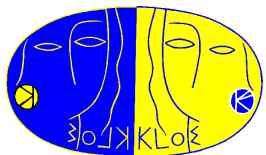


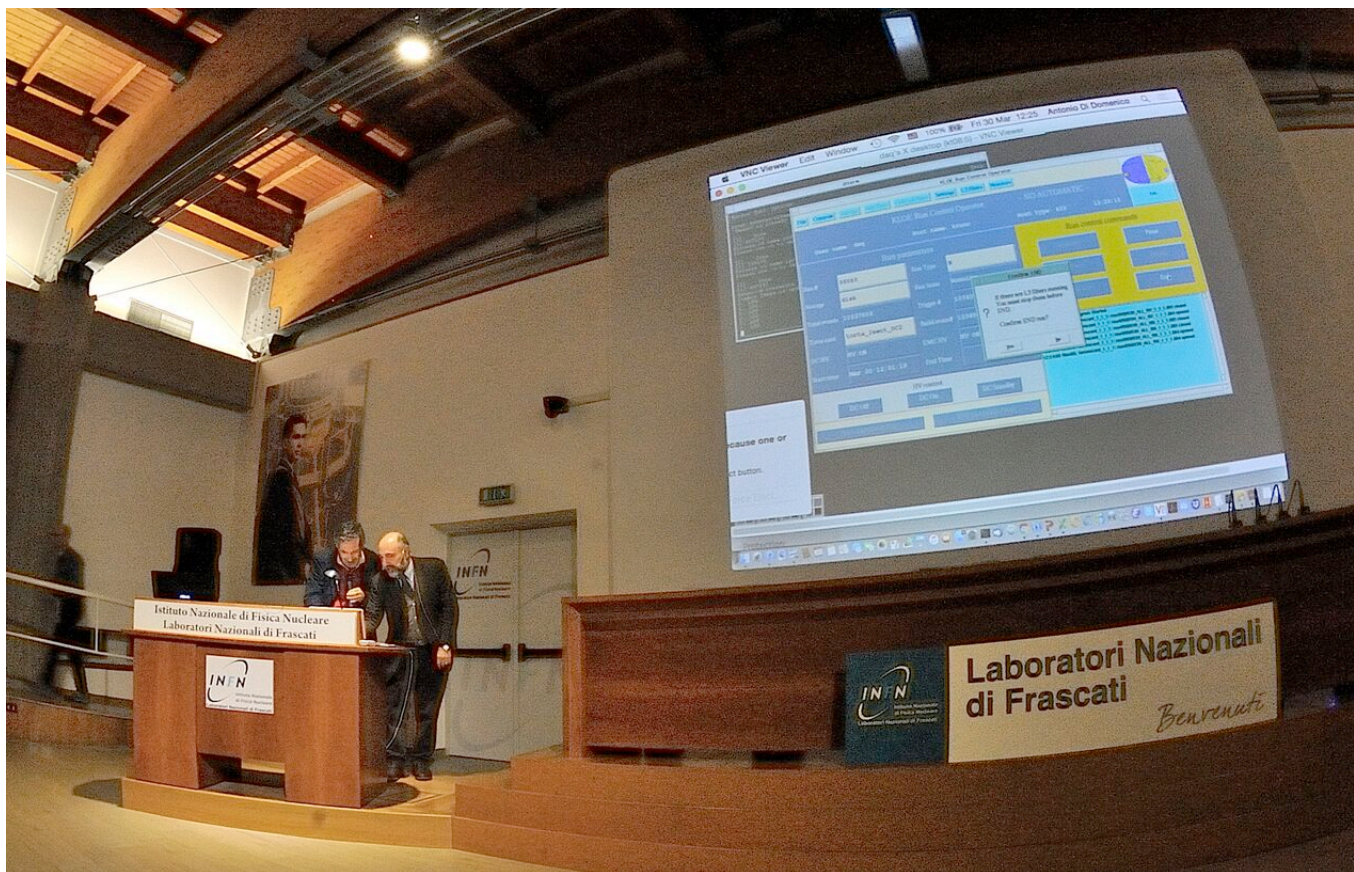
KLOE-2 status



55th LNF Scientific Committee Meeting
May 14, 2018



March 30, 2018

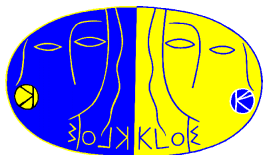


“This is the end ...”



P.Gauzzi

55 LNF S.C. - 14/5/2018

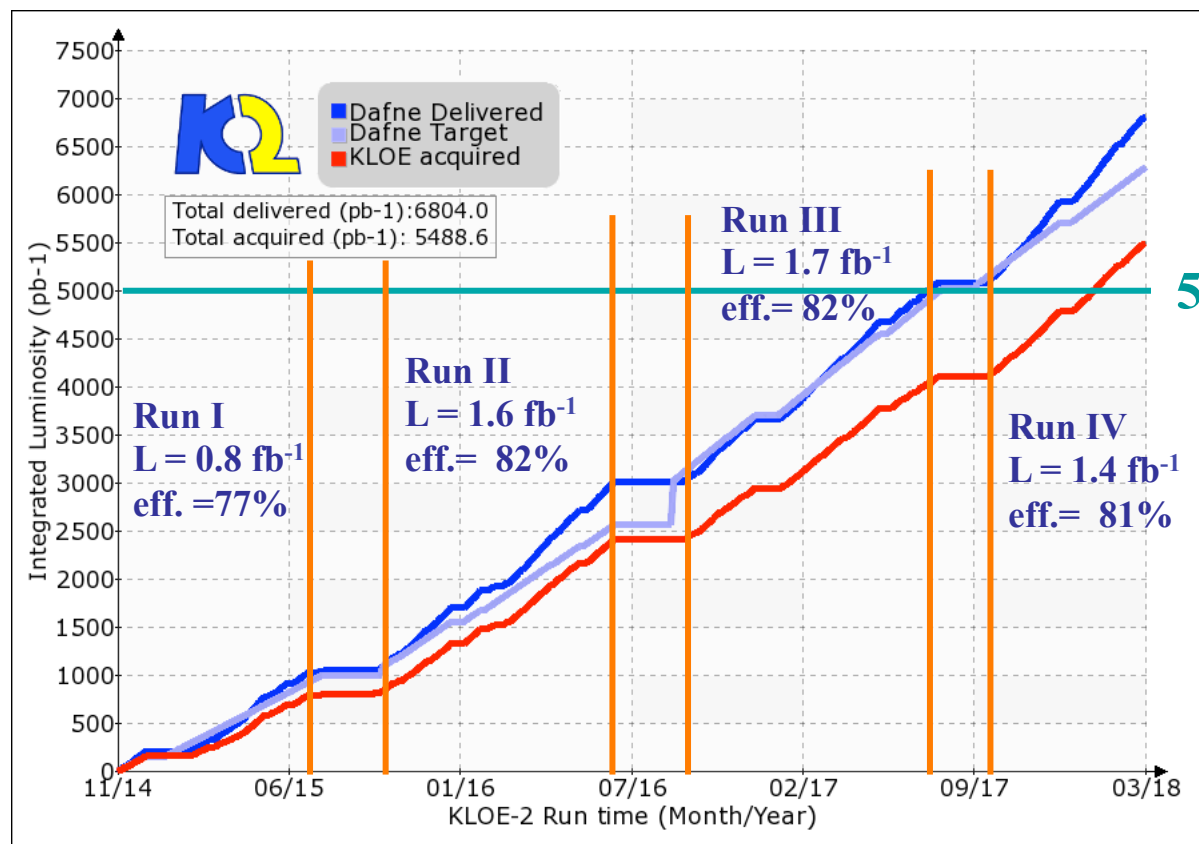


KLOE-2 data

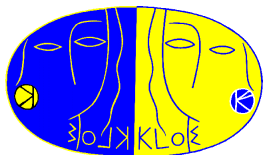


Acquired $L = 5.5 \text{ fb}^{-1}$

Delivered $L = 6.8 \text{ fb}^{-1}$



Goal of 5 fb^{-1} reached, thanks to the combined effort of the KLOE-2 Collaboration and of the DAΦNE team

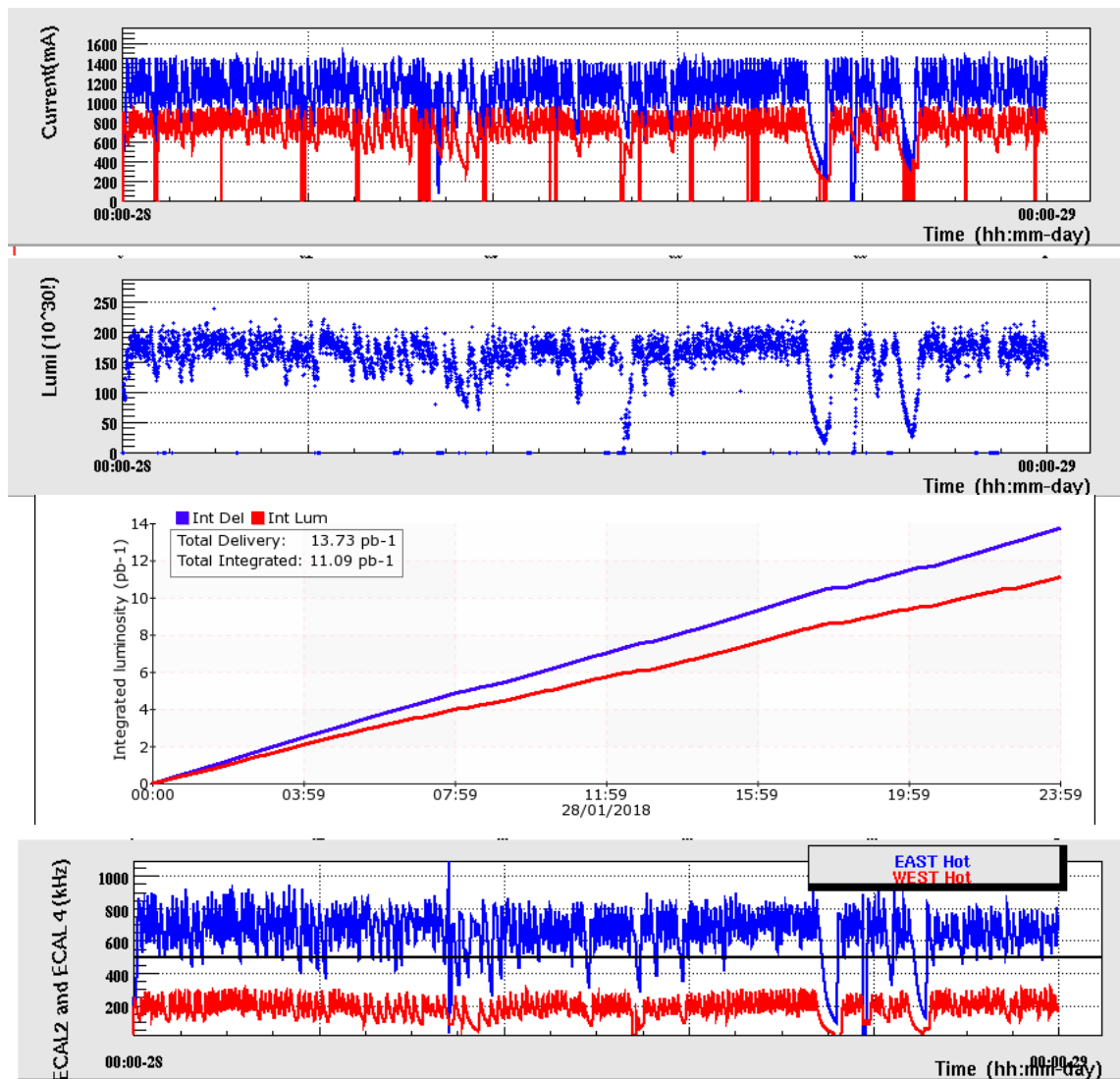


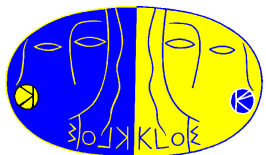
Best day of Run IV



January 28th, 2018

- > 99% uptime
- 13.7 pb⁻¹ delivered
- 11.1 pb⁻¹ acquired
- $L_{\text{peak}} = 2.28 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

