

Multi Leptons in ep Collisions at HERA

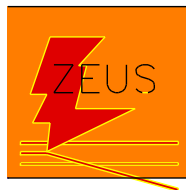
Analyses of multi-muon \mathcal{E} and multi-electron production

Boris Leißner, RWTH Aachen

on behalf of the



and



collaborations



Outline

- How are lepton pairs produced ?

- ➔ Two Photon Physics

- Cross sections for lepton pairs

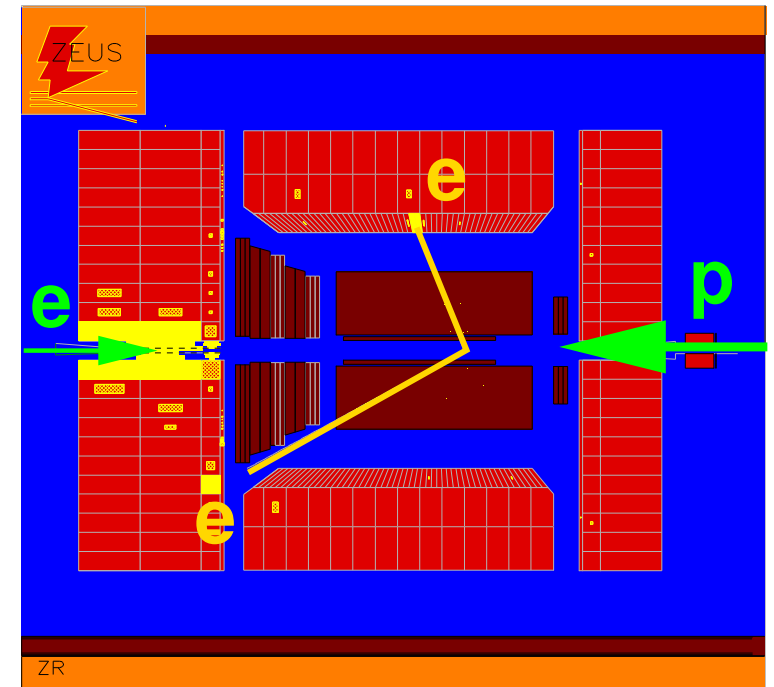
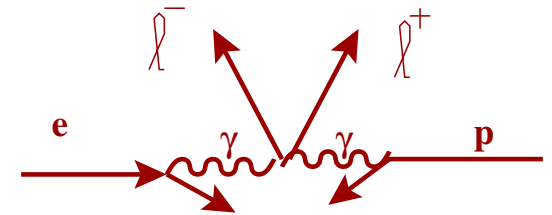
- ➔ Separation of elastic and inelastic processes

- Multi Leptons with high mass

- ➔ Search for anomalous lepton production in the tail of di-lepton mass distributions

- ➔ Looking for additional leptons

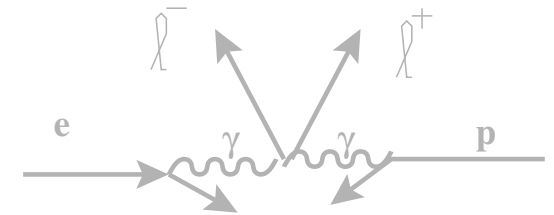
- Conclusions



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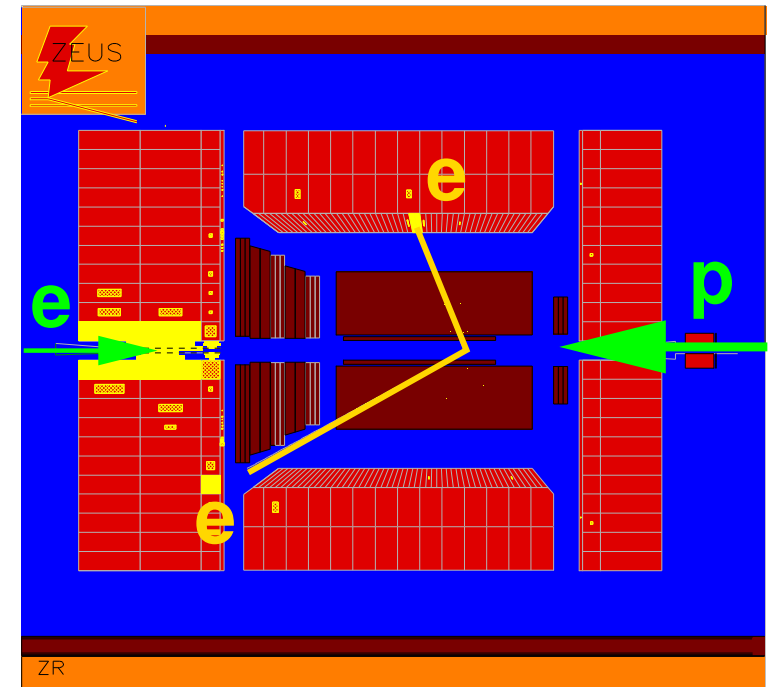
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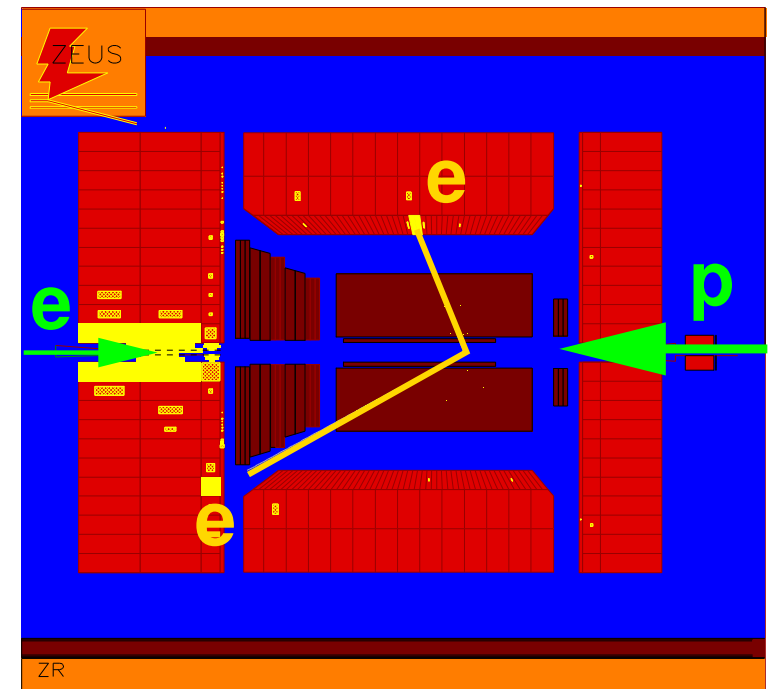
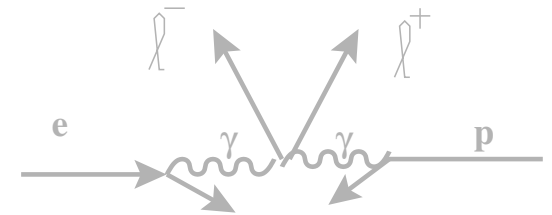
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 - ➔ Separation of elastic and inelastic processes
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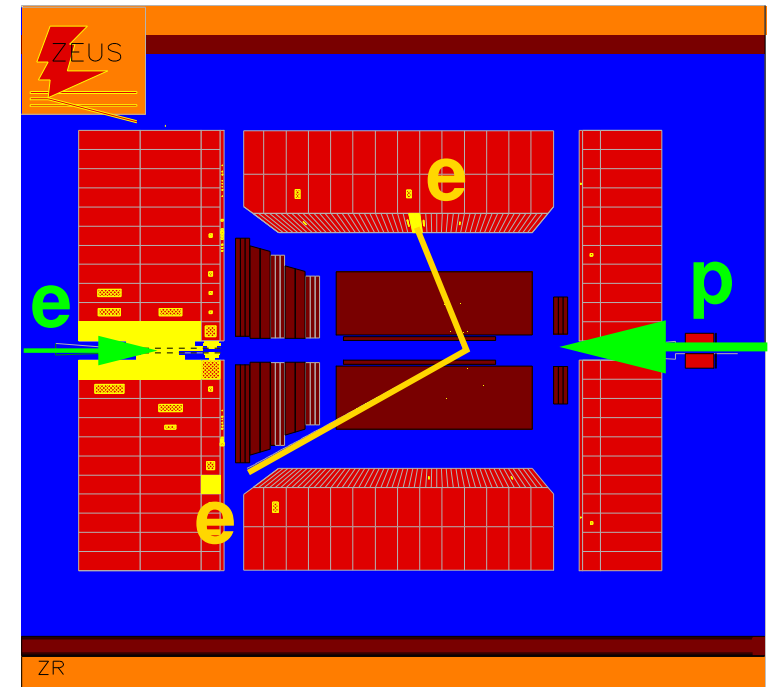
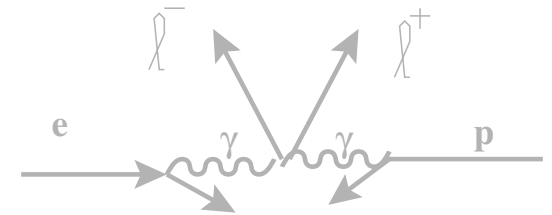
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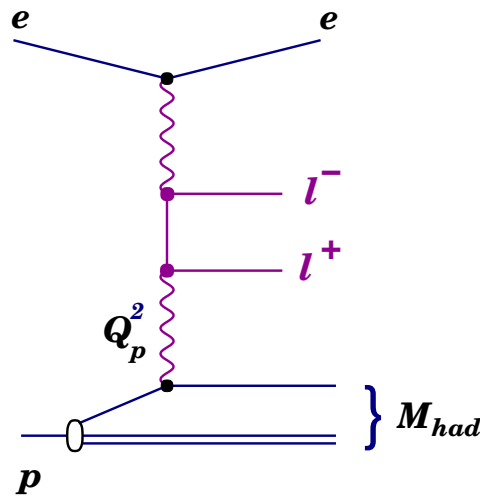
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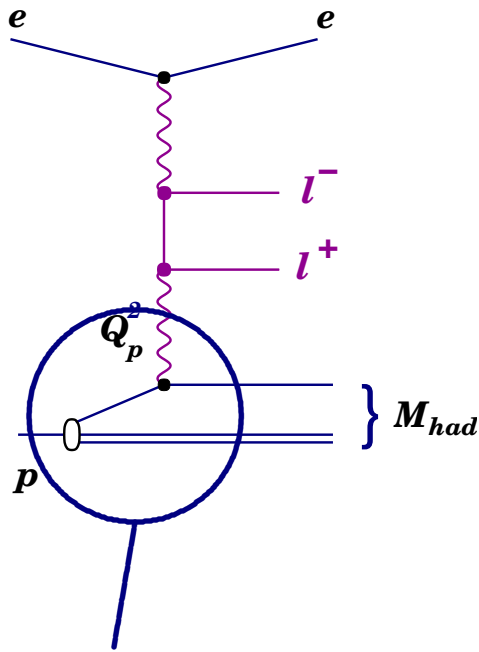
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How are Lepton Pairs produced?



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proton description:

ELA: Form factors

Quasi-ELA: Structure functions

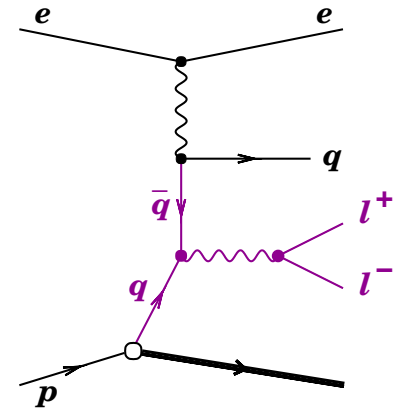
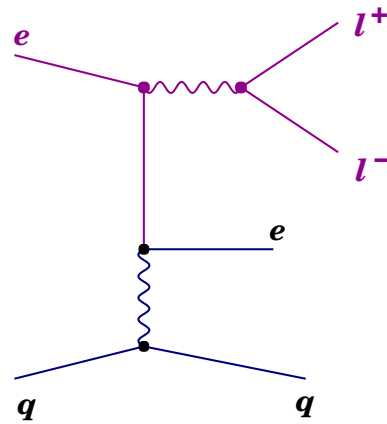
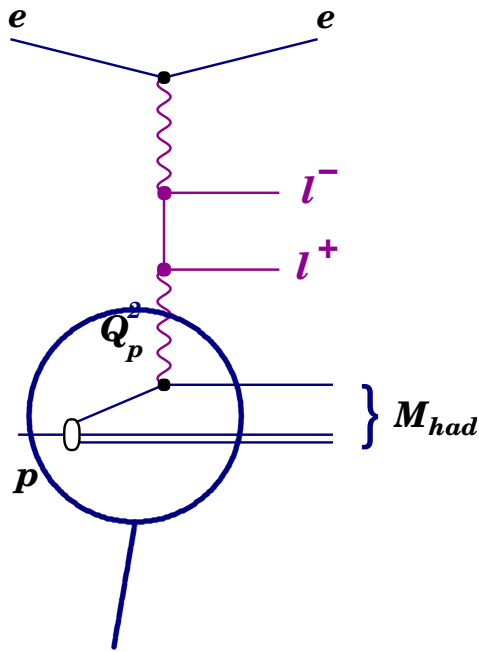
DIS: Quark-Parton-Model

