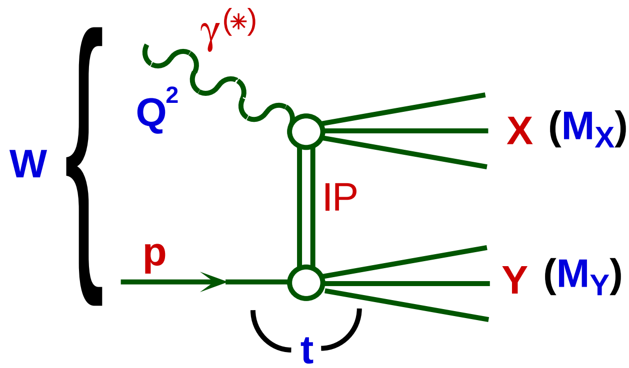
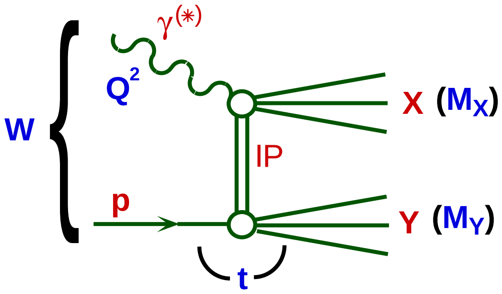
"There is Diffraction at HERA-2"

Paul Newman, Birmingham University



- What have we Learned at HERA-1?
- What Limits our Understanding?
- Do we Have the Necessary Triggers FOR HERA-2?
- Wish List for HERA-2?

Overview of Diffractive Phase Space

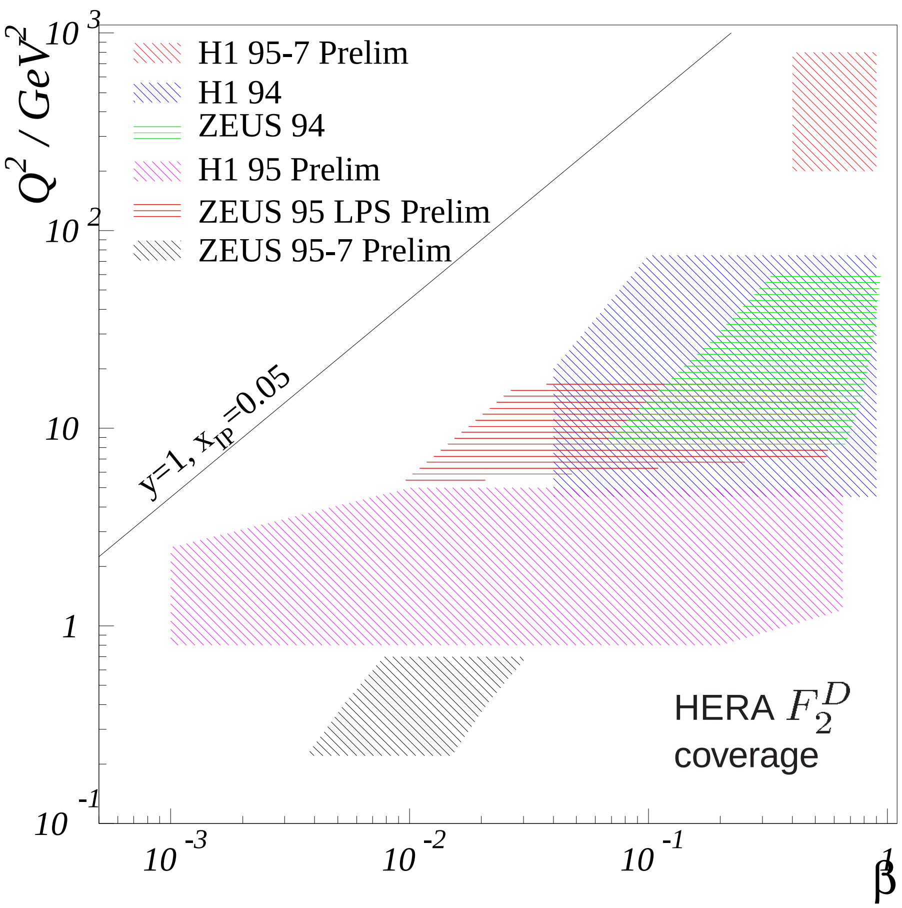


$$x_{I\!P} = \frac{q.(p-Y)}{q.p} = x_{I\!P/p}$$

$$\beta = \frac{Q^2}{q.(p-Y)} = x_{q/I\!P}$$

All five kinematic variables can be measured:

- $Q^2 \sim 0$, $|t| \sim 0$. $\rightarrow$ similar to soft hadronic diffraction.
- Large Q^2. $\rightarrow$ pQCD at $\gamma^* I\!P$ vertex. γ^* ‘probes’ $I\!P$?
- Other scales $\rightarrow$ Jets, heavy quarks $\rightarrow$ pQCD, gluon in $I\!P$
- Large $|t|$. $\rightarrow$ $I\!P$ itself calculable in pQCD?



- Soft Diffraction may end with HERA-1

- F_2^D kinematic plane starts to fill up

  but a long way to go with precision, hard scales . . .

- For high $|t|$, we have barely started!

Factorisation in Diffractive DIS

QCD Hard Scattering Fac'n for Diffractive DIS:-

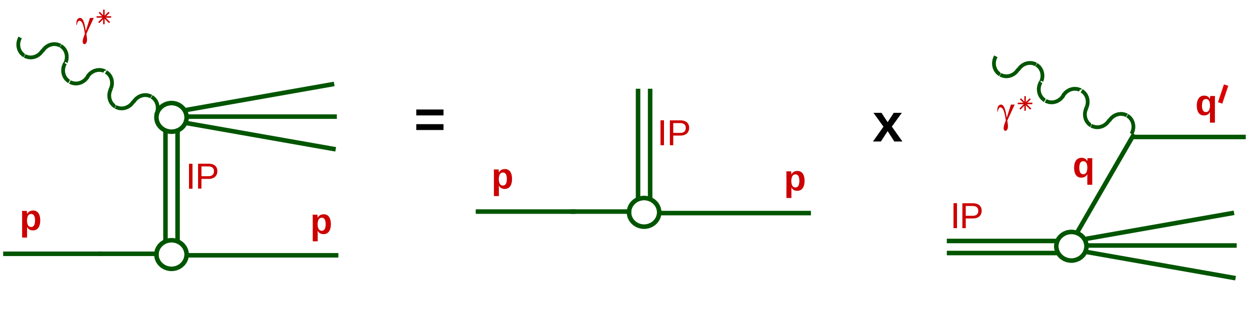
(Trentadue, Veneziano, Berera, Soper, Collins . . .)
Diffractive parton distributions $f(x_{I\!P}, t, x, \mu^2)$ can be defined, expressing proton parton probability distributions with intact final state proton at particular $x_{I\!P}, t \ldots$

$$\sigma(\gamma^* p \to Xp) \sim \sum_i f_{i/p}(x_{I\!P}, t, x, Q^2) \otimes \hat{\sigma}_{\gamma^* i}(x, Q^2)$$

At fixed $x_{I\!P}$, t, diffractive partons evolve in x, Q^2 according to DGLAP equations.

