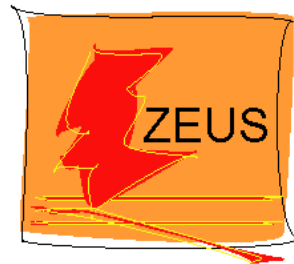


Multilepton production at HERA

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(DESY)



on behalf of the
ZEUS and H1 Collaborations



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Scattering and Related Subjects

Firenze, Italy

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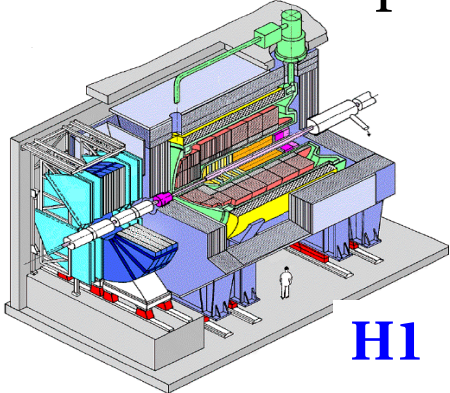


HERA physics

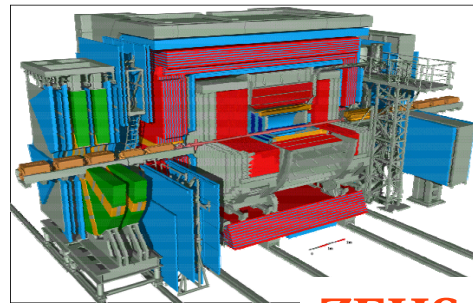
HERA: e^+p collider, $E_{\text{cm}} \sim 318 \text{ GeV}$



ZEUS and **H1**: multipurpose experiments located in two of the interaction points.



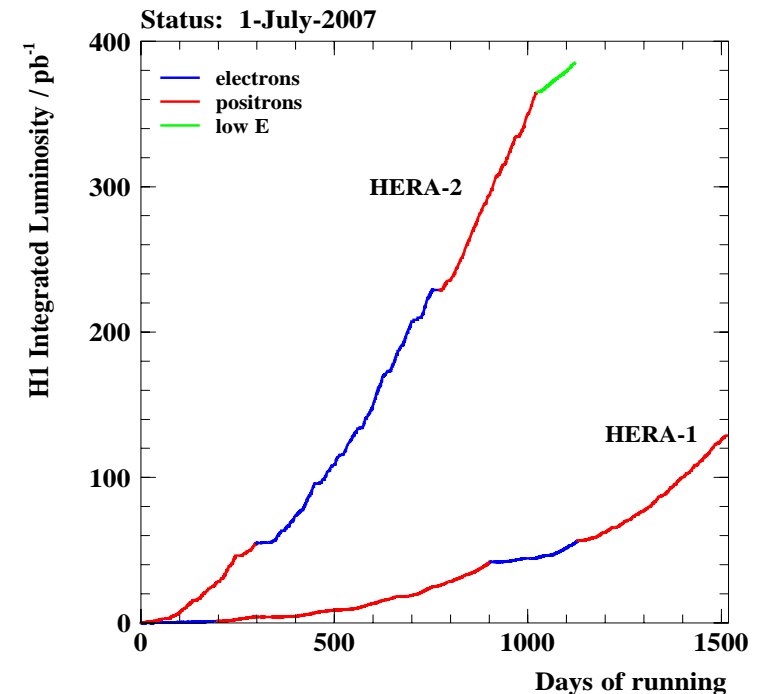
H1



ZEUS

Data taking ended in June 07.

Collected luminosity :
 $\sim 0.5 \text{ fb}^{-1}$ per experiment



Rare ($\sigma \sim 1 \text{ fb}$) phenomena may become visible.

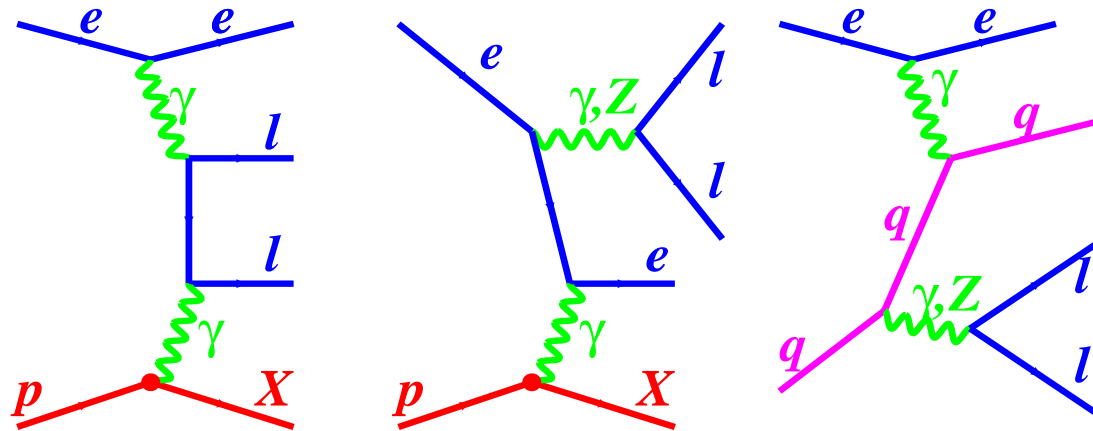
Outline

- Events having **two or more isolated electrons or muons** with high transverse momentum have a clean experimental signature; they are ideal to look for **beyond the Standard Model** (SM) physics.
- The **final results** of the single H1 and ZEUS analyses will be shown.
- The **combination of the data** of the two experiments allows a more stringent test of the SM in the interesting phase space regions: **final results** on a common phase space based on **0.94 fb^{-1}** will be shown.
- Di- τ production with decay into leptons is not vetoed in the analysis. Hadronic τ production is removed by the cuts. **Preliminary results on τ production from ZEUS exist but are not shown here (focus on high- p_T multi-leptons).**



Multileptons at HERA

In e^+p interactions, production is dominated by the $\gamma\gamma$ process:



This is a QED process: the predictions from the Standard Model (SM) are very precise.

The SM cross section at high masses, high p_T is low: we can look for new phenomena.

Background: NC DIS, QED Compton for events with electrons.

