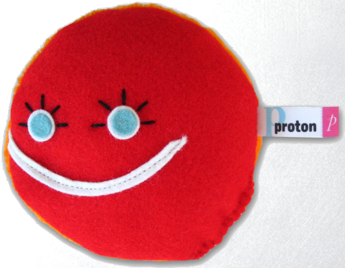
Soft Diffraction

Topics:

- Phenomenology of Soft Diffraction (L1)
- Regge Theory (L1, L2)
- Exclusive Vector Meson Photoproduction (L2, L3)

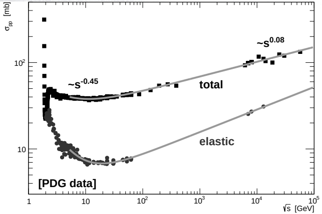
No protons
were harmed
in the making
of this lecture.

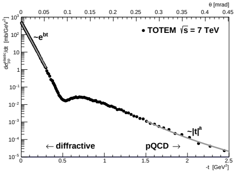


Arthur Bolz
Student Lecture GRK 1940
21 November 2018

Recap Lecture 1

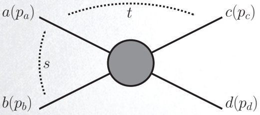
Soft Diffraction





- dominates hadronic interaction
- cross-sections rise with s
- scattering in forward direction
- large rapidity gaps

$2 \to 2$ kinematics



- $s = (p_a + p_b)^2 > 4m^2$
- $t = (p_a - p_b)^2 < 0$
- $\cos\theta \simeq 1 + \frac{2t}{s}$

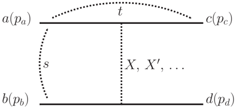
Regge Theory

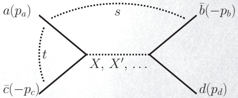
- try to explain $\sigma(s)$-dependence
- scattering theoretical approach
- idea: hadron exchange

scattering theory

- $S(s,t)$ lorentz invariant
- S unitary
  $\to$ optical theorem: $\sigma_{tot}(s) = Im\left[A_{elas}(s, t=0)\right]$
- S analytic: continue to complex $s, t \in \mathbb{C}$
- crossing-symmetry:

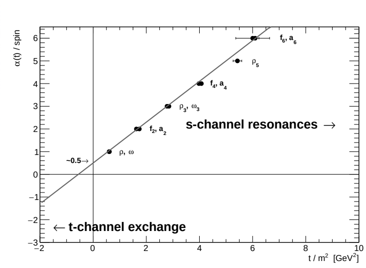
$$A_{ab\to cd}(s,t) = A_{a\bar{c}\to\bar{b}d}(t,s)$$





Recap Lecture 2

—— Regge Theory ——



- exchange orbital hadronic excitations
- lie on Regge Trajectories $\alpha_{\mathbb{R}}(t)$
  $\rightarrow$ lines in spin-M^2 plane w/ universal slope
- $\sigma_{tot}(s) \sim s^{\alpha_{\mathbb{R}}(0)-1}$
  $\rightarrow$ like single particle exchange: "Reggeon"

—— Pomeron ——

- rising cross-section w/ s not described by Reggeon exchange
- introduce ad-hoc trajectory with $\alpha_{\mathbb{P}}(0) = 1 + \epsilon$
  $\rightarrow$ "Pomeron"
  $\rightarrow$ gluon singlet, glueball, magic unicorn, model parameter?!

