Measurement of low energy neutrino cross-sections with the PEANUT experiment

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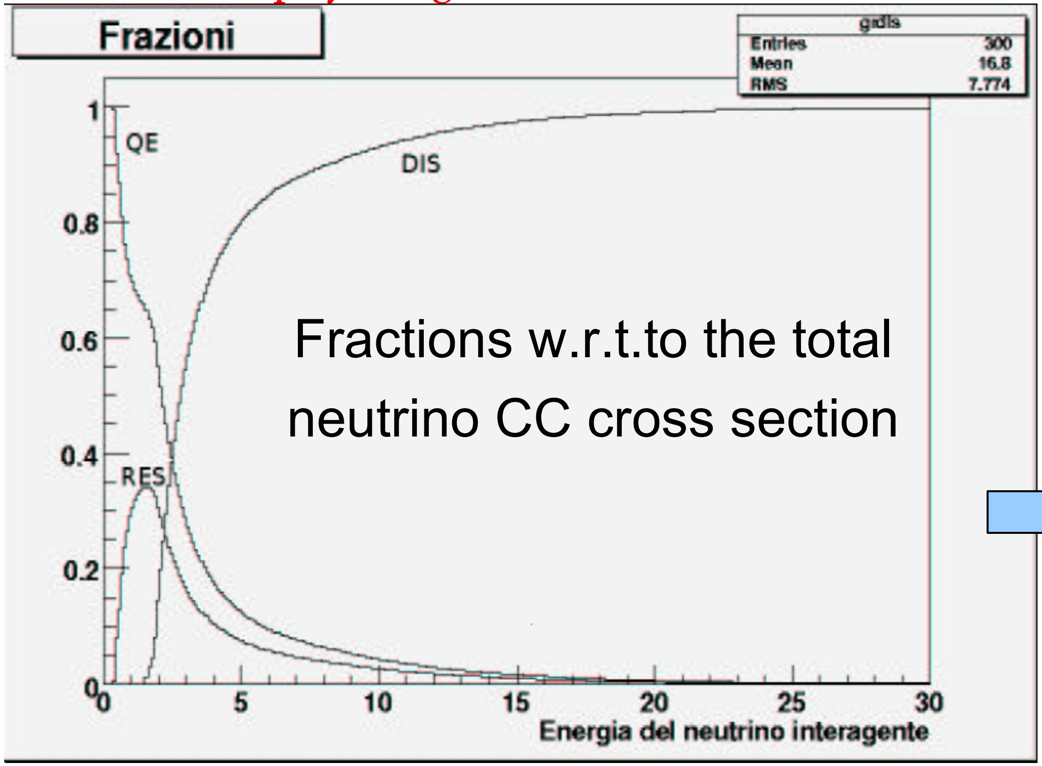
Physics goals

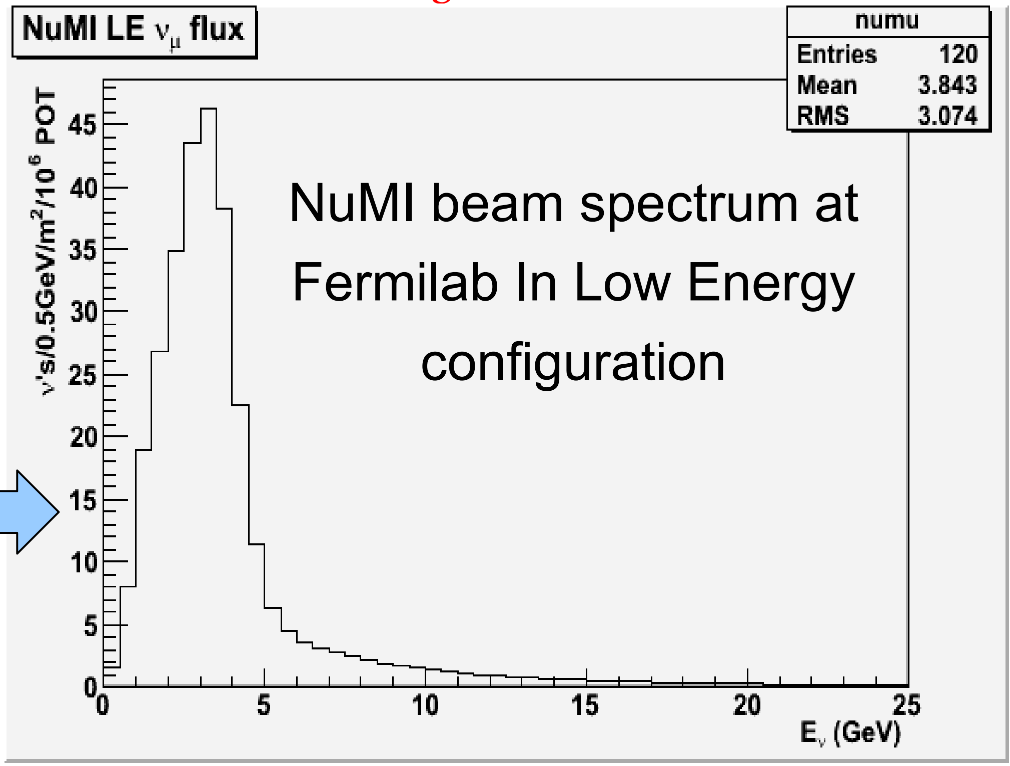
For Charged Current neutrino interactions three dynamics are possible

- Deep Inelastic Scattering (DIS) , Quasi Elastic Scattering (QE) and
- Resonance (Delta particle) production (RES)

Few GeV region (<5 GeV)is complicated because these three dynamics overlap with similar contributions.

The main physics goal is to measure these contributions to the total Charged Current cross section





Expectations for NuMI in Low Energy configuration

(70± 4)% DIS, Phys.Lett.B66:291,1977

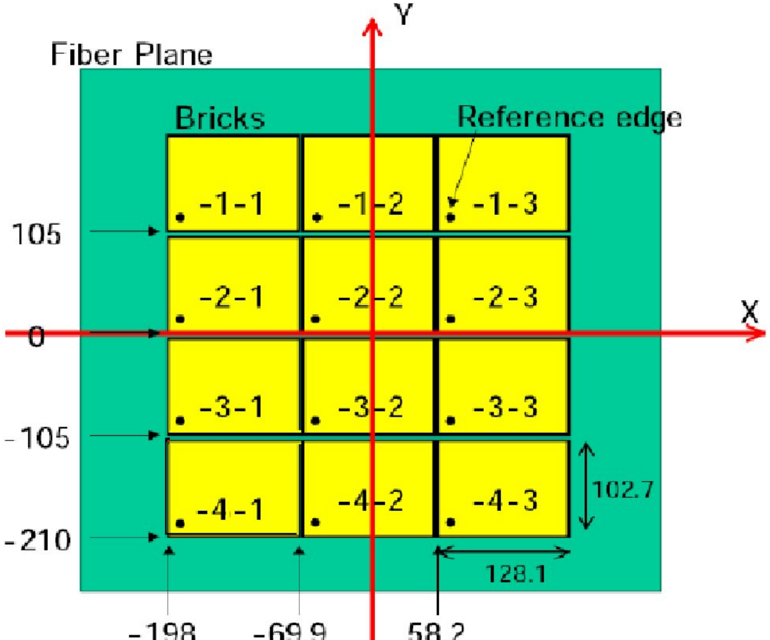
(19± 4)% QE, Phys.Rev.D23:2499-2505,1981

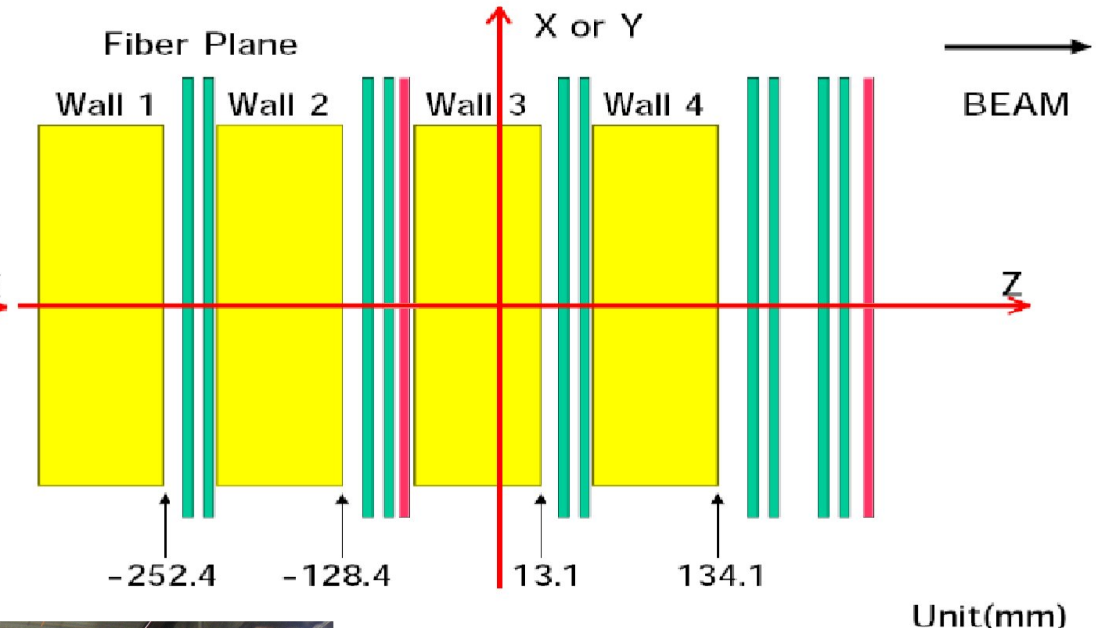
(11± 2)% RES, Phys.Lett.B78:510-514,1978

PEANUT detector

Hybrid detector: Emulsion-lead targets and scintillating fibre tracker (SFT detector)

