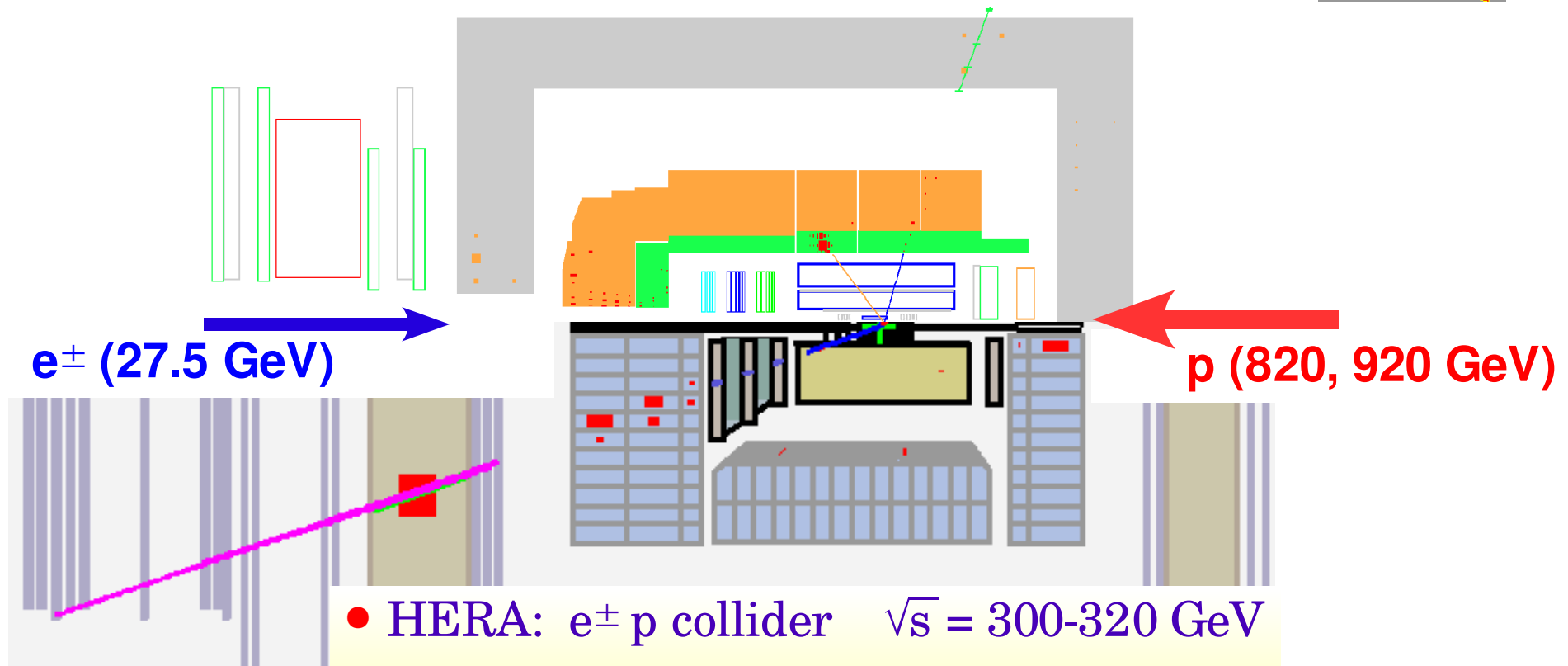


# High $P_T$ multi-lepton events at HERA



Emmanuel Sauvan  
CPPM Marseille

*On behalf of H1 and ZEUS collaborations*

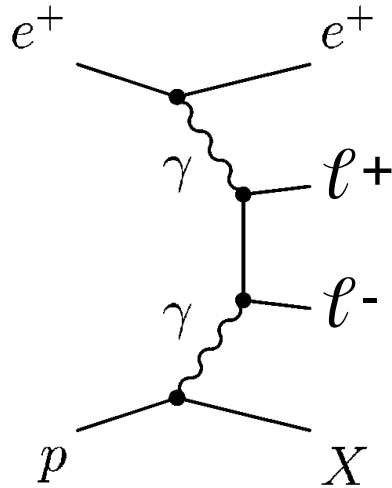


- HERA:  $e^\pm p$  collider  $\sqrt{s} = 300\text{-}320$  GeV
- HERA I:  $\sim 120$  pb $^{-1}$ , H1 and ZEUS
- HERA II:  $45$  pb $^{-1}$ , H1

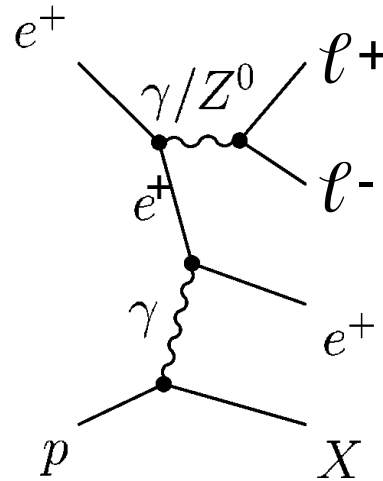
**➔ Outstanding high  $P_T$  multi-electron events observed**

# Multi-lepton events at HERA

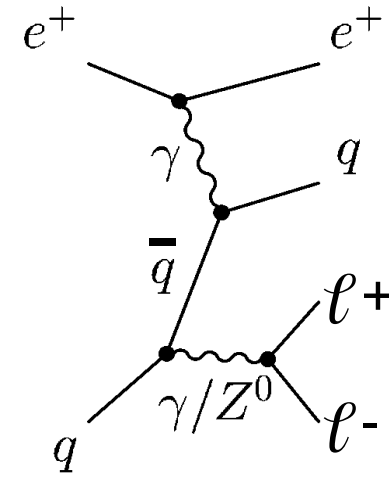
- Mainly via  $\gamma\text{-}\gamma$  collisions in the SM:



$\gamma\text{-}\gamma$  elastic and inelastic  
(dominating at HERA)



$e^+ e^- \rightarrow l^+ l^-$   
(Cabibbo-Parisi)  
(small at HERA)



$q \bar{q} \rightarrow l^+ l^-$   
(Drell-Yan)  
(small at HERA)

- At high invariant mass: sensitive to new phenomena (bileptons, Higgs<sup>++</sup> ?)

- Production of  $e^- e^-$ ,  $\mu^- \mu^-$  or  $\tau^- \tau^-$  pairs



Multi-lepton analysis of  $ee$ ,  $\mu\mu$ ,  $e\mu$ ,  $eee$  and  $e\mu\mu$  topologies

# Multi-electron selection (HERA I)

- $ee$  sample: 2 central isolated electrons

H1	ZEUS
$P_{T^{e1}} > 10, P_{T^{e2}} > 5 \text{ GeV}$	$P_{T^{e1}} > 10, E_{e2} > 10 \text{ GeV}$
$20^\circ < \theta^e < 150^\circ$	$17^\circ < \theta^e < 164^\circ$
+ good track associated to electron shower	

- $eee$  sample: any 3<sup>rd</sup> electron ( $5^\circ < \theta < 175^\circ$ )
- Background: fake electrons
  - NC-DIS: fake 2<sup>nd</sup> electron from radiation or mis-identification
  - Compton:  $e p \rightarrow e \gamma X$  ( $\gamma \rightarrow$  fake 2<sup>nd</sup> e)

[H1, Eur. Phys. J. C31(2003),17]

H1 (115 pb <sup>-1</sup> )	Data	SM	lepton pairs	NC + Compton
$ee$	108	$117.1 \pm 8.6$	$91.4 \pm 6.9$	$25.7 \pm 5.2$
$eee$	17	$20.3 \pm 2.1$	$20.2 \pm 2.1$	$0.1 \pm 0.1$

(statistical and systematic errors)

[ZEUS, Preliminary]

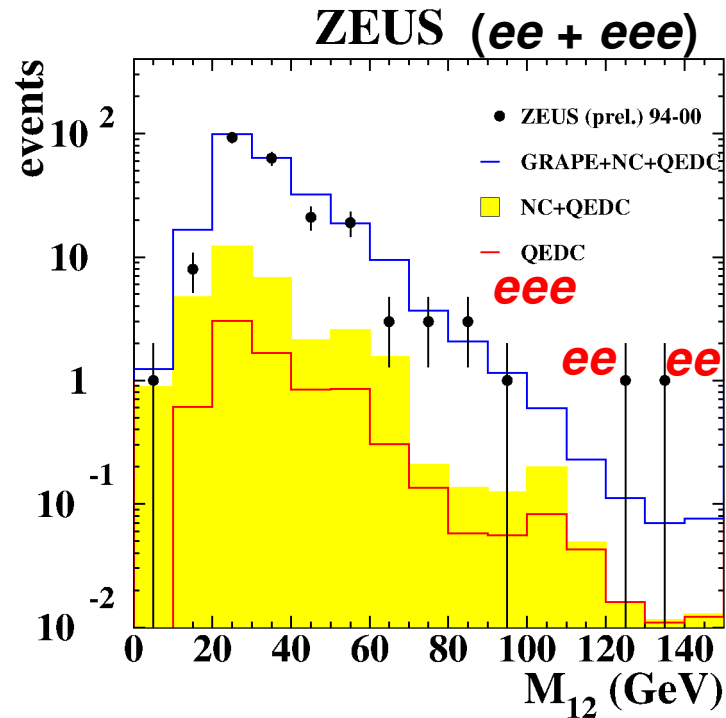
ZEUS (130 pb <sup>-1</sup> )	Data	SM	lepton pairs	NC + Compton
$ee$	191	$213.9 \pm 3.9$	$182.2 \pm 1.2$	$31.7 \pm 3.7$
$eee$	26	$34.7 \pm 0.5$	$34.7 \pm 0.5$	--

(statistical errors)

