



Multileptons and H^{++} at HERA

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on behalf



and



Outlook:

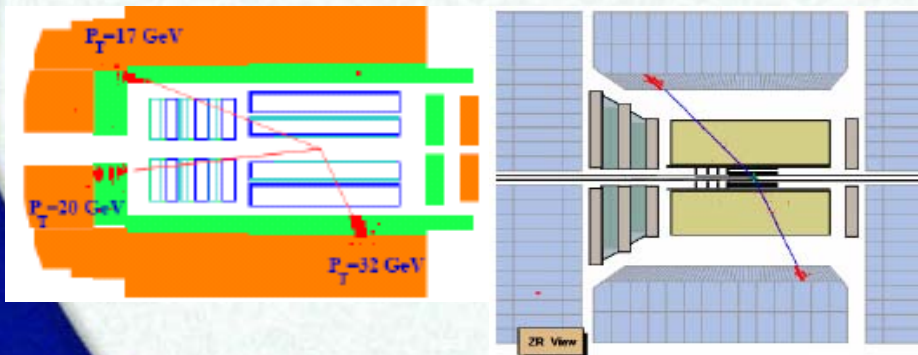
- Introduction
- Multi-leptons at high-pt
- Search for doubly charged Higgs
- Summary

Presented results:

H1: H1prelim 07-062

H1 Coll, Phys. Lett. B 638 (2006) 432

ZEUS: ZEUSprelim 2007



HERA experiments



➤ HERA-I: 1992-2000 $L \sim 120 \text{ pb}^{-1}/\text{exp.}$

➤ HERA-II 2002-2007 $L \sim 350 \text{ pb}^{-1}/\text{exp.}$

-Luminosity upgrade:

~10x more e-p data than in HERA-I

-Longitudinally polarized lepton beam



- ep collision at H1 and ZEUS
- hermetic multi- purpose detectors

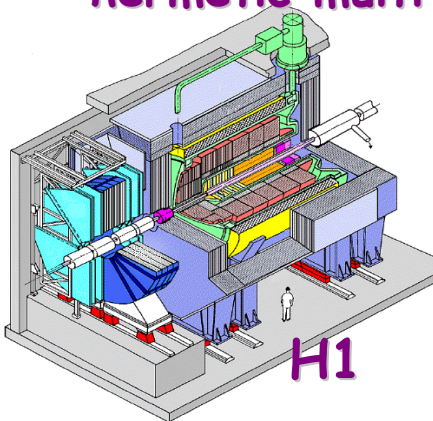
Presented results:

	H1	ZEUS
$e+p$	286 pb ⁻¹	272 pb ⁻¹
$e-p$	173 pb ⁻¹	206 pb ⁻¹
Total	459 pb ⁻¹	479 pb ⁻¹

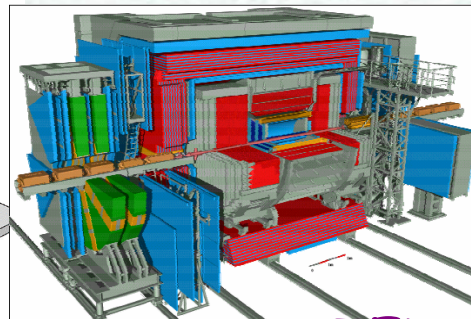
Total luminosity $\sim 1 \text{ fb}^{-1}$

=> rear/new phenomena $\sigma \sim 1 \text{ pb}$

should be visible in HERA



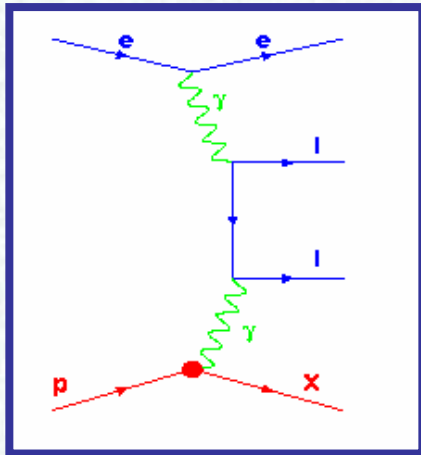
H1



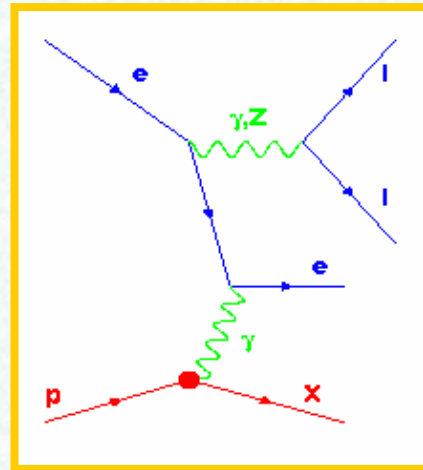
ZEUS

Multi-lepton events at HERA

How are lepton pairs produced ?

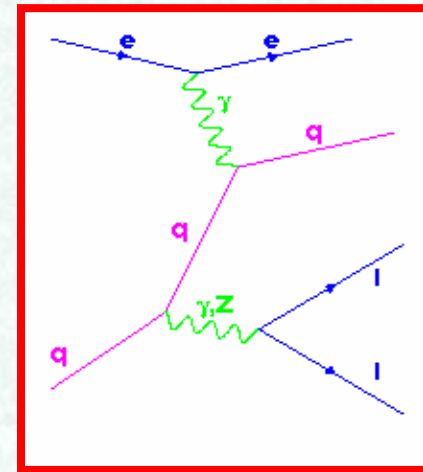


$\gamma\gamma$ process dominant



Cabbibo-Parisi

- $ee \rightarrow ee$ annihilation & Scattering
- $ee \rightarrow \mu\mu$ annihilation



Drell-Yan negligible

Multi-lepton production is a QED process

-very well understood in the Standard Model

Any excess over SM prediction at high mass region is sensitive to new phenomena (e.g. $H^{\pm\pm}$)

Multi-lepton events at high mass

Selection:

- Look for events with **at least 2 high Pt leptons**:
- $P_{\tau}^{l1} > 10$ and $P_{\tau}^{l2} > 5$ GeV and $20^{\circ} < \theta_l < 160^{\circ}$
- Additional lepton: $E_e > 5$ GeV or $P_{\tau}^{\mu} > 2$ GeV ($5^{\circ} < \theta_l < 175^{\circ}$)
- Covered topologies:
 - * **H1**: $ee, e\mu, \mu\mu$ and $eee, e\mu\mu$
 - * **ZEUS**: ee, eee

Dominant background:

- **NC DIS**: DIS e + fake electron
- **QED Compton**: γ misidentified as e

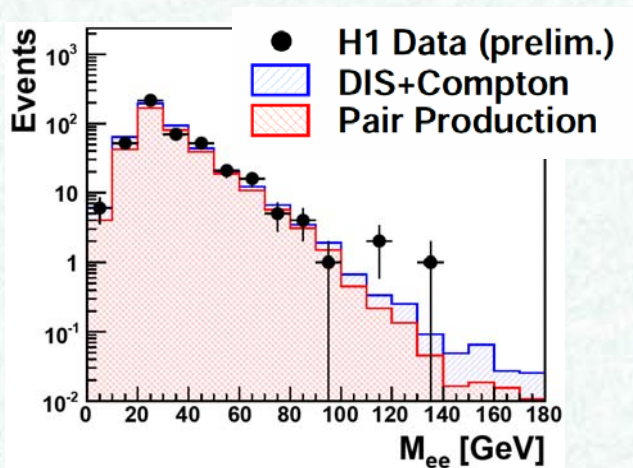
Invariant mass M_{ll} :

- Reconstructed using **2 highest Pt leptons**

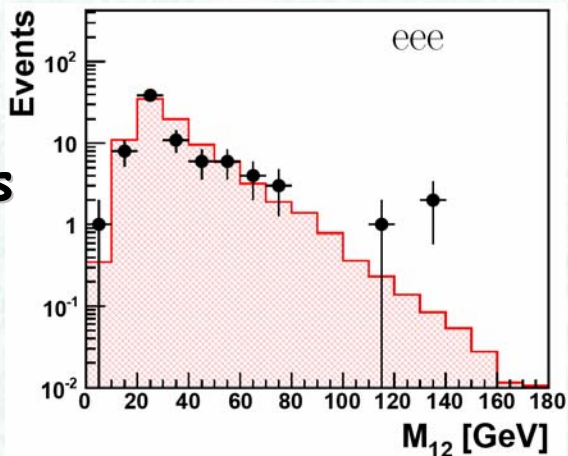
Multi-electron mass

H1: $L = 459 \text{ pb}^{-1}$

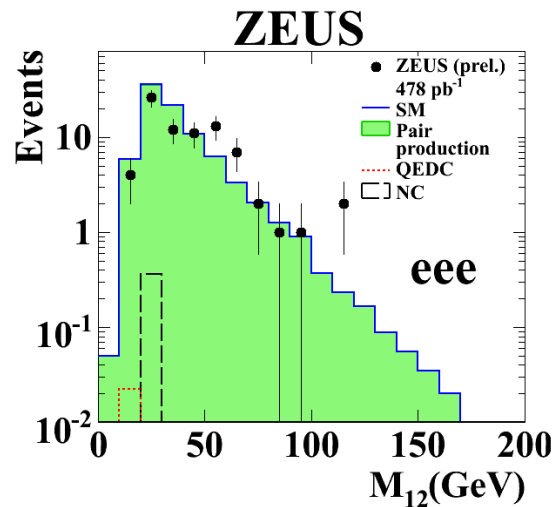
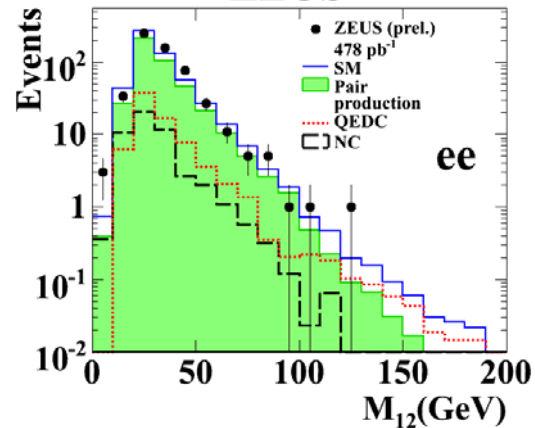
ee events



eee events



ZEUS: $L = 478 \text{ pb}^{-1}$

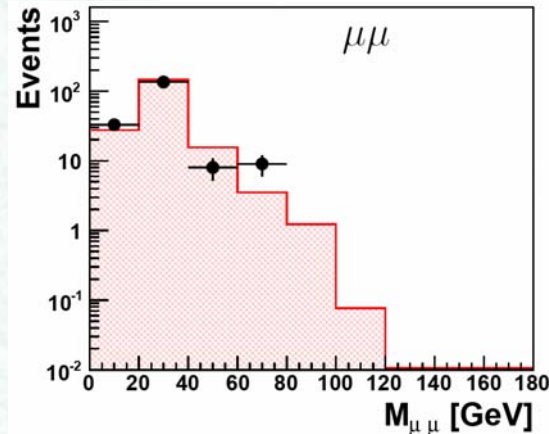
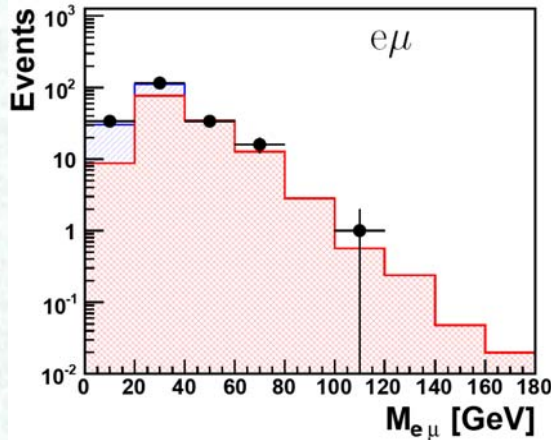


Overall good agreement with the Standard Model

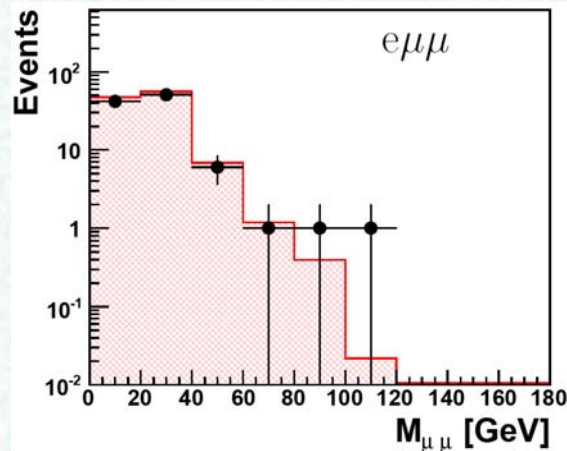
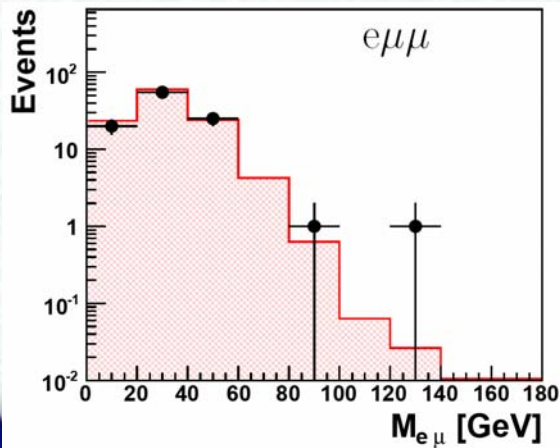
Topologies with $\mu(s)$

