Status of KLOE-2

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on behalf of the KLOE-2 collaboration

LNF Scientific Committee meeting
Frascati, May 7th 2020

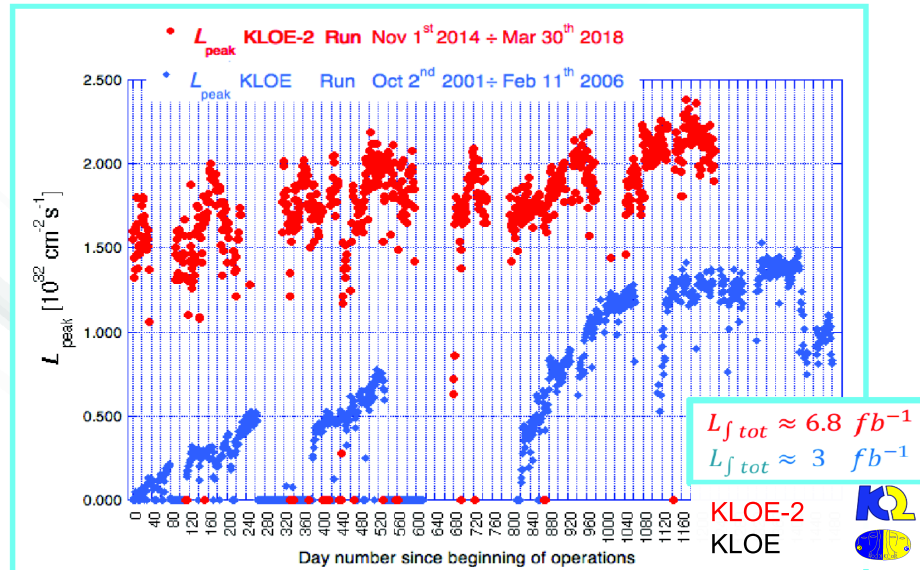
The KLOE-2 data-taking

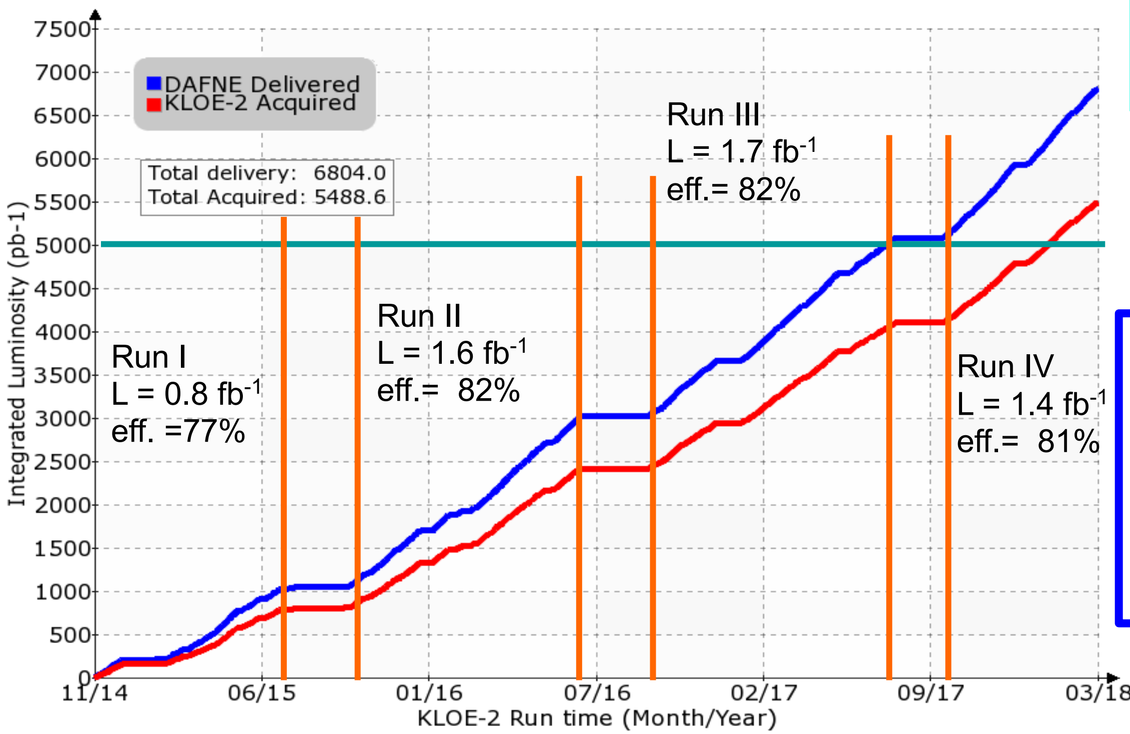
- November 17, 2014: start of KLOE-2 run
- March 30, 2018: End of KLOE-2 data-taking

$\Rightarrow$ 5.5 fb^{-1} collected @$\sqrt{s}=M_{\Phi}$

- Best performance in KLOE-2 run:

$L_{peak} = 2.4 \times 10^{32}\ cm^{-2}s^{-1}$ $\quad \int Ldt = 14\ pb^{-1}/day$





Goal:
5 fb^{-1}

KLOE + KLOE-2 data sample:

~ 8 fb^{-1} $\Rightarrow$ 2.4×10^{10} ϕ's produced

~ 8 $\times 10^{9}$ $K_S K_L$ pairs ~ 3 $\times 10^{8}$ η's

$\Rightarrow$ the largest sample ever collected at the $\phi(1020)$ peak in e^+e^- collisions

Status of data reconstruction : DBV-40

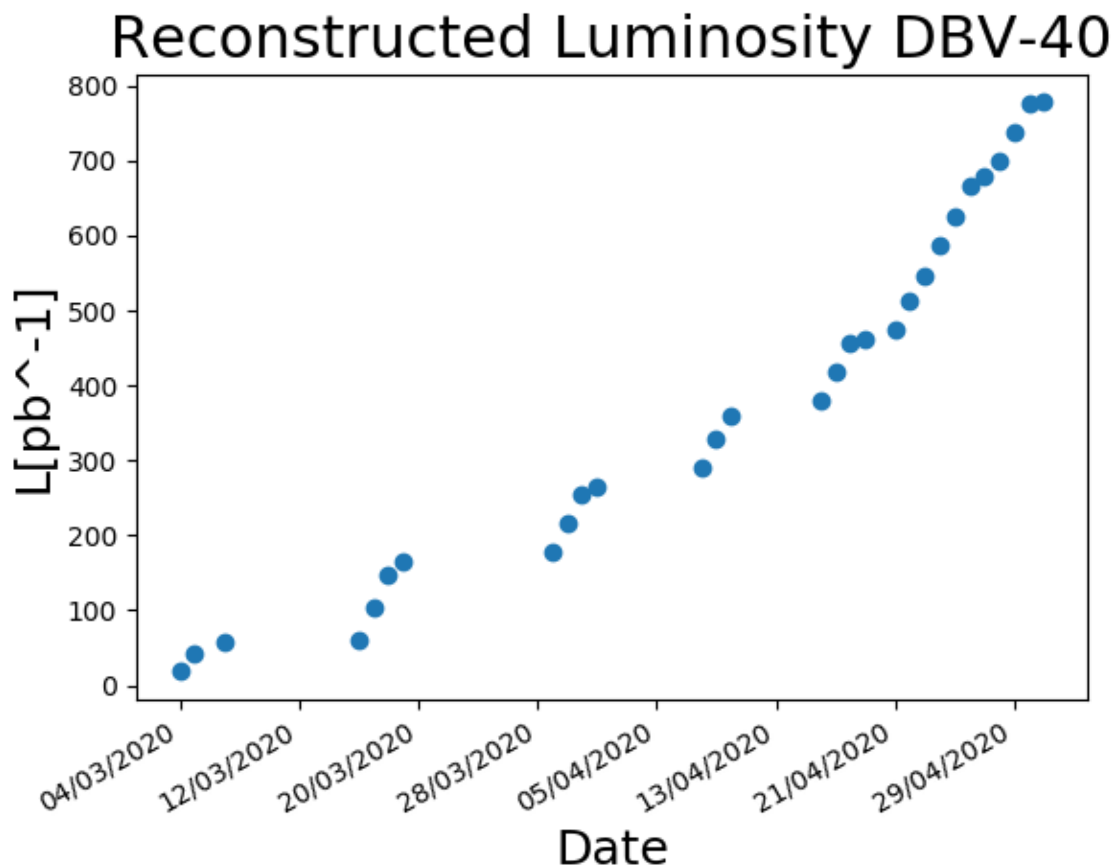
V. De Leo, P. Gauzzi, E. Perez Del Rio

- Final round of data reconstruction started on March 2020

- New Datarec version tag DBV-40:
  - Integrated tracking improvement incorporating the most up-to-date studies of material budget
  - Improved T0 algorithm developed for the specifics of neutral kaon events
  - Improved machine background filter and Bhabha and cosmic event rejection
  - Implementation of Root output for data preservation
  - Drift Chamber full dataset recalibration

- Reconstructed **L_{int} = 800 pb^{-1}** to date
- Reconstruction rate ~30 pb^{-1}/day (only the reconstruction/no dead time)

- Prod2root production
  - Produced **L_{int} = 75 pb^{-1}** with ROOT format output
  - Integration in the DB2 ongoing



DBV-40: New T0 algorithm

- Old T0 algorithm based on the assumption that the first cluster in the Calorimeter is a photon coming from the interaction point
- Not working properly, due to the different machine background conditions → losses, especially of Neutral Kaon events (~20%)

