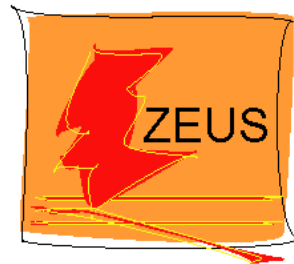


Multilepton production at HERA

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(DESY)



on behalf of the
ZEUS and H1 Collaborations



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Scattering and Related Subjects

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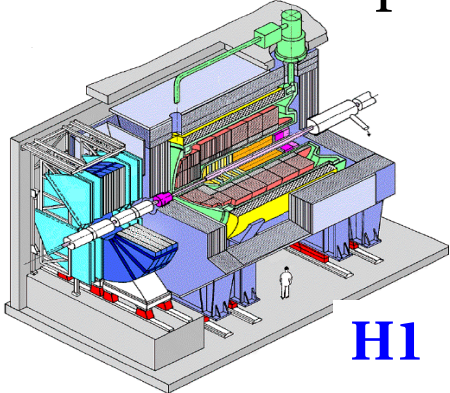


HERA physics

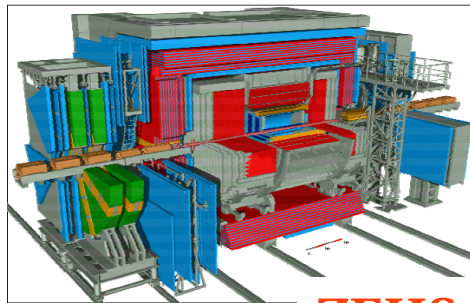
HERA: e^+p collider, $E_{\text{cm}} \sim 318 \text{ GeV}$



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



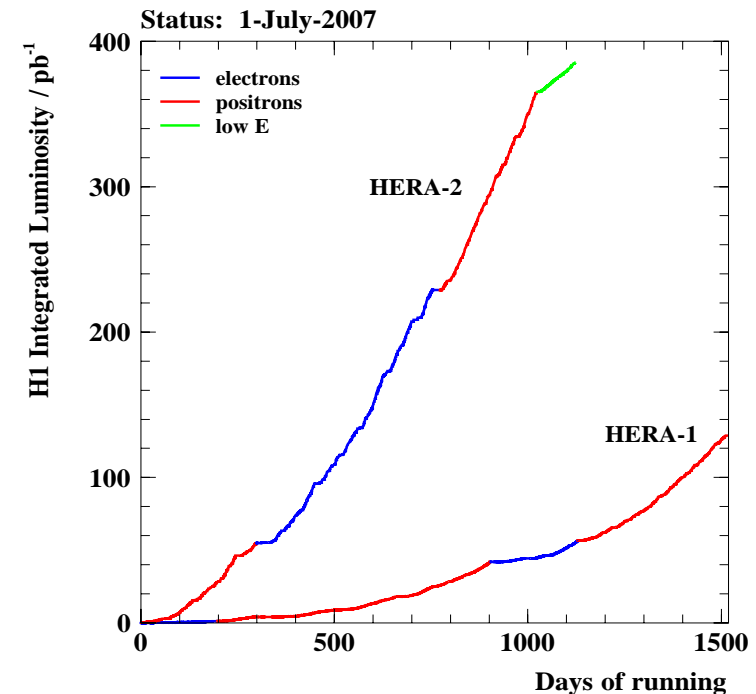
H1



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.

