Searches and Signals of new physics at HERA

Les Rencontres de Physique de la Vallée d'Aoste

La Thuile, Aosta Valley, Italy,

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on behalf of H1 and ZEUS collaborations

Beyond SM searches at HERA I

Searches for new Resonances or Contact-Interactions

- Leptoquark
- Lepton Flavour Violation
- Contact Interaction
- Extra-dimension
- Quark Radius
- Excited Fermion
- SUSY in MSSM R_p conserving model
- SUSY in R_p violating model

Exclusive final states

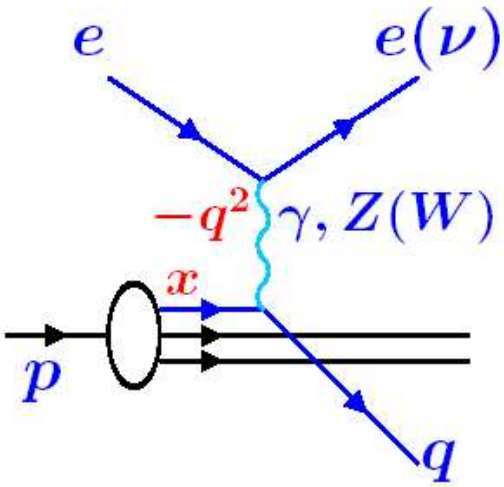
- Isolated e, μ, τ and missing p_T
- Single-top limits
- Multi electron, multi muon events
- Doubly-charged Higgs limits
- General search
- Magnetic Monopoles

Non standard barions

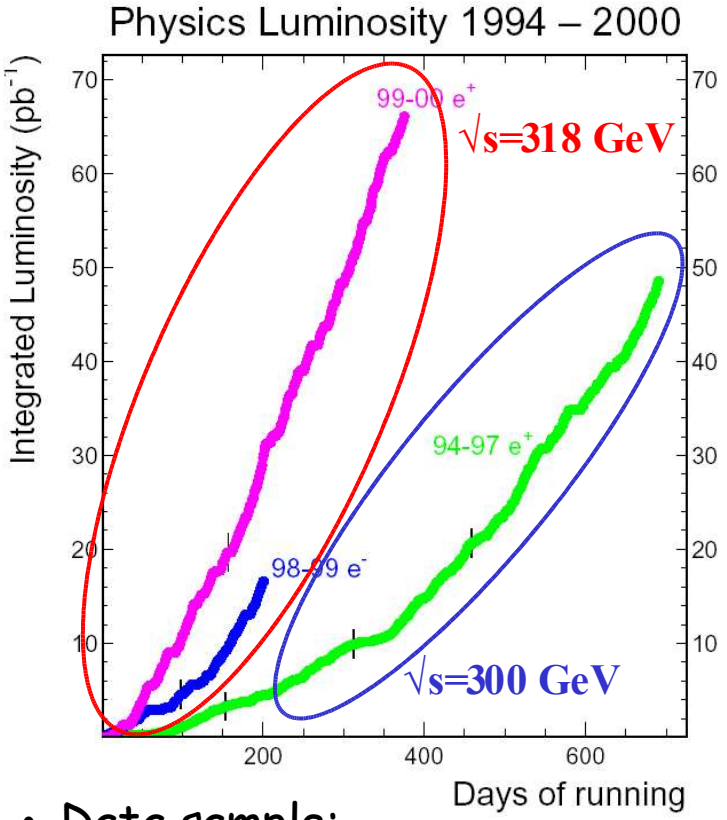
- K^0p resonances

In red the topics covered in this talk

HERA kinematics and luminosity



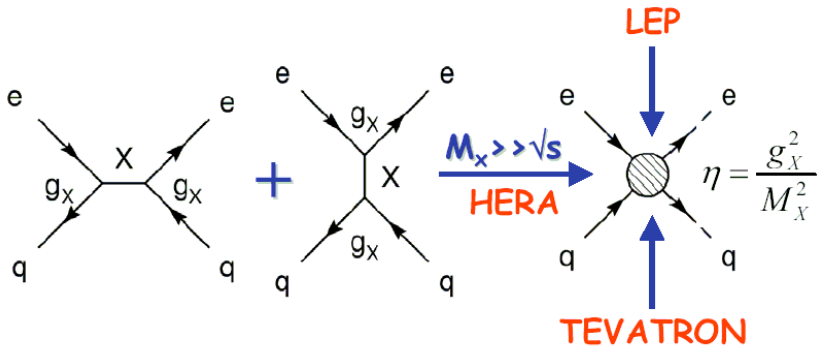
- $Q^2 = -q^2$ four momentum transfer
- $x = Q^2/2pq$ quark momentum fraction of the proton
- y energy transferred from lepton to γ
- $s = Q^2/xy$ (ep CM energy)^2

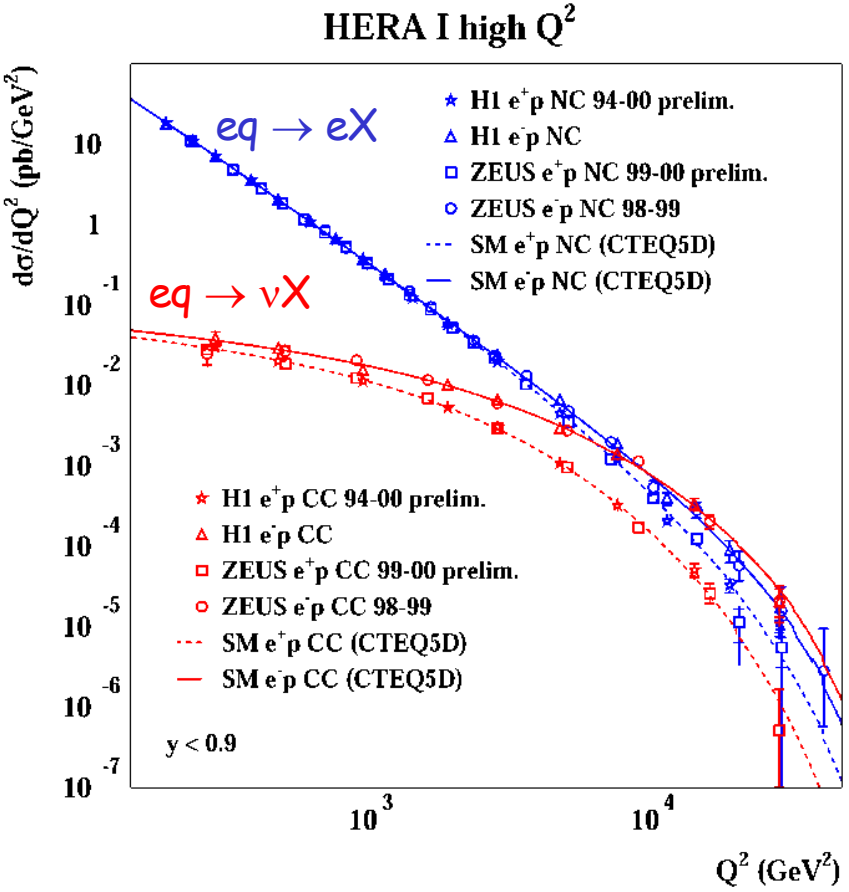


- Data sample:
  - e^+p @ $\sqrt{s}$=300 GeV : 40 pb^{-1}
  - e^+p @ $\sqrt{s}$=318 GeV : 66 pb^{-1}
  - e^-p @ $\sqrt{s}$=318 GeV : 16 pb^{-1}
- Two experiments: ZEUS, H1

Contact Interaction: Introduction

- Large Q^2 covered by HERA up to $4 \cdot 10^4$ GeV^2
- New physics would produce deviations from SM prediction at high Q^2





CI: Quark radius form factor

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

$R_q < 0.85 \times 10^{-16}$ cm (ZEUS)

