Discussion Points on Detector Requirements for low x / high parton density physics

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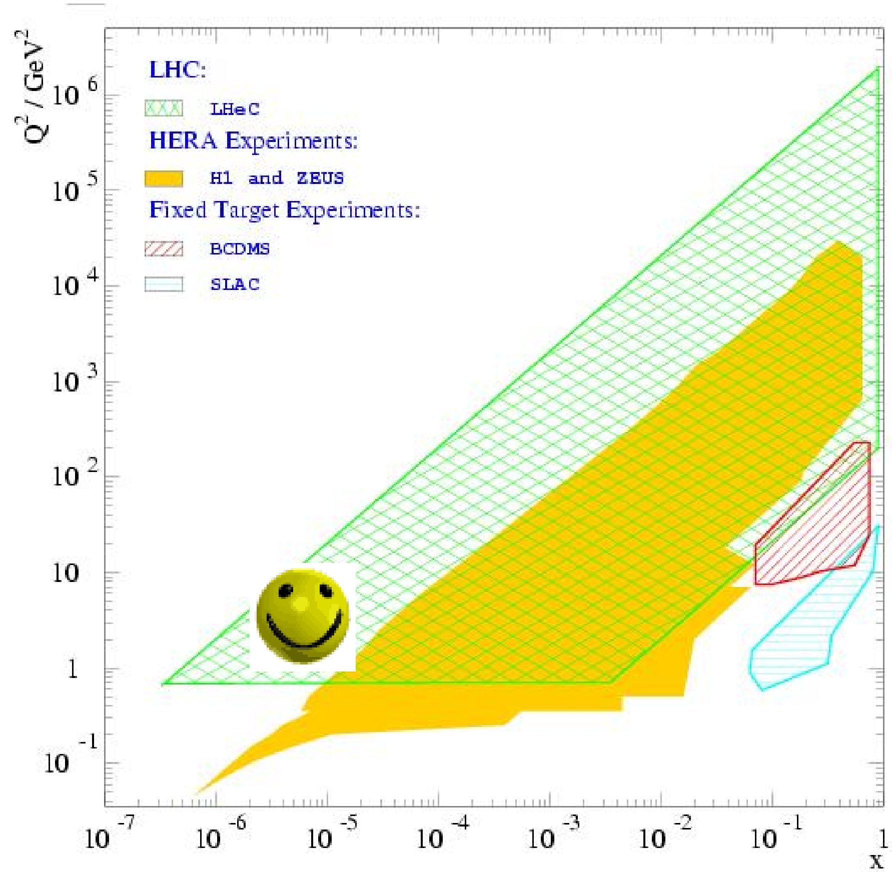
with Nestor Armesto, Brian Cole, Anna Stasto and the low x working group

LHeC @ Divonne
2/9/2009



1) Generalities
2) Inclusive scattering
3) Vector mesons
4) Inclusive diffraction
5) Beam-line detection (e, p, n)
6) Forward jets

Why this talk?

Using beam scenario and luminosity information, making simulated LHeC data points for model comparisons / fits.

- Correctly reflect kinematic range
- Have reasonable estimates of statistical precision
- … but only guesses at resolutions / binning / **systematics** mainly based on experience from HERA

… systs basically define our CDR, and depend crucially on detector design

… Time for more detailed cross-group discussion …

Here, raise a few of the questions faced by low x physics (mostly on acceptance, forward / backward instrumentation rather than detailed detector technologies)

Different requirements from other physics groups!

Scenario for Experimental Precision

To date, we worked with crude assumptions on systematics based on improving on HERA by a factor ~ 2

Lumi = 10^{33} cm^{-2} s^{-1}	(HERA 1-5 x 10^{31} cm^{-2} s^{-1})
Acceptance 10-170° (→179°?)	(HERA 7-177°)
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%)

First `pseudo-data' for F_2, F_L, F_2^D … produced on this basis
Now need to go further

→ More realistic approach to inclusive scattering

→ First serious look at systematics for diffraction and other final state measurements

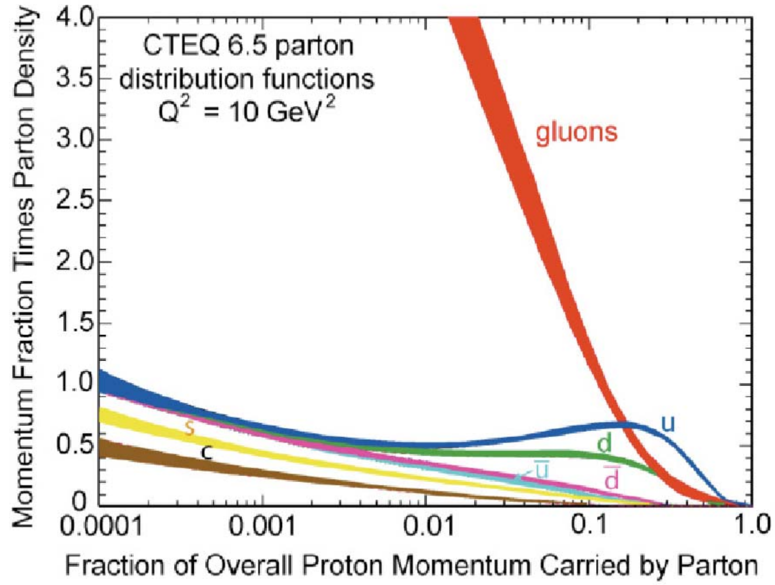
Current Scenarios for Physics Studies

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]

Studying sensitivity to new strong interaction physics at high parton densities for each of these scenarios

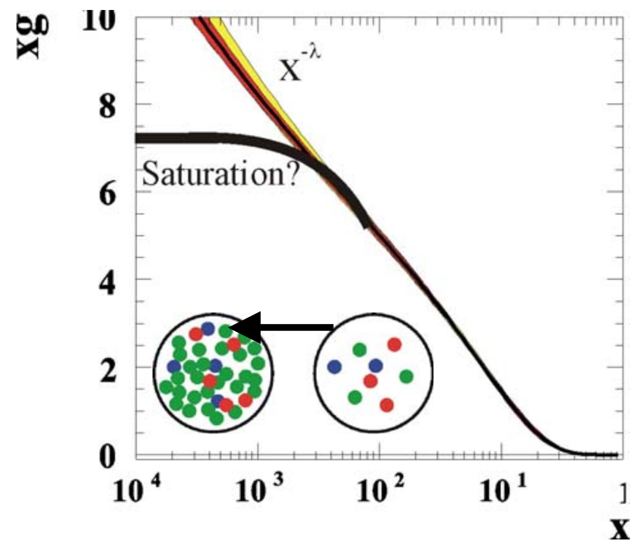
1) Inclusive DIS



- Low x physics is the physics of very large gluon densities… saturation / non-linear dynamics?

- To interpret in terms of quarks and gluons, need to reach very low x in perturbative domain

- Essential to compare ep with eA (~$A^{1/3}$ enhancement factor for nuclear parton denstities)



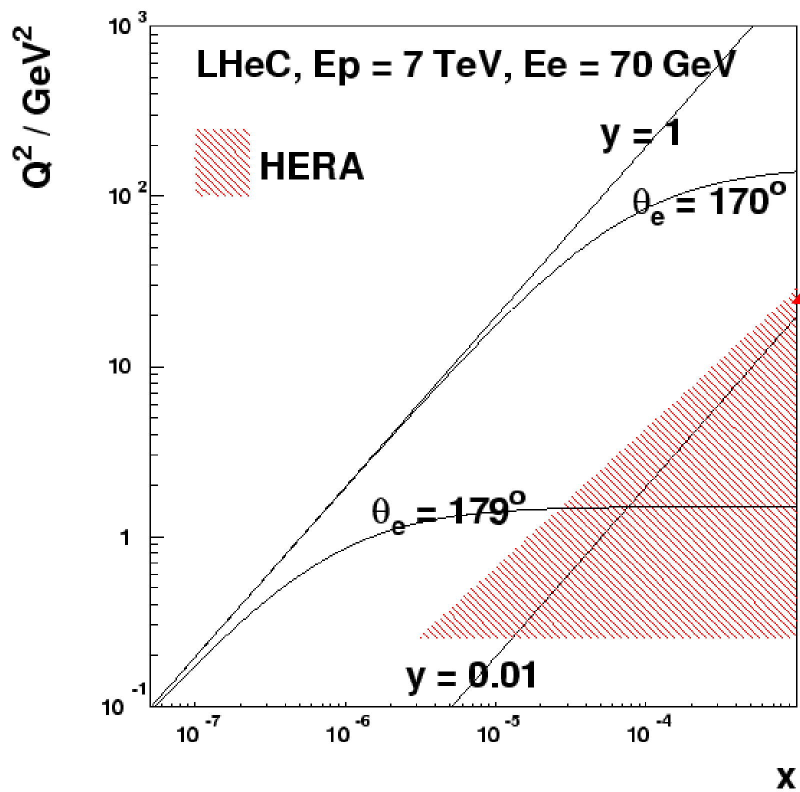
… high y, so can use electron kinematics, but hadrons also go backwards → often tough electron ID

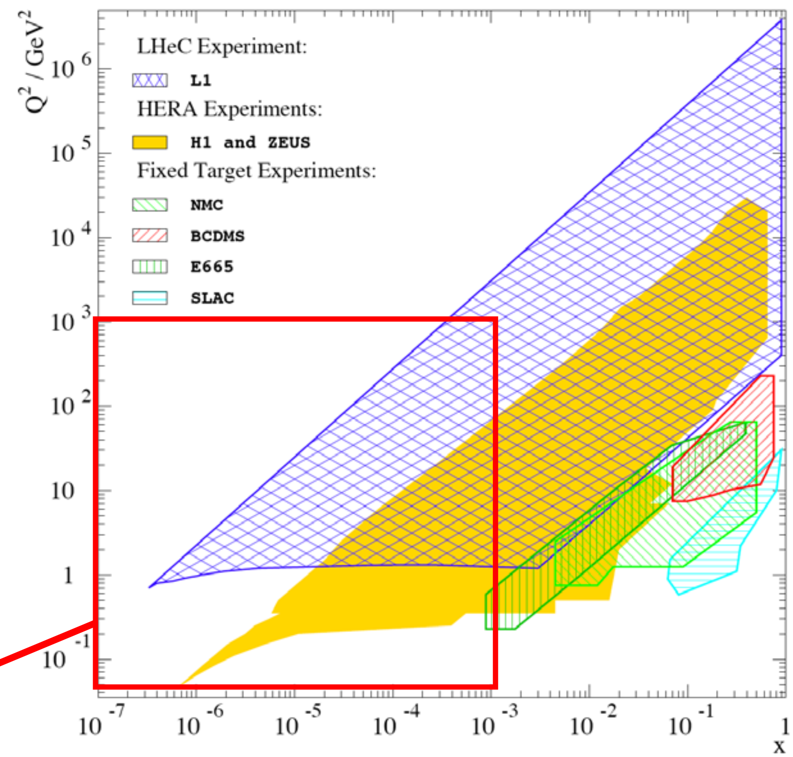
Principle requirement is in acceptance for scattered electron

