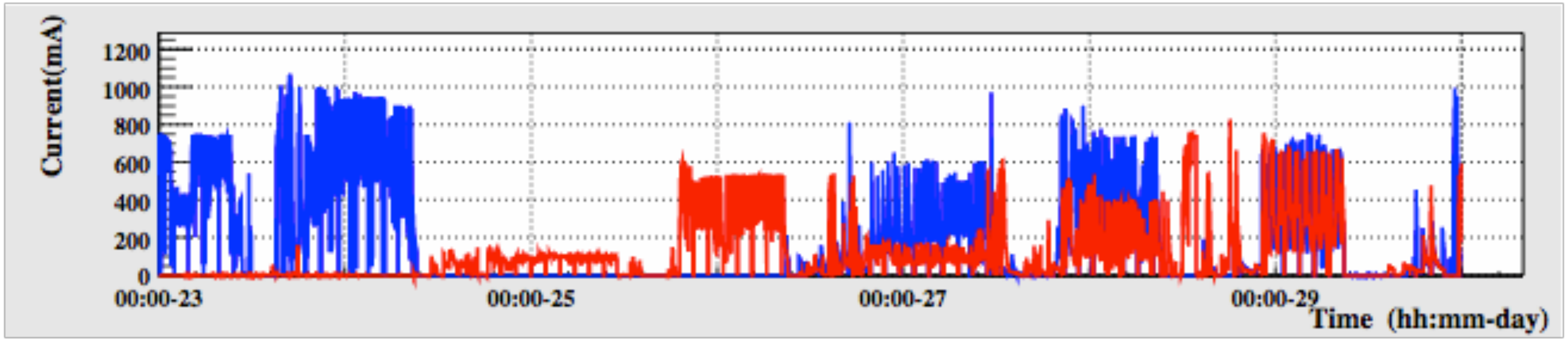
Status and prospects for the KLOE-2 experiment

S. Miscetti (LNF-INFN)

on behalf of the

KLOE-2 collaboration

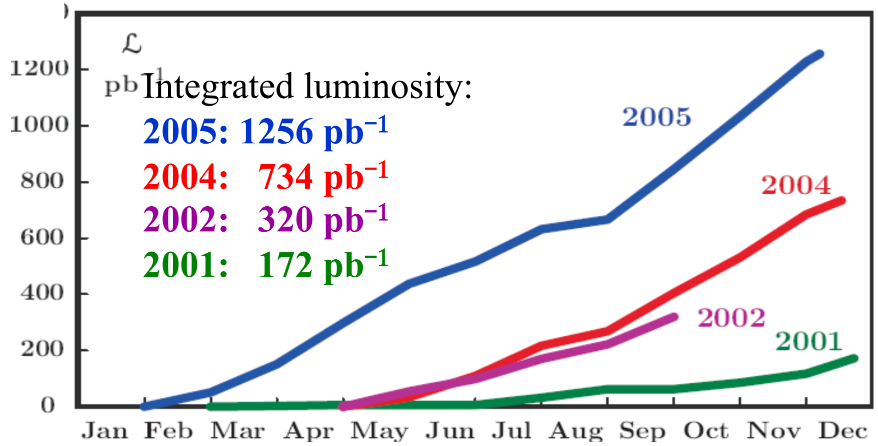


Discrete 2010, 6-11 Dec 2010, Roma

DAΦNE: the Frascati ϕ-factory

KLOE-2

- e^+e^- collider @ $\sqrt{s} = M_\phi = 1019.4$ MeV
- 2 interaction regions
- Separate e^+ e^- rings
- 105+105 bunches, 2.7 ns bunch spacing
- $I^-_{peak} \sim 2.4$ A $\quad I^+_{peak} \sim 1.5$ A
- Injection during data taking
- Crossing angle: 2×12.5 mrad



❖ Running period: 1999-2006

❖ Best performances:

- $L_{peak} = 1.4\times10^{32}$ cm^{-2}s^{-1}
- $\int L dt = 8.5$ pb^{-1}/day

For KLOE experiment

Data taking ended on March 2006

- 2.5 fb^{-1} on tape @ $\sqrt{s} = M_\phi$ $(8\times10^9\ \phi)$
- ~10 pb^{-1} @ 1010, 1018, 1023, 1030 MeV
- 250 pb^{-1} @ 1000 MeV

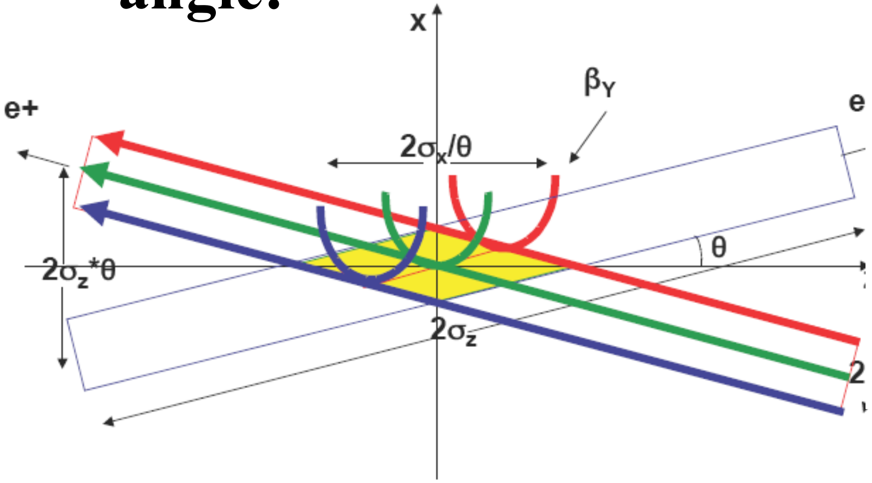
DAΦNE upgrade: the Crab waist

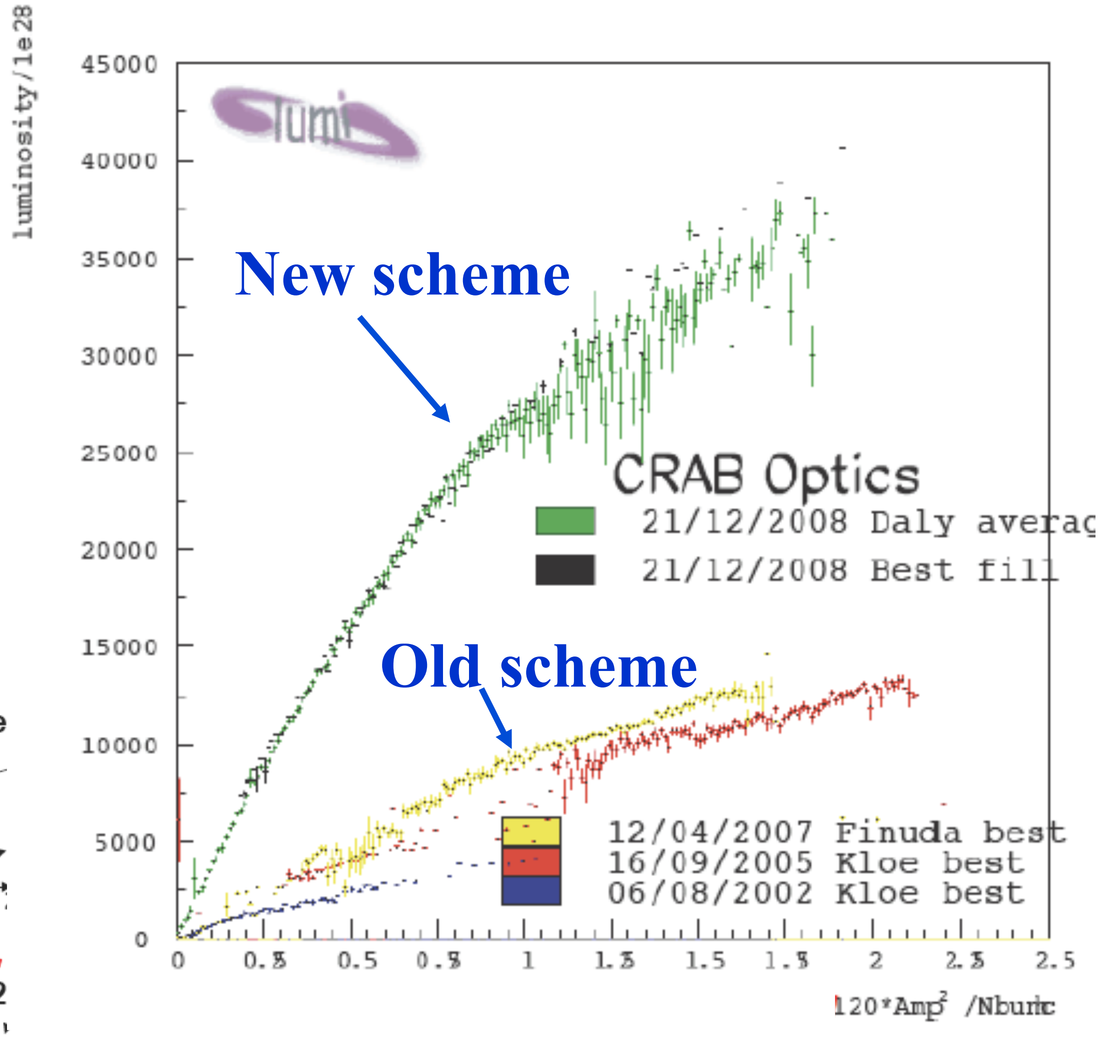
In 2008, new interaction scheme implemented for Siddharta running:

✧ large Piwinsky angle → reduce β_y without affecting the bunch length

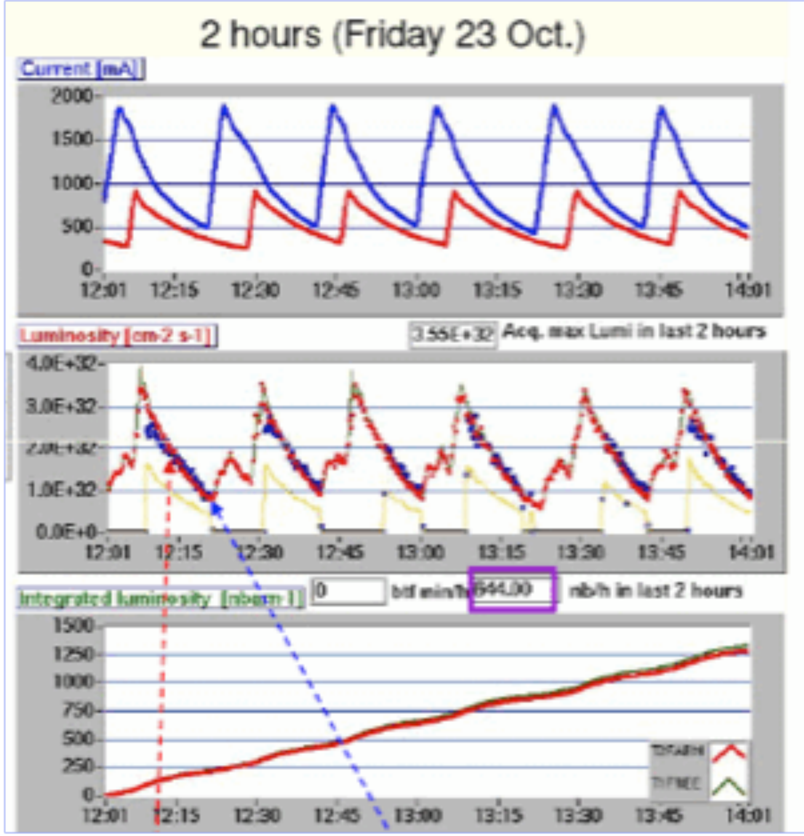
✧ sextupoles for Crab waist optics allows to reduce beam instabilities

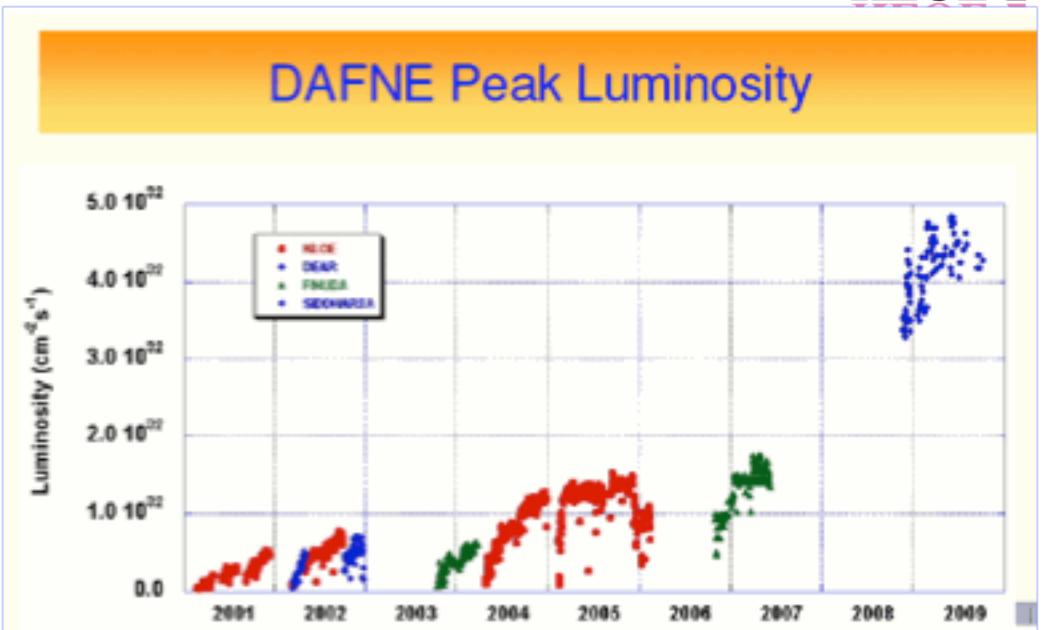
Piwinski angle: $\Phi \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}$





