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Study of tau-pair production at HERA

Masaki Ishitsuka
Tokyo Institute of Technology
for the ZEUS collaboration

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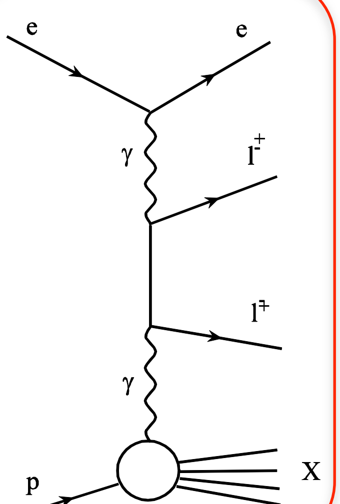
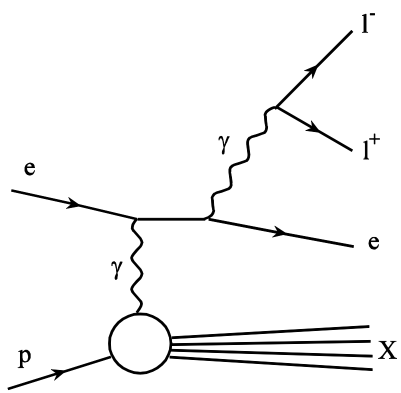
Lepton-pair production at HERA

- Lepton-pair production at ep collision
  - 27.5 GeV electron or positron + 920GeV proton
  - Main process: photon-photon collision
  - Can be test of electroweak interaction in SM
  - Deviation from SM → hint for new physics



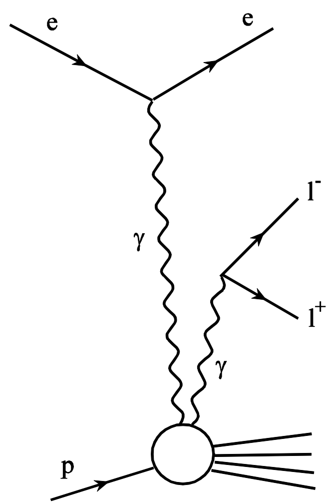
Bethe-Heitler

γ (Z^0)- γ (Z^0) collision



Cabbibo-Parisi

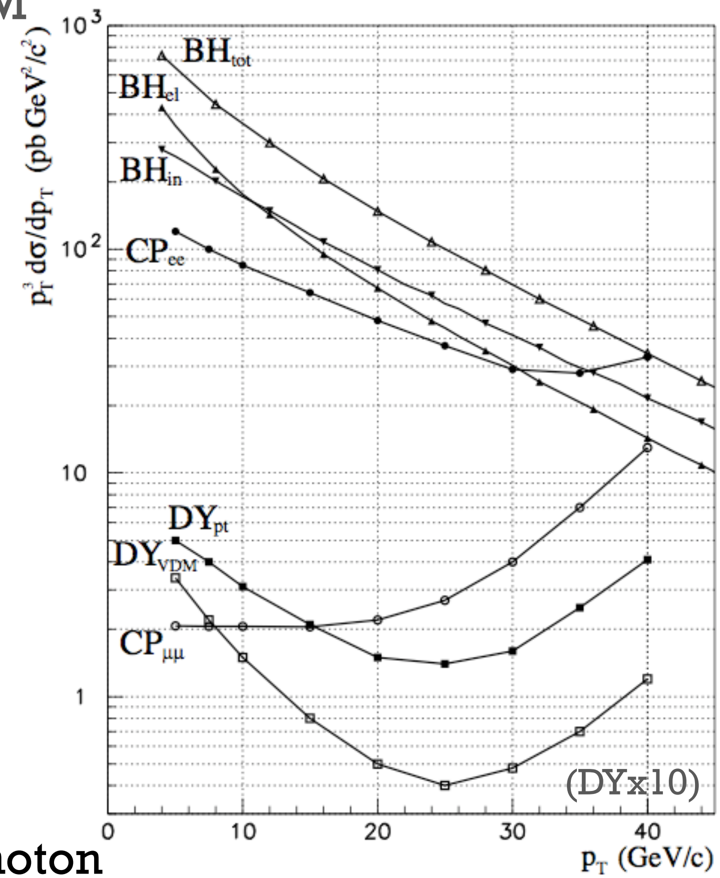
QED-Compton



Drell-Yan

Pair production from radiated photon

Lepton-pair production cross-section at HERA



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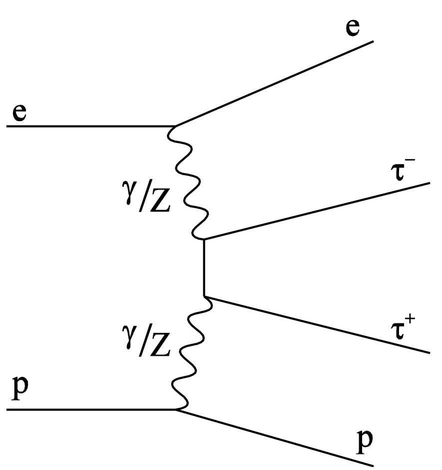
- tau channel
  - Signal: combinations of e, μ and jet from τ decay

Hardly distinguishable from di-electron and di-muon



σ ~10 pb (p_T^{τ} > 5 GeV)

$$\tau^+\tau^- \rightarrow \begin{cases} \sout{e^\pm + e^\mp + \nu's + \cdots \quad \text{(BR: 3\%)}} \\ \sout{\mu^\pm + \mu^\mp + \nu's + \cdots \quad \text{(BR: 3\%)}} \\ e^\pm + \mu^\mp + \nu's + \cdots \quad \text{(BR: 7\%)} \\ e^\pm + h^\mp + \nu's + \cdots \quad \text{(BR: 23\%)} \\ \mu^\pm + h^\mp + \nu's + \cdots \quad \text{(BR: 22\%)} \\ h^\pm + h^\mp + \nu's + \cdots \quad \text{(BR: 42\%)} \end{cases}$$

tau-pair study at ZEUS

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  - Signal: combinations of e, μ and jet from τ decay
- Study at ZEUS
  - 0.33fb^{-1} HERA II data (2004-2007)
    - electron + proton: 0.18fb^{-1}
    - positron + proton: 0.15fb^{-1}

Hardly distinguishable from di-electron and di-muon

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+ tau-pair selection

(1) Low track multiplicity

- Number of tracks: 2 ≦ Ntrk ≦ 7

(2) (Quasi-)elastic selection

- No energy deposit (<1GeV) in forward calorimeter
- Suppress NC DIS (ep→eX) and photoproduction (γp→X) BG

