Experimental study of $K^+ \to \pi^0 \mu^+ \nu_\mu \gamma$ in E787

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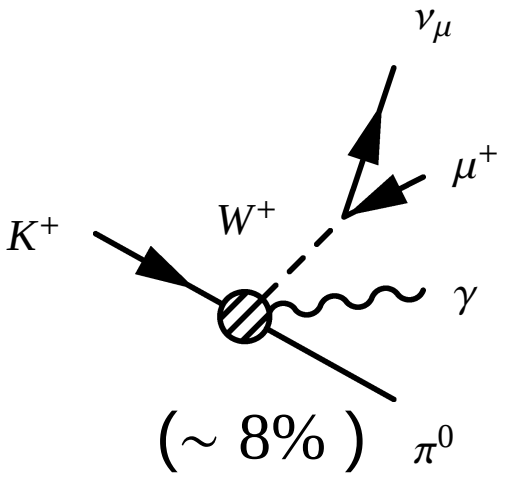
Physics Motivation

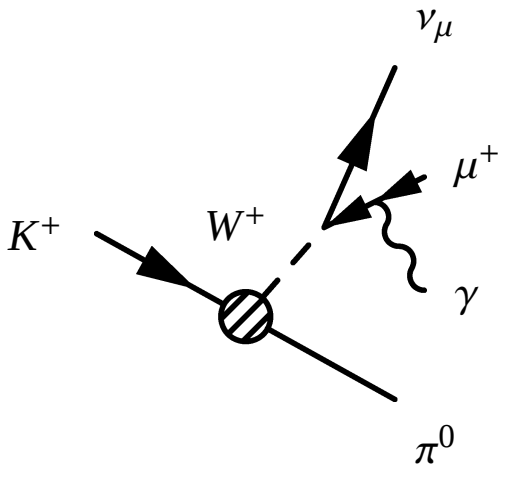
Test of Chiral Perturbation Theory

QCD effective theory in low energy region

quark field → pseudoscalar meson field

(using Only Chiral Symmetry)





Structure Dependent Internal Bremsstrahlung

Branching ratio is predicted as $\sim 2.0 \times 10^{-5}$

$(E_\gamma > 30MeV, \theta_{\mu\gamma} > 20°)$

Experimental Status

First experimental search is
@Argonne National Laboratory(PR D8 1307(1973))

$$BR < 6.1 \times 10^{-5}(CL = 90\%)$$

Recently two measurements are reported.

ISTRA+ $\frac{Br(K_{\mu 3\gamma})}{Br(K_{\mu 3})} = (0.270 \pm 0.029(stat) \pm 0.026(syst)) \times 10^{-2}(5 < E_\gamma < 30)$

$\frac{Br(K_{\mu 3\gamma})}{Br(K_{\mu 3})} = (4.48 \pm 0.68(stat) \pm 0.99(syst)) \times 10^{-4}(30 < E_\gamma < 60)$

(hep-ex/0506023)

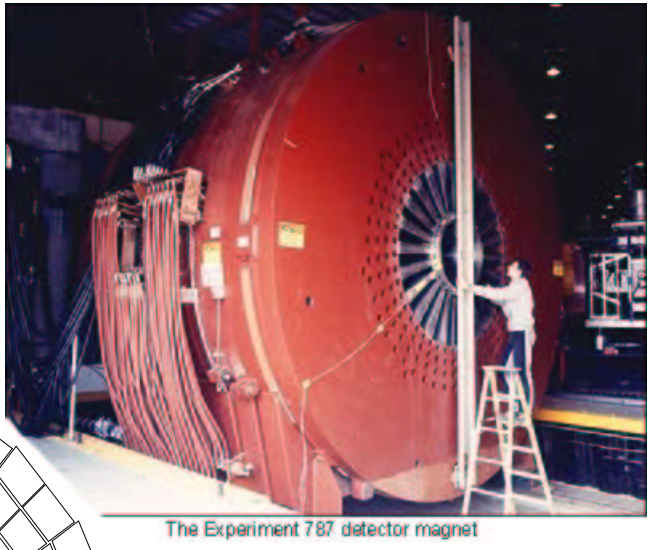
KEK-E470 $Br(E_\gamma > 30MeV, \theta_{\mu^+\gamma} > 20^\circ) = [2.4 \pm 0.5(stat) \pm 0.6(syst)] \times 10^{-5}$

