Multi-Lepton Events at H1 and Search for Doubly Charged Higgs

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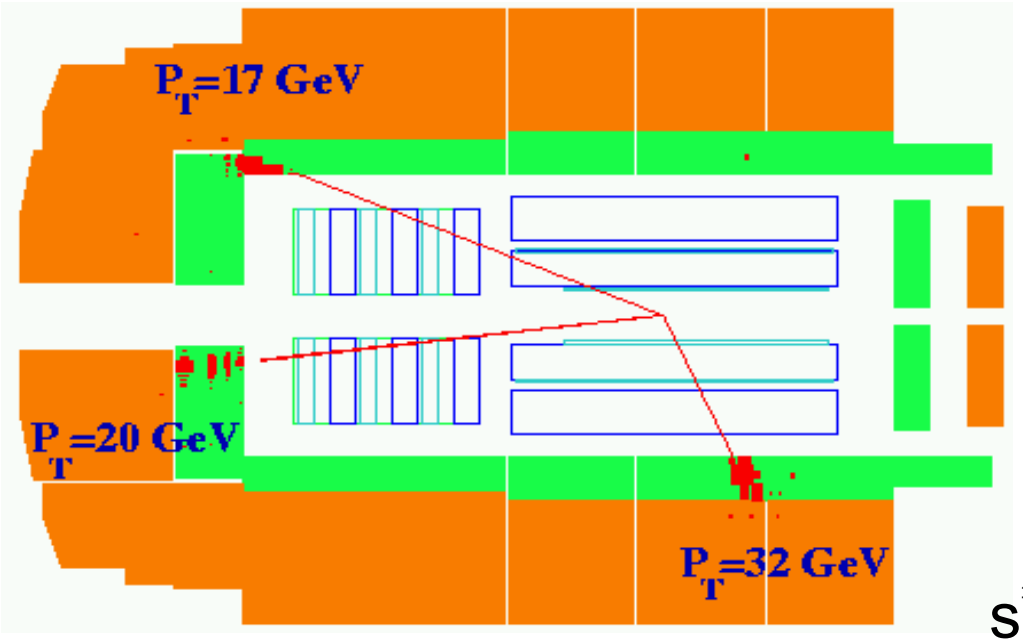
on behalf of the H1 collaboration

Multi-Lepton Events in H1

$e^{\pm}$(27.5 GeV)



p (820/920 GeV)

$s^{½}$= 300/320 GeV

HERA	e^+p	e^-p	total
HERA I	105 pb^{-1}	15 pb^{-1}	120 pb^{-1}
HERA II	45 pb^{-1}	**21 pb^{-1}**	65 pb^{-1}

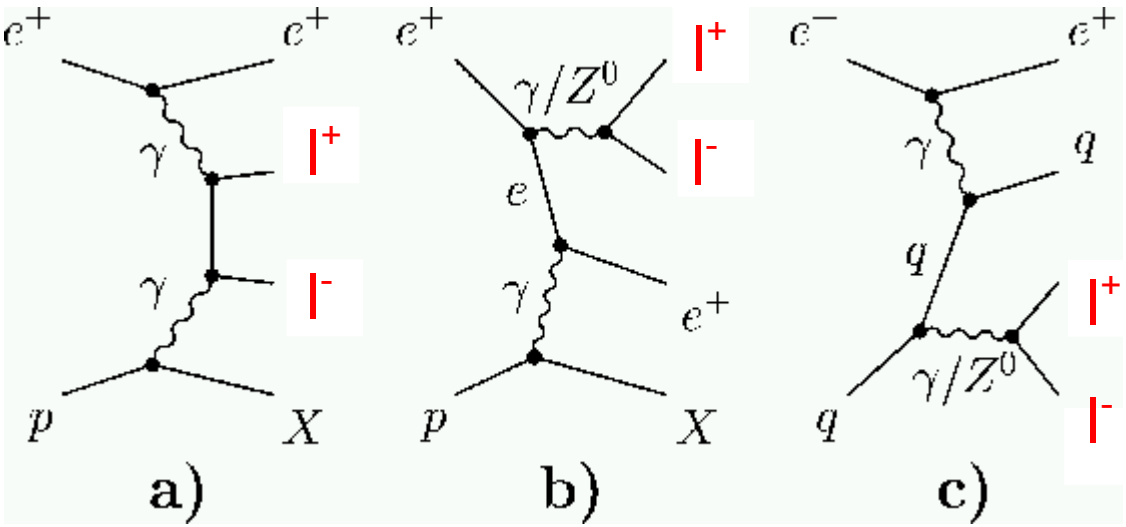
ICHEP 04

new

- Study events with 2 or 3 isolated leptons (electron, muon, tau)

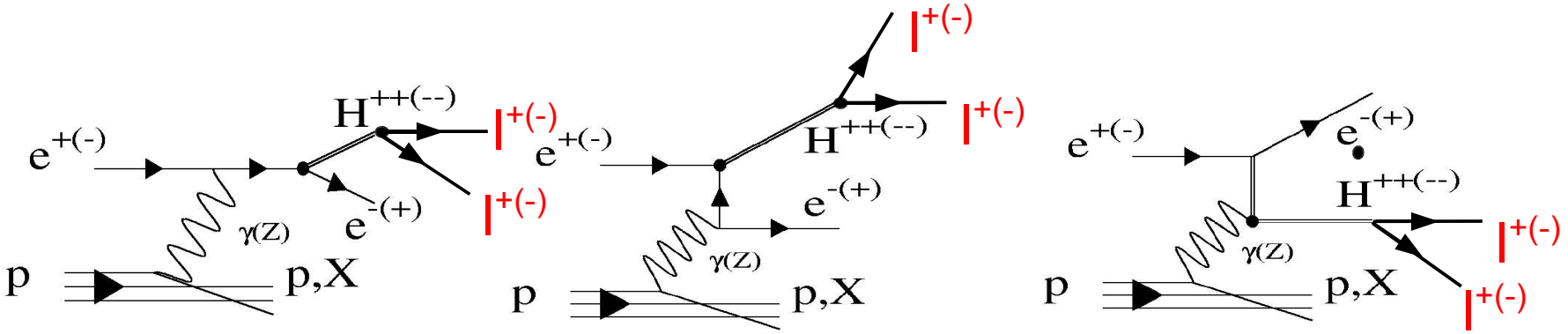
Processes

- SM:



"two photon" (dominant) "Cabibo-Parisi" "Drell-Yan"

- BSM e.g. production of doubly charged Higgs: $H^{\pm\pm} \rightarrow l^{\pm} l^{\pm}$



Overview

- Selections
  - multi-electrons events
  - multi-muons events
- HERA I+II results $e^{\pm}p$ $\mathcal{L}$=165 pb^{-1} (ICHEP 04)
- HERA II update $e^{-}p$ $\mathcal{L}$=21 pb^{-1} (preliminary)

- Doubly Charged Higgs
  - couplings to electrons, muon, or taus
  - results and limits
- Summary

Multi-Electrons

- **Selection:**
  - "2e" sample:

    $p_T^{1,2} > 10, 5$ GeV , $20° < \text{polar angle}^{1,2} < 150°$

    good isolated track associated to electron shower

    $\Rightarrow$ electron-id efficiency $\sim 85\%$

  - "3e" sample:

    "2e" selection +

    $p_T^{3} > 5$ GeV , $5° < \text{polar angle}^{3} < 175°$

- **Background:**
  - Neutral Current

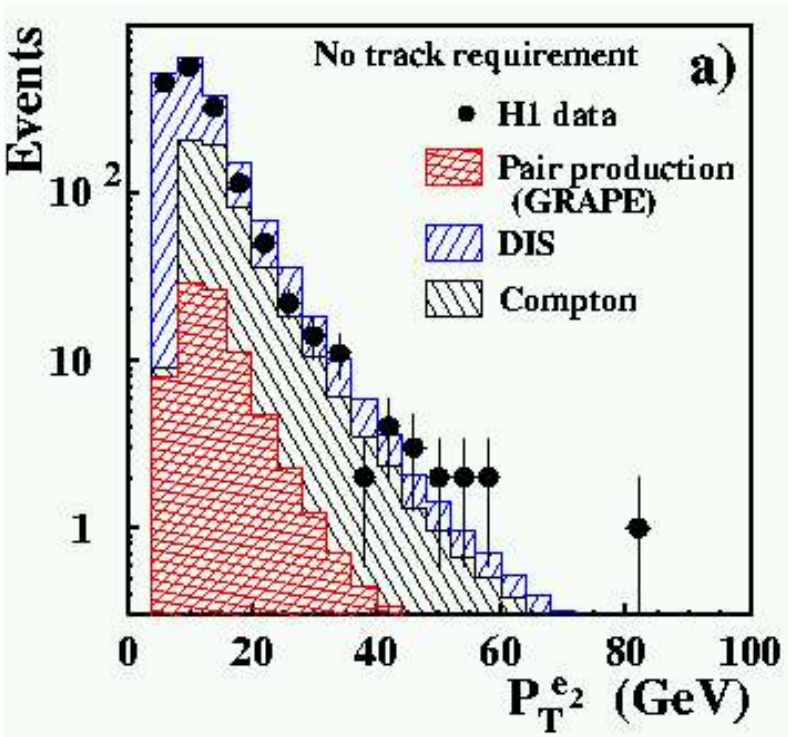
    $ep \rightarrow e\,\gamma\,X$ ("Compton")

    γ mis-identified as electron

    $ep \rightarrow e\,X$ ("NC DIS")