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

CI: Compositeness

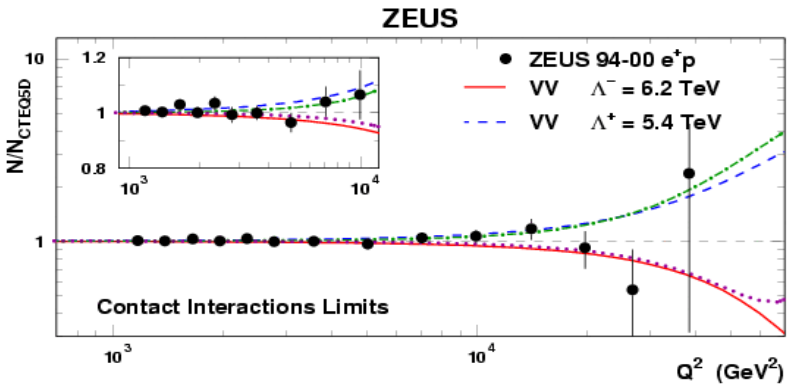
Effective Lagrangian: (vector term only)

$$\eta_{ij}^{q} = \pm\epsilon_{ij}\frac{4\pi}{\Lambda^2}$$

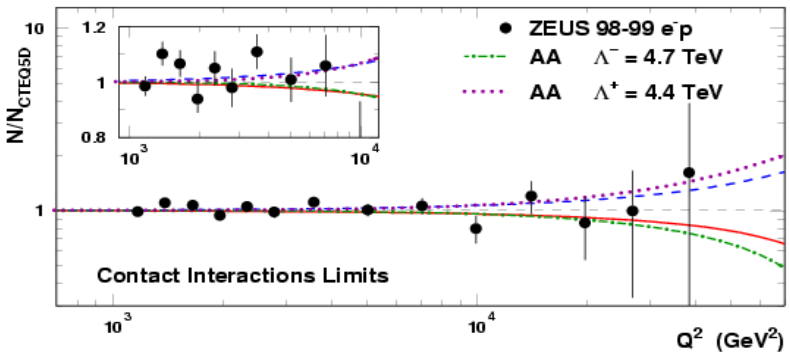
$$L = L_{SM} + \sum_{q=u,d}\sum_{i,j=L,R}\eta_{ij}^{q}\left(\bar{e}_i\gamma^{\mu}e_i\right)\left(\bar{q}_j\gamma_{\mu}q_j\right)$$

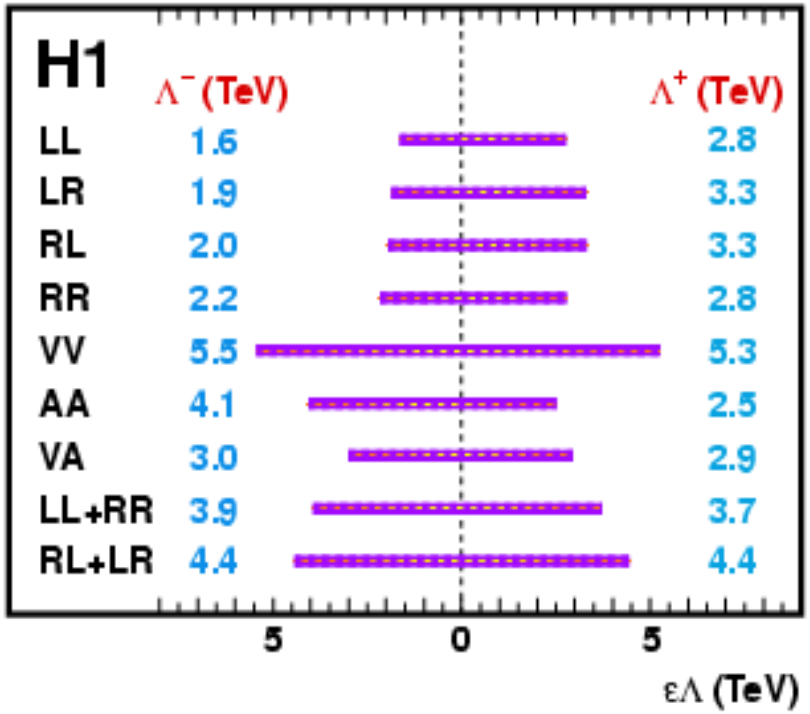
Λ compositeness scale, ε=0,1

$\varepsilon_{LL}=\varepsilon_{LR}=\varepsilon_{RL}=\varepsilon_{RR}$



$\varepsilon_{LL}=-\varepsilon_{LR}=-\varepsilon_{RL}=\varepsilon_{RR}$



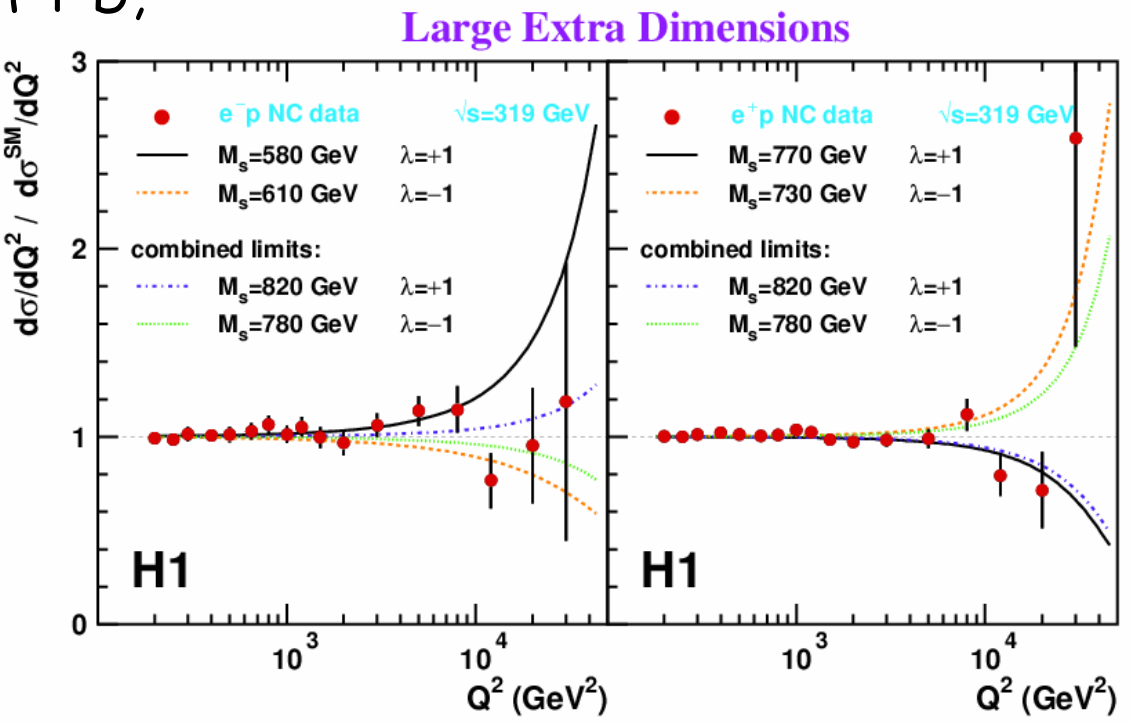


Curves are 95% C.L. exclusion limits for positive ($+\Lambda$) or negative ($-\Lambda$) interference term

CI: Large extra dimensions

Arkani-Hamed et al. [Phys.Lett. B429, 263 (1998)]:

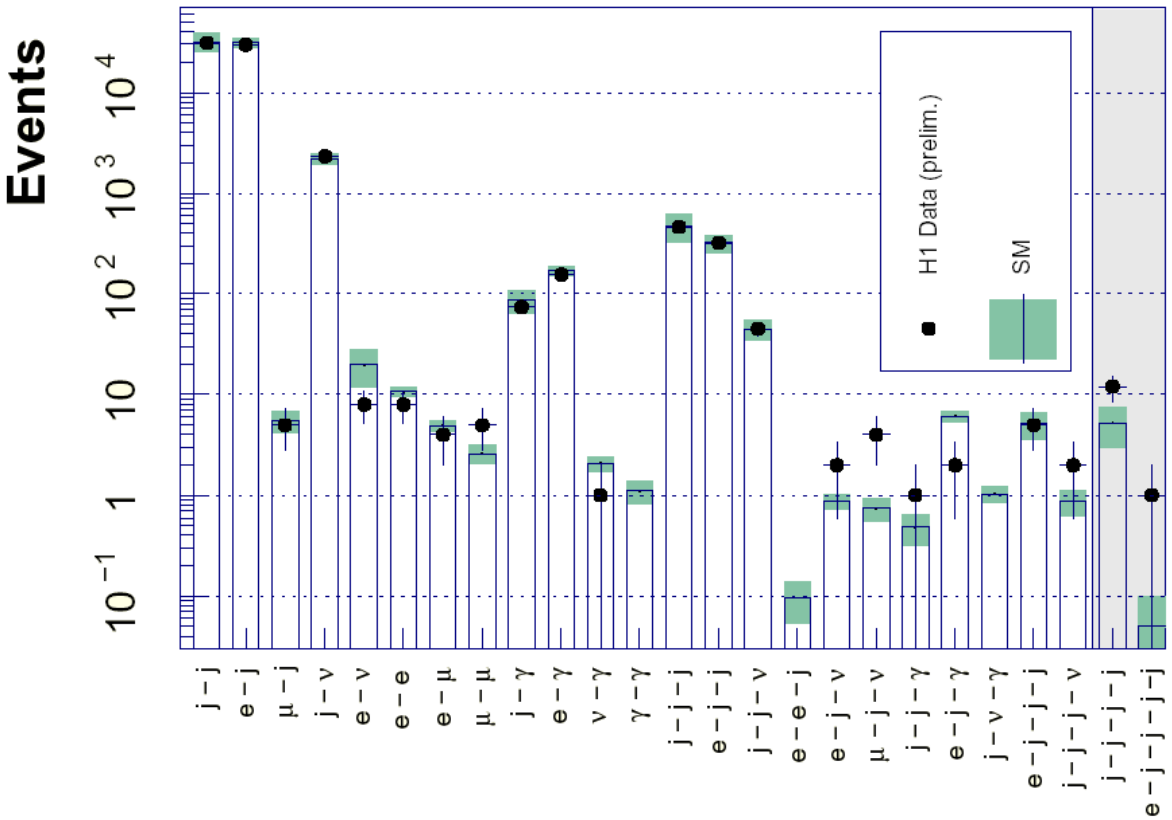
- SM particles propagate in 4-D, gravitons in (4+n)-D
- $M_p^2 = R^n M_s^{2+n}$
  - M_s scale of the 4+n theory (~1 TeV)
  - R = size of n compact extra dimensions
- Virtual Kaluza-Klein "graviton" exchange interferes with γ, Z
- Effective coupling $\eta_G = \lambda / M_s^4$