(Phys.Lett. B633 (2006))

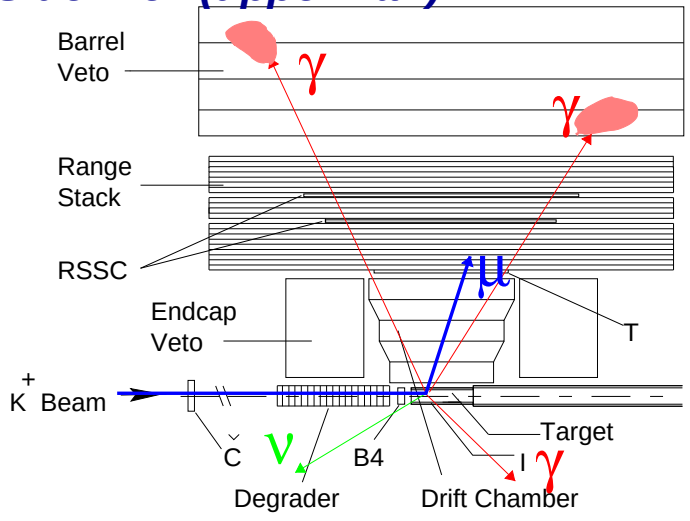
E787 Detector & Detection Method

$$K^+ \to \pi^0 \mu^+ \nu_\mu \gamma$$
$$\hookrightarrow 2\gamma$$

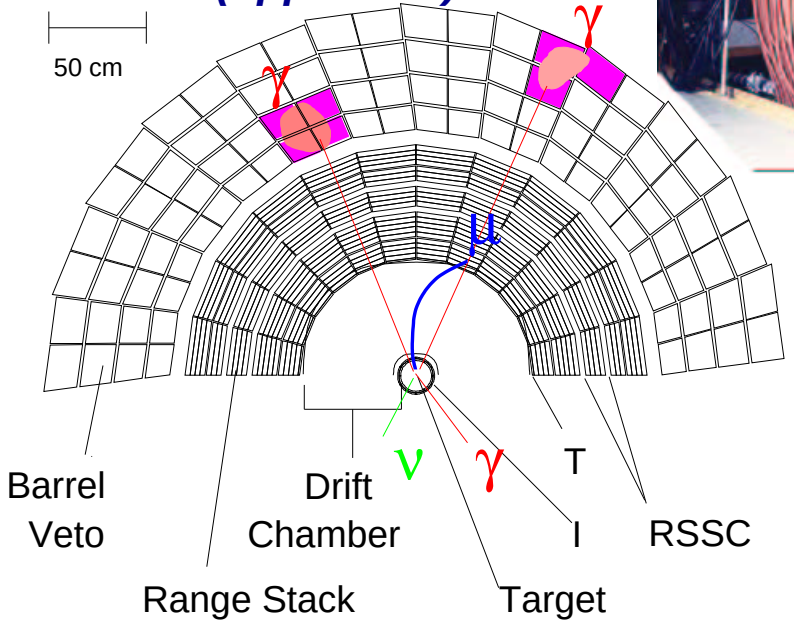
1 charged track & 3 γ and 1 missing(ν)



Side View(upper half)



