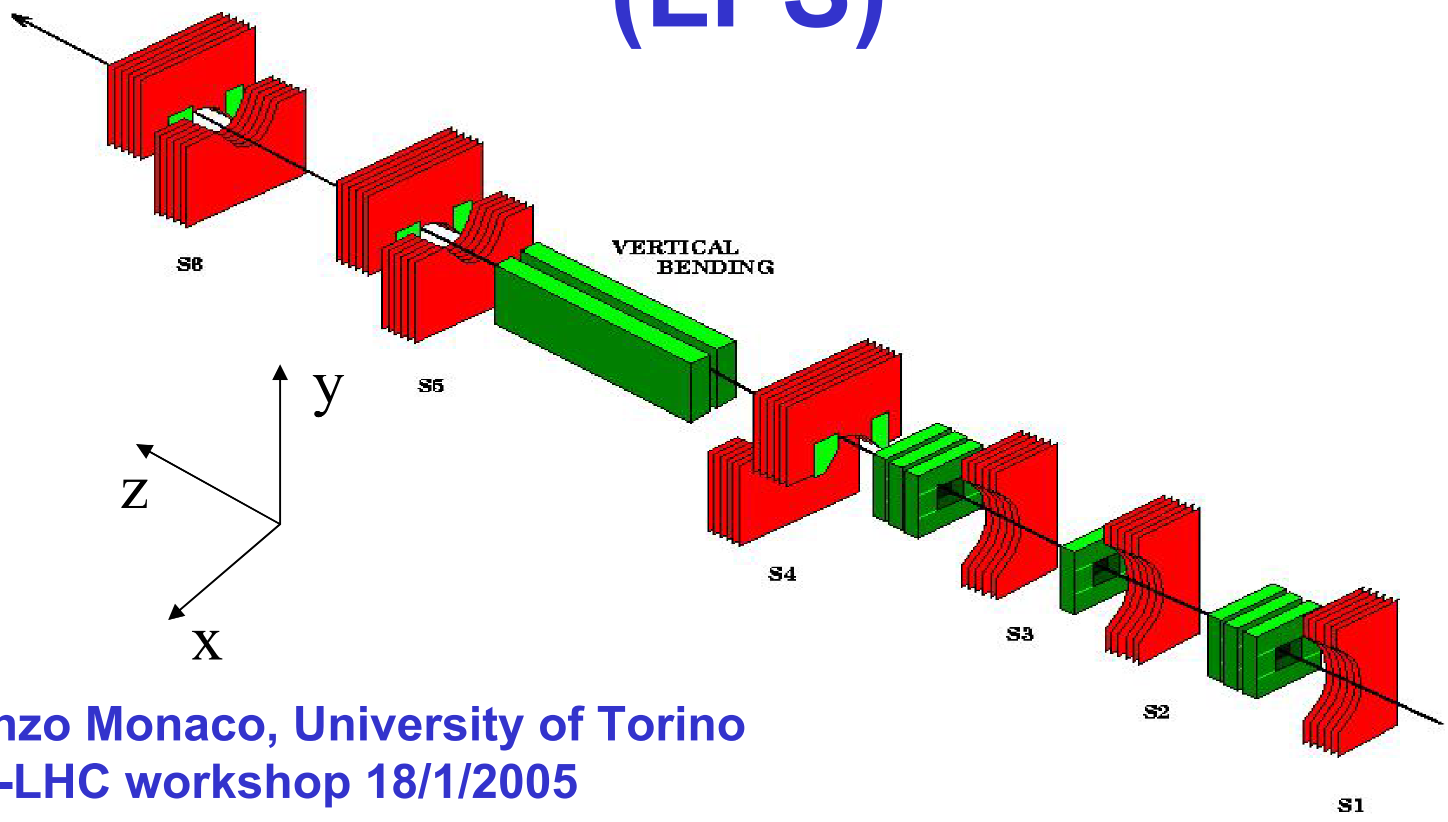
Alignment and calibration of the ZEUS Leading Proton Spectrometer (LPS)

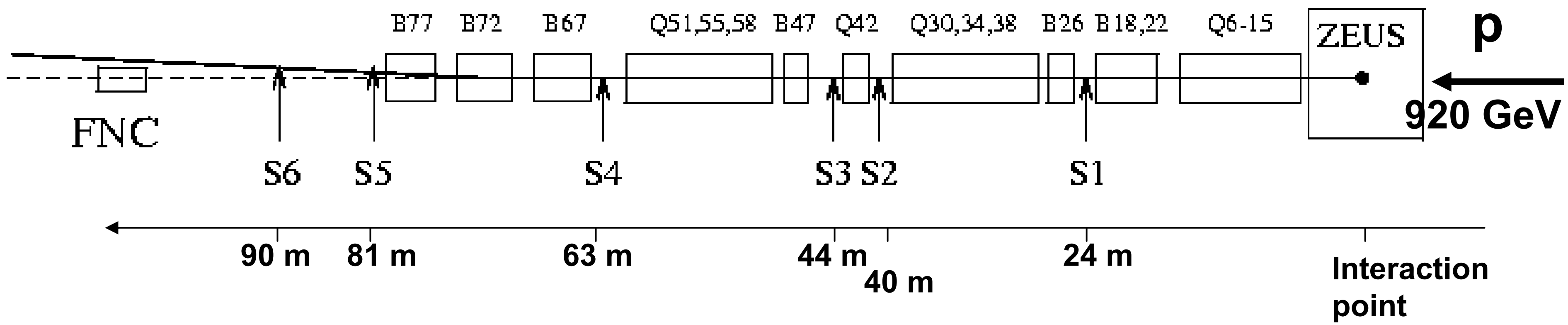


Vincenzo Monaco, University of Torino
HERA-LHC workshop 18/1/2005

presented by M. Arneodo

See also: talk by R. Sacchi in March and Zeus Coll., Z. Phys. C 73 (1997) 253

The Leading Proton Spectrometer



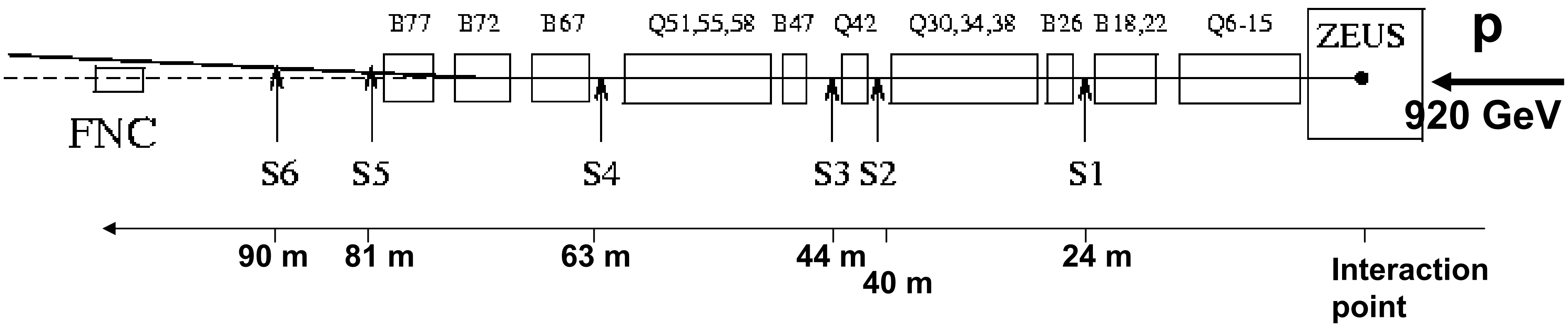
Two independent spectrometers:

S1,S2,S3 – one pot in each station
dipoles with horizontal bending

S4,S5,S6 – two pots in each station
dipoles with vertical bending

In total:
54 Si microstrip detector planes
50,000 channels
23 magnetic elements

The Leading Proton Spectrometer

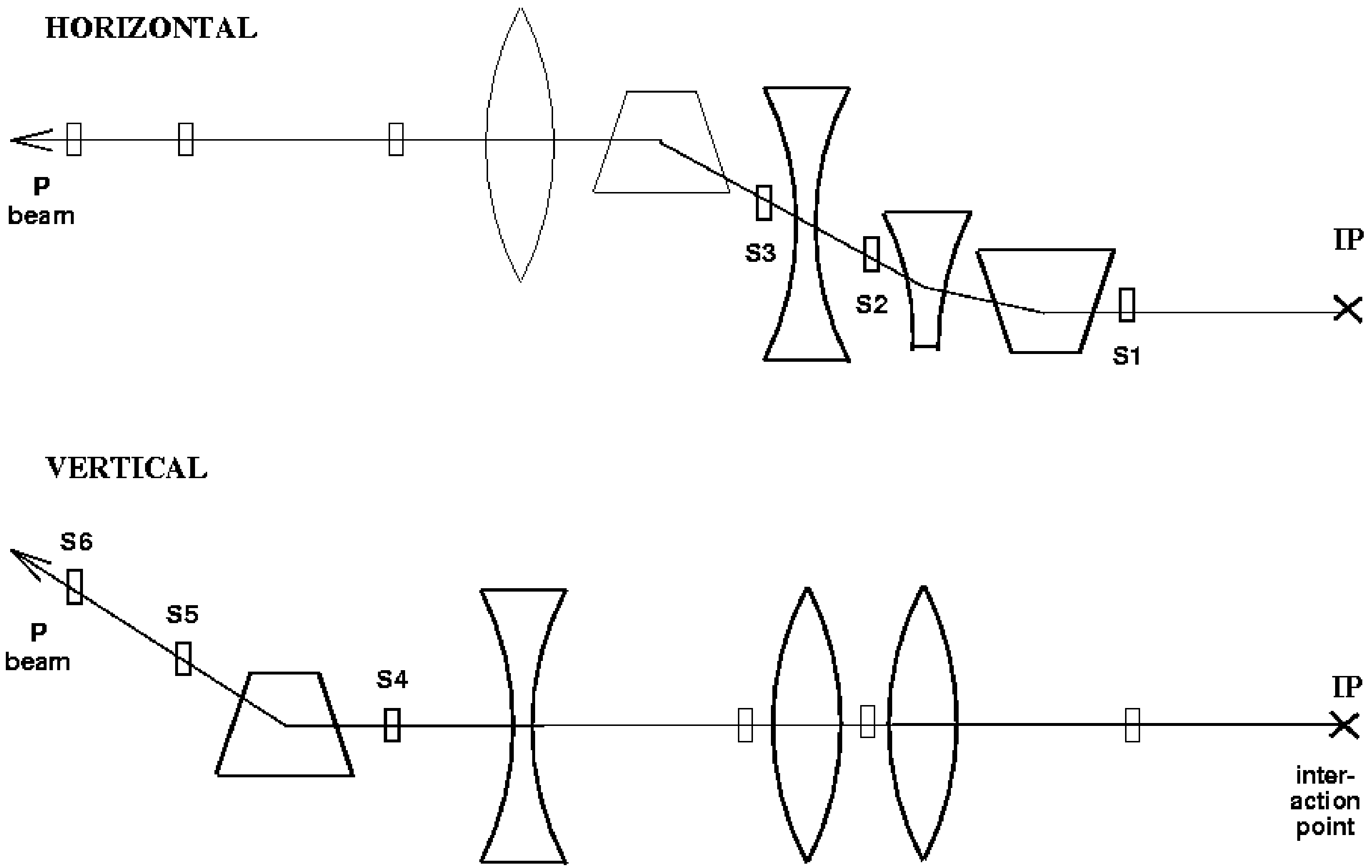


Could measure proton momentum from two types of events:

1) **3-station events: hits in three stations (eg S4, S5, S6)**
as a by-product get coordinates of interaction point

2) **2-station events: hits in two stations (eg S4, S5 only)**
take coordinates of interaction point from ZEUS central detector

