Recent Results from the H1 Experiment

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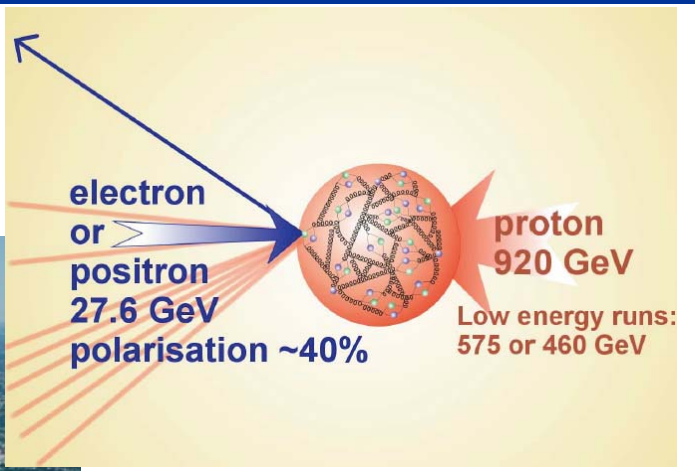
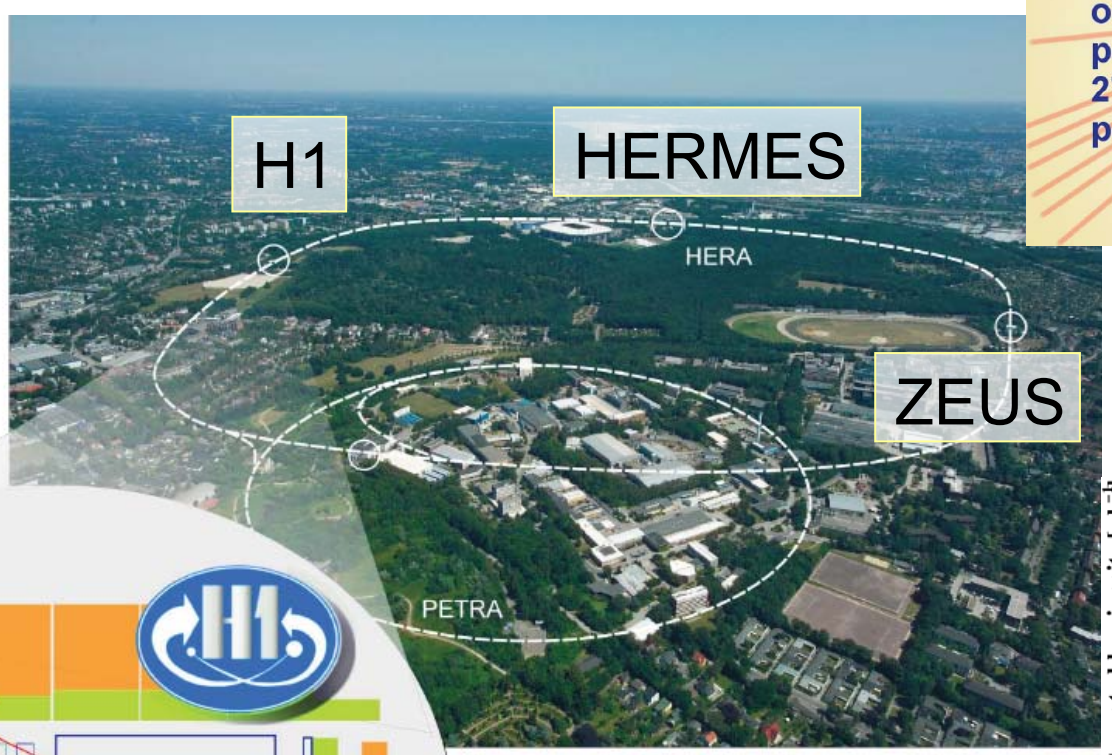
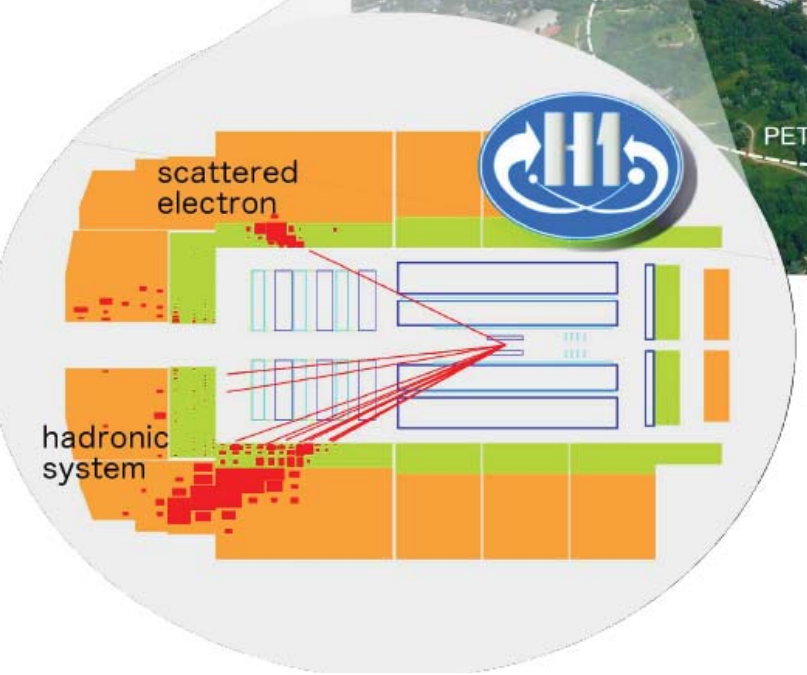
On behalf of the H1 and ZEUS Collaborations

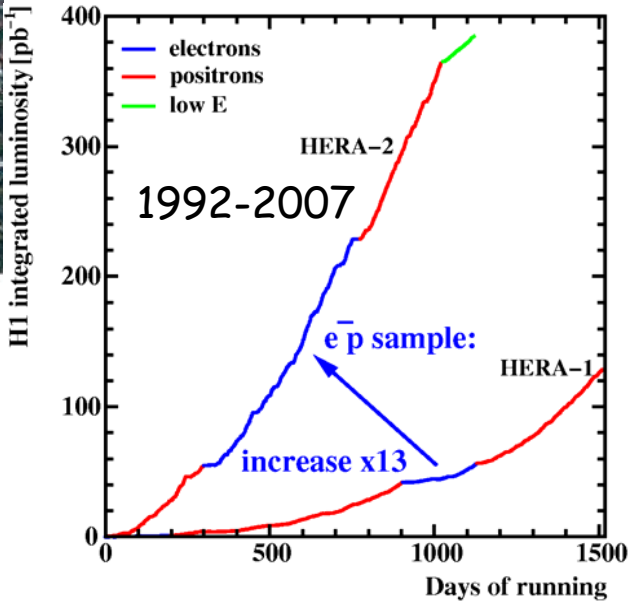
- Inclusive DIS measurements
- Hadronic final states
- Diffraction

HERA- The world's only electron-proton collider



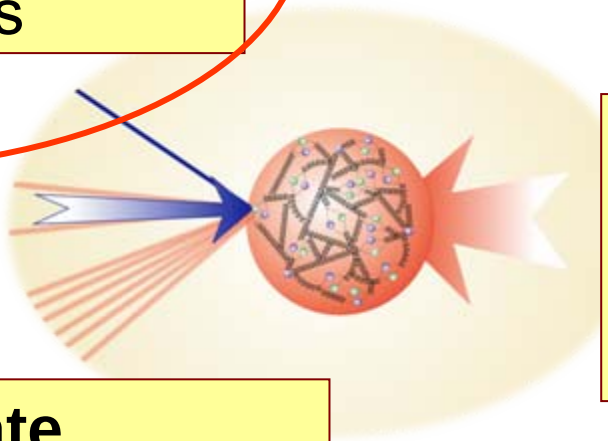






~ 0.5 fb^{-1} data

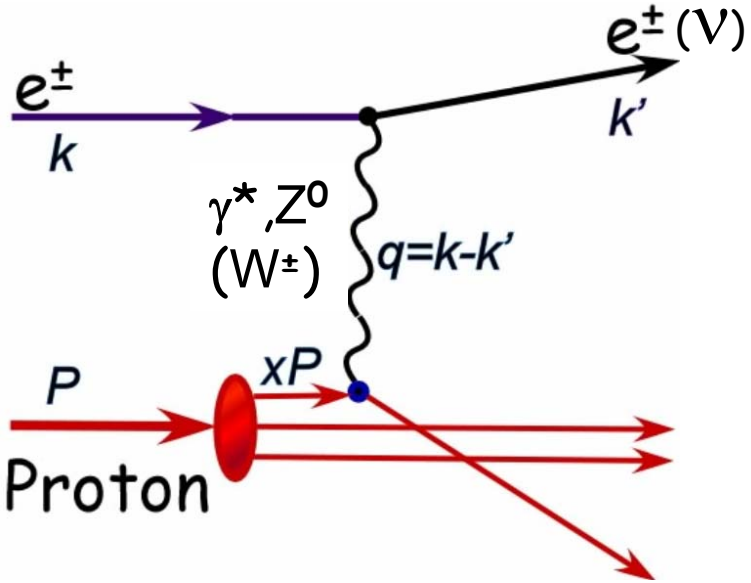
Inclusive measurements
proton structure, PDF
Electroweak effects



Hard diffraction
Diffractive DIS
elastic J/ψ production
diffractive jet production

Hadronic final state
Charged particle production, strangeness
Target fragmentation

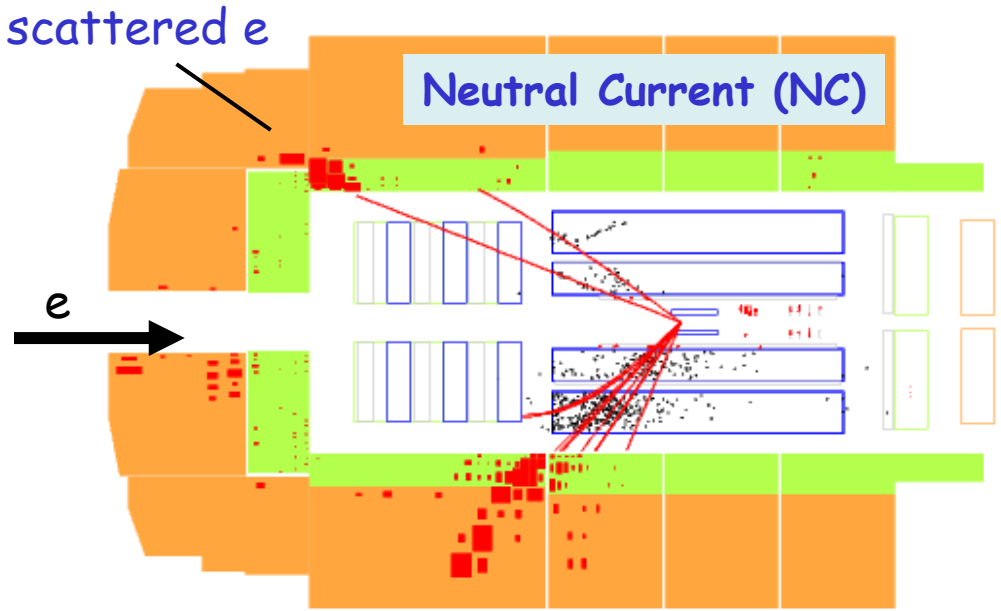
Deep Inelastic electron-proton Scattering (DIS) at HERA

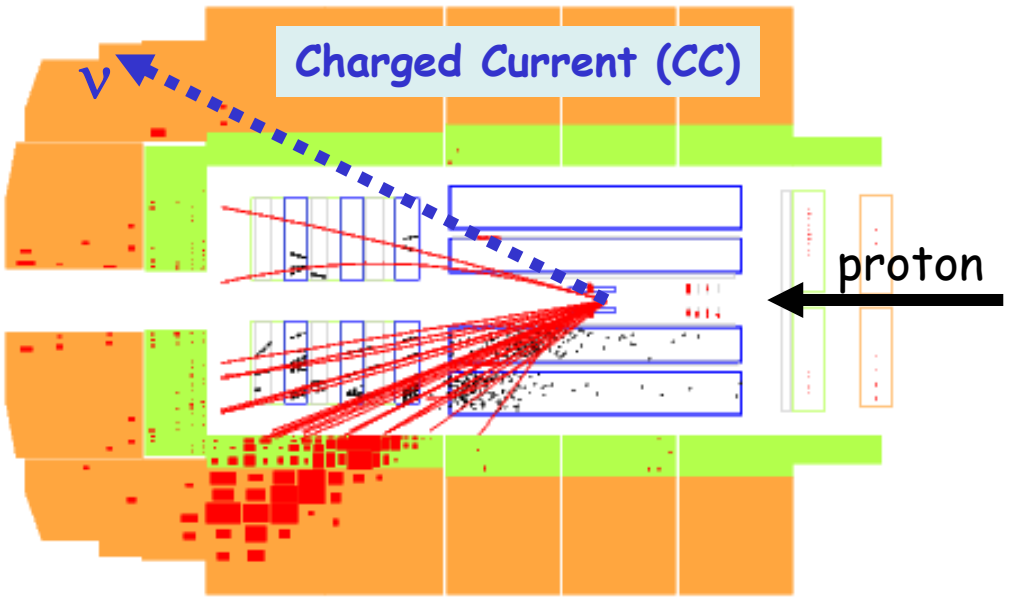


$Q^2=-(k-k')^2$ virtuality of exchanged boson: 'resolving power' of probe

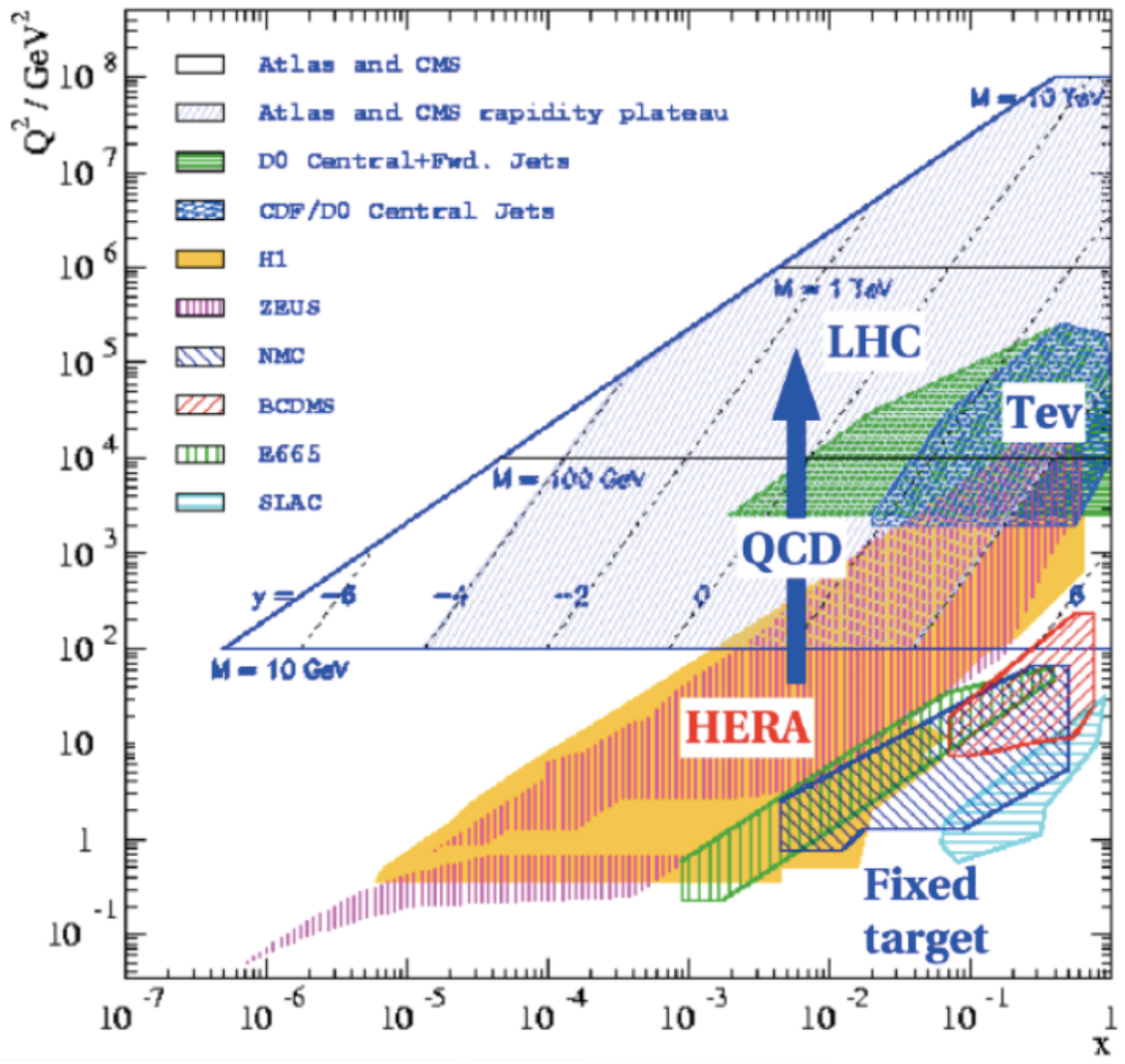
$x=Q^2/2p\cdot q$ fraction of proton momentum carried by struck quark
At HERA $x\sim 10^{-6}$ – 1