Emulsion-lead targets are housed in “miniwalls”, made by 4 rows and 3columns





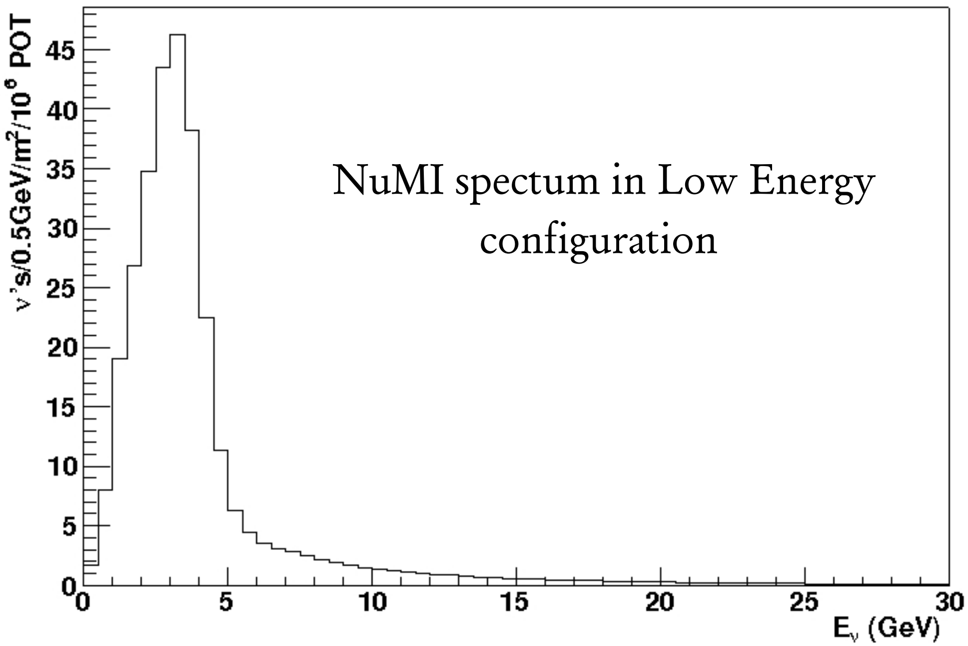
PEANUT in the near detector hall of MINOS

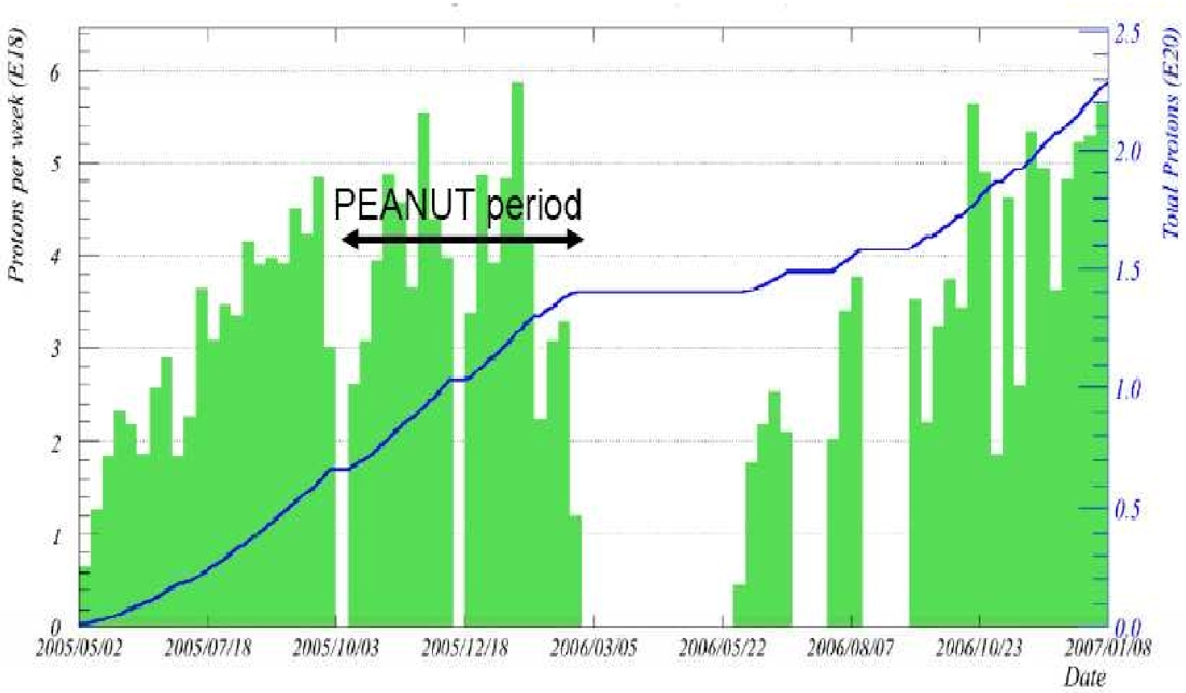
Fibre tracker planes (shown in green) track charged particles produced in ν interactions with high precision (a few hundred micron) and provide timing information

The NuMI beam

NuMI neutrino beam uses 120 GeV protons from the Main Injector accelerator, aimed 58 mrad downward towards Soudan mine.

It can be operated in High Energy, Medium Energy and Low Energy configurations

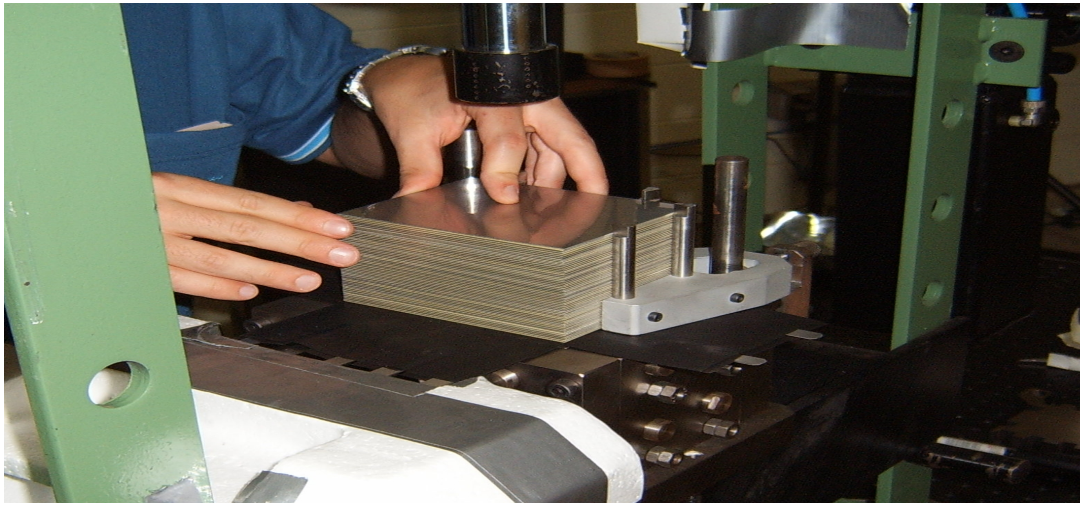




Total number of NuMI protons (blue line) and the protons per week (green) delivered on the target.

Emulsion Cloud Chambers (ECC) in PEANUT detector

Target made of a sandwich of lead plates (passive target) and nuclear emulsions (active tracker detector): Emulsion Cloud Chambers

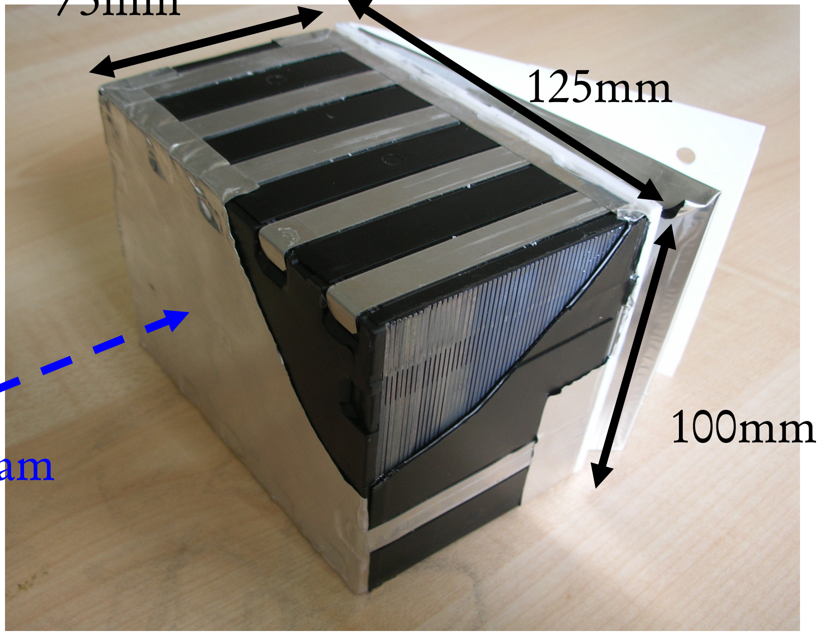


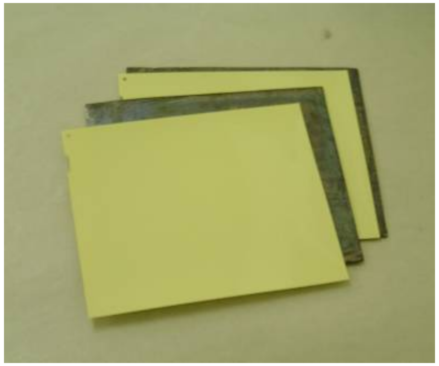
Modular detector: each module (called **brick**) is made of a sandwich of 56 lead plates (passive target) and 57 emulsions films.

ECC combines high density of lead and high-precision tracking performances of emulsion: suitable for low energy neutrino physics

8.3kg

$10X_0$





Emulsion films: 300micron thick

Pb plate : 1mm

Nuclear emulsion films

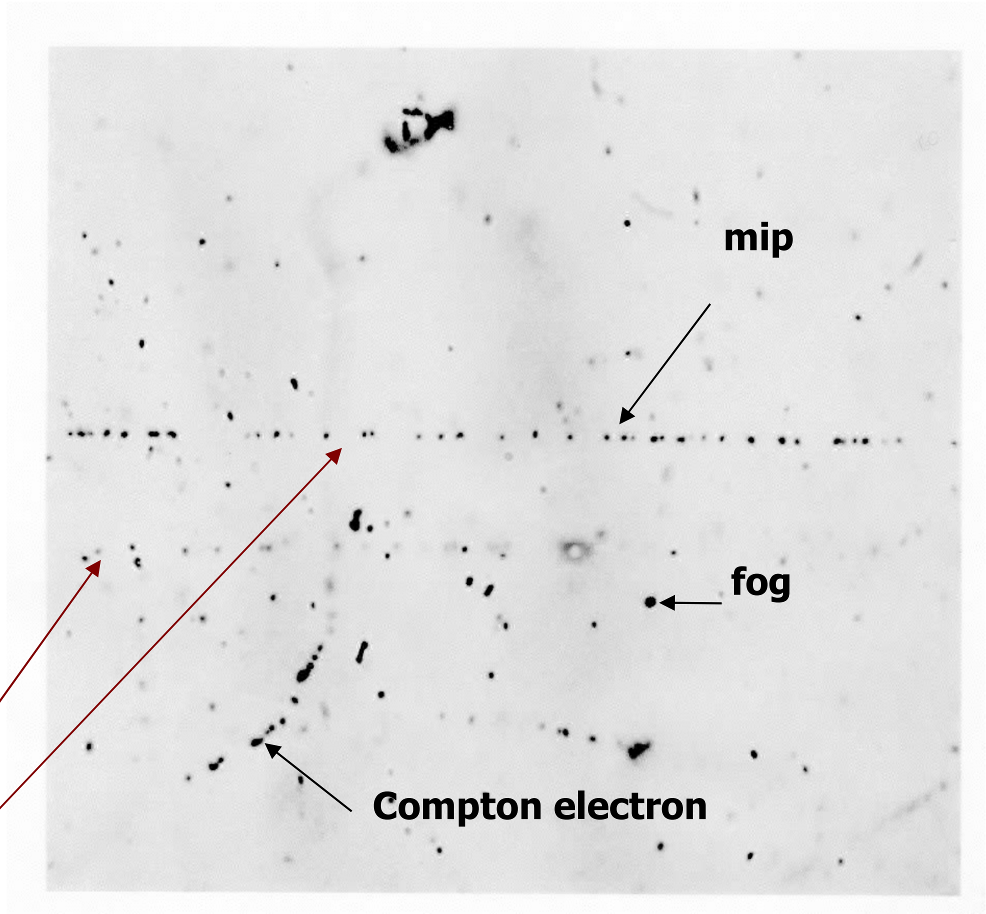
Produced by Fuji Film,
same films as in OPERA detector

