Diffraction and Vector Meson Progress and Pseudo-Data

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Divonne LHeC Workshop,
2 September 2009

- Quick Overview of Diffractive Channels
- Main topic: First vector meson pseudo-data
- Updated inclusive diffraction pseudo-data

See also related talks on detector requirements (PRN)
And diffraction in eA (Henri Kowalski)

Current Scenarios for Physics Studies

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|Pol|	$L/10^{32}$	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp

[2 versions]

Diffractive simulations done with 6 different configurations

Scenario for Experimental Precision

F_2 and F_L pseudo-data based on informed guesstimates …
The new detector ~2 times better than H1 / ZEUS

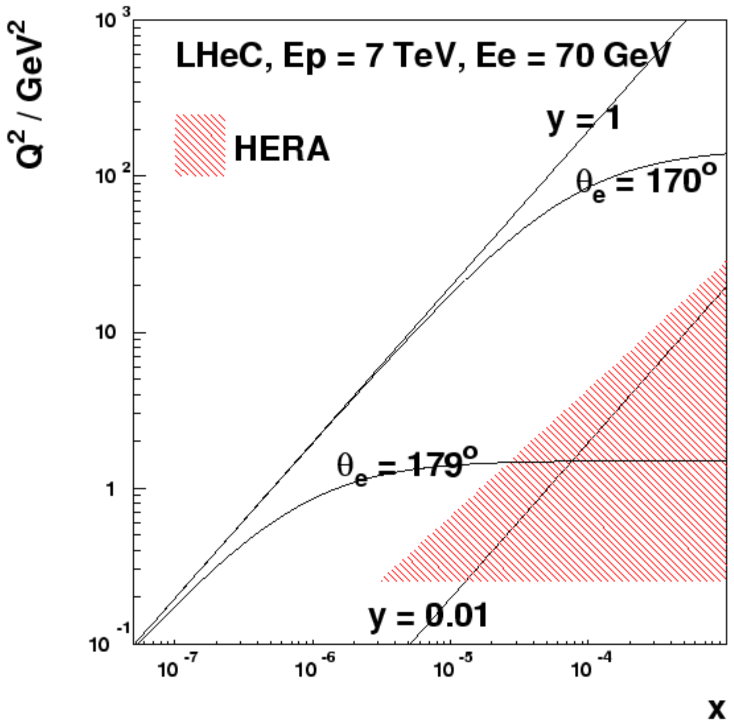
Lumi = 10^{33} cm^{-2} s^{-1}	(HERA 1-5 x 10^{31} cm^{-2} s^{-1})
Acceptance 10-170^{o} (→179^{o}?)	(HERA 7-177^{o})
Tracking to 0.1 mrad	(HERA 0.2 – 1 mrad)
EM Calorimetry to 0.1%	(HERA 0.2-0.5%)
Had Calorimtry to 0.5%	(HERA 1%)
Luminosity to 0.5%	(HERA 1%)

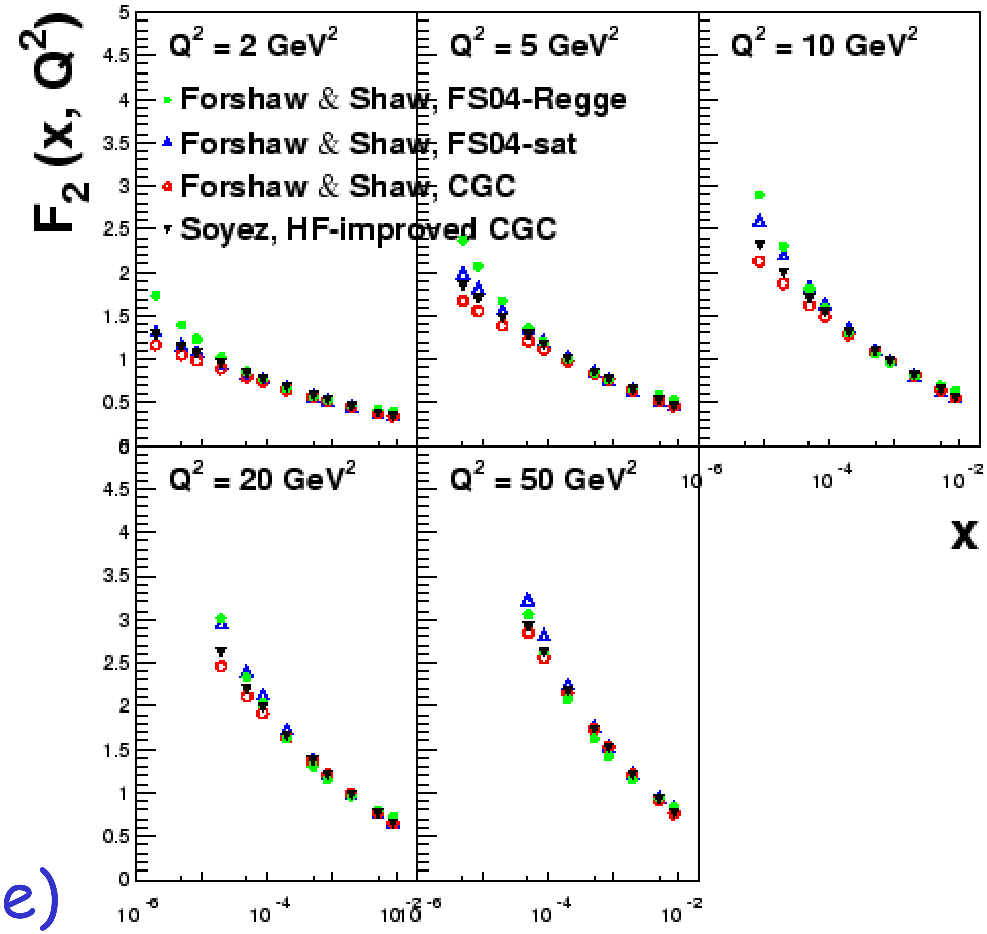
These need refinement based on interaction with detector group

Diffraction specific systematics not yet evaluated at all (depend crucially on unknown forward instrumentation details)

Inclusive Low x Pseudo-Data (Divonne '08 ++)

Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} IF we have acceptance to 179°

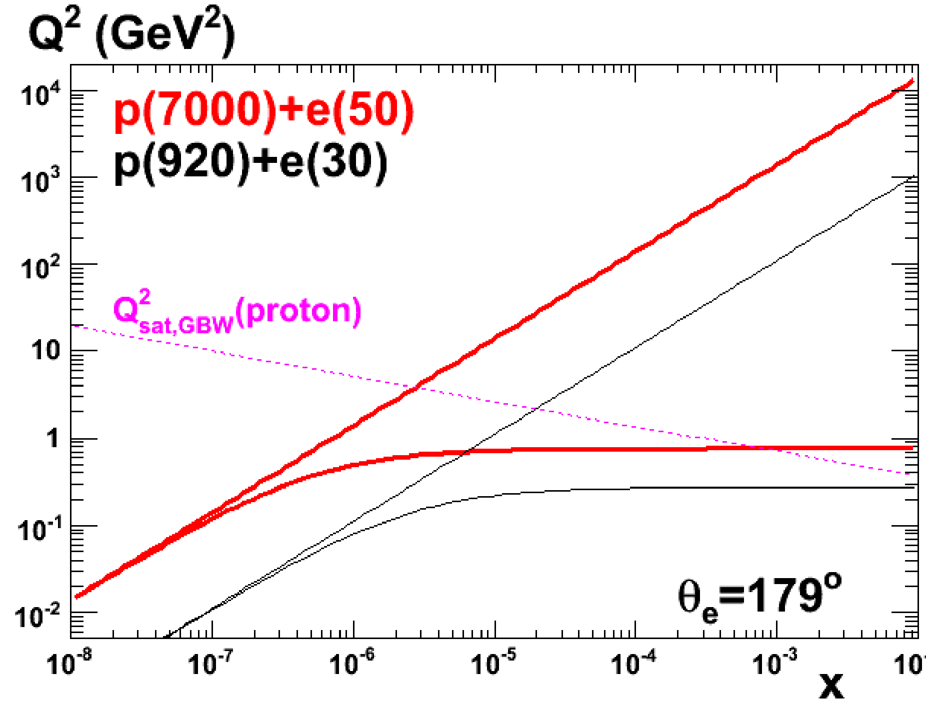




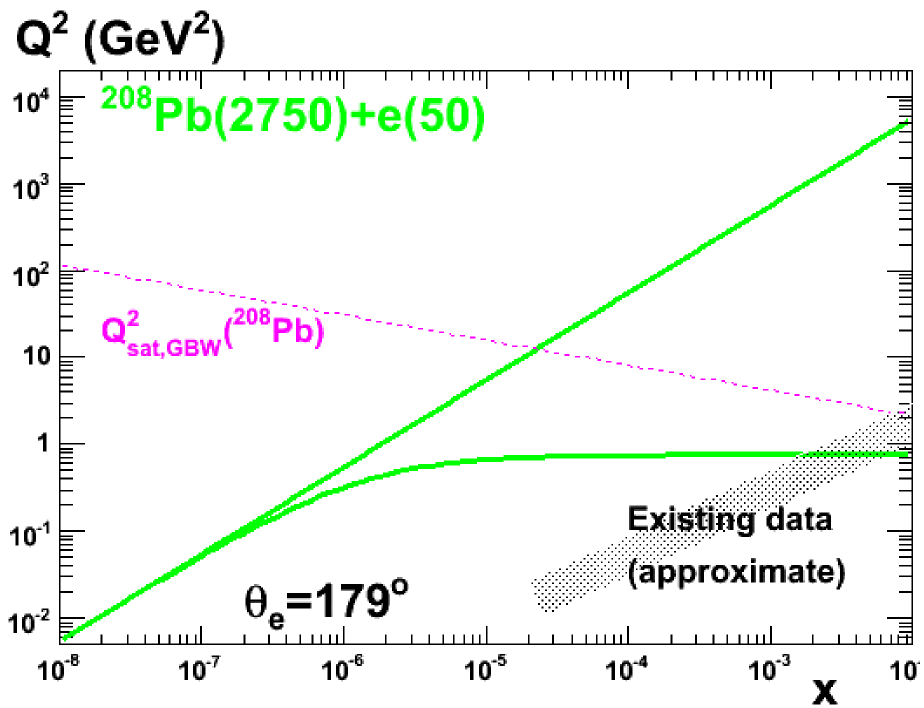
- Comparisons between different extrapolated (dipole) models (see also Albacete)
- Fits testing establishability of saturation (Rojo, Forshaw et al

… main conclusion … non-linear effects hard to see with F_2 only

Low x Possibilities beyond F_2



High Q^2 ep kinematic coverage within saturation Regime (as extrapolated from HERA hints), still not large at LHeC

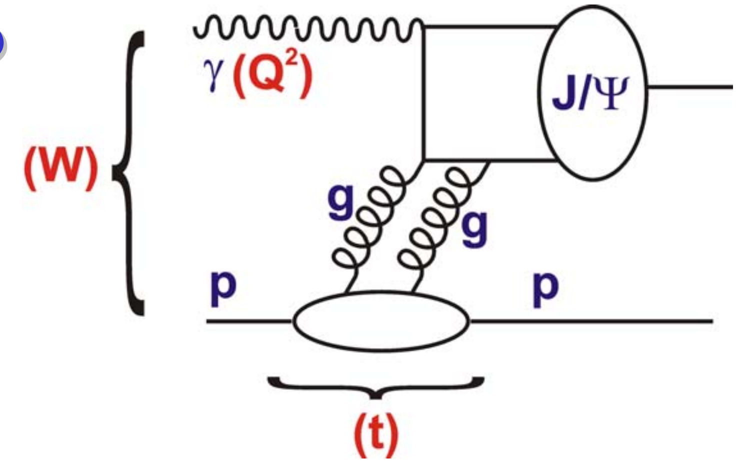


More promising results by fitting F_2 (quarks), F_L (gluons) and their Q^2 dependences together

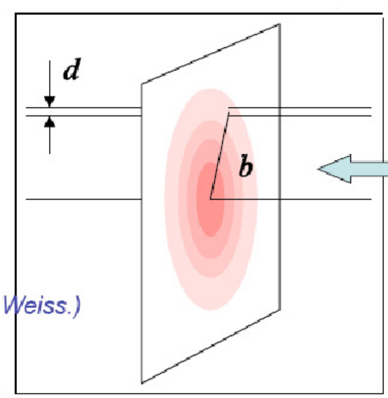
Parton density grows like $A^{1/3}$ (~ 6 for lead) …

What about Diffraction?

Additional variable t gives access to impact parameter (b) dependent amplitudes



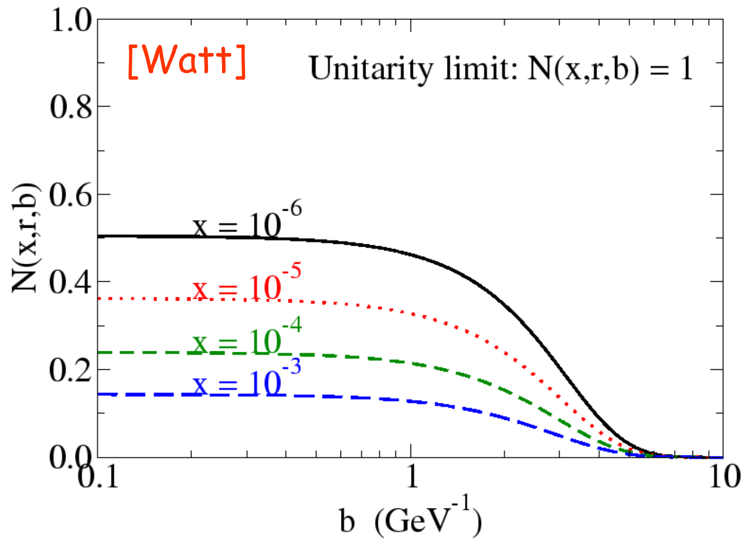
Large t (small b) probes densest packed part of proton … dipole scattering amplitude reaches large fraction of unitarity limit at low x values measurable at LHeC



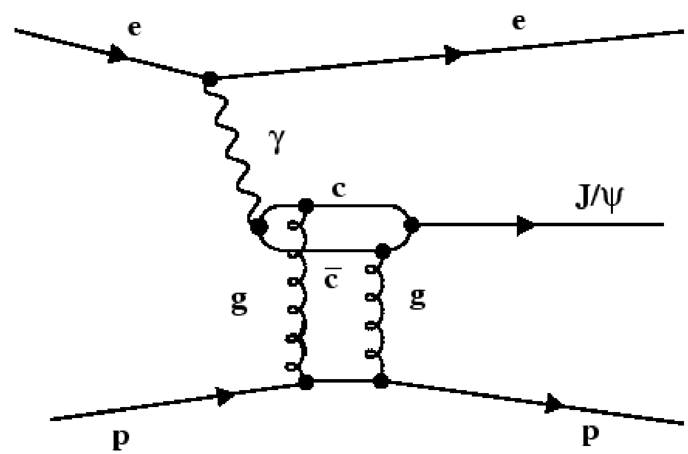
(figure from C. Weiss.)

Central black region growing with decrease of x.

