The H1 forward proton taggers: physics prospects

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(on behalf of the H1 Collaboration)

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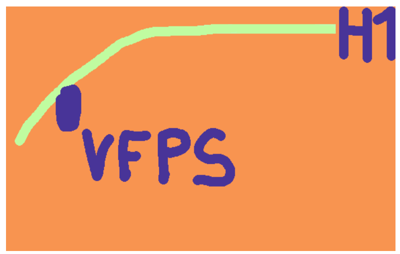
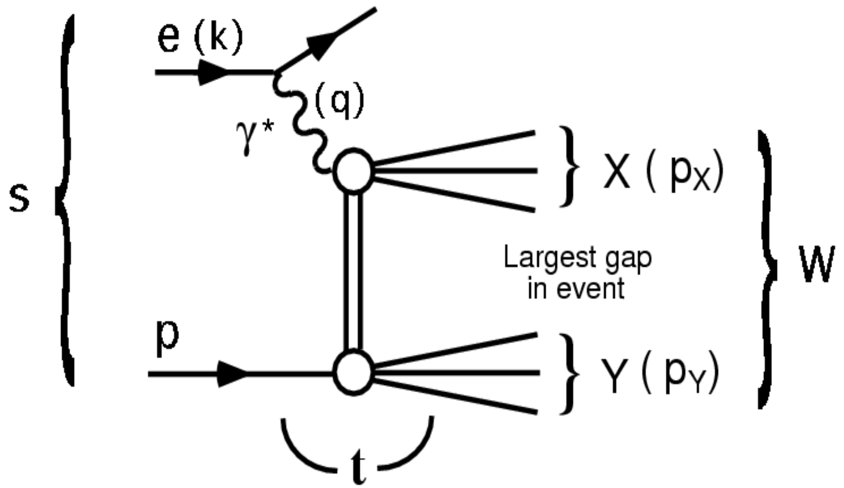
Outline:

- Introduction
- Physics results from HERA I
- Very Forward Proton Spectrometer
- Physics prospects for HERA II



Diffraction at HERA

Large fraction of diffractive events (~ 10%)



- Q^2, x (or W), M_X
- longitudinal momentum fraction of the proton carried by the colourless exchange:

$$x_{IP} = \frac{q \cdot (P - p_Y)}{q \cdot P} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

- longitudinal momentum fraction of the colourless exchange carried by the struck quark:

$$\beta = \frac{x}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^2}$$

- four-momentum transfer squared t

HERA I :

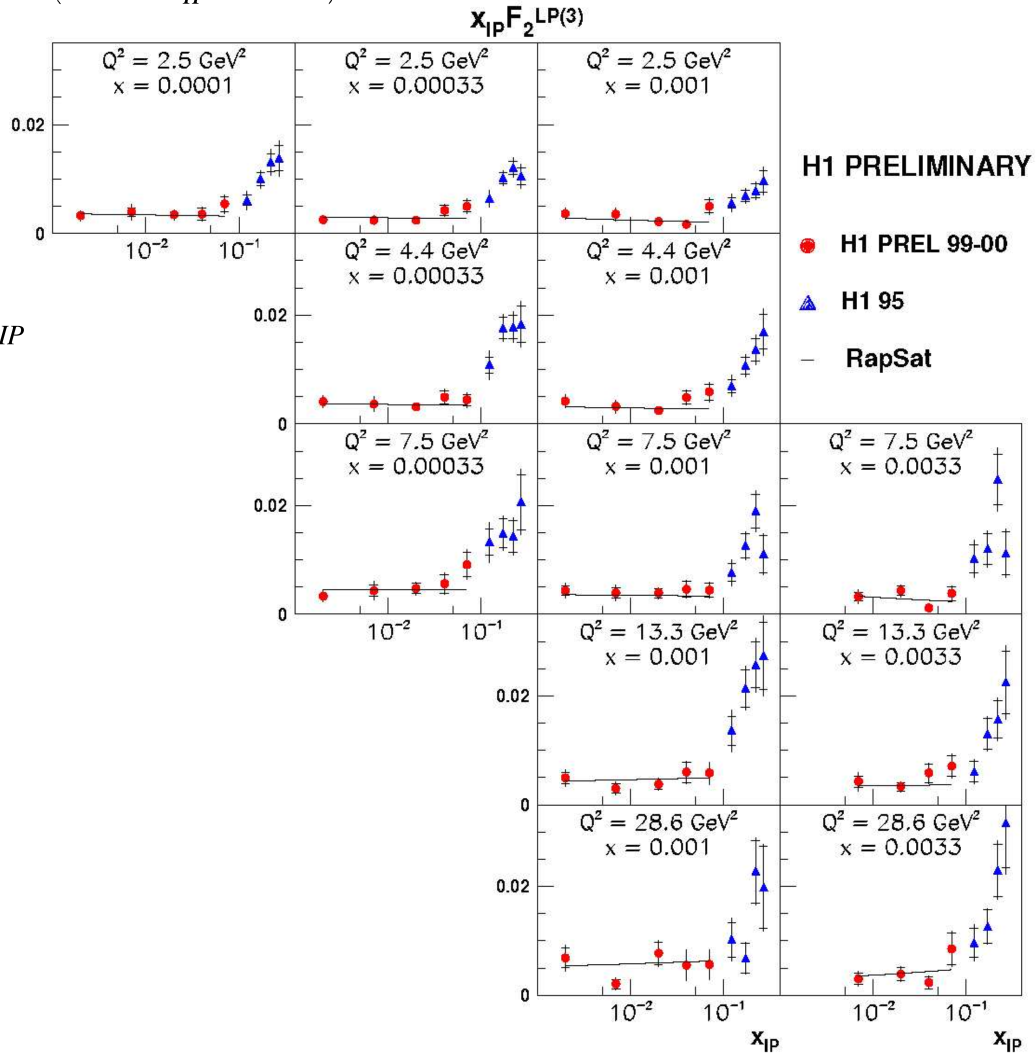
- Measurements of F_2^D, incl. final states, jets, charm, excl.VM, DVCS, ...
- BUT statistically (exclusive channels) and systematically (proton dissociation) limited !

HERA II :

- Major upgrade of the H1 detector
- High luminosity: need for efficient diffractive trigger (low Q^2 downscaled)
- Need for clean selection by directly tagging the elastically scattered proton

HERA I results: F_2^{LP}

$$\frac{d^4\sigma_{ep\to epX}}{dQ^2\, dx_{IP}\, dt\, d\beta} = \frac{4\pi\alpha_{em}^2}{\beta Q^4}\left(1-y+\frac{y^2}{2}\right)F_2^{D(4)}(Q^2, x_{IP}, t, \beta)$$



Horizontal FPS stations:

- At 60 m and 80 m from I.P.
- Acceptance of a few % at high |*t*| and low x_{IP}

Vertical FPS stations:

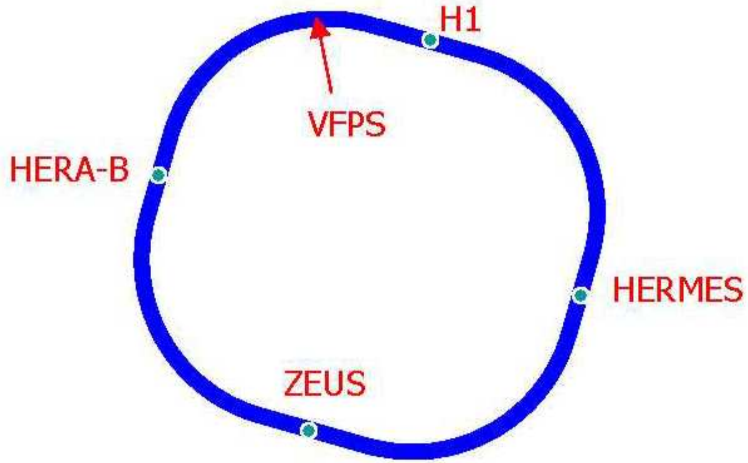
- At 81 m and 90 m from I.P.
- Large acceptance at low |*t*| and large x_{IP}