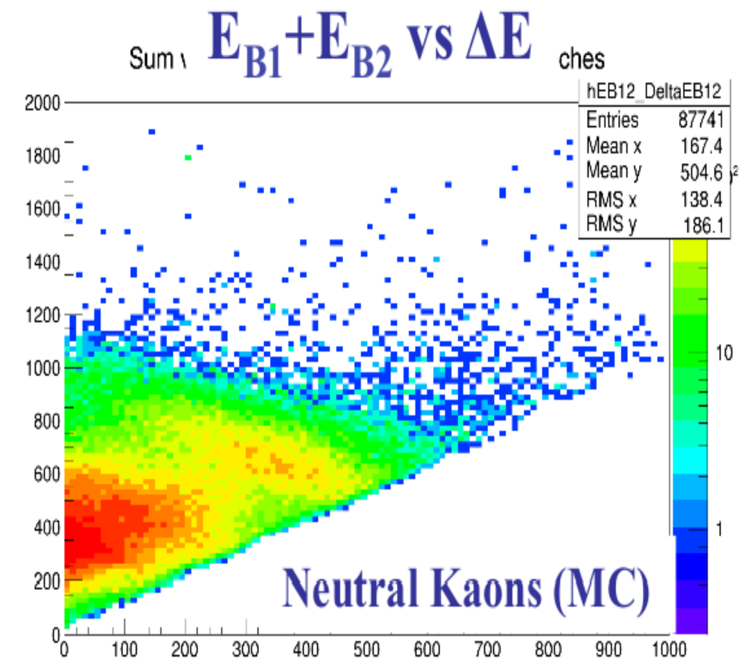
- Associate each EMC cluster to a bunch assuming that the cluster comes from a prompt photon
- Look for the two most energetic bunches, construct $\Delta E = E_{B1} - E_{B2}$ and $\Delta T = T_{B1} - T_{B2}$

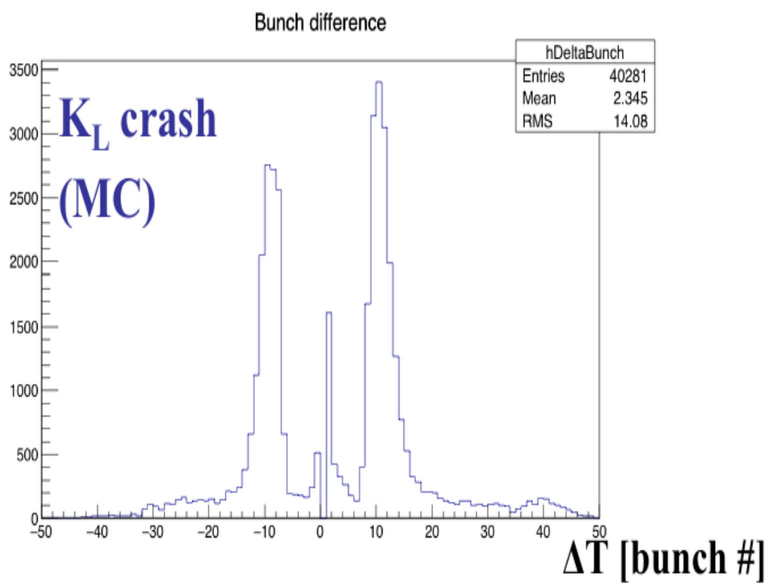
  If ΔE < 550 MeV AND $|\Delta T|$ > 6 bunches (Neutral Kaons)

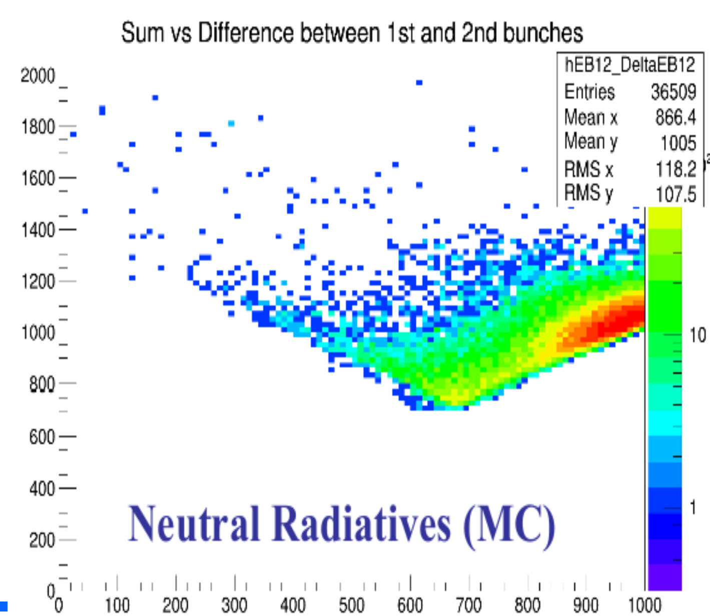
  The T_0 is obtained from the earliest between the two most energetic bunches

  Else (Rad., $\rho\pi$, any other stream)

  The T_0 is obtained from the most energetic bunch







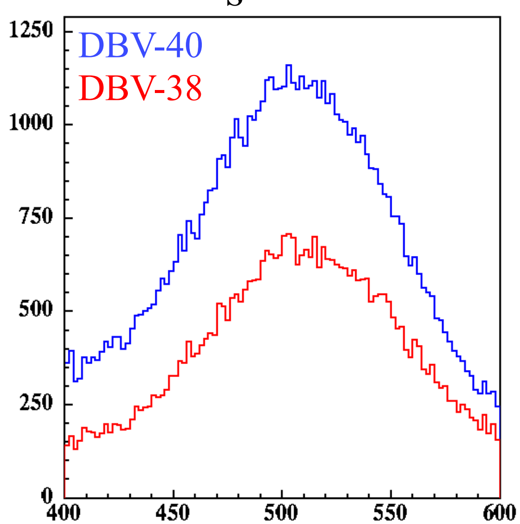
DBV-40 performance

Test on a small sample (1 pb^{-1})

Raw data reduction

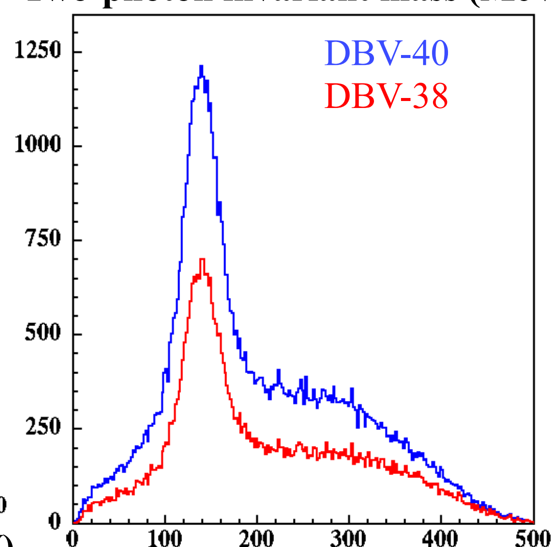
Tot. events	55578747	
Cosmics	10619733	19.1 %
Mach. Bckg	3859906	6.9 %
Bhabha and $\gamma\gamma$	6517569	11.7 %
Tot. rejected evts.		37.8 %

$K_S \to \pi^0\pi^0$



Four photon invariant mass (MeV)

Two-photon invariant mass (MeV)



Comparison with previous reconstruction

		DVB40 vs DBV-38
KL tag	($K_S \to \pi^+\pi^-$)	+ 20 %
KS neut. tag	($K_S \to \pi^0\pi^0$)	+ 73 %
KLcrash	$K_S \to \pi^0\pi^0$	+ 20 %
KLcrash	$K_S \to \pi^+\pi^-$	− 7 %
KS semilept. tag	($K_S \to \pi l \nu$)	+ 21 %
Neutral rad.	7 γ	+ 10 %
Neutral rad.	3 γ	+1 %
Charged rad.	c.rad. tag	
Charged rad.	$\pi\pi\gamma$	− 10 %

Recovery of neutral Kaon events (20% or even more for $K_S \to \pi^0\pi^0$)
Small losses for some tags, but cleaner samples (reduced background contamination)

