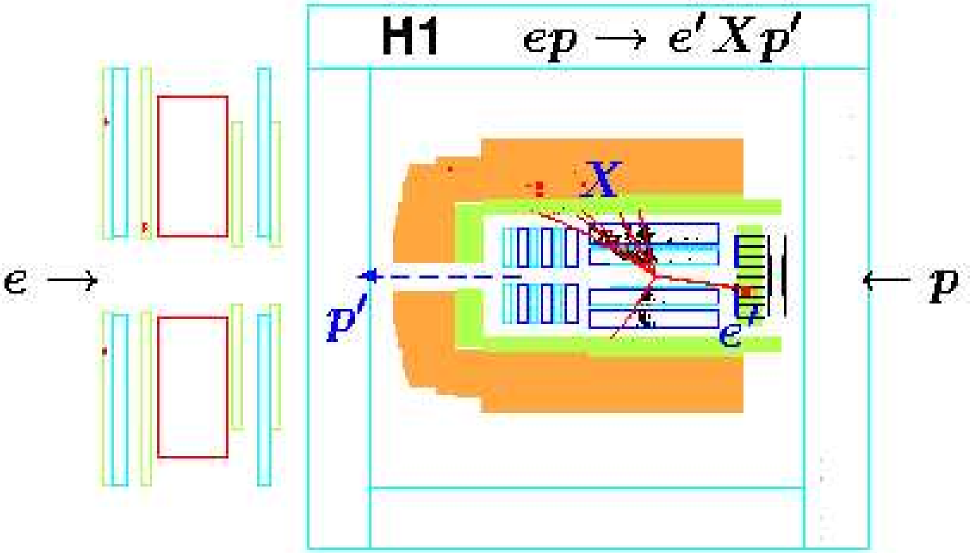
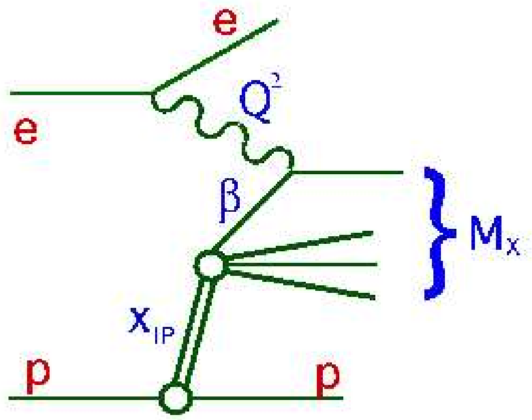
Forward proton detectors for H1

- Forward Proton Spectrometer
  - Purpose, acceptance and detector design
  - FPS upgrade for HERA II
  - Resolution, calibration and momentum reconstruction
  - Physics results
- New Very Forward Proton Spectrometer for HERA II
  - Physics motivation, acceptance and detector design
  - Resolution, calibration and momentum reconstruction
  - Present status
  - Summary and outlook

Selection of diffractive DIS

- Large rapidity gap between leading proton *p'* and *X*
- Leading proton measured by Forward Proton Spectrometer





LRG method:

- Large statistics
- But p dissociation (~10%)
- Forward detector noise

➔systematic errors

$$x_{\mathbb{P}} \cong (Q^2+M_X^2)/(Q^2+W^2)$$

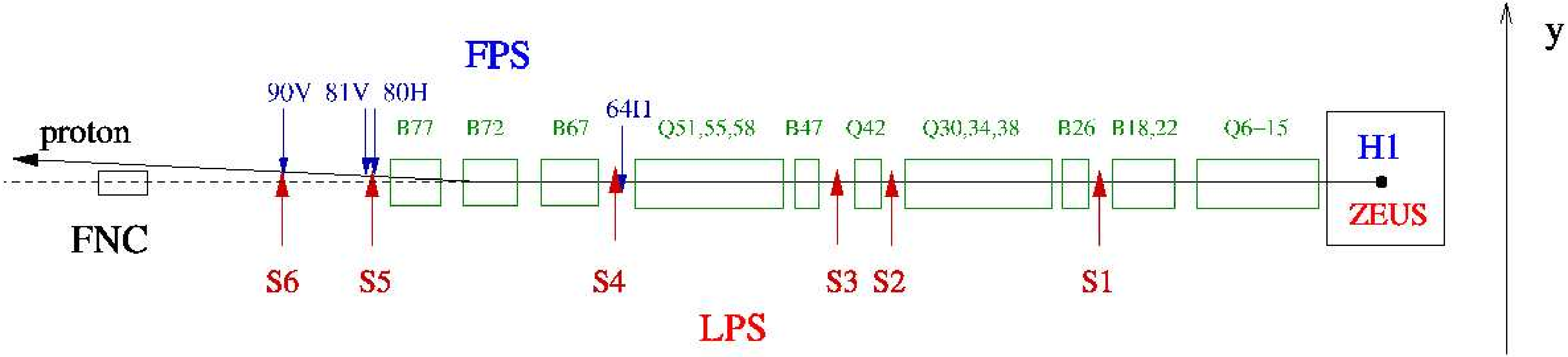
$$\beta \cong Q^2/(Q^2+M_X^2)$$

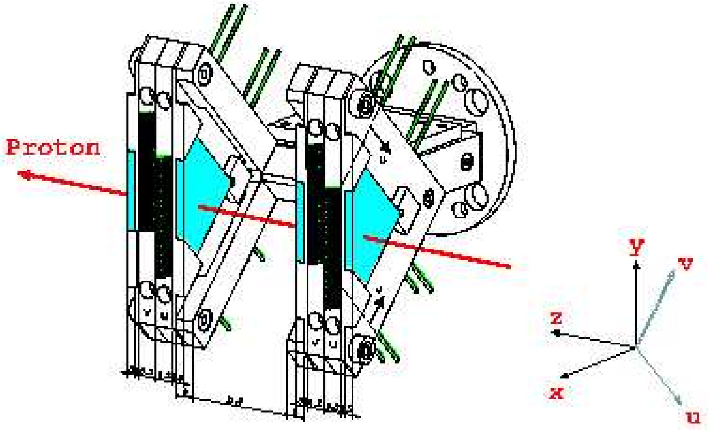
Bjorken scaling variable:

$$x = x_{\mathbb{P}} \cdot \beta$$

Forward Proton Spectrometer

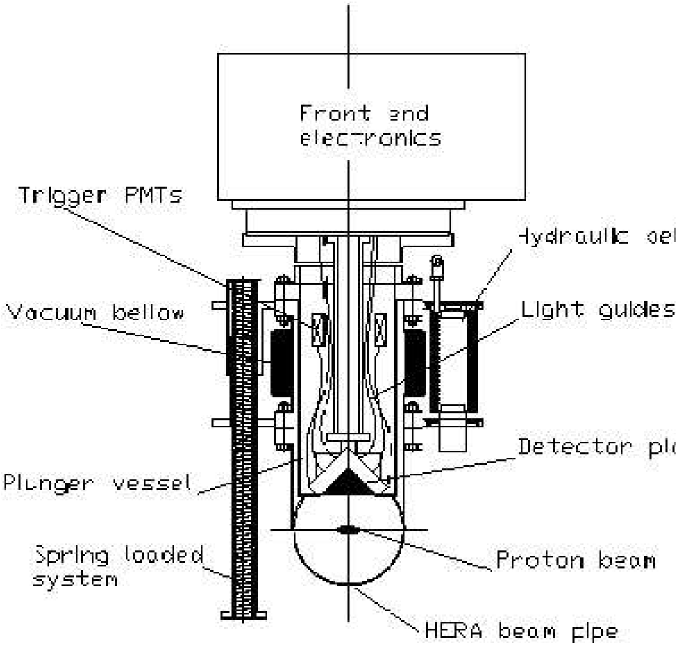
- Roman Pot technology, scintillating fiber detectors readout by position sensitive photo−multipliers

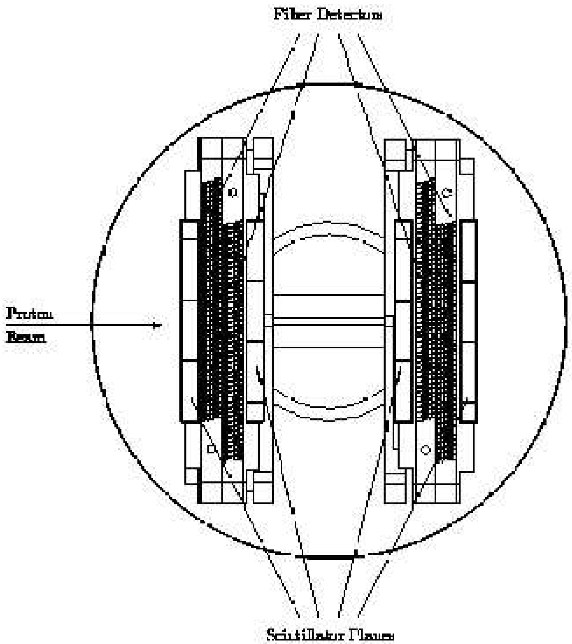


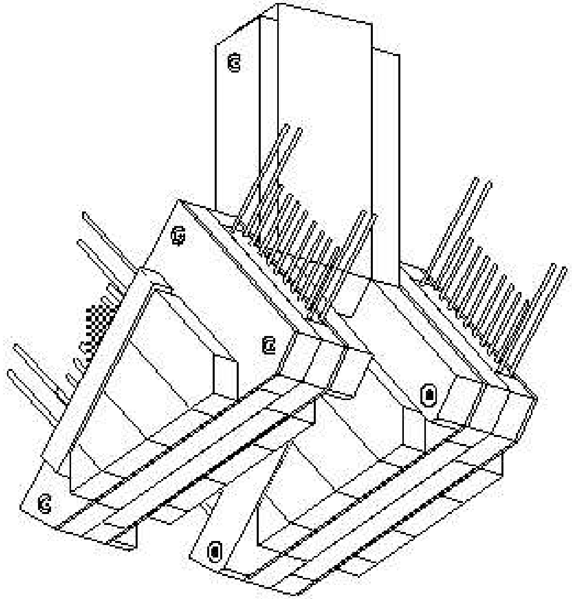


- $x_{\mathbb{P}}$ measurement: $x_{\mathbb{P}} = 1 - E'_p / E_p$
- t−measurement: p_x, p_y, $x_{\mathbb{P}}$
- sensitive in the range $x_{\mathbb{P}} < 0.5$
  but low acceptance in diffractive range
- low proton dissociation background

