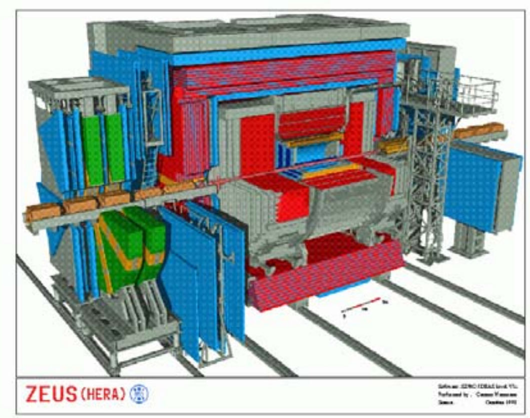
Multi-lepton production at HERA

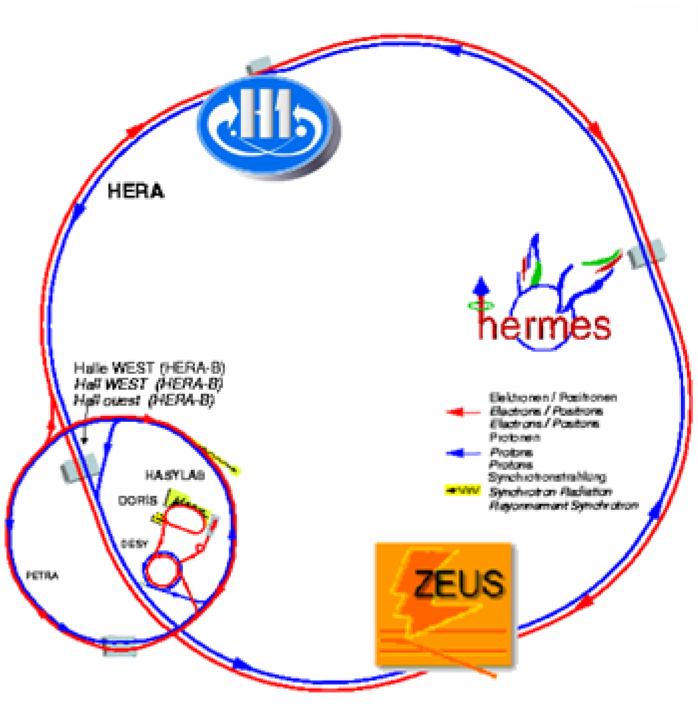
-Using ZEUS detector



University of Tokyo
Nao Okazaki

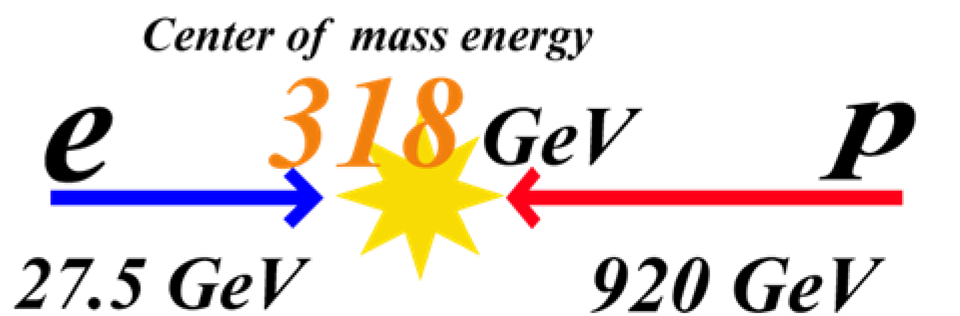
Hadron Electron Ring Accelerator

HERA



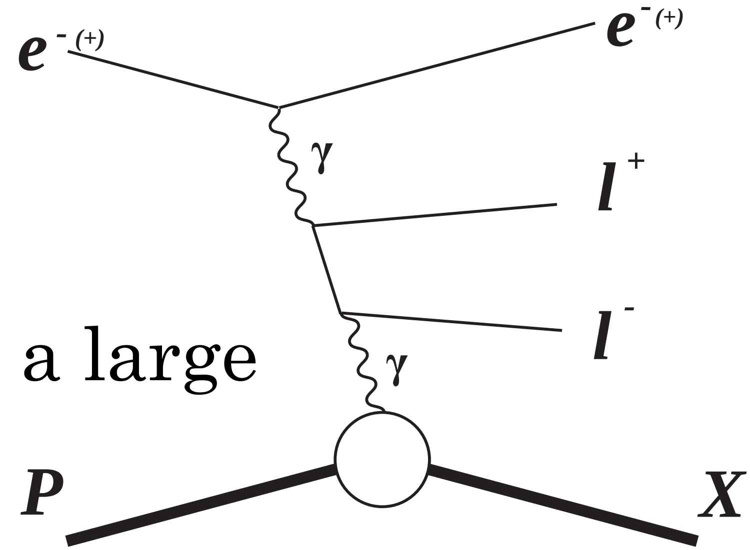
HERA is the only eletron-proton collider in the world.

<u>**large center of mass energy**</u>



Multi-lepton production at HERA

◆Multi-lepton production in $e^{\pm}p$ collision proceeds dominantly via Bethe-Heitler process.



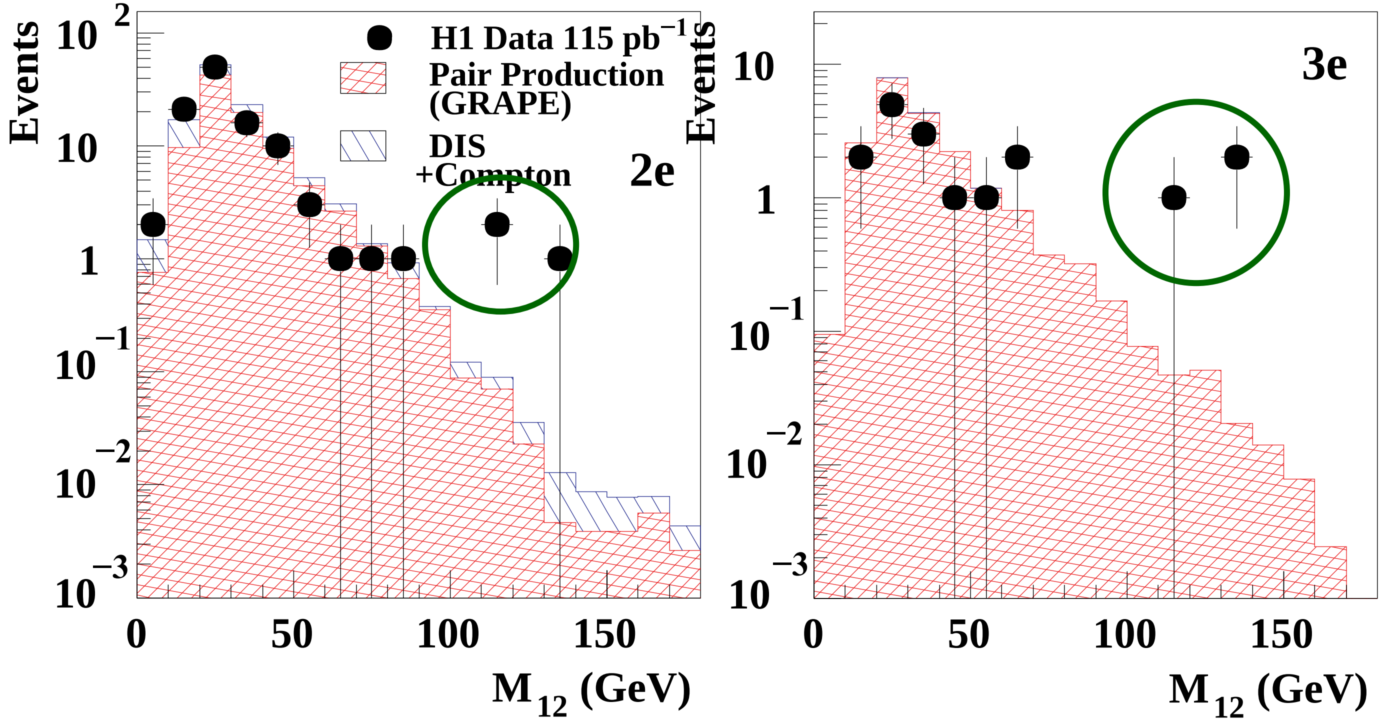
◆At HERA, we can explore up to a large invariant mass , ~150 GeV.

-May be sensitive to new physics.

H1 reported an excess in HERA I data

◆Using 115 pb^{-1} HERA I data

Multi-electron



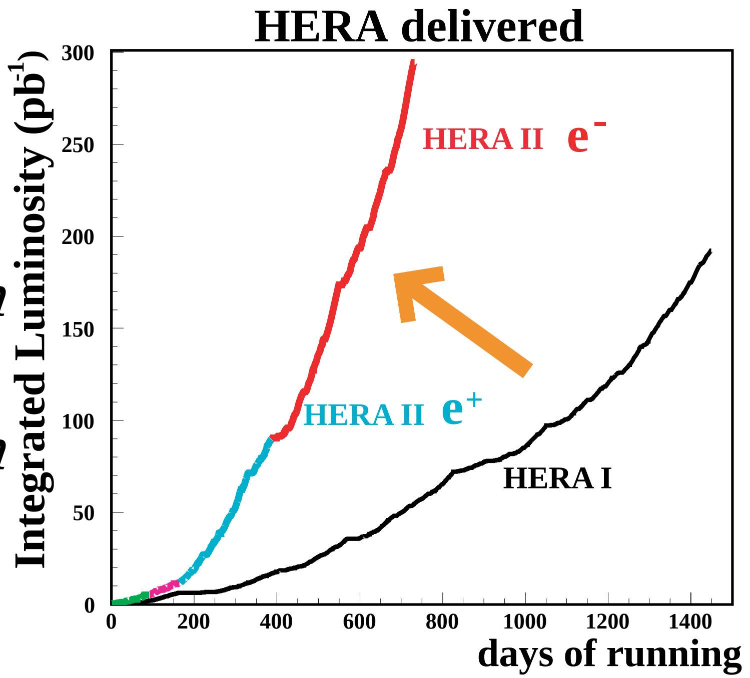
* Eur.Phys.J.C31 (2003)17-29

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.)

In ZEUS analysis

◆Using HERA I ,II data.

◆Multi-electron and di-tau productions are searched for.



