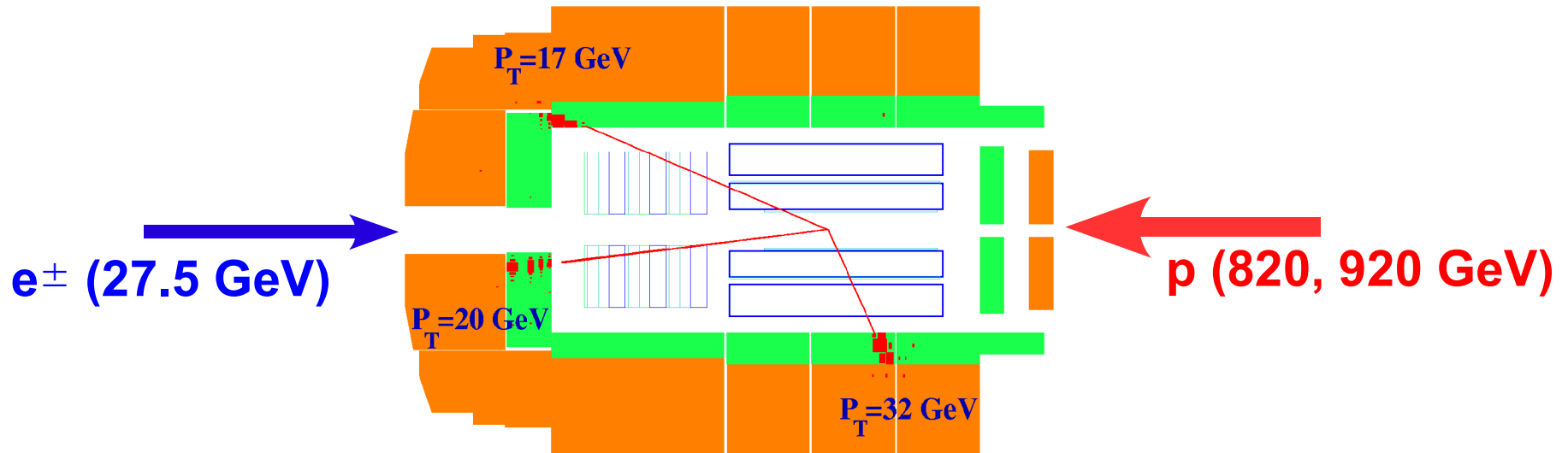# Multi-lepton events and Doubly Charged Higgs at HERA

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H1 collaboration
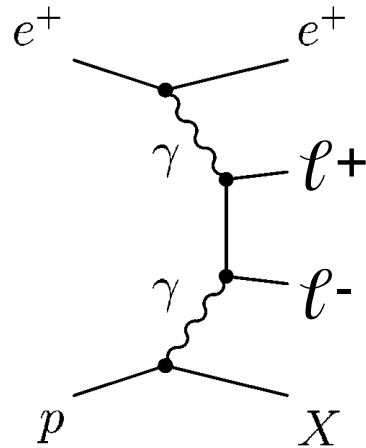

- HERA: $e^{\pm}$ p collider $\sqrt{s}$ = 300-320 GeV
- 1994-2000: $e^{\pm}$ p ~115 pb^{-1}
- 2004: e^+p 50 pb^{-1}
- 2005: e^-p 40 pb^{-1}

➡ **Outstanding high P_T multi-lepton events observed**
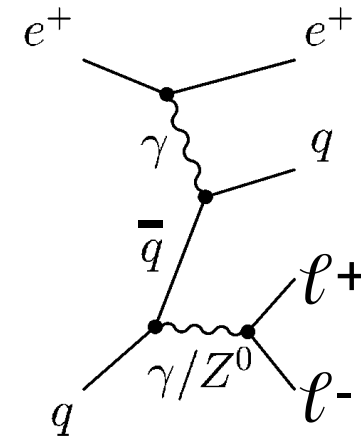
Multi-lepton events at HERA

- Mainly via γ-γ collisions in the SM:

γ-γ elastic and inelastic (dominating at HERA)
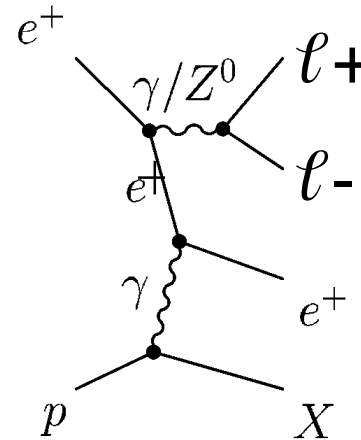
$e+ \, e- \rightarrow l+ \, l-$ (Cabibbo-Parisi) (small at HERA)

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

➜ Production of e - e, μ - μ or τ - τ pairs

↘ At high invariant mass: sensitive to new phenomena

- Measurement of γ-γ cross-section
- Multi-lepton analysis of ee, $\mu\mu$, $e\mu$, eee and $e\mu\mu$ topologies
- Search for Higgs++ production

