KLOE-2 status

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for the KLOE-2 Collaboration

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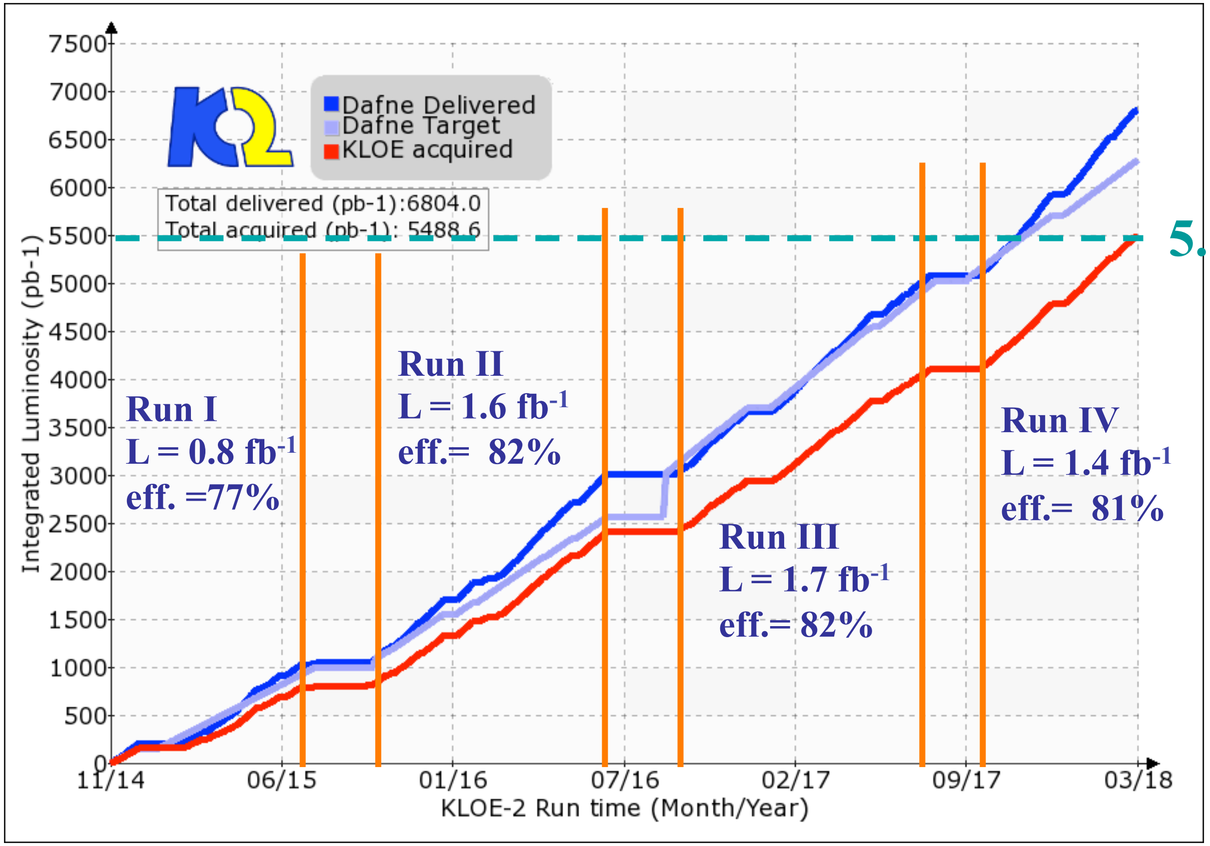
Outline

- **Status of data reconstruction**
- **Monte Carlo simulation**
- **ROOT output implementation**
- **Status of the analysis**
- **Computing**
- **Conclusions**

KLOE-2 data

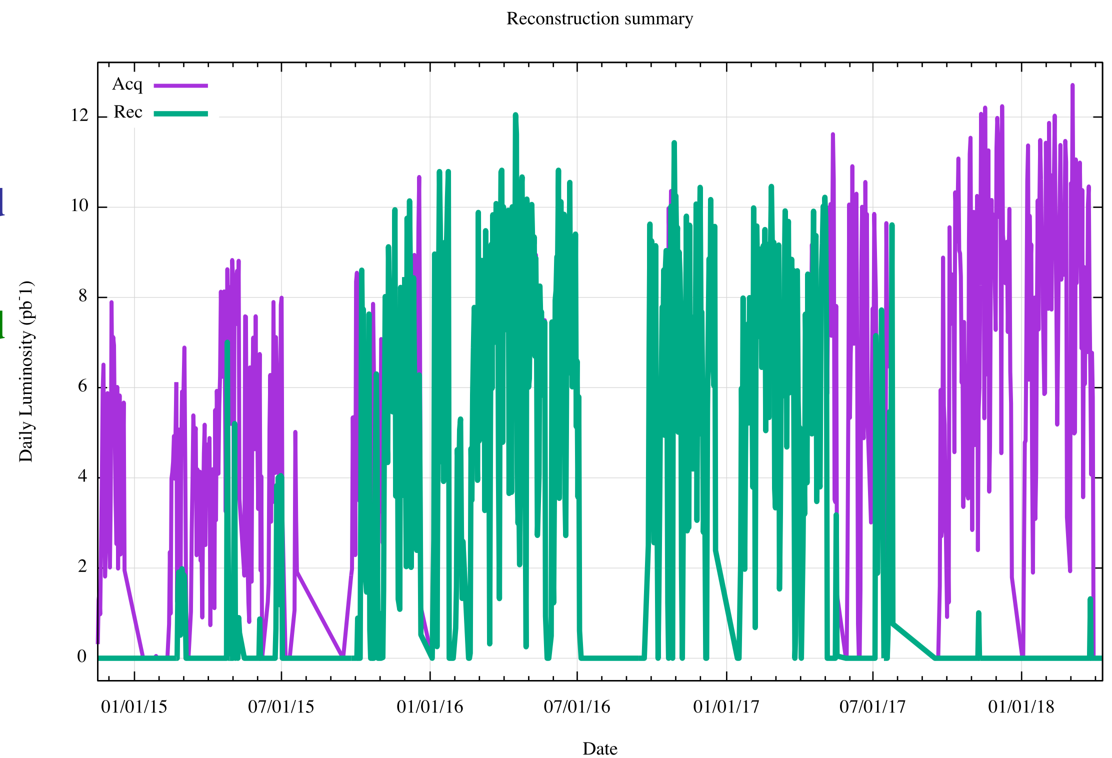
- Data-taking ended on March 30th, 2018
- Total acquired Luminosity = 5.5 fb^{-1}



Data reconstruction

Present 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 $\gamma\gamma$ events

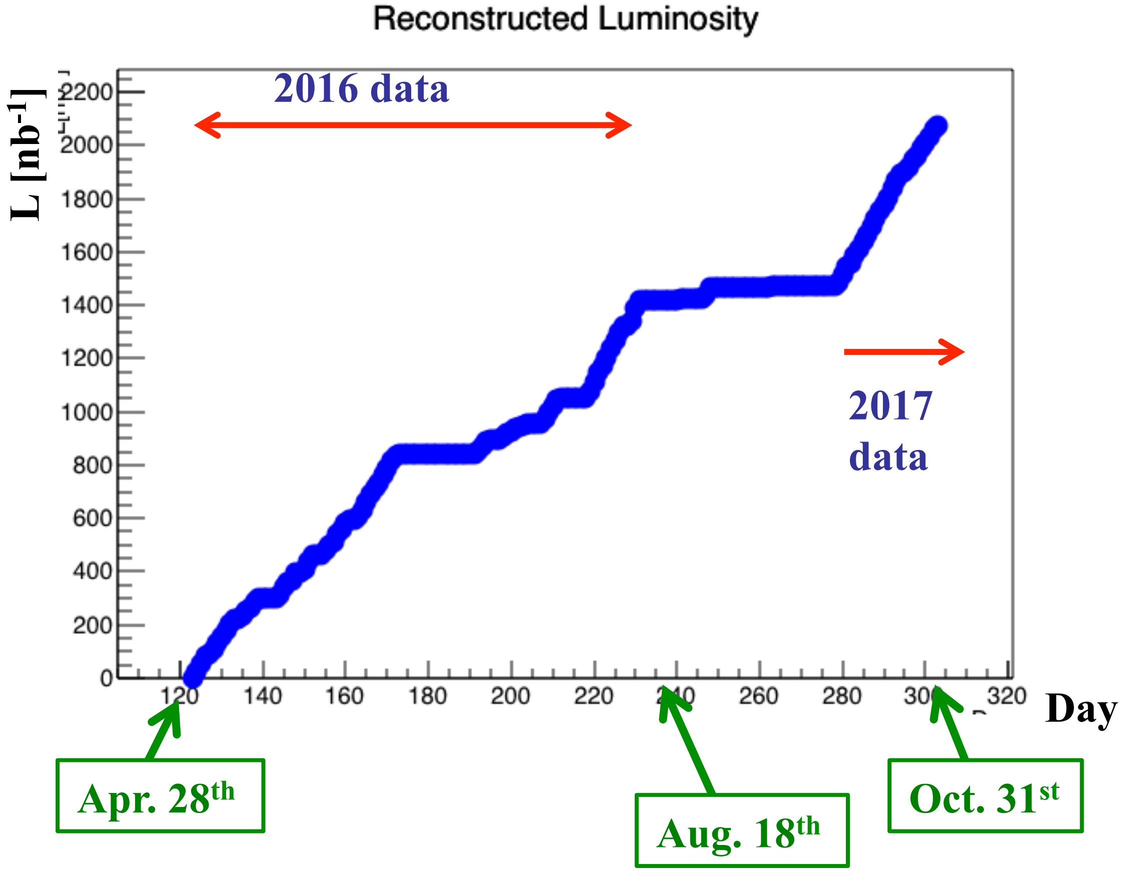


- **2.1 fb^{-1} reconstructed with DBV-38 since April 28th, 2018**
  - ⇒ **38 % of the whole KLOE-2 data set**

	Run-I	Run-II	Run-III	Run-IV
L [pb^{-1}]	800	1620	1680	1400
RAW [TB]	457	867	943	734
REC [pb^{-1}]	31	1328	1159	2

(includes also previous DBVs)