Multi-electron

Data; HERA I (1996-2000)

121 pb^{-1} $e^{\pm}p$ *run*

HERA II (2003-05)

175 pb^{-1} $e^{\pm}p$ *run*

Total

296 pb^{-1}

Di-tau

Data; HERA II (2005)

135 pb^{-1} e^{-} *p run*

<u>Running period;</u>

HERA I 1992-2000

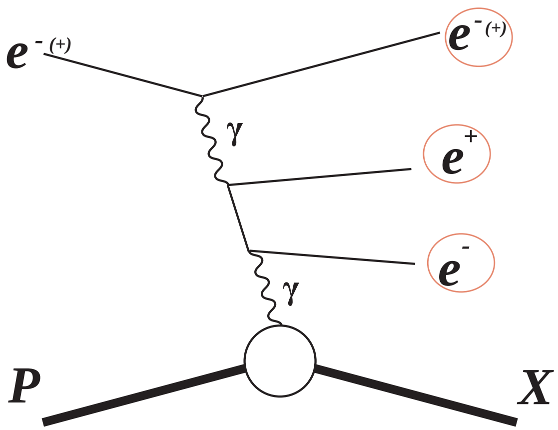
HERA II 2003-2006

-luminosity upgrade

(-longitudinally polarized lepton beam)

Multi-electrons

Event topology ; e,e,(e)



<u>Signal;</u> (simulated by GRAPE)

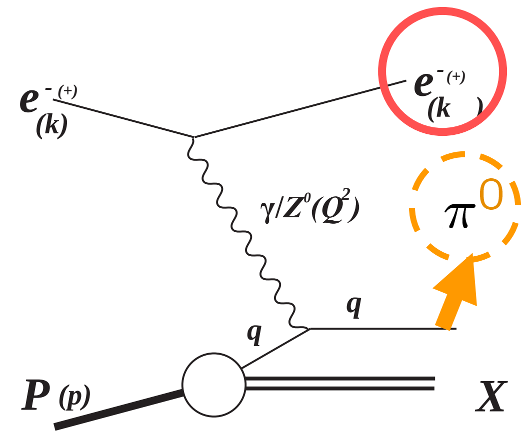
・Electrons from pair production and a scattered electron.

・ One electron is often out of detector acceptance.

<u>Background;</u>

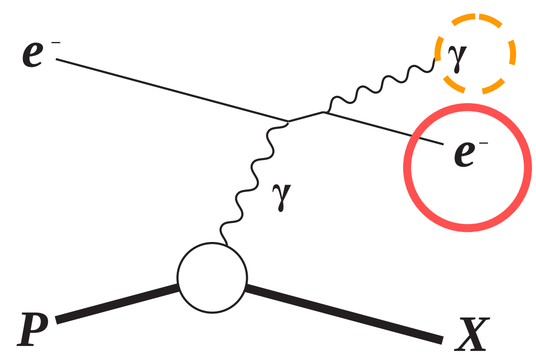
◆Neutral Current Deep Inelastic Scattering (NC DIS) (simulated by DJANGO)

・For example, π^0 in jets is misidentified as an electron.



◆QED Compton (QEDC) (simulated by COMPTON 2.0)

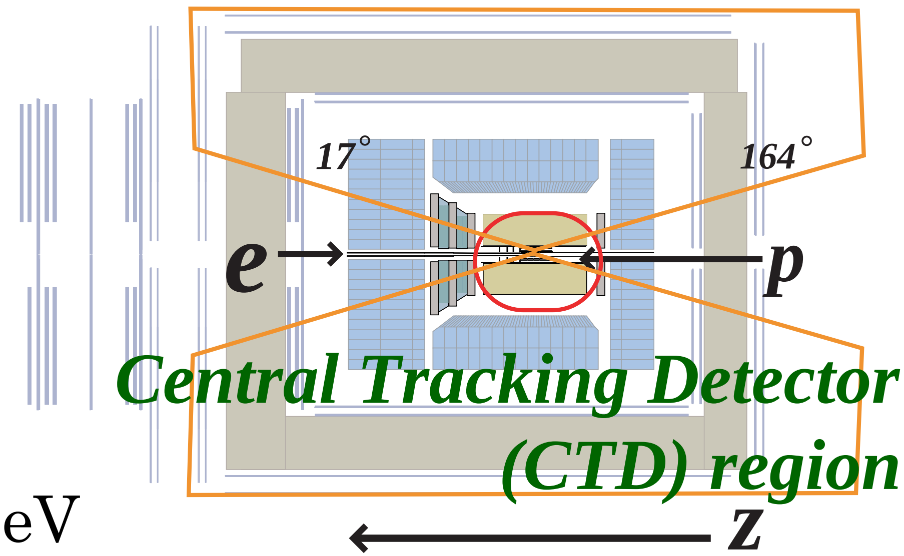
・For example, a photon is misidentified as an electron



Event selection

◆2 or more isolated electromagnetic (EM) clusters in the calorimeter.

◆At least 2 EM clusters are within the Central Tracking region and are associated with a track of CTD.



◆Highest Pt electron,$P_{T,1}$ >10GeV

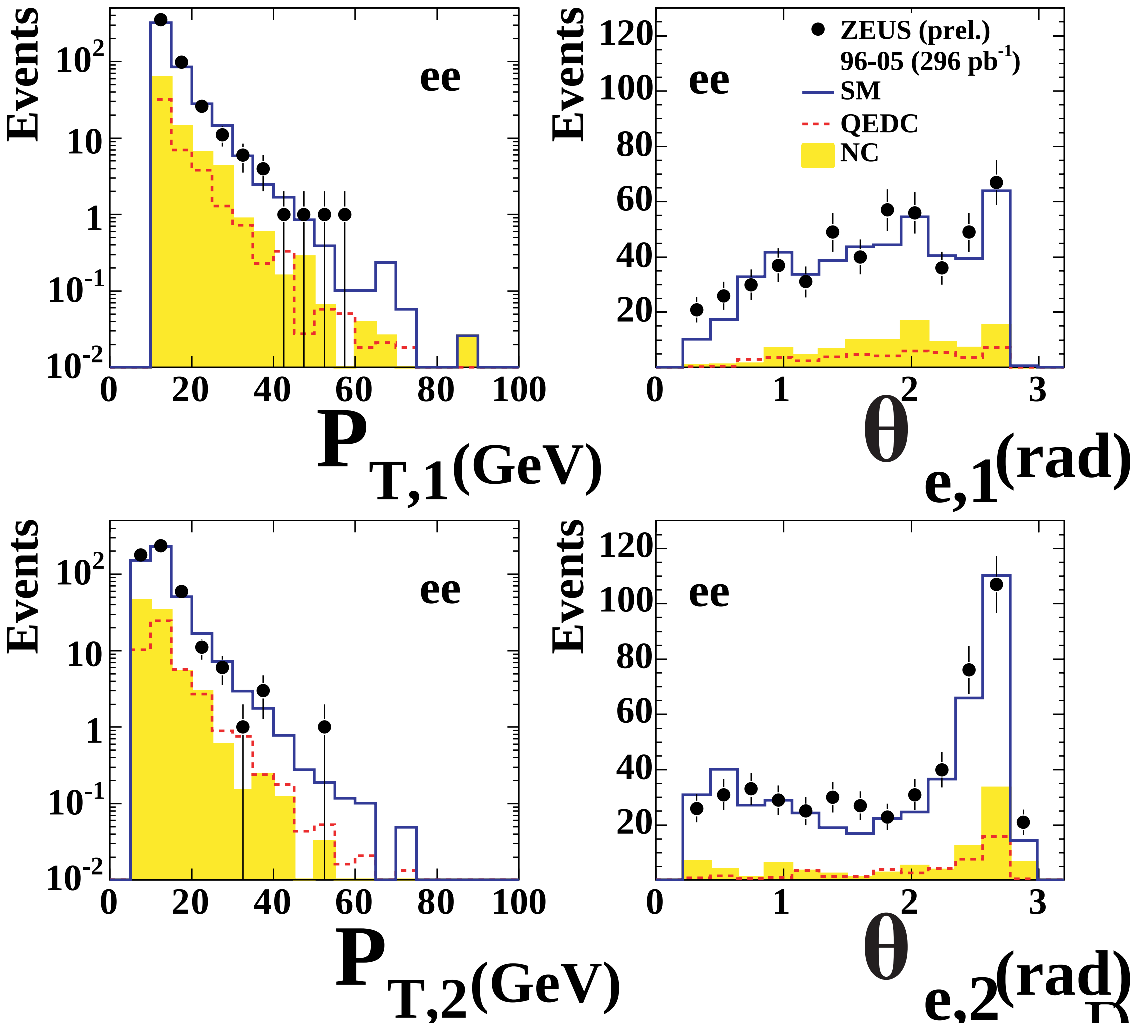
◆Second highest Pt electron,$P_{T,2}$ >5GeV

◆Z position of the primary vertex, $|Z_{vertex}| < 50$cm

Multi-electron (2/7)

Final sample distribution (Pt^e *and* θ^e)

ZEUS

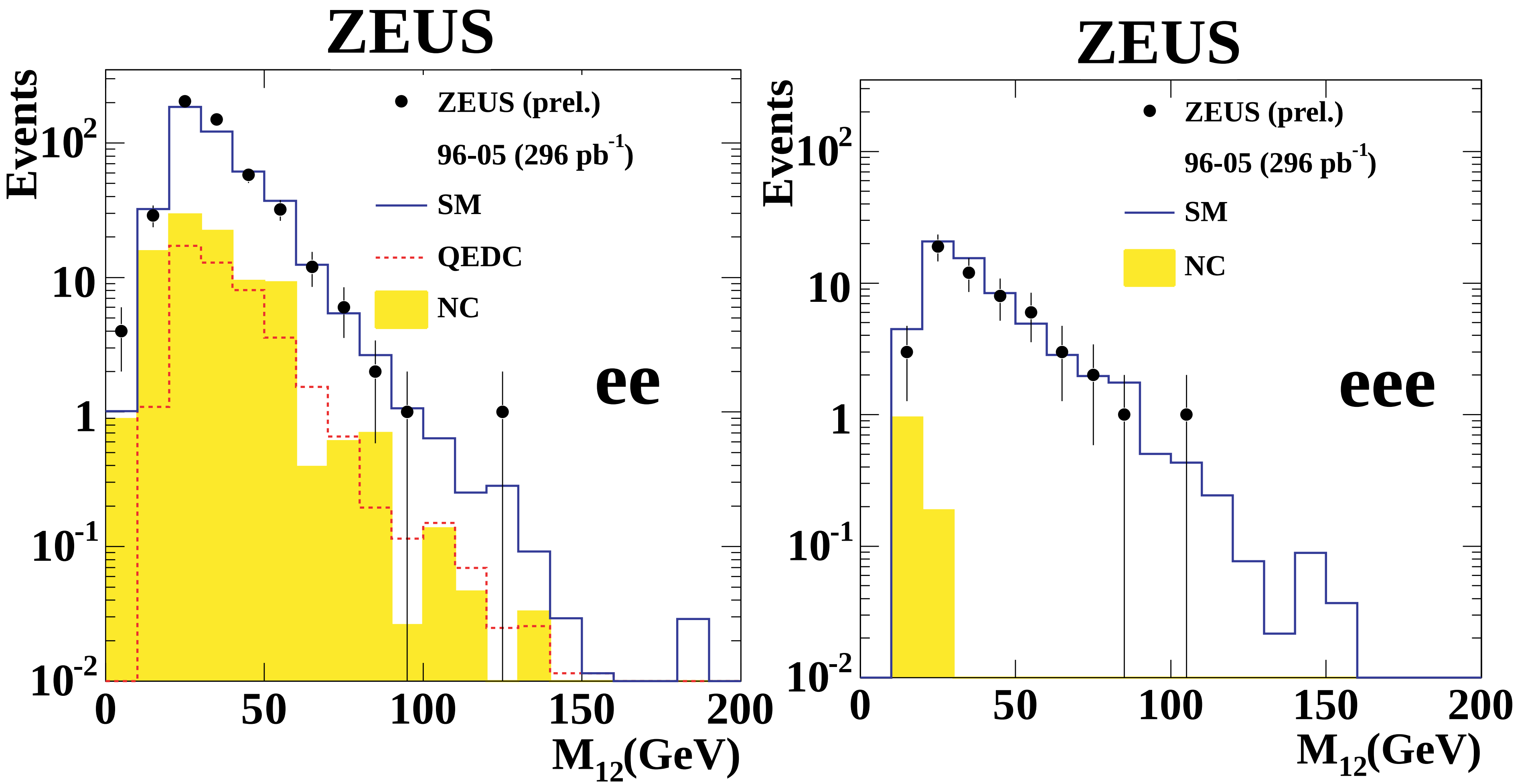


Highest Pt electron

Second highest Pt electron

Data is in good agreement with MC.

