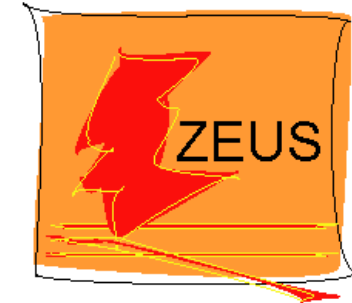


Searches for New Physics at HERA

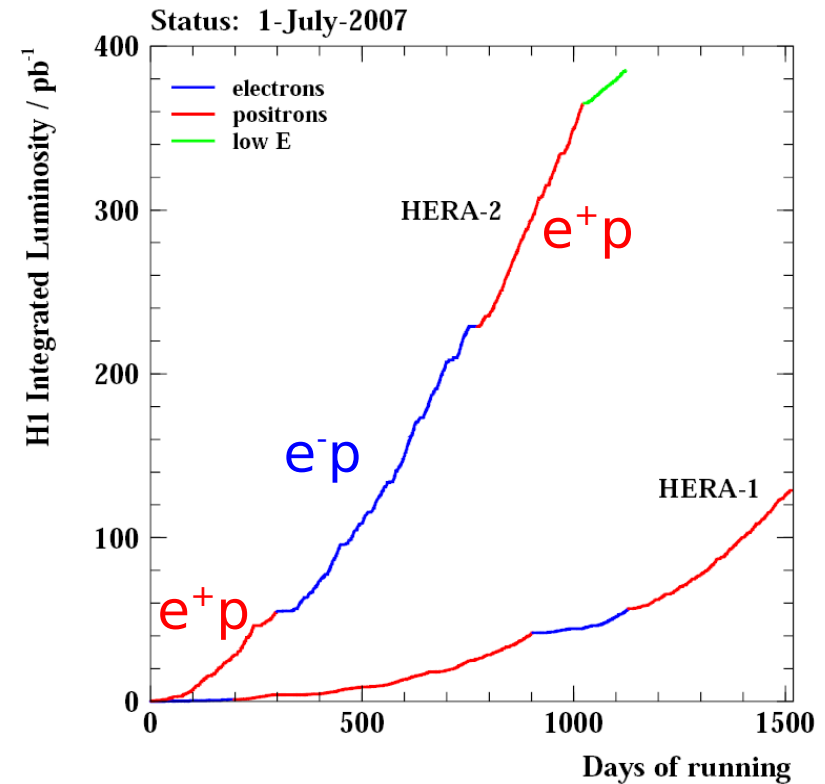
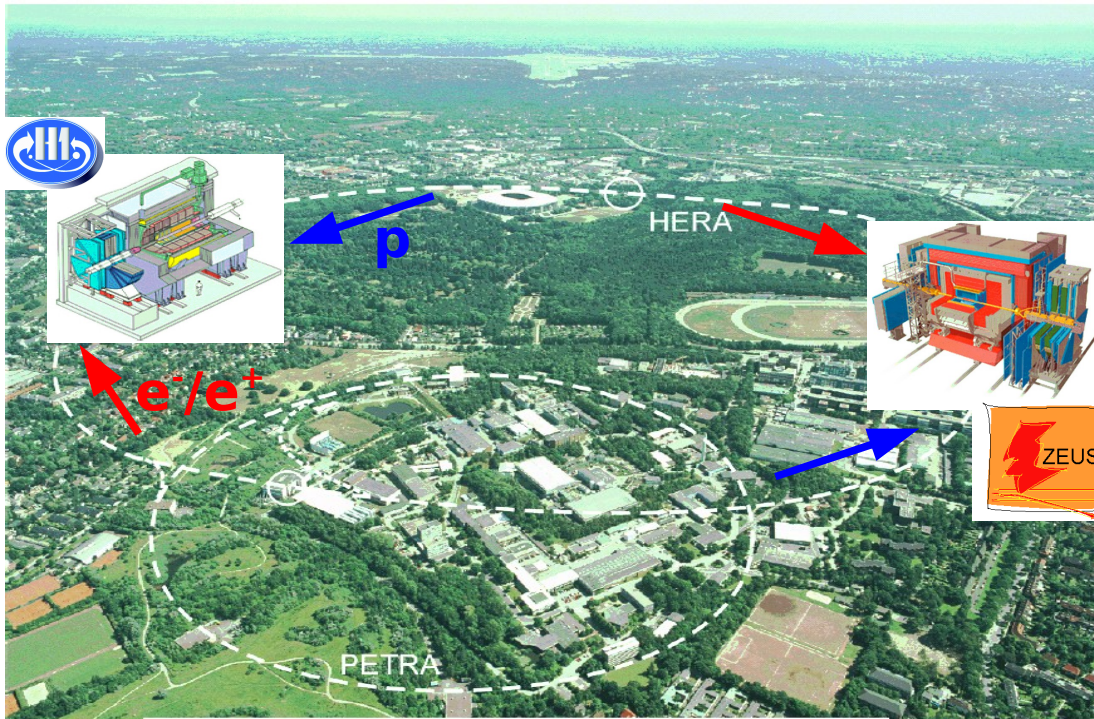
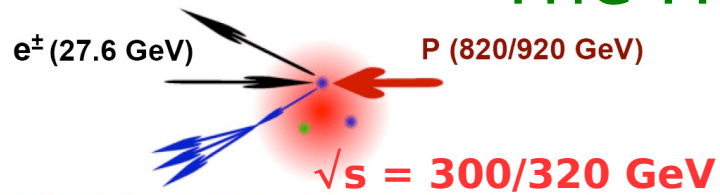


TRINH Thi Nguyet

Laboratoire de Physique Nucléaire et de Hautes Energies - Paris

On behalf of the **H1** and **ZEUS** Collaborations

The HERA collider



➔ HERA I: 1992-2000, $L \sim 120 \text{ pb}^{-1}$

➔ HERA II: 2002-2007, $L \sim 360 \text{ pb}^{-1}$

☛ luminosity upgrade and polarised lepton beams

☛ $\sim 10\times$ more e-p data than in HERA I

➔ HERA's operation ended on June 2007

☛ In total H1 & ZEUS together accumulated: $\sim 1 \text{ fb}^{-1}$

Hints for New Physics at HERA

① Model dependent searches for new particles

➤ Test models and verify predicted signatures;
if non-observation: limits set

- ◆ Lepto-quarks
- ◆ Excited Fermions
- ◆ Single Top quark

② Model independent searches for new physics

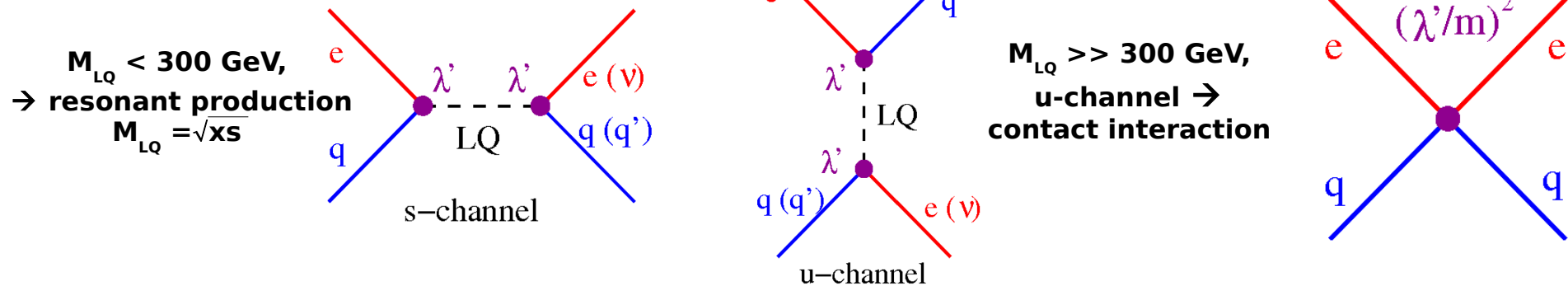
➤ Compare data vs. SM, reveal anomalies above small SM contribution

- ◆ W production ($W \rightarrow e, \mu$)
- ◆ Isolated Tau Events with missing P_T
- ◆ Multi-Lepton Final States
- ◆ A General Search

Leptoquarks

- Leptoquarks (LQs): connect lepton and quark sector

➤ Hypothetical bosons appearing in many SM extensions to explain symmetry between leptons and quarks



➤ LQs couple to the both leptons and quarks, and carry SU(3) colour, fractional electrical charge, baryon (B), lepton (L) numbers

→ Fermion number: $F = 3B + L = 0, 2$

➤ LQs model explored in the Buchmuller-Ruckl-Wyler (BRW) framework

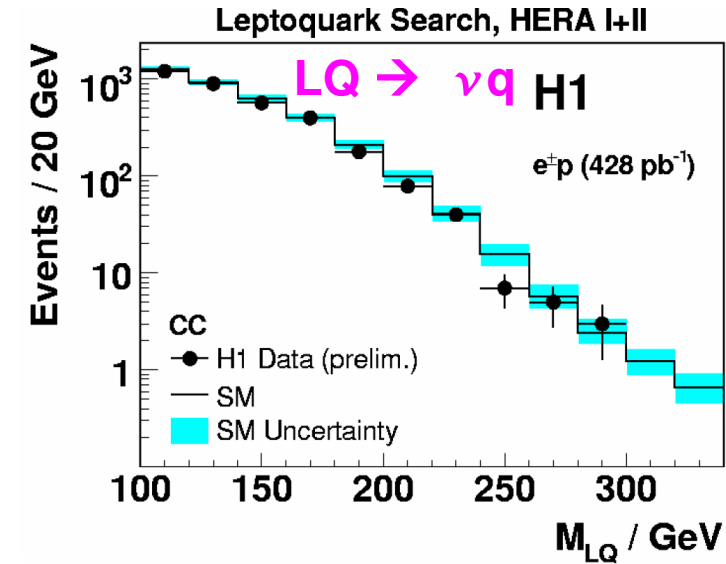
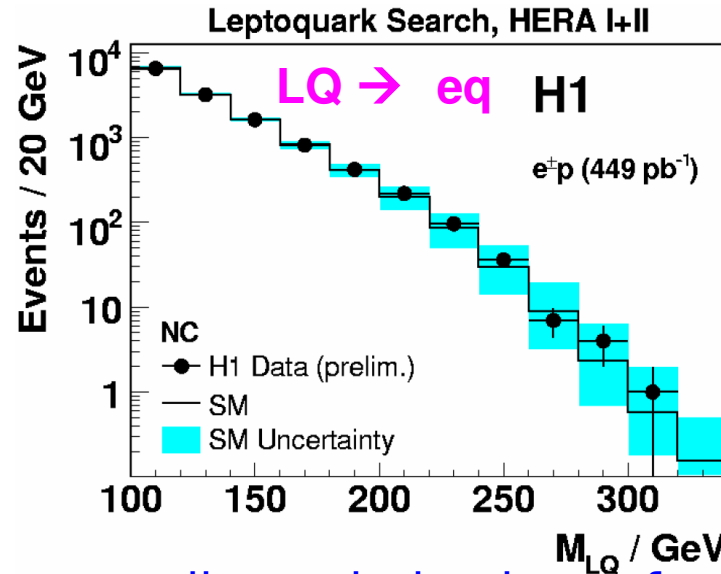
➤ Parameters: M_{LQ} , Yukawa couplings λ_{ij}

➤ Search for lepton-quark resonances (e+jet and ν +jet)