DBV-38 reconstruction rate

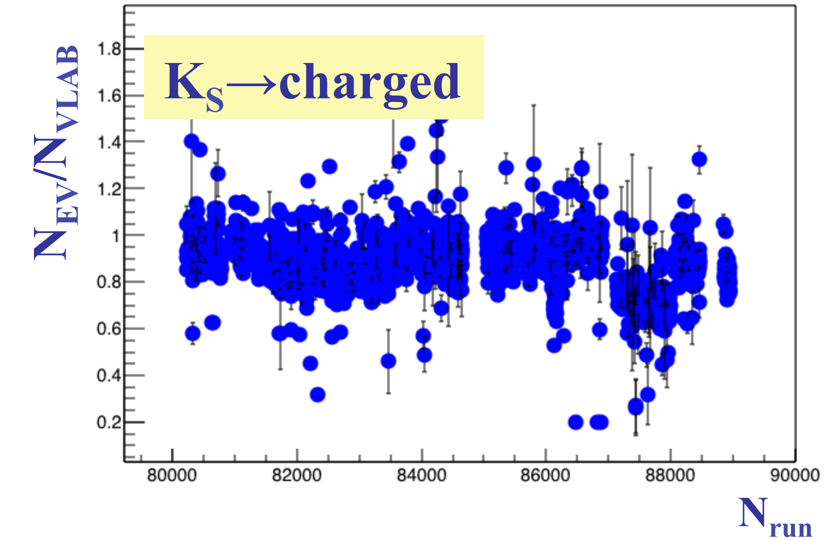


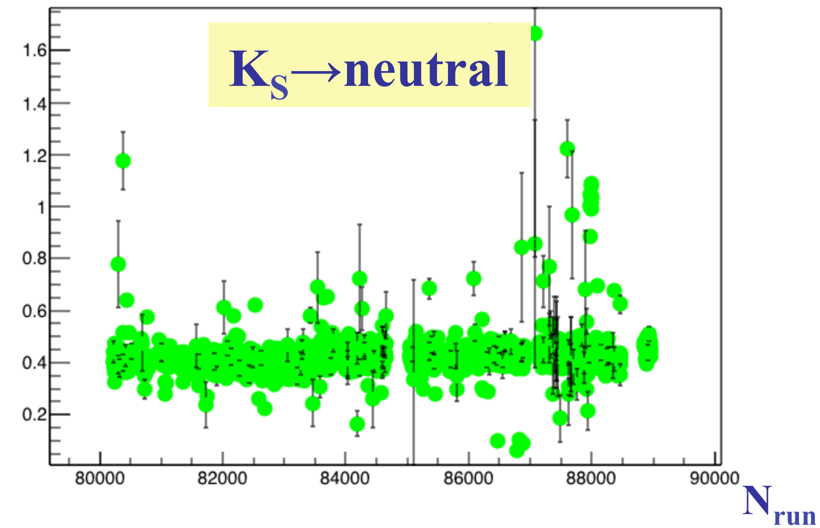
- We started the reconstruction of 2017 data at a rate of ~ 30 pb^{-1}/day
- With this rate: ~ 3.5 months to complete the first round of reconstruction without considering dead times

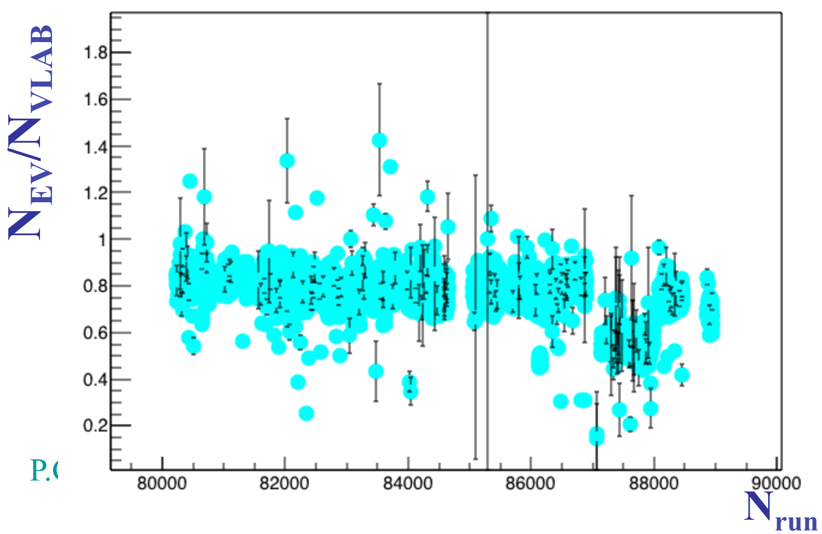
Event Counters

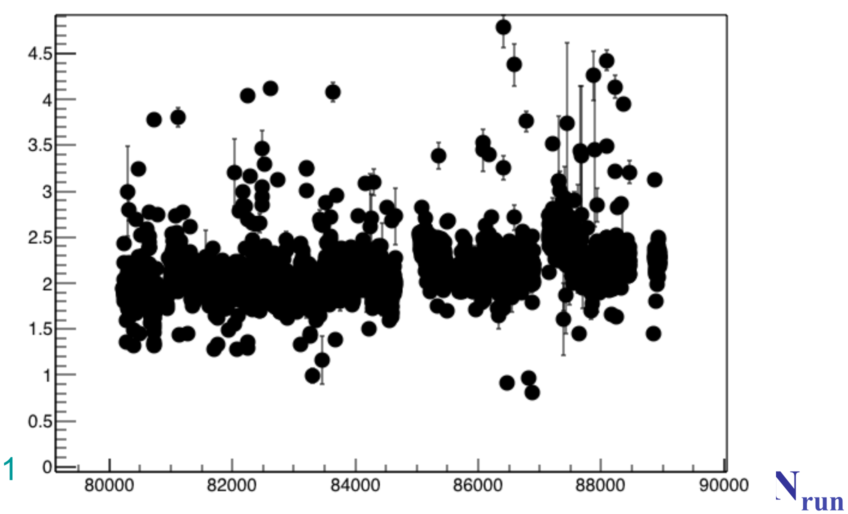
Data reconstructed with DBV-38

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

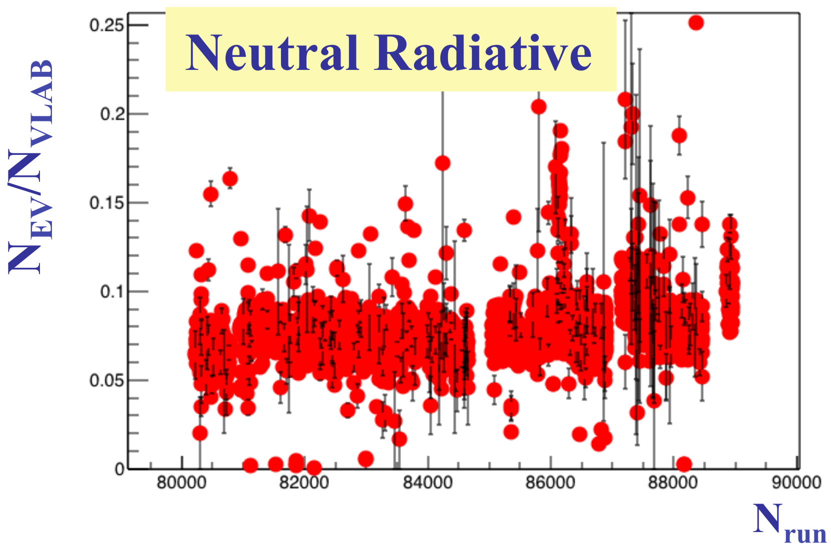


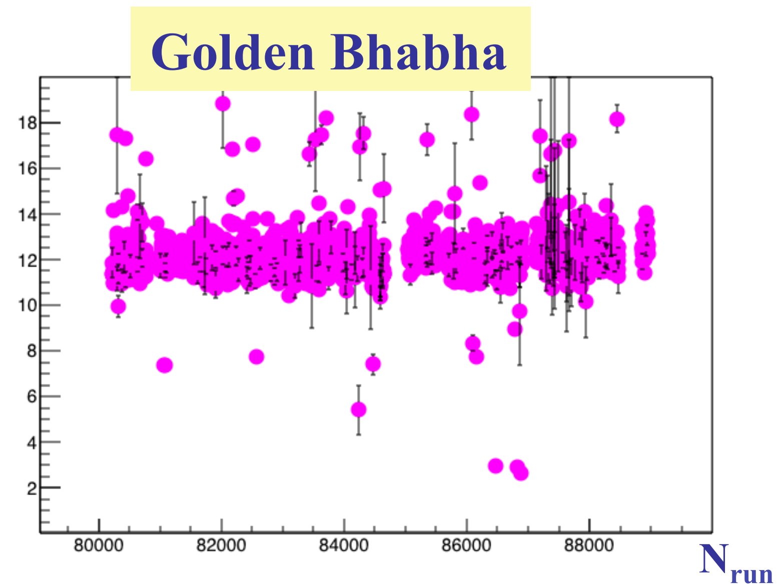


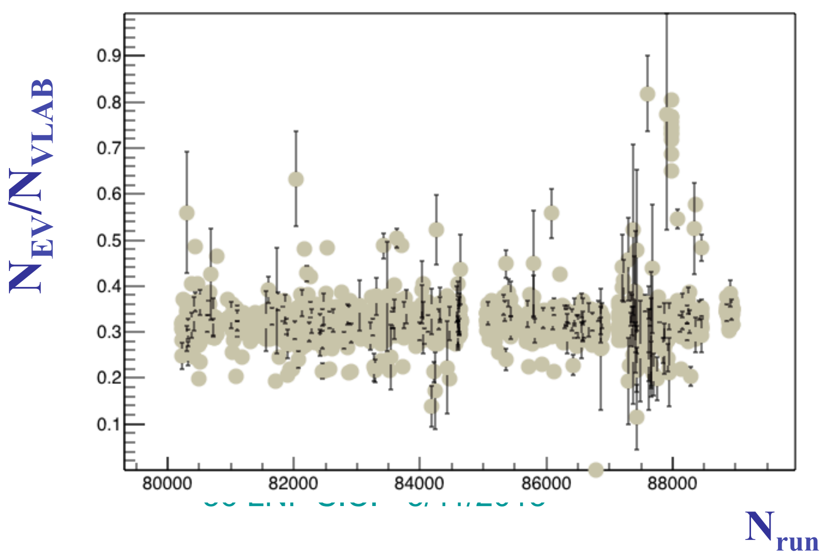




Event counters







MC production

MC first massive production:
(with DBV-38):

