High P_T multi-lepton events at HERA

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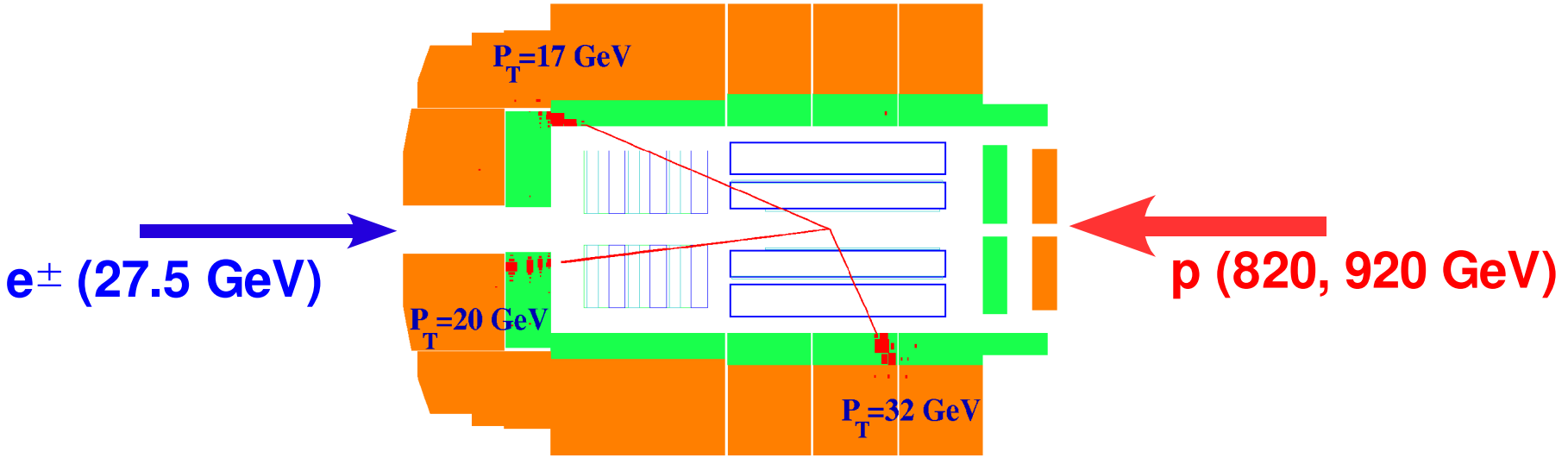
H1 collaboration

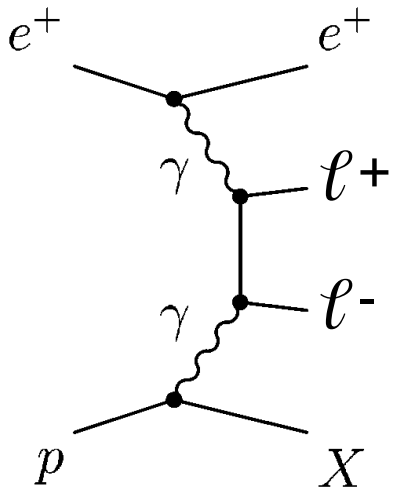


- HERA: $e^{\pm}$ p collider $\sqrt{s}$ = 300-320 GeV
- HERA-I: ~115 pb^{-1}
- HERA-II: 17 pb^{-1}

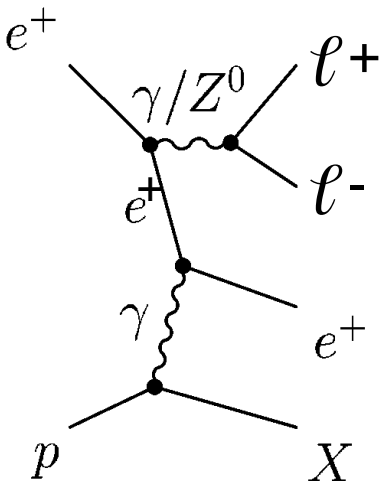
→ **Outstanding high P_T multi-electron events observed**

Multi-lepton events at HERA

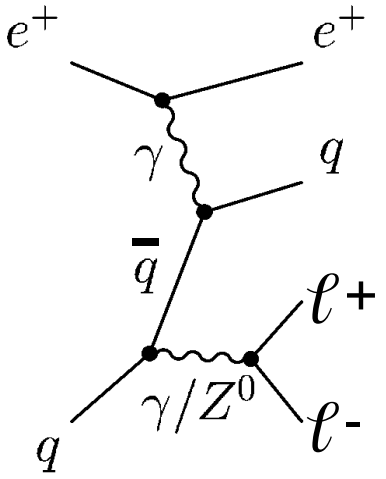
- Mainly via γ-γ collisions in the SM:



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**

2 results published by H1

➘ **At high invariant mass: sensitive to new phenomena (bileptons, Higgs++ ?)**

Multi-electron selection

- "2e" sample: 2 central isolated electrons

	H1	ZEUS
P_T	> 10, 5 GeV	> 10, E > 10 GeV
Lepton polar angle	20° - 150°	17° - 164°

+ good track associated to electron shower

- "3e" sample: any 3rd electron ($5° < \theta < 175°$)

- Background: fake electrons
  - ➔ NC-DIS: fake 2nd electron from radiation or mis-identification
  - ➔ Compton: $e\,p \rightarrow e\,\gamma\,X$ ($\gamma \rightarrow$ fake 2nd e)

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

H1 (115 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	108	117.1 ± 8.6	91.4 ± 6.9	25.7 ± 5.2
3 e	17	20.3 ± 2.1	20.2 ± 2.1	0.1 ± 0.1

(statistical and systematical errors)

[ZEUS, Preliminary]

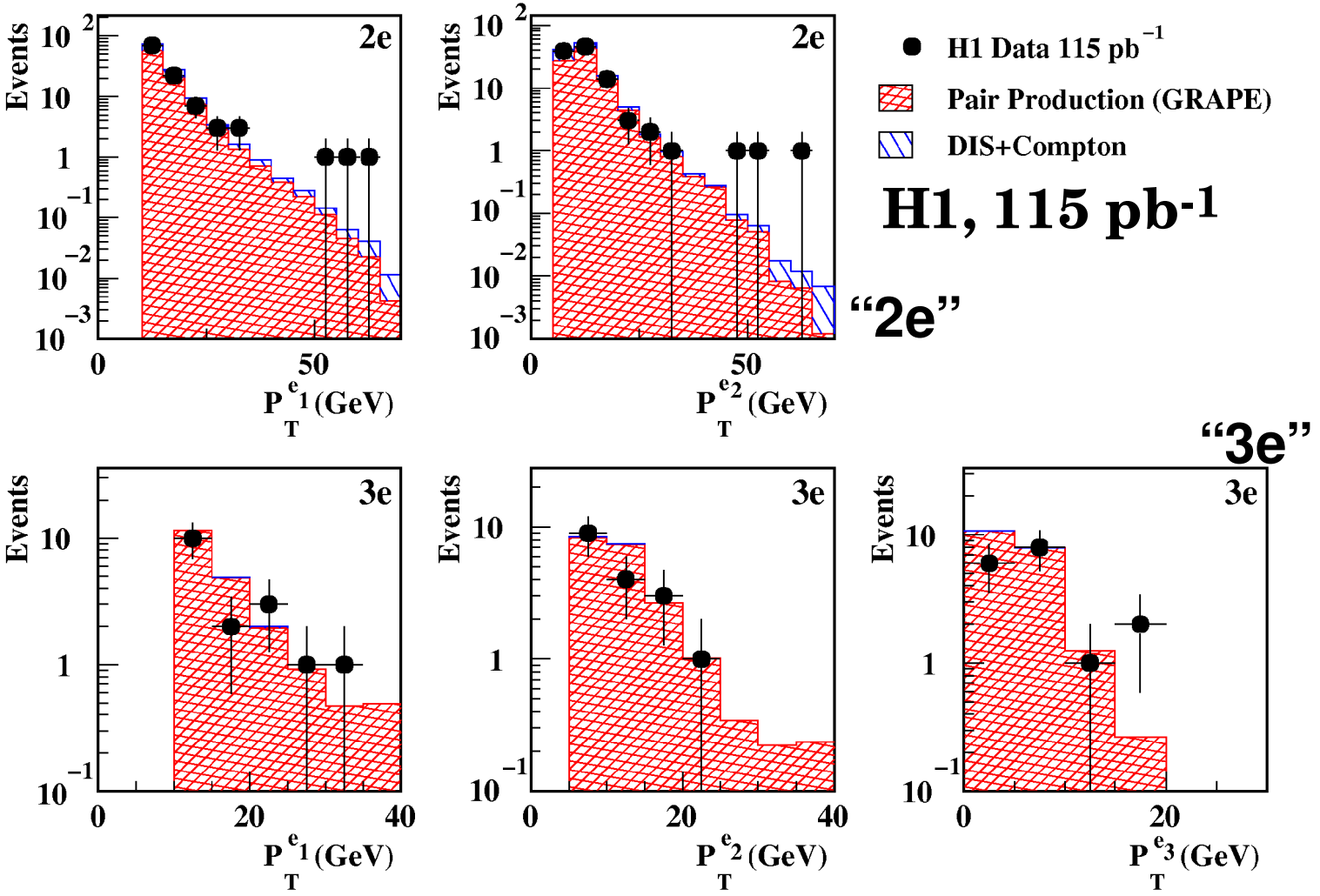
ZEUS (130 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	191	213.9 ± 3.9	182.2 ± 1.2	31.7 ± 3.7
3 e	26	34.7 ± 0.5	34.7 ± 0.5	--

