

*Radiative Corrections in the
KTeV | Vus | Analysis*


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Radcor Workshop
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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) 

=> K_{e3} and $K_{\mu 3}$ form factors with x3 and x5 better precision than PDG02

(corrected for virtual and real γ) 

MOTIVATION

- Rad cor changes $B(K_{e3})$ by 3%
- Rad cor changes K_{l3} form factors by many sigma.

Perspective

Theorist



**Radiative
corrections**



Experimenters



accept with
blind faith

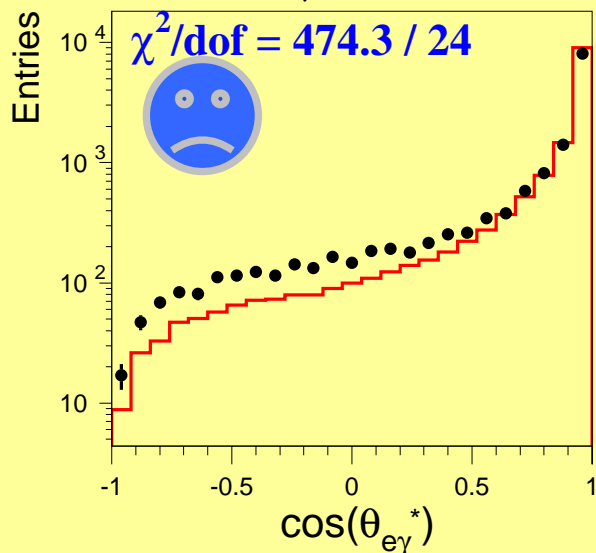
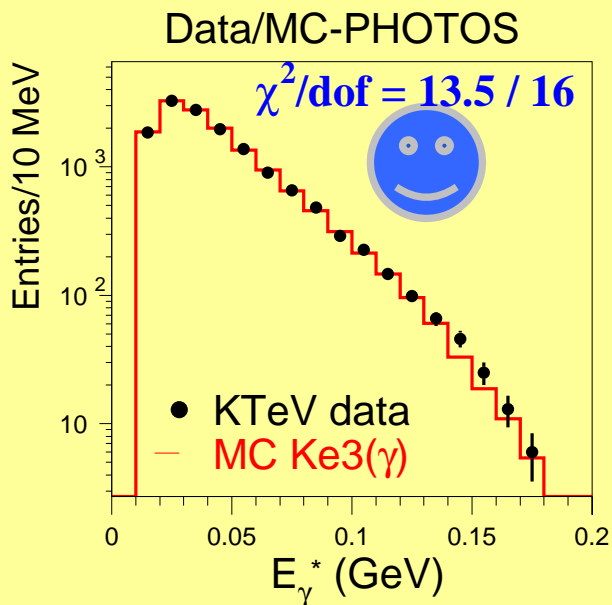


make
crosschecks

Radcor Options (2003)

<i>Option</i>	<i>Virtual</i> γ	<i>Real</i> γ	<i>MC</i> <i>generator</i>
FFS PRD 2, 542 (1970)	no	Yes	Write your own
ChPTh	yes	yes	πe , but no γ (and no $K\mu 3$)
PHOTOS (1993?)	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**

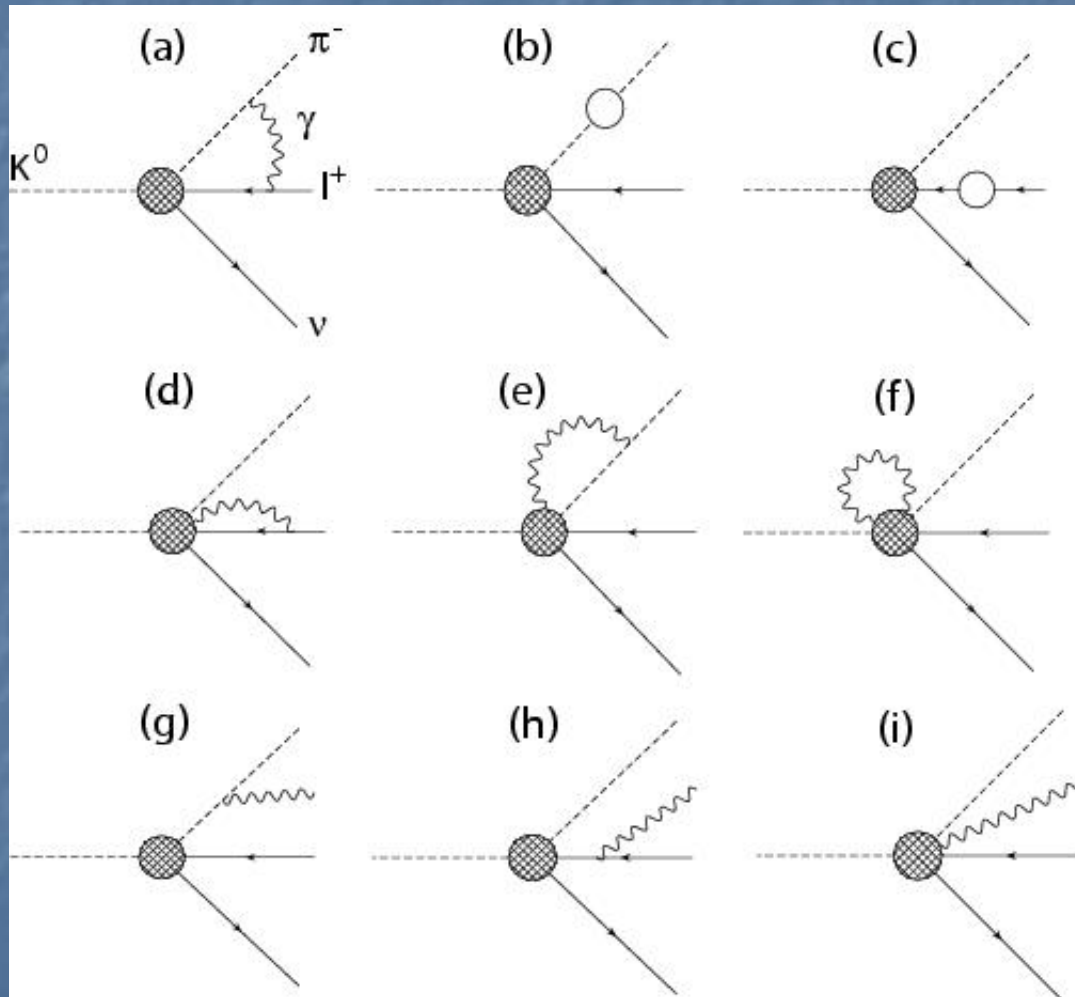
What we used (abandon PHOTOS)