The Leading Proton Spectrometer

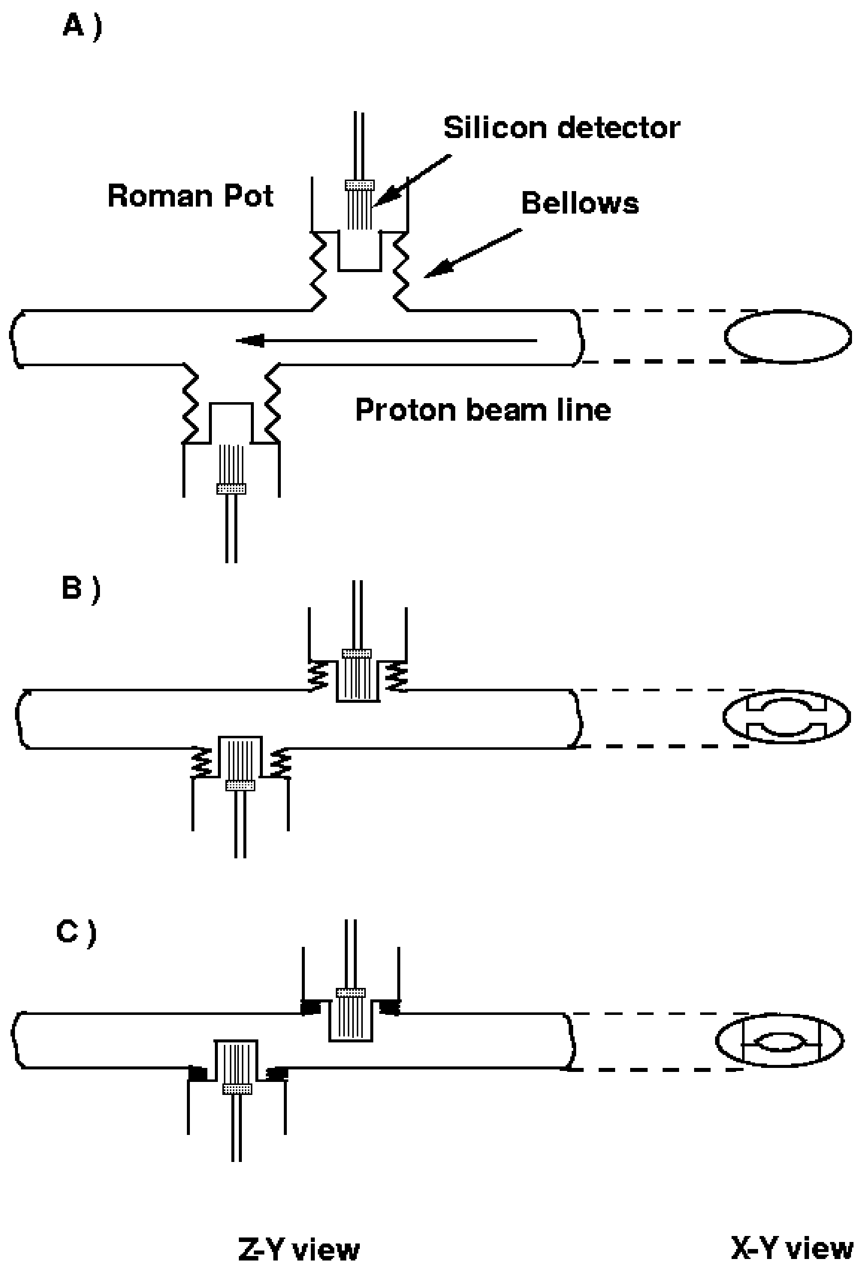


In this talk: focus on S4, S5, S6

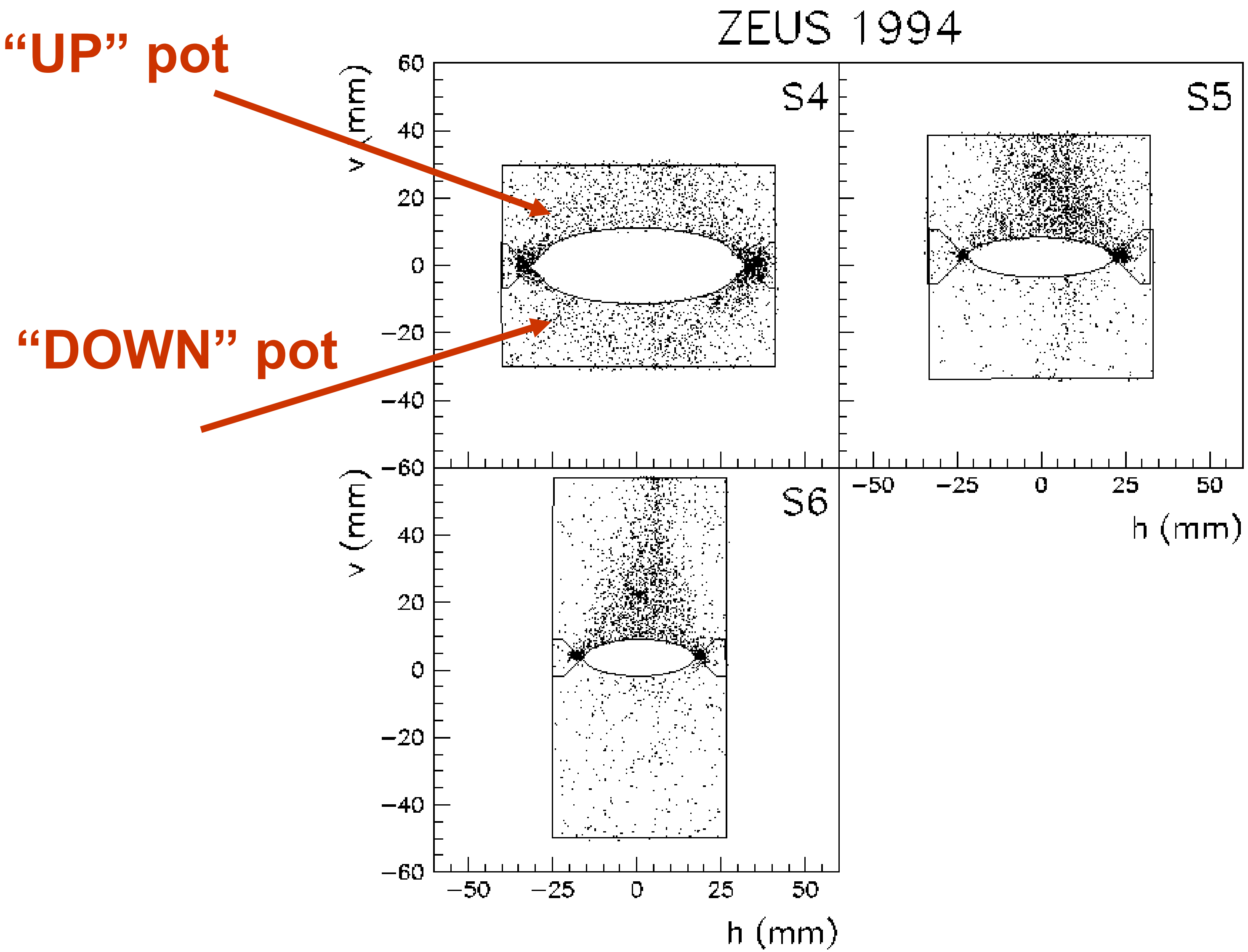
LPS insertion into data-taking position (S4, S5, S6)

- Detector → pot movement: stepping motors
- Pot movement: DC motors
- Lateral movements: stepping motors

In each pot:
6 Si microstrip detector planes
3 different strip orientations
pitch≈ 100μm



Position of hits on detectors



Alignment: preliminaries

- Subdivide the collected luminosity into *running periods* with stable conditions

- A new running period is introduced after
  i) changes in the machine optics
  ii) changes in the detector configuration:
    - new motor calibrations
    - changes in the number of active planes
    - anyway after maintainance work during shutdowns

- The alignment was performed independently for each running period

- Many degrees of freedom to be fixed; long and tedious iterative procedure

Alignment steps (S4, S5, S6)

- For each running period choose a reference run and do the following:

  1) Align the planes with respect to each other in each pot

  2) Align “up” pots with respect to “down” pots

  3) Align the three stations S4, S5 and S6 with respect to each other

  4) Align the whole spectrometer with respect to ZEUS

  Iterative procedure

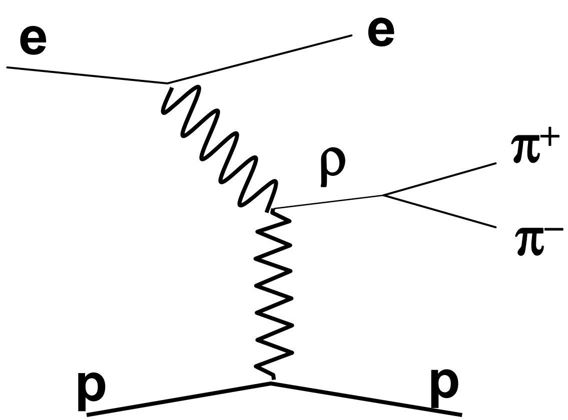
- Verify stability on all data-taking runs (iterate if necessary)

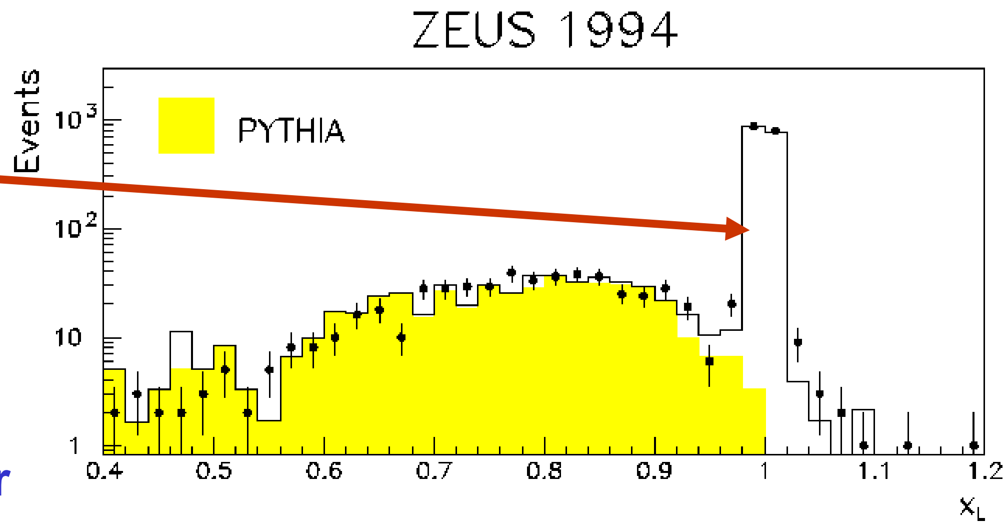
- Determine, for each proton fill, the direction of the incoming proton beam (the “beam tilt”): P_T calibration

- Typical resolutions: 20 μm $\oplus$ 10 μm (S1-S4); 20 μm $\oplus$ 30 μm (S5-S6)

Physics channels

- **Key to any alignment: use tracks whose trajectory is known a priori**
- **Since protons move in magnetic fields (which cannot be turned off !), need tracks of known momentum**
- **Exploit the fact that diffractive cross section peaks at x_L=p'/p=1**
- **Select processes using central detector and then look at proton in LPS**
- **Peak narrow ! For ep $\rightarrow$ eρ^0p, expected x_L width = 10^{-4}**





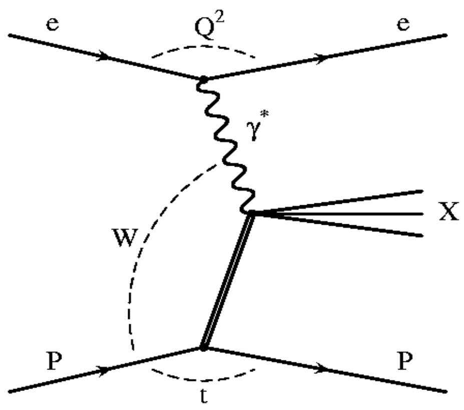
e, π^+,π^- measured in central detector

Physics channels

- Key to any alignment: use tracks whose trajectory is known a priori
- Since protons move in magnetic fields (which cannot be turned off !), need tracks of known momentum
- Exploit the fact that diffractive cross section peaks at $x_L=p'/p=1$
- Select processes using central detector and then look at proton in LPS
- Peak narrow !

