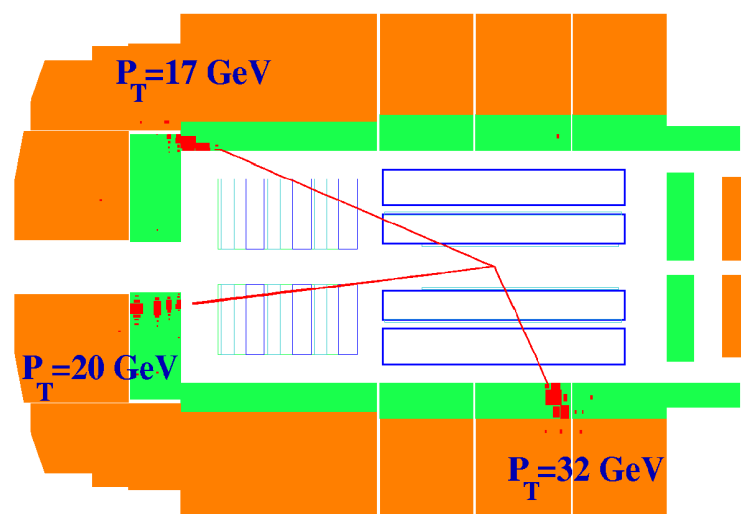


Multi-Lepton Production in ep Collisions at H1

Gerhard Brandt
University of Heidelberg
H1 Collaboration



H1prelim-07-062



April 19, 2007

EW and BSM Session

HERA Running and Data

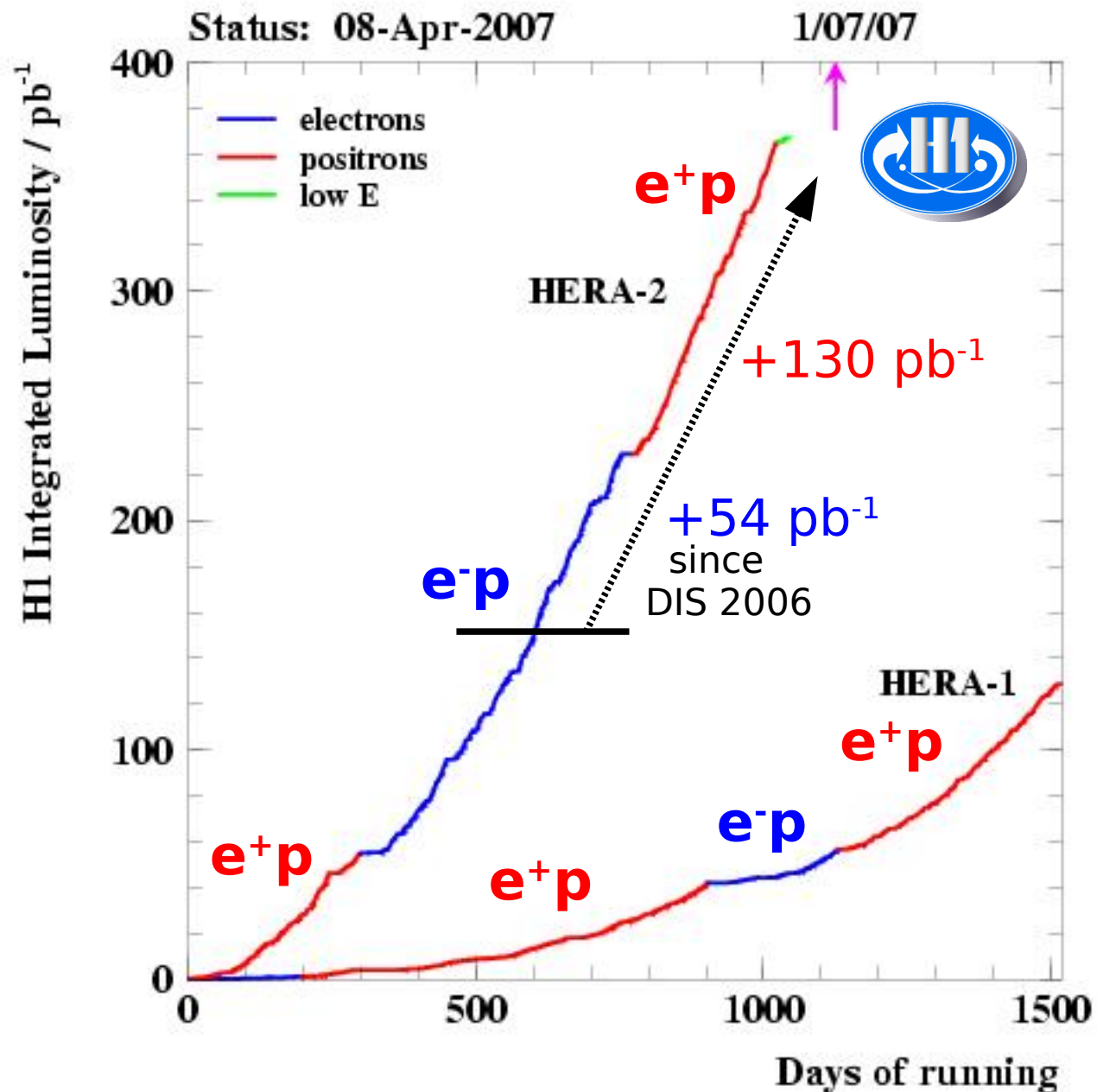
Full HERA high-energy
1994-2007 data of
 $e^\pm p$ collisions
up to $\sqrt{s} = 320$ GeV
analysed

e^+p	286 pb ⁻¹
e^-p	173 pb ⁻¹
$e^\pm p$	459 pb⁻¹

→ next talk:



Data 1996-2007:
 $e^\pm p$ **446 pb⁻¹**



Multi-Lepton Events

- Analysis of events with multiple $e, \mu, (\tau)$
- SM prediction is precise and low
- Many BSM models with these final states (eg. H^{++})

Covered Topologies:



$ee, e\mu, \mu\mu$
 $eee, e\mu\mu$

Not observed:

- $\mu\mu\mu$, 4-lepton

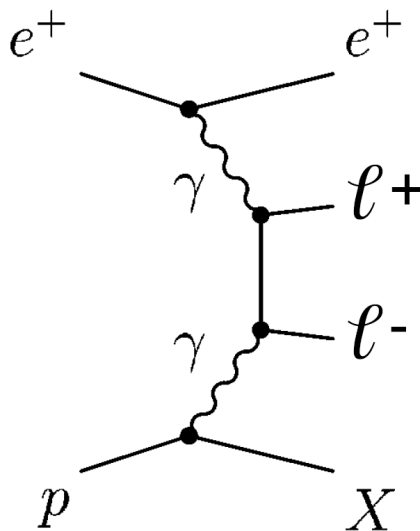
Special selections:
(Previously shown)

- $\tau\tau$ in elastic events
[H1 Coll., Eur. Phys. J. C48 \(2006\) 699](#)
- $e\tau$ in H^{++} Production
[H1 Coll, Phys. Lett. B 638 \(2006\) 432](#)

→ next talk:



ee
 eee
 $\tau\tau \rightarrow e\mu$



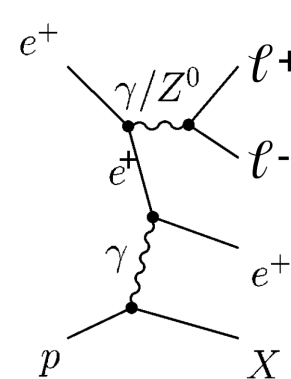
SM Signal Processes (GRAPE)

