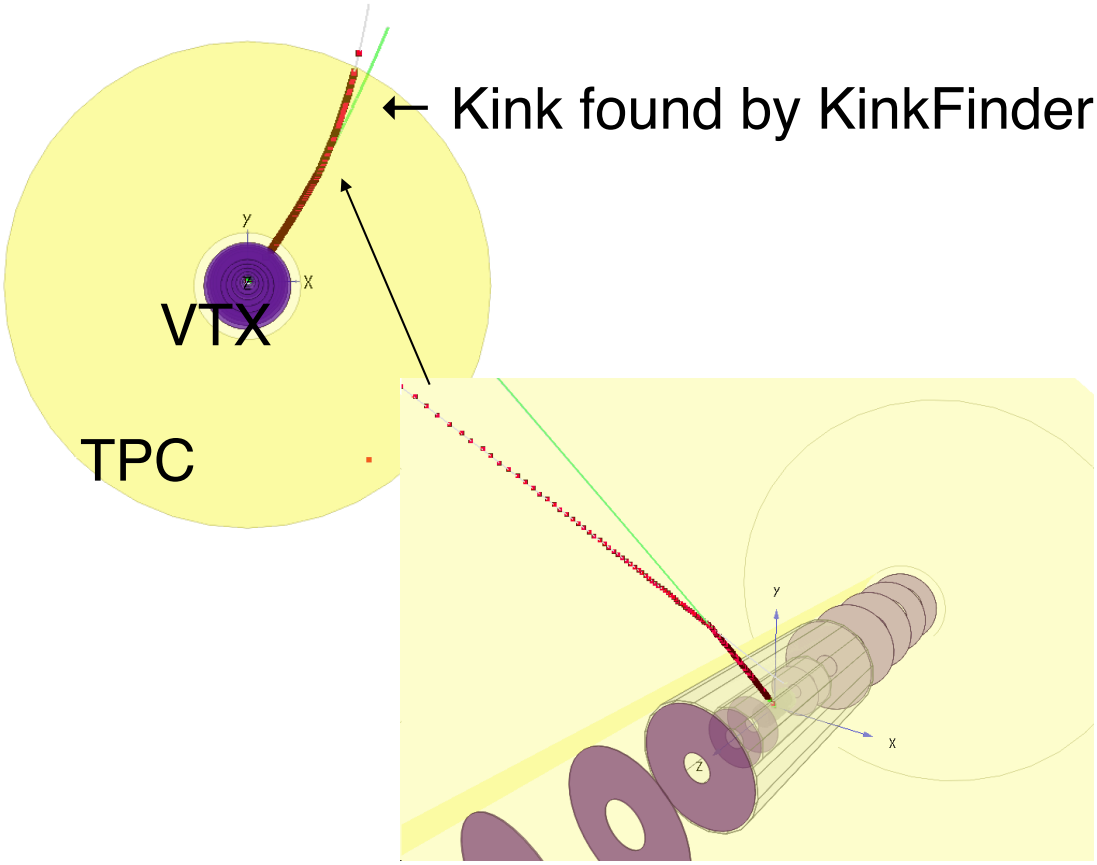
10GeV Kaons simulated and reconstructed in ILD_l5_v02 (CALOS removed)

1. $K^- \to \mu^- \nu_\mu$



2. $K^- \to \pi^- \pi^0$



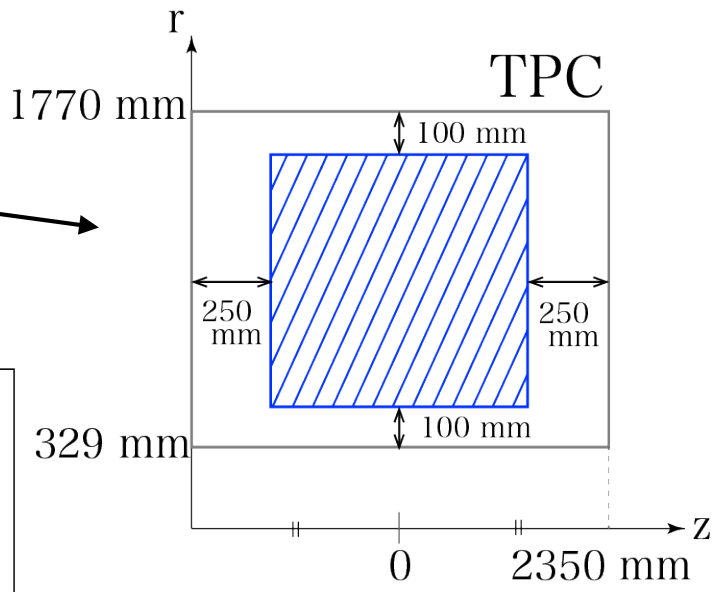


I checked the efficiency of KinkFinder.

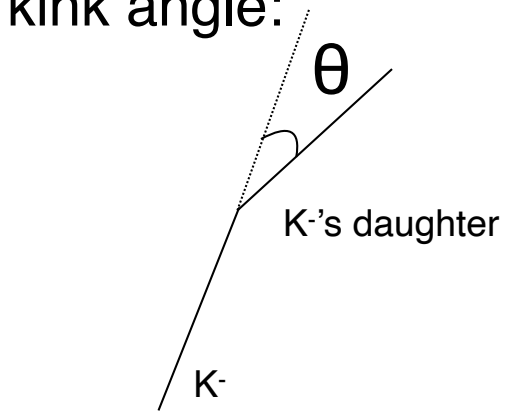
Efficiency dependence on the kink angle - “Standard” KinkFinder

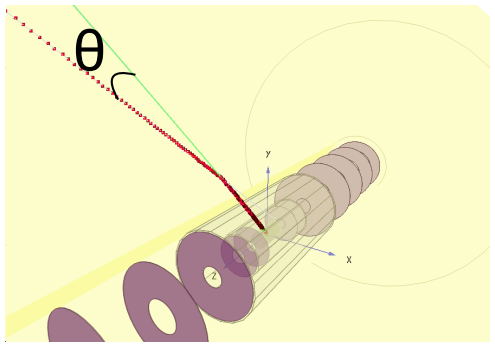
Precut made from **MCparticles**

- K^- (MC) decays inside TPC
- (MC) # of charged daughter of Kaon = 1

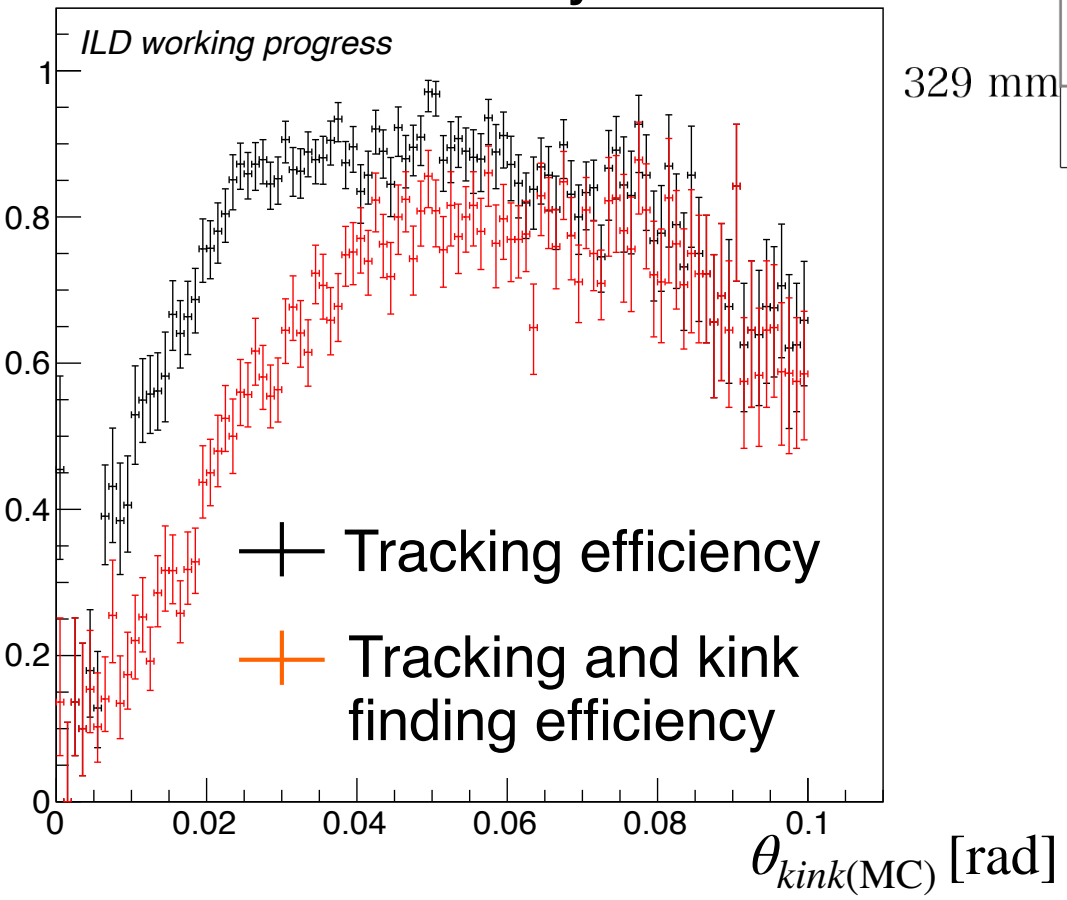


kink angle:





Efficiency



KinkFinder efficiency ~ 80% ($0.04 < \theta_{kink(MC)} < 0.08$)

Estimation of the kink's parent parents mass

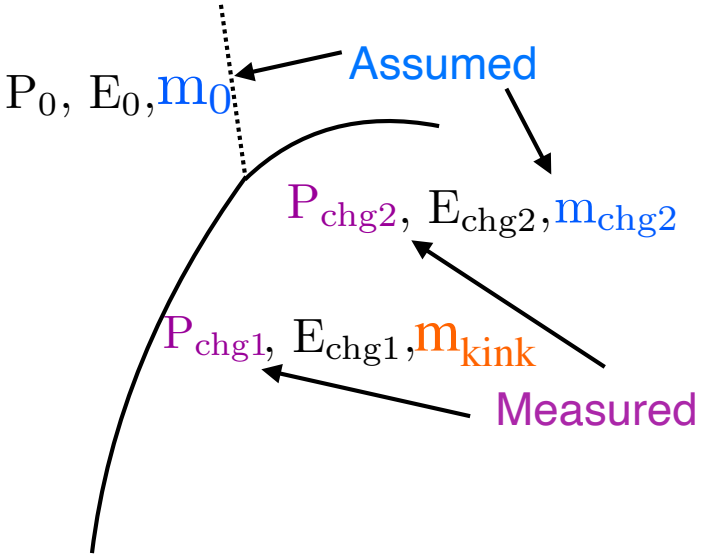
If the mass of the kink's parent particle can be accurately reconstructed, it can help to identify kinks from BSM and SM origin.

More particles - Kaon, Pion, Xi

$$K^- \to \mu^- \nu_\mu \quad \pi^- \to \mu^- \nu_\mu \quad \Xi^- \to \pi^- \Lambda^0$$
$$K^- \to \pi^- \pi^0$$

- 10 GeV particles simulated and reconstructed in ILD

What is kink mass?
which particle produced kink?