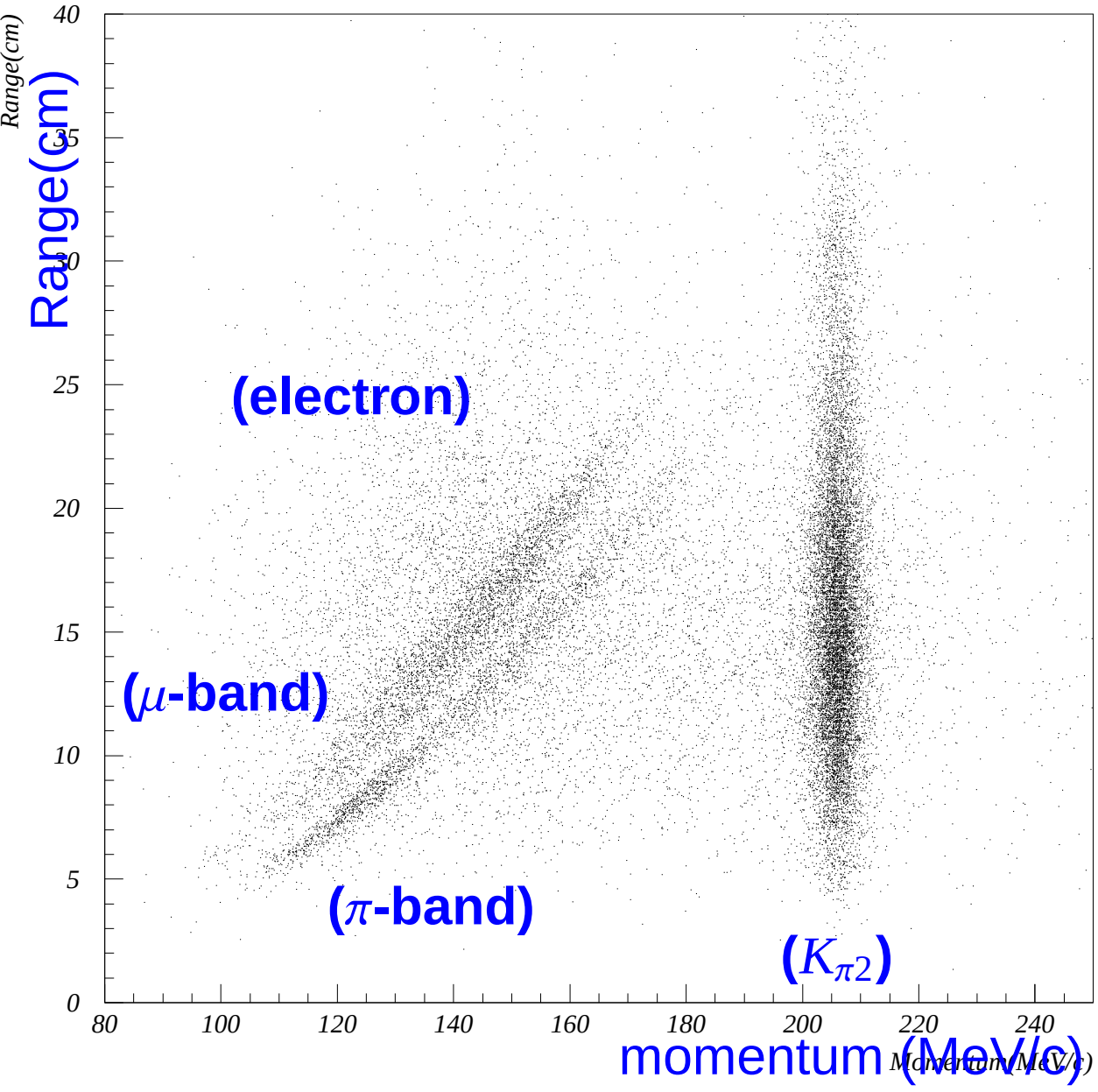
End View(upper half)



Trigger for $K_{\mu 3\gamma}$ ("3gamma" trigger in '98)