"b-Sat" dipole scattering amplitude with $r = 1\ GeV^{-1}$



Vector Mesons Advantages



Elastic J/Ψ production could be our `golden' channel …

→ Unlike inclusive diffraction, 'cleanly' inrterpreted as hard 2g exchange coupling to qqbar

→Unlike light vector mesons, qqbar share energy equally and VM wavefunction issues are simplified

→Very clean experimental signature (just 2 leptons)

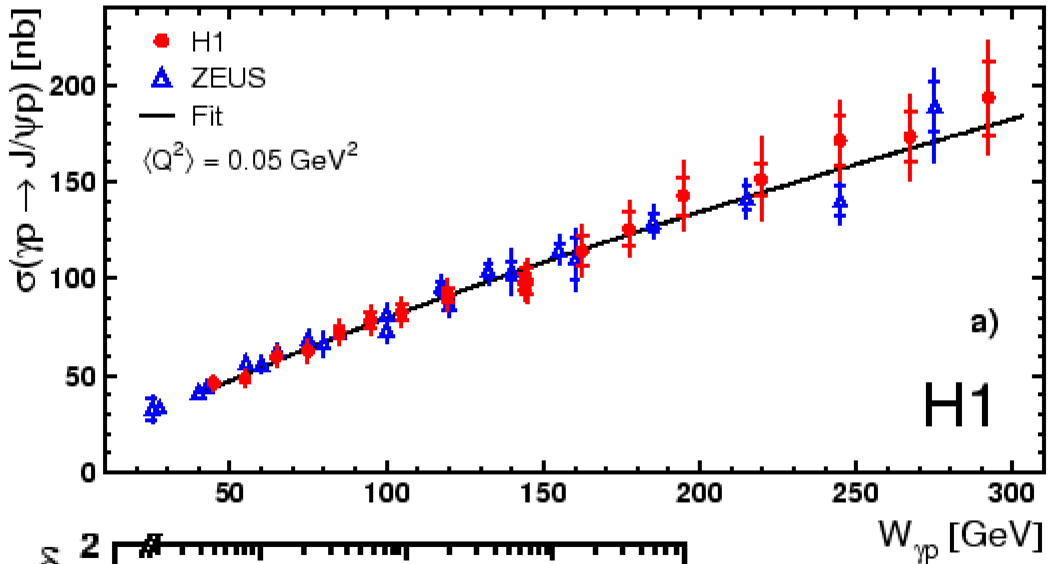
(MNRT etc) $X_g \sim (Q^2 + M_V^2) / (Q^2 + W^2)$ $\overline{Q}^2 = (Q^2 + M_V^2) / 4$

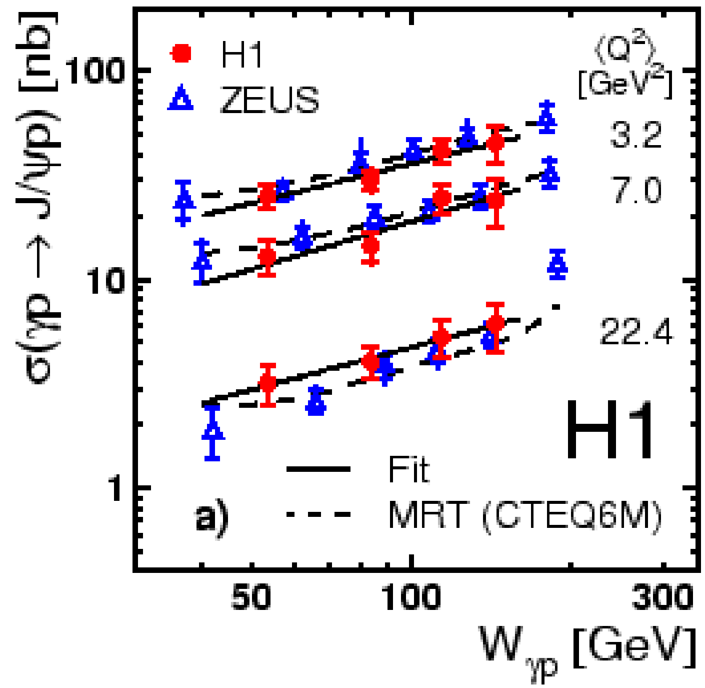
… lower x reach for J/Ψ than for Υ

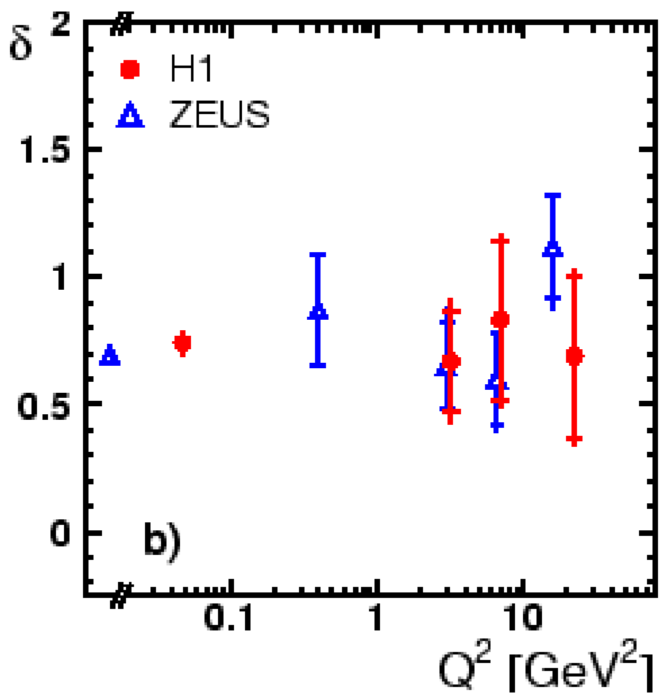
… Best sensitivity to non-linear effects

… Ideally require maximum W (minimum x) and good t measuerments to access small impact parameters

HERA W and Q^2 dependences for J/ψ



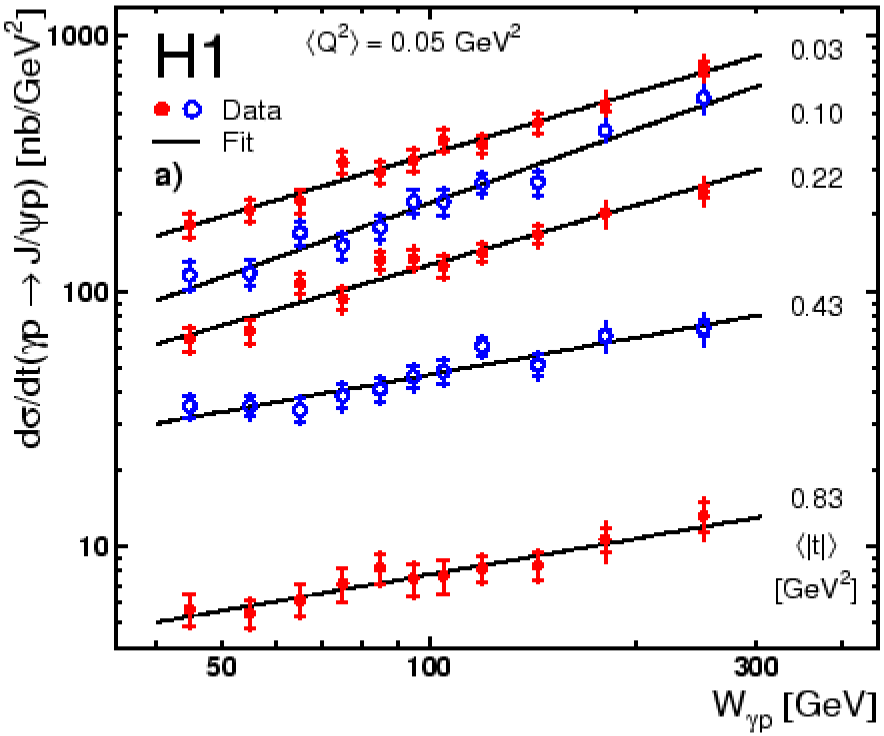


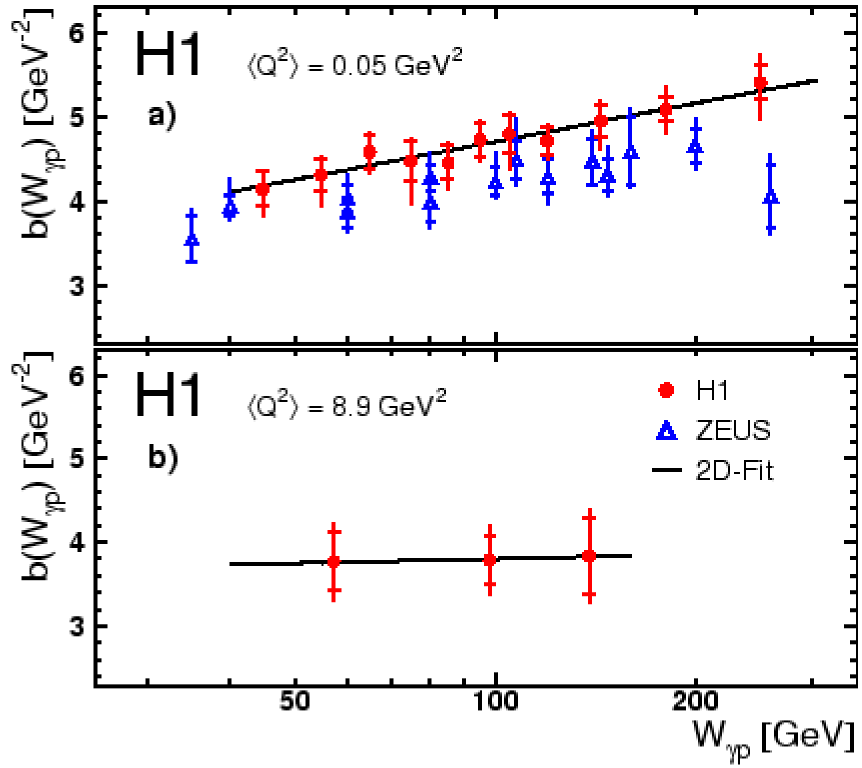


Fits to $\sigma_{\gamma p}(W) = \sigma_0 \, W^{\delta}$

… δ consistent with 0.75 for all Q2 bins

HERA t dependences for J/ψ

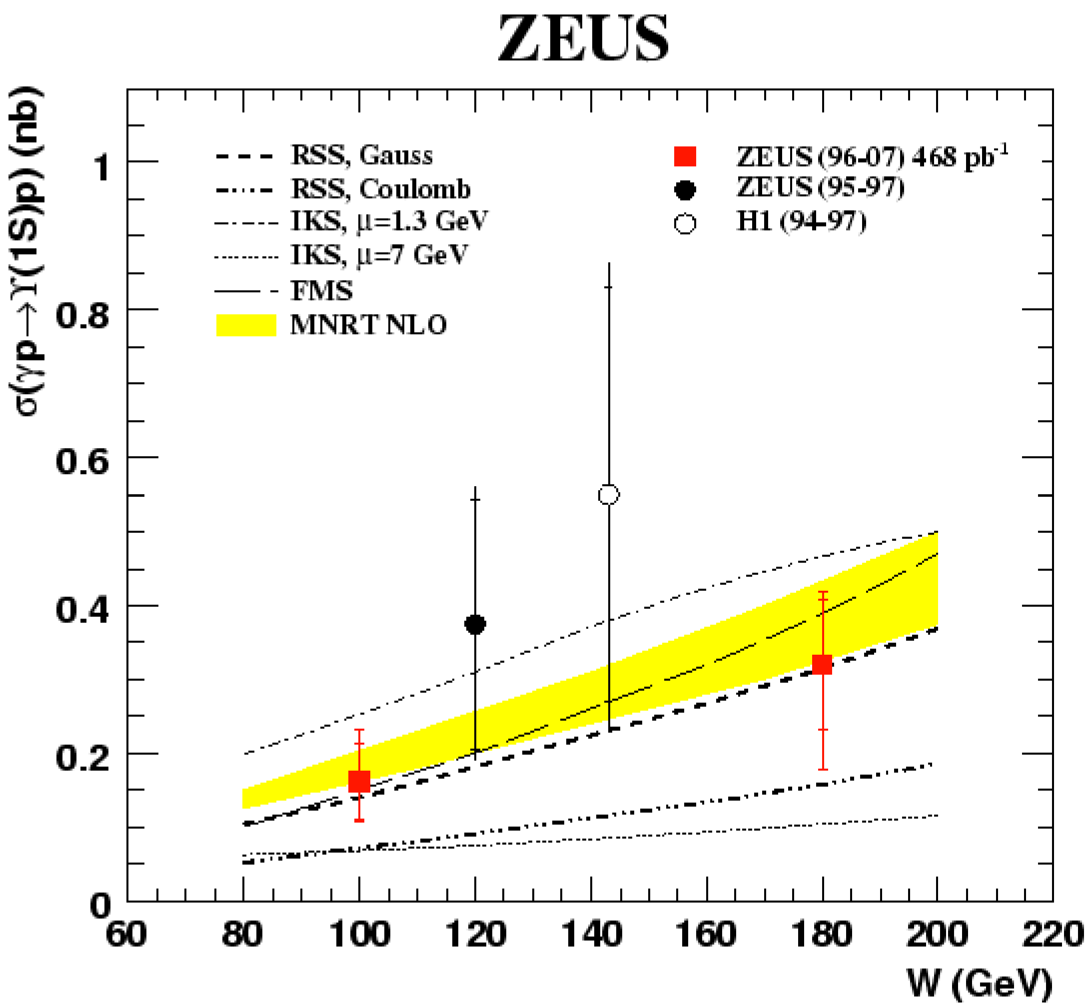




t dependence data (mostly) restricted to $Q^2 = 0$

Slope parameter b (from fits of $d\sigma / dt \,\alpha\, e^{bt}$)
fairly constant at around b = 4.5 GeV^{-2}
(best fits give some shrinkage – $\alpha' \sim 0.1$ GeV^{-2})

HERA data on Υ Production



Υ x-section suppressed by factor ~ 1000 compared with J/ψ

Theory predicts somewhat faster rise with W than J/Ψ

First Look at LHeC Possibilities for Heavy VM

Consider `untagged' photoproduction and `tagged' low Q^2 DIS measurements for J/Ψ and Υ

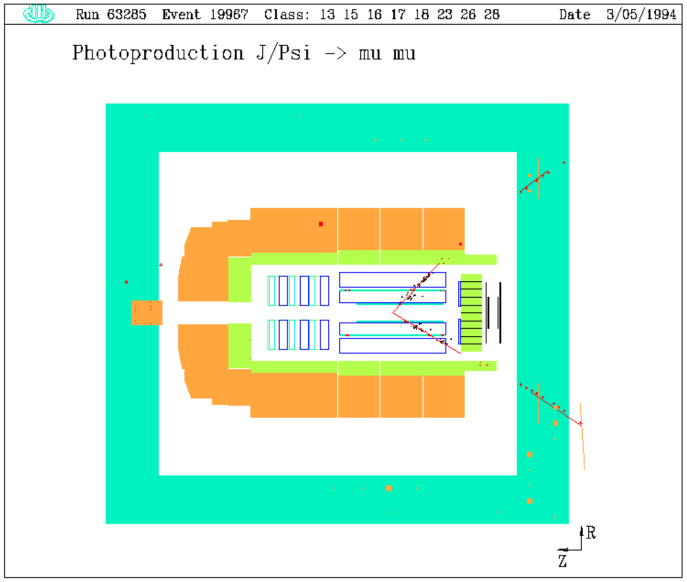
Take one bin for every 50 GeV in W and use H1 t binning

Study acceptances using DIFFVM Monte Carlo
→ simple Regge based model of dynamics
→ full treatment of spin-1 decay, SDMEs …
→ require 30% geometrical acceptance

Predict numbers of events per bin by extrapolation of simple parameterisation of HERA data, hence statistical precision

Systematics not yet done. – Based on HERA experience, typically 10%, fairly correlated between bins.