DAΦNE upgrade: Siddharta Luminosity

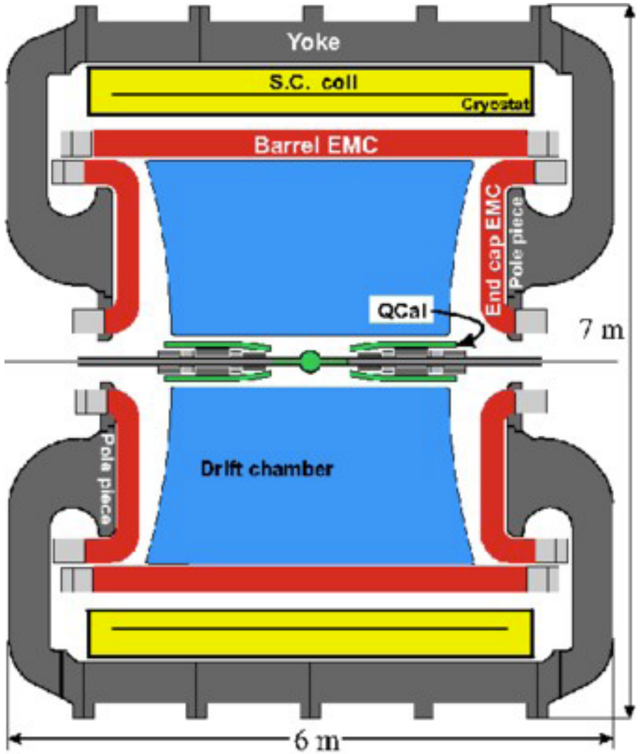




- 10 pb^{-1} delivered daily during best run period (2.8 fb-1 total)
- Siddharta detector could not stand the rate during injection
- 1 pb^{-1}/hour obtained with faster top-up operations

  O(20 pb-1) /day achievable → 0.5 fb-1/month

KLOE & KLOE-2 @ DAΦNE



Drift chamber

- Gas mixture: **90% He + 10% C_4H_{10}**
- **$\delta p_t / p_t < 0.4\%$ (θ>45°)**
- **$\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm**

Electromagnetic calorimeter

- lead/scintillating fibers
- 98% solid angle coverage
- **$\sigma_E / E = 5.7\% / \sqrt{E(GeV)}$**
- **$\sigma_t = 57\ ps / \sqrt{E(GeV)} \oplus 100\ ps$**
- **PID capabilities**

The road towards KLOE-2: two steps upgrade

1) $e^{\pm}$ taggers for $\gamma\gamma$ physics (already installed)

1 year of running → O(5 fb-1).

2) major upgrade (spring 2012)

inner tracker + new small angle calorimeters

×10 increase on integrated Luminosity O(20 fb^{-1})

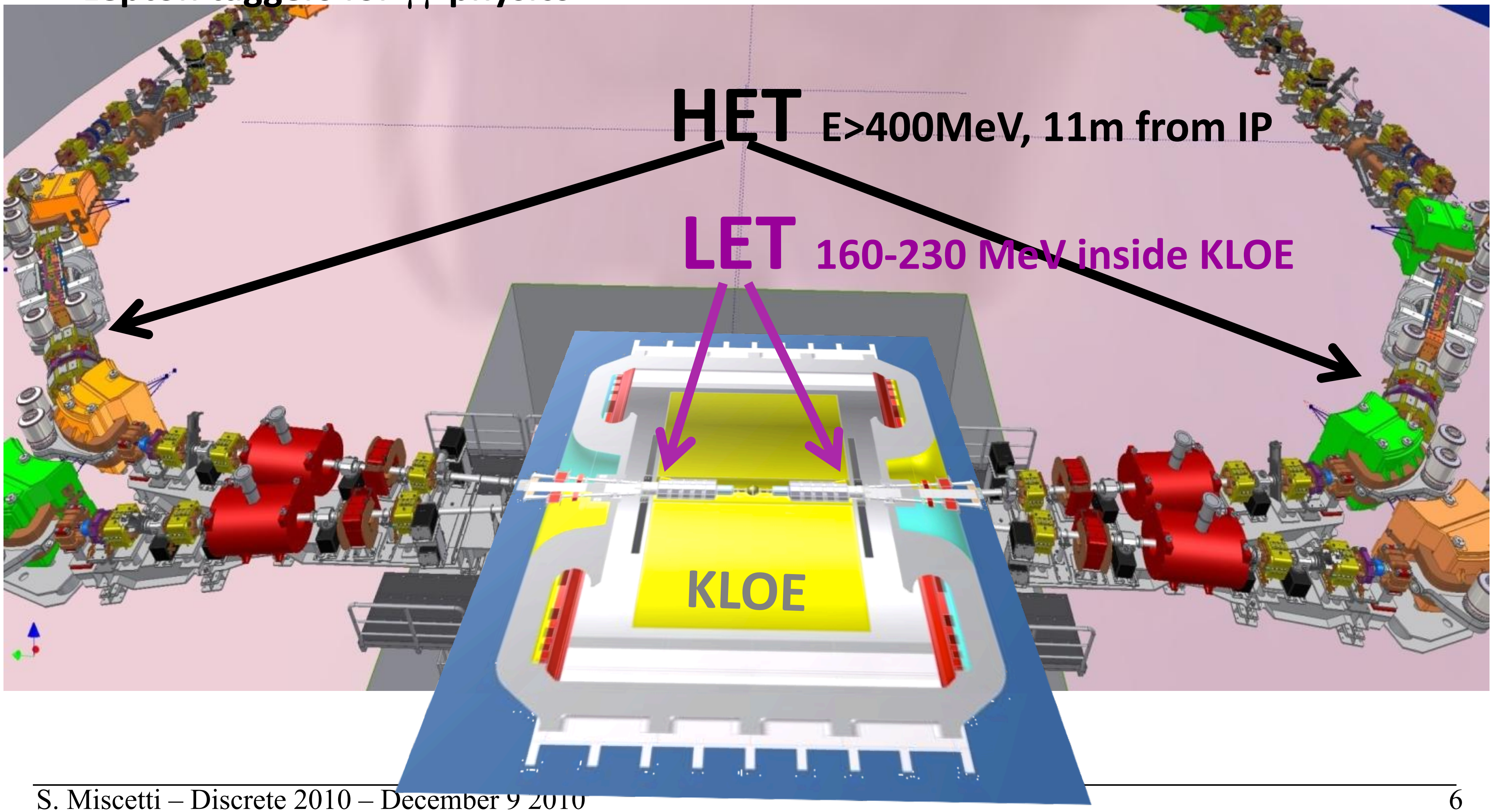
KLOE-2 upgrades: the γγ taggers

1st phase **now :**

Technical Design Report LNF - 10/14(P)

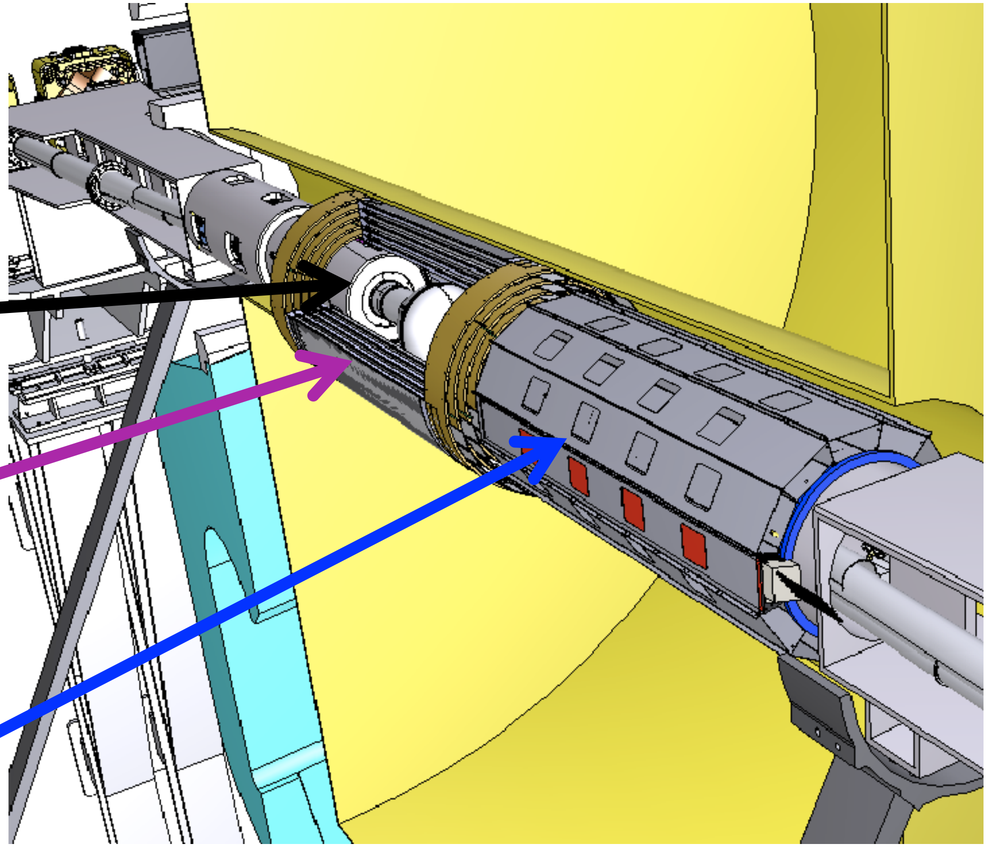
LET & HET

- ✓ **LYSO+SiPMs & Scint+PMTs**
- ✓ **Lepton taggers for γγ-physics**



KLOE-2 upgrades: the second phase

KLOE



CCALT

- ✓ LYSO + APD (SiPM)
- ✓ Increase acceptance for γ's from IP (21°→10°)

INNER TRACKER

Technical Design Report - arXiv:1002.2572

- ✓ 4 layers of cylindrical triple GEM
- ✓ Better vertex reconstruction near IP
- ✓ Larger acceptance for low pt tracks

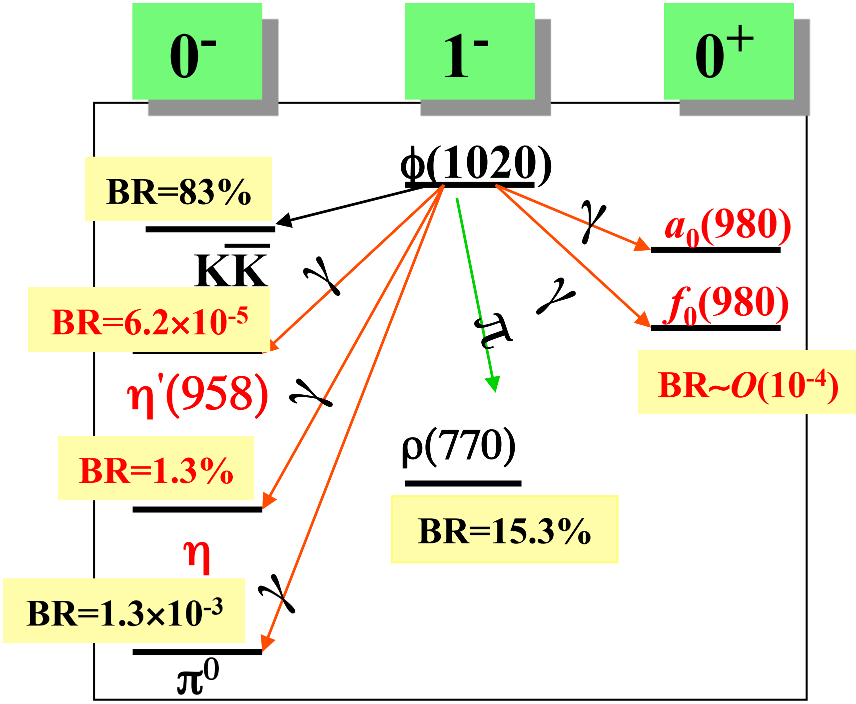
QCALT

- ✓ tiles + WLS/SiPM
- ✓ quadrupoles coverage for K_L decays

Physics at KLOE/KLOE-2

- Kaon physics: $|V_{us}|$ and CKM unitarity, CP and CPT violation, rare decays, χPT tests, quantum mechanics tests
- ϕ radiative decays: pseudoscalar and scalar mesons
- Search for a Dark Gauge sector
- Hadron production in $\gamma\gamma$ collision
- Had cross-section via ISR $[e^+e^- \to \gamma\,(\pi^+\pi^-)]$ hadronic corrections to $(g\text{-}2)_\mu$

