KLOE-2 status

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for the KLOE-2 Collaboration

56th LNF Scientific Committee Meeting
November 5, 2018
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$^{-1}$

- Run I
  - $L = 0.8$ fb$^{-1}$
  - Efficiency = 77%

- Run II
  - $L = 1.6$ fb$^{-1}$
  - Efficiency = 82%

- Run III
  - $L = 1.7$ fb$^{-1}$
  - Efficiency = 82%

- Run IV
  - $L = 1.4$ fb$^{-1}$
  - Efficiency = 81%

Data-taking ended on March 30th, 2018. Total acquired Luminosity = 5.5 fb$^{-1}$. Run I: $L = 0.8$ fb$^{-1}$, efficiency = 77%. Run II: $L = 1.6$ fb$^{-1}$, efficiency = 82%. Run III: $L = 1.7$ fb$^{-1}$, efficiency = 82%. Run IV: $L = 1.4$ fb$^{-1}$, efficiency = 81%. Total delivered (pb-1): 6804.0, Total acquired (pb-1): 5488.6.
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

<table>
<thead>
<tr>
<th></th>
<th>Run-I</th>
<th>Run-II</th>
<th>Run-III</th>
<th>Run-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>L [pb$^{-1}$]</td>
<td>800</td>
<td>1620</td>
<td>1680</td>
<td>1400</td>
</tr>
<tr>
<td>RAW [TB]</td>
<td>457</td>
<td>867</td>
<td>943</td>
<td>734</td>
</tr>
<tr>
<td>REC [pb$^{-1}$]</td>
<td>31</td>
<td>1328</td>
<td>1159</td>
<td>2</td>
</tr>
</tbody>
</table>

(includes also previous DBVs)
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

\[
\frac{N_{EV}}{N_{VLAB}} \quad \text{vs} \quad N_{run}
\]

\[
\frac{N_{EV}}{N_{VLAB}} \quad \text{vs} \quad N_{run}
\]
Event counters

Neutral Radiative

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

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

- Production rate $\approx 15 \text{ pb}^{-1}/\text{day}$ (in parallel with the data reconstruction)

<table>
<thead>
<tr>
<th>Run range</th>
<th>MC (pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>88966-89096</td>
<td>49.46</td>
</tr>
<tr>
<td>85681-86024</td>
<td>91.55</td>
</tr>
<tr>
<td>86025-86511</td>
<td>96.97</td>
</tr>
<tr>
<td>86512-86900</td>
<td>105.64</td>
</tr>
<tr>
<td>80694-81537</td>
<td>92.77</td>
</tr>
<tr>
<td>81538-81973</td>
<td>96.83</td>
</tr>
<tr>
<td>81974-82398</td>
<td>113.21</td>
</tr>
<tr>
<td>82411-82850</td>
<td>103.09</td>
</tr>
<tr>
<td>82851-83145</td>
<td>83.05</td>
</tr>
<tr>
<td>83201-83498</td>
<td>100.86</td>
</tr>
<tr>
<td>83504-84089</td>
<td>117.48</td>
</tr>
<tr>
<td>84114-84385</td>
<td>96.02</td>
</tr>
<tr>
<td>84401-85187</td>
<td>110.27</td>
</tr>
<tr>
<td>85203-85507</td>
<td>82.28</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1339.48</strong></td>
</tr>
</tbody>
</table>
Data-MC comparison

- Neutral events: prompt photon energy and timing

![Graph showing data and MC comparison for photon energy and timing](image-url)
• 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

<table>
<thead>
<tr>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement of the charge asymmetry for $K_S \rightarrow \pi e\nu$ decay and test of CPT symmetry with the KLOE detector</td>
<td>JHEP 1809 (2018) 021 (will appear in next PDG update)</td>
</tr>
<tr>
<td>Combined limit on the production of a light gauge boson decaying into $\mu^+\mu^-$ and $\pi^+\pi^-$</td>
<td>Phys.Lett. B784 (2018) 336</td>
</tr>
</tbody>
</table>

