Status of KLOE-2

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on behalf of the KLOE-2 collaboration

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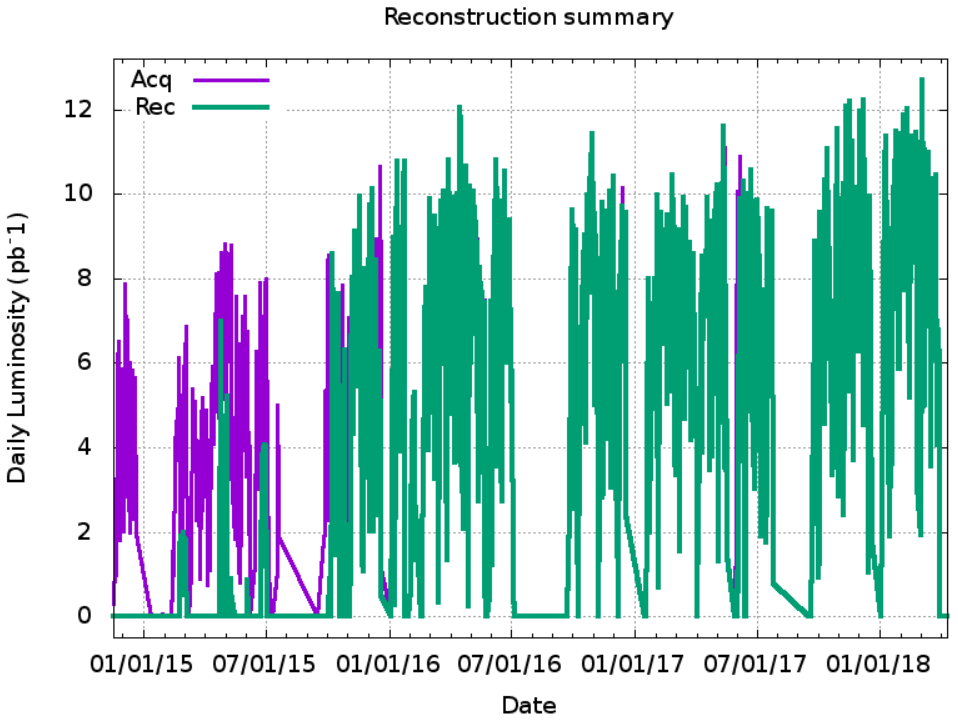
Summary

- Reconstruction and MC summary
- Data consolidation
- Data recovery strategy
- Ongoing Analyses
  - Report of the most recent updates and summaries of KLOE/KLOE-2 analyses

Data reconstruction

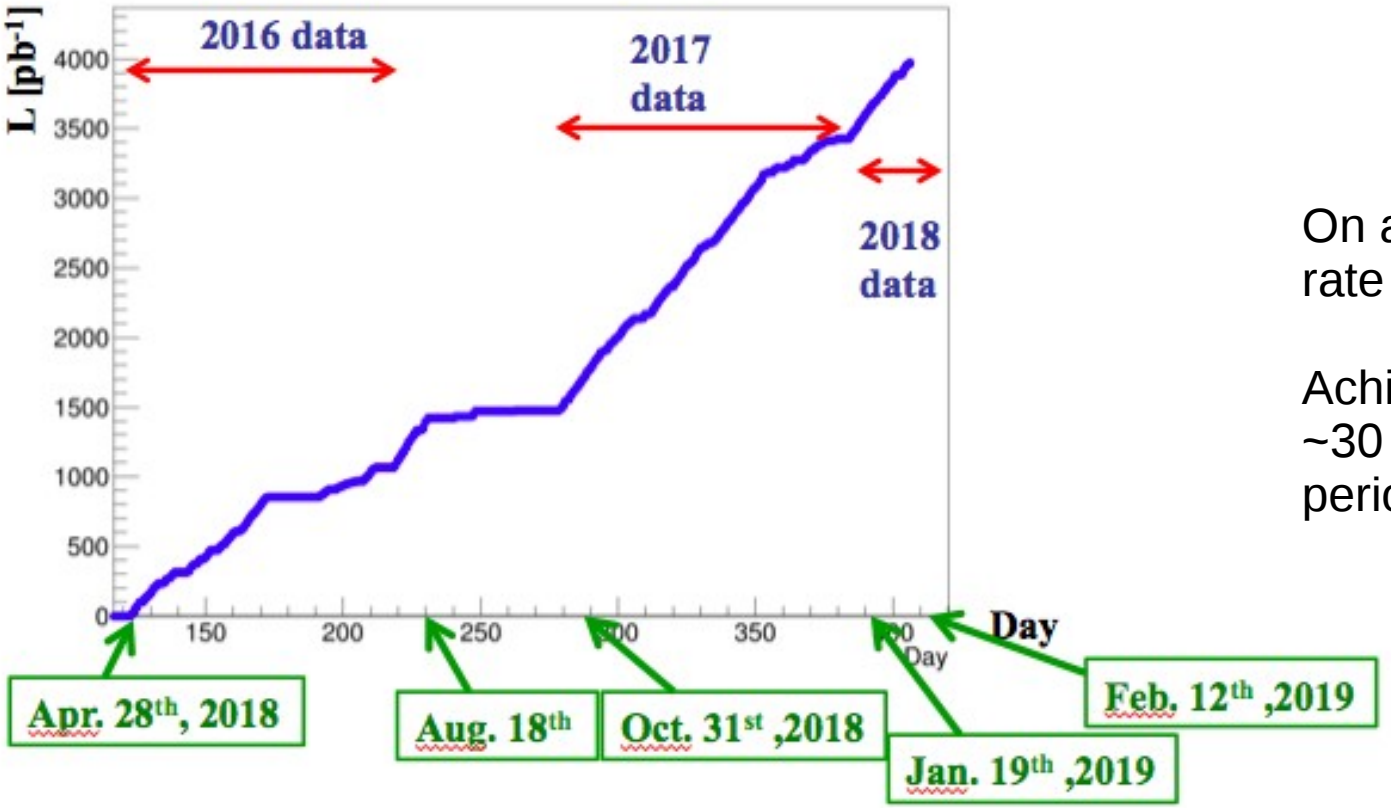
- Reconstruction with DBV-38 finished in February 2019
  - 4 fb^{-1} reconstructed with DBV-38
  - Average reconstruction rate ~20 pb^{-1}/day
- Data Quality performed on this sample
- New reconstruction development version DBV-39 work ongoing
- Prod2root: root output for data preservation
  - Test & official code implementation ongoing
- Start final reconstruction June/July 2019

- MC version 2.0.1 with DBV-38
- Production rate ≈ 15 pb^{-1}/day (in parallel with the data reconstruction)
- All Phi decays produced along with bhabha sample
- MC production 2.3 fb^{-1} available
- Version 2.1.0 developed
  - Data/MC crosscheck
  - Fine tuning of the detectors performances



	Run I	Run II	Run III	Run IV
Lum. Int.	0.7 fb-1	1.4 fb-1	1.6 fb-1	1.3 fb-1
Lum. Reconst.	0.03 fb-1	1.2 fb-1	1.6 fb-1	1.3 fb-1

Data reconstruction with DBV-38



On average reconstruction rate ~20pb^{-1}/day

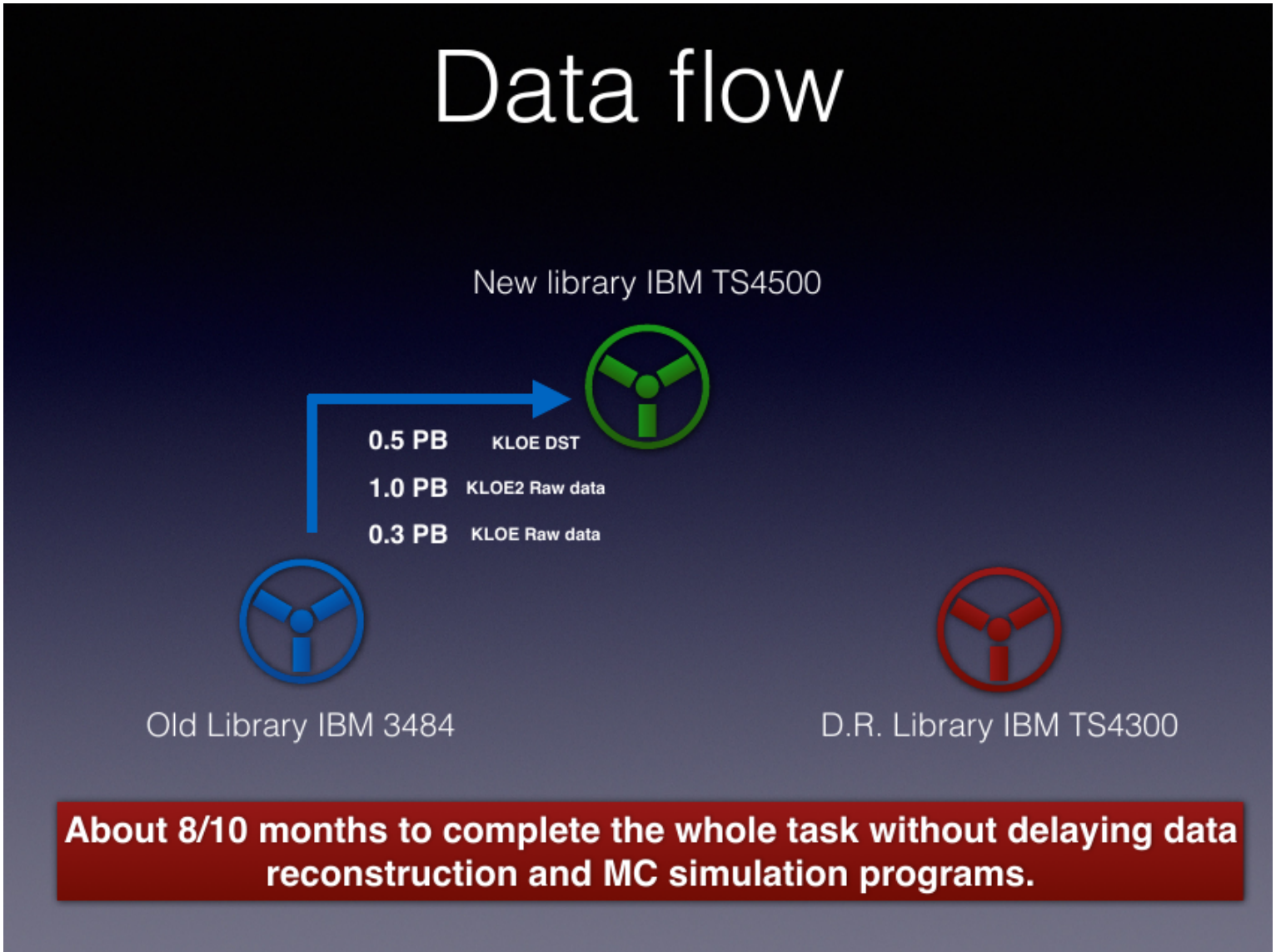
Achieved peak rate of ~30 pb^{-1}/day in the last period