$y=p\cdot q/p\cdot k$ inelasticity variable: $y= Q^2/(s\cdot x)$





DIS at HERA: kinematic coverage



HERA inclusive data are an indispensable input to modern PDF fits

HERA: span 5 orders of magnitude in x and Q^2

Direct overlap with the LHC kinematics:

- HERA covers x range of the LHC, evolution in Q^2 via DGLAP

$$\sigma_{HERA} = PDF \otimes ME$$

$$\sigma_{LHC} = PDF \otimes ME \otimes PDF$$

Inclusive DIS cross sections at high Q^2

Final measurement of inclusive NC/CC cross sections at $\sqrt{s}$=319 GeV with H1 detector

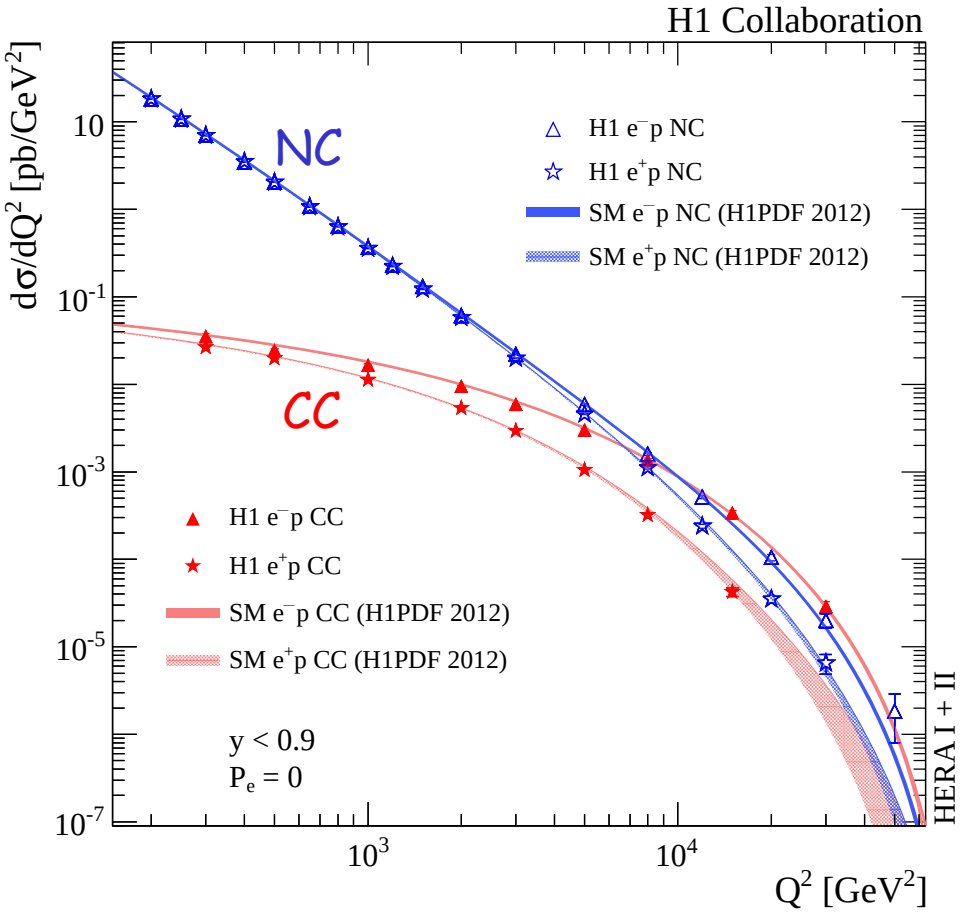
Data: e^-p and e^+p polarized $e^\pm$ beams
→4 distinct data sets
(all HERA-2 data at Ep=920 GeV)

	R	L
e^-p	$\mathcal{L} = 47.3\,\mathrm{pb}^{-1}$ $P_e = (+36.0 \pm 1.0)\%$	$\mathcal{L} = 104.4\,\mathrm{pb}^{-1}$ $P_e = (-25.8 \pm 0.7)\%$
e^+p	$\mathcal{L} = 101.3\,\mathrm{pb}^{-1}$ $P_e = (+32.5 \pm 0.7)\%$	$\mathcal{L} = 80.7\,\mathrm{pb}^{-1}$ $P_e = (-37.0 \pm 0.7)\%$

$60 < Q^2 < 50.000\ \mathrm{GeV}^2$, $0.0008 < x_{Bj} < 0.65$

Typical precision:
NC e^+ ~1.5% ; e^- ~2.0%
CC $e^\pm$ ~4%

$d\sigma/dQ^2$ cross sections of CC and NC



Text-book plot illustrating electroweak unification

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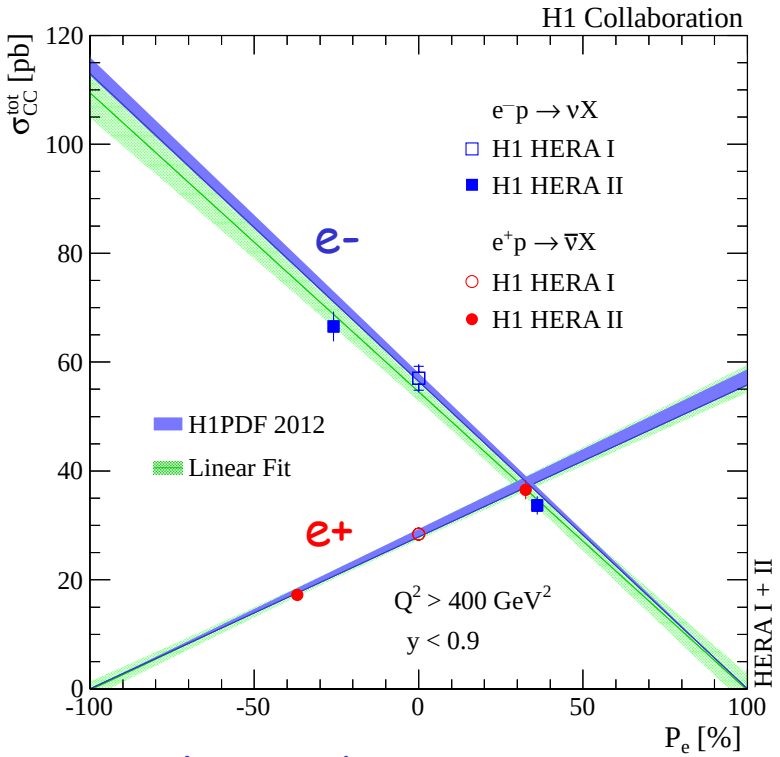
Inclusive DIS polarised cross sections at high Q^2

Polarisation dependence of total CC cross sections SM: $\sigma^{\pm}_{CC}(P_e) = (1 \pm P_e)\sigma^{\pm}_{CC}(0)$



Linear scaling with P_e

Extrapolated cross sections ≈ 0
- at Pe=+1 for e-
- at Pe=-1 for e+

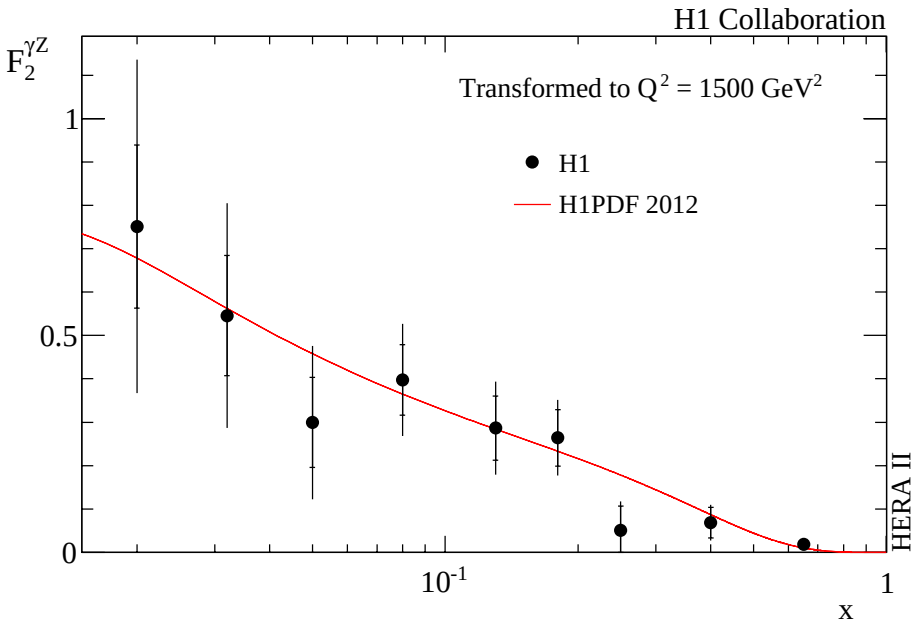
➔ **Text-book plot demonstrating the absence of right handed weak current**

NC polarisation asymmetry

SM: difference in the σ_{NC} for leptons with different helicity states (due to chiral structure of the neutral EW exchange)

Polarisation asymmetry of NC cross section is sensitive to γZ interference terms of structure functions

$$F_2^{\gamma Z} \sim [\sigma^-(P_L) - \sigma^-(P_R)] - [\sigma^+(P_L) - \sigma^+(P_R)]$$



First measurement of $F_2^{\gamma Z}$ structure function

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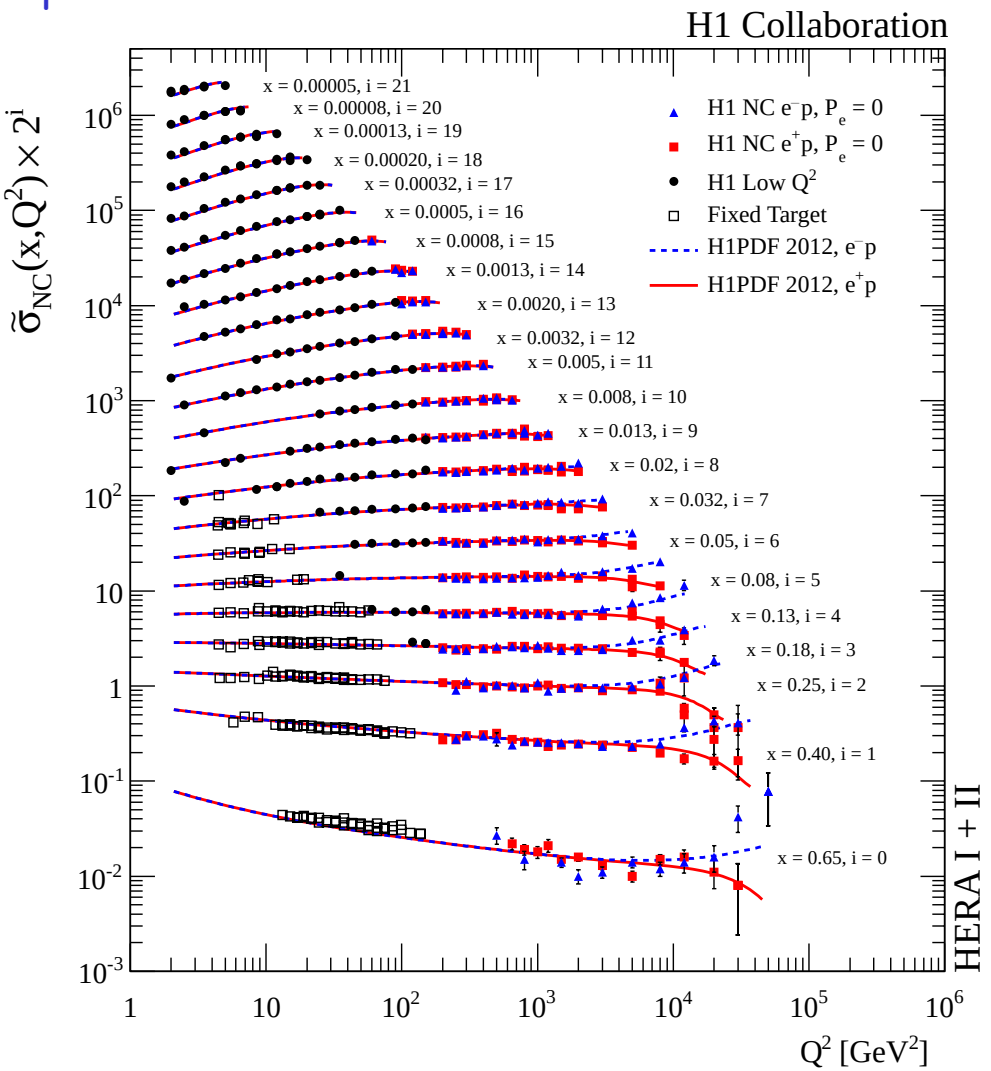
Inclusive DIS cross sections

unpolarised NC cross e^-p and e^+p reduced cross sections

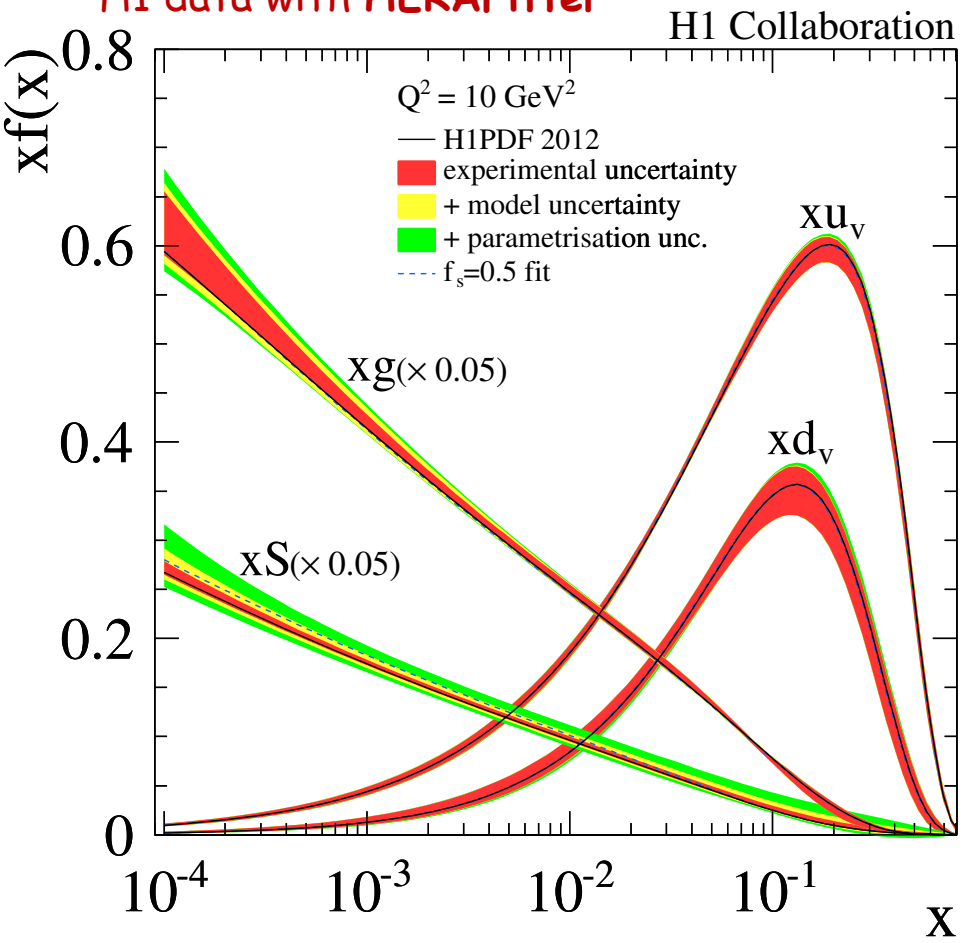
$$\tilde{\sigma}^{\pm}_{\rm NC}(x,Q^2) \equiv \frac{{\rm d}^2\sigma^{\pm}_{\rm NC}}{{\rm d}x{\rm d}Q^2}\frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+} = \left(\tilde{F}_2^{\pm} \mp \frac{Y_-}{Y_+}x\tilde{F}_3^{\pm} - \frac{y^2}{Y_+}\tilde{F}_L^{\pm}\right)(1+\Delta^{\rm weak}_{\rm NC}) \qquad Y_{\pm} = 1 \pm (1-y)^2$$