Asked theory graduate student (T. Andre) to write new $K\ell^3(\gamma)$ generator:

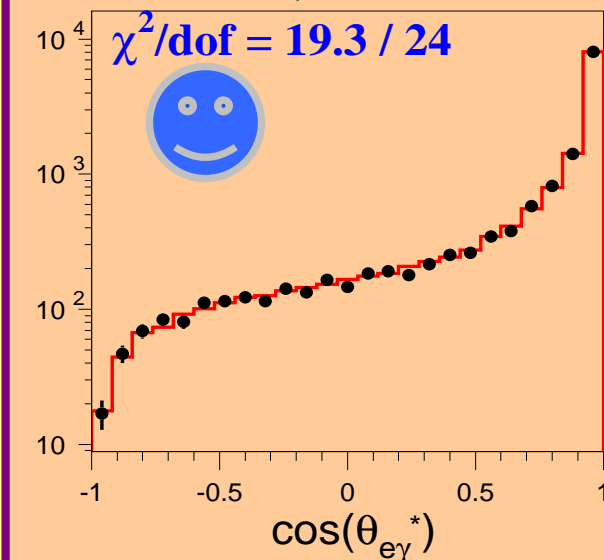
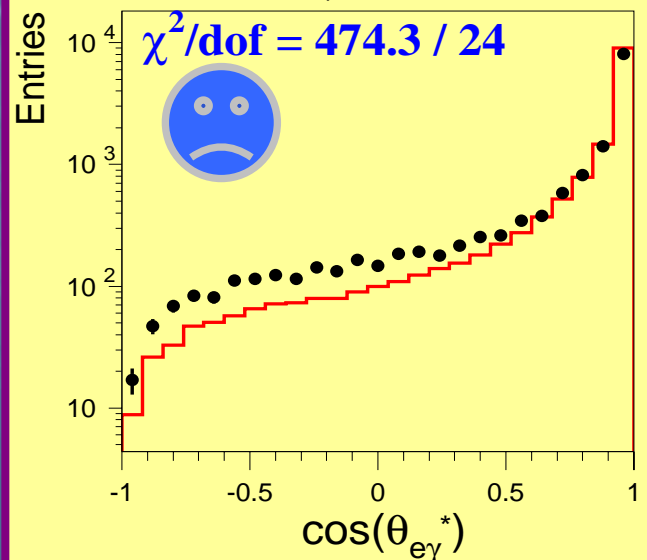
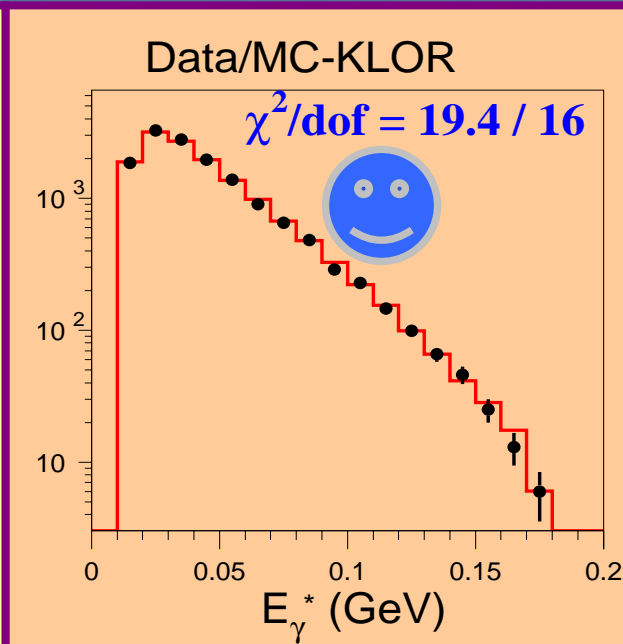
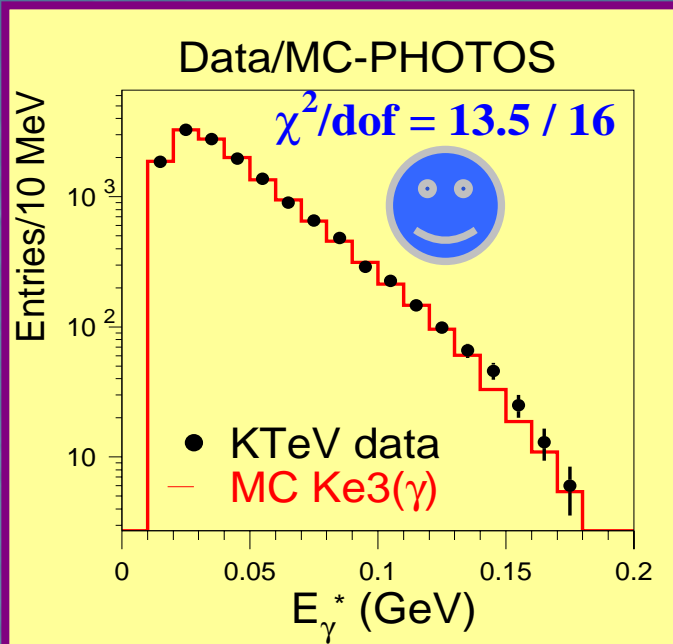
KLOR: Koan Leading Order Radiation

