Multi Leptons in ep Collisions at HERA

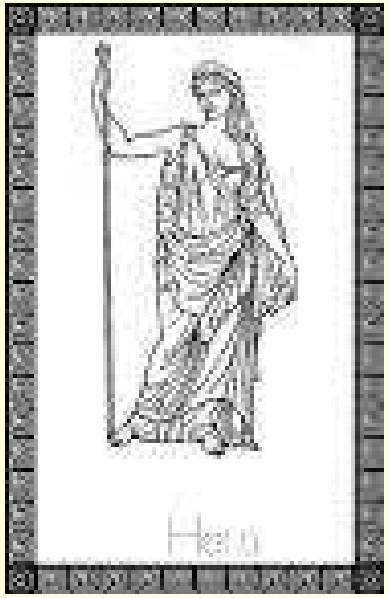
Analyses of multi-muon & and multi-electron production

Boris Leißner, RWTH Aachen

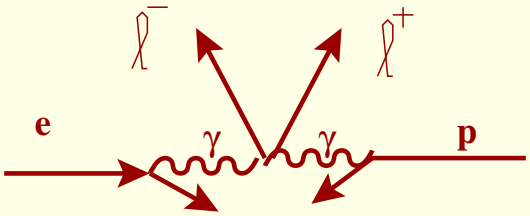
on behalf of the

and

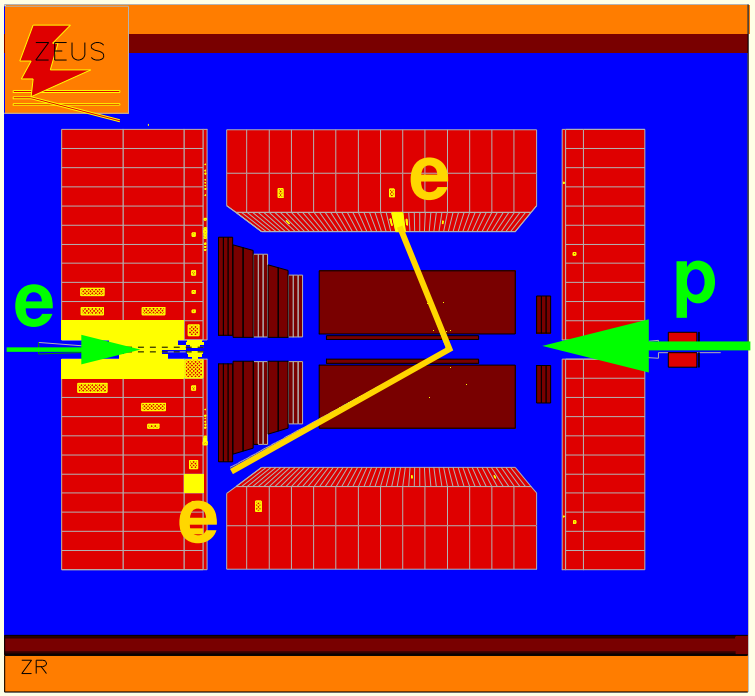
collaborations



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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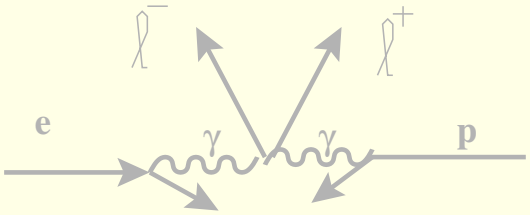

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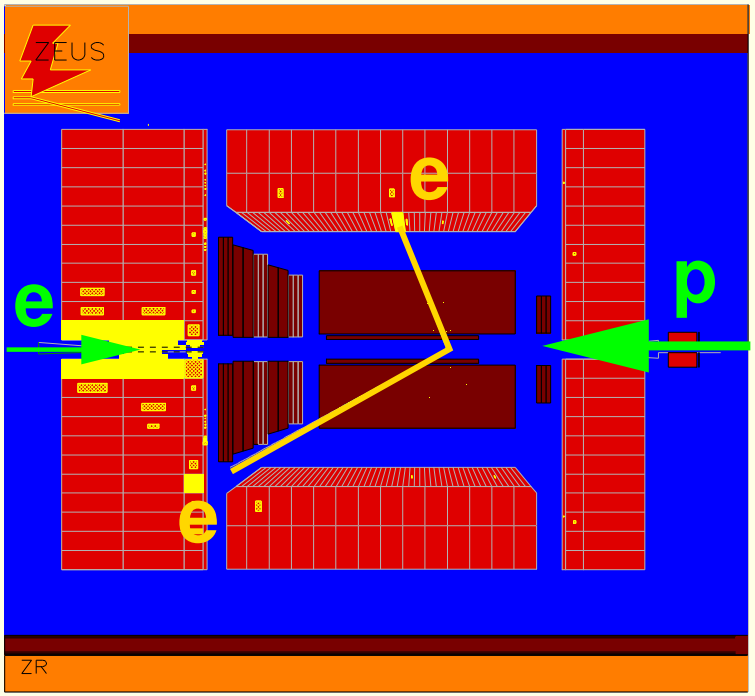

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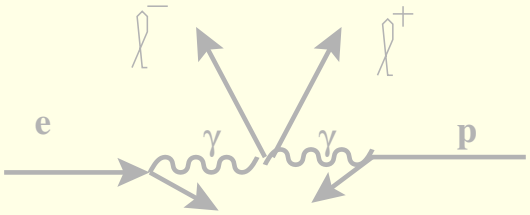

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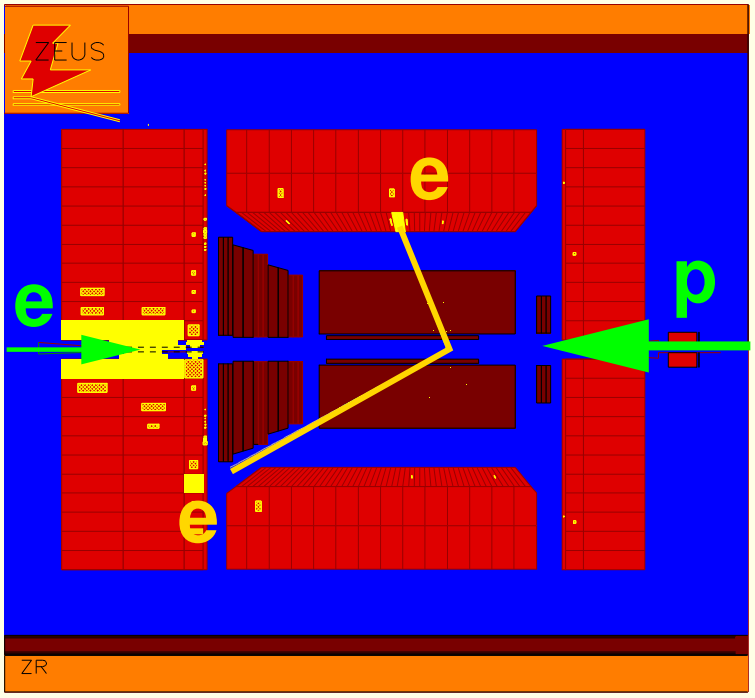

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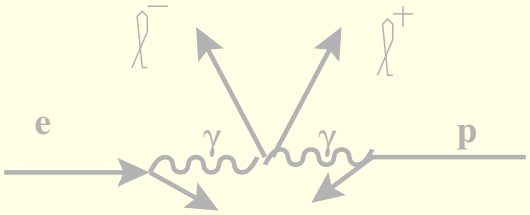

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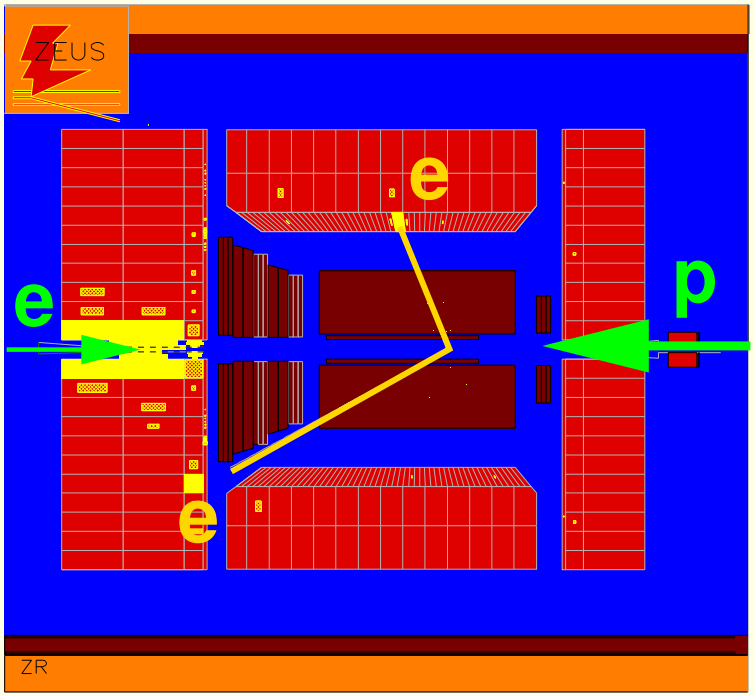

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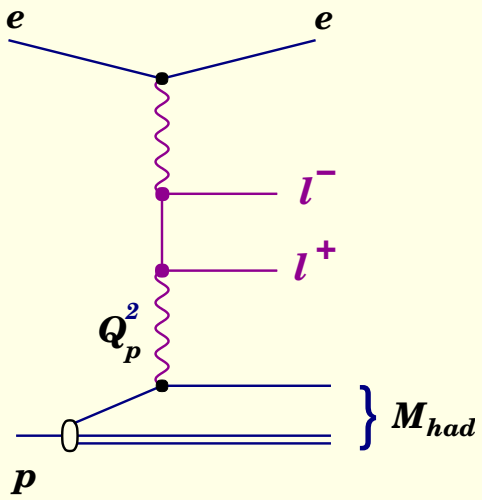

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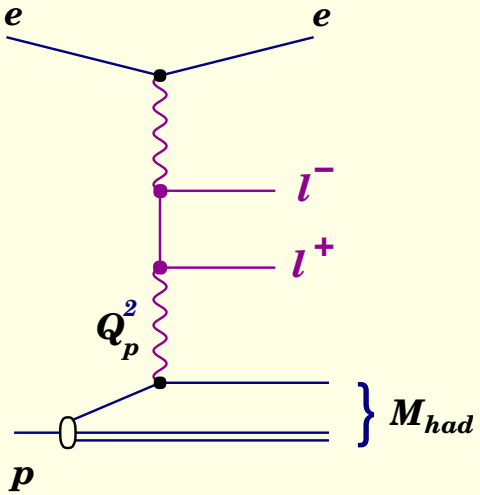