MC status

- **Full MC data sample produced and reconstructed with version DBV-38**

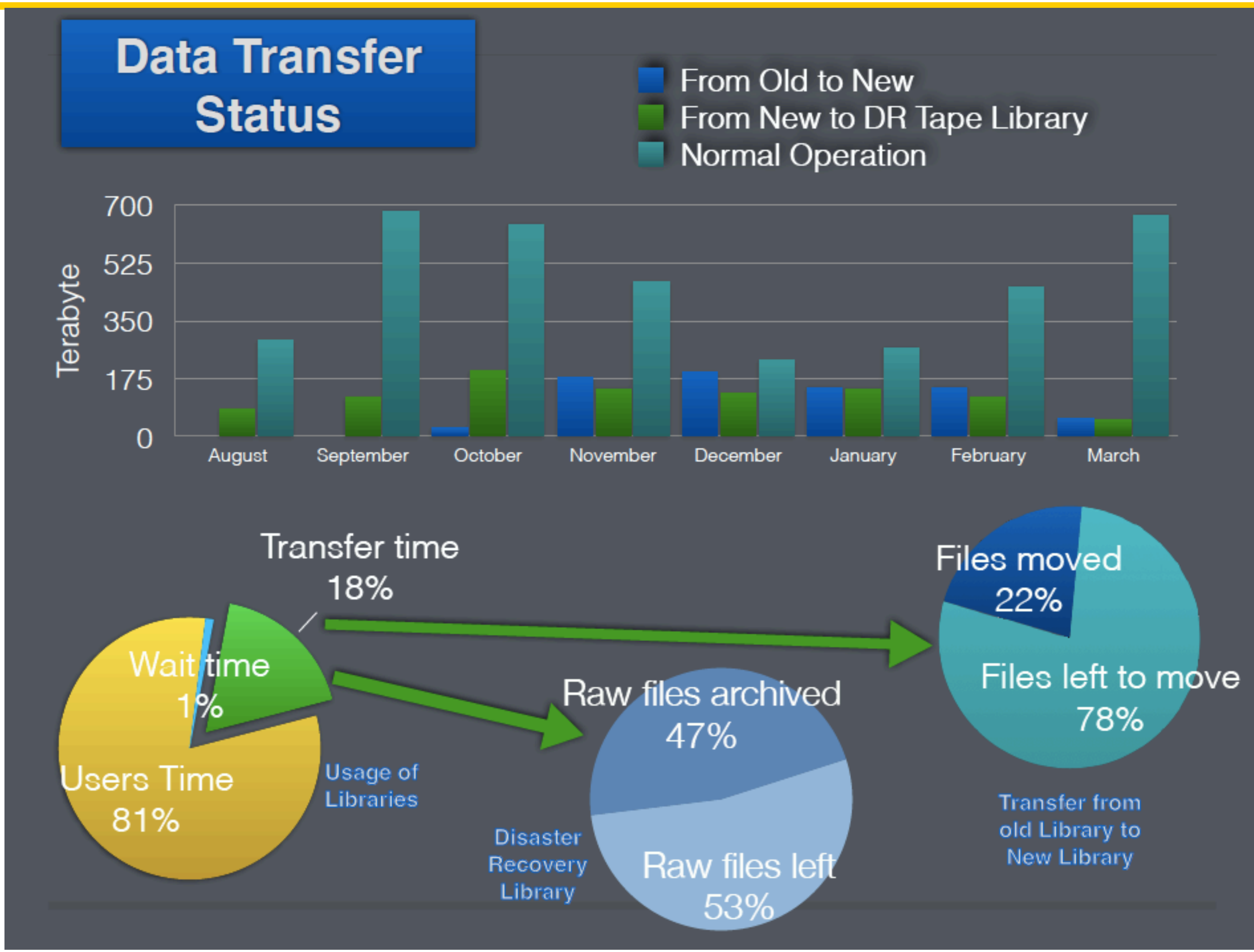
Simulation	DBV Version	MC Version	LSF	Luminosity (pb-1)
$\varphi \rightarrow$ all	38	201	1.00	3703
$K_S \rightarrow 3\pi0$	38	201	1×10^6	2032
e+e- $\rightarrow$ e+e-	38	201	0.01	353
e+e- $\rightarrow \gamma\gamma$	38	201	1.00	23
$\varphi \rightarrow$ all	39	210	1.00	93
e+e-$\rightarrow$ e+e-	39	210	0.01	93

- Production rate ~ 15 pb $^{-1}$ /day (performed in parallel, but by allocating most of the computing power to the data reconstruction).

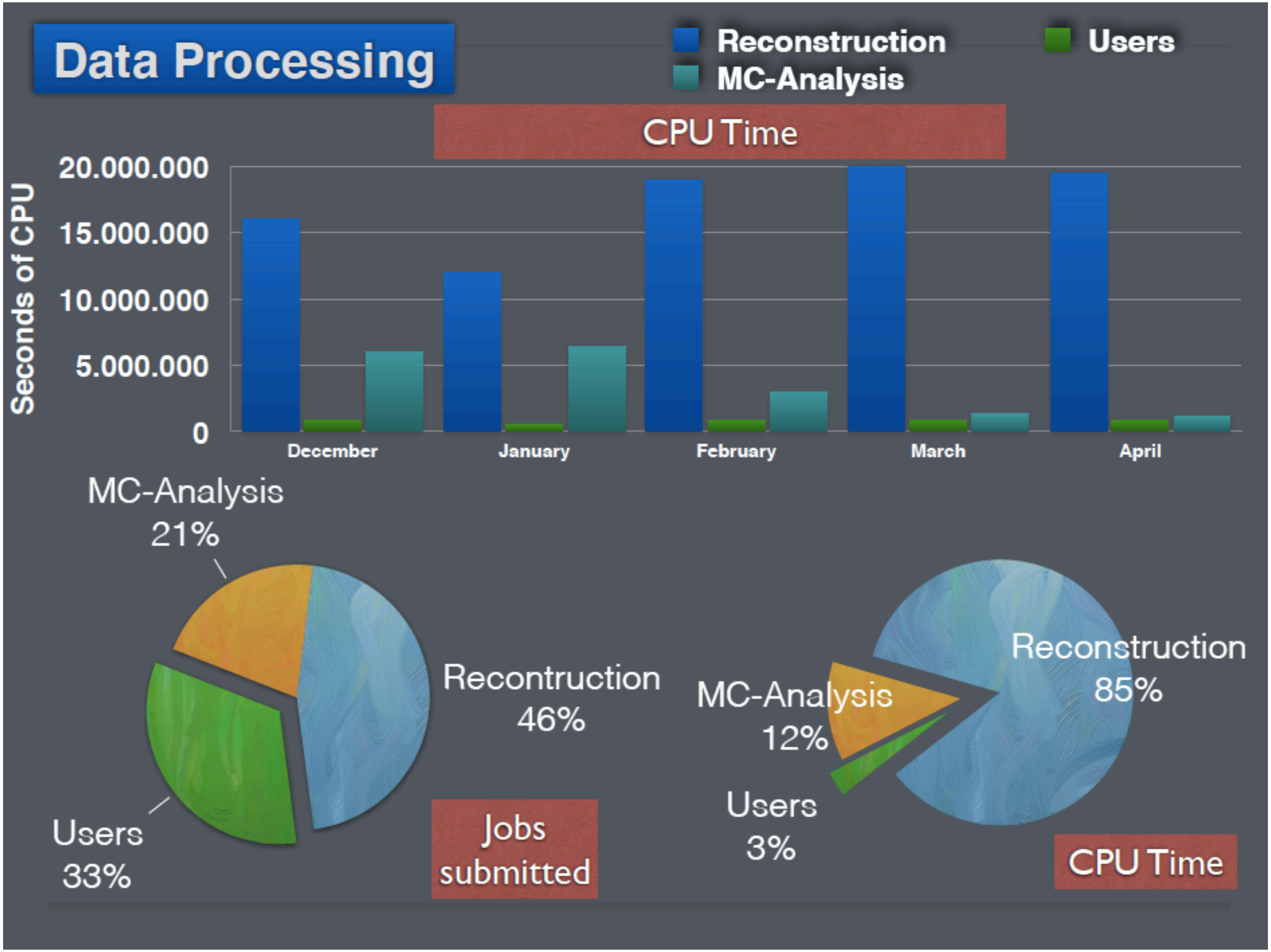
Data consolidation and recovery strategy plan

P. Cifra
G.F. Fortugno
F. Sborzacchi

Data consolidation and recovery strategy plan



Data consolidation and recovery strategy plan



Publications/Ongoing Analysis

Last Publications	
Measurement of the branching fraction for the decay $K_S \to \pi\mu\nu$ with the KLOE detector	Physics Letters B 804 (2020)
Measurement of the charge asymmetry for $K_S \to \pi e \nu$ decay and test of CPT symmetry with the KLOE detector	JHEP 1809 (2018) 021 (result cited in PDG 2019)
Combined limit on the production of a light gauge boson decaying into $\mu^+\mu^-$ and $\pi^+\pi^-$	Phys.Lett. B784 (2018) 336

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 – PhD Thesis
$K_S \to \pi^+\pi^-\pi^0$	KLOE data
$K_S \to 3\pi^0$ (CP viol.)	KLOE-2 data
$\gamma\gamma \to \pi^0$	KLOE-2 data
$\eta \to \pi^0\gamma\gamma$ - χPT golden mode	KLOE / KLOE-2 data
B-boson search in $\phi \to \eta\pi^0\gamma$, $\eta \to \gamma\gamma$	KLOE/KLOE-2 data
$e^+e^- \to \omega\ \gamma_{ISR}$	KLOE data – PhD Thesis
$\eta \to \pi^+\pi^-$ (P and CP viol.)	KLOE data (paper ready, under last Collaboration refereeing) / KLOE-2 data

Branching ratio of $K_S \to \pi\mu\nu$ decay

F. Ceradini
A. Selce

Data sample: $L=1.6\ \text{fb}^{-1}$

$$\mathbf{BR(K_S \to \pi\mu\nu) = (\,4.56 \pm 0.11_{stat} \pm 0.17_{syst}) \times 10^{-4}}$$

First measurement

Physics Letters B 804 (2020) 135378

Contents lists available at ScienceDirect

Physics Letters B

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ELSEVIER

Measurement of the branching fraction for the decay $K_S \to \pi\mu\nu$ with the KLOE detector

The KLOE-2 Collaboration

D. Babusci [d], M. Berlowski [v], C. Bloise [d], F. Bossi [d], P. Branchini [s], A. Budano [r,s], B. Cao [u], F. Ceradini [r,s], P. Ciambrone [d], F. Curciarello [a,d], E. Czerwiński [c], G. D'Agostini [n,o], E. Danè [d], V. De Leo [n,o], E. De Lucia [d], A. De Santis [d], P. De Simone [d], A. Di Cicco [r,s], A. Di Domenico [n,o], D. Domenici [d], A. D'Uffizi [d], A. Fantini [p,q], P. Fermani [d], S. Fiore [t,o], A. Gajos [c], P. Gauzzi [n,o], S. Giovannella [d], E. Graziani [s], V.L. Ivanov [g,h], T. Johansson [u], X. Kang [d], D. Kisielewska-Kamińska [c], E.A. Kozyrev [g,h], W. Krzemien [v], A. Kupsc [u], P.A. Lukin [g,h], G. Mandaglio [f,b], M. Martini [d,m], R. Messi [p,q], S. Miscetti [d], D. Moricciani [d], P. Moskal [c], S. Parzych [c], A. Passeri [s], V. Patera [l,o], E. Perez del Rio [n,o], P. Santangelo [d], M. Schioppa [j,k], A. Selce [r,s,*], M. Silarski [c], F. Sirghi [d,e], E.P. Solodov [g,h], L. Tortora [s], G. Venanzoni [i], W. Wiślicki [v], M. Wolke [u]