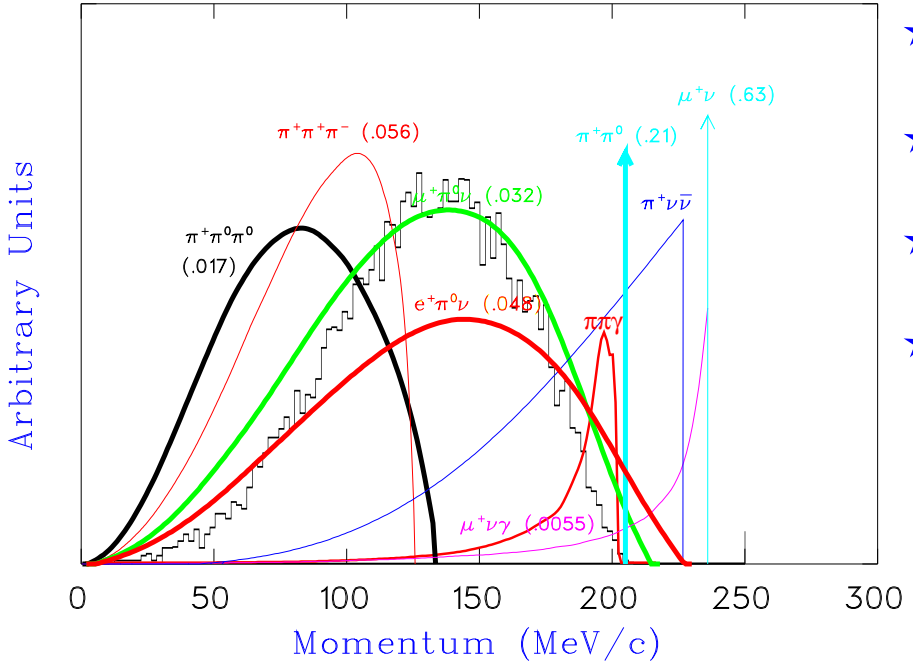
- ★ Inner Layer of RS $\Rightarrow$ Low momentum($100 \sim 180 MeV/c$)
- ★ # of clusters in Barrel-Veto ≥ 3

Data Set Property

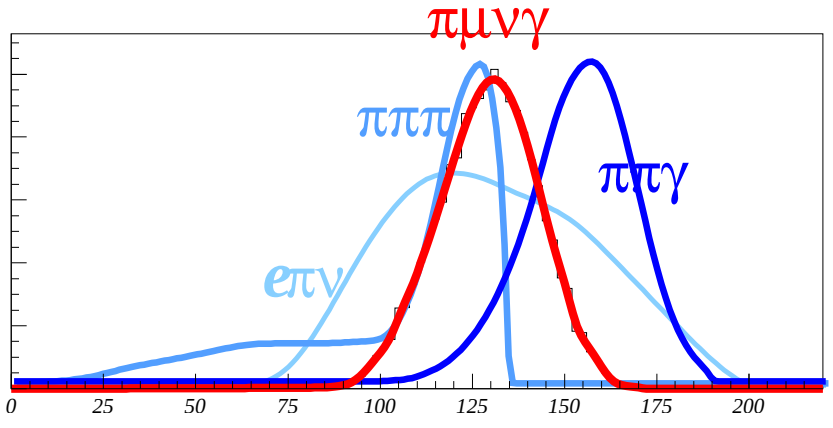


- BNL-E787
  '98 Run (Sep-Dec)
  (by-product of $\pi^+\nu\bar{\nu}$)
- Number of K^+
  $= 3.53 \times 10^{11}$
- trigger rate
  (prescaled by 5)
  $= 5 \sim 7 events/spill$
- Data Set Size:
  ($\sim$ 1TB)

Background Sources



(After 3gamma trigger) ⇓



- ★ $\pi^0\mu^+\nu_\mu$ +accidental/split γ
- ★ $\pi^0 e^+\nu_e$ +accidental/split γ
- ★ $\pi^+\pi^0\pi^0$ +missing/overlapping γ
- ★ $\pi^+\pi^0\gamma$

or

classfication by # of γs

- ★ 4γ + 1γ is missed
  and/or charged track miss-ID
- ★ 3γ + charged track miss-ID
- ★ 2γ + fake γ
  and/or charged track miss-ID

