Radiative Corrections in the KTeV |Vus| Analysis

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MOTIVATION

- KTeV determination of $|V_{us}|$ is based on new measurements of

  => six main K_L branching fractions with sub-percent precision (charged BRs includes radiated γ)

  => Ke3 and $K\mu3$ form factors with x3 and x5 better precision than PDG02 (corrected for virtual and real γ)

MOTIVATION

- Rad cor changes B(Ke3) by 3%
- Rad cor changes Kℓ3 form factors by many sigma.

Perspective

Theorist → Radiative corrections

↓

Experimenters

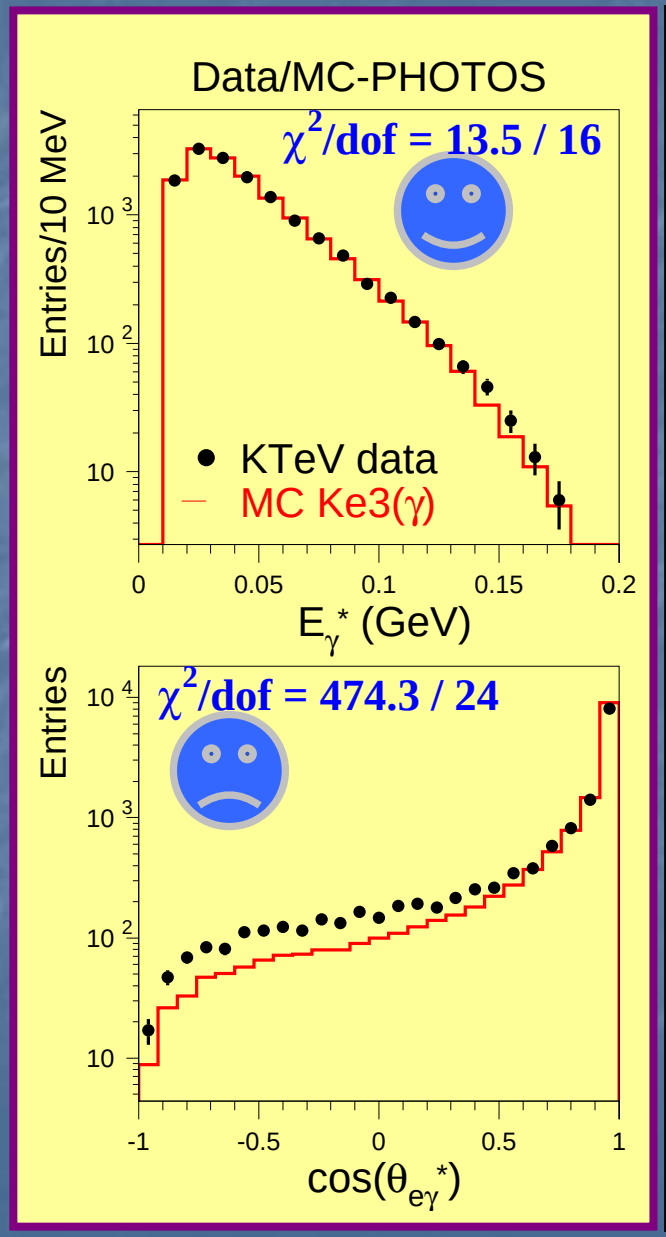
↙ accept with blind faith

↘ make crosschecks

Radcor Options (2003)

Option	***Virtual*** γ	***Real*** γ	***MC generator***
FFS PRD 2, 542 (1970)	no	Yes	Write your own
ChPTh	yes	yes	πe, but no γ (and no $K\mu 3$)
PHOTOS	yes	yes	yes
Start from scratch	?	?	?

What we almost used: PHOTOS



- Re-weight PHOTOS to match data (mainly $\theta_{e\gamma}$)
- Beware: Can only match PHOTOS to 5% of Ke3 data; does NOT correct virtual γ