PUBLISHED

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

Concept:

A. Gajos

First such measurement with kaons

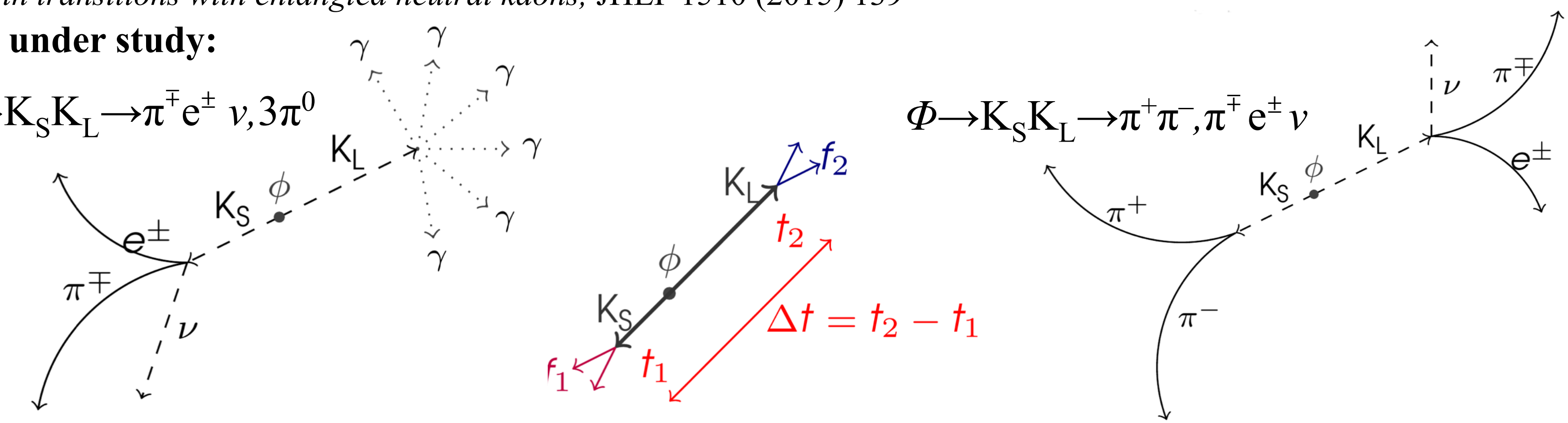
J. Bernabeu, A. Di Domenico and P. Villanueva-Perez,
Direct test of time-reversal symmetry in the entangled neutral kaon system at a Φ factory, Nucl. Phys. B 868 (2013) 102

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

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

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

CPT-violation sensitive

$$R_2^{CPT}(\Delta t) \sim \frac{I(\pi^+ e^- \bar{\nu}, 3\pi^0; \Delta t)}{I(\pi^+\pi^-, \pi^+ e^- \bar{\nu}; \Delta t)}$$

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

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

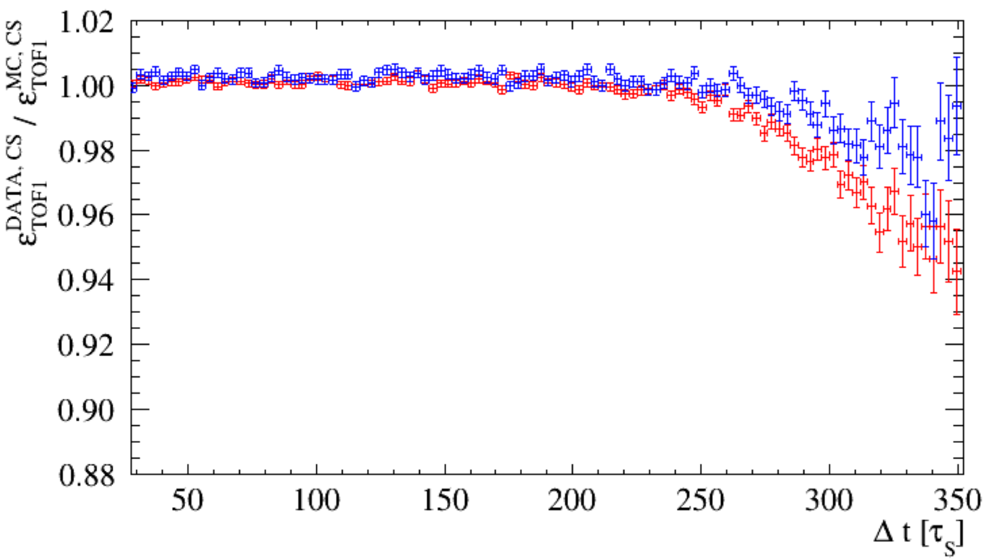
Improved understanding of Monte Carlo efficiencies related to selection of K_L decays involved in the analysis

$$R_2^T = \frac{N(\pi^+e^-,\ 3\pi^0;\Delta t)}{N(\pi\pi,\ \pi^-e^+;\Delta t)} \times \frac{\varepsilon^S(\pi\pi)\ \varepsilon^L(\pi^-e^+;\Delta t) \times C_{DATA/MC}}{\varepsilon^S(\pi^+e^-)\ \varepsilon^L(3\pi^0;\Delta t) \times C_{DATA/MC}}$$

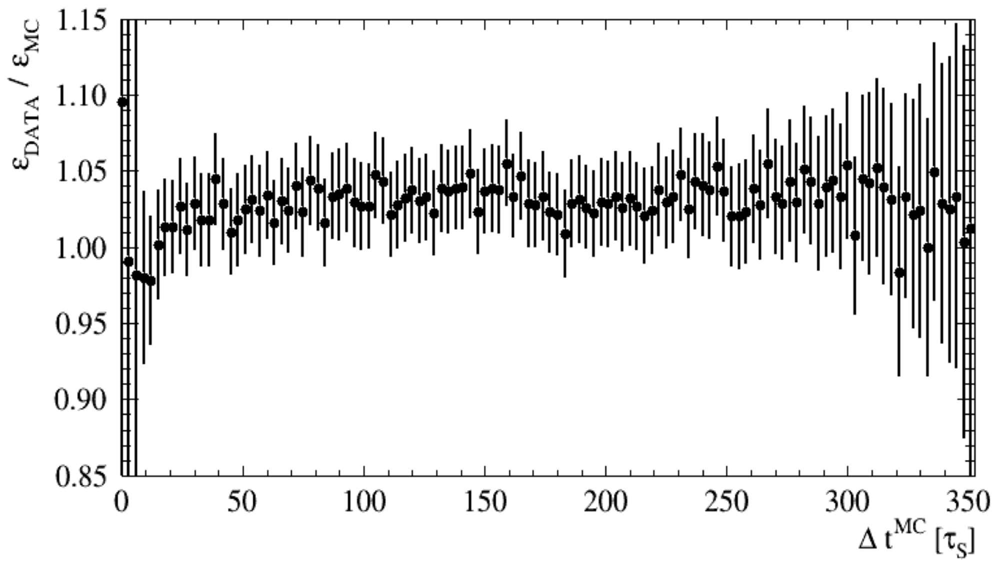
Corrections to MC-based $K_L \to \pi e \nu$ event selection efficiencies based on a control sample tagged by $K_S \to 2\pi^0$

Data-based corrections to MC efficiency of $K_L \to 3\pi^0$ selection, obtained with a control sample tagged by $K_S \to \pi^+\pi^-$

$K_S K_L \to 2\pi^0 \pi e \nu$ DATA / $K_S K_L \to 2\pi^0 \pi e \nu$ MC



$K_S K_L \to \pi^+\pi^- 3\pi^0$ DATA / $K_S K_L \to \pi^+\pi^- 3\pi^0$ MC



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

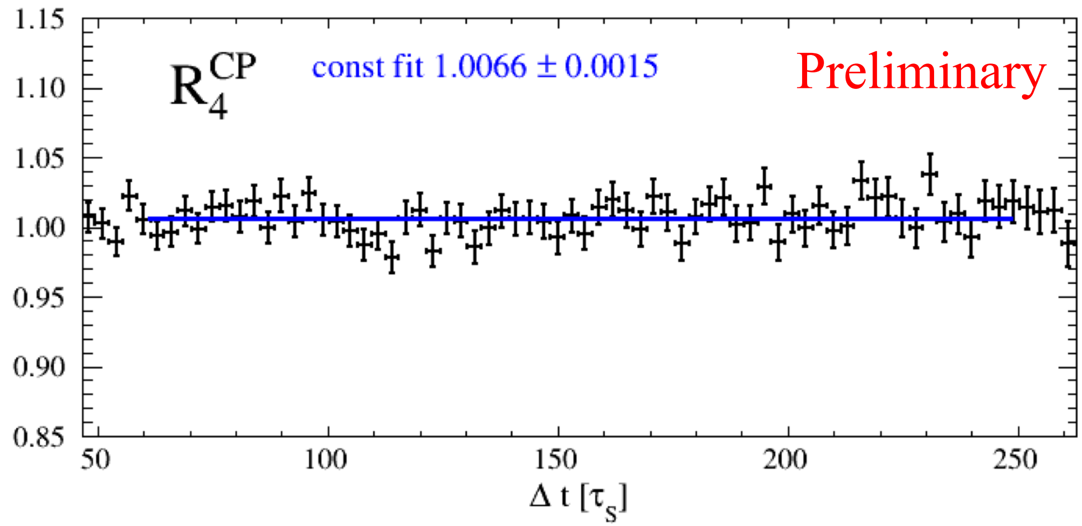
Auxiliary CP-violation sensitive observable shows control over K_L selection efficiencies

$$R_4^{CP}(\Delta t) = \frac{I(\pi^+\pi^-, \pi^- e^+ \nu; \Delta t)}{I(\pi^+\pi^-, \pi^+ e^- \bar{\nu}; \Delta t)}$$

