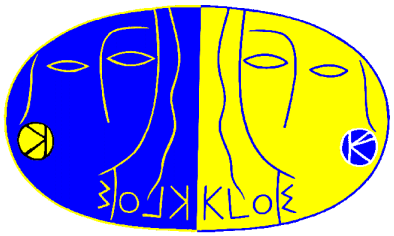
A preliminary measurement of BR($K_L \to \pi^+\pi^-$) *using a double-tag method*



M. Antonelli, M. Dreucci, M. Moulson, T. Spadaro

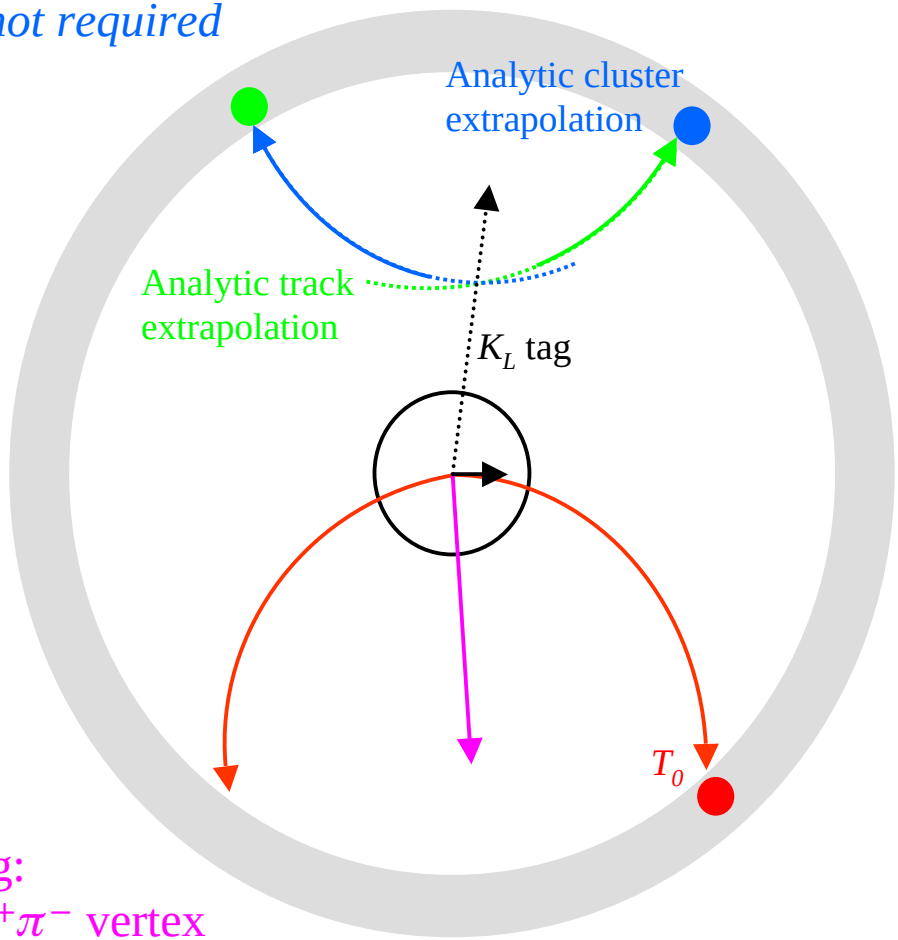
KLOE Physics Workshop, Isola d'Elba, 24 May 2001

The double-tag method

Decay tag:

1 track + cluster opposite

Vertex not required



Event tag:

$K_S \to \pi^+\pi^-$ vertex

Tag cuts:

- Track residual
- Cluster residual
- p^* (CM frame of KL tag)

$N_1 = 2\varepsilon_1 S + B_1$

$N_2 = \varepsilon_1^2(1-\rho)S + B_2$

$S = 4(1-\rho)N_1^2/N_2$

$\varepsilon = 2N_2/[N_1(1-\rho)]$

Input from MC:

Background (B_1, B_2)

Dominantly from $K_{\mu 3}$

Shape from MC

Sideband/fit normalization

Tagging correlation ($1-\rho$):

$(1-\rho) = \varepsilon_2^{MC}/(\varepsilon_1^{MC})^2$

Data and MC samples

Data:

All **ks2p** Ntuples as of 18 May 2001

Runs 13732-14678: July/Aug 2000 (4.1 pb^{-1})

Runs 16211-17186: Nov 2000 (13.3 pb^{-1})

7441626 total K_L tags found

MC Signal:

Y2K **cpv_cksh**, Runs 5-16

$K_S \to \pi^+\pi^-$, $K_L \to \pi^+\pi^-$ ($K_L \to \pi^0\pi^0$ removed)

81755 total K_L tags in FV (208 pb^{-1} assuming $\sigma_\phi = 3.1\ \mu b$)

MC Background:

Y2K **neu_kaon**, Runs 26-225

$K_S \to \pi^+\pi^-$, $K_L \to$ all ($K_S \to \pi^0\pi^0$, $K_L \to \pi^+\pi^-$ removed)

3302226 K_L tags (4.6 pb^{-1} assuming $\sigma_\phi = 3.1\ \mu b$)

K_L tag

1 vertex, zero net charge

$r_{xy} < 5$ cm, -20 cm $< z < 20$ cm

$M - M_K < 20$ MeV

Tree/vertex extension

1 track (or daughter of recognized kink) analytically extrapolates to cluster

$d < 30$ cm, $E > 50$ MeV

Primary decay position from extrapolation of p_{KS} to beam line

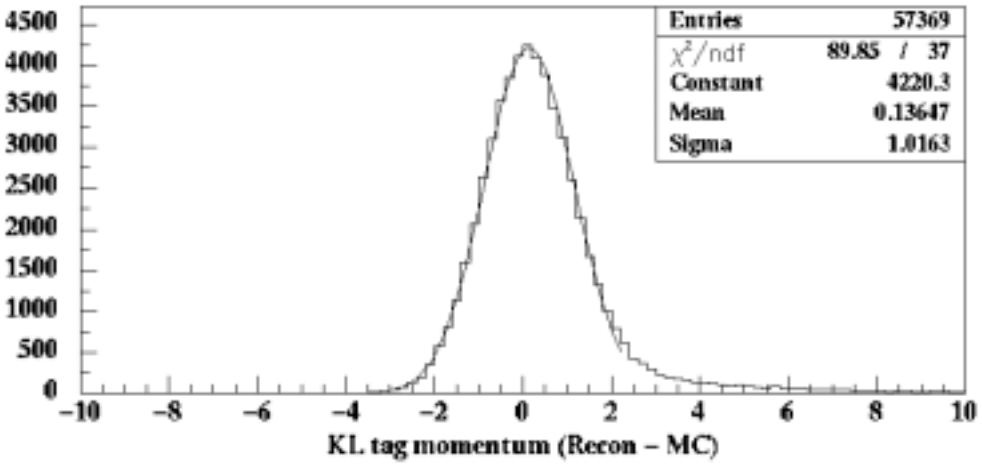
K_S momentum from boost

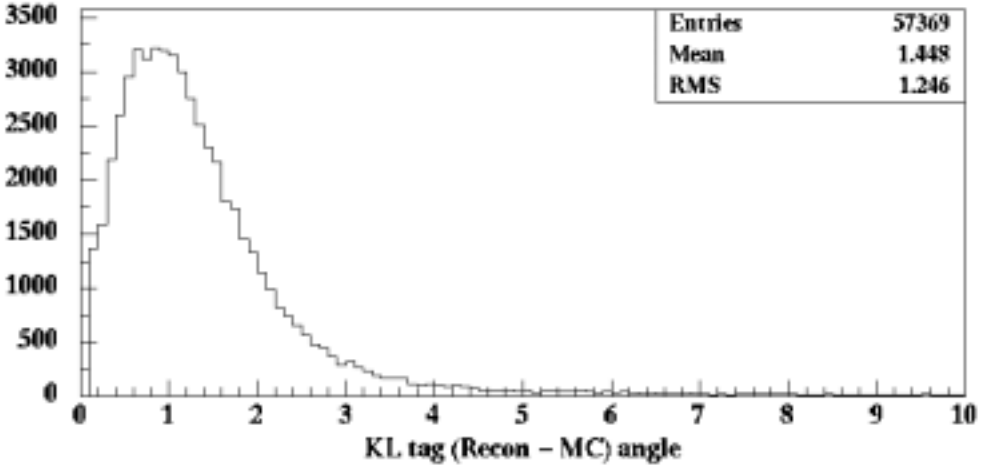
$\sqrt{s}$, boost components run-by-run

$\sigma(K_L$ tag):