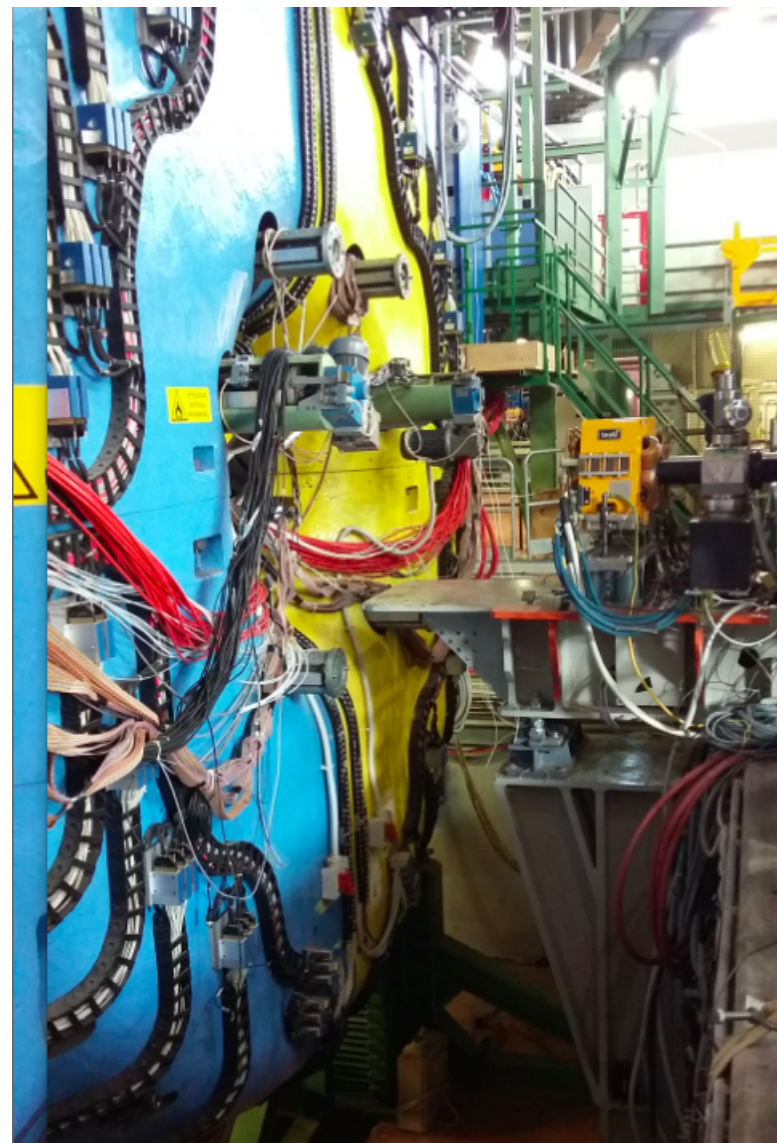


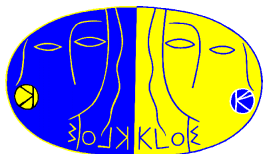


KLOE-2 roll-out

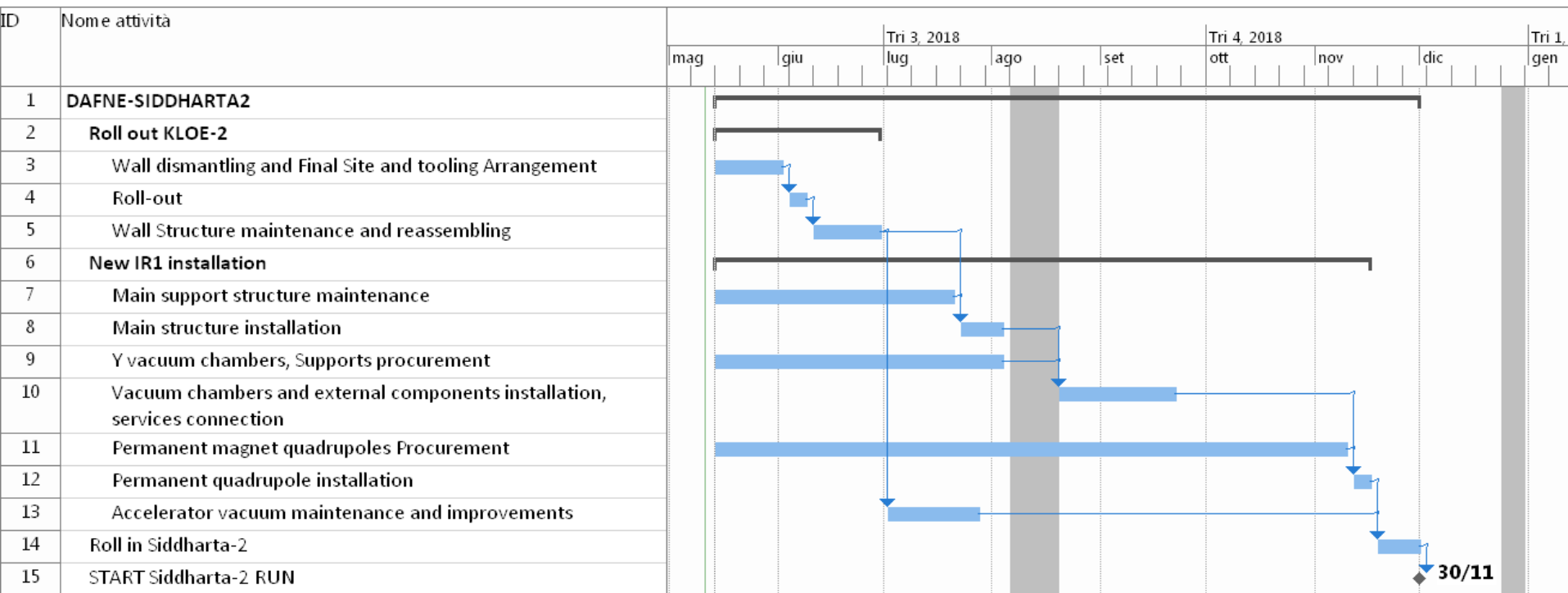


- The detector will be moved on its rails from the IP to the assembly hall with the end-caps closed
- The main steps of the roll-out are:
 1. disconnection of the outer part of beam-pipe
 2. lowering of KLOE (1500 tons)
 3. movement on rails
- The inner part of the beam-pipe will remain inside the detector
- The shielding concrete wall separating the DAΦNE hall and the assembly hall is being dismantled and will be then rebuilt

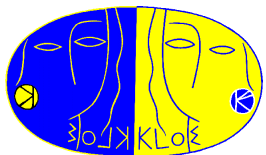




Roll-out schedule



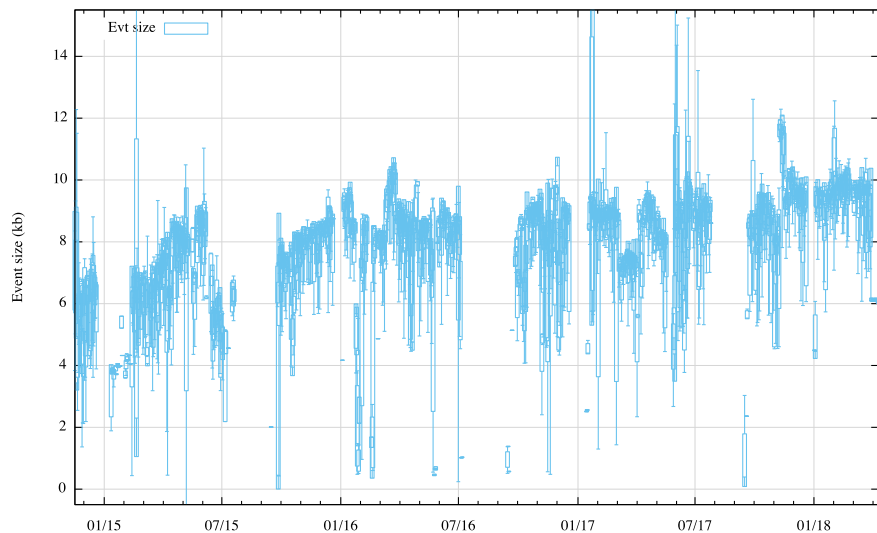
- We are in time with the schedule
- All operations are expected to be completed by end of June



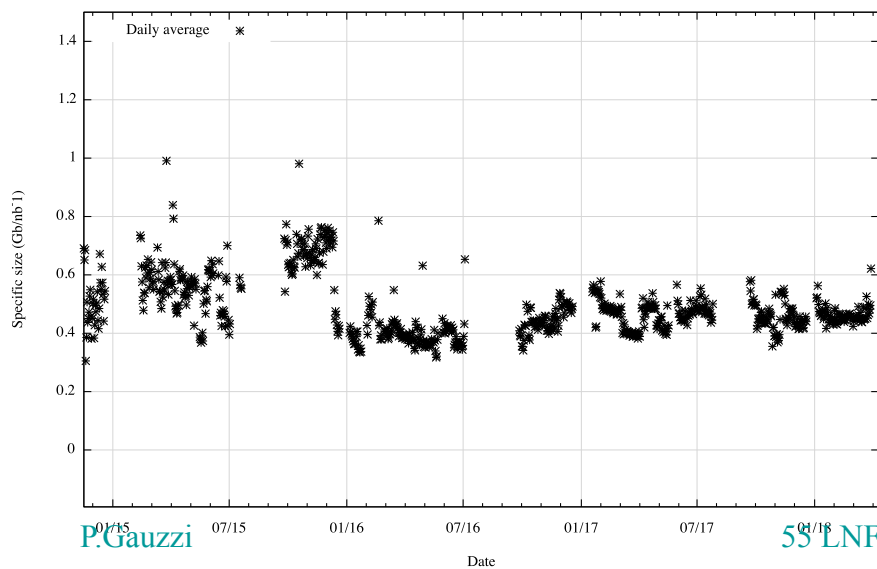
Data-taking summary



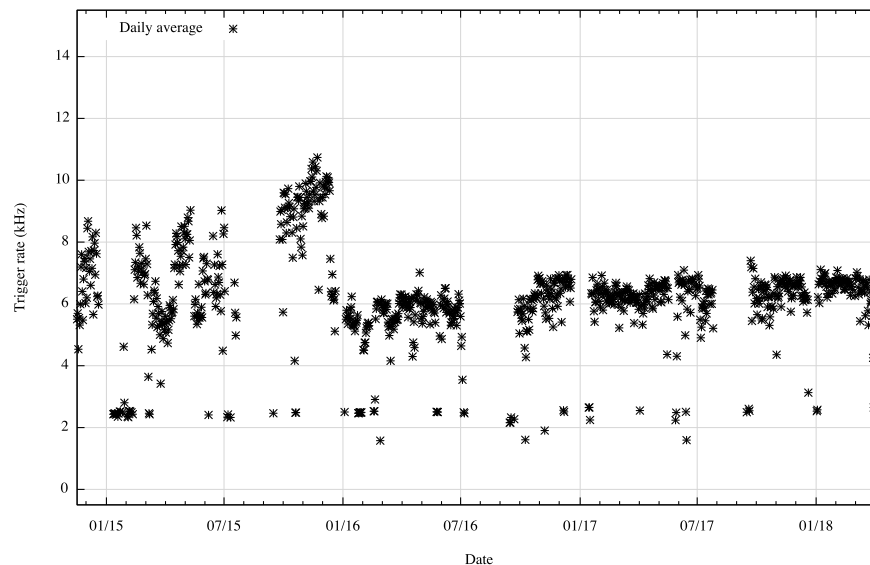
Event size as a function of time



Event size as a function of time

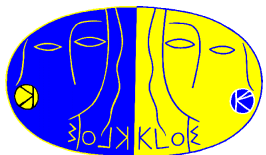


DAQ rate as a function of time



Whole KLOE-2 data set

- Trigger rate ~ 6 kHz
- Event size $\sim 8 - 9$ kB
- Raw data volume ~ 0.5 PB/fb⁻¹