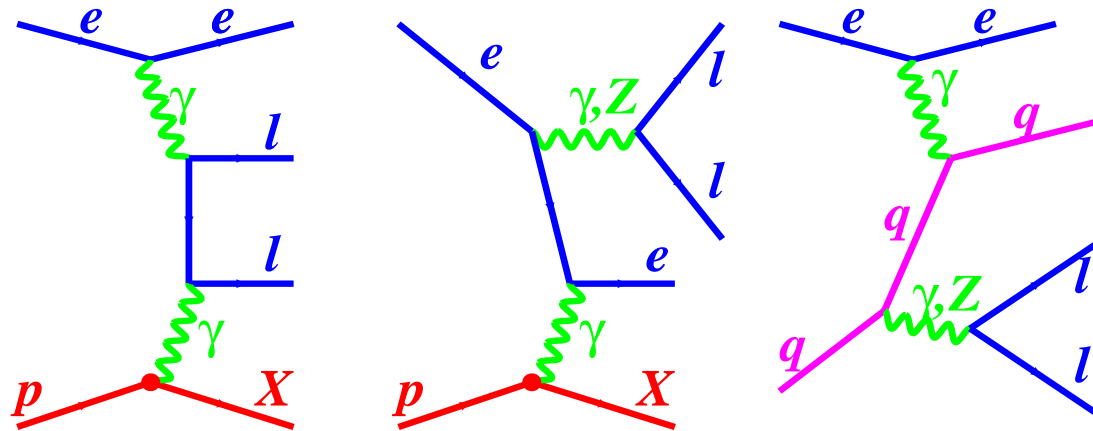
Outline

- 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

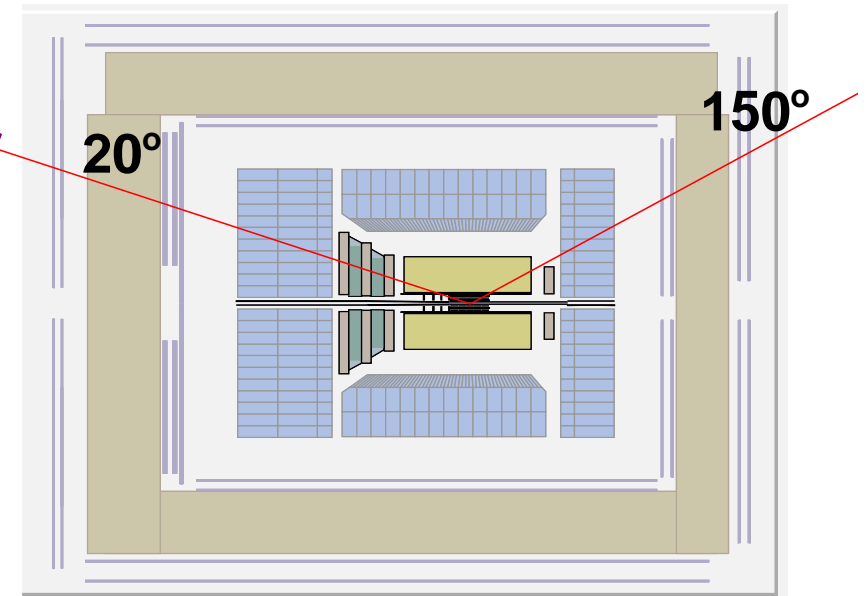
- Events are selected by requiring the presence of **at least two isolated high- p_T leptons (electrons or muons)** in the final state.
- Depending on the number and the flavours of the leptons, the events are classified into **mutually exclusive samples**:
 - *ee sample*: 2 electrons were found, and 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).



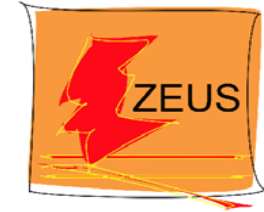
Muons:

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

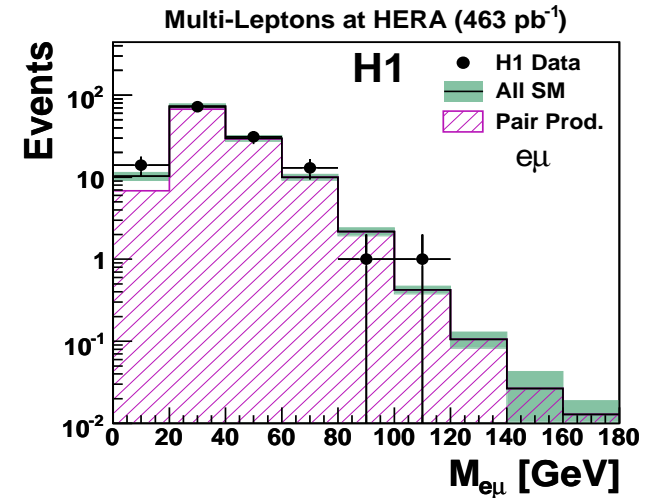
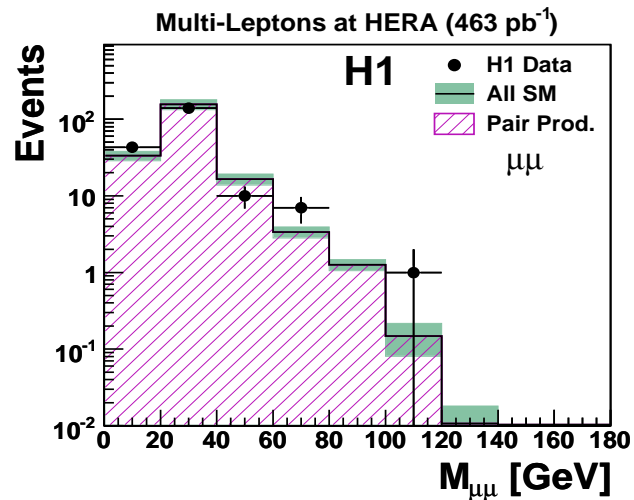
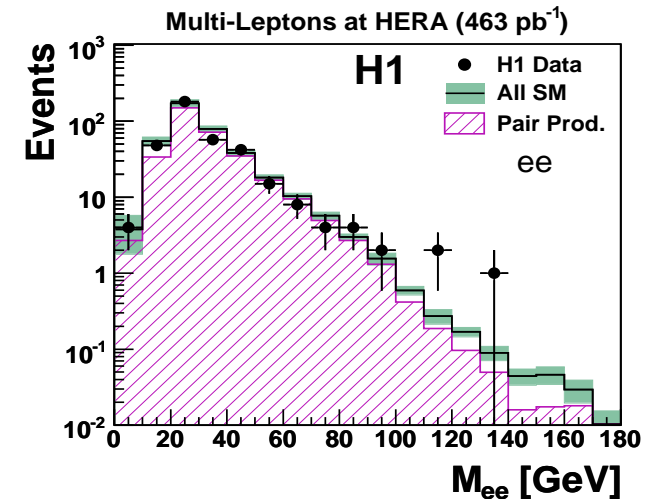
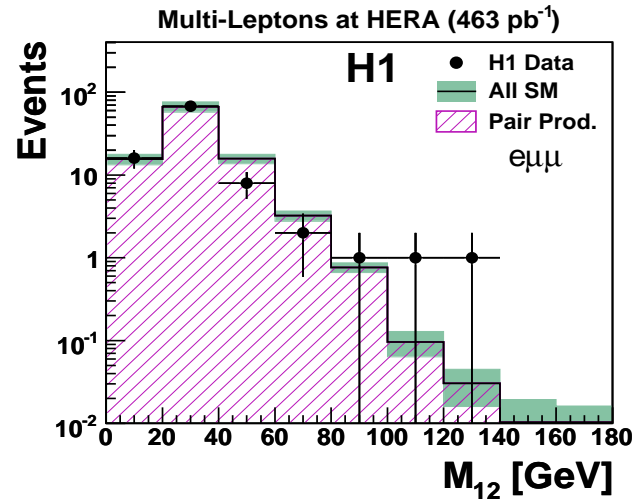
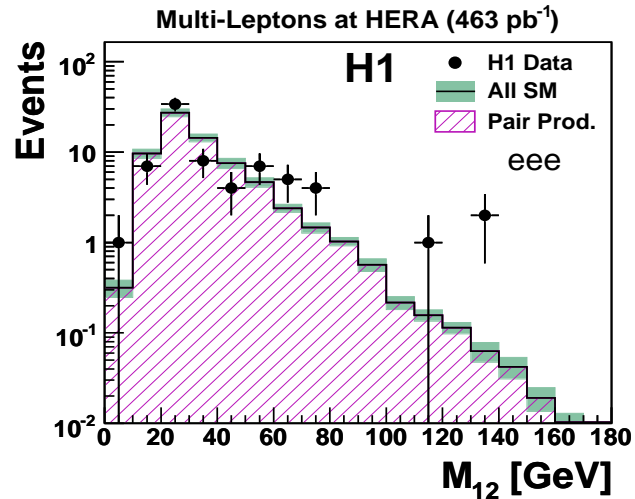
Topology	Data	Total SM	Multi-lepton Production	NC DIS	Compton
ee	545	563^{+29}_{-37}	429^{+21}_{-29}	74 ± 5	60 ± 10
$\mu\mu$	93	106 ± 12	106 ± 12	< 0.5	—
$e\mu$	46	42 ± 4	37^{+3}_{-4}	4.5 ± 1.2	—
eee	73	75^{+5}_{-4}	73^{+4}_{-5}	< 1	< 3
$e\mu\mu$	47	48 ± 5	48 ± 5	< 0.5	—
$eeee$	1	$0.9^{+0.5}_{-0.1}$	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