The first massive reconstruction was completed by February 2019
We reconstructed the 4 fb^{-1} sample in about 10 months

Data consolidation

Old library data is to be moved to the new library and also to the Disaster Recovery unit

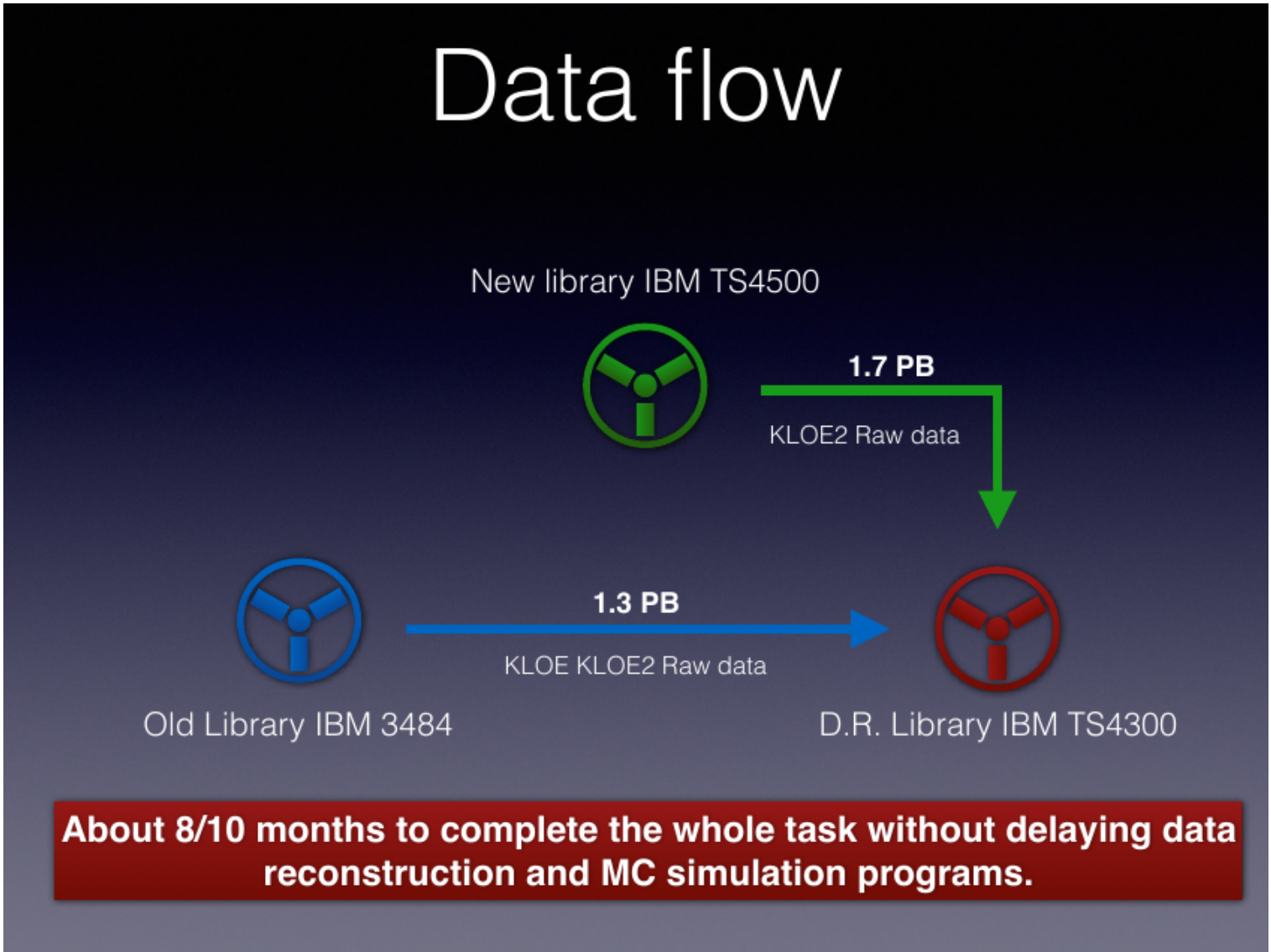
Copying strategy to the new library with priorities: KLOE dst, KLOE-2 raw, KLOE raw ...



Data recovery strategy

Old library data is to be moved to the new library and also to the Disaster Recovery unit

At the same time the raw KLOE and KLOE-2 samples will be copied to the D.R. unit



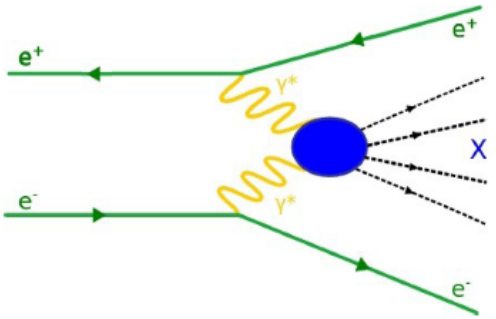
Ongoing Analyses

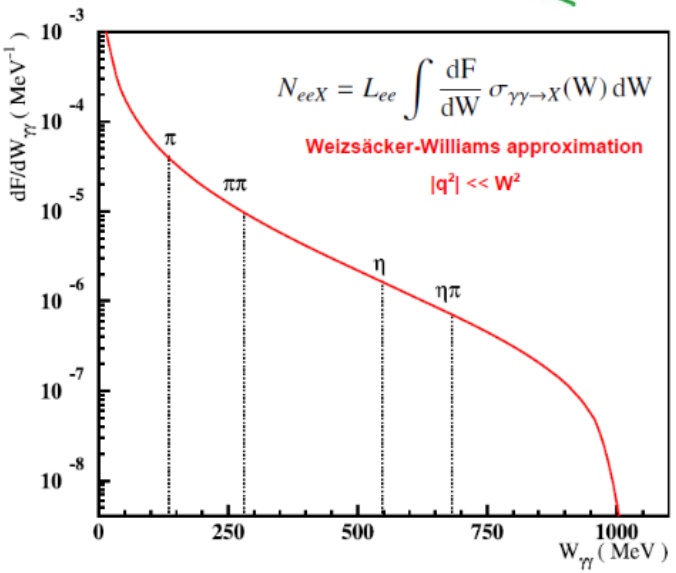
$\gamma^*\gamma^* \rightarrow \pi^0$	KLOE-2 data
$K_S \rightarrow \pi\nu e$ K_L crash	KLOE-2 data
$K_S \rightarrow \pi^+\pi^-$ $K_L \rightarrow \pi^+\pi^-$	KLOE-2 data
$K_S \rightarrow 3\pi^0$ (CP viol.)	KLOE-2 data / KLOE data NN studies
T/CPT test with $\varphi \rightarrow K_S K_L \rightarrow 3\pi^0\, \pi\nu e$, $\pi\pi\, \pi\nu e$	KLOE data: PhD thesis
$K_S \rightarrow \pi\nu e$; $K_S \rightarrow \pi\mu\nu$	KLOE data: PhD thesis
$K_S \rightarrow \pi^+\pi^-\pi^0$	KLOE data
B-boson search in $\varphi \rightarrow \eta\pi^0\gamma$	KLOE/KLOE-2 data
$\eta \rightarrow \pi^0\gamma\gamma$ χ-PT golden mode + B boson search	KLOE/KLOE-2 data
$\eta \rightarrow \pi^+\pi^-$ (P and CP viol.)	KLOE/KLOE-2 data
$e^+e^- \rightarrow \omega\gamma_{ISR}$	KLOE data

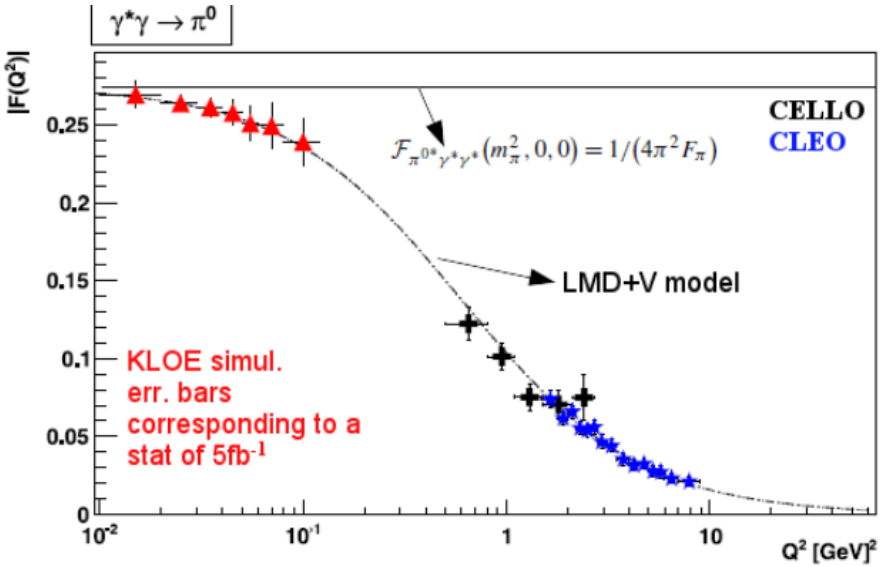
$\gamma^*\gamma^* \rightarrow \pi^0$ HET analysis

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

for quasi-real photons $J^{PC}(X) = \{0^{\pm,+}, 2^{\pm,+}\}$
$\rightarrow X = \{\pi^0, \pi\pi, \eta\}$

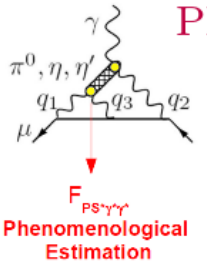






Physics goal:

- Precision measurement (1%) of the $\Gamma_{\pi^0\rightarrow\gamma\gamma}$
  $\Gamma^{Th.}_{\pi^0\rightarrow\gamma\gamma} = 8.09 \pm 0.11$eV (1.4% precision)
  $\Gamma^{Exp}_{\pi^0\rightarrow\gamma\gamma} = 7.82 \pm 0.22$ (2.8% precision, via Primakoff Effect, most precise measurement);
- First measurements of the $F_{\pi^0\gamma^\star\gamma}(q^2, 0)$ in the space-like region for $q^2 < 0.1\,\mathrm{GeV}^2$



Physics motivation:
impact on the value and precision of the $a_\mu^{LbyL;\pi^0}$