Note: OK for BR(Kl3), but NOT for form factors

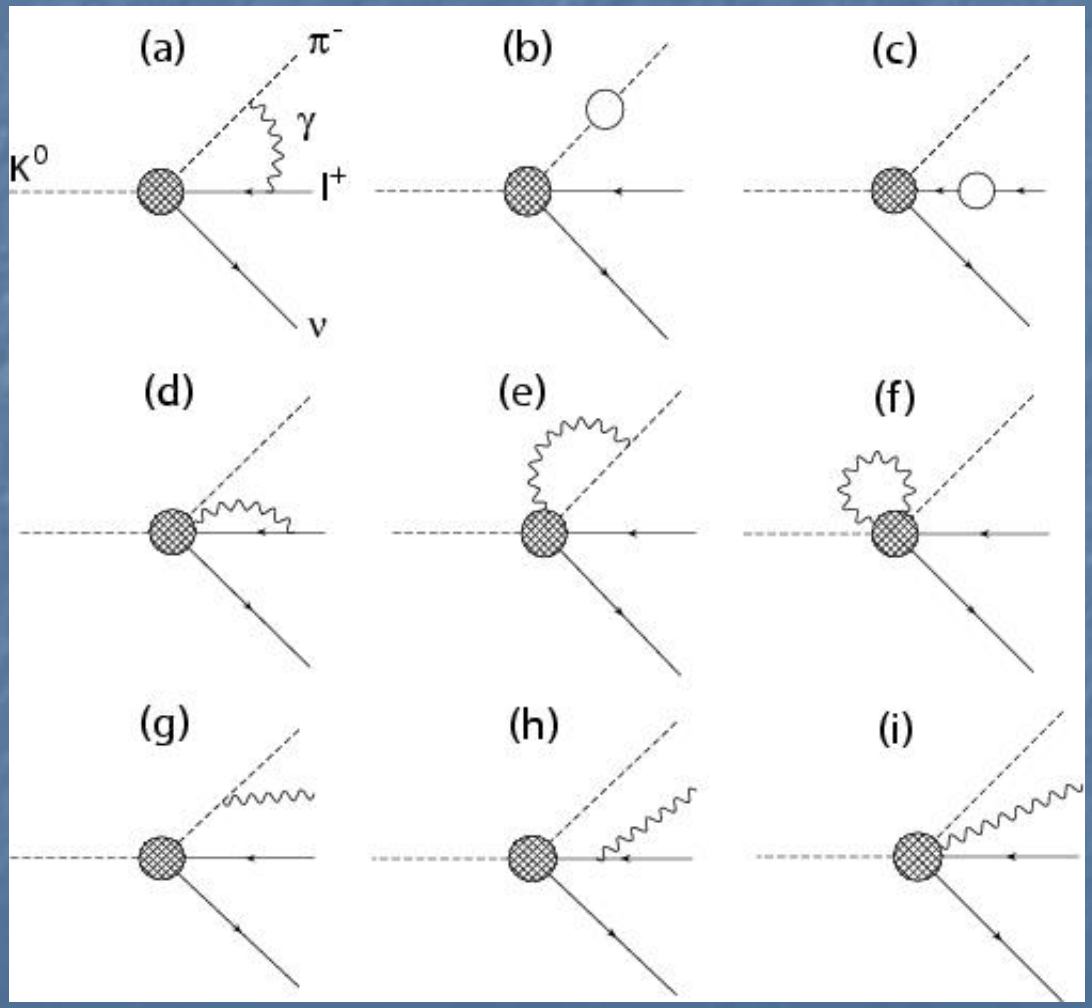
What we used (abandon PHOTOS)

Asked theory graduate student (T. Andre) to write new Kℓ3(γ) generator:

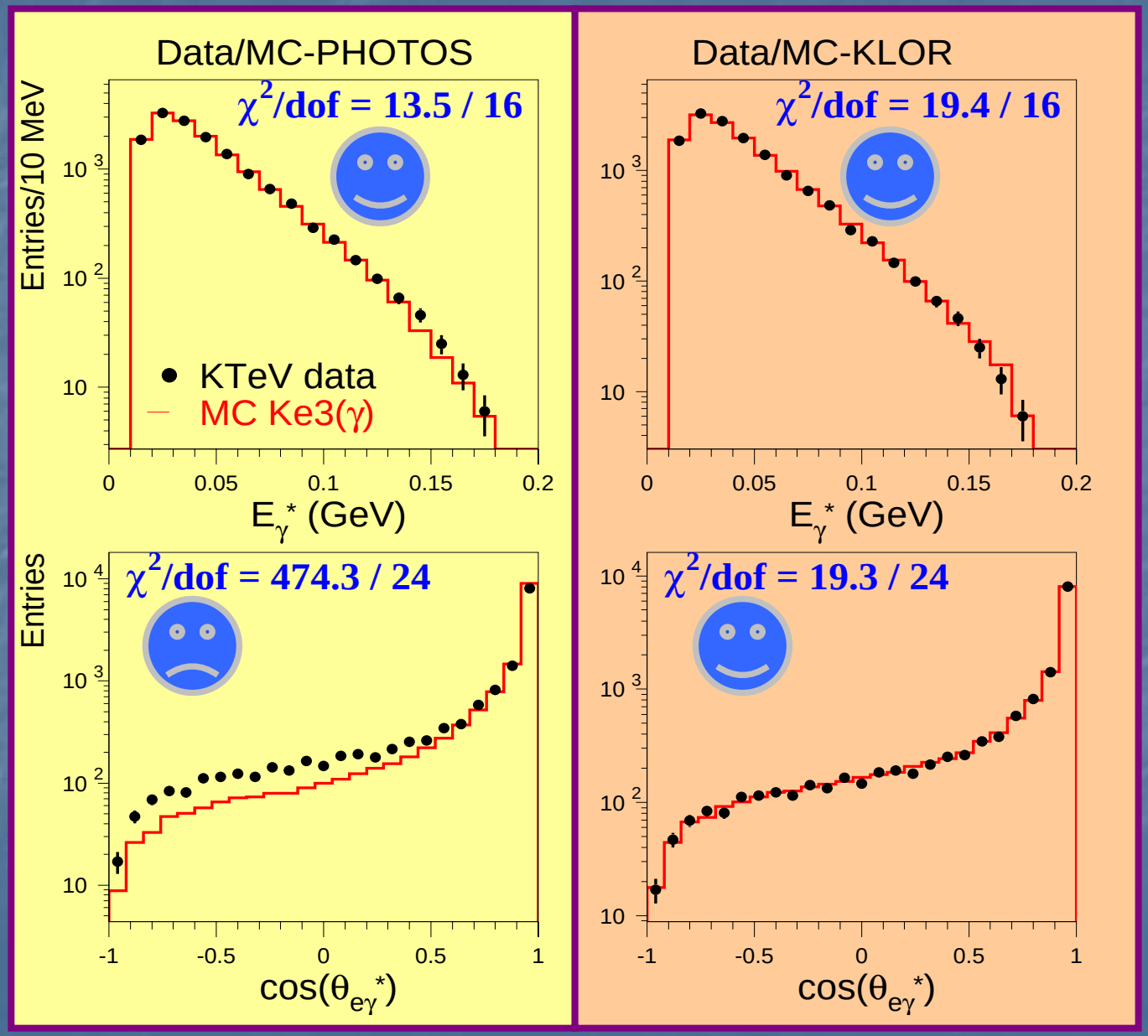
KLOR: Koan Leading Order Radiation

⇒ Ke3(γ) and Kμ3(γ)
⇒ includes 4-body phase space
⇒ virtual and real photons
⇒ Also used to compute long-distance rad-corrections, δ_e and δ_μ
⇒ No tuning to data !