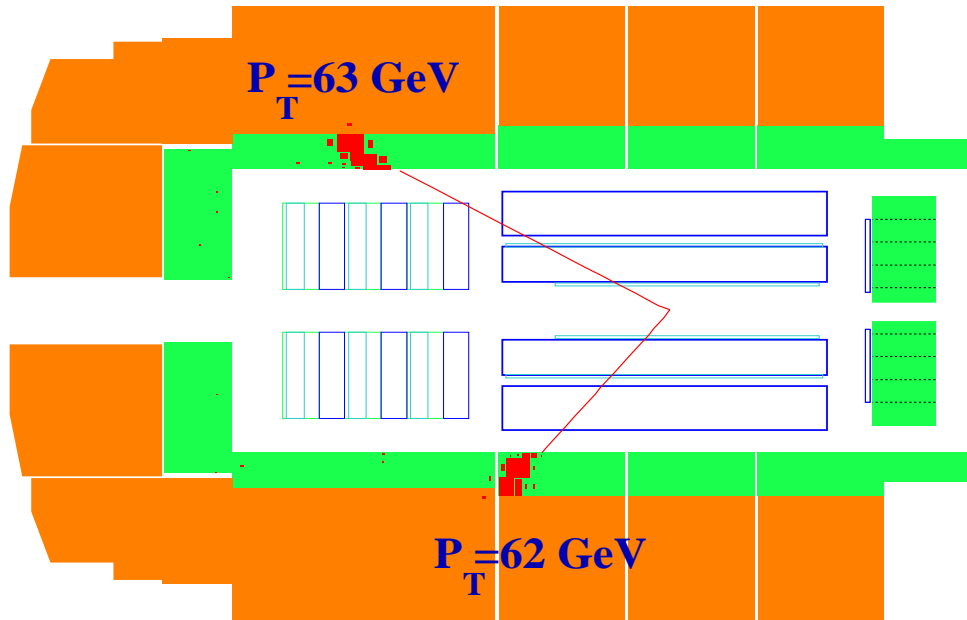
Overall agreement with SM.

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



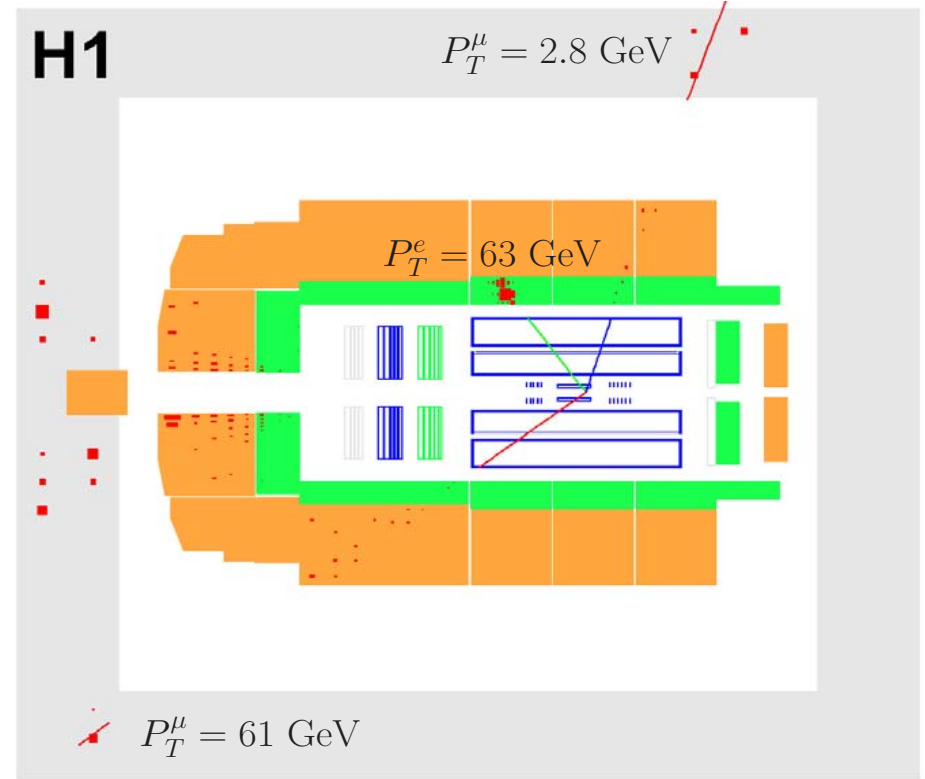


Two H1 events

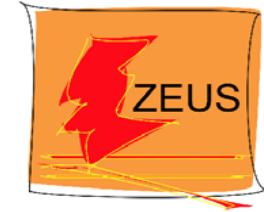


ee event: $M=130$ GeV.