## Ongoing analyses

<table>
<thead>
<tr>
<th>Analysis Description</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma\gamma \rightarrow \pi^0$</td>
<td>KLOE-2 data</td>
</tr>
<tr>
<td>$K_S \rightarrow \pi e\nu$, $K_L \rightarrow \pi^+\pi^-$</td>
<td>KLOE-2 data</td>
</tr>
<tr>
<td>$K_S \rightarrow 3\pi^0$ (CP viol.)</td>
<td>KLOE-2 data</td>
</tr>
<tr>
<td>T/CPT tests with $\phi \rightarrow K_S K_L \rightarrow 3\pi^0 \pi e\nu, \pi\pi \pi e\nu$</td>
<td>KLOE data – PhD Thesis</td>
</tr>
<tr>
<td>$K_S \rightarrow \pi e\nu$, $K_S \rightarrow \pi \mu \nu$</td>
<td>KLOE data – PhD Thesis</td>
</tr>
<tr>
<td>$K_S \rightarrow \pi^+\pi^-\pi^0$</td>
<td>KLOE data – PhD Thesis</td>
</tr>
<tr>
<td>B-boson search in $\phi \rightarrow \eta\pi^0\gamma$</td>
<td>KLOE / KLOE-2 data</td>
</tr>
<tr>
<td>$\eta \rightarrow \pi^0\gamma\gamma$ - $\chi$PT golden mode</td>
<td>KLOE / KLOE-2 data</td>
</tr>
<tr>
<td>$\eta \rightarrow \pi^+\pi^-$ (P and CP viol.)</td>
<td>KLOE / KLOE-2 data</td>
</tr>
<tr>
<td>$e^+e^- \rightarrow \omega \gamma_{ISR}$</td>
<td>KLOE data</td>
</tr>
</tbody>
</table>
**K_S \rightarrow 3\pi^0 - KLOE-2 data**

- Data sample: KLOE-2 data, \( L \approx 1.5 \text{ fb}^{-1} \) (all 2016 reconstructed data)
- CP violating, never observed, expected \( \text{Br} \sim 2 \times 10^{-9} \) (SM)
- Best upper limit by KLOE: \( \text{Br}(K_S \rightarrow 3\pi^0) < 2.6 \times 10^{-8} \) @ 90\% C.L. with 1.7 fb\(^{-1}\) [PLB723(2013)54]

- “\( K_L \) crash” (\( K_L \) in the EMC)  
  + 6 prompt photons
- Main bckg: \( K_S \rightarrow 2\pi^0 \)  
  (4 prompt photons),  
  also used for normalization
- Selection criteria hardened to face the large machine bckg
**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

\[ \Delta E/\sigma_E = (E_{K_S} - \Sigma E_\gamma)/\sigma_E \] 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:**

- **Track Veto:** $\varepsilon = 99.68 \%$
- **$\chi^2_{\text{fit}}$** $\varepsilon = 69.4 \%$
- **$\Delta E/\sigma_E$** $\varepsilon = 83.77 \%$
- **Counting** $\varepsilon = 36.29 \%$
- **$R_{\text{min}}$** $\varepsilon = 85.53 \%$
- **Sbox** $\varepsilon = 73.22 \%$
\[ e^+e^- \rightarrow \gamma^*\gamma^* \rightarrow e^+e^- \pi^0 \]

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

- $\pi^0$s 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.
• 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
$\eta \rightarrow \pi^+ \pi^-$

- 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 $\text{Br} < 1.3 \times 10^{-5}$ @ 90% C.L. ($L = 350$ pb$^{-1}$) [KLOE, PLB606(2005)276]
  LHCb recent measurement: $\text{Br} < 1.6 \times 10^{-5}$ @ 90% C.L. [PLB764(2017)233]

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

- $L = 1.7$ fb$^{-1}$ (KLOE data) ⇒ Very preliminary U.L.: $\text{Br} < 6.3 \times 10^{-6}$ @ 90% C.L.
\( \eta \rightarrow \pi^+\pi^- \) with KLOE-2 data

- Analysis of KLOE-2 data started
  \[ \Rightarrow L \approx 200 \text{ pb}^{-1} \]

- Working to adjust the analysis to the different background conditions

- Combining KLOE + KLOE-2 statistics (8 fb\(^{-1}\))
  U.L. expected \( \sim 3 \times 10^{-6} \)
\[ \eta \rightarrow \pi^0\gamma\gamma \]

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

5 prompt photon sample:
- \( L = 580 \text{ pb}^{-1} \) of KLOE data
- Main bckg is \( \phi \rightarrow \eta \gamma \), with \( \eta \rightarrow 3\pi^0 \) 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±0.091) $\times$ 10$^{-4}$]
- K$_{S\mu3}$ never measured before; expected Br(K$_{S\mu3}$) = (4.69±0.05)$\times$10$^{-4}$ [PDG]

- Extract the Br from the measurement of the ratio K$_{S\nu3}/$(K$_S$$\rightarrow$$\pi^+$)$\pi^-$)
- Tag with K$_L$ crash
- K$_S$ identification: a vertex near the IP with two tracks with opposite charge
• Signal / Background separation with MultiVariate Analysis and ToF exploitation

• Main bckg: $K_S \rightarrow \pi^+ \pi^-$
• **Fit to electron invariant mass to extract the number of events**

