FLAVOUR PHYSICS AND CP VIOLATION AT KLOE-2

ANDREA SELCE

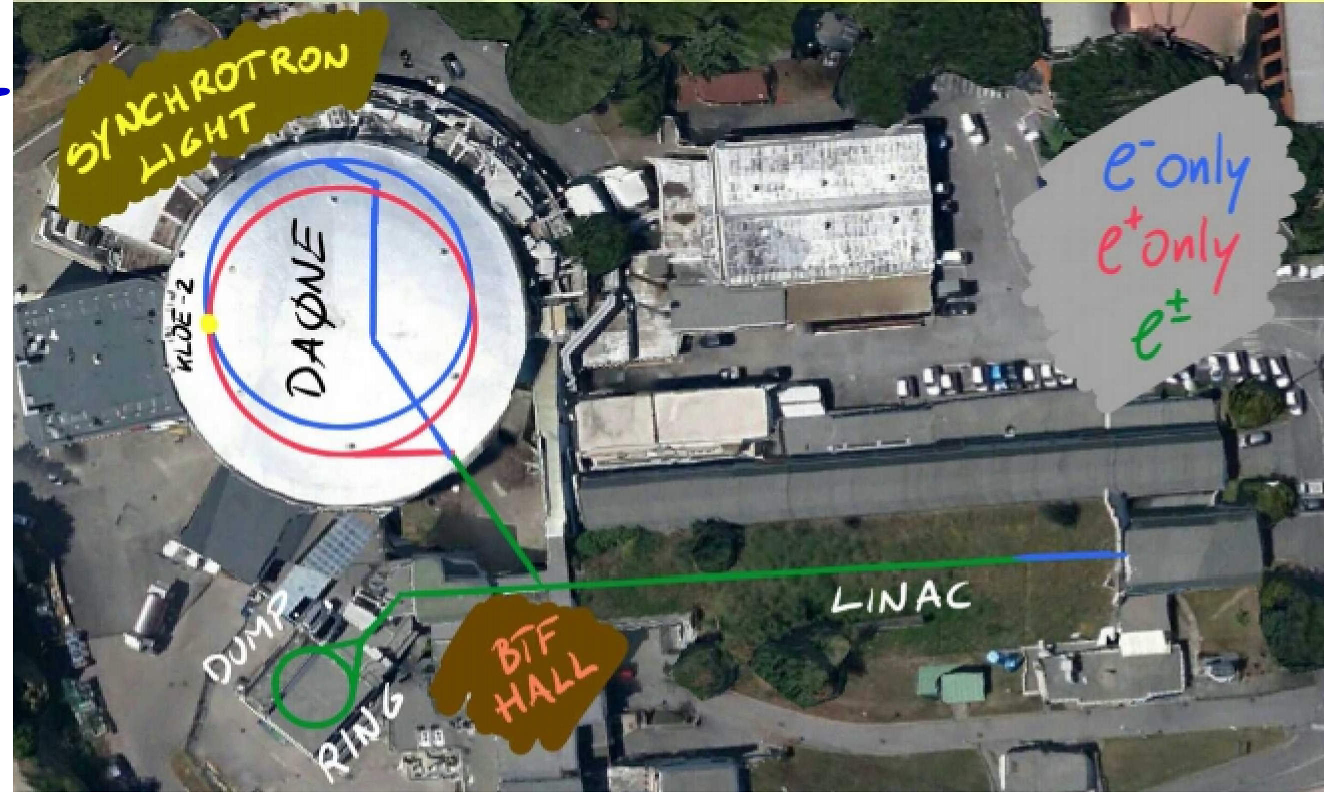
on behalf of the KLOE-2 COLLABORATION

OUTLINE

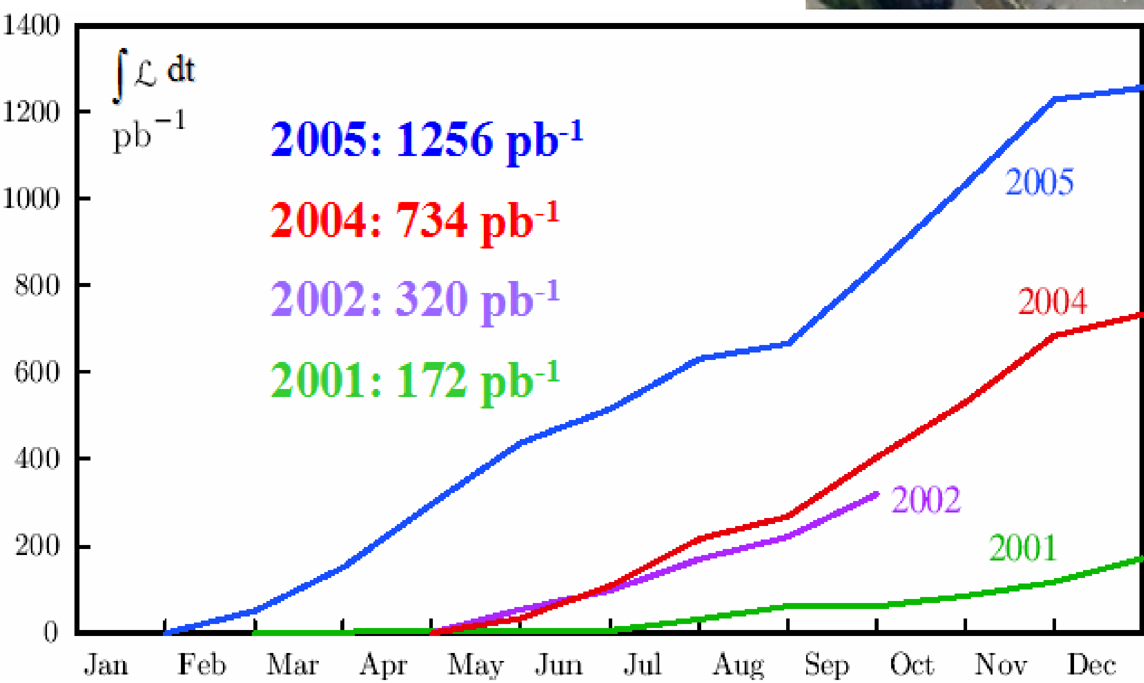
- KLOE & KLOE-2
- PHYSICS @KLOE2
- K_S TAG IN KLOE
- $K_S \to 3\pi^0$
- $K_S \to \pi \ell \nu$
  - ANALYSIS SCHEME
  - $BR(K_S \to \pi\mu\nu)$
- CONCLUSIONS

KLOE @DAϕNE

ϕ-FACTORY



- Collider e^+-e^-
- $\sqrt{s}$ = M(ϕ) = 1019.4 MeV



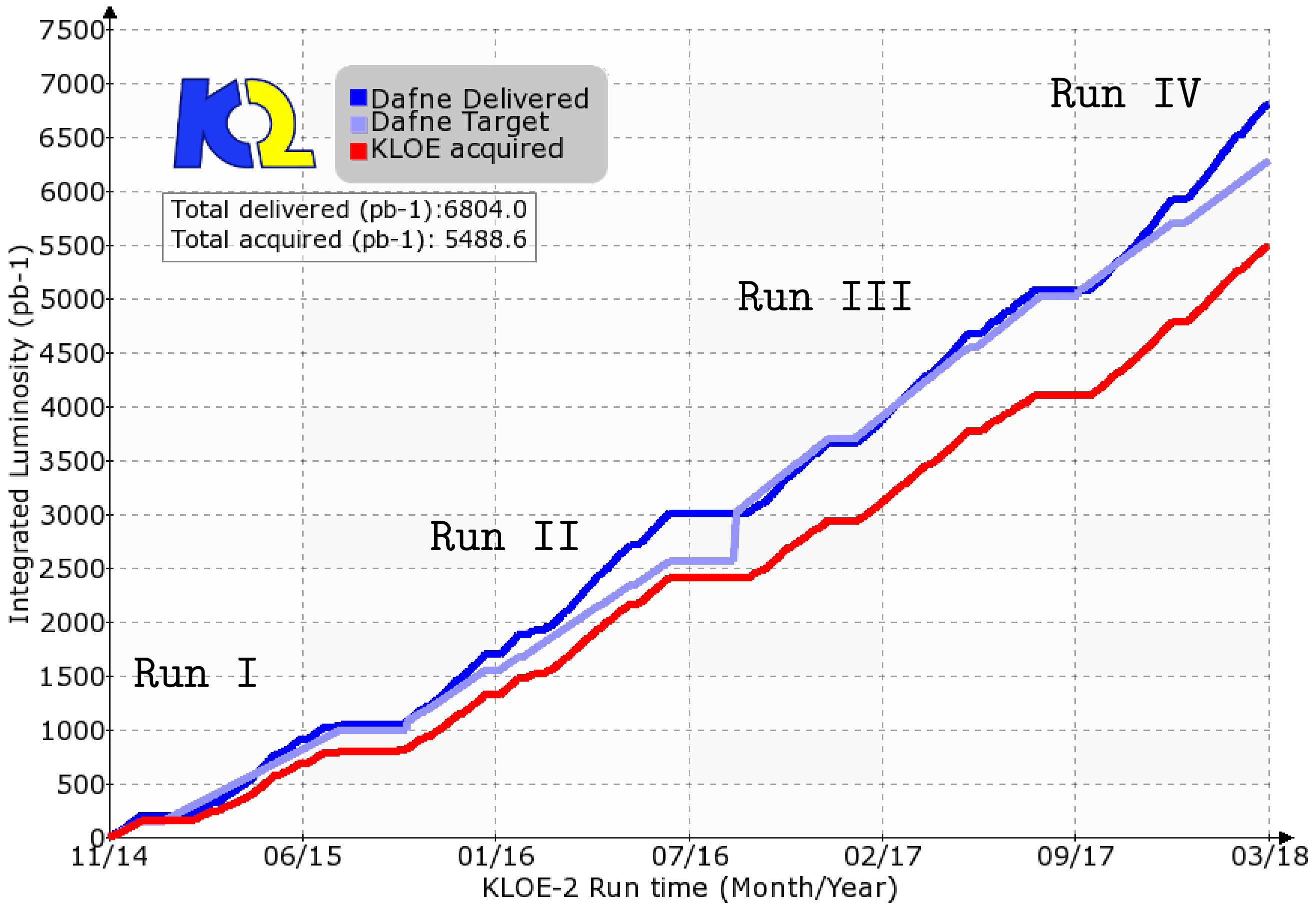
- *KLOE* ~ 2.5 fb^{-1} (2.0 @ $\sqrt{s}$=M(ϕ))
  - Precision Kaon Physics
  - Hadron Physics

[Rivista Nuovo Cimento Vol.31 N.10 (2008)]

- *KLOE-2* ~ 5.5 fb^{-1}
  - Physics program [EPJC 68 (2010)]
    - K_S, η, η' rare decay
    - Quantum interferometry
    - Dark photon searches

KLOE-2 DATA TAKING

- KLOE-2 took data till 31/03/2018
  - TOTAL ACQUIRED LUMINOSITY ~5.5 fb^{-1}

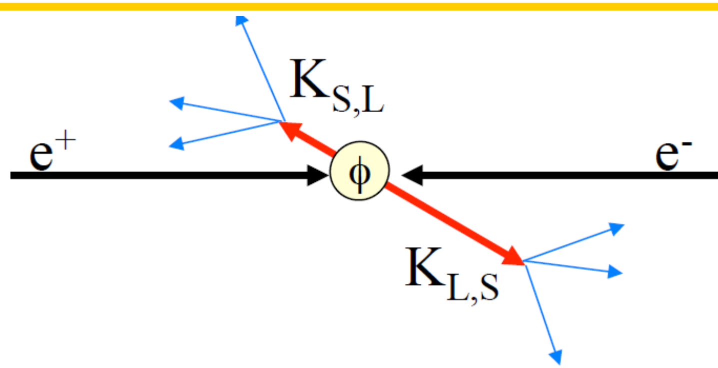


KLOE + KLOE-2 LUMINOSITY ~ 8 fb^{-1}

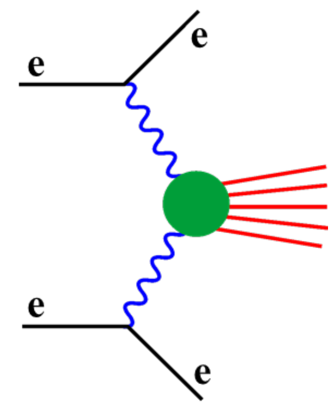
~ 2.4 x 10^{10} ϕ decays, ~ 8x 10^{9} K_L-K_S pairs

<u>Unique data sample for tipology and statistical relevance</u>

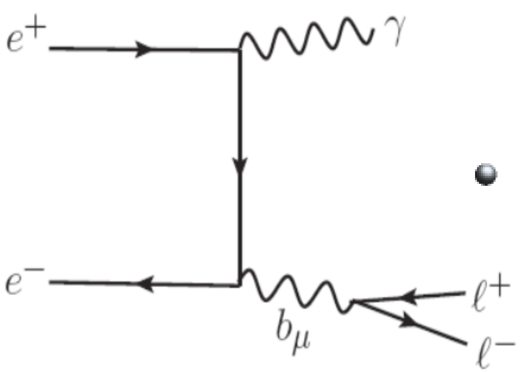
PHYSICS @KLOE-2 [EPJC 68 (2010)]



- Kaon Physics
- Discrete symmetries test

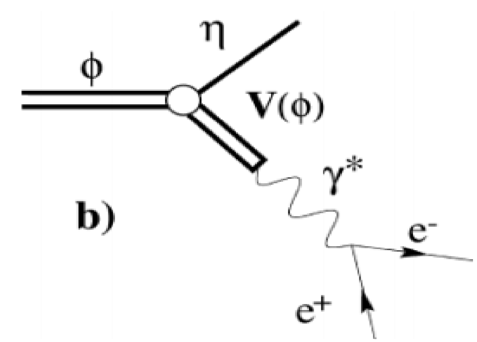


- $\gamma\gamma$ physics e^+e^-->$e^+e^-\gamma^*\gamma^*$ -> e^+e^-X thanks to new tagger detectors