MC Simulation: GRAPE

Electroweak tree-level

ISR + FSR

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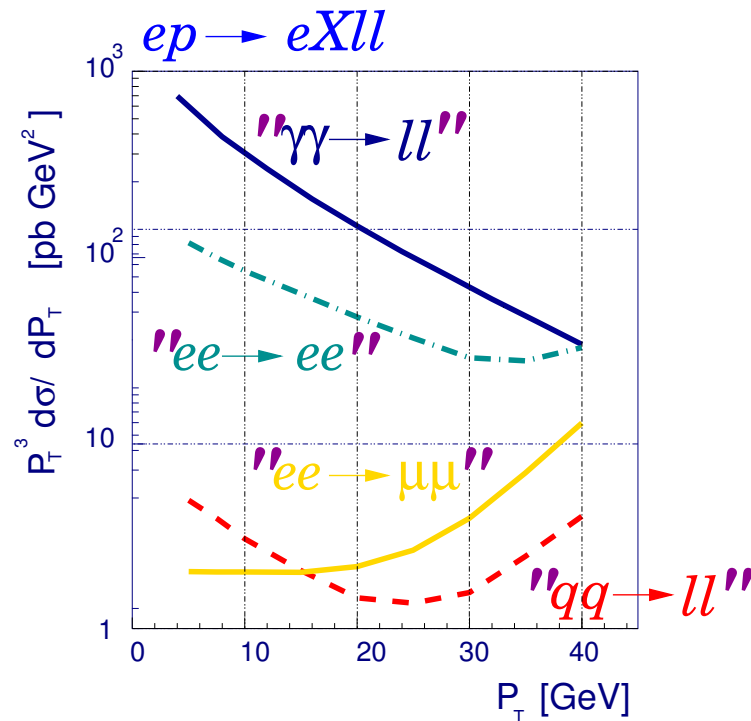
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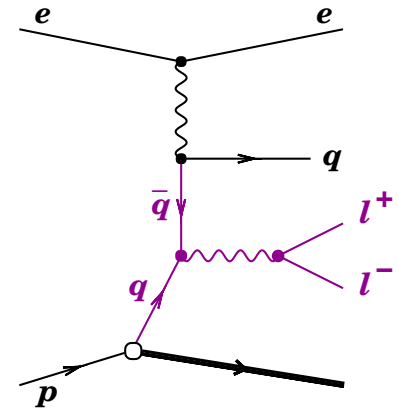
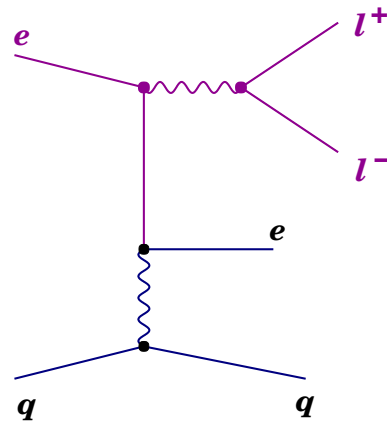
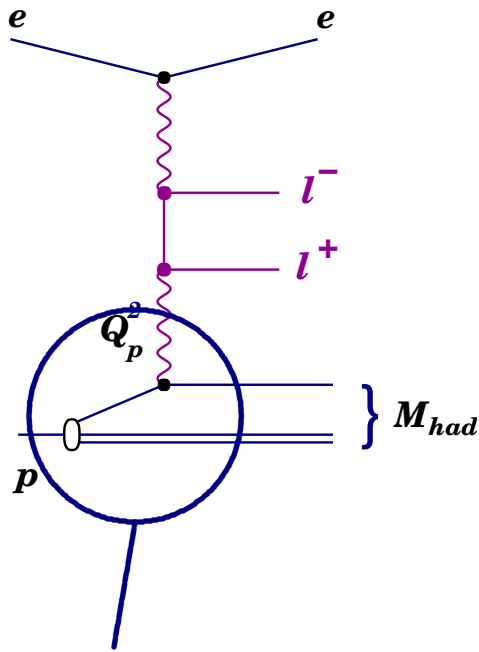
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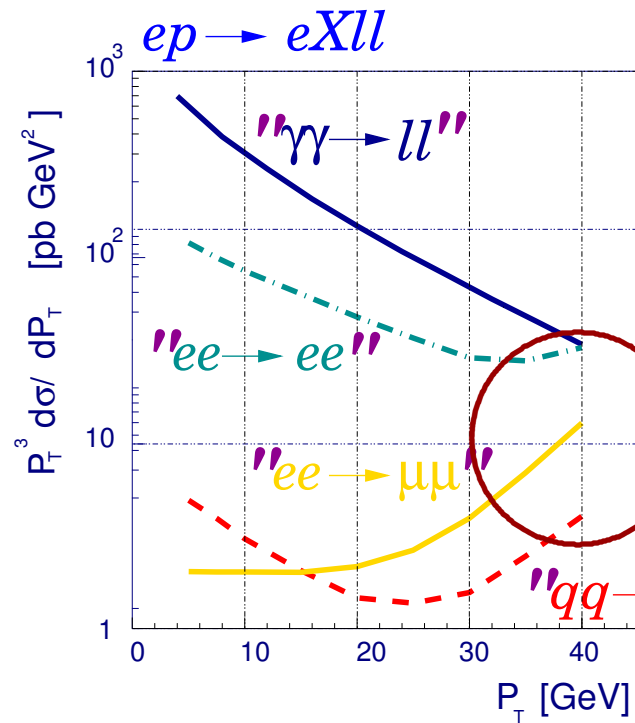
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MC Simulation: **GRAPE**

Electroweak tree-level
 ISR + FSR



$\gamma\gamma$ process dominant!

$ee \rightarrow ee$:
 Annihilation + Scattering
 $ee \rightarrow \mu\mu$:
 Annihilation

Z^0 impact
 Drell-Yan negligible

Multi Lepton Selection at HERA

Two isolated central leptons:

$$20^\circ < \theta < 160^\circ$$

- **Muons:**

Inner track + muon signature
in calorimeter or muon detector

- **Electrons:**

Calorimeter signature + track

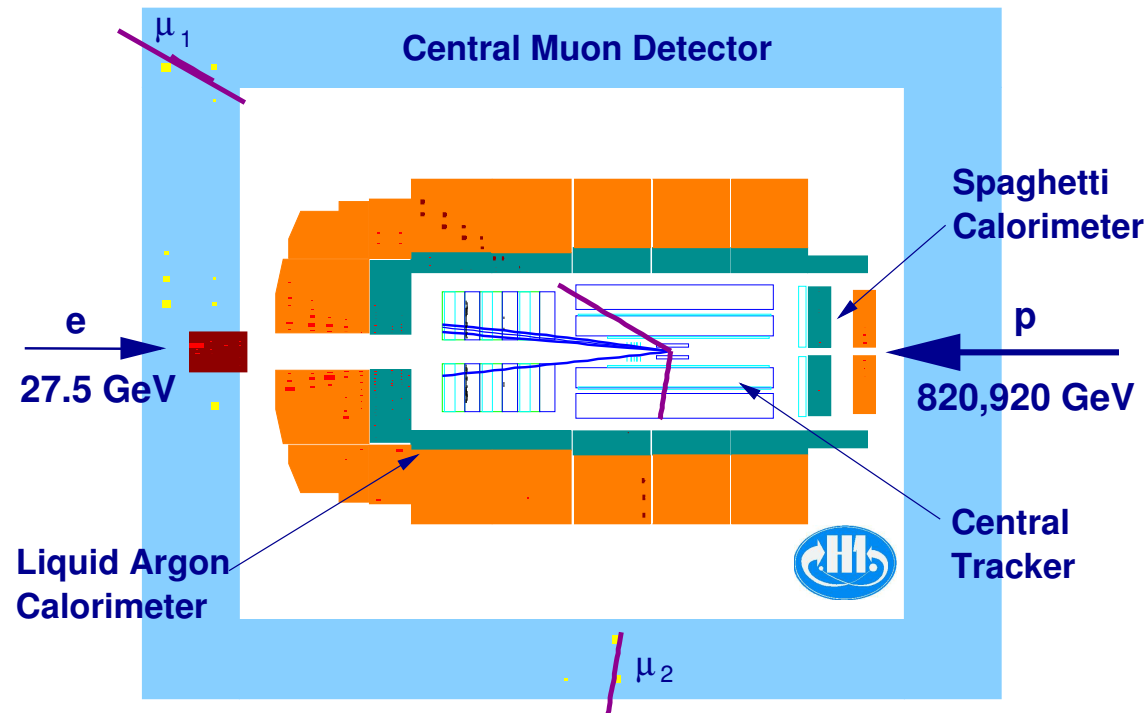
H1: $E_e > 5 \text{ GeV}$

ZEUS: $E_e > 10 \text{ GeV}$

$$17^\circ < \theta_e < 164^\circ$$

Additional 3rd electron identified:

$$5^\circ \lesssim \theta_e \lesssim 175^\circ$$



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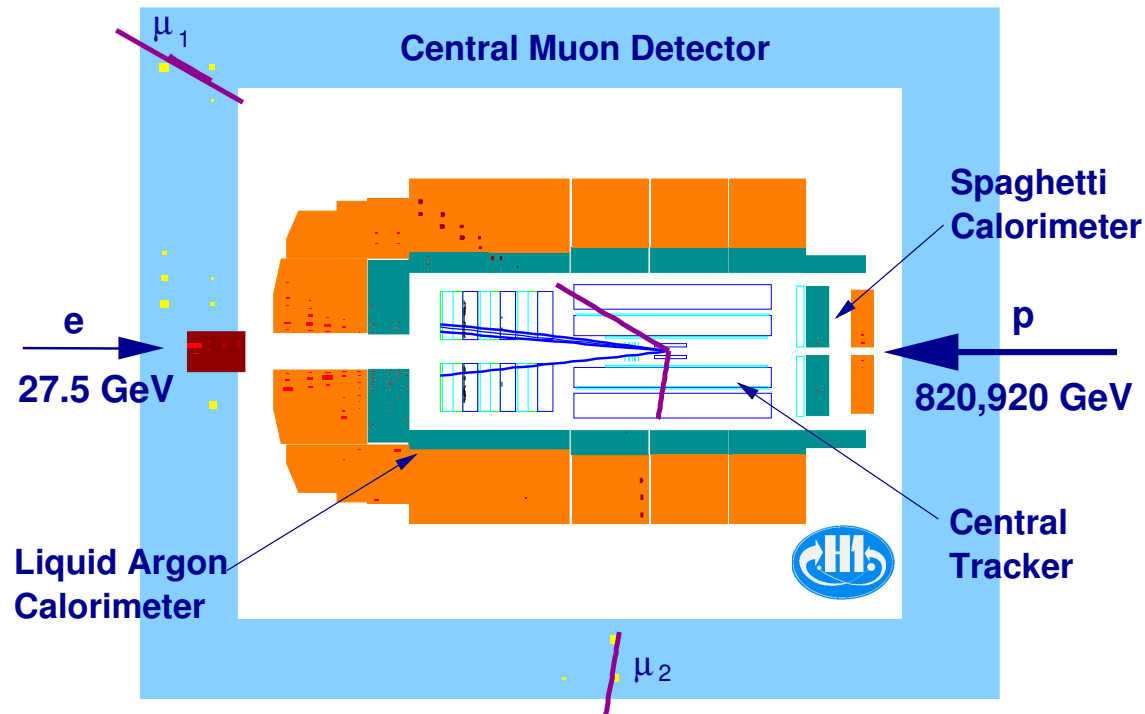
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		$P_{t,min}^{l1}$ [GeV]	$P_{t,min}^{l2}$ [GeV]
	$\mu\mu$	2.0	1.75
	ee	10.0	5.0
	$\mu\mu$	5.0	5.0
	ee	10.0	—