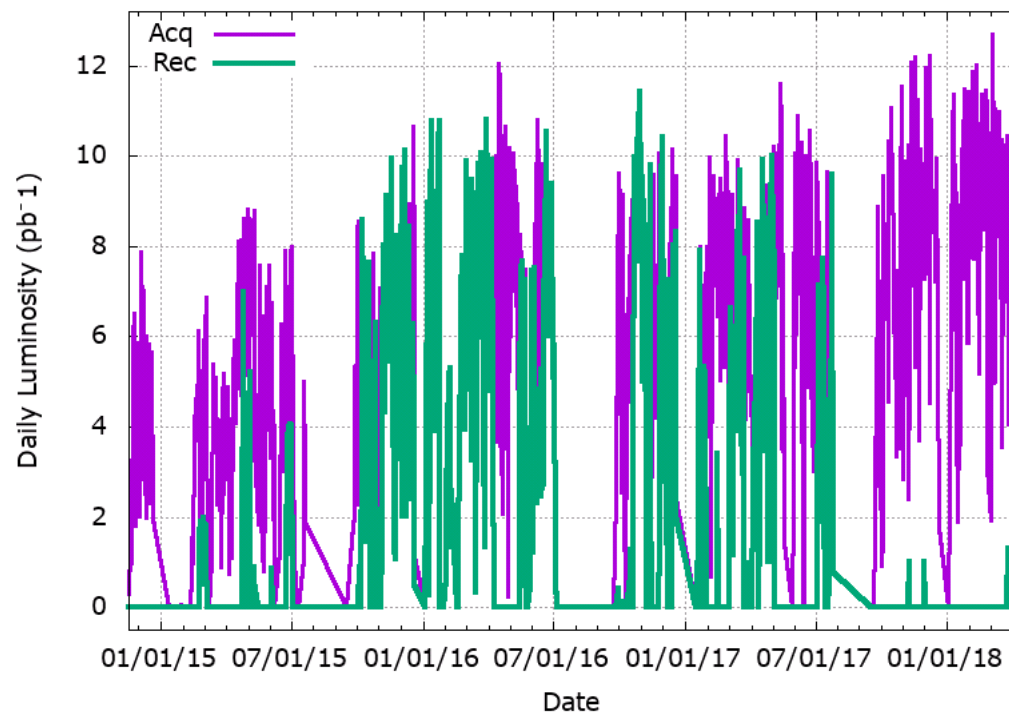


Data reconstruction

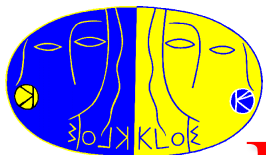
Reconstruction summary

New version (DBV-38) of the data reconstruction program:

- **New background filter implemented**
⇒ **rejects 25 – 30 % of the events**
- **Version 3.0 of the DC-IT integrated tracking**
- **New stream for Single Photon Trigger events implemented**
- **Tests for a new stream of $\gamma\gamma$ physics events**



	Run-I	Run-II	Run-III	Run-IV
L [pb^{-1}]	800	1620	1680	1400
RAW [TB]	457	867	943	734
REC [pb^{-1}]	30	1018	706	3



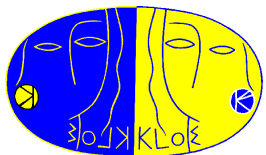
DBV-38 reconstruction rate

- **981 pb⁻¹ reconstructed with DBV-38 since March 21st, 2018**
⇒ **~ 20 % of the whole KLOE-2 data set**

- **New background filter + reconstruction optimization**
⇒ **gain a factor of 2 in reconstruction rate:**

~ 20 pb⁻¹ / day

- **At this rate the first round of all KLOE-2 data reconstruction will be completed in ~ 9 months**

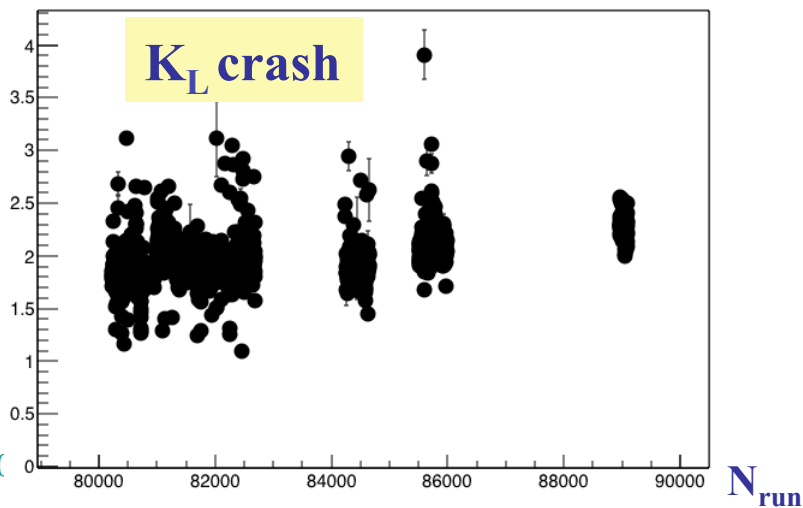
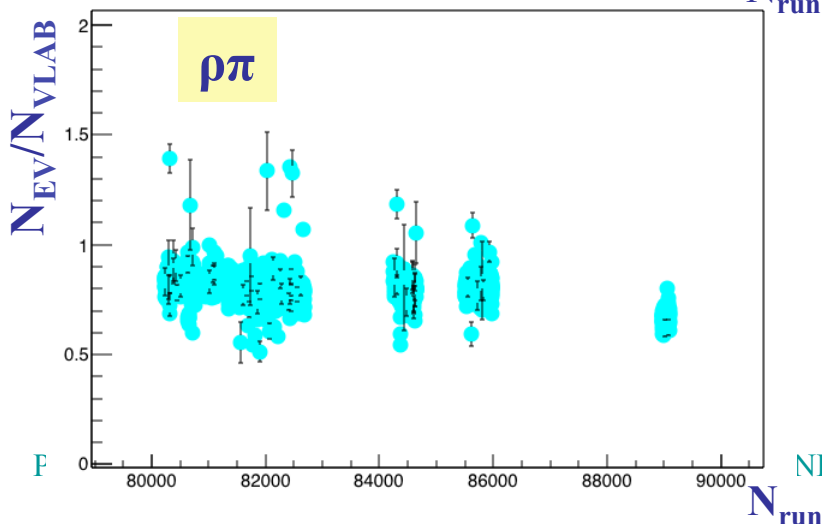
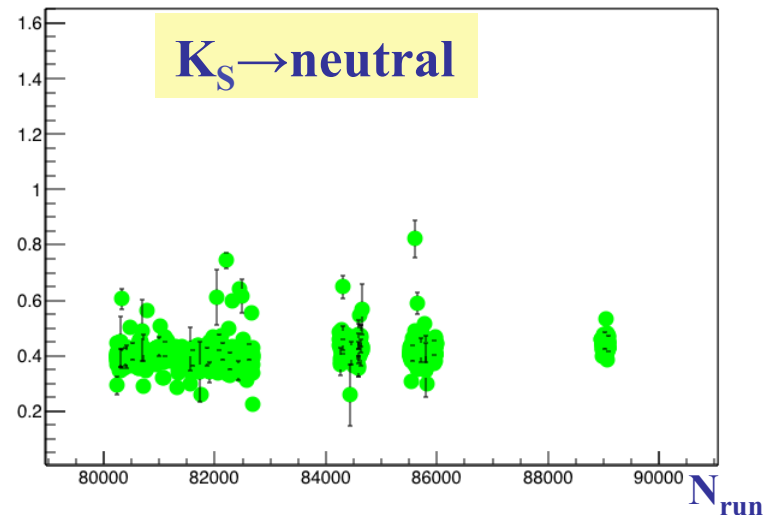
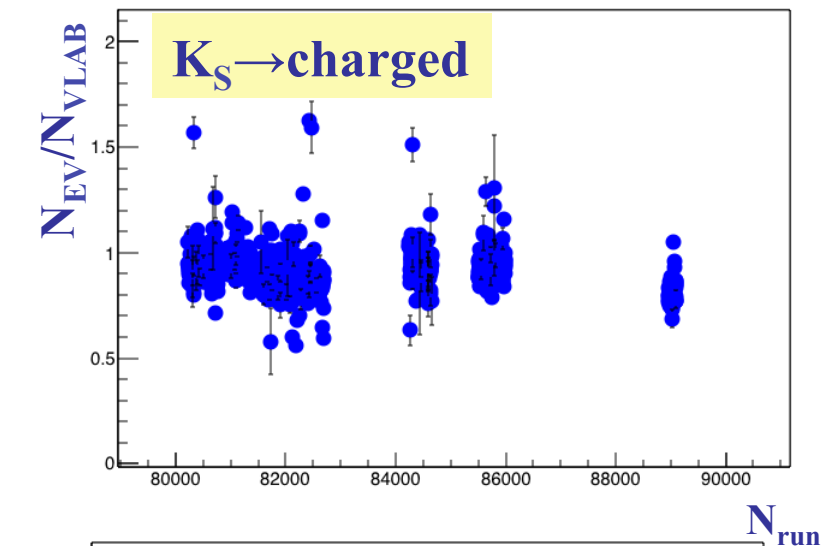