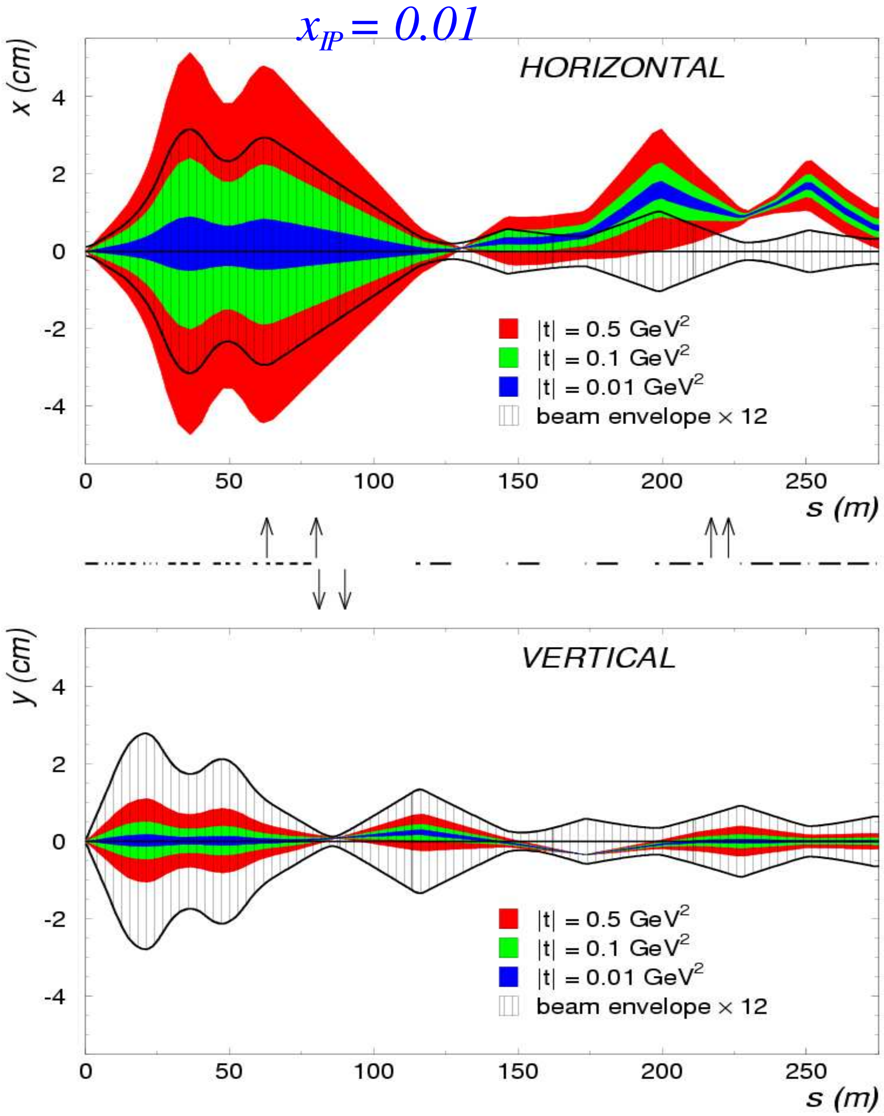
Measurement of F_2^{LP}:

	year	lumi	events
FPS-V	1995	1.4 pb^{-1}	1661
FPS-H	1999/2000	28.8 pb^{-1}	3100

Very Forward Proton Spectrometer

- VPFS location is optimised for acceptance ➜ 220m NL
- Proton beam is approached horizontally (use HERA bend)
- Bypass is needed to access the beam pipe in the cold section of HERA

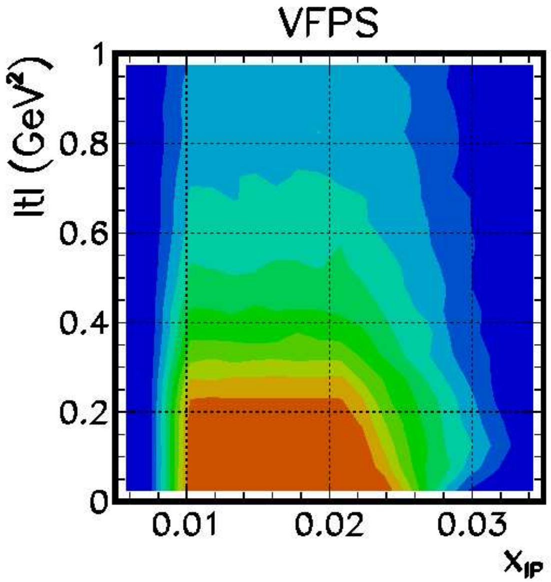




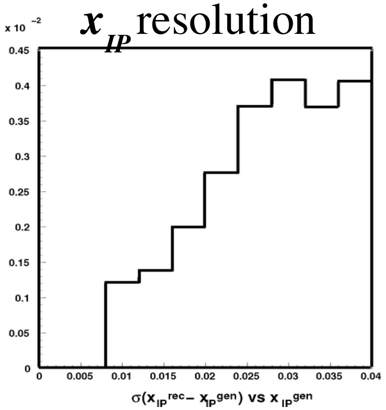
VFPS: Acceptance + Resolution

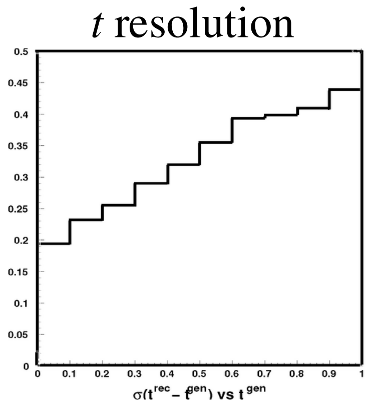
- VFPS uses dispersion of HERA bend to detect protons with small t and x_{IP} (dominant region for IP exchange)
- Acceptance range:

	FPS-H	FPS-V	VFPS
t	0.2 – 0.4	0. - 0.15	0. - 0.25
x_{IP}	$10^{-5} – 10^{-2}$	0.05 – 0.15	0.01 – 0.02
local acc.	~ 30%	~ 100%	~100%



- Resolution dominated by the beam characteristics (with minimal sensitivity to the spatial resolution of the fibre detector)
- x_{IP} resolution is competitive with the x_{IP}^{H1}
- ~ 4 bins in t
- ~ 15 bins in Φ for $|t| > 0.2$ GeV^2



