Search for new physics at HERA using combined H1 and ZEUS data

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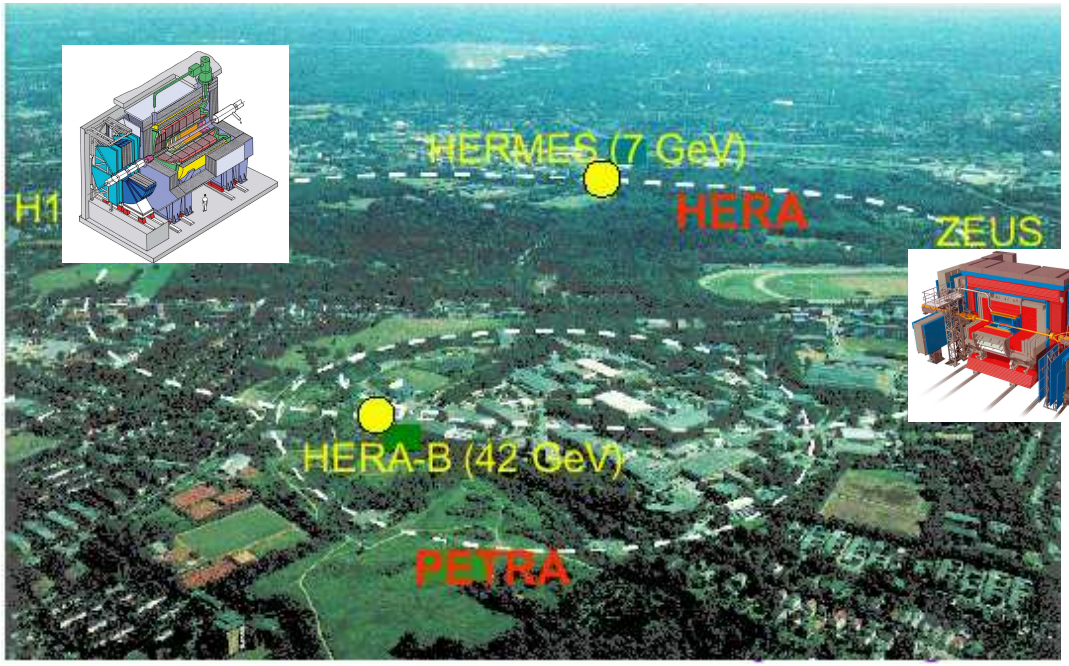
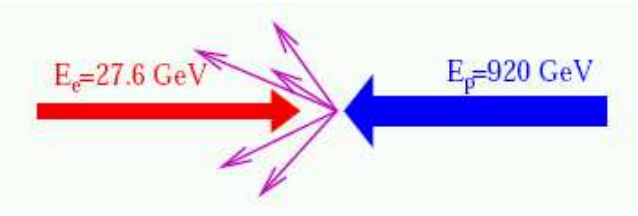
- HERA Collider and Experiments
- Model Independent Search
- Multi-Lepton Topologies
- Events with Isolated Leptons and Missing Transverse Momentum
- Summary

The HERA Collider





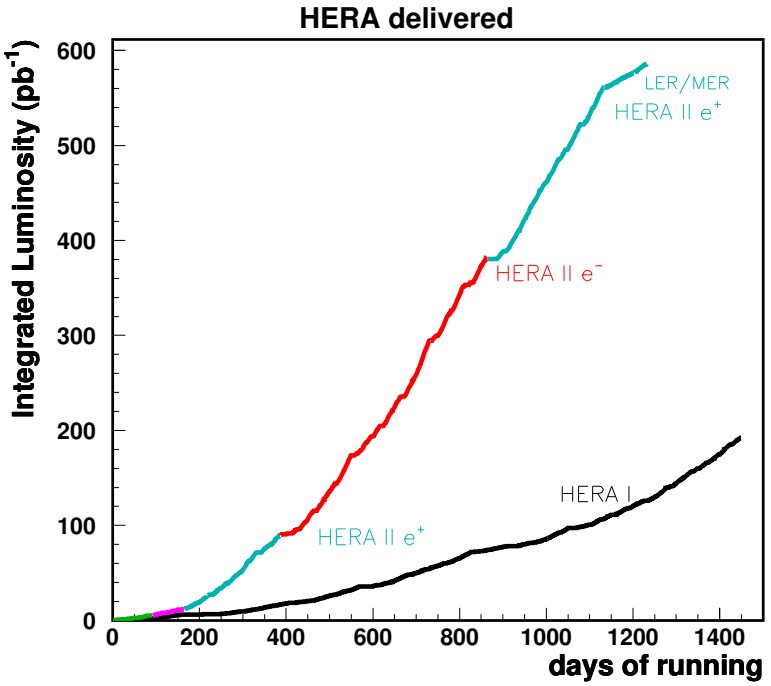
- 1998 E_p upgrade: $820 \Rightarrow 920$ GeV
  ($\sqrt{s}$: $301 \Rightarrow 319$ GeV)
- 2001 HERA-2 upgrade: $\mathcal{L} \times 3$, Polarised e^+/e^-