Background supression

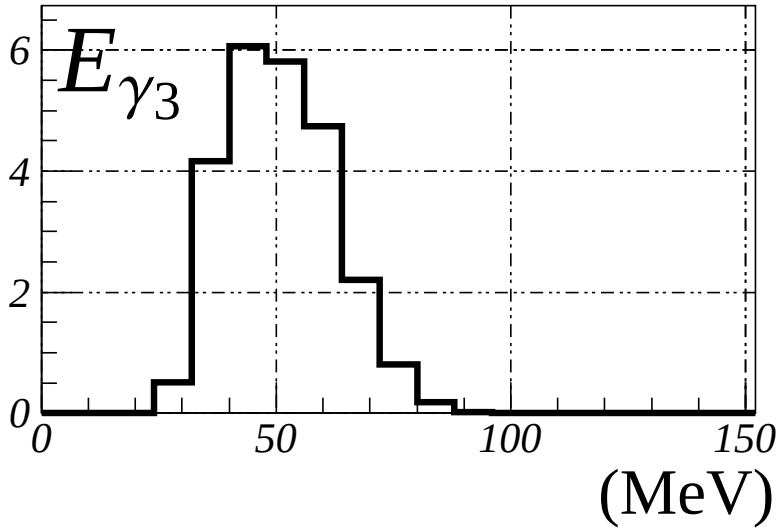
- ★ Charged track PID cuts
  - Muon band cut(π^+, e)
  - dE/dx cut in RS(e)
- ★ γ related cuts
  - Overlapping photon cut($K_{\pi 3}$)
  - Split γ cluster cut($K_{\mu 3}$)
- ★ $K_{\mu 3}$ likelihood cut ($K_{\mu 3}$)
  - $\chi^2_{K\mu 3}$ probability cut
- ★ $K_{\mu 3\gamma}$ consistency cuts
  - Missing energy cut ($K_{\pi 2\gamma}$) $\Leftarrow K_{\mu 3\gamma}$ kinematic fitting
  - $\chi^2_{K\mu 3\gamma}$ probability cut

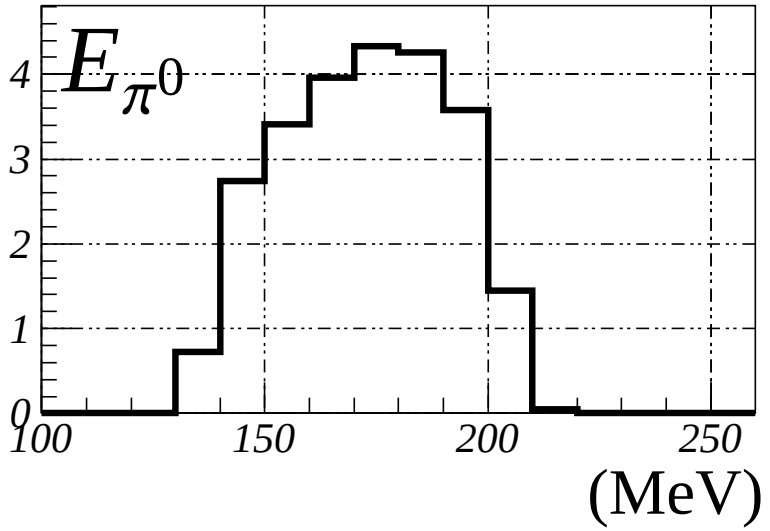
Background Estimates

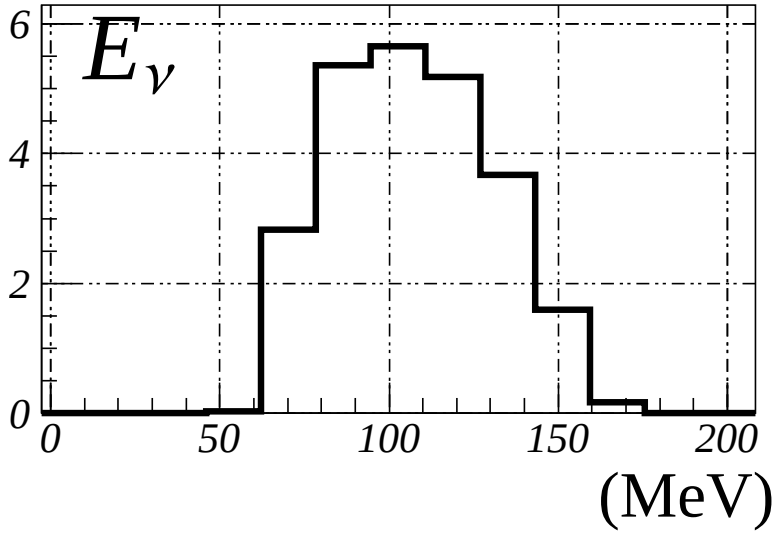
Sources	#events	Estimate Method
$K_{\pi 3}$	3.3±0.56	Data
$K_{\mu 3} + Acc$	6.7±2.1	Data
$K_{e3}/K_{e3\gamma}$	0.2±0.1	Data
$K_{\pi 2\gamma}$	0.27±0.07	M.C.
$K_{\mu 3}$+ split γ	< 0.35(90%CL)	M.C.
All Backgrounds	10.4±2.2	-

