Measurement of Leptonic Structure Functions with the L3 Detector at LEP

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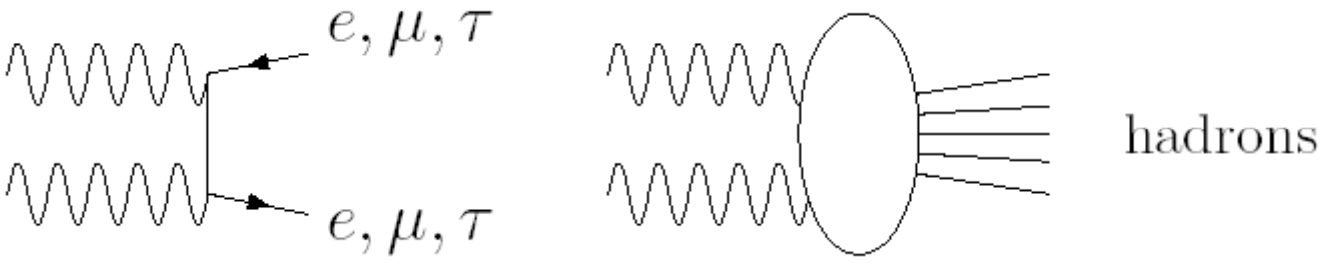
“Structure of the Photon”

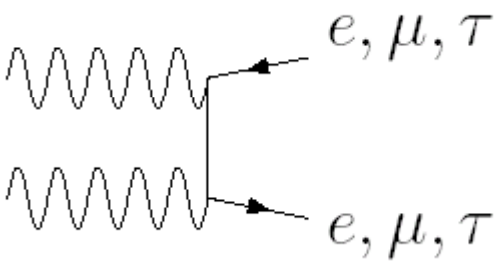
- Dual nature of photons: uncertainty principle allows photon to fluctuate into various states (leptons, quarks, …)

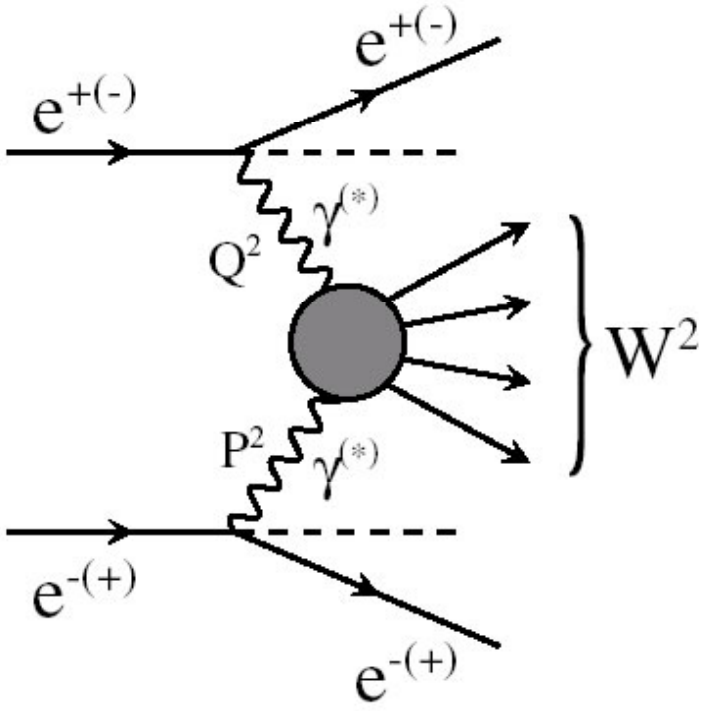
- Photon is ideal tool for probing structure of objects



Dilepton Formalism

$$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\mu^+\mu^-$$

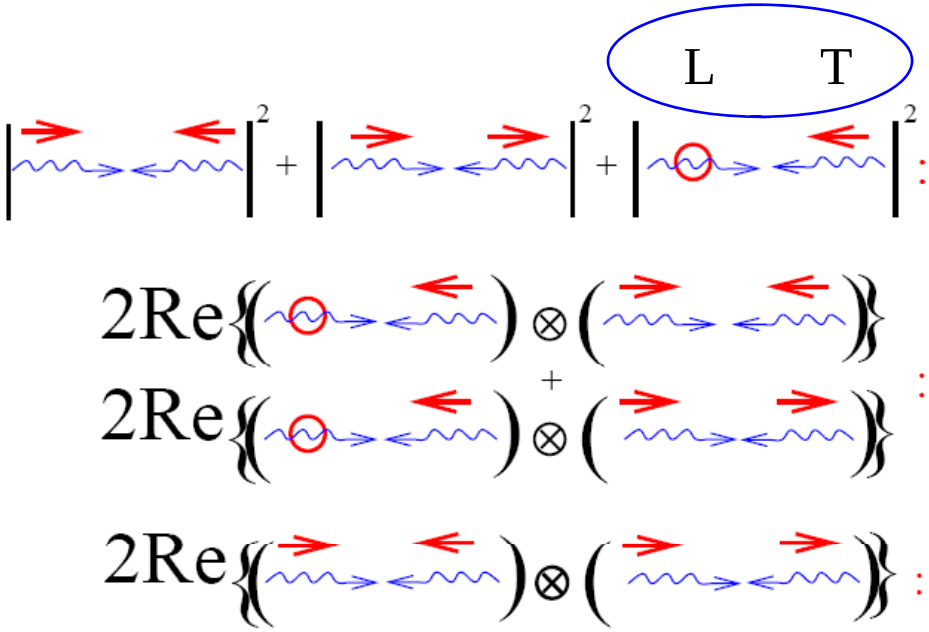




Dilepton Formalism

$$d\sigma = K(4\rho_1^{++}\rho_2^{++}\sigma_{TT} + 2\rho_1^{00}\rho_2^{++}\sigma_{LT} + 2\rho_1^{++}\rho_2^{00}\sigma_{TL} + \rho_1^{00}\rho_2^{00}\sigma_{LL}$$

$$+2|\rho_1^{+-}\rho_2^{+-}|\tau_{TT}\cos 2\tilde{\phi} - 8|\rho_1^{+0}\rho_2^{+0}|\tau_{TL}\cos\tilde{\phi})\frac{d^3p_1' d^3p_2'}{E_1 E_2}$$



$$K = \frac{\alpha^2}{16\pi^4 q_1^2 q_2^2}\sqrt{\frac{\nu^2 - q_1^2 q_2^2}{(p_1 p_2)^2 - m^4}}$$

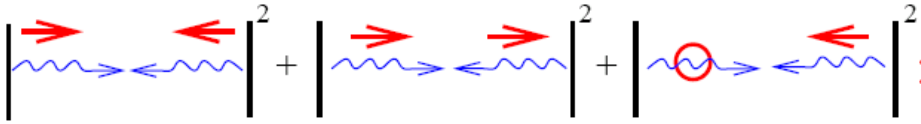
ρ_i^{MN} : density matrix

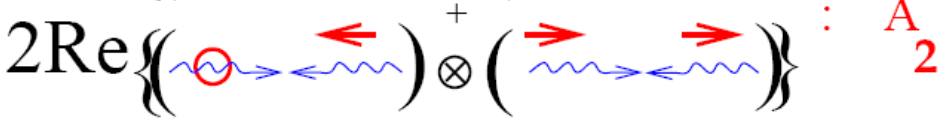
σ_{PQ}, τ_{PQ} : cross-sections for different helicity states of the photon

Dilepton Formalism

$$F_1 = \frac{\sqrt{\nu^2 - q_1^2 q_2^2}}{4\pi^2\alpha}\left(\sigma_{TT} - \frac{1}{2}\sigma_{TL}\right)$$

$$F_2 = \frac{\nu|q_1^2|}{4\pi^2\alpha\sqrt{\nu^2 - q_1^2 q_2^2}}\left(\sigma_{TT} + \sigma_{LT} - \frac{1}{2}(\sigma_{LL} + \sigma_{TL})\right)$$





ρ_i^{MN} : density matrix

σ_{PQ}, τ_{PQ} : cross-sections for different helicity states of the photon

Single Tag Formalism

$\rightarrow$ One electron detected

$\rightarrow$ One electron escapes undetected

$\Rightarrow$ $\boxed{q_2^2 \rightarrow 0}$

$\rightarrow$ Photon with $-q_1^2 = Q^2$: probe photon

$\rightarrow$ Photon with $-q_2^2 = P^2$: target photon

Structure Function

Extraction of $F_{2,QED}^{\gamma}$

Express $d\sigma$ in terms of Structure Functions

$$
\begin{aligned}
d\sigma \;=\; & K\Big(2|\rho_1^{+-}\rho_2^{+-}|\tau_{TT}\cos 2\tilde{\phi} - 8|\rho_1^{+0}\rho_2^{+0}|\tau_{TL}\cos\tilde{\phi} \\
& +2\rho_1^{++}\rho_2^{00}\left\{F_2(W,q_1^2,q_2^2)/D - F_1(W,q_1^2,q_2^2)/C\right\} \\
& +4\rho_1^{++}\rho_2^{++}F_1(W,q_1^2,q_2^2)/C\Big)\frac{d^3p_1' d^3p_2'}{E_1 E_2}
\end{aligned}
$$