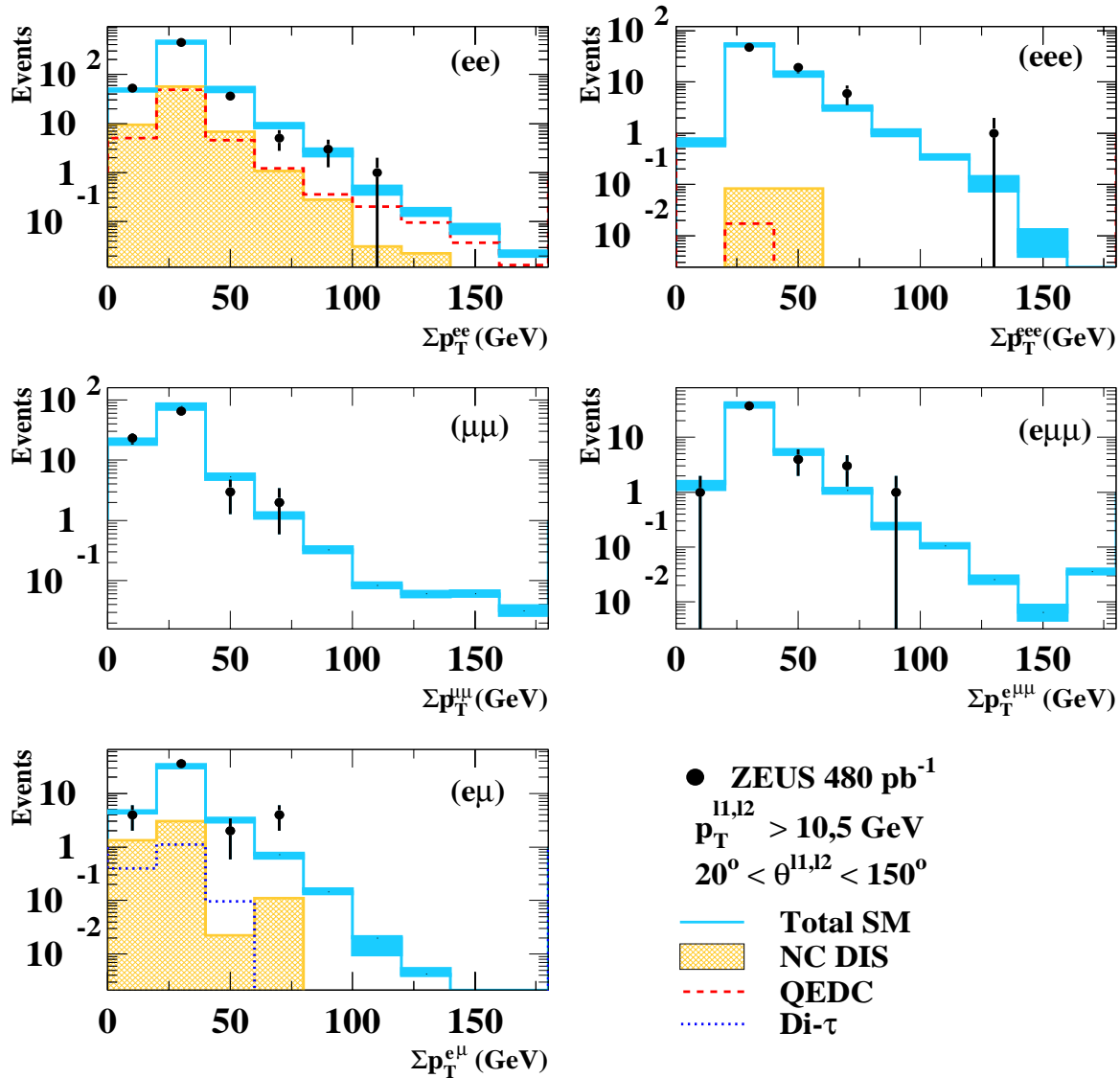
eμμ event: $M=127$ GeV,
given by the electron and
the highest- p_T muon.



Σp_T for the different topologies



ZEUS



Good agreement with the SM for all the topologies.

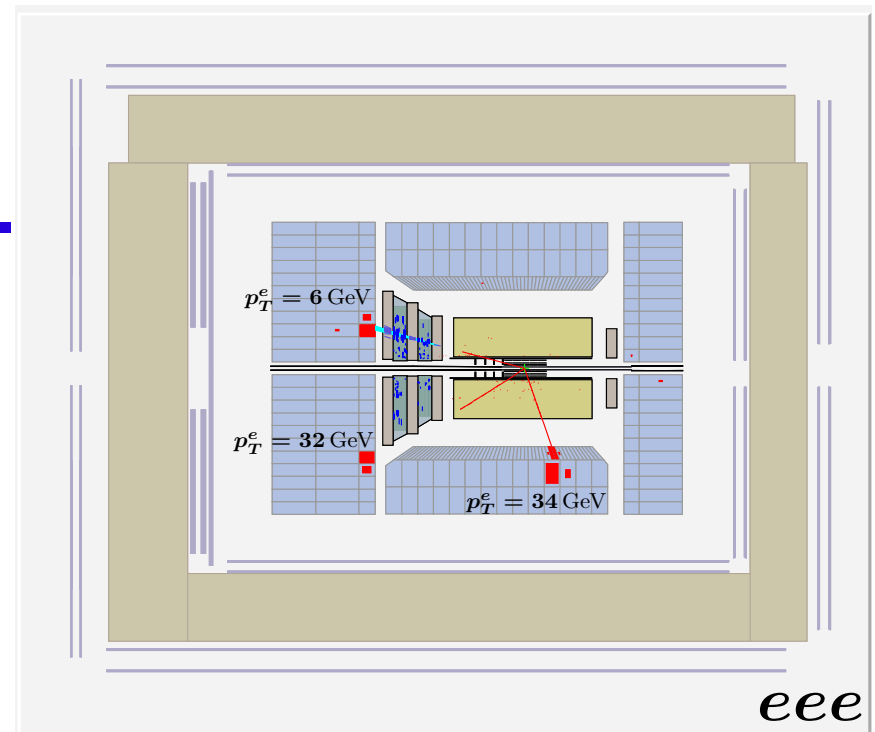
2 events observed with high Σp_T .



