The upper limin on the $K^+ \to \pi^0\pi^0\pi^0 e^+\nu$ decay

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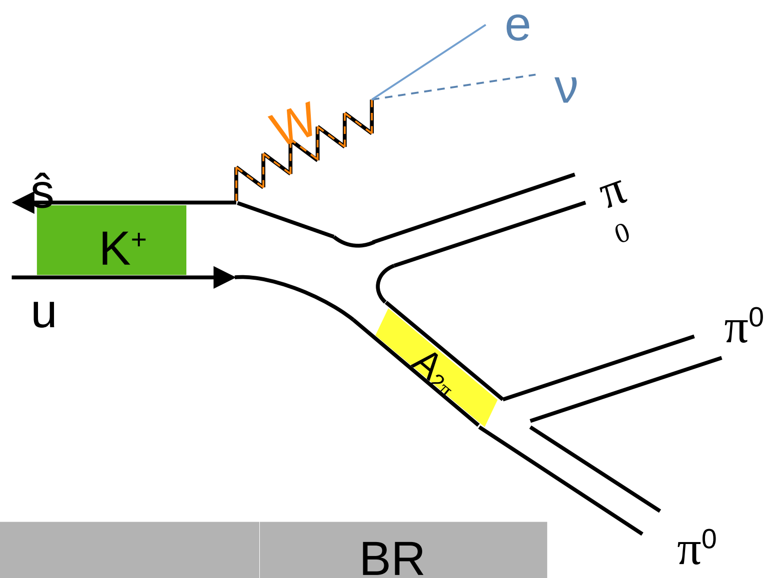
Upper limit $K^+ \to \pi^0\pi^0\pi^0 e^+\nu$ BR<3.5x10^{-6} (PDG 2023)

We improve it considerably

Expected ~ 10^{-11}



Limited phase space enhance ππ-scattering in final state

$\pi^+\pi^-$ - atom $\pi^+\pi^- \to A_{2\pi} \to \pi^0\pi^0$

$BR(A_{2\pi} \to \pi^0\pi^0) \approx 100\%$

$\tau = 3\text{x}10^{-15}$ sec

$m \approx 2m_\pi$

4-body rather than 5-body decay

$\Phi_4 \approx 10^6\ \Phi_5$

Blaser S 1995 Phys Lett B 345, 287-290

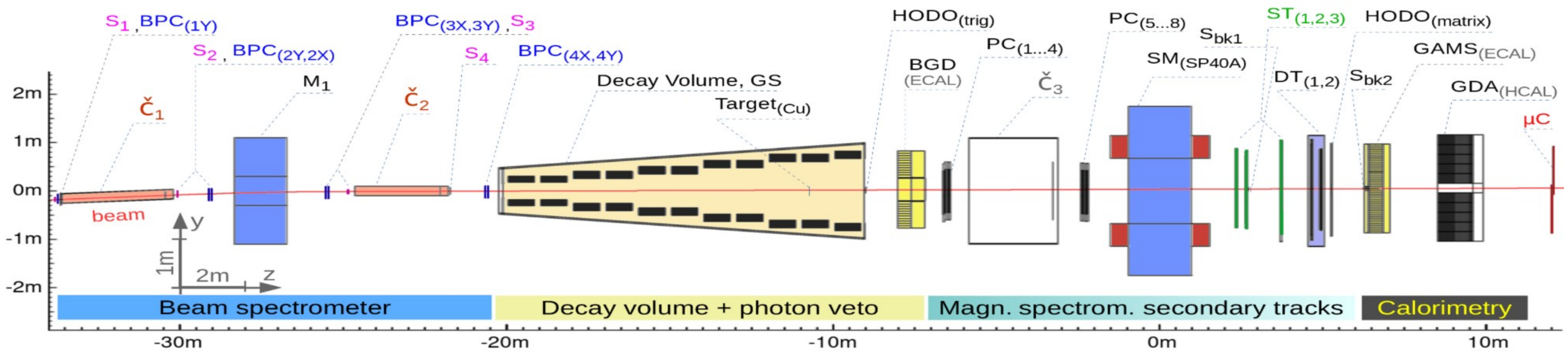
	BR	
$\pi^0 e^+\nu$	5.07x10^{-2}	
$\pi^0\pi^0\pi^0 e^+\nu$	8.5x10^{-12}	We can not
$A_{2\pi}\pi^0 e^+\nu$	8.8x10^{-8}	We can

