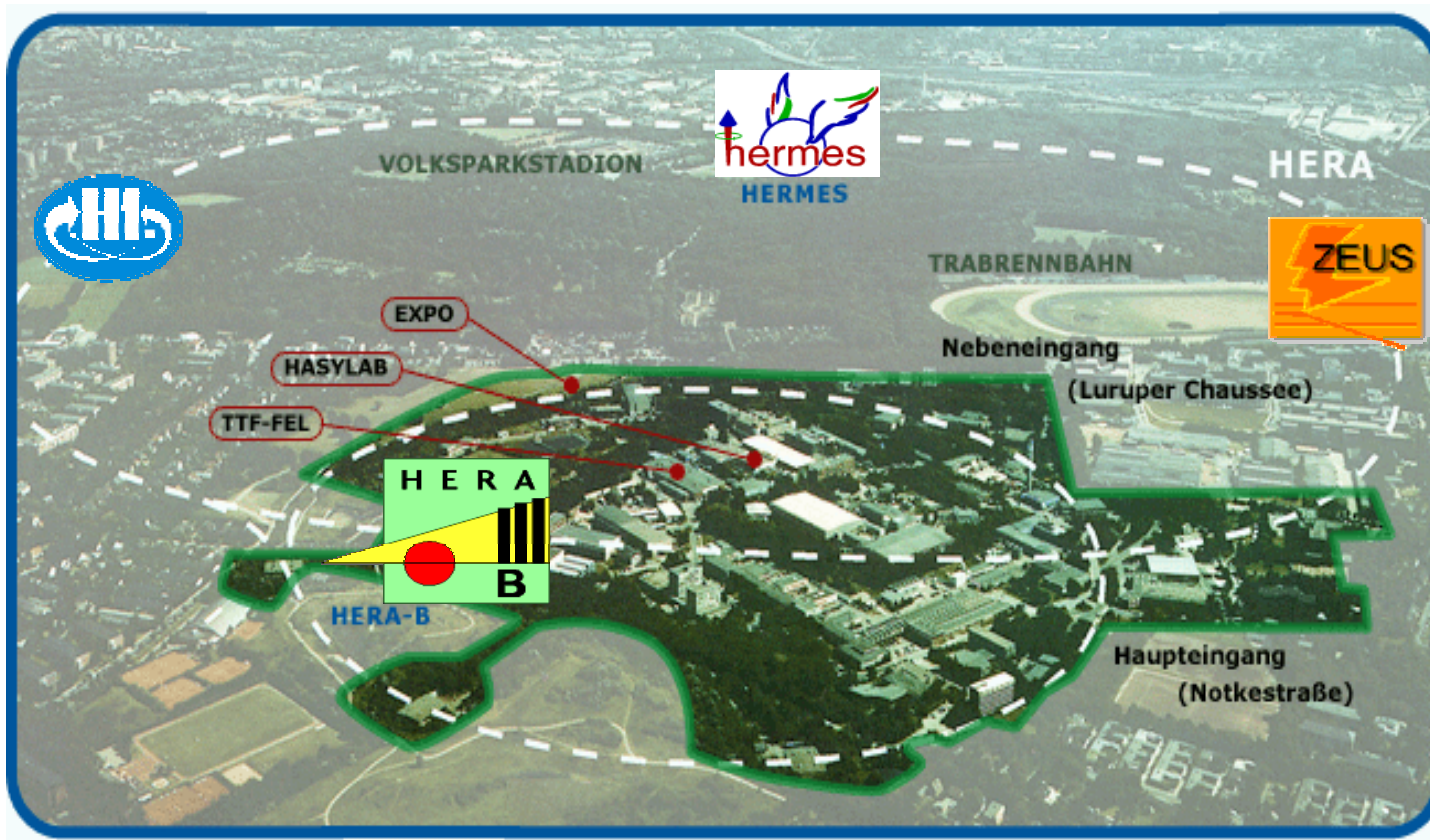


Searches for New Physics at HERA: Highlights

- ☪ What we do NOT see
- ☪ What we MIGHT see
- ☪ What we DO see



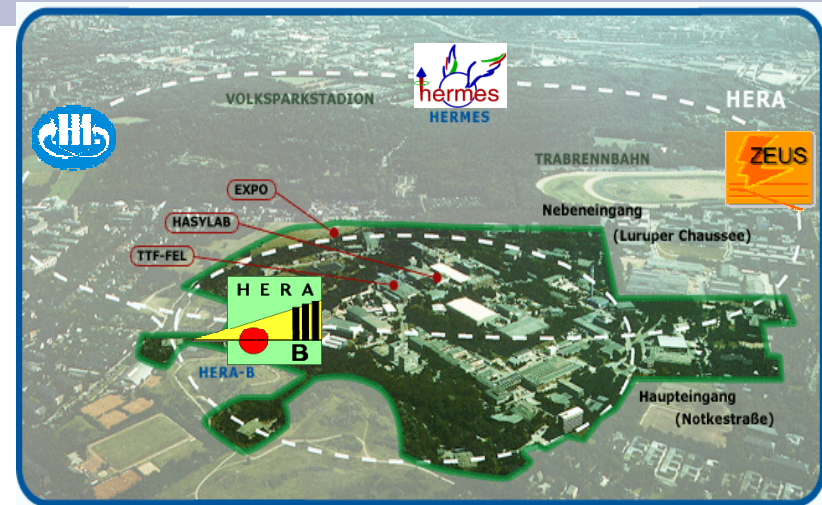
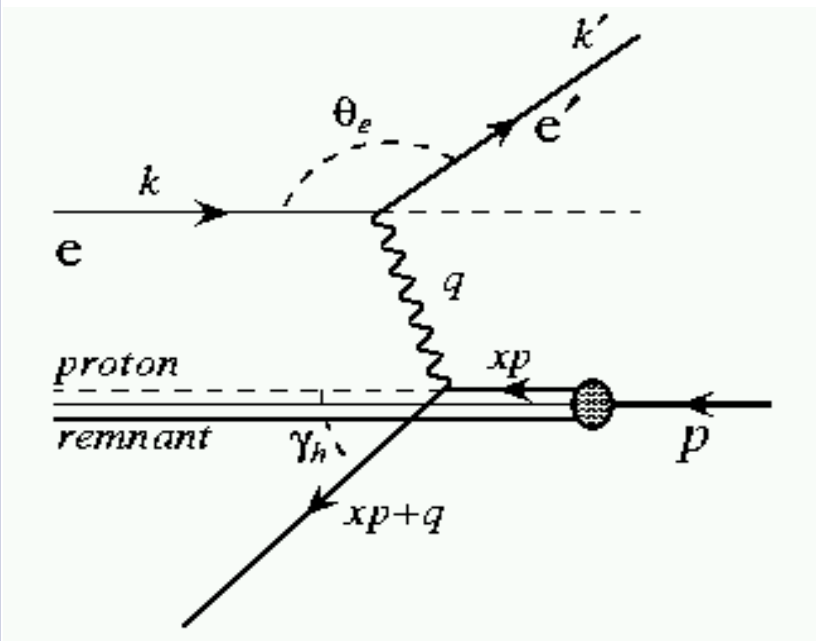
on behalf of
H1, ZEUS,
HERMES and
HERA-B
Collaborations



Short Introduction to HERA

- HERA collides 27.5 GeV e^\pm with 920 (820) GeV protons
 $\sqrt{s} = 320$ (300) GeV

