Momentum Measurements by MCS

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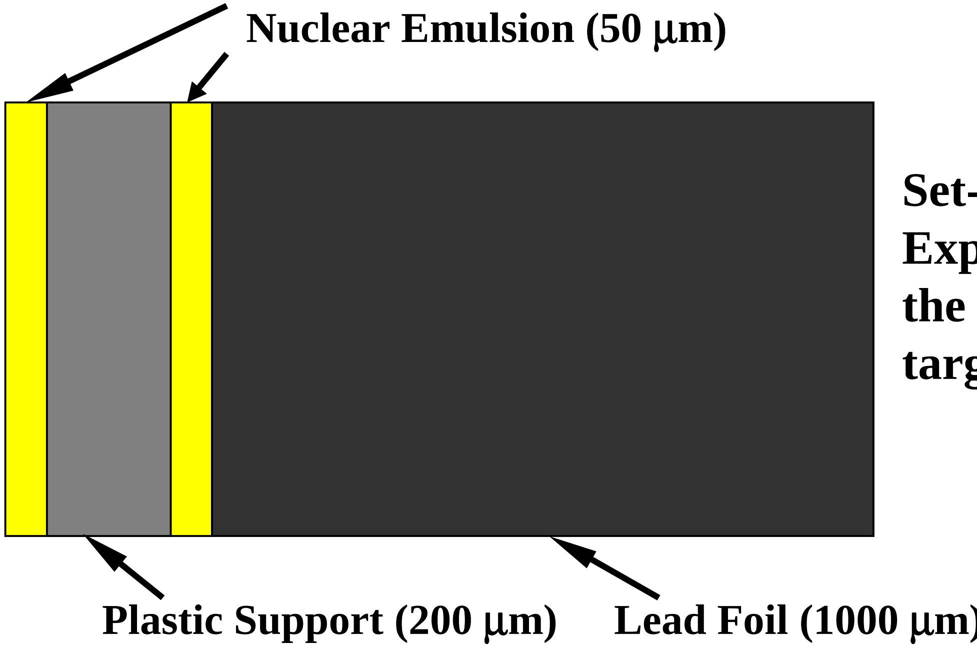
Summary

- Description of the OPERA Test Beam
- Multiple Coulomb Scattering Technique
- Alignment and Position Error
- Momentum Measurements
- MS in CHORUS experiment
- Conclusions and Outlook

Description of MCS Test



Set-up of a cell in the OPERA Experiment. 56 cells compose a brick, the fundamental unit of the OPERA target.

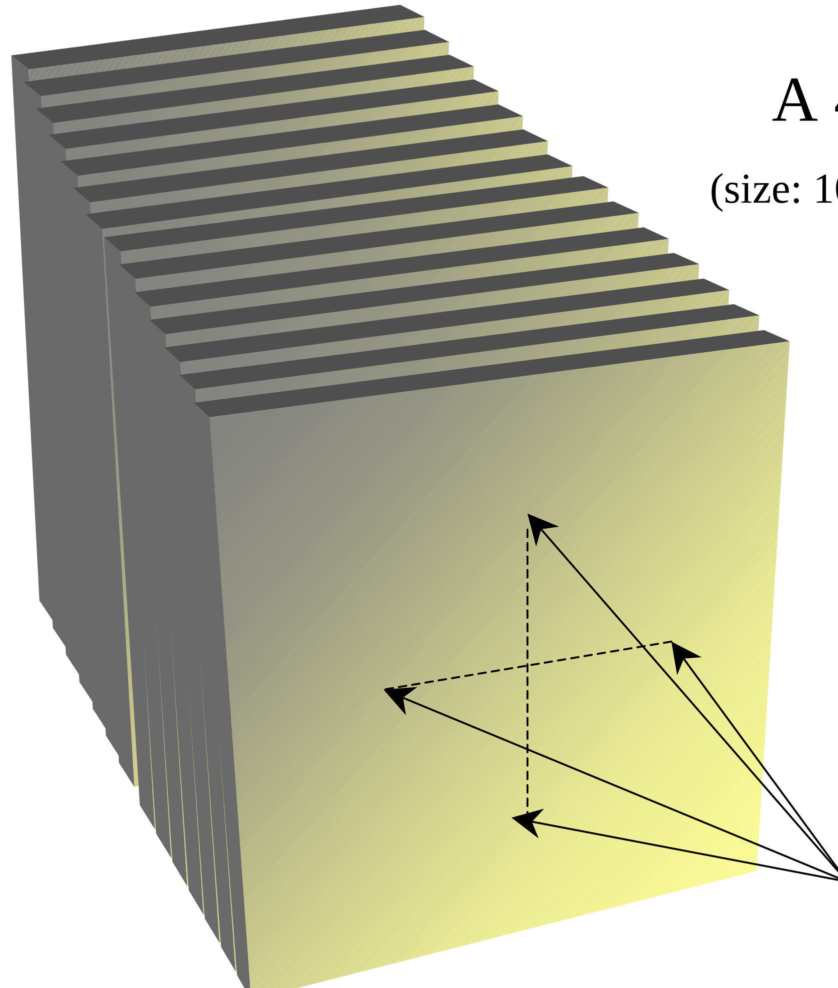
	Base (TAC)	Diluted Emulsion	Lead
Thickness *x* (μm)	**200**	**2×50***	**1000**
Rad. Length X_0 (μm)	**310×10^3**	**55.0×10^3**	**5.6×10^3**
Density δ (g/cm^3)	**1.28**	**2.40**	**11.35**

*Emulsion thickness in opera will be 42 μm.

Description of MCS Test

A 40-cell Target

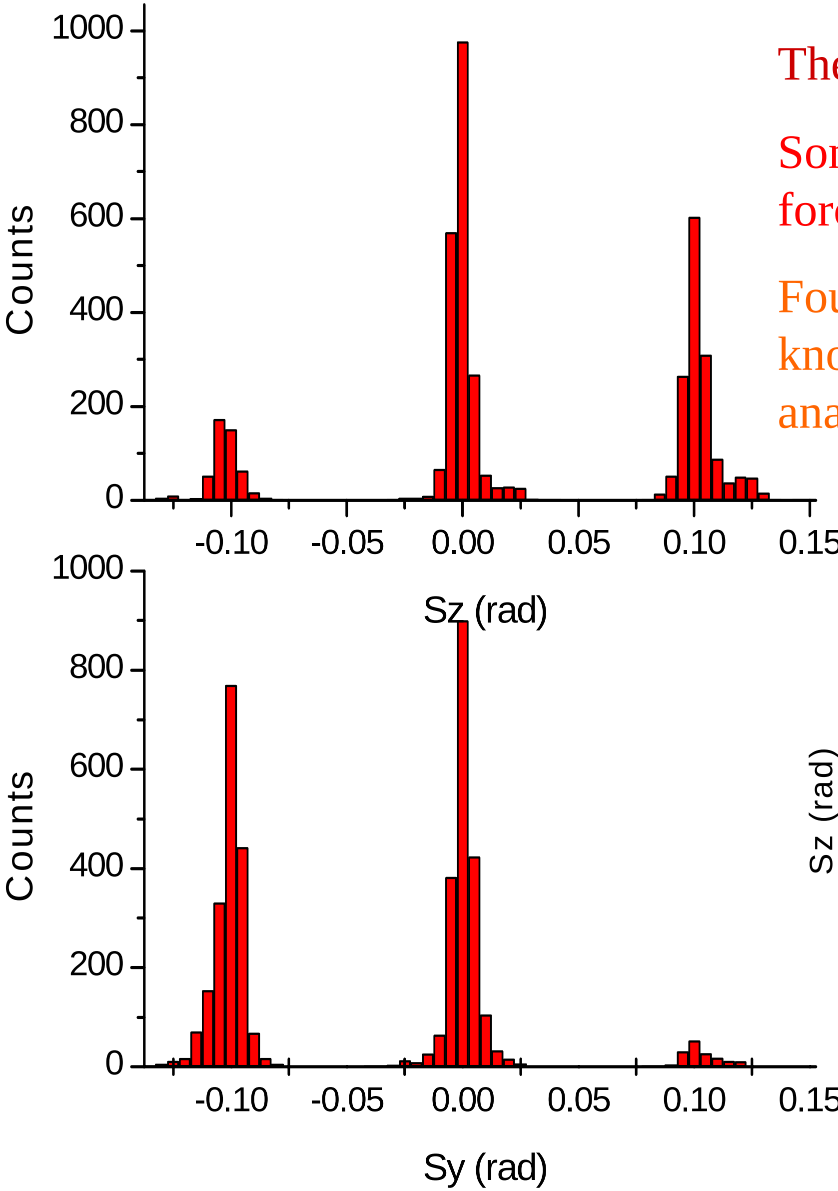
(size: 10×12.5 cm^2, Fomos Gel)



