# TWIST Data analysis techniques

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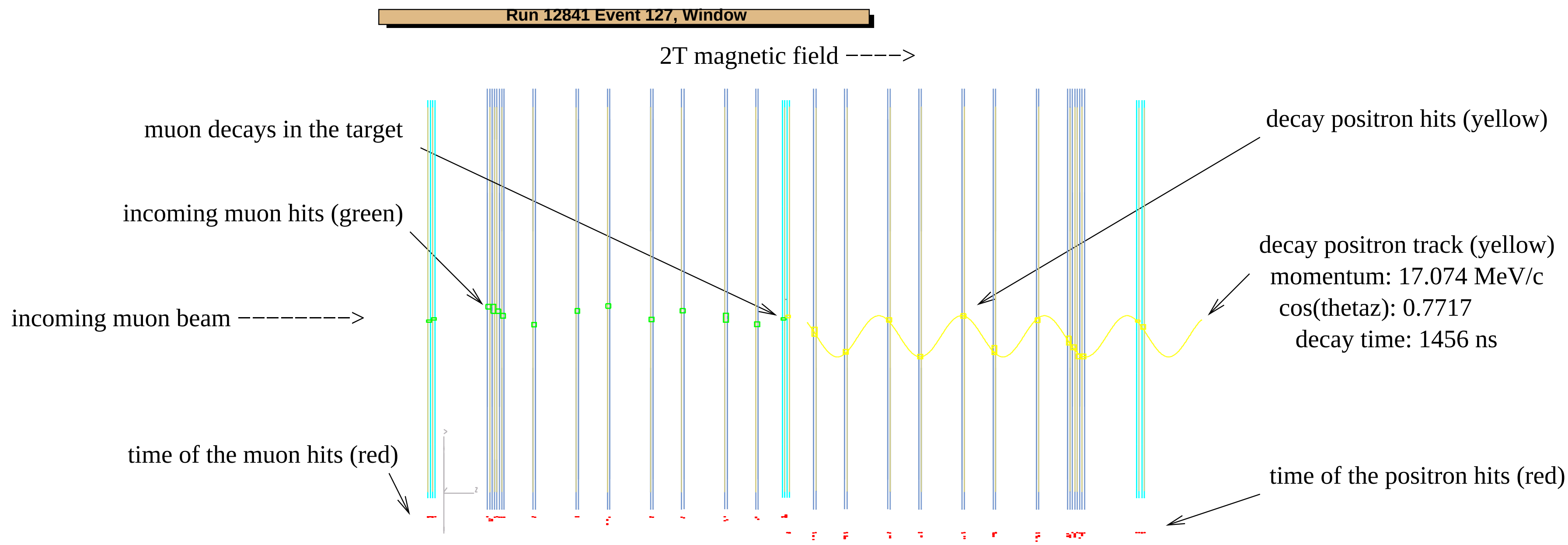
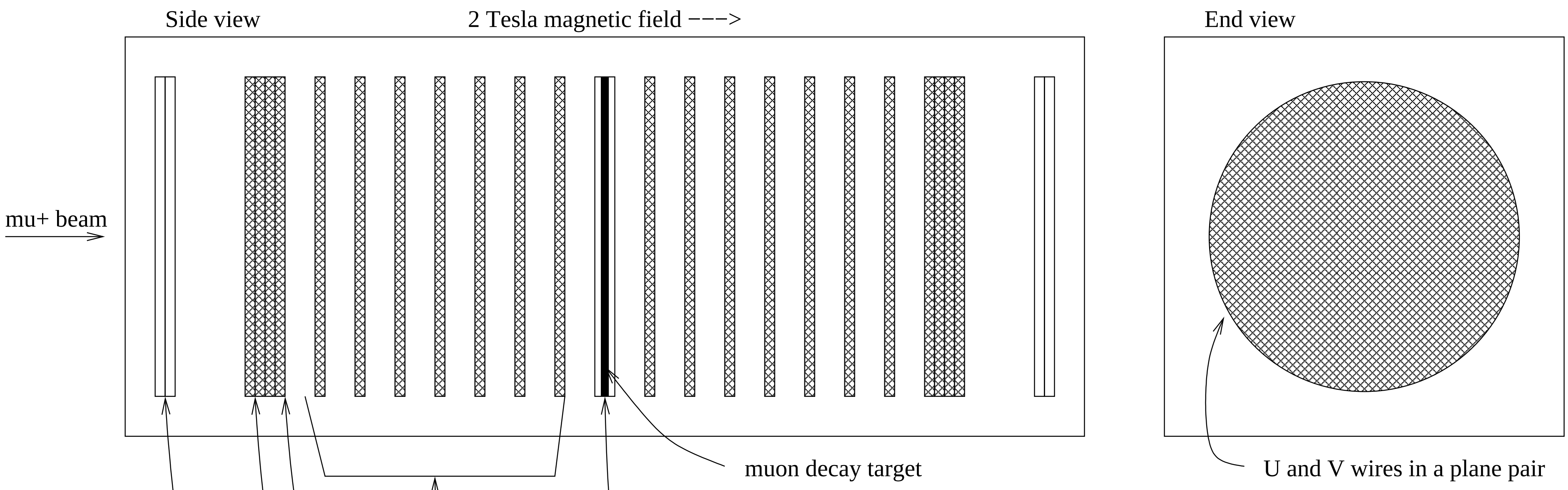