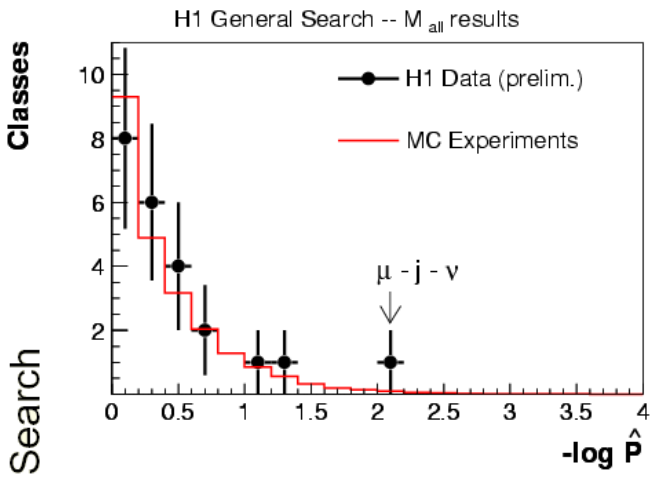


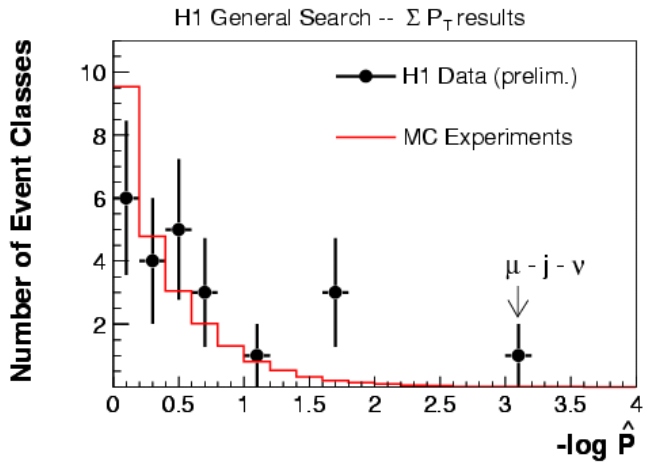
Limits	H1	ZEUS
λ=-1	0.78 TeV	0.82 TeV
λ=+1	0.82 TeV	0.81 TeV

General Search (H1)

- Select events with at least 2 isolated object with $P_T > 20$ GeV and $10^0 < \theta < 140^0$
- Object are: electron, muon, jet and neutrino or non interacting particle
- p statistical estimator to look for large deviation from SM in M_{all} and Σp_T
- $\hat{P}$ probability to observe $p_{min} < p_{min\ data}$
- Largest deviation found in μ-j-ν



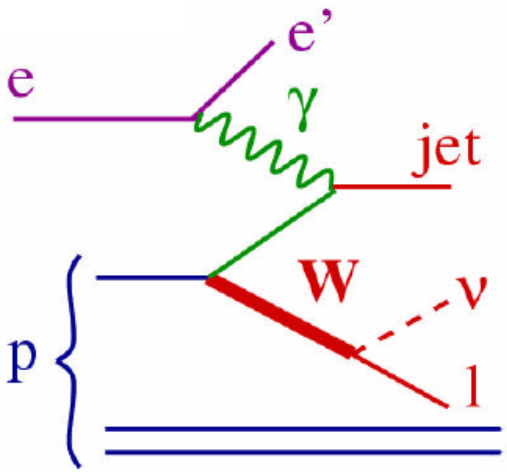




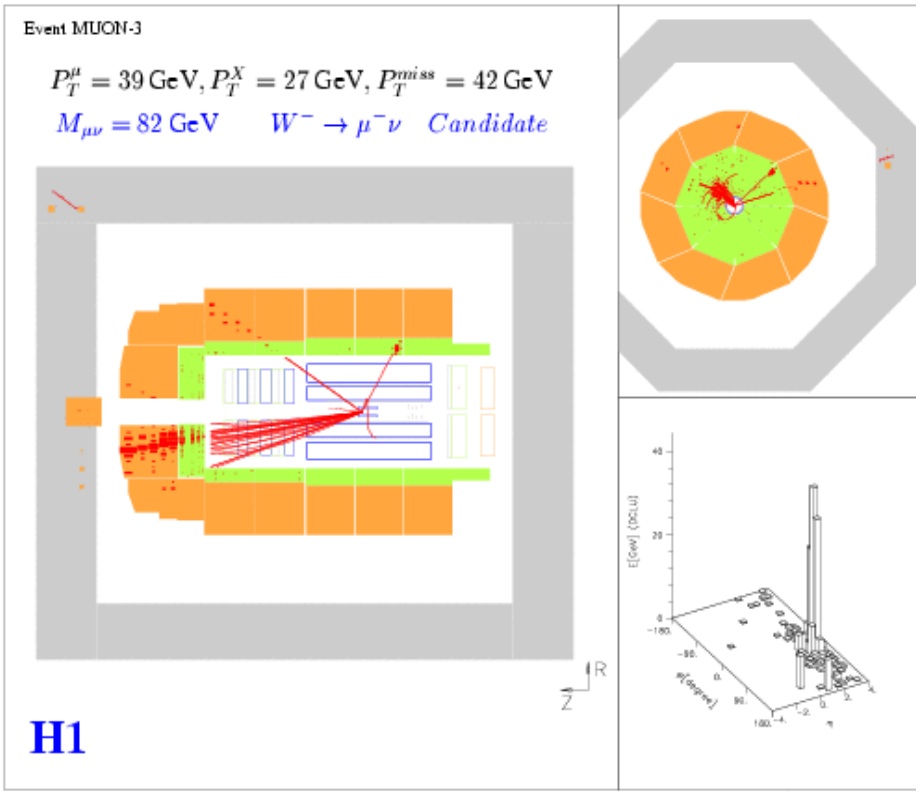
Isolated leptons and missing p_T

Events Topology:

- High p_T lepton (p_T^{track} > 5, 10 GeV)
- Isolated track (D_{jet}>1, D_{track}>0.5)
- Missing P_T (> 20, 25 GeV)
- Jet



$e^+p \to e^+\mu^- X$

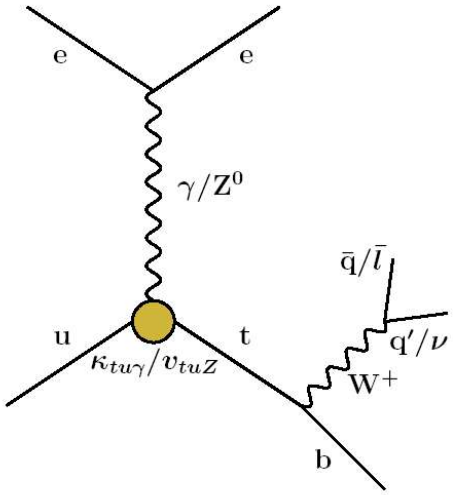


Dominant SM process is W production: $\sigma(ep \to e\, W^{\pm} X) \sim 1$ pb

Isolated leptons and missing p_T (2)

	P_T^X cut	Electrons Obs.	Electrons SM	Electrons W-only	Muons Obs.	Muons SM	Muons W-only
H1 e^+p 105 pb^{-1}	$P_T^X < 12$ GeV	5	6.40 ± 0.79	4.45 ± 0.70	-	-	-
	$12 < P_T^X < 25$ GeV	1	1.96 ± 0.27	1.45 ± 0.24	2	1.11 ± 0.19	0.94 ± 0.18
	$25 < P_T^X < 40$ GeV	1	0.95 ± 0.14	0.82 ± 0.13	3	0.89 ± 0.14	0.77 ± 0.14
	$P_T^X > 40$ GeV	3	0.54 ± 0.11	0.45 ± 0.11	3	0.55 ± 0.12	051 ± 0.12
H1 e^-p 16 pb^{-1}		1	1.69 ± 0.22	-	0	0.37 ± 0.06	-
ZEUS ep 130 pb^{-1}	Total	24	20.6 +1.7/-1.6	17%	12	11.9 +0.6/-0.7	16%
	$P_T^X > 25$ GeV	2	2.9 +0.59/-0.32	45%	5	2.75 ± 0.21	50%
	$P_T^X > 40$ GeV	0	0.94 +0.11/-0.1	61%	0	0.95 +0.14/-0.	61%