Dominant

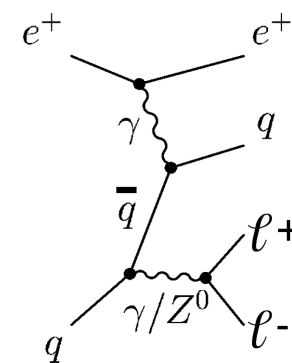
- $\gamma\gamma \rightarrow l^+l^-$
(Elastic, Inelastic & Interference)

Small

- Cabbibo-Parisi



Drell-Yan



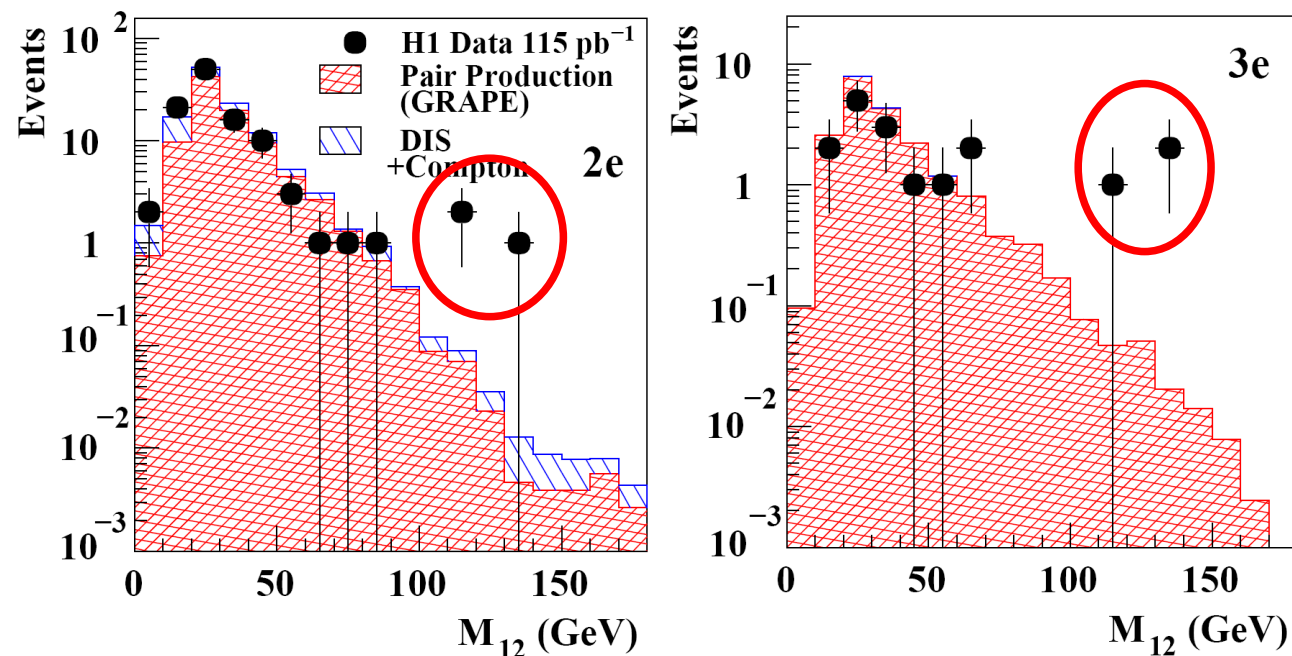
SM Background

- NC DIS (RAPGAP)
 - QED Compton (WABGEN)
- Due to misidentification of photons and hadrons as leptons

Reminder: HERA-1 Results

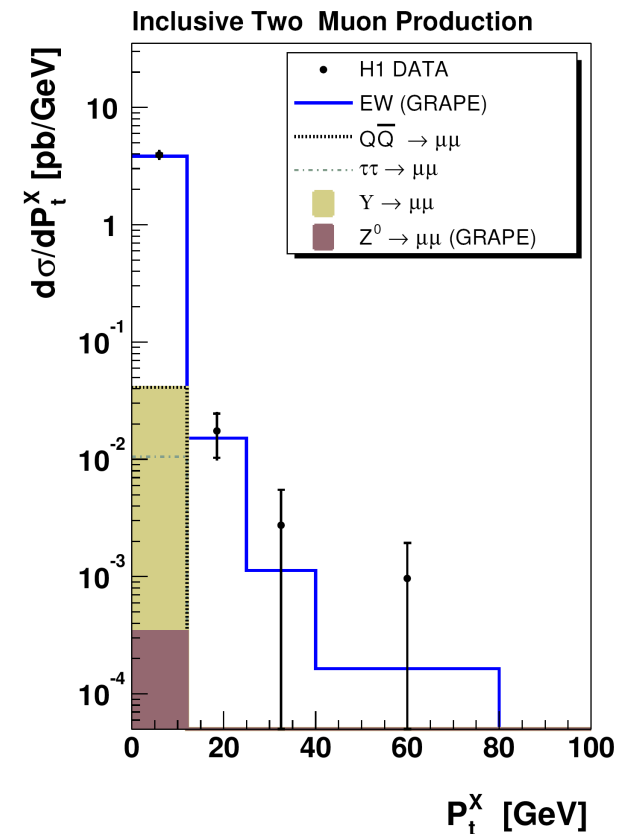
ee, eee

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



$\mu\mu(e)$

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



- Overall agreement with SM good – x-sections measured
- But interesting events at $M_{12} > 100$ GeV:

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.)

H^{±±} production? Not compatible!