Plan:

- Above: typical muon decay event
- describe TWIST detector
- discuss TWIST event reconstruction:
- pattern recognition
- wire−centers track fitting with narrow−windows and kinks
- drift−time track fitting with kinks
- energy scale calibrations and energy loss correction
- extraction of Michel parameters
- estimation of systematic errors
- how it is all done on the WestGrid/UBC 1000−CPU Linux cluster

# Tracking components of the TWIST spectrometer

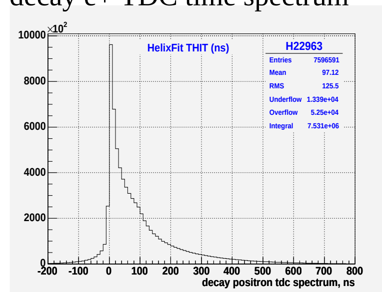



| Component | Chamber type | Wires | Spacing | Patrec | Fit |
|---|---|---|---|---|---|
| target PCs | 2 PC pairs each | 48 | 0.2 cm | yes | no |
| US and DS sparse stacks | 7 DC pairs each | 80 | 0.4 cm | yes | yes |
| US and DS dense stacks | 1 DC pair each | 80 | 0.4 cm | yes | yes |
| US and DS dense stacks | 3 DC pairs each | 48 | 0.4 cm | yes | yes |
| instrumented all dense stack wires (Fall 2003) | | 80 | 0.4 cm | yes | yes |
| US and DS PCs | 2 PC pairs each | 160 | 0.2 cm | yes | no |

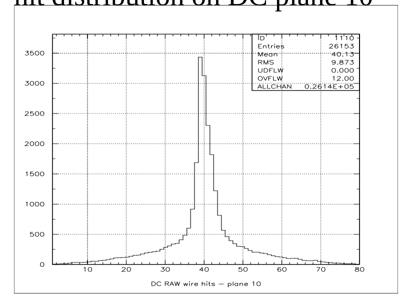
# Track reconstruction sequence

- start with raw TDC hits
- remove cross talk hits
- resolve mu+ and e+ hits in time
- assemble U and V hits into 3D clusters
- particle ID using ADCs and plane multiplicities
- find tracks, resolve charge, helix period
- "narrow windows" wire−centers fit with kinks
- resolve L−R ambiguities, measure decay time
- final drift fit with kinks

decay e+ TDC time spectrum

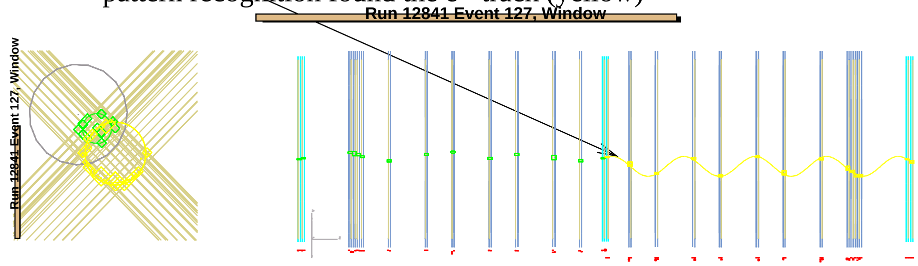



hit distribution on DC plane 10




3D clusters for mu+ hits (green) and e+ hits (yellow)


pattern recognition found the e+ track (yellow)