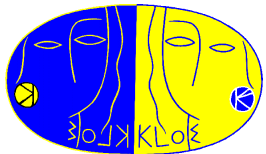
Event Counters



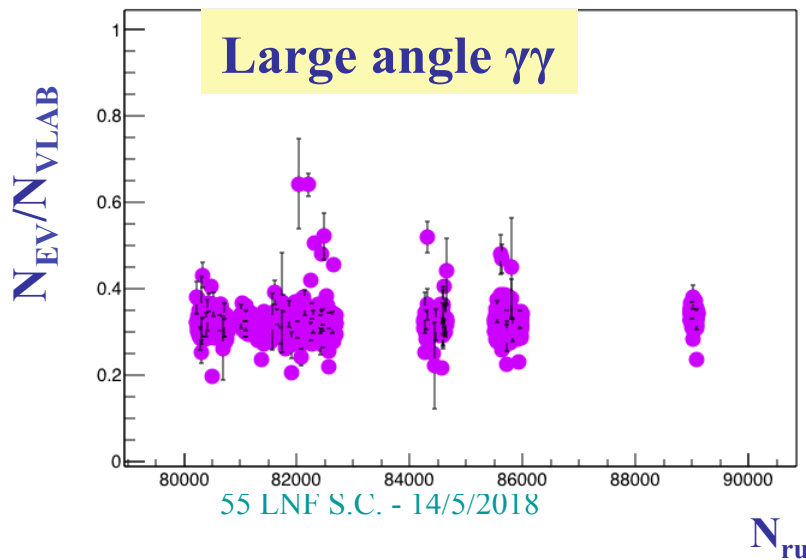
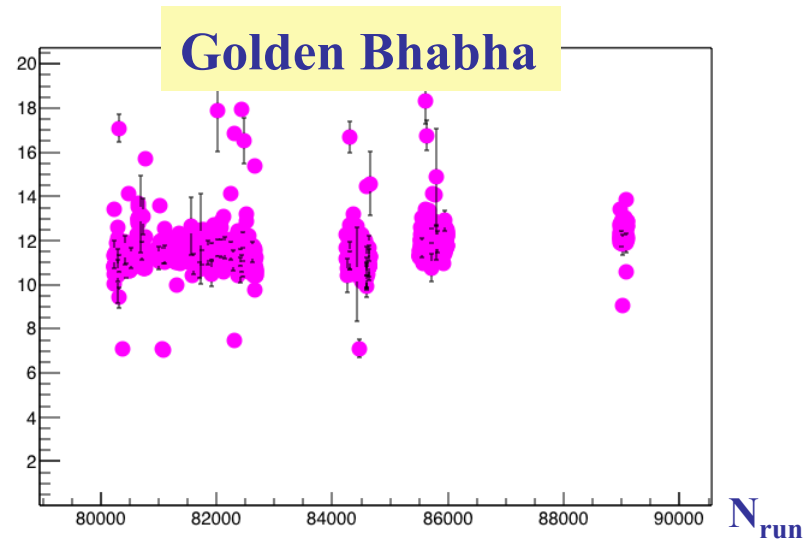
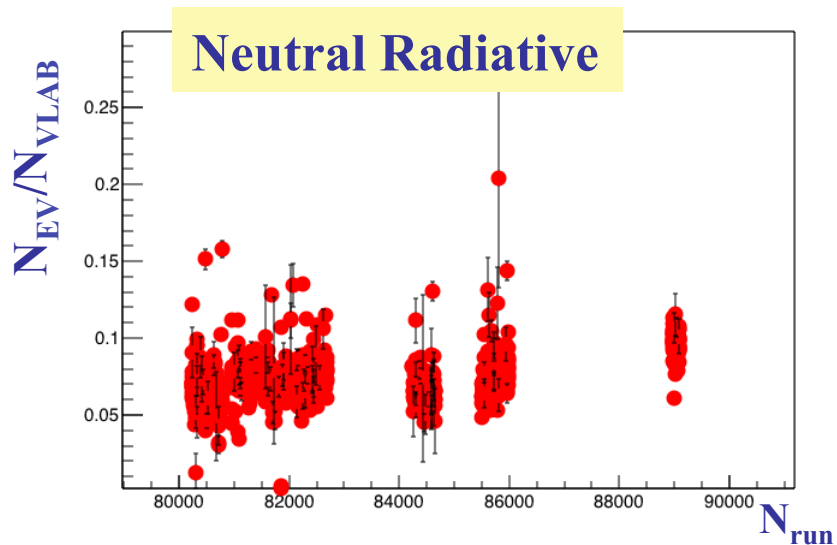
Data reconstructed with DBV-38

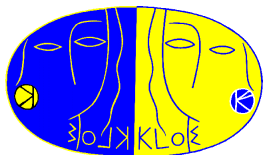
- Event counters, normalized to Very Large Angle Bhabha's





Event counters

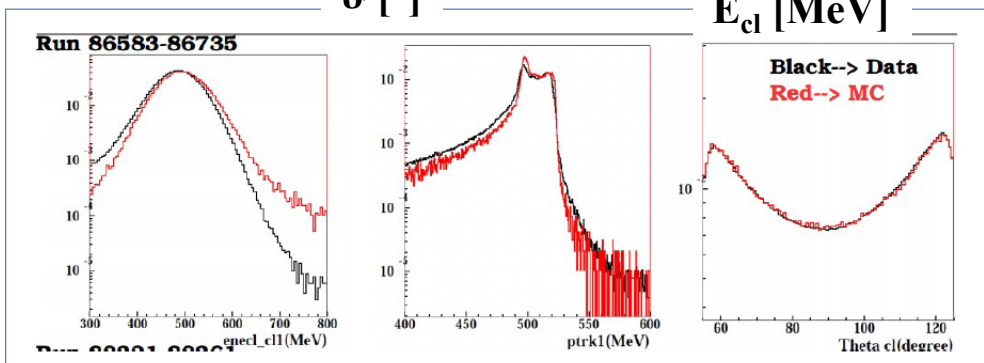
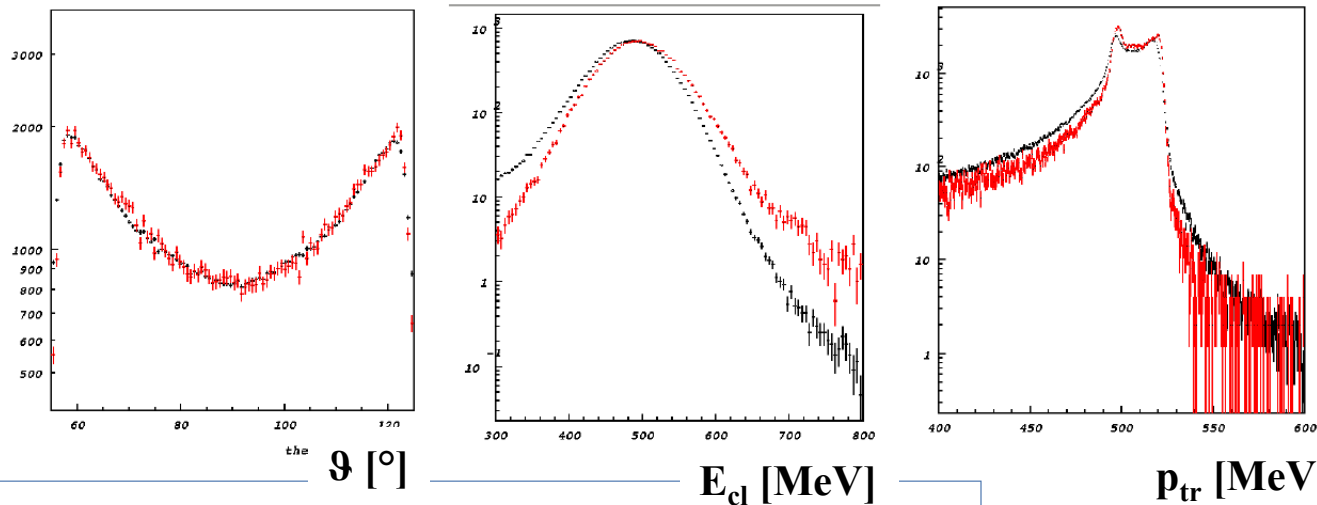




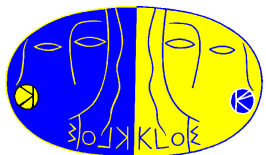
Monte Carlo

- MC all_phys (main ϕ decays + background) production started together with Datarec with DBV-38
- Checks with Golden Bhabha's: data-MC comparison

Runs 89209 – 89252



Run 86XXX
used as
reference



Publications/Analysis

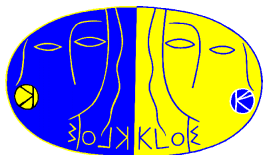


Publications

Combination of σ_{had} meas. and a_μ determination at $0.10 < s < 0.95 \text{ GeV}^2$	JHEP1803(2018)173
Measurement of charge asymmetry of $K_S \rightarrow \pi e \nu$	Paper ready to be submitted to JHEP
Dark Photon search: updated limit on $e^+e^- \rightarrow U\gamma \rightarrow \mu^+\mu^- \gamma$, and combined $\pi^+\pi^-\gamma$ and $\mu^+\mu^- \gamma$	Final result – paper in preparation

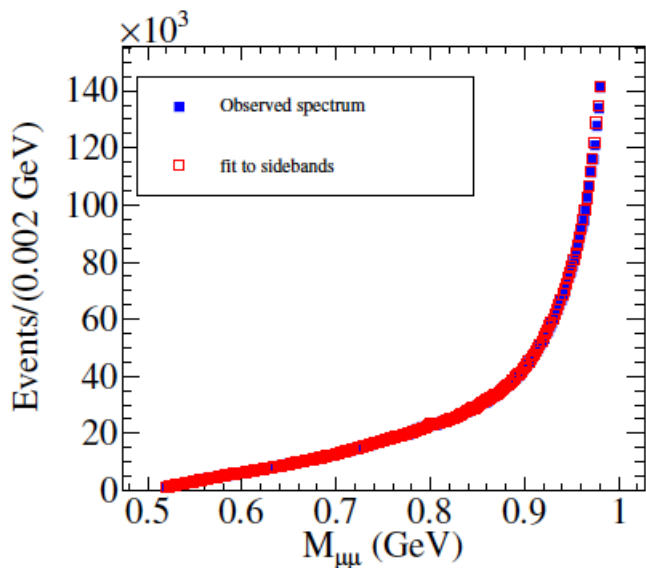
Ongoing analyses

$\gamma\gamma \rightarrow \pi^0$	KLOE-2 data
$K_S \rightarrow \pi e \nu$ K_L crash; $K_S \rightarrow \pi^+\pi^-$ $K_L \rightarrow \pi^+\pi^-$	KLOE-2 data
$K_S \rightarrow 3\pi^0$	KLOE-2 data – preliminary @ EPS 17
T/CPT tests with $\phi \rightarrow K_S K_L \rightarrow 3\pi^0$ $\pi e \nu$, $\pi\pi$ $\pi e \nu$	KLOE data – PhD Thesis (preliminary)
$\text{Br}(K_S \rightarrow \pi e \nu)$	KLOE data
$K_S \rightarrow \pi^+\pi^-\pi^0$	KLOE data
B-boson search in $\phi \rightarrow \eta\pi^0\gamma$	KLOE / KLOE-2 data
$\eta \rightarrow \pi^0\gamma\gamma$ - χ PT golden mode	KLOE / KLOE-2 data
$\eta \rightarrow \pi^+\pi^-$ (P and CP viol.)	KLOE / KLOE-2 data
$e^+e^- \rightarrow \omega \gamma_{\text{ISR}}$	KLOE data

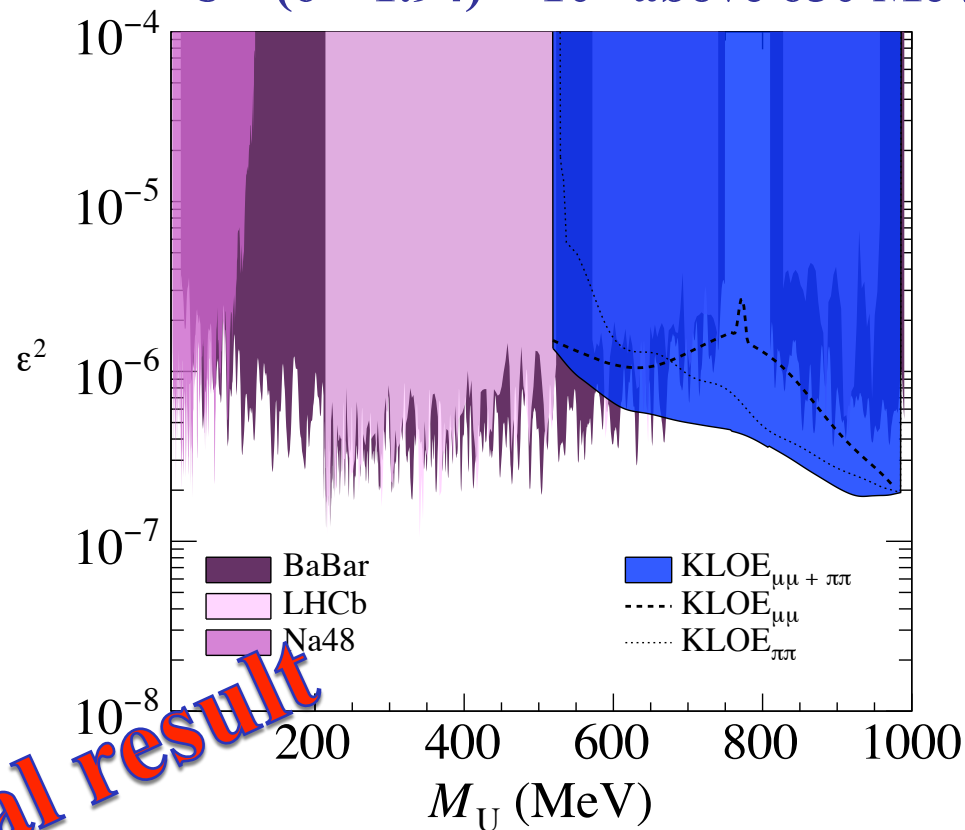


Dark Photon search

- Updated limit on $U \rightarrow \mu^+\mu^-$, with the full KLOE statistics – $L = 1.93 \text{ fb}^{-1}$



