Multi-lepton Events at HERA

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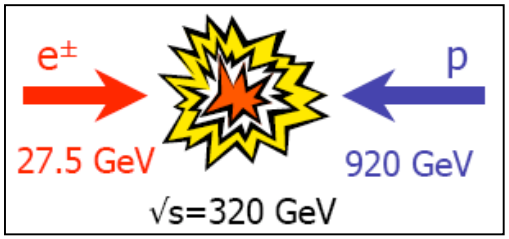
on behalf of the H1 and ZEUS Collaborations

Publications:

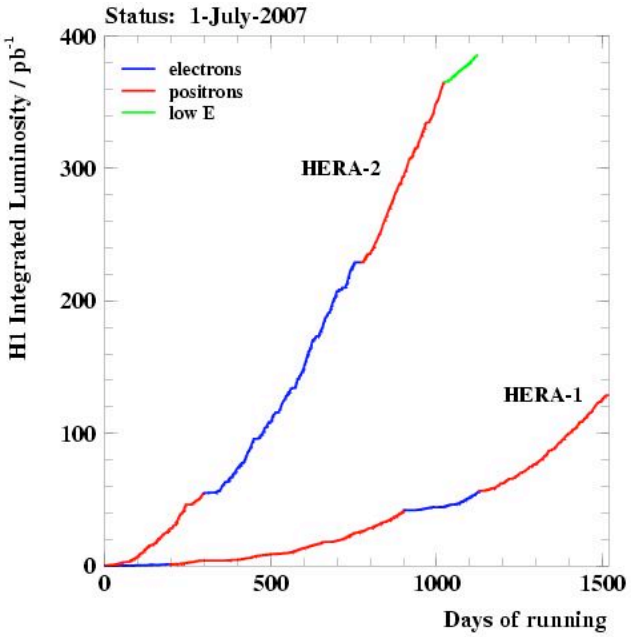
H1: Phys. Lett. B 668 (2008) 268
ZEUS: Phys. Lett. B 680 (2009) 013

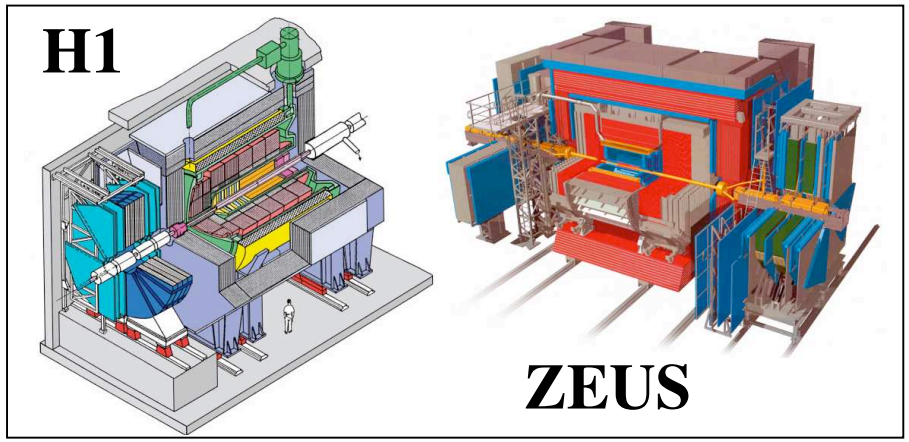
H1+ZEUS: JHEP 0910 (2009) 013

The H1 and ZEUS Experiments at HERA



Data taking
1994 - 2007





Two multi-purpose experiments located at the ep interaction points

- Large increase in data per experiment from HERA II (x3)
- Large increase (x12) in data taken from e^-p collisions; HERA I was mostly e^+p data

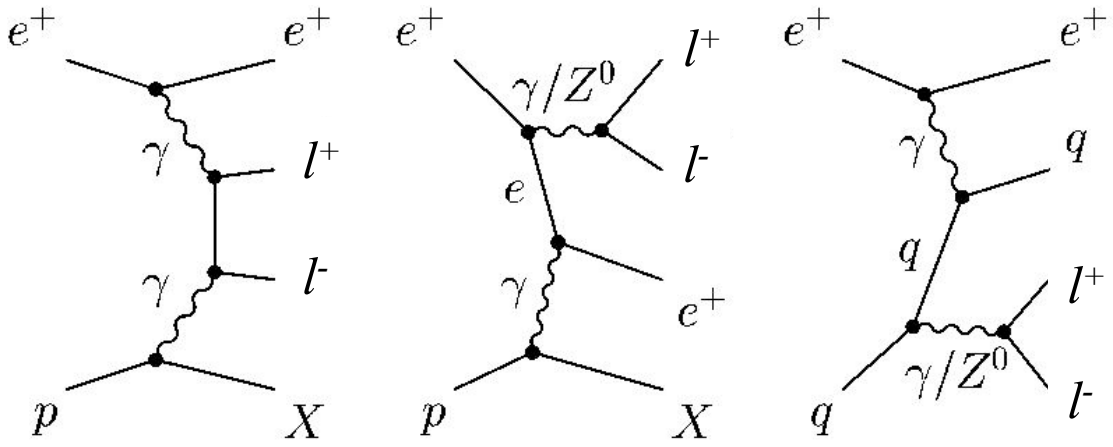
Final combined HERA dataset ~ 1 fb^{-1}

Outline

- Events in which two or more isolated electrons or muons with high transverse momentum are found to give a clean experimental signature
  - Look for signs of physics beyond the Standard Model
- The final results from the individual H1 and ZEUS analyses will be presented
- The combination of the data of the two experiments in a common phase space allows a more stringent test of the SM
  - Final results now also available on the full HERA data
- Di-tau production with decay to leptons are included in the analysis; hadronic tau decays removed by selection

Multi-Lepton Events at HERA

- The main SM process in ep interactions with multi-leptons in the final state is the $\gamma\gamma$ process:



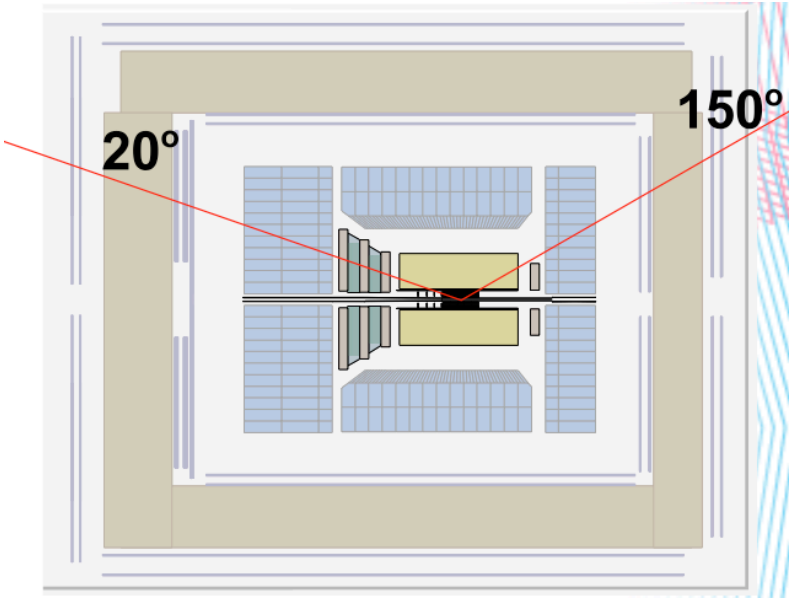
- This QED process, precise SM prediction, modelled by GRAPE

- Cross section low at high mass, P_T: look for signs of new phenomena
  - Examine using the mass of the two highest P_T leptons, M_{12} and the sum of the transverse momentum of all leptons, ΣP_T

- Main SM background: NC-DIS, QED Compton for multi-electron events; very low background for multi-muon events

Multi-Lepton Event Selection

- Electrons
  - Identified with E >10 GeV in the polar angle region $5^O < \theta < 175^O$
  - In the backward region ($\theta > 150^O$) allow lower energy E > 5 GeV
  - Also allow E > 5 GeV up to 20^O *(H1 only)*
  - Isolated with respect to other calorimeter deposits and tracks in the event



- Muons
  - Identified with P_T >2 GeV in the polar angle region $20^O < \theta < 160^O$
  - Isolated from other tracks in the event

- At least 2 leptons are required in the region $20^O < \theta < 150^O$ and to have P_T > 10, 5 GeV

- Depending on the number and flavour of the leptons, the events are classified into exclusive samples: ee, eee, eμ, eμμ, μμ..

Results from the H1 Analysis

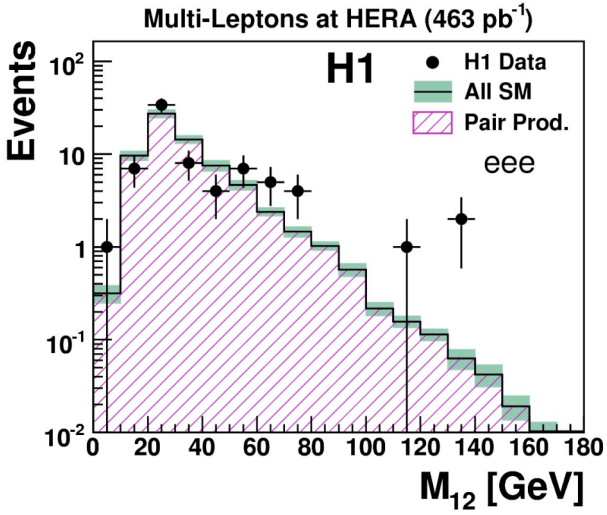
Multi-Leptons at HERA (463 pb^{-1})

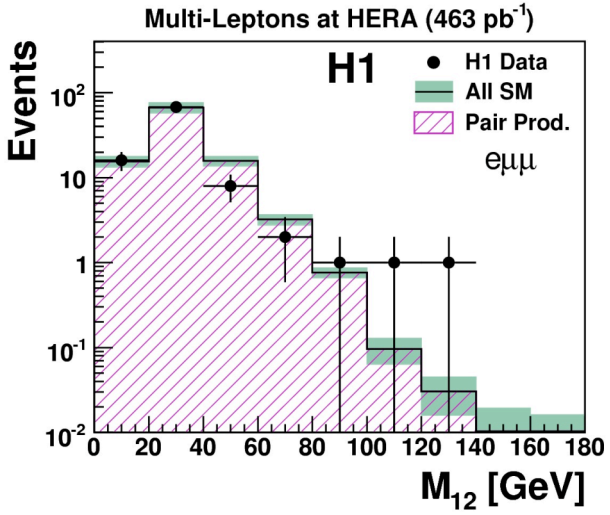
Selection	Data	SM	Pair Production (GRAPE)	NC DIS + Compton
ee	368	390 ± 46	332 ± 26	58 ± 30
$\mu\mu$	201	211 ± 32	211 ± 32	< 0.005
$e\mu$	132	128 ± 9	118 ± 8	10.0 ± 2.5
eee	73	70 ± 7	69.8 ± 7.0	0.2 ± 0.1
$e\mu\mu$	97	102 ± 14	102 ± 14	< 0.005
$ee\mu$	4	1.43 ± 0.26	1.18 ± 0.20	0.25 ± 0.14
$eeee$	1	0.33 ± 0.07	0.33 ± 0.07	< 0.005
$(\gamma\gamma)_e$	146	138 ± 12	135 ± 11	3.0 ± 1.0
$(\gamma\gamma)_\mu$	163	162 ± 24	162 ± 24	< 0.005

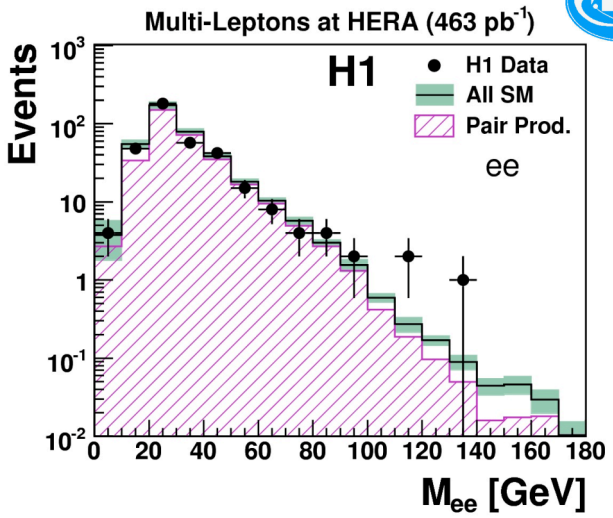
- Good overall description of the data by the SM is observed