428 nb, using L_{datarec}

477 nb, using $\sigma_\phi = 3.1\ \mu$b, $\varepsilon_{\text{KLtag}}$(MC)





K_L tag efficiency

K_L tag efficiencies from MC:

$K_L \to$ all, everywhere: 0.6631 ± 0.0003

$K_L \to \pi^+\pi^-$ in FV: 0.7017 ± 0.0016

Tag bias:

f = 0.945 ± 0.002

Assume 50% systematic error on this correction

$$BR = \frac{N_{\text{decay}} / \varepsilon_{\text{tag}}^{\text{decay}}}{N_{\text{tag}} / \varepsilon_{\text{tag}}}$$

$$f = \varepsilon_{\text{tag}} / \varepsilon_{\text{tag}}^{\text{decay}}$$

MC $K_S \to \pi^+\pi^-$ and:	81755 evts $K_L \to \pi^+\pi^-$ in FV		3302226 evts $K_L \to$ all	
Trigger	77753	0.951	2860194	0.866
FILFO	81643	0.999	3218969	0.975
ECL K_L tag	62277	0.762	2562475	0.775
Our K_L tag selection	59354	0.726	2430574	0.736
Overall	57369	**0.702**	2189761	**0.663**

Decay tag

Tree extend excluding K_S tracks

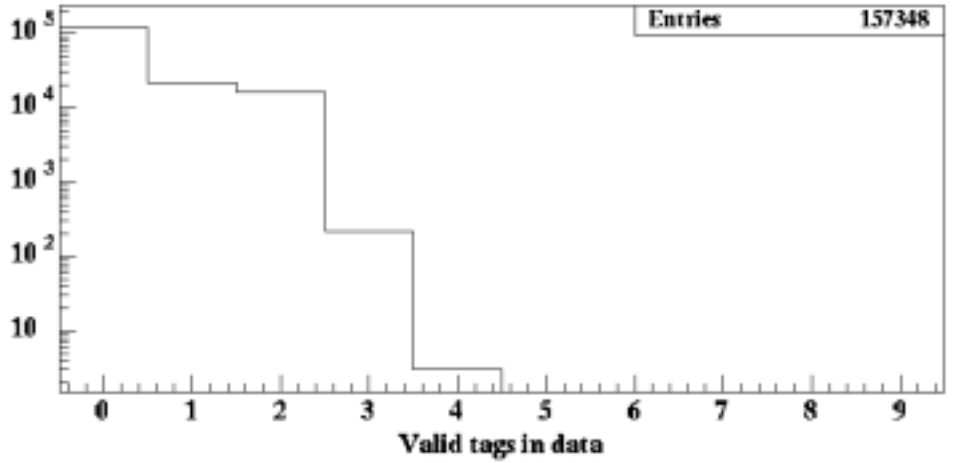
Select branch of each tree with smallest track residual

