Searches for new physics in high energy *ep* collisions

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on behalf of the H1 and ZEUS collaborations

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SPA - BELGIUM

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INTERNATIONAL ADVISORY COMMITTEE

Outline

- Model based searches
  - New physics at DIS
    - Quark radius
    - Contact interactions
    - Heavy Leptoquarks

    presented by F.Januschek in plenary session
  - Lepton Flavour Violation
  - Squark production in RPV SUSY
  - Excited fermions
  - Single top production
- Model independent searches
  - Multi-leptons
    - e/μ channels
    - τ channels
  - Isolated leptons with missing P_T
  - General searches
- Summary

Model based searches

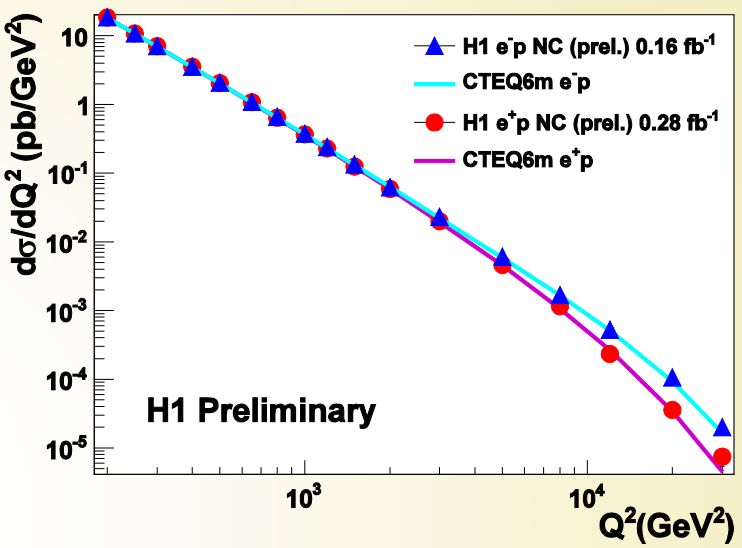
Physics search at DIS

H1prelim-10-161
ZEUS-prel-09-013

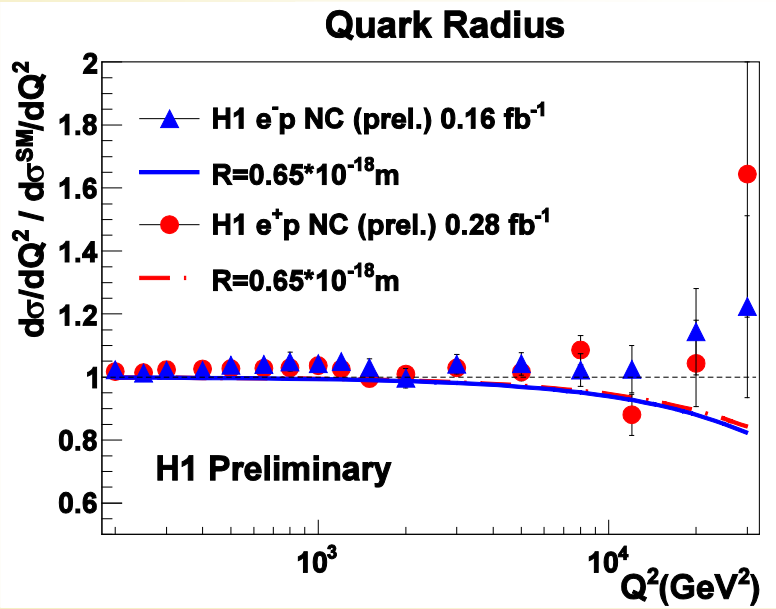
Comparison between measured and expected DIS cross section can search for new physics modeled by several theories.

- Quark radius
- Contact interactions
- Large extra dimentions
- Leptoquark searchs

see F.Januschek's talk



e.g.) Quark radius



Spatial distribution of the quark charge would reduce the SM cross section at high-Q^2.

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \cdot \left[1 - \frac{R_q^2}{6} Q^2\right]^2$$

H1: $R_q < 0.65 \cdot 10^{-18}$ m
ZEUS: $R_q < 0.63 \cdot 10^{-18}$ m

(95% C.L.)

Heavy leptoquarks

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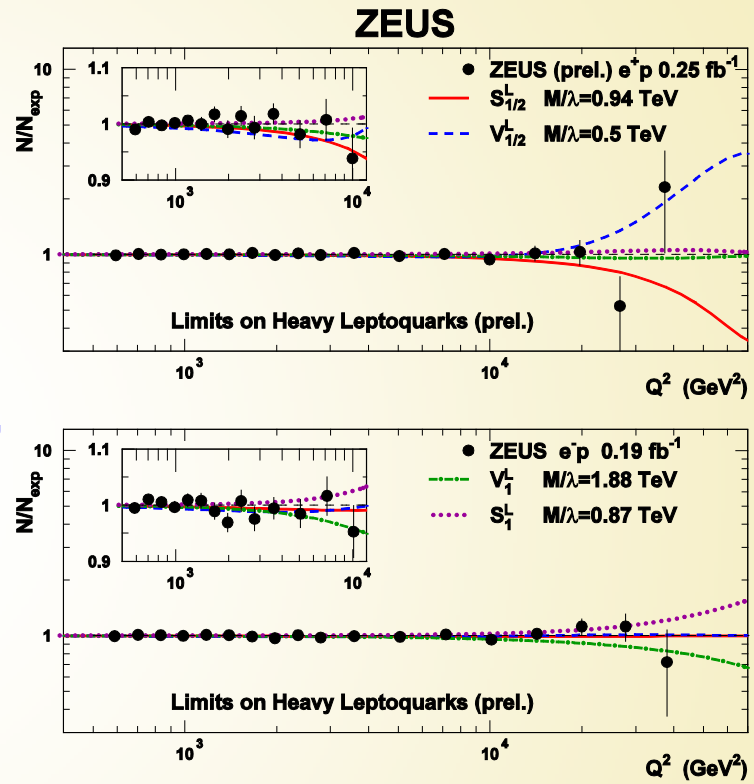
- Scalar/Vector bosons carrying both lepton and baryon number.
- *Buchmüller-Rückl-Wyler* model:
  - SM symmetry, lepton and baryon number conserved.



- 7 scalar and 7 vector 1st generation LQs, same final states as NC/CC DIS
- Heavy LQ exchange can be described by a contact interaction with effective coupling: $\eta \sim \lambda^2 / M_{LQ}^2$

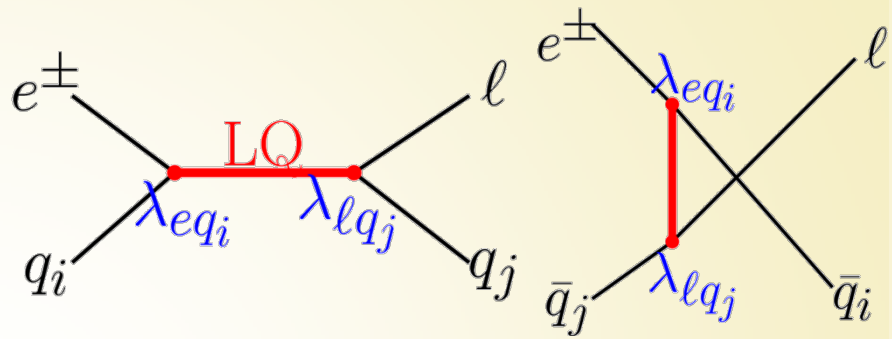
H1: $M_{LQ}/\lambda > 0.4 - 1.94$ TeV
ZEUS: $M_{LQ}/\lambda > 0.41 - 1.88$ TeV

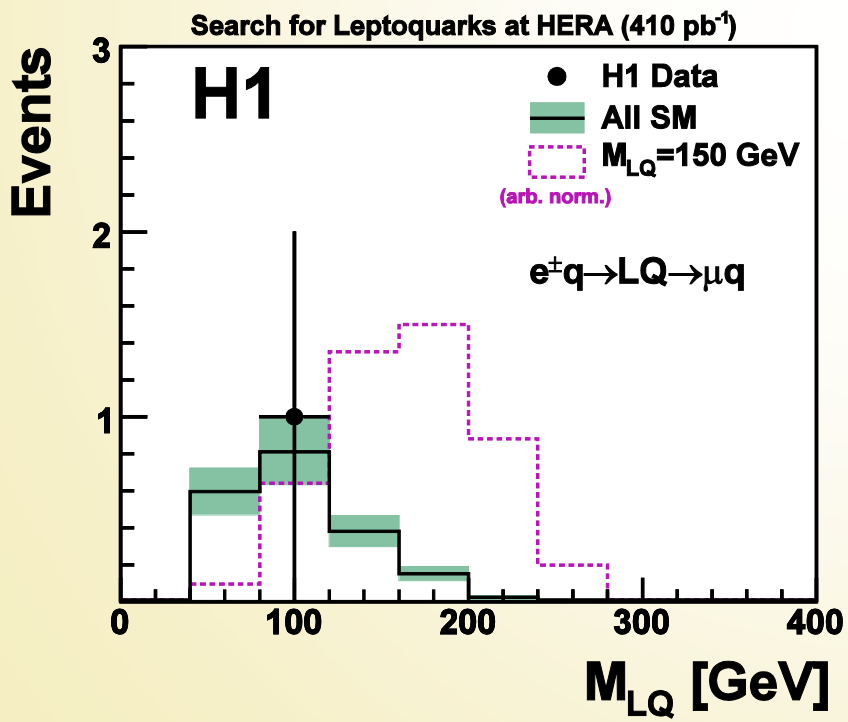
depending on the LQ type (95% C.L.)

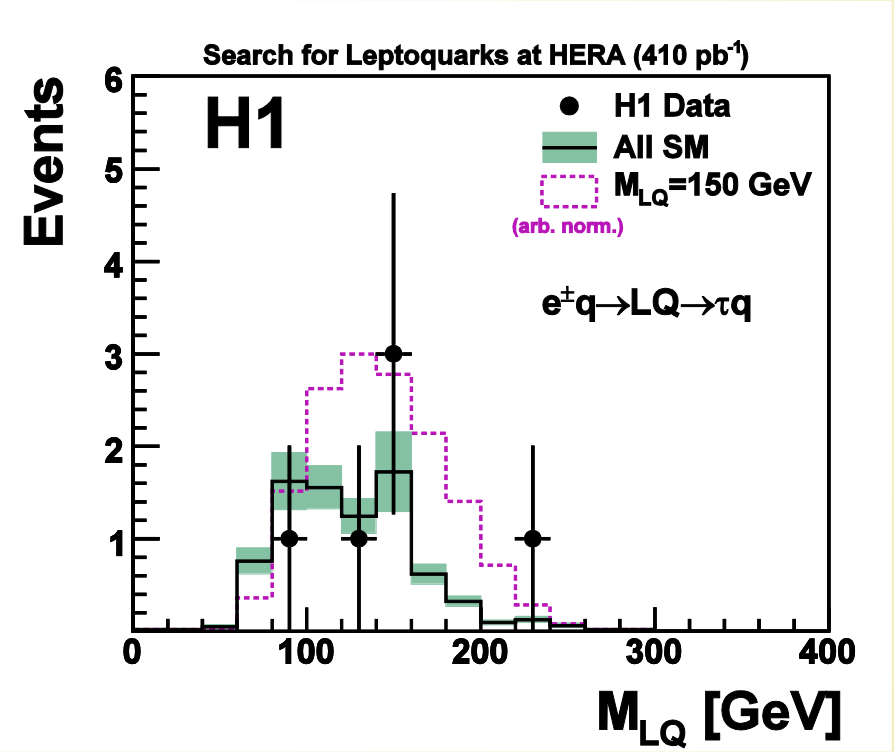
Lepton Flavour Violation

DESY-11-044

- Final states similar to NC events, replacing e by μ or τ.
  - HERA is a unique place to search for LFV as the signals would be clear, changing electron flavour in the initial state to muon or tau lepton flavour in the final state.



