Status of KLOE-2

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on behalf of the KLOE-2 collaboration

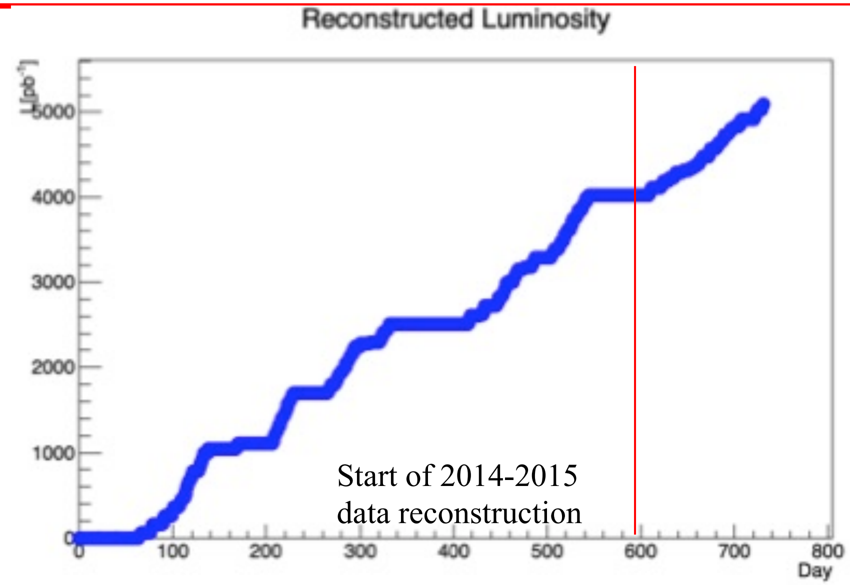
63rd LNF Scientific Committee meeting
Frascati, May 16th 2022

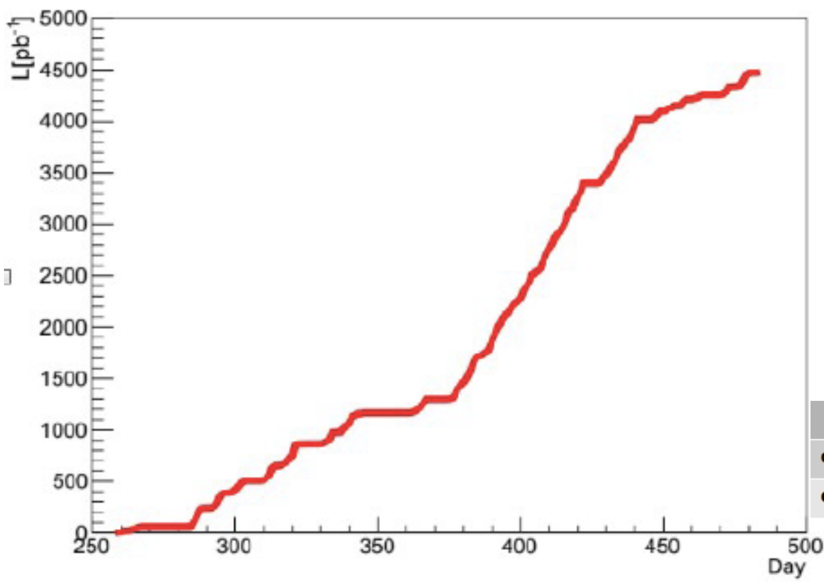
Status of data reconstruction and MC production

The **reconstruction of KLOE-2** data (L_{int} = 5.1 fb^{-1}) with DBV-40 has been **completed**

4.7 fb^{-1} of good quality data available for analysis!

ROOT output production continues : about 2 fb^{-1} already available





MC production almost finished

Final sample size checks are being performed

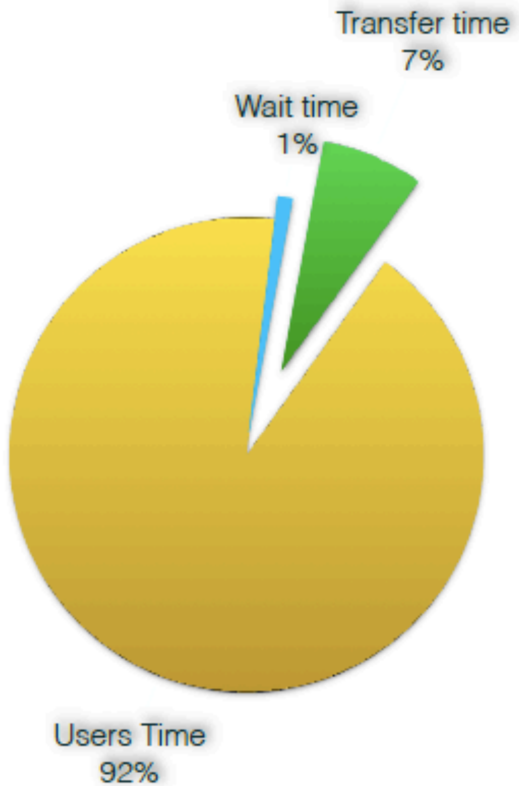
Luminosity produced: 4.5 fb^{-1}, ALL_PHYS card with LSF=1

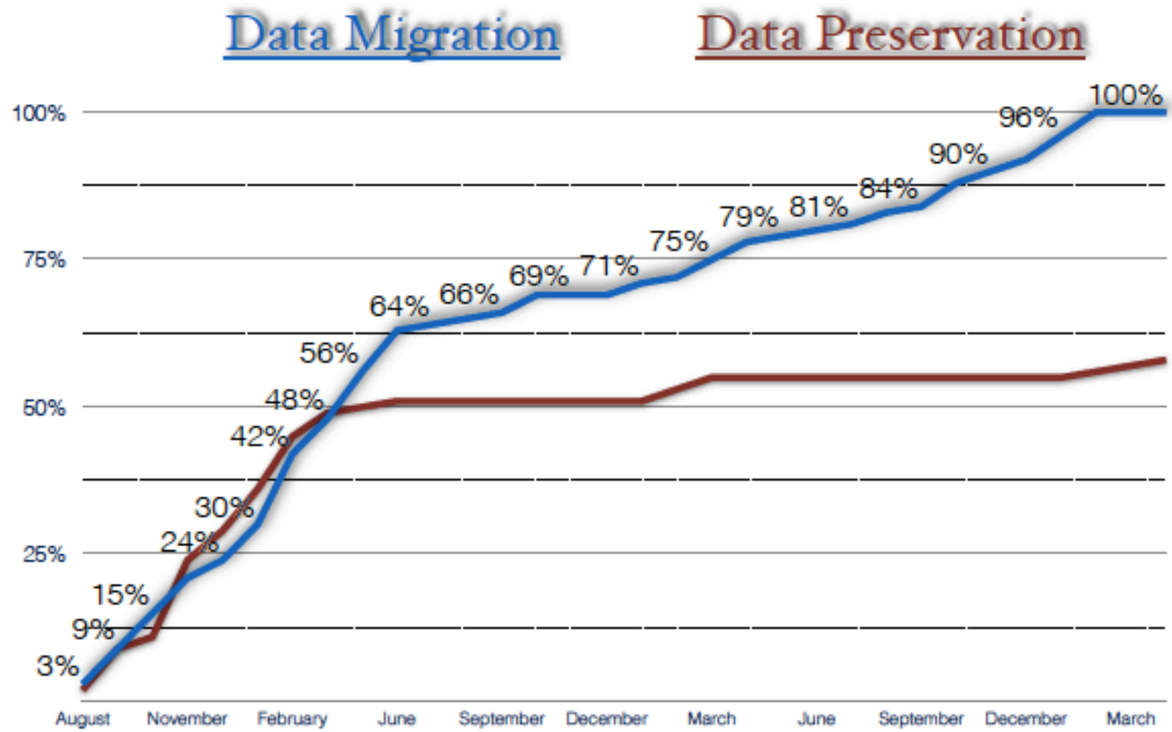
0.2 fb^{-1} can be recovered, in progress

0.4 fb^{-1} not recoverable (partially reconstructed runs)

process	card	Run nr	DCIW (cm)	LSF	L(pb^{-1})
$\varphi \to$ all	all_phys	72649-95093	0.59	1.	4481
e+e- $\to \gamma\gamma$	gg04	80231-85980	0.59	1.	101.6

DATA CONSOLIDATION





The data moving from old library to the new one is over so we restarted the disaster recovery copy (data preservation)

Publications/Ongoing Analysis

Last Publications	
Precision tests of quantum mechanics and CPT symmetry with entangled neutral kaons at KLOE	JHEP 04 (2022) 059
$\eta \to \pi^+\pi^-$ (P and CP viol.)	JHEP 10 (2020) 047
Measurement of the branching fraction for the decay $K_S \to \pi\mu\nu$ with the KLOE detector	Physics Letters B 804 (2020)

Ongoing analyses	
T/CPT tests with $\phi \to K_S K_L \to 3\pi^0\ \pi e\nu,\ \pi\pi\ \pi e\nu$	KLOE data – final result blessed- draft in preparation
$K_S \to 3\pi^0$ (CP viol.)	KLOE-2 data
$K_S \to \pi e\nu$	KLOE-data- final result blessed- paper ready, will be submitted soon
Study of future post-tags the past in $K_S K_L \to 4\pi$	KLOE data-new quantum correlation effect
$\gamma\gamma \to \pi^0$	KLOE-2 data
$\eta \to \pi^0\gamma\gamma$ - χPT golden mode	KLOE / KLOE-2 data, blessing within May
B-boson search in $\phi \to \eta\pi^0\gamma,\ \eta \to \gamma\gamma$	KLOE/KLOE-2 data, close to final result
$e^+e^- \to \omega\ \gamma_{ISR}$	KLOE data - PhD Thesis
$\phi \to \eta\mu^+\mu^- / \eta\pi^+\pi^-$	KLOE data

$$\zeta_{0\bar{0}} = \left(-0.5 \pm 8.0_{stat} \pm 3.7_{syst}\right)\times 10^{-7}$$

Most precise test of quantum coherence in an entangled system

Published

JHEP

Published for SISSA by Springer

Received: November 9, 2021
Accepted: March 15, 2022
Published: April 8, 2022

Precision tests of quantum mechanics and *CPT* symmetry with entangled neutral kaons at KLOE

The KLOE-2 collaboration

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JHEP04(2022)059

Concept:

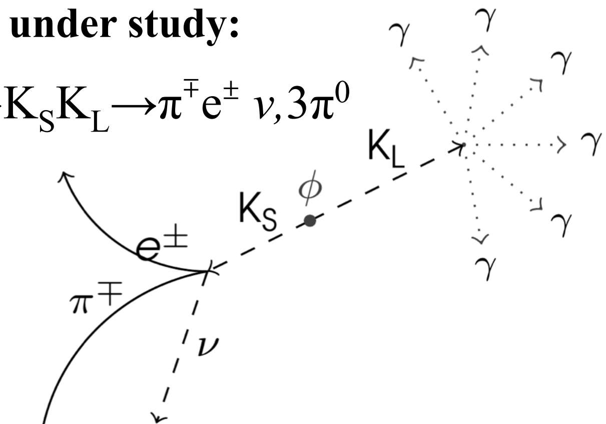
First such measurement with kaons

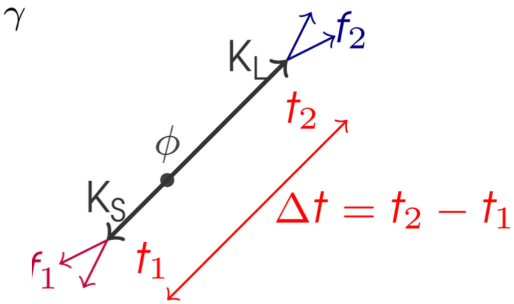
J. Bernabeu, A. Di Domenico and P. Villanueva-Perez,
Direct test of time-reversal symmetry in the entangled neutral kaon system at a Φ factory, Nucl. Phys. B 868 (2013) 102

