MIND status and plans

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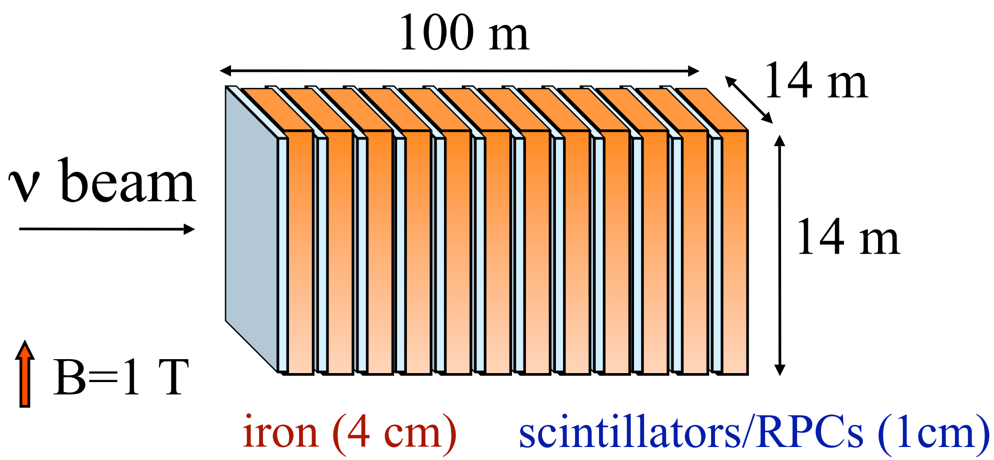
IDS-NF plenary meeting
RAL, 16/01/2008

MIND



M~100 KTon

1cm transverse resolution

- Easy to detect muons in iron by range
- Easy to discriminate against hadron showers
- Easy to magnetise iron

- Based in known technology: ~MINOS
- Can be very massive
- Cost is not prohibitive: 300-400 M$

- cannot detect electrons or taus
- the energy threshold is high

Simulation and reconstruction

Event topology

Assumptions

- Detector effects are not simulated (response of scintillator, PDs and electronics)
- Perfect pattern recognition
- Reconstruction is based on a parameterisation
- Dipole field instead of toroidal field

Energy resolution

Essential to measure the oscillation pattern

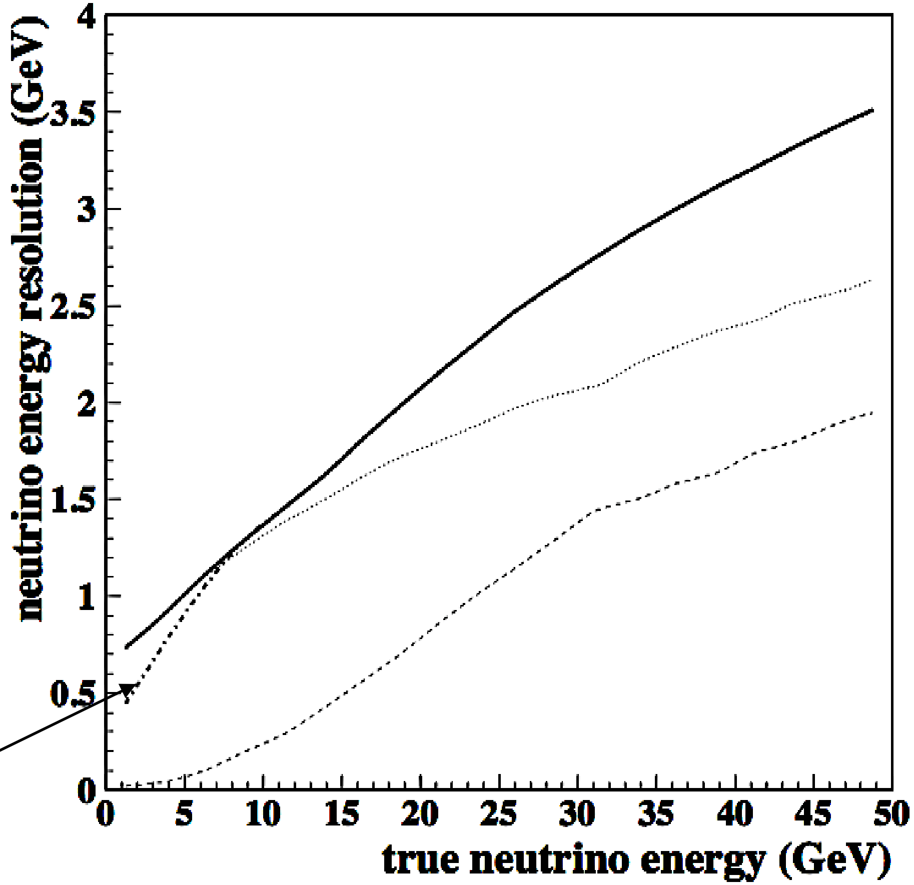
Crucial to solve degeneracies

$$E_\nu^{recon} = E_{had} + E_\mu$$

- Fully contained muons by rage
- Scaping muons by curvature
- Hadron shower:

$$\left(\frac{\delta E}{E}\right)_{had} = \frac{0.55}{\sqrt{E_{had}}}$$

Including QE

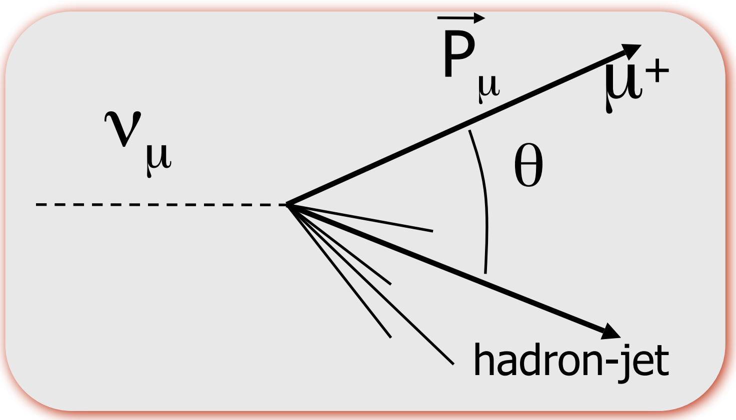


Kinematic cuts

- Soft Combined cut in $E_\nu - P_\mu$ and $E_\nu - Q_t$ planes, for $E_\nu > 7$ GeV
- Kills mostly high energy backgrounds

