Status and Prospects of KLOE on $K^{\pm}$

L. Passalacqua / LNF-INFN
& the KLOE $K^{\pm}$ group.

Outlook

- $K^{\pm}$ Physics
- Experimental issues at the Φ: lessons from KLOE
- Educated guesses on $K^{\pm} \rightarrow \pi^{\pm} \nu\nu$

Leptonic and semileptonic modes

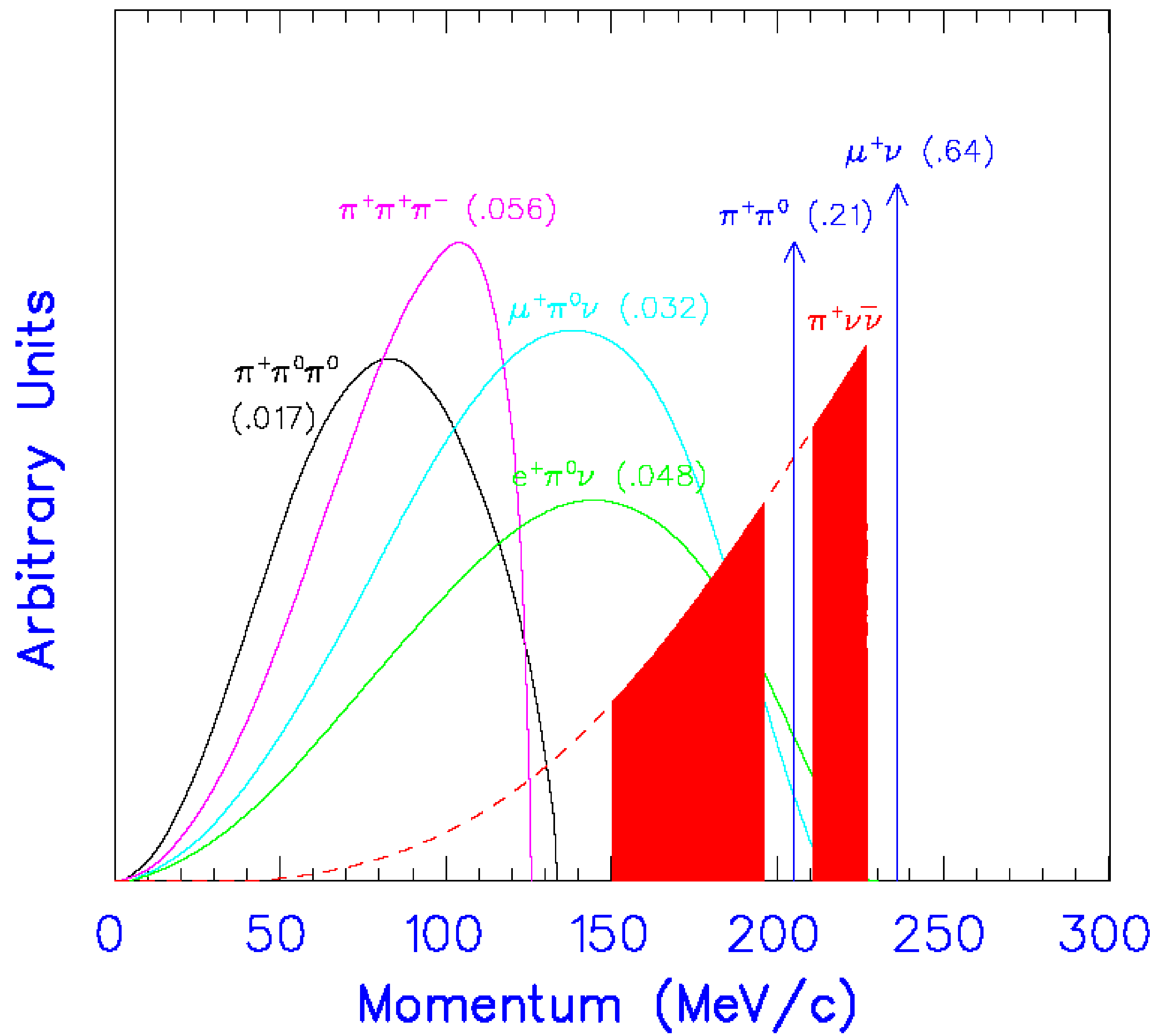
$e^+ \nu_e$	$(1.55 \pm 0.07) \times 10^{-5}$	Universality
$\mu^+ \nu_\mu$	(63.43 ± 0.17) %	Universality
$\pi^0 e^+ \nu_e$ Called K^+_{e3}.	(4.87 ± 0.06) %	V_{us}
$\pi^0 \mu^+ \nu_\mu$ Called $K^+_{\mu 3}$.	(3.27 ± 0.06) %	V_{us}

Hadronic modes

$\pi^+ \pi^0$	(21.13 ± 0.14) %	
$\pi^+ \pi^0 \pi^0$	(1.73 ± 0.04) %	CP violation
$\pi^+ \pi^+ \pi^-$	(5.576 ± 0.031) %	CP violation

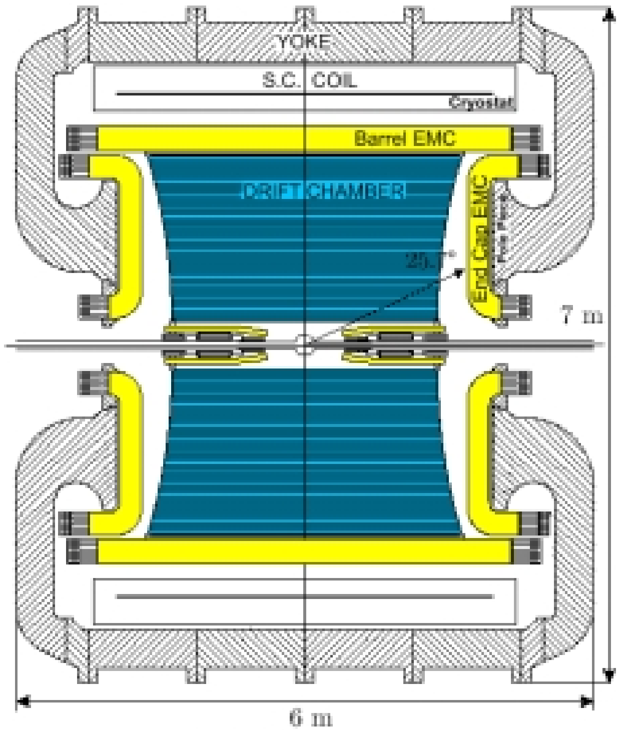
Golden New Physics modes

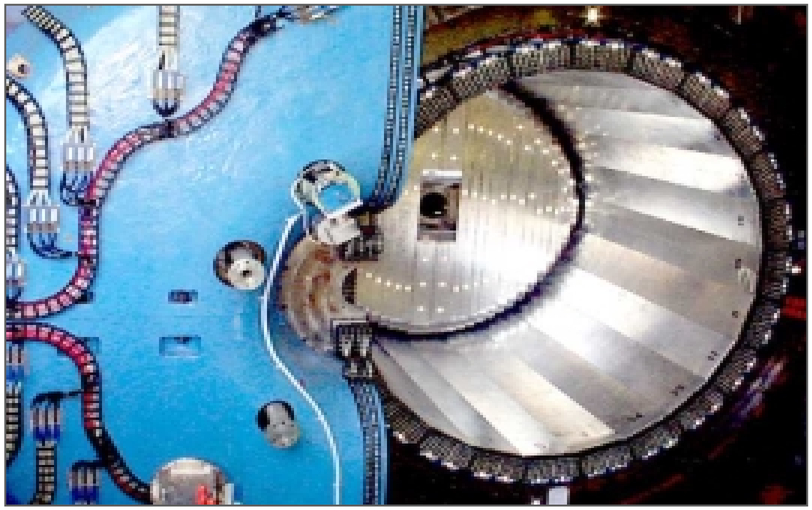
$\pi^+ \nu \overline{\nu}$	*S1*	$(1.6 \, ^{+1.8}_{-0.8}) \times 10^{-10}$	
$\pi^+ \pi^0 \nu \overline{\nu}$	*S1*	$< 4.3 \times 10^{-5}$	CL=90%