Using $P_0 = P_{chg1} - P_{chg2}$, (Momentum conservation)

$$E_0 = \sqrt{P_0^2 + m_0^2} = \sqrt{(P_{chg1} - P_{chg2})^2 + m_0^2}$$

$$E_{chg2} = \sqrt{P_{chg2}^2 + m_{chg2}^2}$$ (Energy conservation)

$$m_{kink} \equiv \sqrt{(E_{chg2} + E_0)^2 - P_{chg1}^2}$$

Tested kink decay in standard kinkfinder

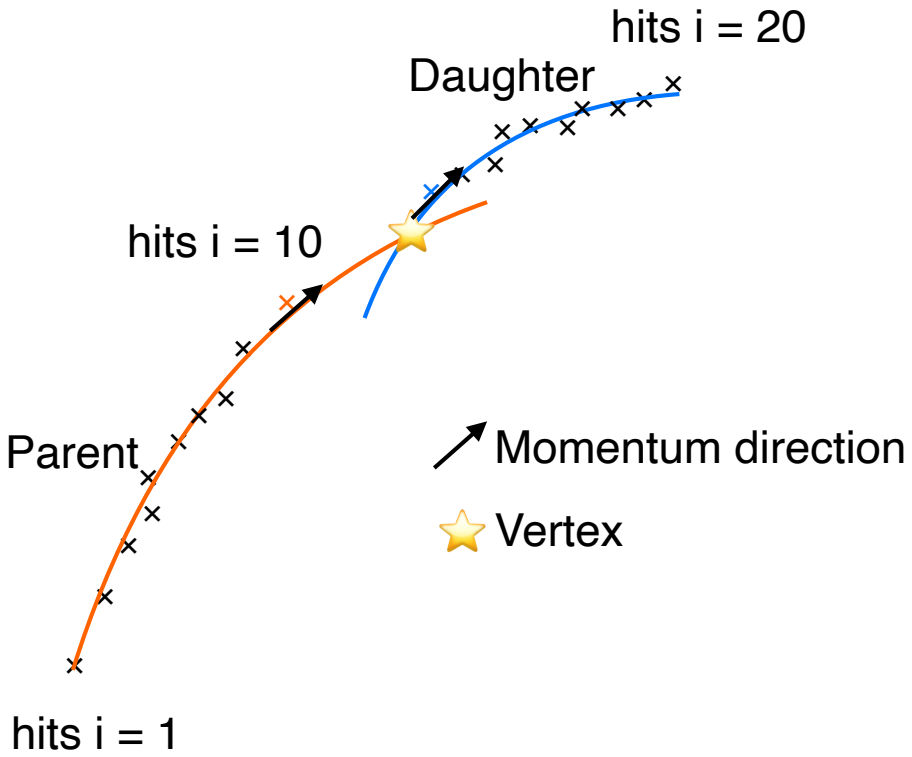
	m_{chg2}	m_0
$\pi^{\pm}/K^{\pm} \to \mu^{\pm}\nu$	m_μ	0
$K^{\pm} \to \pi\pi$	m_π	m_π
$\Sigma^+/\Sigma^- \to \pi n$	m_π	m_n
$\Sigma^+ \to p\pi_0$	m_p	m_π
$\Xi^- \to \pi\Lambda$	m_π	m_Λ

Choose best decay hypothesis using kink mass

Kink mass difference: $\delta m_{kink} = m_{kink} - m_{hypo}$

Improving 1: How to get momentum infomation

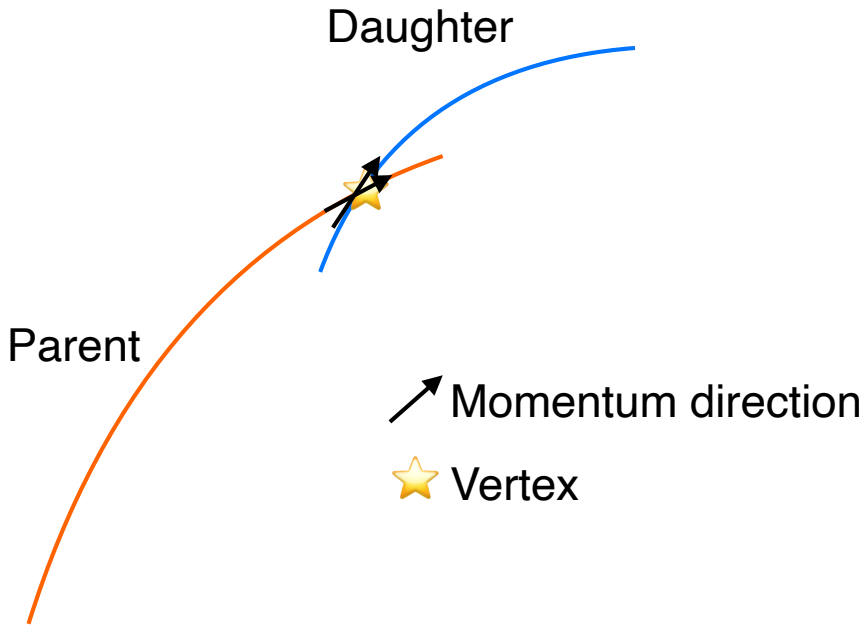
"Standard" KinkFinder



Helix is calculated using the last (first) 10 hits of parent (daughter) track.

Momenta are taken from the helix at last× (first×) hit

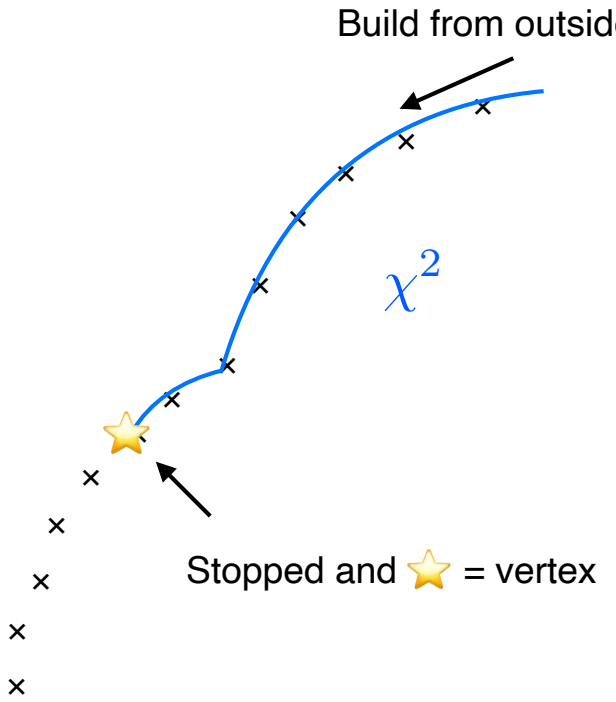
Improved method:
Momentum at vertex

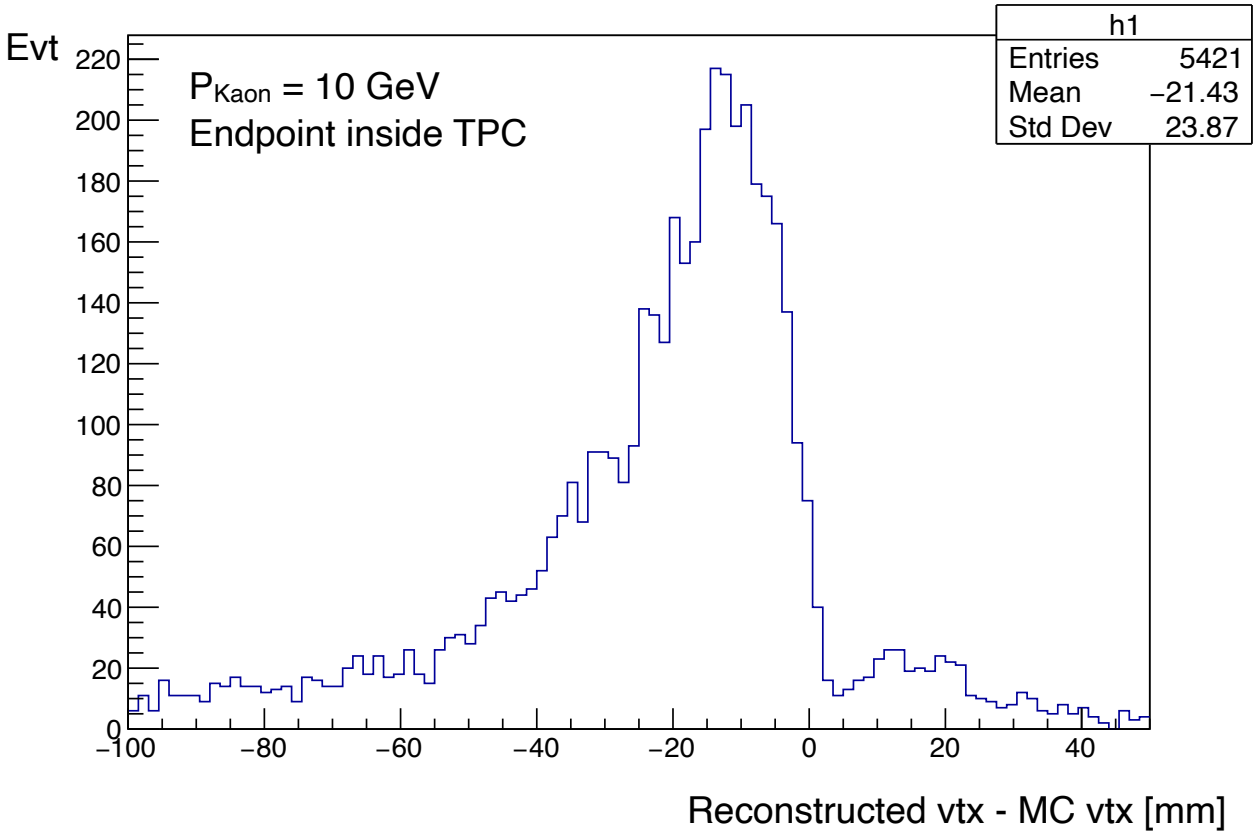


All hits are used to perform full Kalman filter track fits.