All available data analysed (2012, 2013 and 2018 runs)
No signal

Also identified

- $\pi^0 e^+ \nu$ normalization
- $2\pi^0 e^+ \nu$ cross check, 13th bang principle

OKA detector



1. Beam spectrometer: 1mm pitch BPC ~1500 channels; Sc and C counters
2. Decay volume with Veto system:
   L=11m; Veto: 670 Lead-Scintillator sandwiches 20* (5mm Sc+1.5 mmPb), WLS readout
3. PC's, ST's and DT's for magnetic spectrometer:
   ~5000 ch. PC (2 mm pitch) + 1300 DT (1 and 3 cm)
4. Pad(Matrix) Hodoscope ~300 ch. WLS+SiPM readout
5. Magnet: aperture 200*140 cm^2
6. Gamma detectors: GAMS2000, BGD EM cal. ~ 4000 LG.
7. Muon identification: GDA-100 HCAL + 4 muon counters (μC) behind
8. For some runs Cu target inside decay volume was used: Ø=8 cm, t=2mm and C3 big Cerenkov counter

The main triggers	$S_1 \cdot S_2 \cdot S_3 \cdot \overline{C_1} \cdot C_2 \cdot \overline{S_{bk}} \cdot (\Sigma_{GAMS} > 2.5\, GeV) \cup (2 \leq MH \leq 4)$
Prescaled triggers	$S_1 \cdot S_2 \cdot S_3 \cdot C_1 \cdot C_2 \cdot S_{bk}/10$ $\quad S_1 \cdot S_2 \cdot S_3 \cdot C_1 \cdot C_2 \cdot S_{bk} \cdot \mu C\ /4$

3.65×10^9 decays, 8×10^8 with 1 track

Event selection

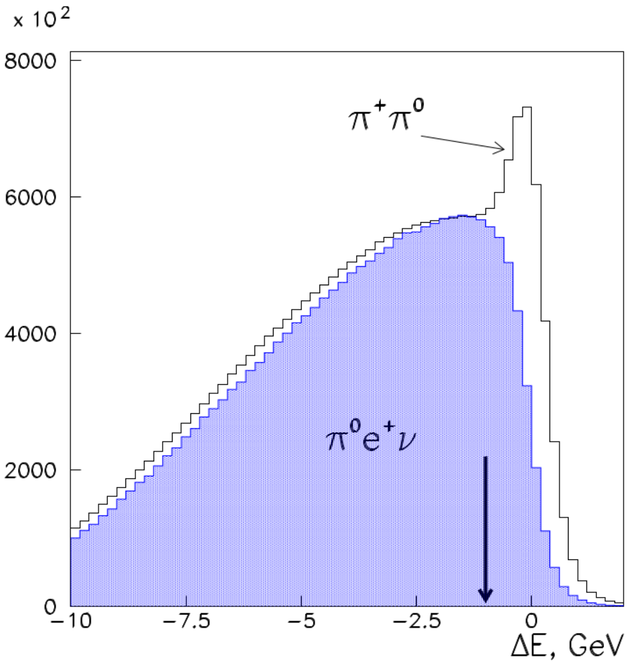
- Single track identified as e^+.
- π^0-mesons found in search through $\gamma_i\gamma_j$ combinations: $N_{\pi 0} = 1,2,3$.

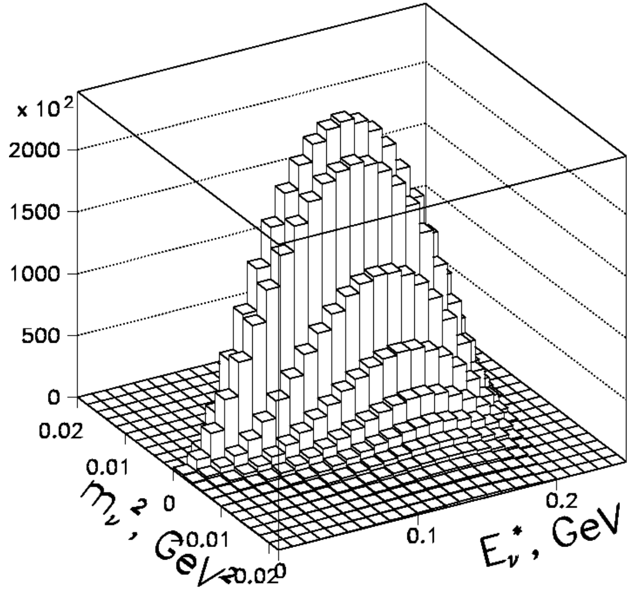
	$\pi^0\pi^0 e^+\nu$	$\pi^0\pi^0\pi^0 e^+\nu$
e^+ ID	E/p	E/p OR C_3
E_γ	>0.5 GeV	>0.3 GeV
N_γ	2,4	≥ 6
GDA showers	0	
e^+ track segments	2	