Pion Beams of different momenta impinged on it having different slopes

By means of the track slope, the particle momentum can be identified

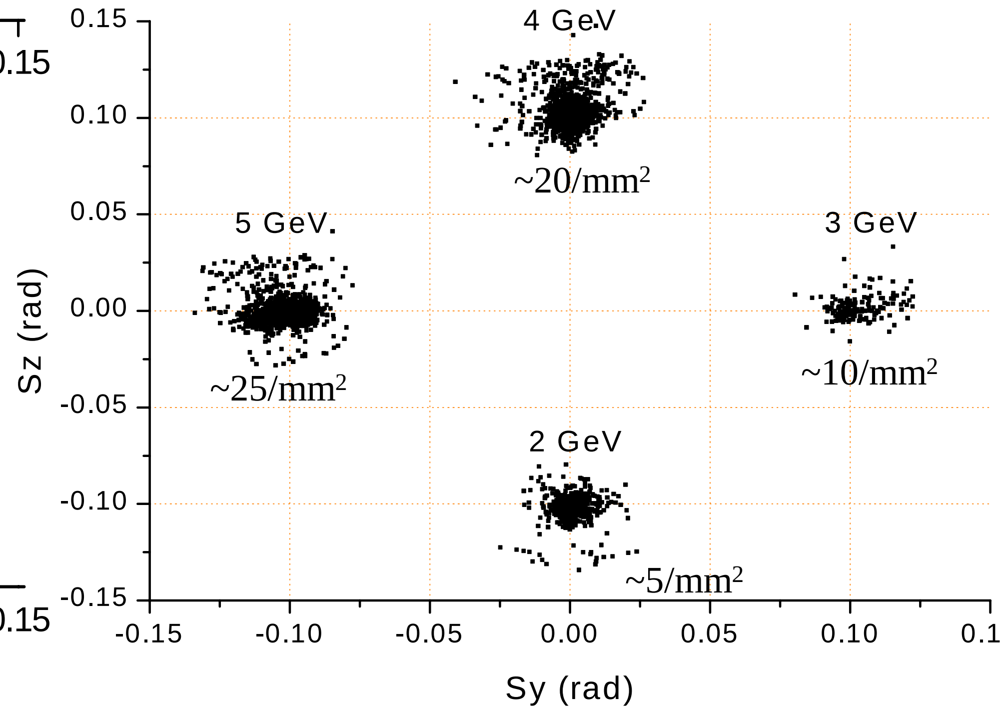
Description of MCS Test



The Slopes Spectrum in a single Emulsion Sheet.

Some areas of very wide distortion were detected. A forced link was therefore necessary.

Four beams can be detected and their momenta are known (a fifth beam was also detected but not analysed).



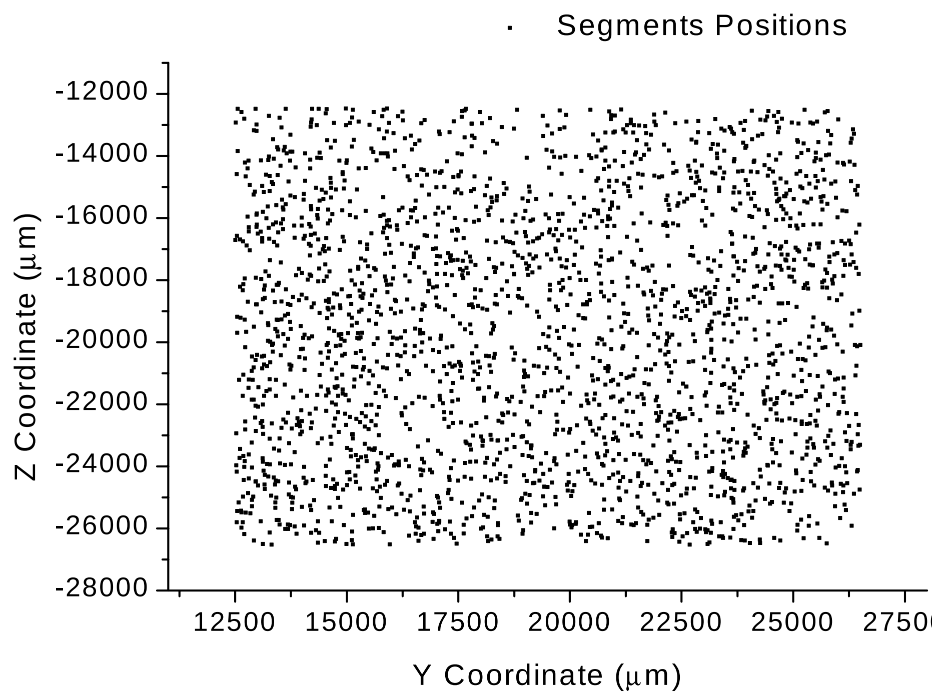
Description of MCS Test

Scanning in Salerno Laboratory

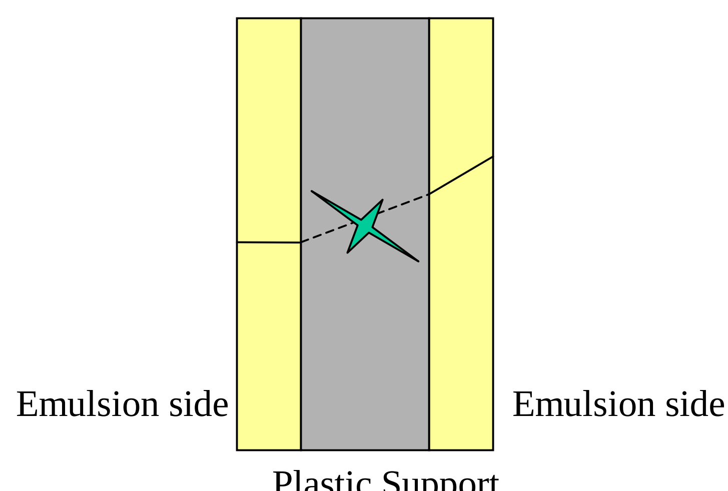
Scanning speed: 1.54 cm^2/h (old scanning system)