Diagrams Evaluated by KLOR



What we used: KLOR



KTeV Kℓ3γ BRs and plots in: PRD 71, 012001 (2005)

Semileptonic Form Factors (to determine I_K integrals)

$$\Gamma_{K\ell 3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW} (1 + \delta_K^\ell) \, |V_{us}|^2 \, |f_+^2(0)| I_K^\ell$$

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} V_{us} \, [f_+(t)(P_K + P_\pi)_\mu \, \overline{u_\ell} \gamma^\mu (1+\gamma_5) u_\nu + f_-(t)(P_K - P_\pi)_\mu \, \overline{u_\ell} \gamma^\mu (1+\gamma_5) u_\nu],$$

where $t = (P_K - P_\pi)^2$ and

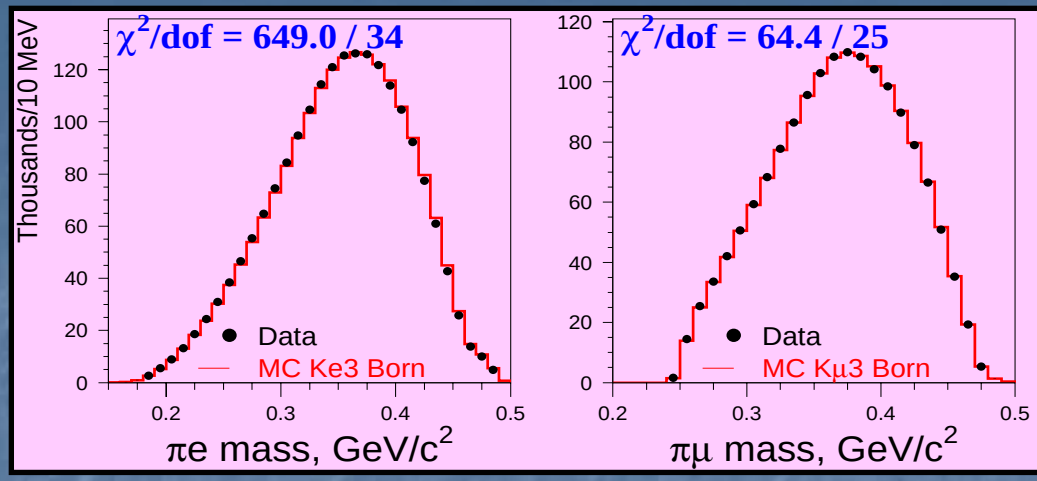
$$f_0(t) = f_+(t) + f_-(t)[t/(m_K^2 - m_\pi^2)]$$

$$I_K^\ell = \mathcal{F}\left(\frac{f_+(t)}{f_+(0)}, \frac{f_0(t)}{f_+(0)}, \Pi_i \frac{d^3\vec{p}_i}{2E_i}\right)$$

[1]

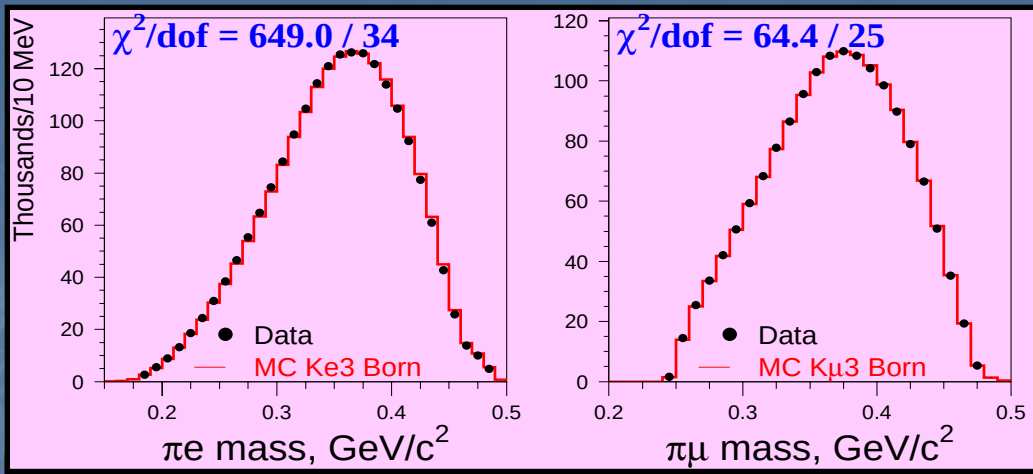
⇒ Assumes pure vector hadron-current.