Basic Kinematics / Acceptance

Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} IF we have acceptance to 179° (and @ low E_e')

Nothing fundamentally new in LHeC low x pnhysics with θ<170°



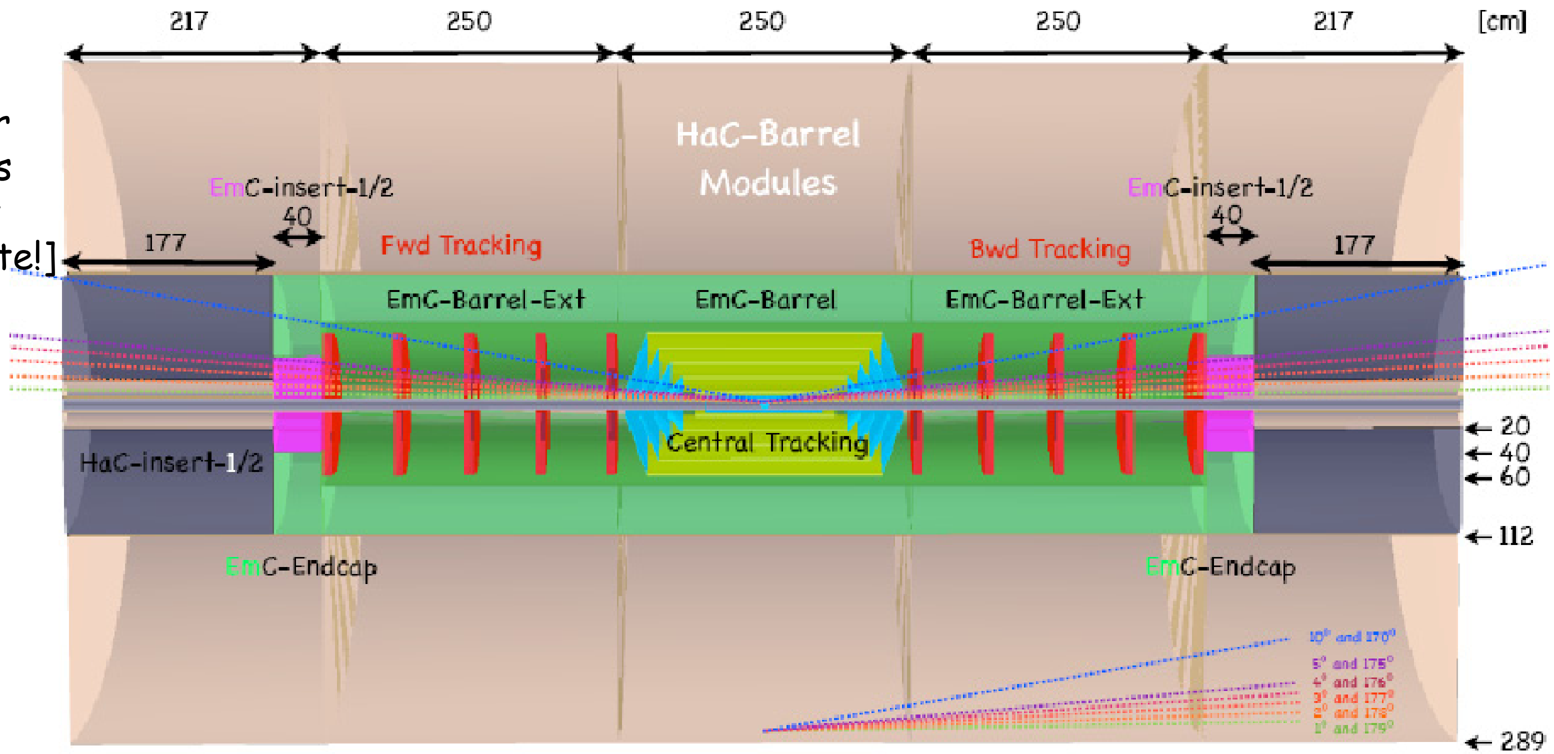


… luminosity in all scenarios ample for most low x processes

? Nothing sacred about 1° or 10°
… beyond 1° would be great!
… sth in between would need study

Low x Detector Design

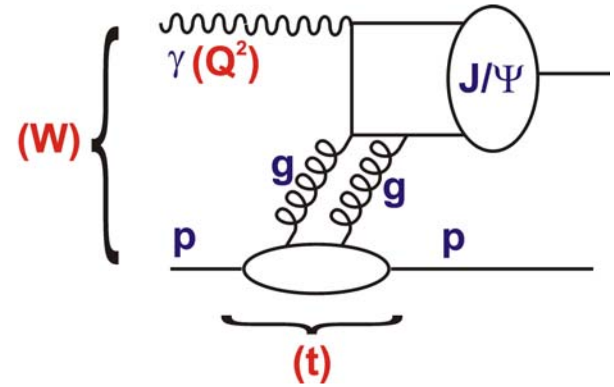
[Detector Convenors … already out of date!]



Need to translate specifications into physics studies …

- How many radiation lengths is backward EMC insert (defined by kinematic peak, which depends on E_e?)
- What about electron energy, angle resolution?
- Other ideas still alive? … 2 detectors? … Instrument inside beampipe? …Dipoles a la EIC? … Magcal?

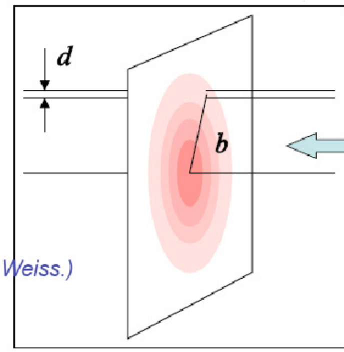
2) Vector Mesons



`Hard' diffractive processes such as heavy vector meson production are well modelled by exchange of 2 gluons … extra sensitivity to parton saturation

J/Ψ "golden channel" – higher cross section and probes lower x than Υ due to smaller mass

Extra variable (t) sensitive to impact parameter … by making t large, can probe densest, most central part of proton

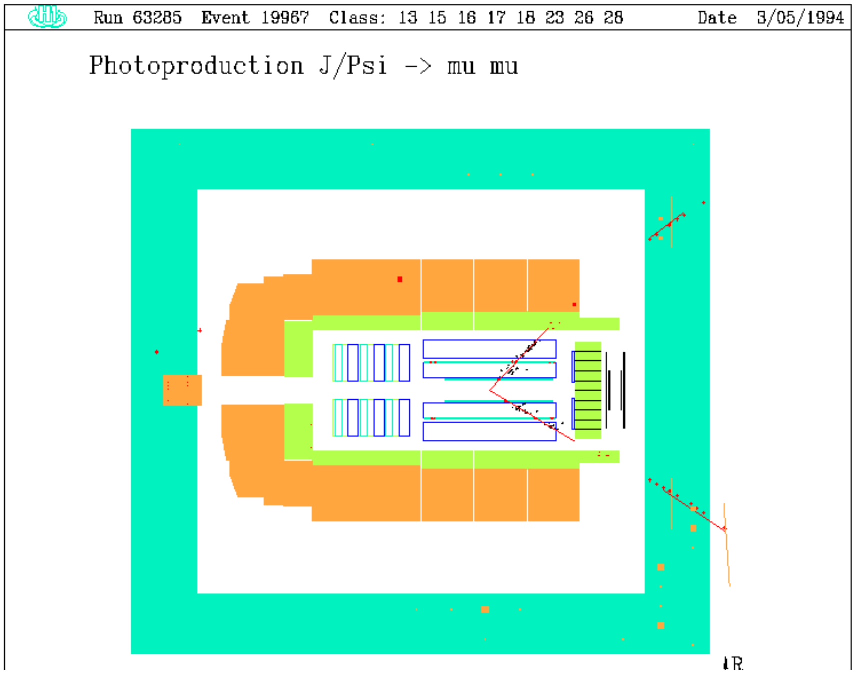


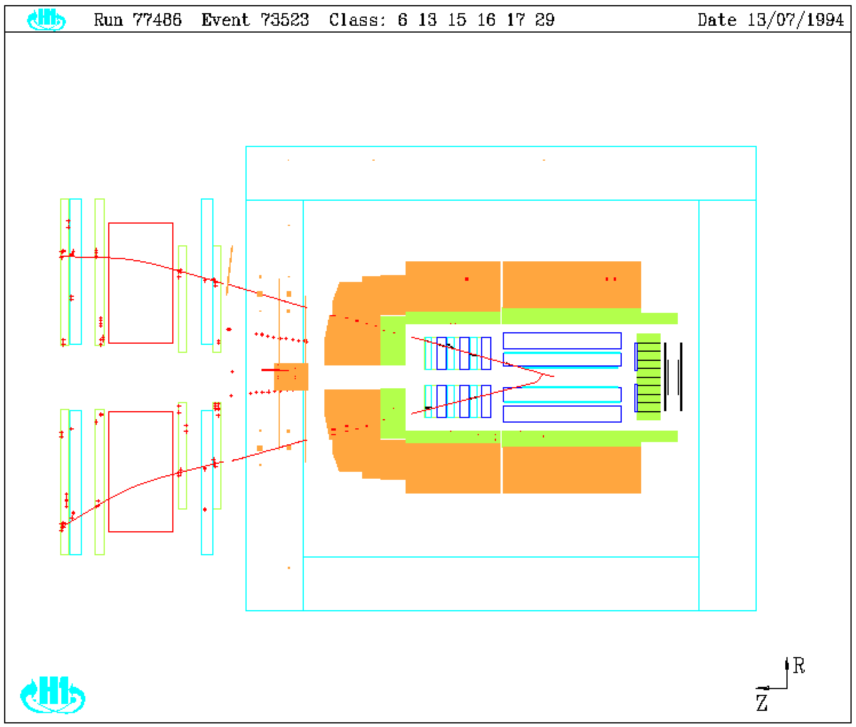
Central black region growing with decrease of x.