Regge Factorisation:-

Soft hadron phenomenology suggests a universal *pomeron* $(I\!P)$ exchange can be introduced, with flux dependent only on $x_{I\!P}, t$ (Donnachie, Landshoff, Ingelman, Schlein, H1 . . .)



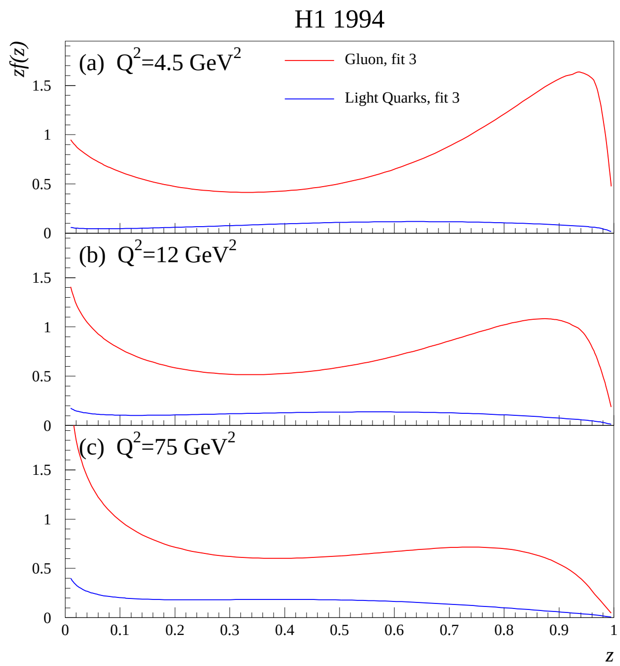
$$\begin{aligned} \sigma(\gamma^* p \to Xp) &\sim f_{I\!P/p}(x_{I\!P}, t) \otimes F_2^{I\!P}(\beta, Q^2) \\ &\sim f_{I\!P/p}(x_{I\!P}, t) \otimes \sum_i f_{i/I\!P}(\beta, Q^2) \\ &\qquad \otimes \hat{\sigma}_{\gamma^* i}(\beta, Q^2) \end{aligned}$$

QCD and Regge Factorisation

F_2^D data consistent with universal $x_{I\!P}$ dependence.

Regge factorisation hypothesis approximately valid.

Pomeron parton distributions extracted from F_2^D.



— Best fit gluon

— Best fit light quarks

All such fits suggest heavy gluon dominance with significant high x contributions.

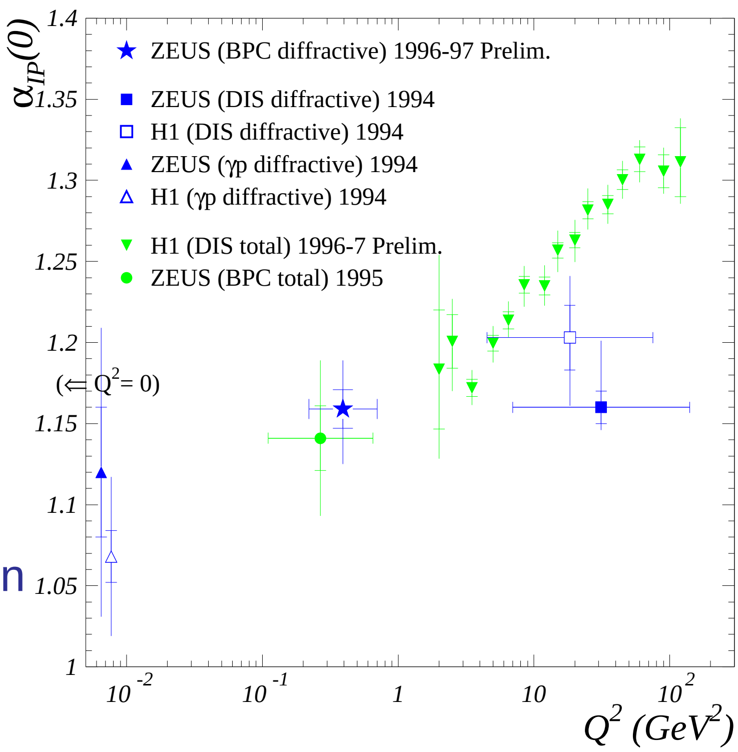
Shape at high x v. poorly determined.

BUT! . . .

- $x_{I\!P}$ dependence stronger than soft hadronic diffraction. (also for VM at large m_V, Q^2)

- Sub-leading exchanges are also present (interference?)

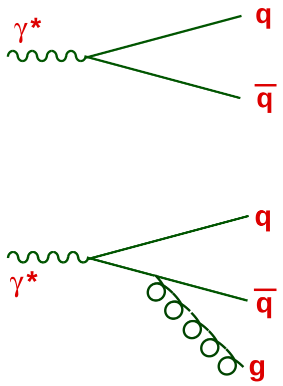
- Need full DGLAP analysis at fixed small $x_{I\!P}$ to avoid Regge factorisation assumption



Dipole Models

$\gamma^* \to q\bar{q}, q\bar{q}g$ well in advance of target . . .

Partonic fluctuations scatter elastically from proton.



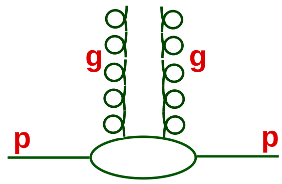
$\times$ Cross section for colour dipole to scatter from proton

Nice feature:
clear relationship between $\sigma_{\rm tot}$, $\sigma_{\rm el}$ and $\sigma_{\rm dif}$ via optical theorem

Different approaches to the dipole cross section:

- Soft Colour: e.g. Buchmüller et al.

- Perturbative: a pair of gluons from proton pdf's with opposite colour charge.



Applicability of Perturbative approach:

Expected to work for small size dipole configurations . . . Vector mesons, high p_T dijets, charm . . .

More quesionable at low β in F_2^D

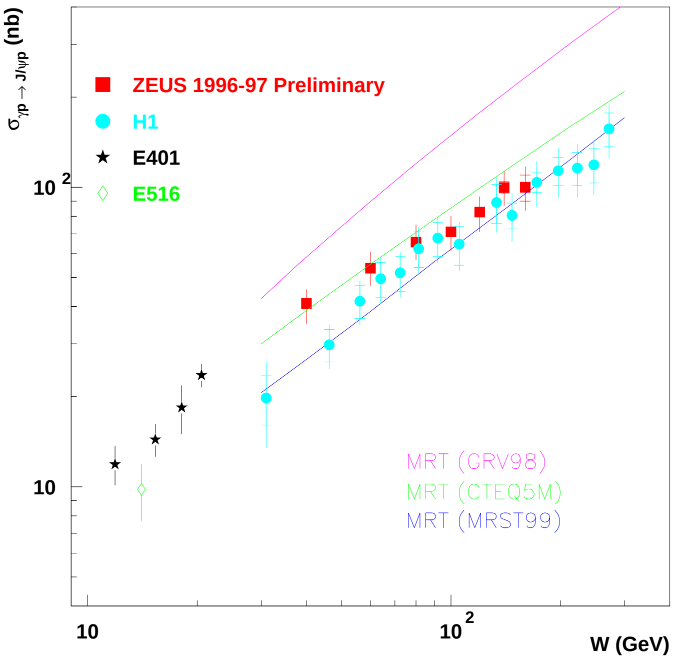
. . . $x_{I\!P}$ factorisation breaking?