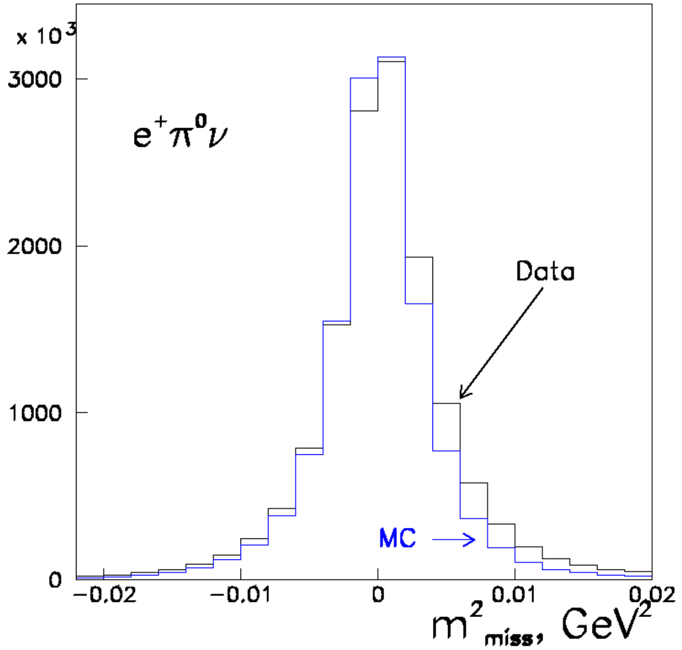
$\pi^0 e^+ \nu$ BR=(5.07±0.04)% normalization