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

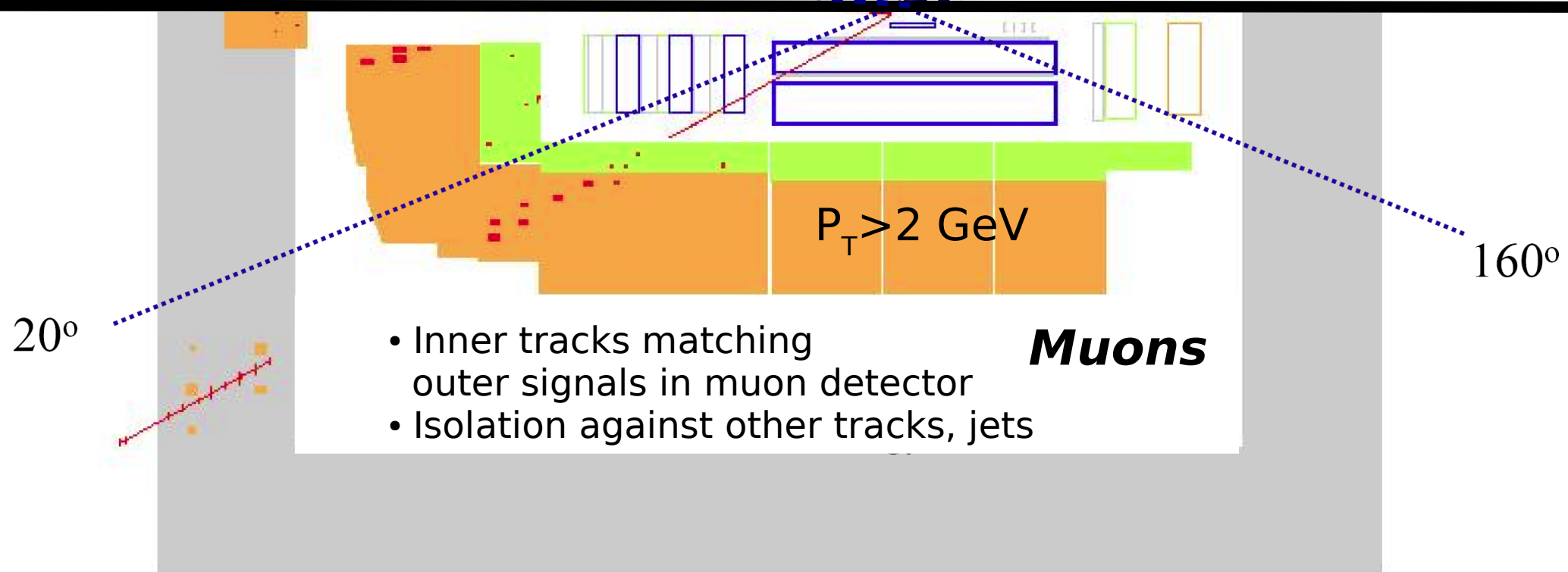
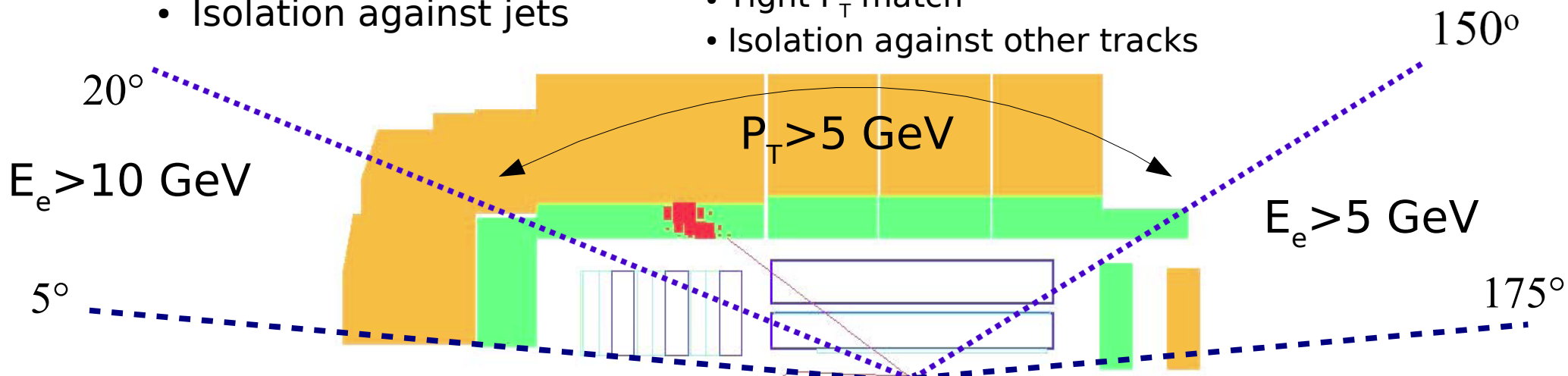
Lepton Identification

Electrons

- Compact em. cluster
- Isolation against jets

Track Requirement in Central Region:

- Tight geometrical match (dca)
- Tight P_T match
- Isolation against other tracks



Selection

- $N_{\text{lept}} \geq 2$
 - $20^\circ < \theta_{1,2} < 150^\circ$
 - $P_T^1 > 10 \text{ GeV}$
 - $P_T^2 > 5 \text{ GeV}$
 - Separated by $D > 0.5$
 - No constraints on any further leptons
- Count leptons + classify*

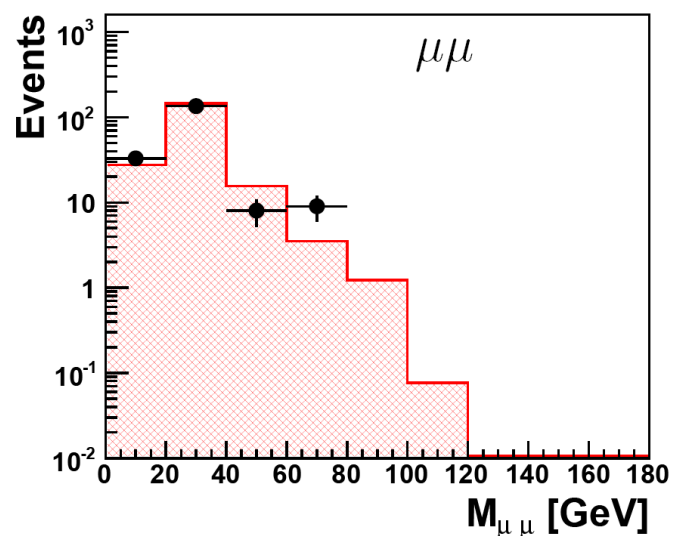
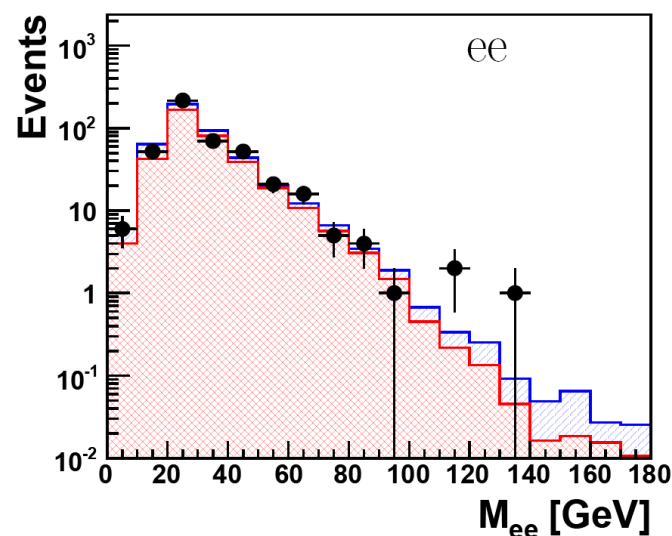
Results:

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

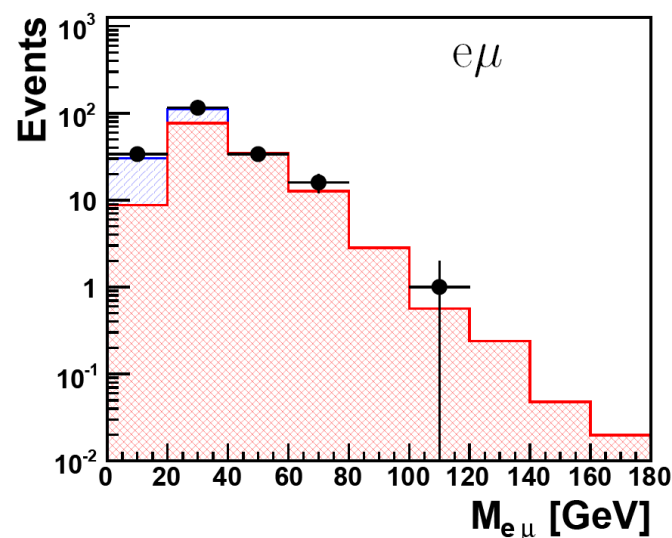
Selection	Data	SM	Pair Production	NC-DIS + Compton
ee	446	450 ± 68	375 ± 42	75 ± 39
μμ	185	194 ± 38	194 ± 38	—
eμ	201	194 ± 26	136 ± 13	58 ± 17
eee	81	90 ± 10	90 ± 10	—
eμμ	102	112 ± 19	112 ± 19	—

Invariant Mass of Dilepton Topologies

H1 Multi-lepton analysis HERA I+II (459 pb^{-1})



