Update $K_S^0 \to \mu^+\mu^-$ on 2 fb^{-1} 2012 data LHCb

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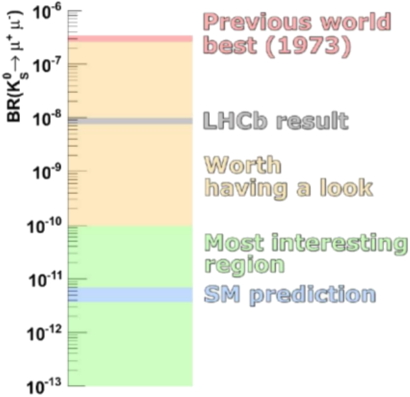
Overview $K_S^0 \to \mu^+\mu^-$

- $\mathcal{B}(K_S^0 \to \mu^+\mu^-)$ in SM $(5.0 \pm 0.2) \cdot 10^{-12}$ [JHEP 0401 (2004) 009]
- Pre-LHCb upper limit $\mathcal{B}(K_S^0 \to \mu^+\mu^-) < 3.1 \cdot 10^{-7}$ [PS@CERN: PLB 44 (1973) 217]
- LHCb 2011 result $\mathcal{B}(K_S^0 \to \mu^+\mu^-) < 9 \cdot 10^{-9}$ at 90% CL with 1fb^{-1} of data (1/3 of what is currently on the tape) [JHEP 01 (2013) 090]



Structure of the analysis

- Only on 2 fb^{-1} 2012 data not merged with the already analyzed $1\mathrm{fb}^{-1}$ 2011 data because of different trigger condition
- Same strategy of 2011 situation
- $K_S^0 \to \pi^+\pi^-$ as normalization channel an also as main bkg $\Rightarrow$ selection for $\pi\pi$ and $\mu\mu$ as similar as possible
- Low trigger efficiency $\Rightarrow$ more (3) different trigger categories included
- MVA selection to reject combinatorial bkg the same for $\pi\pi$ and $\mu\mu$
- Different MVA bins according to the sensitivity
- Data driven method to obtain the efficiencies
- Fit background in the sidebands and extrapolate it into the signal region [492, 504] MeV/c^2 around the K_S^0 mass
- Optimized muonID algorithm

Stripping line: KS02MuMuNoMuID line

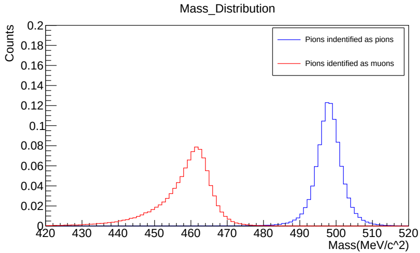
Variables	$K^0_S \to \mu^+\mu^-$	$K^0_S \to \pi^+\pi^-$
Input Protoparticle	StdLooseMuons	StdNoPidsPions
Prescale	1.0	0.001
K^0_S M	[465, 1500] MeV/c^2	[400, 600] MeV/c^2
K^0_S TOF	$> 0.1\ \tau$	$> 0.1\ \tau$
K^0_S IP	< 0.4 mm	< 0.4 mm
K^0_S DIRA	> 0	> 0
K^0_S DOCA	< 0.3 mm	< 0.3 mm
K^0_S P_T	> 0 MeV/c	> 0 MeV/c
Daughters Track χ^2/ndof	< 5	< 5
Daughters IP_{χ^2}	> 100	> 100

Both Std Muons/Pions samples: ($P_T > 250$ MeV/c & $IP\chi^2 > 4$)

- $\chi^2_{SV} < 25$
- $IP_\mu > 0.5$ mm
- $ProbNNghost_\mu < 0.7$
- $P_\mu < 100$ GeV/c
- K^0_S TOF 130 ps
- Cut in AP plot to remove Λ
- $ProbNNK_\mu < 0.85$ to remove the small contribution from $K^{*0} \to K\pi$