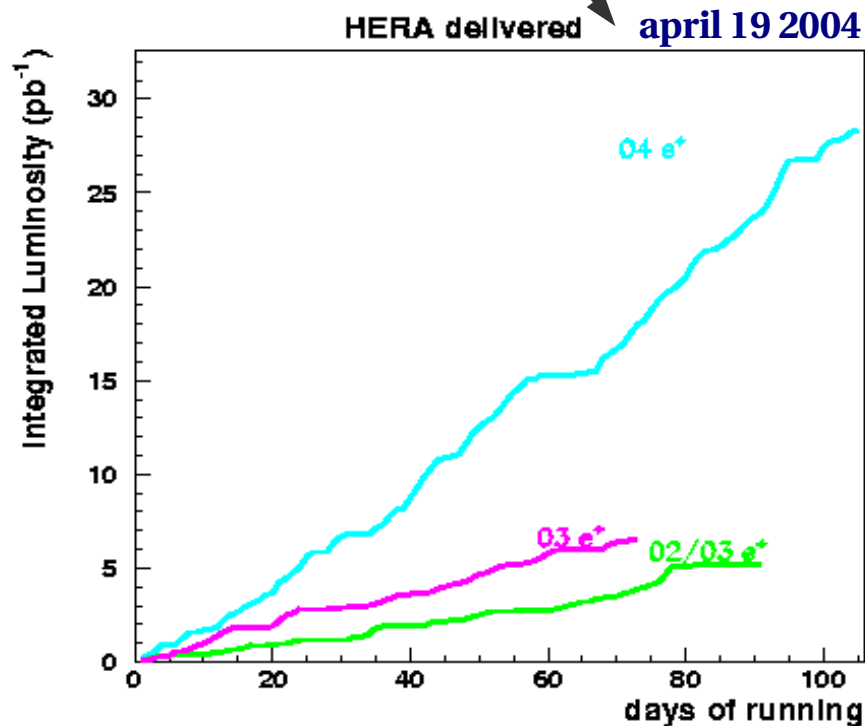
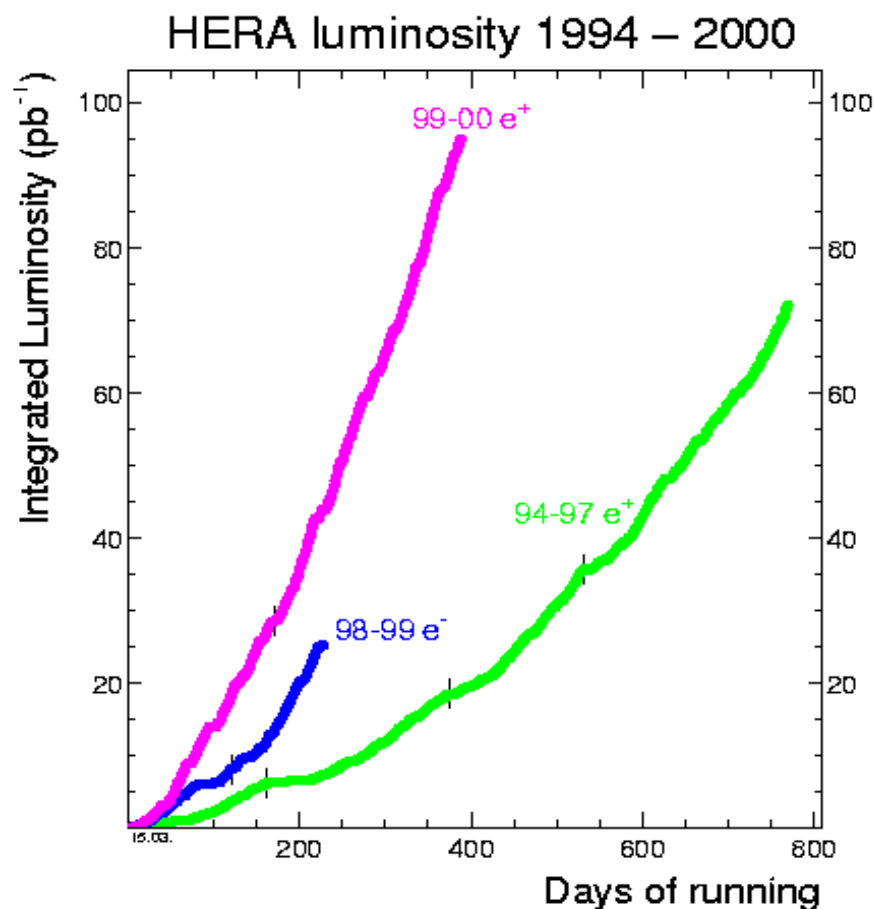
- Example: Neutral Current Exchange



- 2 collider experiments: **H1** and **ZEUS**
- 2 fixed target experiments: **HERMES** and **HERA-B**
- photon virtuality Q^2 :
Deep Inelastic Scattering (DIS):
 $Q^2 > 1 \text{ GeV}$
Photoproduction (PhP):
 $Q^2 < 1 \text{ GeV}$
- Bjorken x
- $\gamma^* p$ center-of-mass energy: W

HERA I & HERA II

- HERA II – collider upgrade to get more luminosity ($\sim 0.75 \text{ fp}^{-1}$)
- Polarized e^\pm beam
- Detectors also upgraded
- Data coming in



New Physics Searches @ HERA I

Searches for new Resonances or Contact-Interactions:

- Leptoquarks
- Lepton Flavor Violation
- **Contact Interactions**
- Extra Dimensions
- **Quark Radius**
- Excited Fermions
- SUSY in MSSM R_p conserving model
- SUSY in R_p violating model

Exclusive final states:

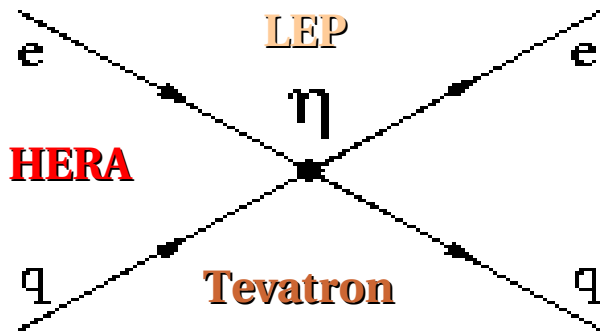
- **Isolated leptons (e, μ, τ) and missing p_T**
- **Single top limits**
- **Multi-leptons events**
- Double-charged Higgs limits
- **General search**
- Magnetic Monopoles
- **Pentaquarks**

in orange topics covered by this talk

HERA II (so far) \rightarrow **general search, isolated leptons with missing p_T , multi-leptons events**

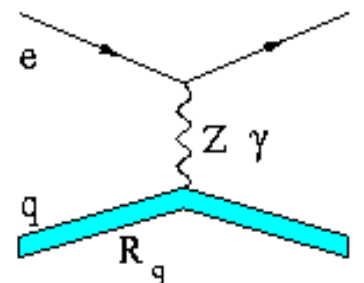
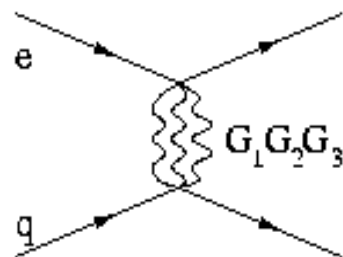
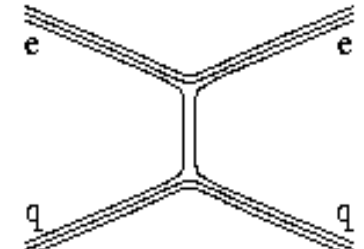
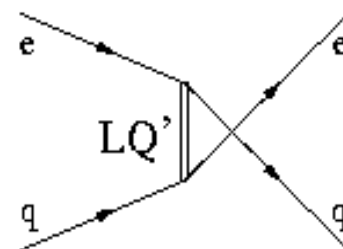
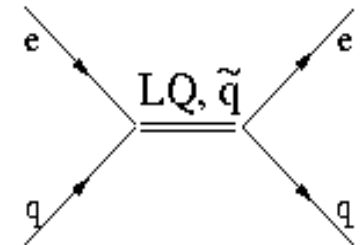
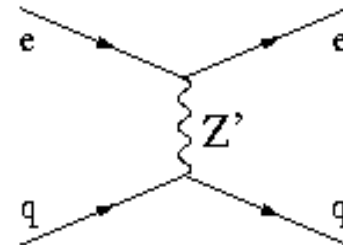
Contact Interactions

$$\mathcal{L}_{CI} = \sum_{\alpha, \beta=L,R}^q \eta_{\alpha\beta}^{eq} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha) (\bar{q}_\beta \gamma_\mu q_\beta)$$



Complementary to LEP and Tevatron

- Leptoquarks
- General Contact Interactions
- Large Extra Dimensions
- Quark Radius

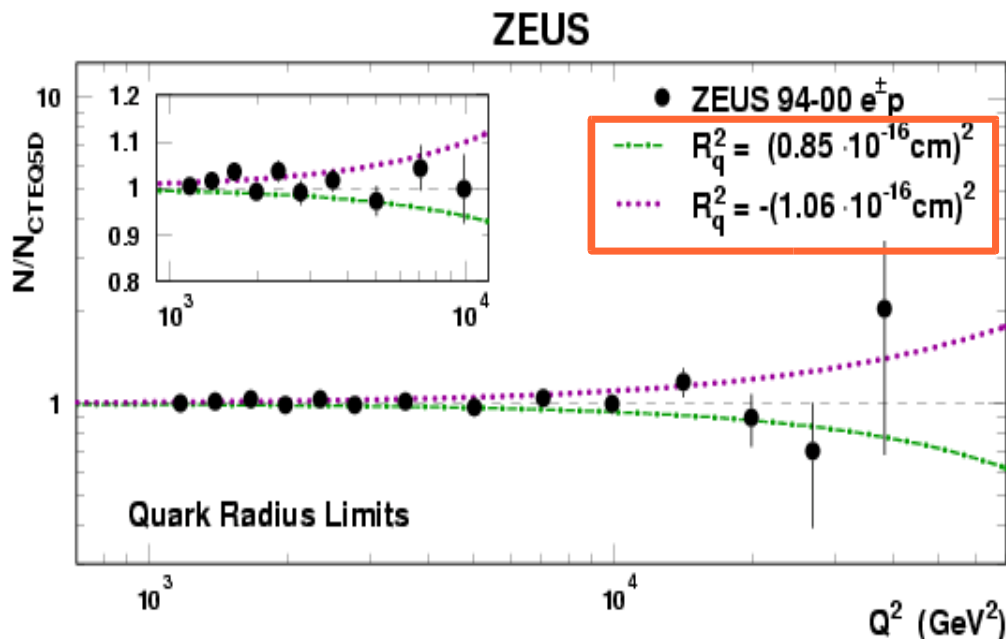


Contact Interactions: quark radius

Example: Limits on quark radius

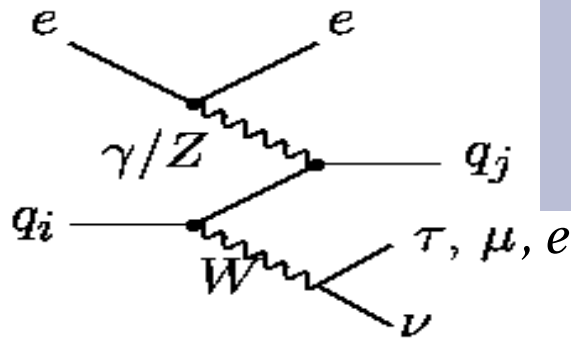
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \left(1 - \frac{R_q^2}{6} Q^2 \right)^2$$