Cross-section of di-electron events

- Measure the cross-section of $\gamma\gamma \to e^+ e^-$

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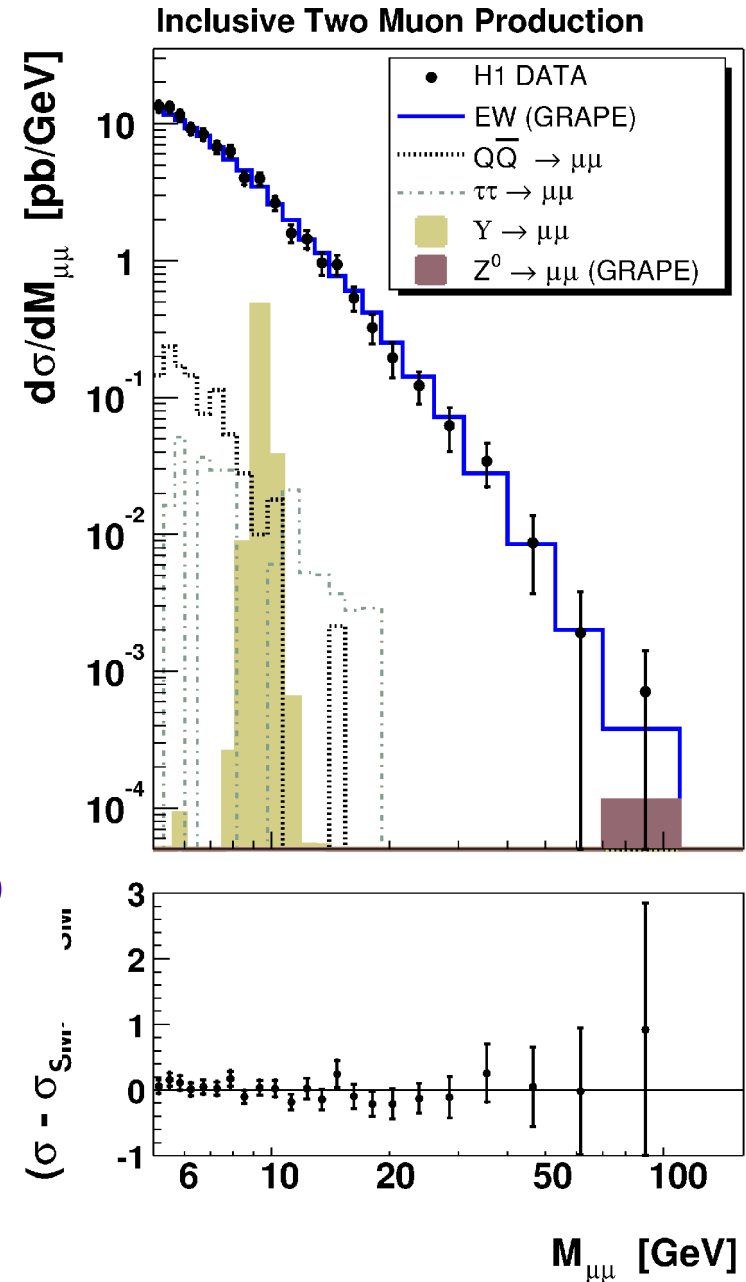
- 42 (data) / 44.9 ± 4.2 (MC) (1.2 ± 0.4 background)

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

(115 pb^{-1})

- H1 Data
- SM (GRAPE)
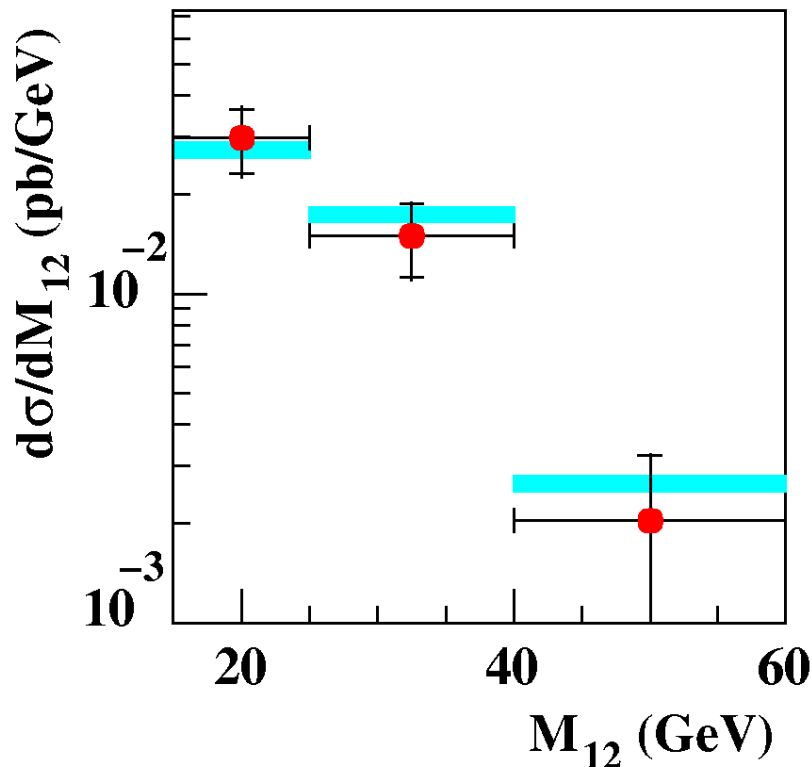
➔ **Good agreement with the SM in this phase space**

Cross-section of di-muon events

[H1, Phys. Lett. B583 (2004), 28]   (71 pb^{-1})

- μ identified in central tracker, calorimeter and muon chambers

- $P_T^{\mu 1} > 2$ GeV, $P_T^{\mu 2} > 1.75$ GeV

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

- $20° < \theta_\mu < 160°$

➔ $\sigma_{\mu\mu}$ = 46.4 ± 1.3 ± 4.5 pb

SM: 46.1 ± 1.4 pb (lepton pairs)

➔ **Good agreement with SM**

Inclusive Two Muon Production

Legend:
- H1 DATA
- EW (GRAPE)
- $Q\bar{Q} \rightarrow \mu\mu$
- $\tau\tau \rightarrow \mu\mu$
- $Y \rightarrow \mu\mu$
- $Z^0 \rightarrow \mu\mu$ (GRAPE)

Y-axis: $d\sigma/dM_{\mu\mu}$ [pb/GeV]

Lower plot y-axis: $(\sigma - \sigma_{SM})/\sigma_{SM}$

X-axis: $M_{\mu\mu}$ [GeV]