Momentum of this fitted track at reconstructed vertex is used

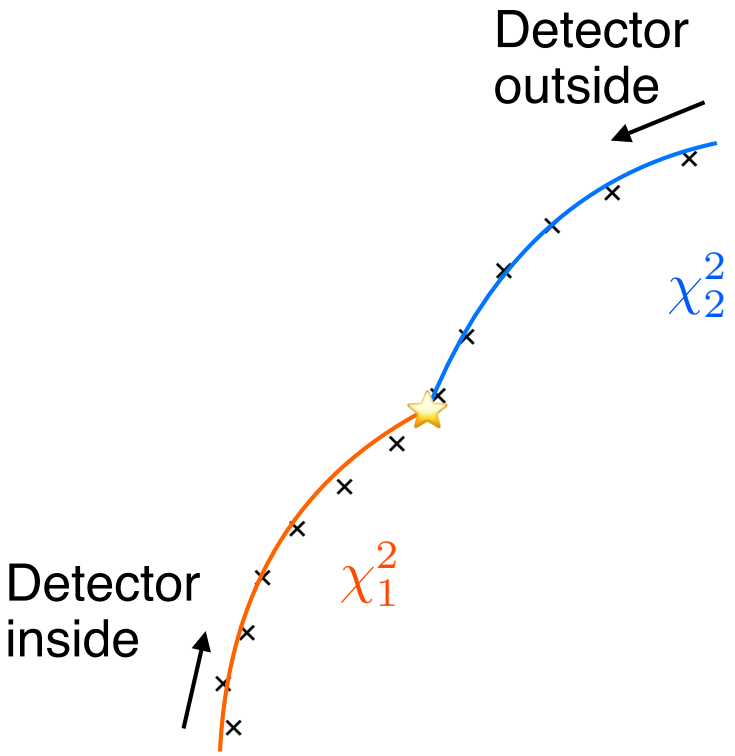
Marlin track bias

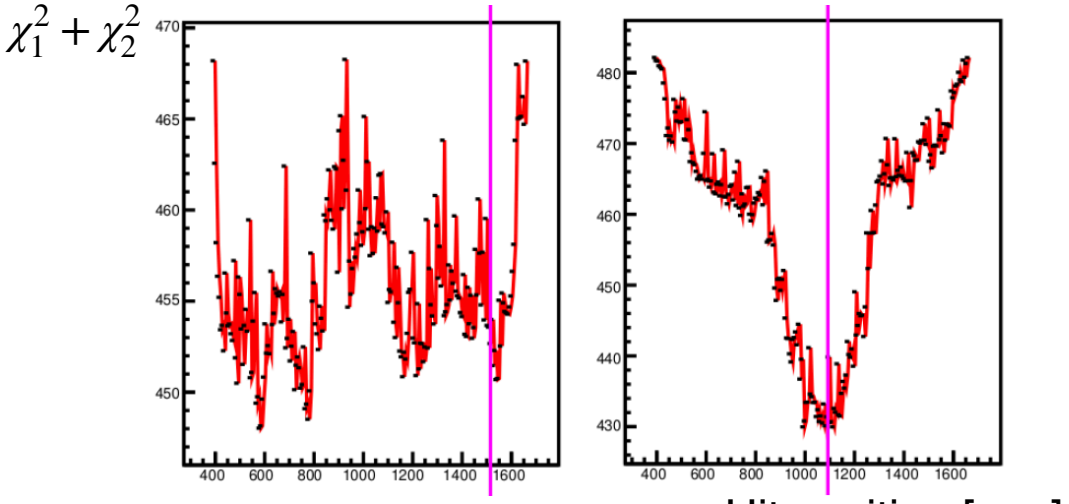


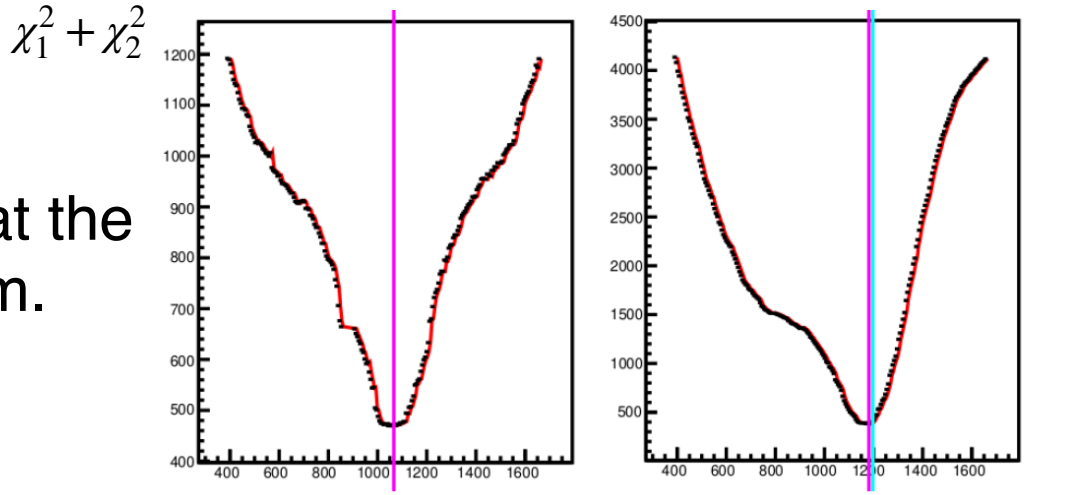


In Marlin track reconstruction, tracks are build from outside to in. It is terminated when track χ^2 become too large
-> vertex is biased to smaller radius.

Improving 2: How to get vertex infomation







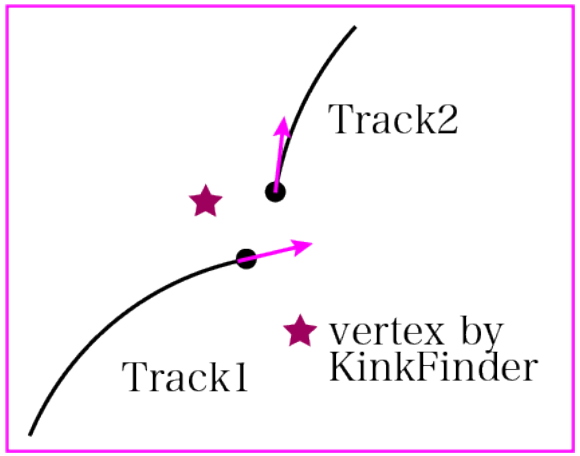
The combined track pair was cut at the hit for which $\chi_1^2 + \chi_2^2$ was minimum.

This point is assumed as the reconstructed vertex position.

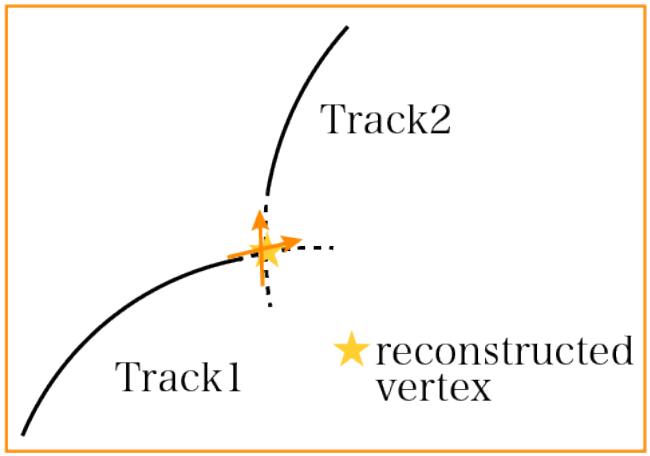
Figures by Daniel

Comparison of kink mass difference : Standard vs New

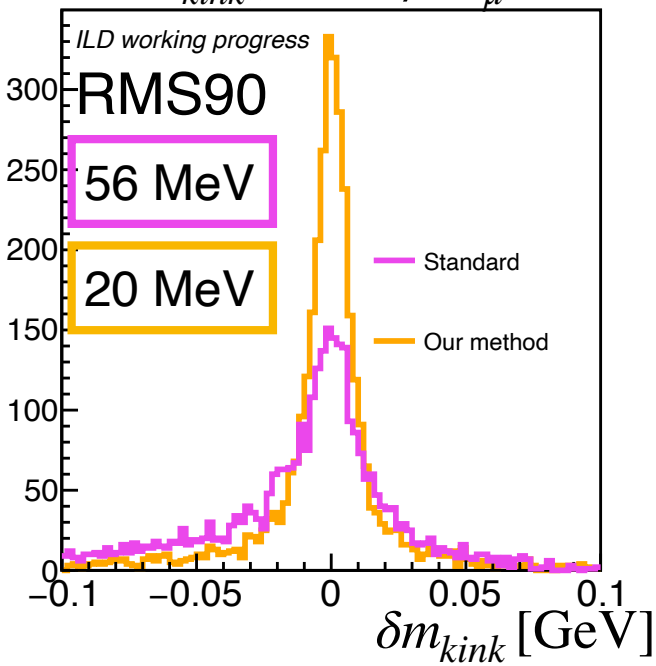
Standard KinkFinder



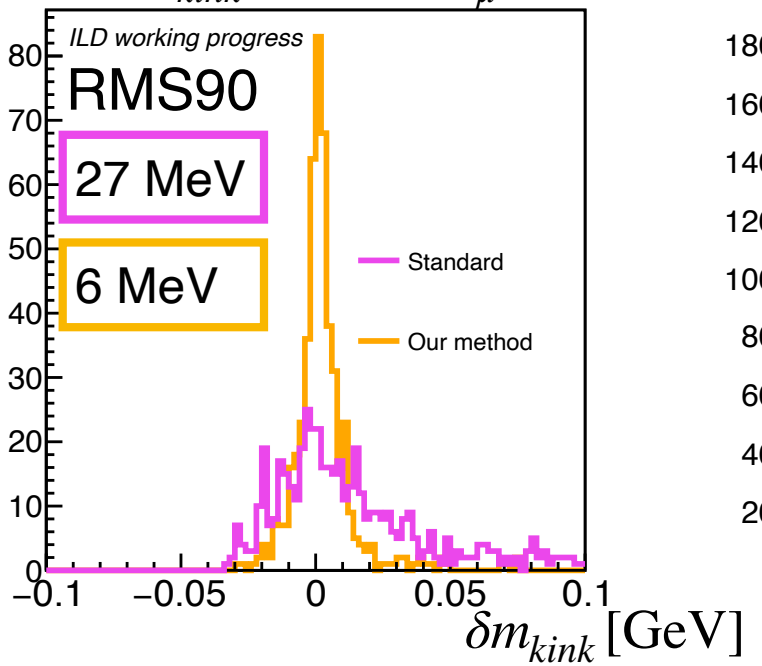
Our new method



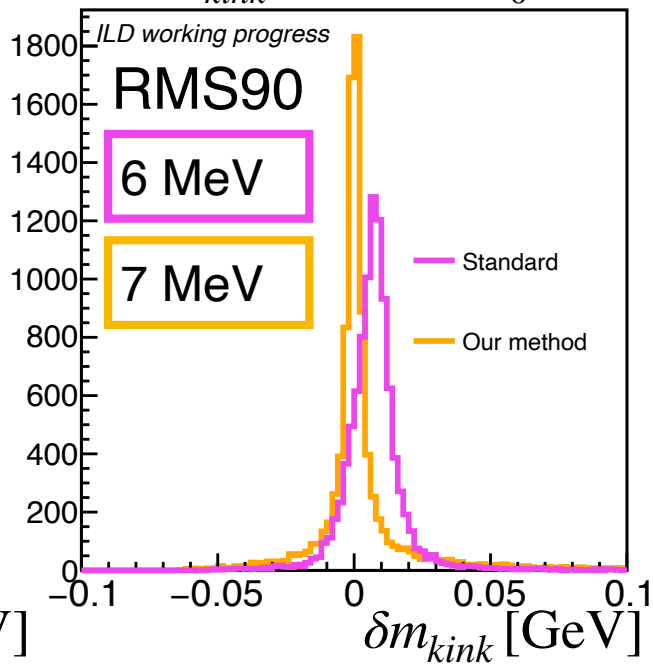
$\delta m_{kink}(K^- \to \mu^- \nu_\mu)$