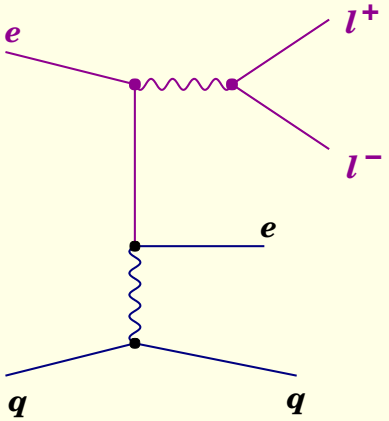

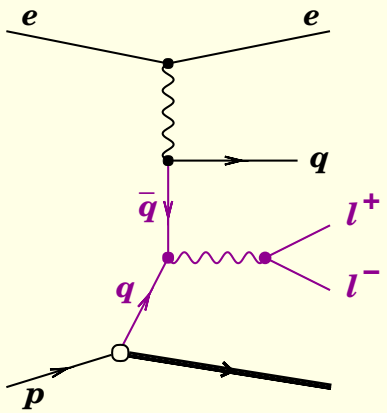

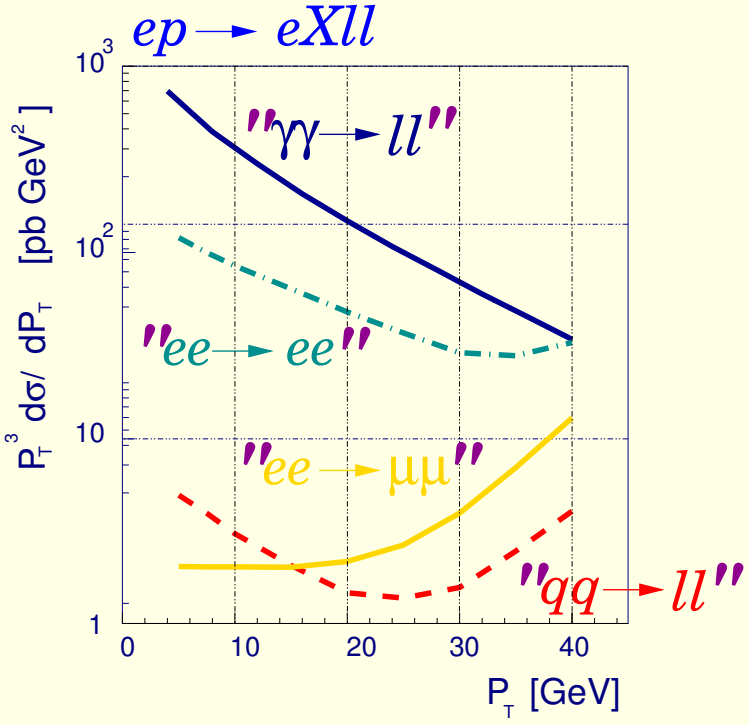

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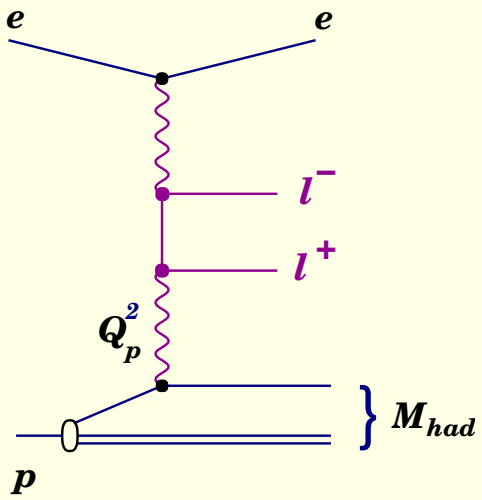

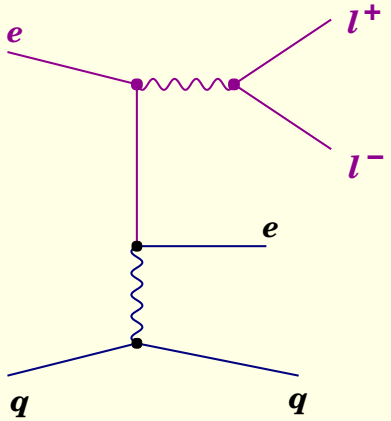

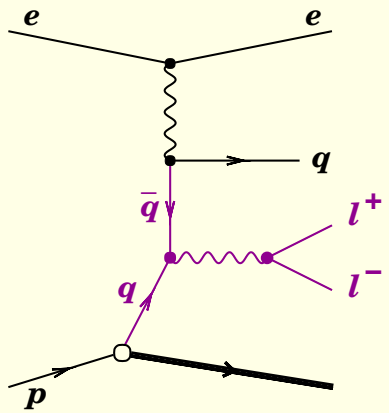

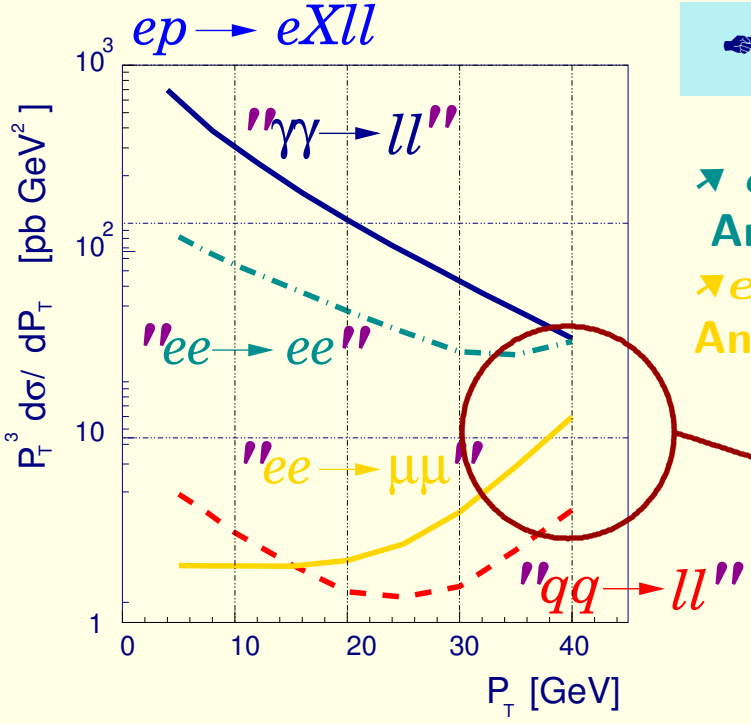

☛ $\gamma\gamma$ process dominant

↗ $ee \to ee$:
Annihilation ✚ Scattering

↗ $ee \to \mu\mu$:
Annihilation

Z^0 impact

Drell-Yan negligible

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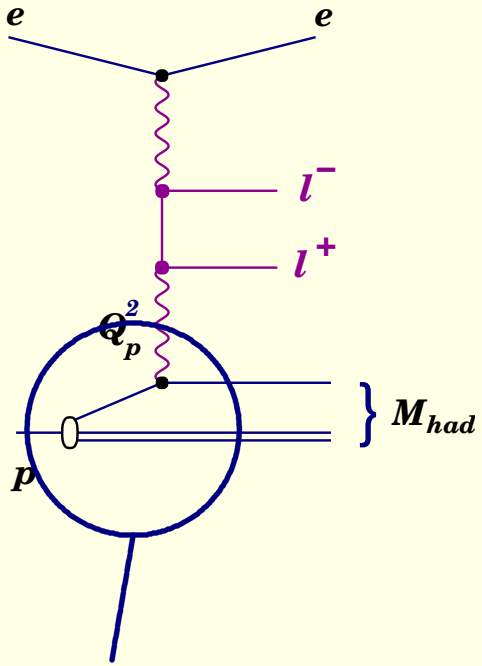
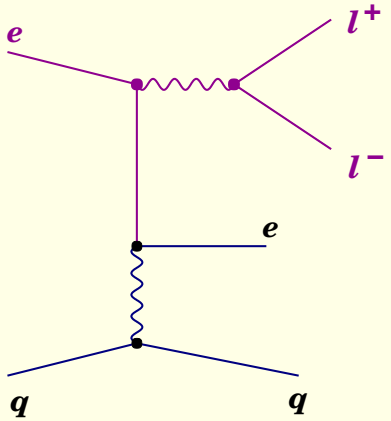
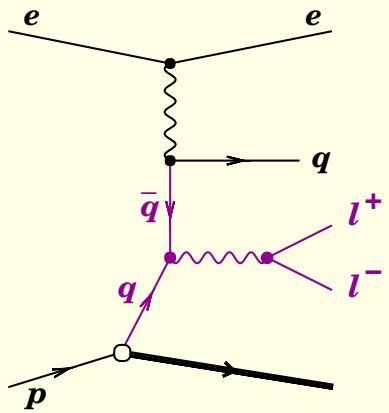






proton description:

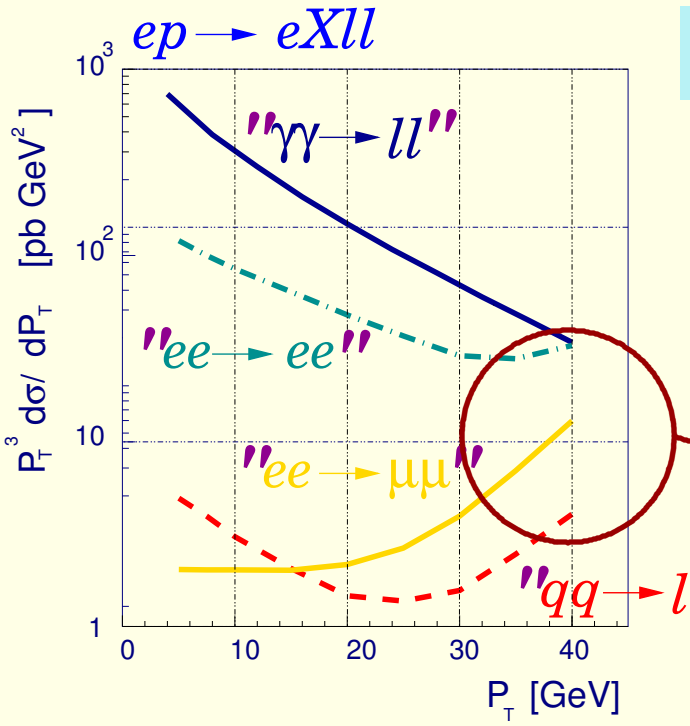
ELA: Form factors

Quasi-ELA: Structure functions

DIS: Quark-Parton-Model

MC Simulation: GRAPE

Electroweak tree-level
ISR ✚ FSR



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➘ $ee \to ee$:
Annihilation ✚ Scattering

➘ $ee \to \mu\mu$:
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

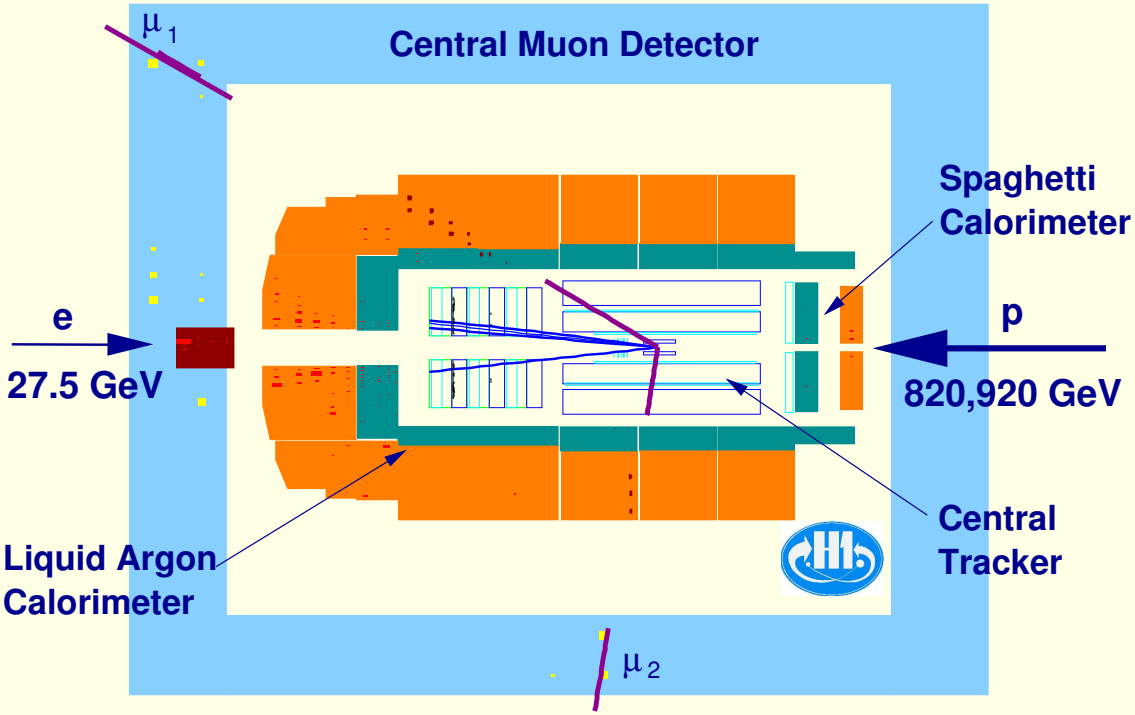
  H1: $E_e > 5$ GeV

  ZEUS: $E_e > 10$ GeV

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

  Additional 3rd electron identified:

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



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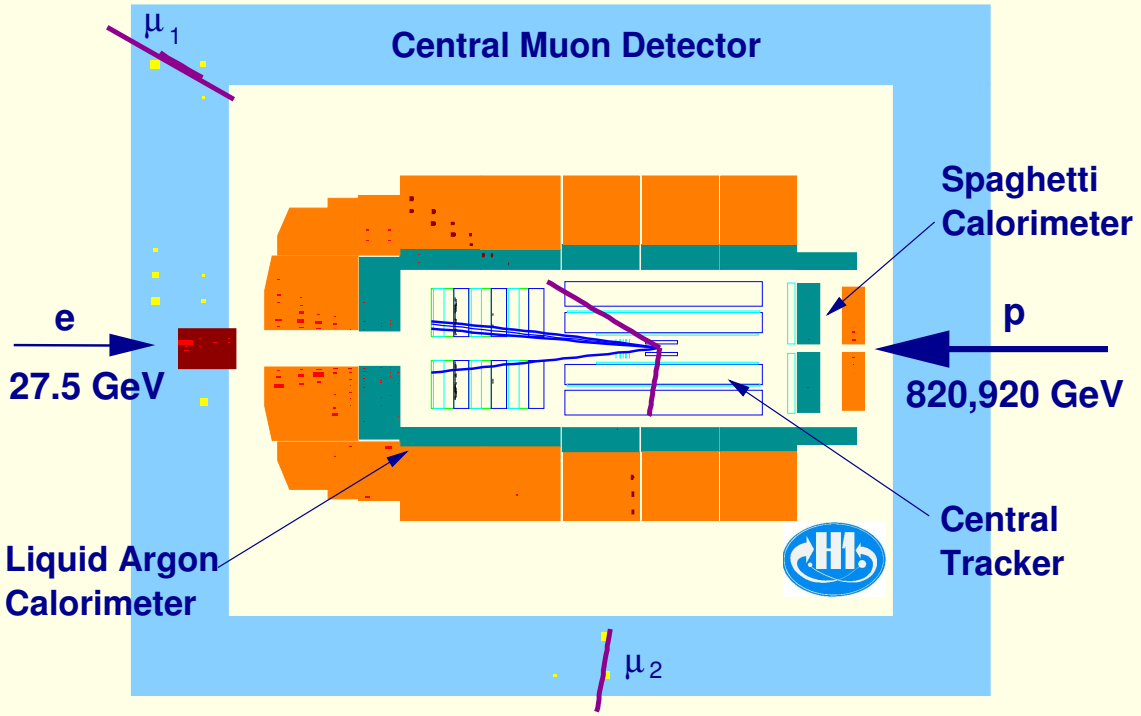

		$P_{t,min}^{l1}$ [GeV]	$P_{t,min}^{l2}$ [GeV]
H1	$\mu\mu$	2.0	1.75
	ee	10.0	5.0
ZEUS	$\mu\mu$	5.0	5.0
	ee	10.0	–

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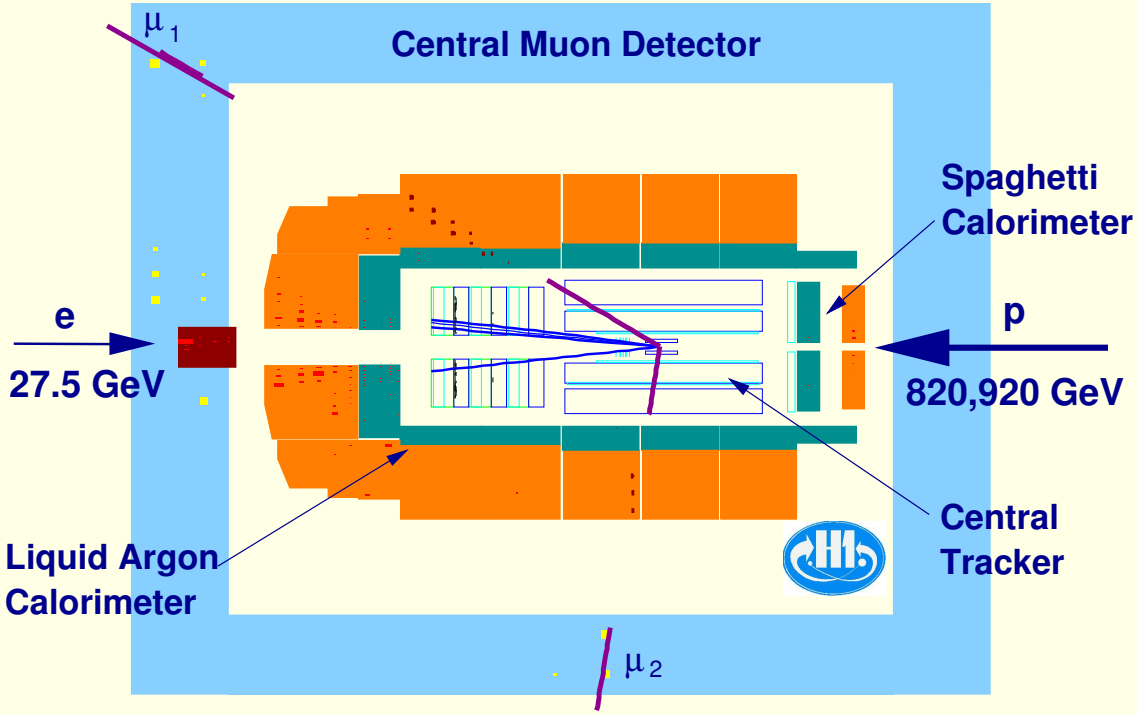

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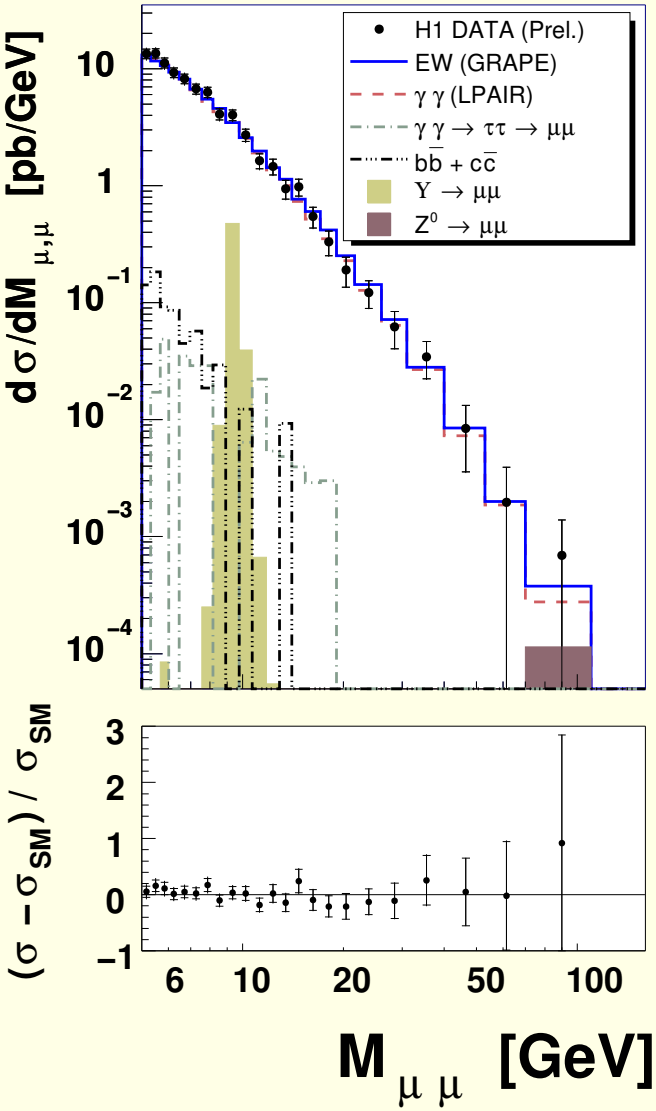
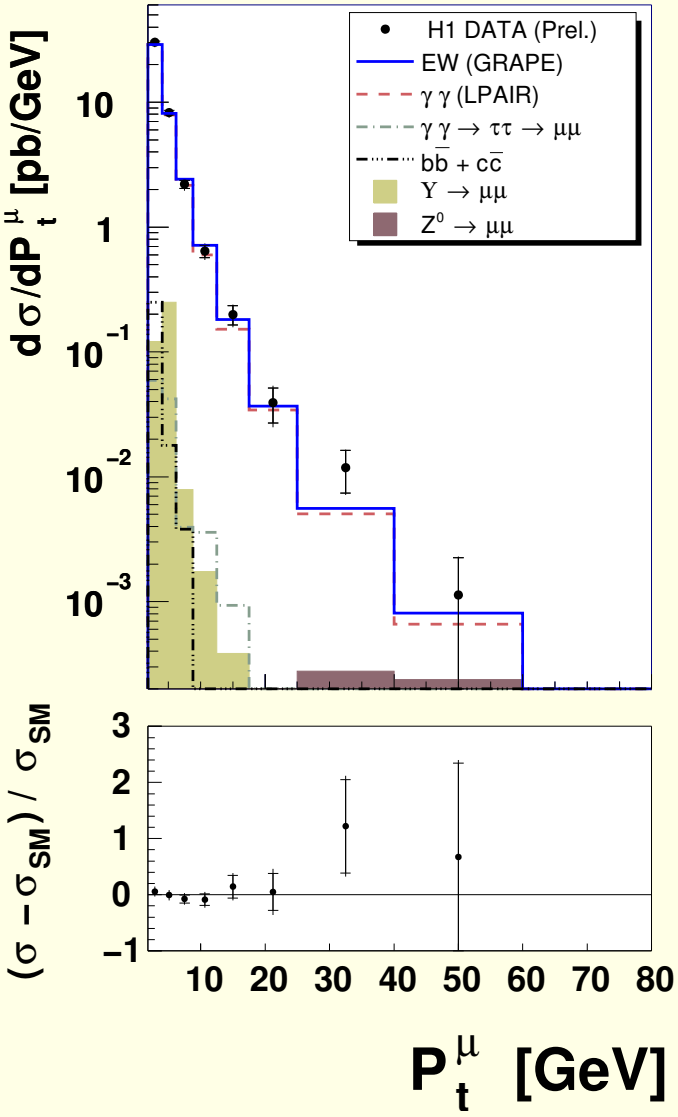
Cross Sections - Muon Pair Production at H1