$$R_q < 1.0 \times 10^{-16} \text{ cm (H1)}$$



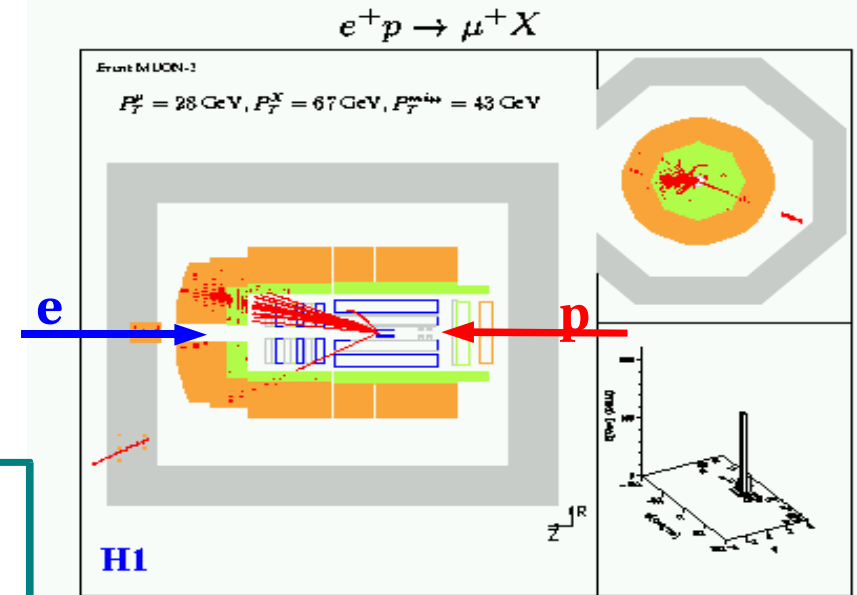
Similar limits from
H1 and **ZEUS**, of
the order of
 $1 \times 10^{-16} \text{ cm}$

Isolated leptons with missing p_T



- Isolated lepton (e, μ, τ) with high p_T , p_T^{miss} and jet (p_T^X)
- Main SM process – W production

spectacular event found in H1 detector:



Total HERA I data sample, e^+p



118.4 pb⁻¹

	Electrons		Muons	
	obs.	SM (W^\pm)	obs.	SM (W^\pm)
Total	11	11.54±1.5 (71%)	8	2.94±0.5 (86%)
$p_T^X > 40$ GeV	3	0.66±0.13 (80%)	3	0.64±0.14 (92%)

130 pb⁻¹



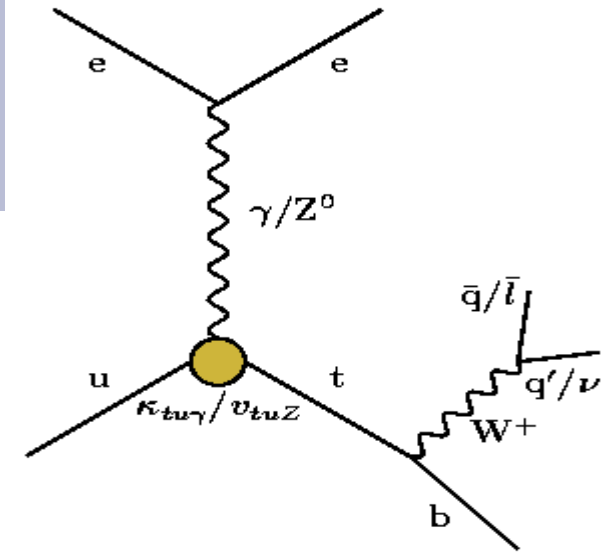
	Electrons		Muons	
	obs.	SM (W^\pm)	obs.	SM (W^\pm)
Total	24	20.6±1.7 (17%)	12	11.9±0.7 (16%)
$p_T^X > 40$ GeV	0	0.94±0.1 (61%)	0	0.95±0.14 (61%)

- H1: excess of events with high p_T^X
- no excess in hadronic channel
- ZEUS in agreement with SM

Single Top Production

Is excess of events in e^+p collisions with high p_T^X a sign of new physics?

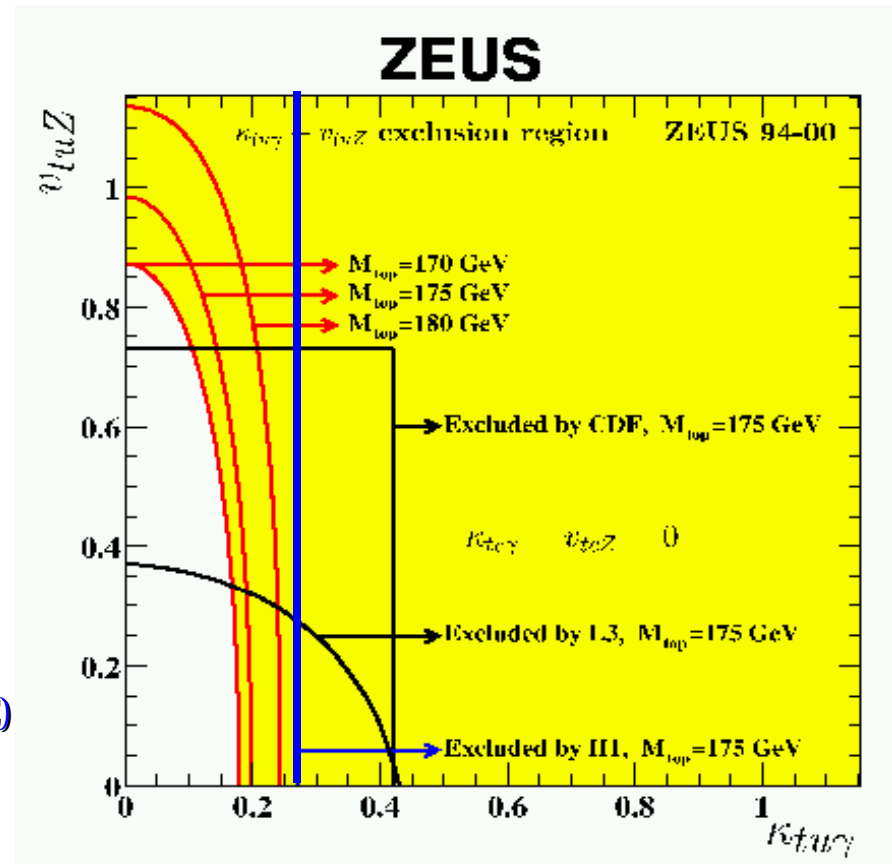
- Single top production via anomalous magnetic and vector FCNC top coupling $k_{tu\gamma}, v_{tuZ}$



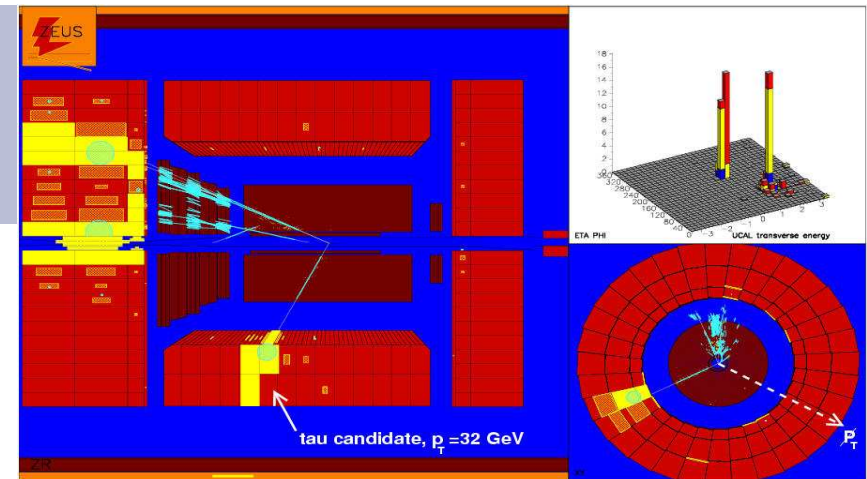
- selection cuts optimized for single top search
- ZEUS does not see any excess in leptonic or hadronic channel
- H1 see excess in leptonic channel
5 events (3e, 2μ, SM: 1.31 ± 0.22)
- H1: no excess in hadronic channel