Multi-lepton events at high P_T

- Look for events with at least 2 high P_T electrons or muons
- HERA I+II data (209 pb^{-1}) (includes latest e-p data)

- At least 2 leptons: $P_T^{l1} > 10$ GeV, $P_T^{l2} > 5$ GeV, $(20° < \theta_{l1,2} < 150°)$
- Any additional μ: $P_T^\mu > 2$ GeV, $(20° < \theta_\mu < 160°)$
- Any additional e: $E_e > 5$ GeV, $(5° < \theta_e < 175°)$

➜ Tight identification criteria for e and μ

➜ ee, $\mu\mu$, $e\mu$, eee and $e\mu\mu$ topologies

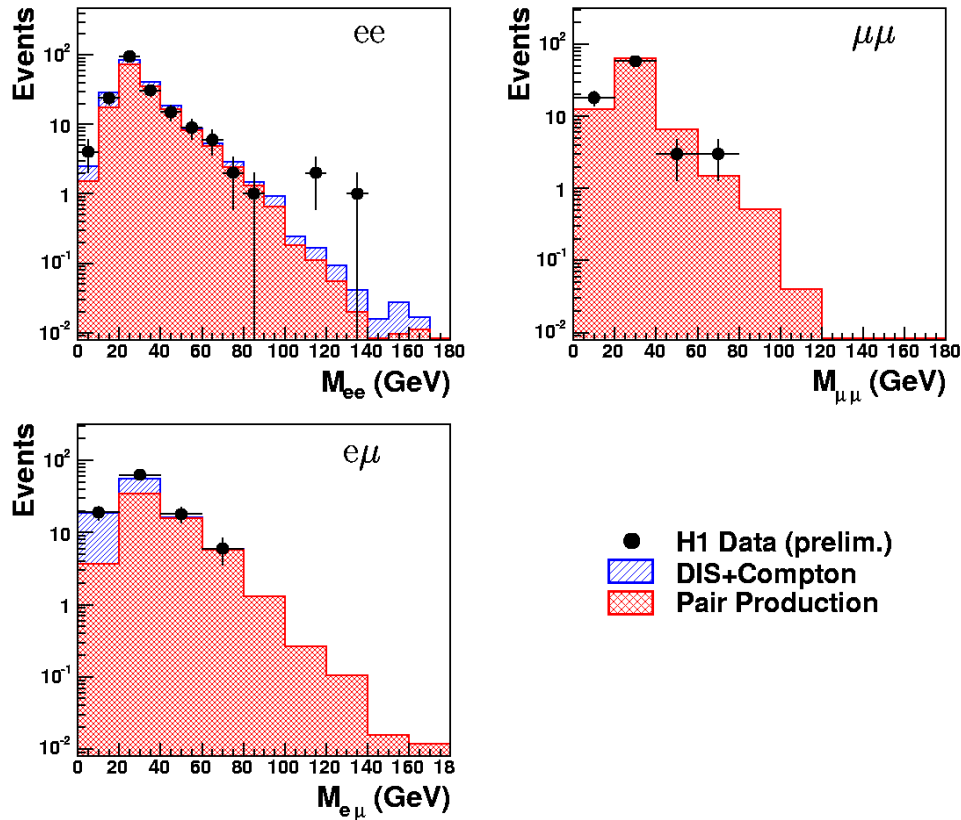| Selection	Data	SM	Pair Production (GRAPE)	NC-DIS + Compton
ee	190	196 ± 29	163 ± 17	33 ± 20
$\mu\mu$	82	85 ± 16	85 ± 16	—
$e\mu$	106	99 ± 13	61 ± 5	38 ± 10
eee	37	39 ± 4	39 ± 4	0.1 ± 0.1
$e\mu\mu$	50	51 ± 8	51 ± 8	—

➜ In agreement with the SM for all classes

Multi-leptons: mass distributions

- **2 leptons classes**

- **3 leptons classes**

➜ **3 *ee* events M$_{ee}$ > 100 GeV (HERA I)**

➜ **2 *eμμ* events with M > 100 GeV (HERA II)**

➜ **3 *eee* events from HERA I**

➜ **At low mass: good agreement with the SM**

Event yields at high mass

- **e+ beam**

Selection	Data	SM	Pair Production (GRAPE)	NC-DIS + Compton
ee M_{12} >100 GeV	3	0.44 ± 0.10	0.29 ± 0.09	0.15 ± 0.04
$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.035 ± 0.02	0.035 ± 0.02	—
$e\mu$ $M_{e\mu}$ >100 GeV	0	0.29 ± 0.03	0.29 ± 0.03	—
eee M_{12} >100 GeV	3	0.29 ± 0.06	0.29 ± 0.06	—
$e\mu\mu$ $M_{e\mu}$ >100 GeV	1	0.04 ± 0.01	0.04 ± 0.01	—
$e\mu\mu$ $M_{\mu\mu}$ >100 GeV	1	0.015 ± 0.007	0.015 ± 0.007	—

- **e- beam**

| Selection	Data	SM	Pair Production (GRAPE)	NC-DIS + Compton
ee M_{12} >100 GeV	0	0.17 ± 0.04	0.10 ± 0.03	0.07 ± 0.02
$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.012 ± 0.01	0.012 ± 0.01	—
$e\mu$ $M_{e\mu}$ >100 GeV	0	0.11 ± 0.02	0.11 ± 0.02	—
eee M_{12} >100 GeV	0	0.1 ± 0.03	0.1 ± 0.03	—
$e\mu\mu$ $M_{e\mu}$ >100 GeV	0	0.01 ± 0.003	0.01 ± 0.003	—
$e\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.005 ± 0.003	0.005 ± 0.003	—