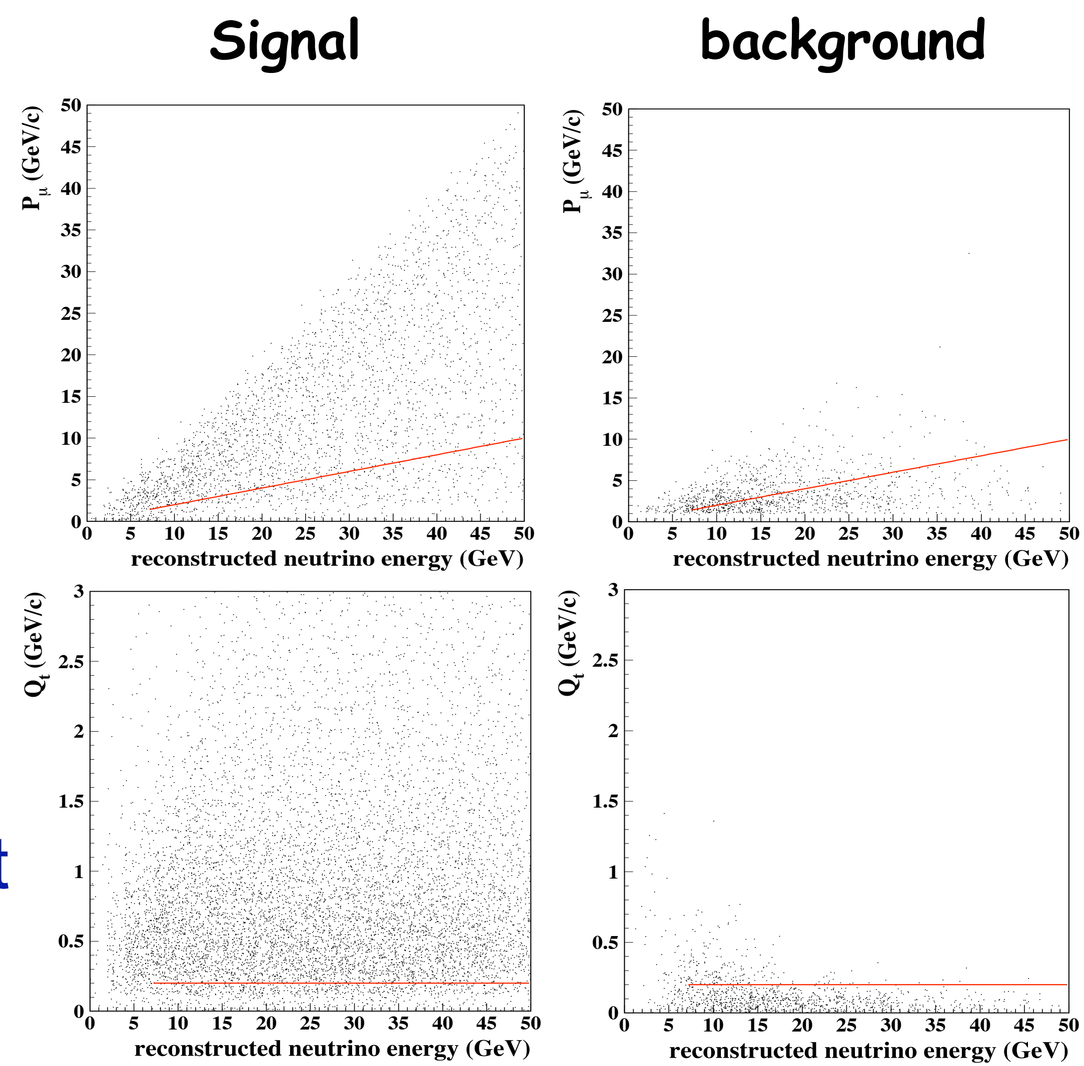
$$P_\mu = |P_\mu|$$

$$Q_t = P_\mu \sin^2\theta$$



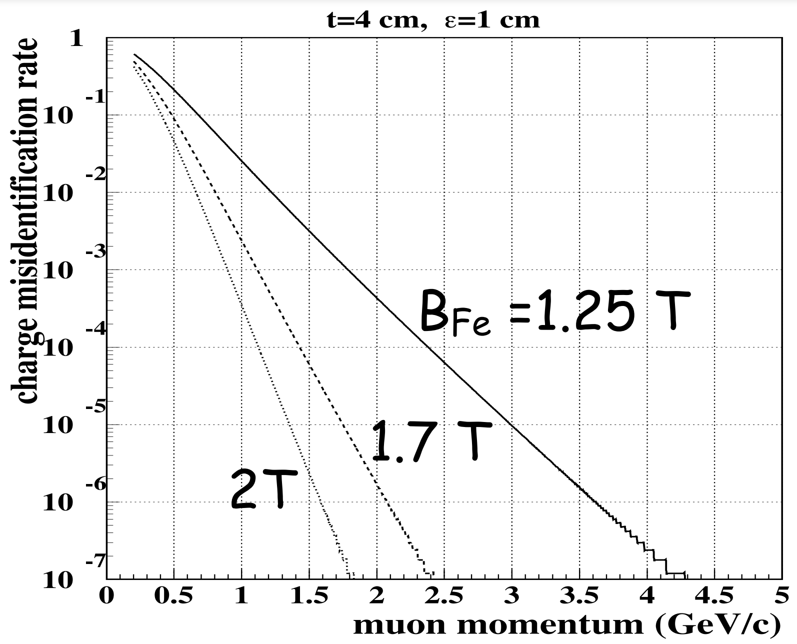
P_μ

Q_t

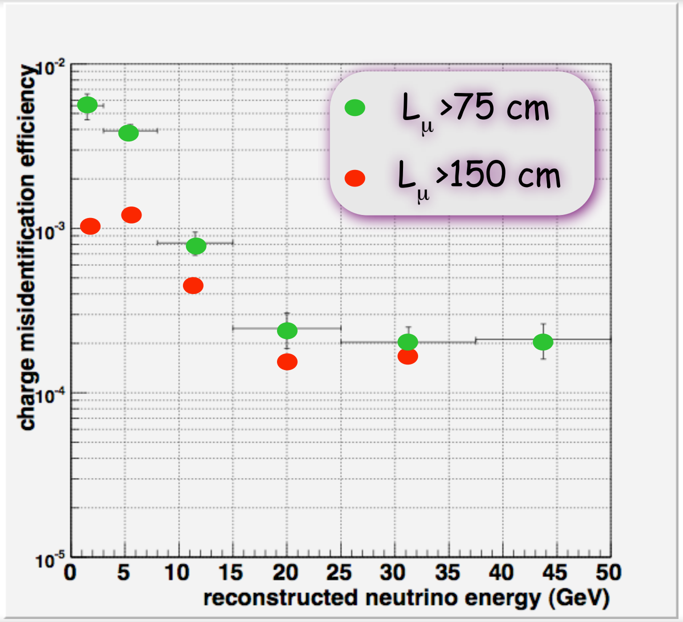


Charge identification

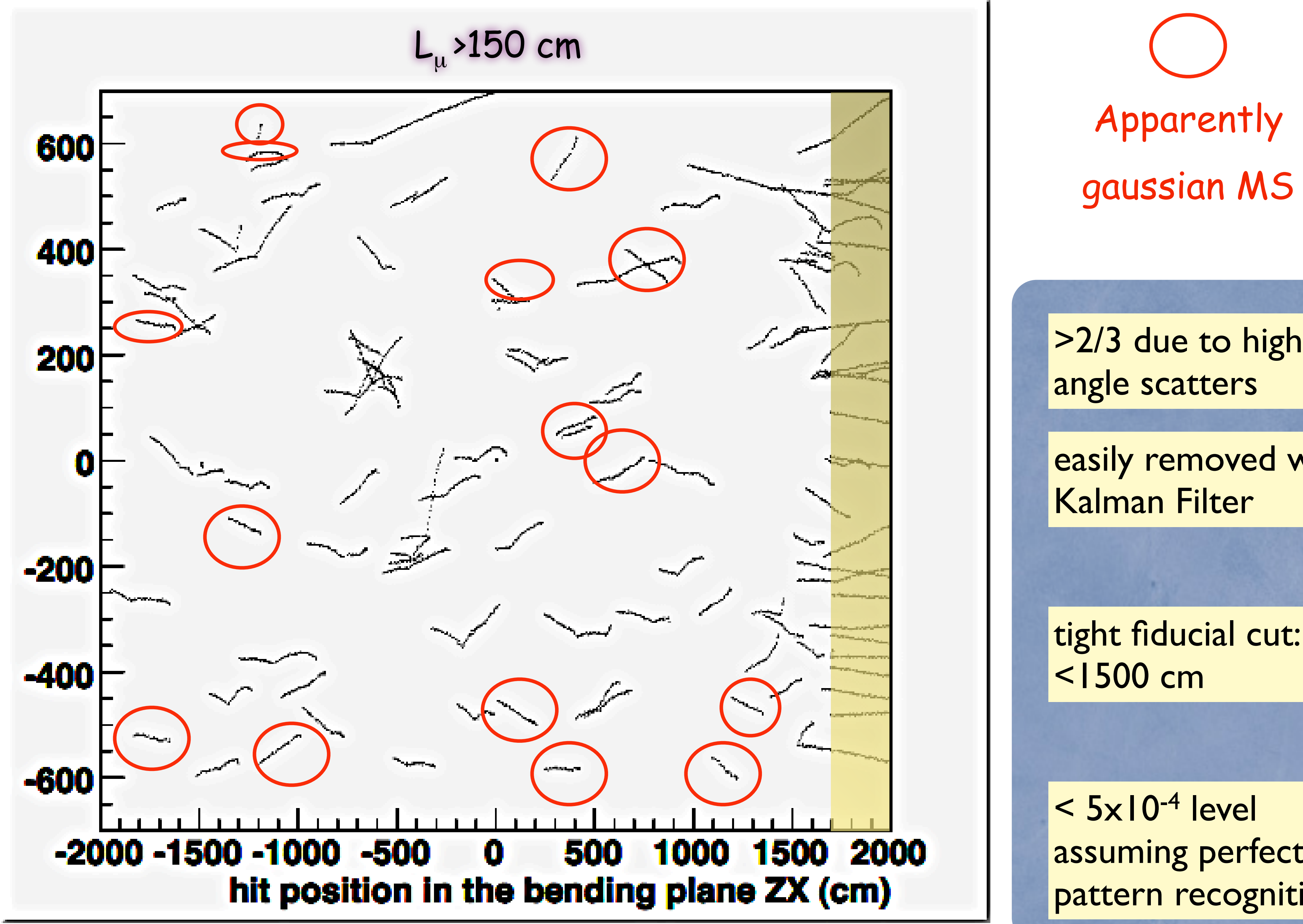
- Simple exercise. Assumptions:
  - No border effects
  - Non-gaussian scatters can be identified via local χ^2 criterion with a Kalman Filter
    - Assume gaussian MS
  - Gluckstern formula + MS term



