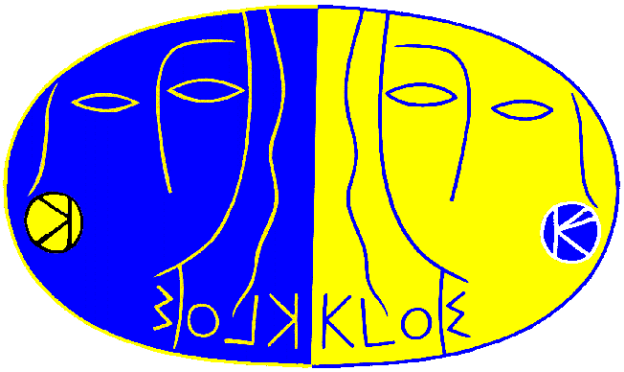
Analysis status of KLOE



P.Gauzzi

(Universita' La Sapienza e INFN – Roma)

for the KLOE / KLOE-2 Collaborations

46th meeting of LNF Scientific Committee

9 - May - 2013

Progress since last SC

Published papers	
$\eta \to \pi^+\pi^-\gamma$	PLB718(2013)910
$\phi \to \eta e^+e^-$; $\eta \to \pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$ (U-boson search)	PLB720(2013)111
σ_{had}: $\pi\pi\gamma / \mu\mu\gamma$	PLB720(2013)336
$\gamma\gamma \to \eta \to \pi^+\pi^-\pi^0$	JHEP01(2013)119
$\gamma\gamma \to \eta \to \pi^0\pi^0\pi^0$	
$K_S \to \pi^0\pi^0\pi^0$	accepted by PLB – arXiv:1301.7623

Advanced analyses	
$K^+ \to \pi^+\pi^+\pi^-$	preliminary (almost final) result
$\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ (CPT and Lorentz violation)	final result
$\phi \to \eta e^+e^-$; $\eta \to \pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$ (Transition FF slope)	in progress
$\phi \to \pi^0 e^+e^-$	in progress
$e^+e^- \to U\gamma \to \mu^+\mu^-\gamma$	almost final result
$e^+e^- \to Uh' \to \mu^+\mu^-$ + missing energy	preliminary result

σ_{had} from $\pi\pi\gamma / \mu\mu\gamma$

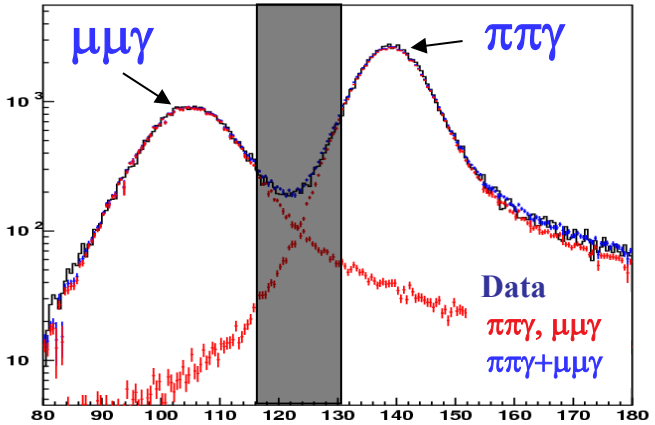
- $|F_\pi|^2$ from the ratio $\sigma(e^+e^-\to\pi^+\pi^-\gamma)/\sigma(e^+e^-\to\mu^+\mu^-\gamma)$ at $\sqrt{s} = M_\phi$
  Small Angle analysis (photon not detected; $\vartheta_\gamma < 15°$)

[PLB720(2013)336]

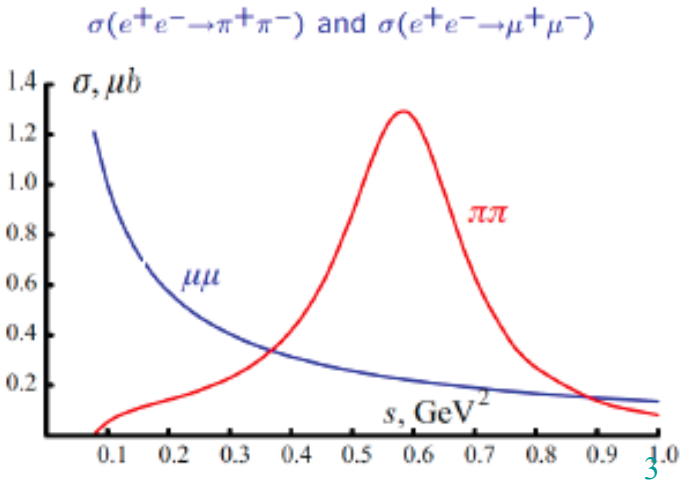
$$|F_\pi(s')|^2 \approx \frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3} \quad \frac{d\sigma_{\pi\pi\gamma}/ds'}{d\sigma_{\mu\mu\gamma}/ds'}$$

kinematical factor ($\sigma_{\mu\mu}^{Born} / \sigma_{\pi\pi}^{Born}$)

meas. quantities



- Many factors cancel in the ratio:
  - radiator function
  - luminosity from Bhabhas
  - vacuum polarization



Separation btw $\pi\pi\gamma$ and $\mu\mu\gamma$ using M_{TRK}

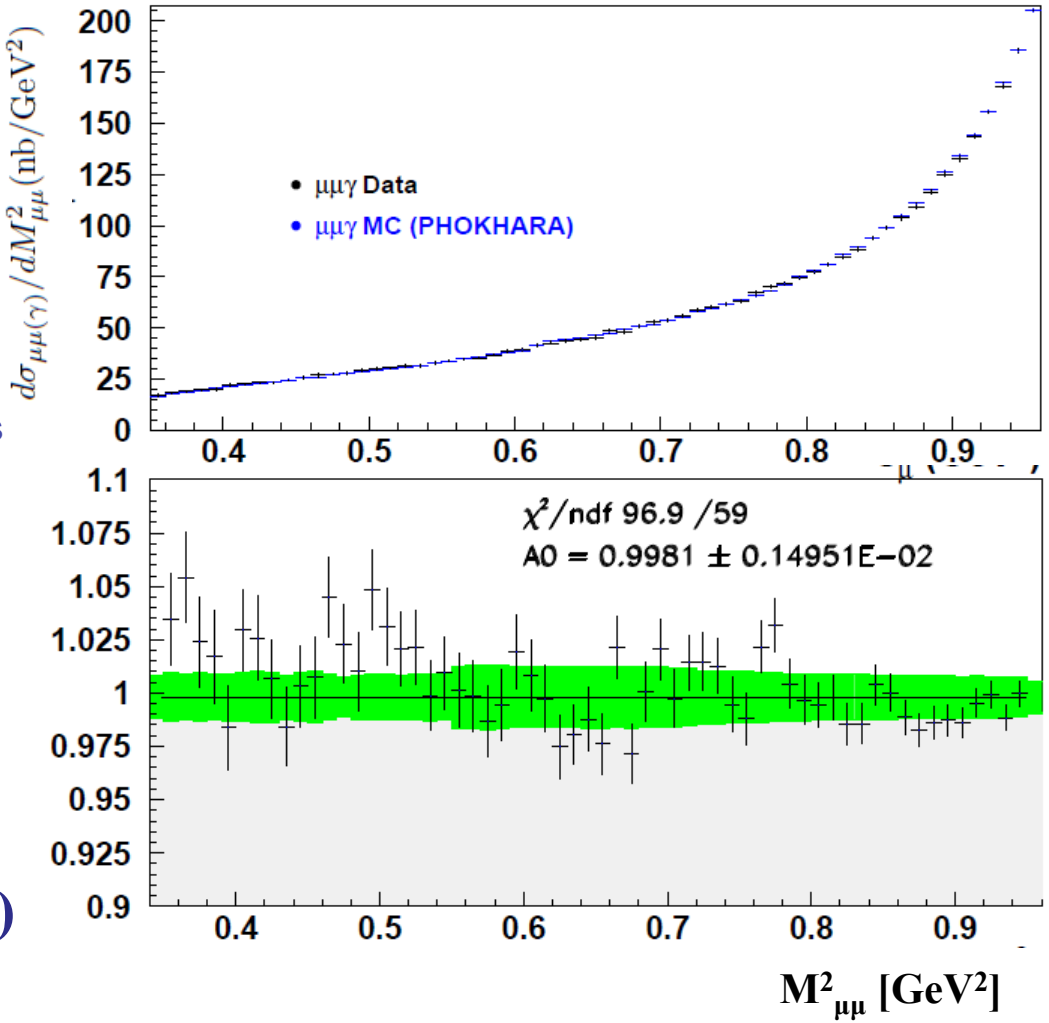
- **muons: $M_{Trk} < 115$ MeV**
- **pions : $M_{Trk} > 130$ MeV**