HERA I: Vertical FPS detectors

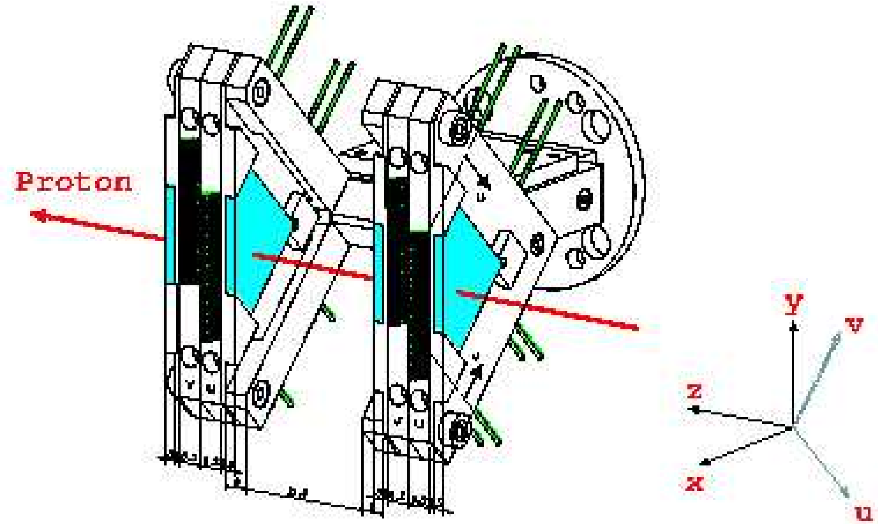


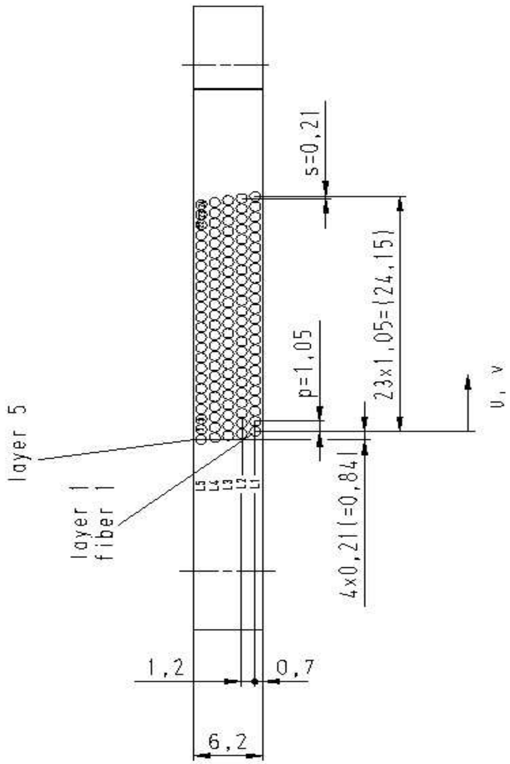




- 2 Roman Pots ⇒2 fiber detectors per Pot ⇒ U/V coordinates
- 5 fiber layers per coordinate, 48 fibers of 1 mm in one layer
- 4 fibers corresponding to 4 trigger tiles ⇒ 1 PSPM pixel
- Four 64−pixel fine mesh Hamamatsu PSPMs per Pot

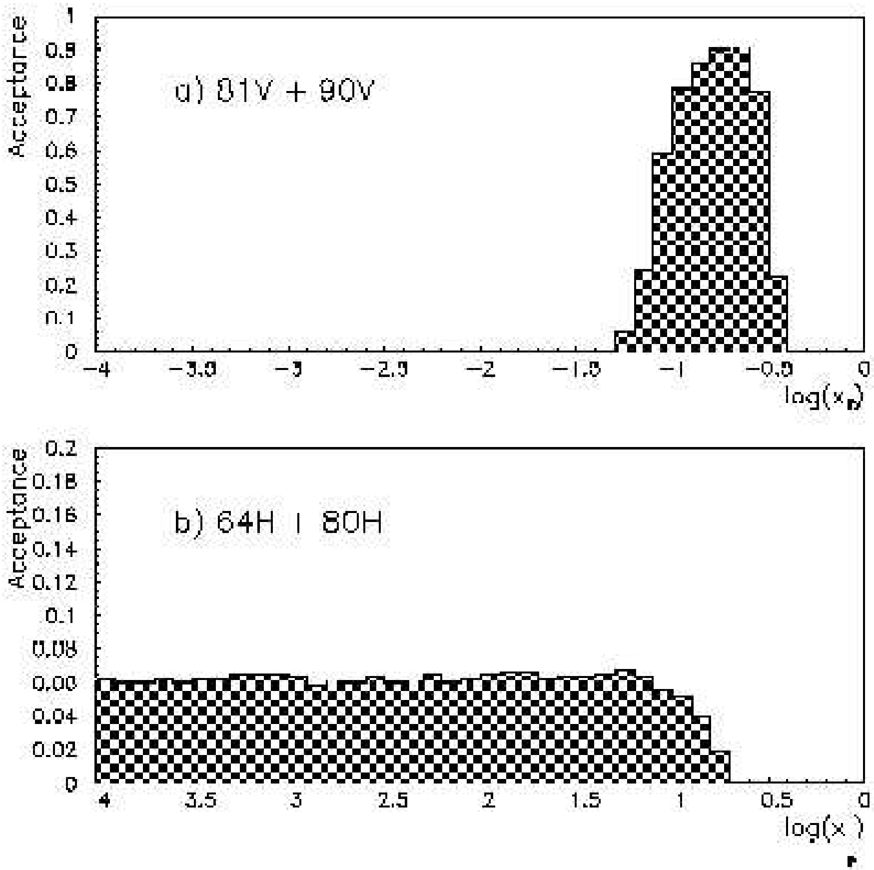
HERA I: Horizontal FPS detectors

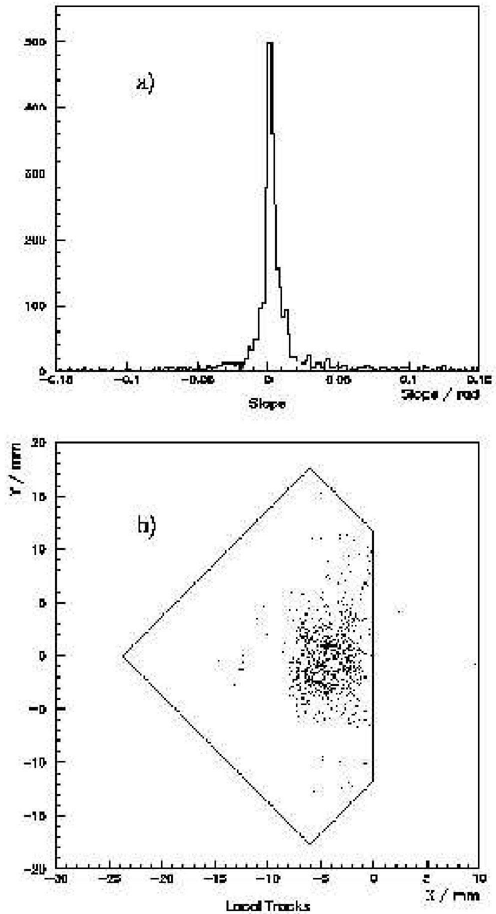




- 2 Roman Pots ⇒2 fiber detectors per Pot ⇒ U/V coordinates
- 5 fiber layers per coordinate, 24 fibers of 1 mm in one layer
- no multiplexing: 1 fiber ⇒ 1 PSPM pixel
- Four 124−pixel micro−channel plate PSPMs per Pot

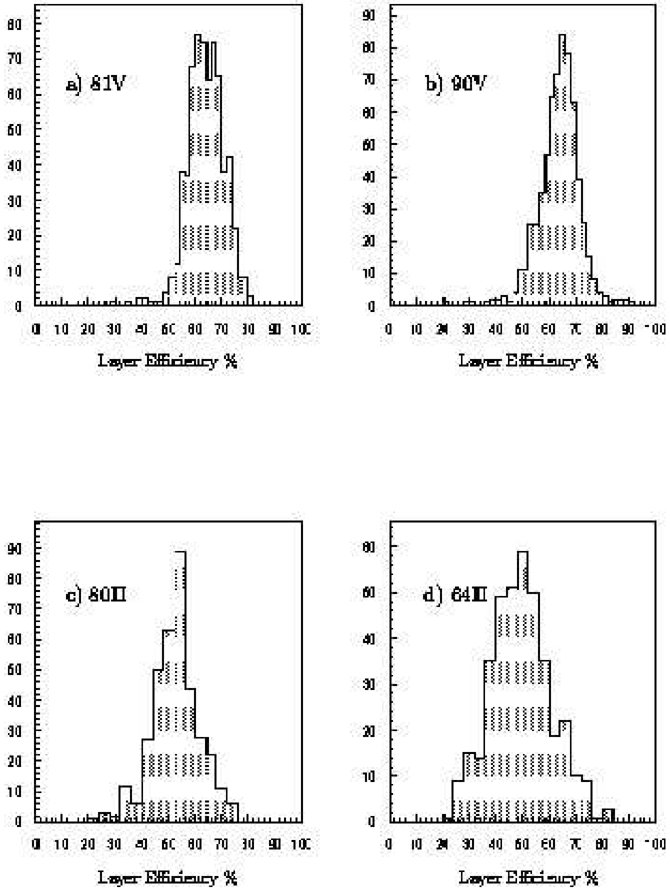
HERA I: FPS acceptance





- Vertical FPS acceptance: $0.1 < x_{\mathbb{P}} < 0.5$ and $p_t < 0.4$ GeV
- Horizontal FPS acceptance: $x_{\mathbb{P}} < 0.15$ and $0.06 < |t| < 0.6$ GeV^2