Invariant mass of e_1,e_2



- The SM gives a good description of the measurements.
- One event is found at $M_{1,2} > 100$ GeV.

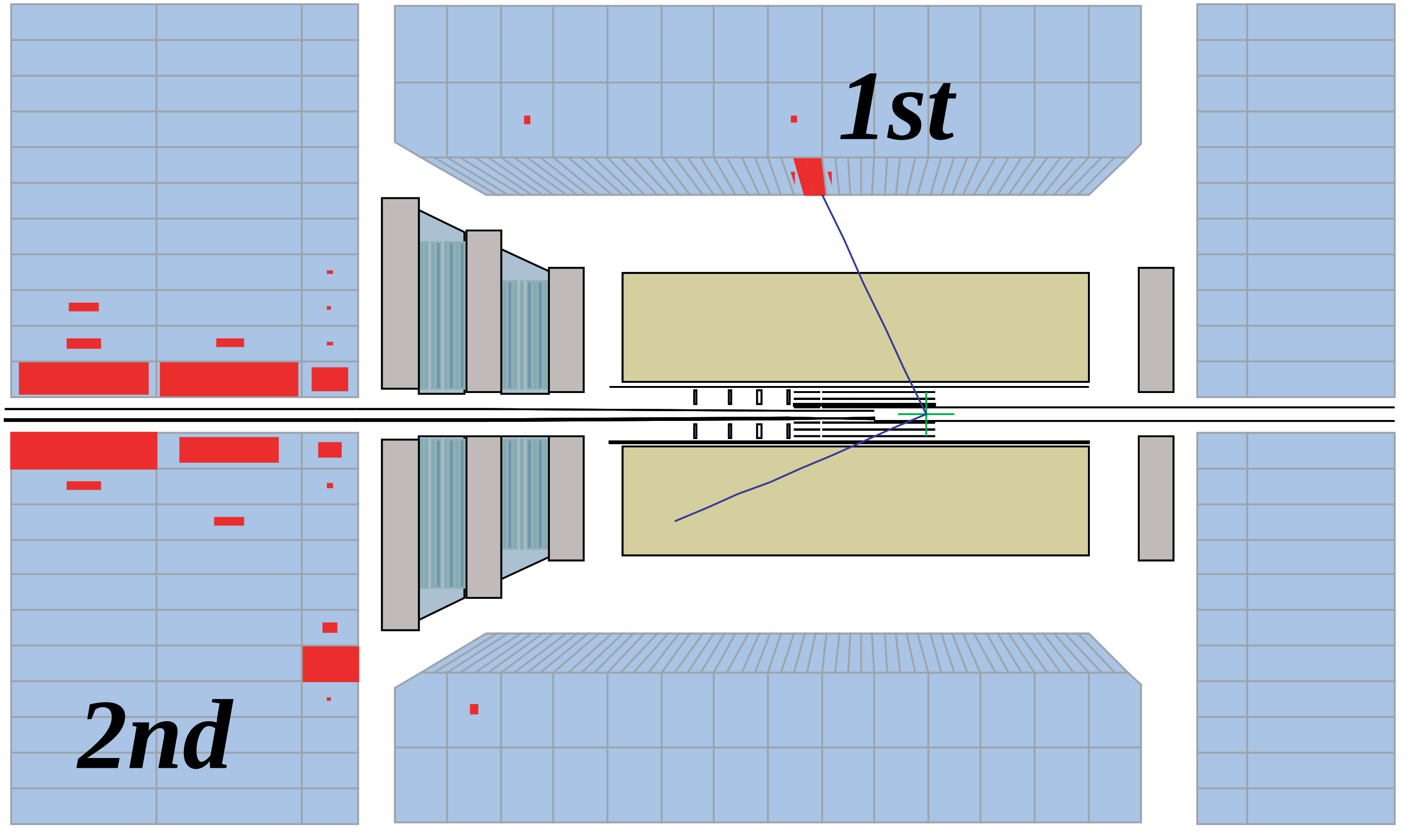
Event yields at large $M_{1,2}$

Selection	Data	SM total	Background
$e^{\pm} 296 pb^{-1}$			
2e $M_{1,2} > 50 GeV$	53	67 ± 7.1	19 ± 2.6
$> 100 GeV$	1	1.5 ± 0.5	0.6 ± 0.3
3e $M_{1,2} > 50 GeV$	12	15 ± 1.3	< 0.5
$> 100 GeV$	1	$0.8^{+0.3}_{-0.04}$	< 0.4

The measured event yields agree with the SM predictions.

Event displays

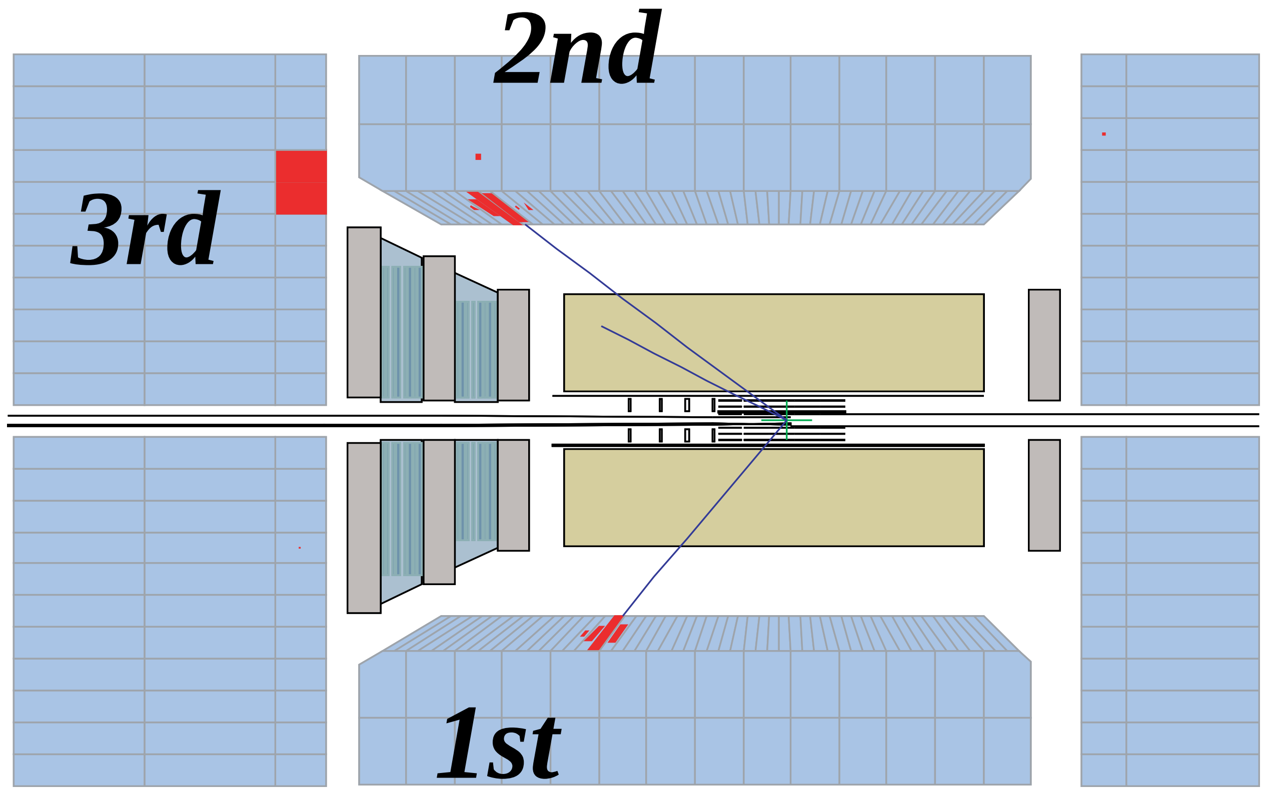
The highest M_{12} event of the 2e event.



$$M_{1,2} = 123GeV$$

$$Pt^e_1 = 55GeV, \; Pt^e_2 = 54GeV$$

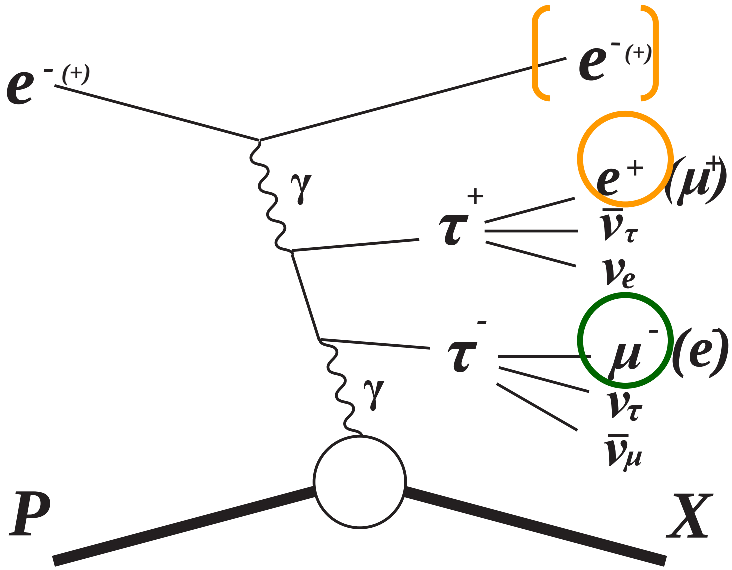
The highest M_{12} event of the 3e event.



$$M_{1,2} = 103GeV$$
$$Pt_1^e = 62GeV$$
$$Pt_2^e = 47GeV$$
$$Pt_3^e = 35GeV$$

Di-tau

Event topology ; e, μ



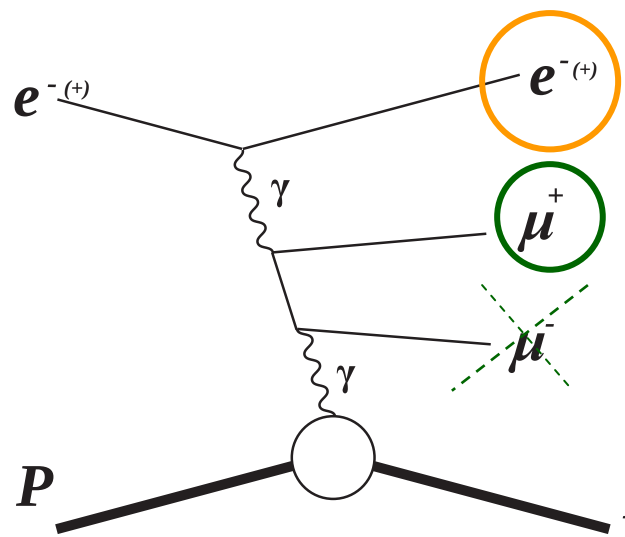
Signal;

In this analysis, events in which one tau decays to an electron and the other decays to a muon are searched for.

$$\begin{cases} \tau \rightarrow e, \nu_e, \nu_\tau \\ \tau \rightarrow \mu, \nu_\mu . \nu_\tau \end{cases}$$

Background;

Di-muon events in which one muon escapes detection, for example, by passing through beam pipe.