Nuclear emulsion is a film made of AgBr crystals in organic gelatine. They record the passage of charged particles with an accuracy better than 1 μm

charged particles crossing emulsions ionize AgBr atoms. *Fixing* and *development* treatments turn ionized atoms into black grains

A track is defined as a sequence of aligned black grains

(to show the grain density, the picture shows an exposure parallel to the film)



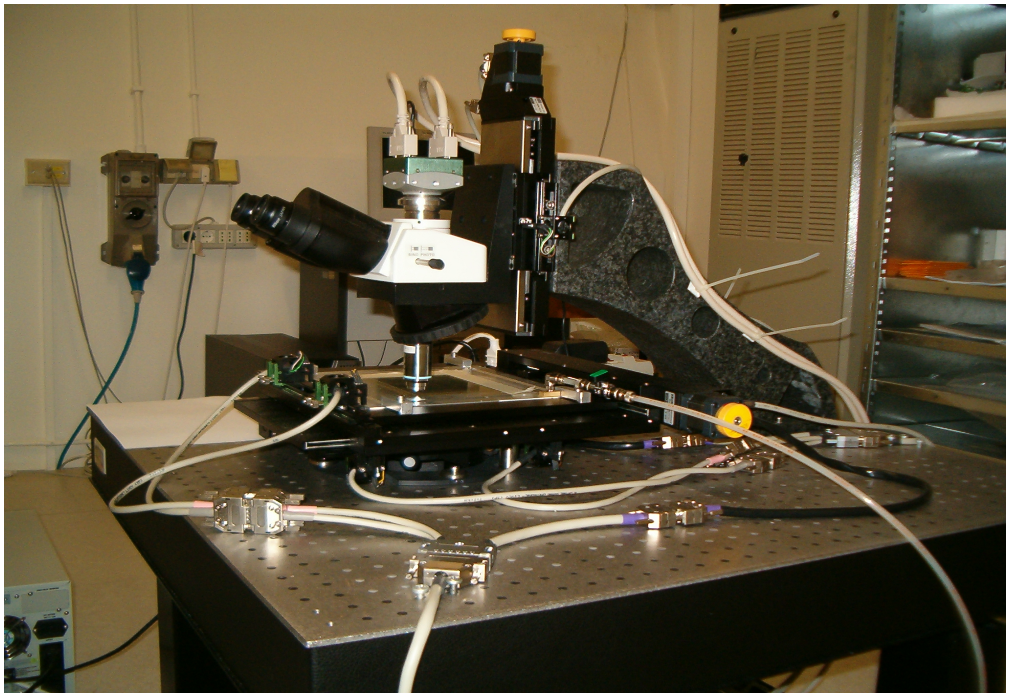
- **sensitivity**
  ~ 36 grains per 100 μm for mip tracks
- **background**
  ~ 9 grains per 1000 μm^3

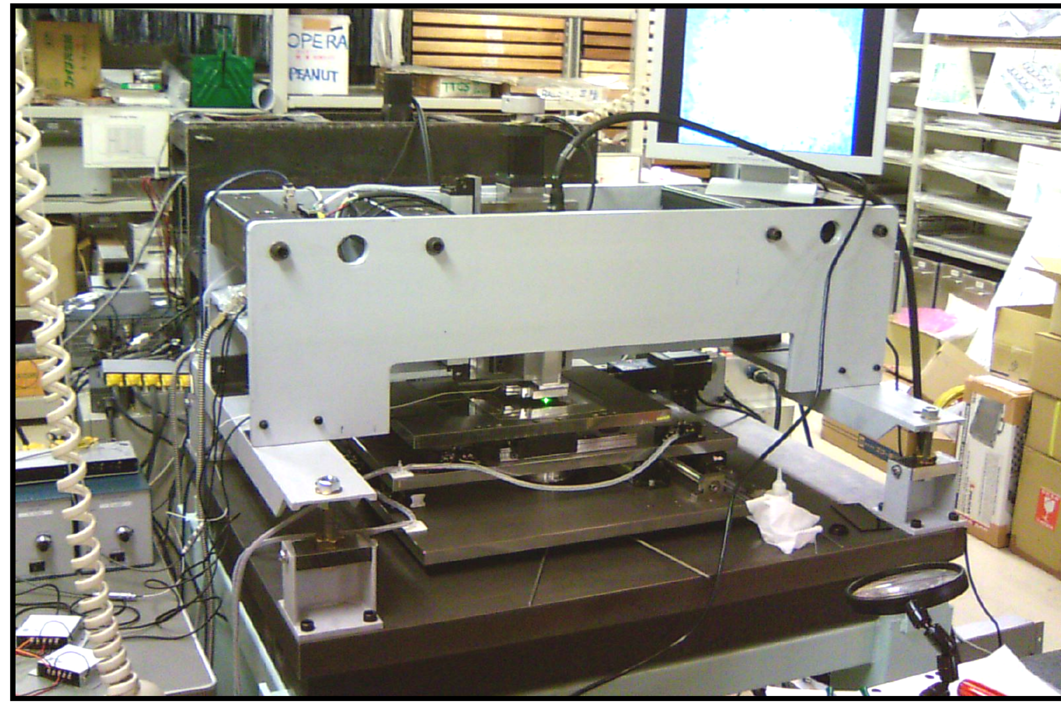
Emulsion Scanning

European Scanning System (ESS)

S-UTS (Japan)

Design based on two different approaches





Commercial hardware,
software-based approach

Hard-coded algorithm

Performances:

>90% tracking efficiency for small angle tracks

Spatial and angular resolutions are $\cong 1\mu m$, $\cong 2$ mrad

Reconstruction of neutrino events in PEANUT

- Trigger + select events "on time" with NuMI beam spill cycle
- Electronic detector information are processed by a software reconstruction program that reconstructs charged tracks crossing the detector

– After a few weeks exposure, bricks were removed from the detector, exposed to cosmic rays, and developed

Bricks analysis

- Two analysis procedures were followed

1) Scanback analysis:

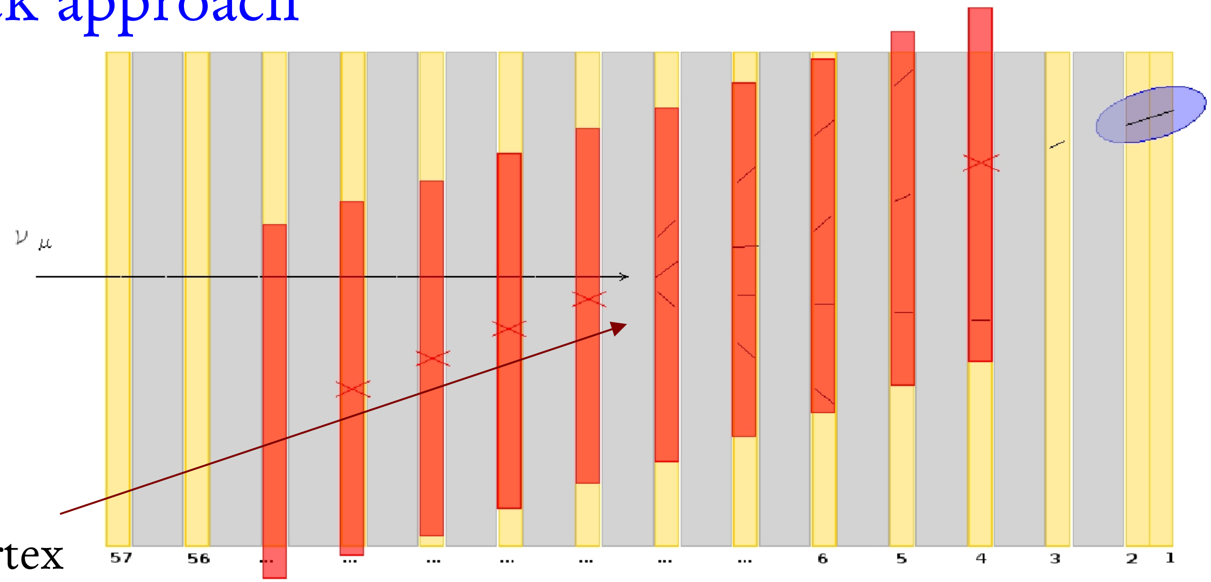
- Scanning of the two most downstream films of the bricks in search for tracks related to neutrino events (confirmed by SFT).
- These tracks are followed up in the brick up to the neutrino interaction vertex
- neutrino vertex reconstruction

2) General scan

- Full surface scanning of all the films of the brick and reconstruction of all neutrino event candidates
- Selection of neutrino events on the basis of the confirmation of SFT

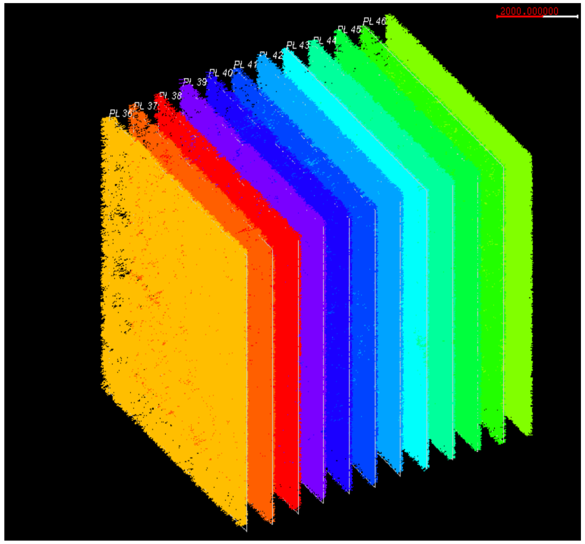
These two procedure allow to select CC neutrino interactions with a purity ≅98%