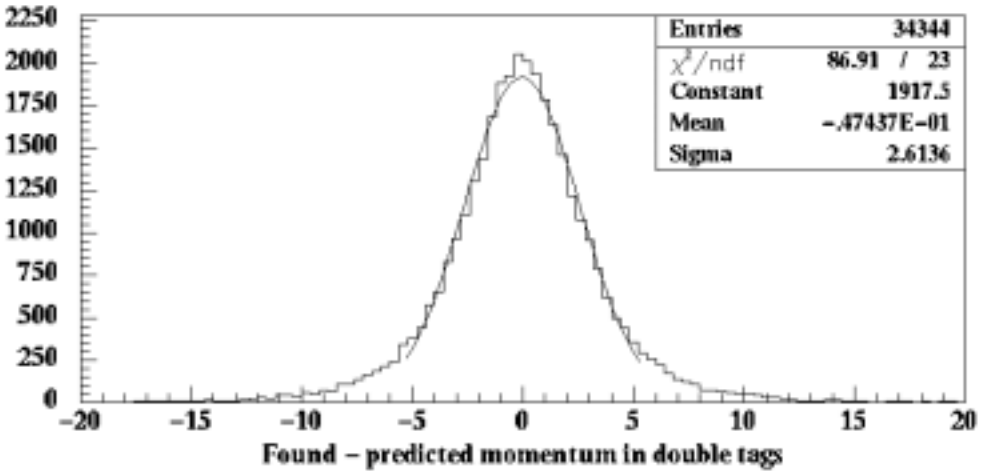
Construct p_{miss} from p, p_{KL}

Analytically extrapolate to EmC

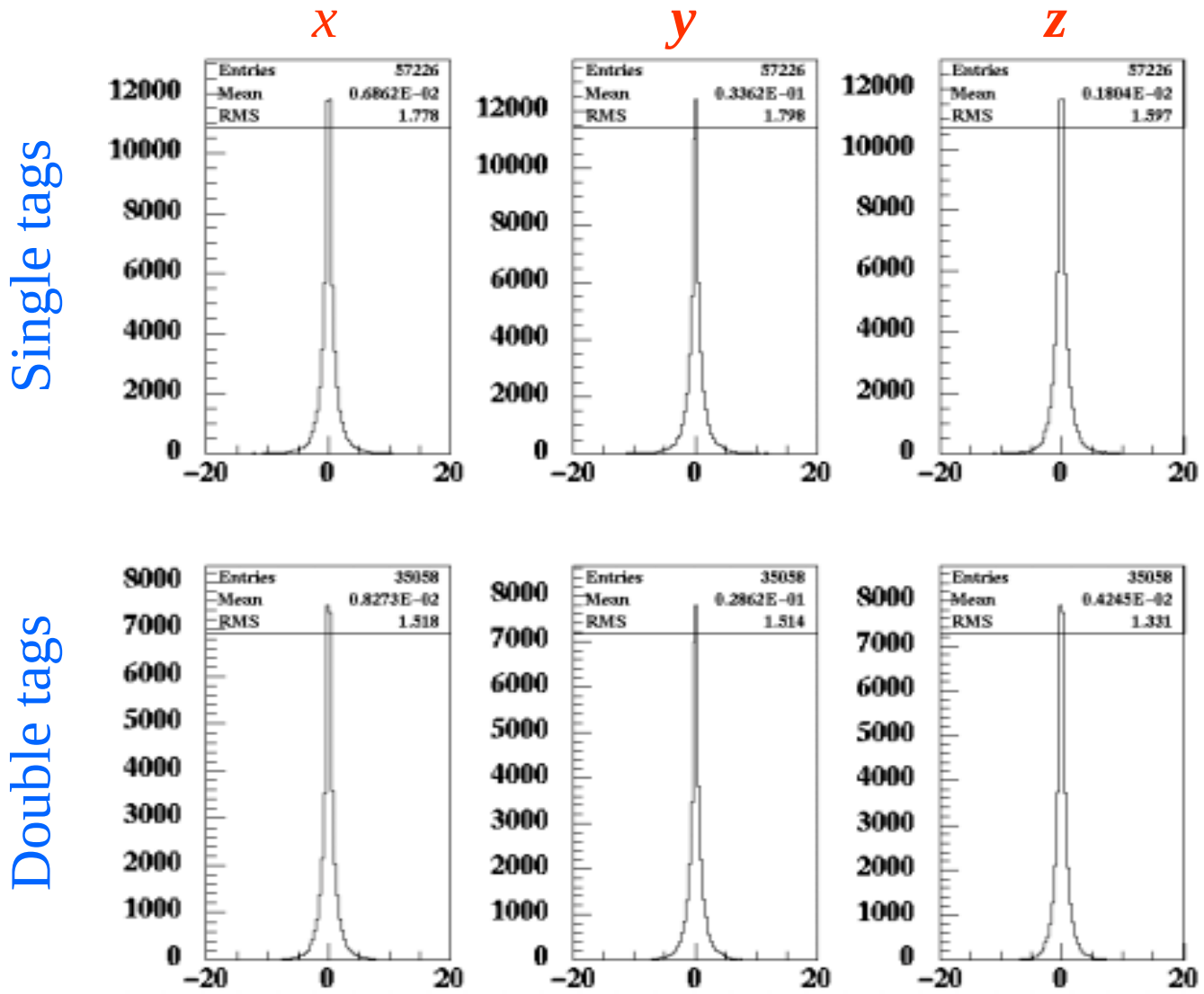
Apply track, cluster distance cuts

Retain $+/-$ track with best p^*





Fiducial volume

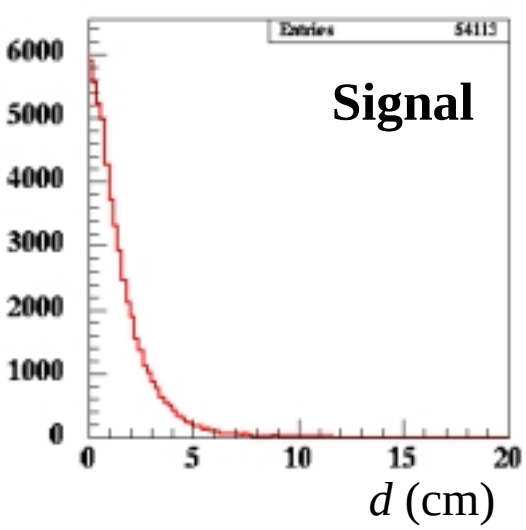


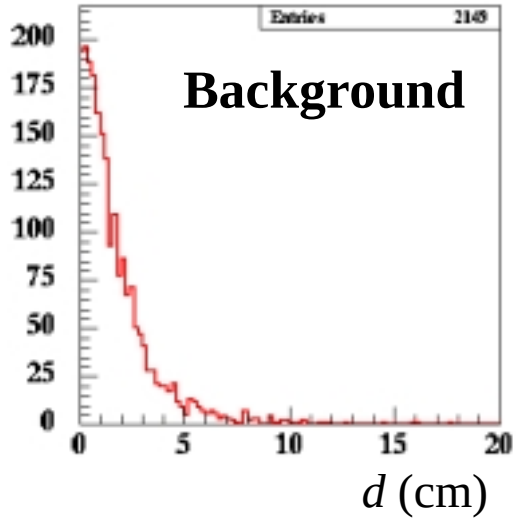
Fiducial volume:
35 cm < r_{xy} < 150 cm
-100 cm < z < 100 cm