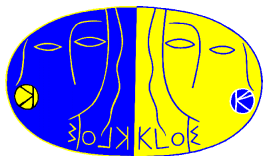
$\epsilon < (6 - 1.94) \times 10^{-7}$ above 650 MeV



- Combination of $\mu^+\mu^-\gamma$ and $\pi^+\pi^-\gamma$ final states

$[\pi^+\pi^-\gamma: \text{PLB757(2016)356}]$

Paper in preparation



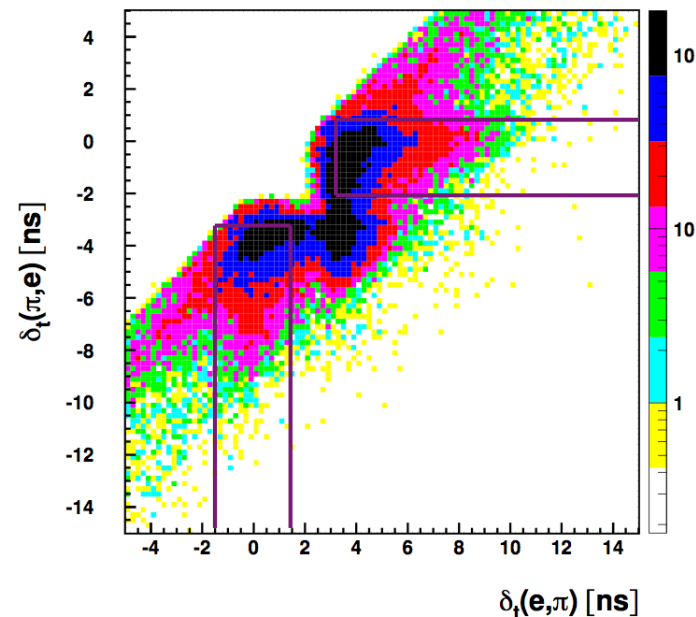
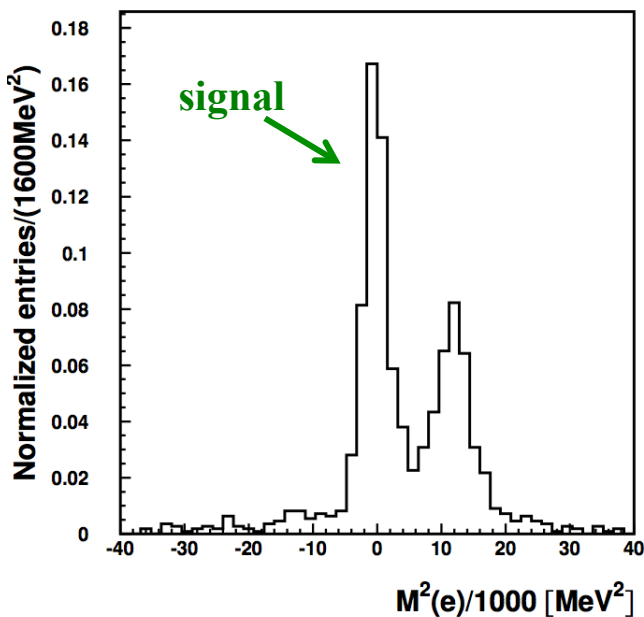
$K_S \rightarrow \pi e \nu$ on KLOE-2 data

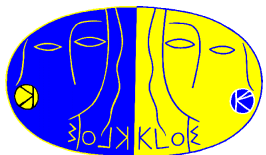


Full analysis chain run on KLOE-2 data

(IT contributing to the tracks)

- K_S semileptonic decay tagged with K_L crash (K_L interaction in the calorimeter)
- Vertex selected in the fiducial volume
- $300 < M(\pi\pi) < 490$ MeV
- TOF in e and π hypotheses



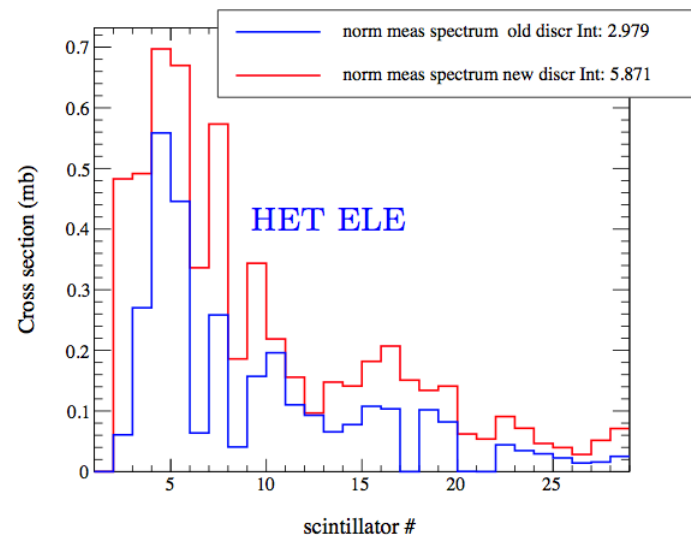


HET analysis

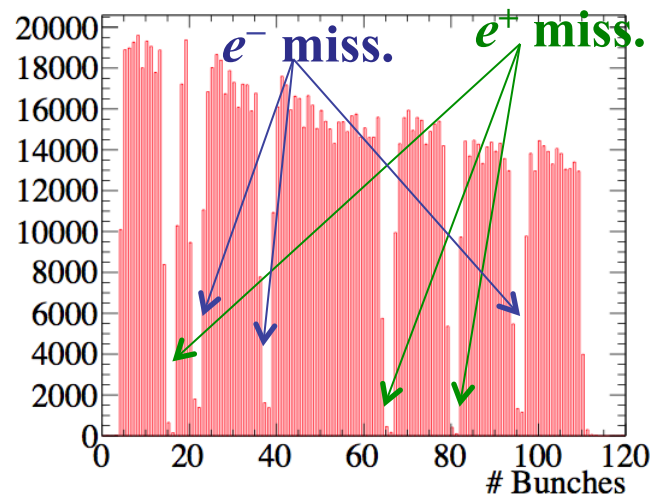


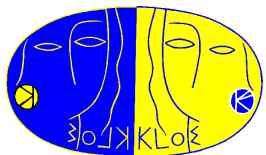
Efficiency measurements:

- Relative efficiencies of the different scintillators by measuring the Bhabha scattering flux, by moving the HET detectors with respect to the beams
 - Efficiencies normalized to the Bhabha flux on the long scintillator
 - Factor of 2 improvement with the new discriminators (installed at the end 2016)
 - HET counting rate dominated by Bhabha scattering \Rightarrow measurement of the Bhabha cross-section at very low angle
- Validation of BBBREM generator in progress



Run 92861: special pattern of bunch filling

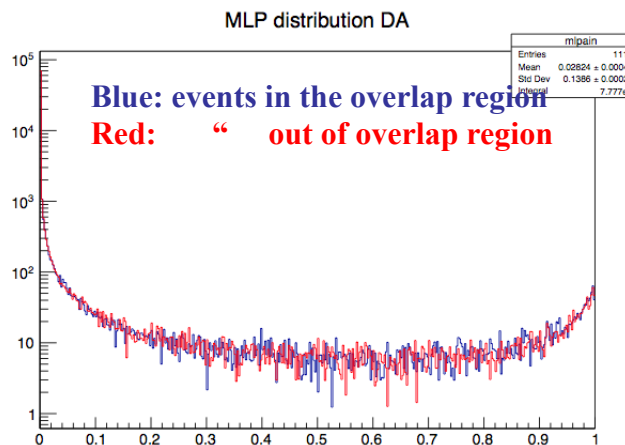
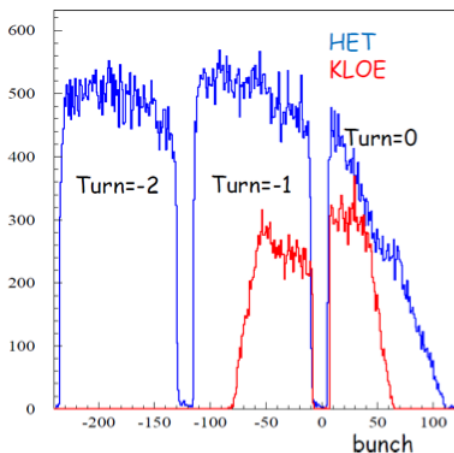




HET analysis – $\gamma\gamma \rightarrow \pi^0$

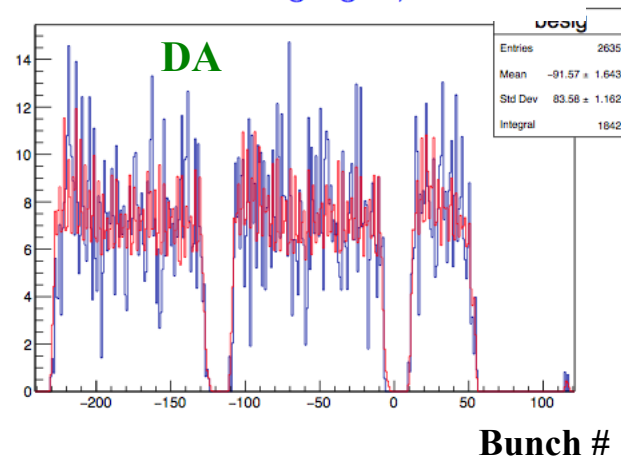


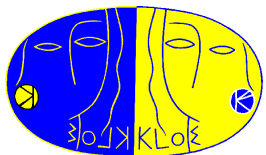
Multivariate Analysis on Double Arm (DA) and Single Arm (SA) samples ($L = 550 \text{ pb}^{-1}$):



- No significant evidence of $\gamma\gamma \rightarrow \pi^0$ tagged events both for DA and SA samples
- Analysis based on info of the two EMC clusters associated to π^0 candidates
- Future plans:
 - Reconstruction of a new sample of 500 pb^{-1} of data taken with new discriminators
 - New data reduction on the analyzed samples, exploiting the whole event information

Red : events in the bckg region
Blue: events in the sig region, MLP > 0.9





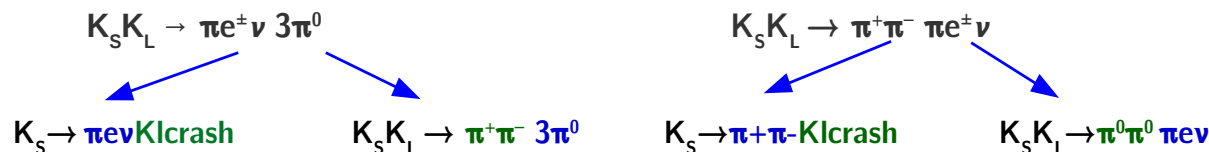
T and CPT test with KLOE data



First test of T and CPT in transitions with neutral kaons

[JHEP 10 (2015) 139
NPB 868 (2013) 102]