Scan-back approach

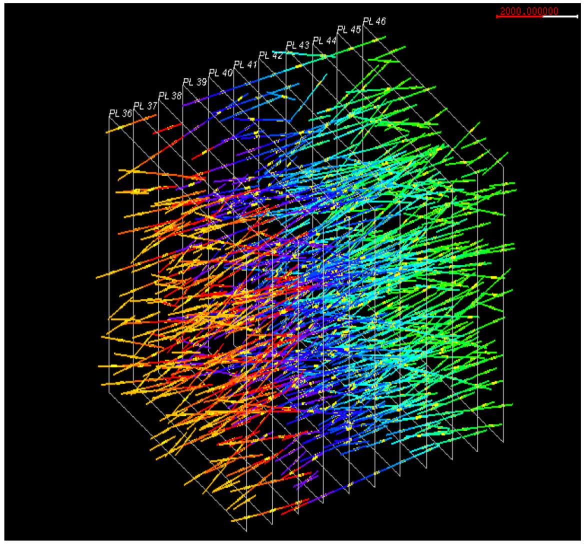


Emulsion track matched with SFT detector, followed up to the ν interaction point

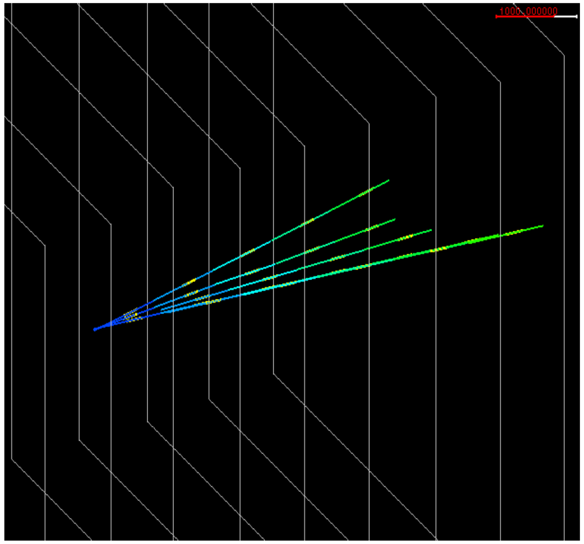
General-scan approach



Large surface scanning



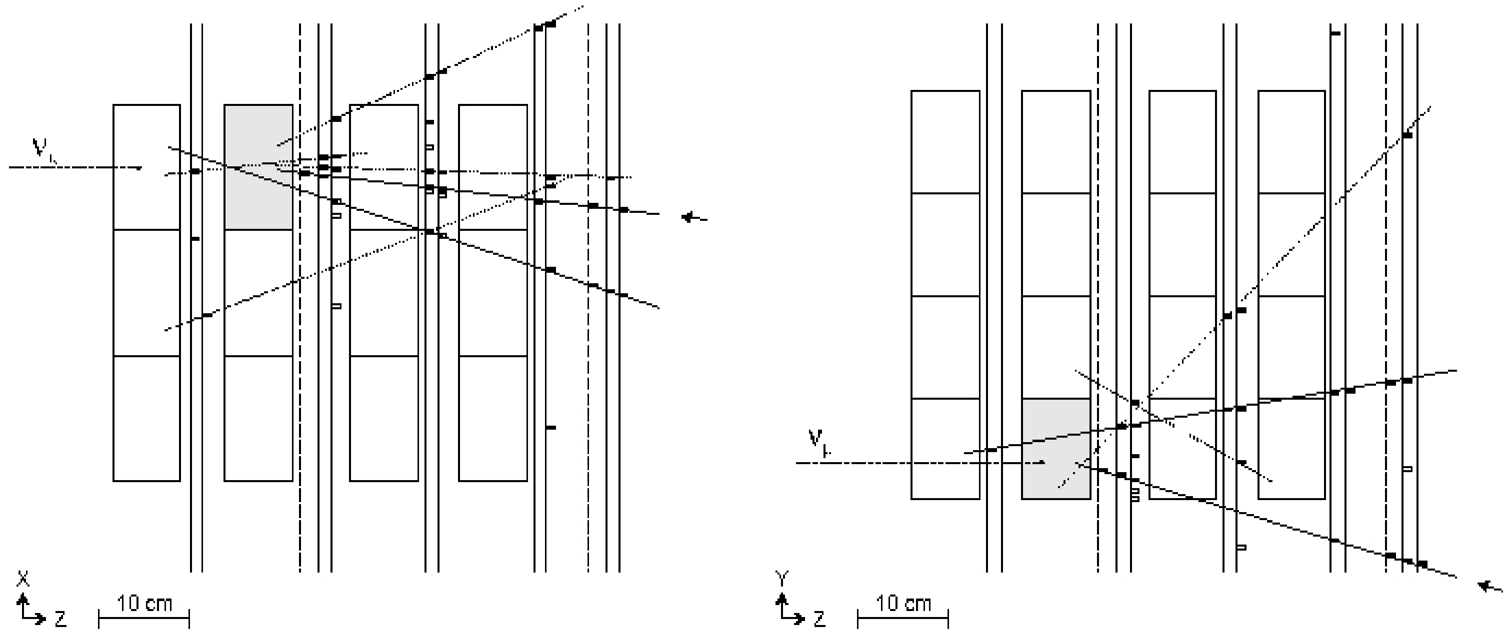
3D Track reconstruction in emulsion



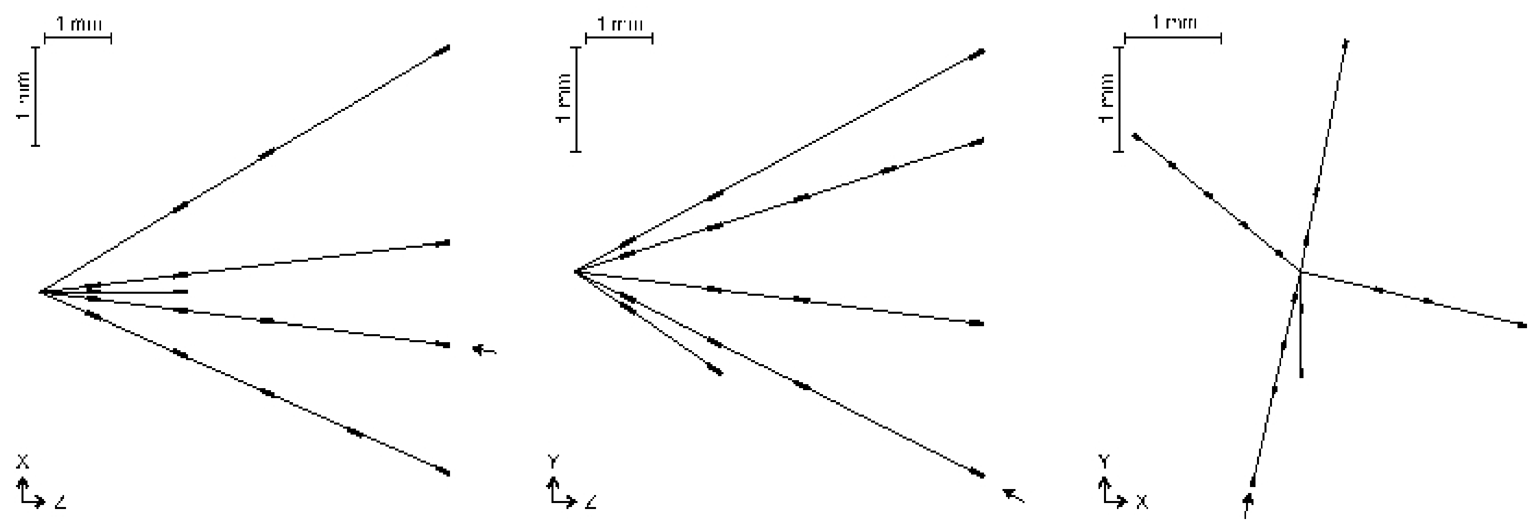
Neutrino vertex reconstruction

Neutrino events in PEANUT: an example

Hits in scintillating fibre planes and reconstructed tracks



Same event reconstructed in emulsion



Neutrino event data and MC-data comparison

Data-MC comparison performed on all aspects of the reconstruction of ν events

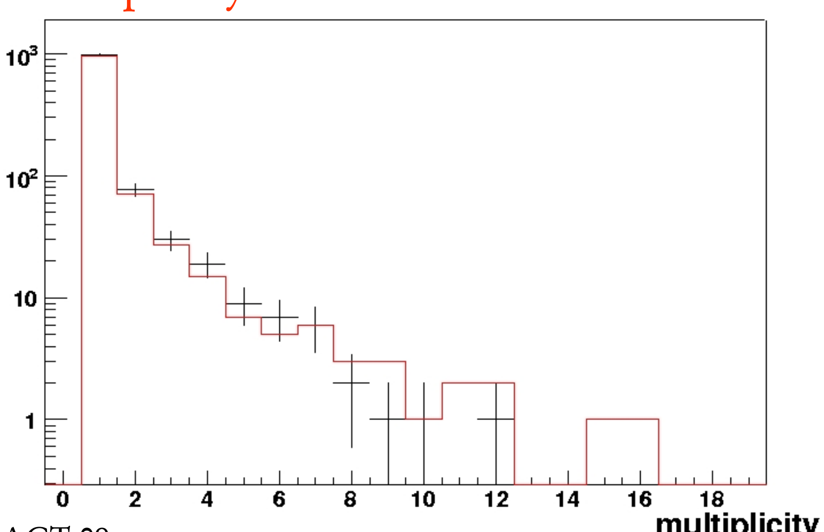
SFT data reconstruction

Detailed MC study shows that our ν event selection is strongly biased in favour of CC interactions even without muon identification. Contamination from NC events is reduced from ≅17% to ≅1% requiring ν event candidates to be confirmed by SFT