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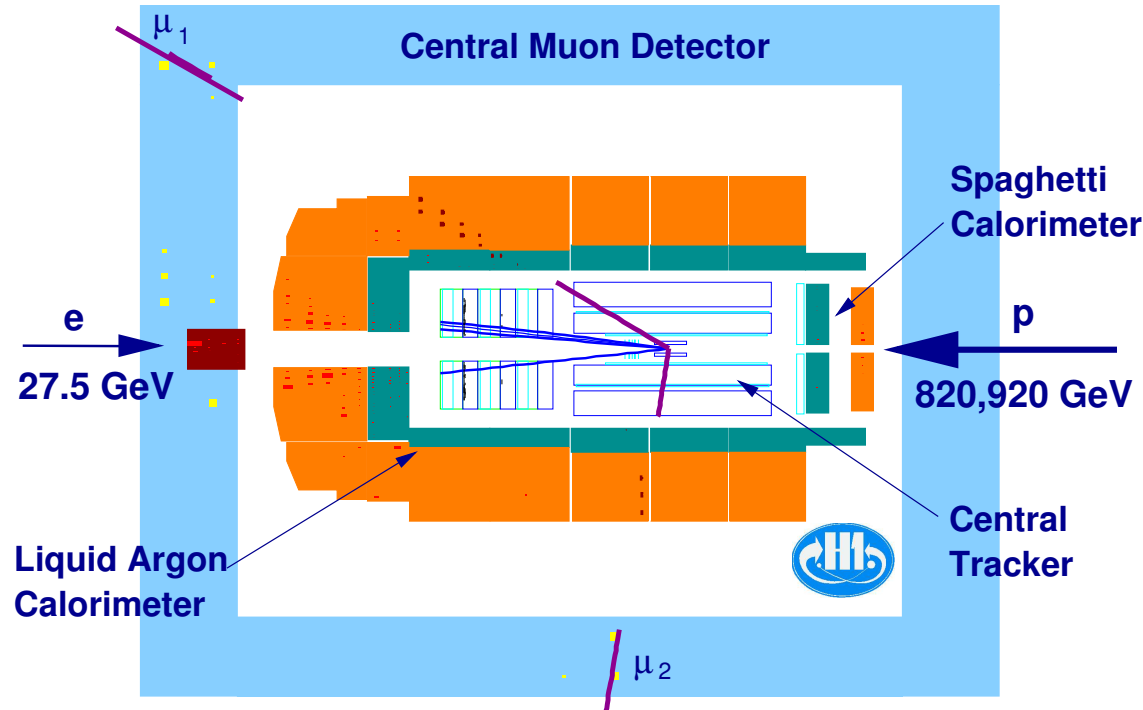
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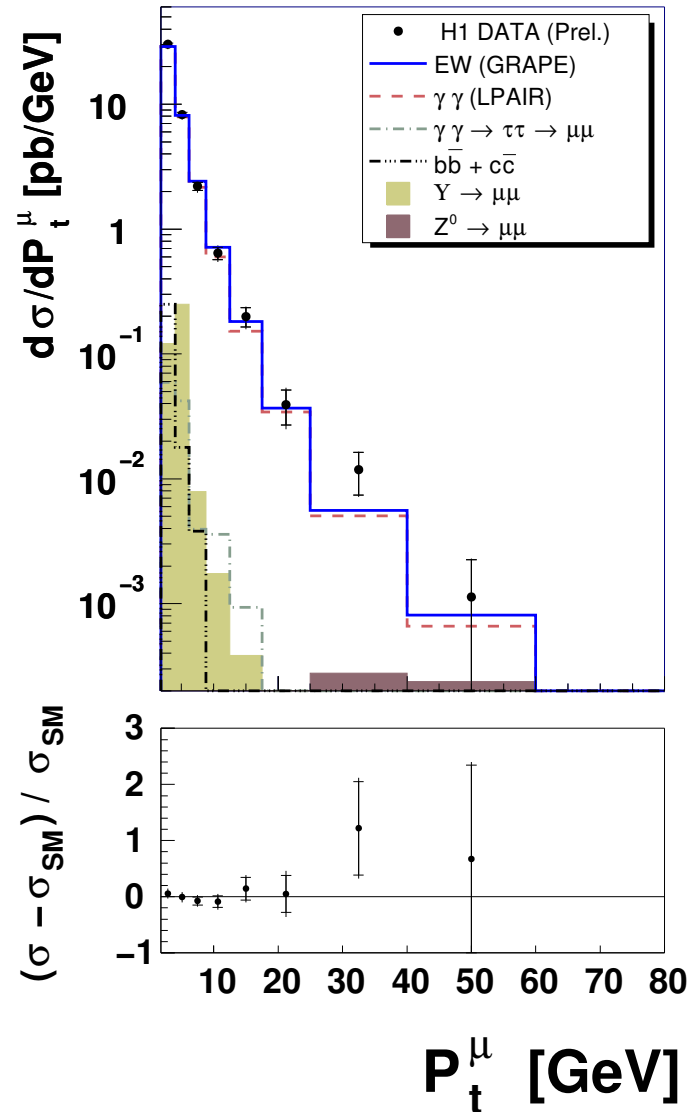
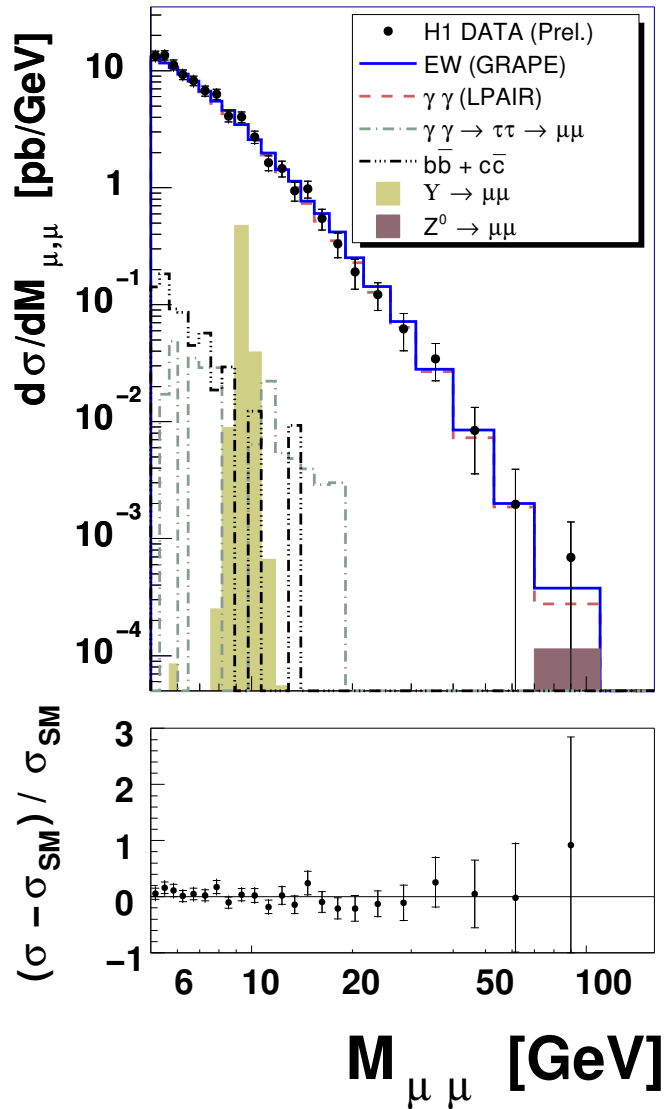
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Cross Sections - Muon Pair Production at H1



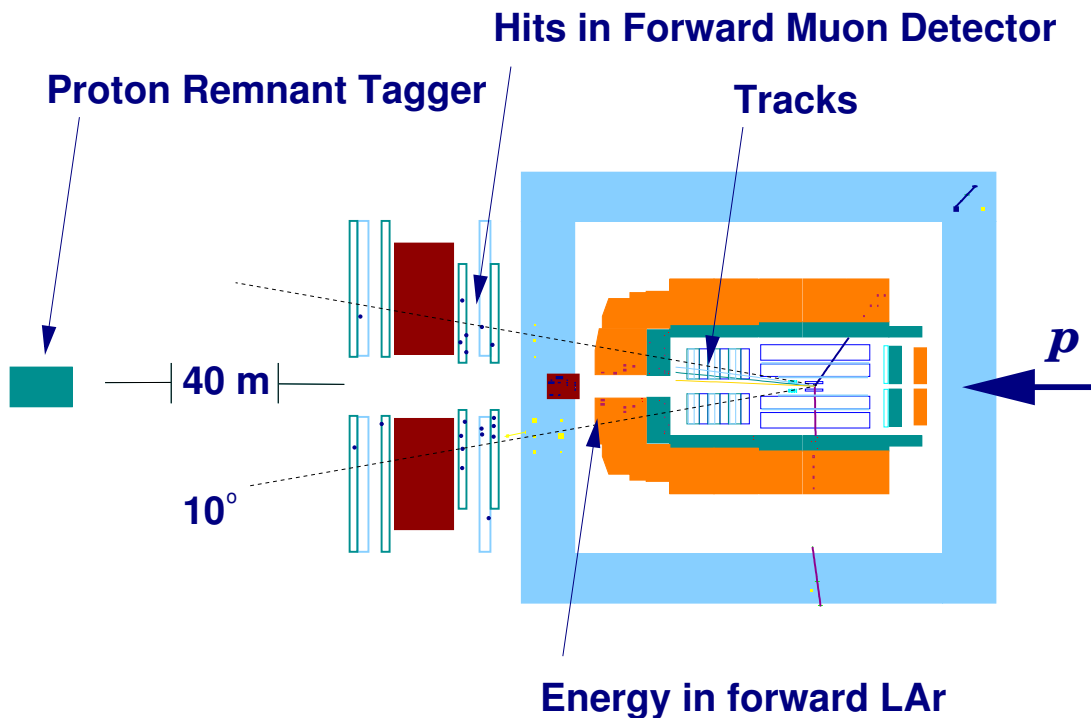
$\mathcal{L} = 71 \text{ pb}^{-1}$
 $\sqrt{s} = 318 \text{ GeV}$

➡ Good agreement over 4 decades with SM

Elastic and Inelastic Production Processes

- **elastic:** $ep \longrightarrow e\mu\mu$
 $M_{had} = M_P$

- **inelastic:** $ep \longrightarrow e\mu\mu X$
 $M_{had} > M_P + M_\pi$

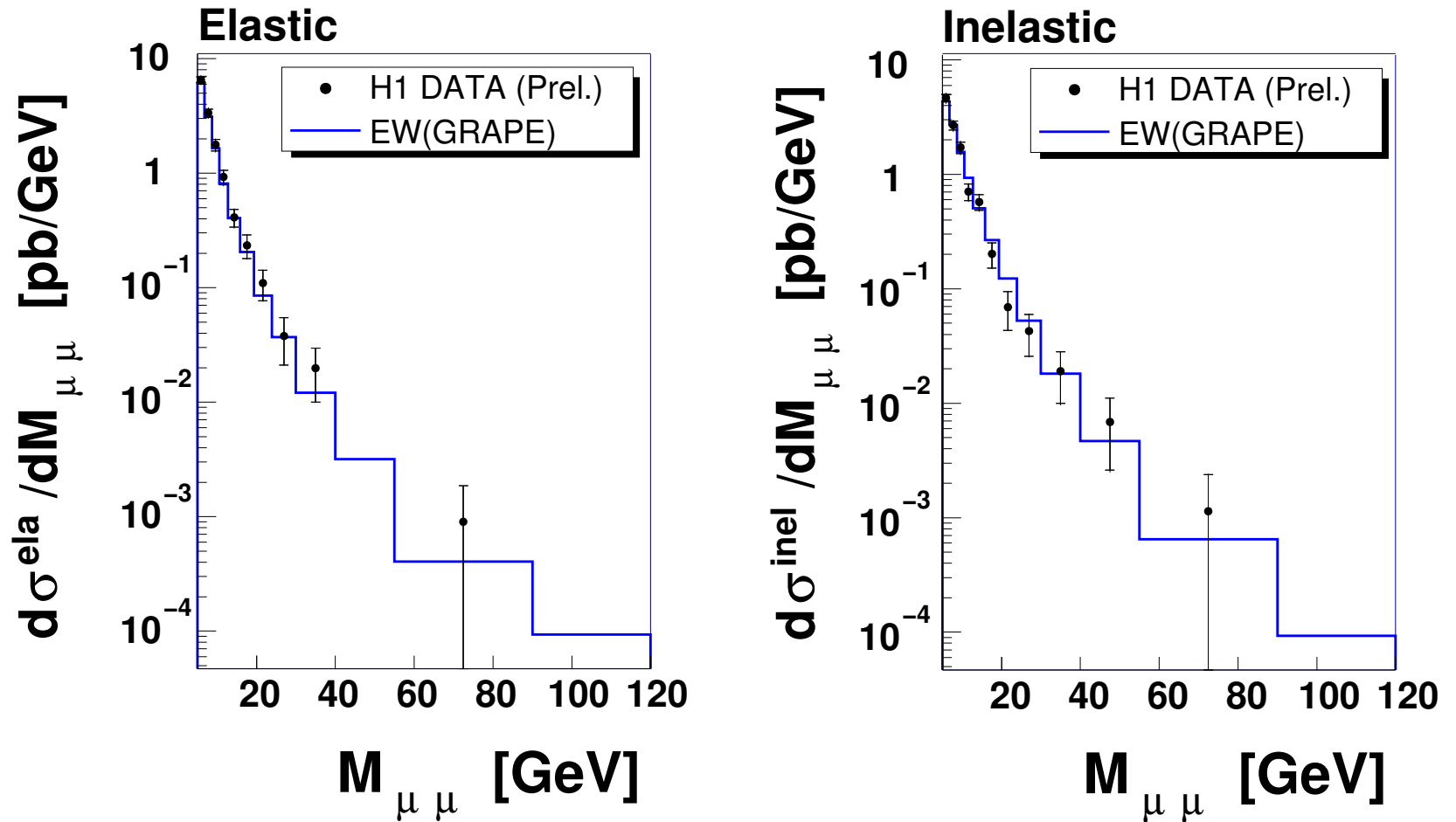


Tag of inelastic Events:

- Proton Remnant Tagger
- Forward Muon Detector
- LAr ($E_{\theta < 10^\circ}$)
- No additional Tracks

✎ tagging efficiency: 92 %
 tagging misidentification: 13 %

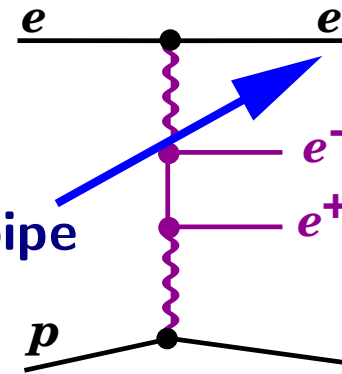
Cross Sections - Elastic & Inelastic Muon Pairs



➡ Both processes are well described by the SM!

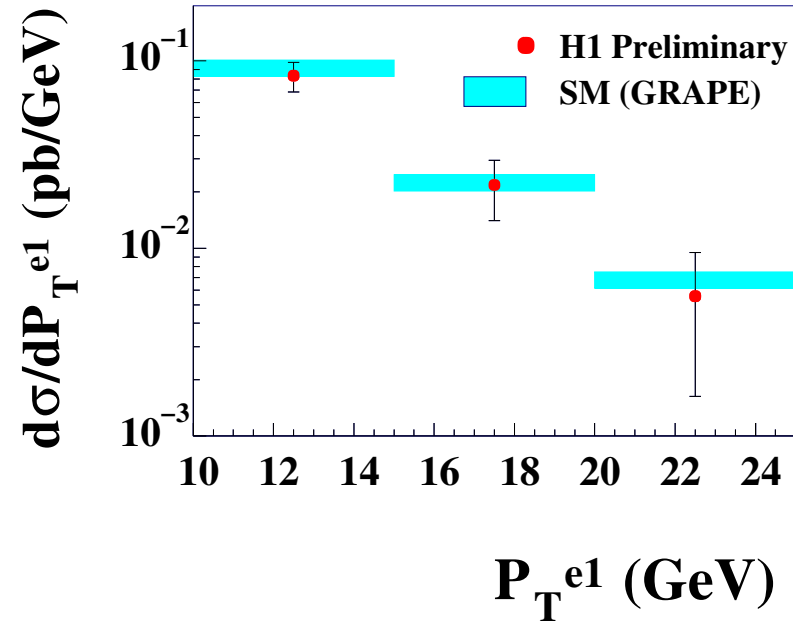
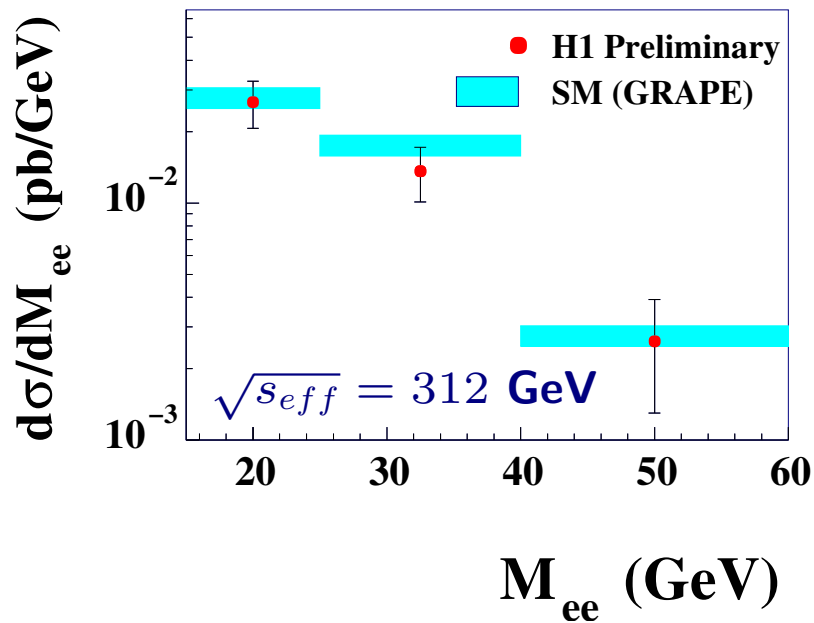
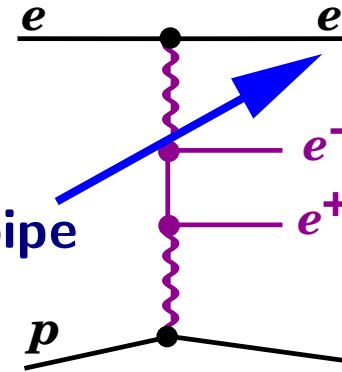
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$E - P_z < 45 \ll 2E_e \Rightarrow$ scattered e in beam pipe