Text-book plot: scaling violation

Combined H1 data probe the proton over nearly 5 orders of magnitude

NLO QCD fit to all published NC and CC H1 data with **HERAFitter**



➔ H1PDF 2012

➔ Improvement in precision for all PDFs in the full x range

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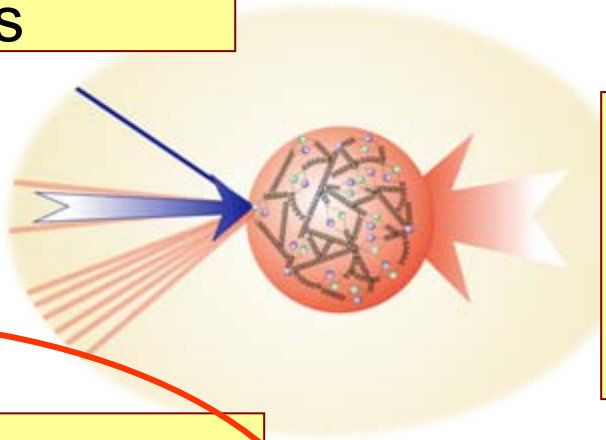
Inclusive measurements
proton structure, PDF
Electroweak effects

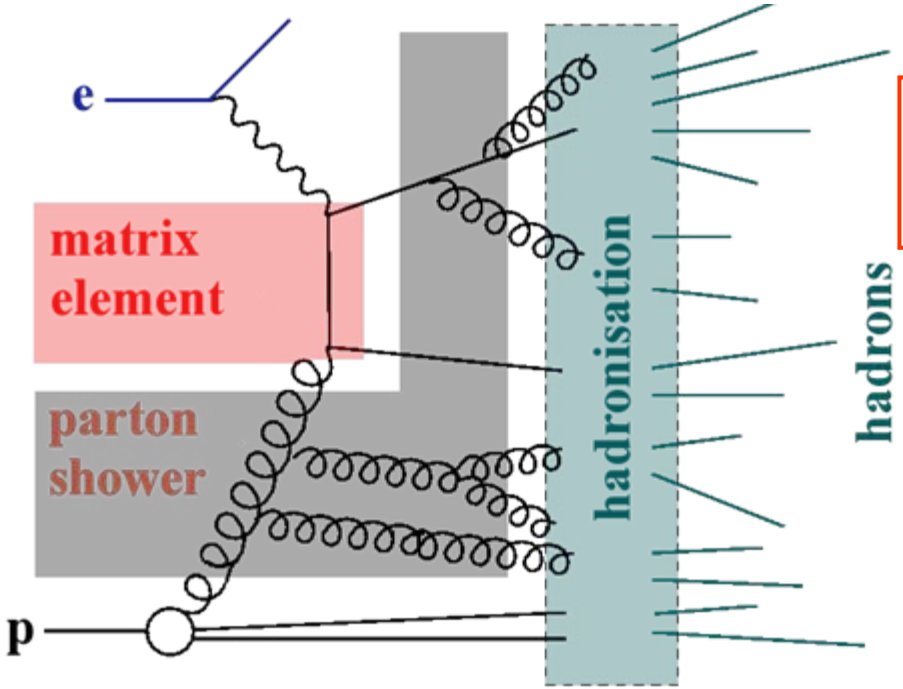


Hard diffraction
Diffractive DIS
elastic J/ψ production
diffractive jet production

Hadronic final state
Charged particle production, strangeness
Target fragmentation

Charged particle densities in DIS

A large amount of the experimental data on charged particle production spectra has been accumulated during last decades.
However the underlying dynamics of hadron production in high energy particle interaction is still not fully understood.



Several mechanisms contribute to hadron production

$$PDF \otimes \text{Parton dynamics} \otimes Hadronisation \Rightarrow HFS$$

→ Different kinematic ranges sensitive to different effects

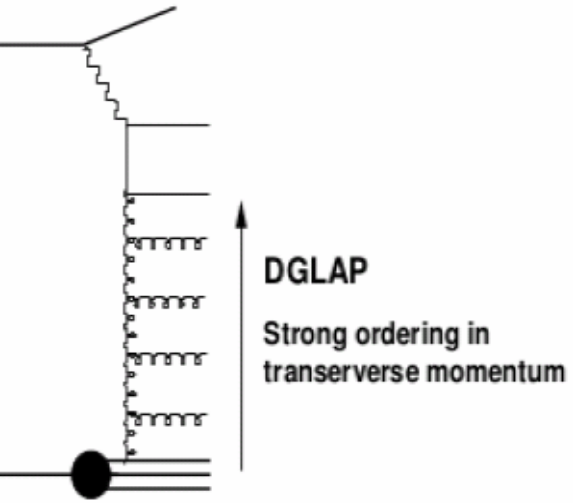
Low p_T region
- Hadronisation effects dominate

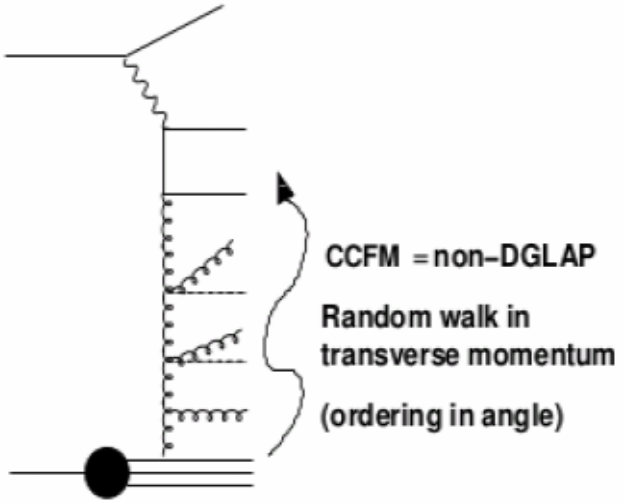
High p_T region
- Parton dynamics effects dominate

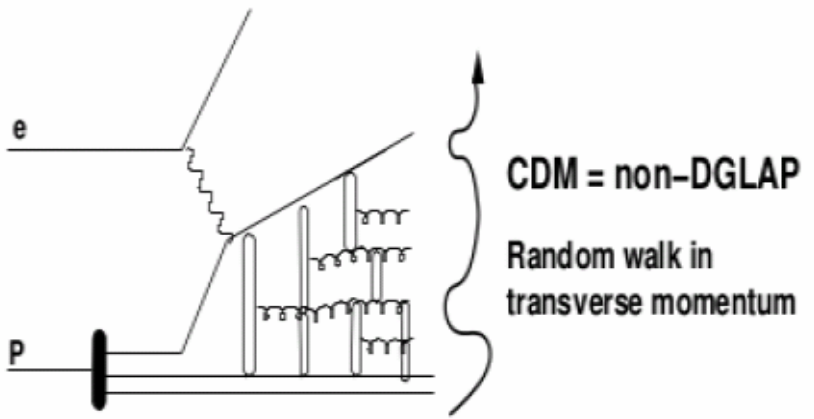
New H1 results on charged particle spectra:
with proton energy E_p =920 GeV ($\sqrt{s}$ = 319 GeV)
and proton energy E_p=460 GeV ($\sqrt{s}$ = 225 GeV)

Analyses performed in γ^*p frame (η^*, p_T^*)

Parton evolution models







DGLAP:

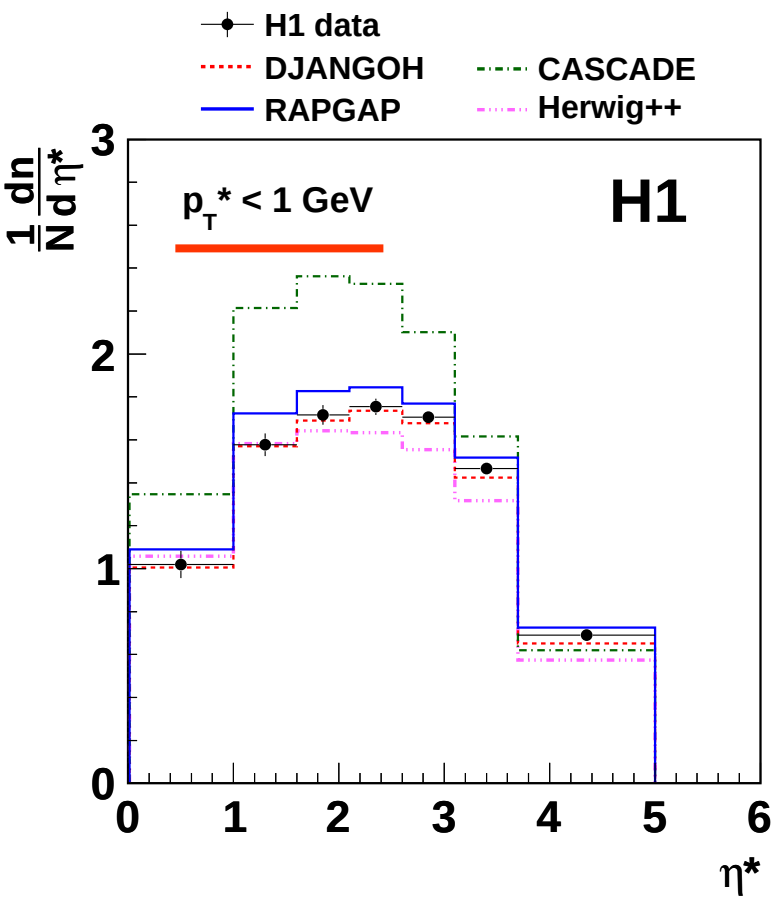
- strong k_T ordering $k^2_{T0} << ... << k^2_{Ti} << ... << Q^2$
- matrix elements + parton showers
- valid when Q^2 is large and x not too small
- RAPGAP, Herwig++ MC

beyond DGLAP:

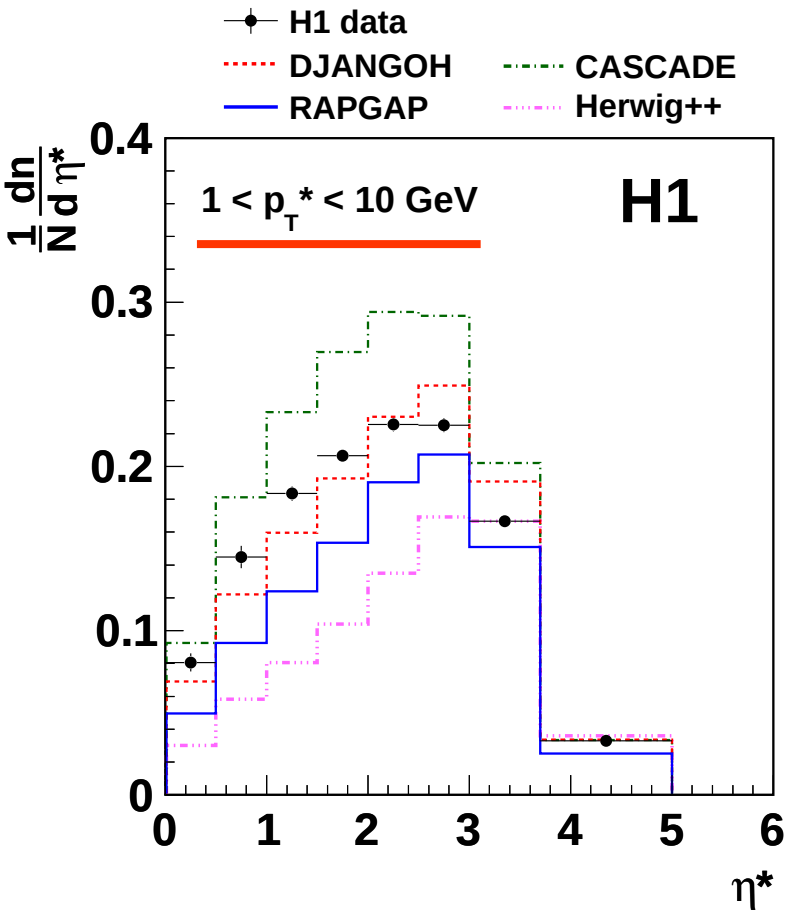
- random walk in k_T
- CCFM model
- valid for both: large and small x
- CASCADE MC
- Colour Dipole Model (CDM)
- BFKL like parton evolution) valid at low x and not large Q^2
- DJANGOH MC

Hadronisation parameters tuned to e^+e^- data (ALEPH tune)