⇒ Scalar and tensor terms < few percent (NA48)



No rad cor => bad χ^2

pion-lepton mass



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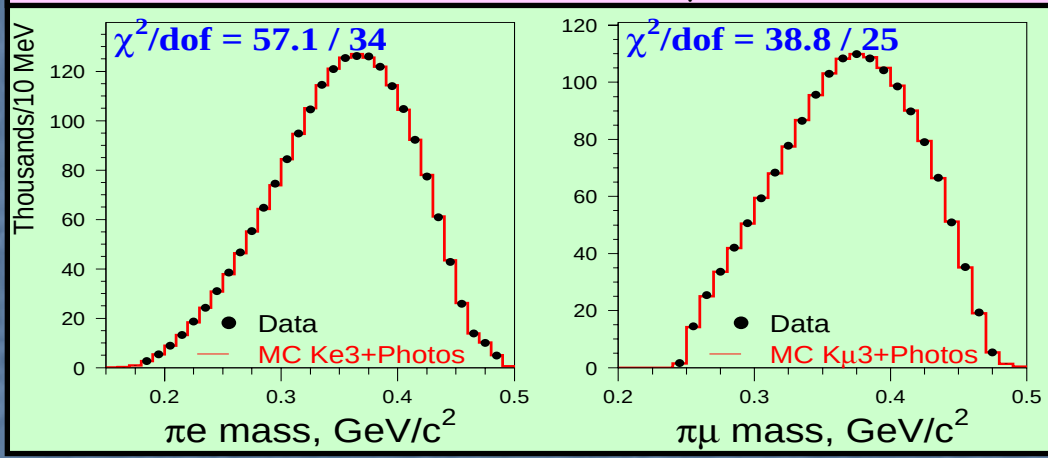
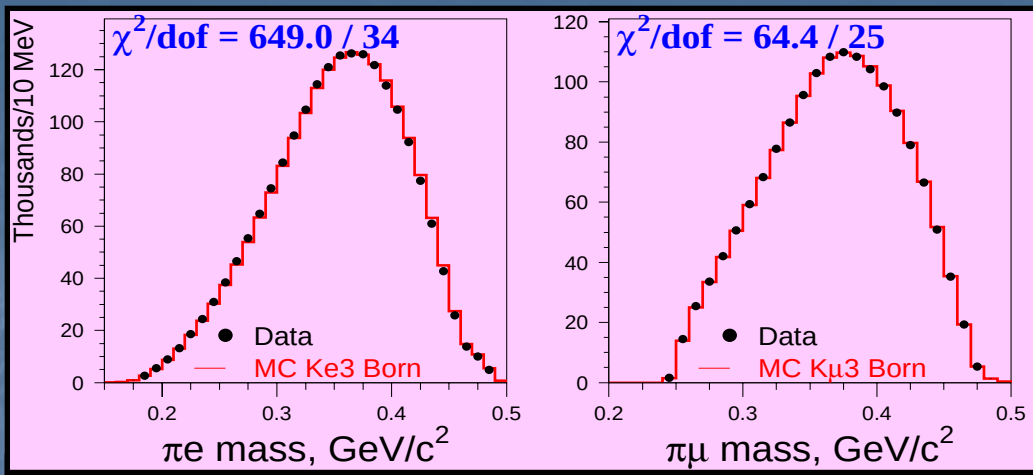
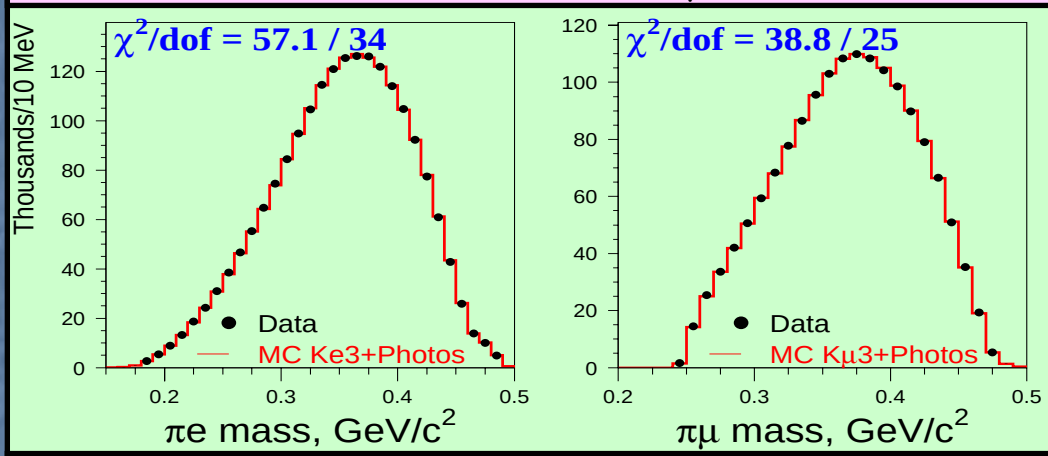


