Status of $K_S \rightarrow \pi^+\pi^0\pi^-$ Analysis

Alessandro Di Cicco

Analysis scheme – *A cut-based analysis*

- Tag K_S mesons with KLCRASH technique
- Pre-selection cuts to retain events with signal topology
  - 2 prompt photons
  - 2 tracks from IP with opposite curvature connected to a vertex close to IP
- Kinematical cuts to largely reduce background
  - π^0 reconstruction from selected prompt photons to improve 3π-system mass
  - β* hard cut
  - 3π-system invariant mass cut
- Signal Box definition to extract signal events in data with a fit in signal hypothesis
- Control regions to cross-check background normalization given by the fit
- Fit in background-only hypothesis to verify that signal hypothesis is favored
- Extract BR value:

$$BR(K_S \to \pi^+\pi^0\pi^-) = \frac{1}{N_{\mathrm{K_S}}^{\mathrm{TAG}}} \frac{N_{\pi^+\pi^0\pi^-}}{\varepsilon_{\mathrm{ANA}}}$$

- Stability study of the BR measurement

Pre-selection cuts

- 2 and only 2 prompt clusters with
  - E_{cl} > 7 MeV and $|\cos\theta_{cl}| < 0.915$
  - $|t_{cl} - R_{cl}/c| = min\{3.5\sigma_t, 2\ \text{ns}\}$
- 2 and only 2 tracks with opposite curvature with
  - $\rho_{PCA} < 4$ cm, $|z_{PCA}| < 10$ cm, $\rho_{FH} < 41$ cm
- Tracks connected to a vertex close to IP
  - $|\rho_{VTX} - \rho_{\phi}| < 5$ cm and $-7.5\ \text{cm} < |z_{VTX} - z_{\phi}| < 8.5$ cm

- Pre-selection efficiency by MC signal simulation: $\varepsilon_{PRE} = 0.2622 \pm 0.0061$

Number of events after pre-selection cuts normalized to data integrated luminosity

	Data	K^+K^-	$\pi^+\pi^-(\gamma)$	$\pi^0\pi^0$	$\phi \to \pi^+\pi^0\pi^-$	*Other*	Signal
	3483015	1519997	1238388	182766	360126	182101	45
B/S		3.4×10^4	2.8×10^4	4.1×10^3	8.0×10^3	4.1×10^3	

Branching ratio evaluation

Our measurement:

$BR(K_S \rightarrow \pi^+\pi^0\pi^-) = (4.3 \pm 1.6_{stat} \pm 1.2_{syst}) \times 10^{-7}$

$$\mathscr{B}(K_S \to \pi^+\pi^0\pi^-) = \frac{N_{\pi^+\pi^0\pi^-}}{N_{KS}^{TAG}\varepsilon_{tot}},$$

$$\left(\frac{\Delta\mathscr{B}}{\mathscr{B}}\right)^2 = \left(\frac{\Delta N_{\pi^+\pi^0\pi^-}}{N_{\pi^+\pi^0\pi^-}}\right)^2 + \left(\frac{\Delta N_{KS}^{TAG}}{N_{KS}^{TAG}}\right)^2 + \left(\frac{\Delta\varepsilon_{tot}}{\varepsilon_{tot}}\right)^2$$