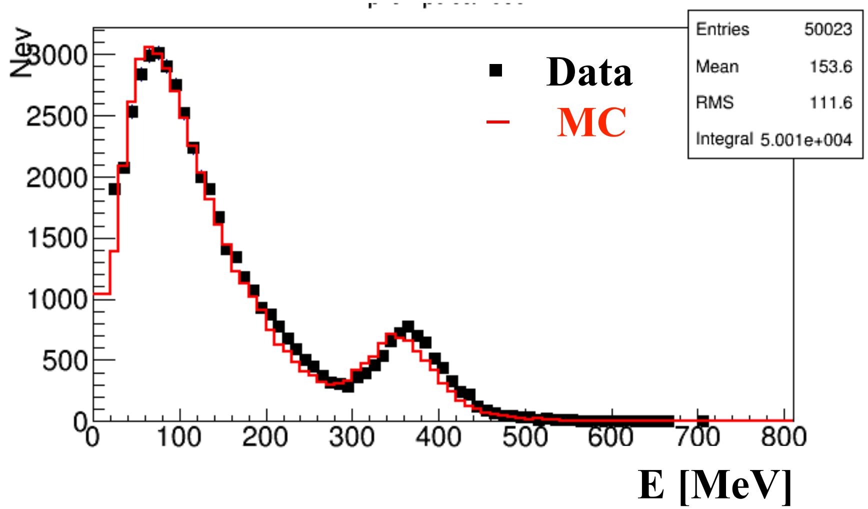
- Simulation of 2016 data, all ϕ decays started on April 20th (same luminosity of data)

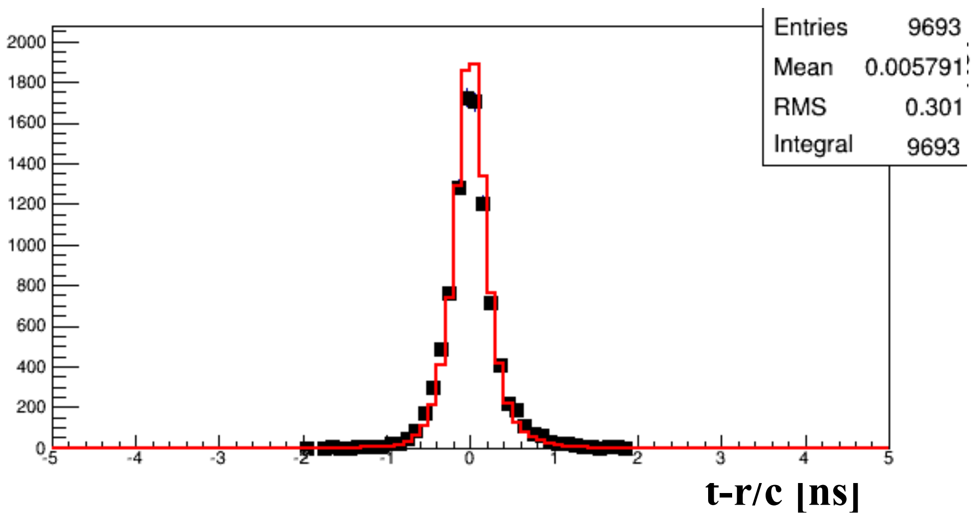
- Production rate ≈ 15 pb^{-1}/day (in parallel with the data reconstruction)

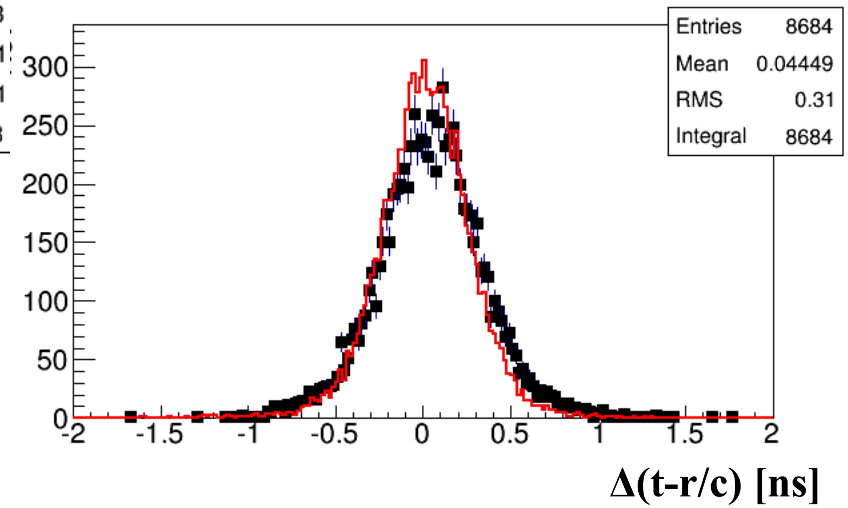
Run range	MC (pb-1)
88966-89096	49.46
85681-86024	91.55
86025-86511	96.97
86512-86900	105.64
80694-81537	92.77
81538-81973	96.83
81974-82398	113.21
82411-82850	103.09
82851-83145	83.05
83201-83498	100.86
83504-84089	117.48
84114-84385	96.02
84401-85187	110.27
85203-85507	82.28
TOTAL	**1339.48**

Data-MC comparison

- **Neutral events: prompt photon energy and timing**







ROOT output

- **Motivations: make analysis easier especially for young people and choose a suitable format for data preservation purposes**
- **ROOT User's Workshop in September in Sarajevo: meetings with the ROOT experts to discuss our use case**
- **The idea is to replace the DSTs with ROOT files, using the same structure of the Hbook ntuples that we are largely using in our analyses**
- **This is done by Fortran module, PROD2ROOT, that fills the commons and calls the C++ functions to pass the data structures to the C++ code, Fort2C.cpp that writes the TTree**
- **This part is almost complete, with the help of our summer student Luigi Berducci (Rome - La Sapienza University)**
- **Work in progress to check of the output, file and memory management**
- **Full test foreseen with the data that we are reconstructing now**

ROOT for data preservation

- An alternative possibility, very interesting for data preservation, has been discussed during the Sarajevo Workshop with the developers of RDataFrame and RDataSource of ROOT v6
- The idea is to directly read the YBOS data structure (our raw data format) and make the analysis with ROOT
- The same type of work has been already done for other collaborations like ATLAS and CMS
- The experts offered to help us in case we decided to adopt this solution

Publications/Analyses

Publications	
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 (will appear in next PDG update)
Combined limit on the production of a light gauge boson decaying into $\mu^+\mu^-$ and $\pi^+\pi^-$	Phys.Lett. B784 (2018) 336

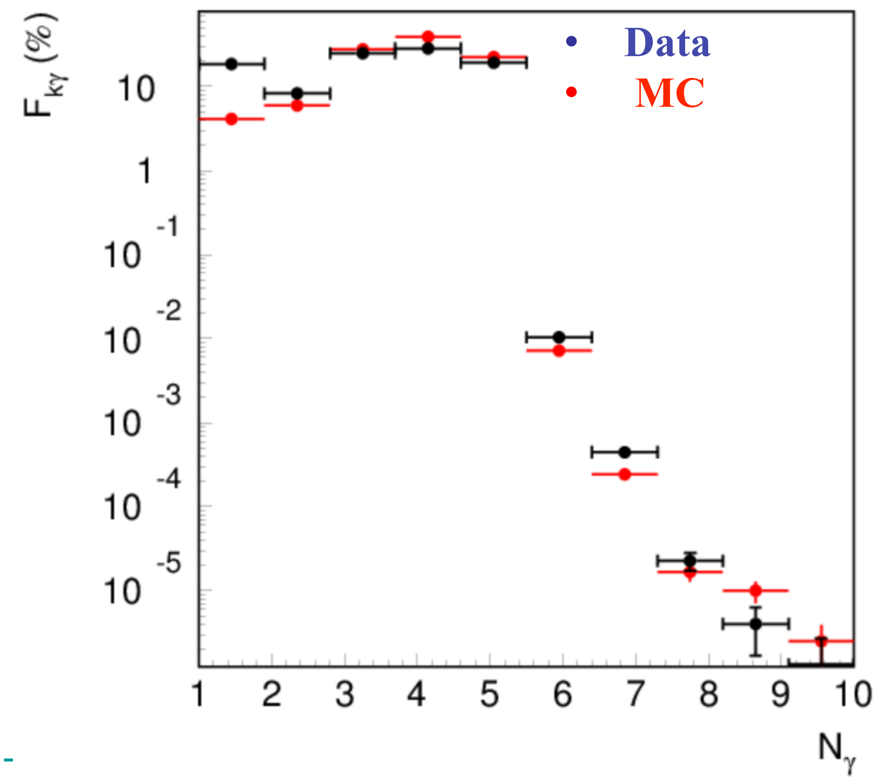
Ongoing analyses	
$\gamma\gamma \to \pi^0$	KLOE-2 data
$K_S \to \pi e \nu$ K_L crash; $K_S \to \pi^+\pi^-$ $K_L \to \pi^+\pi^-$	KLOE-2 data
$K_S \to 3\pi^0$ (CP viol.)	KLOE-2 data
T/CPT tests with $\phi \to K_S K_L \to 3\pi^0\ \pi e \nu$, $\pi\pi\ \pi e \nu$	KLOE data – PhD Thesis
$K_S \to \pi e \nu$; $K_S \to \pi \mu \nu$	KLOE data – PhD Thesis
$K_S \to \pi^+\pi^-\pi^0$	KLOE data – PhD Thesis
B-boson search in $\phi \to \eta\pi^0\gamma$	KLOE / KLOE-2 data
$\eta \to \pi^0\gamma\gamma$ - χPT golden mode	KLOE / KLOE-2 data
$\eta \to \pi^+\pi^-$ (P and CP viol.)	KLOE / KLOE-2 data
$e^+e^- \to \omega\ \gamma_{ISR}$	KLOE data

$K_S \to 3\pi^0$ – KLOE-2 data

- Data sample: KLOE-2 data, $L \approx 1.5\ fb^{-1}$ (all 2016 reconstructed data)
- CP violating, never observed, expected $Br \sim 2\times10^{-9}$ (SM)
- Best upper limit by KLOE: $Br(K_S \to 3\pi^0) < 2.6\times10^{-8}$ @ 90% C.L. with $1.7\ fb^{-1}$ [PLB723(2013)54]