Very important control of π/μ separation in the ρ region ($\sigma_{\pi\pi} >> \sigma_{\mu\mu}$)

μμγ - data/MC comparison

$$\frac{d\sigma^{obs}_{\mu\mu\gamma(\gamma)}}{dM^2_{\mu\mu}} = \frac{\Delta N_{Obs} - \Delta N_{Bkg}}{\Delta M^2_{\mu\mu}} \cdot \frac{1}{\varepsilon_{Sel}} \cdot \frac{1}{\int L dt}$$

$$\frac{d\sigma^{DATA}_{\mu\mu\gamma(\gamma)}}{d\sigma^{MC}_{\mu\mu\gamma(\gamma)}} = 0.998 \pm 0.001_{stat} \pm 0.011_{sys}$$

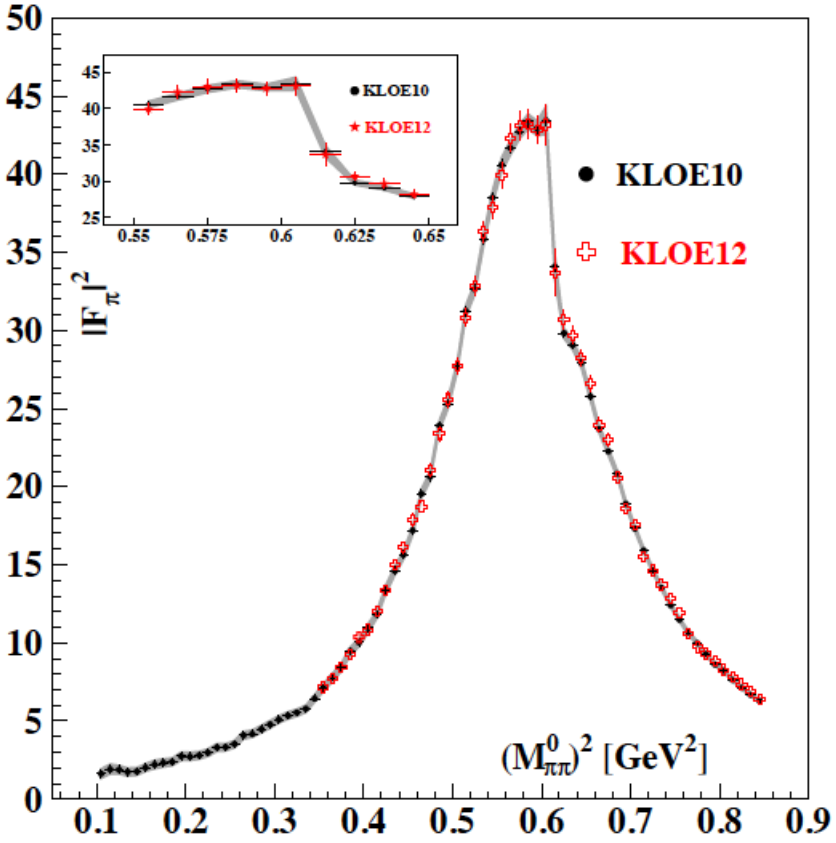


- The systematic error has been averaged on $M^2_{\mu\mu}$
- Good agreement with PHOKHARA MC (QED @ NLO)

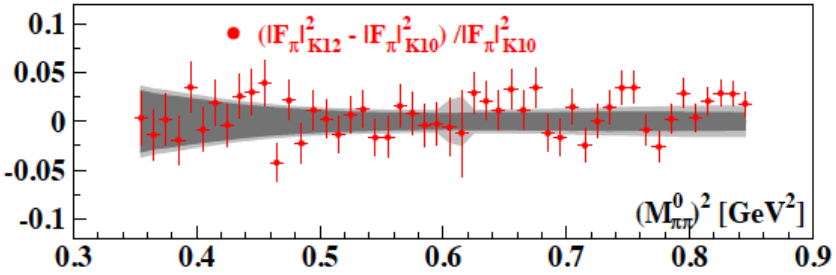
KLOE12 vs KLOE10

KLOE12: ππγ / μμγ [PLB720(2013)336]

KLOE10: Large Angle analysis (photon detected at $\vartheta_\gamma > 50°$) – off peak data [PLB700(2011)102]



Fractional difference:



band: KLOE10 error

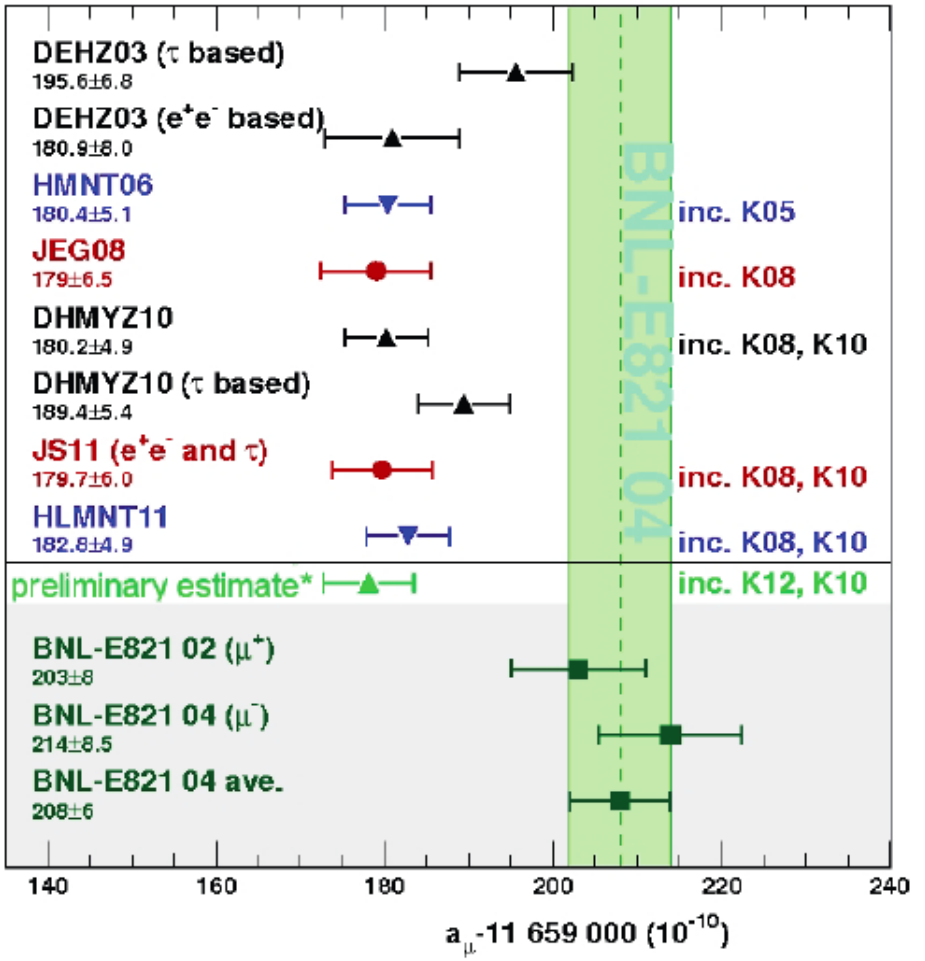
Excellent agreement between the two independent measurements