Successes for 2-gluon exchange Models

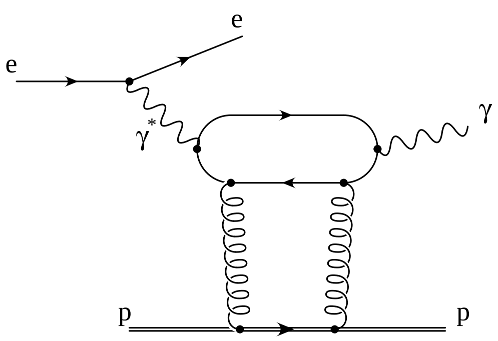
2-gluon models broadly successful where easily applied

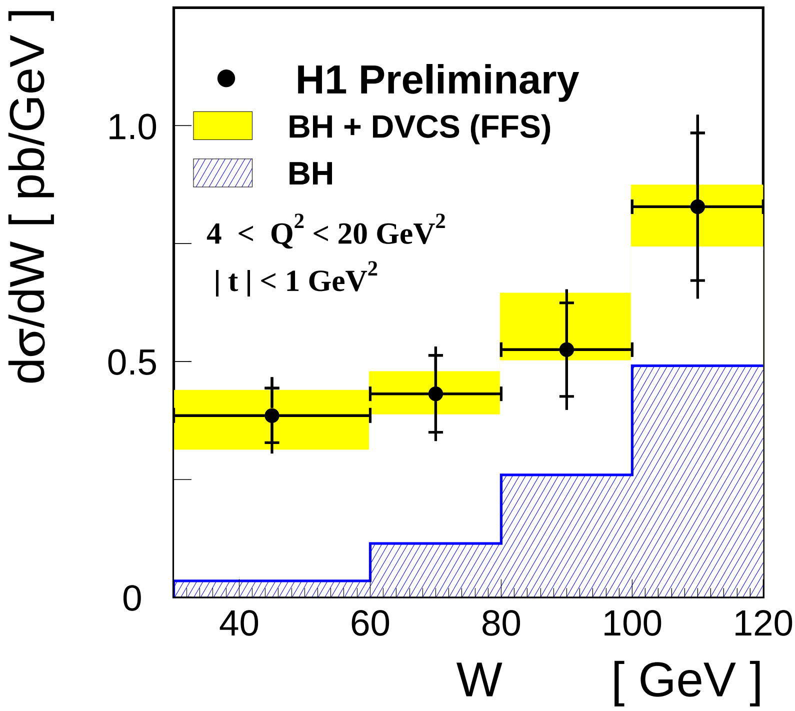
e.g. J/ψ, ρ predictions work.

Theoretical uncertainties due to gluon, VM wavefunction Fermi motion need resolving.



DVCS: diffractive $ep \to e\gamma p$





Excellent agreement with calculations.

Largest theoretical uncertainties from t dependence (bands).

2-gluon Models and F_2^D

More tricky! . . . But reasonable consensus on what's needed

High β: $\gamma_L^* \rightarrow q\bar{q}$

Intermediate β: $\gamma_T^* \rightarrow q\bar{q}$

Low β: $\gamma_T^* \rightarrow q\bar{q}g$

e.g. 'Saturation' Model (Golec-Biernat & Wüsthoff)

Serious attempt to calculate F_2^D including all 3 components

Free parameters in σ (dipole)

fixed by fits to $F_2(x, Q^2)$

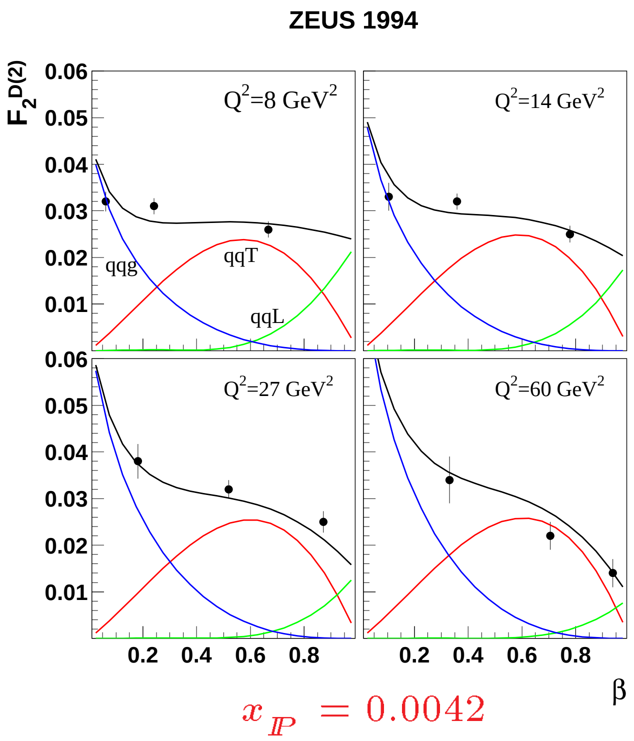
Diffractive cross section calculated

(2 gluon exchange instead of 1)

with only 1 extra parameter (t slope)

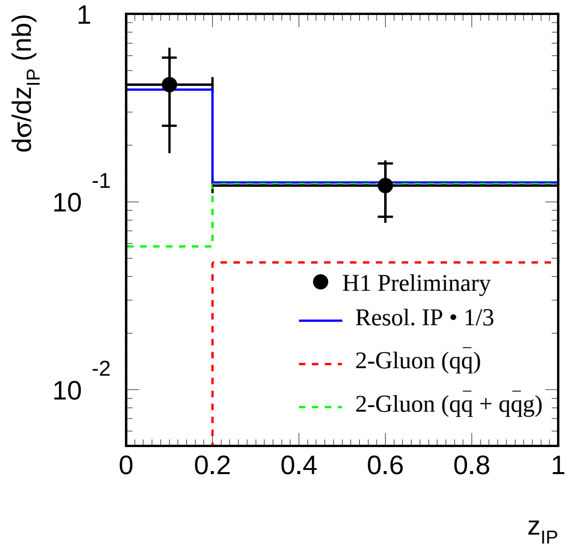
Impressive agreement with

F_2^D data.



Can the Data Distinguish Between Models?