Leptoquarks

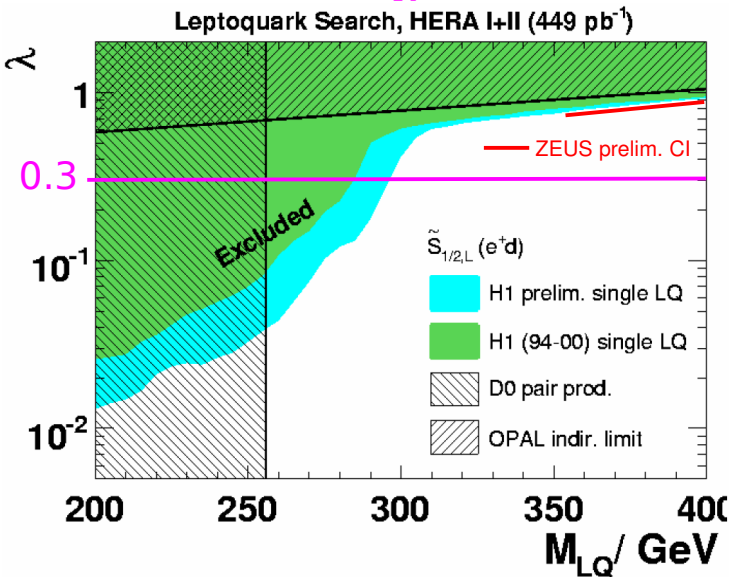
● Complete H1 data analysed (449 pb^{-1})

➤ No deviations from SM

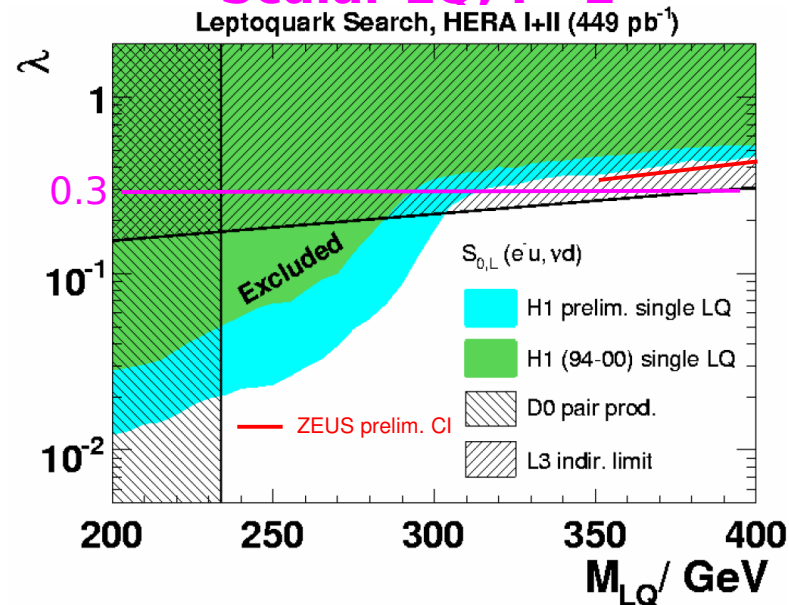


● Limits on LQ Yukawa coupling λ derived as a function of M_{LQ}

Scalar LQ, $F=0$



Scalar LQ, $F=2$



➤ For electromagnetic strength $\lambda \approx 0.3$:
 $M_{LQ} < 291-330 \text{ GeV}$
 can be ruled out



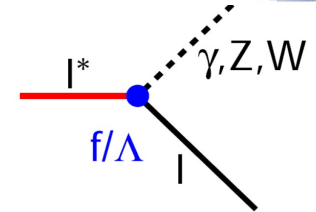
➤ HERA limits competitive with LEP and TEVATRON limits

Excited Leptons: H1 final results



- Excited fermions: direct signature of a new scale of matter
- (De-)excitation described by the effective Lagrangian:

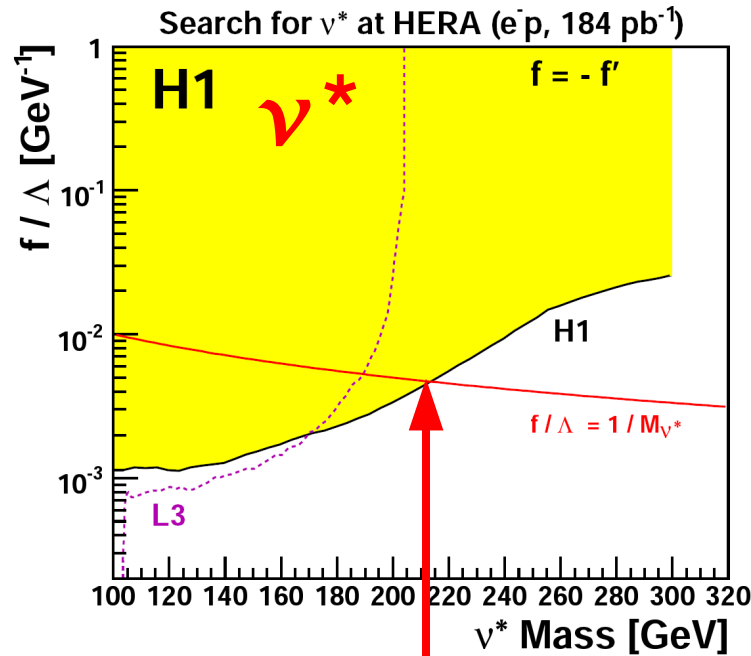
$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[\underset{\text{SU}(2)}{gf \frac{\tau^a}{2}} W_{\mu\nu}^a + \underset{\text{U}(1)}{g' f' \frac{Y}{2}} B_{\mu\nu} + \cancel{\underset{\text{SU}(3)}{g_s f_s \frac{\lambda^a}{2}} G_{\mu\nu}^a} \right] F_L$$



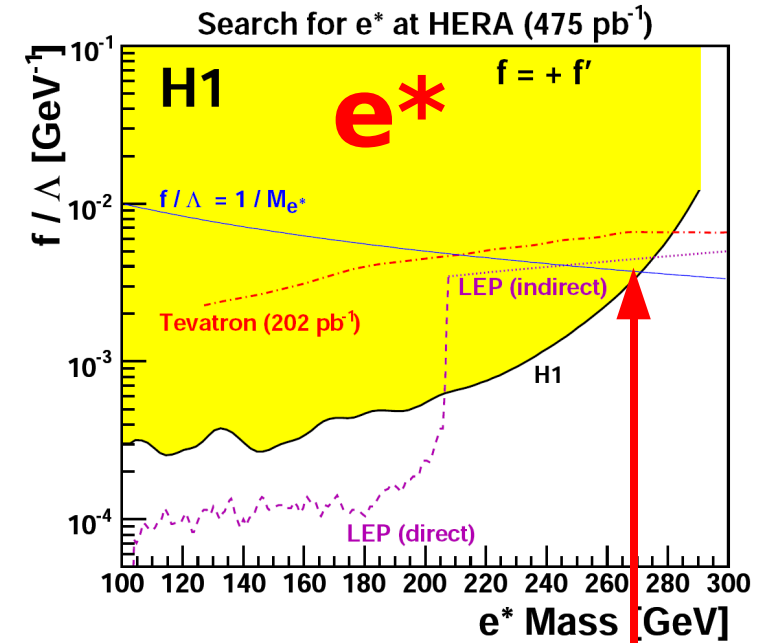
- Analysis of full H1 HERA I+II data (**475 pb⁻¹**)

[Phys. Lett. B663: 382-389]

[Phys. Lett. B666: 131-139]



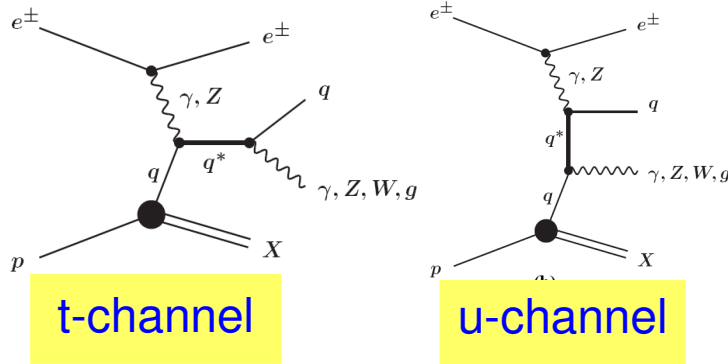
✚ If $f = -f'$ and $f/\Lambda = 1/M_{\nu^*}$:
 $M_{\nu^*} < 213 \text{ GeV}$ are excluded



✚ If $f = +f'$ and $f/\Lambda = 1/M_{e^*}$:
 $M_{e^*} < 272 \text{ GeV}$ are excluded

✚ Large new parameter space explored at high mass

Excited Quarks

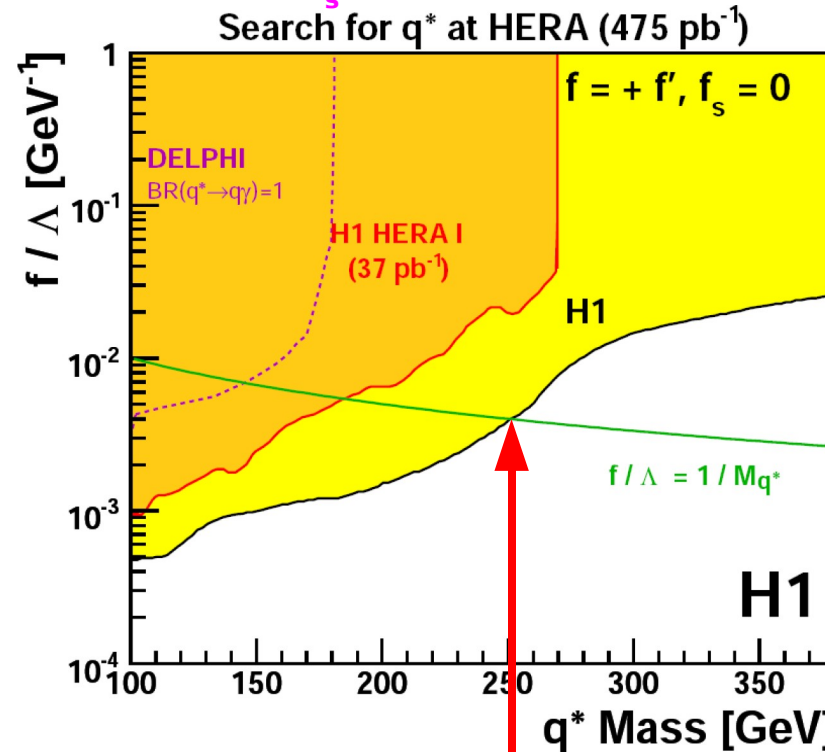
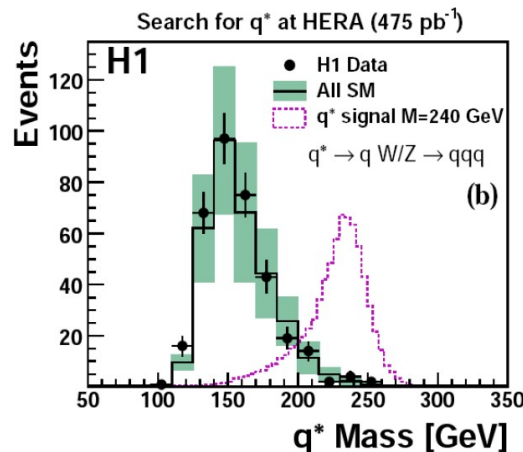
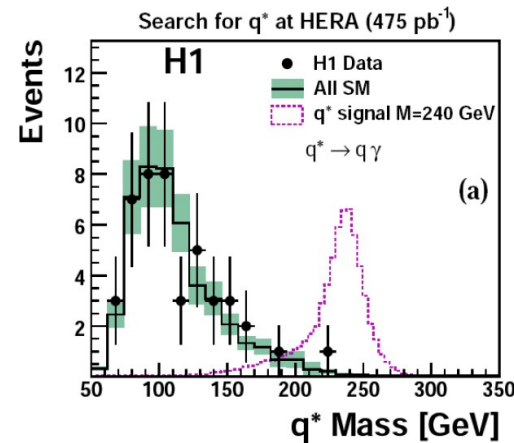