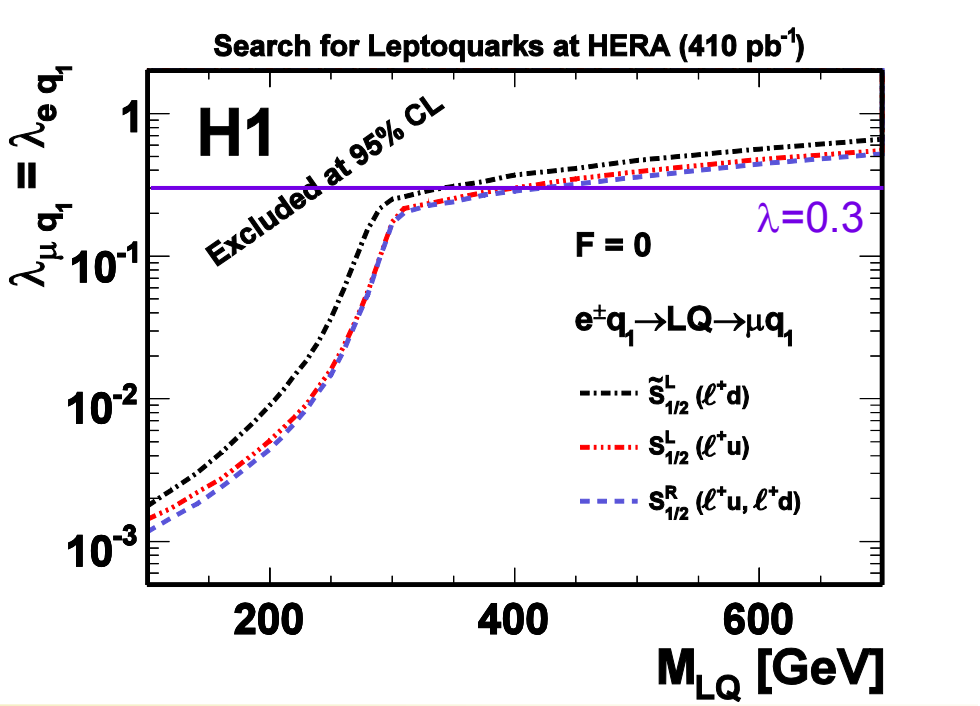


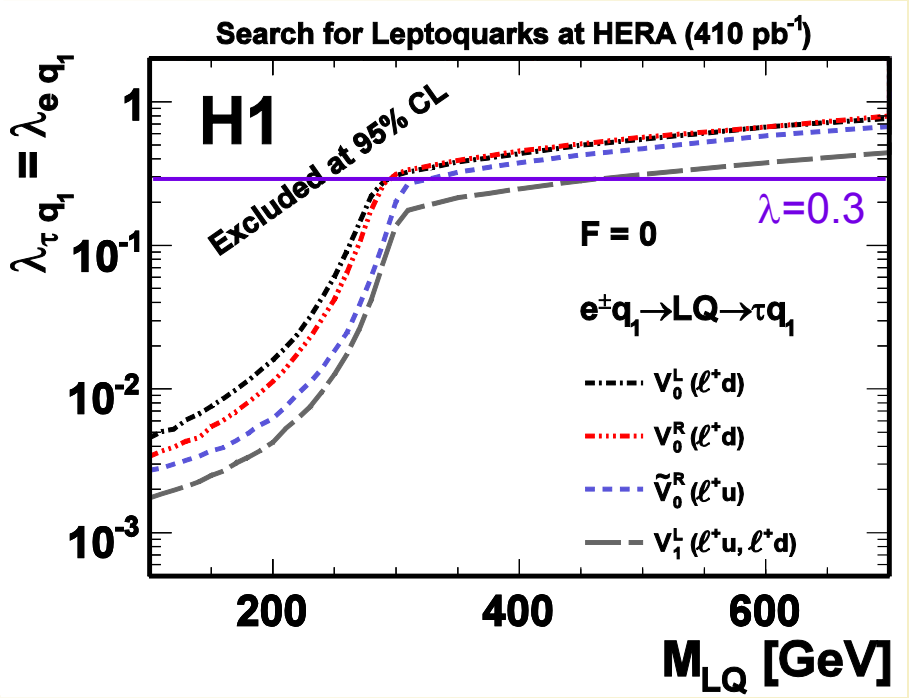


Lepton Flavour Violation

DESY-11-044

- No signal observed, compatible to previous investigation at HERA-I.
- New constraints on LQ are set.



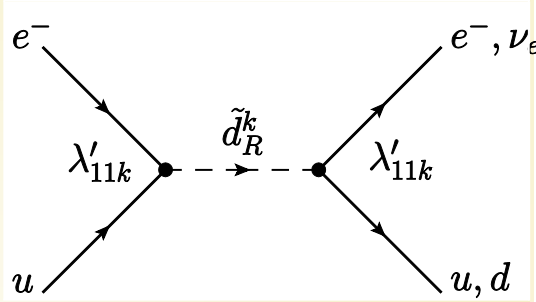


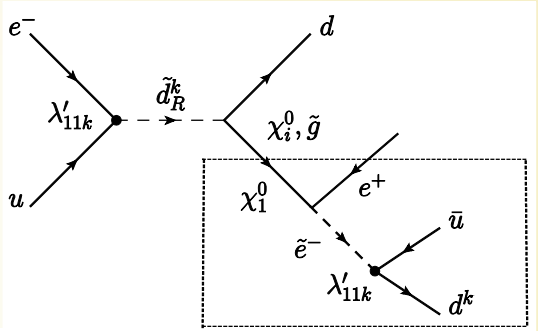
For $\lambda_{eq}=\lambda_{\mu q}=0.3$ and $\lambda_{\tau q} = 0$,
M_{LQ} > 304-530 GeV depending on LQ type

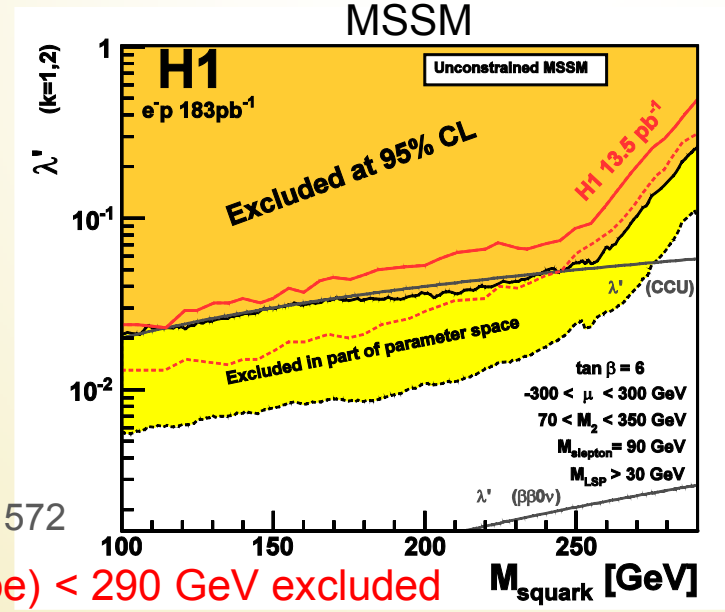
For $\lambda_{eq}=\lambda_{\tau q}=0.3$ and $\lambda_{\mu q} = 0$,
M_{LQ} > 272-450 GeV depending on LQ type

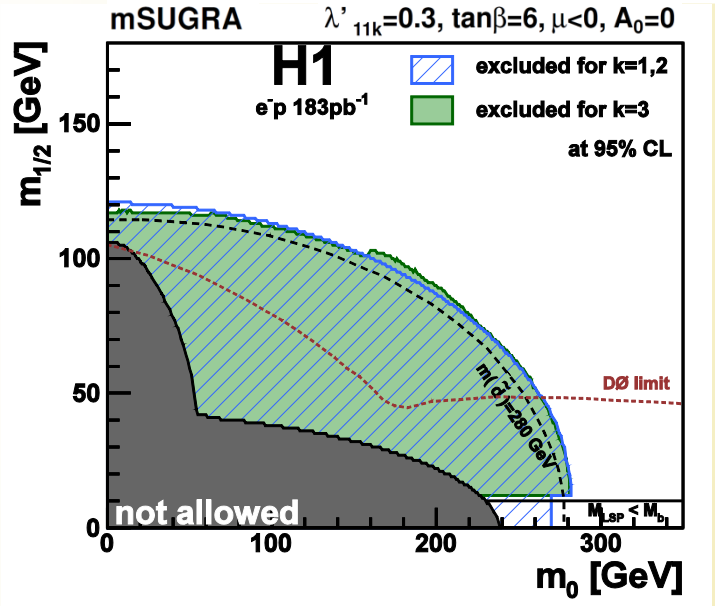
Squark production in RPV SUSY

- In R-Parity Violating SUSY, squarks can couple to electron and quarks via Yukawa couplings λ'.
- Final states
  - lepton + quark (DIS-like)
  - quark + gaugino (i.e. multi-jets event)
- e^-p data are sensitive to down-type squark, while e^+p data to up-type.
  - See F.Januschek's talk for up-type squark result.









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M(down-type) < 290 GeV excluded

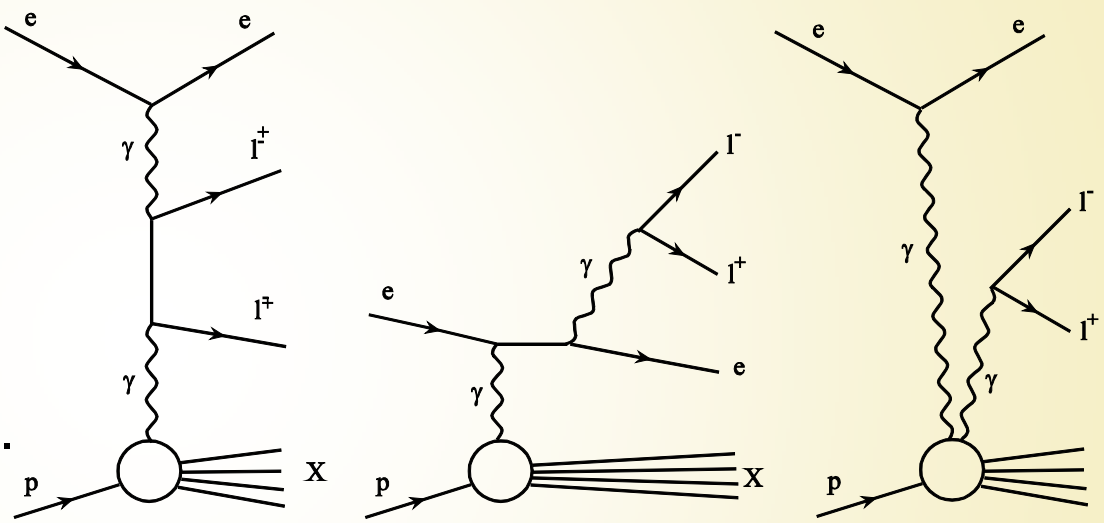
Model independent searches

Multi-leptons

- At least 2 isolated high-p_T leptons (e or μ) are looked for.

- The main SM process:
  → γ-γ interactions

- very precisely calculable
  – Deviation from SM would be indication of new phenomena.



- H1 and ZEUS combined their results. (i.e. L=0.94fb^{-1})

- Searched topologies : *ee*, *eee*, *e*μ, $\mu\mu$, *e*$\mu\mu$

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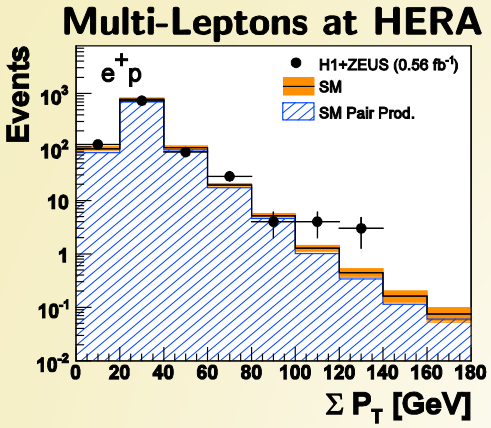
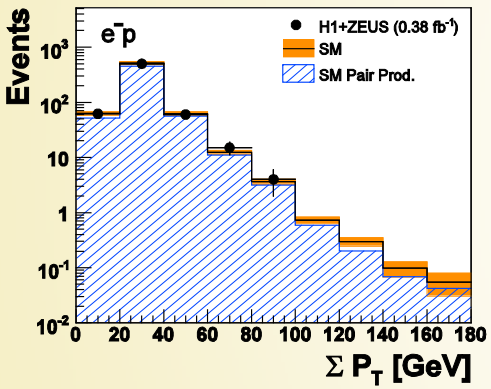
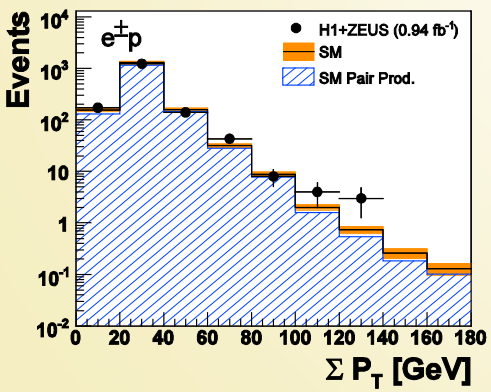
Multi-leptons