- ⇒ $Ke^3(\gamma)$ and $K\mu^3(\gamma)$
- ⇒ 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



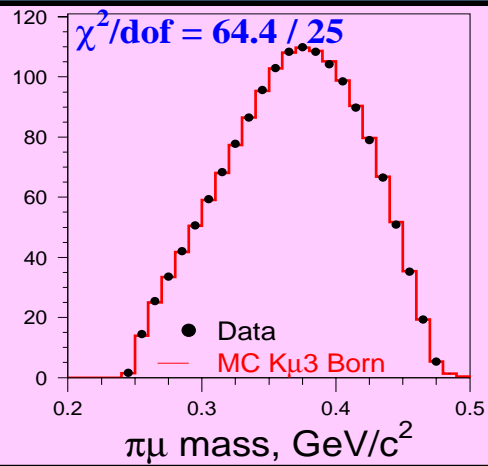
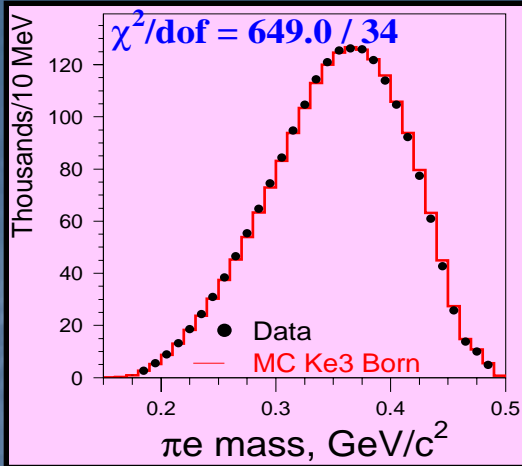
**KTeV
K ℓ 3 γ BRs
and plots
in:
PRD 71,
012001
(2005)**

Semileptonic Form Factors (to determine I_K integrals)

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

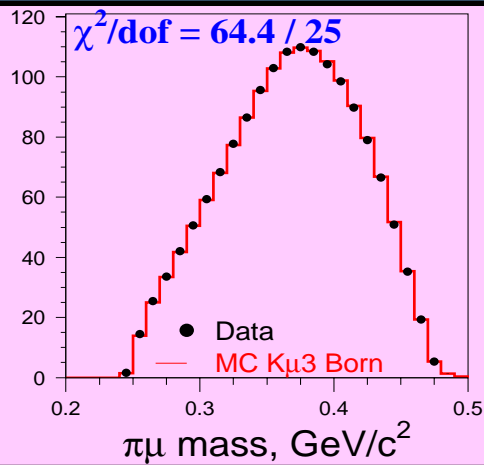
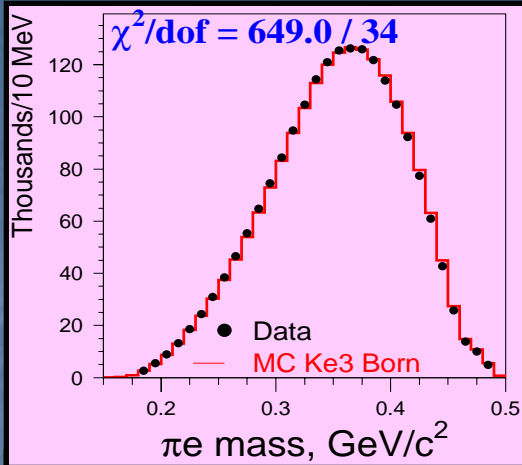
Radiative corrections for $K_L \rightarrow \pi \ell \nu$ affect:

- pion-lepton mass
- methods to fit form factors

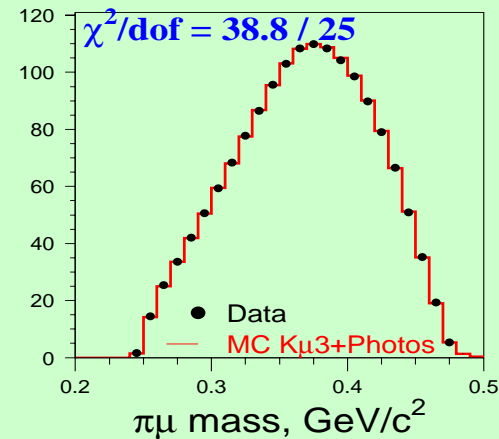
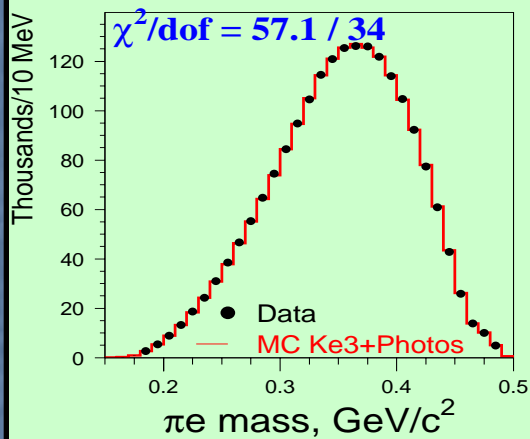