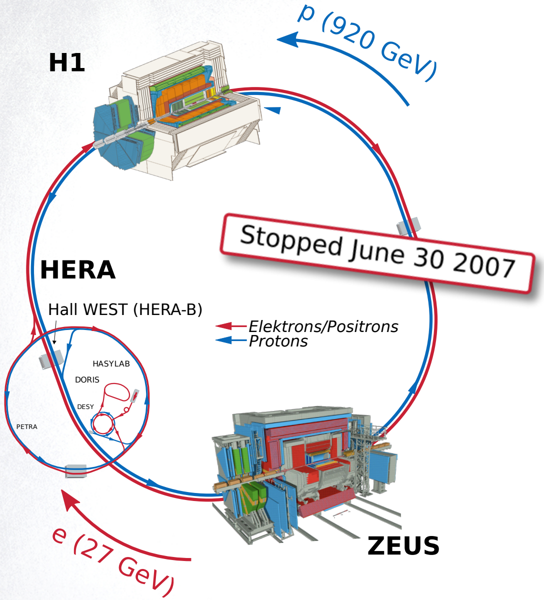
—— Today ——

- measure leading trajectory via:

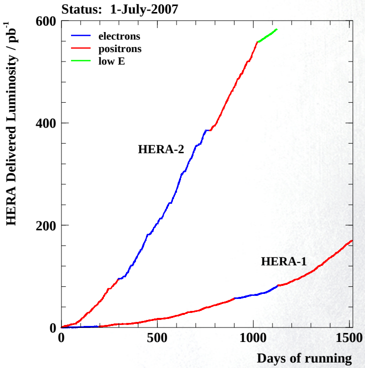
$$\frac{d\sigma_{elas}}{dt}(t, W_{\gamma p}) \sim s^{2(\alpha_{\mathbb{P}}(t)-1)}$$

- in exclusive ρ^0 photoproduction at HERA

HERA $e^{\pm}p$ Collider at DESY

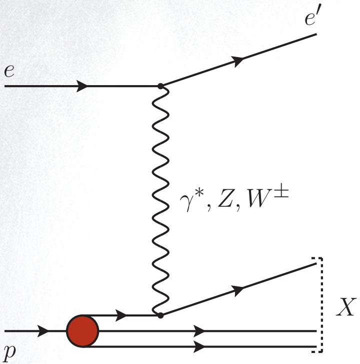


- $E_e = 27.6$ GeV
- $E_p = 920$ (460) GeV
- $\sqrt{s} = 319$ GeV
- $\mathcal{L}_{int} \sim 0.5\ \text{fb}^{-1}$ per experiment



[H1 Collaboration]

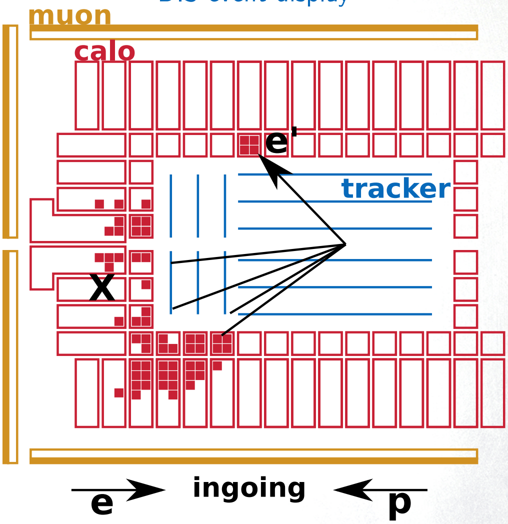
HERA Bread and Butter: Deep Inealstic *ep* Scattering



kinematics:

- $s = (e+p)^2$
- $Q^2 = -q^2 = (e-e')^2$
- Bjorken $x = \dfrac{Q^2}{2p\cdot q}$
- (inelasticity $y \simeq Q^2/sx$)