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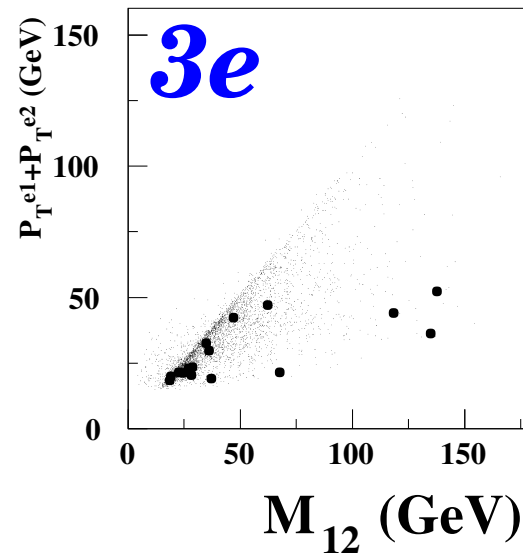
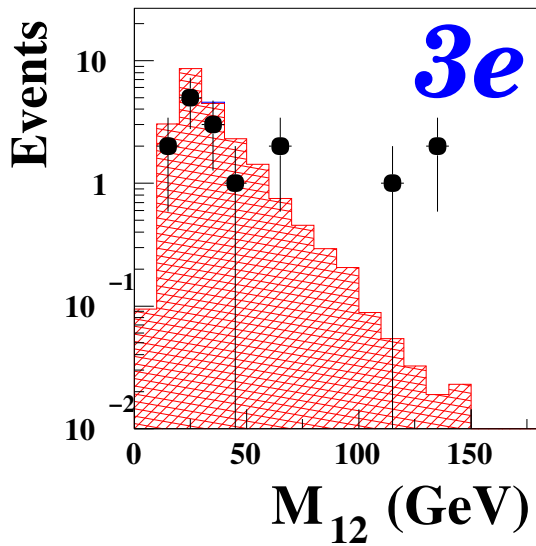
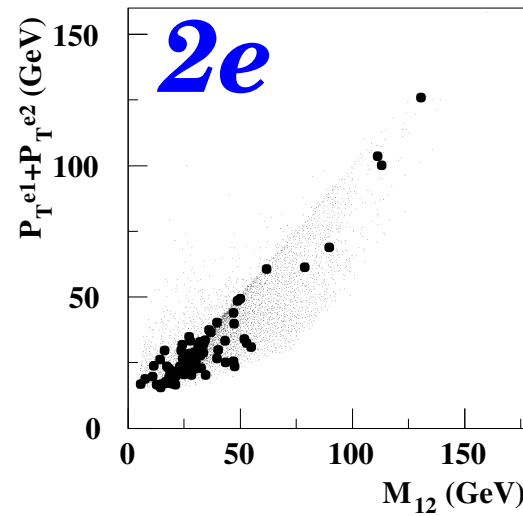
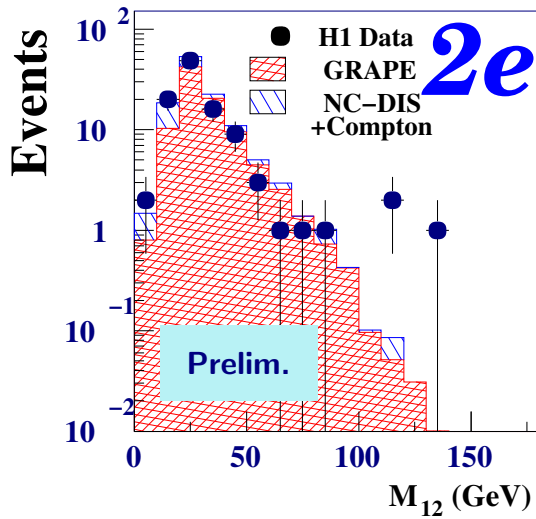
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Both cross sections are well described by the MC

Multi Leptons with High Mass - Electrons at H1

now: scattered may enter the detector!



Total:

Sample	Data	SM
2e	105	118.2 ± 12.8
3e	16	21.6 ± 3.0

$M_{12} > 100$ GeV:

Sample	Data	SM
2e	3	0.25 ± 0.05
3e	3	0.23 ± 0.04

➤ M_{12} = mass of the highest p_t electrons

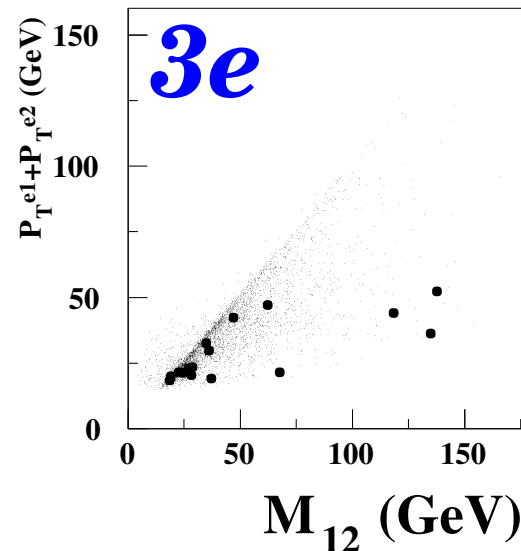
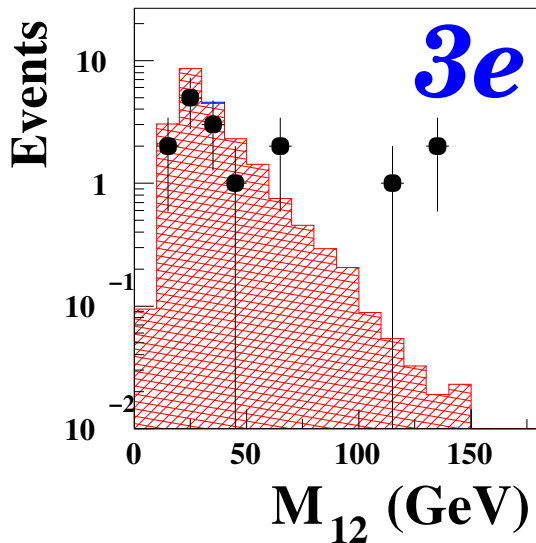
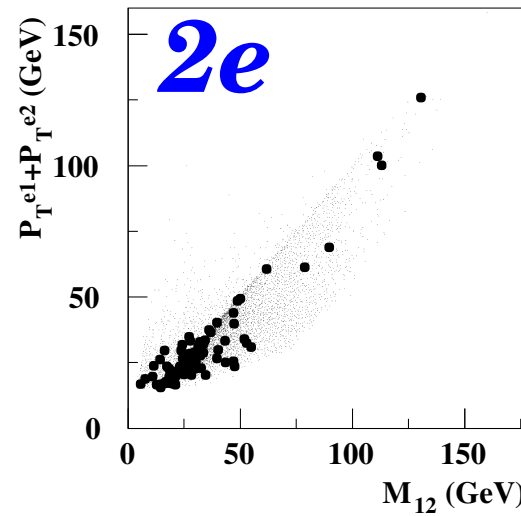
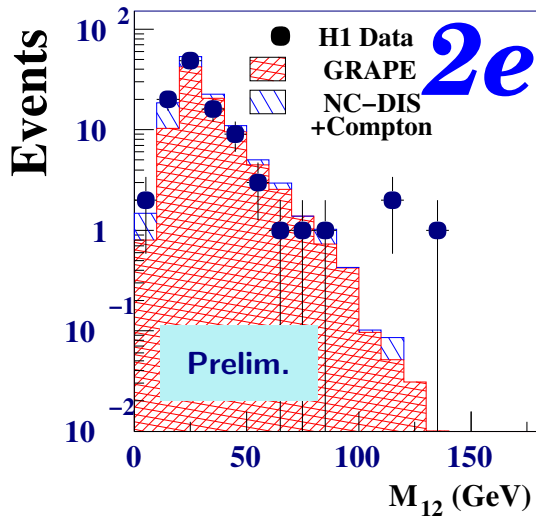
➤ $\mathcal{L} = 115 \text{ pb}^{-1}$