Re-weighted PHOTOS => so-so χ^2

pion-lepton mass



No rad cor => bad χ^2



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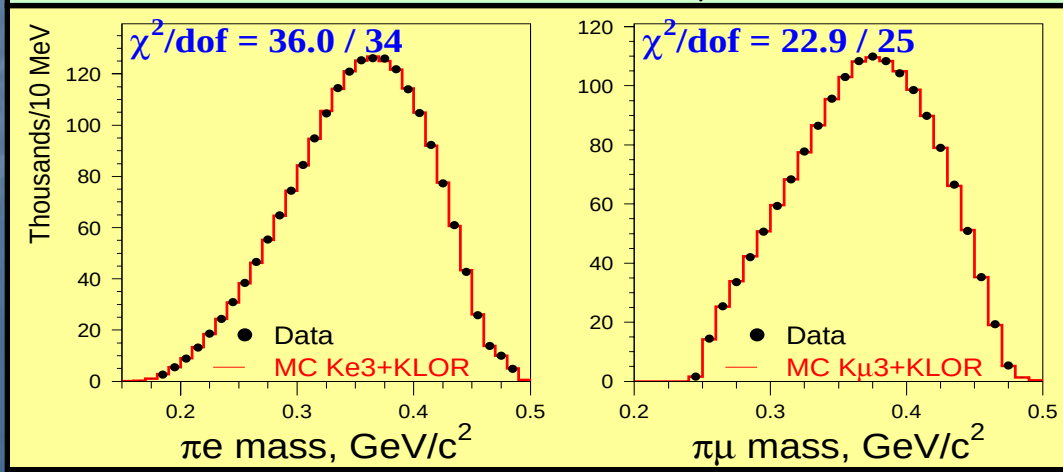
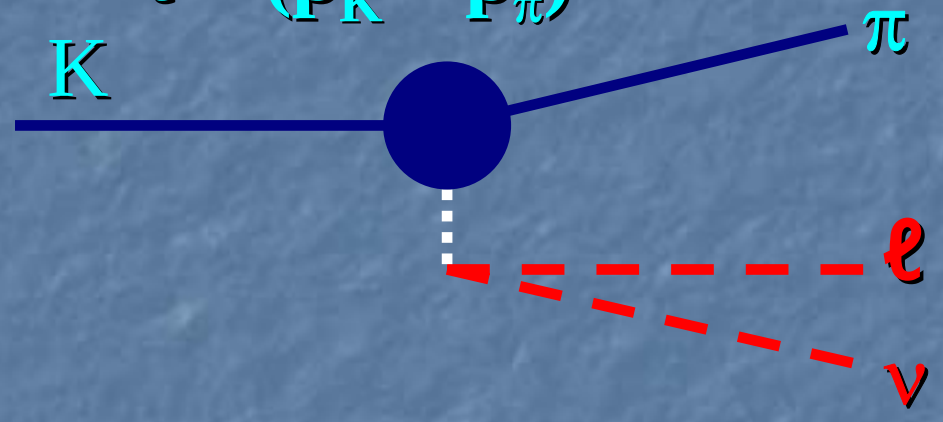


KLOR => excellent χ^2

Form Factor Fitting Techniques

$$t = (p_K - p_\pi)^2$$



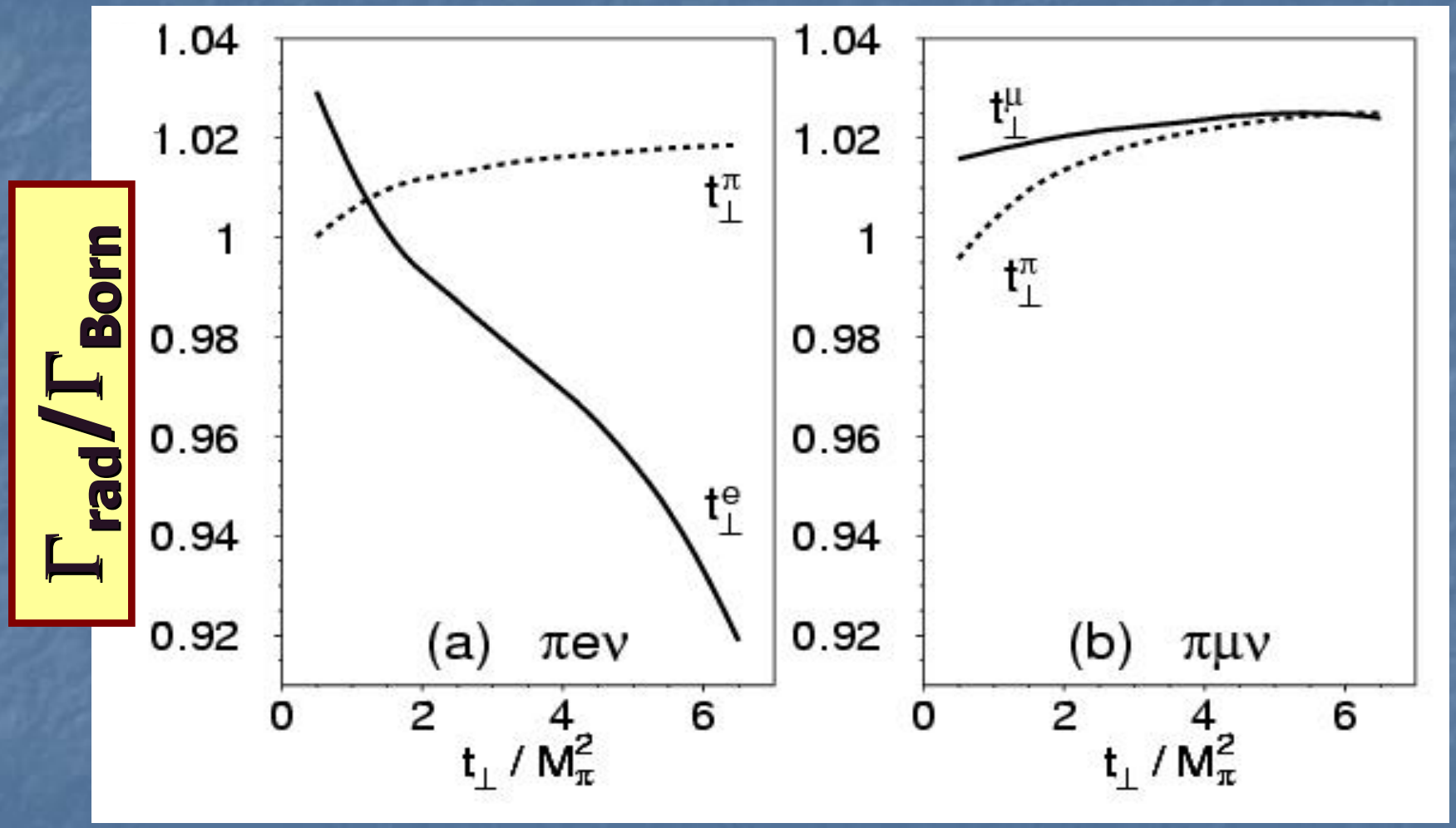
* Kinematic ambiguity => two possible t-values