H1: $L = 459 \text{ pb}^{-1}$

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



Di-lepton topology



Tri-lepton topology

Overall good agreement with the Standard Model

Event yields at high $M_{ll} > 100$ GeV

H1 Preliminary: $L = 459 \text{ pb}^{-1}$

	Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p collisions (286 pb^{-1})					
e^+p	$ee M_{12} > 100 \text{ GeV}$	3	1.0 ± 0.2	0.6 ± 0.2	0.4 ± 0.1
	$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.06 ± 0.03	0.06 ± 0.03	—
	$e\mu M_{e\mu} > 100 \text{ GeV}$	1	0.53 ± 0.05	0.53 ± 0.05	—
	$eee M_{12} > 100 \text{ GeV}$	3	0.6 ± 0.1	0.6 ± 0.1	—
	$e\mu\mu M_{e\mu} > 100 \text{ GeV}$	1	0.04 ± 0.02	0.04 ± 0.02	—
	$e\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	1	0.007 ± 0.005	0.007 ± 0.005	—
e^-p collisions (173 pb^{-1})					
e^-p	$ee M_{12} > 100 \text{ GeV}$	0	0.55 ± 0.1	0.3 ± 0.1	0.25 ± 0.07
	$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.03 ± 0.02	0.03 ± 0.02	—
	$e\mu M_{e\mu} > 100 \text{ GeV}$	0	0.3 ± 0.05	0.3 ± 0.05	—
	$eee M_{12} > 100 \text{ GeV}$	0	0.32 ± 0.06	0.32 ± 0.06	—
	$e\mu\mu M_{e\mu} > 100 \text{ GeV}$	0	0.04 ± 0.01	0.04 ± 0.01	—
	$e\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.006 ± 0.004	0.006 ± 0.004	—

All high mass events $M_{ll} > 100 \text{ GeV}$ from e^+p data

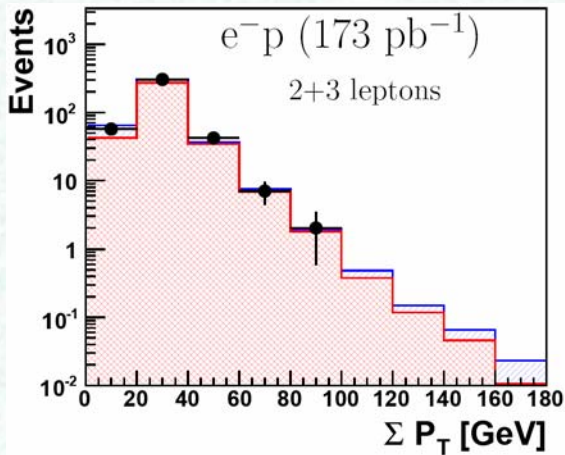
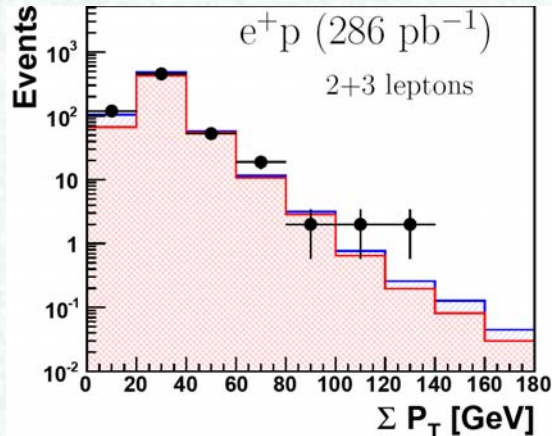
ZEUS Preliminary: $L = 478 \text{ pb}^{-1}$

e^+p ($L = 272 \text{ pb}^{-1}$) e^-p ($L = 206 \text{ pb}^{-1}$)

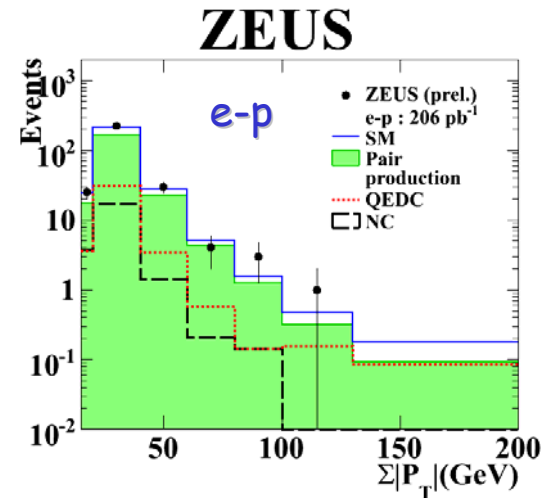
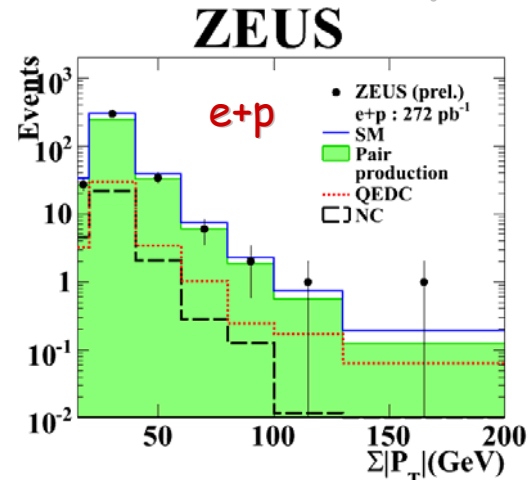
	Data sample	Data	SM	Pair Production	Compton	NC DIS
e^+p	ee	1	0.9 ± 0.1	0.5 ± 0.07	0.4 ± 0.12	0.07 ± 0.03
	eee	2	$0.6^{+0.5}_{-0.07}$	0.6 ± 0.07	< 0.01	< 0.5
e^-p	ee	1	0.8 ± 0.08	0.4 ± 0.04	0.39 ± 0.10	0.04 ± 0.01
	eee	0	$0.4^{+0.5}_{-0.05}$	0.4 ± 0.05	< 0.01	< 0.5