(3) Identification of tau decay

(3a) tau-jet identification

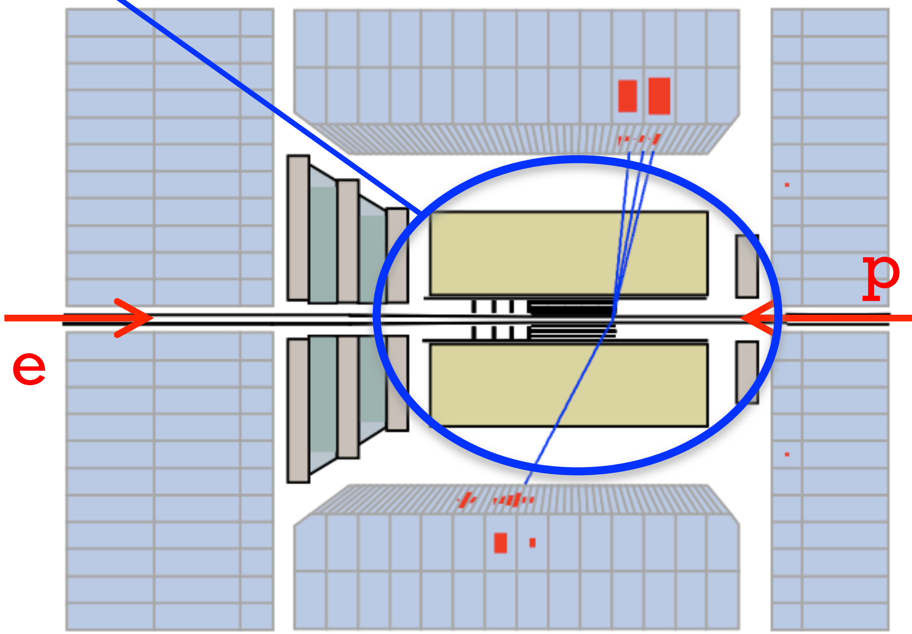
- Multi variable discrimination

(3b) Electron identification

- Track and calorimeter matching

(3c) Muon identification

- Track, calorimeter and muon chamber matching



(4) Charge cut

- Two decay candidates should have opposite charge

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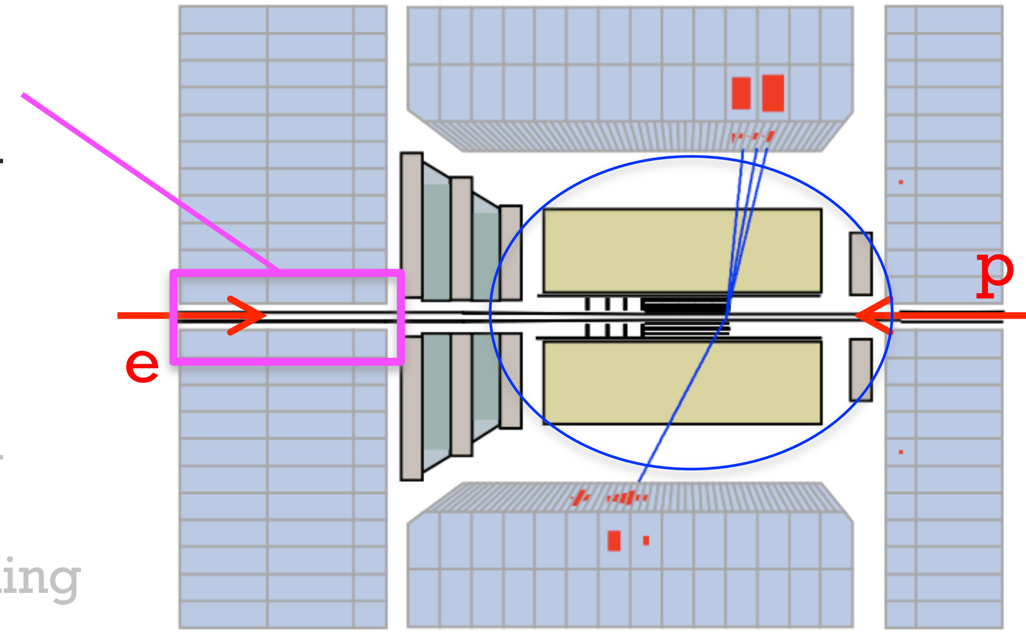

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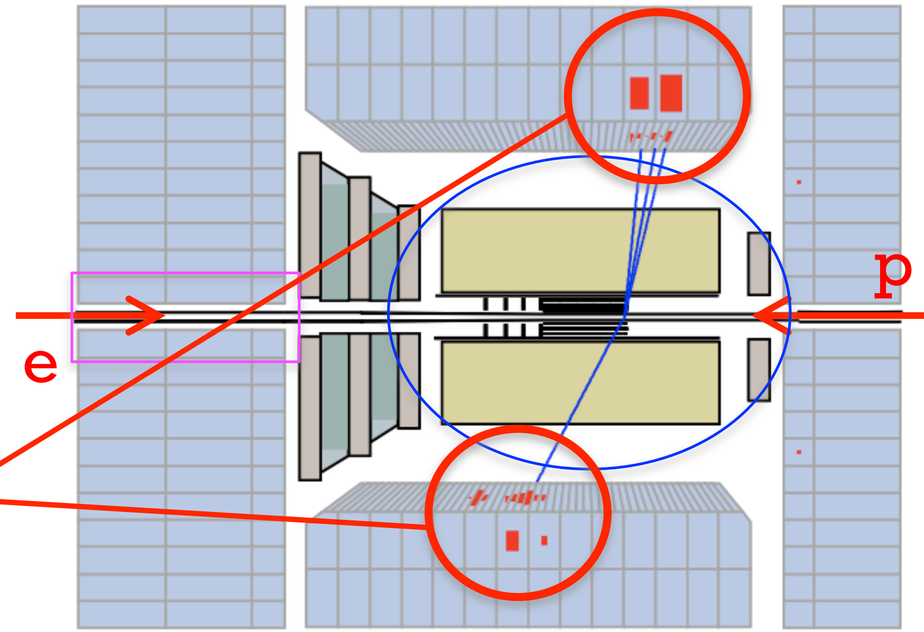

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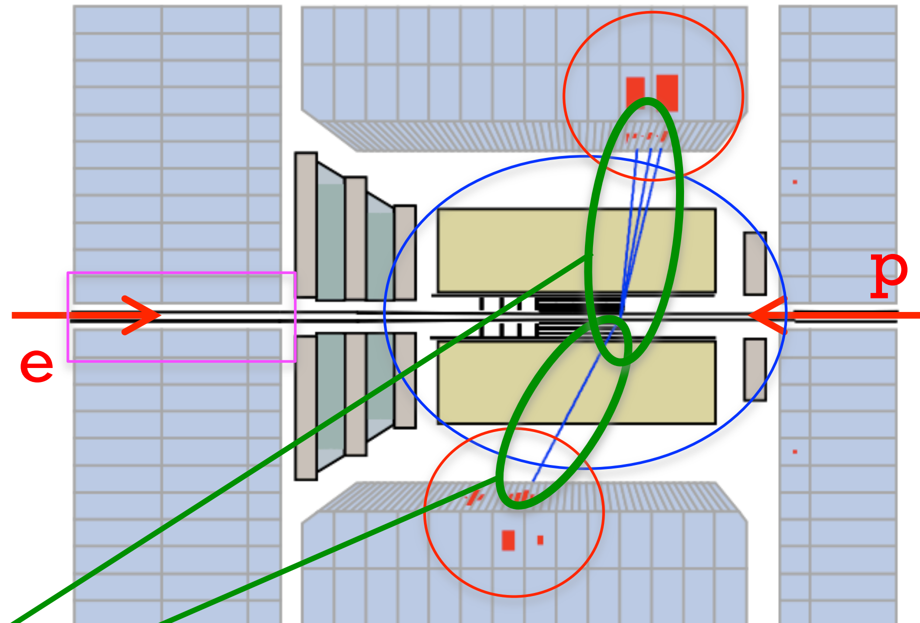

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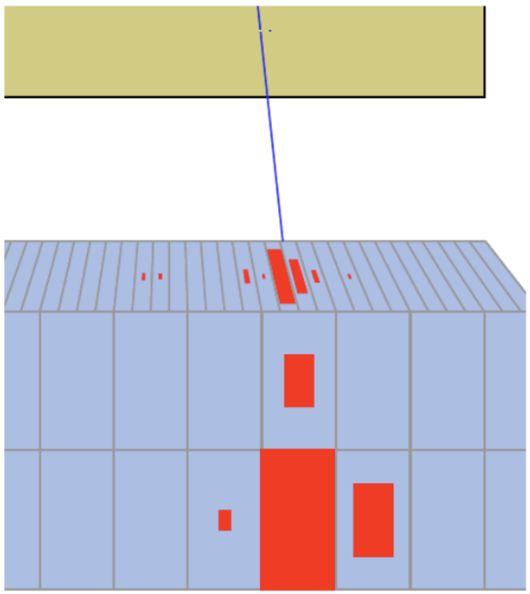