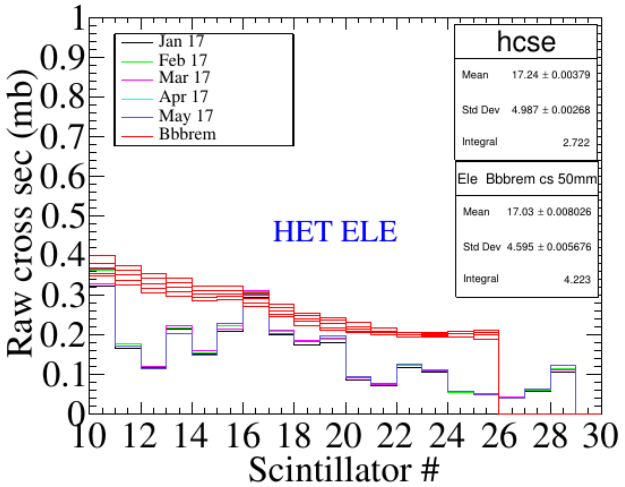
$\gamma^*\gamma^* \rightarrow \pi^0$ HET analysis

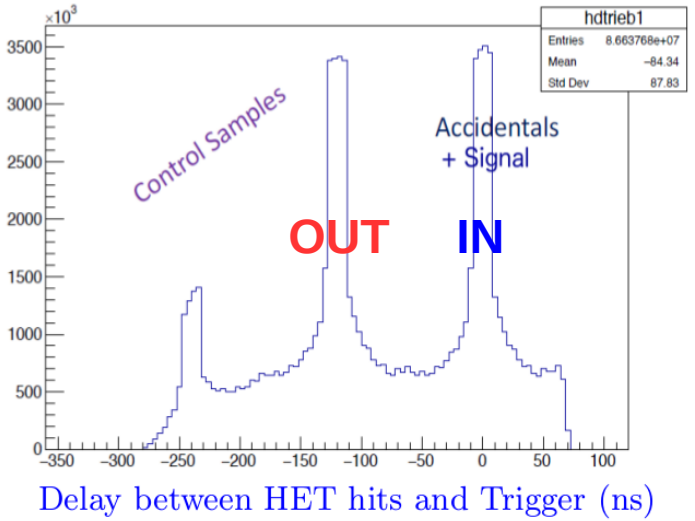
- Independent analysis
- Data sample: 500 pb^{-1} (+ 700 pb^{-1} reconstructed data with analysis ongoing)
- Reconstruction is ongoing for the whole sample
- Data is stored in root format
- Three levels of data reduction applied

Analysis strategy
Hits in one HET station and at least one bunch in KLOE associated with only 2 clusters in the EMC

Data Quality performed over the whole KLOE-2 sample
To undertsand the stability of the period
Bhabha online luminosity and raw cross section measured by KLOE to obtain σ x A x ε
Stability of the plastic scintillators studied → most stable channels used to perform the π^0 analysis

HET and KLOE data are acquired asynchronously. HET acquisition time 2.5 times larger than KLOE → out-coincidence (HET only) sample + in-coincidence sample → background subtraction

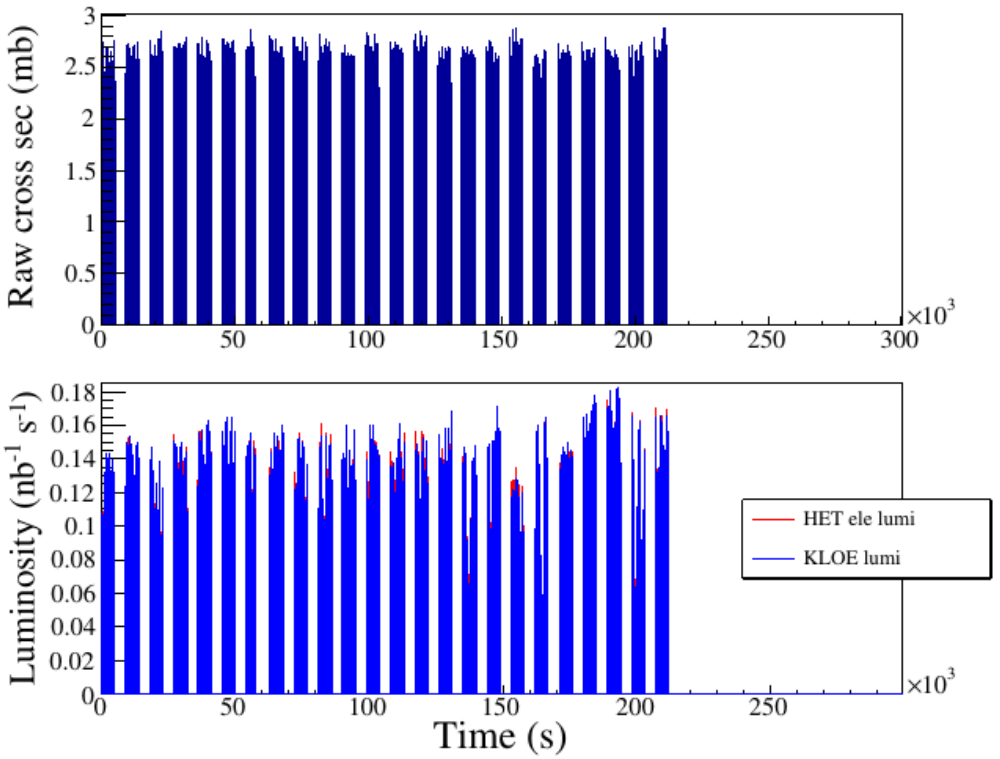




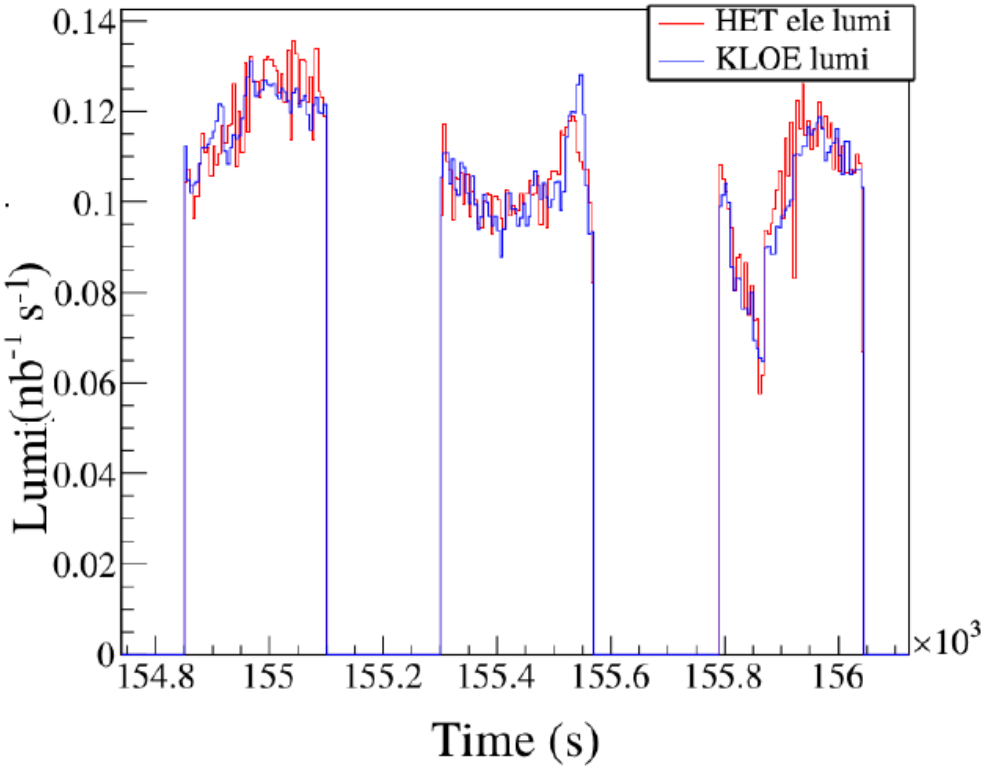
$\gamma^*\gamma^* \rightarrow \pi^0$ HET analysis

24 runs acquired from January to May 2017 for HET ele, plast ≥ 11

Stability of raw cross section per second (up) lumi timeline (bottom)



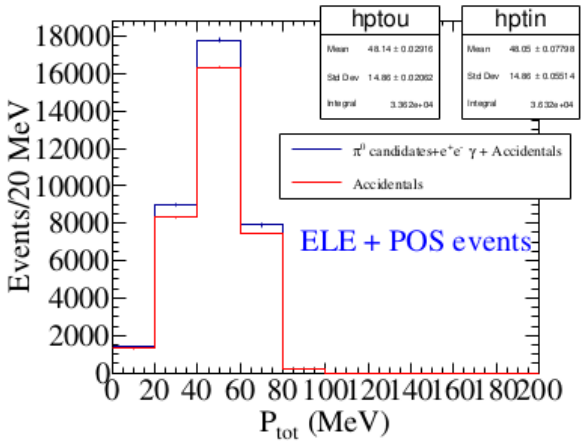
Luminosity pattern measured by HET and KLOE



$$\mathcal{L}\,[\mathrm{nb}^{-1}\mathrm{s}^{-1}] = (\mathrm{Rate} \times 10^3)/(\mathrm{Trigrate} \times \sigma[\mathrm{mb}] \times 2 \times 120 \times 2.712[\mathrm{ns}])$$

$\gamma^*\gamma^* \rightarrow \pi^0$ HET analysis

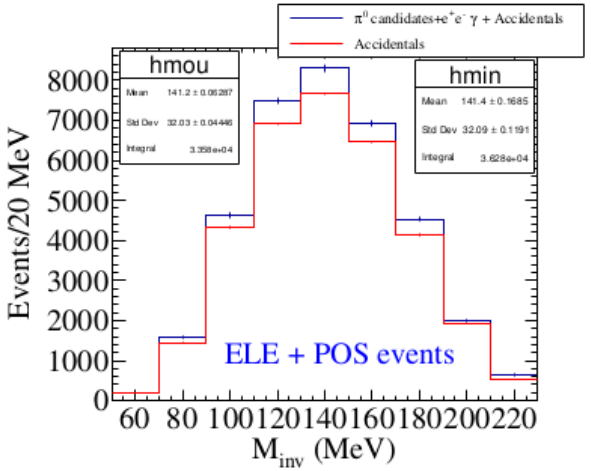
Ptot distributions of coincidence and out-of-coincidence events