HERA I: FPS fiber layer efficiency



- Vertical FPS: fiber layer efficiency of 60−70% resulted in:

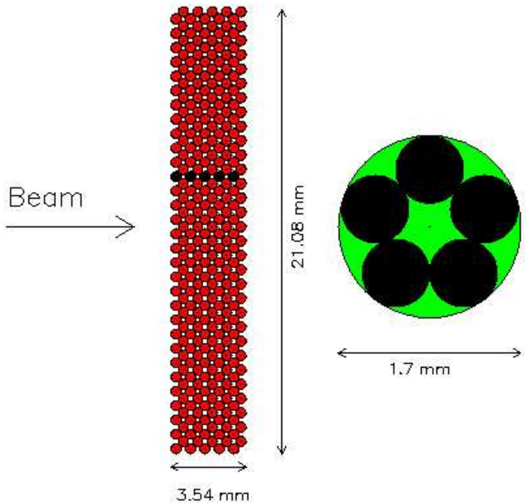
➔ track reconstruction efficiency in 2 Pots: ~50%, reduced to 30% for 5 years

- Horizontal FPS: fiber layer efficiency ~50% resulted in:

➔ track reconstruction efficiency in 2 Pots: ~30%, reduced to 20% for 2 years

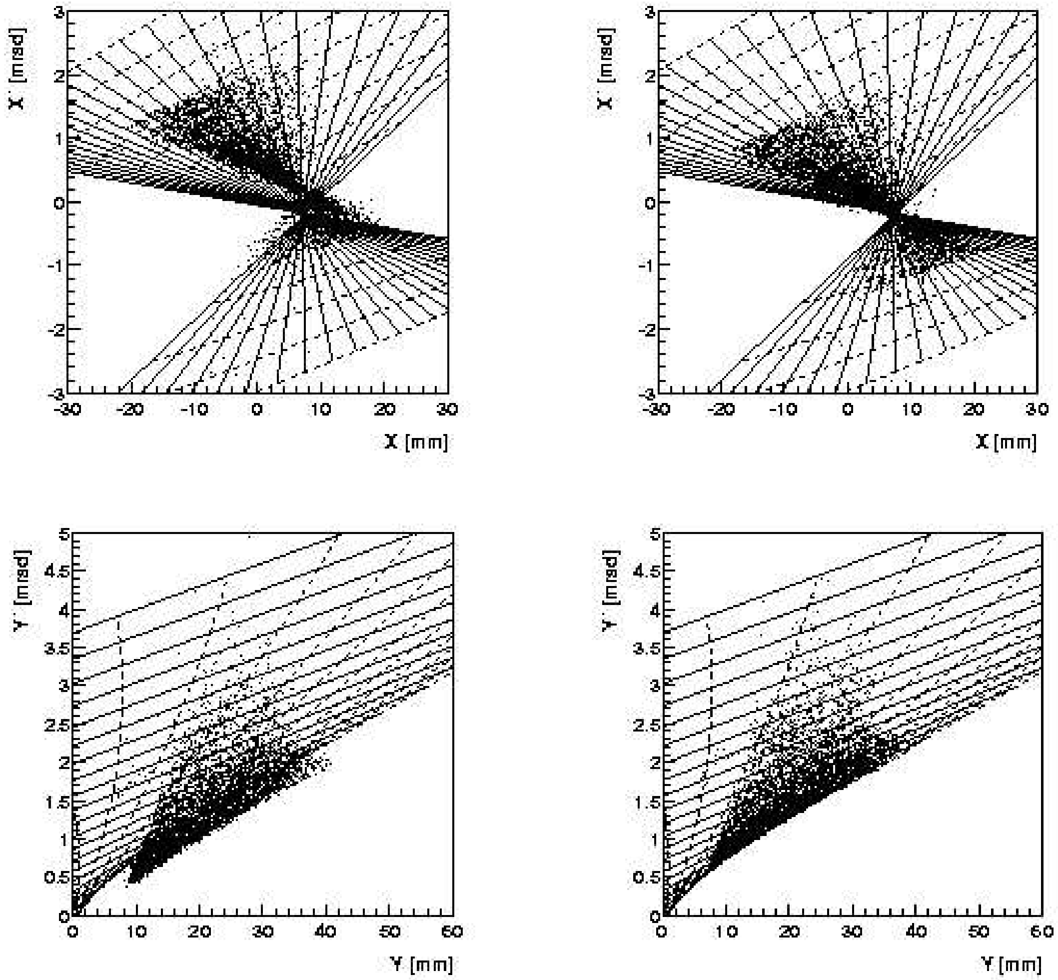
- Reason: radiation degradation of scintillating fibers, reduced PSPM detection efficiency ⇒ FPS detector upgrade for HERA II

HERA II: FPS detector upgrade



- New fiber detector technology:
  - radiation resistant scintillating fibers
  - 0.48mm fibers $\rightarrow$ better spatial resolution
  - fit to less expensive metal channel PSPM
  - 5 fiber layers $\rightarrow$ 1 road
- Horizontal FPS: 1 road $\rightarrow$ 1 PSPM pixel
  - four 64−pixel PSPMs per Pot
- Vertical FPS:
- 4 road multiplexing $\rightarrow$ 1 PSPM pixel
- Eight 16−pixel PSPMs per Pot

Vertical FPS calibration

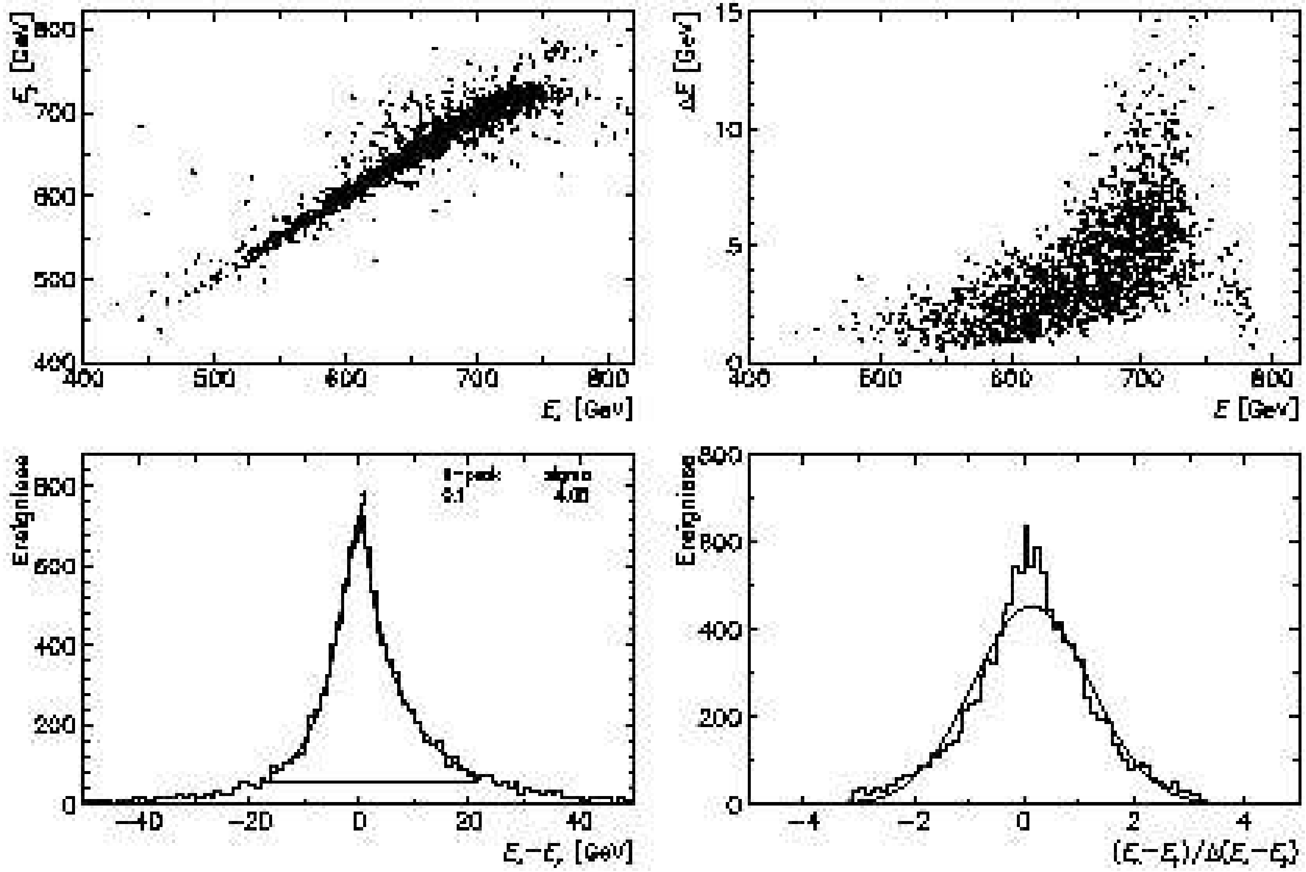


- Pot position calibration $\rightarrow \Delta X, \Delta X', \Delta Y, \Delta Y'$ by minimizing number of tracks in forbidden region