Energy balance $\Delta E < -1$GeV

MC ~1% background



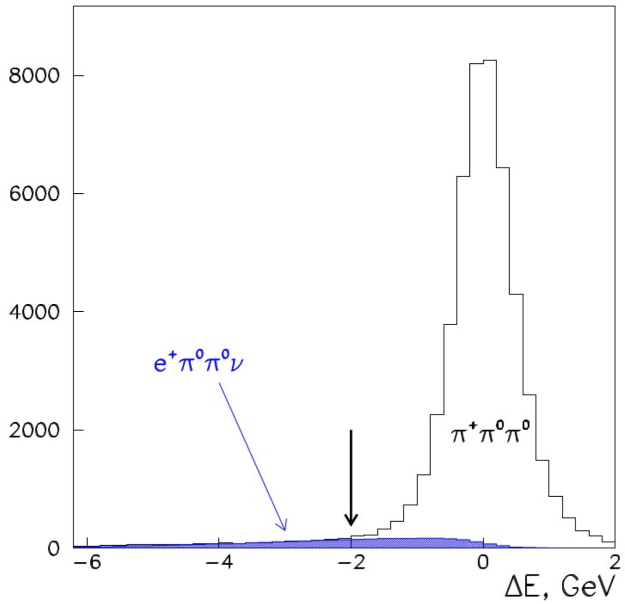


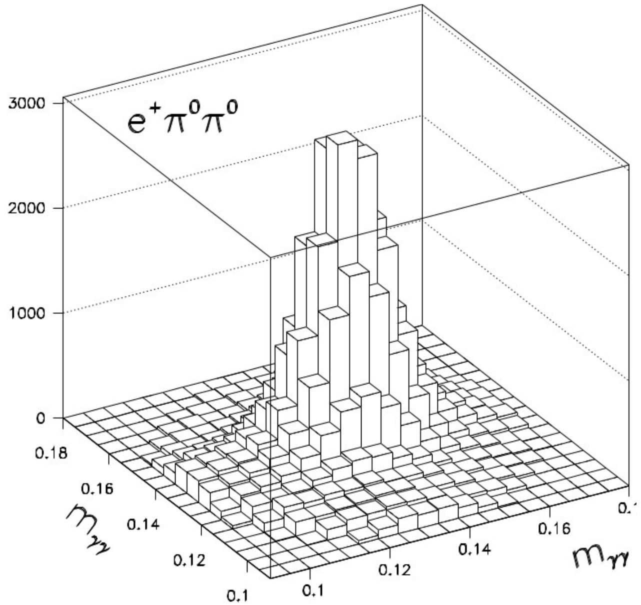


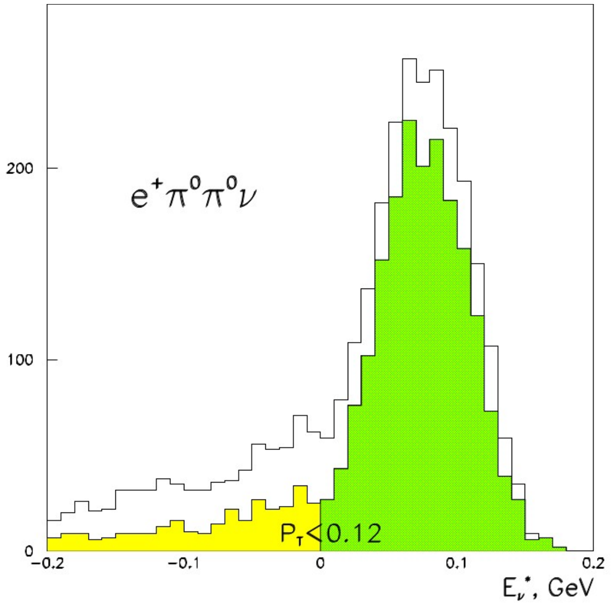
$\pi^0\pi^0 e^+\nu$

Major background: $\pi^+\pi^0\pi^0$

- $\Delta E < -2GeV$
- $P_T < 0.12GeV$ $p_{\nu,max}=0.173GeV$
- $E^*_{miss} > 0$ energy in K^+ rest frame