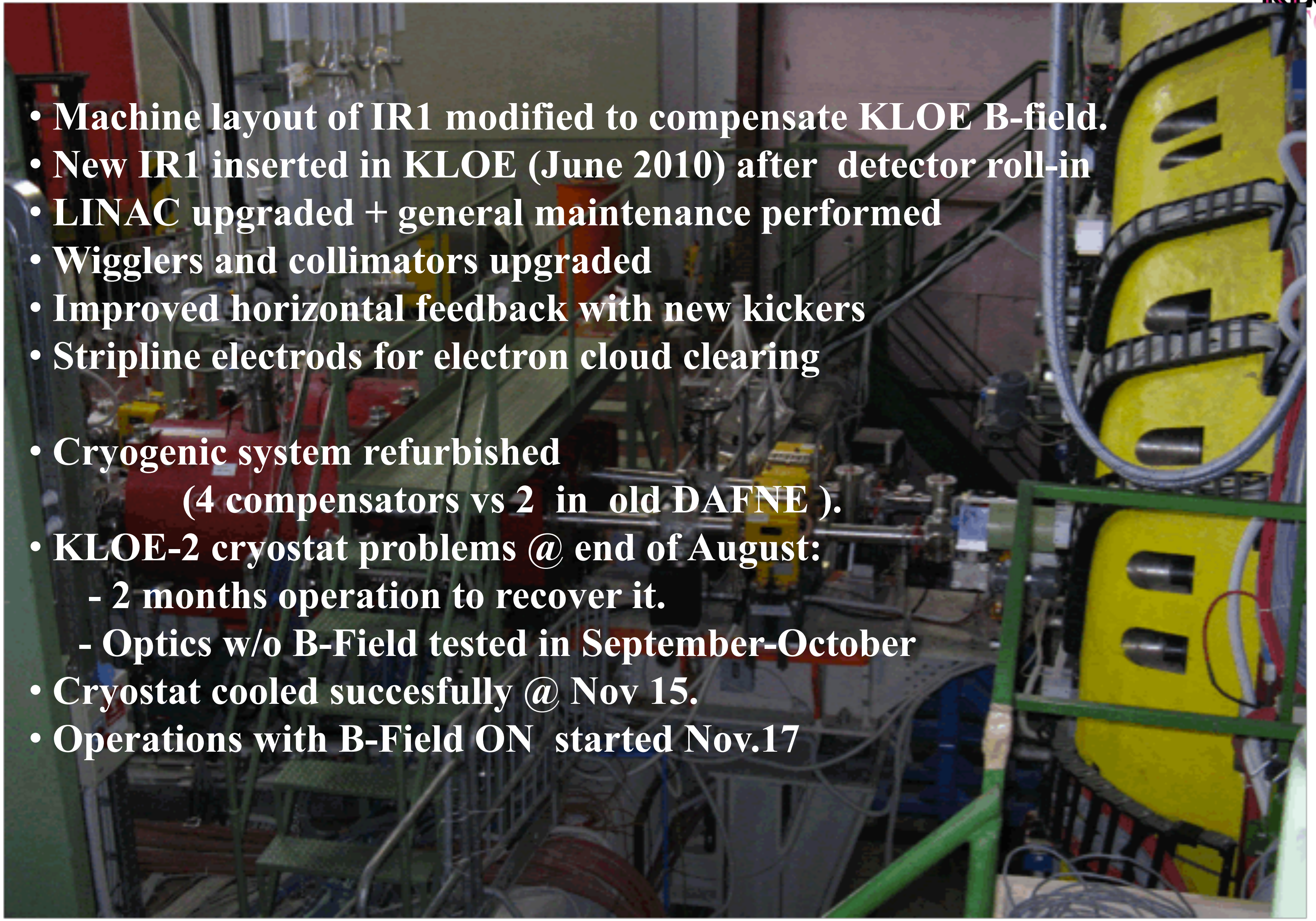
Decay channel	Events (2.5 fb^{-1})
K^+K^-	3.7×10^9
$K_L K_S$	2.5×10^9
$\rho\pi + \pi^+\pi^-\pi^0$	1.1×10^9
$\eta\gamma$	9.7×10^7
$\pi^0\gamma$	9.4×10^6
$\eta'\gamma$	4.6×10^5
$\pi\pi\gamma$	2.2×10^6
$\eta\pi^0\gamma$	5.2×10^5



KLOE-2 physics program: [G.Amelino-Camelia et al., EPJC 68, 619 (2010).]

DAΦNE upgrade for KLOE-2 (2010)

KLOE-2



- Machine layout of IR1 modified to compensate KLOE B-field.
- New IR1 inserted in KLOE (June 2010) after detector roll-in
- LINAC upgraded + general maintenance performed
- Wigglers and collimators upgraded
- Improved horizontal feedback with new kickers
- Stripline electrods for electron cloud clearing

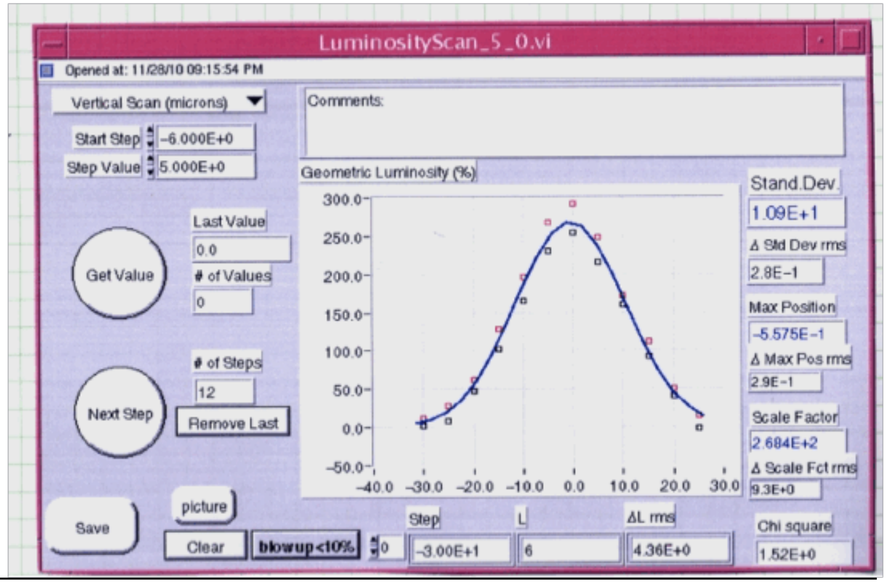
- Cryogenic system refurbished
  (4 compensators vs 2 in old DAFNE).
- KLOE-2 cryostat problems @ end of August:
  - 2 months operation to recover it.
  - Optics w/o B-Field tested in September-October
- Cryostat cooled succesfully @ Nov 15.
- Operations with B-Field ON started Nov.17

DAΦNE status: today

KLOE-2

Commissioning phase started:

- ❑ In two weeks, e- (e+) currents up to 800 (600) A → beam conditioning is being carried out to improve vacuum
- ❑ Background level in KLOE still too high (> 2 MHz on EMC) → working on Collimators
- ❑ Optics optimization performed with both beams
- ❑ Beam Beam vertical scan performed Nov the 28th
- ❑ Optimization of beam beam interaction, luminosity and background reduction in next weeks

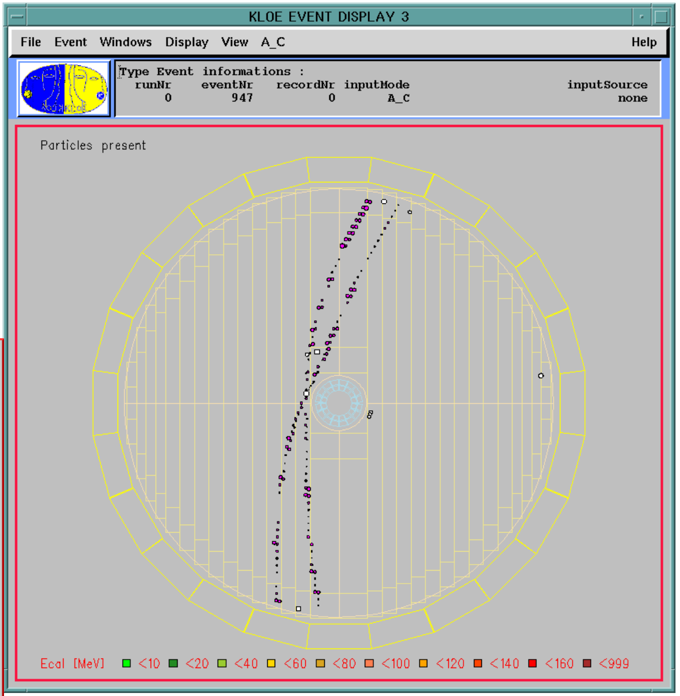


Start of real collisions expected for middle of January 2011

KLOE-2 status

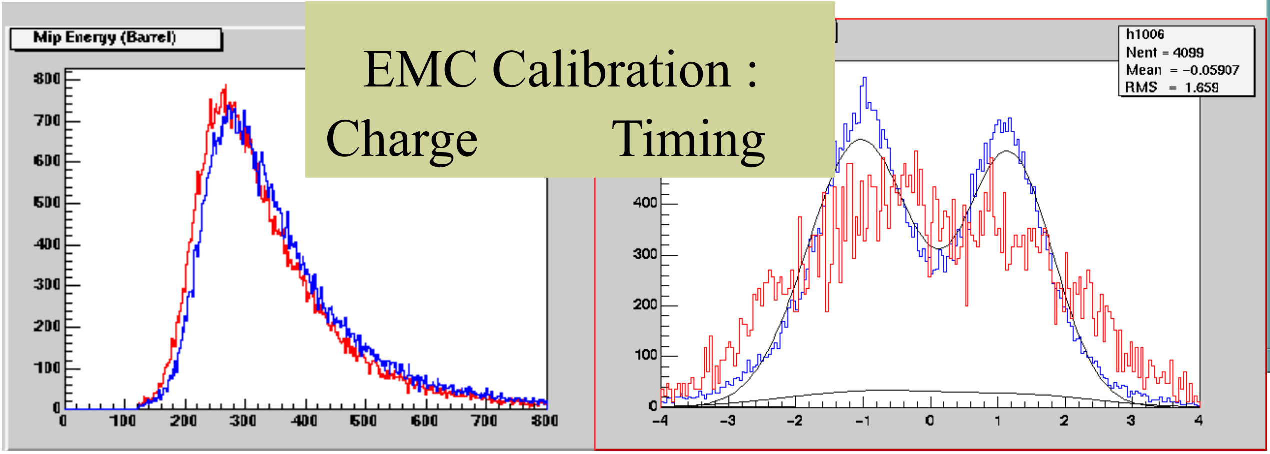
KLOE-2 detector ready:

- EMC+DC OK → Calibration done with CR
- DAQ + slow control tested with long automatic running procedures
- DC in standby during this commissioning run

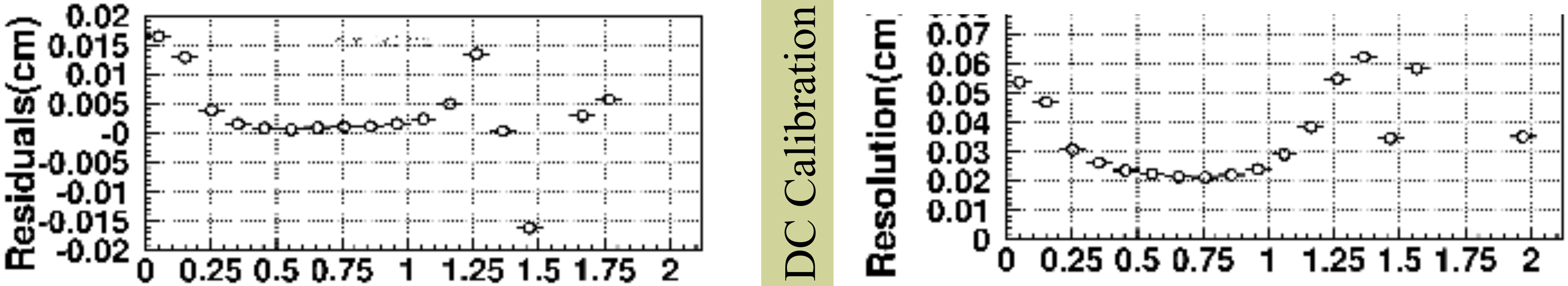


EMC Calibration :

Charge Timing



DC Calibration



KLOE-2: physics shopping list for Step-0

- ✧ $\gamma\gamma$ physics : measurement of the tagger acceptance vs Q^2
  π^0 width, Meson transition form factor

- ✧ $\phi \to \eta\, e^+ e^-$: measurement of the form factor
- ✧ $\eta' \to \eta\, \pi^+ \pi^-$: measurement of the $M_{\pi\pi}$ distribution
- ✧ $\phi \to$ Ks Ks γ : improve limit, first evidence of the decay
- ✧ Exclusion plot for dark forces U(1), h'
  - $e^+ e^- \to U\gamma \to l^+ l^- \gamma$,
  - $e^+ e^- \to \eta U \to \eta\, l^+ l^-$
  - $e^+ e^- \to h\,\gamma \to X_{Miss}\, l^+ l^-$

- ✧ $K_S \to \pi^0 \pi^0 \pi^0$
- ✧ $K_S K_S \to \pi^0 \pi^0 \pi^+ \pi^-$ Measurement of $Im(\varepsilon'/\varepsilon)$

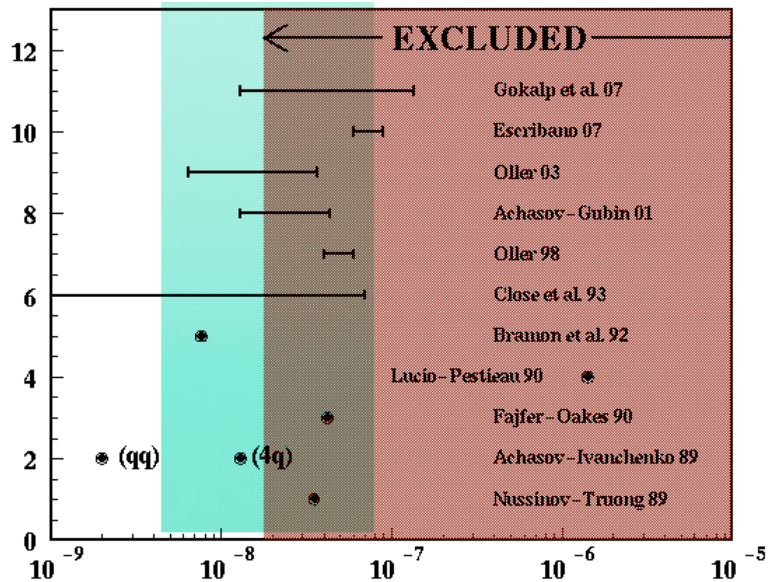
Search for $\phi \rightarrow K^0K^0\gamma$ events

KLOE-2

- Proceeds as: $\phi \rightarrow [f_0(980)+a_0(980)]\gamma \rightarrow K^0K^0$ → **Never been observed**
- Final State: $K_SK_S\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-\gamma$ Clean topology, 24% BR reduction
- Selection cuts optimized on MC (bckg: **$K_SK_L(\gamma)$** , **$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-(\gamma)$**)
- 2.18 fb^{-1} data @ M_ϕ : **PLB 679 (2009) 10**
  - **5 EVENTS IN DATA**
  - **2.5 + 0.7 BCKG EVENTS (MC)**

$$BR(\phi \rightarrow K^0\overline{K}^0\gamma) < 1.9\times10^{-8} \text{ @ } 90\% \text{ C.L.}$$