limits on couplings and cross section set

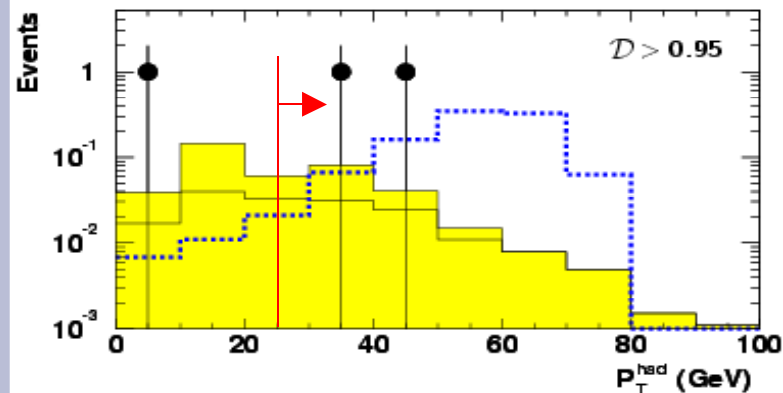
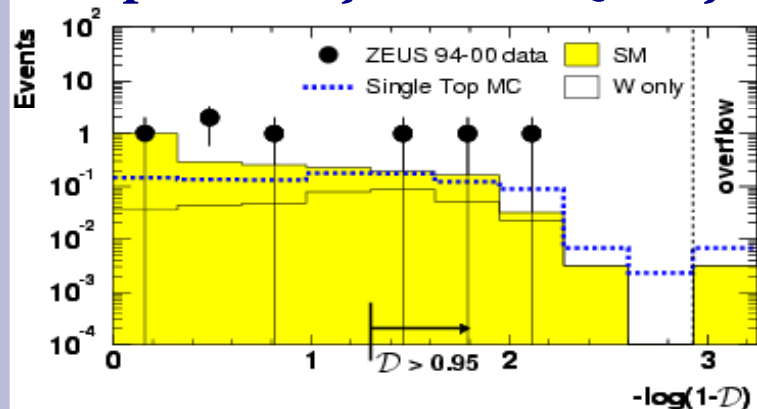
- H1: $\sigma(ep \rightarrow et X) \sim 0.29 + 0.15 / - 0.14$ pb (if FCNC)
- ZEUS: $\sigma(ep \rightarrow et X) < 0.225$ pb @ 95% CL



Isolated Taus



- ZEUS uses multivariate technique to separate τ -jets from QCD-jets

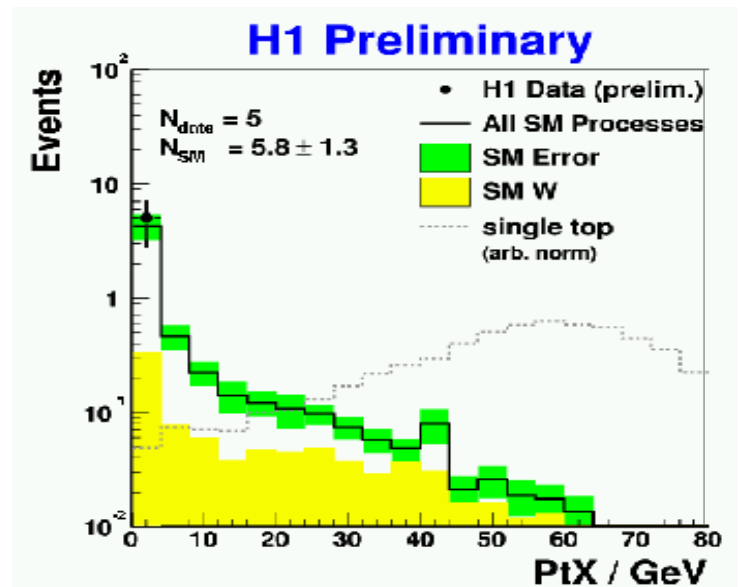


ZEUS:

- 3 events observed, $0.40 +0.12 -0.13$ expected
- for $p_T^X > 25$ GeV: **2 observed, 0.20 ± 0.05 exp.** (probability 1.8%)

H1 (new preliminary):

- 5 events observed, 5.81 expected
- for $p_T^X > 25$ GeV: **0 observed, 0.53 exp.**



Isolated Leptons: Summary



1994-2000 ep 118 pb ⁻¹ Full Sample	Electron observed / expected 11 / 11.54	Muon observed / expected 8 / 2.94	Tau (108 pb ⁻¹) observed / expected 5 / 5.81
P _T X > 25 GeV	5 / 1.76	6 / 1.68	0 / 0.53
P _T X > 40 GeV	3 / 0.66	3 / 0.64	0 / 0.22



1994-2000 ep 130 pb ⁻¹ Full Sample	Electron observed / expected 24 / 20.6	Muon observed / expected 12 / 11.9	Tau observed / expected 3 / 0.40
P _T X > 25 GeV	2 / 2.9	5 / 2.75	2 / 0.20
P _T X > 40 GeV	0 / 0.94	0 / 0.95	1 / 0.07

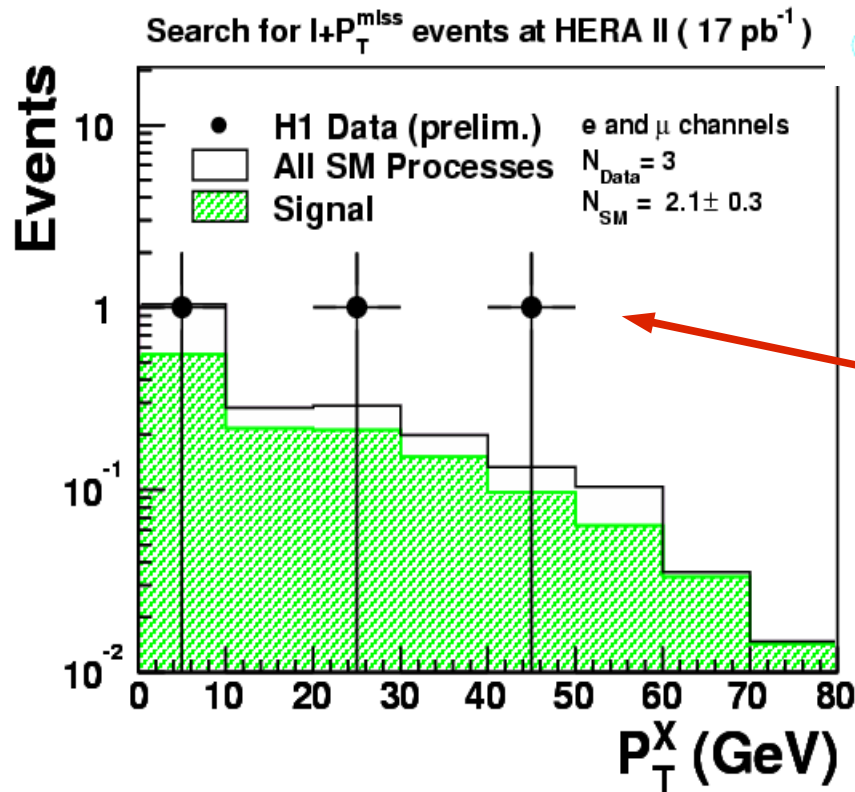
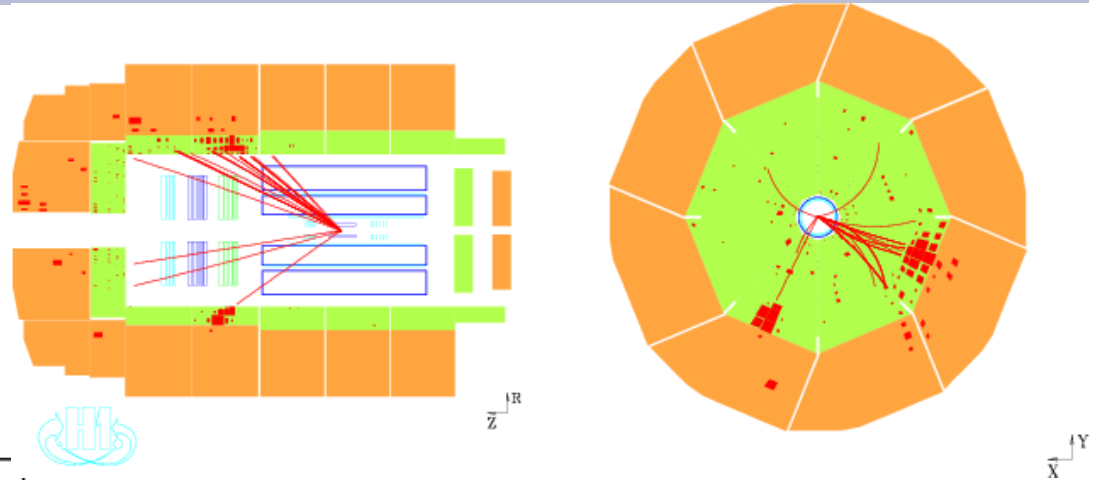
Where do we go from here?