6 outstanding events at $M_{12} > 100$ GeV

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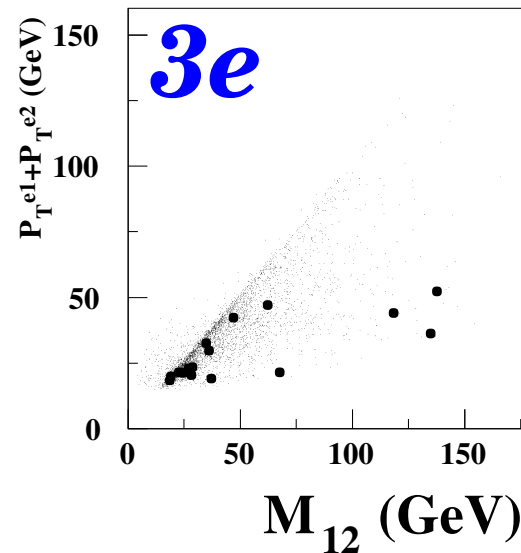
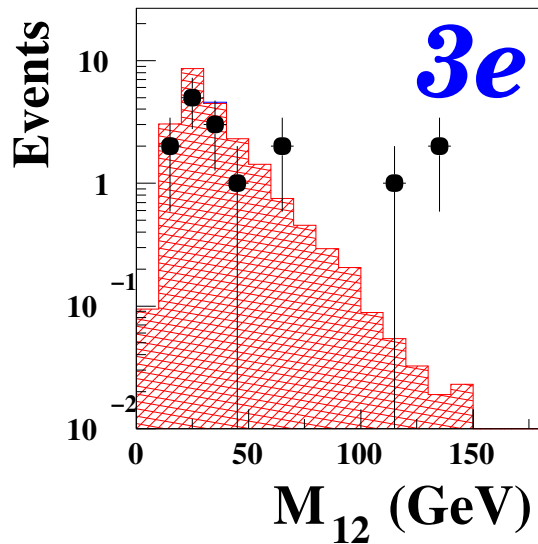
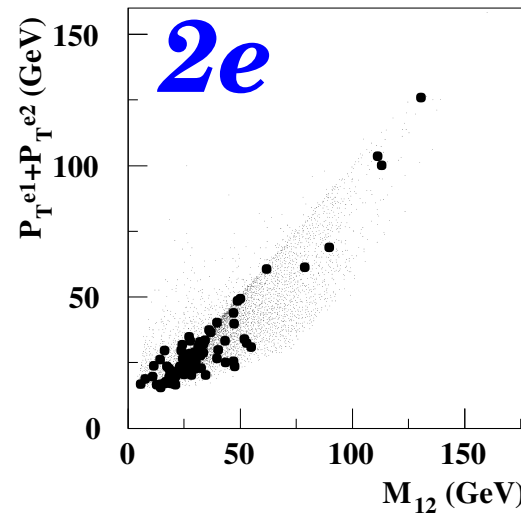
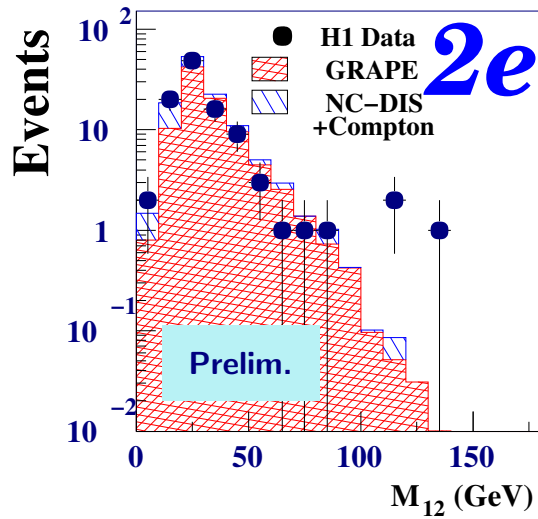
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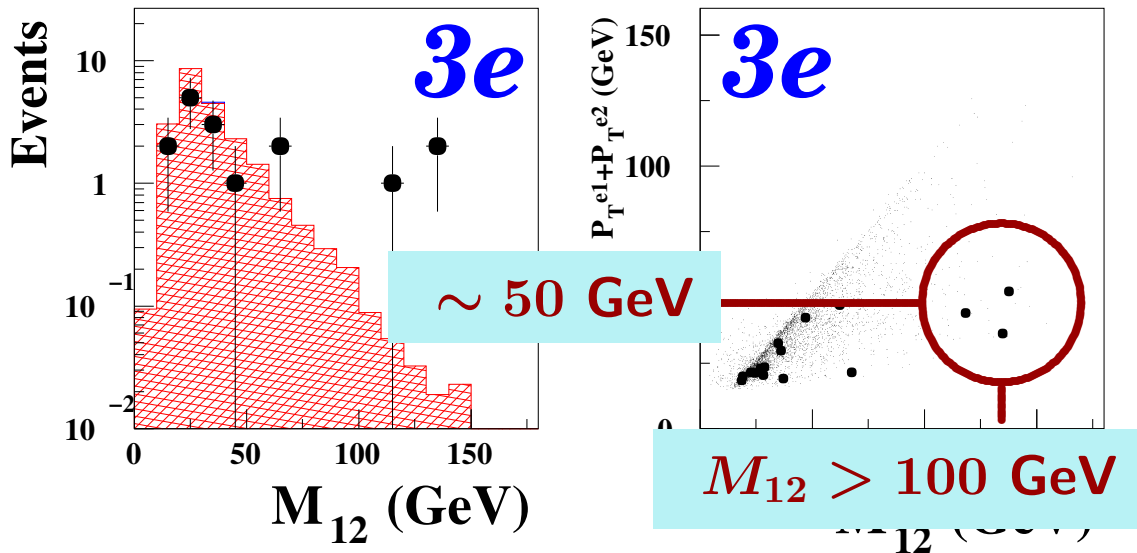
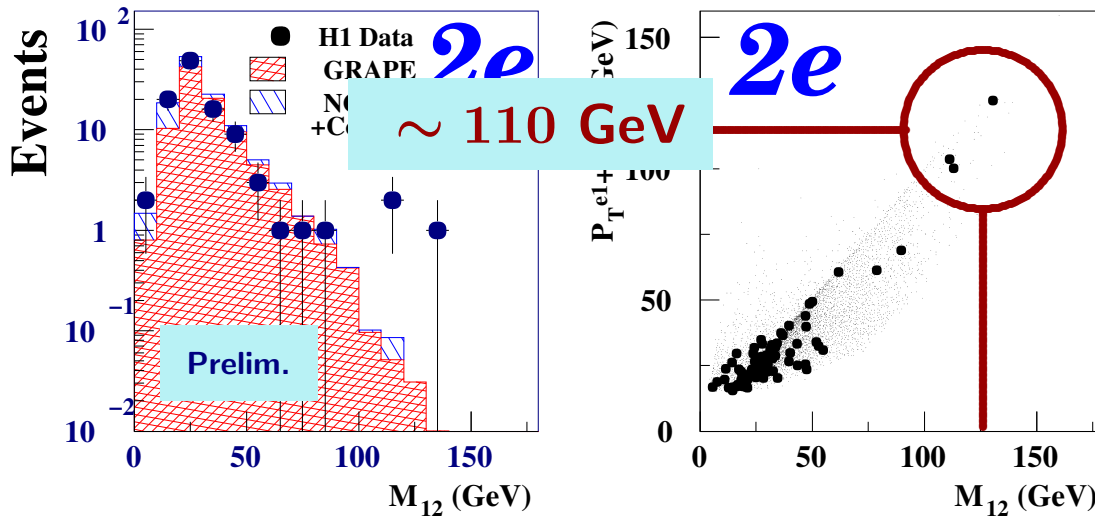
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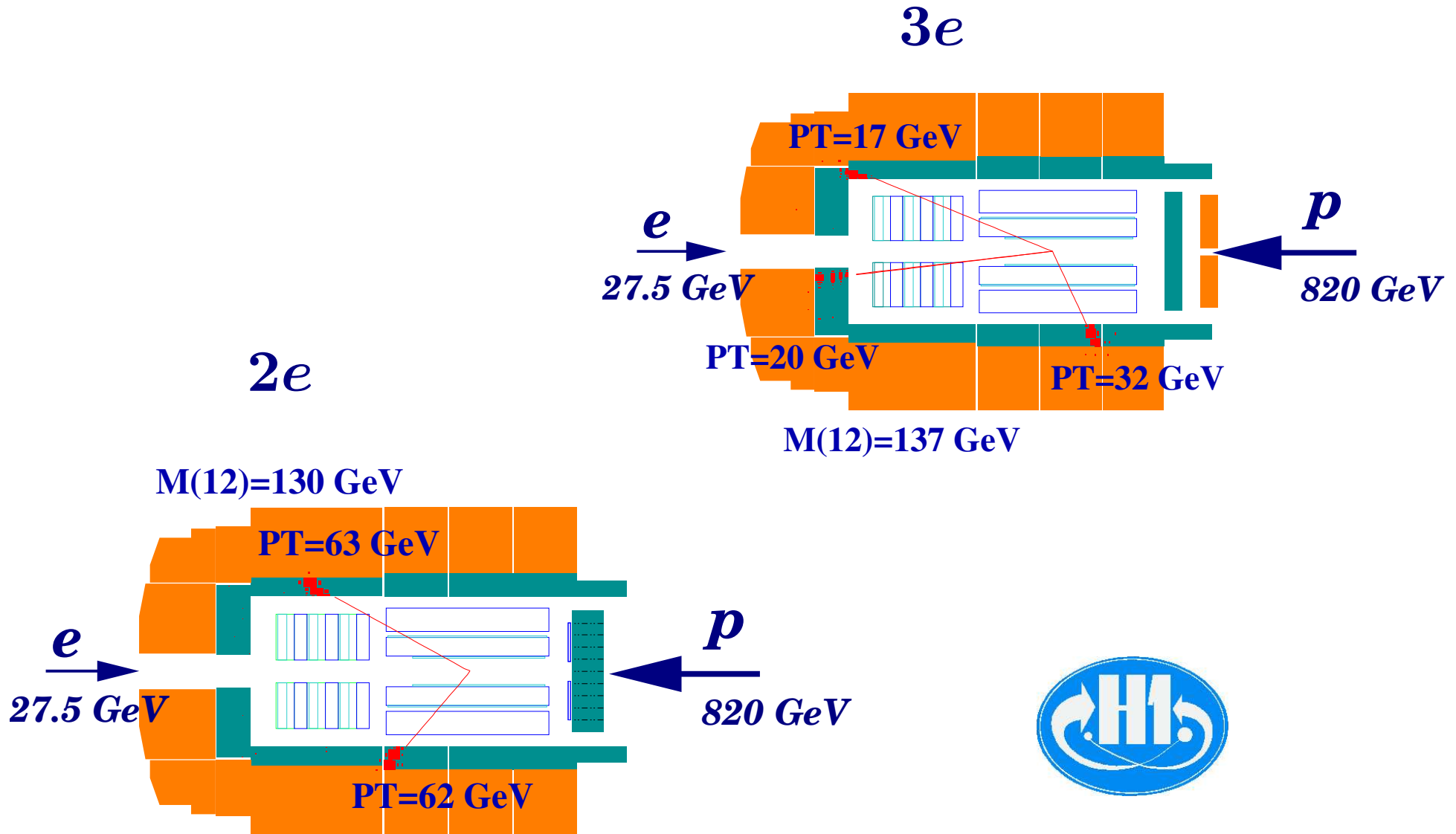
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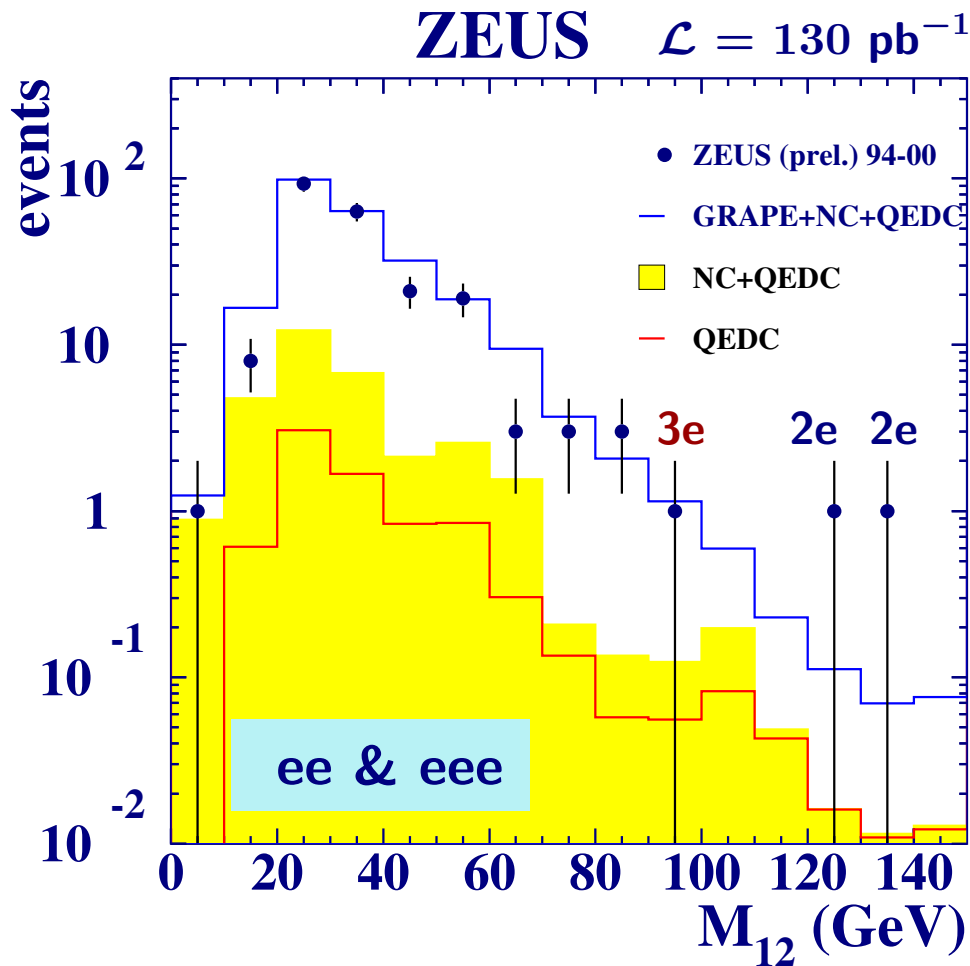


6 outstanding events at $M_{12} > 100 \text{ GeV}$

Multi Electrons Events with $M_{12} > 100$ GeV



Multi Leptons with high Mass - Electrons at ZEUS



Total:

Sample	Data	SM
2e	191	213.9 ± 3.9
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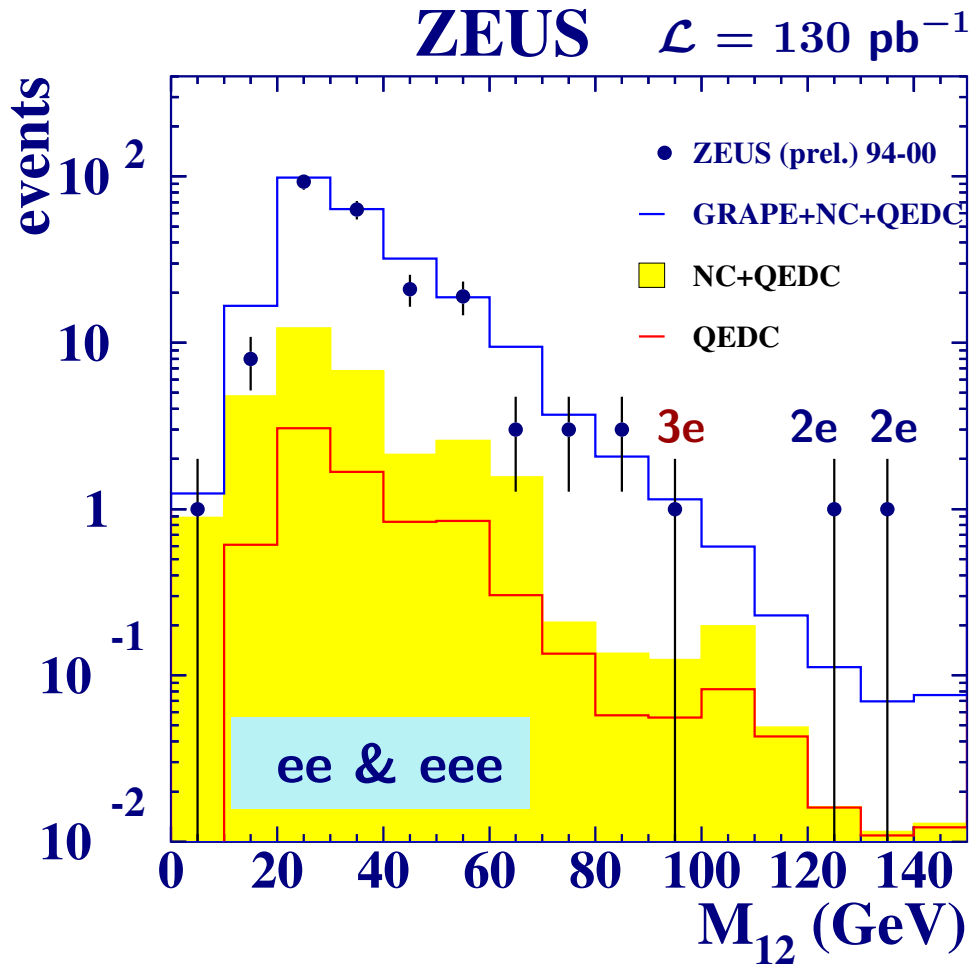


Data and MC are in good agreement!