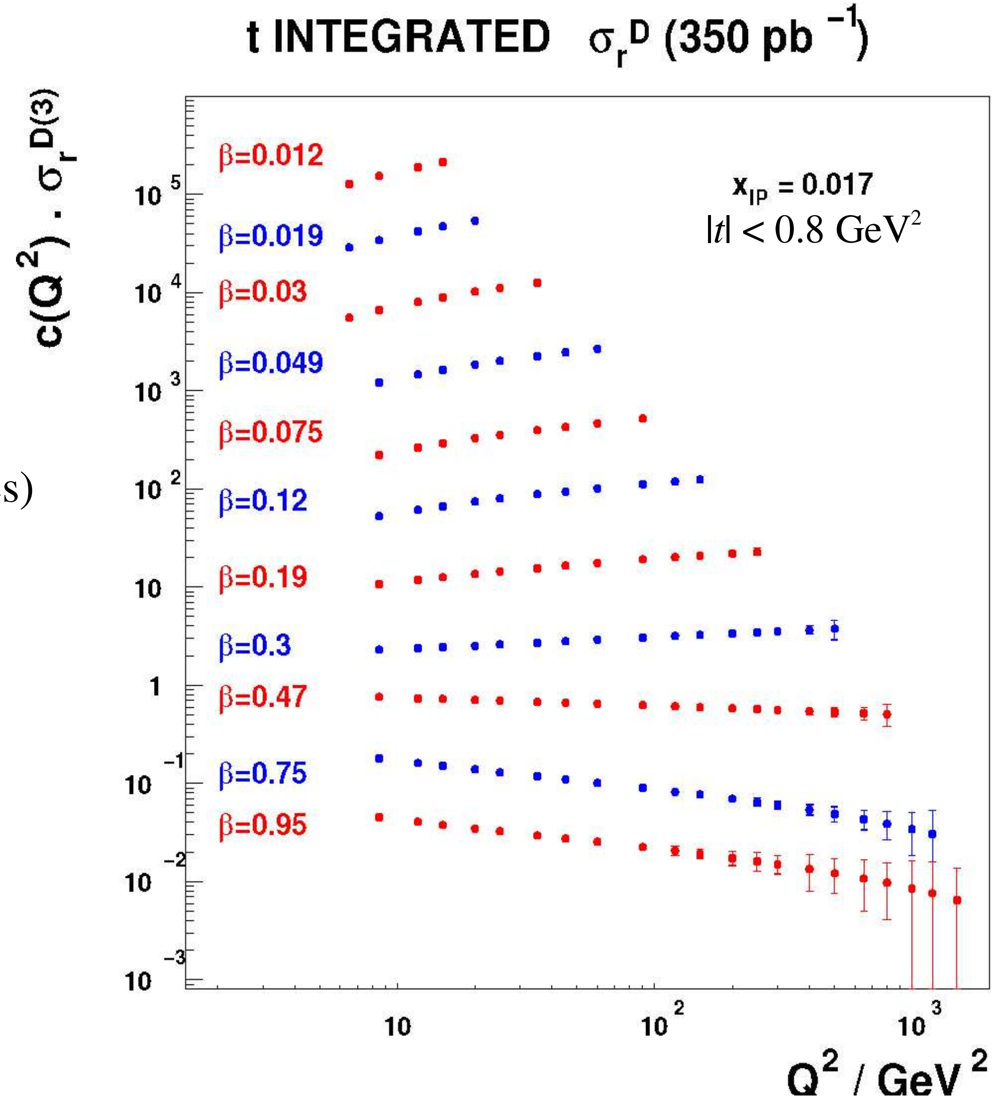


Physics prospects: Inclusive diffraction

Luminosity 350 pb^{-1} (3 years of HERA II running with 50% VFPS operation efficiency)

- Measure full $F_2^{D(4)}(Q^2, \beta, x_{IP}, t)$
- Systematic errors can approach the level of F_2
- Study t dependence $F_2^{D(4)}(Q^2, \beta, x_{IP}, t)$
- Test hard scattering factorisation (extract diffr. pdf's at fixed x_{IP} and t + predict final states)
- Test Regge factorisation (look for variations in diffr. pdf's with x_{IP} and t)
- Event yields:

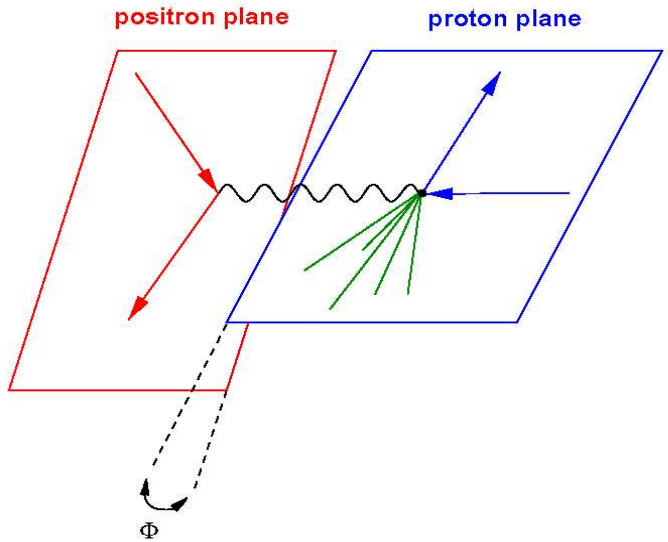
event sample	
$0.0 < \lvert t\rvert < 0.2$ GeV^2	810000
$0.2 < \lvert t\rvert < 0.4$ GeV^2	160000
$0.4 < \lvert t\rvert < 0.6$ GeV^2	23000
$0.6 < \lvert t\rvert < 0.8$ GeV^2	3000



Physics prospects: F_L measurements

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+\frac{y^2}{2})} F_L^{D(4)}$$

$$y = Q^2 / s_{ep} x$$



Φ asymmetry:

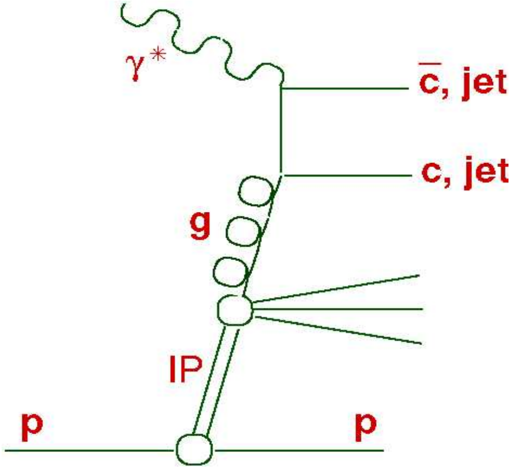
- Access to longitudinal and transverse polarized photon contributions to cross-section
- pQCD calculable higher twist F_L^D expected dominant at high β

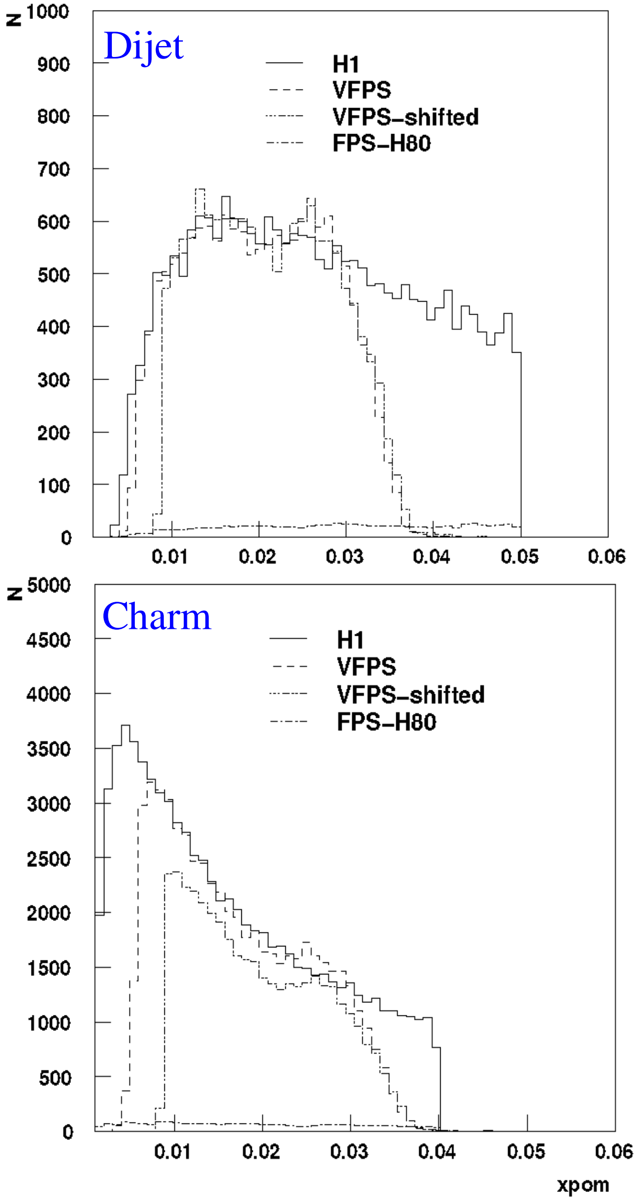
  ⟶ Measure Φ asymmetries as a function of β (and Q^2) (VFPS can measure 15 bins in Φ)

Leading twist F_L^D:

- Indirect extraction at low β from NLO QCD fits (gluons!) to $\sigma_r^{D(4)}$

Physics prospects: Hadronic final states





Diffractive Dijet electroproduction (photoproduction):

- 96/97 dijet analysis yielded: 2500 events
- HERAII/VFPS expectation: 22900 events

Open charm production:

- 96/97 D^* analysis yielded: 46 ± 10 events
- HERAII/VFPS expectation: 380 events