- Event simulation
  - Realistic flux
  - Non-gaussian MS
  - Border effects
  - LSQ fit



Wrong charge assignments



>2/3 due to high angle scatters

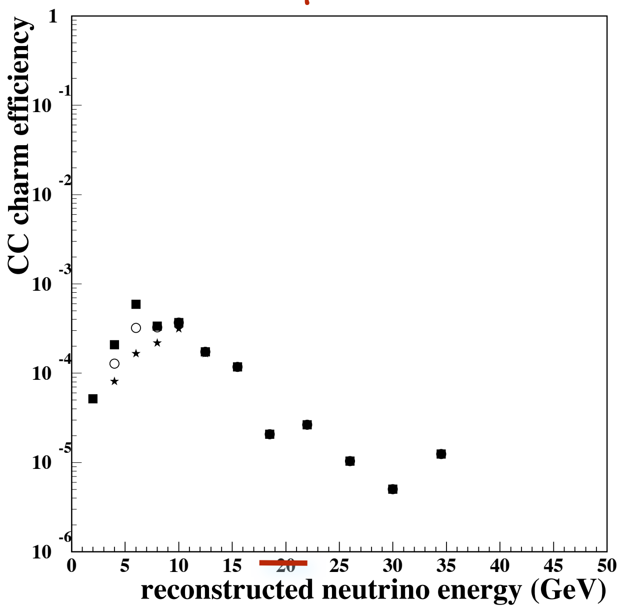
easily removed with Kalman Filter

tight fiducial cut: <1500 cm

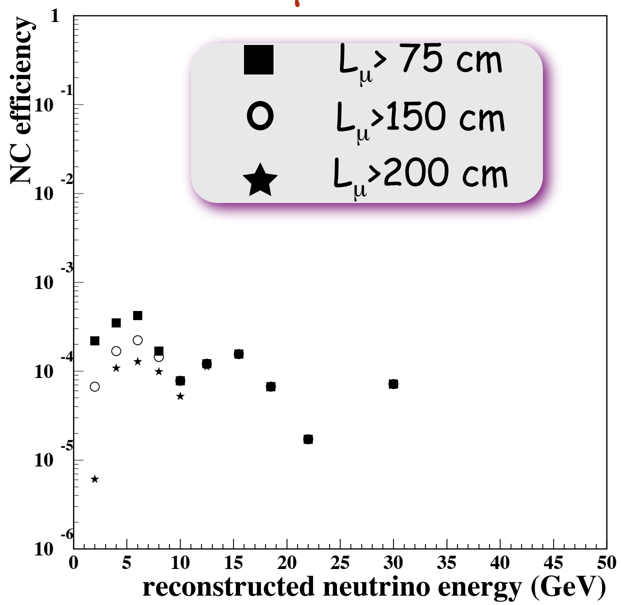
< 5×10^{-4} level assuming perfect pattern recognition

Backgrounds

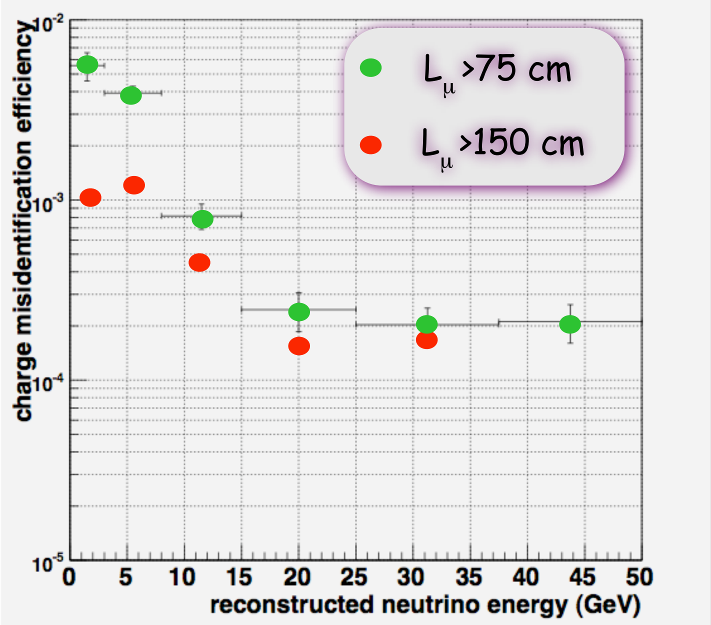
ν_μCC



$\bar{\nu}_\mu$NC



Charge mid-ID



Simulation

Charm x-section ?

non-Gaussian MS

non-DIS events

Showering profiles

Reconstruction

Muon/hadron separation

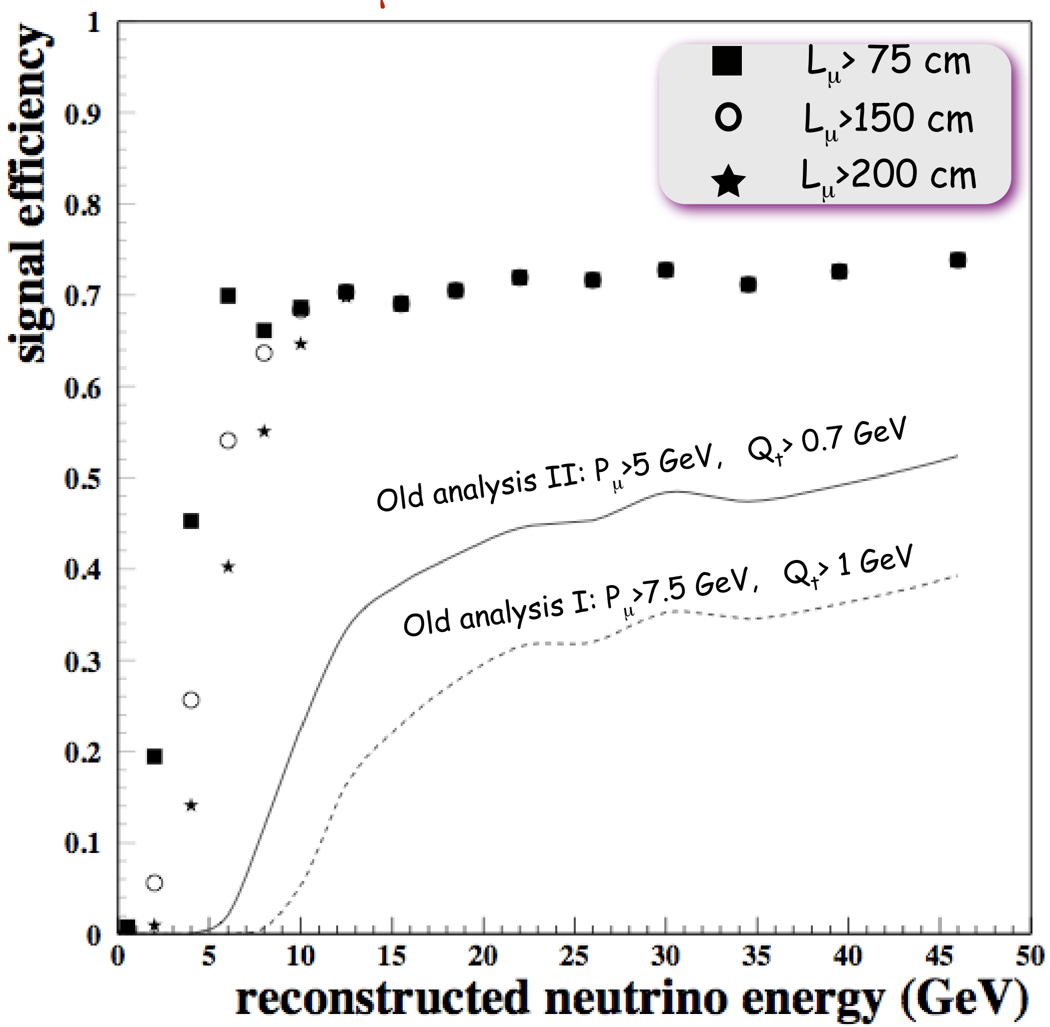
Muon hit finding

Signal efficiency

- Efficiency plateau between 5 and 8 GeV depending on L_μ^{cut}

- baseline: L_μ > 150 cm
- Ensures charge mis-ID below 10^{-3}

ν_μCC signal



Aims of full simulation/reconstruction

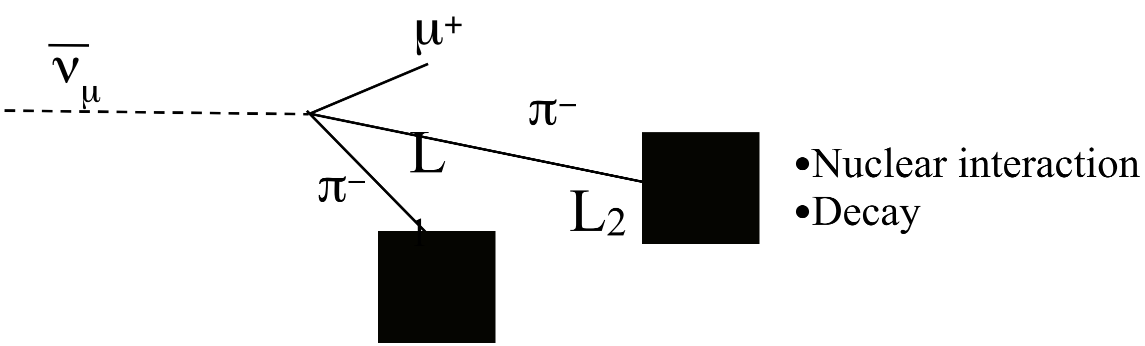
- Demonstrate that for $E_\nu < 10$ GeV
  - Backgrounds are below 10^{-3}
  - The efficiency can be increased with respect to fast analysis
- Compute:
  - Signal and backgrounds efficiency as a function of energy
  - Energy resolution as a function of energy
- Identify crucial parameters to be optimised to maximise the sensitivity to the osc. parameters