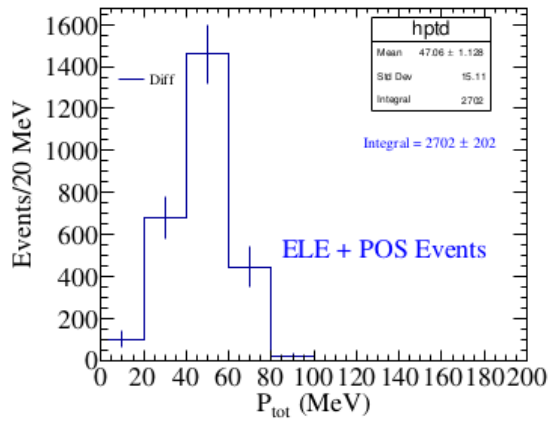


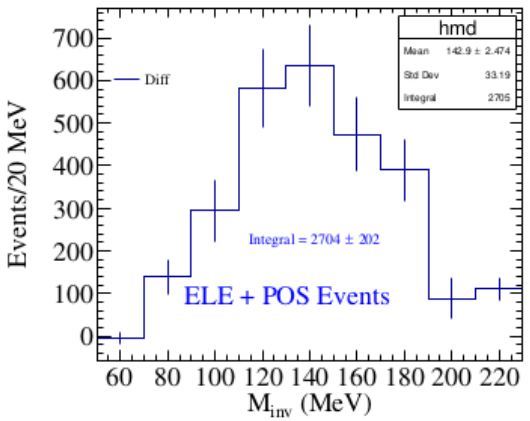
OUT

IN

$M_{\gamma\gamma}$ distributions of coincidence and out-of-coincidence







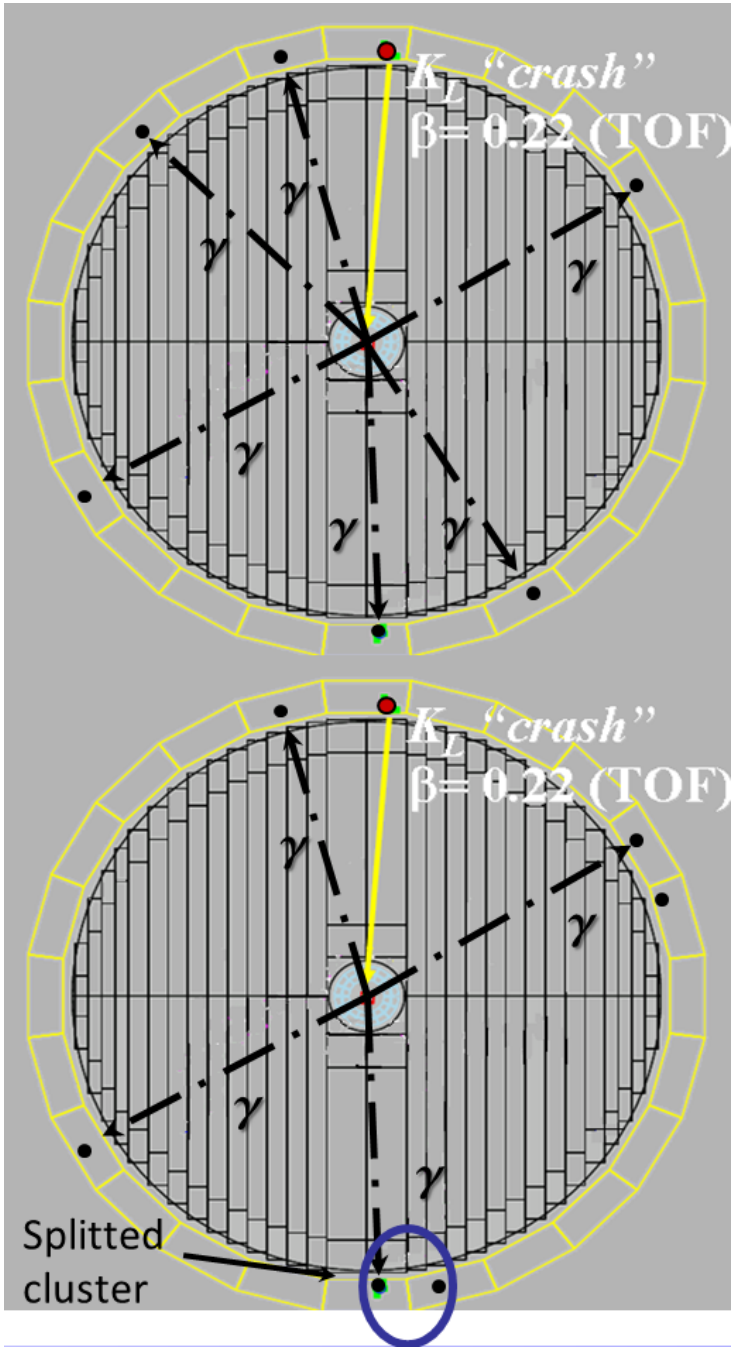
$\gamma^*\gamma^* \rightarrow \pi^0$ signal is expected at low P_{tot} of the 2γ

From the TMVA studies we understand that radiative Bhabha's events are on top of the signal events

Identification of the background events work in progress

$K_S \rightarrow 3\pi^0$

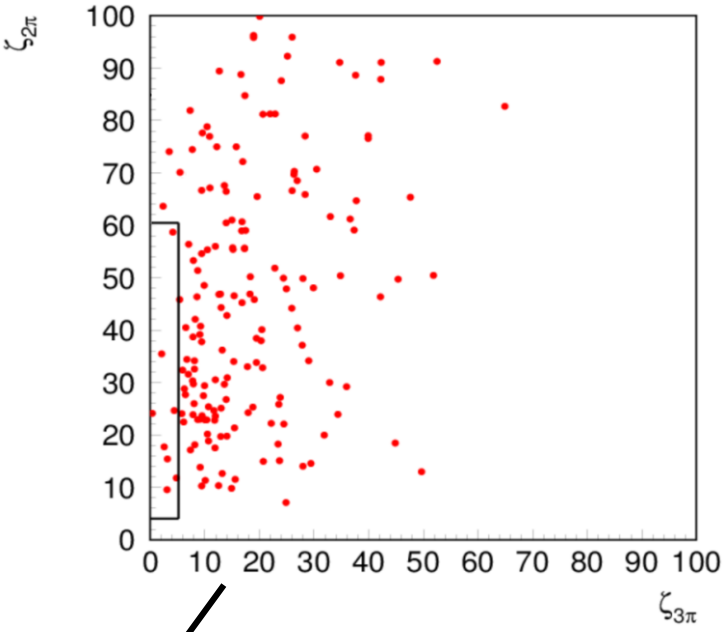
- Data sample: KLOE-2 data (~1.5 fb^{-1})
  + corresponding MC simulations
- Preselection with the following requirements:
  - K_L-crash: E>150 MeV, $0.2 < \beta < 0.225$
  - prompt photons: $E_{cl} > 20$ MeV; $|\cos\theta_{cl}| \leq 0.915$ and $|\Delta T_{cl}| \leq \text{Min}(3 \cdot \sigma_T(E_{cl}), 2\ \text{ns})$
  - $K_S \rightarrow 2\pi^0$ (4 prompt photons) used for normalization
  - Main background source: $K_S \rightarrow 2\pi^0$ with two additional clusters (shower splitting/accidentals)



Cut-based analysis:

- **Track Veto:** rejection events with at least one reconstructed track from the IP
- **Kinematic fit:** K_S mass, total 4-momentum conservation, consistency between the measured time and position of each cluster

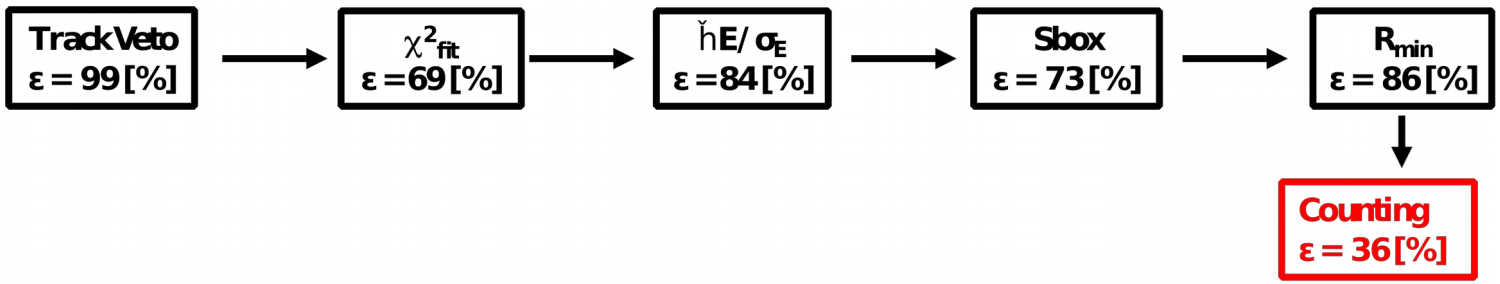
$K_S \rightarrow 3\pi^0$



- **$\Delta E/\sigma_E = (E_{Ks} - \Sigma E_\gamma)/\sigma_E$ cut:** consistency between the K_S energy reconstructed by tagging and the sum of energies of four „best" photons
- **Signal region definition:**

  $\zeta^2_{2\pi}$ - pairing of 4 out of 6 photons (π^0 masses, E_{Ks}, P_{Ks}, angle between π^0's)

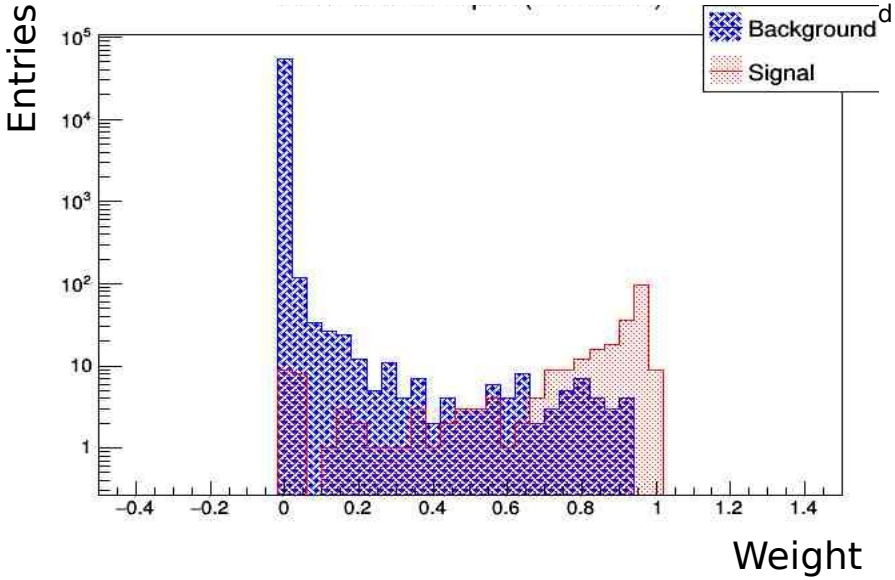
  $\zeta^2_{3\pi}$ - pairing of 6 clusters with best π^0 mass estimates
- **R_{min}** : the minimum distance between clusters



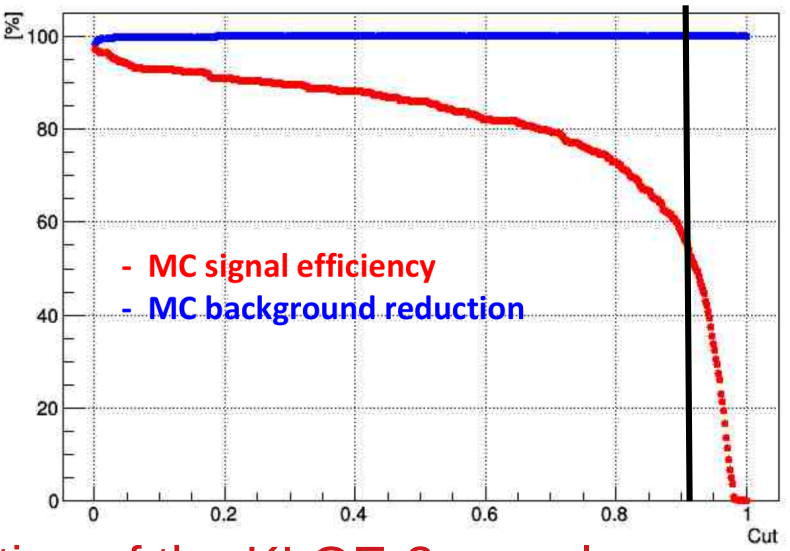
- Refinement of the MC selection is in progress. Zero candidates from MC imposing additional conditions reduces the efficiency to 29%.