➔ High mass events are recorded in e+p collisions
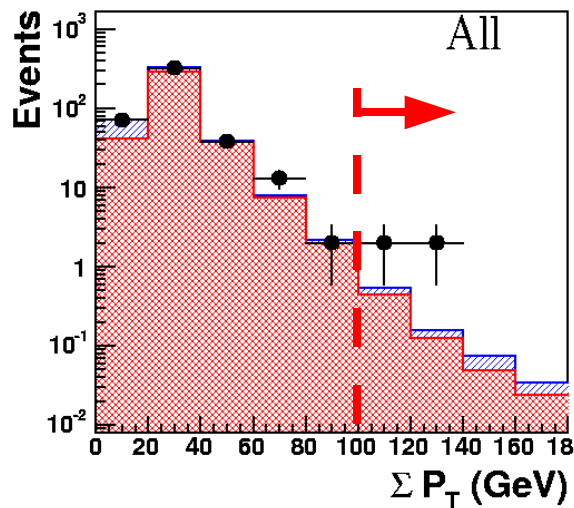
➔ No such high mass event in e-p yet

ΣP_T distributions

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

H1 Preliminary   Multi-lepton analysis (209 pb^{-1})
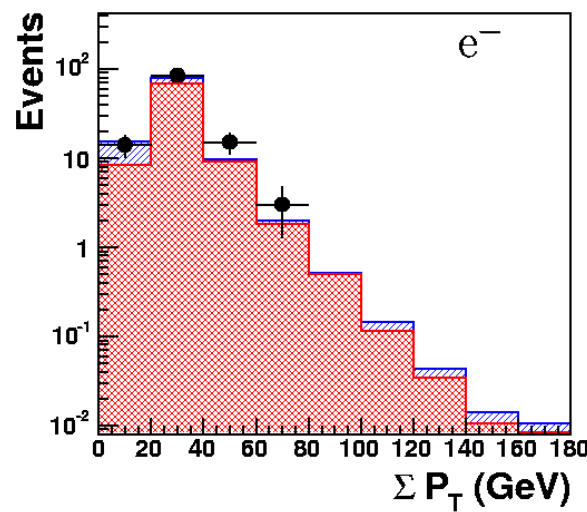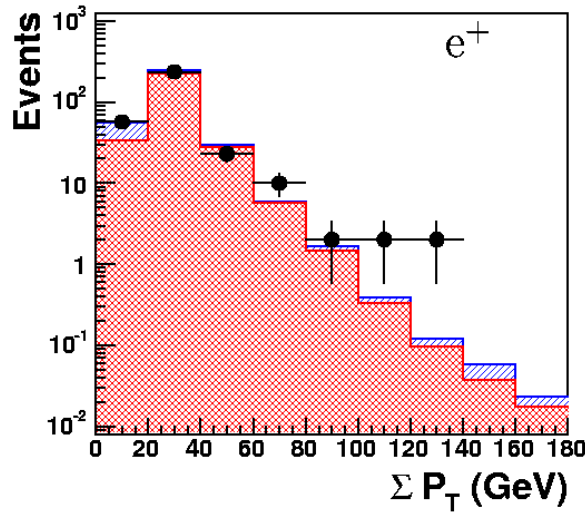
- ➜ Agreement with the SM at low ΣP_T
- ➜ for $\Sigma P_T > 100$ GeV:
  - 4 events for 0.81 ± 0.14 expected
    - ➜ 3 *ee* events (HERA I)
    - ➜ 1 *eμμ* event (HERA II)
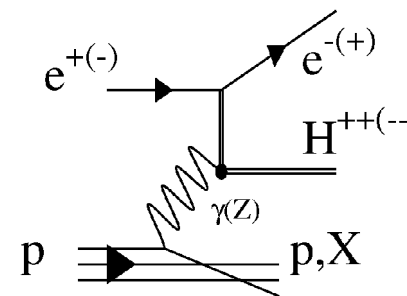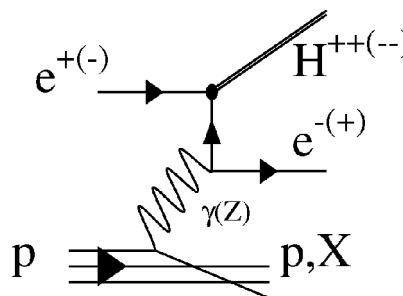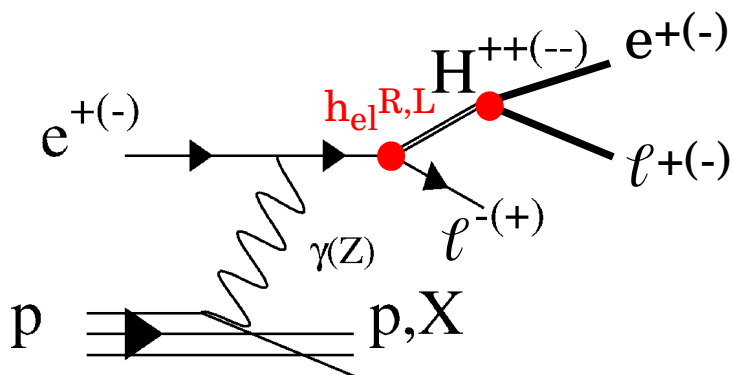
Search for doubly charged Higgs

- In extension to SM: $H^{\pm\pm}$ appears in Higgs triplet(s) of non-zero hypercharge
- Left-right symmetries: $SU(2)_R \times SU(2)_L \times U(1)_{B-L}$
- vev might give 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: $h_{el} \gg 0$, others ~ 0