● H1 Data (prelim.)
 ■ DIS+Compton
 ■ Pair Production

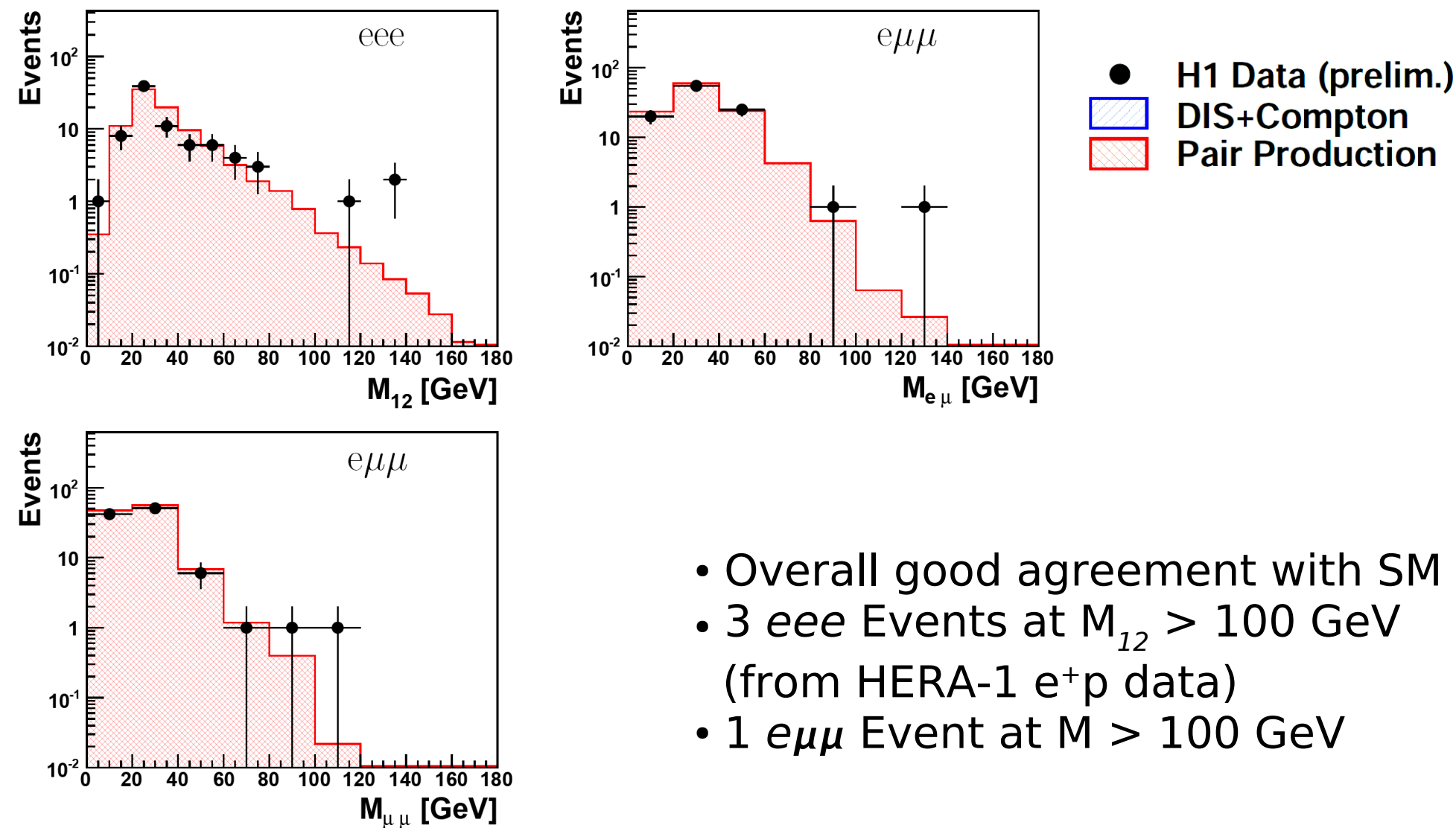


- Overall good agreement with SM
- 3 ee Events at $M_{ee} > 100 \text{ GeV}$
(from HERA-1 e^+p data)

$ee M_{12} > 100 \text{ GeV}$	3	1.5 ± 0.3	0.9 ± 0.2	0.6 ± 0.2
$\mu\mu M_{\mu\mu} > 100 \text{ GeV}$	0	0.09 ± 0.05	0.09 ± 0.05	—
$e\mu M_{e\mu} > 100 \text{ GeV}$	1	0.9 ± 0.1	0.9 ± 0.1	—

Invariant Mass of Trilepton Topologies

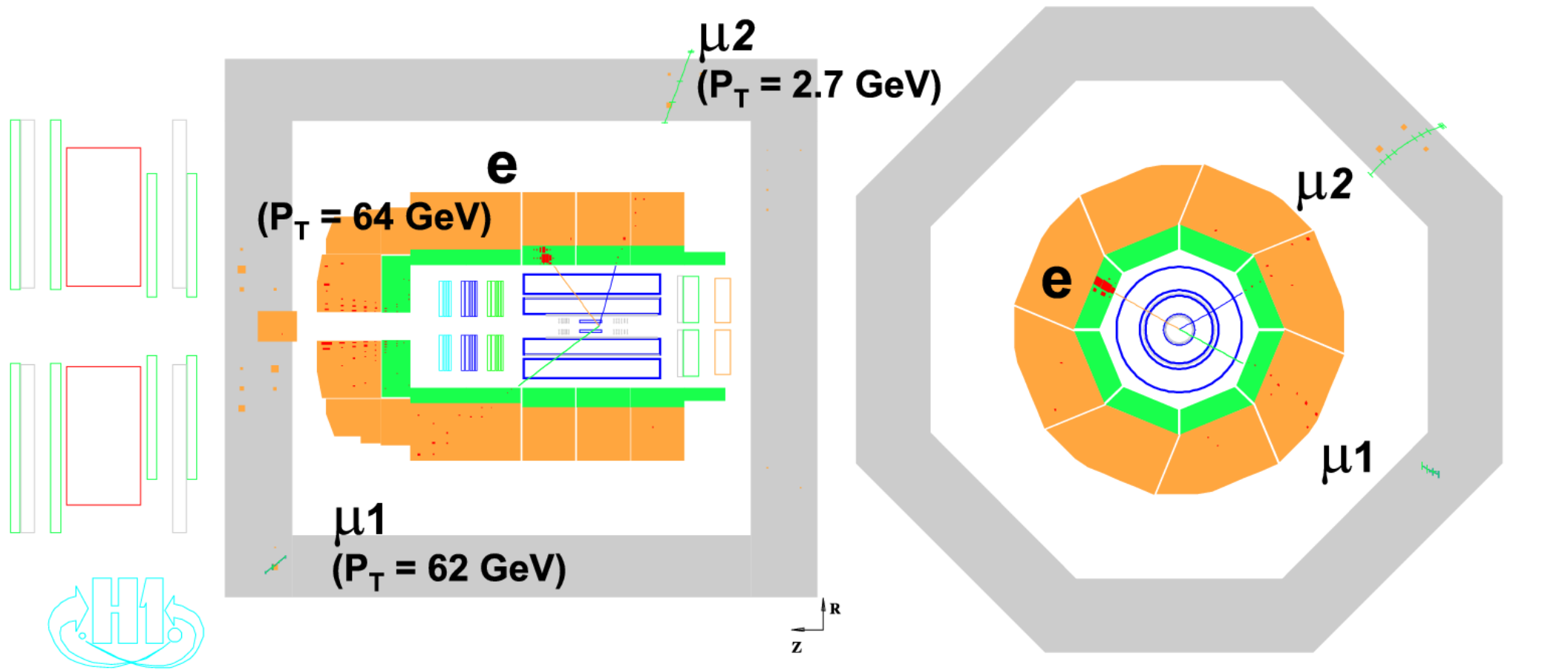
H1 Multi-lepton analysis HERA I+II (459 pb^{-1})