- Is the excess in e^+p collision at high p_T^X new physics?
- Single top production via anomalous magnetic and vector FCNC top coupling $k_{tu\gamma}$, v_{tuZ}
- SM cross-section ~ 1fb^{-1}

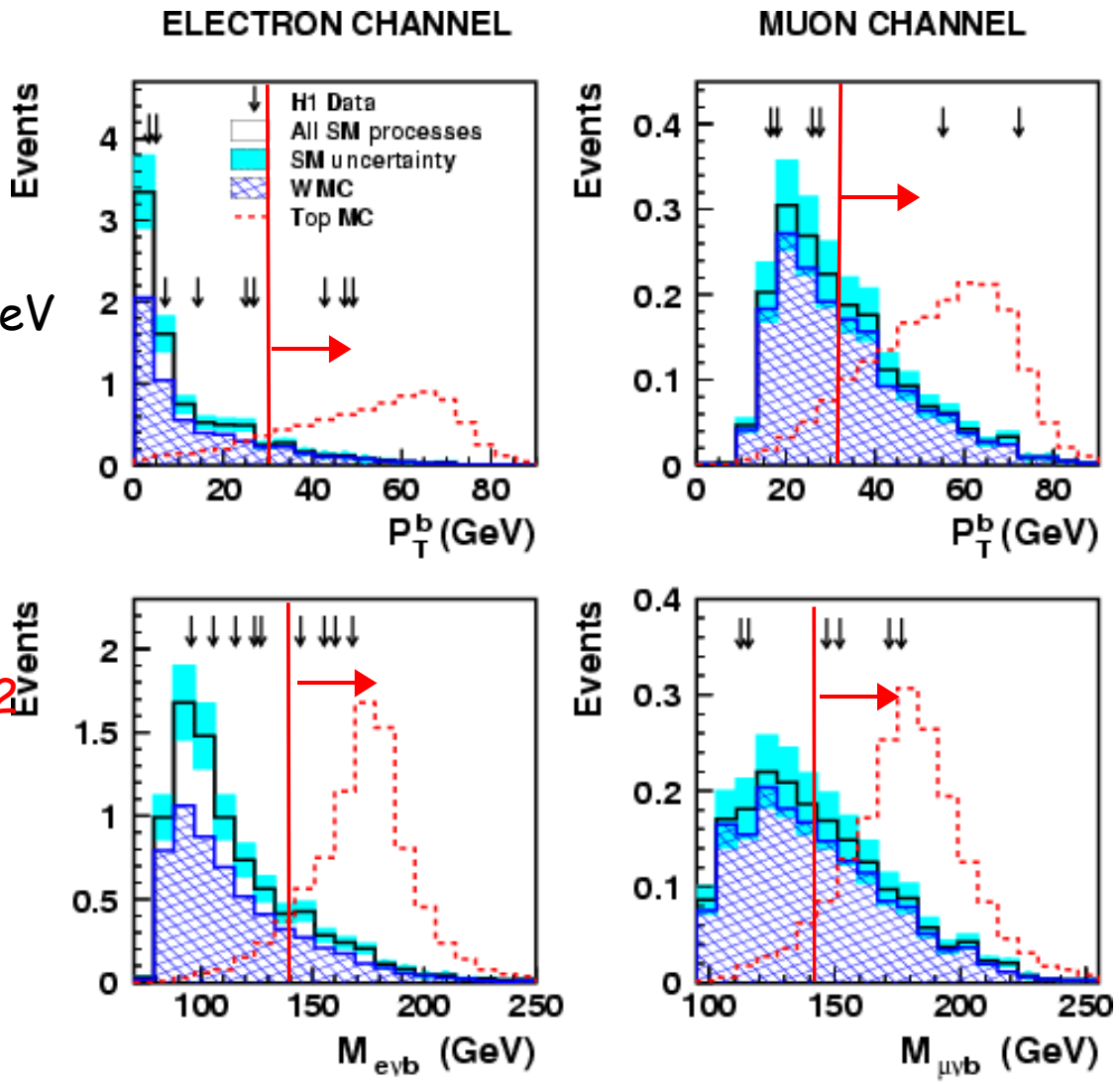


Single top: semi-leptonic decays

- ZEUS: no events with $P_T^X > 40$ GeV
- H1: further cuts to select top
  - Only positive leptons
  - $P_t^{jet} > 30$ GeV, $M_{l\nu b} > 140$ GeV

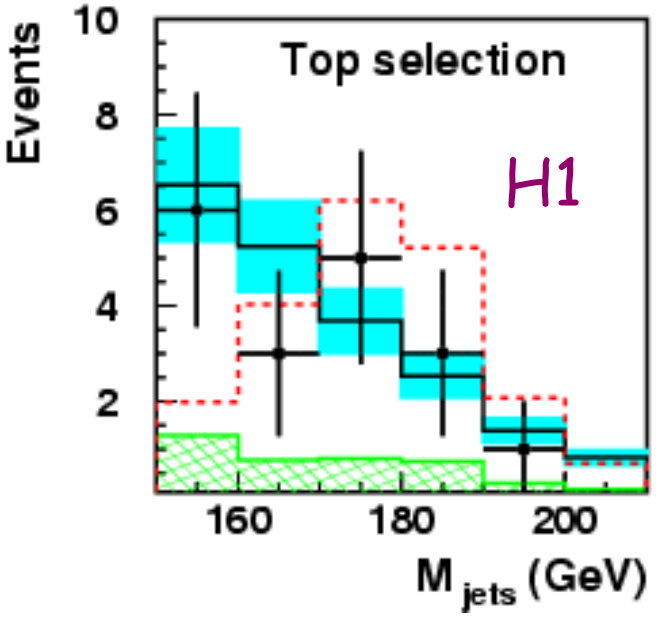
5 events (3e,2μ) – SM 1.31± 0.22

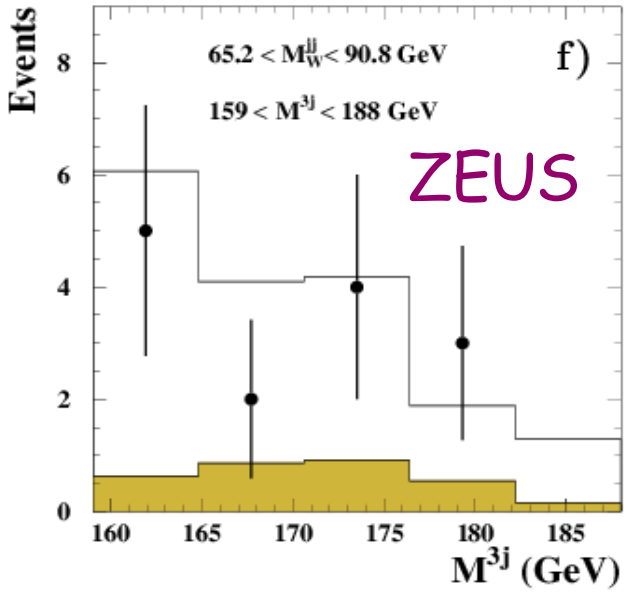
Top efficiency:
36% electron
38% muon



Single top: hadronic decays

Cut	H1	ZEUS
P_T^{jet}	40,30,15 GeV	40,25,14 GeV
W mass window	$65 < M_{jj} < 95$ GeV	$62.5 < M_{jj} < 90.8$ GeV
Top mass window	$150 < M_{jets} < 210$ GeV	$159 < M_{jets} < 188$ GeV