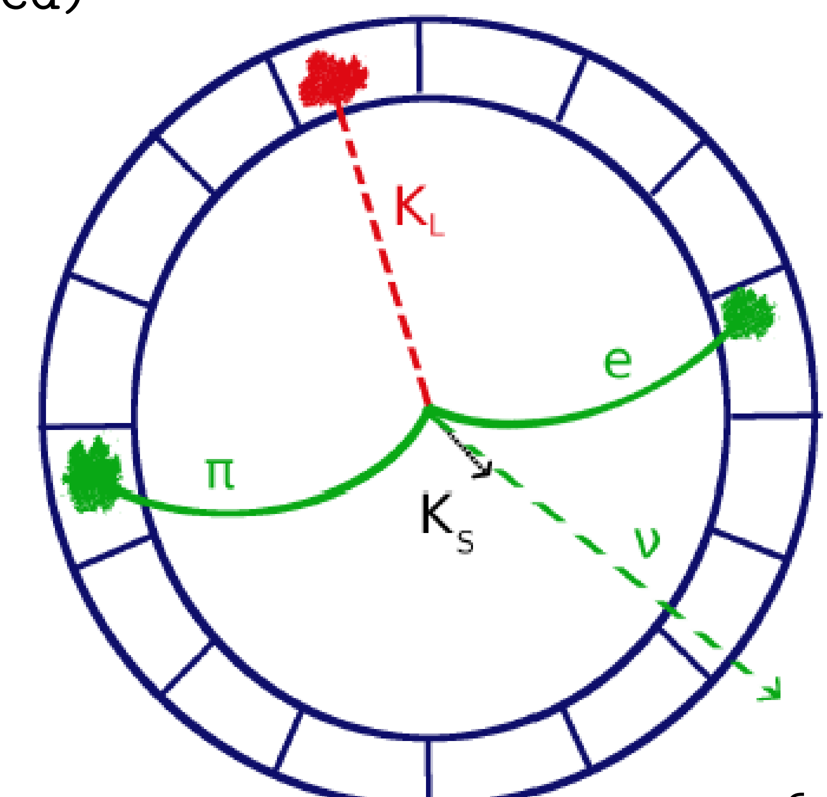
- Search of dark force mediators in various channels (ex: e^+e^-->$e^+e^-U\gamma$; e^+e^-->$e^+e^-U\gamma$->$e^+e^-\ell^+\ell^-\gamma$)

- Hadronic physics around 1GeV



K_S TAG IN KLOE

- Kaon pairs from ϕ meson decays have the same quantum numbers as the ϕ, pure $J^{PC}=1^{--}$ state
- Detection of K_S (K_L) guarantees the presence of a K_L (K_S) with known momentum and direction
- K_S tag is done using K_L interaction in the calorimeter (K_L-crash): one isolated cluster (no track associated) with E_{crash}> 100 MeV and $0.18<\beta<0.27$
- Efficiency ~30% (due to K_L decay lenght)
- K_S angular resolution: ~1°
- K_S momentum resolution: ~2 MeV



$K_S \to \pi^o\pi^o\pi^o$

- Direct search for the pure CP violating decay
  - Standard Model expectation $BR(K_s \to \pi^o\pi^o\pi^o) = 1.9 \times 10^{-9}$
- Best upper limit is from KLOE
  - $BR(K_s \to \pi^o\pi^o\pi^o) < 2.6 \times 10^{-8}$ @90% CL with 1.63 fb^{-1} [PLB 723 (2013) 54]
- ANALYSIS SCHEME:
  - K_L-crash E_{crash}>150MeV, $0.20<\beta<0.225$
  - $K_s \to \pi^o\pi^o$ (main background) used as normalization

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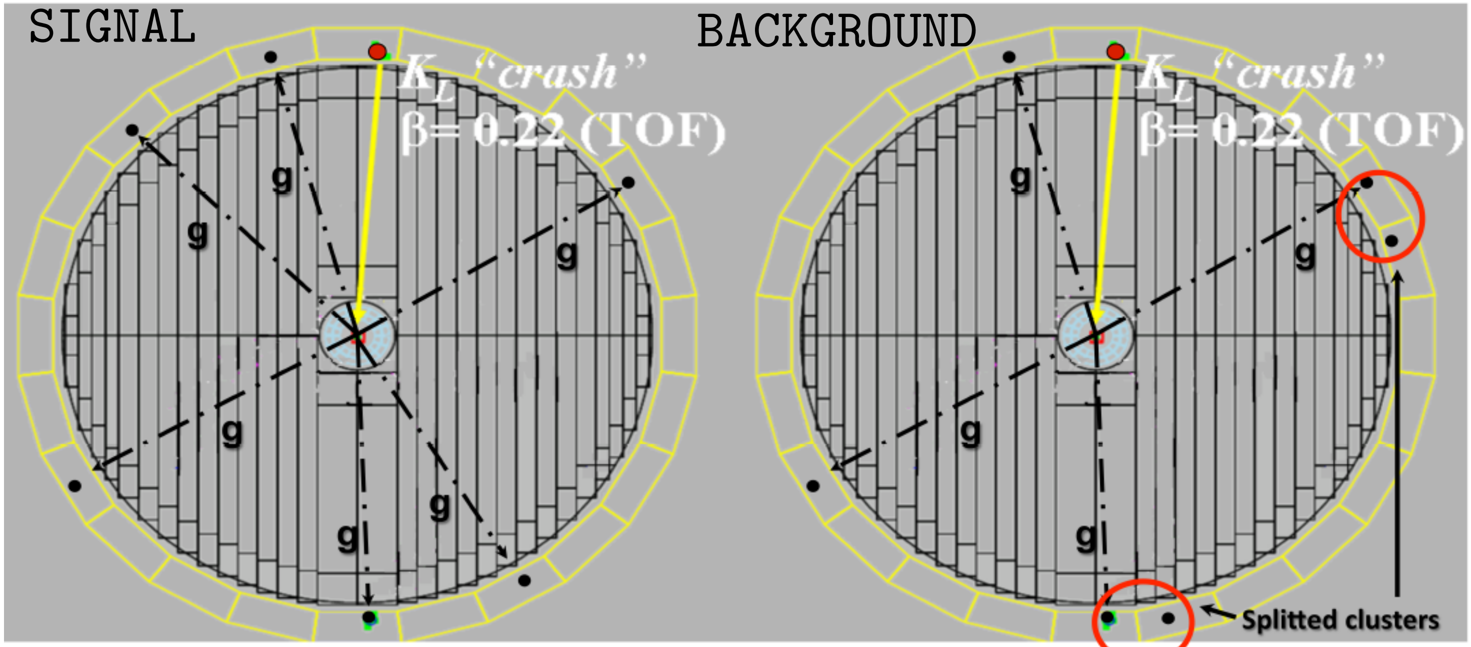

- $K_s \to 3\pi^o \to 6\gamma$

- $K_s \to 2\pi^o \to 4\gamma$ +accidental/split clusters
- $K_L \to 3\pi^o$, $K_s \to \pi^+\pi^-$ ("fake K_L-crash")

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    - SIGNAL/BACKGROUND DISCRIMINATION:
      - Kinematic fit
      - Comparing signal 6γ (signal) and 4γ hypothesis (background)
      - Cut on distance between cluster to reduce cluster splitting

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  - K_L-crash E_{crash}>150MeV, 0.20<β<0.225
  - $K_s \to \pi^0\pi^0$ (main background) used as normalization
- Analyzing KLOE-2 data (using 2 fb^{-1} from 2016)
  - Hardened selection criteria to cope with background increase
    - ~10x better background rejection respect to KLOE selections with similar efficiency
  - Exploring Neural Network analysis approach
    - Preliminary studies on KLOE data:
      - same MC efficiency with ~2x better background rejection
  - Goal:
    - ~2x better limit with KLOE-2 statistics and optimized analysis
    - Upper limit ~ 10^{-8} with KLOE+KLOE-2 data

$K_S \to \pi \ell \nu$ - MOTIVATION

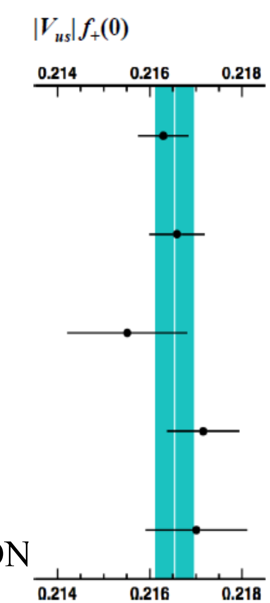
- Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix
- V_{ij} are fondamental parameters of the Standard Model of particle interactions

$$V_{\rm CKM} = \begin{pmatrix} V_{\rm ud} & V_{\rm us} & V_{\rm ub} \\ V_{\rm cd} & V_{\rm cs} & V_{\rm cb} \\ V_{\rm td} & V_{\rm ts} & V_{\rm tb} \end{pmatrix}$$

- V_{us} matrix element is best measured from Kaon meson semileptonic decays

$$\Gamma_{K\ell 3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW}(1+\delta_K^\ell + \delta_{SU2})C^2|V_{us}|f_+^2(0)I_K^\ell$$

- BR($K_s \to \pi e \nu$) is the less precise contribution
  - BR($K_s \to \pi e \nu$)=(7.046 ± 0.078 stat ± 0.049 syst)×10^{-4} [PLB 636 (2006) 173]
    - Measured by KLOE with 0.4 fb^{-1}
    - 1.4% uncertainties level
    - 1.1 % stat ± 0.7 % syst
  - Redo BR($K_s \to \pi e \nu$) mesurement on all KLOE statistics 1.63 fb^{-1}
- First measurement of BR($K_s \to \pi \mu \nu$)



			Approx. contrib. to % err from:			
		% err	BR	τ	Δ	Int
$K_L e3$	0.2163(6)	0.26	0.09	0.20	0.11	0.05
$K_L \mu 3$	0.2166(6)	0.28	0.15	0.18	0.11	0.06
$K_S e3$	0.2155(13)	0.61	0.60	0.02	0.11	0.05
$K^\pm e3$	0.2172(8)	0.36	0.27	0.06	0.23	0.05
$K^\pm \mu 3$	0.2170(11)	0.51	0.45	0.06	0.23	0.06

E. Passemar, KAON2016

$K_S \to \pi \ell \nu$ - ANALYSIS STRATEGY

- Measuring the ratio $N(K_s \to \pi \ell \upsilon)/N(K_s \to \pi^+\pi^-)$

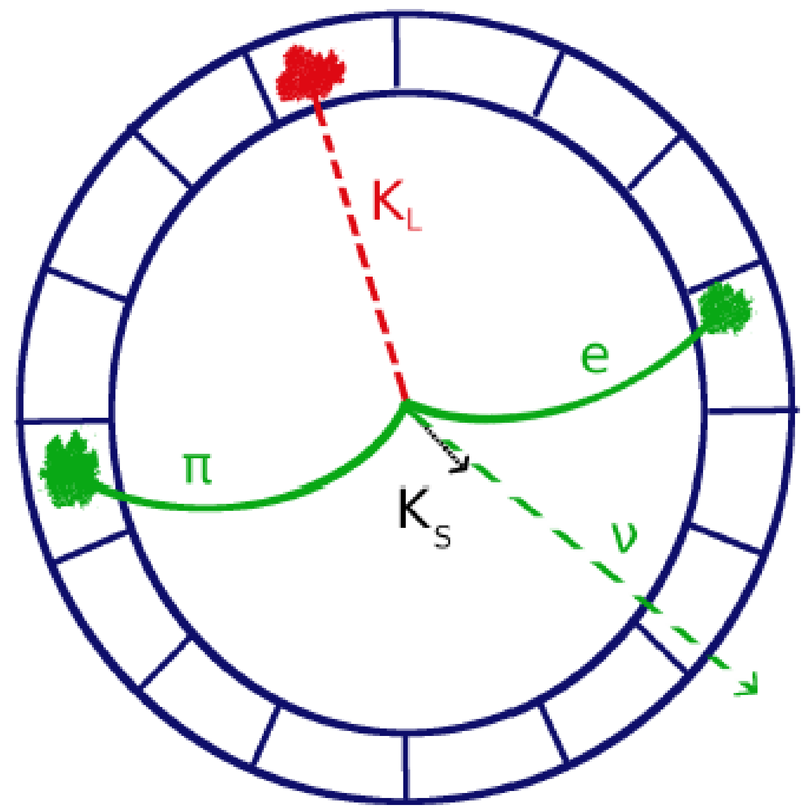
$$BR(K_S \to \pi \ell \nu) = \frac{N_{\pi \ell \nu}}{\epsilon_{\pi \ell \nu}} \times \frac{\epsilon_{\pi^+\pi^-}}{N_{\pi^+\pi^-}} \times R_\epsilon \times BR(K_S \to \pi^+\pi^-)$$

- R_ϵ: ratio of common selections between $K_s \to \pi \ell \upsilon$ and $K_s \to \pi^+\pi^-$

- $BR(K_s \to \pi^+\pi^-) = 0.69196 \pm 0.00051$ (KLOE, PLB 636 (2006) 173)

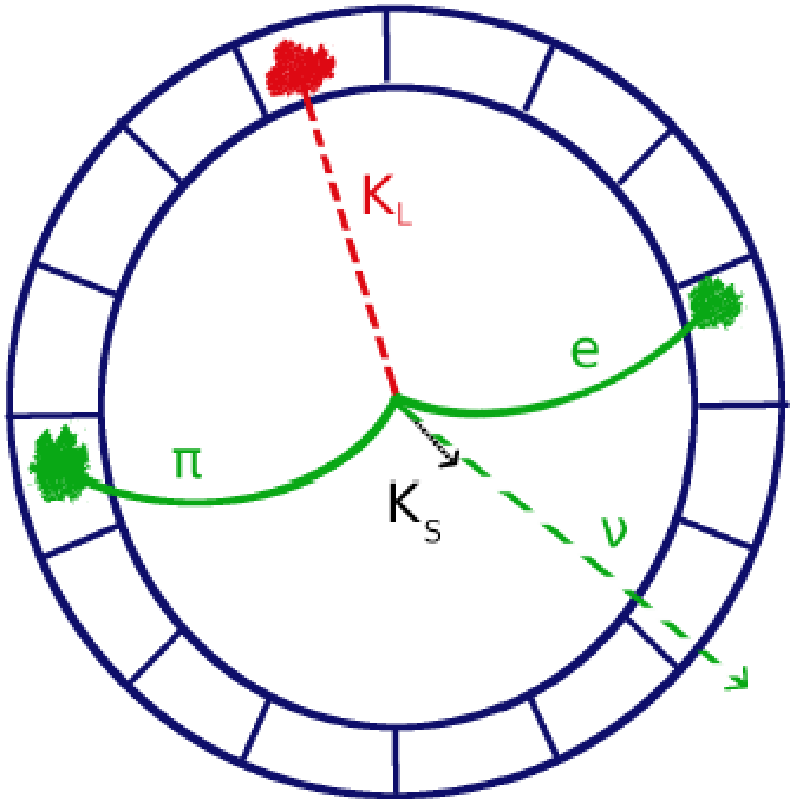
- $BR(K_s \to \pi e \upsilon) \sim BR(K_s \to \pi^+\pi^-)/1000$

- $BR(K_s \to \pi \mu \upsilon)$ expected $2/3 \times BR(K_s \to \pi e \upsilon)$
  - More difficult measurement due to $K_s \to \pi\pi \to \pi\mu\upsilon$ background