Expected:

$$R_4^{CP}(\Delta t \gg \tau_S) = 1 + 4\Re\epsilon \approx 1.0064$$

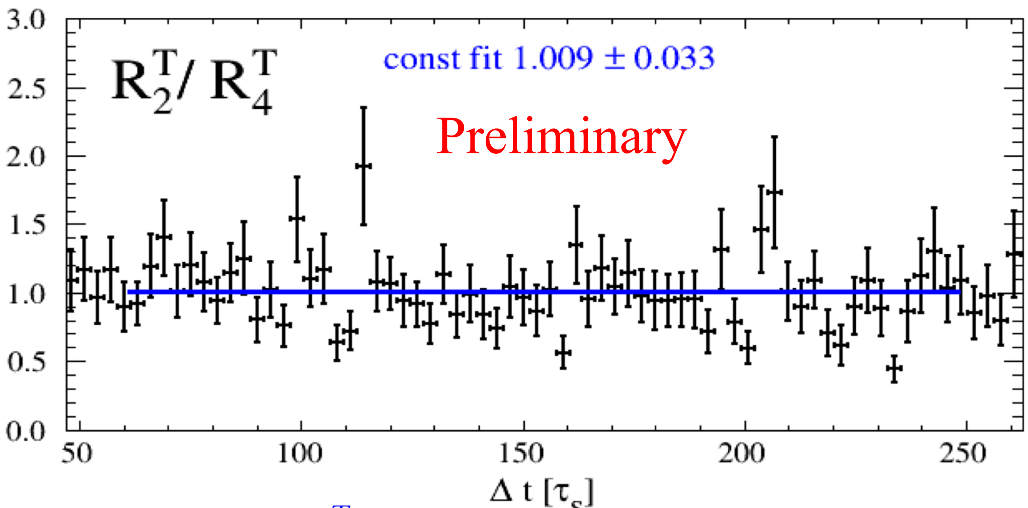
$L = 1.7\,fb^{-1}$

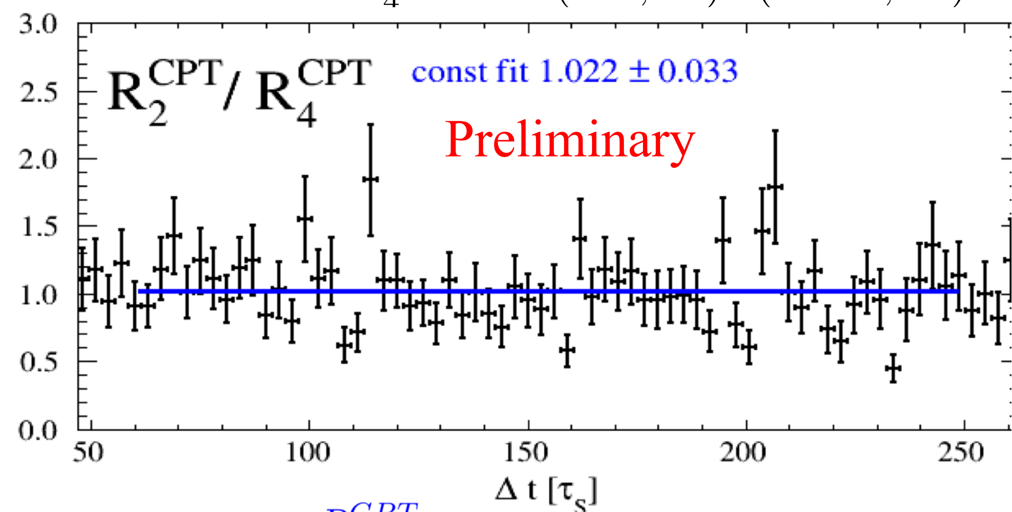


Double ratios:

T asymmetric $\dfrac{R_2^T}{R_4^T} = \dfrac{I(3\pi^0, e^-)}{I(3\pi^0, e^+)} \dfrac{I(\pi^+\pi^-, e^-)}{I(\pi^+\pi^-, e^+)}$

CPT asymmetric $\dfrac{R_2^{CPT}}{R_4^{CPT}} = \dfrac{I(3\pi^0, e^-)}{I(3\pi^0, e^+)} \dfrac{I(\pi^+\pi^-, e^+)}{I(\pi^+\pi^-, e^-)}$





Expected: $\dfrac{R_2^T}{R_4^T} \overset{\Delta t \gg \tau_S}{\cong} 1 - 8\mathrm{Re}(\epsilon)$

Expected: $\dfrac{R_2^{CPT}}{R_4^{CPT}} \overset{\Delta t \gg \tau_S}{\cong} 1 - 8\mathrm{Re}(\delta)$

Measurement of BR ($K_S \rightarrow \pi^+\pi^0\pi^-$)

$K_S \rightarrow \pi^+\pi^0\pi^-$ rare process not forbidden by CP-symmetry conservation, SM prediction BR($K_S \rightarrow \pi^+\pi^0\pi^-$) = $3.5 \cdot 10^{-7}$
BR($K_S \rightarrow \pi^+\pi^0\pi^-$) connected to the phase of the mixing parameter ϵ
No direct measurements of BR($K_S \rightarrow \pi^+\pi^0\pi^-$) available up to date
First direct measurement with 1.7 fb^{-1} KLOE data set, **achievable accuracy 30%**
Profit of K_L mesons interaction in the KLOE calorimeter to tag K_S mesons decaying to $\pi^+\pi^0\pi^-$ final state
Accuracy is expected to be improved by a factor of 2 using KLOE and KLOE-2 data samples

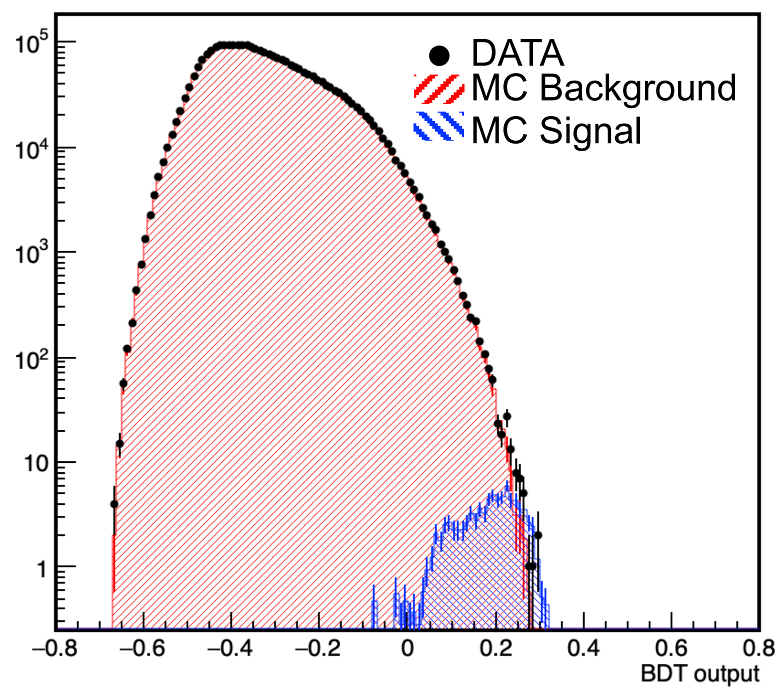
Analysis Strategy

- Preselection cuts aimed at selecting $K_S \rightarrow \pi^+\pi^0\pi^-$ decays topology
- Kinematical cuts to reject large background
- Multivariate Analysis: BDT to distinguish tiny signal and large background in data
- Fit data with MC shapes of expected signal and background : simultaneous estimation of signal events and background normalization

$K_L \rightarrow \pi^+\pi^0\pi^-$ Control Sample

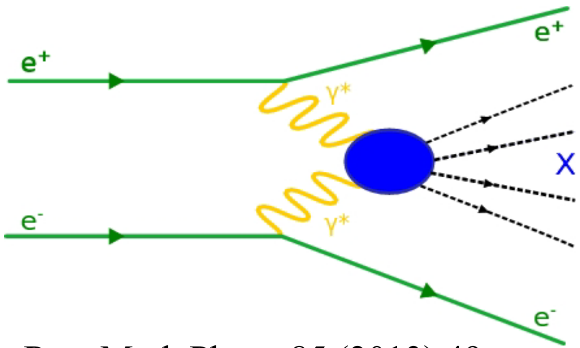
- Evaluate selection efficiencies and systematics

Fit to BDT response normalized spectra



γγ physics with High Energy Tagger (HET)