$K_S \rightarrow 3\pi^0$

- In parallel MVA analysis has been started
- Feasibility studies on the 2004 – 2005 KLOE data (1.7 fb^{-1})
- Preselection with K_L-crash & acceptance as in the cut-based analysis
- Data reduction with R_{min}
- Training done with all the other discriminant variables
- Analysis optimized with Monte Carlo resulted in N_{exp}=0 candidates in data and N_{MC}=0 events expected from simulations



- The analysis efficiency increases by almost a factor of two with respect to the 2013 measurement
- This result corresponds to two times lower upper limit on BR($K_S \rightarrow 3\pi^0$) than previously published with the same data sample [PLB723(2013)54]



The present study aims to improve the selection of the KLOE-2 sample

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

Direct tests of the T and CPT symmetry
by comparison of rates
of the following processes:

- $\Phi \to K_S K_L \to \pi e \nu, 3\pi^0$
- $\Phi \to K_S K_L \to \pi^+\pi^-, \pi e \nu$

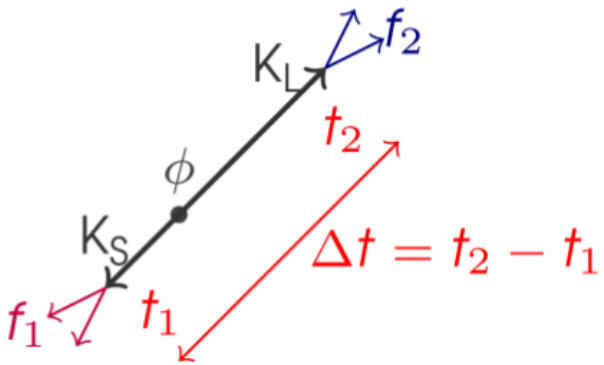
- J. Bernabeu, A. Di Domenico and P. Villanueva-Perez, *Direct test of time-reversal symmetry in the entangled neutral kaon system at a Φ factory*, Nucl. Phys. B 868 (2013) 102
- J. Bernabeu, A. Di Domenico and P. Villanueva-Perez, *Probing CPT in transitions with entangled neutral kaons*, JHEP 1510 (2015) 139

Observables (Focusing on the asymptotic region $\Delta\tau >> \tau_S$):

T-violation sensitive:

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

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



CPT-violation sensitive:

$$R^{exp}_{2,\mathcal{CPT}}(\Delta t) = \frac{I(\pi^+ e^- \bar{\nu}, 3\pi^0; \Delta t)}{I(\pi^+\pi^-, \pi^+ e^- \bar{\nu}; \Delta t)}$$

$$R^{exp}_{4,\mathcal{CPT}}(\Delta t) = \frac{I(\pi^- e^+ \nu, 3\pi^0; \Delta t)}{I(\pi^+\pi^-, \pi^- e^+ \nu; \Delta t)}$$

Double ratios:

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

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

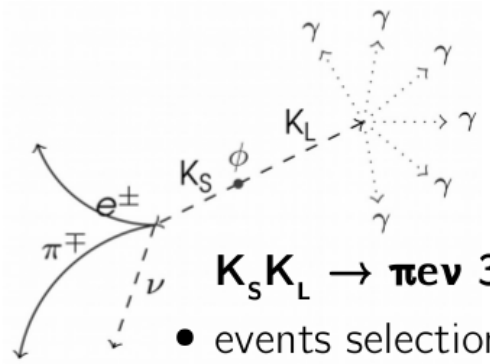
CP-violation sensitive (auxilliary):

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

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

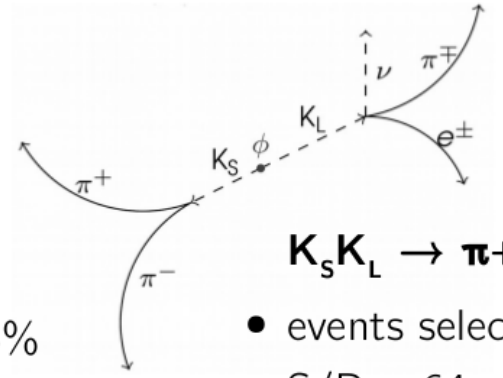
T/CPT test with $\varphi \to K_S K_L \to 3\pi^0\, \pi\nu e,\ \pi\pi\ \pi\nu e$

Event subsample selection:



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

- events selection efficiency ~10.5%
- S/B = 28



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

- events selection efficiency ~14 %
- S/B = 64

- Division of each process in 2 subsamples by lepton charge
- Estimation of the selection efficiency using control samples

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

$K_S \to \pi e \nu$ K_L(EMC)

$K_S K_L \to \pi^+\pi^-\ 3\pi^0$

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

$K_S \to \pi^+\pi^-$ K_L(EMC)

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

- Calculation of single and double T and CPT asymmetry ratios
- Constant fit of the ratios to the region $\Delta t >> \tau_S$

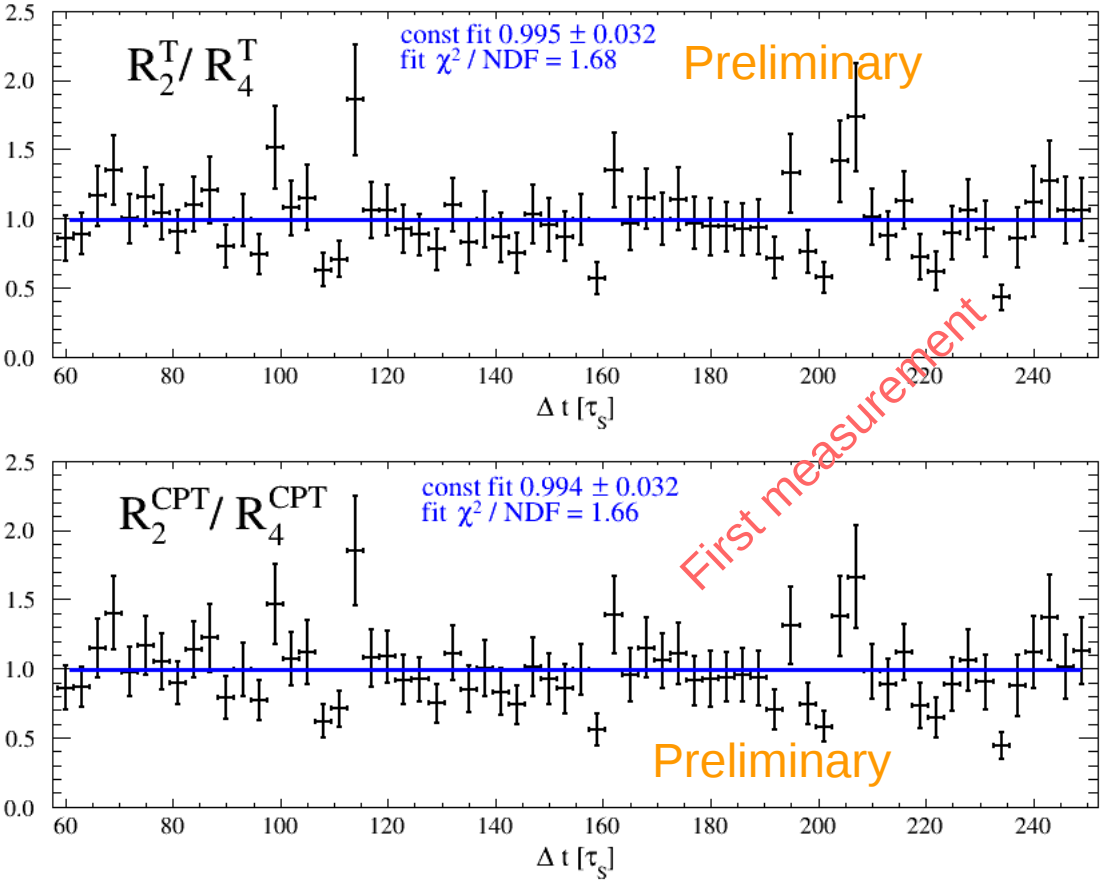
T/CPT test with $\varphi \to K_S K_L \to 3\pi^0\,\pi\nu e,\ \pi\pi\,\pi\nu e$

T asymmetric R_2^T / R_4^T

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

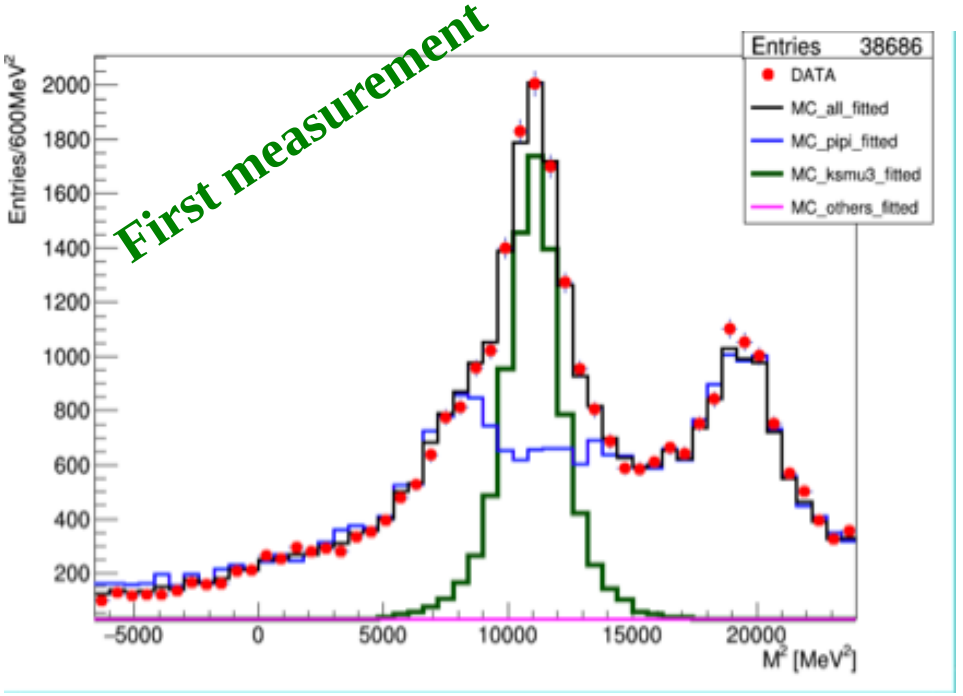
CPT asymmetric R_2^{CPT} / R_4^{CPT}

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



$K_S \rightarrow \pi\mu\nu$

- **First measurement** of Ks →πμν Branching Ratio
  - 7223 events from 1.6 fb^{-1}
  - Expected value Br(KSμ3) = (4.69 ± 0.05)×10^{-4} [from KLOE + KTeV + e/mu universality]
- Lepton universality test
- Uncertainties preliminary measurement
  - 2.5 % stat ± 3.1 % sys
- Analysis is almost finished
  - final checks on some systematic uncertainties ongoing



M^2_μ [MeV²]

[1] KTeV Collaboration, T. Alexopoulos, et al., Phys. Rev. D 70 (2004) 092007.