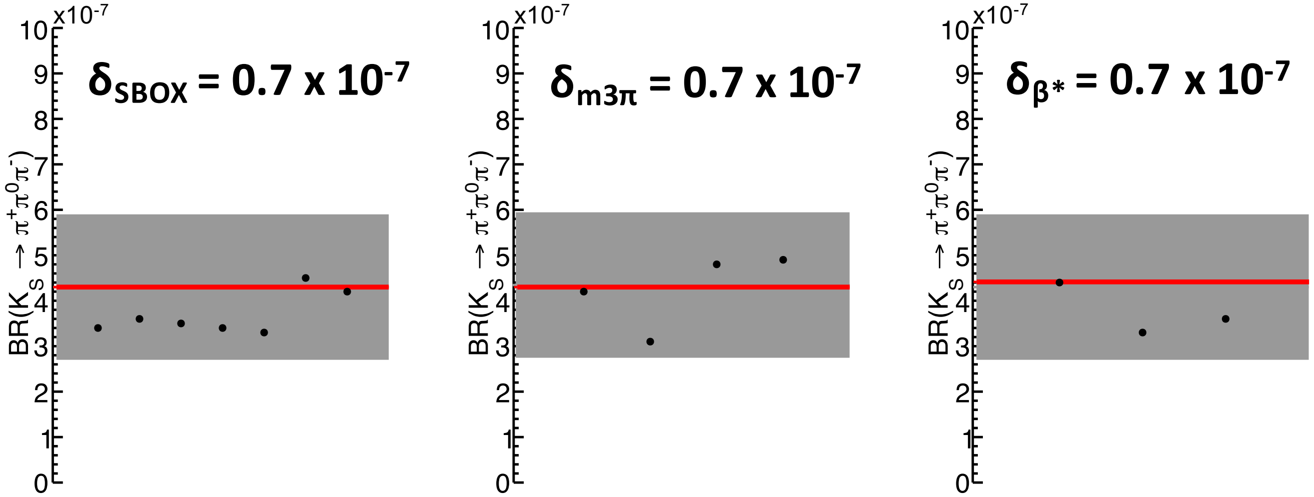
$N_{\pi+\pi0\pi-} = 39 \pm 15$

$N_{K_S}^{TAG} = 5.26 \times 10^8$

37% statistical uncertainty

Stability study of the measurement

- systematics from analysis cuts
- vary each cut a time and repeat analysis
- take RMS of BR dispersion



	BR $\times 10^{-7}$	Stat. Uncertainty	Syst. Uncertainty
KLOE preliminary	4.3	± 1.6	± 1.2
E621	4.8	$^{+2.2}_{-1.6}$	± 1.1
NA48	2.5	$^{+1.3}_{-1.0}$	$^{+0.5}_{-0.6}$
CPLEAR	4.7	$^{+2.2}_{-1.7}$	$^{+1.7}_{-1.5}$

First direct measurement of $BR(K_S \rightarrow \pi^+\pi^0\pi^-)$ with competitive accuracy is possible

Analysis scheme – *Using a MVA technique*

- Same pre-selection cuts to retain events with signal topology
- Same π^0 fit to improve 3π-system invariant mass resolution
- β^* distribution smearing to improve data-MC agreement
- **Looser kinematical cuts on β^* and $m_{3\pi}$**
- **Usage of BDT technique to disentangle signal and background**
- **Fit** (not cut on) **BDT output distribution to count singnal and background evnets**
- Evaluate BR value using this formula:

$$\mathcal{B}(K_S \to \pi^+\pi^-\pi^0) = \frac{\Gamma(K_S \to \pi^+\pi^-\pi^0)}{\Gamma(\text{all allowed } K_S \text{ decays})} = \frac{N^{sel}_{K_S \to \pi^+\pi^-\pi^0}}{\mathcal{L} \cdot \sigma_\phi \cdot \mathcal{B}(\phi \to K_L K_S) \cdot \epsilon_{sel}}$$

N_{sel}	$= 68.3 \pm 16.7$

ε_{sel}	$= 0.0835 \pm 3.2\%$
L	$= 1.7\ fb^{-1} \pm 2\%$
σ_ϕ	$= 3.1\ \mu b \pm 2.2\%$
B	$= 0.342 \pm 1.2\%$

- Result of this explorative analysis:

$$\mathcal{B}(K_S \to \pi^+\pi^-\pi^0) = \left[4.5 \pm 1.1_{stat} \pm 0.4_{sist} \pm (0.5 \div 1.1)_{BDT}\right] \times 10^{-7}$$

24% statistical uncertainty

Some considerations (Prof. Ceradini's)

Technically BDT works and does not introduce distortions

Background events are divided into three main categories that sum up to 99.4%

Fractions found by the fit to the data sum up to 98.0%

Some missing events in the MC? e.g. e+e- -> ργ , ωγ , radiative Bhabha , ...

The fit does not find the same events in the same category of the MC

	Fraction in MC	Fraction from fit to MC	Relative difference	Fraction from fit to data	Relative difference
$K_S \to \pi^0\pi^0$	0.09235	0.09272	+0.4%	0.07068	-23.5%
$K_S \to \pi^+\pi^-(\gamma)$	0.35974	0.35945	-0.8%	0.33716	-6.3%
$\phi \to K^+K^-$	0.54214	0.54197	-0.3%	0.57263	+5.6%
	0.99423	0.99414		0.98047	

Not easy to assign a systematic error to the reliability of application of BDT , no clean 'control' data samples are available in the data because the background events are pathologically distorted by the pre-selection to mimic the signal

Some considerations

- Some relevant background processes are missing in all_phys simulation
  e.g. e+e- → ργ, ωγ non-resonant processes, (radiative) Bhabha-scattering events
- Only e+e- → ωπ → $\pi^0\pi^0\gamma$ is simulated with CR = 8.3 nb in all_phys simulation
- Resonant processes e+e- → ϕ → πππ, ππγ are not directly simulated, but they are introduced in all_phys via the process e+e- → ϕ → ρπ

