Small Q^2 eP and eA Physics

I will discuss:

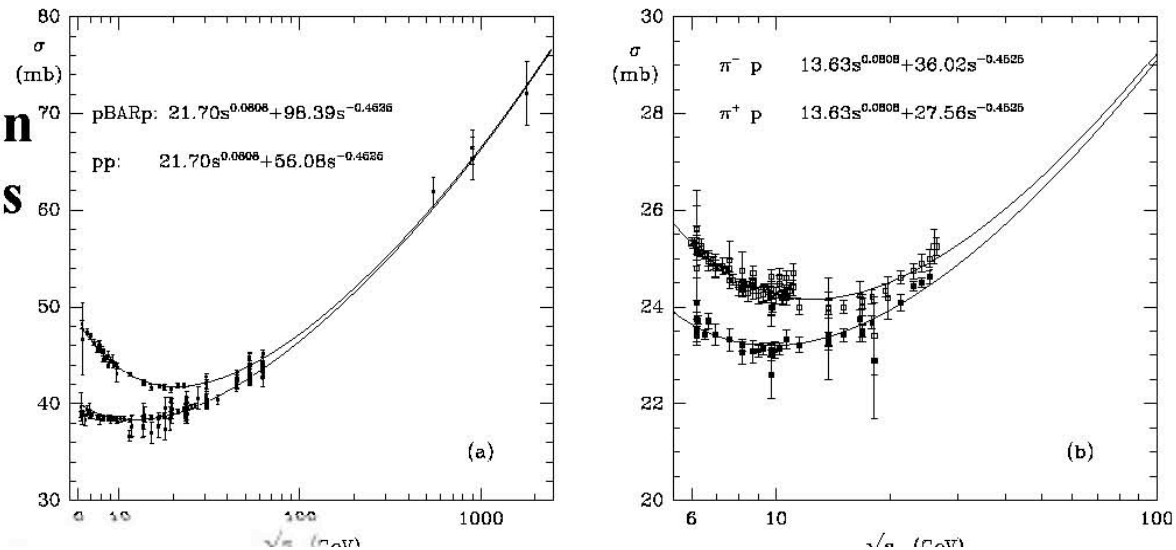
1. The total photoproduction cross section
2. The transition from photoproduction to DIS
3. Photoproduction of VM (J/psi)

Common themes - the structure of nuclear matter
- need for the right detector

Not discussed – jets, spin

Hadron-Hadron Cross Section

Hadron-hadron scattering cross section versus CM energy

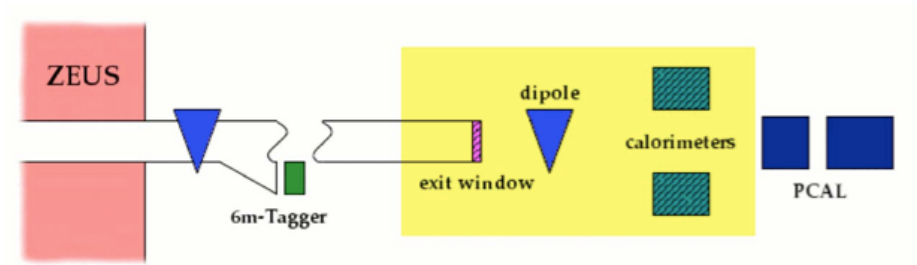


$\sigma \propto s^{0.08}$

What about eA ?

HERA: total photoproduction cross section

$$s_{\gamma P} = W^2 \approx \frac{Q^2}{x}$$



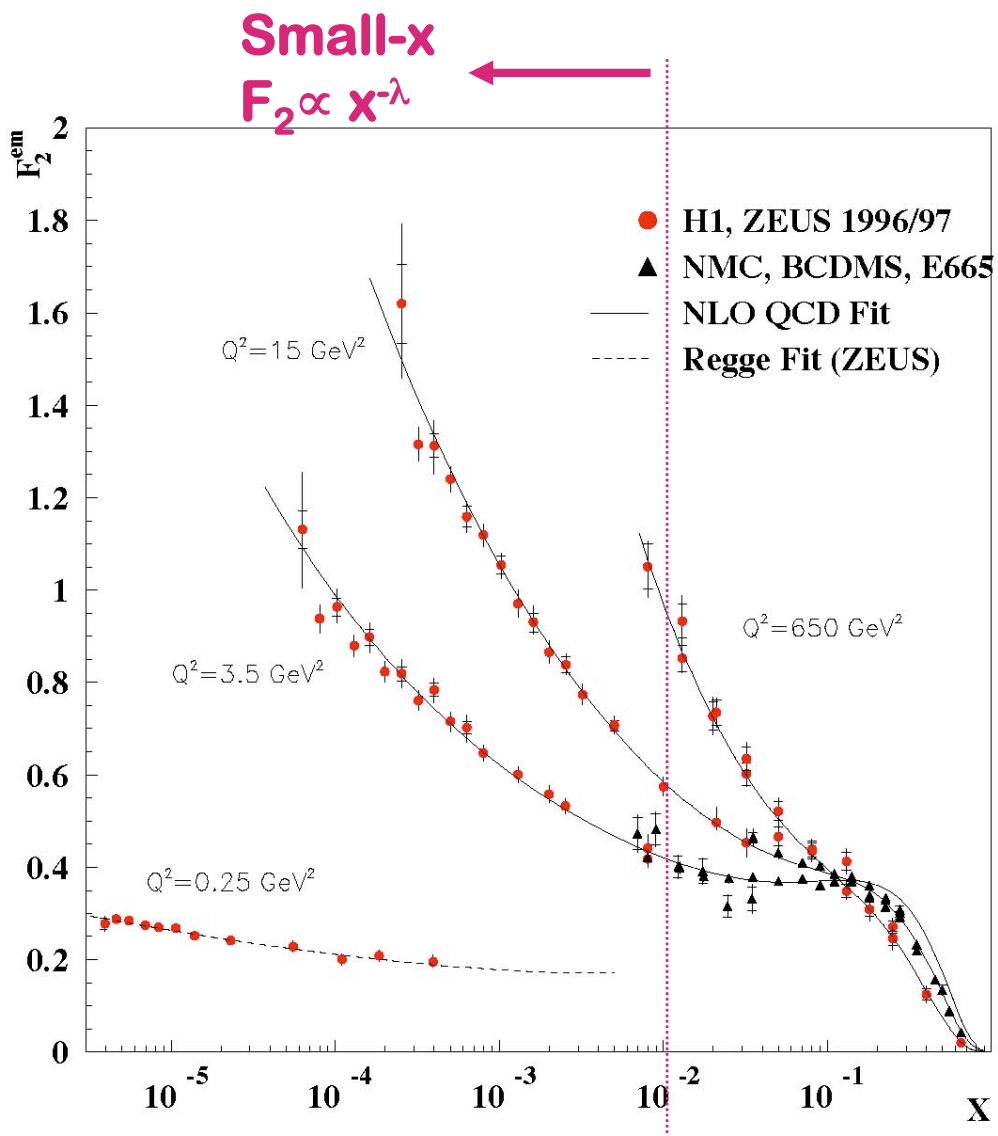
$\sigma \propto (W^2)^{\varepsilon}$

$$\varepsilon = 0.070 \pm 0.007(\text{stat.}) \pm 0.021(\text{syst.}) \pm 0.050(\text{6mT})$$

ZEUS prel.

HERA Discovery!

The rise of the parton densities (and of F_2) with decreasing x is strongly dependent on Q^2. Implies very large density of partons in the proton when probe at high energies !