B-boson searches

- B boson couples mainly to quarks
- Most basic model → coupling to baryon number

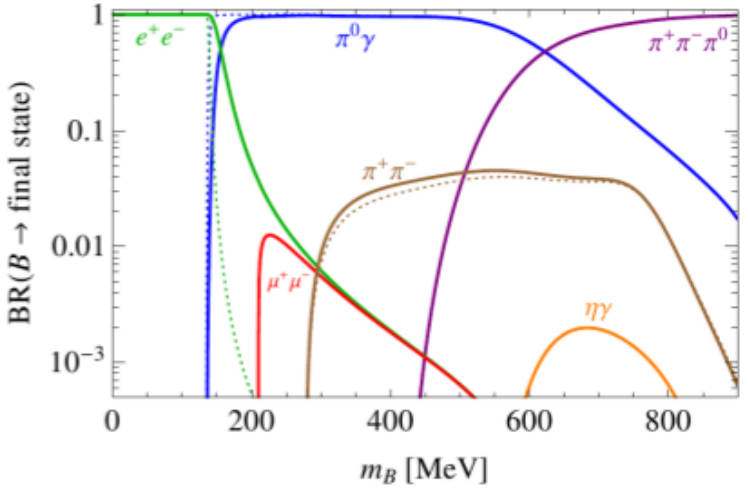
$$\mathscr{L} = \frac{g_B}{3}\,\bar{q}\gamma^{\mu} q B_{\mu}$$

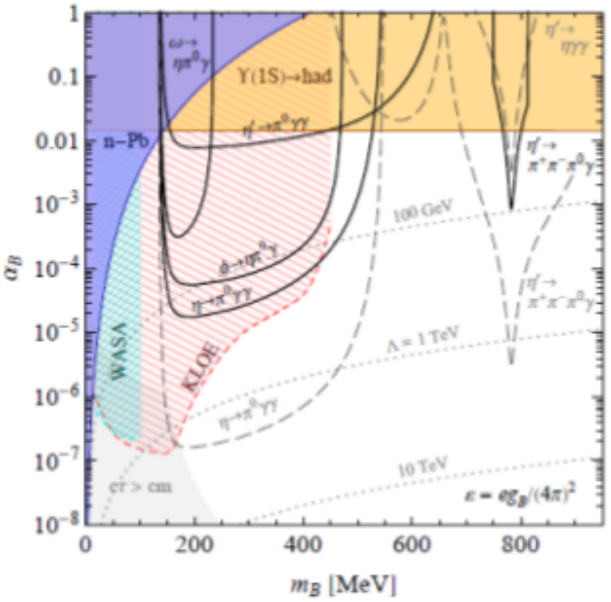
- Discovery signal depends on mass m_B

$$g_B \lesssim 10^{-2} \times (m_B/100\ \text{MeV})$$

$$\alpha_B = \frac{g_B^2}{4\pi} \lesssim 10^{-5} \times (m_B/100\,\text{MeV})^2$$

S. Tulin (Phys. Rev. D 89, 114008 (2014))





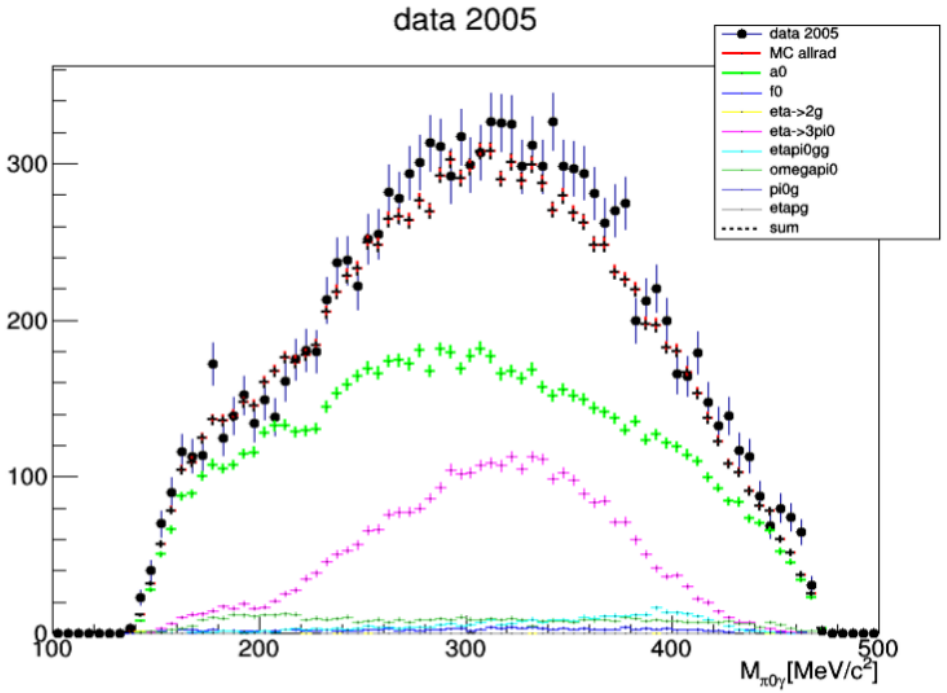
Decay → / Production ↓	$B \to e^+e^-$ $m_B \sim 1-140$ MeV	$B \to \pi^0\gamma$ 140–620 MeV	$B \to \pi^+\pi^-\pi^0$ 620–1000 MeV	$B \to \eta\gamma$
$\pi^0 \to B\gamma$	$\pi^0 \to e^+e^-\gamma$	...	...	...
$\eta \to B\gamma$	$\eta \to e^+e^-\gamma$	$\eta \to \pi^0\gamma\gamma$	...	...
$\eta' \to B\gamma$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

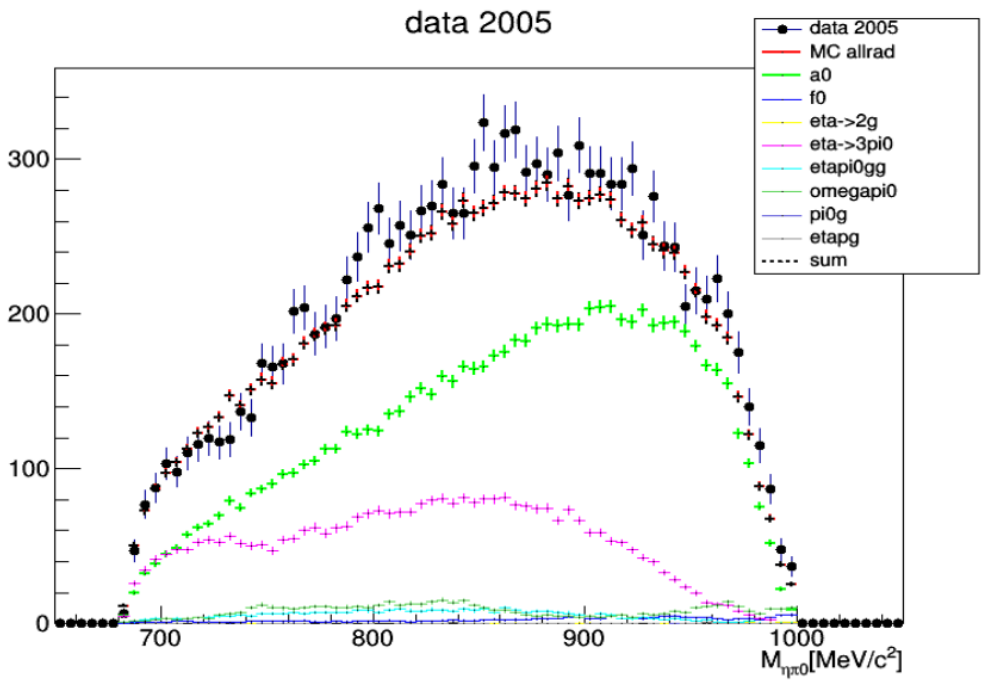
KLOE/KLOE-2 searches

B-boson search in $\varphi \to \eta\pi^0\gamma$

- Current study done with ~0.8 fb^{-1} of KLOE data. To be extended to the whole KLOE/KLOE-2 sample
  - Analysis of the whole sample ~1.7fb^{-1} ongoing
- Main irreducible background from SM: $\varphi \to a0\ \gamma \to\ \eta\pi^0\gamma$ and $\varphi \to \eta\gamma \to 3\pi^0\gamma$ with lost or merged photons

- Signal efficiency ~12.5%
- Extraction of UL





$\eta \to \pi^0\gamma\gamma$ χ-PT golden mode

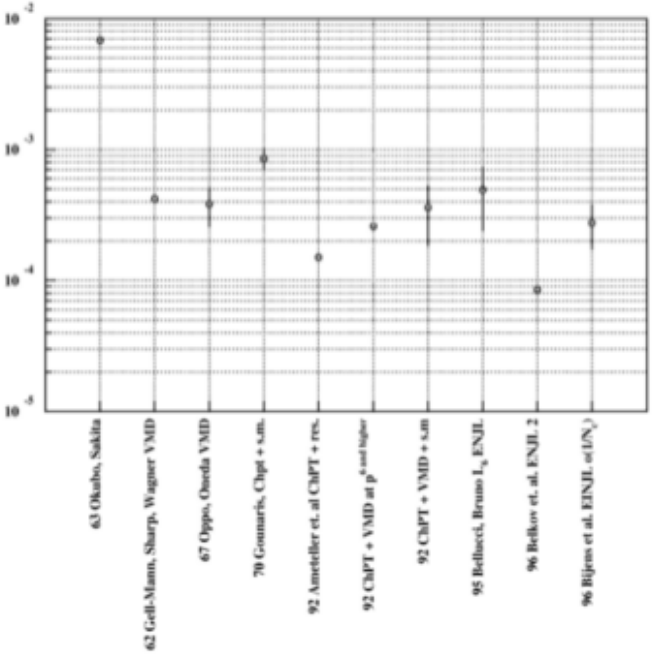
$\eta \to \pi^0\gamma\gamma$ (from $\phi \to \eta\gamma$): χPT golden mode