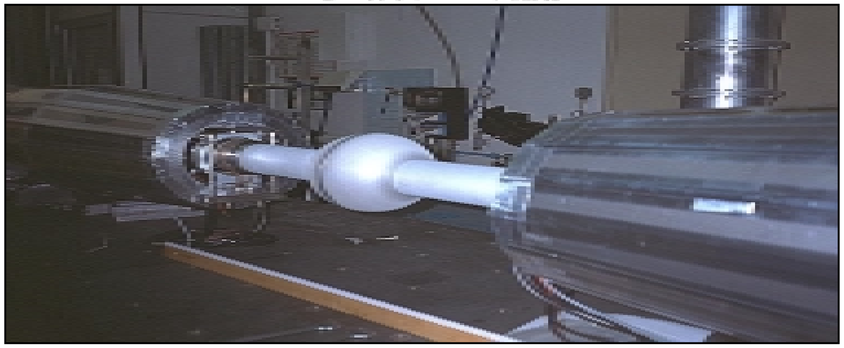


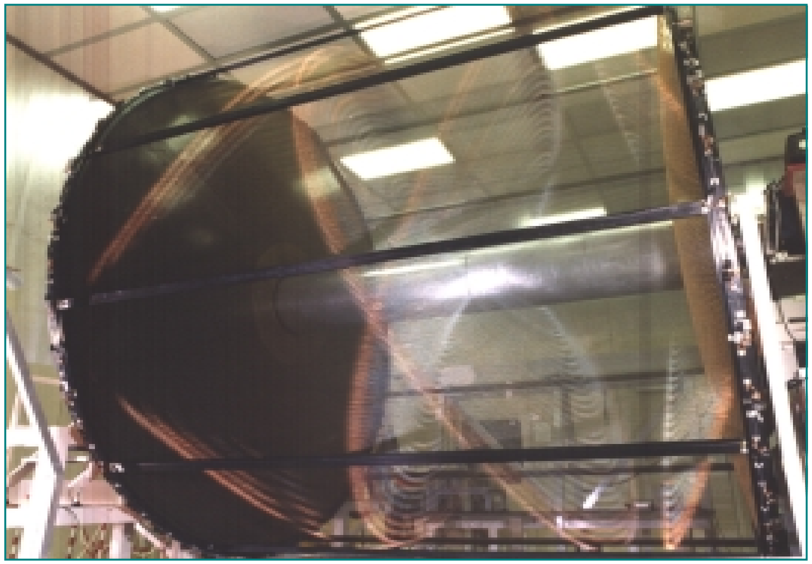
Arbitrary Units
Momentum (MeV/c)
0
50
100
150
200
250
300
$\pi^+\pi^0\pi^0$ (.017)
$\pi^+\pi^+\pi^-$ (.056)
$\mu^+\pi^0\nu$ (.032)
$e^+\pi^0\nu$ (.048)
$\pi^+\pi^0$ (.21)
$\mu^+\nu$ (.64)
$\pi^+\nu\bar{\nu}$

The KLOE detector









Experimental Issues: Tracking

Fully stero geometry → a) 2D+2D (*default*) / b) 3D

Instrumented from 25 *cm* from beam line

First 4 layers at lower voltage (less efficient) to prevent aging

⇒ Relevant (~2.5) penalty factor for $K^{\pm}$

In addition (different from any other e^+e^- detector):

Second Pass tracking to account for low β

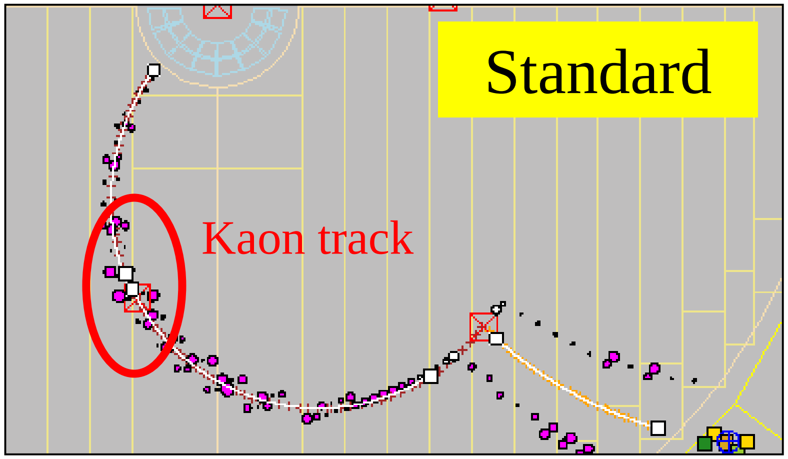
Ad hoc treatment of Coulomb diffusion

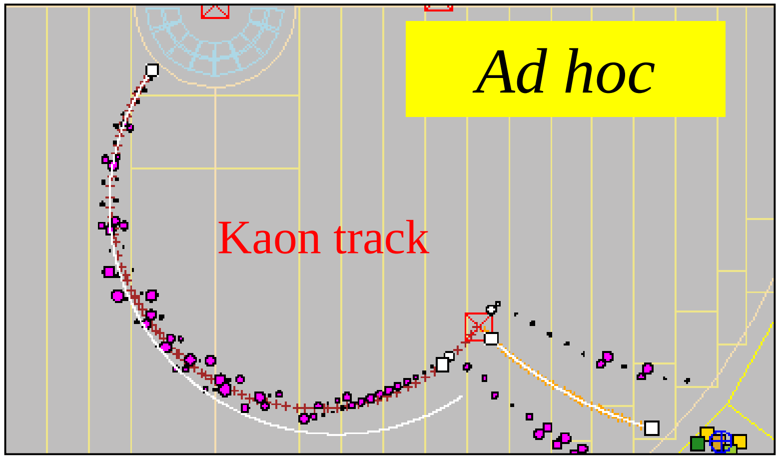
Ad hoc treatment of fake verteces (track splitting)

Fake Verteces (Track Splitting)

Track splitting is due to a compromise between vertex and pattern efficiency. In a stero chamber is complicated by the “natural” derivative of the curvature due to non-axial projection. Kaons suffer more because of low β.

Ad hoc treatment brought fake verteces @ 2% level (x10 improvement)





Coulomb Diffusion

Correct treatment of Coulomb Diffusion is the key ingredient to get accurate tracking error matrices, which are needed by the vertexing algo's. Due to low β K are particularly affected.

Two options:

a) Fit track parameters + coordinates of 'scattering points' (tracking *à la* Lutz);

b) Fit track parameters with point-to-point correlation matrix.

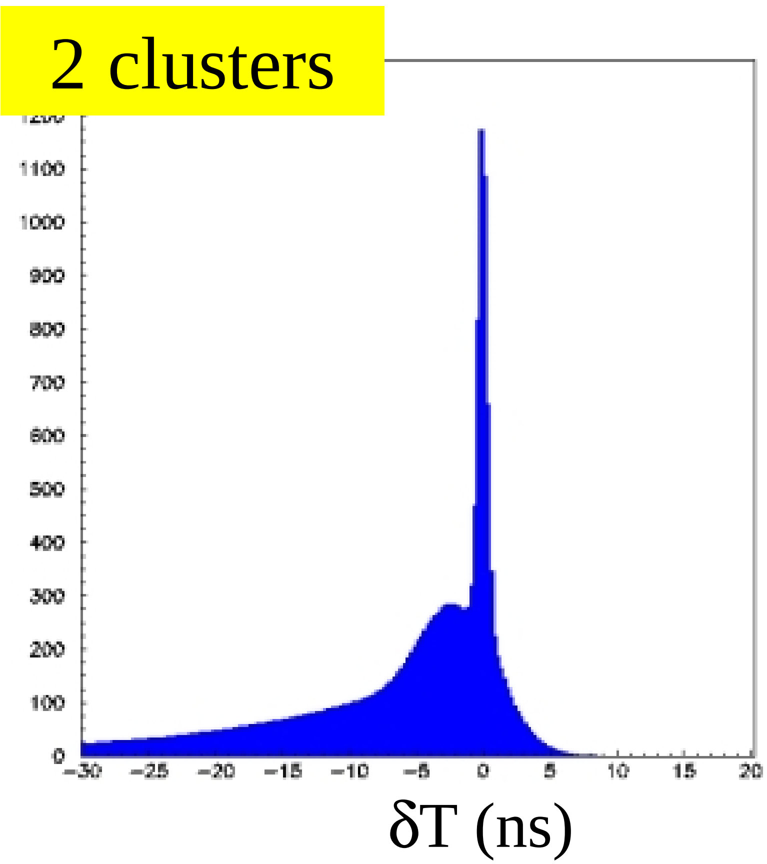
+ several description of *Landau* tails (Highland, Lynch-Dahl, …)

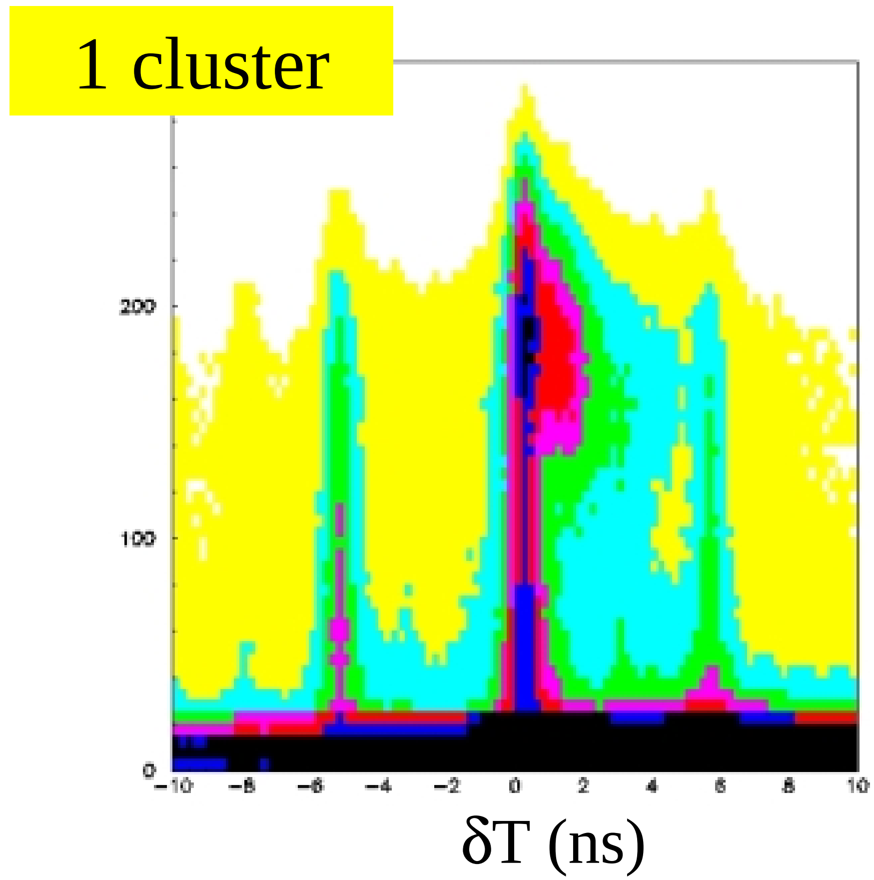
	Resolution		Pull	
	(a)	(b)	(a)	(b)
$K^{\pm}$	3.00	1.66	1.67	1.33
$\mu^{\pm}$	1.42	1.06	1.29	1.19

We found approach (b) works better.