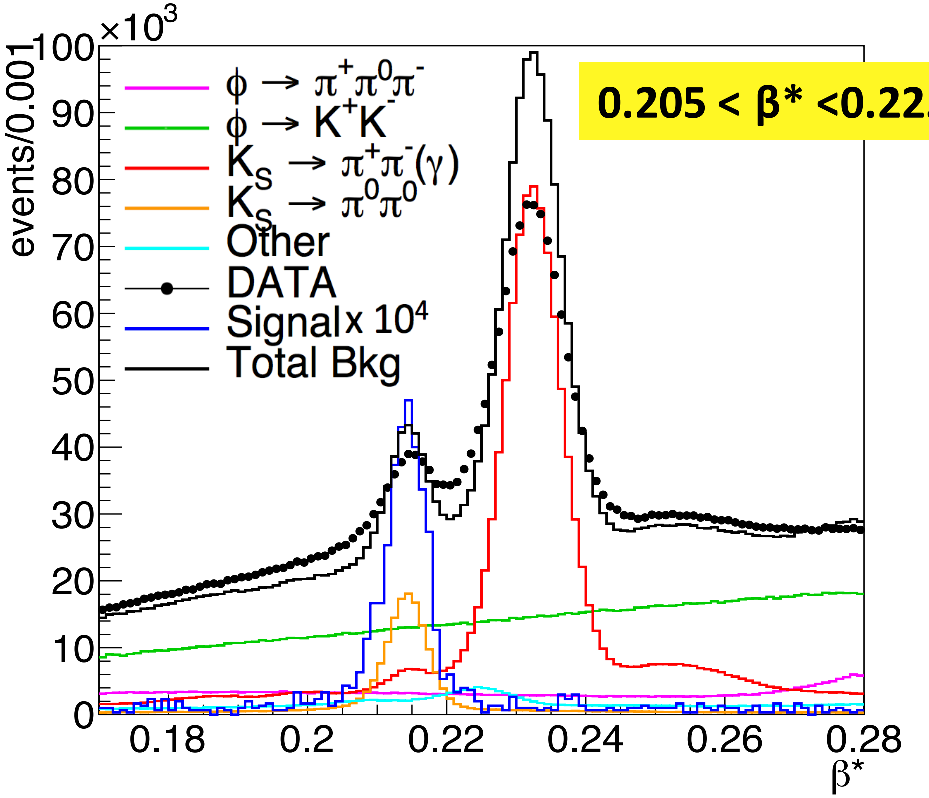
- *Looser cuts* may help in retaining more events thus having smaller statistical uncertainty,
  but *how to distinguish a rare signal in a large background with loose cuts?*
  Find smarter variables?
- Usage of BDT may help in disentangling signal from background, but systematic uncertainty evaluation may be hard to be accomplished

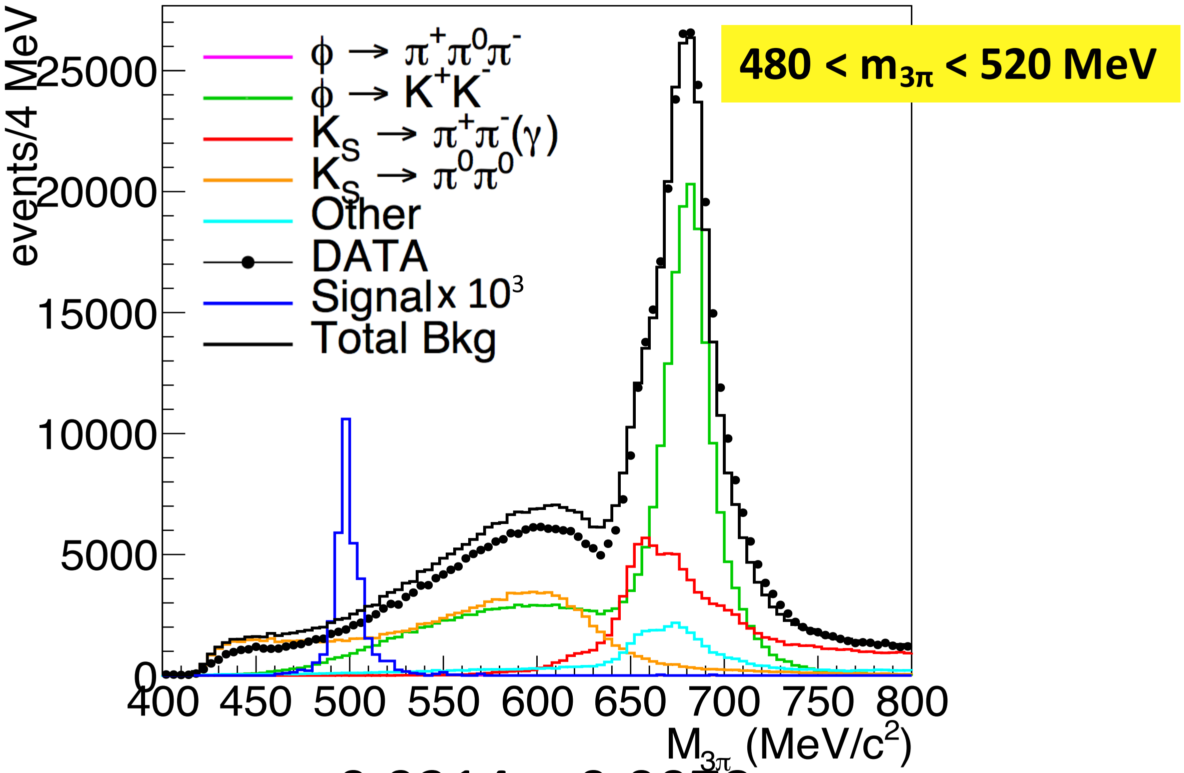
- A larger sample of MC signal is necessary to better study properties of signal shapes
  (a 100x sample is needed to make this analysis)