No rad cor \Rightarrow
bad χ^2

pion-lepton mass

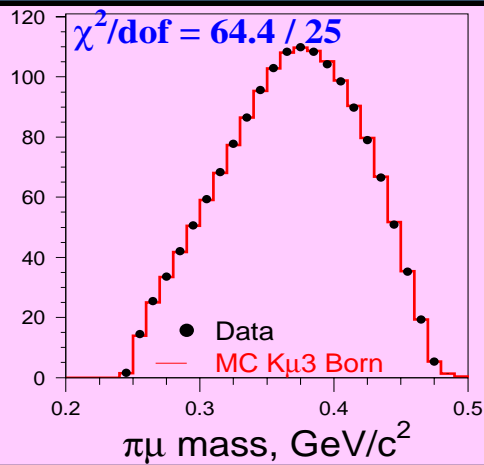
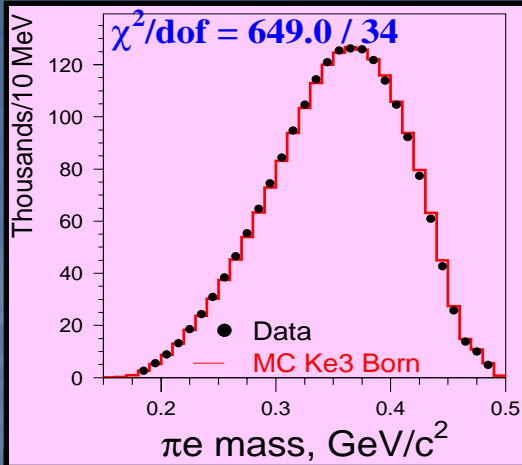


No rad cor =>
bad χ^2

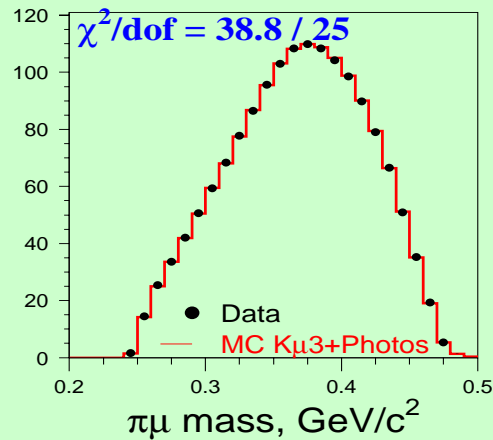
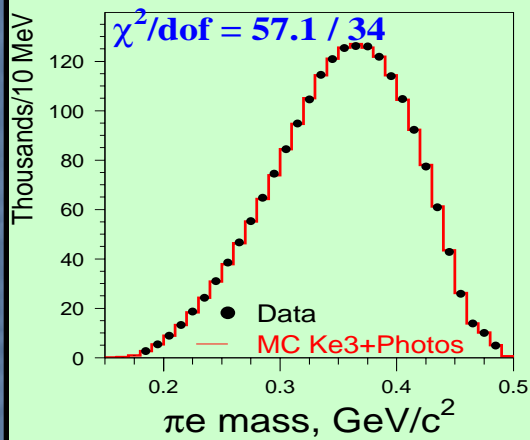


Re-weighted
PHOTOS =>
SO-SO χ^2

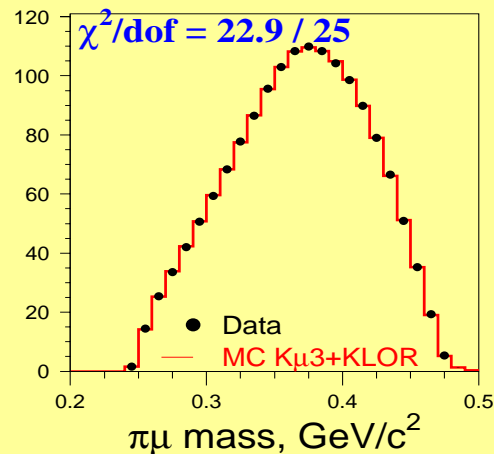
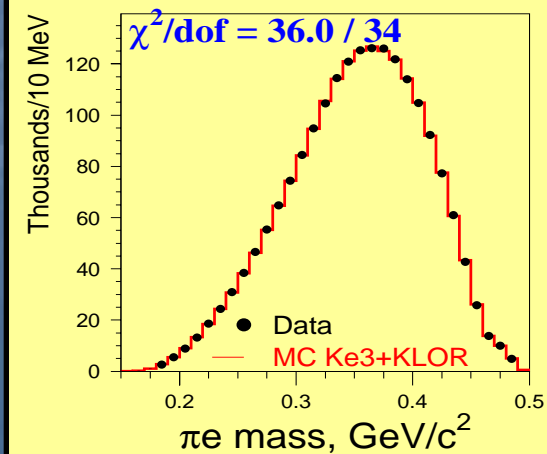
pion-lepton mass