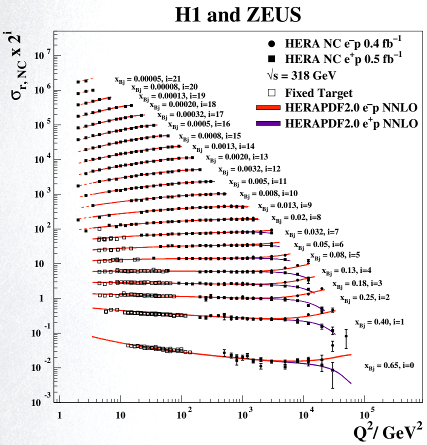
— DIS event display —



$\Rightarrow$ probe proton structure

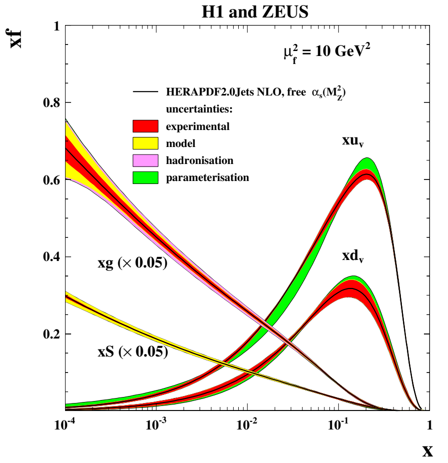
NC: $\frac{d^2\sigma^{e^\pm p}}{dxdQ} \propto \frac{2\pi\alpha^2}{xQ^4}\left((1+(1-y)^2)F_2 - y^2 F_L \mp xF_3\right)$ $\Rightarrow$ structure functions $\leftrightarrow$ pdf: $F_2 \propto x\sum_q f_q + \bar{f}_q$

—— Reduced Neutral Current Cross-Section ——

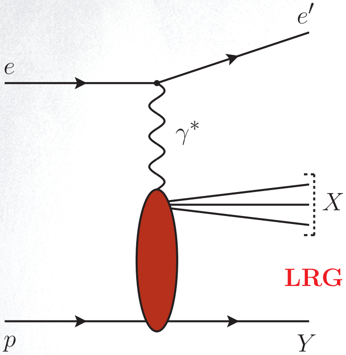


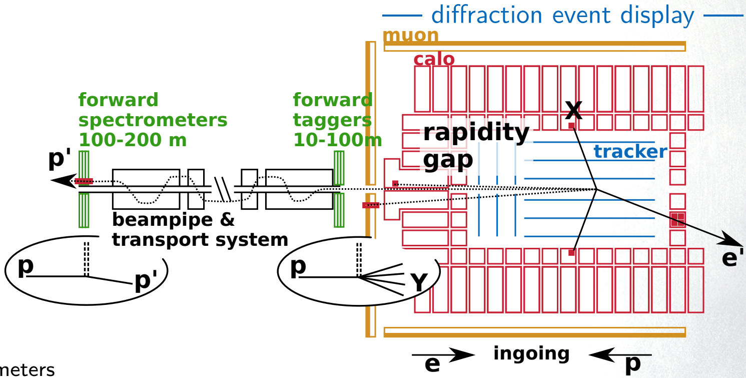
$+\ldots \Rightarrow$

—— PDF ——



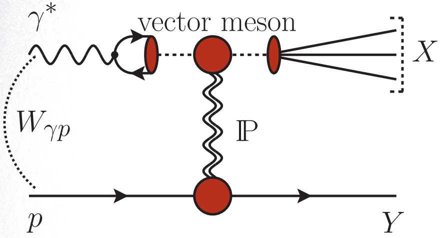
Diffraction at HERA





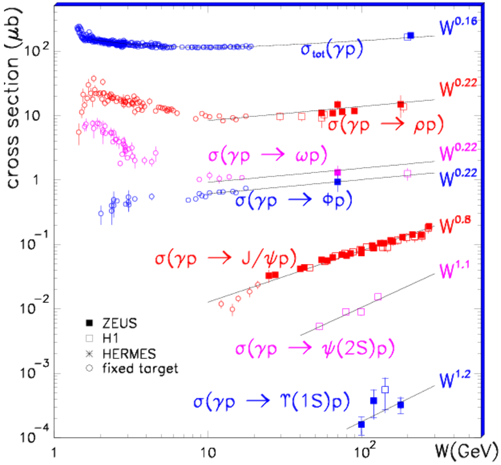
- "elastic scattering": $Y == p$
  → tagging w/ special forward spectrometers
  → exploit beam transport system
- "proton dissociation": $M_Y > m_p$
  → tagging w/ forward detectors $\eta \lesssim 8$