$\delta m_{kink}(\pi^- \to \mu^- \nu_\mu)$



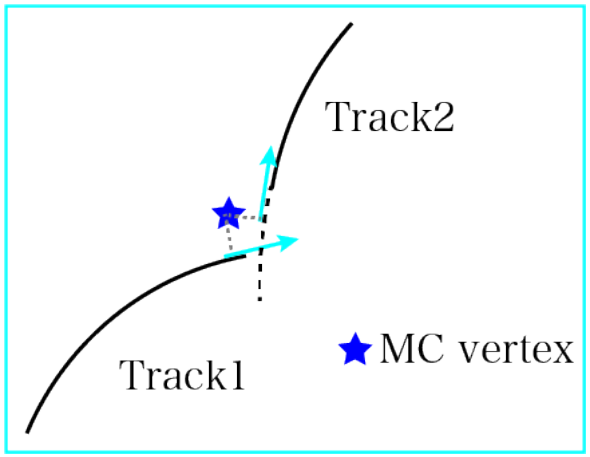
$\delta m_{kink}(\Xi^- \to \pi^- \Lambda_0)$



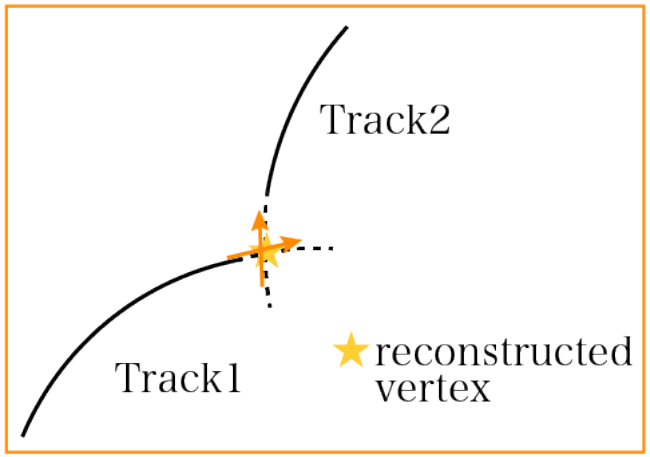
Improving mass resolution!

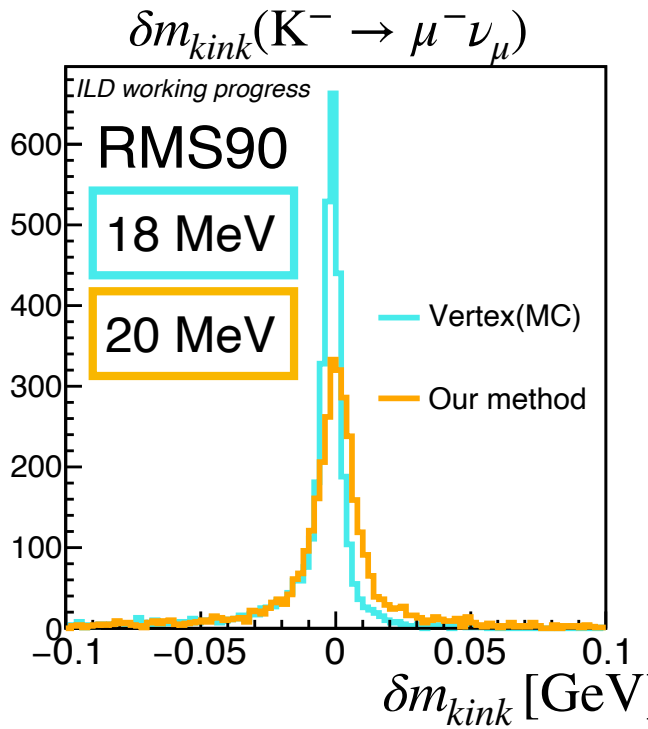
Comparison of kink mass difference : MC vs New

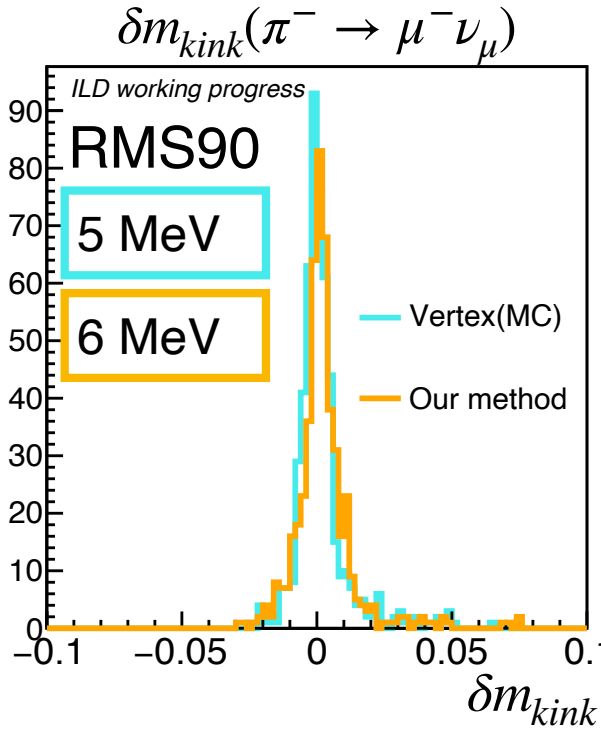
Vertex with MC info.

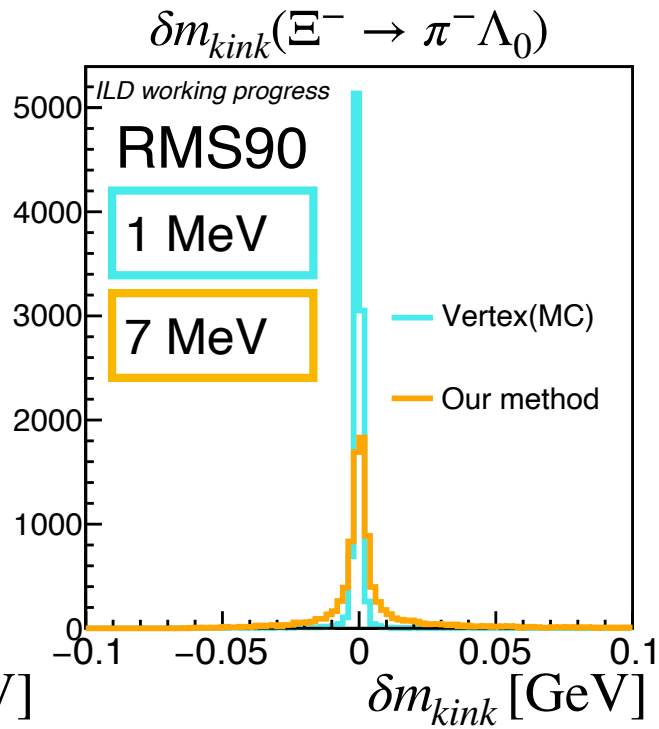


Our new method









There's room for improvement.

Summary

Kink is useful for LLP search!

☑ **Background** study with **SM** particles

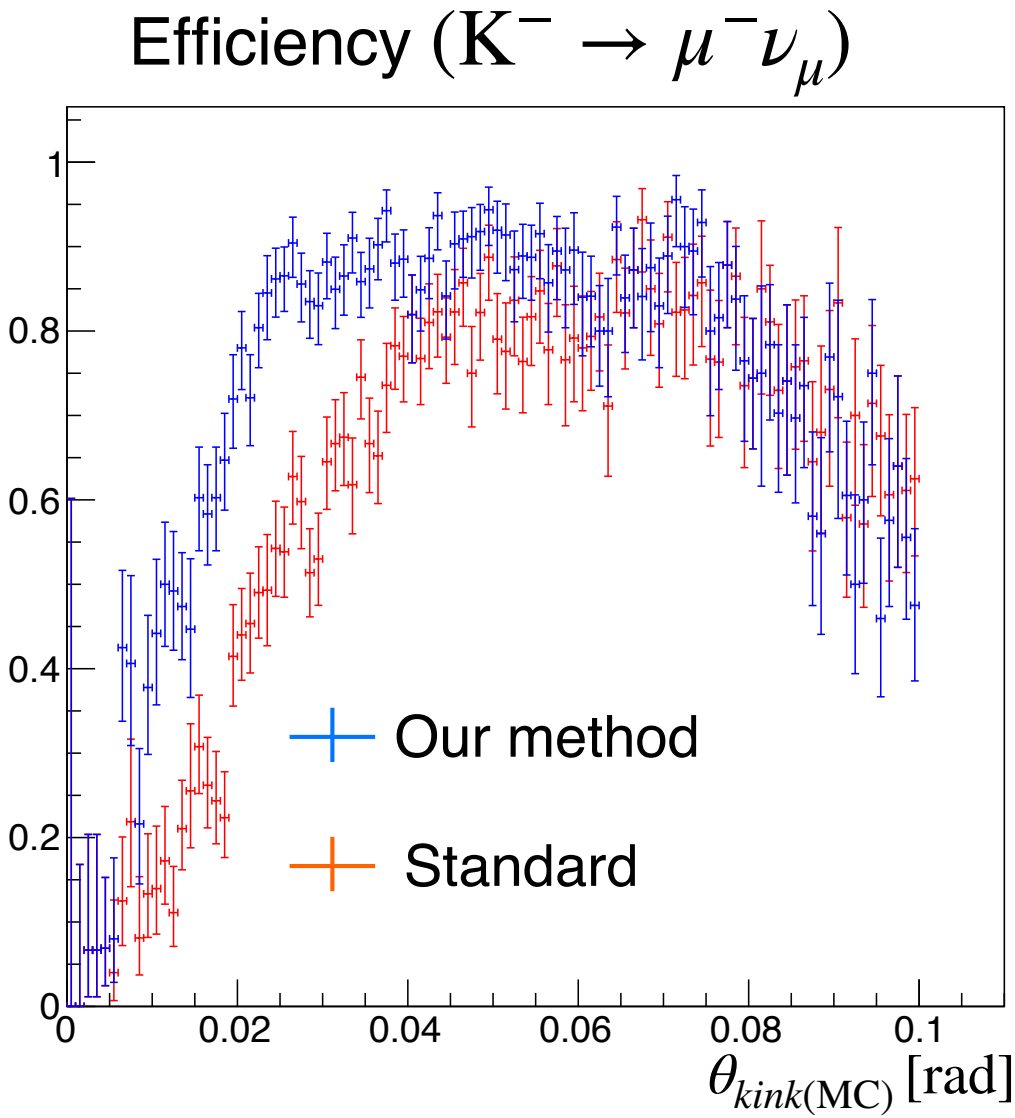
☑ KinkFinder efficiency is about **80%** ($0.04 < \theta_{kink(MC)} < 0.08$)