Timing

Absolute timing is needed to reject the huge low-energy photon background from DAΦNE

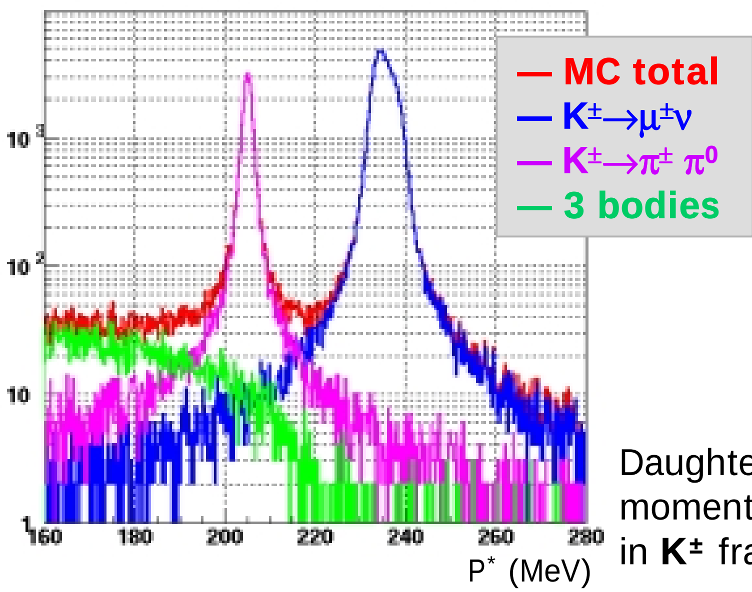




Tagging

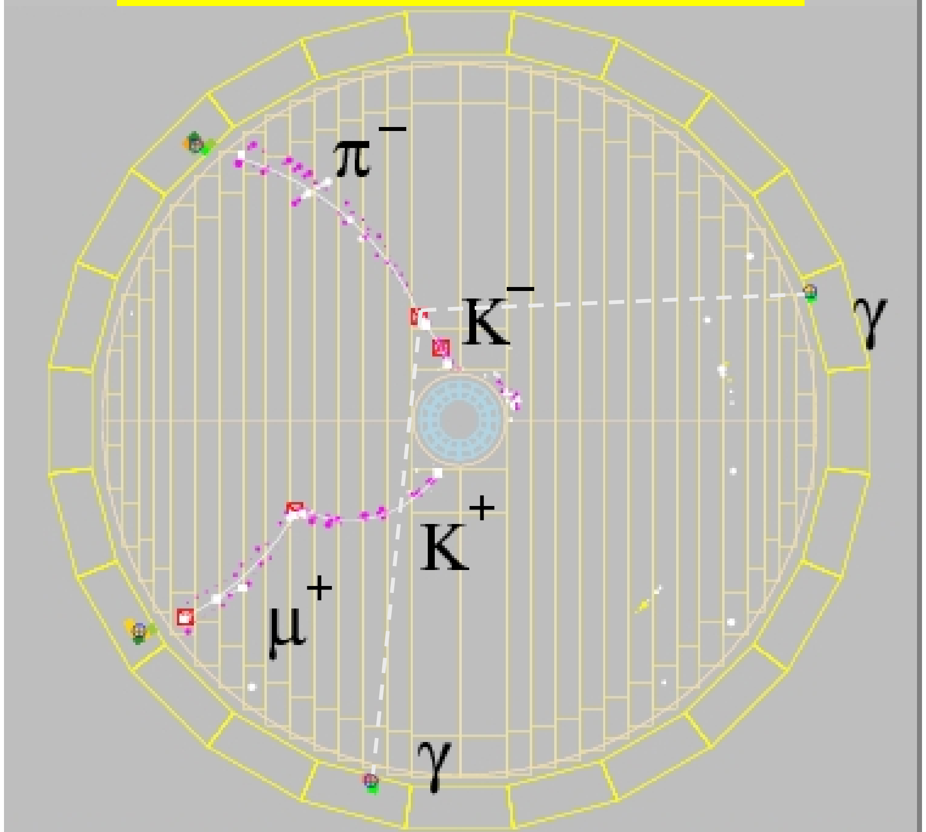
- 1 hemisphere **tagging** strategy: $\mu^{\pm}\nu_{\mu}$, $\pi^{\pm}\pi^{0}$
  p^{*} peaks are used to tag $K^{\pm}$

a) Reject non-K background
b) Fix absolute Timing
c) Satisfy Trigger requirements