J. Bernabeu, A. Di Domenico and P. Villanueva-Perez,
Probing CPT in transitions with entangled neutral kaons, JHEP 1510 (2015) 139

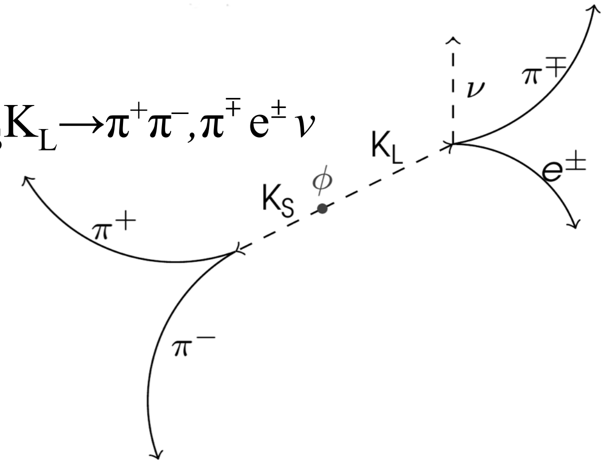
Processes under study:

$\Phi \to K_S K_L \to \pi^{\mp} e^{\pm} \nu, 3\pi^0$





$\Phi \to K_S K_L \to \pi^+\pi^-, \pi^{\mp} e^{\pm} \nu$



Observables of the tests (we focus on the asymptotic region $\Delta t \gg \tau_s$):

T-violation sensitive

$$R_2^T(\Delta t) = \frac{\mathrm{I}(\pi^+ e^- \overline{\nu}, 3\pi^0; \Delta t)}{\mathrm{I}(\pi^+\pi^-, \pi^- e^+ \nu; \Delta t)} \times \frac{1}{D}$$

$$R_4^T(\Delta t) = \frac{\mathrm{I}(\pi^- e^+ \nu, 3\pi^0; \Delta t)}{\mathrm{I}(\pi^+\pi^-, \pi^+ e^- \overline{\nu}; \Delta t)} \times \frac{1}{D}$$

CPT-violation sensitive

$$R_2^{CPT}(\Delta t) = \frac{\mathrm{I}(\pi^+ e^- \overline{\nu}, 3\pi^0; \Delta t)}{\mathrm{I}(\pi^+\pi^-, \pi^+ e^- \overline{\nu}; \Delta t)} \times \frac{1}{D}$$

$$R_4^{CPT}(\Delta t) = \frac{\mathrm{I}(\pi^- e^+ \nu, 3\pi^0; \Delta t)}{\mathrm{I}(\pi^+\pi^-, \pi^- e^+ \nu; \Delta t)} \times \frac{1}{D}$$

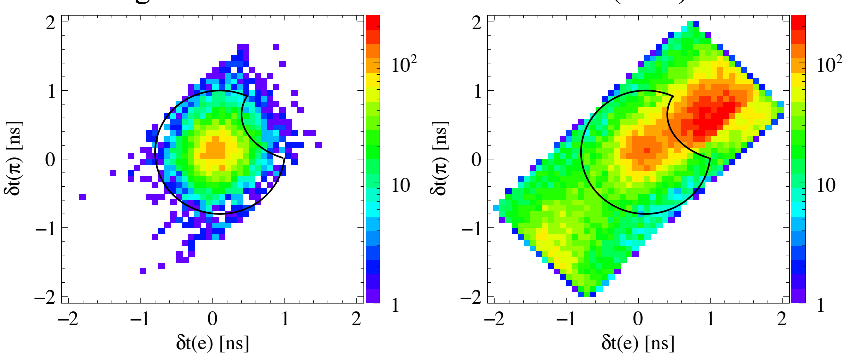
Double ratios:

$$\frac{R_2^T}{R_4^T}(\Delta t) = \frac{I(3\pi^0, e^-)}{I(3\pi^0, e^+)} \frac{I(\pi^+\pi^-, e^-)}{I(\pi^+\pi^-, e^+)}$$

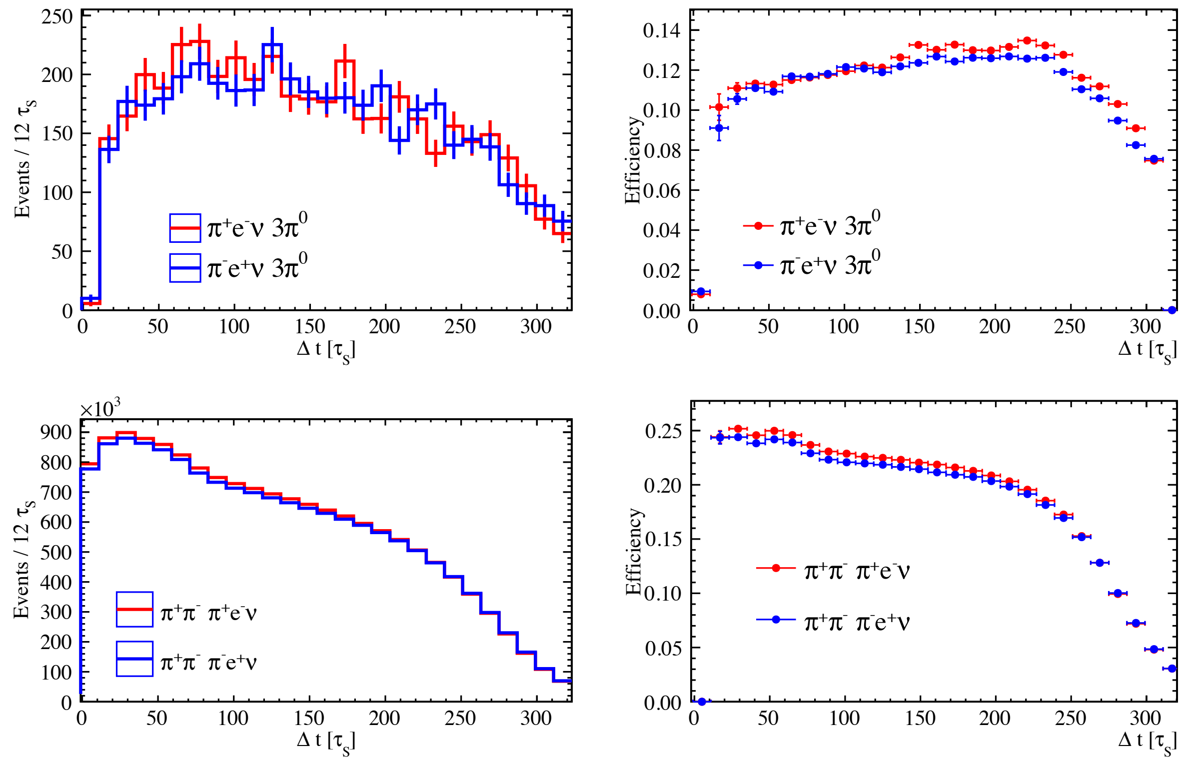
$$\frac{R_2^{CPT}}{R_4^{CPT}}(\Delta t) = \frac{I(3\pi^0, e^-)}{I(3\pi^0, e^+)} \frac{I(\pi^+\pi^-, e^+)}{I(\pi^+\pi^-, e^-)}$$

T/CPT Tests with $\phi \to K_S K_L \to 3\pi^0 \pi\nu e, \pi\pi\, \pi\nu e$

- Analyzed data L=1.7 fb^{-1}
- Four processes studied: $\phi \to K_S K_L \to \pi e^{\pm}\nu\, 3\pi^0$ and $\pi^+\pi^-\, \pi e^{\pm}\nu$ in the asymptotic regime: $\Delta t \gg \tau_S$
- Time of flight technique to identify semileptonic decays



Measured double kaon decay intensities

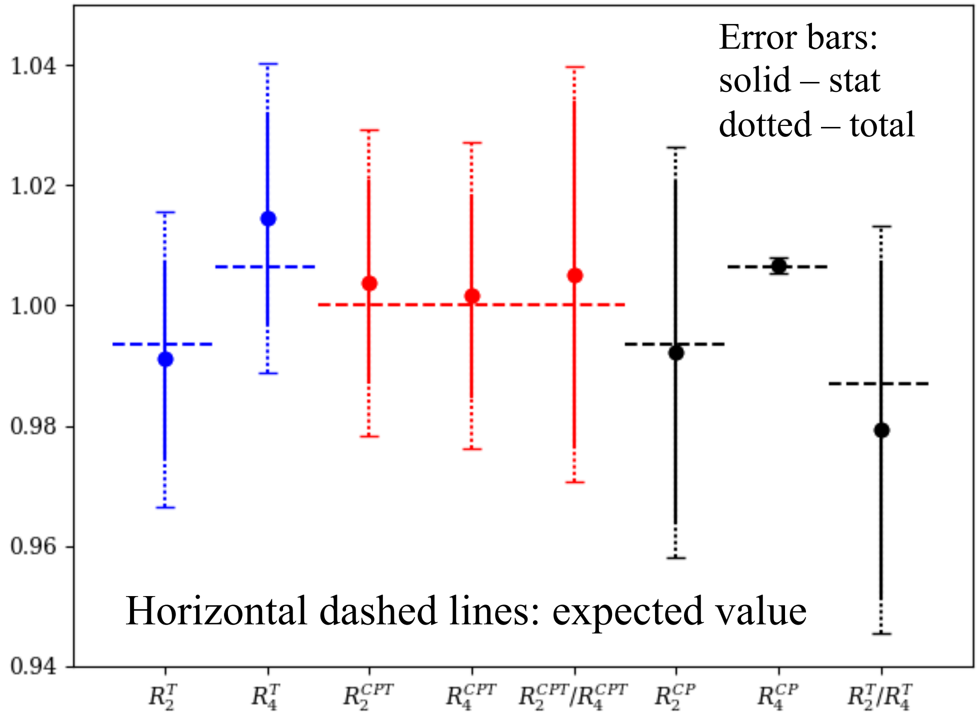


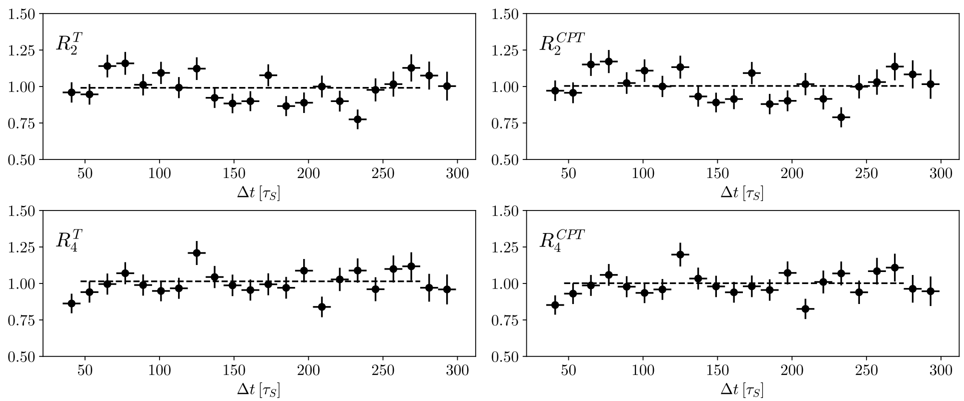
- residual background subtraction for $\pi e^{\pm}\nu\, 3\pi^0$ channel
- MC selection efficiencies corrected from data with 4 independent control samples