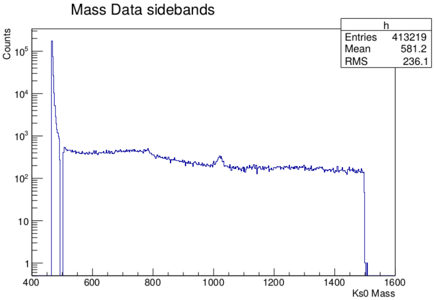
Main backgrounds

$K_S^0 \to \pi^+\pi^-$ misID $\Rightarrow$ mass shift



MC $K_S^0 \to \pi^+\pi^-$

Combinatorial



Real Data $K_S^0 \to \mu^+\mu^-$ (no muonID required)

Good mass resolution to disentangle between signal and misID $K_S^0 \to \pi^+\pi^-$ ($\sim$ 4 MeV/c^2-only long tracks considered) $\Rightarrow$ only the tail overlaps with the signal region

2011 vs 2012 trigger conditions

Variables	**2011**	**2012**	**2011**	**2012**
	L0Muon			
P_T^{fist}	> 1480 MeV/c	**> 1760 MeV/c**		
	HLT1TrackMuon		**HLT1DiMuonLowMass**	
Track χ^2/ndof	< 2	**< 2.5**	< 4	**< 3**
P	> 8 GeV/c	**> 3 GeV/c**	> 6 GeV/c	**> 0 GeV/c**
P_T	> 1.0 GeV/c	> 1.0 GeV/c	> 500 MeV/c	**> 0 MeV/c**
IP	-	**> 0.1 mm**	-	-
IPχ^2	> 16	> 16	> 3	**> 6**
DiMuons M	-	-	> 1000 MeV/c^2	**> 0 MeV/c^2**
	HLT2DiMuonDetached			
DiMuon P_T	> 1500 MeV/c^2	**> 600 MeV/c**		
DiMuon M	> 1000 MeV/c^2	**> 0 MeV/c^2**		

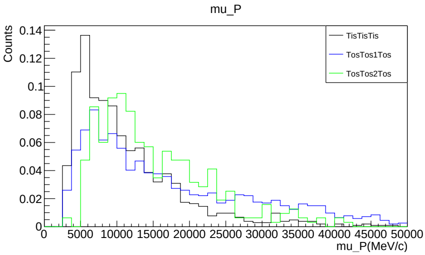
Large improvement compared to 2011 but although fraction of triggered signal events still small (2.7 %)

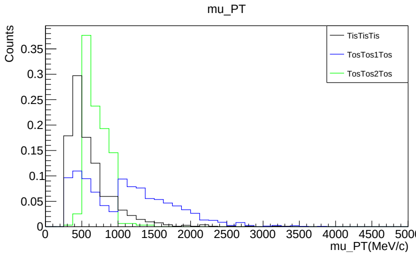
- Study from MC $K_S^0 \to \mu^+\mu^-$ events with 5M stats, only $\sim$ 61k (1.2%) reconstructed and selected.
- A fraction of 2.7% (1638) fire the trigger (factor 3 better than 2011).
- Main lines: L0Muon, HLT1TrackMuon (Tos1), HLT1DiMuonLowMass (Tos2), HLT2 = HLT2DiMuonDetached

Trigger line	**Nu. of events**	**included**
TosTos1Tos	828 (50%)	yes
TosTos2Tos	165 (10%)	yes
TisTos1Tos	58 (4%)	no
TisTos2Tos	96 (6%)	no
TisTisTos	491 (30%)	yes

In summary: the entire TisTisTos (only hlt2 trigger bias), TosTos1Tos ($\sim$ 3% shared with TisTisTos removed), TosTos2Tos ($\sim$ 60% shared with TosTos1Tos removed).

- MVA to discriminate between signal and combinatorial background (presented here)
- Proxy signal sample: $K_S^0 \to \pi^+\pi^-$ data which do **not** suffer of bias due to trigger selection as the $K_S^0 \to \mu^+\mu^-$ signal $\Rightarrow$ cuts on muon P-PT to emulate the trigger effects
- Must not learn mass and muonID
- Different proxy, tuning and training for each trigger category (different distribution of kinematic and MVA variables)





MVA variables common to all samples:

- lowest $IP\chi^2$ of the two muons
- K_S^0 $IP\chi^2$
- DOCA
- SV χ^2
- $\cos(\theta)$, $\theta =$ decay angle of the daughter particles in the K_S^0 frame
- Vertex isolation, $\Delta\chi^2$ of vertex fit adding a track (new wrt 2011)