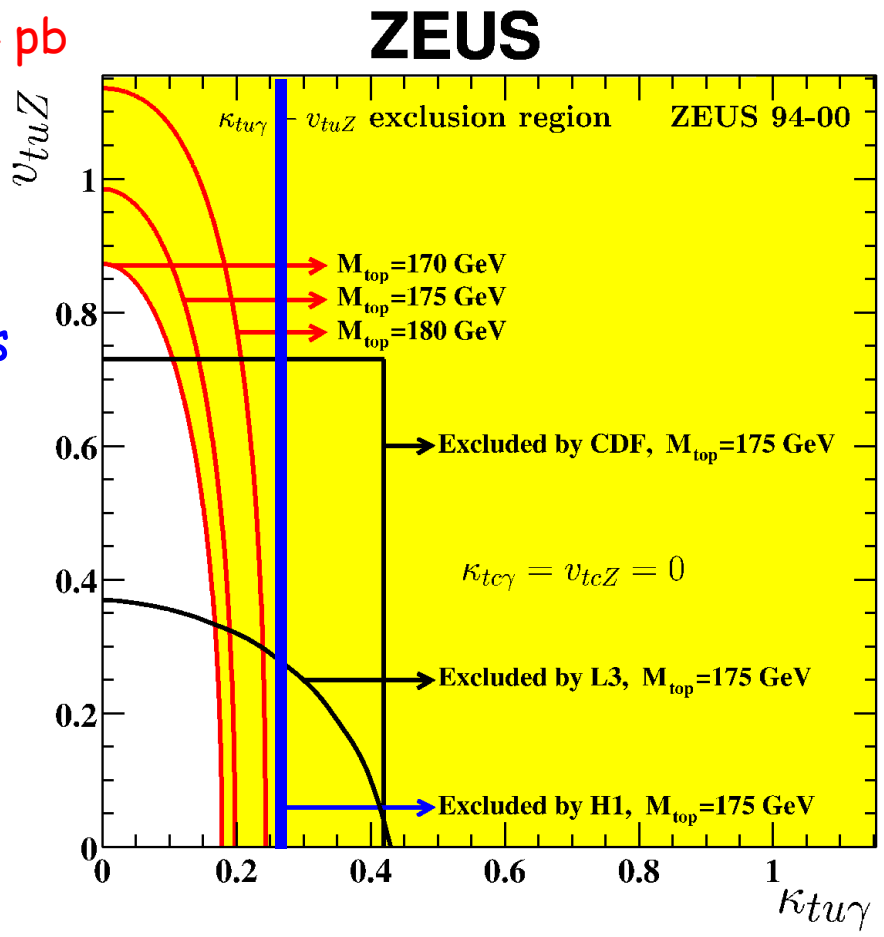




Both experiments agree with SM in the hadronic channel

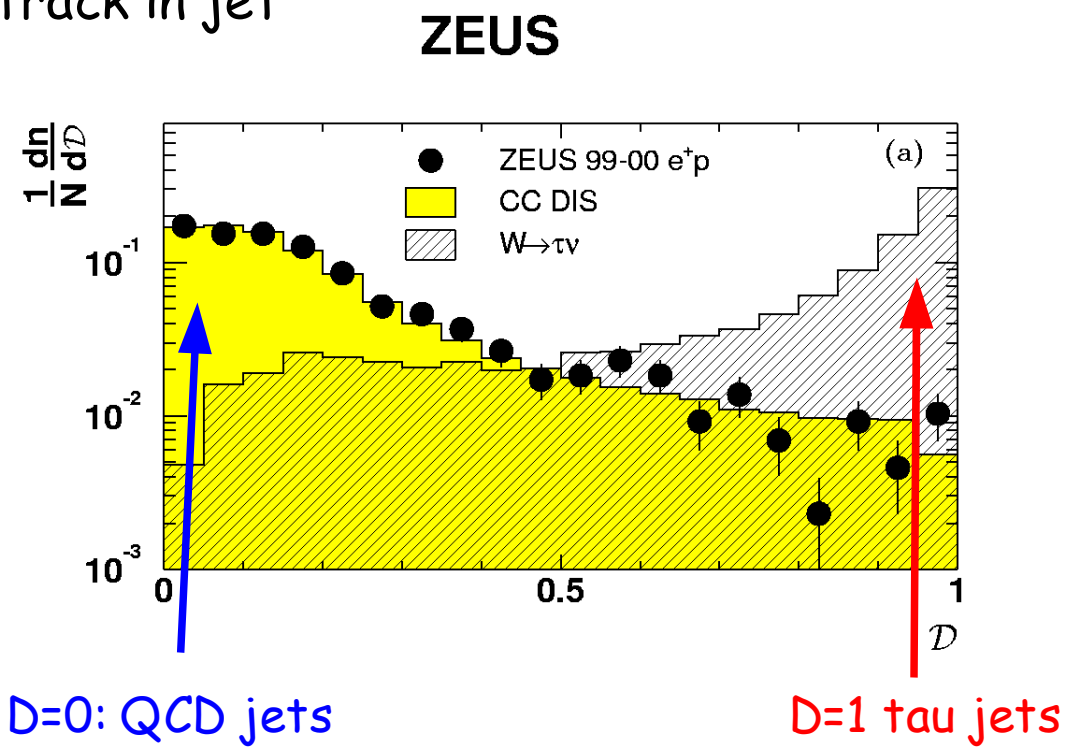
Single top search: Results

- H1 observe excess in leptonic channel (e+μ), agreement with SM in hadronic channel
  - Is this single top via FCNC?
  - ✔ If yes $\sigma(ep \to e\, t\, X) \sim 0.29^{+0.15}_{-0.14}$ pb
  - ✔ If not upper limit on $k_{tu\gamma} < 0.55$ @ 95% CL
- ZEUS: Good agreement with SM in both leptonic and hadronic channels
  - $\sigma(ep \to etX, \sqrt{s}=318\text{GeV}) < 0.225$ pb @ 95% CL
  - Zeus efficiency evaluated also for Z-exchange
  - Limit calculated in NLO for γ-exchange, LO for γ/Z exchange



Isolated τ events

- Extend search for isolated high-p_T leptons and missing p_T to τ-lepton decaying hadronicaly
- τ selected using discriminant D base on jet-shape variable: pencil-like jet, only 1 track in jet

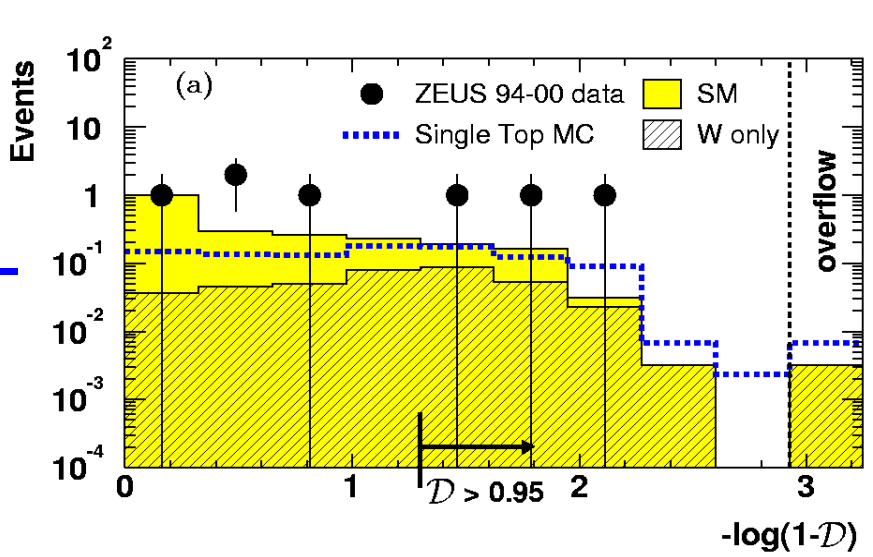


Isolated τ events

- $p_T^{miss} > 20$ GeV
- Isolated track, $p_T^{track} > 5$ GeV

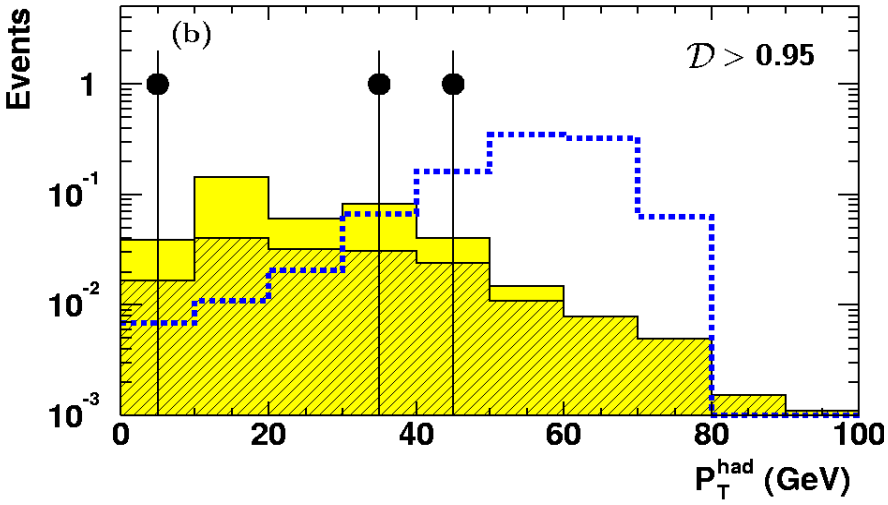
Cut	Data	SM
$\phi_{aco} > 8^0$	7	2.2 +0.39/-0.58
D>0.95	3	0.40 +0.12/-0.13
$P_T^X > 25$ GeV	2	0.20 ± 0.05

(Prob. statistical fluctuation 1.8%)