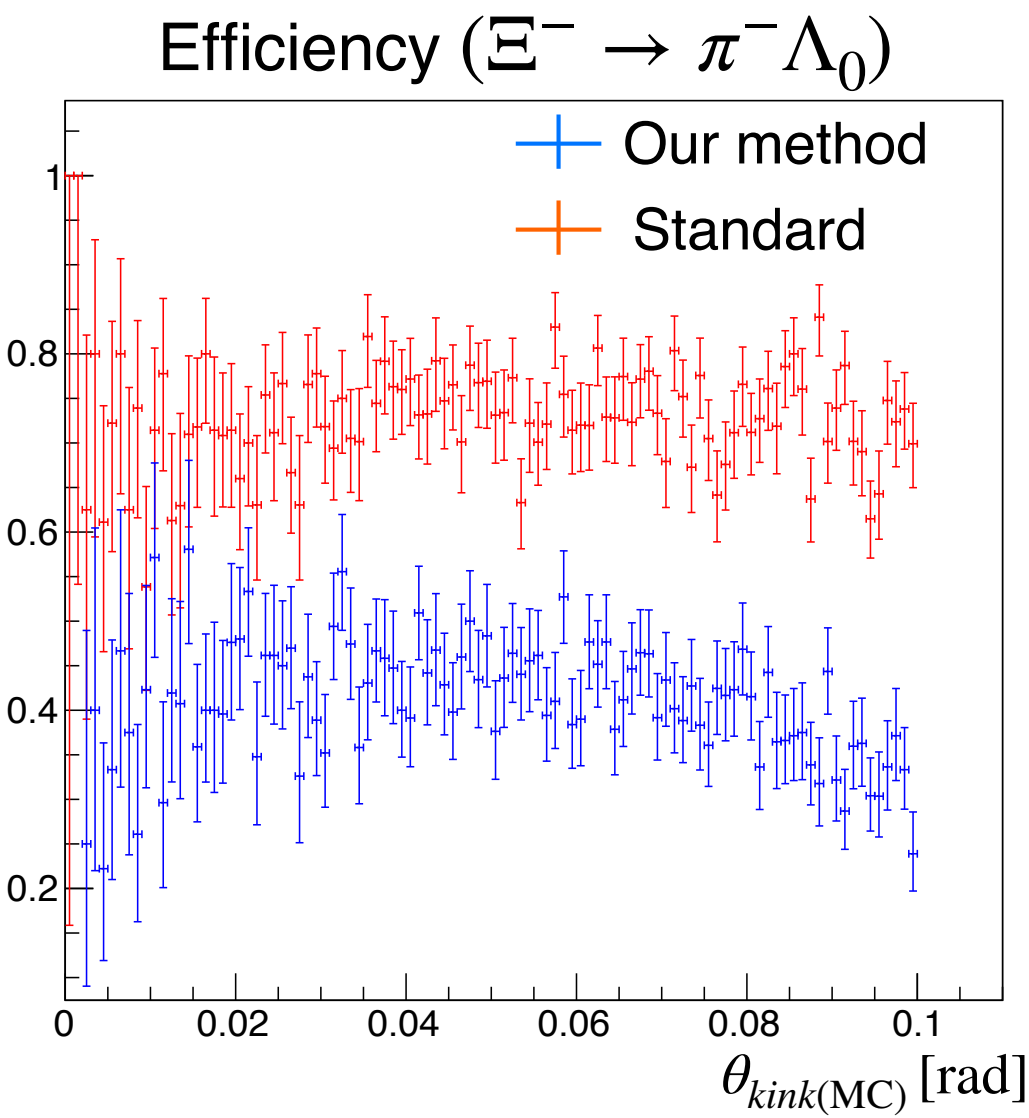
☑ **Improving mass resolution**
<- better vertex position
<- better track momentum at vertex
-> ~20 MeV kink mass precision

Next steps
- Improving efficiency at small and large kink angle
- Kinematic vertex fitting
- SM kinks with other momenta
- Interpret results with BSM models

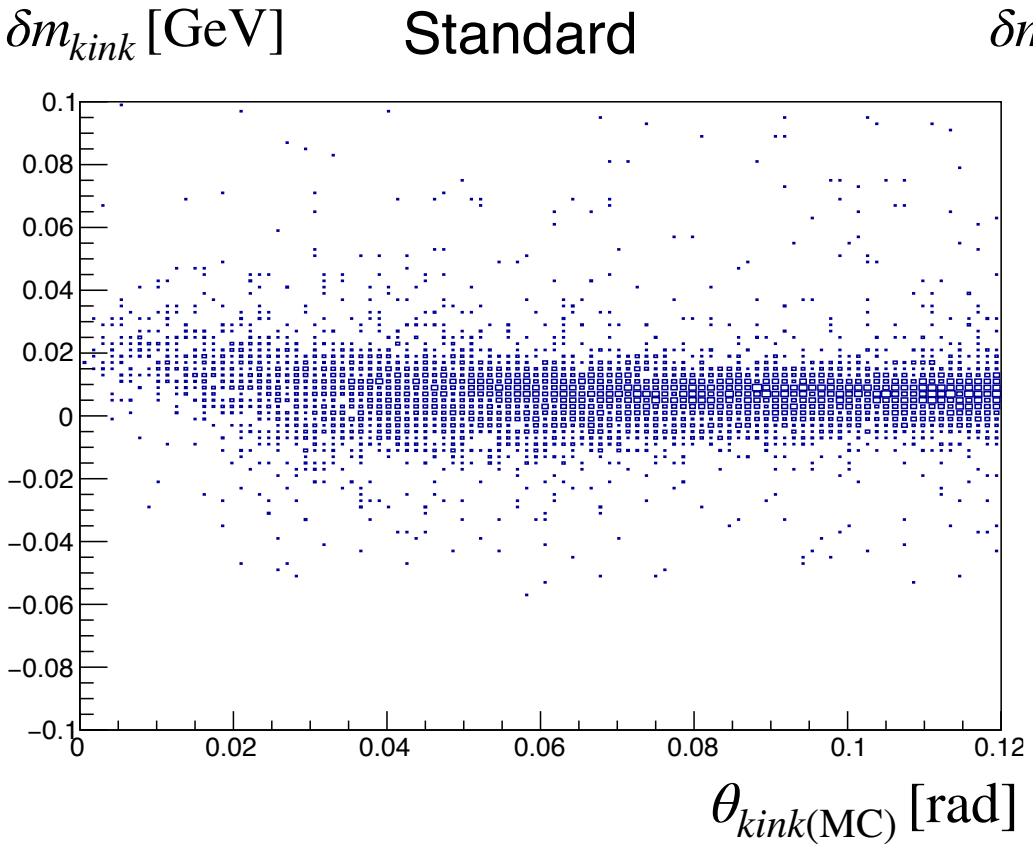
Back-up

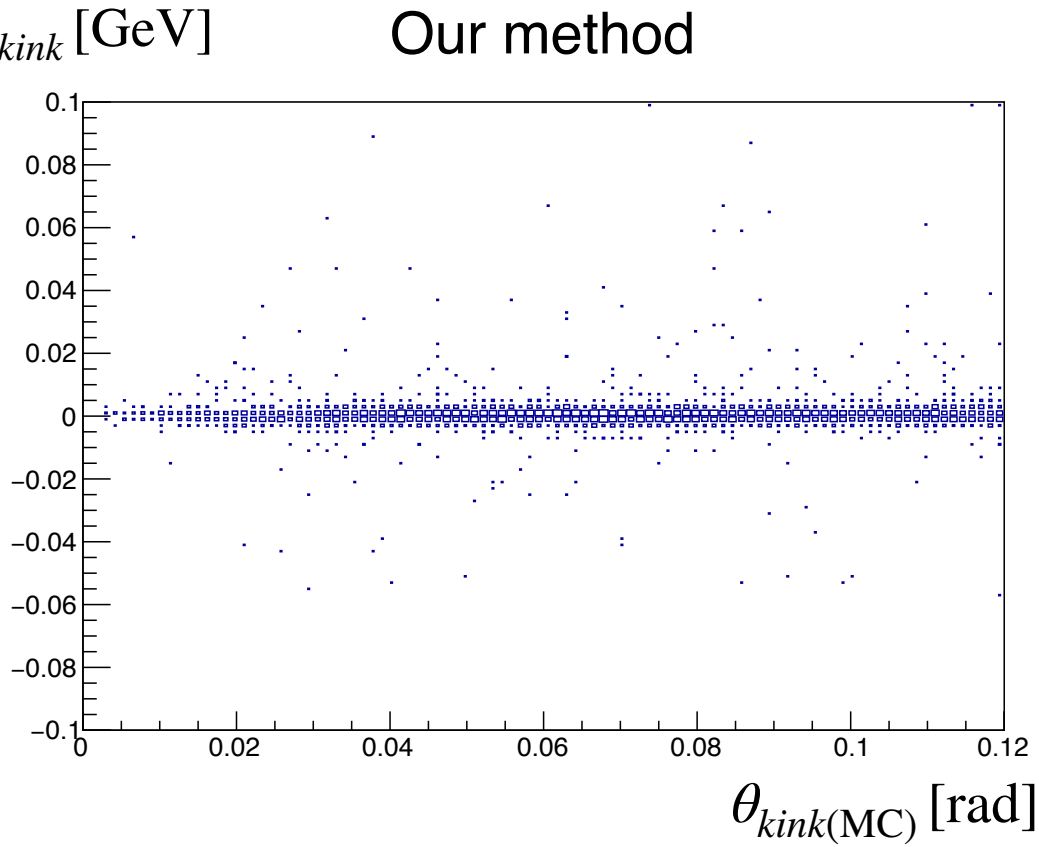
Efficiency dependence on the kink angle - Standard vs Our method





Kink angle vs kink mass difference Ξ - Standard vs Our method





How do I identify kinks? - KinkFinder

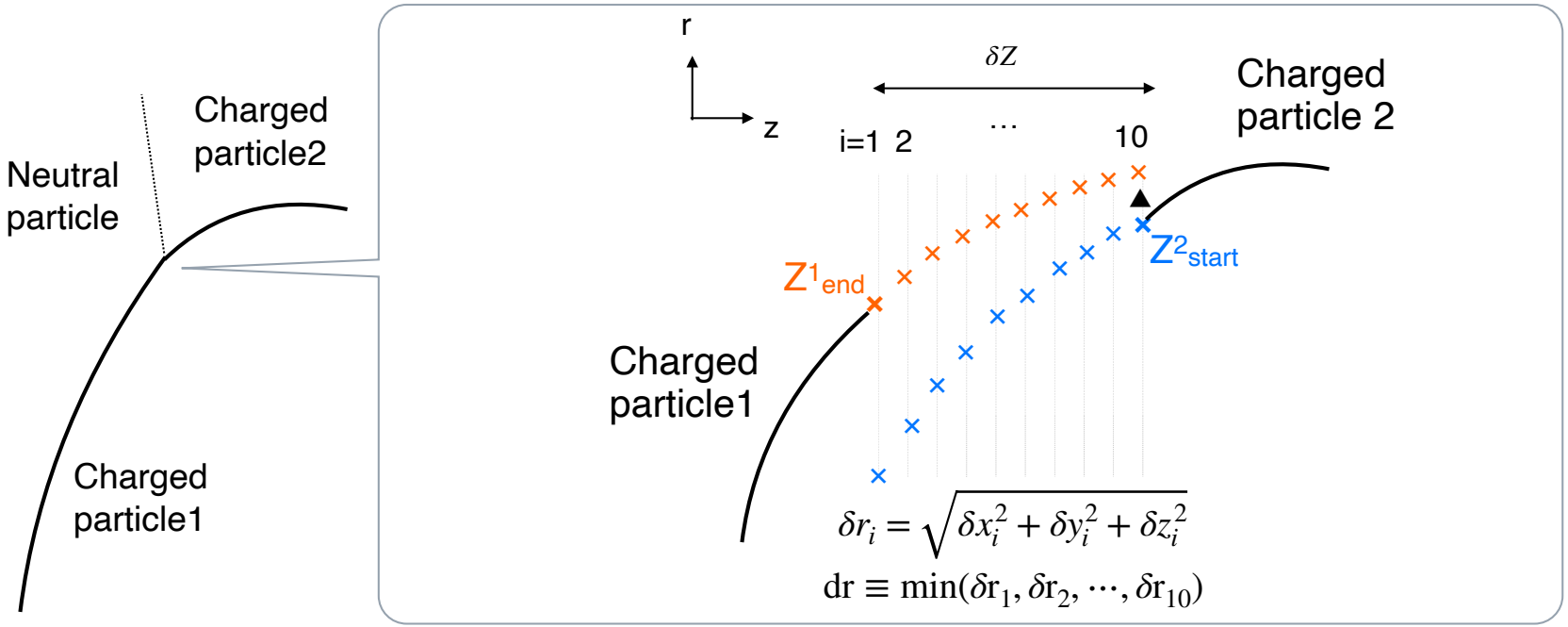
in MarlinReco/Tracking/KinkFinder

I want to study kinks from LLPs but firstly I try to check "standard kinks" from **SM particles (eg. Kaon…)**