- To complete the excited lepton searches

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[\underset{\text{SU}(2)}{g f \frac{\tau^a}{2} W_{\mu\nu}^a} + \underset{\text{U}(1)}{g' f' \frac{Y}{2} B_{\mu\nu}} + \underset{\text{SU}(3)}{g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a} \right] F_L$$

- Analysis of full H1 HERA I+II data (**475 pb⁻¹**)

◆ For $f=f', f_s=0$ and $M_{q^*} = \Lambda$

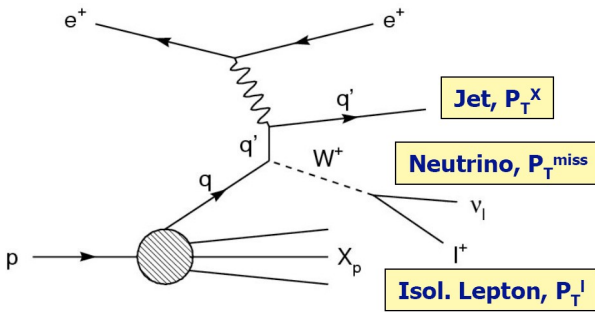


↘ If $f=+f', f_s=0$ and $f/\Lambda=1/M_{q^*}$:

$M_{q^*} < 259 \text{ GeV}$ are excluded

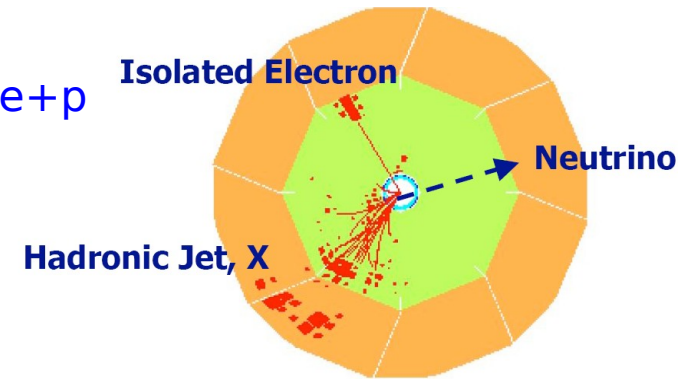
Isolated lepton (e, μ) + P_T^{miss} events: H1 final result

Look for events “signal”: which contain an high- P_T e or μ , missing P_T and hadronic system X (P_T^X)

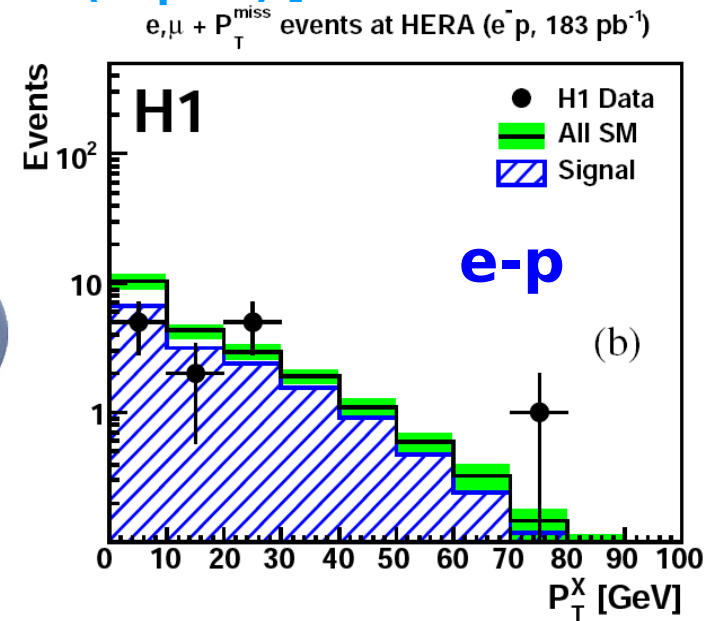
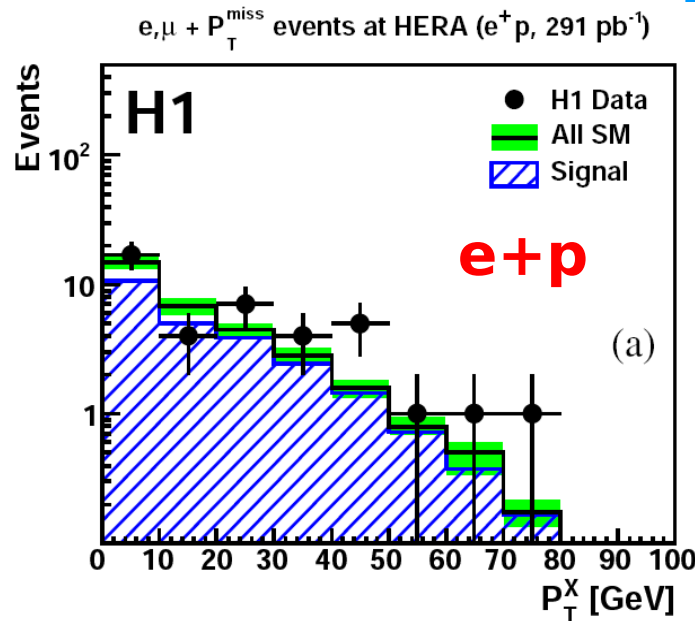


$\sigma \sim 1.3 \text{ pb}$

- HERA I, $P_T^X > 25 \text{ GeV}$: an excess of $e+p$ data events (3σ)
- SM signal: real W production
- Full H1 HERA I+II data (474 pb^{-1})



[arXiv:0901.0488 (hep-ex)]



Different observation in $e+p$ and $e-p$ data

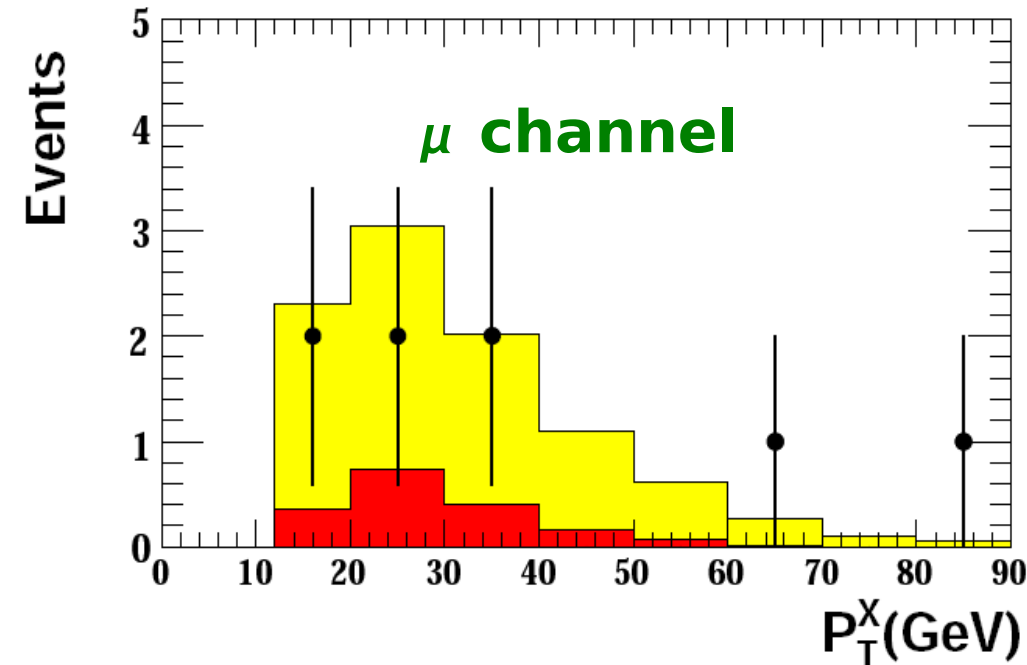
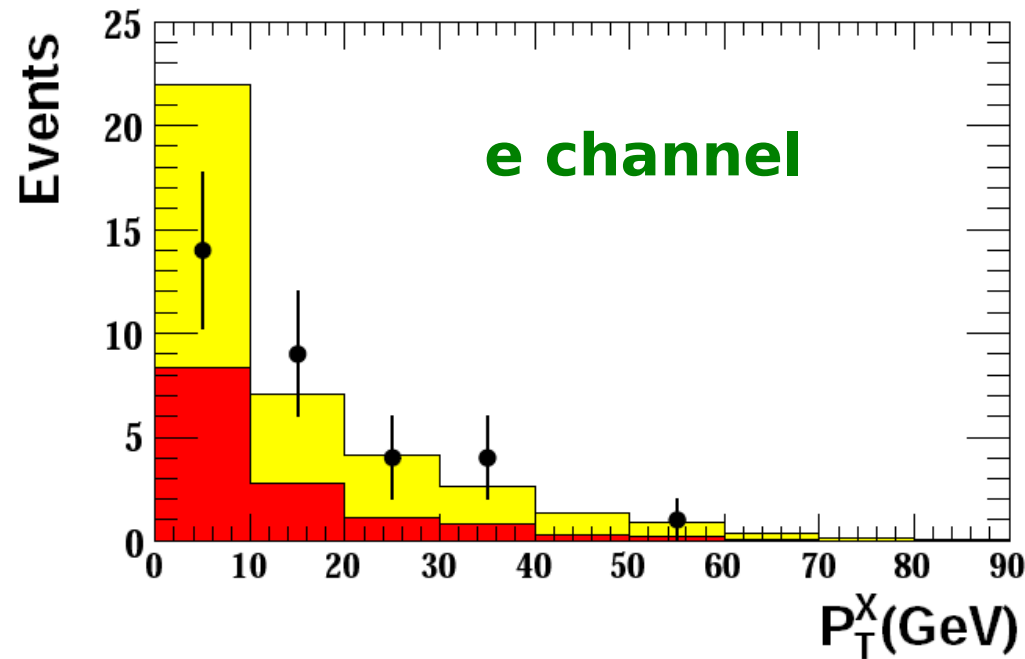
Excess not clarified with HERA II data: 2.4σ ($17 / 8.03 \pm 1.29$) in $e+p$

Isolated lepton (e, μ) + P_T^{miss} : ZEUS final result



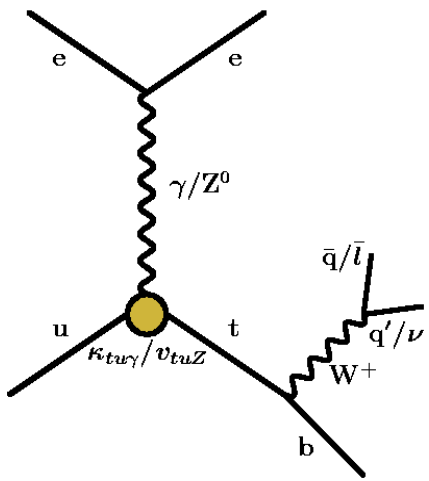
- Analysis also performed by ZEUS, using all HERA I+II data: 504 pb⁻¹

[Phys. Lett. B672: 106-115 (2009)]