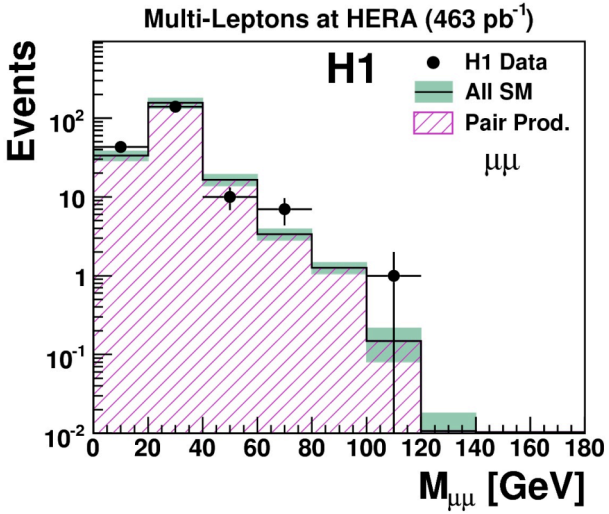
- The $\gamma\gamma$ selections are sub-samples of the ee and $\mu\mu$ samples, and are used to measure the lepton pair production cross section

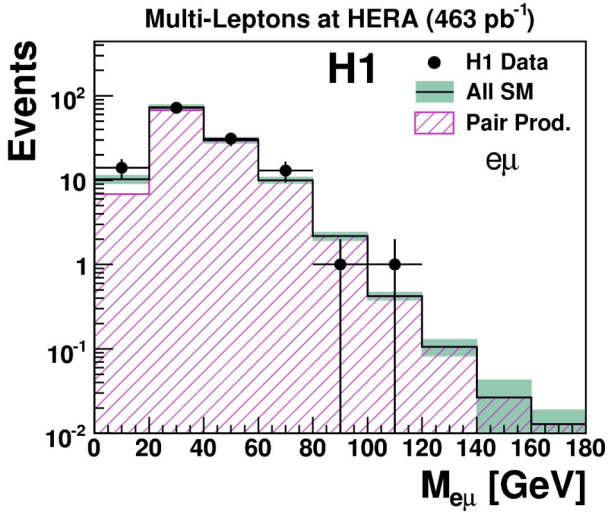
Mass Distributions from the H1 Analysis







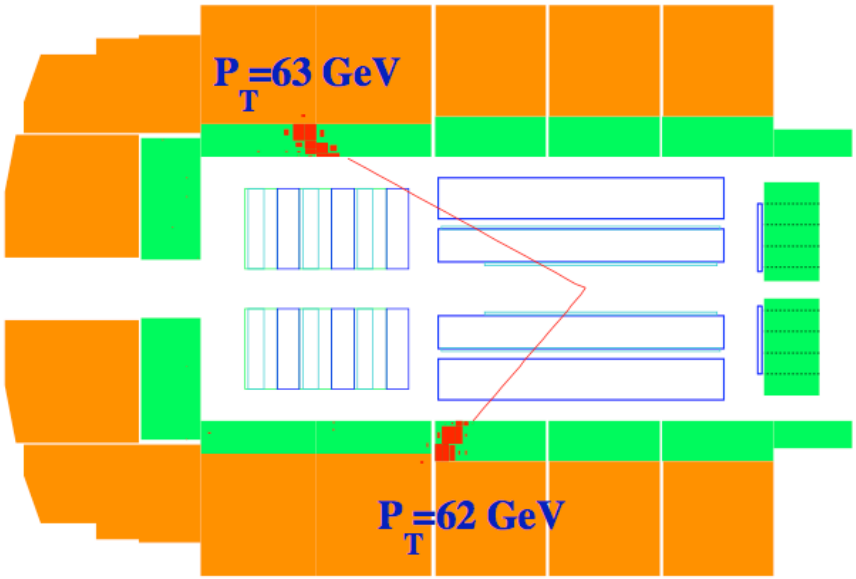


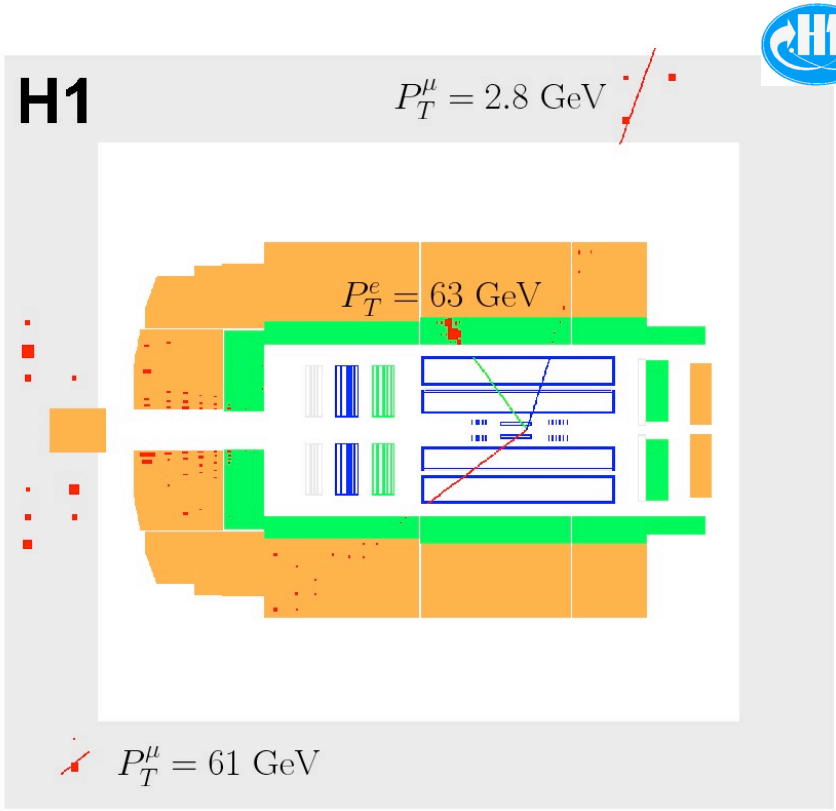


Good overall agreement observed with the SM

High mass events seen in ee, eee and eμμ topologies

Two Events Selected by the H1 Analysis





ee event, M_{12} = 130 GeV