Larger expectation than H1 due to:

- ▶ larger polar angular range
- ▶ higher background

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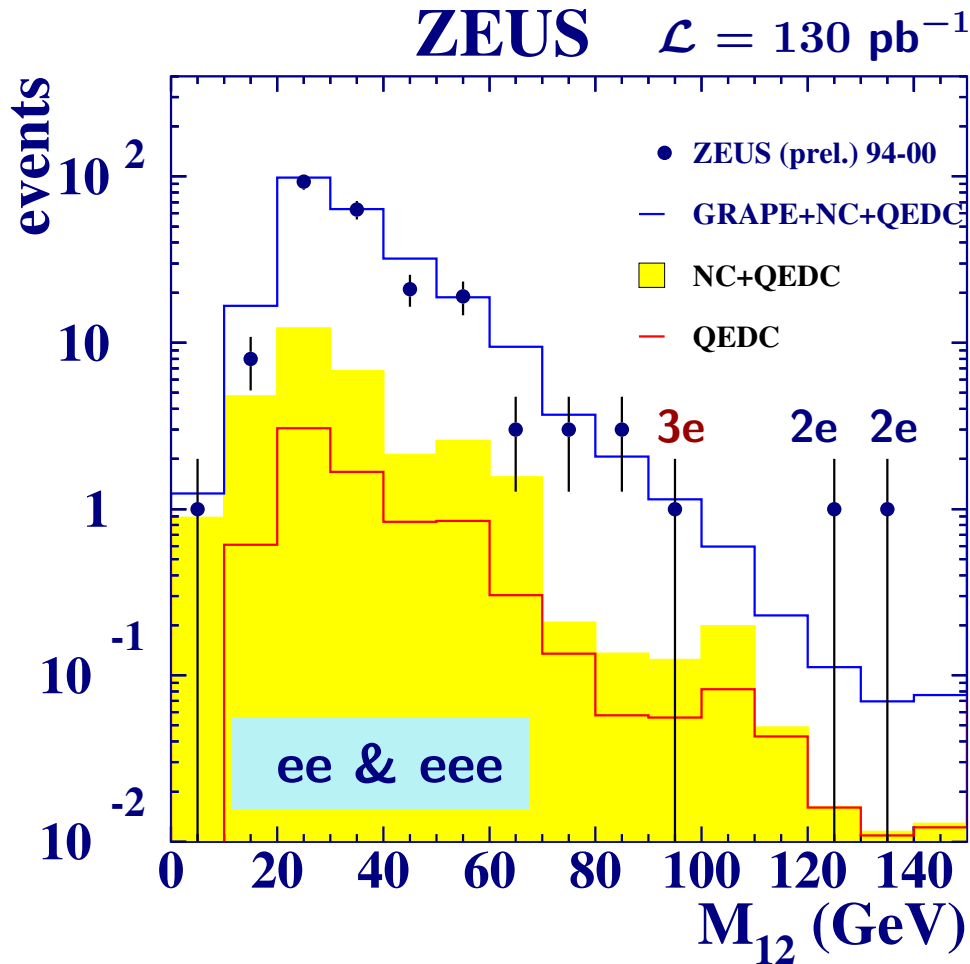


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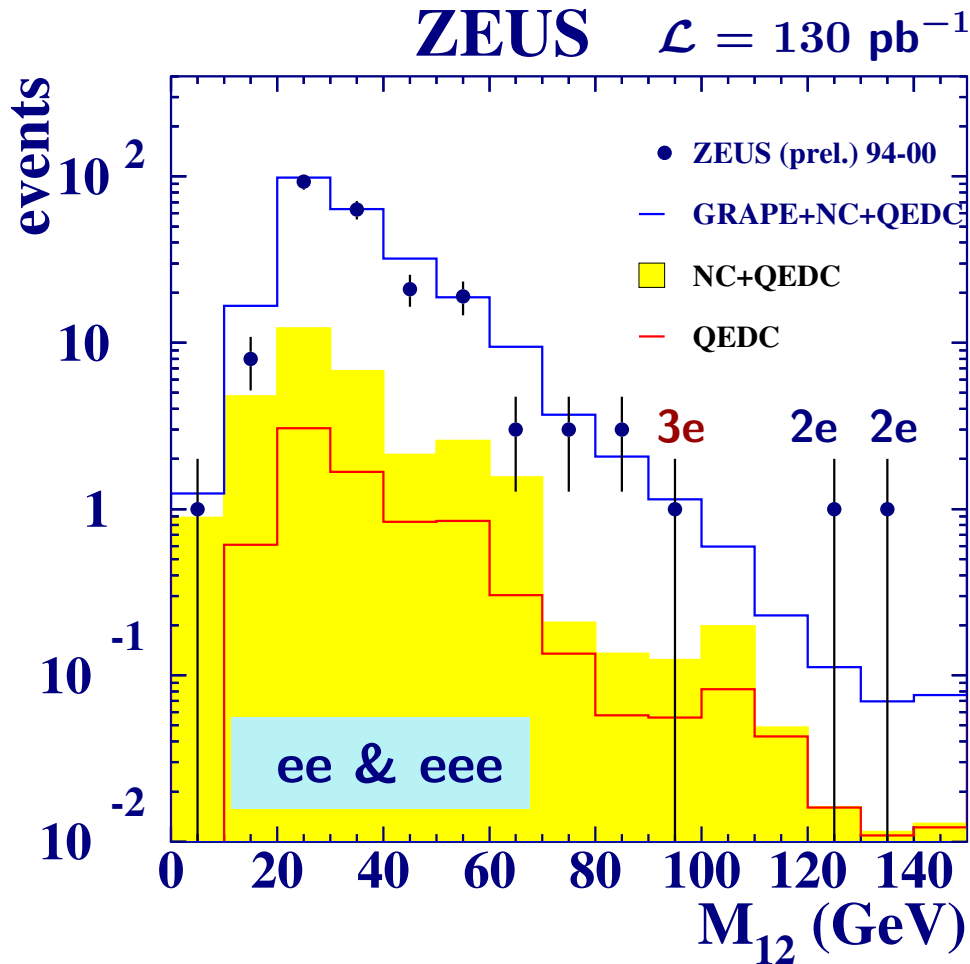
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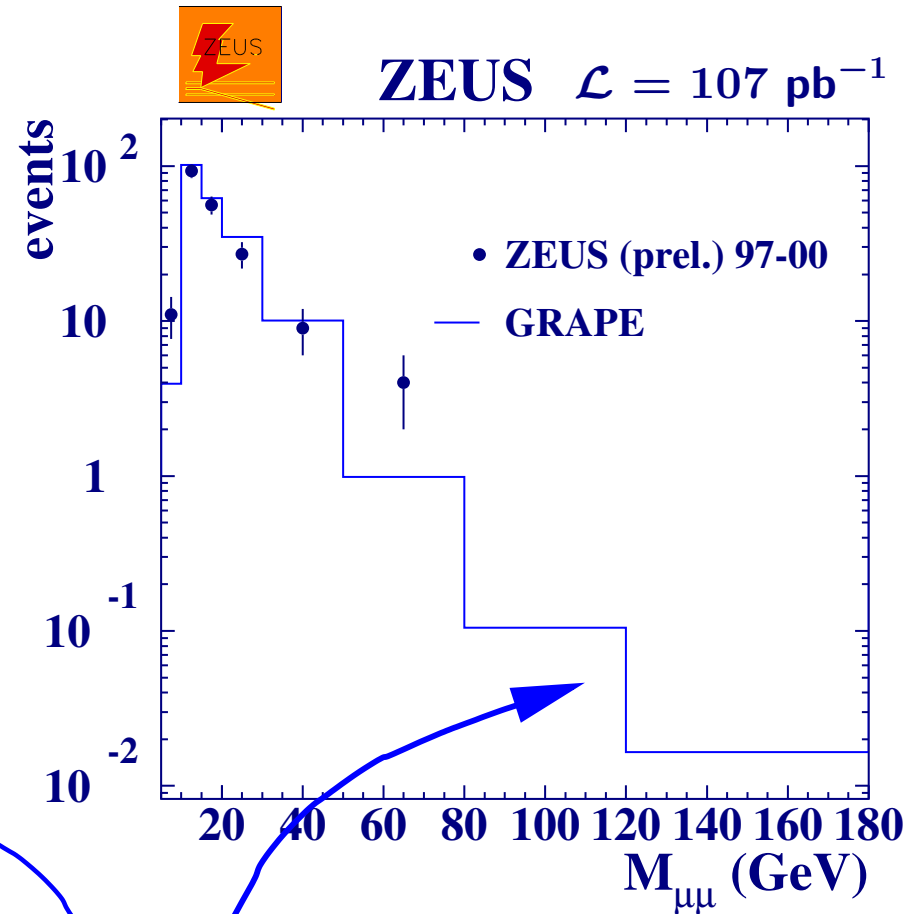
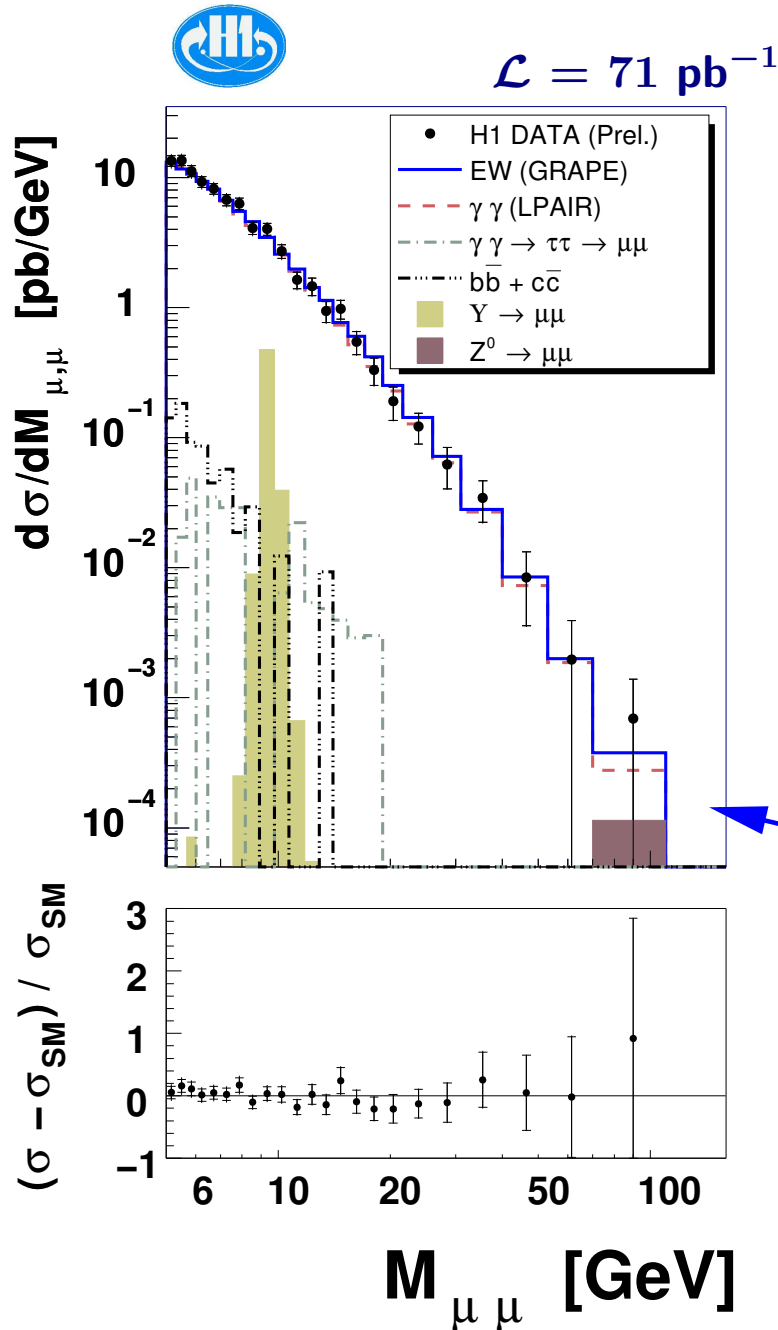
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Multi Leptons with high Mass - Muons at HERA



➡ No Events at $M_{\mu\mu} > 100 \text{ GeV}$!

Multi Leptons with high Mass - Muons at HERA



$\mathcal{L} = 71 \text{ pb}^{-1}$

• H1 DATA (Prel.)

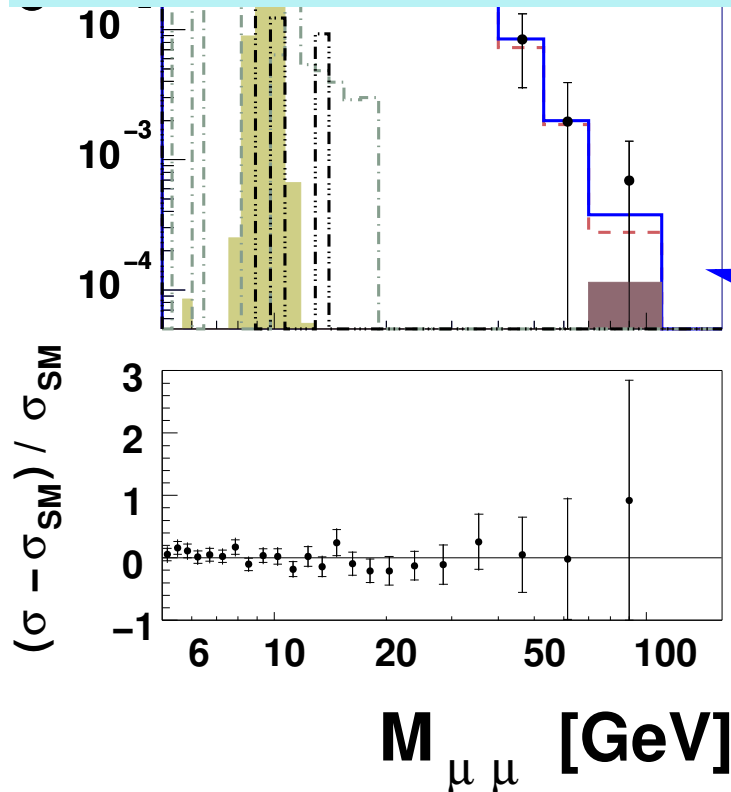
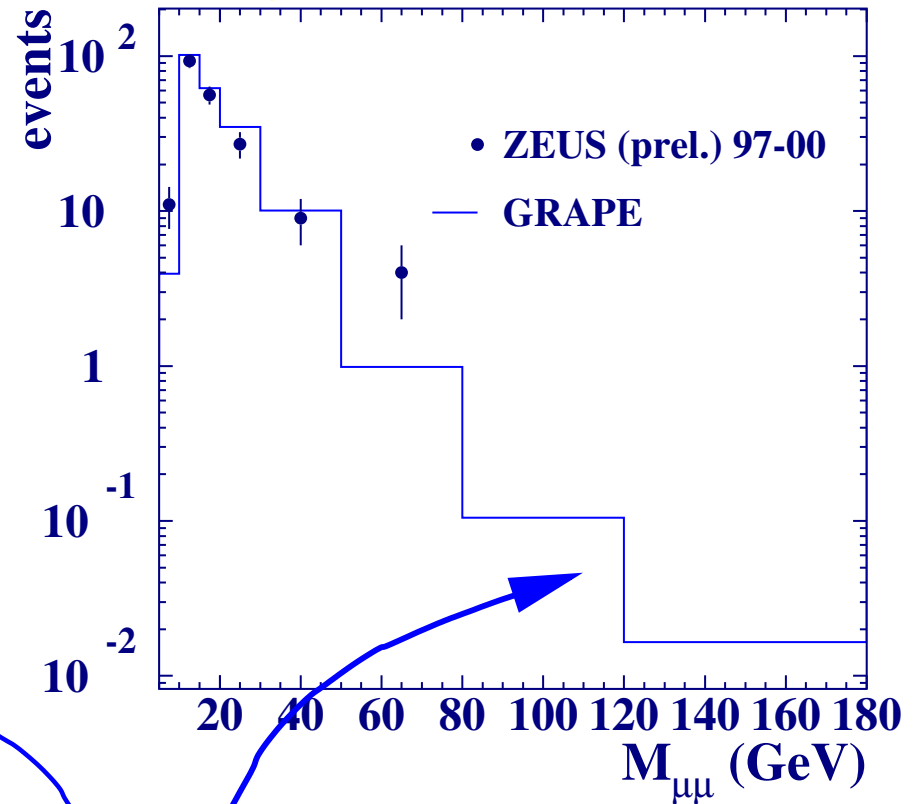
Expectation $M_{\mu\mu} > 100 \text{ GeV}$:

$\mu\mu$: $\lesssim 0.1$ events

ee : expectation factor 2 bigger
due to scattered electron
 $M_{12} \neq M_{ee}$!