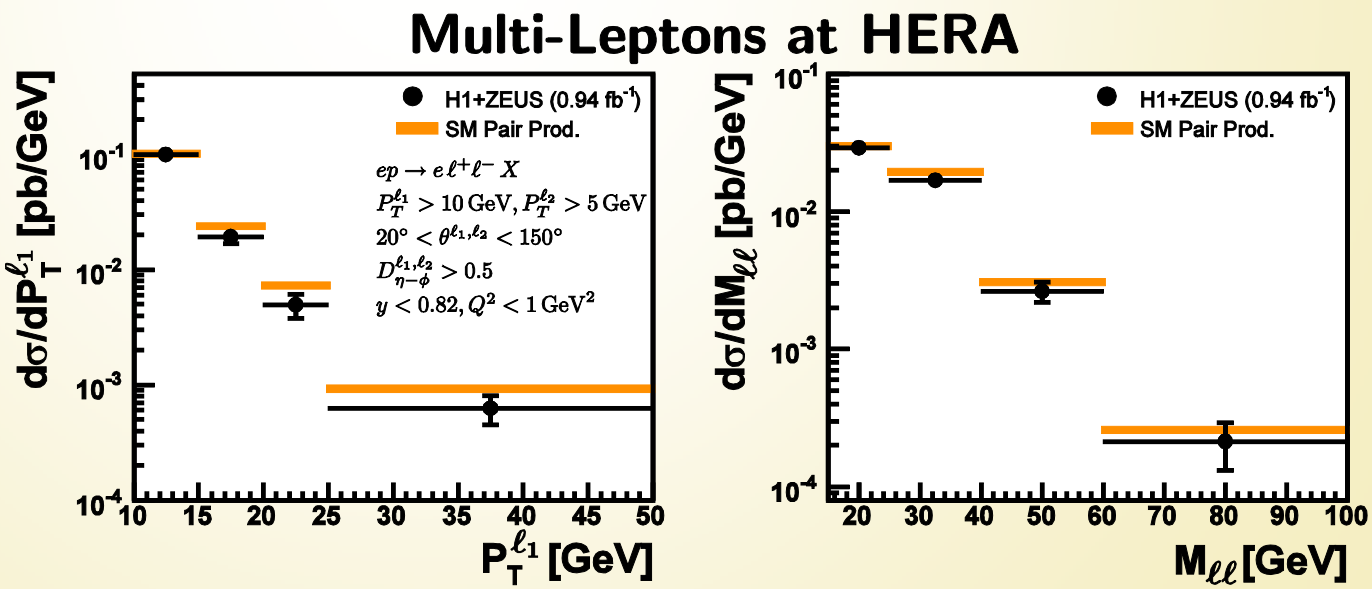




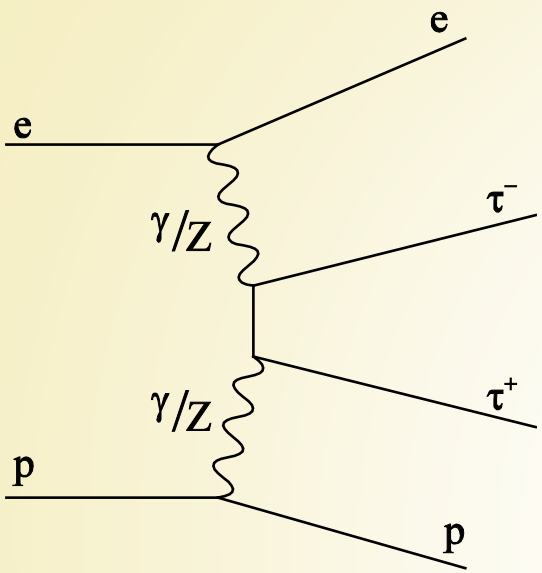
Distributions of the scalar sum of the two highest P_T leptons are in good agreement with SM.

All high p_T/mass events observed by both experiments originate from only e^+p collisions…

Differential cross section for the highest P_T lepton and the invariant mass has been also extracted.



Multi-leptons: tau channel



$\sigma \sim 10$ pb ($P_T^{\tau} > 5$ GeV)

also looked into tau channel…

$$\tau^+\tau^- \longrightarrow \begin{cases} e^{\pm} + \mu^{\mp} + \nu_{\tau} + \cdots & \text{(BR : ~6.8\%)} \\ e^{\pm} + h^{\mp} + \nu_{\tau} + \cdots & \text{(BR : ~23\%)} \\ \mu^{\pm} + h^{\mp} + \nu_{\tau} + \cdots & \text{(BR : ~22\%)} \\ h^{\pm} + h^{\mp} + \nu_{\tau} + \cdots & \text{(BR : ~42\%)} \end{cases}$$

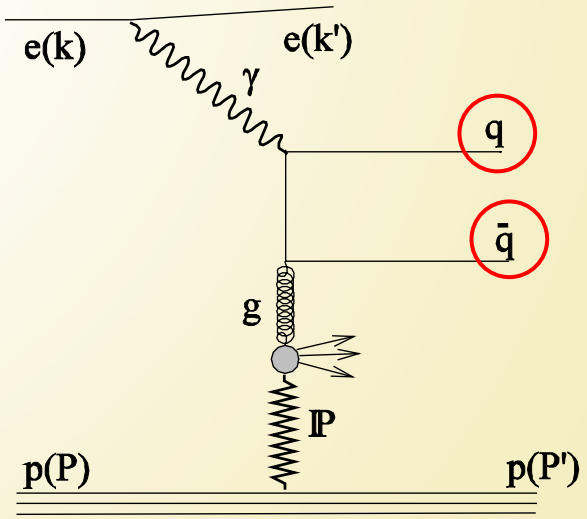
Hadrons from τ decay is identified by "jet".

(Other topologies could not be distinguished from di-electron and di-muon process.)

There are many kinds of large background…

e.g.) diffractive photoproduction

σ~300 nb (2 jets w/ E_T>4 GeV)



The most difficult/important thing

➔ separate a τ–jet from quark/gluon induced jets

tau–jet ID for τ channel analysis

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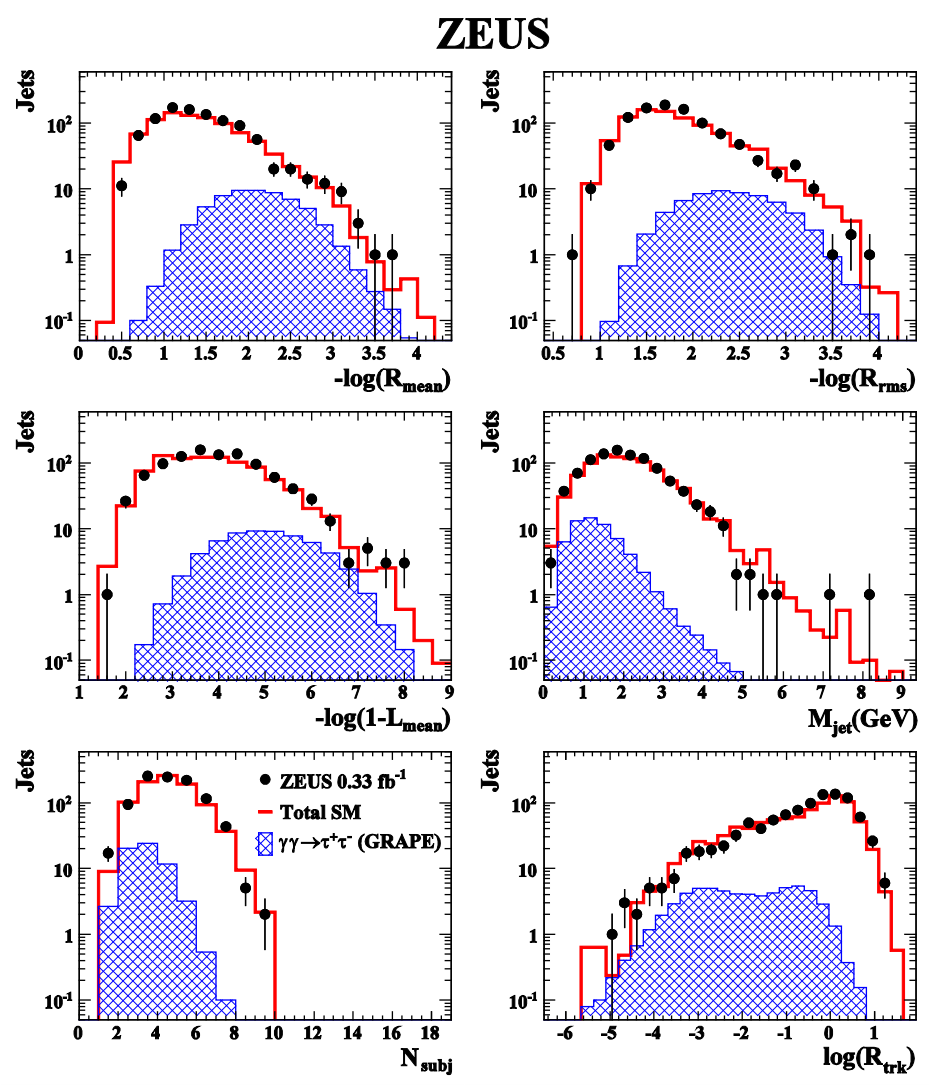


6 variables are prepared for discrimination from QCD-jets.

R_{mean}, R_{rms} : 1st and 2nd moment of radial extension

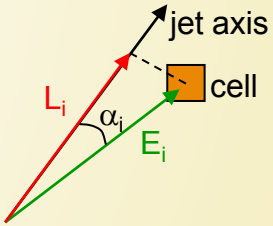
$$R_{mean} = \langle R \rangle = \frac{\sum_i \{E_i \cdot R_i\}}{\sum_i E_i} \qquad R_{rms} = \sqrt{\frac{\sum_i E_i \cdot (\langle R \rangle - R_i)^2}{\sum_i E_i}}$$

M_{jet} : invariant mass of clustered CAL cells

$$M_{jet} = \sqrt{(\sum_i E_i)^2 - (\sum_i p_{i,x})^2 - (\sum_i p_{i,y})^2 - (\sum_i p_{i,z})^2}$$

L_{mean} : 1st moment of longitudinal extension

$$L_{mean} = \langle L \rangle = \frac{\sum_i E_i \cdot \cos\alpha_i}{\sum_i E_i}$$



R_{trk} : The sum of distance between the jet axis and the tracks associated with the jet

$$R_{trk} = \sum_i^{Ntrk} \sqrt{(\Delta\eta_i^2 + \Delta\phi_i^2)}$$

N_{subj} : Number of subjets (y_{cut}=5×10^{-4})

tau–jet ID for τ channel analysis

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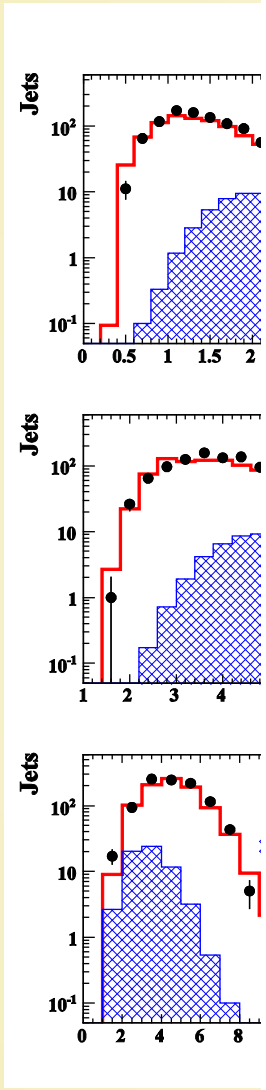
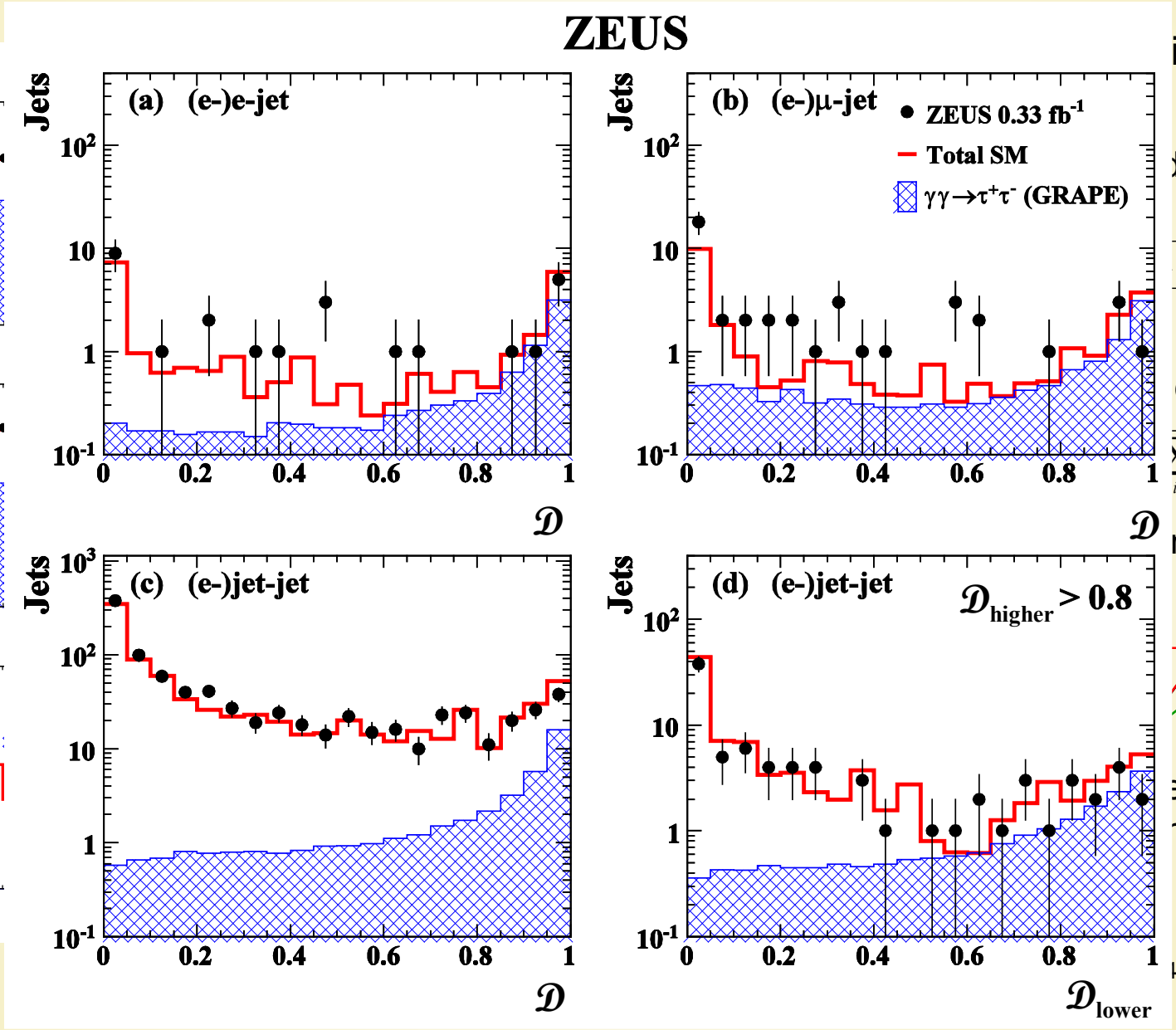