(statistical errors)

➔ no 4-electron event found by H1 or ZEUS

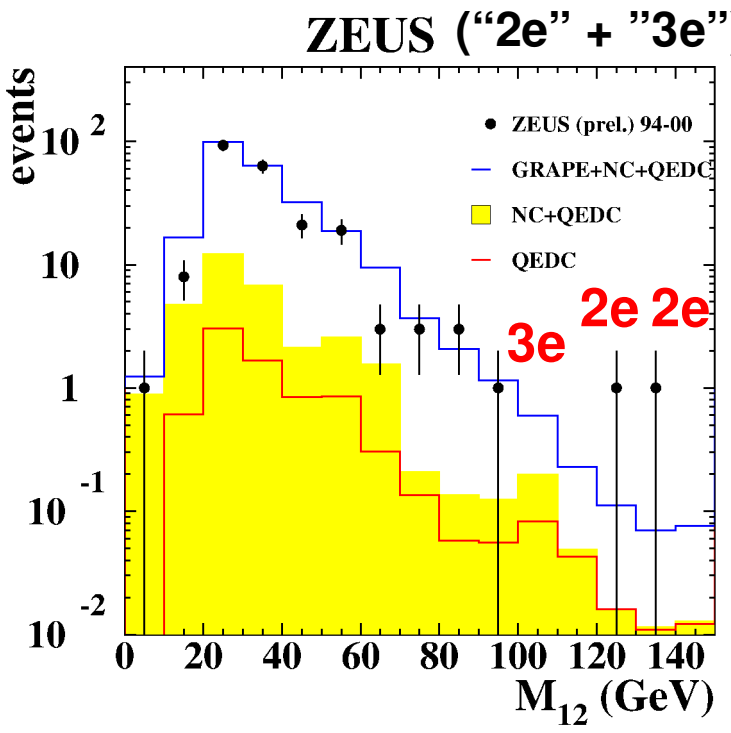
Multi-electron: transverse momenta

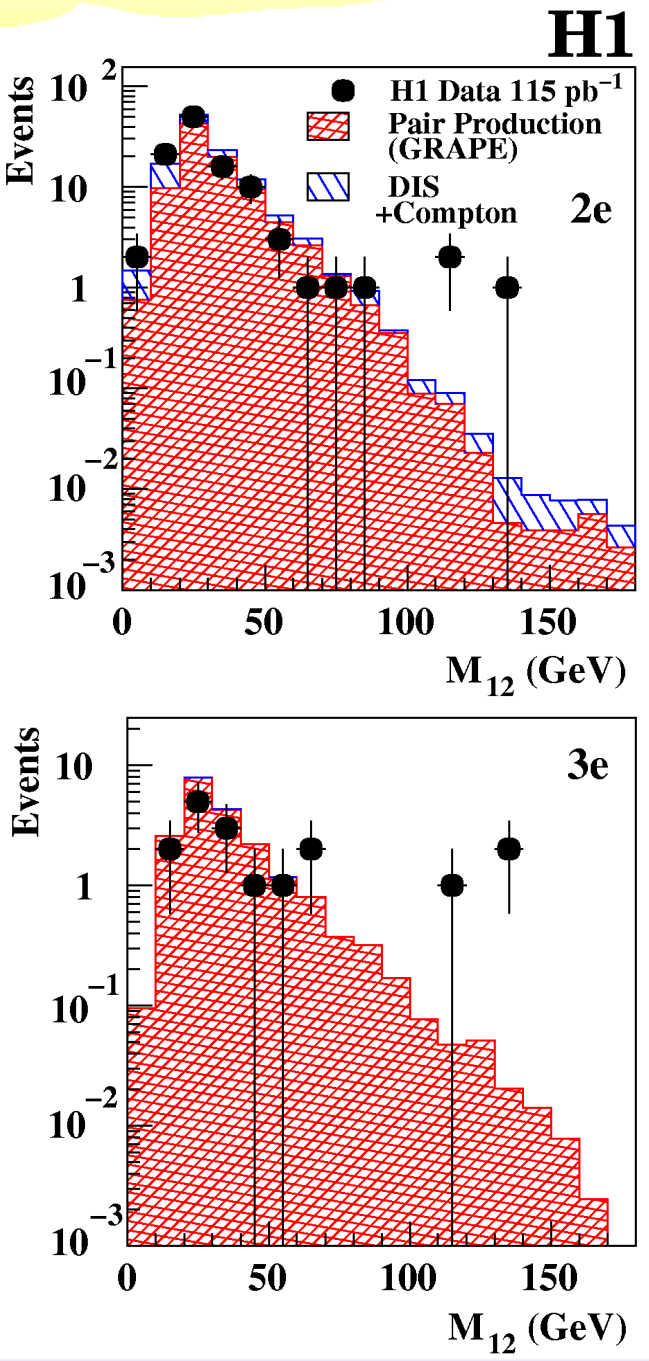
- Good overall agreement
- H1: 3 "2e" events $P_T > 50$ GeV
- ZEUS: 2 events $P_T > 50$ GeV



Invariant mass distributions

- Mass of 2 highest P_T electrons in the event:





➔ Good overall agreement

➔ **Several events at high mass M_{12} > 100 GeV**

Multi-electron: events at $M_{12} > 100$ GeV

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

H1 (115 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	3	0.30 ± 0.04	0.21 ± 0.03	0.09 ± 0.02
3 e	3	0.23 ± 0.04	0.23 ± 0.03	< 0.02 (95% C.L.)

(statistical and systematical errors)

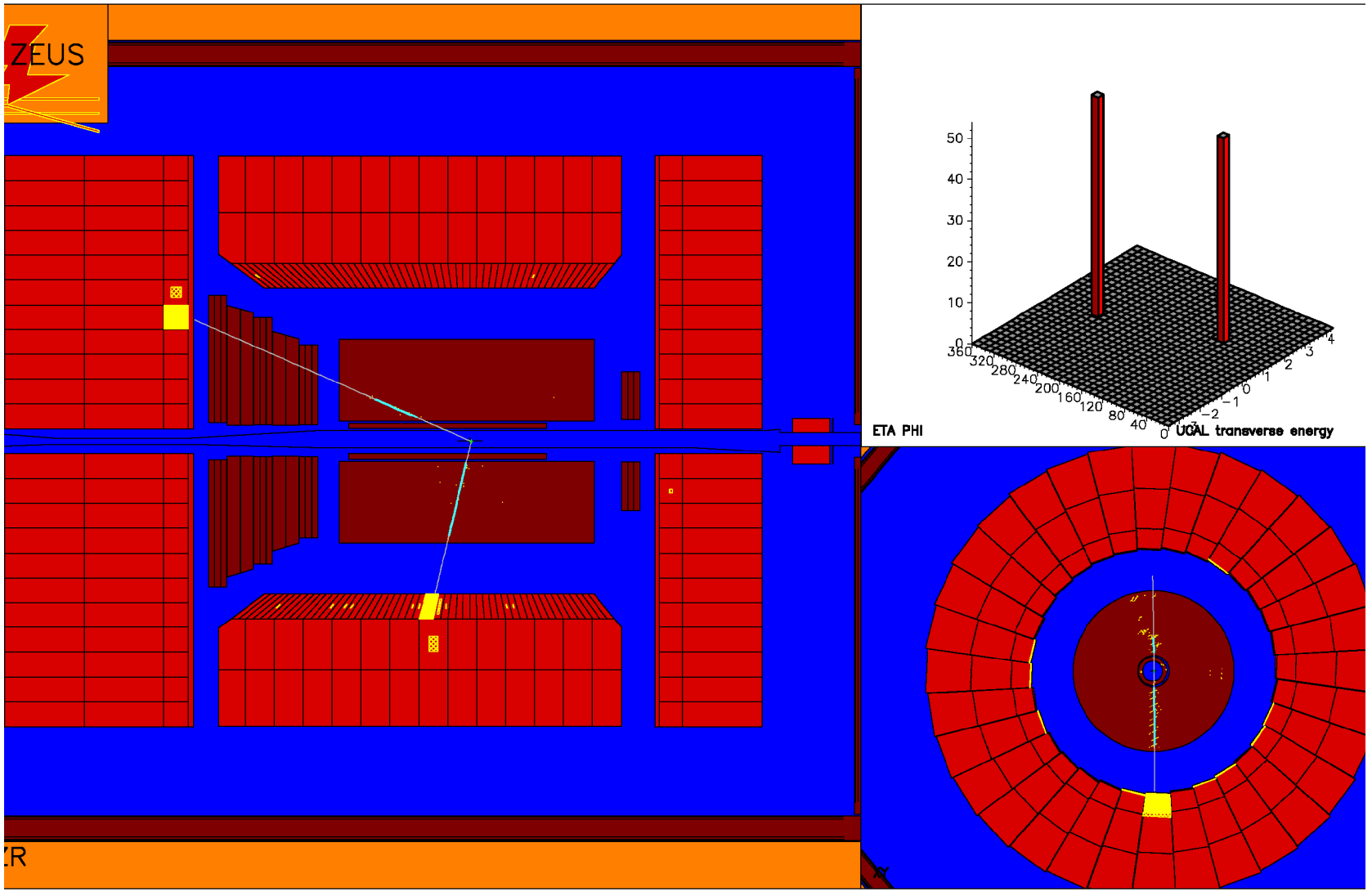
[ZEUS, Preliminary]