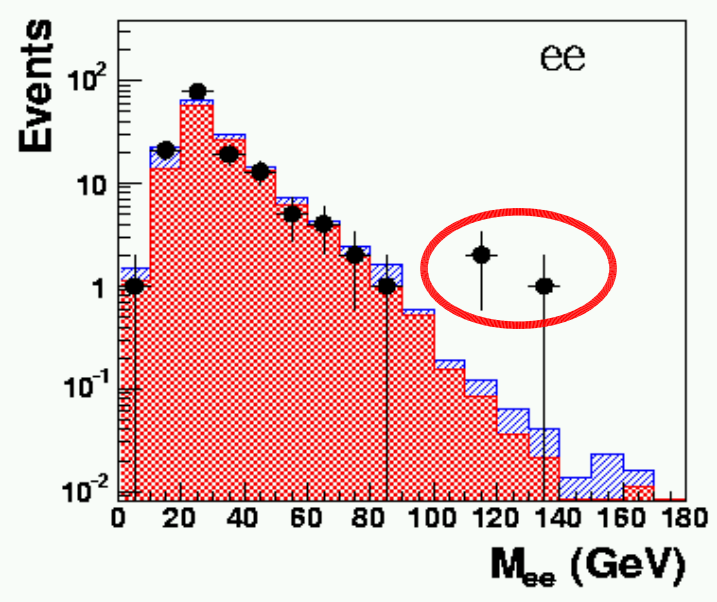
    hadrons mis-identified as electron

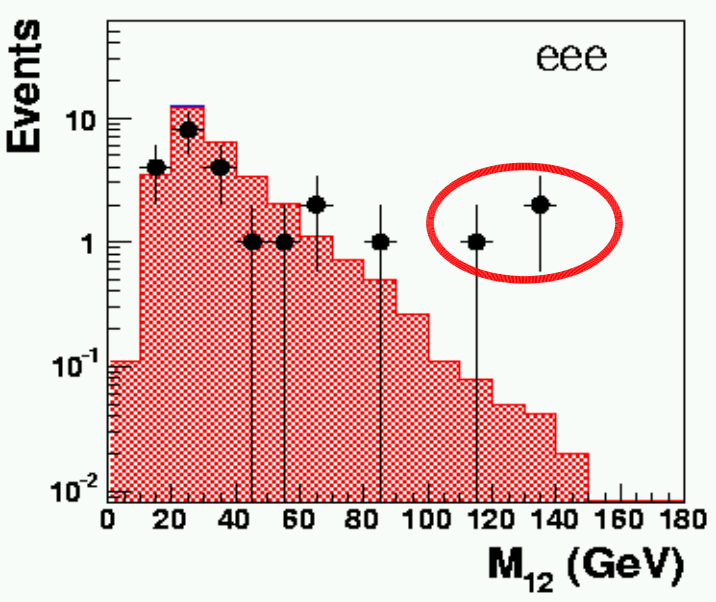
H1 Collab., Eur Phys J C31 (2003) 17



HERA II Preliminary

1996-2004 $e^{\pm}p$ $L=163pb^{-1}$ (ICHEP 04)





(HERA I+II)	data($L=163pb^{-1}$)	SM	Pair Production (Grape)
ee	147	149.8 ± 24.8	125.5
eee	24	30.4 ± 3.9	30.4

⇒ good agreement with SM

$M_{12}>100$ GeV

(HERA I+II)	data($L=163pb^{-1}$)	SM	Pair Production (Grape)
ee $M_{12}>100$ GeV	3	0.44 ± 0.10	0.32
eee $M_{12}>100$ GeV	3	0.31 ± 0.08	0.31

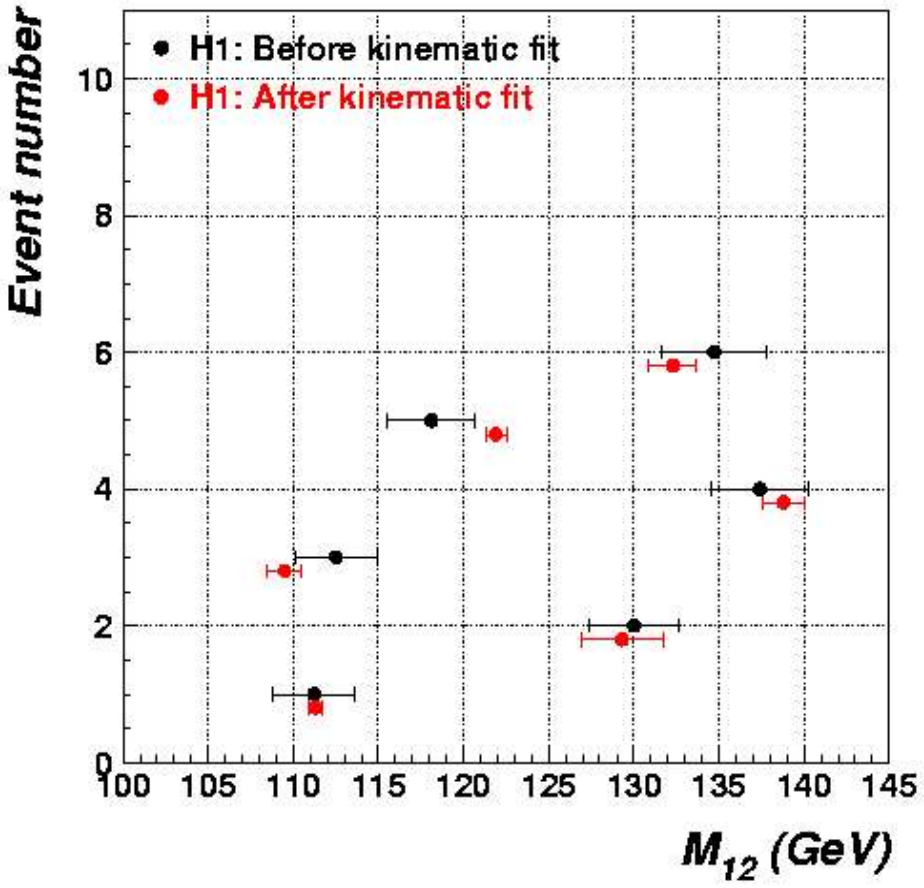
⇒ excess at high invariant mass

Precise M_{ee} Determination

To improve invariant mass resolution:

- exploit logitudinal and transverse energy and momentum conservation
- apply constrained kinematic fit

⇒ significant improvement of precision in M_{12}



⇒ values not compatible with a single narrow resonance

Di-Muon Events

H1 Collab., Phys. Lett. B583 (2004) 28

- Selection:
  - inclusive di-muon sample:

    $P_T^{\mu} > 2, 1.75$ GeV

    $20° <$ polar angle $< 160°$

    good central track matching muon signature in calorimeter or central muon system

    $M_{\mu\mu} > 5$ GeV

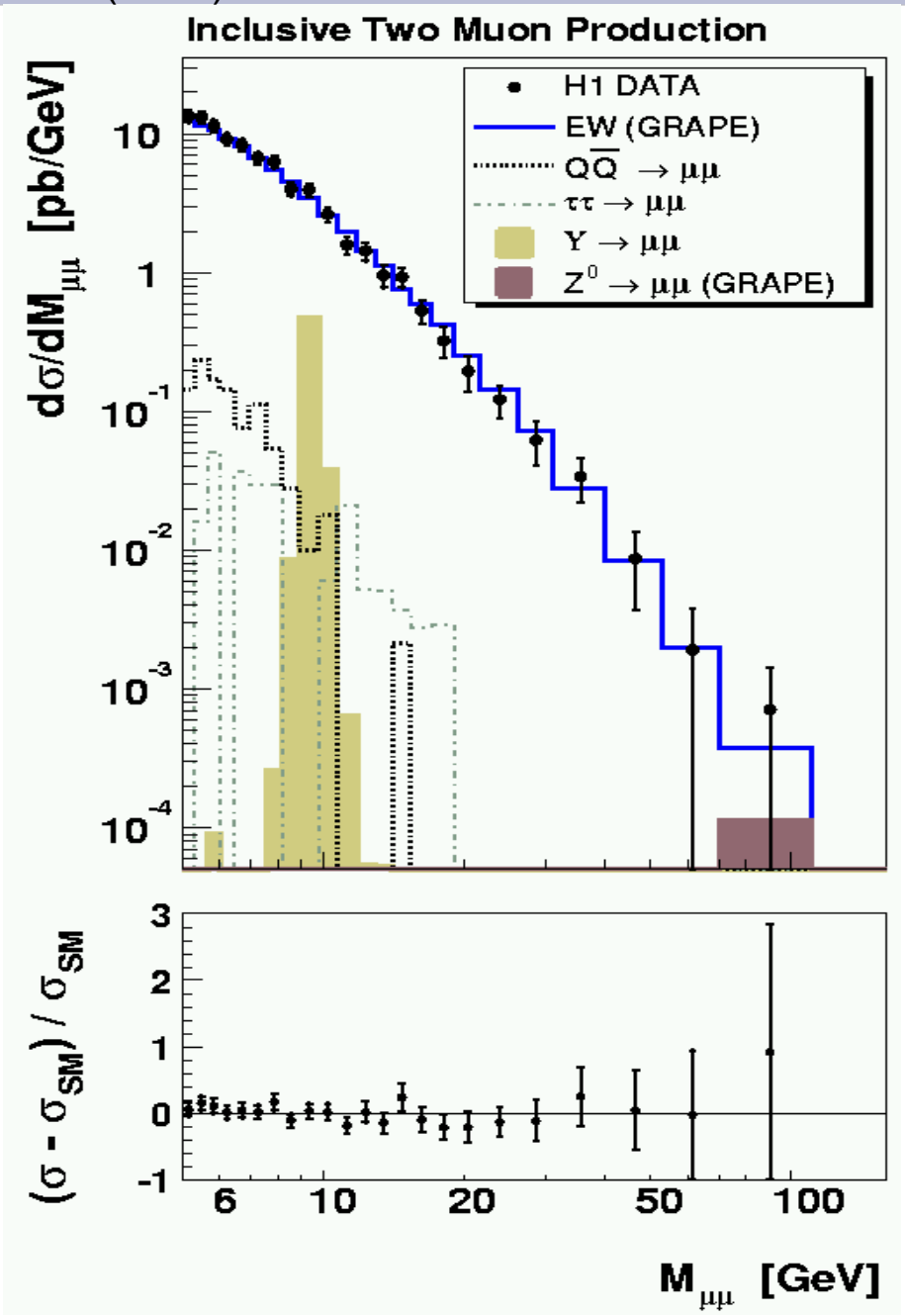
    $\Rightarrow$ muon-id efficiency $\sim 75\%$