Scanned surfaces: 3.72cm^2 (both sides)

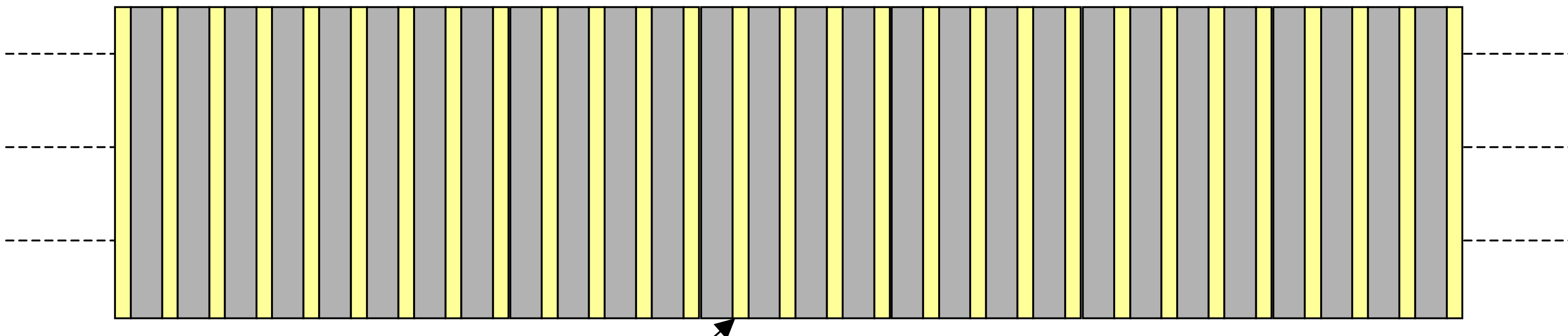
Positions of the tracks segments in Sheet #6.



In large distortion areas the detection of the segment belonging to the track is difficult because linking the two sides of the emulsion sheet may fail (even 50÷70 mrad discrepancy).



Description of MCS Test



Sheet #21 (just in the middle of the stack!) was not available for scanning in our laboratory

This gave problems for two main reasons:

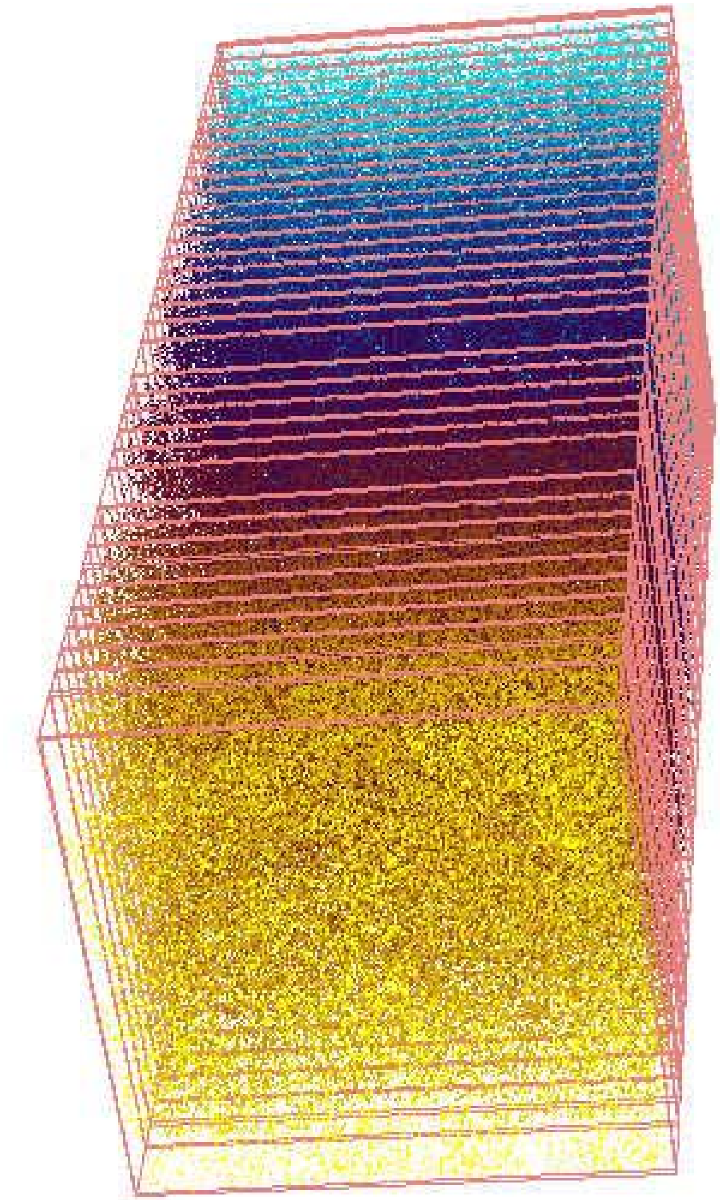
• the connection between the two part of the stack (1-20 and 22-40) was not so satisfactory

• the systematic lack of a segment for each track in the middle of the stack affected momentum measurements

Description of MCS Test

In the scanning laboratory, a huge amount of data coming from emulsion had to be processed and stored.

Total Scan Display

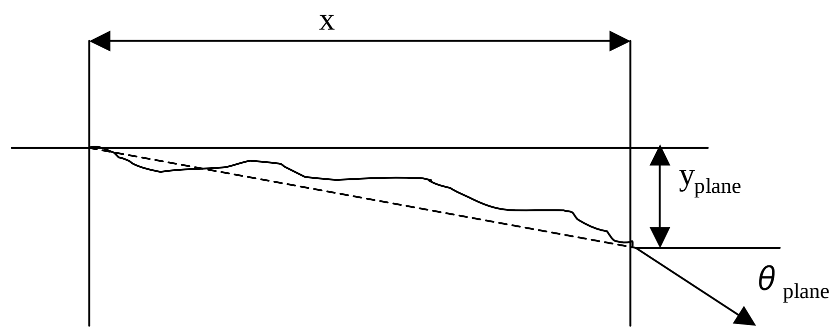


13000 Segments × 2 Sides × 39 Sheets

Multiple Scattering Technique

Momentum *p* is related to RMS of angular differences θ_0

$$\theta_0 = \frac{0.0136 GeV}{\beta p (GeV/c)} z \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln\left(\frac{x}{X_0} \right) \right] (rad)$$



But it is also related to RMS of second position differences.

$$p = \frac{0.0136 GeV}{y_{plane}^{rms}} x \sqrt{\frac{2x}{3X_0}} \left[1 + 0.038 \ln\left(\frac{x}{X_0} \right) \right] (GeV/c)$$