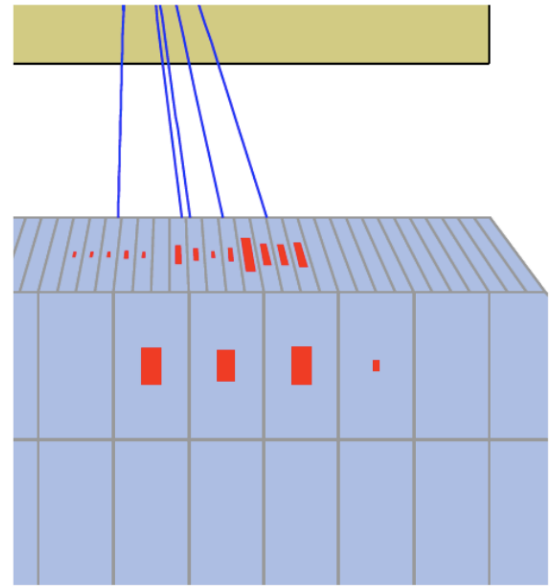

- tau-jet
  - Low multiplicity
  - Pencil-like shape
  - Track charge = ±1
- QCD jet
  - High multiplicity
  - Broad shape

→ Identify hadronic tau decay by a multi-variable discrimination technique based on the characteristics

tau-jet identification

Signal: tau-jet
Background: QCD-jet

- 1st and 2nd moment of radial extension

$$R_{mean} = \langle R \rangle = \frac{\sum_i \{E_i \cdot R_i\}}{\sum_i E_i}, \quad R_{rms} = \sqrt{\frac{\sum_i E_i \cdot (\langle R \rangle - R_i)^2}{\sum_i E_i}}$$

- 1st moment of longitudinal extension

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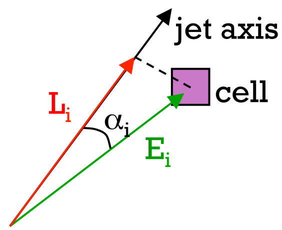
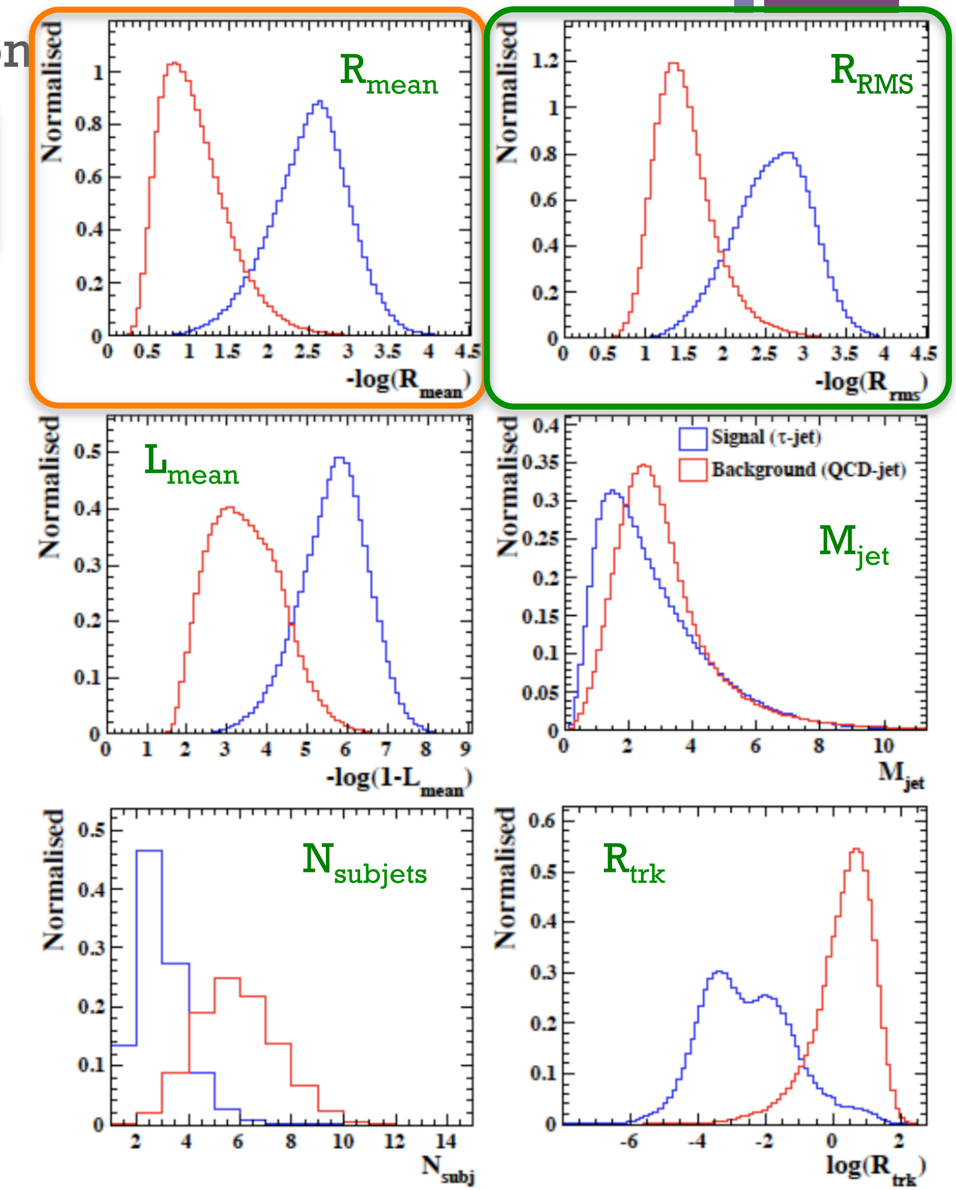


- Invariant mass clustered CAL cells

$$M_{jet} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i p_{i,x}\right)^2 - \left(\sum_i p_{i,y}\right)^2 - \left(\sum_i p_{i,z}\right)^2}$$

- No. of subjets ($y > 5\times10^{-4}$) $N_{subjets}$
- Sum of distance between jet axis and tracks associated with jet

$$R_{trk} = \sum_i^{Ntrk} \sqrt{(\Delta\eta_i^2 + \Delta\phi_i^2)}$$



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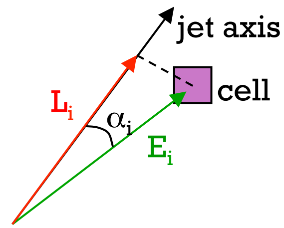