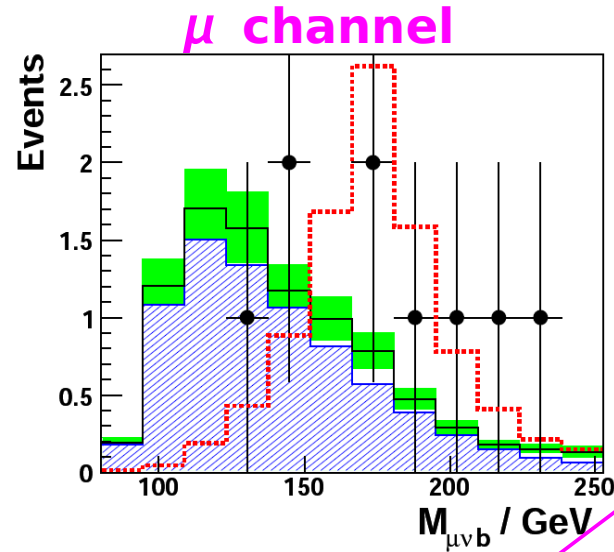
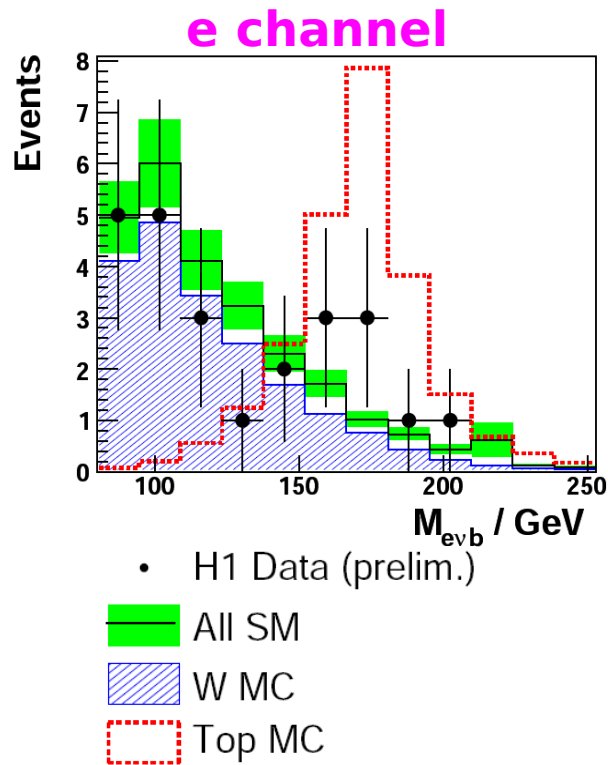


- ↘ A good agreement with SM is observed in both e+p and e-p data
- ↘ A similar excess was not observed by ZEUS
- ➔ H1 and ZEUS results combined in common phase-space is ongoing

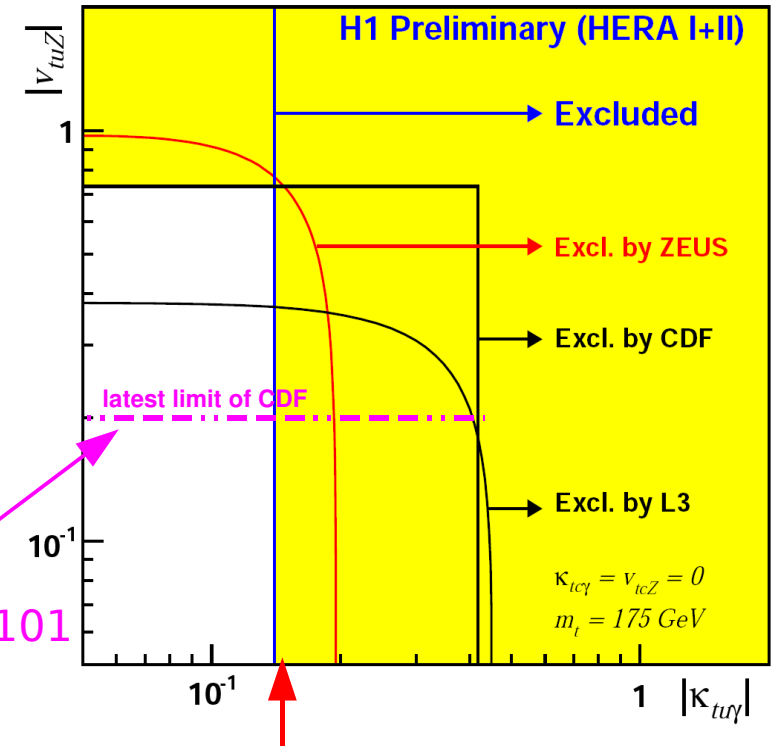
Anomalous Single Top production



- SM single top cross-section at HERA: $\sim 1 \text{ fb}$
 $\sim 1000 \times$ smaller than W production
- BSM: top production via Flavor Changing NC
 at high P_T^X isolated leptons signature compatible to anomalous single top production
- Study using effective couplings K_{tuy} , V_{tuZ}
- Full H1 HERA data used: 474 pb^{-1}



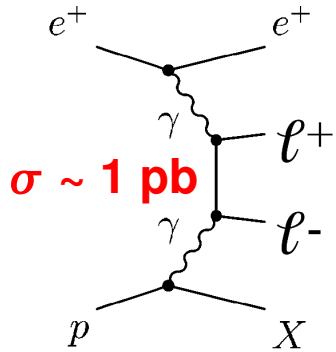
[Phys. Rev. Lett. 101 (2008) 192002]



↘ H1: most stringent limit on K_{tuy}

Multi-Leptons Events: HERA final result

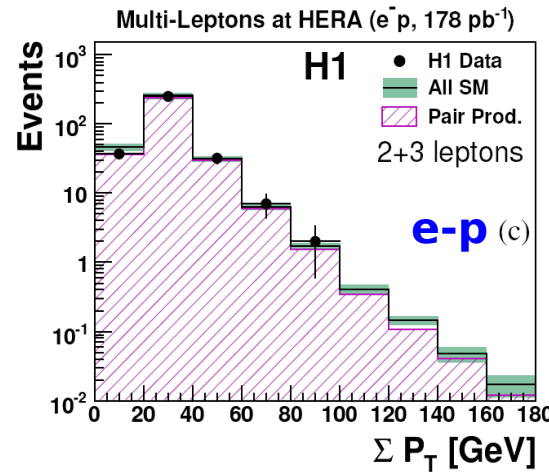
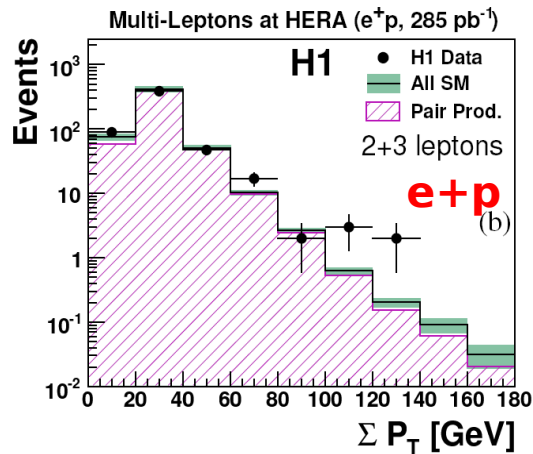
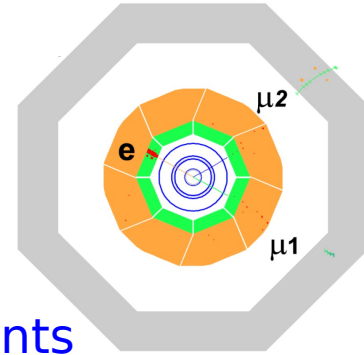
➤ Motivation: if anomalous $l-\nu$ production, what's about $l-l$ final states?



➤ Multi-lepton (e or μ) production is studied at high- P_T

- Covered topologies: $ee, eee, e\mu, \mu\mu, e\mu\mu$
- SM signal: dominated by $\gamma\text{-}\gamma$ processes
- Full HERA I+II data (H1: 463 pb^{-1} , ZEUS: 480 pb^{-1})

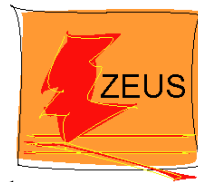
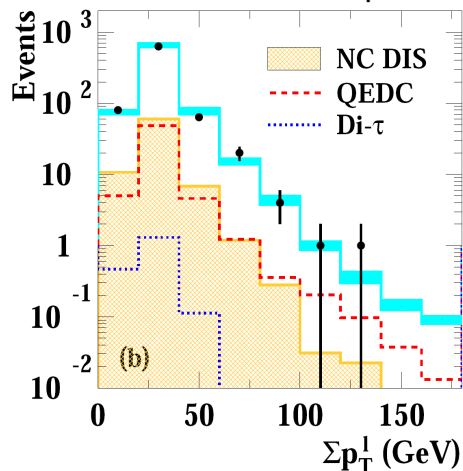
➔ Look at ΣP_T distribution: “hardness scale” of the events



[**Phys. Lett. B 668 (2008) 268**]

➤ Good agreement with SM

➤ In e^+p data, $\Sigma P_T > 100 \text{ GeV}$:
5 / 0.96 ± 0.12 events



(Hottest ZEUS results! Released very recently.)

• ZEUS 480 pb^{-1}
 $p_T^{11,12} > 10.5 \text{ GeV}$
 $20^\circ < \theta^{11,12} < 150^\circ$

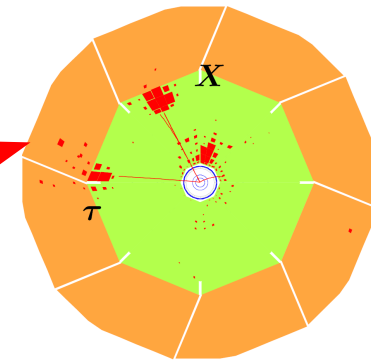
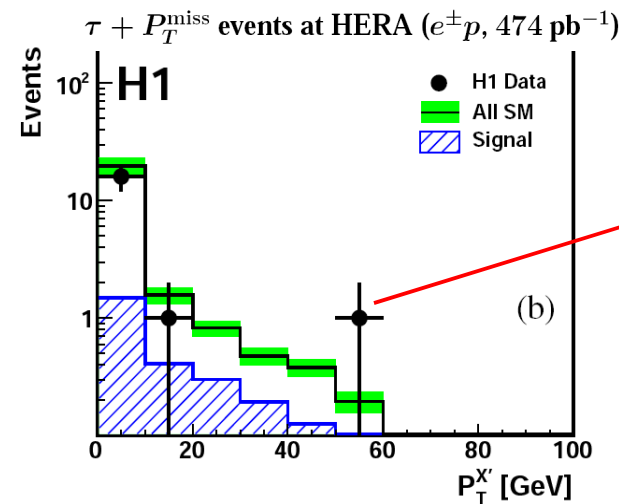
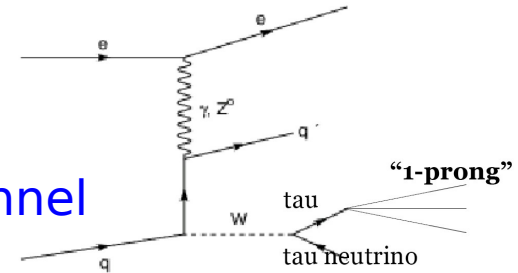
— Total SM
■ NC DIS
--- QEDC
... Di- τ

➤ Good agreement with the prediction of SM, results comparable to H1

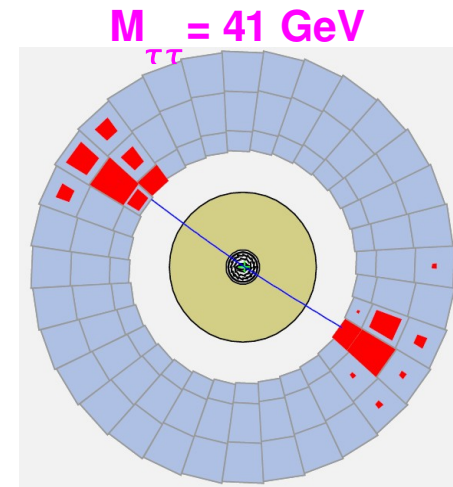
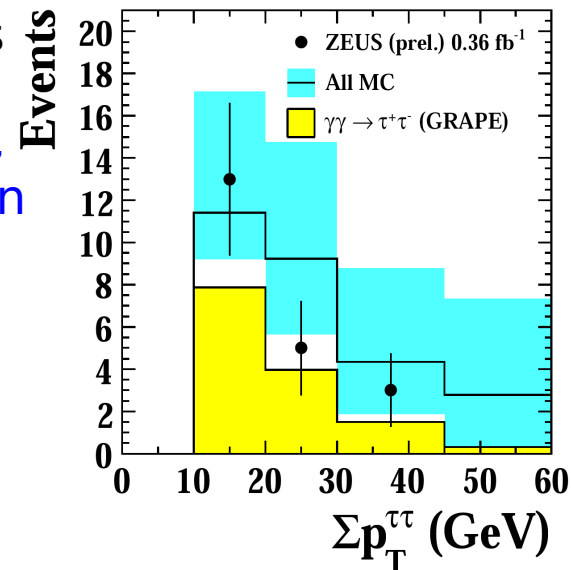
➔ H1 and ZEUS results combined in common phase-space is ongoing

Isolated tau (τ) + P_T^{miss} and di- τ events

- To complete electron and muon channels
- H1: analysis performed for isolated $\tau + P_T^{\text{miss}}$ events
 - ➔ τ leptons identified in the hadronic (1-prong) decay channel
 - ➔ look for events contain:
 - P_T^{miss} & narrow jets (1-prong)
 - ➔ H1: full HERA I+II data (474 pb⁻¹)
 - Good agreement with SM
 - At high $P_T^X > 25$ GeV:
 - ◆ H1: 1 obs. / 1.5 ± 0.21 exp.