eμμ event, M_{12} = 127 GeV, from the electron and the highest P_T muon

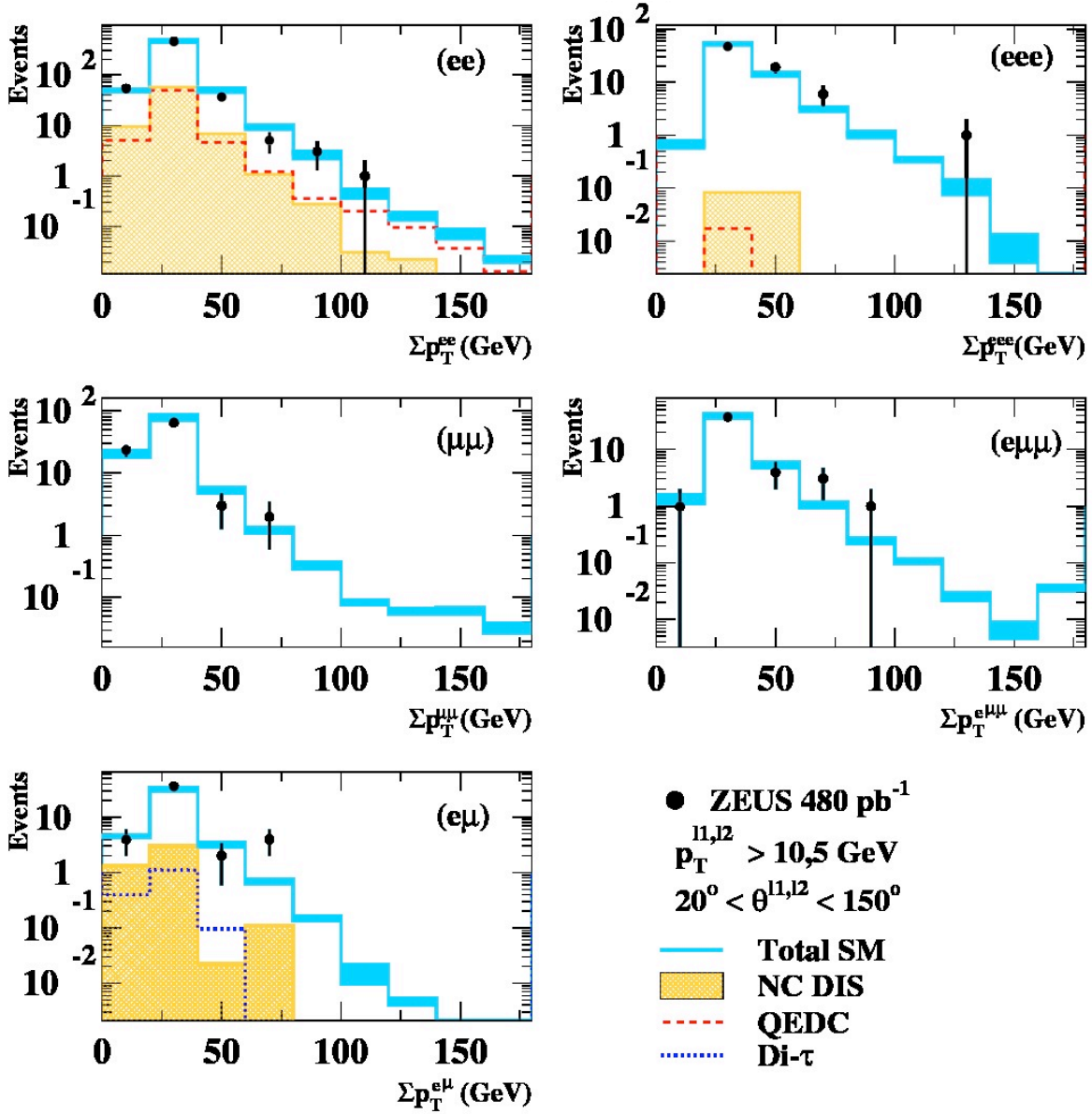
Results from the ZEUS Analysis

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

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	–

- As in the H1 analysis, a good overall description of the data by the SM is observed
  - Again, can now look for possible deviations in the high mass and high ΣP_T regions

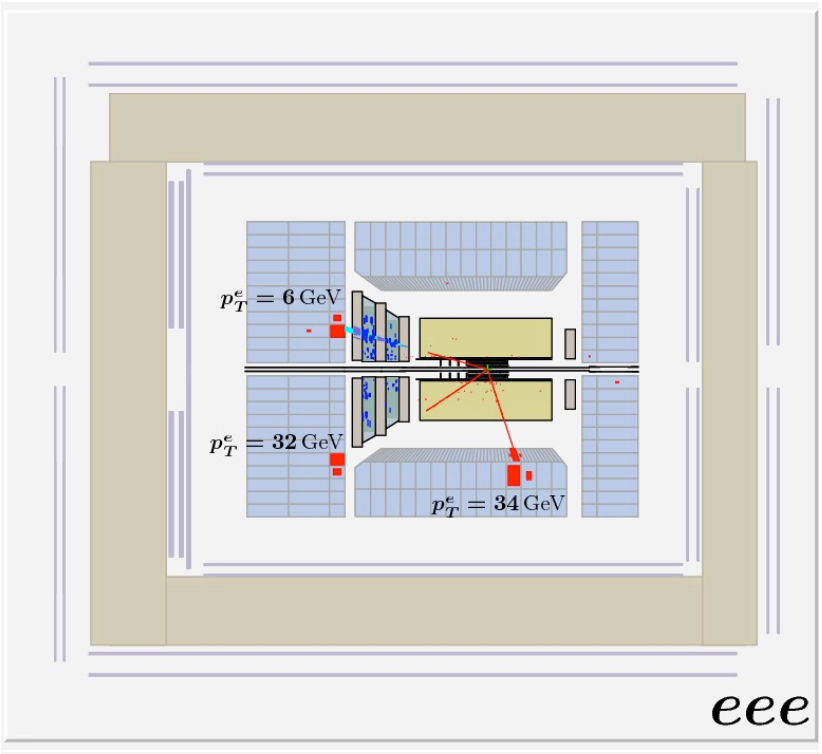
ΣP_T Distributions from the ZEUS Analysis