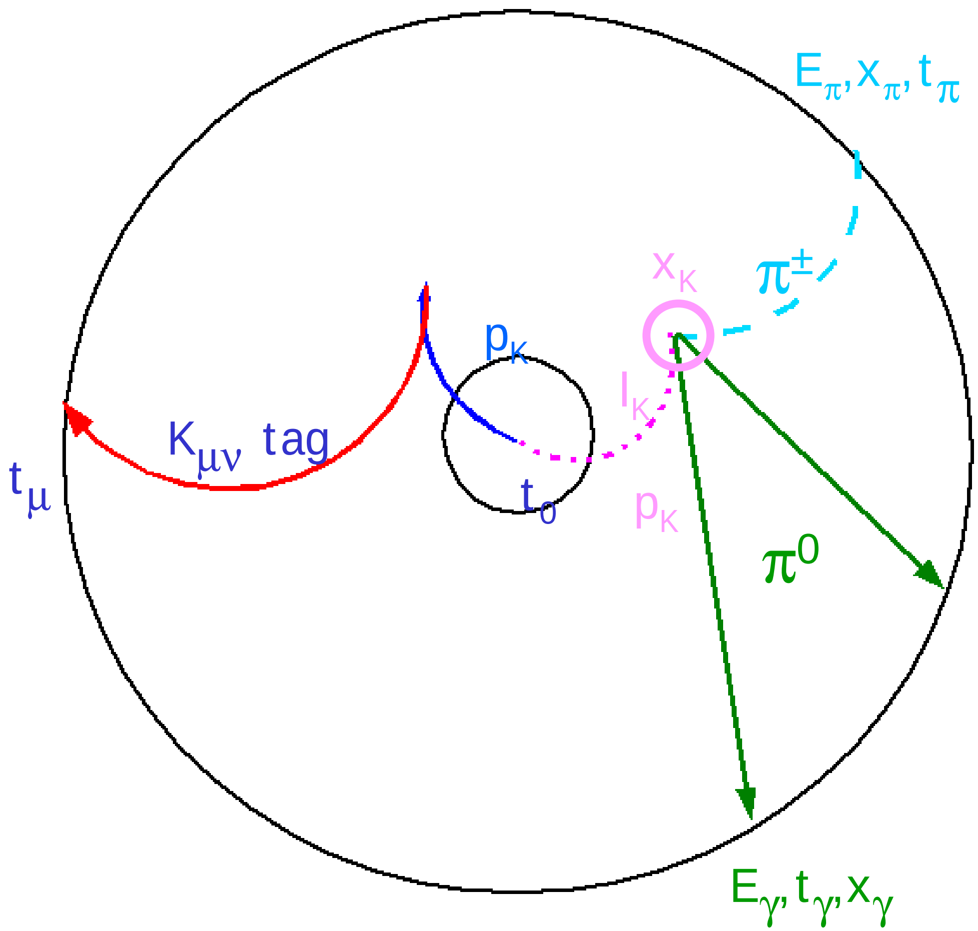
Daughter momentum in **K±** frame

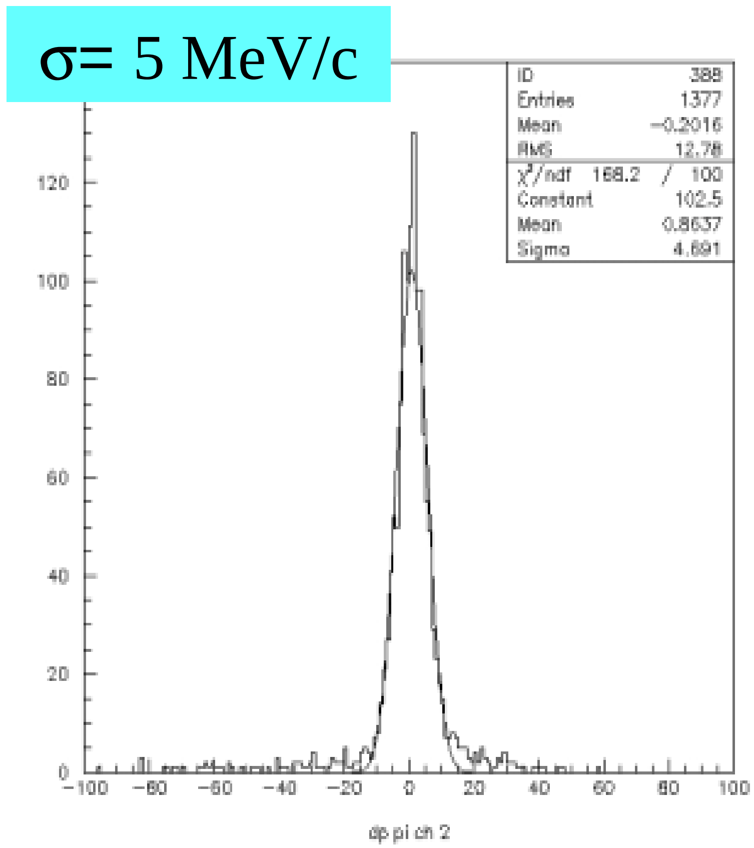
Eff. (single arm) ~ 25%



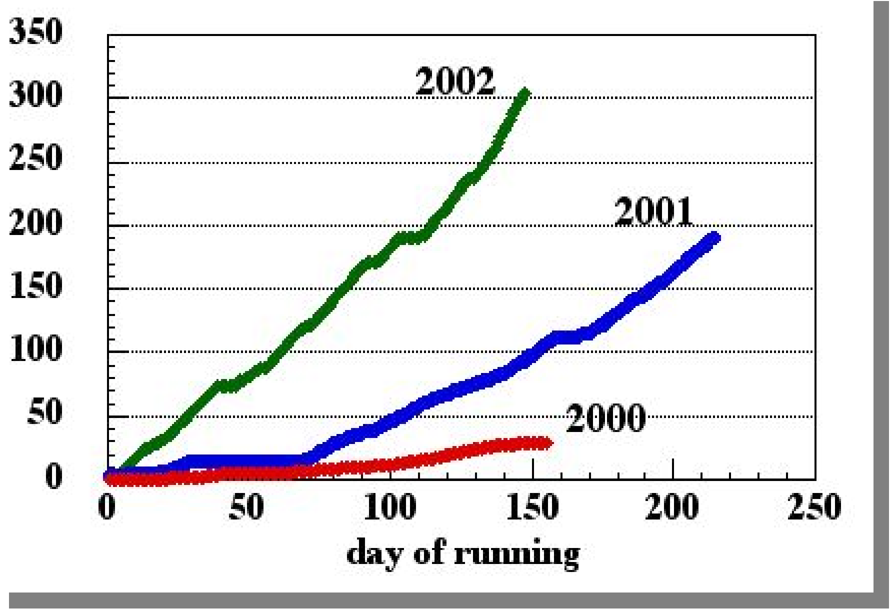
$\phi \to K^{+}K^{-}$; $K^{+} \to \mu^{+}\nu_{\mu}$, $K^{-} \to \pi^{-}\pi^{0}$

Tracking systematics





Summary of DAΦNE Operations



	Design	2002
◆ Max number of bunches	120	51
◆ Lifetime (min)	120	40
◆ Bunch current (mA)	40	20
◆ Single Bunch lum. (10^{30} $cm^{-2}s^{-1}$)	4.4	1.5
◆ Peak Luminosity (10^{32} $cm^{-2}s^{-1}$)	5.3	0.75
◆ ϕ per year (10^{9})	15	0.9

March 1st 1998:
First collisions

1999 run: **2.5 pb^{-1}**
detector calibration

2000 run: **25 pb^{-1}**
7.5×10^{7} ϕ
first published results

2001 run: **190 pb^{-1}**
5.7×10^{8} ϕ
analysis in progress

2002 run: **300 pb^{-1}**
9.0×10^{8} ϕ
analysis in progress

V_{us} from $K_{\ell 3}$ decays

$$\underbrace{\Gamma(K_{e3})} = \frac{G_F^2 m_K^5}{192\pi^3} C_K^2 |V_{us}|^2 \underbrace{|f_+^{K\pi}(0)|^2} I_K(m_K^2, m_\pi^2, m_\ell^2, \underbrace{\tilde{f}_+^{K\pi}(q^2)})$$

measuring

$BR(K_{l3})/\tau_K$

provided by the theory

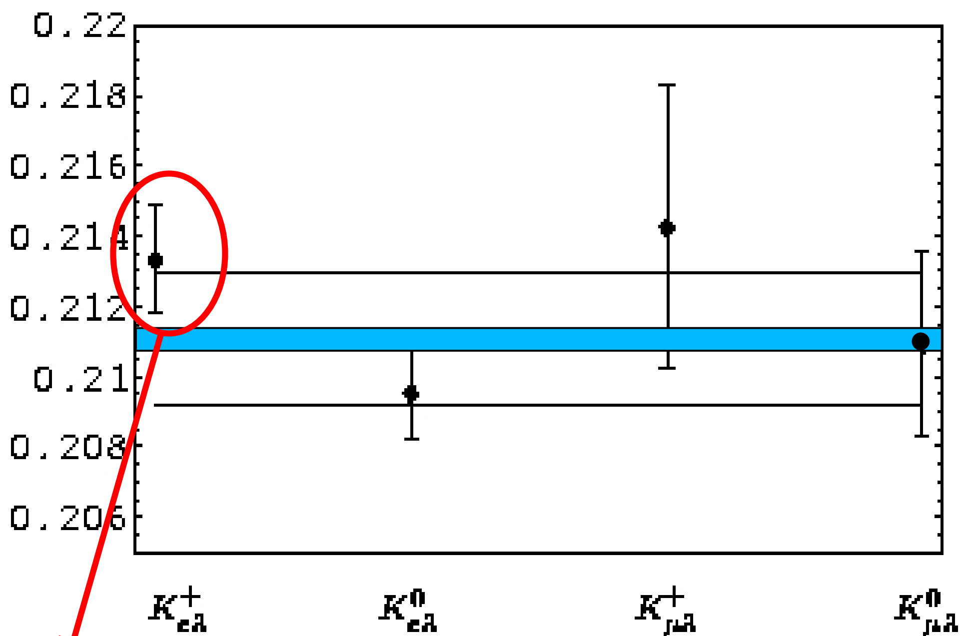
measuring q^2 evolution of the form factor:

$$f_x^{K\pi}(q^2) = f_x^{K\pi}(0) \cdot \left(1 + \frac{\lambda_+^{K\pi}}{m_\pi^2} q^2\right)$$

The observable is: $|V_{us}||f_+(0)|$

Contributions to ΔV_{us}

$|V_{us}||f_+(0)|$



Theoretical error

$$\frac{\Delta|V_{us}|}{|V_{us}|} = 0.5\left(\frac{\Delta BR_{K_{e3}}}{BR_{K_{e3}}} + \frac{\Delta\tau}{\tau}\right) + 0.05\frac{\Delta\lambda_+}{\lambda_+} + \frac{\Delta f_+(0)}{f_+(0)}$$

