Multilepton production at HERA

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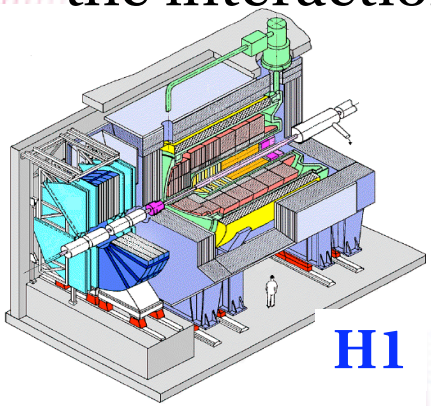
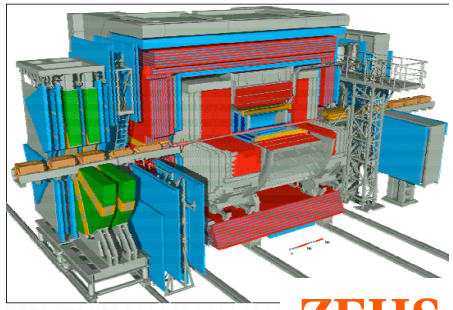
HERA physics

HERA: $e^{\pm}p$ collider, E_{cm} ~ 318 GeV

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



H1

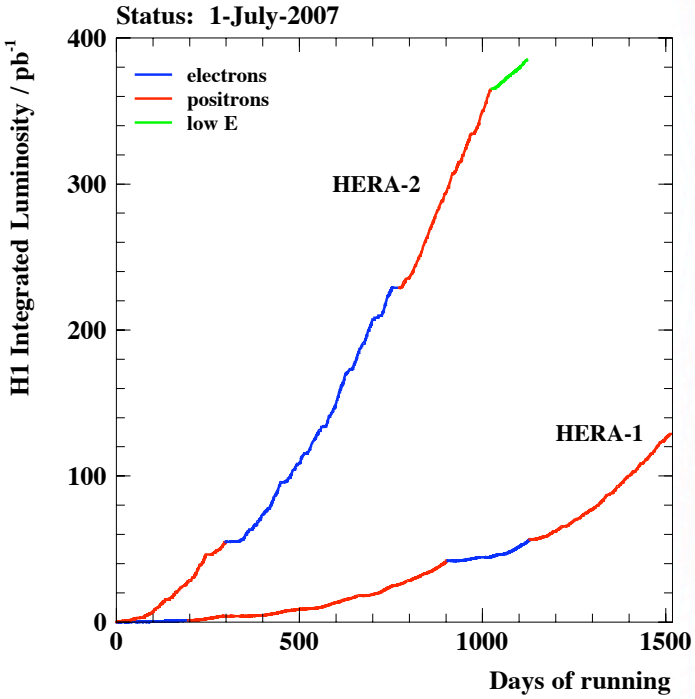


ZEUS

Data taking ended in June 07.

Collected luminosity :

~0.5 fb^{-1} per experiment



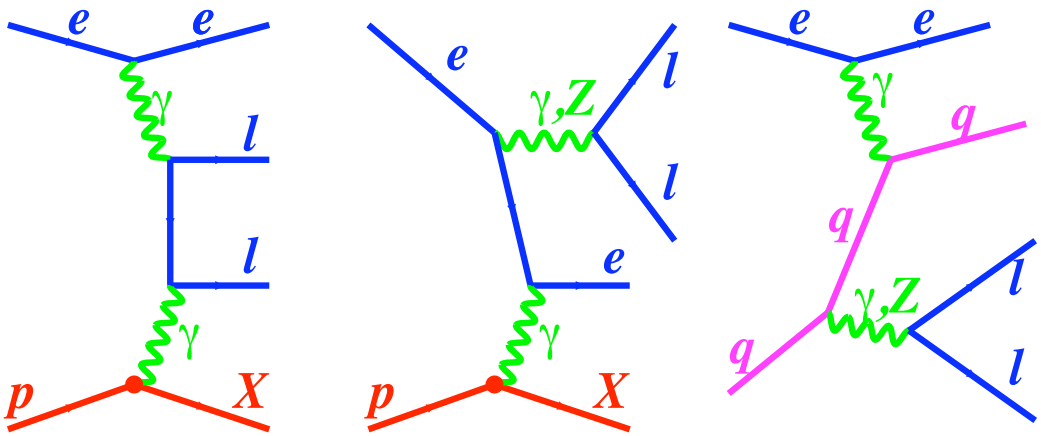
Rare (σ ~ 1 fb) phenomena may become visible.

Outline

- Events in which two or more isolated electrons or muons with high transverse momentum are found give a clean experimental signature where to look for signatures of 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: preliminary 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 *ep* interactions, dominated by the γγ 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.

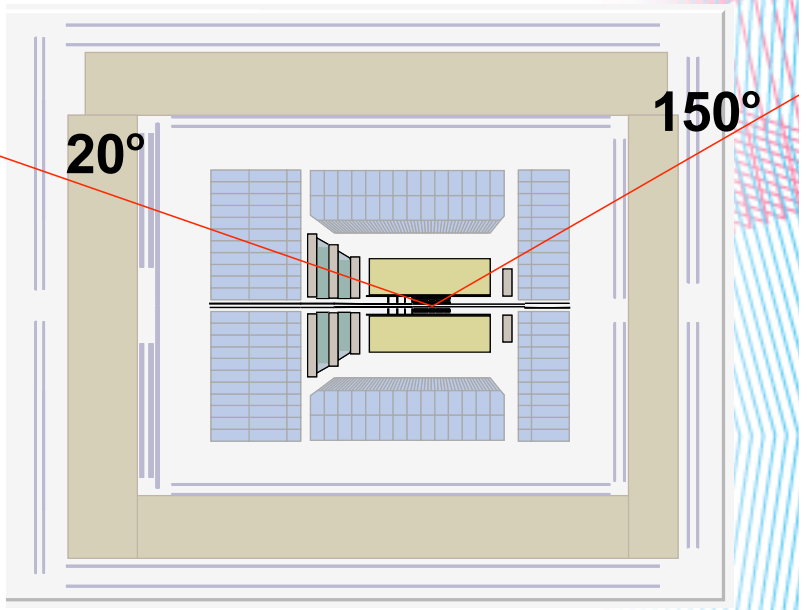
Strategy of the analysis

- 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 independent samples.
  - *ee sample:* 2 electrons were found, and no other lepton;
  - *eee*: 3 electrons are found, and no other lepton; does not contain the *ee sample*;
  - eμ: 1 electron and 1 muon;
  - and so on for eμμ, μμ...
- 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 $5^o<\theta<175^o$, with E>5 GeV for $\theta>150^o$, 10 GeV elsewhere (H1: 5 GeV up to 20^o).
- Isolated (looking at tracks and calorimeter deposits).