Six track fit parameters: decay time, helix center u and v, radius (pt), 1/period (1/pl) and mean phase

Main methods used:
- Gauss−Newton method for non−linear Least−Squares (Numerical Recipes)
- wire−centers reconstruction using "narrow windows" (F.James, CERN, 1982)
- "kink method" for handling multiple scattering (G.Lutz, NIMA, 1988)

# The Gauss−Newton method for non−linear least squares and the kink method

$$(chi)^2 = \sum \frac{(trk(par) - hit)^2}{\sigma^2} \xrightarrow[par]{} \min$$

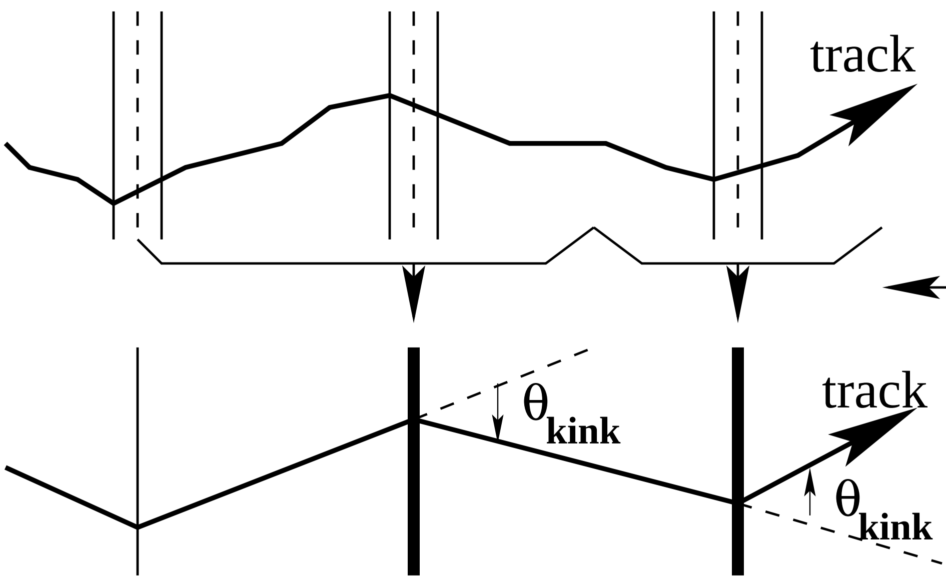
Linearize: **trk(par(n+1)) = trk(par(n)) + dtrk/dpar*(par(n+1)−par(n))**

gradients are computed numerically

Iterate: **par(0) = from pattern recognition**

**par(n+1) = par(n) + A*(trk(par(n)−hits))**

Account for scattering by adding kinks (G. Lutz, NIMA, 1988):