- $\phi \rightarrow K_S K_L \rightarrow \pi e^\pm \nu 3\pi^0$ and $\pi^+ \pi^- \pi e^\pm \nu$ ($L=1.7 \text{ fb}^{-1}$)
- Selection efficiencies estimated from data with 4 independent control samples



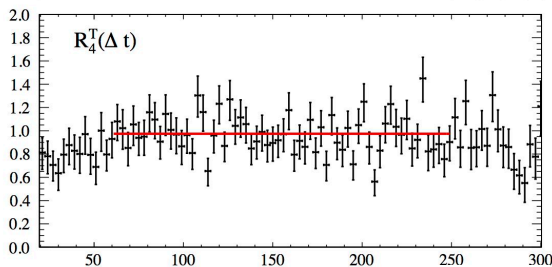
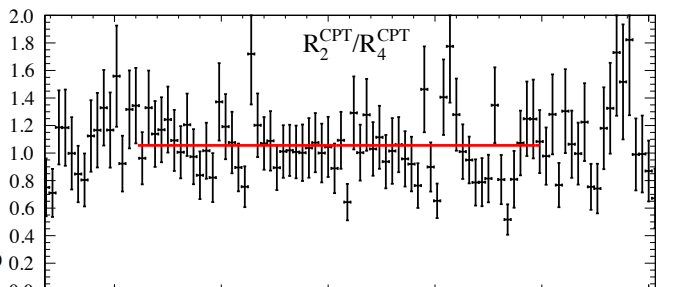
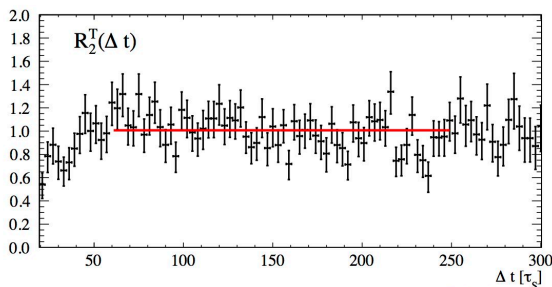
T and CPT observables

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

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

$$R_2^{CPT}(\Delta t) = \frac{I(\ell^-, 3\pi^0; \Delta t)}{I(\pi\pi, \ell^-; \Delta t)}$$

$$R_4^{CPT}(\Delta t) = \frac{I(\ell^+, 3\pi^0; \Delta t)}{I(\pi\pi, \ell^+; \Delta t)}$$



$\Delta t [\tau_S]$

$$\sigma(R_2^T) = 0.017$$

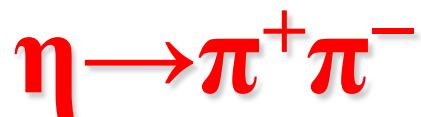
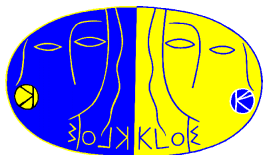
$$\sigma(R_4^T) = 0.017$$

$$\sigma(DR^{CPT}) = 0.028^{5/20}$$

$$(\text{T invariance} \rightarrow R_2^T = 1; \text{SM} \rightarrow R_2^T = 0.993)$$

$$(\text{T invariance} \rightarrow R_4^T = 1; \text{SM} \rightarrow R_4^T = 1.007)$$

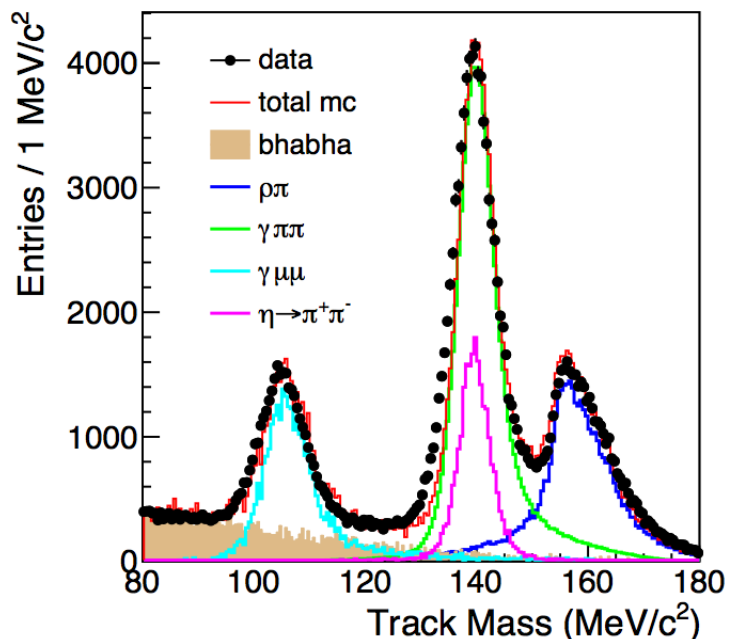
$$(\text{CPT invariance} \rightarrow R_2^{CPT}/R_4^{CPT} = 1)$$



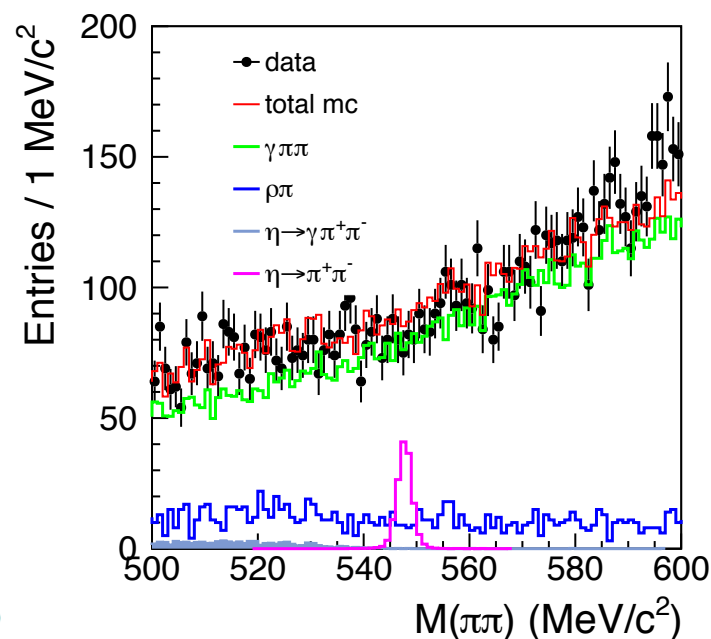
- P and CP violating, Br expected of order 10^{-27} in the SM
- Detection at any accessible level would be signal of CP violation beyond the SM

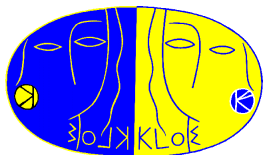
Best limit $\text{Br} < 1.3 \times 10^{-5}$ @ 90% C.L. ($L = 350 \text{ pb}^{-1}$) [KLOE, PLB606(2005)276]
[scaling to $8 \text{ fb}^{-1} \Rightarrow 2.7 \times 10^{-6}$]

After cut: $129 < M_{\text{tr}} < 149 \text{ MeV}$



LNF S.C. - 14/5.

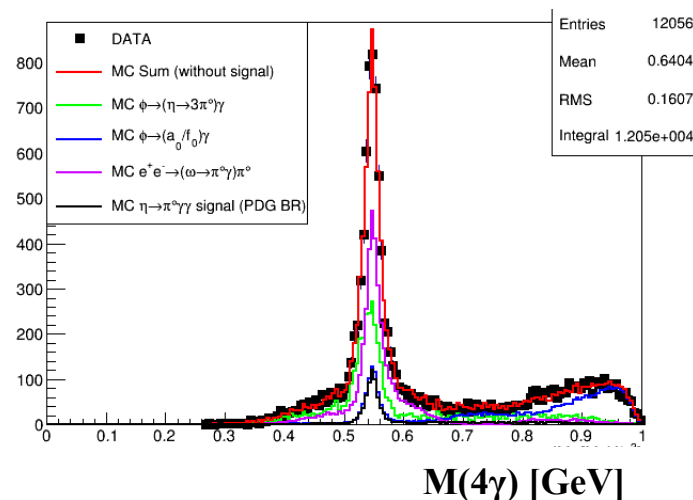




5 prompt γ sample



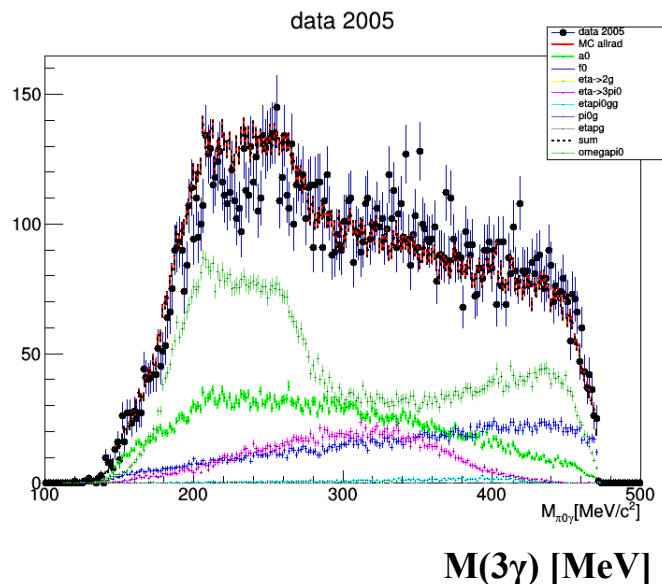
- $\eta \rightarrow \pi^0 \gamma \gamma$ (from $\phi \rightarrow \eta \gamma$): χ PT golden mode, $O(p^2)$ null, $O(p^4)$ suppressed**
 \Rightarrow sensitive to $O(p^6)$ terms
Br = $(22.1 \pm 2.4 \pm 4.7) \times 10^{-5}$ CB@AGS(2008)
Br = $(25.2 \pm 2.5) \times 10^{-5}$ CB@MAMI(2014)
Old KLOE preliminary: $(8.4 \pm 2.7 \pm 1.4) \times 10^{-5}$

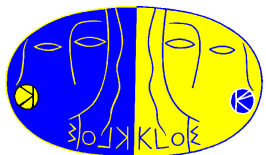


- B-boson search: Leptophobic Dark Force mediator coupled to baryon number with the same quantum numbers of the $\omega(782) \Rightarrow I^G=0^-$**
- Dominant decay ($m_B < 600$ MeV): $B \rightarrow \pi^0 \gamma$**
 \Rightarrow Look for resonances in $\pi^0 \gamma$ invariant mass

$\phi \rightarrow \eta B, B \rightarrow \pi^0 \gamma \Rightarrow \eta \pi^0 \gamma$ final state

(also $\eta \rightarrow B \gamma \Rightarrow \pi^0 \gamma \gamma$, and $e^+ e^- \rightarrow \pi^0 \gamma \gamma_{ISR}$)

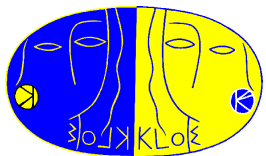




Plans for KLOE-2 data



- **KLOE + KLOE-2 data sample: $8 \text{ fb}^{-1} \Rightarrow 2.4 \times 10^{10}$ ϕ mesons produced, the largest sample ever collected at the $\phi(1020)$ peak**
- **Last SC Findings & Recommendations: “The SC recommends that the KLOE-2 Collaboration prepares a plan for data preservation”**
- **CERN experts contacted through the LNF Director (Sünje Dallmeier-Tiessen and Salvatore Mele)**
- **The idea: “Data Preservation for KLOE would be an excellent test bed as the data set is not gigantic and the basic idea would be to have a Root-compatible set of ntuples with reconstructed data.”**
- **February 20th @LNF: First meeting with Sünje Dallmeier-Tiessen and KLOE-2 detector, offline, and computing experts**
- **First step: Change present DST Data output format to ROOT-compatible (with the assistance of experts: Axel Naumann and Federico Carminati)**
- **First tests planned before summer**