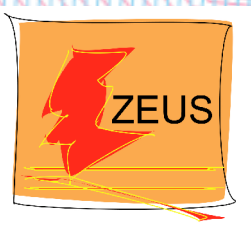
Muons:

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

At least 2 leptons have to be in $20^o<\theta<150^o$, 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

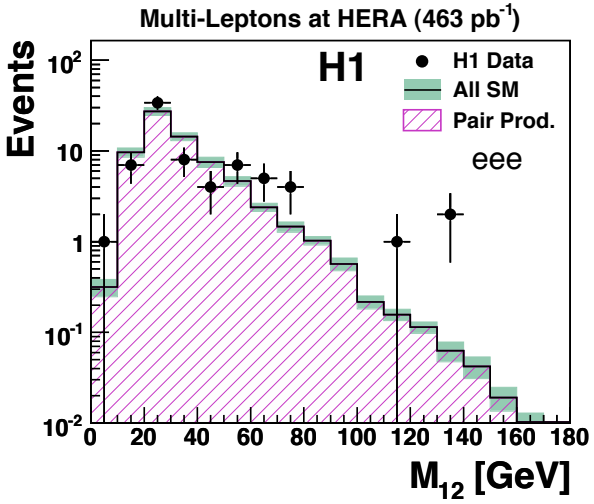


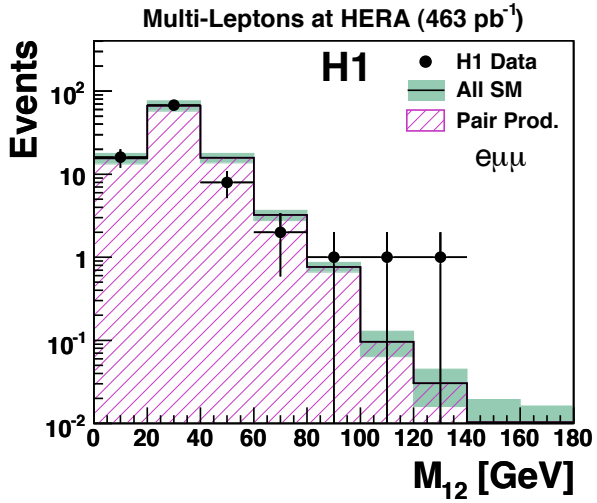
ZEUS ($\mathcal{L} = 480\,\mathrm{pb}^{-1}$)

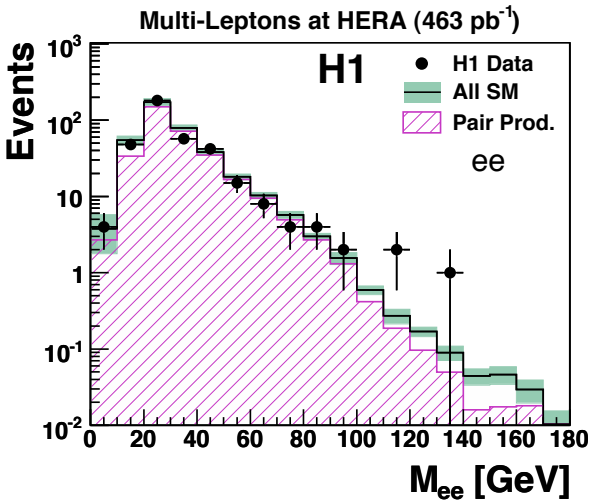
Topology	Data	Total SM	Pair Production	NC DIS	Compton
ee	545	563^{+29}_{-37}	429^{+21}_{-29}	74 ± 5	60 ± 10
$\mu\mu$	93	106 ± 12	106 ± 12	< 0.5	
$e\mu$	46	42 ± 4	37^{+3}_{-4}	4.5 ± 1.2	
eee	73	75^{+5}_{-4}	73^{+4}_{-5}	< 1	< 3
$e\mu\mu$	47	48 ± 5	48 ± 5	< 0.5	
$eeee$	1	$0.9^{+0.5}_{-0.1}$	0.6 ± 0.1	< 0.4	< 1
$ee\mu\mu$	2	$0.5^{+0.3}_{-0.1}$	0.4 ± 0.1	< 0.5	
All 4-leptons	3	$1.4^{+0.6}_{-0.2}$	1.0 ± 0.2	< 0.5	
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