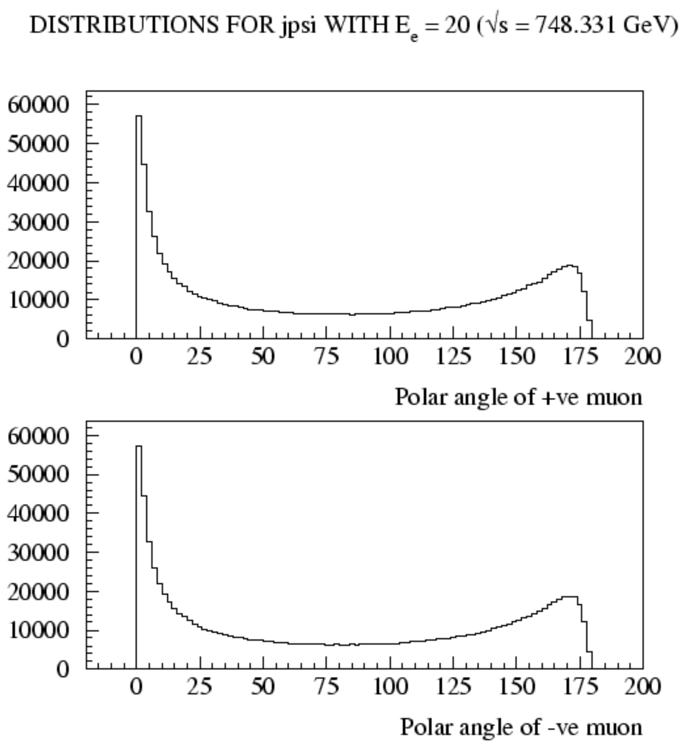
SPL Scenario (20 GeV electrons)

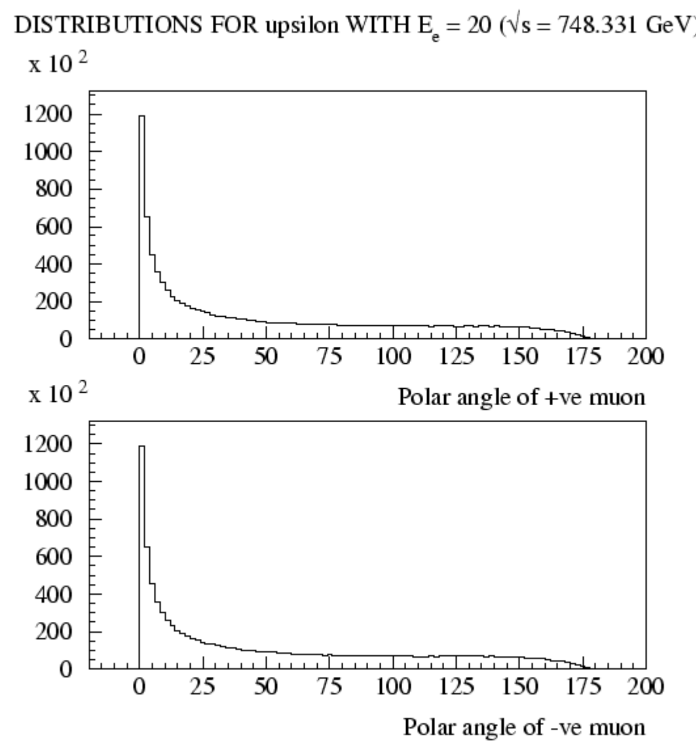


Boost in forward, outgoing proton direction ($\theta \rightarrow 0$)

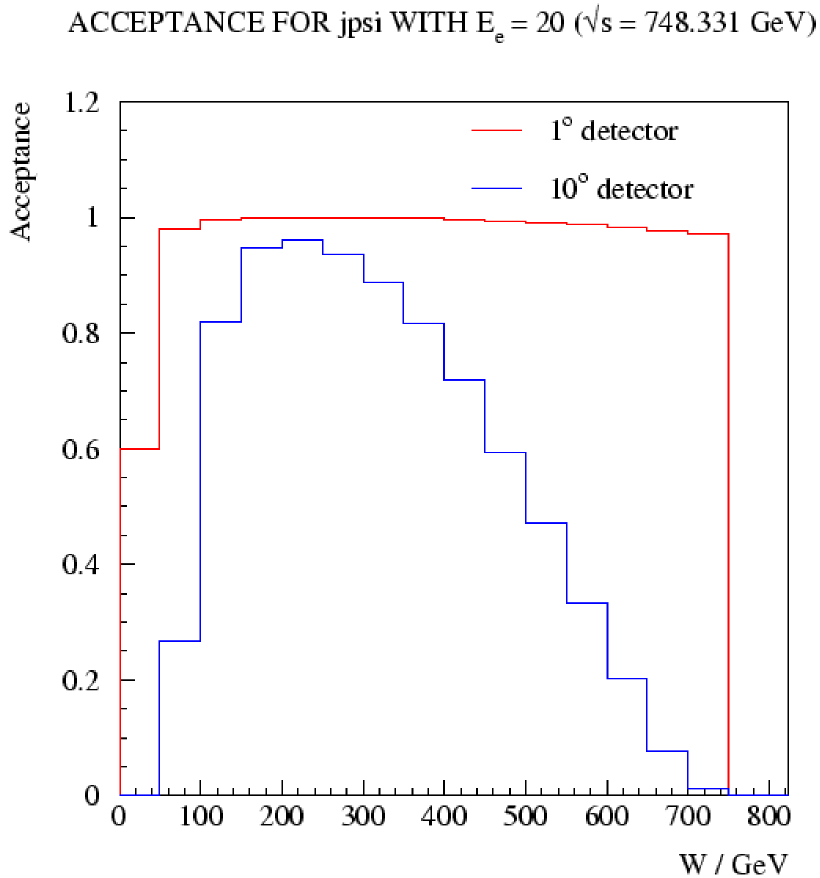
… more pronounced for heavier Υ than for J/ψ

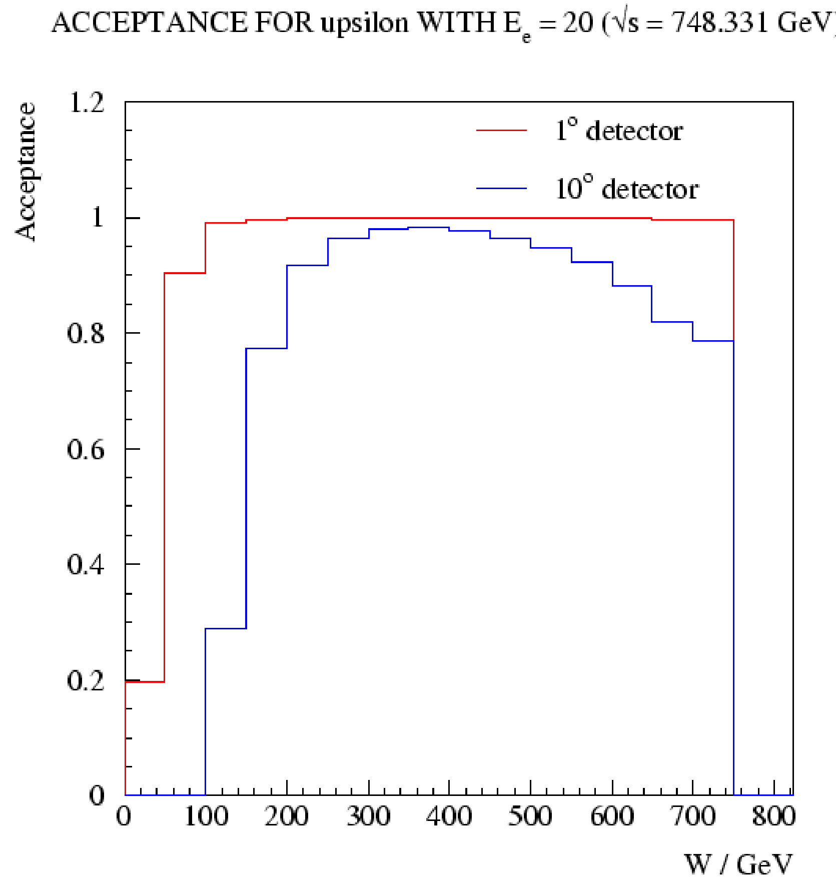
Angular distributions of vector meson decay leptons





SPL Scenario





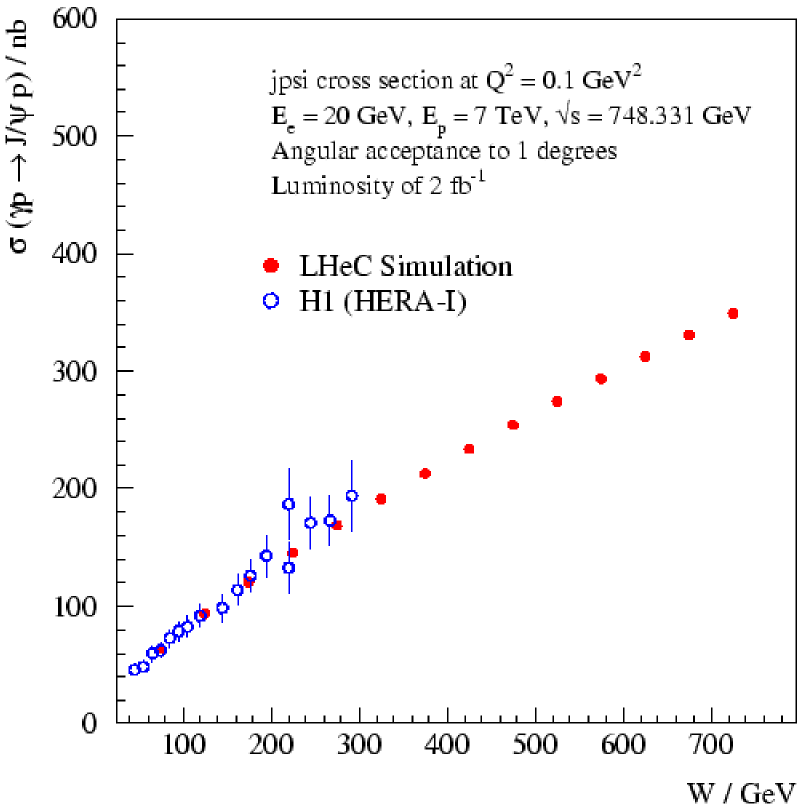
Possibility of reaching W ~ 700 GeV if detector has good enough polar angle coverage.

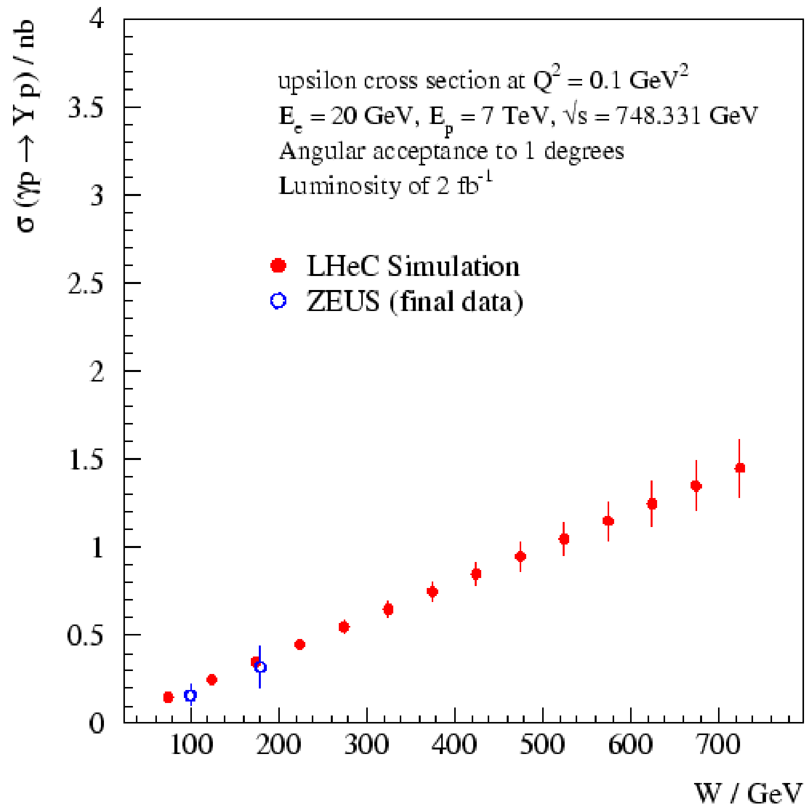
Corresponds to $x_g \sim M_\psi{}^2/W^2 \sim 2.10^{-5}$ for J/ψ, $(2.10^{-4}$ for $\Upsilon)$

at eff scale $\sim M_\psi{}^2 / 4 \sim 2.5$ GeV^2 for J/ψ, (25 GeV^2 for Υ)

c.f. GB-W model $x_s \sim 7.10^{-6}$ at $Q^2 \sim 2.5$ GeV^2 … need t dep!?!

SPL Scenario - photoproduction cross secs





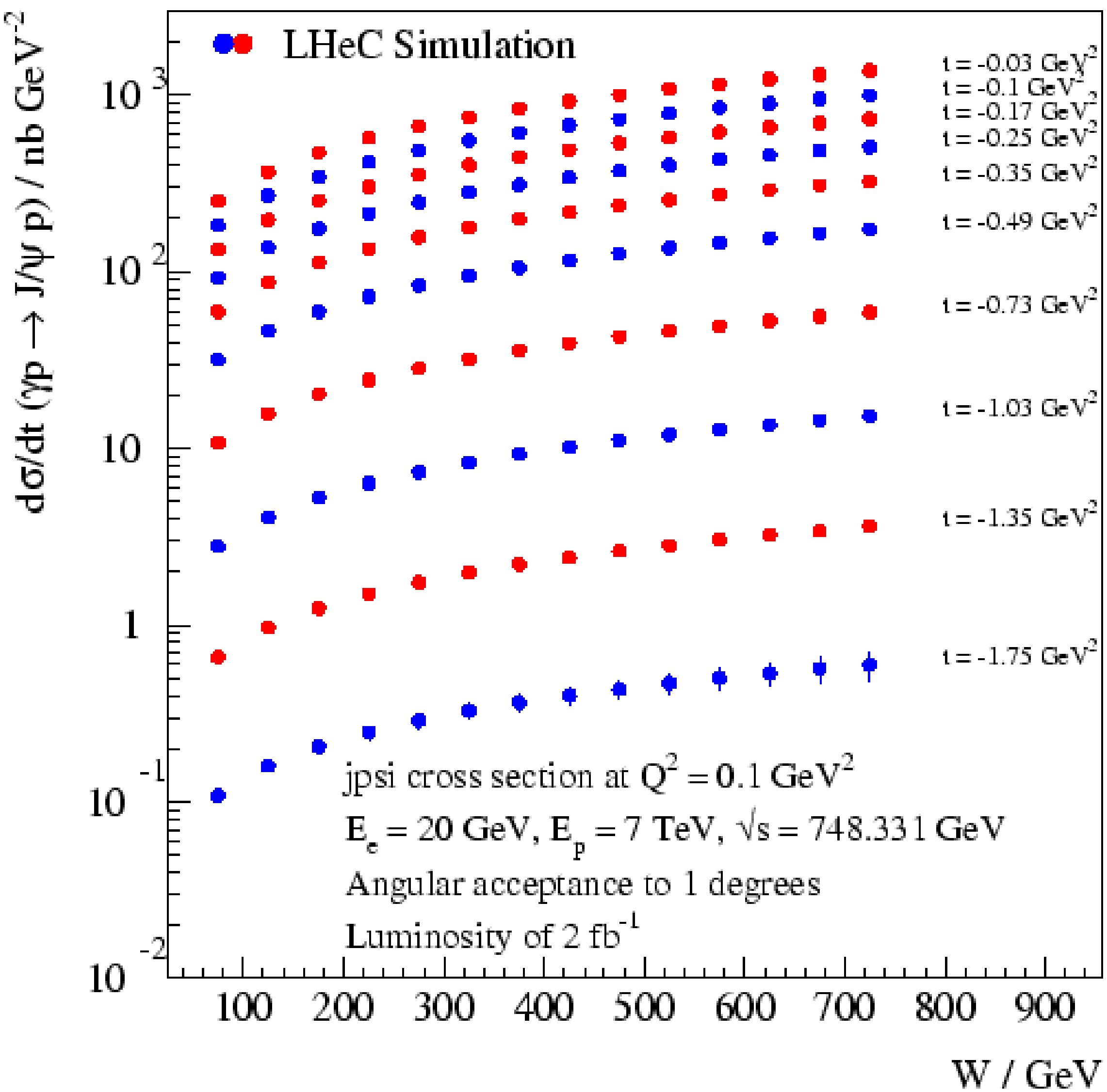
1^{o} acceptance yields cross sections almost to kinematic limit