$$X = a_X(E) + b_X(E)\cdot\Theta_X$$

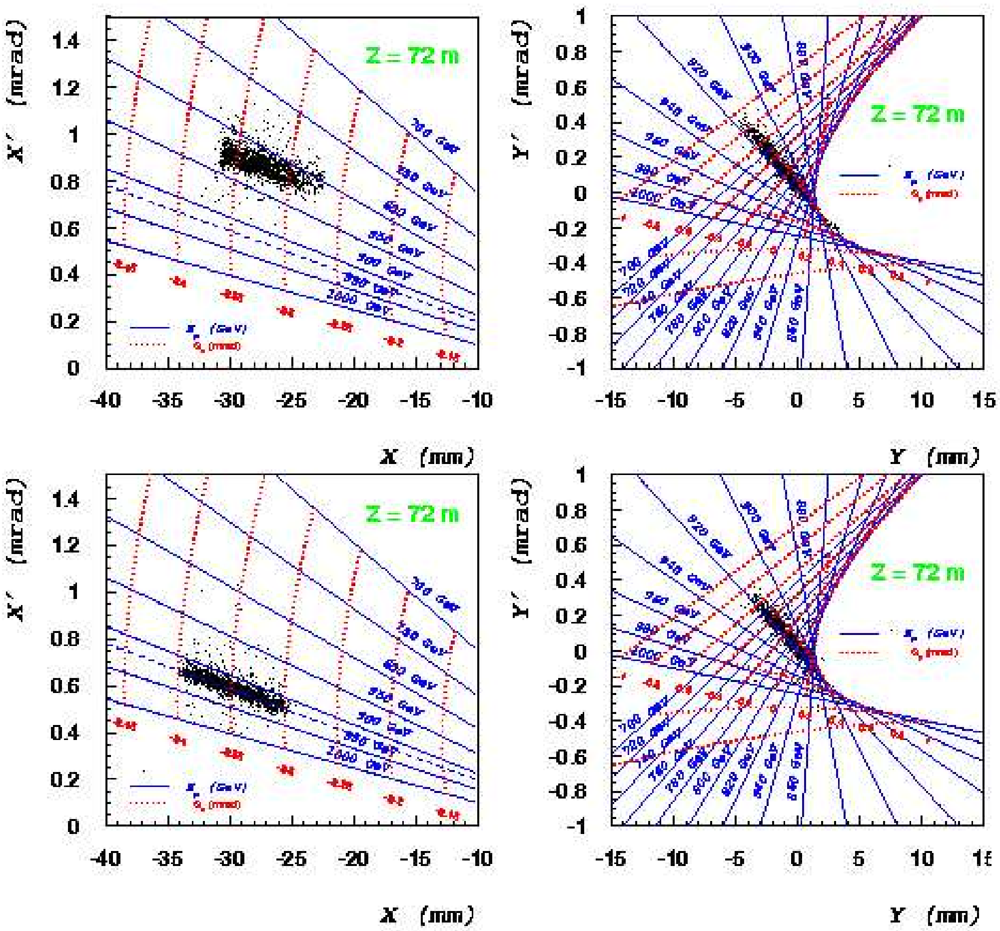
$$X' = c_X(E) + d_X(E)\cdot\Theta_X$$

Vertical FPS energy resolution

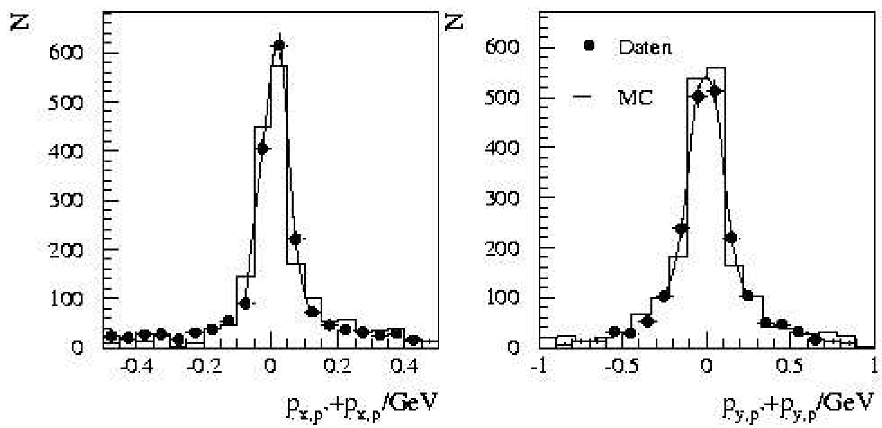


- E_p resolution 1.5−6 GeV in E_p range 500−700 GeV
- $x_{\mathbb{P}}$ resolution 5%→0.5% in $x_{\mathbb{P}}$ range 0.15→0.4

Horizontal FPS calibration



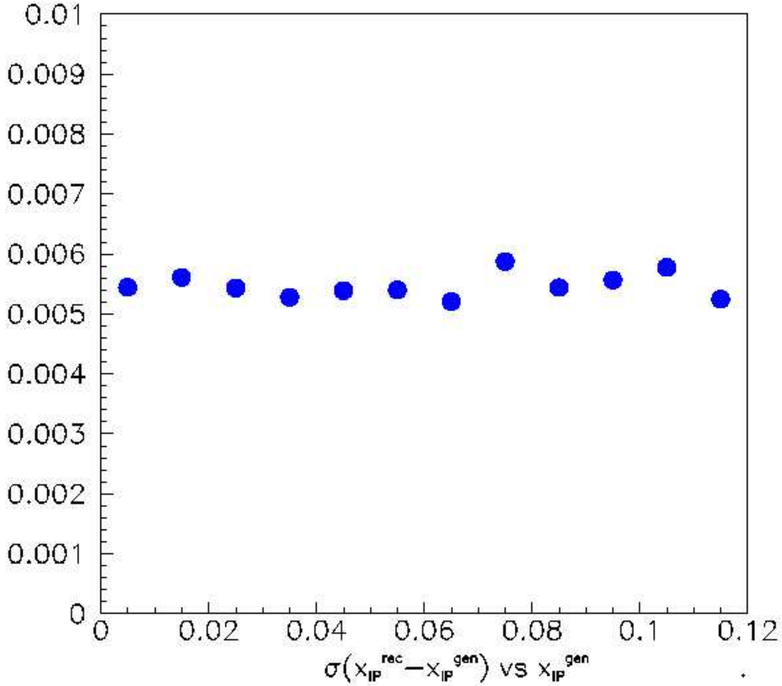
- Elastic ρ−meson photo production events: γp →ρp′
- Momentum balance between ρ−meson and leading proton