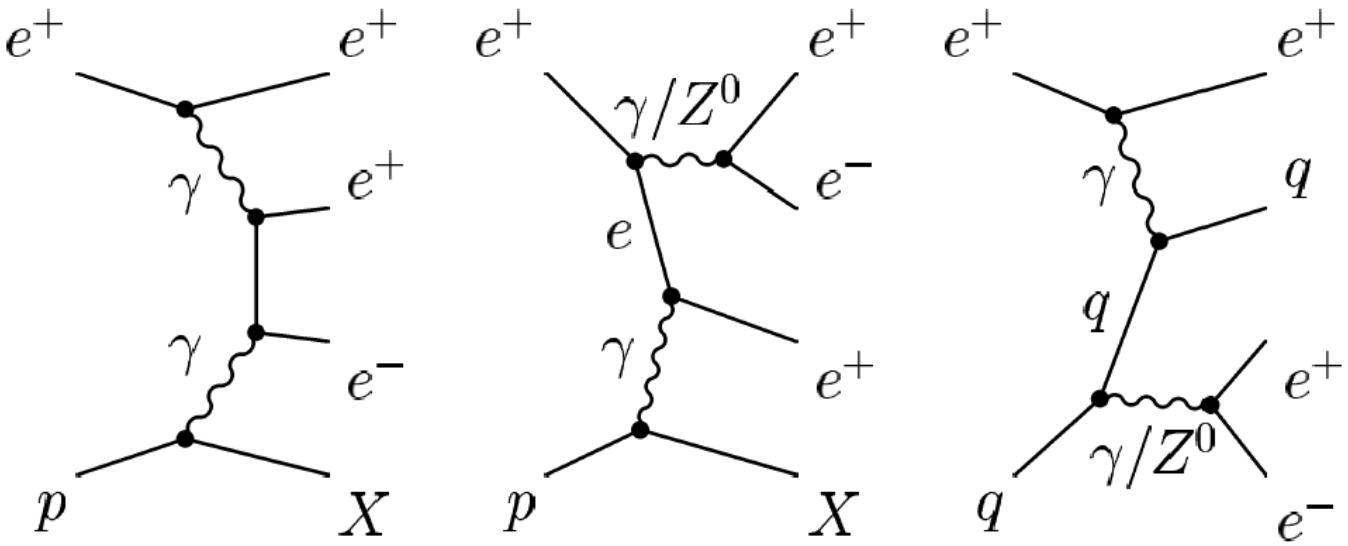


- Not compatible with e/μ/jet channels
- 2 events have opposite charge while top produce anti-lepton (anti-top production highly suppress in ep collision)

$\Rightarrow$ unlikely to be single top



Search for multi lepton events



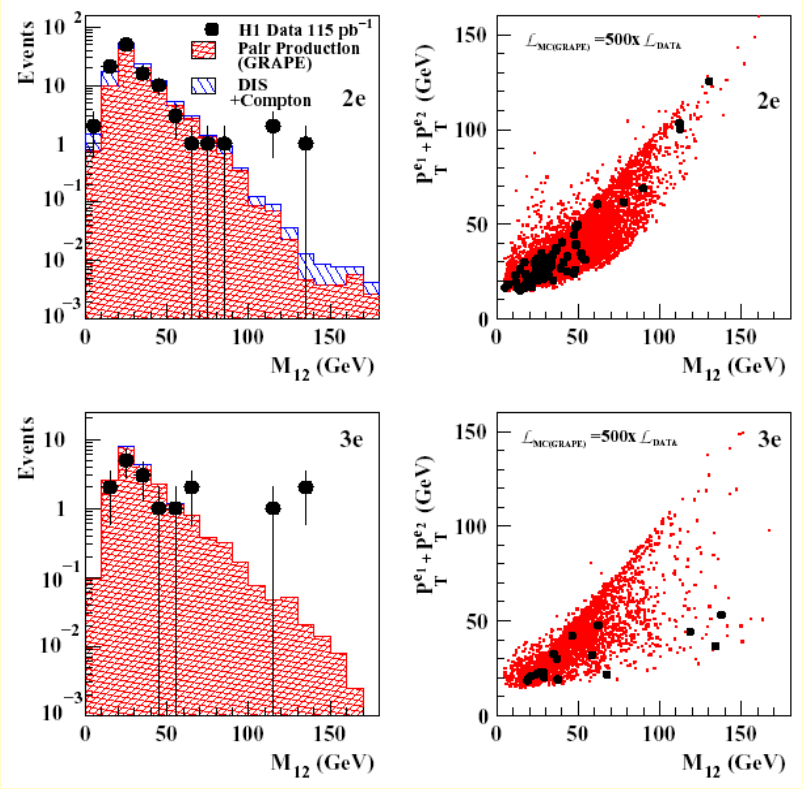
Very clean process which can be sensitive to new physics at high di (tri)-lepton invariant mass

Selection:

- 2 isolated electrons ($20^0 < \theta_e < 150^0$ H1, $17^0 < \theta_e < 164^0$ ZEUS)
- $p_T > 5$ GeV and 10 GeV
- 3rd electron with $5^0 < \theta_e < 175^0$ and $E_e > 5$(rear), 10(forward) GeV

Multi electron events

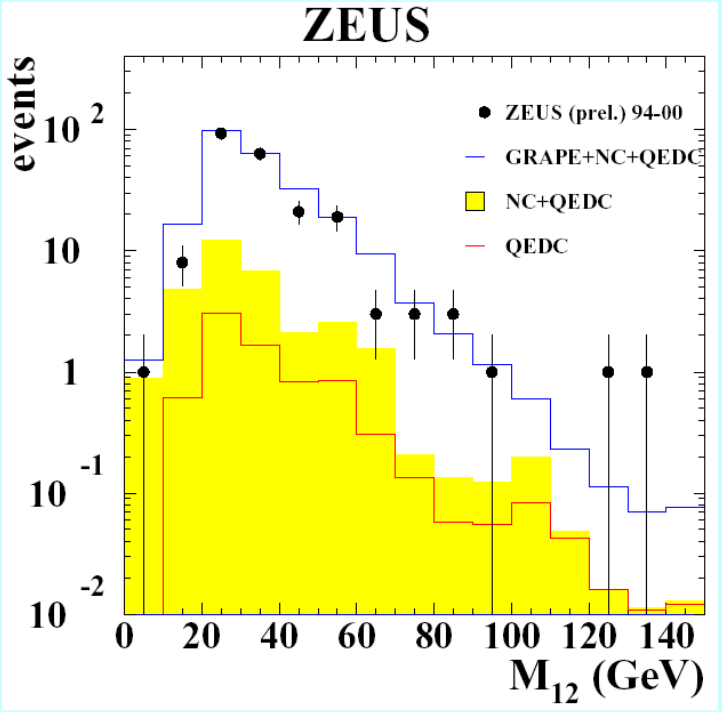
H1



Sample	Data	SM
2e Total	108	117±8.6
3e Total	17	20.3±2.1
2e M_{12}>100 GeV	3	0.30±0.04
3e M_{12}>100 GeV	3	0.23±0.04

6 outstanding events M_{12} > 100 GeV

ZEUS

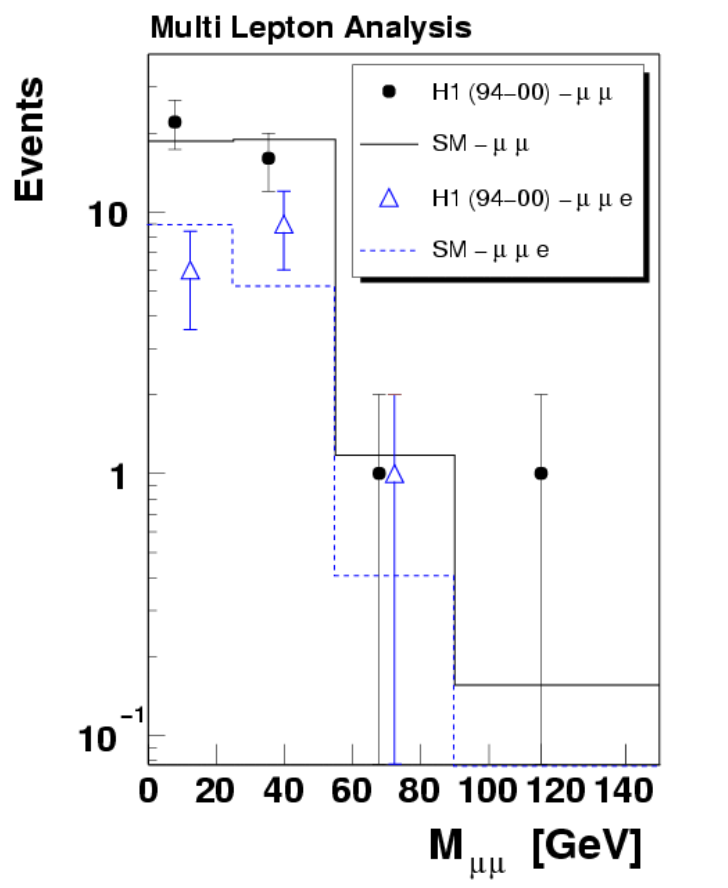


Sample	Data	SM
2e Total	191	213.9±3.9
3e Total	26	34.7±0.5
2e M_{12}>100 GeV	2	0.77±0.08
3e M_{12}>100 GeV	0	0.37±0.04