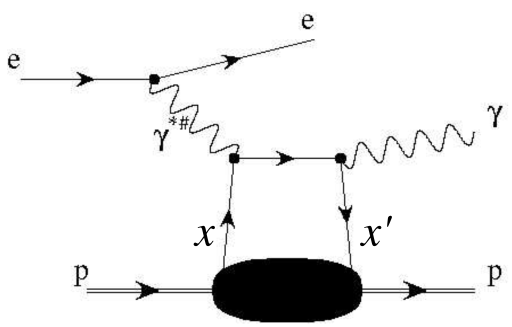
→ more differential studies

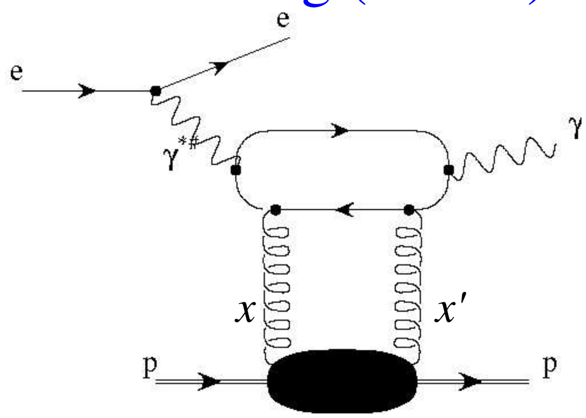
→ direct vs resolved photon contributions (rapidity gap survival probabilities)

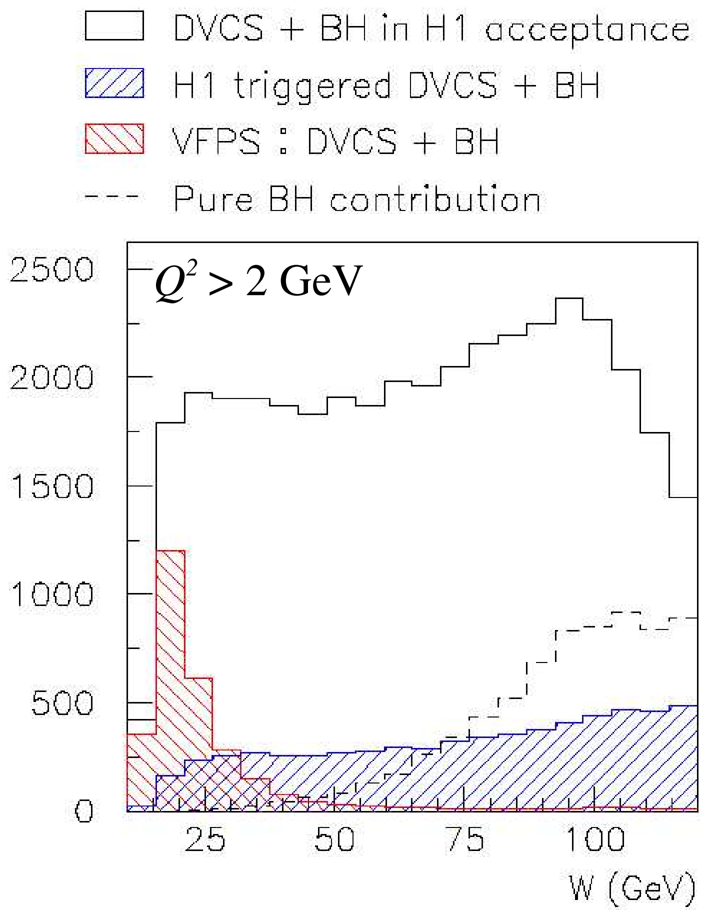
→ tests of diffractive factorisation theorem (with cancellation of VFPS systematics)

Physics prospects: Exclusive channels

Deeply Virtual Compton Stattering (DVCS):







- Calculable in pQCD
- Sensitive to GPD's (extension of pdf for $x \neq x'$) via interference with Bethe-Heitler process

  ⟶ Measure charge ($\Re e(A_{DVCS})$) and helicity ($\Im m(A_{DVCS})$) asymmetries

Vector Meson production:

$$e + p \rightarrow e + p + VM \; ; VM = \rho \; , J/\psi \; , \ldots$$

- Clean elastic channel BUT only low W accesible

Summary

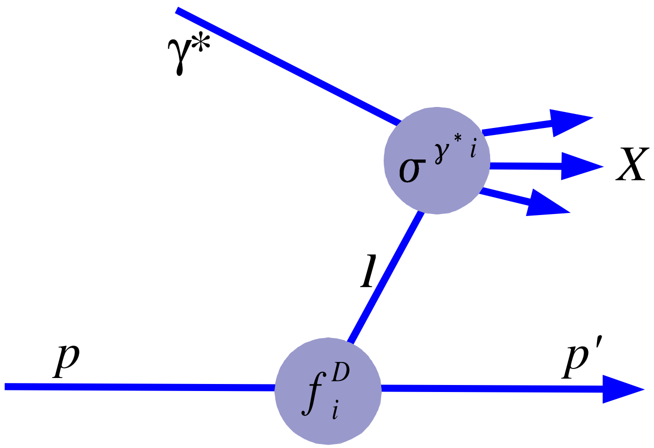
- VFPS needed to trigger diffractive events at HERA II
- Clean tagging of diffractive scattered proton
- High and well understood acceptance in window around $x_{IP} = 0.01$
- Good resolution on reconstructed proton momentum
- Installation cold beam line bypass successful
- VFPS completely installed and operational
- Many interesting physics results to come:
  - F_2^D, t dependence, F_L^D and Φ asymmetries
  - Final states (dijet, open charm) + tests of factorisation
  - DVCS (access to GPD's) and Vector Meson production

Backup slides

QCD and Regge factorisation

QCD hard scattering factorisation:

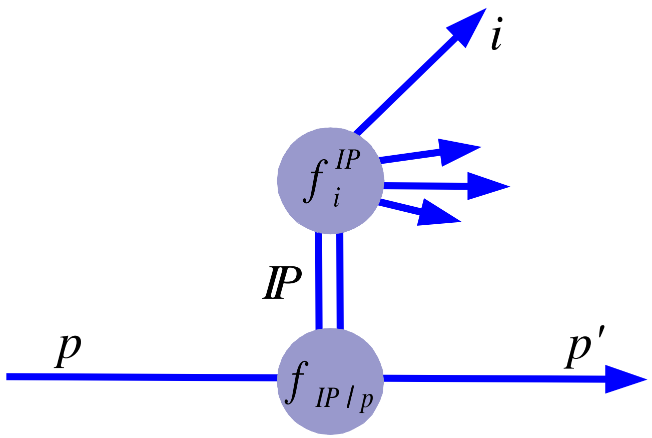
$$\sigma^{\gamma^* p \to p' X} = \sigma^{\gamma^* i} \otimes f_i^D$$



- $\sigma^{\gamma^* i}$ the universal partonic cross section (same as in inclusive DIS)
- f_i^D the parton distribution function for a parton i under the constraint that the proton survives the diffractive scattering (f_i^D should obey the DGLAP evolution equations)

Regge factorisation:

$$f_i^D(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \,.\, f_i^{IP}(\beta = x/x_{IP}, Q^2)$$



- $f_{IP/p}$ "pomeron flux factor" (can be parameterized according to Regge theory)
- f_i^{IP} "pomeron parton distribution"