- Results (L=71 pb^{-1}):

  data: $\sigma_{\mu\mu} = 46.4 \pm 1.3_{(stat)} \pm 4.5_{(syst)}$

  SM: $\sigma_{\mu\mu}^{SM} = 46.1 \pm 1.4 \pm 4.5$

  $\Rightarrow$ good agreement



Multi-Leptons with High p_T Muons

- Selection:
  - multi-lepton sample with $\geq 2\mu$:

2μ $P_T^{\mu 1,2} > 10, 5$ GeV
$20° < \text{polar angle}^{1,2} < 150°$

idea: similar phase space compared to multi-electrons

$2\mu+1$ $\oplus$ Any additional muon $P_T^{\mu 3} > 1.75$ GeV , $20° < \text{polar angle}^{3} < 160°$
$\oplus$ Any additional electron $E_e > 5$ GeV , $5° < \text{polar angle}^{3} < 175°$
(similar to multi-electron analysis)

- Results (L=114 pb^{-1}):

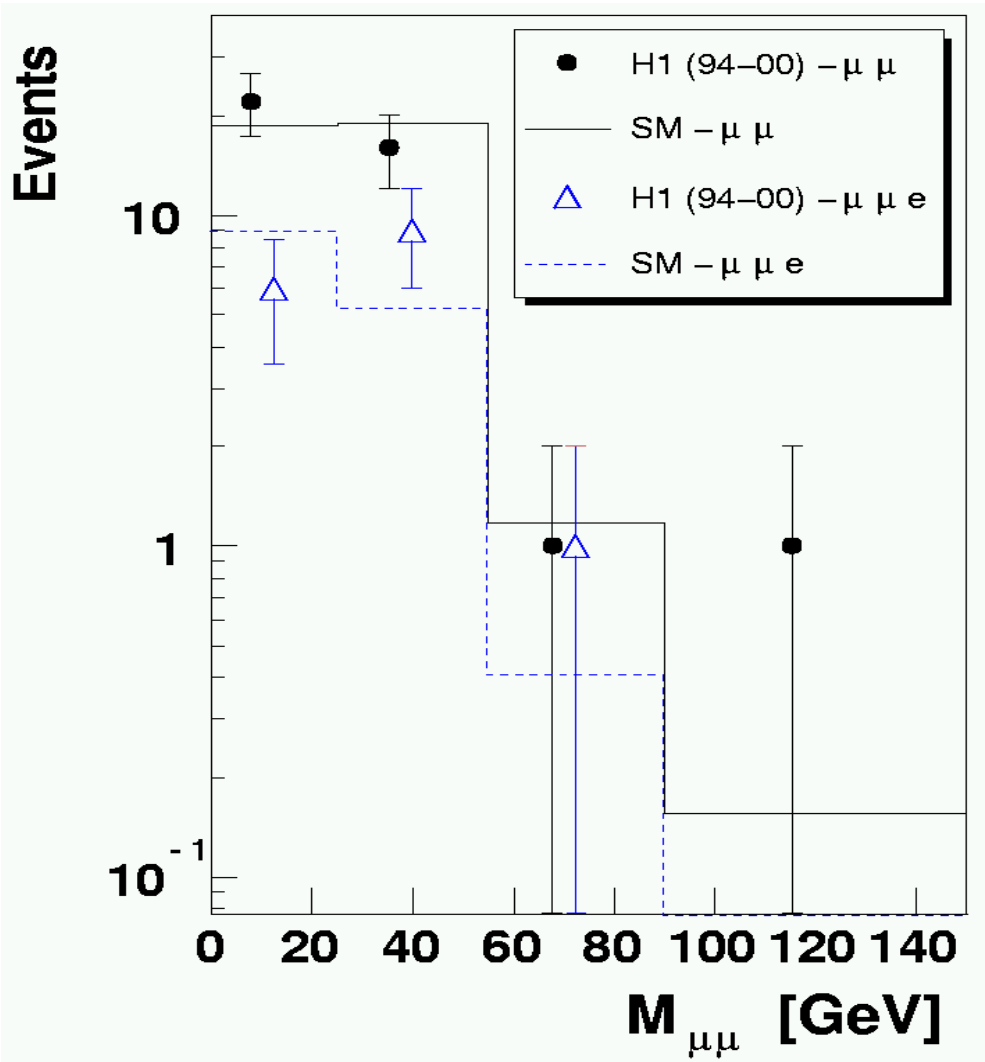
H1 (L=115pb^{-1})	data	SM
$\mu\mu$	40	39.9 ± 4.2
$\mu\mu e$	16	14.9 ± 1.6