Two ZEUS events

Highest mass event containing only electrons (eee):

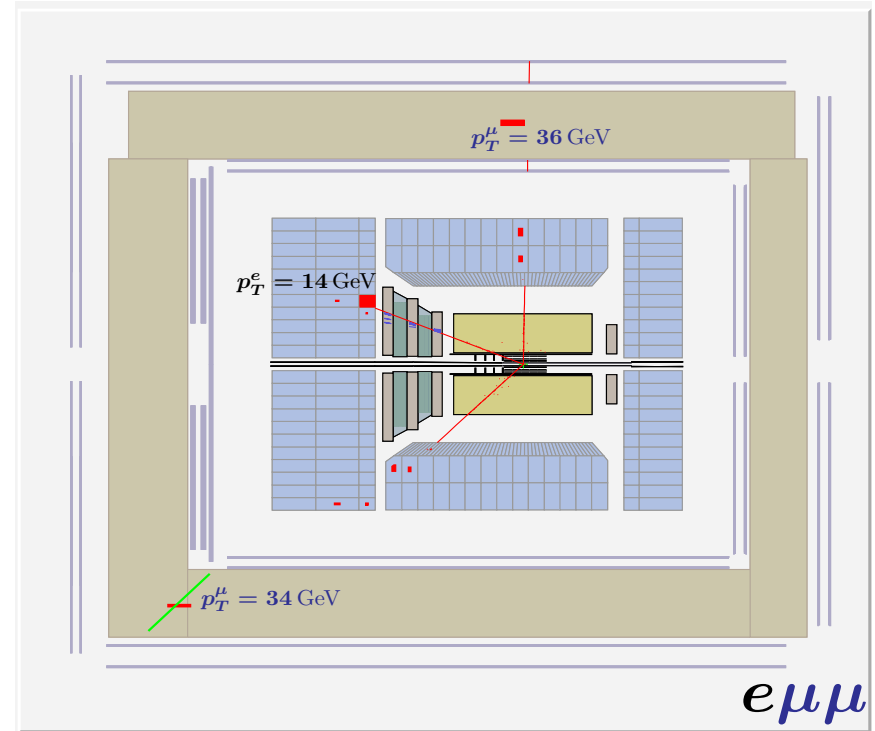
$M=113$ GeV



eee

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

$M=77.5$ GeV



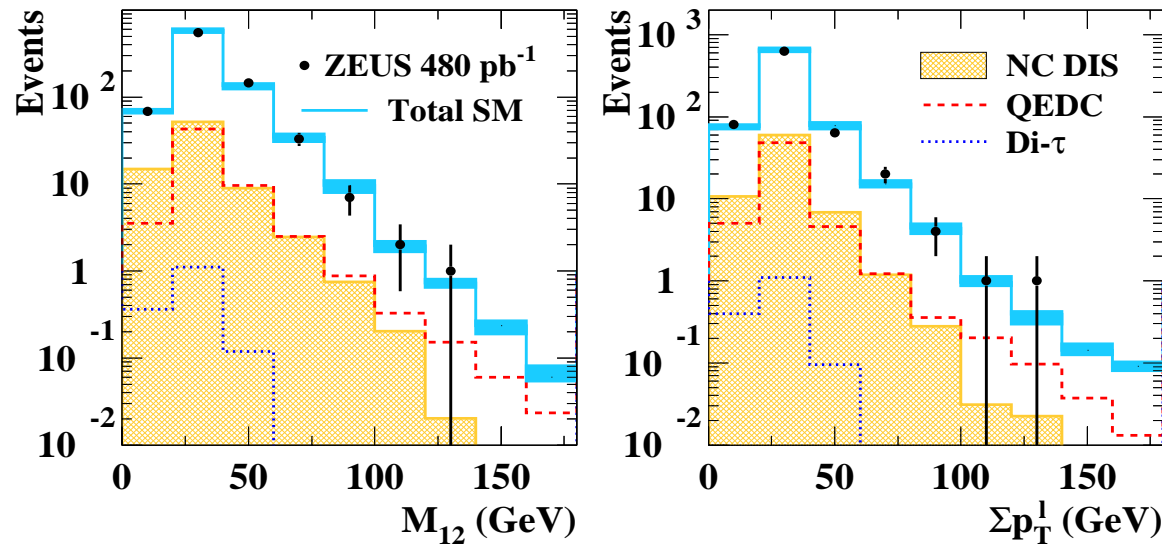
$e\mu\mu$



Combination of the topologies



ZEUS

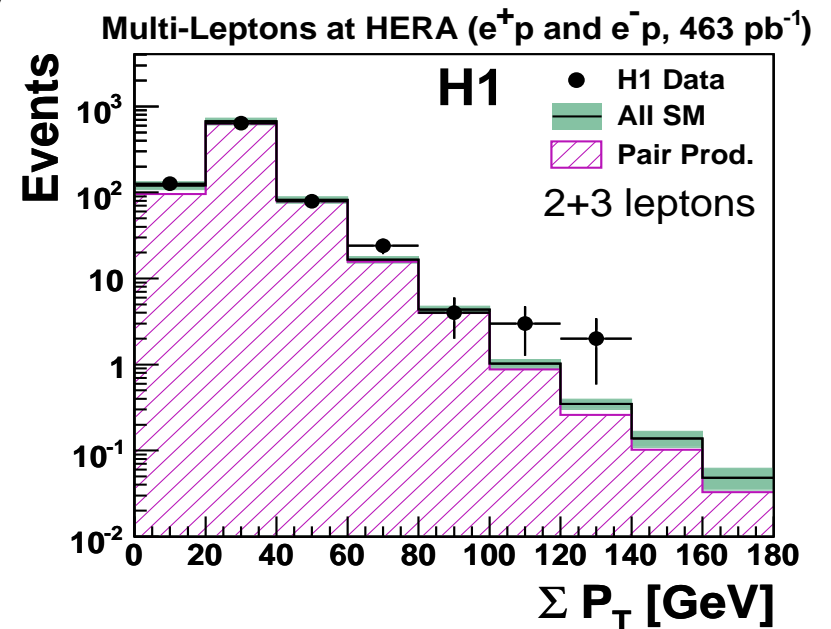


Good agreement between the data and the SM.