Ongoing activities and Plans

- Detailed checks of MC sample
  - consistency of variables in ntuples to understand if KCP library routines allows to recognize all simulated decays as reported in the MC card
- Checking code of all analysis steps by reviewing KCP lib routines (old code, no documentation, many changes in time)
- Implementing beta* correction as done in other analyses to understand if any improvement comes out
  - think about a smearing as done in D. Gelfusa's analysis
- **Produce a larger sample of signal MC**
- Improve fit to count signal and background events
- Evaluate BR by measuring $K_S \rightarrow \pi^+\pi^0\pi^-/K_S \rightarrow \pi\pi$ with same data sample to improve control of systematics, provided that event selection does not vetoes control samples
- **Estimation of efficiencies from data**
- **Improve evaluation of systematic uncertainties**
- A time scale is under estimation

Kinematical cuts





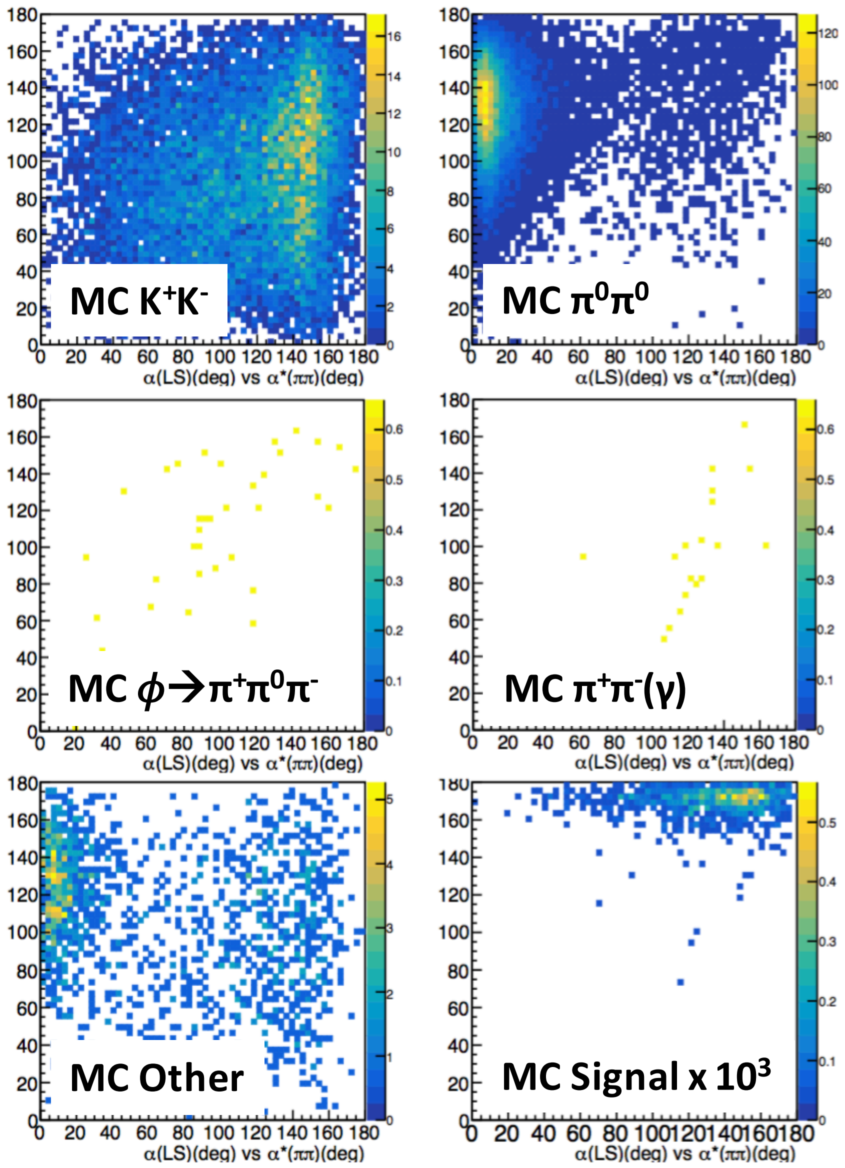
$\varepsilon_{\beta*} = 0.779 \pm 0.011$
from MC signal simulation