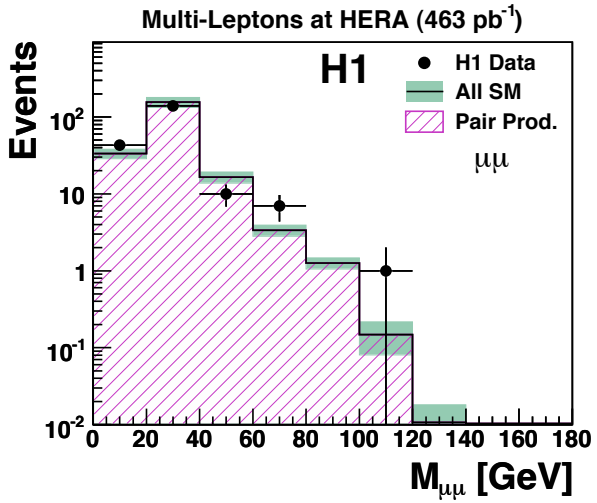


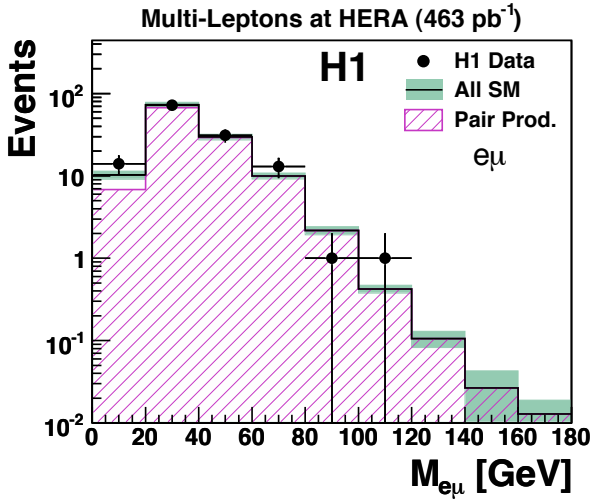




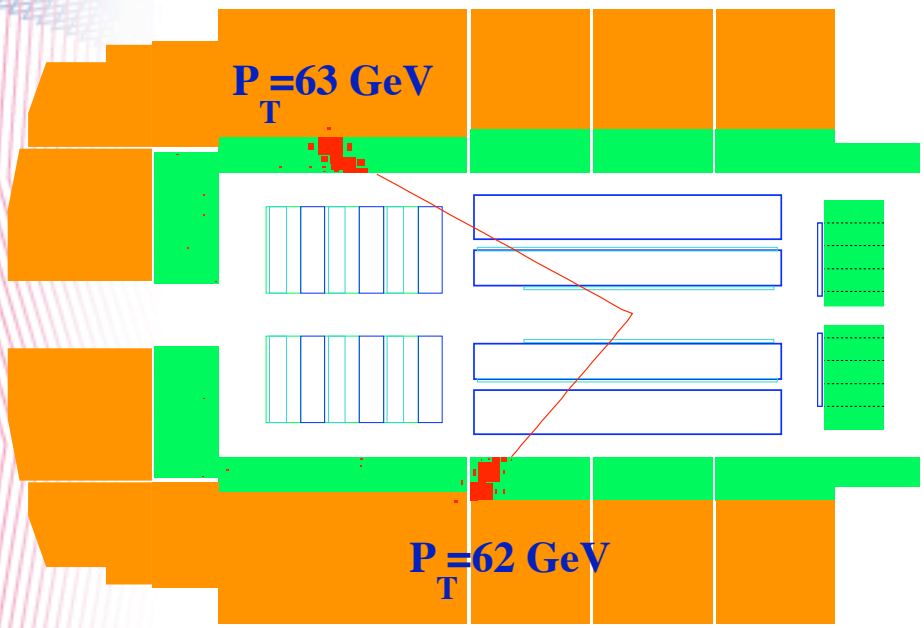
Overall agreement with SM.

High mass events observed in ee, eee, eμμ topologies.