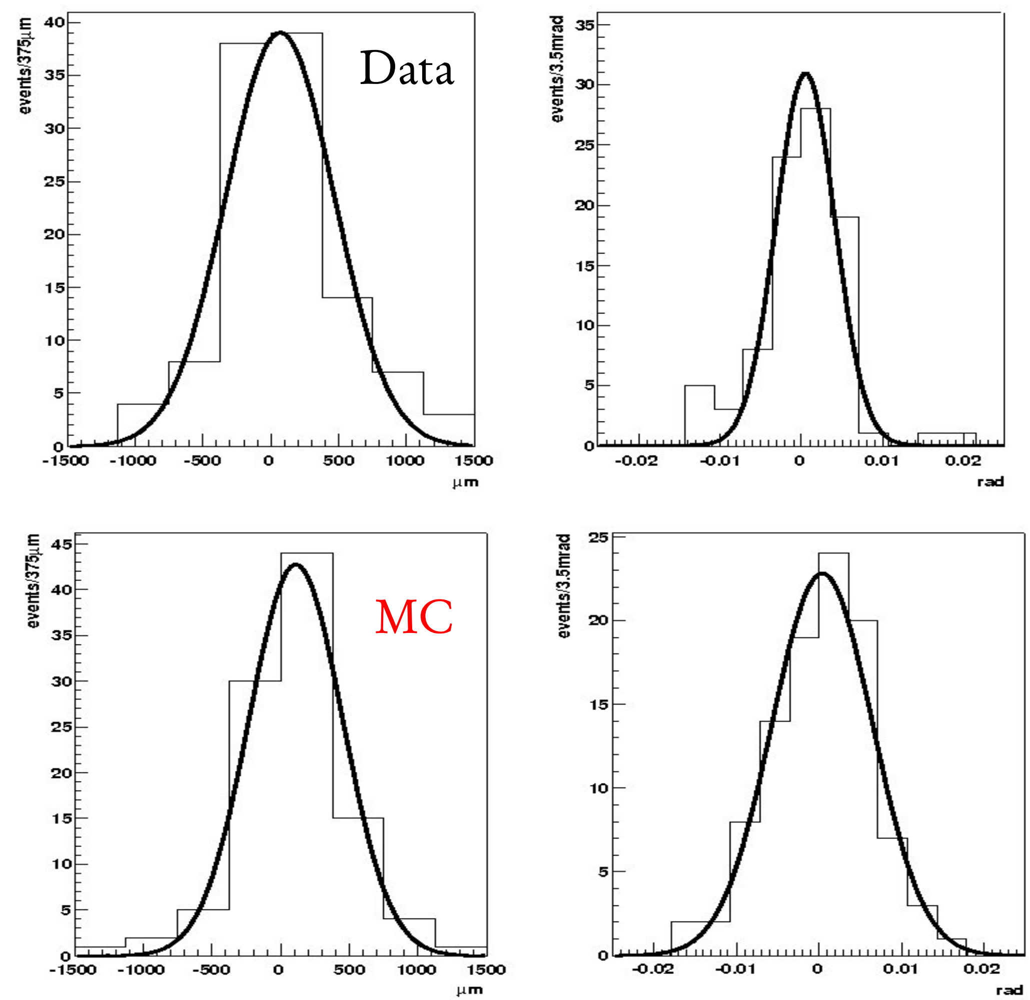
Ingredients of MC:

- 70% DIS, 19% QE, 11% RES
- No neutral current events

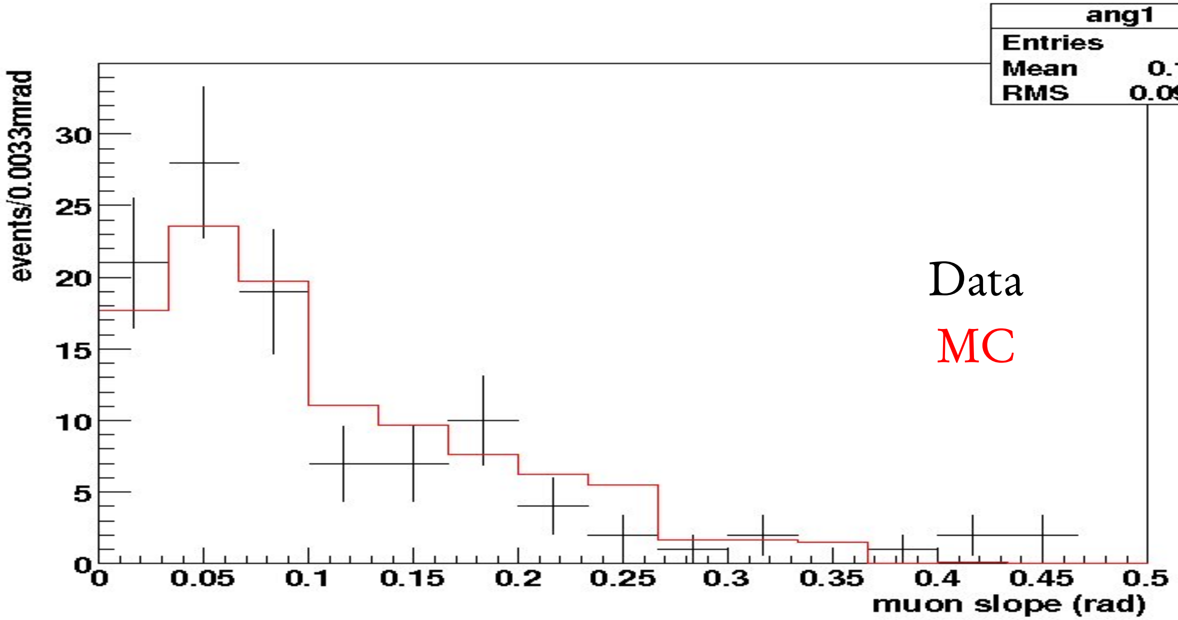
Multiplicity of SFT tracks in ν events



Residuals between SFT and emulsion tracks

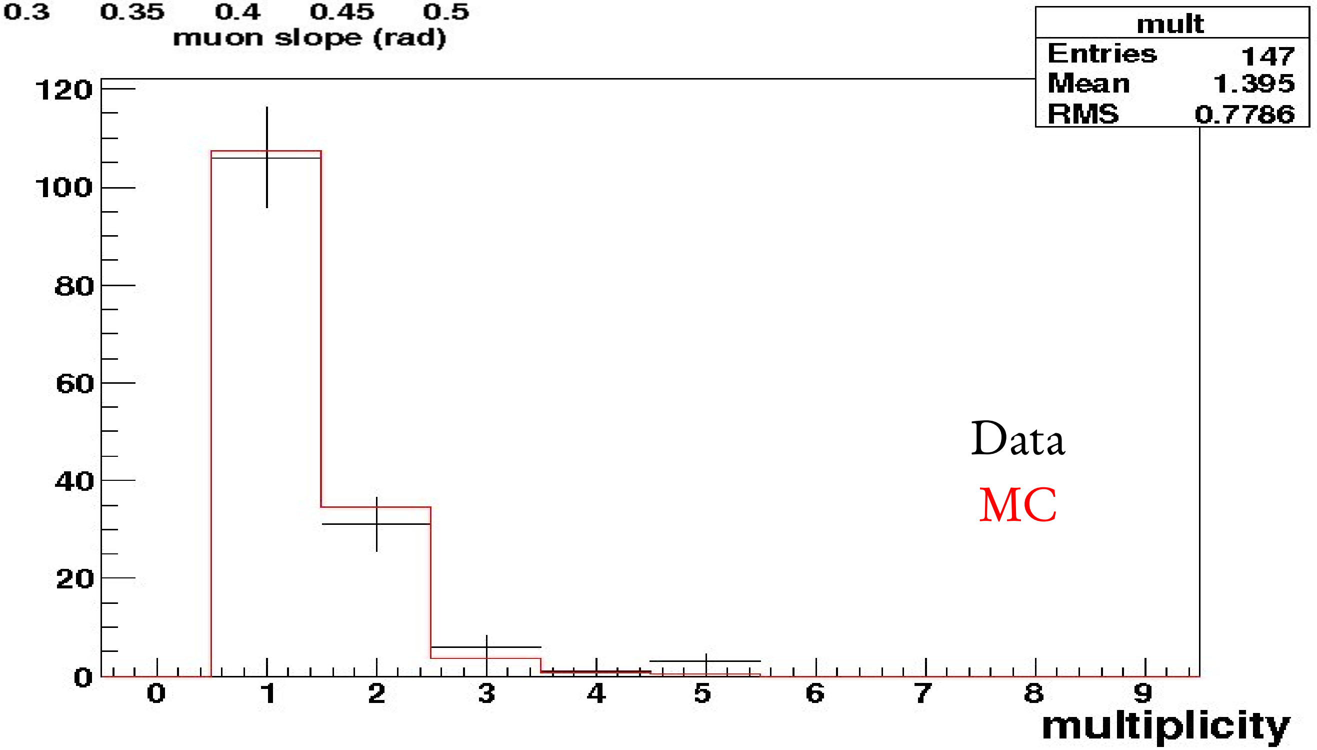


Neutrino event data and MC-data comparison



Muon slope distribution (muon defined as emulsion track in ν event matched with SFT track. This selection ensures ≅98% purity)

Charged multiplicity at neutrino vertices



Cross-section measurements

- The measured charged multiplicity distribution is sensitive to the ratio of DIS, QE and RES wrt to the total CC cross section
- These ratios can be obtained minimizing the difference between the multiplicity distributions in MC and data, with the ratio of Resonances to Quasi Elastic kept fixed to 0.58. The ratio of DIS wrt to total CC cross section acts as a free parameter in this minimization
- The best-fit values are:

$f_{QE} = 0.20^{+0.06}_{-0.07}$ (stat) $\pm$ 0.02(syst)

$f_{DIS} = 0.68^{+0.09}_{-0,07}$ (stat) $\pm$ 0.02(syst)

$f_{RES} = 0.12 \pm 0.04$(stat) $\pm$ 0.02(syst)

The expected values are (see Phys. Lett. B66 (1977) 291, Phys. Rev. D23 (1981) 2499, Phys. Lett. B78 (1978) 510):

$f_{QE} = 0.19 \pm 0.04$

$f_{DIS} = 0.70 \pm 0.04$

$f_{RES} = 0.11 \pm 0.02$

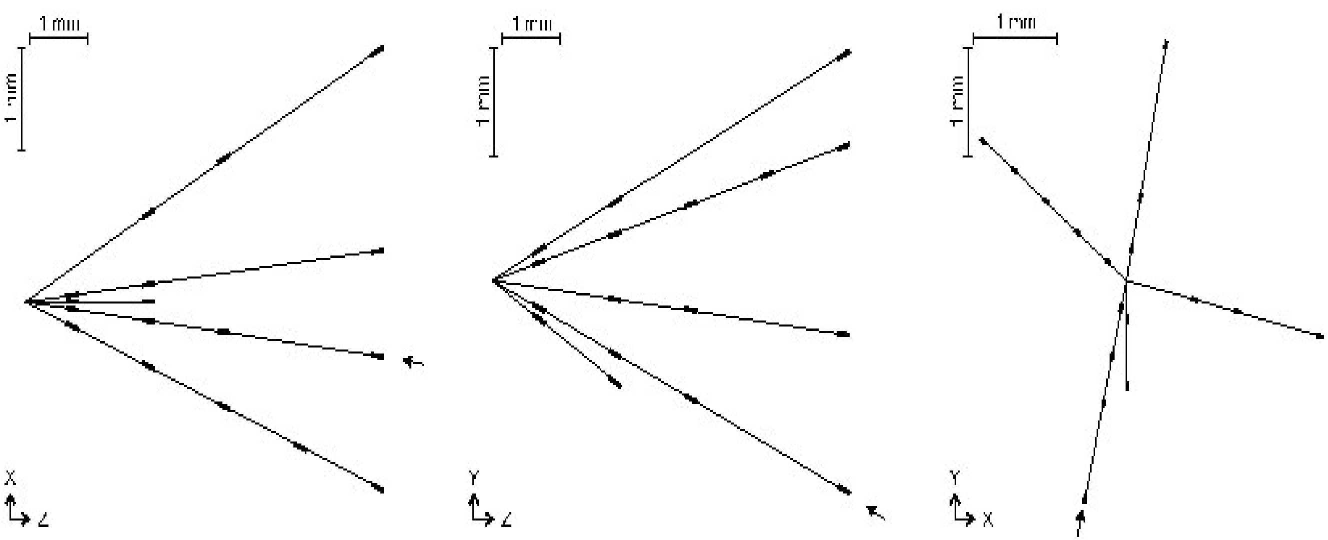
The main source of systematic error comes from the uncertainty on the ratio RES/QE