Plans for KLOE-2 data (2)



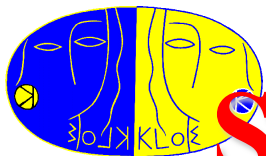
- **End 2018 – Beginning of 2019:**

Complete first round of KLOE-2 data reconstruction +
production of $\sim 1 \text{ fb}^{-1}$ of all_phys Monte Carlo

- **Immediately after:**

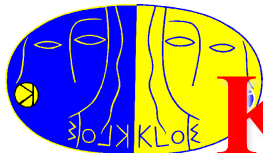
Start a second round of data reconstruction, with an improved
version of Datarec

Implement the ROOT output instead of the present DST format



Short-term plans for analysis

- **October 2018:**
 - Preliminary results on the 5 prompt photon sample ($\eta \rightarrow \pi^0\gamma\gamma$ and B-Boson search) on old data
- **End 2018:**
 - $\gamma\gamma \rightarrow \pi^0$: analysis of the second sample of 500 pb⁻¹,
Bhabha cross-section measurement at very low angle with HET
 - $K_S \rightarrow 3\pi^0$: preliminary result on KLOE-2 data
 - $\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$: update of the analysis on KLOE-2 data
 - T, CPT tests with $\phi \rightarrow K_S K_L \rightarrow 3\pi^0 \pi e\nu, \pi\pi \pi e\nu$: update of the analysis on KLOE data
- **Beginning of 2019:**
 - $K_S \rightarrow \pi e\nu$: update of the analysis of KLOE-2 data
 - $\eta \rightarrow \pi^+\pi^-$: preliminary result on old data + first look at KLOE-2 data



KLOE-2 Physics

KLOE-2 Coll., EPJC68(2010)619
[http:// agenda.infn.it/event/kloe2ws](http://agenda.infn.it/event/kloe2ws)
Proceedings: 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:

$$K_S \rightarrow 3\pi^0$$

direct measurement of $\text{Im}(\epsilon'/\epsilon)$ (lattice calc. improved)

- CKM V_{us} :

K_S semileptonic decays and A_S
(CP and CPT test)

$K_{\mu 3}$ form factors, K_{l3} radiative corrections

- $\chi p T$: $K_S \rightarrow \gamma\gamma$
- Search for rare K_S decays

Hadronic cross section:

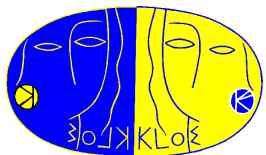
- ISR studies with 3π , 4π final states
- F_π with increased statistics
- Measurement of a_μ^{HLO} in the space-like region using Bhabha process

Dark force searches:

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

Light meson Physics:

- η decays, ω decays
- Transition Form Factors
- C,P,CP violation: improve limits on
 $\eta \rightarrow \gamma\gamma\gamma, \pi^+\pi^-, \pi^0\pi^0, \pi^0\pi^0\gamma$
- Improve $\eta \rightarrow \pi^+\pi^-e^+e^-$
- $\chi p T$: $\eta \rightarrow \pi^0\gamma\gamma$
- Light scalar mesons: $f_0(500)$ in $\phi \rightarrow K_S K_S \gamma$
- $\gamma\gamma$ Physics: $\gamma\gamma \rightarrow \pi^0$ and π^0 TFF
- $e^+e^- \rightarrow \pi^0\gamma\gamma_{\text{ISR}}$ (π^0 TFF)
- Search for axion-like particles

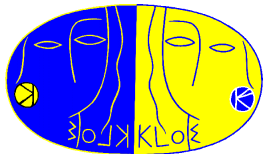


Conclusions

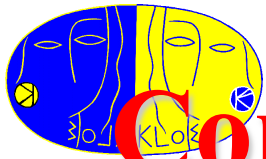
- **KLOE-2 data taking successfully closed on March 30**
Luminosity goal reached \Rightarrow acquired $L = 5.5 \text{ fb}^{-1}$
KLOE + KLOE-2 sample $\Rightarrow \sim 8 \text{ fb}^{-1}$ at the ϕ peak
- **Detector roll-out in progress**

... of course this is not the end of KLOE-2

- **Now the effort of the Collaboration is focused on Data reconstruction and simulation**
- **First round of data reconstruction expected by the end of 2018 – beginning of 2019**
- **Analysis short-term plans defined**



Spare



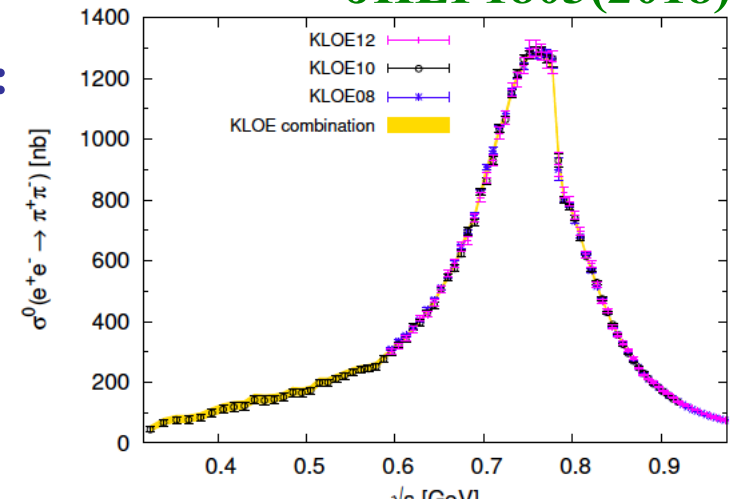
Combination of $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma(\gamma))$

JHEP1803(2018)173

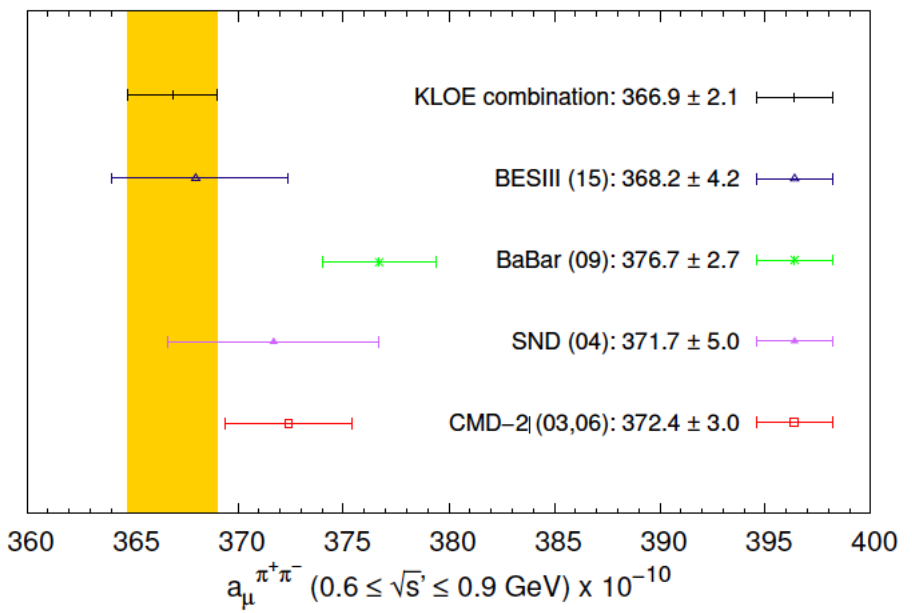
Combination of three KLOE measurement:

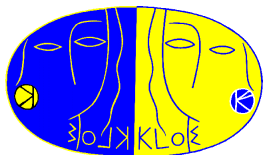
1. PLB670(2009)285 – KLOE08
2. PLB700(2011)102 – KLOE10
3. PLB720(2013)336 – KLOE12

- Improved uncertainties
- Correlation of statistic and systematic uncertainties



⇒ determination of a_μ in the range $0.10 < s < 0.95 \text{ GeV}^2$



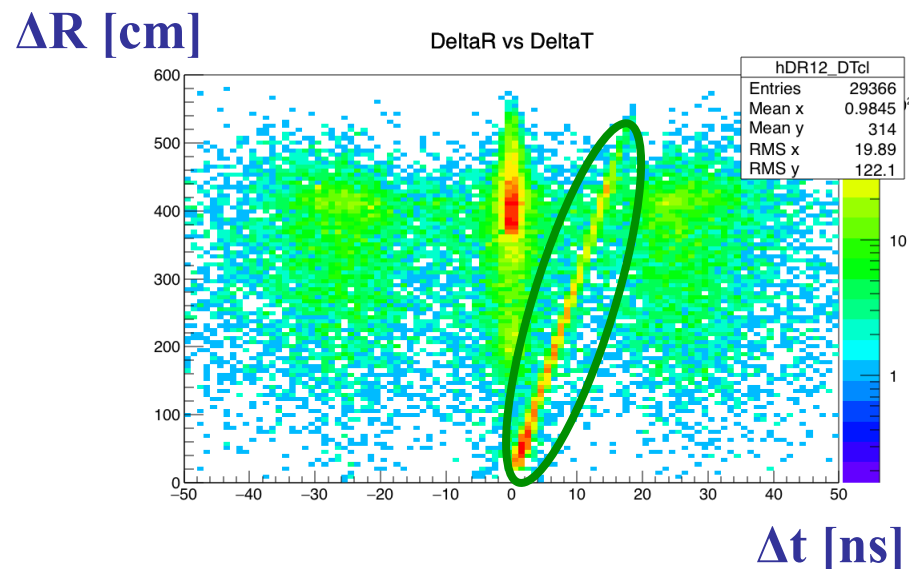
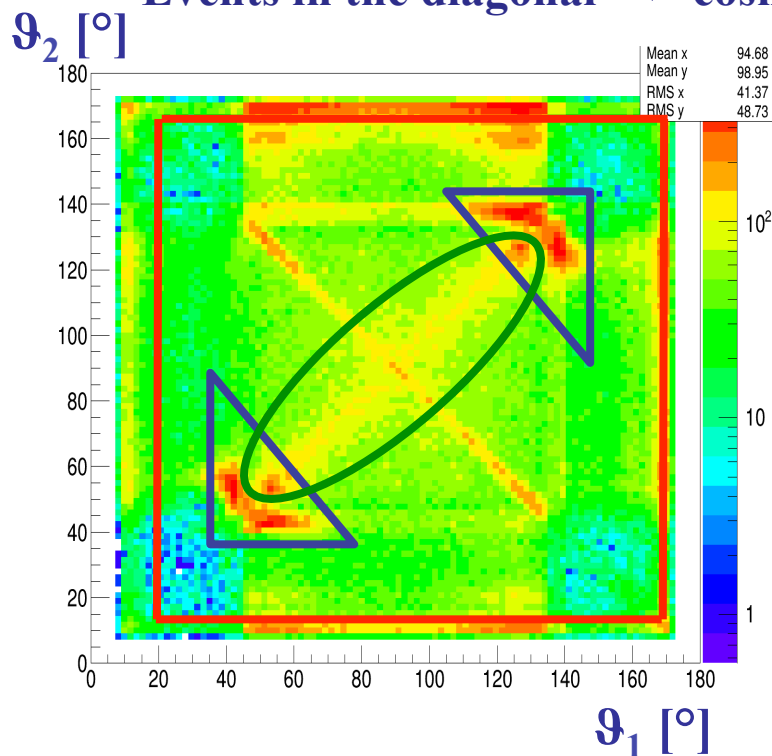