Multi-leptons: scalar ΣP_T distribution

H1: $L = 459 \text{ pb}^{-1}$



ZEUS: $L = 478 \text{ pb}^{-1}$



Good agreement with SM

Event yields at scalar $\Sigma P_t > 100 \text{ GeV}$

H1 Preliminary: $L = 459 \text{ pb}^{-1}$ Multileptons: electrons and muons

Data sample	Data	SM	Pair Production	NCDIS + Compton
e+p L=286pb	4	1.2 ± 0.2	1.0 ± 0.2	0.2 ± 0.1
e-p L=173pb	0	0.8 ± 0.2	0.6 ± 0.2	0.2 ± 0.1
All L=459pb	4	1.9 ± 0.4	1.5 ± 0.3	0.4 ± 0.1

H1: All events at high ΣP_t come from e+p data

ZEUS Preliminary: $L = 478 \text{ pb}^{-1}$ Multileptons: electrons only

Data sample	Data	SM	Pair Production	Compton	NC DIS
e+p L=272pb	2	$0.93^{+0.10}_{-0.09}$	0.67 ± 0.07	$0.23^{+0.07}_{-0.06}$	0.02 ± 0.01
e-p L=206pb	1	$0.65^{+0.08}_{-0.07}$	0.41 ± 0.04	$0.24^{+0.07}_{-0.06}$	0.01 ± 0.01
All L=478pb	3	$1.58^{+0.16}_{-0.12}$	1.08 ± 0.11	$0.47^{+0.15}_{-0.11}$	0.03 ± 0.01

Search for doubly charged Higgs

In extension to SM:

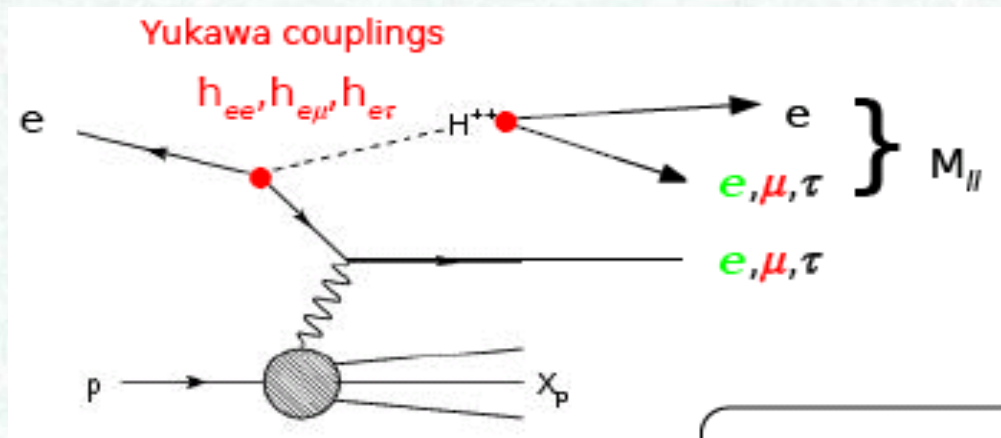
- $H^{\pm\pm}$ appears in Higgs triplet(s) of non-zero hypercharge
- Left-right symmetries: $SU(2)_R \times SU(2)_L \times U(1)_{B-L}$
- provides mass to Majorana neutrinos
- Couplings to leptons $h_{ll}^{R,L}$ unknown

Democratic scenario: $h_{ee} = h_{e\mu} = h_{e\tau}$

One dominant coupling $h_{e\ell} \gg 0$, others ~ 0

HERA: $e^\pm p \rightarrow l^\pm H^{\pm\pm} X$

where $H^{\pm\pm} \rightarrow e^\pm l^\pm$



Double charged Higgs

Selection:

- ✓ Data: HERA-I $L=118 \text{ pb}^{-1}$
- ✓ ee , $e\mu$: based on multi-lepton analysis
- ✓ $e\tau$ with $\tau \rightarrow e, \mu$ and hadrons
- ✓ 2 high-Pt leptons with the same charge as a beam lepton
- ✓ Reconstruct inv. mass Higgs candidates - $M_{H^{\pm\pm}}$

Results:

$M_{H^{\pm\pm}} > 65 \text{ GeV}$

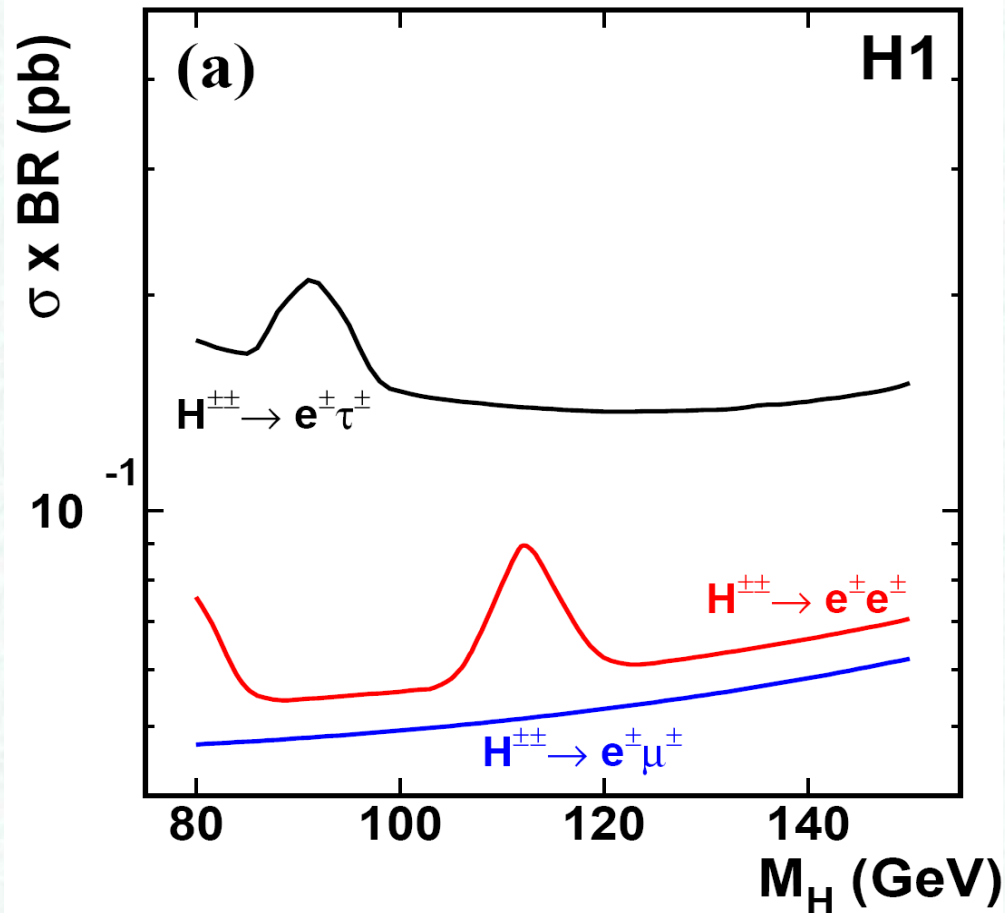
	Obs	SM exp.
ee	3	2.45 ± 0.11
$e\mu$	1	4.17 ± 0.44
$e\tau$	1	2.1 ± 0.5