"kink method" approximation:
mass is concentrated
in "scattering" planes

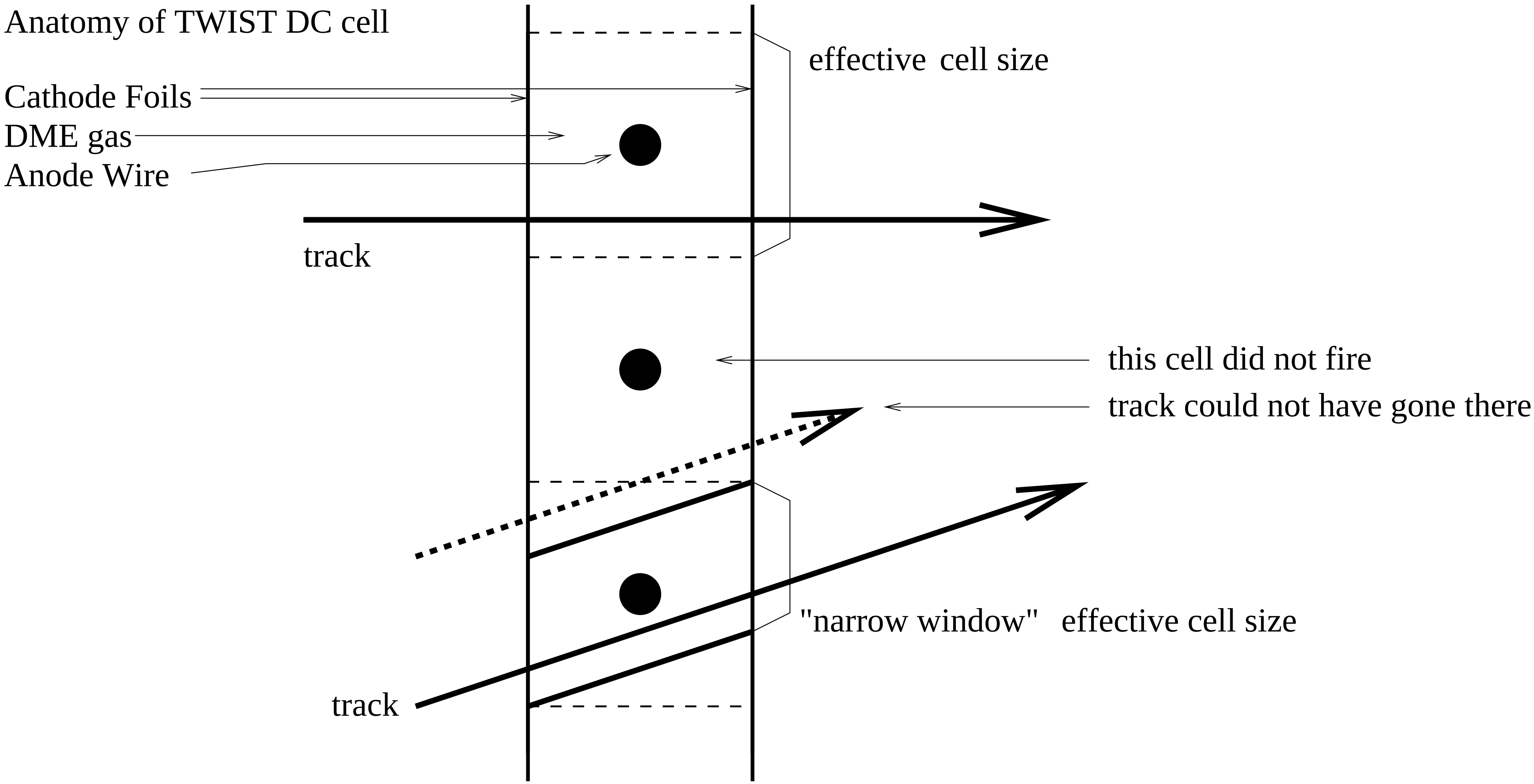
$$(chi)^2_i = \sum \frac{res^2}{\sigma^2} + \sum \frac{\theta^2_{kink}}{\sigma^2_{kink}}$$

expected average kink angles
are computed using PDG formulas

# Narrow−windows method for wire−centers reconstruction (F.James, CERN, 1982)

$$(\mathrm{chi})_i^2 = \sum \frac{\mathrm{res}^2}{\sigma^2}$$

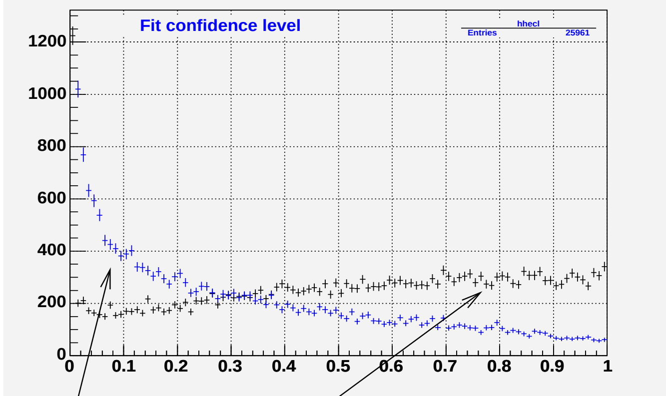
$\sigma$ ← (effective cell width)/sqrt(12)