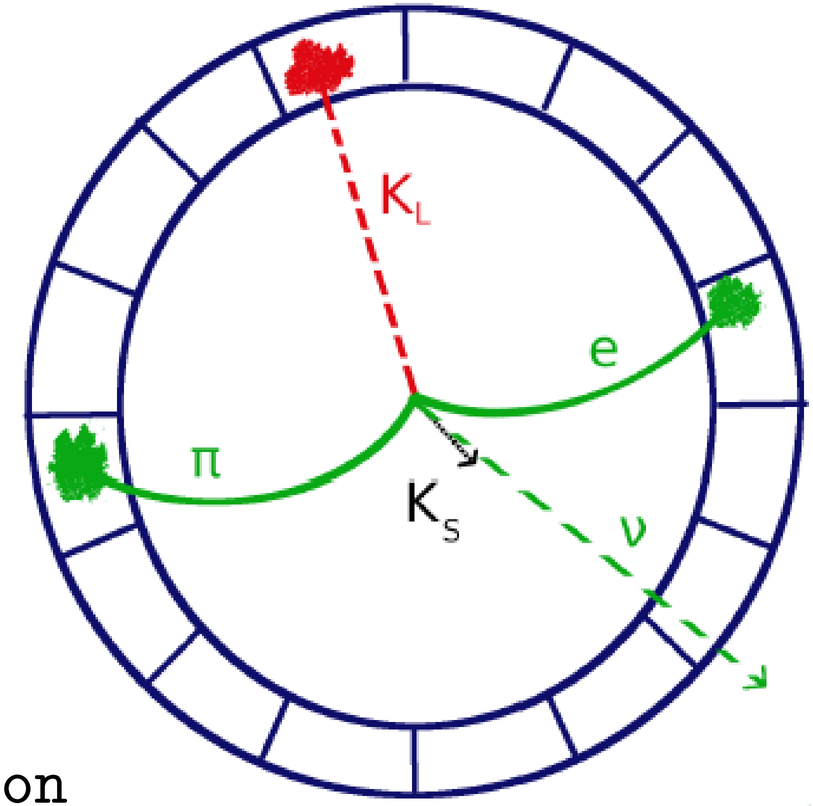
K_{e3}->$\pi e \nu$ – COMMON PRESELECTIONS

- Trigger, On-line machine background filter (FILFO), Event streaming
- K_S TAG by K_L-crash:
  - one isolated cluster (no track associated) E_{crash}>100MeV, $0.18<\beta<0.27$
- K_s identification (ID):
  - two tracks of opposite charge determining one vertex in a cylinder r<5cm,|z|<10cm
- $\pi^+\pi^-$ selection and count after K_L-crash and K_S-ID
  - $N_{\pi\pi}/\epsilon_{\pi\pi}=(292.10 \pm 0.26) \times 10^6$ events



$K_S \to \pi \ell \nu$ - ANALYSIS SCHEME

- $K_s \to \pi \ell \upsilon$ selection from background (mainly $\pi^+\pi^-$)
  - Preselection:
    - Track to Cluster Association (TCA)
    - Very loose cut on kinematic variables ($15° < \theta_{cl} < 165°$, $p < 330$ MeV, ...)
  - MultiVariate Analysis (MVA)
    - BoostedDecisionTree (BDT) with only tracking-related variables
  - Time Of Flight analysis with calorimeter timing
  - Fit on M^2 to extract $N_{\pi \ell \upsilon}$
- Main efficiencies calculated from $K_L \to \pi \ell \upsilon$ data control sample
  - Purity > 95% after unbiased selection



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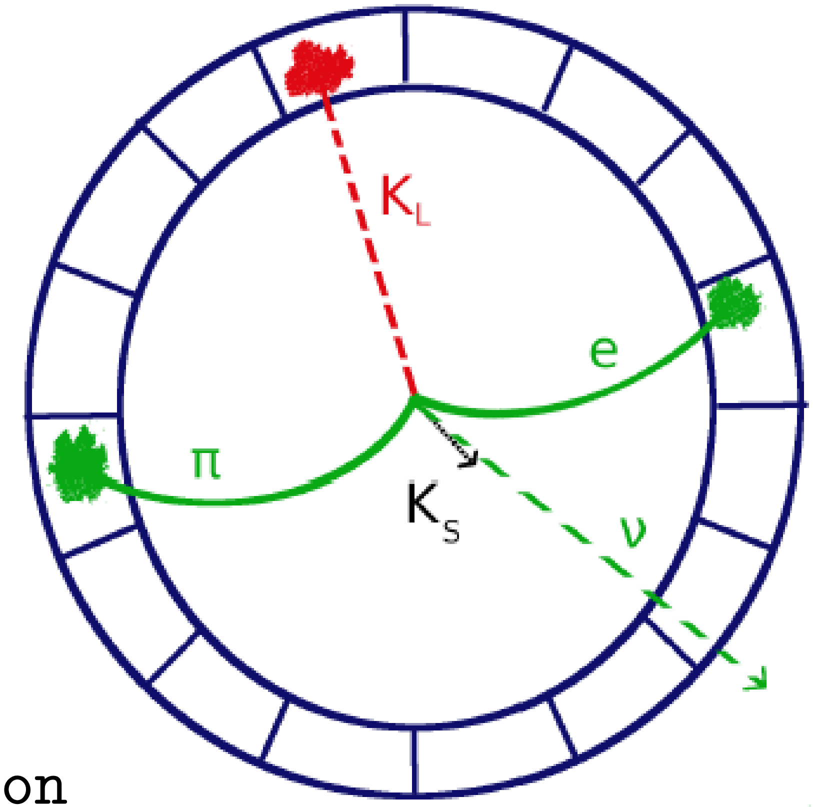
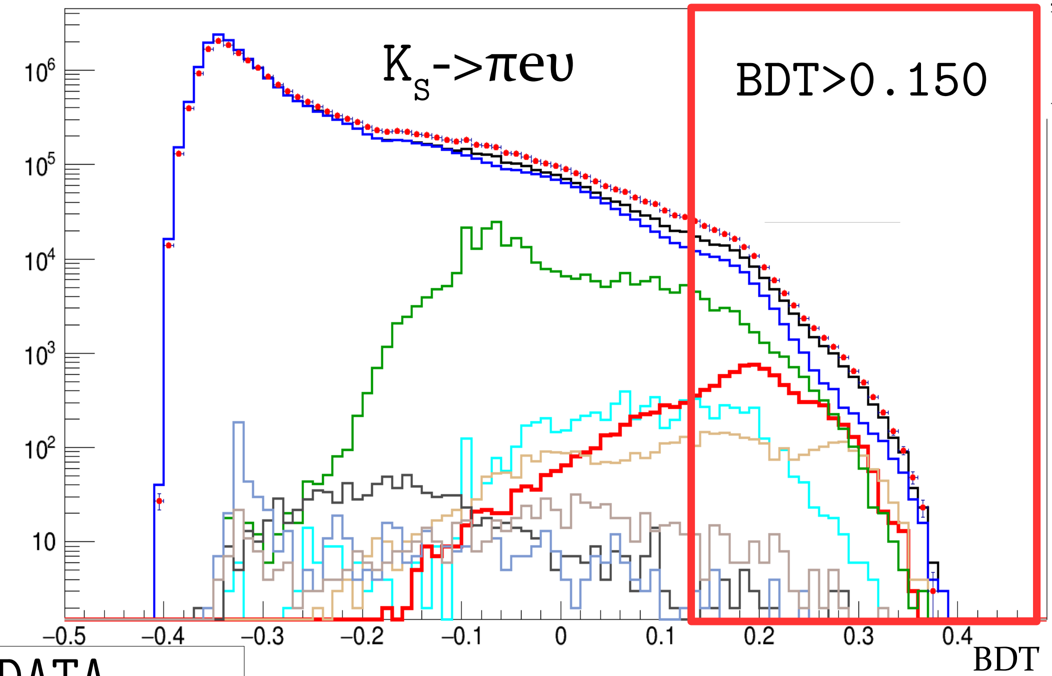
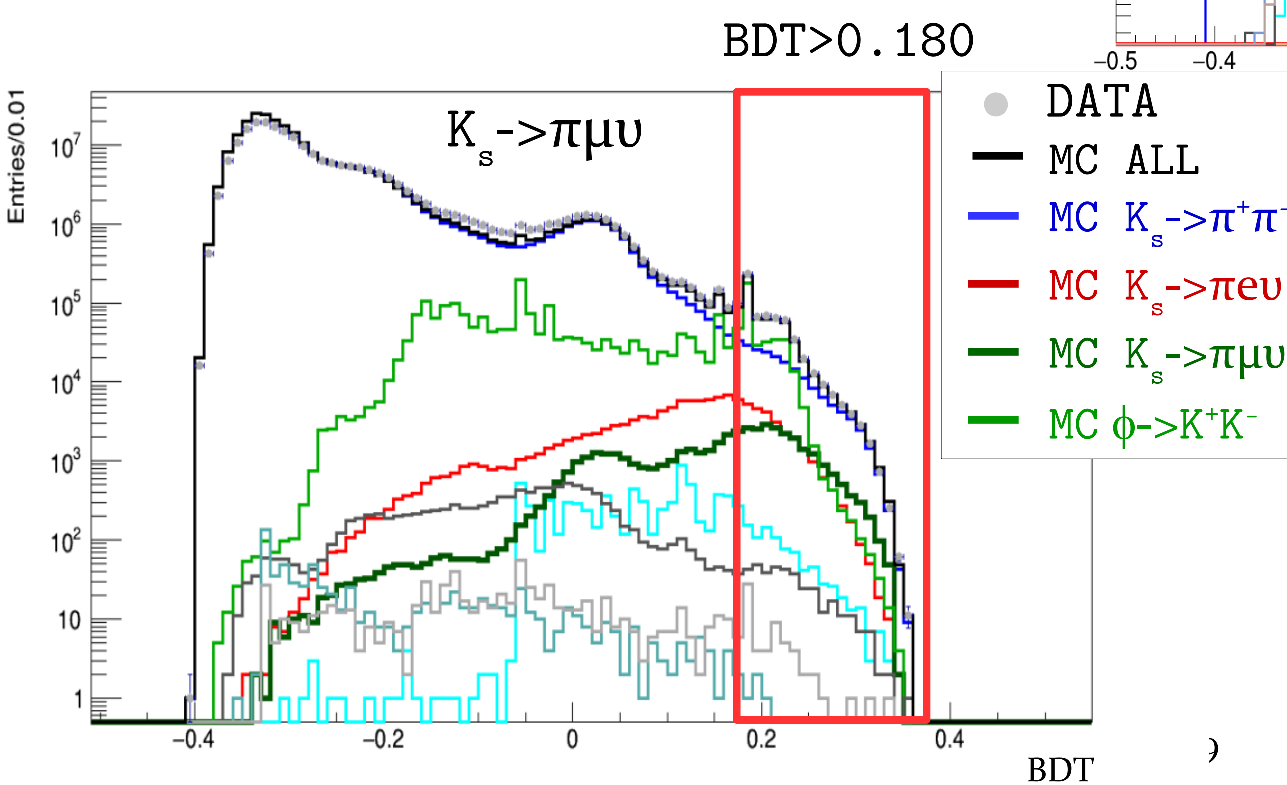


$K_S \to \pi \ell \nu$ BDT

- MultiVariate Analysis (MVA)
  - BoostedDecisionTree (BDT) with only tracking-related variables
  - Separate training with $K_S \to \pi e \nu$ and $K_S \to \pi \mu \nu$ MC signal





- Harder cut for $K_S \to \pi \mu \nu$ to avoid $K_S \to \pi\pi \to \pi \mu \nu$ background

$K_S \to \pi \ell \nu$ - ANALYSIS SCHEME

- $K_S \to \pi \ell \nu$ selection from background (mainly $\pi^+\pi^-$)
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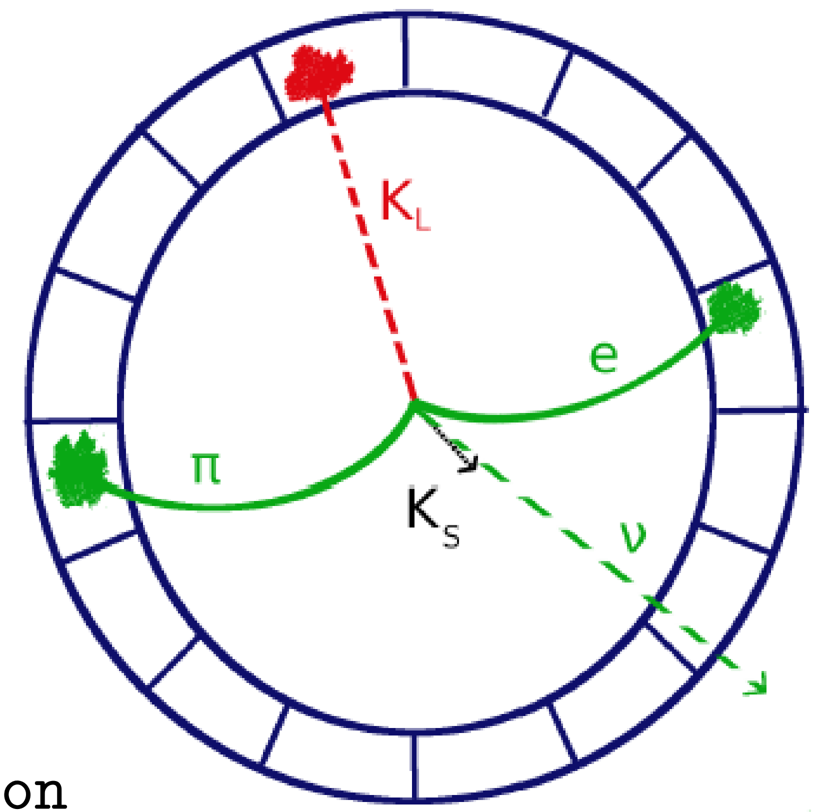

$K_S \to \pi l \nu$ DTOF SELECTIONS

- Time of Flight (TOF) differences

very good time resolution of the EMC
(300 ps for 200MeV particle)

$$DTOF_i = T_{cl,i} - L_i/(c*\beta_i(m_x))$$

T_{cl} = time of the cluster associated to the track

L=Track length

$\beta(m_x)=p/\mathrm{sqrt}(p^2+m_x^2)$

- $dDTOF=DTOF_1-DTOF_2$ to avoid systematics due to T0 event time

Computed for different mass hypotheses

- Under $\pi\pi$ mass hypothesis: $dDTOF(\pi\pi)\sim 0$ for $\pi\pi$ bkg

$K_S \to \pi l \nu$ DTOF($\pi\pi$) SELECTION

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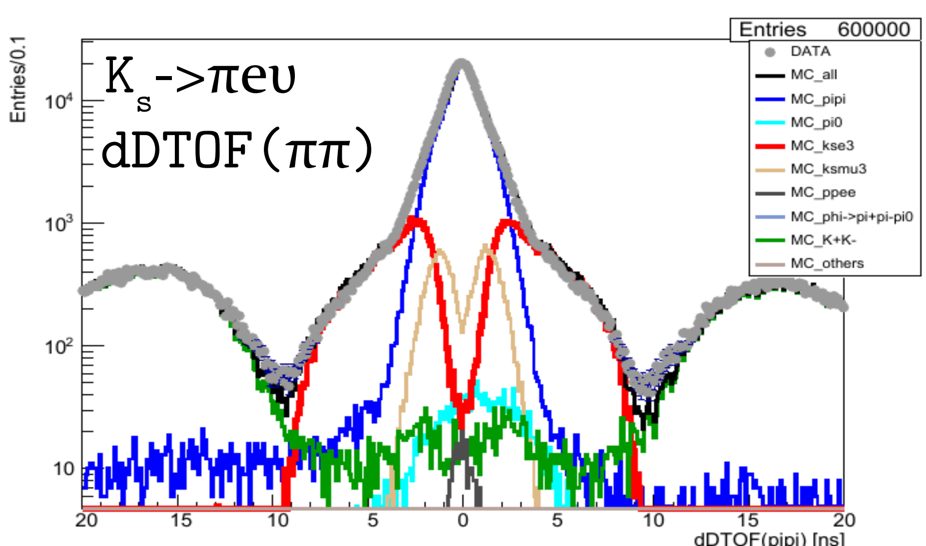