- at HERA : $e^{\pm} p \to l^{\mp} H^{\pm\pm} X$, $H^{\pm\pm} \to e^{\pm} l^{\pm}$, only sensitive to h_{el}
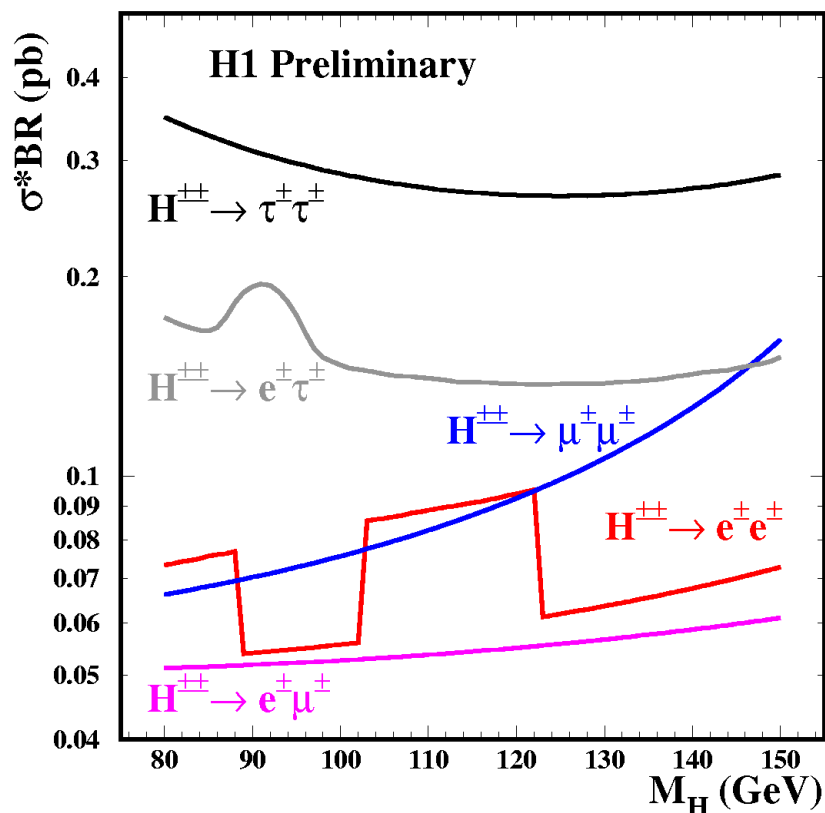
Doubly Charged Higgs selection

↘ Look for 2 equally charged high P_T leptons
(lepton charges = beam charge)

- ee, $\mu\mu$, eμ channels:
  ➔ Based on multi-lepton analysis
  ➔ Ask for lepton charges compatible with beam charge

  ↘ Only one *ee* (HERA-I) event fulfills charge
  requirements

- $\tau\tau$, eτ channels:
  ➔ Dedicated analysis ($\mathscr{L}$ = 65 pb^{-1})
  ➔ All τ decays considered
    - e, μ, τ-jet (hadronic decay) identification
    - P_T^τ > 10, 5 GeV
    - 20° < θ^τ < 150°
    - Isolation in η-ϕ cone 0.15 < R < 1.5

Doubly Charged Higgs: results

➔ No $\mu\mu$, $e\mu$, $\tau\tau$ or $e\tau$ event found at high mass

- σ * branching ratio

- Example of limit on h_{ee} (h_{ee} dominant)

H1 Higgs search: $H^{\pm\pm}$ limits

H1 Preliminary

$H^{\pm\pm} \rightarrow \tau^{\pm}\tau^{\pm}$

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

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

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

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

σ*BR (pb)

M_H (GeV)

H1 limits on left- and right-handed couplings h_{ee}^L, h_{ee}^R

$h_{ee}^{L,R}$

Excluded by LEP

Excluded by CDF, h_{ee}^R

Excluded by CDF, h_{ee}^L

$BR(H^{\pm\pm} \rightarrow e^{\pm}e^{\pm})$=100%

H1 Preliminary

Excluded via Bhabha Scattering

OPAL

OPAL BR($H^{\pm\pm} \rightarrow e^{\pm}e^{\pm}$)=100%

M_H (GeV)
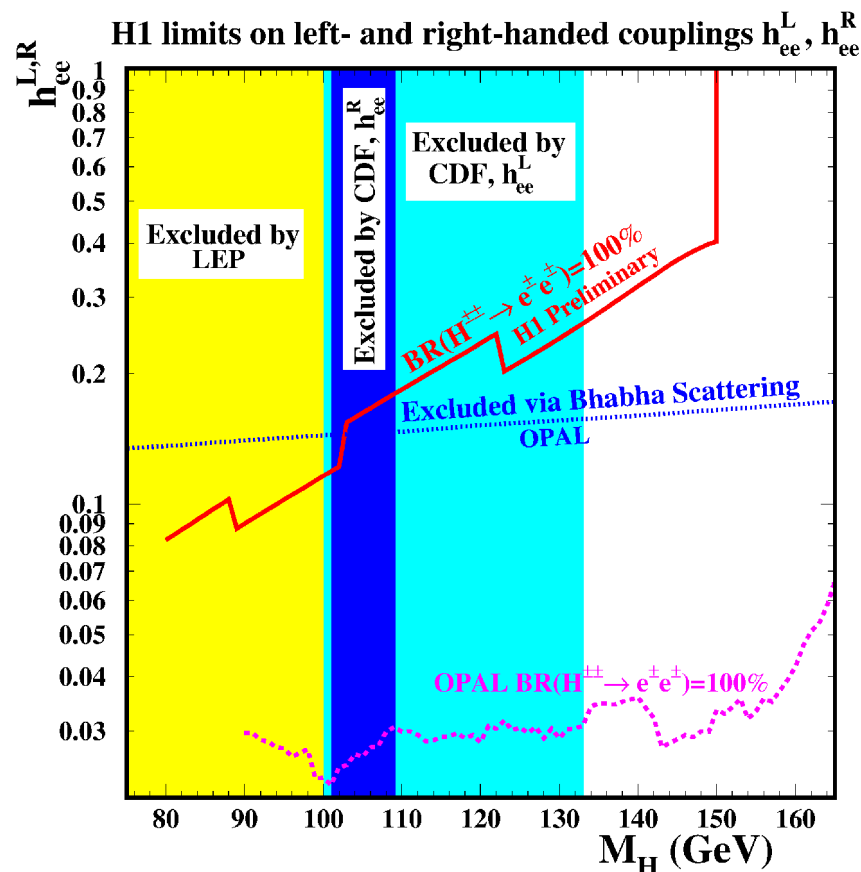
↘ Confirms that high P_T multi-electron events are unlikely to be due to $H^{\pm\pm}$ decay