2 fb^{-1} is already plenty of lumi for J/ψ

c.f. HERA-I analyses based on 50 pb^{-1}

SPL Scenario - photoproduction t dependence

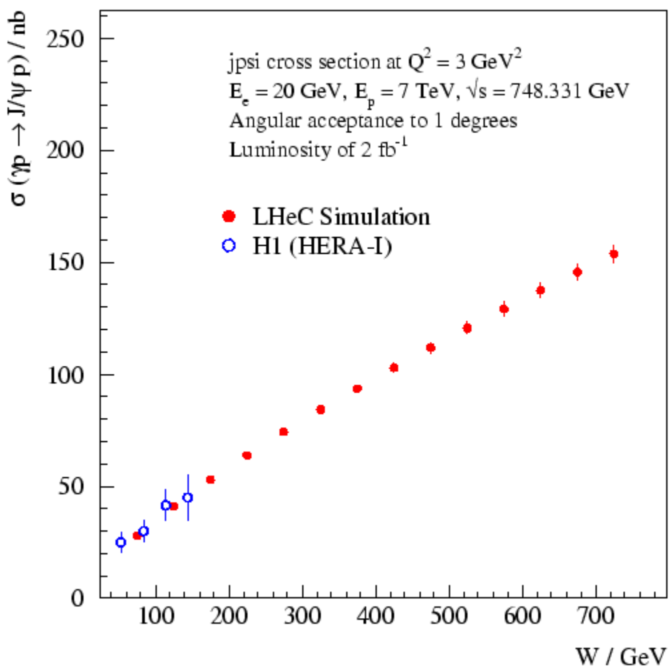
Any sensitivity to saturation likely to need impact parameter dependence (large t ←→small b) and eA to benefit from nuclear parton density enhancement



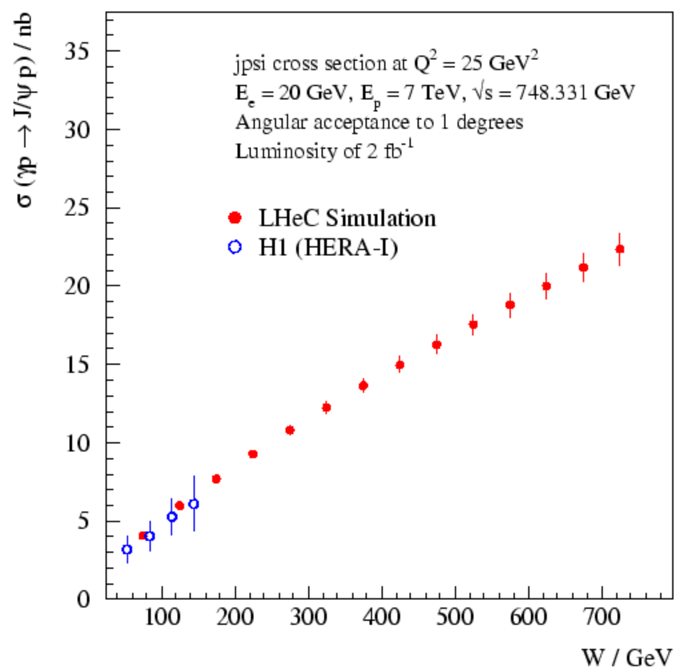
Double differential photoproduction measurement in W and t looks very promising for J/ψ

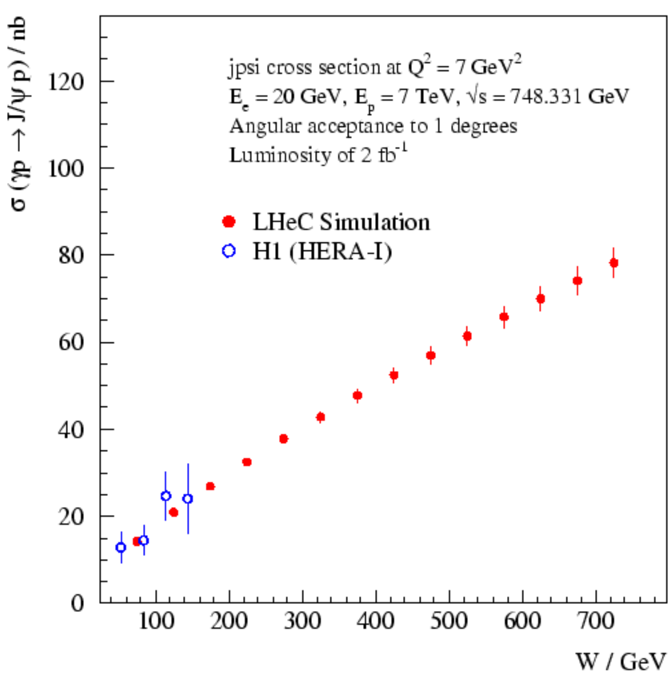
Typical number of events per bin 100 … 10000

SPL Scenario – Q^2 dependence



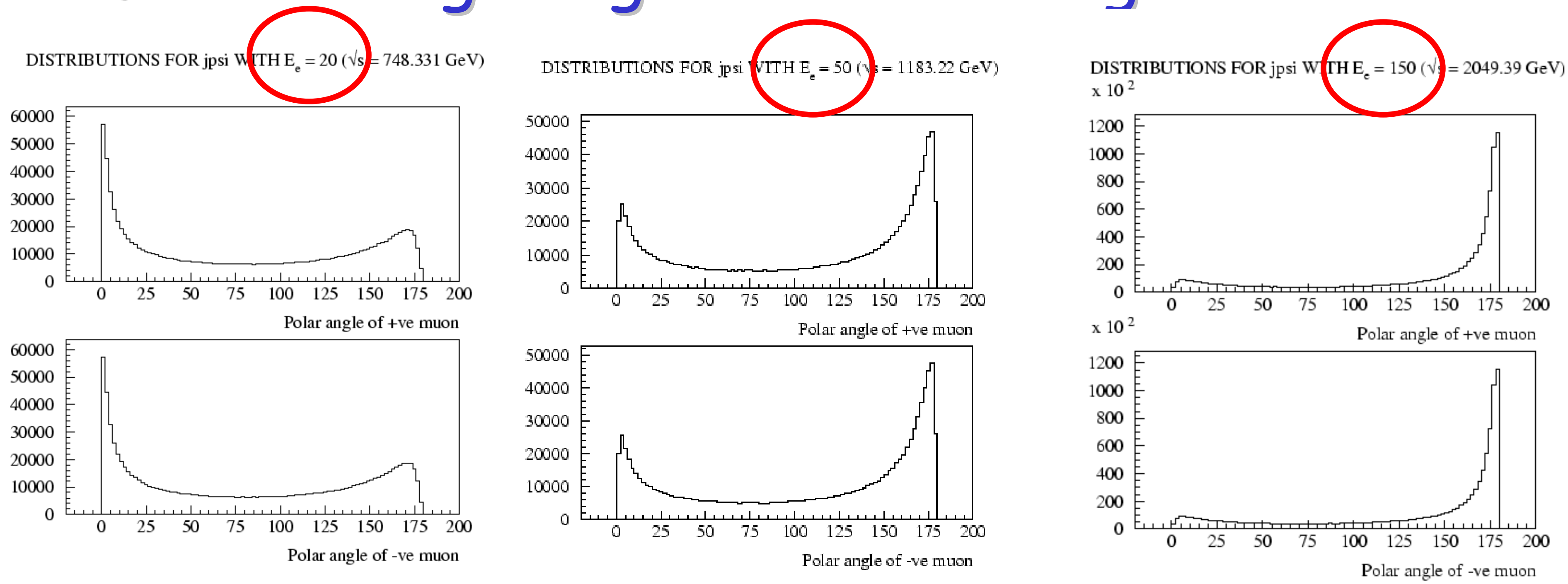
Plenty of J/ψ statistics (t dependence pseudo-Data also promising at high Q^2)





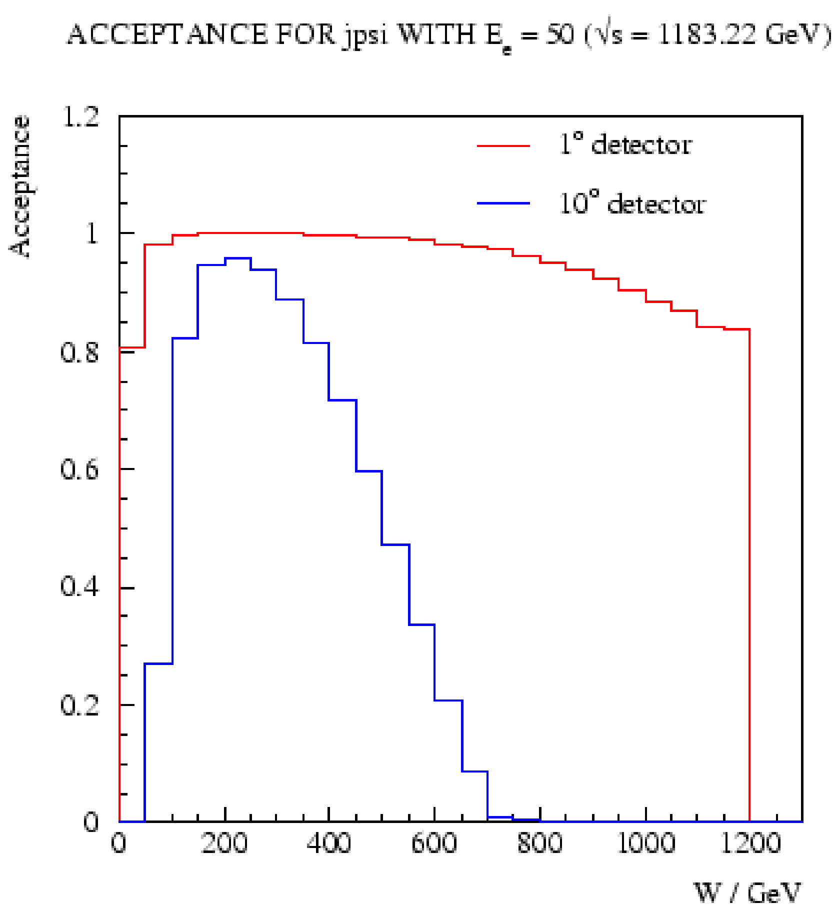
Conclusion: can do a lot with VM in SPL scenario and reasonable lumi…
… but x reach only to few . 10^{-5}

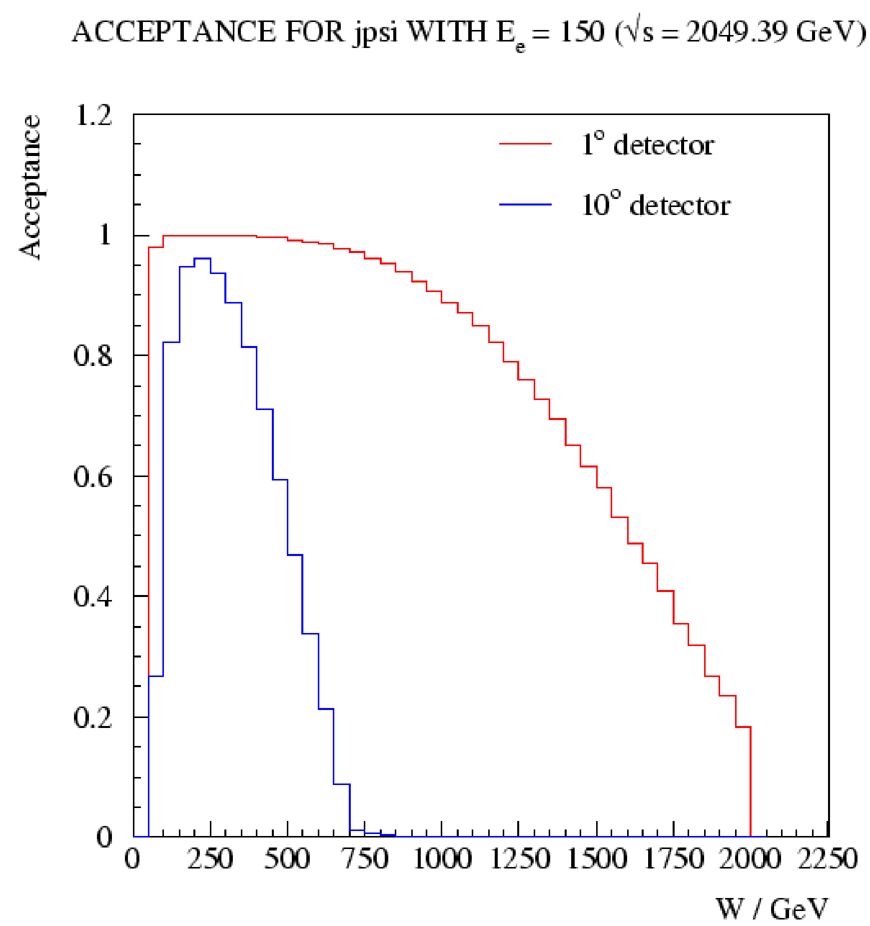
J/Ψ in Ring-Ring and Linac-Ring Scenarios



As Ee increases, leptons pushed further and further into outgoing electron beam direction (losing high W acceptance)

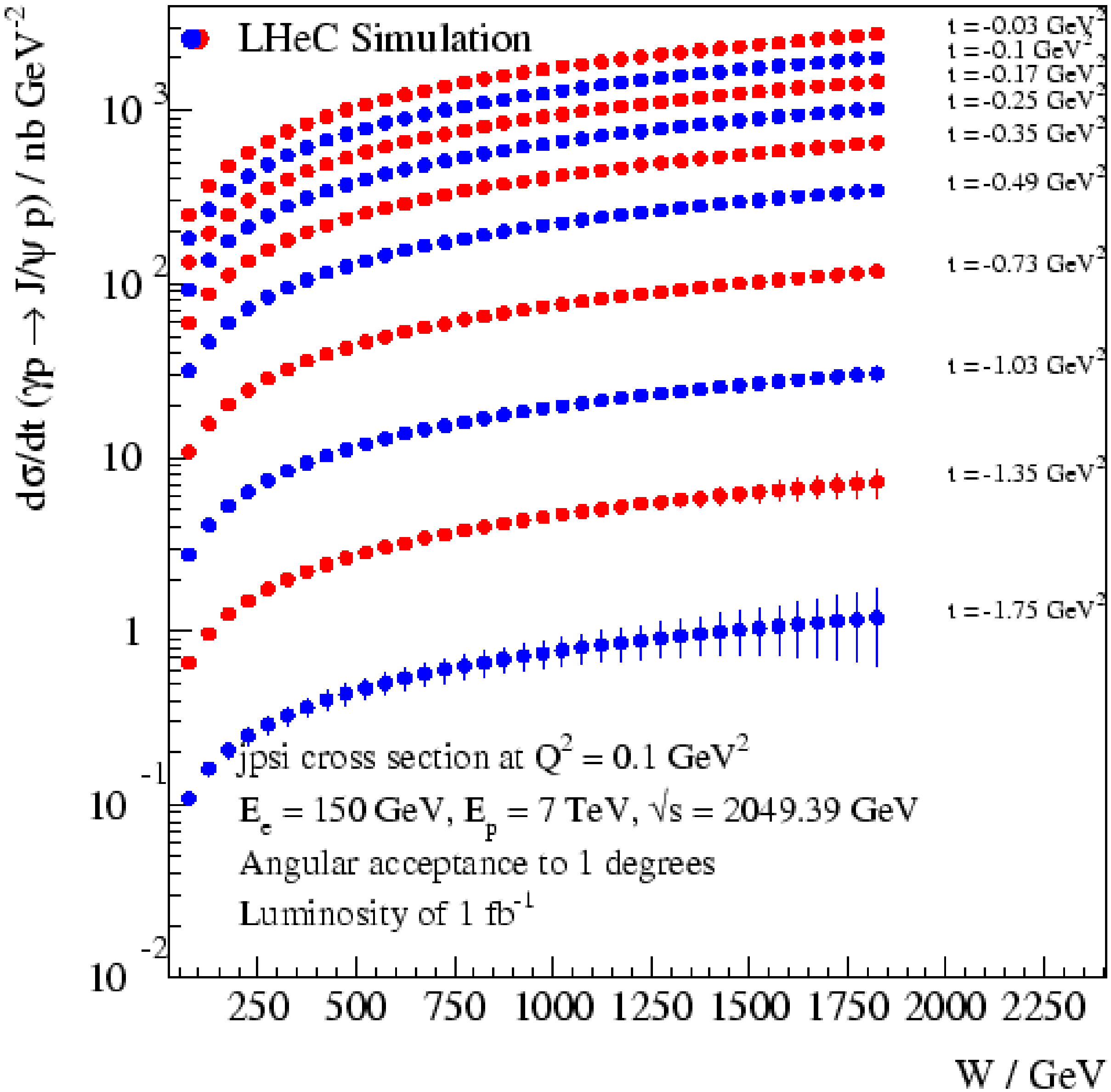
Ring-Ring and Linac-Ring J/Ψ Scenarios





For a limited (170°) backward, geometrical acceptance in W
Does not improve at large E_e!
Acceptance high at large E_e to kinematic limit for $\theta < 179°$

Dedicated Low x Linac-Ring Scenario



Dream scenario!!!