Multiple Scattering Technique

The position displacement for two consecutive cells is expected to be the result of the contribution of two terms: the multiple scattering and the measurement error:

$$(\Delta y)^2 = \left[y^{rms}_{plane}(X_n)\right]^2 + \left[y^{meas\_err}_{plane}\right]^2 = \left[A(p)\cdot X_n\right]^2 + \left[y^{meas\_err}_{plane}\right]^2$$

Where *A* coefficient is related to the momentum *p*:

$$A(p) = \frac{0.0136}{p} d \sqrt{\frac{2d}{3X_0}}$$

d is the unitary cell length

And the quantity X_n is related to the cell length *x*:

$$X_n = x_n^{\frac{3}{2}}\left[1 + 0.038\ln\left(\frac{d\cdot x_n}{X_0}\right)\right]$$

Multiple Scattering Technique

$$(1)\quad (\Delta y)^2 = \left[y^{rms}_{plane}(X_n)\right]^2 + \left[y^{meas\_err}_{plane}\right]^2 = \left[A(p)\cdot X_n\right]^2 + \left[y^{meas\_err}_{plane}\right]^2$$

Contribution by Multiple Scattering

Contribution by Measurement Error

The only parameter to be set in equation (1) is $A(p)$ because, we know that y^{meas_err} must be similar to the value that we got in the alignment procedure.

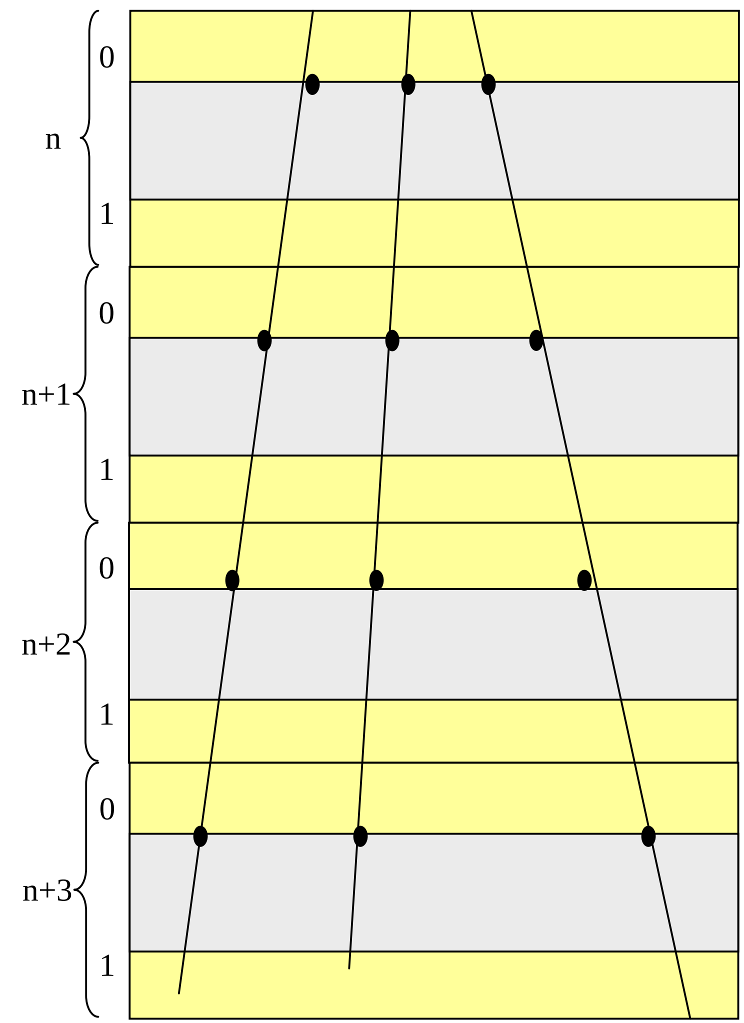
Therefore a good determination of y^{meas_err} is crucial to measure momentum accurately.

The lower the value of y^{meas_err} the higher the maximum momentum we can measure.

Alignment and Position Error

Procedure of estimation of the alignment error.

For each emulsion sheet we can calculate RMS of transverse position displacements between tracks position on the sheet and intercepts of linear fit on the sheet.



Alignment and Position Error

Position Error Estimation

We considered 5 GeV beam for two main reasons:

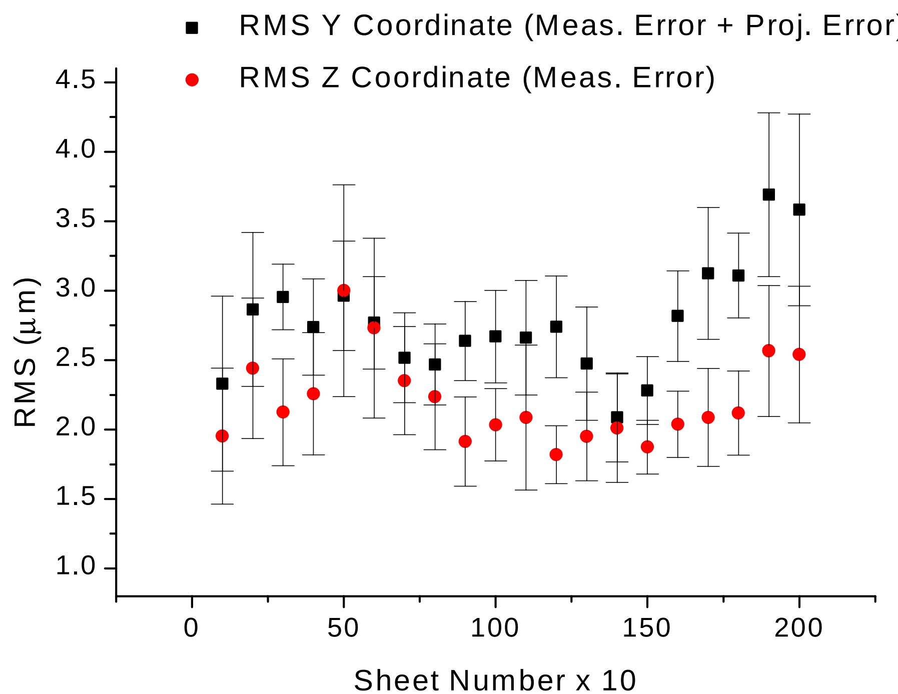
• minimizing the multiple scattering contribution to the position displacements;

• minimizing statistical uncertainty because of its high density with respect to the other beams

Hint for next tests: a beam at (0,0) slopes…

Alignment and Position Error

Position Error must be measured **sheet by sheet** ...