imination

dial

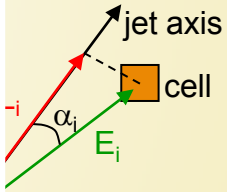
$\cdot(\langle R\rangle - R_i)^2$

$\sum_i E_i$

cells

$\sum_i p_{i,z})^2$

nsion



e jet axis

ne jet

Multi-leptons: tau channel result

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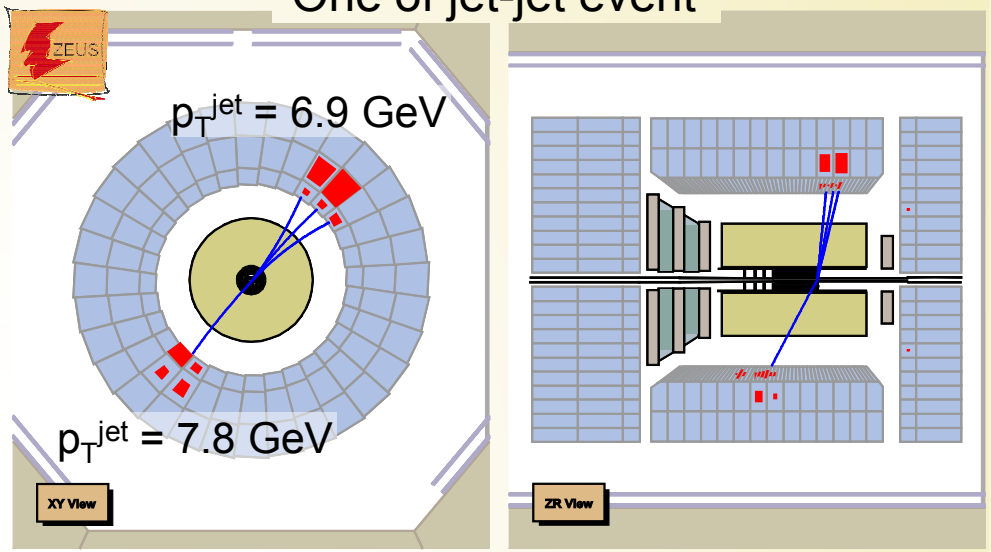
- ZEUS selected 25 ditau events with 67% purity, in 0.33 fb^{-1}
  - One of the most difficult to select in HERA

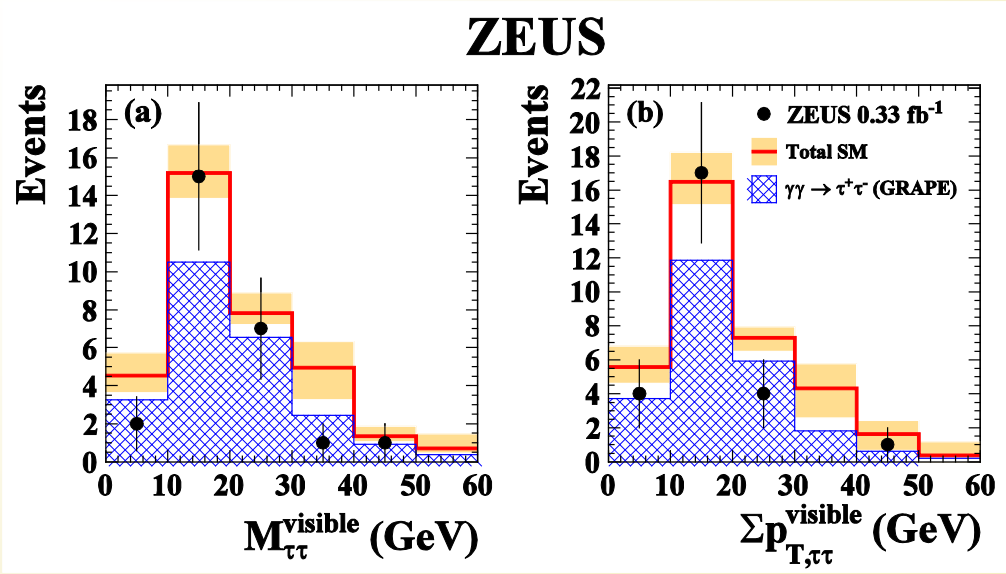
One of jet-jet event



- No surprise at high mass and high total P_T.
  - Cross section in the kinematic region $p_T(\tau) > 5$ GeV and $17^o < \theta(\tau) < 160^o$ for both τ,

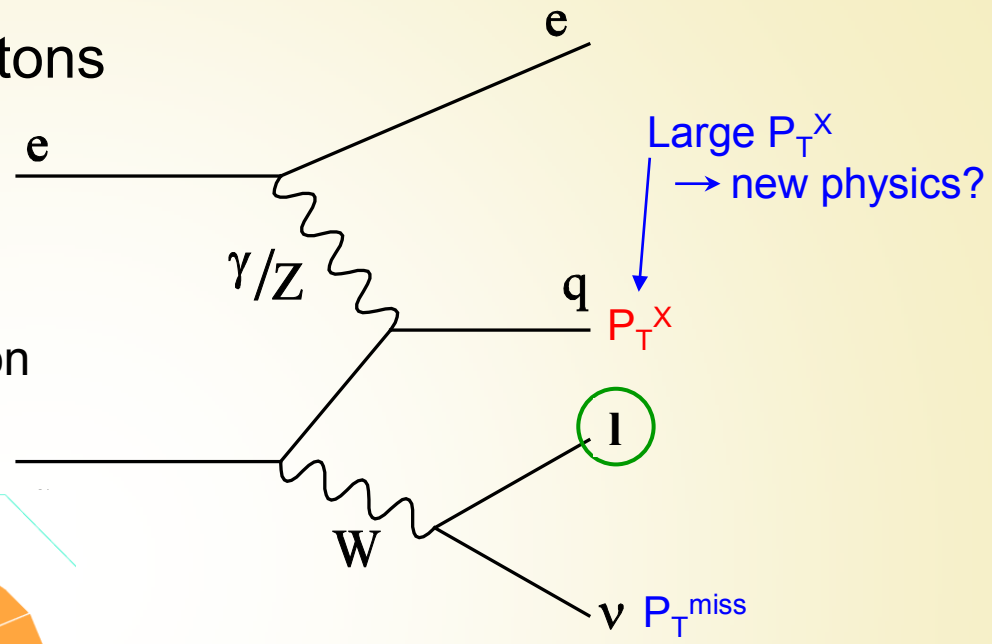
$$\sigma = 3.3 \pm 1.3\,(\text{stat.})\ ^{+1.0}_{-0.7}\ (\text{syst.})\ \text{pb}$$

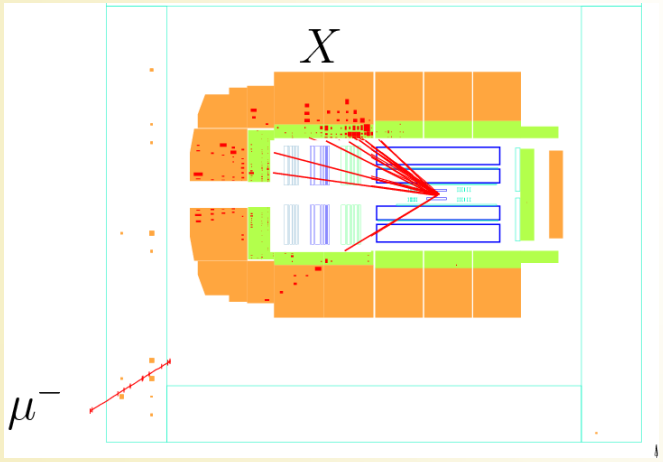
$$\left(\text{SM}\ \sigma = 5.67 \pm 0.16\,(\text{theor.})\ \text{pb}\right)$$

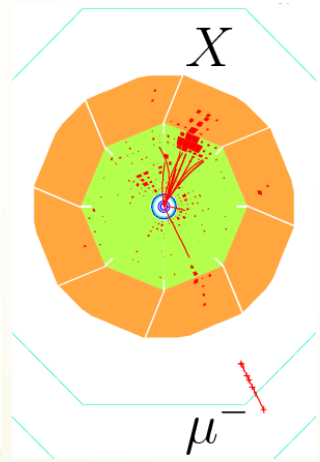


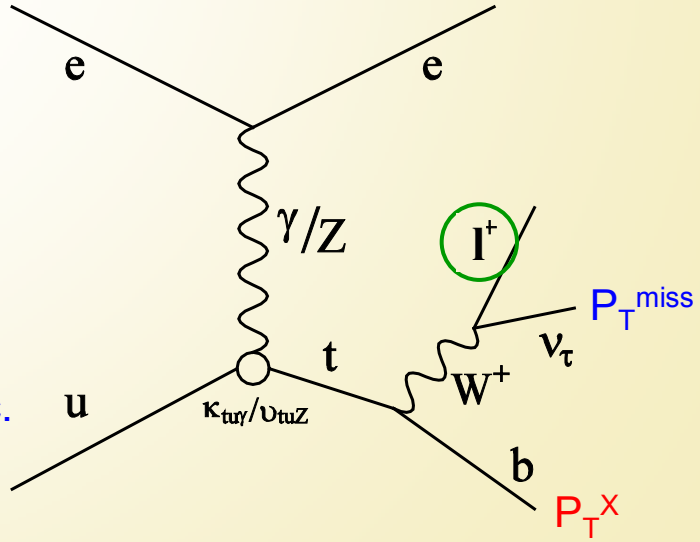
Isolated leptons with missing P_T

- Look for events with isolated leptons and missing P_T
- Rare process ($\sigma \times BR \sim 0.1\,\mathrm{pb}$), but sensitive to new physics
  - Main SM process : single W production with subsequent decay W $\rightarrow l\nu$.









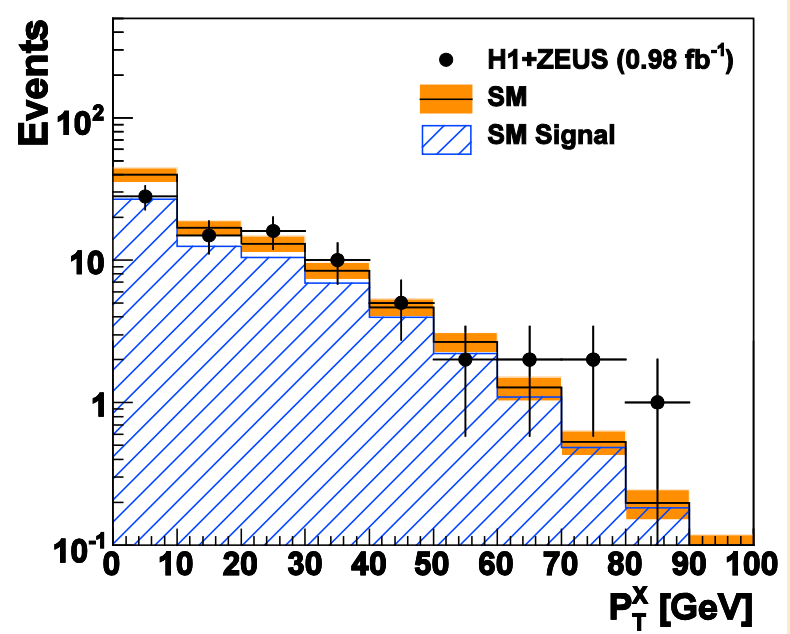
An excess at high p_T^X could be a sign of new physics.