$\varepsilon_{m3\pi} = 0.9314 \pm 0.0078$
from MC signal simulation

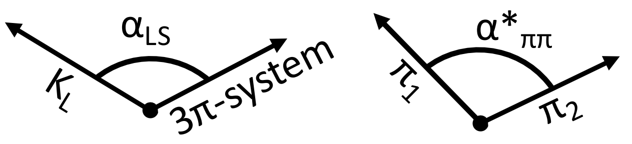
Number of events after $480 < m_{3\pi} < 520$ MeV/c^2 cut normalized to data integrated luminosity

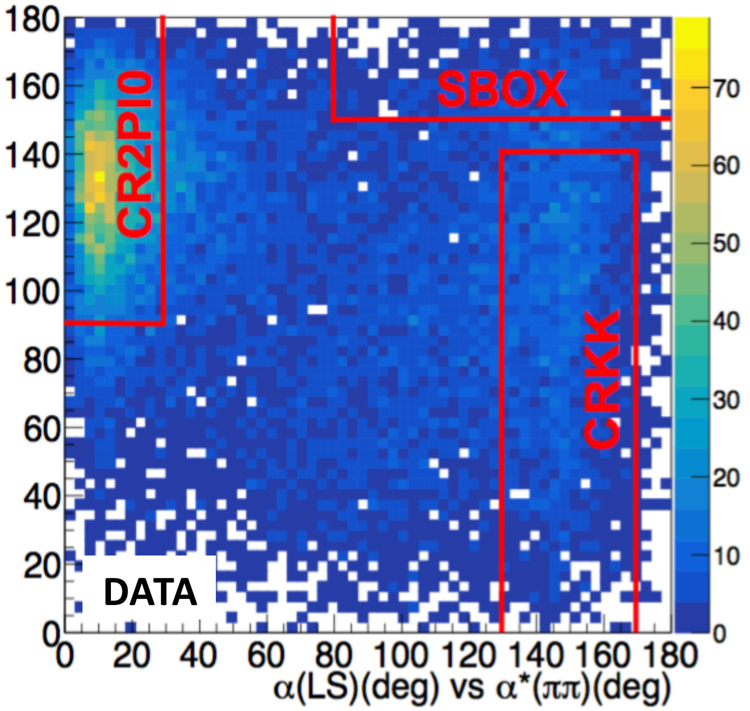
	Data	K^+K^-	$\pi^+\pi^-(\gamma)$	$\pi^0\pi^0$	$\phi \to \pi^+\pi^0\pi^-$	*Other*	Signal
	20346	9035	24	14989	13	1038	33
B/S		2.8×10^2	0.7	4.6×10^2	0.4	31.8	

Signal Box and Control Regions



- α_{LS} x $\alpha^*_{\pi\pi}$ correlation study





Signal Box & Control Regions:

- SBOX:
  $80° < \alpha^*_{\pi\pi} < 180°$ $\vee$ $150° < \alpha_{LS} < 180°$
- CRKK:
  $130° < \alpha^*_{\pi\pi} < 170°$ $\vee$ $0° < \alpha_{LS} < 140°$
- CR2PI0:
  $0° < \alpha^*_{\pi\pi} < 30°$ $\vee$ $90° < \alpha_{LS} < 180°$

Number of events in SBOX normalized to data integrated luminosity

	Data	K^+K^-	$\pi^+\pi^-(\gamma)$	$\pi^0\pi^0$	$\phi \to \pi^+\pi^0\pi^-$	$Other$	Signal
SBOX	1003	565	4	381	1	45	30
B/S		28.6	0.2	13.5	3.2×10^{-2}	2.3	