Consistent with KLOE couplings from $\phi \rightarrow \pi\pi\gamma$, $\phi \rightarrow \eta\pi\gamma$ in the K-Loop model



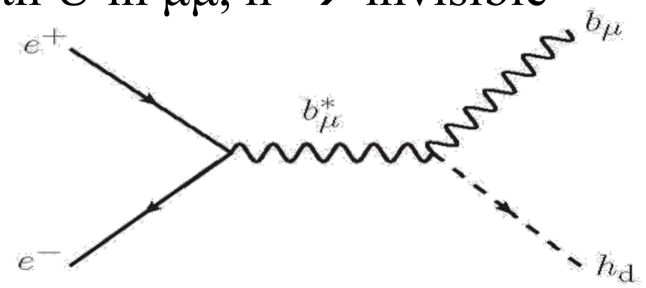
- **Same analysis @ 10 fb-1 : $BR(\phi \rightarrow K_SK_S\gamma) < 1\times10^{-8}$**
  - **Other theoretical predictions can be ruled out**
- **With IT: $BR(\phi \rightarrow K_SK_S\gamma) < 0.5\times10^{-8}$ →KLOE allowed region covered**
  - **→First observation possible**

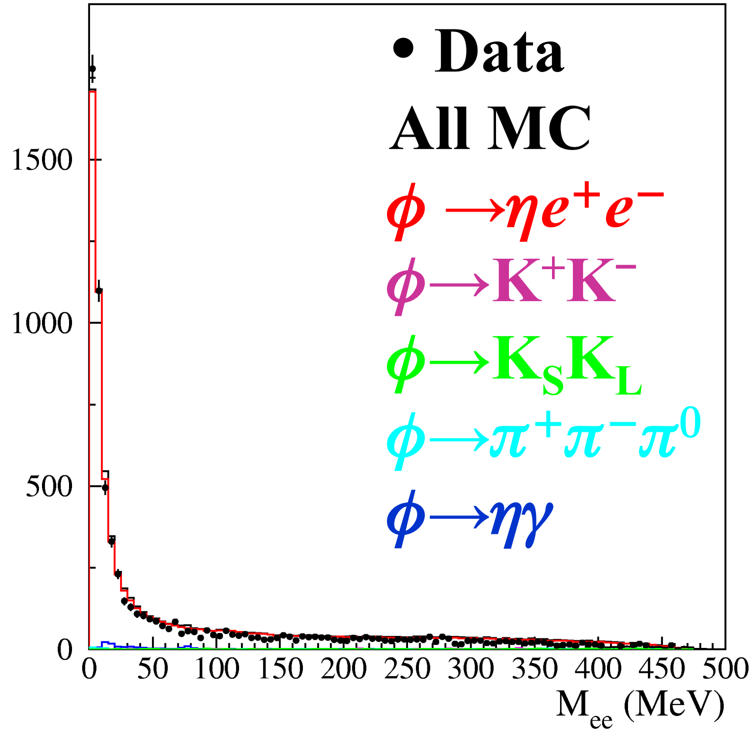
$\phi \rightarrow \eta$ e+e- events: searching for U

Puzzling astrophysical results (DAMA, PAMELA, INTEGRAL…) can be explained with a new light "dark" gauge boson (U/A′…) weakly coupled to SM particles via a kinetic mixing mechanism: $\varepsilon F_{\mu\nu} F_d^{\mu\nu}$

Most advanced search in KLOE by means of $e^+ e^- \rightarrow \eta U \rightarrow \eta\, e^+ e^-$

- ✧Preliminary exclusion plots on ε obtained with 700 pb-1 and $\eta \rightarrow \pi^+\pi^-\pi^0$ final state.
- ✧ other decay chains for η under study
- ✧ Search for higgs'strahlung in progress with U in μμ, h' → invisible





For more details → see "S.Giovannella" talk on Friday afternoon session

Kaons: search for Ks → 3 π^0 events

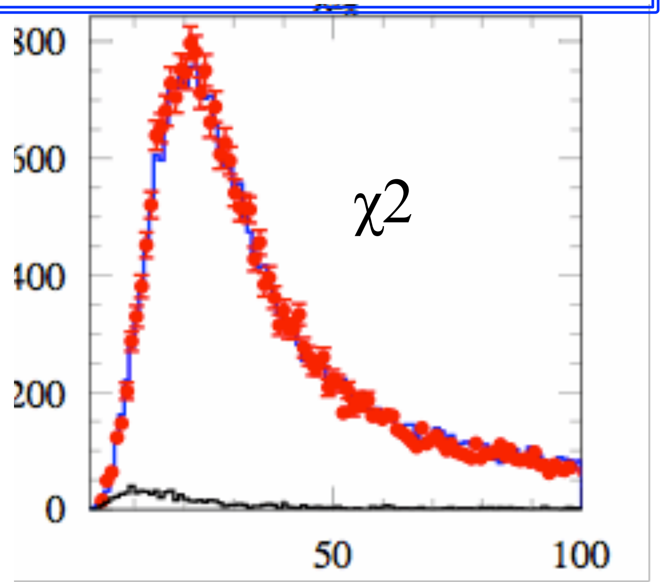
SND (direct search) :	$BR(K_S \to 3\pi^0) < 1.4 \cdot 10^{-5}$
NA48 (interference measurement):	$BR(K_S \to 3\pi^0) < 7.4 \cdot 10^{-7}$
KLOE	$BR(K_S \to 3\pi^0) < 1.2 \cdot 10^{-7}$

SM prediction: $BR(K_S \to 3\pi^0) = 1.9 \cdot 10^{-9}$

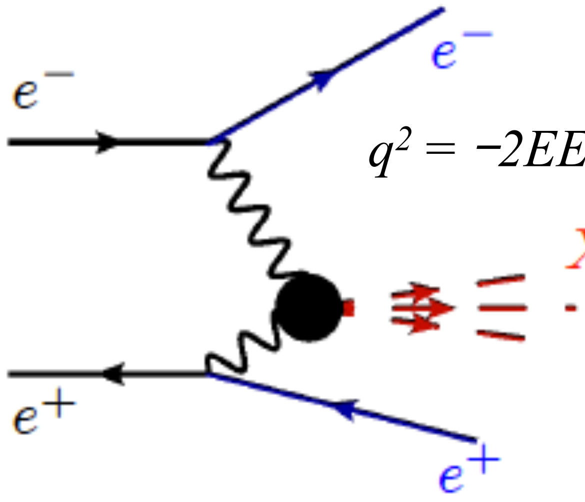
- Ks tag by KL interaction on EMC
- Six photon events
- Discriminant analysis

CP violation in Ks system

- Best limit from KLOE with 400 pb^{-1} based on 30 million tags
  → 2 candidates, 3.13 exp Bkg
  (Cluster splits + fake tags)
- Analysis in progress with x 4 statistics
  - Fake reduction improvement > 30
  - Split rejection improvement > 20
- Feasible to bring UL ~ 10^{-8} with O(5 fb-1)

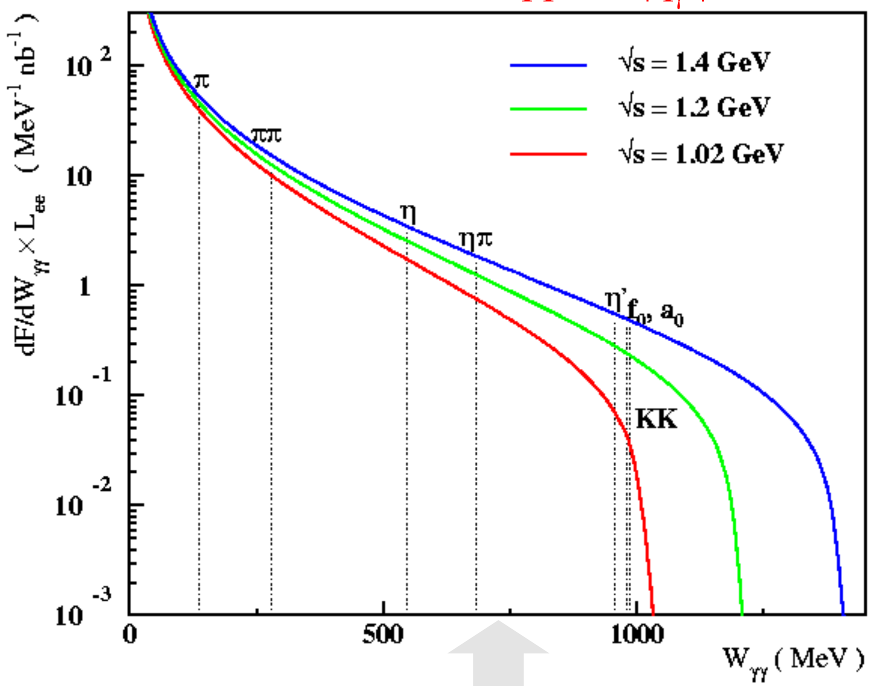


$\gamma\gamma$ physics: the $e^+e^- \to e^+e^-X$ process



$q^2 = -2EE'(1\text{-}\cos\theta)$

Weizsäcker-Williams approx, $|q_\gamma^2| \ll W^2$



Tagger is essential to reduce bckg from ϕ and to close kinematics

$$N_{e^+e^-\to e^+e^-X} = L_{ee}\int \frac{dF_{\gamma\gamma}}{dW_{\gamma\gamma}}\sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})\,dW_{\gamma\gamma}$$

$$\sigma_{e^+e^-\to e^+e^-X} = \frac{16\alpha^2\Gamma_{X\gamma\gamma}}{m_X^3}\left(\ln\frac{E_b}{m_e}\right)^2\left((y^2+2)^2\ \ln\frac{1}{y} - (1-y^2)\ (3+y^2)\right)$$

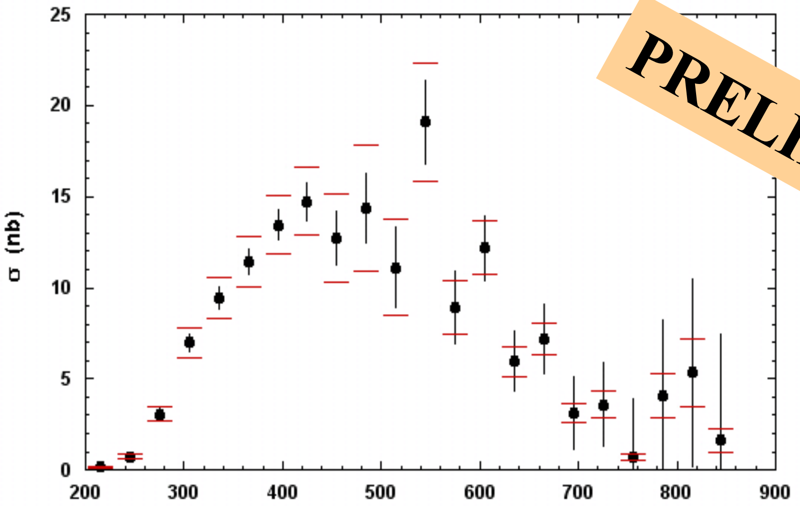
$$y = m_X/(2E_b)$$

$L_{int} = 1\ fb^{-1}$

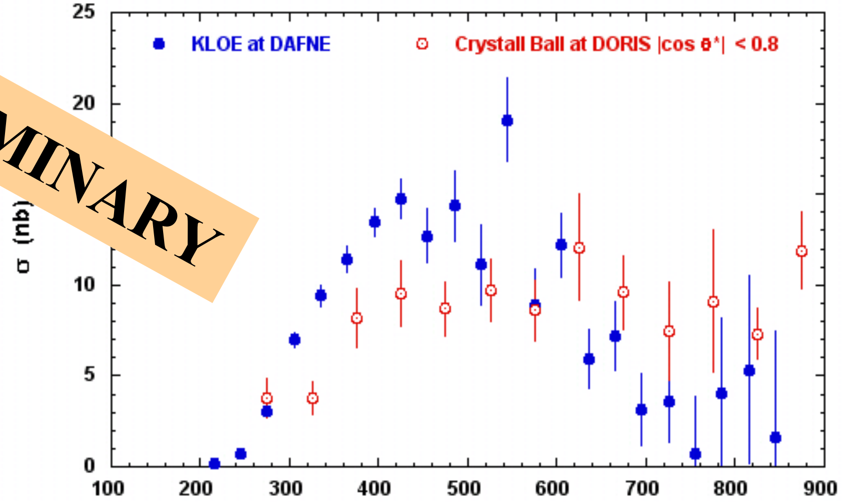
$\sqrt{s}$ (GeV)	π^0	η	η'
1.02	4.1×10^5	1.2×10^5	1.9×10^4
2.4	7.3×10^5	3.7×10^5	3.6×10^5

KLOE: γγ physics w/o tagger

KLOE-2

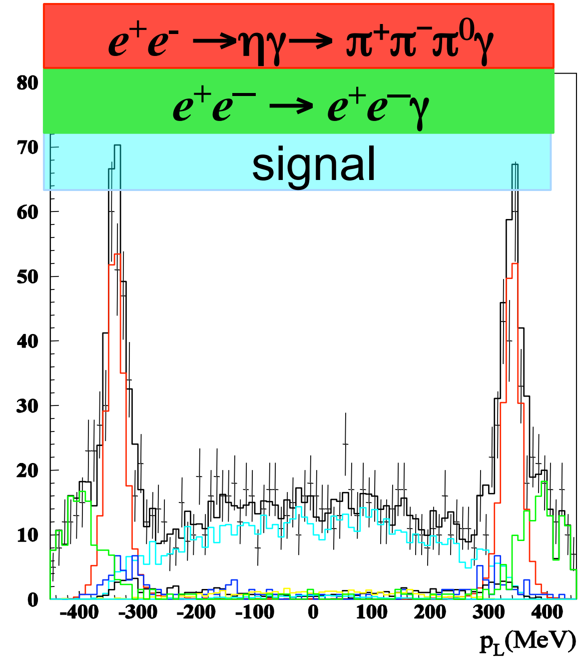


PRELIMINARY



◆ $M(\pi^0\pi^0)$ @ 1000 MeV (200 pb^{-1}), high statistics, high bkg

◆Systematic error band: normalization, efficiency, ana cuts



◆ Study of single "η" production with the same sample In the $\pi^+\pi^-\pi^0$ final state.