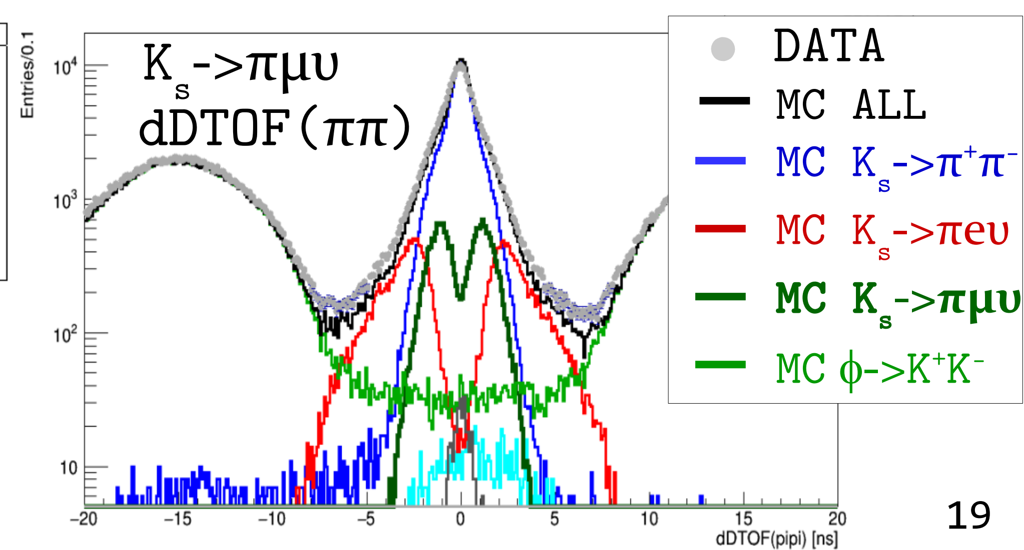

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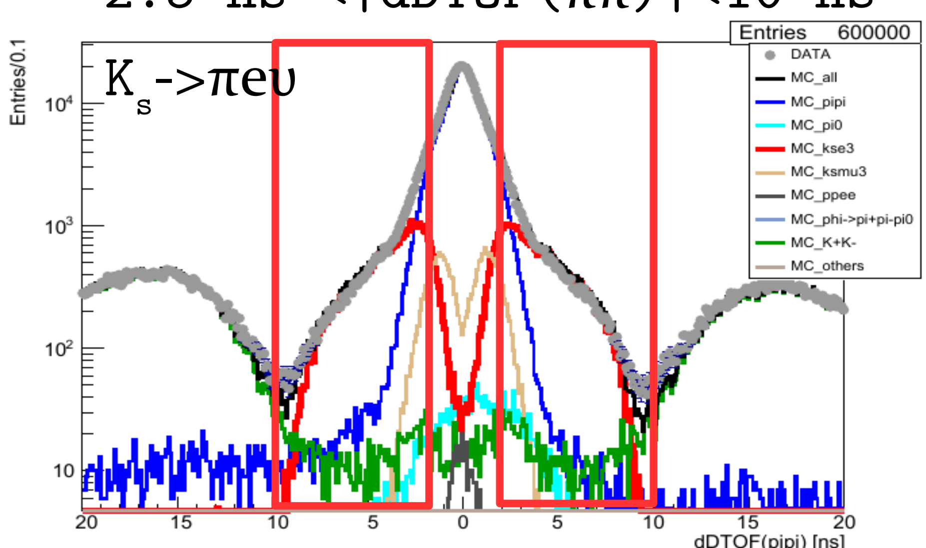
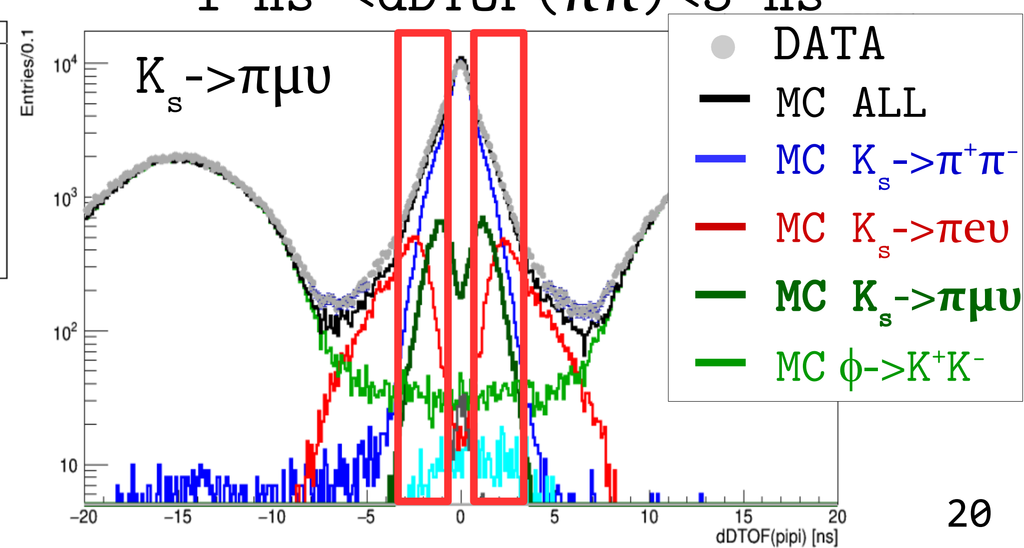
Computed for different mass hypotheses

2.5 ns <|dDTOF($\pi\pi$)|<10 ns



1 ns <dDTOF($\pi\pi$)<3 ns



$K_S \to \pi l \nu$ DTOF($\pi\pi$) SELECTIONS

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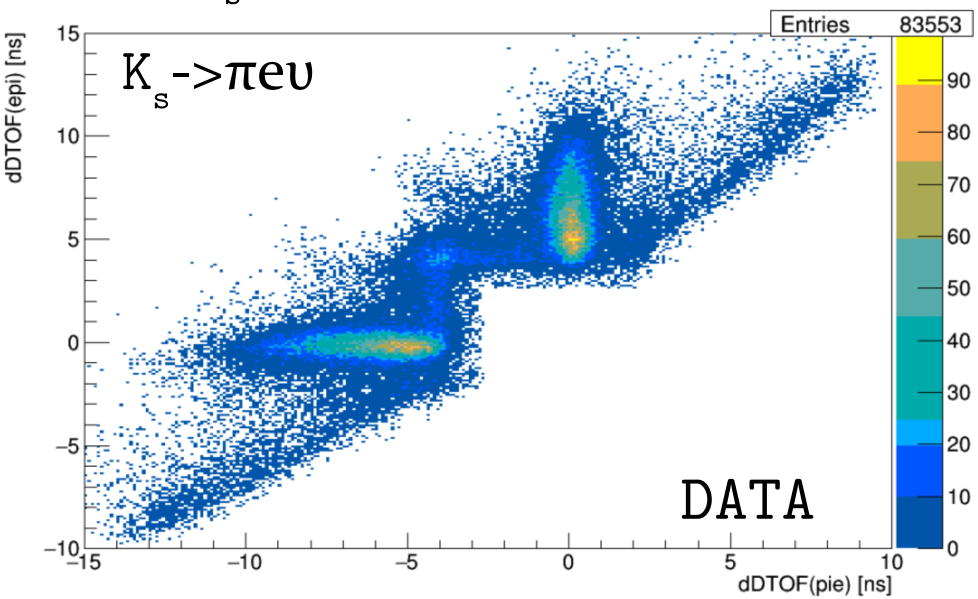
- $dDTOF=DTOF_1-DTOF_2$ to avoid systematics due to T0 event time

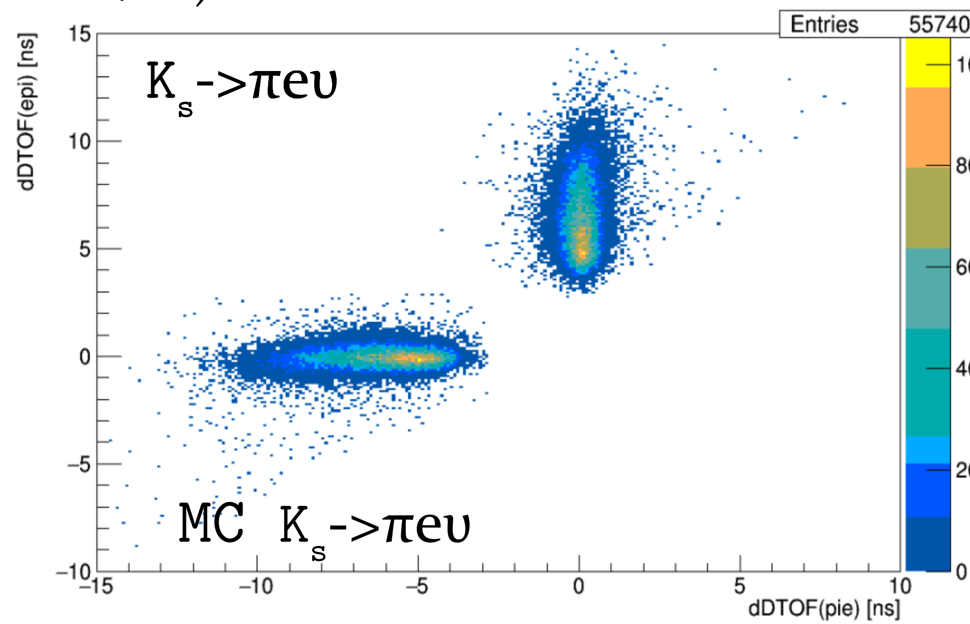
Computed for different mass hypotheses

- Under $\pi\pi$ mass hypothesis: $dDTOF(\pi\pi)\sim 0$ for $\pi\pi$ bkg
  - For $K_s \to \pi e \nu$: 2.5 ns $<|dDTOF(\pi\pi)|<$ 10 ns
  - For $K_s \to \pi \mu \nu$: 1 ns $<dDTOF(\pi\pi)<$ 3 ns
- For survived events, both the πl and $l\pi$ mass hypotheses are tested