Event selection

◆The proton is scattered elastically.

- Energy deposit around beam pipe < 1GeV
- 0< Number of tracks <4

◆To be with one muon and one or more electrons.

Electron identification;

- Energy > 4GeV
- θ e < 2.6 rad

Muon identification;

- By combined information from the muon detectors, the calorimeters, the tracking detectors.
- Pt > 2 *GeV*

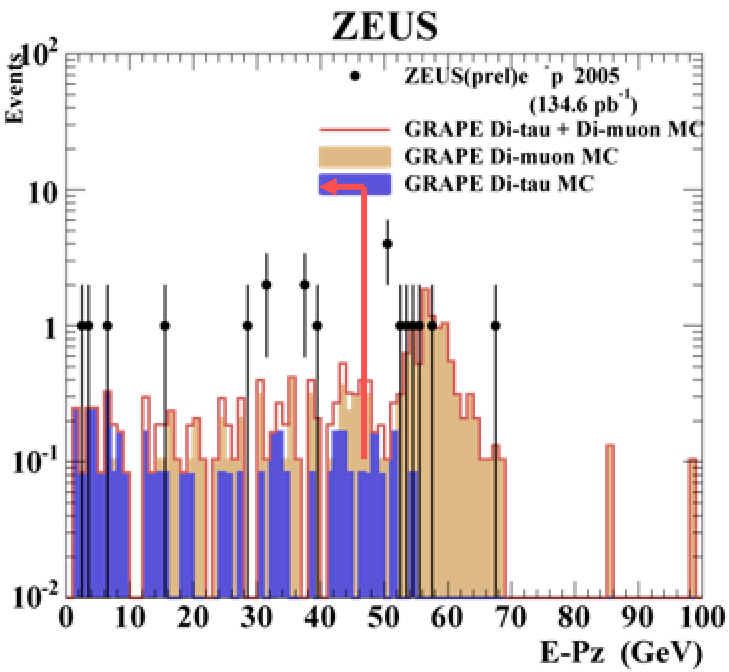
-MC expectation-

Signal	4.1	events
Di-muon background	15.7	events

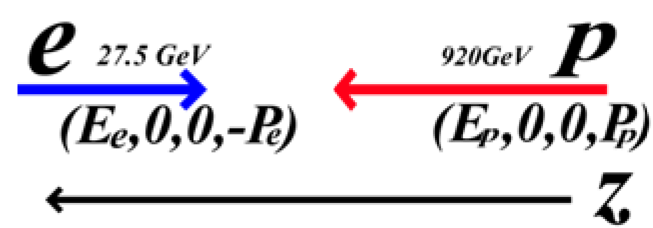
Need further di-muon background rejection

Background rejection

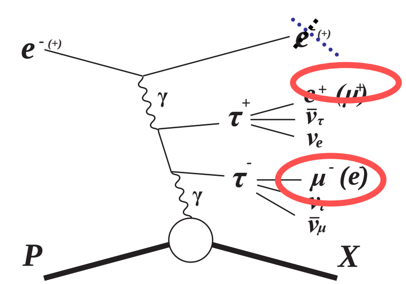
◆ $\text{E-Pz} = (\text{E-Pz})_{\text{CAL}} + (\text{E-Pz})_{\text{Muon}} < 45\ \text{GeV}$



E-Pz is conserved to be 55 GeV $(2E_e^{beam})$ unless particles escape in –z direction.



Because a scattered electron often escapes to –z direction in di-tau events, E-Pz becomes lower.

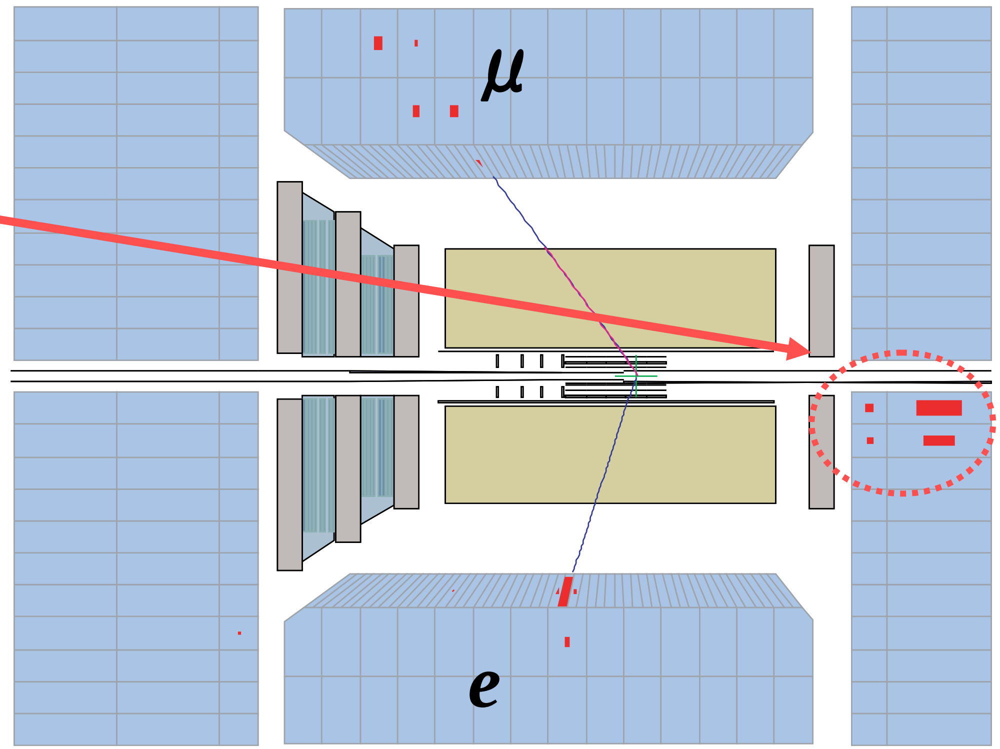


On the other hand as the electron in di-muon events must be a scattered electron, E-Pz peaks at 55GeV.

Background rejection (cont'd)

◆There is no extra muon candidates found by loosen selection criteria.

For example,
a calorimeter energy deposit which is consistent with a Minimum Ionizing Particle. (MIP)