$K_S K_L \to \pi e^{\pm}\nu\, 3\pi^0$ → $K_S \to \pi e\nu$ Klcrash ; $K_S K_L \to \pi^+\pi^-\, 3\pi^0$

$K_S K_L \to \pi^+\pi^-\, \pi e^{\pm}\nu$ → $K_S \to \pi^+\pi^-$-Klcrash ; $K_S K_L \to \pi^0\pi^0\, \pi e\nu$

T/CPT Tests with $\phi \to K_S K_L \to 3\pi^0 \pi \nu e, \pi\pi\, \pi \nu e$



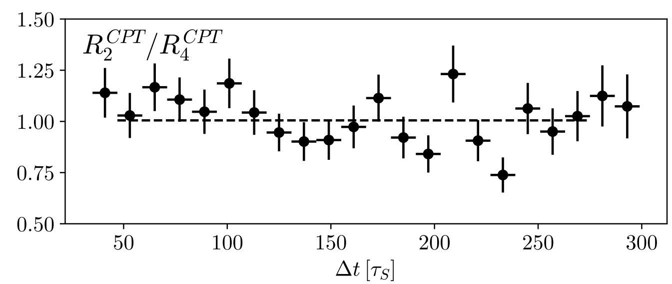


KLOE-2 result (2022)

(paper in preparation)

$$R_2^T = 0.991 \pm 0.017_{stat} \pm 0.014_{syst} \pm 0.012_D,$$
$$R_4^T = 1.015 \pm 0.018_{stat} \pm 0.015_{syst} \pm 0.012_D,$$
$$R_2^{CPT} = 1.004 \pm 0.017_{stat} \pm 0.014_{syst} \pm 0.012_D,$$
$$R_4^{CPT} = 1.002 \pm 0.017_{stat} \pm 0.015_{syst} \pm 0.012_D,$$
$$R_2^{CP} = 0.992 \pm 0.028_{stat} \pm 0.019_{syst},$$
$$R_4^{CP} = 1.00665 \pm 0.00093_{stat} \pm 0.00089_{syst},$$
$$R_2^T/R_4^T = 0.979 \pm 0.028_{stat} \pm 0.019_{syst},$$
$$R_2^{CPT}/R_4^{CPT} = 1.005 \pm 0.029_{stat} \pm 0.019_{syst}.$$

$$D = \frac{\mathrm{BR}(\mathrm{K_L} \to 3\pi^0)\tau_S}{\mathrm{BR}(\mathrm{K_S} \to \pi\pi)\tau_L} = 0.5076(59) \times 10^{-3}$$ → from past KLOE measurements



First T and CPT test in kaon transitions

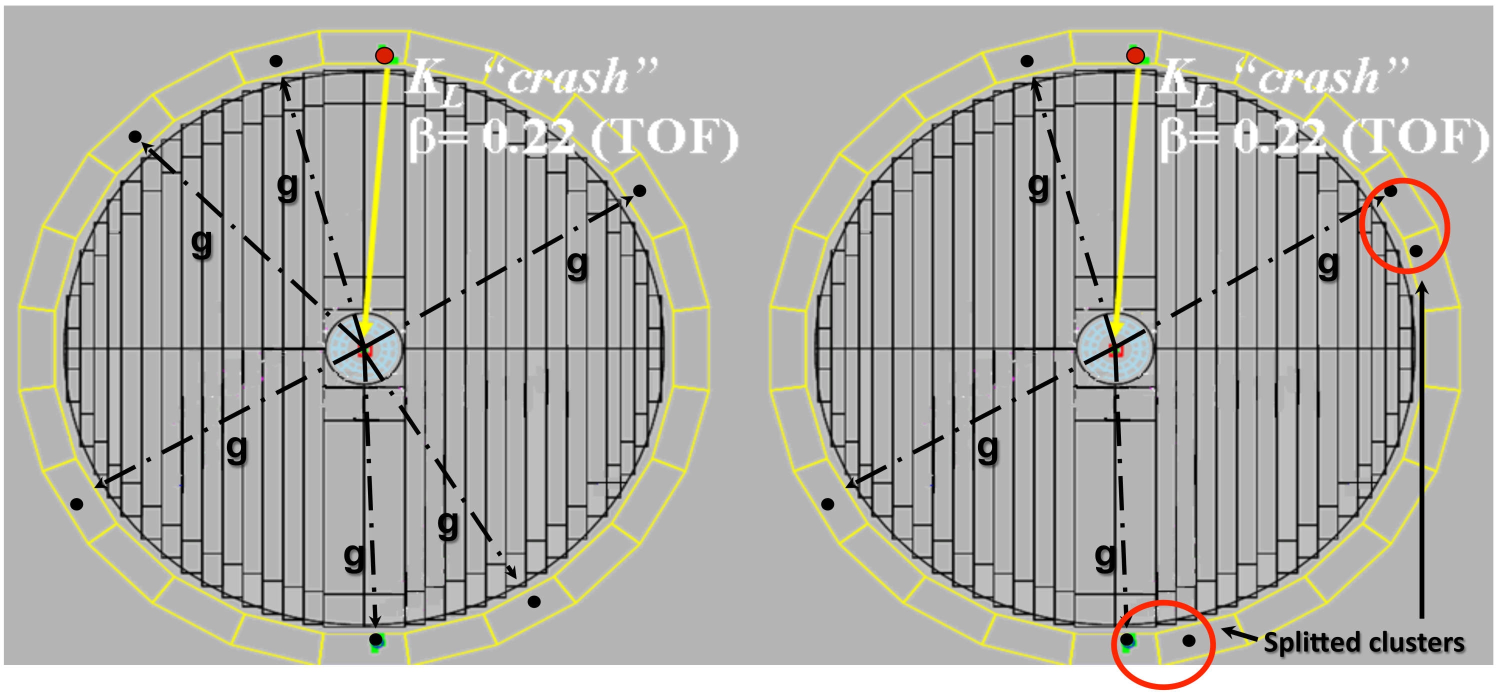
$3\pi^0$ is a pure CP=-1 state; observation of $K_S \to 3\pi^0$ is an unambiguous sign of CP violation in mixing and/or in decay.

Standard Model prediction: $BR(K_S \to 3\pi^0) = 1.9 \cdot 10^{-9}$ PLB 723 (2013) 54

Best upper limit by KLOE with 1.7 fb^{-1}

$BR(K_S \to 3\pi^0) < 2.6 \times 10^{-8}$ @ 90% CL

SIGNAL **BACKGROUND**



$K_S \to 3\pi^0 \to 6\gamma$

$K_S \to 2\pi^0$ + accidental/splitted clusters
$K_L \to 3\pi^0$, $K_S \to \pi^+ \pi^-$ („fake K_L crash")

Analysed data: 4 fb^{-1}, Datarec v38

MC simulations:

$K_S \rightarrow 3\pi^0$ signal: 1.7 fb^{-1}, Datarec v38, LSF = 10^6)

All backgrounds: ~4 fb^{-1}, Datarec v38, LSF=1)

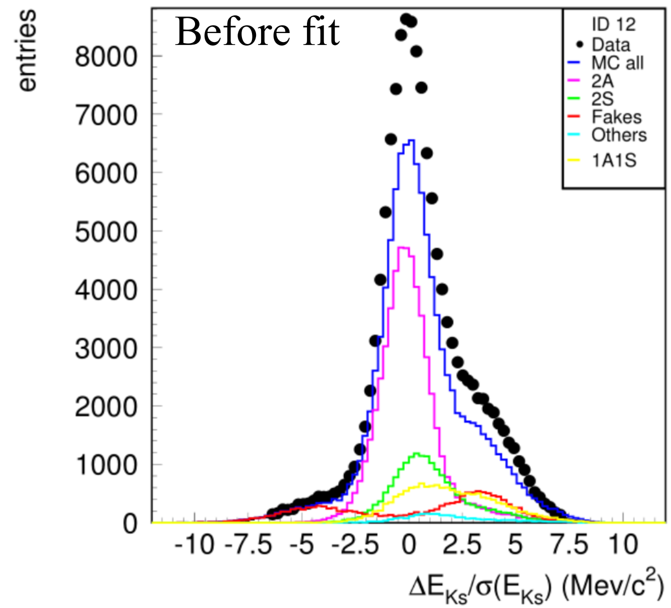
Preselection with the following requirements:

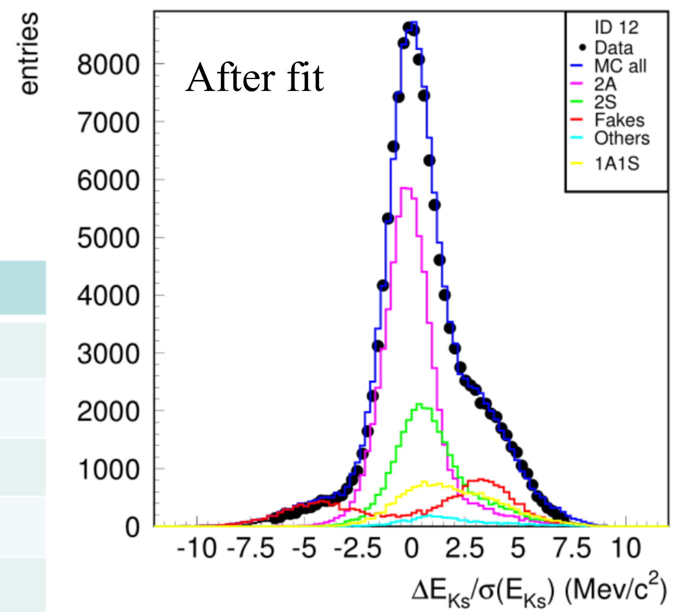
- K_L-crash: E>150 MeV, 0.2< β < 0.225
- prompt photons: E_{cl} > 20 MeV; $|\cos\theta_{cl}| \leq 0.915$ and $|\Delta T_{cl}| \leq \mathrm{Min}(3.0\cdot\sigma_T(E_{cl}),2\ \mathrm{ns})$