Charged particle density: sensitivity to parton cascade models



All models (except CASCADE) describe the data within PDF uncertainties

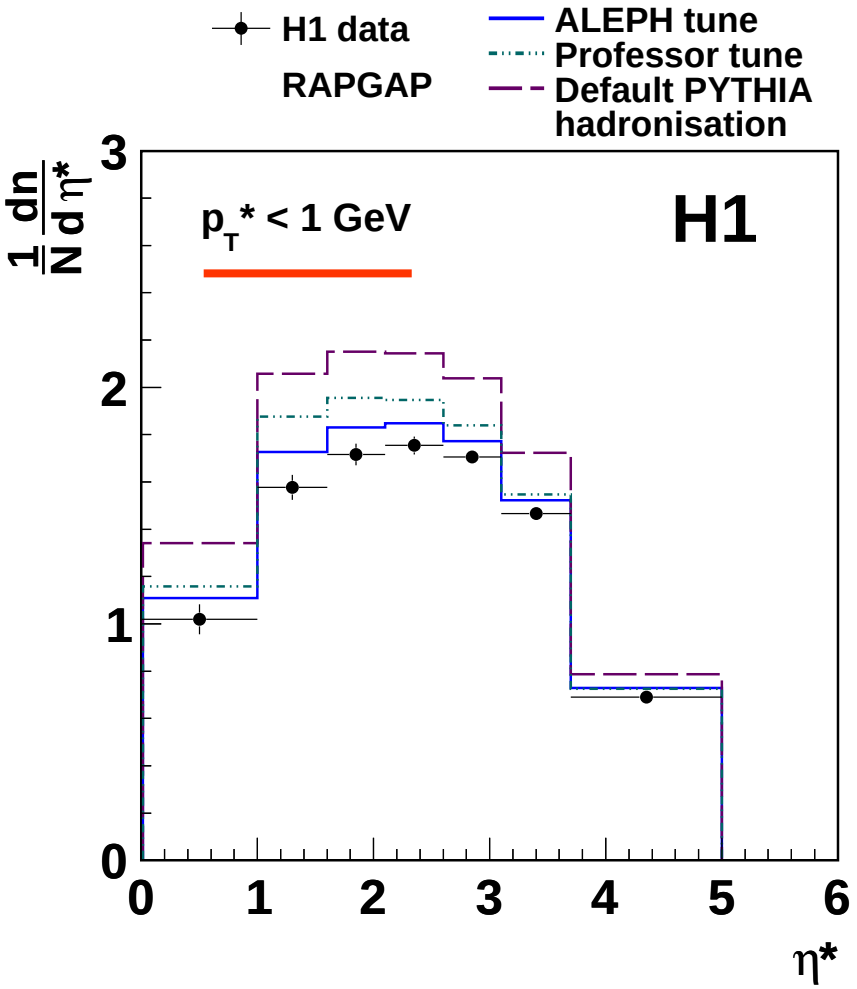


Strong sensitivity to parton dynamics at large p_T
DGLAP models (RAPGAP and HERWIG) underestimate the data for $\eta^*<3$

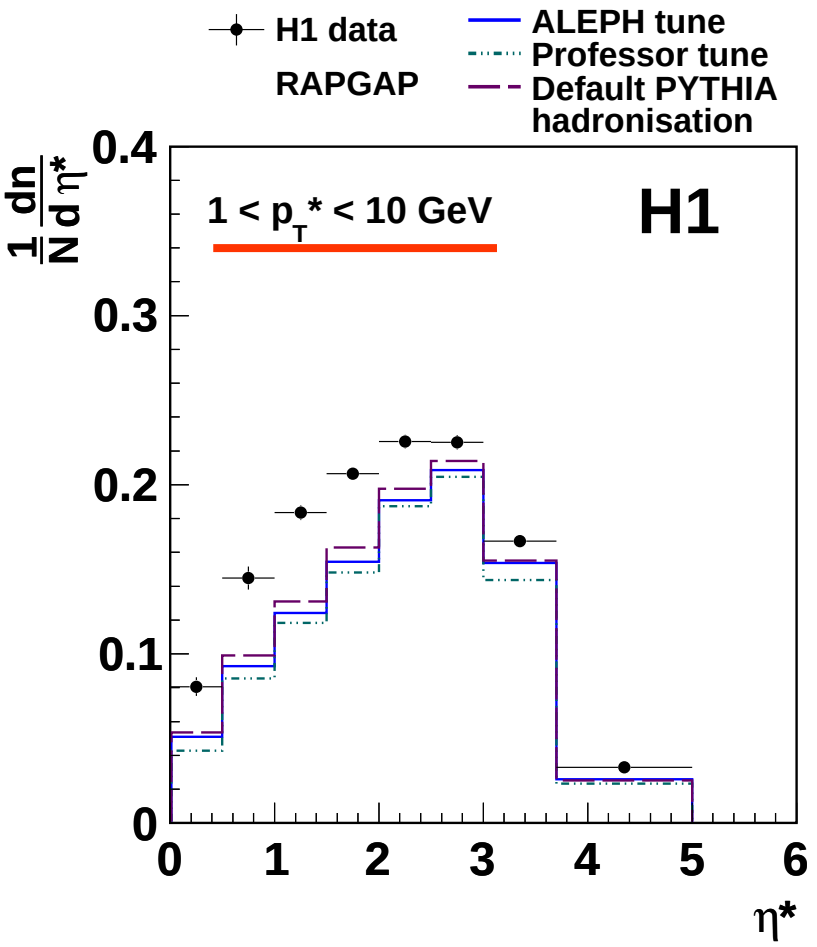
Best description at all p_T^* by DJANGOH (CDM)

EPJ C73 (2013) 2406

Charged particle density: sensitivity to hadronisation models



- Large sensitivity to the tuning of hadronisation parameters
- Data are best described by ALEPH tune (e+e-)



- Essentially no sensitivity to hadronisation expected
- None of the tunes describes the data

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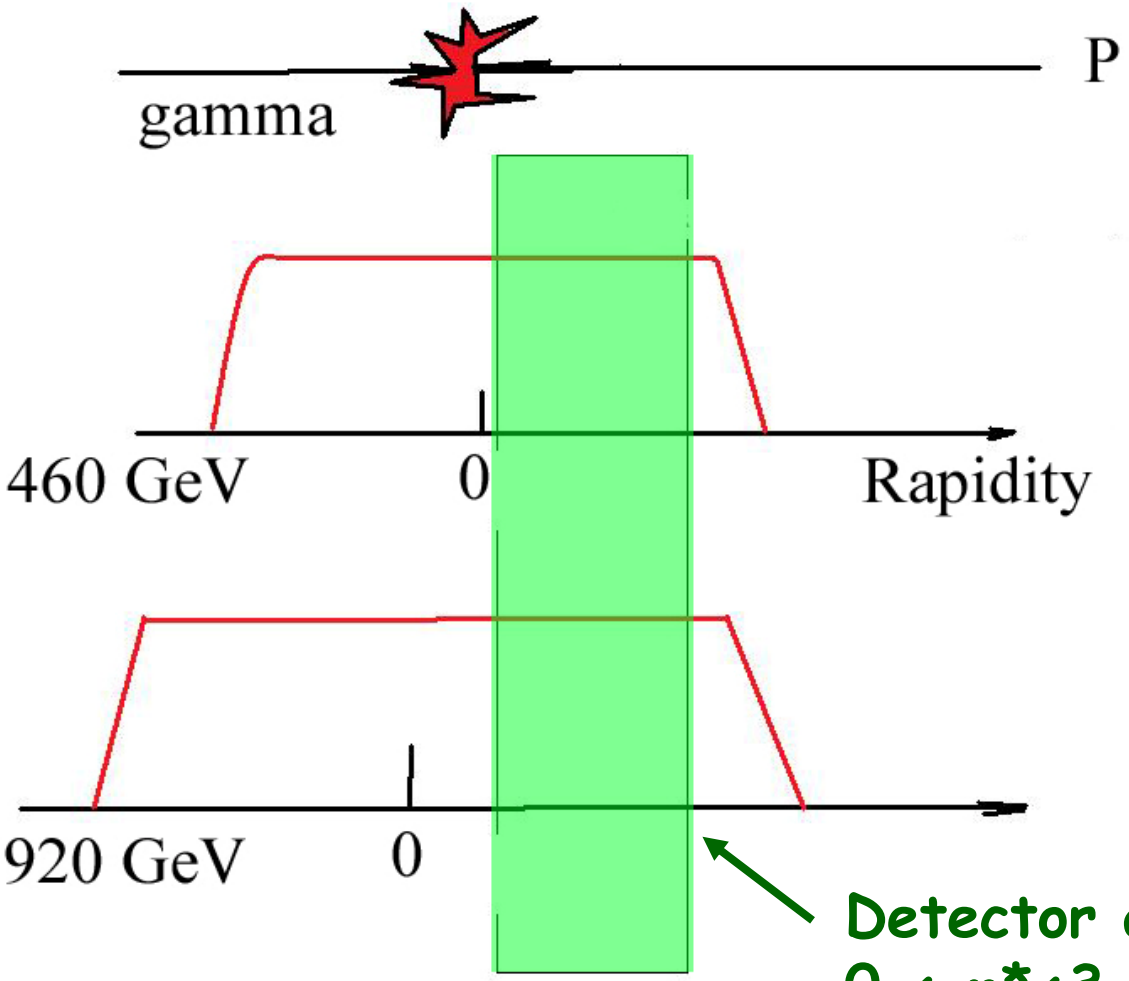
DIS at HERA is the unique possibility to study the transition between the proton and the photon hemispheres and change in the hadroproduction dynamics



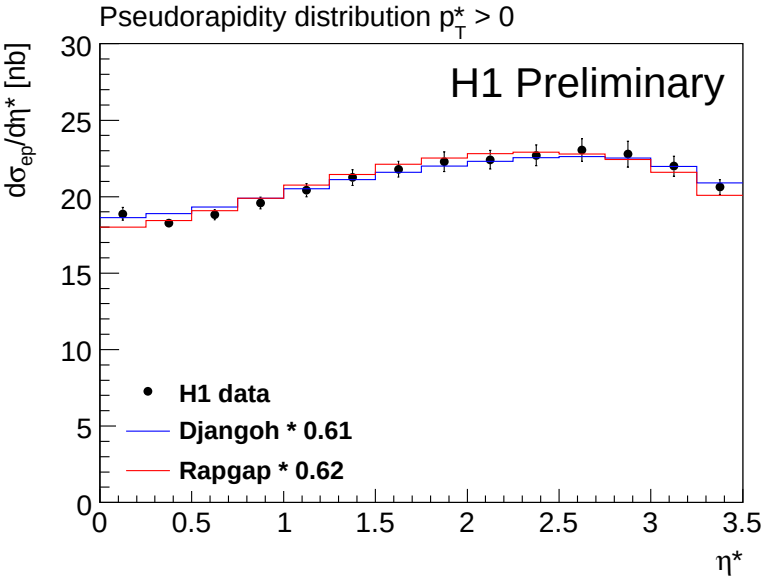
Use data with reduced proton beam energy E_p = 460 GeV to have good acceptance and high resolution in η* closer to the central region

- high y: $0.35 < y < 0.8$

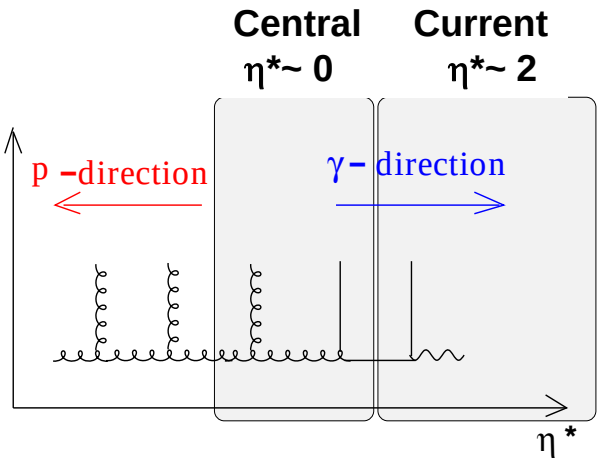
- low Q^2: $5 < Q^2 < 10\ GeV^2$

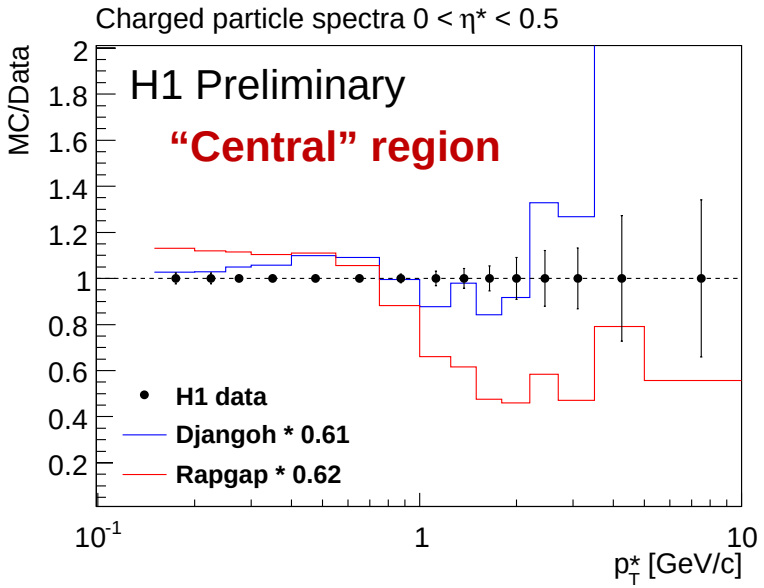
Charged particle density at low Ep: Comparison with MC