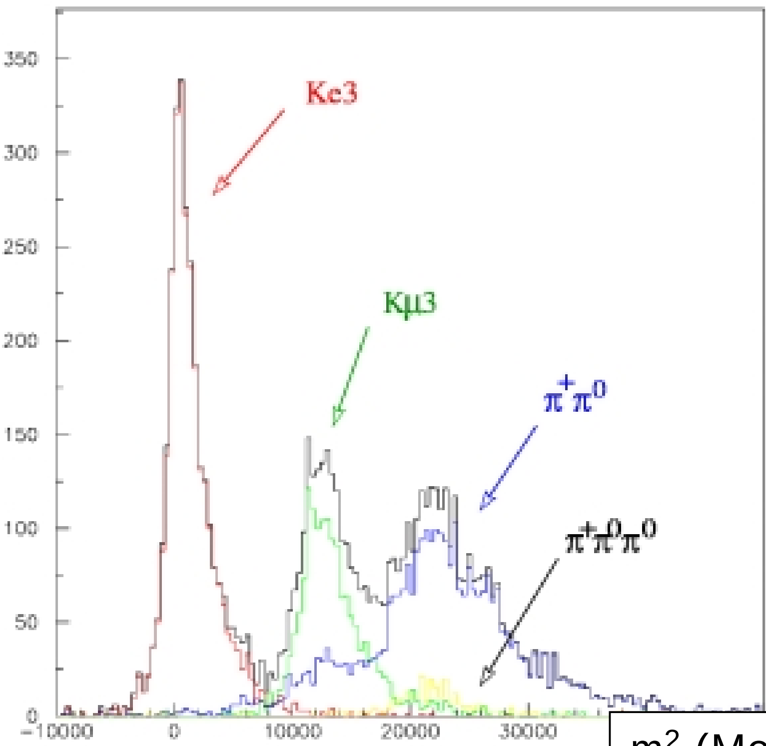
$K^{\pm}_{e3}$ 0.59% 0.22% 0.86%

can be reduced…

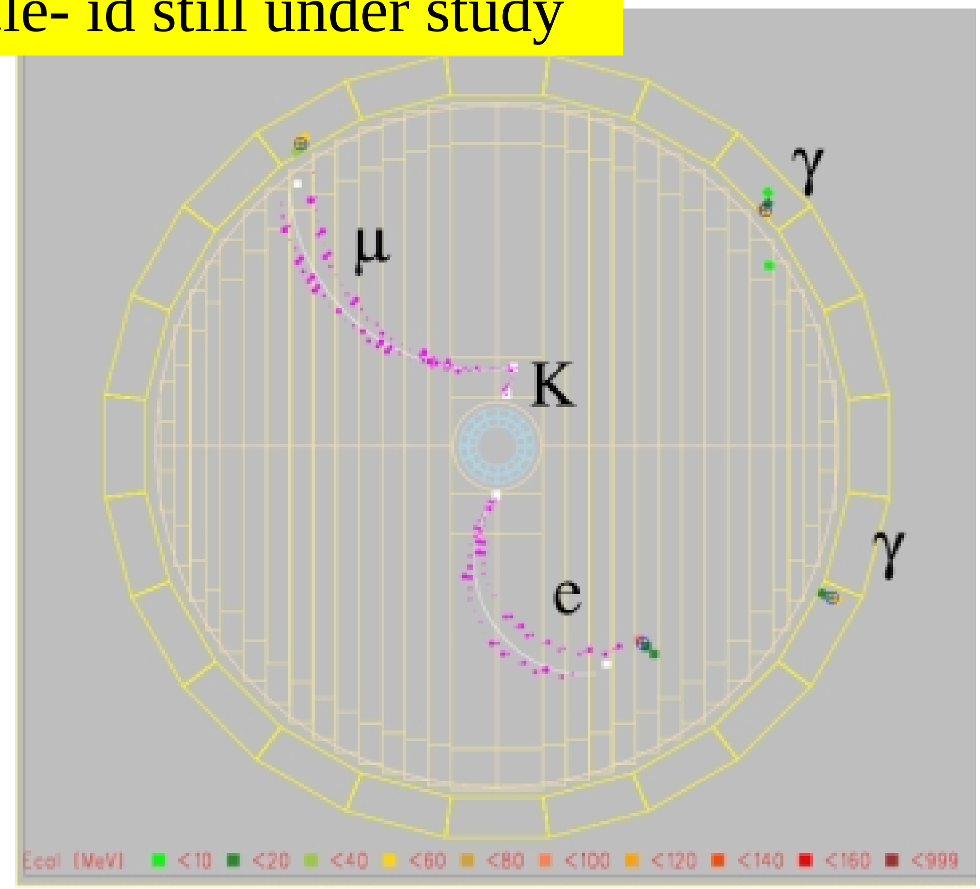
K_{e3} decays

Dedicated Particle- id still under study

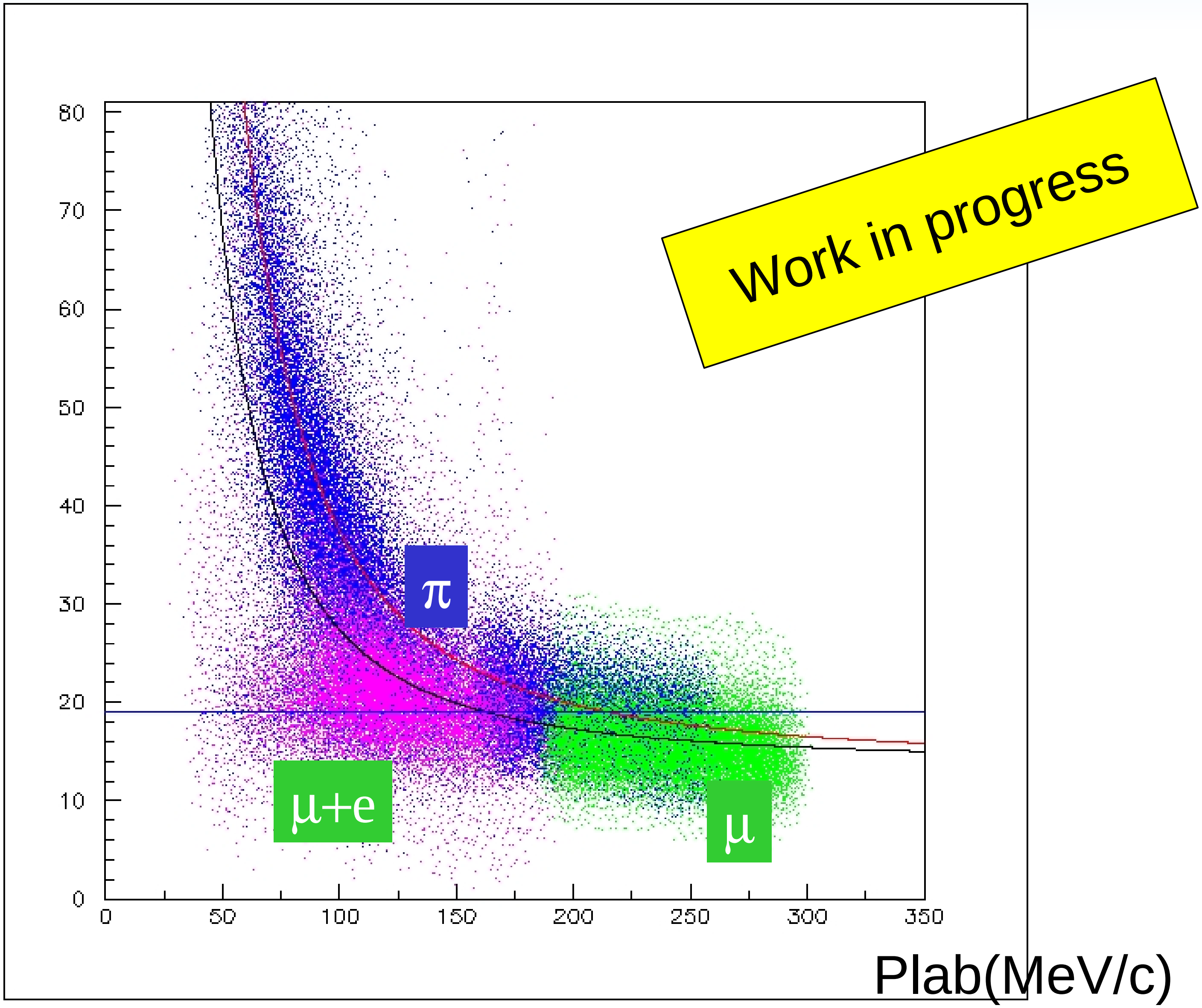
Pid with ToF



m² (MeV²)



dE/dx


80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
π
μ+e
μ
Work in progress
Plab(MeV/c)

$K^\pm \to \pi^\pm \pi^0 \pi^0$

- ❑ Determination of Dalitz plot parameters
- ❑ Test of CP asymmetry $A_g = (g_+ - g_-)/(g_+ + g_-)$
  Theory: $A_g \sim 10^{-6}$ up to 10^{-4}.

$N(\pi\pi^0{}_{tag}) = 30798 \pm 100$, $N(\mu\nu_{tag}) = 52253 \pm 230$

$BR(K^\pm \to \pi^\pm \pi^0 \pi^0) =$

$(\mathbf{1.781} \pm \mathbf{0.013}_{stat} \pm \mathbf{0.016}_{syst})\%$

PDG fit(02) : $(1.73 \pm 0.04)\%$

$L_{int} = 441\ pb^{-1}$
2001+2002 data

Selection

- ⇨ $\mu\nu/\pi\pi^0$ – tagging
- ⇨ 2-tracks vtx in DC volume
- ⇨ $p^* < 135$ MeV/c
- ⇨ ≥4 clusters ontime @ vtx ($\Delta t < 4\sigma$)
- ⇨ $E_{tot} < 450$ MeV

Background: main $K^\pm$ decays, K_{e4}'

Dalitz plot : $F(X,Y) = 1 + \mathbf{g}Y + \mathbf{h}Y^2 + \mathbf{k}X^2$

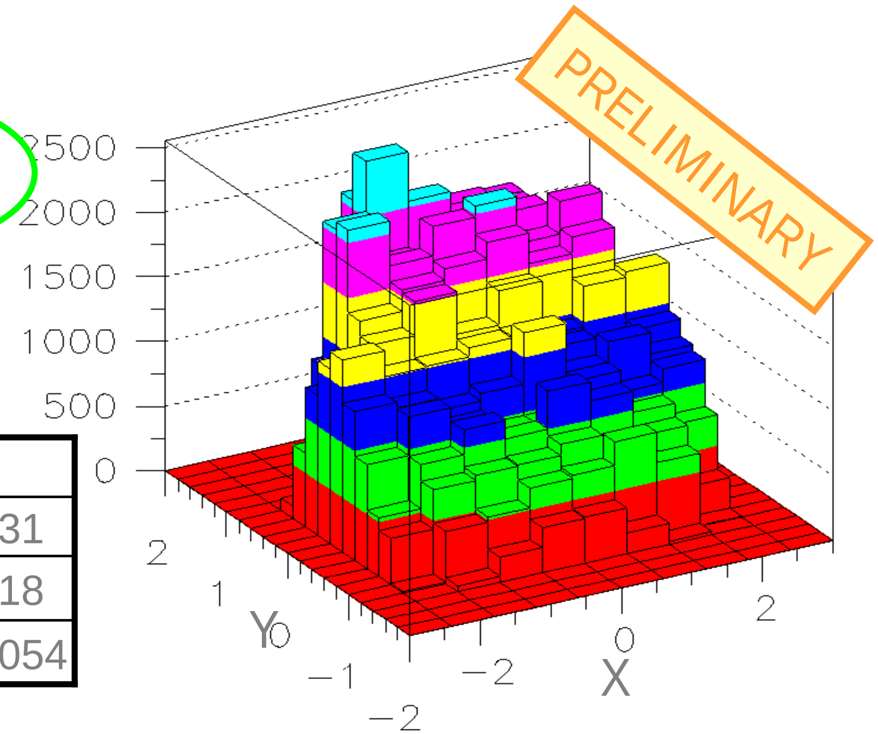
$s_i = (P_K - P_i)^2$

$s_0 = \sum_i s_i/3$;

$\mathbf{X} = (s_1 - s_2)/m_\pi^2$

$\mathbf{Y} = (s_3 - s_0)/m_\pi^2$

	KLOE 6.33 pb^{-1}	PDG
g	0.607±0.026	0.652±0.031
h	0.026±0.027	0.057±0.018
k	0.0080±0.0037	0.0197±0.0054