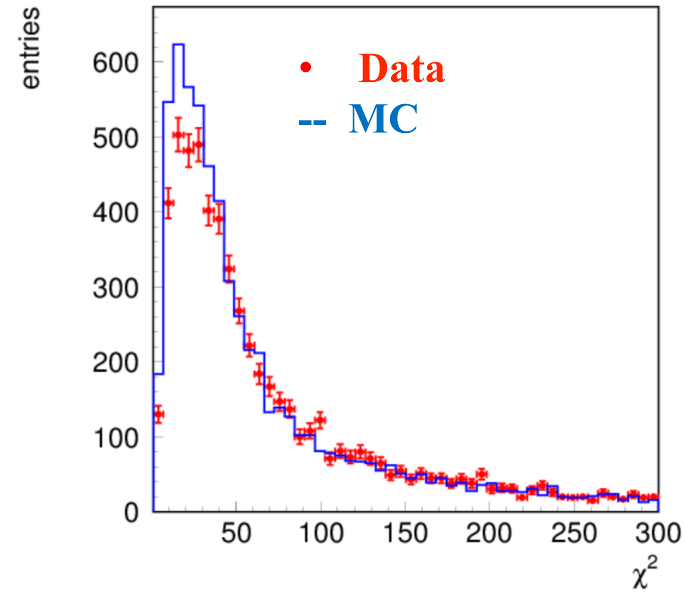
- “K_L crash” (K_L in the EMC) + 6 prompt photons
- Main bckg: $K_S \to 2\pi^0$ (4 prompt photons), also used for normalization

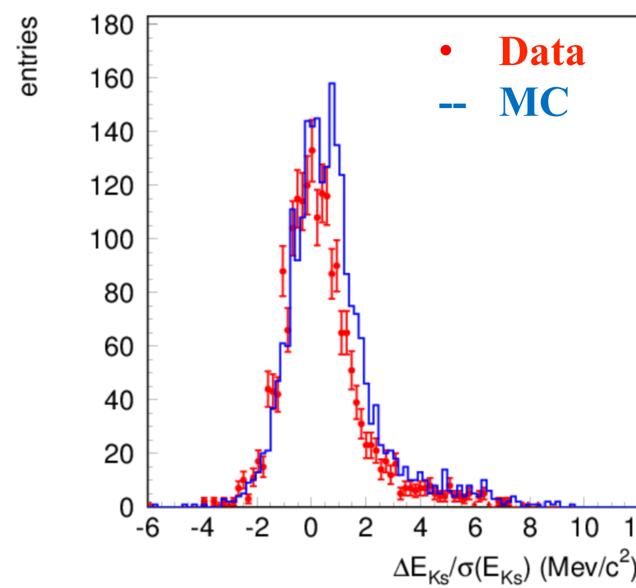
- Selection criteria hardened to face the large machine bckg



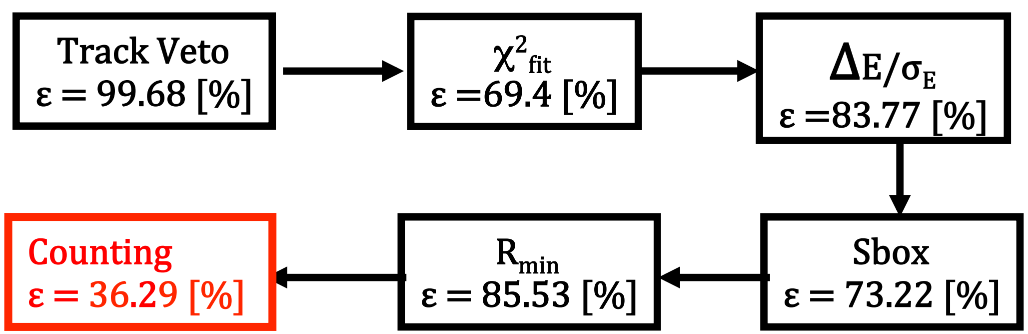
$K_S \to 3\pi^0$

- **Track Veto: Reject 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**
- **$\Delta E/\sigma_E = (E_{KS} - \Sigma E_\gamma)/\sigma_E$ cut: consistency between the K_S energy reconstructed by tagging and the sum of energies of four "best" photons**
- **Signal box definition in the $\zeta^2_{2\pi} - \zeta^2_{3\pi}$ plane (photon pairing variables)**
- **Cut on min distance between clusters**



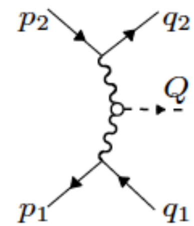


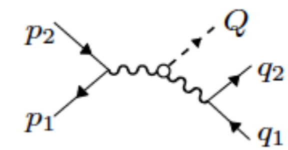
- **Analysis chain efficiency:**



$e^+e^-\rightarrow\gamma^*\gamma^*\rightarrow e^+e^-\pi^0$

- **Chiral anomaly in QCD predicts the π^0 width with percent precision. The improvement of the experimental measurement to 1% is a fundamental test of QCD at the confinement scale**



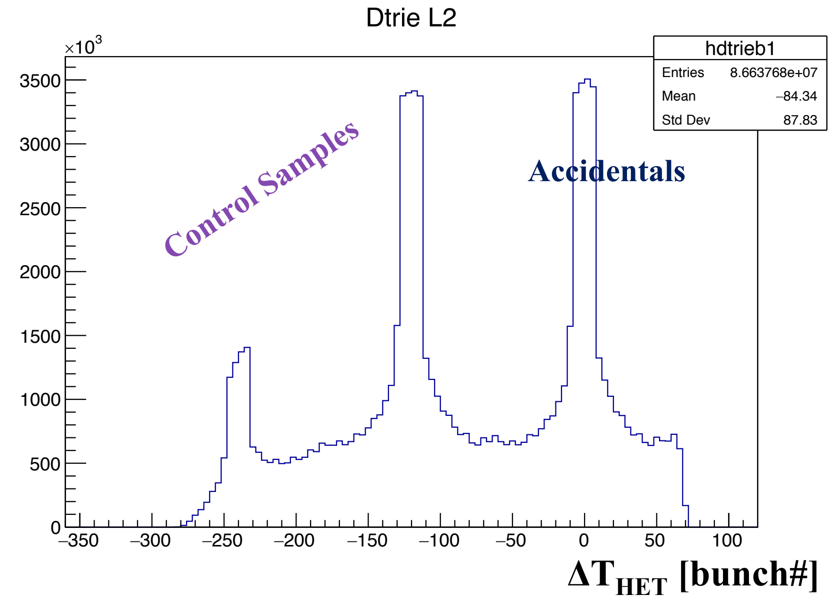


- **π^0s from $\gamma\gamma$ interactions are very low in momentum, near KLOE trigger threshold**
- **Time-coincidence with signals in the High Energy Tagger from leptons in the final state studied**
- **HET stations are installed in Roman Pots at the exit of KLOE dipoles, 11 m from the IP**
- **HET DAQ is independent from KLOE DAQ: KLOE DAQ stores ~1 DAΦNE turn, HET DAQ 2-3 DAΦNE turns; synchronization done with the fiducial signal from DAΦNE RF.**
- **Details on false coincidences (mostly Bhabha's in the HET + any trigger in KLOE) are obtained from HET turns outside the KLOE DAQ time window.**
- **Signal has been simulated using the EKHARA code. Tracking of the leptons from IP to the HET stations with a GEANT4-based code.**
- **The analysis of ~ 0.5 fb^{-1} taken in 2015 did not lead to any firm evidence of the signal.**
- **Some issues with the HET FEE, affecting HET efficiency, discovered and fixed with the installation of new discriminators in January 2017**

- **The analysis of another sample of ~ 0.5 fb^{-1} taken in 2017-2018 is undergoing**

HET analysis

- The reconstruction of 0.5 fb^{-1} has been completed
  - Reconstruction output (ntuples) 6.55 TB
  - Data stored in ROOT format 3.37 TB
  - 3 levels of data reduction applied 0.45 TB → 86 GB → 4.65 GB

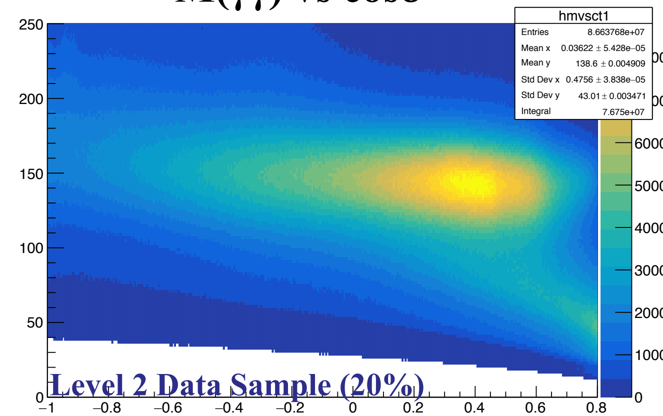


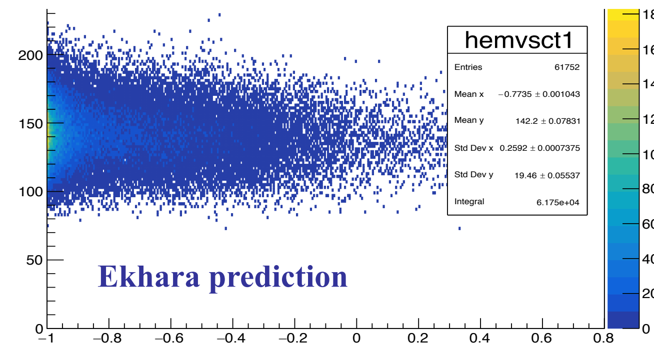
- This new selection stores all infos on the reconstruction of any event
  - with hits in both HET stations with |ΔT| within 4 DAΦNE bunches (no requirement on the KLOE side)
  - with hits in one HET station and
    - at least one bunch in KLOE associated with only 2 clusters in the calorimeter barrel.
    - KLOE and HET Bunch Times compatible with Trigger signal. DAΦNE turn not considered → the control sample is stored as well.
    - Very loose kinematics cuts on the selected clusters applied