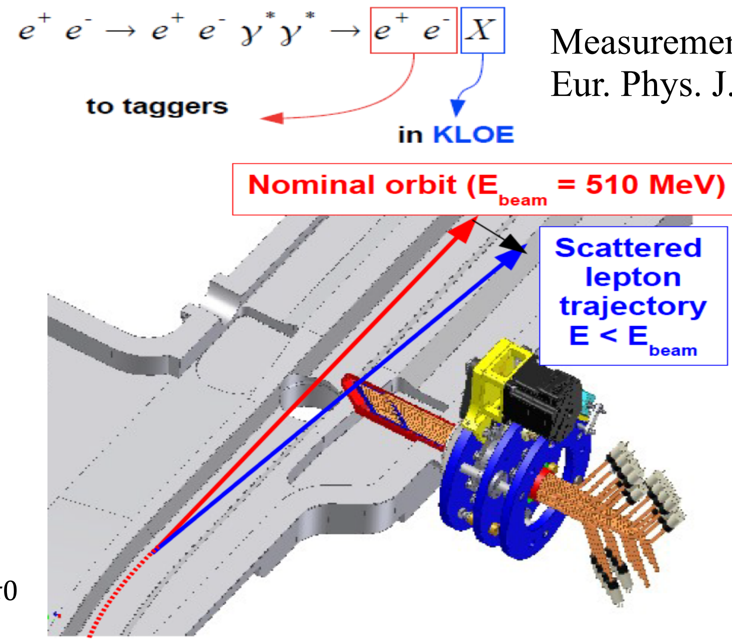
$$e^+e^- \to e^+e^-\gamma^\star\gamma^\star \to e^+e^- X$$



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

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

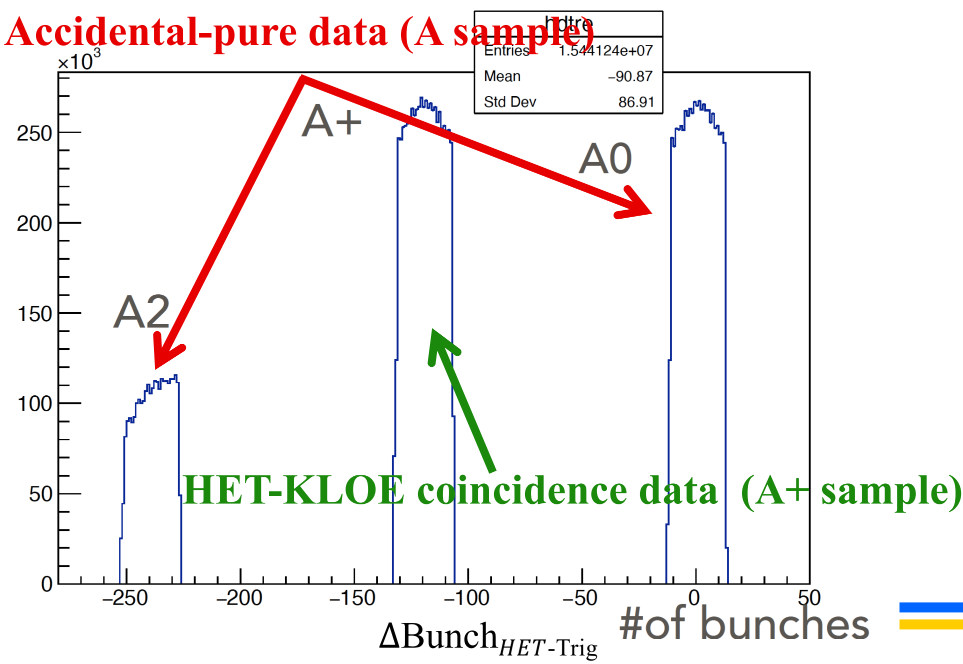
Rev. Mod. Phys., 85 (2013) 49



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

D.Babusci
C. Blosie
F. Curciarello
R. Messi
D. Moricciani

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



First bending dipoles of DAΦNE act as spectrometers for the scattered e^+/e^- ($420 < E < 495$ 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

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

The analysis cannot be based on HET-KLOE coincidence only, the uncorrelated time coincidences have to be subtracted

Signal simulation performed with EKHARA generator interfaced with Geant4 toolkit for lepton transport on DAΦNE layout

Status of $\gamma\gamma \rightarrow \pi^0$ Search

1.5fb^{-1} of data have been re-reprocessed with optmized calibration constants to improve time and energy resolutions

Single-arm selection:

-Sample of 2 clusters associated with the same bunch crossing in the KLOE barrel calorimeter

-Selected bunch crossing, and, independently selected HET signal, are in a time window of 40 ns around the KLOE trigger

-Comparison of A/A+ samples for 1fb^{-1} sample shows 3.5(0.7)k tagged events in the $M\gamma\gamma$ Vs $\Delta T\gamma\gamma$ region where π^0's from $\gamma\gamma$ fusion are expected

-Fit using A sample as background model with TfractionFitter provides coherent, stable results but background still too high

-Plans to improve measurement accuracy:

- improve modelling of the expected signal to give more credible pdfs to MVA →

feedbacks from new resolution and trigger threshold studies for low energy photons with LA radiative bhabha's control sample

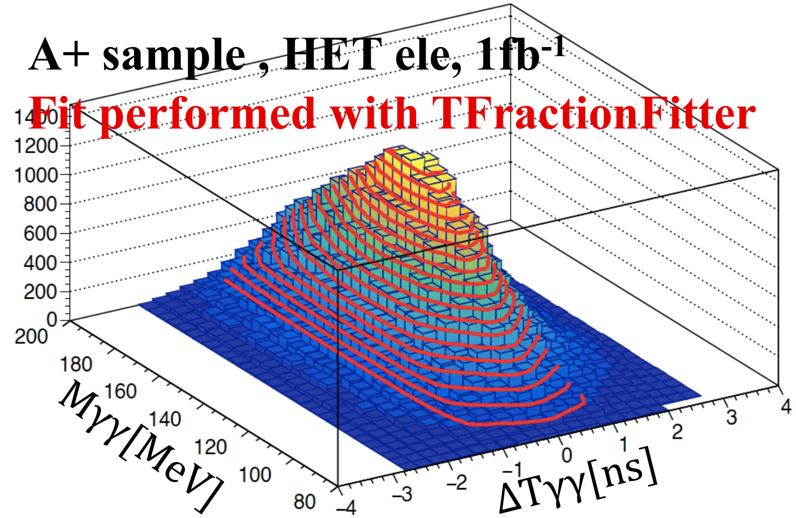
-reduce background with careful cuts considering more information on KLOE trigger

-Acceptance validation with EKHARA and BBBREM generators is in progress

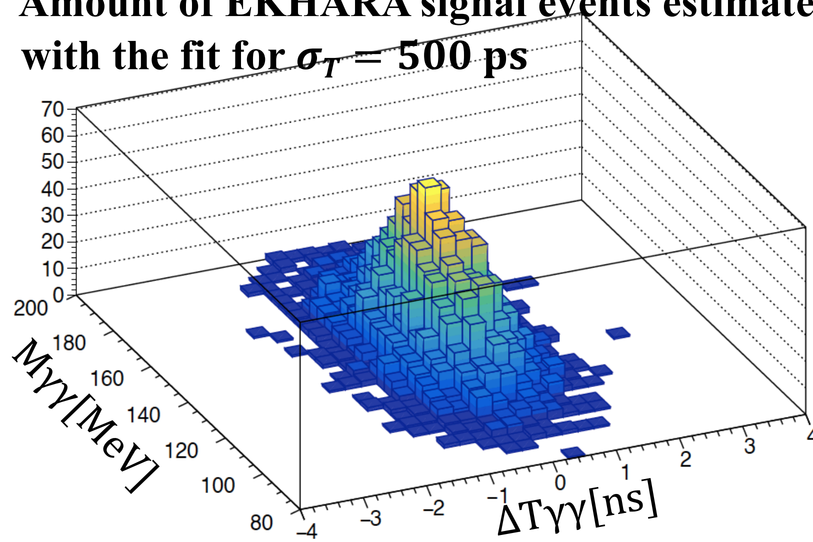
-Low angle radiative bhabha cross section measurement run by run, to use low angle raditive bhabhas as normalization channel, in progress

A+ sample , HET ele, 1fb^{-1}

Fit performed with TFractionFitter



Amount of EKHARA signal events estimated with the fit for $\sigma_T = 500$ ps



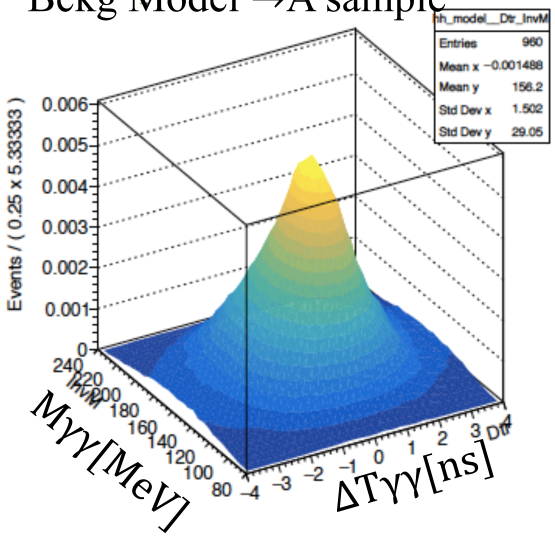
Blinding the Analysis

In the optmization of analysis cuts to improve the precision, we would avoid human biases related to the knowledge of the number of π^0 obtained

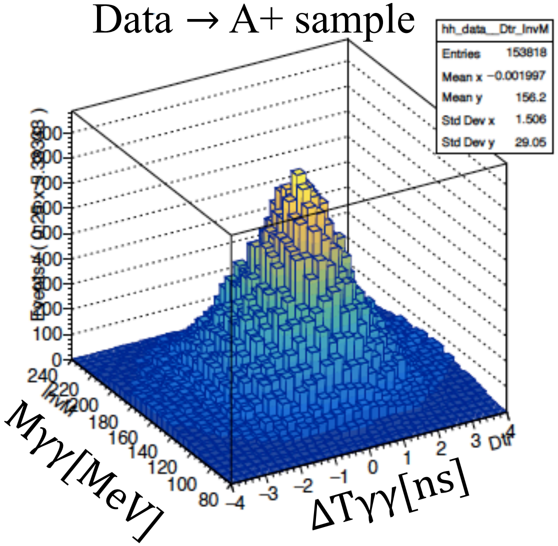
We are implementing and testing procedures to blind signal counting while mantaining any other information useful for the development of the analysis and avoiding to loose avalilable statistics