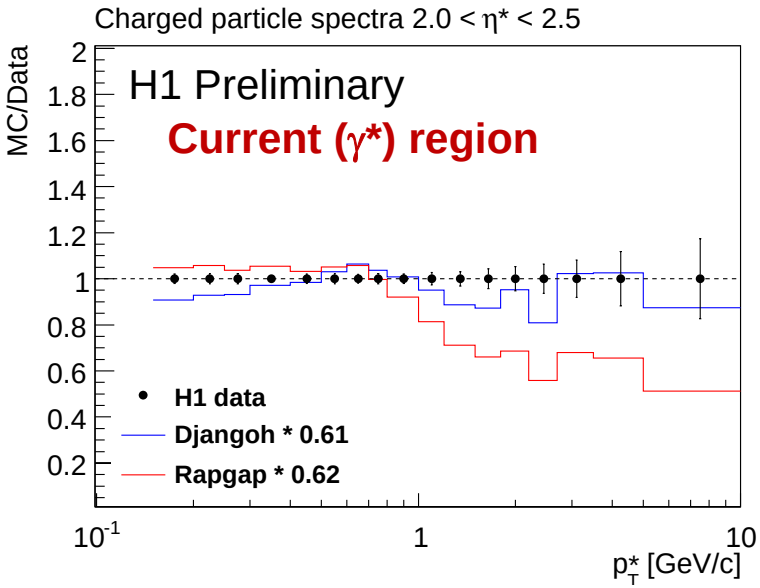
H1prelim-13-032



DJANGOH and RAPGAP describe the shape of η* distribution well



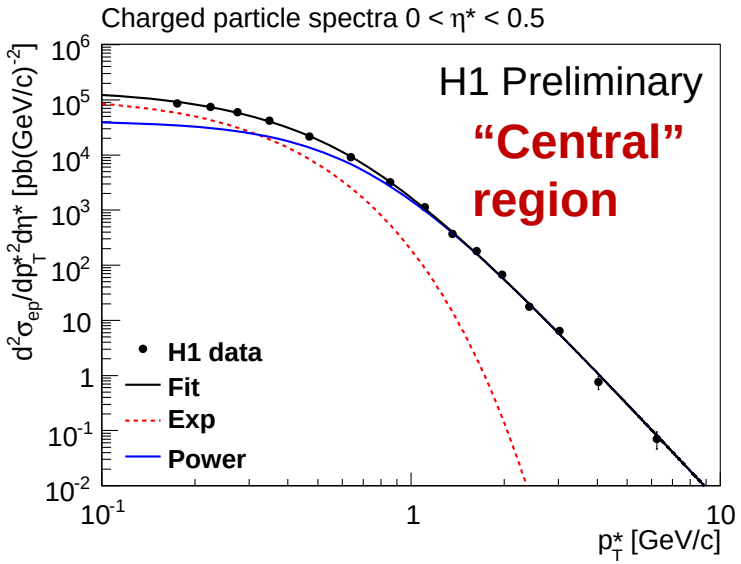


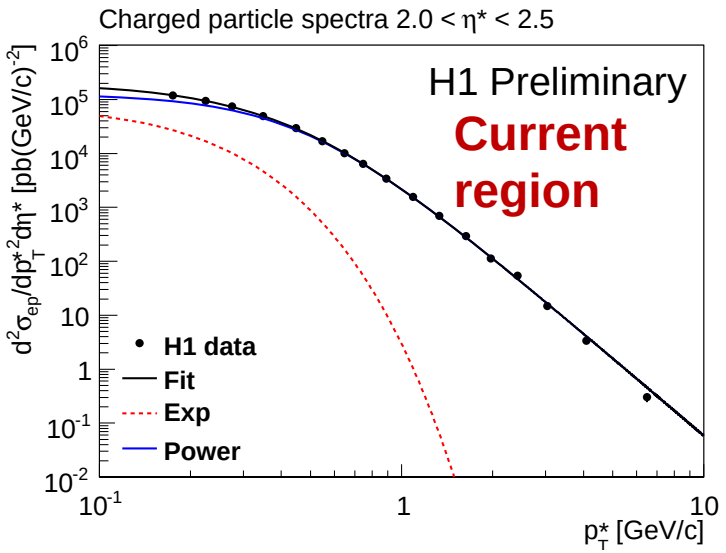


Models don't describe the p_T^*, η^* double differential cross sections

Charged particle density at low Ep

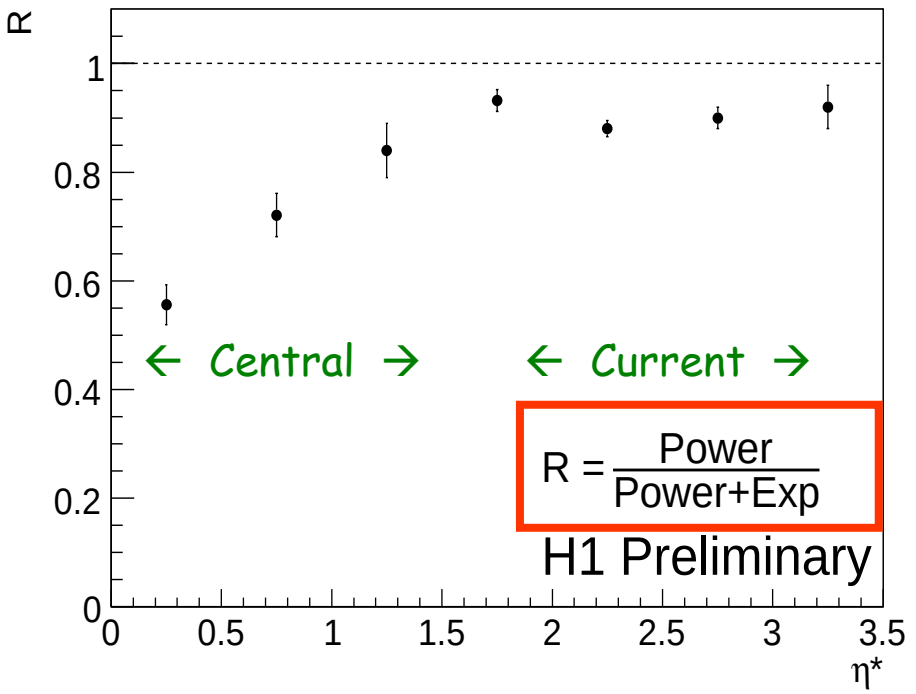
Compare measurements with a phenomenological model (A.Bylinkin, A.Rostovtsev): describe p_T spectra by a sum of exponential (Boltzmann-like) and a power-law functions





Observe transition between two contributions

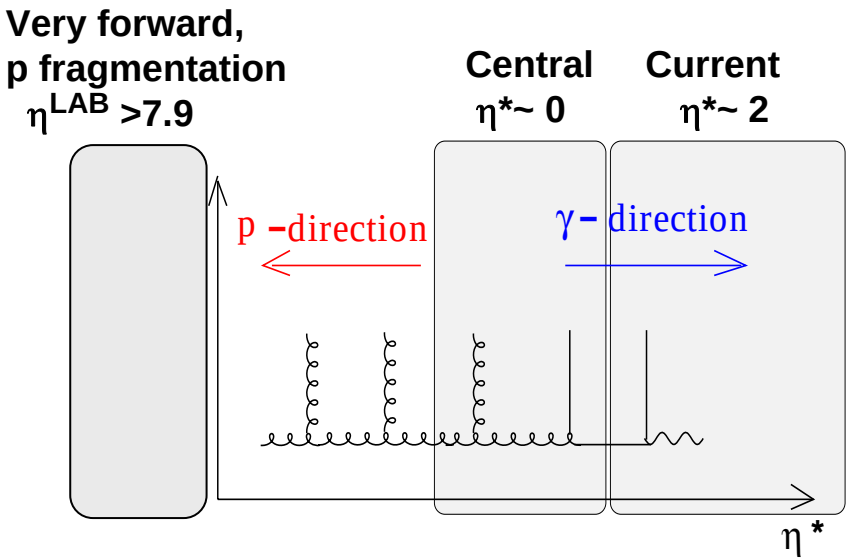
power-law distribution in the current region; significant exponential contribution when approaching the proton fragmentation region



H1prelim-13-032

Very Forward Neutron and Photon Production in DIS

Measurements of Forward Particles are important for the understanding of proton fragmentation mechanisms, and, in particular, interesting for tuning hadron interaction in Cosmic Ray models.



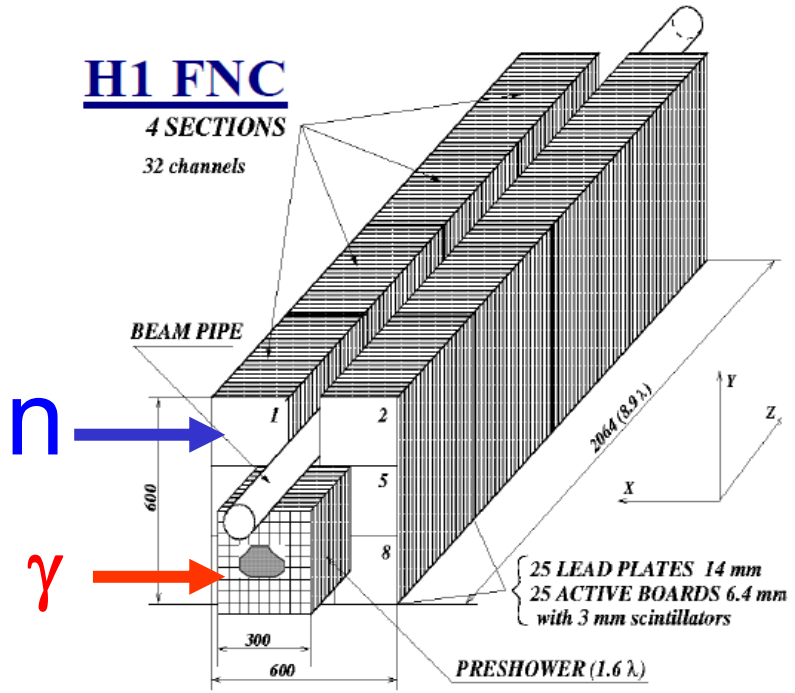
- Forward Photons are produced mainly in π^0 decay from hadronisation of the proton remnant

- Forward Neutrons are produced in proton fragmentation and by the π-exchange mechanisms, p→n+π+

Forward photons and neutrons (η^{Lab}>7.9) measured in the FNC Calorimeter (106m from IP)

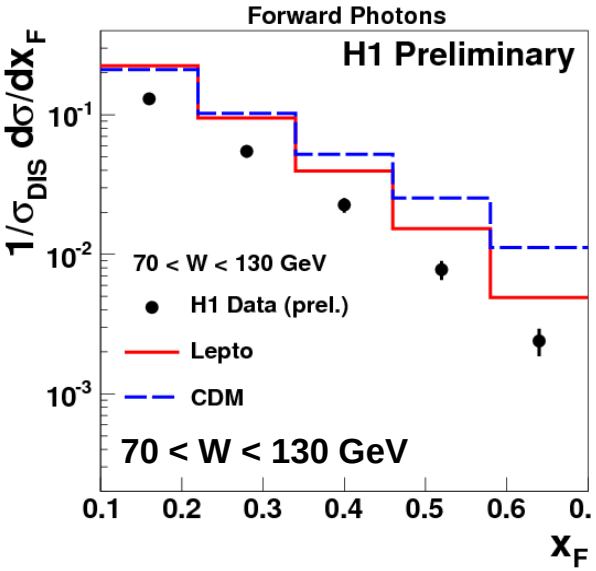
Study Feynman-x distributions at different γ*p CM energies:

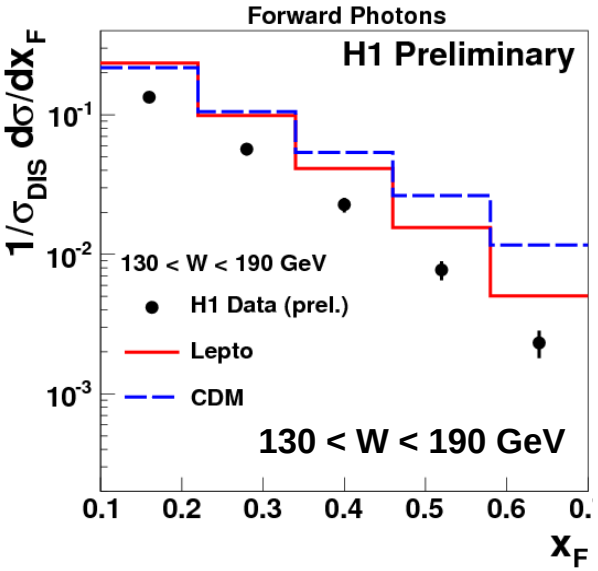
$x_F = p^*_{||}/p^*_{||max} = 2p^*_{||}/W$

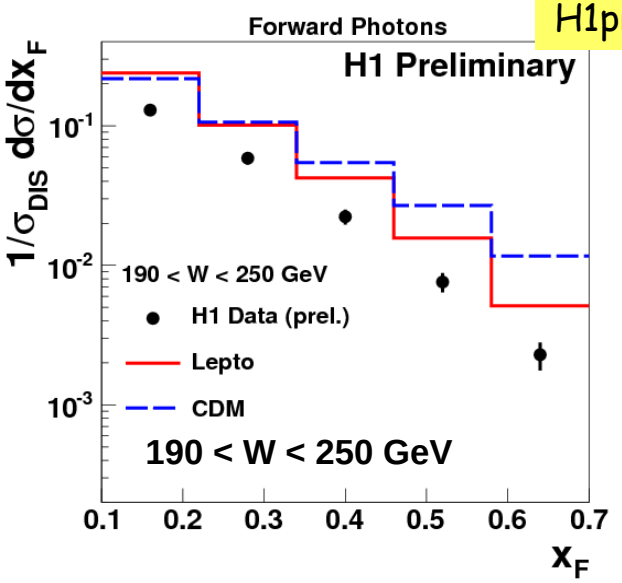


Very forward photons and neutrons: $1/\sigma_{DIS}\, d\sigma/dx_F$ distributions vs W

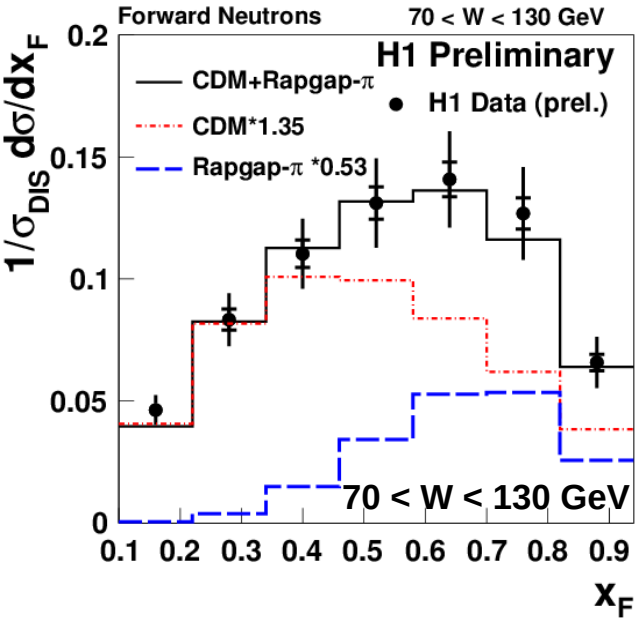
H1prelim-13-012

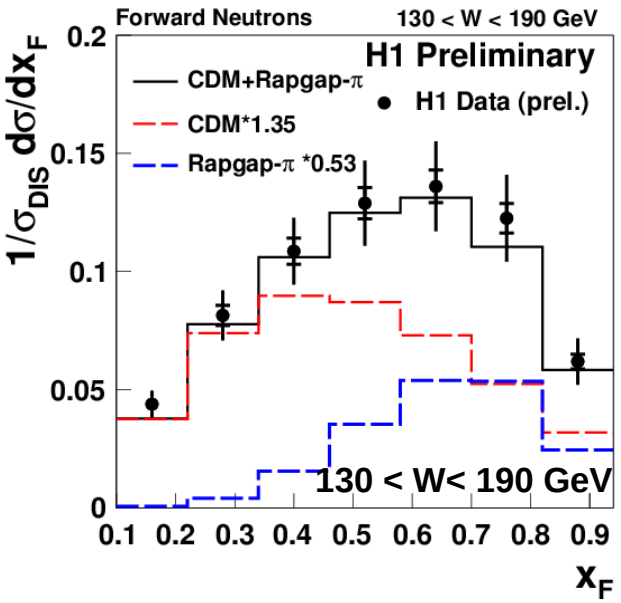


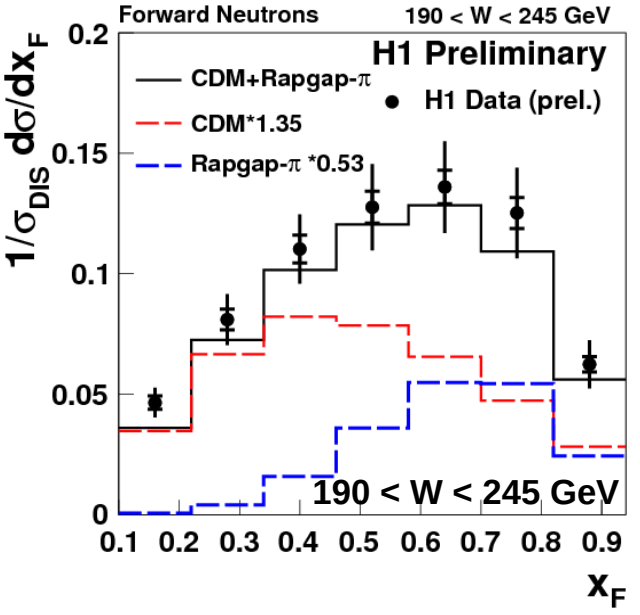




- Photon rate in all MC models used is significantly (70%) higher than in the data at all W
- CDM predict much harder x_F spectra