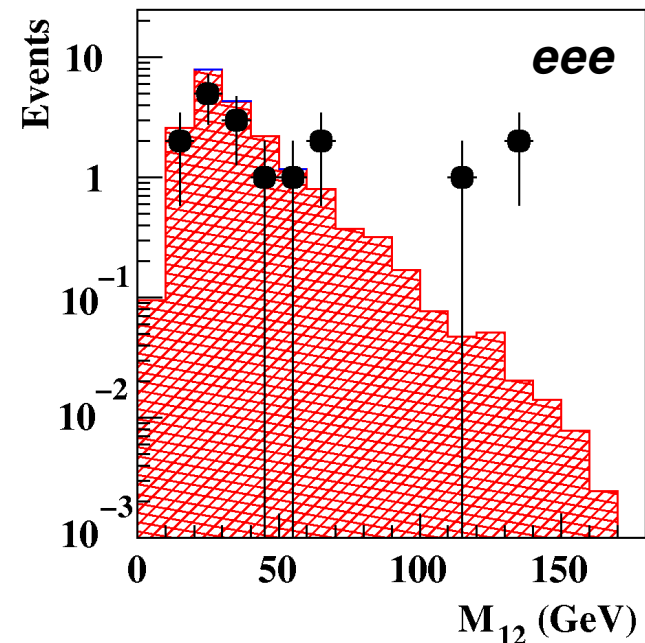
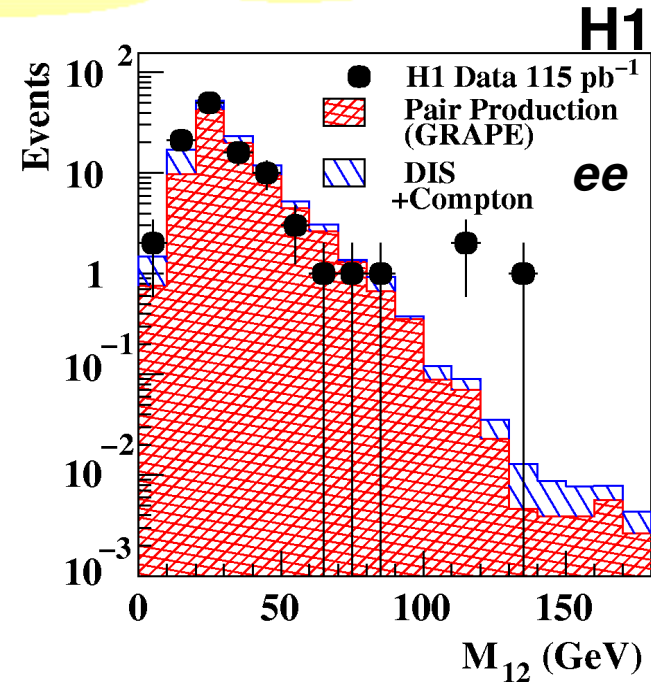
→ no 4-electron event found by H1 or ZEUS

# Invariant mass distributions (HERA I)

- Mass of 2 highest  $P_T$  electrons in the event:



- Good overall agreement
- Several events at high mass  $M_{12} > 100$  GeV



# Multi-electron: events at $M_{12} > 100 \text{ GeV}$

[H1, Eur. Phys. J. C31(2003),17]

H1 (115 pb <sup>-1</sup> )	Data	SM	lepton pairs	NC + Compton
<i>ee</i>	3	0.30 ± 0.04	0.21 ± 0.03	0.09 ± 0.02
<i>eee</i>	3	0.23 ± 0.04	0.23 ± 0.03	< 0.02 (95% C.L.)

(statistical and systematic errors)

[ZEUS, Preliminary]

ZEUS (130 pb <sup>-1</sup> )	Data	SM	lepton pairs	NC + Compton
<i>ee</i>	2	0.77 ± 0.08	0.47 ± 0.05	0.30 ± 0.07
<i>eee</i>	0	0.37 ± 0.04	0.37 ± 0.04	--

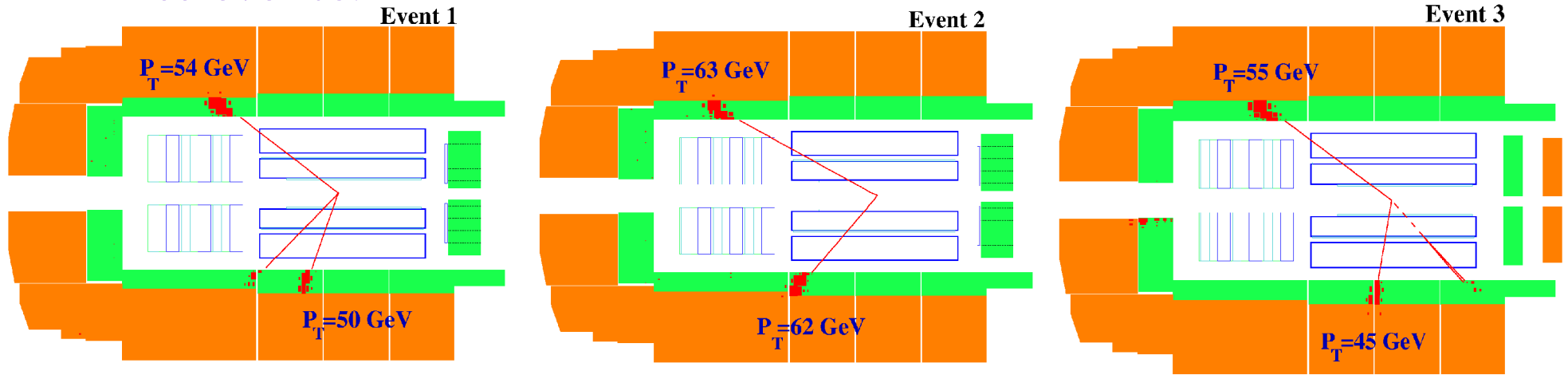
(statistical errors)



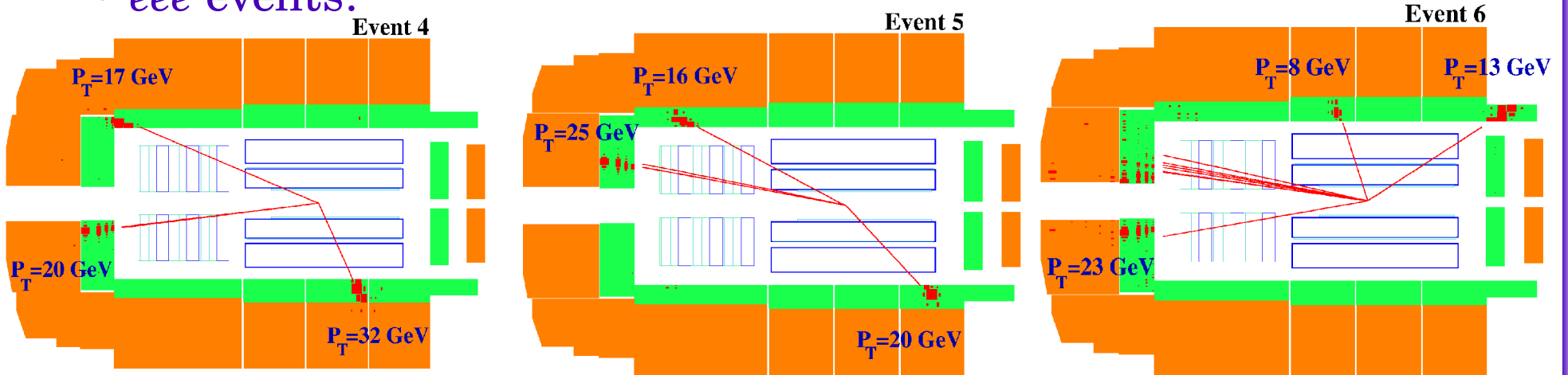
(different polar angle domains for H1 / ZEUS)

# H1 high mass events, $M_{12} > 100$ GeV

## • $ee$ events:



## • $eee$ events:



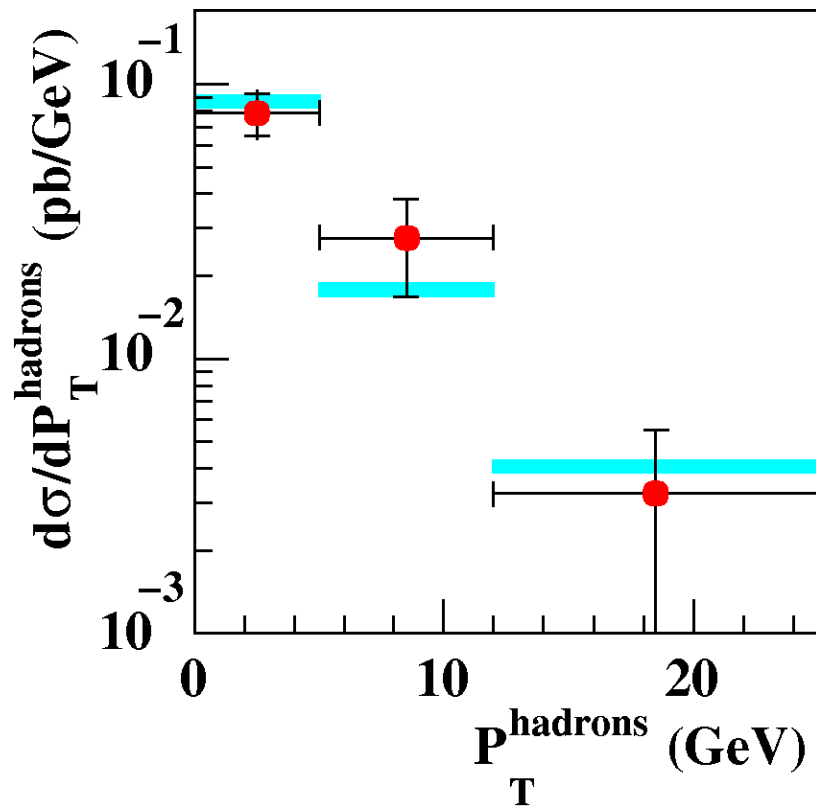
→ Precise  $M_{12}$  mass determination using a kinematic fit:

↘  $M_{12}$  values are not compatible with a single narrow resonance decay

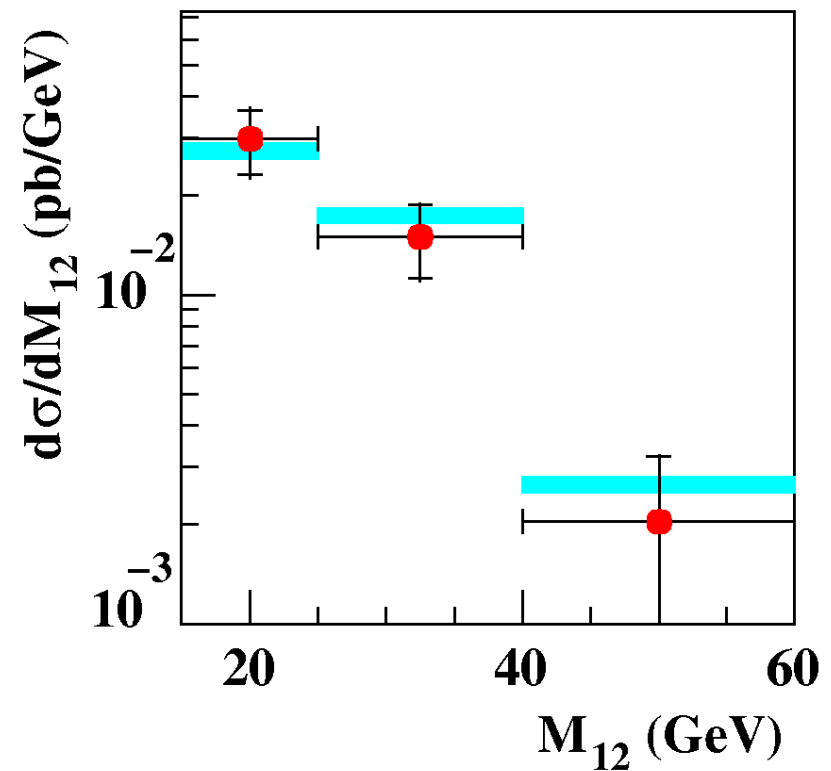
# H1: Cross-section measurement

$$\gamma\gamma \rightarrow e^+e^-$$

- $ee$  sample +  $E-P_z < 45$  GeV, opposite charges,  $y < 0.82$ ,  $Q^2 < 1$  GeV<sup>2</sup>
- 42 (data) /  $44.9 \pm 4.2$  (MC) ( $1.2 \pm 0.4$  background)



→ Inelastic process well described

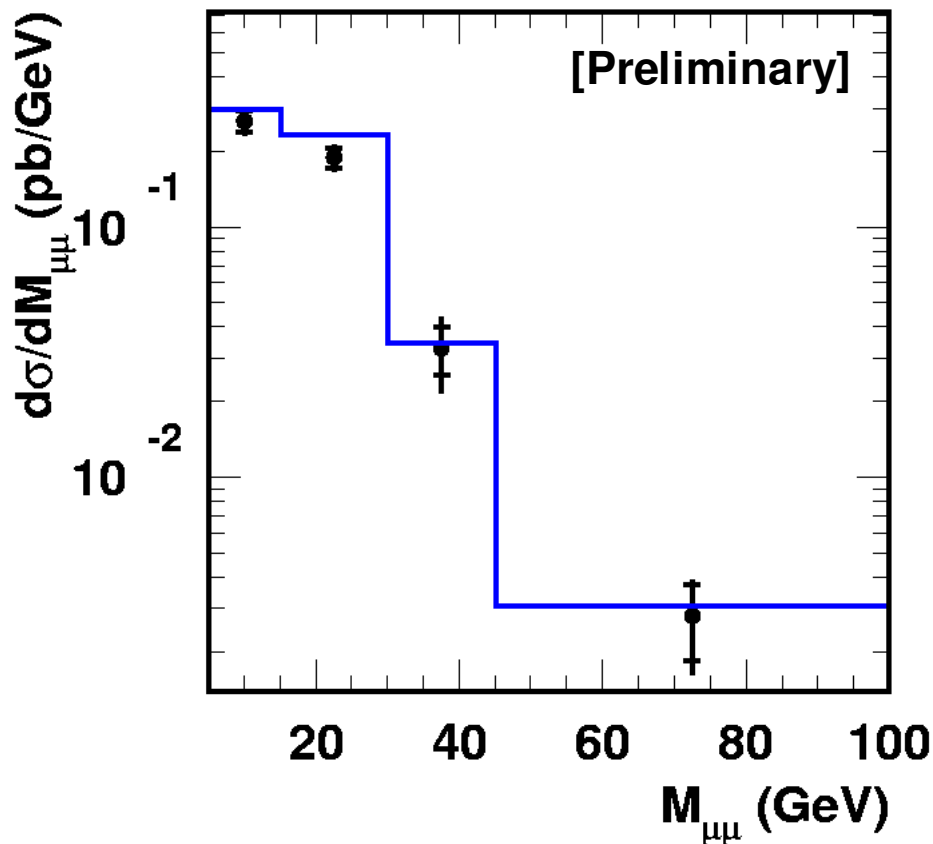


→ Good agreement with the SM in this phase space

# Di-muon: results from ZEUS (HERA I)

- $\mu$  identified in central tracker, calorimeter and muon chambers
- $P_T^\mu > 5 \text{ GeV}$ ,  $12^\circ < \theta_\mu < 164^\circ$ ,  $\geq 2$  isolated  $\mu$
- $M_{\mu\mu} > 5 \text{ GeV}$

(101 pb<sup>-1</sup>)



→ 255 (data) /  $294.9 \pm 2.7$  (SM)  
(statistical errors)

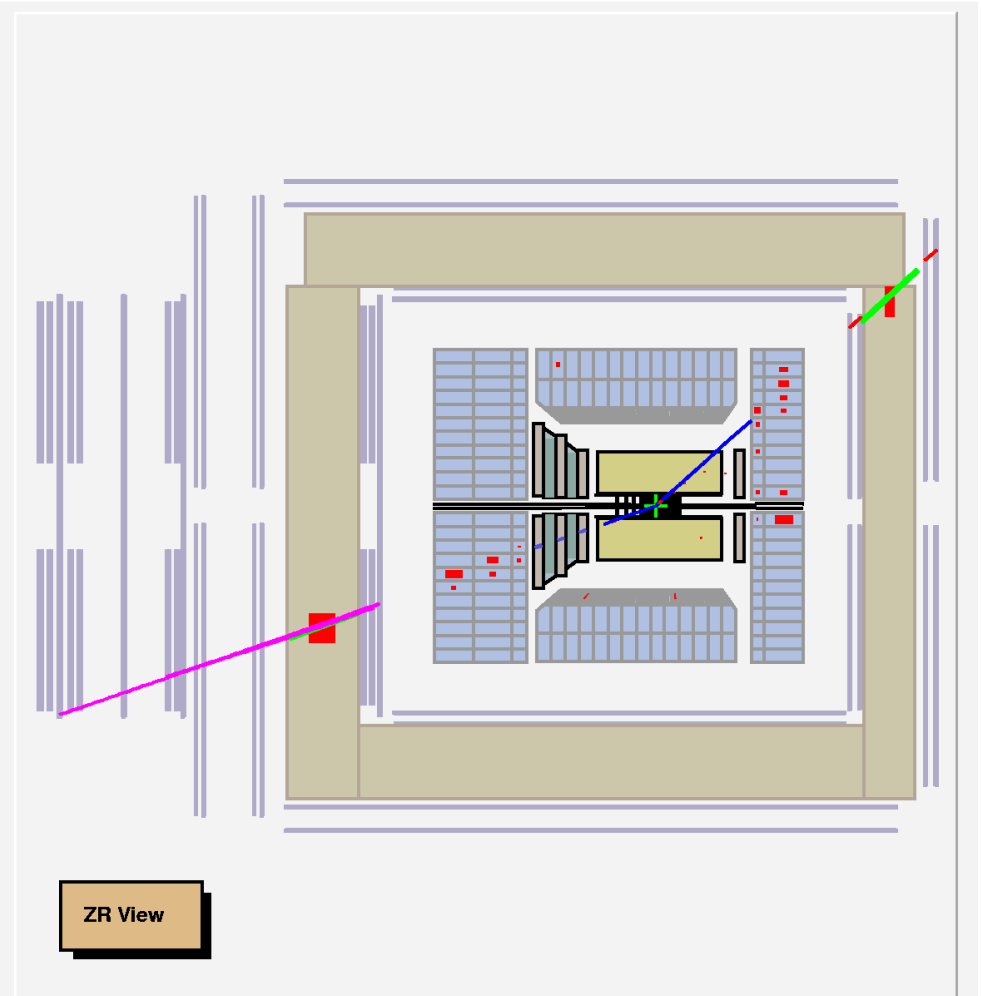
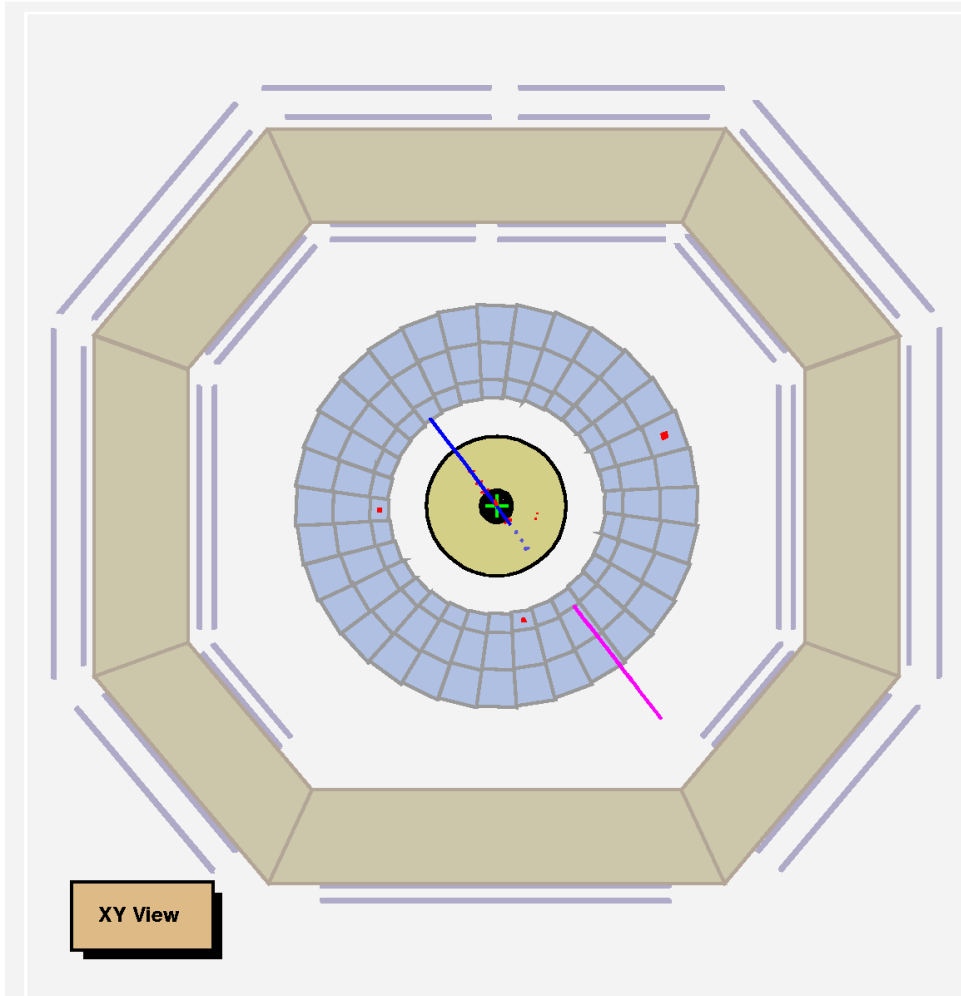
→ For  $M_{\mu\mu} > 100 \text{ GeV}$ :  
2 (data) /  $2.16 \pm 0.45$  (SM)