- Overall good agreement with SM
- 3 eee Events at $M_{12} > 100 \text{ GeV}$ (from HERA-1 e^+p data)
- 1 $e\mu\mu$ Event at $M > 100 \text{ GeV}$

eee $M_{12} > 100 \text{ GeV}$	3	0.9 ± 0.2	0.9 ± 0.2	—
$e\mu\mu$ $M_{e\mu} > 100 \text{ GeV}$	1	0.1 ± 0.04	0.1 ± 0.04	—
$e\mu\mu$ $M_{\mu\mu} > 100 \text{ GeV}$	1	0.03 ± 0.02	0.03 ± 0.02	—

$e\mu\mu$ Event in HERA-2 data



Event Yields at High Mass in e^+p / e^-p

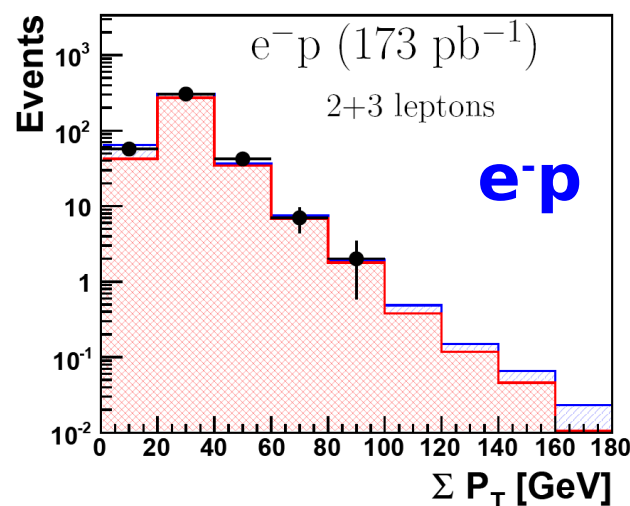
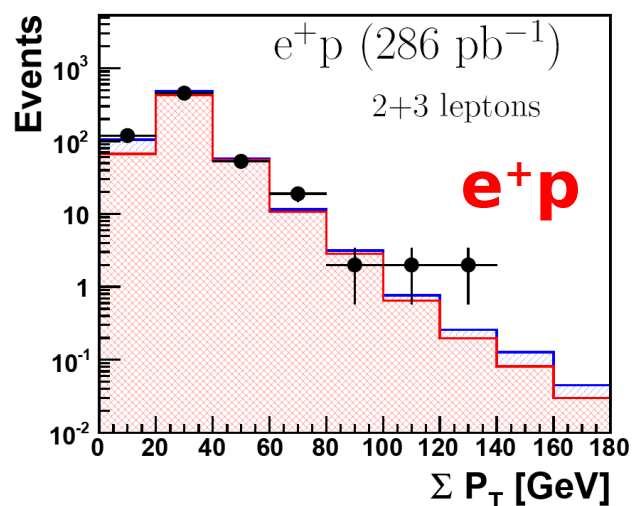
H1 Multi-lepton analysis HERA I+II (preliminary)

Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p collisions (286 pb^{-1})				
$ee M_{12} > 100 \text{ GeV}$	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})				
$ee M_{12} > 100 \text{ GeV}$	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	—

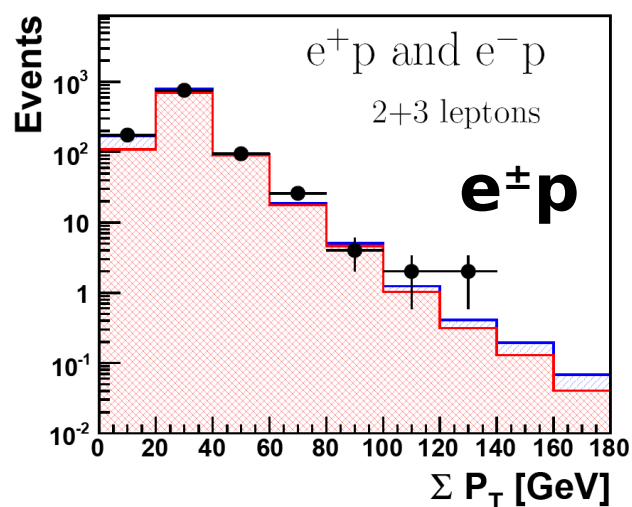
- All events at high inv. mass are from e^+p data

Transverse Momentum Sums in e^+p / e^-p

H1 Multi-lepton analysis HERA I+II (459 pb^{-1})



● H1 Data (prelim.)
 DIS+Compton
 Pair Production



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

$\Sigma E_T > 100 \text{ GeV}$				
Data sample	Data	SM	Pair Production	NC-DIS + Compton
e^+p (286 pb^{-1})	4	1.2 ± 0.2	1.0 ± 0.2	0.2 ± 0.1
e^-p (173 pb^{-1})	0	0.8 ± 0.2	0.6 ± 0.2	0.2 ± 0.1
All (459 pb^{-1})	4	1.9 ± 0.4	1.5 ± 0.3	0.4 ± 0.1

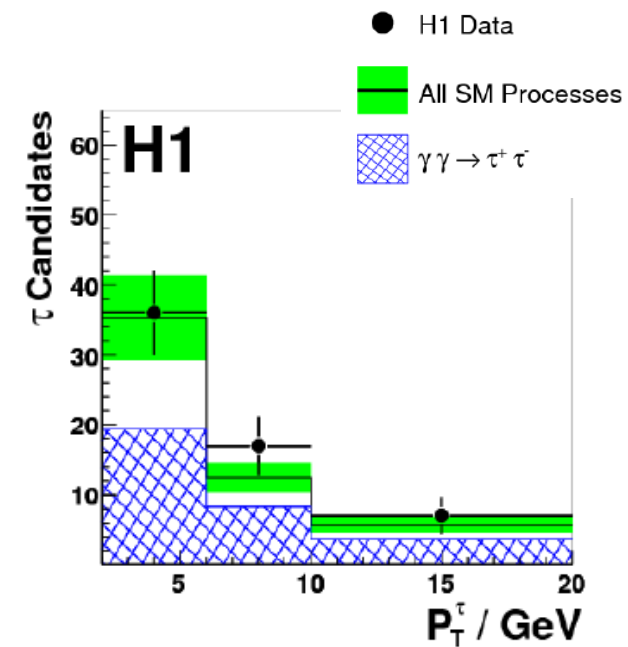
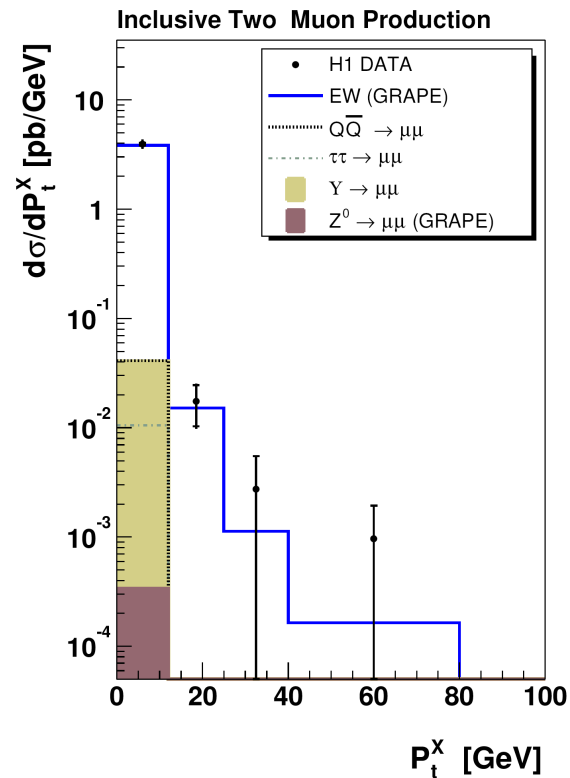
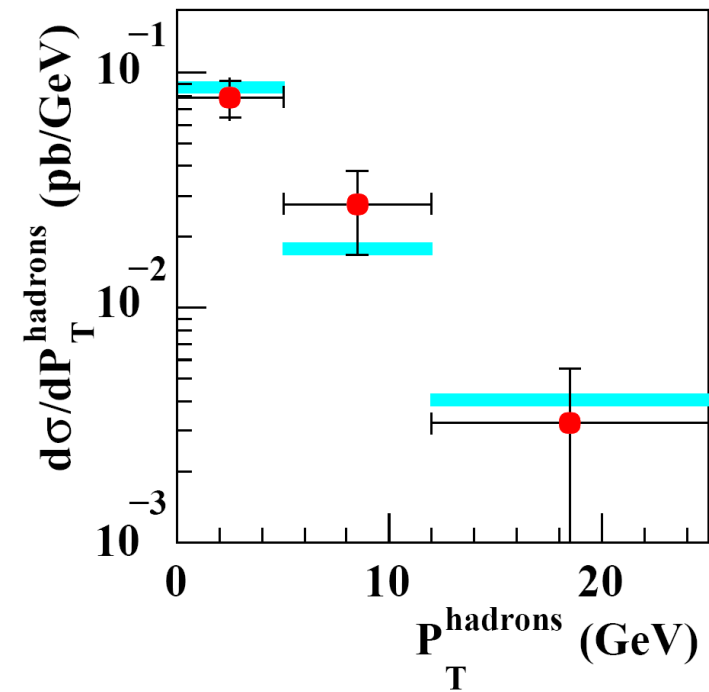
- „Hardness Scale“
- Good agreement with SM
- All 4 events at $\Sigma P_T > 100 \text{ GeV}$ in e^+p