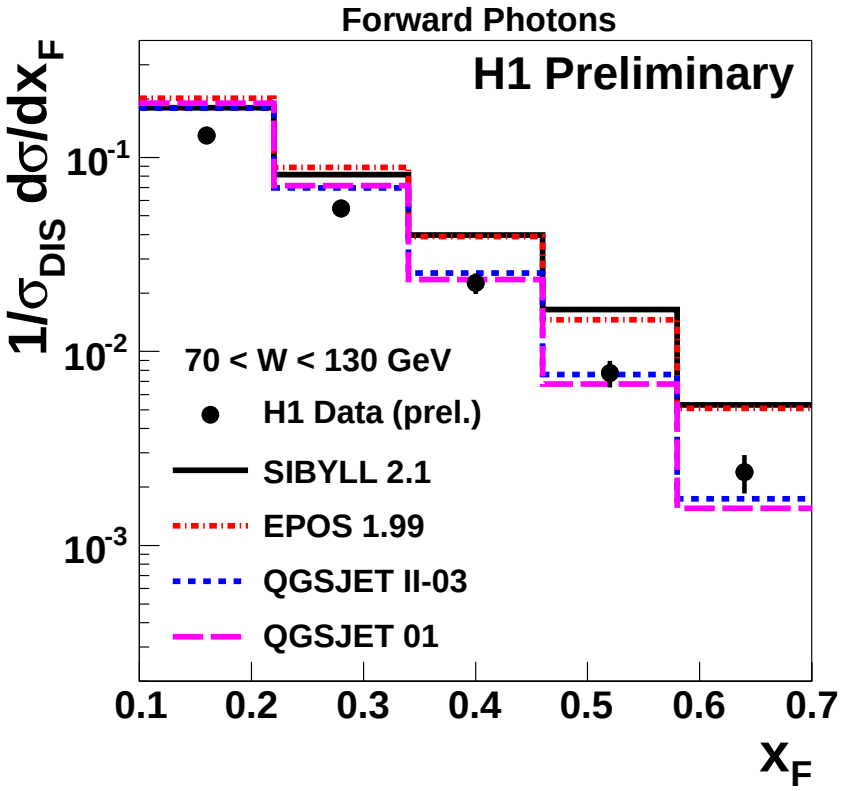


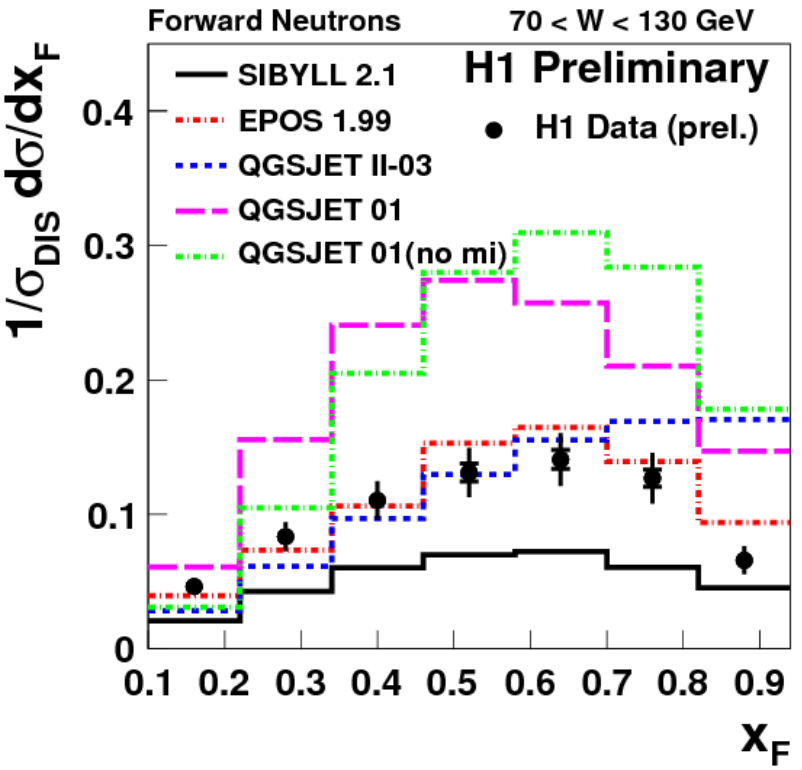




Neutron rate described by combination of π-exchange (RAPGAP) and 'standard' fragmentation models

Very forward photons and neutrons: comparison with the Cosmic Ray hadronic interaction models

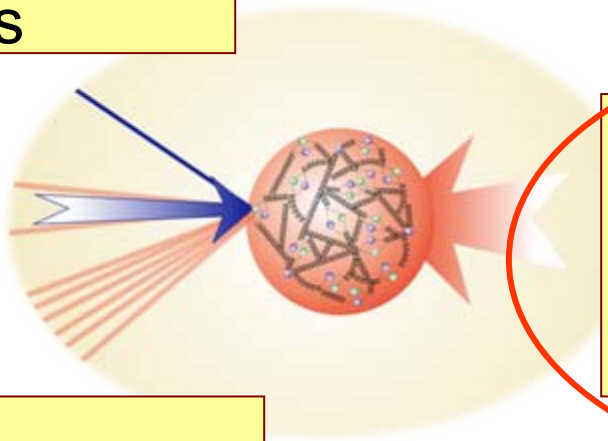




- Large differences between the Cosmic Ray model predictions
- None of models describes simultaneously the photon and neutron measurements

H1prelim-13-012

Inclusive measurements
proton structure, PDF
Electroweak effects

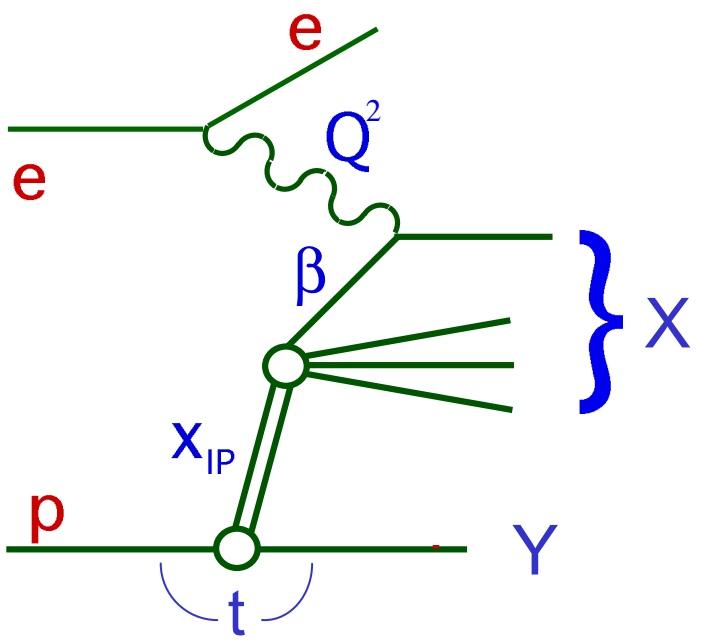


Hard diffraction
Diffractive DIS
elastic J/ψ production
diffractive jet production

Hadronic final state
Charged particle production, strangeness
Target fragmentation

Diffraction in ep collisions

One of first HERA surprises: ~10% of DIS events have no activity in proton direction, i.e. they are from *diffractive interactions*

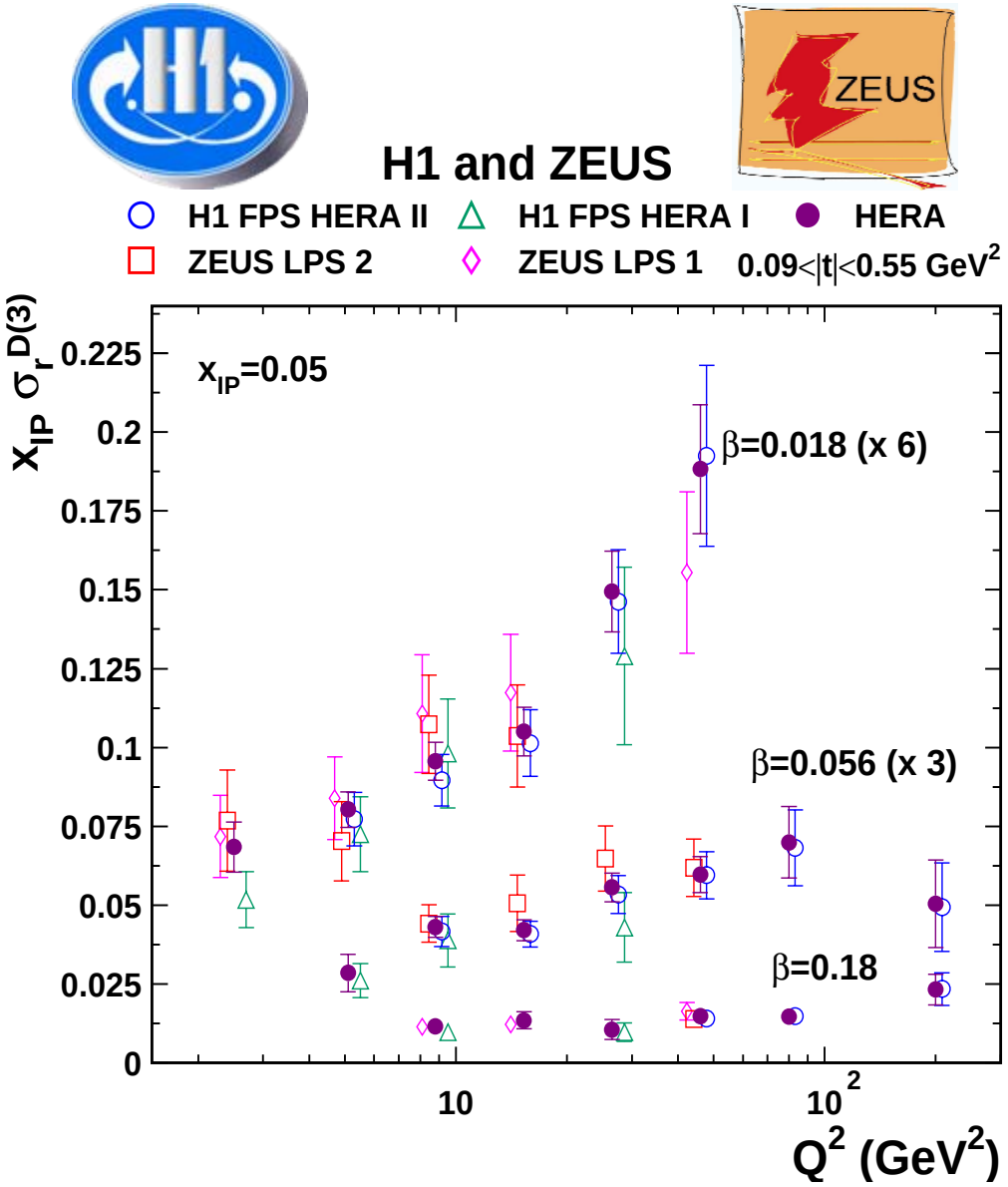


- t-channel exchange of vacuum quantum numbers
- proton survives the collision intact or dissociates to low mass state, $M_Y \sim O(m_p)$
- large rapidity gap
- small t (four-momentum transfer), small x_{IP} (fraction of proton momentum); $M_X \ll W$

- access to the structure of the colour-singlet exchange
- description in terms of diffractive parton densities (DPDF)
- different experimental methods to select diffraction:
  - large rapidity gap
  - leading proton tagging

H1/ZEUS Combined Inclusive Diffractive DIS Cross Sections measured with forward proton spectrometers

EPJ C72 (2012) 2175



Proton Spectrometer data in $0.09<|t|<0.55\ GeV^2$

➔ Consistency between H1 and ZEUS data sets

➔ Combination method uses iterative χ^2 minimization and include full error correlations

➔ Profit from different detectors: Two experiments 'calibrate' each other resulting in reduction of systematic uncertainties

Combined data have ~25% smaller uncertainties then the most precise data alone

Important input to diffractive PDFs

Diffractive Jet Photoproduction with a Leading Proton

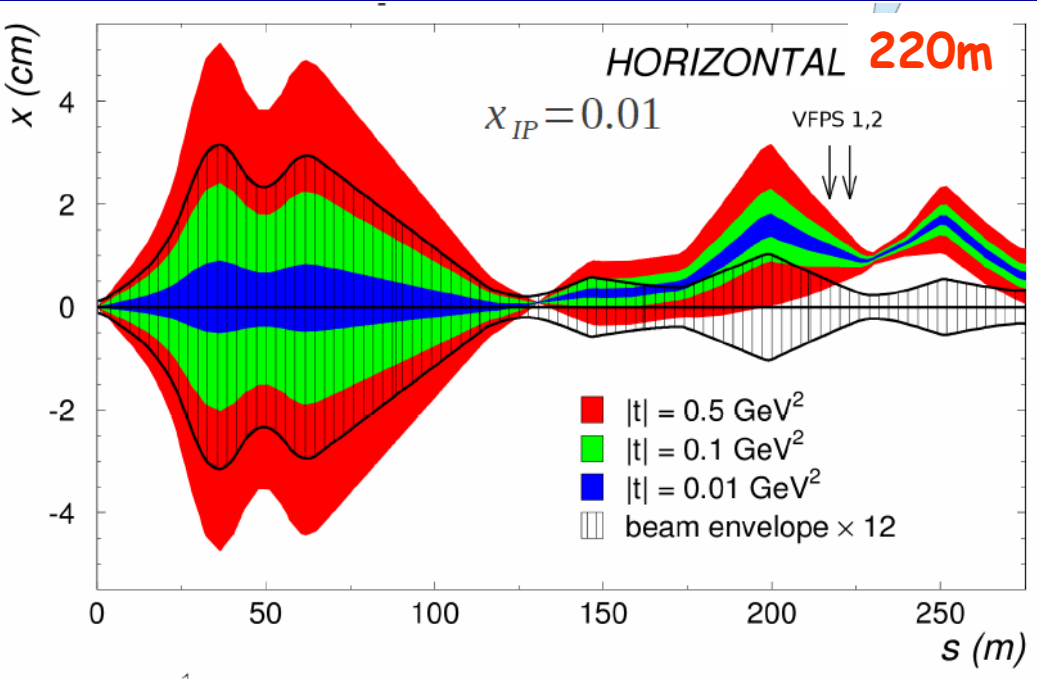
2006-2007 data, integrated luminosity 30pb^{-1}

Leading proton measured in the Very Forward Spectrometer (VFPS):
two stations at 218m and 222m
Reconstruction efficiency >96%
background <1%