*To avoid ambiguity, compute "$t_\perp$" using only transverse quantities:

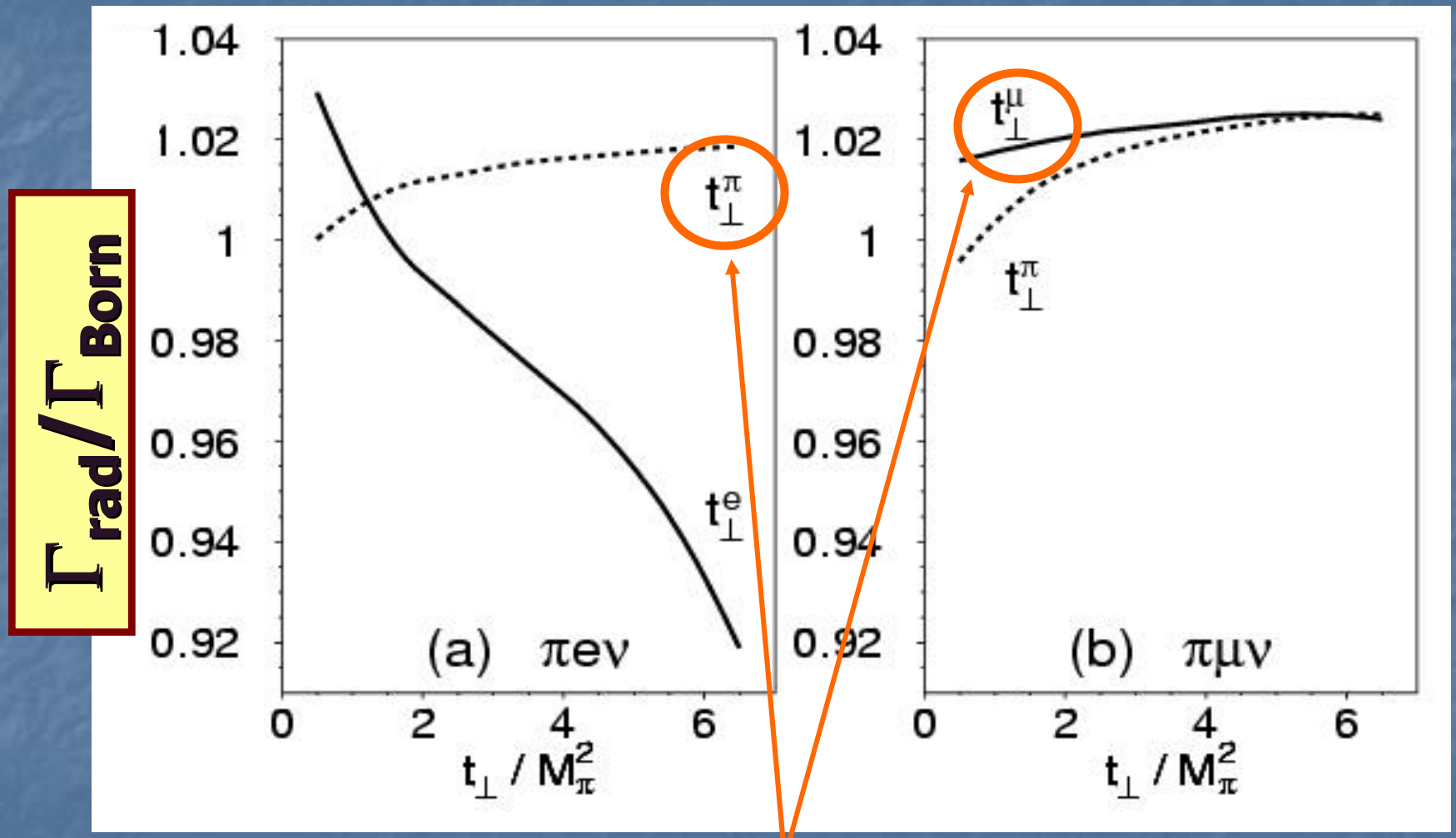
$$t_{\perp,\pi} = (P_{\perp,K} - p_{\perp,\pi})^2 \qquad P_{\perp,K} = (E_K, 0)$$