No rad cor \Rightarrow
bad χ^2

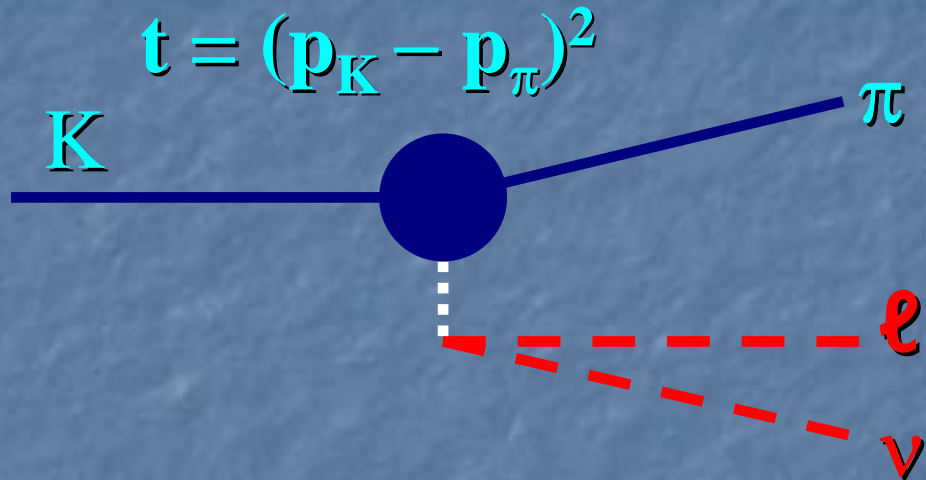


Re-weighted
PHOTOS \Rightarrow
so-so χ^2



KLOR \Rightarrow
excellent χ^2

Form Factor Fitting Techniques



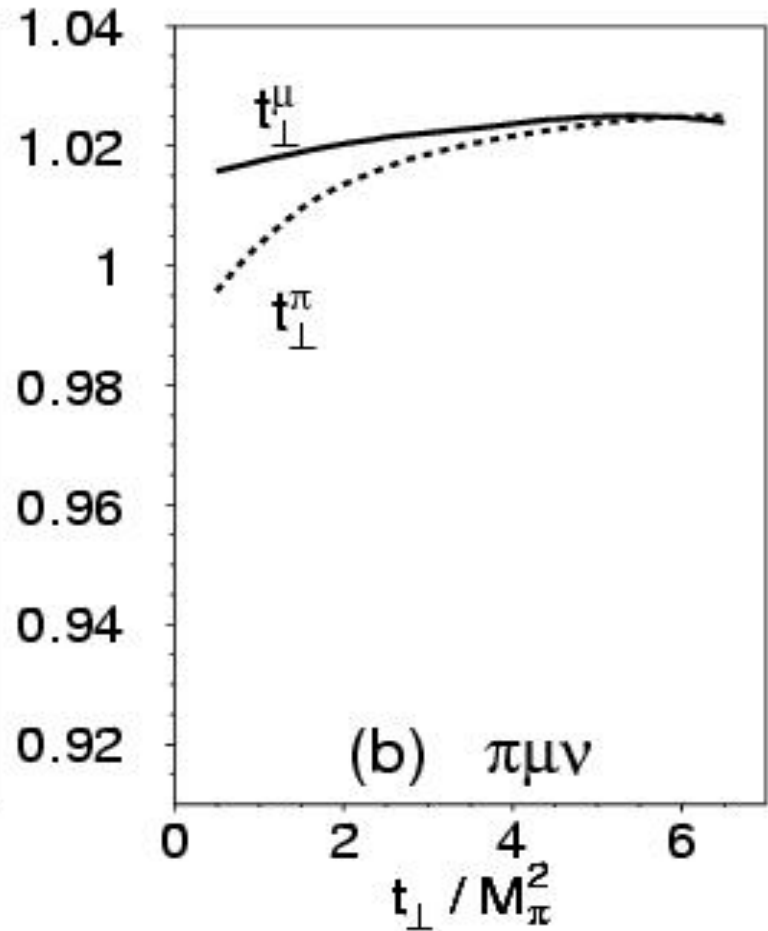
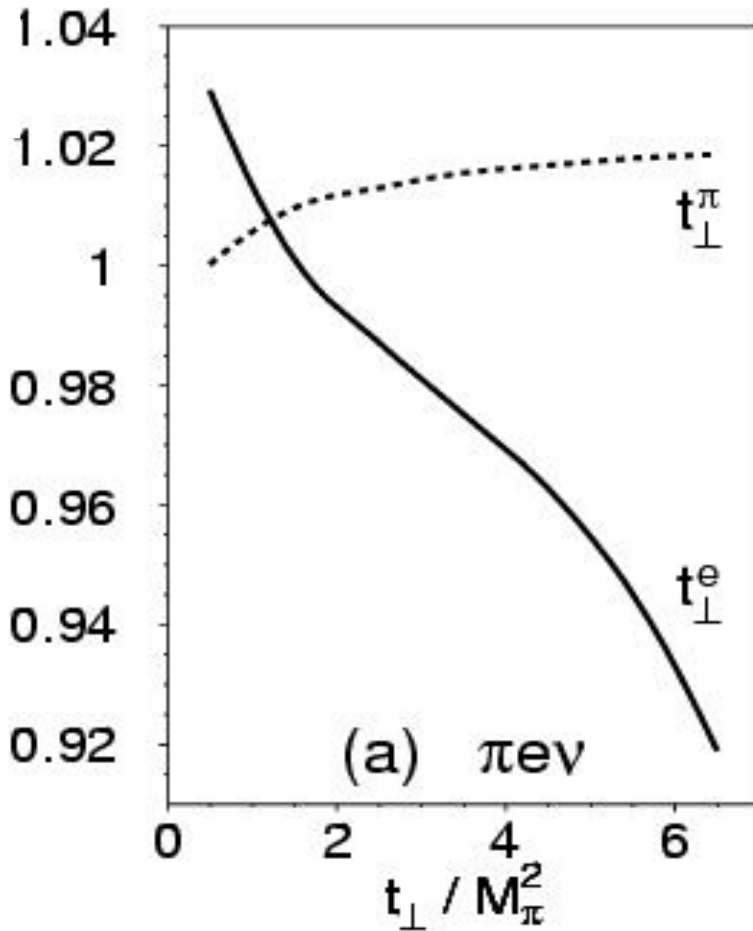
- * **Kinematic ambiguity** \Rightarrow two possible t -values
- * **To avoid ambiguity, compute “ t_\perp ” using only transverse quantities:**