Fit with Signal

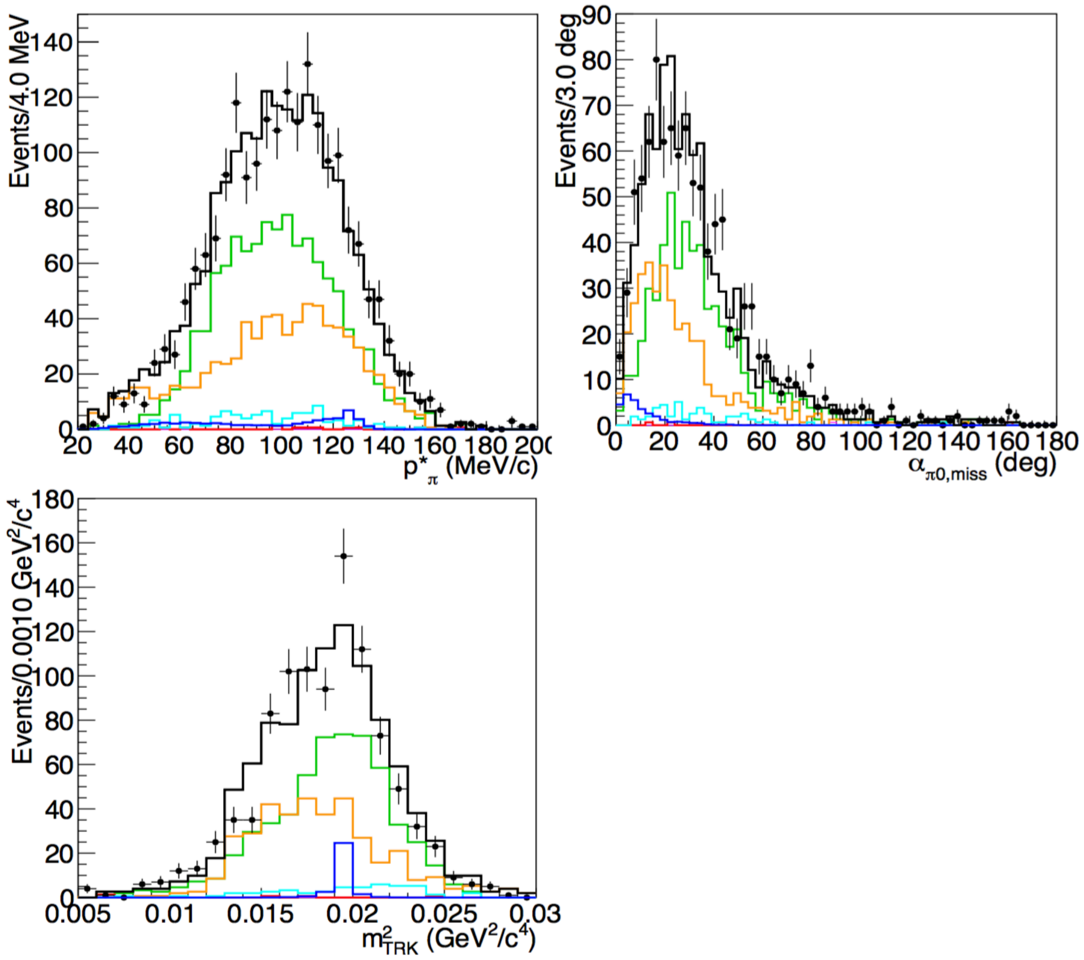
Binned likelihood fit with Poisson statistics to extract signal events in data.
Procedure accounts for finite statistics both in MC and data.

Inputs:

MC shapes of 3 background categories and signal.

Outputs:

fractions of signal and background events in data.



Simultaneous fit of 3 distributions:

- **$\alpha_{\pi0,miss}$** : angle between fit-improved π^0 and missing momentum
- **p^*_π** : π momentum in K_S rest frame
- **m^2_{trk}** : obtained imposing that the $K_L\pi^+\pi^-$-system coincides with the π^0 when the two tracks have the same mass, i.e.

$$(\sqrt{s} - E_L - \sqrt{p_+^2 + m_{trk}^2} - \sqrt{p_-^2 + m_{trk}^2})^2 - (\vec{p}_+ + \vec{p}_-)^2 = m_{\pi^0}^2$$