HERA-1 (1993-2000) $\simeq 120$ pb^{-1}

HERA-2 (2003-2007) $\simeq 380$ pb^{-1}

Final Data samples

H1+ZEUS: 2×0.5 fb^{-1}



H1 + ZEUS Combination

- **Motivation**
  - ▷ HERA data will remain unique for a long time ⇒ Fully exploit their potential ($1\text{fb}^{-1} \Rightarrow$ sensitivity to rare processes, $\sigma \leq 0.1$ pb)

- **Benefits**
  - ▷ statistically limited samples: gain in statistical significance (e.g. searches)
  - ▷ large statistics samples: also further improve systematics by cross calibration of the experiments (e.g. F_2 measurement)

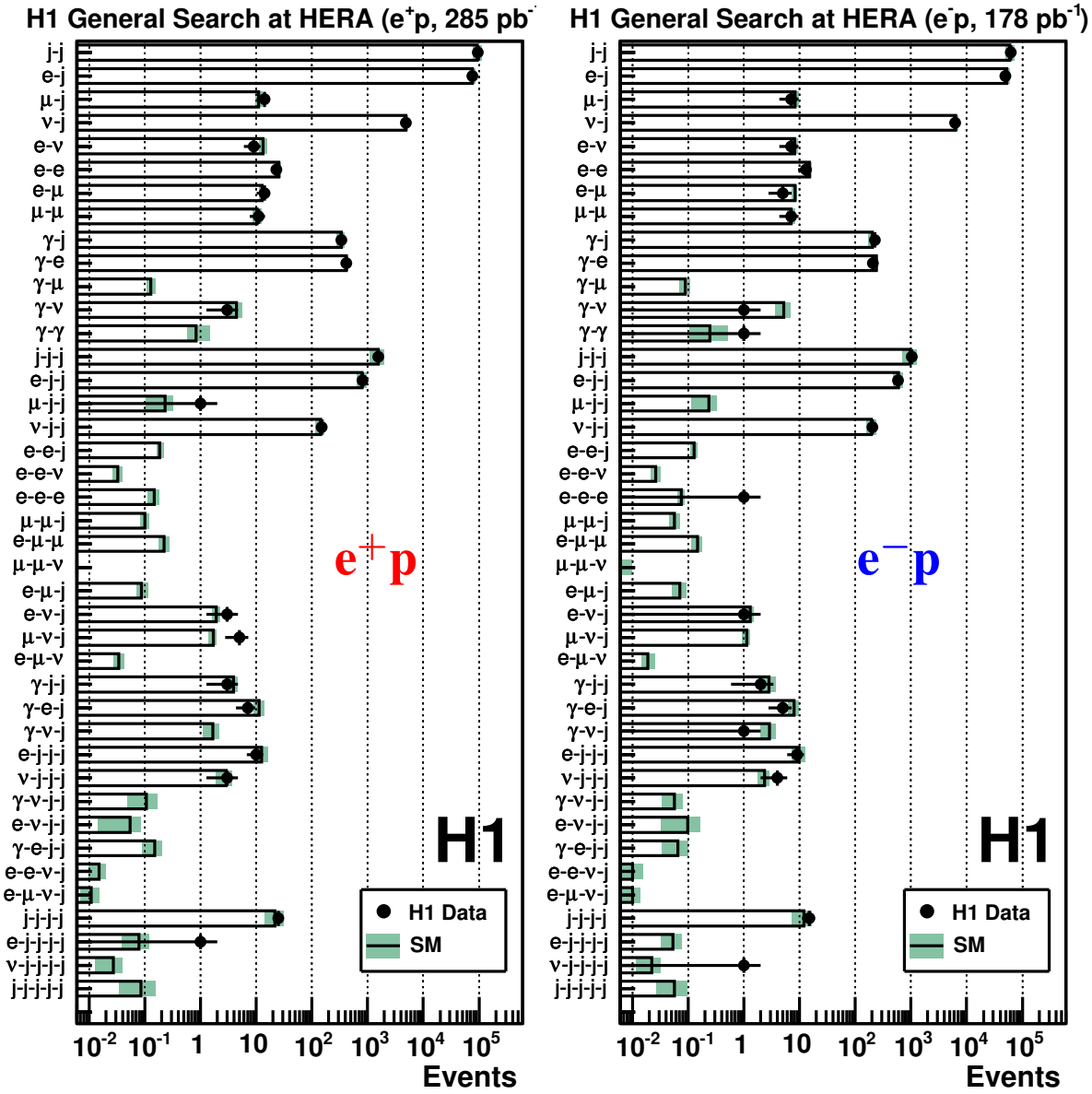
- **Strategy** (for this combination)
  - ▷ perform individual analyses optimally using detector capabilities
  - ▷ determine common phase space, unify cuts against bgr, binning
  - ▷ combine data (and SM predictions) bin by bin ⇒ look for possible deviations
  - ▷ measured cross sections are determined as weighted average