Summary on a_μ

$a_\mu^{exp} - a_\mu^{theo,SM}$:
3.3 σ discrepancy confirmed

$$\Delta a_\mu^{\pi\pi} = \int_{s_{min}}^{s_{max}} \sigma^0_{\pi\pi(\gamma)}(s) \cdot K(s) ds$$

Data	$\Delta^{\pi\pi} a_\mu \cdot 10^{10}$ $0.35 < s < 0.85$ GeV^2
$\sigma_{\pi\pi(\gamma)} / \sigma_{\mu\mu(\gamma)}$, SA- γ_{ISR}	$377.4 \pm 1.1_{stat} \pm 2.7_{sys+th}$
Abs. $\sigma_{\pi\pi(\gamma)}$, SA- γ_{ISR}	$379.6 \pm 0.4_{stat} \pm 3.3_{sys+th}$
Abs. $\sigma_{\pi\pi(\gamma)}$, LA- γ_{ISR}	$376.6 \pm 0.9_{stat} \pm 3.3_{sys+th}$



* Our extrapolation based on DHMYZ10

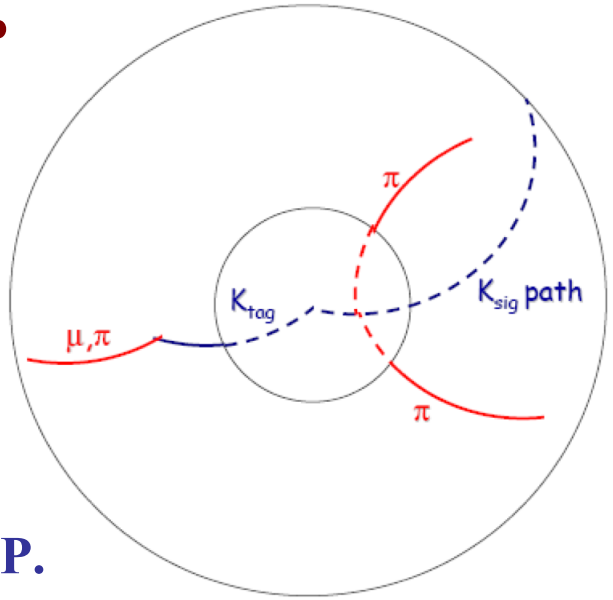
BR($K^+ \to \pi^+\pi^+\pi^-(\gamma)$)

- Measurement of the absolute BR, to complete the program of precise measurement of the dominant $K^\pm$ decay channels
- The amplitude enters the cusp analysis of $K^\pm \to \pi^\pm\pi^0\pi^0$ to extract the $\pi\pi$ phase shift done by NA48
- Previous measurements :

  Chiang ('72) (2330 evts) BR = (5.56 ± 0.20)% ⇒ $\Delta BR / BR = 3.6 \times 10^{-2}$

  KLOE (2008) (fit to $1-\Sigma_i BR_i$) BR = (5.68 ± 0.22)%

  Flavianet fit (2010) : BR = (5.73 ± 0.16) %



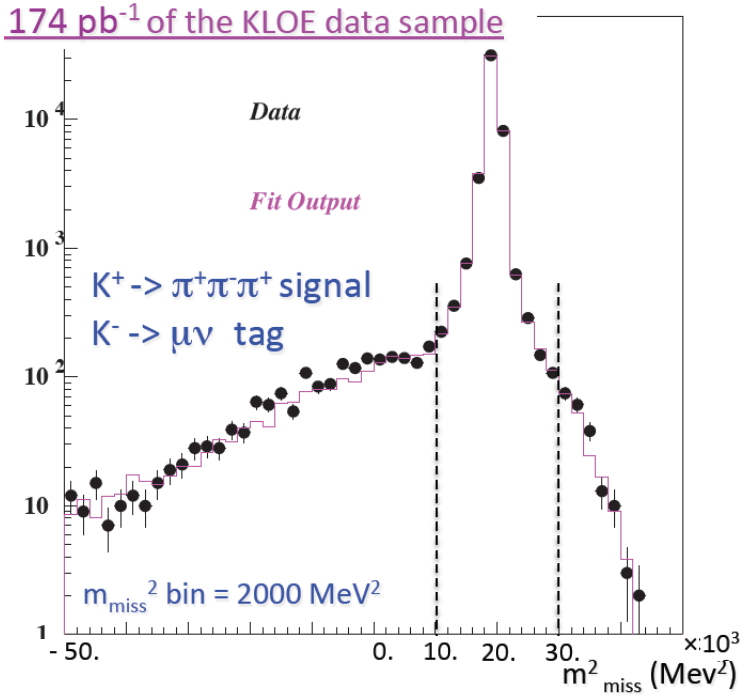
- Signal selection:
  - tag with $K \to \mu\nu, \pi\pi^0$
  - 2 tracks with vertex along the K path before the DC wall
  - K path from the extrapolation of the tag K to I.P.
  - signal peak in the missing mass distribution (3rd pion)

BR($K^+ \to \pi^+\pi^+\pi^-(\gamma)$)

- Analyzed sample: 174 pb^{-1}
- Efficiency evaluated by MC and corrected from data-MC comparison
- Signal extraction from fit to m^2_{miss} spectrum with signal and bckg shapes from MC

$$N(K^+ \to 3\pi) = 45054.1 \pm 212.2 \text{ evts}$$

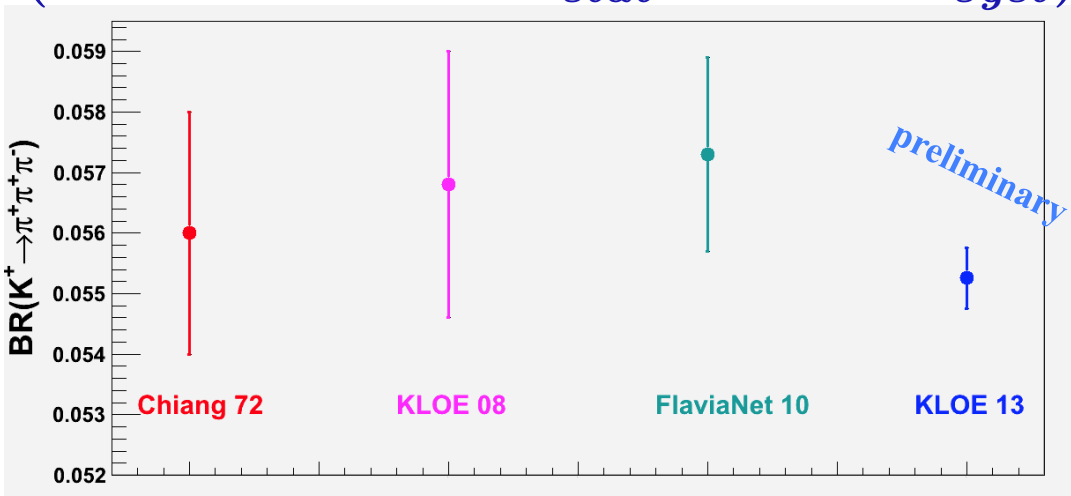
$$N(K^- \to \mu\nu) = 12065087$$



Presented at KAON13

$$BR(K^+ \to \pi^+\pi^+\pi^-(\gamma)) = (0.05526 \pm 0.00035_{stat} \pm 0.00036_{syst})$$

$$\Delta BR/BR = 9.2 \times 10^{-3}$$



$\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$

- **Standard Model Extension** [Kostelecky et al., PRD61(1999)016002,PRD64(2001)076001]