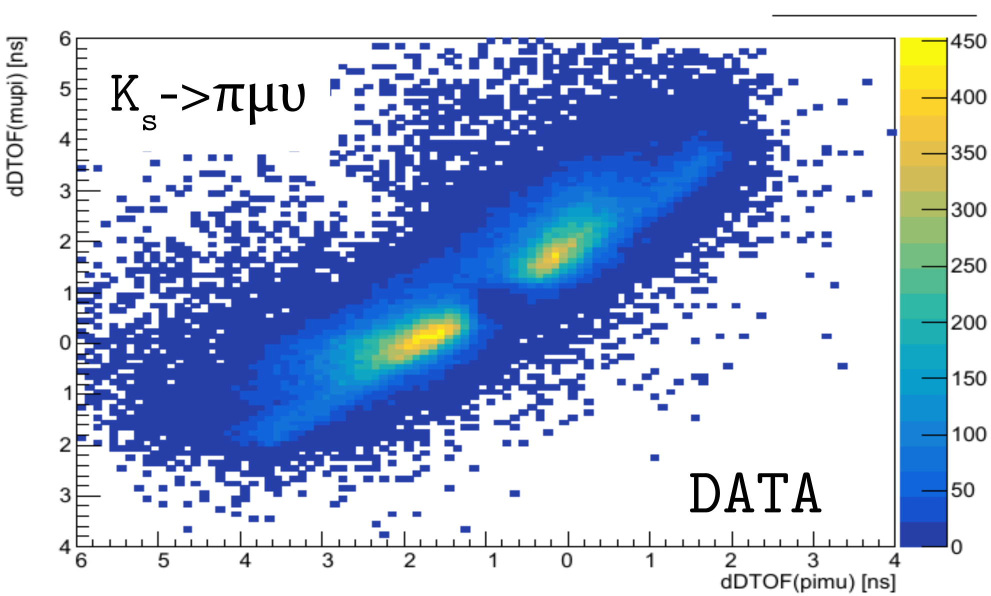
$K_s \to \pi l \nu$ dDTOF(πl) SELECTION

- For $K_s \to \pi e \nu$, both dDTOF(πe) and dDTOF($e\pi$) are tested

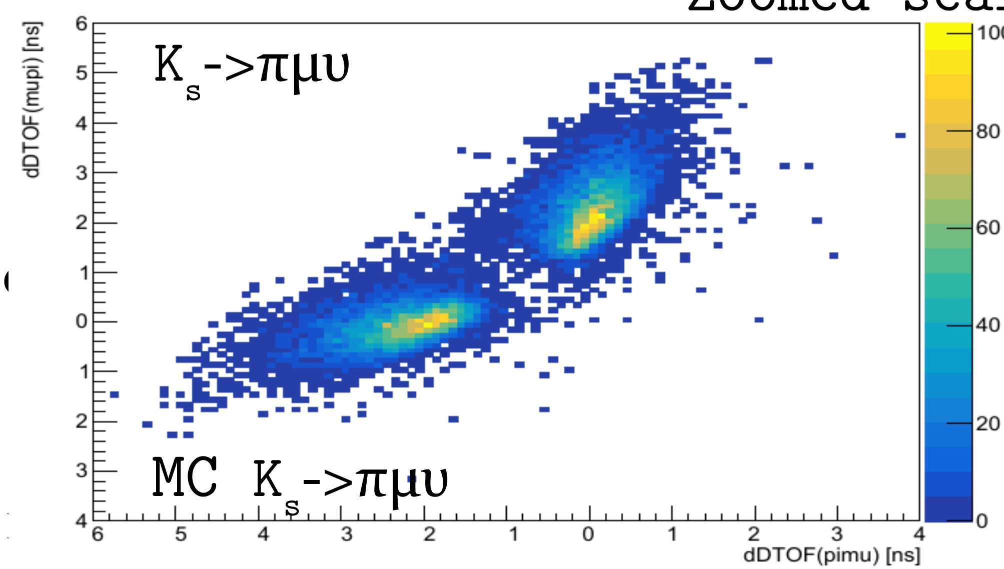




- For $K_s \to \pi \mu \nu$, both dDTOF($\pi\mu$) and dDTOF($\mu\pi$) are tested

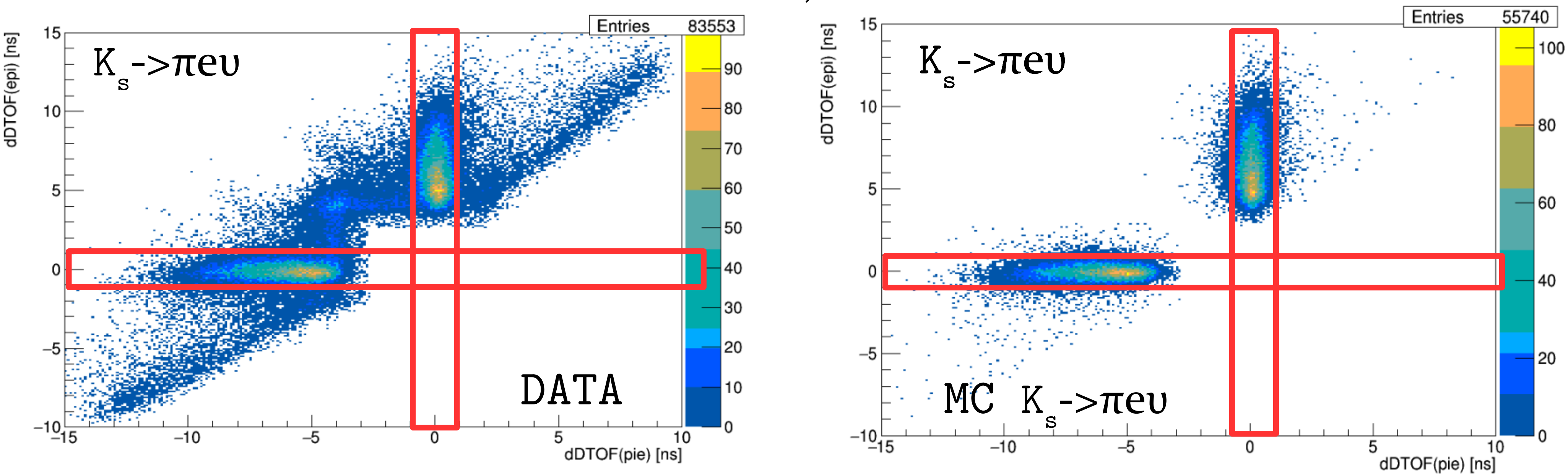


Zoomed scale

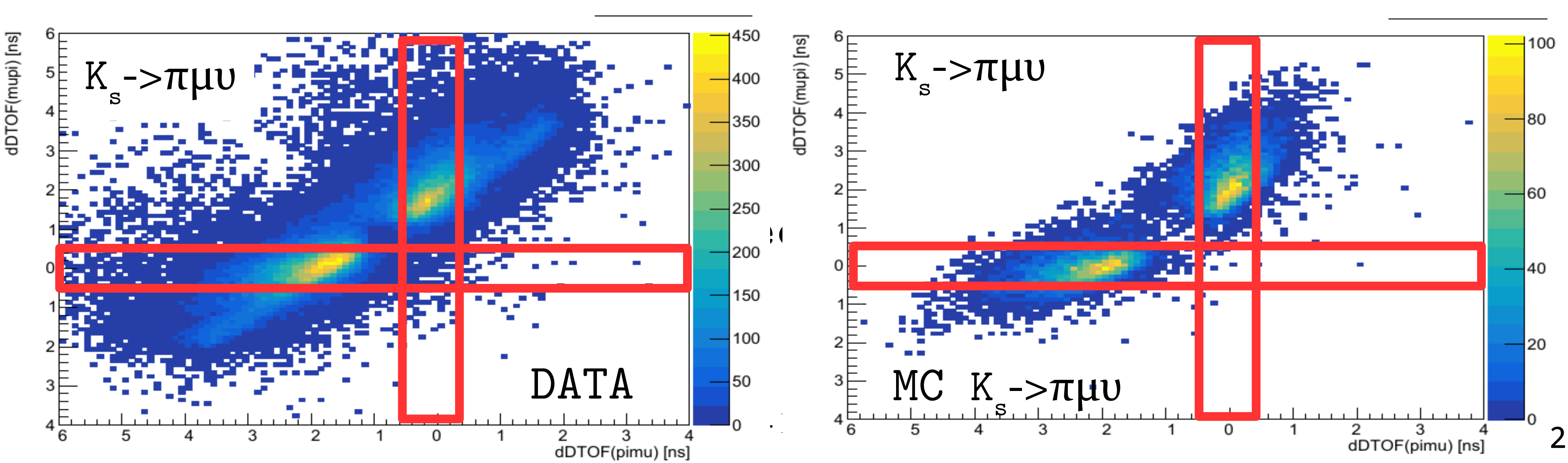


$K_S \to \pi l \upsilon$ dDTOF(πl) SELECTION

- |dDTOF(πe)|<1 ns or |dDTOF(eπ)|<1 ns



- |dDTOF($\pi\mu$)|<0.5 ns or |dDTOF($\mu\pi$)| <0.5 ns



$K_\ell \to \pi \ell \nu$ - ANALYSIS SCHEME

- $K_s \to \pi \ell \nu$ selection from background (mainly $\pi^+\pi^-$)
  - Preselection:
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  - Fit on M^2 to extract $N_{\pi \ell \nu}$
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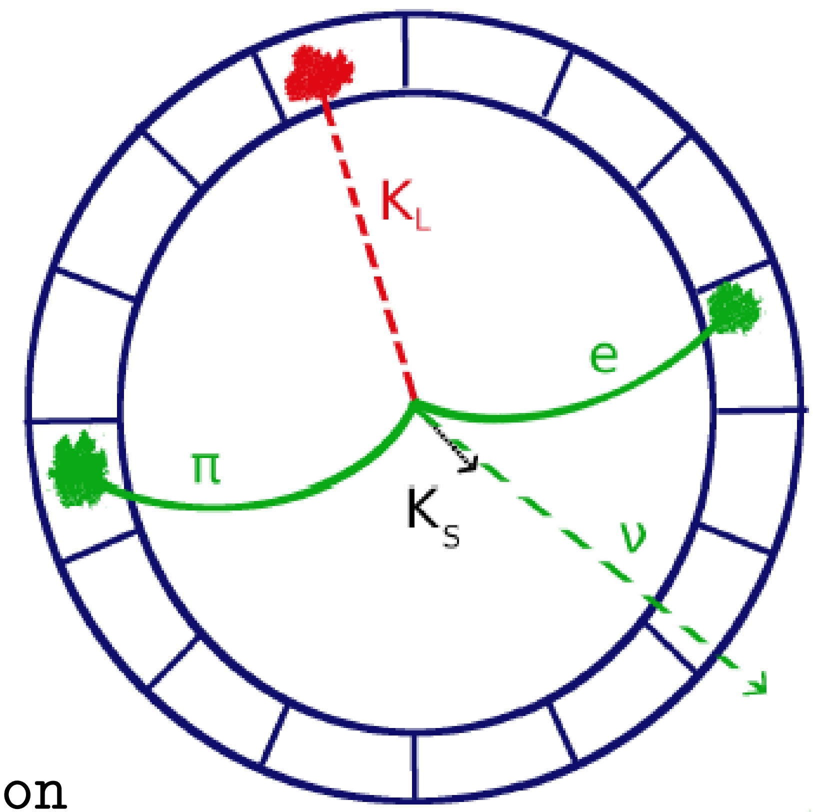
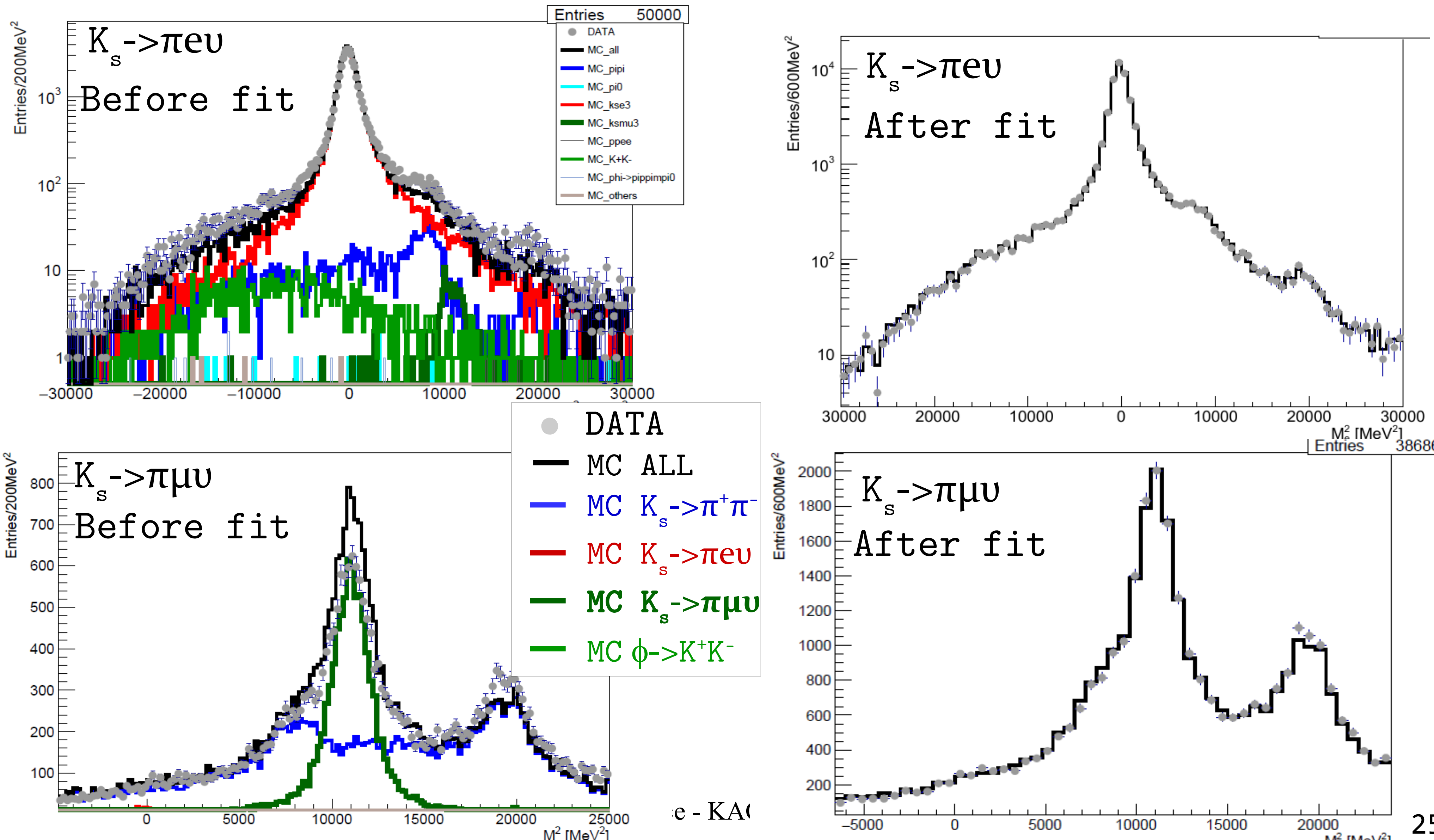
  - Purity > 95% after unbiased selection



$K_S \rightarrow \pi \ell \nu$ M^2 DISTRIBUTION & FIT

- Fit DATA invariant mass distribution with MC shapes to extract signal counts $M^2_\ell = (E_{Kstag} - E_\pi - p_{mis})^2 - p^2_\ell$



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$K_S \to \pi \ell \upsilon$ M^2 DISTRIBUTION & FIT

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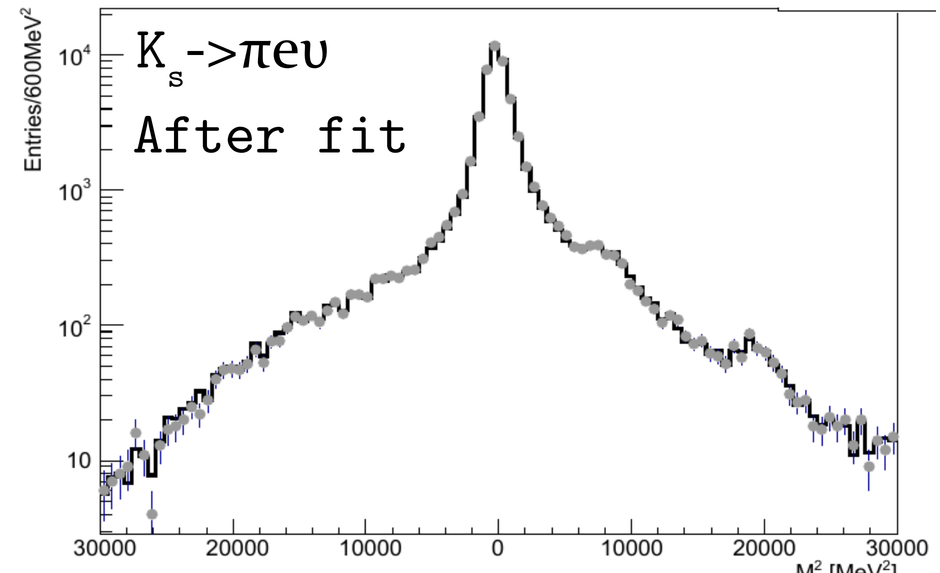
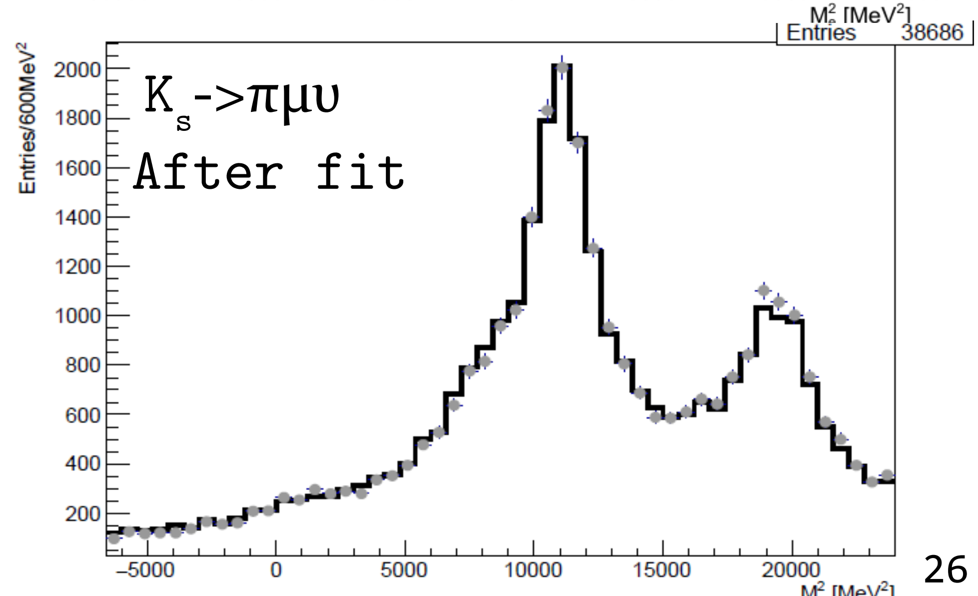
- $K_s \to \pi e \upsilon$

	fraction	events	relative error [%]
$\pi e \nu$	0.8652	49 652 ± 351	0.71
$\pi^+\pi^-$	0.0758	4 350 ± 392	9.00
all others	0.0590	3 388 ± 384	11.33
Total		57 389	