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

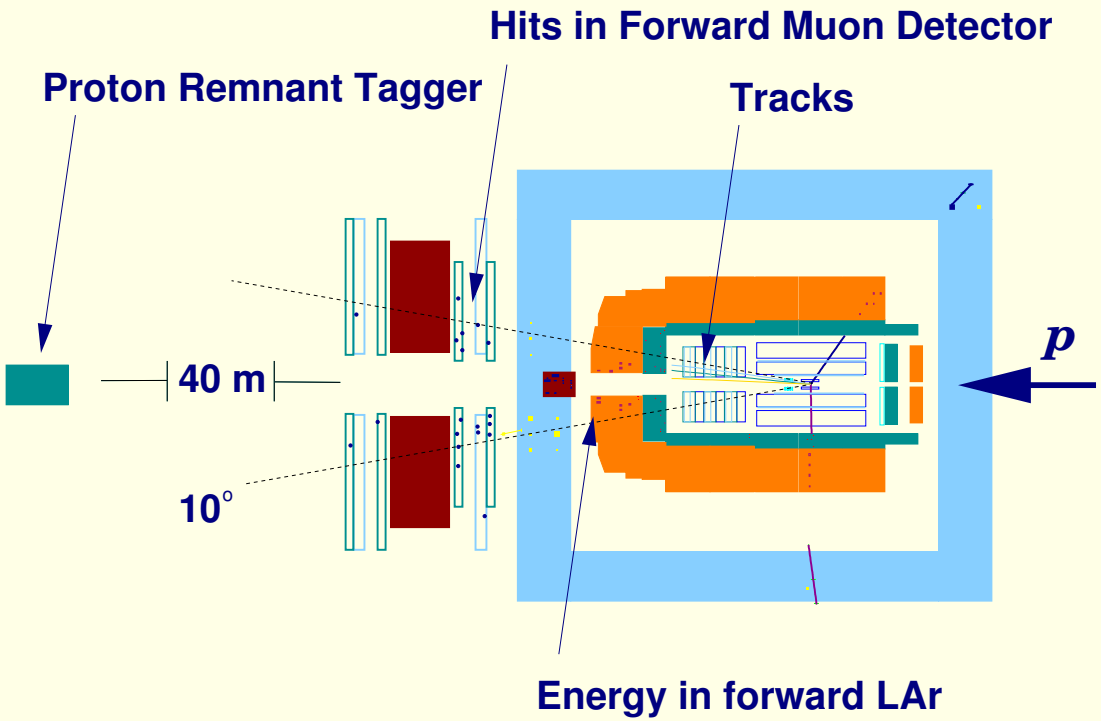
$\sqrt{s} = 318\ \mathrm{GeV}$

☛ **Good agreement over 4 decades with SM**

Elastic and Inelastic Production Processes

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

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

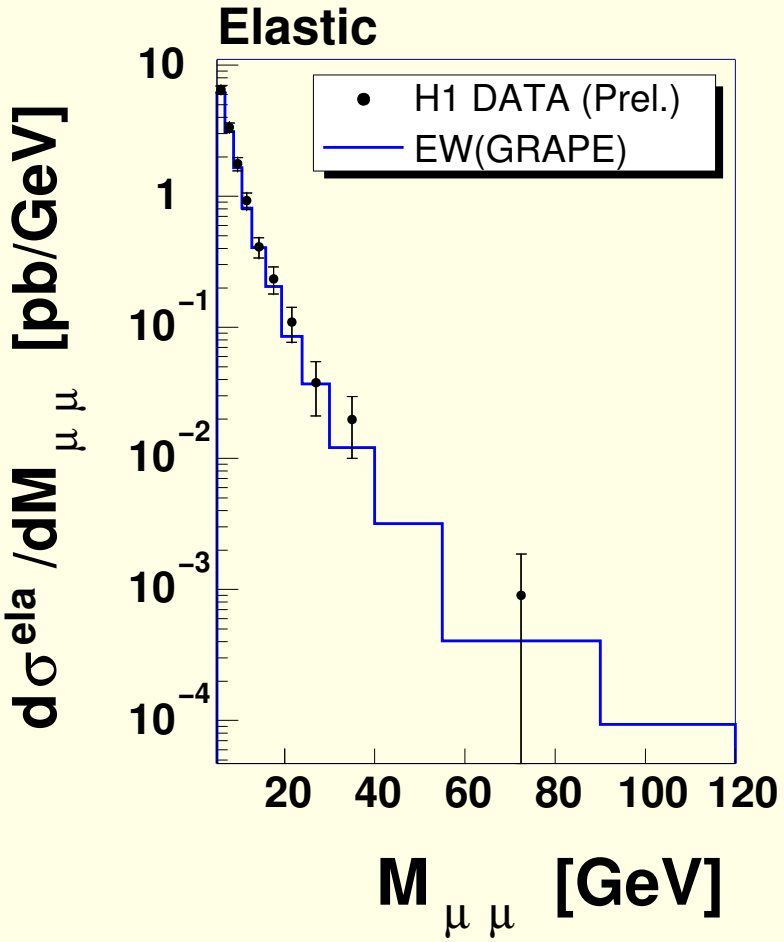


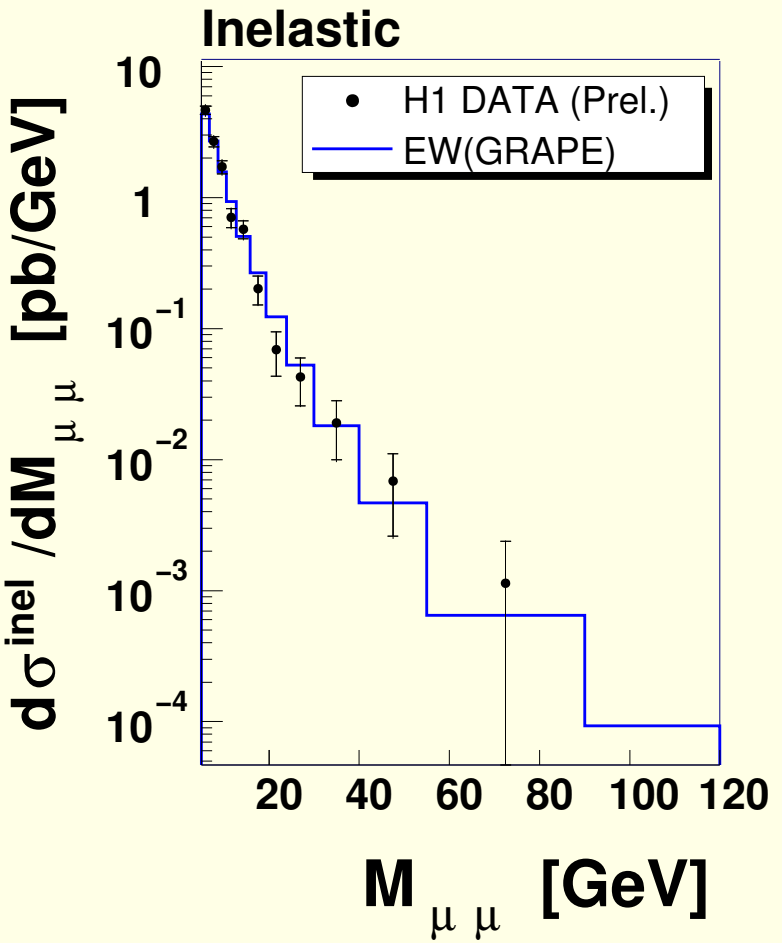
Tag of inelastic Events:

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

☛ tagging efficiency: 92 %
tagging misidentification: 13 %

Cross Sections - Elastic & Inelastic Muon Pairs

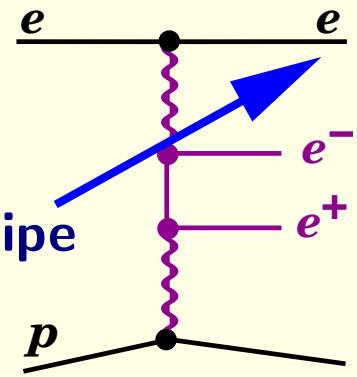




☛ **Both processes are well described by the SM!**

Cross Sections - Electron Pair Production

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



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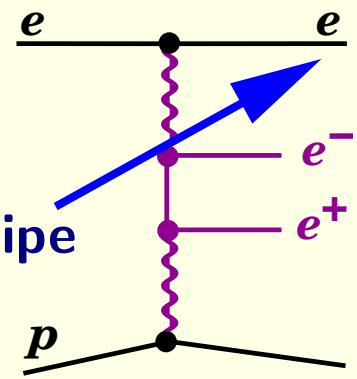
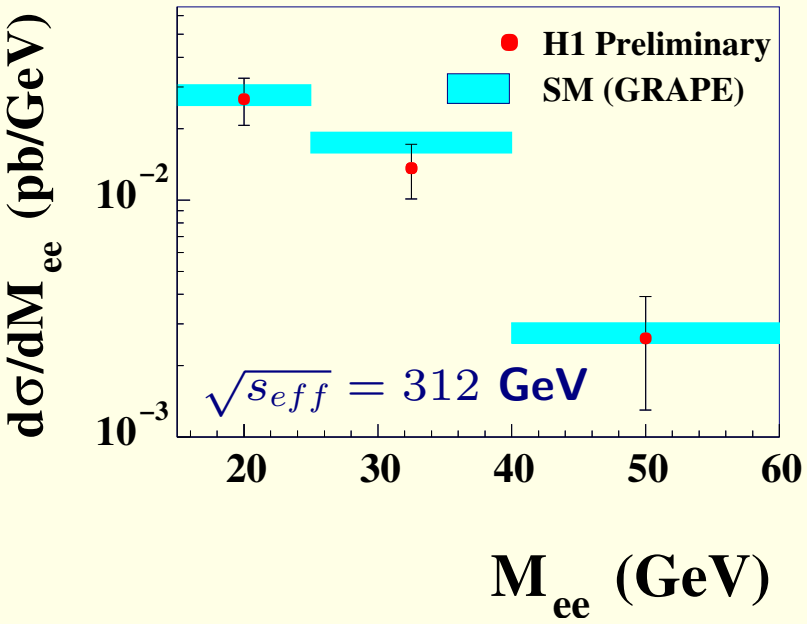
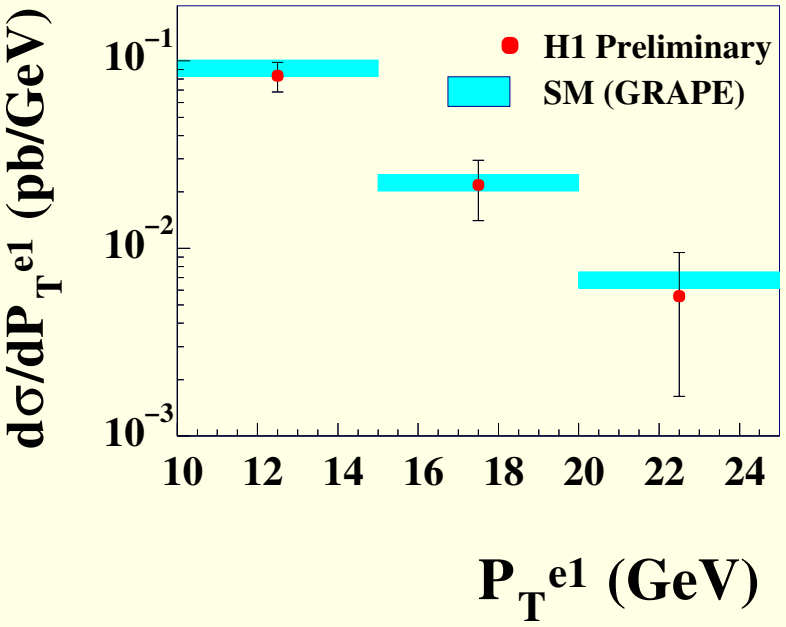