Perspectives of ECC in future ν experiments

ECC could be used to study few GeVs neutrino beams (currently done in T2K). Micrometric resolution of emulsion allows to measure precisely:

1) neutrino event topology

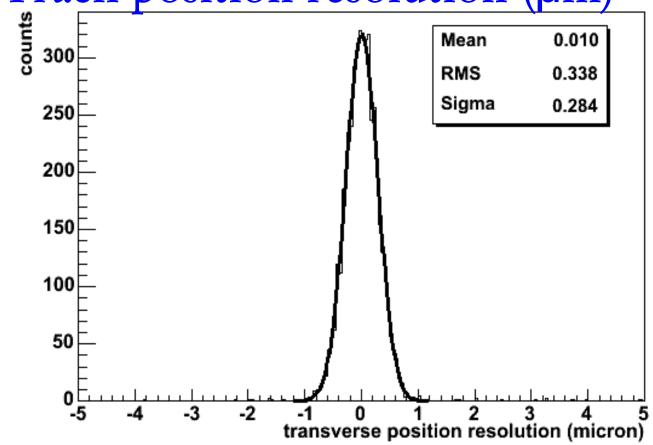
2) pseudo-rapidity distributions of charged particles



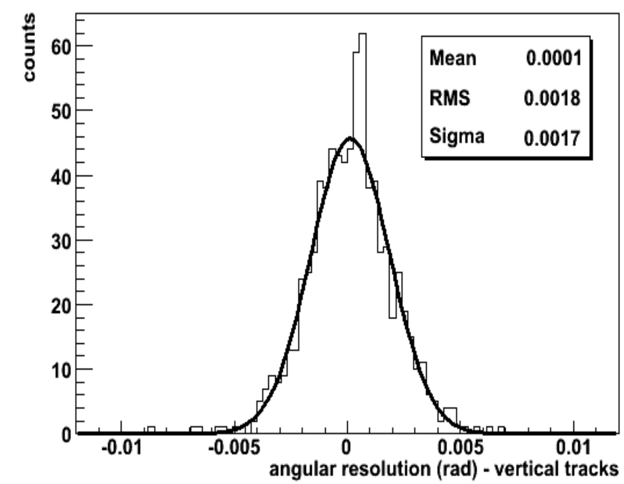
Cross section measurements:

In PEANUT QE,RES and DIS cross sections measured with ≅15% precision (precision limited by statistics)

Track position resolution (μm)



Track slope resolution (mrad)



Kinematical measurements in ECC

Relevant kinematical variables (i.e. P_T, hadron momentum distribution, energy of electromagnetic component of shower) in ν interactions can be measured

Multiple Coulomb Scattering in lead plates exploited in momentum measurement

$$\Theta^2 = \delta^2 + (14MeV/\beta p)^2 X/X_0$$

Coulomb scattering term

Measurement error (≅2 mrad)

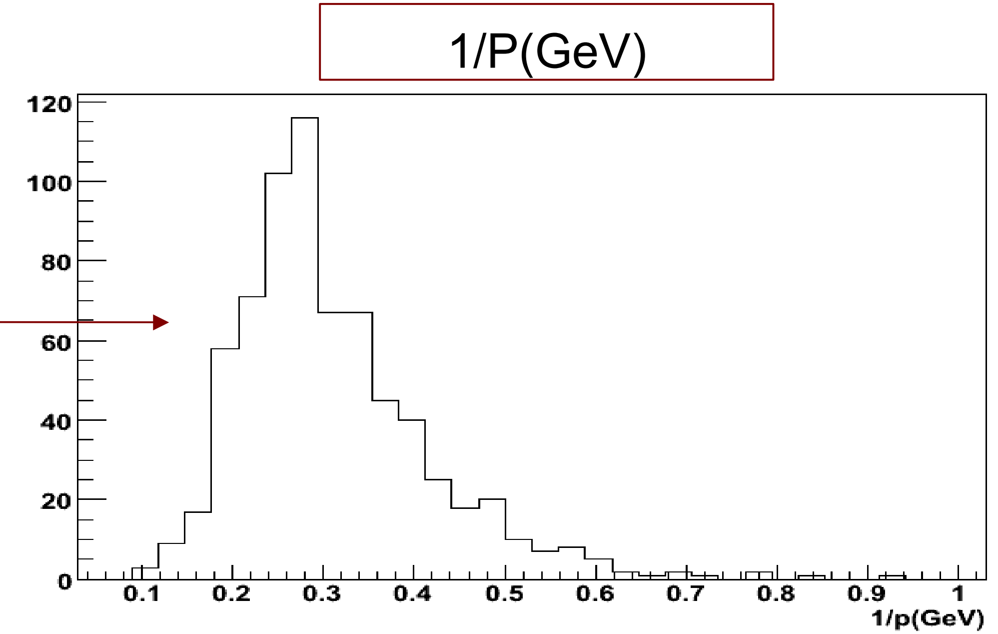
Transverse angular deviation

An ECC is ≅ 10 X_0

charged-particle momentum can be measured with

precision < 25% up to 4GeV

Example: momentum measurement for 4GeV simulated pions in ECC



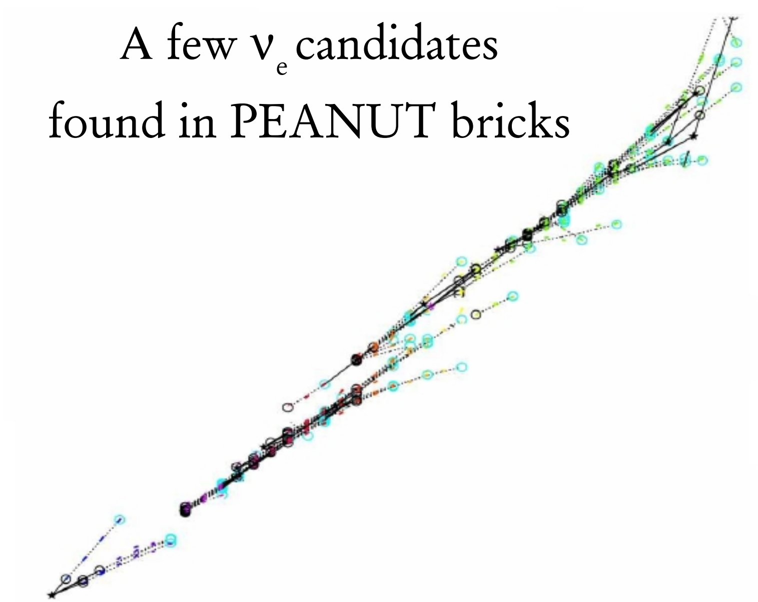
Neutrino beam monitoring

Both ν_μ and ν_e detectable in ECC

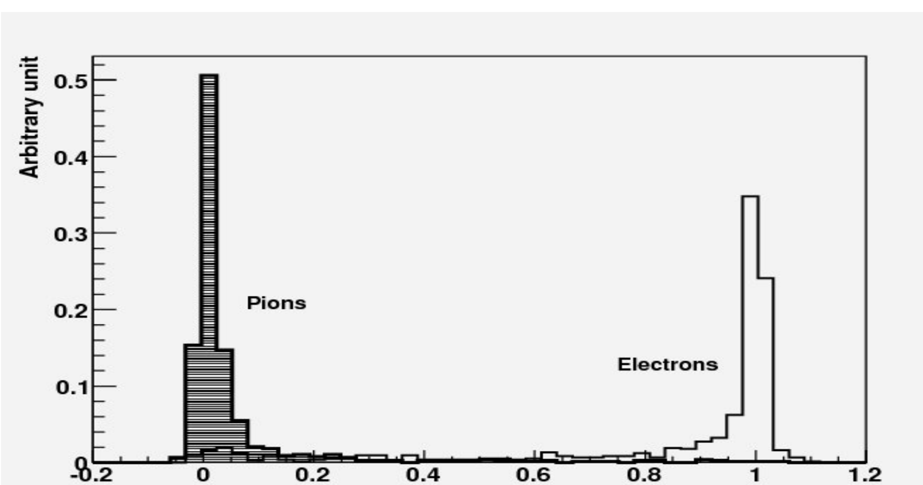
few percents contamination in non pure ν beams measurable

Reconstruction of electromagnetic showers in emulsion: a 6GeV electron shown here

A few ν_e candidates found in PEANUT bricks



Neural network approach allows to have >90% efficiency and <1% misidentification in the identification of >2GeV e.m. showers