HERA I results: *t* measurement

$$\frac{d\sigma}{dt} \sim e^{-bt}$$

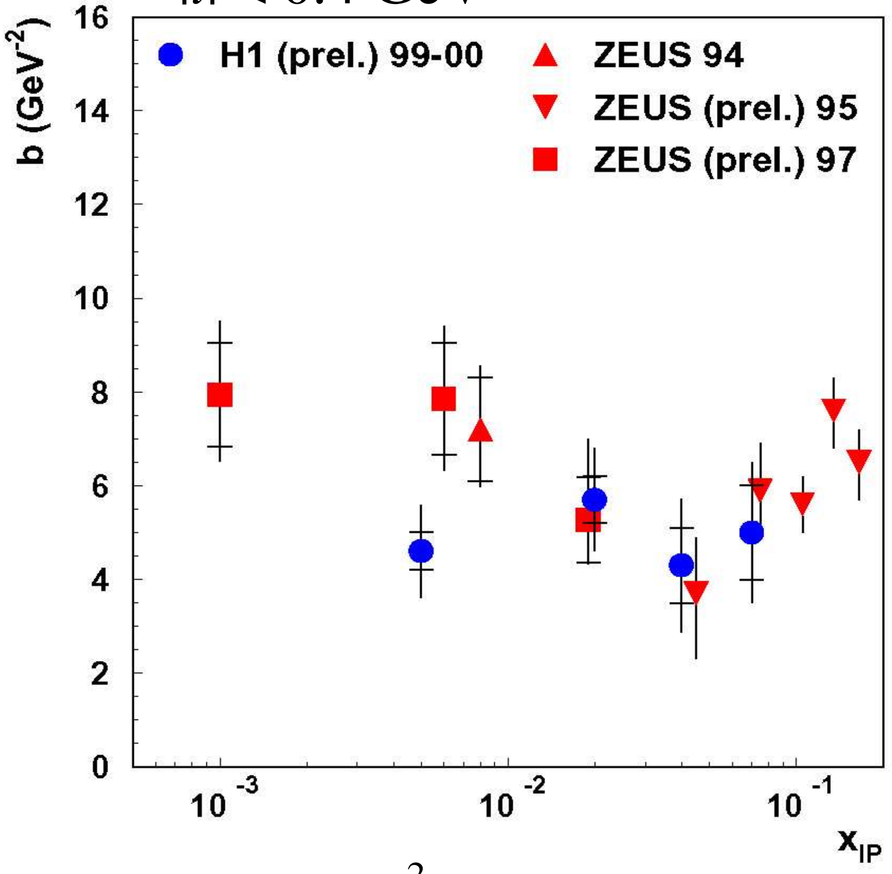
Regge phenomenology:
expect shrinkage with *W*

$$b = b_0 + 2\alpha'_{IP} \log\left(\frac{1}{x_{IP}}\right)$$

→ Inconclusive so far

→ Need more data !

$|t| < 0.4$ GeV^2



$$W^2 \sim \frac{M_X^2}{x_{IP}}$$

Beam simulation studies

Linear beam transport:

Beam optics transport matrix

Beam spread and divergence at IP

$$\begin{pmatrix} x(s) \\ x'(s) \\ \xi(s) \end{pmatrix} = \begin{pmatrix} T_x^{11}(s_0,s) & T_x^{12}(s_0,s) & D_x(s_0,s) \\ T_x^{21}(s_0,s) & T_x^{22}(s_0,s) & D'_x(s_0,s) \\ 0 & 0 & 1 \end{pmatrix} \cdot \left[\begin{pmatrix} x_0 \\ x'_0 \\ \xi_0 \end{pmatrix} + \begin{pmatrix} 0 \\ \theta_x \\ -x_{I\!P} \end{pmatrix} \right]$$

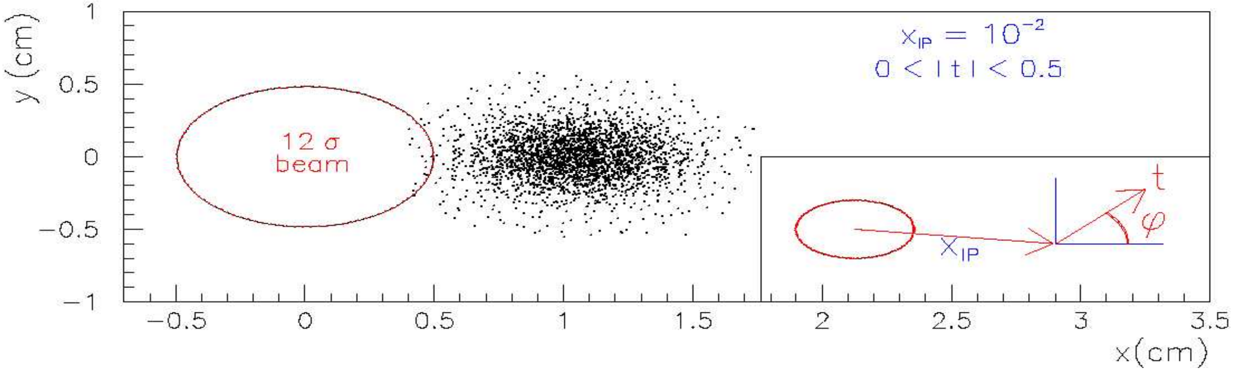
Position, slope and energy at VFPS

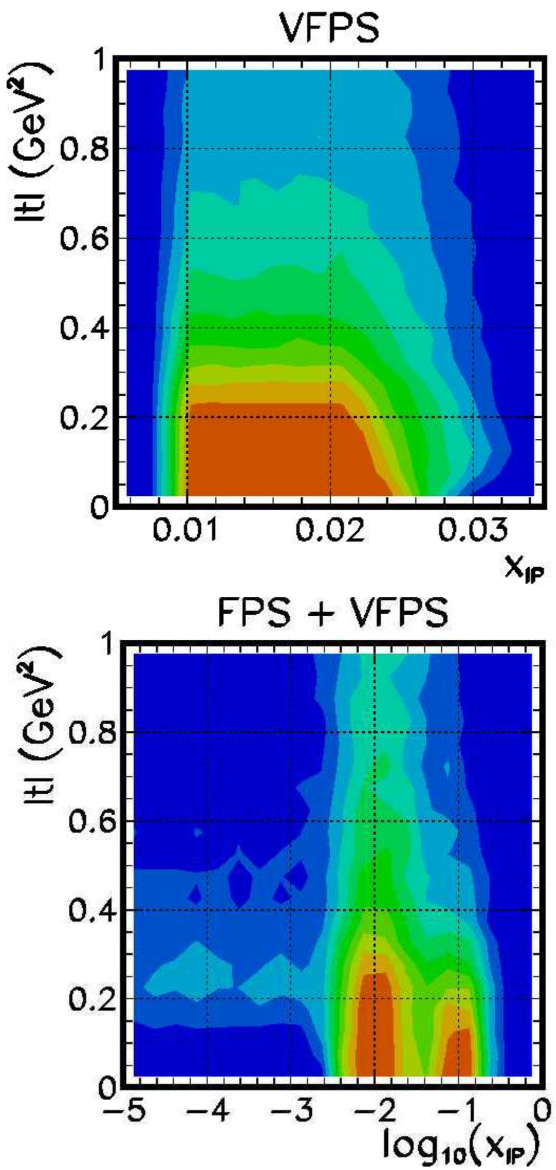
Diffractive variables

Non-linear corrections !

- Non-linear effects in energy deviation
- Sextupoles
- Offset, tilted magnets

VFPS Acceptance





- Use beam line simulation
- Detectors approach beam up to 12 times the beam enveloppe + 3 mm "coasting beam margin"
- Horizontal FPS needs large t to separate protons
- Vertical FPS uses dispersion of magnet, needs large x_{IP}
- VFPS uses dispersion of HERA bend to detect protons with small t and x_{IP} (dominant region for *IP* exchange)
- Acceptance range:

	FPS-H	FPS-V	VFPS
t	0.2 – 0.4	0. - 0.15	0. - 0.25
x_{IP}	$10^{-5} – 10^{-2}$	0.05 – 0.15	0.01 – 0.02
local acc.	~ 30%	~ 100%	~100%

VFPS Reconstruction

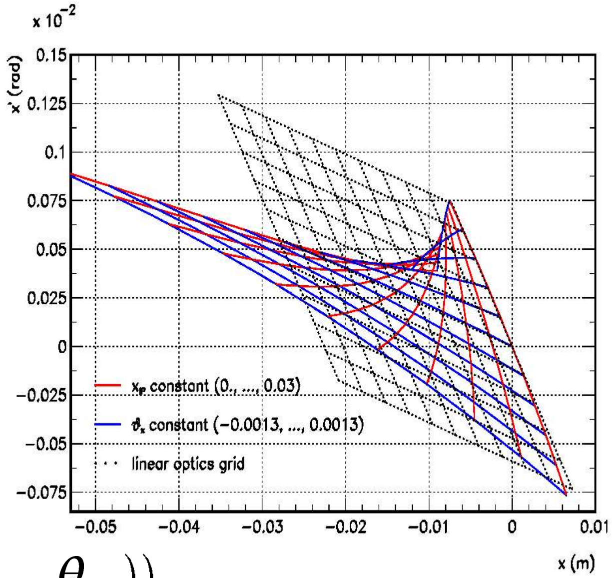
- 2 Roman Pot stations, 2 detectors each
- Measure position and slope in between both Roman Pot stations
- Reconstruct proton momentum $(x_{IP}, t, \Phi) \sim (x_{IP}, \theta_x, \theta_y)$
- Reconstruction fit:

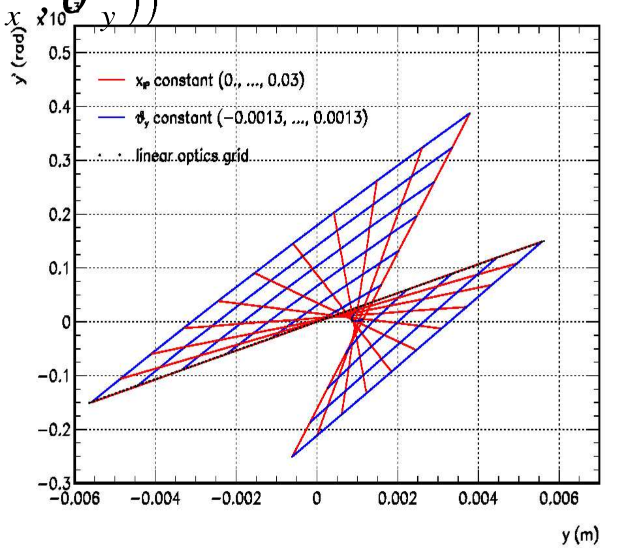
$$\chi^2 = \Sigma_{ij} (x_i^m - x_i(x_{IP}, \theta_x, \theta_y)) c_{ij} (x_j^m - x_j(x_{IP}, \theta_x, \theta_y))$$

where c_{ij} is the covariance matrix containing:

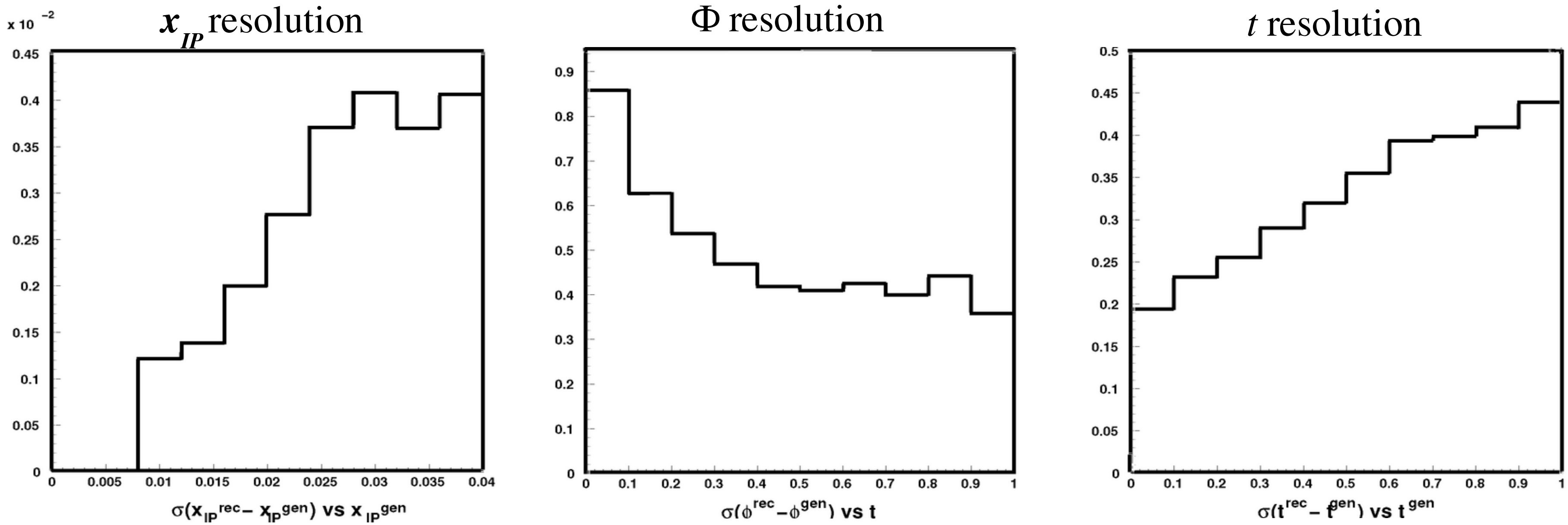
- beam characteristics (spread, divergence)
- fibre detector resolution

non-linear effects complicate the reconstruction!



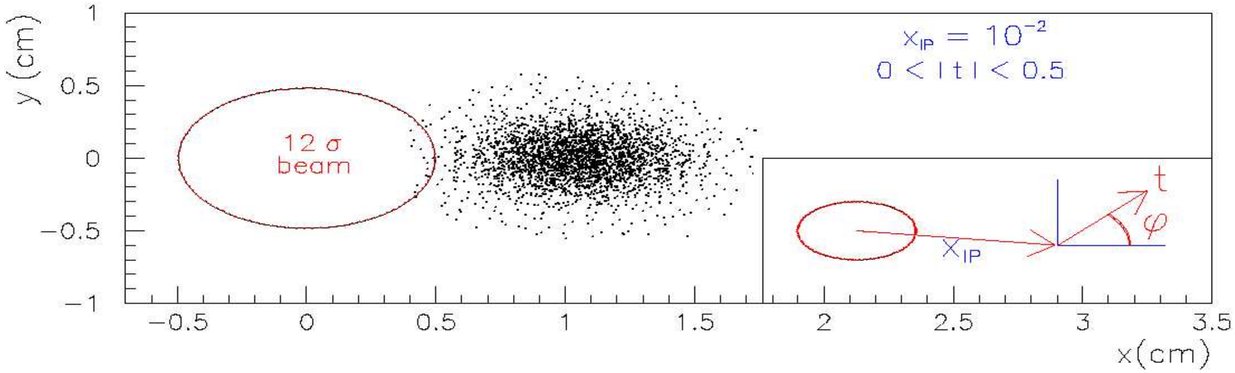


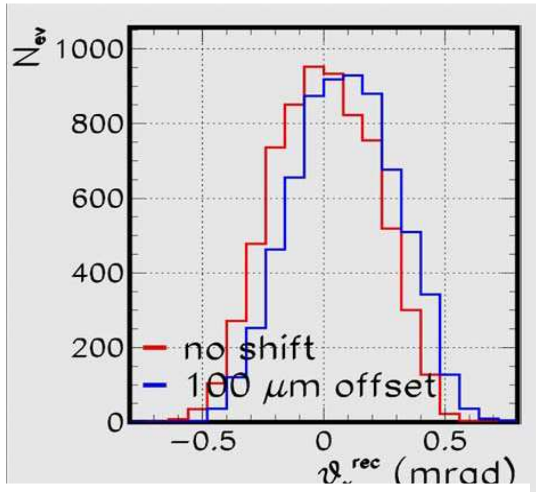
VFPS Resolution



- Resolution dominated by the beam characteristics (with minimal sensitivity to the spatial resolution of the fibre detector)
- x_{IP} resolution is competitive with the reconstruction of x_{IP} by H1
- ~ 4 bins in t
- ~ 15 bins in Φ for $|t| > 0.2$ GeV^2

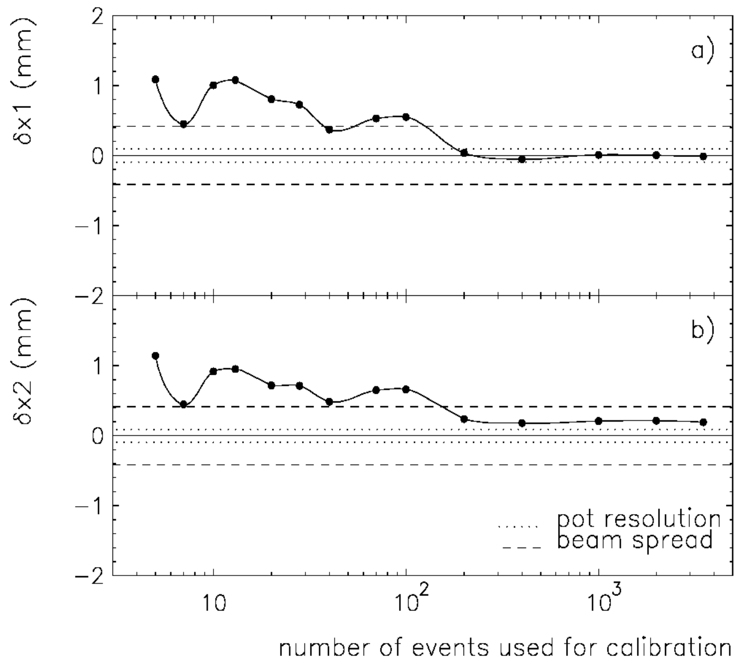
VFPS Alignment





- Relative positioning of the pots vs the nominal beam
- Exploit x_{IP} measurement by H1
- Use forward peak $t = 0$
- Calibration fit:

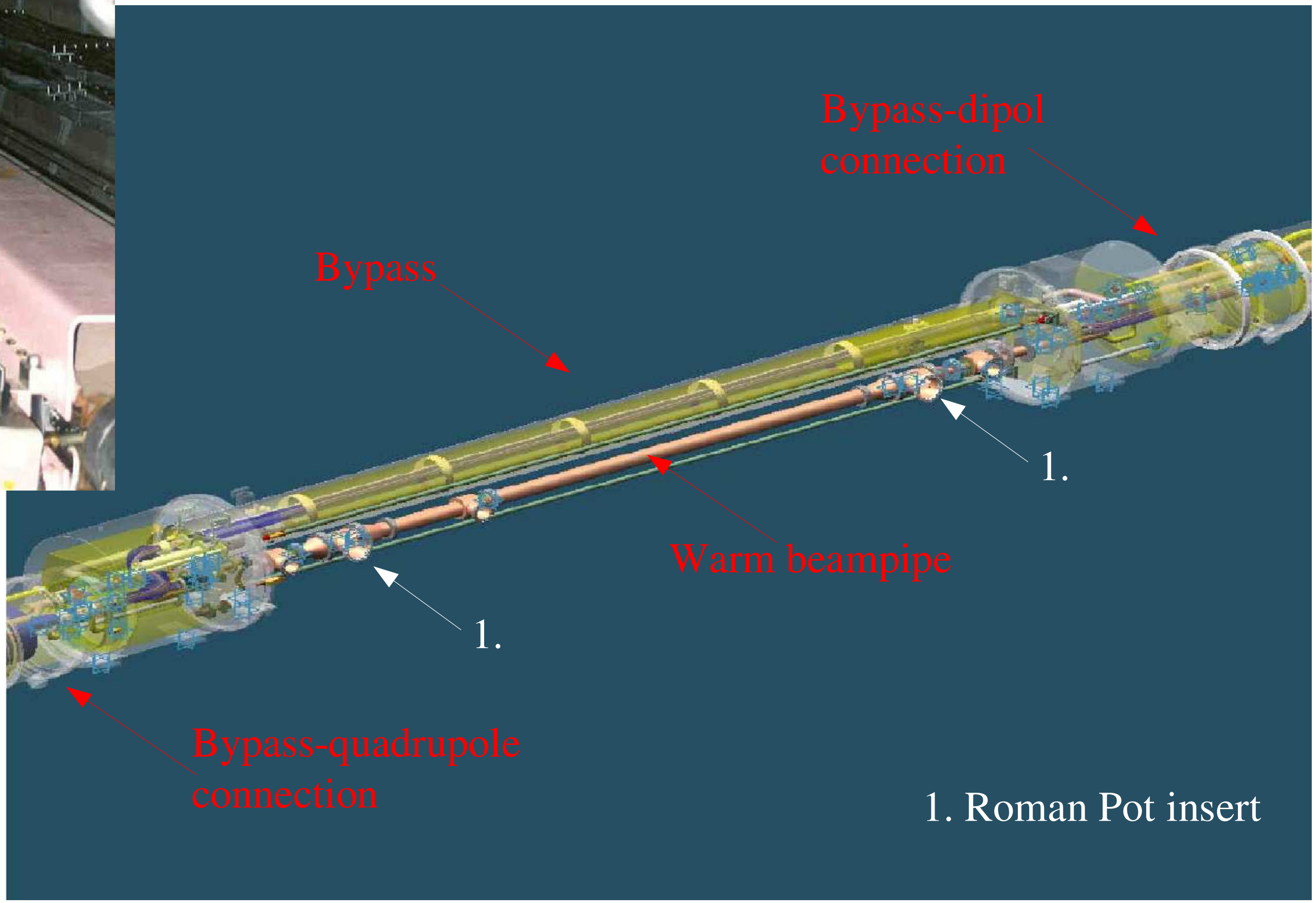
$$\chi^2 = \frac{\theta_x^2}{\sigma_x^2} + \frac{\theta_y^2}{\sigma_y^2} + \frac{(x_{IP} - x_{IP}^{H1})}{\sigma^2_{(x_{IP} - x_{IP}^{H1})}}$$



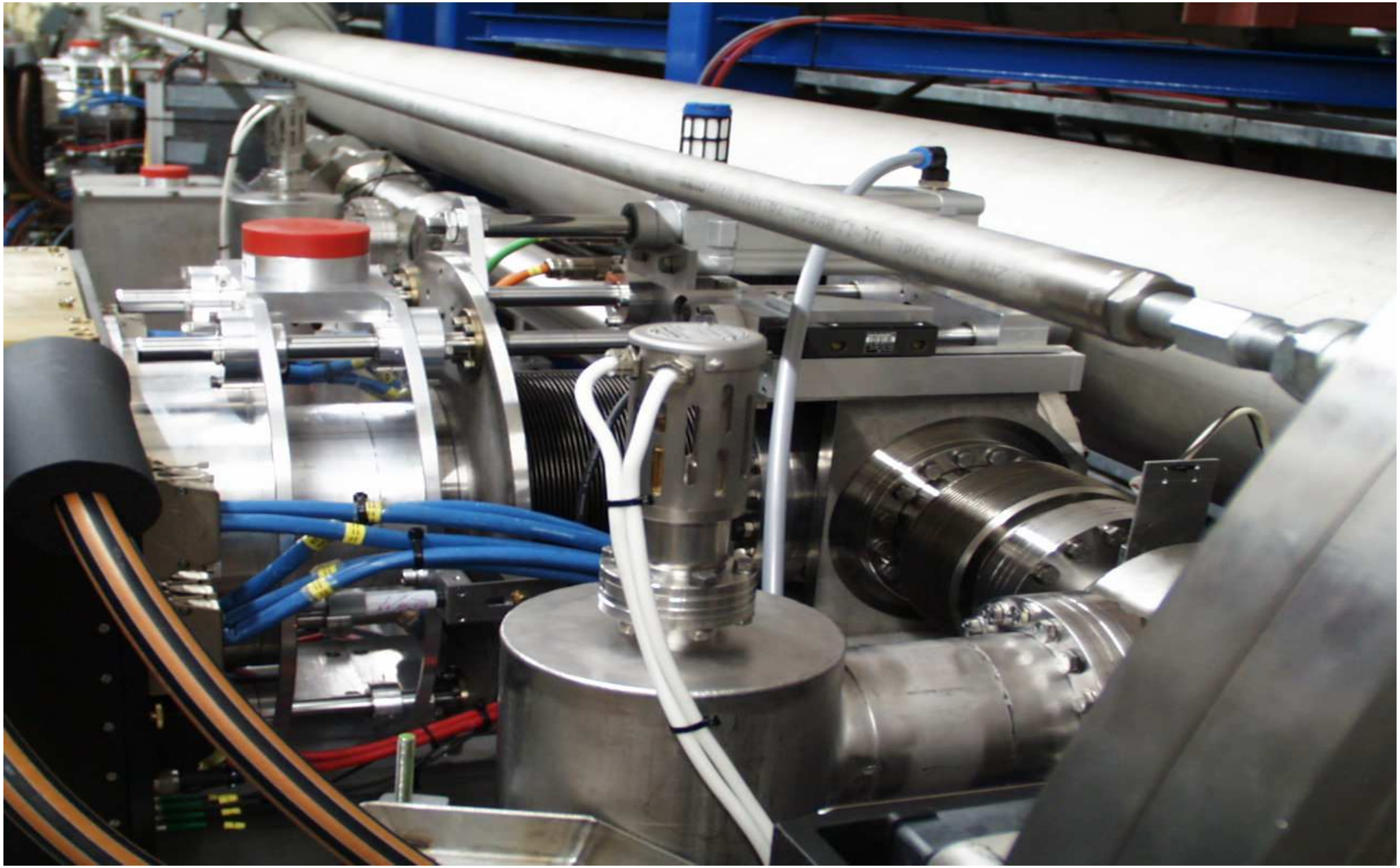
- Alignment precision of ~100 μm is feasible
- Alternative fits are possible with e.g. elastic rho mesons