$\rightarrow$ no $\mu\mu\mu$ event

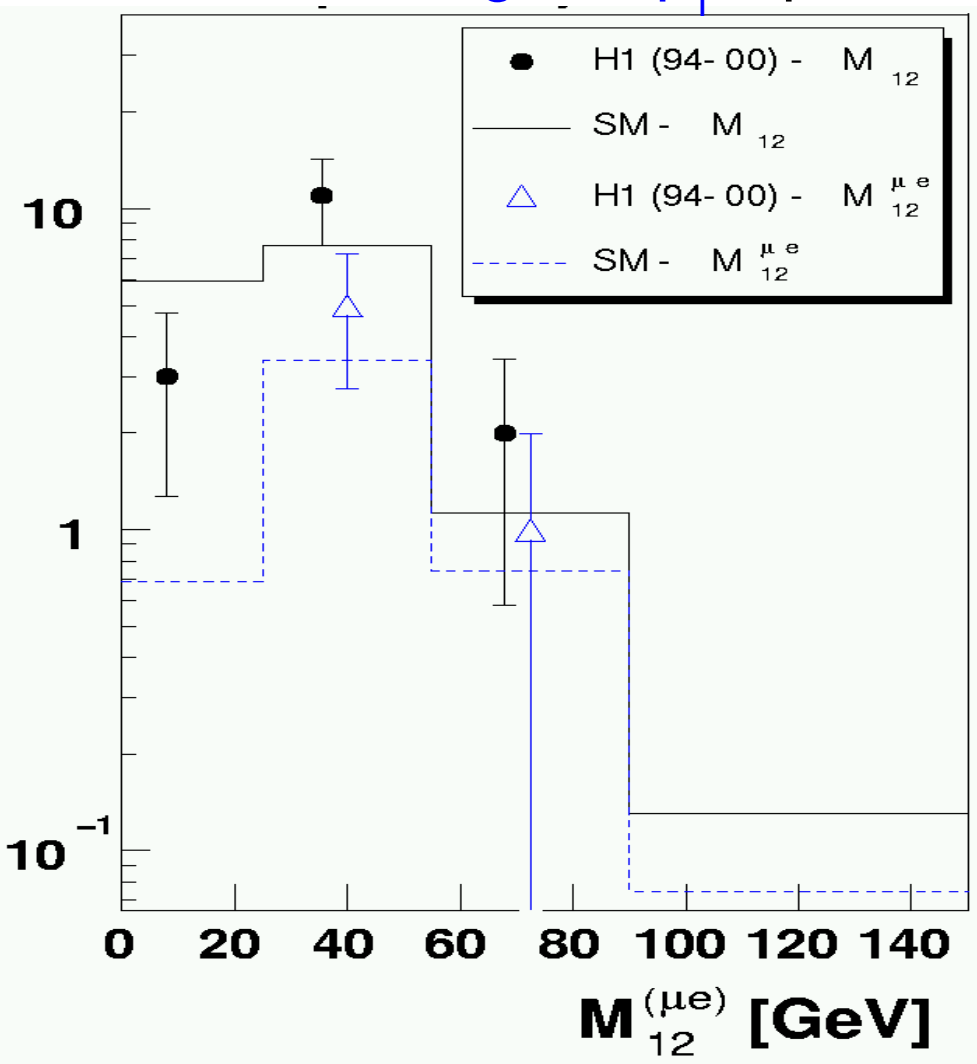
$\Rightarrow$ good agreement

High p_T Muons - Results

$\mu\mu$ invariant mass



inv. mass highest p_T leptons

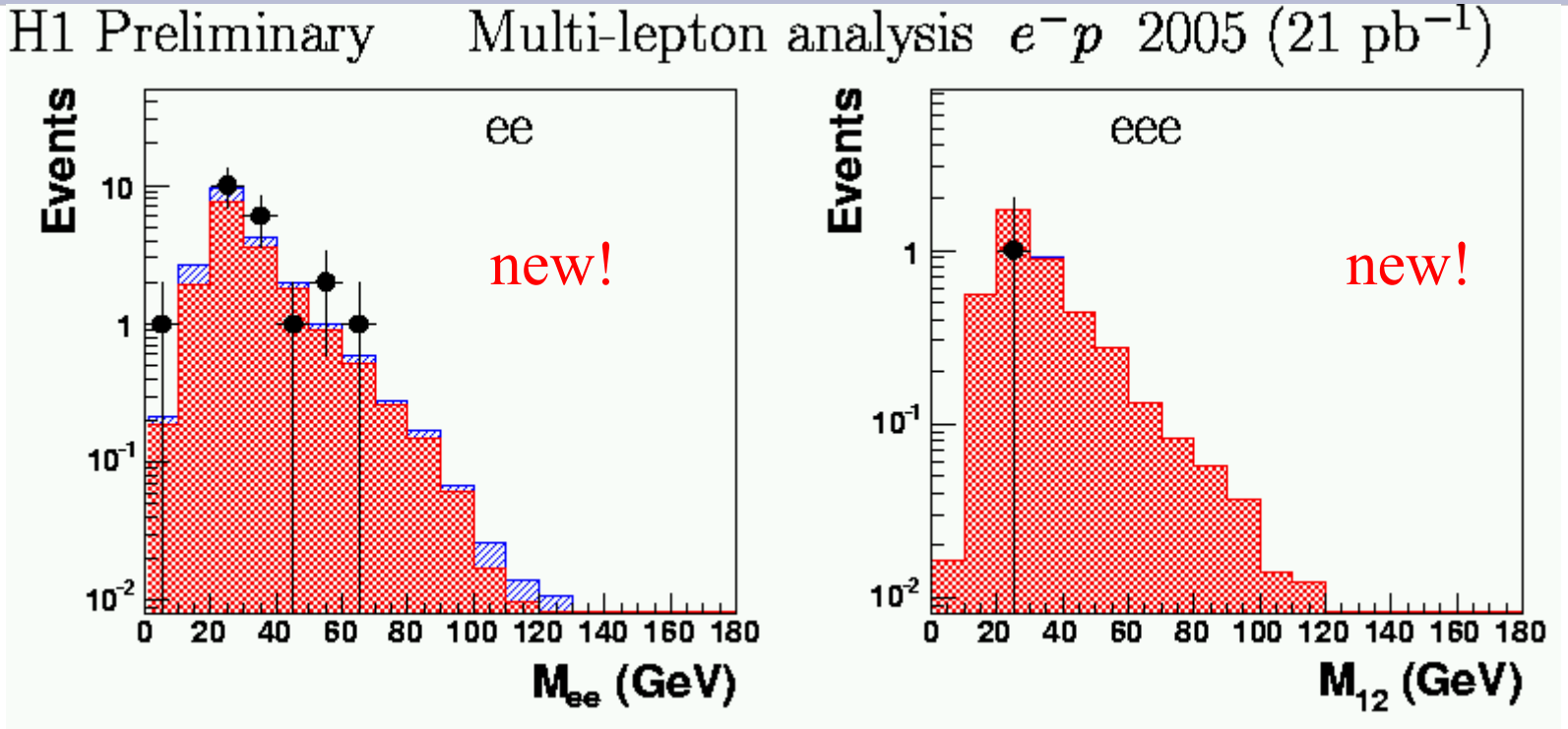


→ highest event with $M_{\mu\mu} = 102 \pm 10$ GeV

($M_{\mu\mu} > 100$ GeV: 0.08 ± 0.01 SM expectation)

⇒ good agreement with SM
statistics low!

HERA II 04/05 Preliminary



2004-2005 e^-p (Preliminary)

(HERA 04/05)	data(L=21 pb^{-1})	SM	Pair Production (Grape)
ee	21	21.1 ± 1.9	17.2
eμ	8	10.8 ± 2.5	6.6
eee	1	4.2 ± 0.7	4.2
eμμ	6	5.4 ± 0.9	5.4

$\Sigma E_T > 100$ GeV: 0 data for 0.08±0.008 expected

no event for $M > 100$ GeV

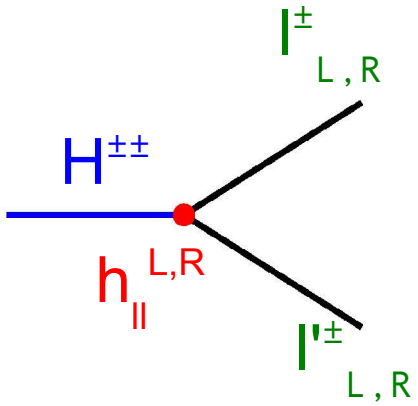
⇒ no new high mass events

Doubly Charged Higgs Intro

Motivation:

- H^{++} appear in Higgs triplet(s) of non-zero hypercharge
- occur in extension of the SM
- e.g. Left-Right symmetries: $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- vev might give mass to Majorana neutrinos

- couplings to standard leptons unknown:



$$h_{ll'}^{L,R} = \begin{vmatrix} h_{ee} & h_{\mu e} & h_{\tau e} \\ h_{e\mu} & h_{\mu\mu} & h_{\tau\mu} \\ h_{e\tau} & h_{\mu\tau} & h_{\tau\tau} \end{vmatrix}$$

expectation:

- 2 equally charged high p_T leptons
- lepton charge = beam charge

e.g. - democratic scenario: $h_{ee} = h_{\mu\mu} = h_{\tau\tau}$

- one dominant coupling: $h_{ee} >> 0$ or $h_{e\mu} >> 0$, others ~ 0

Doubly Charged Higgs Selection

Selections:

ee and μμ and eμ channel:

→ ask for lepton charges compatible with beam charge in addition to multi-lepton analyses

⇒ one high p_T ee event survives

ττ channel:

→ dedicated analysis considering all τ-decay channels ($L=65pb^{-1}$):

- e, μ, τ-jet (hadronic decay) identification
- isolation in η-ϕ cone $0.15 < R < 1.5$
- $p_T^{l,track} > 10, 5$ GeV
- 20° < polar angle < 150°

→ classification of different final states:

charge requirement

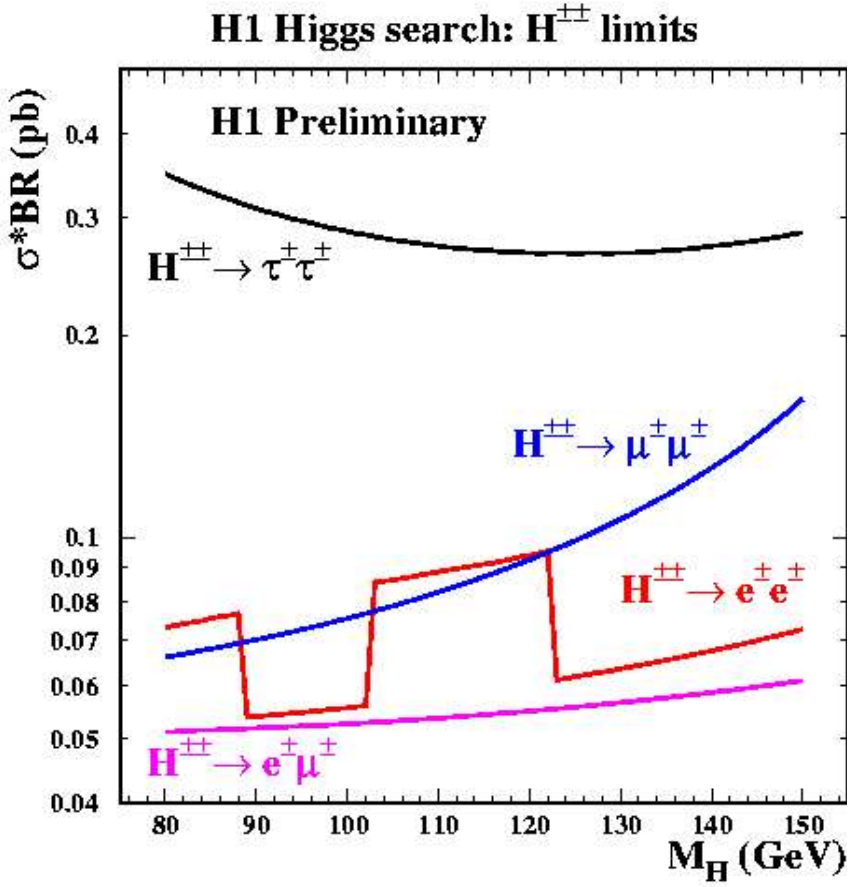
final state	ττ preselection data	ττ preselection SM	ττ preselection ττ (Grape)	final selection data	final selection SM
eμ	0	0.29 ± 0.03	(0.11)	0	0.09 ± 0.01
ej	0	1.20 ± 0.24	(0.31)	0	0.78 ± 0.16
μj	0	0.25 ± 0.05	(0.16)	0	0.03 ± 0.01
jj	1	0.38 ± 0.10	(0.16)	0	0.13 ± 0.08