- $K_s \to \pi \mu \upsilon$

	fraction	events	relative error [%]
$\pi \mu \nu$	0.23	7 223 ± 180	2.49
$\pi^+\pi^-$	0.77	23 764 ± 270	1.13
Total		30 987	
ndf	48		
χ^2/ndf	1.29		



$K_S \to \pi \ell \upsilon$ M^2 DISTRIBUTION & FIT

- Fit DATA invariant mass distribution with MC shapes to extract signal counts $M^2_\ell = (E_{Kstag} - E_\pi - p_{mis})^2 - p^2_\ell$

- $K_s \to \pi e \upsilon$
- Finalization of the BR($K_s \to \pi e \upsilon$) measurement is ongoing
  - Very preliminary total uncertainties < 1%

NDF=48

$K_S \to \pi \ell \nu$ M^2 DISTRIBUTION & FIT

- Fit DATA invariant mass distribution with MC shapes to extract signal counts $M^2_\ell = (E_{Kstag} - E_\pi - p_{mis})^2 - p^2_\ell$

- $K_s \to \pi e \nu$
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- $K_s \to \pi \mu \nu$
- Preliminary result on BR($K_s \to \pi \mu \nu$) measurement

$K_S \to \pi \ell \upsilon$ M^2 DISTRIBUTION & FIT

- Fit DATA invariant mass distribution with MC shapes to extract signal counts $M^2_\ell = (E_{Kstag} - E_\pi - p_{mis})^2 - p^2_\ell$

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- $K_s \to \pi \mu \upsilon$
- Preliminary result on BR($K_s \to \pi \mu \upsilon$) measurement
  - Main analysis efficiencies computed directly on data $K_L \to \pi \mu \upsilon$ sample with purity > 95%
    - Total analysis efficiency $\epsilon_{\pi\mu\upsilon} = (5.50 \pm 0.16)\%$

$K_S \to \pi \ell \nu$ M^2 DISTRIBUTION & FIT

- Fit DATA invariant mass distribution with MC shapes to extract signal counts $M^2_\ell = (E_{Kstag} - E_\pi - p_{mis})^2 - p^2_\ell$

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- Preliminary result on BR($K_s \to \pi \mu \nu$) measurement
  - Main analysis efficiencies computed directly on data $K_L \to \pi \mu \nu$ sample with purity > 95%
    - Total analysis efficiency $\epsilon_{\pi\mu\nu} = (5.50 \pm 0.16)\%$
  - Total systematic error 3.5%
    - Mainly due to dDTOF($\pi\pi$) cut variation in a ~3σ interval

$BR(K_S \to \pi\mu\upsilon)$ PRELIMINARY RESULT

$$BR(K_S \to \pi\mu\nu) = \frac{N_{\pi\mu\nu}}{\epsilon_{\pi\mu\nu}} \times \frac{\epsilon_{\pi^+\pi^-}}{N_{\pi^+\pi^-}} \times R_\epsilon \times BR(K_S \to \pi^+\pi^-)$$

- with 1.63 fb^{-1}, $N_{\pi\mu\upsilon}$ = 7223 ± 180, $\epsilon_{\pi\mu\upsilon}$=(5.50 ± 0.16)%
- $N_{\pi\pi}/\epsilon_{\pi\pi}$=(292.10 ± 0.26) × 10^6 events
- R_ϵ = 1.472 ± 0.003
- $BR(K_s \to \pi^+\pi^-)$=0.69196±0.00051 (KLOE, PLB 636 (2006) 173)

- PRELIMINARY RESULT:

$BR(K_s \to \pi\mu\upsilon)$= (4.57 ± 0.11 stat ± 0.16 sys) × 10^{-4}

with 2.5 % stat ± 3.5 % sys uncertainties

BR($K_S \to \pi\mu\nu$) PRELIMINARY RESULT

$$BR(K_S \to \pi\mu\nu) = \frac{N_{\pi\mu\nu}}{\epsilon_{\pi\mu\nu}} \times \frac{\epsilon_{\pi^+\pi^-}}{N_{\pi^+\pi^-}} \times R_\epsilon \times BR(K_S \to \pi^+\pi^-)$$

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BR($K_s \to \pi\mu\nu$) = (4.57 ± 0.11 stat ± 0.16 sys) × 10^{-4}

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- Assuming Lepton Universality, BR($K_s \to \pi e\nu$), KTeV K_L phase space ratio [PRD 70 (2004) 092007] and long distance radiative correction [T.C.André, Ann. Phys. 332 (2007) 2518] the expected result is:

BR($K_s \to \pi\mu\nu$) = (4.69 ± 0.06) × 10^{-4}

BR($K_s \to \pi\mu\nu$) PRELIMINARY RESULT

$$BR(K_S \to \pi\mu\nu) = \frac{N_{\pi\mu\nu}}{\epsilon_{\pi\mu\nu}} \times \frac{\epsilon_{\pi^+\pi^-}}{N_{\pi^+\pi^-}} \times R_\epsilon \times BR(K_S \to \pi^+\pi^-)$$

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First preliminary measurement of BR($K_s \to \pi\mu\upsilon$)

- PR...

BR(... sys) × 10^{-4}

... 3.5 % sys uncertainties

- Assumi... Lepton Universality, BR($K_s \to \pi e\upsilon$), KTeV K_L phase space ratio [PRD 70 (2004) 092007] and long distance radiative correction [T.C.André, Ann. Phys. 332 (2007) 2518] the expected result is:

$$BR(K_s \to \pi\mu\upsilon) = (4.69 \pm 0.06) \times 10^{-4}$$

CONCLUSIONS

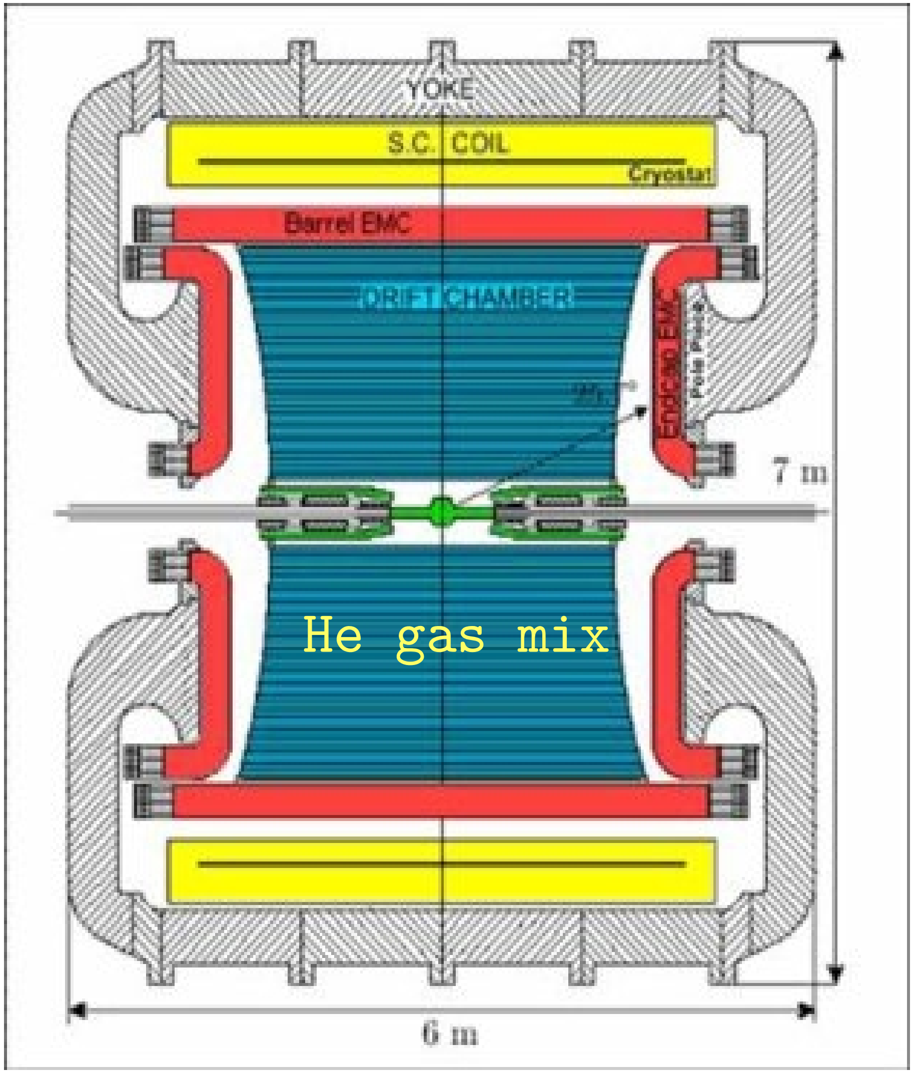
- KLOE-2 data-taking ended on 31th March 2018, collecting ~5 fb^{-1}
- KLOE+KLOE-2 data sample consist in $\int Ldt \sim 8\ fb^{-1}$ unique for typology and statistical relevance
- Analyses are ongoing on KLOE and KLOE-2 data
  - $BR(K_S \to \pi^o\pi^o\pi^o) < 2.6 \times 10^{-8}$ @90% CL on 1.63 fb^{-1} KLOE data
    - Measurement on KLOE-2 data is on going
  - First preliminary measurement of $BR(K_s \to \pi\mu\upsilon)$ on 1.63 fb^{-1}
    - $BR(K_s \to \pi\mu\upsilon) = (4.57 \pm 0.11\ stat \pm 0.16\ sys) \times 10^{-4}$
    - 2.5 % stat ± 3.5 % sys
  - Finalization of the $BR(K_s \to \pi e \upsilon)$ measurement in ongoing
    - Very preliminary total uncertainties < 1%

THANK YOU FOR YOUR ATTENTION

SPARES

KLOE DETECTOR - DC

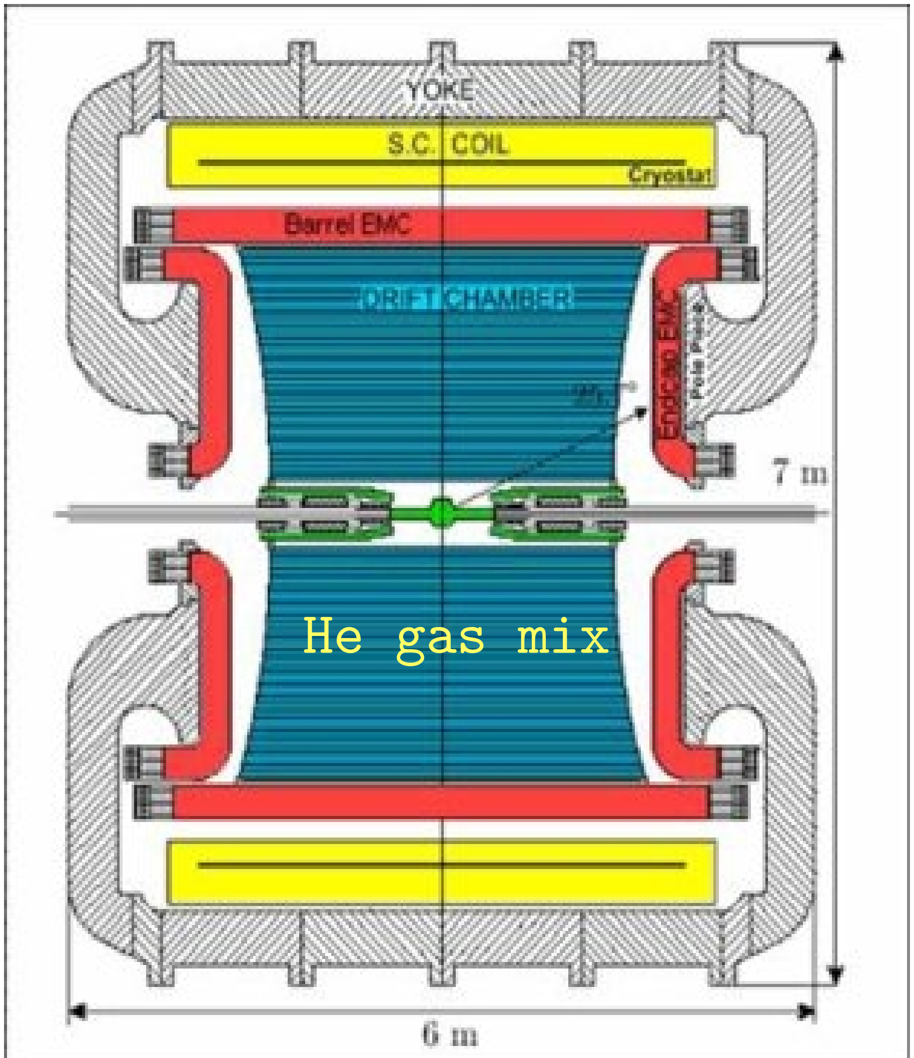
Superconducting coil, B = 0.52 T

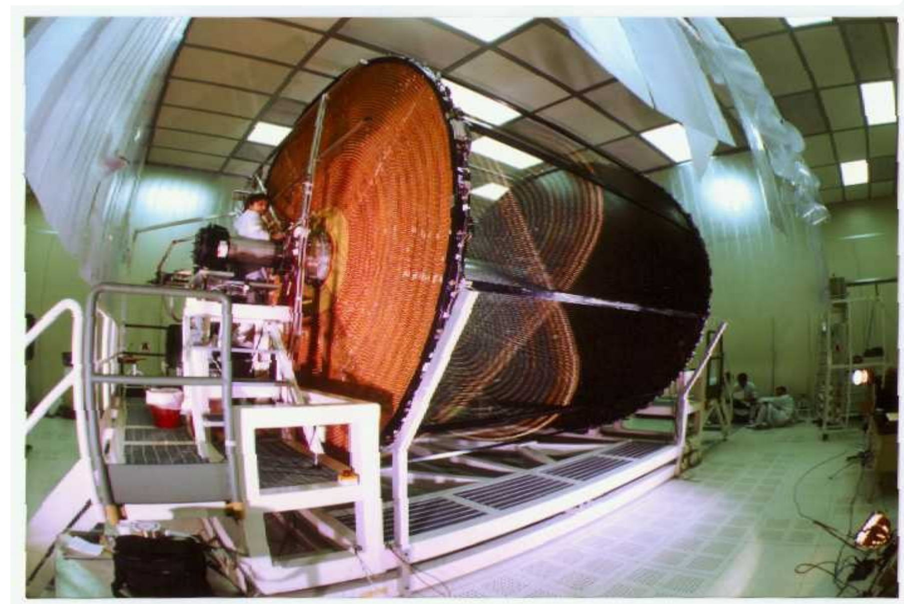


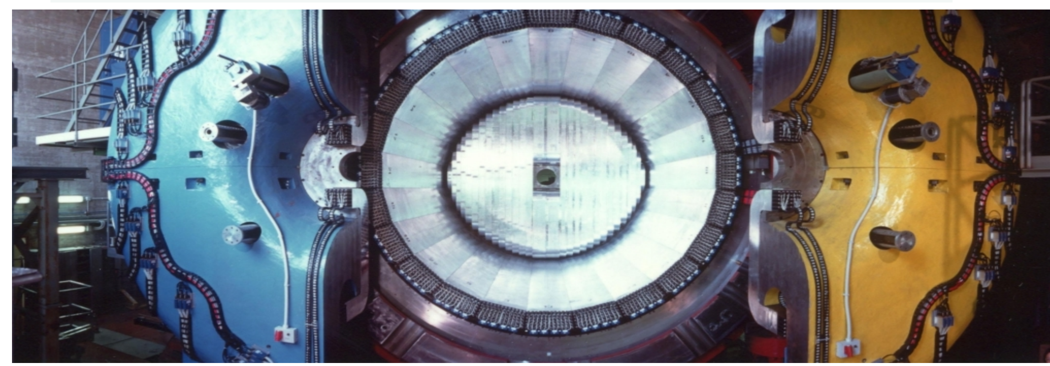
- Full stereo geometry
- 4m diameter
- 52140 total wires
- $\sigma_p/p = 0.4\%$ (for $45^0 < \vartheta < 135^0$ tracks)
- $\sigma_{x,y} \approx 150\ \mu m$, $\sigma_z \approx 2$ mm