The Concept of Model Independent Search

- Perform model independent generic search (data vs SM)
- Identify promising topologies
- Make dedicated detailed analysis on those topologies

General search for New Phenomena

- Identify isolated ($D(\eta\phi) > 1$) particles (objects): e, μ, γ, j, ν
- Select events, having at least two objects with high $P_T > 20$GeV in the detector acceptance ($10^o < \theta < 140^o$)
- Classify into exclusive channels containing from 2 to 5 objects
- Compare with SM predictions
  $\Rightarrow$ **good overall agreement**



H1 Coll. PL B674 (2009) 257-268

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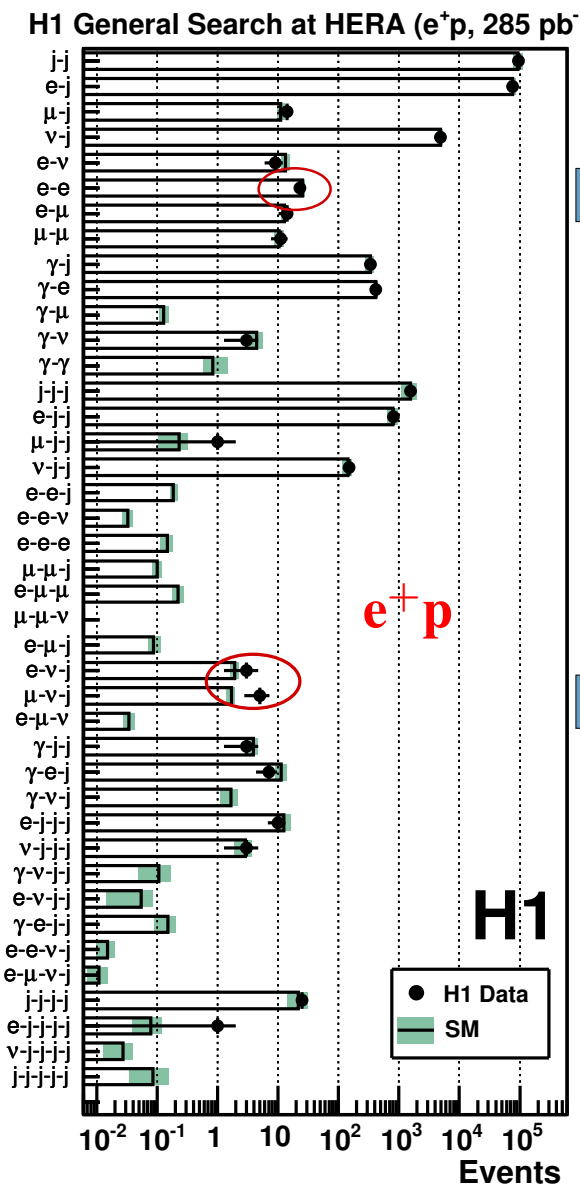
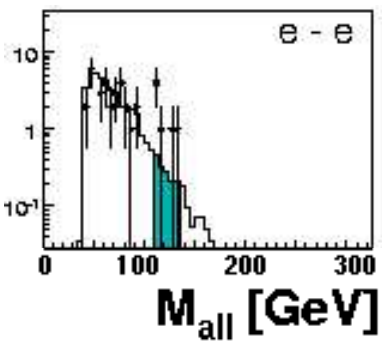
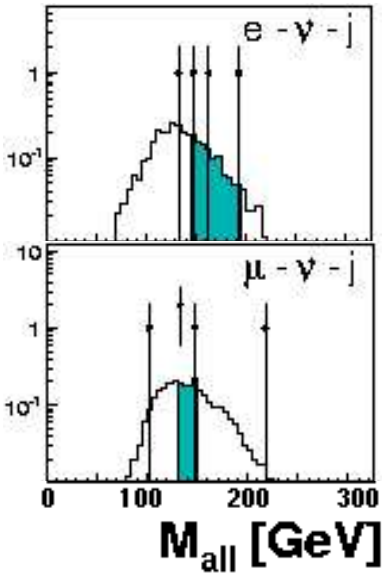
- Find interesting regions with greatest deviations from SM in kin. distributions ($M_{\rm all}$, ΣP_T)





biggest deviation in H1



most interesting channels in HERA-1

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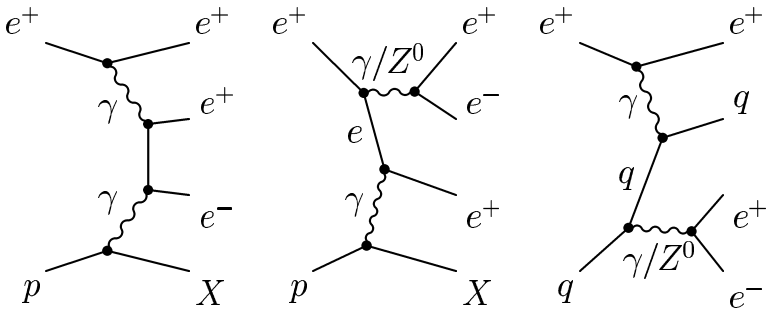
Multi-lepton Events in H1 and ZEUS