⇒ possibility of violation of CPT and Lorentz invariance

$$\varepsilon_{L,S} = \varepsilon_K \pm \delta$$

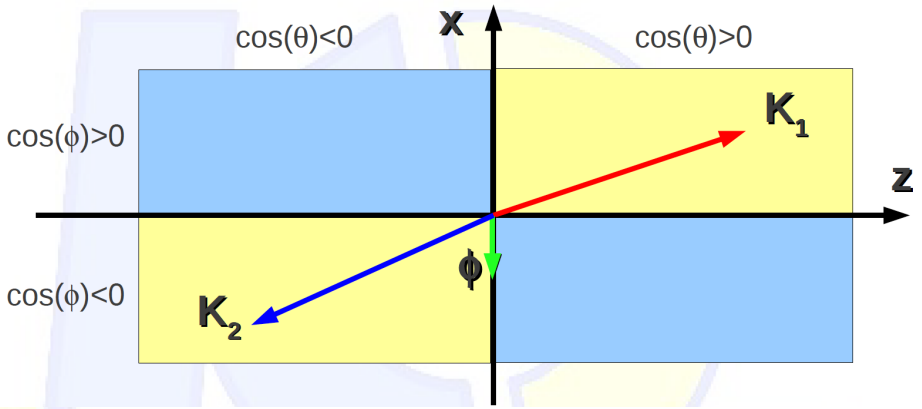
$$\delta \simeq i \sin\phi_{SW} e^{i\phi_{SW}} \gamma_K (\Delta a_0 - \vec{\beta}_K \cdot \Delta\vec{a})/\Delta m$$

- **δ depends on the orientation of the K momentum with respect to the fixed vector Δ*a* :**
  - **angular distributions**
  - **earth rotation effects (T_{sid} = sidereal time)**

$$\begin{aligned}\delta_K(\vec{P}_K, T_{sid}) = \frac{i \sin\phi_{SW} e^{i\phi_{SW}}}{\Delta m}\gamma_K \Big[& \Delta a_0 + \beta_K \Delta a_Z (\cos\vartheta\cos\chi - \sin\vartheta\cos\varphi\sin\chi) \\ & -\beta_K \Delta a_X \sin\vartheta\sin\varphi\sin\omega_E T_{sid} \\ & +\beta_K \Delta a_X (\cos\vartheta\sin\chi + \sin\vartheta\cos\varphi\cos\chi)\cos\omega_E T_{sid} \\ & +\beta_K \Delta a_Y (\cos\vartheta\sin\chi + \sin\vartheta\cos\varphi\cos\chi)\sin\omega_E T_{sid} \\ & +\beta_K \Delta a_Y \sin\vartheta\sin\varphi\cos\omega_E T_{sid}\Big]\end{aligned}$$

Analysis strategy

- **L = 1.7 fb^{-1} analyzed**
- **Kaons ordered according the z momentum component**



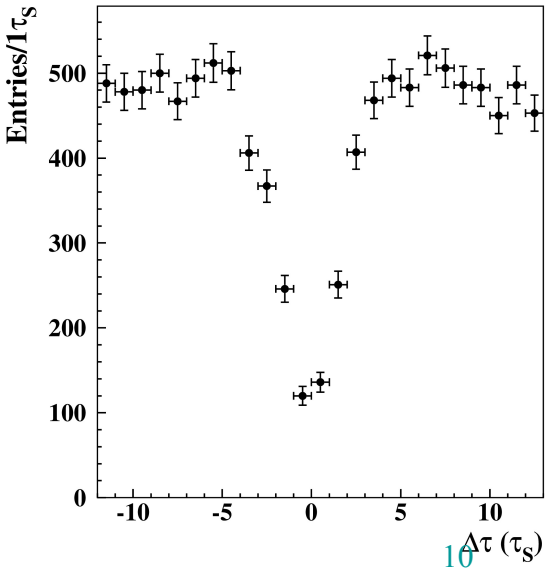
$$I(\Delta t, T_{sid}, \vartheta_{K_1}, \varphi_{K_1}) \propto$$

$$e^{-\Gamma|\Delta\tau|}\Big[|\varepsilon_K - \delta_K(\vec{P}_1)|^2 e^{\frac{\Delta\Gamma}{2}\Delta\tau} + |\varepsilon_K - \delta_K(\vec{P}_\phi - \vec{P}_1)|^2 e^{-\frac{\Delta\Gamma}{2}\Delta\tau} -$$

$$-2\Re e\Big((\varepsilon_K - \delta_K(\vec{P}_1))(\varepsilon_K - \delta_K(\vec{P}_\phi - \vec{P}_1)^*)e^{-i\Delta m\Delta\tau}\Big)\Big]$$

- **Data divided into 8 samples: 4 sidereal time bins × 2 angular bins**

$$\int_{\Delta\tau_i} d\Delta\tau \int_{\Delta T_j} dT \int_{\Delta\Omega_h} d\Omega_{K_1}\, \rho(\Omega_{K_1}, T)\, I(\Delta\tau, T, \Omega_{K_1})$$



- **Simultaneous fit of the Δτ distributions to extract the Δa_μ parameters**

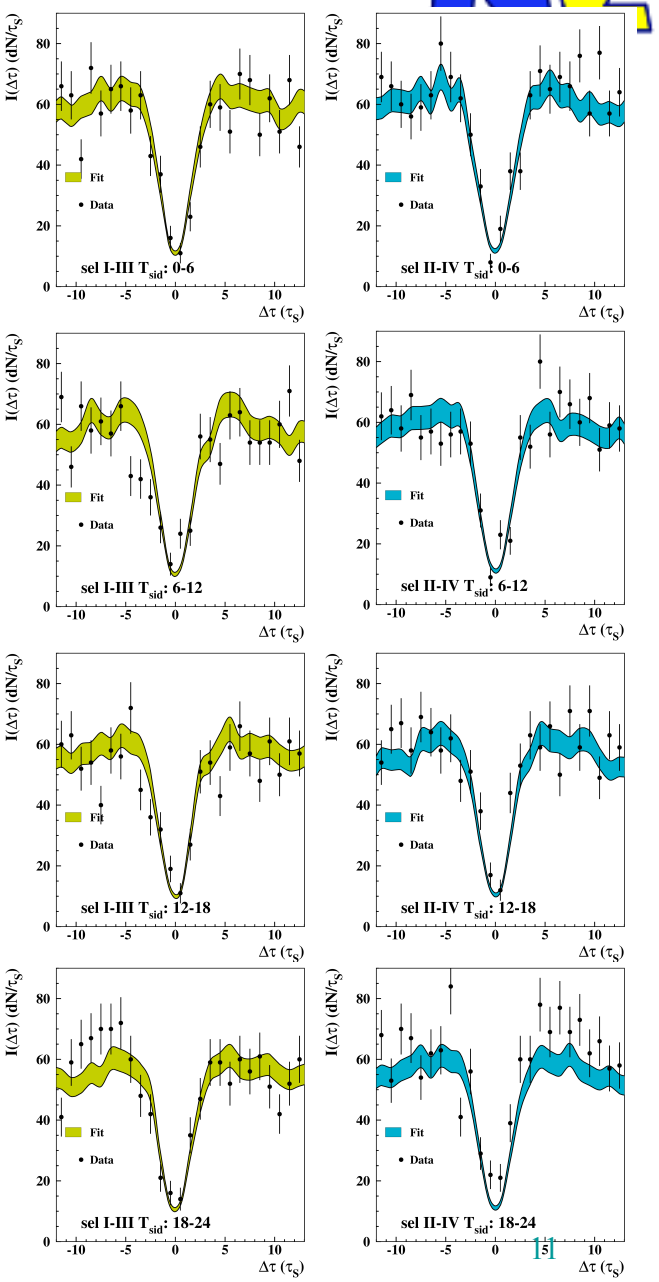
Fit result

Presented at KAON13

$$\Delta a_0 = (-6.0 \pm 7.7_{stat} \pm 3.1_{sys}) \cdot 10^{-18}\ GeV$$
$$\Delta a_X = (\ 0.9 \pm 1.5_{stat} \pm 0.6_{sys}) \cdot 10^{-18}\ GeV$$
$$\Delta a_Y = (-2.0 \pm 1.5_{stat} \pm 0.5_{sys}) \cdot 10^{-18}\ GeV$$
$$\Delta a_Z = (\ 3.1 \pm 1.7_{stat} \pm 0.6_{sys}) \cdot 10^{-18}\ GeV$$