→ Good agreement with the SM

→  $\sigma_{\mu\mu} = 6.17 \pm 0.39 \pm_{0.43}^{0.49} \pm 0.12 \text{ pb}$   
SM: 7.13 pb (GRAPE)



# Exemple of a $\mu\mu$ event (ZEUS)



# Di-muon events: H1 (HERA I)

[H1, Phys. Lett. B583 (2004), 28] H1: (71 pb<sup>-1</sup>)

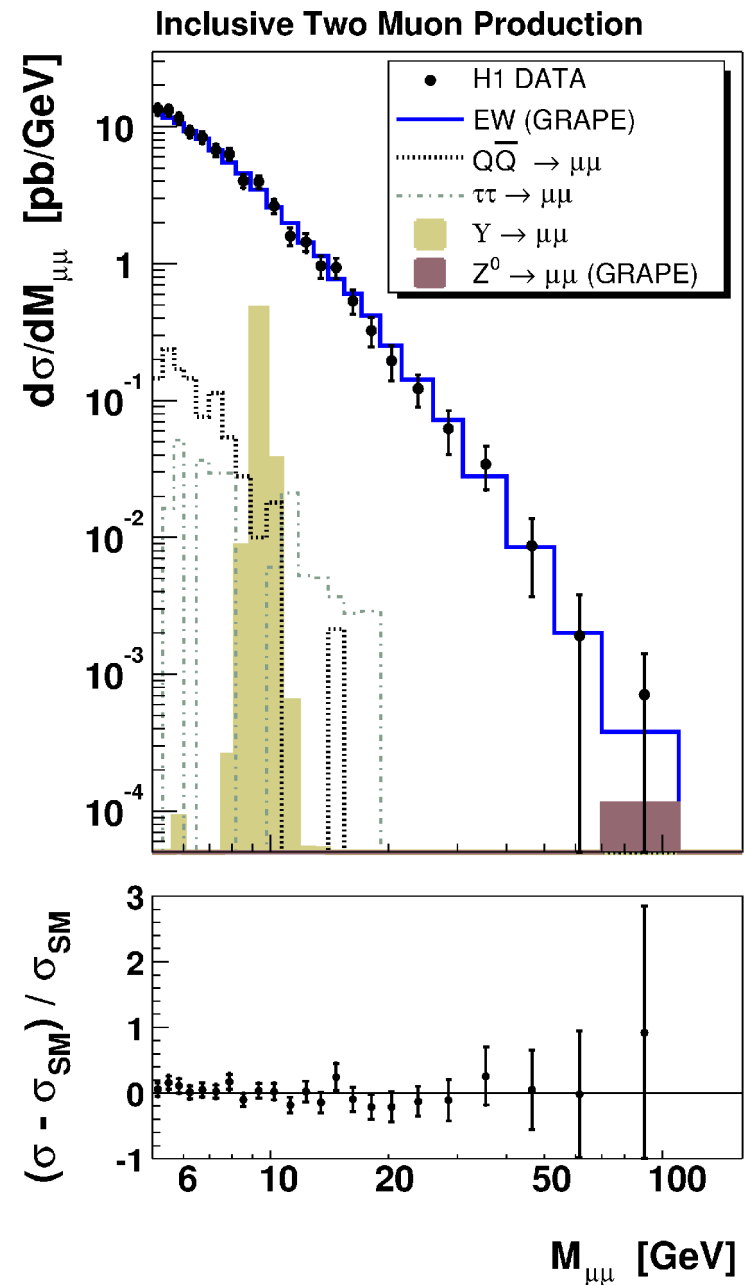
- $\mu$  identified in central tracker, calorimeter and muon chambers
- $P_{T\mu 1} > 2 \text{ GeV}$ ,  $P_{T\mu 2} > 1.75 \text{ GeV}$
- $M_{\mu\mu} > 5 \text{ GeV}$
- $20^\circ < \theta_\mu < 160^\circ$

→  $\sigma_{\mu\mu} = 46.4 \pm 1.3 \pm 4.5 \text{ pb}$   
 SM:  $46.1 \pm 1.4 \text{ pb}$  (GRAPE)

→ Good agreement with SM

→ No  $\mu\mu$  event observed with  
 $M_{\mu\mu} > 100 \text{ GeV}$

→ Extrapolation of  $ee$  to  $\mu\mu$ :  
 $\sim 1 \mu\mu$  expected



# Multi-lepton events at high $P_T$ (H1) (HERA I+II)

- Include muons in an analysis equivalent to multi-electron
  - HERA I data (118 pb<sup>-1</sup>) + new HERA II data (45 pb<sup>-1</sup>)
  - At least 2 leptons:  $P_T^{l1} > 10$  GeV,  $P_T^{l2} > 5$  GeV, ( $20^\circ < \theta_{l1,2} < 150^\circ$ )
  - Any additional  $\mu$ :  $P_T^\mu > 2$  GeV, ( $20^\circ < \theta_\mu < 160^\circ$ )
  - Any additional e:  $E_e > 5$  GeV, ( $5^\circ < \theta_e < 175^\circ$ )
- $ee, \mu\mu, e\mu, eee$  and  $e\mu\mu$  topologies

H1 Preliminary 163 pb<sup>-1</sup> (HERA I+II)

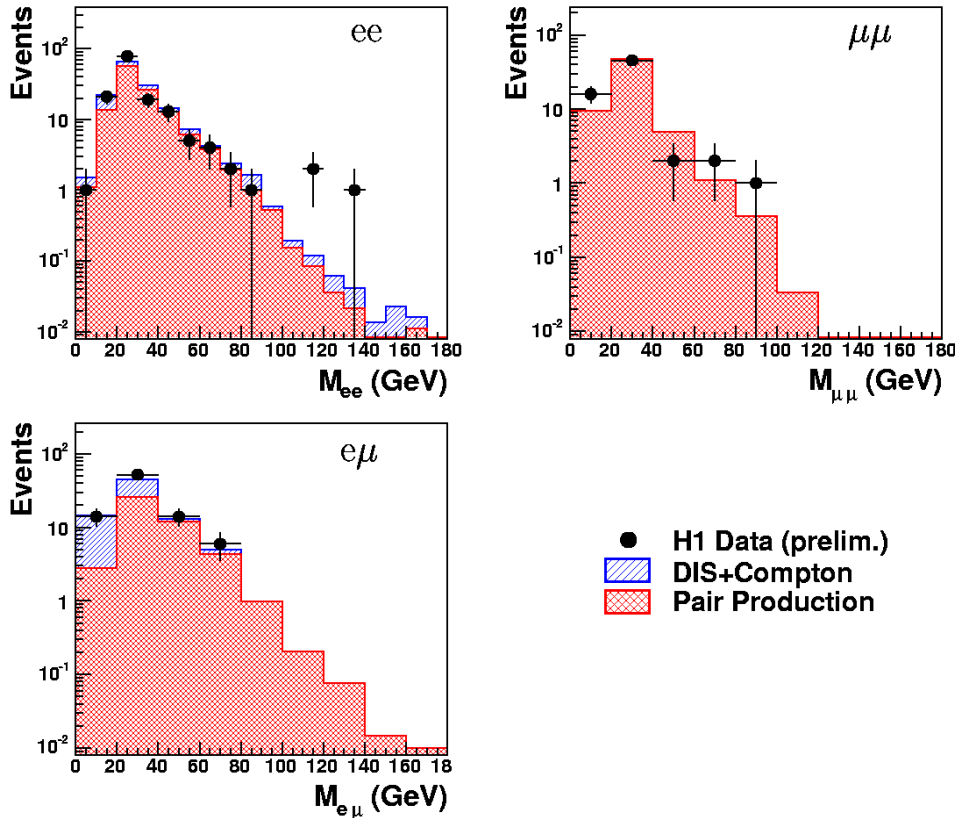
Selection	Data	SM	Pair Production (GRAPE)	DIS + Compton
ee	147	149.8 ± 24.8	125.5 ± 13.0	24.3 ± 18.7
$\mu\mu$	66	63.7 ± 12.7	63.7 ± 12.3	—
$e\mu$	86	78.4 ± 12.0	46.4 ± 3.8	31.9 ± 9.9
eee	24	30.4 ± 3.9	30.41 ± 3.9	0.04 ± 0.06
$e\mu\mu$	41	39.5 ± 6.5	39.5 ± 6.5	—

→ In agreement with the SM for all classes

# Multi-leptons: mass distributions

## • 2 leptons classes

H1 Preliminary Multi-lepton analysis HERA I+II (163 pb<sup>-1</sup>)