- Clean signature, precise SM prediction (mainly via $\gamma\gamma$ process) - modelled using GRAPE

  $\Rightarrow$ High sensitivity to new physics



- SM backgrounds: NC-DIS, QED Compton due to misidentification of h, γ as electrons (also small non-ep bgr from cosmics in multi-muon events)

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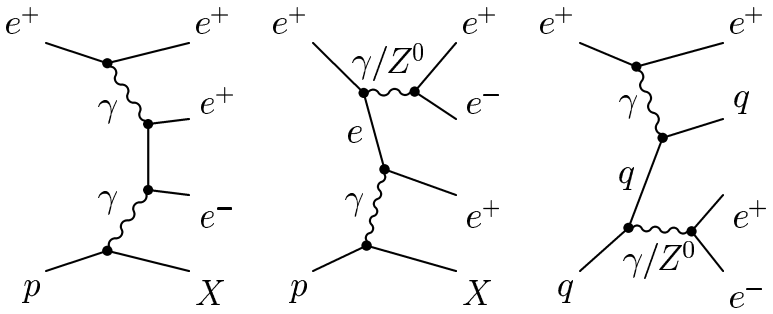

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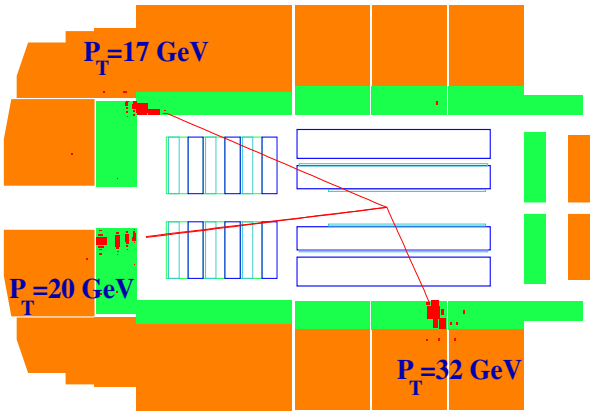


eee event in H1

- Lepton selection

  e : $E > 10$GeV (in $5^o < \theta < 175^o$), $E > 5$GeV (in $\theta > 150^o$)

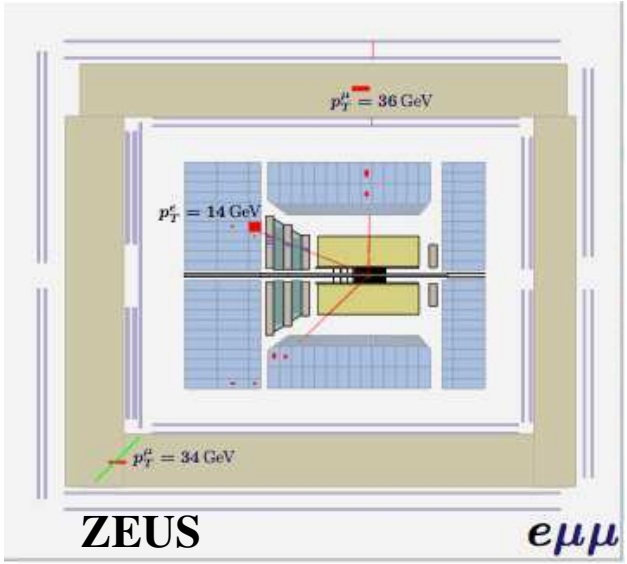
  μ : $P_T > 2$ GeV in the region $20^o < \theta < 160^o$

- Event selection

  At least two leptons must be found in the region $20^o < \theta < 150^o$ and have $P_T > 10,\ 5$ GeV

- Events are classified into mutually exclusive samples:

  $ee,\ eee,\ \mu\mu,\ e\mu,\ e\mu\mu,\ \ldots$



Multi-lepton Topologies and Measurement of $\sigma(\gamma\gamma \rightarrow l^+l^-)$

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

Overall good agreement observed with the SM prediction

use $\gamma\gamma$ selections to measure the cross sections in photoproduction regime