→ **more data needed: HERA II**

H1 started to look into new data!

Isolated Leptons – HERA II

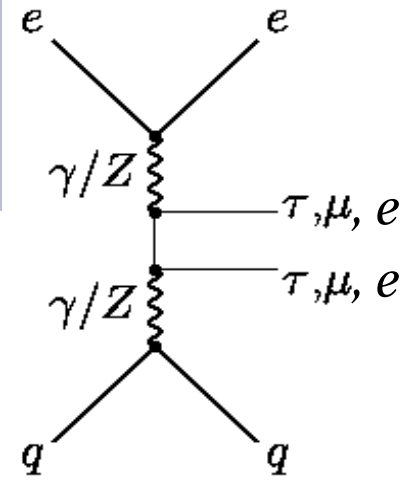
with 17 pb^{-1} H1 starts to see isolated leptons again



no excess so far

- **seen:**
 - **3 electrons** (expected 1.61 ± 0.29)
 - **0 muons** (expected 0.44 ± 0.32)

Multi-electrons



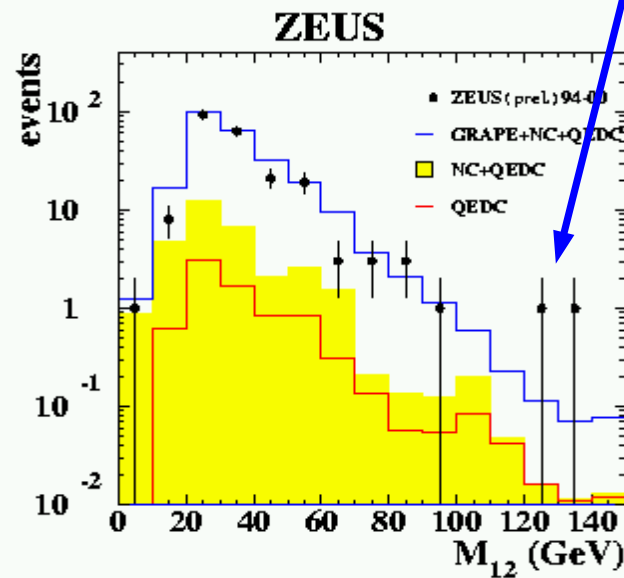
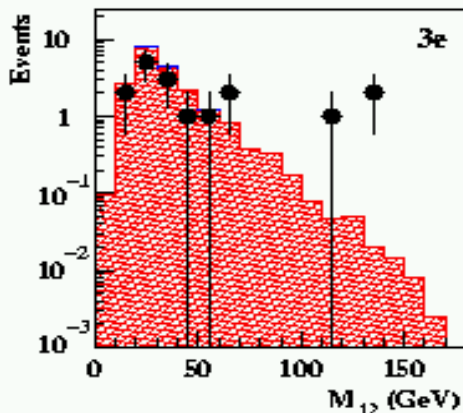
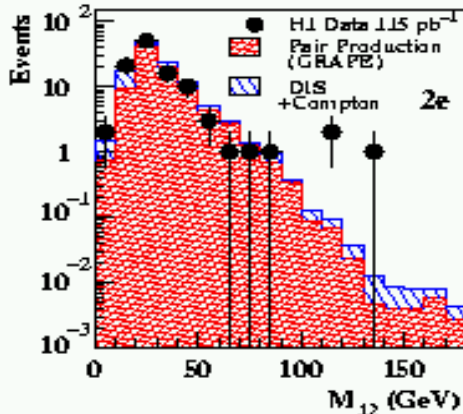
- at least 2 isolated high p_T leptons
- 100-200 events selected
- overall good agreement with SM
- **excess in H1 data for high mass** →
- → **6 outstanding events with $M_{12} > 100$ GeV**

[H1, Eur. Phys. J. C31(2003),17]

H1 (115 pb ⁻¹)	Data	SM
2e	3	0.30 ± 0.04
3e	3	0.23 ± 0.04

[ZEUS, Preliminary]

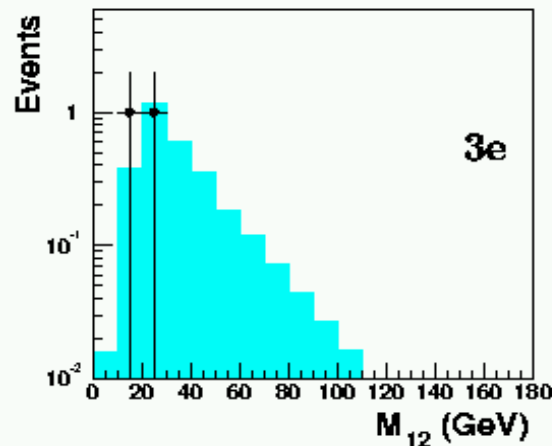
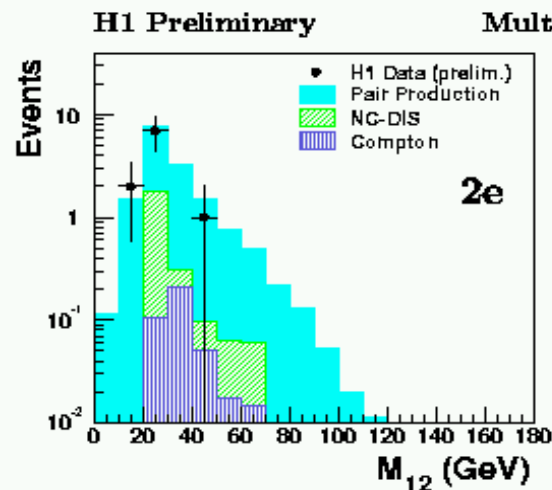
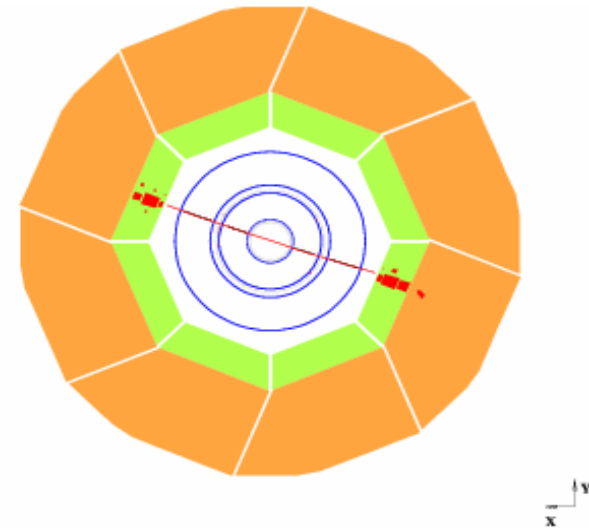
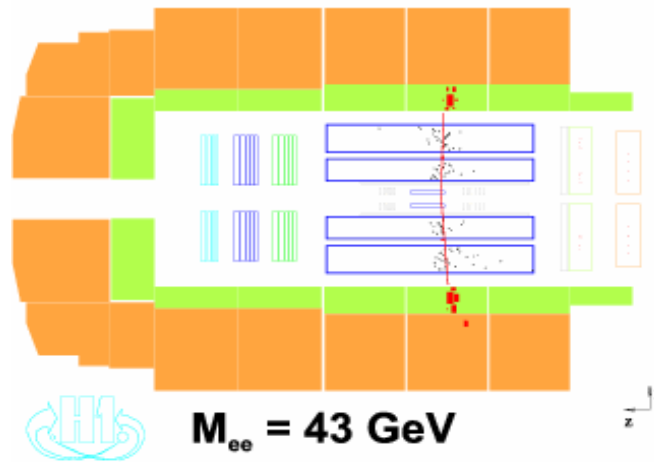
ZEUS (130 pb ⁻¹)	Data	SM
2e	2	0.77 ± 0.08
3e	0	0.37 ± 0.04



good agreement with SM for di-muons and di-taus (new H1 preliminary)