Alternatively: inclusive diffraction (slightly wider diffractive peak, but more events)

e, X measured in central detector



1) Align planes within each pot

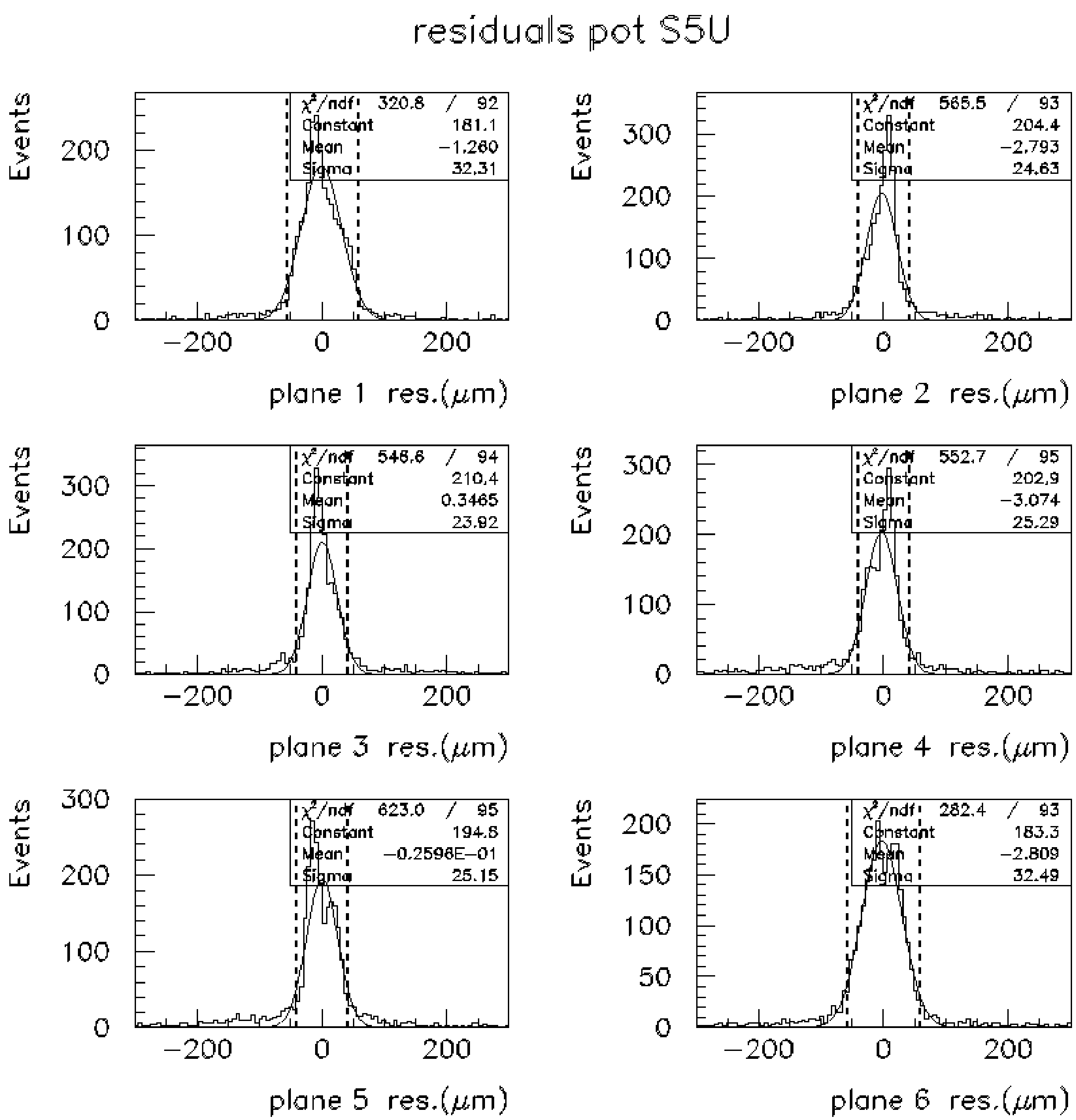
- **Track impact point in pot determined using planes with two different orientations**

- **Compare with the other planes**

- **Residuals in the other planes are minimized by translating the planes in the x/y plane and rotating them around the z-axis**

- **The procedure is iterated on all planes**

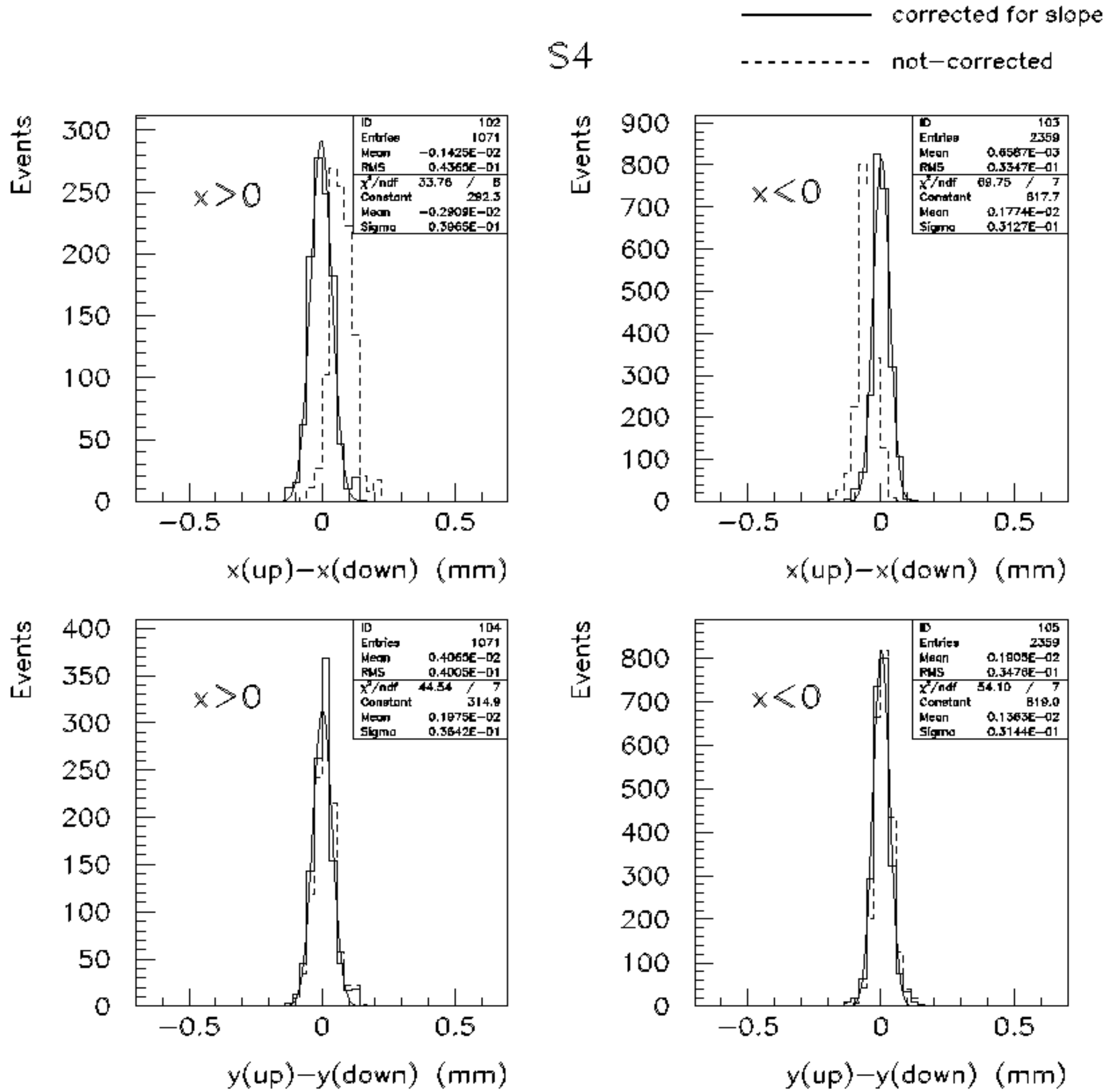
The procedure is cross-checked by looking at the residuals of the hits in each plane with respect to the track fitted through the entire spectrometer.