⇒ data consistent with SM

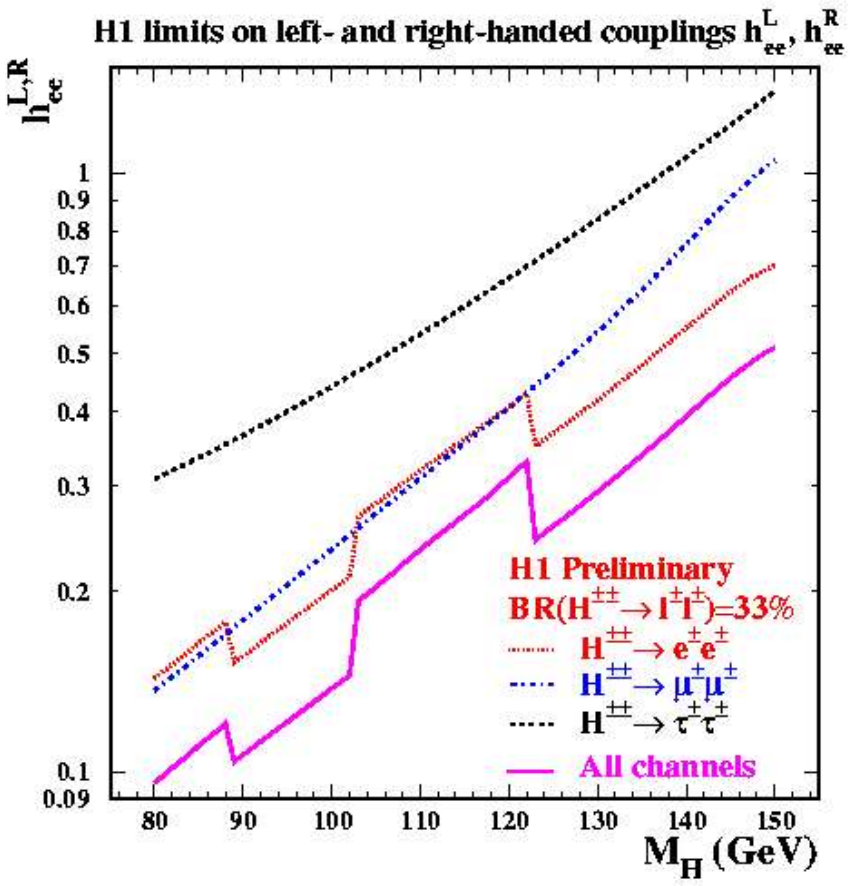
Doubly Charged Higgs Results

HERA I 1996-2000

Sigma x Branching Ratio



Democratic Couplings

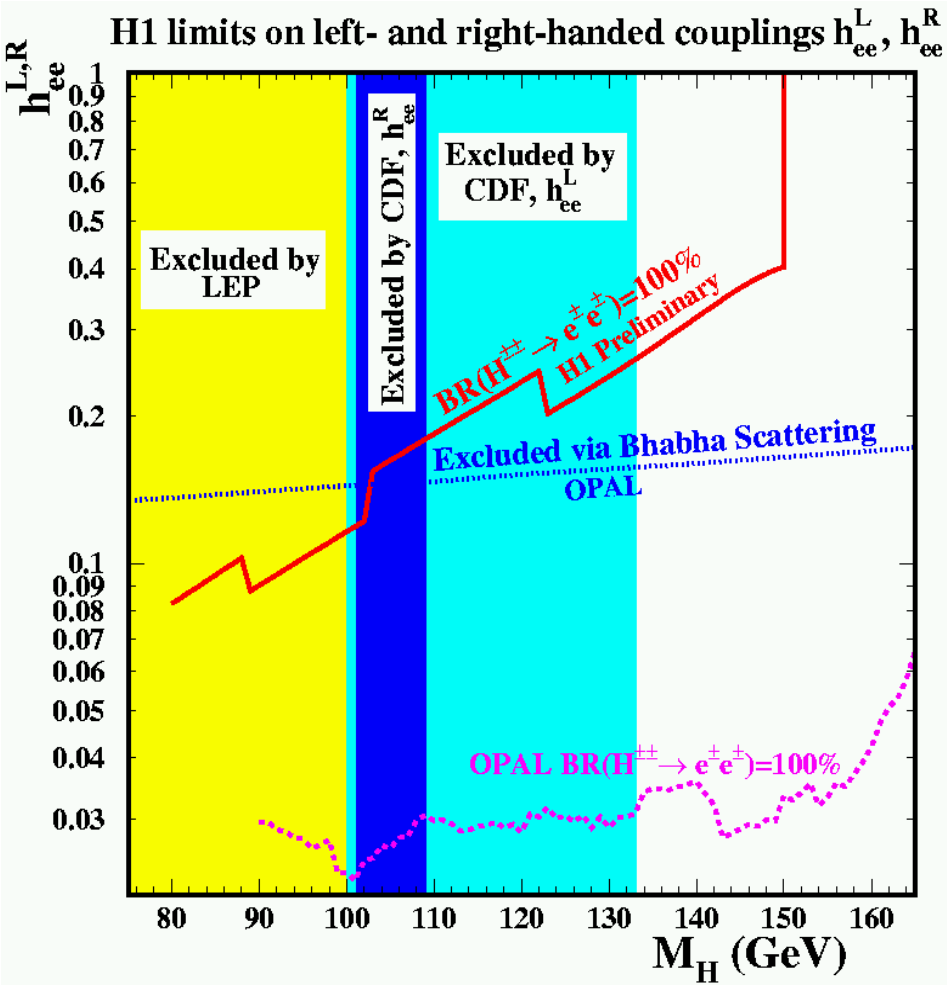


$\Rightarrow$ combined limits

Doubly Charged Higgs Limits

HERA I 1996-2000

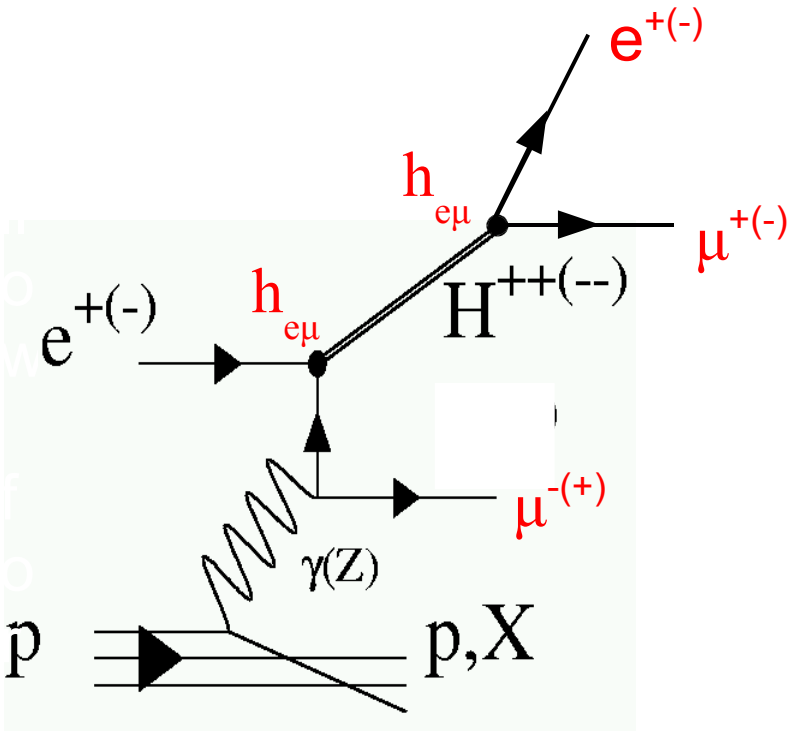
h_{ee} dominant:



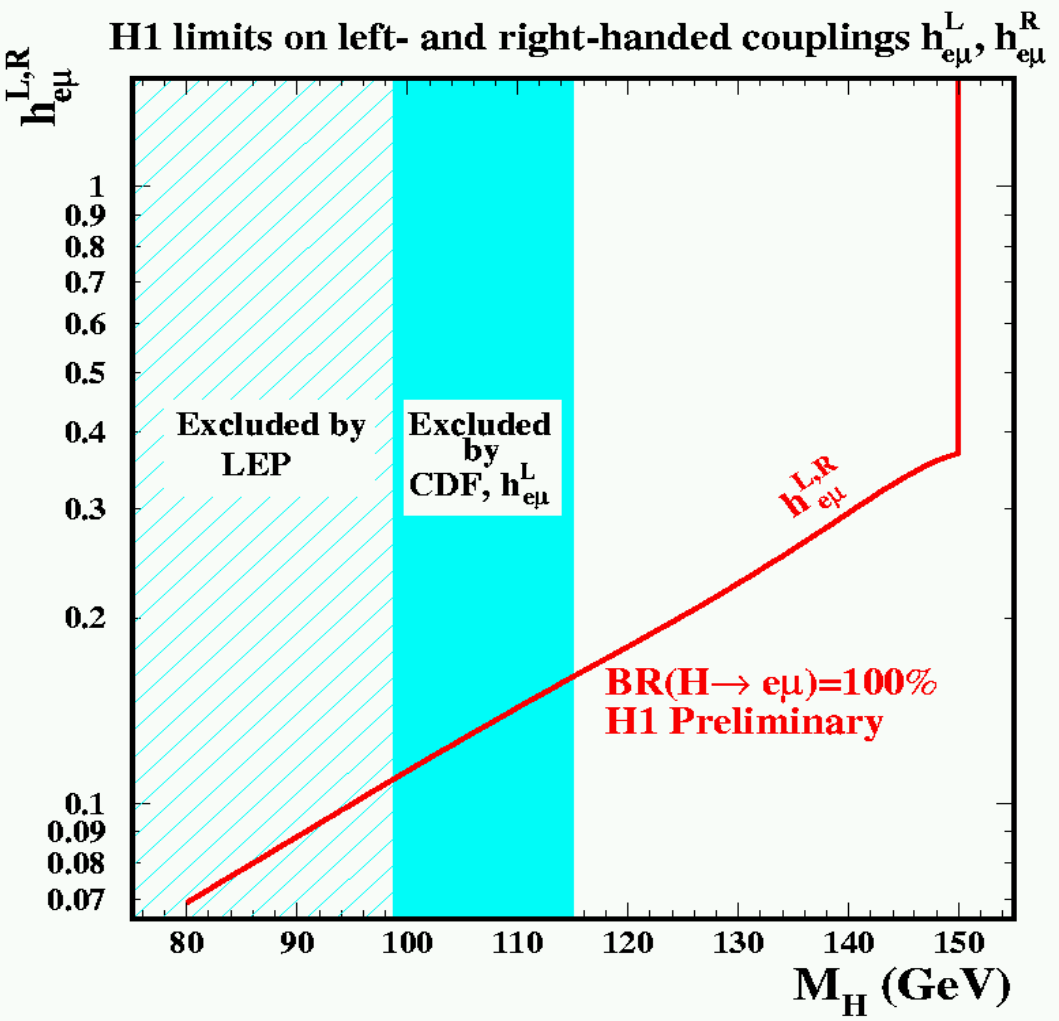
⇒ excess of high mass multi-electrons cannot be explained by doubly charged Higgs hypothesis