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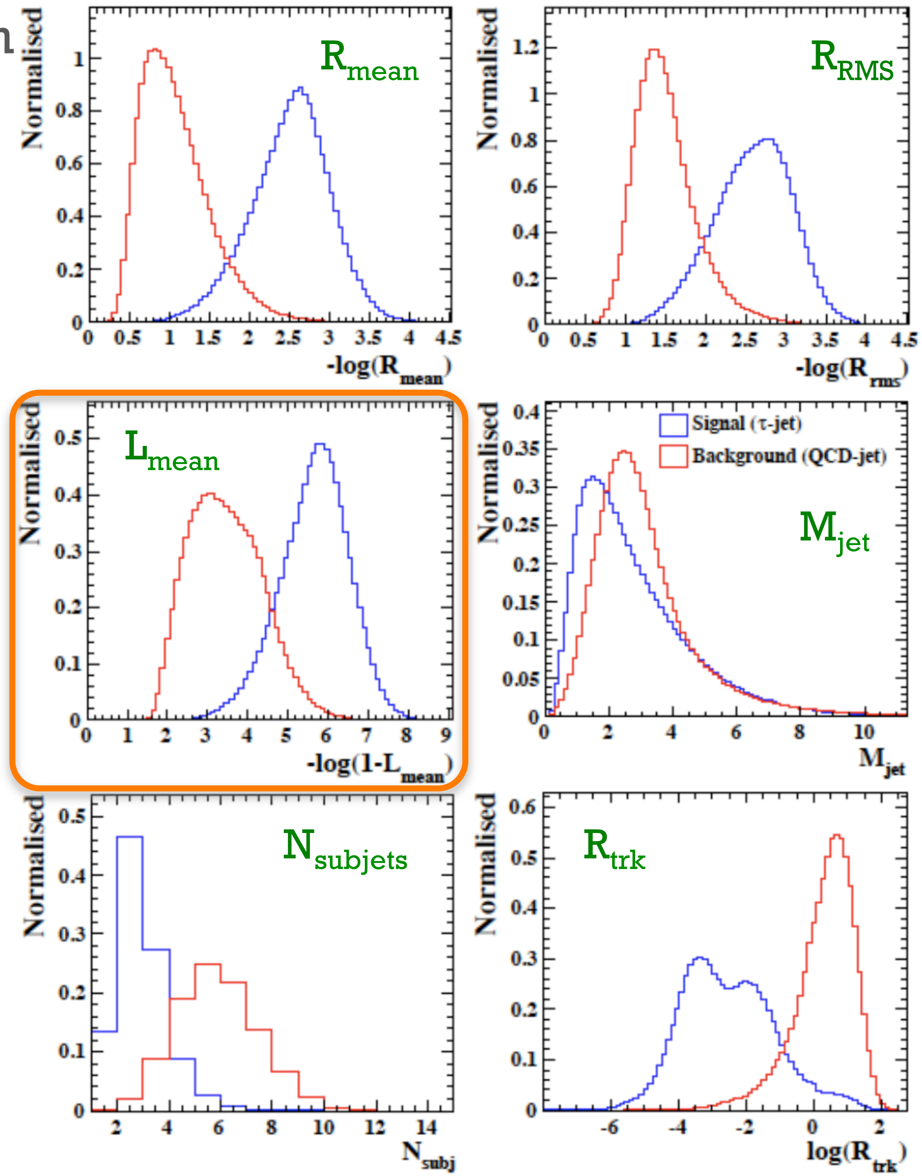

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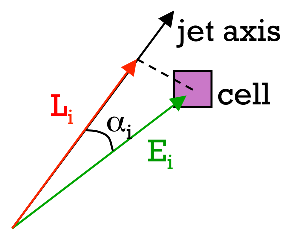

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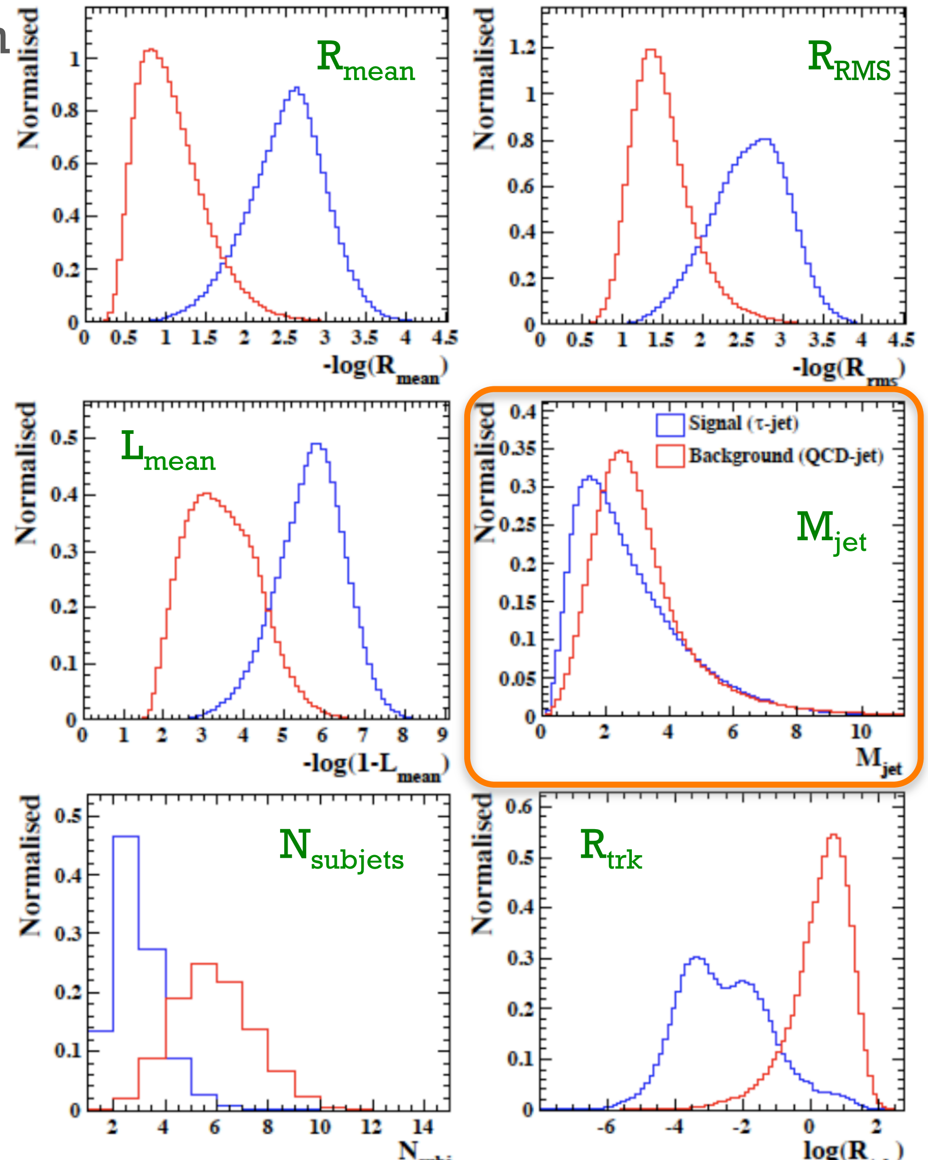

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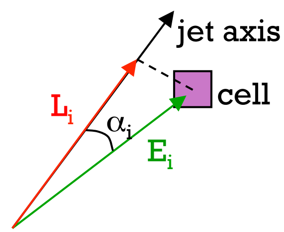