- Optimise segmentation and B field based on the above parameters and taking into account feasibility and cost

Hadron shower

Fast analysis

- Hadrons are stopped when they decay or undergo a nuclear interaction
- We then record their energy and momenta: $p_1, p_2, \ldots, E_1, E_2, \ldots$
- Their length is also recorded: $L_1, L_2, \ldots$



$$E_{had} = \sum_i E_i$$

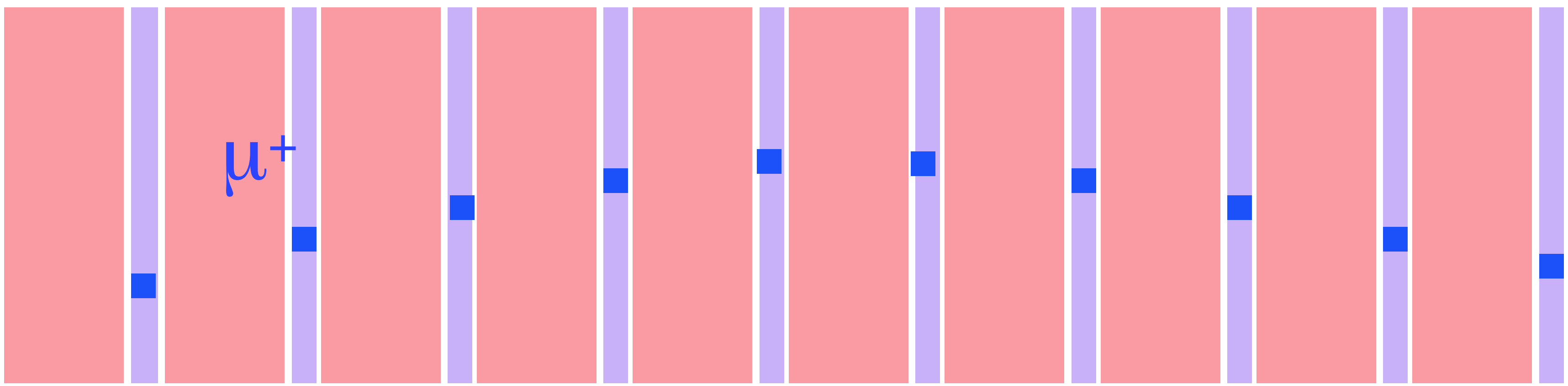
$$\vec{P}_{had} = \sum_i \vec{p}_i$$

The hadron shower energy and angle are smeared according to MINOS proposal + MINOS CalDet + Monolith testbeam

Muon

Fast analysis

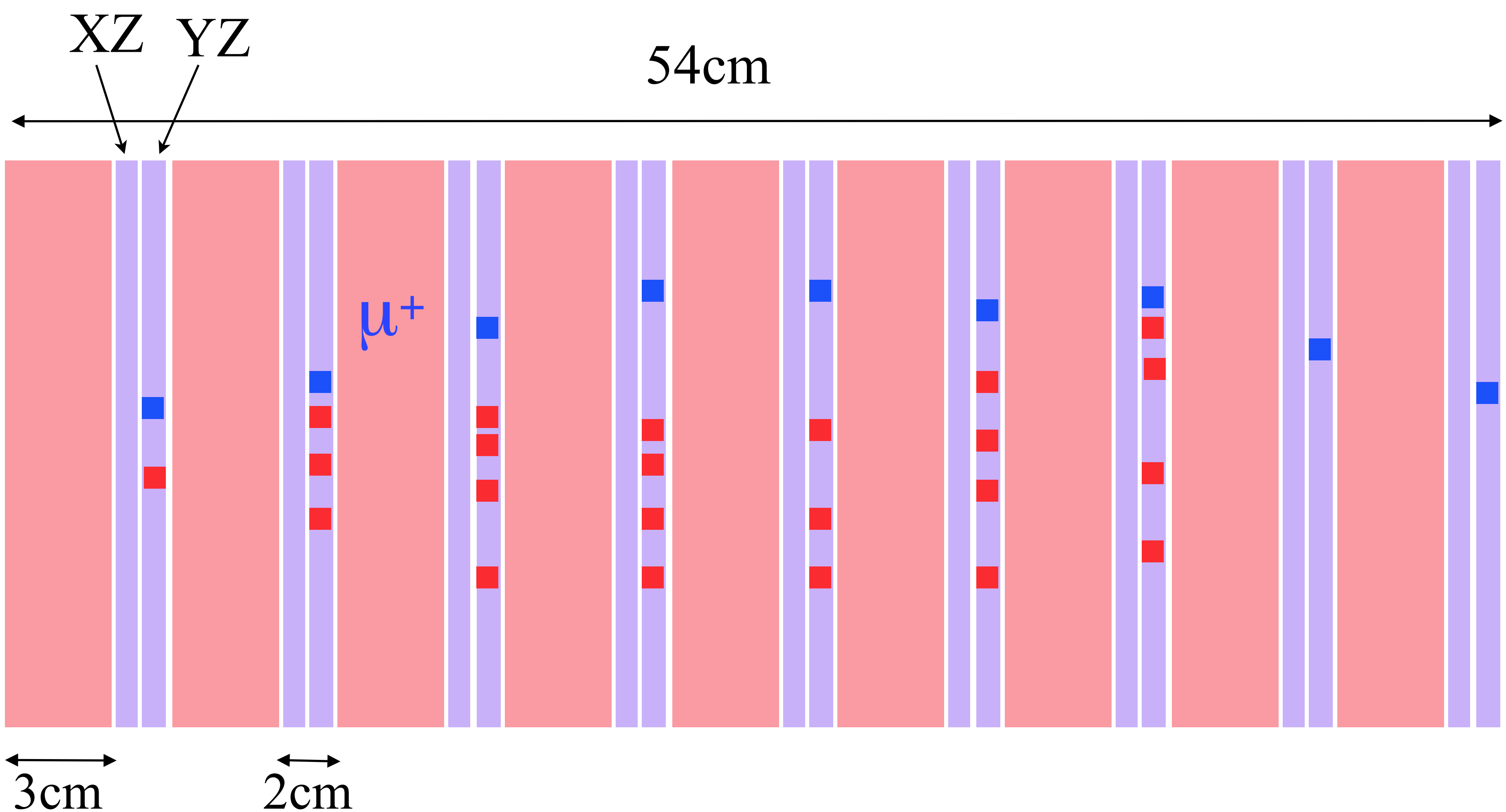
- Muon is followed until it stops, decays or escapes the detector
- The position of all hits is recorded
- And also its 3-momentum