Minimum distance hit – fitted track

2) Align "up" pots wrt "down" pots

- **Use tracks in the overlap region**
- **Use inclusive diffractive events**
- **Slopes dx/dz, dy/dz from global fit**



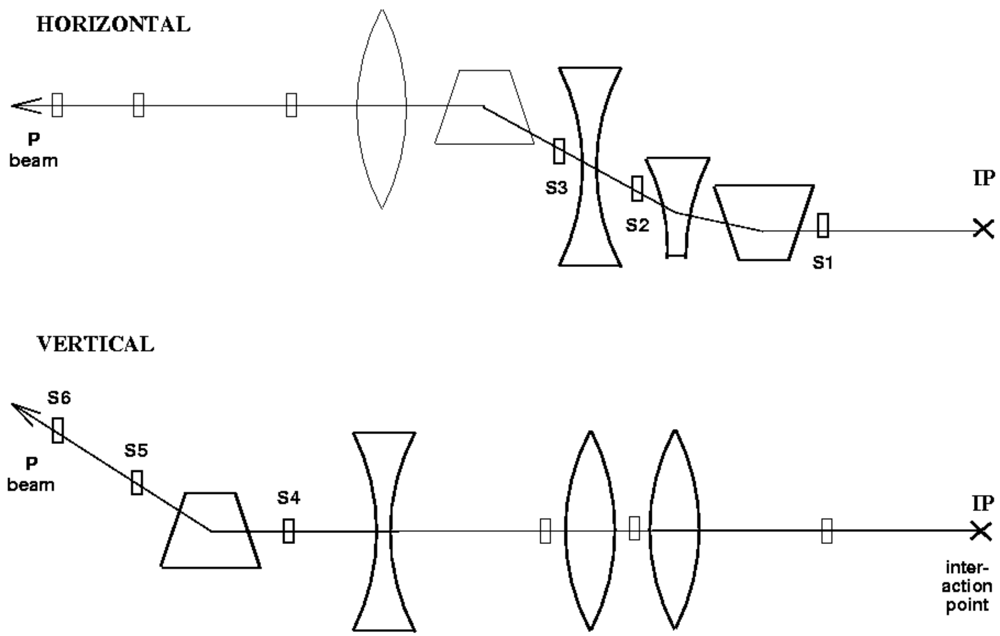
3) Align the three stations relative to each other

- **Horizontal plane: no bending, can use any track !**

- **Vertical plane: dipole magnet, use x_L=1 tracks from ρ^0 events (straight in beam reference frame !)**

- **In the two planes separately: define lines using two stations and extrapolate to third**

- **The third station is traslated in the x/y plane and rotated around z-axis until residuals with respect to the extrapolation of fitted line minimised**



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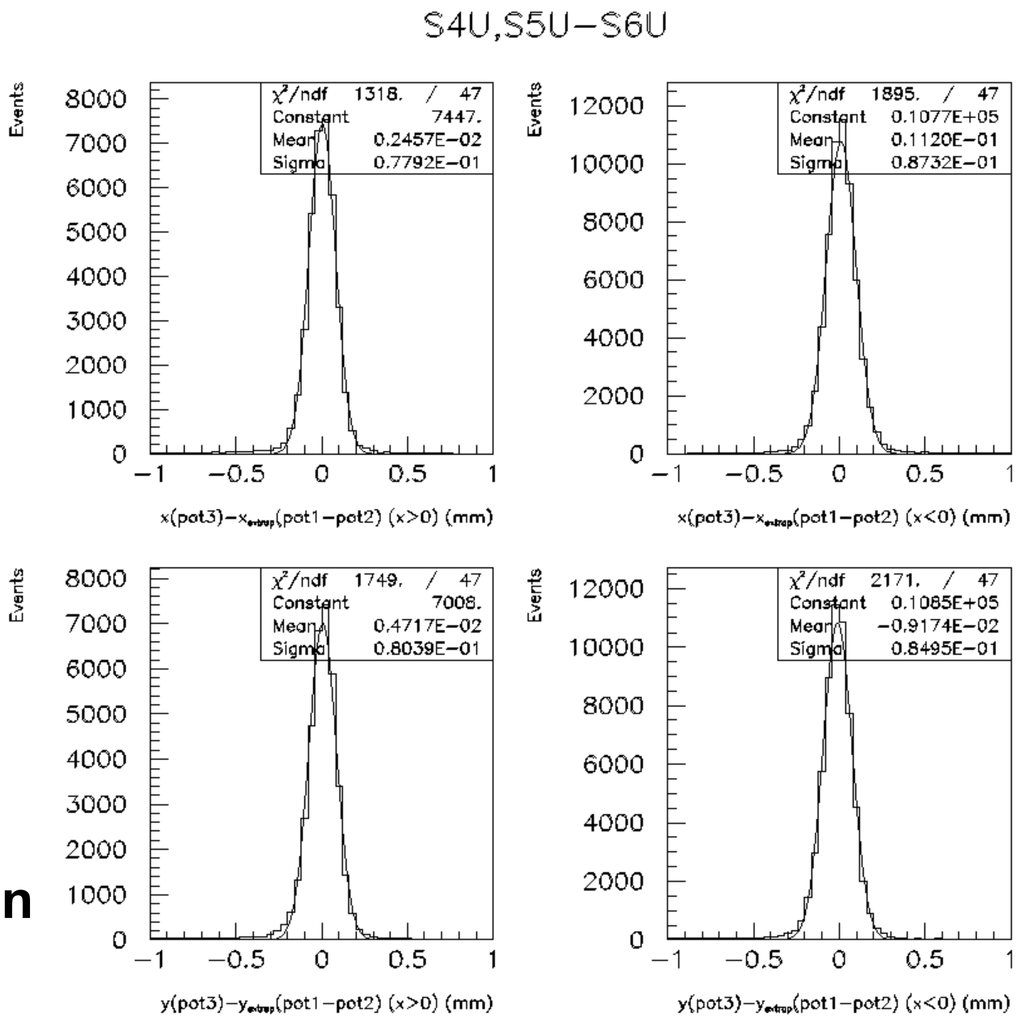


4) Align LPS relative to ZEUS

- Three-station tracks fitted without vertex constraint

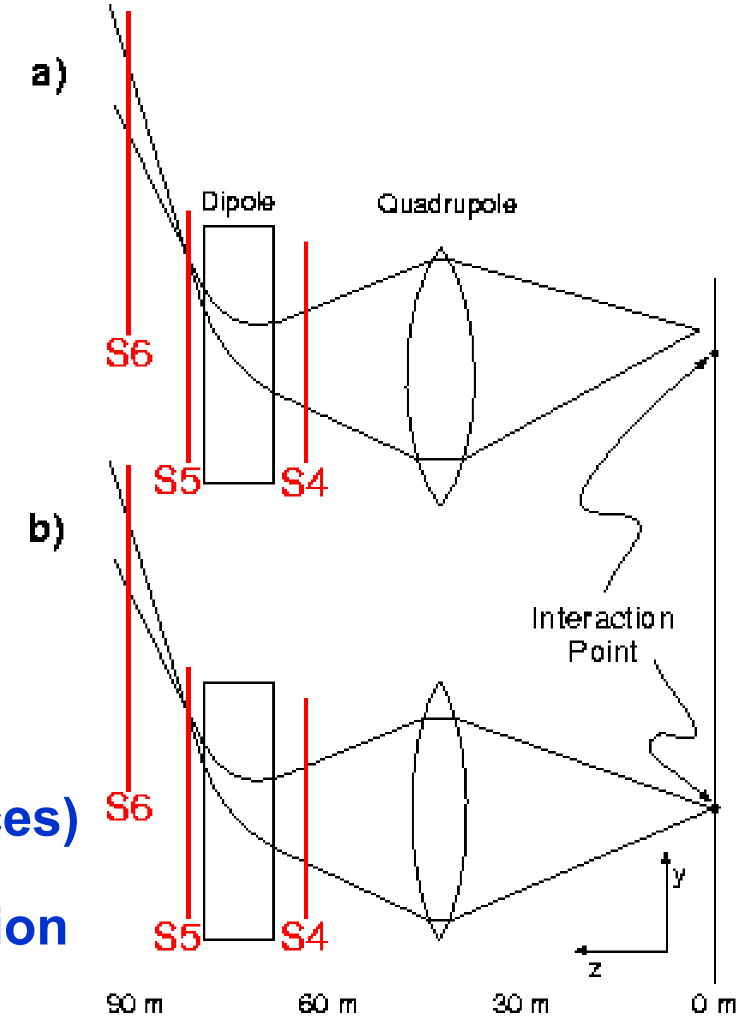
- Extrapolate to z=0 to measure transverse coordinates of vertex