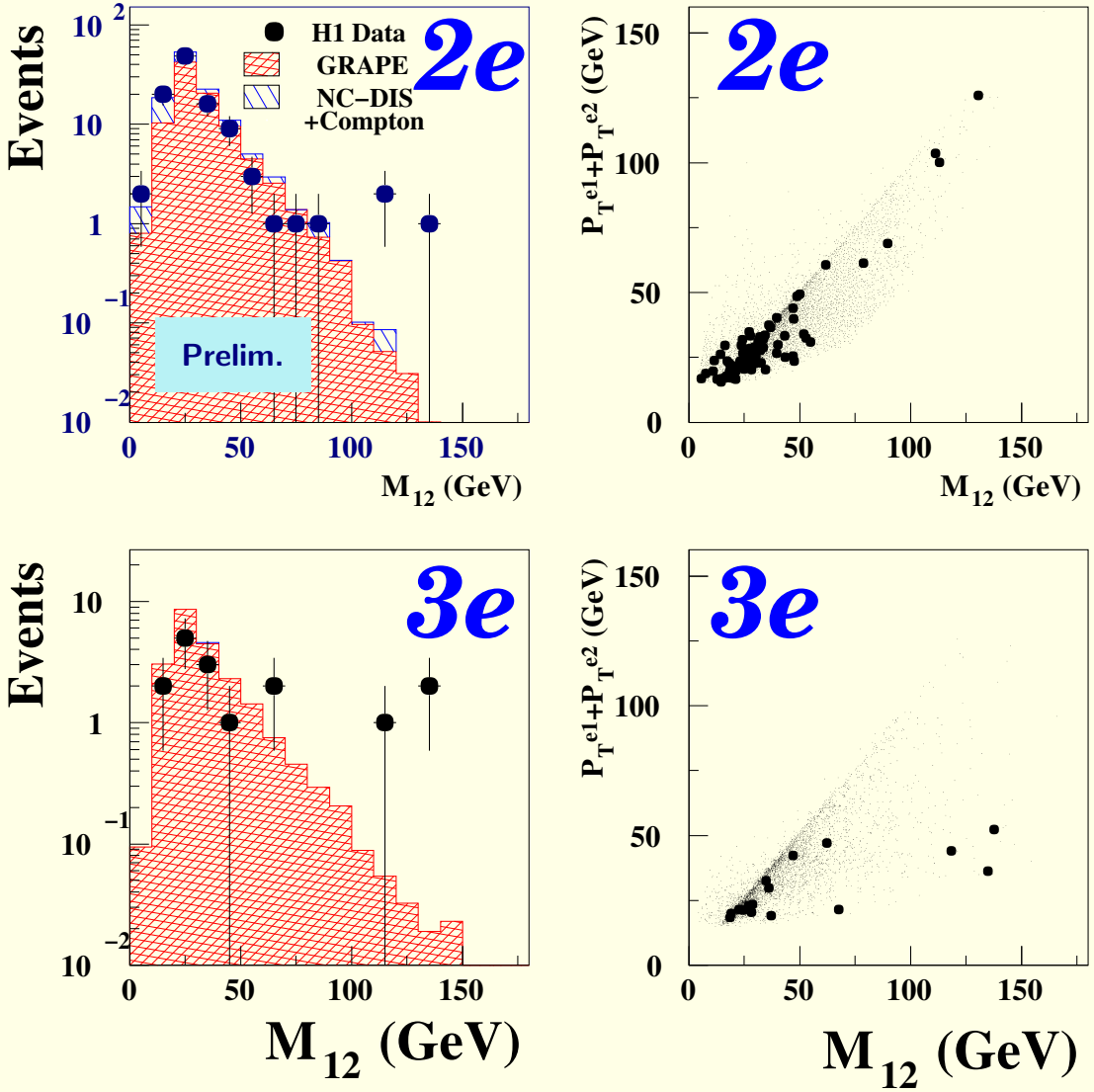


☛ **Both cross sections are well described by the MC**

➹ **Phase Space:** $y < 0.82$, $Q_e^2 < 1$ **GeV**

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

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

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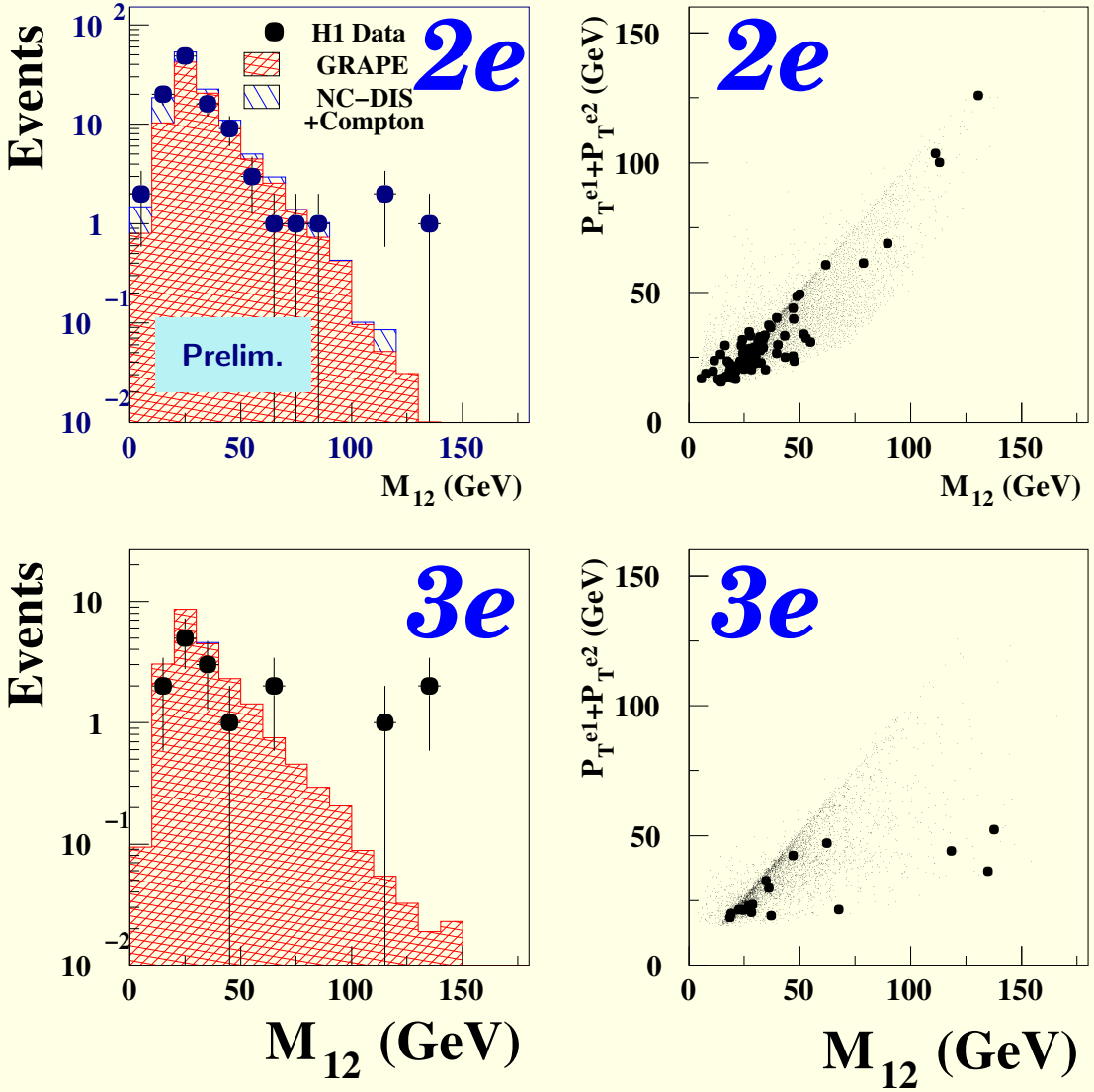

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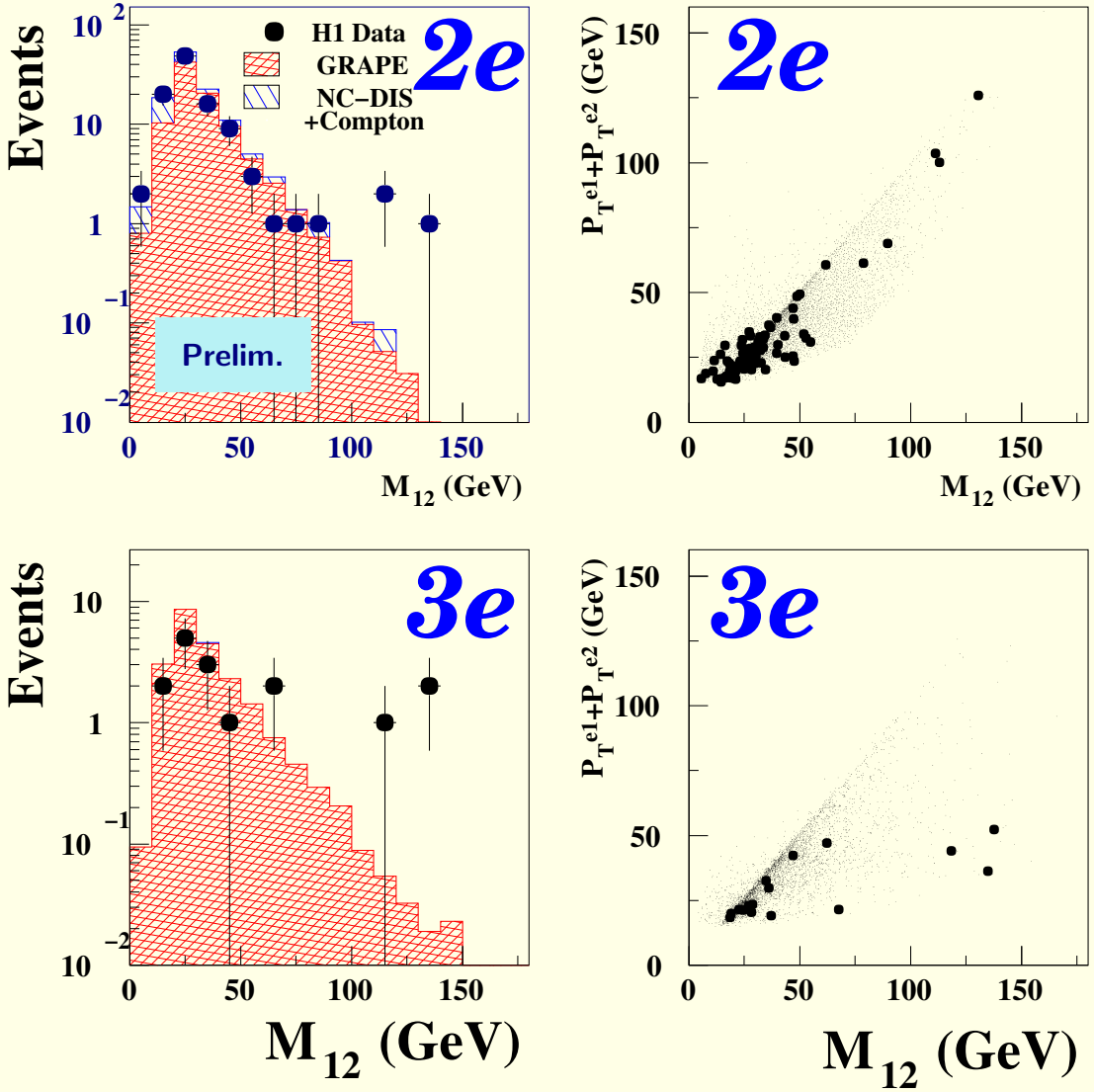

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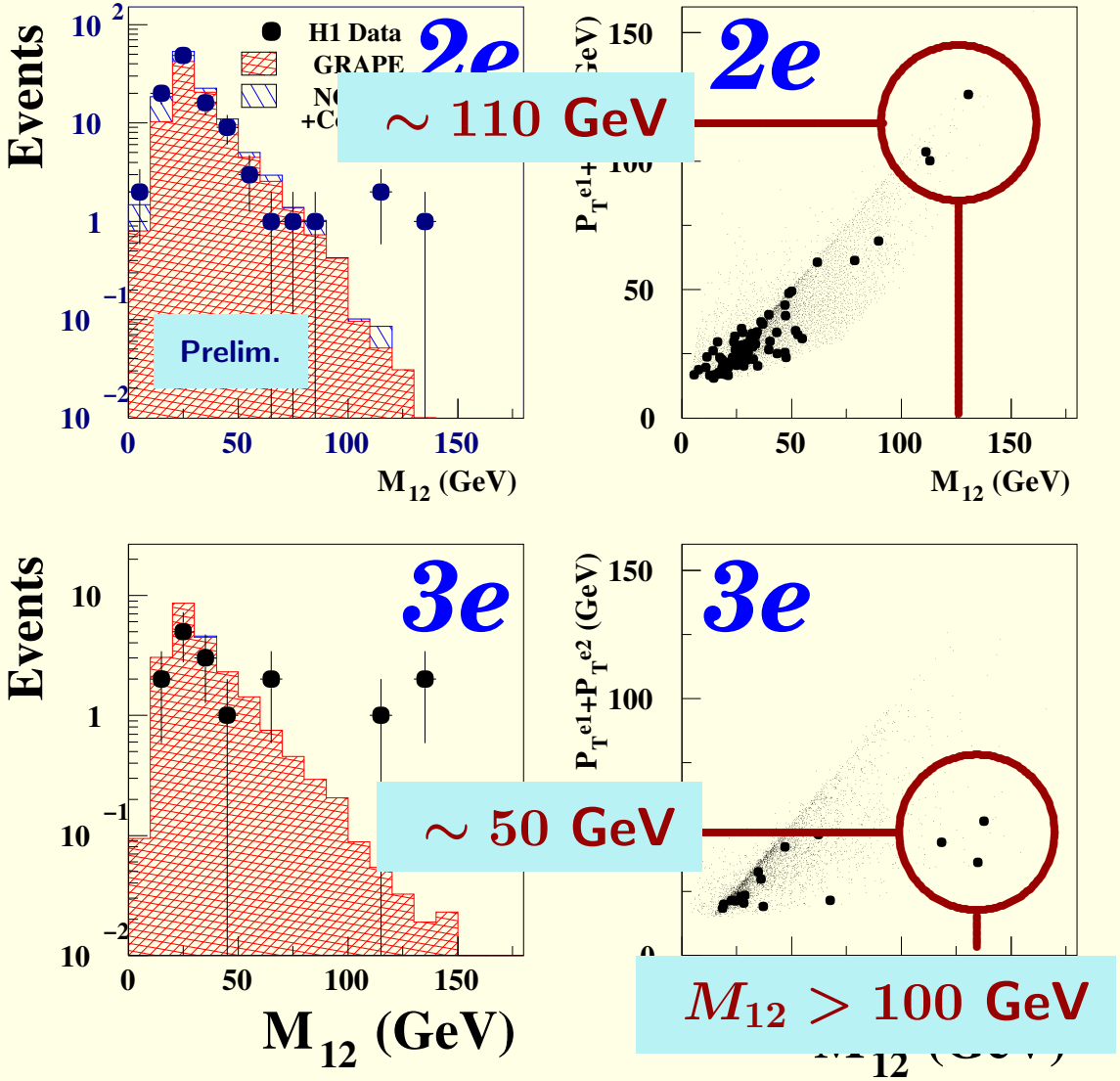