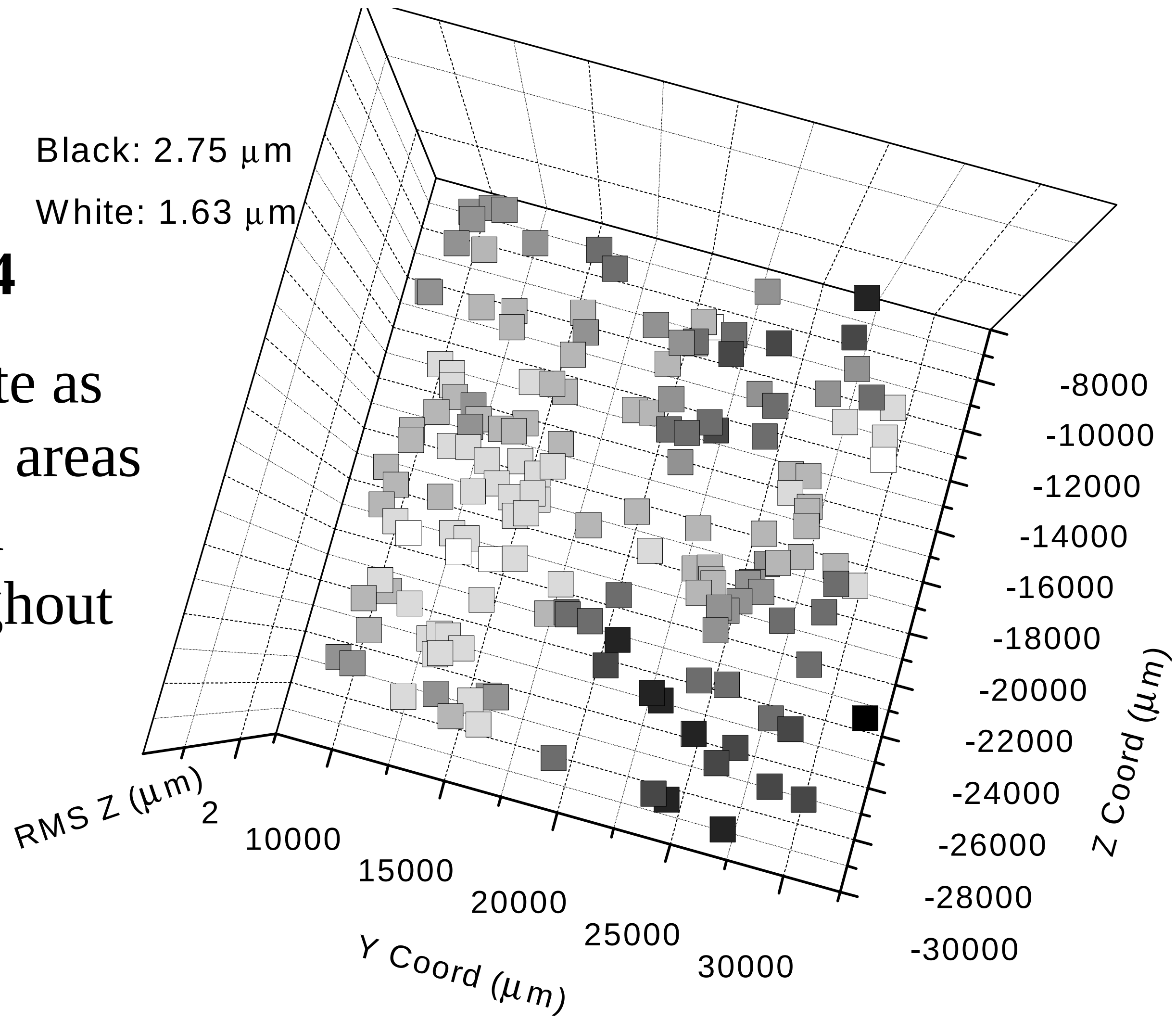
Due to 5 GeV beam slopes (Sy = -0.1 rad, Sz = 0 rad), alignment along Y axis is also affected by projection error.

Alignment and Position Error

... and, for each sheet, **place by place**.

Example: Sheet 14

RMS of Z coordinate as measured in several areas of 6.25 mm^2 around tracks linked throughout several sheets



Momentum Measurements

$$(\Delta y)^2 = \left[y_{plane}^{rms}(X_n)\right]^2 + \left[y_{plane}^{meas\_err}\right]^2 = \left[A(p)\cdot X_n\right]^2 + \left[y_{plane}^{meas\_err}\right]^2$$

It is interesting to check for each track:

- the behaviour of $(\Delta y)^2$ when X_n (related to the cell length) increases
- the behaviour of the measured momentum for each cell length.

Let’s show an example...

Momentum Measurements

$$(\Delta y)^2 = [A(p) \cdot X_n]^2 + [y_{plane}^{meas\_err}]^2$$

Track #: 9570

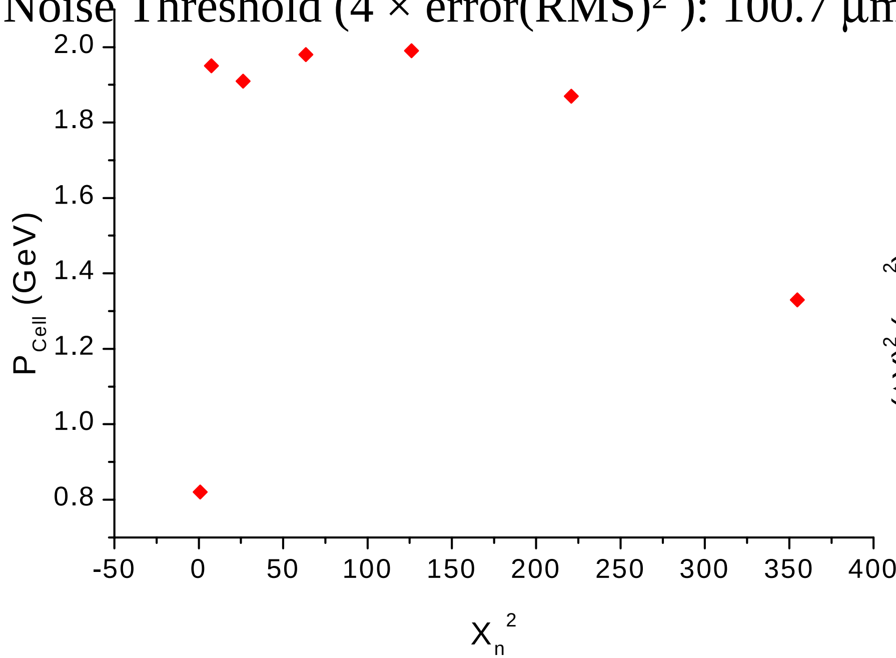
RMS on a single sheet: 2.05 μm

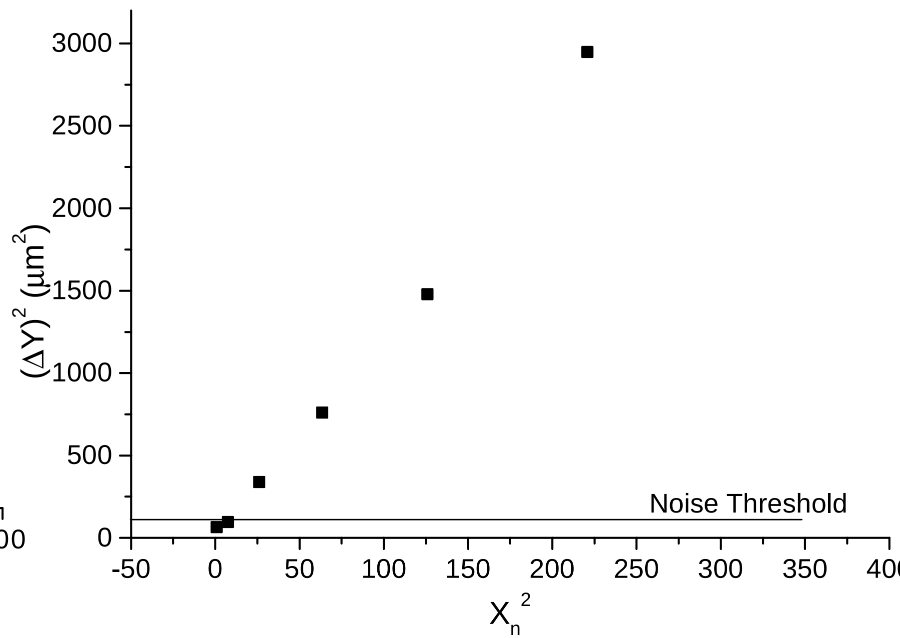
$$y^{meas\_err} = \sqrt{6}RMS = 5.02\mu m$$