○ $K_S \rightarrow 2\pi^0$ (4 prompt photons) used for normalization

○ For each sample we apply cosmic veto and check ECLtag & FILFO words

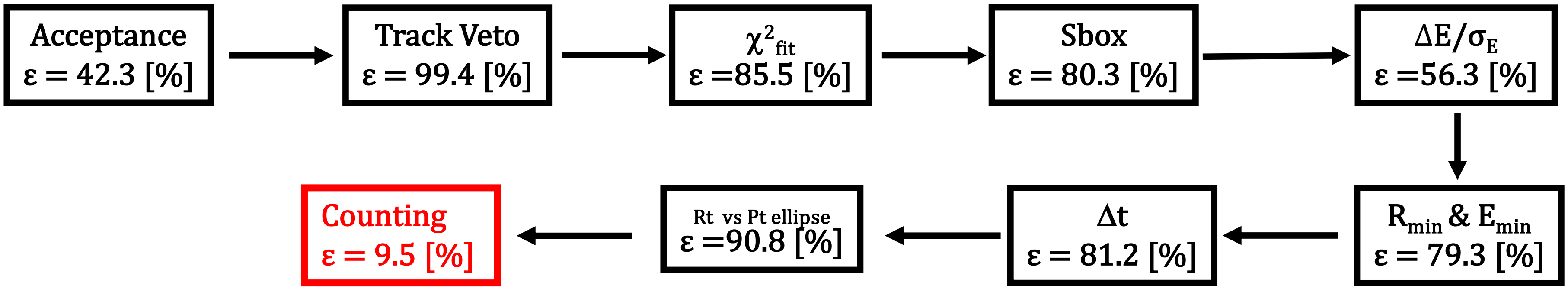
6γ sample: MC fractions fit to data





Category	Weight
2A	1.242 ± 0.032
1A1S	1.79 ± 0.22
Fakes	1.52 ± 0.15
2S	1.617 ± 0.033
OTHERS	1.617 ± 0.033

The optimized analysis chain efficiencies:



Status of the analysis:

- At the end of the analysis we count **0 candidates** in the background simulations.
- Kinematic fit optimization completed, reprocessing the whole statistics
- Final corrections for the backgrounds simulations in progress
- Expected sensitivity on BR at full KLOE statistics and optimized analysis $\sim 10^{-8}$

Measurement of the $K_S \to \pi e \nu$ branching ratio

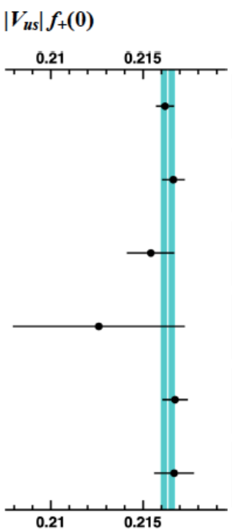
$|V_{us}|$ CKM matrix element is best measured from Kaon meson semileptonic decays

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

BR($K_s \to \pi e \upsilon$) less precise than K_L and K^+/K^-

BR($K_s \to \pi e \upsilon$)=(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

Improve BR($K_s \to \pi e \upsilon$) measurement to have a |Vus| evaluation from $K_s \to \pi e \upsilon$ decay comparable with others contribution

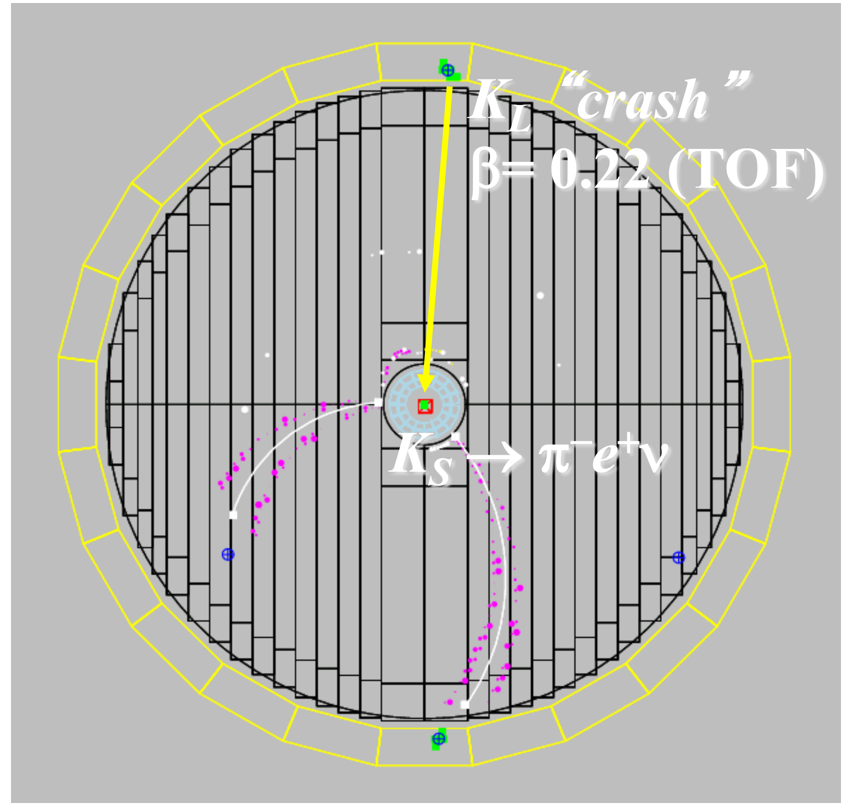


		% err	BR	τ	Δ	Int
K_Le3	0.2162(5)	0.23	0.09	0.20	0.02	0.05
$K_L\mu3$	0.2167(6)	0.29	0.15	0.18	0.11	0.07
K_Se3	0.2154(13)	0.60	0.60	0.02	0.02	0.05
$K_S\mu3$	0.2126(47)	2.2	2.2	0.02	0.11	0.07
$K^\pm e3$	0.2167(7)	0.32	0.27	0.06	0.17	0.05
$K^\pm\mu3$	0.2167(11)	0.50	0.45	0.06	0.21	0.07

Approx. contrib. to % err from: BR, τ, Δ, Int

Average: $|V_{us}| f_+(0)$ = 0.21635(38) χ^2/ndf = 2.14/5 (83%)

V_{us} from kaon decays – M. Moulson, E. Passemar – CKM 2021 – University of Melbourne, 22-26 Nov 2021 26

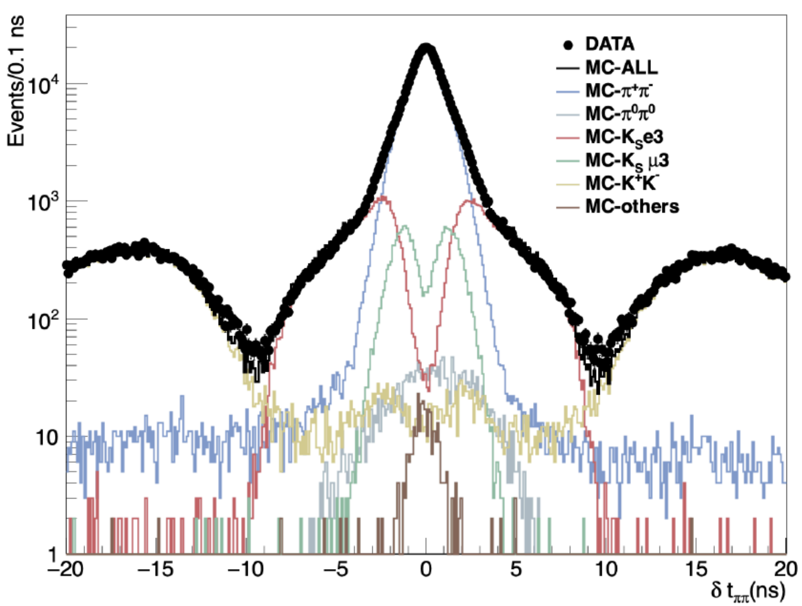


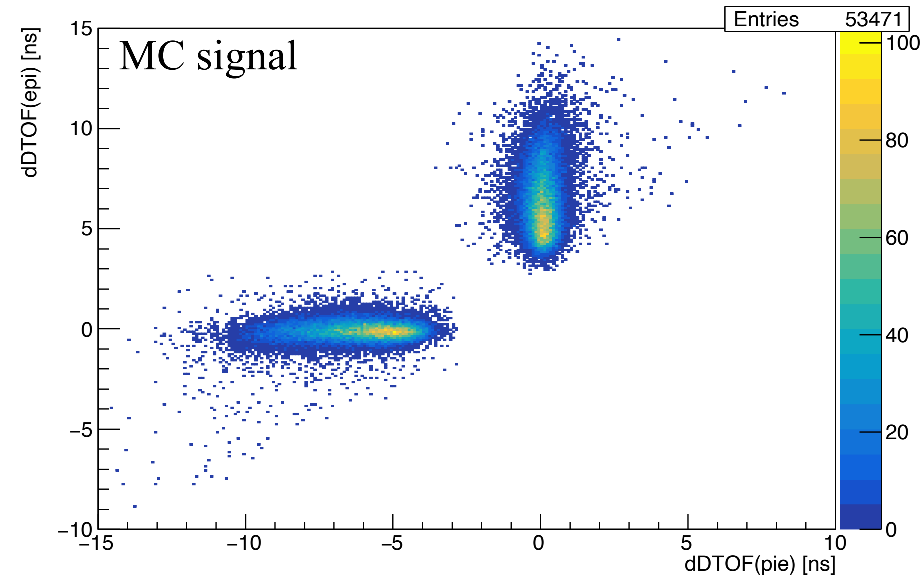
***K_S* tagged by *K_L* interaction in EMC**
Possibility to have pure Ks beam
Efficiency ~ 30% (largely geometrical)
K_S angular resolution: ~ 1° (0.3° in φ)
K_S momentum resolution: ~ 2 MeV

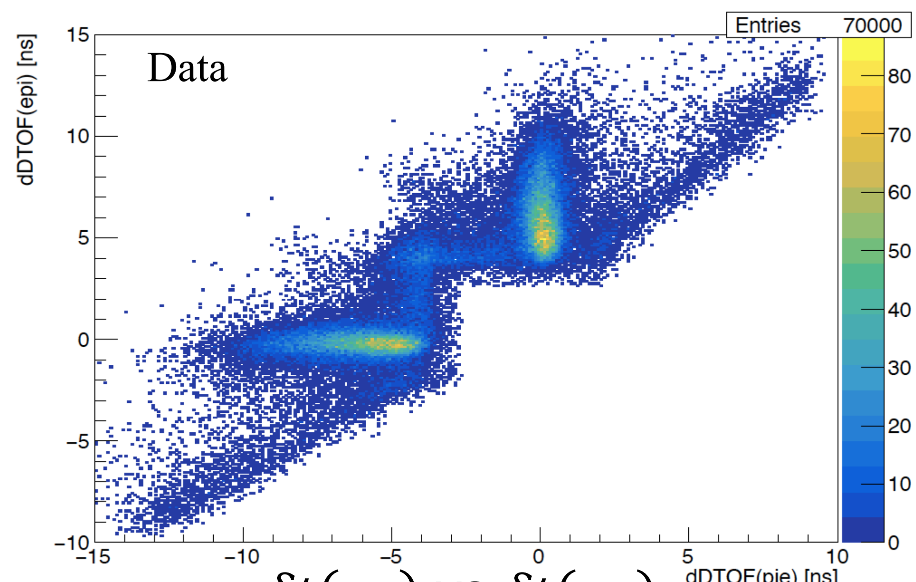
Measurement of the $K_S \to \pi e \nu$ branching ratio