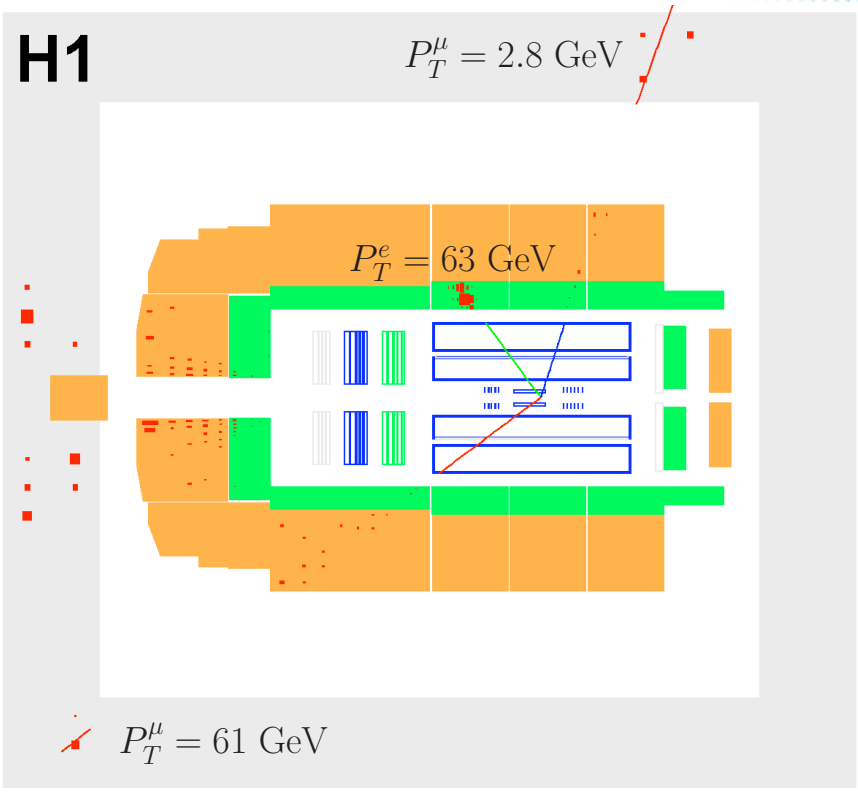


Two H1 events

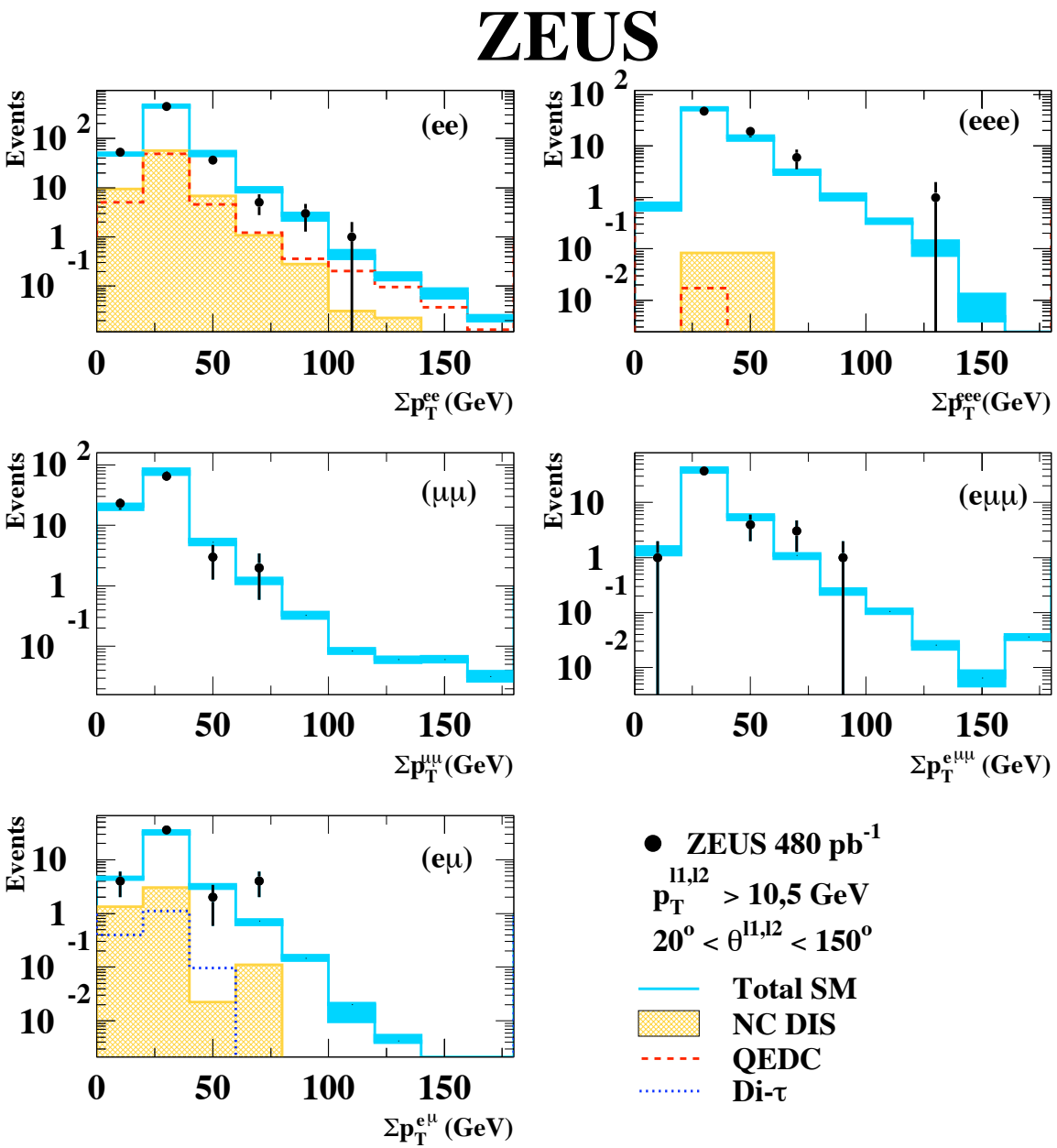


ee event: M=130 GeV.

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



Σp_T for the different topologies



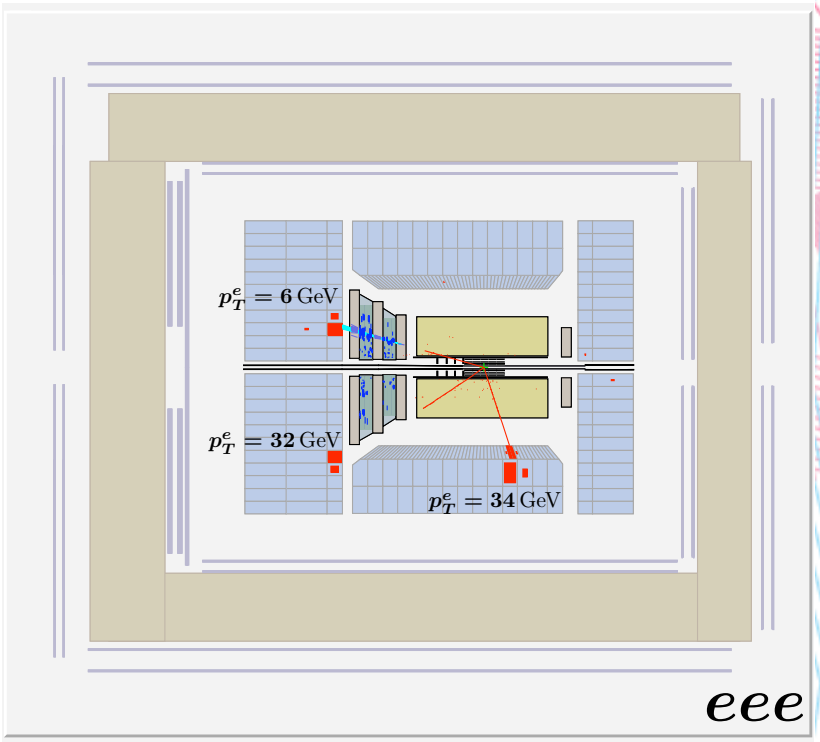
Good agreement with the SM for all the topologies.

2 events observed with high Σp_T.