(figure from C. Weiss.)

Requirements:

- Acceptance for μ, e at high W (low x) in ep and eA
- Good t measurement (tracking / muon resolution)
- Good control of Detector noise





Vector Meson Signatures

Study J/Ψ, Υ via decays to e or μ pairs

High W (low x) events yield 2 backward going leptons

Low W (high x) events yield 2 forward going leptons

Can be studied in `untagged' photoproduction ($Q^2 \rightarrow 0$) … event otherwise empty

Also at larger Q^2, with scattered electron visible

Vector Meson Simulations

First simulations to look at acceptance and statistics

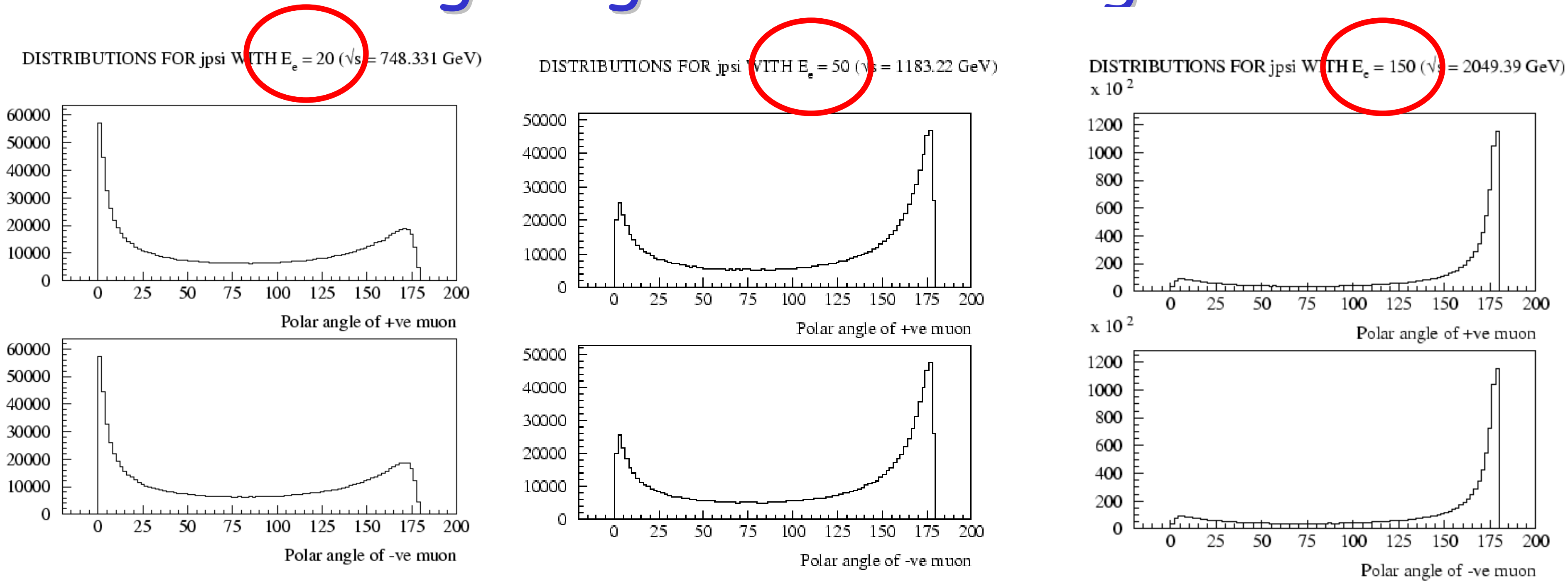
Systematics not yet included (depend heavily on detector),

Systematics on cross section 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%

$t = p_t^2(\mu 1 + \mu 2)$ … measurement presicion depends mainly on tracking resolution. → Need to define that as $f(\theta)$

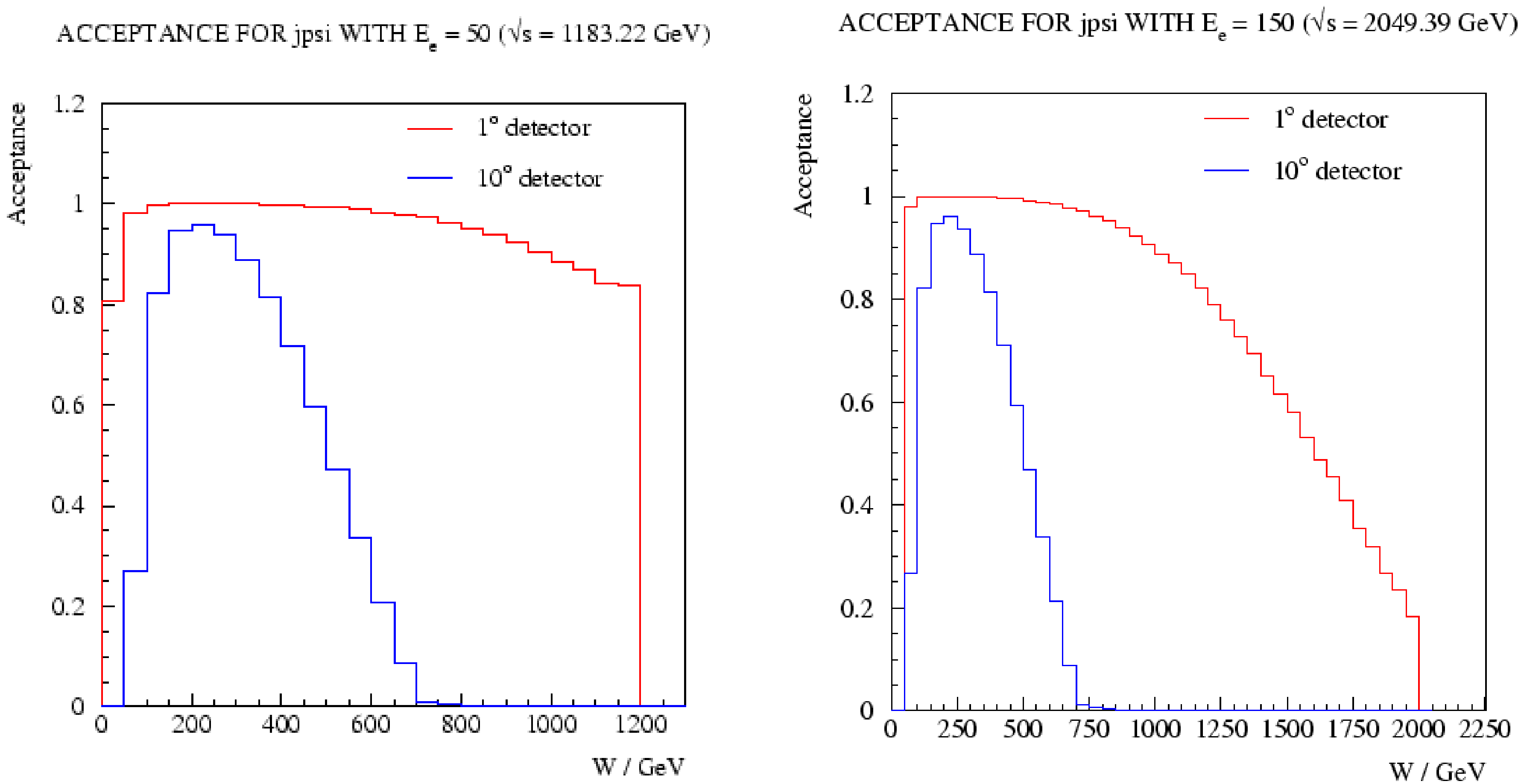
J/Ψ in Ring-Ring and Linac-Ring Scenarios



As Ee increases, outgoing leptons move further and further backward (losing acceptance at high W / low x)

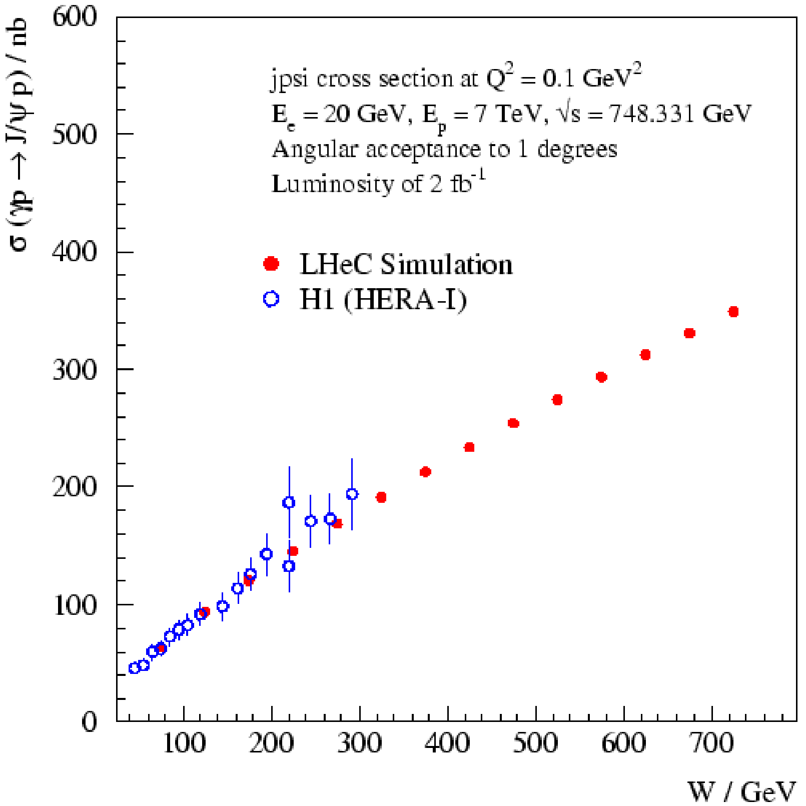
? Acceptance limit for μ?... place behind focusing magnets?
? How much multiple scattering in focusing magnets?...
? What sort of tracking precision at high θ (t measurement)