- Analyzed $L = 1.63\ \text{fb}^{-1}$
- 1 vtx close to IP + K_L interaction in the calorimeter (KL crash)
- $K_S \to \pi^+\pi^-$ as normalization sample
- K_S semileptonic signal selection:
  - boosted decision tree (BDT) with kinematic variables to reject main background from $K_S \to \pi^+\pi^-$ and $\phi \to K^+K^-$
  - PID with Time of Flight

$$2.5\ \text{ns} < |\delta t_{\pi\pi}| < 10\ \text{ns}$$

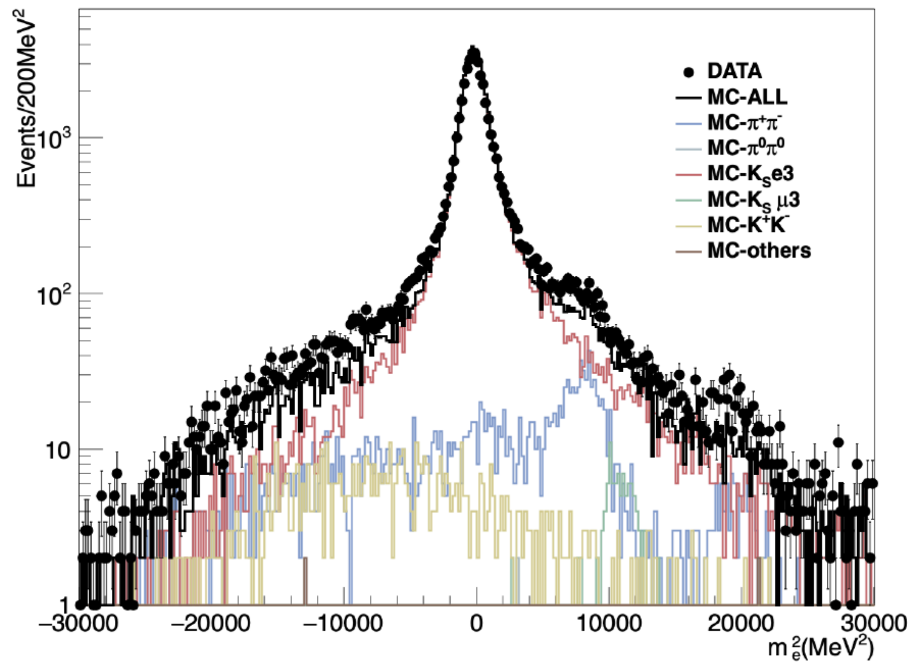






$\delta t(e\pi)$ vs $\delta t(\pi e)$

- Signal count from fit to $M^2(e)$ distribution
- 49647 ± 316 K_{Se3} events
- Selection efficiency from $K_S \to \pi^+\pi^-$ $K_L \to \pi e \nu$ close to IP data control sample
- $\varepsilon = (19.38 \pm 0.04)\%$
- Study of systematic uncertainties from: BDT and TOF selection cuts, fit range, trigger, on-line filter, event classification, T0 determination, K_L-crash and β^* selection, K_S identification



Selection	$\delta\epsilon^{\rm syst}_{\pi e\nu}$ [%]	$\delta\epsilon^{\rm syst}_{\pi^+\pi^-}$ [%]
TCA efficiency	0.009	
BDT selection	0.276	
TOF selection	0.308	
MC control sample statistics	0.108	
MC signal statistics	0.143	
Fit	0.153	
$\pi^+\pi^-$ efficiency & MC statistics		0.091
Total	0.477	0.091

Relative systematic uncertainties of efficiencies

$$\mathrm{BR}(K_S \to \pi e \nu) = (7.211 \pm 0.046_{stat} \pm 0.052_{syst}) \times 10^{-4}$$

Measurement of the $K_S \rightarrow \pi e \nu$ branching ratio

- Combination of the previous result from KLOE based on an independent data sample ($L=0.41$ fb^{-1}) $BR(K_{Se3})=(7.046 \pm 0.078 \pm 0.049)\times10^{-4}$ [KLOE PLB636 (2006)] gives:

$$BR(K_S \rightarrow \pi e \nu) = (7.153 \pm 0.037_{stat} \pm 0.043_{syst})\times 10^{-4}$$

- From

$$\mathcal{B}(K_S \to \pi \ell \nu) = \frac{G^2 (f_+(0)|V_{us}|)^2}{192\pi^3} \tau_S m_K^5 I_K^\ell S_{\rm EW} (1 + \delta_{\rm EM}^{K\ell})$$

Using the values $S_{EW} = 1.0232 \pm 0.0003$ [Marciano, Sirlin PRL 71 (1993) 3629] and $I_K^e = 0.15470 \pm 0.00015$ and $\delta_{EM}^{Ke} = (1.16 \pm 0.03)\times 10^{-2}$ [Seng, Galviz, Marciano, Meissner, PRD 105, (2022) 013005] we derive:

$$f_+(0)\,|V_{us}| = 0.2170 \pm 0.0009$$

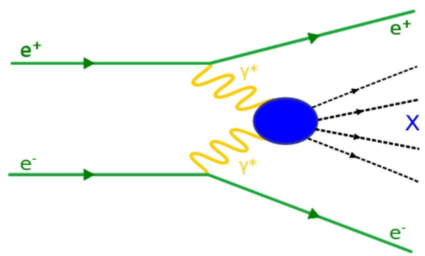
KLOE-2 result (2022)
Paper draft ready

$\gamma\gamma$ physics with High Energy Tagger (HET)

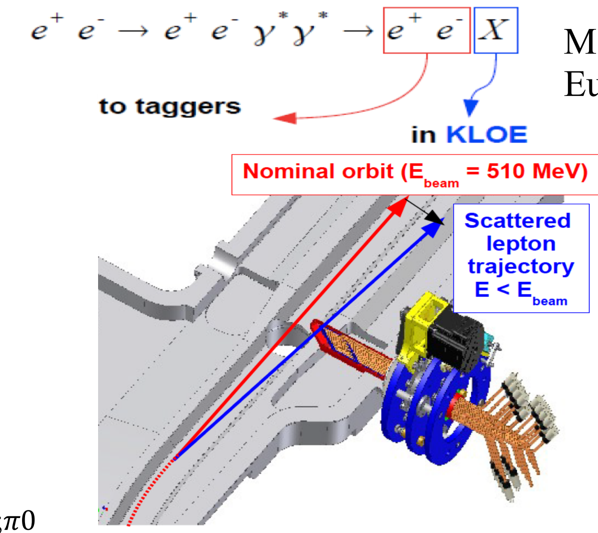
$$e^+e^- \to e^+e^-\gamma^\star\gamma^\star \to e^+e^- X$$

$$[\mathbf{C}(\mathbf{X}) = +\mathbf{1}]$$

$$\mathbf{X} = \pi^0, \pi\pi, \eta$$

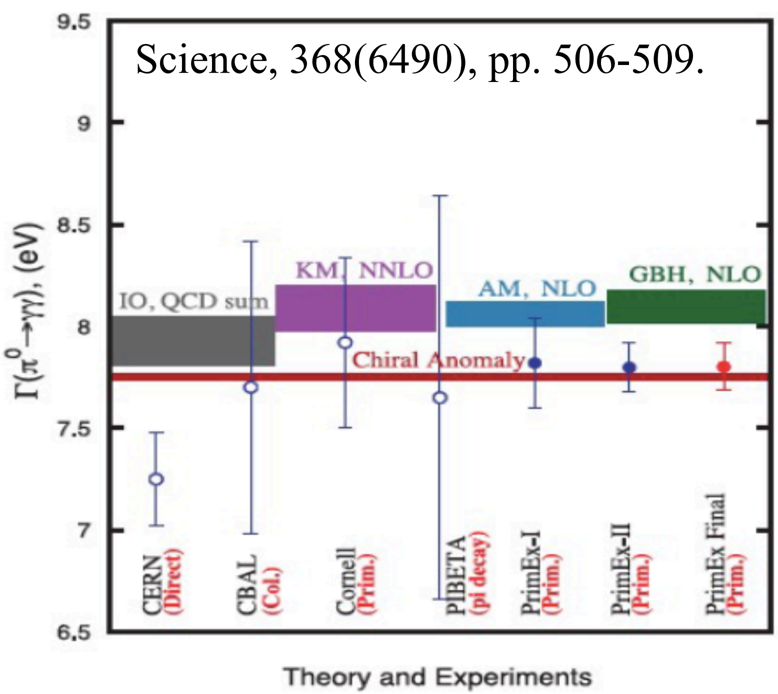


Rev. Mod. Phys., 85 (2013) 49



Measurement concept:
Eur. Phys. J. C 72 (2012) 1917

- Precision measurement of $\Gamma(\pi^0\to\gamma\gamma)$
- Transition form factor $F_{\pi\gamma\gamma^*}(q^2,0)$ at space-like q^2 ($|q^2|< 0.1$ GeV^2), impact on value and precision of $a_\mu^{LbyL;\pi 0}$
  Info on TFF slope



First bending dipoles of DAΦNE act as spectrometers for scattered leptons (420 < E < 495 MeV)

Scintillator hodoscope + PMTs, inserted in Roman pots
pitch: 5 mm, ~ 11 m from IP (σ_E~2.5 MeV σ_t~500 ps)

HET is acquired asynchronously w.r.t. the KLOE-2 DAQ (Xilinx Virtex 5 - FPGA), synchronization with the «Fiducial» signal from DAΦNE (each 325 ns) and the KLOE trigger

HET acquisition window corresponds to about 2.5 DAΦNE revolutions, data are recorded only when a KLOE trigger is asserted

Cross section measurement concept:

Normalization channel: very small angle radiative Bhabha's
(Simulation: Bbbrem generator+BDSIM transport)

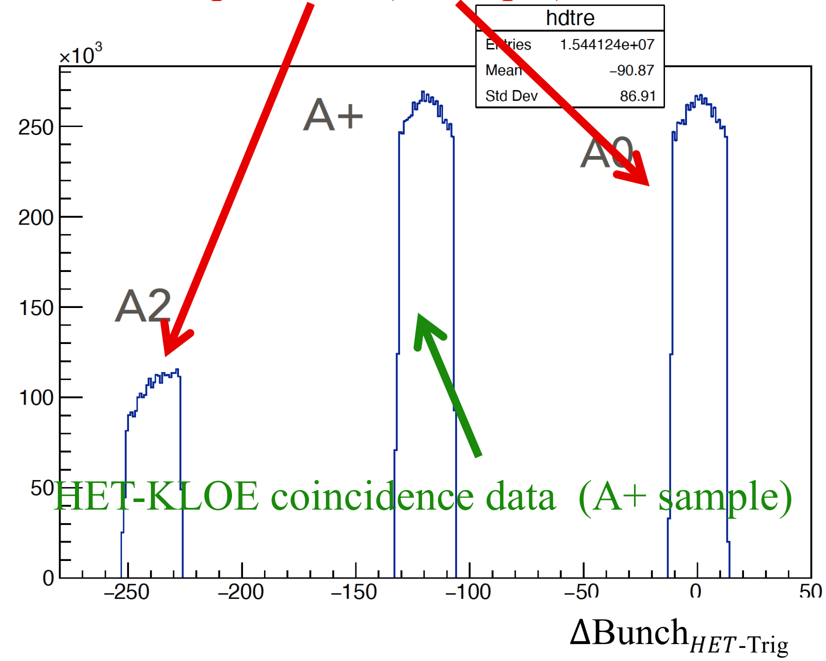
$$\frac{\sigma_{\pi^0}}{\sigma_{\rm Bha}} = \frac{N^{\rm meas}_{\pi^0}}{\epsilon_{\rm ana} N^{\rm meas}_{\rm Bha}} \frac{A_{\rm Bha}}{A_{\pi^0}}$$