Strategy of the analysis

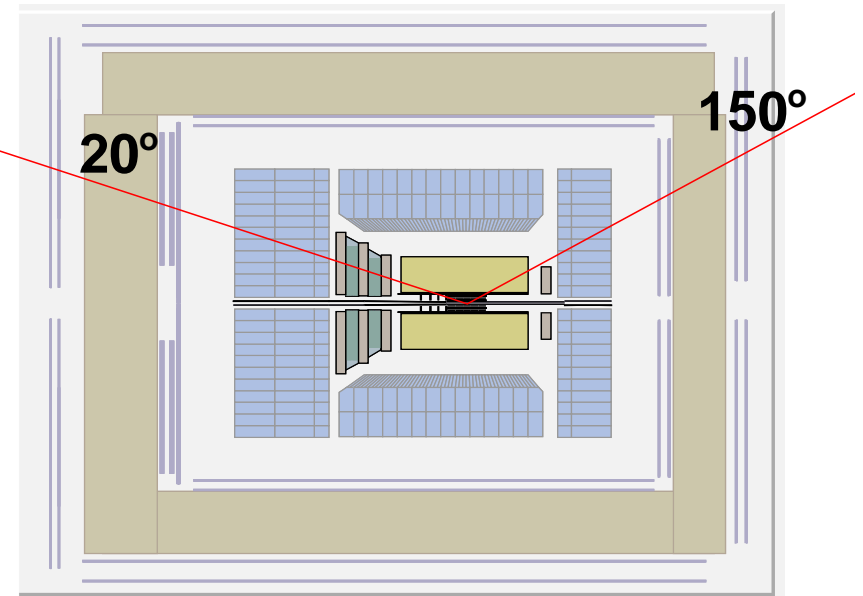
- Events are selected by requiring the presence of **at least two isolated high- p_T leptons (electrons or muons)** in the final state.
- Depending on the number and the flavours of the leptons, the events are classified into **mutually exclusive samples**:
 - *ee sample*: 2 electrons were found, and no other lepton;
 - *eee sample*: 3 electrons are found, and no other lepton; does not contain the *ee sample*;
 - *e μ sample*: 1 electron and 1 muon;
 - and so on for *e $\mu\mu$* , *$\mu\mu$* ...
- Each sample is compared to the SM predictions, looking for possible deviations. The **mass of the two highest p_T leptons, M_{12}** , and the **Σp_T of all the leptons** are considered.



Data selection

Electrons:

- Identified in $5^\circ < \theta < 175^\circ$, with $E > 5$ GeV for $\theta > 150^\circ$, 10 GeV elsewhere (H1: 5 GeV up to 20°).
- Isolated (looking at tracks and calorimeter deposits).



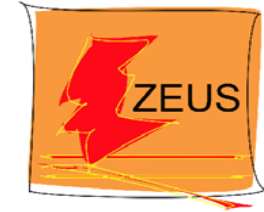
Muons:

- Identified in $20^\circ < \theta < 160^\circ$, with $p_T > 2$ GeV.
- Isolated from tracks.

At least 2 leptons have to be in $20^\circ < \theta < 150^\circ$, with $p_T > 10, 5$ GeV.

- Events are assigned to exclusive classes depending on the number and flavour of leptons.
- All possible topologies investigated.

Observed topologies



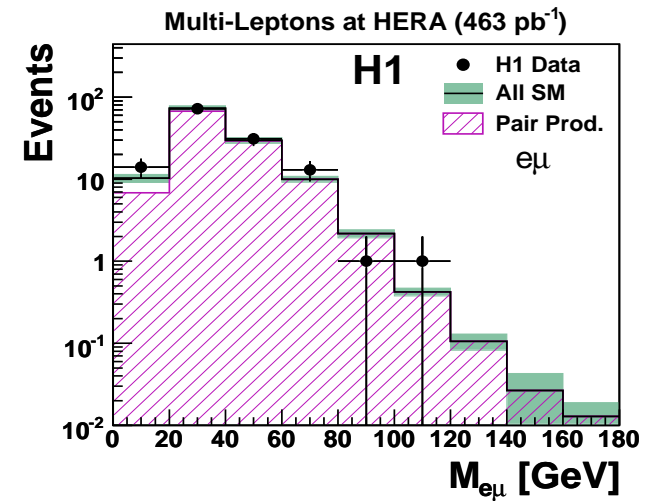
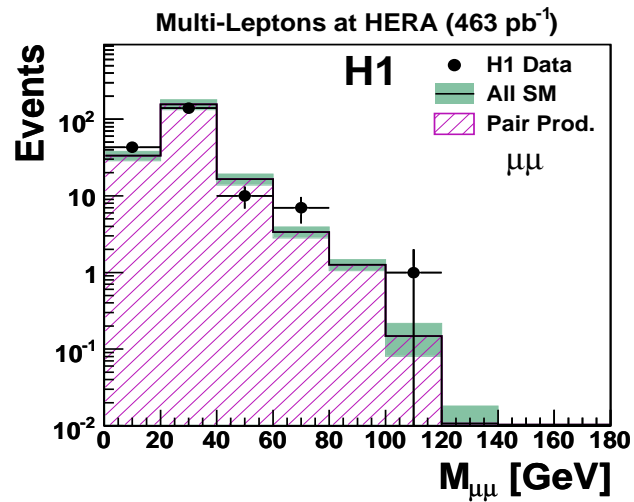
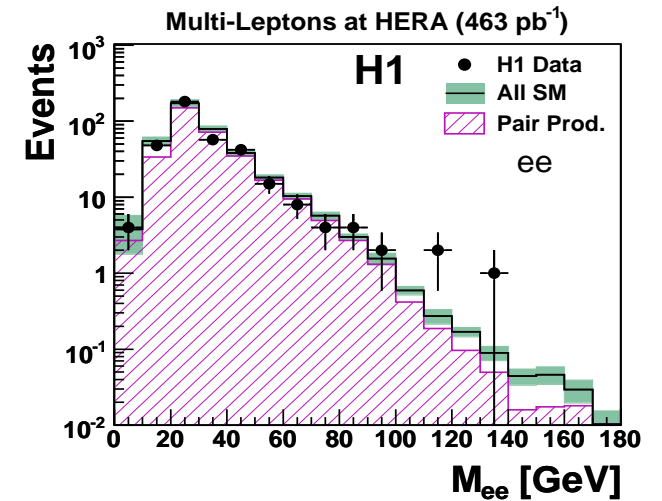
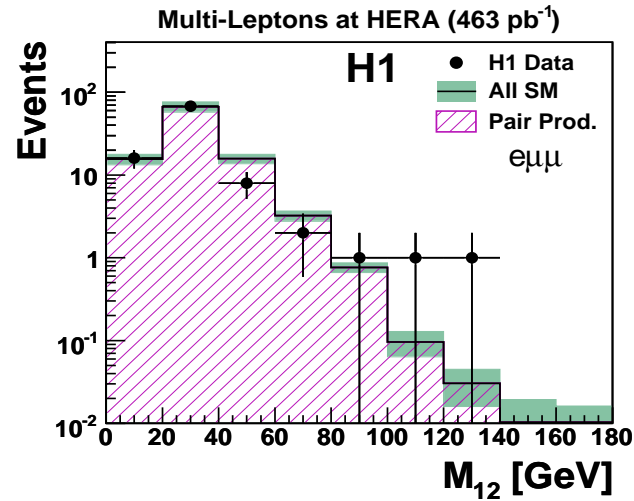
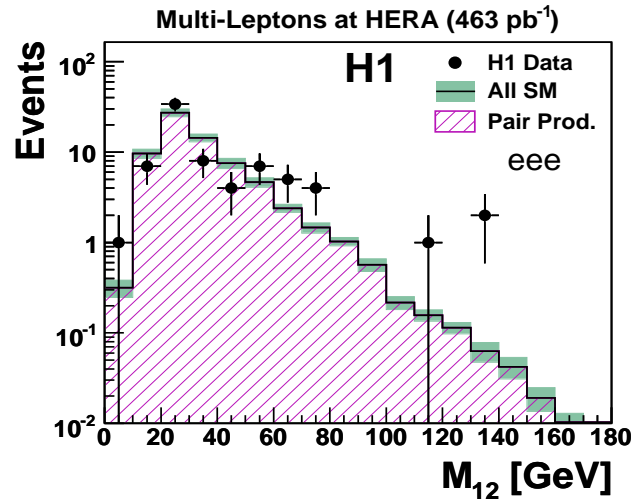
ZEUS ($\mathcal{L} = 480$)