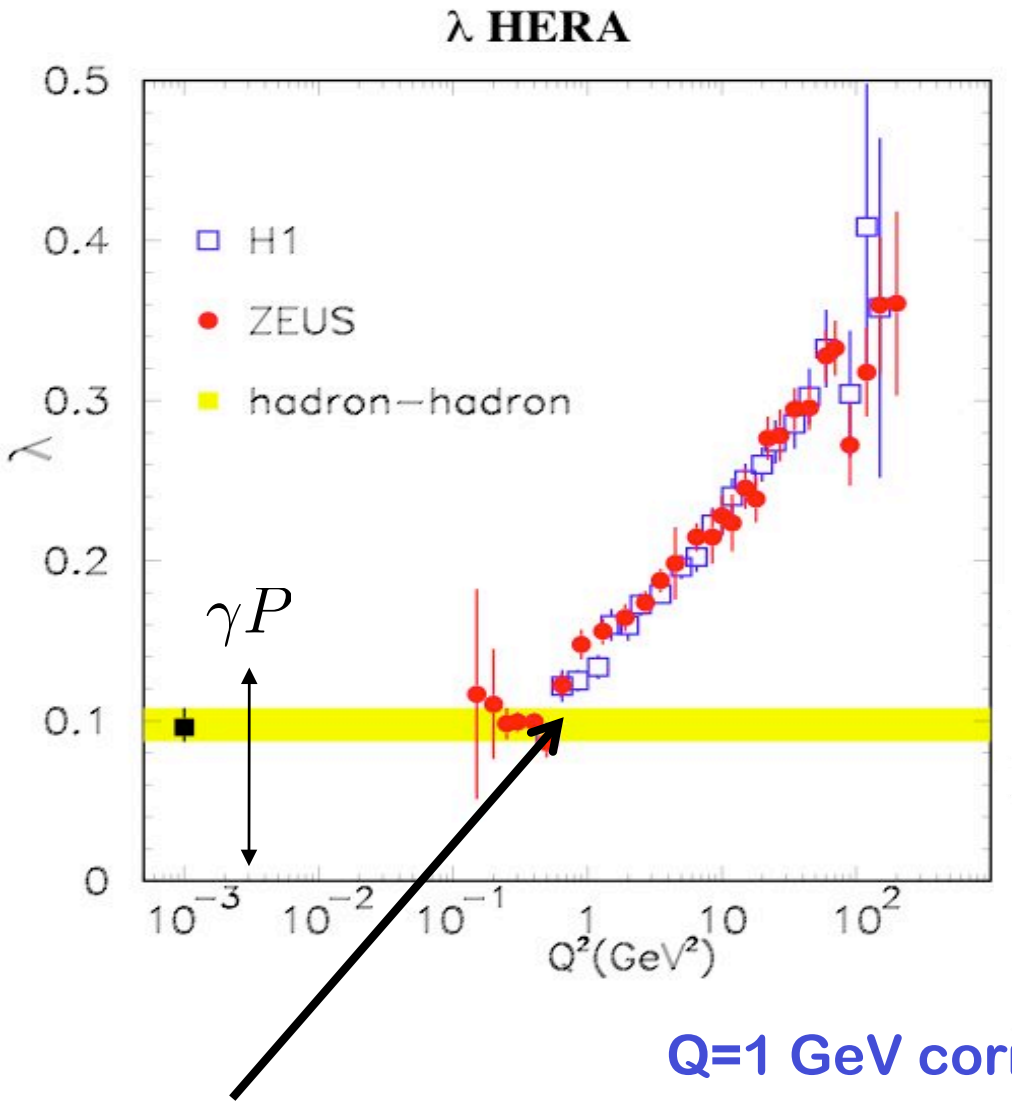


Small fraction of HERA data

The rise at small x

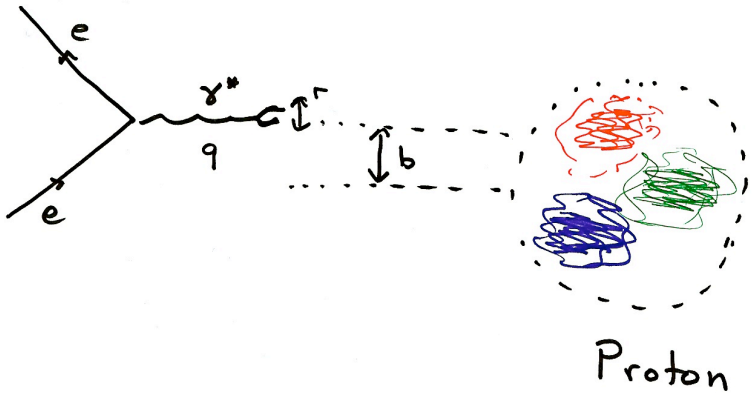
Parametrize:

$$F_2 = C(Q^2)x^{-\lambda} \qquad x < 0.01$$



Below $Q^2 \approx 0.5$ GeV^2, see same x (energy) dependence as observed in hadronic interactions