Other variables, depending on trigger category:

- K_S^0 Lifetime
- SV x, y, z coordinates
- IsMaterial (Secondary vertex in the material)
- K_S^0 PT

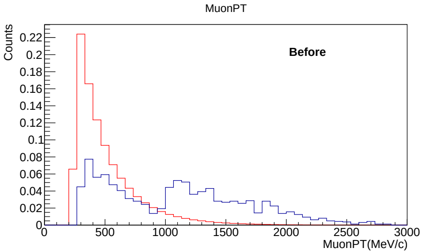
Cuts to simulate the trigger effects for the TosTos1Tos category

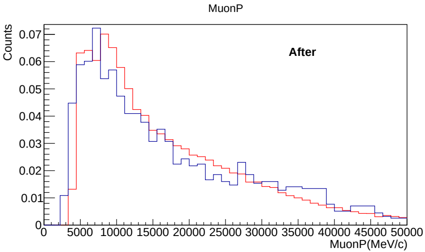
- $P_{\mu}(H) > 7500$ MeV/c, $P_{\mu}(\mathrm{L}) > 4500$ MeV/c to simulate the MuonID
- $PT_{\mu}(H) > 1130$ MeV/c for the HLT1, 20% resolution smearing applied because of the L0/offline PT difference
- $PT_{di-muon} > 600$ MeV/c, HLT2 replica

For TisTisTos only the HLT2 cut is needed.

The TosTo2Tos case implicit bias in muon P and PT are present due to the muonID request.

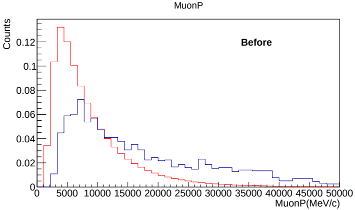
Cuts validate on MC (MB) and then applied on real data $K_S^0 \to \pi^+\pi^-$ all TIS re-weight in $(PT)_{K_S^0}$ to the NoBias sample (low statistics)