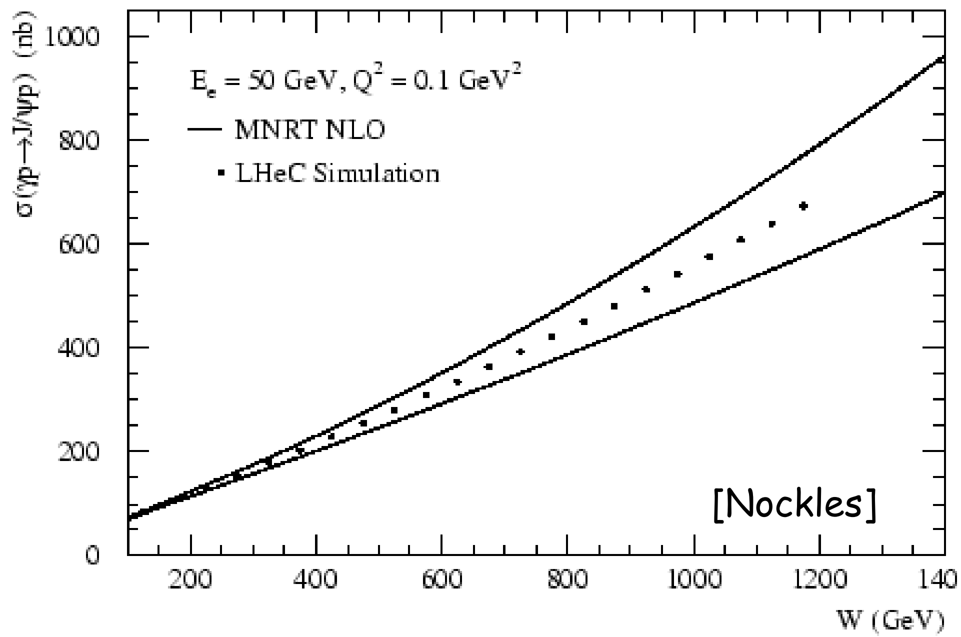
J/ψ photoproduction double differentially in W and t,
E_e=150 GeV
1° acceptance

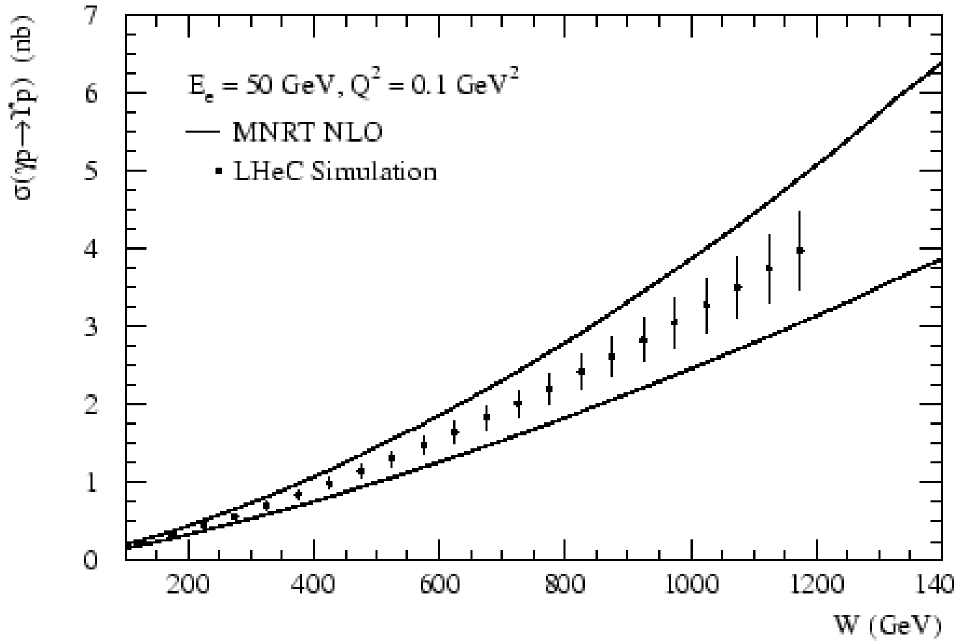
Probing x ~ 3.10^{-6} at Q^2 ~ 2.5 GeV^2

c.f. GB-W model x_s ~ 7.10^{-6} at Q^2 ~ 2.5 GeV^2

☺

Some First Model Implementations





- MNRT (2 gluon) model … results of fits to HERA J/Ψ data for gluon density extrapolated into LHeC range

- Pseudo-data statistical errors well within error bands (also differentially in Q^2) … Good LHeC constraints on model

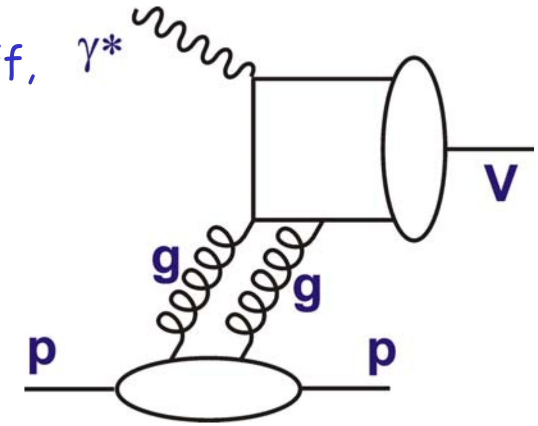
→ Compare with other models / extrapolations?
→ Fit pseudo-data to find achievable precision on low x gluon

Dipole Model of J/ψ Photoproduction

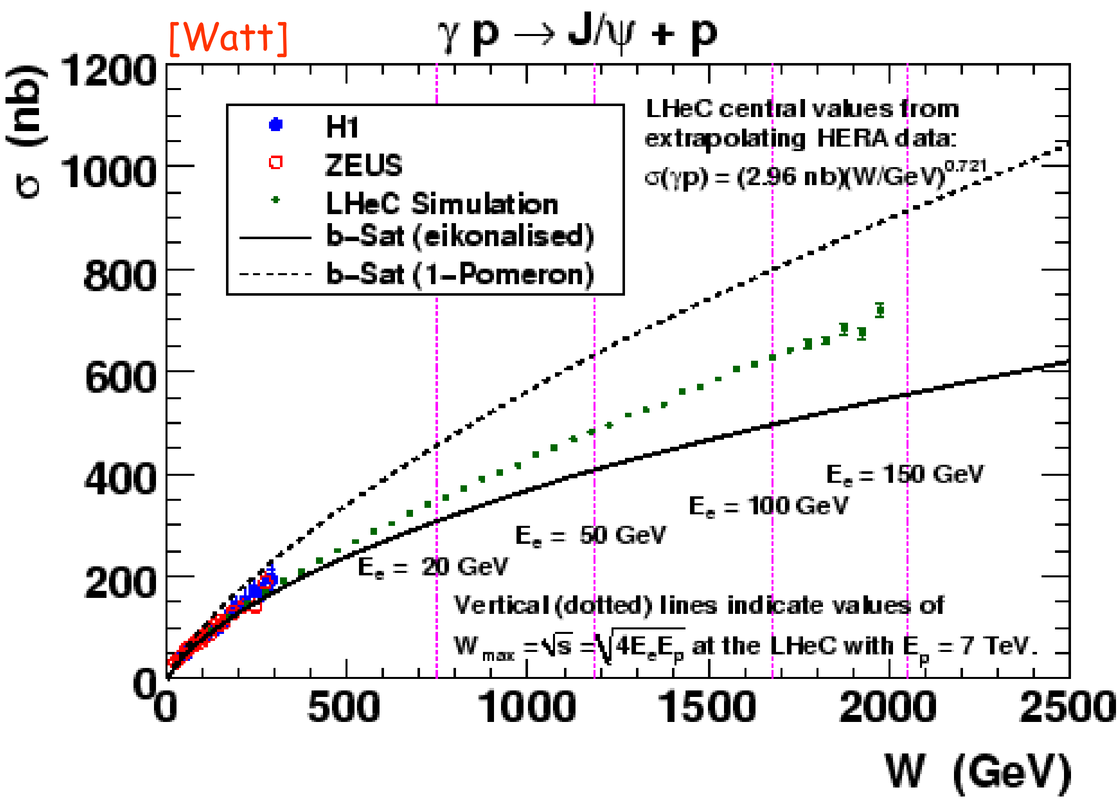
e.g. "b-Sat" Dipole model [Golec-Biernat, Wuesthoff, Bartels, Teaney, Kowalski, Motyka, Watt] ...

"eikonalised": with impact-parameter dependent saturation

"1 Pomeron": non-saturating



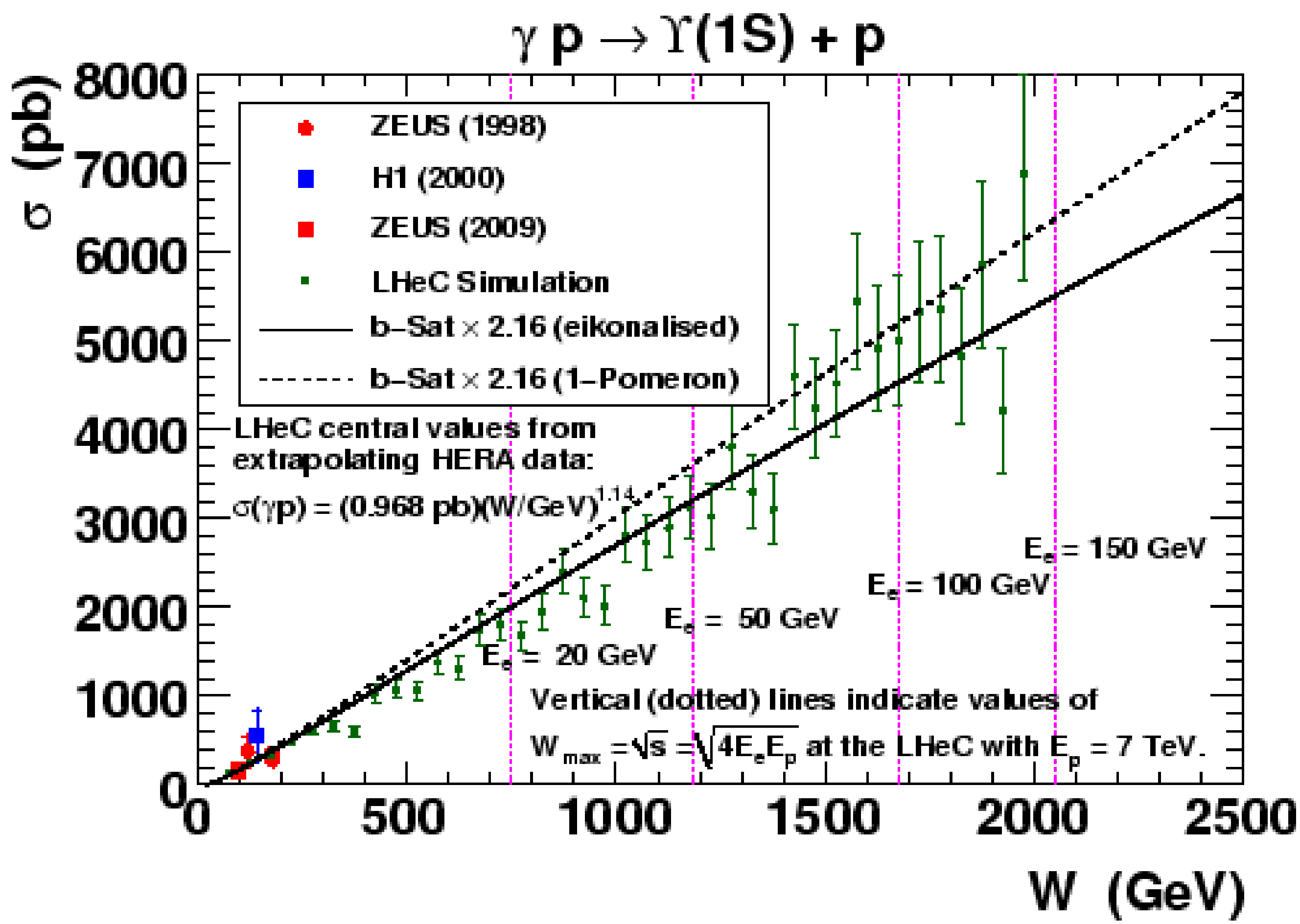
[Watt]



- Significant non-linear effects expected even for t-integrated cross section in LHeC kinematic range.
- Data shown are extrapolations of HERA power law fit for E_e = 150 GeV…

→ Sat^{n} smoking gun?

Similar Study for Upsilon



Saturation effects smaller for Upsilon than for J/psi (smaller dipole sizes and higher x).

Cross sections also much smaller.

Not so promising for non-linear effects, but tests many things!

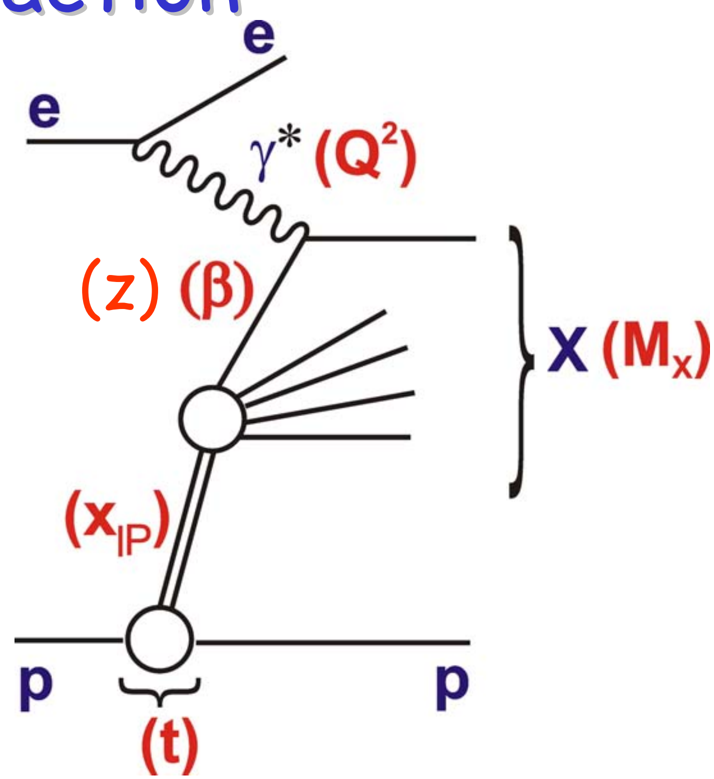
Inclusive Diffraction

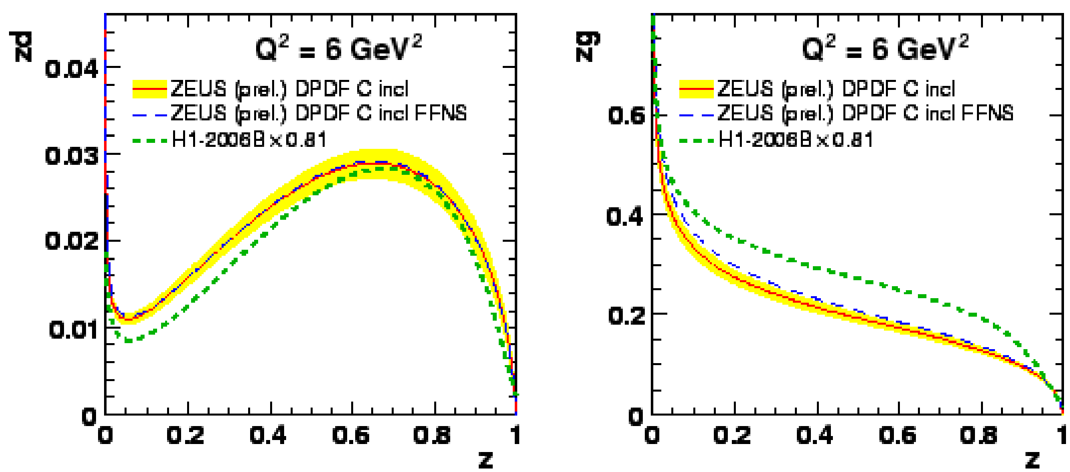
Additional variables …

x_{IP} = fractional momentum loss of proton (momentum fraction IP/p)