$$r \sim \frac{\hbar c}{Q}$$

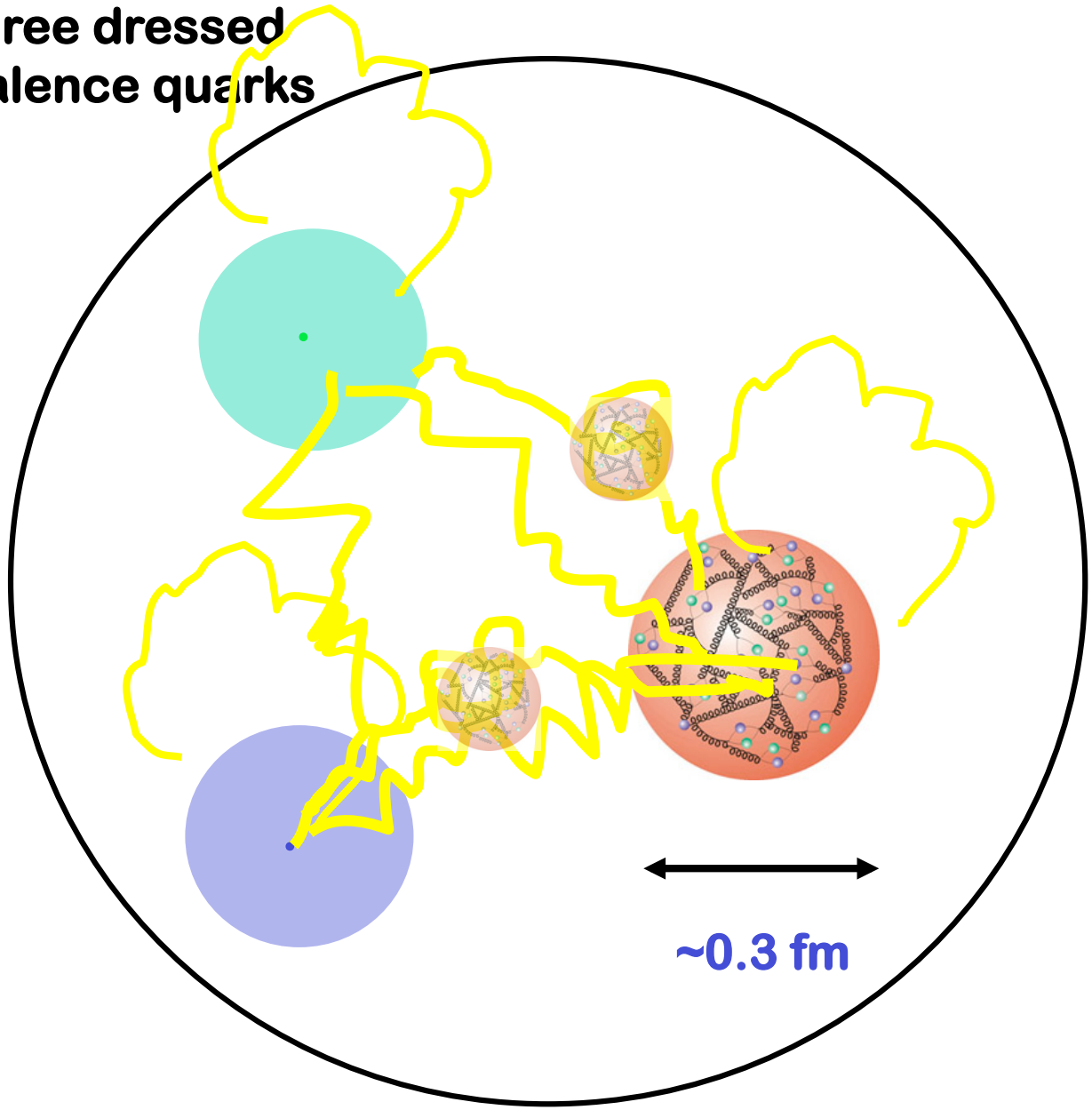


Q=1 GeV corresponds to about 0.2 fm

Transition region

EM proton radius about 0.9 fm, so structure appears at smaller scale

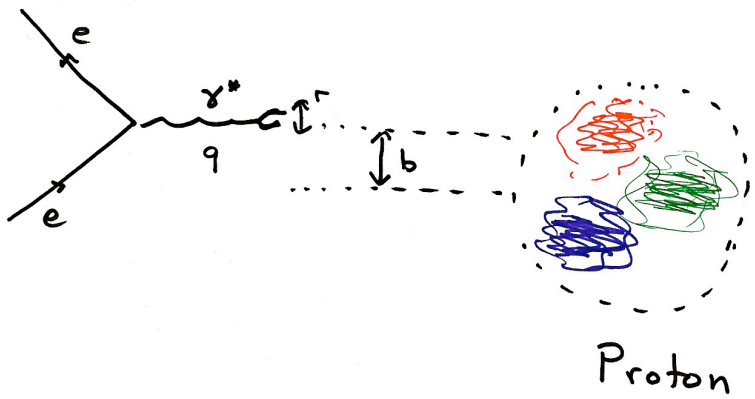
Proton with three dressed valence quarks +

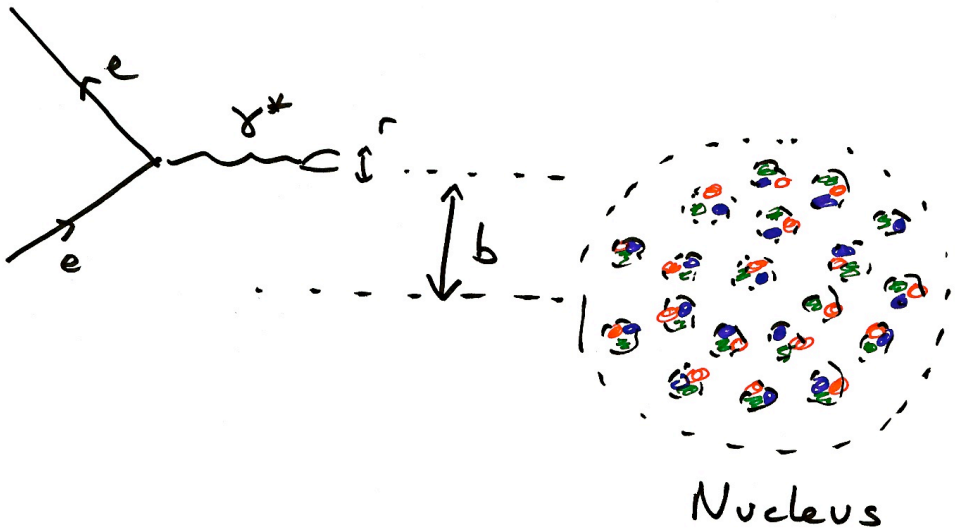


'Quark substructure' can be seen when we get resolution smaller than about 0.3 fm. With finer resolution, see that the three quarks are composed of many subconstituents.

Small colorless gluon clusters between the valence quarks. Colorless clusters have similar structure as valence quarks.

Plus short lived fuzz outside (the expanding proton).





Does the rise in F_2 set in at the same Q^2 in eA and in eP ?

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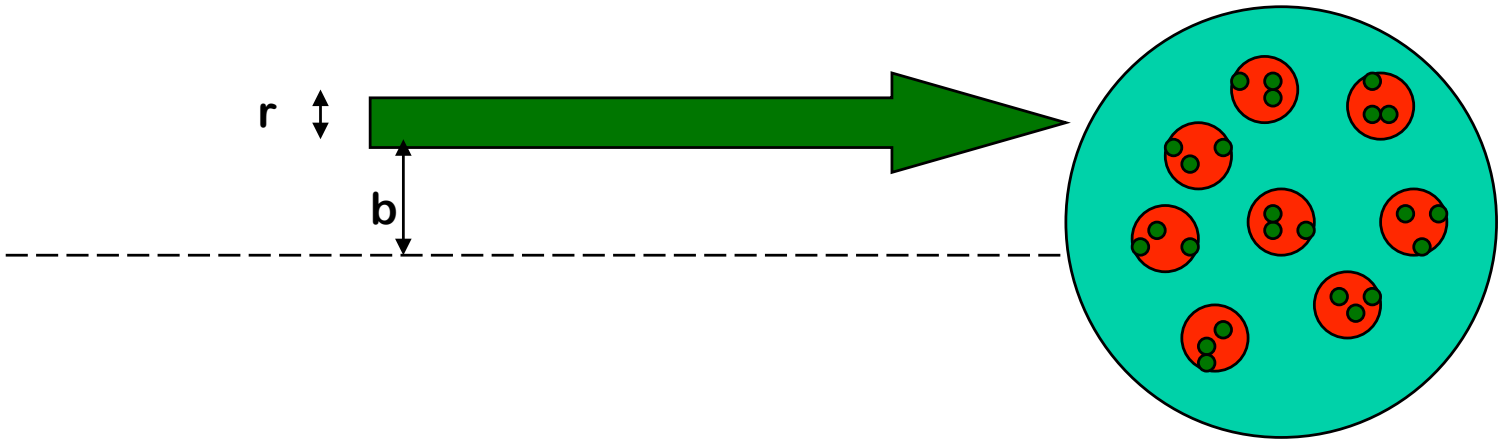


At small x, the scattering is coherent over nucleus, so the photon sees much larger # of partons:

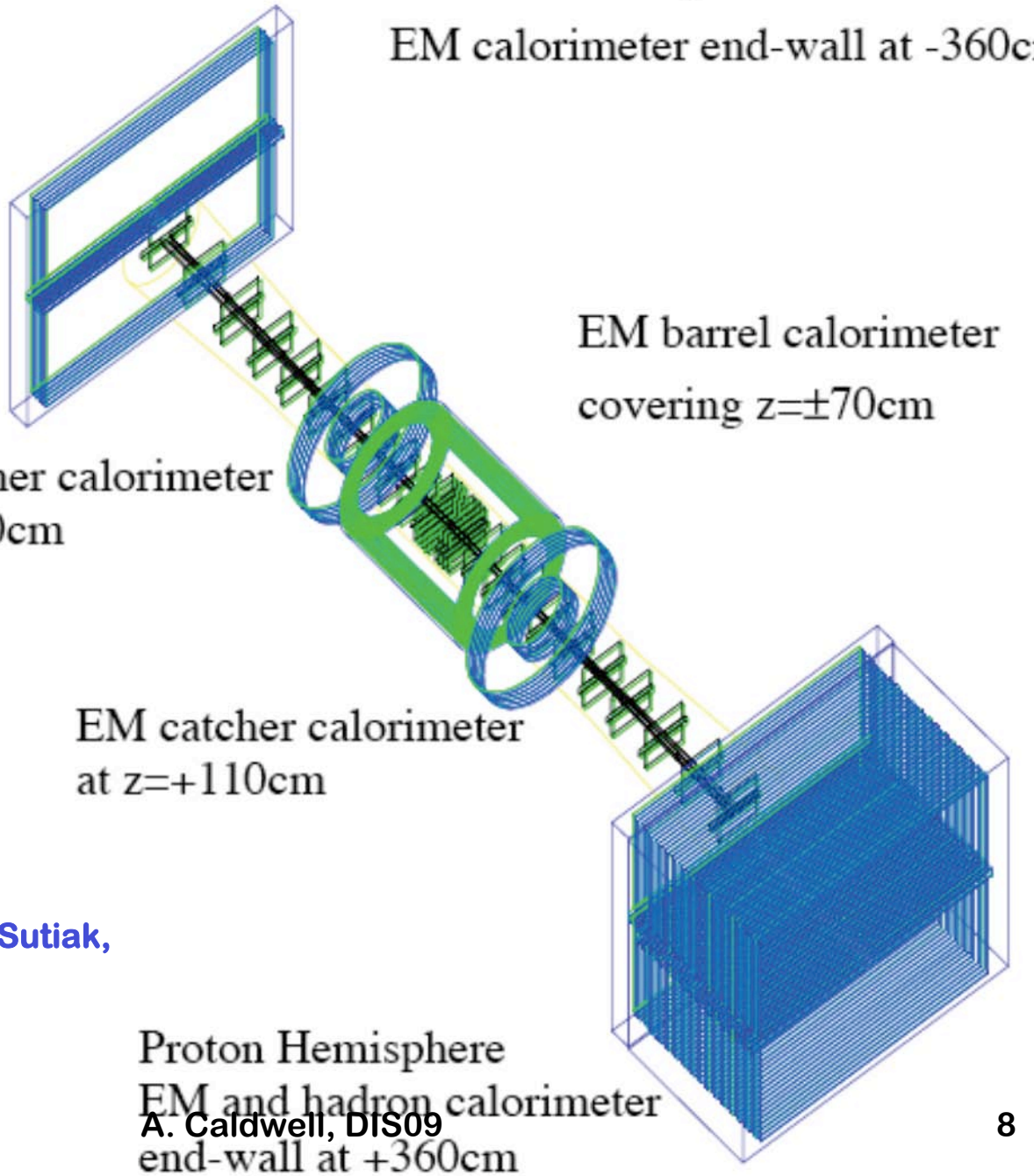
$xg(x_{eff},Q^2) = A^{1/3}\, xg(x,Q^2)$, **at small-x,** $xg \propto x^{-\lambda}$, **so**

$x_{eff}^{-\lambda} = A^{1/3} x^{-\lambda}$ **so** $x_{eff} \approx xA^{-1/3\lambda} = xA^{-3}\ (Q^2 < 1\ \mathrm{GeV}^2)$

$= xA^{-1}\ (Q^2 \approx 100\ \mathrm{GeV}^2)$

Lower effective x, but x-dependence at fixed Q^2 ?

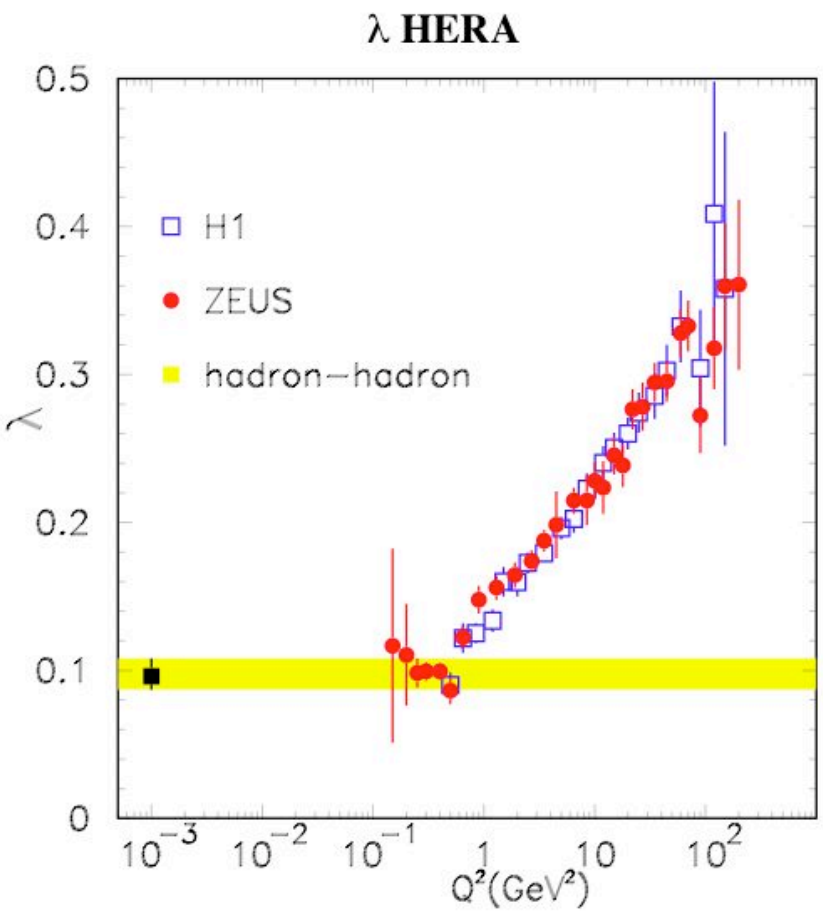
Optimized detector design will make a big difference in the physics which can be accessed. Towards Bjorken's FAD.