<table>
<thead>
<tr>
<th>Selection</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCA</td>
<td>0.4639 ± 0.0020</td>
</tr>
<tr>
<td>CS Preselection</td>
<td>0.9720 ± 0.0007</td>
</tr>
<tr>
<td>MC Preselection</td>
<td>0.9661 ± 0.0002</td>
</tr>
<tr>
<td>BDT selection</td>
<td>0.6534 ± 0.0018</td>
</tr>
<tr>
<td>TOF selection</td>
<td>0.7168 ± 0.0018</td>
</tr>
<tr>
<td>FIT interval</td>
<td>0.9985 ± 0.0001</td>
</tr>
<tr>
<td>TOT</td>
<td>0.2106 ± 0.0032</td>
</tr>
</tbody>
</table>

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

Ongoing studies show possible improvement
• Same analysis scheme as for the electron case

<table>
<thead>
<tr>
<th>Selection</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCA</td>
<td>$0.347 \pm 0.002$</td>
</tr>
<tr>
<td>CS preselection</td>
<td>$0.986 \pm 0.004$</td>
</tr>
<tr>
<td>MC preselection</td>
<td>$0.996 \pm 0.002$</td>
</tr>
<tr>
<td>BDT selection</td>
<td>$0.417 \pm 0.003$</td>
</tr>
<tr>
<td>TOF selection</td>
<td>$0.401 \pm 0.005$</td>
</tr>
<tr>
<td>FIT interval</td>
<td>$0.989 \pm 0.001$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$0.057 \pm 0.001$</td>
</tr>
</tbody>
</table>

The relative systematic error is given in the table below:

<table>
<thead>
<tr>
<th>Selection</th>
<th>Relative systematic error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOF</td>
<td>2.97</td>
</tr>
<tr>
<td>BDT</td>
<td>0.30</td>
</tr>
<tr>
<td>$K_L$ CS statistics</td>
<td>0.45</td>
</tr>
<tr>
<td>$\pi^+\pi^-$ CS statistics</td>
<td>$2 \times 10^{-4}$</td>
</tr>
<tr>
<td>MC sample statistics</td>
<td>0.168</td>
</tr>
<tr>
<td>$\pi^+\pi^-$ efficiency II</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3.09</td>
</tr>
</tbody>
</table>
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

Kloe Detector

Kloe second Room

KLOE CED and CR
Network now

169 Ethernet addresses
# KLOE-2 Resources

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

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

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

Expected with KLOE-2 data (statistics + improved tracking): \(\delta A_S(\text{stat}) \rightarrow \sim 3 \times 10^{-3}\)
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 \( \text{Im}(\varepsilon'/\varepsilon) \) (lattice calc. improved)
- CKM \( V_{us} \):
  \[ K_S \] semileptonic decays and \( A_S \)
  (CP and CPT test)
  \[ K_{\mu3} \] form factors, \( K_{l3} \) radiative corrections
- \( \chi_{\mu T} : K_S \rightarrow \gamma\gamma \)
- Search for rare \( K_S \) decays

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:
- \( \eta \) decays, \( \omega \) decays
- Transition Form Factors
- C,P,CP violation: improve limits on
  \[ \eta \rightarrow \gamma\gamma\gamma, \pi^+\pi^-, \pi^0\pi^0, \pi^0\pi^0\gamma \]
  \[ \text{Improve } \eta \rightarrow \pi^+\pi^- e^+e^- \]
- \( \chi_{PT} : \eta \rightarrow \pi^0\gamma\gamma \]
- Light scalar mesons: \( f_0(500) \) in \( \phi \rightarrow K_SK_S\gamma \)
- \( \gamma\gamma \) Physics: \( \gamma\gamma \rightarrow \pi^0 \) and \( \pi^0 \) TFF
  \[ e^+e^- \rightarrow \pi^0\gamma\gamma_{\text{ISR}} (\pi^0 \text{ TFF}) \]
- Search for axion-like particles

Hadronic cross section:
- ISR studies with 3\( \pi \), 4\( \pi \) final states
- \( F_\pi \) with increased statistics
- Measurement of \( a_{\mu}^{\text{HLO}} \) in the space-like region using Bhabha process

P. Gauzzi

56 LNF S.C.
T and CPT test with KLOE data

First test of T and CPT in transitions with neutral kaons

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

$K_S K_L \rightarrow \pi^+ \pi^- 3\pi^0$
$K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^- \nu$
$K_S \rightarrow \pi^+ \pi^- K_{l\text{crash}}$
$K_S K_L \rightarrow \pi^+ \pi^- K_{l\text{crash}}$
$K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^- \nu$
$K_S \rightarrow \pi^+ \pi^- K_{l\text{crash}}$

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

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

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

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

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

[Reference: JHEP 10 (2015) 139
NPB 868 (2013) 102]
Dark Photon search

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

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

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