- ZEUS: analysis performed for di- τ events
 - ➔ 1st τ is required to decay hadronically, 2nd τ either in an electron or in hadron
 - ➔ ZEUS: full HERA II data (360 pb⁻¹)
 - ◆ ZEUS: 21 obs. / 27.2 ± 7.1 exp.
 - Good agreement with SM



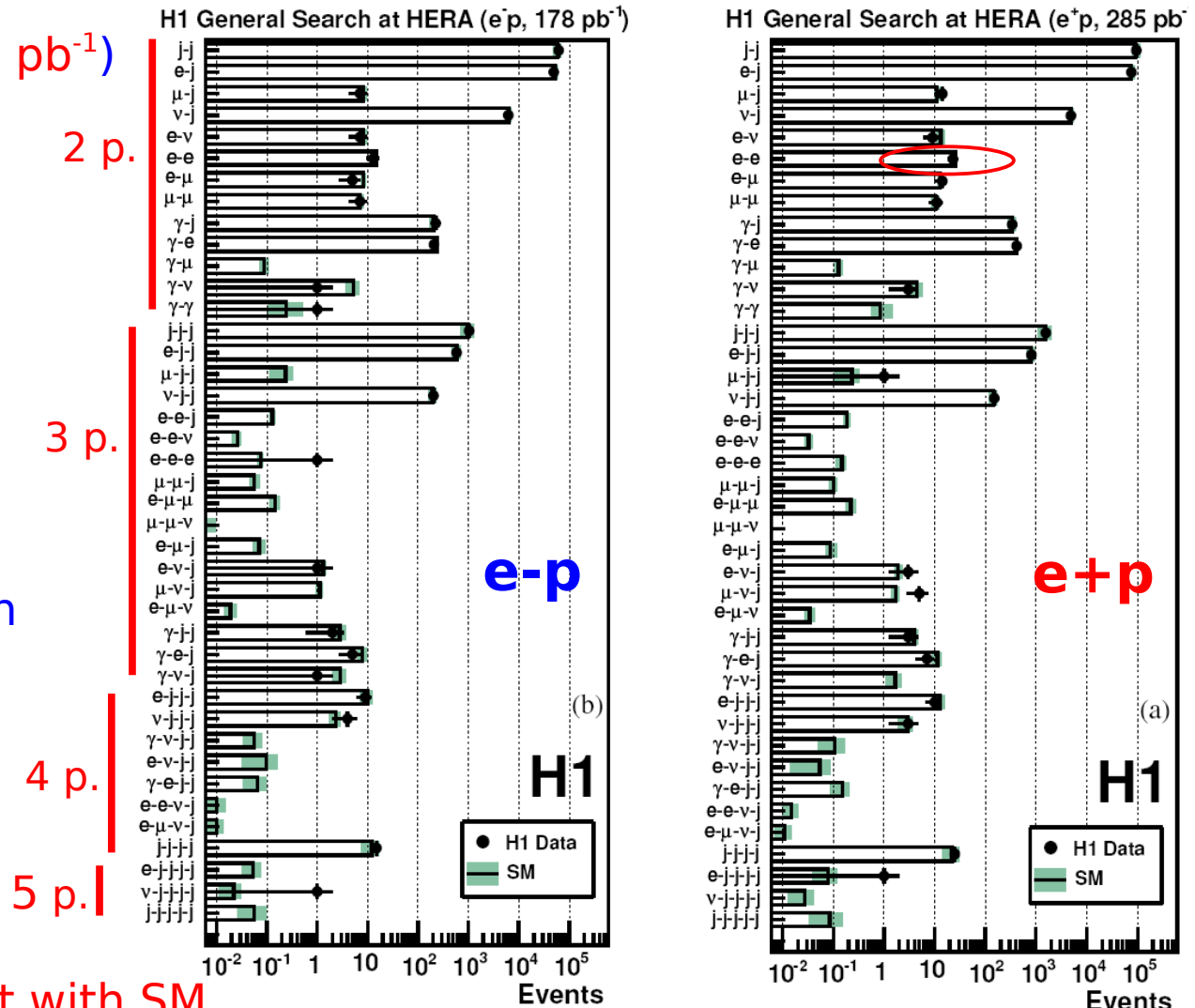
A General Search: H1 final result

Model independent search for deviation from SM examines all possible different high transverse momentum final states

[arXiv:0901.0507 (hep-ex)]

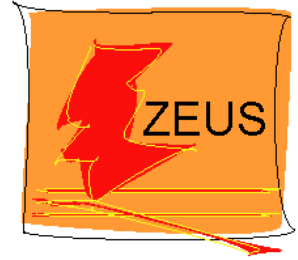
- H1: full HERA I+II data (463 pb^{-1})
- Signature:
isolated particles at high P_T ($e, \gamma, \mu, \text{jet}, \nu$)
- Unique phase space:
 $P_T > 20 \text{ GeV}$ & $10^\circ < \theta < 140^\circ$
- Look for possible deviation in ΣP_T and M_{all} distributions
- Statistical analysis to quantify the significance of deviation
- in general: good agreement with SM,
at least one event is found in 27 topologies for all ep data

➔ Most significant deviation: $e-e$ in e^+p





Summary



- HERA ended on June 2007 after 15 years of successful operation

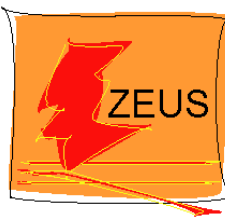
✚ $\sim 0.5 \text{ fb}^{-1}$ collected per experiment

- ➔ All analyses use the full dataset
- ➔ H1 and ZEUS combination ongoing for isolated leptons and multi-leptons ➔ $\sim 1 \text{ fb}^{-1}$
- ➔ Results show no significant deviations to SM
- ➔ but HERA is competitive in setting limits

Back up

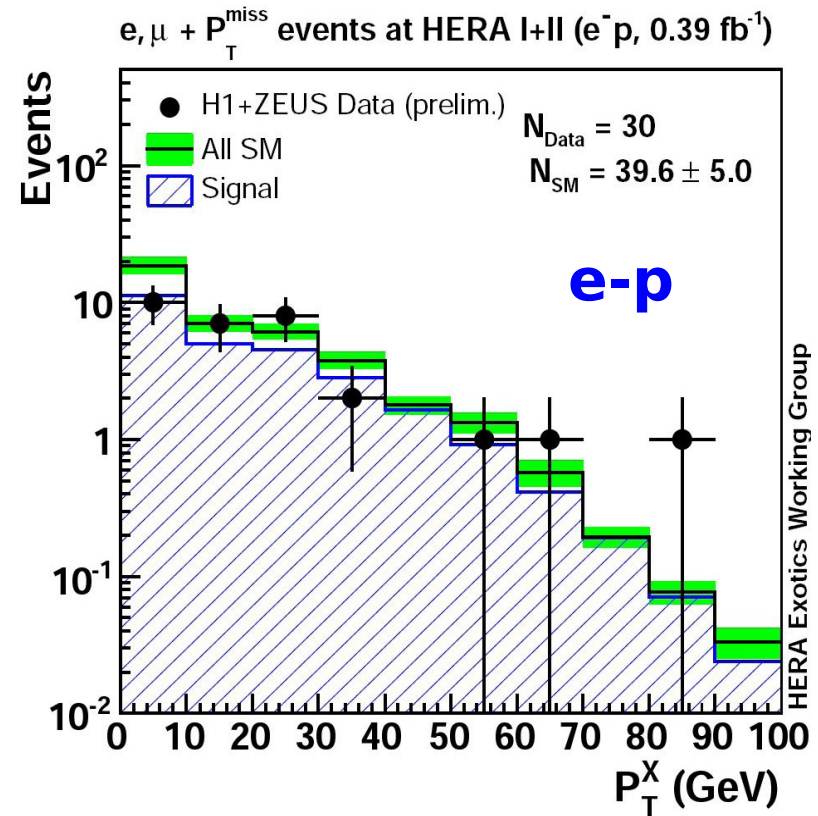
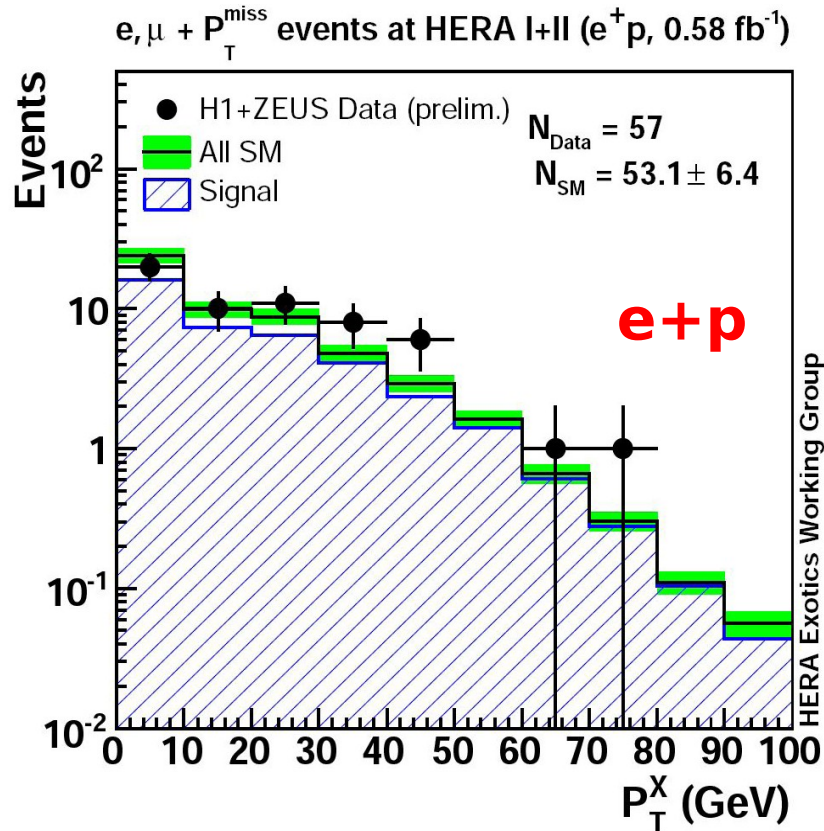