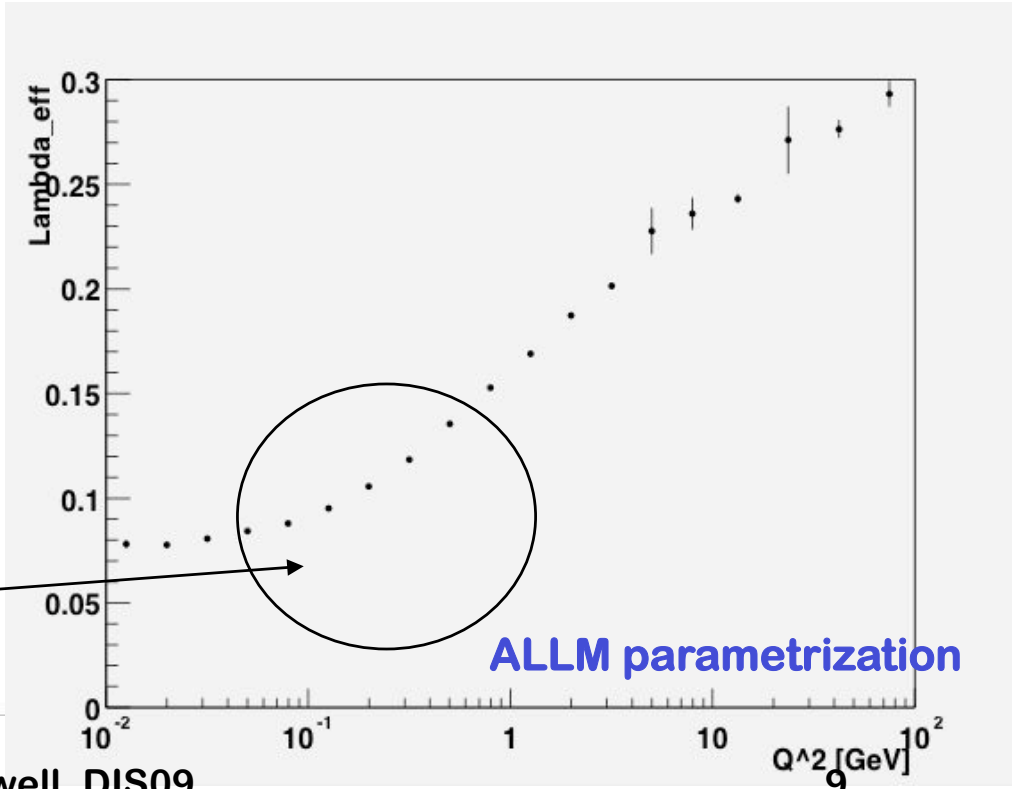
See:

I.~Abt, A.~Caldwell, X.~Liu and J.~Sutiak, arXiv:hep-ex/0407053

Probing the parton-hadron transition

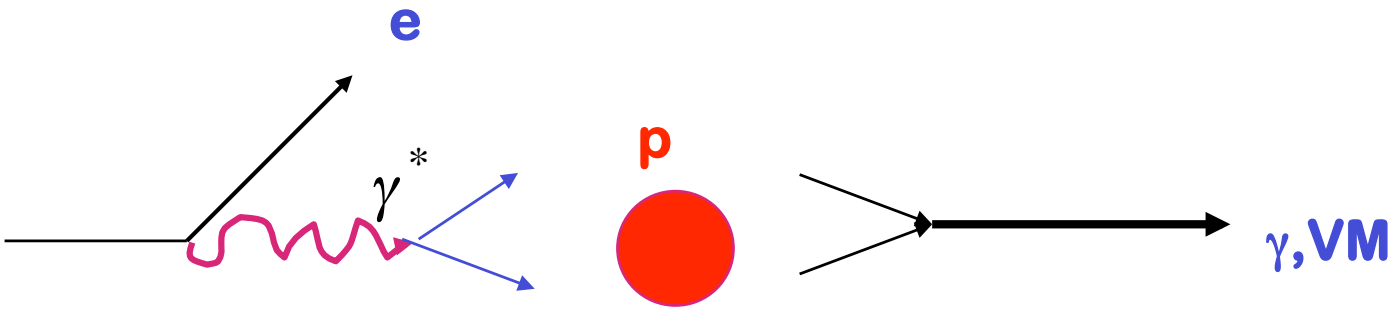


λ eRHIC



Extremely precise measurements possible in this interesting region

Exclusive Processes



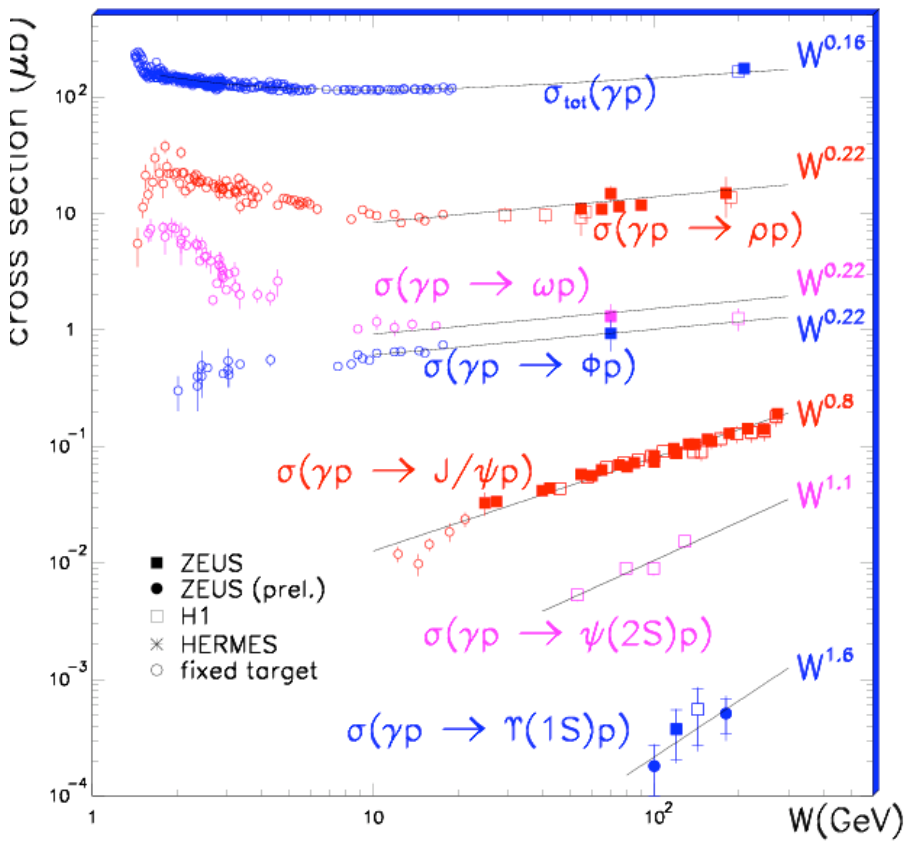
A long list of processes have been measured:

$$eP \rightarrow ePV \quad V = \rho,\omega,\varphi,J/\psi$$

$$eP \rightarrow eNV \quad V = \rho,\omega,\varphi,J/\psi$$

N is low mass system

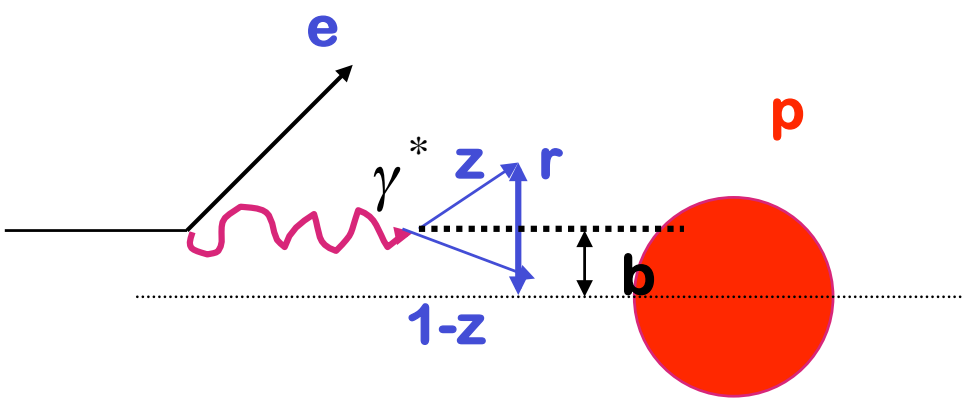
and $eP \rightarrow eP\gamma$ QCD

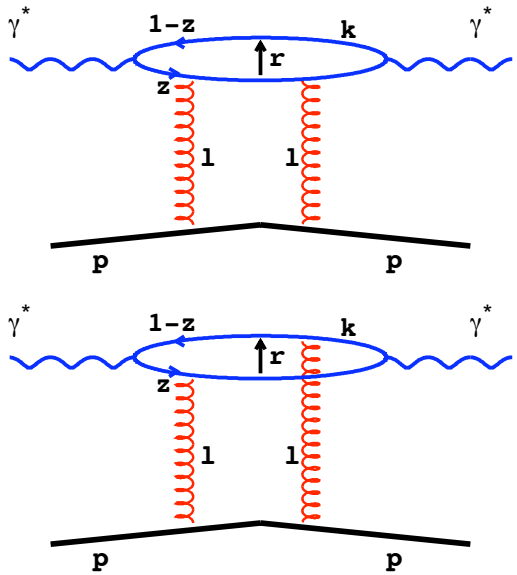


Color Dipole Model

GBW - first Dipole Saturation Mode

Golec-Biernat, Wuesthoff





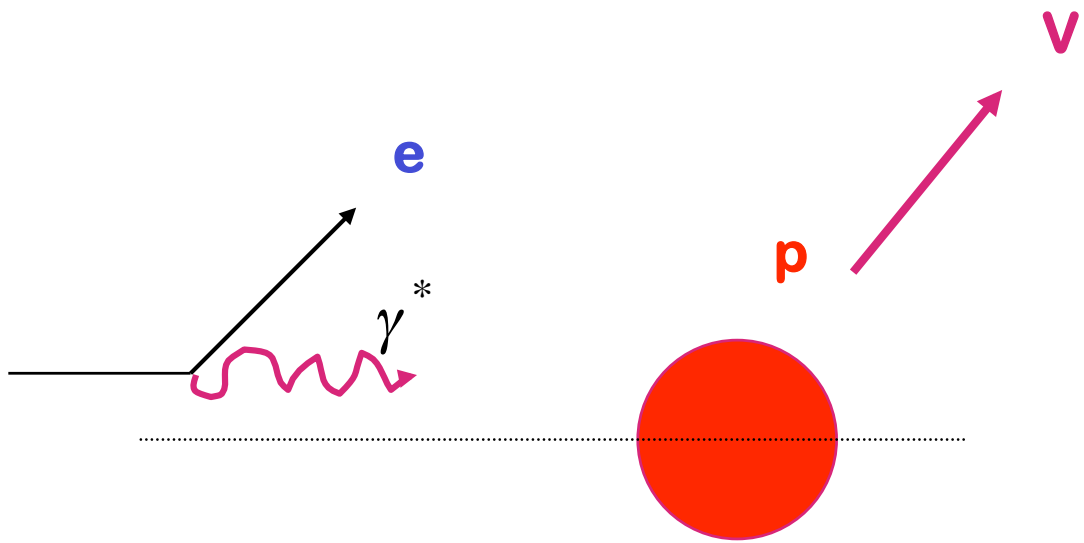
Components:

$\Psi(r,z)$ the quark-antiquark wavefunction of the photon, known from QED

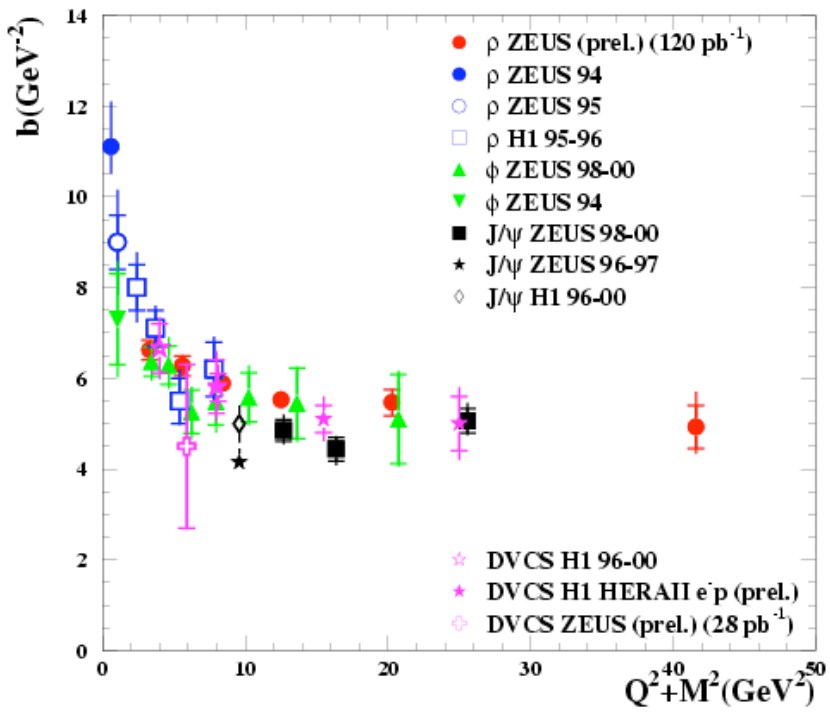
$\sigma_{q\bar{q}p}$ the dipole scattering cross section. Depends on impact parameter,b, and dipole transverse size, r

$$\sigma^{\gamma P} = \int d^2\vec{r} \int_0^1 dz \int d^2b \Psi^* \sigma_{q\bar{q}p} \Psi$$

Exclusive Processes



$$\frac{d\sigma}{dt} \propto e^{-bt}, \qquad b \rightarrow R_g$$



b=4 GeV^{-2} found corresponds to an rms impact parameter of ~0.6 fm. smaller than the proton charge radius of 0.870 [PDG] …

Elastic J/psi Scattering

Ideal process to measure hadronic structure:

- **Seeing J/psi in final state ensures compact probe**
- **Large J/psi photoproduction cross section**
- **Precision reconstruction possible** $J/\psi \to \mu^+\mu^-$ $J/\psi \to e^+e^-$

Detector requirements:

- **forward electron spectrometer**
- **forward p,A reconstruction (veto of dissociation)**
- **precision tracking in central detector**

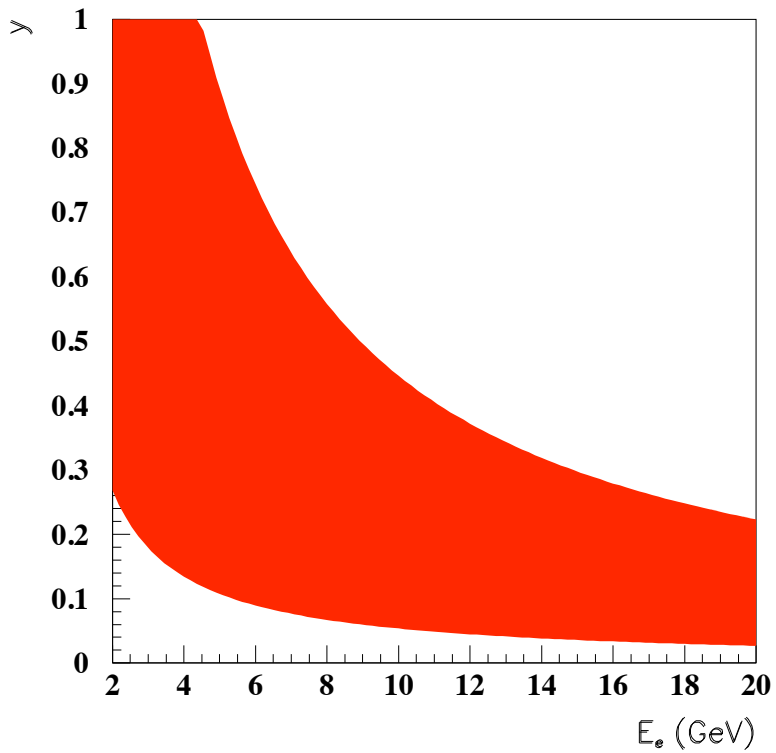
Accelerator requirements:

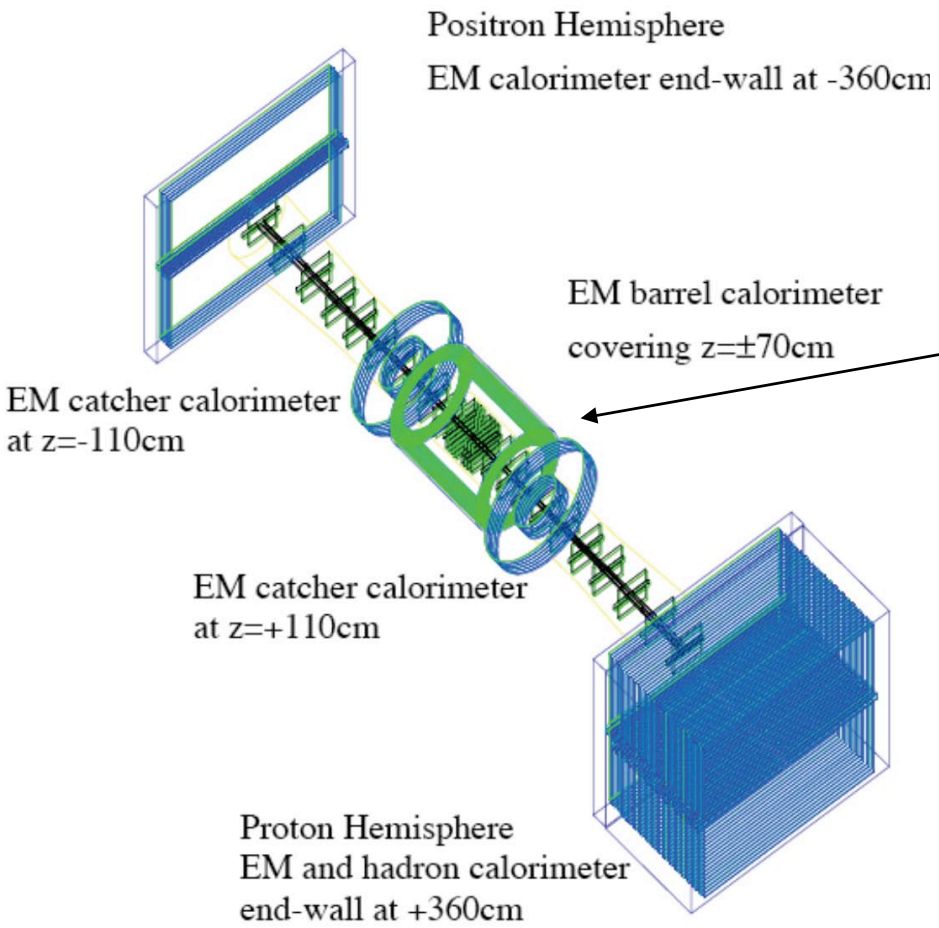
- **substantial component free region around IP**
- **small P_T of beam particles (< few MeV)**

$$\frac{d\sigma}{dW^2} = \frac{\alpha}{2\pi}\frac{1}{s}\left[\frac{1+(1-y)^2}{y}\ln\frac{Q^2_{max}}{Q^2_{min}} - \frac{2(1-y)}{y}\left(1-\frac{Q^2_{min}}{Q^2_{max}}\right)\right]\cdot\sigma^{\gamma p}(W^2)$$

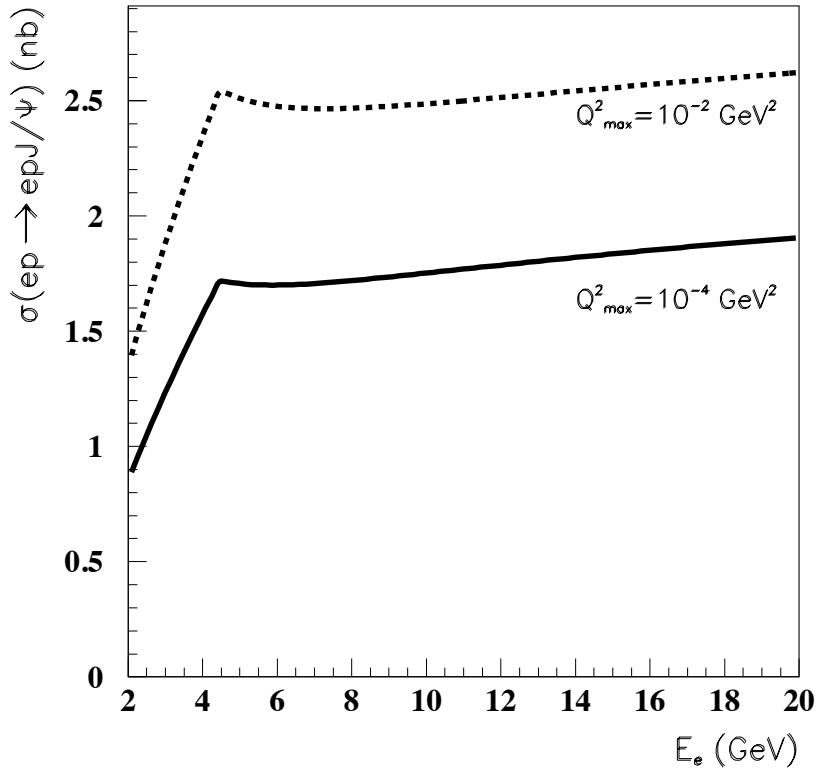
$$\sigma^{\gamma p\to J/\psi p}(W^2) \approx 75\text{nb}\cdot\left(\frac{W^2}{8100}\right)^{0.35}$$

Require that J/psi is produced centrally (less than 4 GeV longitudinal momentum) for good acceptance in central detector.

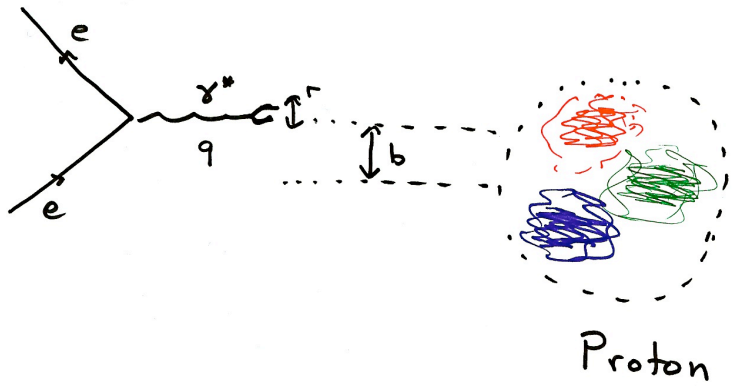




For this study, assume excellent central tracking (e.g., TPC in strong B field)