Signal yield estimate: fit outcome and cross-checks

Fit in Signal Hypothesis

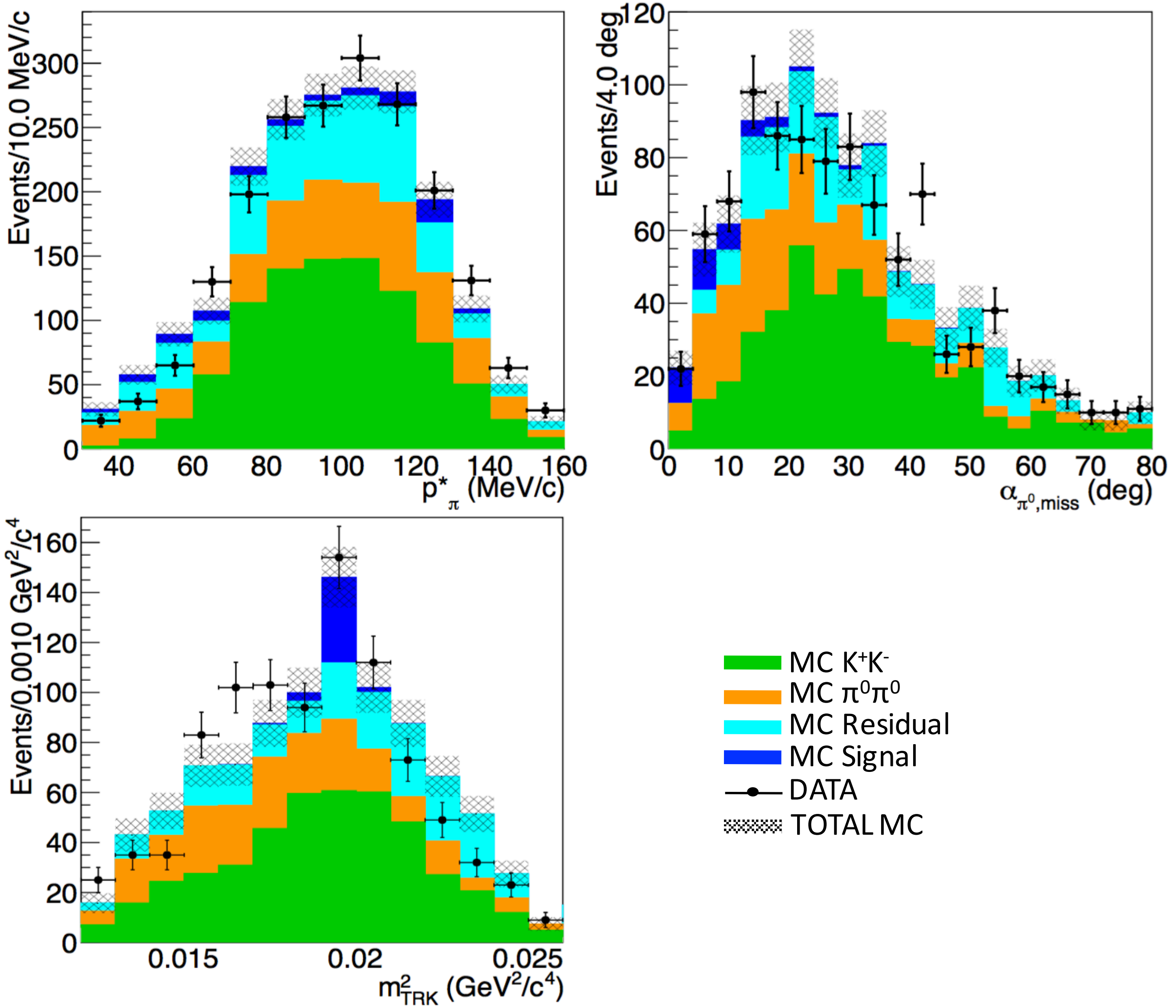
f_{signal}	0.039 ± 0.015
$f_{K^+K^-}$	0.472 ± 0.067
$f_{\pi^0\pi^0}$	0.246 ± 0.071
f_{resid}	0.242 ± 0.052
χ^2/n_{dof}	1.022
$P(\chi^2)$	0.397

→ $N_{\pi+\pi0\pi-} = 39 \pm 15$

Fit in Background Hypothesis

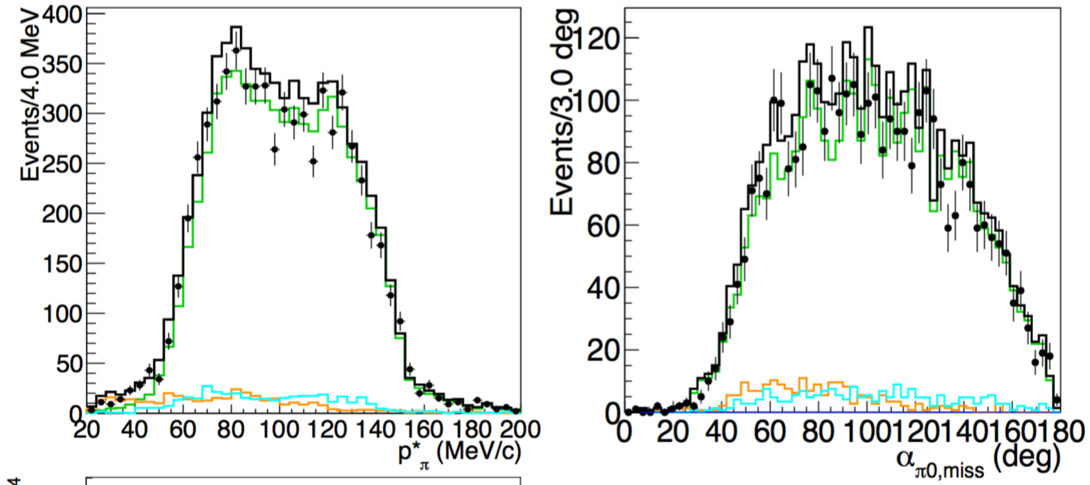
$f_{K^+K^-}$	0.632 ± 0.046
$f_{\pi^0\pi^0}$	0.368 ± 0.045
f_{resid}	0.000 ± 0.021
χ^2/n_{dof}	1.110
$P(\chi^2)$	0.125