H1+ZEUS W production at HERA ($W \rightarrow e, \mu$)



● H1 and ZEUS results combined in common phase-space

✚ Total luminosity $L \sim 0.97 \text{ fb}^{-1}$



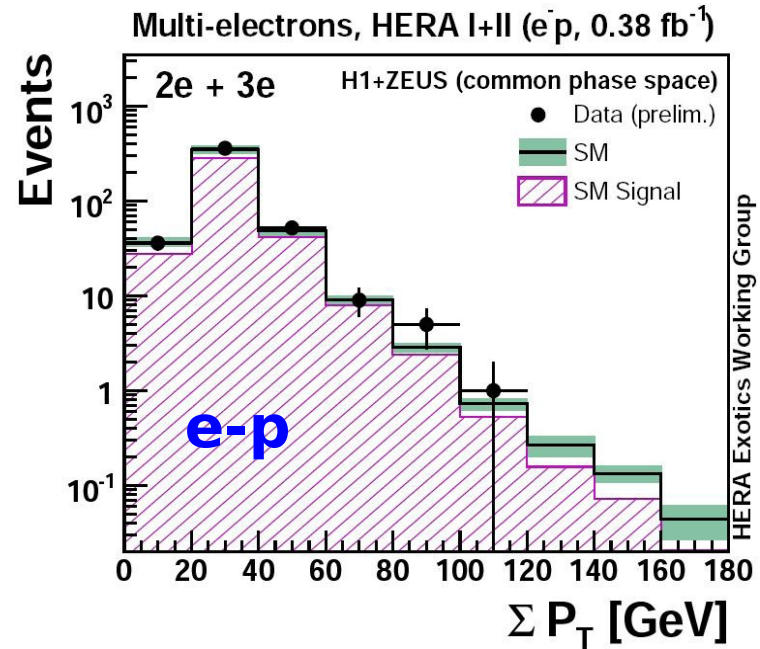
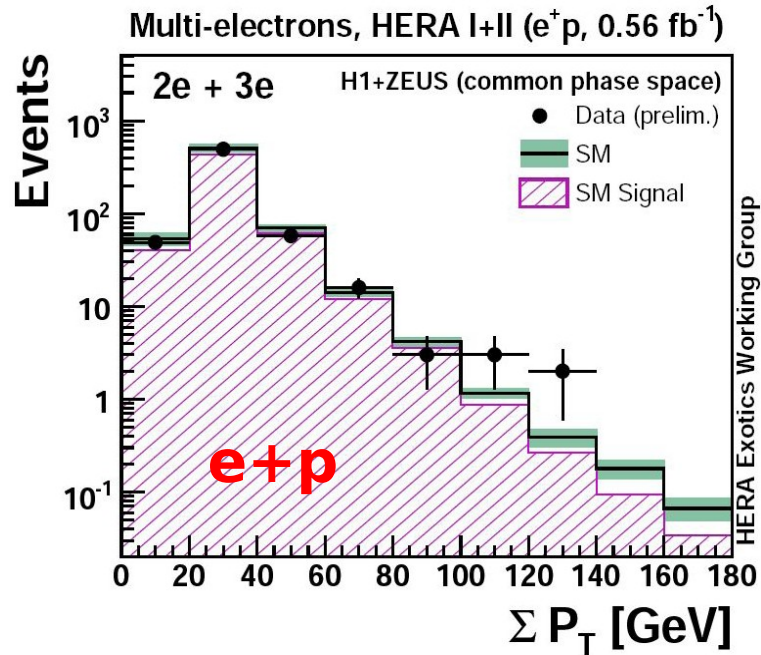
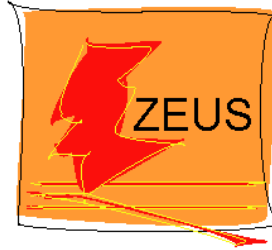
✚ Good agreement with SM in the global sample

✚ Fluctuation in $e+p$ for $P_T^X > 25 \text{ GeV}$ is reduced 1.8σ ($23 / 14.5 \pm 1.8$)

(Note: shown is based on preliminary results. Combination with final result is ongoing)

H1+ZEUS Multi-Electrons Events

- H1 and ZEUS results combined in common phase-space
 - ↘ Total luminosity $L \sim 0.94 \text{ fb}^{-1}$



$\Sigma P_T > 100 \text{ GeV}$

Data sample	Data	SM
e^+p (0.56 fb^{-1})	5	1.82 ± 0.21
e^-p (0.38 fb^{-1})	1	1.19 ± 0.14
$e^\pm p$ (0.94 fb^{-1})	6	3.00 ± 0.34

- ↘ Few high P_T events observed mainly in $e+p$ data

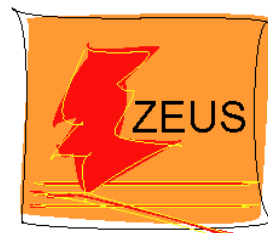
ZEUS Multi-Leptons Events

- ZEUS: analysis also performed for multi-leptons events

➤ Covered topologies: ee , eee , $e\mu$, $\mu\mu$, $e\mu\mu$

➤ Full ZEUS HERA data used: 480 pb^{-1}

(Hottest ZEUS results! Released very recently.)

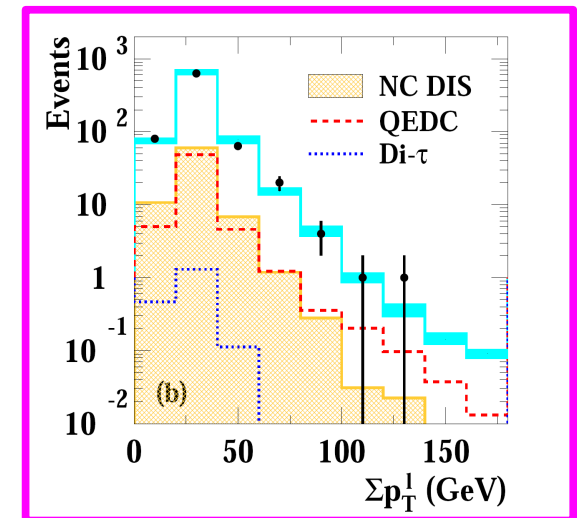
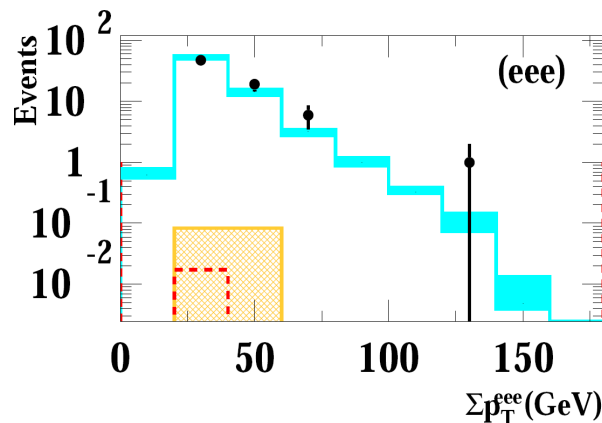
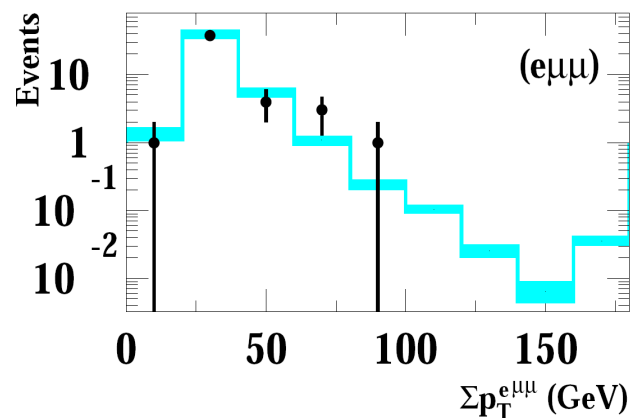
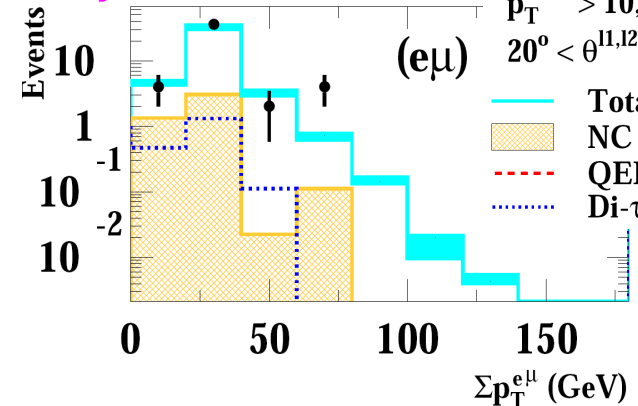
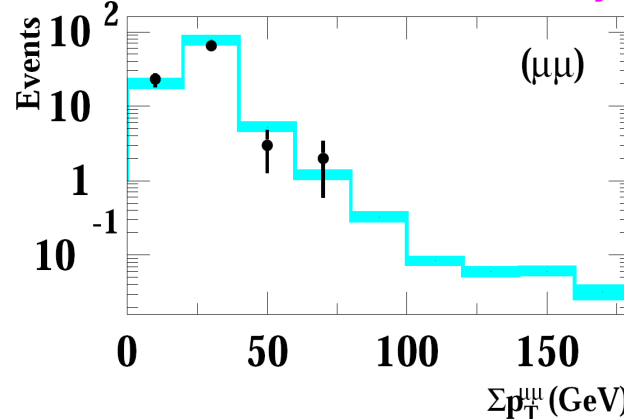
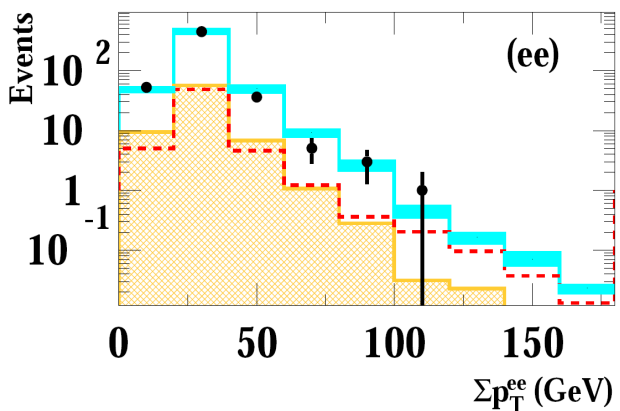