Two ZEUS events

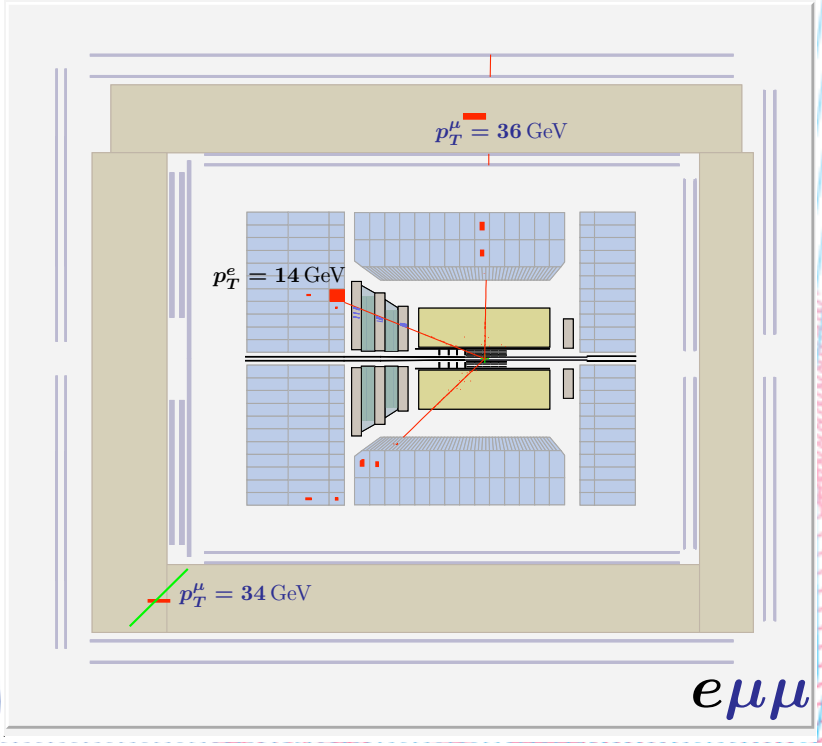
Highest mass event containing only electrons (eee):

m=113 GeV

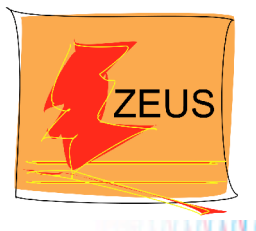


Highest mass event with muons (eμμ):

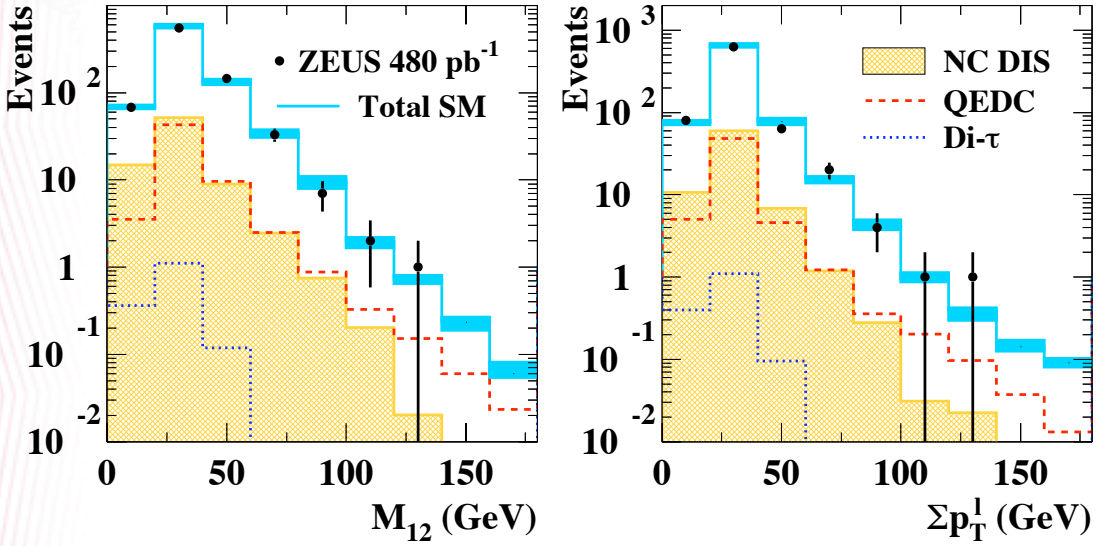
m=77.5 GeV



Combination of the topologies



ZEUS

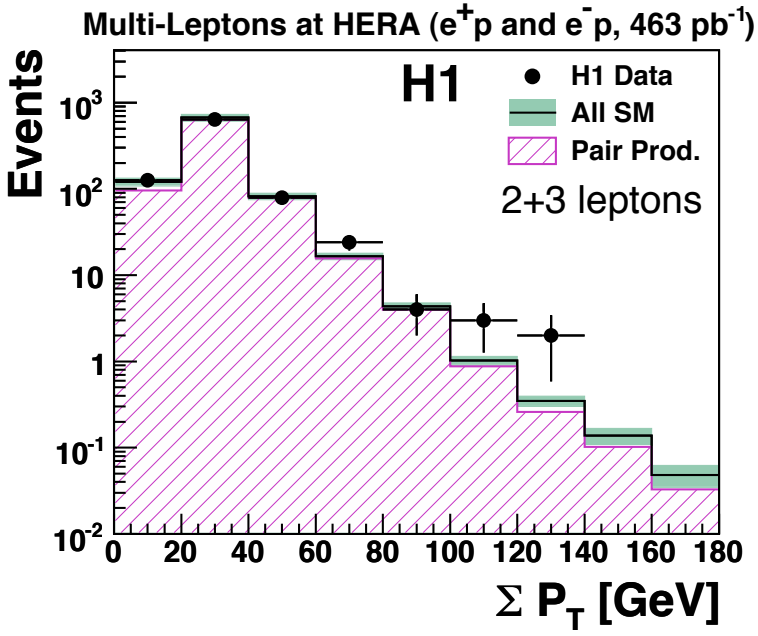


Good agreement between the data and the SM.