Doubly Charged Higgs Limits

- allow for LFV couplings:



HERA I 1996-2000



⇒ limit on LFV coupling $h_{e\mu}$ set

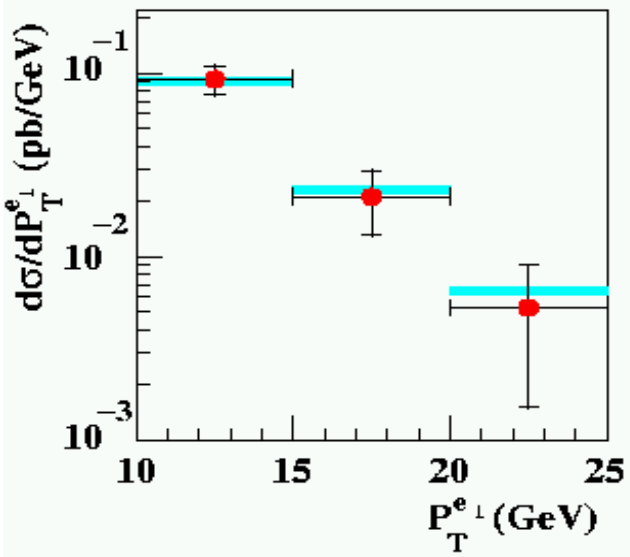
in regions not excluded by other experiments

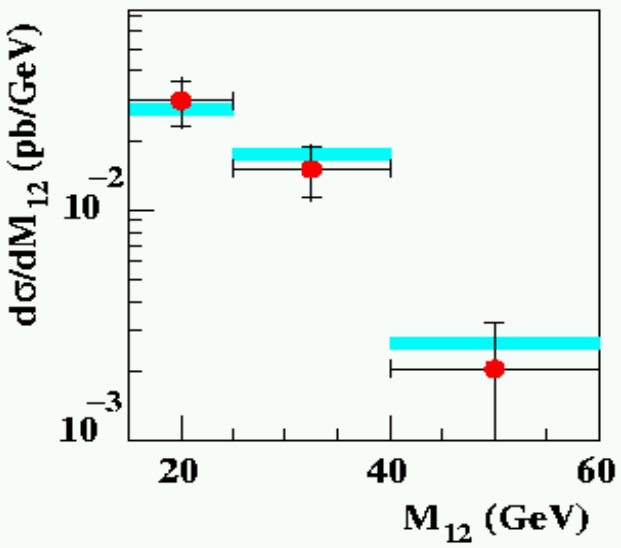
Summary

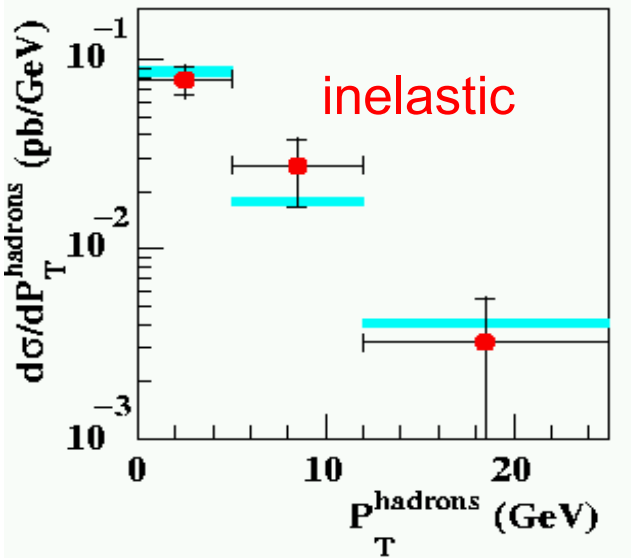
- Lepton Pair Production of electron, muon and tau pairs studied in different channels
- in general good agreement with SM expectation found
- excess seen in multi-electron channels at HERA I at high mass
- identical analysis repeated using recent e^+p and $e^- p$ HERA II data indicates no excess at high mass
- investigated Doubly Charged Higgs interpretation, excess of multi-electron events inconsistent with $H^{\pm\pm}$ hypothesis.
- limits on several $H^{\pm\pm}$ couplings set. Most stringent limit on $h_{e\mu}$

Backup: Cross Check Analysis

process: $\gamma\gamma \rightarrow e^+ e^-$ opposite charges, $E\text{-}p_z < 45$ GeV







$e\,p \rightarrow e\,e^+e^-X$

$P_T^{e_1} \geq 10$ GeV, $P_T^{e_2} \geq 5$ GeV

$20^\circ \leq \theta^{e_1,e_2} \leq 150^\circ$

$y \leq 0.82$, $Q^2 \leq 1$ GeV^2

H1 Data

SM (GRAPE)

After selection:

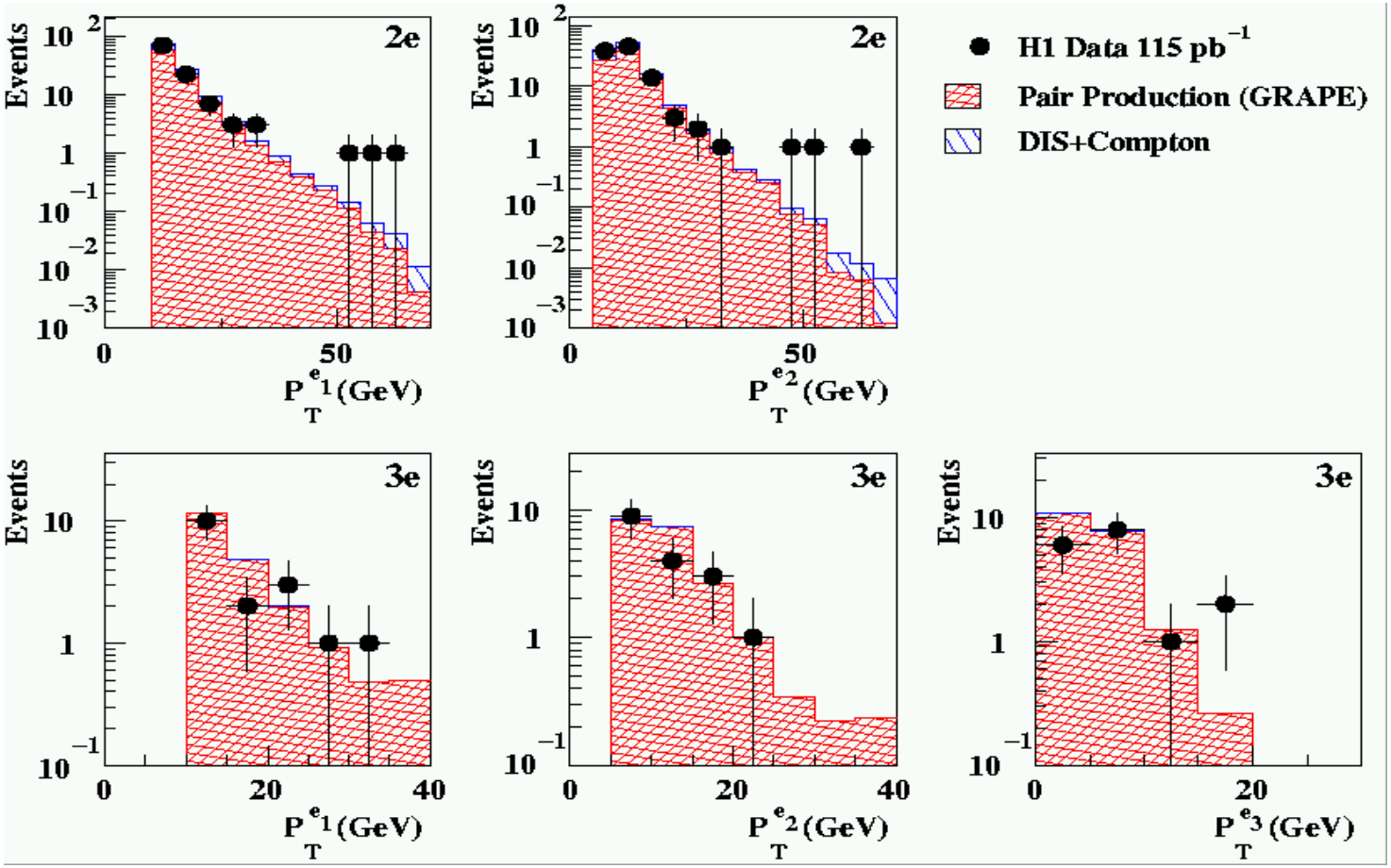
42 data

44.9 ± 4.2 MC

$(1.2 \pm 0.4$ background)