ZEUS (130 pb-1)	Data	SM	lepton pairs	NC + Compton
2 e	2	0.77 ± 0.08	0.47 ± 0.05	0.30 ± 0.07
3 e	0	0.37 ± 0.04	0.37 ± 0.04	--

(statistical errors)

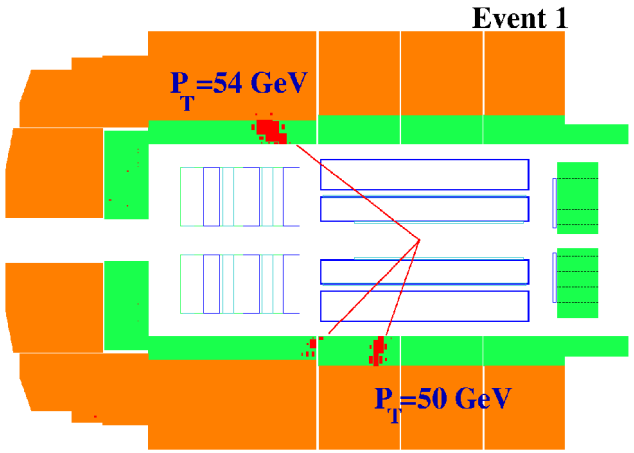
(different polar angle domains for H1 / ZEUS)

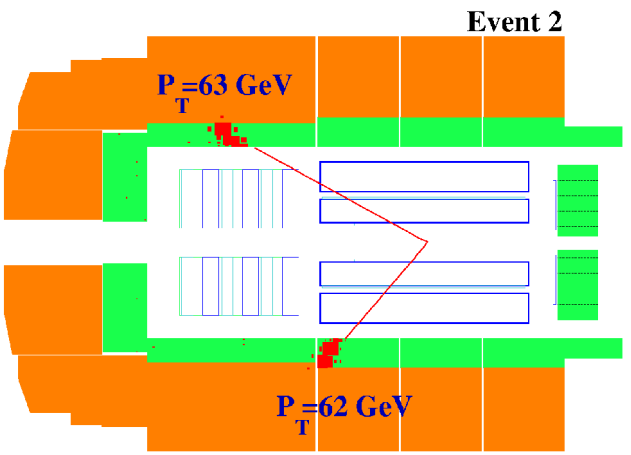
2e event (ZEUS) M_{12} = 134 GeV

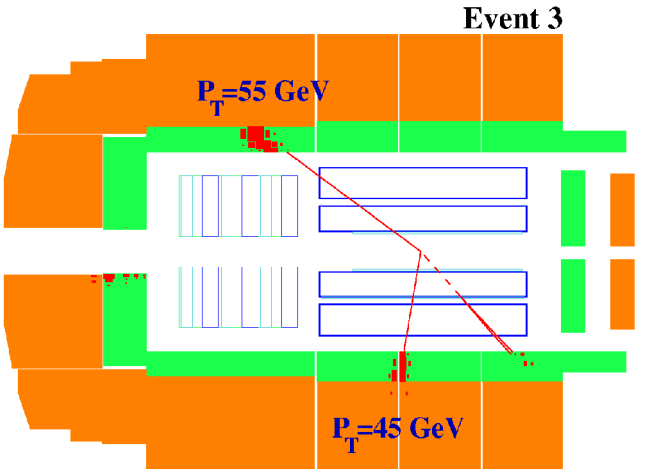


H1 high mass events, $M_{12} > 100$ GeV

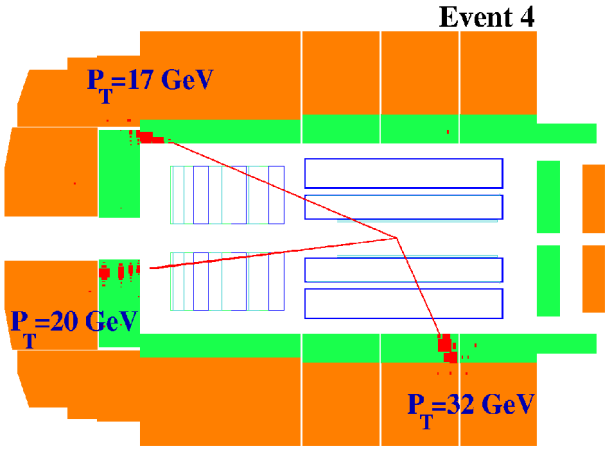
- "2e" events:

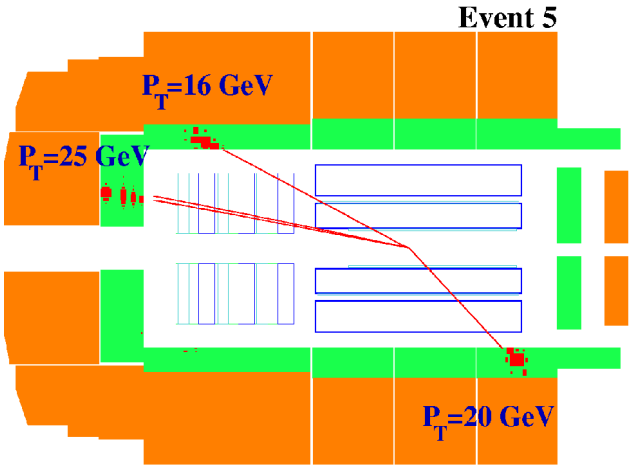


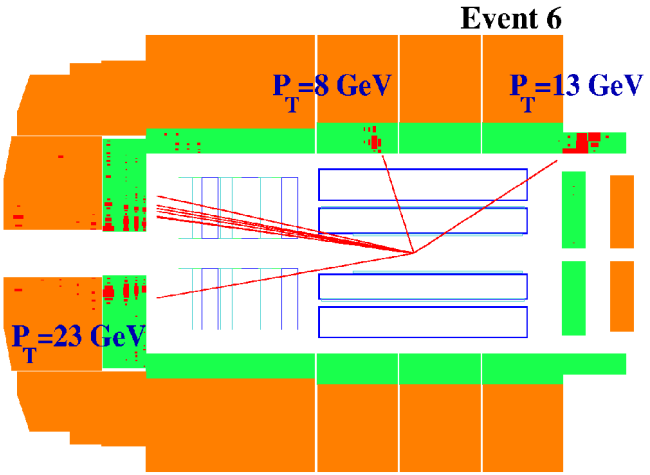




- "3e" events:

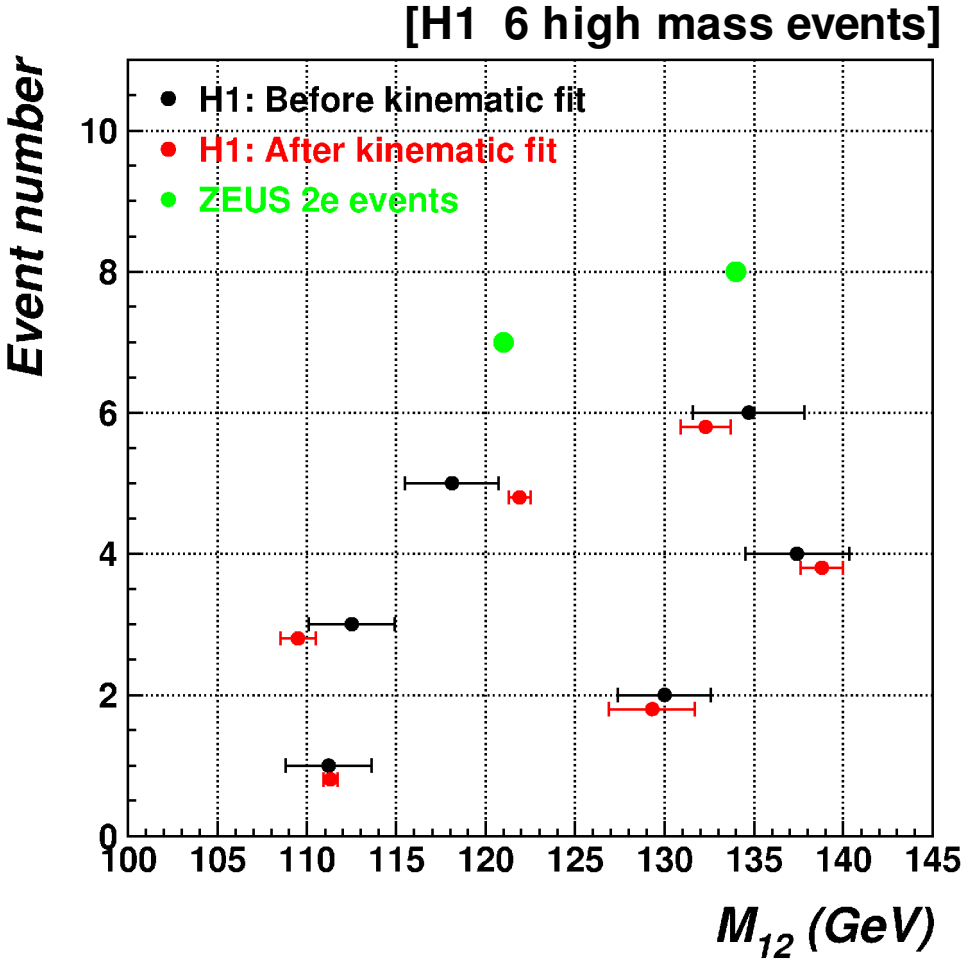






Precise M_{12} mass determination

- Try to improve the kinematic measurement:
  - ➔ Imposing longitudinal and transverse momentum conservation for fully contained events ($E\text{-}P_z$ = 55.2 GeV and P_T^{miss} = 0 GeV)
  - ➔ Constrained kinematic fit
- Errors reduced by more than a factor of 2
- Kinematic of the events well understood

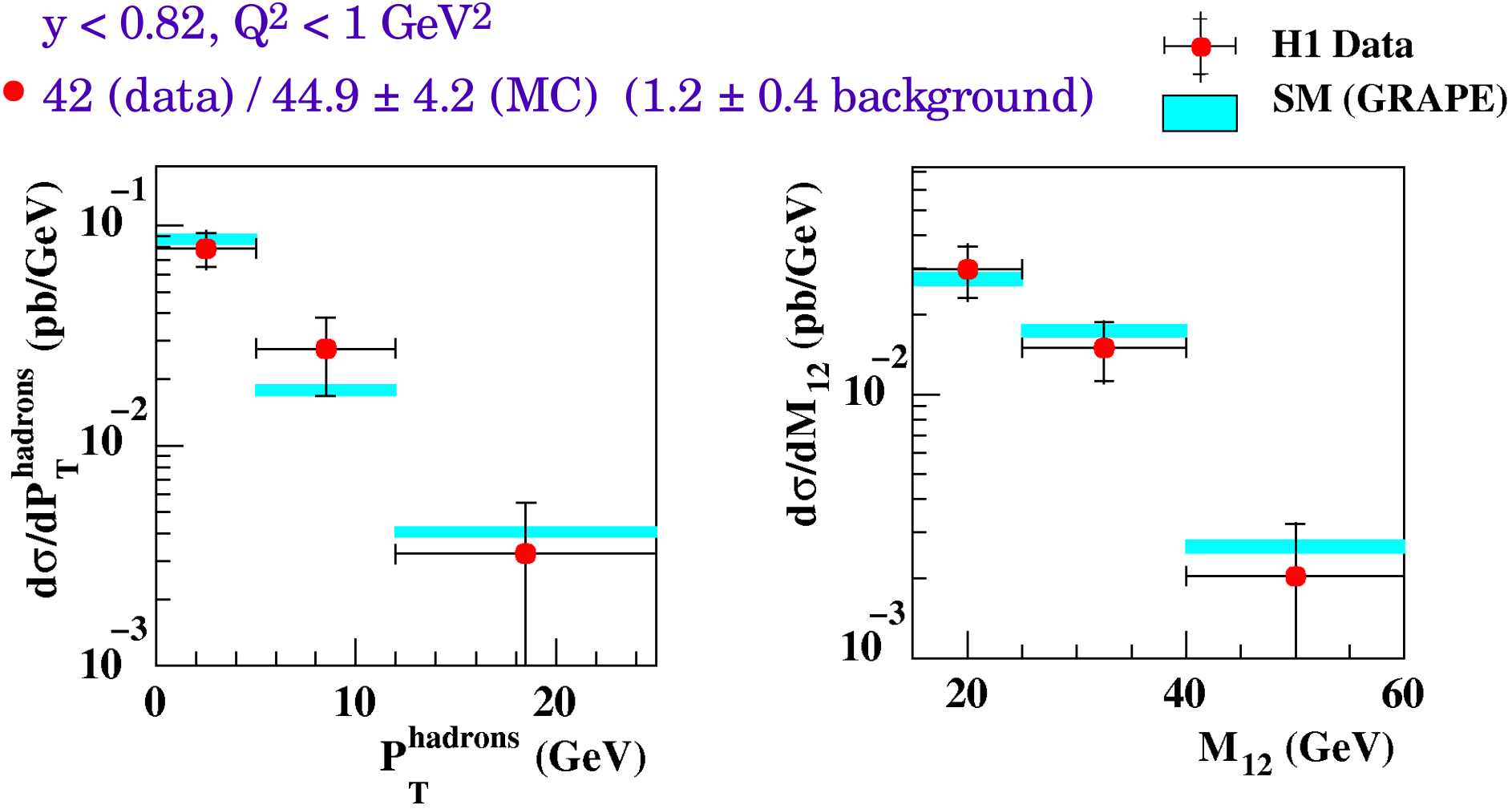


➔ **M_{12} values are not compatible with a single narrow resonance decay**

H1: Cross-section measurement

$\gamma\gamma \rightarrow e^+e^-$

- 2e 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)



➔ **Inelastic process well described**

➔ **Good agreement with the SM**

Di-muon events

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

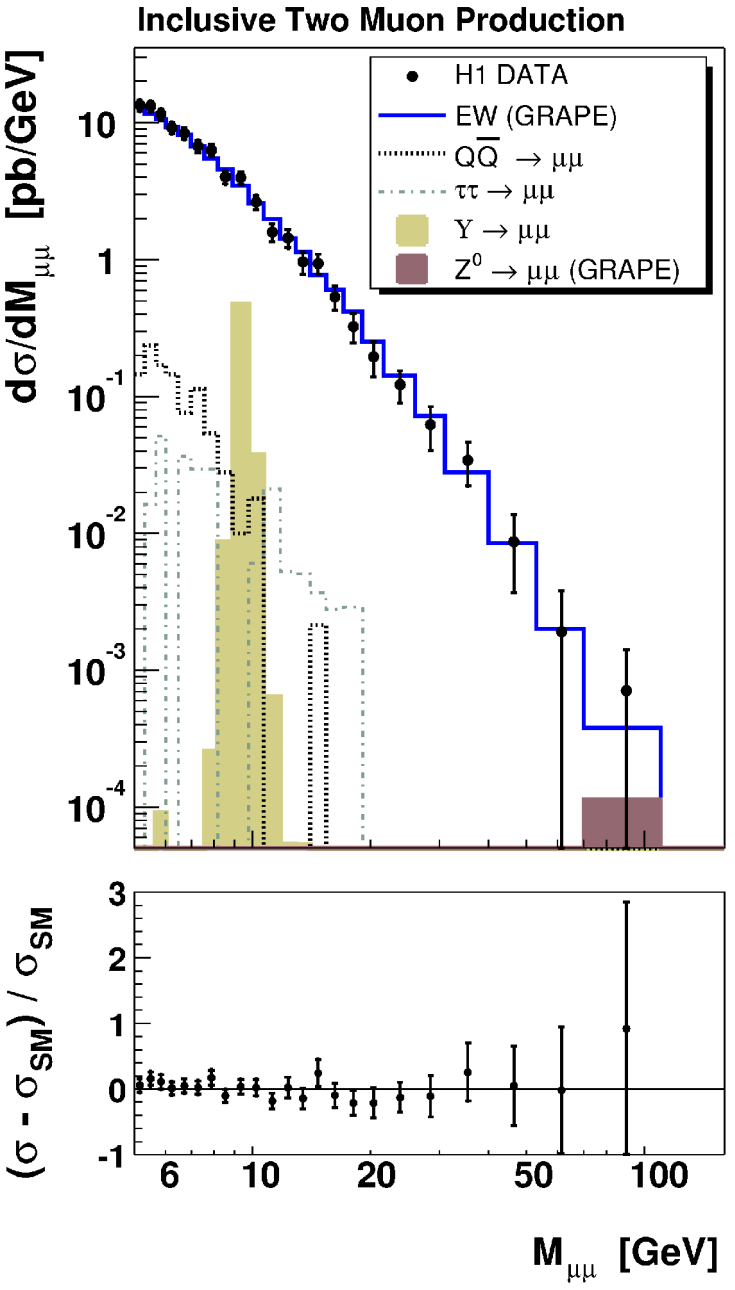
- μ identified in central tracker, calorimeter and external muon chambers
- $P_T^{\mu 1} > 2$ GeV, $P_T^{\mu 2} > 1.75$ GeV
- $M_{\mu\mu} > 5$ GeV
- $(20° < \theta_\mu < 160°)$