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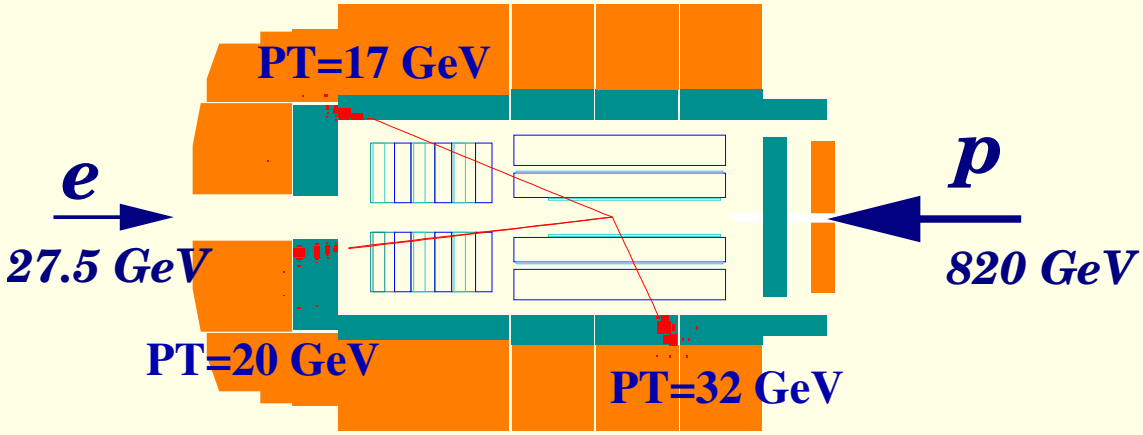
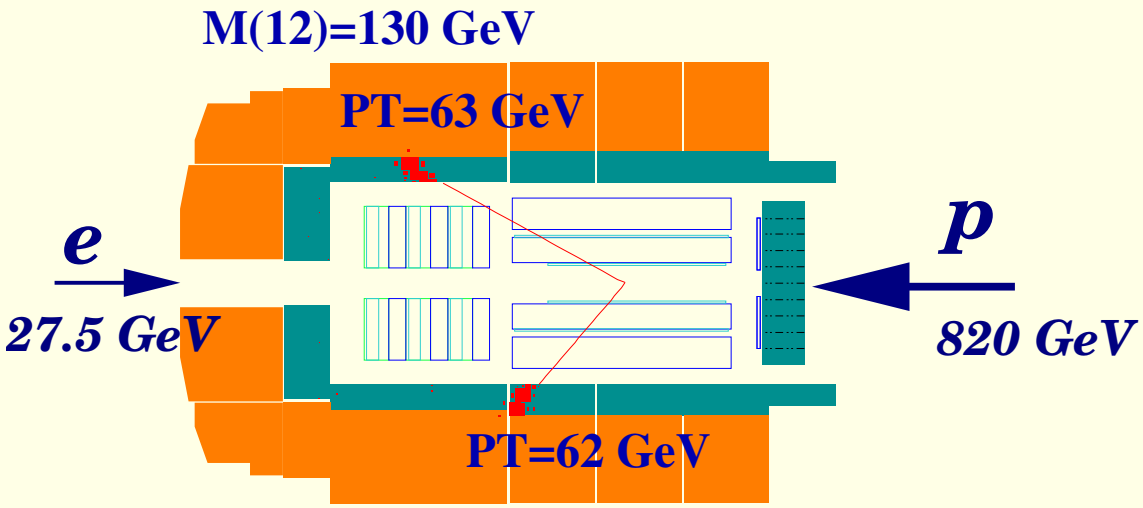
Multi Electrons Events with $M_{12} > 100$ GeV

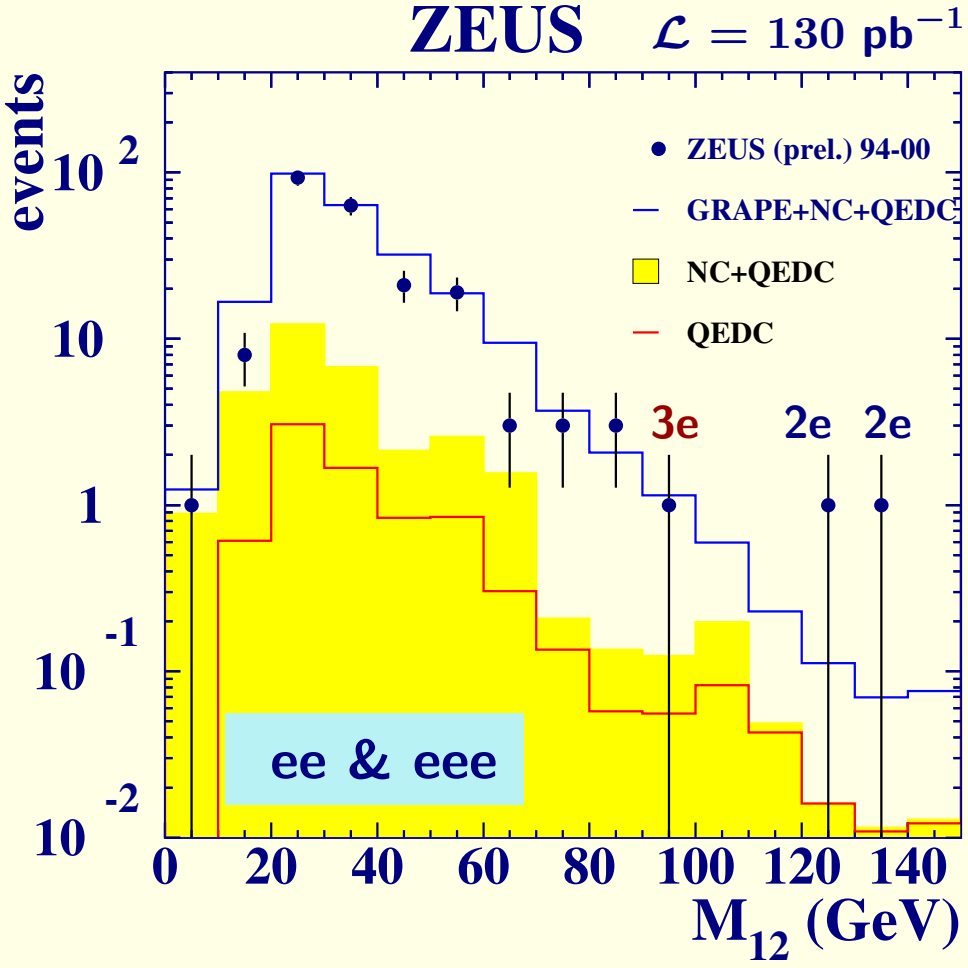
$3e$



$2e$



Multi Leptons with high Mass - Electrons at ZEUS



Total:

Sample	Data	SM
2e	191	213.9 ± 3.9
3e	26	34.7 ± 0.5

$M_{12} > 100$ GeV:

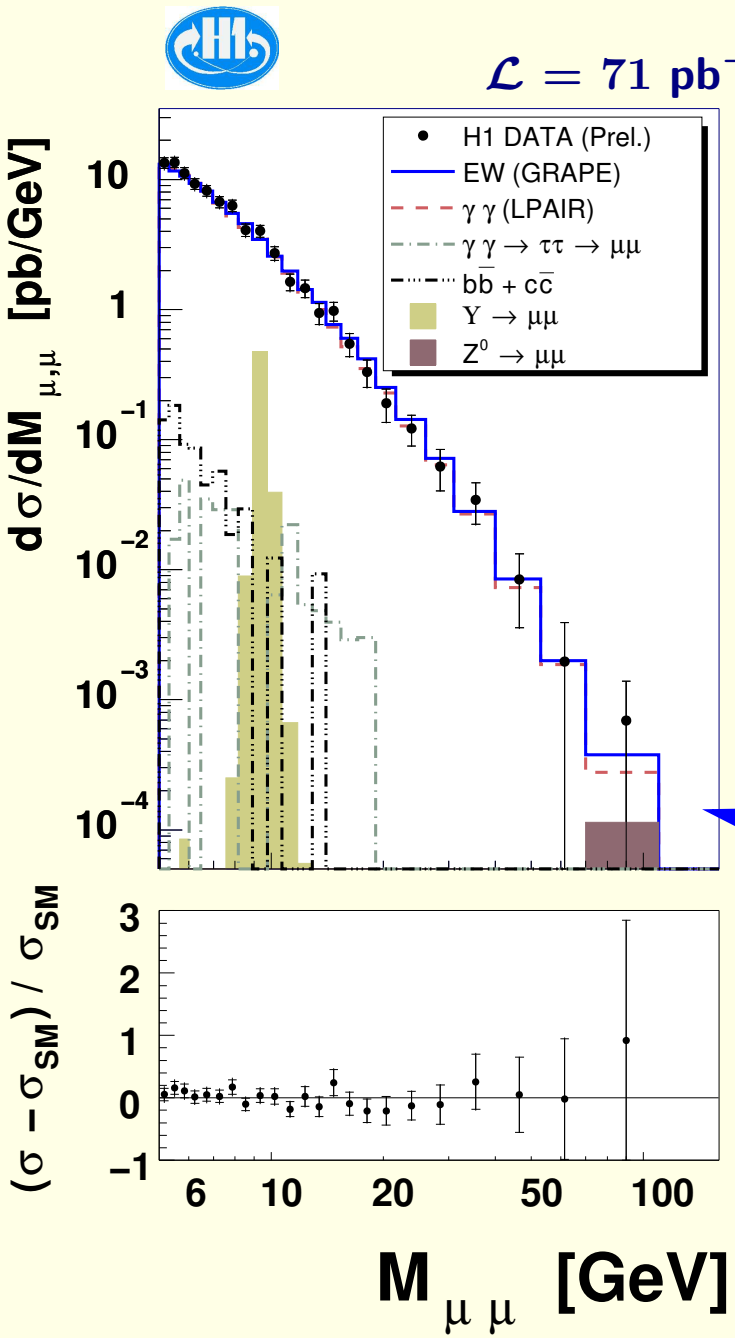
Sample	Data	SM
2e	2	0.77 ± 0.08
3e	0	0.37 ± 0.04

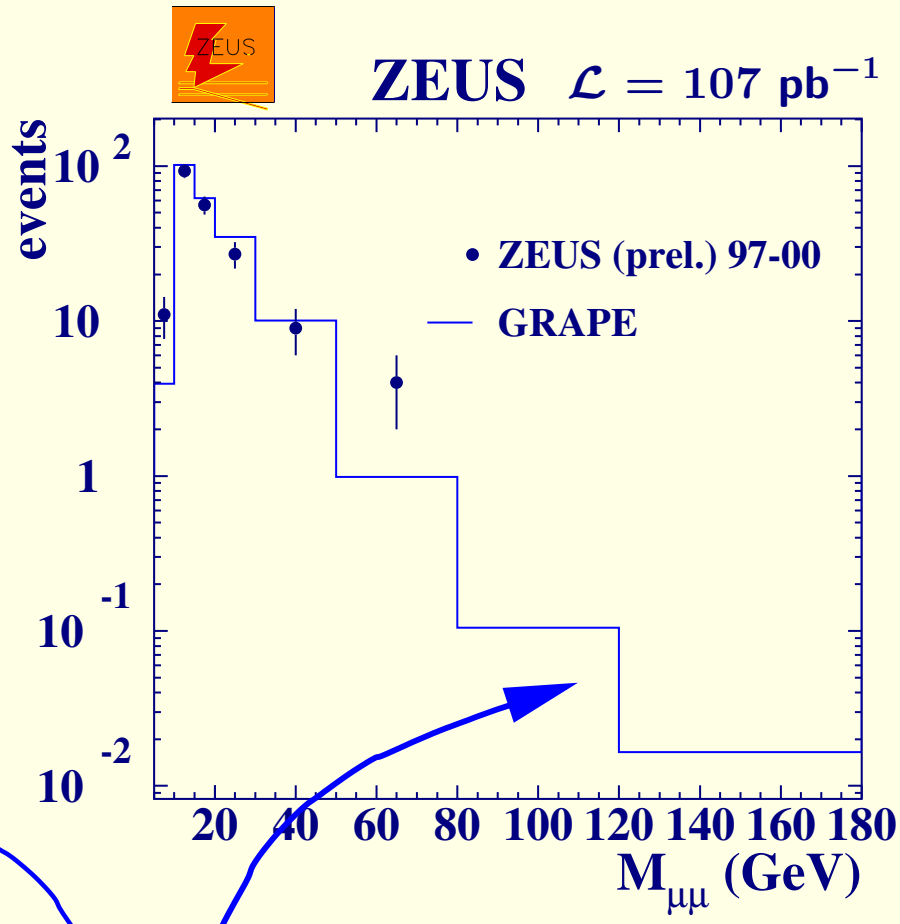
☛ **Data and MC are in good agreement!**