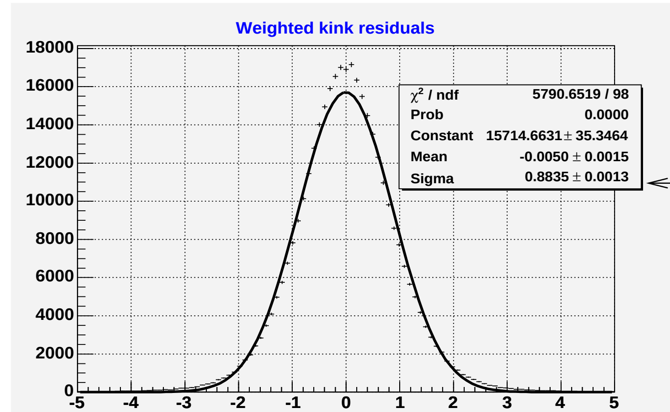


# Using the "kink" method to handle multiple scattering

## Kinks in wire−centers fits of geant3 data

Confidence levels of wire−centers fits



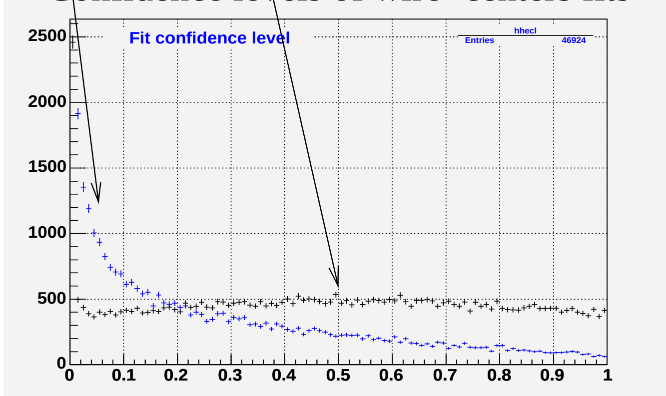



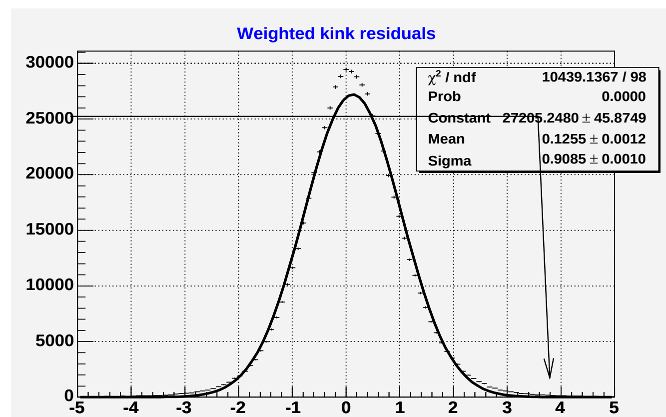

kink angle/kink weight (rad/rad)

CL without kinks     CL with kinks     width is close to 1

## Kinks in wire−centers fits of run 8168 data

Confidence levels of wire−centers fits

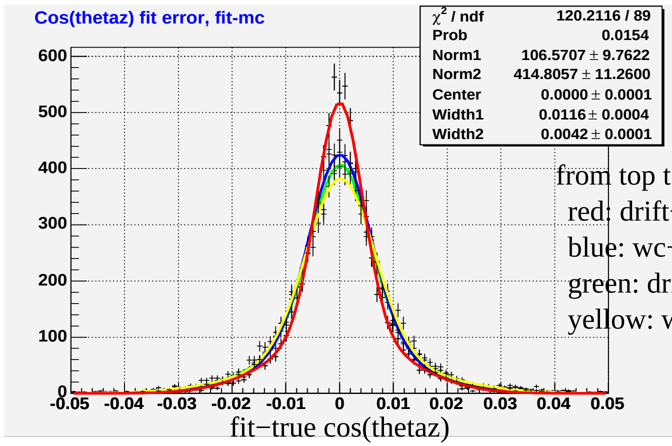



kink angle/kink weight (rad/rad)