-MC expectation-

Signal	4.1	→	2.0	events
Di-muon background	15.7		<0.2	events

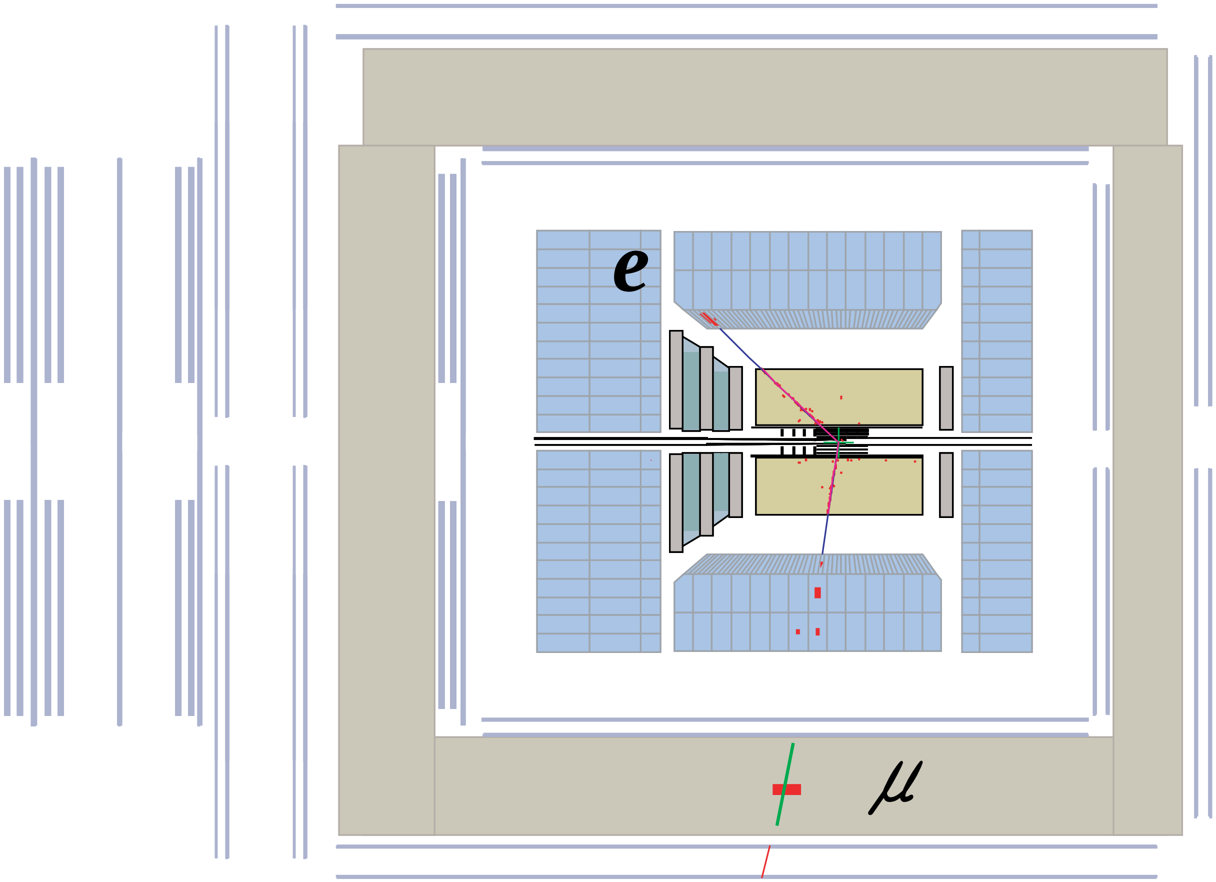
Results

Event yields

Data	2τ(Signal)	2μ(Background)
$e^{-}135pb^{-1}$		
3	2.0 ± 0.8	< 0.2

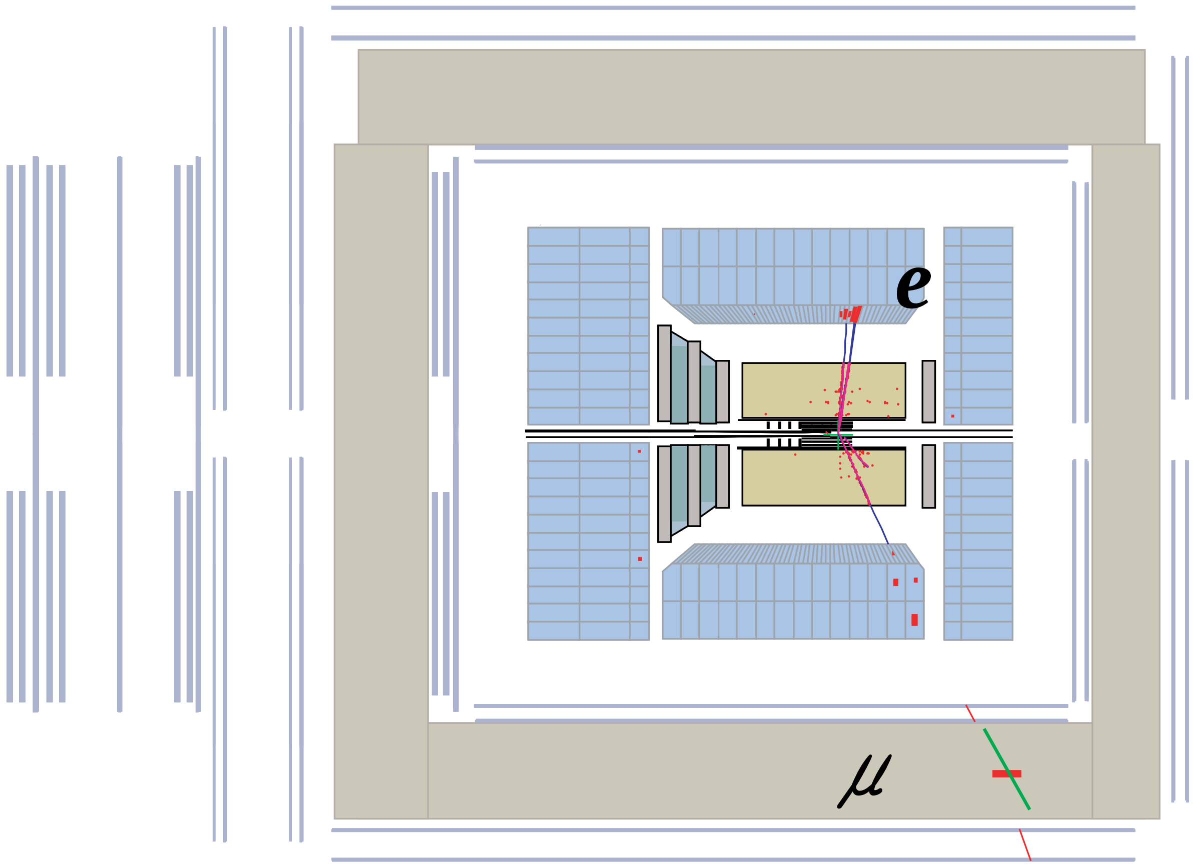
- ◆3 Events are found
- ◆Event yield is consistent with the SM.