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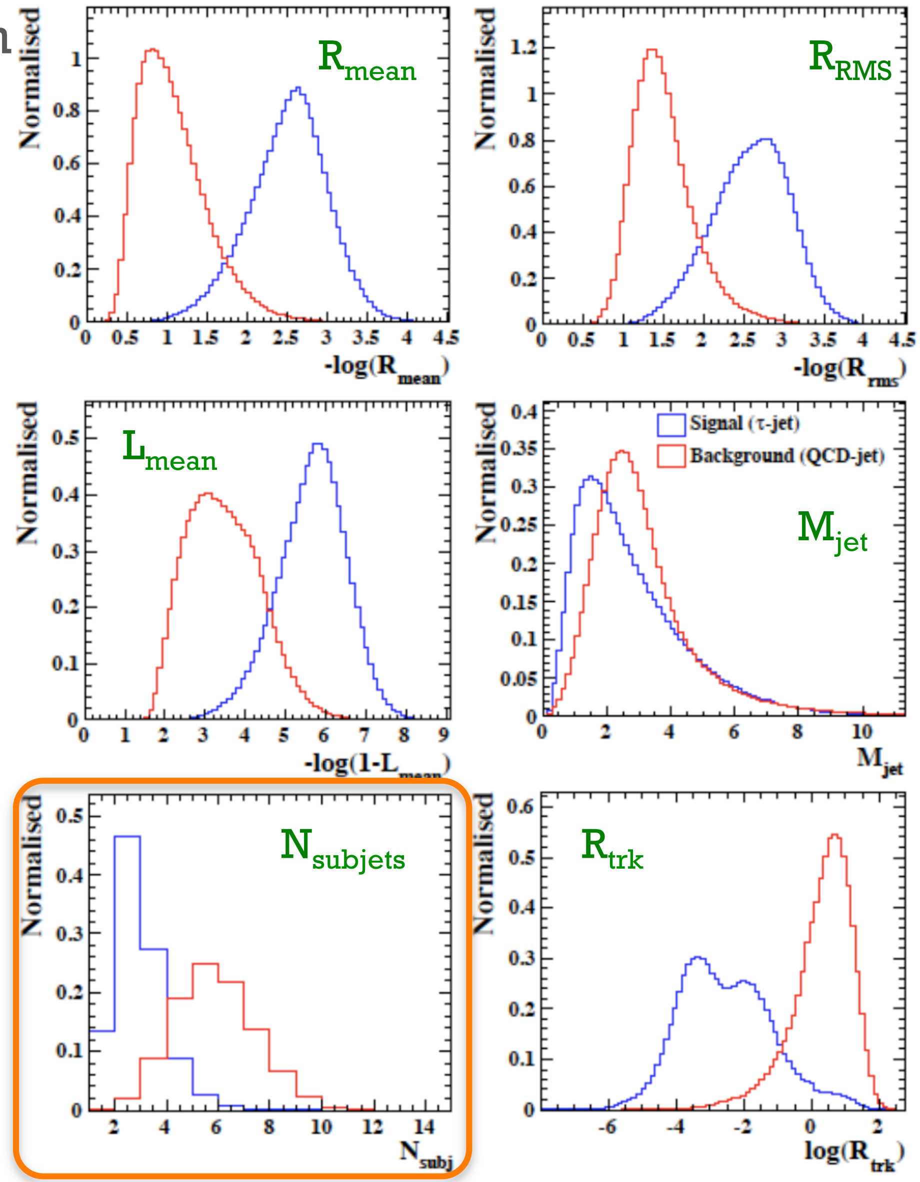

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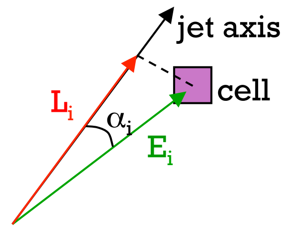

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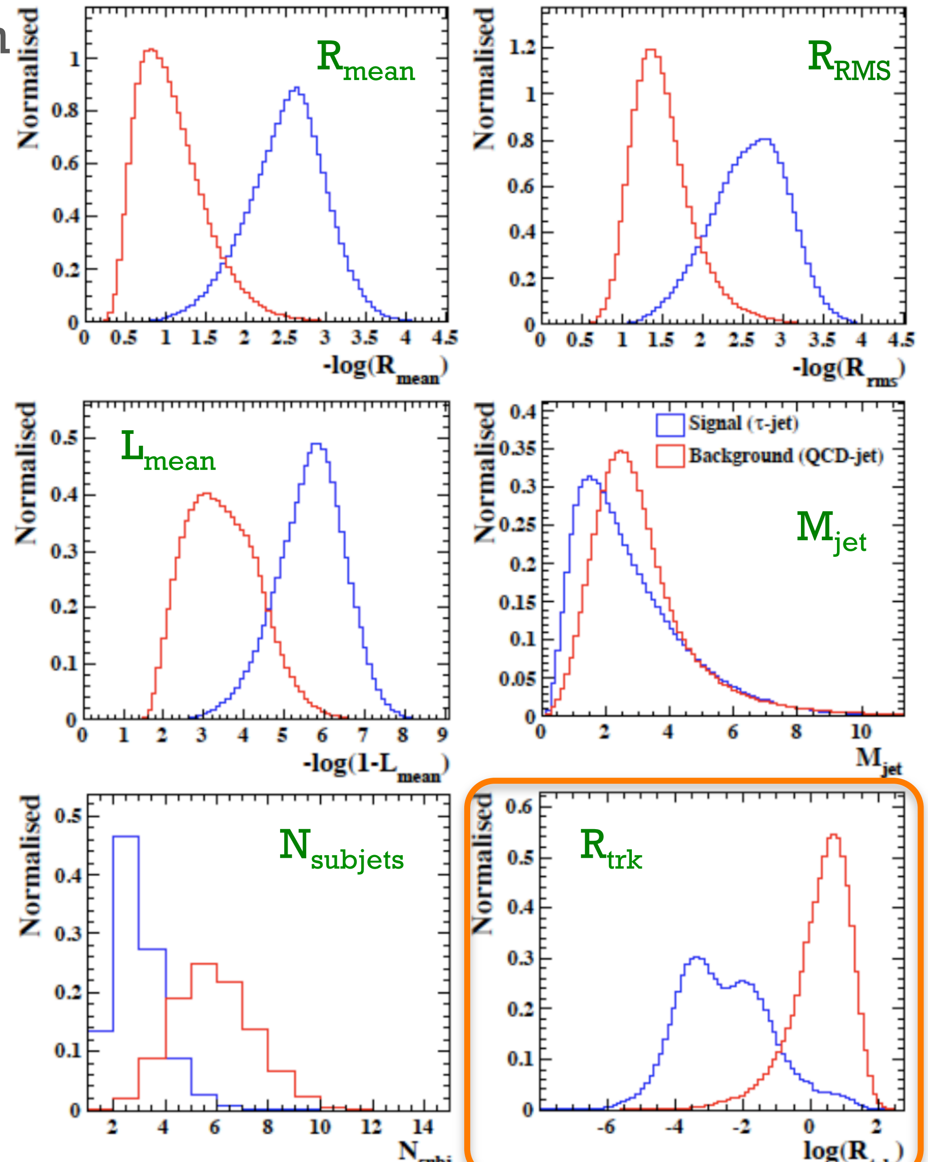

+ tau-jet identification

Data (ZEUS 0.33fb^{-1})
Total SM
$\gamma\gamma \rightarrow \tau^+\tau^-$

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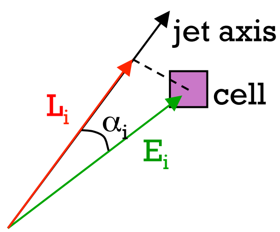