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 $20° < \theta < 150°$: 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

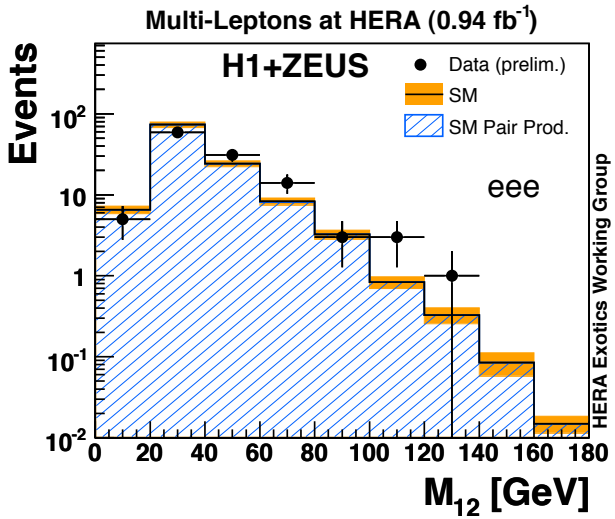
Multi-Leptons at HERA (0.94 fb^{-1})

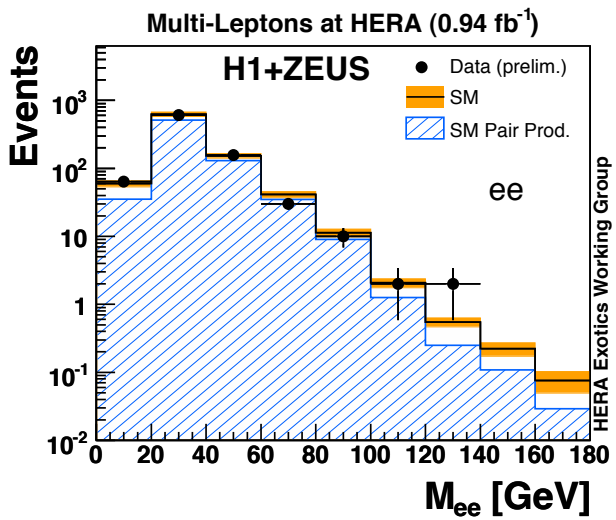
Selection	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
ee	873	895 ± 57	724 ± 41	171 ± 28
$\mu\mu$	298	320 ± 36	320 ± 36	< 0.5
$e\mu$	173	167 ± 10	152 ± 9	15 ± 3
eee	116	119 ± 7	117 ± 6	< 4
$e\mu\mu$	140	147 ± 15	147 ± 15	< 0.5
$(\gamma\gamma)_e$	284	293 ± 18	289 ± 18	4 ± 1
$(\gamma\gamma)_\mu$	235	247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

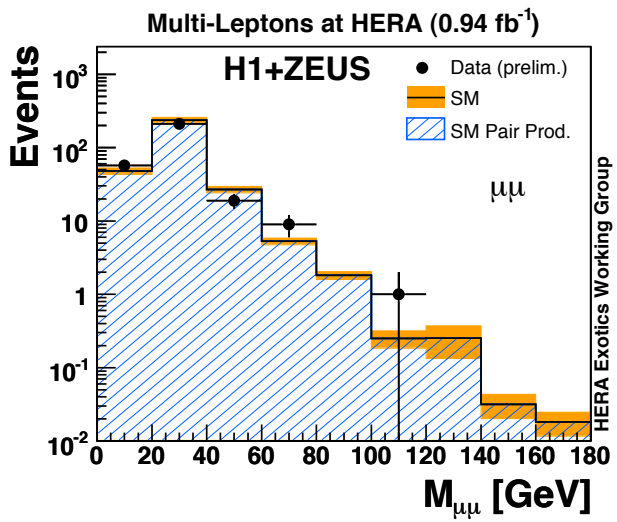
Good agreement with the Standard Model.

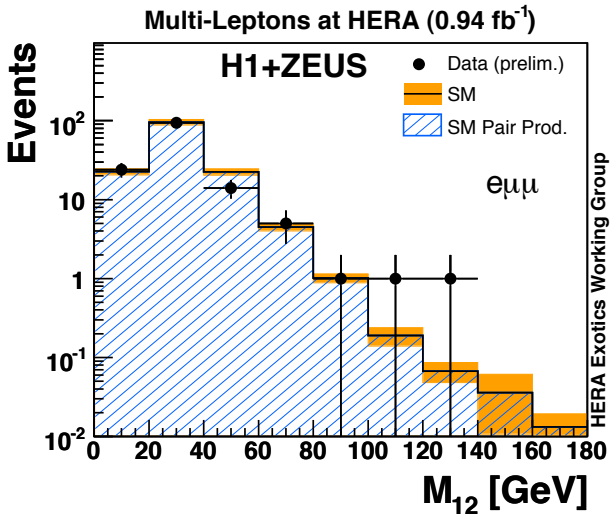
Let's look at the high-mass and high-Σp_T regions.