| Topology | Data | Total SM | Multi-lepton Production | NC DIS | Compton |
|-----------------------------------|------|---------------------|-------------------------|---------------|---------------|
| ee | 545 | 563^{+29}_{-37} | 429^{+21}_{-29} | 74 ± 5 | 60 ± 10 |
| $\mu\mu$ | 93 | 106 ± 12 | 106 ± 12 | < 0.5 | — |
| $e\mu$ | 46 | 42 ± 4 | 37^{+3}_{-4} | 4.5 ± 1.2 | — |
| eee | 73 | 75^{+5}_{-4} | 73^{+4}_{-5} | < 1 | < 3 |
| $e\mu\mu$ | 47 | 48 ± 5 | 48 ± 5 | < 0.5 | — |
| $eeee$ | 1 | $0.9^{+0.5}_{-0.1}$ | 0.6 ± 0.1 | < 0.4 | < 1 |
| $ee\mu\mu$ | 2 | $0.5^{+0.3}_{-0.1}$ | 0.4 ± 0.1 | < 0.5 | — |
| All 4 leptons | 3 | $1.4^{+0.7}_{-0.1}$ | 1.0 ± 0.2 | < 1.4 | |
| ee ($\gamma\gamma$ sample) | 166 | 185^{+8}_{-14} | 183^{+8}_{-14} | 1.4 ± 1.0 | 1.4 ± 0.6 |
| $\mu\mu$ ($\gamma\gamma$ sample) | 72 | 85^{+9}_{-10} | 85^{+9}_{-10} | < 0.5 | — |

Data are overall well described by the SM including pair production and background. **Let's look at the high-mass and high- Σp_T regions.**



Masses for the different topologies



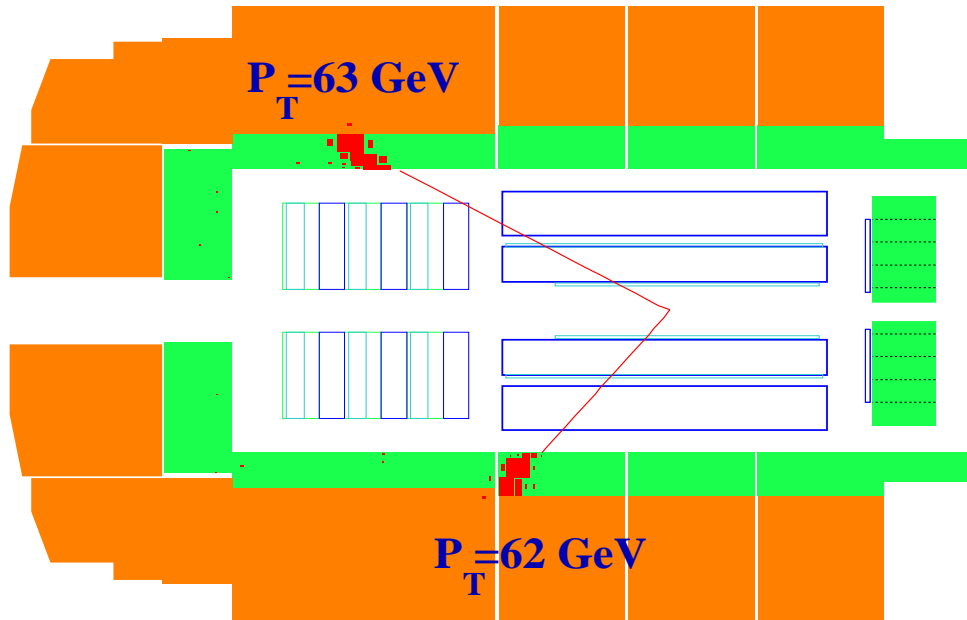
Overall agreement with SM.

High mass events observed in ee , eee , $e\mu\mu$ topologies.



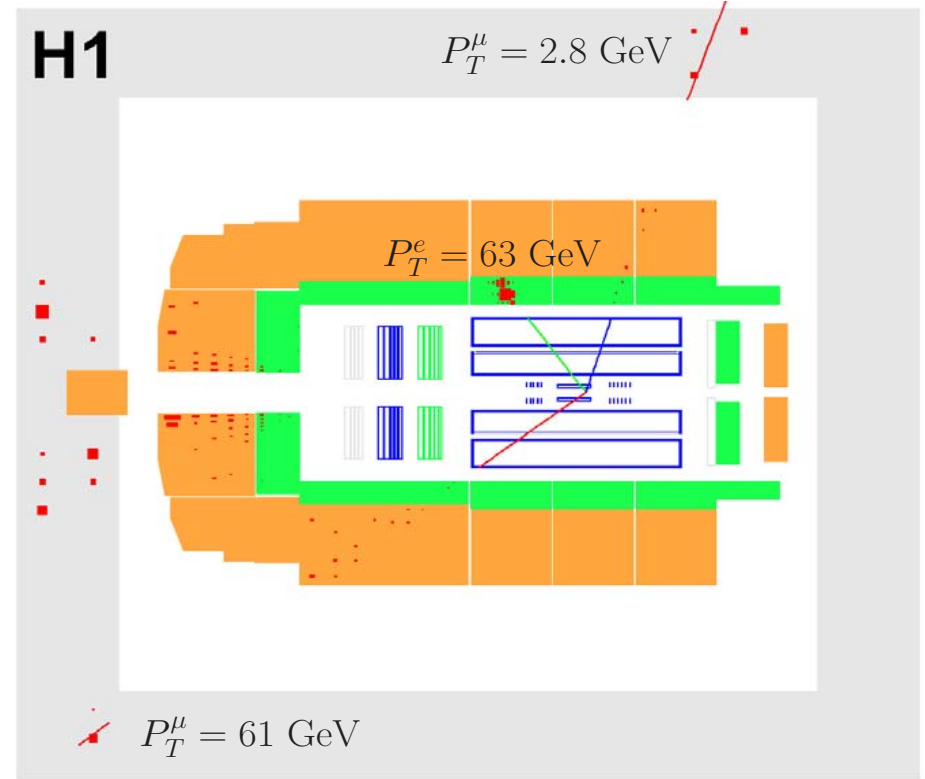


Two H1 events

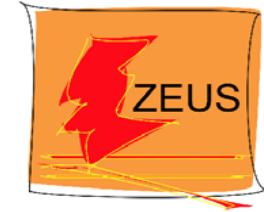


ee event: $M=130$ GeV.