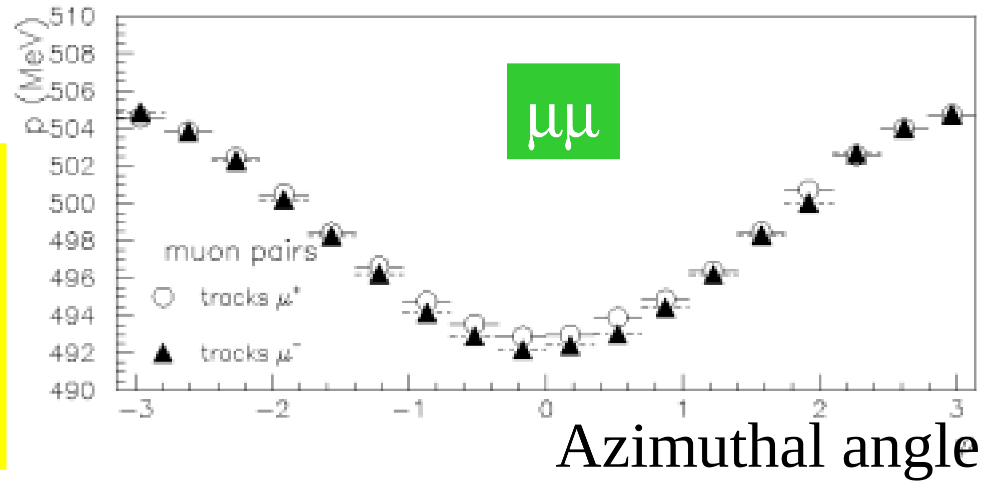
$K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$

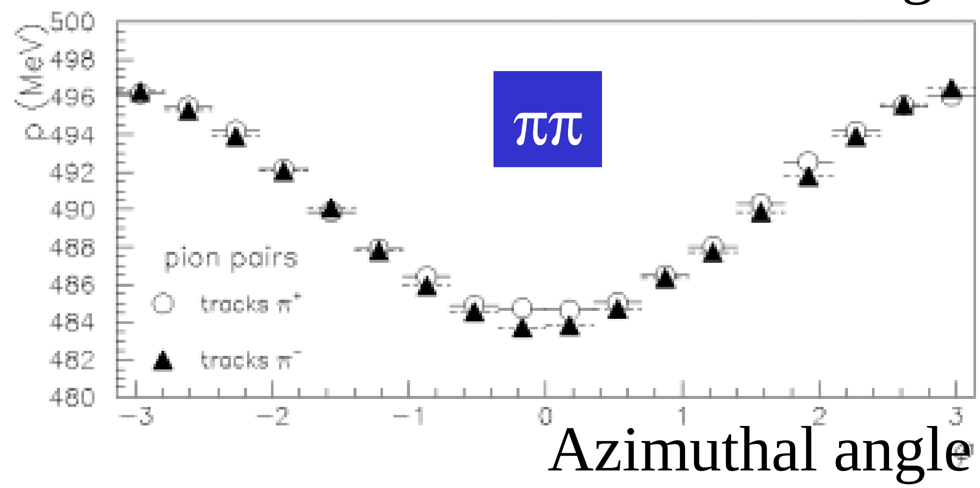
Limiting systematics will be charge-dependent detector effects

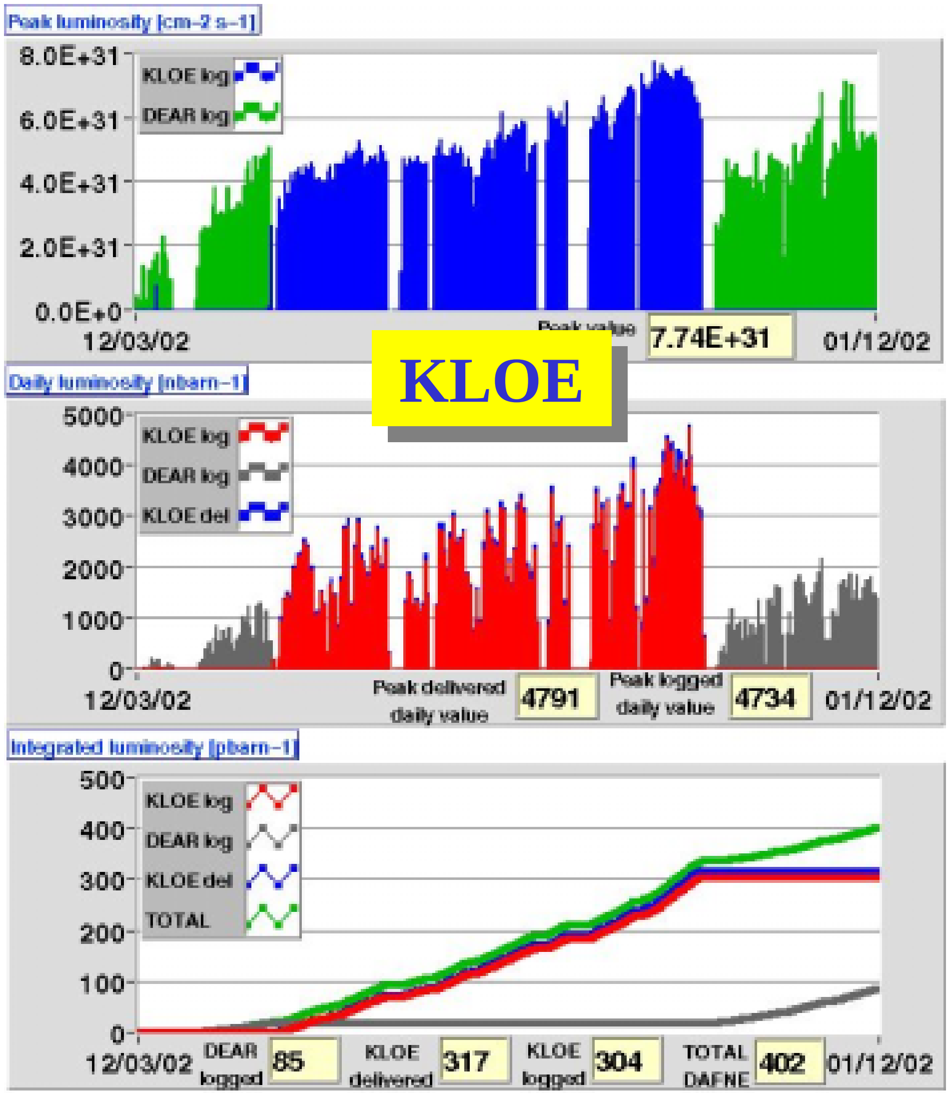
e.g. Gravitational Sag effects

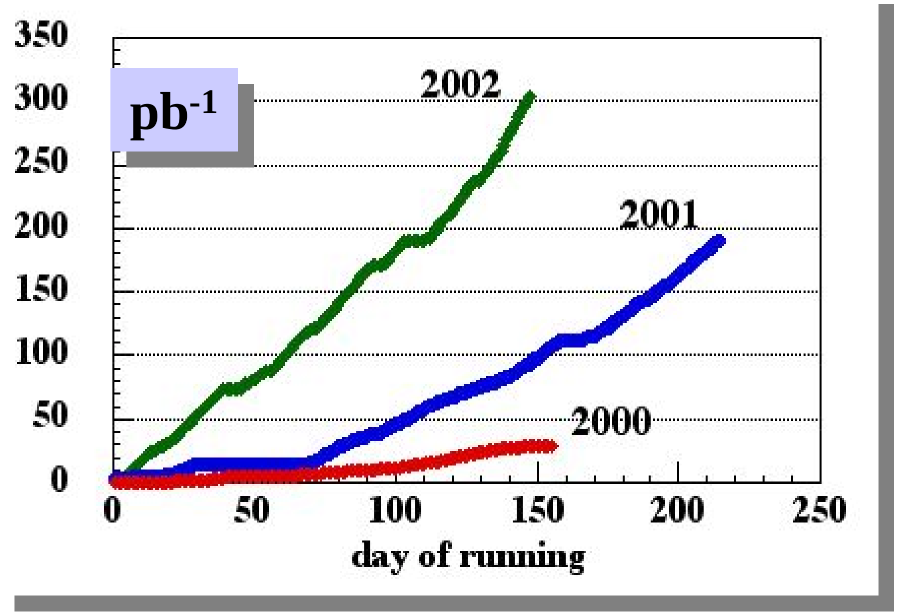
(now taken into account)

Should be @ 0.1%









3.5 pb^{-1}/day x 200 days x (10^{32} /7 10^{31}) = 1 fb^{-1}

1 year @ 10^{32} = 1 fb^{-1}

$1 \text{ year} @ 10^{32} = 1 \text{ fb}^{-1} \approx 3\ 10^9\ \Phi \approx 3\ 10^9\ K^\pm$

→ Allows few per mil measurement of O(1%) BRs
V_{us} @ / below 1% (theor. error…?)
$\delta_g(K^\pm \to \pi^\pm 2\pi^0)$ below 1 %

$1 \text{ year} @ 5 \cdot 10^{33} = 50 \text{ fb}^{-1} \approx 1.5\ 10^{11}\ \Phi \approx 1.5\ 10^{11}\ K^\pm$

→ $\approx 2\ 10^6\ K^\pm \to e^\pm \nu$ produced
$\approx 15\ \ K^\pm \to \pi^\pm \nu\nu$ produced

$1 \text{ year} @ 10^{35} = 10^3 \text{ fb}^{-1} \approx 3\ 10^{12}\ \Phi \approx 3\ 10^{12}\ K^\pm$

→ $\approx 300\ K^\pm \to \pi^\pm \nu\nu$ produced

$K^{\pm} \to \pi^{\pm} \nu\nu$ Tagging

$$K^{\pm} \to \mu^{\pm} \nu \ / \ \pi^{\pm} \pi^{0}$$

1

$K^{\mp} \to X^{\mp} \to Y^{\mp} \to$ Calo

Anti-Tag π^0

Obvious bkg :$K^{\mp} \to \pi^{\pm} \pi^{0}$

$R_J = (R_\gamma)^2 \cdot R_{kine} \approx 10^{-8}$

NOT OPTIMIZED !!