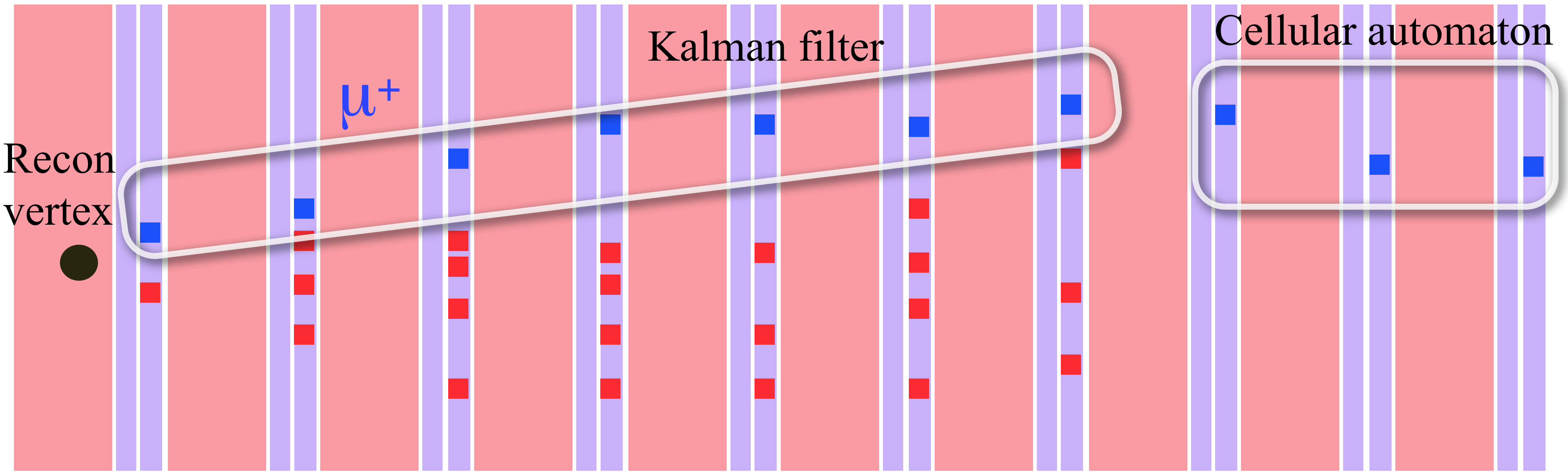
- Muon hits are smeared with 1cm transverse resolution
- A track fit gives its charge
- For the kinematical analysis the muon momentum is smeared according to Gluckstern formula + MS term

In real life

- The muon is not isolated: pattern recognition
- 2 independent views XZ and YZ that should be matched
- The event sense can be computed from timing (?)



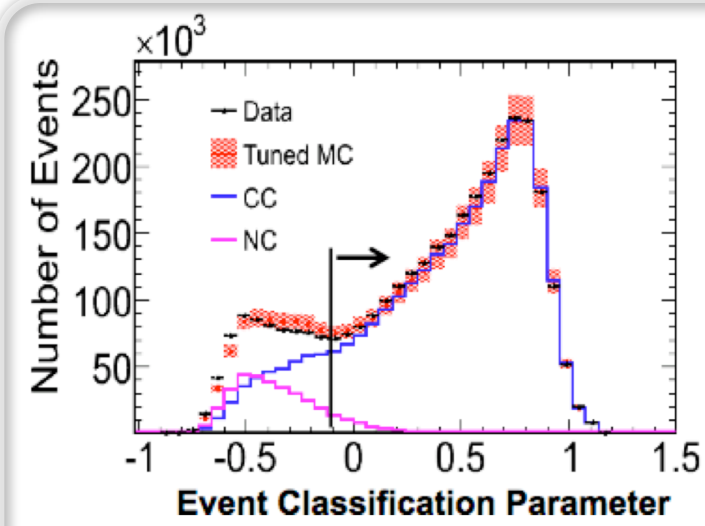
Muon reconstruction



1. Reconstruct the vertex from event topology
2. Cellular automaton or Hough transform for planes with small activity
3. Match X and Y views in planes with small activity
4. Find approximate muon parameters based on these planes and vertex
5. Incremental Kalman Filter from the end of the track towards vertex
   - Multiple scattering, energy loss and B field map

Steps

1. Likelihood method (à la MINOS) to discriminate between ν_μ CC and NC, a la MINOS, maximising the purity of NC
   - Cut should depend on neutrino energy

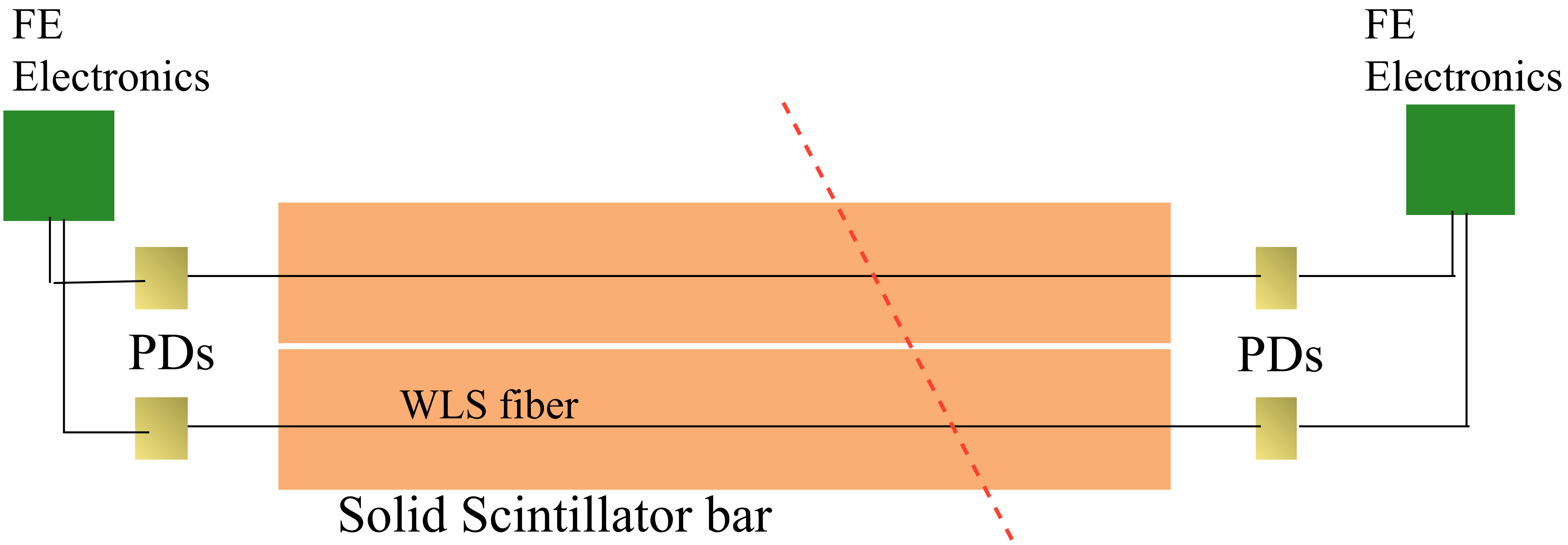


- Event length
- Track pulse height
- pulse-height/plane

2. If NC → reject
3. If ν_μ CC:
   A. Muon reconstruction based on previous method
   B. if μ^+ or kink → reject
   C. if μ^- with no kink
      - reconstruct hadron shower
      - compute muon momentum and neutrino energy
      - kinematical analysis

Full simulation

- Fully simulate hadron shower and muon
  - Distribution of energy deposition per plane
  - Simulate detector response
    - Attenuation along the scintillator bars (double end readout)
    - Photodetector efficiency, gain and noise
    - Electronic gain and noise



Input from real data

- In a second step:
  - Use MINOS showering profiles to tune the MC

Event generation

- Only DIS interactions as coming from LEPTO has been generated so far
- Including QE and RES should have a big impact at low neutrino energies:
  - No hadron shower:
    - Easy pattern recognition
    - Better neutrino energy resolution
  - Help in improving the threshold energy and reduce backgrounds
- Generators
  - Nuance, Neut, Neugen, Genie

Synergies with TASD

$$\lim_{Fe\to 0} \mathrm{MIND(Fe)} = \mathrm{TASD}$$

- Scintillator bars, PD and electronics are the same. This is the most difficult part
- B field production is different: a minor issue

A common framework for simulation and reconstruction (M. Ellis)