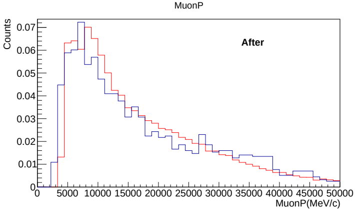


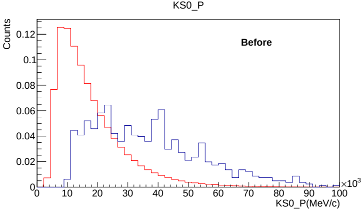


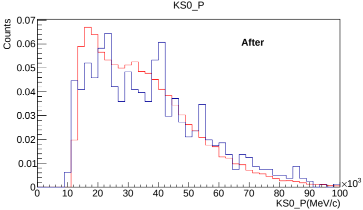
Red: Proxy

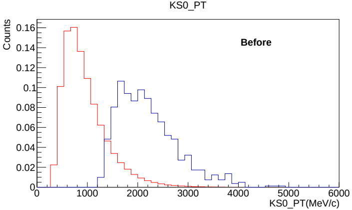
Blue: Signal

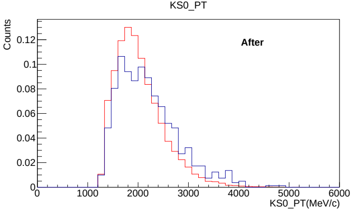






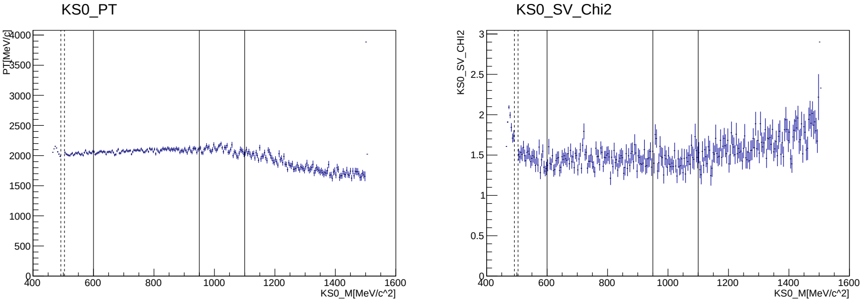






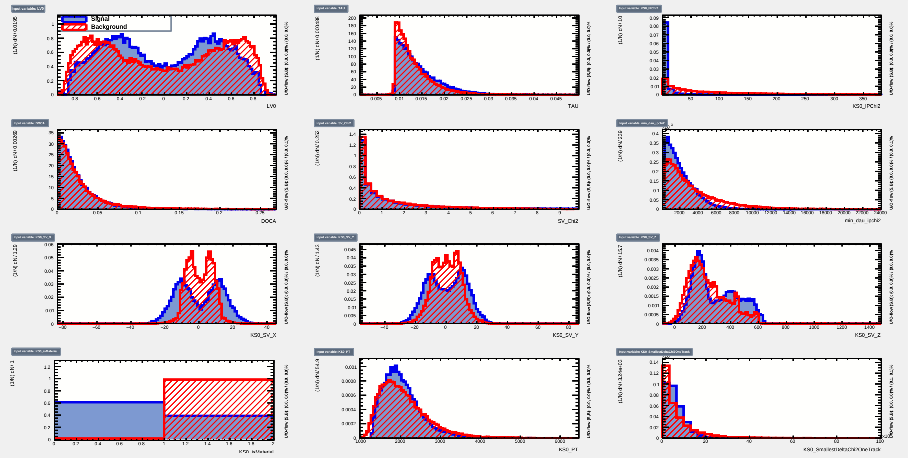
Background proxy

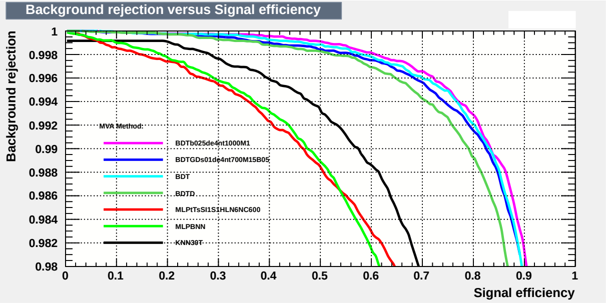
- Data right sideband closer to the signal region to avoid dependence on the mass ([600, 950] MeV/c^2), with the exclusion of the ϕ mass range.
- No overlap between with the bkg extrapolation fit region [465, 600] MeV/c^2



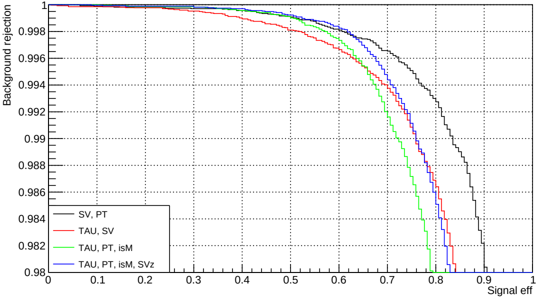
MVA input variables

combinatorial bkg sgn





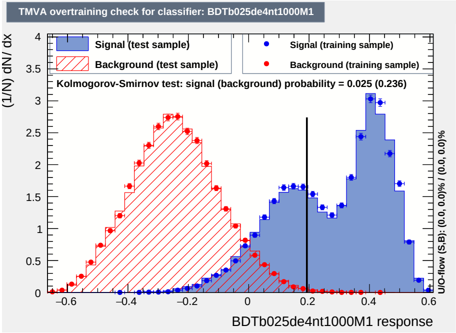
Different MVA methods tested: best response for BDT