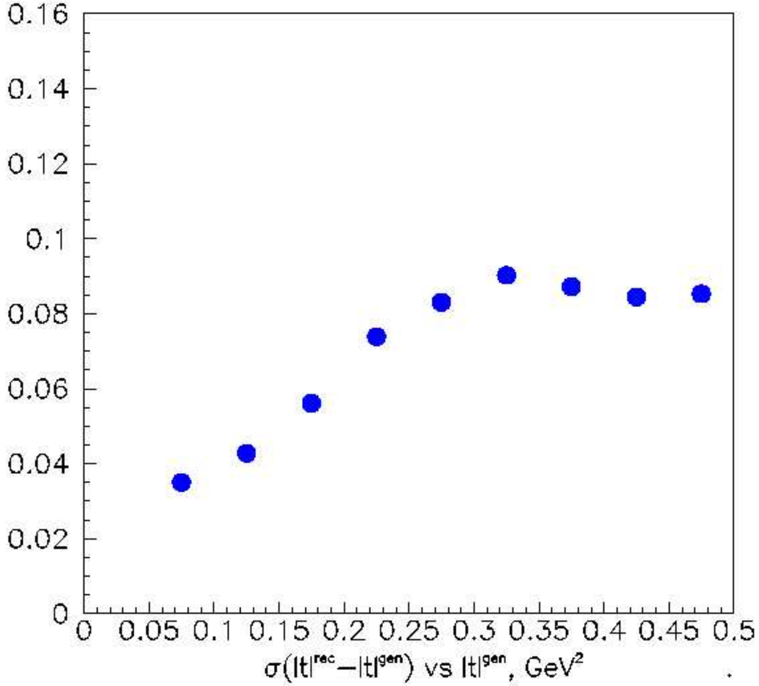


Horizontal FPS resolution

$X_{\mathbb{P}}$ resolution

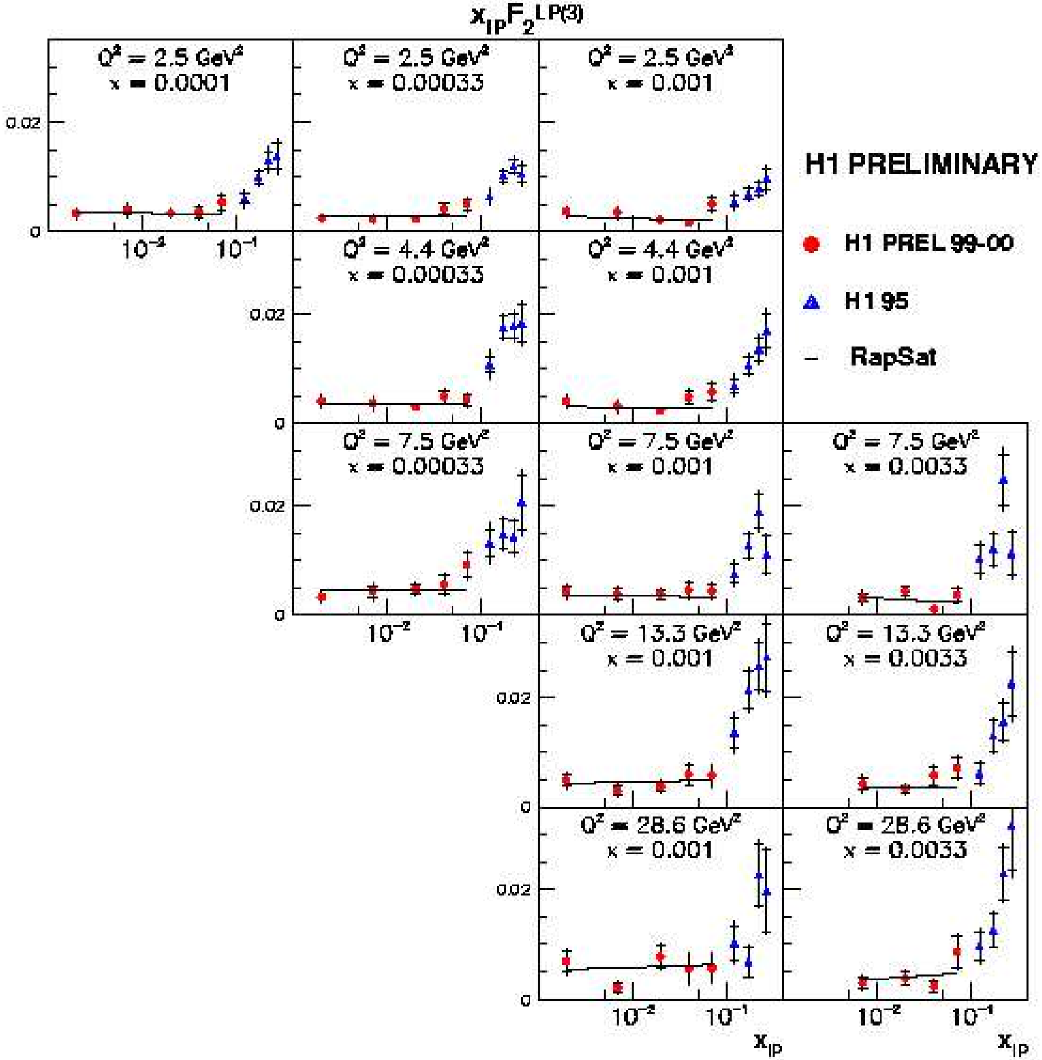
t resolution, GeV^2





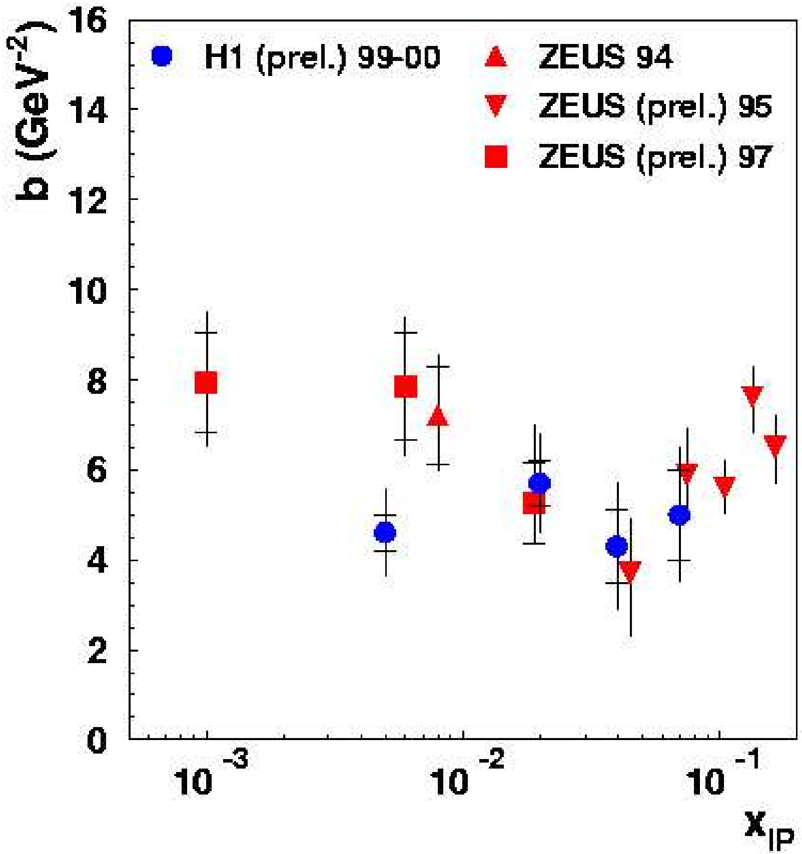
- Resolution is dominated by beam optics, fiber detector resolution and Pot position calibration → $(x_{\mathbb{P}},t)$
- $x_{\mathbb{P}}$ resolution is better than LRG resolution for $x_{\mathbb{P}}>0.02$
- $t\rightarrow$ 4 bins for $0.08<|t|<0.5$ GeV^2, $x_{\mathbb{P}}\rightarrow$ 4 bins for $x_{\mathbb{P}}<0.1$

FPS: $F_2^{D(3)}$ measurement



- $x_{\mathbb{P}} \cdot F_2^{D(3)} \propto x_{\mathbb{P}}^{2-2\alpha}$
- smooth transition from diffractive low $x_{\mathbb{P}}$ region ($\mathbb{P}$ exchange, α~1) to non−diffractive high $x_{\mathbb{P}}$ region ($\mathbb{R}$ exchange, α~0.5)
- Colour dipole "saturation" model describes diffractive low $x_{\mathbb{P}}$ region

t−distribution in diffractive DIS



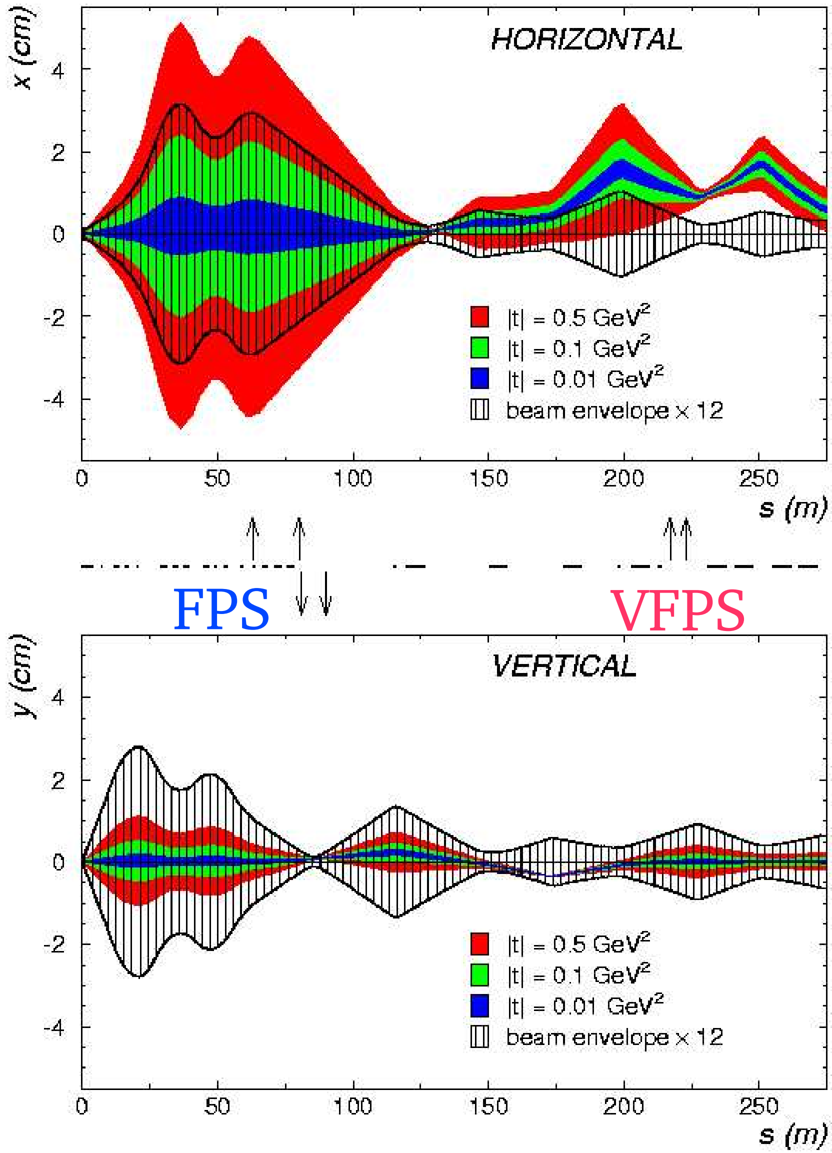
- $d\sigma/dt \propto \exp(bt)$
- b slope is measure of interaction radius $b = R^2/4$
- Regge predicts "shrinkage" ("soft" pomeron) $b = b_0 + 2\alpha' \ln(1/x_{\mathbb{P}})$
- "hard" QCD pomeron – no shrinkage $\alpha' = 0$
- b slope is "soft" or "hard"?