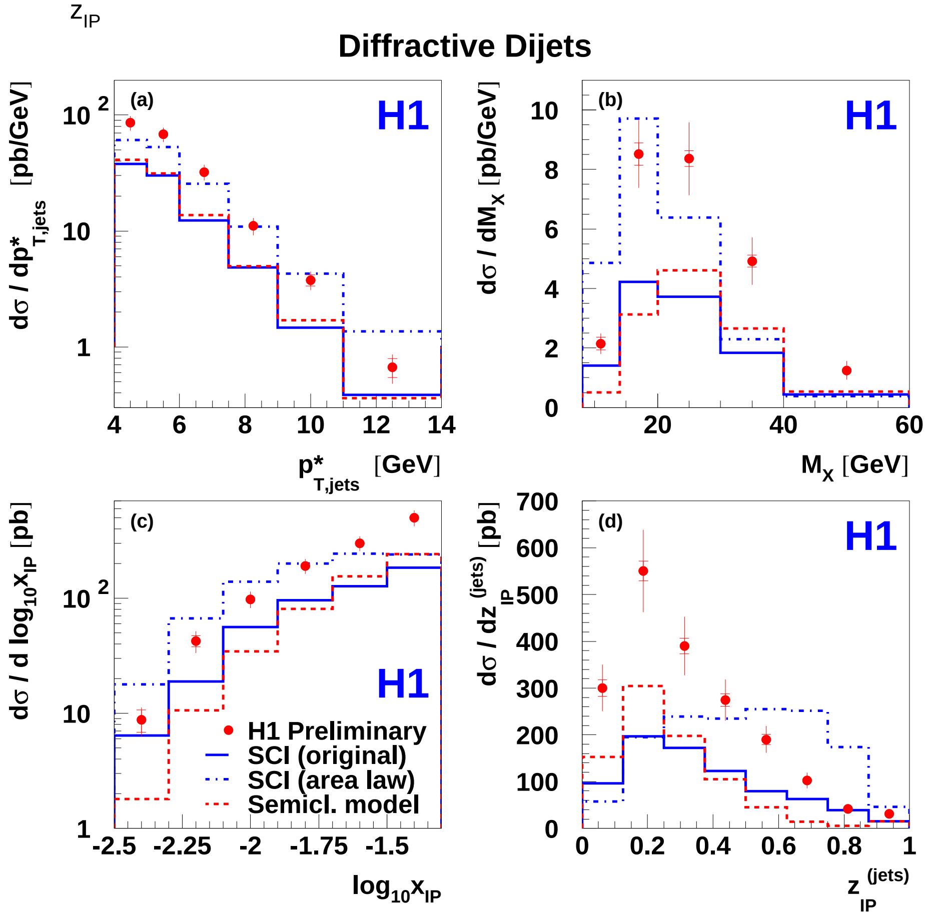
Most models formulated to describe existing F_2^D data



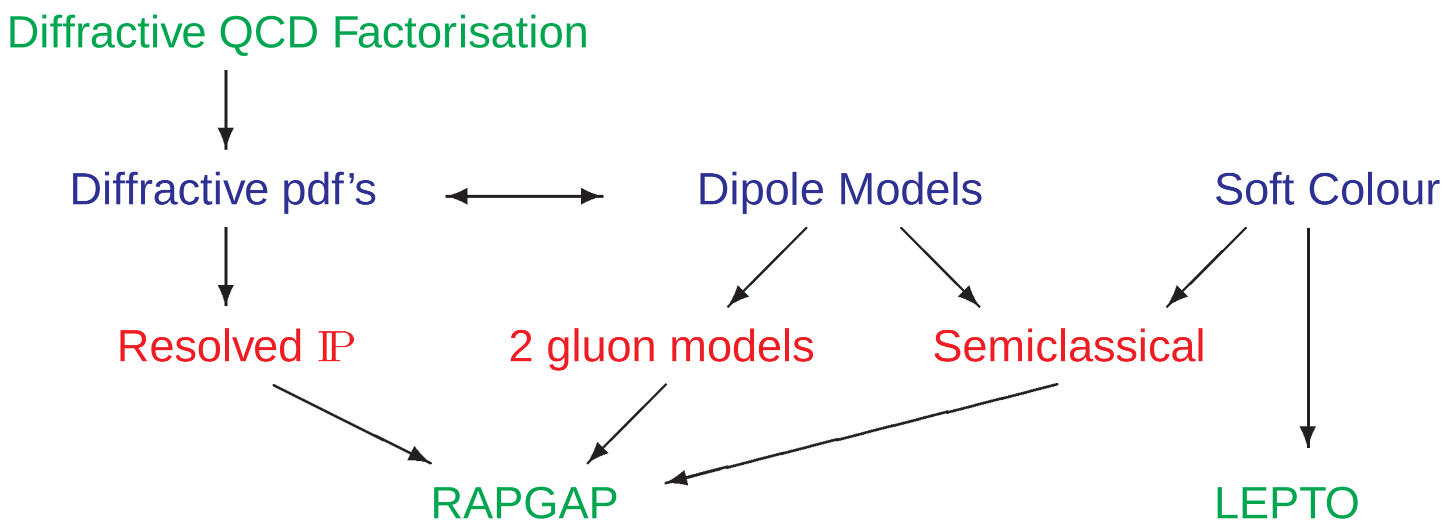
e.g. Jets and Charm are powerful tools to distinguish between models or improve them.

Even the low statistics charm data can distinguish!

Largely on the basis of these data, QCD models are improving fast!



How Do the Models Fit Together?



Rapidly evolving field, both theoretically and experimentally

. . . 1992	Little theory, no data.
1993-00	Loads of data from HERA-1
1994 . . .	Theory catching up!

No sign of theoretical activity diminishing

Models likely to improve considerably before HERA-2 data analysed.

Improved data will be needed!

What Limits our Understanding?

1) Statistics

F_2^D systematically limited for $Q^2 \lesssim 100\,\mathrm{GeV}^2$? after HERA-1

Many exclusive final states remain statistically limited. e.g. D^*

Vector meson channels statistically limited for high Q^2 of $|t|$

PROCESS	HERA-1 ($100\ \mathrm{pb}^{-1}$)	HERA-2 ($1\ \mathrm{fb}^{-1}$)
Elastic ρ^0 ($Q^2 > 20\ \mathrm{GeV}^2$)	1000	10000
Elastic ϕ ($Q^2 > 20\ \mathrm{GeV}^2$)	125	1250
Elastic J/ψ ($Q^2 > 20\ \mathrm{GeV}^2$)	140	1400
Elastic Υ (all Q^2)	50	500
Diffractive D^* ($Q^2 > 10\ \mathrm{GeV}^2$)	100 (H1)	1000

Essential to efficiently trigger data for ‘rare’ processes!

What Limits our Understanding?

2) Experimental Systematics

e.g. Approximate systematics break-down for F_2^D

SOURCE	SYSTEMATIC UNCERTAINTY
Inclusive Kinematics	$\sim 3\%$
M_X Measurement	$\sim 4\%$
Acceptance / migration corrections	$\sim 4\%$
Correction to $M_Y < 1.6\ \mathrm{GeV}, \|t\| < 1\ \mathrm{GeV}^2$	$\sim 10\%$

Rapgap selection method gives dominant systematics due to:

- Poorly constrained Forward detector efficiencies
- Poorly known t distribution
- Poorly known proton dissociation norm$^{\mathrm{n}}$, M_Y dependence

3) Model Comparisons

Unknown t dependence can make model comparisons hard.

e.g. Normalisation of dipole models highly sensitive $\sim 1/B$

Direct tagging of leading protons would improve matters enormously

Can we Trigger the Data

Fast Track Trigger: Trigger signals derived from selected CJC wires . . .

L1: 2.3 µs	**L2**: 25 µs	**L3**: ≈100 µs
QT analysis, Track-Segment-Finding	Track-Segment-Linking, momenta, momentum sums	event reconstruction, jets, invariant masses, Δm. . .

Efficient on-line (L2-3) identification of D^*, ρ, ϕ, J/ψ, Υ should be available from 2002.

Jet Trigger: Lower thresholds possible

Can *SPACAL* $\times$ *jet trigger* be used for dijets with $p_T > 5\,\mathrm{GeV}$?

Can LAr-IF be used for a rapidity gap based trigger?