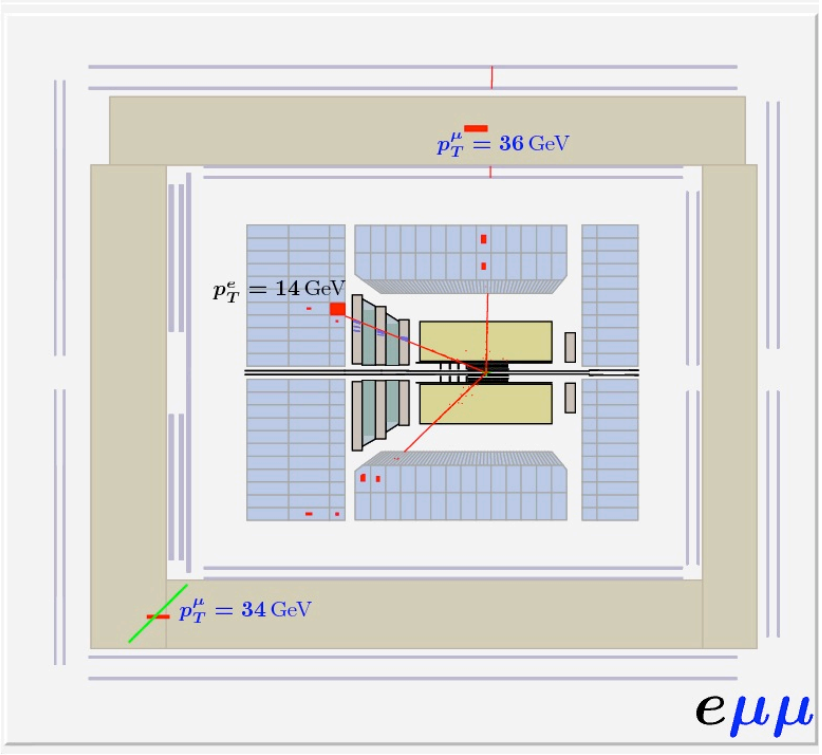


Overall agreement observed with the SM

Two events observed with large ΣP_T

Two Events Selected by the ZEUS Analysis

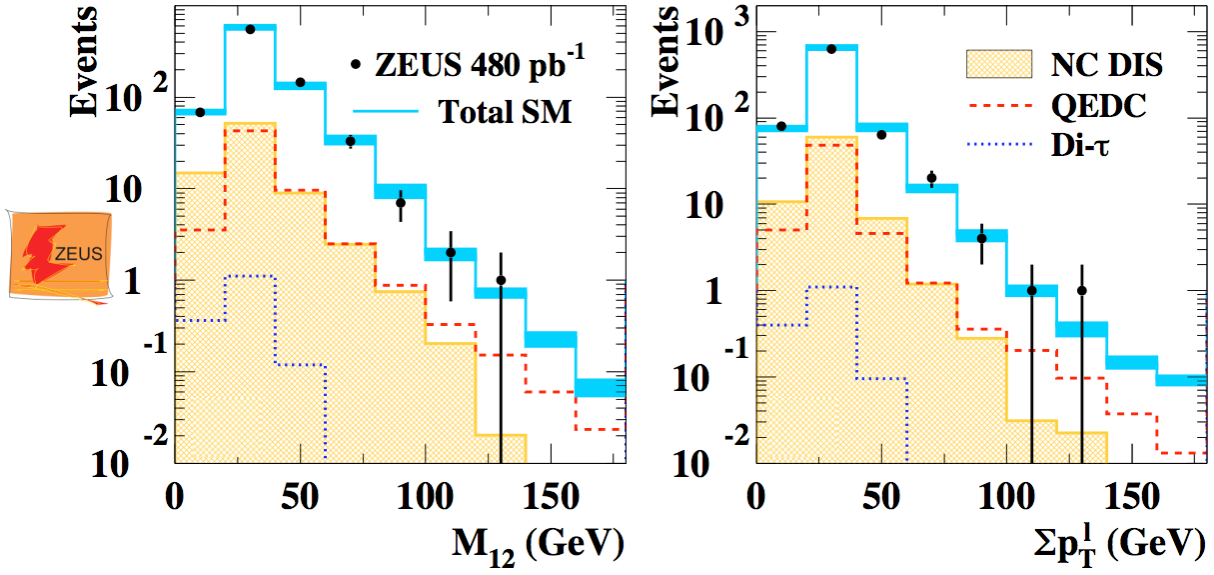




eee event, M_{12} = 113 GeV

Highest mass event with muons from ZEUS analysis (eμμ), M_{12} = 77.5 GeV

Combination of All Topologies



Good agreement between data and SM

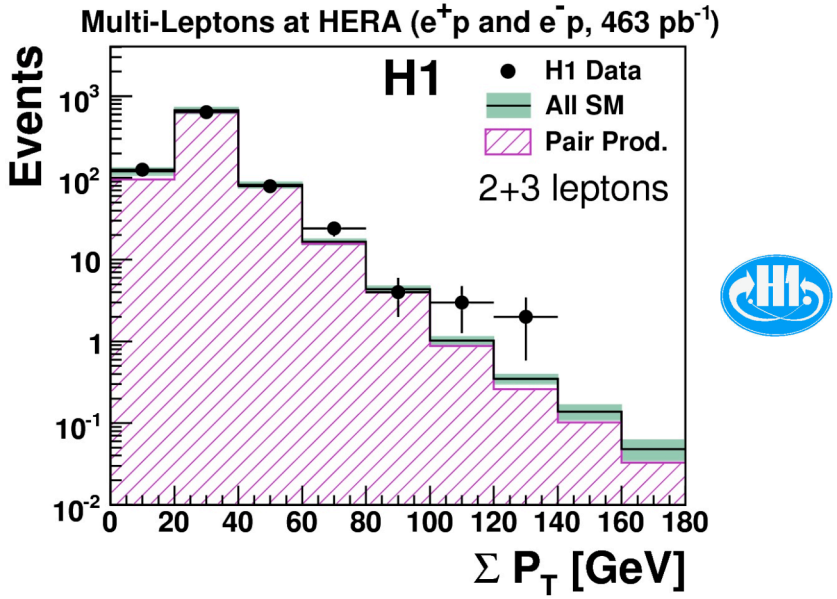
Some events at high mass and large ΣP_T

For ΣP_T > 100 GeV

ZEUS has 2 events in the data

H1 has 5 events in the data

Let's combine the data..

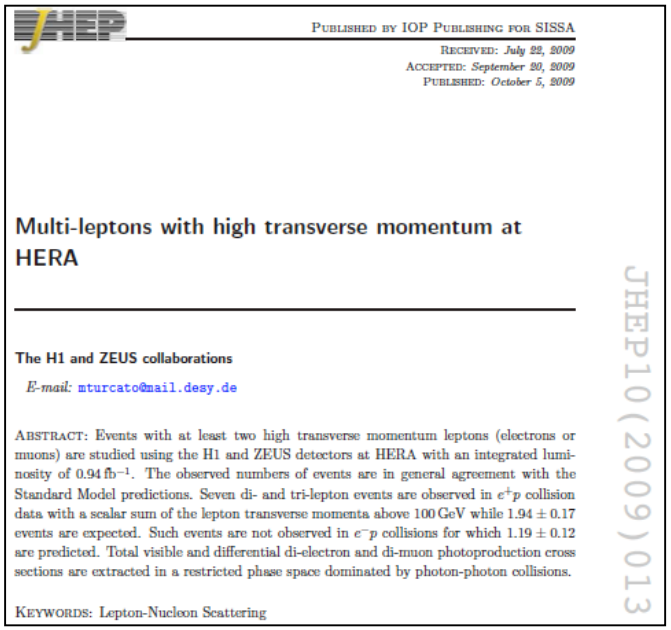


A Combined H1 and ZEUS Analysis

- The H1 and ZEUS analyses are now done in an identical way apart from the lower electron energy threshold in the forward region ($5^O < \theta < 20^O$) in the H1 analysis
  - This cut is increased to E > 10 GeV for the combination

- The measurements are combined assuming that all systematic uncertainties except that from the theory are fully uncorrelated
  - The theory uncertainty is fully correlated, both experiments using the same model