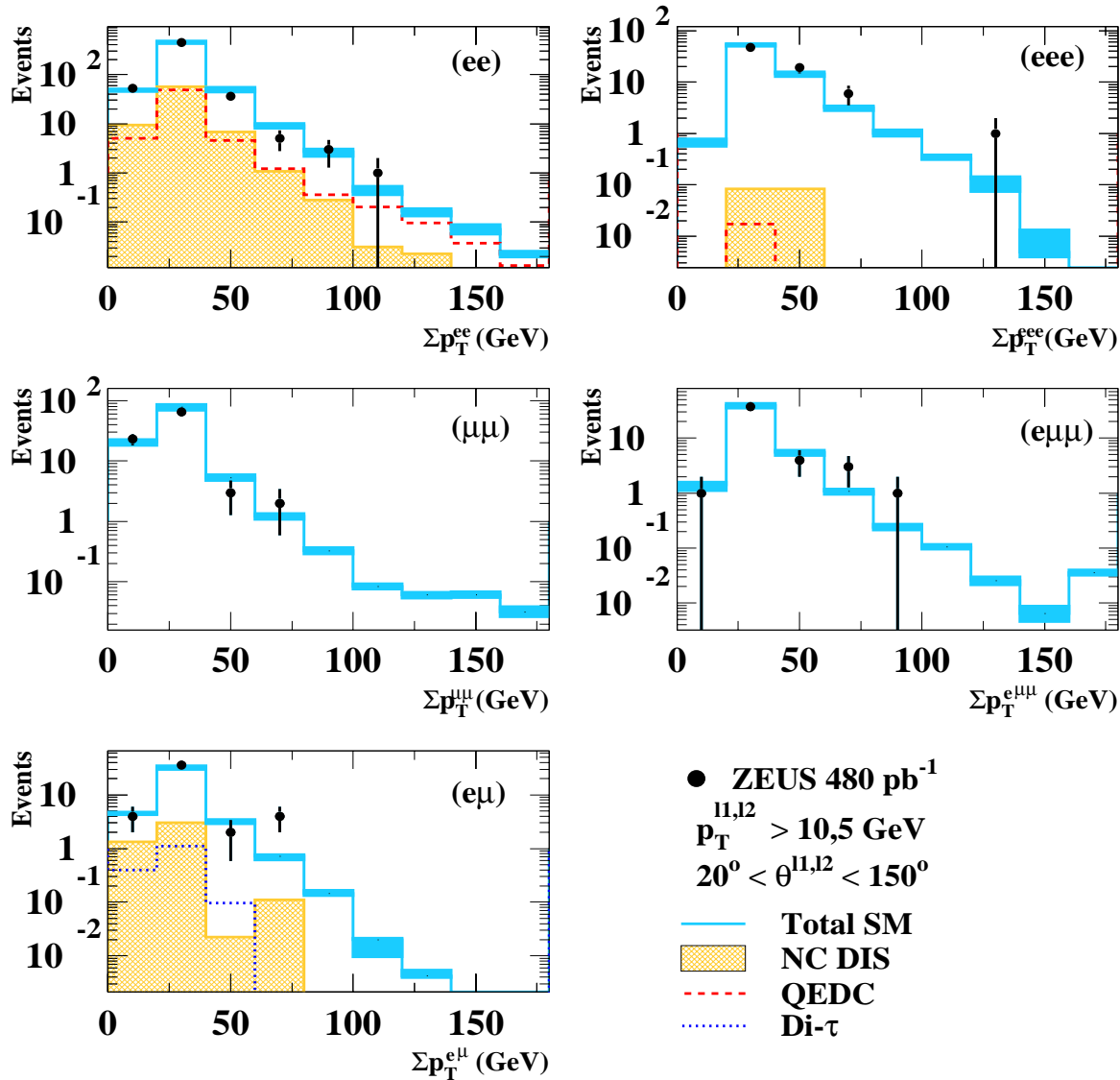
eμμ event: $M=127$ GeV,
given by the electron and
the highest- p_T muon.



Σp_T for the different topologies



ZEUS



Good agreement with the SM for all the topologies.

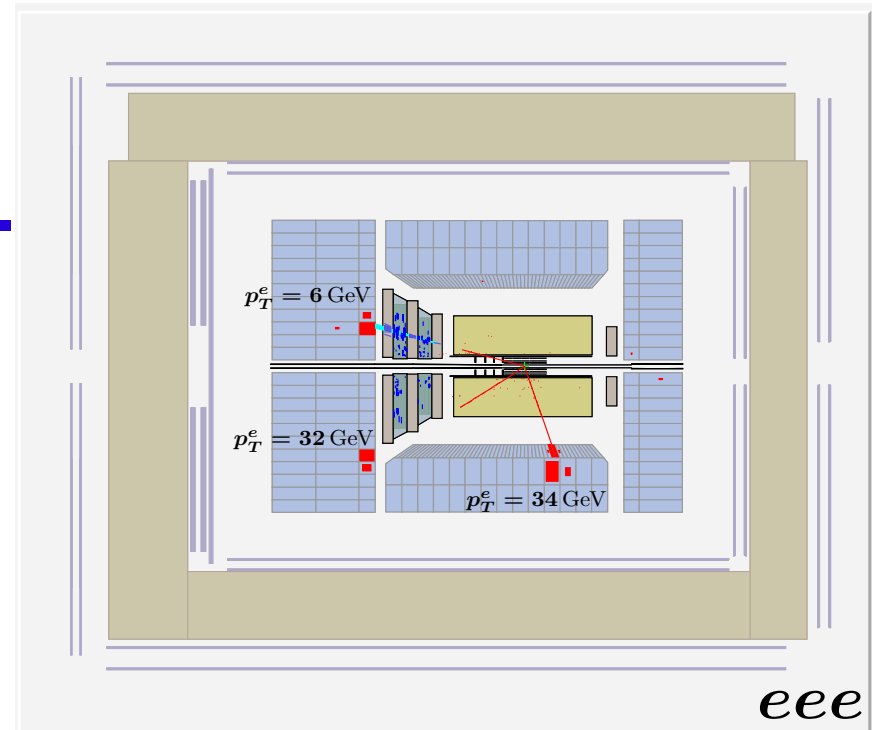
2 events observed with high Σp_T .