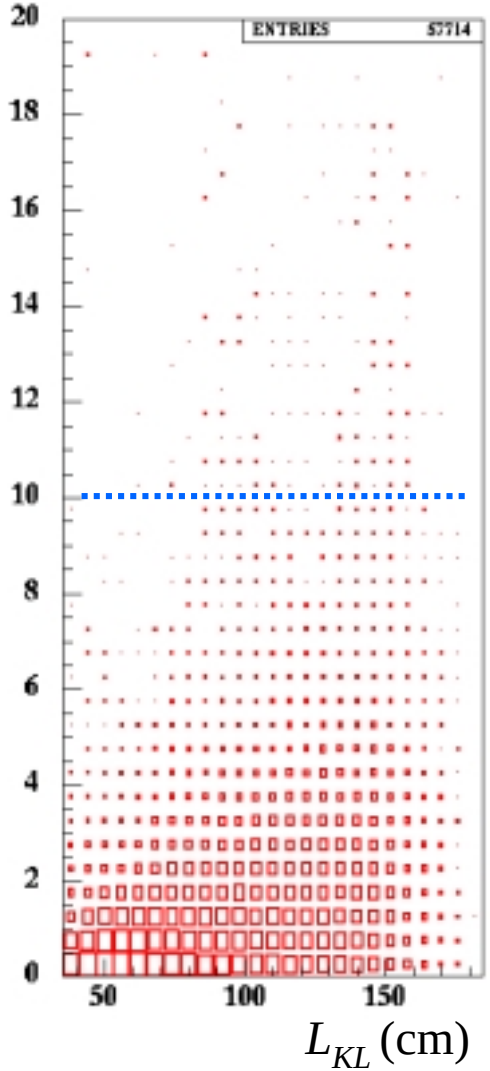
ε_{FV} from MC:
0.2653 ± 0.0009

Not explicitly in expression for BR
Enters via $(1-\rho)$

Track residual cut







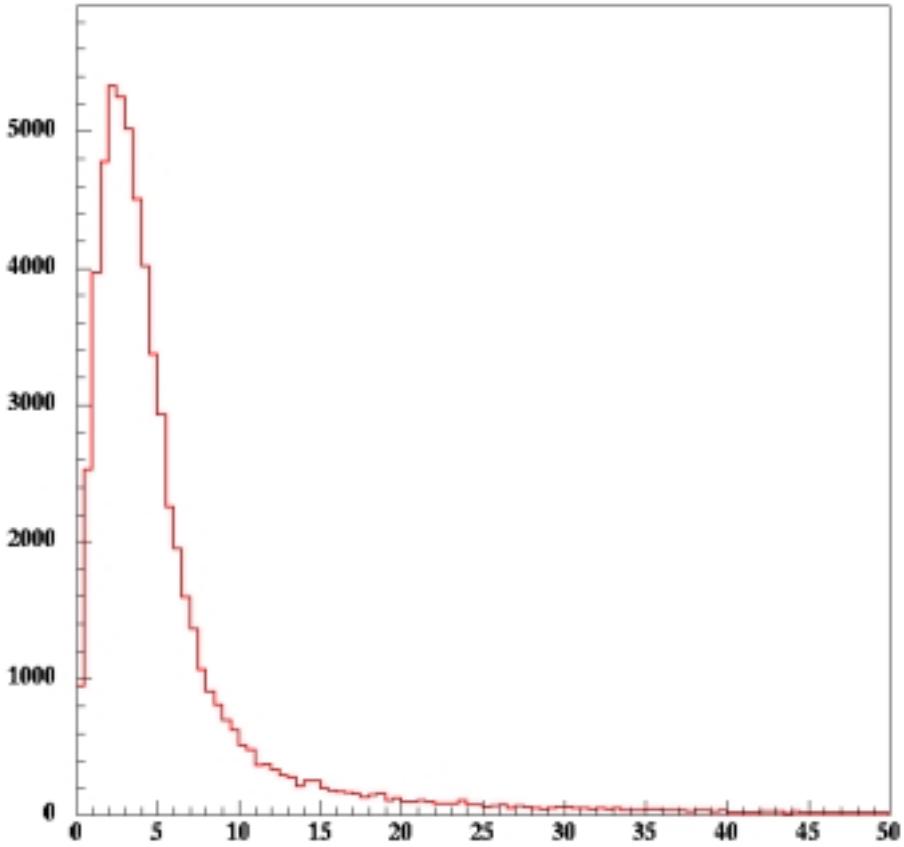
Important for cleaning events

No background rejection

Cut placed at 10 cm

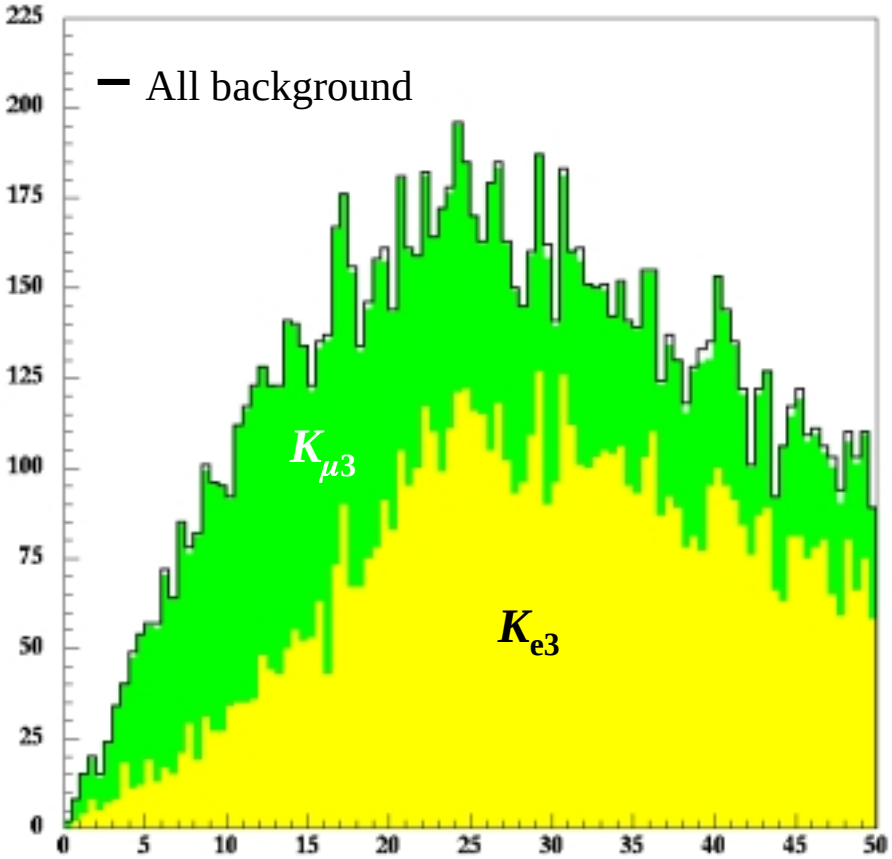
Cluster residual cut

Signal



$d_\perp$ (cm)

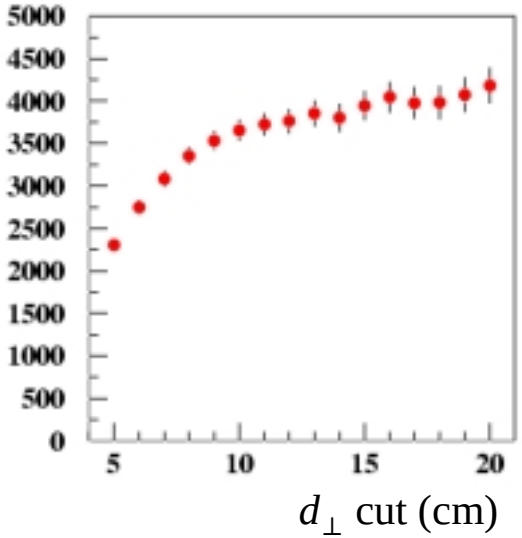
Background

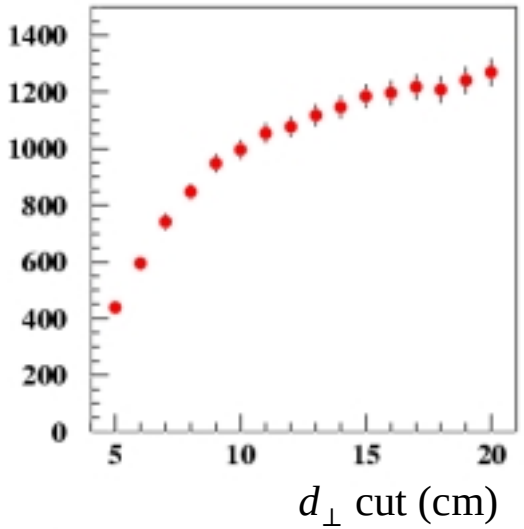


$d_\perp$ (cm)

Optimization of cluster residual cut

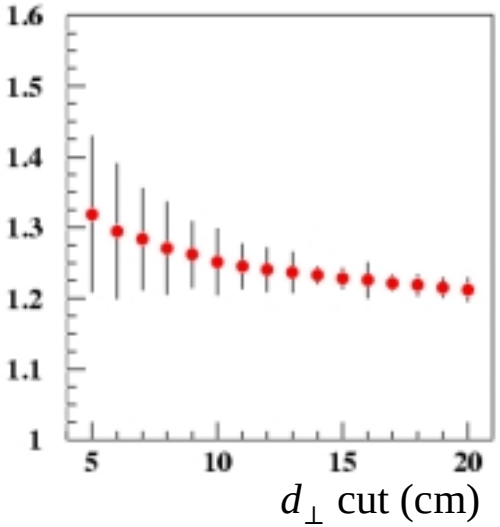
Single tags from fit with error from *S*/*B*

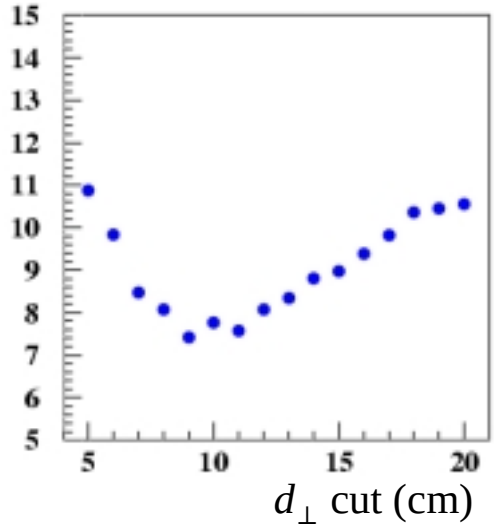




Double tags from fit

Correlation $(1-\rho)$: Error includes systematic as estimated from $\varepsilon_1(\text{MC}) \Leftrightarrow \varepsilon_1(\text{tag})$





Overall error on signal counts

Time of flight

ΔTOF =

T_{cl} –
$L_{KL}/c\beta(p_{KLtag})$ –
$L_{proj}/c\beta(p_{proj})$ –
0.42 ns

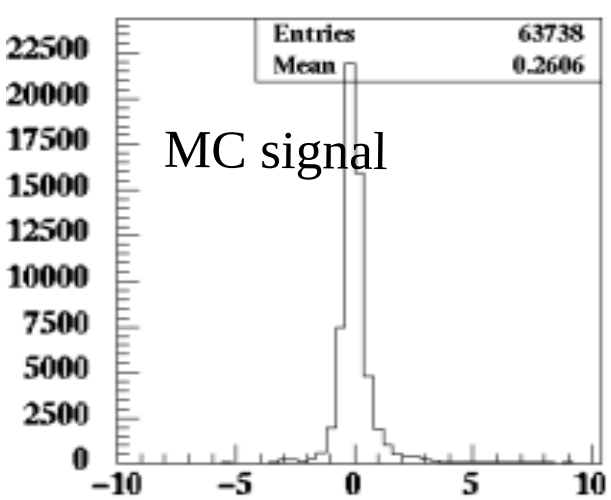
No rejection power beyond cluster distance cut