◆ Clean signal observed in Pl and Mmiss variables

PRELIMINARY

$\sigma(e^+e^- \to e^+e^-\eta, \sqrt{s}=1\text{ GeV}) = (50 \pm 2_{stat} \pm 6_{syst})$ pb

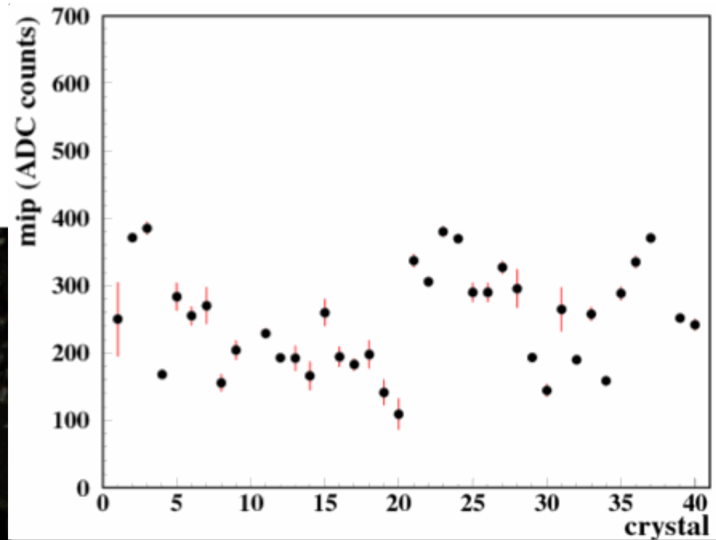
KLOE-2: $\gamma\gamma$ taggers (LET)

LET should tag e+e- of 160-230 MeV

- No correlation btw position momentum due to deflection of off-axis particles from QD0
- Two calorimeters with 20 LYSO crystals/side readout by 3x3 mm^2 Hamamatsu SIPM
- SICCAS crystals (500 pe/MeV, 5% LRU)

Assembling the calorimeters

- Let inserted the fourth of June. Cables routed.
- FEE boards ready, HV driver ok, DAQ OK
- Calibration in progress → first CR data acquired



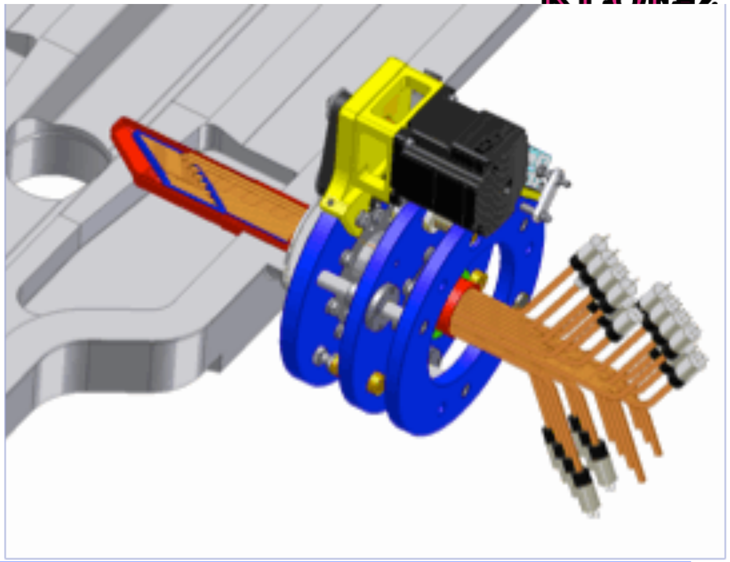
Testing and closing

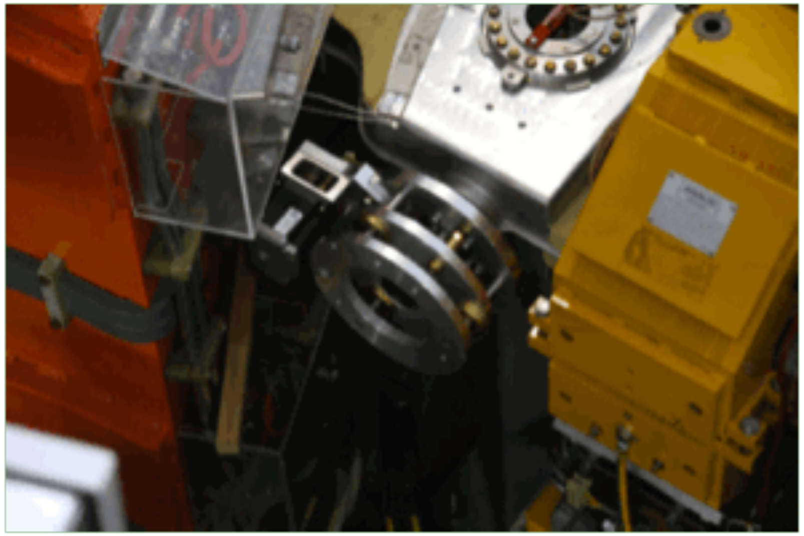
LET in place

KLOE-2: $\gamma\gamma$ taggers (HET)

HET should tag e+ e- > 400 MeV

- ❖ High correlation between position and momentum due to the bending of first Dipole
- ❖ 1 mm resolution → 0.6 MeV
- ❖ Detector will be inserted in Roman Pots already installed in DAFNE Beam-Pipe





Two scintillator hodoscopes (e^+/e^-):
28 plastic scint 3x5x6 mm^3
2 plastic scint 3x120x6 mm^3

Total : 60 Channels for the 2 HET
-Scintillators + l.guides + PM ok
- PM's holder under realization
- final detector + FEE/DAQ march 2011

Now testing "machine" environment (Temperature, Rate) with "test detectors/sensors" inside nose of Roman Pots.

$\gamma\gamma$ tagger: usage @ 5 fb-1

KLOE-2

Learn to use the taggers → acceptance/bkg

- **If single tag enough for bkg reduction O(30%) acceptance on $\pi\pi$ final state**
- **If double tag needed O(10%)**
- **HET•HET tags enough for determination of π^0-width**
- **HET•HET+LET•KLOE OK for slope of π/η transition form factors**

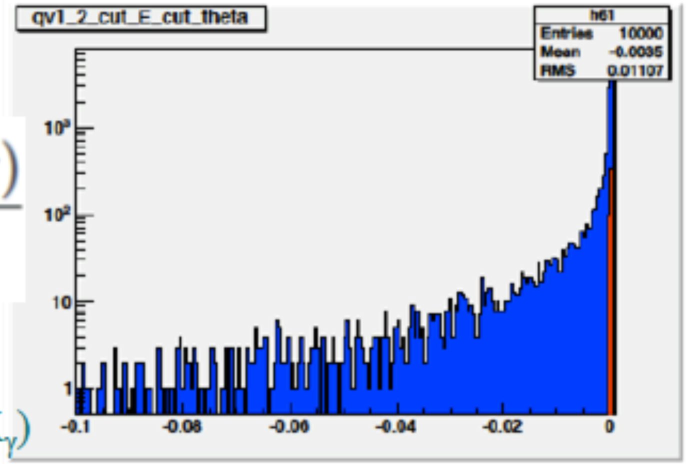
$\Gamma(\pi^0 \rightarrow \gamma\gamma)$

$$\mathcal{F}^2_{\pi^0\gamma\gamma}(m^2_{\pi^0},0,0) = \frac{1}{(4\pi\alpha)^2}\frac{64\pi\Gamma(\pi^0\to\gamma\gamma)}{M^3_{\pi^0}}$$

$$\sigma \approx \Gamma(\gamma^*\gamma^*\rightarrow\pi^0)\Gamma(\pi^0\rightarrow\gamma\gamma) = \Gamma^2(\pi^0\rightarrow\gamma\gamma)$$

$\sigma_{tot}(1020\text{ MeV}) = 0.28$ nb $\quad \sigma_{exp}=\sigma_{tot}*1.9\%\ (H_e*H_e*K_\gamma*K_\gamma)$

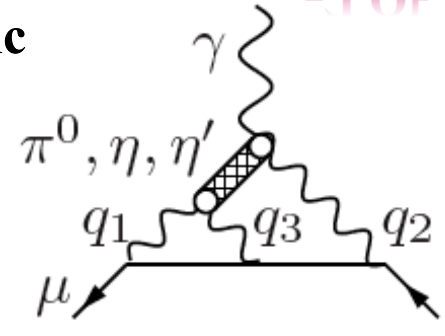
$N_{ev}=\sigma_{exp}L_{ee}\varepsilon \quad (\varepsilon=50\%) \qquad N_{ev}=13300/(5\text{ fb}^{-1})$



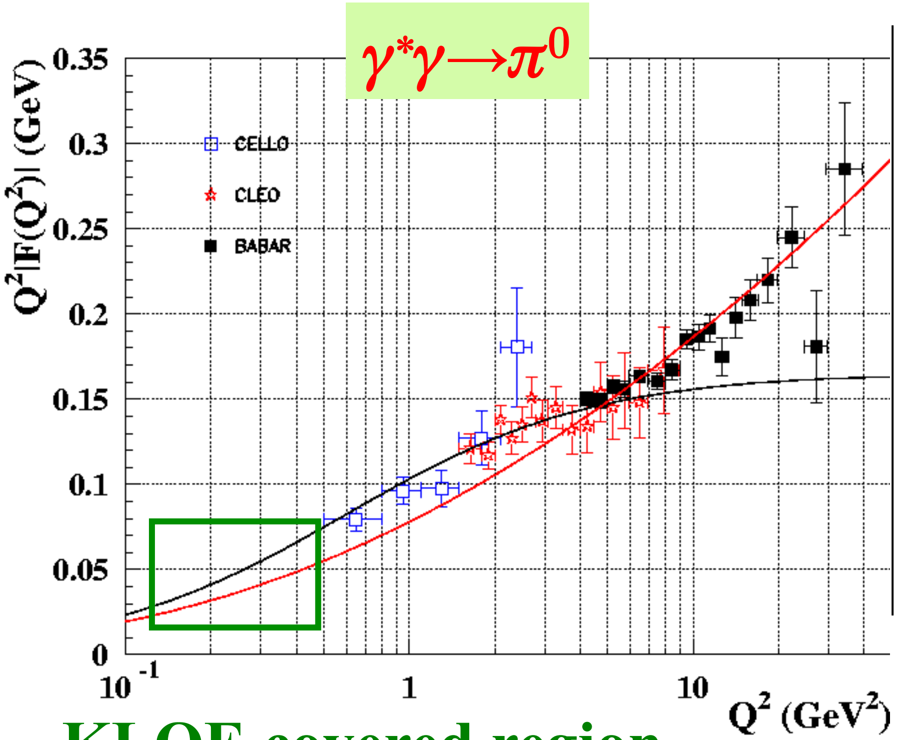
$\gamma\gamma$ taggers: meson transition form factors

Slope of transition form factors near q^2=0 crucial for hadronic light-by-light contributions to (g-2)μ

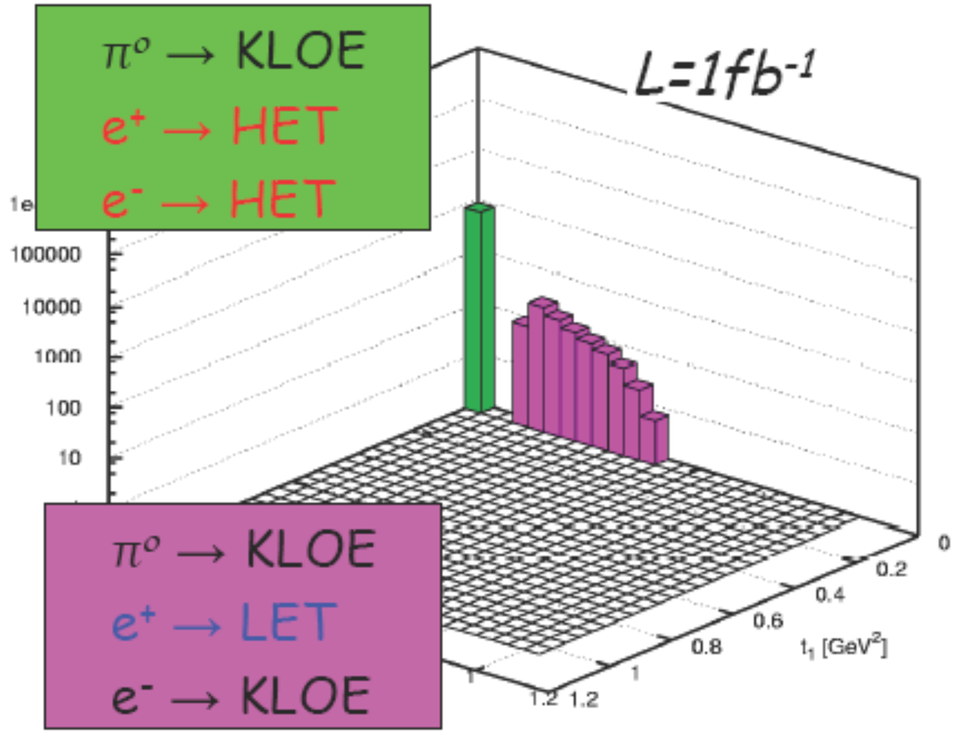
$$\sigma_{\gamma\gamma\to R}(q_1,q_2) \propto \Gamma_{R\to\gamma\gamma}\frac{8\pi^2}{M_R}\delta((q_1+q_2)^2 - M_R^2)\left|F(q_1^2,q_2^2)\right|^2$$