$H^{\pm\pm}$: limits on $h_{e\mu}$
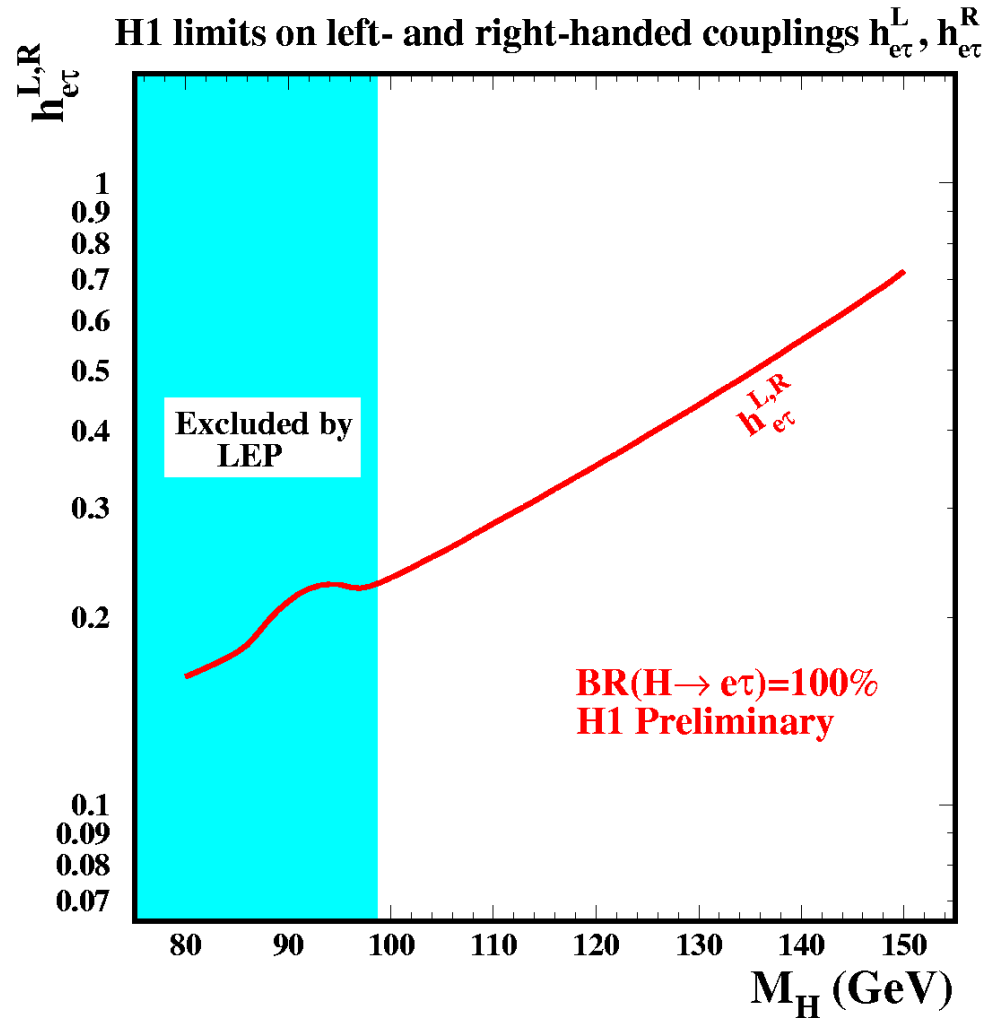
H1 limits on left- and right-handed couplings $h^L_{e\mu}$, $h^R_{e\mu}$
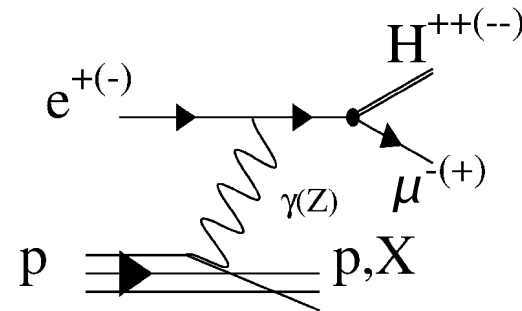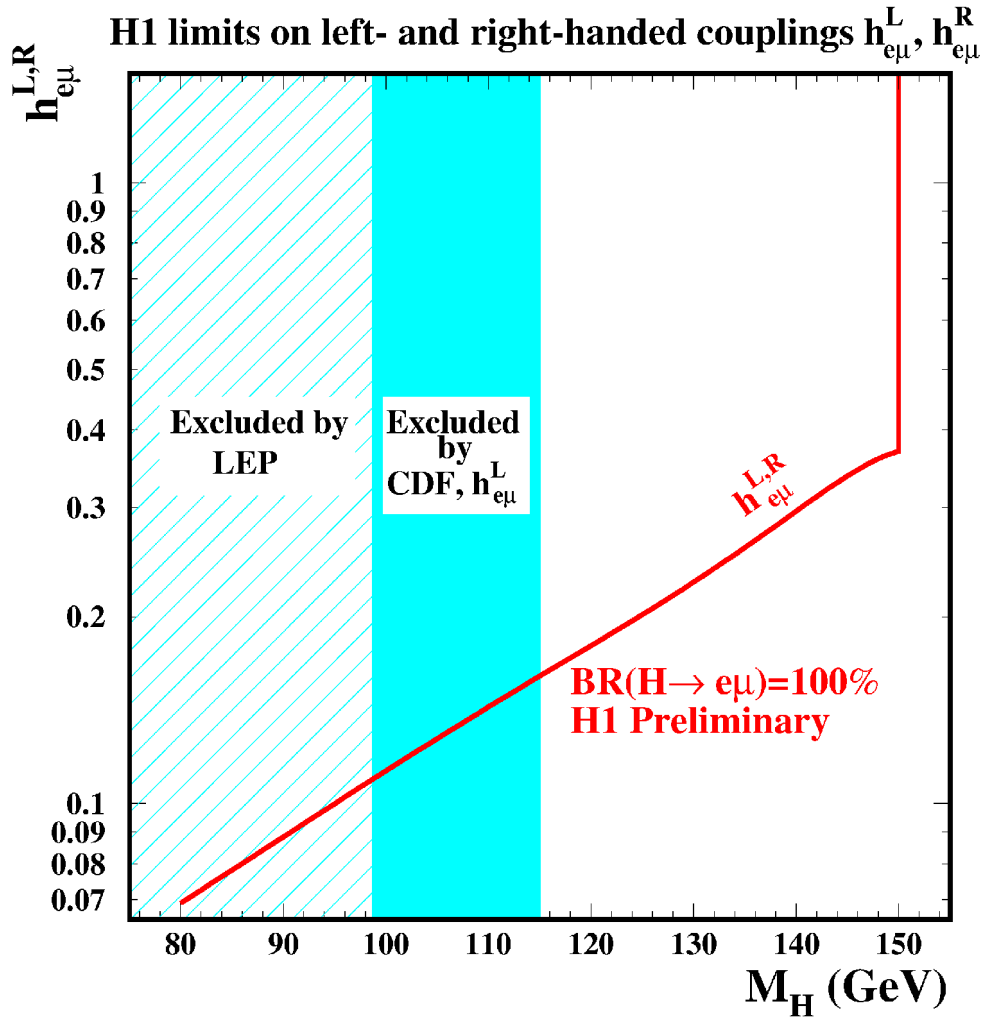
- Off-diagonal coupling $h_{e\mu}$ considered at the production and decay of $H^{\pm\pm}$