New background filter



Based on the two most energetic clusters in EMC

- Reject events at small polar angle \Rightarrow machine bckg
- Events in the overlap Barrel-Endcap region \Rightarrow Mach.bcgd. + cosmys
- Events in the diagonal \Rightarrow cosmys



- Overall rejection factor of $\sim 25\%$,
- Small decrease in efficiency for good events (few %)



Dark Photon → invisible

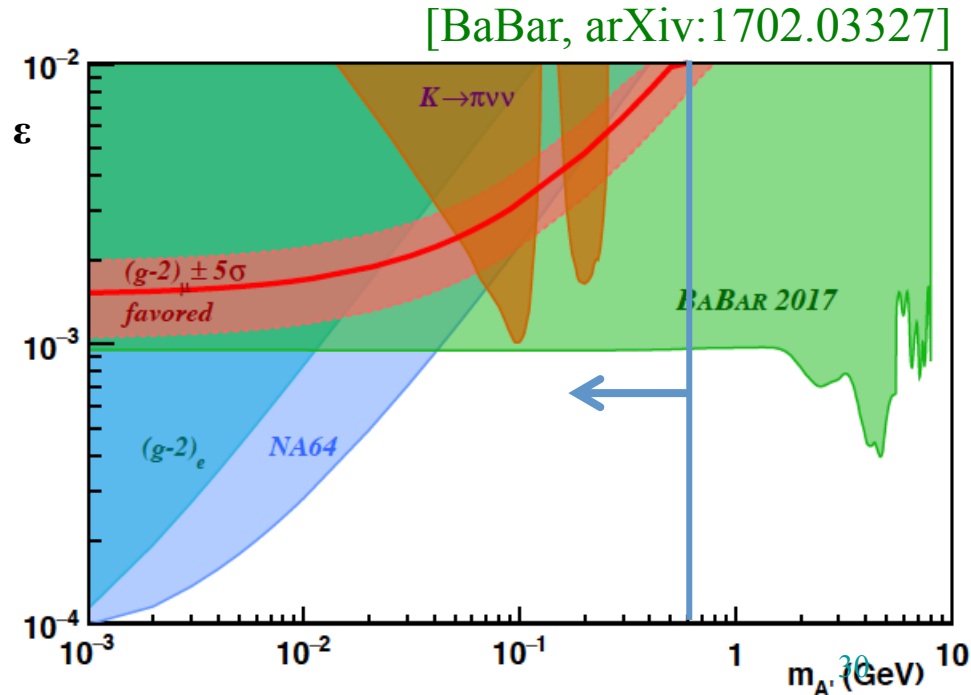
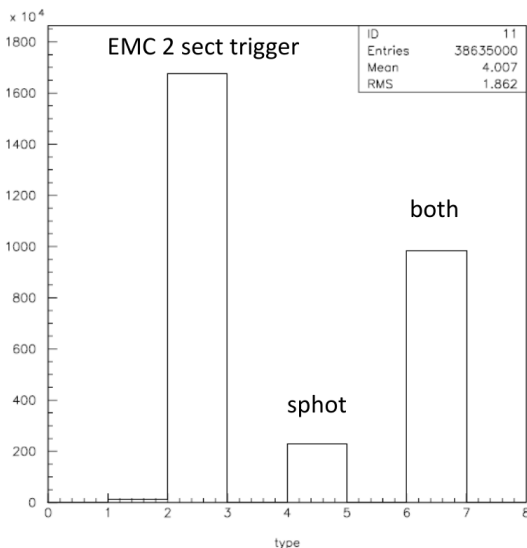
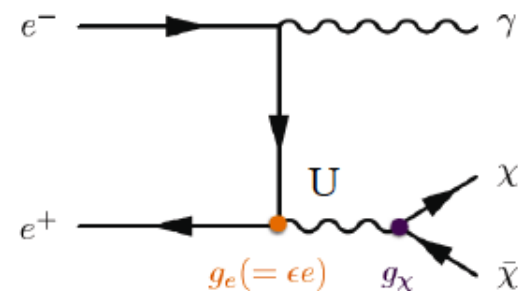


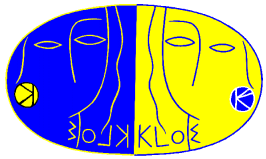
- Invisible decay of U-boson
- Signature: monochromatic photon
- **Single Photon Trigger implemented in Nov. 2016**

with 350 MeV threshold (on the barrel calorimeter)

$$\Rightarrow M_U < 570 \text{ MeV}$$

- $\sim 2 \text{ fb}^{-1}$ collected with SPT
- $\sigma \sim 1/\text{s}$, ~ 100 times higher than at B-factories
- New stream implemented in Datarec
- Problem: machine bckg. rejection



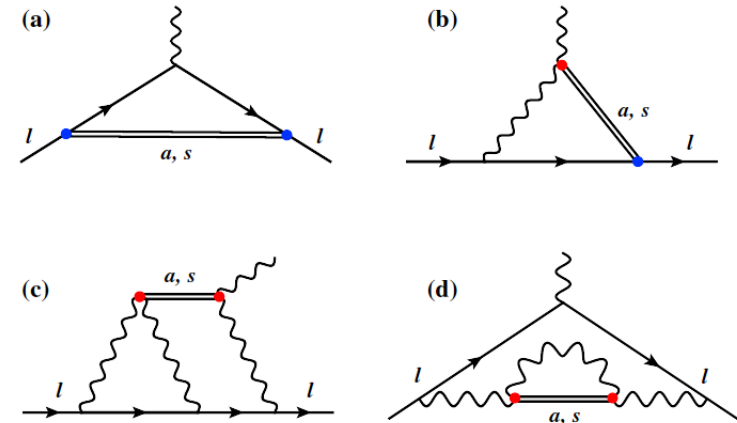


ALPs at KLOE-2



- Light spin 0 (scalars or pseudoscalars) \Rightarrow **Axion-Like Particles**
- Generalization of QCD axions, with arbitrary mass or couplings to other particles [Marciano et al., PRD94(2016)115033]
- Possible explanation of the $(g-2)_\mu$ discrepancy
- KLOE can set limits on the processes:

– $e^+e^- \rightarrow \gamma^* \rightarrow a\gamma$, with $a \rightarrow \gamma\gamma$



$$\sigma_{a\gamma}(\sqrt{s} = 1 \text{ GeV}, m_a = 150 \text{ MeV}) = 9 \text{ pb} \left(\frac{g_{a\gamma\gamma}}{10^{-2} \text{ GeV}^{-1}} \right)^2$$

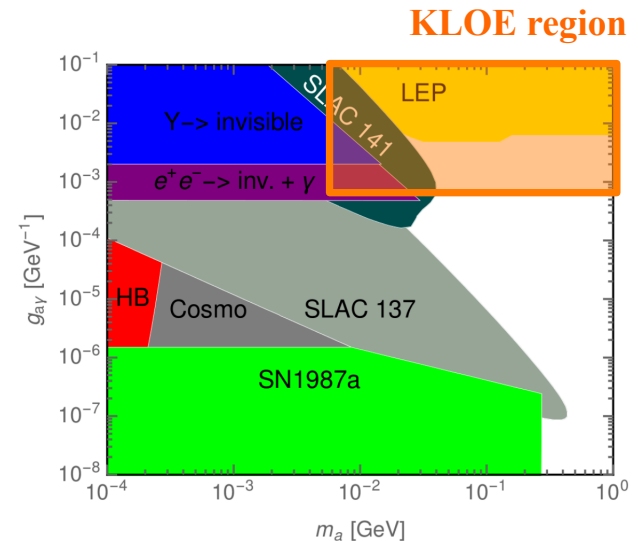
Expected with 5 fb^{-1} $N(a \rightarrow \gamma\gamma) \sim 400 - 4 \times 10^4$ evts.

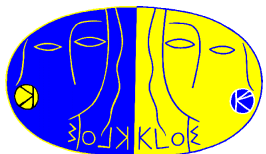
$$(g_{a\gamma\gamma} \sim 10^{-3} - 10^{-2} \text{ GeV}^{-1})$$

– $e^+e^- \rightarrow e^+e^-a$ ($\gamma^*\gamma^* \rightarrow a$)

$$\sigma_{eea}(\sqrt{s} = 1 \text{ GeV}, m_a = 150 \text{ MeV}) = 31 \text{ pb} \left(\frac{g_{a\gamma\gamma}}{10^{-2} \text{ GeV}^{-1}} \right)^2$$

Expected $N(eea) \sim 1.5 \times 10^3 - 1.5 \times 10^5$ evts.

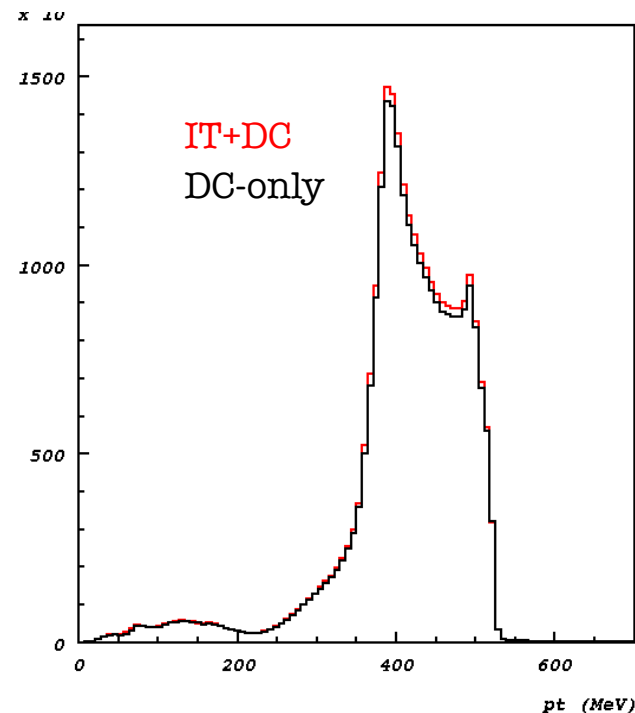
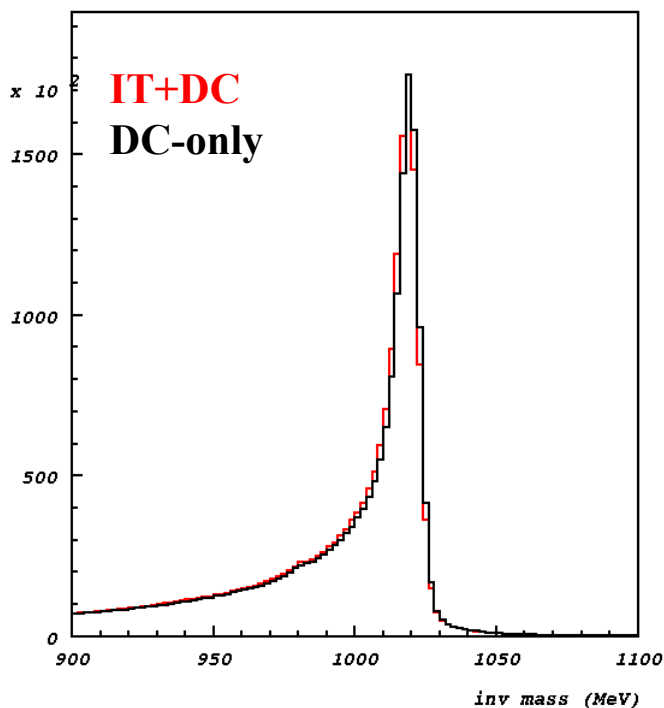




Checks with Bhabha's



- Invariant mass of e^+e^- and transverse momentum



- Good agreement between Integrated Tracking and DC only