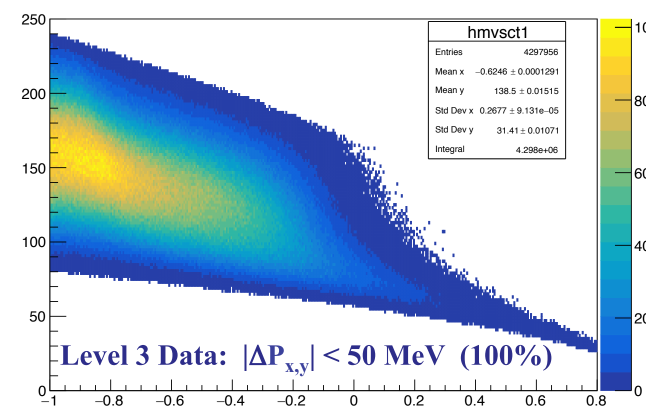
HET analysis

- First level of data reduction analyzed: extra-clusters energy, position, time analyzed and compared with extra-clusters of Bhabha's and $e^+e^- \rightarrow \gamma\gamma$ samples
- The agreement of Energy, Position, Time distribution of the two samples brought to the decision not to apply any cut on the extra clusters in the event
- Second level of data reduction analyzed: $|\Delta P_{x,y}| < 50$ MeV very effective and applied at level 3
- Third level of data reduction is used to start the multivariate analysis
- Procedure for training and data analysis ready: tests undergoing
- Short data taking sample planned to be recorded during Siddharta commissioning to exclude any rate dependence on the magnetic layout

M(γγ) vs cosϑ





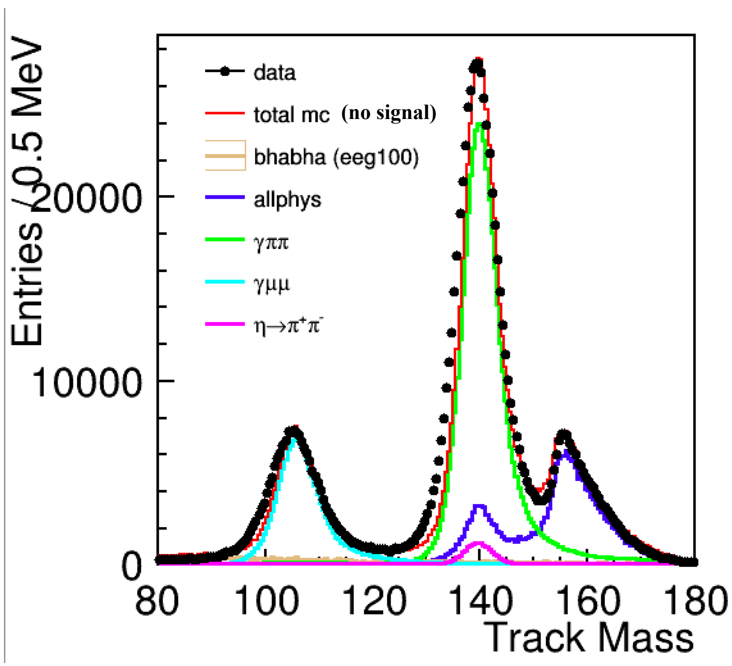


$\eta \rightarrow \pi^+\pi^-$

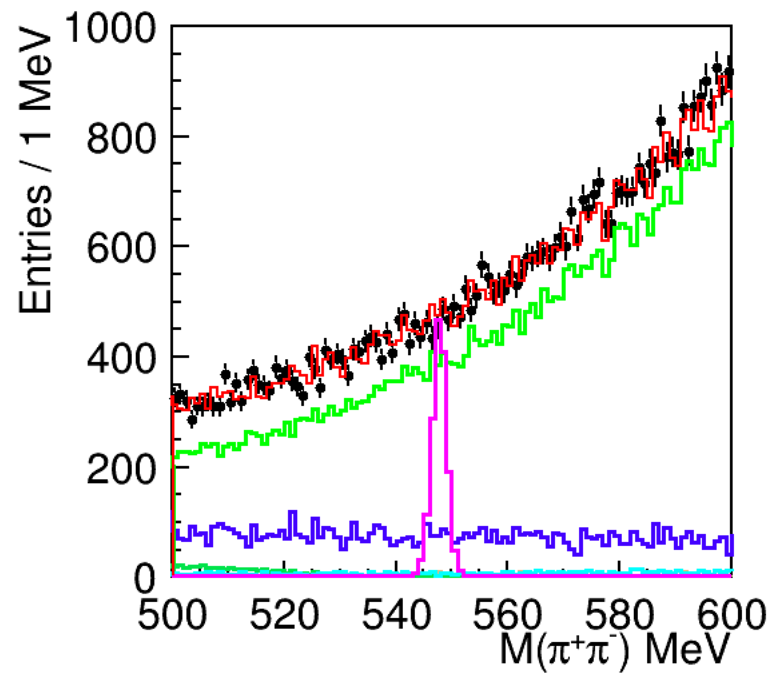
- **P and CP violating, Br expected of order 10^{-27} in the SM**
- **Detection at any accessible level would be signal of CP viol. beyond the SM**

Best limit Br<1.3×10^{-5} @ 90% C.L. (L = 350 pb^{-1}) [KLOE, PLB606(2005)276]

LHCb recent measurement: Br<1.6×10^{-5} @ 90% C.L. [PLB764(2017)233]



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



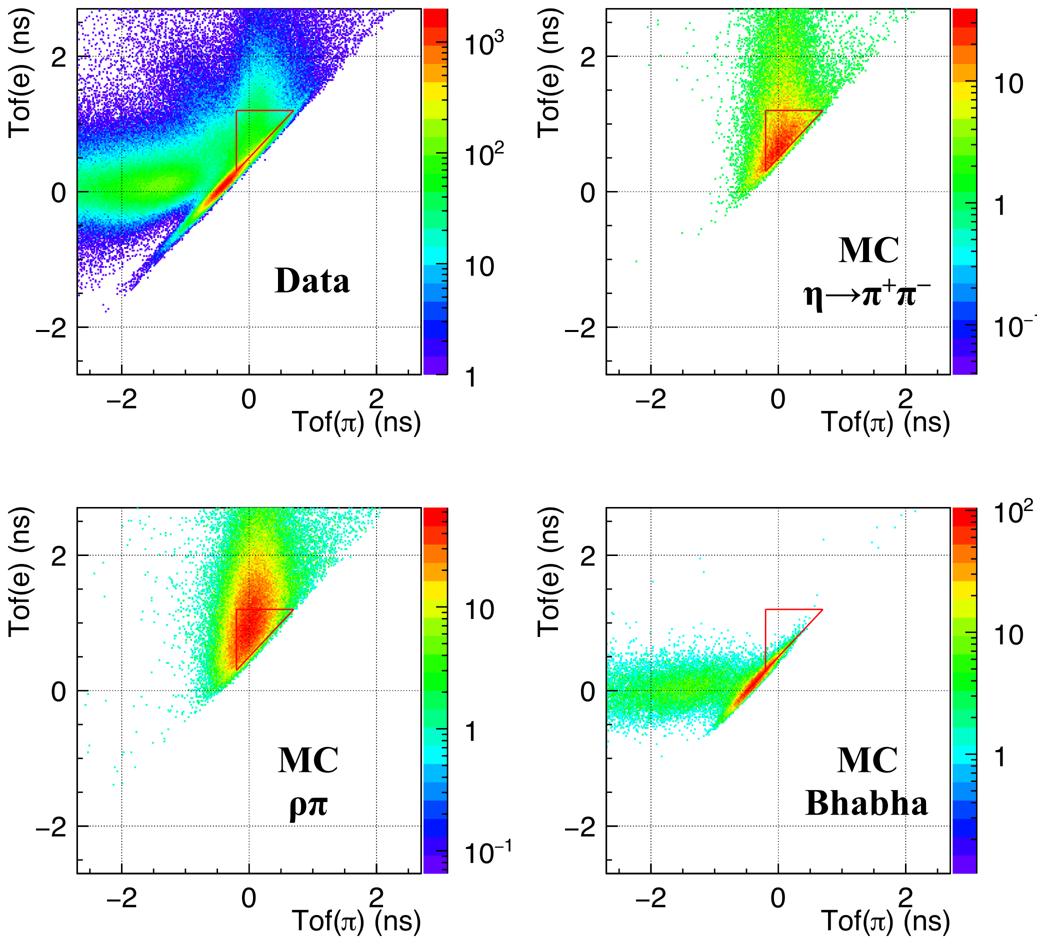
- **L = 1.7 fb^{-1} (KLOE data) ⇒ Very preliminary U.L.: Br < 6.3×10^{-6} @ 90% C.L.**

$\eta \rightarrow \pi^+\pi^-$ with KLOE-2 data

- **Analysis of KLOE-2 data started**
  ⇒ L ≈ 200 pb^{-1}

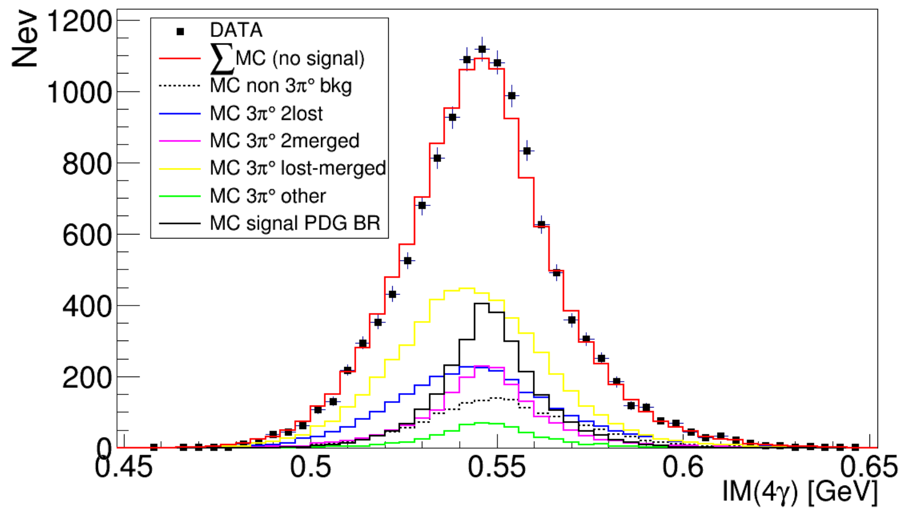
- **Working to adjust the analysis to the different background conditions**

- **Combining KLOE + KLOE-2 statistics (8 fb^{-1})**
  U.L. expected ~ 3×10^{-6}



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

- $\eta\rightarrow\pi^0\gamma\gamma$ (from $\phi\rightarrow\eta\gamma$): χPT golden mode, $O(p^2)$ null, $O(p^4)$ suppressed
  $\Rightarrow$ sensitive to $O(p^6)$
  Br = $(22.1 \pm 2.4 \pm 4.7)\times10^{-5}$ 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)