Two ZEUS events

Highest mass event containing only electrons (eee):

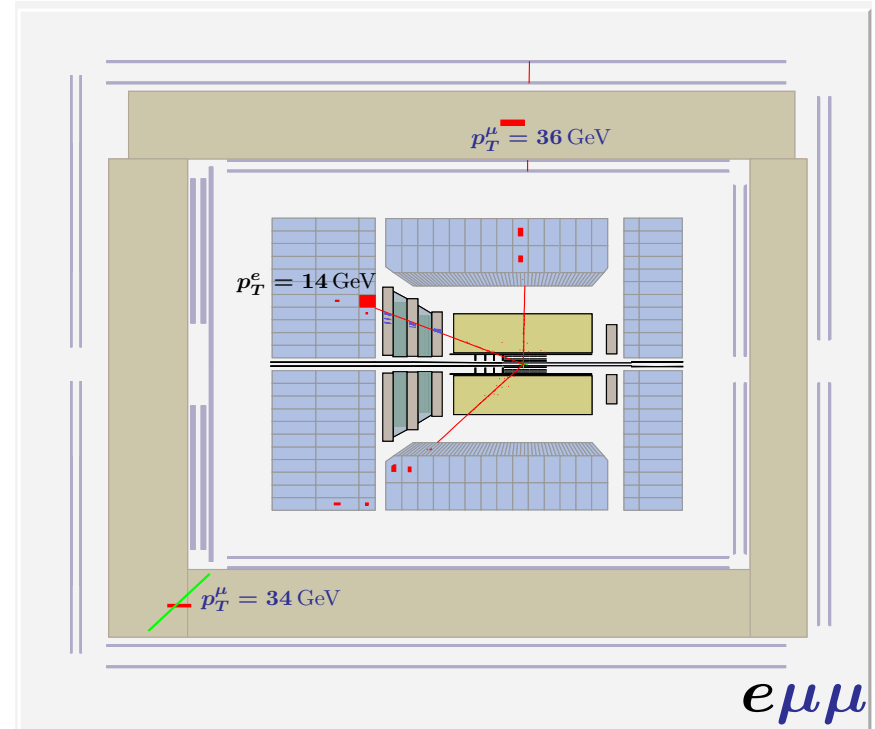
$M=113$ GeV



eee

Highest mass event with muons ($e\mu\mu$):

$M=77.5$ GeV



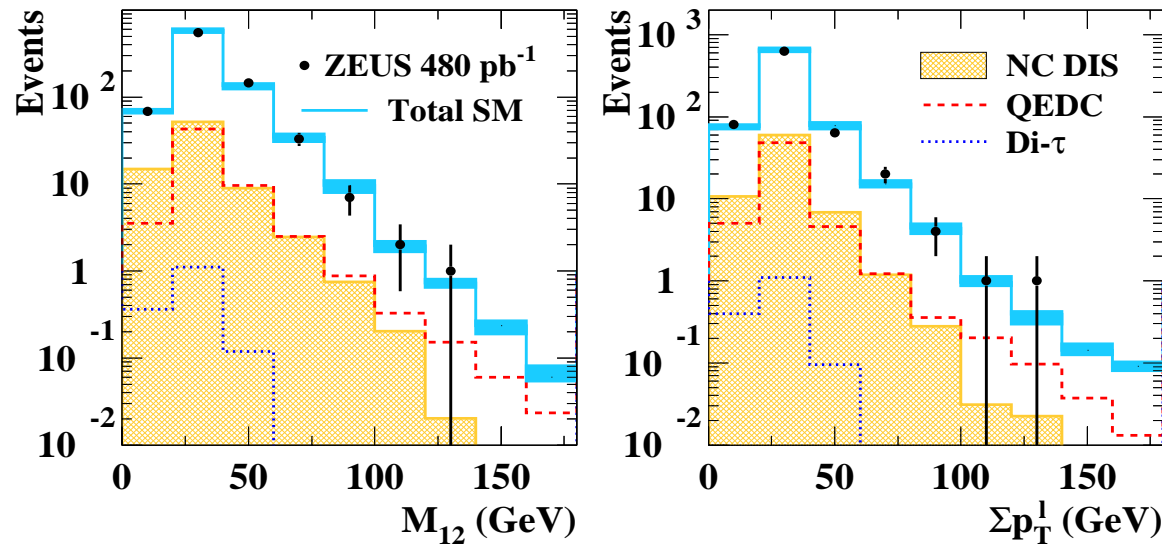
$e\mu\mu$



Combination of the topologies



ZEUS

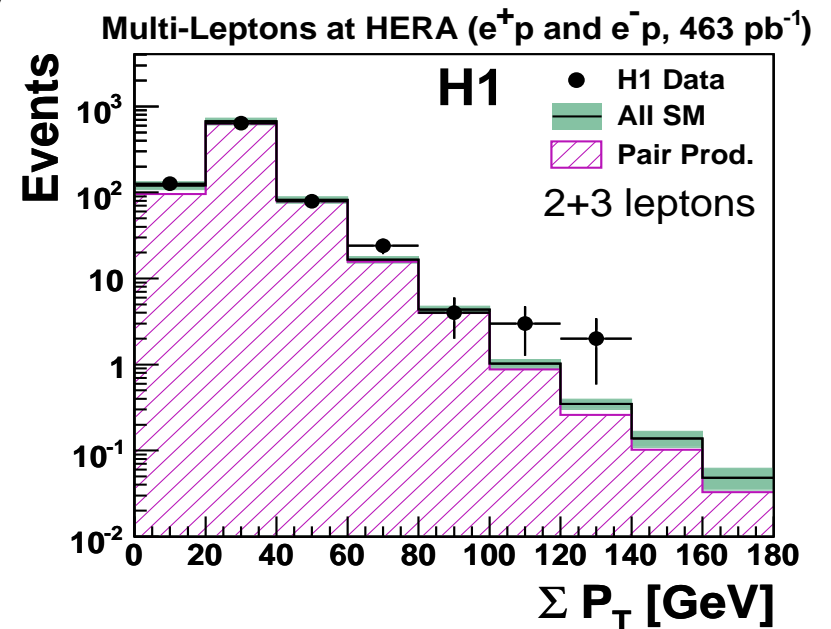


Good agreement between the data and the SM.

Some events in the high mass and high Σp_T region.

H1: 5 events at high Σp_T , ZEUS has 2

Let's combine the data...



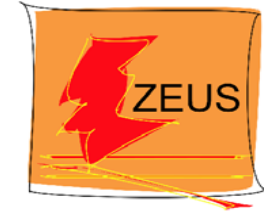
Combined analysis

- The ZEUS and H1 analyses are done in exactly the same way, apart from:
 - H1 cuts at 5 GeV for the electron in the region $20^\circ < \theta < 150^\circ$ the cut has been increased to 10 GeV for the combination with ZEUS.
- The measurements are dominated by the statistical error, the systematic uncertainty is uncorrelated between the two experiments (except for the theory error):
 - we combine the results with the above assumption, taking the **theory uncertainty to be fully correlated** (the model is the same).





Combined topologies table



Multi-Leptons at HERA (0.94 fb^{-1})

| Sample | Data | SM | Pair Production (GRAPE) | NC DIS + QEDC |
|----------------------|------|--------------|-------------------------|---------------|
| ee | 873 | 895 ± 57 | 724 ± 41 | 171 ± 28 |
| $\mu\mu$ | 298 | 320 ± 36 | 320 ± 36 | < 0.5 |
| $e\mu$ | 173 | 167 ± 10 | 152 ± 9 | 15 ± 3 |
| eee | 116 | 119 ± 7 | 117 ± 6 | < 4 |
| $e\mu\mu$ | 140 | 147 ± 15 | 147 ± 15 | < 0.5 |
| $(\gamma\gamma)_e$ | 284 | 293 ± 18 | 289 ± 18 | 4 ± 1 |
| $(\gamma\gamma)_\mu$ | 235 | 247 ± 26 | 247 ± 26 | < 0.5 |

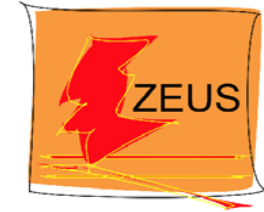
Good agreement with the Standard Model.