$\beta = x / x_{IP}$ (momentum fraction q / IP)

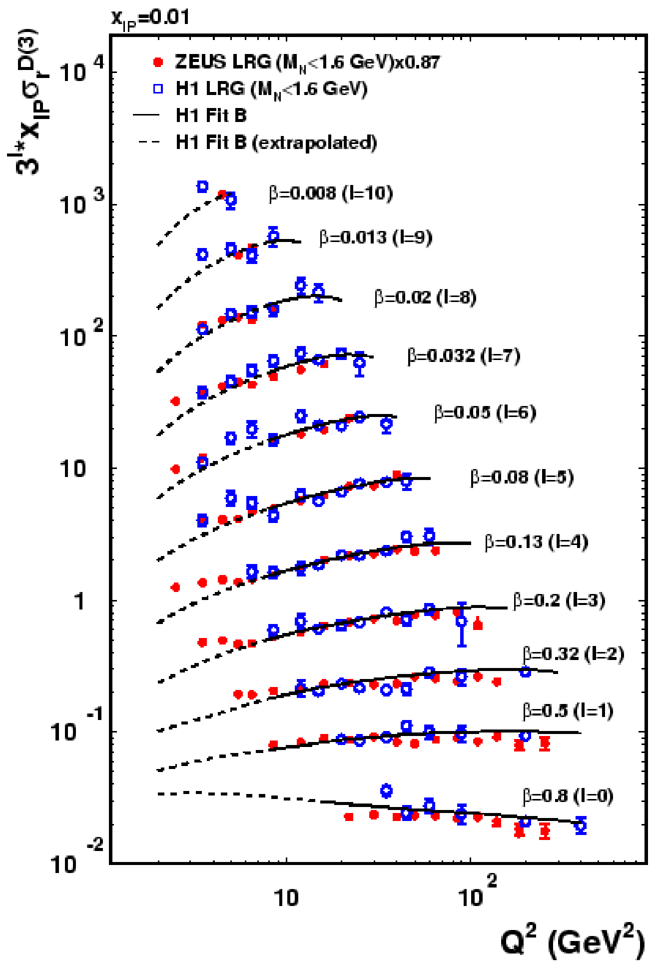
… both obtained from Mx



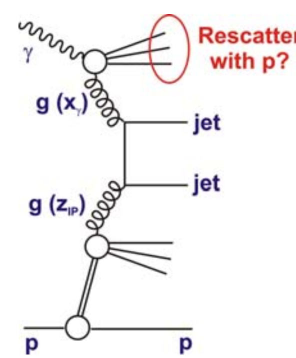


QCD analysis leads to diffractive parton densities of the proton

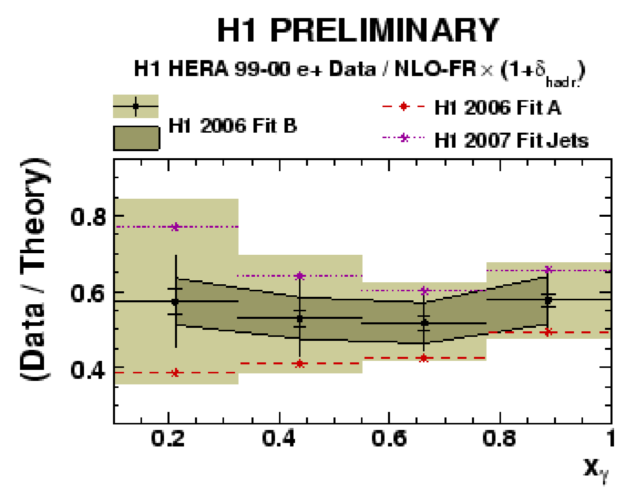
Inclusive Diffraction @ HERA



- Unexpectedly big story @ HERA
- Diffractive parton densities and factorisation now 'mature' subject
- Sensitivity to non-linear effects
- Rapidity gap survival dynamics



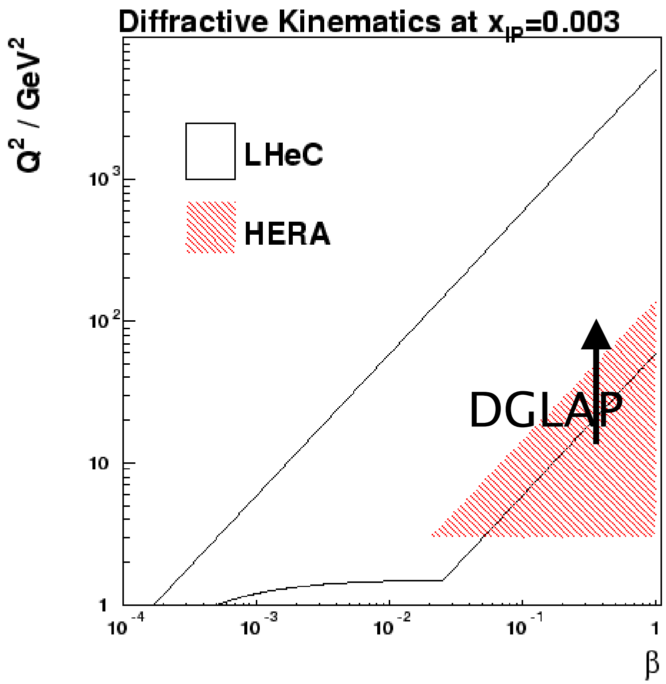
Still some unexplained features …

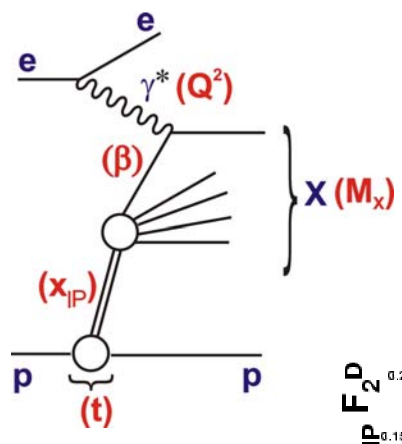


→ Low Q^2 flattening of F_2^D?

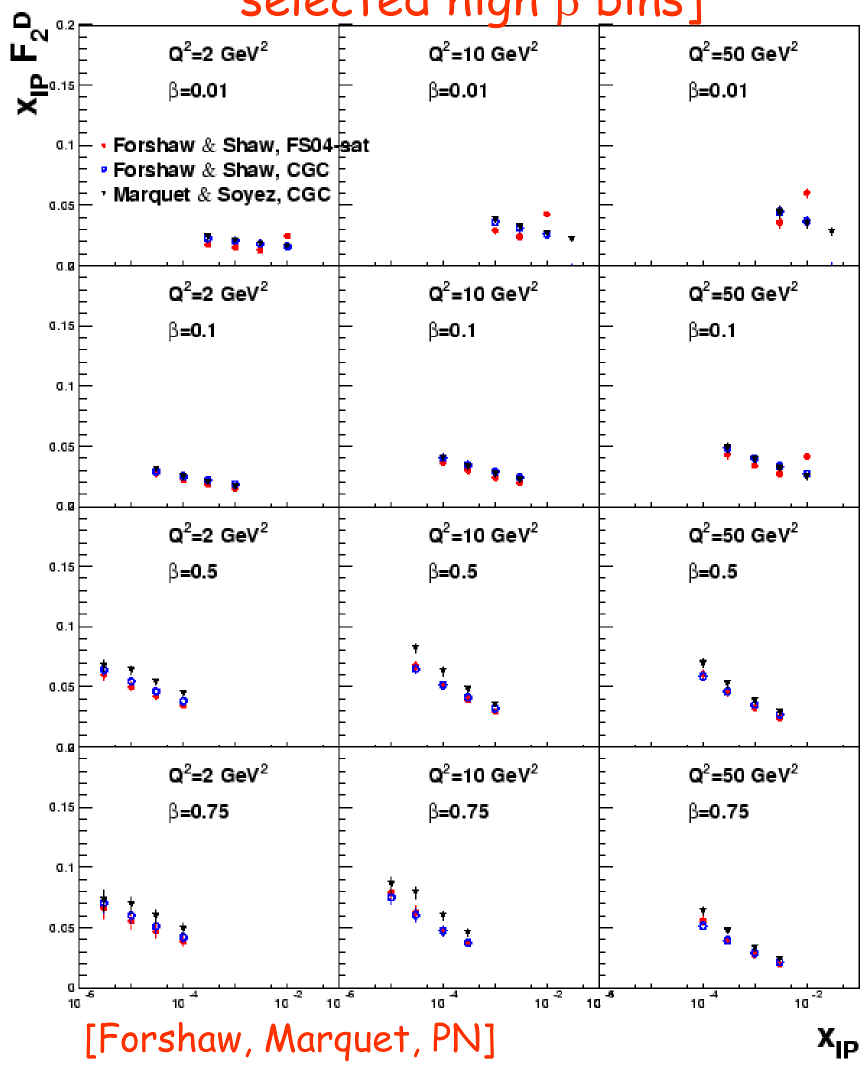
→ Anomalous survival probabilitiy in resolved photoproduction?

Previous LHeC Pseudo-data





[1° acceptance, 1 fb^{-1}, E_e = 70 GeV, selected high β bins]

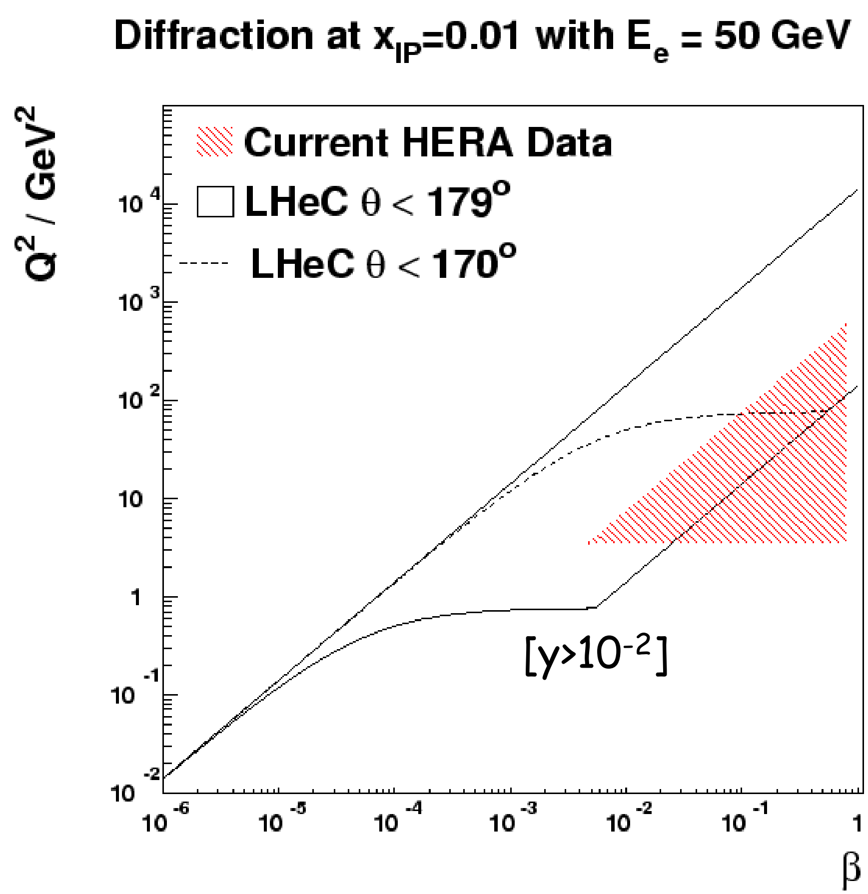


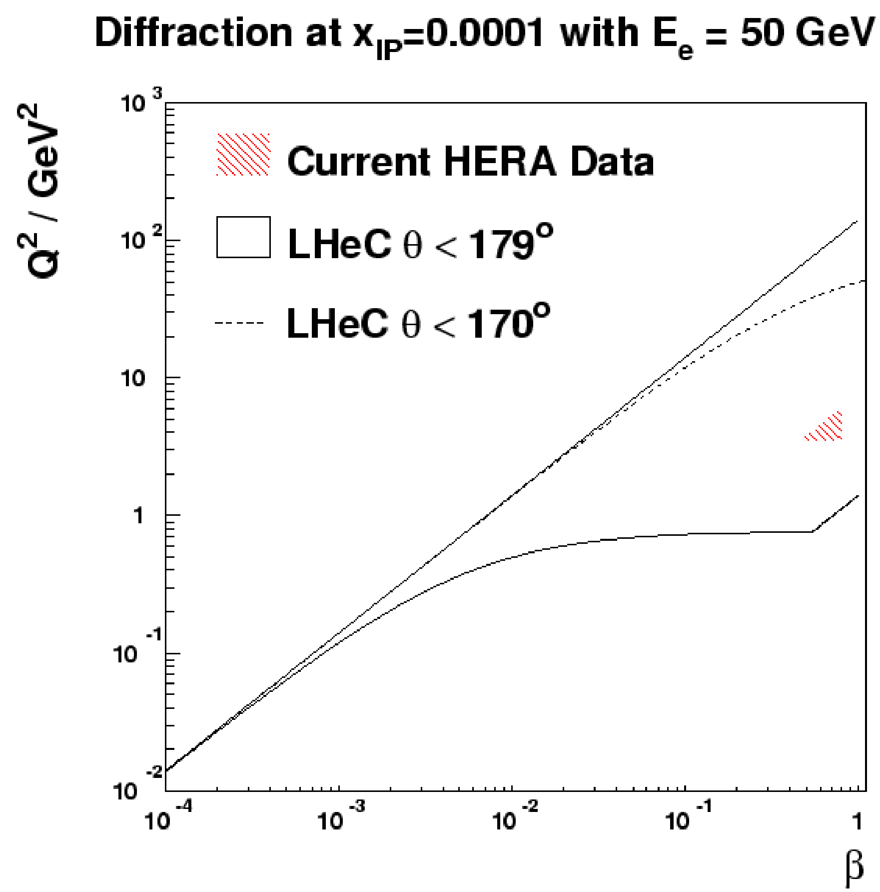
[Forshaw, Marquet, PN]

... Statistical precision <1%, systs 5-10% depending strongly on forward detector design