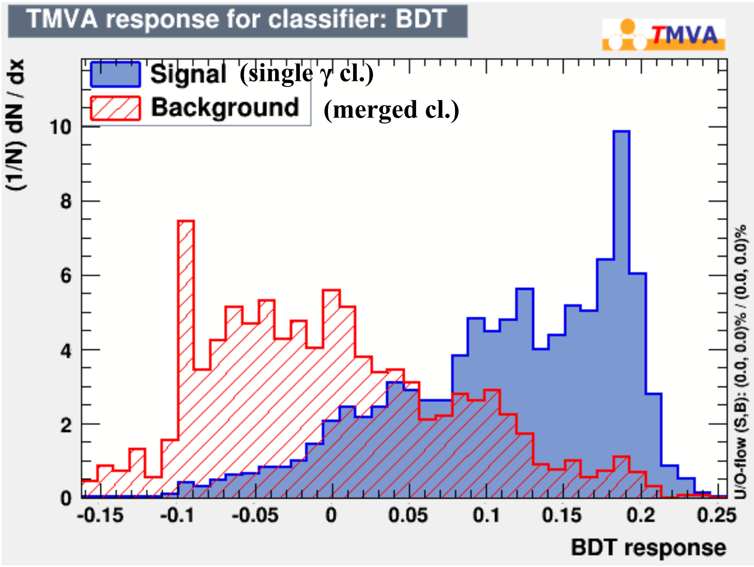


5 prompt photon sample:

- L = 580 pb^{-1} of KLOE data

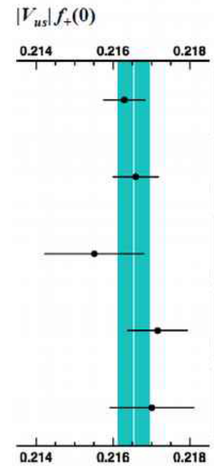
- Main bckg is $\phi\rightarrow\eta\gamma$, with $\eta\rightarrow3\pi^0$ with lost or merged photons

- Use of BDT with cluster shape variables to separate single photon from merged photon clusters seems promising



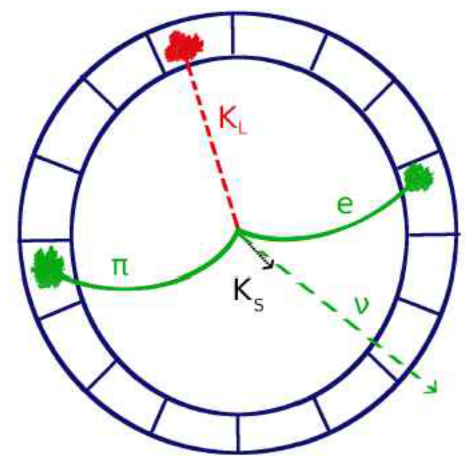
K_S semileptonic decays

- Motivation: improve the knowledge of V_{us} of the CKM matrix
- K_{Se3} gives the largest contribution to the uncertainty [old KLOE meas. $Br(K_{Se3}) = (7.046 \pm 0.091) \times 10^{-4}$]
- $K_{S\mu3}$ never measured before; expected $Br(K_{S\mu3}) = (4.69 \pm 0.05) \times 10^{-4}$ [PDG]



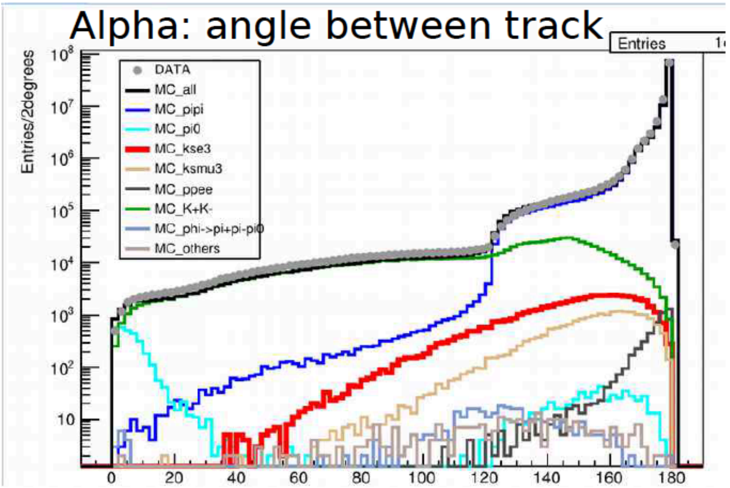
	$\vert V_{us}\vert f_+(0)$	% err	BR	τ	Δ	Int
			Approx. contrib. to % err from:			
K_Le3	0.2163(6)	0.26	0.09	0.20	0.11	0.05
$K_L\mu3$	0.2166(6)	0.28	0.15	0.18	0.11	0.06
K_Se3	0.2155(13)	0.61	0.60	0.02	0.11	0.05
$K^{\pm}e3$	0.2172(8)	0.36	0.27	0.06	0.23	0.05
$K^{\pm}\mu3$	0.2170(11)	0.51	0.45	0.06	0.23	0.06

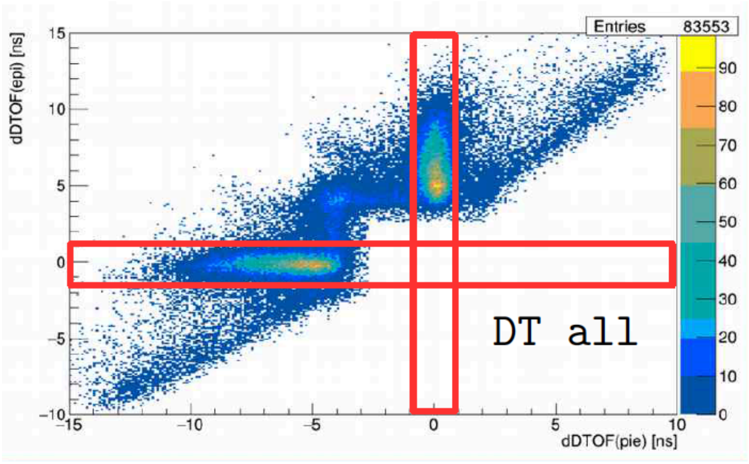
- Extract the Br from the measurement of the ratio $K_{Sl3}/(K_S \to \pi^+\pi^-)$
- Tag with K_L crash
- K_S identification: a vertex near the IP with two tracks with opposite charge

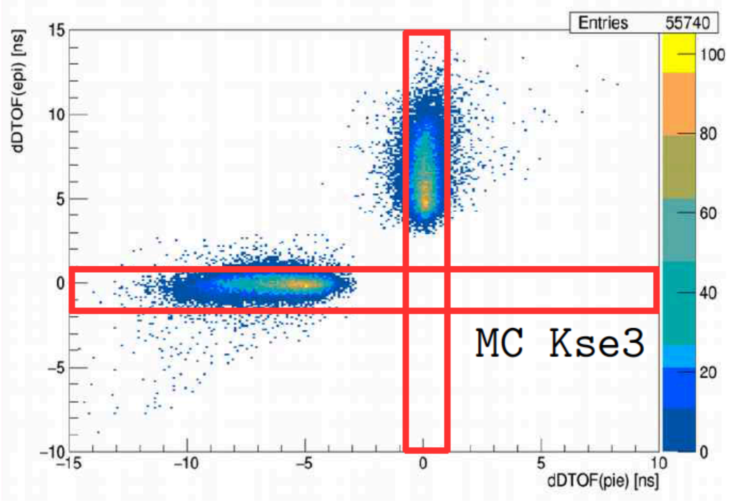


K_{Se3}

- **Signal / Background separation with MultiVariate Analysis and ToF exploitation**
- **Main bckg: $K_S \to \pi^+\pi^-$**



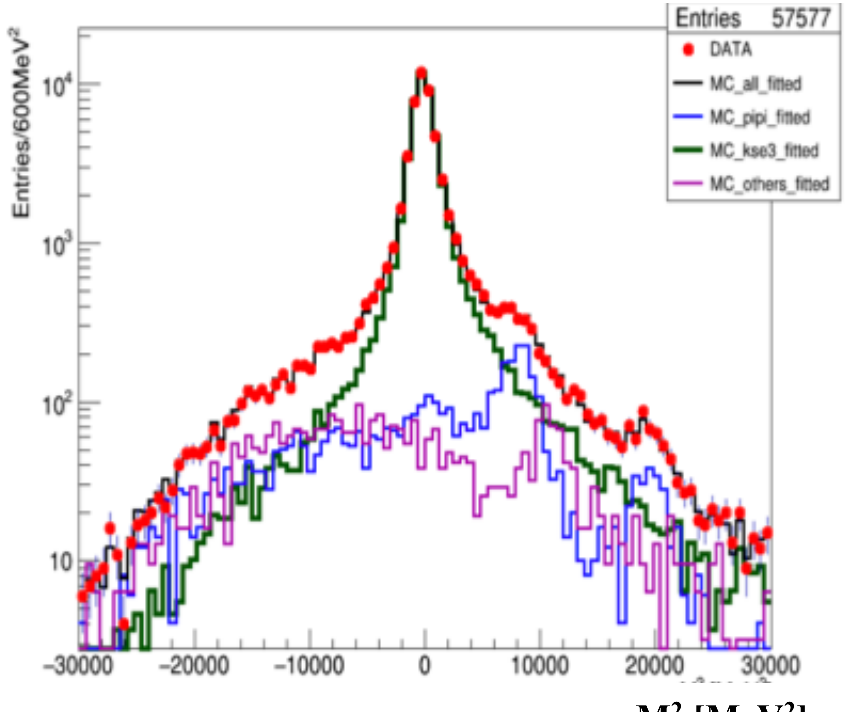




K_{Se3}

- **Fit to electron invariant mass to extract the number of events**

Selection	Efficiency
TCA	0.4639 ± 0.0020
CS Preselection	0.9720 ± 0.0007
MC Preselection	0.9661 ± 0.0002
BDT selection	0.6534 ± 0.0018
TOF selection	0.7168 ± 0.0018
FIT interval	0.9985± 0.0001
TOT	0.2106 ± 0.0032



Selection	Relative systematic error [%]
TOF	0.672
BDT	0.276
K_L CS statistics	0.108
$\pi^+\pi^-$ CS statistics	$2\ 10^{-4}$
MC sample statistics	0.143
Total	0.754

Preliminary evaluation of the systematic uncertainty at the same level of the previous KLOE measurement