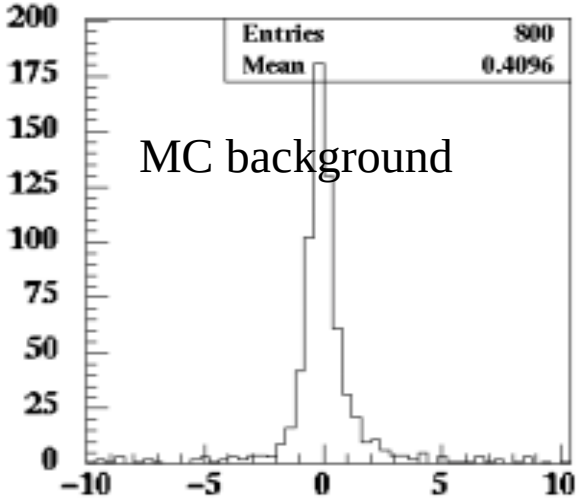
Loose cut applied at 2.5 ns
Slewing correction undone, but not in these plots

E/*p* also explored, no help

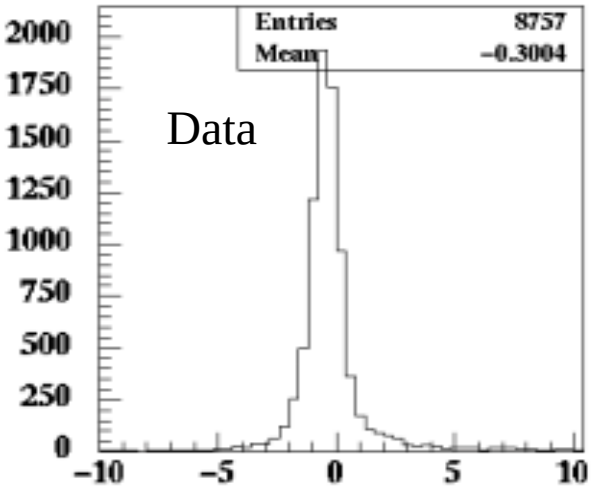
Can only eliminate background from *e* (not μ, π)

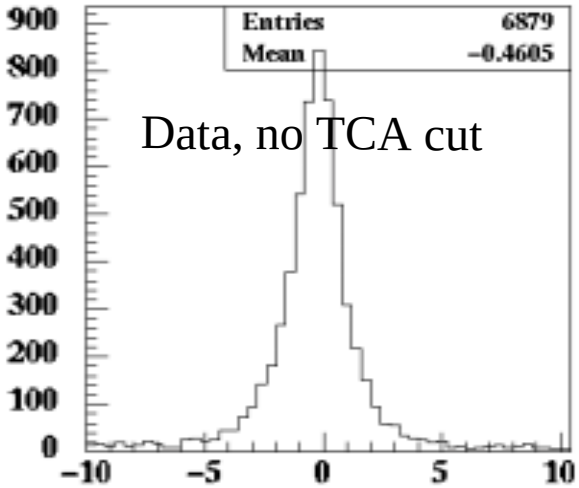
K_{e3} less than 50% of background





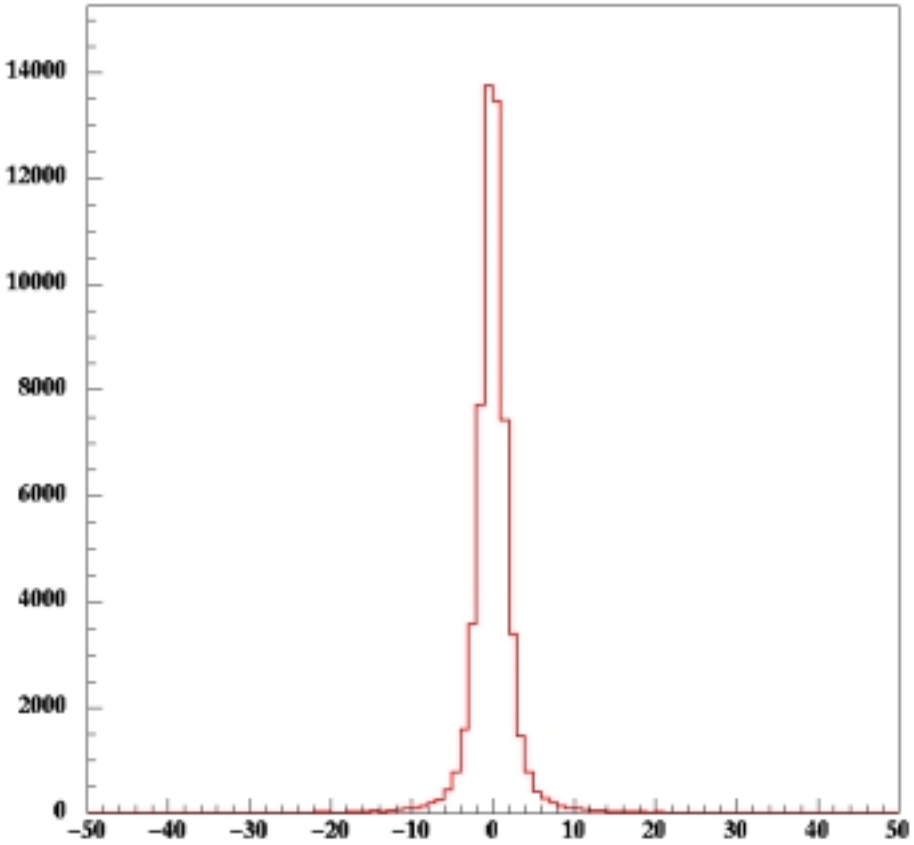
ΔTOF (ns)





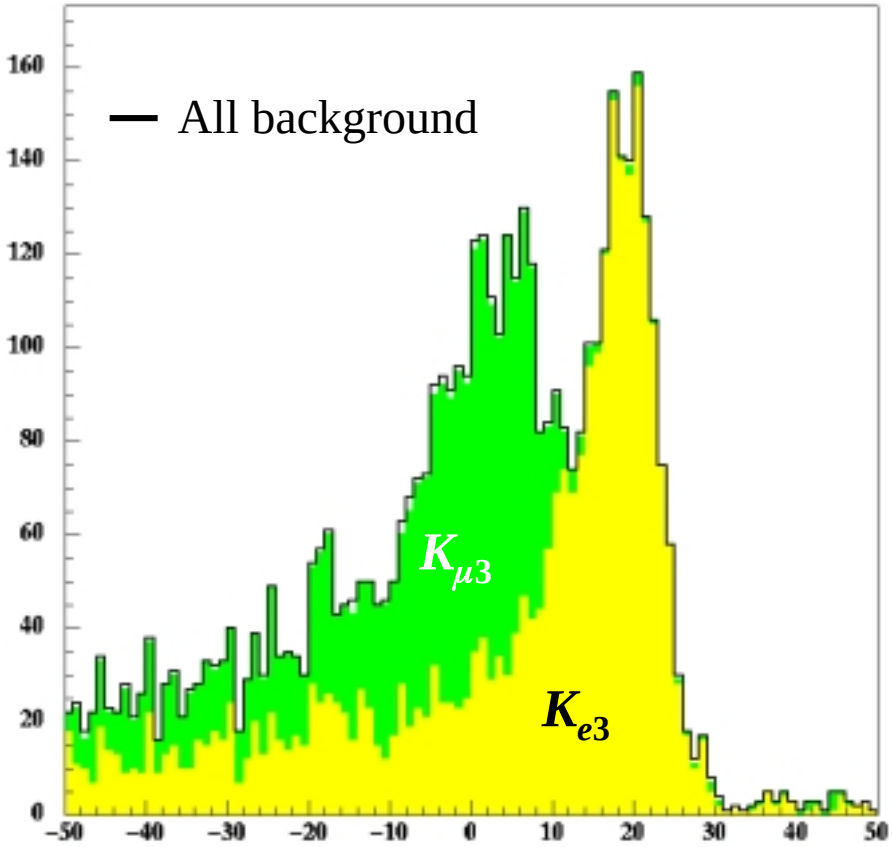
Single tag p spectra*

Signal (~210 pb-1)