Very Forward Proton Spectrometer

- Purpose: measure scattered proton with large acceptance at low $x_{\mathbb{P}}$
- HERA II beam optics:

➔ best location for detector is 220m in horizontal plane

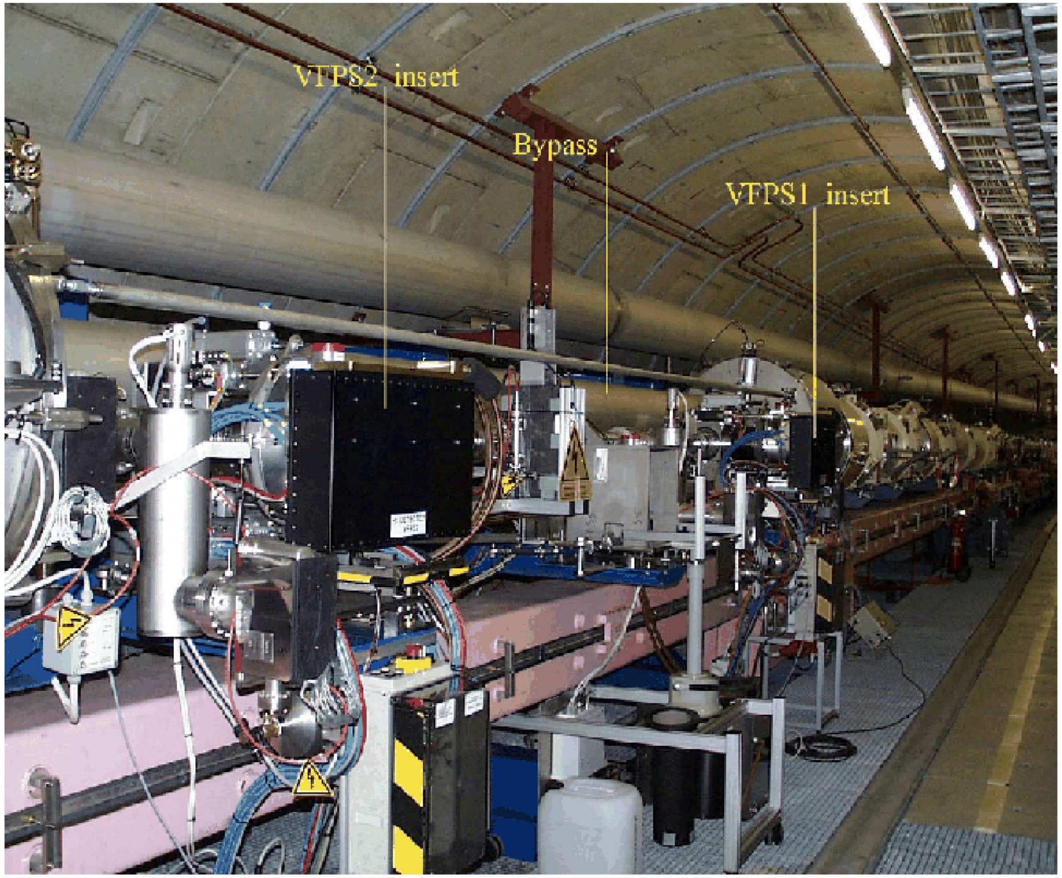
➔ But cold magnet section – need bypass to access proton beam pipe



Bypass of Cold Beam Line

- Horizontal bypass for helium and superconductor lines
- New 10m long warm beam pipe

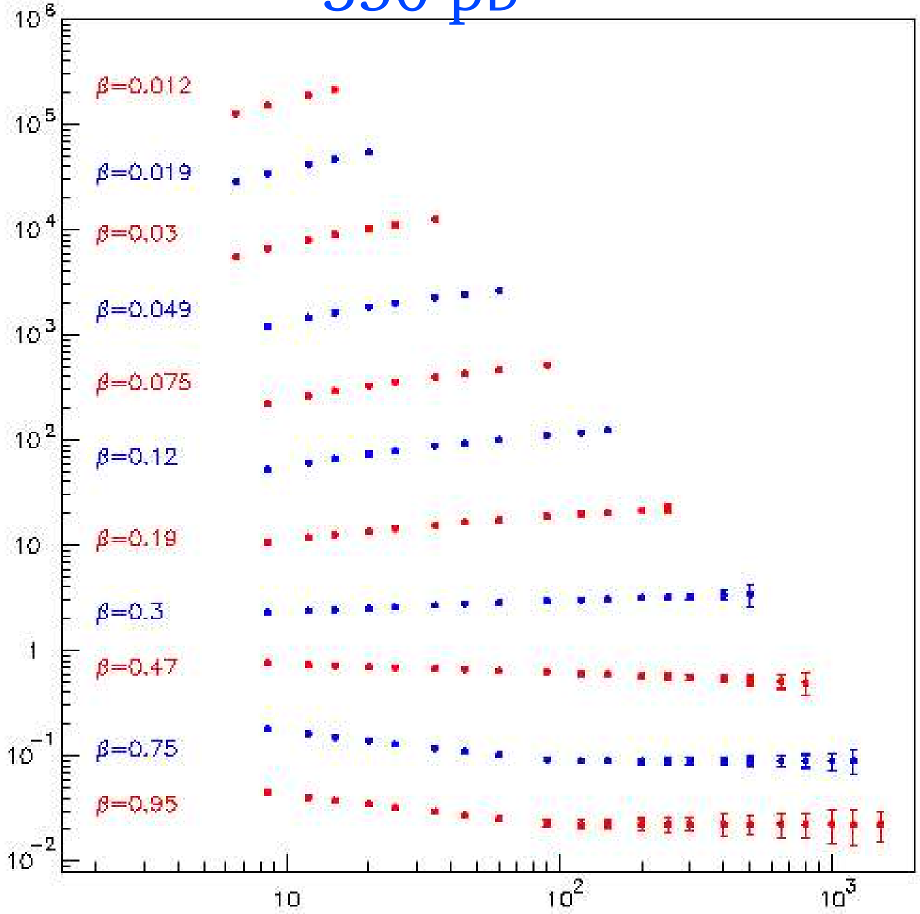
before installation



after installation

VFPS: physics motivation

350 pb^{-1}



➔Main H1 diffraction trigger for HERA II

Inclusive diffraction:

- upto 10^6 events for $Q^2 > 5$ GeV^2
- t−measurement $\rightarrow F_2^{D(4)}(Q^2,\beta,x_{\mathbb{P}},t)$
- φ−assymetry $\rightarrow F_L^D$
  $\rightarrow \beta, Q^2$ dependence

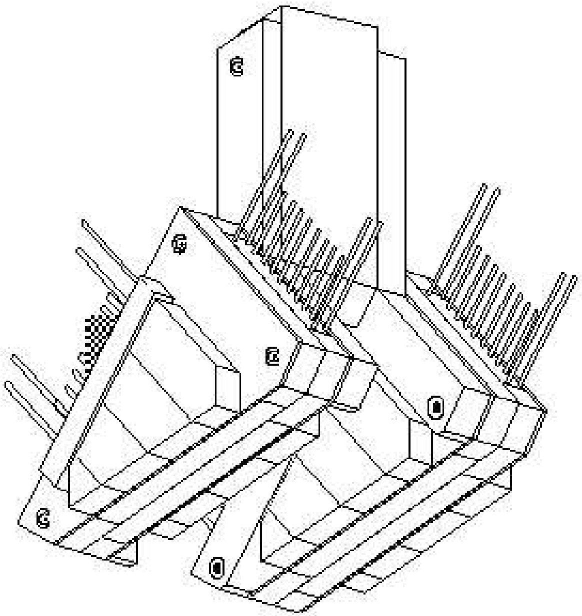
Diffractive Final states:

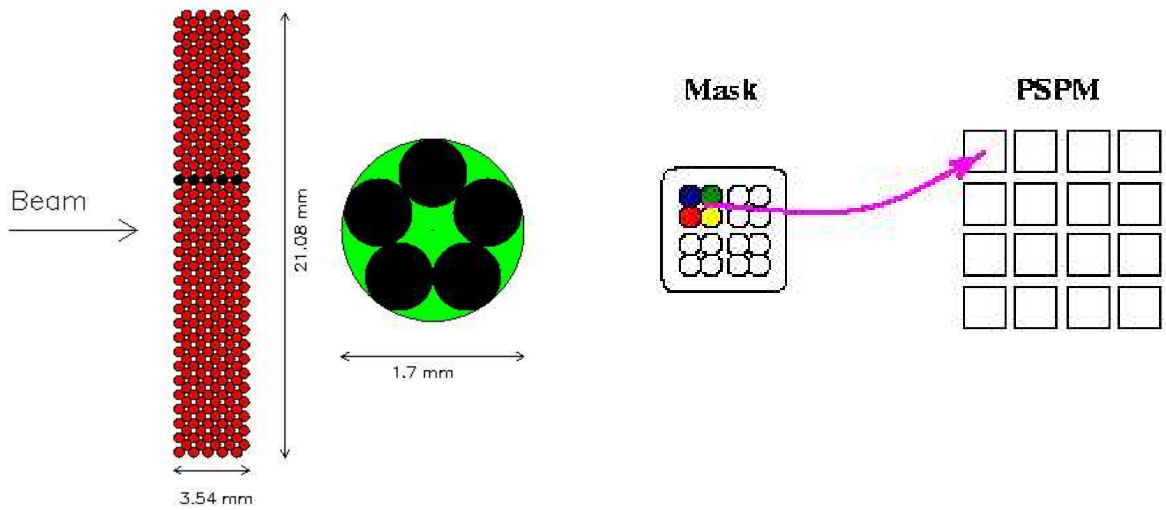
- Di−jets and open charm in DIS
  $\rightarrow$ test hard scattering factorization

Exclusive channels:

- Deeply Virtual Compton Scattering

VFPS fiber detectors

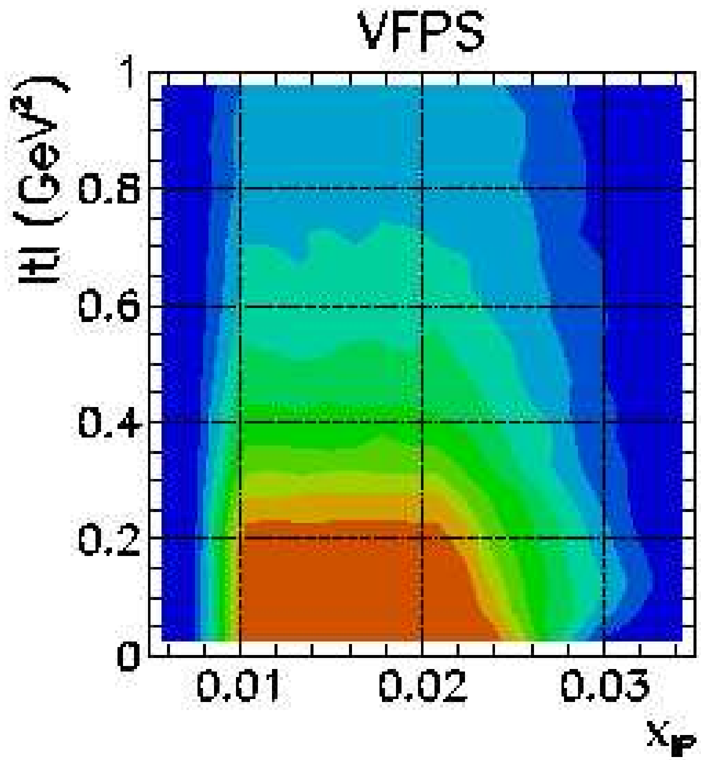


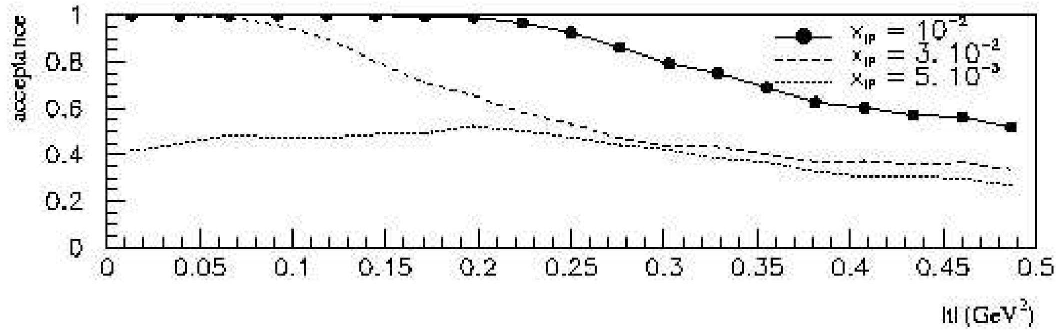


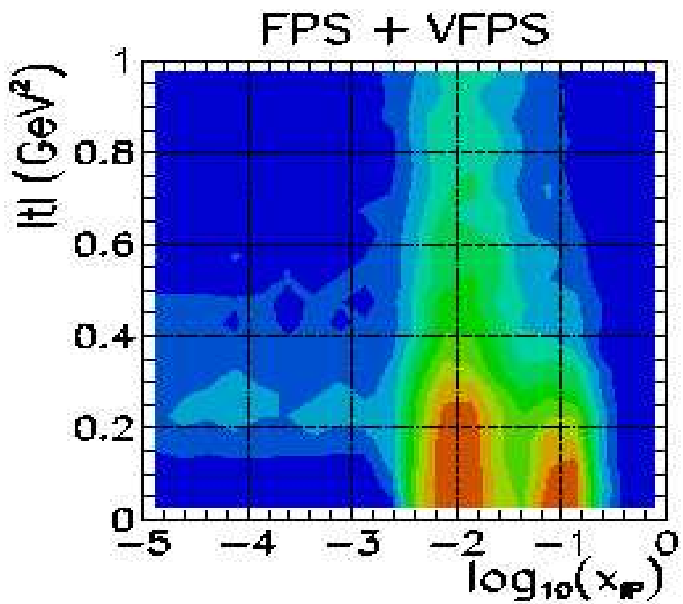
VFPS detectors similar to Vertical FPS:

- 2 Roman Pots ⇒2 fiber detectors per Pot ⇒ U/V coordinates
- 5 fiber layers per coordinate ⇒ 1 fiber road
- 4 fiber roads corresponding to 4 trigger tiles ⇒ 1 PSPM pixel
- Eight 16−pixel PSPMs per Pot

VFPS acceptance





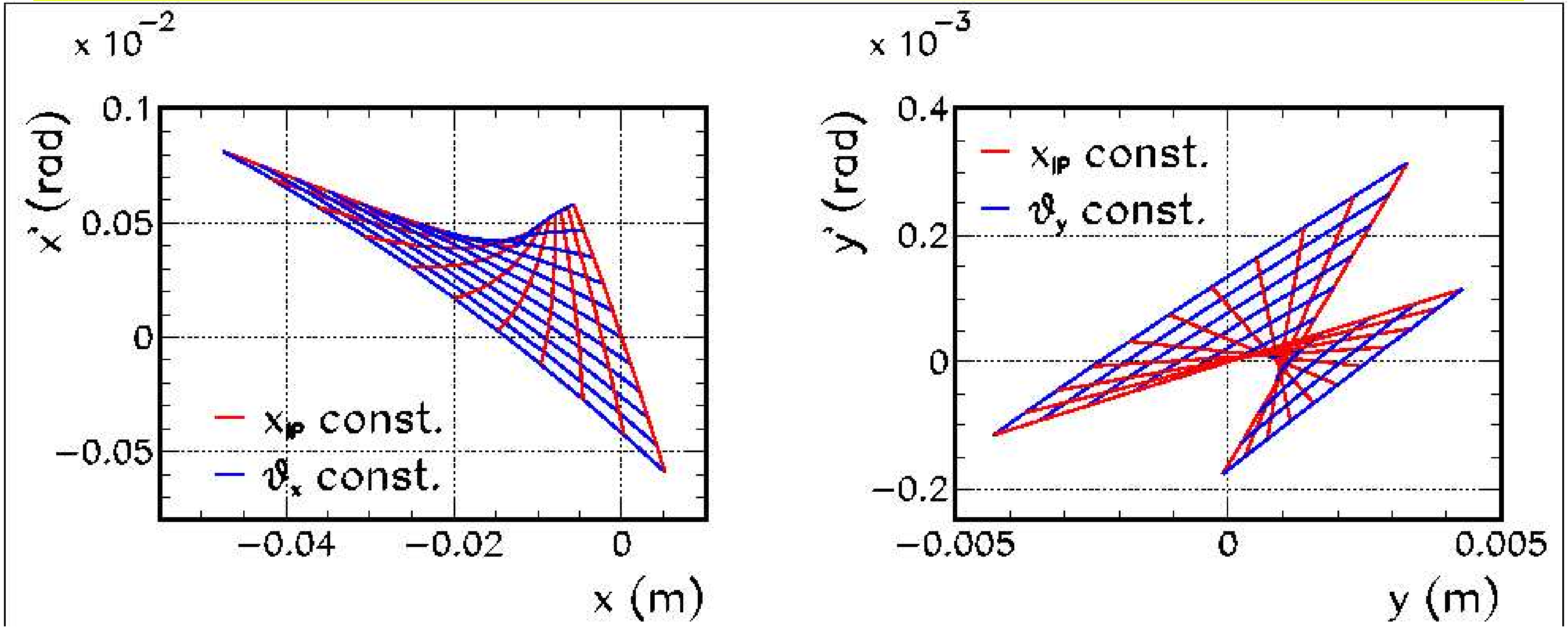


Acceptance defined by beam optics

and beam envelope (12σ):

- 100% acceptance for $|t| \leq 0.2$ GeV^2 and $0.01 \leq x_{\mathbb{P}} \leq 0.02$
- complimentary to Vertical FPS acceptance (high $x_{\mathbb{P}}$ range)

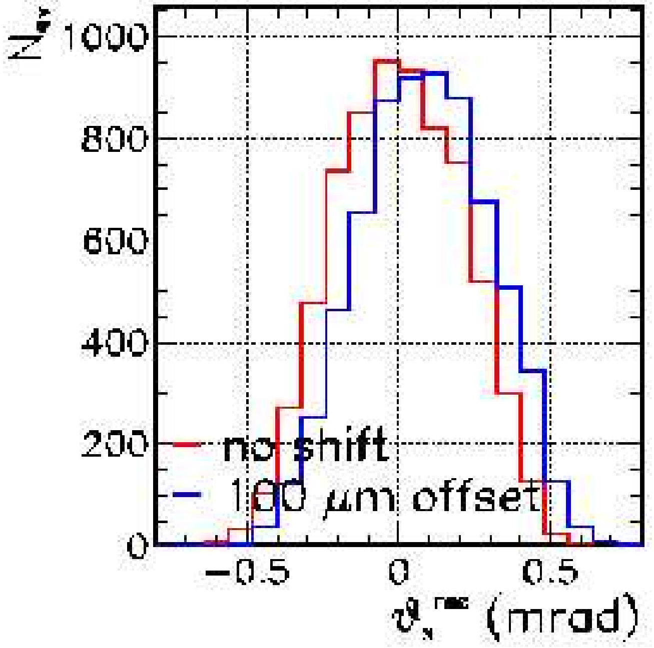
VFPS energy reconstruction



$(x,y,x',y') \rightarrow$ beam optics $\rightarrow (t, x_{\mathbb{P}}$, azimuth $\varphi)$

- beam optics, tilt, smearing
- non−linear effects in $x_{\mathbb{P}}$ measurement: sex−tuple magnets
- fiber detector resolution (~100μm) + Pot position calibration

VFPS position calibration

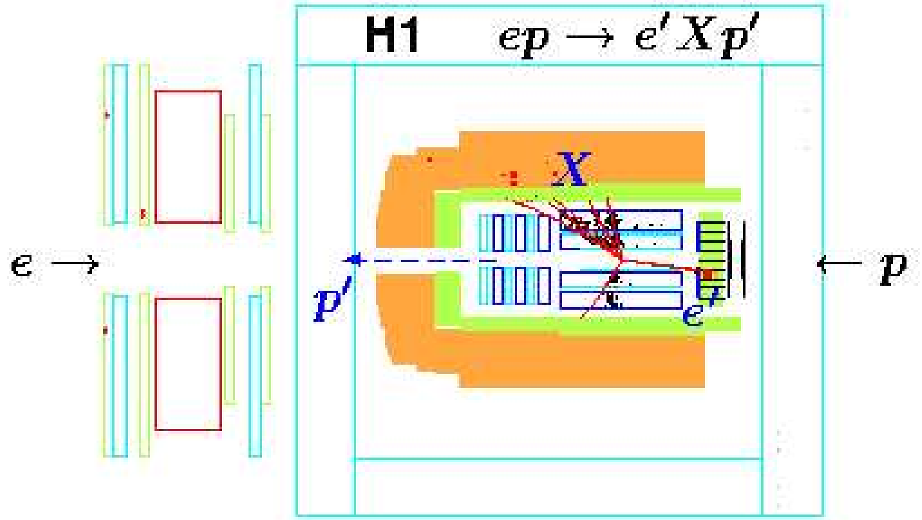


Pot position relative proton beam:

➔Forward kinematic peak in θ_x, θ_y ,
$x_{\mathbb{P}}$ measurement from LRG method
(>200 events for stable calibration)

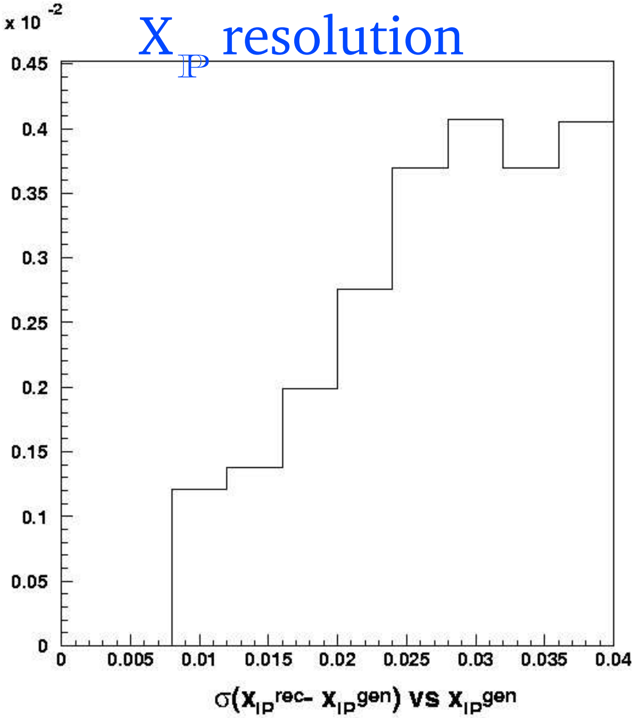
➔Cross calibration with elastic meson photo−production events as for Horizontal FPS

Pot position calibration with accuracy ~100μm

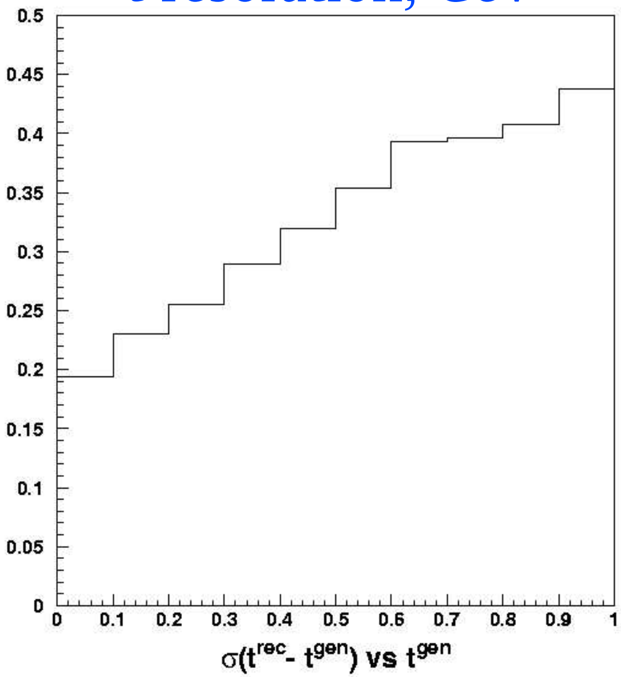


VFPS resolution

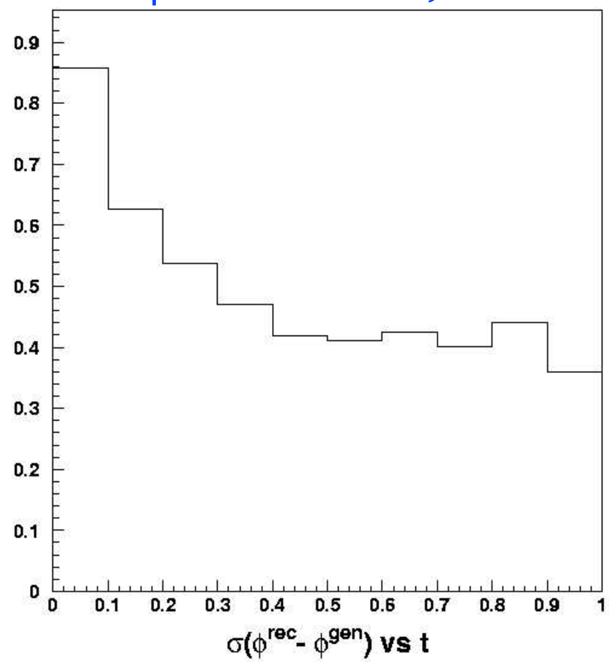
$X_{\mathbb{P}}$ resolution



t resolution, GeV^2



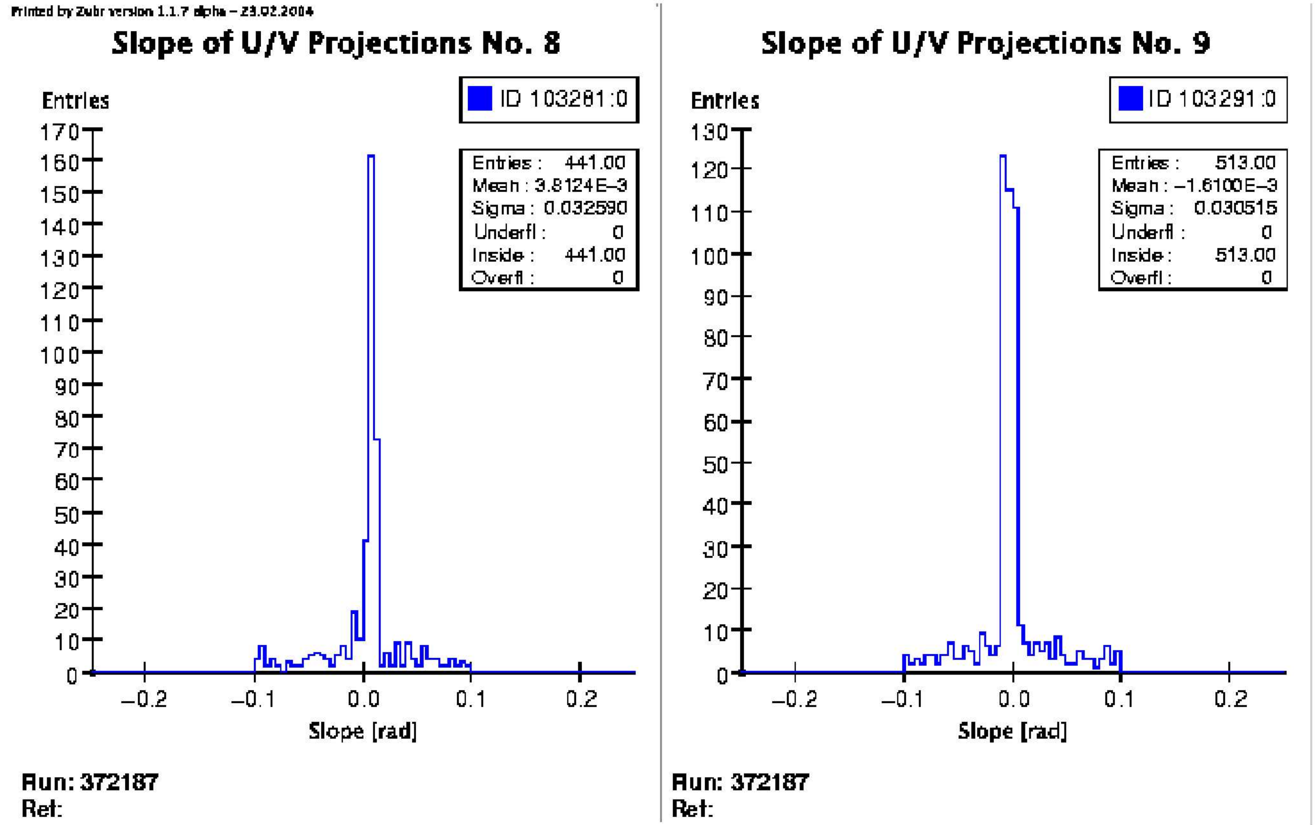
φ resolution, rad



Resolution is dominated by beam optics and sensitive to fiber detector resolution and Pot position calibration (t, $x_{\mathbb{P}}$, azimuth φ)

- $x_{\mathbb{P}}$ resolution (~10%) is competitive with $x_{\mathbb{P}}$ resolution of LRG method
- ~4 bins in |t|, ~15 bins in φ for |t|>0.2 GeV^2

VFPS present status



- VFPS installation is done in autumn 2003
- Now commissioning of the whole system $\rightarrow$ readout, slow control, track and momentum reconstruction
- Clear forward tracks are visible in the track slope distribution

Important aspects of detector design

- Radiation hard detectors
- Low sensitivity to stray magnetic field
- Clear process for calibration, possibility for cross calibration
- Reliable mechanics and electronics for long running without access to detectors
- Monitoring system to control detector position relative to beam, rates, magnet currents
- Many measured points per coordinate to suppress detector noise and fake track combinations

Summary and outlook

- H1 Forward Proton Spectrometer:
  - based on Roman Pot technology, scintillating fiber detectors readout by position sensitive photo−multipliers
  - allowed to measure $F_2^{D(3)}$ structure function, t−dependence of DIS cross section, photo−production with leading proton
  - upgraded for HERA II to increase detection efficiency and radiation resistance
- New Very Forward Proton Spectrometer for HERA II:
  - Based on the technology similar to FPS
  - large acceptance at low $x_{\mathbb{P}}$ $\rightarrow$ high potential for diffractive physics (inclusive, jets, charm, DVCS)
  - present status: installed and measured first forward protons