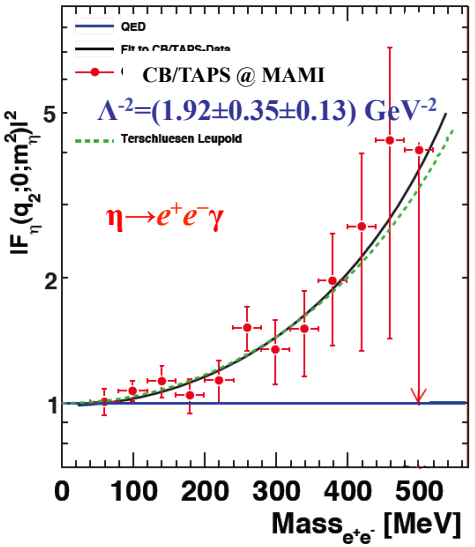
$$\chi^2/ndf = 211.7/184 \quad \Rightarrow \quad P(\chi^2) = 8\%$$

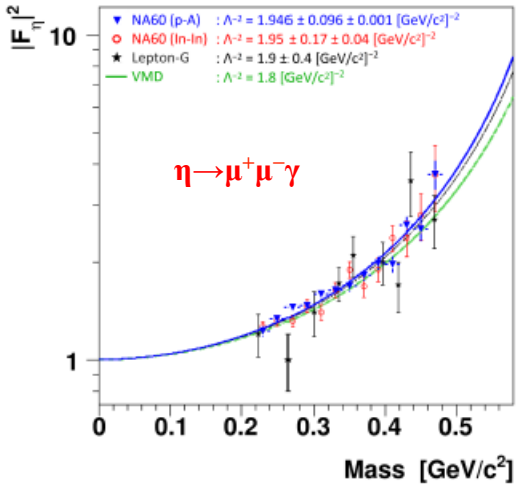
Paper in preparation

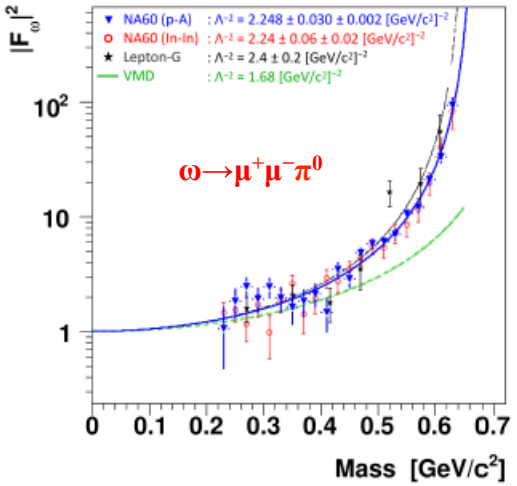


Transition FFs from Dalitz decays

- Naive VMD approach well describes $\eta \to \gamma \ell^+ \ell^-$, but fails for $\omega \to \pi^0 \ell^+ \ell^-$



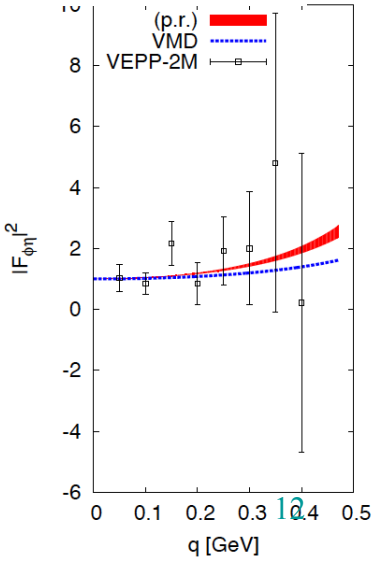




$$b = \Lambda^{-2} = \left.\frac{dF(q^2)}{dq^2}\right|_{q^2=0} \qquad (q^2 = M^2_{\ell^+\ell^-})$$

- $\phi \to \eta e^+ e^-$: $\Lambda^{-2} = (3.8 \pm 1.8)$ GeV^{-2} (~ 50% error) SND @ VEPP-2M
  VMD ⇒ $\Lambda^{-2} \approx M_\phi^{-2} \approx 1$ GeV^{-2}

- $\phi \to \pi^0 e^+ e^-$: no data available on FF slope; VMD ⇒ $\Lambda^{-2} \approx 1.6$ GeV^{-2}



$\phi \rightarrow \eta e^+ e^-$

- $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\eta \rightarrow \pi^0\pi^0\pi^0$ decays analyzed
- Processes already exploited for Dark Force searches

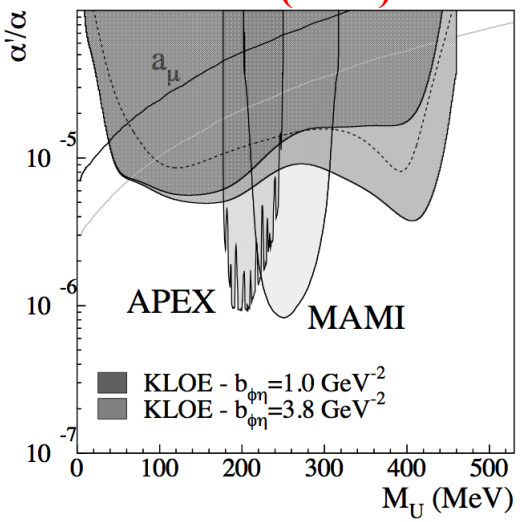
$\eta \rightarrow \pi^+\pi^-\pi^0$:

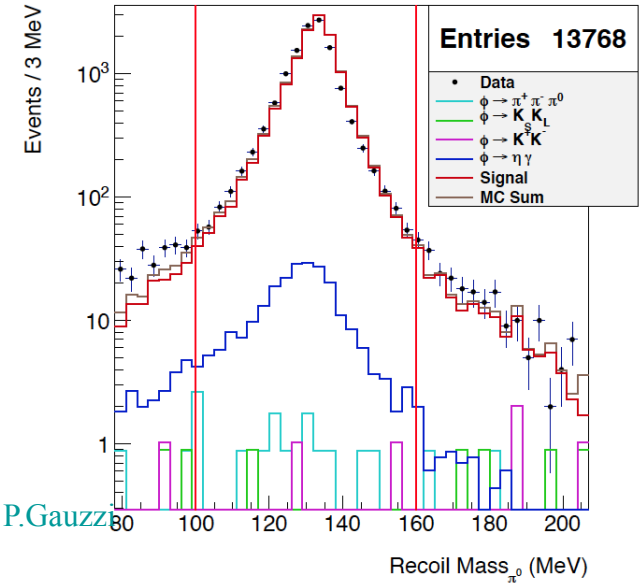
- Data sample: 1.5 fb^{-1}
- 4 tracks + 2 prompt photons
- Best $\pi^+\pi^-\gamma\gamma$ match to the η mass

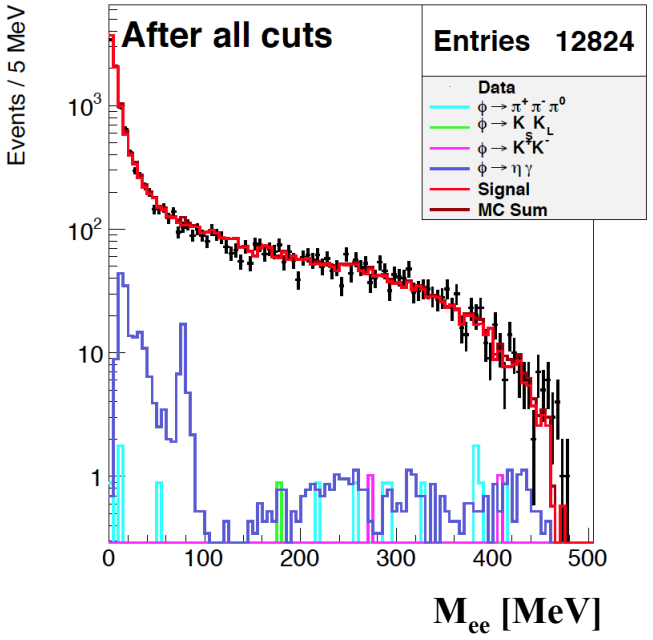
$535 < M_{recoil}(ee) < 560$ MeV

~13000 $\phi \rightarrow \eta e^+ e^-$ ($\eta \rightarrow \pi^+\pi^-\pi^0$) candidates