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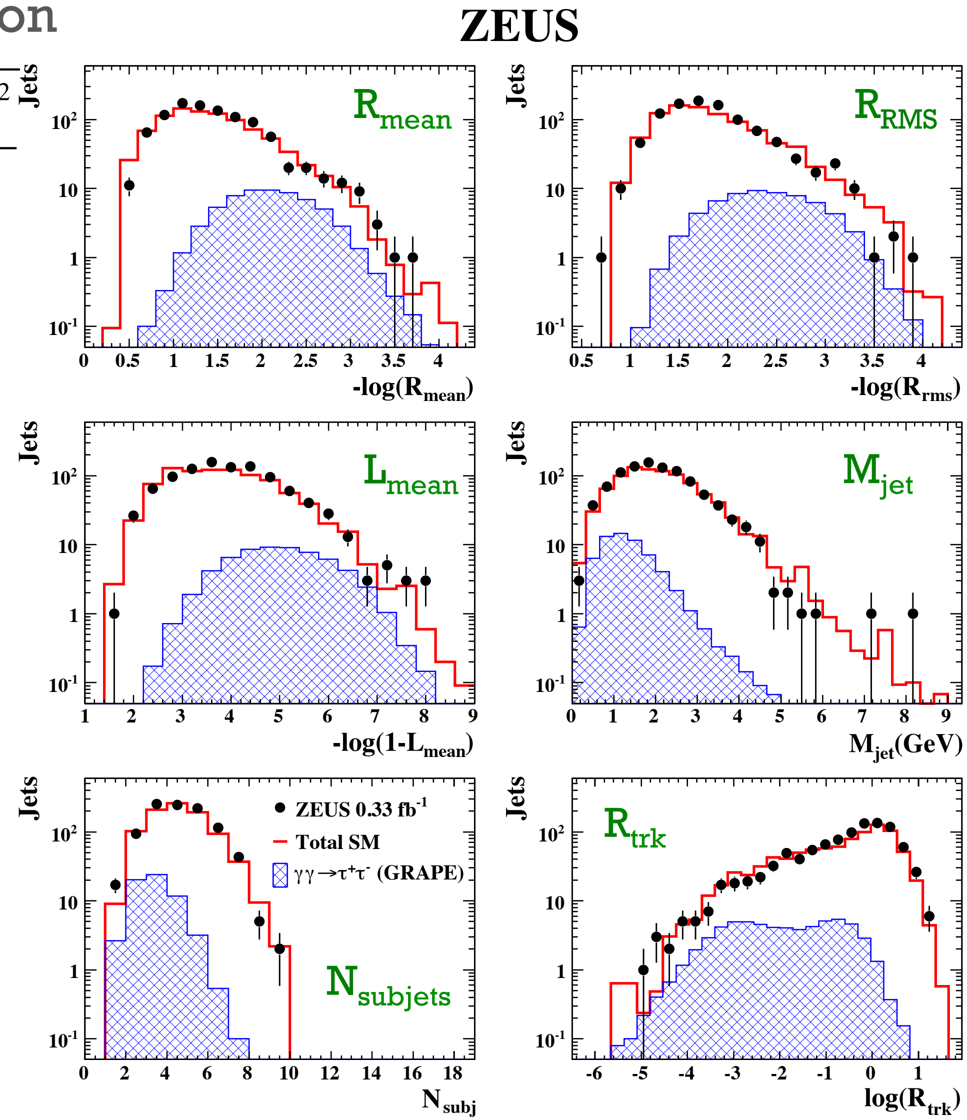
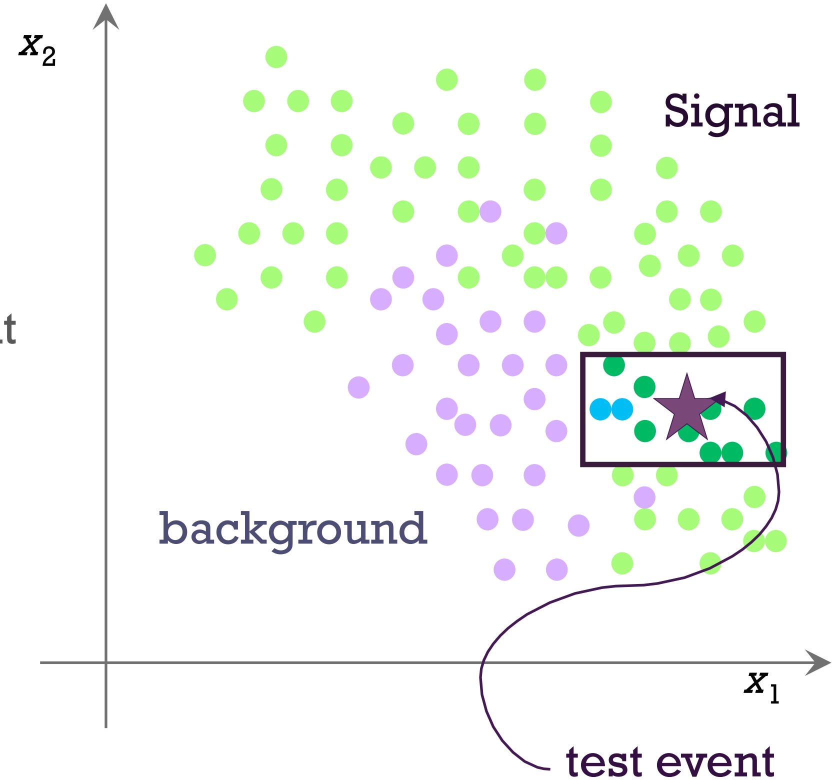


Discriminant for tau jets

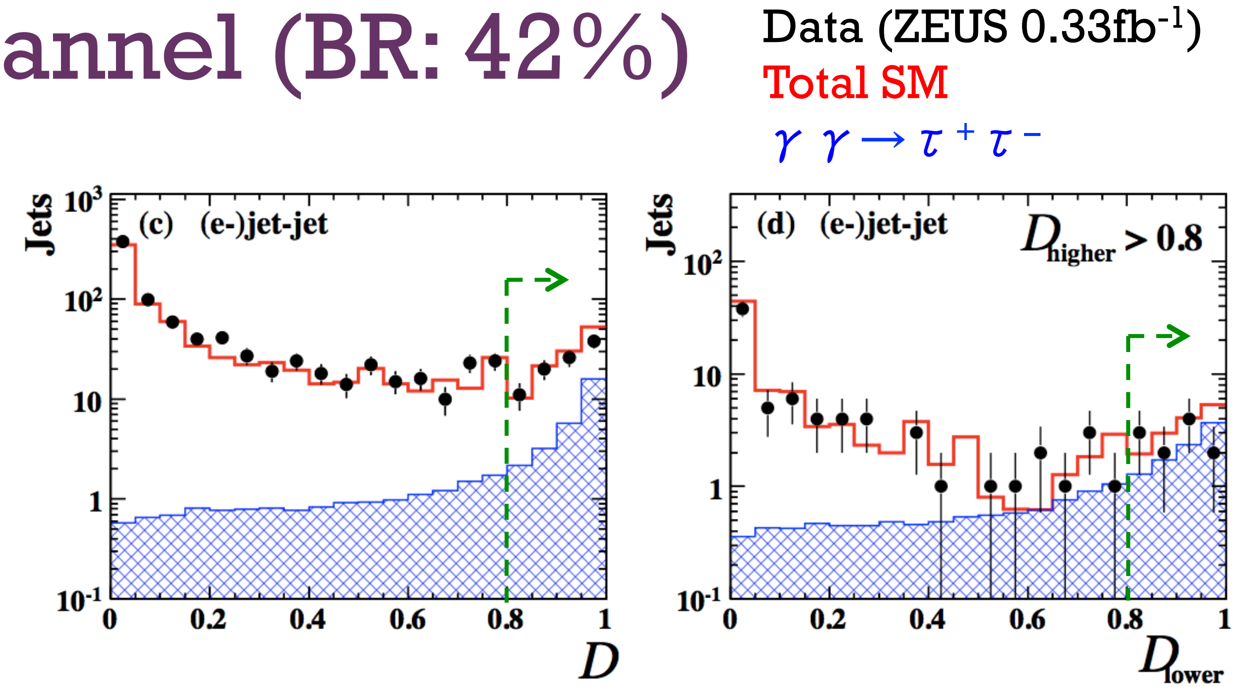
- Expansion of likelihood approach to n-dimensions
  - Count number of signal and background events (training sample) nearby test event