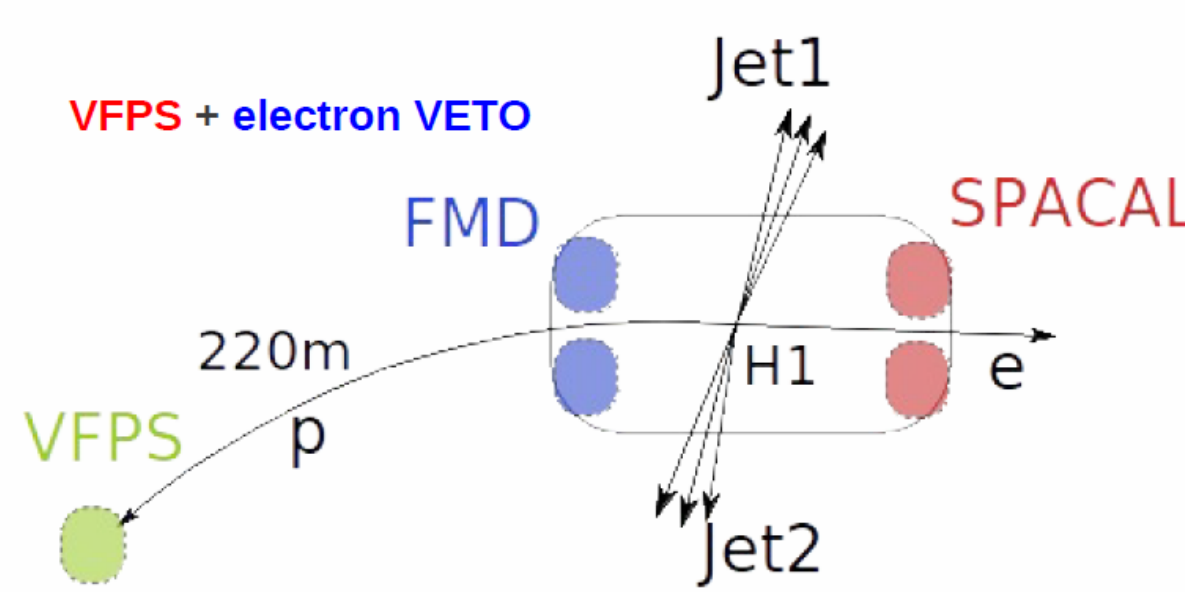
Two jets with E_T>5.5 (4) GeV

0.01<x_{IP}<0.024, |t|<-0.6 GeV^2

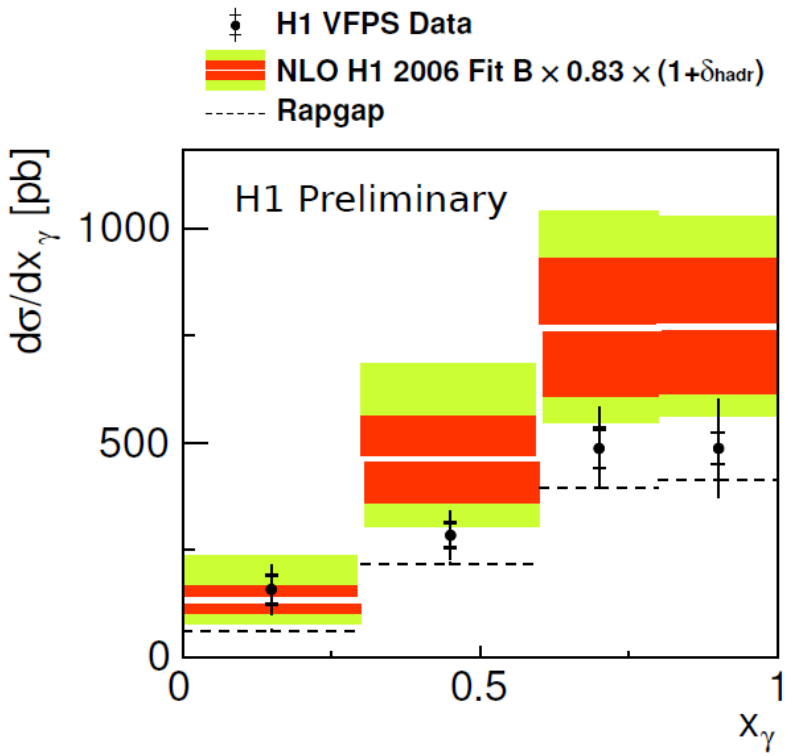
➔ ~4800 events selected

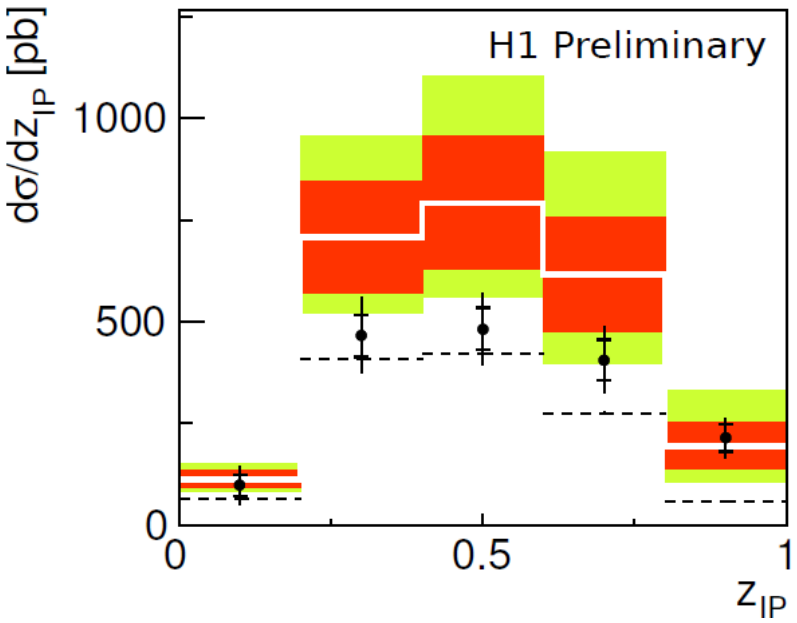


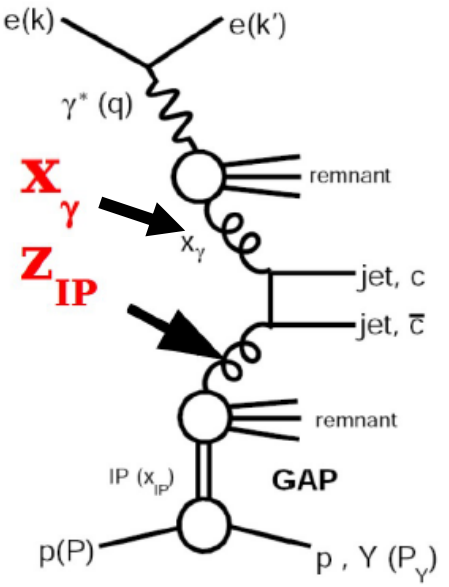
Data unfolded to hadron level using Singular Value Decomposition of the response matrix



Diffractive Jet Photoproduction with a Leading Proton







Data suppressed in comparison with NLO QCD by factor 0.67

$\sigma_{data}/\sigma_{nlo}$=0.67 ±0.04 (stat)±0.09 (sys)±0.20 (scale)±0.14(pdf)

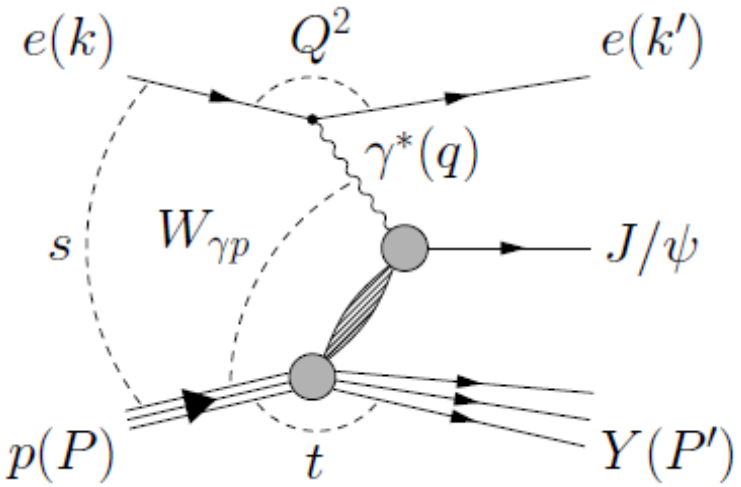
No obvious dependence of suppression on x_γ

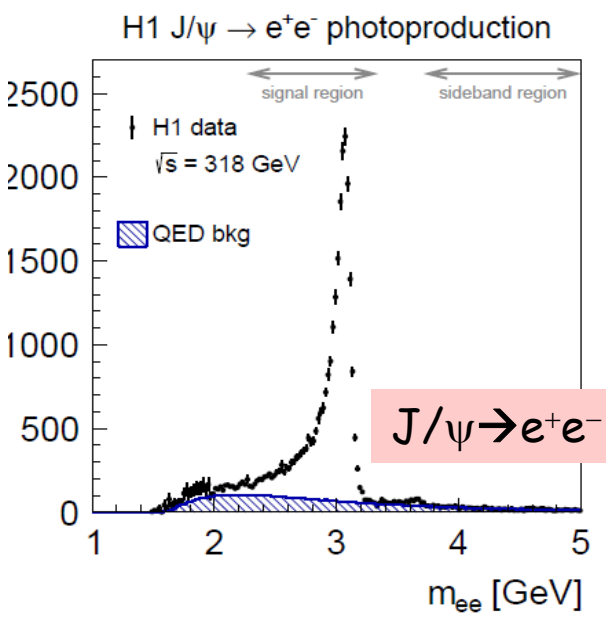
Large theoretical uncertainties connected with the DPDF uncertainty and scale variation

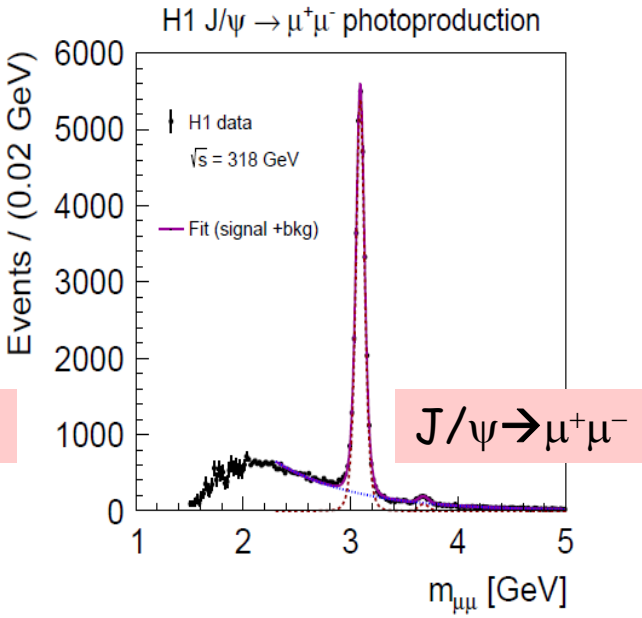
RAPGAP MC describes the shape quite well

Diffractive Photoproduction of J/ψ mesons

arXiv:1304.5162

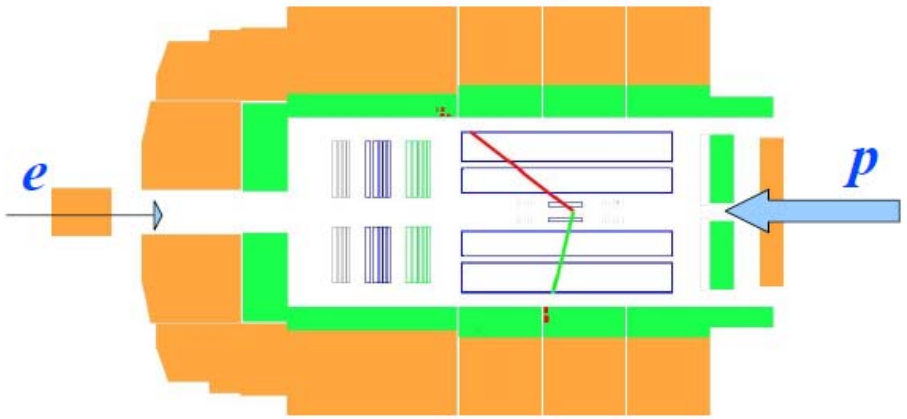




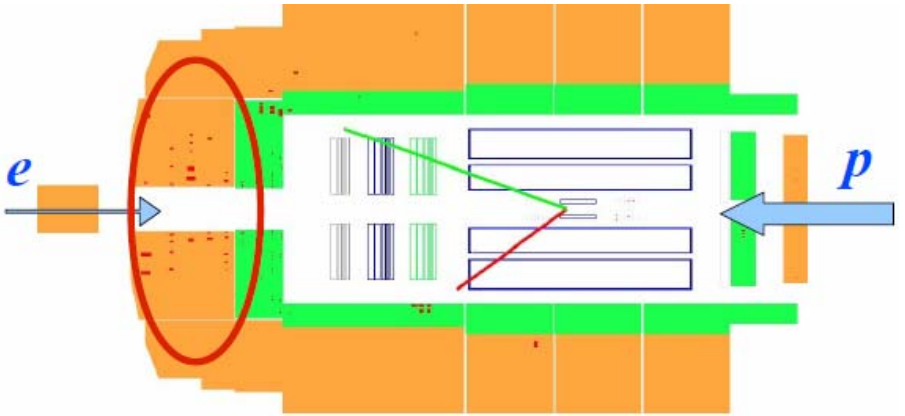


- clean experimental signature

Elastic: ep→ e+ J/ψ +p



Proton dissociation : ep→ e+ J/ψ +Y



J/ψ elastic and p-diss. photoproduction cross sections vs $W_{\gamma p}$

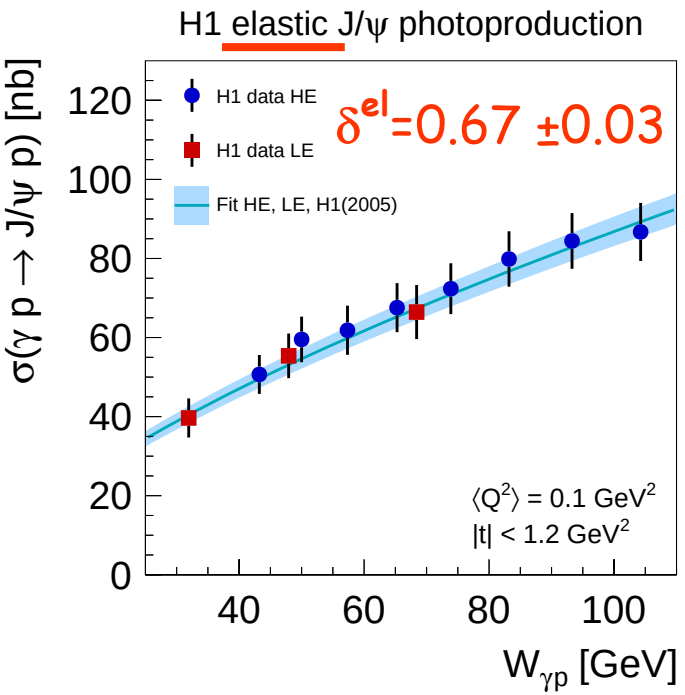
arXiv:1304.5162

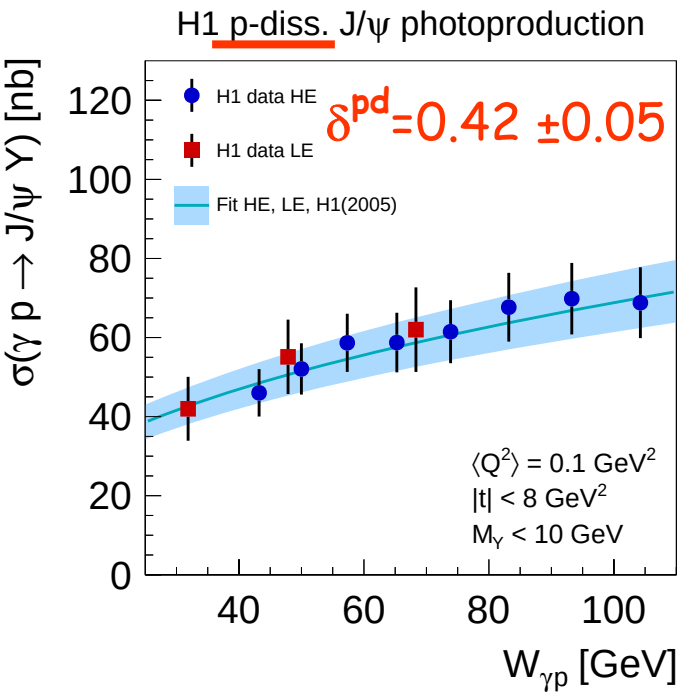
Elastic and proton-dissociation cross sections measured simultaneously using Regularised Unfolding