Larger expectation than H1 due to:

- larger polar angular range
- higher background

Multi Leptons with high Mass - Muons at HERA





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

Doubly Charged Higgs at H1

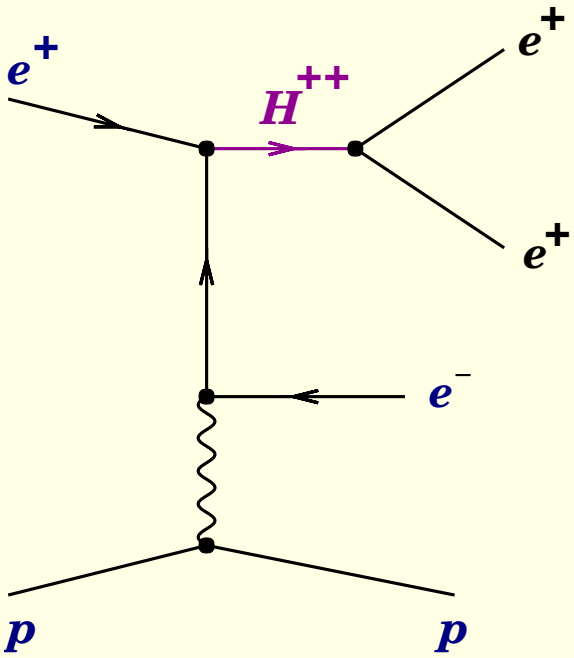
SUSYRL

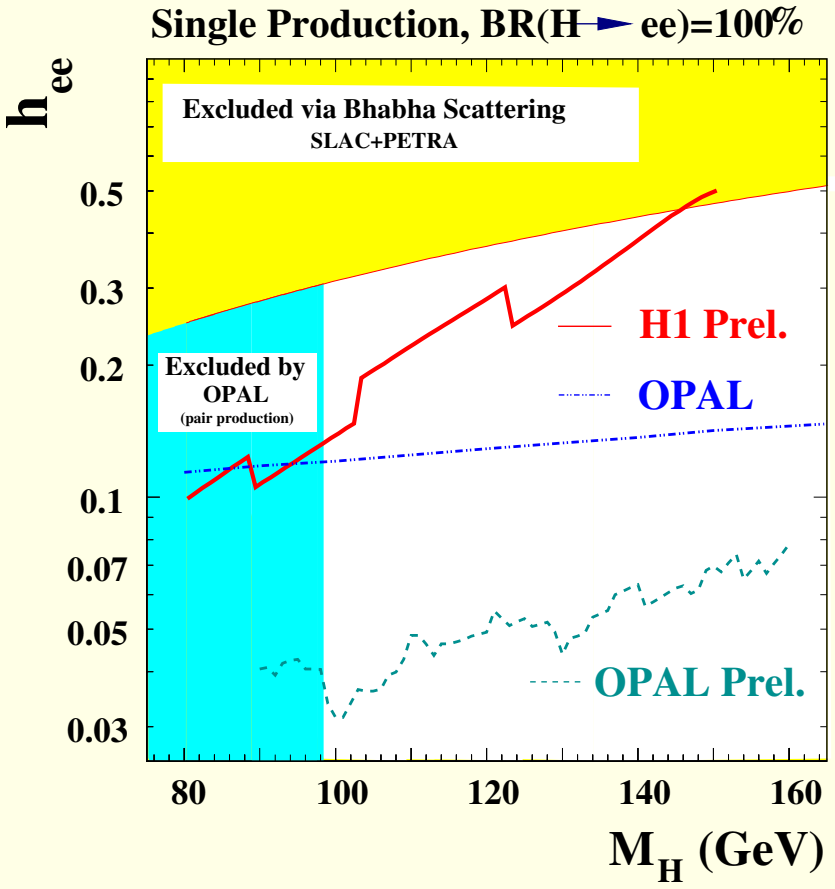
➜ $H_{R,L} = (H^0_{R,L}, H^+_{R,L}, H^{++}_{R,L})$

➜ 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 ✚ $\sum p_t^e$)

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: Excess in 2e/3e

$M_{12} > 100$ GeV:

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

Conclusions

- Cross Sections for Lepton Pair Production

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

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- **Multi Leptons at high Mass**

  ☛ **No high mass events in $\mu\mu$!**

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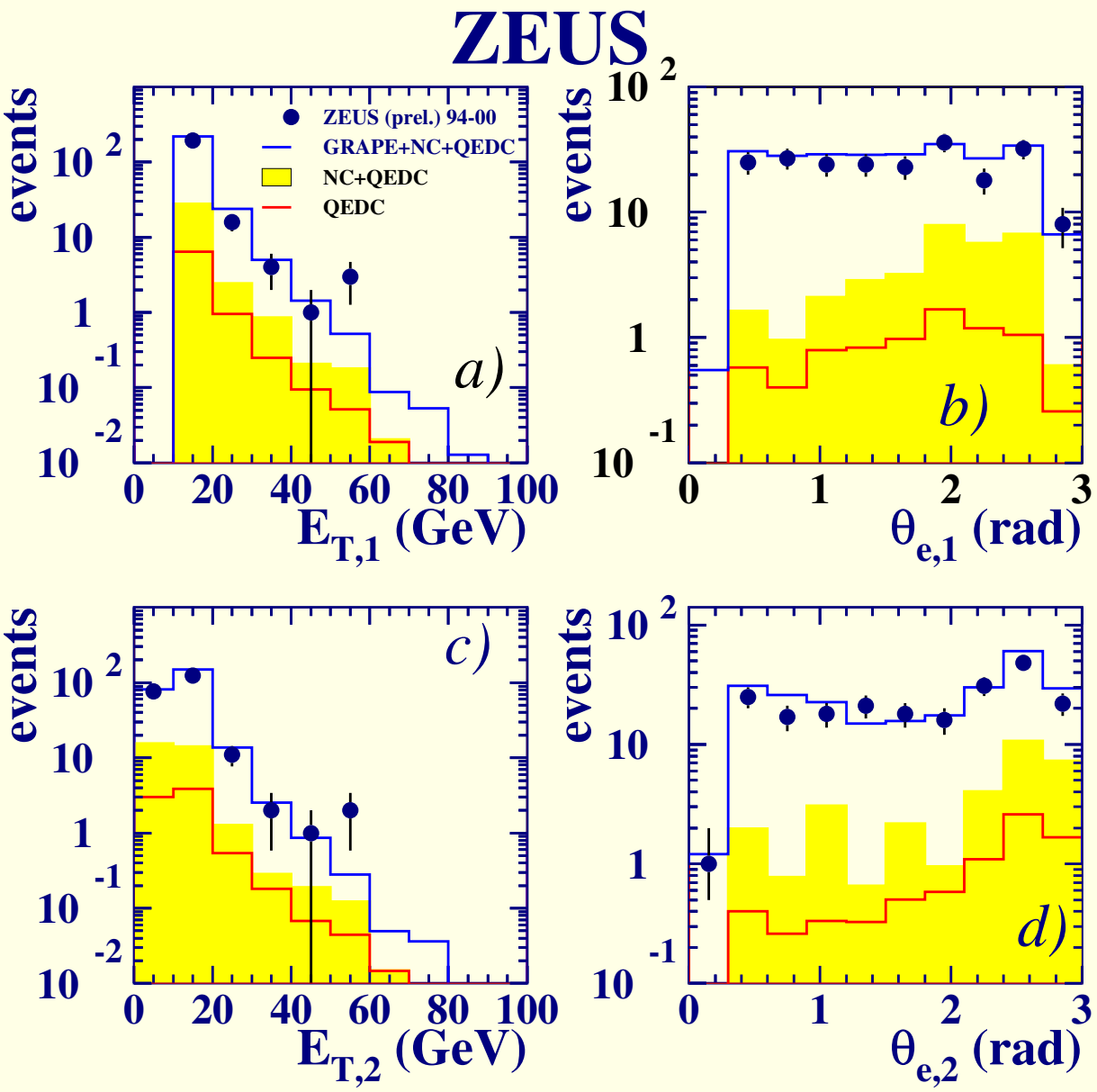
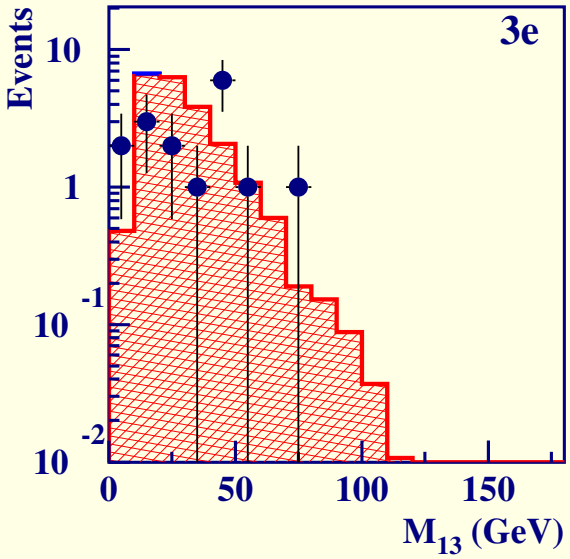
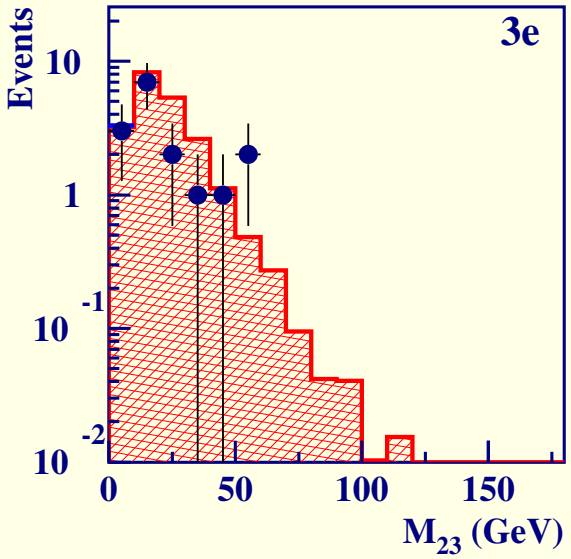
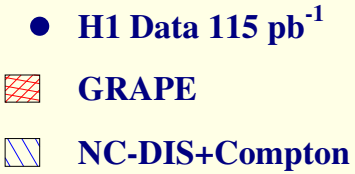
Additional Plots - ZEUS: E_T^e & θ^e Distributions