KLOE DETECTOR - EMC

Superconducting coil, B = 0.52 T

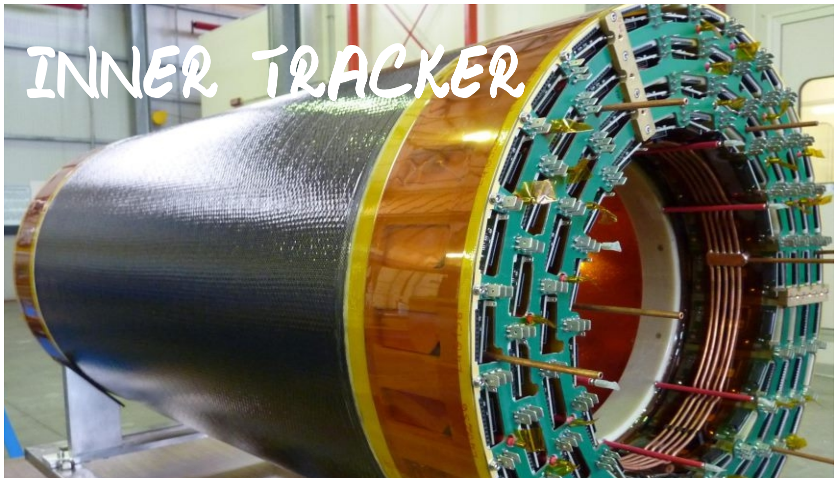


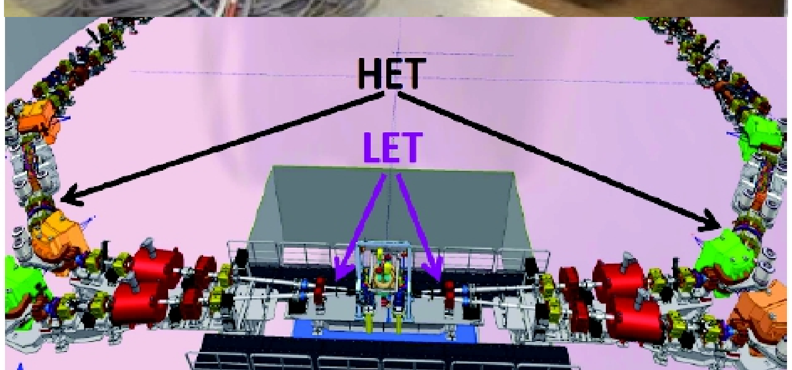




- Pb-SciFi Calorimeter
- 15 X0 depth, 98% solid angle
- $\sigma_E/E = 5.7\% / \sqrt{E(\mathrm{GeV})}$
- $\sigma_T = 54 \text{ ps} / \sqrt{E(\mathrm{GeV})} \oplus 100 \text{ ps}$

KLOE-2 NEW DETECTORS





IMPROVE VERTEX AND TRACKING CLOSE TO IP

INNER TRACKER

- 4 layers of cylindrical triple GEM tracker

INCREASE CALORIMETER HERMETICITY

QCALT

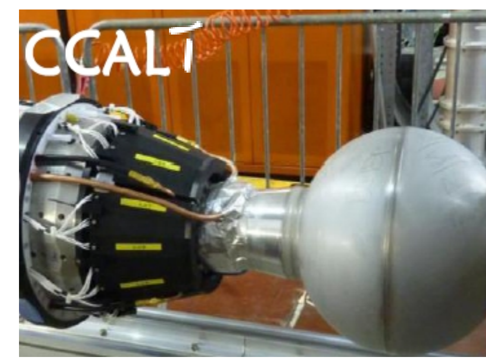
W + Scint. + WLS&SiPMs

- 'Low-beta' quadrupole coverage

CCALT

LYSO+APDs

- Better photon/electron acceptance (20°-->10°)



LET&HET

LYSO+SiPMs&Scint+PMTs

- e^+/e^- taggers for $\gamma\gamma$ physics

$K_S \to \pi \ell \nu$ - MOTIVATION

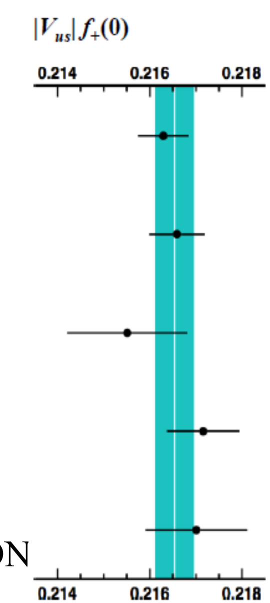
- Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix
- V_{ij} are fondamental parameters of the Standard Model of particle interactions

$$V_{\rm CKM} = \begin{pmatrix} V_{\rm ud} & V_{\rm us} & V_{\rm ub} \\ V_{\rm cd} & V_{\rm cs} & V_{\rm cb} \\ V_{\rm td} & V_{\rm ts} & V_{\rm tb} \end{pmatrix}$$

- V_{us} matrix element is best measured from Kaon meson semileptonic decays

$$\Gamma_{K\ell 3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW}(1+\delta_K^\ell + \delta_{SU2}) C^2 |V_{us}| f_+^2(0) I_K^\ell$$

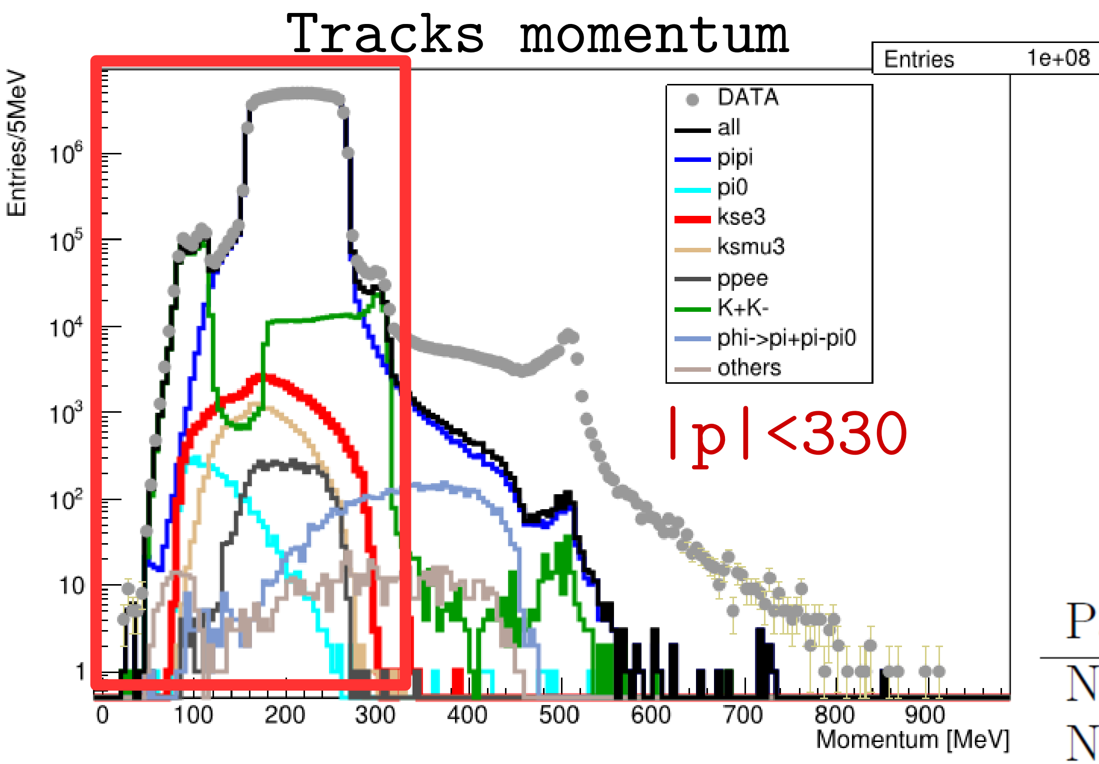
- S_{EW} is the short-distance radiative correction
- δ^ℓ_K (or Δ) is the mode-dependent long-distance radiative correction
- $f_+(0)$ is the form factor at zero momentum transfer to the $\ell\nu$ system
- C=1 is the isospin factor for neutral Kaon decay and
- I^ℓ_K is the phase-space integral.
- δ_{SU2} = 0 for the neutral kaons



		% err	Approx. contrib. to % err from: BR	τ	Δ	Int
K_Le3	0.2163(6)	0.26	0.09	0.20	0.11	0.05
$K_L\mu3$	0.2166(6)	0.28	0.15	0.18	0.11	0.06
K_Se3	0.2155(13)	0.61	0.60	0.02	0.11	0.05
$K^\pm e3$	0.2172(8)	0.36	0.27	0.06	0.23	0.05
$K^\pm\mu3$	0.2170(11)	0.51	0.45	0.06	0.23	0.06

E. Passemar, KAON2016

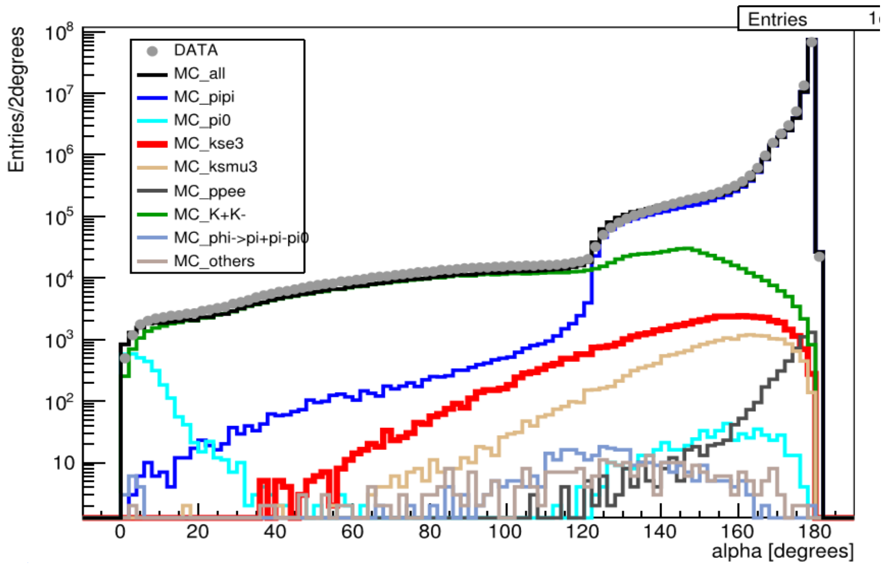
$K_S \to \pi l \nu$ BDT INPUT VARIABLES & PARAMETERS



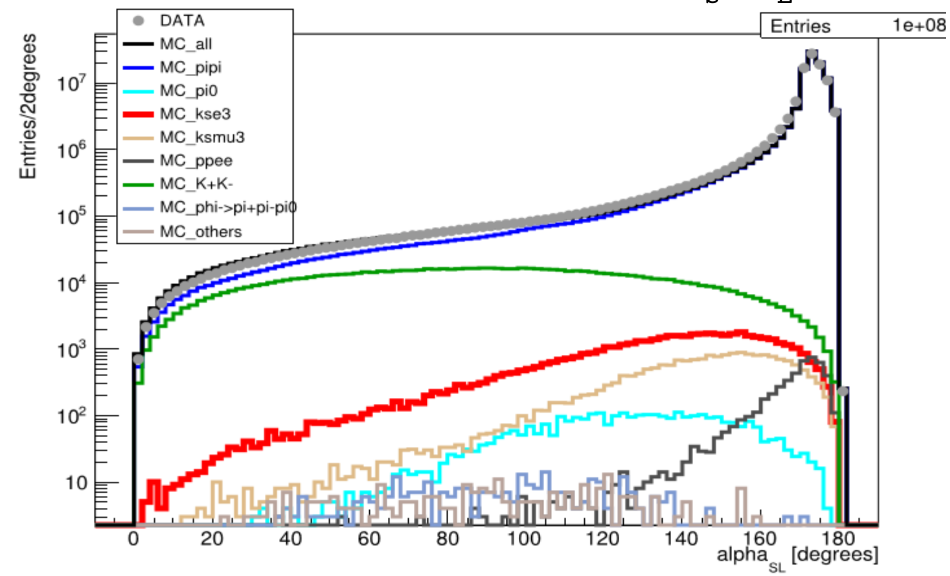
Parameter	value
N. of signal training events	5 000
N. of background training events	30 000
N. of signal test events	5 000
N. of background test events	30 000
Boost type	AdaBoost
AdaBoost β	0.5
N. of trees	850
Max tree depth	3
Min node size	2.5%
nCuts	20