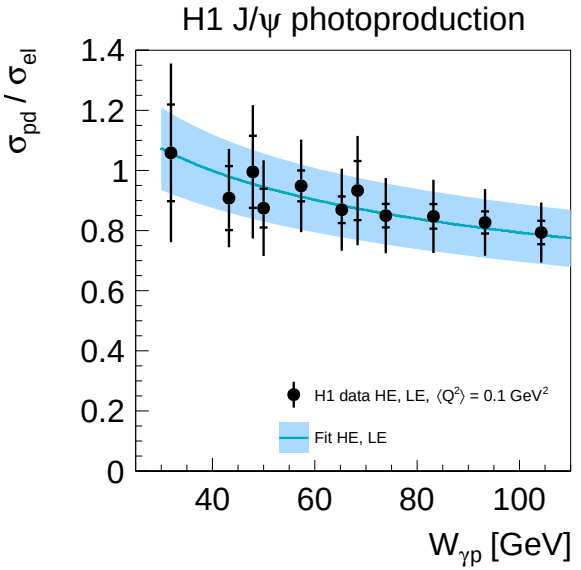
- Simultaneous fit to $W_{\gamma p}$ distributions, taking into account correlations between elastic and p-diss. cross sections

$$\sigma = N\left(\frac{W_{\gamma p}}{W_0}\right)^{\delta}$$

$W_0 = 90$ GeV







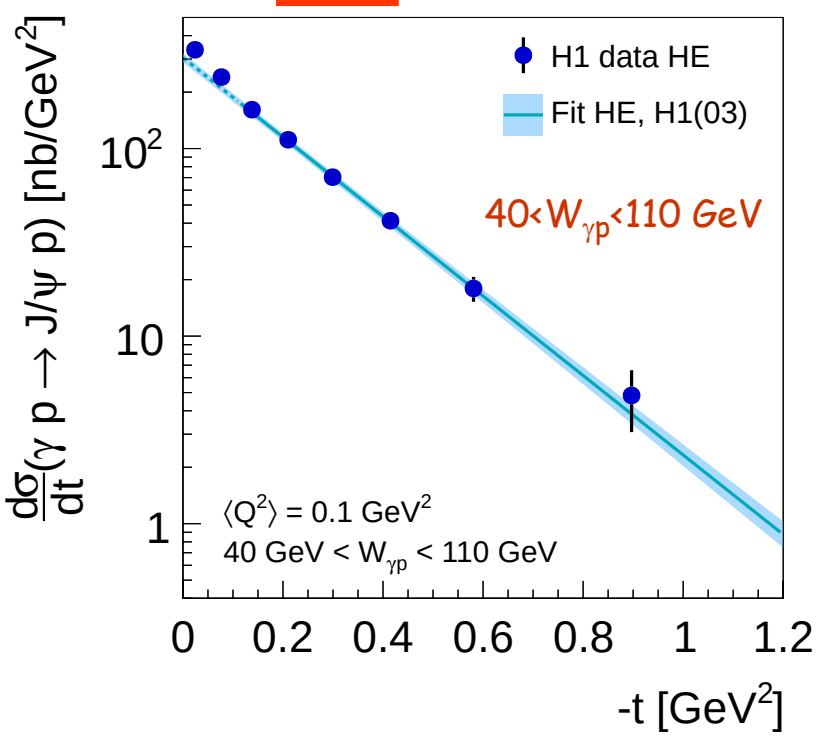
➔ Ratio σ_{pd}/σ_{el} slowly decreasing with $W_{\gamma p}$

J/ψ elastic and p-diss. photoproduction cross sections vs t

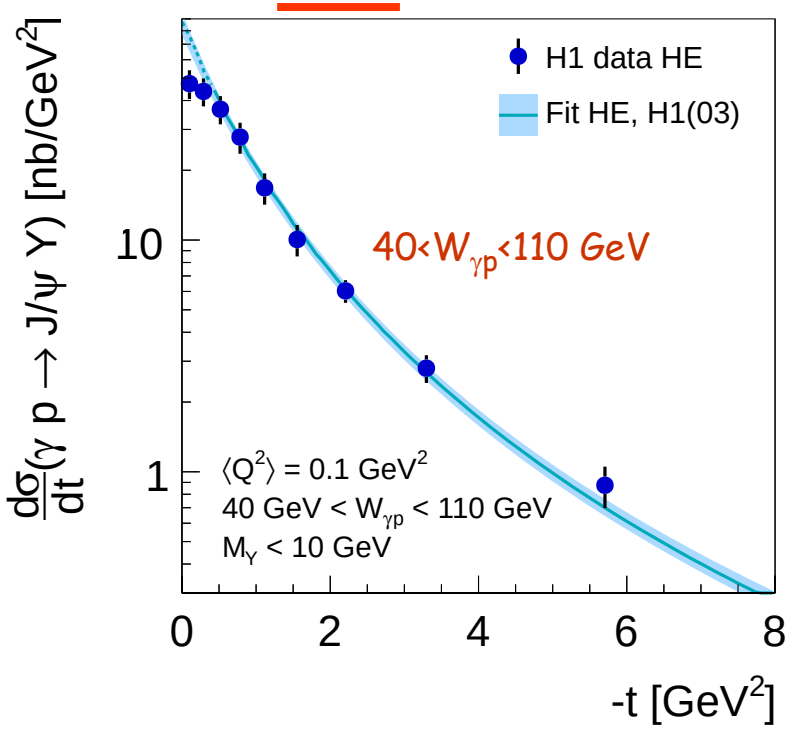
arXiv:1304.5162

t -momentum transfer squared at the proton vertex

H1 elastic J/ψ photoproduction



H1 p-diss. J/ψ photoproduction



$$\frac{d\sigma}{dt} \sim e^{-b_{el}|t|}$$

b_{el}= 4.88 ± 0.15 GeV²

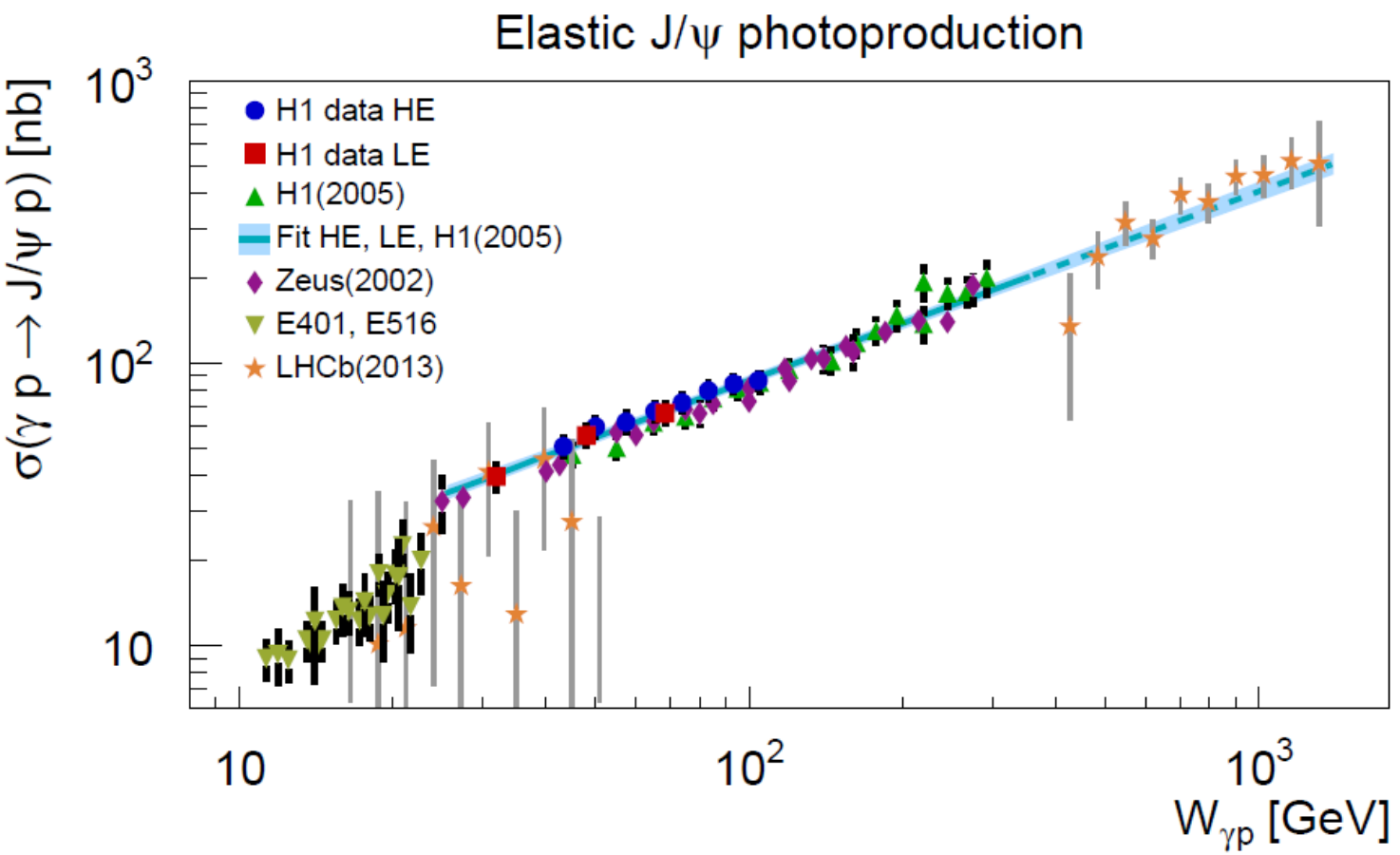
$$\frac{d\sigma}{dt} = N_{pd}\left(1+\frac{b_{pd}}{n}|t|\right)^{-n}$$

b_{pd}= 1.79 ± 0.12 GeV²

b is related to the transverse size of interaction: b_{pd} is significantly lower than b_{el}

J/ψ elastic photoproduction cross sections vs t

arXiv:1304.5162



New H1 measurement- two energy ranges: $W_{\gamma p}$=40-110 GeV and $W_{\gamma p}$=25-80 GeV

- Transition region from fixed target to previous HERA data
- Good agreement with previous HERA measurements
- Fixed target data: steeper slope, lower normalisation
- Extrapolation of H1 data to high W agrees with LHCb measurement

Conclusions

Six years after the end of data taking, H1 is an active experiment producing valuable results in a broad area of physics.

New results presented:

- Final measurement of inclusive NC/CC cross sections
- Several new measurements of hadronic final state and particle production
- Combined H1/ZEUS measurement of inclusive diffractive DIS with leading proton
- Diffractive jet and J/ψ production

HERA has a rich physics program that has to be completed !

Recent H1 results

DESY-13-058 Elastic and Proton-Dissociative Photoproduction of J/ψ Mesons at HERA

DESY-13-012 Measurement of Charged Particle Spectra in Deep-Inelastic ep Scattering at HERA

DESY-12-172 Combination and QCD Analysis of Charm Production Cross Section Measurements in Deep-Inelastic ep Scattering at HERA

DESY-12-107 Inclusive Deep Inelastic Scattering at High Q^2 with Longitudinally Polarised Lepton Beams at HERA

DESY-12-100 Combined Inclusive Diffractive Cross Sections Measured with FPS in DIS at HERA

H1prelim-13-033: K^0_S Production at low Q^2 in DIS at HERA

H1prelim-13-032: Measurement of Charged Particle Production in DIS at $\sqrt{s}$=225 GeV

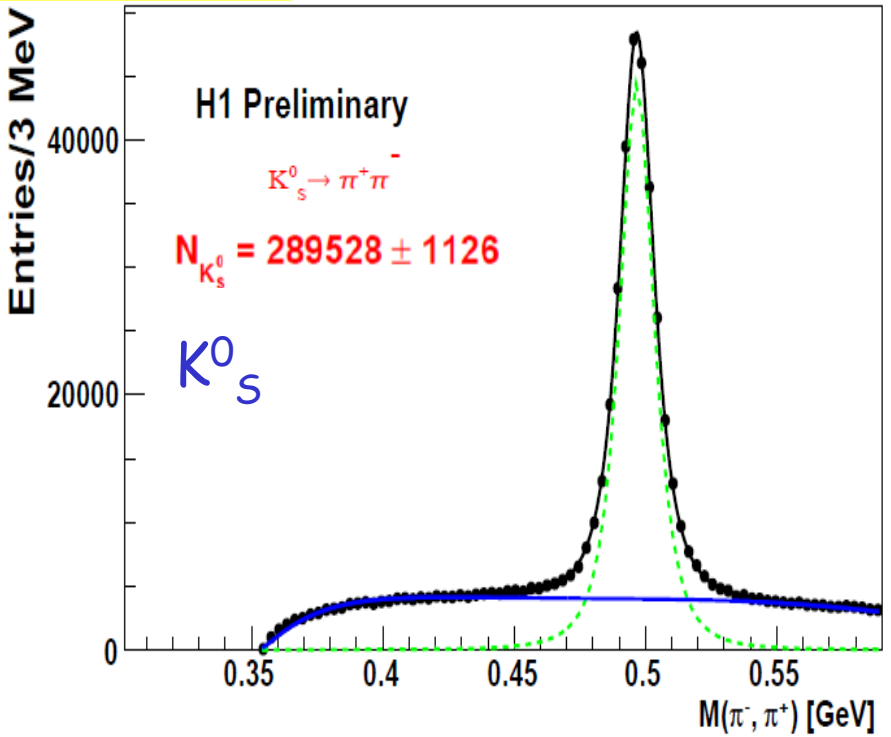
H1prelim-13-031: Lambda Baryons at high Q^2 at HERA

H1prelim-13-012 : Analysis of Feynman scaling of Photon and Neutron Production in the Very Forward Direction in DIS at HERA

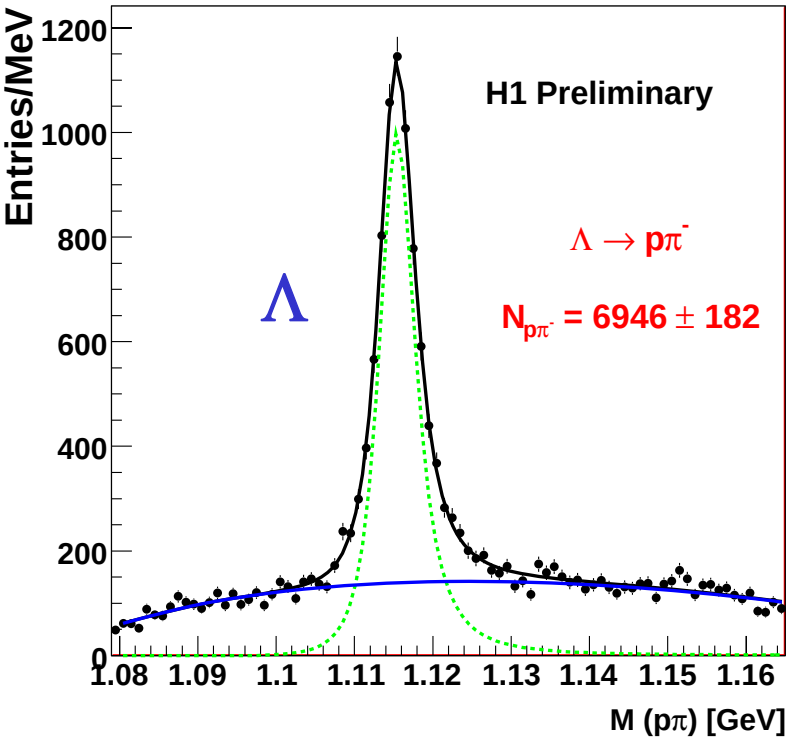
H1prelim-13-011: Measurement of Diffractive Dijet Photoproduction with Leading Proton

Strangeness production in DIS: visible cross sections for K^0_S and Λ

H1prelim-13-033



H1prelim-13-031



$7 < Q^2 < 100$ GeV^2 , $0.1 < y < 0.6$

$145 < Q^2 < 20000$ GeV^2 , $0.2 < y < 0.6$

$$\sigma_{vis}(ep \to eK^0_S X) = 10.66 \pm 0.04(stat.)^{+0.50}_{-0.53}(sys.)\,nb$$

$$\sigma_{vis}(ep \to e\Lambda X) = 144.7 \pm 4.7(stat.)^{+9.4}_{-8.5}(sys.)\,pb$$

λ_s	0.286
$\sigma_{vis}(ep \to eK^0_s X)$ CDM	9.88 nb
$\sigma_{vis}(ep \to eK^0_s X)$ MEPS	10.93 nb

λ_s	0.220	0.286
$\sigma_{vis}(ep \to e\Lambda X)$ CDM	136 pb	161 pb
$\sigma_{vis}(ep \to e\Lambda X)$ MEPS	120 pb	144 pb