- The H1+ZEUS multi-lepton analysis is the first combined HERA publication!



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Multi-leptons with high transverse momentum at HERA

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Abstract: Events with at least two high transverse momentum leptons (electrons or muons) are studied using the H1 and ZEUS detectors at HERA with an integrated luminosity of 0.94 fb^{-1}. The observed numbers of events are in general agreement with the Standard Model predictions. Seven di- and tri-lepton events are observed in e^+p collision data with a scalar sum of the lepton transverse momenta above 100 GeV while 1.94 ± 0.17 events are expected. Such events are not observed in e^-p collisions for which 1.19 ± 0.12 are predicted. Total visible and differential di-electron and di-muon photoproduction cross sections are extracted in a restricted phase space dominated by photon-photon collisions.

Keywords: Lepton-Nucleon Scattering

JHEP10(2009)013

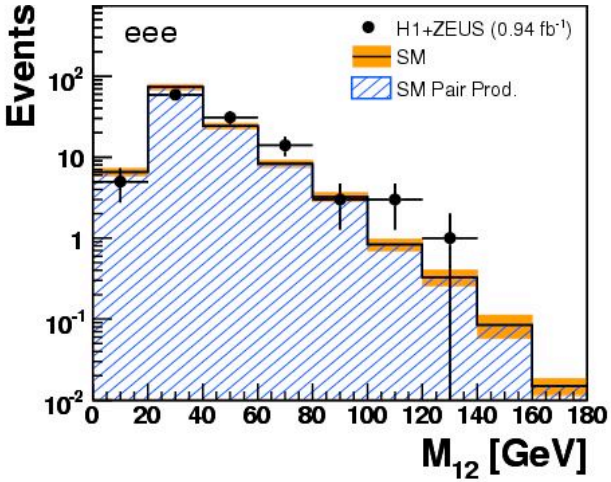
H1+ZEUS Topologies Table

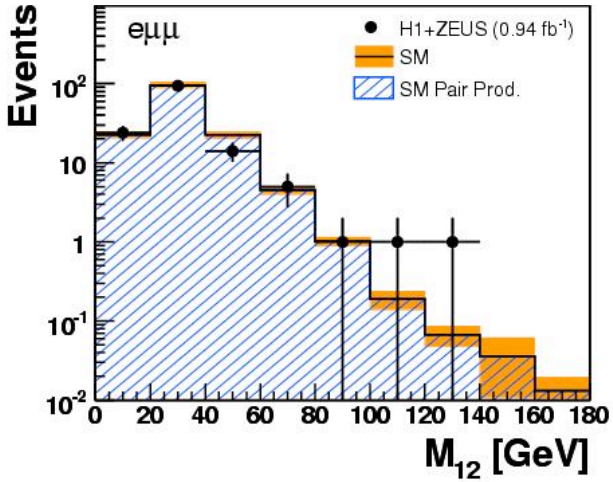
Multi-Leptons at HERA ($0.94\ \mathrm{fb}^{-1}$)