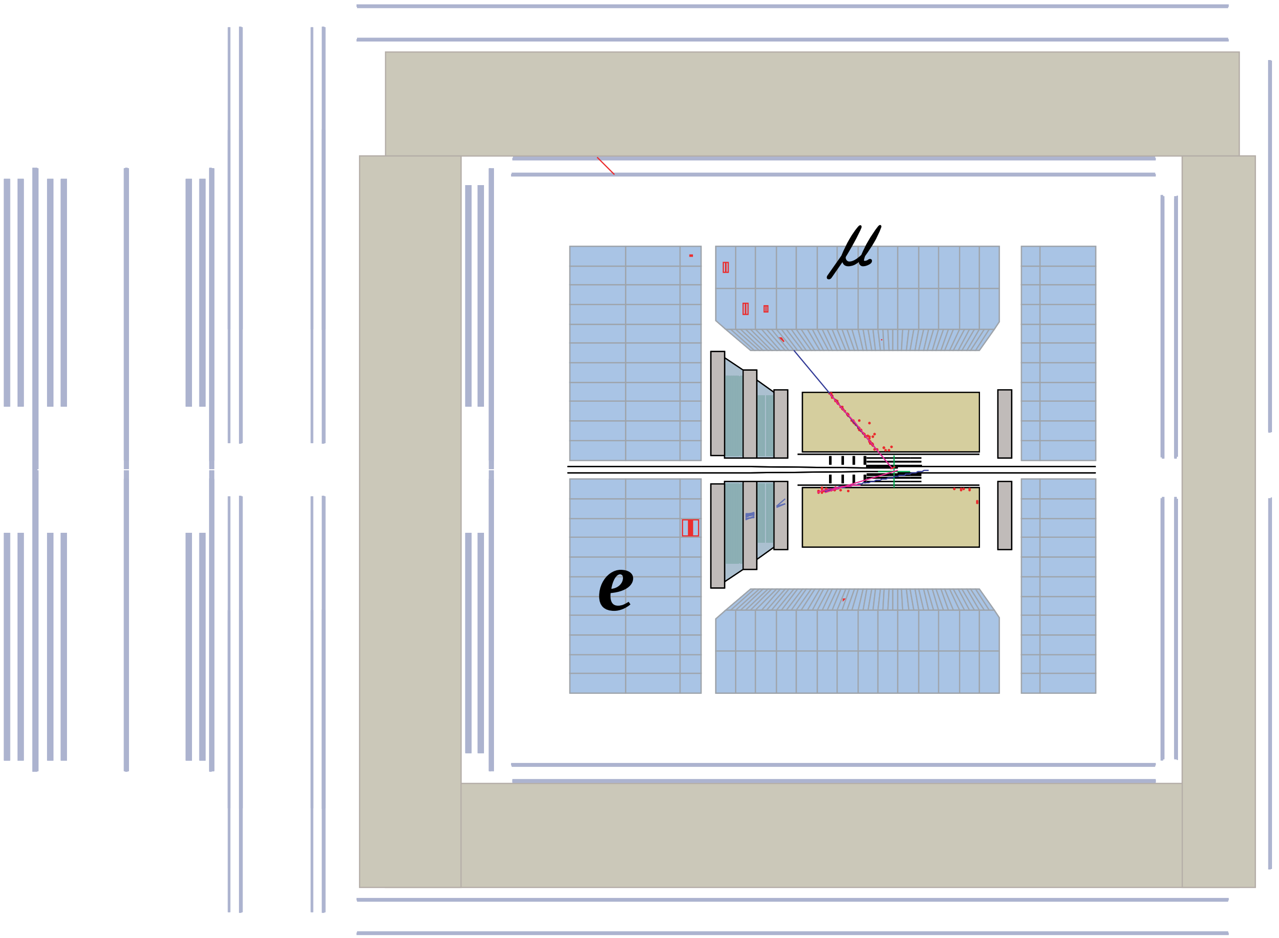
Event displays



$$M_{e,\mu} = 9.8GeV$$
$$Pt_e = 3.5GeV,$$
$$Pt_\mu = 4.9GeV$$

$$M_{e,\mu} = 15.7GeV$$
$$Pt_e = 12.6GeV,$$
$$Pt_\mu = 4.8GeV$$

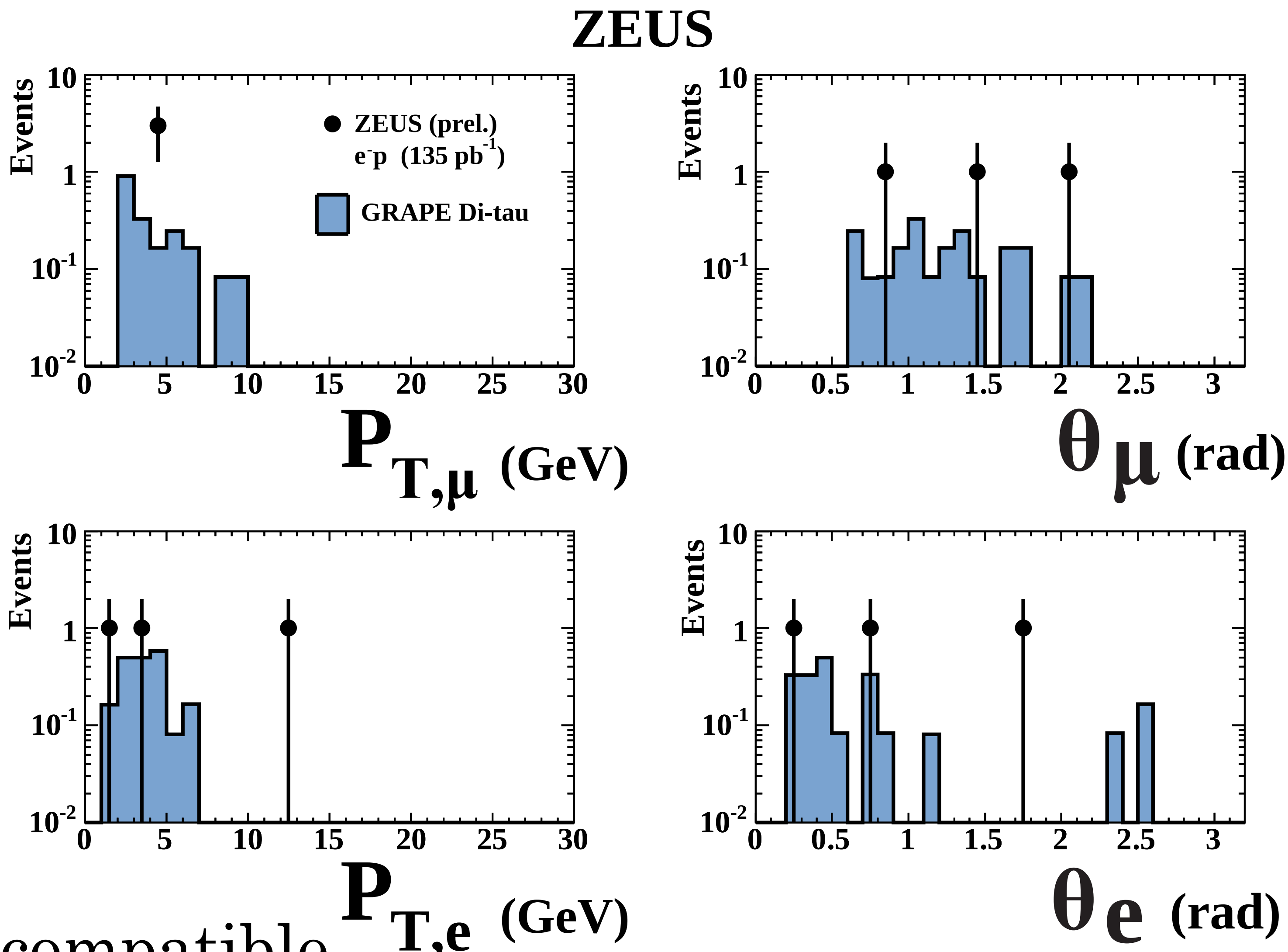




$$M_{e,\mu} = 5.8GeV$$
$$Pt_e = 1.4GeV$$
$$Pt_\mu = 4.2GeV$$

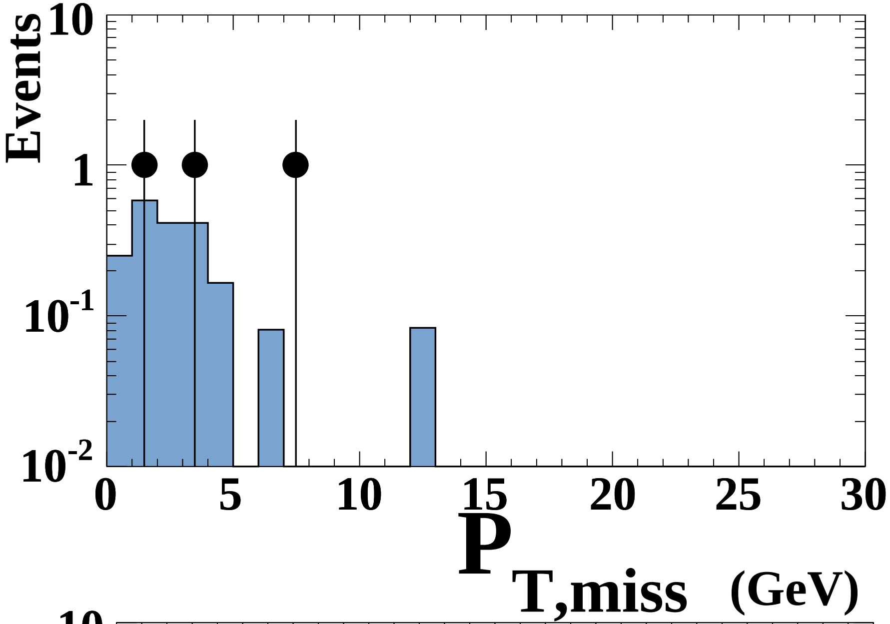
Di-tau (8/10)

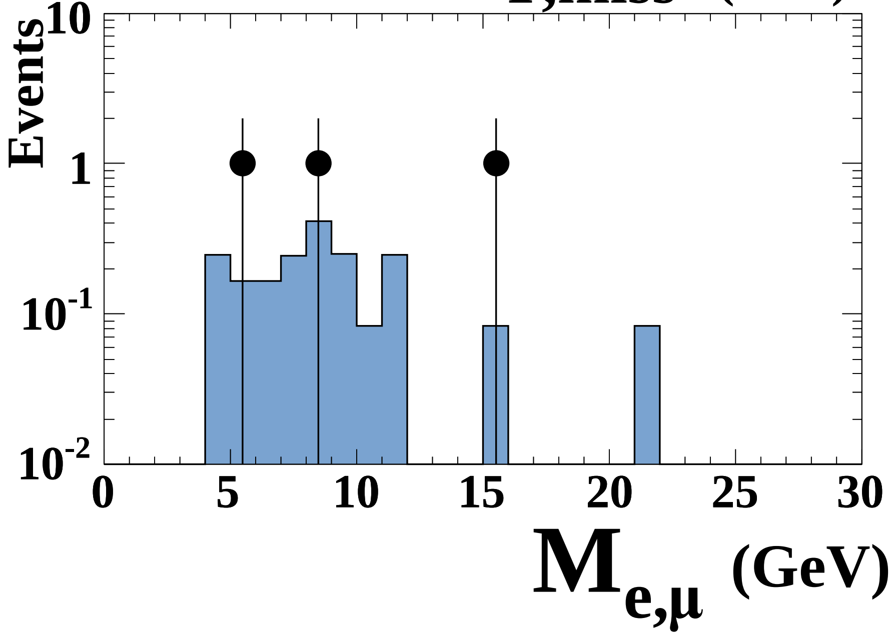
Final sample distributions $(Pt_l \ and \ \theta_l)$



◆Data is compatible with the SM prediction.

Missing Pt, $M_{e,\mu}$





◆Data is compatible with MC.

Summary

◆Multi-electron production has been studied by using 296 pb^{-1} of the HERA I and II $e^{\pm}p$ data.

- One event is found for $M_{1,2}$ > 100 GeV in 2e and 3e sample.
- No excess is observed.

◆The di-tau production has been studied by using 135 pb^{-1} of the HERA II $e^{-}p$ data.

- 3 events are found.

◆The measured event yields are found to be in agreement with the predictions from the SM.

Backup slides

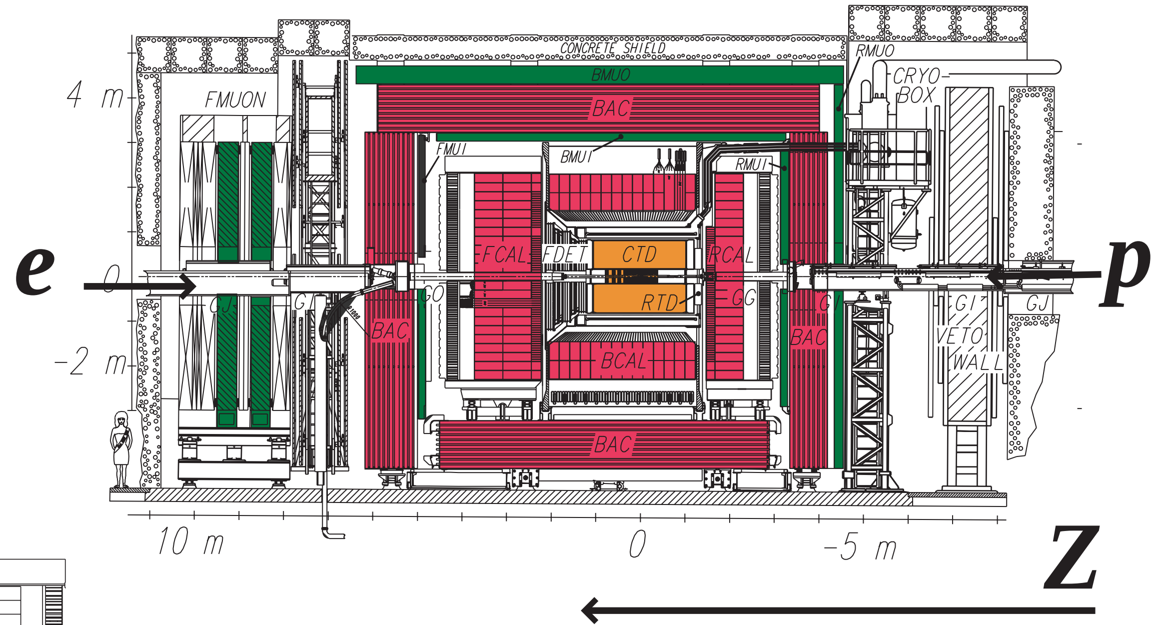
ZEUS detctor

<u>Overview (y-z plane)</u>

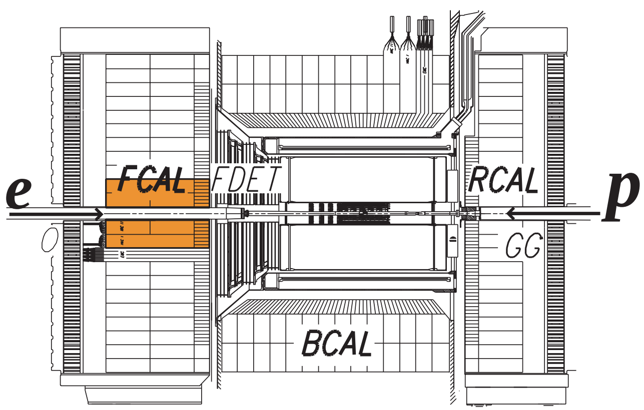
Tracking detectors

Calorimeters

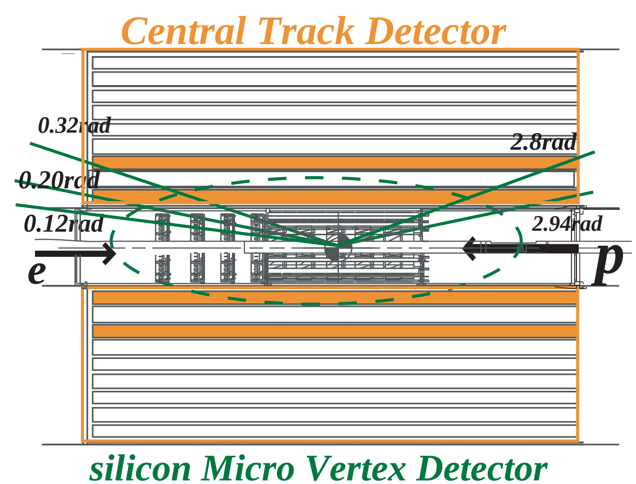
Muon detectors



[FCAL inner ring]



<u>The tracking detectors</u>



Data sample

Multi-electron

Data; HERA I (1996-2000) $17pb^{-1}$ $e^{-}p\ run$ / $104pb^{-1}$ $e^{+}p\ run$ → $121pb^{-1}$

HERA II (2003-05) $135pb^{-1}$ $e^{-}p\ run$ / $40pb^{-1}$ $e^{+}p\ run$ → $175pb^{-1}$

Total $296pb^{-1}$

Di-tau

Data; HERA II (2005) $135pb^{-1}$ $e^{-}p\ run$

High statistics data is used

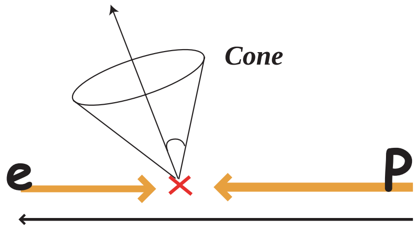
Multi-electron analysis at ZEUS

Electron identification;

◆To be found by an algorithm which combined information from the calorimeter and the tracking detector.

◆Energy not associated with electron in an η - ϕ cone of radius 0.8 <0.3 GeV

- $Forward\ (\theta_e < 17^\circ)$ $Energy > 10GeV$
- $Central\ (17^\circ < \theta_e < 164^\circ)$ $Energy > 10GeV$
  $[CentralTrackingDetector\ region]$
- $Rear\ (\theta_e > 164^\circ)$ $Energy > 5GeV$



$$R = (\Delta\eta^2 + \Delta\phi^2)^{\frac{1}{2}}$$

$$\eta = -ln(tan\frac{\theta}{2})$$

For central region;

DCA between the CAL energy deposit and the track < 8cm

Number of tracks except the matching track in an η - ϕ cone of radius 0.4 = 0

Multi-electron analysis at ZEUS (cont'd)

Systematic uncertainly

- The energy scale varied conservatively by ±2% for the calorimeters.