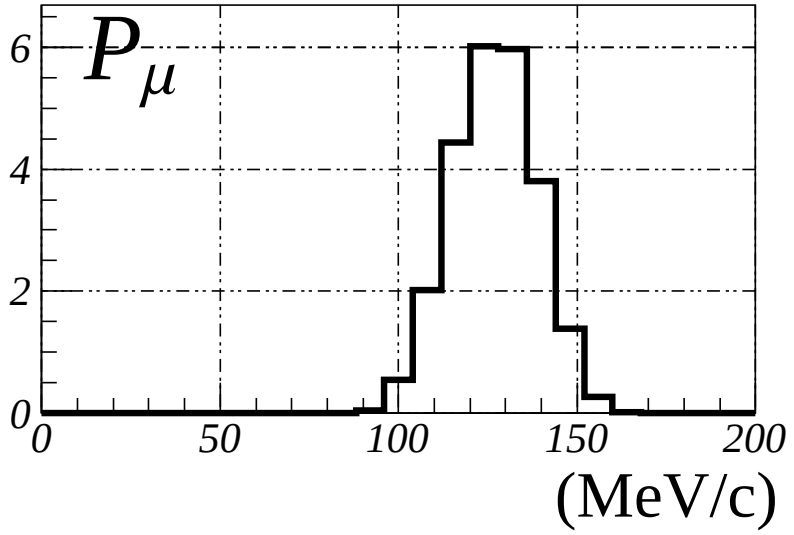
Background levels are well controled .
"$K_{\mu 3}$+ splitted γ" background is negligible.