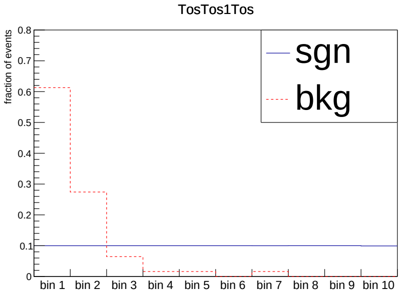


Four different variables combinations are studied and the best is used

Overtraining checks

combinatorial bkg sgn

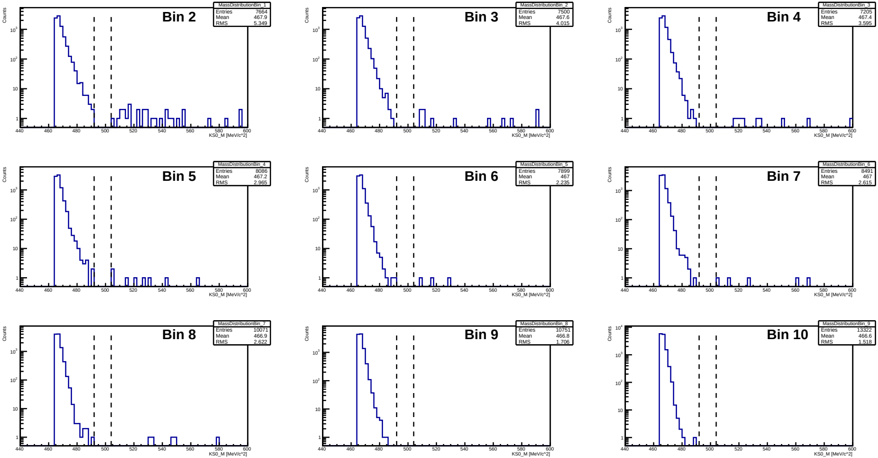




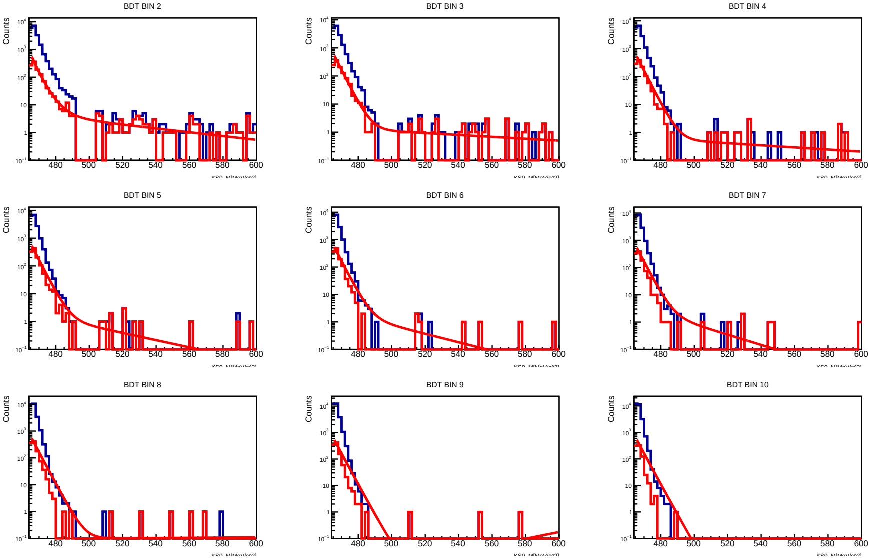
Double peak in the signal due to the usage of IsMaterial Cut on BDT for 99.8% bkg rejection efficiency

Split the analysis in 10 bins

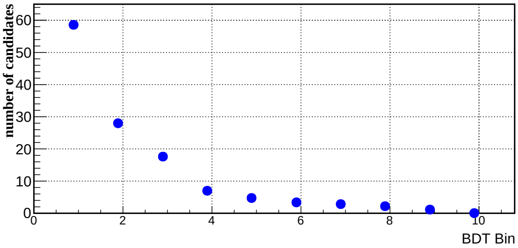
Mass distribution in each bin



Tuned algorithm for the muonID (here) to reduced $K_S^0 \to \pi^+\pi^-$ misID pions and cut optimized with the Punzi FOM



Preliminary bkg estimation from fit (using the same function of 2011), work in progress for improvement



- The muonID requirement efficiency reduced from 98% to about 75% (2011 case not optimized)
- The bkg estimation in the most sensitive bins similar to the 2011 case.
- The reconstruction and selection efficiency are expected to be comparable to the 2011 analysis.
- Improvement on upper limit expected > 4 (trigger + luminosity)

Ongoing work

- New stripping-filtered MC production almost ready. Needed to study the signal proxy for the other BDT categories and to finish the muon ID studies
- Create all proxies and develop all MVA for each trigger category
- Trigger efficiency measurement in progress
- Fit on $K_S^0 \to \pi^+\pi^-$ background in progress
- Systematics to be finalized (improved by the larger control samples and more stable data acquisition conditions)
- Analysis note in preparation