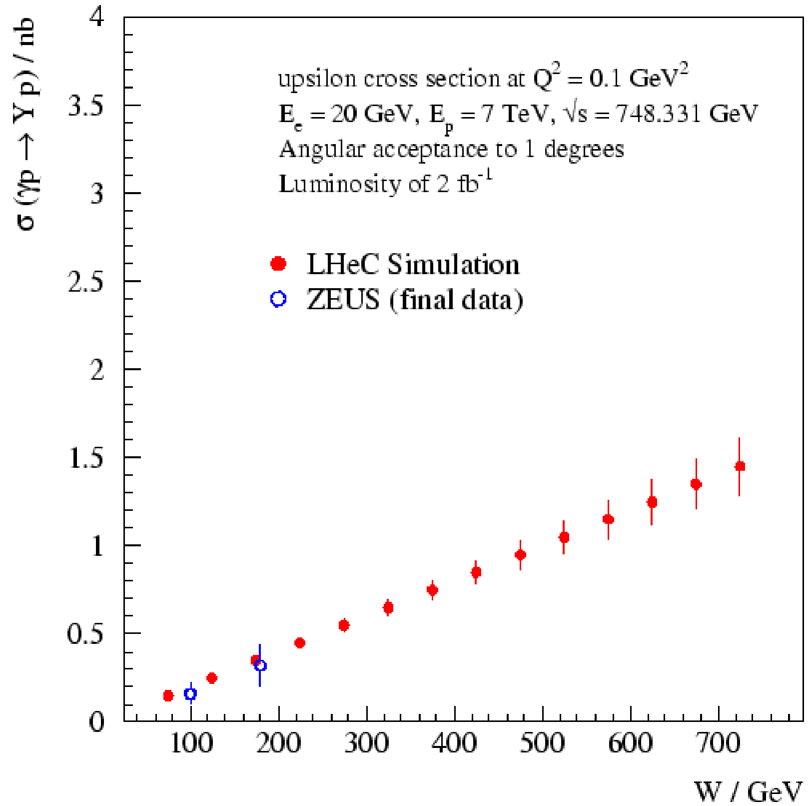
Ring-Ring and Linac-Ring J/Ψ Scenarios



For a θ < 170° cut, the geometrical acceptance in W does not improve as E_e increases!
Acceptance remains good to kinematic limit for θ < 179°

SPL (20 GeV) Scenario - J/Ψ cross secs

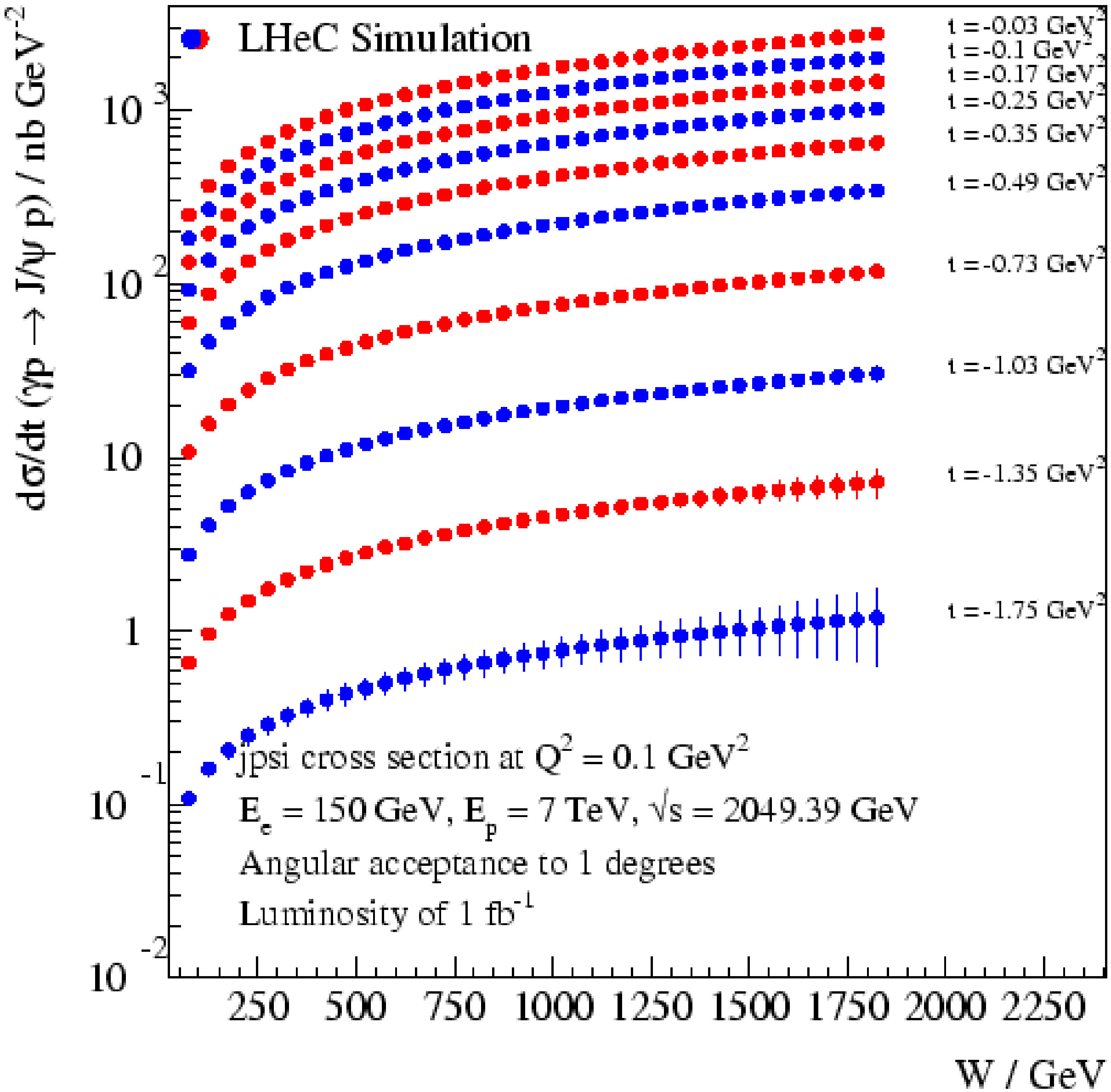




This is $Q^2 = 0$ (assumed <u>untagged</u> e), also done for high Q^2 and differentially in t

1^o acceptance yields cross sections almost to kinematic limit
2 fb^{-1} is already plenty of lumi for J/ψ, even t differential

Linac Ring 150 GeV Low x Dedicated Scenario



☺

With 1° acceptance and lumi ~ 1 fb-1, we would have some very nice data indeed, probing well into saturation regime …

PS: $\rho \rightarrow \pi\pi$ still to be studied, but $J/\Psi \rightarrow \mu\mu$ likely to be main case study

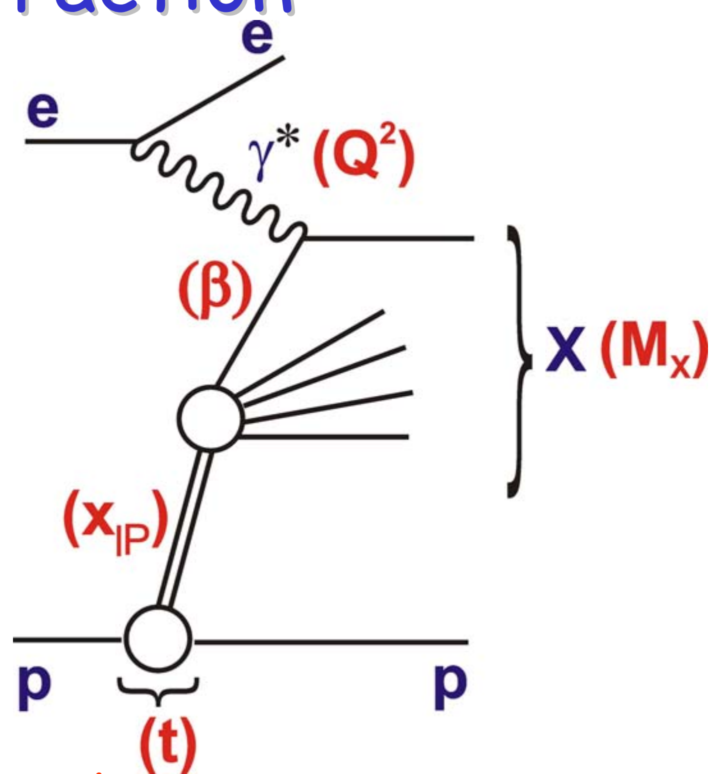
3) Inclusive Diffraction

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



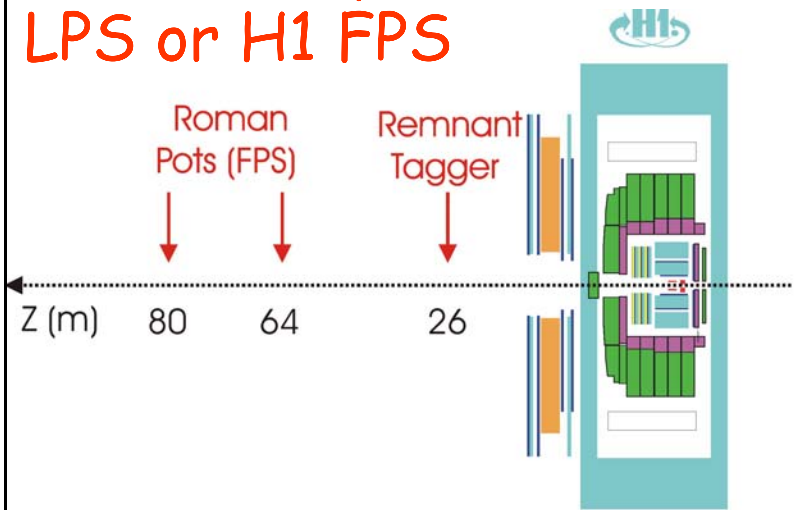
→ Large cross section
→ Further sensitivity to saturation phenomena
→ Can relate to nuclear shadowing … Link between ep and eA

Requirements:

- Electron acceptance / measurement as in inclusive DIS
- Tracking / HCAL / energy flow algorithm for M_x rec^n
- Selection method based on intact final state proton

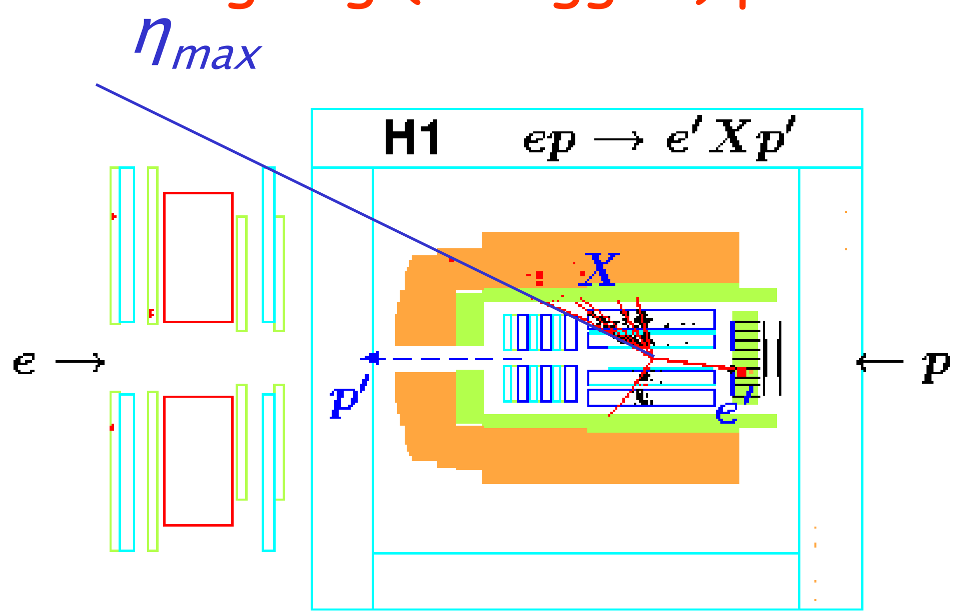
Signatures and Selection Methods at HERA

Scattered proton in ZEUS LPS or H1 FPS



- Allows t measurement
- Limited by stats and p-tagging systs

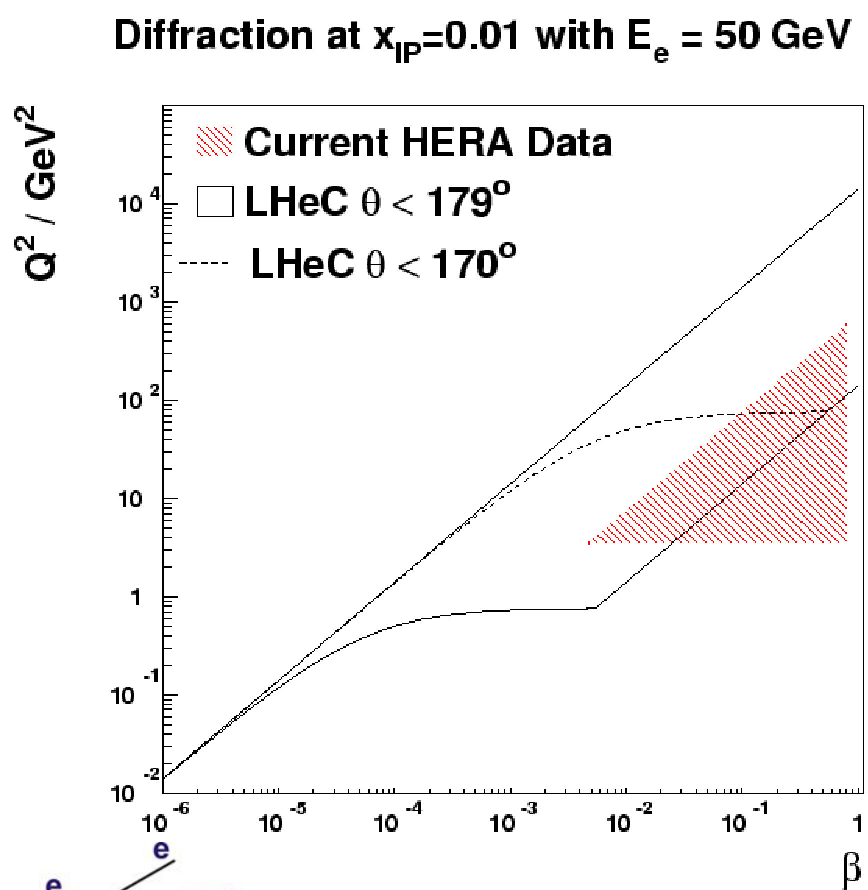
'Large Rapidity Gap' adjacent to outgoing (untagged) proton

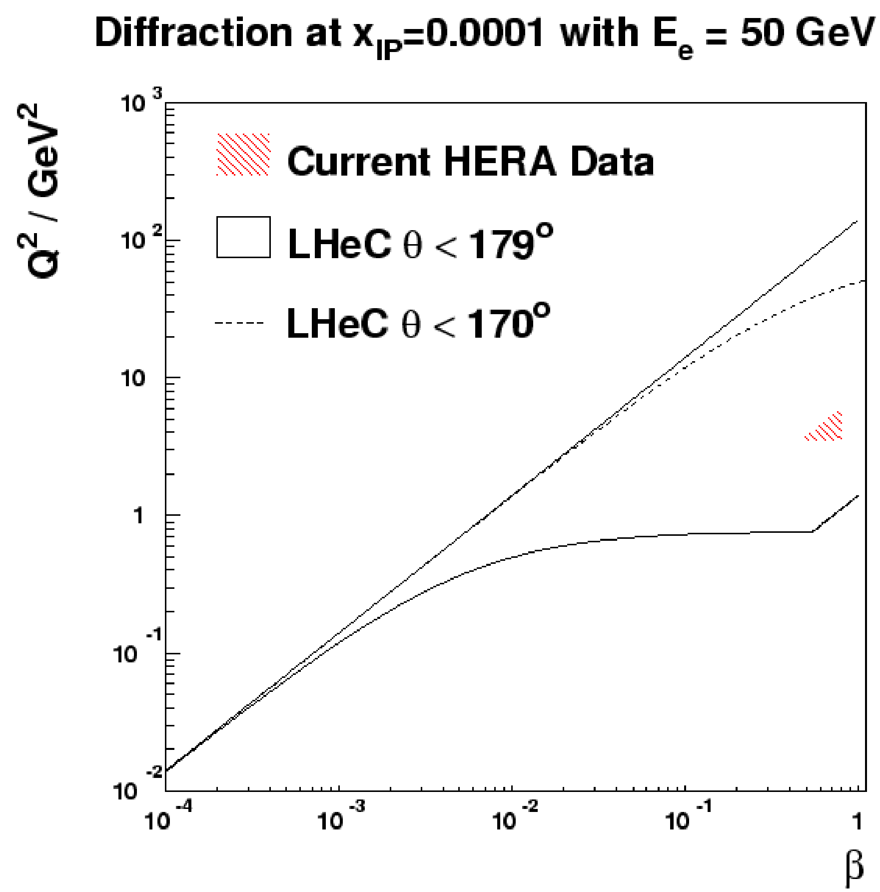


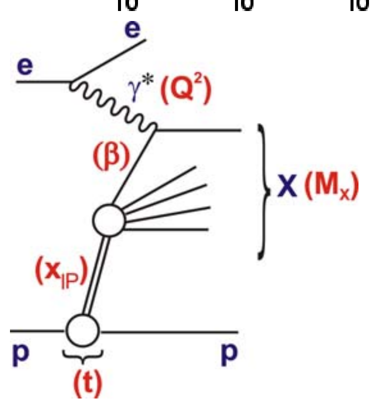
Limited by p-diss systs

Worked well: The methods have very different systs!
What is possible at LHeC?...