Meas.:18 (only a half-stack was considered)

Noise Threshold (4 × error(RMS)^2): 100.7 μm^2

Cell	X_n^2	$(\Delta y)^2$ (μm^2)	P_{cell} (GeV)
1	0.89	65.2	0.82
2	7.52	95.9	1.95
3	26.18	338.9	1.91
4	63.45	758.9	1.98
5	126.04	1479.0	1.99
6	220.81	2947.7	1.87
7	354.71	9301.8	1.33





Momentum Measurements

General requirements of the procedure

Momentum measurements using tracks coordinates.

Track by track analysis (looking at the behaviour of the rise and at the noise threshold for each track) .

We choose very safe conditions to accept a multiple scattering signal:

Tracks in well aligned areas (RMS $< 3\mu m$)

Estimation of the momentum possible at least up to cell length 5.

RMS of displacements at least 4 times above the noise threshold.

Very evident saturation of the momentum measurement (around 20% discrepancy) in cells above the noise threshold.

Momentum Measurements

These cuts reduced a lot our statistics but gave us the chance to detect some Multiple Scattering signal.

13000 linked segments per sheet

↓

Alignment and Linking Procedure Cuts (segments for which a candidate is not found in adjacent sheets).

↓

2, 3 and 4 GeV linked tracks (at least 4 measurements) ~ 2100

↓

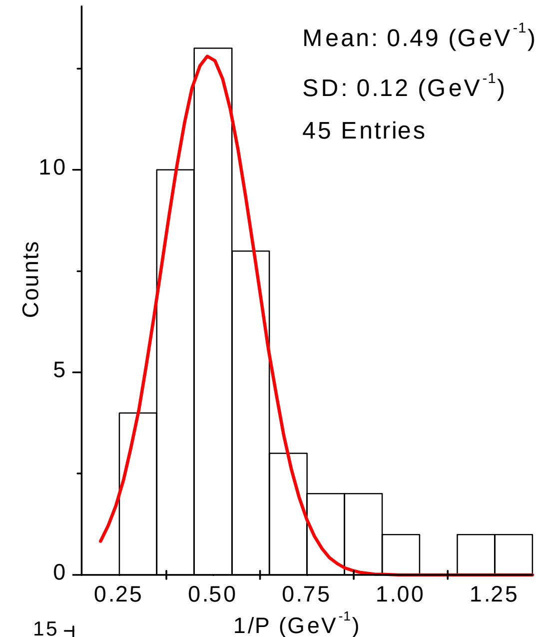
Momentum measurements Cuts (segments number for each track, cell number cuts and quality cuts).

↓

~ 180 tracks

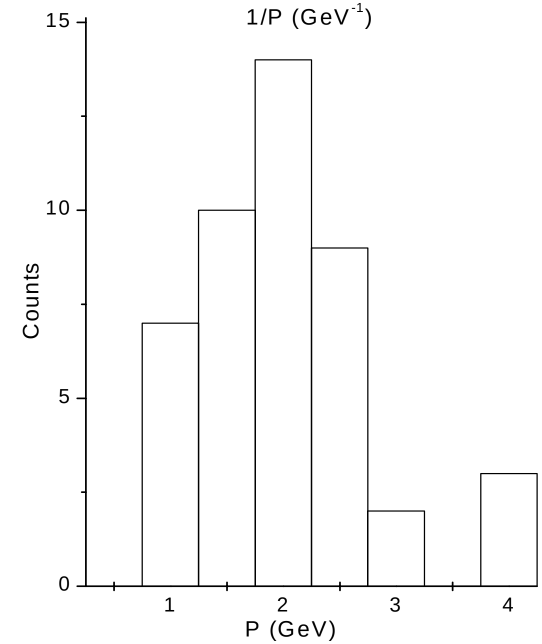
Momentum Measurements

Measurements of momentum for tracks belonging to "2 GeV Beam".



Gaussian Fit (1/P)
Mean: 0.49 GeV^{-1}
Sigma: 0.12 GeV^{-1}

$\Rightarrow$ $P = 2.0^{+0.7}_{-0.4}$ GeV



All Data (1/P)
Avg: 0.57 GeV^{-1}
RMS: 0.23 GeV^{-1}

$\Rightarrow$ $P = 1.8^{+1.2}_{-0.5}$ GeV

Momentum Measurements

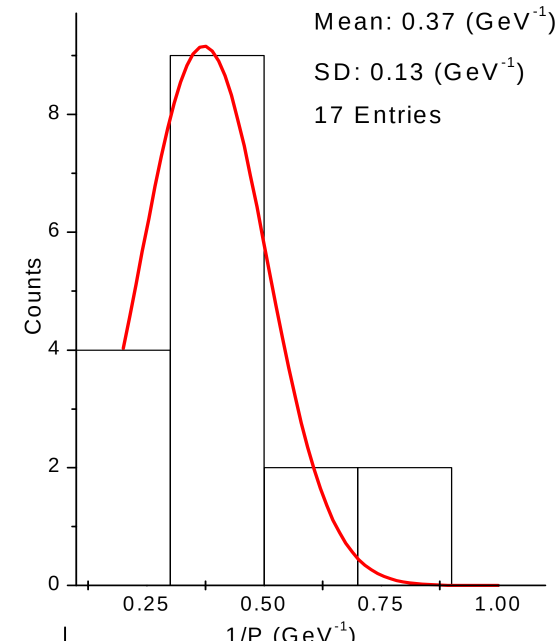
Measurements of momentum for tracks belonging to “3 GeV Beam”.