- $e^\pm\, p \rightarrow \mu^\mp\, H^{\pm\pm}\, X \rightarrow \mu^\mp\, e^\pm\, \mu^\pm\, X$

- leads to $e\mu$, $e\mu\mu$ topologies

↘ H1 limit extends the excluded region

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

- **Similar limit on $h_{e\tau}$:**

H1 limits on left- and right-handed couplings $h_{e\tau}^{L}$, $h_{e\tau}^{R}$

Excluded by LEP

$h_{e\tau}^{L,R}$

BR(H→ eτ)=100%
H1 Preliminary

M_{H} (GeV)

↘ Limit set in region not excluded by other experiments

Summary ...

- Multi-lepton production has been measured in *ep* collisions (209 pb^{-1})

  ➜ *ee, μμ, eμ, eee* and *eμμ* topologies studied

  ➜ At high $\Sigma\, P_T > 100$ GeV:

  - 4 events for 0.81 ± 0.14 expected

  ➜ Outstanding events at high mass, observed in *e$^+$p* collisions

- γγ cross-sections in agreement with the SM at low mass

- Exotic production of H$^{\pm\pm}$ has been studied

  ➜ All *e, μ* and *τ* topologies analysed

  ➜ Limits set on diagonal (h$_{ee}$) and non-diagonal couplings (h$_{e\mu}$, h$_{e\tau}$)

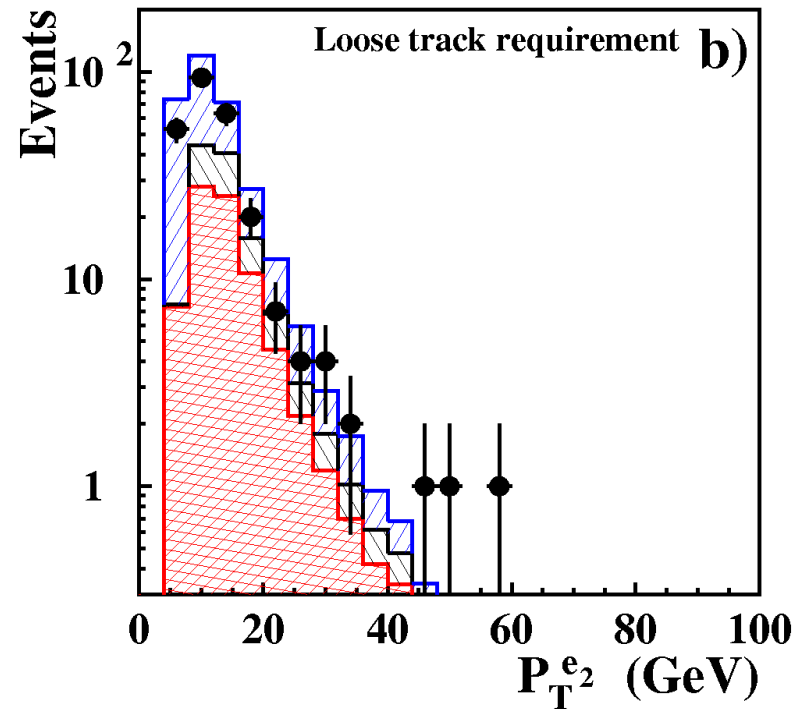↘ **Outlook:** increase the luminosity for further clarification