Multi-electrons: HERA II

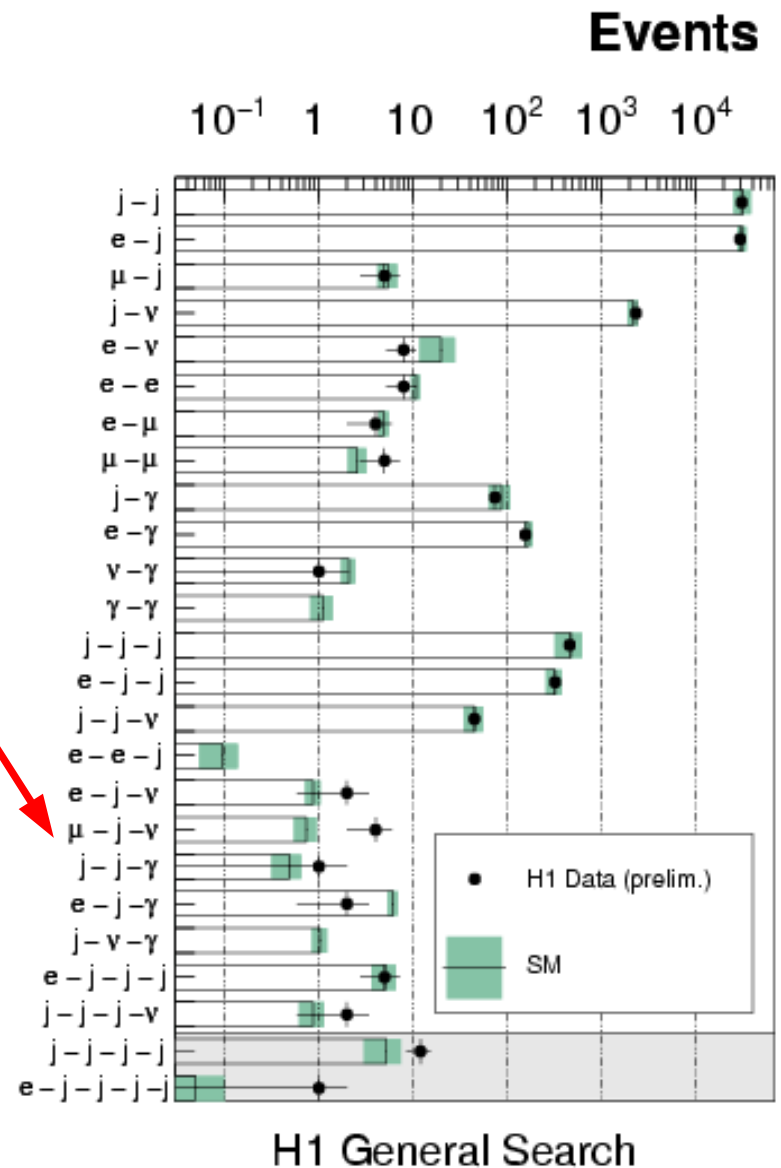
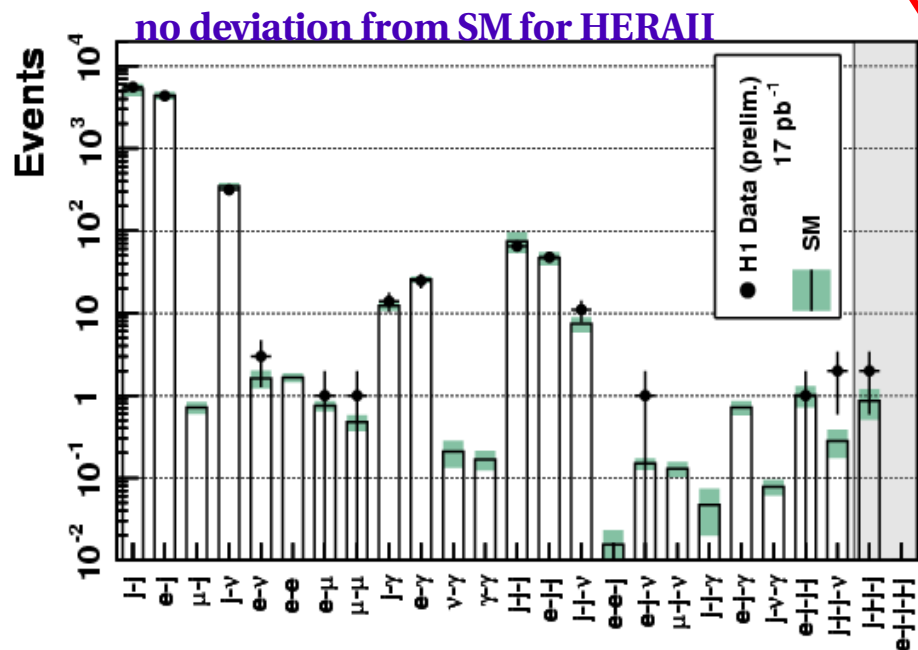
H1 looked for multi-electrons with 17 pb⁻¹ of HERA II data



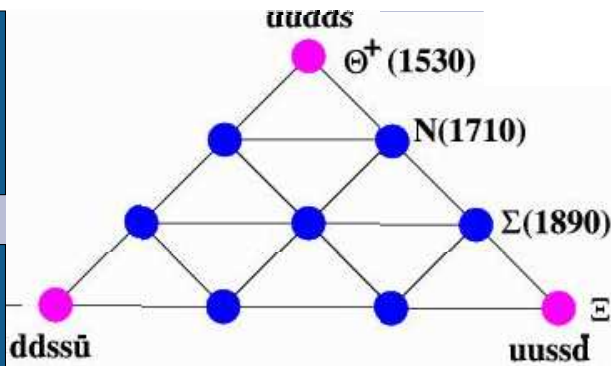
- data in agreement with SM
- no high mass events YET

General Search

- **Object: $e, \mu, \gamma, \nu, \text{jet}$**
- **common phase-space:**
 - $p_T(\text{object}) > 20 \text{ GeV}$
 - $10 < \theta(\text{object}) < 140$
 - isolation: $R_{\eta\phi}(\text{object}) > 1.0$
- **consider topologies with 2 or more objects**
- **search for deviation from SM**



θ^+ Strange Pentaquark

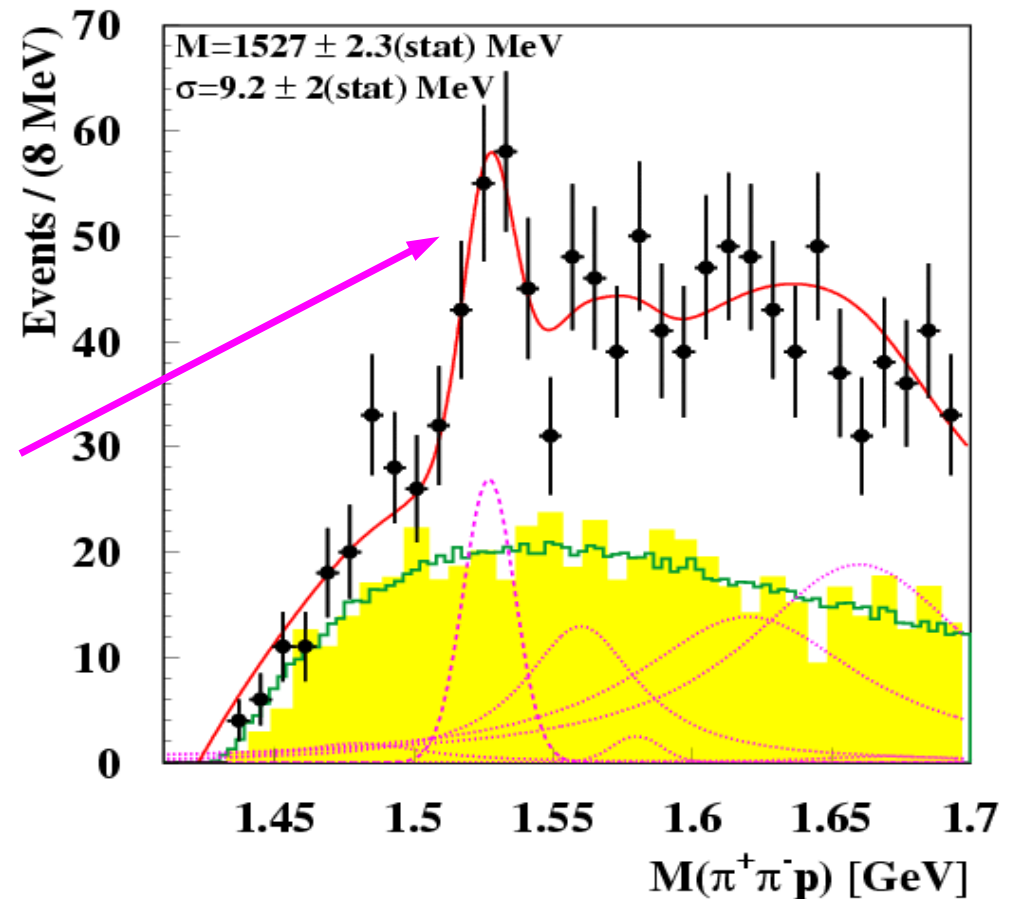


- protons and pions identified by RICH
- K_s reconstructed using decay length
- $p\pi^-$ events from $\Lambda(1116) \pm \sigma$ range excluded
- resonance in $K_s p \rightarrow \pi^+ \pi^- p$