$M_{H^{\pm\pm}} > 100 \text{ GeV}$

Only one ee event satisfies
the final selection criteria

No evidence for $H^{\pm\pm} \Rightarrow$ set limits

Double charged Higgs: results



Upper limits for H^{++} production at 95% C.L. derived by modified frequentist method

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

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

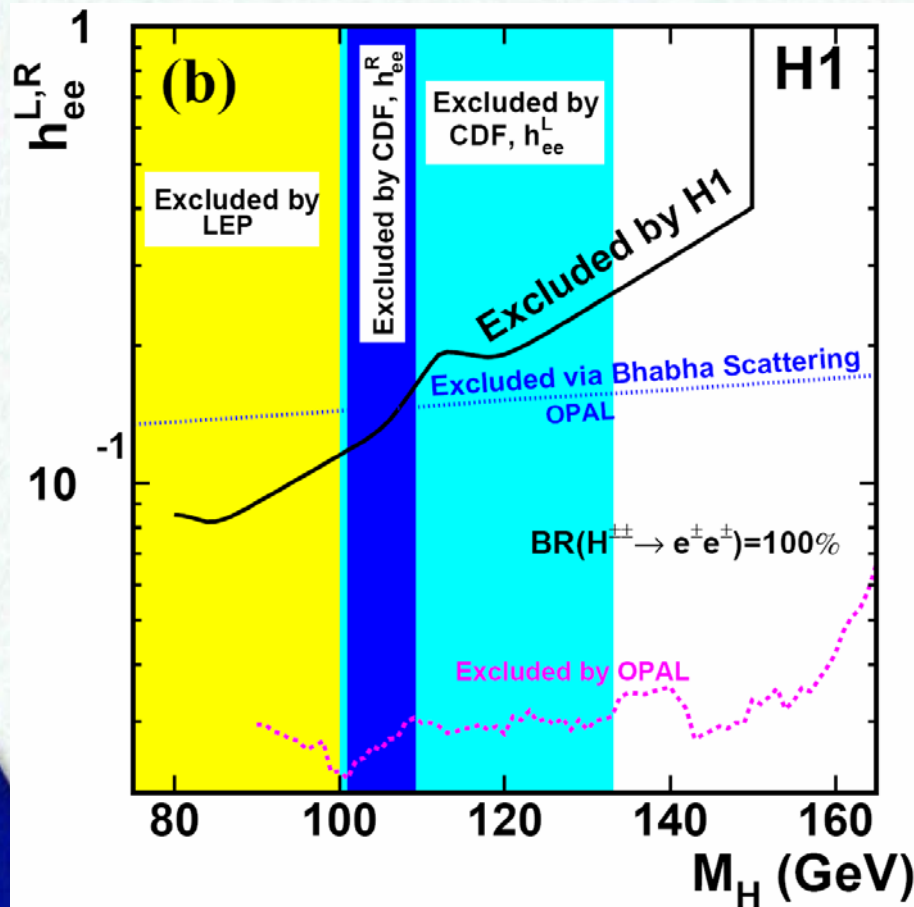
$$H^{++} \rightarrow e^{+}\mu^{+}$$

Best sensitivity:
 $\sigma \times \text{Br}(h_{e\mu}) < 0.05 \text{ pb}$

Double charged Higgs: upper limits on h_{ee}

$H^{\pm\pm}$ boson couples to **electron-electron pair** only

Topologies: ee and eee (excess was observed in HERA I data)



LEP, TeVatron:

- $H^{\pm\pm}$ Pair Production: h_{ei} independent

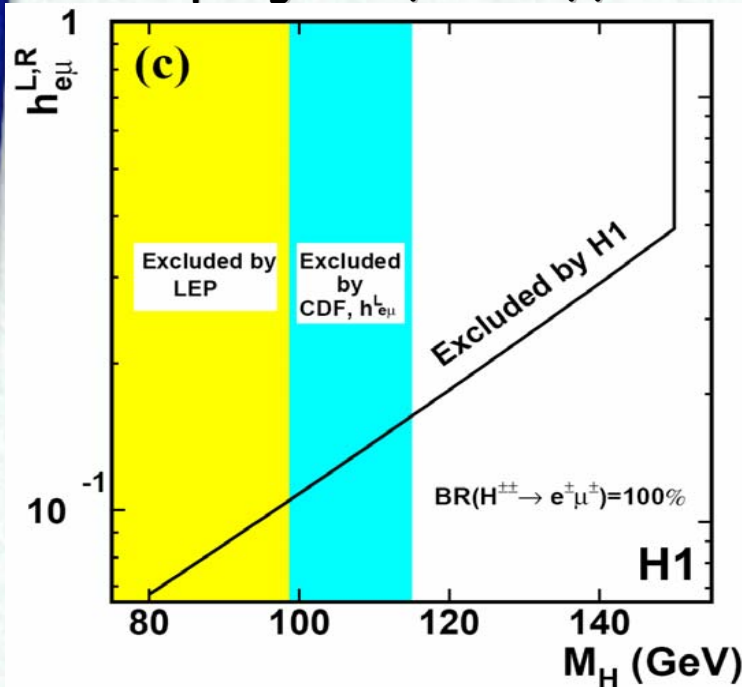
OPAL:

- $H^{\pm\pm}$ single production

Limits are set for left- and right-handed h_{ee} couplings

Doubly charged Higgs: upper limits on $h_{e\mu}$ and $h_{e\tau}$

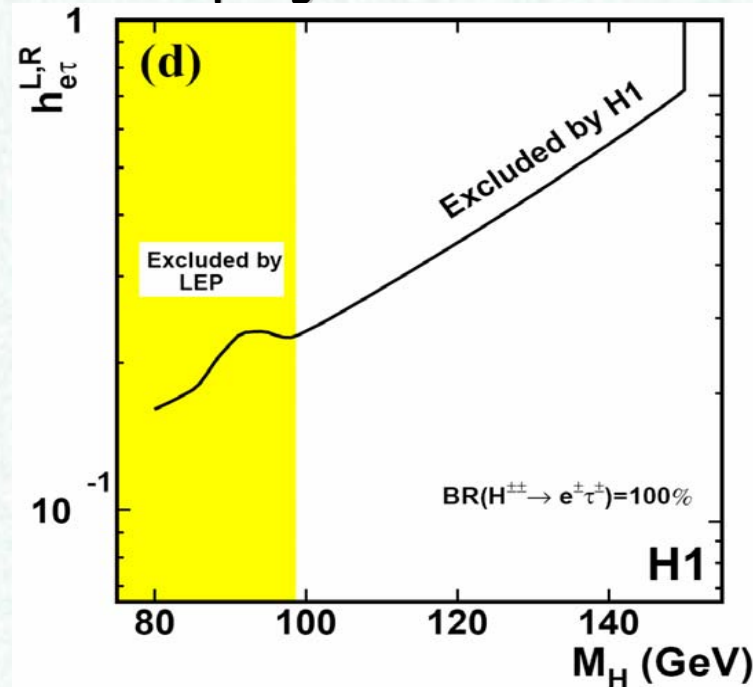
- $H^{\pm\pm}$ boson couples to **electron-muon pair** only
- Topologies: $e\mu$ and $e\mu\mu$



For couplings of em. strength $h_{e\mu} \sim 0.3$: mass exclusion $M_{H^{\pm\pm}} > 141 \text{ GeV}$

$h_{e\tau} \sim 0.3$: mass exclusion $M_{H^{\pm\pm}} > 112 \text{ GeV}$

- $H^{\pm\pm}$ boson couples to **electron-tau pair** only
- Topologies: $e\tau$ and $e\tau\tau$



HERA limits extend beyond LEP, TeVatron reach

Summary

➤ Multi-lepton production has been investigated in ep collision

- all HERA data were analysed by both ZEUS and H1 coll. (~1fb)
- general good agreement with the SM prediction
- Events at scalar $\Sigma P_t > 100$ GeV:

H1: 4 observed where 1.9 is expected (all events in e+p collision)

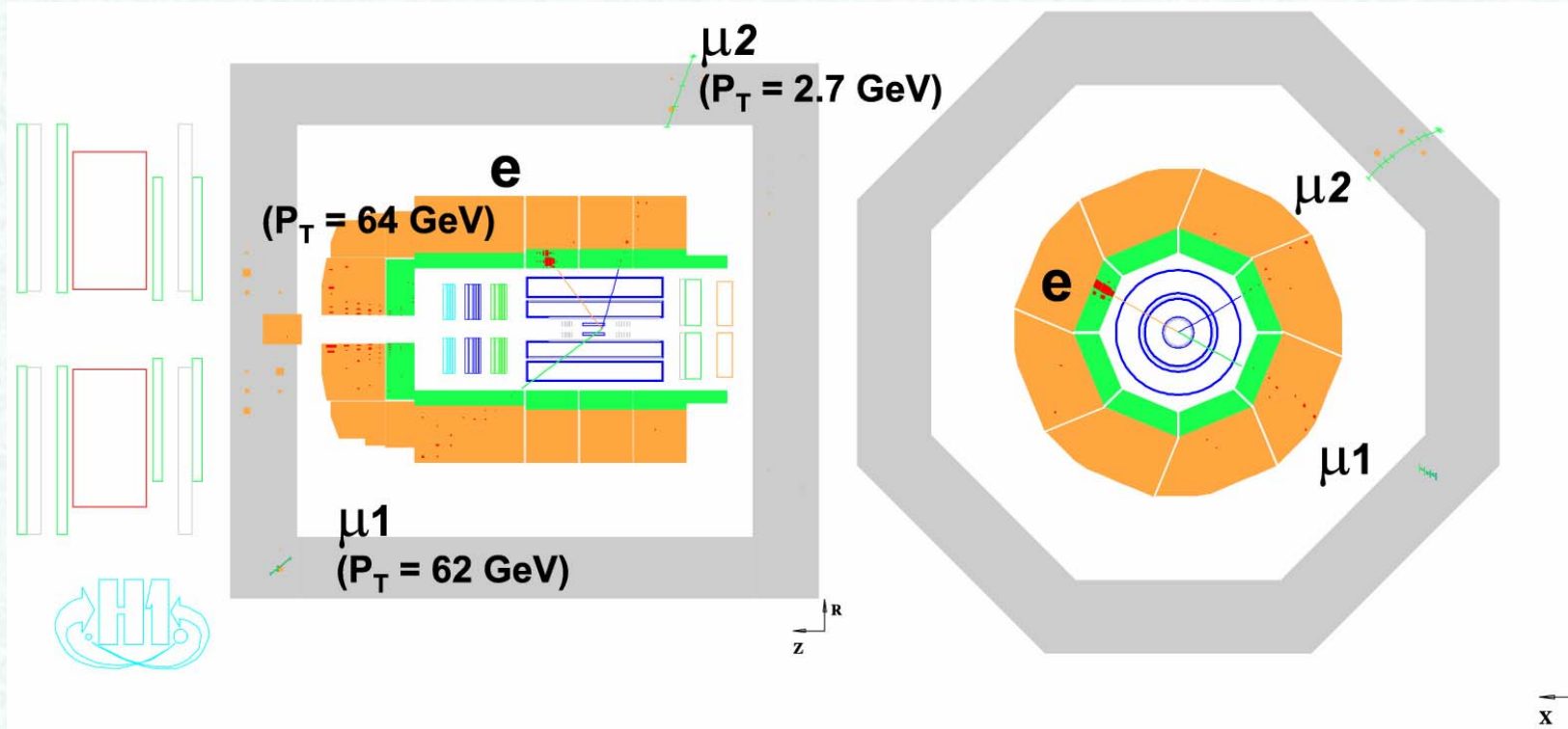
ZEUS: 3 observed where 1.6 is expected (2 in e+p and 1 in e-p collision)

➤ Exotic production of $H^{\pm\pm}$ has been studied by H1:

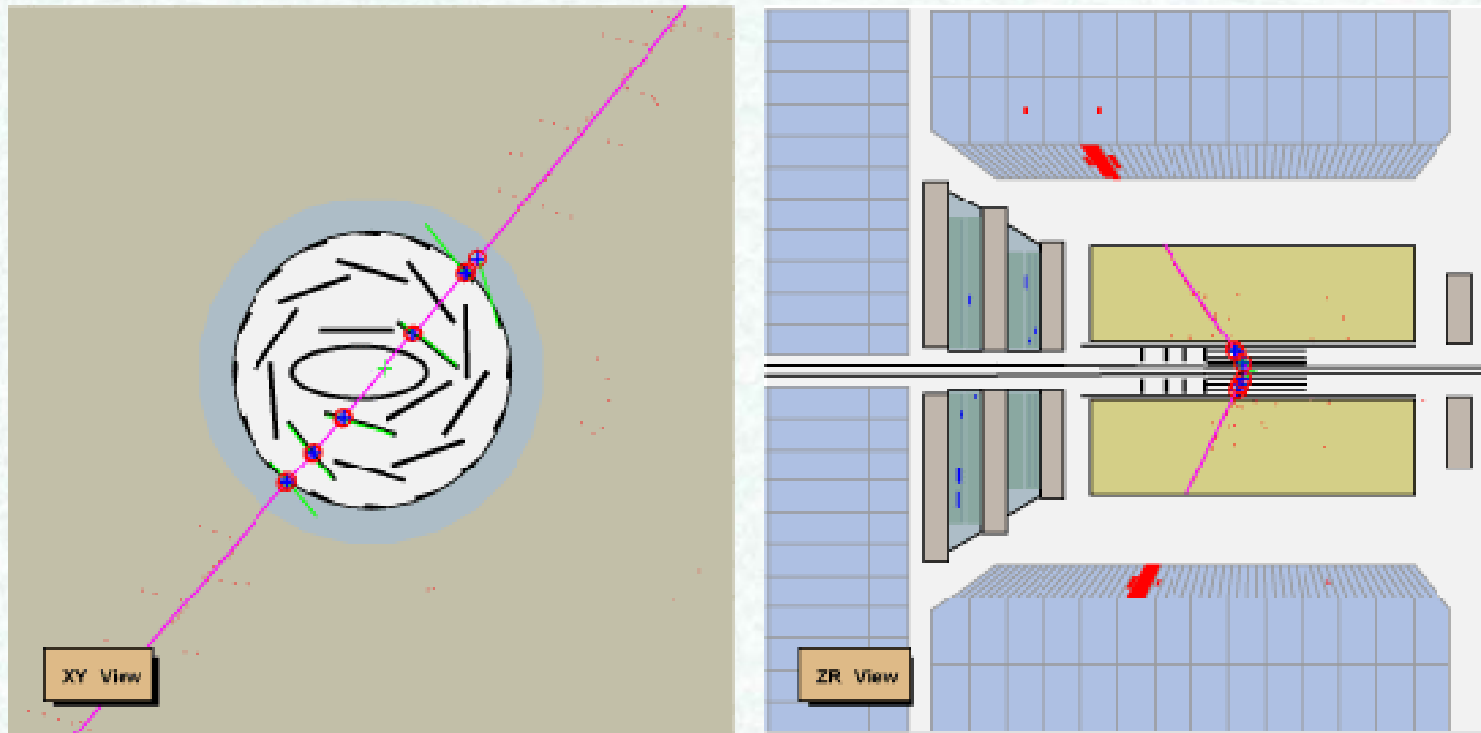
- All e, μ , τ topologies analysed
- Constrains on the $H^{\pm\pm}$ production cross-section \times Br were obtained
- Limits were set on diagonal h_{ee} and non-diagonal couplings $h_{e\mu}$, $h_{e\tau}$
- HERA limits extend beyond LEP and TeVatron reach

Backup slides

High mass events H1



High mass events ZEUS



**Mass = 100.8 GeV, $P_{t^{e1}} = 50.4$ GeV, $P_{t^{e2}} = 50.0$ GeV,
 $\theta_{e1} = 1.12(\text{rad})$, $\theta_{e2} = 0.97(\text{rad})$.**

Multi-electrons: summary tables

H1 HERA-I+II (L=459pb⁻¹, preliminary)

H1 Multi-lepton analysis HERA I+II (459 pb⁻¹, preliminary)

Selection	Data	SM	Pair Production	NC-DIS + Compton
ee	446	450 ± 68	375 ± 42	75 ± 39
μμ	185	194 ± 38	194 ± 38	—
eμ	201	194 ± 26	136 ± 13	58 ± 17
eee	81	90 ± 10	90 ± 10	—
eμμ	102	112 ± 19	112 ± 19	—

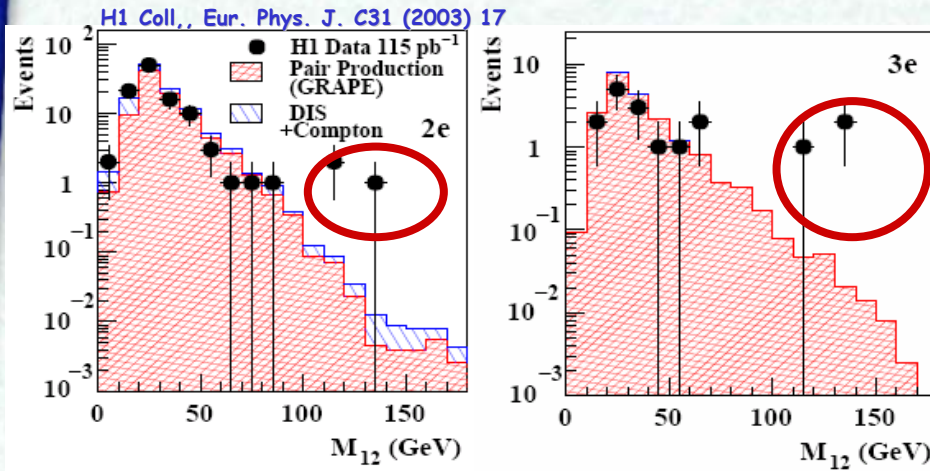
ZEUS HERA-I+II (L=478pb⁻¹, preliminary)

Type	DATA	SM	Pair production	QEDC	NC
2e	573	561 ± 36.2	431.2 ± 25	79.1 ± 26.1	50.6 ± 4.6
3e	79	88.8 ± 5.7	88.4 ± 5.7	0.02 ± 0.01	0.4 ± 0.01
2e+3e	652	649.7 ± 36.4	519.6 ± 25.6	79.1 ± 26.1	51.0 ± 4.6

Motivation

➤ H1 results for ee and eee channels (HERA-I data)