PLB720(2013)111



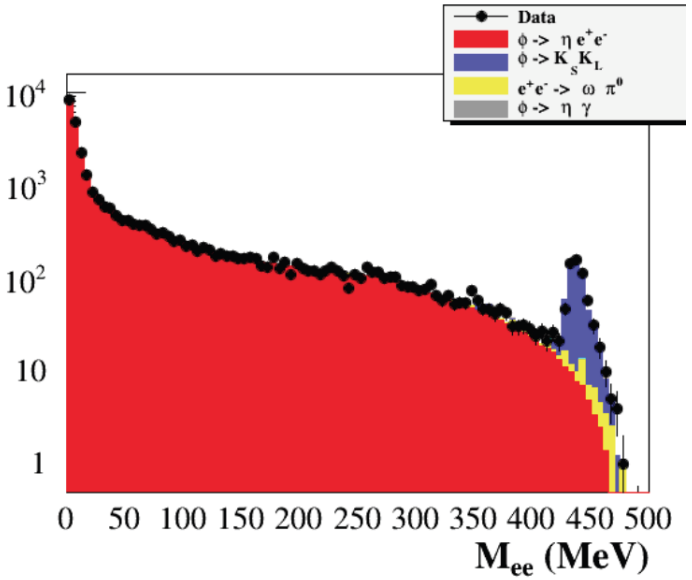




$\phi \rightarrow \eta e^+e^-$

$\eta \rightarrow \pi^0\pi^0\pi^0$:

- **Data sample: 1.7 fb^{-1}**
- **2 tracks + 6 prompt photons**
  $536.5 < M_{recoil}(ee) < 554.5$ MeV
  ~ 30000 $\phi \rightarrow \eta e^+e^-$ ($\eta \rightarrow \pi^0\pi^0\pi^0$) after background subtraction



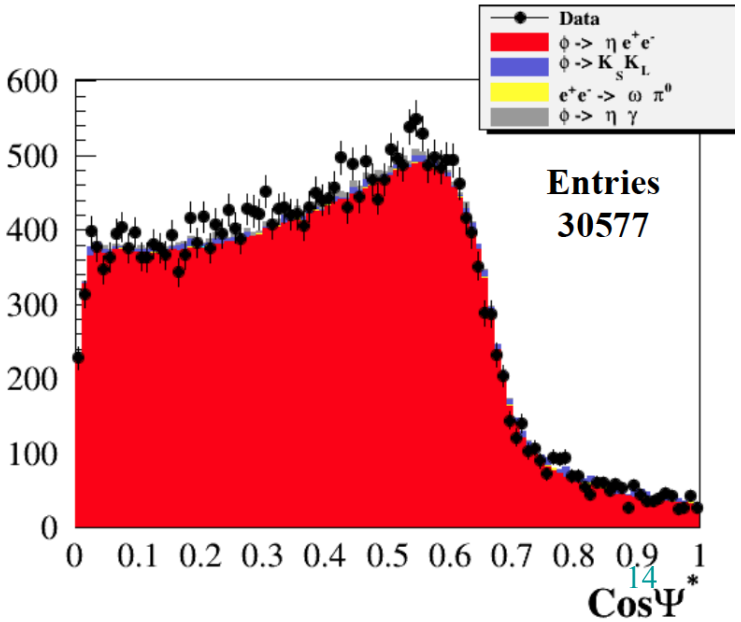
- **In progress: fit of both M_{ee} distributions to** [Landsberg, Phys.Rept.128(1985)301]

$$\frac{d\Gamma(\phi \to \eta e^+e^-)}{dq^2} = \frac{\alpha}{3\pi}\frac{|F_{\phi\eta}(q^2)|^2}{q^2}\sqrt{1-\frac{4m^2}{q^2}}\left(1+\frac{2m^2}{q^2}\right)\cdot$$

$$\cdot\left[\left(1+\frac{q^2}{m_\phi^2-m_\eta^2}\right)^2-\frac{4m_\phi q^2}{\left(m_\phi^2-m_\eta^2\right)^2}\right]^{\frac{3}{2}}$$

$$F_{\phi\eta}(q^2) = \frac{1}{1-b_{\phi\eta}q^2}$$

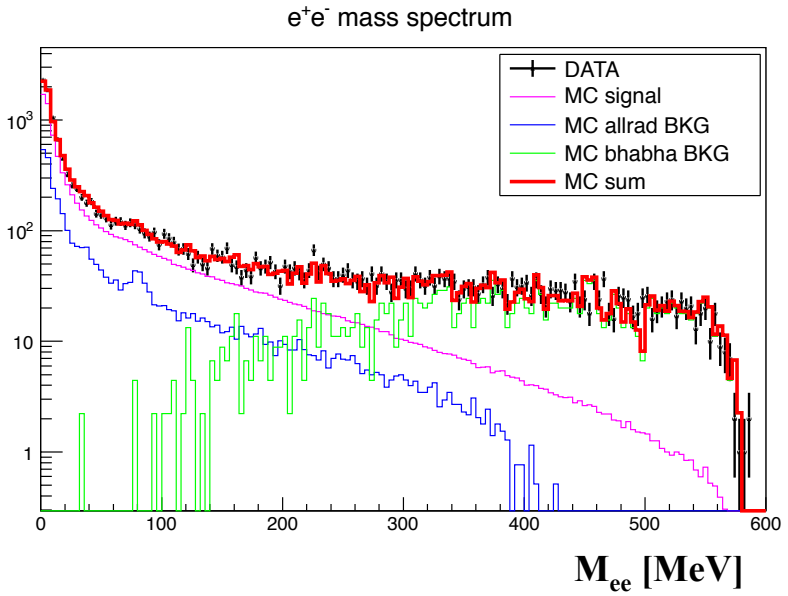
to obtain the slope $b_{\phi\eta}$ and the BR



$\phi \to \pi^0 e^+ e^-$

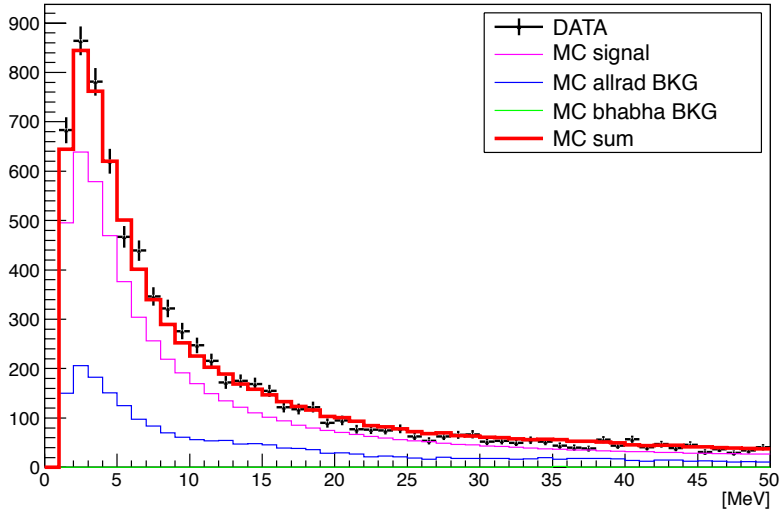
- $BR(\phi \to \pi^0 e^+ e^-) = (1.12 \pm 0.28) \times 10^{-5}$
  $\Rightarrow$ 25% uncertainty – SND $\Rightarrow$ 52 events; CMD-2 $\Rightarrow$ 46 events
- TFF $F_{\phi\pi 0}(q^2)$ never measured before
- Can help to constrain the single pion contribution to the Light-by-Light scattering relevant for $(g-2)_\mu$

- Analyzed sample: 1.7 fb^{-1}
- Events with 2 tracks + 2 prompt photor
- Background:
  radiative Bhabha scattering
  $\phi \to \pi^0 \gamma$ with photon conversion