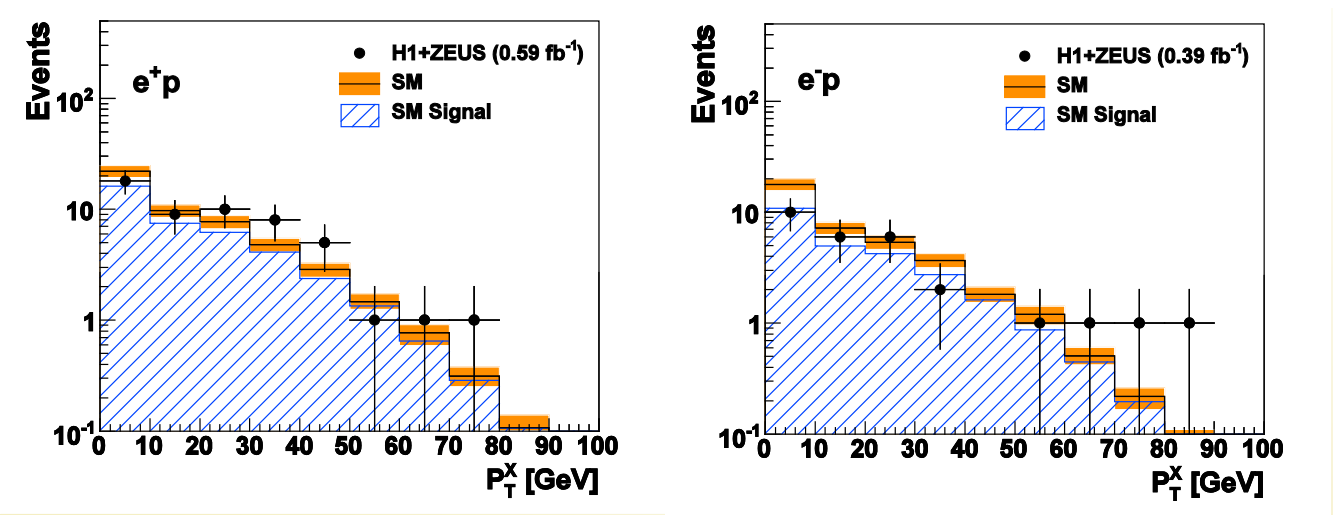
→ single top production via FCNC etc.

Isolated leptons with missing P_T

- H1 and ZEUS results were combined. → L ~ 0.98 fb^{-1}

- For P_T^X>25GeV,
  - No excess in e^-p data
  - In e^+p data, 23 events observed while 14.0±1.9 events expected.





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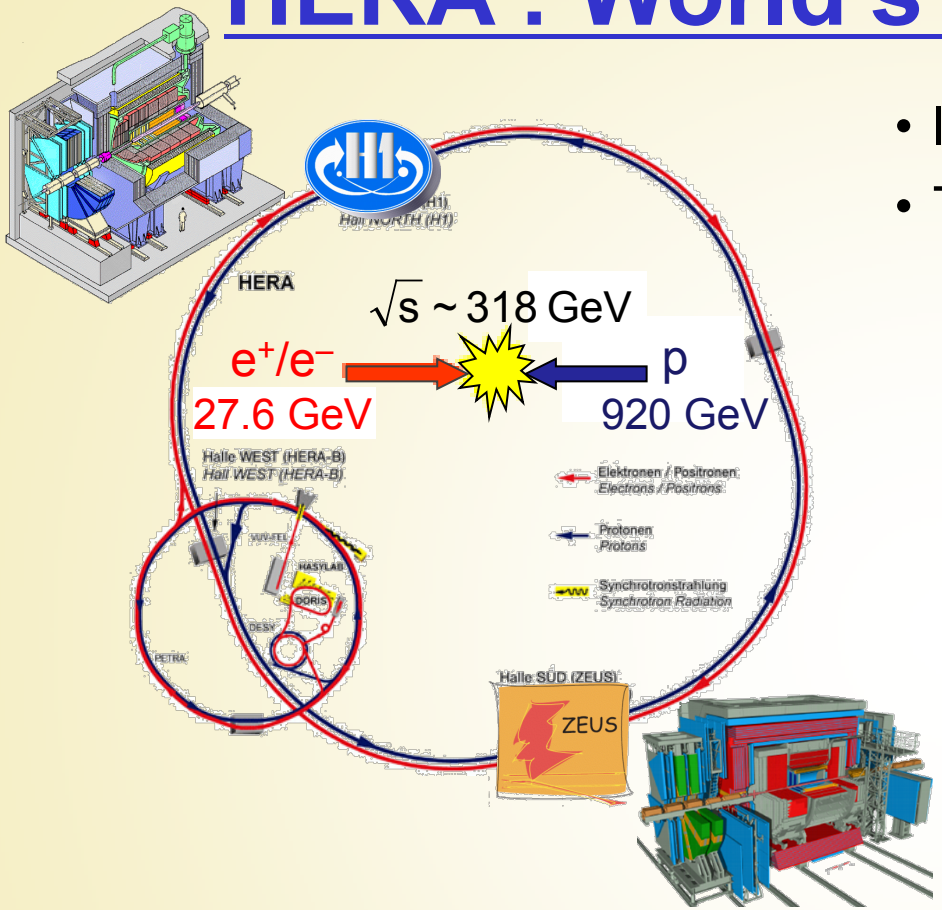
Summary

- Searches for new physics in ep collisions have been performed by the H1 and ZEUS collaboration with the full data sets of ~0.5 fb^{-1} per experiment.
  - Some results have been combined, corresponding to an integrated luminosity of ~1 fb^{-1}.

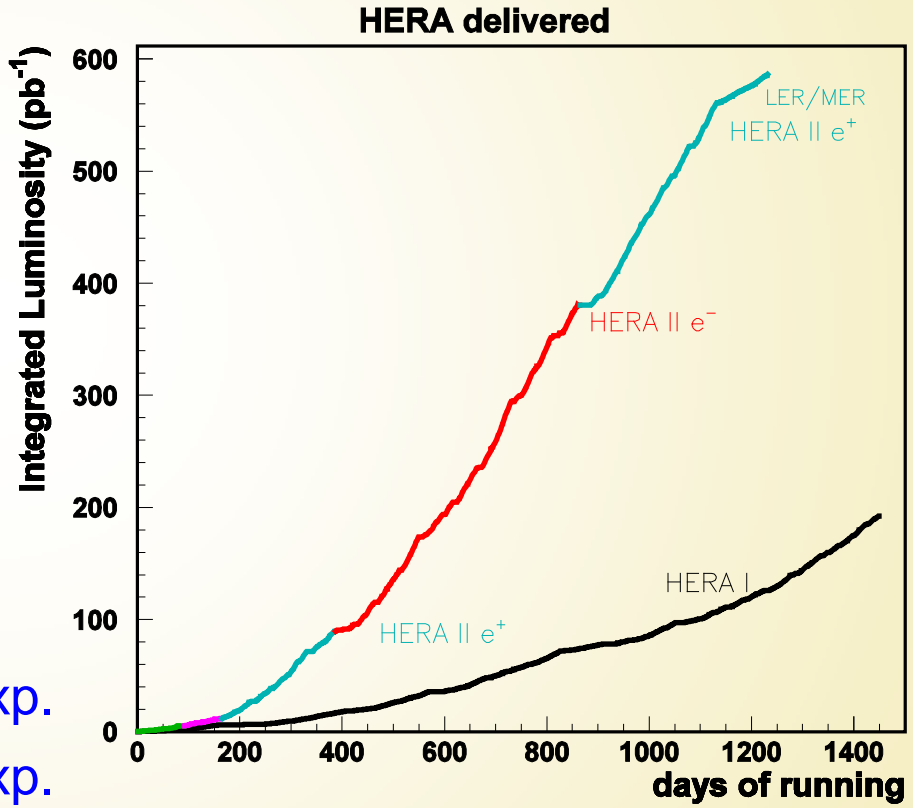
- Good agreement with the Standard Model – No sign of new physics at HERA is observed.

Backup slides

HERA : World's Only *ep* Collider



- located at DESY in Hamburg
- Two collider experiments: H1 and ZEUS



- **HERA–I (1992~2000) :** L~120 pb^{-1}/exp.
- **HERA–II (2002~2007) :** L~350 pb^{-1}/exp.
  - luminosity upgraded
  - longitudinally polarized lepton beam
  - detector upgrades

⟶ ~0.5 fb^{-1} data for each experiment!

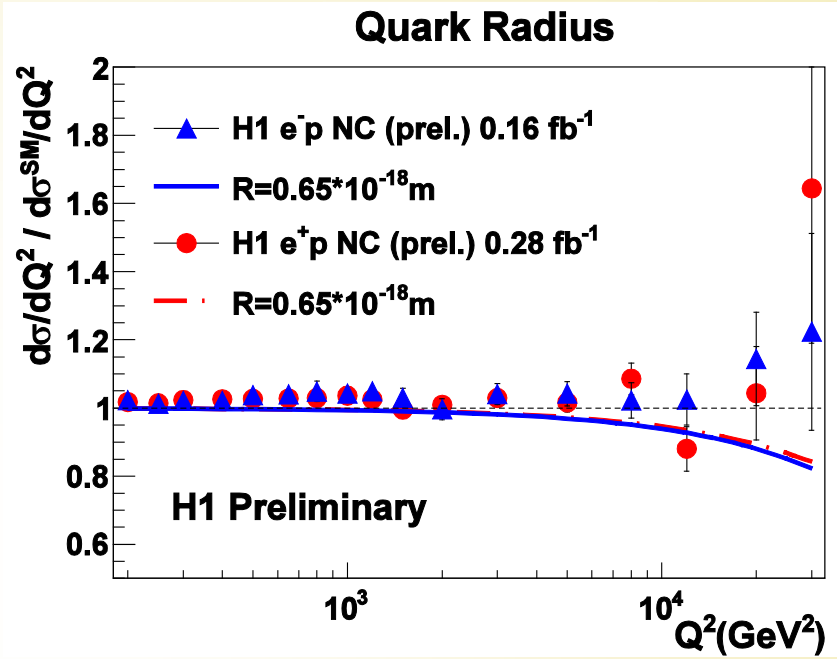
Quark radius

H1prelim-10-161
ZEUS-prel-09-013

- Spatial distribution of the quark charge would reduce the SM cross section at high-Q^2.

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \cdot \left[1 - \frac{R_q^2}{6} Q^2 \right]^2$$

R_q^2 : root mean square radius of the electroweak charge distribution in the quark.

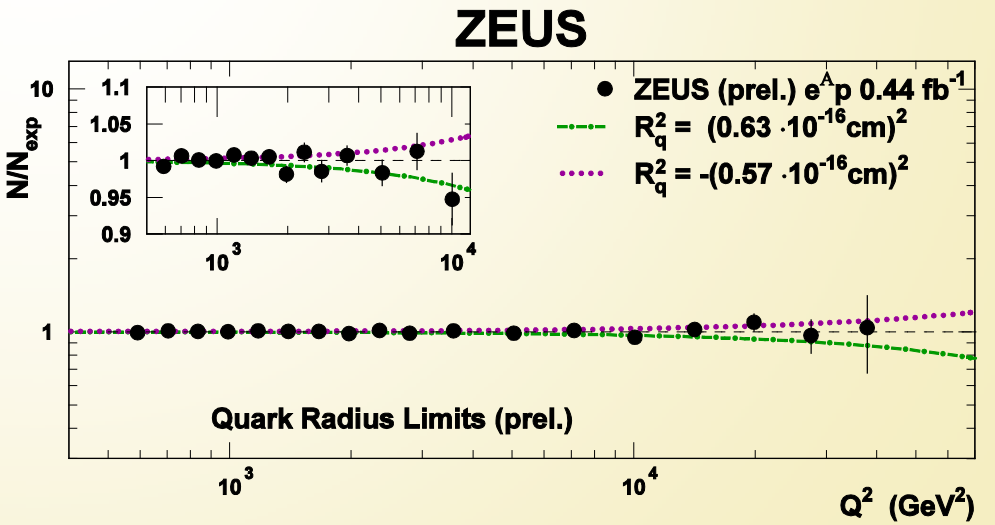


- Good agreement with SM expectation

→ Limits are set using full HERA data assuming electron as point-like (~440 pb^{-1} for each experiment.)

H1: $R_q < 0.65 \cdot 10^{-18}$ m
ZEUS: $R_q < 0.63 \cdot 10^{-18}$ m

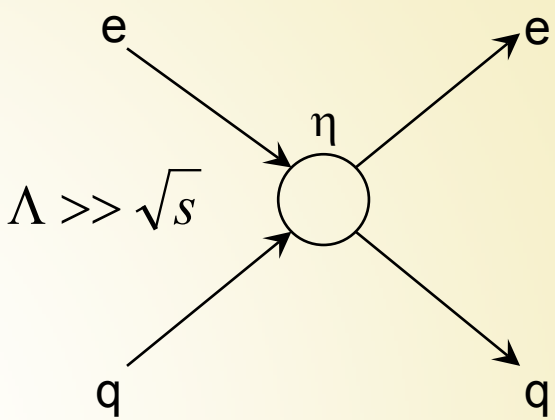
(95% C.L.)



Contact interactions

H1prelim-10-161
ZEUS-prel-09-013

- Modifications of high Q^2 cross sections via virtual effects.