Summary

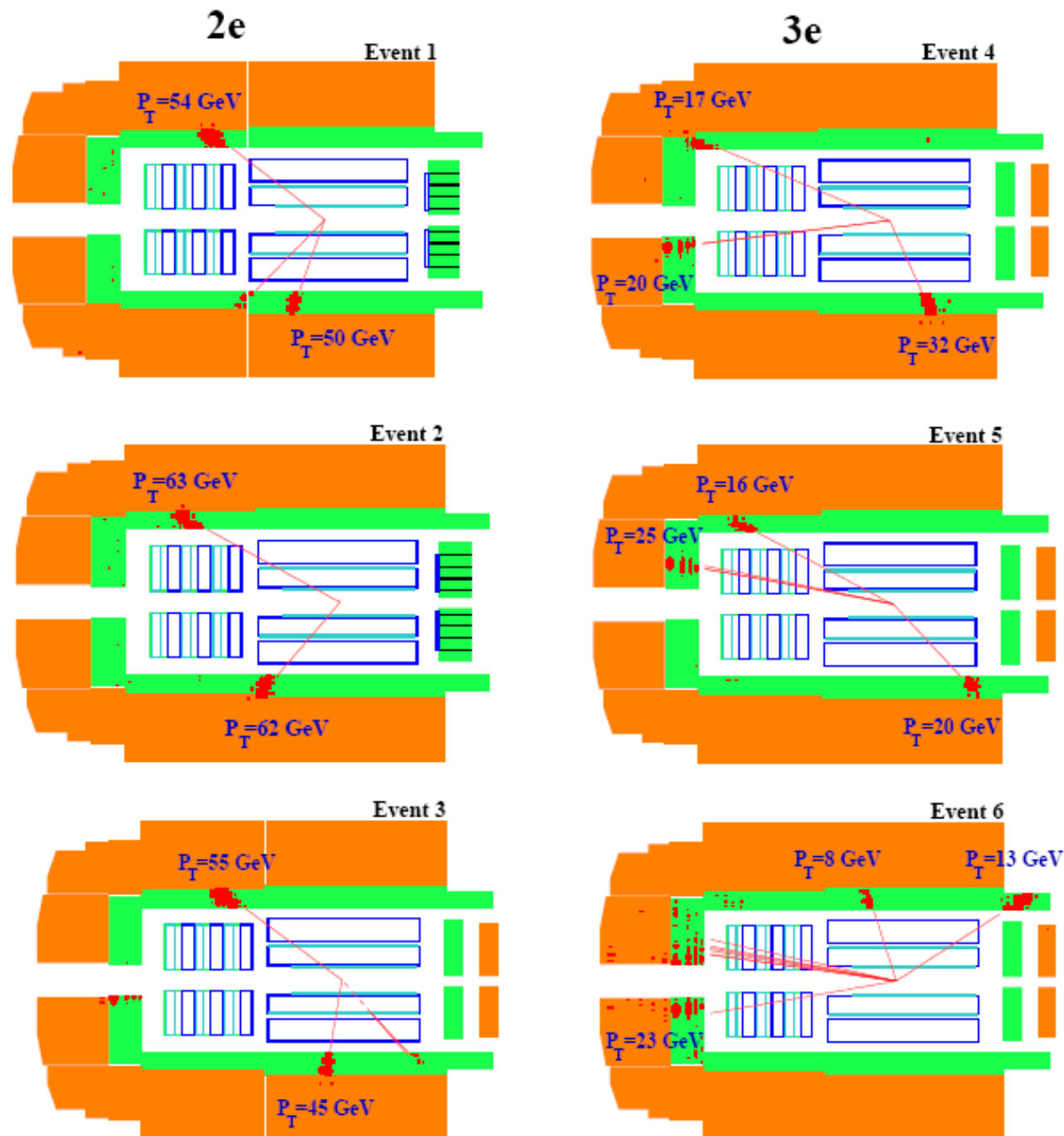
- Di- and trilepton topologies with high P_T electrons and muons observed in full H1 HE dataset: $459 \text{ pb}^{-1} \text{ ep coll.}$
- General good agreement with the SM prediction
- 4 events with a scalar sum of $P_T > 100 \text{ GeV}$
where 1.9 ± 0.4 are expected
(In e^+p collisions only where expectation 1.2 ± 0.2)

backup

$\gamma\gamma \rightarrow \ell\ell$ Crosssections

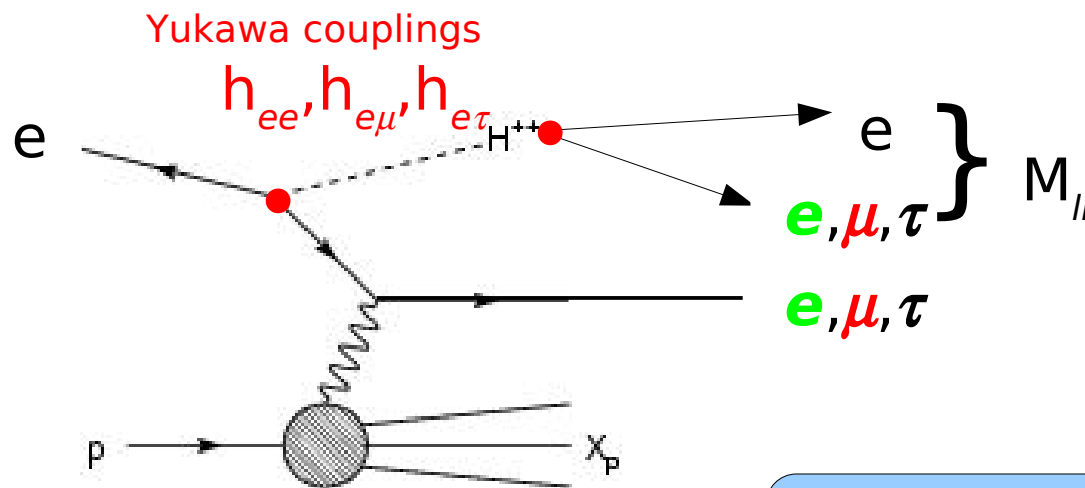


HERA-1 Events at $M_{12} > 100$ GeV



Search for Doubly Charged Higgs $H^{\pm\pm}$

- Occur in extensions of the Higgs sector with H triplet(s) with $Y \neq 0$
- Explanation for events at high $M_{ee} / \sum P_T$ observed in HERA-I ee sample?