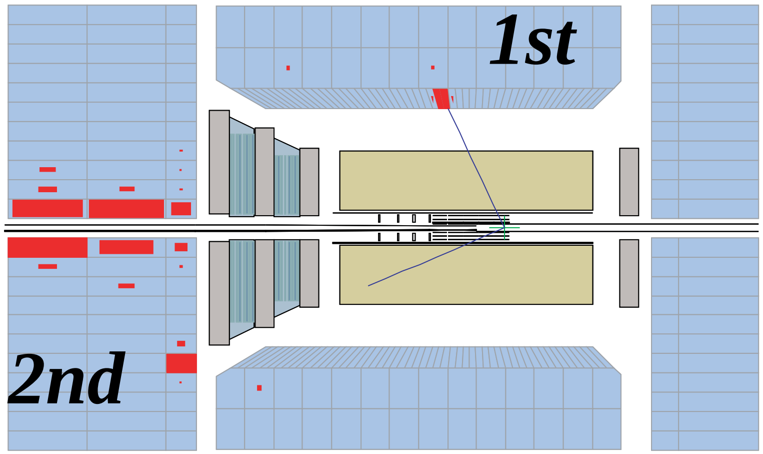
2e;	6.4%(+2%)	-5.2%(-2%)
3e;	5.8%(+2%)	-4.2%(-2%)

Background

	Total background	QED Compton	NC DIS
2e	26.0%	10.7%	15.2%
3e	1.0%	0.27%	1.2%
Total	23%	9.4%	13.4%

Multi-electron analysis at ZEUS (cont'd)

Event displays



The highest Pt electron;

[Theta]	1.2 rad
[Charge]	positive

The 2nd highest Pt electron;

[Theta]	0.5 rad
[Charge]	negative

The highest Pt electron;

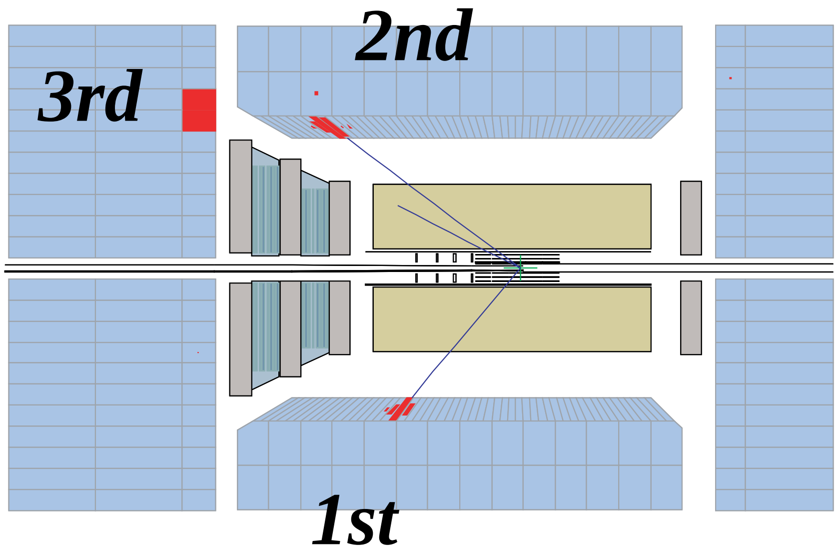
[Theta]	0.10 rad
[Charge]	positive

The 2nd highest Pt electron;

[Theta]	0.76 rad
[Charge]	negative

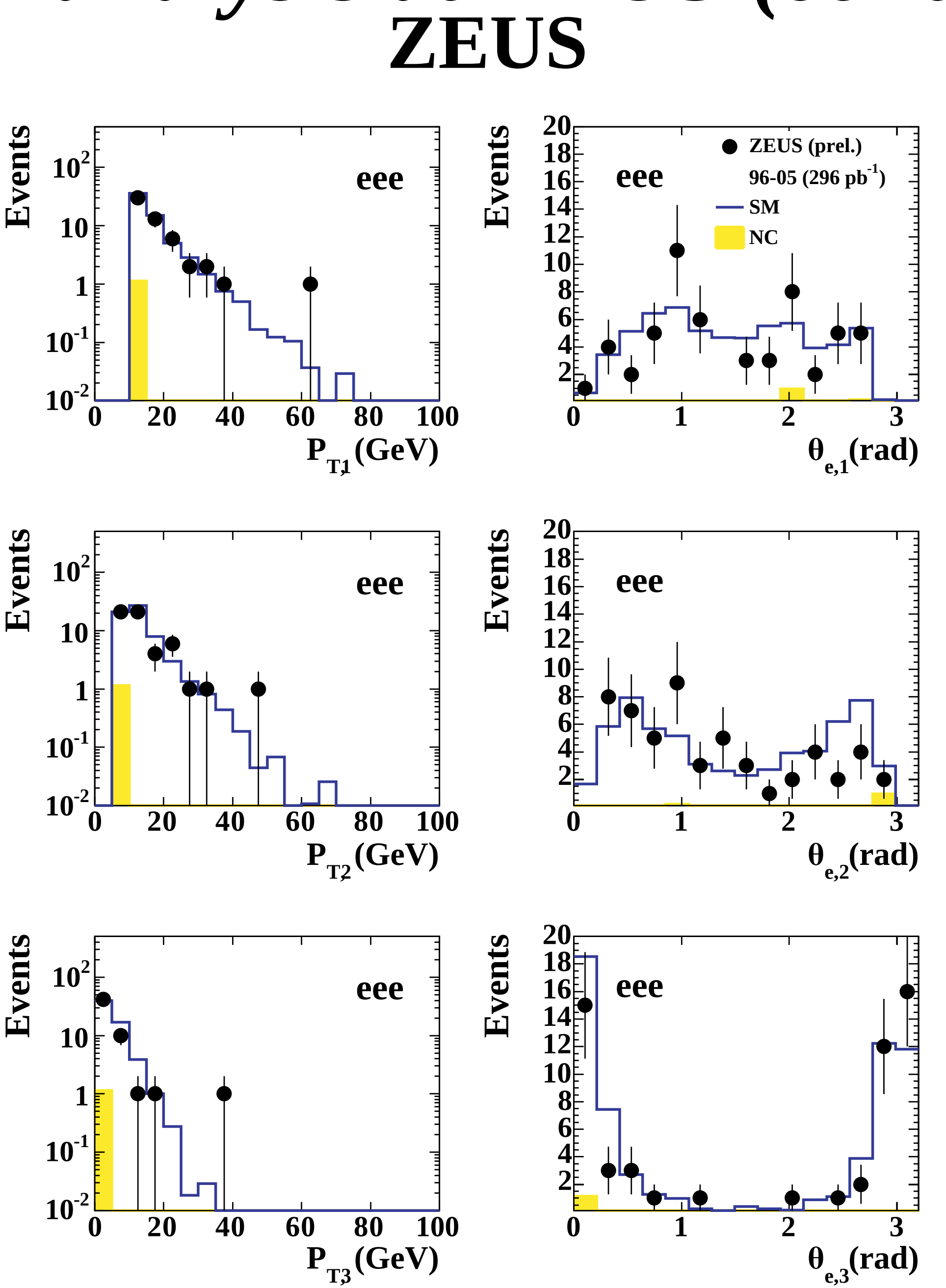
The 3rd highest Pt electron:

[Theta]	0.58rad
[Charge]	positive

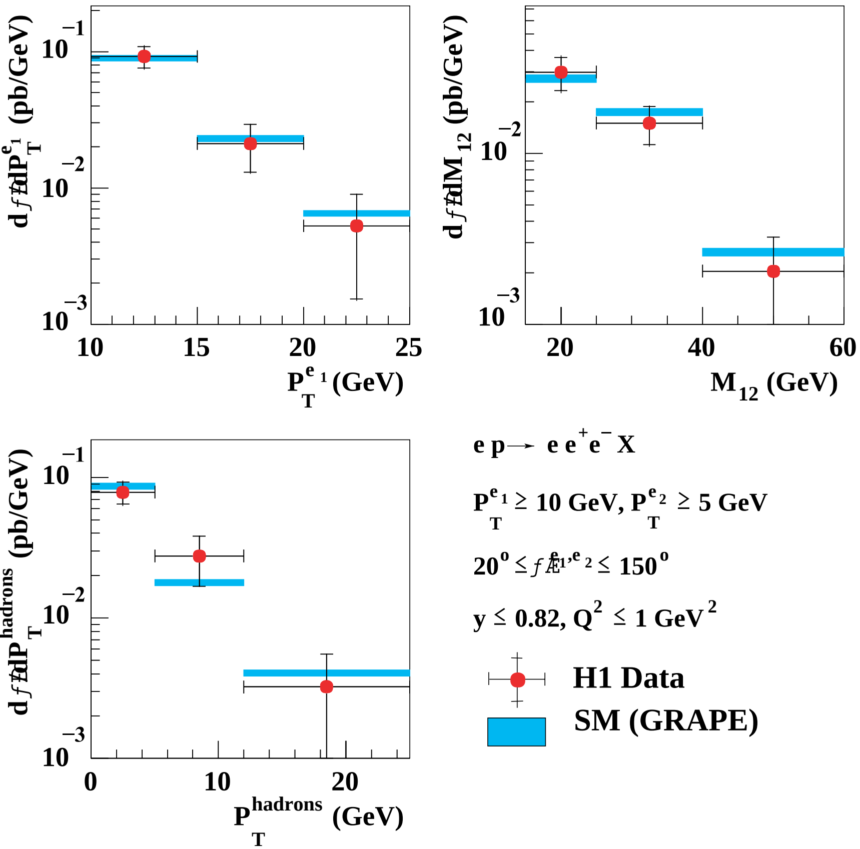


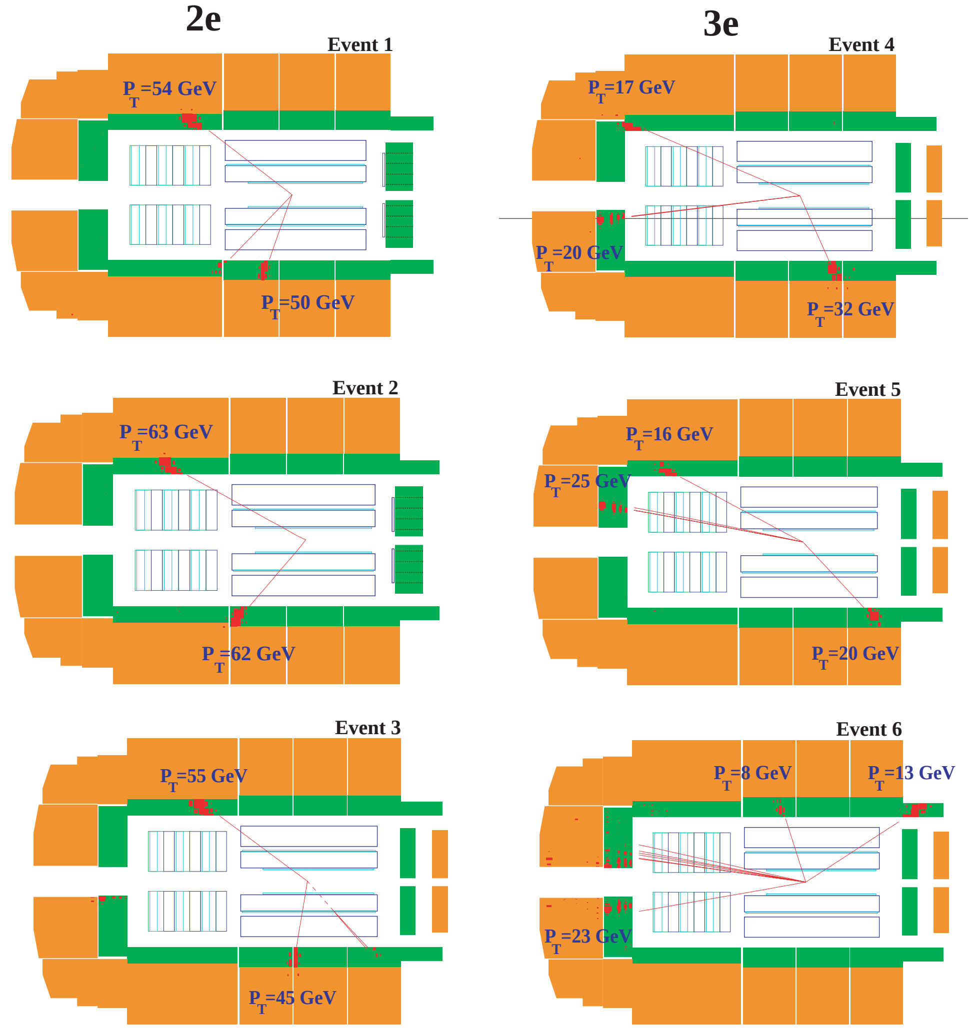
Multi-electron analysis at ZEUS (cont'd)

Distributions of Pt and θ in 3e sample



Multi-electron analysis at H1



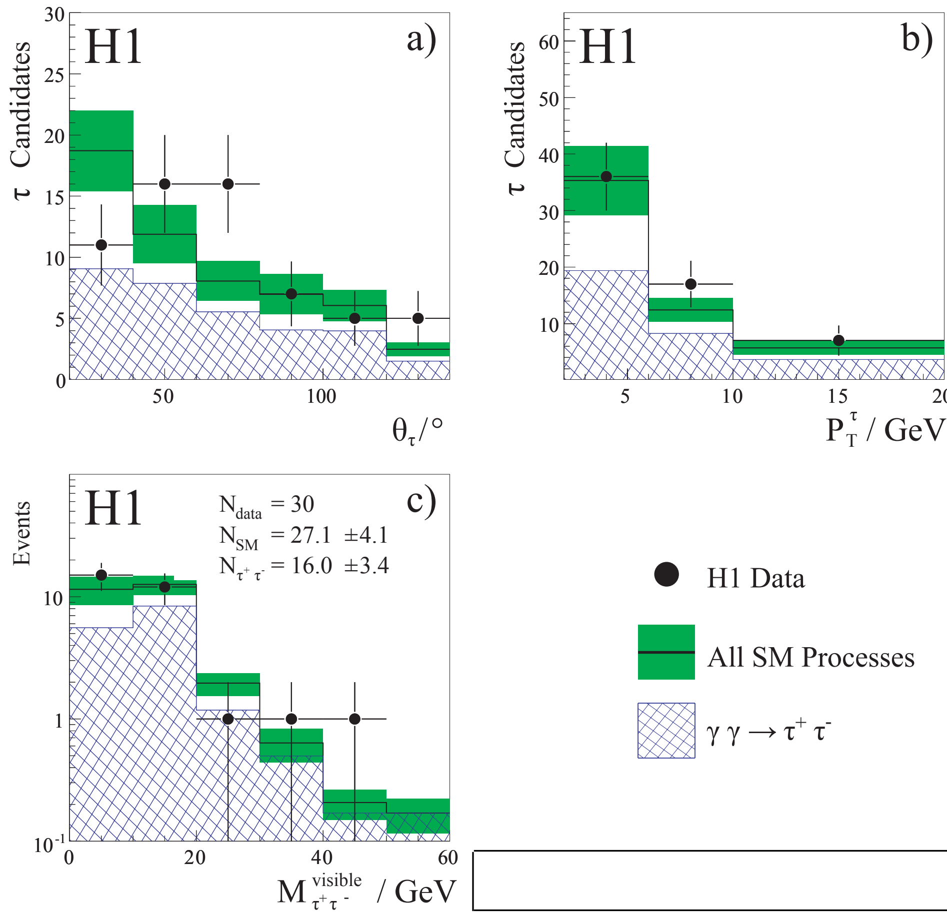


with $M_{1,2}$>100 GeV

The cross section integrated over the phase space defined above.

$$\sigma = (0.59 \pm 0.08 \pm 0.05)pb$$

Tau pair production at H1



*hep-ex/0604022
accepted by Eur.Phys.J.C

$\tau^+\tau^-$ **Results**					
Decay Channel	**Leptonic**	**Semi leptonic**		**Hadronic**	**Total**
	e □	e τ □jet	μ τ □jet	τ □jet τ □jet	
H1 Data	7	2	10	11	30
SM	2.9 – 0.4	6.3 – 0.9	7.0 – 1.3	11.0 – 2.0	27.1 – 4.1
$\tau^+\tau^-$	56%	47%	85%	50%	59%

Di-tau analysis at ZEUS

Event selection

Trigger; with muon candidates found by the muon detectors. $|Z_{vertex}| < 50cm$

Vertex; $(X_{vertex} - 1.33)^2 + (Y_{vertex} - 0.22)^{2\frac{1}{2}} < 1.5cm$

Muon candidates definition

Pt > 2GeV

To match with track

Electron candidates definition

θ <2.6rad

- $For\ centralregion\ (0.3 < \theta_e < 2.6\ rad)$
- $Momentumoftrack \geq 2\ GeV$
- $DCA < 10\ cm$

Energy > 4GeV

Energy in cone not from an electron candidate < 5GeV

◆Events are required to have one or more muons and one or more electrons

◆Number of good tracks = 1,2,3

(Pt of track >0.15 GeV,inner layer<2,outer layer >2)

If there are more than 1 track, at least a track is required to match an electron

◆FCAL 1nd + 2nd inner ring energy <1GeV

Di-tau analysis at ZEUS (cont'd)

Event selection (cont'd)

◆Number of muons =1.

(Pt >1.5 or momentum>1.5 GeV)

◆0.1<colinearity<2.7 (*rad*)

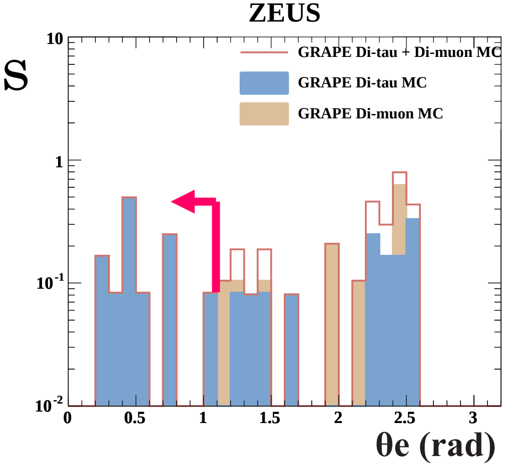
◆E-Pz <45 *GeV*

◆There is no calorimeter energy deposit which is consistent MIP.

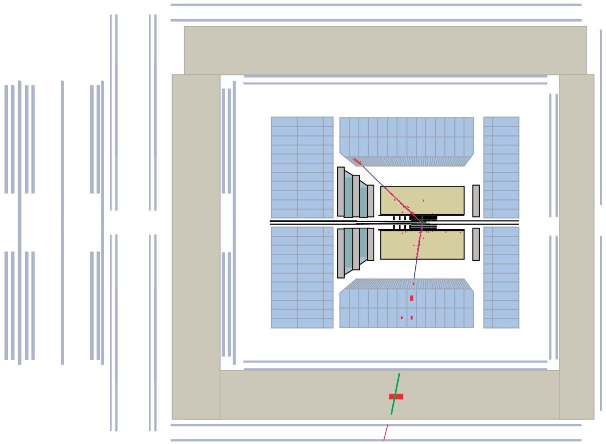
Not to be CAL noise. Not match above electron candidates and a muon candidates. 0.2< Energy of EMC < 1.5 GeV and 0.5 <Energy of HAC <2.5 GeV.

◆ θ e< 1.0 rad if there are electron candidates

which have negative charge.

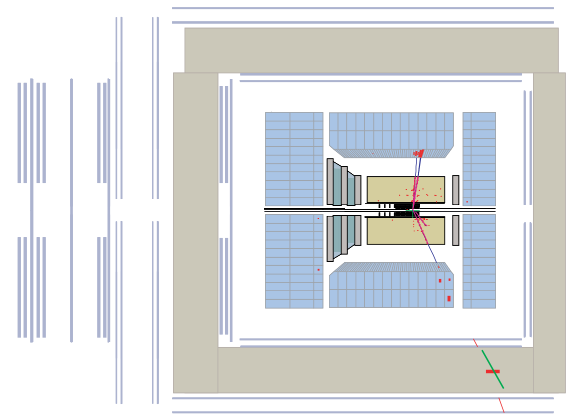


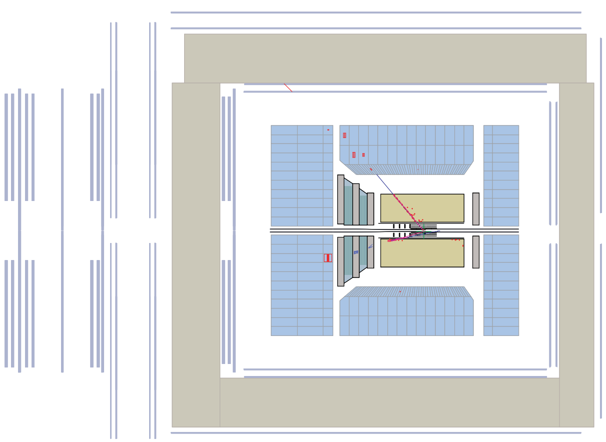
Di-tau final samples



Nmu	Emncand			
1	1			
Muqual	Mupt	Muth	Muph	Mucharge
4	4.86	1.41	0.033	1
EM Ee	Emth	Emph	Emtrkq	
5.38	0.71	2.92	-1	

Nmu	Emncand			
1	1			
Muqual	Mupt	Muth	Muph	Mucharge
4	4.78	2.04	3.46	1
EM Ee	Emth	Emph	Emtrkq	
12.83	1.75	0.34	1	





Nmu	Emncand			
1	1			
Muqual	Mupt	Muth	Muph	Mucharge
3	4.91	0.83	3.31	1
EM Ee	Emth	Emph	Emtrkq	
5.56	0.26	0.083	-1	