Good agreement with SM

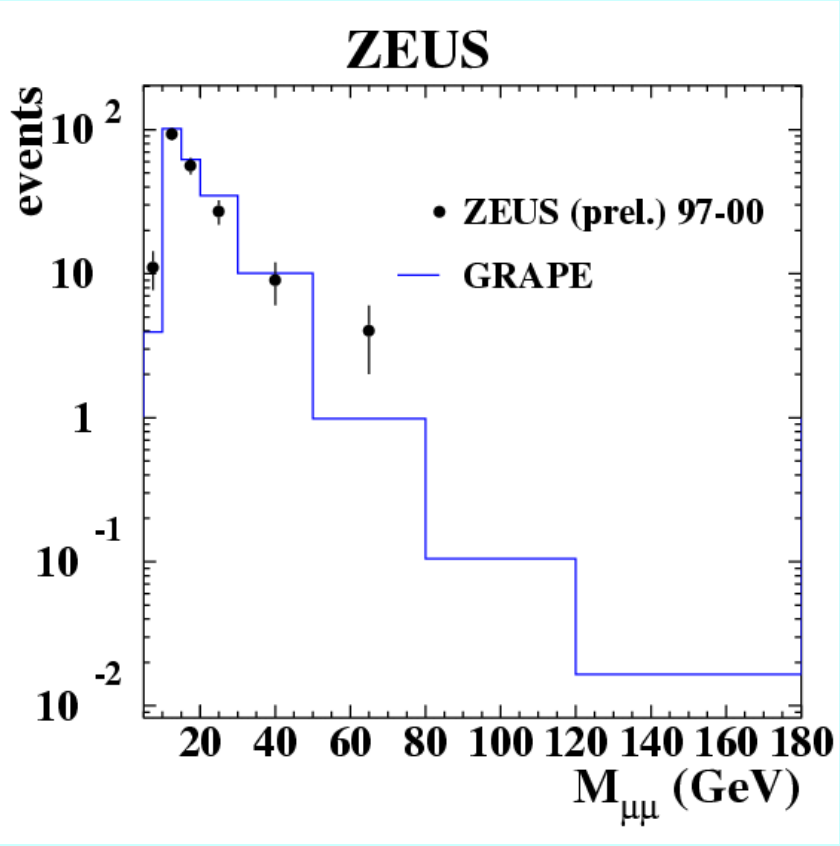
Di-muon events

H1



- pT > 5 GeV and 10 GeV
- Good agreement with SM
- 1 μμ event with M>100 GeV

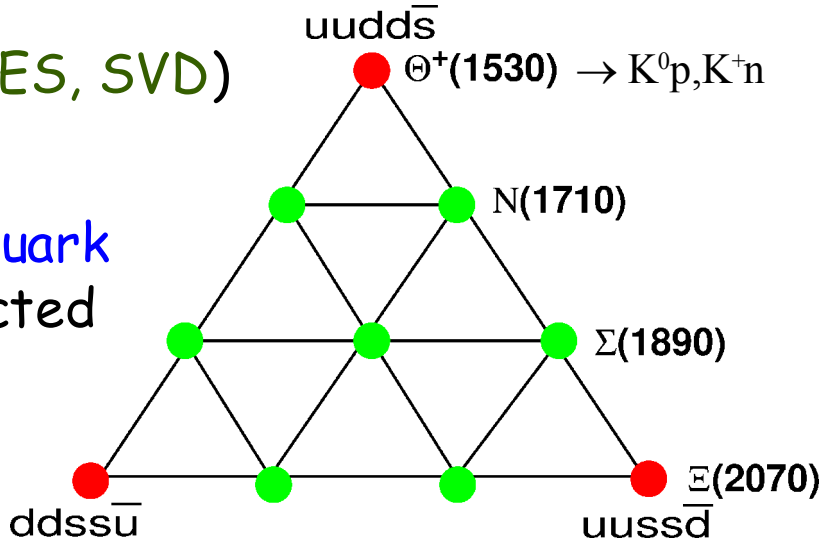
ZEUS



- Good agreement with SM
- 0 μμ event with M>100 GeV

Search for $K^0_s p$ resonance

- Several fixed target experiments observe a narrow baryon S=+1 resonance ~1530 MeV, (LEPS, DIANA, CLAS, SAPHIR, HERMES, SVD)



- Observation compatible with Θ^+ pentaquark at 1530 MeV and width <15 MeV, predicted in the soliton model by D.Diakonov, V.Petrov and M.Polyakov
- Search of pentaquark reconstructing K_s^0-(anti)proton invariant mass
- The search is performed in the central-tracking region, where hadron production is dominated by fragmentation

Search for $K^0_S p$ resonance: K^0_S selection

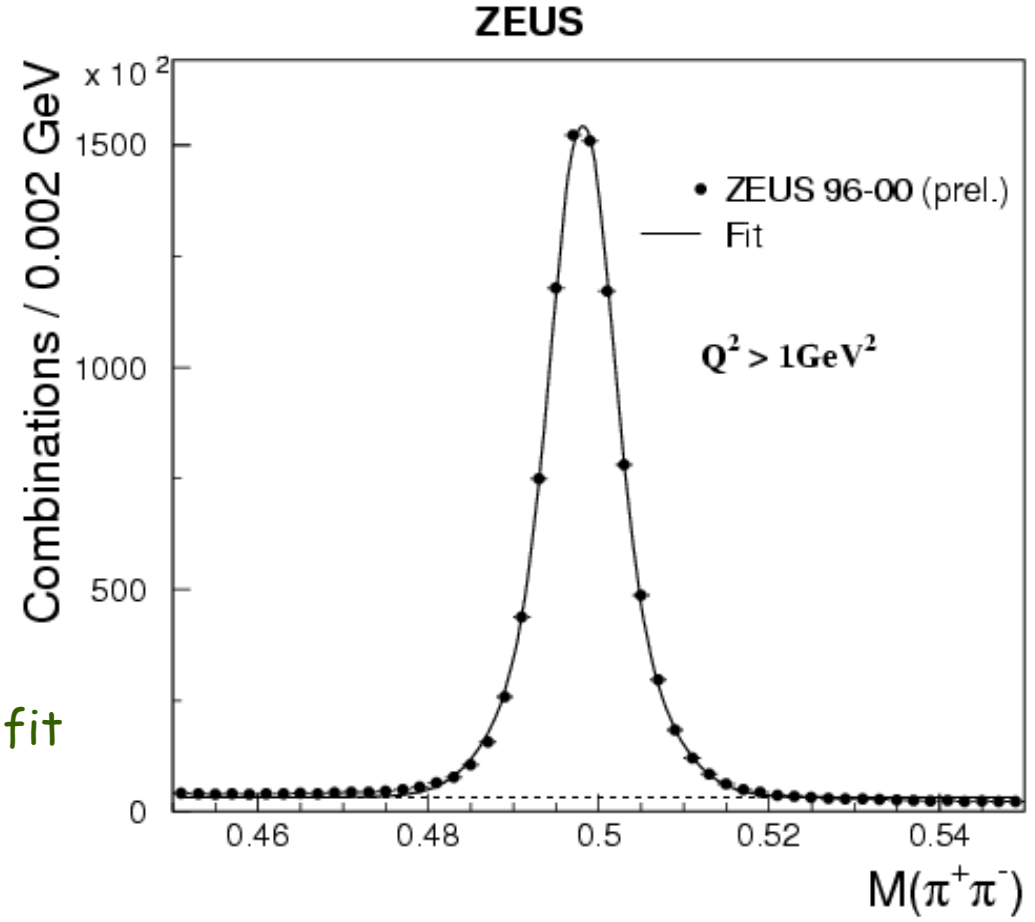
Data Set

- 121 pb^{-1}, 1996-2000 $e^{\pm}p$ data @ 300-319 GeV
- DIS events $Q^2 > 1$ GeV

K^0_S selection: $K^0 \rightarrow \pi^+\pi^-$

- CTD tracks, $p_T > 150$ MeV, $|\eta| < 1.75$
- K^0_S from secondary vertex
- Photon conversion removed: $M(e^+e^-) < 50$ MeV
- Λ's removed $M(\pi p) < 1121$ MeV
- $p_T(K^0) > 300$ MeV; $|\eta(K^0)| < 1.5$