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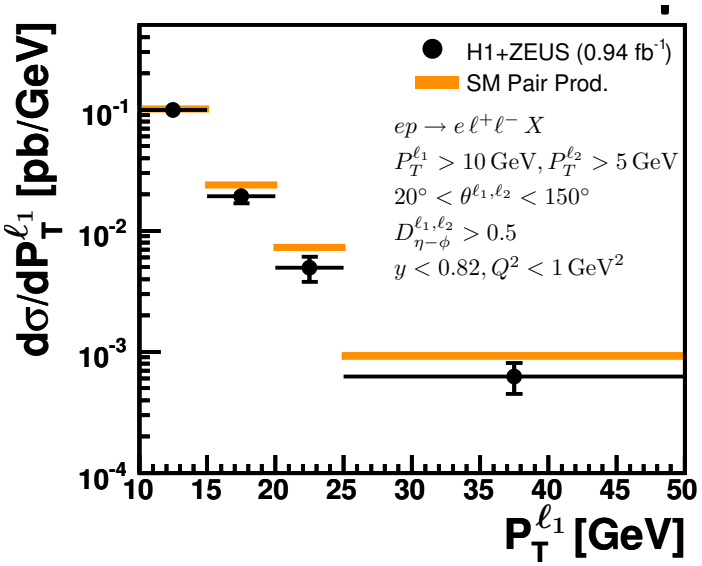
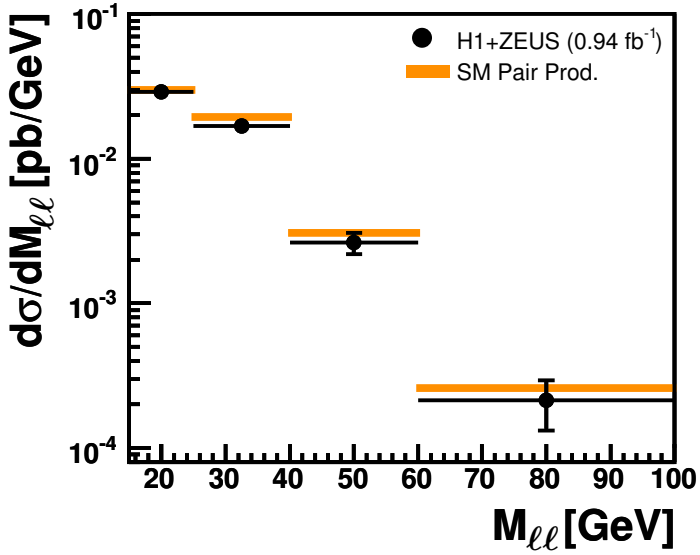




Q^2<1 GeV^2

Total visible cross section measured $0.66 \pm 0.03(\text{stat.}) \pm 0.03(\text{sys.})$ pb
in good agreement with SM prediction 0.69 ± 0.02 pb (from GRAPE MC)

Multi-lepton Events at High Mass and High ΣP_T

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

M_{12} >100 GeV

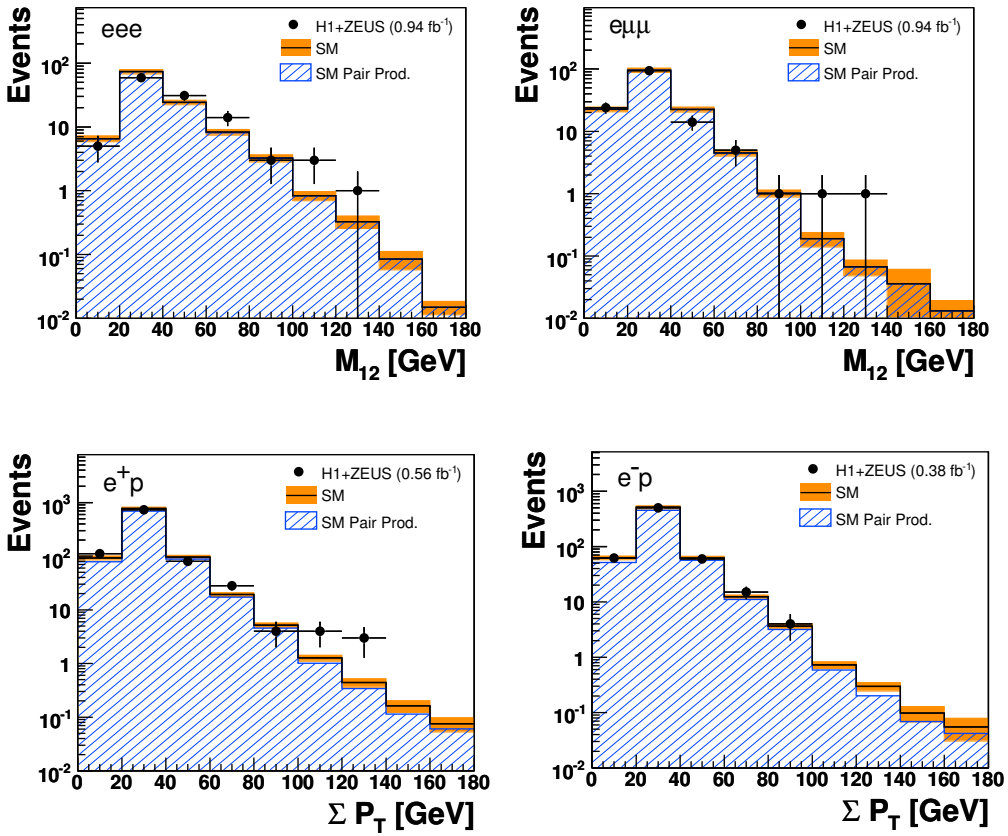
Sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
e^+p collisions (0.56 fb^{-1})				
ee	4	1.68 ± 0.18	0.94 ± 0.11	0.74 ± 0.12
$\mu\mu$	1	0.32 ± 0.08	0.32 ± 0.08	< 0.01
$e\mu$	1	0.40 ± 0.05	0.39 ± 0.05	< 0.02
eee	4	0.79 ± 0.09	0.79 ± 0.09	< 0.03
$e\mu\mu$	2	0.16 ± 0.04	0.16 ± 0.04	< 0.01
e^-p collisions (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