$$D(\vec{x}) = \frac{\rho_{sig}(\vec{x})}{\rho_{sig}(\vec{x}) + \rho_{bkg}(\vec{x})}$$



suggested by T. Carli and B.Koblitz, NIM A 501 (2003) 576

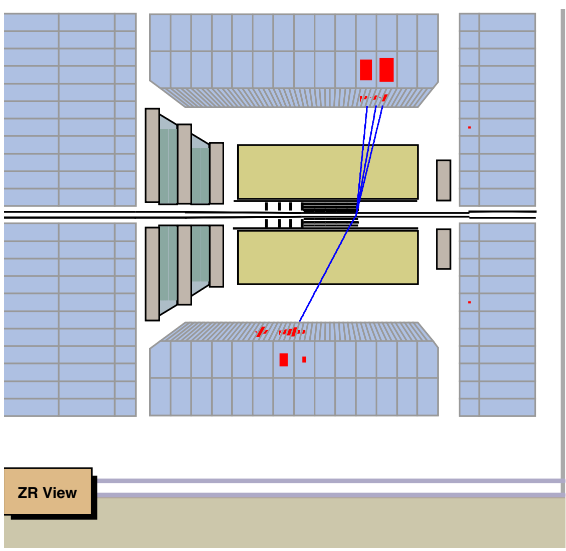
(e)-jet-jet channel (BR: 42%)



Selection criteria

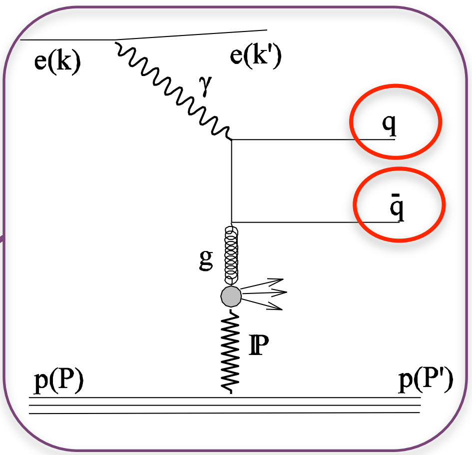
- Jet
  - $p_T > 5$ GeV
  - $|\eta| < 2$
  - $D > 0.8$
- Opposite charge for two jets

Example of jet-jet event



Results

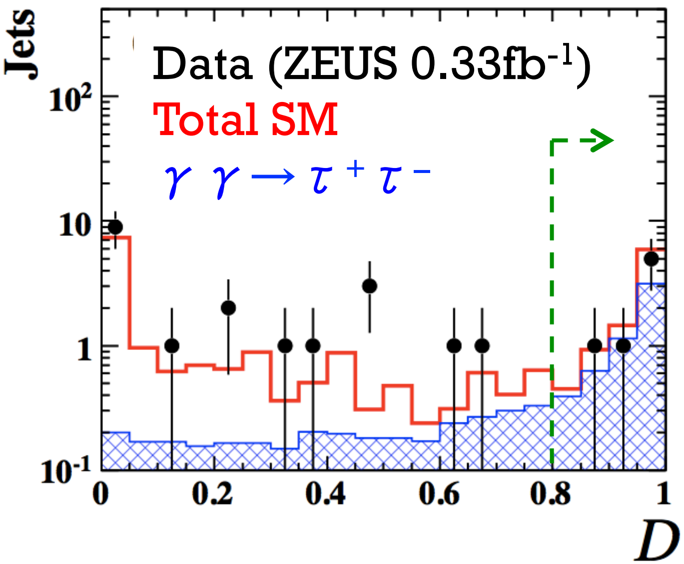
- $14.4^{+2.2}_{-3.5}$ events expected
  - $9.0^{+0.4}_{-0.3}$ tau-pair (purity 63%)
  - BG: photoproduction
- 10 events observed



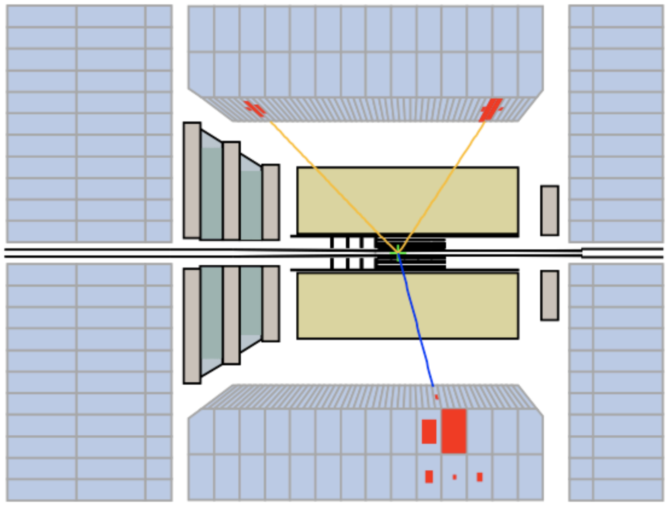
(e)-e-jet channel (BR: 23%)

Selection criteria

- Electron
  - $p_T > 2$ GeV, $17^\circ < \theta < 160^\circ$
  - Opposite charge to beam ($\theta > 1$)
- Jet
  - $p_T > 5$ GeV, $|\eta| < 2$
  - $D > 0.8$
- Opposite charge for e and jet



Example of e-e-jet event



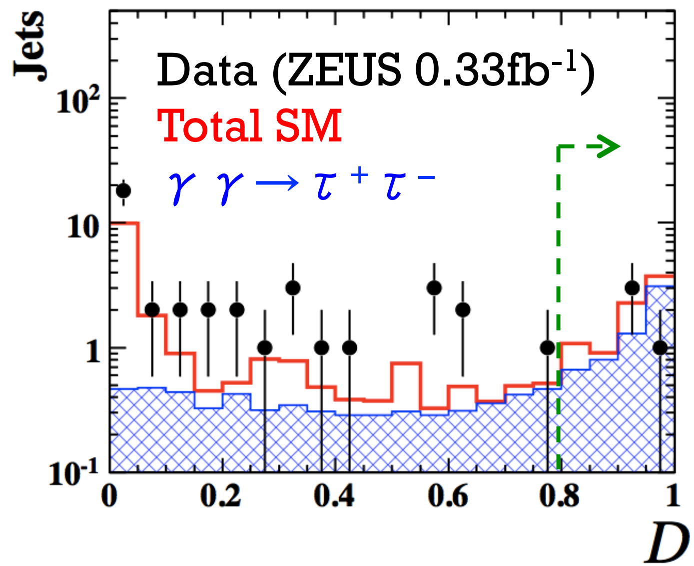
Results

- $8.8^{+1.8}_{-0.8}$ events expected
  - $5.3^{+0.3}_{-0.2}$ tau-pair (purity 60%)
  - BG: di-electron, DIS
- 7 events observed

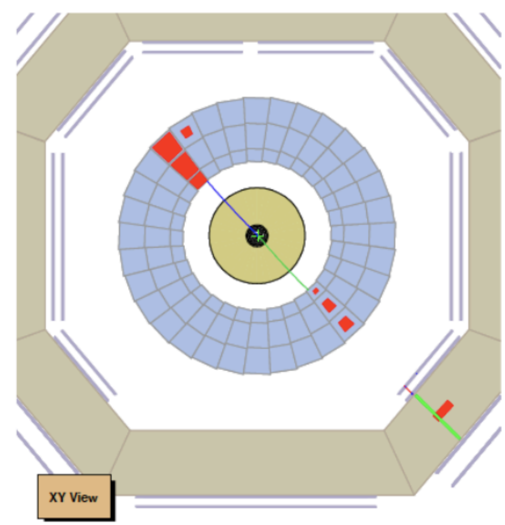
(e)- μ -jet channel (BR: 22%)