$\gamma^*\gamma\to$M **F(M^2,q^2,0)**



KLOE covered region



Upgrades: The QCALT calorimeter

KLOE-2

QCALT : veto photons from KL

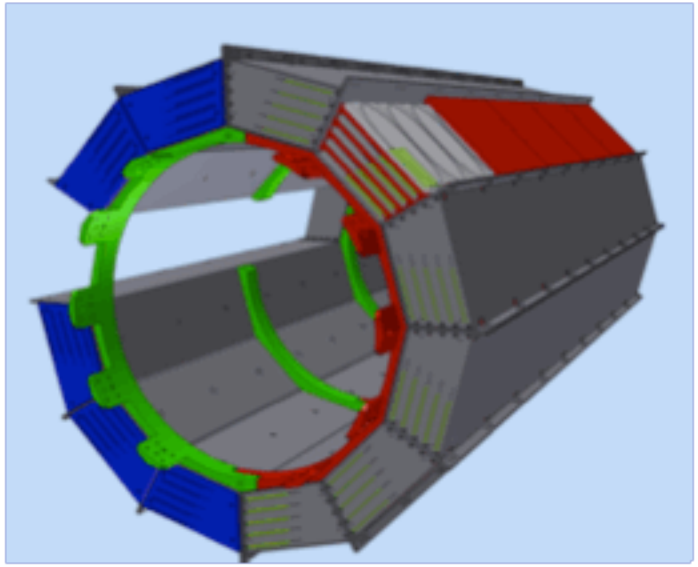
New IR1 → new veto calorimeter on Inner Quads

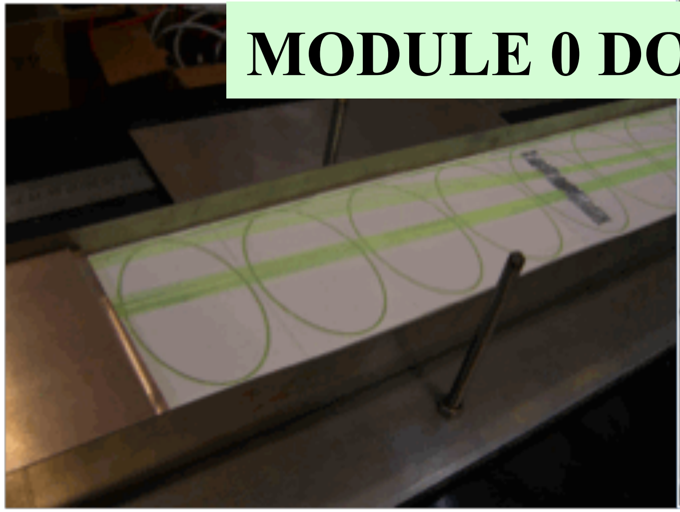
✧ Dodecagonal structure of 5 layers sampling calorimeter (3.5 mm W+5 m thick scintillating tiles), ~ 5 X_0

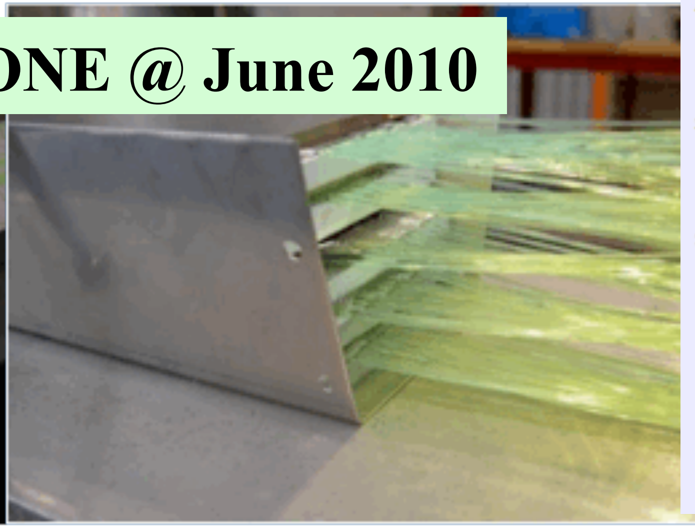
✧ WLS + SIPM readout (1.2 mm φ IRST/FBK)

✧ high granularity (5x8 cm^2 tiles) to get ~ 1.5 cm resolution → 2000 readout channels

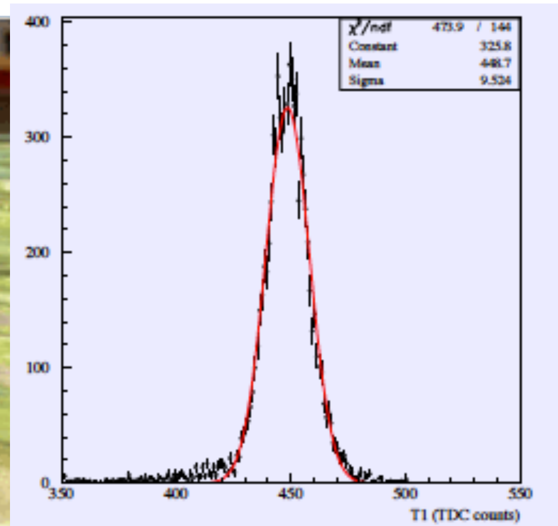
✧ High L.Y. (20 p.e./MIP) /good timing (1 ns)







MODULE 0 DONE @ June 2010



Construction starts on 2011 → completion expected end 2011

Upgrades: The CCALT calorimeter

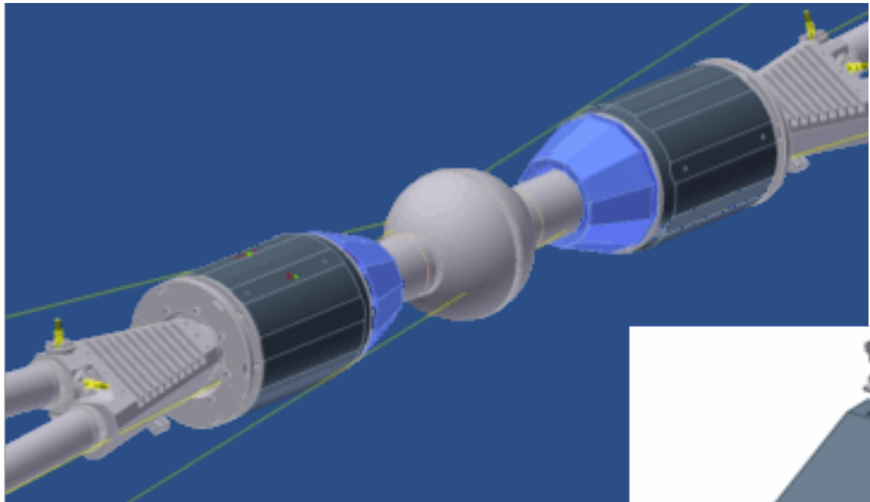
KLOE-2

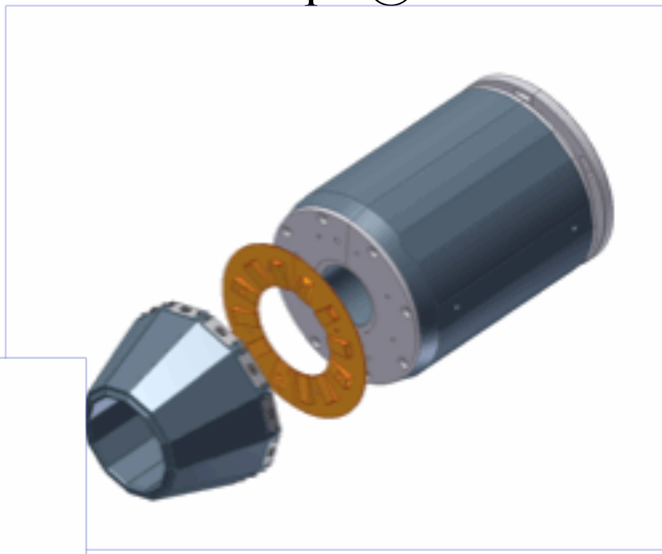
CCALT (Crystal Calorimeter with Timing)

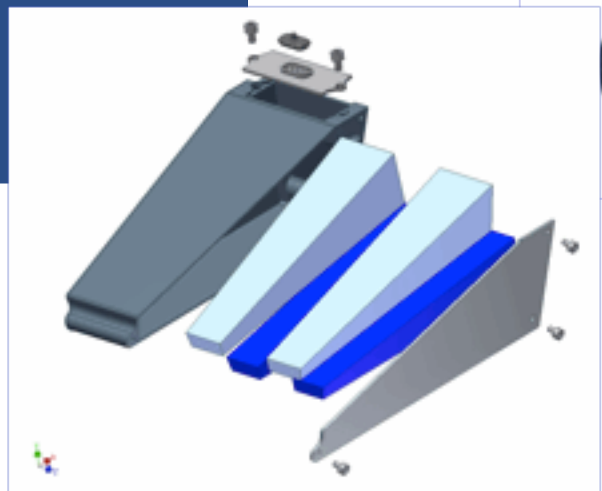
✧ Dodecagonal structure of ~ 10 cm long LYSO crystals → increase coverage for low energy photons down to 10 degrees (i.e. just in fron of first Quad (QD0).

✧ Large L.Y. with APD's, Timing resolution of 100 ps @ 20 MeV

✧Final readout by means of LA SIPM (6x6 mm2 Hamamatsu or 4x4 mm2 IRST) to avoid heat dissipation in a critical region → time res of ~ 300 ps @ 30 MeV



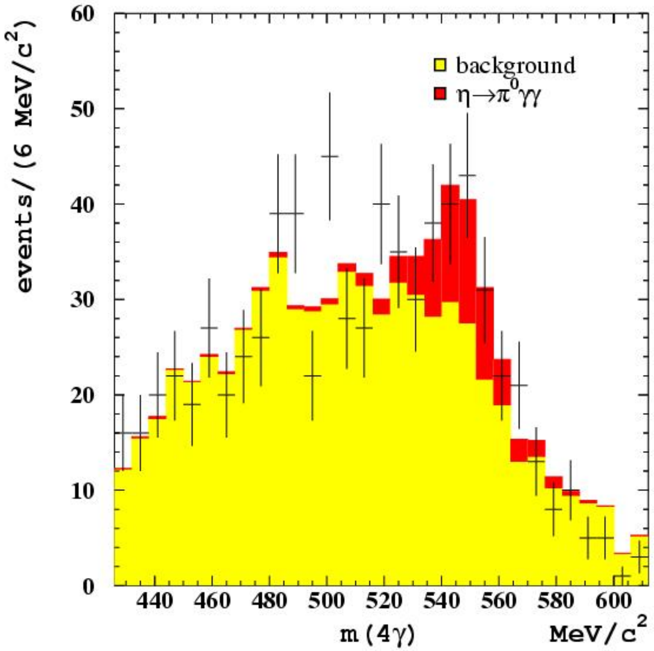




CCALT: Search for rare Ks, η decays

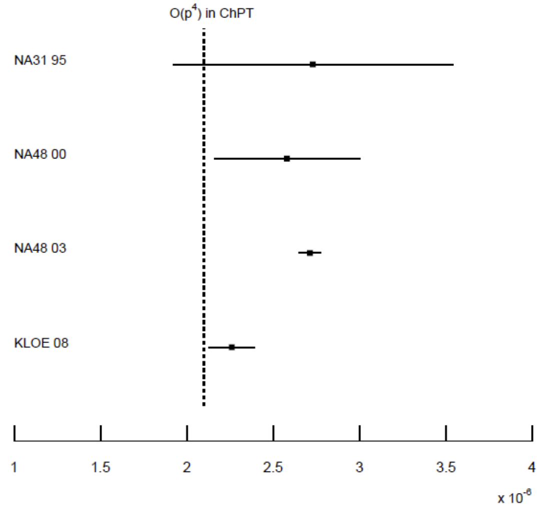
CB@AGS: BR = (22.1 ± 2.4 ± 4.7) × 10^{-5}
PRC 78 (2008) 015206 ~ 500 signal events
CB@MAMI-B: BR = (22.5 ± 4.6 ± 1.7) × 10^{-5}
Preliminary, arXiv:0910.1331 ~ 150 signal events

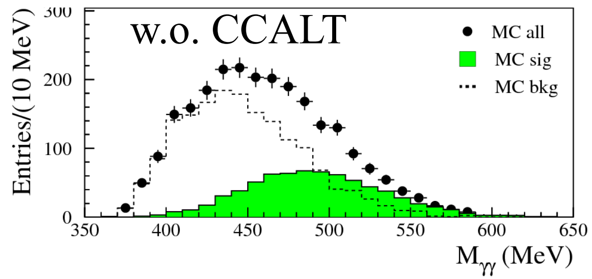
$$\mathbf{BR(\eta \to \pi^0 \gamma\gamma) = (8.4 \pm 2.7_{stat} \pm 1.4_{syst}) \times 10^{-5}}$$

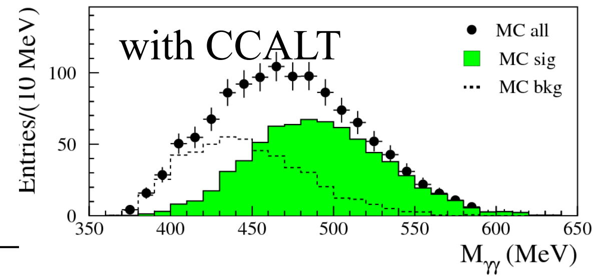


(1) BR with 2-3%
(2) Study of $M_{\gamma\gamma}$ spectra
(3) Improving bkg rejection