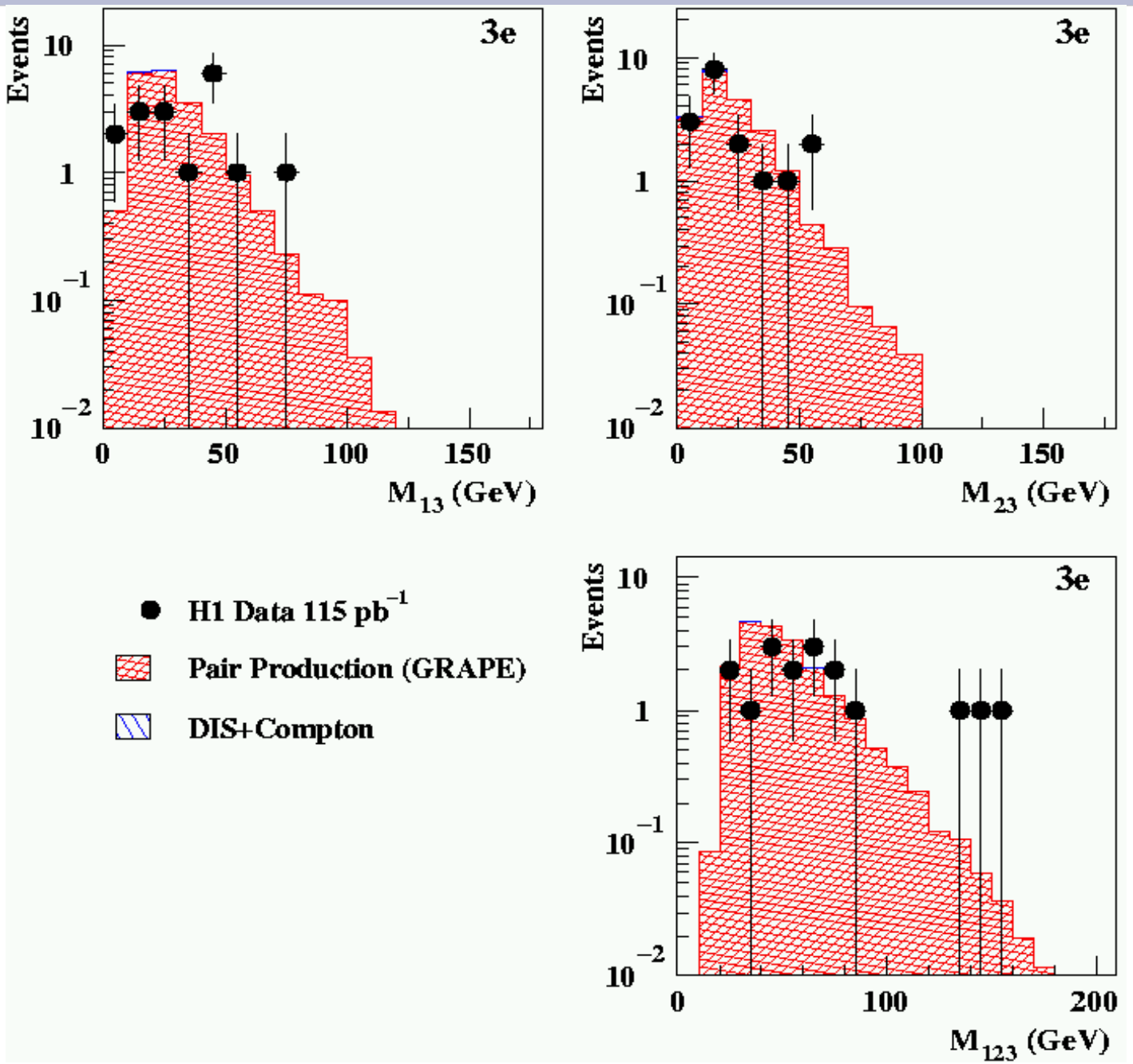
$\Rightarrow$ good agreement

Backup: Multi-Electrons HERA I



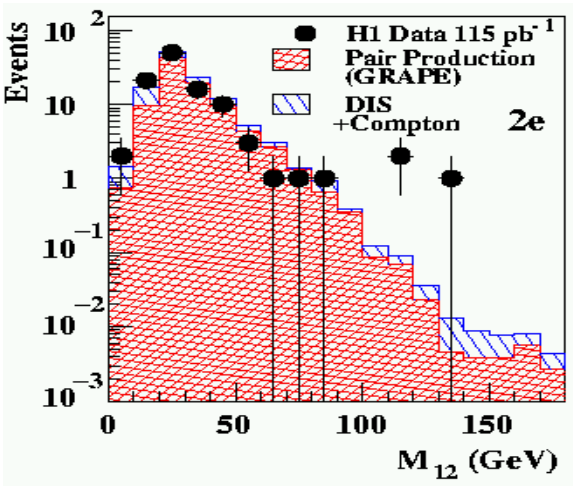
Selection	Data	SM	Pair Production (GRAPE)	DIS + Compton
"2e"	108	117.1 ± 8.6	91.4 ± 6.9	25.7 ± 5.2
"3e"	17	20.3 ± 2.1	20.2 ± 2.1	0.1 ± 0.1
"4e" or more	0	0.12 ± 0.04	0.12 ± 0.04	< 0.02 (95% C.L.)

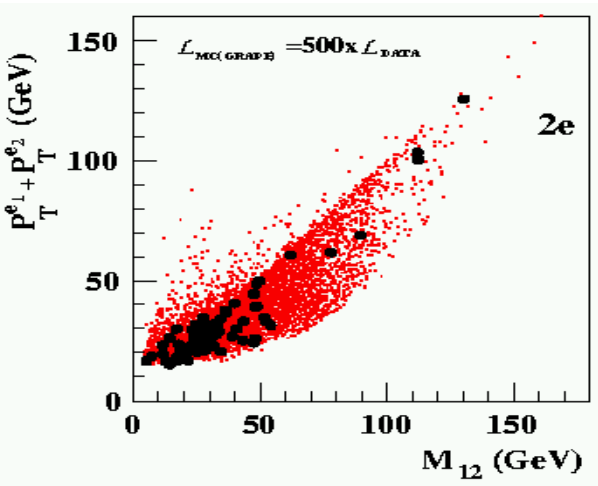
Backup: Tri-electron HERA I



Backup: Multi-e HERA I (cont'd)

"2e"



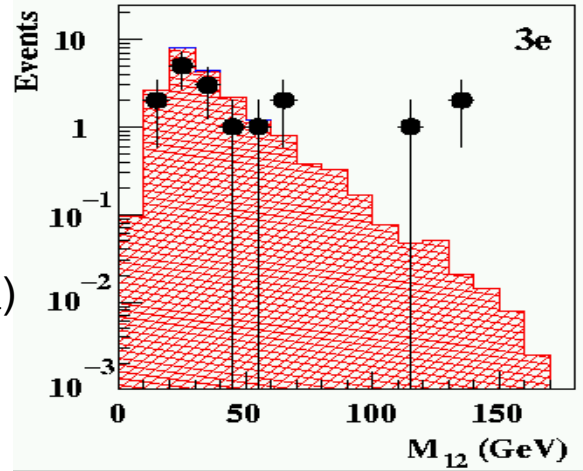


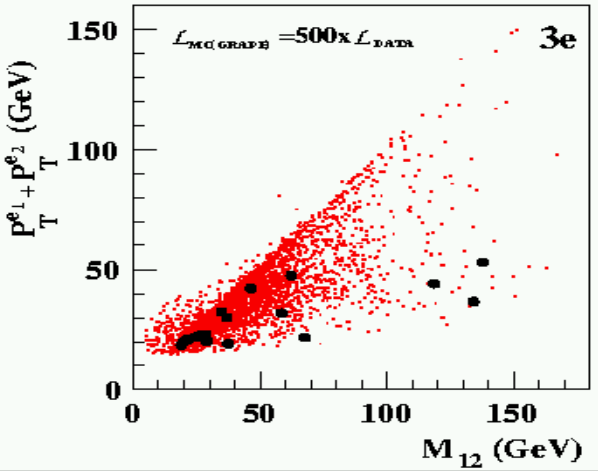
central

forw.-backw.

"3e"

(ordered in p_T)