ZEUS $\mathcal{L} = 107 \text{ pb}^{-1}$



☞ **No Events at $M_{\mu\mu} > 100 \text{ GeV}$!**

Doubly Charged Higgs at H1

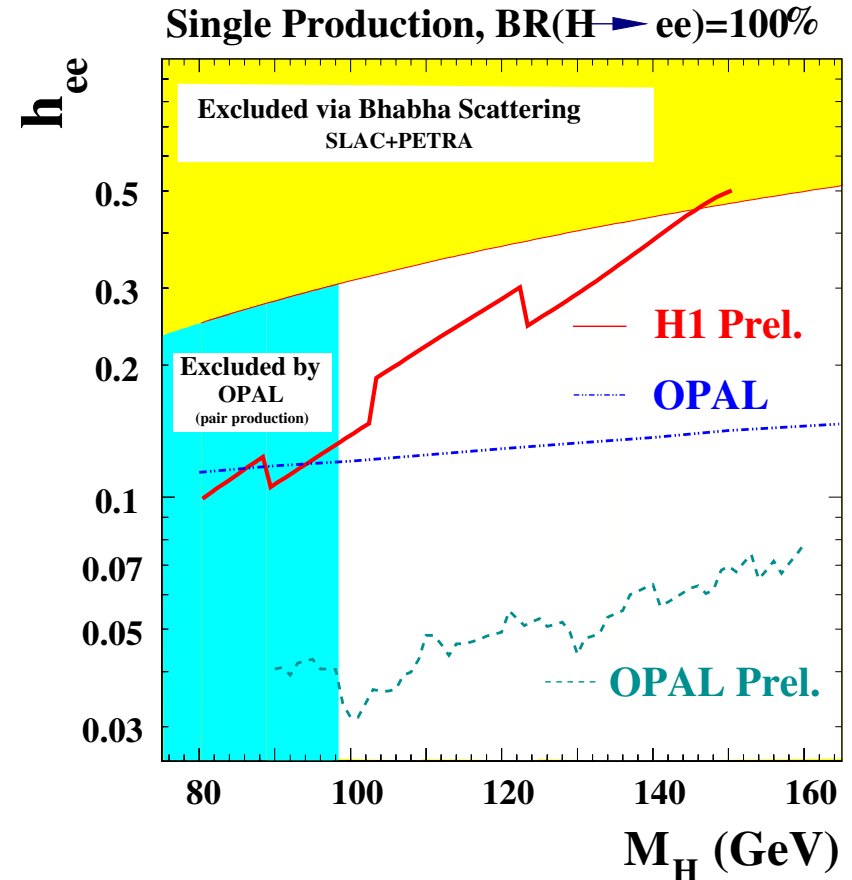
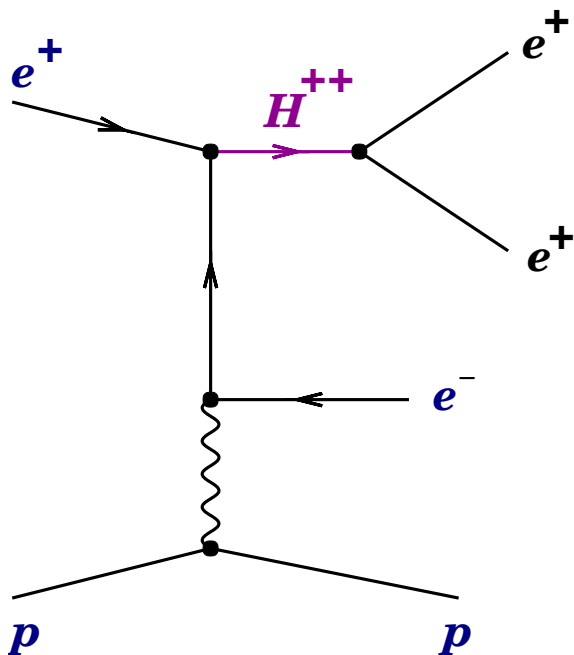
SUSYRL

$$\rightarrow H_{R,L} = (H_{R,L}^0, H_{R,L}^+, H_{R,L}^{++})$$

$$\rightarrow \text{decay modes: } H^{++} \rightarrow \mu^+ e^+$$

$$H^{++} \rightarrow e^+ e^+$$

$$H^{++} \rightarrow \mu^+ \mu^+$$



➡ Only 1 event of the 6 high mass events is kinematically compatible with $H^{\pm\pm}$ (Charge $\pm \sum p_t^e$)

Conclusions

● Cross Sections for Lepton Pair Production

$\mu\mu$: Inclusive, Separation Elastic & Inelastic

ee : $y < 0.82$, $Q^2 < 1$

☞ All measured cross sections agree well with the SM !

● Multi Leptons at high Mass

☞ No high mass events in $\mu\mu$!

☞ ZEUS: Good agreement in 2e/3e

☞ H1: Access in 2e/3e ?

$M_{12} > 100$ GeV:

	DATA	SM
$\mu\mu$	0	$\lesssim 0.1$
ZEUS 2e	2	0.77 ± 0.08
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ee : $y < 0.82$, $Q^2 < 1$

☞ All measured cross sections agree well with the SM !

- Multi Leptons at high Mass

☞ No high mass events in $\mu\mu$!

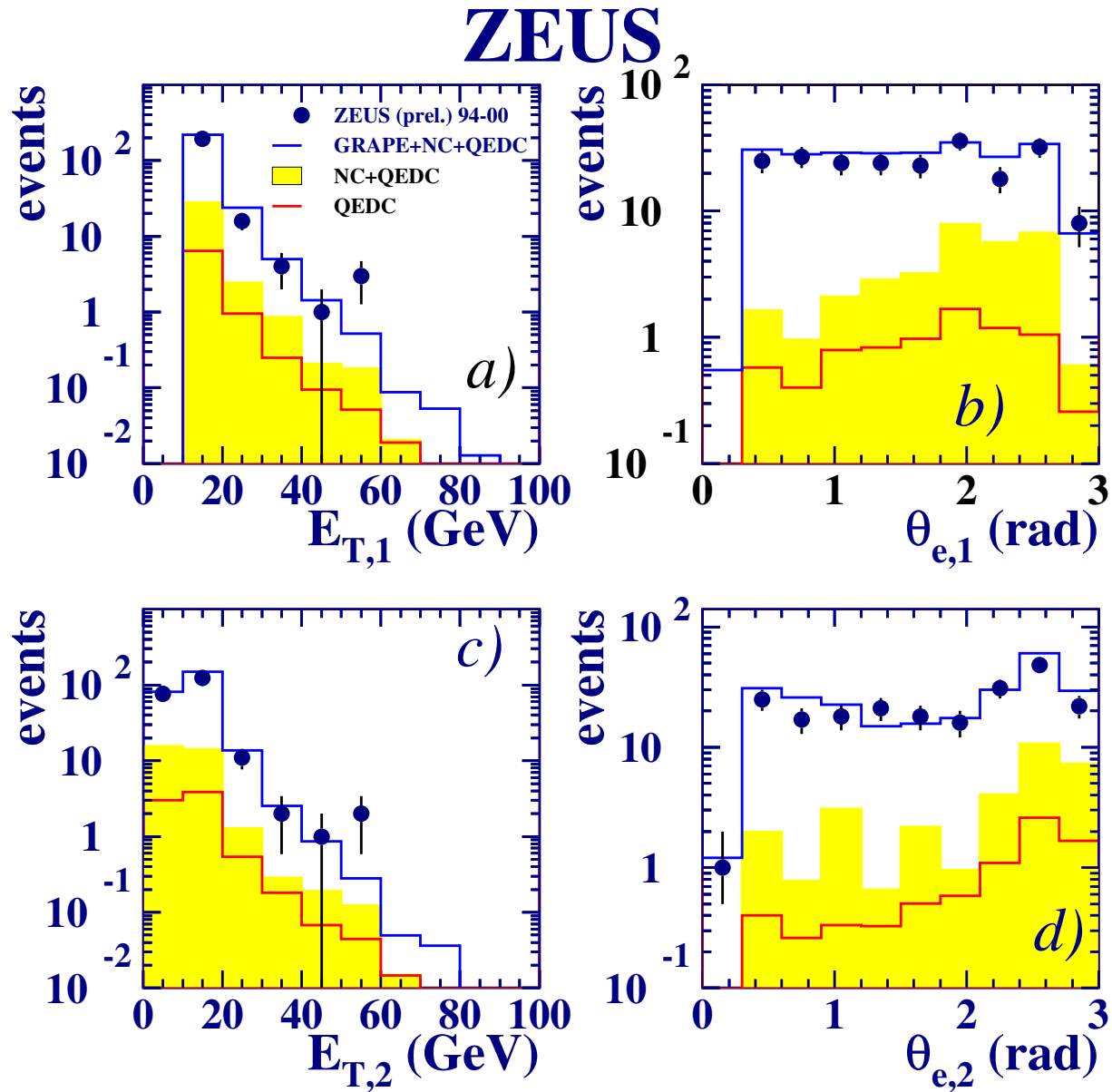
☞ ZEUS: Good agreement in 2e/3e

☞ H1: Access in 2e/3e ?

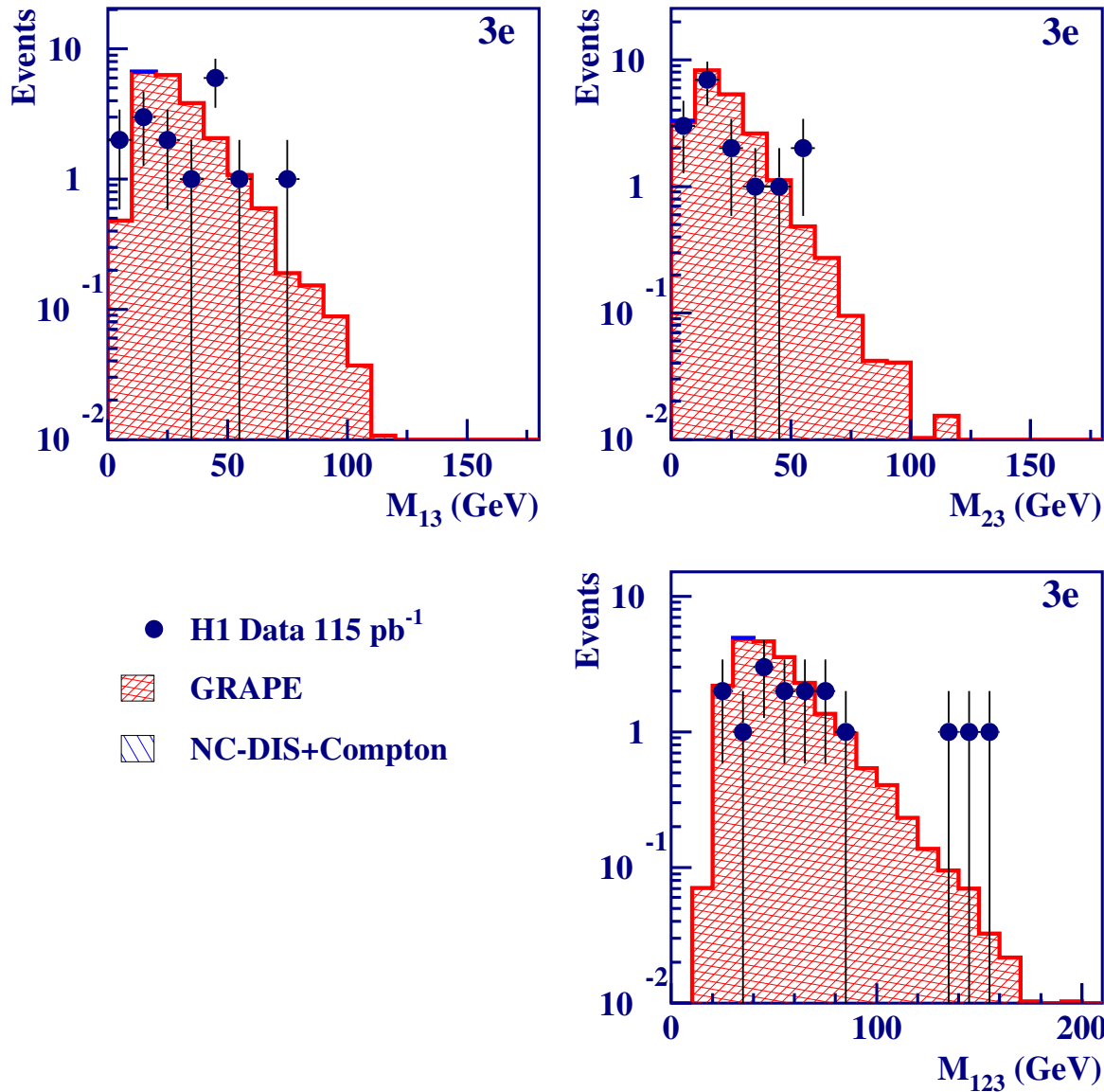
$M_{12} > 100$ GeV:

	DATA	SM
$\mu\mu$	0	$\lesssim 0.1$
ZEUS 2e	2	0.77 ± 0.08
3e	0	0.37 ± 0.04
$\mu\mu$	0	$\lesssim 0.1$
H1 2e	3	0.25 ± 0.05
3e	3	0.23 ± 0.04

Additional Plots - ZEUS: E_T^e & θ^e Distributions



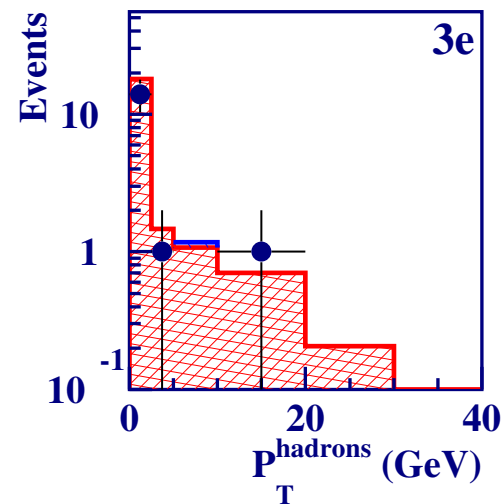
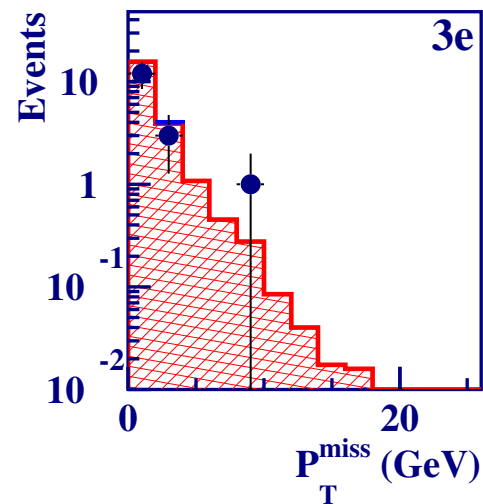
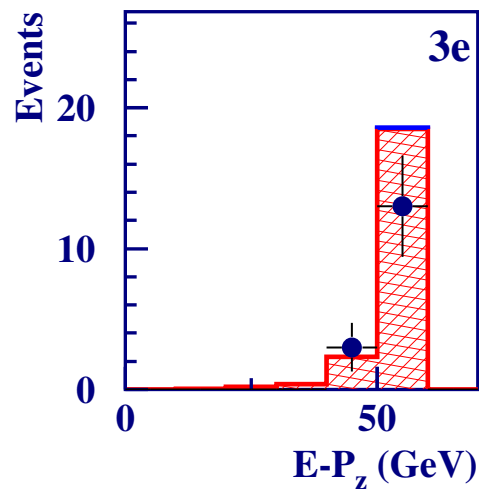
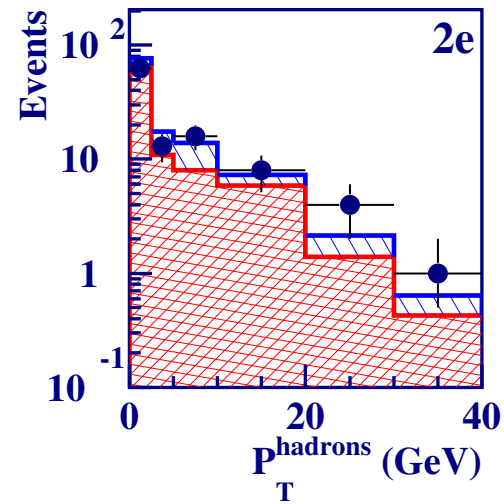
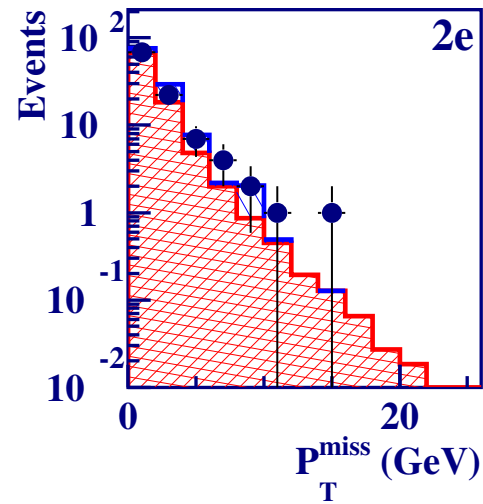
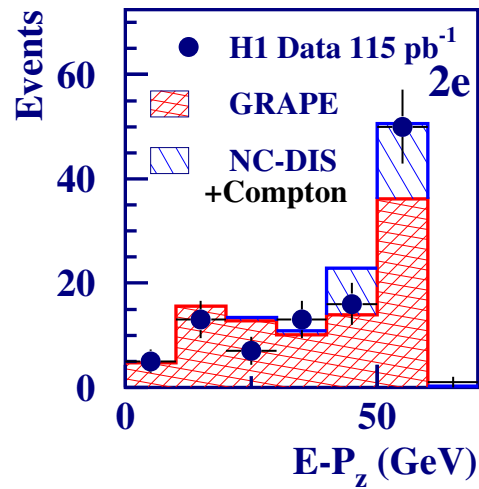
Additional Plots - H1: Electron Mass Distributions



Additional Plots - H1: More Electron Distributions I

H1 Preliminary

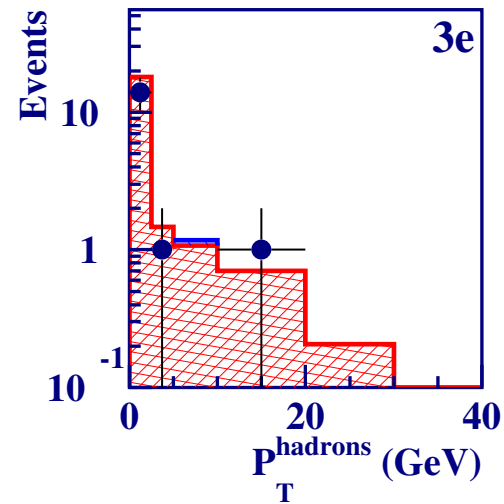
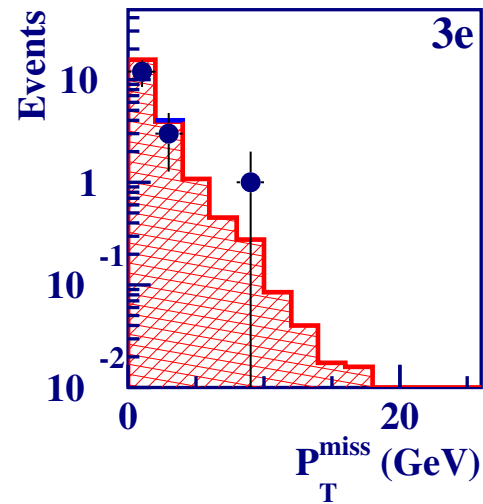
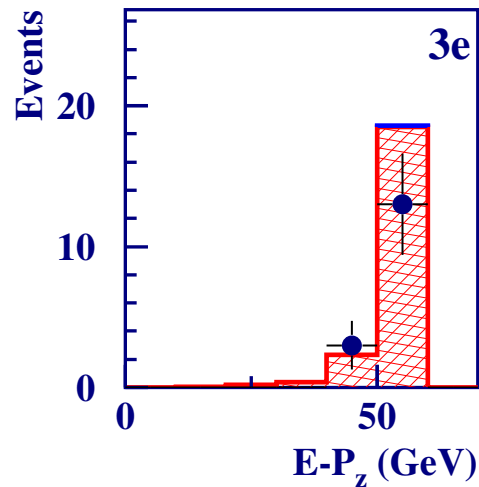
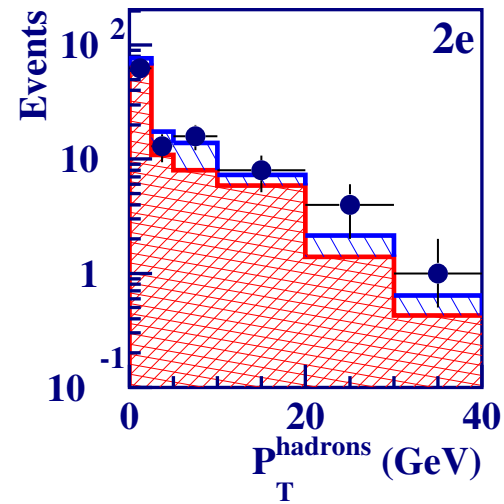
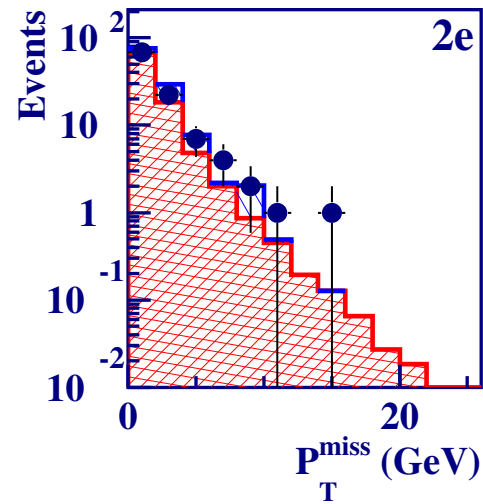
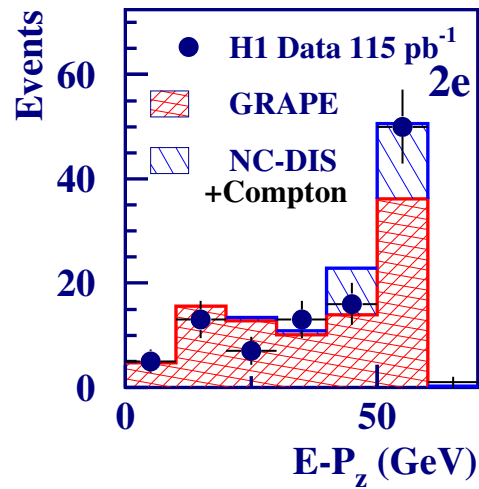
Multi-electron Analysis



Additional Plots - H1: More Electron Distributions II

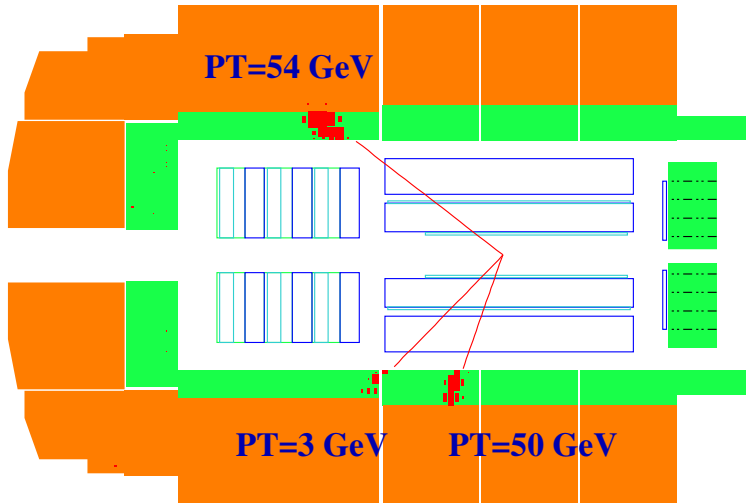
H1 Preliminary

Multi-electron Analysis



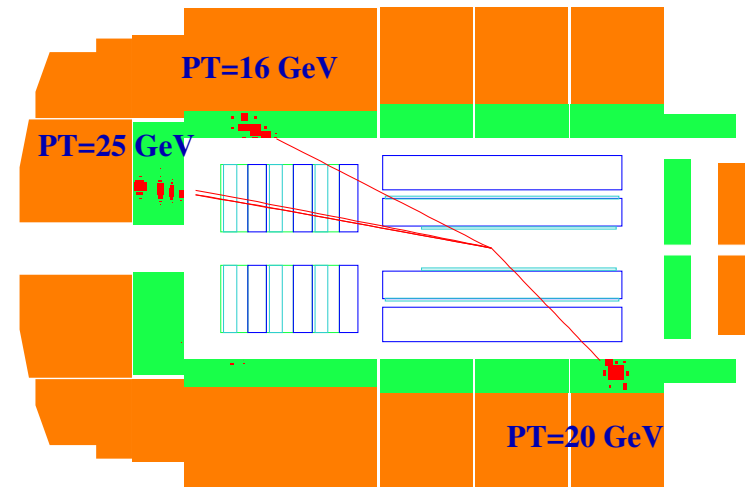
H1: More high mass events

Multi-electron Event $M(12)=111$ GeV



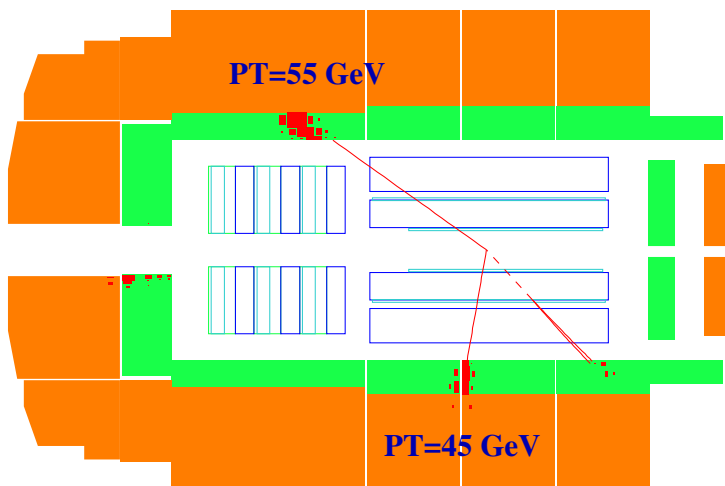
$2e$

Multi-electron Event $M(12)=118$ GeV



$3e$

Multi-electron Event $M(12)=113$ GeV



Multi-electron Event $M(12)=135$ GeV