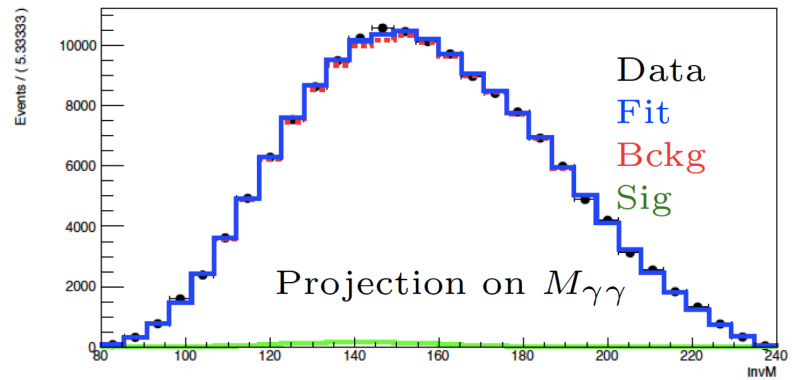
Roofit tool provides the possibility to blind fit parameters and we are evaluating the possibility to adopt it

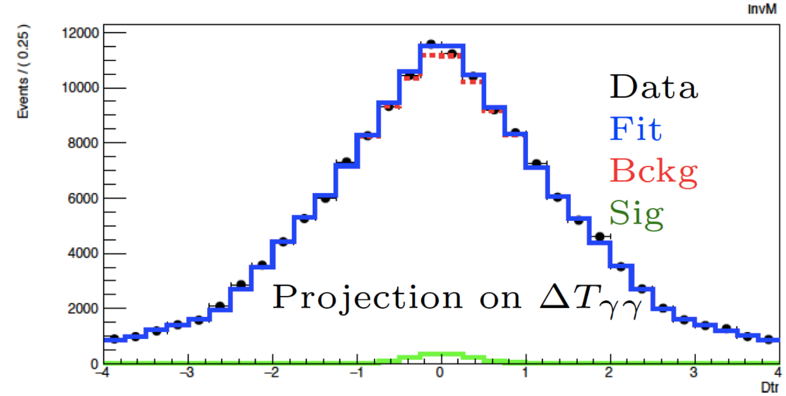
Bckg Model →A sample



Data → A+ sample



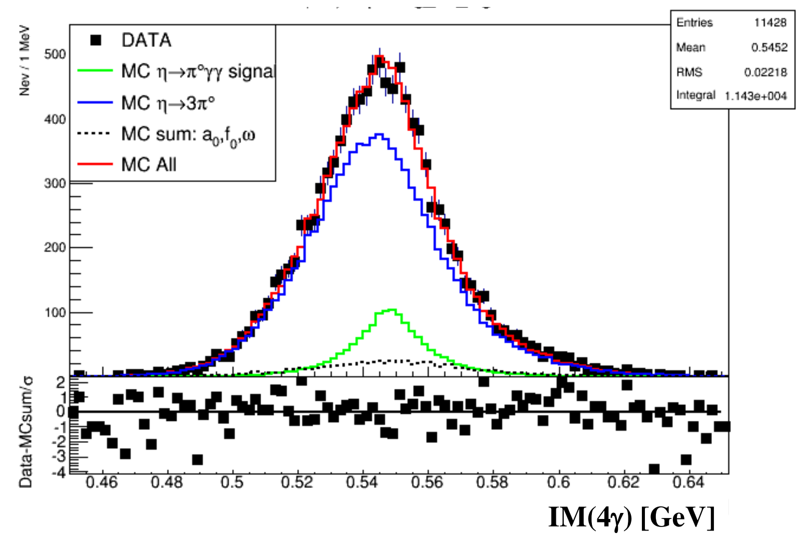




$\eta \rightarrow \pi^0\gamma\gamma$ decay

M. Berlowski

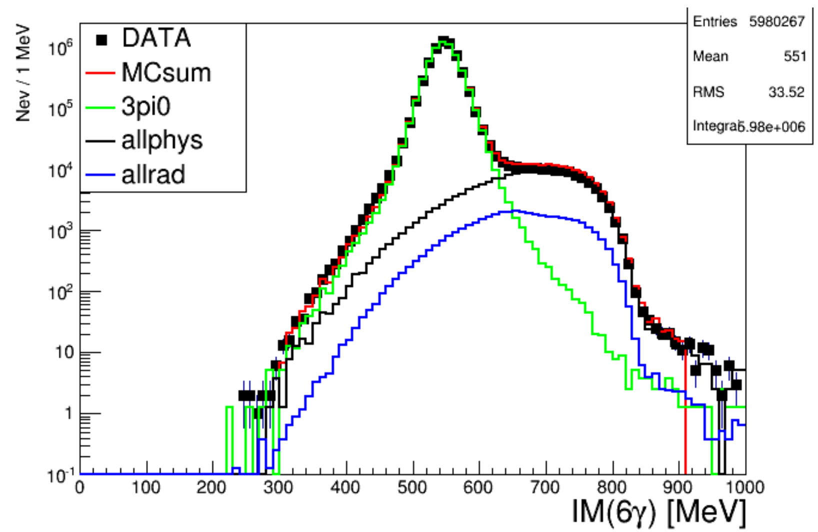
- $\eta \rightarrow \pi^0\gamma\gamma$ (from $\phi \rightarrow \eta\gamma$): χPT golden mode,
  $O(p^2)$ null, $O(p^4)$ suppressed $\Rightarrow$ sensitive to $O(p^6)$
  BR = $(22.1 \pm 2.4 \pm 4.7) \times 10^{-5}$ CB@AGS (2008)
  BR = $(25.2 \pm 2.5) \times 10^{-5}$ CB@MAMI (2014)
  Old KLOE preliminary: $(8.4 \pm 2.7 \pm 1.4) \times 10^{-5}$
  (L = 450 pb^{-1} ~ 70 signal events)



- Fit to data with signal+background MC shapes

5 prompt photon sample:

- L = 1.7 fb^{-1} of KLOE data
- Main background is $\phi \rightarrow \eta\gamma$, with $\eta \rightarrow 3\pi^0$ with lost or merged photons
- Multivariate Analysis with cluster shape variables to separate single photon from merged photon clusters
- Signal evidence on data distribution S/B~0.4 achieved with ε_S~21%
- Statistical uncertainty reduced by a factor two wrt preliminary KLOE result
- Consistency check of different fitting strategies and systematic uncertainty evaluation ongoing



- Normalization to $\eta \rightarrow 3\pi^0$ sample

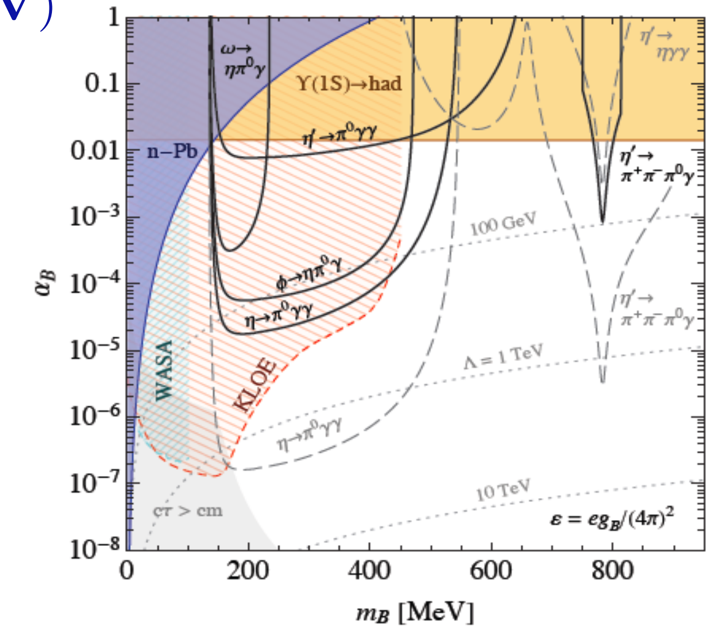
E. Perez Del Rio

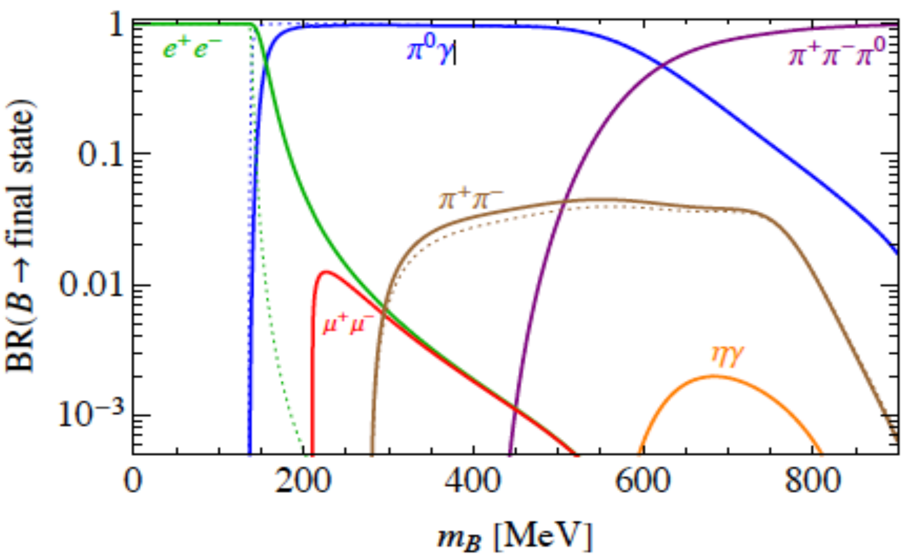
- Dark Force mediator coupled to baryon number (B-boson) with the same quantum numbers of the ω(782) ⇒ $I^G=0^-$

$$\mathcal{L} = \frac{1}{3} g_B \bar{q}\gamma^\mu q B_\mu \qquad \alpha_B = \frac{g_B^2}{4\pi} \lesssim 10^{-5} \times (m_B/100\,\text{MeV})$$