Background studies: NC-DIS

- Study of electron mis-identification in central region
- Selection of Neutral Current DIS events
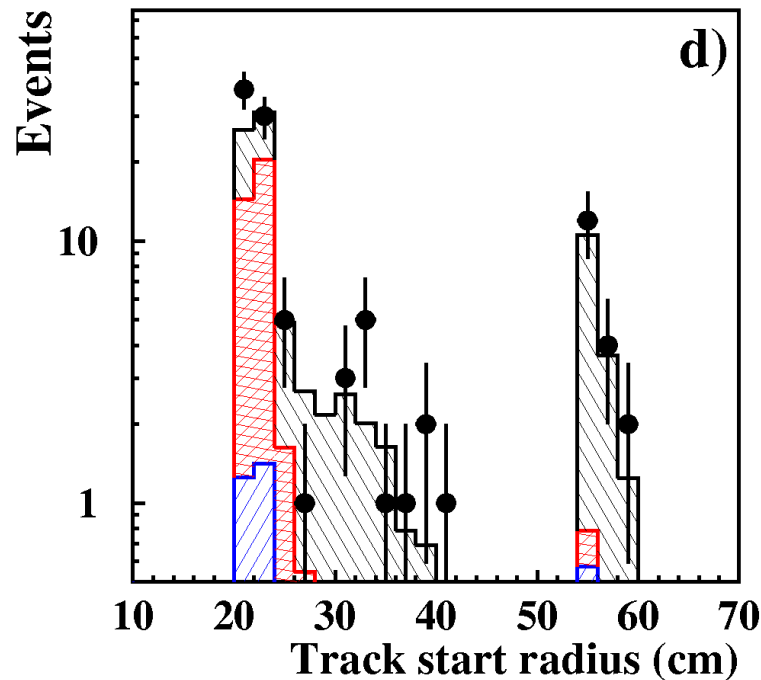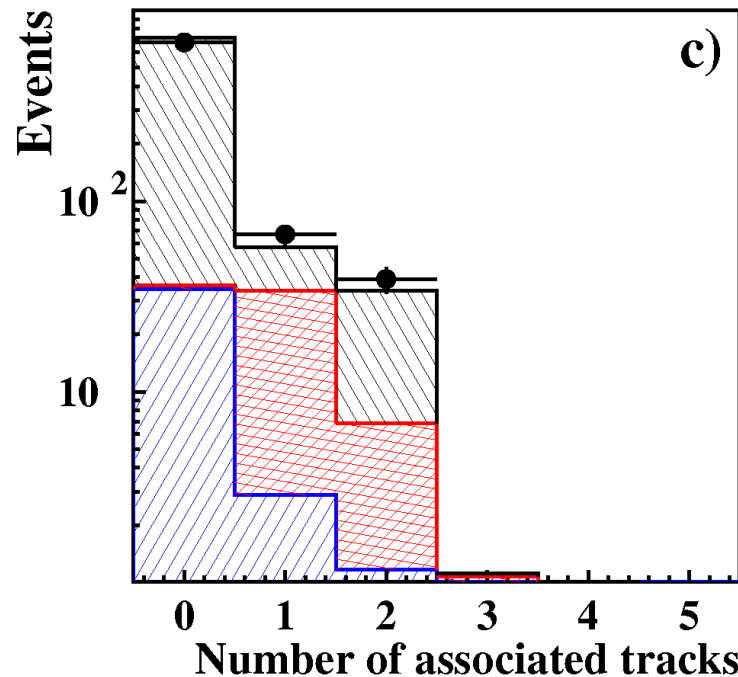 ➔ Events with a 2nd electromagnetic cluster
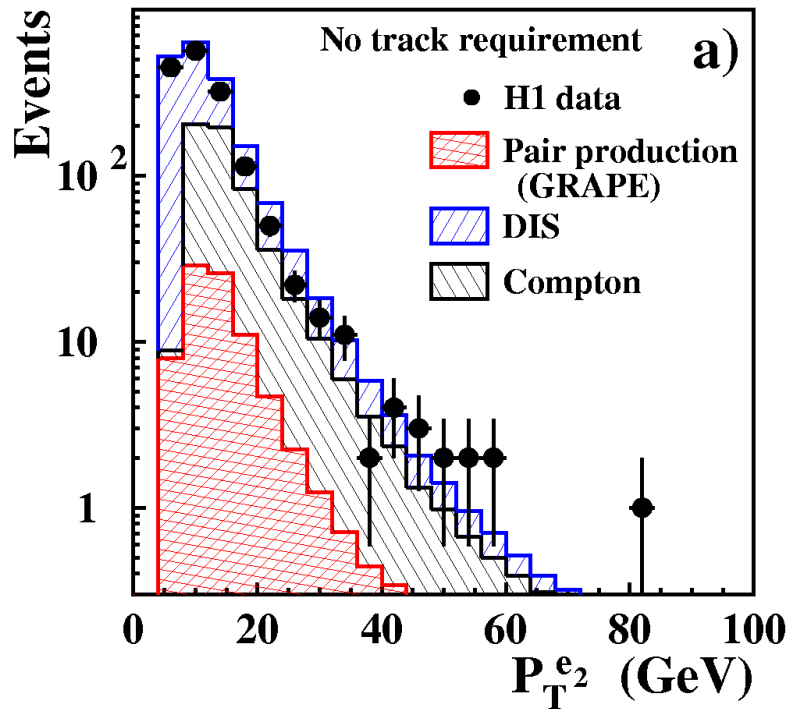
➔ No track required   ➔ Loose track required

➔ **Described at the 20% level**

Background studies: Comptons

- Study of photon conversion

- Sample enriched with elastic Compton events
  - ➜ 1 central electron + a 2nd electromagnetic cluster (photon candidate)

➜ Number of associated tracks   ➜ Track starting radius

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