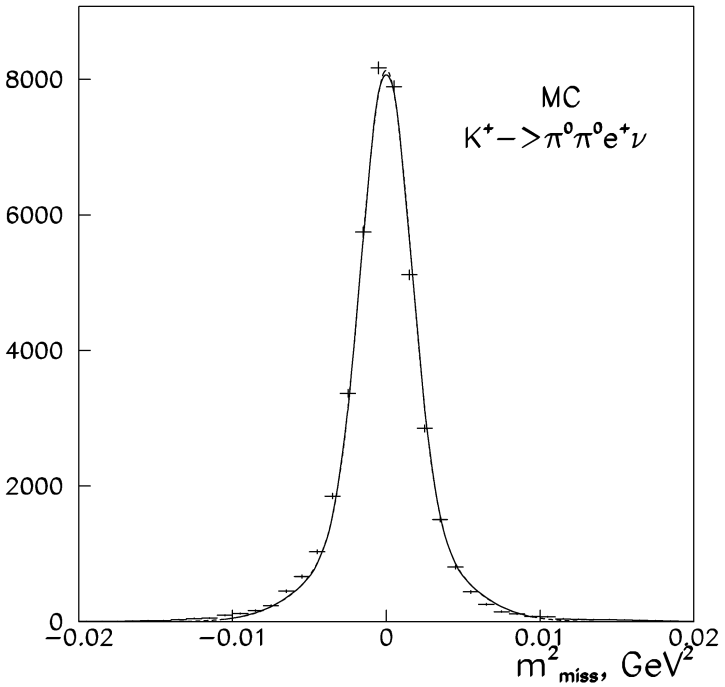


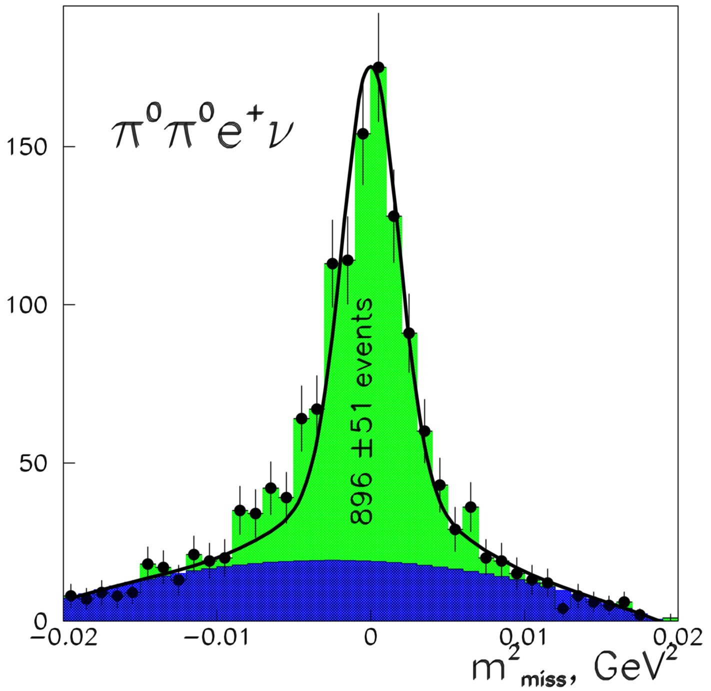




$\pi^0\pi^0 e^+\nu$

Fit MC to G+G
Fit data to MC shape + P2

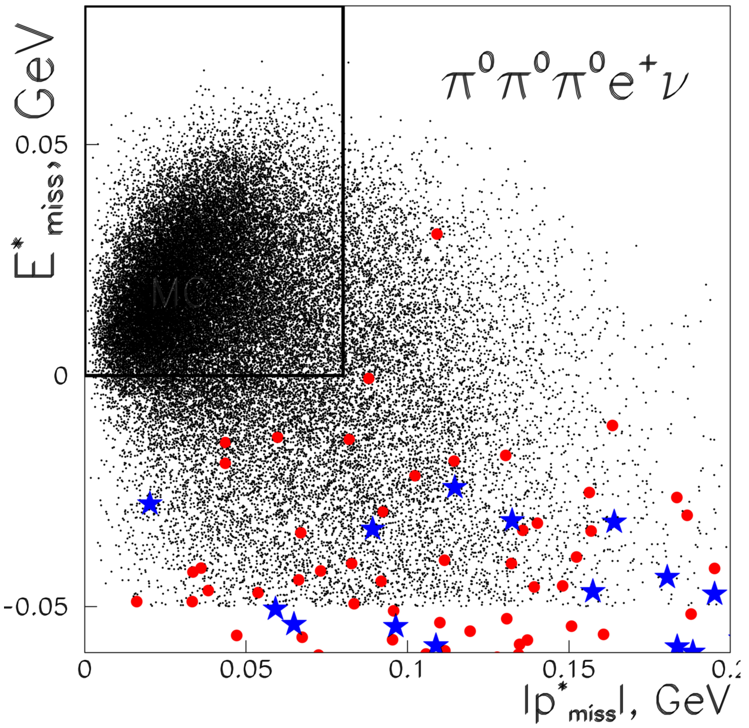




$\pi^0\pi^0\pi^0 e^+\nu$

- $P^*_{miss} < 0.08$GeV $p^*_{\nu,max} = 0.08$GeV
- $E^*_{miss} > 0$ energy in K^+ rest frame

Background-free



Matrix elements

$$M \sim (\bar{e}\gamma_\alpha(1+\gamma_5)\nu)H_\alpha$$

Lorentz invariance + Bose-statistics limit hadron current to

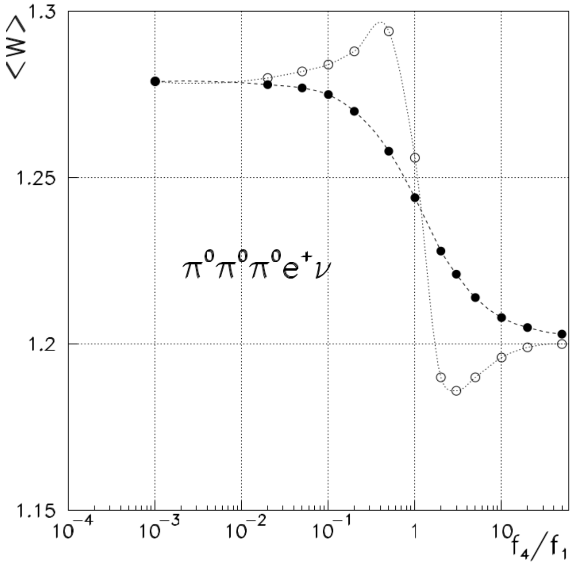
$$f_3 \sim \left(\frac{m_e}{m_K}\right)^2 \approx 0$$