- Reconstructed vertex required to be consistent with the interaction vertex measured in ZEUS for all x_L values. Use diffractive events at x_L =1, and non-diffractive events at low x_L

- The three stations (S4,S5,S6) are traslated/rotated as a rigid body

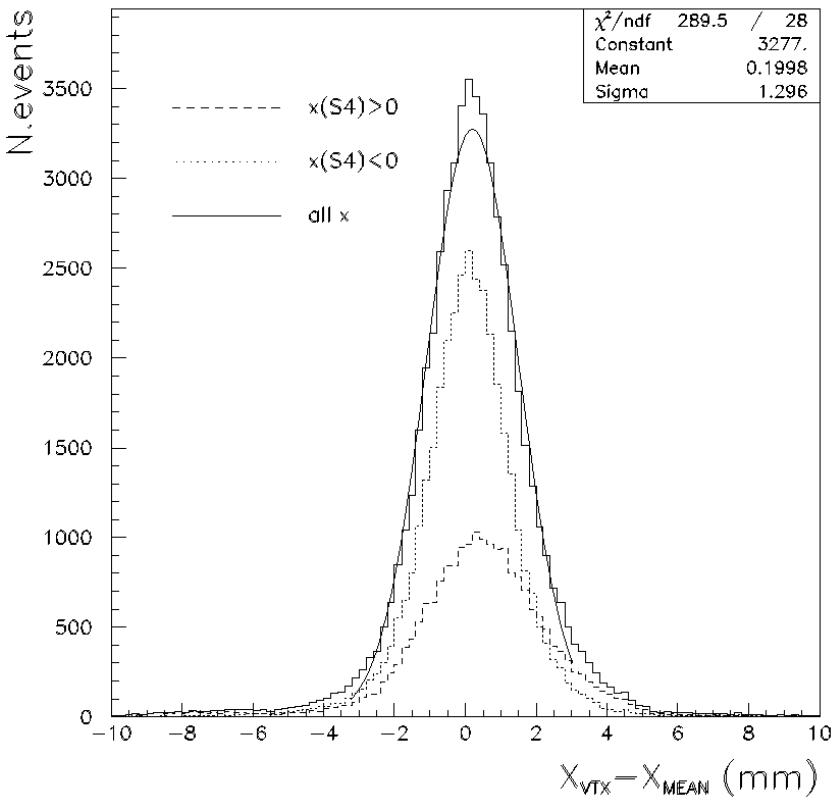
- Good knowledge of the quadrupoles focal lengths and axes positions required (if needed, allowed to vary within tolerances)

- Beam-halo tracks do not point to interaction point

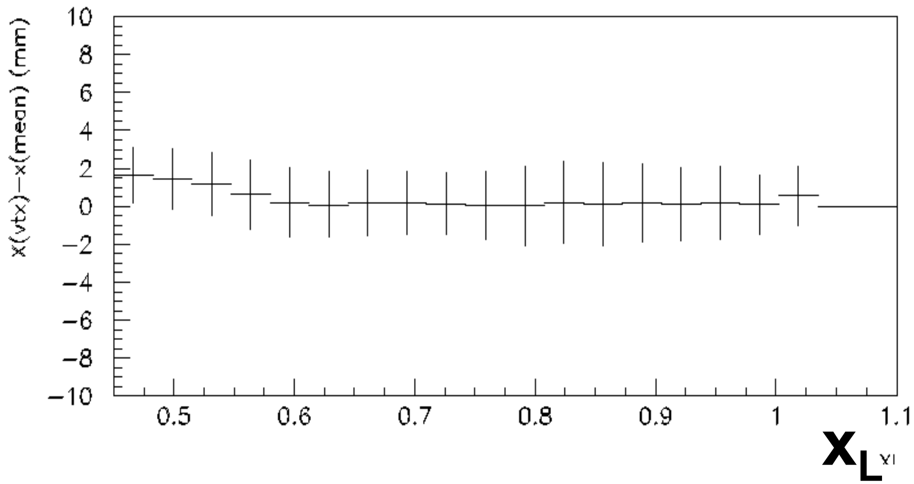


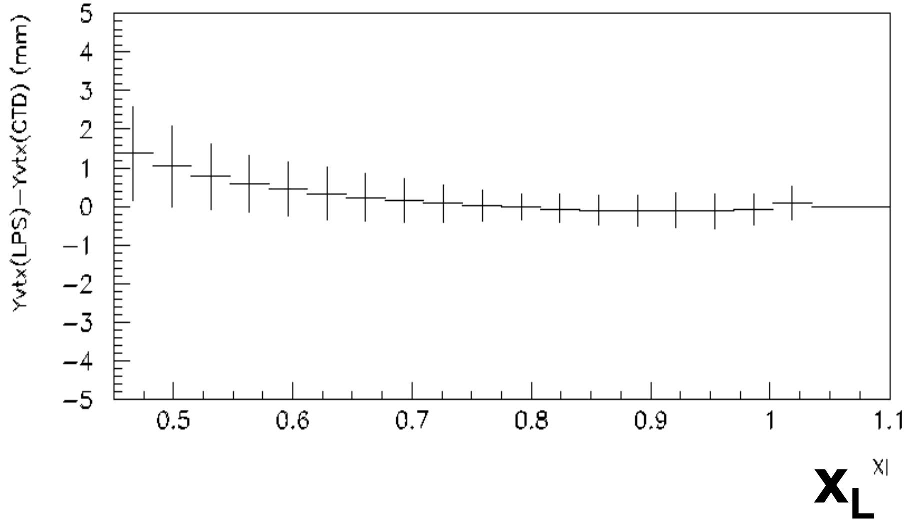
4) Align LPS relative to ZEUS

ρ^o events



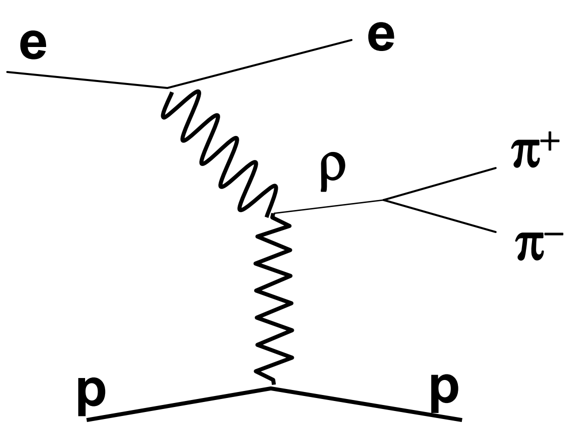
Inclusive events





Determine direction of incoming proton beam: p_T calibration

- **Alignment completed: can measure x_L**
- **Cannot yet measure the transverse momentum of scattered proton since direction of incoming proton beam unknown**
- **Use again elastic production of ρ^0, at Q^2=0:**



- **Q^2=0: scattering angle of electron=0, ie p_T(electron) =0**
- **Transverse momentum of proton balanced by transverse momentum of pions (measured in central detector)**
- **Determine incoming proton beam direction**