$N^{\rm meas}_{\rm Bha} = \sigma^{\rm meas}_{\rm Bha} \int {\rm Ldt}$

$\sigma^{\rm meas}_{\rm Bha}$ measured at few % level

$\int {\rm Ldt}$ from KLOE online/$\gamma\gamma$ control sample

Accidental-pure data (A sample)



HET-KLOE coincidence data (A+ sample)

$N_{\pi 0}$ estimation :

-Statistics : 3fb^{-1}

-Single arm selection :

- -Two-cluster bunches in the KLOE barrel EMC
- -Selected bunch crossing and HET signal in a time window of 40 ns around the KLOE Trigger
- -Very loose kinematic cuts

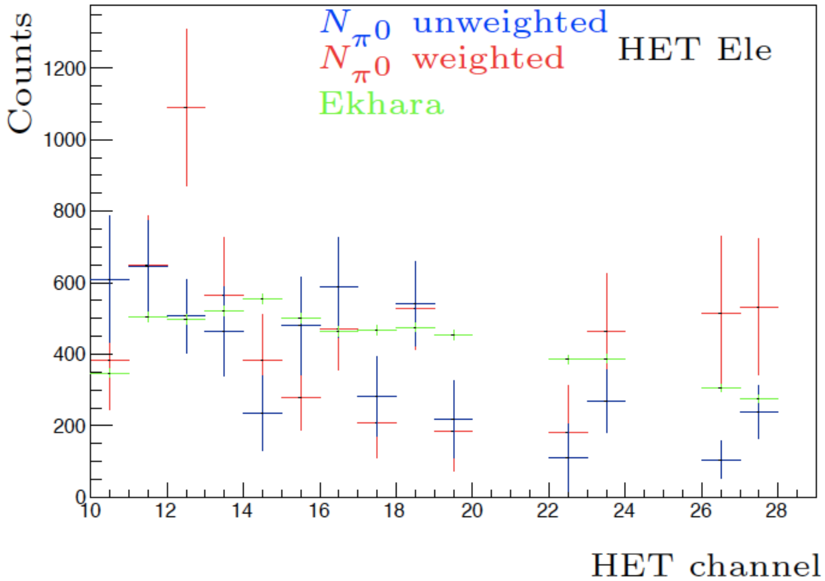
Analysis based on A+/A comparison with ML fits

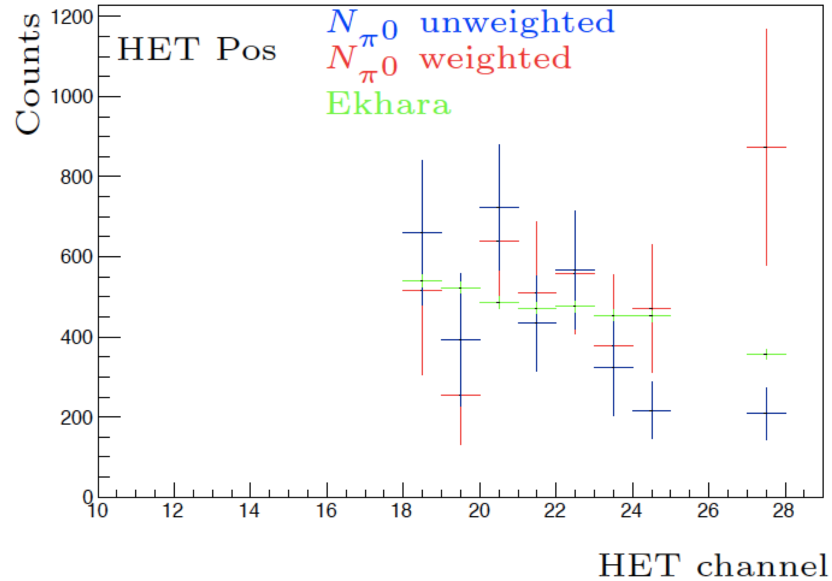
A sample used for background modelling (shape and number)

Signal pdfs by Ekhara simulation , control samples and BDSIM transport

Fits performed both per period or per single HET channel to check result consistency

π^0 counting equalized taking into account differences in plastic response and analysis efficiency along data taking





Unweighted counting results: 5292(430) Ele, 3526(377) Pos
Combined unweighted results (Ele+Pos): 8818 (572), about 6.5% precision

Status of the measurement:

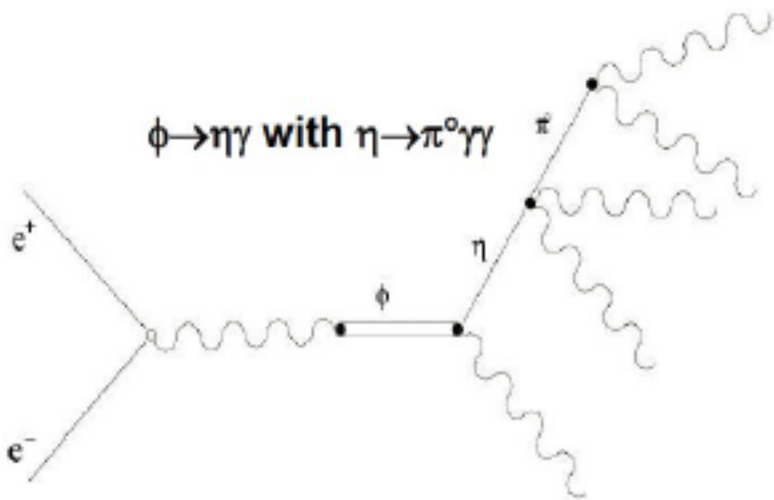
N_{π^0}: **weighted counting performed, final checks on weights ongoing**

ϵ_{ana} : **analysis efficiency evaluation completed**

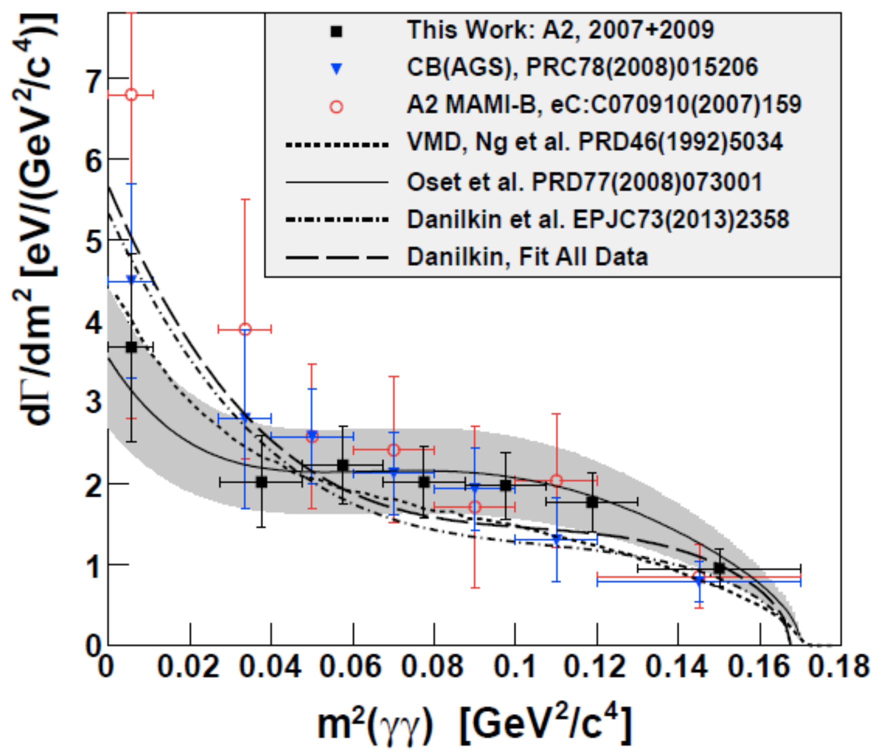
$\int Ldt$: **luminosity measurement performed both with KLOE online and cross checked with $\gamma\gamma$ control sample**

$\frac{A_{Bha}}{A_{\pi^0}}$: **Take on MC Bbbrem/Ekhara at production level to estimate acceptance uncertainty, in progress**

$\eta \to \pi^0\gamma\gamma$ (from $\phi \to \eta\gamma$): χPT golden mode,
$O(p^2)$ null, $O(p^4)$ suppressed $\Rightarrow$ sensitive to $O(p^6)$



Latest theoretical studies by Escribano et al.
PRD 102 (2020) 034026 : calculated BR = $1.30(1)\times10^{-4}$
Many previous predictions differ by a factor ~2

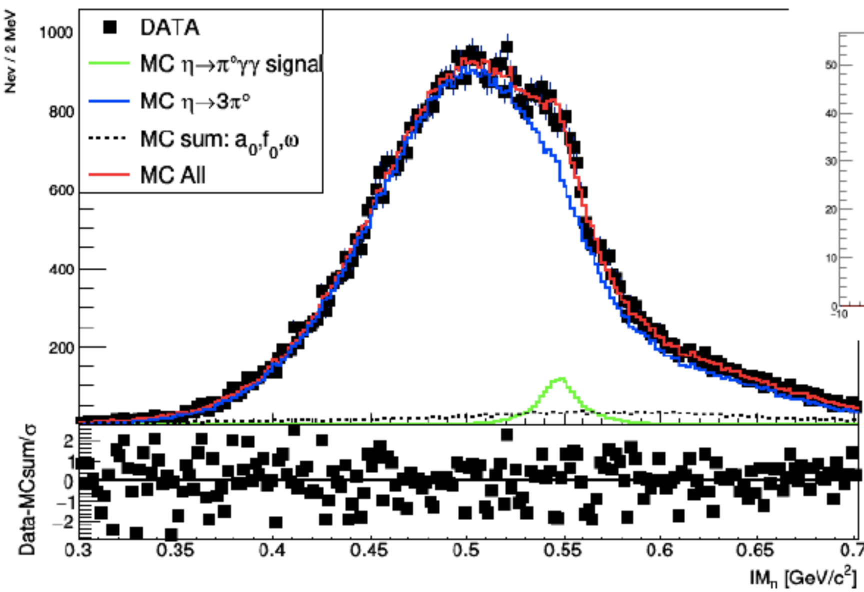


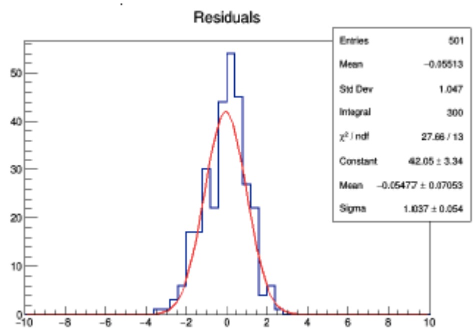
BR = $(22.1 \pm 2.4 \pm 4.7)\times10^{-5}$ **CB@AGS** (2008)

BR = $(25.2\pm2.5)\times10^{-5}$ **CB@MAMI** (2014)
A2 MAMI [PRC 90 (2014) 025206]
Sample of ~6.107 η's , ~1200 $\eta\to\pi^0\gamma\gamma$ events found

Old KLOE preliminary: $(8.4\pm2.7\pm1.4)\times10^{-5}$
(L = 450 pb^{-1} ~ 70 signal events)