Cold beam line bypass

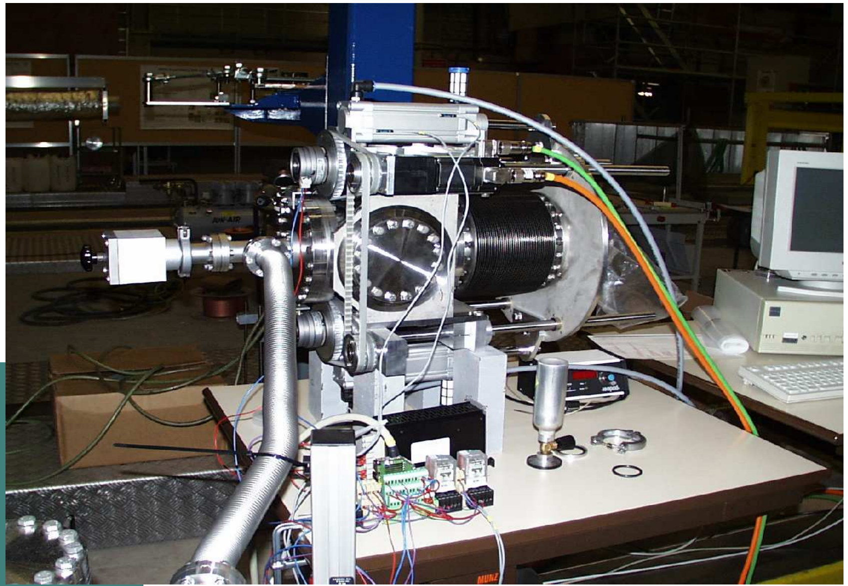
Modification of 10m drift segment: horizontal bypass for helium and superconductor lines

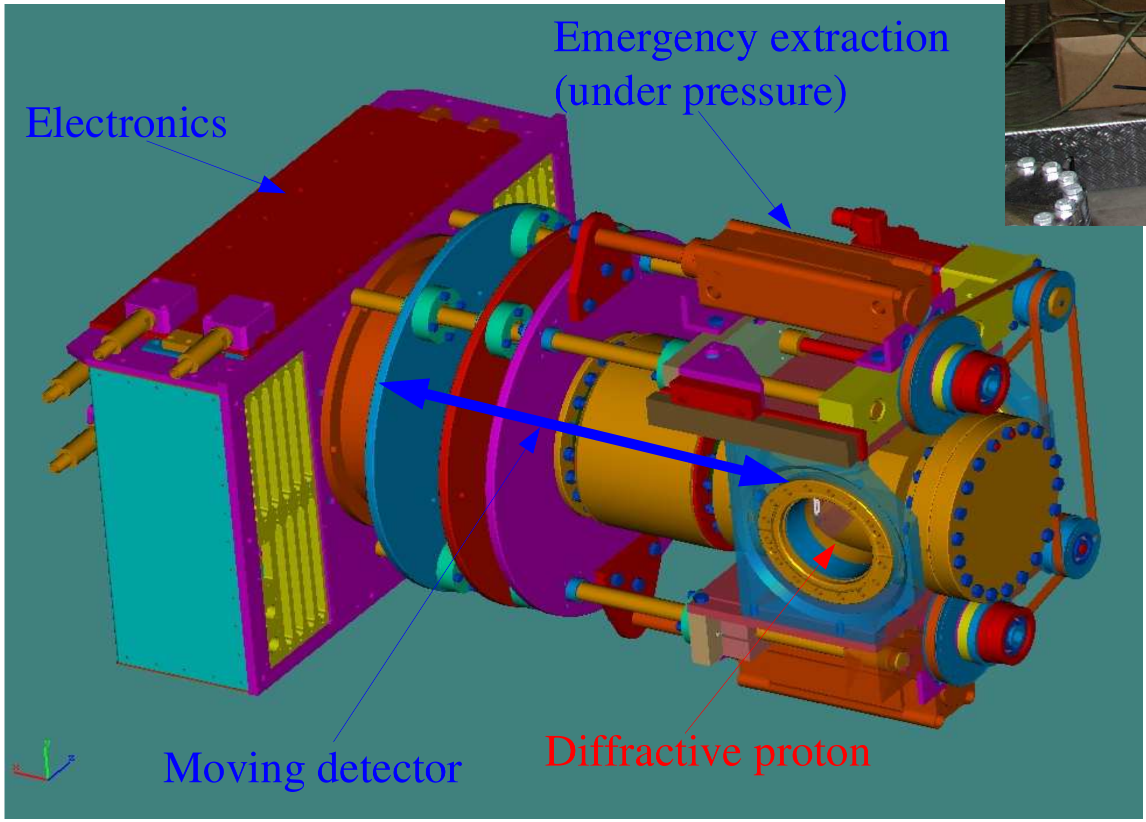


Cold beam line bypass



Roman Pot insert

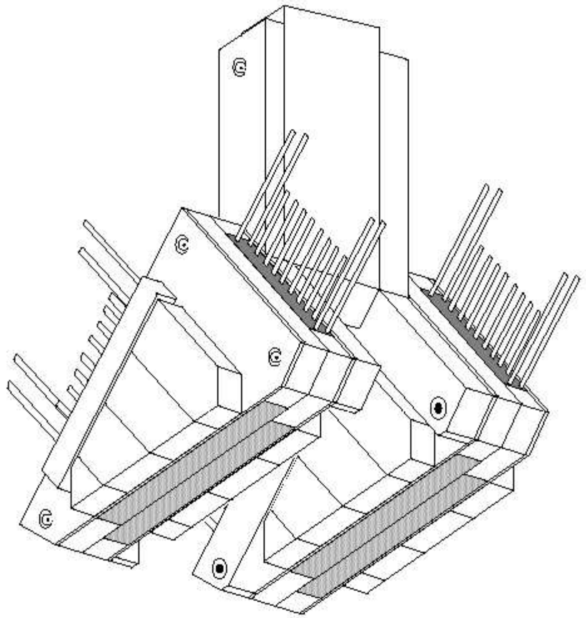




VFPS detector

VFPS detector:

- 2 detectors per Roman Pot station
- 1 detector: 4 trigger tiles in u-direction +
  u fibre plane +
  v fibre plane +
  4 trigger tiles in v-direction
- Spatial detector resolution ~ 100 μm
- Cosmic tests: very good efficiency (~99%)

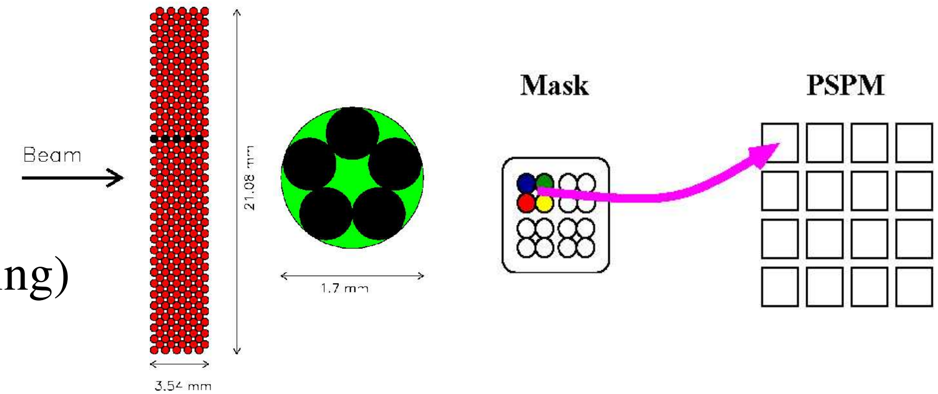


Fiber specifications:

- Diameter 480 μm
- Pitch 340 μm

Optical connection:

- 5 fibre layers (= 1 plane) → 1 light guide
- 4 light guides → 1 PSPM pixel (multiplexing)



VFPS in the HERA tunnel