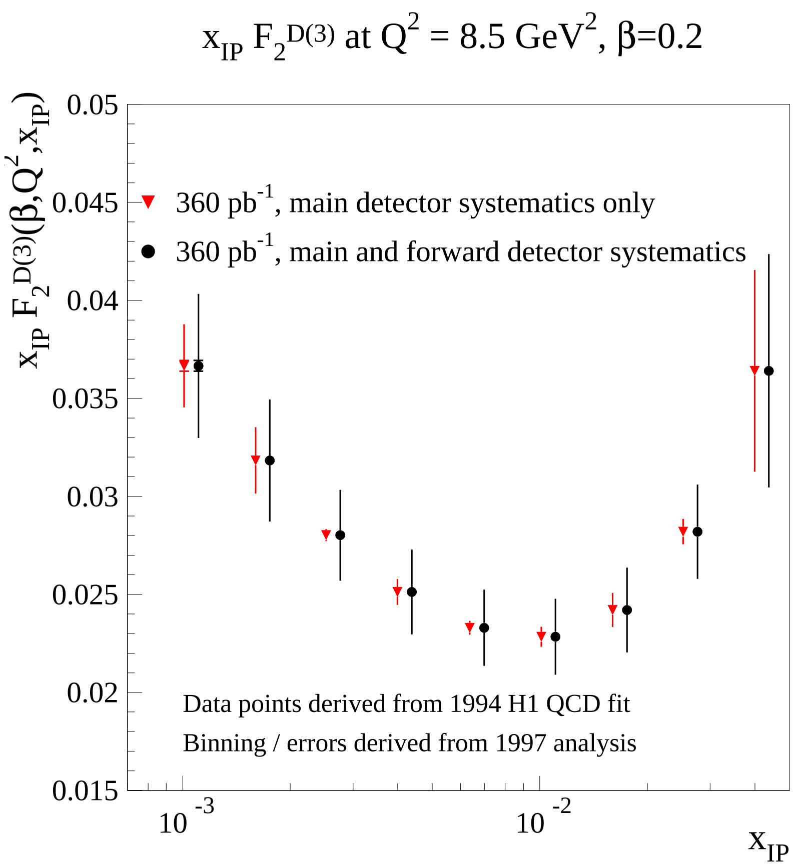
Other Channels: e.g. inclusive diffraction

May be problematic until we can trigger on leading protons . . .

Very Forward Proton Spectrometer

Roman pots near $z = 200\,\mathrm{m}$ from 2002 shutdown . . .

- High acceptance for low $x_{I\!P}$ to lowest $|t|$ allowing precision studies of $ep \to eXp$



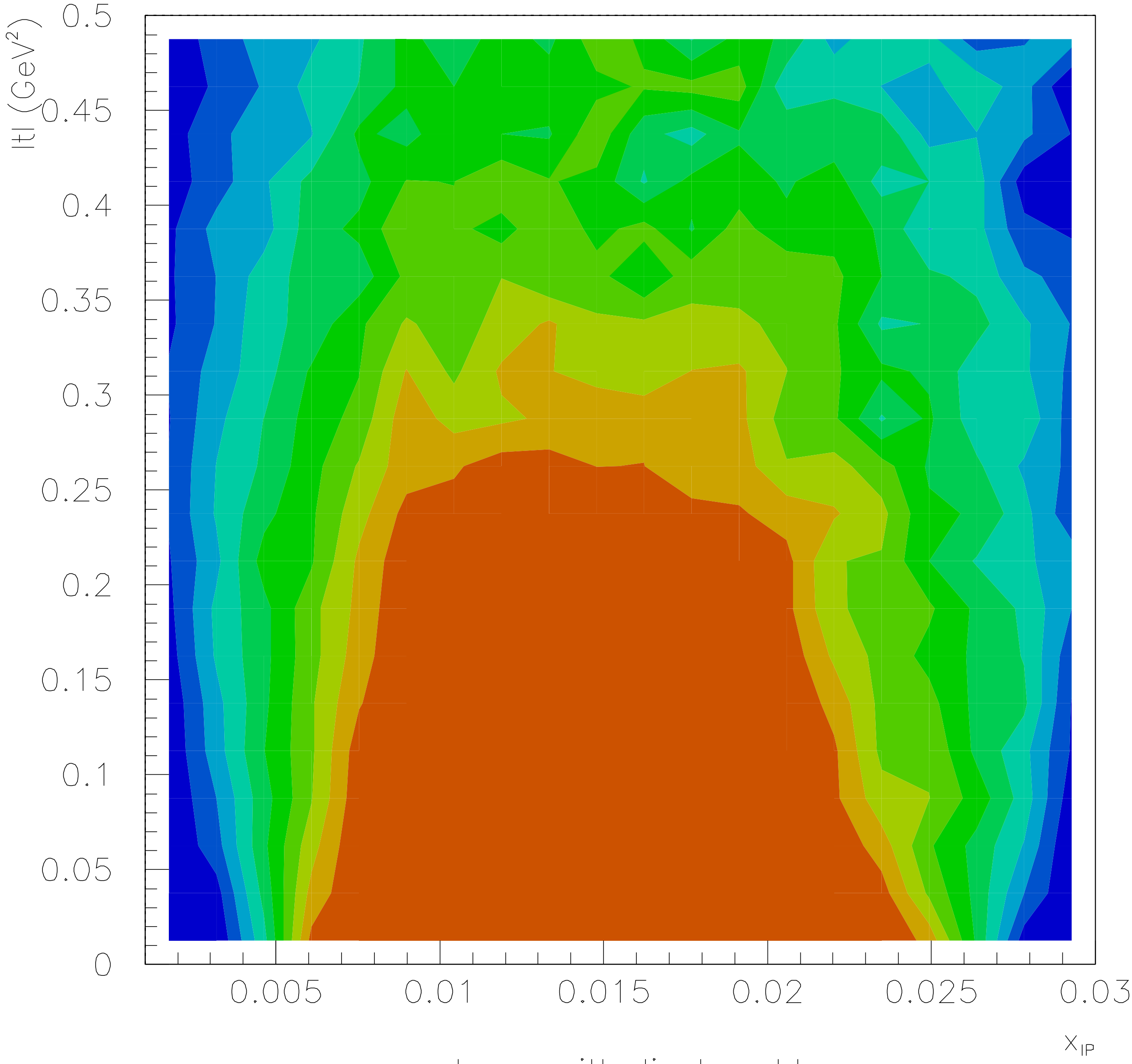
- Large reductions in systematics relative to present 'rapidity gap' selection.

3 years' data ($360\,\mathrm{pb}^{-1}$) expected.

- Collect high statistics for all proton elastic channels
- Measure t dependences.

Trigger is planned at L1/2 - will hopefully become the main means of triggering diffraction

VFPS Acceptance



acceptance with displaced beam

Wish List 1 - t Measurements

Constraints on t dependences needed because:-

- Dipole / 2 gluon exchange calculations yield $\left\{ \frac{\mathrm{d}\sigma}{\mathrm{d}t} \right\}_{t=0}$
- We measure $\int_{-1\,\mathrm{GeV}^2}^{t_{min}} \frac{\mathrm{d}\sigma}{\mathrm{d}t}\ \mathrm{d}t$
- We will never be able to fully test validity of QCD models until t dependence is extracted experimentally.
- *Variation* of t slope with other variables ($x_{I\!P}, W \ldots$) contains important dynamical information (α', shrinkage)
- Can we measure $B(\beta, Q^2, x_{I\!P})$?

For VM, extract t from p_T of decay products.

For photon dissociation, need to measure p_T of proton.