$$t_{\perp,\ell} = (p_{\perp,\ell} + p_{\perp,\nu})^2$$

Form Factor Fitting Techniques



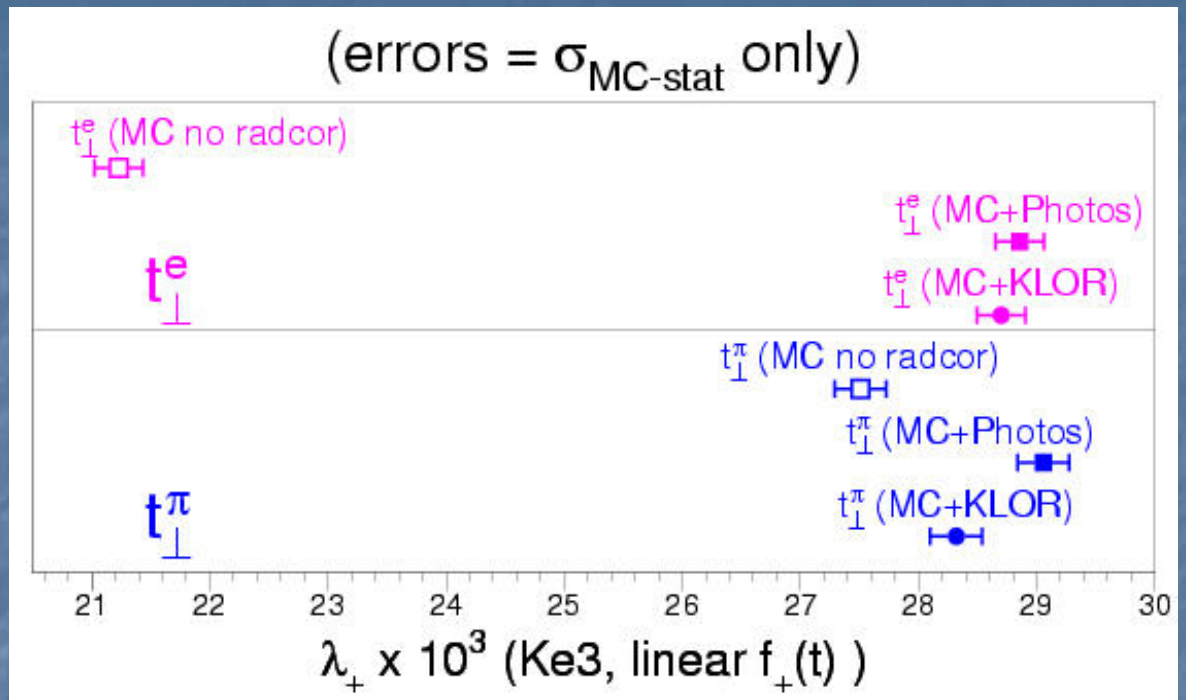
Form Factor Fitting Techniques



Variables used to fit form factors

Form Factor Sensitivity to Radiative Corrections.

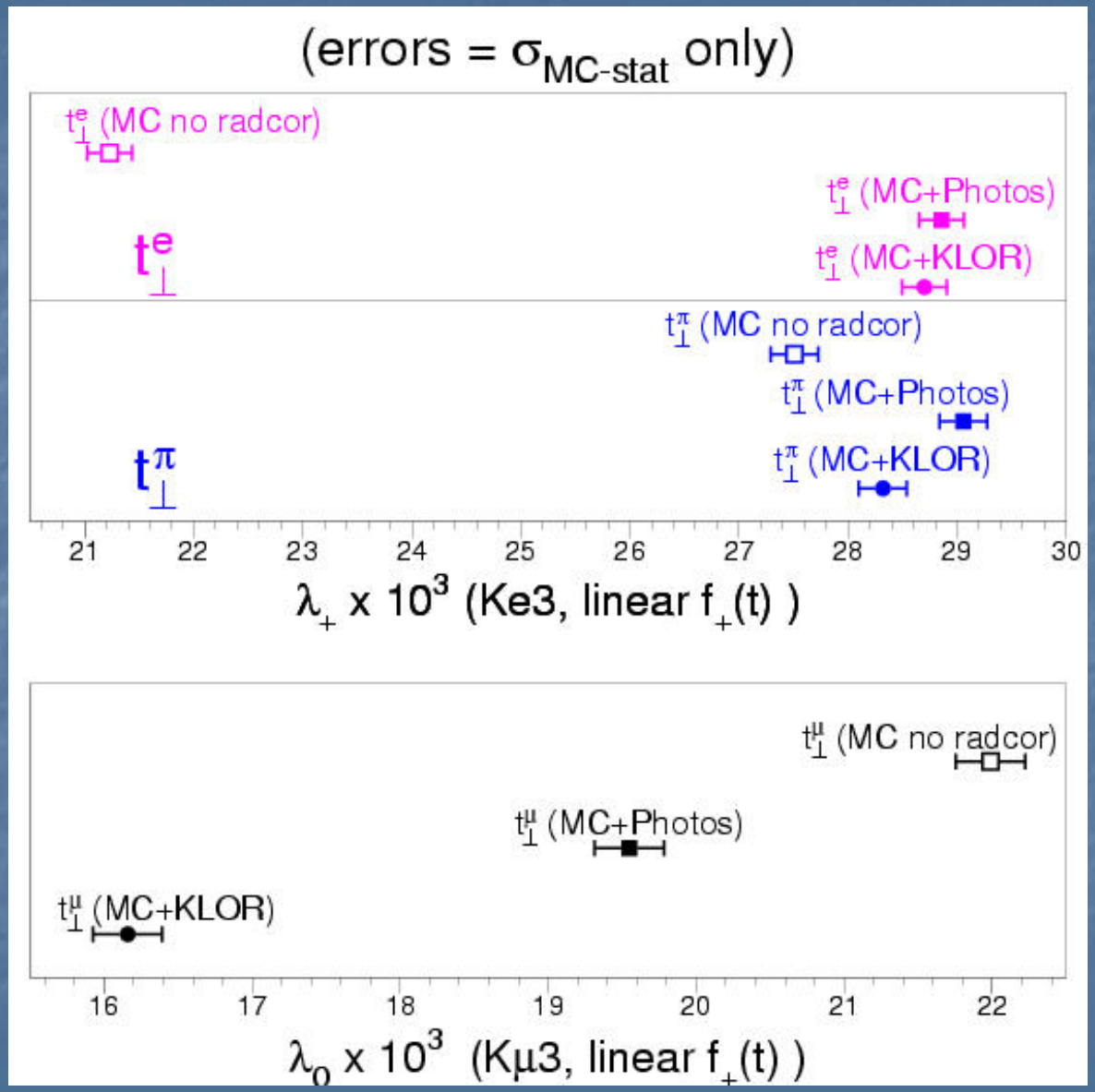
KTeV results use MC+KLOR.