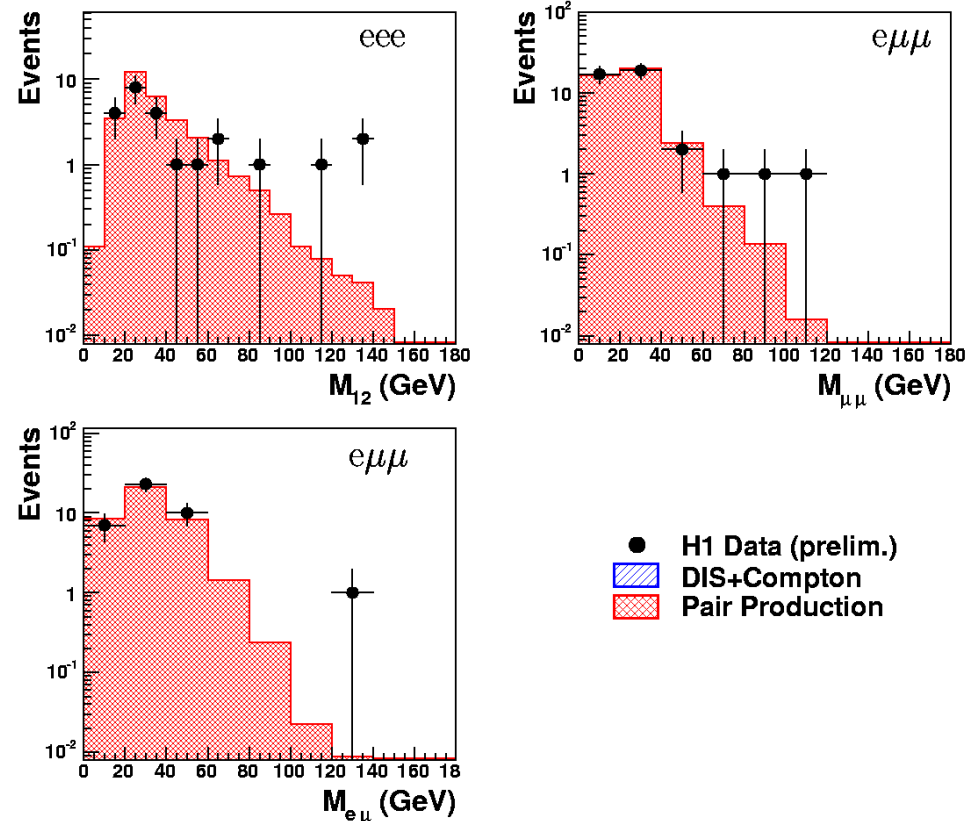


→ 3  $ee$  events  $M_{ee} > 100$  GeV (HERA I)

→ At low mass: good agreement with the SM

## • 3 leptons classes

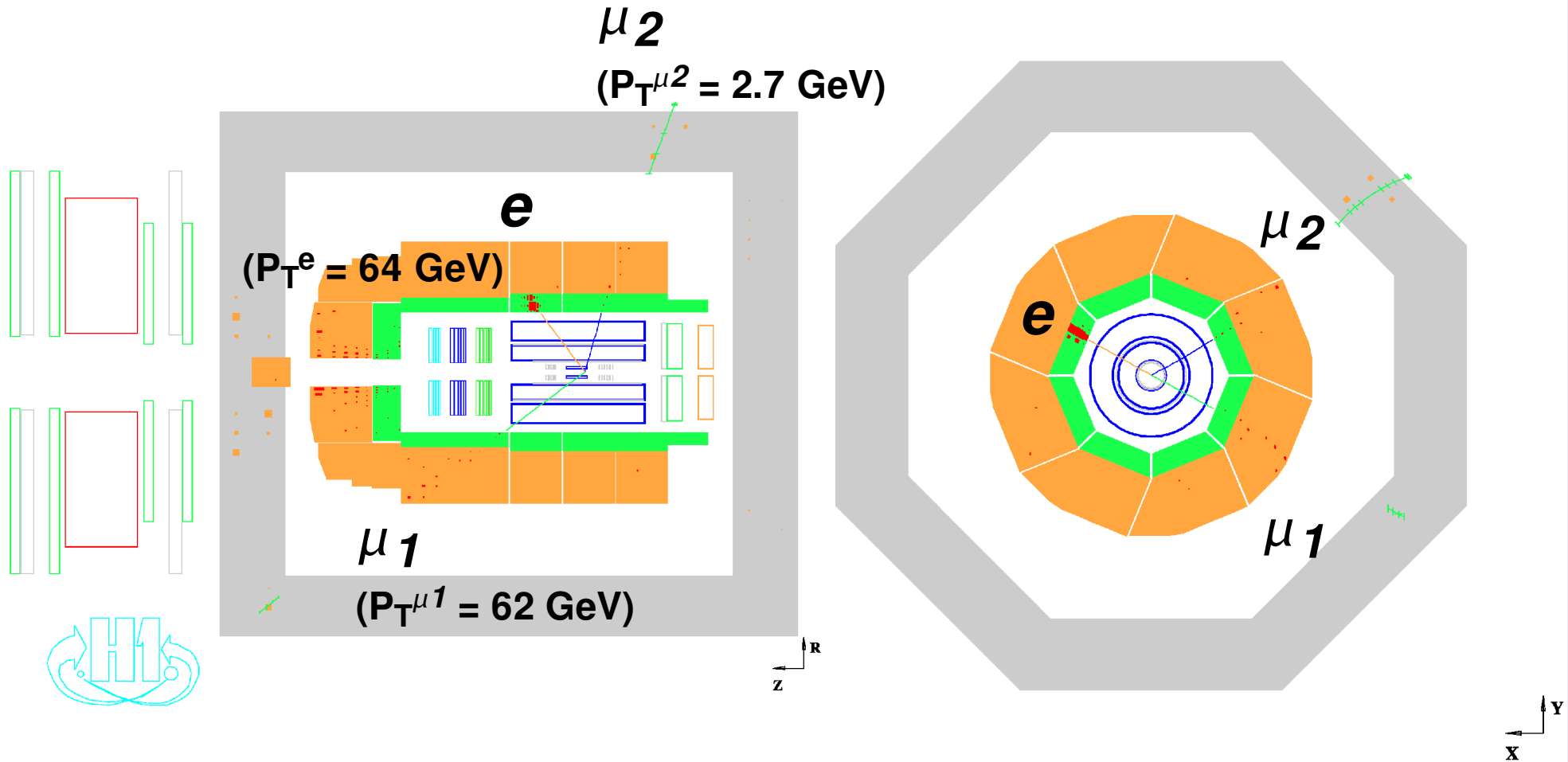
H1 Preliminary Multi-lepton analysis HERA I+II (163 pb<sup>-1</sup>)



→ 2  $e\mu\mu$  events with  $M > 100$  GeV (HERA II)

→ 3  $eee$  events from HERA I

# High mass $e\mu\mu$ event (HERA II)



# Event yields at high mass

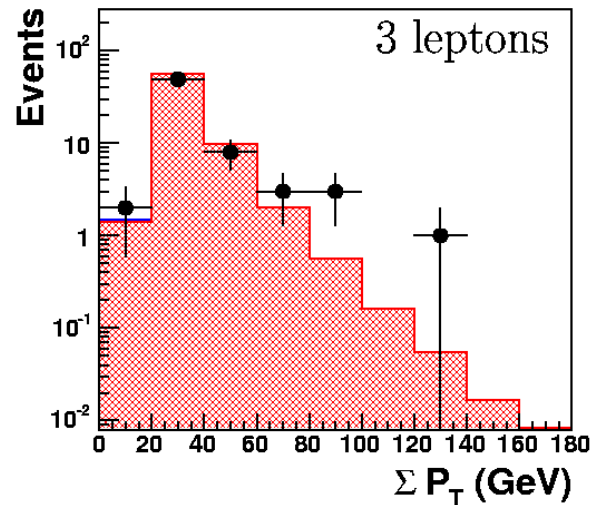
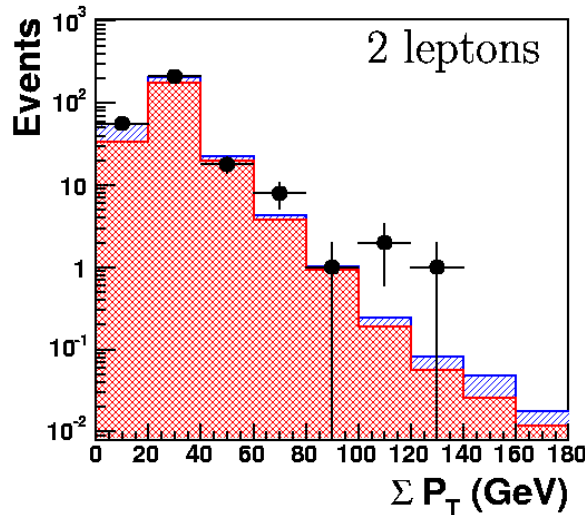
H1 Preliminary 163 pb<sup>-1</sup> (HERA I+II)

Selection	Data	SM	Pair Production (GRAPE)	DIS + Compton
$ee M_{ee} > 100 \text{ GeV}$	3	$0.44 \pm 0.10$	$0.32 \pm 0.10$	$0.12 \pm 0.03$
$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	$0.04 \pm 0.02$	$0.04 \pm 0.02$	—
$e\mu M_{e\mu} > 100 \text{ GeV}$	0	$0.31 \pm 0.03$	$0.31 \pm 0.03$	—
$eee M_{12} > 100 \text{ GeV}$	3	$0.31 \pm 0.08$	$0.31 \pm 0.08$	—
$e\mu\mu M_{e\mu} > 100 \text{ GeV}$	1	$0.04 \pm 0.01$	$0.04 \pm 0.01$	—
$e\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	1	$0.02 \pm 0.01$	$0.02 \pm 0.01$	—

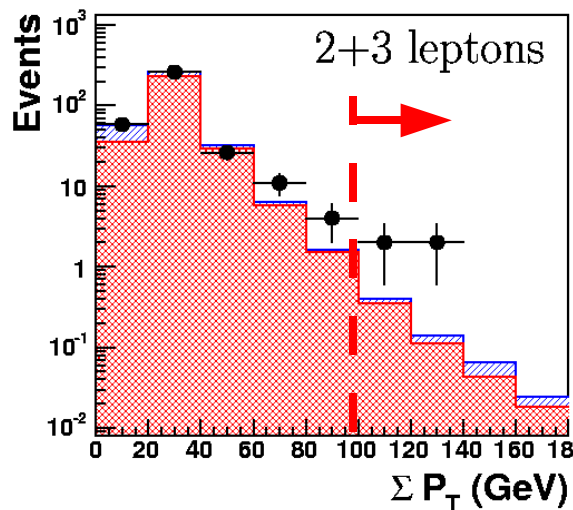
# $\Sigma P_T$ distributions

- Distributions of scalar sum of transverse momenta
  - Combination of all classes

H1 Preliminary Multi-lepton analysis HERA I+II (163 pb<sup>-1</sup>)