... first comparisons made with extrapolated dipole models

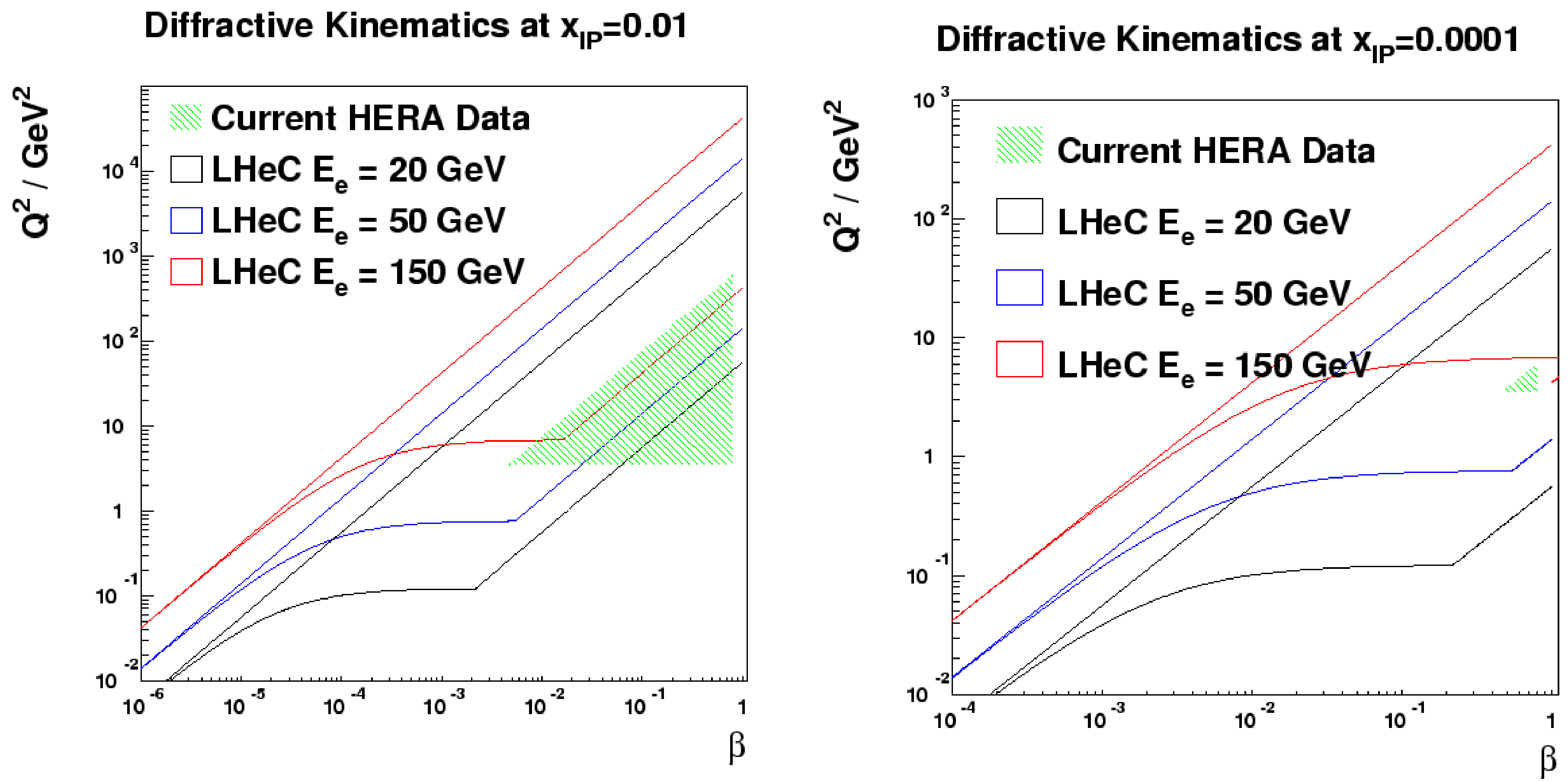
Diffractive Kinematic Plane at 50 GeV





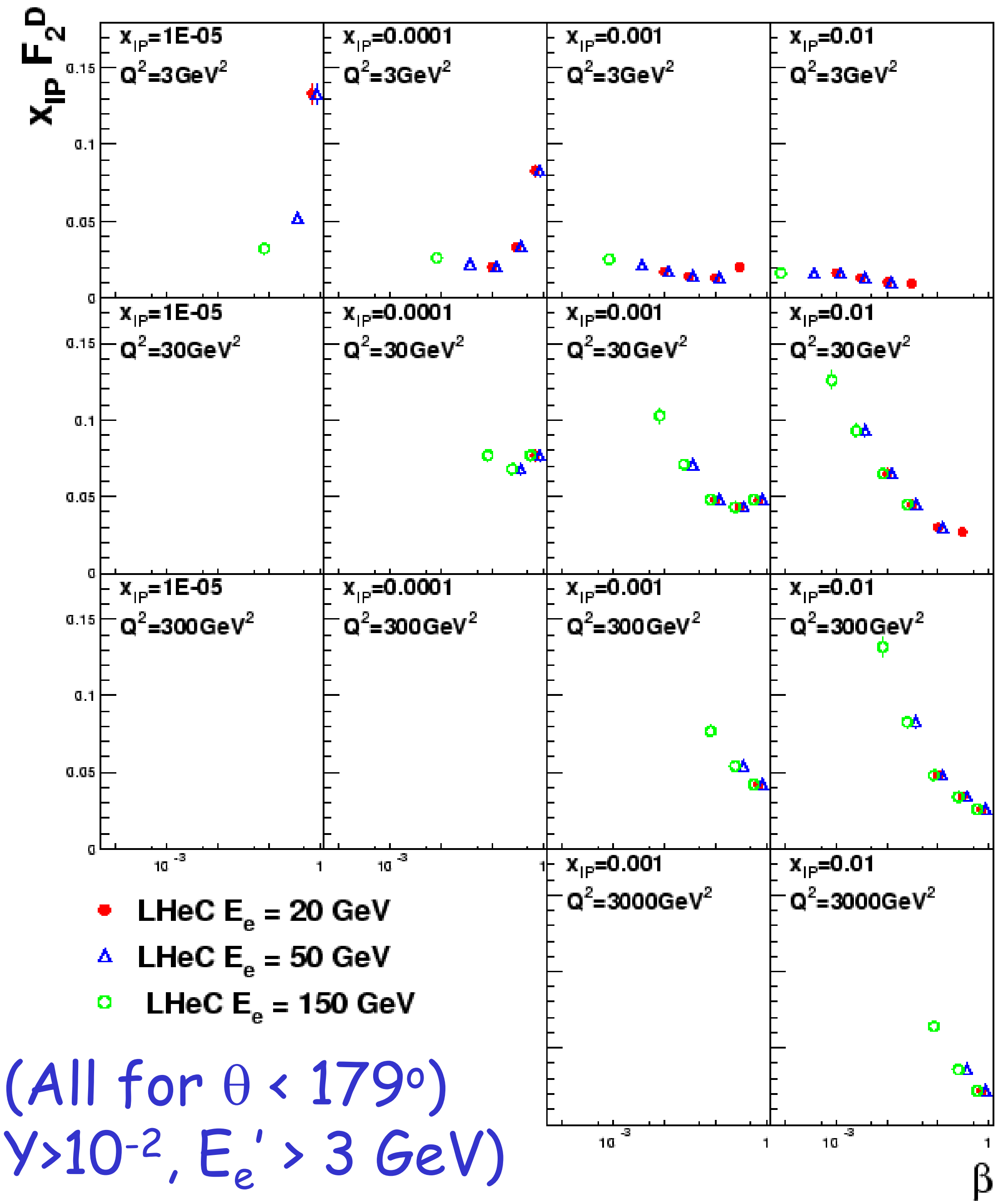
- Similar story to the inclusive case … low β at fixed x_{IP} if we have good enough e acceptance
- Whole new regions (e.g. low x_{IP}) open up
- … but limited gain over HERA with θ < 170°

Diffractive Kinematic Plane at LHeC



Higher E_e yields acceptance at higher Q^2 (pQCD),
Also lower x_{IP} and β

New pseudo-data



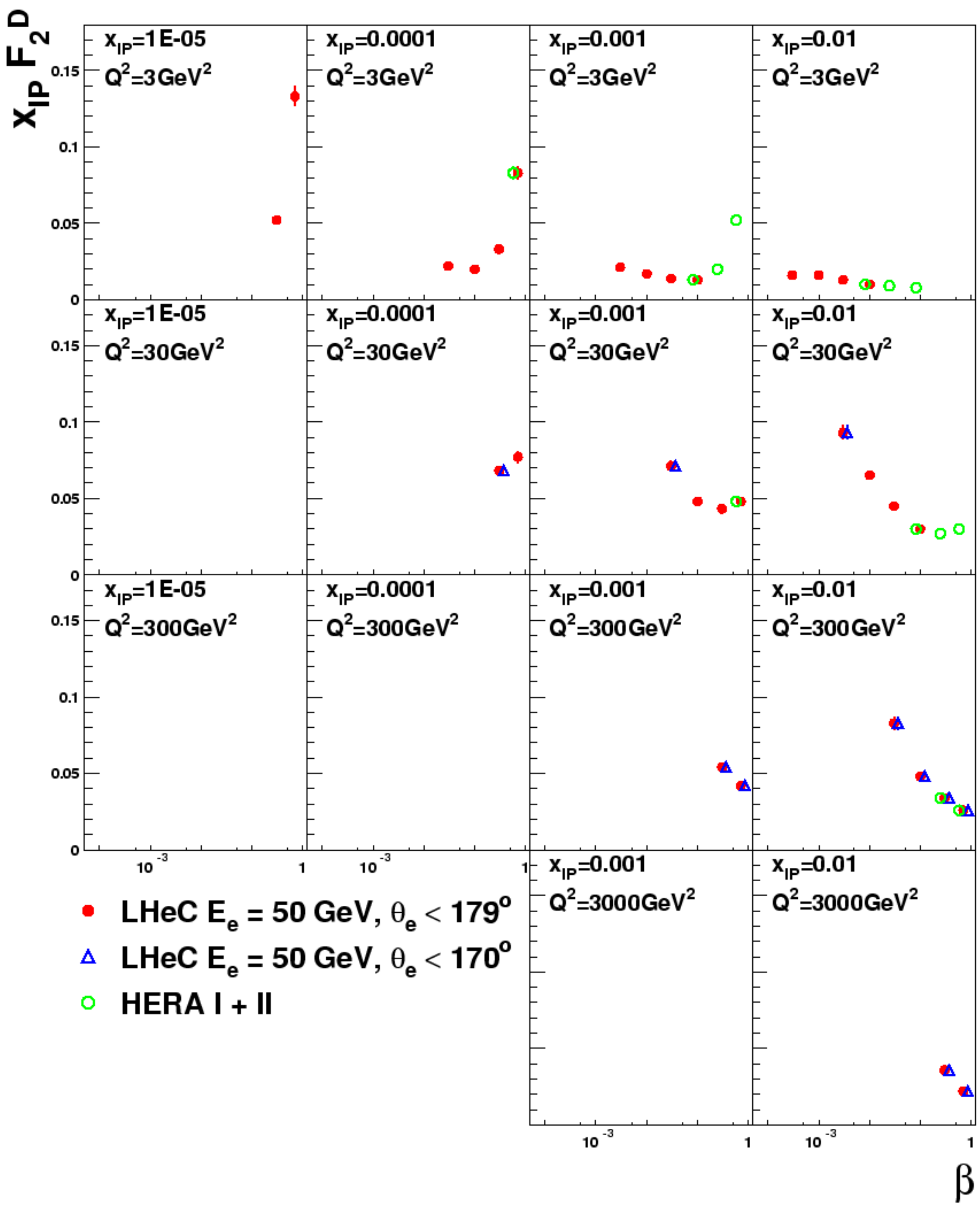
(All for θ < 179°)
$y>10^{-2}$, E_e' > 3 GeV)

Produced for all 6 scenarios, including eA

Binning easily modified → currently designed to emphasise β dependence in 4 wide x_{IP} bins and 4 wide Q^2 bins

Statistical precision not an issue … phase space runs out before data

Sysytematics fixed to 5% guesstimate.



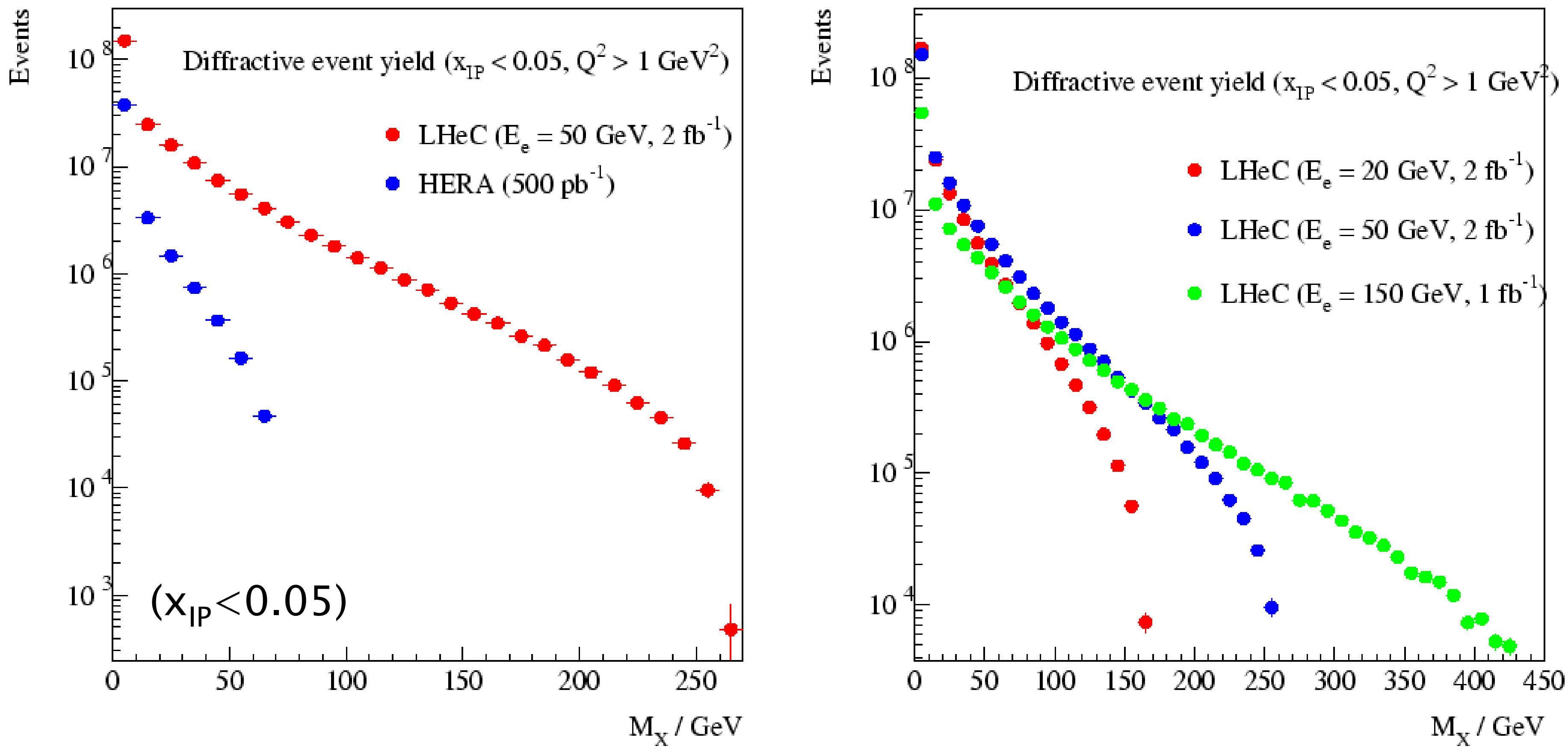
New pseudo-data

- With θ < 170°, limited coverage, separated from HERA range

- With θ < 179°, 50 GeV data overlap nicely with HERA and extend to lower β, lower x_{IP} and higher Q^2

New region of Diffractive Masses

Large x_{IP} region highly correlated with large Mx

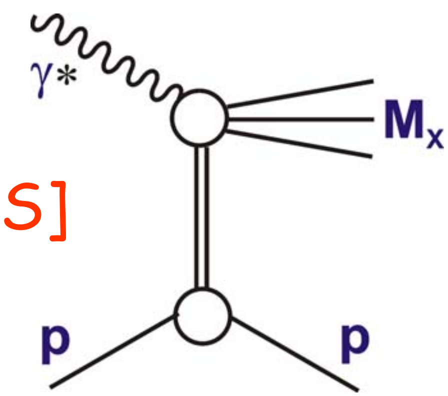


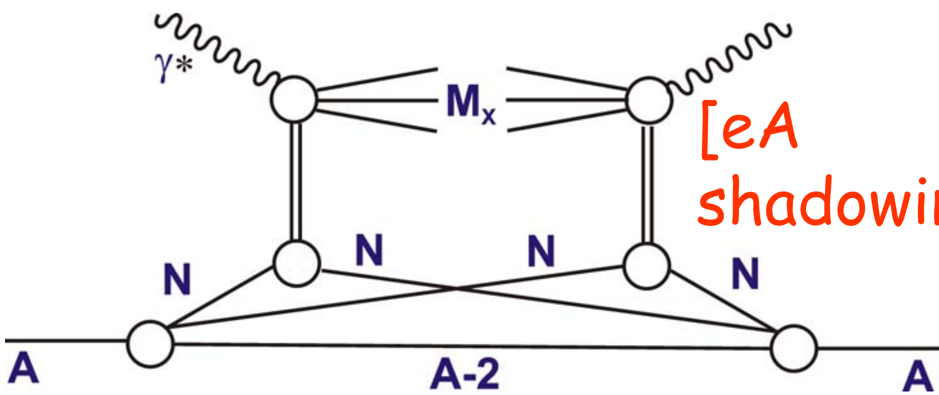
- \`Proper' QCD (e.g. large E_T) with jets and charm accessible
- New diffractive channels … beauty, W / Z / H(?) bosons
- Unfold quantum numbers / precisely measure new 1^- states