Structure Function

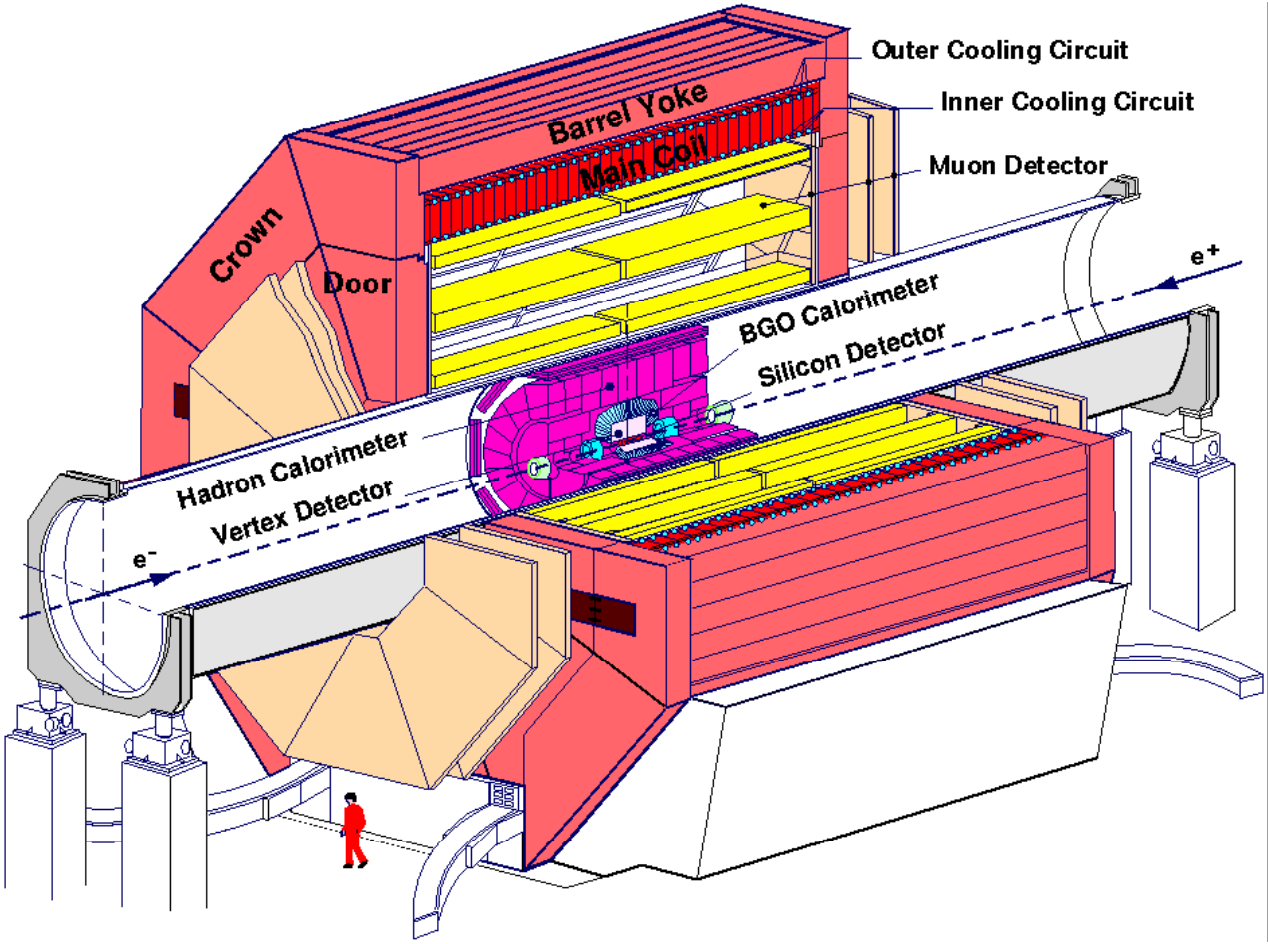
Extraction of $F_{2,QED}^{\gamma}$

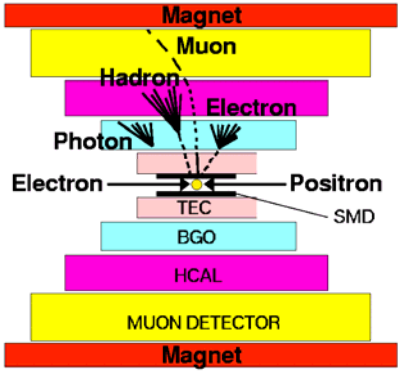
Normalize the portion of $F_{2,QED}^{\gamma}$

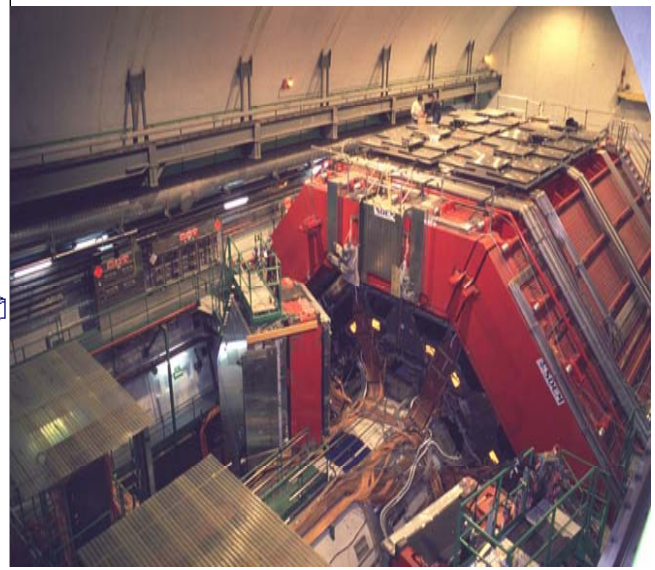
$$F_2(W, q_1^2, q_2^2) \equiv 1$$

$$F_2^{\gamma}/\alpha = \frac{d\sigma_{measured}}{d\sigma_{Galuga, F_2=1}}$$

L3 – The Detector







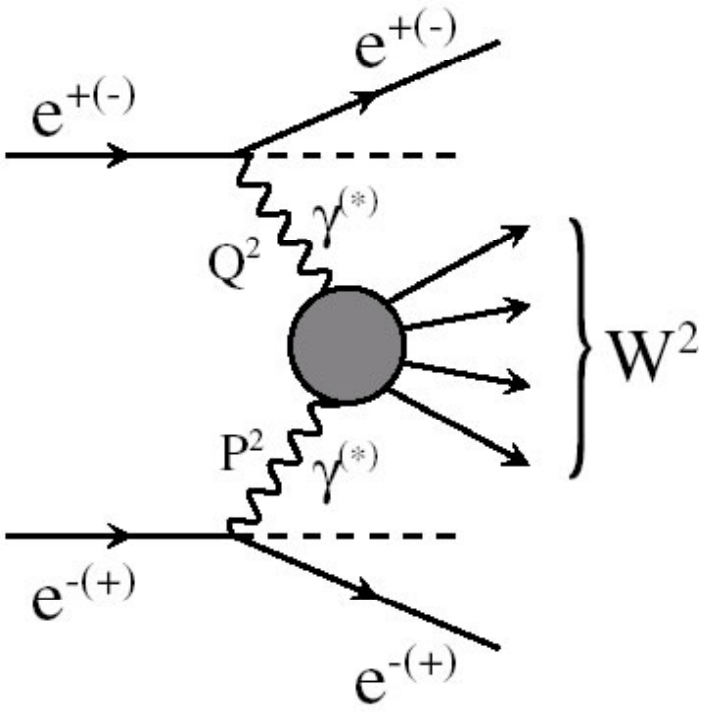
Two-Photon Interactions with Dimuon Events

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

Data sample:

$E_{cms} = 189 \ldots 206\, GeV$

$\mathcal{L}_{int} = 600\, pb^{-1}$



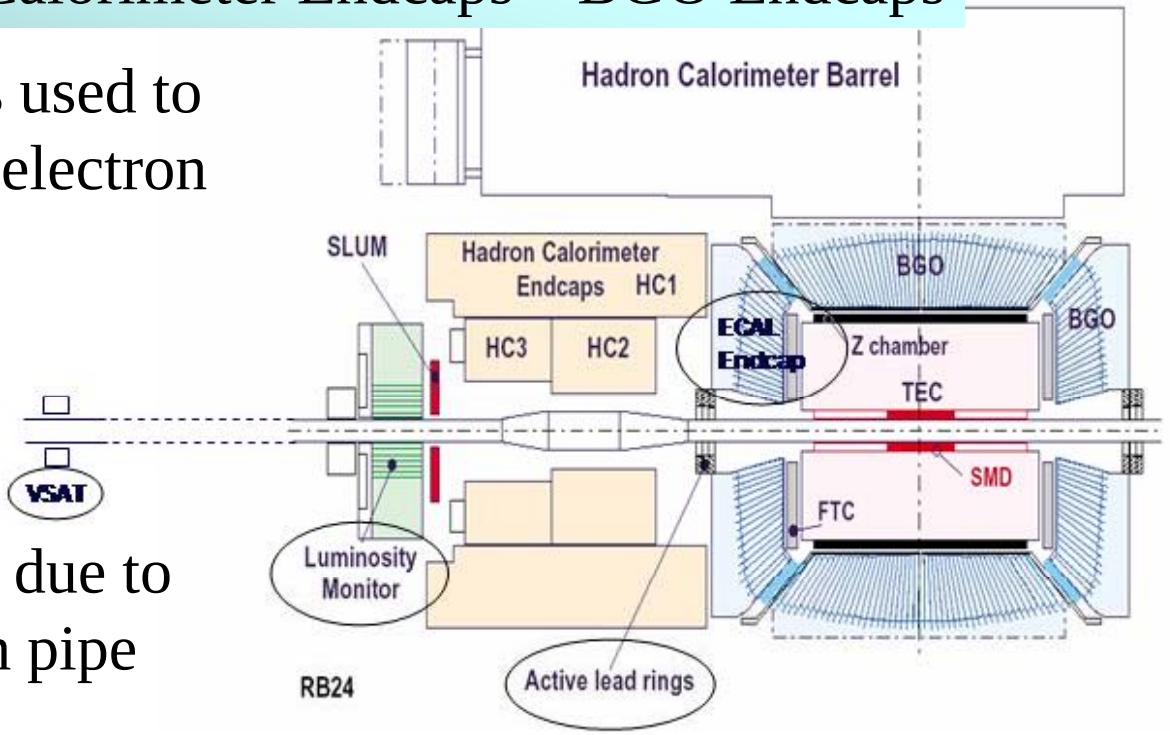
Event Signature:

- Single Tagged Electron, High Energy Deposition in Electromagnetic Calorimeters
- Two tracks, at least one to be identified as a lepton ($\mu^{\pm}$)
- VERMASEREN Monte Carlo generator

L3 Tagging Subdetectors

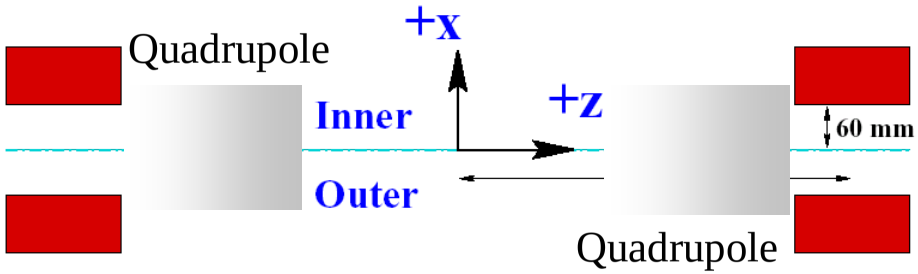
Very Small Angle Tagger – VSAT
Luminosity Monitor – LUMI
Active Lead Ring – ALR
Electromagnetic Calorimeter Endcaps – BGO Endcaps

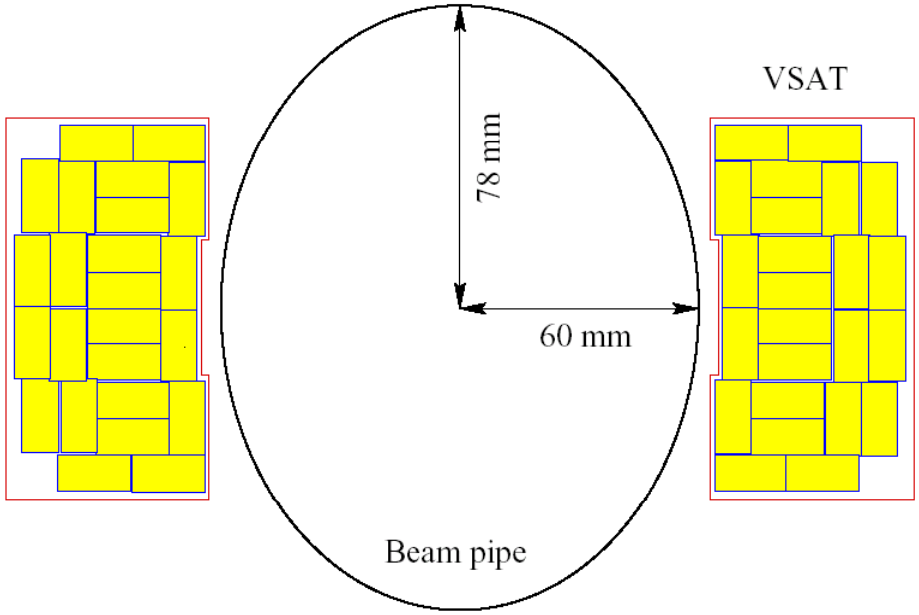
Tagging detectors used to identify scattered electron

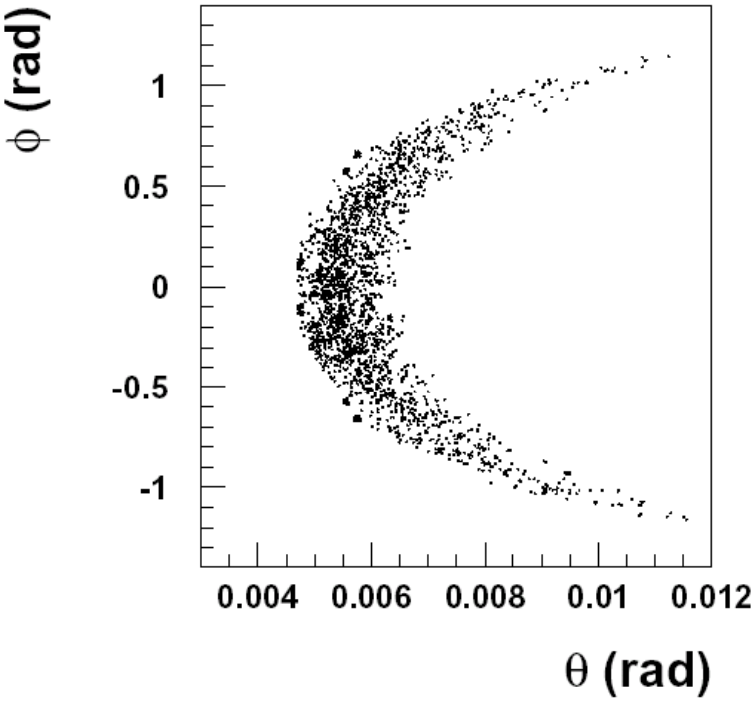


VSAT: background due to proximity to beam pipe

L3 Tagging Subdetectors: VSAT







Selection Criteria

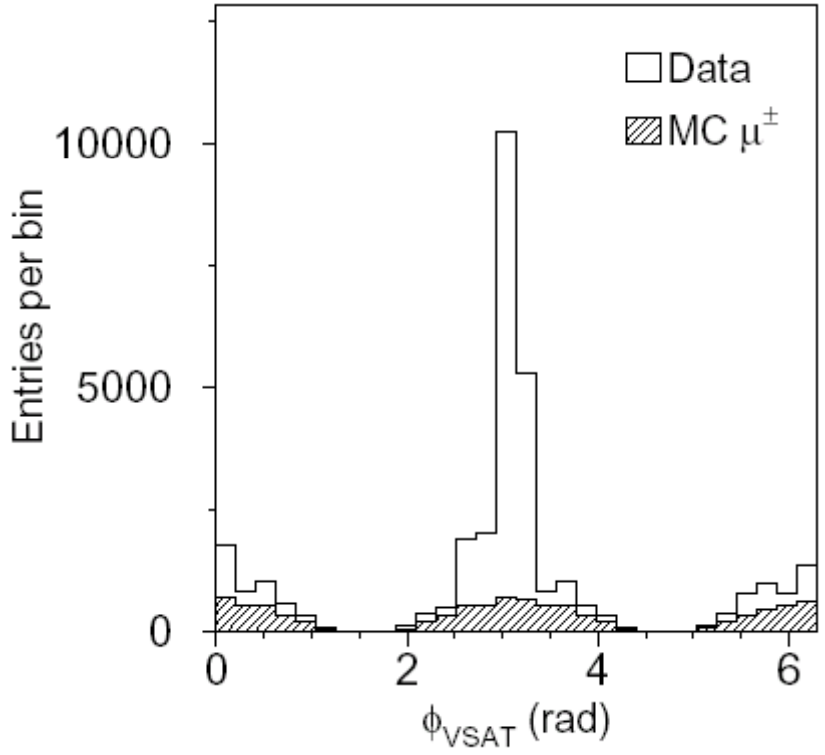
- Single tag: $0.5 \times E_{beam} \leq E_{VSAT}$
  and only one
- Two well-measured tracks with $\Sigma Q_i = 0$
- At least one track to be identified as μ
- Squared four-momentum transfer:

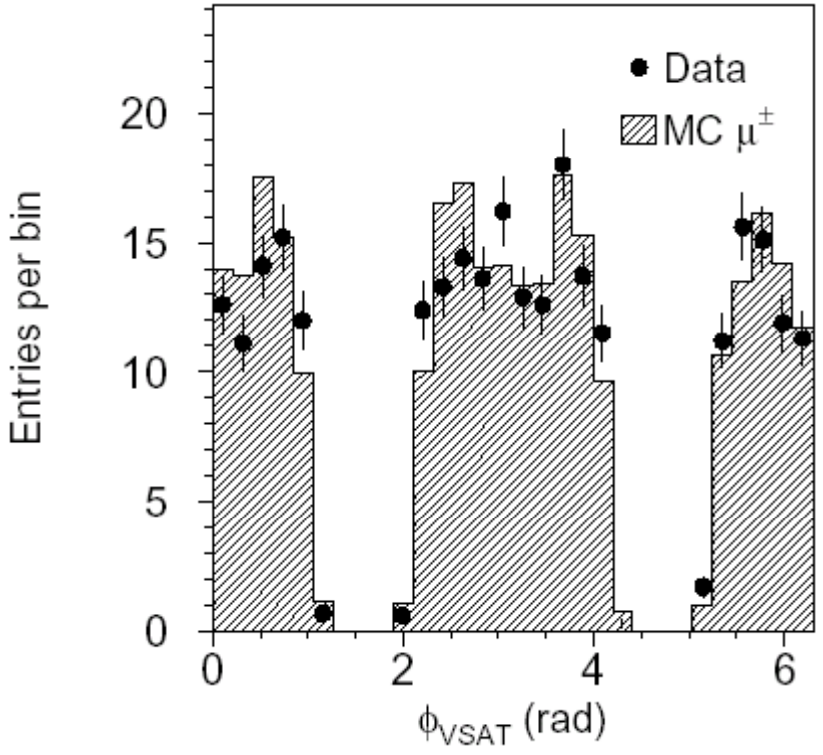
$$0.2\,GeV^2 \leq Q^2 \leq 0.85\,GeV^2$$