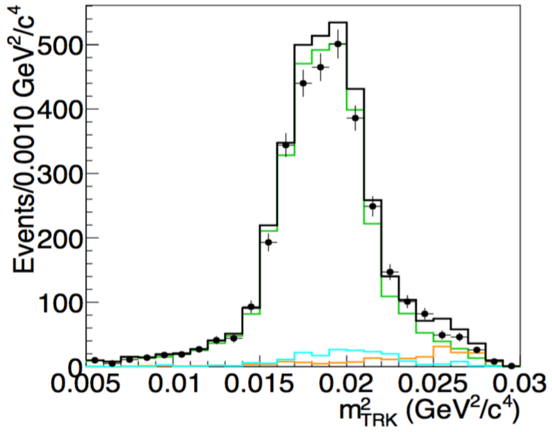
Fit with no signal is disfavored

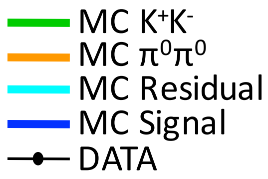


Background normalization check from CR's

CRKK with 90% K^+K^- events



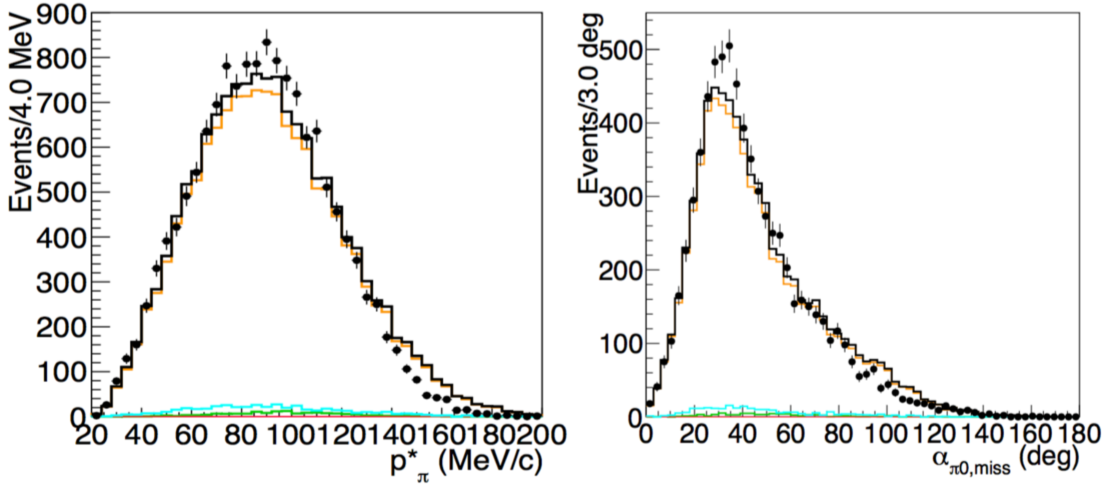


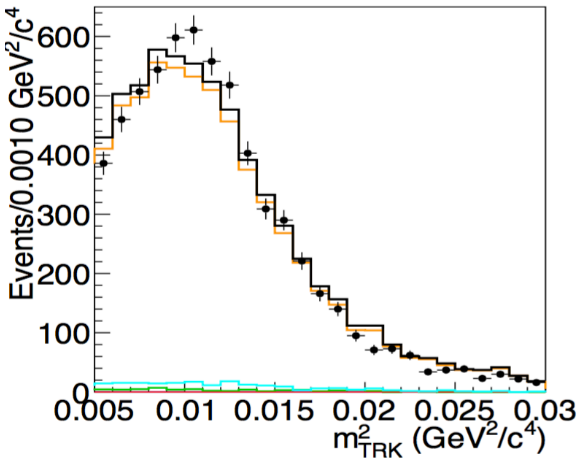


$$R^{CR}_{K^+K^-} = 1.047 \pm 0.026$$

$$R^{CR}_{\pi^0\pi^0} = 0.6293 \pm 0.0094$$

CR2PI0 with 96% $\pi^0\pi^0$ events





	K^+K^-	$\pi^0\pi^0$	Residual
CR's	496 ± 71	155 ± 45	369 ± 90
Fit	473 ± 67	247 ± 71	243 ± 52

Number of background events from fit compared to CR's analysis