⟶ Background study

2 tracks with

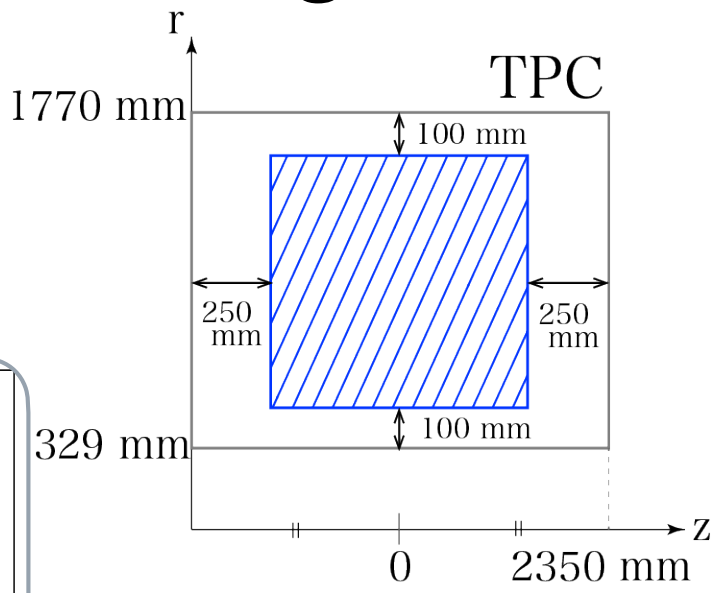
- Same sign
- Different momenta
- Small distance of closest approach



Efficiency dependence on the kink angle

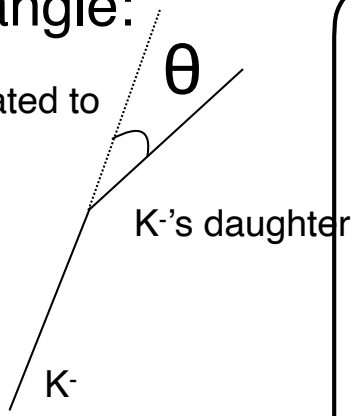
Precut made from **MCparticles**

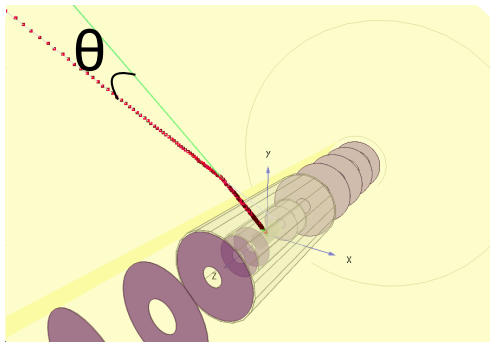
- Endpoint(MC) inside TPC:
  $329 + 100 < r < 1770 - 100\,[\mathrm{mm}]$, $|z_{max}| < 2350 - 250[\mathrm{mm}]$
- (MC) # of charged daughter of Kaon = 1



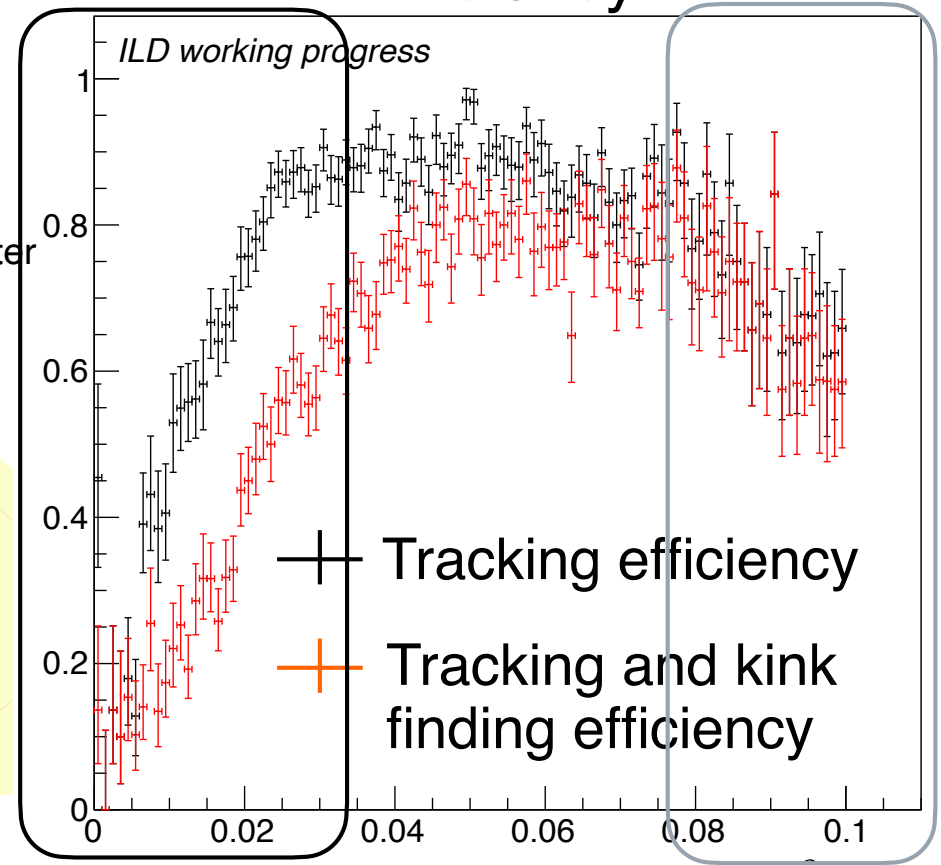
kink angle:

Track extrapolated to K-





Efficiency

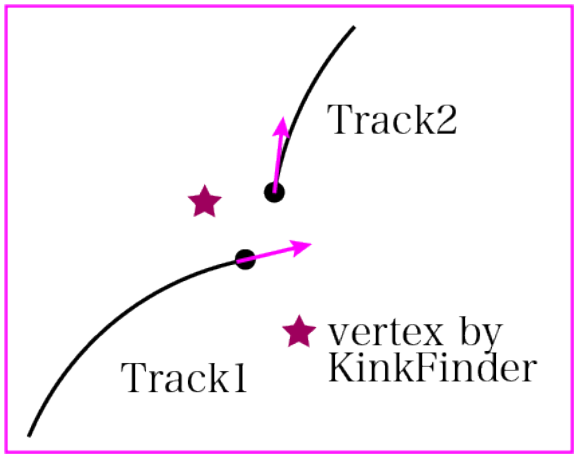


Merged into **single** track?

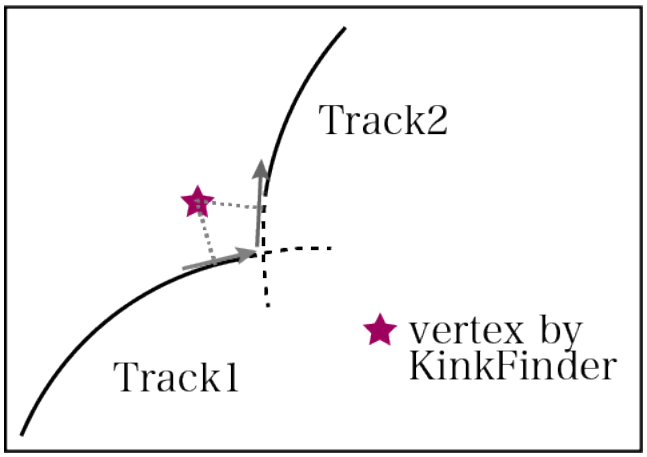
Efficiency for very displaced 2nd track?

Comparison of δm distribution

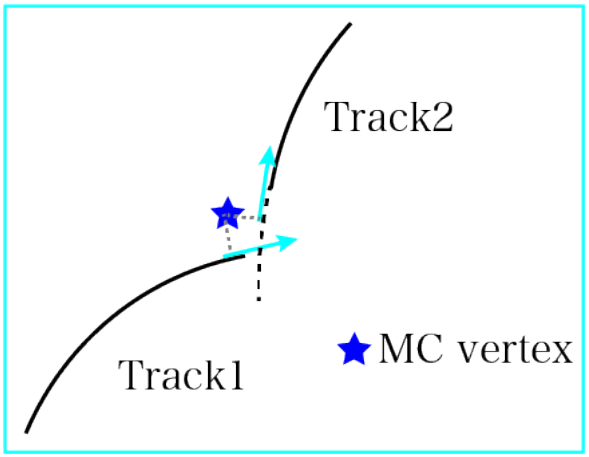
$$\delta m_{kink} \equiv m_{reco_K} - m_{true_K}$$



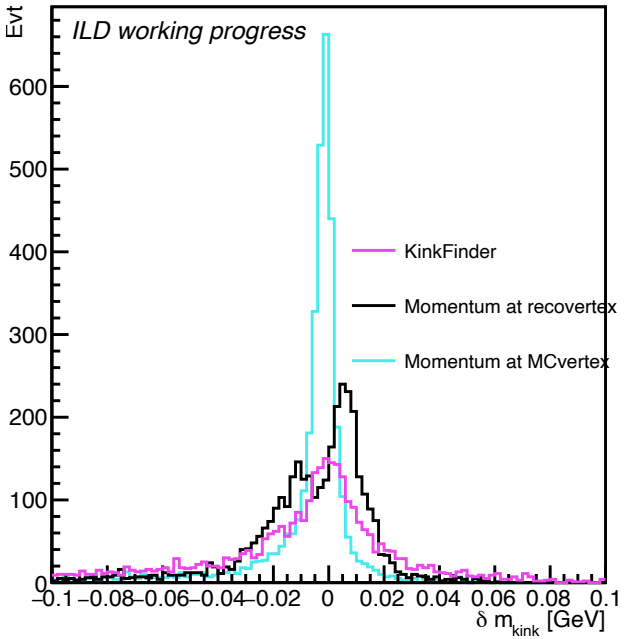
δ m_{kink} ($K^- \to \mu^- \nu$)