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

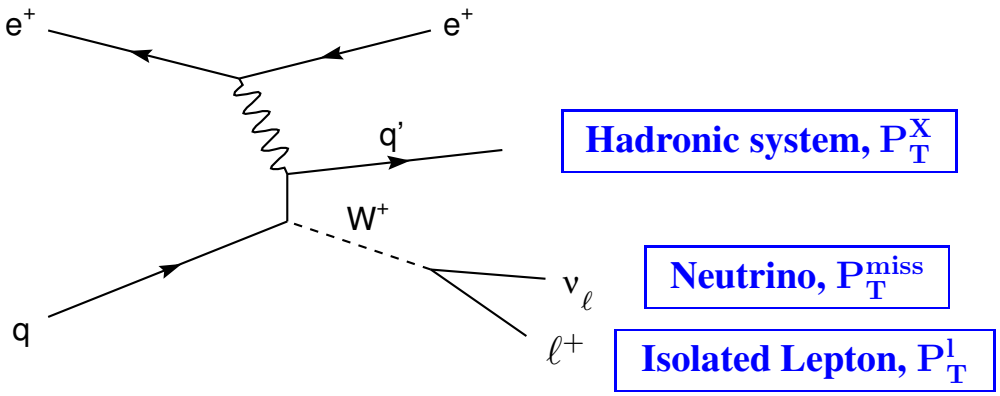
12 events in high mass region found
9 from H1 and 3 from ZEUS



Events at high mass and high ΣP_T are observed by both H1 and ZEUS, but only in e^+p data. There the excess over SM has significance of 2.6σ

Events with Isolated Leptons and Missing P_T

- The main SM process in ep interactions leading to the event topology with high P_T isolated lepton in conjunction with large missing transverse momentum in the final state is single W production:



- W's are predominantly produced in NC reactions, but CC contributes as well at smaller level
  Even smaller ($\sim 3\%$) contribution to signal topology comes also from $Z^o \rightarrow \nu\bar{\nu}$ production

- Total W production cross section at HERA, as predicted by SM, is ~ 1.3 pb
  with $\sim 11\%$ of W decaying to each lepton flavour.
  It is modelled using EPVEC MC with NLO QCD corrections, leading to 15% uncertainty

- Main SM backgrounds are NC-DIS, CC-DIS and lepton pair production processes

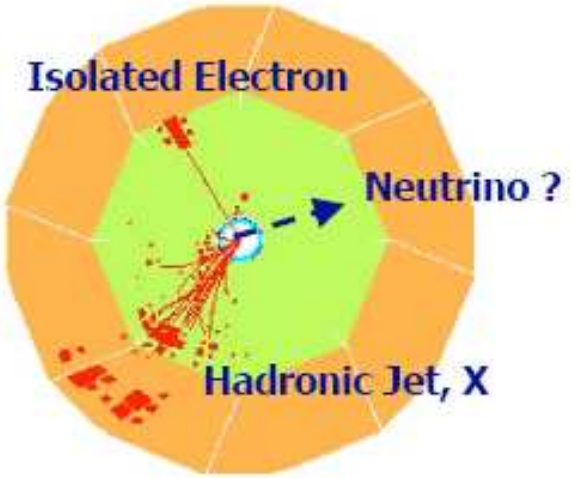
Isolated Leptons and Missing P_T: Event Selection

- Common H1+ZEUS analysis phase space is defined as events with isolated e or μ satisfying $P_T > 10$ GeV, in the range $15^o < \theta < 120^o$ and $P_T^{\text{miss}} > 12$ GeV

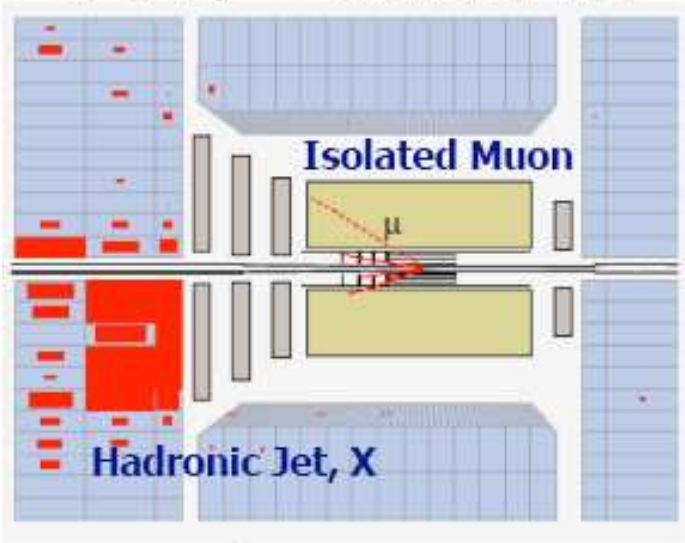
- Electron and muon channels are exclusive, and are combined in the measurement and in the W production cross section determination