*p** (MeV)

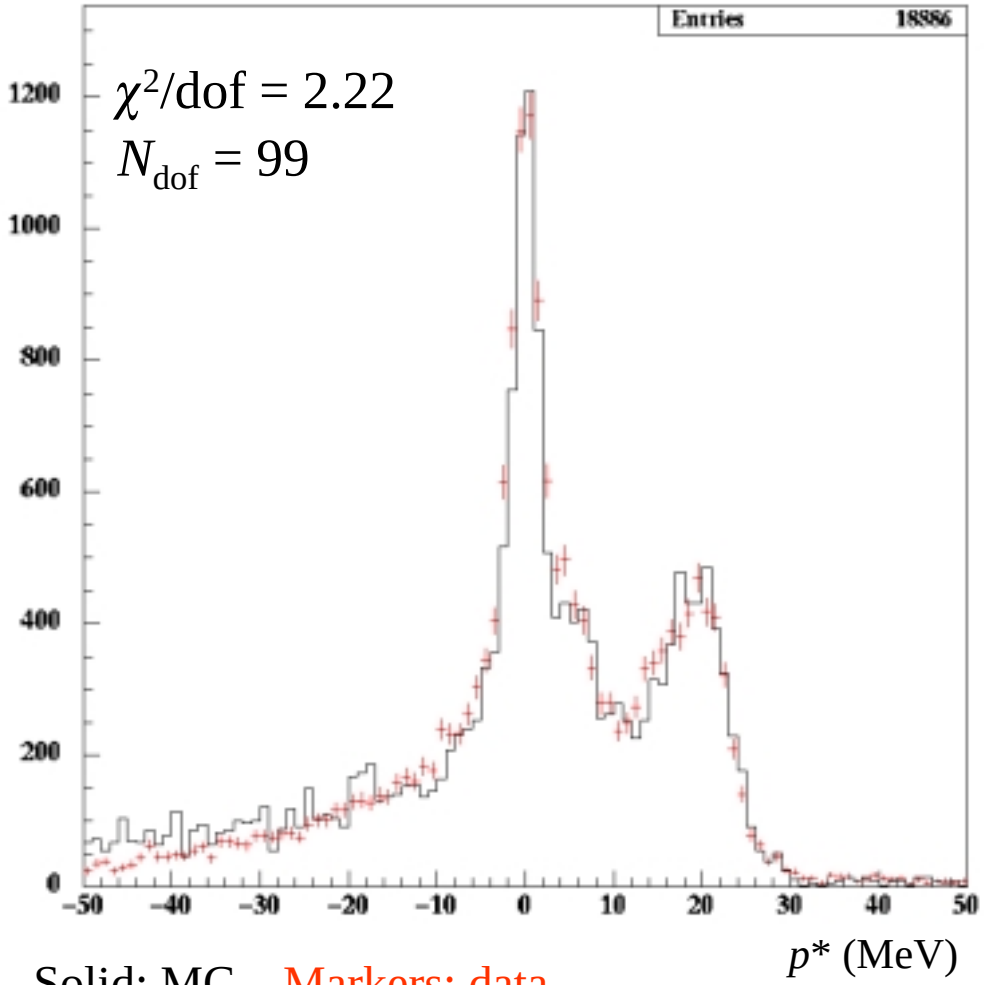
Background (~4.6 pb-1)



*p** (MeV)

Analysis of single-tag p spectrum*

MC signal + background, norm $|p^*| < 50$ MeV



Solid: MC Markers: data

MC roughly reproduces p^* spectrum
- Resolution underestimated
- Background overestimated at low p^*

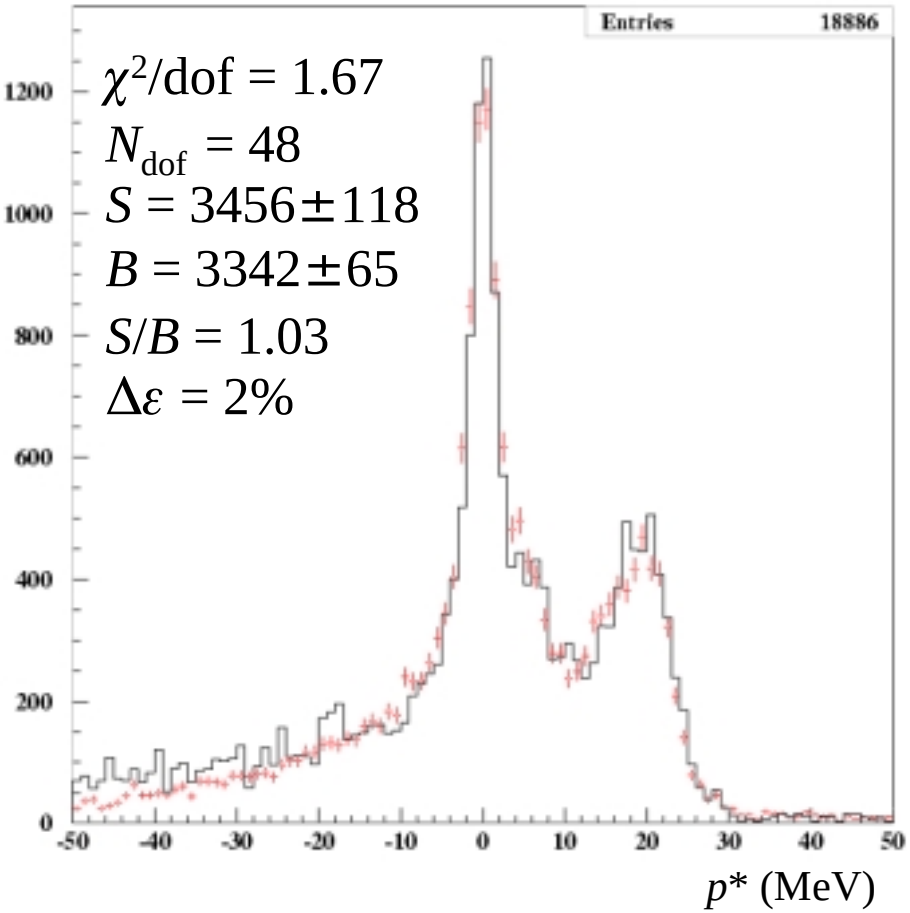
Signal extraction by HMCMLL fit to
- MC signal
- MC background
- S, B fit parameters
- Optional Gaussian convolution