invariant mass observed at

1527 ± 2.3 (stat) ± 2.1 (syst) MeV

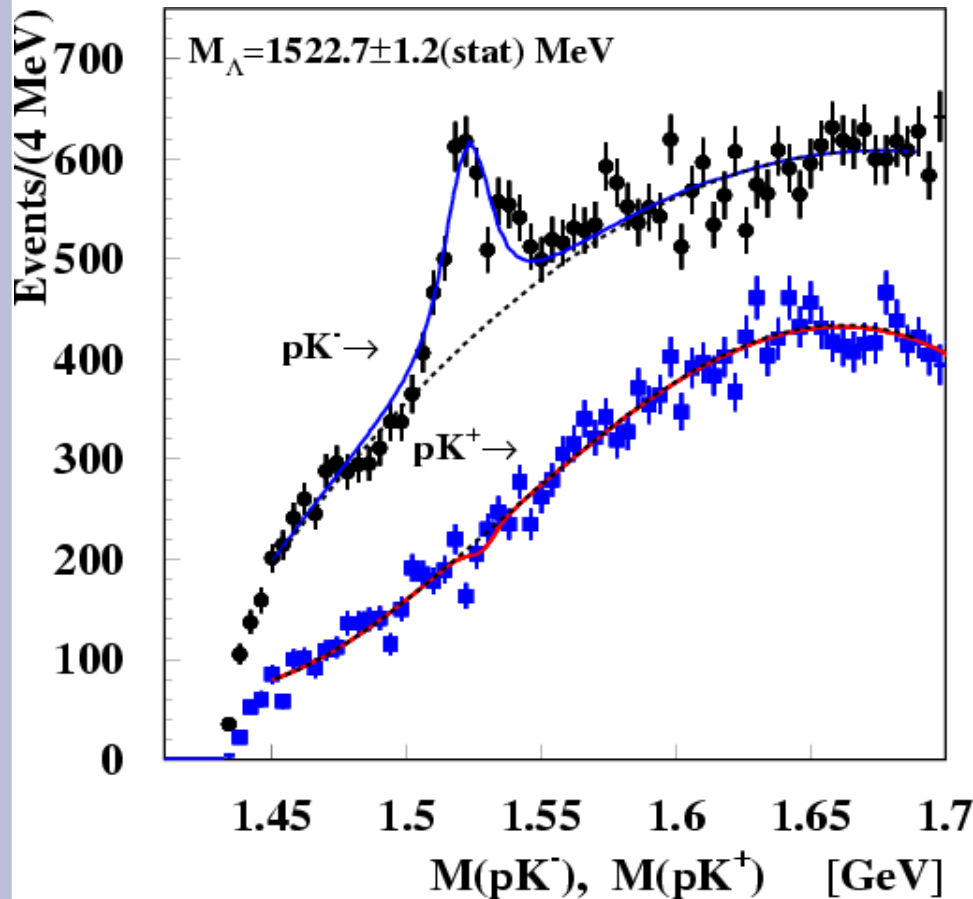
- width:
 22 ± 5 (stat) ± 2 (syst) MeV
dominated by exp. resolution





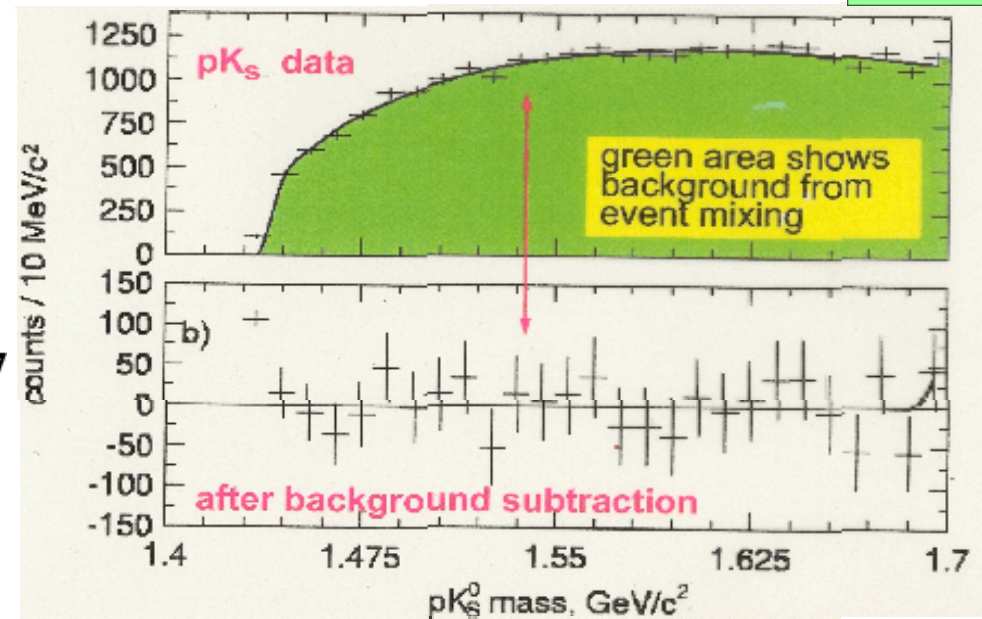
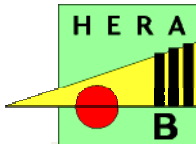
θ^+ Strange Pentaquark

no peak for θ^{++} in K^+p



- if no $\theta^{++} \rightarrow \theta^+$ probably isosinglet

- no statement from H1 yet
- no peak in $K_s p$ final state found by HERA-B (hep-ex/0403020)

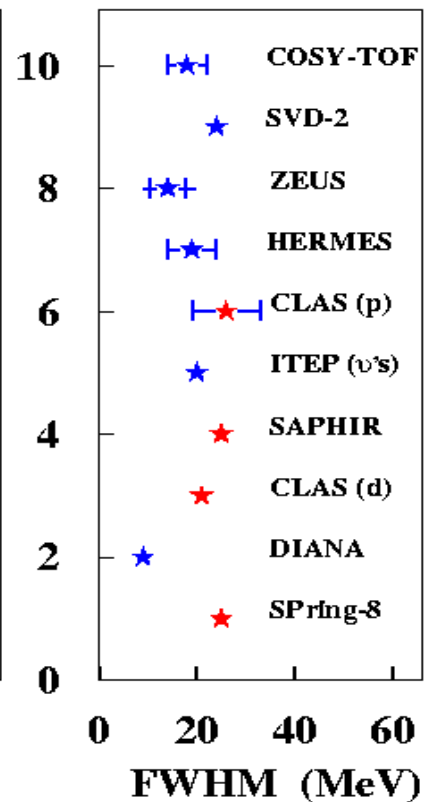
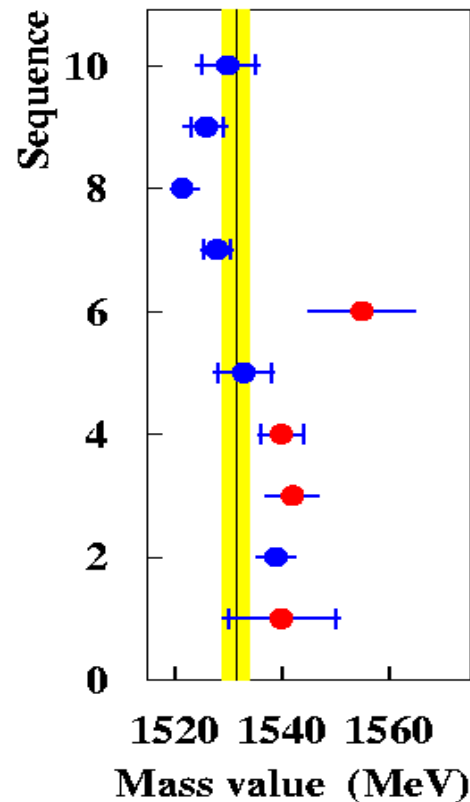
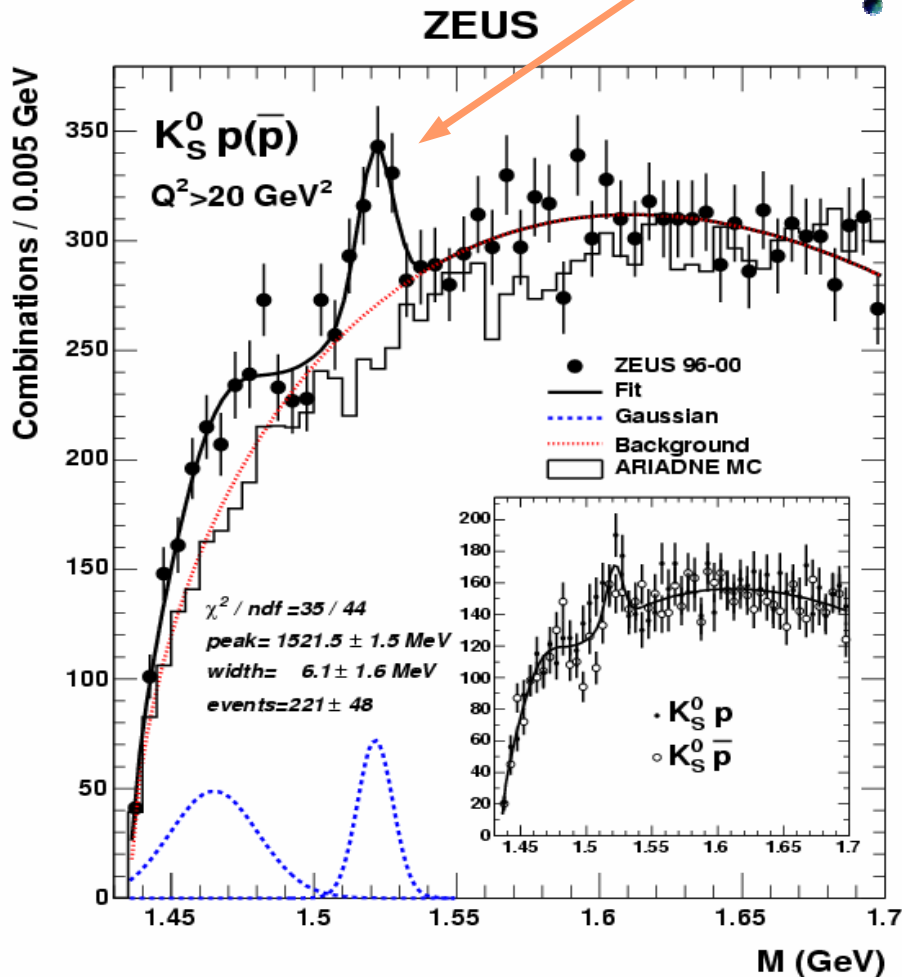