$$t_{\perp,\pi} = (\mathbf{P}_{\perp,K} - \mathbf{p}_{\perp,\pi})^2 \quad \mathbf{P}_{\perp,K} = (\mathbf{E}_K, \mathbf{0})$$

$$t_{\perp,\ell} = (\mathbf{p}_{\perp,\ell} + \mathbf{p}_{\perp,\nu})^2$$

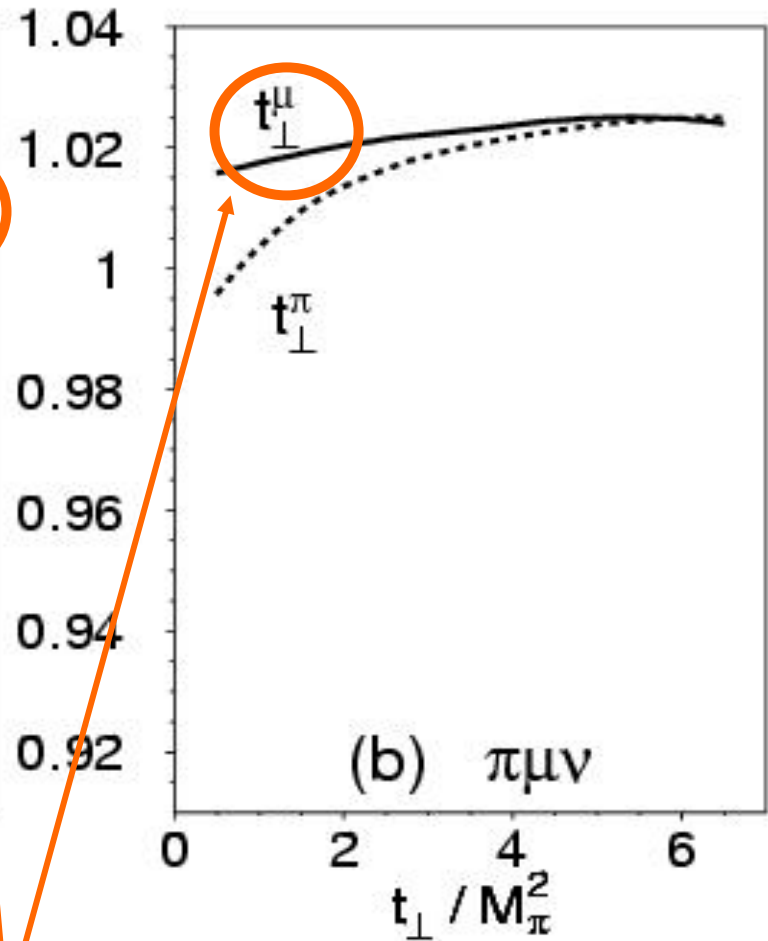
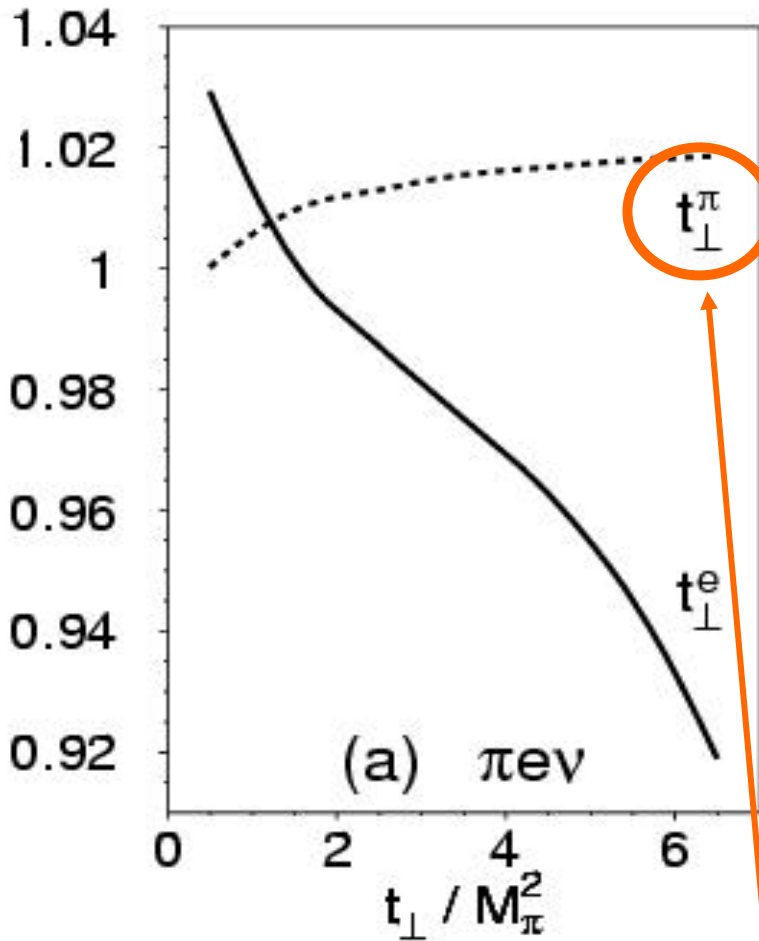
Form Factor Fitting Techniques