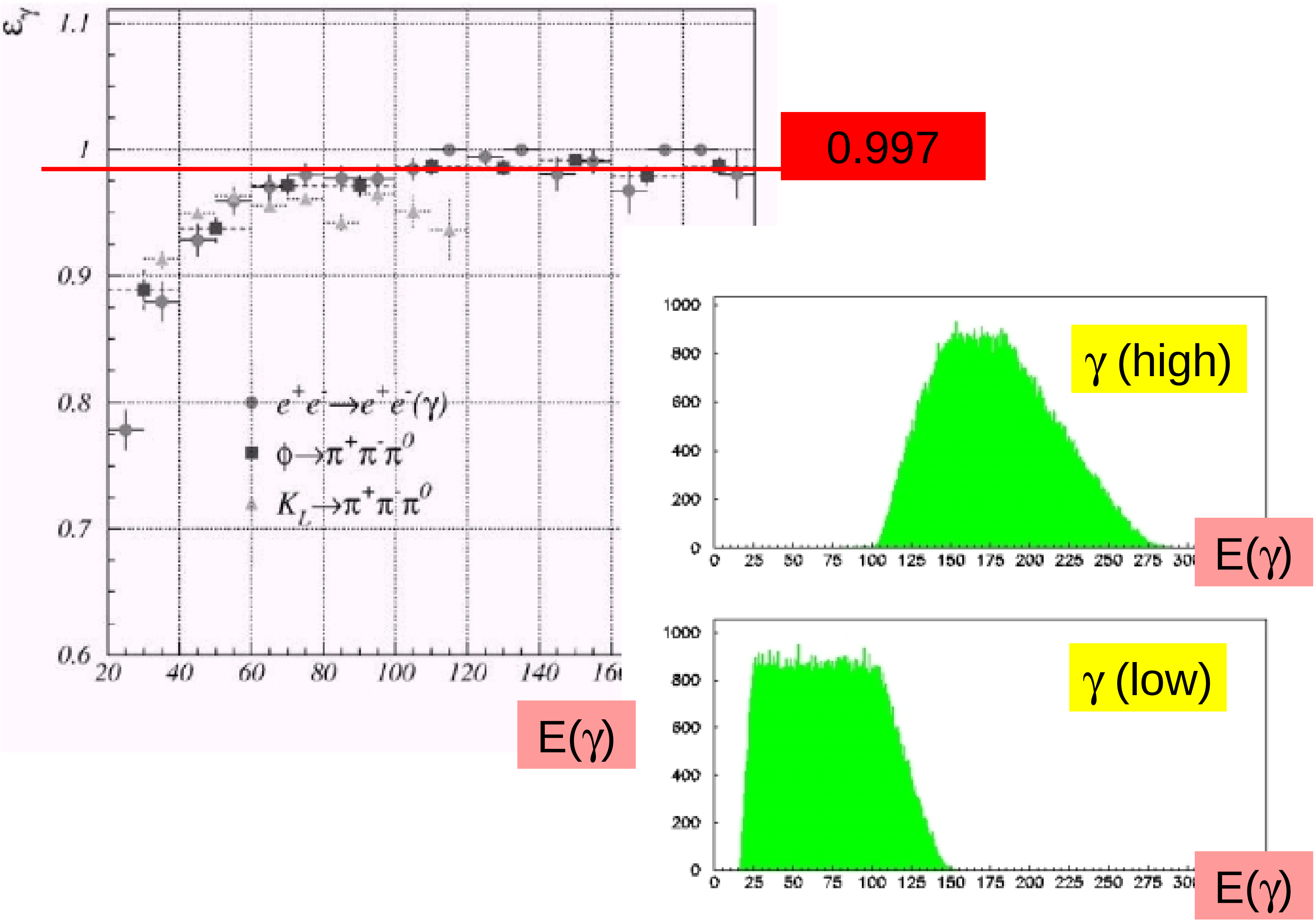
2

$K^{\mp} \to X^{\mp} \to$ Calo

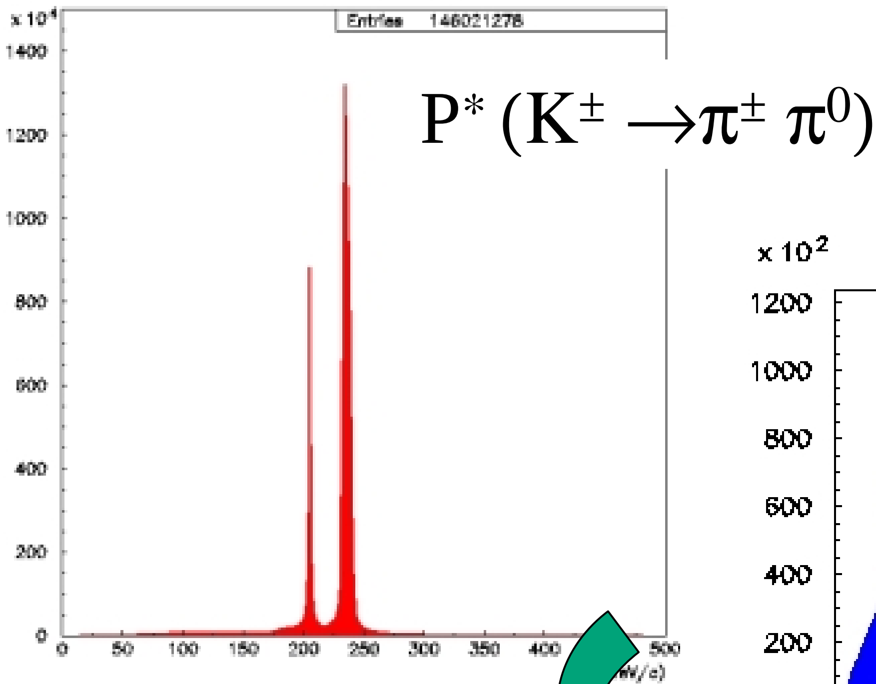
Anti-Tag π^0

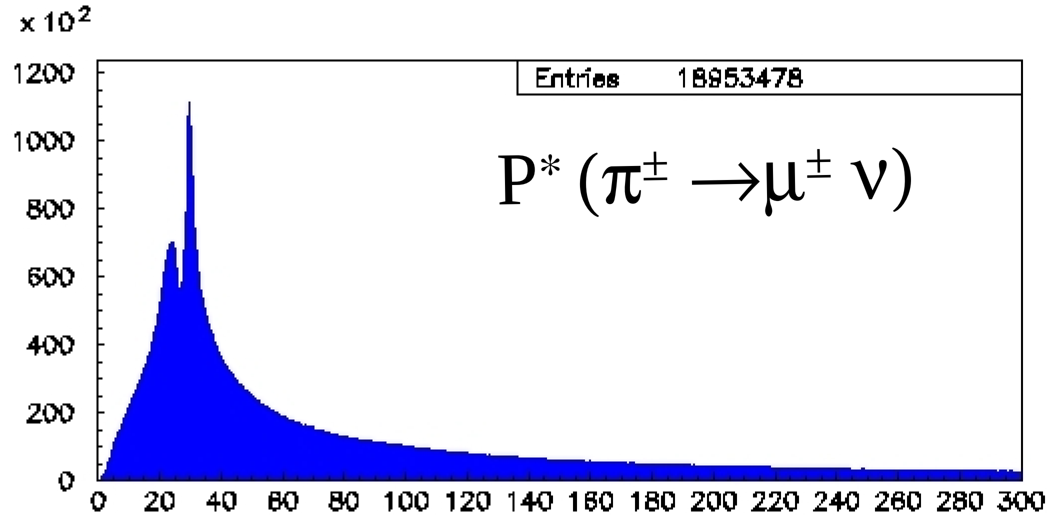
Obv. bkg $K^{\pm} \to \mu^{\pm} \nu\ (\gamma)$

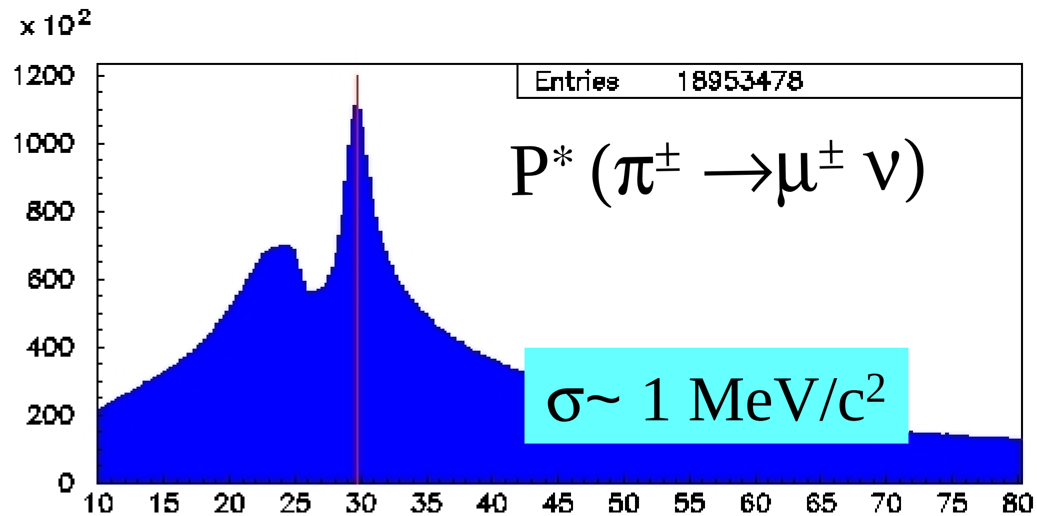
$R_J = R_{kine} \cdot R_{\pi\mu}$



εγ
1.1
1
0.9
0.8
0.7
0.6
20 40 60 80 100 120 140 16
e+e- → e+e-(γ)
φ → π+π-π0
KL → π+π-π0
0.997
E(γ)
1000 800 600 400 200 0
0 25 50 75 100 125 150 175 200 225 250 275 30
γ (high)
E(γ)
1000 800 600 400 200 0
0 25 50 75 100 125 150 175 200 225 250 275 30
γ (low)
E(γ)