➔ $\sigma_{\mu\mu} = 46.4 \pm 1.3 \pm 4.5$ pb
SM prediction (GRAPE): 46.1 ± 1.4 pb

➔ Good agreement with SM

➔ No μ-μ event observed with $M_{\mu\mu} > 100$ GeV

➔ Extrapolation of "2e" to μ-μ: ~1 μ-μ expected



Multi-lepton Events at high P_T: e-μ-μ, μ-μ

- Lumi = 114 pb^{-1}, full HERA-I data
- Motivation: **analysis equivalent to multi-electron**
- At least 2 μ: $P_T^{\mu 1} > 10$ GeV, $P_T^{\mu 2} > 5$ GeV, $(20° < \theta_{\mu 1,2} < 160°)$
- Any additional μ: $P_T^{\mu 3} > 1.75$ GeV, $(20° < \theta_{\mu 3} < 160°)$
- Any additional e: $E_e > 5$ GeV, $(5° < \theta_e < 175°)$

H1 (114 pb-1)	Data	SM
μ - μ	40	39.9 $\pm$ 4.2
e - μ - μ	16	14.9 $\pm$ 1.6

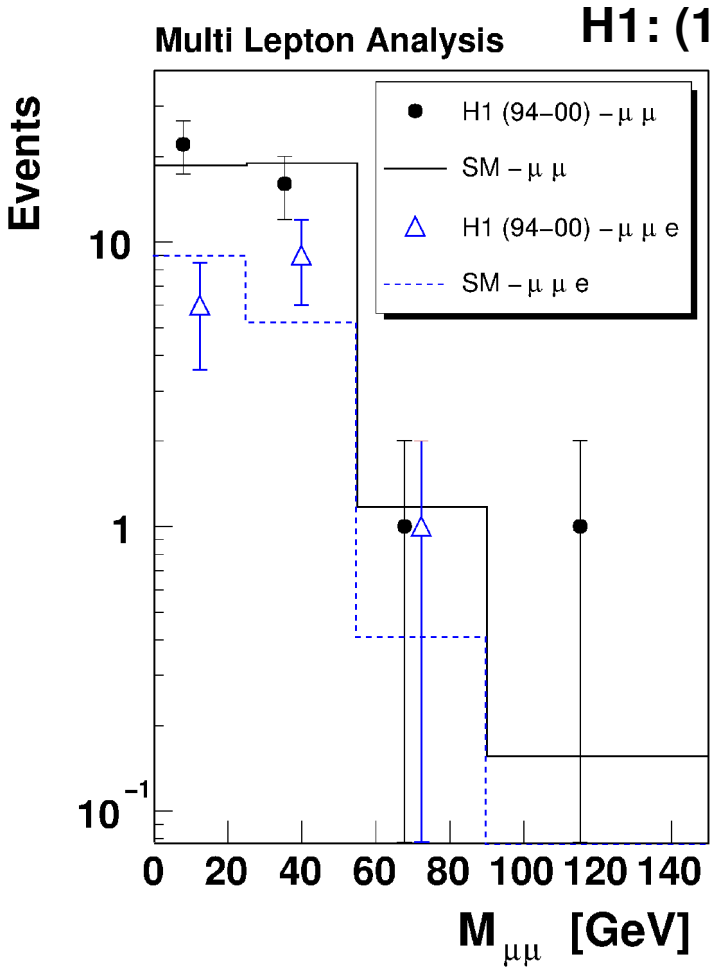
➔ $M_{\mu\mu} > 100$ GeV: 1 μ-μ event observed for 0.08 $\pm$ 0.01 predicted

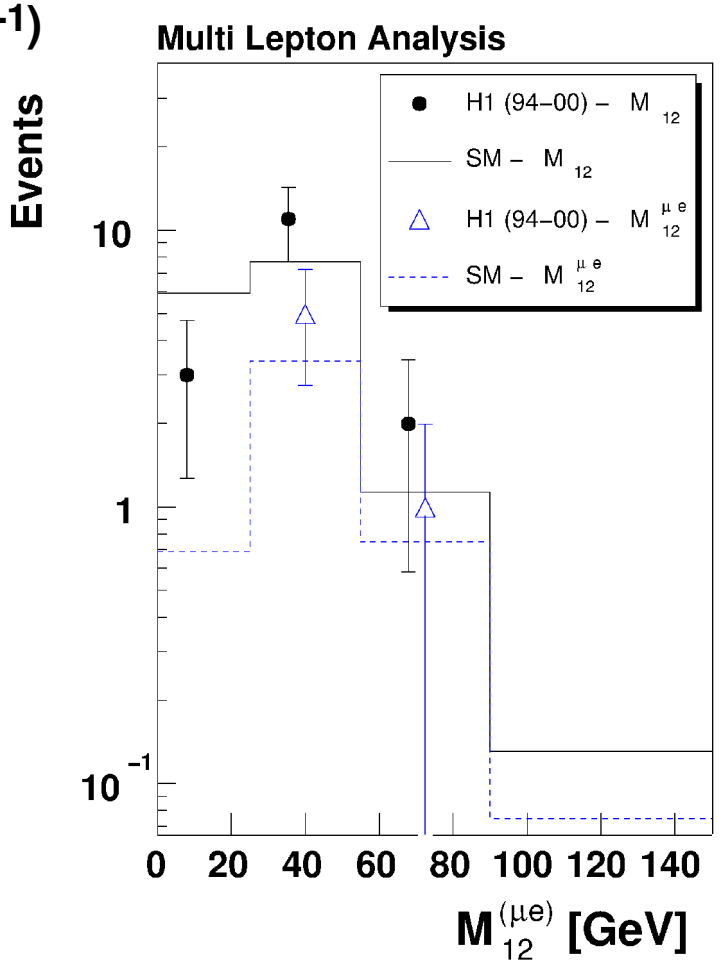
➔ $M_{\mu\mu} = 102 \pm 11$ GeV

➔ No 3 μ event

Multi-lepton events: mass distributions

- Mass of the μ-μ pair
- Mass of the 2 higest P_T leptons (equivalent to multi-electron)



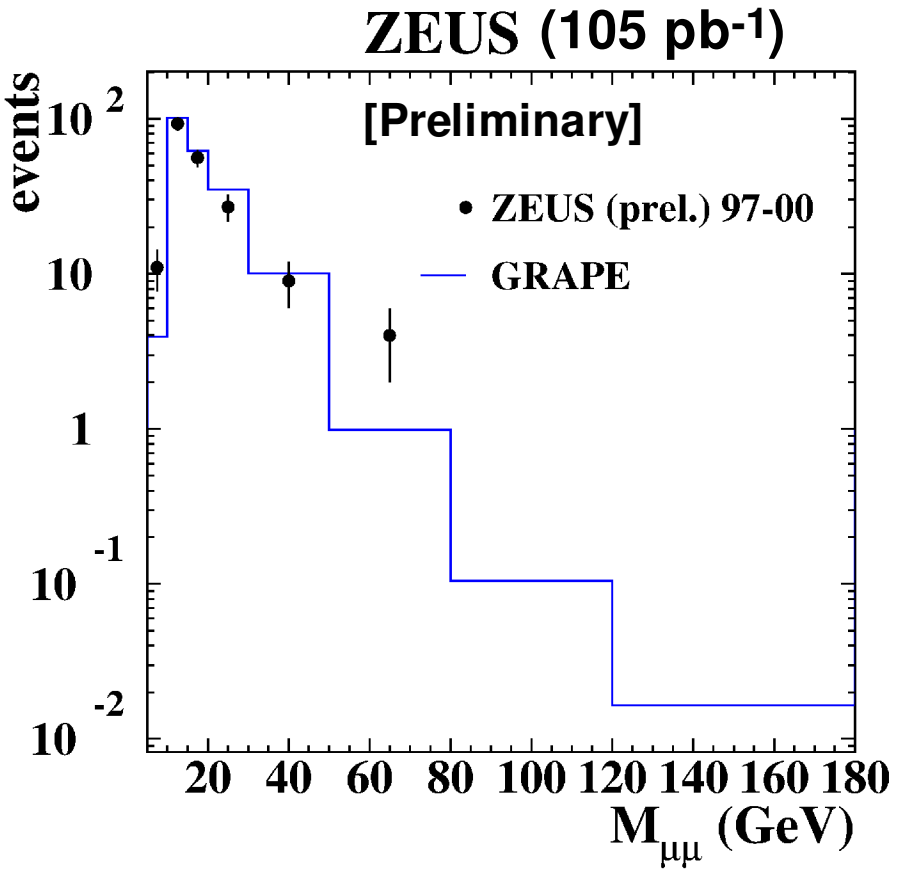


➔ Agreement with the SM

➔ But limited statistics

Di-muon results from ZEUS

- μ identified in central tracker, calorimeter and external muon chambers
- $P_T^{\mu} > 5$ GeV, $(20° < \theta_{\mu} < 160°)$, ≥ 2 isolated μ