KLOE measurement of
BR(Ks → γγ)
differs of 3 σ from NA48





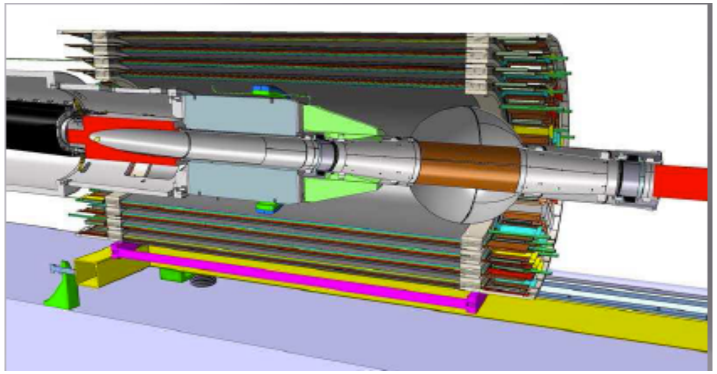


Upgrades: The Inner Tracker

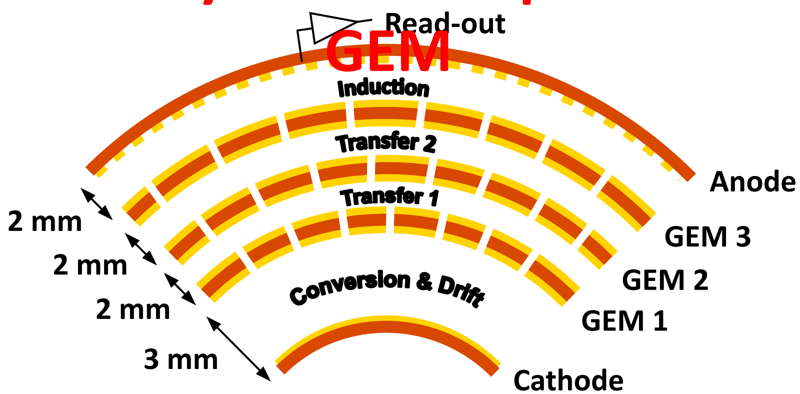
The IT @ CGEM is a low-mass, fully cylindrical and dead-zone-free GEM based detector: no support frames are required inside the active area

IT: Improve vertex reconstruction of K_s, η, η' rare decays and K_s- K_L interference measurements :

- $\sigma_{r\phi} \sim 200\ \mu m$ and $\sigma_z \sim 500 \mu m$
- low material budget:<2%X_0
- 5 kHz/cm^2 rate capability



Cylindrical Triple GEM



- ♦ **4 CGEM layers with radii from 13 to 23 cm from IP and before DC Inner Wall**
- ♦ **700 mm active length**
- ♦ **XV strips-pads readout (40° stereo angle)**
- ♦ **1.5% X_0 total radiation length in the active region with Carbon Fiber supports**

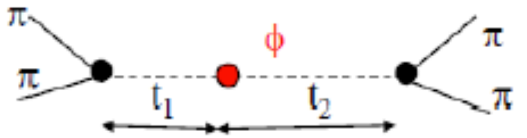
$K_S \rightarrow \pi\,\pi$ vtx resolution will improve of about a factor 3 from present 6 mm

IT: Implication on interferometry

- Kaon pairs @ φ are produced in a pure quantum state ($J^{pc} = 1^{--}$)
- Interferometry studies can be carried out so to perform relevant QM, EPR, CPT and Lorentz violation tests.

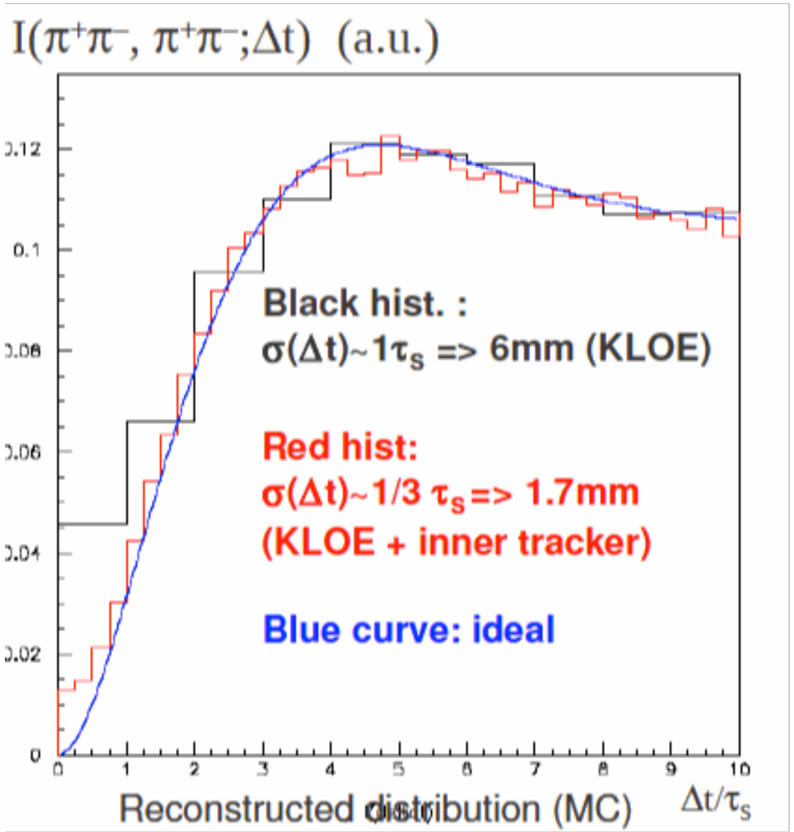
Assuming same final state: $\pi^+\pi^-$

$$\Delta t = |t_1 - t_2|$$



EPR correlation:

no simultaneous decays (Δt=0) in the same final state due to the destructive quantum interference

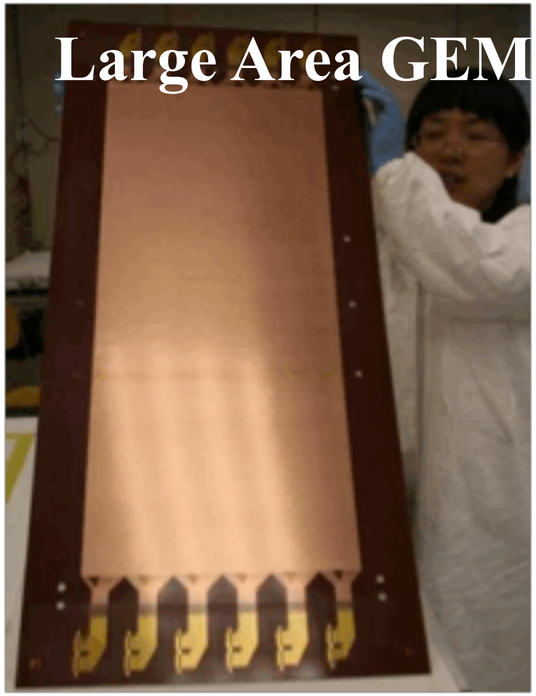


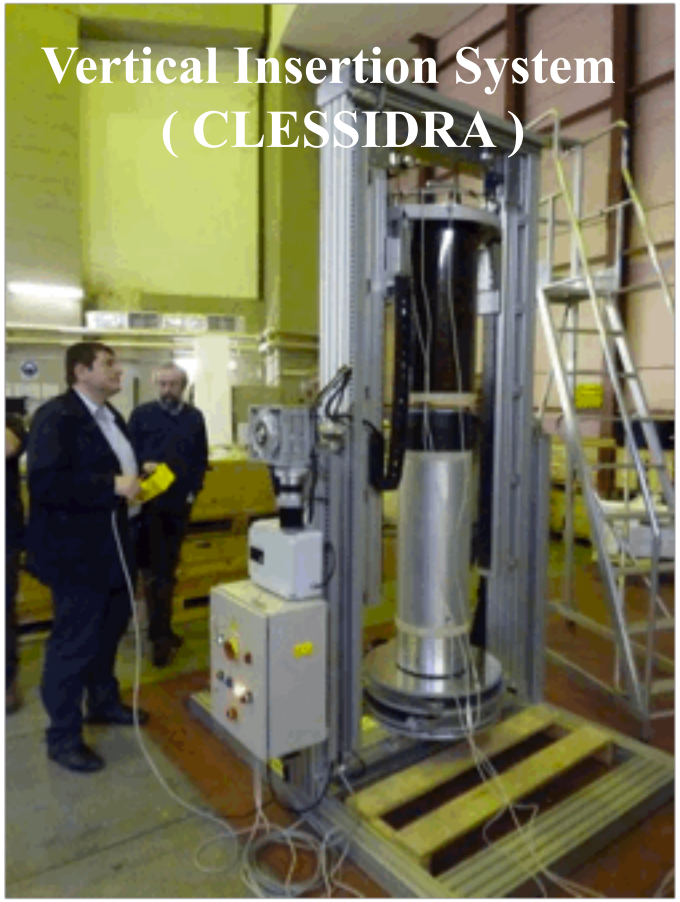
The benefit of larger statistical samples from DAFNE gain additional x 4 increase due to the IT vtx resolution improvement.

For a full report on KLOE/KLOE-2 interferometry studies → see "A.DeSantis" talk on Tuesday afternoon session

IT: Detector Construction

- R&D phase completed
- Large Area GEM exist and work
- Mechanics + FEE OK
- Tooling completed
- Construction of Layer 2 in progress





IT: overall status

- Detector mechanics, assembly and quality control tools ready ✓
- Test beam @ CERN-PS with Large Area Planar Prototype and final FEE + DAQ ✓

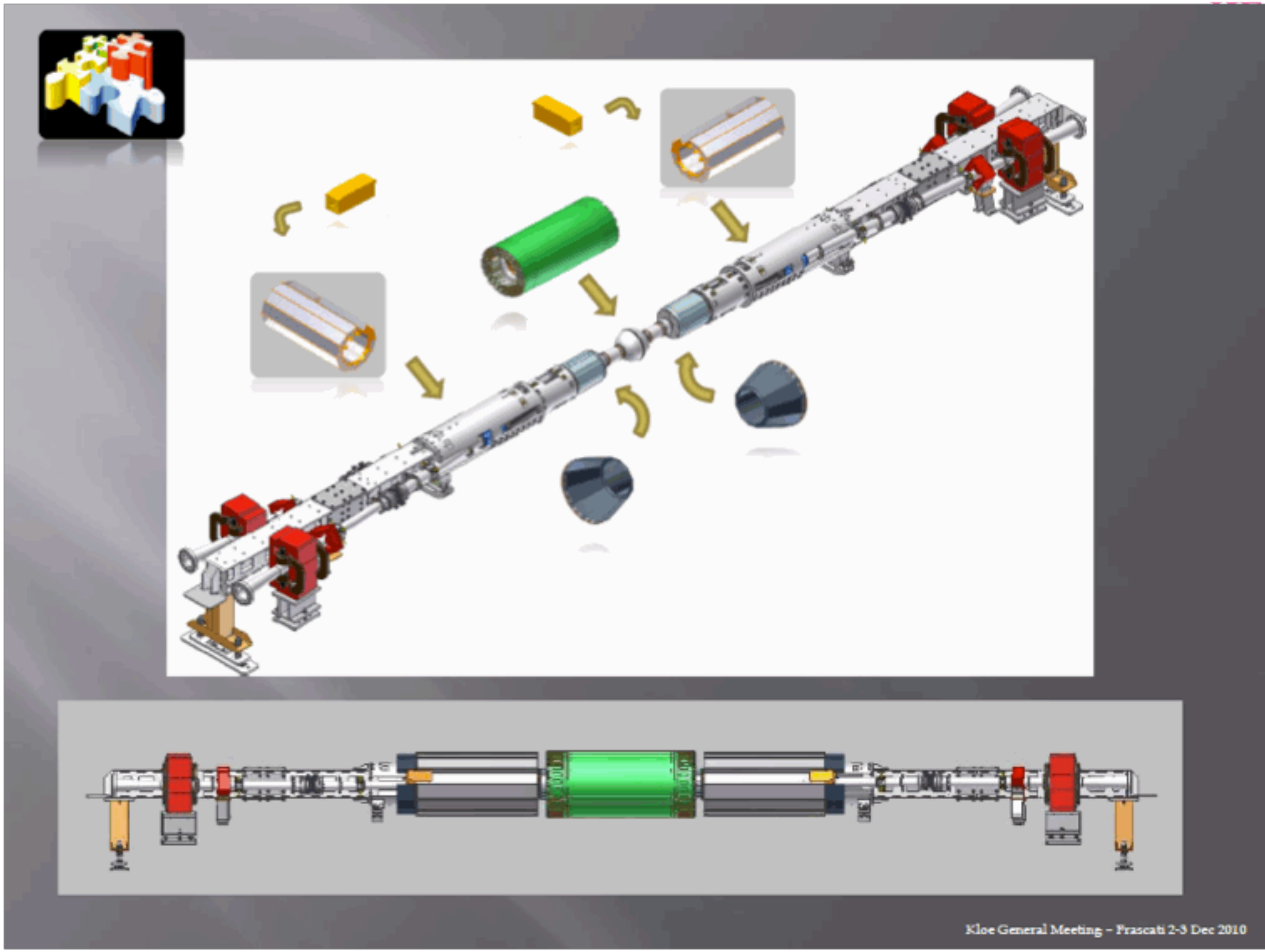
- **Start of Layer #2 construction** delayed due to:
  1. TS-DEM CERN Lab errors in anode and GEM construction (GEMs delivered in October) → GEMS now OK
  2. final layout of anode readout in progress

- FEE final production (700 chips) *Starting*
- **Completion of Clean Room for IT construction** :
  - *Delivery expected by March*