• ZEUS 480 pb^{-1}

$p_T^{11,12} > 10,5 \text{ GeV}$

$20^\circ < \theta^{11,12} < 150^\circ$

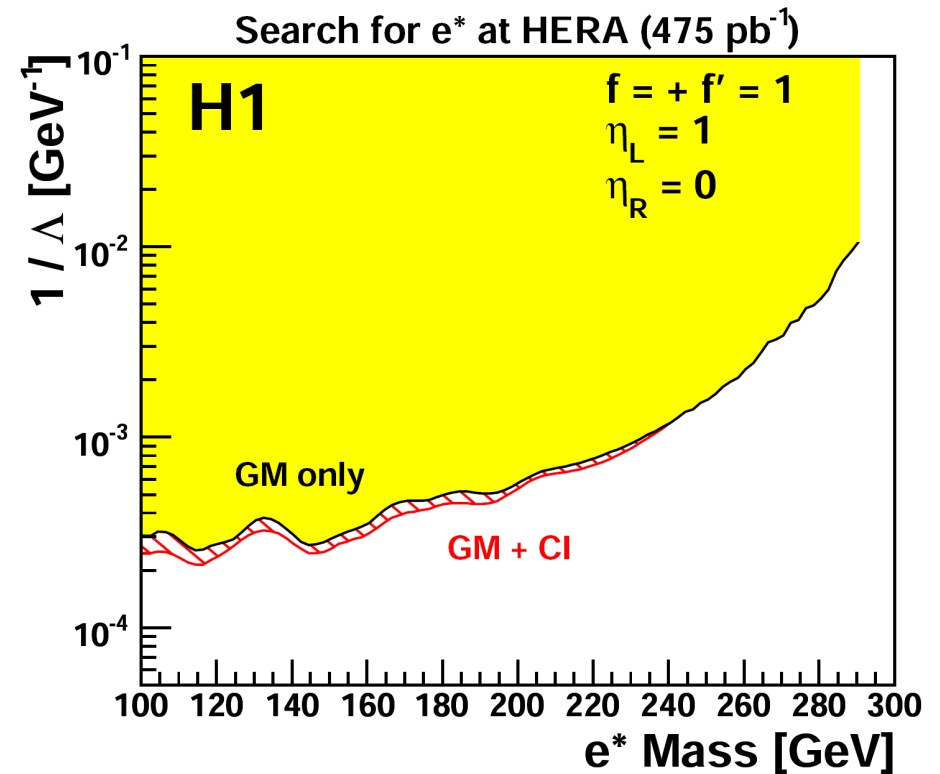
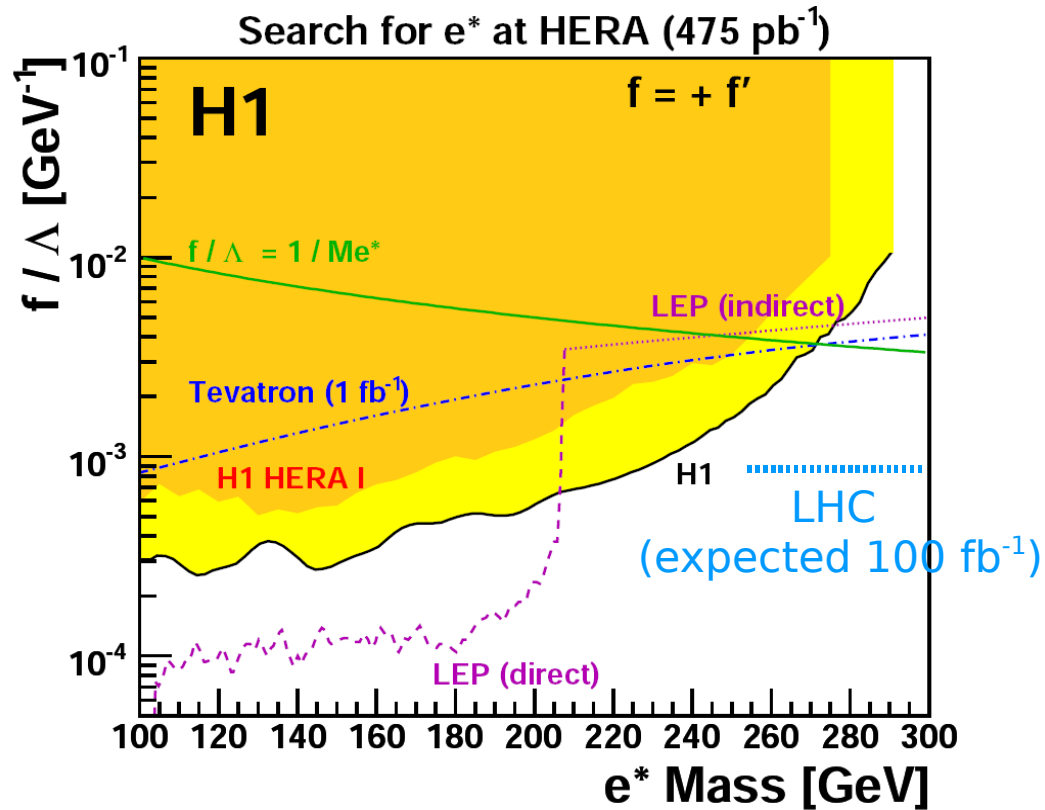
— Total SM
 ■ NC DIS
 - - QEDC
 ··· Di- τ



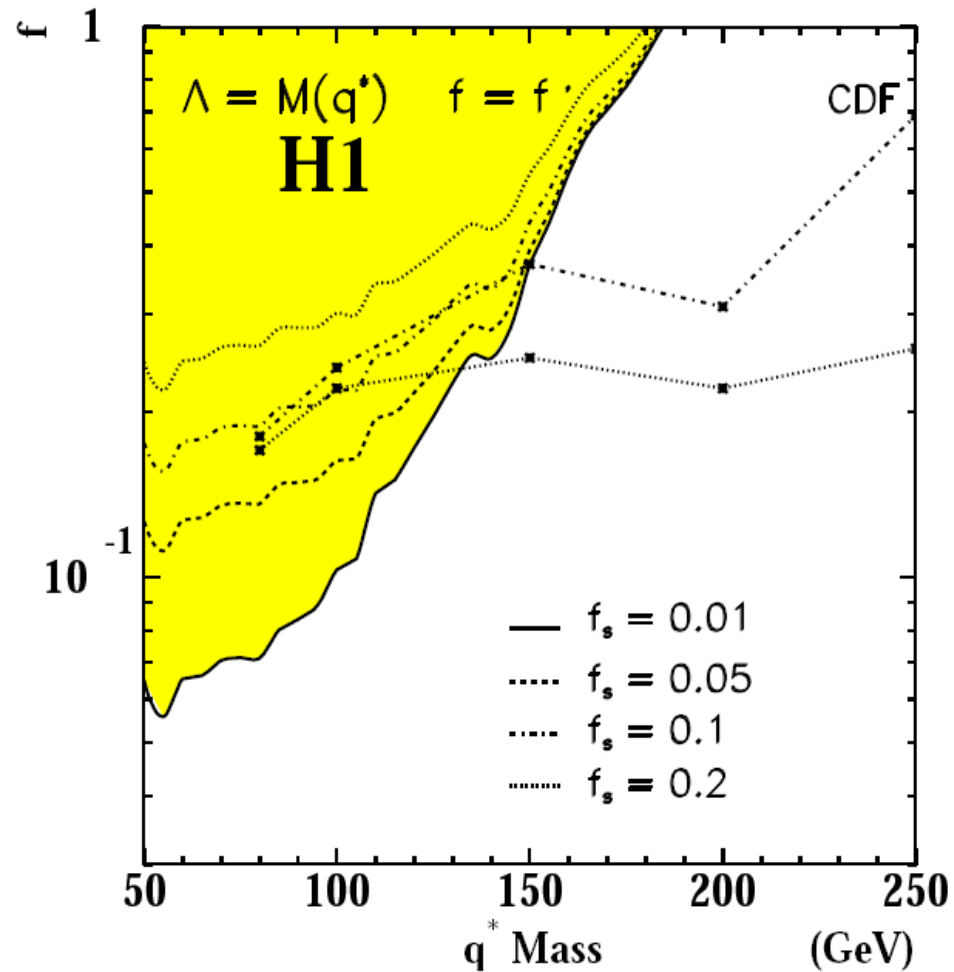
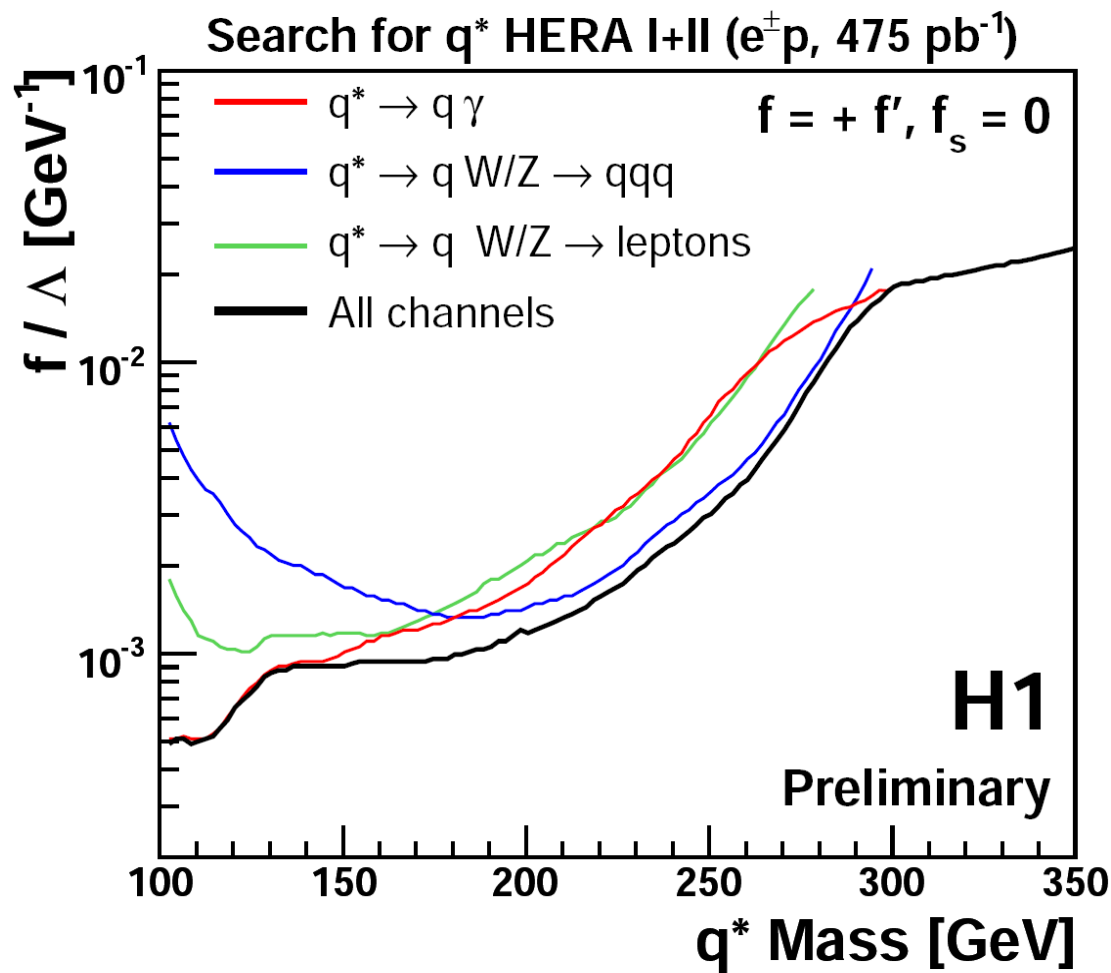
➤ ZEUS: Good agreement with the prediction of SM, results comparable to H1

➔ H1 and ZEUS results combined in common phase-space is ongoing

Excited Electrons at HERA



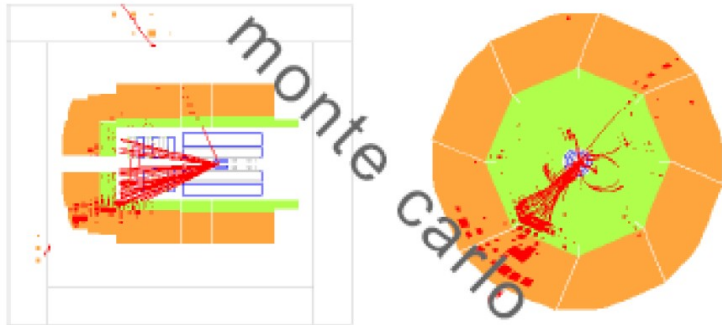
Excited Quarks at HERA



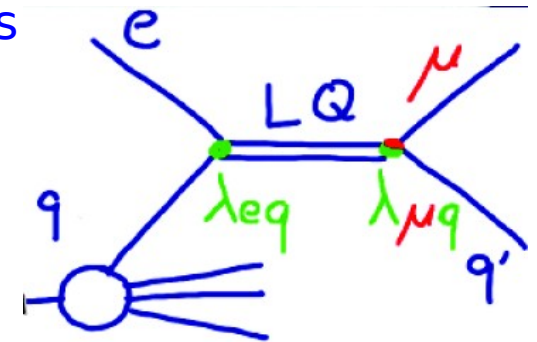
or Lepton Flavor Violation (LVF)