- H1 Data (prelim.)
- ▨ DIS+Compton
- ▨ Pair Production



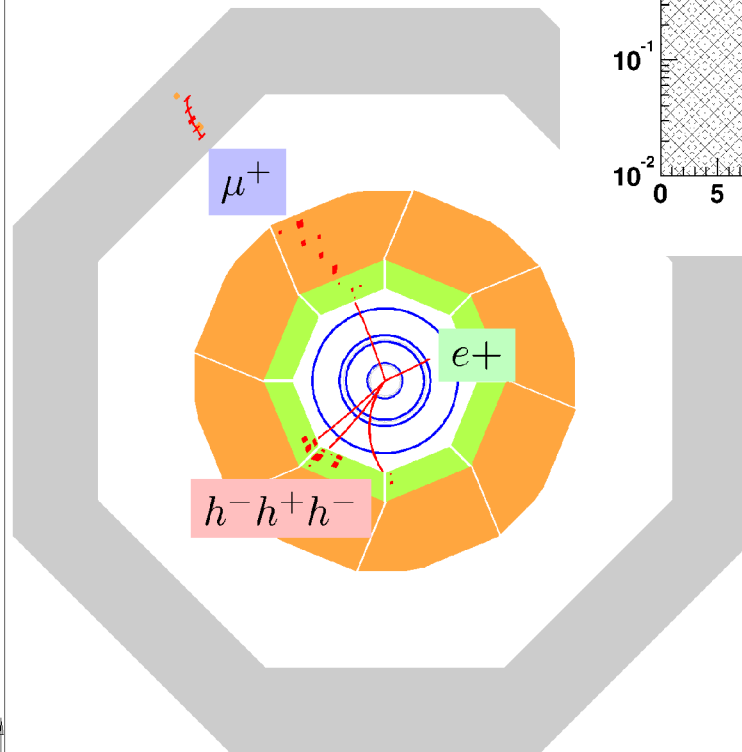
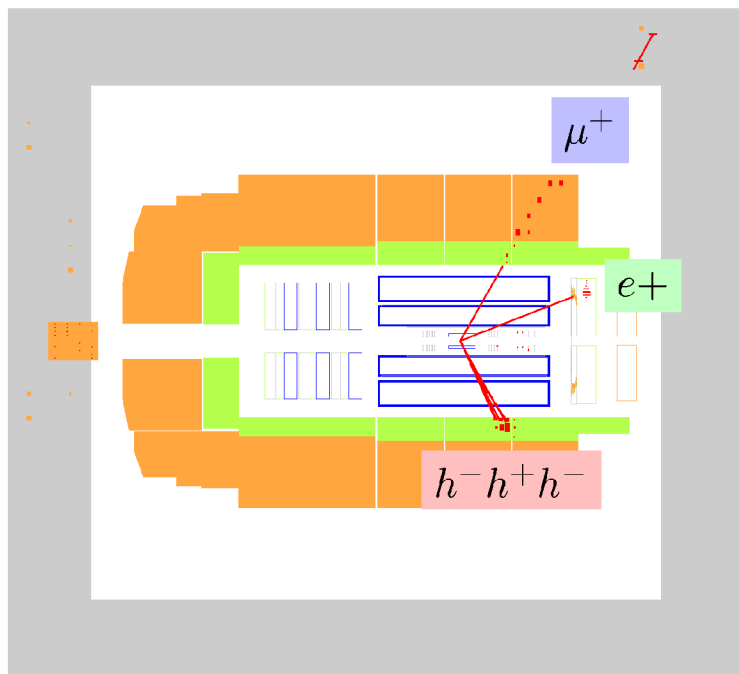
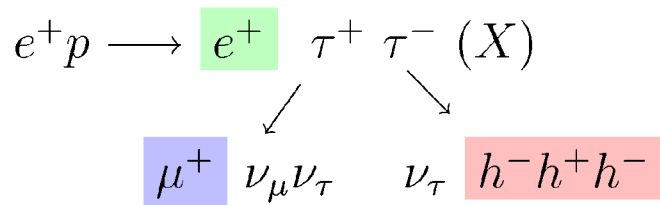
→ Agreement with the SM at low  $\Sigma P_T$

→ for  $\Sigma P_T > 100$  GeV:

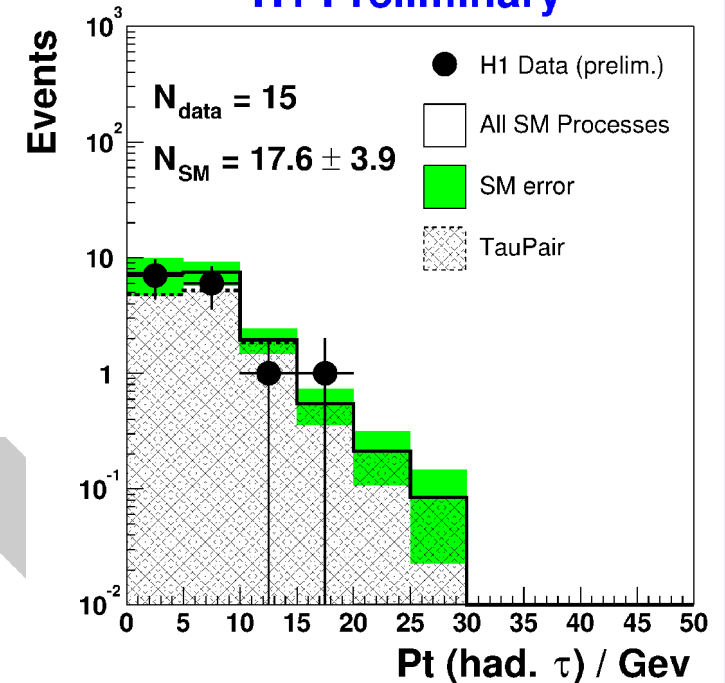
- 4 events for  $0.61 \pm 0.11$  expected
  - 3  $ee$  events (HERA I)
  - 1  $e\mu\mu$  event (HERA II)

# Production of $\tau$ pairs (HERA I)

- Observation of elastic  $\tau$  pairs by H1
  - 1  $\tau$  with leptonic decay
  - 1  $\tau$  with 1- or 3-prong decay
- $P_T$  of the  $\tau$  with hadronic decay



H1 Preliminary

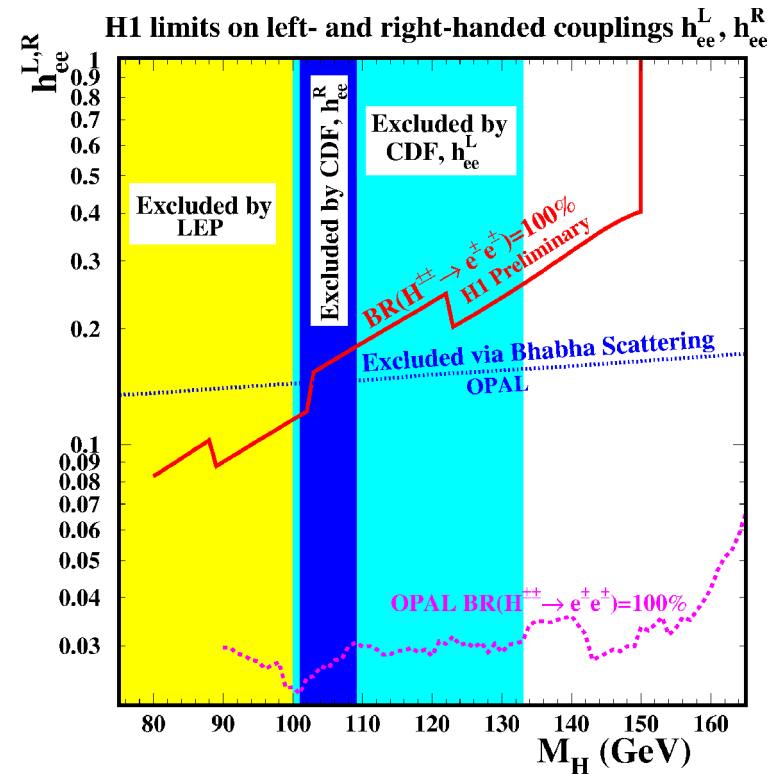
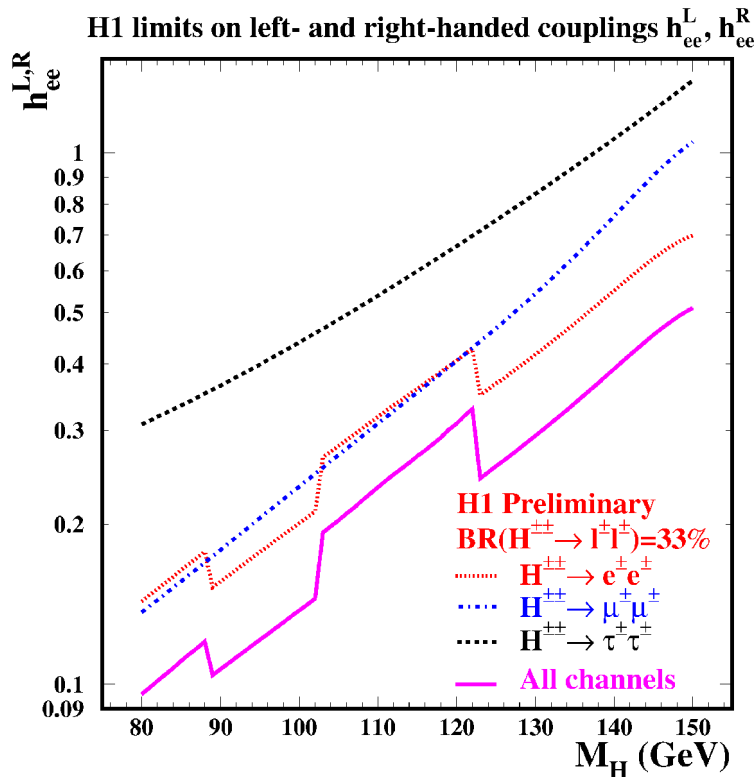
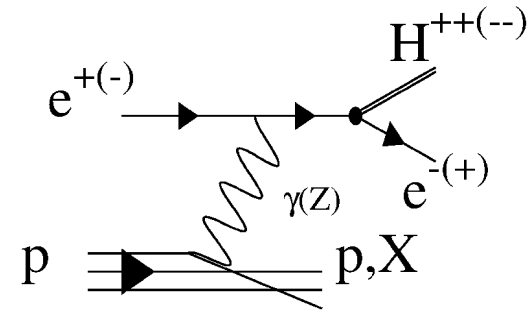