Monte Carlo Signal Distributions





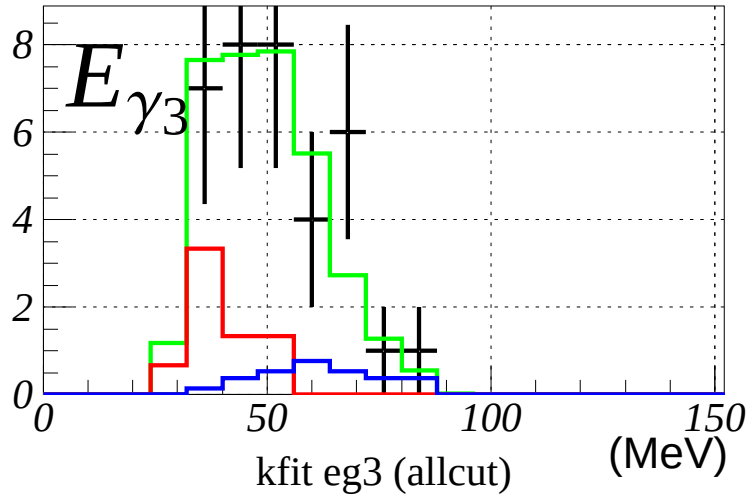




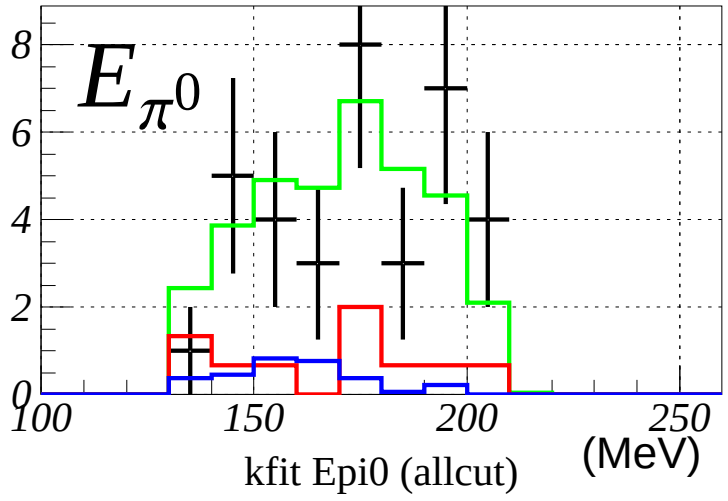
Signal Candidates

Data ,$K_{\mu 3}$ background, $K_{\pi 3}$ background, signal+background

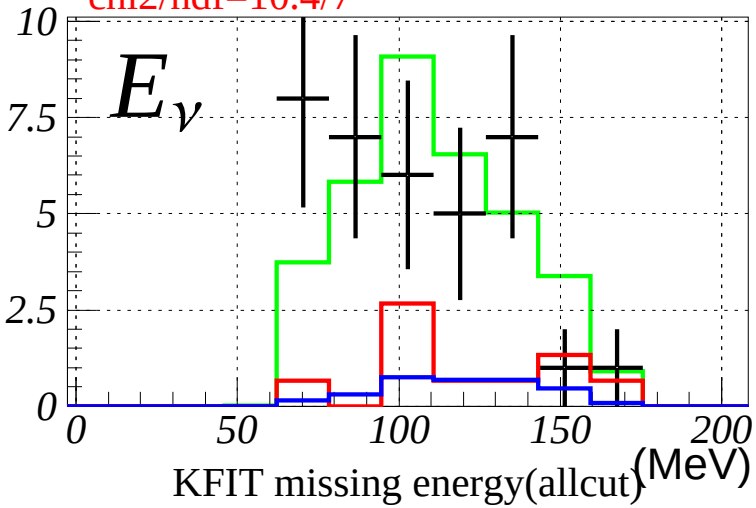
chi2/ndf=7.97/8



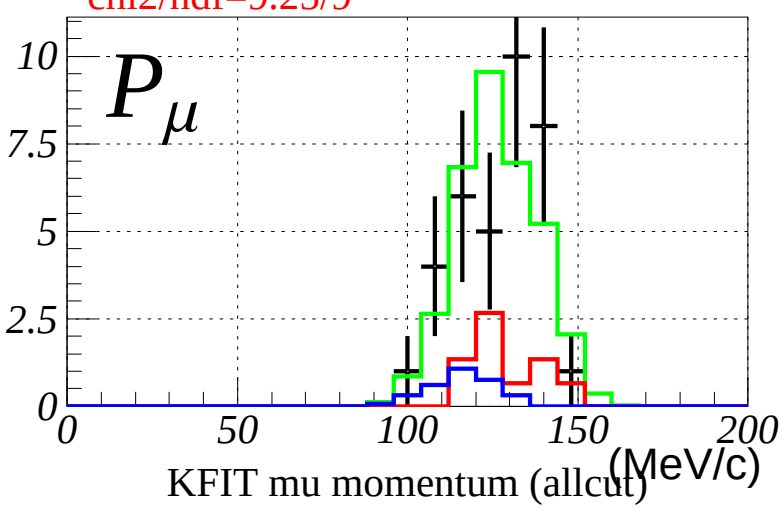
chi2/ndf=7.98/8



chi2/ndf=10.4/7

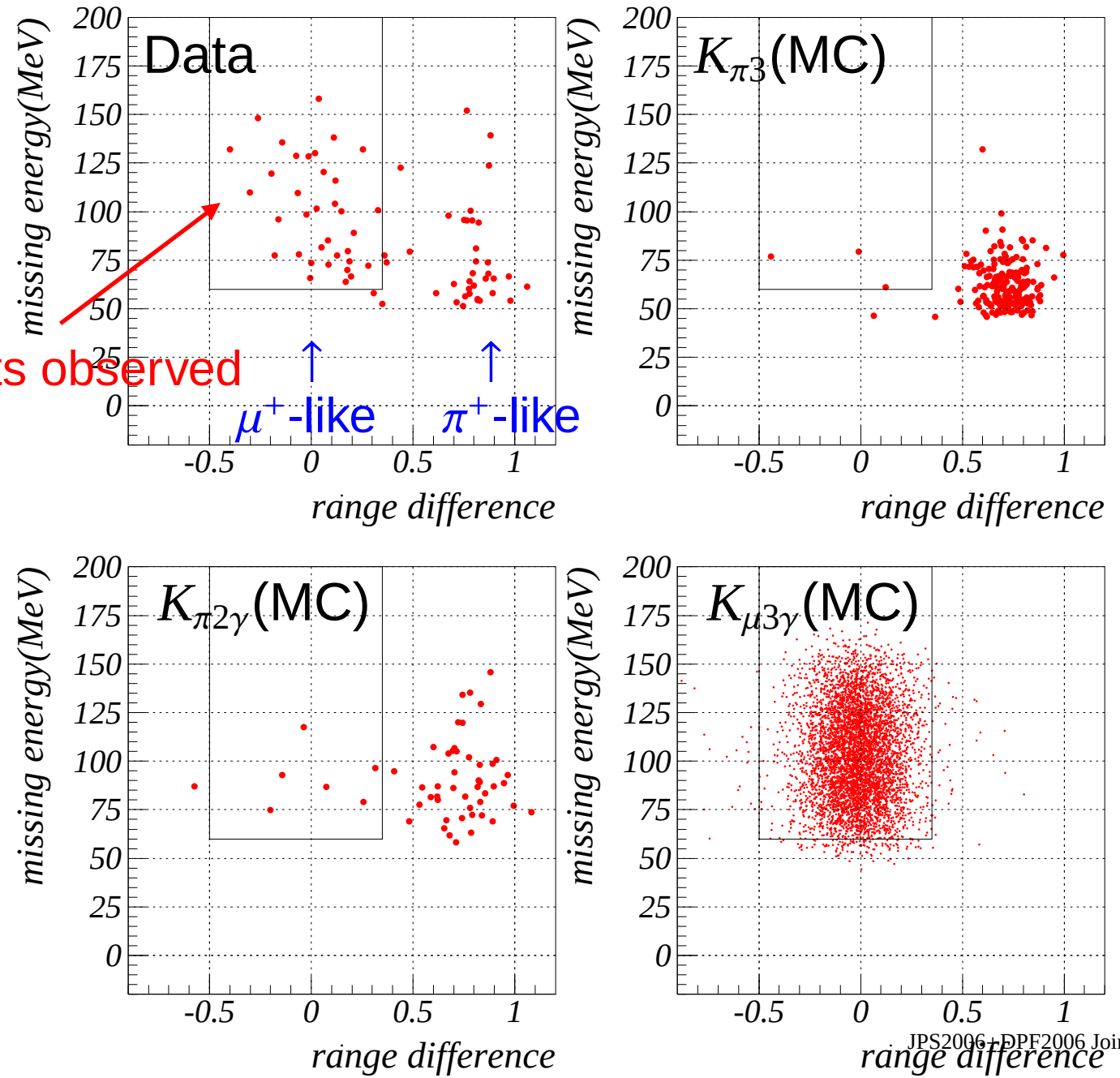


chi2/ndf=9.25/9



signal candidates are consistent with $K_{\mu 3\gamma}$ MC

Signal Candidates



Singel Event Sensitivity

- ★ Number of $K^+ = 3.5338 \times 10^{11}$
- ★ Acceptance(trigger*offline) = $(5.25 \pm 0.06) \times 10^{-6}$
  - trigger = 8.64×10^{-4}
  - offline = 5.67×10^{-3}
    - fiducial cut = 0.738
    - charged track cut = 0.853
    - photon cut = 0.254
    - kinematics cut = 0.165
    - physics cut = 0.346
    - taget & beam cut = 0.684
- ★ K^+ stop efficiency F_s normalized to $K_{\pi 2\gamma} = 0.441 \pm 0.001$

$\rightarrow$ Single Event Sensitivity $= (\#K^+ \times Acceptance \times F_s)^{-1}$

$= (1.22 \pm 0.01) \times 10^{-6}$

Results: Branching Ratio

- ★ Number of events in signal box = 35
- ★ Backgrounds = 10.4 ± 2.2
- ★ Estimated Systematic Uncertainties = ± 5.9 %

$\rightarrow$ BR($K_{\mu 3\gamma}$) = $(3.00 \pm 0.77(stat) \pm 0.18(syst)) \times 10^{-5}$

Consistent with SM prediction (= 2.0×10^{-5})