$H_\alpha = f_1 p_\alpha + f_3(k_e + k_\nu)_\alpha$ $\pi^0 e^+ \nu$

$= f_1(p_1 + p_2)_\alpha$ $\pi^0\pi^0 e^+ \nu$

$= f_1(p_1 + p_2 + p_3)_\alpha + f_4 q_\alpha,$ $\pi^0\pi^0\pi^0 e^+ \nu$

$$q = \frac{\{(p_1 \cdot p_2)p_3\}_{123}}{m_\pi^2}$$



$p_1 \cdot p_2 \approx m_\pi^2 \ \rightarrow\ q \approx p_1 + p_2 + p_3, \ \ H_\alpha \approx (f_1 + f_4)(p_1 + p_2 + p_3)$

Branching ratios

Decay	Events	ε	BR	PDG
$\pi^0 e^+ \nu$	$8.4\text{x}10^{6}$	$1.08\text{x}10^{-2}$	Normalization	$(5.07\pm0.04)\text{x}10^{-2}$
$\pi^0\pi^0 e^+ \nu$	896 ± 51	$2.3\text{x}10^{-3}$	$(2.54\pm0.14)\text{x}10^{-5}$	$(2.55\pm0.04)\text{x}10^{-5}$
$\pi^0\pi^0\pi^0 e^+ \nu$ $f_4/f_1=-3$	0	$1.89\text{x}10^{-3}$	$<5.4\text{x}10^{-8}$ 90% CL	$<3.5\text{x}10^{-6}$ 90% CL

Systematic errors

- f_4/f_1 unknown, BR can be 10% less
- BR($K^+ \to \pi^0 e^+ \nu$) = (5.07±0.04)%, <1%

BR($\pi^0\pi^0 e^+\nu$) agrees → ε's are correct to ±6%
σ_ε is only 2nd order correction to upper limit
n = (ε ± σ_ε)B, n = 0, B < ?

$$P_0 = \frac{1}{\sqrt{2\pi}\sigma_\epsilon} \int \exp\left[-(\epsilon + x)B - \frac{x^2}{2\sigma_\epsilon^2}\right] dx =$$

$$= e^{-A}, \quad A = \epsilon B \left[1 - \left(\frac{\sigma_\epsilon}{\epsilon}\right)^2 \times \frac{\epsilon B}{2}\right] \approx \epsilon B \left[1 - 1.15 \left(\frac{\sigma_\epsilon}{\epsilon}\right)^2\right],$$

$$\epsilon B \approx 2.3 \left[1 + 1.15 \left(\frac{\sigma_\epsilon}{\epsilon}\right)^2\right], \quad \frac{\sigma_\epsilon}{\epsilon} << 1.$$

Roger Barlow, “Systematic Errors: Facts and Fictions”, arXiv:hep-ex/0207026v1 6Jul 2002