- Vector type as additional term to SM Lagrangian:

$$L_{CI} = \sum_{a,b=L,R}^{q=u,d} \eta_{ab}^{q} (\bar{e}_a \gamma_\mu e_a)(\bar{q}_b \gamma^\mu q_b)$$

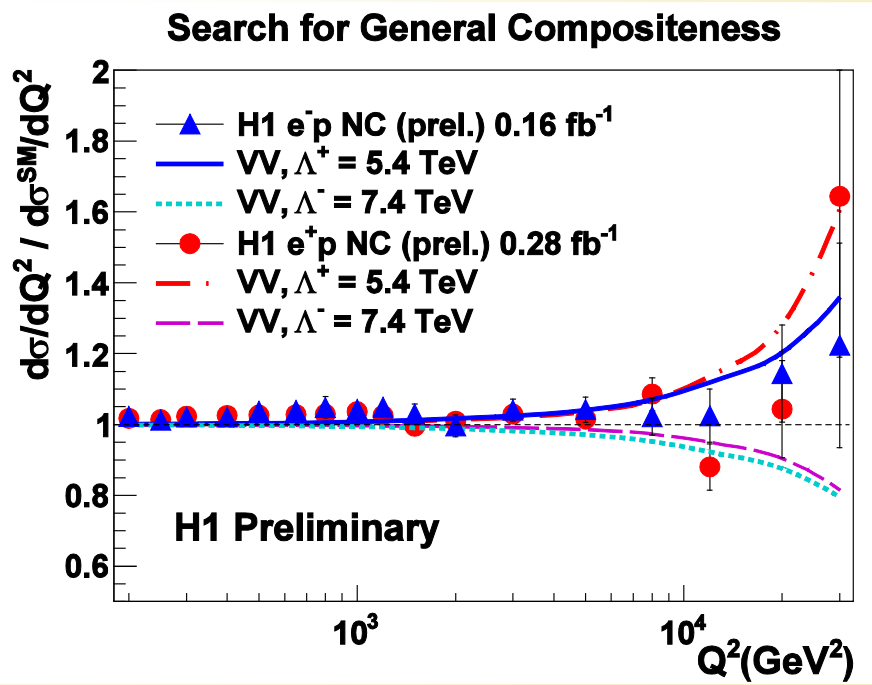
where

$$\eta_{ab}^{q} = \pm 4\pi / \Lambda^2$$

- No deviations from NC DIS seen by H1 and ZEUS:

H1: Λ > 3.7 – 7.4 TeV
ZEUS: Λ > 3.8 – 8.9 TeV

depending on 19 models with different helicity structure (95% C.L.)



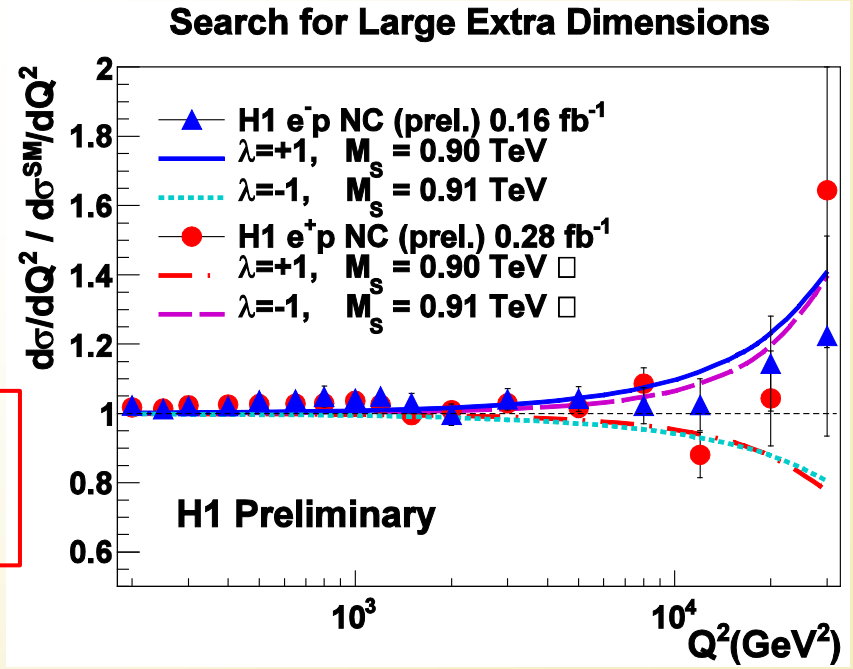
Large extra dimensions

H1prelim-10-161
ZEUS-prel-09-013

- ADD (Arkani-Hamed, Dimopoulos, Dvali) model: Space time is 4+*n* dimensional.
- The gravity can propagate into extra dimensions.

- Effective mass scale M_S can be ~1 TeV.
- Virtual graviton exchange contribution to *eq*→*eq* scattering described by contact interaction with effective coupling:

$$\eta_G = \pm\lambda \cdot \frac{\varepsilon^2}{M_S^4}$$

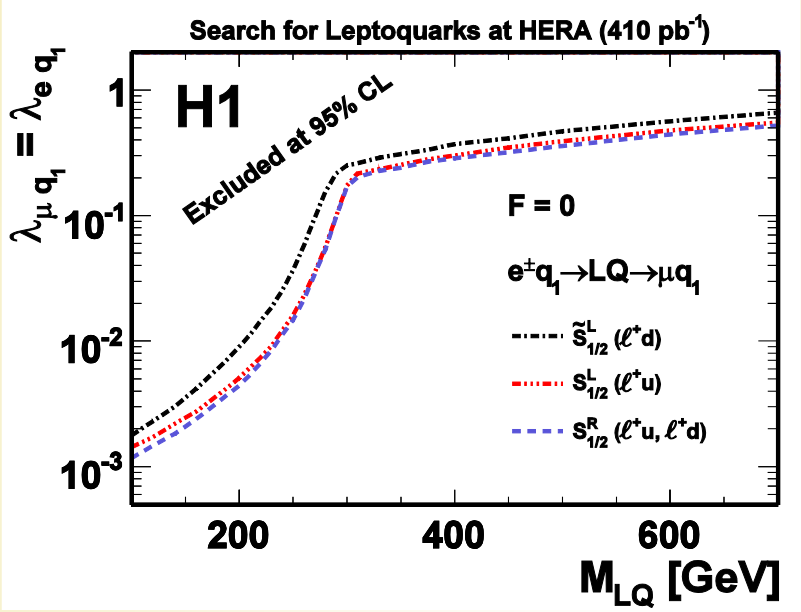


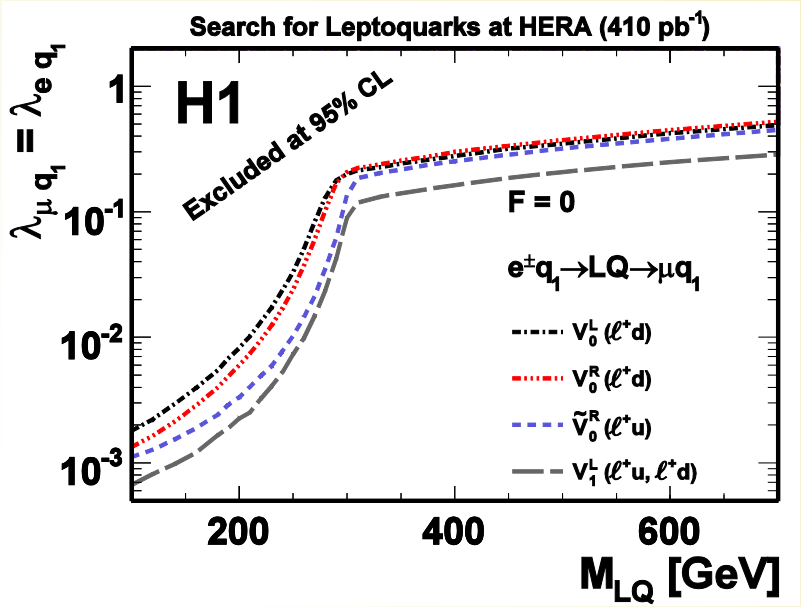
H1: $M_S^+ > 0.90$ GeV, $M_S^- > 0.91$ TeV
ZEUS: M_S^+, $M_S^- > 0.94$ TeV

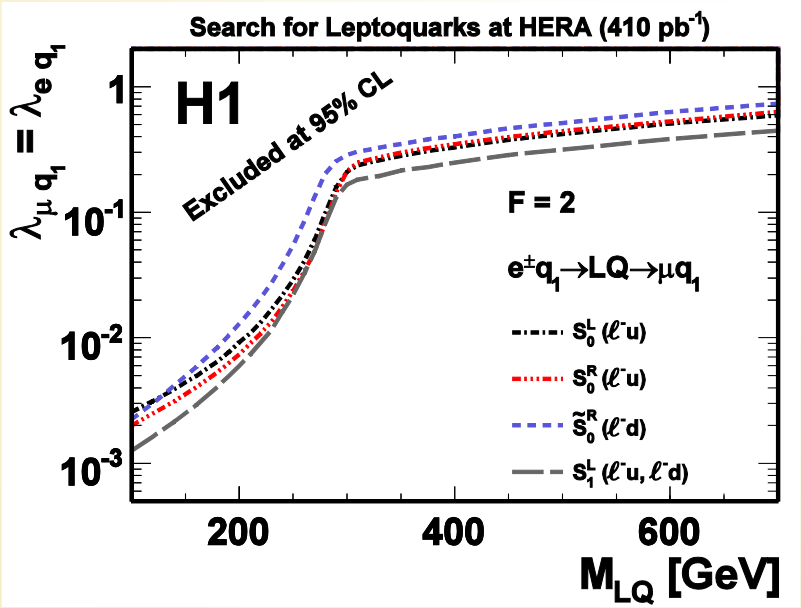
independent of *n* (95% C.L.)

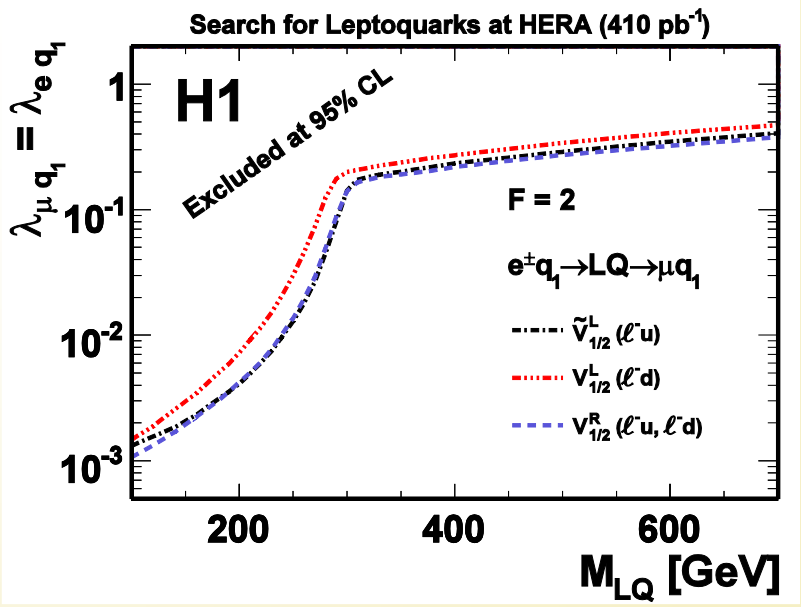
Lepton Flavour Violation (e→μ)