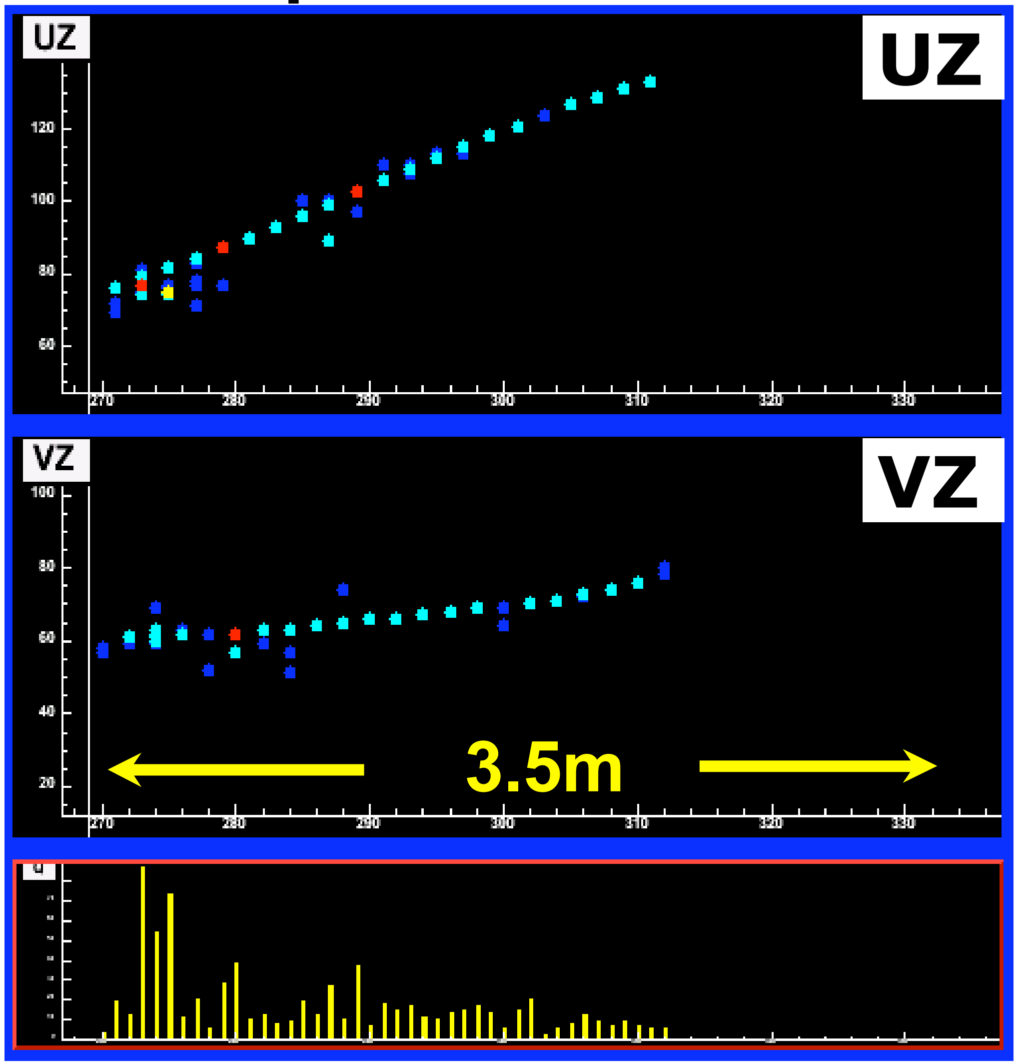
Detector optimisation

Pattern recognition

MINOS

ν_μ CC Event

Monte Carlo

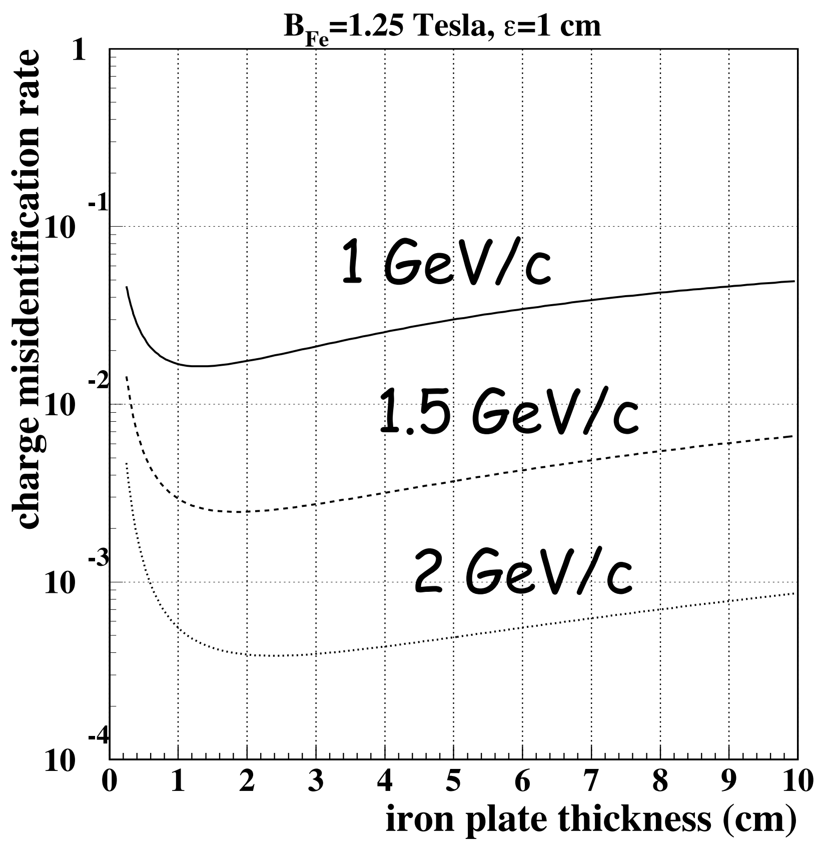


from Z. Pavlovic Talk

long μ track & hadronic activity at vertex

Longitudinal segmentation

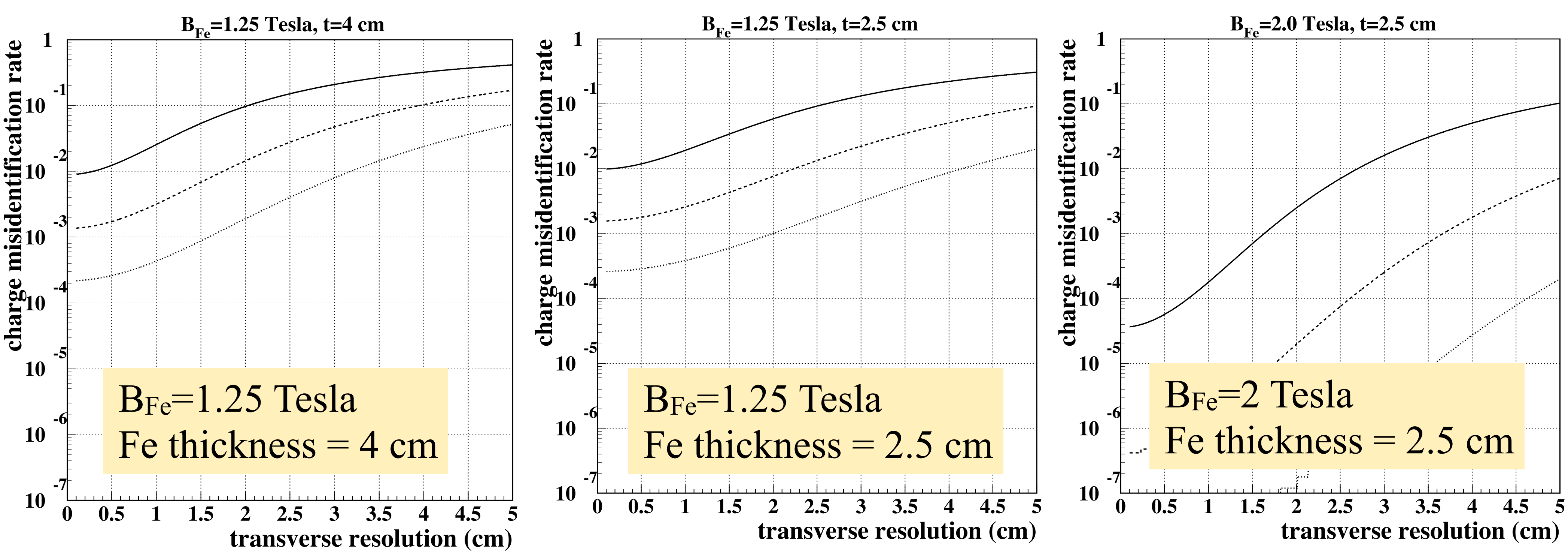
- MINOS should be close to the optimum (2.5 cm iron plates)
- Charge measurement assuming perfect pattern recognition
  - Any iron thickness between 1-5 cm should do the work
  - For very thin plates, (<1 cm) the average B field decreases dramatically and resolution worsens
- Thinner iron plates should improve the pattern recognition
  - less smearing due to MS
- Thicker active plates (or gaps) also favour pattern recognition
  - more separation between hits
- Need full MC simulation to prove that