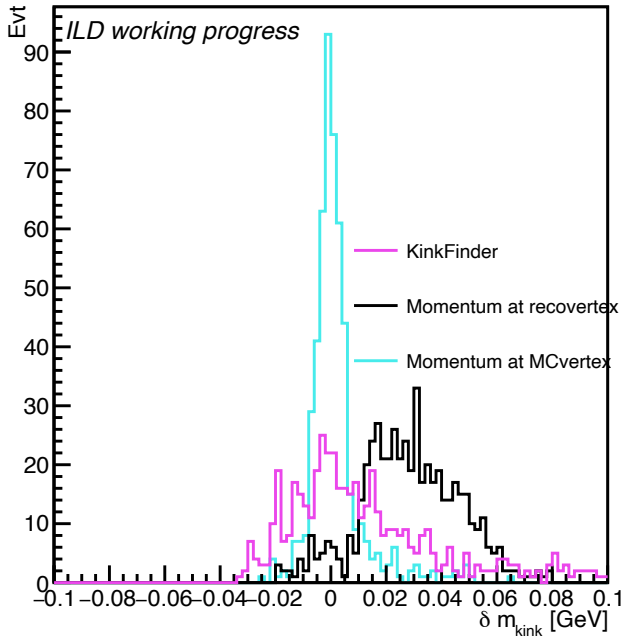


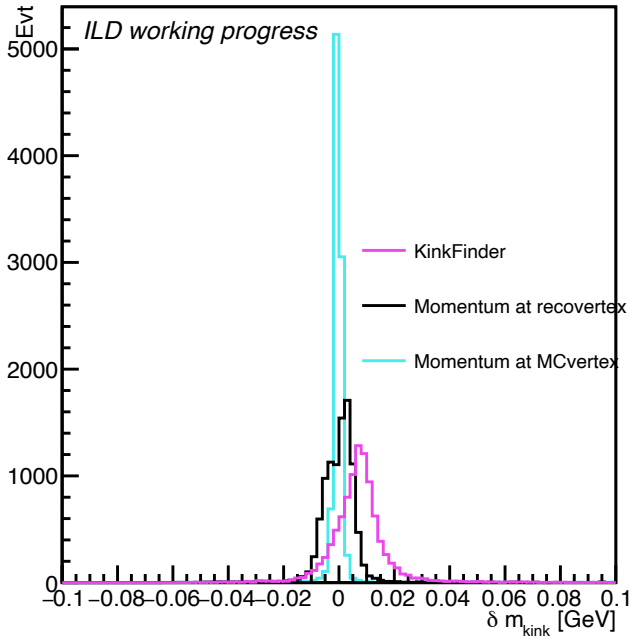
δ m_{kink} ($\pi^- \to \mu^- \nu$)



δ m_{kink} ($\Xi^- \to \pi^- \Lambda$)







Vertex reconstruction improved
→ δm distribution is improved !

New likelihood function - try1

KinkFinder

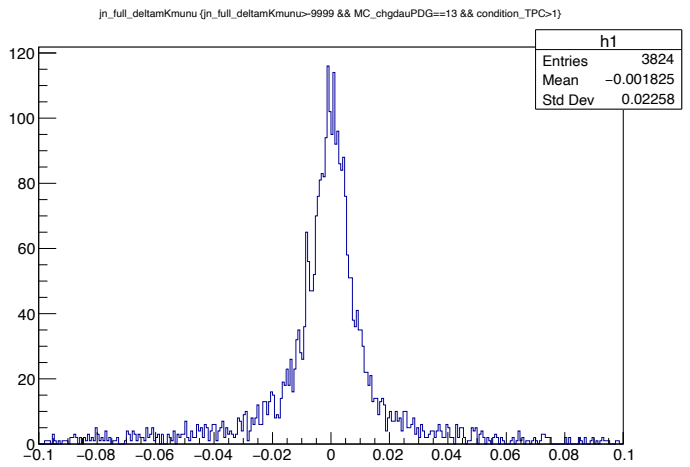
$$\text{likelihood K} \equiv 3.125 \times \delta\text{K} \times \delta\text{K} + t\text{K} \qquad \delta K \equiv \frac{|m_{kink} - m_K|}{\text{K mass resolution (0.075 [GeV])}}$$

$$\mathrm{L_K} \equiv \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{\delta m_K}{\sigma}\right)^2} \times e^{-tK}$$

Ignoring

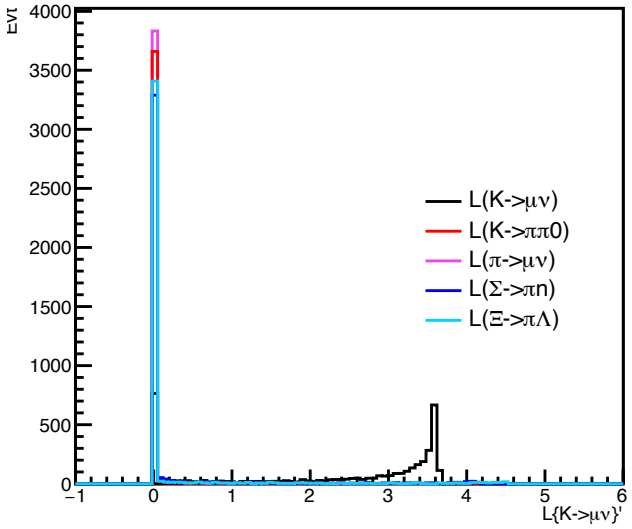
$$\delta \mathrm{m_K} \equiv \mathrm{m_{reco_K}} - \mathrm{m_{true_K}}$$

I find σ from δK', δπ', δΣ' and δΞ' distribution.
I used "RMS90".

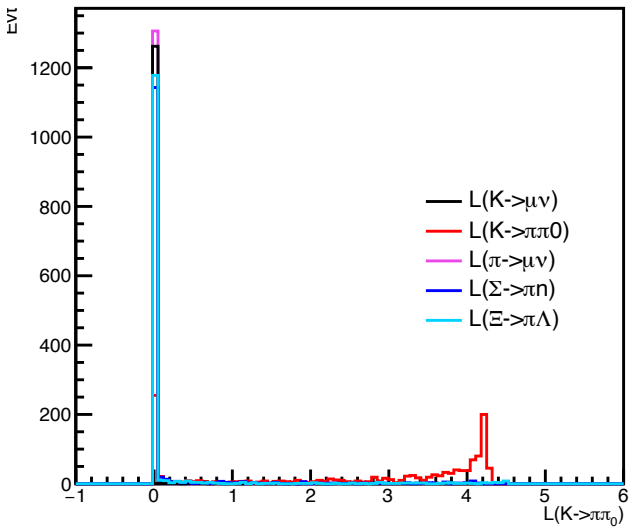


Distribution of new likelihood function

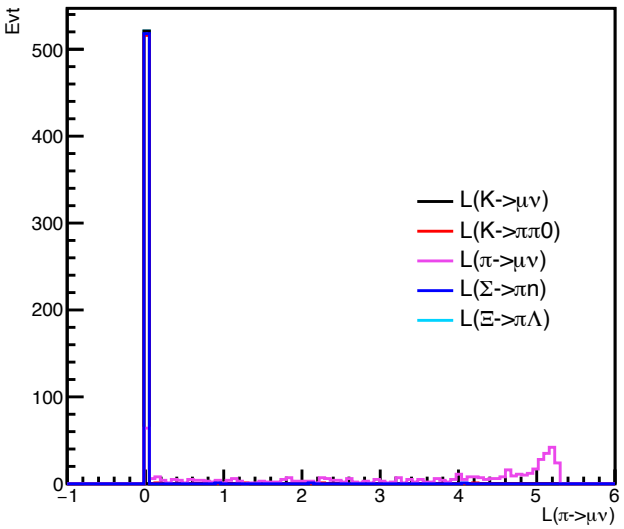
Likelihood(K->μν)



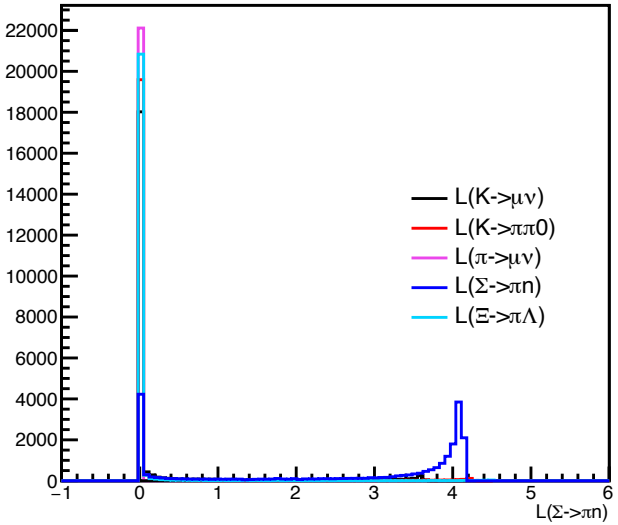
Likelihood(K->$\pi\pi_0$)



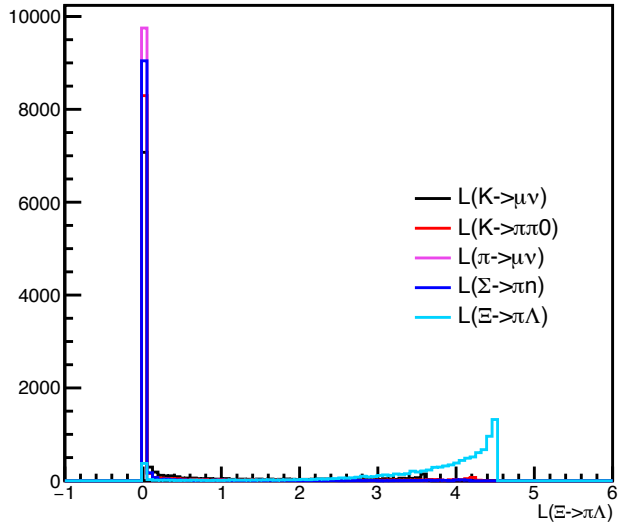
Likelihood(π->μν)



Likelihood(Σ->πn)



Likelihood(Ξ->πΛ)