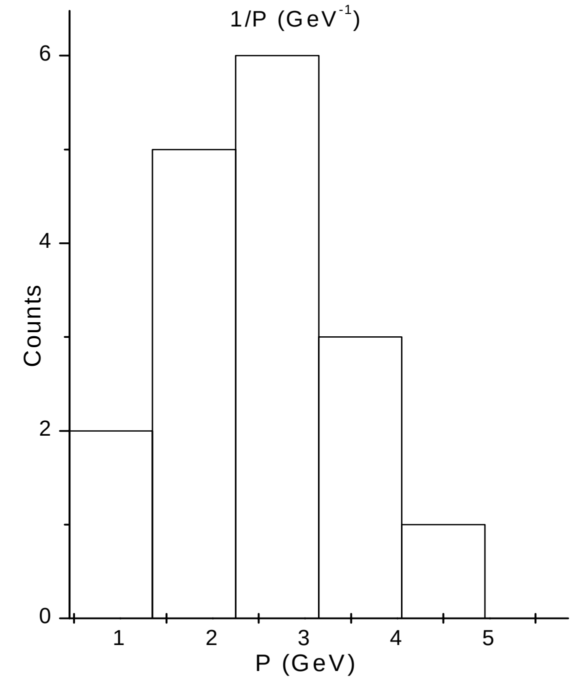
Gaussian Fit (1/P)
Mean: 0.37 GeV^{-1}
Sigma: 0.13 GeV^{-1}

$\Rightarrow$ $P = 2.7\ ^{+1.5}_{-0.7}$ GeV

All Data (1/P)
Avg: 0.43 GeV^{-1}
RMS: 0.17 GeV^{-1}

$\Rightarrow$ $P = 2.3\ ^{+1.5}_{-0.6}$ GeV



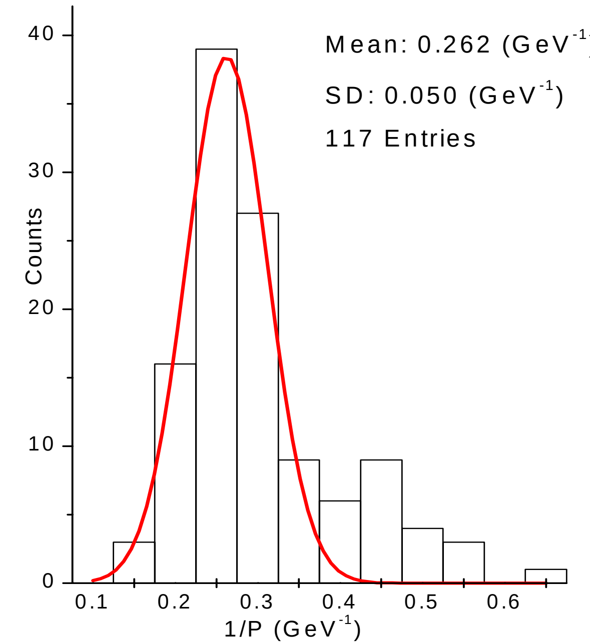


Momentum Measurements

Measurements of momentum for tracks belonging to "4 GeV Beam".

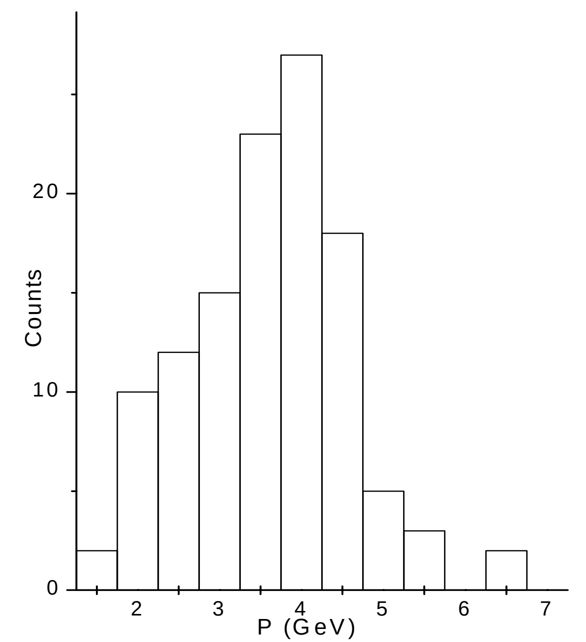
Gaussian Fit (1/P)
Mean: 0.26 GeV^{-1}
Sigma: 0.05 GeV^{-1}

→ $P = 3.8^{+0.9}_{-0.5}$ GeV



All Data (1/P)
Avg: 0.3 GeV^{-1}
RMS: 0.1 GeV^{-1}

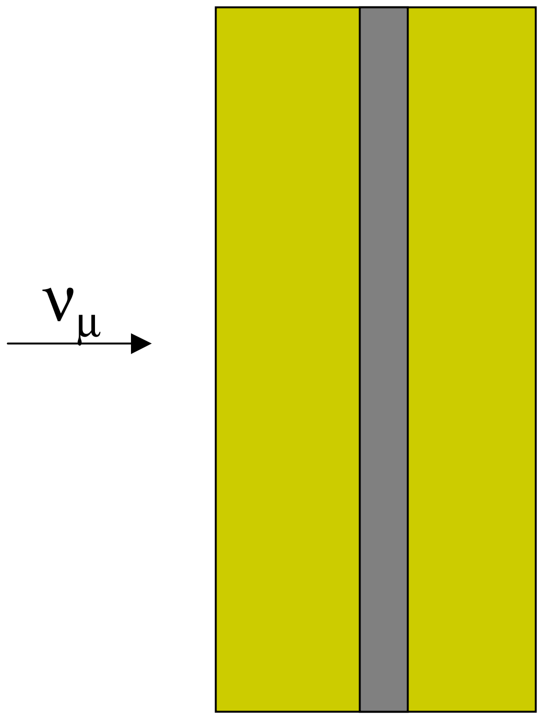
→ $P = 3.3^{+1.7}_{-0.8}$ GeV



For some 4 GeV tracks, positions were available through the whole stack (39 sheets)

MS in CHORUS Environment

	Base	Emulsion
Thickness x(μm)	90	2×350
Radiation Length X_0(μm)	424×10^3	28.9×10^3
Density δ(g/cm^3)	1.032	3.815



36 Sheets

MS in CHORUS Environment

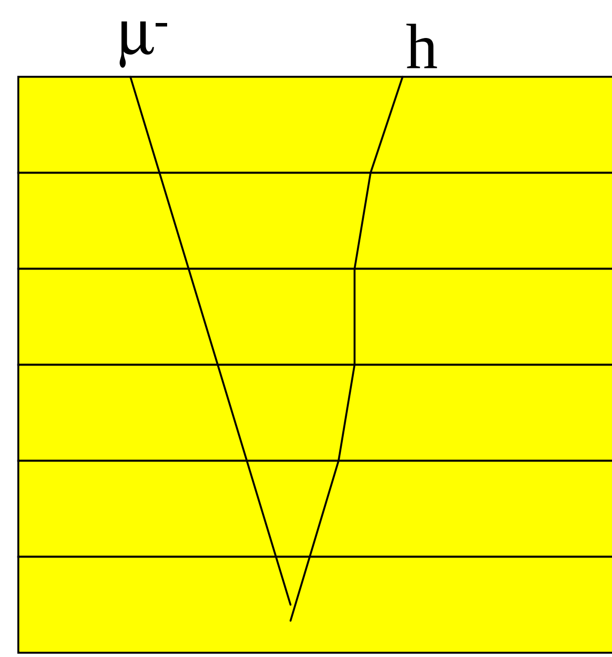
Scan-back Tracks

Alignment of emulsion sheets shows up a $\sigma \sim 10 \mu m$ in the scan-back phase but these general alignment can be avoided using reference tracks belonging to the same reconstructed event:

• 2 scan-back tracks of the same event that led to the interaction vertex;

• 1 scan-back track is choosen to be an high momentum muon (~10 GeV) with negligible contribution due to MS.