Conclusion

$$BR(K^+ \to \pi^0\pi^0\pi^0 e^+\nu) < 5.4 \times 10^{-8} \quad 90\%\ CL$$

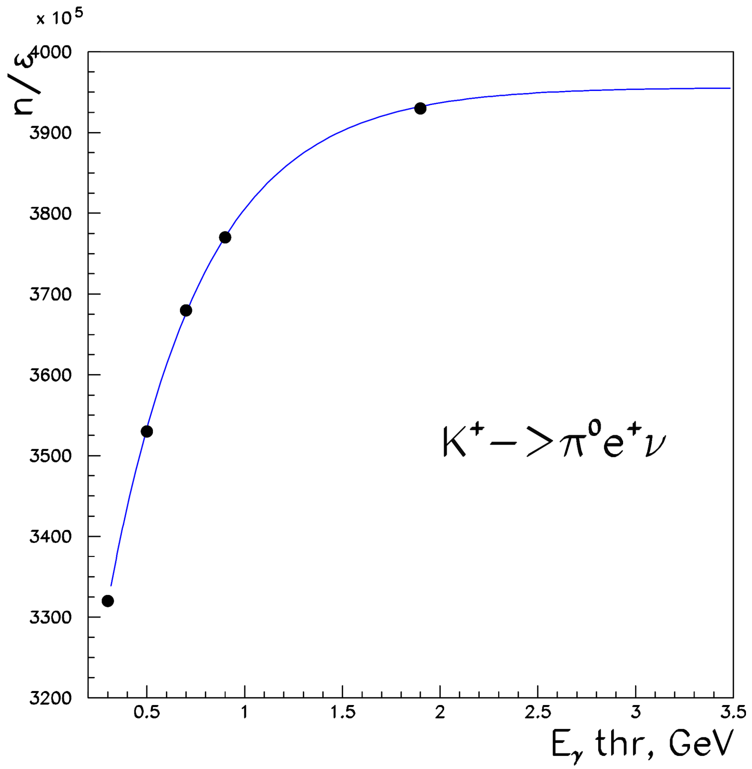
65 times better than current PDG

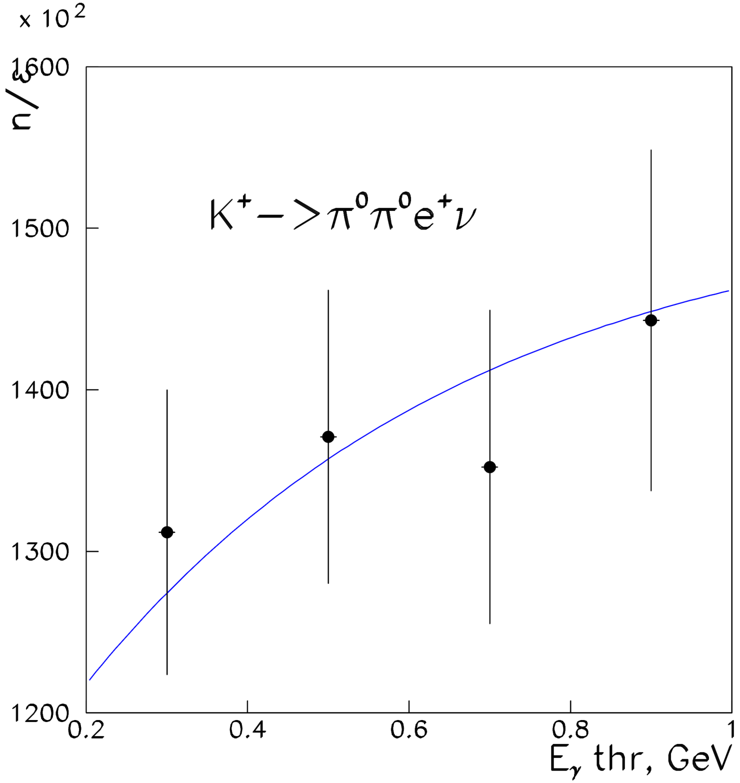
Background-free experiment

BR ~ 1/M rather than 1/√M

Paves the road for future high-statistics experiments

Eγ threshold





Формфакторы

Параметризация f_1 мало влияет на эффективность

max/min ≈ 1.09