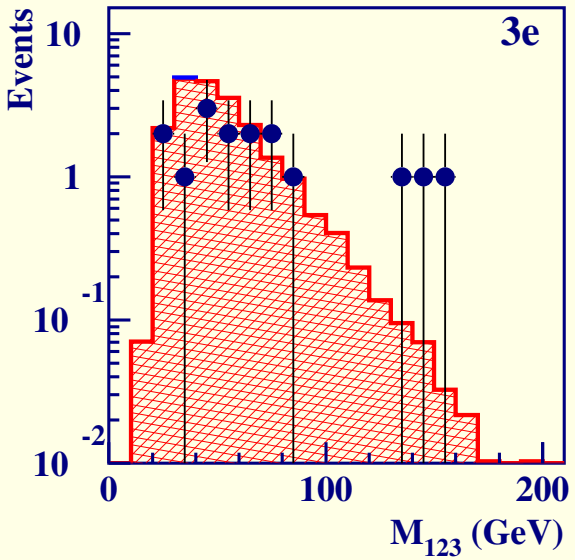


Additional Plots - H1: Electron Mass Distributions

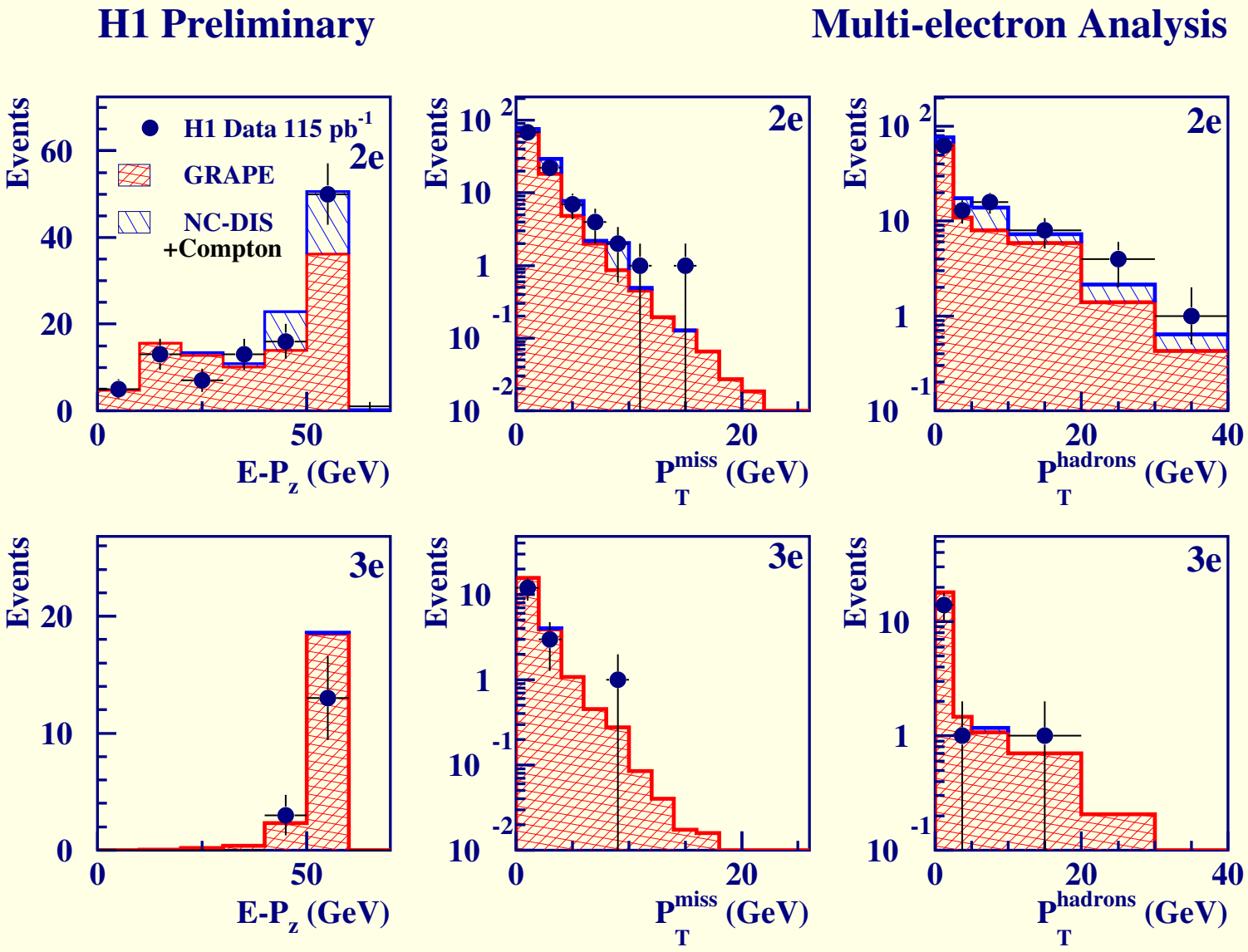




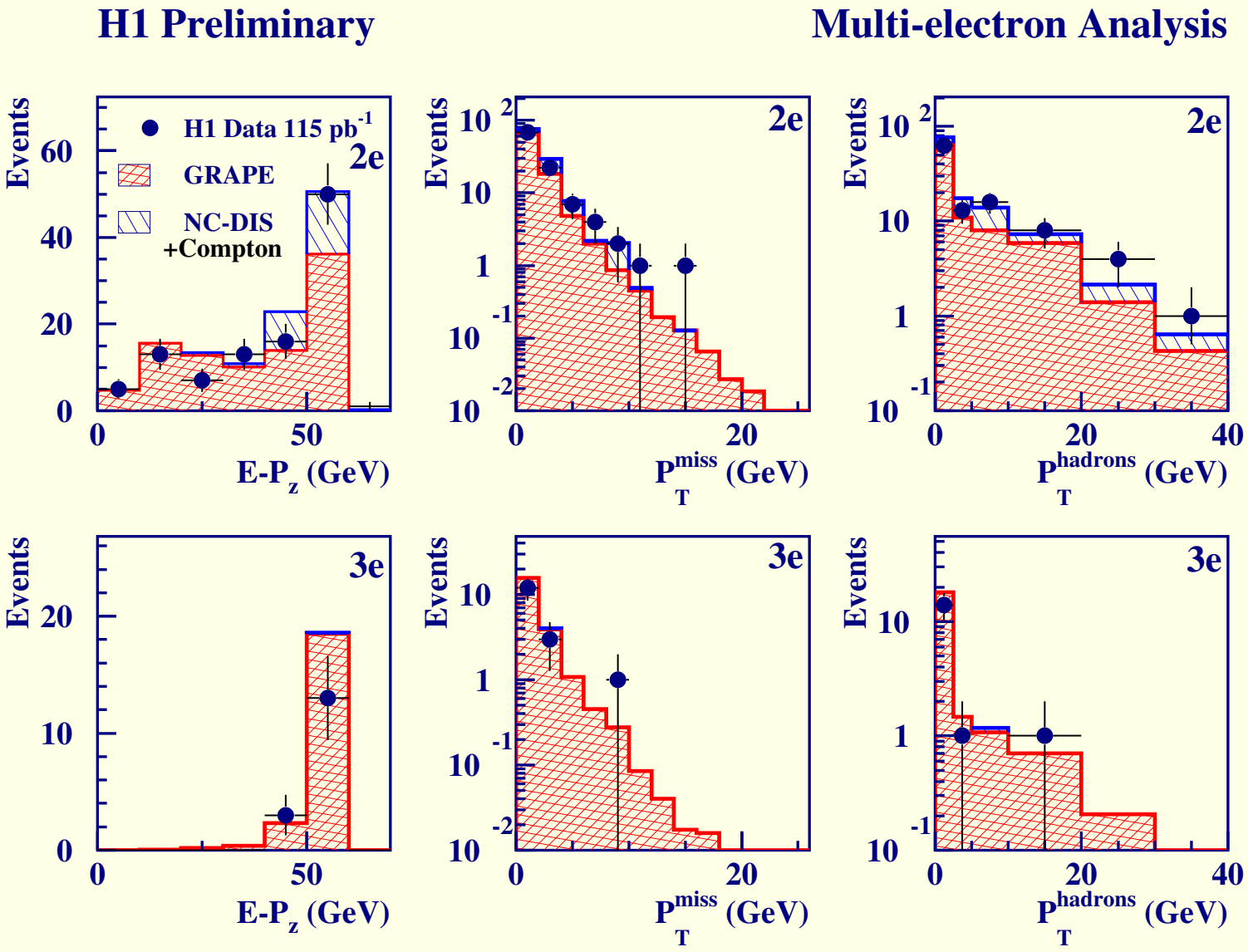




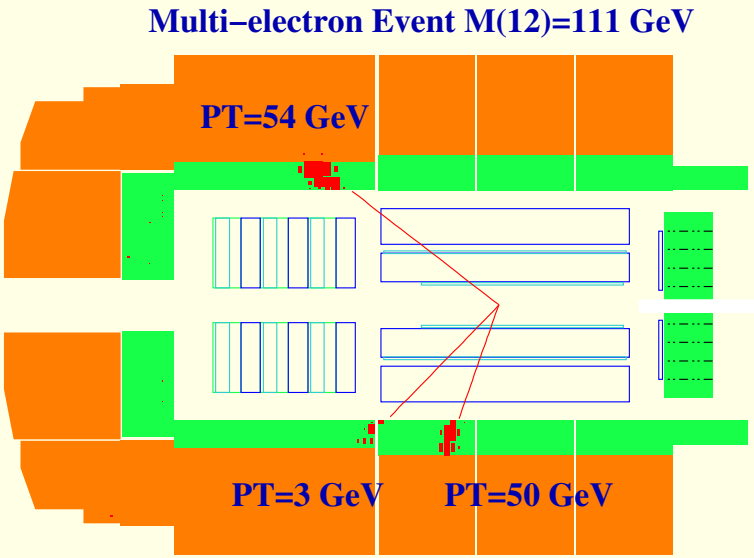
Additional Plots - H1: More Electron Distributions I

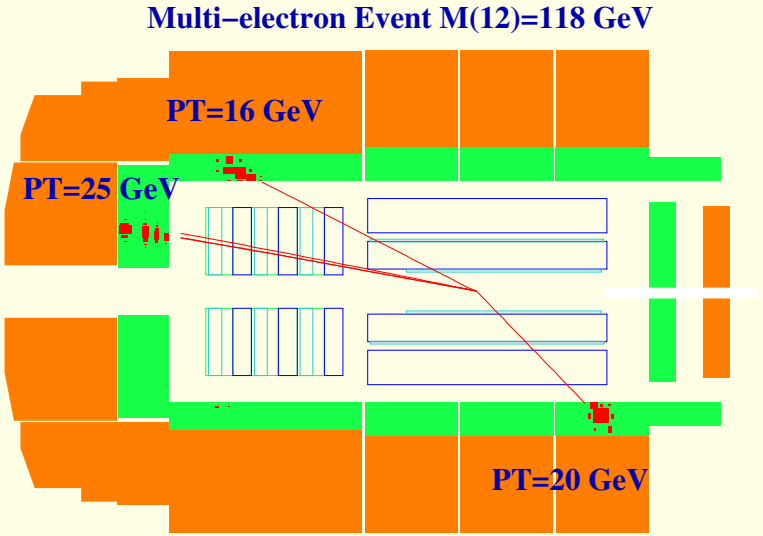


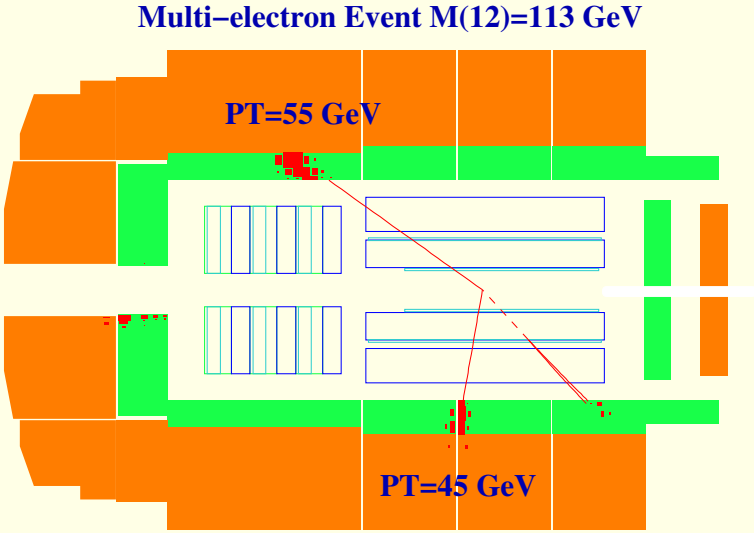
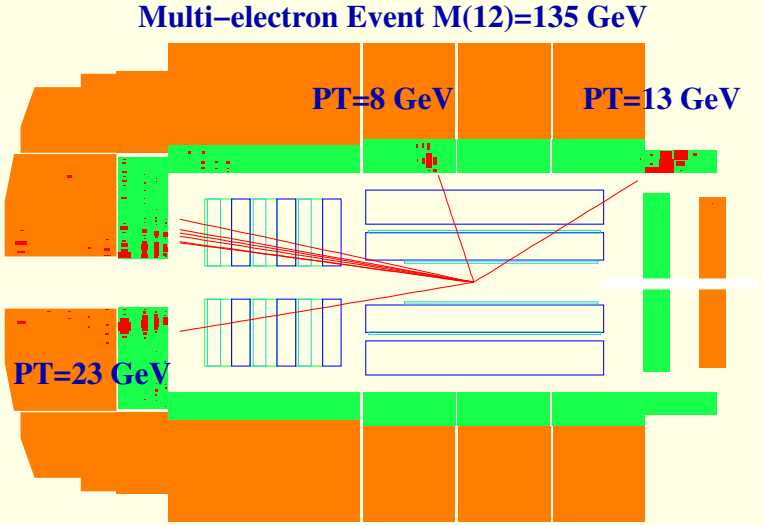
Additional Plots - H1: More Electron Distributions II



H1: More high mass events





$2e$

$3e$