Combined mass distributions

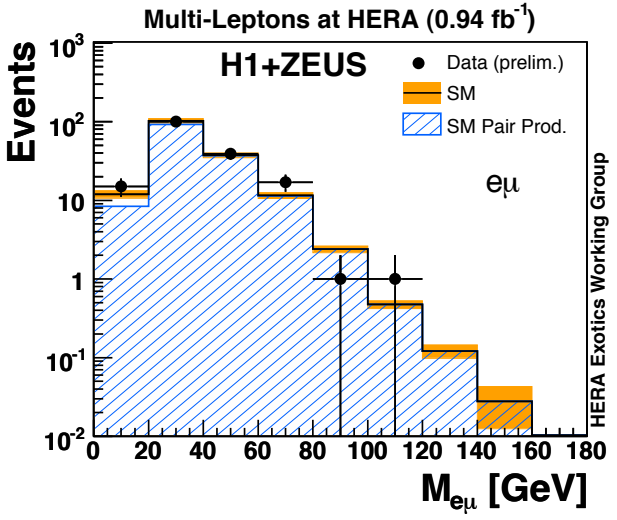








Good agreement with the SM, some events with high masses observed



Combined mass table

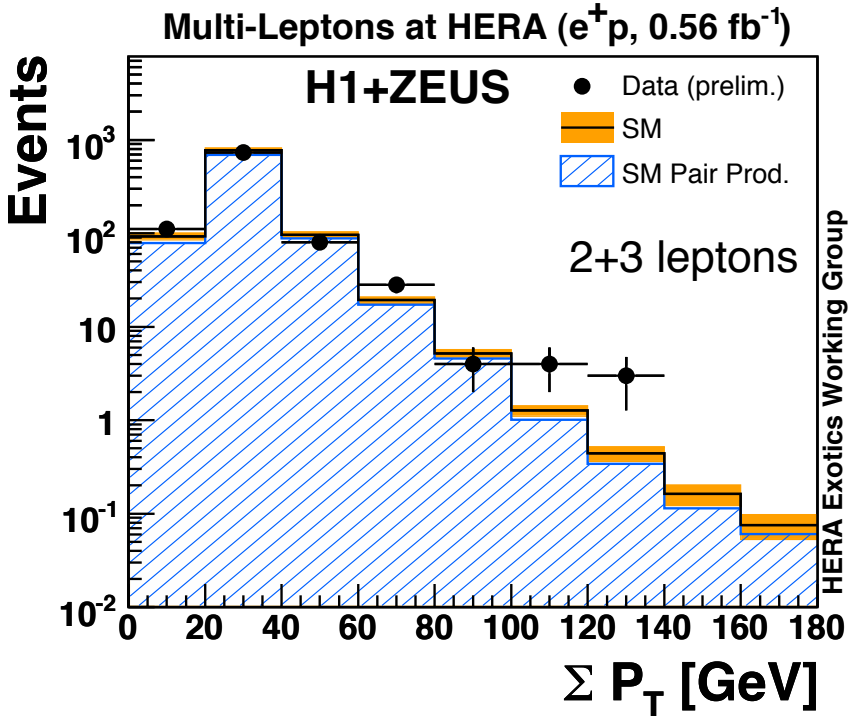
All the high-mass events are seen in e^+p collisions.

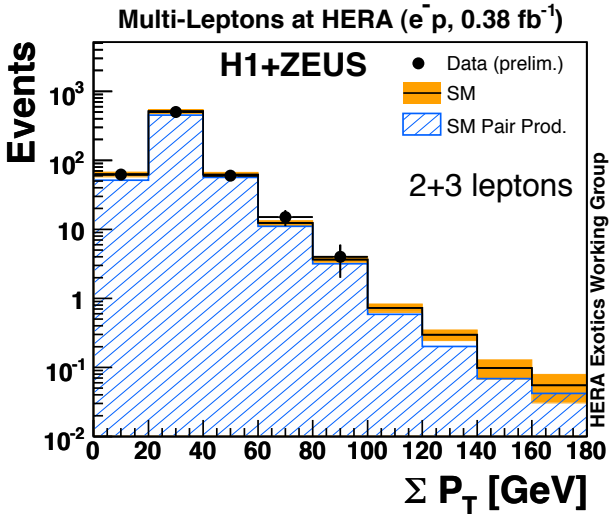
3 events come from ZEUS, 9 from H1.

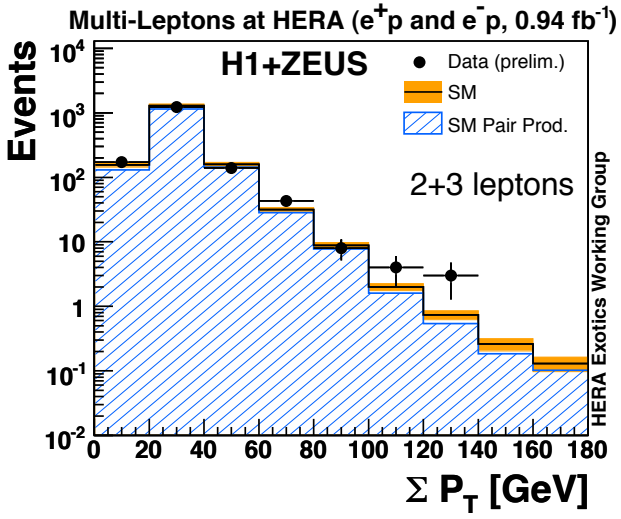
H1+ZEUS Multi-Lepton analysis HERA I+II (0.94 fb^{-1}, preliminary)

		M_{12} >100 GeV		
Selection	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
		All data (0.94 fb^{-1})		
ee	4	2.98 ± 0.28	1.69 ± 0.15	1.29 ± 0.16
$\mu\mu$	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
		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 ± 0.74	0.49 ± 0.07	< 0.03
$e\mu\mu$	0	0.14 ± 0.05	0.14 ± 0.05	< 0.01

Σp_T distributions







7 high-$\sum p_T$ events

observed in e^+p data

(significance 2.6σ)

H1+ZEUS Multi-Lepton analysis HERA I+II (0.94 fb^{-1}, preliminary)