- Set of cuts applied to further reduce SM background, rejecting e.g. back-to-back topologies in NC and lepton pair production processes

- The overall H1(ZEUS) efficiency to select SM $W \to e\nu$ events is $30\%(31\%)$ and to select $W \to \mu\nu$ events is $11\%(9\%)$, as calculated using EPVEC



e + P_T^{Miss} event in H1

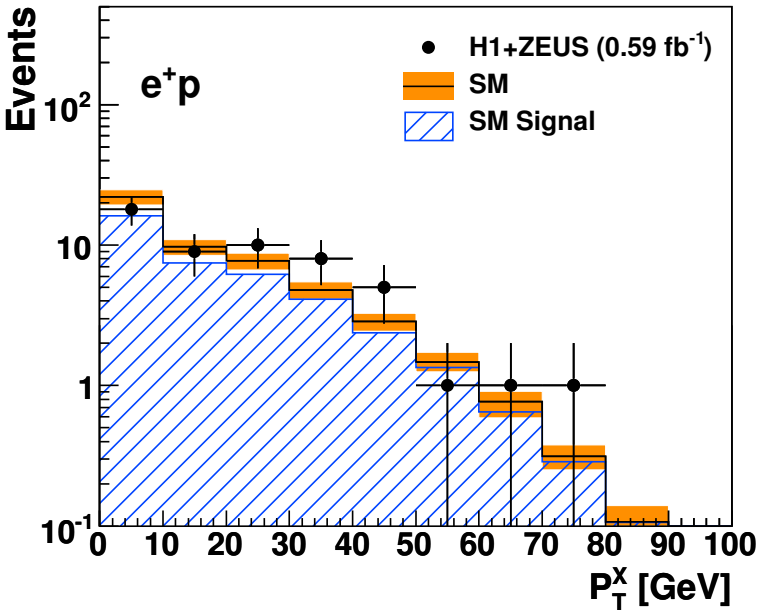


μ + P_T^{Miss} event in ZEUS

H1+ZEUS Isolated Leptons: e^+p Data

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

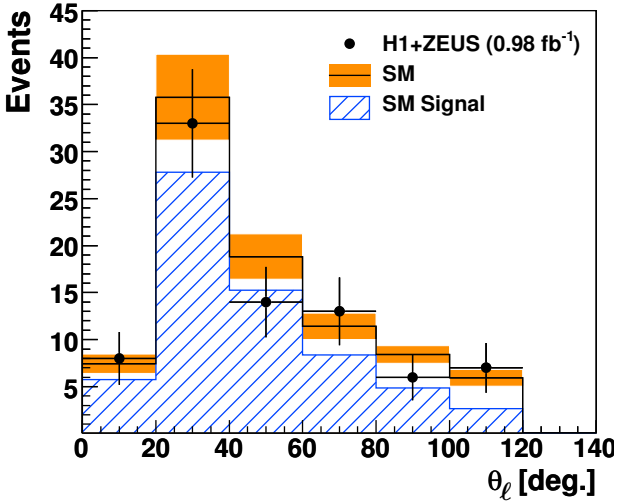
17 H1 + 6 ZEUS events at high P_T^X

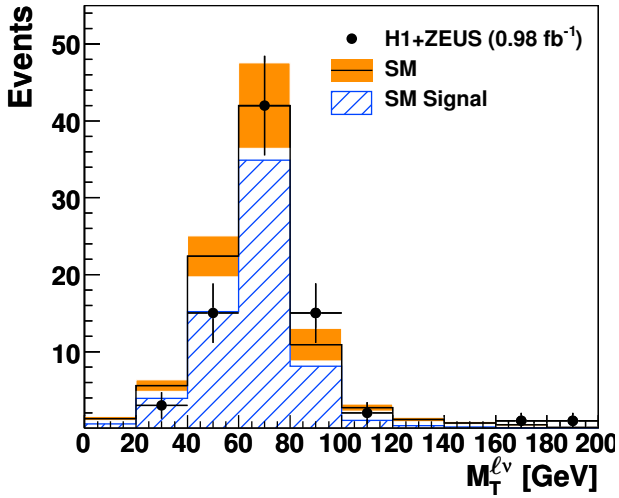


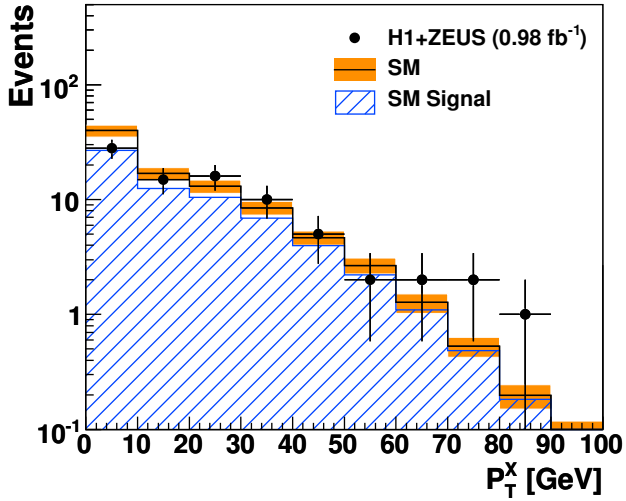
- 2.4σ excess in the data event yield at large P_T^X seen in H1 analysis is not confirmed in the ZEUS analysis