Selection

- Sample: HERA-I (118 pb^{-1})
 - $ee, e\mu$ (based on Multi-Leptons)
 - $e\tau$ with $\tau \rightarrow e, \mu, \text{hadrons}$
- 2 high- P_T leptons with same charge as beam lepton
- Reconstruct invariant mass M_{\parallel} of Higgs candidate

$H^{\pm\pm}$ Analysis Results

At $M_{\parallel} > 65 \text{ GeV}$:

ee 3 obs. / 2.45 ± 0.11 exp.

$e\mu$ 1 obs. / 4.17 ± 0.44 exp.

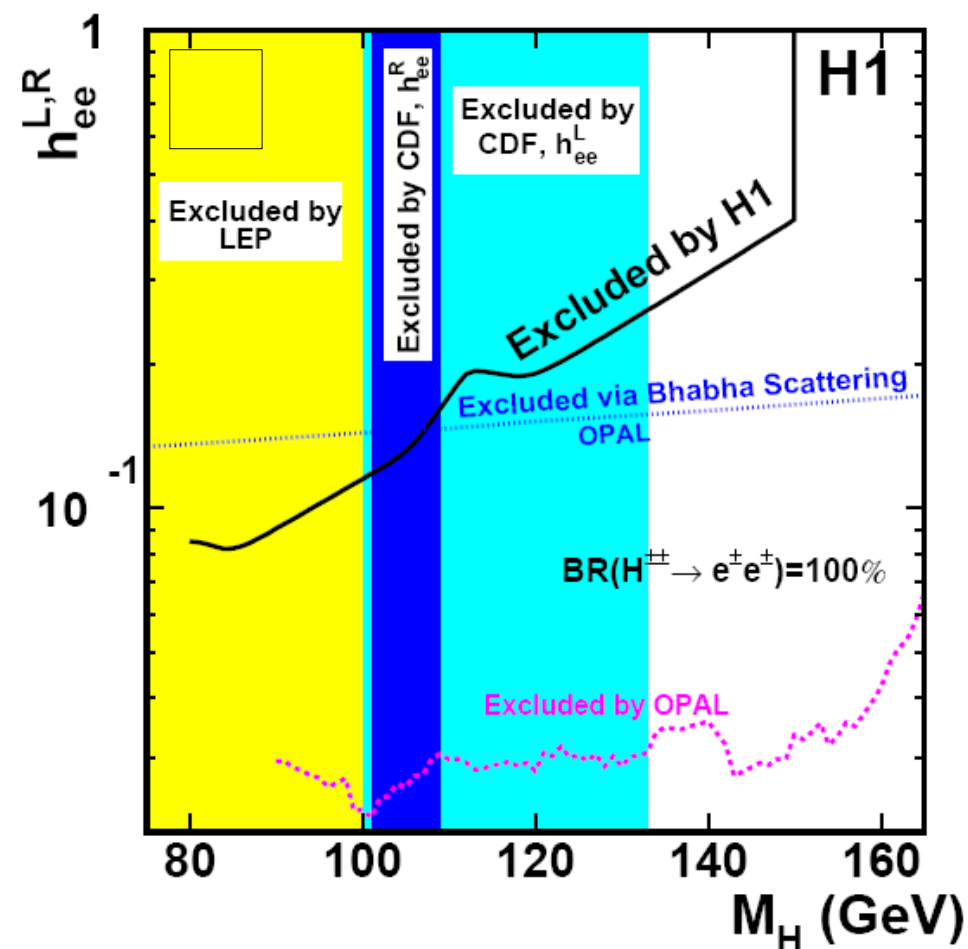
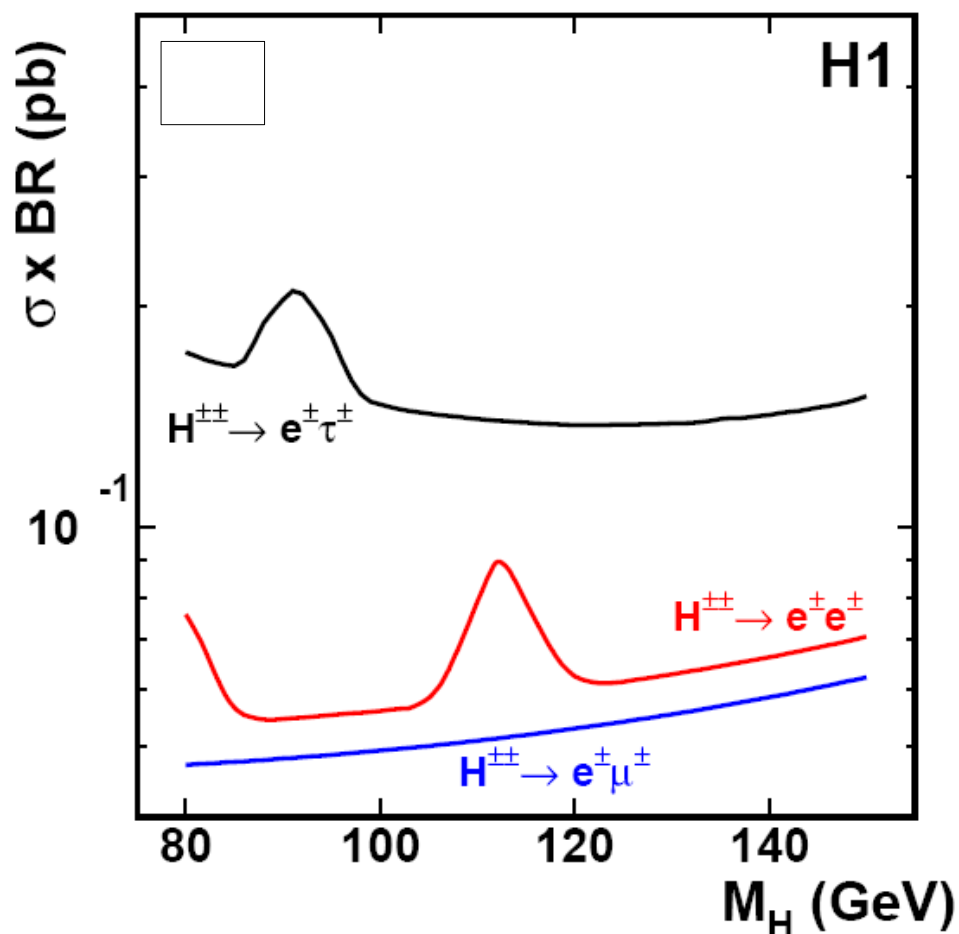
$e\tau$ 1 obs. / 2.07 ± 0.54 exp.