Diffractive Kinematic Plane at 50 GeV



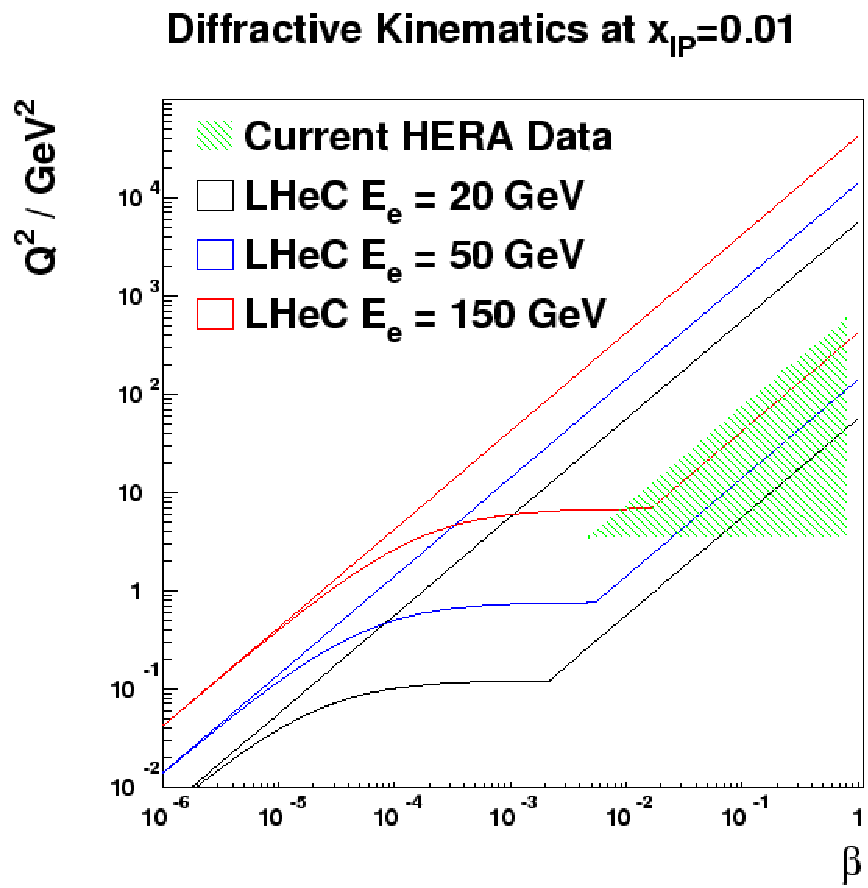


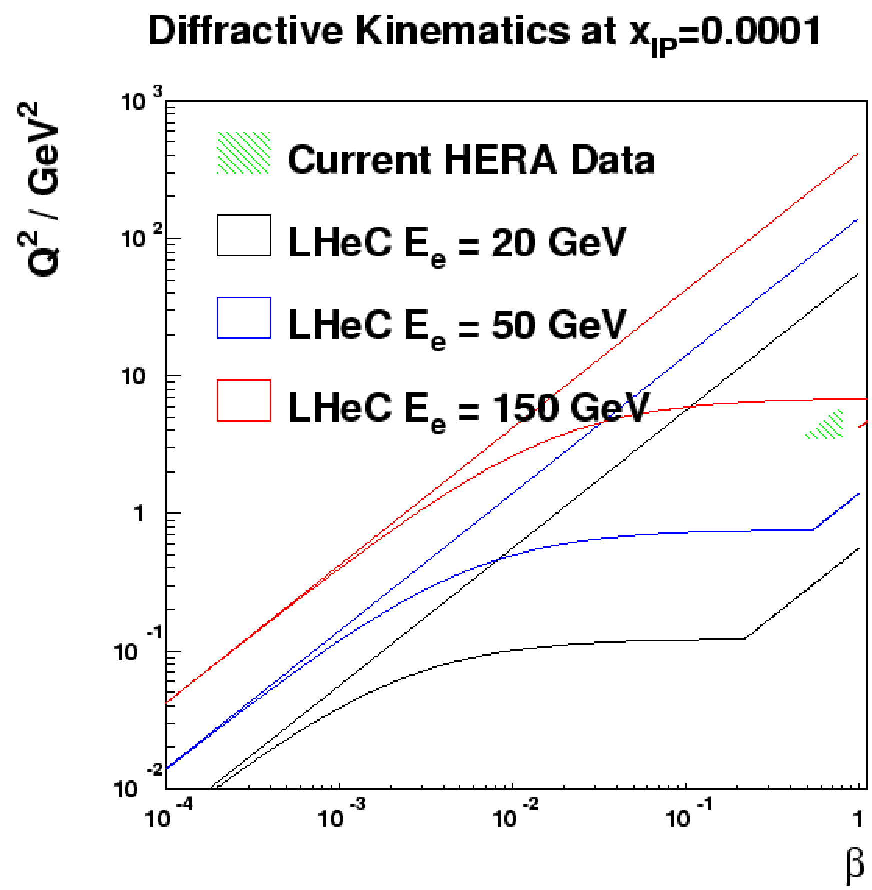


- Similar story to the inclusive case … low β at fixed x_{IP} if we have good enough e acceptance
- Whole new regions (e.g. low x_{IP}) open up

… but limited gain over HERA with $\theta < 170^o$

Diffractive Kinematic Plane at LHeC





Higher E_e yields acceptance at higher Q^2 (pQCD) and lower β (also lower x_{IP} - not shown)

… but what about the hadron measurement?

Forward and Diffractive Detectors

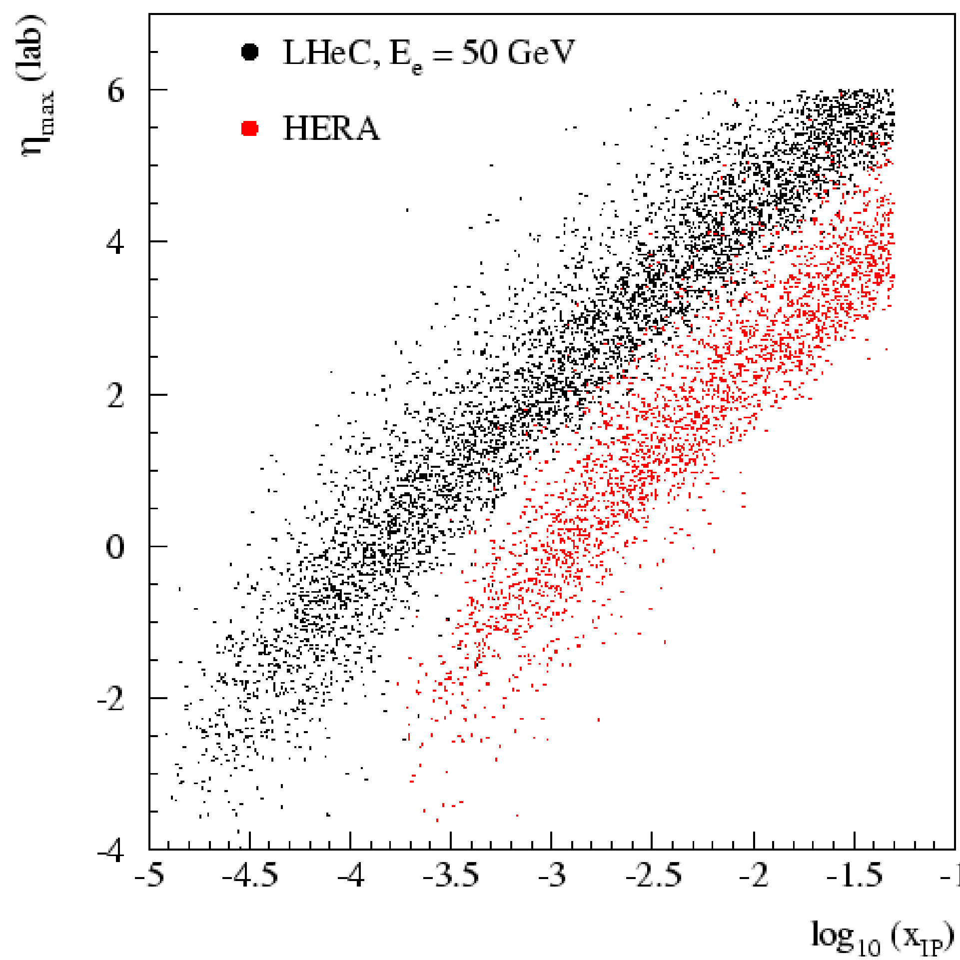
- For large rapidity gap method, life harder than HERA …

- Reaching $x_{IP} = 1 - E_p'/E_p = 0.01$ in diffraction with rapidity gap method requires η_{max} cut around 5 … corresponds to <u>$\theta > 1^o$</u>

- For $x_{IP} = 0.001$ η_{max} cut around 3 … similar to H1 LAr cut … and still lots of Data …

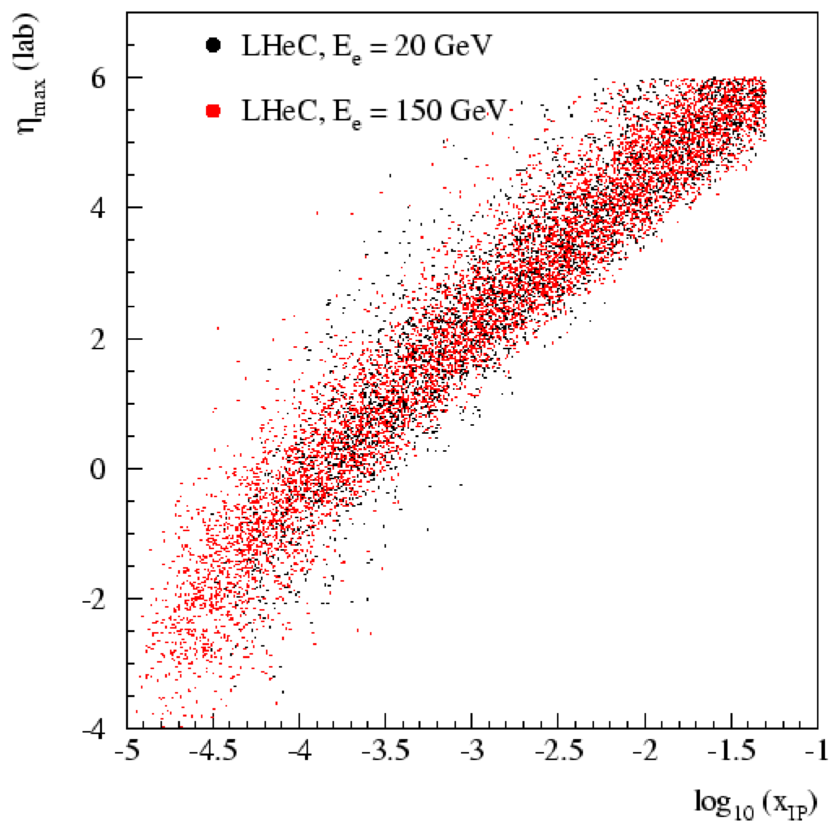
… but miss many important LHeC advantages associated with high Mx

η_{max} from LRG selection …



Correlation Depends on E_p, not on E_e

… x_{IP} = 1 – Ep' / Ep defines kinematics of X system in terms of scattered proton energy only.