• Relative positions of scan-back tracks wrt high energy muons are used for MS computation (inercalibration errors are reduced and only the measurement error survives).



MS in CHORUS Environment

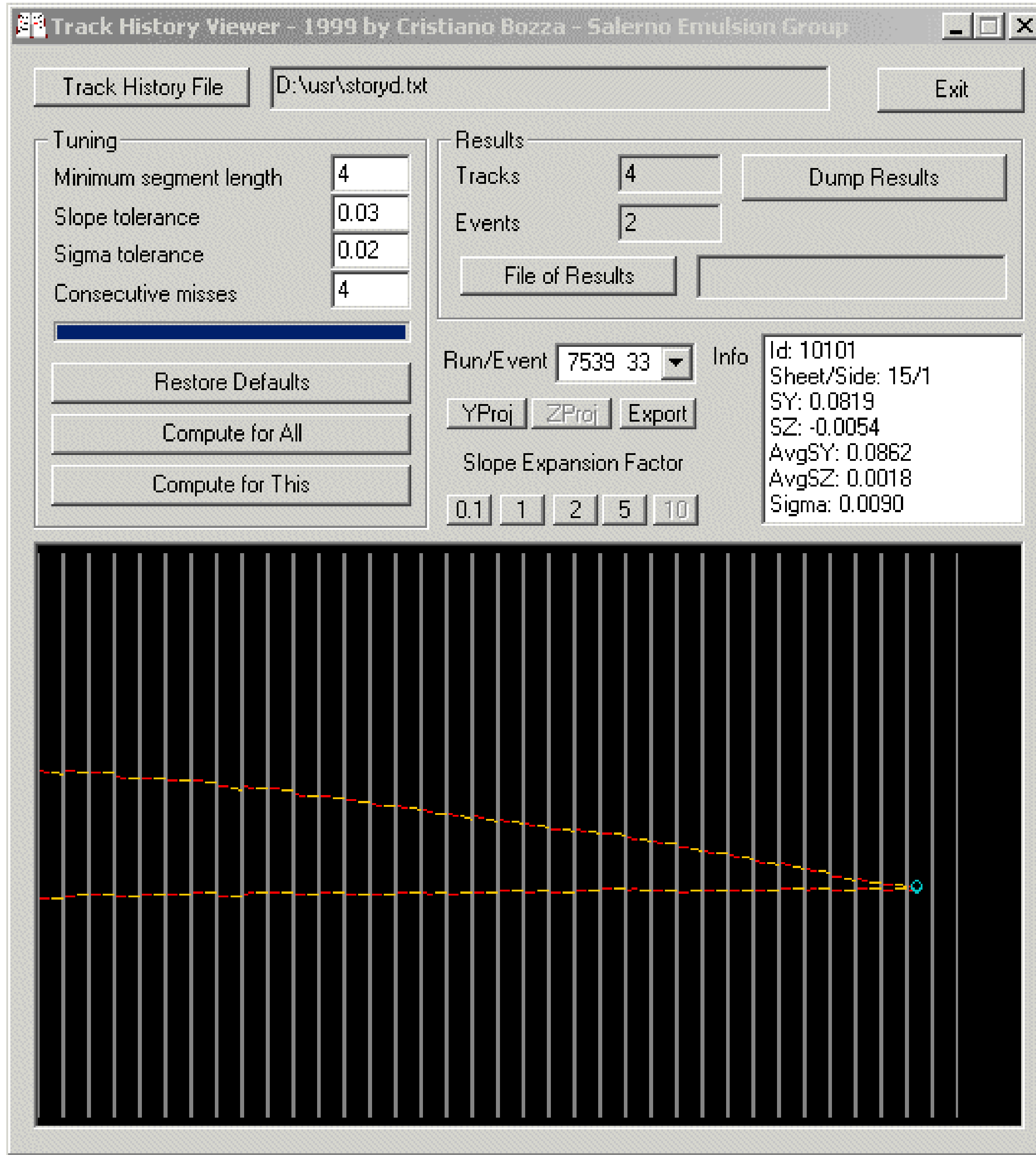
Scan-back Tracks

Run 7539 Event 339

Muon: P = -17.2 GeV in spectrometer

Event located using 2 scan-back Tracks in sheet #35

Measured momentum for the other track: $1.0^{+0.2}_{-0.1}$GeV



MS in CHORUS Environment

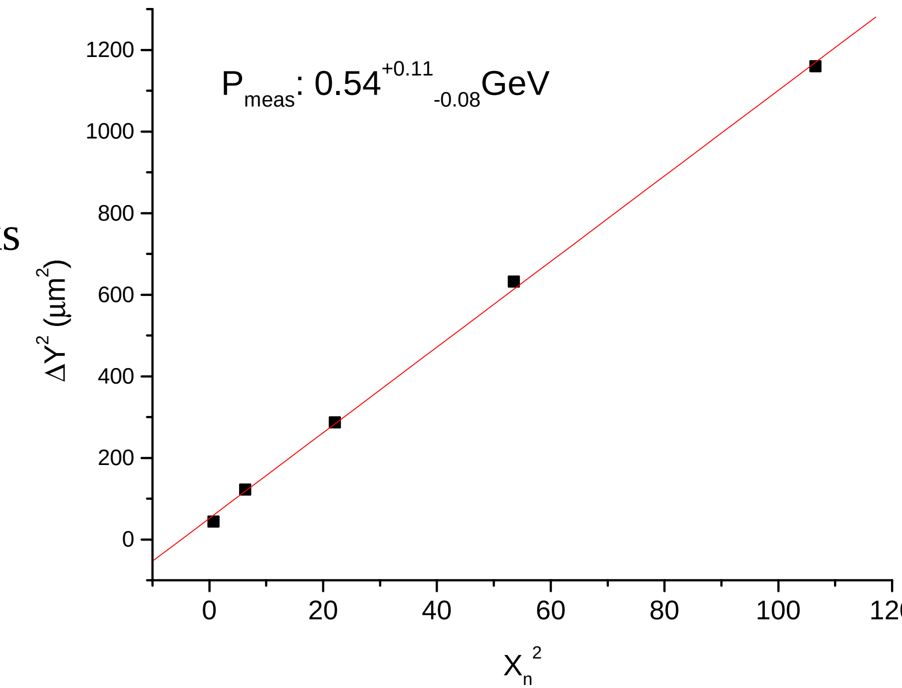
Scan-back Tracks

Run 7598 Event 5236

Muon: P = -9.23 GeV in spectrometer

Event located using 2 scan-back Tracks in sheet #25

Measured momentum for the other track: $P = 0.54^{+0.11}_{-0.08}$GeV



Run 7764 Event 2551

Muon: P = -16.78 GeV in spectrometer

Event located using 2 scan-back Tracks in sheet #34

Measured momentum for the other track: $P = 1.27^{+0.20}_{-0.16}$GeV

Measured momentum by electronic detector: P = 1.296 GeV

Conclusions and Outlook

- Even in very hard conditions (high distortion, low number of measurements, etc...) it is possible to extract a MS signal up to 4 GeV in a OPERA-like setup;
- Low momenta can be measured in the CHORUS target set-up (not properly designed to measure momentum by MS);
- More tests, in better conditions, are needed to confirm and possibly improve these results...