with track information: $Q^2 = (\vec{p}_{T,1} + \vec{p}_{T,2})^2$

Selection Criteria

"Cleans" up from unidentified background





Background sources

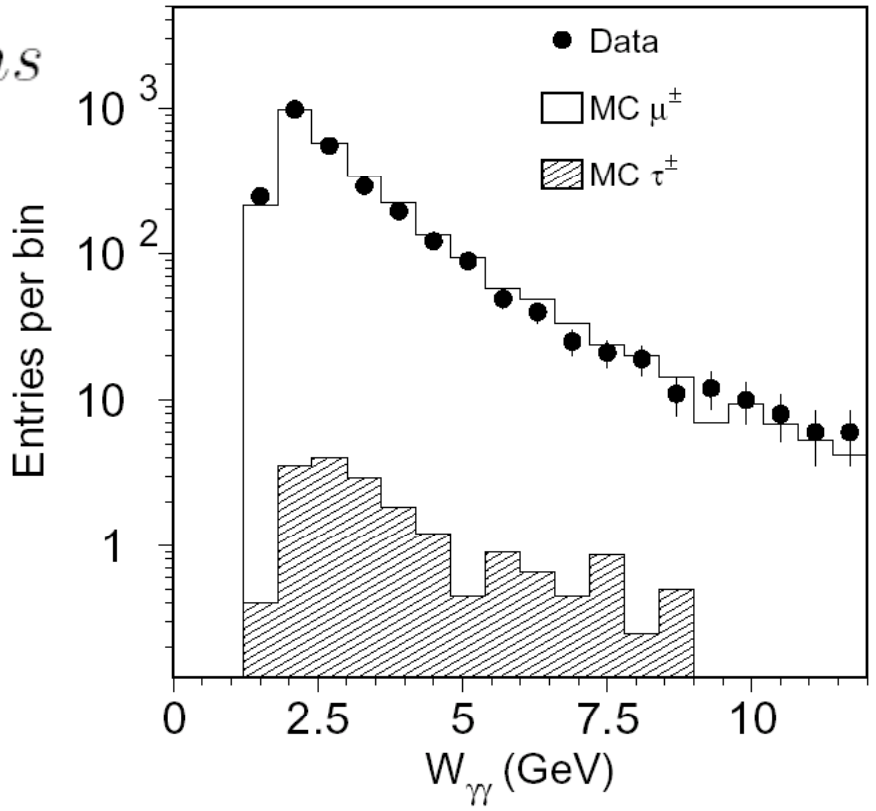
$$e^-e^+ \to e^-e^+l^-l^+ \ (l = e, \mu)$$ → Non Multiperipheral

$$e^-e^+ \to e^-e^+q\bar{q} \to hadrons$$

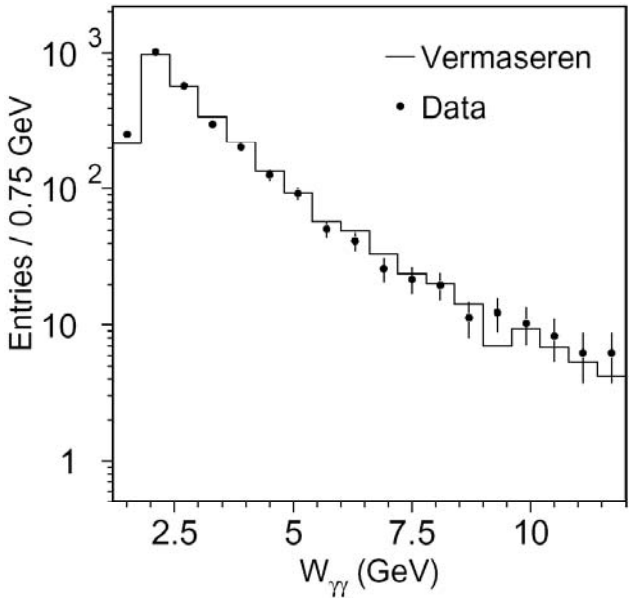
$$e^-e^+ \to e^-e^+e^-e^+$$

$$e^-e^+ \to e^-e^+\tau^-\tau^+$$

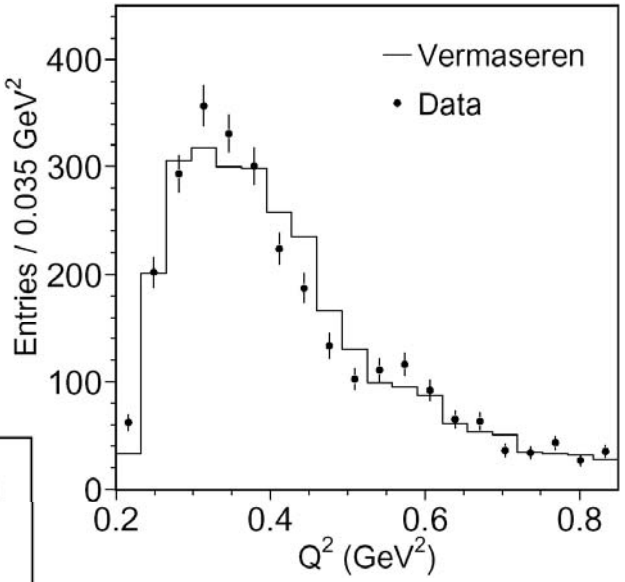
$$e^-e^+ \to e^-e^+\mu^-\mu^+(\gamma)$$

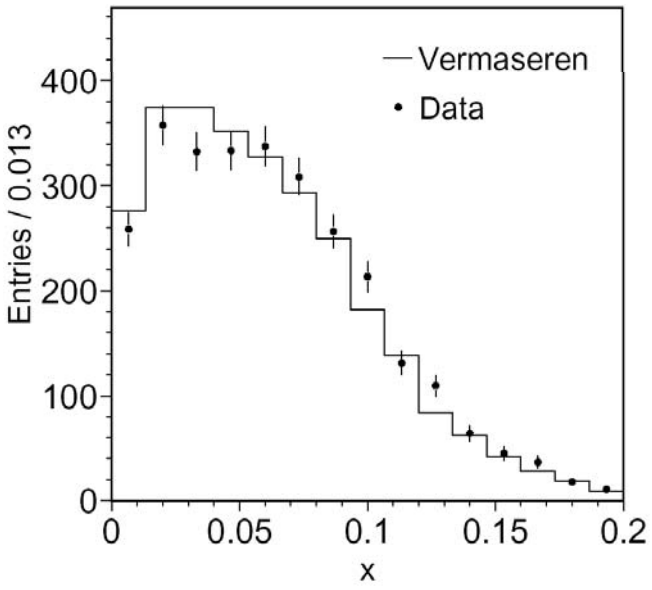


Data Analysis Summary



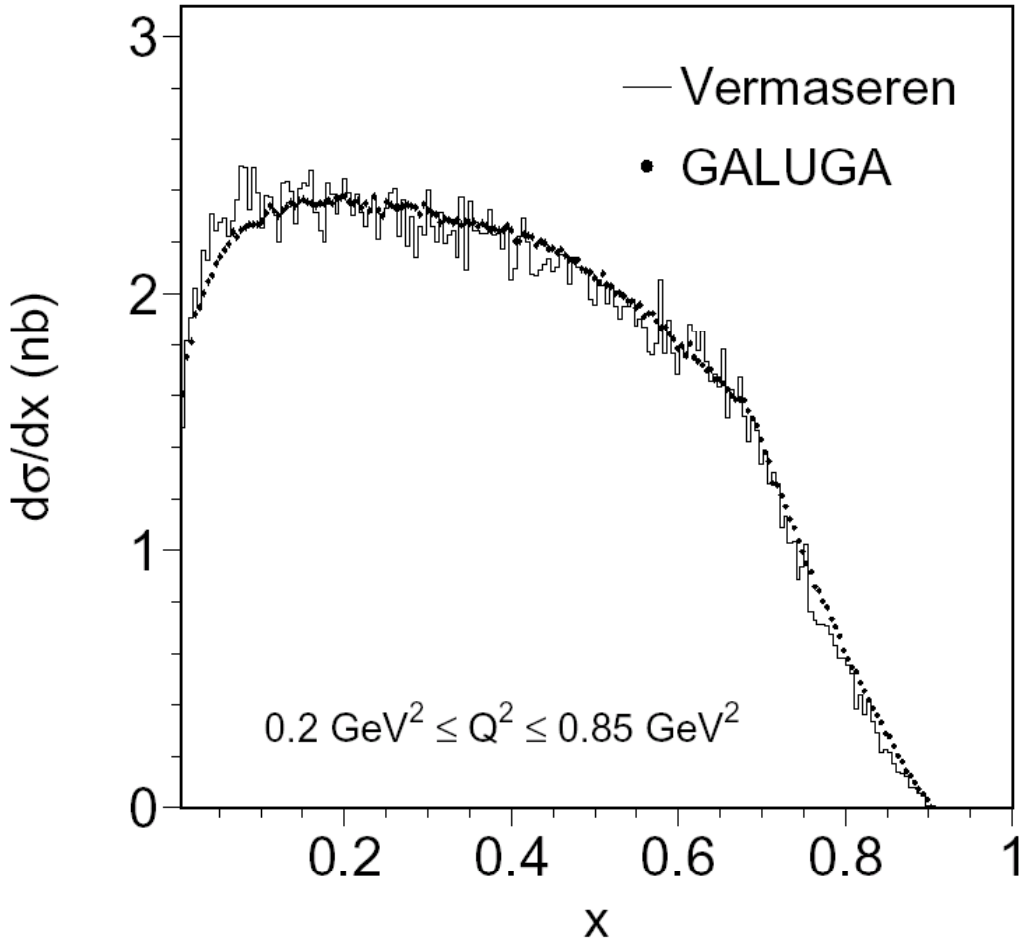
$$N_{physical} = \frac{N_{data} - N_{background}}{\varepsilon_{trigger}}$$