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...



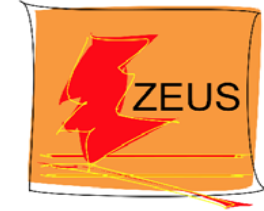
Combined analysis

- 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

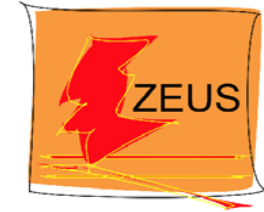
Good agreement with the Standard Model.

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

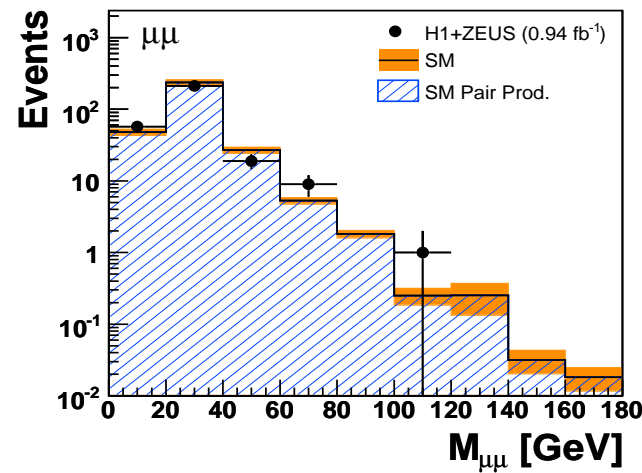
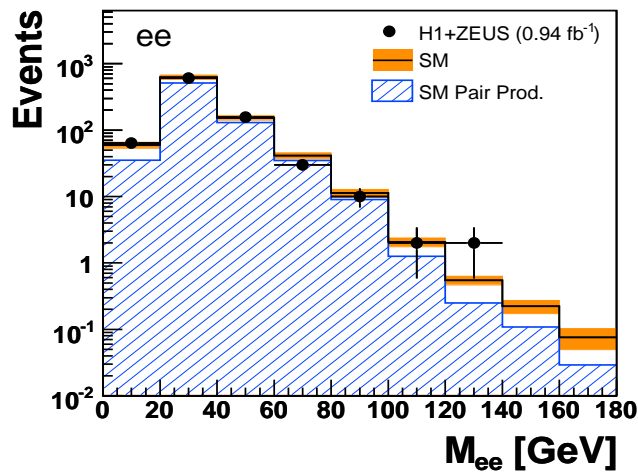
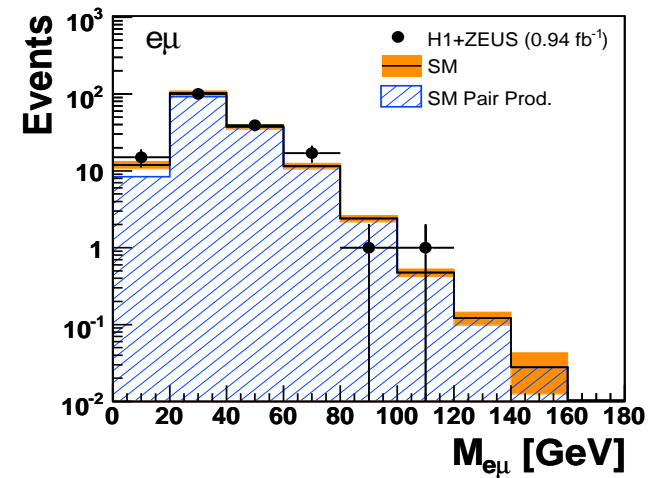
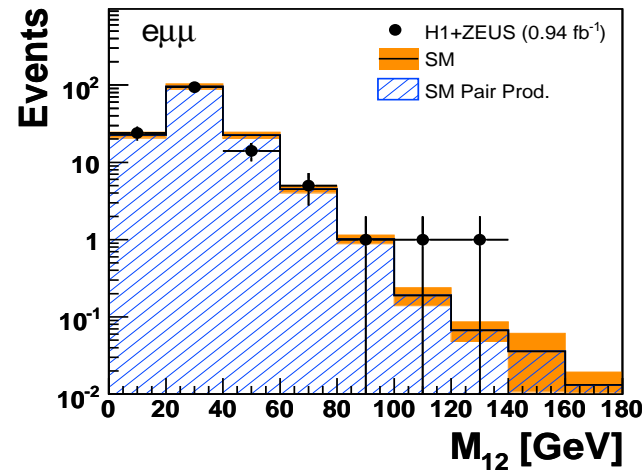
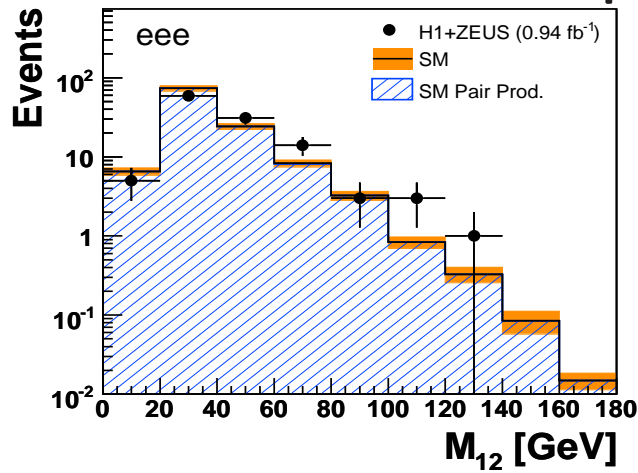




Combined mass distributions



Multi-Leptons at HERA

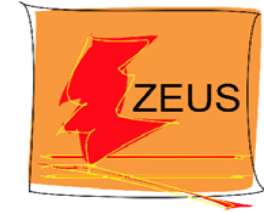


Good agreement with the SM, some events with high masses observed





Combined mass table



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

3 events come from ZEUS, 9 from H1.