Obtaining LRG data over Full x_{IP} range requires …

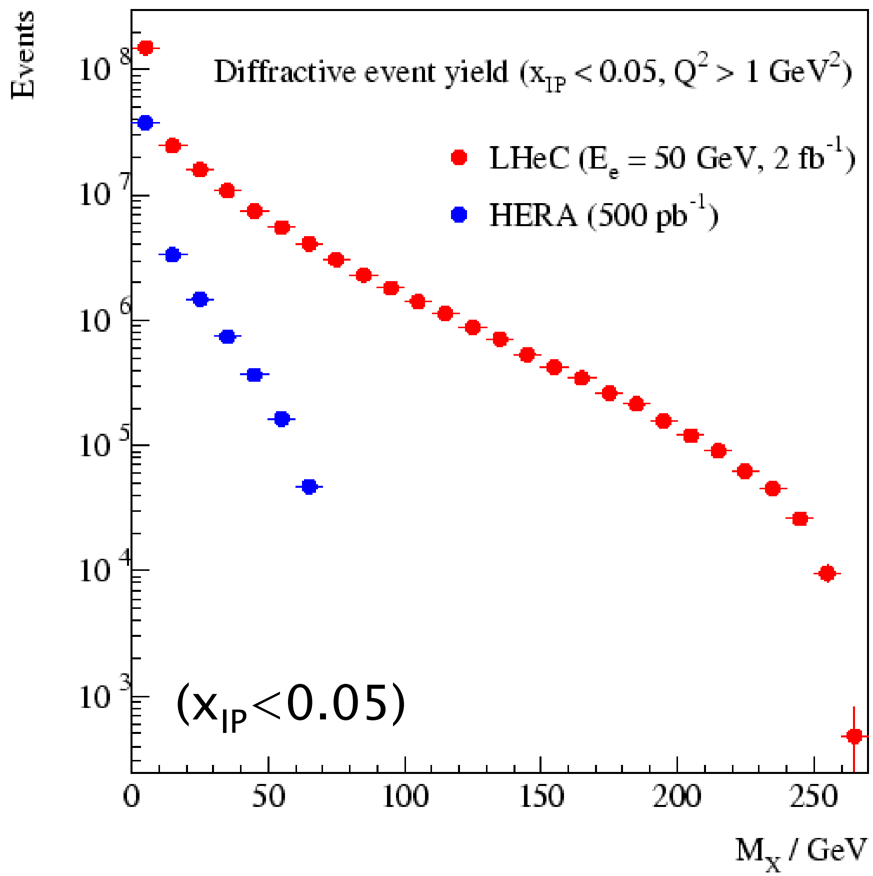
… calorimetry a little beyond chosen η_{max} cut with sufficient granularity for spatial resolution and good control of noise to clearly identify a rapidity gap…

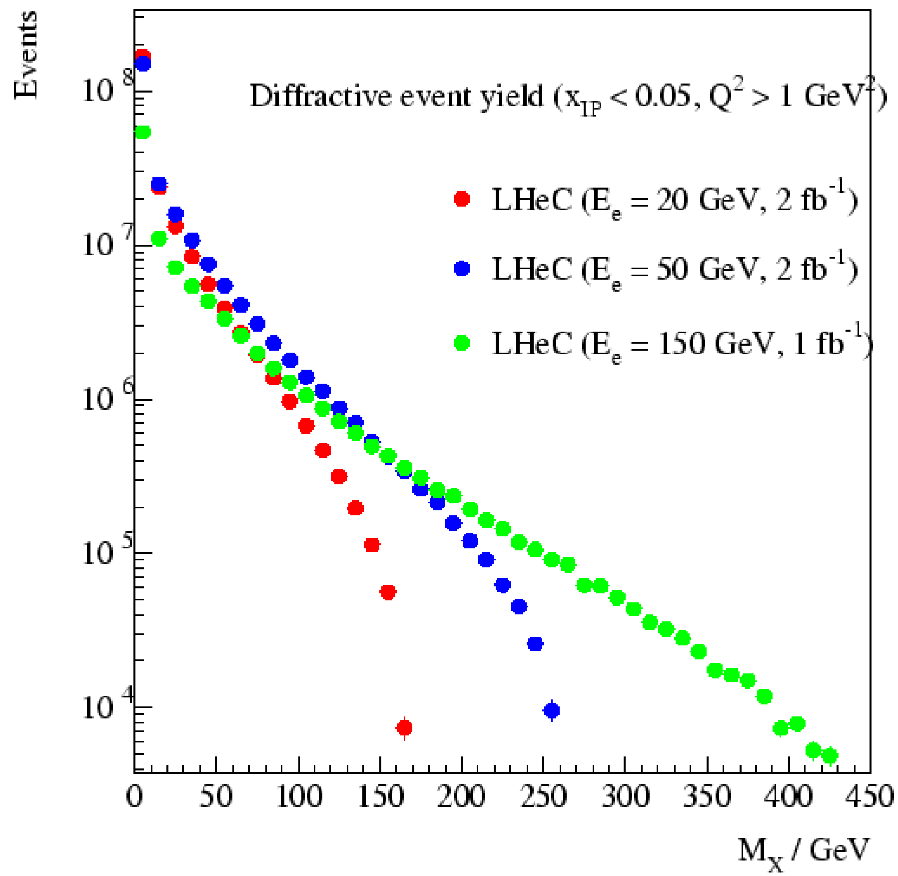
… energy resolution / shower containment less important

… Mx reconstruction → hadronic resolution / Eflow algorithm

Why care about large x_{IP} Diffraction?

Large x_{IP} also highly correlated with large Mx

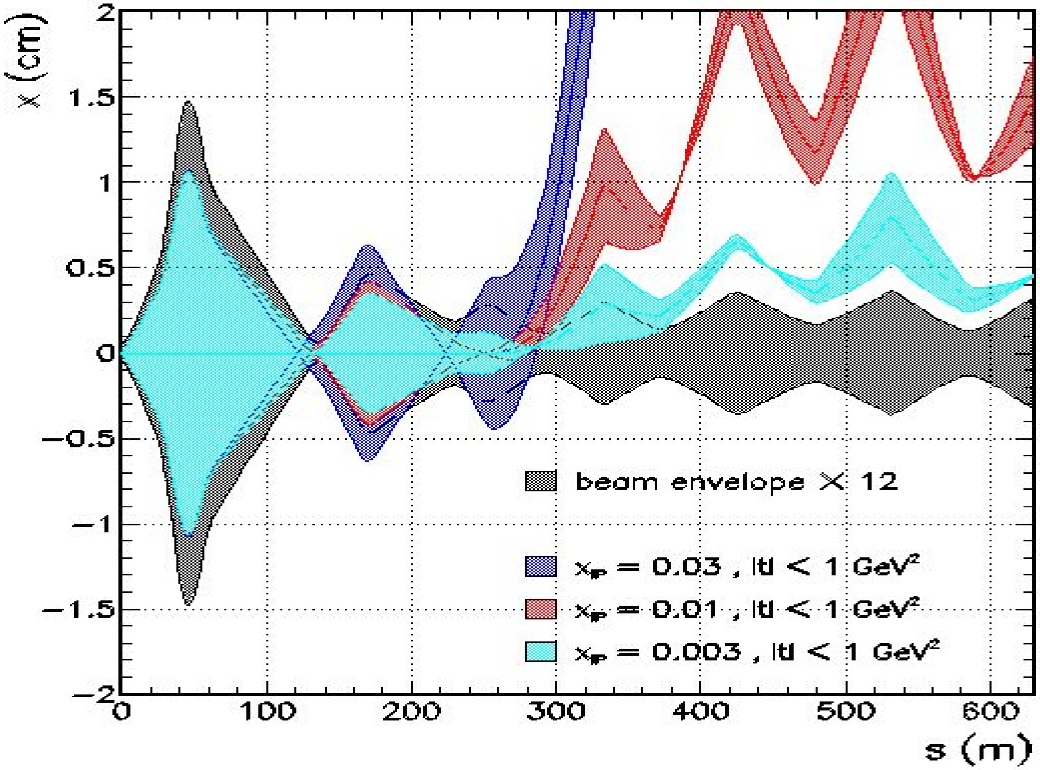




- `Proper' QCD (e.g. large E_T) with jets and charm accessible
- New diffractive channels … beauty, W / Z / H(?) bosons
- Unfold quantum numbers / precisely measure new 1^- states

A High Acceptance Proton Spectrometer?

[van Mechelen]



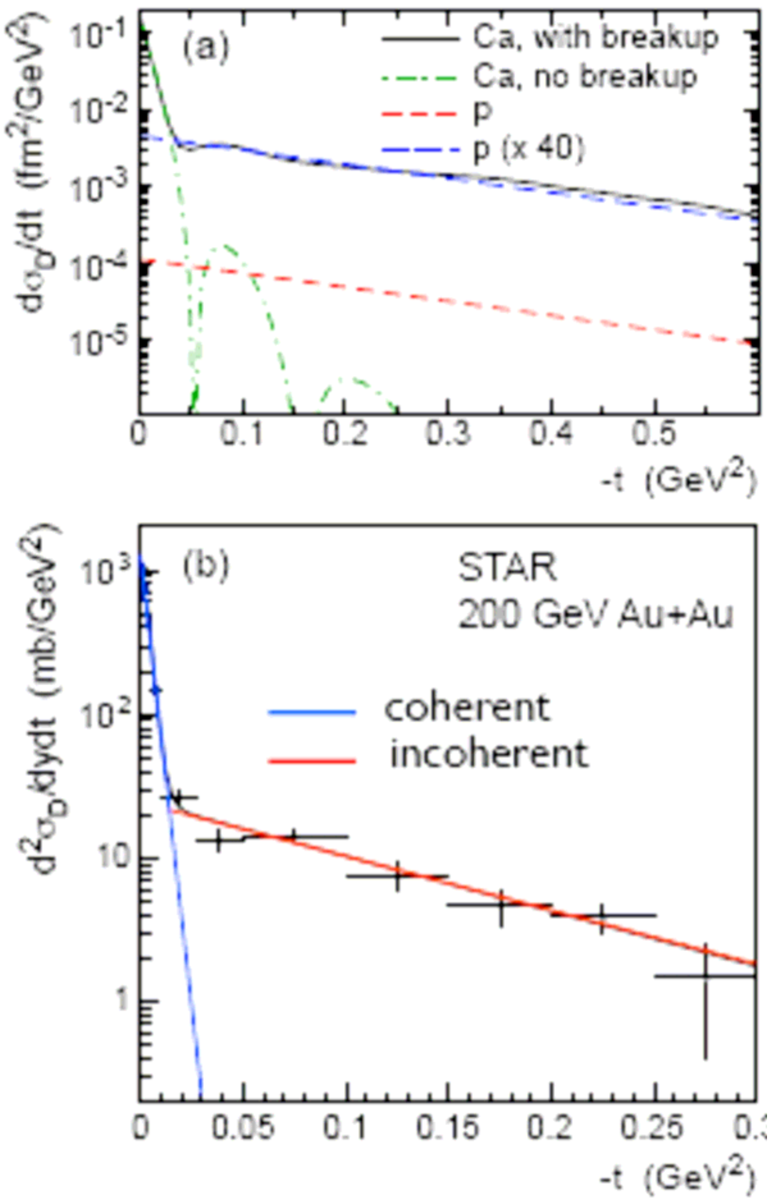
With `FP420'-style proton spectrometer, could tag and measure elastically scattered protons with high acceptance over a wide x_{IP}, t range

? Any complications if there's a finite crossing angle?
? Dependence on proton beampipe appertures near IP?
? Further pots closer to the IP?