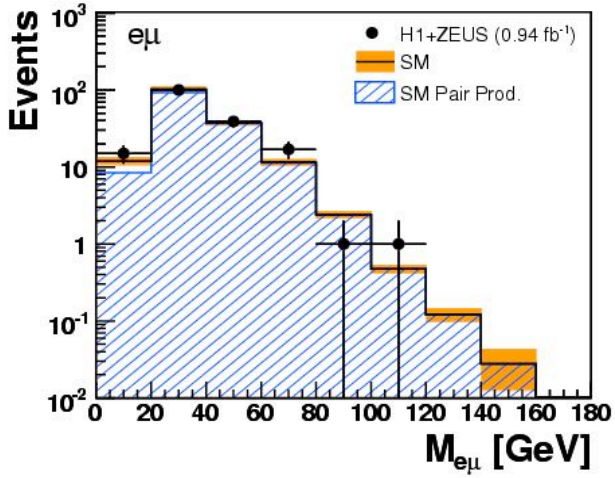
Sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
ee	873	895 ± 57	724 ± 41	171 ± 28
$\mu\mu$	298	320 ± 36	320 ± 36	< 0.5
$e\mu$	173	167 ± 10	152 ± 9	15 ± 3
eee	116	119 ± 7	117 ± 6	< 4
$e\mu\mu$	140	147 ± 15	147 ± 15	< 0.5
$(\gamma\gamma)_e$	284	293 ± 18	289 ± 18	4 ± 1
$(\gamma\gamma)_\mu$	235	247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

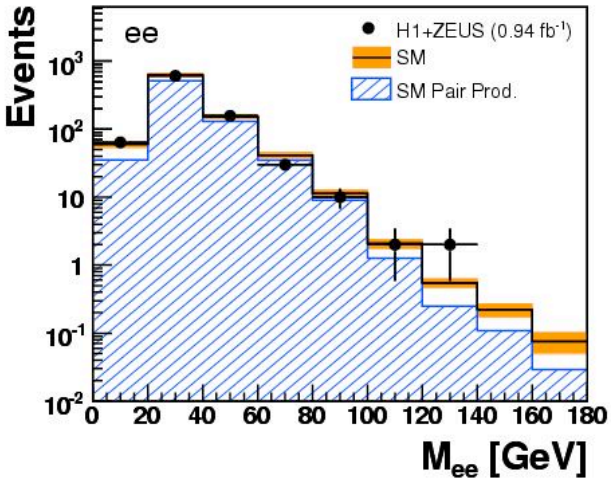
- Overall good agreement seen with the SM prediction
- Looking at the high mass and high P_T regions, a few interesting events show up in the data

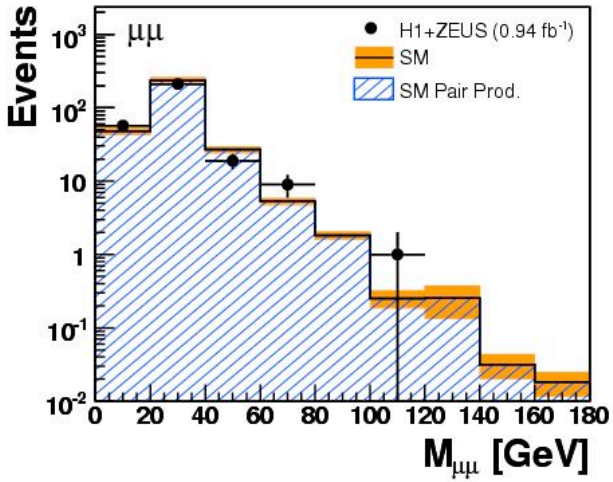
H1+ZEUS Mass Distributions











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

H1+ZEUS Multi-lepton Events at High Mass

All high mass events seen in the e^+p data

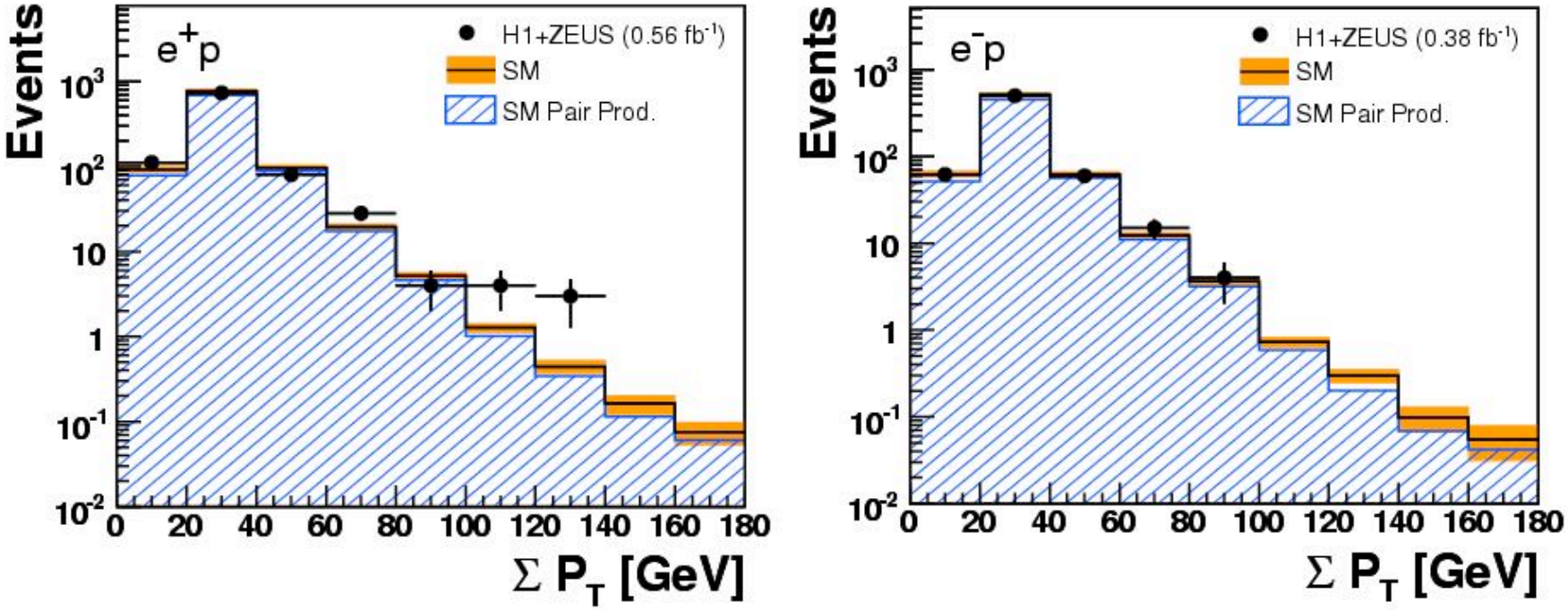
9 from H1
3 from ZEUS

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 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