Existing FPS-V (81, 90 m) should give smallest systematics on t measurement, but limited acceptance

VFPS will give 3-4 bins for $0 < |t| < 0.6\ \mathrm{GeV}^2$.

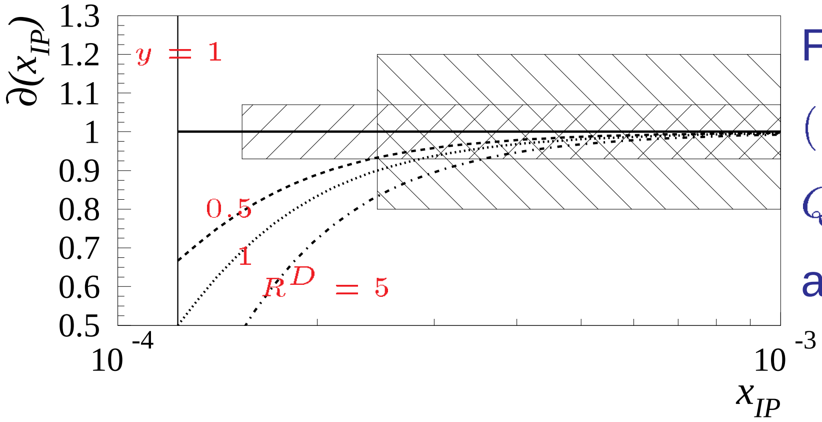
Calibration systematic on t slope $\sim 10\%$?

Wish List 2 - Longitudinal Cross Sections

- σ_L probably dominates diffraction for high β
- VM data already show this (decay angular distributions)
- $F_L^D(\beta, Q^2, x_{I\!P})$ would be a fundamental test of QCD factorisation in diffraction (gluon at NLO)

3 methods proposed, no results yet!

1) Measure $\sigma(\beta, Q^2)$, vary y by changing $x_{I\!P}$



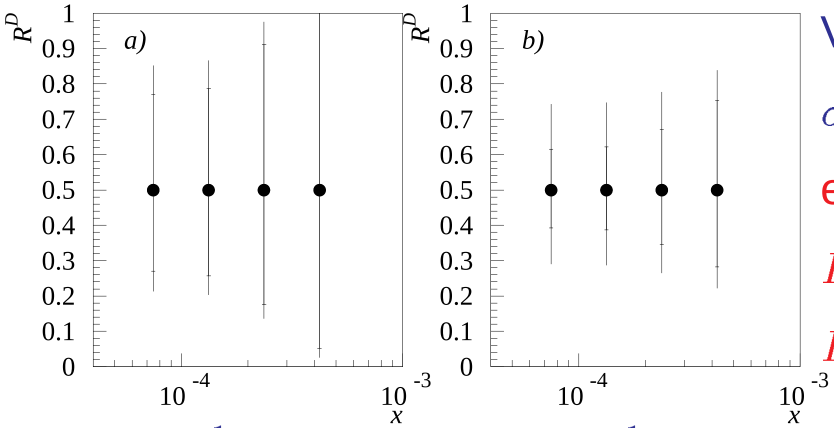
Fractional deviation from $(1/x_{I\!P})^{2\alpha(t)-1}$ for $Q^2 = 20\ \mathrm{GeV}^2$, $\beta = 0.5$ and different R^D

Needs $\sim 10\%$ precision for $y > 0.7$

Requires Regge factorisation assumption and full understanding of sub-leading $\mathbb{R}$

Wish List 2 - Longitudinal Cross Sections

2) Vary beam energies



$10\,\mathrm{pb}^{-1}$ @ $500\,\mathrm{GeV}$ $\quad$ $50\,\mathrm{pb}^{-1}$ @ $500\,\mathrm{GeV}$

$50\,\mathrm{pb}^{-1}$ @ $820\,\mathrm{GeV}$ $\quad$ $250\,\mathrm{pb}^{-1}$ @ $820\,\mathrm{GeV}$

Vary s to get

$\sigma(\beta, Q^2, x_{I\!P})$ at different y

e.g. $E_p = 820\,\mathrm{GeV}, y \sim 0.5$

$E_p = 500\,\mathrm{GeV}, y \sim 0.8$

$R^D = 0.5$

Many possible scenarios, changing E_e may be better

In this example, statistical and systematic errors comparable with $50\,\mathrm{pb}^{-1}$ at $E_p = 500\,\mathrm{GeV}$. R^D measured to 40%.

Can be done without VFPS. - Rapgap selection is enough.

With VFPS, could try to measure t dependence too.

3) Azimuthal Correlations

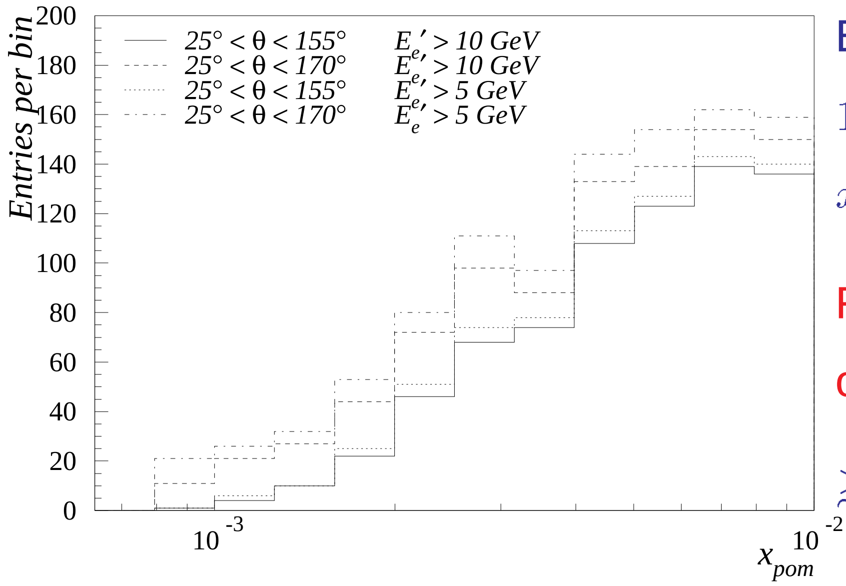
Interference between transverse and longitudinal photon induced processes leads to modulation in $\cos\phi_{ep}$.

Predicted $\sim 20\%$ for $\beta > 0.8$.

VFPS expect to measure $\cos\phi_{ep}$ in 4-5 bins.