DESY-11-044



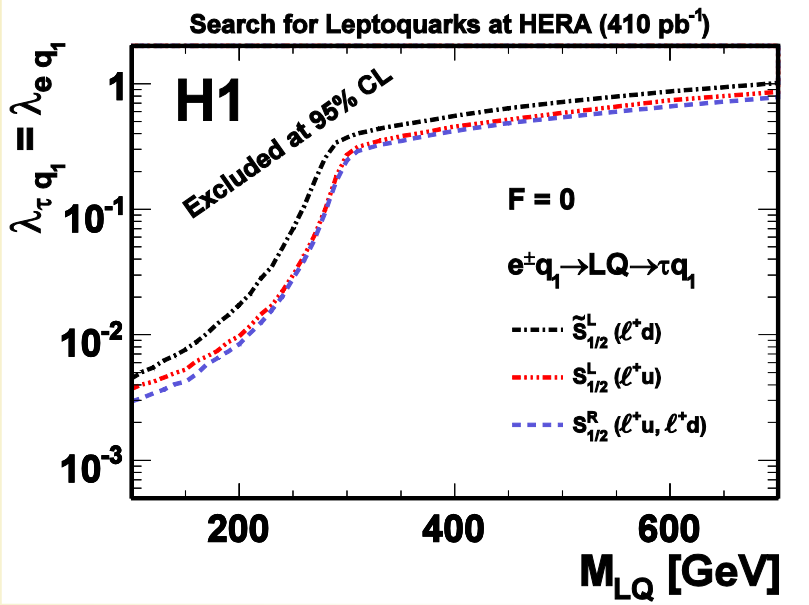


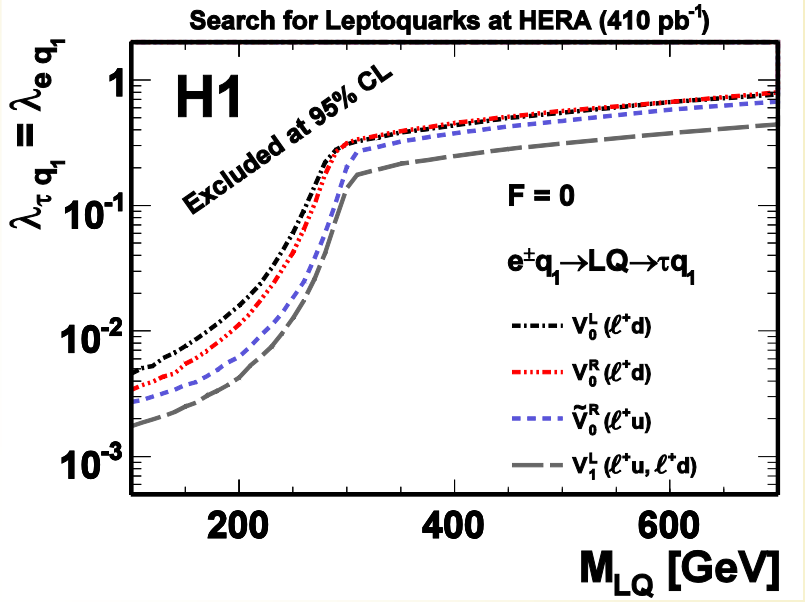


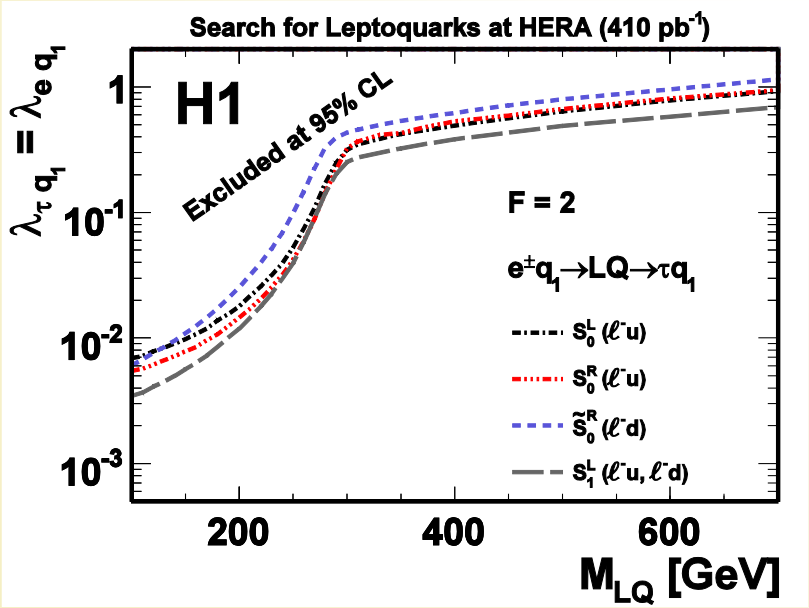


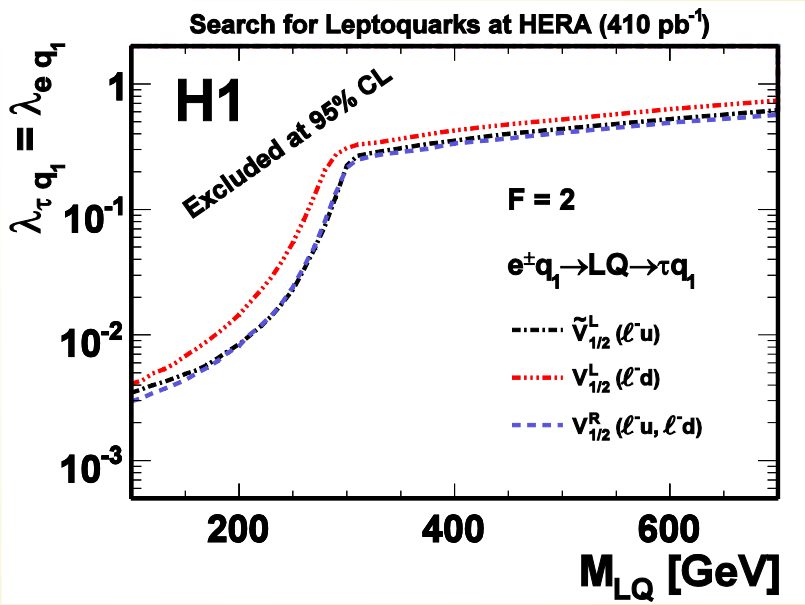
Lepton Flavour Violation (e→τ)

DESY-11-044



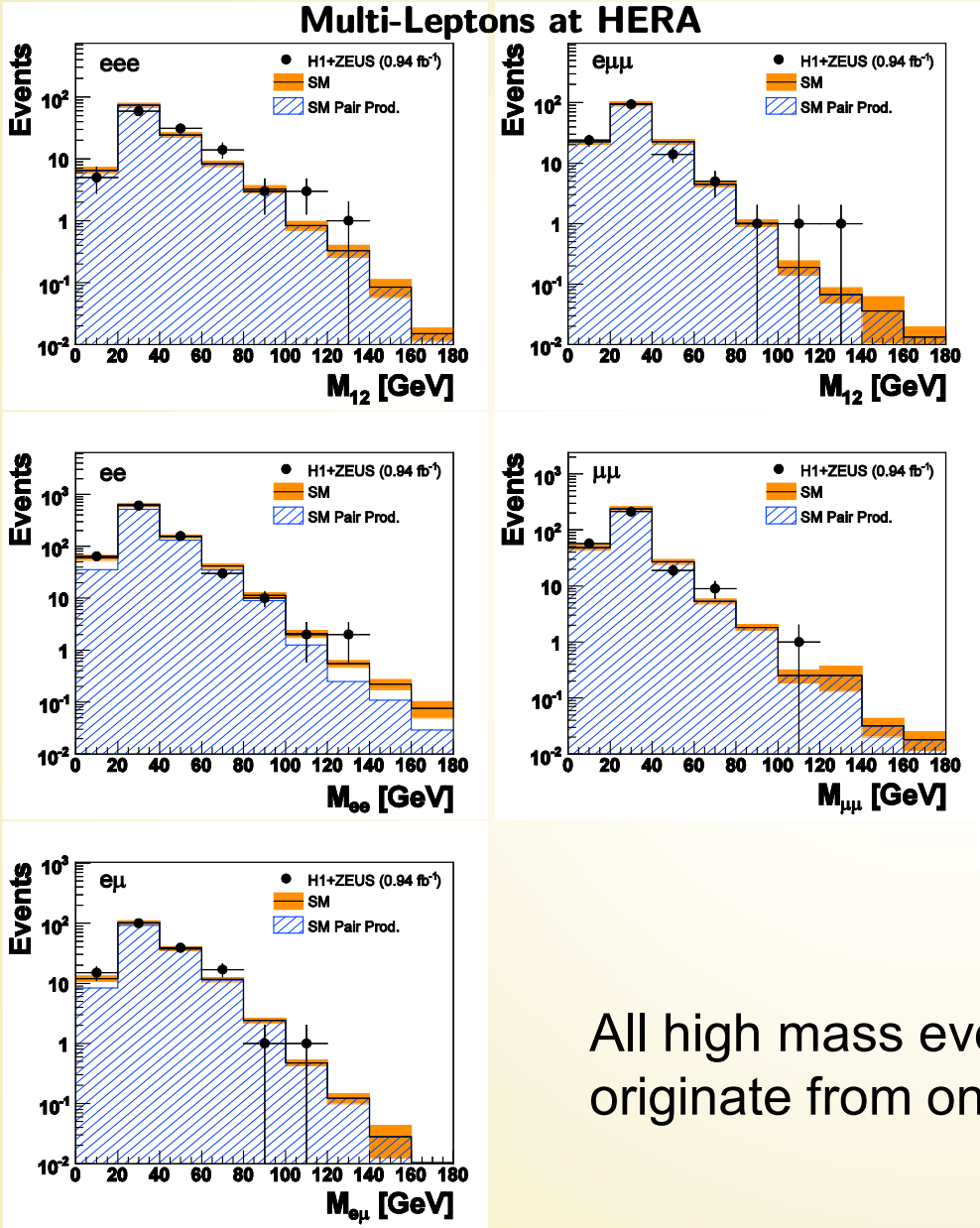






Multi-leptons

JHEP 10 (2009) 013

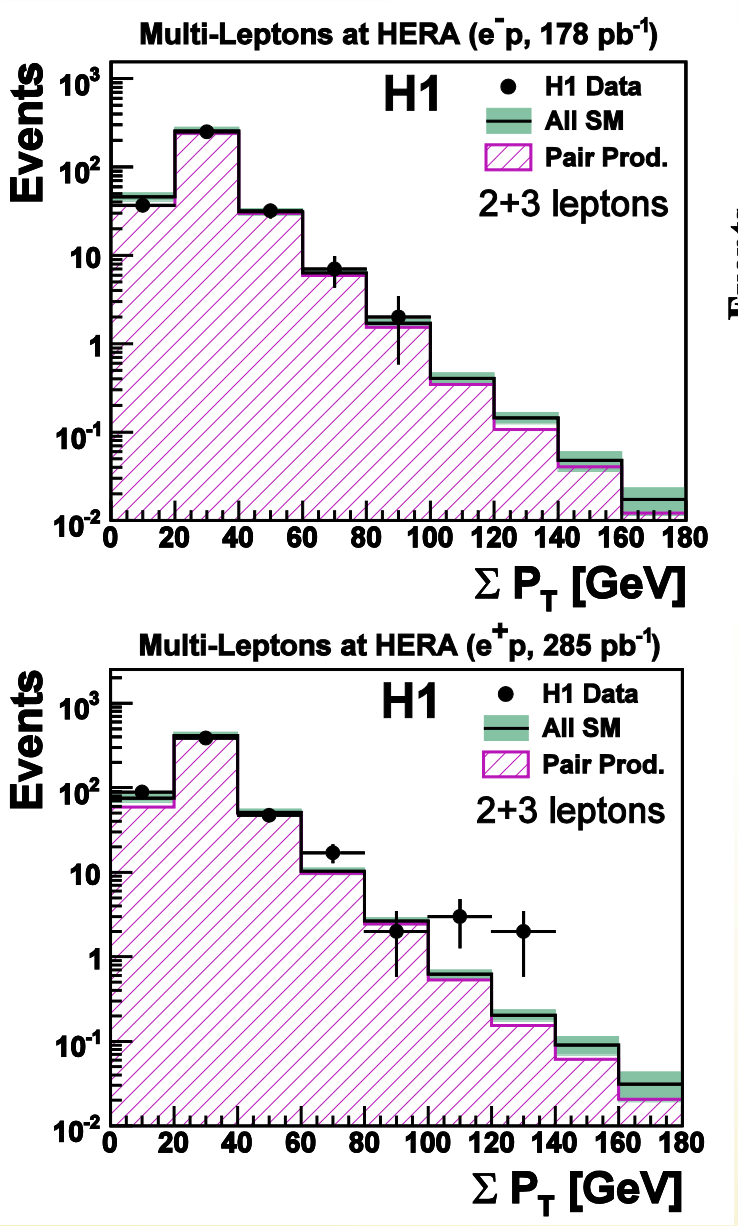


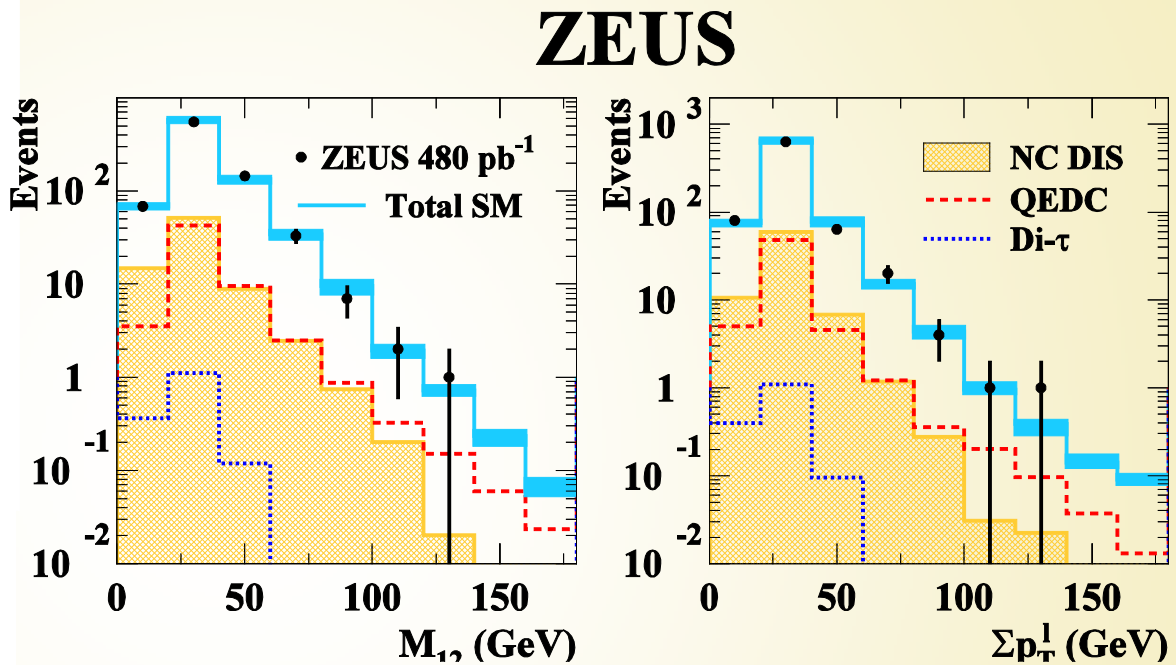
Distributions of the invariant mass of the two highest P_T leptons for each topologies are in good agreement with the SM.