Transverse segmentation

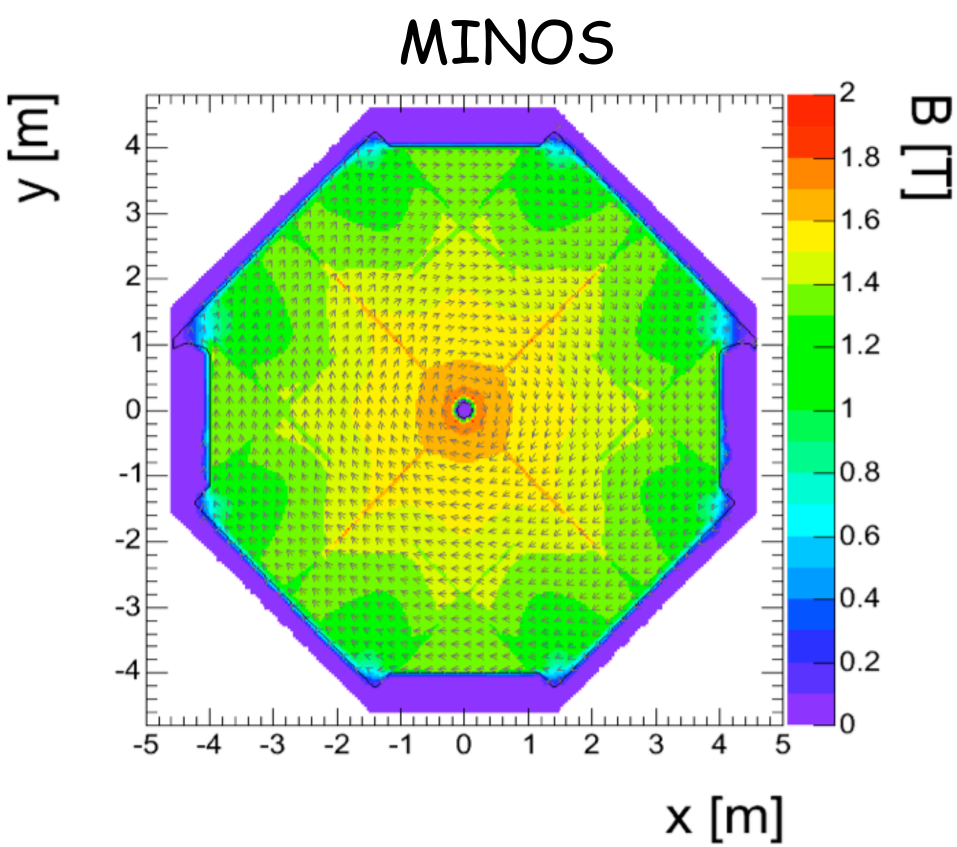
- Assuming perfect pattern recognition 1 cm transverse resolution is enough for charge and Q_t measurements
- Pattern recognition:
  - better segmentation should improve it
  - which resolution saturates the patter recognition performance ?

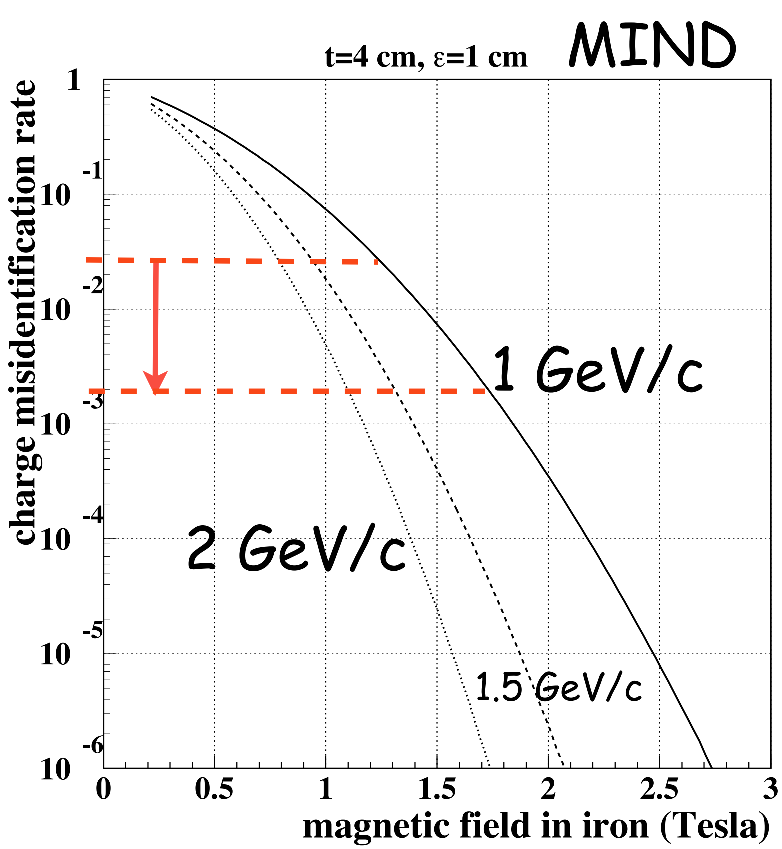
Lines: 1, 1.5 and 2 GeV/c muon momentum



Magnetic field

- Even if we are able to isolate a 1 GeV/c muon, the ratio curvature/MS is not sufficient. ~5% charge mis-ID
- The magnetic field strength is the crucial parameter
  - Going from 1.25 to 1.7 Tesla average is feasible (J. Nelson, Golden07)
  - > 1 o.o.m improvement at 1 GeV/c. 10^{-3} level





Conclusions

- Fast simulation/reconstruction was very useful until now

- But it’s time to move forward with a full simulation/ reconstruction
  - What are the main backgrounds at low energies ?
  - What is the background level ?
  - Where is the efficiency plateau ?
  - What are the parameters to be optimised ?

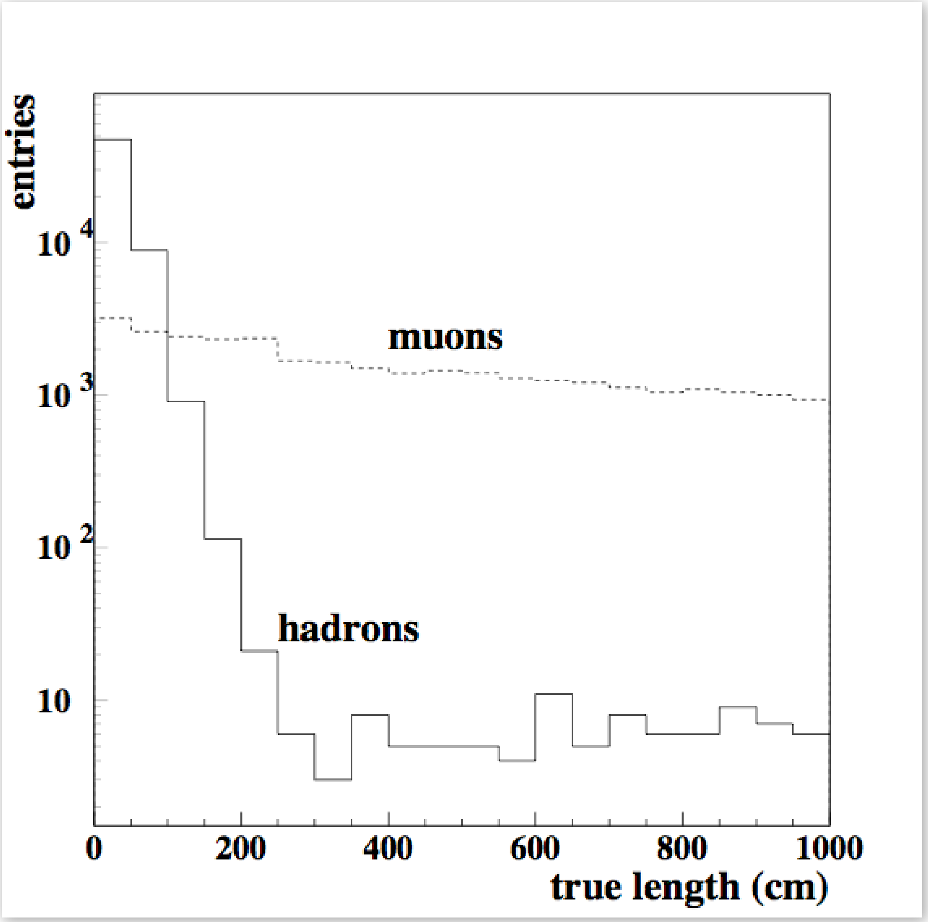
- Prototyping program should go in parallel