H1+ZEUS Multi-lepton Events at High ΣP_T



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

$\sum P_T$ >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

7 events observed, all in the e^+p data with ΣP_T > 100 GeV, where the significance of excess of SM expectation is 2.6σ

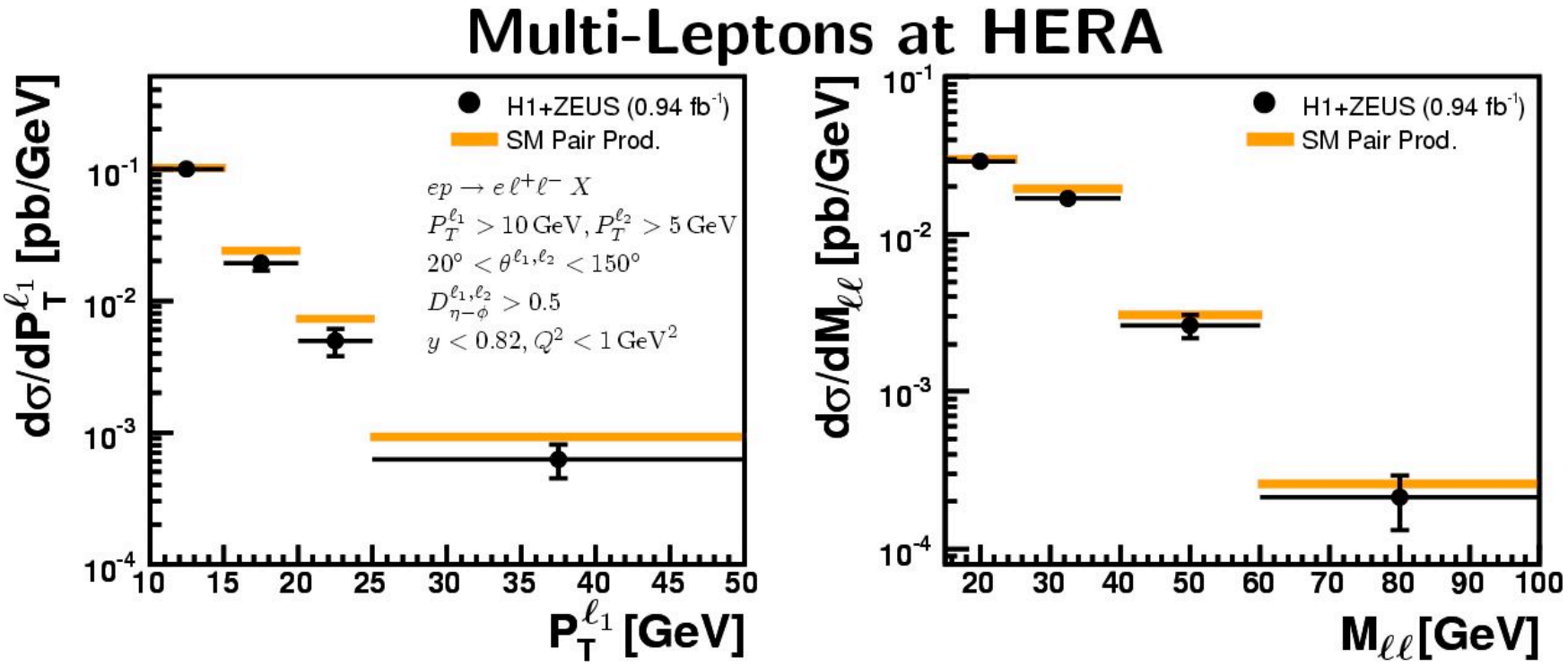
Measurement of the $\gamma\gamma \rightarrow l^+l^-$ Cross Section

- In order to select lepton pair events in photoproduction, the requirement $E - P_z < 45$ GeV is introduced, forming sub-samples of the ee and $\mu\mu$ samples
  - This ensures a sample which is only populated with two leptons of the same flavour in the final state
  - The contribution from $\tau^+\tau^-$ events is found to be negligible

- Cross sections evaluated for the two photon process in the kinematic region
  - Photoproduction regime: $Q^2 < 1$ GeV^2, $y < 0.82$
  - High transverse momentum: $P_T^{1,2} > 10, 5$ GeV
  - In the main body of the detectors: $20^O < \theta < 150^O$
  - Leptons are isolated ($\Delta r > 0.5$ in the pseudorapidity-azimuth plane)

- Weighted average done of the electron and muon channels to form the $\gamma\gamma \rightarrow l^+l^-$ cross section

Measurement of the $\gamma\gamma \to l^+l^-$ Cross Section



- Differential cross sections measured as a function of the P_T of the leading lepton and the invariant mass of the lepton pair

- Total visible cross section measured 0.66 ± 0.03 (stat.) ± 0.03 (sys.) pb in good agreement with the SM prediction of 0.69 ± 0.02 pb from GRAPE

Conclusions

- Multi-lepton production has been studied at HERA
  - Looking for possible deviations from the SM in the high mass and high ΣP_T regions
- All event topologies containing combinations of electrons and muons have been investigated
  - A good overall agreement with the SM is observed
- A combined analysis is performed in a common phase space to achieve greater sensitivity
  - Some events observed at high ΣP_T and high mass by both experiments and only in the e^+p data
- Cross sections for the $\gamma\gamma \to l^+l^-$ process have been measured using the complete HERA data