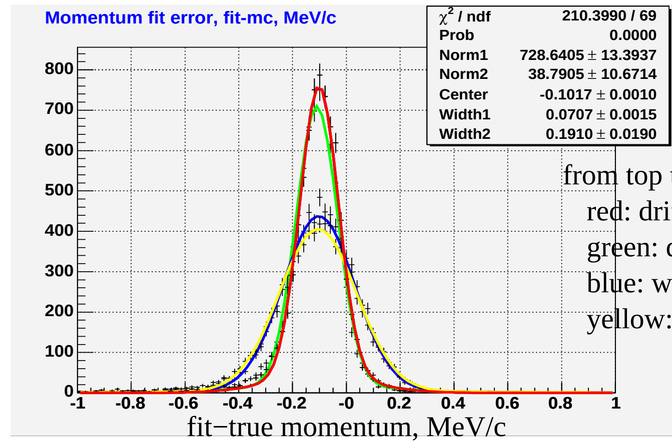
# Resolution of helix fits

## cos(thetaz) resolution



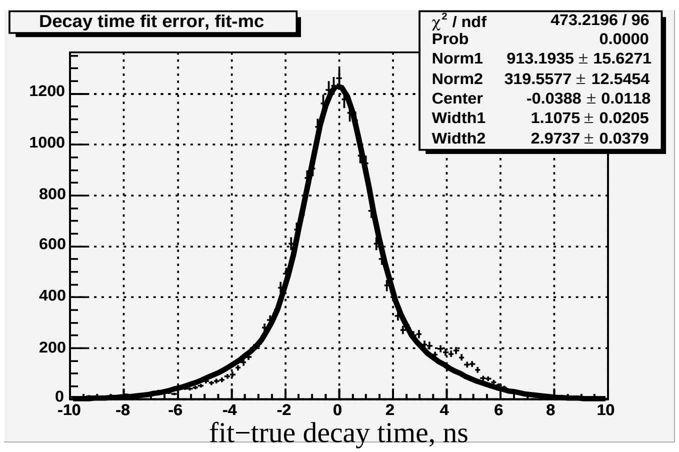

from top to bottom:
- red: drift+kinks
- blue: wc+kinks
- green: drift, no kinks
- yellow: wc, no kinks

## Momentum resolution




from top to bottom
- red: drift+kinks
- green: drift, no kinks
- blue: wc + kinks
- yellow: wc, no kinks

## Decay time resolution




## Resolution of drift fits with kinks:

− cos(thetaz): 0.0057 (includes scattering in the target)

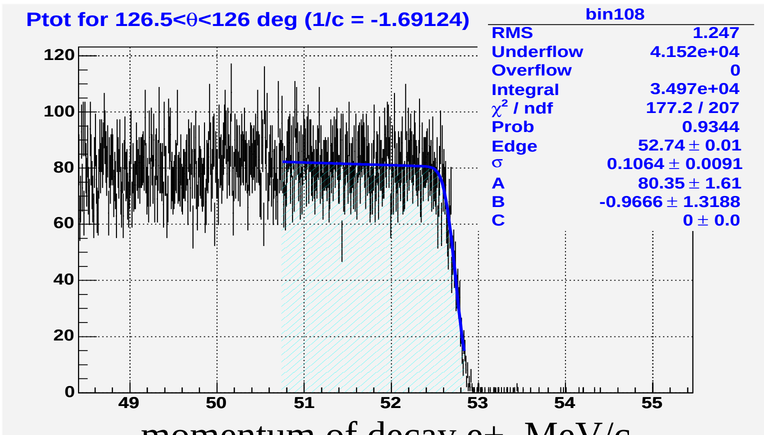
− momentum: 0.077 MeV/c

− shift in momentum is due to energy loss corrected later by energy scale calibration