$f_1(q^2,z^2) = f_1(0,0)(1+az^2+bz^4+c(m_{e\nu}/m_\pi)^2)$

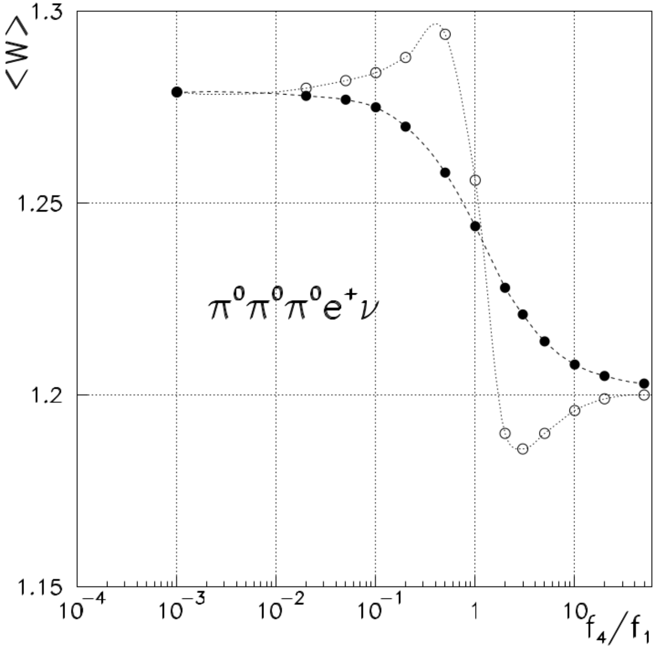
$z = m_{\pi\pi}/m_\pi$

$a = 0.092 \pm 0.021$

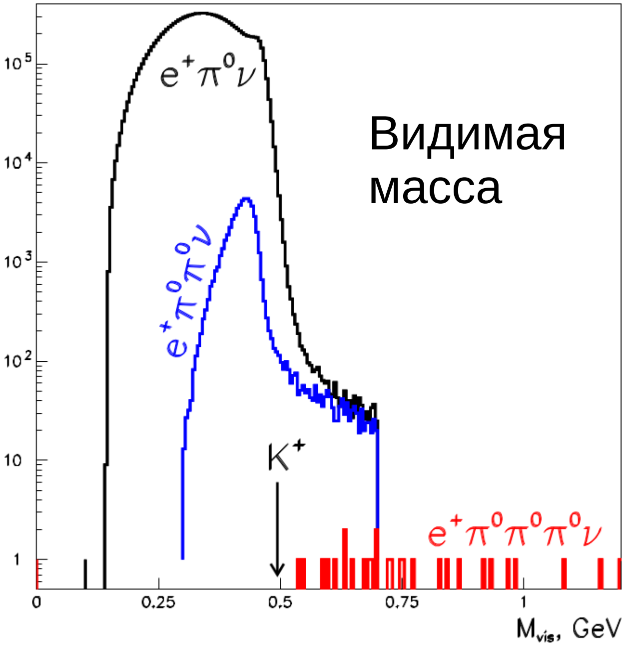
$b = (-5.6 \pm 2.4) \times 10^{-3}$

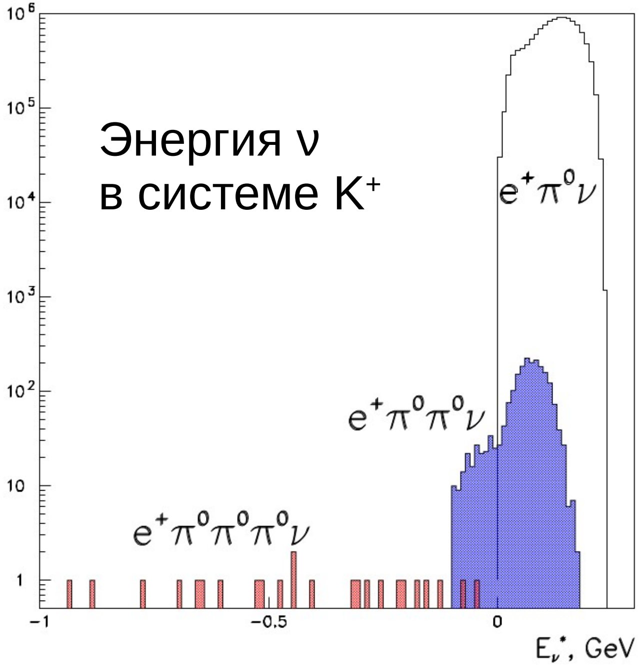
$c = 0.036 \pm 0.007$

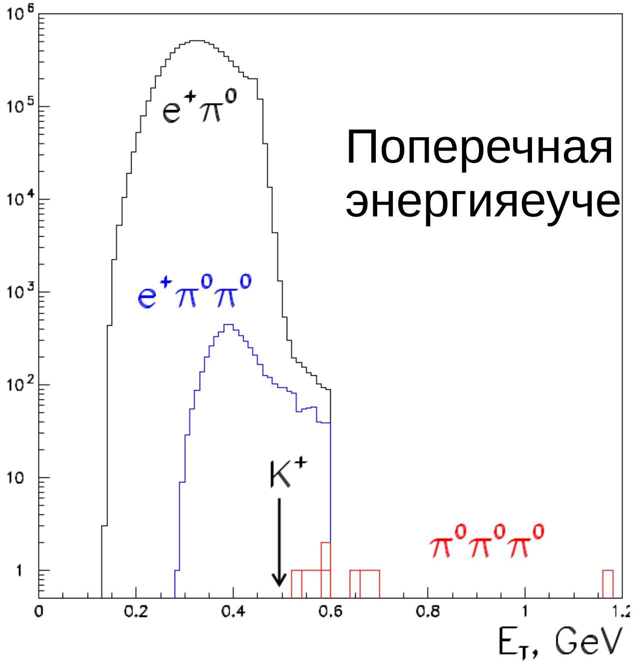
NA48/2 JHEP08 (2014) 159
ArXiv ePrint: 1406.4749



События $\pi^0\pi^0\pi^0e^+$







Мотивация