→ Crucial to pursue these questions further … we need this!

Forward Ion Spectrometry?

Is proton spectrometry also possible in eA case?…



In incl ed, was scatter off p or n?
In diff eA, did nucleus break up?
Can we tag coherently scattered A?

←Based on Au + Au diffractive data from RHIC, coherent diffraction is at very low t … |t| < 0.03 GeV2 …

pt (Au) < 0.17 GeV …

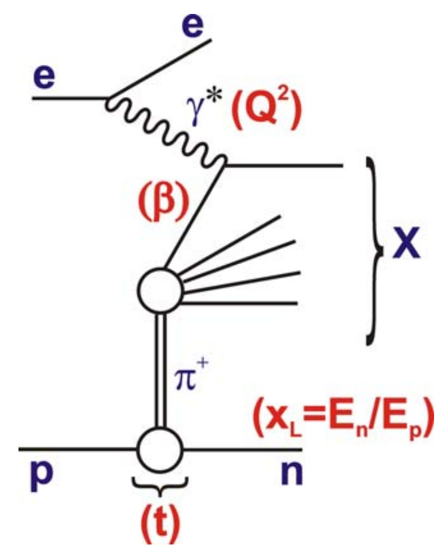
$\theta \sim$ pt(Au) / (A. E_N)

$\sim 3 \cdot 10^{-4}$ mrad ?!?!

… Separable from beam?

… much better chance to tag protons in break-up case.

What about Leading Neutrons?

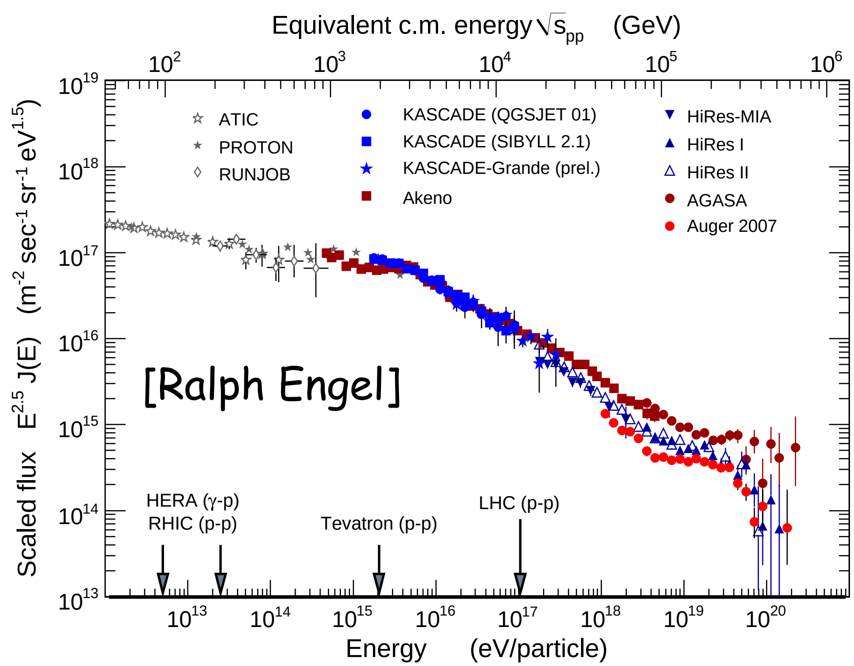


Interesting in ep for π structure function, absorptive / gap survival effects and related to cosmic ray physics

Crucial in inclusive ed, to distinguish scattering from p or n

Crucial in diffractive eA, to distinguish coherent from incoherent diffraction

Both HERA expts had a FNC



Very radiation hard detectors needed for LHC environment c.f. Similar detectors (ZDCs) at ATLAS and CMS

Leading Neutron Ideas (Buyatyan, Lytkin)

- Size & location determined by available space in tunnel and beam-line appertures
- Requires a straight section at $\theta \sim 0^o$ after beam is bent away.
- H1 version → 70x70x200cm Pb-scintillator (SPACAL) @ 100m →θ<0.8mrad (p_t <~ 500 MeV)

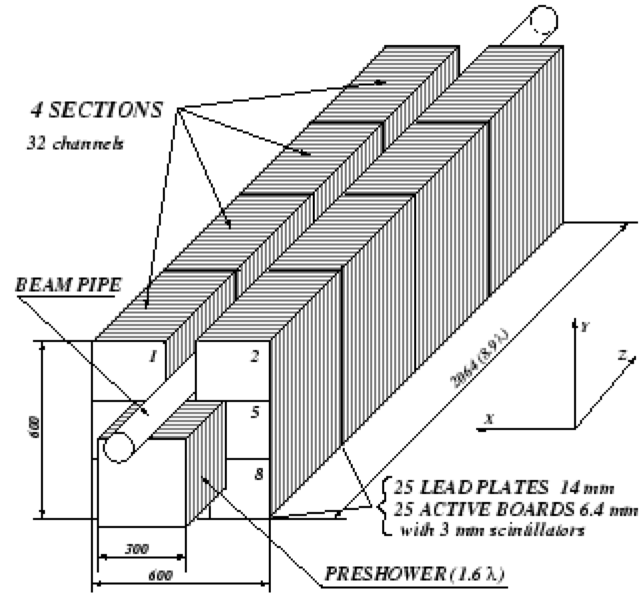
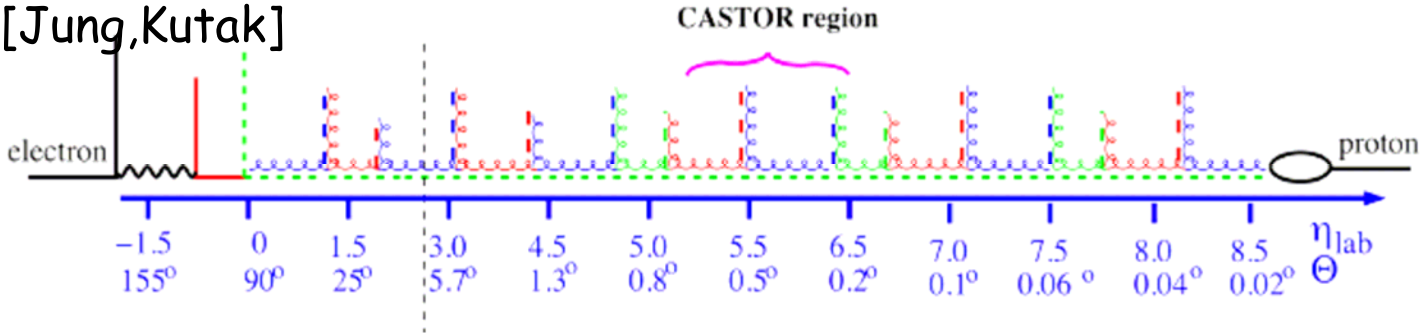


Figure 5: General view of the H1-FNC calorimeter

- LHeC: aim for similar θ range?... more would be nice!
- Need ~ 10λ to contain 95% of 7 TeV shower
- 2λ high granularity pre-sampler to reject EM showers from photon background and get impact point
- Main calorimeter coarser with 4-5 longitudinal segments?
- Achievable resolution could be σ/E ~ 60%/sqrt(E)

4) Forward Jets

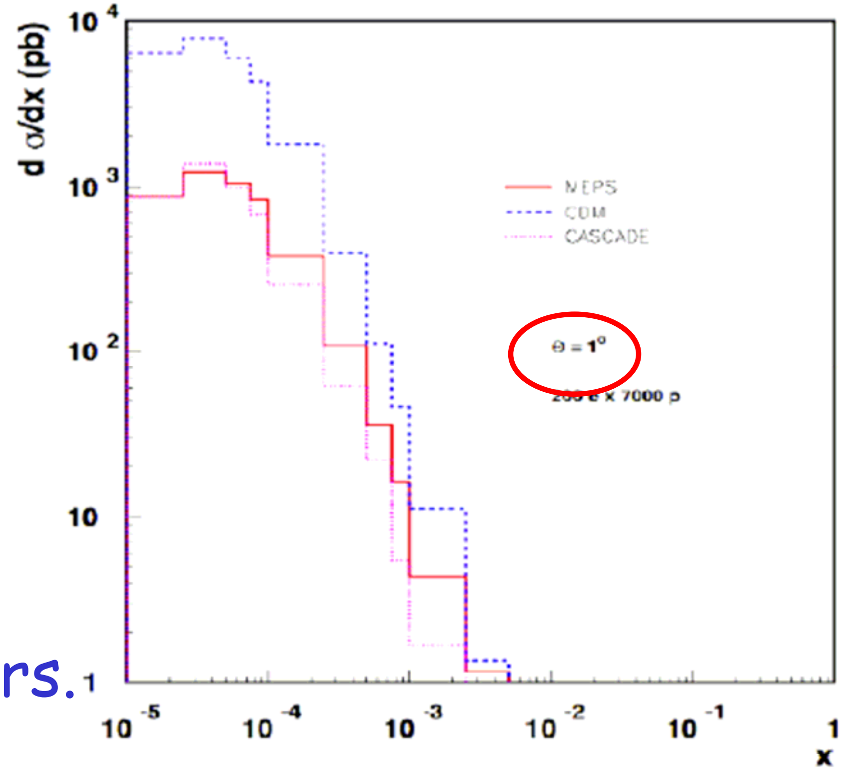
[Jung,Kutak]



$x_{jet} > 0.03$

$0.5 < \frac{p_{t\,jet}^2}{Q^2} < 2$

Parton cascade dynamics / non-DGLAP evolution and other novel QCD effects require study of very forward jets.



X range of sensitivity depends strongly on θ cut

? Achievable spatial resolution at high η? Energy resolution matters.

? Typical jet energies ?... to be defined

Questions and Comments

- Achievable precision, background rejection θ and E_e' ranges for scattered electron in low Q2 DIS?
- Magcal and other more exotic ideas to be pursued?
- Tracking precision and noise rejection for vector mesons?
- What acceptance is achieavble for muon detection?
- Forward tracking / calorimetry for rapidity gap identification and forward jets?
- Other rapidity gap identifiers (scintilators round beampipe?)
- Hadronic calorimtery / Eflow algorithm resolution for M_x rec, jets …
- Proton (and ion?) spectrometry and forward neutrons?
- Low angle electron tagging?… Tagged photoproduction