Wish List 3 - Diffractive Open Charm

- Important probe of gluon, complementary to dijets
- Important to resolve apparent H1 / ZEUS differences
- The only channel that currently shows deviations from 'Resolved pomeron' model
- With FTT, we can expect high trigger efficiency from 2002
- Would be nice to measure $F_2^{D(4),c\bar{c}}(\beta, Q^2, x_{I\!P}, t)$



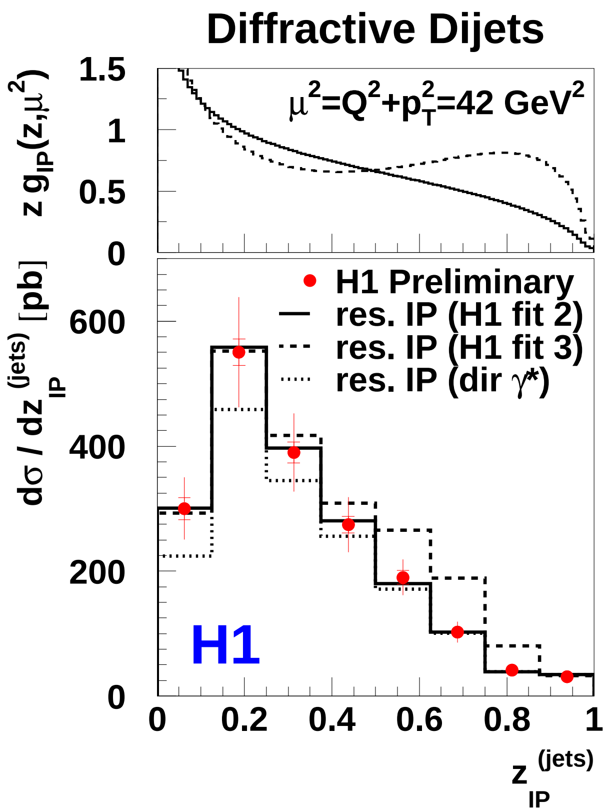
Expected D^* yields for $10 < Q^2 < 25\ \mathrm{GeV}^2$ and $x_{I\!P} < 0.01$

From $750\ \mathrm{pb}^{-1}$ (res $I\!P$) or $\sim 2\ \mathrm{fb}^{-1}$ (H1 data)

$\gtrsim 10\%$ stat. in this binning

- Unlikely ever to see more than double differential distributions at low $x_{I\!P}$
- Still a very powerful measurment!
- Worth looking at silicon vertex distribions, other decay channels / inclusive muons . . .

Wish List 4 - Diffractive Dijets



DIS dijets already proved highly sensitive to diffractive gluon distribution.

High power to distinguish between models.

Improved stats at low $x_{I\!P}$ would remove many remaining uncertainties.

t measurement crucial for QCD dipole model comparisons (VFPS expects 10k events)

Theoretical predictions most reliable for *exclusive* $q\bar{q}$ (high $z_{I\!P}$)

e.g. Azimuthal correlation between jet and lepton scattering planes differentiates between BGF and 2-gluon exchange.

Distinguish at 4σ level with 10% measurement in 7 ϕ bins $\rightarrow 250\,\mathrm{pb}^{-1}$.

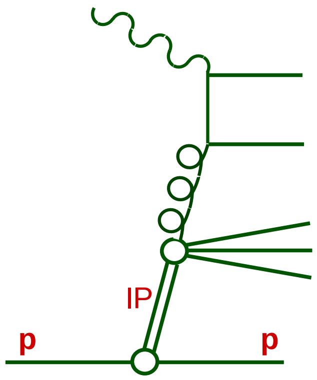
Wish List 4 - Diffractive Dijets

Diffractive QCD factorisation fails badly at the Tevatron

Is underlying event / remnant reinteractions the reason?

Diffractive dijet photoproduction provides a control experiment

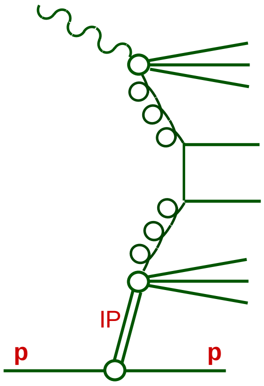
Photon interactions with and without remnants . . .



DIRECT

$x_\gamma^{\rm jets} \sim 1$

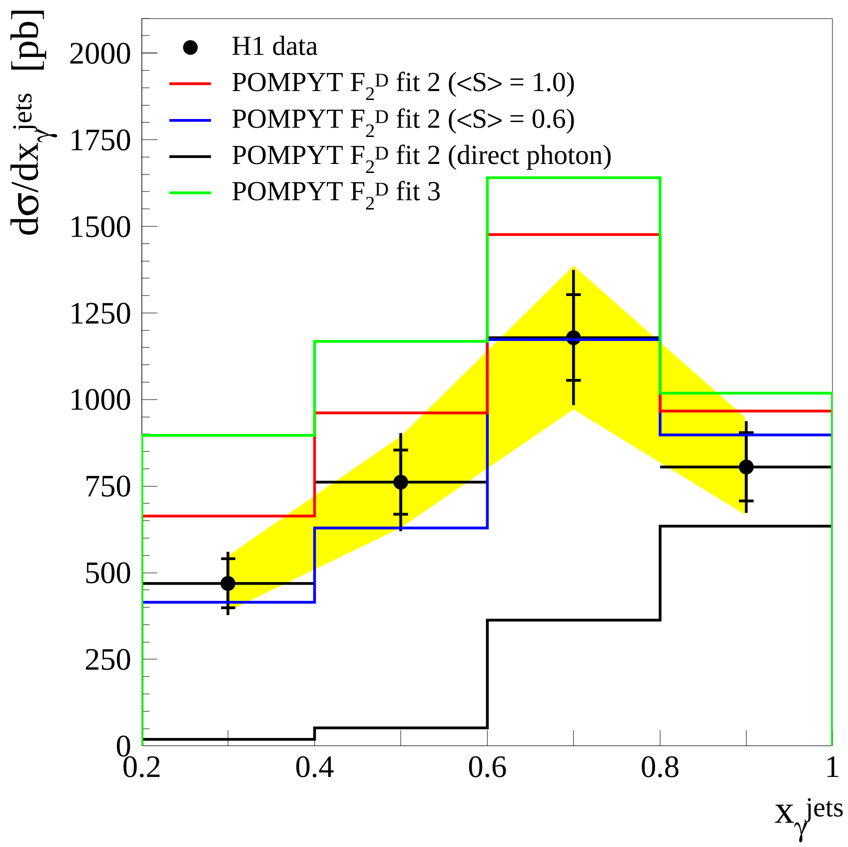
All gaps survive?



RESOLVED

$x_\gamma^{\rm jets} < 1$

Some gaps destroyed?



Description based on diffractive partons improved by suppressing resolved interactions by ‘gap survival probability’ of 0.6

Use Jet Trigger?

VFPS expects 60k events

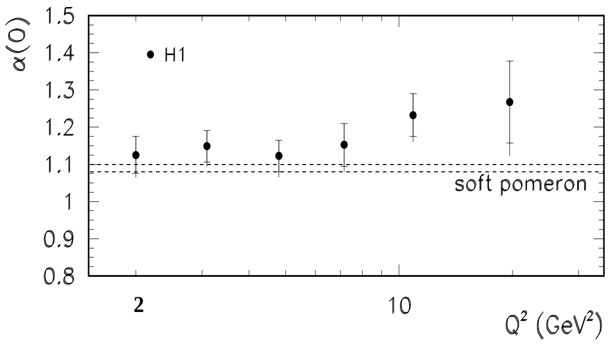
Modelling uncertainties also need to improve