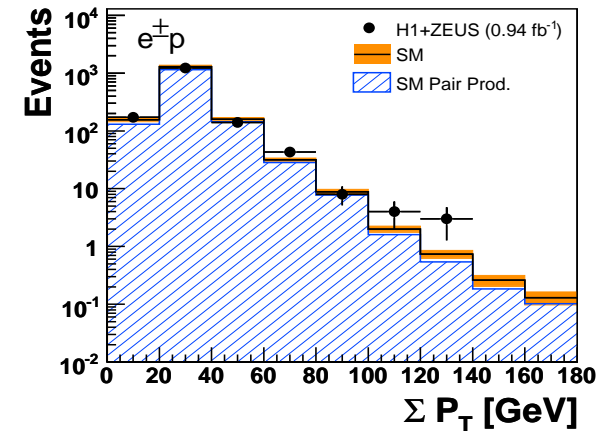
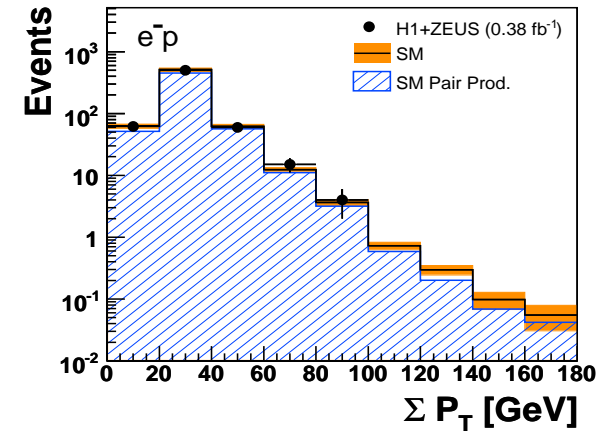
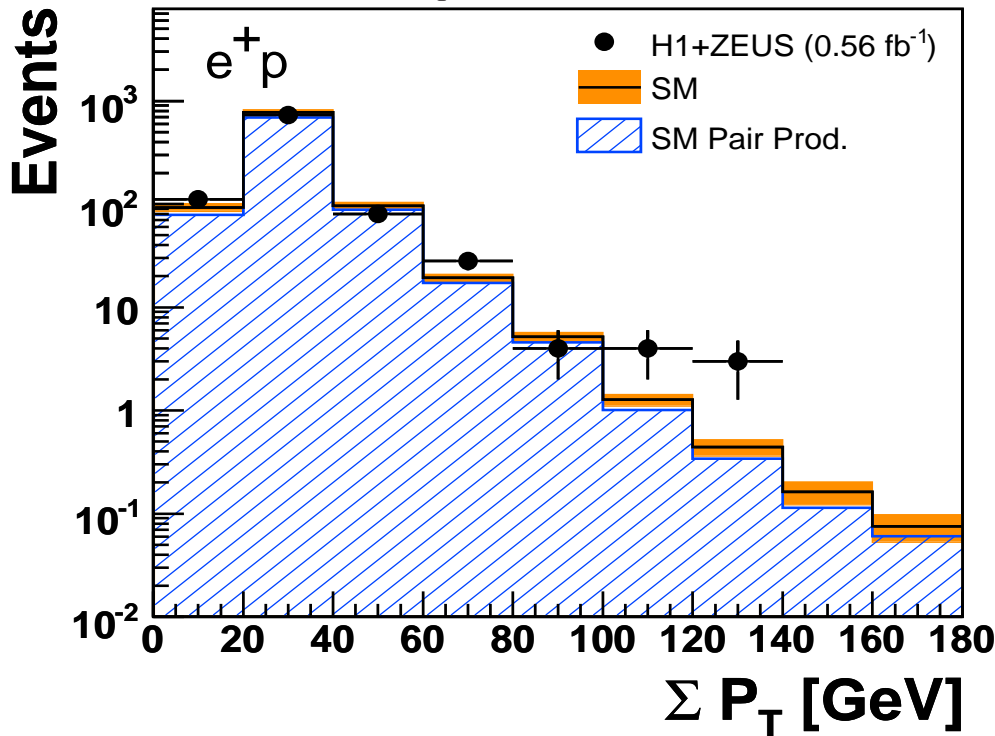
Multi-Leptons at HERA (0.94 fb^{-1})				
$M_{12} > 100 \text{ GeV}$				
Sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
e^+p collisions (0.56 fb^{-1})				
ee	4	1.68 ± 0.18	0.94 ± 0.11	0.74 ± 0.12
$\mu\mu$	1	0.32 ± 0.08	0.32 ± 0.08	< 0.01
$e\mu$	1	0.40 ± 0.05	0.39 ± 0.05	< 0.02
eee	4	0.79 ± 0.09	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

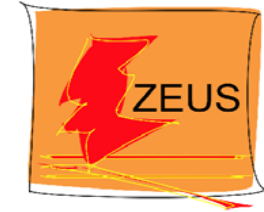


Measurement of the cross sections

- 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
 - $20^\circ < \theta < 150^\circ$