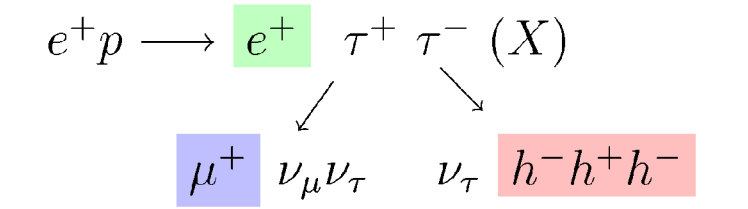
➔ **200 (data) / 213 ± 11 (SM)**

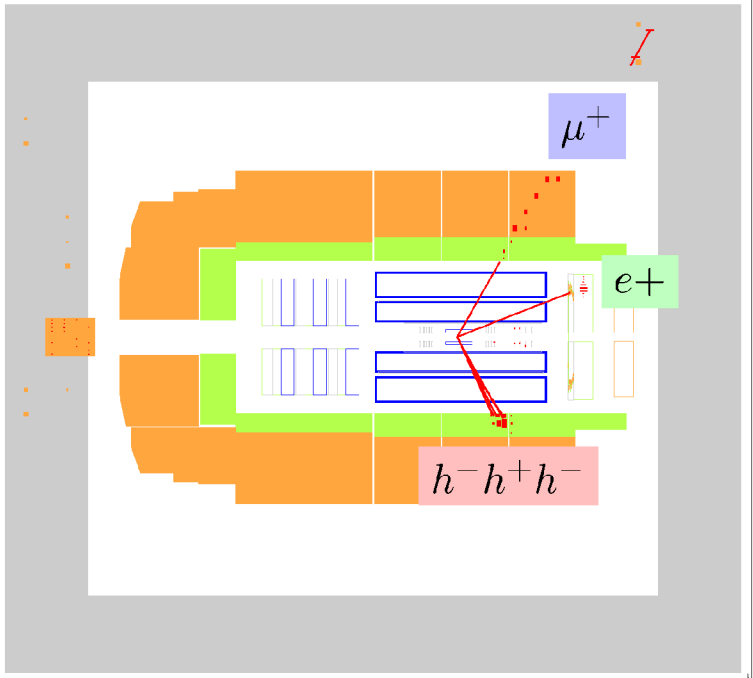
➔ No μ-μ event observed with $M_{\mu\mu} > 100$ GeV

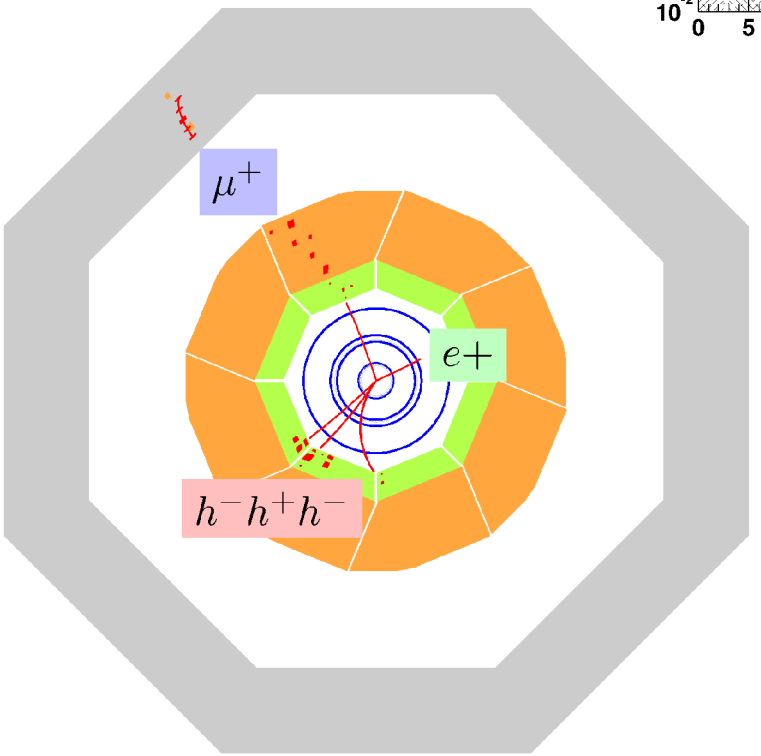
➔ Good agreement with the SM

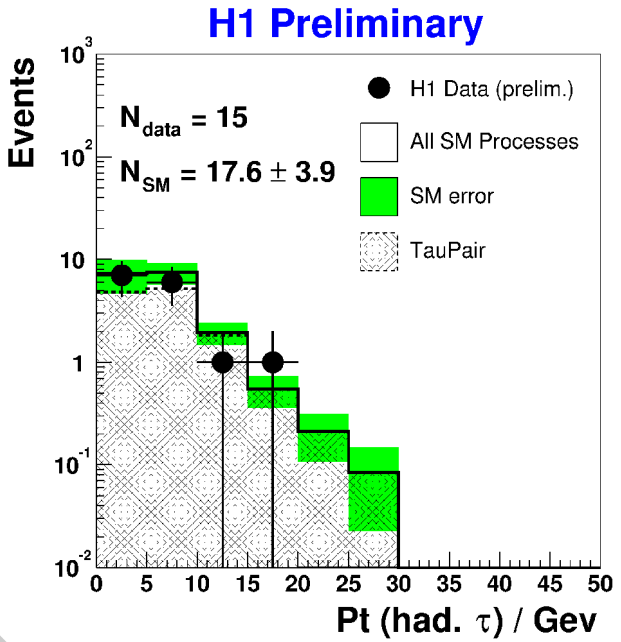
Production of τ pairs

- Observation of τ pairs by H1
  (see talk by G. Brandt)