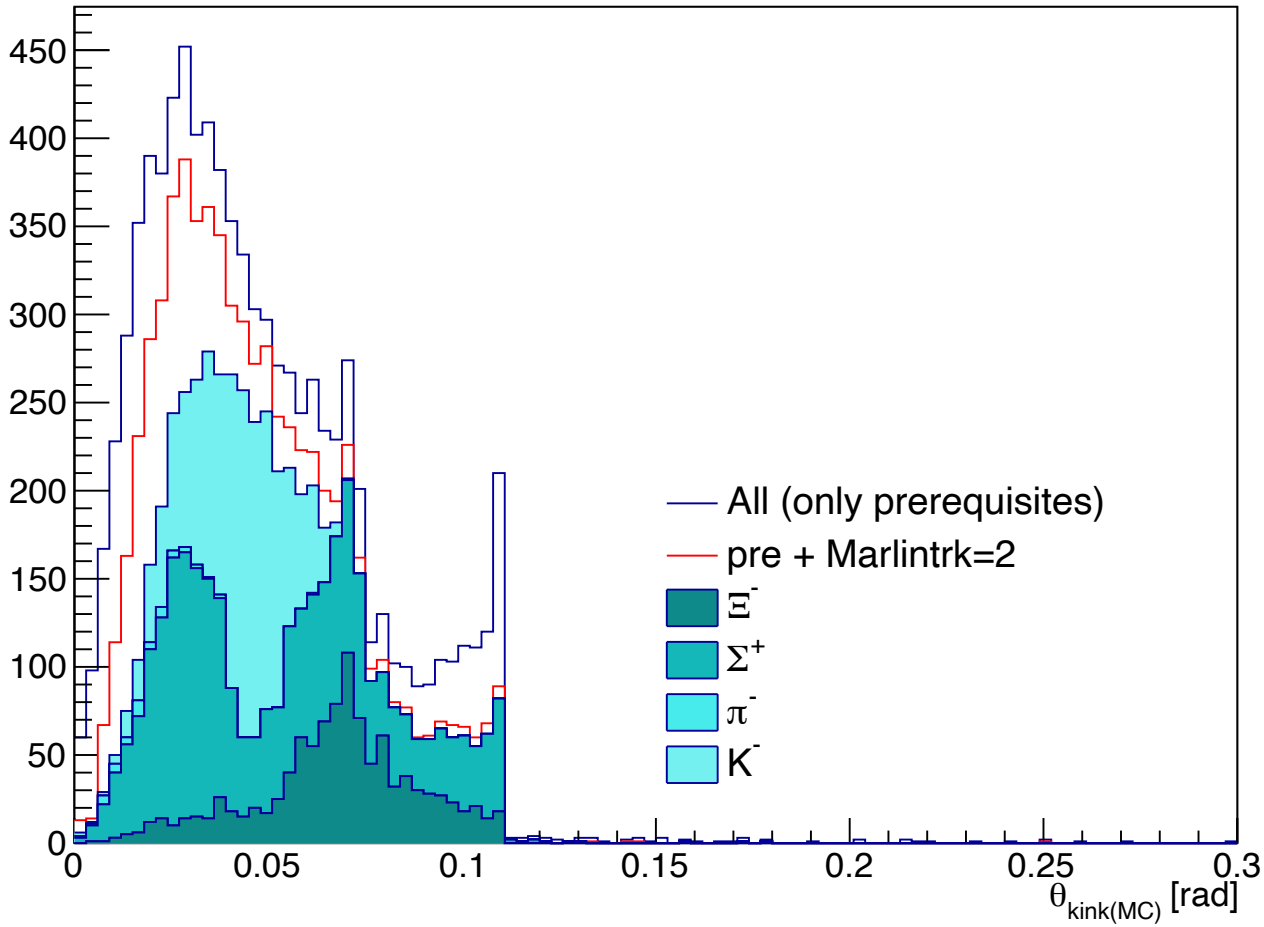


Kink angle on each pdgs - KinkFinder

Prerequisites made from **MCparticles**

- Endpoint(MC) inside TPC: $329 + 100 < r < 1770 - 100\,[\mathrm{mm}]$ $|z_{max}| < 2350 - 250[\mathrm{mm}]$
- (MC) # of charged daughter of Kaon = 1

- Each pdg plots are imposed Marlintrk = 2 and reconstructed kink exists

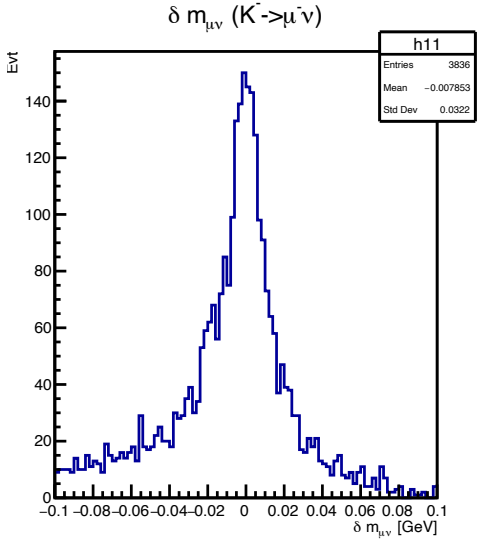


In Kaon samples, many kinks are misidentified

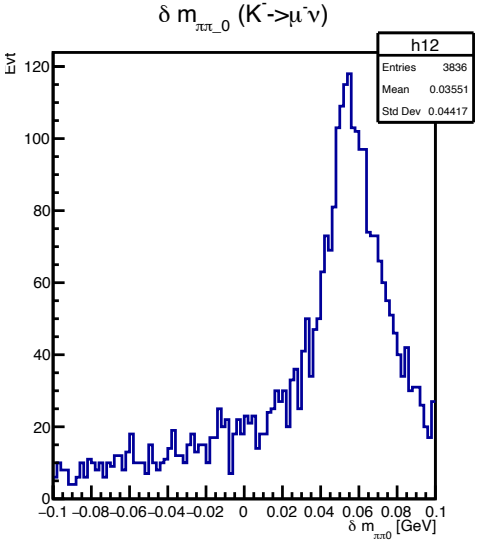
KinkFinder vs New - δm distribution (Kaon)

decay mode:

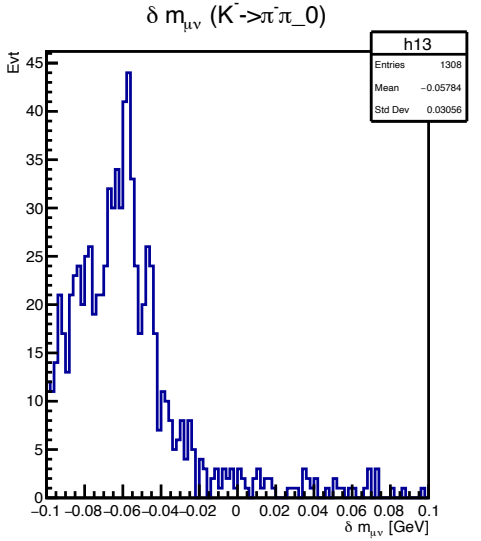
True



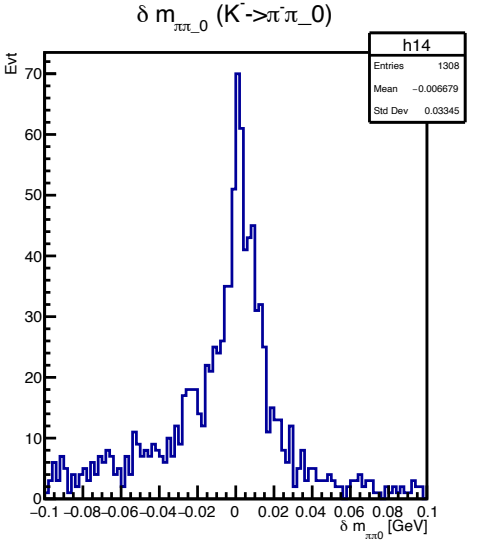
False

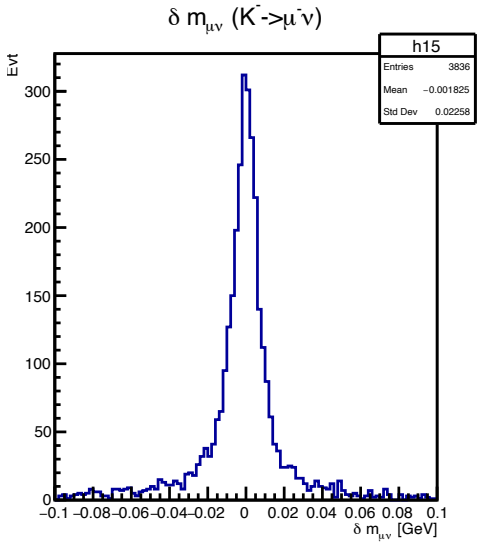


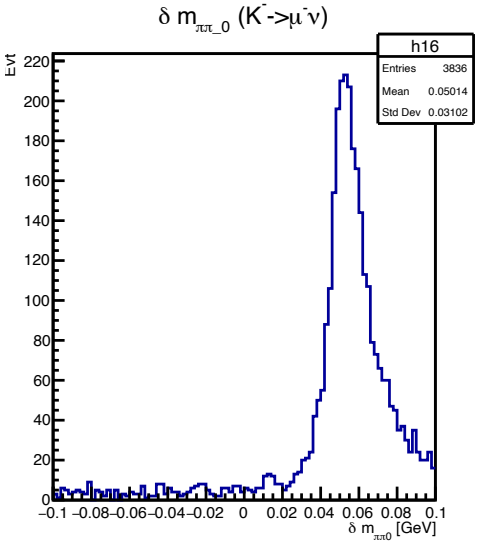
False

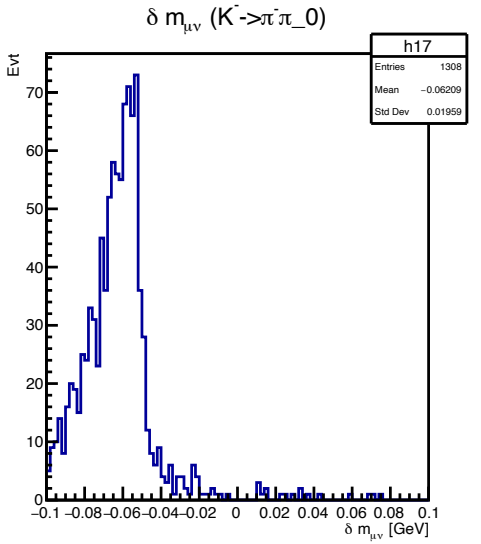


True









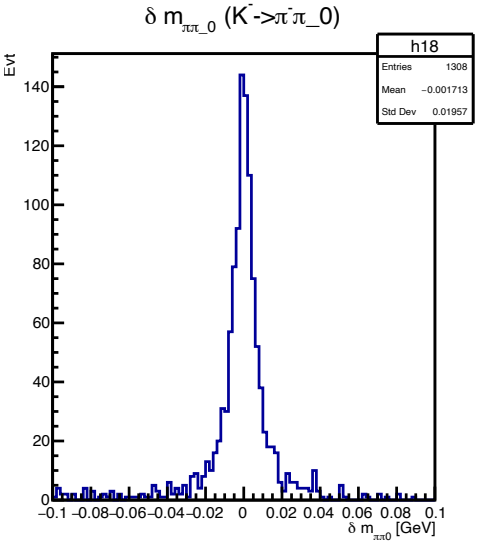


Table: sigma by RMS 90 - New

	Sigma	Error of sigma
K-> munu	0.012136338	0.00015802845
K->pipi0	0.0088005273	0.00019342986
Pi->munu	0.0057965286	0.00019430008
Si->pin	0.0093852586	4.3146168E-05
Xi->pilamda	0.0078814737	3.9757787E-05