Inclusive Diffraction and the ep / eA Interface

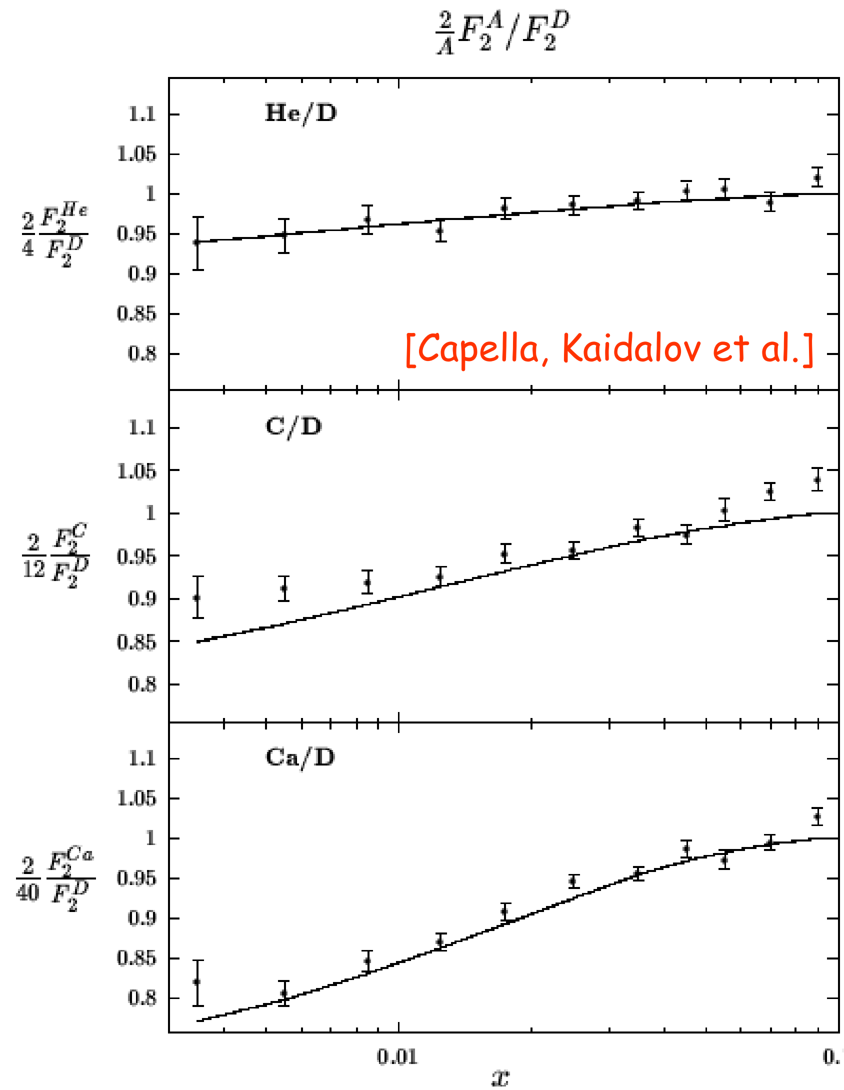
Nuclear shadowing can be described (Gribov-Glauber) as multiple interactions, starting from ep DPDFs

[Diff DIS]



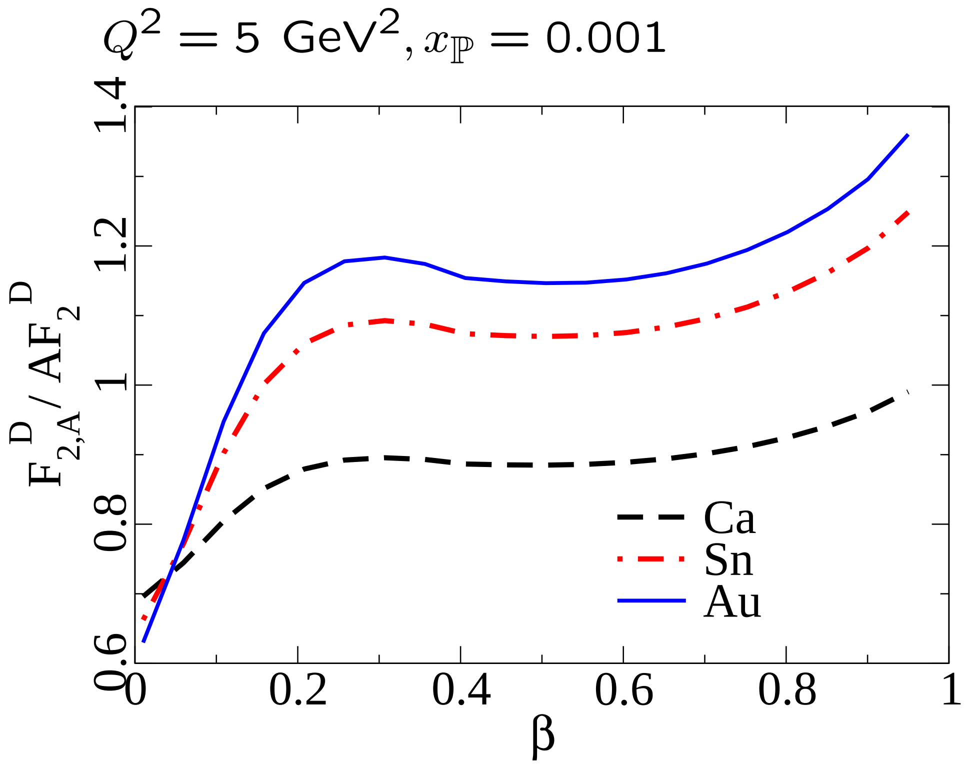


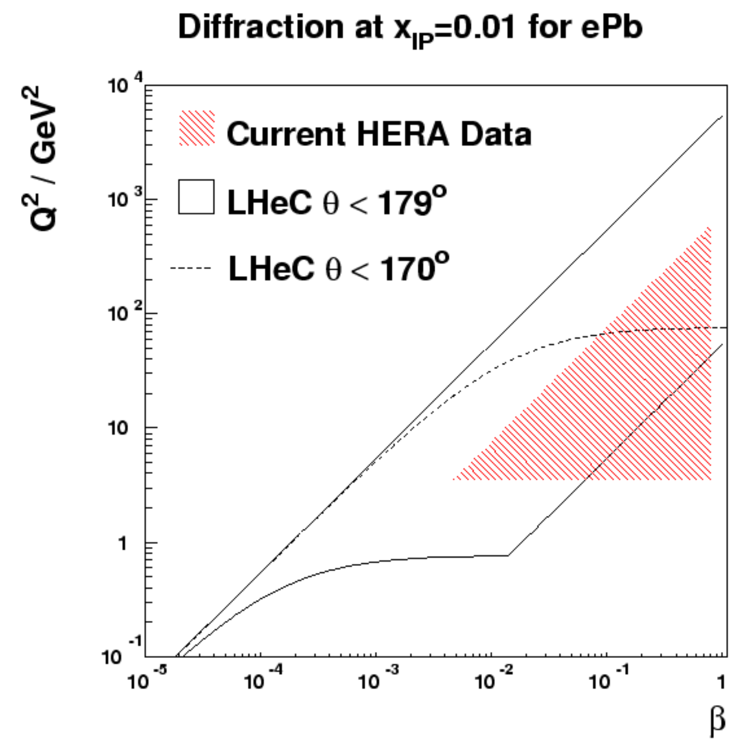
[eA shadowing]



… starting point for extending precision LHeC studies into eA collisions

Diffraction in eA





Dipole based model now exists for nuclear (anti-) shadowing in diffraction [Kowalski, Lappi, Marquet, Venugopalan]

→ Nuclear effects give high β enhancement (qqbar dipole)

→ Nuclear effects suppress low β (qqbarg dipole)

… More in Henri's talk.

→ Compare Predictions here (and others?) with pseudo-data

Where to Find the Pseudo-Data (soon!)

The LHeC and Physics at High Parton Densities

The working group on `Physics at High Parton Densities (ep and eA)' plans to explore new opportunities in low x physics at the LHeC with electrons scattering on protons and heavy ions. If you are interested in participating in these studies, please contact the convenors as soon as possible.

Previous studies at HERA, RHIC and the Tevatron have shown gluon and sea quark densities which grow fast as x decreases, leading to questions of unitarisation, parton recombination, the Colour Glass Condensate and other novel strong interaction dynamics. As yet, however, no clear picture has been established. The previously unexplored LHeC low x kinematic region (reaching $x \sim 10^{-6}$ at $Q^2 \sim 1$ GeV^2) could provide a clear understanding of physics at high parton densities in a kinematic region to which perturbative techniques may be applied. Some topics for possible study are listed below. We welcome further suggestions!

- *Measuring F_2 and F_L in low x ep and eA Collisions* (some first simulated data)
- *Nucleon PDFs at small x*
- *Nuclear PDFs*
- *Resummation at Low x*
- *Non-linear Evolution Equations*
- *Observing the onset of Parton Saturation in ep Physics*
- *The Dipole approach to Low x Physics*
- *Geometric Scaling*
- *Theory of High Density QCD at eA Colliders*
- *Mueller-Navelet Jets and Other `Forward' Observables*
- *Describing Low x Evolution Dynamics (DGLAP, CCFM, BFKL ...)*
- *Monte Carlo modelling at Low x*
- *Measuring Vector Meson and DVCS Processes*
- *Generalised Parton Densities*
- *Measuring Diffractive DIS (Rapidity Gaps and tagged protons)* (some first simulated data)

- *Theory of Diffractive DIS and Diffractive Factorisation*
- *Multiple Interactions and Rapidity Gap Survival*
- *Leading Neutron Measurements*
- *Heavy Flavour Measurements as Low x Probes*
- *Quark Fragmentation*

(http://www.lhec.org.uk/lowx.html)

Summary

New round of pseudo-data available for ep and eA inclusive diffraction and heavy vector mesons

Systematics still to be included … discussions with detector group needed to get an idea of them

Diffractive jets and charm still not studied

Light vector mesons could also be simulated if their is an interest

No progress since 2008 on DVCS … but should be a major topic for us

Please use the pseudo data and have fun ☺

Back-Ups Follow

Statistical Precision

Take one bin for every 50 GeV in W

To crudely predict numbers of events per bin …

- Assume a similar measurement to HERA

- $Q^2 < 2$ GeV^2 … only see 2 muons in detector

- Simple $\gamma^{(*)}p$ cross section parameterisation:

$$\sigma(\gamma p \rightarrow Vp) = \sigma_0 \,.\, W^{\delta} \,.\, e^{bt}$$

- Fix $\delta = 0.75$ (J/ψ) and 1.00 (Υ)
  $b = 4.5$ GeV^{-2}
  σ_0 by normalising to HERA data

- Convert to ep cross section with photon flux from Weizsaecker-Williams approximation

Corrections and Systematics

Require geometric acceptance above 30%

Assume selection efficiency = 50% (20-40% at HERA)

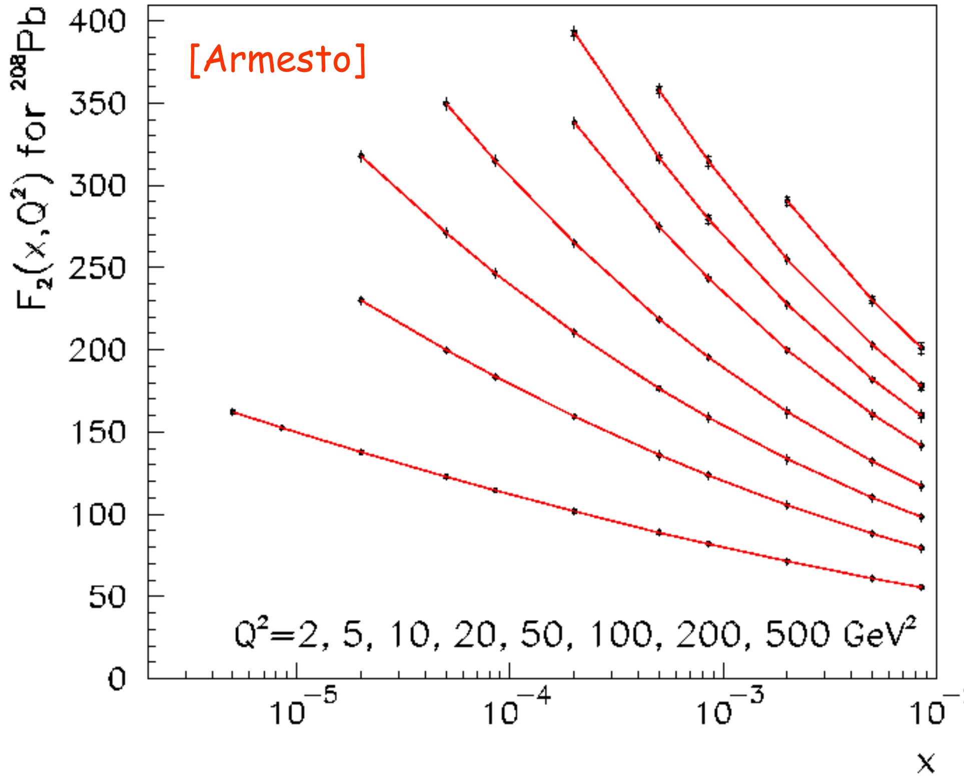
Correct for branching ratios to $\mu\mu$ (ee results would be similar, possibly except for detector acceptance)

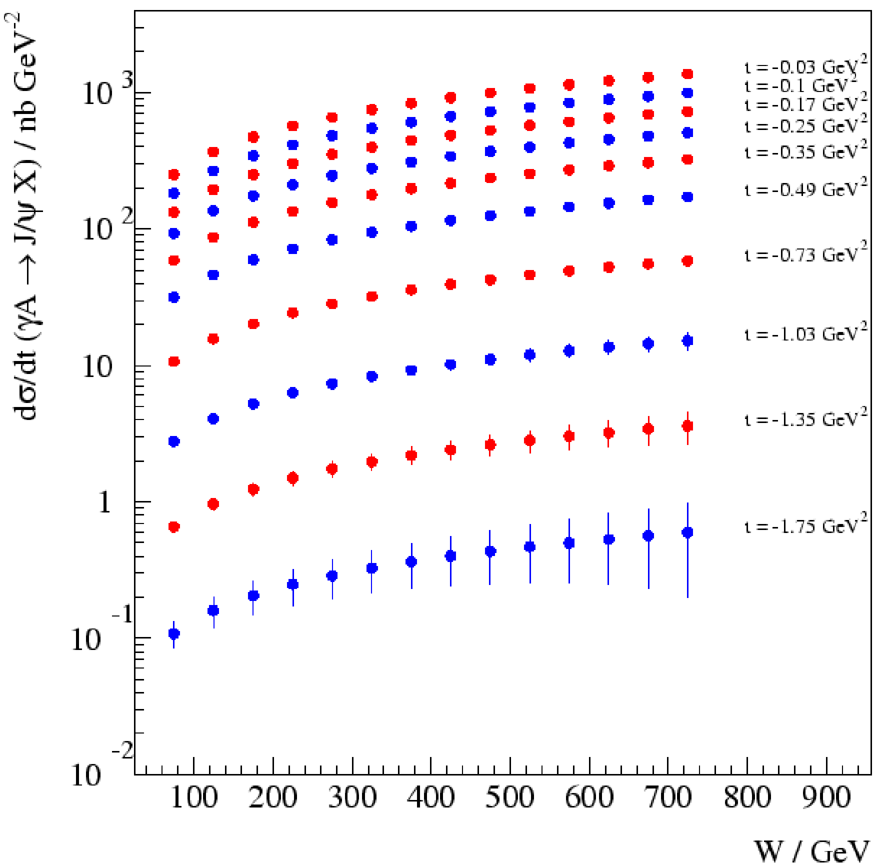
Systematics not yet included (depend heavily on detector), but some hints from HERA:

- → Total syst ~ 10% (fairly correlated between bins)
- → Trigger efficiency ~ 5%
- → Selection efficiency ~ 5%
- → Proton dissociation corrections ~ 5%
- → Model dependences on geometric acceptance ~5%
- → Lumi ~ 2%
- → Branching ratio ~ 2%

First ePb Simulations (Ee = 50 GeV, 2 fb^{-1})

Precise inclusive data over vast new eA kinematic range





Very promising J/ψ cross section: to $W_{\gamma p}$ ~ 700 GeV and t > 1 GeV^2 … well within expected saturation region