Double Gaussian + linear background fit



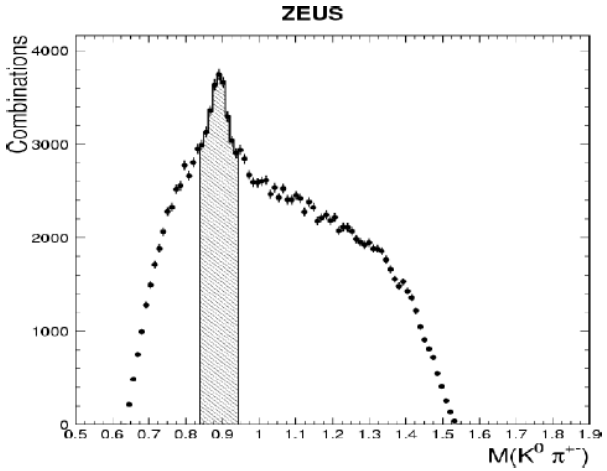
869690 ± 1016 K^0 candidate

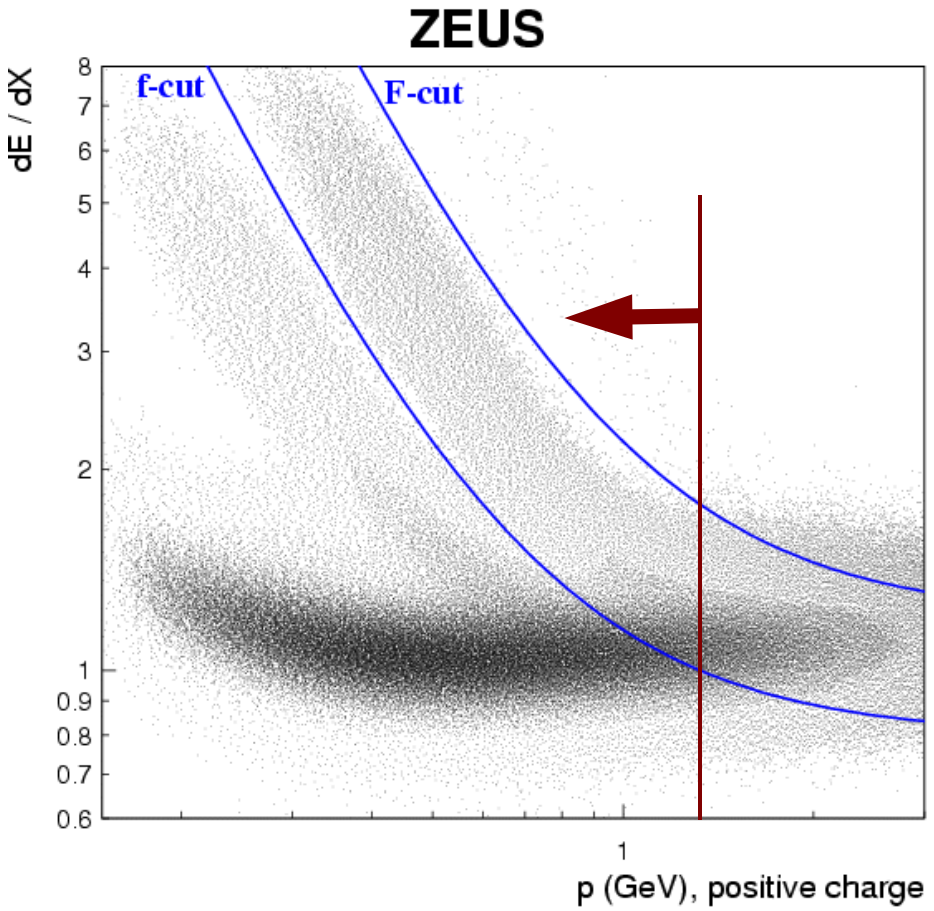
background ~ 6%

Peak at 498.12 ± 0.01 (stat) MeV

Search for $K^0_s p$ resonance: p selection

- Most of the signal p~0.8-2 GeV
- p<1.3 GeV inside dE/dx band
- E(proton) > E(K^0)
- Assign pion mass to proton candidate, reconstruct $K^0\pi$, reject pions from K*: 800 < M($K^0\pi$) <980 MeV

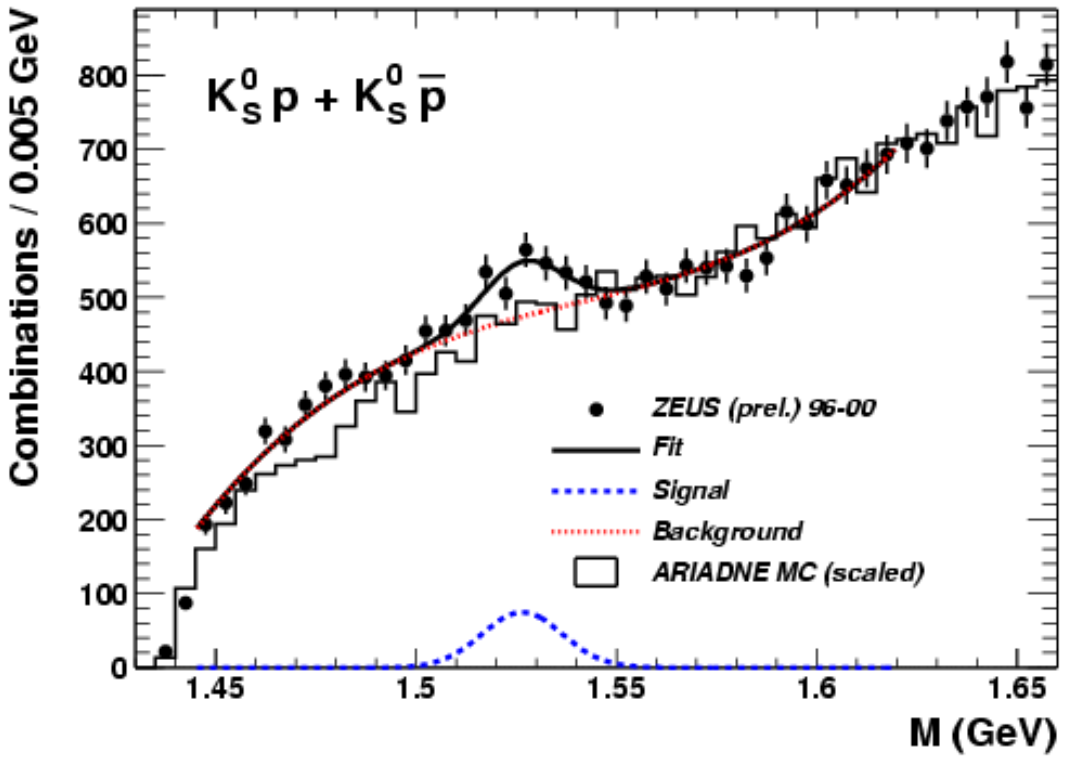




$K^0_s p$(anti-p) invariant mass

Fit: Gaussian +p3(free parameter)

ZEUS preliminary



Combined sample: 372±75 candidates

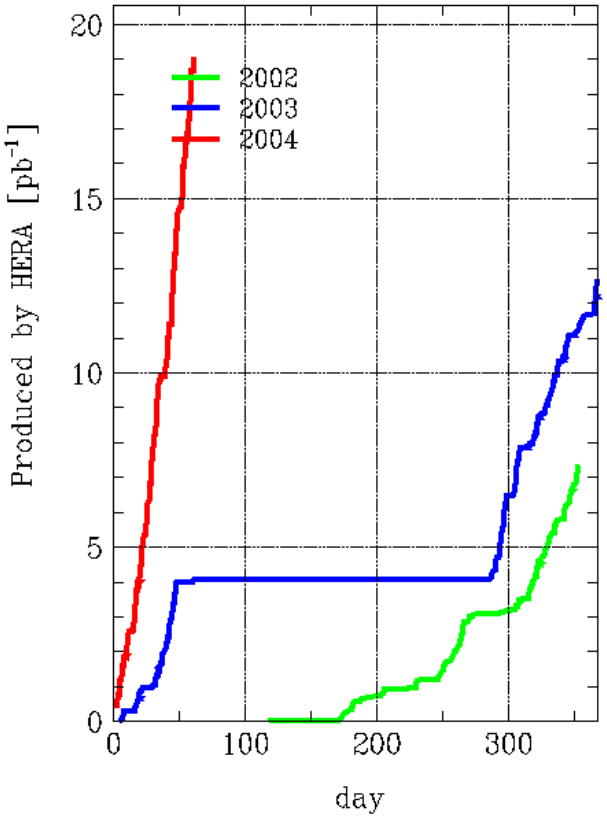
Peak 1527 ± 2(stat) MeV, width 10 ± 2(stat) MeV

(Mass resolution from MC simulation: 4±1 MeV)

Outlook

- HERA II delivered ~ 30 pb^{-1} of luminosity in 2003-2004
- Instantaneous luminosity ($3 \cdot 10^{31}$ $cm^{-2}s^{-1}$) already higher then HERA I
- Longitudinal electron polarization > 30%

2002-2004



1992-2000