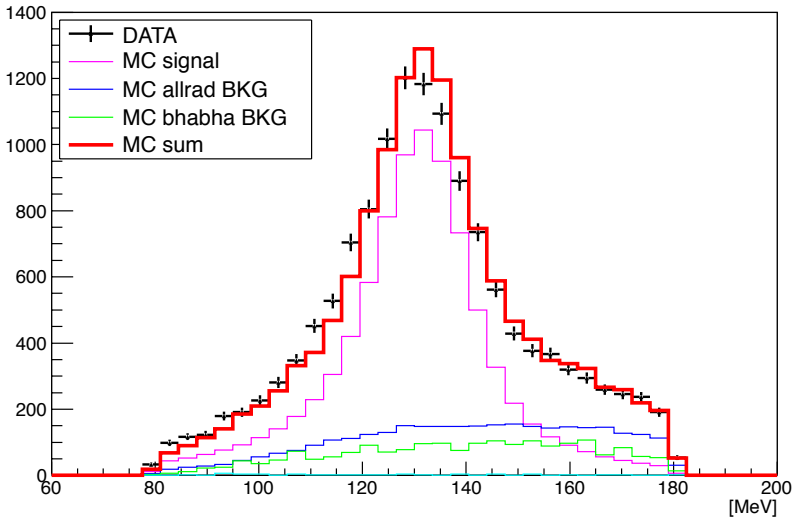


$\phi \rightarrow \pi^0 e^+ e^-$

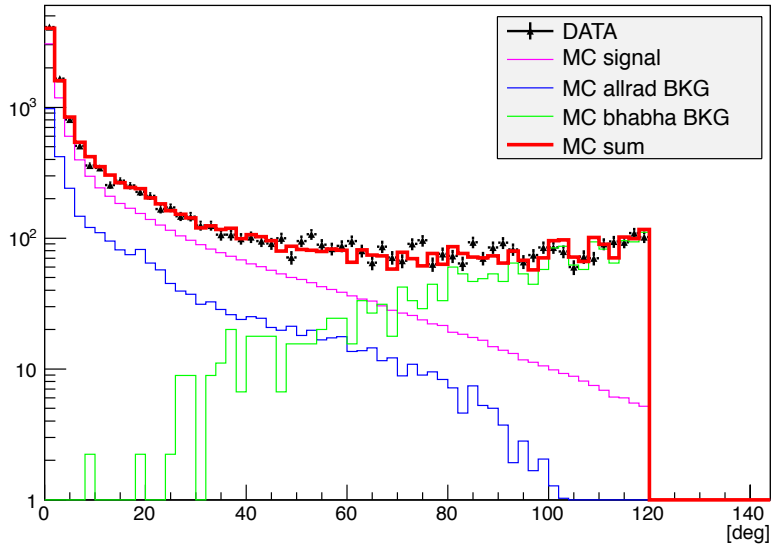
e^+e^- mass spectrum (zoom)



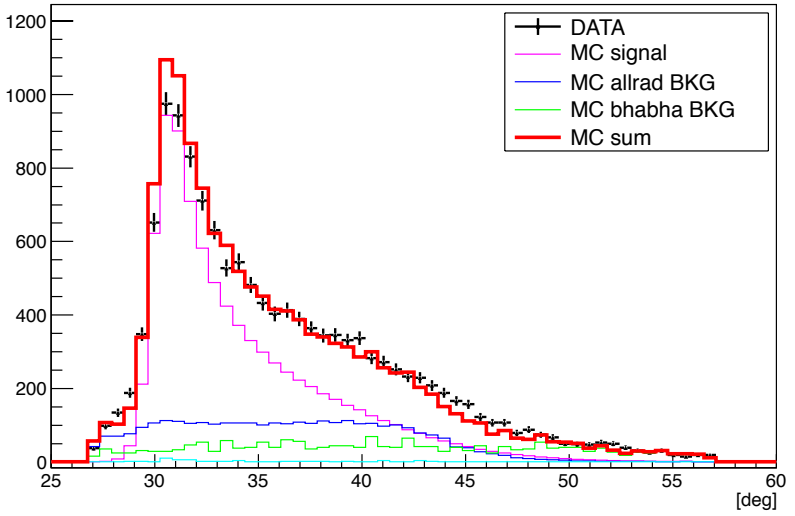
e^-e^+ missing mass



e^+e^- opening-angle



$\gamma\gamma$ opening-angle



C. -

KLOE computing

- The INFN CSN1 requested KLOE to change the computing model to make possible the usage of INFN TIERs
- The SC requested to be informed on that

  ⇒ Document on computing has been submitted

– The computing hardware needed for the KLOE-2 data-taking has been renovated and is operative since the beginning of DAΦNE commissioning in 2010

– It is dimensioned for a 4 – 5 fb^{-1} data-taking and data-processing

– The whole computing chain has been operative during the 2012 data-taking with the carbon target for AMADEUS

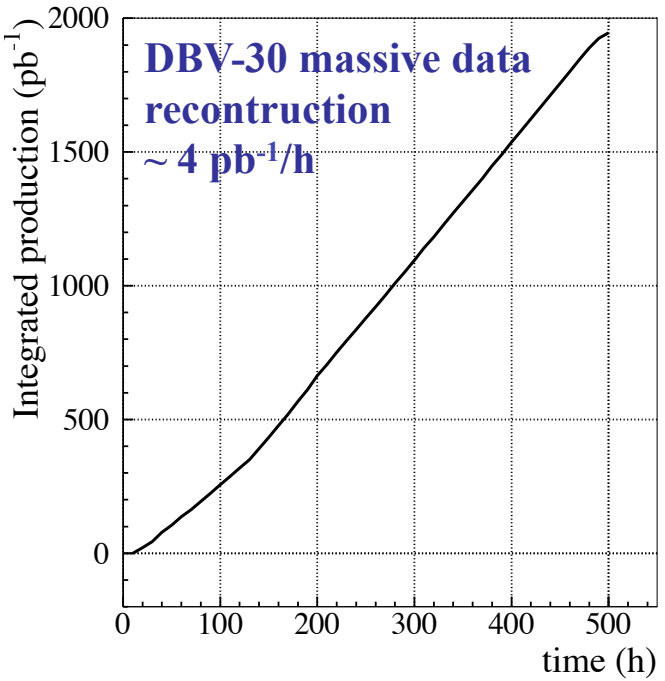


Table 1: KLOE-2 computing components.

Component	Description	year
L2 SBC	VME SBC MVME6100	2008-2012
L3 CPU	Run-control, Slow-control, DB-servers; Online-servers	2007-2008
Networking -LAN	CISCO 6006 (Central); CISCO 6009 (on Detector);	2001
Disk buffer	L3 farm (6 TB); DAS (30 TB); SAN (220 TB)	2008-2012
Tape library	IBM-3494, IBM-3592 Drives	2011
Networking -SAN	2+2 FC switches	2012
Data servers	2 IBM-P6 9117-MMA	2007
Other servers	User-Servers; AFS-Servers;	2007-2008
Computing farm	1 Rack - 4 P5–, 2 P7–SMPs	2008-2010

KLOE computing

Migration to other computer centers:

- **KLOE data at CNAF: the raw-data archiving at CNAF has been implemented since 2011; automatic trasfer from LNF to CNAF during data-taking has been routinely obtained and the reconstruction at LNF of data recalled from CNAF has been succesfully tested**

- **The possibility to run the KLOE software on data reconstruction and simulation on other computer centers requires dedicated efforts of expert people both from KLOE and from the hosting site to:**
  - **migrate and validate the KLOE code to Linux-OS**
  - **have a data-base with all information needed**
  - **have a user data interface complying with the rules of the computing center**

⇒ At present KLOE-2 does not have such expert people

- **The only opportunity has been the participation to the Data Preservation project of ASI, CNR, INFN (PIDES proposal to MIUR) - under evaluation**