(opposite charges sample)



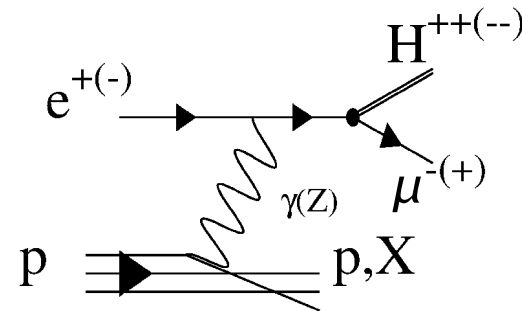
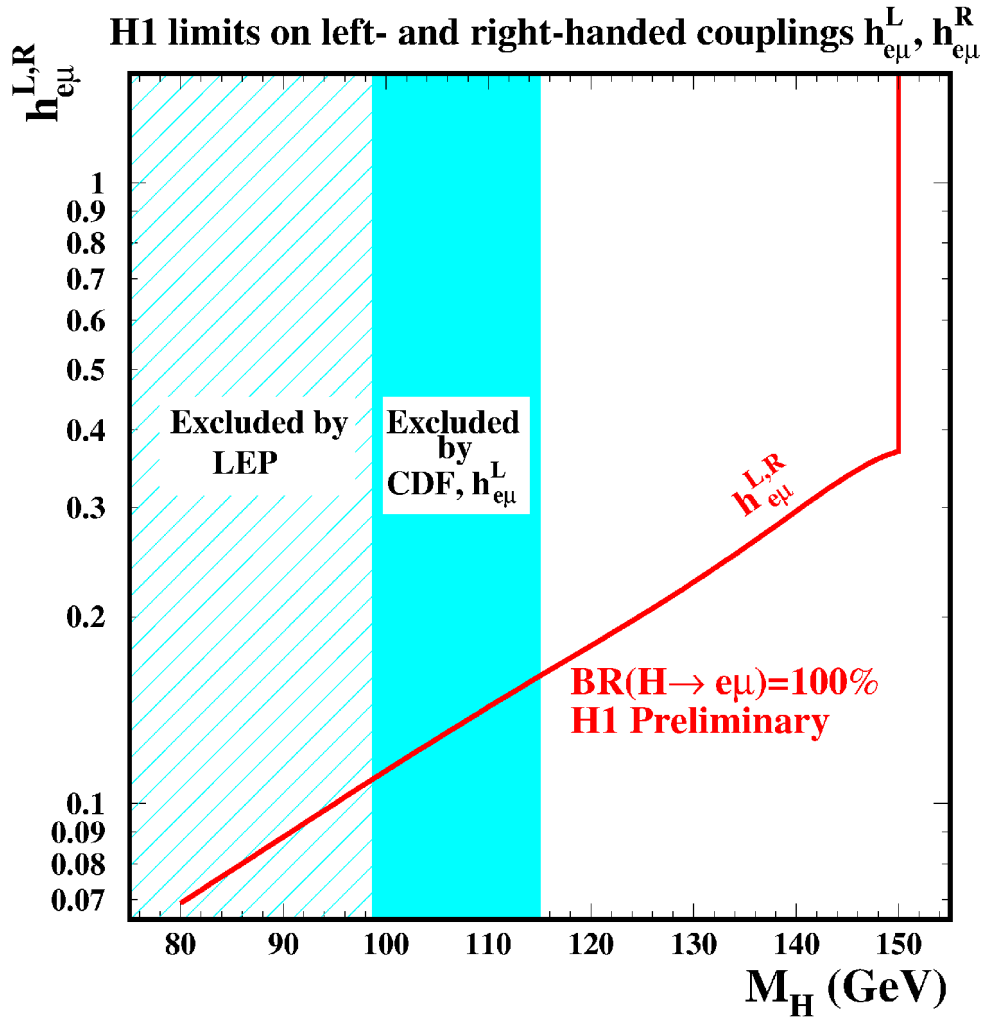
# Doubly charged Higgs at HERA ? (H1, HERA I)

- at HERA :  $e^\pm p \rightarrow e^\mp H^{\pm\pm} X$ ,  $H^{\pm\pm} \rightarrow l^\pm l^\pm$ , sensitivity to  $h_{ee}$  coupling
- ➔ All  $ee$ ,  $\mu\mu$ ,  $e\mu$ ,  $eee$ ,  $e\mu\mu$  and  $\tau\tau$  channels are studied
- ➔ Only one  $ee$  fulfills charge requirements



- ➔ Multielectron events not due to  $H^{\pm\pm}$  decay
- ➔ no  $\mu\mu$ ,  $\tau\tau$  or  $e\mu$  found in the same mass domain

# $H^{\pm\pm}$ : limits on $h_{e\mu}$



- Off-diagonal coupling  $h_{e\mu}$  considered at the production and decay of  $H^{\pm\pm}$
  - $e^\pm p \rightarrow \mu^\mp H^{\pm\pm} X \rightarrow \mu^\mp e^\pm \mu^\pm X$
  - leads to  $e\mu, e\mu\mu$  topologies
- ↘ H1 limit extends the excluded region

# Summary ...

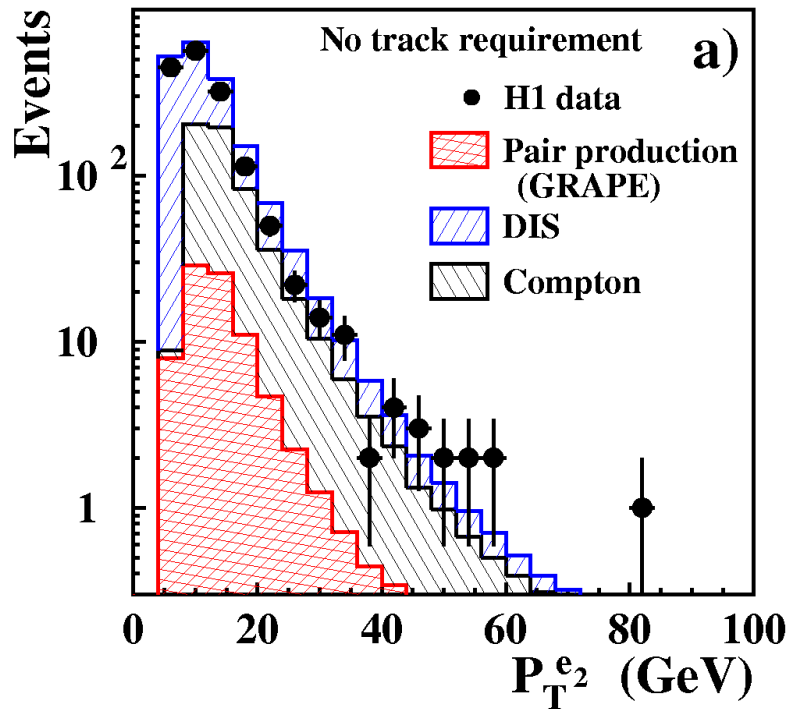
- Multi-lepton production has been measured in  $ep$  collisions
- $\gamma\gamma$  cross-sections in agreement with the SM at low mass
- Multi-electron:
  - Outstanding events at high mass:
    - H1: 3  $ee$  and 3  $eee$ , for 0.3 and 0.23 predicted (HERA I)  
3  $ee$  and 3  $eee$ , for 0.44 and 0.31 predicted (HERA I+II)
    - ZEUS: 2 di-electrons (0.77 predicted)
- Muon pairs:
  - High mass observations in agreement with the SM
- Multi-lepton and extension to HERA II:  $163 \text{ pb}^{-1}$ 
  - $ee$ ,  $\mu\mu$ ,  $e\mu$ ,  $eee$  and  $e\mu\mu$  topologies studied
  - At high  $\Sigma P_T > 100 \text{ GeV}$ :
    - 4 events for  $0.61 \pm 0.11$  expected

➤ **Outlook:** increase the luminosity for further clarification

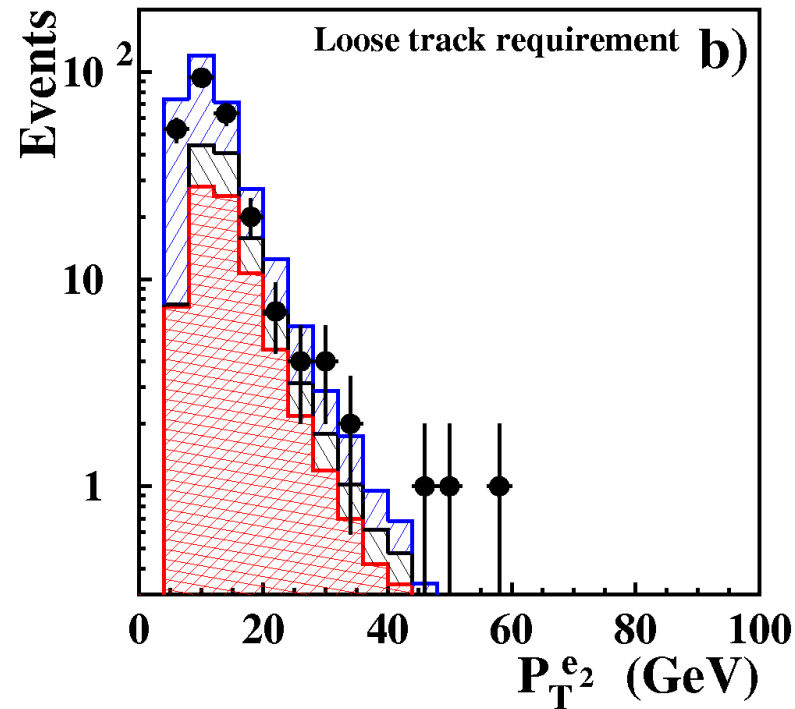
# Background studies: NC-DIS

- Study of electron mis-identification in central region
- Selection of Neutral Current DIS events