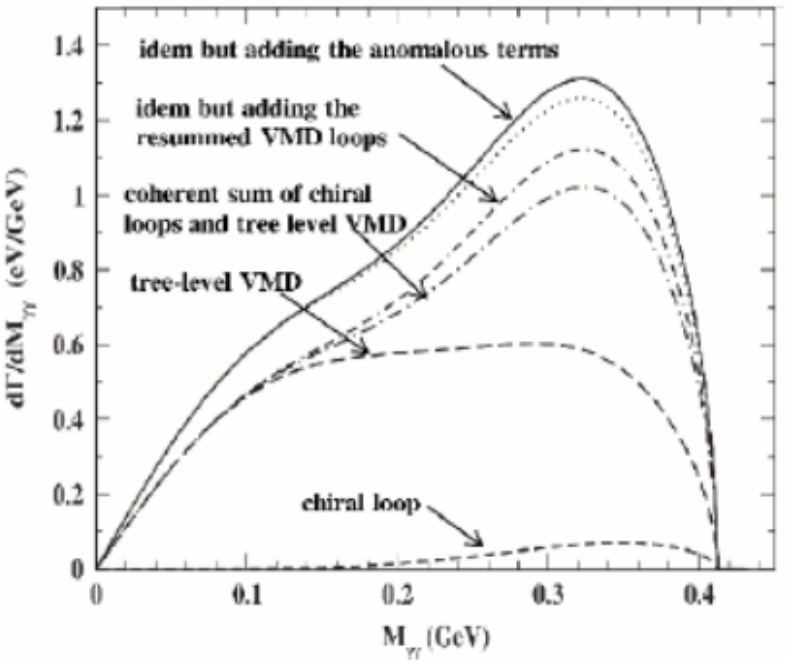
Imput for χPT parameters: $O(p^2)$ null at tree level, $O(p^4)$ suppressed by G-parity at first loop ⇒ sensitive to **$O(p^6)$**

Br = $(22.1 \pm 2.4 \pm 4.7)\times10^{-5}$ CB@AGS(2008)
Br = $(25.2\pm2.5)\times10^{-5}$ CB@MAMI (2014)

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

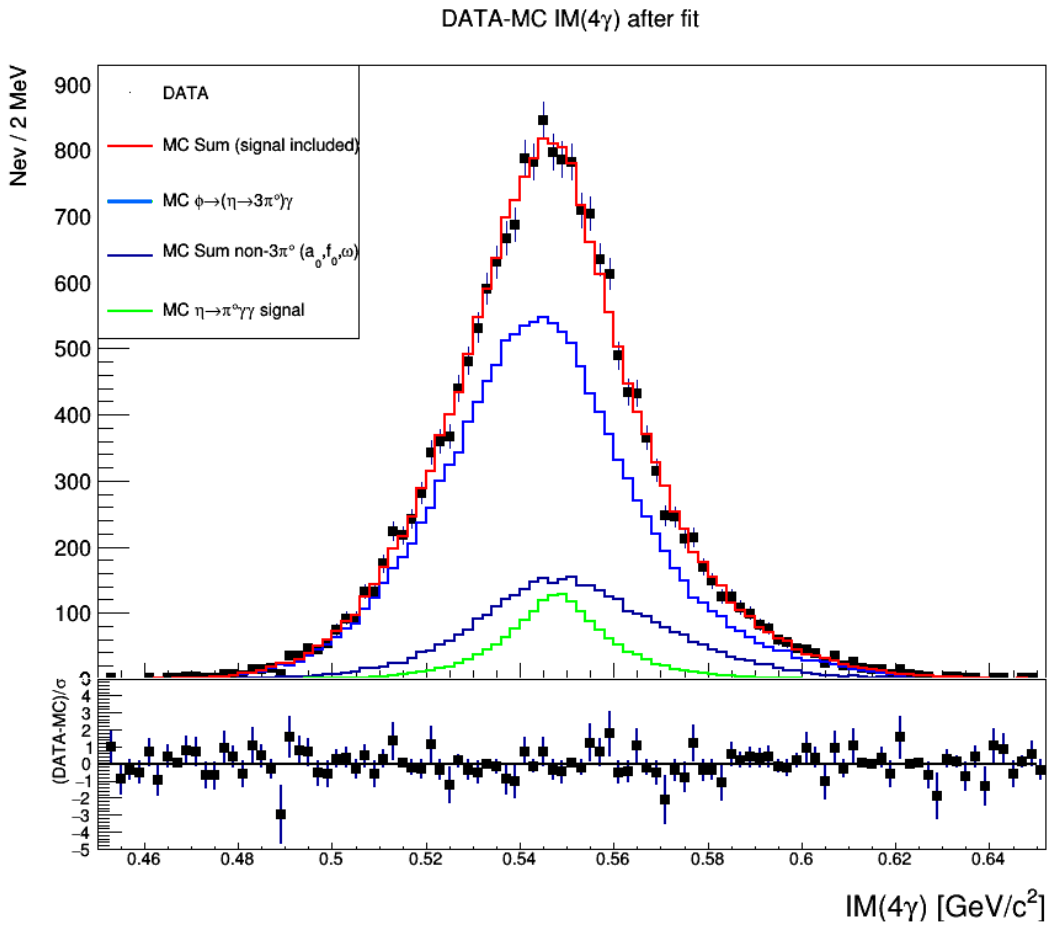
Search for new physics: B boson signature in $M(\pi^0\gamma)$





E. Oset et al, Phys. Rev. D 67, 073013 (2003),
S. Prakhov et al., Phys. Rev. C 78, 015206 (2008),
B. Di Micco et al., Acta Phys. Slov. 56, 403 (2006),
Ll. Ametller et al. Phys. Lett. B 276(1), 185-190 (1984),

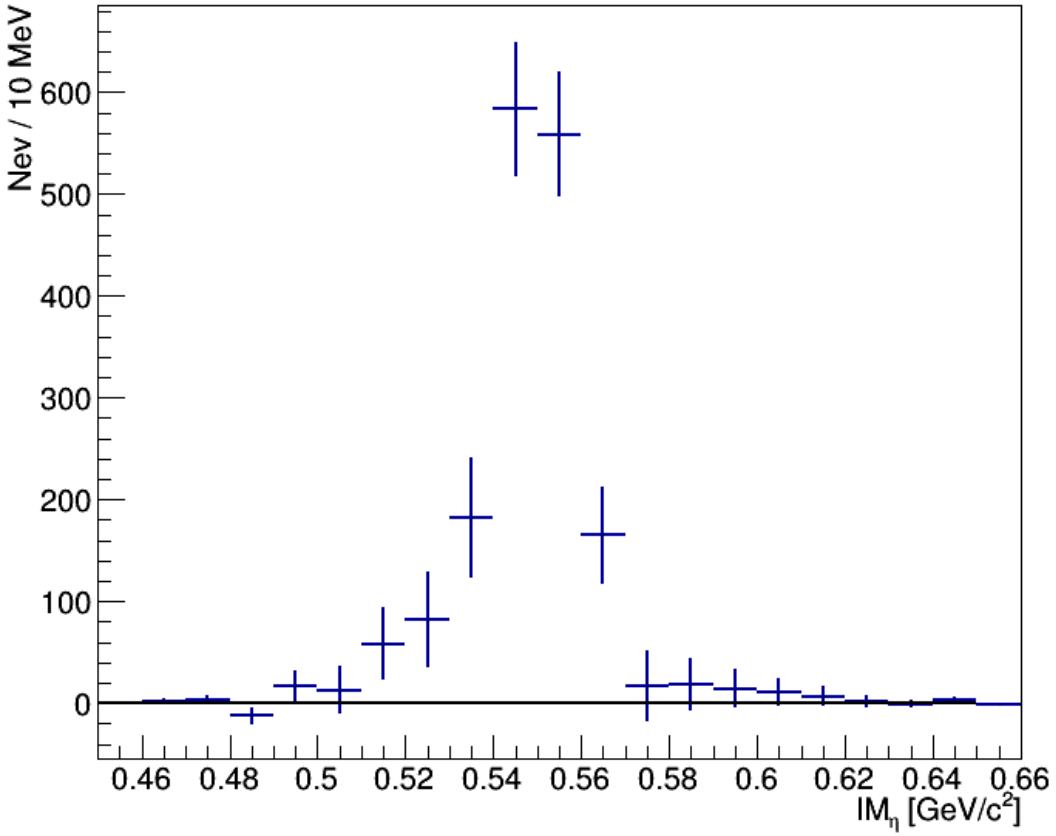
$\eta \to \pi^0\gamma\gamma$ χ-PT golden mode



- 1.7 fb^{-1} KLOE data used
- New TMVA-BDT based rejection which allows to remove 50% of the background generating from $\eta \to 3\pi^0$ while keeping a good efficiency for the signal
  - Global signal efficiency 21%

The invariant mass distribution cannot be explained without the presence of the signal.
Normalization and calculation of the BR is ongoing.

$\eta \to \pi^0\gamma\gamma$ χ-PT golden mode



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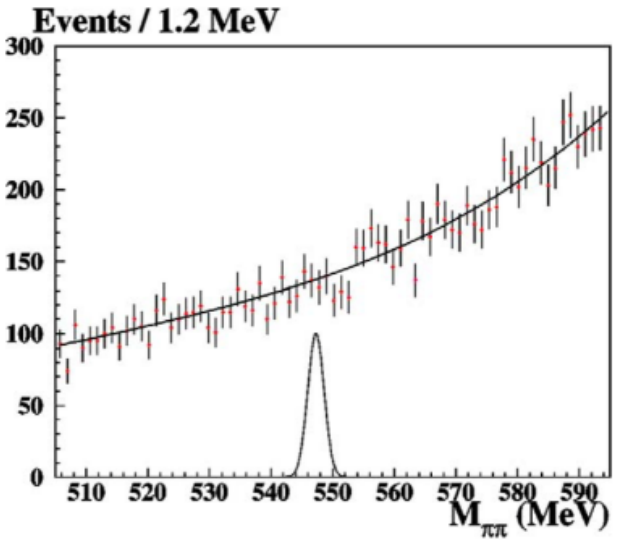
$\eta \to \pi^+\pi^-$ (P and CP viol.)