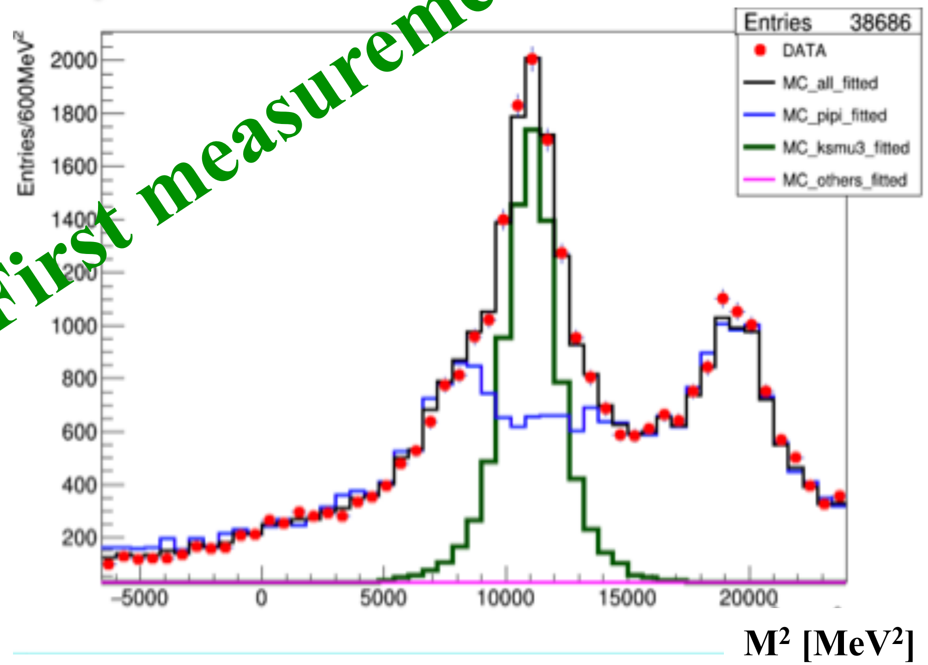
Ongoing studies show possible improvement

$K_{S\mu3}$

- **Same analysis scheme as for the electron case**

Selection	Efficiency
TCA	0.347± 0.002
CS preselection	0.986 ±0.004
MC preselection	0.996± 0.002
BDT selection	0.417± 0.003
TOF selection	0.401 ±0.005
FIT interval	0.989 ±0.001
Total	0.057 ±0.001

First measurement



Selection	Relative systematic error [%]
TOF	2.97
BDT	0.30
K_L CS statistics	0.45
$\pi^+\pi^-$ CS statistics	$2\ 10^{-4}$
MC sample statistics	0.168
$\pi^+\pi^-$ efficiency II	0.09
Total	3.09

KLOE-2 Computing

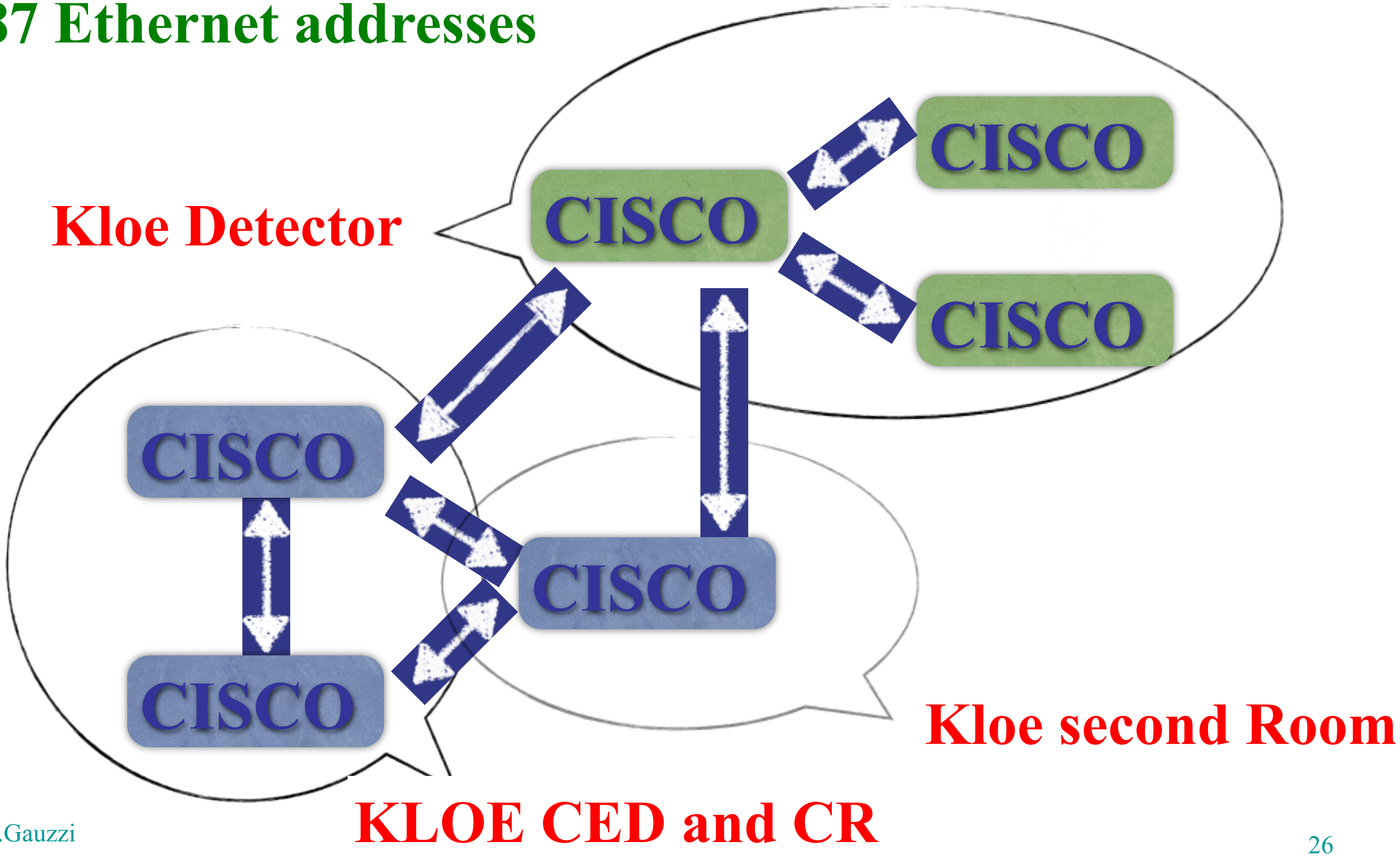
- After the data taking we decided to switch our computer system to a lightweight infrastructure and a low complexity architecture

- We also decreased the year maintenance cost and cut the request of new hardware off.

- Data Direct 9900 (buffer area, 800 TB, used at CNAF before coming to KLOE): after more than 2 years of usage for the data reconstruction, we had to replace it because of the more and more frequent blocking failures that caused problems to the data reconstruction and to the analysis

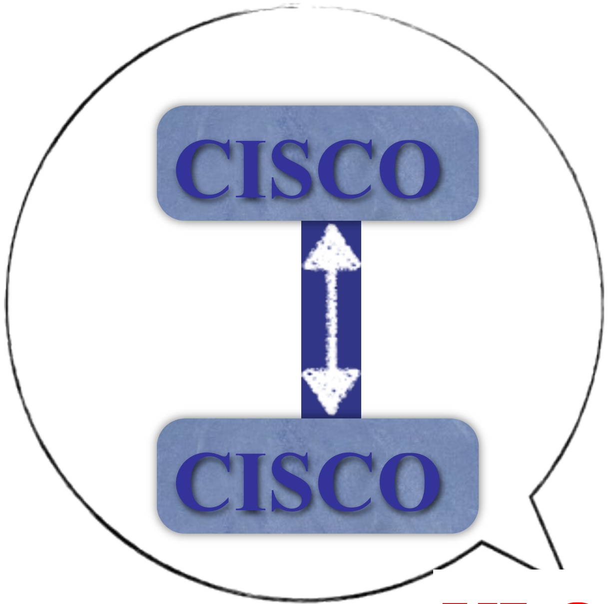
Network during data-taking

487 Ethernet addresses



Network now

169 Ethernet addresses



KLOE-2 Resources

Devices	Present capacity	Expandibility
disk arrays	600 TB 150 TB	1.2 Petabyte -
CPU P8	400 Threads	960 Threads …
CPU P7	64 Threads	-
New tape library	5 Petabyte 4 tape drive 10 TB	16 Petabyte 32 tape drive 20 TB
Old tape library	3.3 Petabyte 8 tape drive 1 TB	5.5 Petabyte -
Fiber channel switch	4 x 48 8GBit ports throughput 192 GB/s	8x48 16 GBit ports throughput 768 GB/s
Ethernet Switch	192 Gbit/s ports 10 10Gbit/s ports	- -

Conclusions and plans

- First round of reconstruction planned to be completed in the first months of 2019
- Implementation of the ROOT output instead of the present DST format is in an advanced stage
- Massive production of MC started
- Analysis of KLOE-2 data in progress
- Analysis of old KLOE is still ongoing
- Start soon the second round of data and MC production:
  - improved version of Datarec
  - new version of the Inner Tracker + Drift Chamber integrated tracking
  - new stream for $\gamma\gamma$ events (HET analysis)
  - ROOT output