Vector Meson Dominance



- photon $\rightarrow$ $q\bar{q}$ fluctuations $\rightarrow$ bound states
- $J^{PC}(\gamma) = 1^{--}$ $\rightarrow$ vector mesons $(\rho, \omega, \phi, \ldots)$
- "long lifetime" $\rightarrow$ can interact strongly

Vector Meson Photoproduction

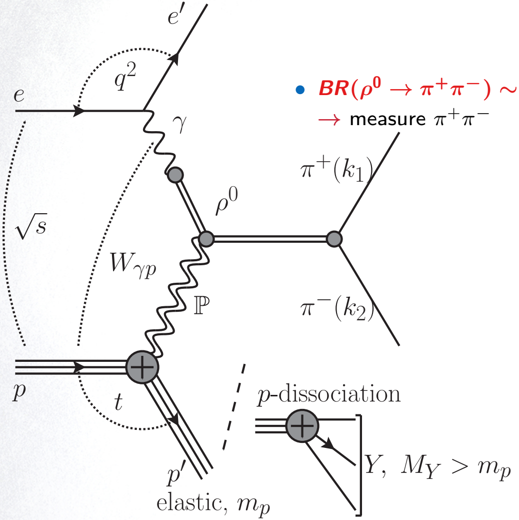


$W = \sqrt{s}$ photon-proton center of mass energy

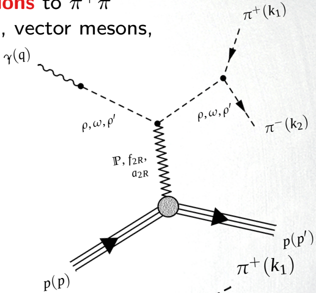
Diffractive $\rho^0 \to \pi^+\pi^-$ Photoproduction at HERA

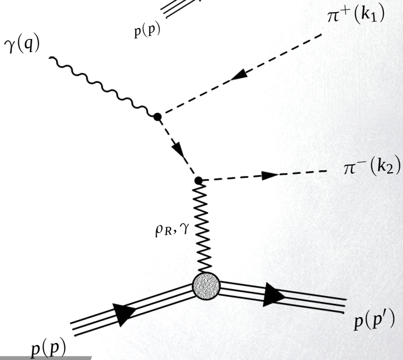
- **electro- $\to$ photoproduction**
  $Q^2 = -q^2 \to 0$ GeV with quasi-real γ

- ***BR*$(\rho^0 \to \pi^+\pi^-) \sim 100\%$**
  $\to$ measure $\pi^+\pi^-$



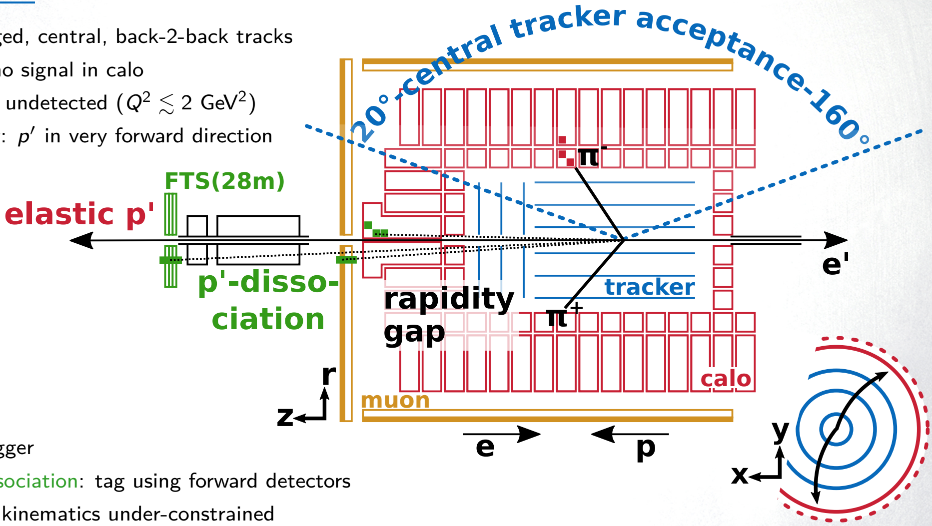
- **other contributions** to $\pi^+\pi^-$
  other exchanges, vector mesons,
  non-resonant, . . .