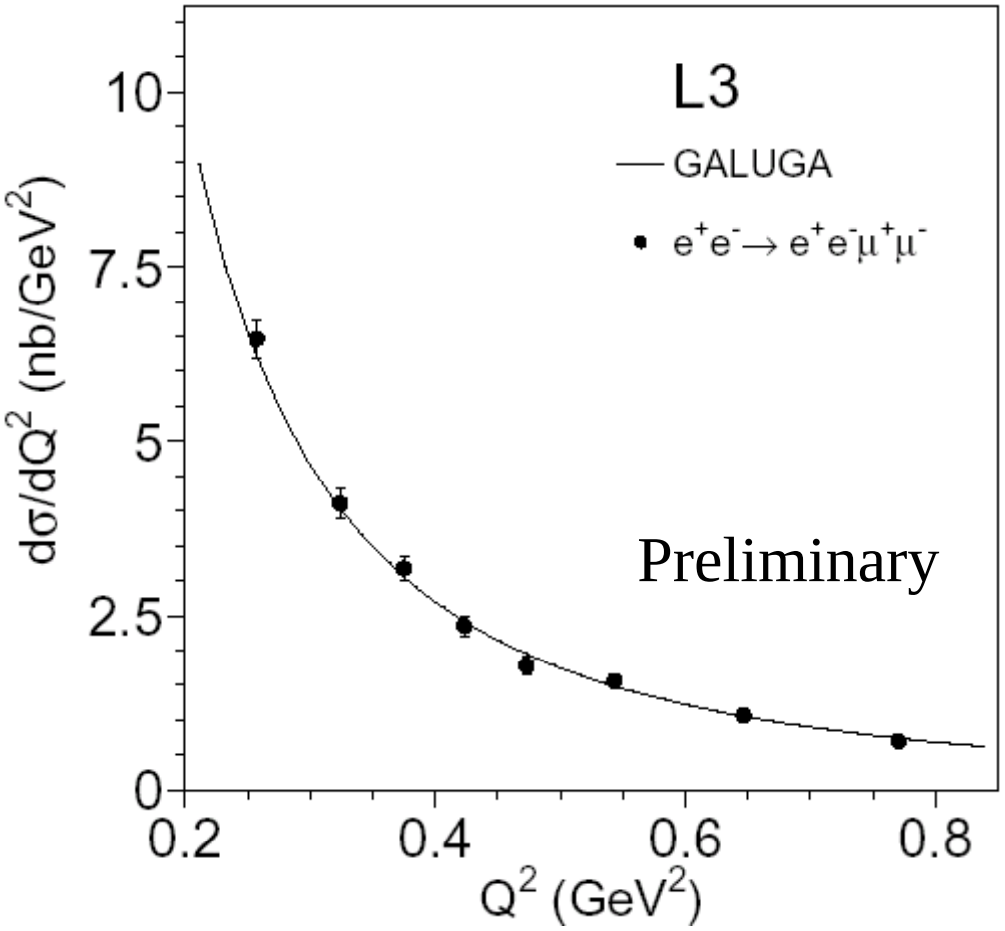


Cross-Section & Structure-Function VERMASEREN - GALUGA

Adaptation of parameters
GALUGA - VERMASEREN



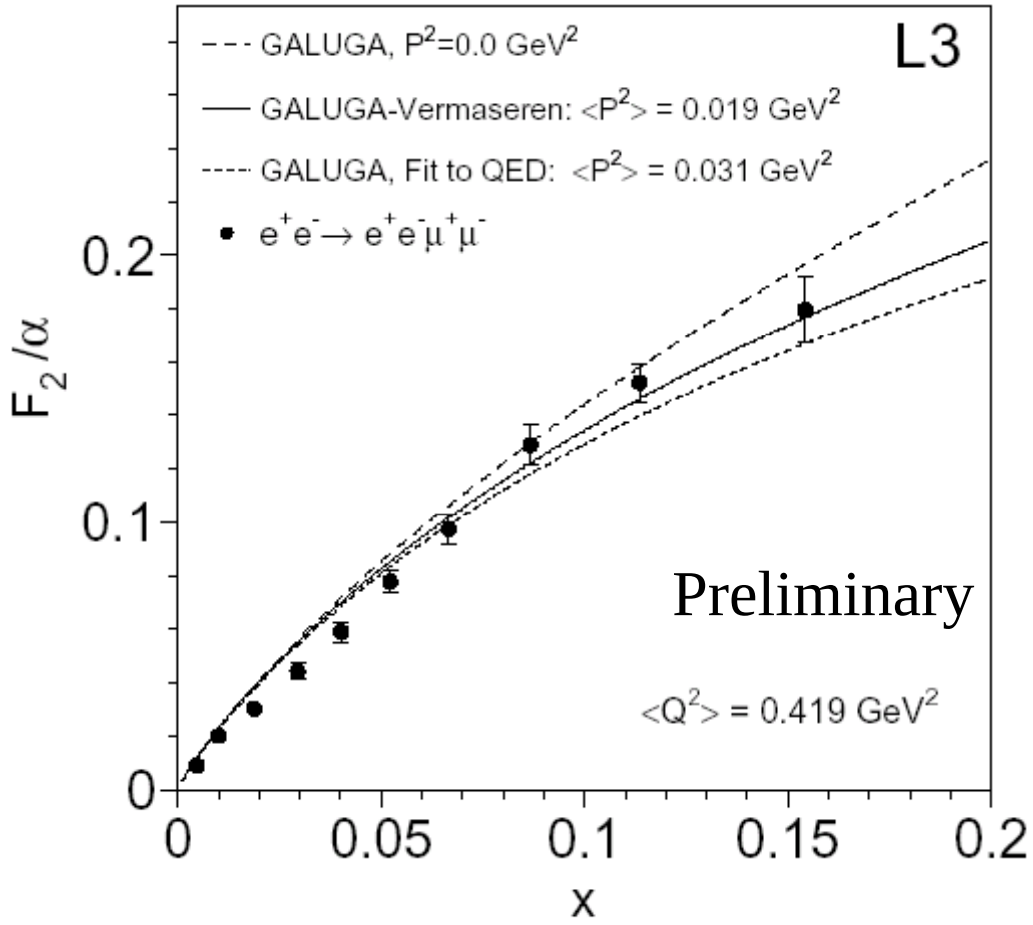
Cross-Section & Structure-Function VERMASEREN - GALUGA



Differential Cross-Section

$$\frac{d\sigma}{dQ^2} = \frac{N_{data}}{\Delta Q^2 \cdot \mathcal{A} \cdot \varepsilon \cdot \mathcal{L}}$$

Cross-Section & Structure-Function VERMASEREN - GALUGA



Leptonic Structure-Function

F_2

Limited x-range

due to small Q^2

Summary

- ✓ Measurement of
  - differential cross-section $\frac{d\sigma}{dQ^2}$
  - structure-function $F_{2,QED}^{\gamma}$

  in the kinematical range $0.2\,GeV^2 \leq Q^2 \leq 0.85\,GeV^2$, $189\,GeV \leq \sqrt{s} \leq 206\,GeV$
- ✓ Data suggest $P^2 > 0$

Outlook

- ✓ Measurement of
  - differential cross-section $\frac{d\sigma}{dQ^2}$
  - structure-function $F_{2,QED}^{\gamma}$

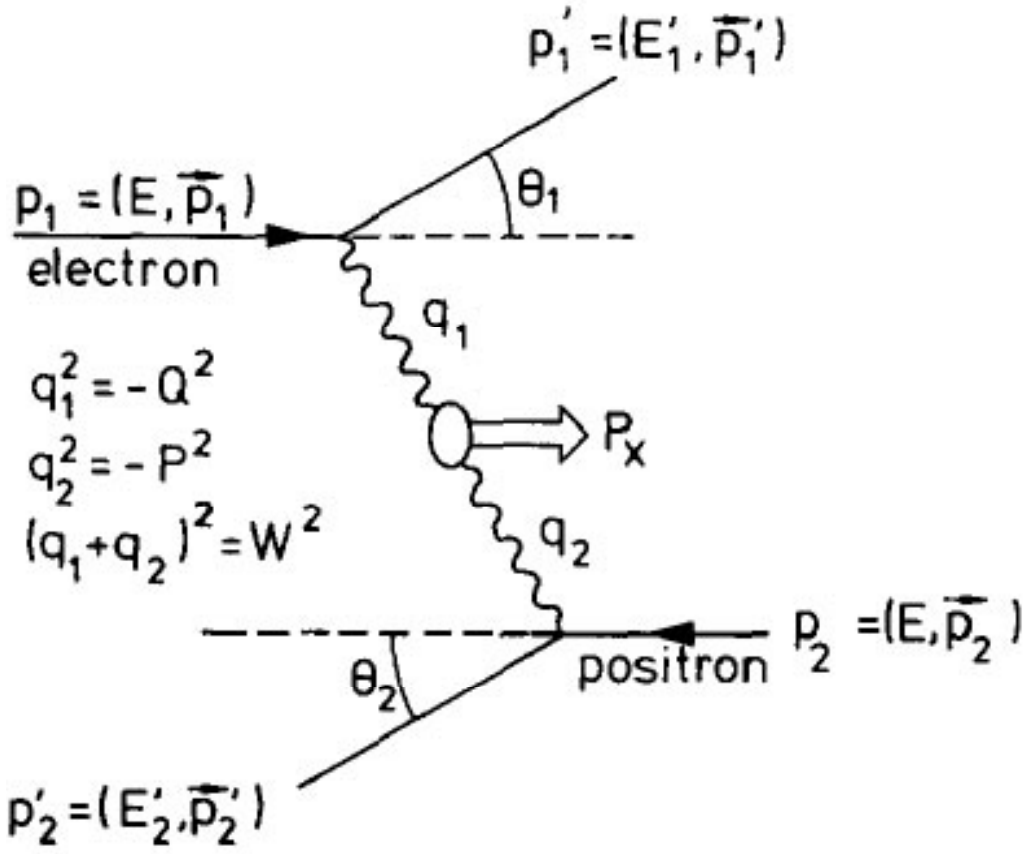
with LUMI in progress

Backup Slides

Dilepton Formalism

Tagging cases:

1. Single Tag
2. Anti Tag
3. Double Tag



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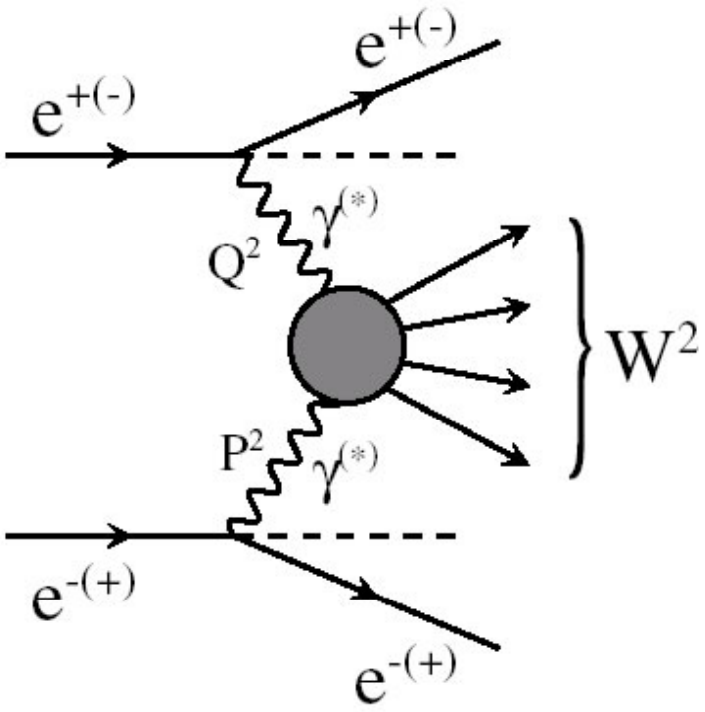

Data sample:

$E_{cms} = 189 \ldots 206\,GeV$

$\mathcal{L}_{int} = 600\,pb^{-1}$

$$\begin{aligned} Q^2 &= \left(\vec{p}_{T,1} + \vec{p}_{T,2}\right)^2 \\ x &= \frac{Q^2}{Q^2 + P^2 + W^2_{\gamma\gamma}} \\ &= \frac{Q^2}{Q^2 + W^2_{\mu\mu}} \\ &\Rightarrow \quad P^2 = 0 \end{aligned}$$

Two-Photon Interactions with Dimuon Events

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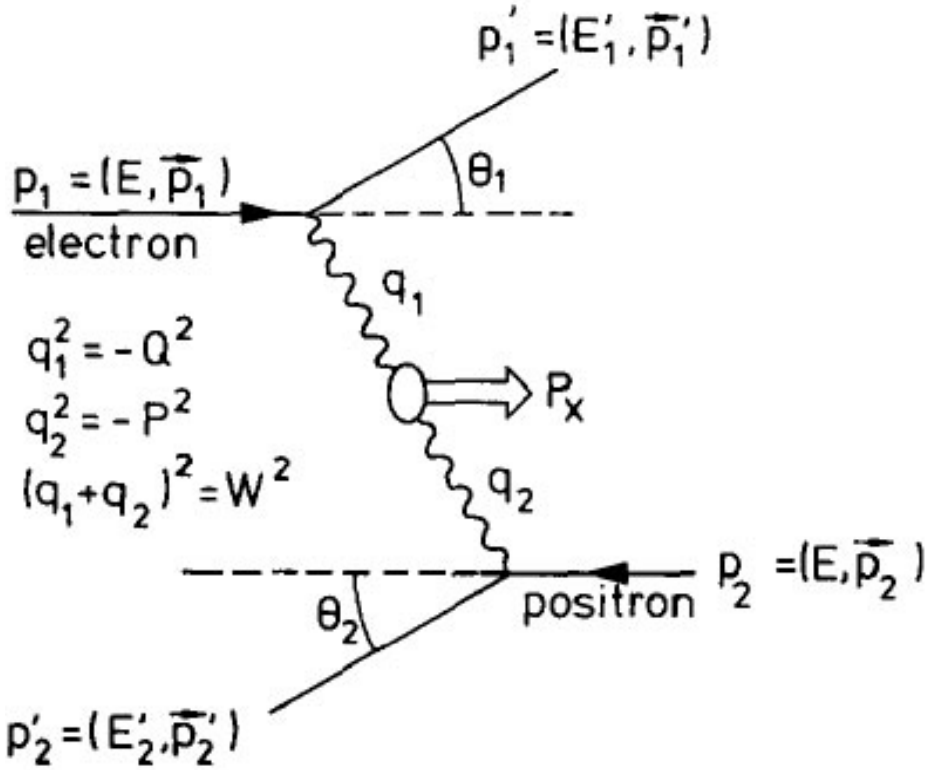

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$E_{cms} = 189 \ldots 206\,GeV$

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$$\begin{aligned} Q^2 &= \left(\vec{p}_{T,1} + \vec{p}_{T,2}\right)^2 \\ x &= \frac{Q^2}{Q^2 + P^2 + W^2_{\gamma\gamma}} \\ &= \frac{Q^2}{Q^2 + W^2_{\mu\mu}} \\ &\Rightarrow \; P^2 = 0 \end{aligned}$$

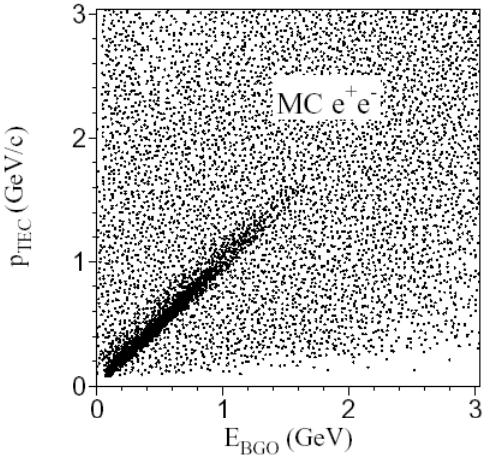
Trigger Efficiency

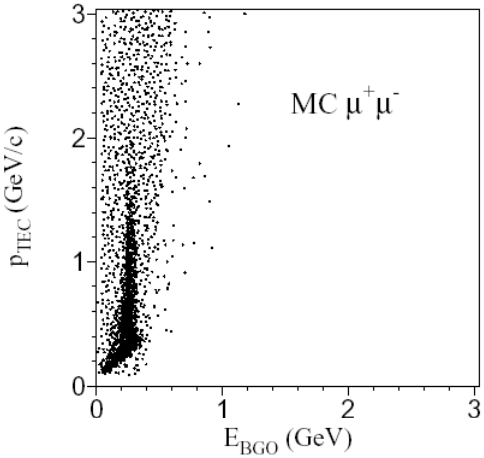
Bit Code	Trigger description
1	Level 0 muon trigger
2	Inner TEC trigger
3	Forward/Backward muon trigger
5	Prescaled LUMI (single tag)
6	Scintillator for muon trigger coincidence
7	Muon trigger
8	TEC trigger
9	Level 0 energy trigger
10	Fast lumi trigger , flagging only
11	LUMI trigger
12	Scintillator multiplicity trigger
13	Beam gate
14	Cosmic trigger
15	Energy trigger

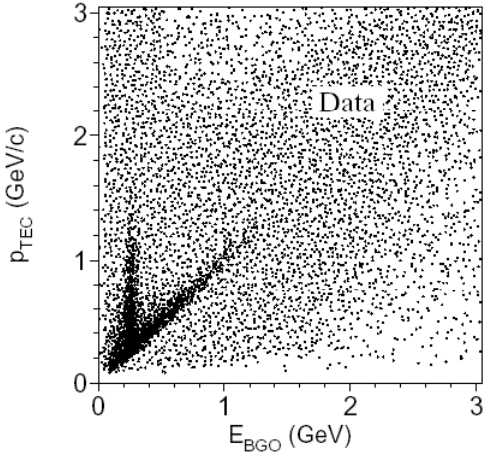
Channel	Trigger Bit	Fraction in %
$ee \rightarrow ee\mu\mu$	1	18.5
	2	55.2
	3	5.2
	6	96.8
	7	14.6
	8	80.8
	15	2.8

Selection Criteria

- Muon identification:





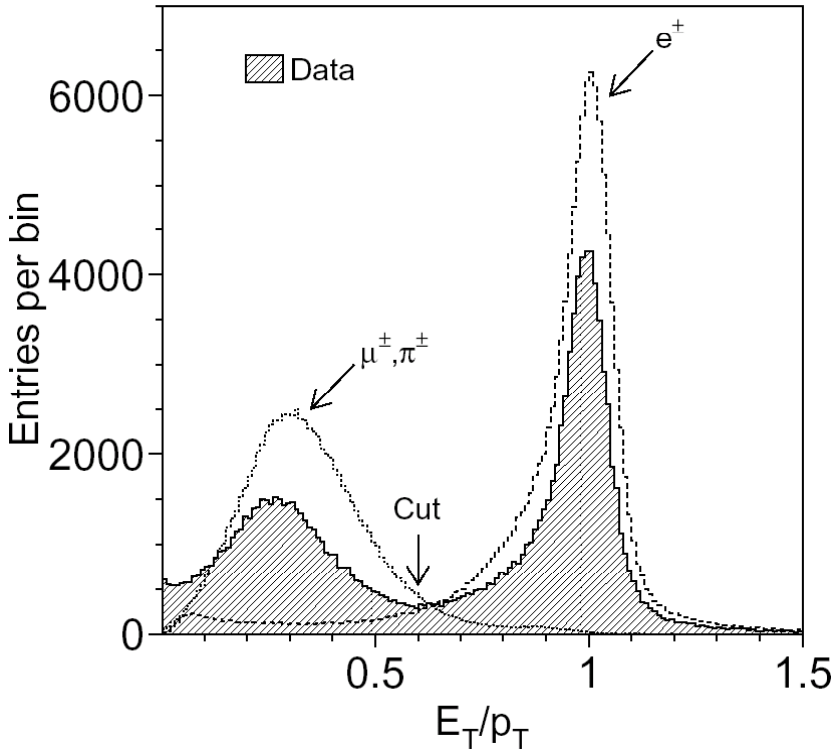


$$E_{BGO} \leq 0.4\,GeV$$

Selection Criteria

- Muon identification:

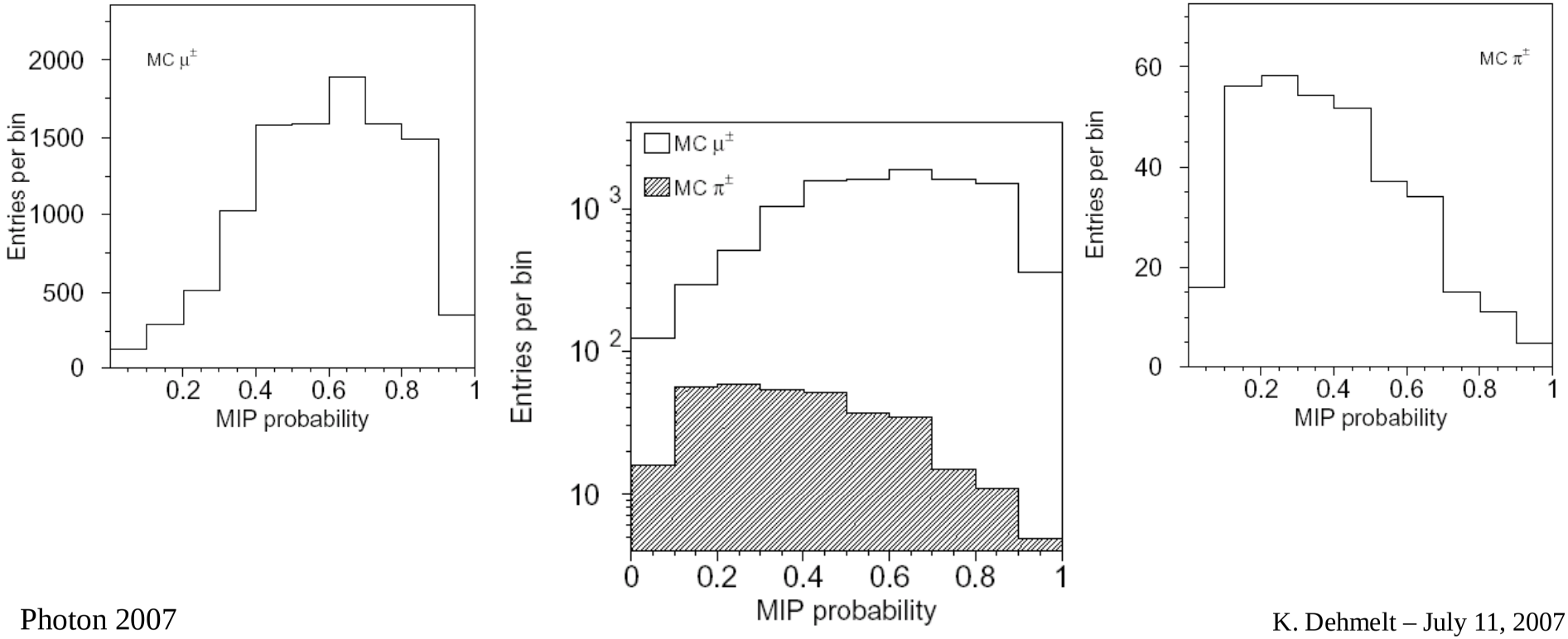
$$E_t/p_t \leq 0.6 \quad \text{with} \quad E_t = E_{BGO} \cdot \sin\theta$$



Selection Criteria

- Muon identification:

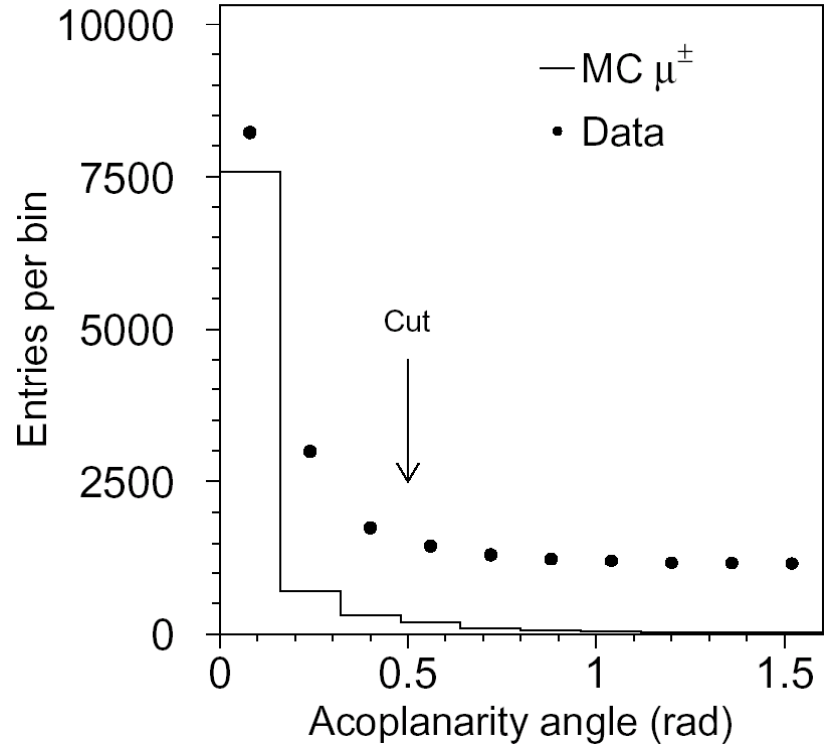
HCAL MIP probability > 0.5



Selection Criteria

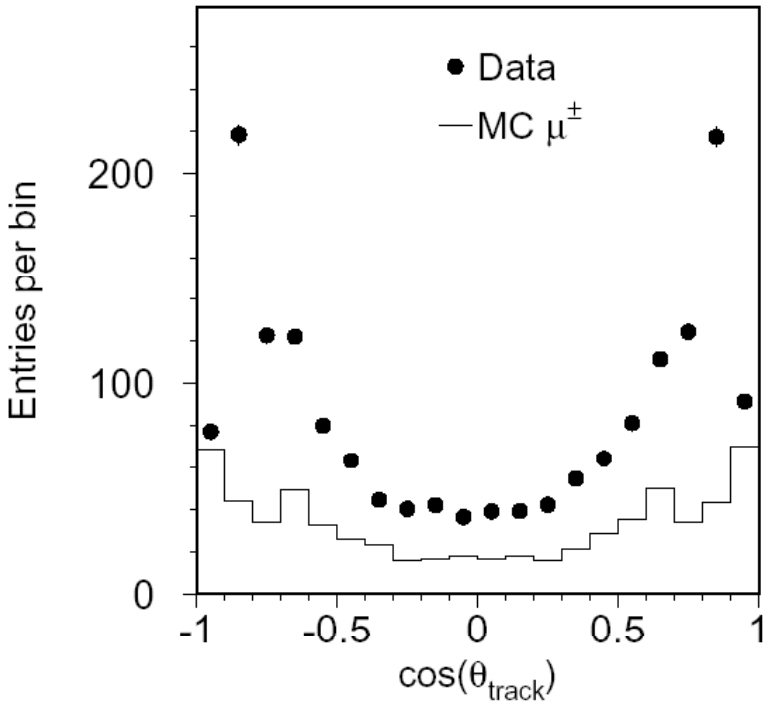
- Muon identification:

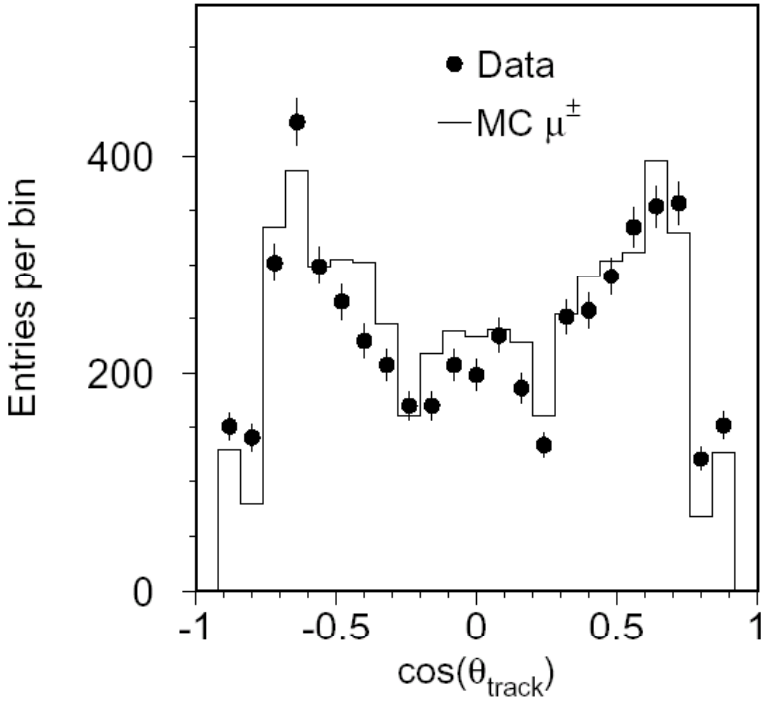
$$\phi_{aco} = \left|\pi - \left(\overline{\phi}_{tracks} - \phi_{VSAT}\right)\right| \leq 0.5 rad$$