$K_s \to \pi l \nu$ INPUT VARIABLES

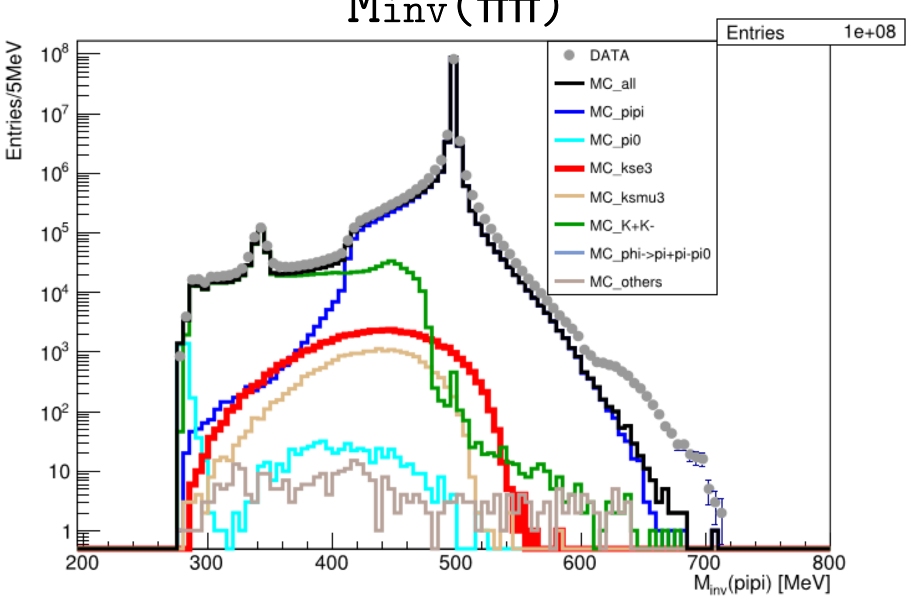
Angle between tracks from K_s



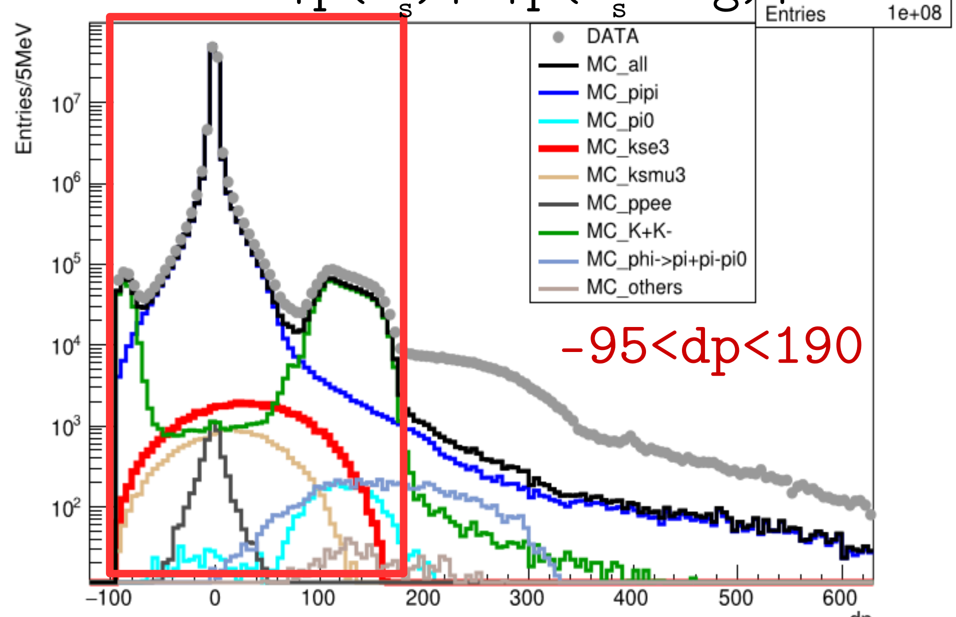
Angle between K_s-K_L



$M_{inv}(\pi\pi)$

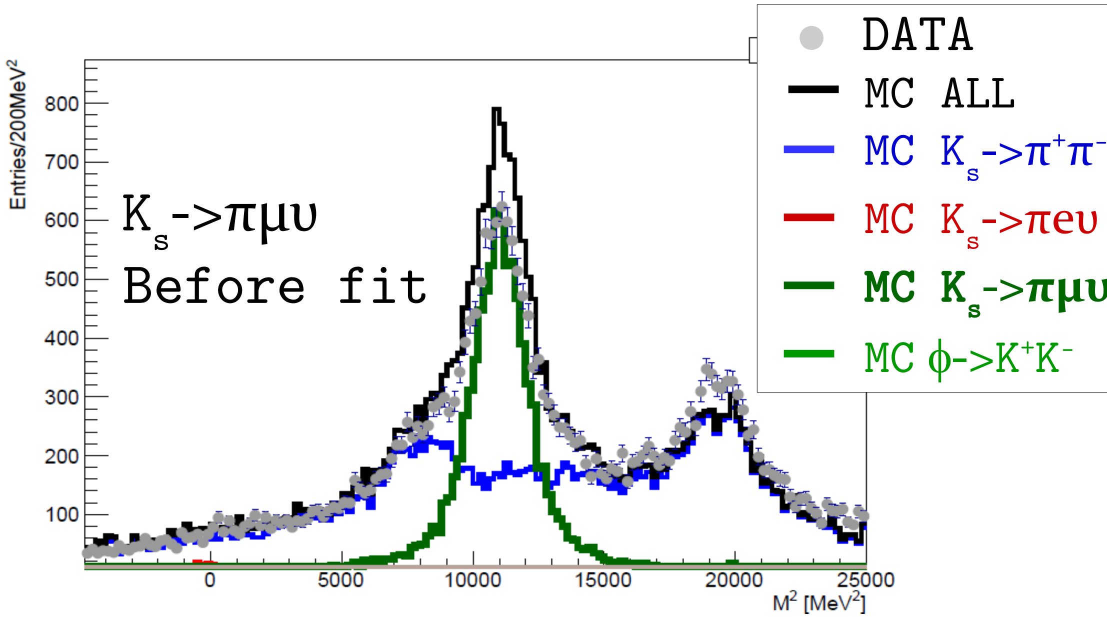


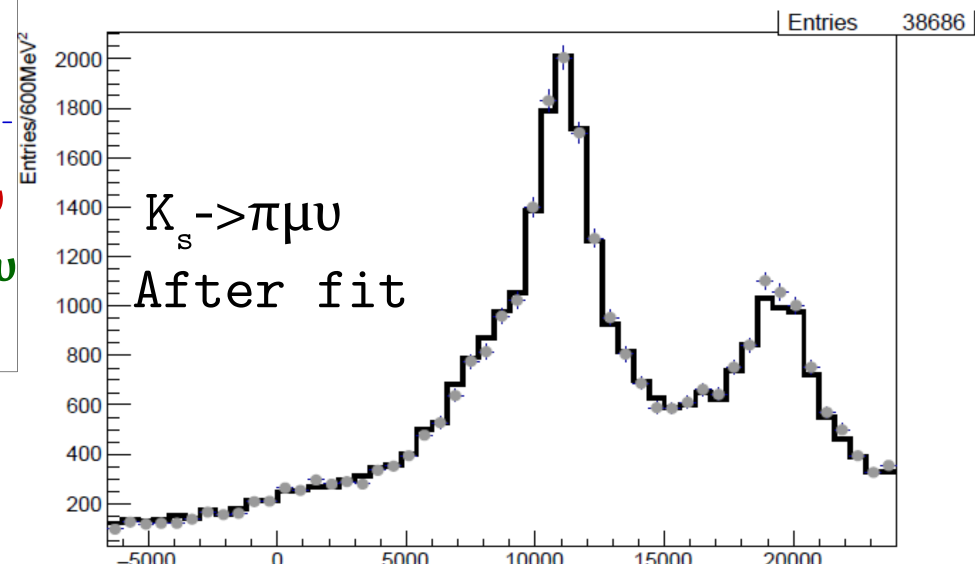
$|p(K_s)|-|p(K_s\text{-tag})|$

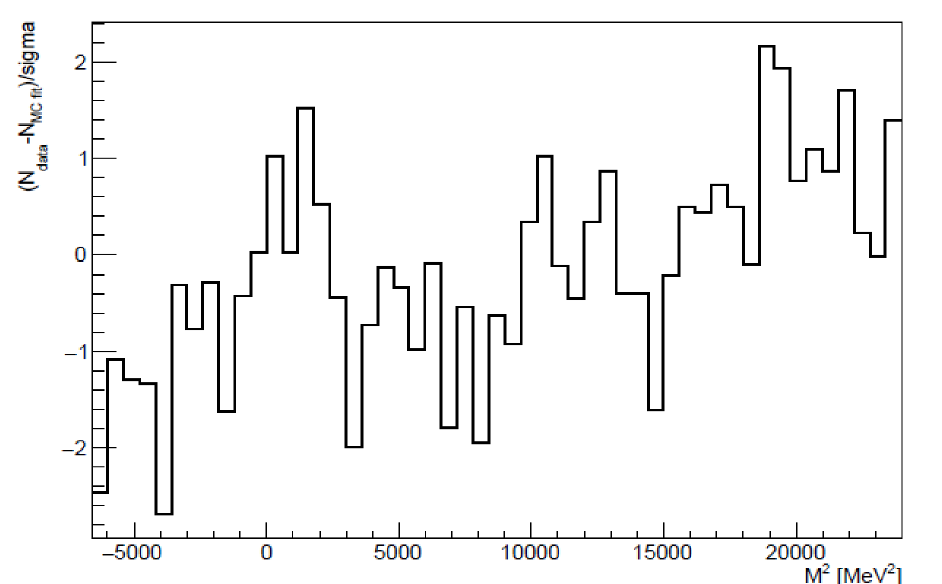


$K_S \to \pi \ell \upsilon$ M^2 DISTRIBUTION & FIT

- Fit DATA invariant mass distribution with MC shapes to extract signal counts $M^2_\ell = (E_{Kstag} - E_\pi - p_{mis})^2 - p^2_\ell$







	fraction	events	relative error [%]
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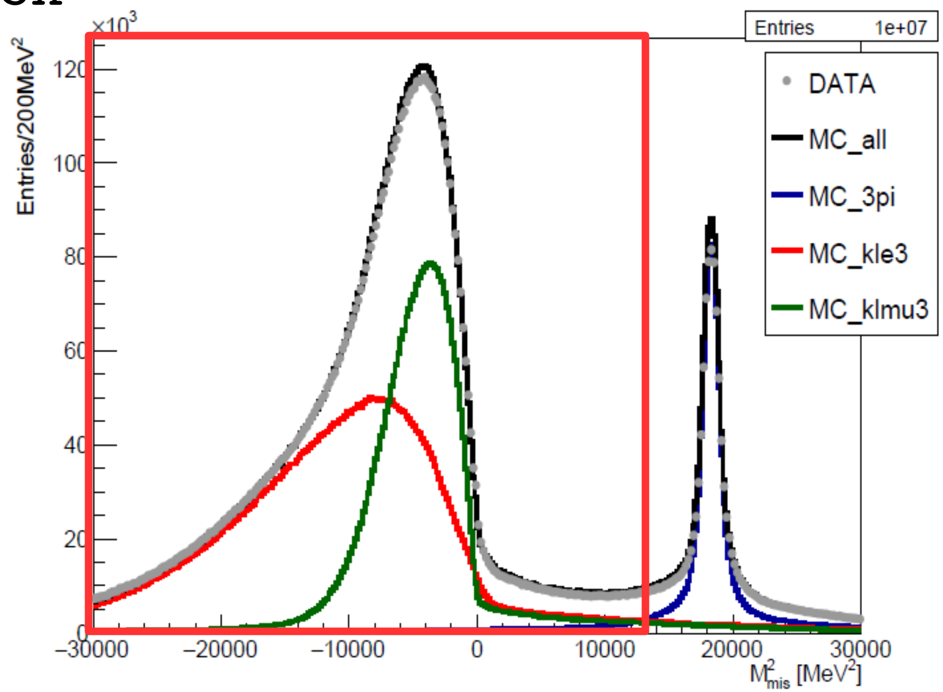
Total		30 987	
ndf	48		
χ^2/ndf	1.29		

$K_L \to \pi \ell \nu$ CONTROL SAMPLE

- Same kinematic of $K_S \to \pi \ell \nu$ if vertex close to the Interaction Point
- Same preselection as for $K_S \to \pi \ell \nu$
- To compute:
  - ϵ_{preMVA}, ϵ_{BDT}
  - ϵ_{TCA}, ϵ_{DTOF}
- Selection to increase purity
  - $K_L \to 3\pi^0$ rejection: vertex request
  - $K_L \to \pi^+\pi^-\pi^0$ rejection: loose cut on M^2_{mis}<15000
  - More difficult to avoid the other semileptonic decay



$K_L \to \pi \ell \nu$ CONTROL SAMPLE

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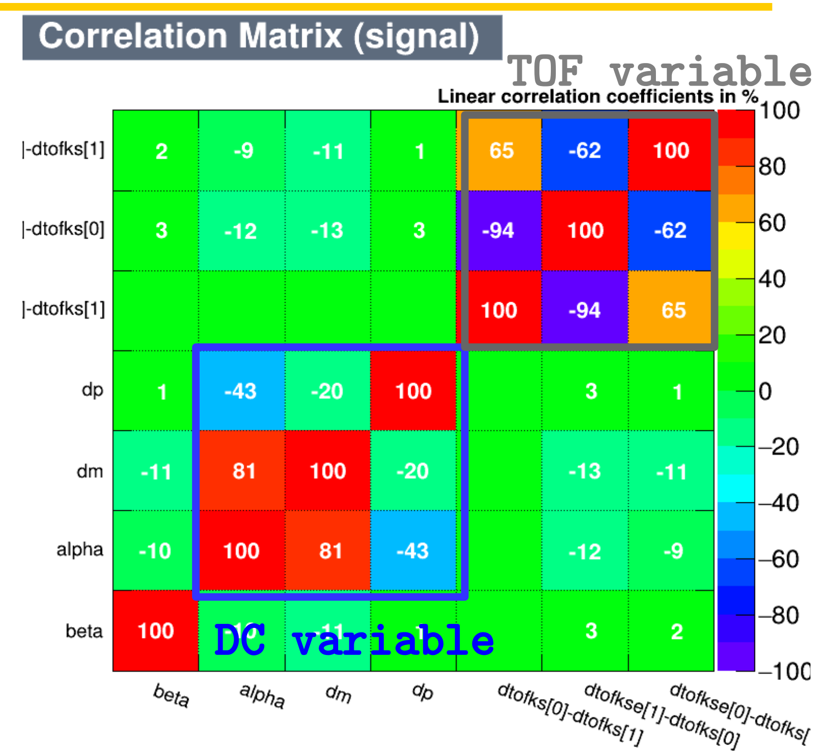
  - ϵ_{preMVA}, ϵ_{BDT}
  - ϵ_{TCA}, ϵ_{DTOF}



- Selection to increase purity

  - Cutting on variable not correlated with the selection we want to compute efficiency on

    - ϵ_{preMVA} and ϵ_{BDT}: cut on TOF variable

      PURITY= 95-97%

    - ϵ_{TCA} and ϵ_{DTOF}: cut on DC variable

$K_S \to \pi^o\pi^o\pi^o$

- Direct search for the pure CP violating decay
  - Standard Model expectation $BR(K_s \to \pi^o\pi^o\pi^o) = 1.9 \times 10^{-9}$
- Best upper limit is from KLOE
  - $BR(K_s \to \pi^o\pi^o\pi^o) < 2.6 \times 10^{-8}$ @90% CL with 1.7 fb^{-1} [PLB 723 (2013) 54]
- ANALYSIS SCHEME:
  - K_L-crash E_{crash}>150MeV, $0.20<\beta<0.225$
  - $K_s \to \pi^o\pi^o$ (main background) used as normalization
  - SIGNAL/BACKGROUND DISCRIMINATION:
    - Kinematic fit
    - Comparing signal 6γ (signal) and 4γ hypothesis (background)
    - Cut on distance between clusters to reduce cluster splitting