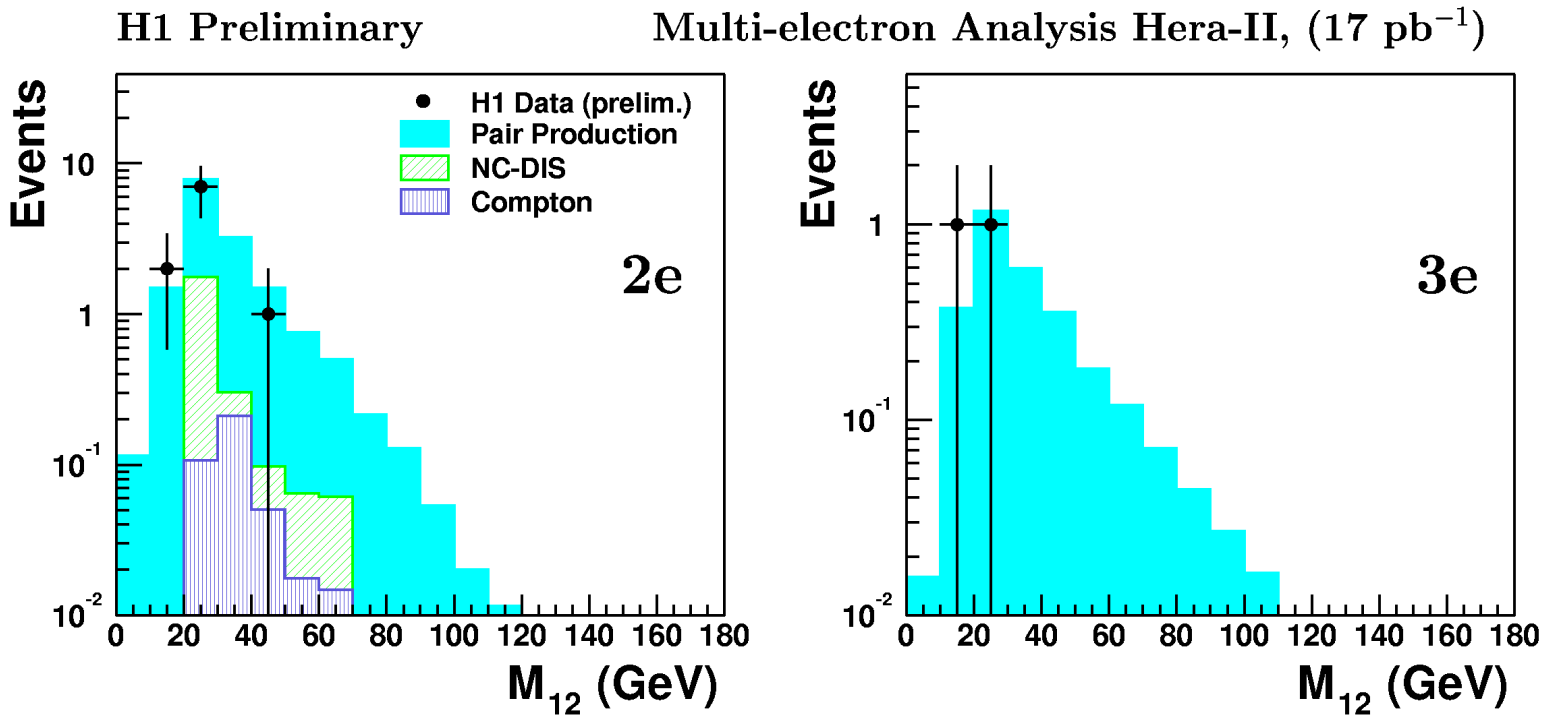




HERA-II: H1 multi-electron analysis

- HERA-II is running: analyses re-started
- Preliminary results with 17 pb^{-1}

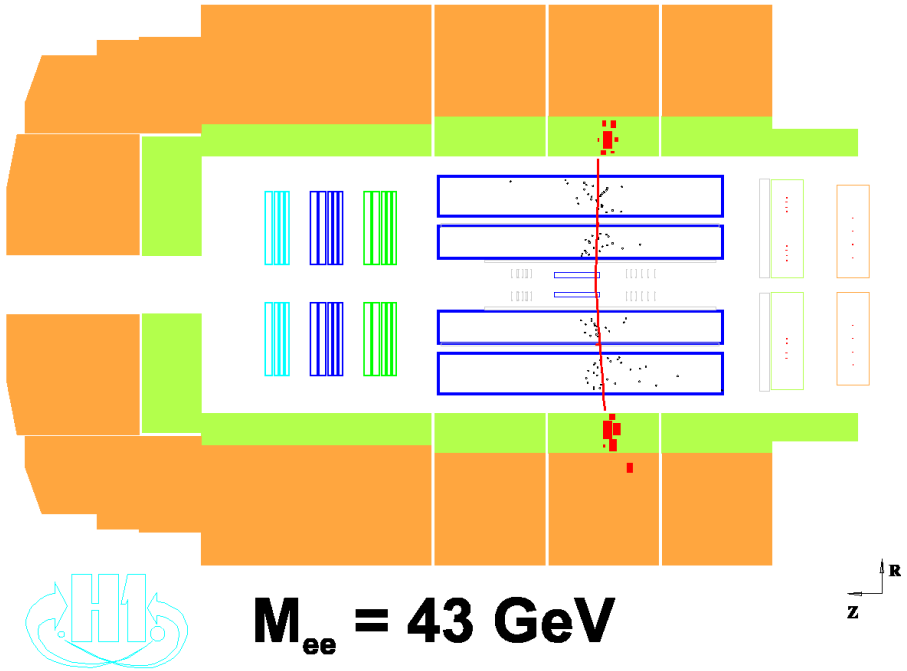
Selection	Data	SM	Pair Production (GRAPE)	NC-DIS + Compton
"2e"	10	15.8 ± 1.7	13.5 ± 1.4	2.3 ± 0.5
"3e"	2	3.0 ± 0.4	3.0 ± 0.4	—



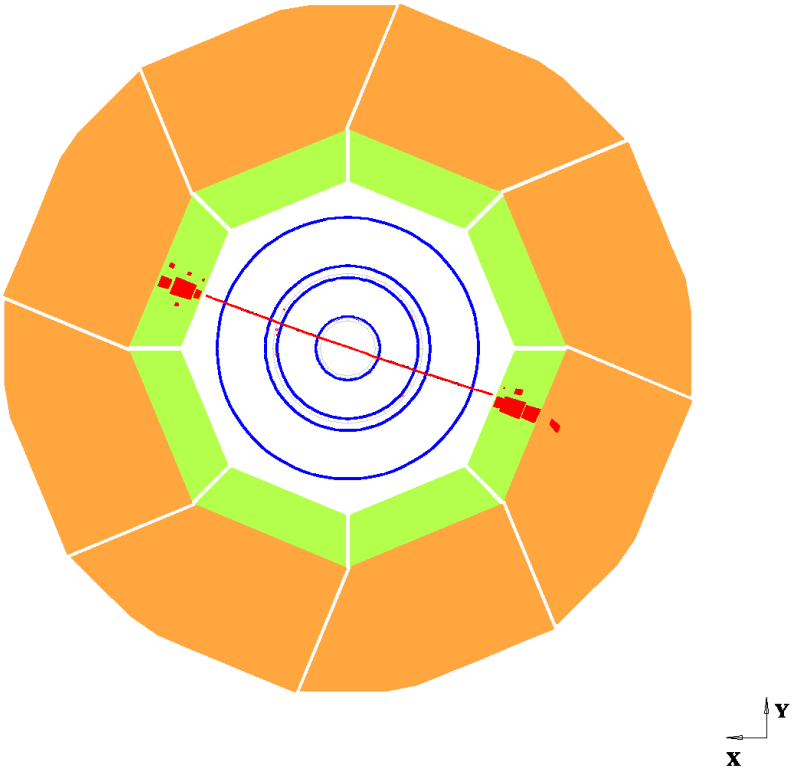
➔ **Agreement with SM expectation**

➔ **No new events at high mass**

HERA-II: di-electron event



M_{ee} = 43 GeV



Summary ...

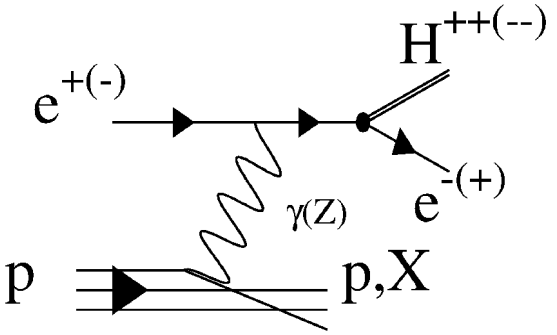
- Multi-lepton production has been measured in ep collision
- Multi-electron:
  - ➔ $\gamma\gamma$ cross-section in agreement with the SM
  - ➔ Outstanding events at high mass:
    - H1: 3 "2e" and 3 "3e", for 0.3 and 0.23 predicted
    - ZEUS: 2 di-electron
- Muon pairs:
  - ➔ Cross-section also in good agreement with the SM
  - ➔ e - μ - μ analysis using all HERA-I data

↘ **Outlook:**

- ➔ HERA-II is now running and these analyses re-started
- ➔ First multi-electron measurement done with 17 pb^{-1}
- ➔ **Wait now for full HERA-II luminosity: 1 fb^{-1}**

Doubly charged Higgs at HERA ?

- at HERA : $e^+ p \rightarrow e^- H^{++} X$, $H^{++} \rightarrow l^+ l^+$, sensitivity to h_{ee} coupling