Multi-Leptons at HERA (0.94 fb^{-1})				
M_{12} >100 GeV				
Sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
e^+p collisions (0.56 fb^{-1})				
ee	4	1.68 ± 0.18	0.94 ± 0.11	0.74 ± 0.12
$\mu\mu$	1	0.32 ± 0.08	0.32 ± 0.08	< 0.01
$e\mu$	1	0.40 ± 0.05	0.39 ± 0.05	< 0.02
eee	4	0.79 ± 0.09	0.79 ± 0.09	< 0.03
$e\mu\mu$	2	0.16 ± 0.04	0.16 ± 0.04	< 0.01
e^-p collisions (0.38 fb^{-1})				
ee	0	1.25 ± 0.13	0.71 ± 0.11	0.54 ± 0.08
$\mu\mu$	0	0.23 ± 0.10	0.23 ± 0.10	< 0.01
$e\mu$	0	0.26 ± 0.03	0.25 ± 0.03	< 0.02
eee	0	0.49 ± 0.07	0.49 ± 0.07	< 0.03
$e\mu\mu$	0	0.14 ± 0.05	0.14 ± 0.05	< 0.01

All high mass events observed by both experiments originate from only e^+p collisions…

Multi-lepton (H1 : ZEUS)





τ–jet ID@ ZEUS

τ–ID using PDE Range Searching (discriminant)

- Generalization of one–dimensional PDE approach to *n* dimensions
  - Counts number of signal and background events (training sample) in *"vicinity" V* of the test event
  - Implemented as PDERS in *T*MVA (one of toolkit in ROOT)

Discrimination value

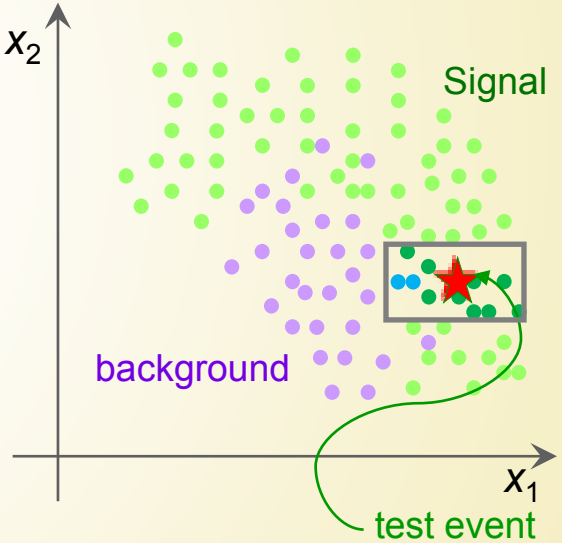
#signal events in *V*

#all signal events

$$D(i_{event}, V) = \frac{n_S(i_{event}, V) / N_S}{n_S(i_{event}, V) / N_S + n_B(i_{event}, V) / N_B}$$

#background events in *V*

#all background events



suggested by T.Carli, B.Koblitz.
NIM**A**501(2003)576

Isolated leptons with missing P_T

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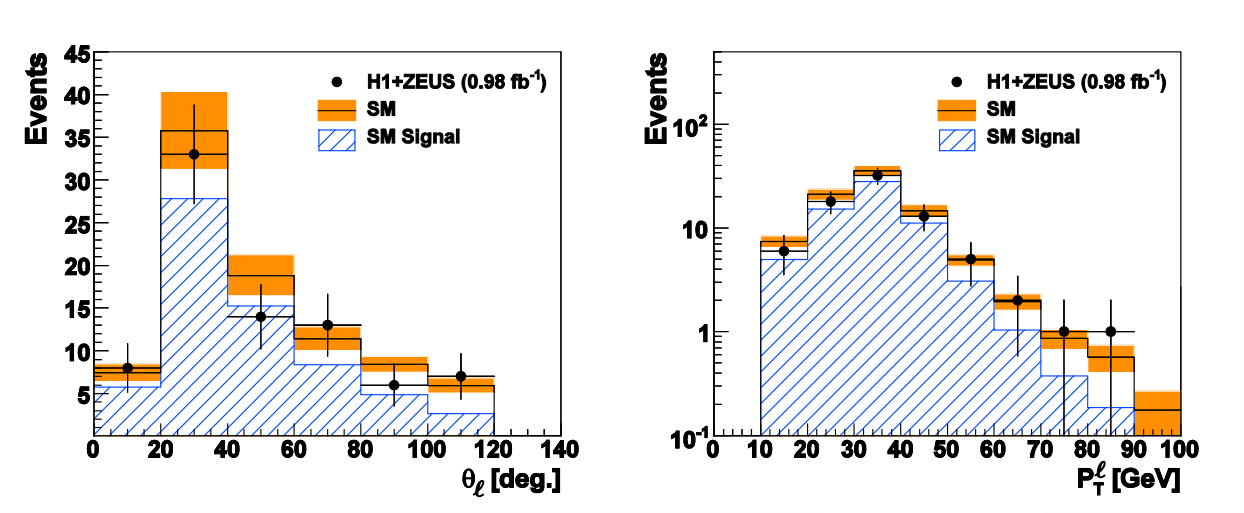

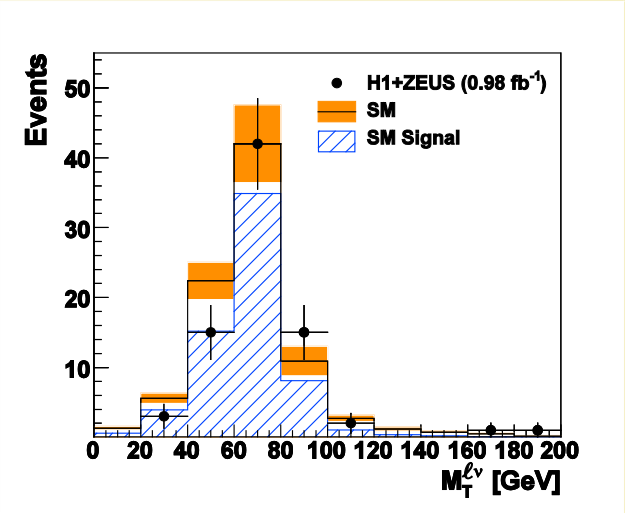

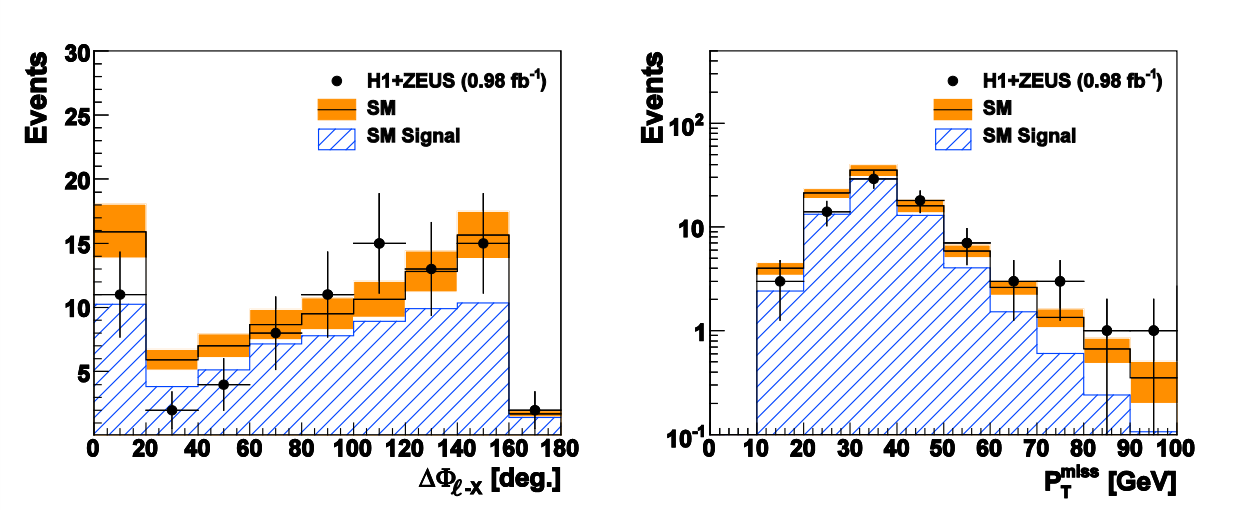

Isolated leptons with missing P_T

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H1+ZEUS 1994–2007 $e^{\pm}p$ 0.98 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	61	69.2 ± 8.2	48.3 ± 7.4	20.9 ± 3.2
	$P_T^X > 25$ GeV	16	13.0 ± 1.7	10.0 ± 1.6	3.1 ± 0.7
Muon	Total	20	18.6 ± 2.7	16.4 ± 2.6	2.2 ± 0.5
	$P_T^X > 25$ GeV	13	11.0 ± 1.6	9.8 ± 1.6	1.2 ± 0.3
Combined	Total	81	87.8 ± 11.0	64.7 ± 9.9	23.1 ± 3.3
	$P_T^X > 25$ GeV	29	24.0 ± 3.2	19.7 ± 3.1	4.3 ± 0.8

H1+ZEUS 1998–2006 $e^{-}p$ 0.39 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	24	30.6 ± 3.6	19.4 ± 3.0	11.2 ± 1.9
	$P_T^X > 25$ GeV	4	5.6 ± 0.8	4.0 ± 0.6	1.6 ± 0.4
Muon	Total	4	7.4 ± 1.1	6.6 ± 1.0	0.9 ± 0.3
	$P_T^X > 25$ GeV	2	4.3 ± 0.7	3.9 ± 0.6	0.4 ± 0.2
Combined	Total	28	38.0 ± 3.4	26.0 ± 3.4	12.0 ± 2.0
	$P_T^X > 25$ GeV	6	10.0 ± 1.3	7.9 ± 1.2	2.1 ± 0.5

H1+ZEUS 1994–2007 $e^{+}p$ 0.59 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	37	38.6 ± 4.7	28.9 ± 4.4	9.7 ± 1.4
	$P_T^X > 25$ GeV	12	7.4 ± 1.0	6.0 ± 0.9	1.5 ± 0.3
Muon	Total	16	11.2 ± 1.6	9.9 ± 1.6	1.3 ± 0.3
	$P_T^X > 25$ GeV	11	6.6 ± 1.0	5.9 ± 0.9	0.8 ± 0.2
Combined	Total	53	49.8 ± 6.2	38.8 ± 5.9	11.1 ± 1.5
	$P_T^X > 25$ GeV	23	14.0 ± 1.9	11.8 ± 1.9	2.2 ± 0.4

W production measurement

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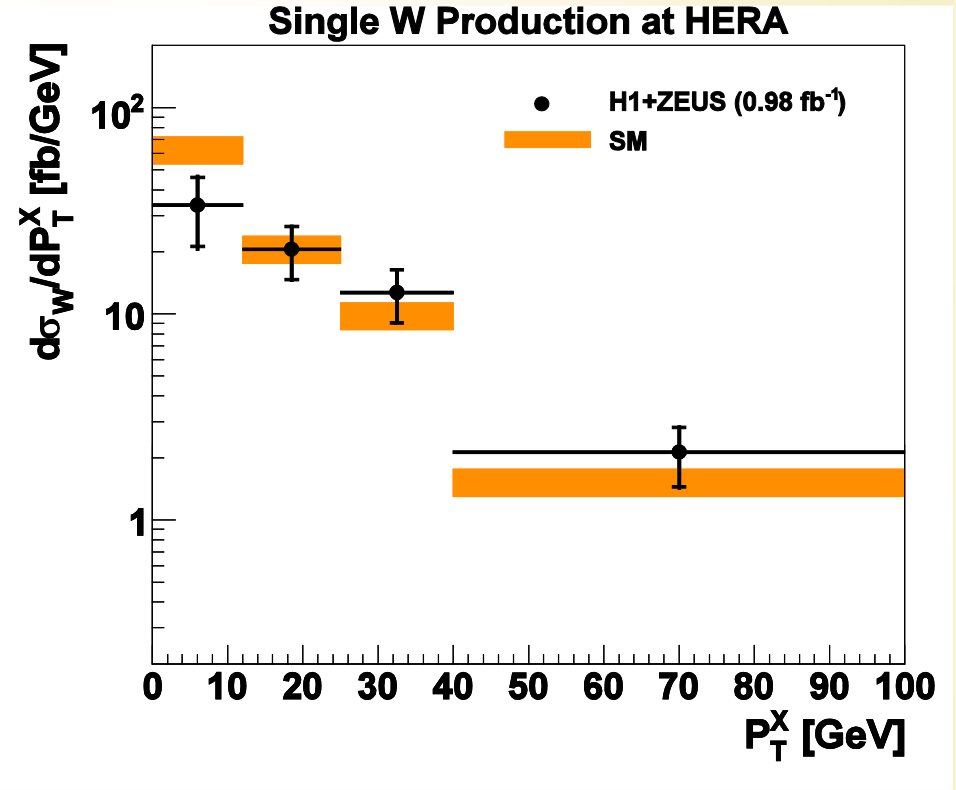
- Cross section for single-W production is also extracted using H1+ZEUS combined data.

- The total single-W production cross section is:

$$1.06 \pm 0.16\,(\text{stat.}) \pm 0.07\,(\text{sys.})\,\text{pb}$$

with good agreement with the SM prediction of 1.26 ± 0.19 pb.

- The differential cross sections, in bins of hadronic transverse momentum, are also extracted.