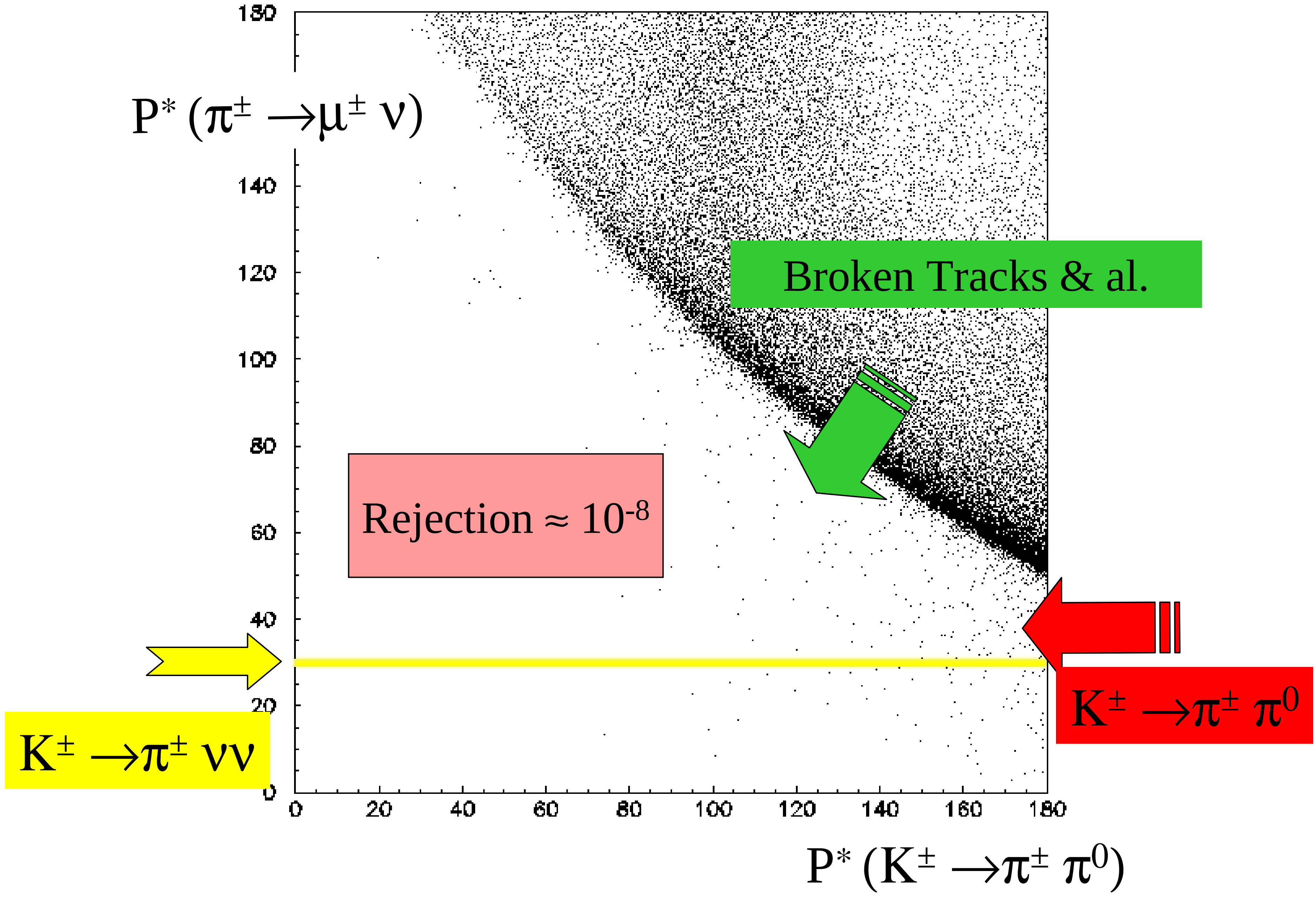




$K^{\pm} \rightarrow \pi^{\pm}\, \pi^{0}$

$\quad\quad\;\; \lfloor\!\rightarrow \mu^{\pm}\, \nu$

gives a reasonable estimate
of Efficiency (~25%)
x Acceptance (~10%)



P* (π± →μ± ν)
180
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
Broken Tracks & al.
Rejection ≈ 10-8
K± →π± νν
K± →π± π0
P* (K± →π± π0)

$$\varepsilon_a = \varepsilon_{acc}(K) \cdot \varepsilon_t(K) \cdot \varepsilon_t(\pi) \cdot \varepsilon_{vtx}(K\pi) \sim 30\%$$

$$\varepsilon_b = \varepsilon_{acc}(\pi^\pm \to \mu^\pm \nu) \cdot \varepsilon_t(\mu) \cdot \varepsilon_{vtx}(\pi\mu) \sim 2.5\%$$

$\varepsilon(p^* < 180\,\text{MeV})$ for $K^\pm \to \pi^\pm \nu\nu = 30\%$

$K^\mp \to X^\mp \to$ Calo $\qquad \varepsilon_{START} = (2\varepsilon_a) \cdot 0.85 \cdot (2\varepsilon_a) \cdot 0.3 \sim 9\%$

$K^\mp \to X^\mp \to Y^\mp \to$ Calo $\qquad \varepsilon_{START} = 9\% \cdot (2\varepsilon_b) \sim 0.5\%$

Efficiency in 10% range requires $\pi\mu$ separation

Conclusions

- KLOE has already enough data to measure:

V_{us} @ or below 1% (improvement of theor. error…?)

$\delta_g(K^{\pm} \to \pi^{\pm} 2\pi^0)$ @ 1 %

- Systematics limits in the 'few' per mil range

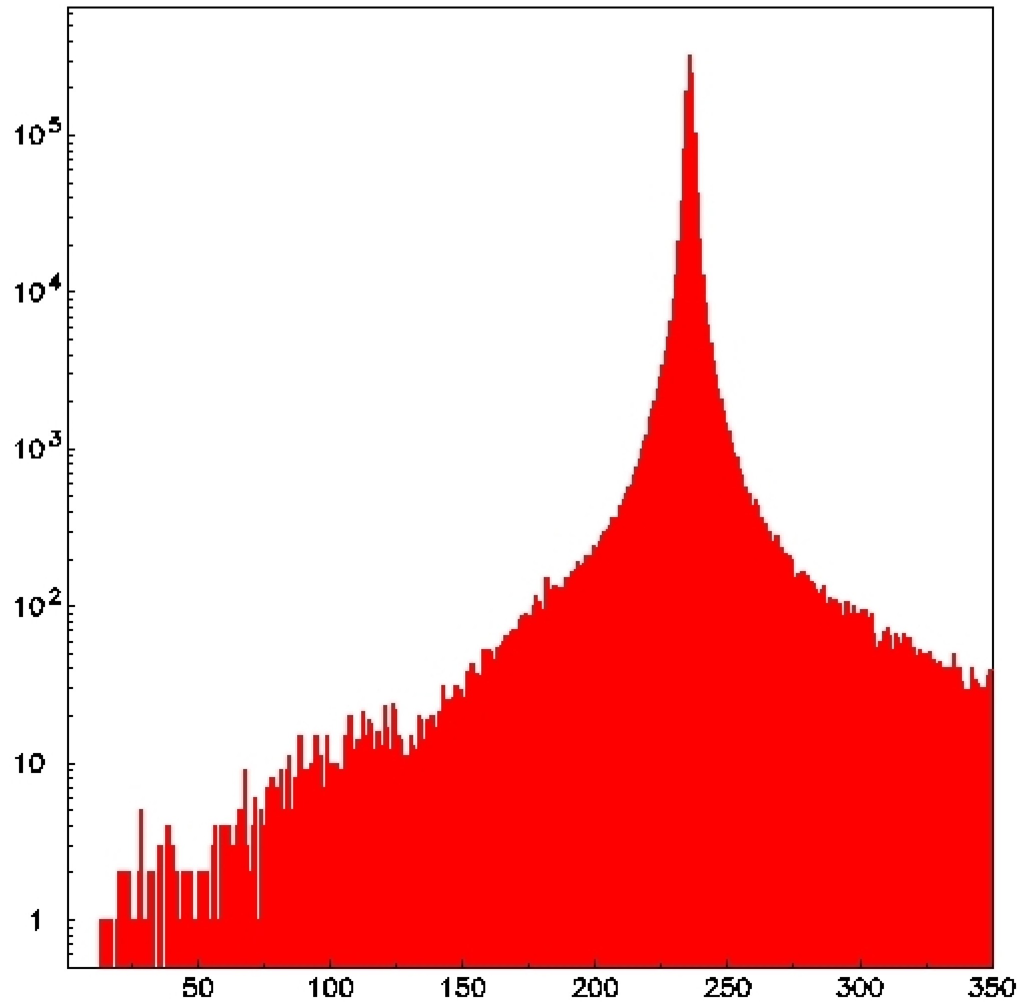
- A KLOE-like detector can possibly reach a sound rejection factor to address $K^{\pm} \to \pi^{\pm} \nu\nu$.

Minimum luminosity should be 10^{35}.

Should add a micro-vertex.

Should add a non-γ-distructive $\pi\mu$ separation system

Anti-Tagging γ's



P* (MeV)