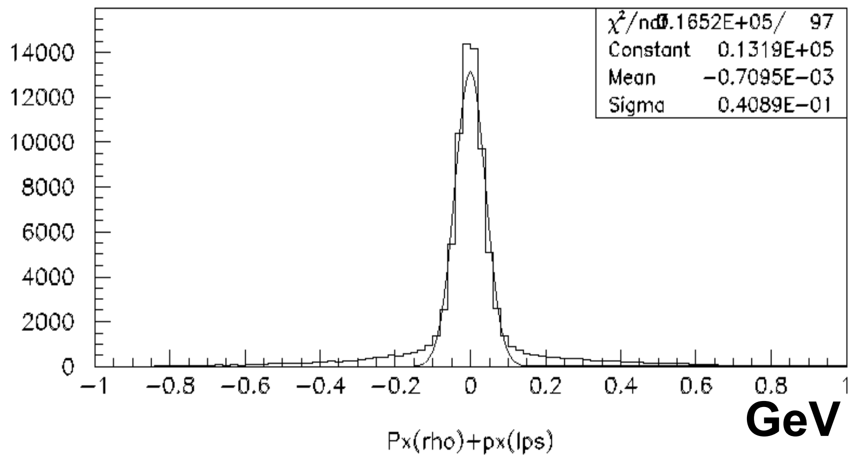
Determine direction of incoming proton beam: p_T calibration

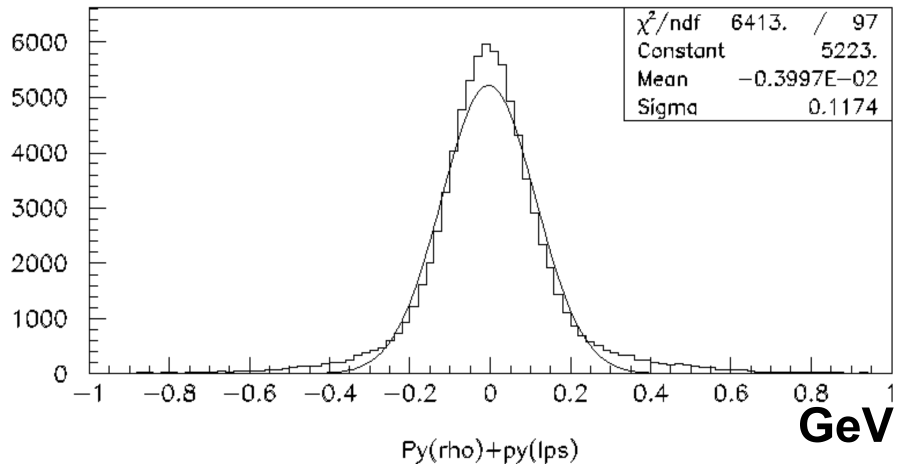
$$e\,p \rightarrow e\ \rho^0\ p$$
$$\rho^0 \rightarrow \pi^+\pi^-$$

ρ^0 photoproduction at $Q^2\sim 0$

$$\mathbf{p_x}(\mathbf{LPS}) + \mathbf{p_x}(\rho) = 0$$
$$\mathbf{p_y}(\mathbf{LPS}) + \mathbf{p_y}(\rho) = 0$$

The ρ^0 transverse momentum balances the transverse momentum of the scattered proton (with respect to the beam)





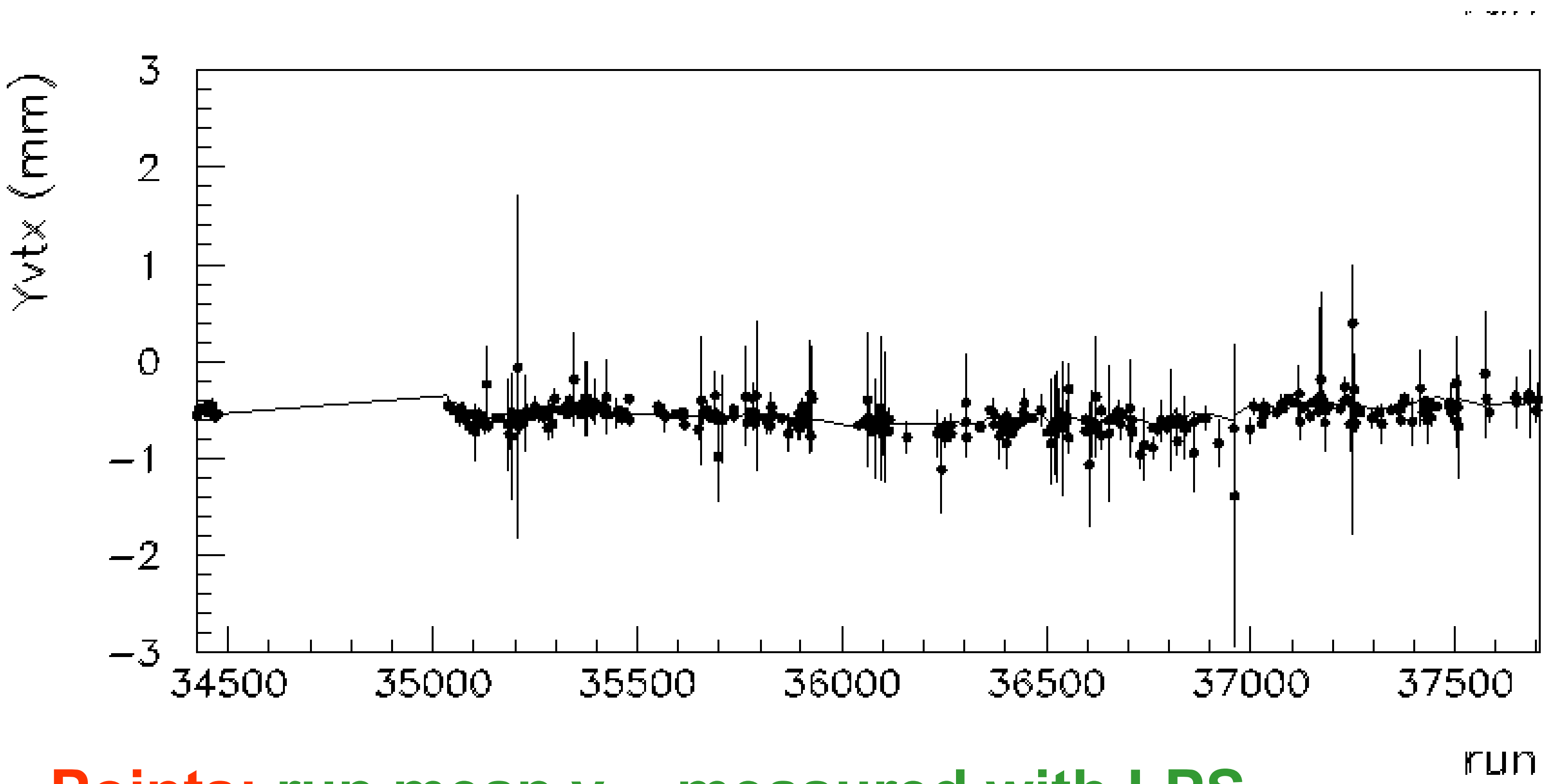
- Spread determined by the beam emittance:
  40 MeV in horizontal plane and 100 MeV in vertical plane
- Calibration done for every proton fill

Systematic checks

- Check residuals vs run number
- Position and width of the x_L=1 peak -- stability vs run number
- χ^2 independent of x_L and p_T
- Check position of the beam pipe apertures
- …