Let's look at the high-mass and high- Σp_T regions.

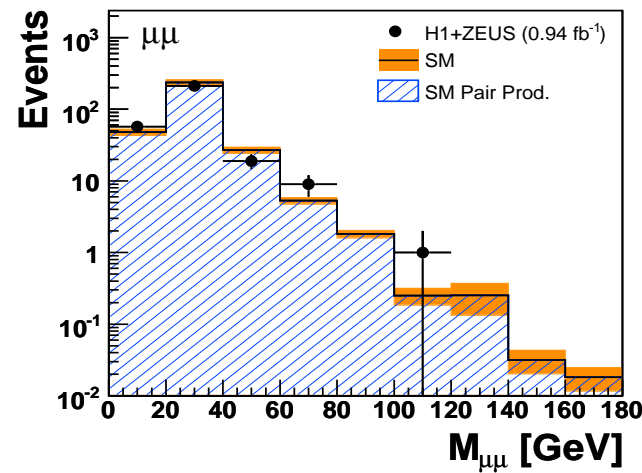
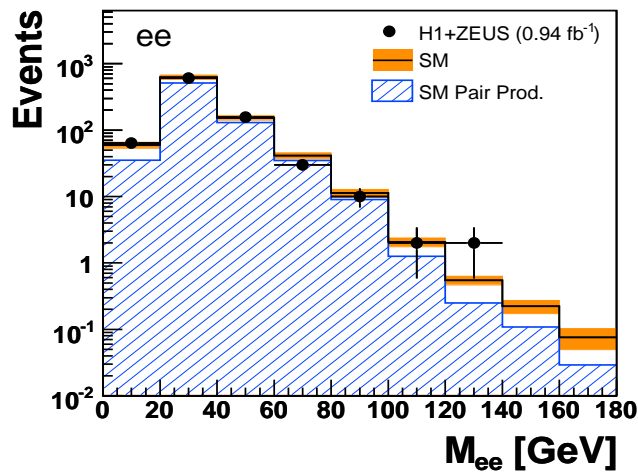
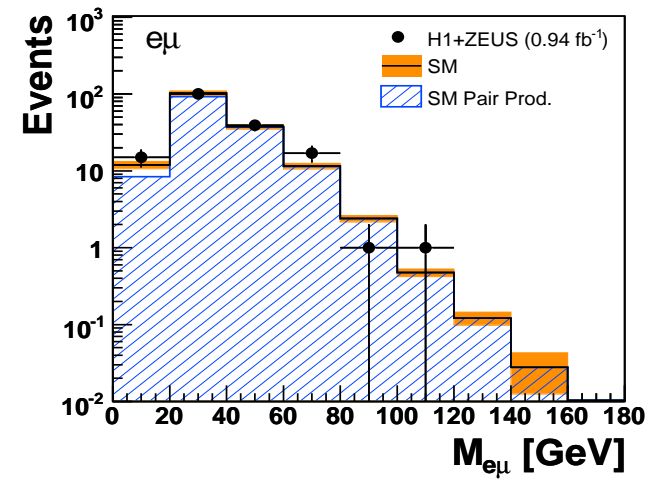
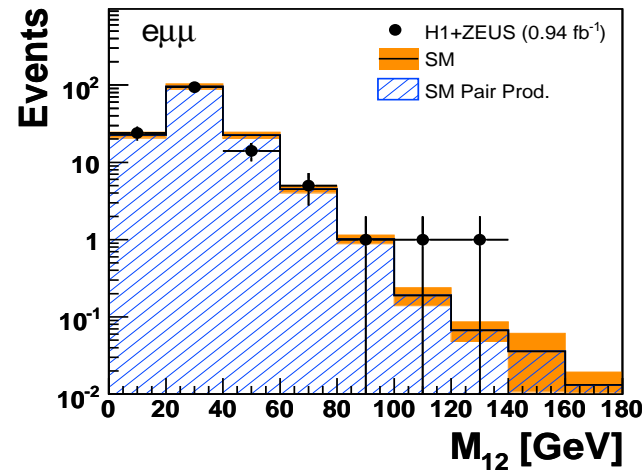
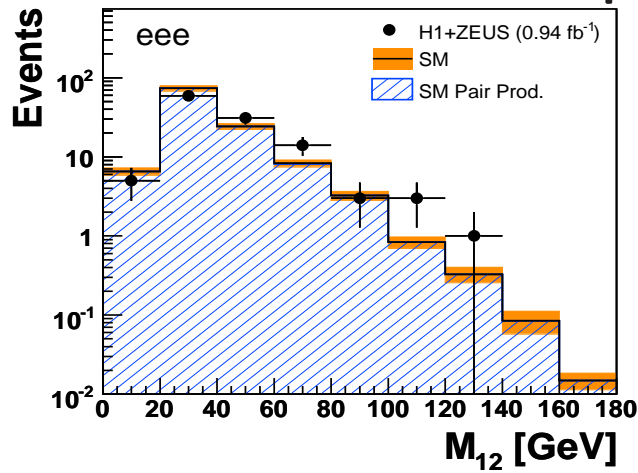




Combined mass distributions



Multi-Leptons at HERA

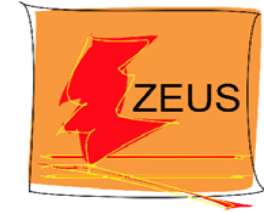


Good agreement with the SM, some events with high masses observed





Combined mass table



All the high-mass events are seen in e^+p collisions.