<u>Selection criteria</u>

- Muon
  - $p_T > 2$ GeV, $34° < \theta < 157°$
- Jet
  - $p_T > 5$ GeV, $|\eta| < 2$
  - $D > 0.8$
- Opposite charge for μ and jet



Example of μ -jet event



<u>Results</u>

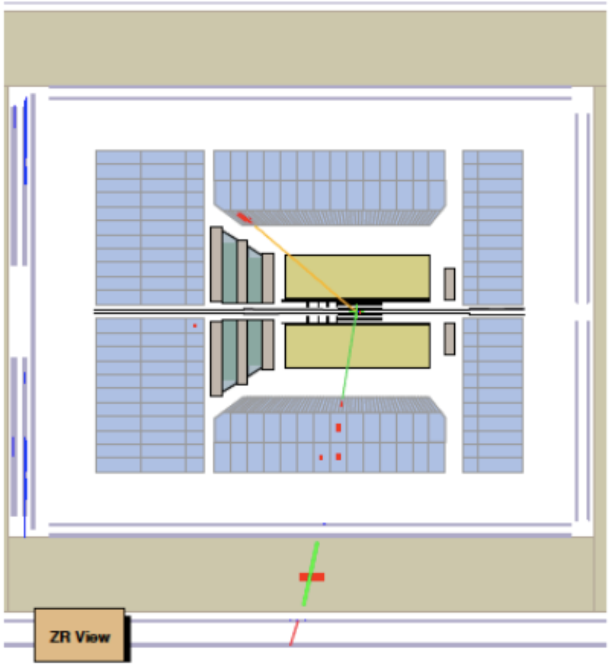
- $8.0^{+2.2}_{-1.2}$ events expected
  - $5.9^{+0.5}_{-0.5}$ tau-pair (purity 73%)
  - BG: di-muon, photoproduction
- 4 events observed

+ (e)-e-μ channel (BR: 7%)

Selection criteria

- Electron
  - $p_T > 2$ GeV, $17° < \theta < 160°$
  - Opposite charge to beam ($\theta > 1$)
- Muon
  - $p_T > 2$ GeV, $34° < \theta < 157°$
- Opposite charge for e and μ

Example of e-μ event



Results

- $3.6^{+1.3}_{-0.3}$ events expected
  - $3.0^{+0.3}_{-0.2}$ tau-pair (purity 82%)
  - BG: di-muon, DIS
- 4 events observed

Results (all channels)

- tau-pair events at HERA II ($L=0.33fb^{-1}$)
- $\sigma = 3.26 \pm 1.30(\text{stat.})\ ^{+0.99}_{-0.73}(\text{syst.})$ pb
  - Kinematic region:
    $p_T > 5$ GeV, $17° < \theta < 160°$
  - SM prediction: 5.67 ±0.16 pb
- Data agree with SM prediction

Topology	(e-)e-μ	(e-)e-jet	(e-)μ-jet	(e-)jet-jet	Total
Data	4	7	4	10	25
Total MC	$3.6^{+1.3}_{-0.3}$	$8.8^{+1.8}_{-0.8}$	$8.0^{+2.2}_{-1.2}$	$14.4^{+2.2}_{-3.5}$	$34.8^{+3.9}_{-3.8}$
$\tau^+\tau^-$ MC	$3.0^{+0.3}_{-0.2}$	$5.3^{+0.3}_{-0.2}$	$5.9^{+0.5}_{-0.5}$	$9.0^{+0.4}_{-0.3}$	$23.2^{+0.7}_{-0.7}$
Purity	82%	60%	73%	63%	67%

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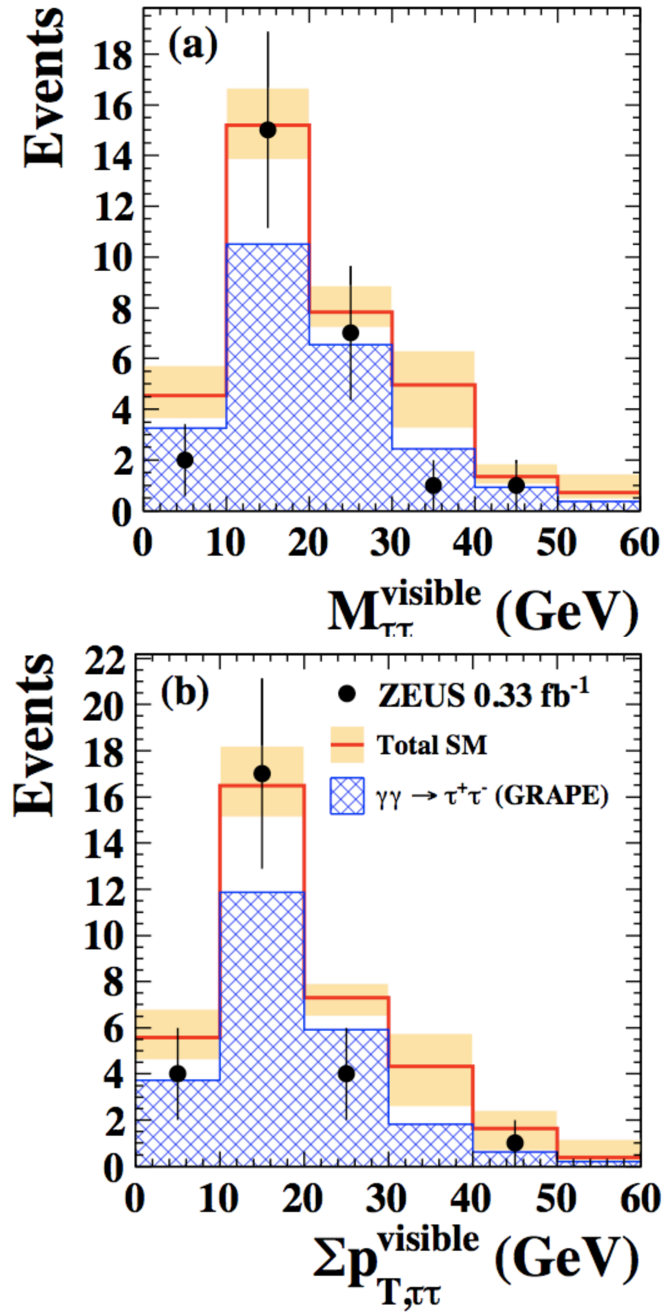
- Data agree with SM prediction
- No excess at high p_T and $M_{\tau\tau}$
  - No evidence of physics beyond SM



Summary

- tau-pair production at electron(positron)-proton collision was studied at ZEUS
  - Integrated luminosity of $0.33fb^{-1}$ at HERA II
  - Beam energy: 27.5GeV ($e^{\pm}$) and 920GeV (p)
- 25 tau-pair candidates were found with 67% purity
- Cross-section was measured in kinematic region:
  $p_T(\tau) > 5GeV$, $17^\circ < \theta(\tau) < 160^\circ$ (acceptance of 1.23% due to p_T cut)
  - $\sigma = 3.26 \pm 1.30(stat.)\ ^{+0.99}_{-0.73}(syst.)$ pb
    (SM prediction: 5.67 ± 0.16 pb (theor.))