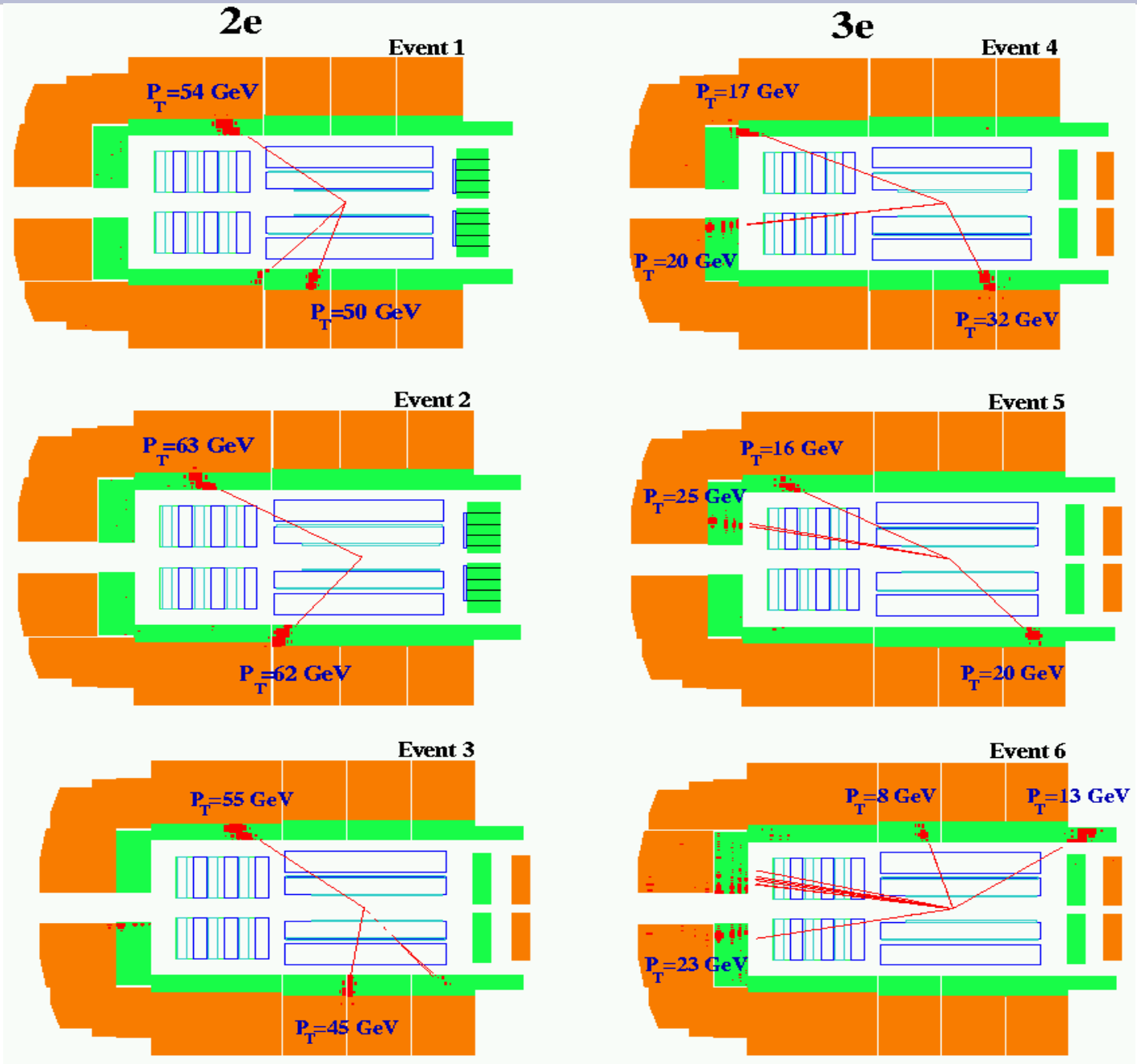


central

forw.-backw.

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

Backup: Multi-Electrons Events



Backup: HERA I+II Results (ICHEP 04)

1996-2004 $e^{\pm}p$ All

(HERA I+II)	data(L=163pb^{-1})	SM	Pair Production (Grape)
ee	147	149.8 ± 24.8	125.5
μμ	66	63.7 ±12.7	63.7
eμ	86	78.4 ± 12.0	46.4
eee	24	30.4 ± 3.9	30.4
eμμ	41	39.5 ± 6.5	39.5

⇒ good agreement with SM

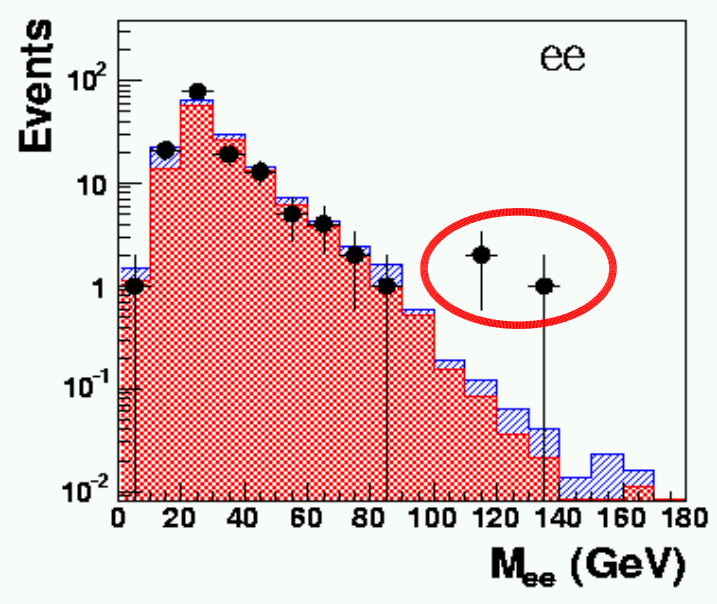
1996-2004 $e^{\pm}p$ M>100 GeV

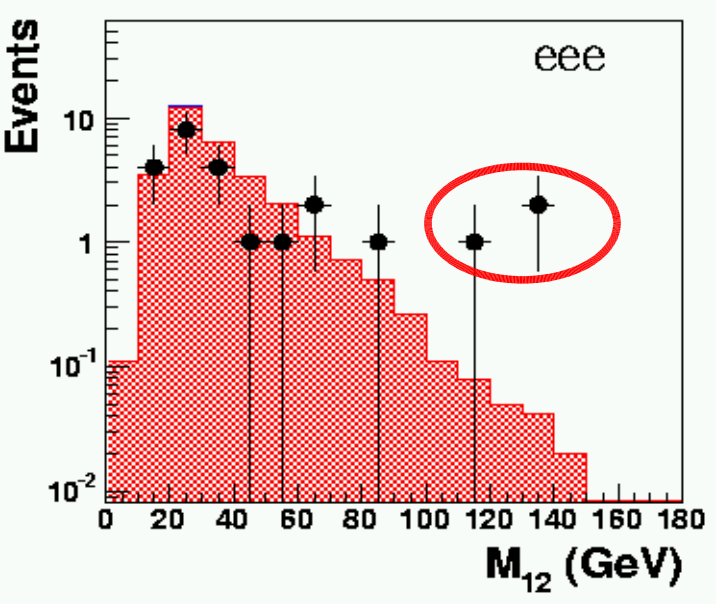
(HERA I+II)	data(L=163pb^{-1})	SM	Pair Production (Grape)
ee M_{12}>100 GeV	3	0.44 ± 0.10	0.32
μμ M_{12}>100 GeV	0	0.04 ± 0.02	0.04
eμ M_{12}>100 GeV	0	0.31 ± 0.03	0.01
eee M_{12}>100 GeV	3	0.31 ± 0.08	0.31
eμμ $M_{e\mu}$>100 GeV	1	0.04 ± 0.01	0.04
eμμ $M_{\mu\mu}$>100 GeV	1	0.02 ± 0.01	0.02

⇒ multi-electrons excess

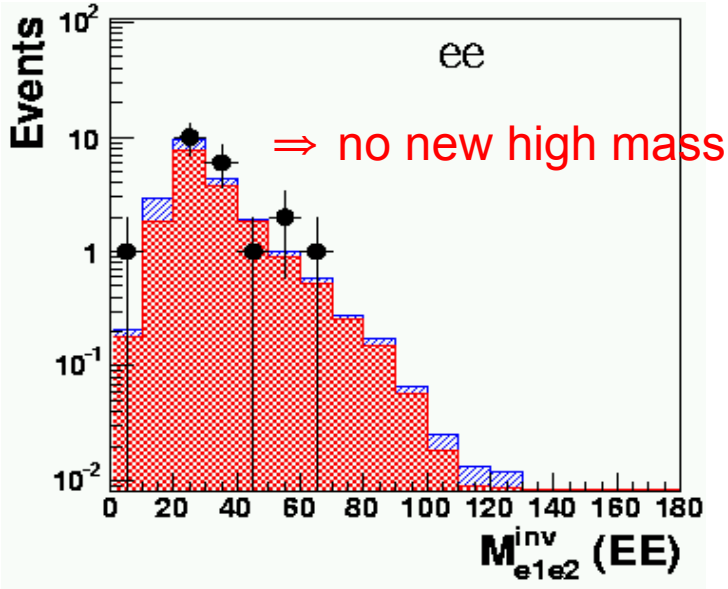
Backup: Mulit-e HERA I+II

1996-2004 $e^{\pm}p$ $L=163pb^{-1}$ (ICHEP 04)

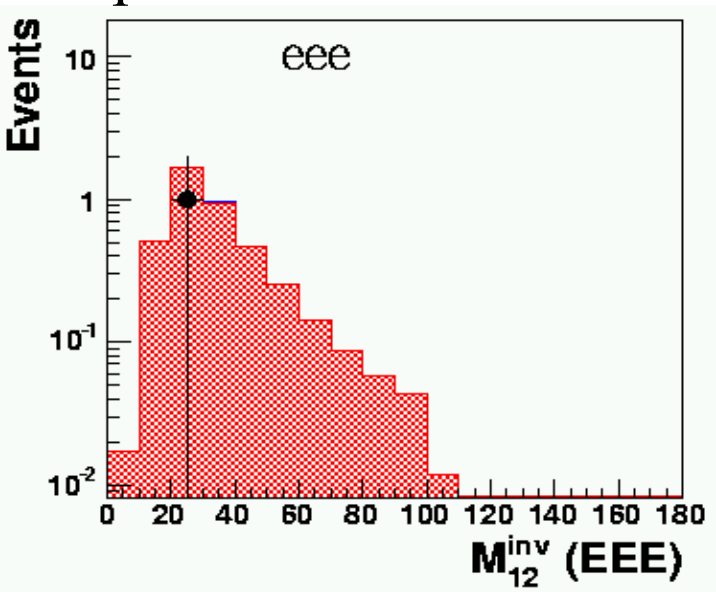




2004-2005 $e^{-}p$ $L=22pb^{-1}$ new!



⇒ no new high mass events



Backup: Multi-e All Recent Numbers

1996-2004 e^+p (e^-p) All

(HERA I+II)	data(L=163pb^{-1})	SM	Pair Production (Grape)
ee	147	149.8 ± 24.8	125.5
μμ	66	63.7 ±12.7	63.7
eμ	86	78.4 ± 12.0	46.4
eee	24	30.4 ± 3.9	30.4
eμμ	41	39.5 ± 6.5	39.5

⇒ good agreement with SM

2004-2005 e^-p All

(HERA I+II)	data(L=22pb^{-1})	SM	Pair Production (Grape)
ee	21	21.1 ± 1.9	17.2
eμ	8	10.8 ± 2.5	6.6
eee	1	4.2 ± 0.7	4.2
eμμ	6	5.4 ± 0.9	5.4

Σ E_T>100 GeV: 0 data for 0.08±0.008 expected

M>100 GeV: 0 data

⇒ also consistent with SM