3 events come from ZEUS, 9 from H1.

| Multi-Leptons at HERA (0.94 fb^{-1}) | | | | |
|--|------|-----------------|-------------------------|-----------------|
| $M_{12} > 100 \text{ GeV}$ | | | | |
| 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 data (0.94 fb^{-1}) | | | | |
| ee | 4 | 2.93 ± 0.28 | 1.65 ± 0.16 | 1.28 ± 0.18 |
| $\mu\mu$ | 1 | 0.55 ± 0.12 | 0.55 ± 0.12 | < 0.01 |
| $e\mu$ | 1 | 0.65 ± 0.07 | 0.64 ± 0.06 | < 0.02 |
| eee | 4 | 1.27 ± 0.12 | 1.27 ± 0.12 | < 0.03 |
| $e\mu\mu$ | 2 | 0.31 ± 0.06 | 0.31 ± 0.06 | < 0.01 |

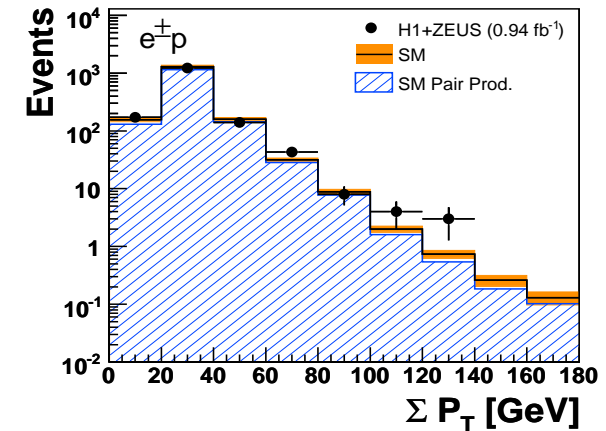
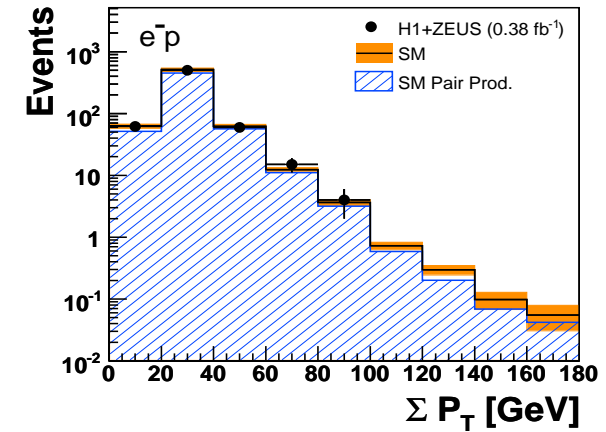
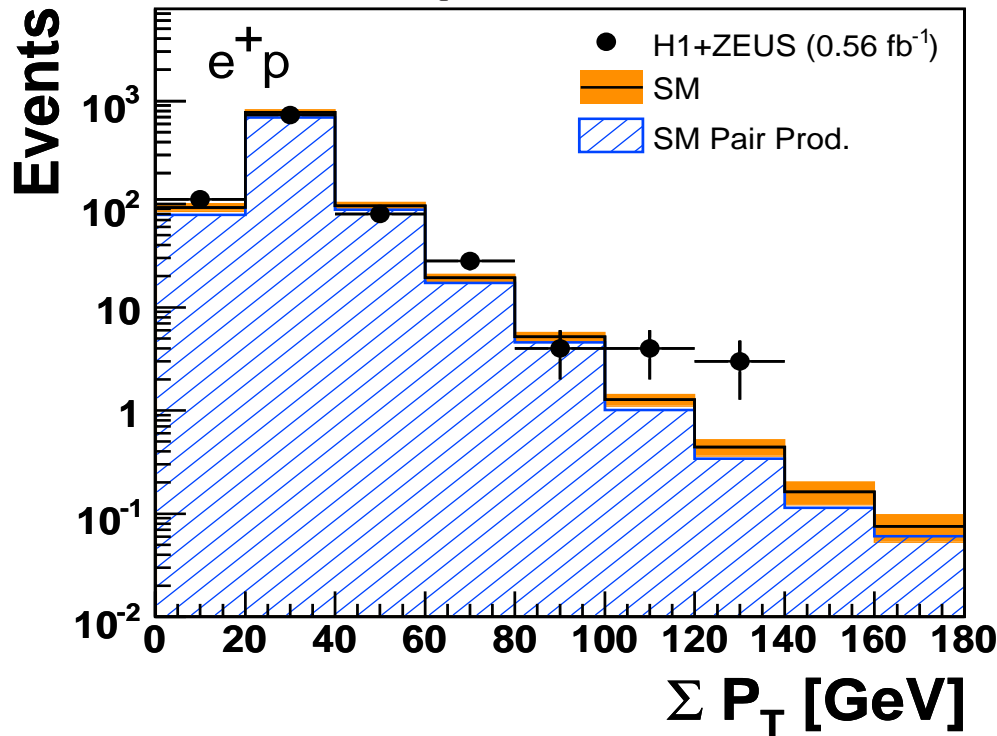




Σp_T distributions



Multi-Leptons at HERA



7 high- Σp_T events
observed in e^+p data

Multi-Leptons at HERA (0.94 fb^{-1})

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

| Data sample | Data | SM | Pair Production (GRAPE) | NC DIS + QEDC |
|-----------------------------------|------|-----------------|-------------------------|-----------------|
| e^+p (0.56 fb^{-1}) | 7 | 1.94 ± 0.17 | 1.52 ± 0.14 | 0.42 ± 0.07 |
| e^-p (0.38 fb^{-1}) | 0 | 1.19 ± 0.12 | 0.90 ± 0.10 | 0.29 ± 0.05 |
| All (0.94 fb^{-1}) | 7 | 3.13 ± 0.26 | 2.42 ± 0.21 | 0.71 ± 0.10 |

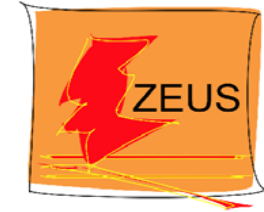


Measurement of the cross sections

- In order to select a sample enriched in photoproduction events, the cut $E-p_z < 45$ GeV was imposed.
- In this way the sample is constituted by events in which two leptons of the same flavour are found in the final state.
- Cross sections are evaluated for the $\gamma\gamma \rightarrow t^+t^-$ process in the kinematic region:
 - leptons must be isolated
($D^{11,12} > 0.5$ in the pseudorapidity-azimuth plane)
 - $Q^2 < 1$ GeV², $y < 0.82$ (photoproduction regime)
 - $p_T^{11,12} > 10,5$ GeV
 - $20^\circ < \theta < 150^\circ$