$\eta \rightarrow \pi^0\gamma\gamma$ decay





S/B ~ 2.5%

N_s ~ 1.2k

Prob ~ 2%

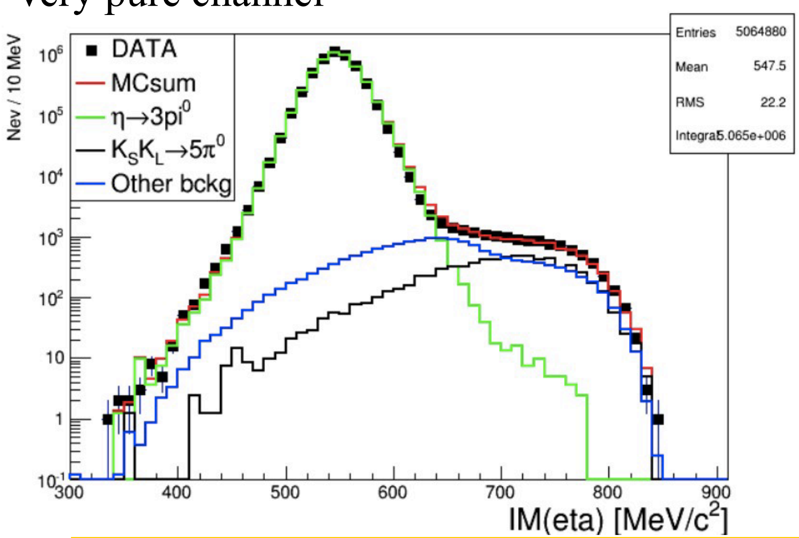
Eff_S ~ 15%

A new analysis of KLOE data, using ~4x larger data sample (1.7 fb^{-1}, 7 $\times 10^7$ η's)

- Main background from $\phi \rightarrow (\eta \rightarrow 3\pi^0)\gamma$ with lost or merged photons
- Variables corrected by a kinematic fit to improve resolution

Normalization to $\phi \rightarrow (\eta \rightarrow 3\pi^0)\gamma \rightarrow 7\gamma$

Very pure channel

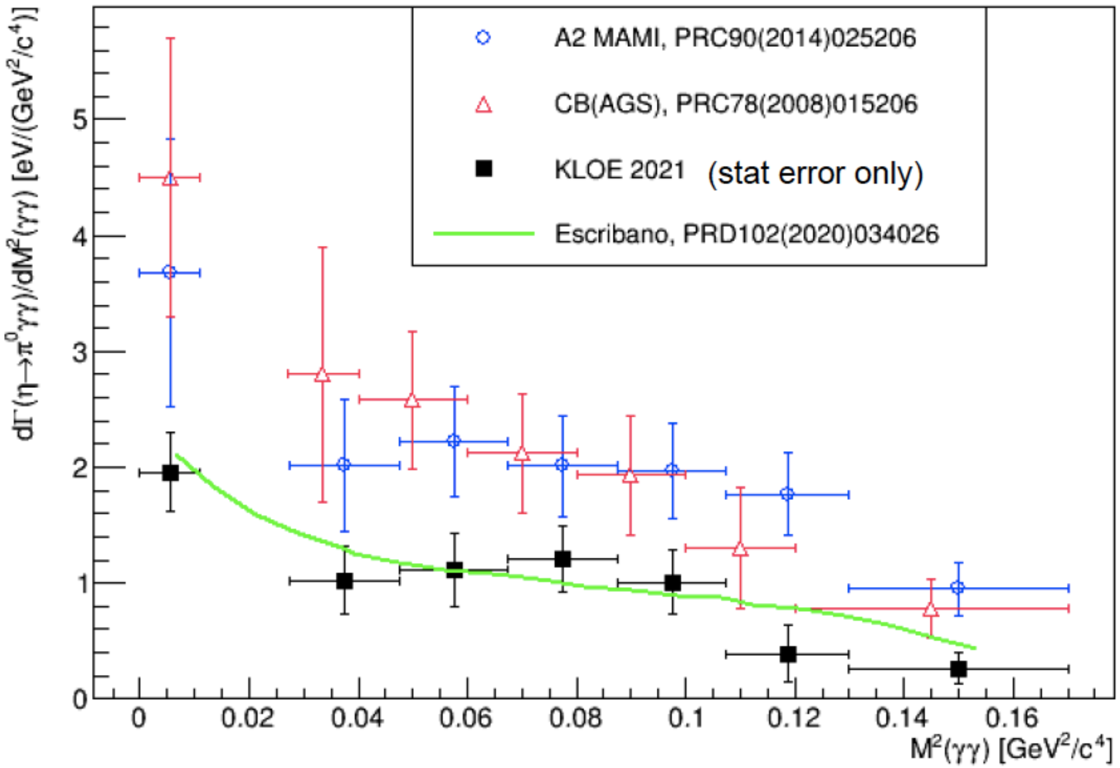


From the full spectrum using 3 component fit with $\eta \rightarrow 3\pi^0$ (7γ normalization):

BR=(1.21 ± 0.13stat) $\times 10^{-4}$

Escribano PRD 102 (2020) prediction BR=1.30(1) $\times 10^{-4}$

$\eta \to \pi^0\gamma\gamma$ decay



Separate fits to M(eta) in $M^2(\gamma\gamma)$ slices

Missing bins due to $\pi^0\pi^0$ veto

Status of the measurement:

Evaluation of analysis systematics completed, small refinement needed

Systematic determination of $d\Gamma/dM^2(\gamma\gamma)$ in progress

Analysis report and paper draft underway

Conclusions

KLOE-2 data reconstruction with final DBV has been completed. Data available for analyses.

MC production with final DBV almost completed, final checks ongoing

ROOT output production continues, about 2 fb^{-1} already available

New KLOE paper on precision tests on QM and CPTV with entangled Kaons: JHEP 04 (2022) 059

One other paper draft ready: $K_s e3$ (under final KLOE-2 revision)

T/CPT tests with $\phi \to K_S K_L \to 3\pi^0 \, \pi e \nu, \pi\pi \, \pi e \nu$: final result blessed, writing paper draft

$\eta \to \pi^0 \gamma\gamma$: close to final result, blessing within this month

The other analyses are in a very advanced state

A new quantum time correlation effect is being studied with $\phi \to K_S K_L \to 4\pi$

Recommendations to KLOE-2: none

Observations to KLOE-2:

1- The KLOE collaboration has continued the data and MC reprocessing with version DBV-40. For data 4.5/fb are done and the remaining 1/fb is in progress and expected to be done by January. For MC, the production for DBV-38 is finished and for DBV-40 0.5/fb of inclusive phi production is done.

2- KLOE has made significant progress in the data analyses that were planned since the last meeting. The analysis probing CPT violation in KSKL->4p was finalized and has been submitted to JHEP. Several other analyses were presented in preliminary form at the EPS conference in July and are now being finalised for publication. In particular, a clear signal is observed in the gg->p0 production mode with the HET tagger used for tagging the outgoing e+e-. Here, the remaining work ongoing is the estimate of the ratio of acceptances for the signal events and the normalisation channel (Bhabha events).

3- It is expected that the six analyses which are well advanced will conclude by summer of 2022. However, none of these analyses uses the full dataset of 5.5/fb, they are based on up to 2/fb only and with an older software version. Many of the results are still statistically limited and an analysis of the full dataset with DBV-40 would be highly desirable as they present a unique opportunity and are world- leading. In the spring of 2022, the collaboration plans to start discussing on how to "open" these data and on the future of the collaboration.

SPARE SLIDES

KLOE-2 Physics

KLOE-2 coll. EPJC (2010) 68, 619
http:// agenda.infn.it/event/kloe2ws procs. EPJ WoC 166 (2018)

KAON Physics:

- CPT and QM tests with kaon interferometry
- Direct T and CPT tests using entanglement
- CP violation and CPT test:
  $K_S \to 3\pi^0$
  direct measurement of Im(ε'/ε) (lattice calc. improved)
- CKM Vus:
  K_S semileptonic decays and A_S
  (also CP and CPT test)
  $K\mu3$ form factors, $Kl3$ radiative corrections
- χpT : $K_S \to \gamma\gamma$
- Search for rare K_S decays

Hadronic cross section

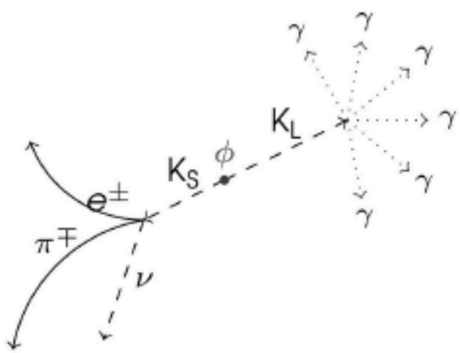
- ISR studies with 3π, 4π final states
- F_p with increased statistics
- Measurement of a_μ^{HLO} in the space-like region using Bhabha process

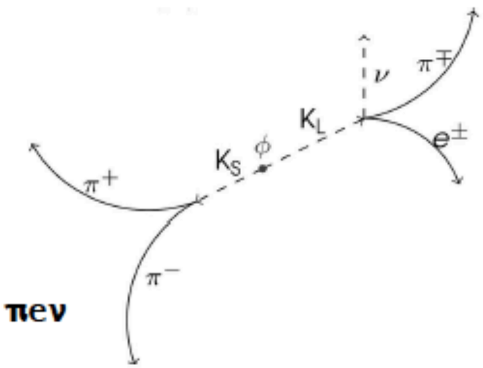
Dark forces:

- Improve limits on:
  $U\gamma$ associate production
  $e^+e^- \to U\gamma$, $U \to \mu\mu, \pi\pi$, ee
- Higgstrahlung
  $e^+e^- \to Uh' \to \mu^+\mu^-$ + miss. energy
- Leptophobic B boson search
  $\phi \to \eta B$, $B \to \pi^0\gamma$, $\eta \to \gamma\gamma$
  $\eta \to B\gamma$, $B \to \pi^0\gamma$
- Search for U invisible decays

Light meson Physics:

- η decays, ω decays
- Transition Form Factors
- C,P,CP violation: improve limits on
  $\eta \to \gamma\gamma\gamma$, $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^0\pi^0\gamma$
- improve $\eta \to \pi^+\pi^-e^+e^-$
- χpT : $\eta \to \pi^0\gamma\gamma$
- Light scalar mesons: $f_0(500)$ in $\Phi \to K_S K_S \gamma$
- $\gamma\gamma$ Physics: $\gamma\gamma \to \pi^0$ and π^0 TFF
- Search for axion-like particles





$K_S K_L \to \pi e\nu\ 3\pi^0$

- **Preselection:**
  - Vtx with 2 tracks close to IP (cutting close to IP to reject $K_S \to \pi\pi \to \pi\mu$)
  - 6 neutral clusters' set
  - Reconstructing $K_L \to 3\pi^0$
- Reconstruction of kaon decay times and Δt
- **Analysis:**
  - basic $K_s \to \pi e\nu$ selection cuts
  - TCA requirement for 2 tracks
  - Time of flight analysis and cuts
  - Cut on R/(T*c) for neutral clusters to reject $K_s \to \pi^0\pi^0$
  - Kinematic fit
  - ANN-based classification of e/π and e/μ EMC clusters and tracks

S/B ≈ 23

- **Residual background subtraction using a MC-based model**

$K_S K_L \to \pi^+\pi^-\ \pi e\nu$

- **Preselection:**
  - vtx with 2 tracks close to IP
  - M(ππ) and |p| cuts for 2 tracks
  - Exactly 1 other vtx with 2 tracks passing a missing mass cut
- Reconstruction of kaon decay times and Δt
- **Analysis:**
  - TCA requirement for 2 tracks from K_L decay vertex
  - Time of flight analysis and cuts