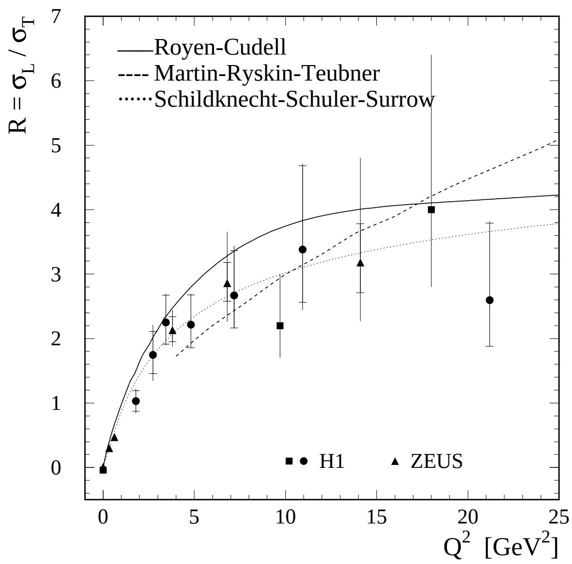
Wish List 5 - Vector Mesons

Many vector meson measurements remain statistically limited

- High Q^2: Poor stats due to $\sim 1/Q^2$ suppression relative to σ_{tot}

Access to σ_L, fac$^{\rm n}$ breaking





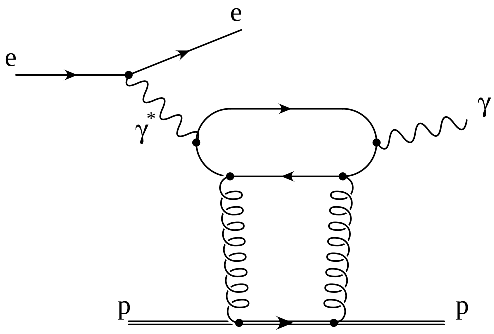
- Gluon: With better understanding, could be highly competitive constraint on gluon in proton

- High $|t|$: Should be measured as differentially as possible

- Υ: Important to compare to J/ψ - W dependence even stronger in QCD models

- SCHC breaking: Detailed dependence on Q^2, t needed for comparisons with QCD models.

Wish List 6 - DVCS



First data showed that pQCD model basically works.

At HERA-2, should have programme to extract *skewed* parton densities.

Will improve many diffractive predictions.

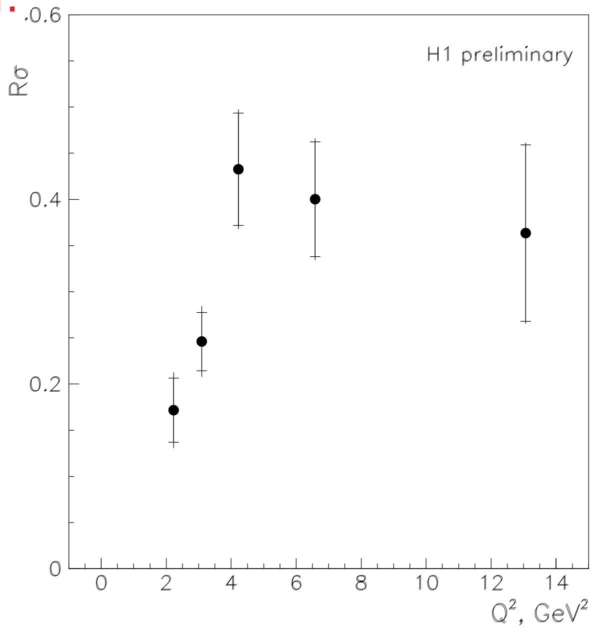
VFPS has high acceptance at low W, where BH interference smallest

Wish List 7 - Proton Dissociation

P-diss channels poorly measured so far.

Some surprises! $\sigma(PD)/\sigma(EL)$ for ρ seems to show strong Regge factorisation breaking!

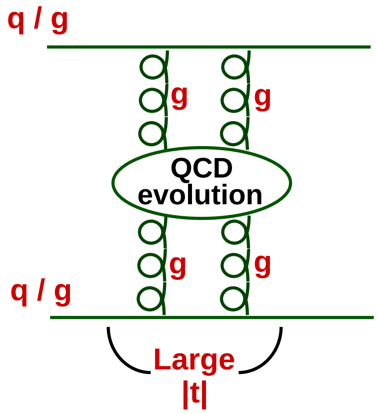
PD:EL ratio can be measured from differences between VFPS and rapidity gap cross sections



Wish List 8 - Rapgaps between Jets

Parton level

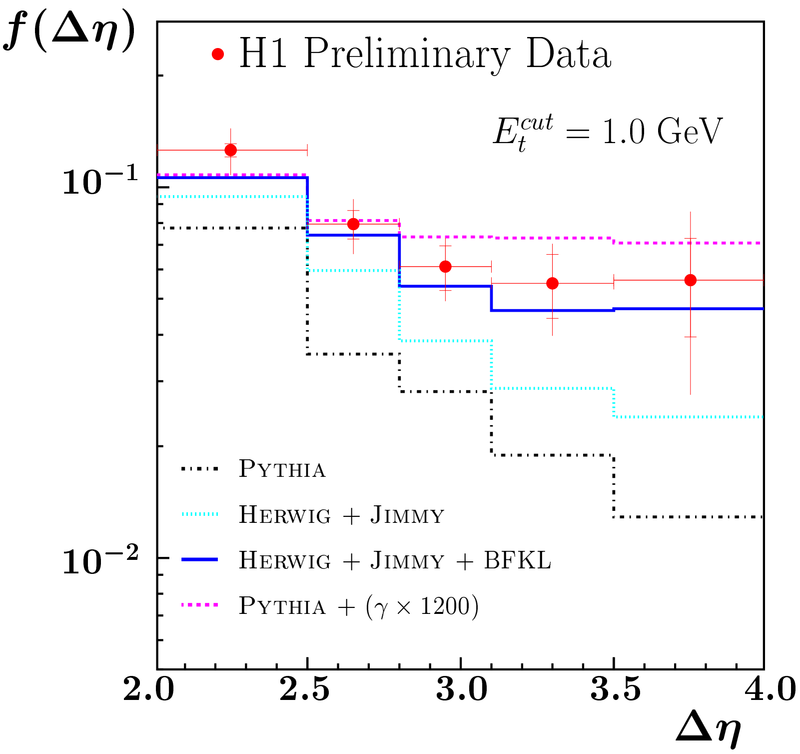
Elastic parton-parton scattering
in Regge limit ($\hat{s} \gg \hat{t}$), yet
pQCD calculable ($\hat{t}$ large)? . . . BFKL?



Hadron level Classic experimental signature is rapidity gap between high p_T jets. $|\hat{t}| \sim p^2_{t,jet}$

Gap fraction at large $\Delta\eta$ significantly larger than Tevatron $p\bar{p}$.

Calculation based on BFKL pomeron can describe data.



Stats should improve with remaining HERA-1 data, but lots more can be done!

Systs dominated by LAr scale

Important channel due to BFKL possibilities.

Triggering not obvious!

Needs thought

Summary

In answer to the Physics Coordinator's Questions . . .

- "What is the Physics Potential for HERA-2?"

  Most areas of Diffraction still on Wish List.

- "Which Data Sets Do we Want Until 2005/6? (e^+e^- higher or lower energy)"

  e^+e^- makes no difference.

  Big diffractive interest in lower energy running.

  Large lumi needed for F_L^D.

- "What Should be our Emphasis in Trigger Conditions / Special Runs?"

  Make sure we trigger D^*, vector mesons with FTT.

  VFPS will trigger most low $|t|$ elastic protons.

  Jet trigger possibilities to be investigated?

- "What are our Limiting Systematics? Do we need Special Efforts to Reduce them?"

  Forward detectors, unknown t distributions

  VFPS should address both problems

  Work on fwd dets for rapgap method also needed.

There is very definitely diffraction at HERA-2! . . .