θ^+ : Strange Pentaquark

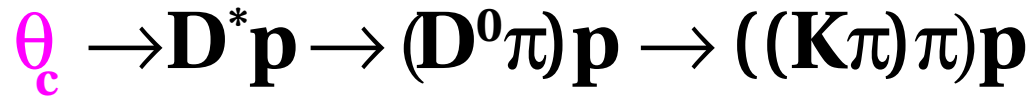


- $Q^2 > 20 \text{ GeV}^2$
- p/\bar{p} identified by dE/dx
- K_S^0 reconstructed from decay to $\pi^+ \pi^-$

- resonance observed at **$1521.5 \pm 1.5 \text{ (stat)} + 2.8/-1.7 \text{ (syst) MeV}$**
- width **2 MeV** consistent exp. resolution
- probability of fluctuation (1500-1560 MeV) below 6×10^{-6}
- no peak for θ^{++} in $K^+ p$

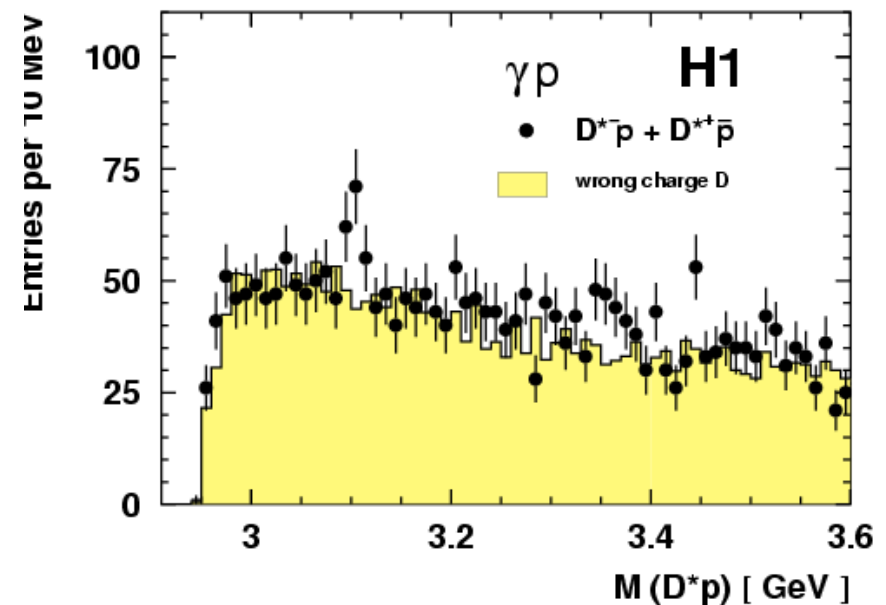
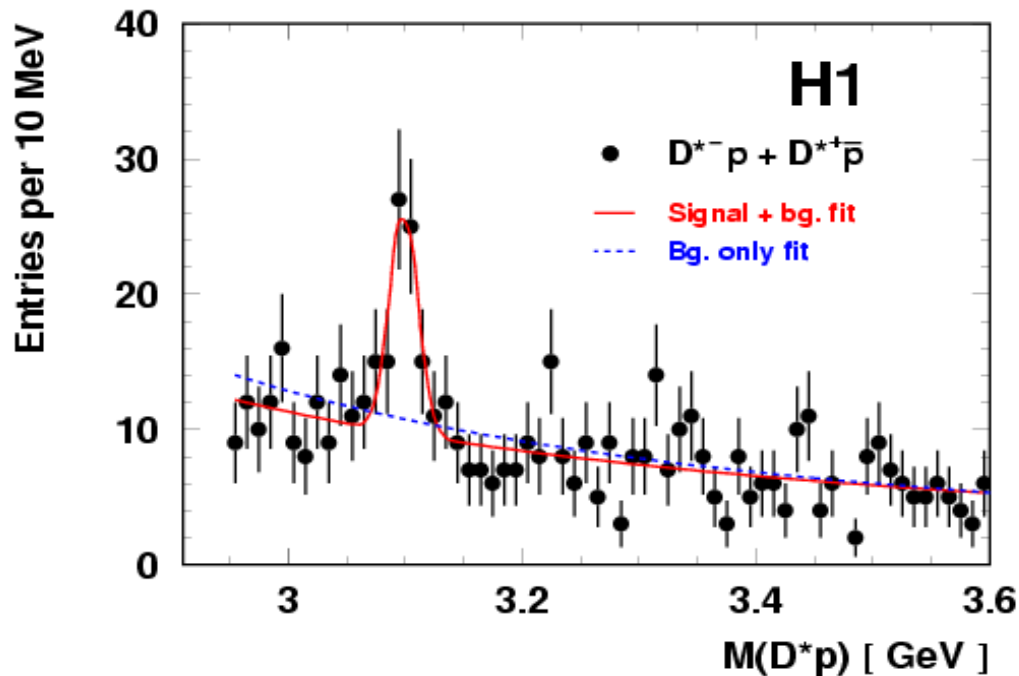


Θ_c : Charmed Pentaquark

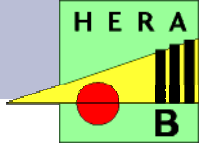


- resonance in $D^* p$ invariant mass observed in DIS at
 3099 ± 3 (stat) ± 5 (syst) MeV
- width:
 12 ± 3 (stat) MeV
consistent with exp. resolution

signal visible also in
photoproduction sample

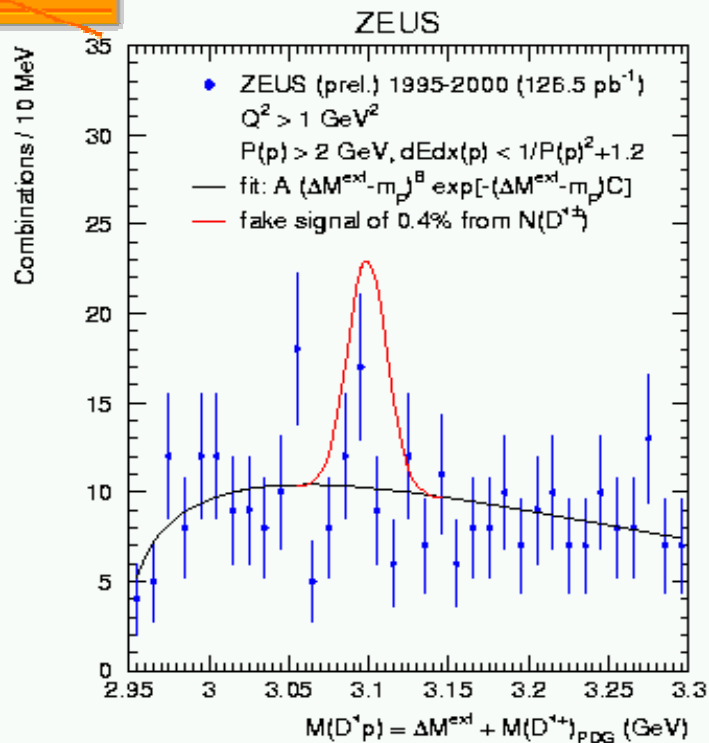


Pentaquarks @ HERA



$$\theta_c \rightarrow D^* p$$

- ZEUS searched for the same state
- no resonance found



- ZEUS and HERA-B: no signal for Ξ^- in $\Xi - \pi^-$ invariant mass spectrum

Pentaquarks @ HERA

- HERMES and ZEUS observe θ^+ and no θ^{++}
 - no confirmation from HERA-B
- H1 observes θ_c
 - no confirmation from ZEUS
- ZEUS and HERA-B does not see Ξ^{--}
- **situation not clear...**

Summary

- HERA performs wide range of searches for physics BSM
- **No evidence for new physics found yet**
- **Some very interesting results:**
 - **Excess of H1 isolated high- p_T electrons and muons**
 - **Excess of ZEUS isolated high- p_T taons**
 - **Excess of multi-electrons events seen by H1**
 - **θ^+ pentaquark observed by HERMES and ZEUS (no θ^{++})**
 - **θ_c pentaquark observed by H1**
 - **lack of Ξ^- pentaquark observed by ZEUS and HERA-B**
- **HERA II delivers data, new results coming in, stay tuned...**