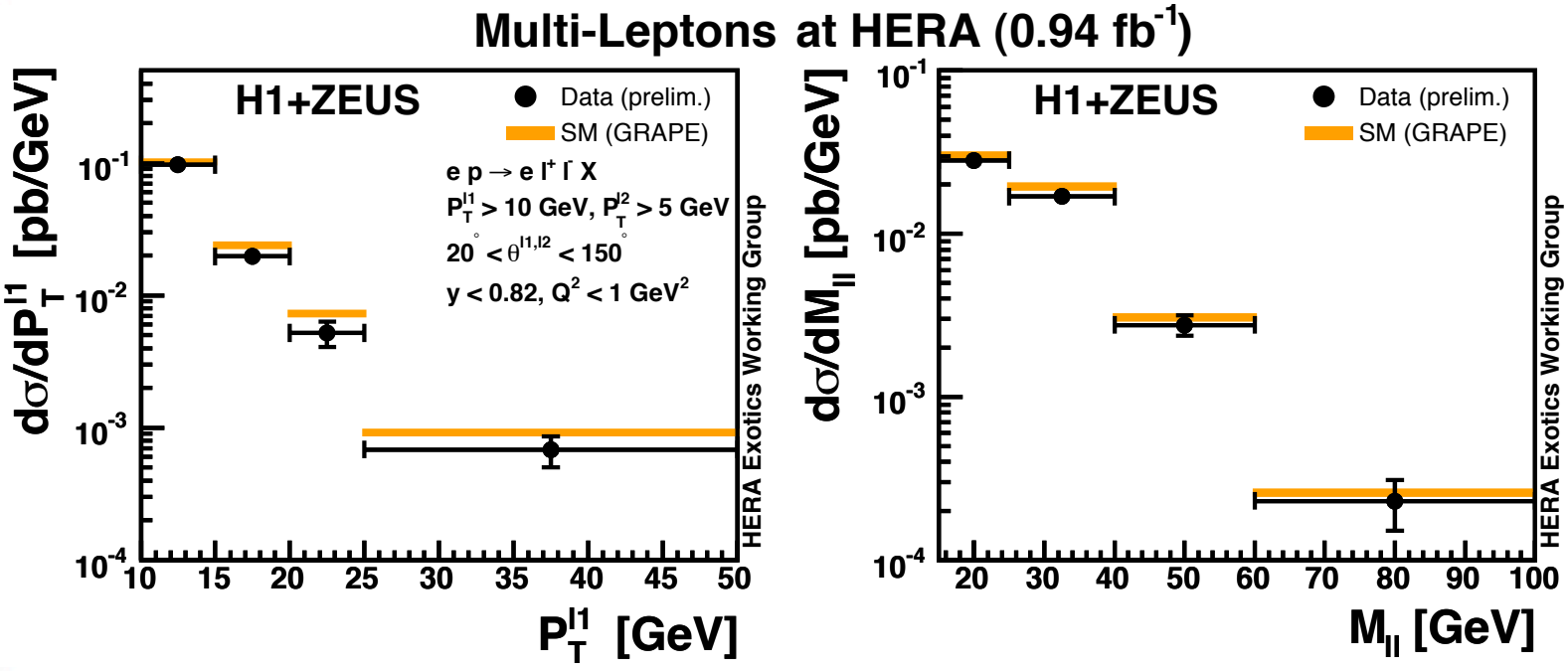
$\sum P_T$ >100 GeV				
Data sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
e^+p (0.56 fb^{-1})	7	1.94 ± 0.17	1.52 ± 0.14	0.42 ± 0.07
e^-p (0.38 fb^{-1})	0	1.19 ± 0.12	0.90 ± 0.10	0.29 ± 0.05
All (0.94 fb^{-1})	7	3.13 ± 0.26	2.42 ± 0.21	0.71 ± 0.10

Measurement of the cross sections

- In order to select a sample enriched in photoproduction events, the cut $E\text{-}p_z < 45\ GeV$ 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 $\gamma\gamma \rightarrow ll$ process in the kinematic region:
  - leptons must be isolated ($\Delta r > 0.5$ in the pseudorapidity-azimuth plane)
  - $Q^2 < 1\ GeV^2$, $y < 0.82$ (photoproduction regime)
  - $p_T^{l1,l2} > 10{,}5\ GeV$
  - $20^o < \theta < 150^o$

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.



Conclusions

- Multilepton production has been studied at HERA, looking for possible deviations from the SM in the high mass and high-$\sum p_T$ 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-$\sum p_T$ 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.

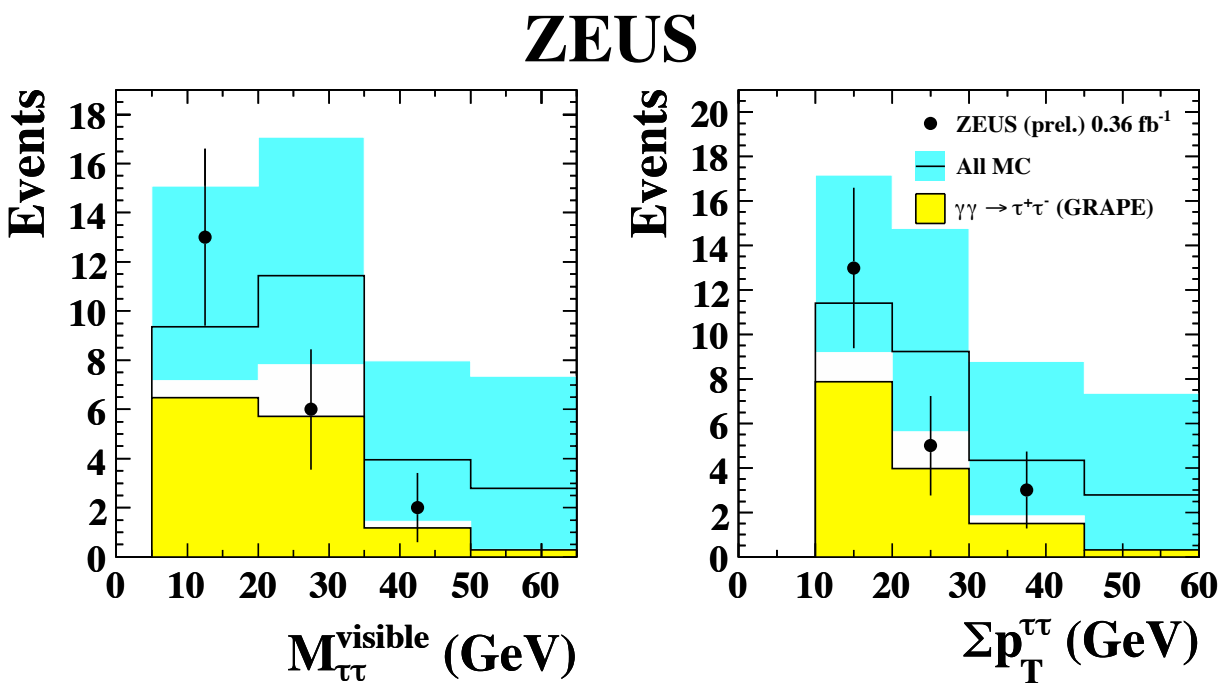
Backup

Di-τ

ZEUS ditau events HERA II data (L=0.36 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%)

Analysis performed on the HERAII data.
Topologies with jets and electrons investigated.



Masses for the different topologies