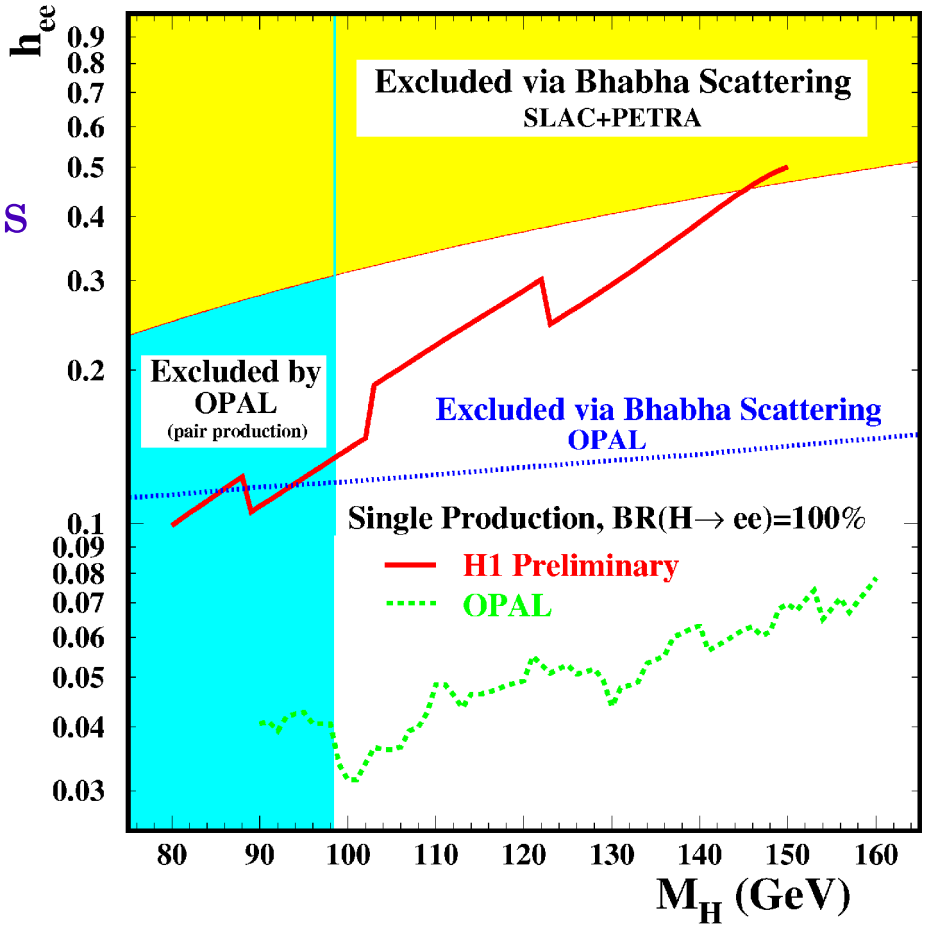


➔ H1: on top of multi-electron selection, combines e and μ channels

- Only 1 2e fulfils charge requirements

  ➔ Doubly charged Higgs very unlikely

  ➔ Strong bounds on Yukawa coupling h_{ee} by OPAL

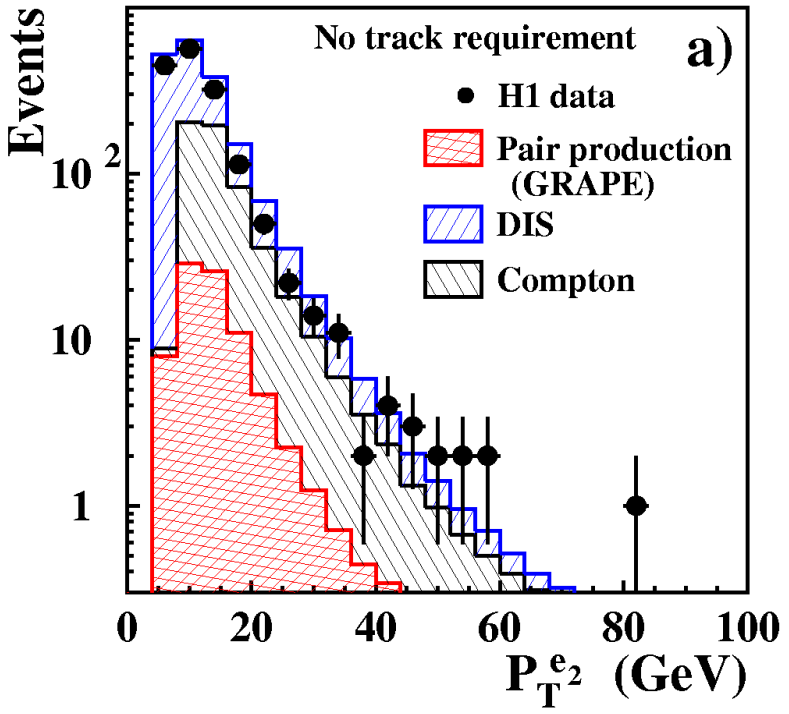


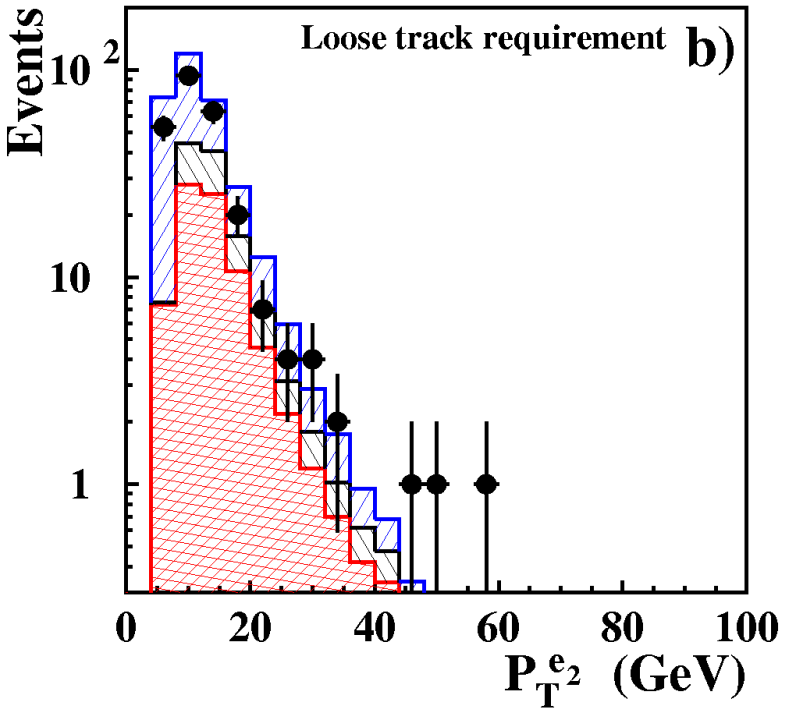
➔ **Multi-electron events not due to H^{++} decay**

Background studies: NC-DIS

- Study of electron mis-identification in central region
- Selection of Neutral Current DIS events

➔ Events with a 2nd electromagnetic cluster





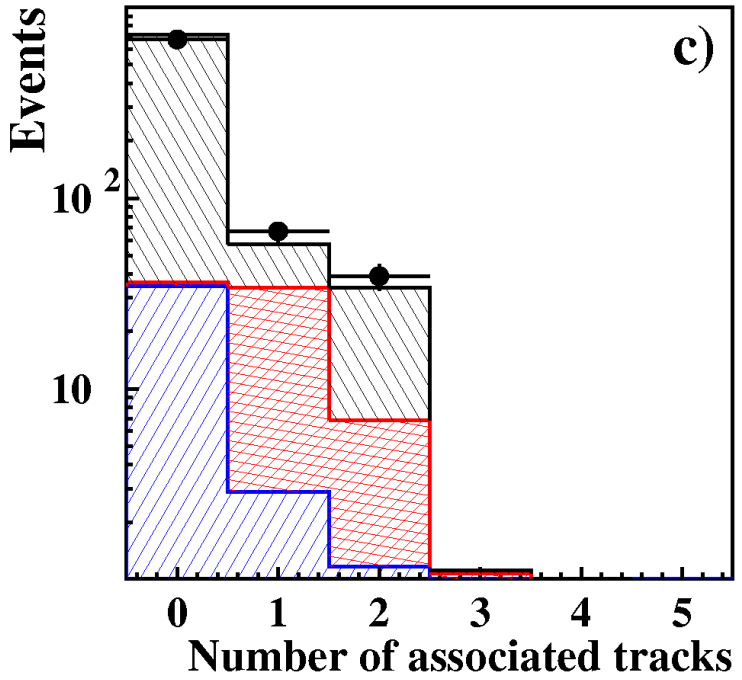
➔ No track required

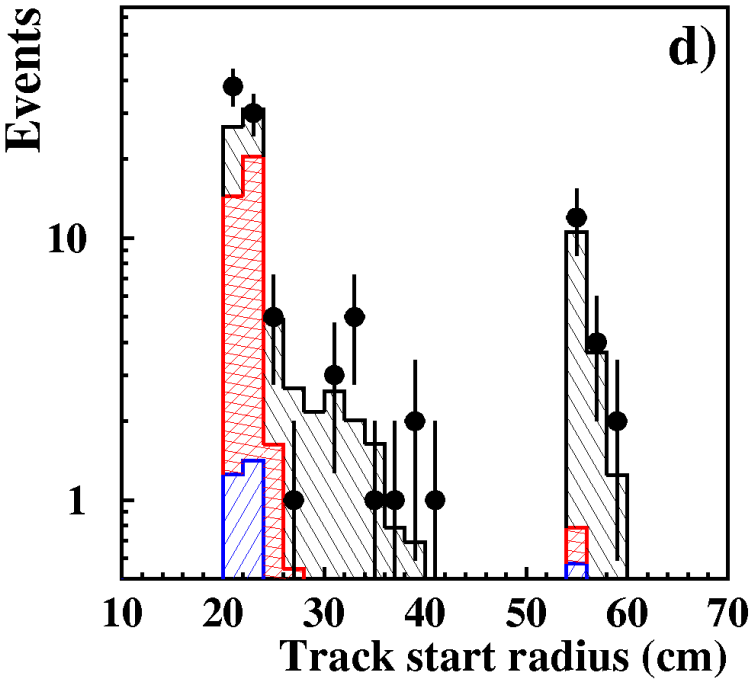
➔ Loose track required

➔ **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%**