Event Topology

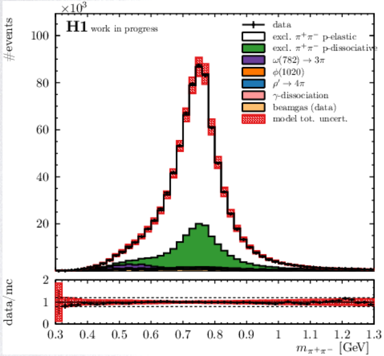
- two oppositely charged, central, back-2-back tracks
- $p_T \lesssim 1$ GeV: often no signal in calo
- photoproduction: e' undetected ($Q^2 \lesssim 2$ GeV^2)
- diffractive scattering: p' in very forward direction



Challenges

- trigger: L1 track trigger
- elastic vs proton-dissociation: tag using forward detectors
- $Q^2 > 0$, $M_Y \neq m_p$: kinematics under-constrained
- tracker acceptance: many (small) backgrounds

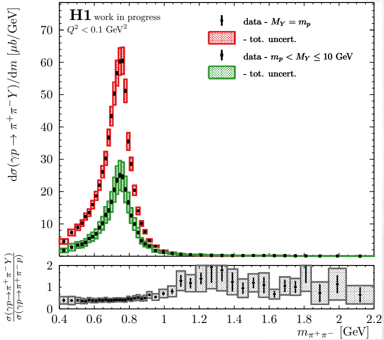
— Reconstructed Events —



— Unfolding — ⇒

- correct efficiency, acceptance, resolution
- subtract backgrounds
- separate elastic/p-dissociation

— $\pi^+\pi^-$ Cross-Section —



- elas. + p-dissoc. signal + backgrounds
- $\sim 7 \cdot 10^5$ selected events

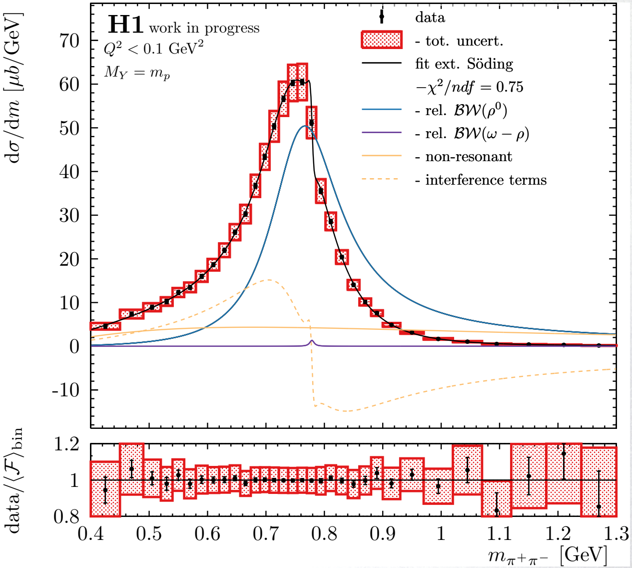
Problem: Irreducible Backgrounds

- small contributions but large interference
- separate via line-shape fits to $m_{\pi\pi}$ (model dependent)
- extract ρ^0 contribution to fit

$$\frac{d\sigma(\gamma p \to \pi^+\pi^- Y)}{dm_{\pi\pi}} \propto \left| A_{\rho,\omega} + A_{non-res} \right|^2$$

$$\Rightarrow \sigma(\gamma p \to \rho^0 Y) \sim \int \left| A_\rho \right|^2 dm_{\pi\pi}$$