- $\eta \to \pi + \pi -$ is P and CP violating process

- The BR prediction in SM [Phys. Scripta T99, 23 (2002)]
  - proceeds only via the CP-violating in weak interaction → 10^{-27}
  - introducing a CP violating term in QCD → to 10^{-17}
  - allowing CP violation in the extended Higgs sector → 10^{-15}

- **Any observation of larger branching ratio would indicate a new source of CP violation in the strong interaction**

- The best limit **Br($\eta \to \pi + \pi -$) <1.3×10^{-5}** @ 90% C.L. by **KLOE** with L_{int} ~ 350 pb^{-1}
- A recent limit BR($\eta \to \pi + \pi -$)<1.6×10^{-5} @ 90% C.L. from the LHCb with Lint~3.3 fb^{-1}



$\eta \to \pi^+\pi^-$ KLOE sample

Two analysis using

~1.6 fb^{-1} KLOE data

~ 0.4 fb^{-1} KLOE-2 data

Selection of $\varphi \to \eta\gamma$, $\eta \to \pi^+\pi^-$ events:

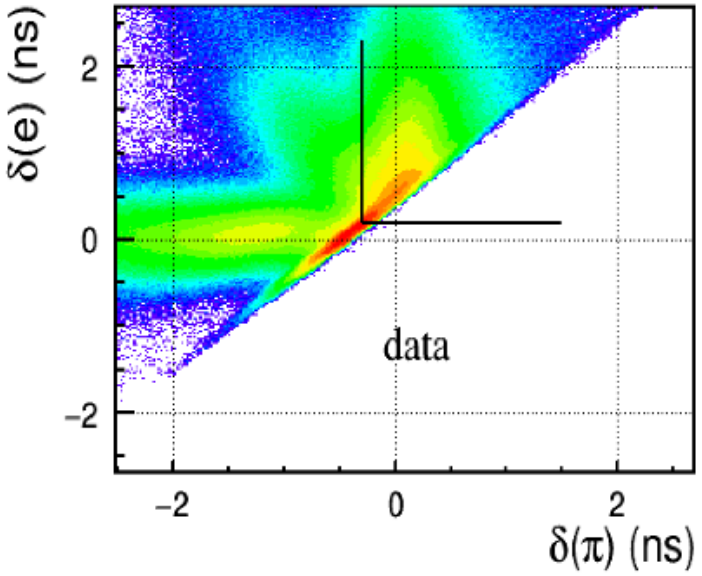
one vertex with two opposite charged tracks (reaching EMC)

tracks required to be at large angle $45^\circ < \theta_{trk} < 135^\circ$

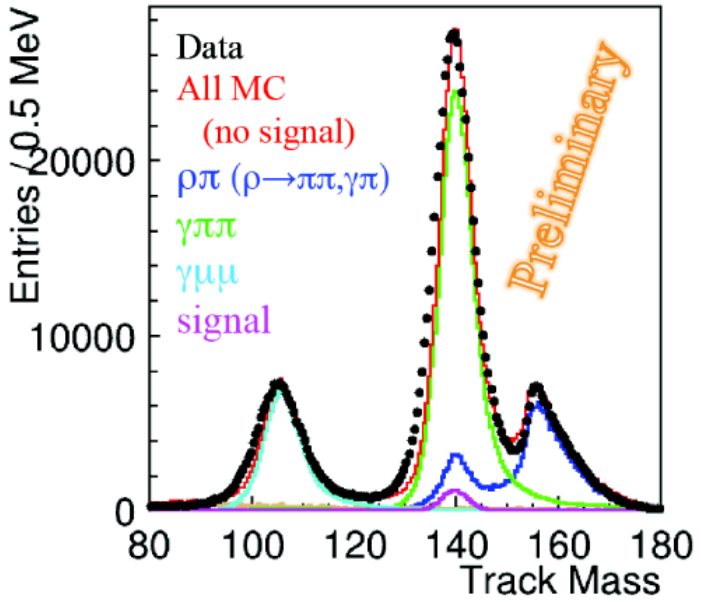
one prompt photon in time with $45^\circ < \theta_\gamma < 135^\circ$ to suppress ISR

Angle between p_{miss} and prompt photon direction < 0.03 rad

PID with ToF technique to reject e + e − γ background $0.3 < \delta t(e)$ and $-0.2 < \delta t(\pi)$



Track mass $125 < M_{trk} < 150$ MeV to reject $\mu^+\mu^-\gamma$ and $\pi^+\pi^-\pi^0$ backgrounds

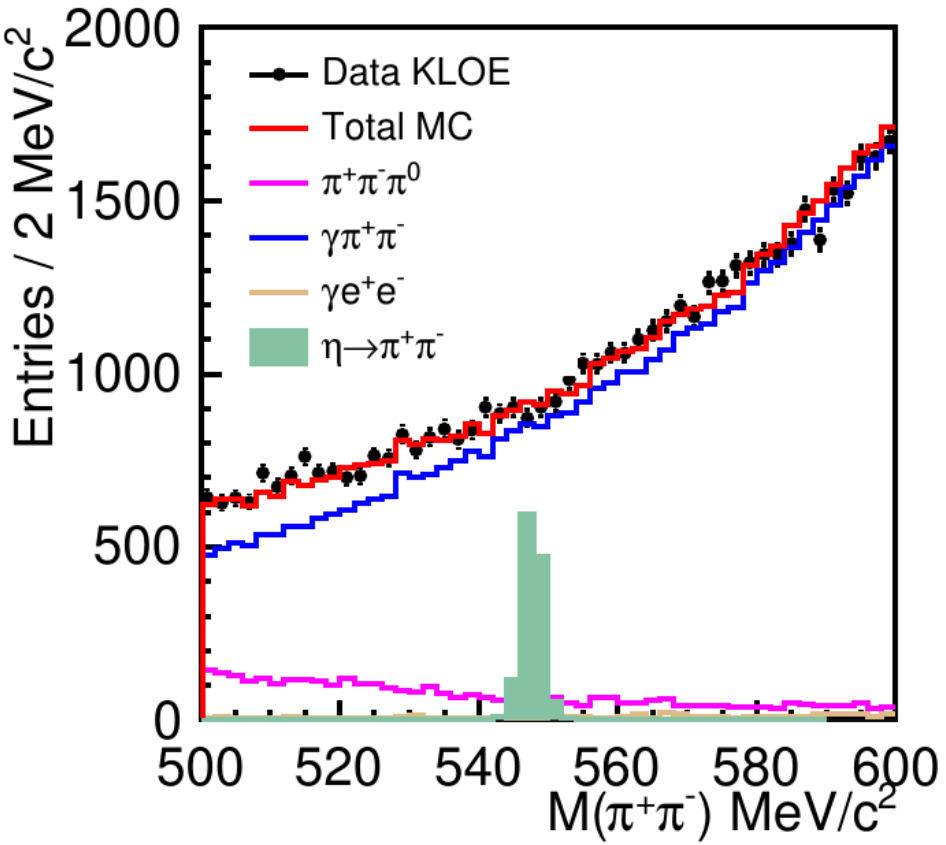


$\eta \to \pi^+\pi^-$ KLOE sample

Preliminary results for 1.6 fb^{-1} of KLOE sample:
Continue backgrounds from $\pi\pi\gamma$
After all the cuts, efficiency for KLOE is 14%
No event excess in the η region
Fit with 3rd polynomial function + MC signal shape

UL systematics: alternative fits performed, negligible difference found

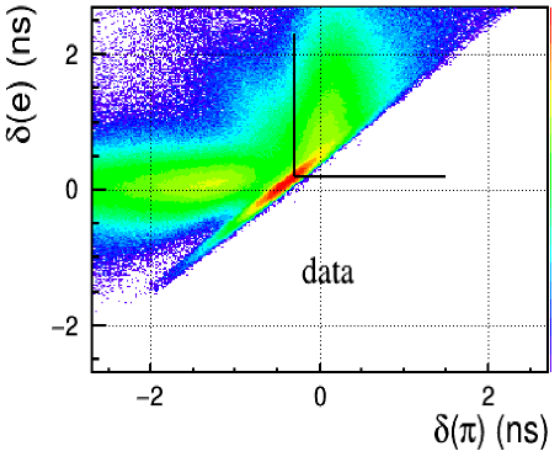
Br($\eta \to \pi + \pi -$)<5.8×10^{-6} @ 90% C.L.

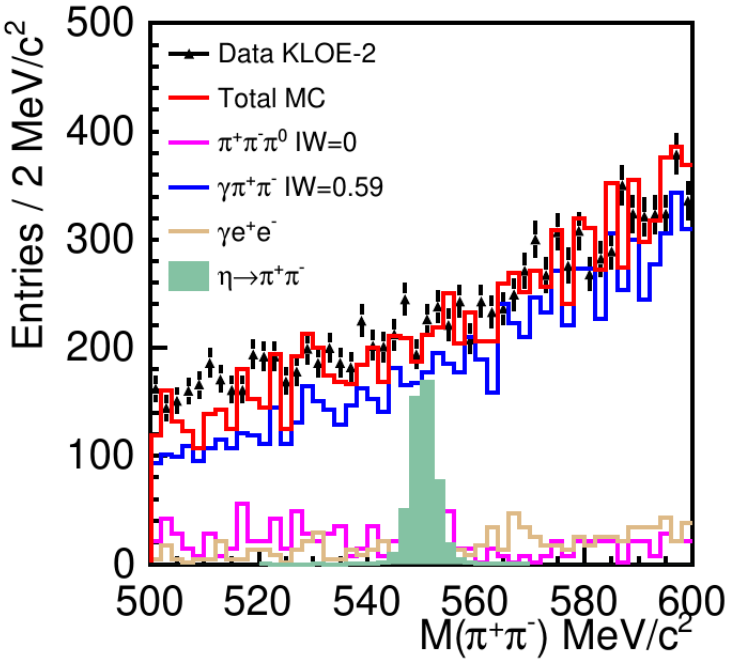


The analysis is completed
Internal documentation ready
Plan of publication in next months: Discussion with internal referees has started

$\eta \to \pi^+\pi^-$ KLOE-2 sample

- KLOE-2 data under analysis
  - ~ 0.4 fb^{-1} analyzed so far
- Cuts tuned for the KLOE-2 sample
- For KLOE-2 the efficiency is 12%
  - higher backgrounds from $\pi^+\pi^-\pi^0$ and γe^+e^-
- More statistics are being analyzed





With all KLOE/KLOE-2 data → the upper limit is expected to reach 2.7×10^{-6} @ 90% CL

56th Scientific Committee Recommendations

Recommendation n.1
The list of remaining analyses and the associated manpower and timeline is very useful. It would be welcome if this list could be updated as time goes on.

The status of the present ongoing analyses has been shown in this talk.
The timeline for the different milestones of the collaboration will be discussed with the KLOE-2 referees.

Recommendation n.2
The translation to ROOT is very much appreciated. It would be good to finalize this, so that the next reconstruction version can produce the ROOT output.

ROOT output is planned to be implemented for the start of the second round of reconstruction, which is expected to start in June/July 2019.

Recommendation n.3
The SC invites the collaboration to make sure that the next version of data reconstruction includes all required improvements to support the KLOE-2 data analyses, so that this is the *final* version all papers can be based on.

Data Quality performed on DBV-38.
New reconstruction development version DBV-39 work ongoing.
New MC Version 2.1.0 developed with fine tuning of the detectors performances.

Conclusions

- We have completed the first round of reconstruction with 4 fb-1
- MC production for the same period has been produced
- New and final reconstruction expected to start before summer and last about 9/10 months
  - Refinement in progress
  - Insertion of root output
  - MC fine tuning
- Several analysis ongoing both with KLOE and KLOE-2 samples with preliminary results presented at international conferences