Selection Criteria

"Cleans" up from unidentified background



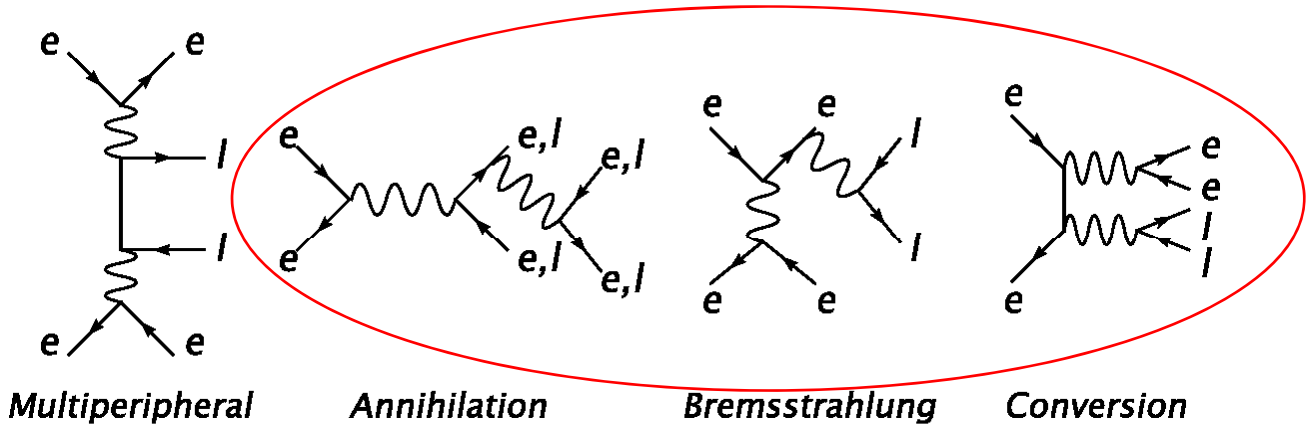


Systematic Error Estimation

Error source	Error contribution (in %)
Luminosity Data	0.06
Luminosity MC	0.90
Background	0.09
Radiative events	0.60
Trigger efficiency	0.12
Selection criteria	2.36
GALUGA	2.16
Total	3.38

Background sources

$$e^- e^+ \rightarrow e^- e^+ l^- l^+ \ (l = e, \mu) \rightarrow \text{Non Multiperipheral}$$



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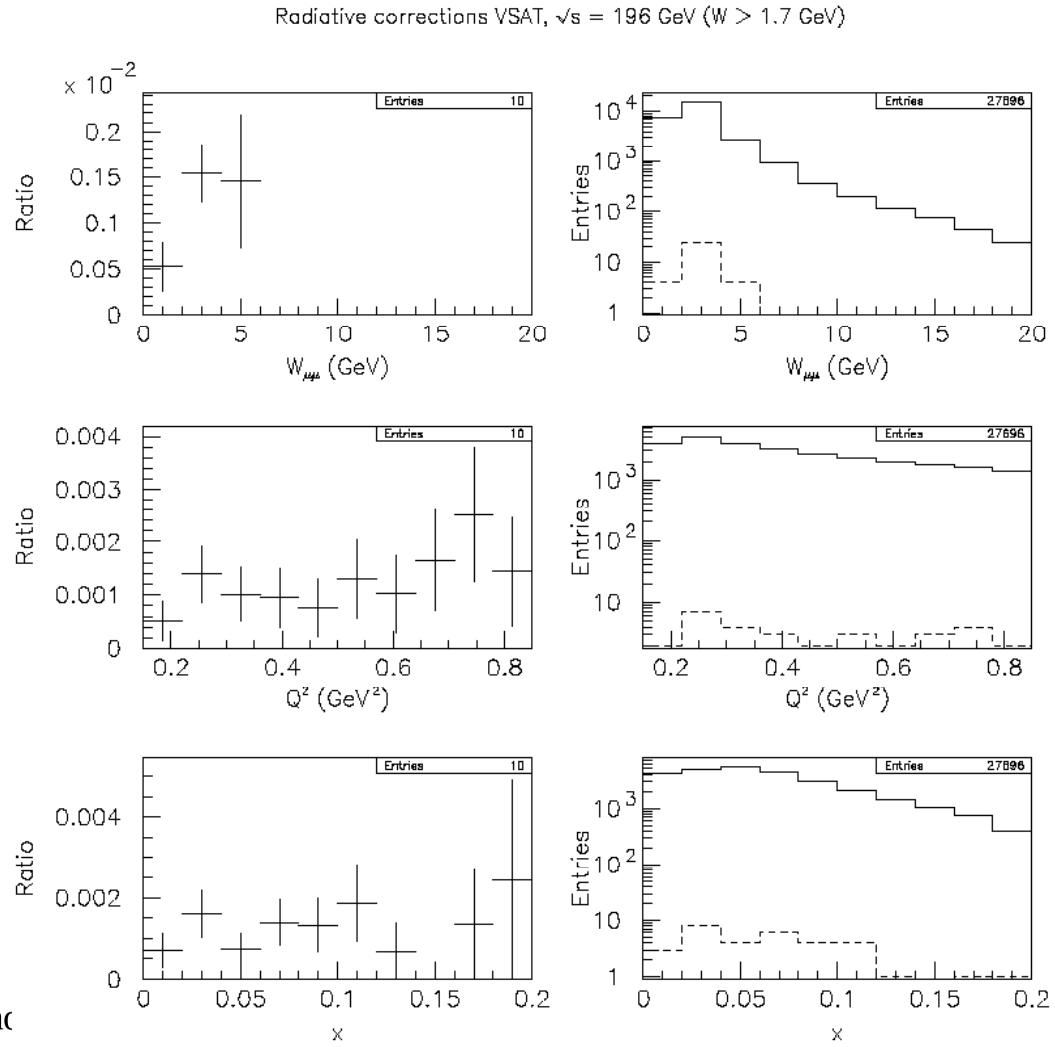
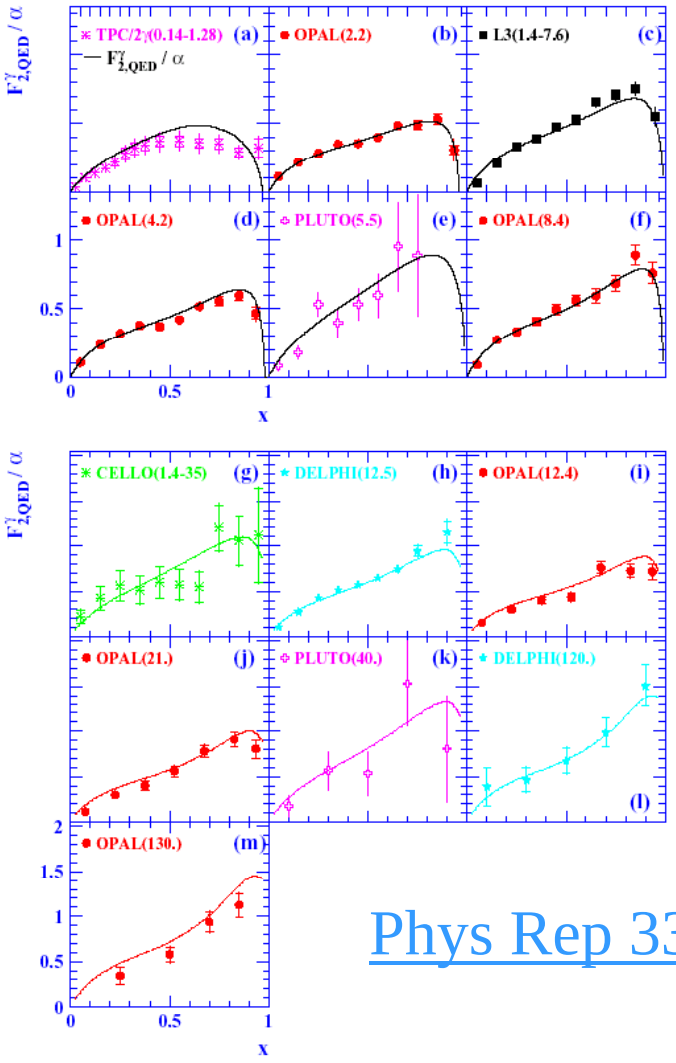


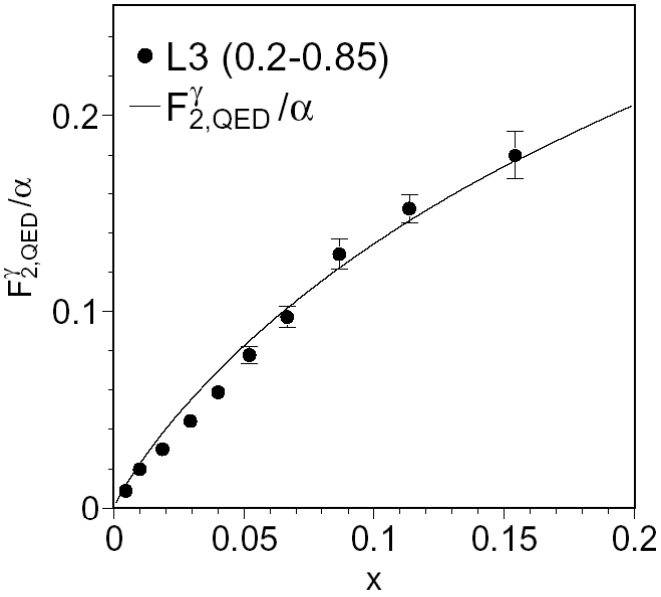
$$e^-e^+ \longrightarrow e^-e^+\mu^-\mu^+(\gamma)$$

Data Analysis Summary

Process	Selected events from data	Expected events from MC	Ratio	Expected Back-ground	Systematic Uncer-tainty
$ee \to ee\mu\mu$	2817±53	2819±53	0.999	0.30%	3.38%

Summary





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