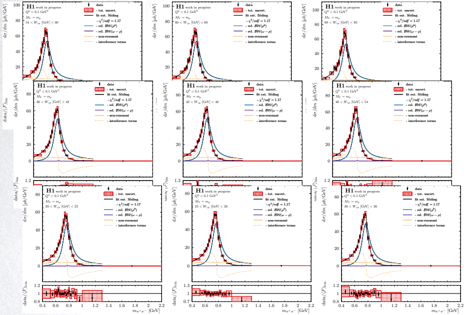
$d\sigma(\gamma p \to \pi^+\pi^- p)/dm_{\pi\pi}$



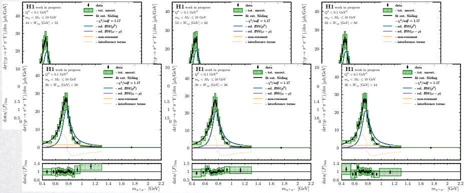
$d\sigma(\gamma p \to \pi^+\pi^- Y)/dm_{\pi\pi}(m_{\pi\pi}; W_{\gamma p}) \to \sigma(\gamma p \to \rho^0 Y)(W_{\gamma p})$

— $d\sigma(\gamma p \to \pi^+\pi^- Y)/dm_{\pi\pi}(m_{\pi\pi})$ —

in 9 elastic $W_{\gamma p}$ bins

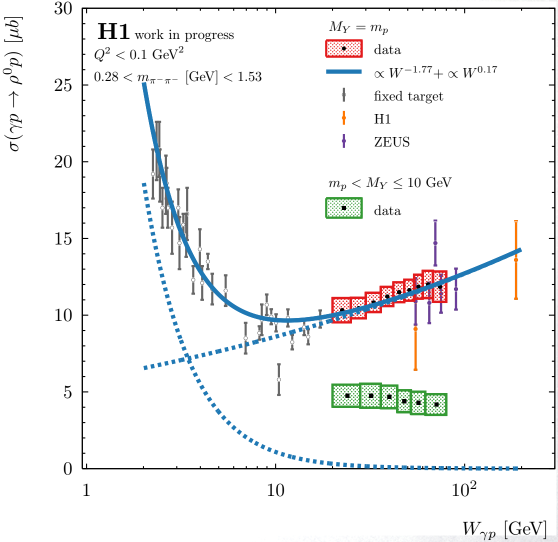


+ 6 p-dissoc. bins



$\Rightarrow$

— $\sigma(\gamma p \to \rho^0 Y)(W_{\gamma p})$ —



$d^2\sigma(\pi^+\pi^-)/dmdt(m_{\pi\pi})$

in $W_{\gamma p}$ and t bins

cannot be shared

$\Rightarrow$

$d\sigma(\gamma p \to \rho^0 p)/dt(W_{\gamma p}, t)$

fit $d\sigma/dt \propto W_{\gamma p}^{4(\alpha(t)-1)}$

cannot be shared

$\Rightarrow$

$\alpha(t)$

cannot be shared

compare next slide

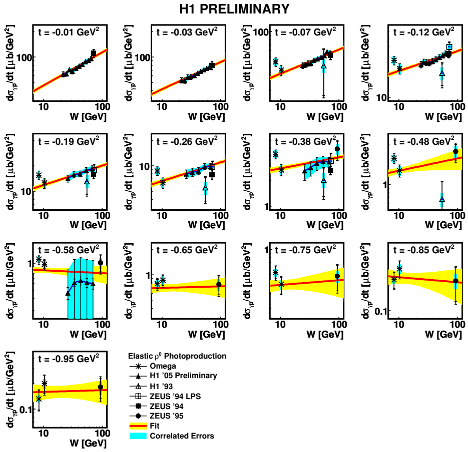
- $\alpha(t)$ also linear in t channel exchange $t < 0$. Compare Chew-Frautchi hadron plots.
- (potential deviations at large $|t|$)

from [H1prelim-09-016]

$d\sigma(\gamma p \to \rho^0 p)/dt(W_{\gamma p}, t)$

$\alpha(t)$

fit $d\sigma/dt \propto W_{\gamma p}^{4(\alpha(t)-1)}$



$\Rightarrow$