Distribution of inv. Mass of 2 highest Pt electrons



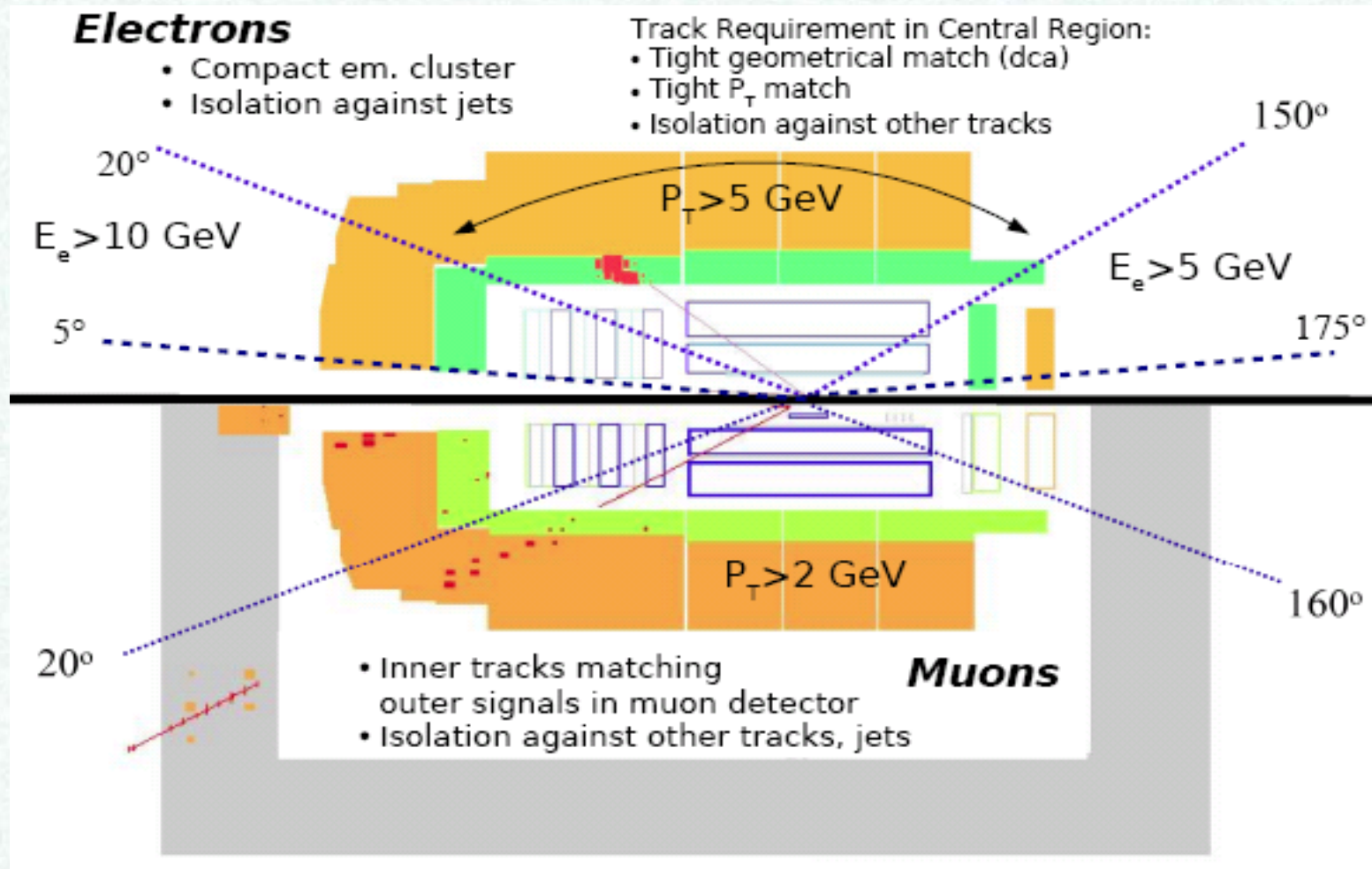
- General good agreement with SM
- Interesting events at $M_{ee} > 100 \text{ GeV}$

Selection	Data	SM	Pair Production (GRAPE)	DIS + Compton
"2e" $M_{12} > 100 \text{ GeV}$	3	0.30 ± 0.04	0.21 ± 0.03	0.09 ± 0.02
"3e" $M_{12} > 100 \text{ GeV}$	3	0.23 ± 0.04	0.23 ± 0.03	< 0.02 (95% C.L.)



H^{\pm} production?

Event Selection H1



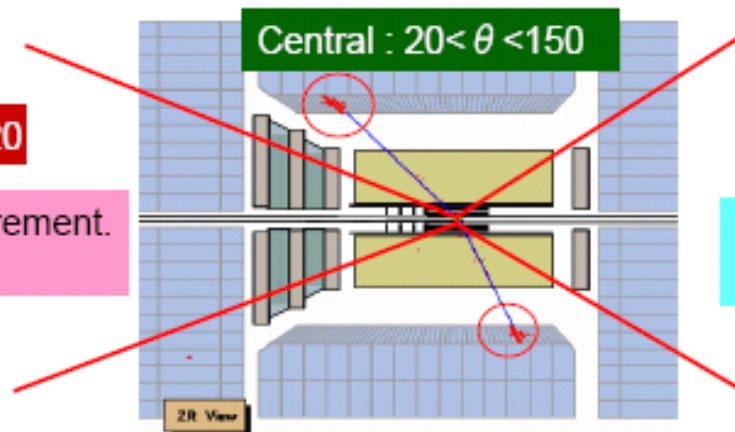
Event Selection ZEUS

- ◆ Require 2 or more EM-clusters in CAL.
- ◆ Track match : $P_{\text{trk}} > 3\text{GeV}$, $\text{DCA} < 8\text{cm}$
- ◆ $E_e > 10\text{GeV}$

- ◆ Prim fitted track ←new
- ◆ MVD hit : $r+z \geq 2$ ←new
- ◆ Track Isolation : $\text{Imppar} < 2\text{cm}$ ←new

Forward : $5 < \theta < 20$

- ◆ No track requirement.
- ◆ $E_e > 10\text{GeV}$



Rear : $150 < \theta < 175$

- ◆ No track requirement.
- ◆ $E_e > 5\text{GeV}$

- ◆ For central electron:
 - $P_t > 10\text{GeV}$: 1st electron.
 - $P_t > 5\text{GeV}$: 2nd electron.

- ◆ Geometry cuts:
 - Super crack cut
 - RCAL radius cut
 - Chimney cut