$\Gamma_{\text{rad}}/\Gamma_{\text{Born}}$



Form Factor Fitting Techniques

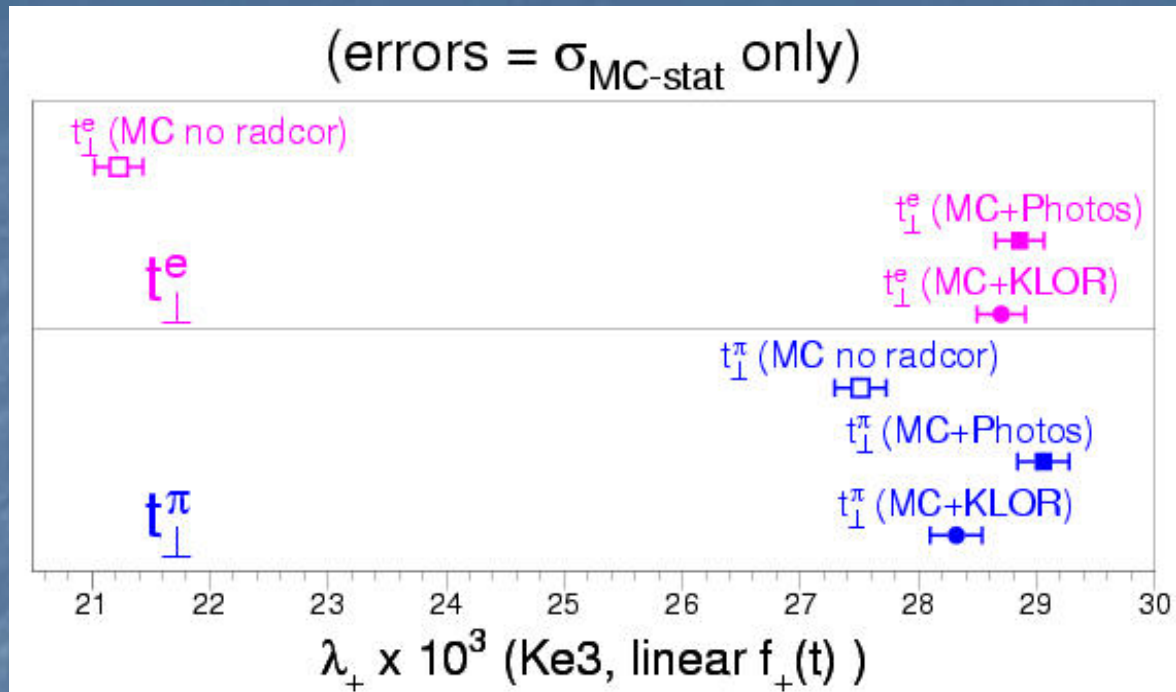
$\Gamma_{\text{rad}}/\Gamma_{\text{Born}}$



Variables used to fit form factors

Form Factor Sensitivity to Radiative Corrections.

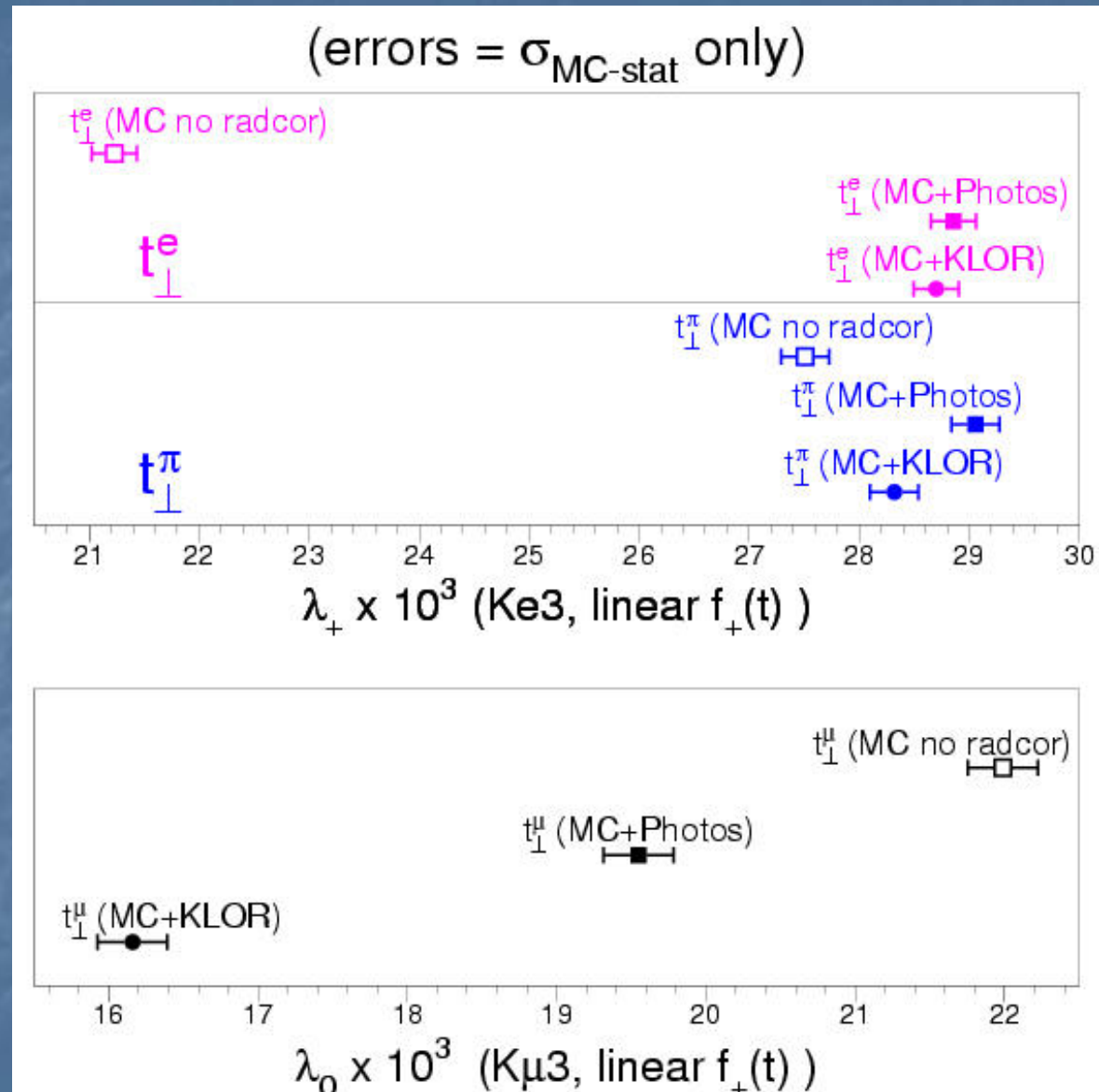
KTeV results
use
MC+KLOR.