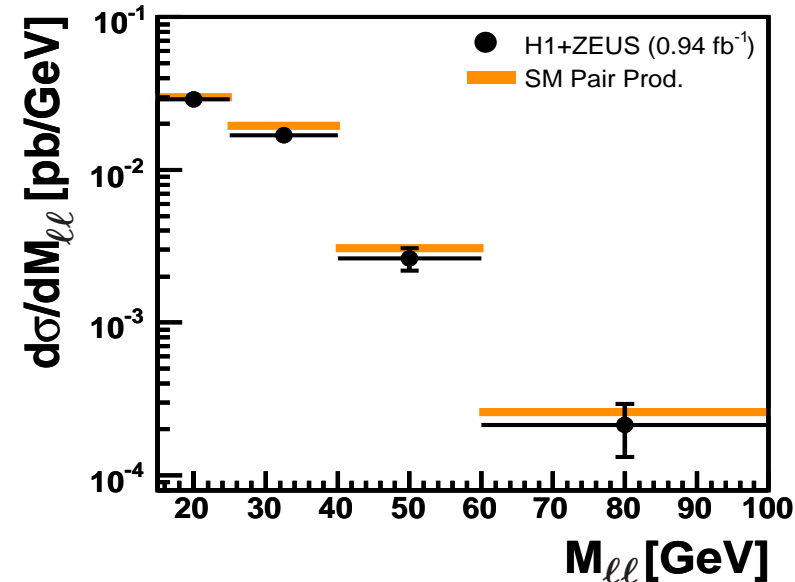
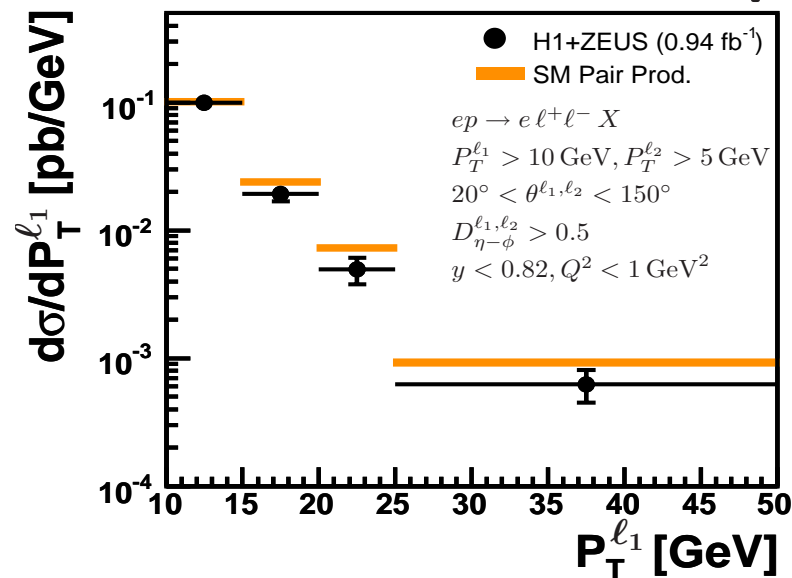


Combined cross sections



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 ($L=0.36 \text{ fb}^{-1}$)

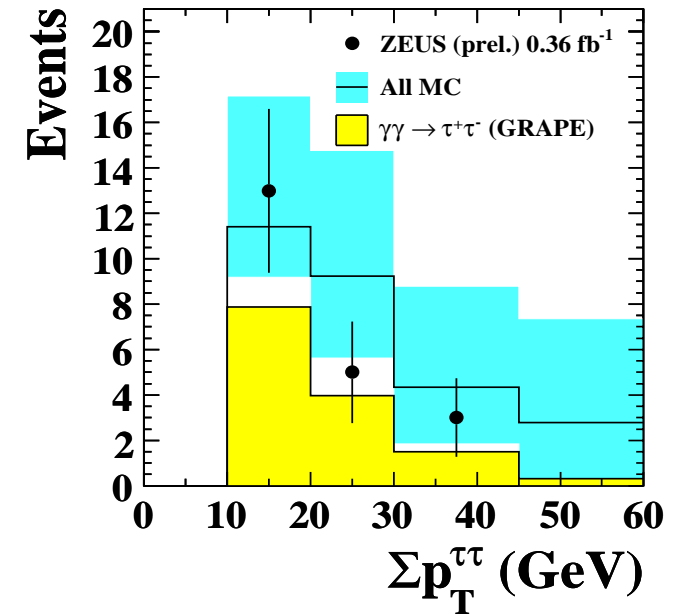
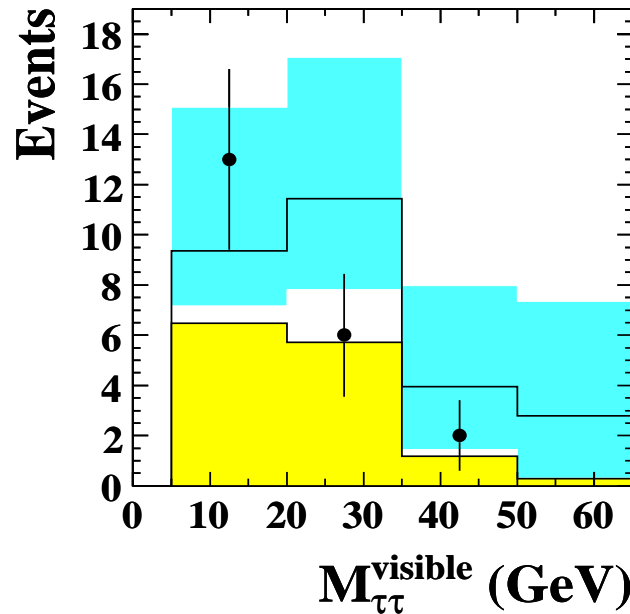
Topology	All	jet-jet	e-jet-jet	e-jet	e-e-jet
D cut		0.80	0.50	0.90	0.90
Data	21	14	3	4	0
Total SM	$27.2^{+7.1}_{-6.3}$	$20.2^{+6.8}_{-5.7}$	$1.4^{+3.3}_{-0.2}$	$4.9^{+3.1}_{-1.3}$	$0.7^{+4.4}_{-0.1}$
ditau MC	$13.2^{+0.6}_{-1.0}$	$9.1^{+0.4}_{-0.8}$	1.4 ± 0.1	2.2 ± 0.1	0.5 ± 0.1
(purity)	(49%)	(45%)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