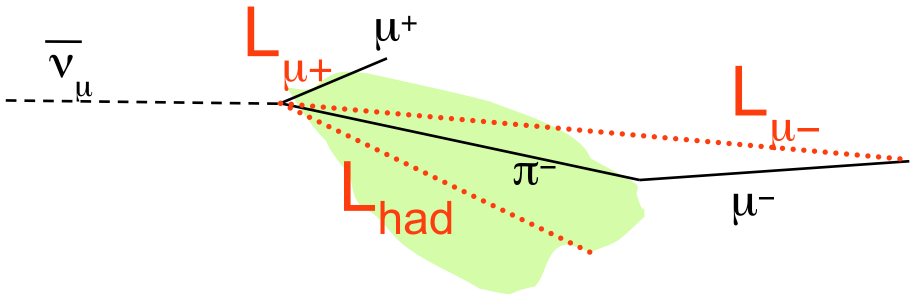
Backup slides

Muon identification

Muons go far beyond the end of the hadron shower

They can be identified by range



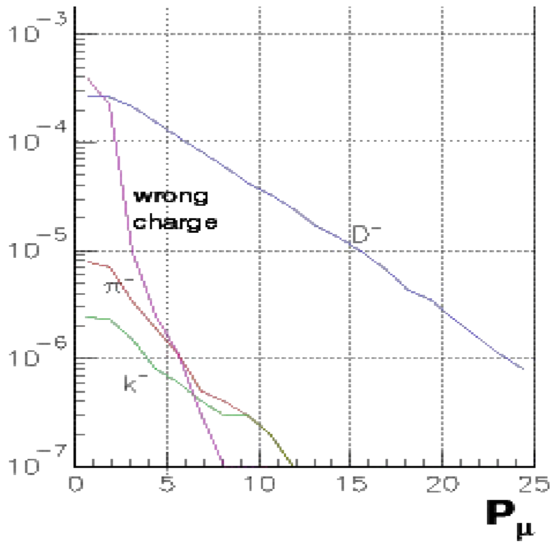


Muon identification criterion

$$L_{\mu^-} - L_{had} > 75cm$$

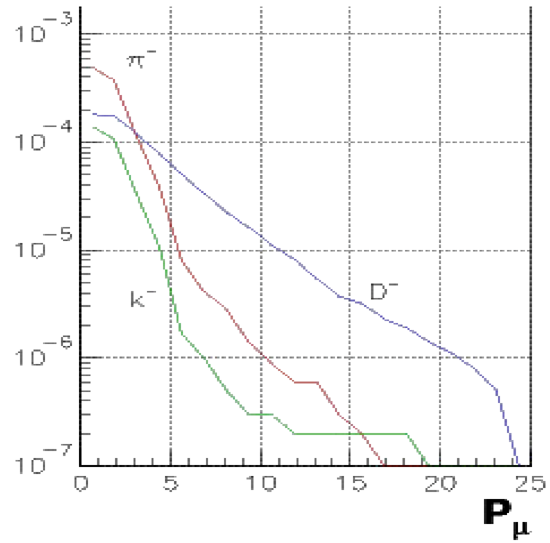
Before kinematical cuts

$\bar{\nu}_\mu$ CC



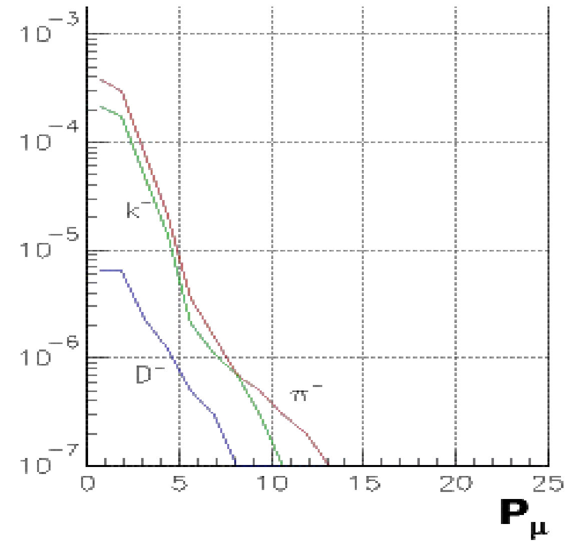
- Charge mis-id
- Charm decay

$(\bar{\nu}_\mu+\nu_e)$ NC



- Pion decay

ν_e CC



- Pion-kaon decay

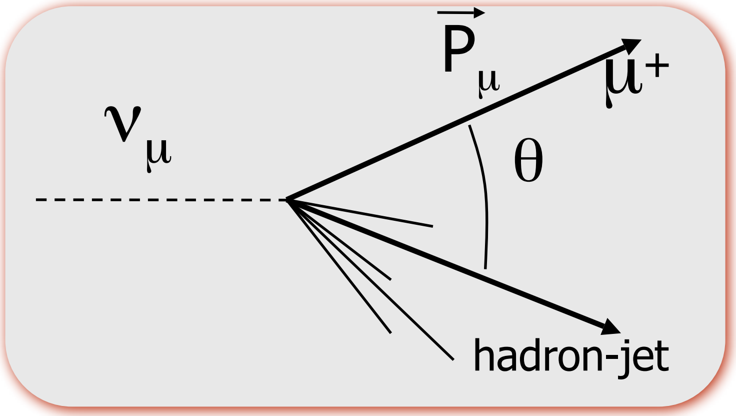
Before kinematical cuts the main backgrounds are of comparable order (1-5)x10^{-4}

Kinematic analysis

- Kinematic analysis
  - MC reconstructed variables:

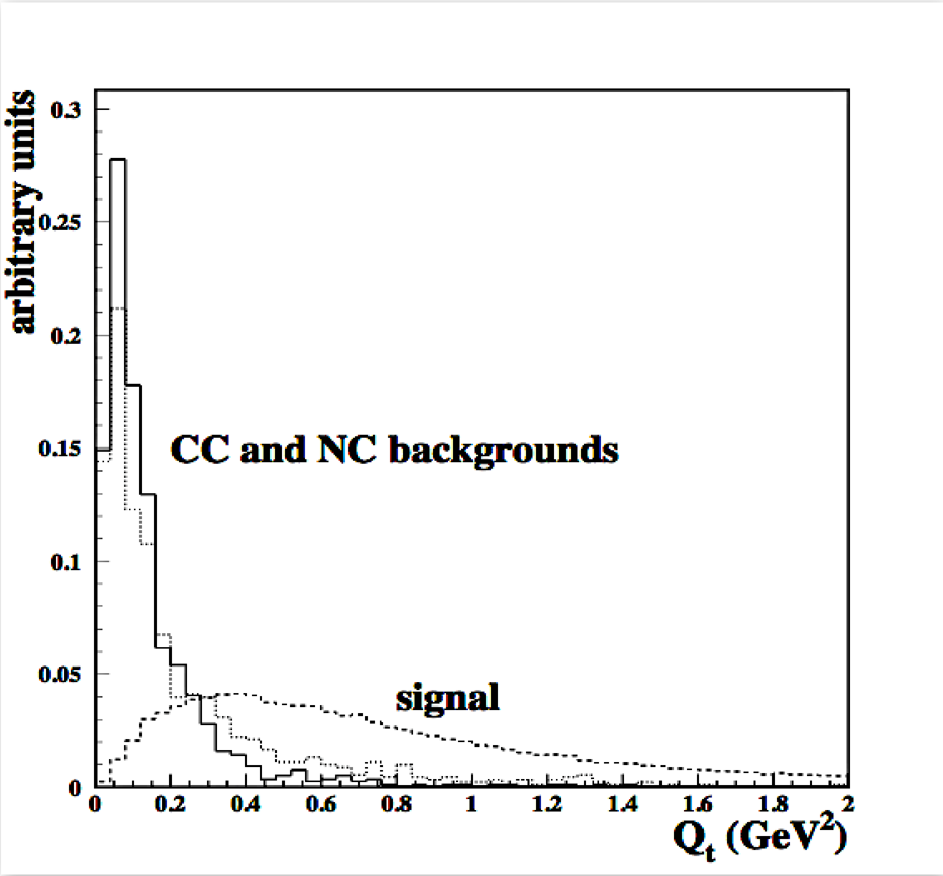
    p_{μ}, E_{had}, θ_{had}

  - Variables used in the analysis



$$P_{\mu} = |P_{\mu}|$$

$$Q_t = P_{\mu} \sin^2\theta$$



Sim/Rec/Ana task list

- Event simulation (NUANCE)--> bHEP1
  - converter between NUANCE and bHEP format (Malcolm)
- Event transport (GEANT4) --> bHEP2
  - Geometry and bHEP interface
  - Malcolm, euronu
- Digitisation --> bHEP3
  - hits:
    - 2D points, pulse height, time
    - link to true particle
    - euronu
  - Dummy digitisation with MIND fast simulation (Anselmo)
- Reconstruction --> root file
  - Build the framework: Andrew, Anselmo, Javier
    - Define bHEP format
    - Read dst (bHEP): Javier
    - event likelihood: Andrew
    - cellular automaton (import from T2K, Federico's help): Andrew
    - kalman filter (RecPack): Anselmo

Nufact08

- MIND
  - Preliminary pattern recognition studies
  - Charge misid with pattern recognition and Kalman Filter
- TASD
  - Pattern recognition, electrons
- Simulation/recon/analysis framework
  - Let’s find an acronym
- Emulsions
- Near detector