- Only about 1.9σ excess remains in the common phase space of the combined H1+ZEUS analysis

H1+ZEUS Isolated Leptons: $e^{\pm}p$ Data







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

Overall good agreement is observed with the SM expectation

Extract σ_W

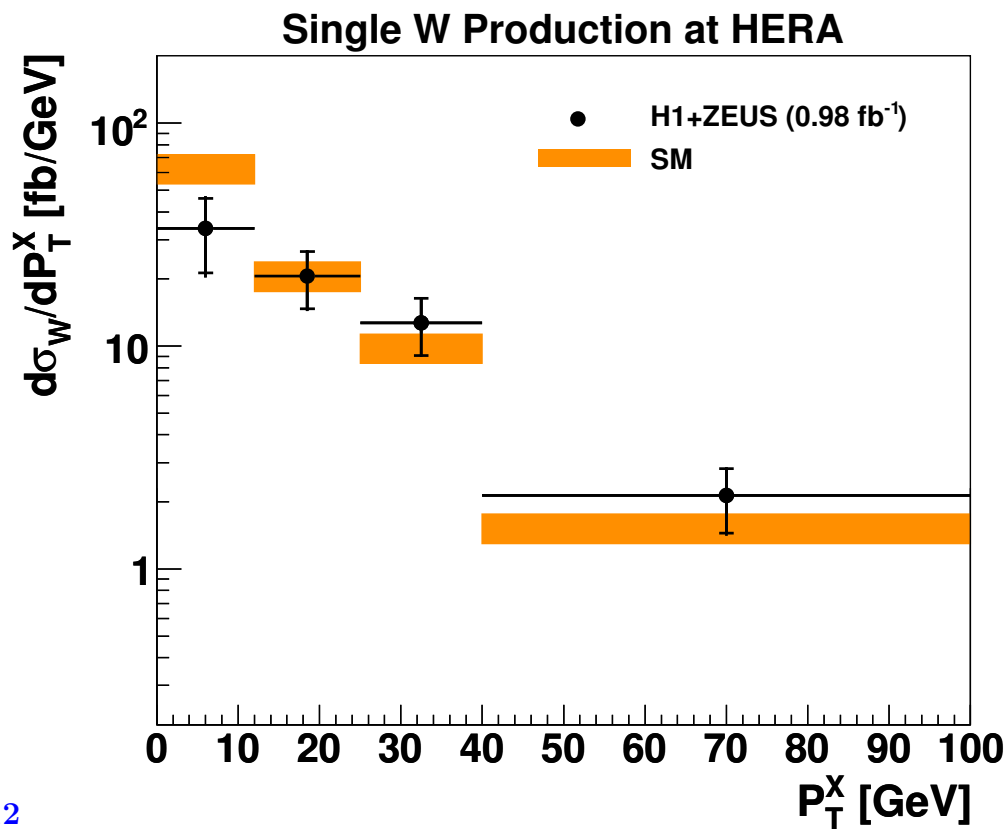
Single W Cross Section

- Determination of the Single W cross section is performed in the common analysis phase space, then extrapolated to the full phase space using EPVEC

- Branching ratio of W decays to leptons used to calculate the full W production cross section

- As there is no measurement in the $P_T^X < 12$ GeV bin in the muon channel, the electron channel is used under the assumtion of lepton universality:

$$\sigma_l^{all P_T^X} = \sigma_e^{P_T^X > 12} + \sigma_\mu^{P_T^X > 12} + 2\sigma_e^{P_T^X < 12}$$



- The total single W cross section (at $\sqrt{s} = 317$ GeV) $= 1.06 \pm 0.16(\text{stat.}) \pm 0.07(\text{sys.})$ pb in good agreement with SM prediction 1.26 ± 0.19 pb (from EPVEC at NLO)

Summary

- Combined H1 + ZEUS analyses have been performed to take advantage of full HERA statistics. 'The final word from HERA' is published on
  - Multi-leptons: JHEP 0910:013 (2009)
  - Isolated Leptons + $P_T^{\rm miss}$: (JHEP 2/2010), arXiv:0911.0858 [hep-ex]

- Cross sections of rare processes measured with greater precision as compared to individual publications.
  A good agreement with the Standard Model is observed

- Although interesting events are observed at high P_T and high mass in e^+p data, both in H1 and ZEUS, no evidence for new physics above 3σ is found

- Standard Model survived full **HERA** dataset and is still in a good shape.
  Perhaps next challenge will come from the **LHC** ...