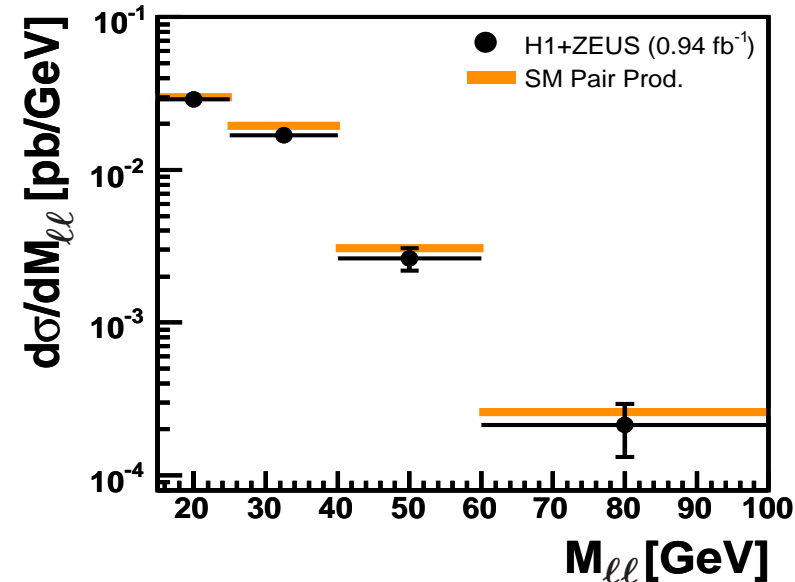
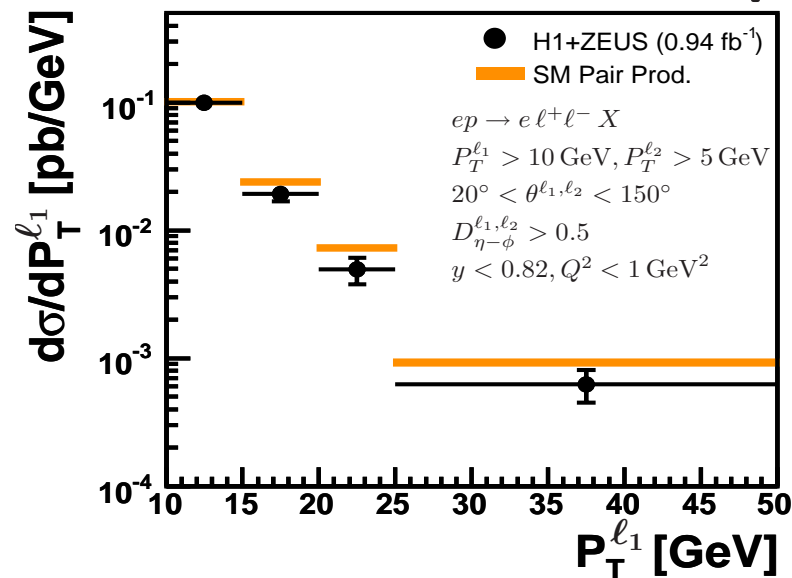


Combined cross sections



Differential cross sections measured as a function of the mass of the dilepton system and of the p_T of the highest- p_T lepton.

Multi-Leptons at HERA



Conclusions

- Multilepton production has been studied at HERA, looking for possible deviations from the SM in the high mass and high- Σp_T regions.
- All the event topologies containing electrons and/or muons have been investigated. An overall good agreement with the SM has been found.
- The results of the H1 and ZEUS experiments have been combined to reach best sensitivity: some events with high- Σp_T and high masses have been observed, for both experiments only in e^+p collisions.
- Cross sections for the process $\gamma\gamma \rightarrow l^+l^-$ have been measured using the full available HERA statistics.



References

- ZEUS Coll., Multi-lepton production at high transverse momentum at HERA, published on [Phys. Lett. B 680 \(2009\) 13-23](#);
- H1 Coll., Multi-Lepton Production at High Transverse Momenta in ep Collisions at HERA, published on [Phys. Lett. B 668 \(2008\) 268-276](#);
- H1 and ZEUS Coll., Multi-Leptons with High Transverse Momentum at HERA, published on [JHEP10\(2009\)013](#);
- ZEUS Coll., Study of tau-pair production with the ZEUS detector at HERA, ZEUS-prel-08-009.



Backup



ZEUS ditau events HERA II data ($L=0.36 \text{ fb}^{-1}$)

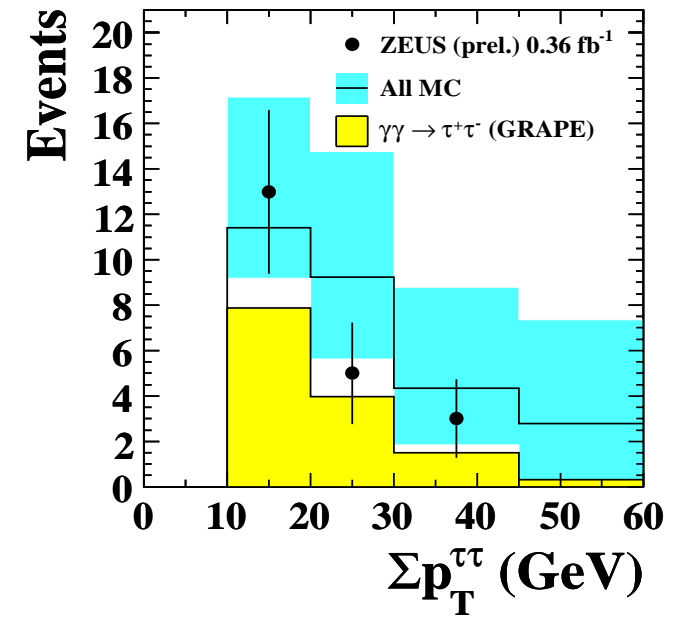
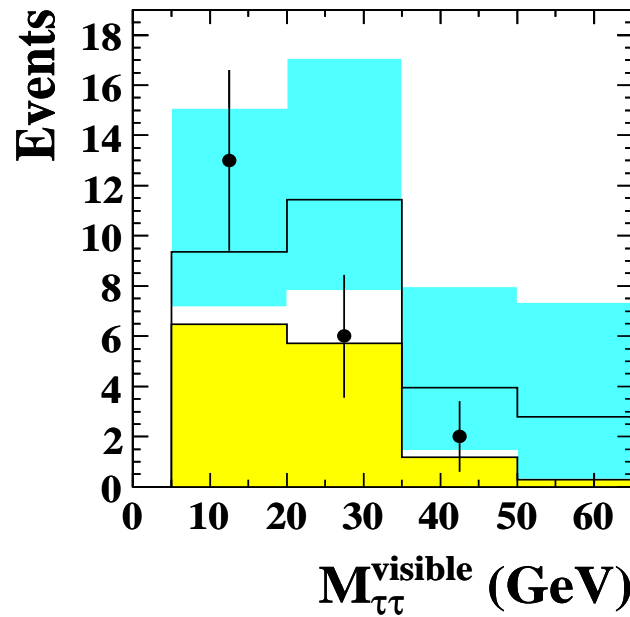
| Topology | All | jet-jet | e-jet-jet | e-jet | e-e-jet |
|----------|----------------------|----------------------|---------------------|---------------------|---------------------|
| D cut | | 0.80 | 0.50 | 0.90 | 0.90 |
| Data | 21 | 14 | 3 | 4 | 0 |
| Total SM | $27.2^{+7.1}_{-6.3}$ | $20.2^{+6.8}_{-5.7}$ | $1.4^{+3.3}_{-0.2}$ | $4.9^{+3.1}_{-1.3}$ | $0.7^{+4.4}_{-0.1}$ |
| ditau MC | $13.2^{+0.6}_{-1.0}$ | $9.1^{+0.4}_{-0.8}$ | 1.4 ± 0.1 | 2.2 ± 0.1 | 0.5 ± 0.1 |
| (purity) | (49%) | (45%) | (97%) | (46%) | (74%) |

Di- τ

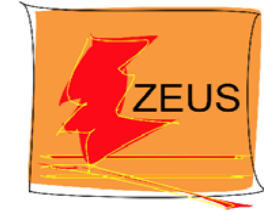


Analysis performed on the HERA II (2004-2007) data. Topologies with jets and electrons investigated.

ZEUS



Masses for the different topologies



ZEUS