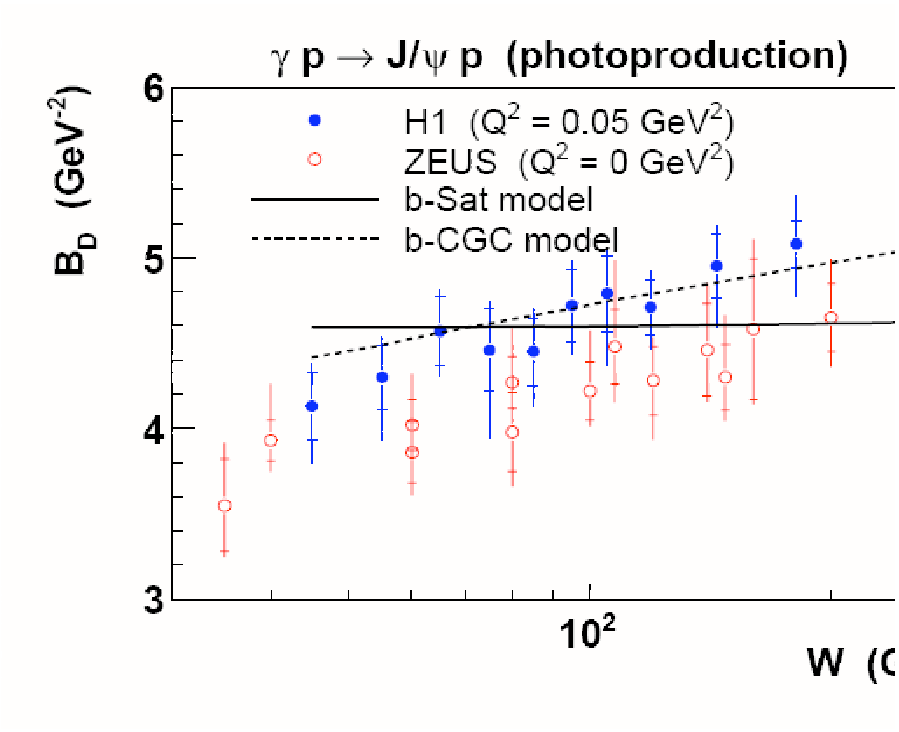


Visible eP cross section about 2 nb



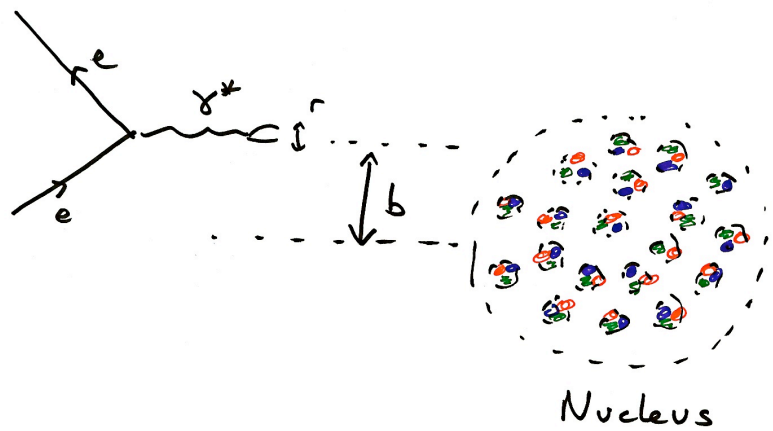
$$\sqrt{< r_{2g}^2 >} = \sqrt{3B_G} \approx \sqrt{3(B_D - 0.6\mathrm{GeV}^{-2})}$$

Correction for J/psi size



$$\sqrt{< r_{2g}^2 >} \approx 0.6 - 0.7\mathrm{fm}$$

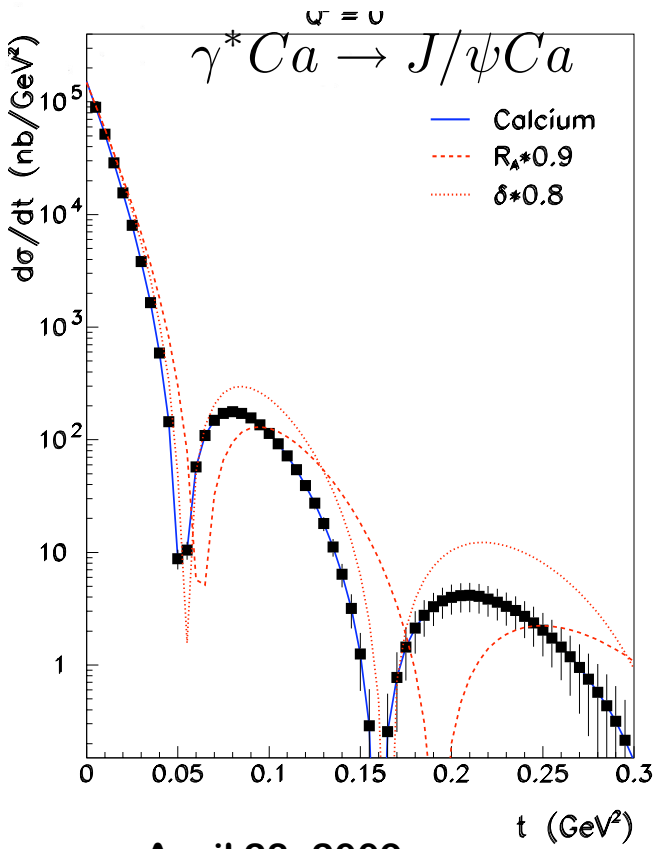
Can get excellent precision with right detector, high lumi. Study growth with W, …



$$R_A = 1.2A^{1/3}\ \mathrm{fm}$$

Elastic scattering on full nucleus means long wavelength gluons (small t)

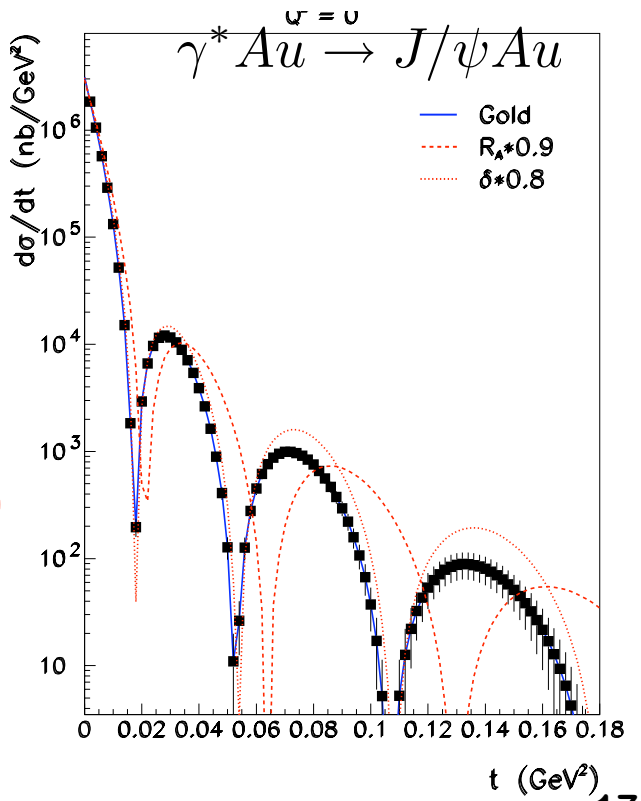
Woods-Saxon potential



Expectations for 1 Million

$$J/\psi \rightarrow \mu^+\mu^-$$

Momentum resolution of <10 MeV, great t resolution



Summary

Low Q^2 measurements will yield fascinating new information on hadronic structure.

The cross sections are large, but

Need to optimize the detector and accelerator for this physics