Conclusions

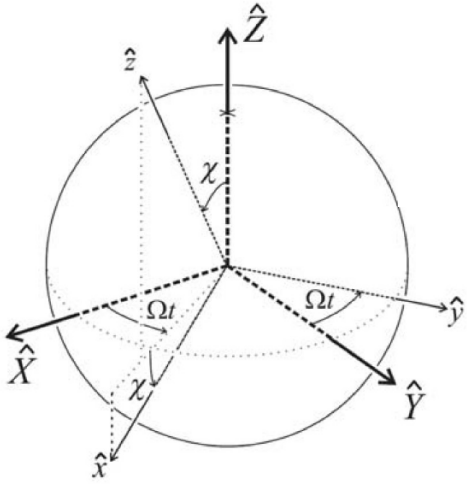
- **Although our commitment is the installation, testing and integration in the DAQ of the KLOE-2 upgrades, we are continuing to exploit the data collected during the first KLOE data-taking to produce physics results**

- **Achievements in first half of 2013:**
  - **4 published papers**
  - **1 paper accepted by PLB**
  - **6 analyses in well advanced stage**
  - **other studies in progress**

- **3 PhD theses completed in 2012 (Krakow, Roma Tor Vergata, Roma Tre)**
- **8 PhD theses ongoing on KLOE data (2 Krakow, 2 Messina, Roma Tor Vergata, Roma Tre, 2 Uppsala)**

Spare

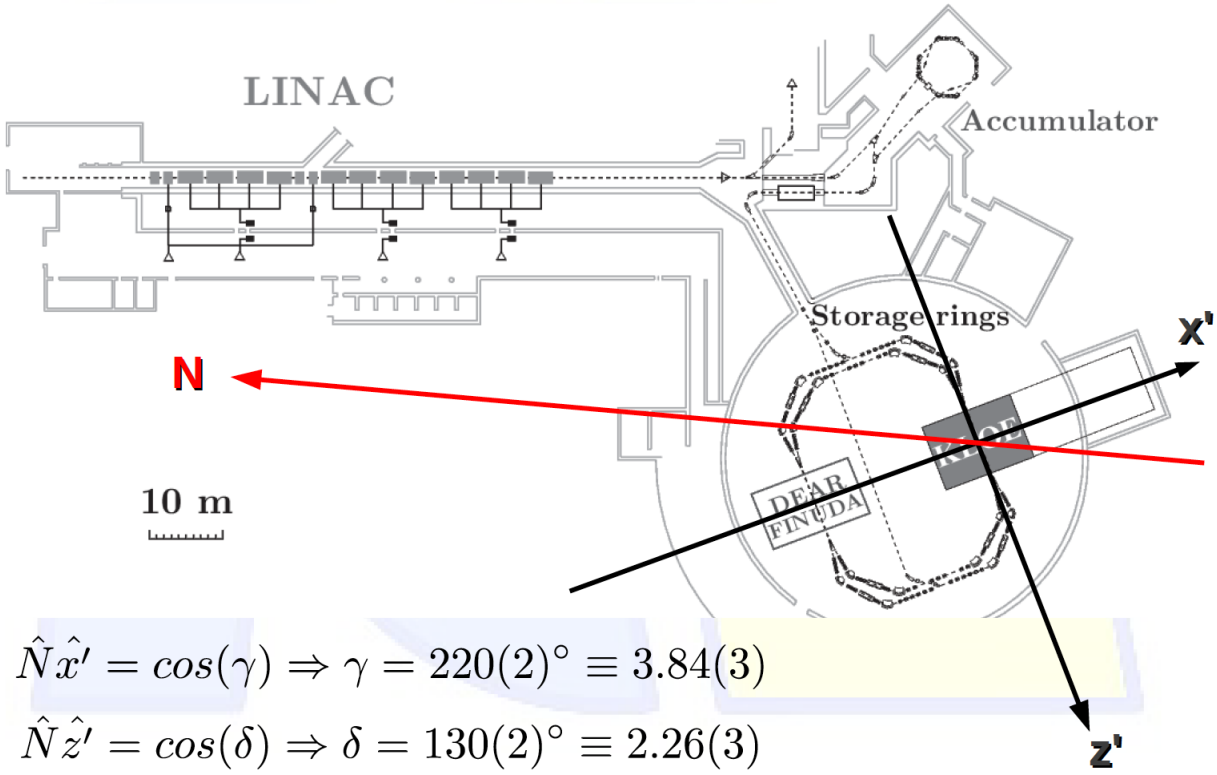
$\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$



XYZ: non rotating reference frame

xyz: rotating reference frame
z axis = DAΦNE beam axis

KLOE reference frame & SME reference frame



$z' = z$

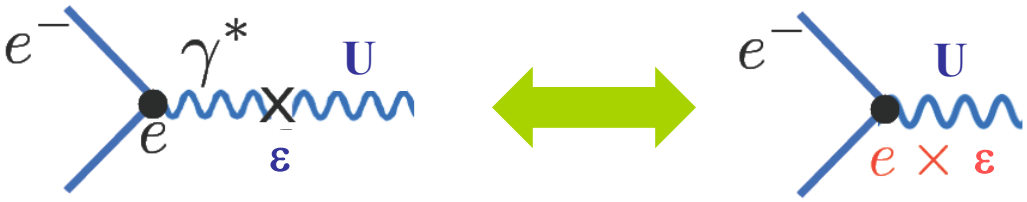
$x' \neq x$

$$\hat{N}\hat{x}' = cos(\gamma) \Rightarrow \gamma = 220(2)^\circ \equiv 3.84(3)$$

$$\hat{N}\hat{z}' = cos(\delta) \Rightarrow \delta = 130(2)^\circ \equiv 2.26(3)$$

Search for dark forces

- **Recent astrophysical observations (PAMELA, ATIC, INTEGRAL, DAMA/LIBRA) could be interpreted by assuming the existence of a light dark sector that interacts with SM particles through a mixing of a new gauge boson (U-boson) with *O*(1 GeV) mass, with the photon**



[Arkani-Hamed et al. PRLD79(2009), 015014
Essig et al., PRD80(2009)015003]

$$\varepsilon^2 = \frac{\alpha'}{\alpha_{em}}$$

- **If the mixing parameter ε ~ 10^{-3} – 10^{-4} ⇒ could be observable at KLOE**

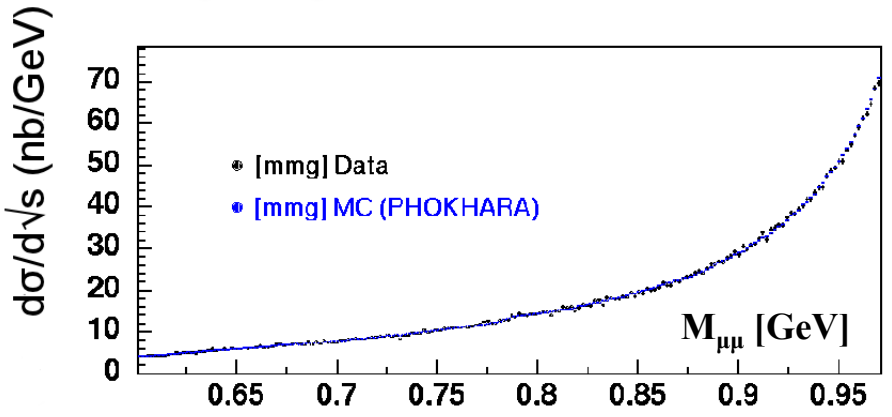
- **Signatures : $\phi \to \eta U$, $U \to \ell^+\ell^-$ ⇒ $\phi \to \eta e^+e^-$**

  $e^+e^- \to U\gamma \to \mu^+\mu^-\gamma$

  $e^+e^- \to h'U \to \mu^+\mu^-$ + missing energy

$e^+e^- \to U\gamma$; $U \to \mu^+\mu^-$

- Search for peaks in the $\mu^+\mu^-$ invariant mass
- Upper Limit @ 90% C.L. on number of events obtained with the CL_S method
- 2 MeV step



- Work in progress to extend the exclusion region below 600 MeV