S/B ≈ 70

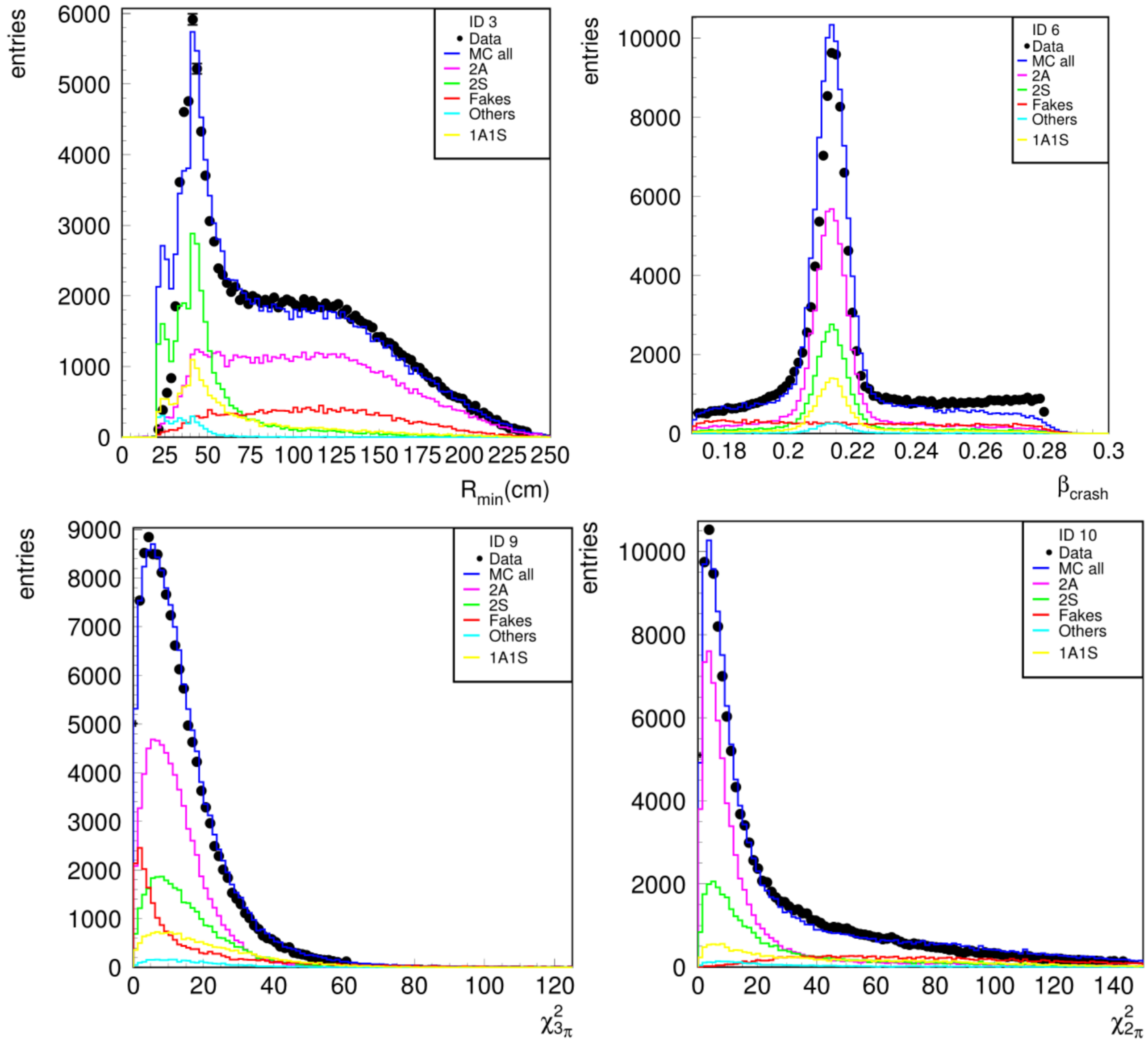
T/CPT Tests with $\phi \rightarrow K_S K_L \rightarrow 3\pi^0 \pi\nu e, \pi\pi\ \pi\nu e$

Effect	R_2^T	R_4^T	R_2^{CPT}	R_4^{CPT}	R_2^T/R_4^T	R_2^{CPT}/R_4^{CPT}	R_2^{CP}	R_4^{CP}
Residual background model	0.002738	0.004615	0.002789	0.004429	0.004432	0.004414	0.004369	–
Smoothing of efficiencies from MC	0.002460	0.005310	0.002430	0.005260	0.006700	0.006830	0.006760	0.000165
Δt bin width	0.008000	0.005000	0.007500	0.005500	0.009000	0.009000	0.008900	0.000030
Fit range position	0.007250	0.007280	0.007270	0.007260	0.005140	0.005270	0.005200	0.000205
Fit range width	0.001110	0.005080	0.000858	0.005050	0.006070	0.005480	0.005780	0.000359
Effects of cuts in the $\pi e \nu\ 3\pi^0$ selection								
K_S vertex ρ	0.000411	0.002300	0.000417	0.002260	0.002240	0.002290	0.002270	–
K_S vertex z	0.000397	0.000242	0.000405	0.000239	0.000736	0.000760	0.000748	–
$M(\pi,\pi)$	0.002480	0.001340	0.002520	0.001310	0.001560	0.001630	0.001600	–
1^{st} TOF cut	0.001600	0.002220	0.001620	0.002190	0.003830	0.003950	0.003890	–
2^{nd} TOF cut parameter A	0.000671	0.000581	0.000684	0.000569	0.000878	0.000899	0.000889	–
2^{nd} TOF cut parameter B	0.000369	0.000433	0.000375	0.000426	0.000076	0.000077	0.000076	–
2^{nd} TOF cut parameter C	0.000152	0.000399	0.000154	0.000393	0.000278	0.000283	0.000281	–
2^{nd} TOF cut parameter D	0.001420	0.000850	0.001450	0.000836	0.002050	0.002110	0.002080	–
3^{rd} TOF cut circle R	0.005140	0.004470	0.005230	0.004390	0.003560	0.003640	0.003600	–
3^{rd} TOF cut ellipse A	0.002280	0.001020	0.002320	0.001000	0.002760	0.002850	0.002800	–
3^{rd} TOF cut ellipse B	0.000412	0.000993	0.000420	0.000973	0.000956	0.000975	0.000965	–
$e/\pi/\mu$ classification	0.004000	0.004330	0.004070	0.004250	0.009100	0.009340	0.009220	–
Classifier training with data/MC	0.002620	0.000800	0.002630	0.000810	0.002050	0.002170	0.002110	–
Effects of cuts in the $\pi^+\pi^-\ \pi e \nu$ selection								
K_S vertex ρ	0.000002	0.000002	0.000002	0.000002	0.000000	0.000000	–	0.000000
K_S vertex z	0.000007	0.000003	0.000003	0.000007	0.000004	0.000004	–	0.000005
$M(\pi,\pi)$	0.002220	0.002280	0.002240	0.002260	0.000024	0.000024	–	0.000027
$\lvert\vec{p}_{tot}\rvert$	0.000152	0.000181	0.000178	0.000154	0.000021	0.000021	–	0.000022
$m_+^2 + m_-^2$	0.001480	0.001320	0.001310	0.001490	0.000202	0.000208	–	0.000210
1^{st} TOF cut parameter A	0.000021	0.000385	0.000389	0.000020	0.000392	0.000405	–	0.000426
1^{st} TOF cut parameter B	0.001450	0.001080	0.001070	0.001470	0.000407	0.000417	–	0.000417
2^{nd} TOF cut parameter R_1	0.000171	0.000256	0.000262	0.000175	0.000126	0.000130	–	0.000140
2^{nd} TOF cut parameter R_2	0.001570	0.001200	0.001190	0.001590	0.000399	0.000410	–	0.000414
Total systematic uncertainty	**0.014**	**0.015**	**0.014**	**0.015**	**0.019**	**0.019**	**0.019**	**0.00089**
Uncertainty on the D factor	0.012	0.012	0.012	0.012				
Including the D factor	0.018	0.019	0.019	0.019				

Table 7.1.: Systematic uncertainties

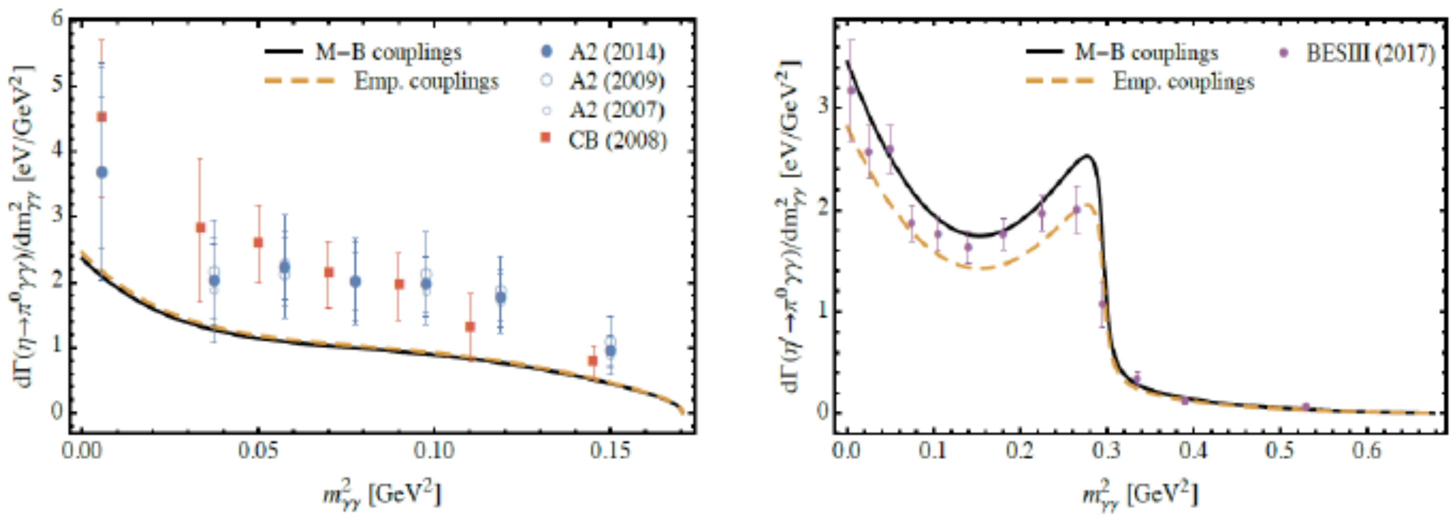
Search for the CP violating $K_S \to \pi^0\pi^0\pi^0$ decay

6γ sample: MC fractions fit to data



New $\eta \rightarrow \pi^0\gamma\gamma$ prediction

- Coming from Escribano et al. *[**PRD** 102 (2020) 034026]*
- Claims that previous calculations were overestimated by a factor of two due to not taking into account the same non-π° two photons in the final state when relating decay amplitude with it's width
- Why we should believe them? They can predict $\eta' \rightarrow \pi^\circ\gamma\gamma$ using the same method that matches BESIII data *[**PRD** 96 (2017) 012005]*.



(a) $\eta \to \pi^0\gamma\gamma$ decay.

(b) $\eta' \to \pi^0\gamma\gamma$ decay.