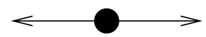
− decay time: 1.5 ns

# Calibration and correction of energy scale and energy loss.

## Kinematic edge of Michel spectrum

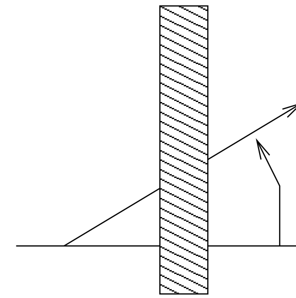



momentum of decay e+, MeV/c




max E(e+) = M(mu+)/2

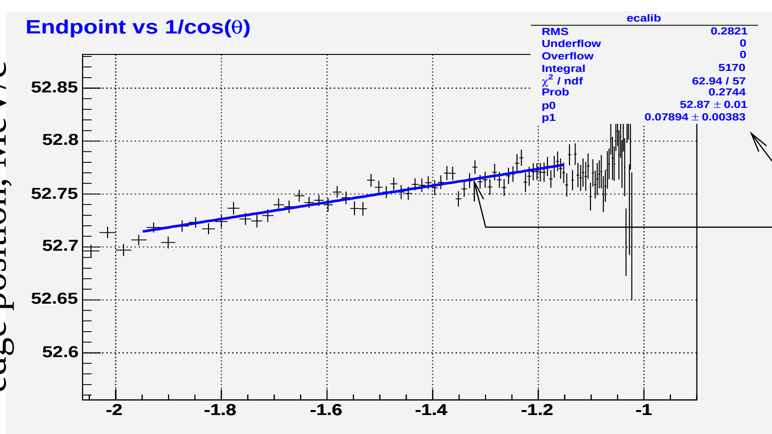
## Energy Loss




Ploss=Eloss=alpha/cos(theta)

## Measured edge as function of 1/cos(theta)

edge position, MeV/c




1/cos(theta), upstream

## Calibration and correction:

Model:

Pmeasured = Ptrue * B/Btrue − Ploss

At edge:

Pedge = PtrueEdge * B/Btrue − alpha/cos(theta)

straight−line fit yelds B/Btrue and alpha

Energy scale and energy loss correction:

Pcorrected = Pmeasured * Btrue/B + alpha/cos(theta)

# Extraction of Michel parameters

**T(p,cost,rho,eta,...) = A(p)*rho + B(p)*eta + C(p,cost)*Pmu*xi + D(p,cost)*Pmu*xi*delta**

theoretical spectrum of decay e+ is linear in Michel parameters

"derivative" coefficient is computed numerically

**E(p,cost) = F(T(p,cost,rho,eta,...)) = F(T_blind) + dF/dRho*delta_rho + ...**

= rho−rho_blind

measured experimental spectrum

secret "blind" reference spectrum

detector response function is linear in Michel parameters

fit delta_rho, delta_eta, ... to match E() and F(T)

Above linear expansion yelds delta_rho, delta_eta, ... as linear function of E(), F(T_blind), dF/dRho, ...

Blinding:

1) use secret T_blind(rho_blind,...) with Michel parameters offset from Standard Model values

2) measure delta_rho, delta_eta, ... as above

3) "open the box", compute and publish: rho = rho_blind + delta_rho, ...

# Estimation of systematic errors on Michel parameters

**E(p,cost) = F(T(p,cost,rho,eta,...))**

experimental spectrum

theoretical spectrum

how well do we need to know the detector response function?

how well do we need to know the experimental spectrum? (i.e. variations between data runs)

Quantify the uncertainty in E() and F() in terms of variations in (blinded) Michel parameters (delta_rho, ...)

1) compare data with simulations (what is the variation between data sets?)

E = E(T_blind) + dF/dRho*delta_rho + ... −−−> rho_true = rho_blind + delta_rho, ...