- LFV can be mediated by LQs in family non-diagonal modes

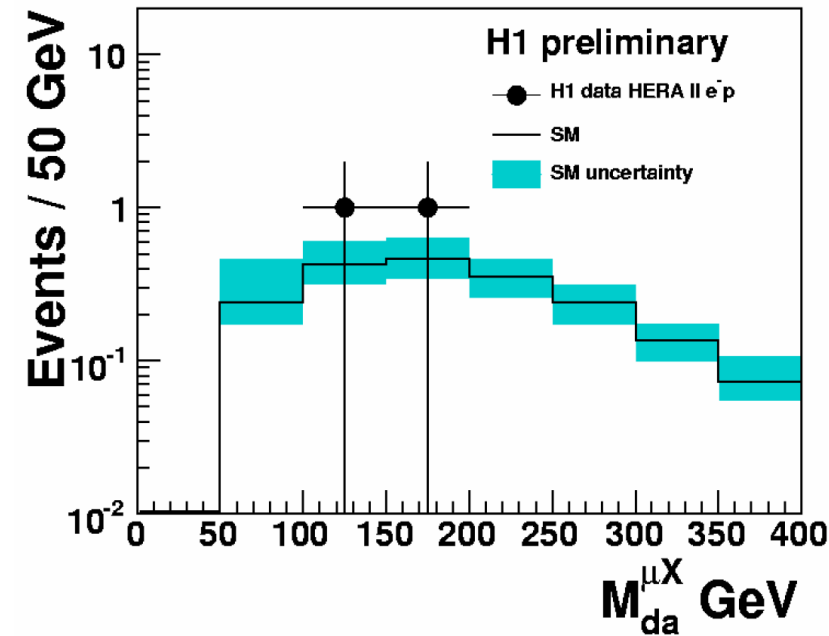
- Incoming $e \rightarrow \mu$ or τ in the final state
- Process: $e-p \rightarrow \mu X$ mediated by $F=2$ LQ in e-p data



Isolated muon
 $P_t^{\text{calo}} > 20 \text{ GeV}$
 back to back topology

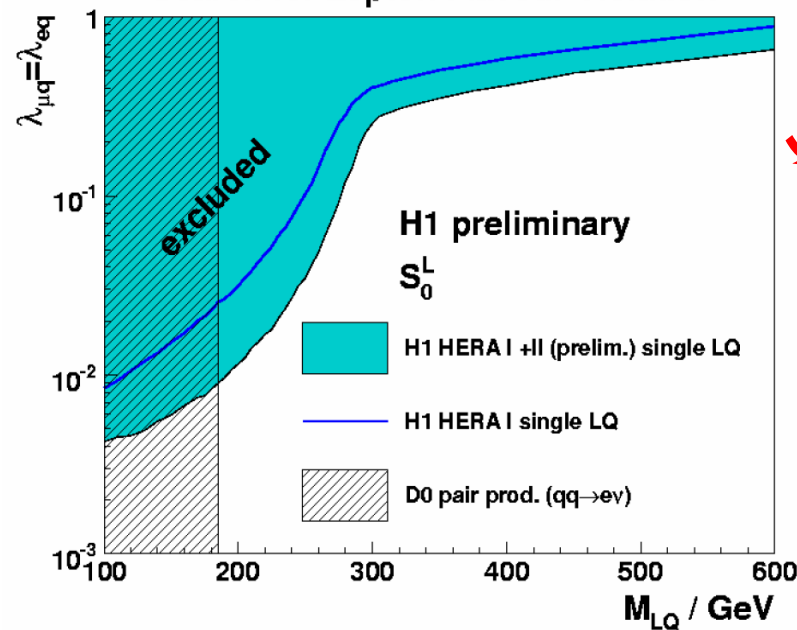


Search for Lepton Flavour Violation



- Limit derived on coupling λ , assuming: $\lambda_{eq} = \lambda_{\mu q}$

Search for Lepton Flavour Violation



For $\lambda \approx 0.3$:
 $F=2$ LQs with M_{LQ}
 up to 433 GeV
 can be ruled out



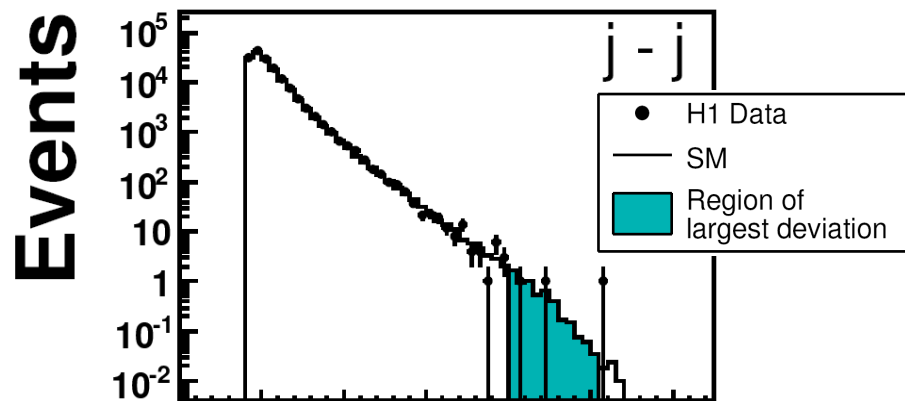
Statistical Interpretation of General Search

➤ Looking for possible deviation in ΣP_T and M_{all} distributions

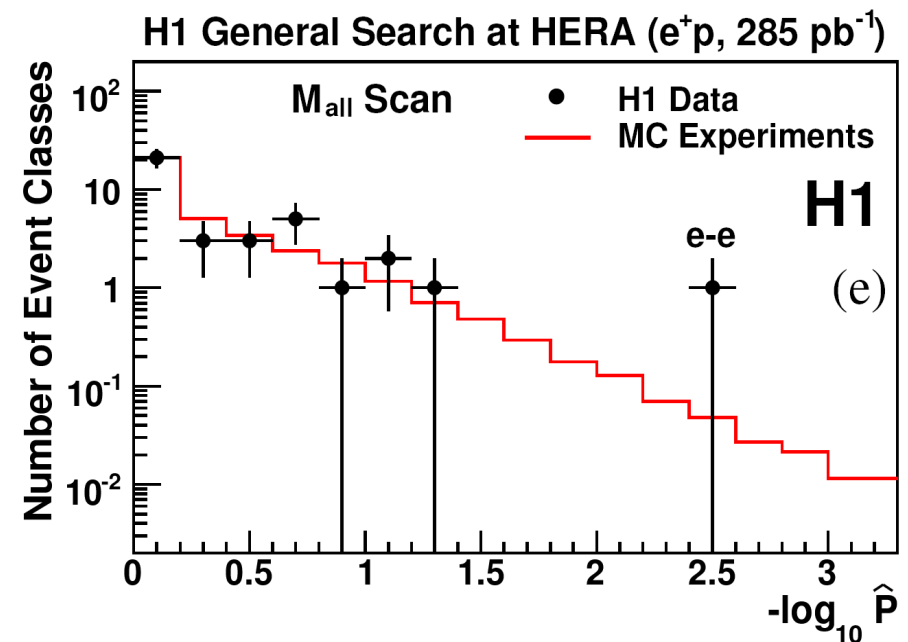
➔ Quantify possible deviation

- Identify regions of largest deviations between Data/MC

- Significant deviation: $p \ll 1$ (p : probability of up or down fluctuation in each region)



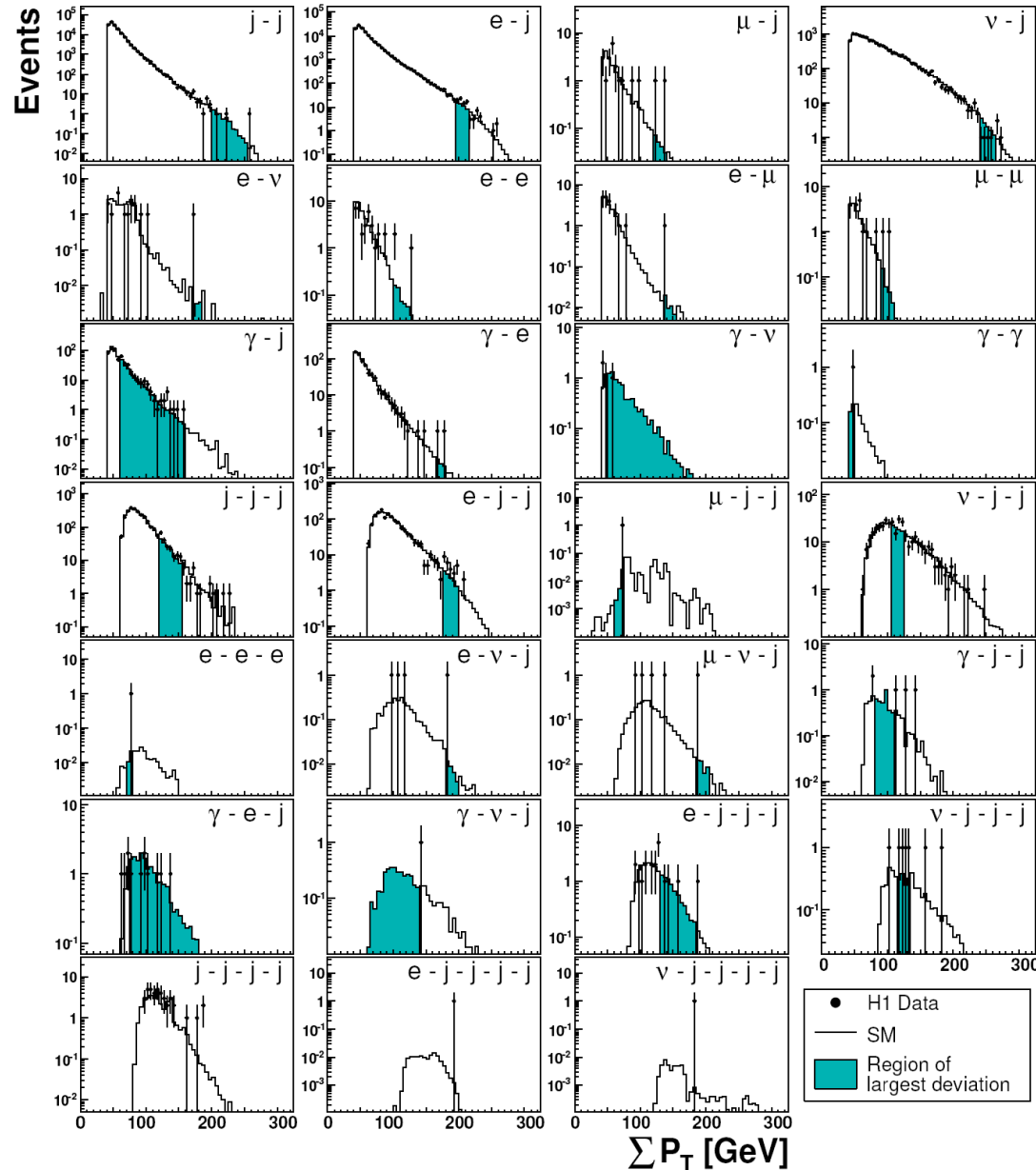
- What's the probability P to observe such a deviation?



➤ Most significant deviation at HERA: e-e in e^+p

A General Search: H1 final result

H1 General Search at HERA (e^+p , 463 pb^{-1}) - ΣP_T Distributions



H1 General Search at HERA (e^+p , 463 pb^{-1}) - M_{all} Distributions