At $M_{\parallel} > 100 \text{ GeV}$:

Only 1 ee event survives

No excess – set limits

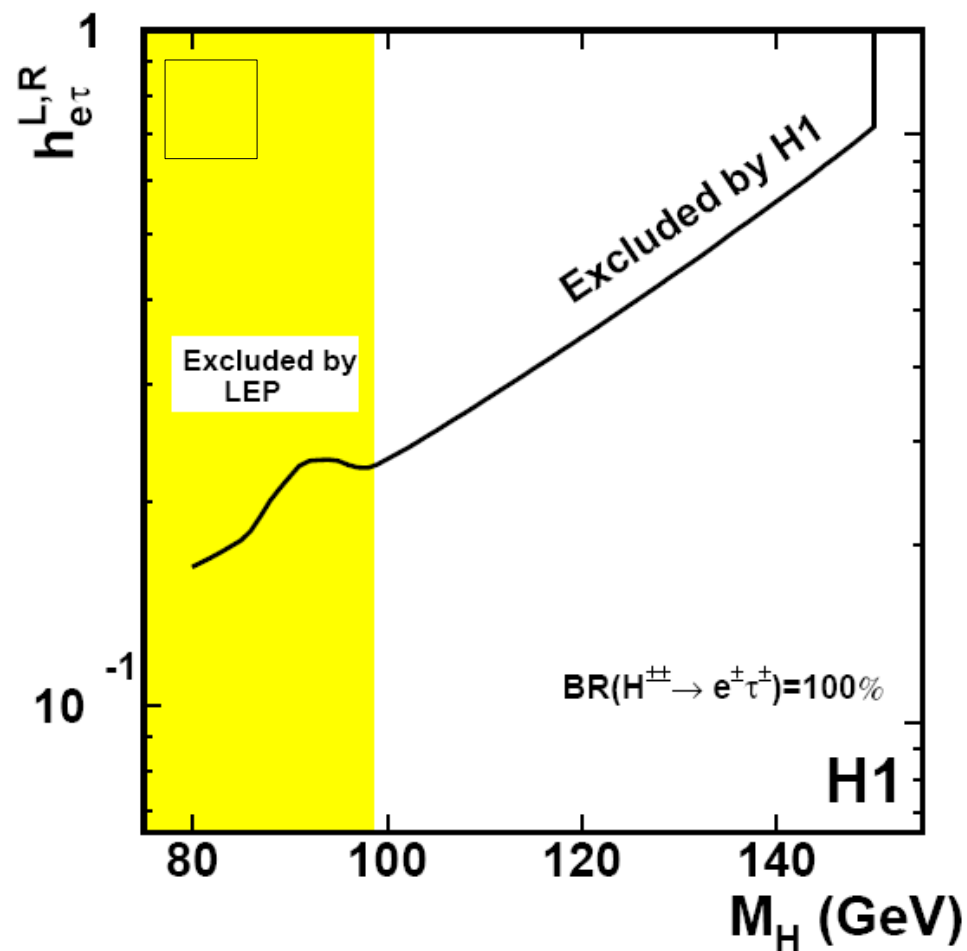
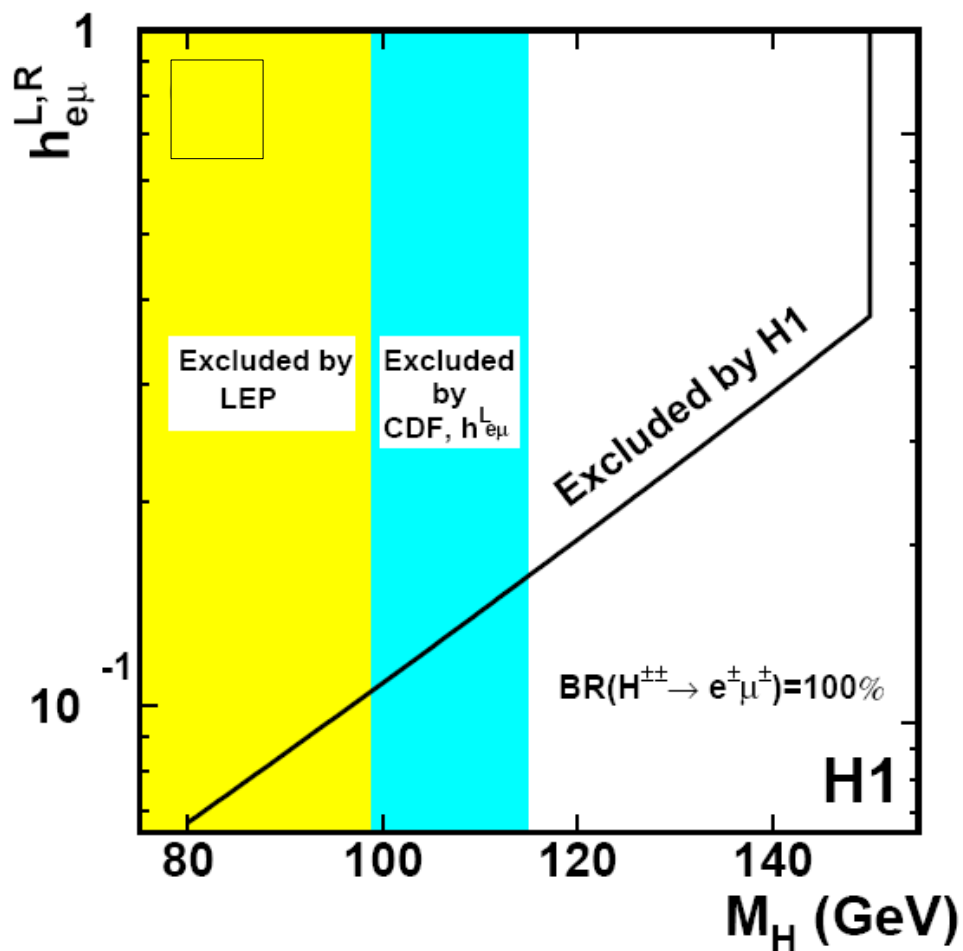
$H^{\pm\pm}$ Limits for $\sigma \times Br$ and dominating h_{ee} coupling



- Upper limits for $H^{\pm\pm}$ production at 95% C.L. derived by modified frequentist method
- Best sensitivity: $\sigma \times Br(h_{e\mu}) < 0.05$ pb

- $H^{\pm\pm}$ Interpretation for ee excess observed in HERA-I at H1 ruled out by **OPAL** ($H^{\pm\pm}$ Single Production)
- LEP, TeVatron: $H^{\pm\pm}$ Pair Production

$H^{\pm\pm}$ Limits for dominating $h_{e\mu}$ or $h_{e\tau}$ coupling



- For $h_{e\mu} = 0.3$ (em. strength): $M_{H^{\pm\pm}} > 141$ GeV
- For $h_{e\tau} = 0.3$: $M_{H^{\pm\pm}} > 112$ GeV
- HERA limits extend beyond LEP, TeVatron reach

Tau Pair Events



Measurement of $\sigma(\gamma\gamma \rightarrow \tau\tau)$

(HERA-I $e^\pm p$, 118 pb^{-1})

- Final states: $e\text{-}\mu$, $e\text{-jet}$, $\mu\text{-jet}$, jet-jet
- vis. $P_T > 2 \text{ GeV}$, $20^\circ < \theta < 140^\circ$

30 obs. / $27.1 \pm 4.1 \text{ exp.}$ ($\sim 60\% \tau\tau$)

$$\sigma_{\text{measured}}^{\tau\tau} = 13.6 \pm 5.7 \text{ pb}$$

$$\sigma_{\text{expected}}^{\tau\tau} = 11.2 \pm 0.3 \text{ pb}$$