Statistical error includes MC statistics

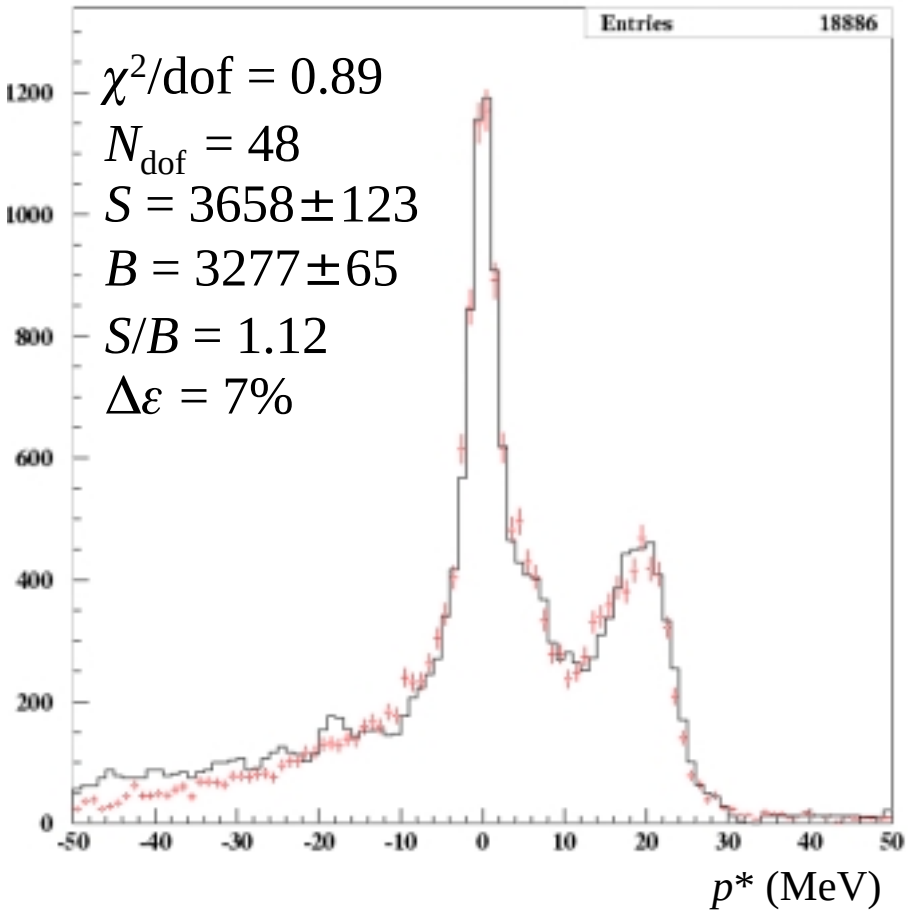
Fit region: $|p^*| < 25$ MeV
Signal region: $|p^*| < 5$ MeV

Effect of smearing MC distributions

No convolution

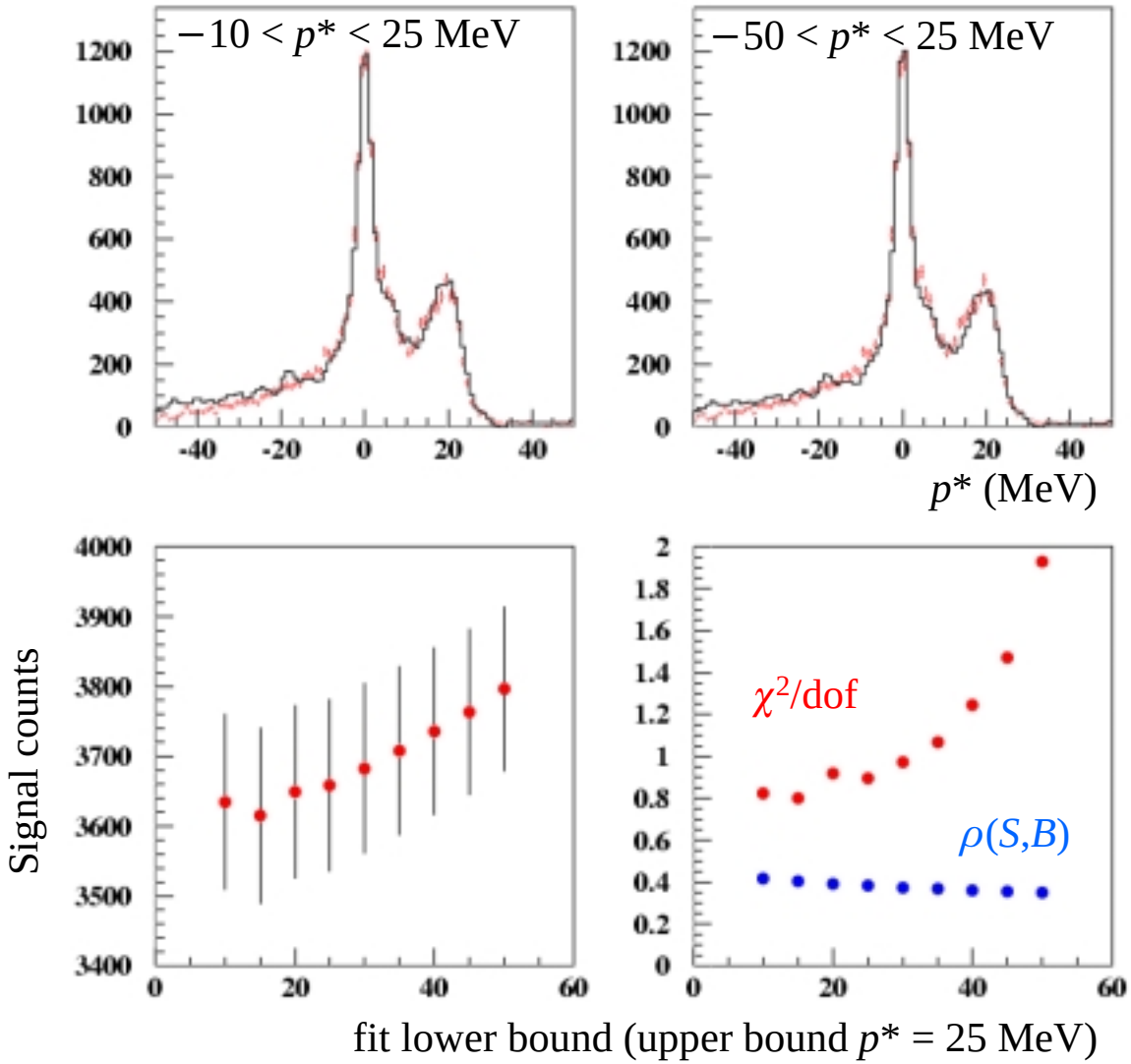


Convolution, σ = 0.7 MeV



Solid: fit Markers: data Fit interval: $|p^*| < 25$ MeV Signal region: $|p^*| < 5$ MeV

Single tag fit systematics



Fit interval:

Upper bound p^* = 25 MeV

Lower bound −10 → −35 MeV

2.0% effect on *S*

χ^2/dof blows up for broader range

Shape agreement:

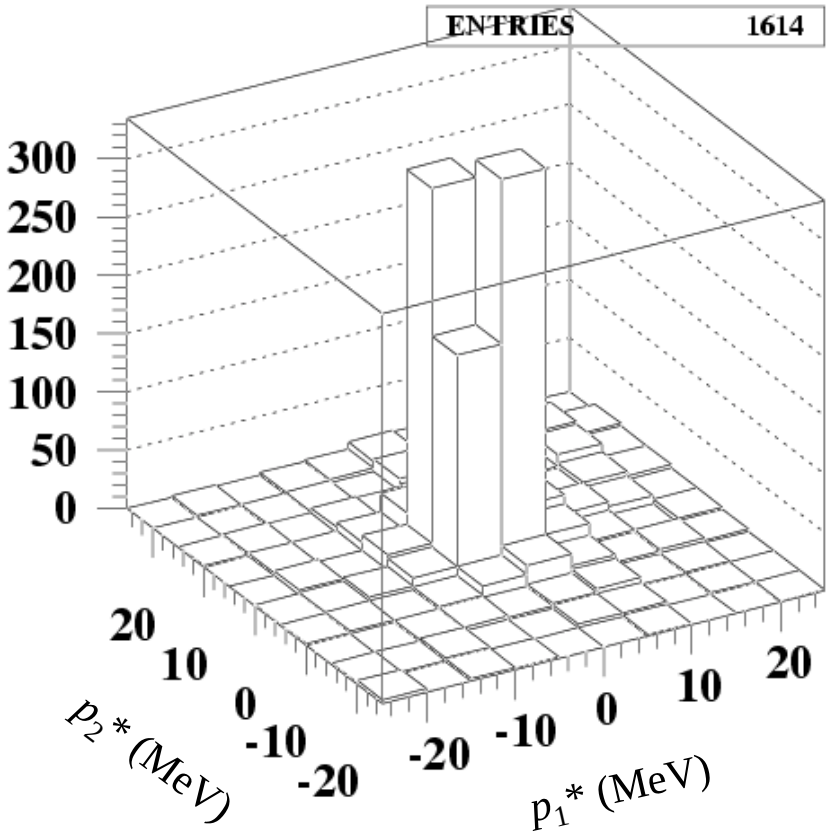
Explored effect of varying σ

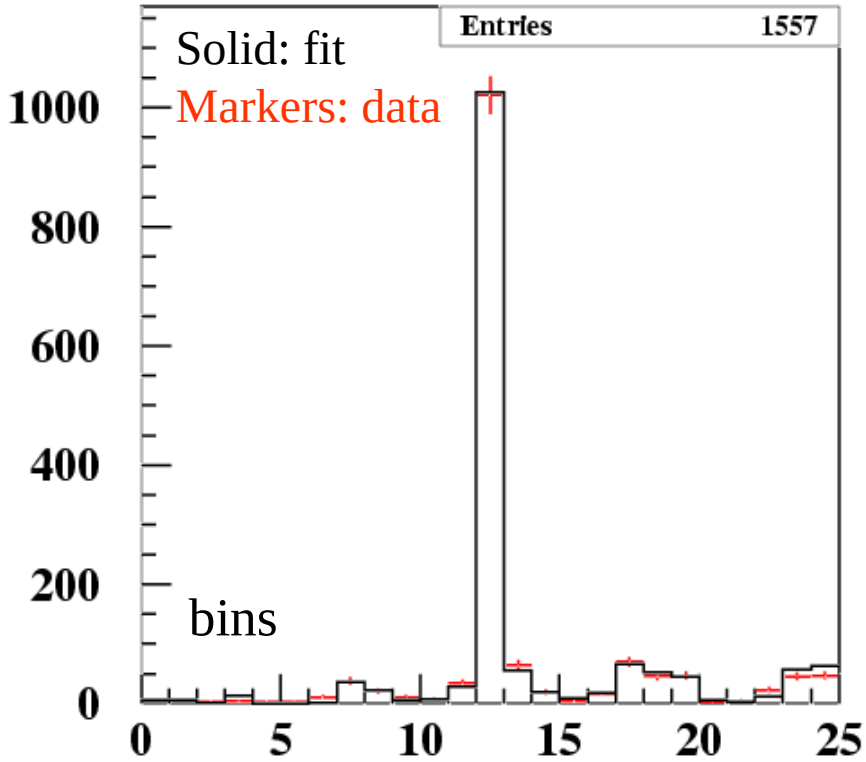
With σ a free parameter

Some probs. with convergence

σ → 0.94 MeV, **3.0% effect on *S***

Analysis of double-tag p spectrum*

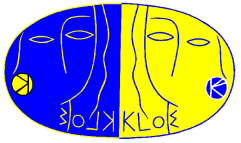




Fit analogous to single-tag fit
No convolution performed

$S = 996 \pm 34$ $S/B = 34.7$
$B = 29 \pm 3$ $\chi^2/\mathrm{dof} = 0.49$
$N_{\mathrm{dof}} = 23$

MC efficiencies and correlation



MC signal sample:

57369 $K_L \to \pi^+\pi^-$ decays in FV

53729 single tags

15839 double tags

Tagging efficiency:

$\varepsilon_1 = N_1/2N_{\mathrm{KLFV}}$
$= 0.468 \pm 0.002$

$\varepsilon_2 = N_2/N_{\mathrm{KLFV}}$
$= 0.276 \pm 0.002$

Correlation:

$1-\rho = \varepsilon_2/\varepsilon_1^2$
$= 1.259 \pm 0.012$

Cross checks:

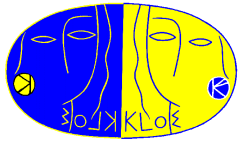
Tagging efficiency from "data"
$\varepsilon_1 = 2N_2/N_1(1-\rho)$
0.433 ± 0.019

Conditional tag efficiency:
$R_{21} = 2N_2/N_1 = \varepsilon_1(1-\rho)$
0.590 ± 0.003 MC
0.545 ± 0.006 Data

Safe systematic error on $(1-\rho)$:

50% of difference in R_{21} (3.8%)

Preliminary estimate of $\mathrm{BR}(K_L \to \pi^+\pi^-)$



Summary (stat. error only):

N_1 = 3658 ± 123 (210 datarec pb)

N_2 = 996 ± 34 (57 datarec pb)

$1-\rho = 1.259 \pm 0.012$

$\varepsilon_{\mathrm{tag}} = 2N_2/N_1(1-\rho) = 0.433 \pm 0.019$

$N_{\pi+\pi-} = N_1/2\varepsilon_{\mathrm{tag}} = 4226 \pm 287$

$N_{KS} = 7441626$

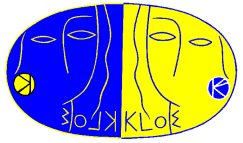
$\varepsilon_{\mathrm{FV}} = 0.2653 \pm 0.0009$

$f = 0.945 \pm 0.002$

Single tag	6.7%
Double tag	3.4%
Sample correlation	−3.4%
Tag correlation	0.9%
Fiducial volume*	0.3%
Statistical error	**6.8%**
Conditional track efficiency	3.8%
Tag bias	2.8%
Fit interval	2.0%
Resolution MC/data	3.0%
Systematic error	**5.9%**
Total error	**9.1%**

$\mathrm{BR}(K_L \to \pi^+\pi^-) = fN_{\pi+\pi-}/N_{KS}\varepsilon_{\mathrm{FV}} = (2.02 \pm 0.19) \times 10^{-3}$

Conclusions



BR($K_L \to \pi^+\pi^-$)	**$(2.02 \pm 0.19) \times 10^{-3}$**	**KLOE preliminary?**
	$(2.056 \pm 0.033) \times 10^{-3}$	**PDG 2000**

Prospects for reducing systematic errors:

Fit-related problems tractable

More MC statistics, background from data, work on fit technique

Errors on $1-\rho$, f are more difficult but have been conservatively estimated

Statistical error considerations:

Error scales as $2\sqrt{(S+2B)} \approx 4\sqrt{S}$

100 pb^{-1} = 21000 single tags = 2.8% statistical error

Compare vertex method with kinematic fit, assume error simply $\sqrt{S}$

17.4 pb^{-1} = 2260 events = 2.1% statistical error

100 pb^{-1} = 13000 events = 0.9% statistical error

Recommendation: pursue vertex method without abandoning this approach

Valuable checkpoint

Mature structure for tracking efficiency estimates