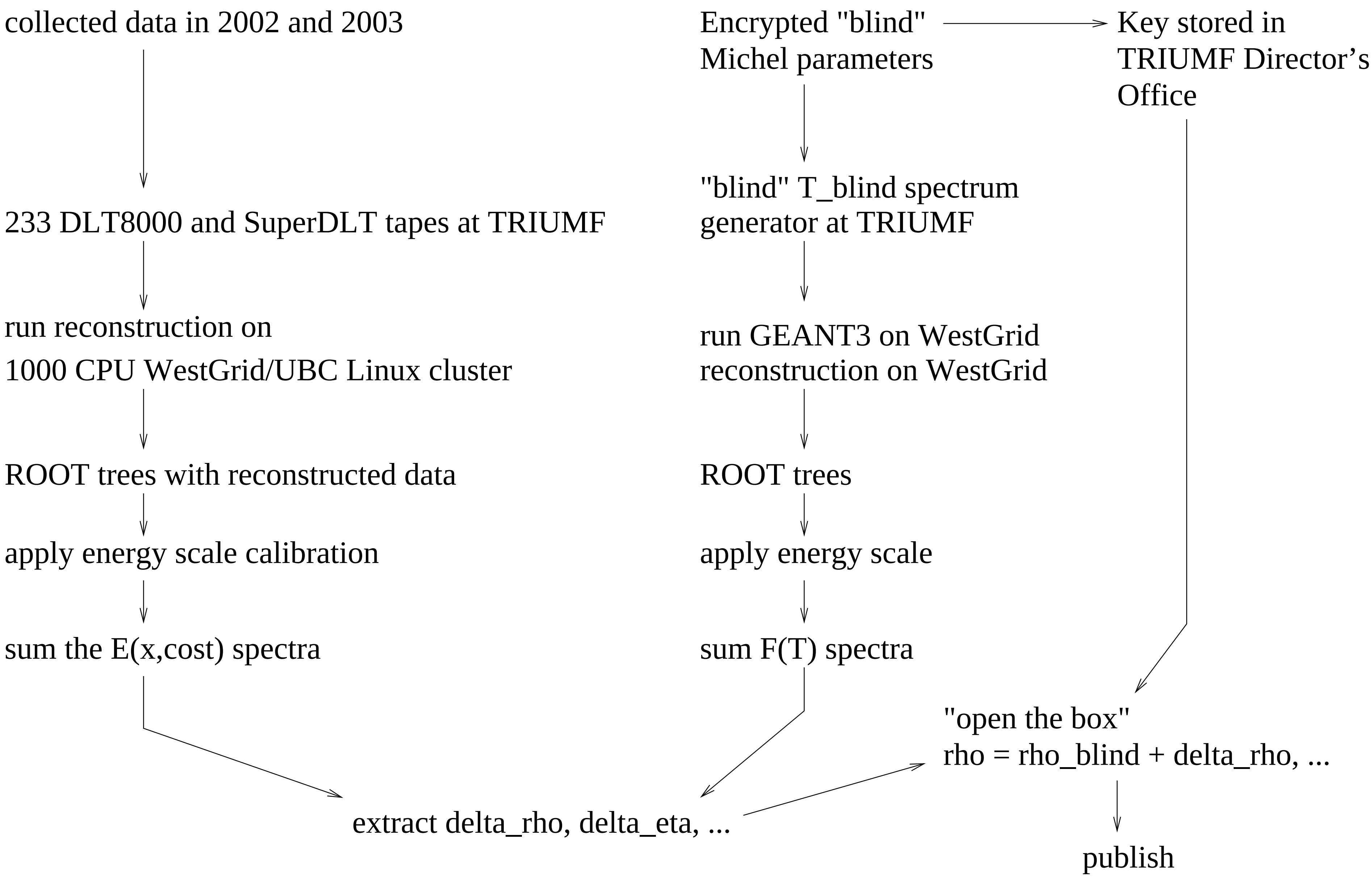
2) compare data with data (E1, E2) (e.g. measure effect of changing beam rates)

E1 = E2 + dF/dRho*delta_rho + ... −−−> delta_rho = systematic error due to difference between E1 and E2

3) compare MC with MC (F1, F2) (e.g. shadow the data−to−data comparisons for MC verification)

F1(T_blind) = F2(T_blind) + dF/dRho*delta_rho + ... −−−> delta_rho = systematic error

# Data processing on WestGrid



# Summary

− have excellent detector− high precision construction, 100% efficient, no noise

− have large data set

− developed fast and efficient event reconstruction program by combining several well known methods

− developed and validated GEANT3 based simulation

− developed blinding technique for extracting Michel parameters

− learned how to efficiently use the 1000 CPU WestGrid/UBC Linux cluster

− presently processing data and geant− main data set and systematics data sets