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

Form Factor Sensitivity to Radiative Corrections.

KTeV results use MC+KLOR.



Very High Statistics Ke3 γ

- **KTeV Ke3 γ sample (published),
E $_{\gamma}$ > 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 Ke3 γ with E $_{\gamma}$ > 10 MeV!
(Ke3 collected for ϵ' acceptance studies)**
- **MC stats = data stats
=> 1.8 billion generated Ke3!
(4 CPU months on FNAL PC farm)**

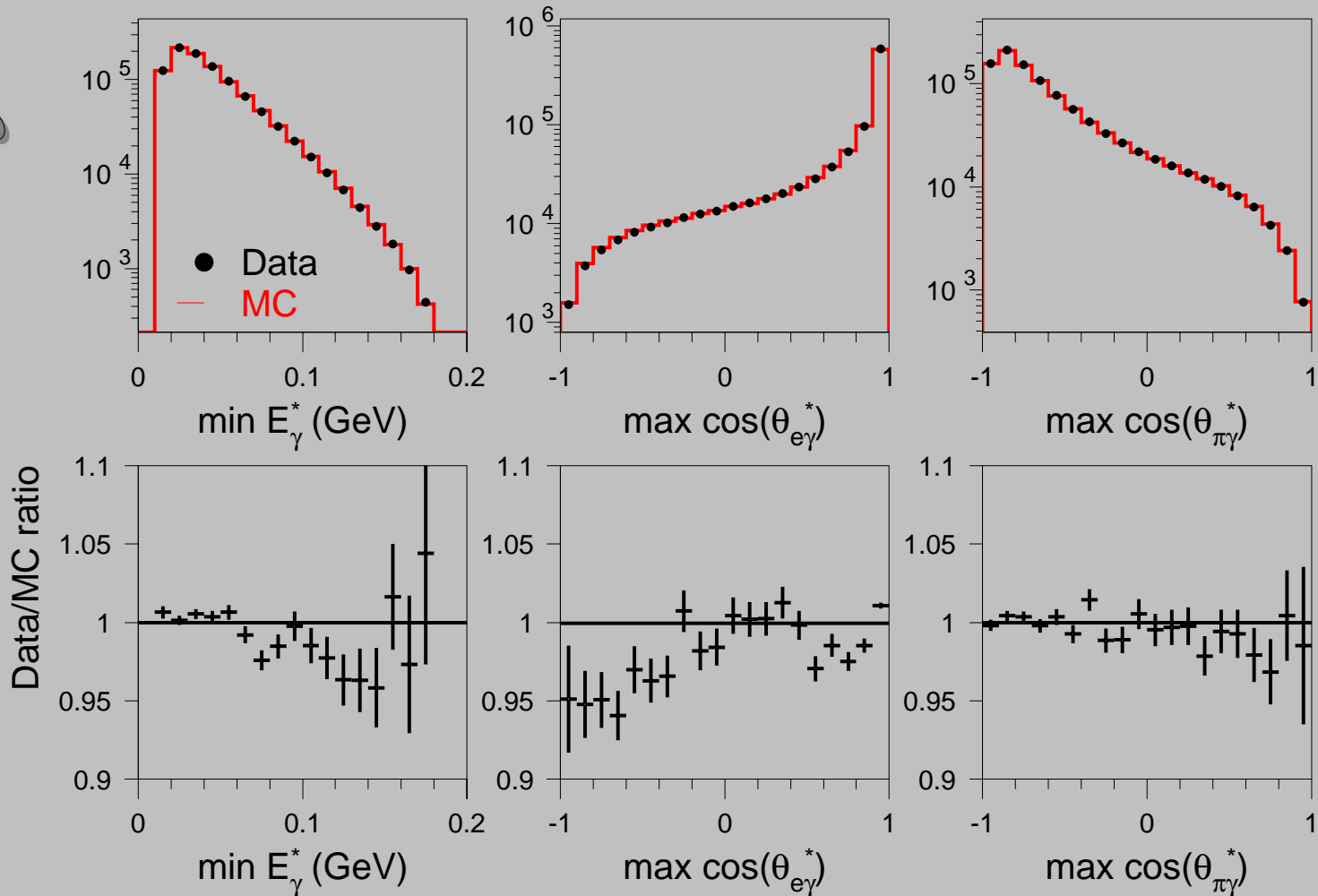
Preliminary

Physics Possibilities with High Statistics $\text{Ke3}(\gamma)$

- ◆ **$1 \times 10^6 \text{ Ke3}_\gamma \Rightarrow$ search for
direct emission γ**
- ◆ **$1-2 \times 10^8 \text{ Ke3} \Rightarrow$ search for scalar and
tensor form factors.**

KTeV Data/MC(KLOR) for 10^6 Ke 3γ

Preliminary



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

Conclusions

- Radiative corrections are important for precision measurements of $K\ell 3$ form factors and branching fractions.
- New MC- $K\ell 3$ generator has been developed.
- Extensive data-MC comparisons validate new generator (virtual and real γ)
- Unclear prospects for million $Ke3\gamma$... (need 2nd order radcor ?)