→ Events with a 2<sup>nd</sup> electromagnetic cluster



→ No track required

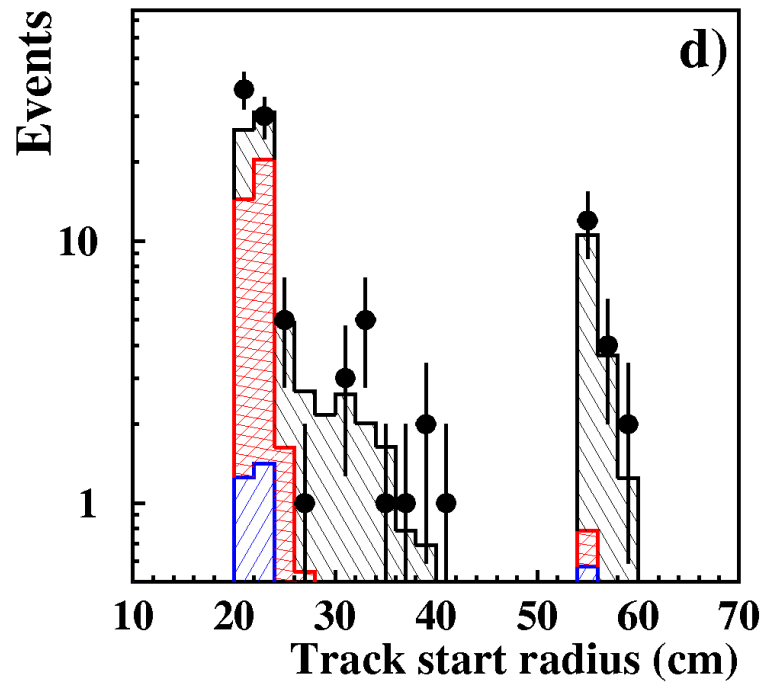
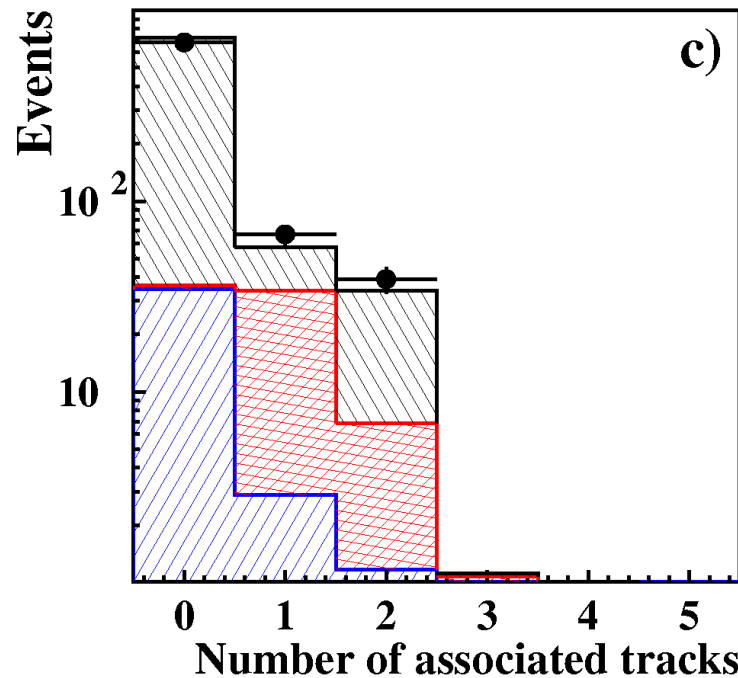


→ Loose track required

→ Described at the 20% level

# Background studies: Comptons

- Study of photon conversion
- Sample enriched with elastic Compton events
  - 1 central electron + a 2<sup>nd</sup> electromagnetic cluster (photon candidate)



→ Number of associated tracks

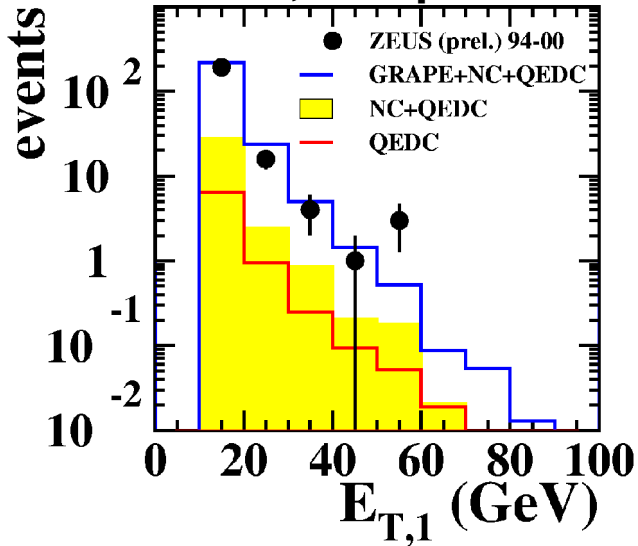
→ Track starting radius

→ Conversions described by the simulation,  
at better than 20%

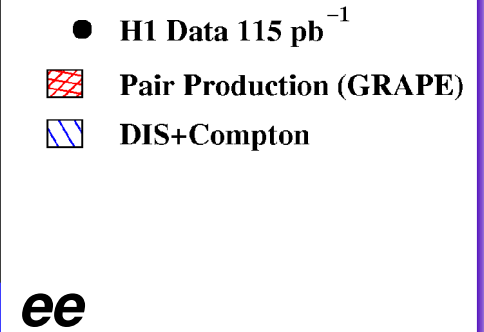
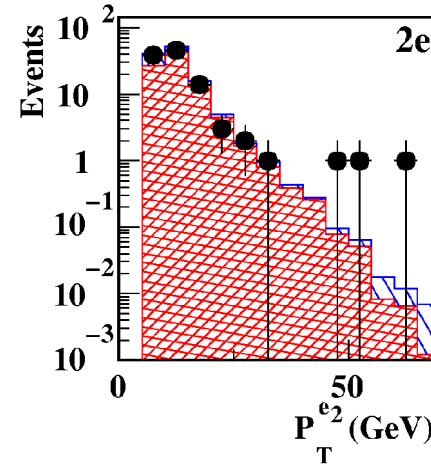
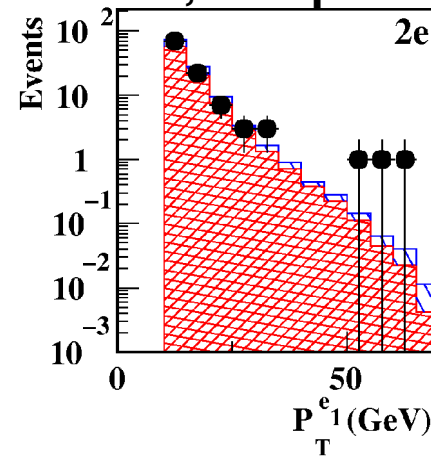
# Multi-electron: transverse momenta

- Good overall agreement
- H1: 3  $ee$  events  $P_T > 50$  GeV
- ZEUS: 2 events  $P_T > 50$  GeV

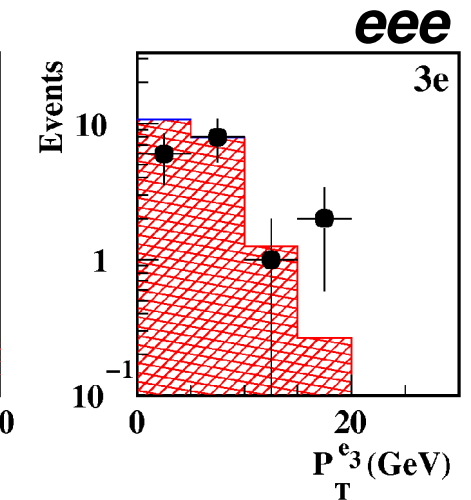
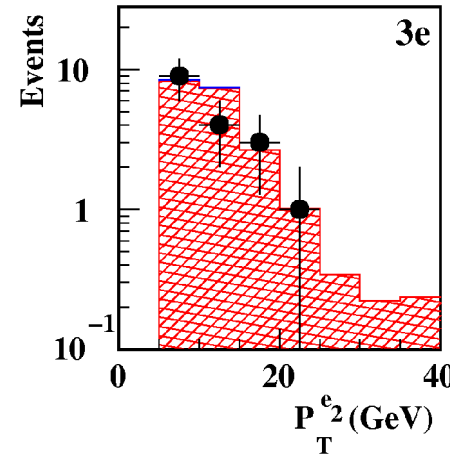
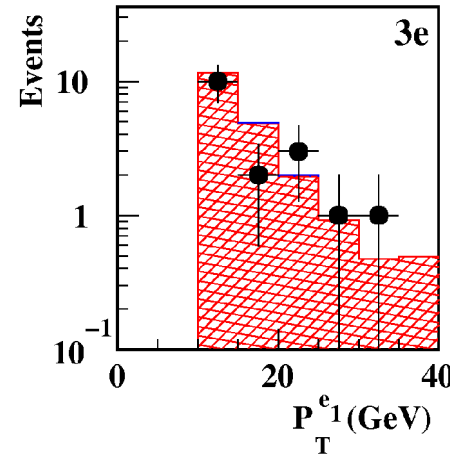
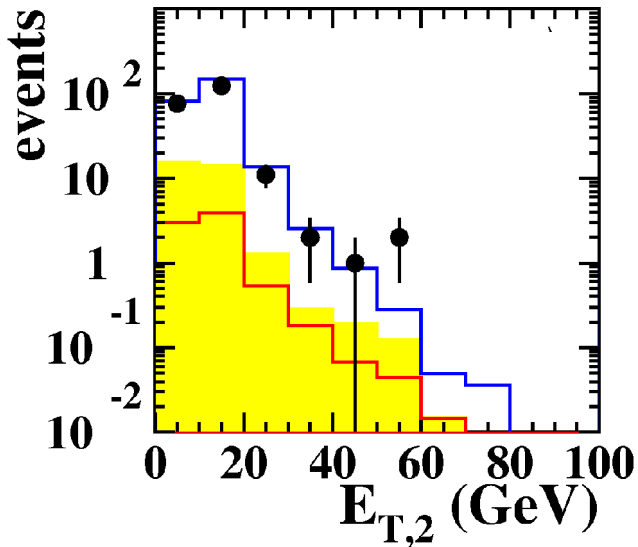
ZEUS, 130 pb<sup>-1</sup>



H1, 115 pb<sup>-1</sup>



$ee$



$eee$

# Precise $M_{12}$ mass determination

- Try to improve the kinematic measurement:

→ Imposing longitudinal and transverse momentum conservation

( $E - P_z = 55.2$  GeV and  $P_T^{\text{miss}} = 0$  GeV)

→ Constrained kinematic fit

- Errors reduced by more than a factor of 2
- Kinematics of the events well understood

→  $M_{12}$  values are not compatible with a single narrow resonance decay