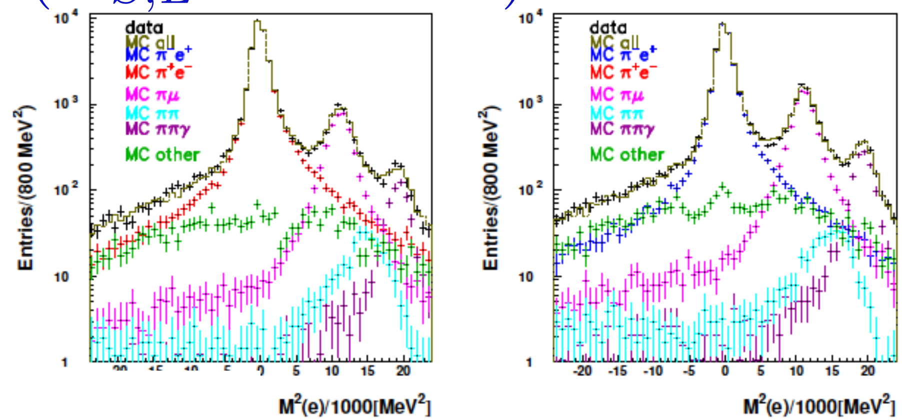
Spare

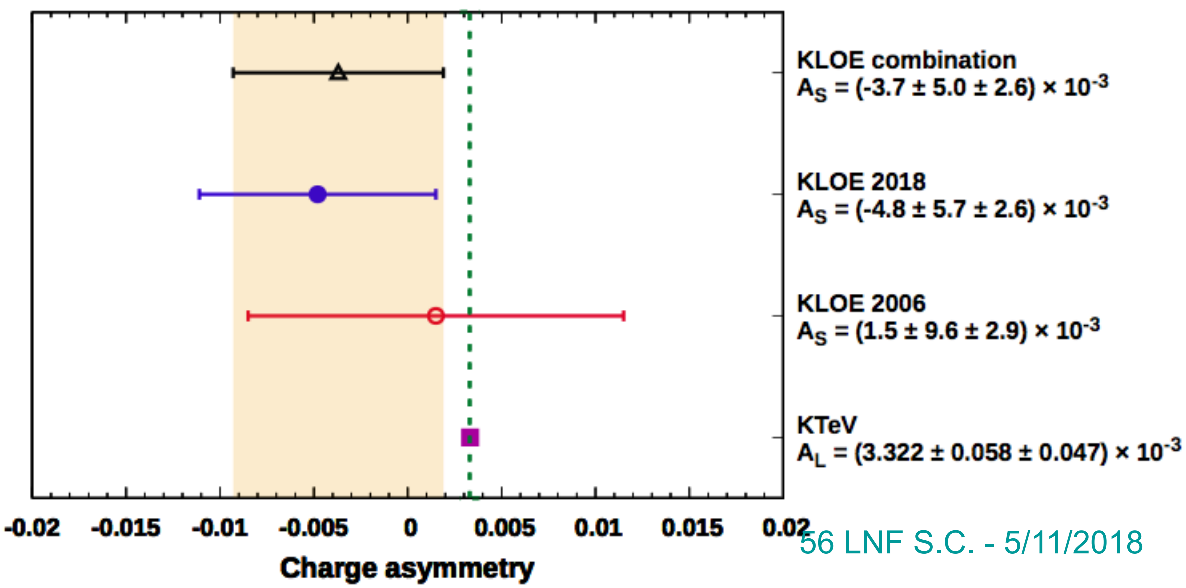
K_S charge asymmetry

[JHEP 1809 (2018) 021]

$$A_{S,L} = \frac{\Gamma(K_{S,L} \to \pi^- e^+ \nu) - \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})}{\Gamma(K_{S,L} \to \pi^- e^+ \nu) + \Gamma(K_{S,L} \to \pi^+ e^- \bar{\nu})}$$

- $A_{S,L} \neq 0 \Rightarrow$ CP violation
- $A_S \neq A_L \Rightarrow$ CPT violation
- 1.7 fb^{-1}; ~ 4 × statistics w.r.t. the previous KLOE measurement





Expected with KLOE-2 data (statistics + improved tracking):
$\delta A_S(stat) \to \sim 3\times10^{-3}$

KLOE-2 Physics

KLOE-2 Coll., EPJC68(2010)619
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:
  $K_S \to 3\pi^0$
  direct measurement of Im(ε′/ε) (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
- χpT : $K_S \to \gamma\gamma$
- 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
  - Uγ associate production
    $e^+e^- \to U\gamma \to \pi\pi\gamma, \mu\mu\gamma$
  - Higgsstrahlung:
    $e^+e^- \to Uh' \to \mu^+\mu^-$ + miss. energy
- Leptophobic B boson search:
  $\phi \to \eta B$, $B \to \pi^0\gamma$, $\eta \to \gamma\gamma$
  $\eta \to B\gamma$, $B \to \pi^0\gamma$, $\eta \to \pi^0\gamma\gamma$
- Search for U invisible decays

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

T and CPT test with KLOE data

First test of T and CPT in transitions with neutral kaons

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

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

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

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

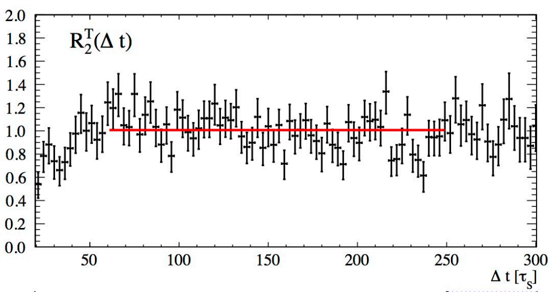
T and CPT observables

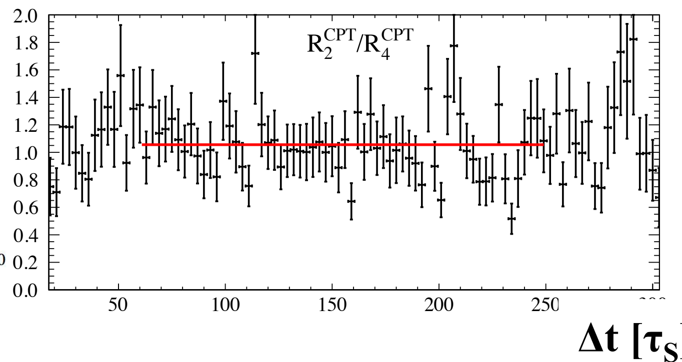
$$R_2^T(\Delta t) = \frac{I(\ell^-, 3\pi^0; \Delta t)}{I(\pi\pi, \ell^+; \Delta t)}$$

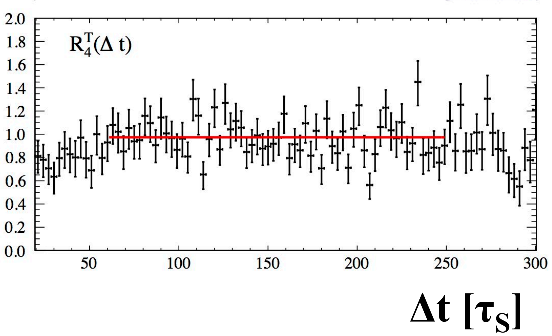
$$R_4^T(\Delta t) = \frac{I(\ell^+, 3\pi^0; \Delta t)}{I(\pi\pi, \ell^-; \Delta t)}$$

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

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







$$\sigma(R_2^T) = 0.017$$
$$\sigma(R_4^T) = 0.017$$
$$\sigma(DR^{CPT}) = 0.028$$

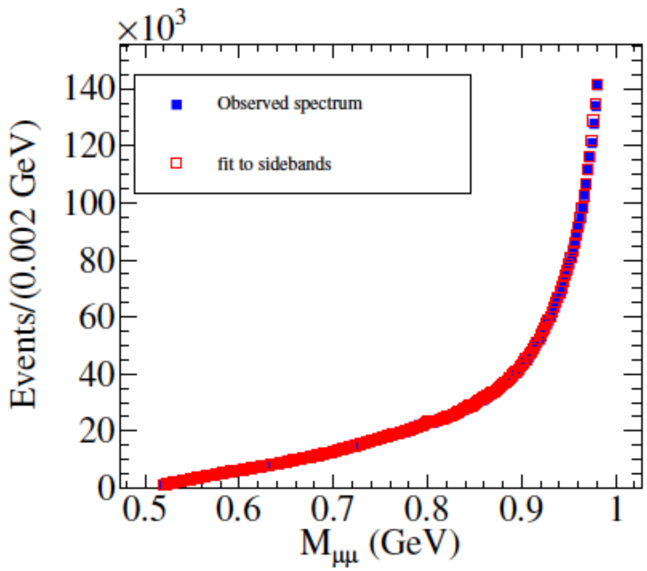
(T invariance $\to R_2^T = 1$; SM $\to R_2^T = 0.993$)

(T invariance $\to R_4^T = 1$; SM $\to R_4^T = 1.007$)

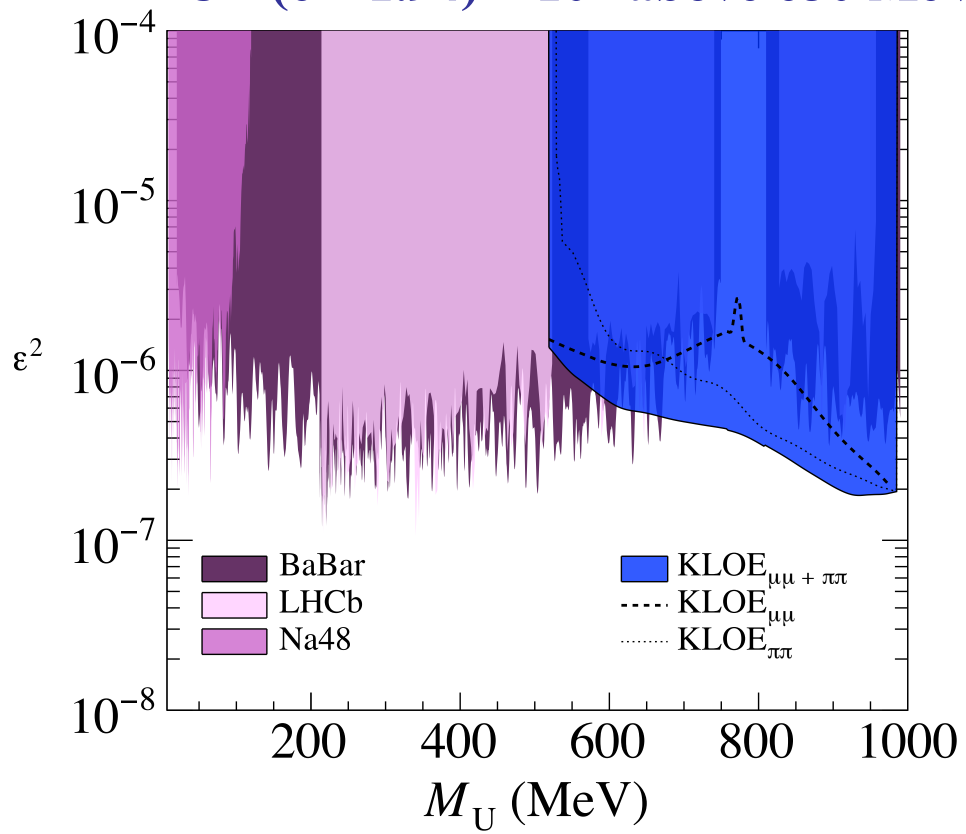
(CPT invariance $\to R_2^{CPT}/R_4^{CPT} = 1$)

Dark Photon search

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



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



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

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