See JINST 2:P02001,2007

Conclusions

- PEANUT experiment was designed to investigate neutrino interactions at low energies (i.e. few GeV)
- Hybrid detector: scintillating fibre tracker and ECC target
- A sample of 147 ν_μ CC events has been analysed
- MC simulation based on the neutrino event generator used in the OPERA experiment (optimized on the data of NOMAD experiment) shows good agreement between data and the expectations
- Charged multiplicity in ν_μ CC interactions has been measured and DIS, RES, and QE contributions to total CC cross section has been estimated. All values are compatible with expectations based on past measurements
- A paper on PEANUT results is in preparation
- This kind of detector can be used to monitor ν beams in future experiments
- Cross sections, relevant topological and kinematical variables, ν_e contamination in non pure beams can be measured

spares

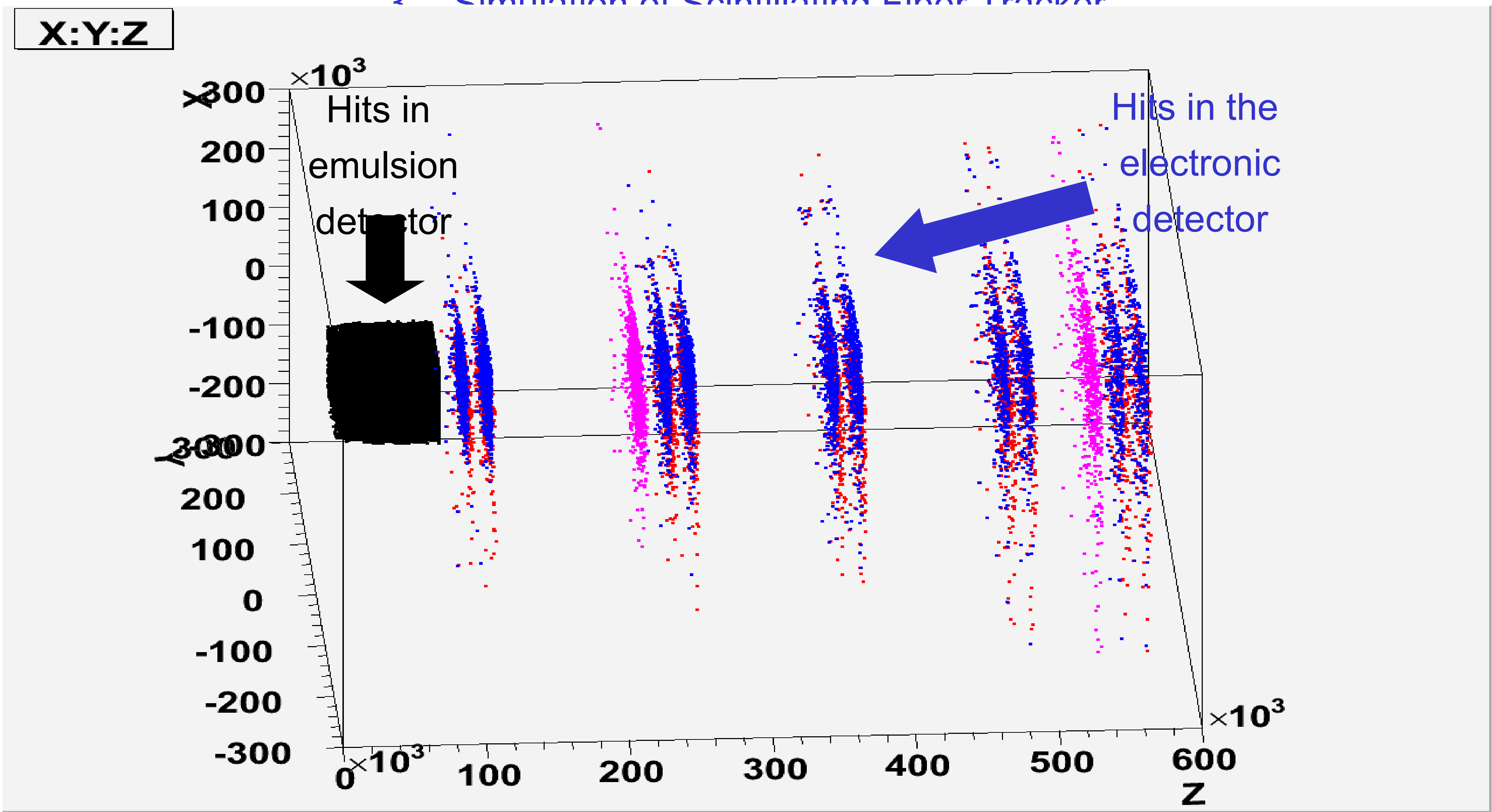
Emulsion Scanning

Two scanning systems, developed by European and Japanese scanning laboratories

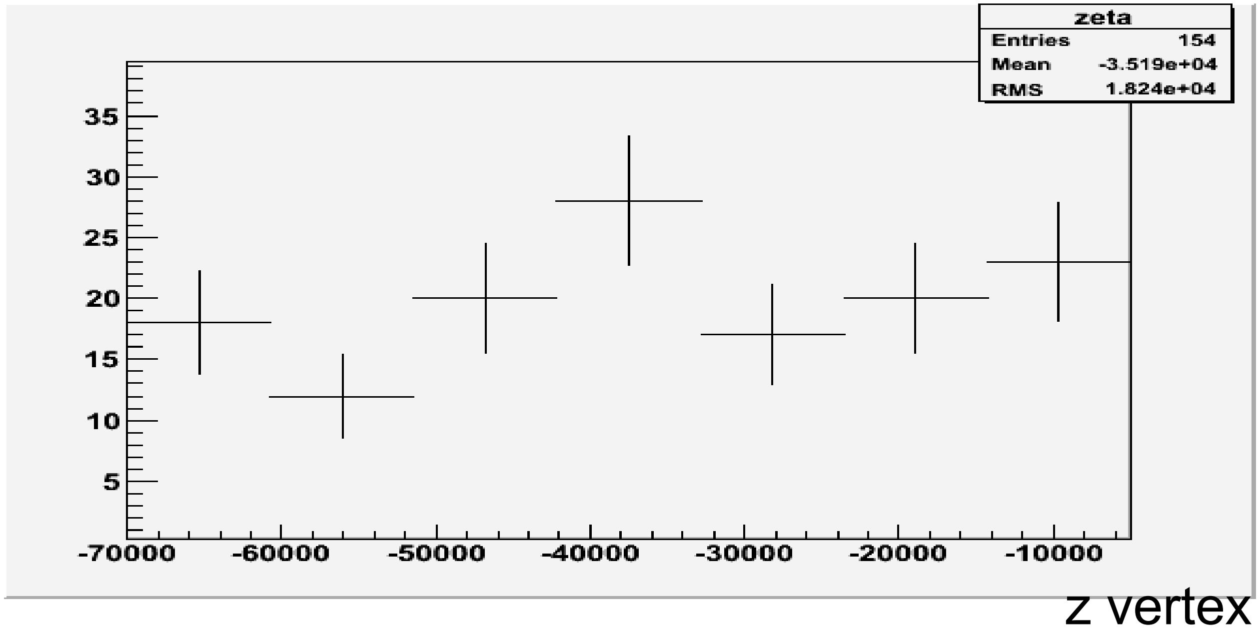
Monte Carlo simulation

A dedicated Monte Carlo simulation is used to estimate the performances of PEANUT detector. It provides both:

2. Simulation of ECC targets
3. Simulation of Scintillating Fiber Tracker



Vertices' distribution in brick



data

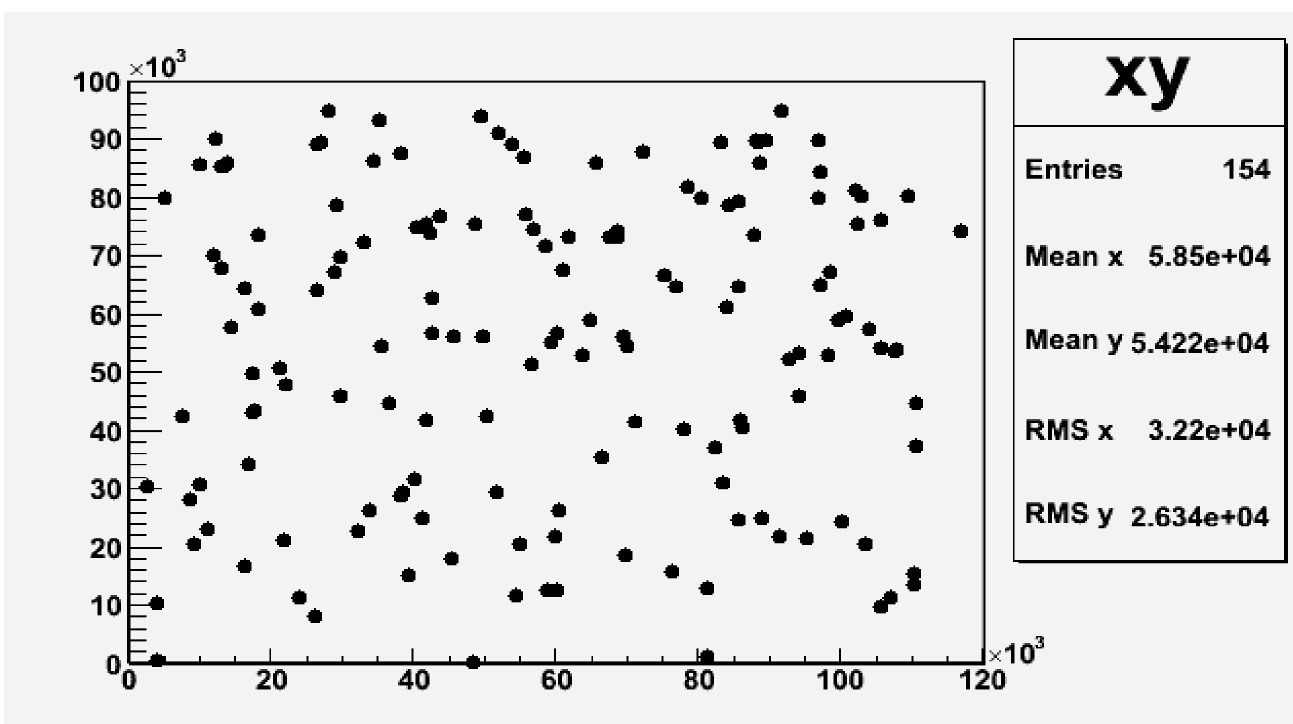
Mean = -3.5*10e4 μm

RMS = 1.8*10e4 μm

Expected

Mean = -3.8*10e4 μm

RMS = 1.9*10e4 μm



Expected

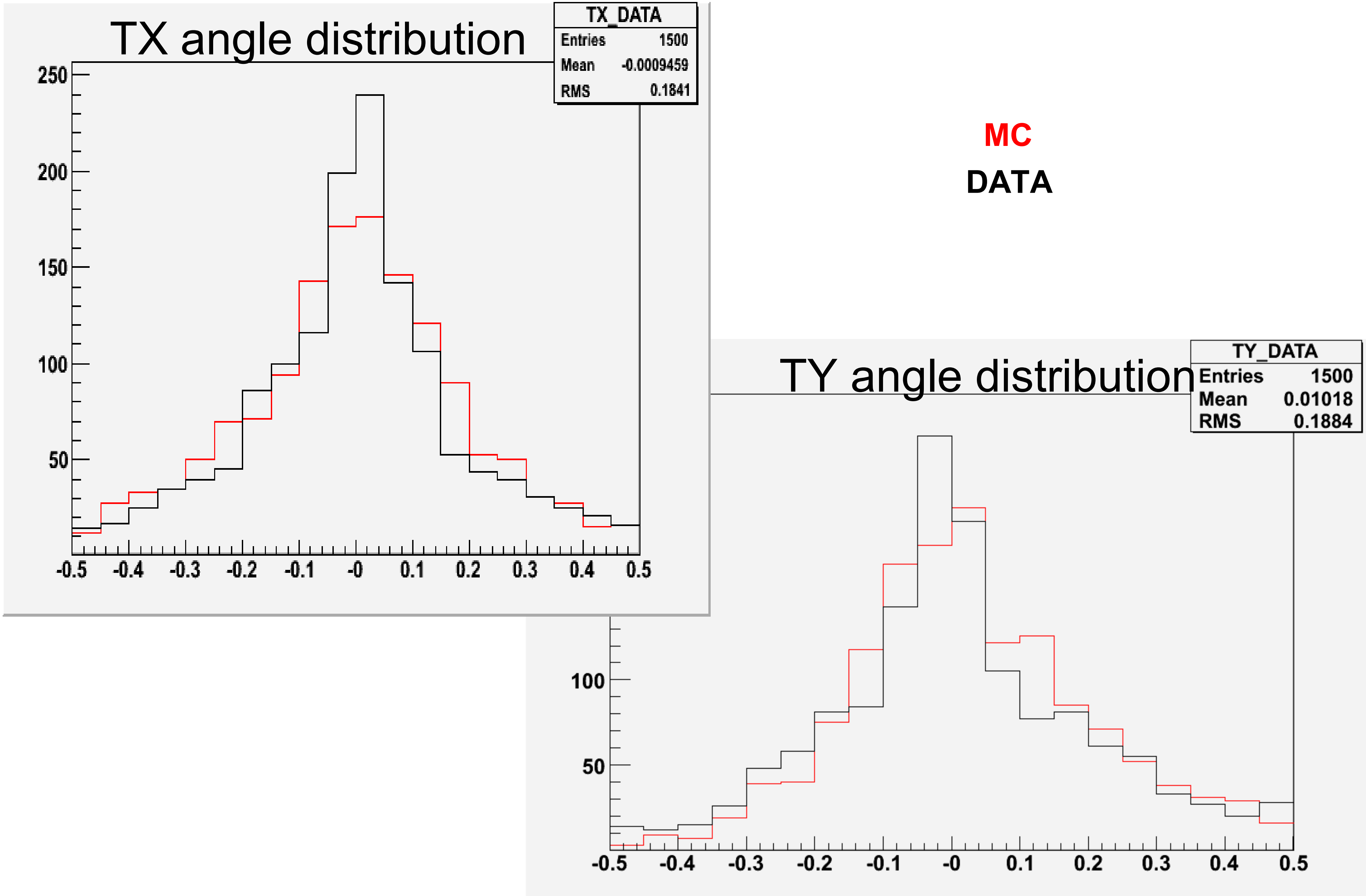
MeanX = 6.0*10e4 μm

RMSX = 3.3*10e4 μm

MeanY = 5.0*10e4 μm

RMSY = 2.8*10e4 μm

MC Data comparison ((electronic detector

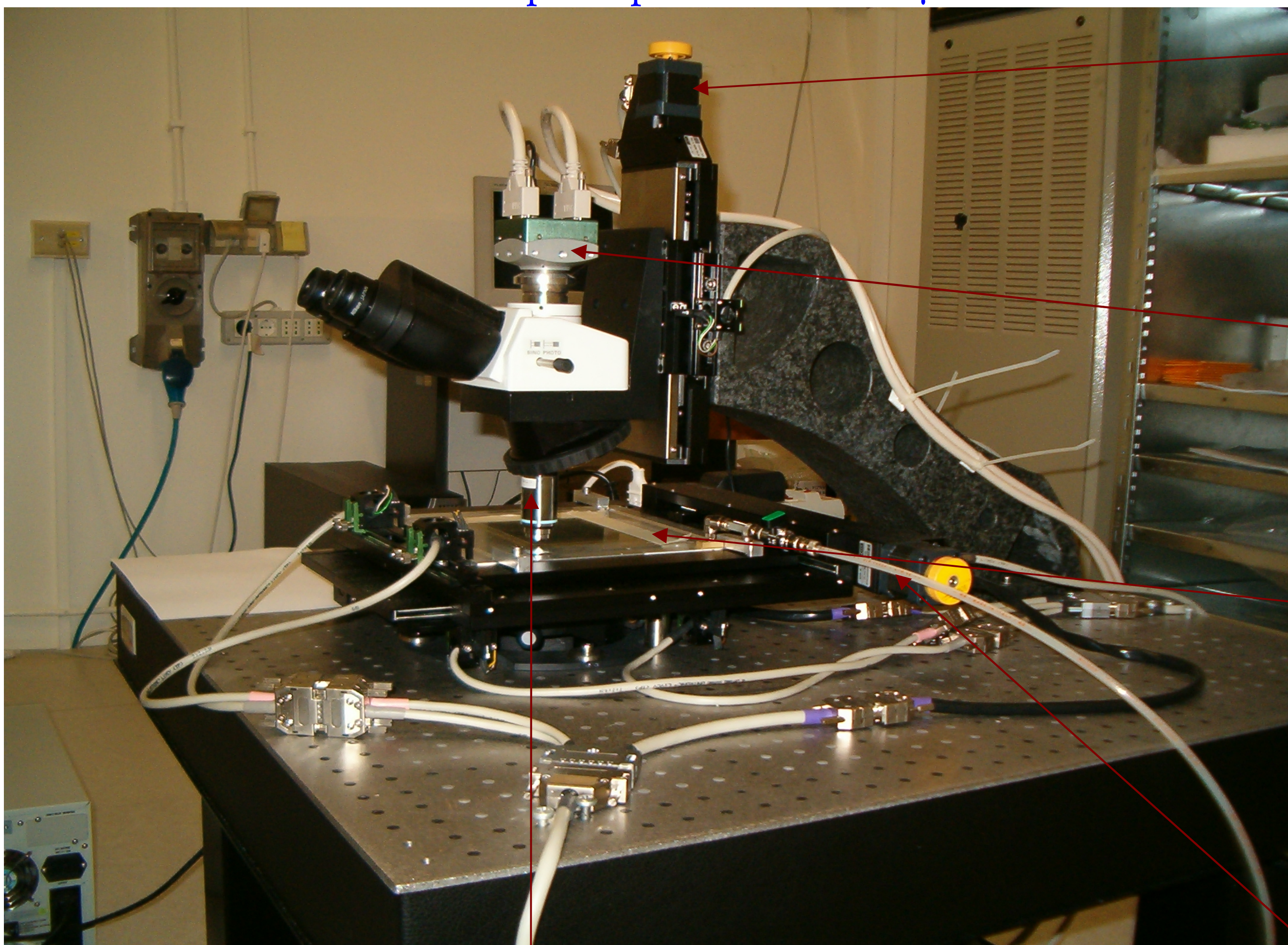


The European Scanning System (ESS)

Developed by European emulsion laboratories:

scanning speed: ~ 20 cm^2/h

spatial precision: ~ 0.5 μm



Z stage (Micos)
0.05 μm resolution

CMOS camera
Full Camera Link
1280×1024 pixels
256 gray levels

Emulsion film

XY stage (Micos)
0.1 μm resolution

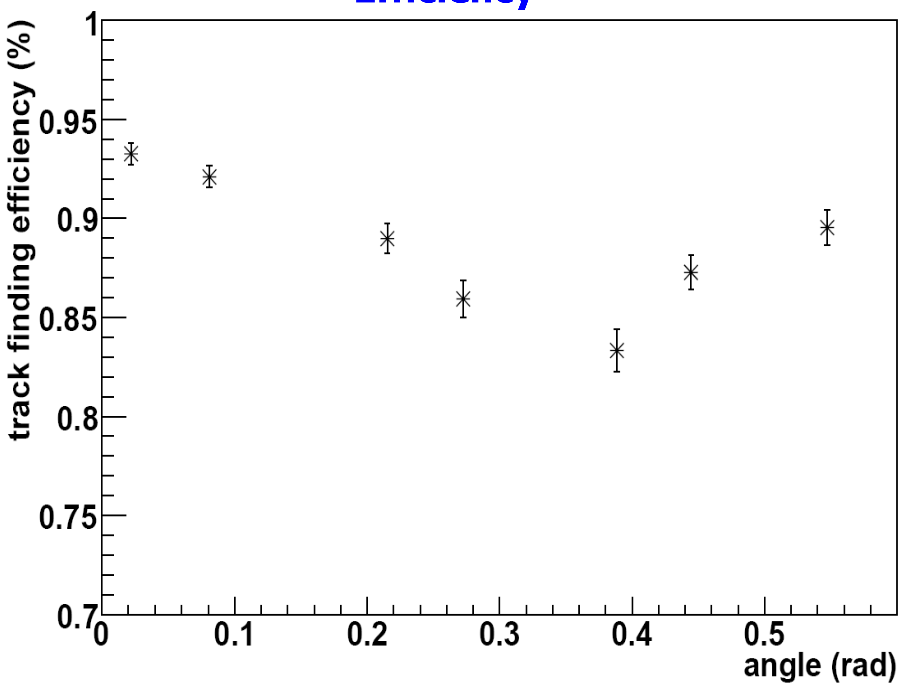
Optical system:
50x objective

Performances of the ESS

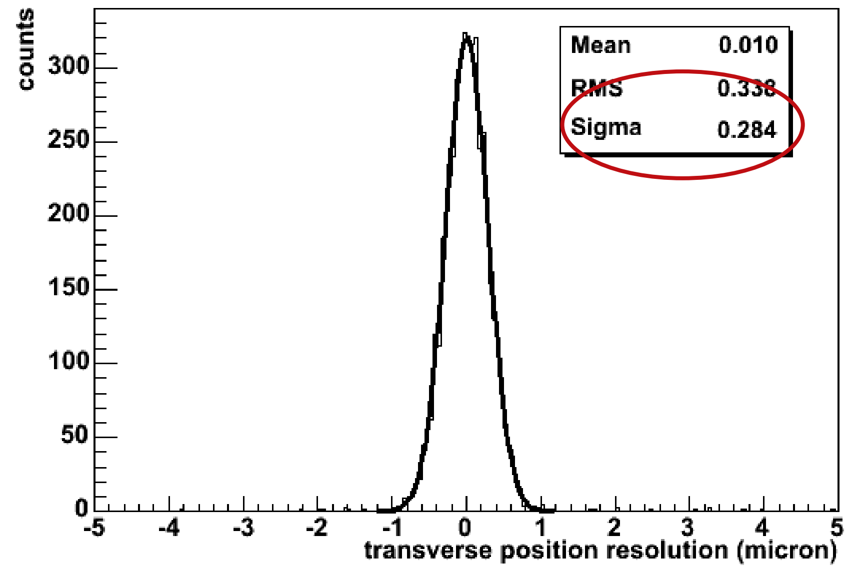
Scanning speed: 20 cm²/h/side

Tracking efficiency up to 95%
for small angle tracks

Efficiency



Position resolution (µm)



Angular resolution (µm)