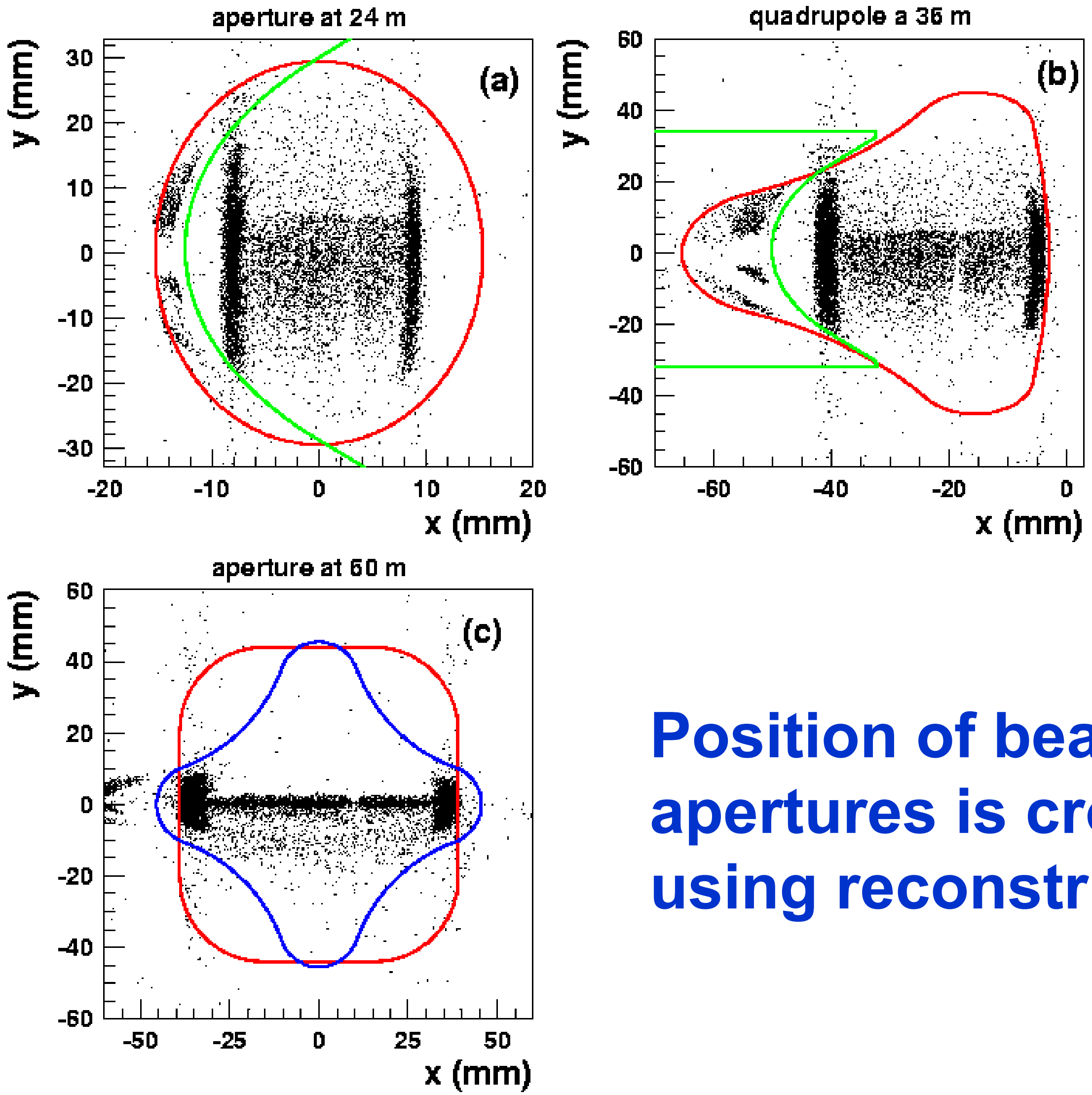
Stability vs run number

All residuals are checked on a run-by-run basis to assure the stability of the alignment



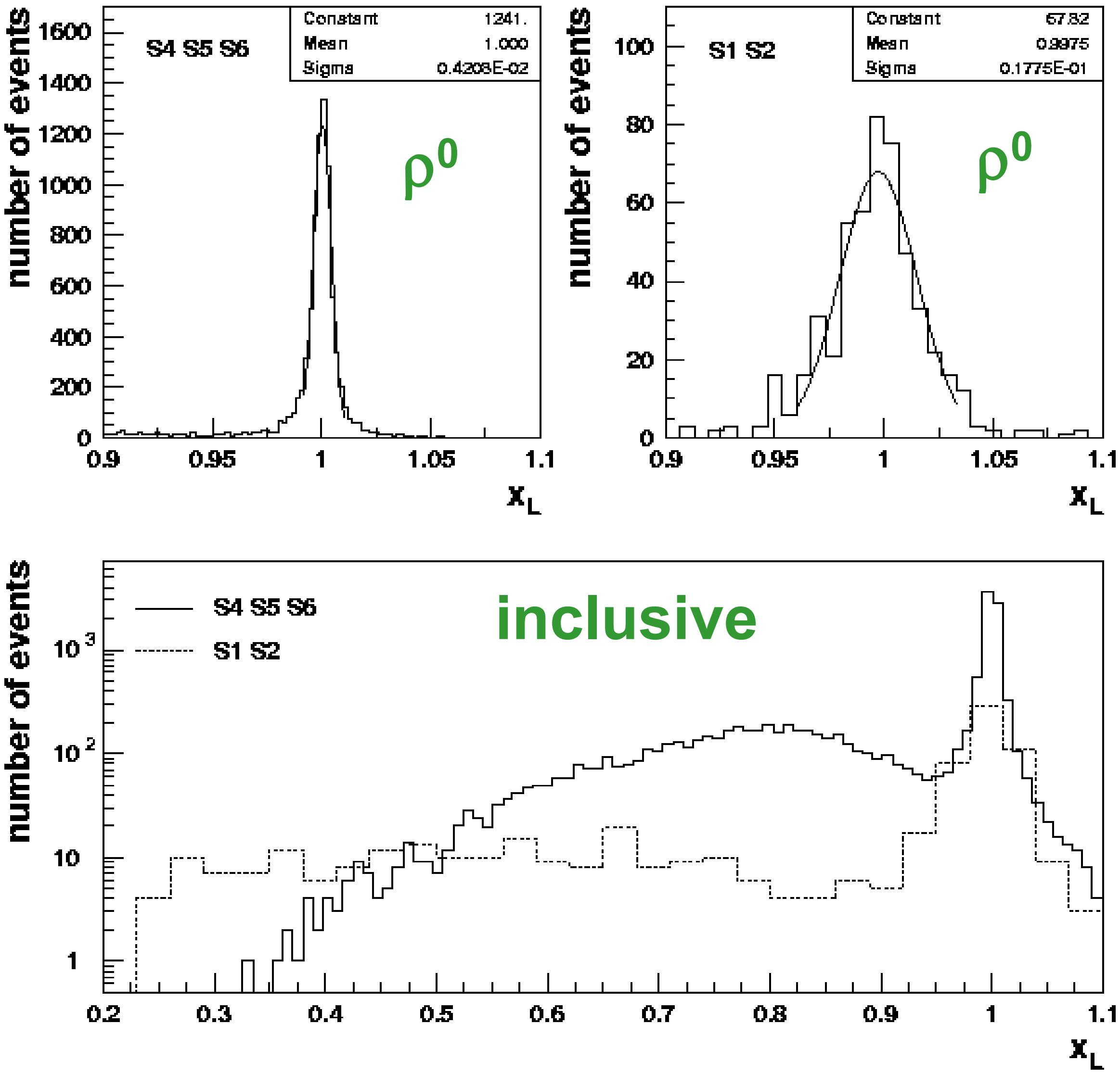
Points: run mean y_{vtx} measured with LPS
Line: run mean y_{vtx} measured with central detector

Beam-pipe apertures



Position of beam pipe apertures is cross-checked using reconstructed tracks

The resulting x_L distributions



x_L resolution:

$$\frac{\sigma(x_L)}{x_L}(S4,S5,S6) \approx 0.4\%$$

$$\frac{\sigma(x_L)}{x_L}(S1,S2,S3) \approx 2\,\%$$

Conclusions

- Alignment of LPS was the most difficult, time-consuming and tedious part of the analysis. Not a job for a student.

- Critical to have a reaction which produced plenty of nearly monochromatic protons with a priori known trajectory in the LPS

- Survey results useless

- HERA Beam Position Monitors also useless for alignment – but very good to monitor relative changes of beam orbit

- It pays to have data-taking conditions as stable as possible: detectors always in the same position, stable beam tilt etc