$(\sigma_{syst} \sim 2\sigma_{MC\text{-}stat})$

Form Factor Sensitivity to Radiative Corrections.

KTeV results use MC+KLOR.



Very High Statistics Ke3γ

- **KTeV Ke3γ sample (published), E_γ>10 MeV: 14,000 using low-intensity beam.**

- **Let's peak at prelim data-MC comparisons for large high-intensity sample with 0.97 million Ke3γ with E_γ > 10 MeV ! (Ke3 collected for ε' acceptance studies)**

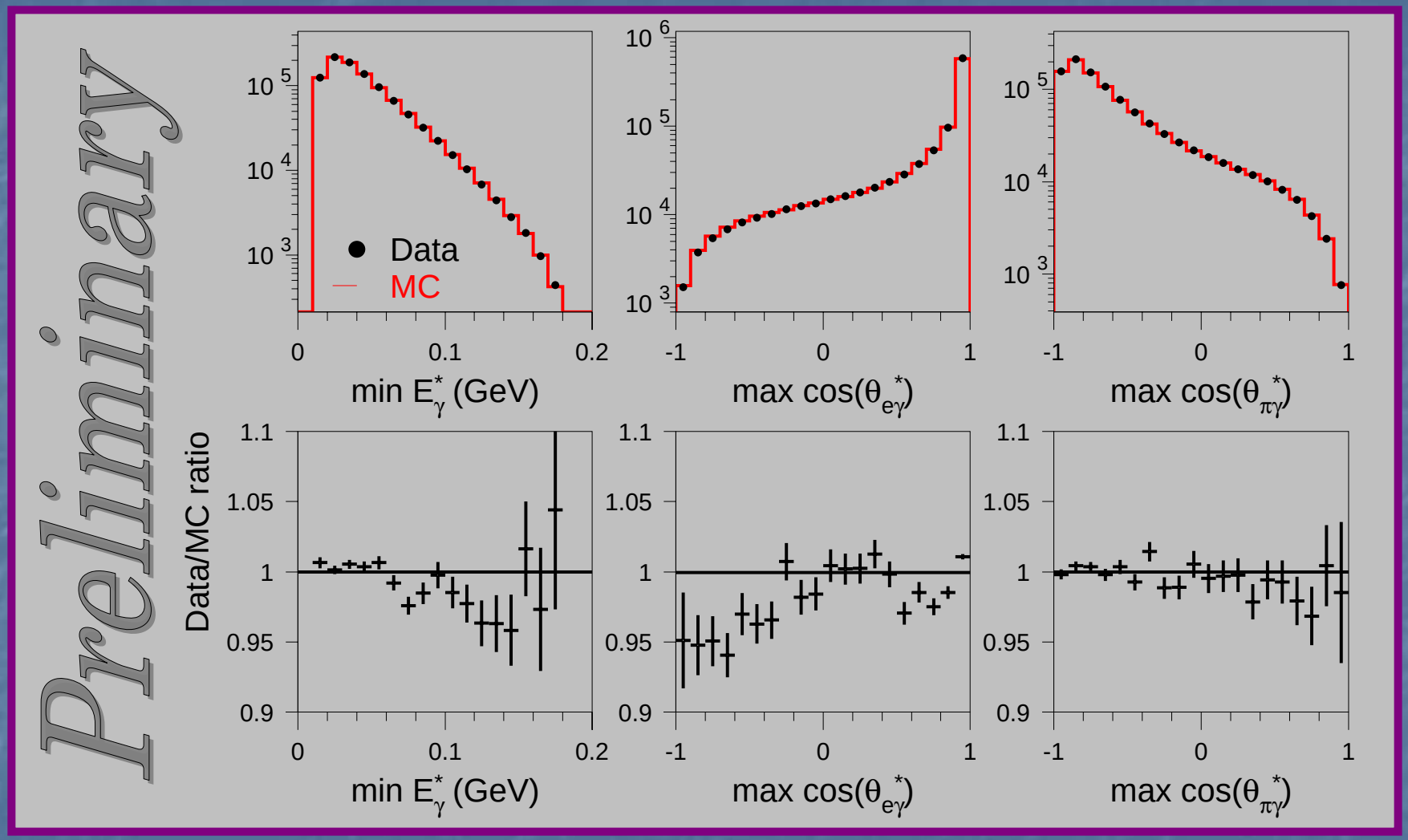
Preliminary

- **MC stats = data stats => 1.8 billion generated Ke3! (4 CPU months on FNAL PC farm)**

Physics Possibilities with High Statistics Ke3(γ)

- **1×10^6 Ke3γ => search for direct emission γ**
- **$1\text{-}2 \times 10^8$ Ke3 => search for scalar and tensor form factors.**

Data/MC(KLOR) for 10^6 Ke3γ



- Do we need 2nd order rad cor ?
- Is photon simulation precise enough ?

Conclusions

- Radiative corrections are important for precision measurements of Kℓ3 form factors and branching fractions.
- New MC-Kℓ3 generator has been developed.
- Extensive data-MC comparisons validate new generator (virtual and real γ)
- Unclear prospects for million Ke3γ ... (need 2nd order radcor ?)