- Dominant decay channel (m_B < 600 MeV): $B \to \pi^0\gamma$
- Can be studied in:
  $\phi \to \eta B \Rightarrow \eta\pi^0\gamma \Rightarrow$ 5 prompt γ final state
  $\eta \to B\gamma \Rightarrow \pi^0\gamma\gamma$
  $e^+e^- \to \pi^0\gamma\,\gamma_{ISR}$

[Tulin, PRD89(2014)114008]





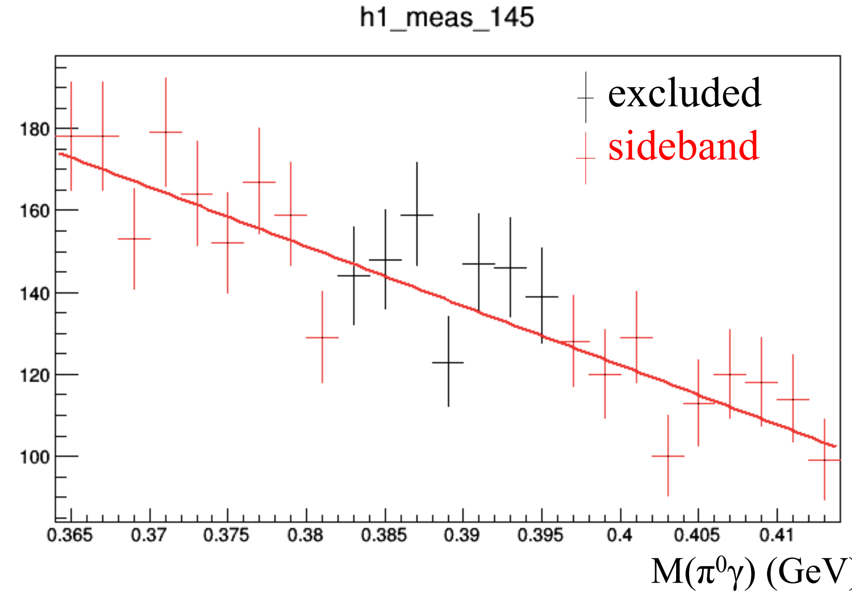
Decay → Production ↓	$B \to e^+e^-$ $m_B \sim 1 - 140$ MeV	$B \to \pi^0\gamma$ 140–620 MeV	$B \to \pi^+\pi^-\pi^0$ 620–1000 MeV	$B \to \eta\gamma$
$\pi^0 \to B\gamma$	$\pi^0 \to e^+e^-\gamma$	...	...	...
$\eta \to B\gamma$	$\eta \to e^+e^-\gamma$	$\eta \to \pi^0\gamma\gamma$	...	...
$\eta' \to B\gamma$	$\eta' \to e^+e^-\gamma$	$\eta' \to \pi^0\gamma\gamma$	$\eta' \to \pi^+\pi^-\pi^0\gamma$	$\eta' \to \eta\gamma\gamma$
$\omega \to \eta B$	$\omega \to \eta e^+e^-$	$\omega \to \eta\pi^0\gamma$	...	...
$\phi \to \eta B$	$\phi \to \eta e^+e^-$	$\phi \to \eta\pi^0\gamma$	...	

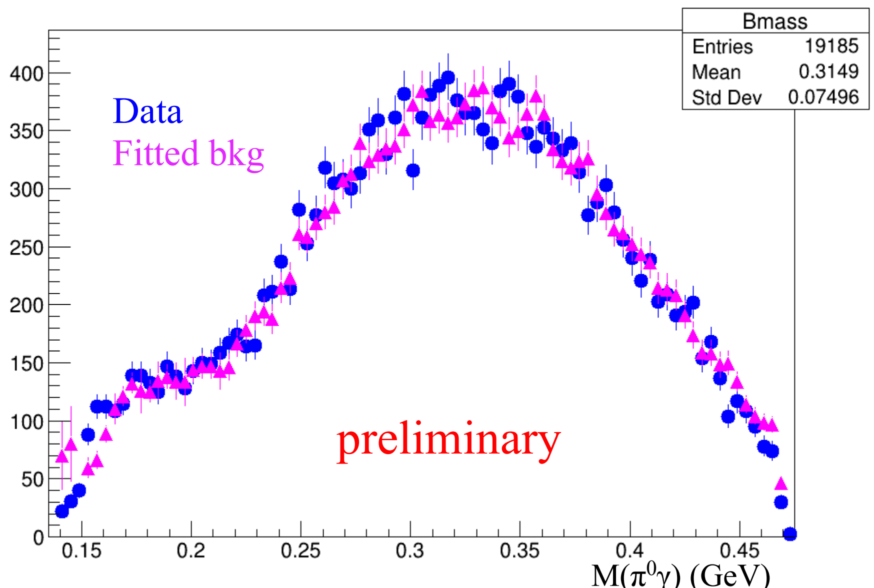
Search for the B boson

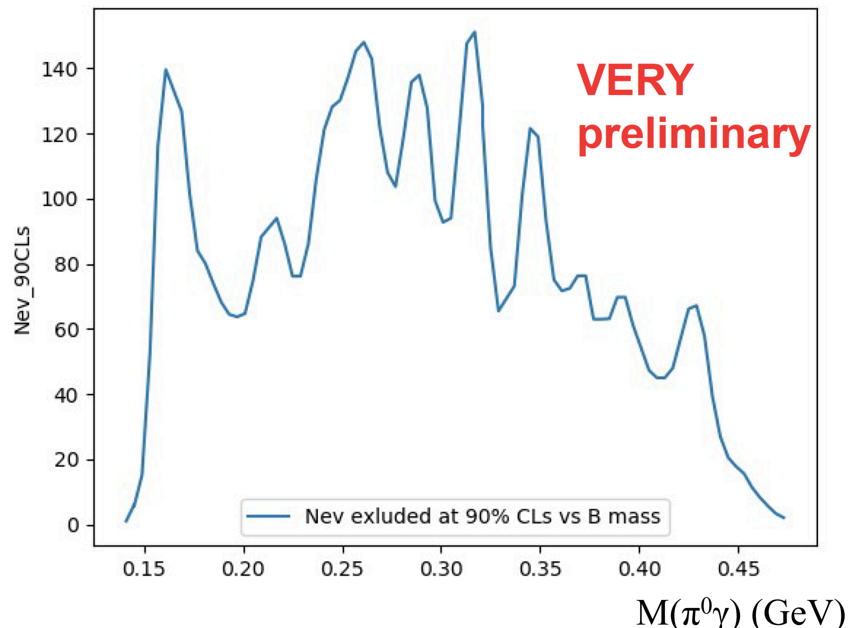
Study on ~1.7 fb^{-1} full data sample
Sidebands background extraction for Upper Limit calculation

Analysis of the systematic uncertainties ongoing

Selection of 5 prompt γ's
Kinematic fit
Main residual background from $\phi \to a0\gamma \to \eta\pi^0\gamma$ and $\phi \to \eta\gamma \to 3\pi^0\gamma$ with lost or merged photons.







Conclusions

- Final round of Data Reconstruction started on March, about 800 pb^{-1} produced with several improvements with respect to the previous version;
- Root output implemented, about 75pb^{-1} produced, integration on DB2 ongoing
- Full MC data sample produced and reconstructed with version DBV-38, need for data-quality feedbacks
- Data transfer and consolidation in advanced state, performed in background, not interfering with offline activities
- Several analysis ongoing both with KLOE and KLOE-2 samples with preliminary results presented at international conferences
- $K_{S\mu 3}$ paper published on March 2020
- Paper on $\eta \rightarrow \pi^+ \pi^-$ ready (X. Kang), under last Collaboration revision, to be submitted soon

Recommendations KLOE:

1) For the HET analysis, the committee advises to review if the current analysis strategy is adequate to ensure the result is unbiased. Now that the main experimental challenges have been understood, it would be good to review this before looking at the full dataset.

We are aware of this problem. At the present stage of the analysis,
no tuning of cuts and procedures has been performed on data while relying only on Ekhara MC.
In view of the optimization of the analysis cuts, we are implementing a procedure to blind the signal counting.
Presently we have started testing the ROOFIT method.

2) In general, the committee emphasizes that it is important to focus on the journal publication rather than preliminary results. It might be useful to explore if the time between "having the result" and publishing it can be further reduced.

Triggered by this specific recommendation, we critically reviewed our internal rules (firmly established in the KLOE/KLOE-2 collaboration since long time) and the process which brings an analysis to yield first a public preliminary result and subsequently a final result for publication in a peer-reviewed journal.

Considering the chronic problem of lack of manpower, which has even worsened in the last times, we believe that in general little can be done to speed-up this process while keeping lively the scientific discussion of a result inside the collaboration, and maintaining the high scientific quality of KLOE-2 publications.

To this aim, we have identified and implemented a more active role of internal reviewers in gathering comments and suggestions to the authors that might speed-up the path towards publications.