ONE YEAR of construction →

IT expected to be fully instrumented in Spring 2012

Upgrades: integration

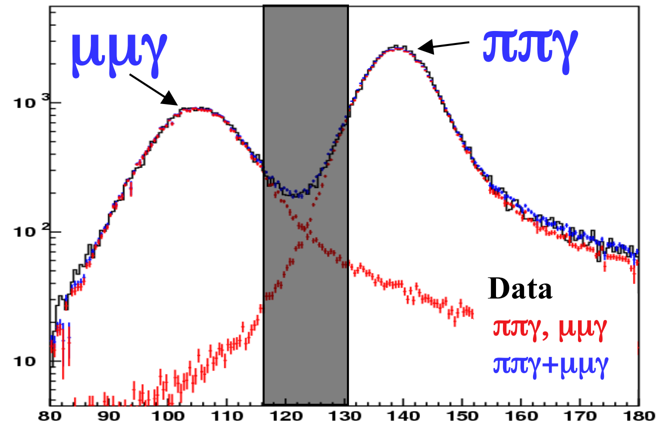


Prospects for σ(had) measurement

KLOE-2

In progress: $|F_\pi|^2$ from the ratio $\sigma(e^+e^-\to\pi^+\pi^-\gamma)/\sigma(e^+e^-\to\mu^+\mu^-\gamma)$

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



$$\left(\sqrt{s}-\sqrt{p_1^2+M_{trk}^2}-\sqrt{p_2^2+M_{trk}^2}\right)^2-(p_1+p_2)^2=0$$

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

δa_μ^{HLO}=5.3=3.3(√s<1GeV) ⊕3.9(1< √s<2GeV) ⊕1.2(√s>2GeV)

- **KLOE-2:**

  δσ ~ 0.4% (vs 0.7% now) for √s < 1 GeV @ 1 GeV, 2 fb^{-1}

  δσ ~ 2% (vs 6% now) for 1<√s < 2 GeV with energy scan

  (if DAΦNE energy → 2 – 2.5 GeV)

Conclusions/plans

KLOE-2

- **Since November the 15th DAFNE machine has started commissioning with KLOE-2 installed and fully operational.**
  - Currents of 800 (600) mA reached for both beams.
  - Conditioning of machine & bkg reduction in progress.
  - First collisions @ low current tried → real collisions middle of January
  - $\gamma\gamma$ taggers installed
- One year of continuous running @ Φ planned to get O(5 fb-1) and perform the first set of physics measurement.
- Request of O(1 fb-1) @ 1000 MeV being proposed to complete σ(had), $\gamma\gamma$-physics measurement and searches of U, h' boson.
- Upgrades for phase two are under construction:
  -- IT will start integrating first layer next spring
  -- QCAL construction is starting now
  -- CCAL mechanical drawings exist

All upgrades expected completion → spring 2012

Additional material

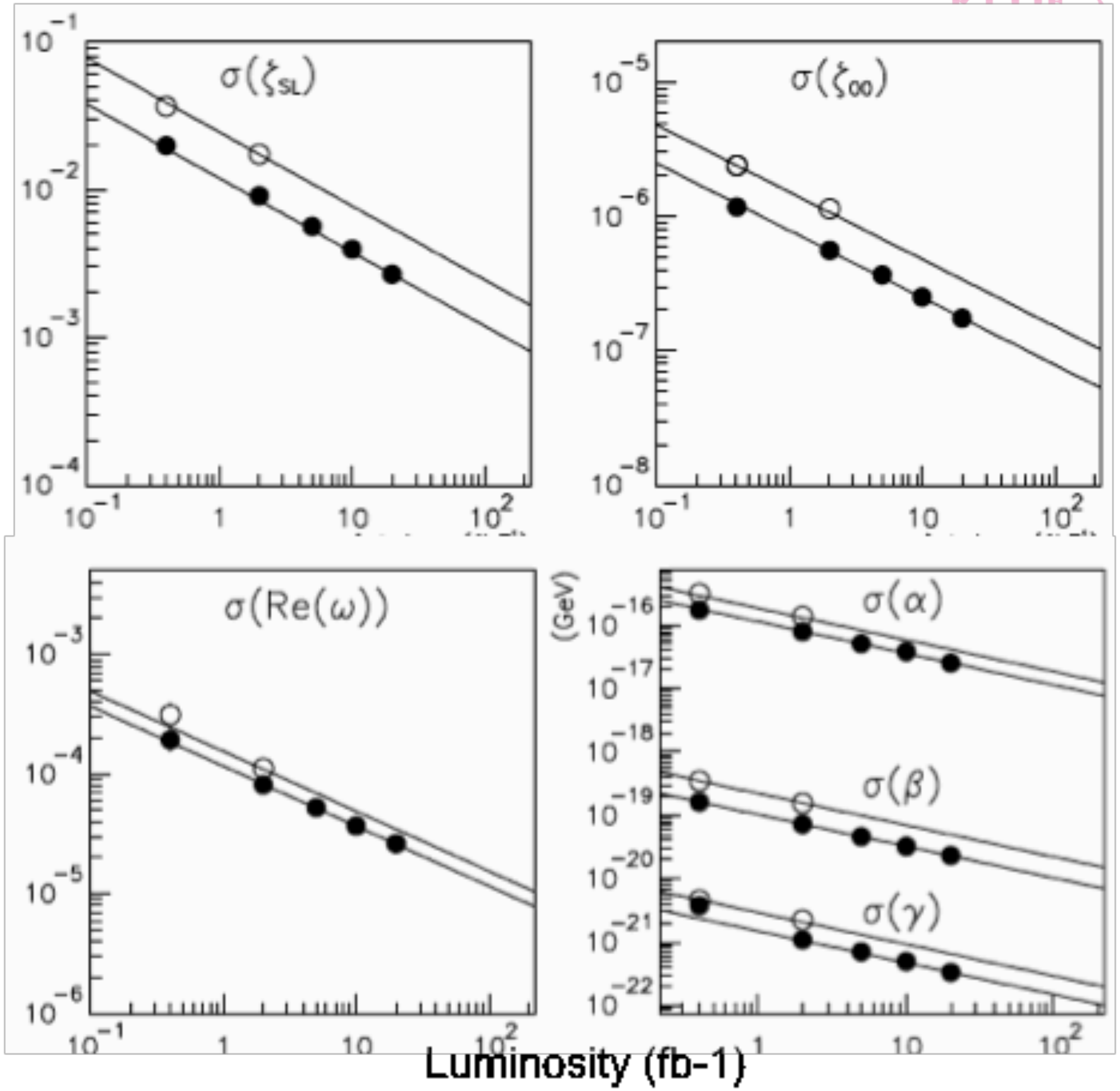
IT: Implication on interferometry

Most of the interesting QM, CPT and QM, CPT and EPR parameters can be improved @ KLOE-2 due:

i) to larger samples

ii) to IT resolution

~ x 4 stat. increase



Decoherence and CPT violation

Modified Liouville – von Neumann equation for the density matrix of the kaon system:

$$\dot{\rho}(t) = \underbrace{-iH\rho + i\rho H^{+}}_{\text{QM}} + L(\rho)$$

extra term inducing decoherence:
pure state => mixed state

Possible decoherence due quantum gravity effects:

Black hole information loss paradox => Possible decoherence near a black hole.
Hawking [1] suggested that at a microscopic level, in a quantum gravity picture, non-trivial space-time fluctuations (generically space-time foam) could give rise to decoherence effects, which would necessarily entail a violation of CPT [2].

J. Ellis et al.[3-6] => model of decoherence for neutral kaons => 3 new CPTV param. α,β,γ:

$$L(\rho) = L(\rho;\alpha,\beta,\gamma)$$

$$\alpha,\gamma > 0 \quad , \quad \alpha\gamma > \beta^2$$

At most: $\alpha,\beta,\gamma = O\left(\frac{M_K{}^2}{M_{PLANCK}}\right) \approx 2\times 10^{-20}$ GeV

[1] Hawking, Comm.Math.Phys.87 (1982) 395; [2] Wald, PR D21 (1980) 2742;[3] Ellis et. al, NP B241 (1984) 381; PRD53 (1996)3846 [4] Huet, Peskin, NP B434 (1995) 3; [5] Benatti, Floreanini, NPB511 (1998) 550 [6] Bernabeu, Ellis, Mavromatos, Nanopoulos, Papavassiliou: Handbook on kaon interferometry [hep-ph/0607322]

IT implication on QM

KLOE-2

Many of the interesting QM, EPR, CPT parameters can be improved @ KLOE-2 due to larger samples. IT resolution ~ x 4 stat. increase

Mode	Test of	Param.	Present best published measurement	KLOE-2 $L=25\ fb^{-1}$
$\pi^+\pi^-\ \ \pi^+\pi^-$	QM	ζ_{00}	$(0.1 \pm 1.0) \times 10^{-6}$	$\pm\ 0.1 \times 10^{-6}$
$\pi^+\pi^-\ \ \pi^+\pi^-$	QM	ζ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm\ 0.2 \times 10^{-2}$
$\pi^+\pi^-\ \ \pi^+\pi^-$	CPT & QM	α	$(-0.5 \pm 2.8) \times 10^{-17}$ GeV	$\pm\ 2 \times 10^{-17}$ GeV
$\pi^+\pi^-\ \ \pi^+\pi^-$	CPT & QM	β	$(2.5 \pm 2.3) \times 10^{-19}$ GeV	$\pm\ 0.2 \times 10^{-19}$ GeV
$\pi^+\pi^-\ \ \pi^+\pi^-$	CPT & QM	γ	$(1.1 \pm 2.5) \times 10^{-21}$ GeV compl. pos. hyp. $(0.7 \pm 1.2) \times 10^{-21}$ GeV	$\pm\ 0.3 \times 10^{-21}$ GeV compl. pos. hyp. $\pm\ 0.2 \times 10^{-21}$ GeV
$\pi^+\pi^-\ \ \pi^+\pi^-$	CPT & EPR corr.	$Re(\omega)$	$(-1.6 \pm 2.6) \times 10^{-4}$	$\pm\ 3 \times 10^{-5}$
$\pi^+\pi^-\ \ \pi^+\pi^-$	CPT & EPR corr.	$Im(\omega)$	$(-1.7 \pm 3.4) \times 10^{-4}$	$\pm\ 4 \times 10^{-5}$
$K_{S,L} \to \pi e \nu$	CPT & Lorentz	Δa_0	$[(0.4 \pm 1.8) \times 10^{-17}$ GeV$]$	$\pm\ 2 \times 10^{-18}$ GeV
$\pi^+\pi^-\ \ \pi^+\pi^-$	CPT & Lorentz	Δa_Z	$[(2.4 \pm 9.7) \times 10^{-18}$ GeV$]$	$\pm\ 1 \times 10^{-18}$ GeV
$\pi^+\pi^-\ \ \pi e \nu$	CPT & Lorentz	$\Delta a_{X,Y}$	$[<10^{-21}$ GeV$]$	$\pm\ 6 \times 10^{-19}$ GeV

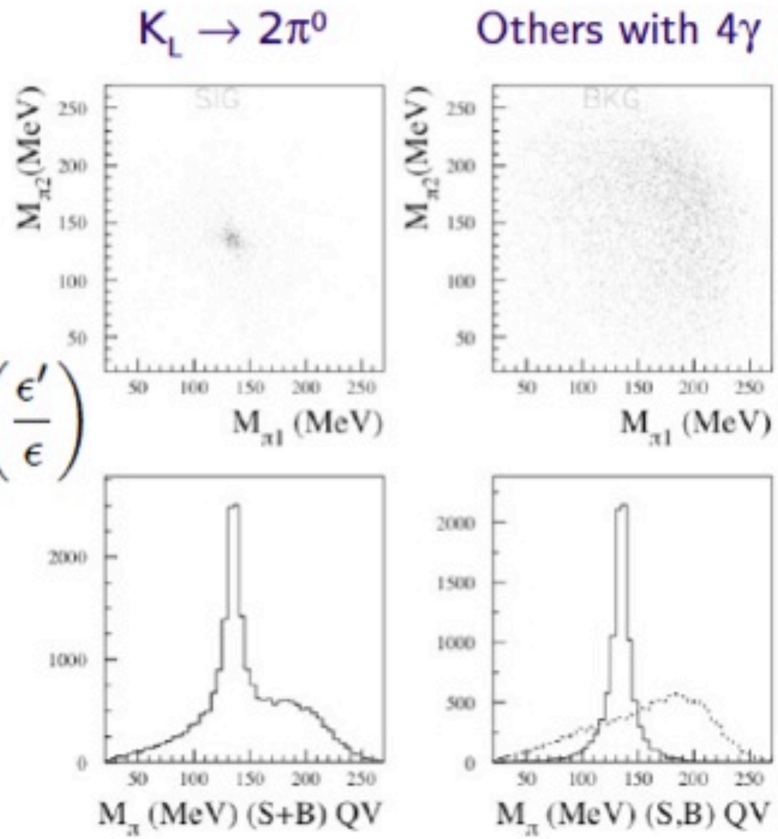
Mode	Test of	Param.	Present best published measurement	KLOE-2 $L=25\ fb^{-1}$
$K_S \to \pi e\nu$	CP, CPT	A_S	$(1.5 \pm 11) \times 10^{-3}$	$\pm 1 \times 10^{-3}$
$\pi^+\pi^-$ $\pi e\nu$	CP, CPT	A_L	$(332.2 \pm 5.8 \pm 4.7) \times 10^{-5}$	$\pm 4 \times 10^{-5}$
$\pi^+\pi^-$ $\pi^0\pi^0$	CP	$Re(\varepsilon'/\varepsilon)$	$(1.65 \pm 0.26) \times 10^{-3}$ (*)	$\pm 0.3 \times 10^{-3}$
$\pi^+\pi^-$ $\pi^0\pi^0$	CP, CPT	$Im(\varepsilon'/\varepsilon)$	$(-1.2 \pm 2.3) \times 10^{-3}$ (*)	$\pm 4 \times 10^{-3}$
$\pi e\nu$ $\pi e\nu$	CPT	$Re(\delta)+Re(x_-)$	$Re(\delta) = (0.25 \pm 0.23) \times 10^{-3}$ (*) $Re(x_-) = (-4.2 \pm 1.7) \times 10^{-3}$ (*)	$\pm 0.3 \times 10^{-3}$
$\pi e\nu$ $\pi e\nu$	CPT	$Im(\delta)+Im(x_+)$	$Im(\delta) = (-0.6 \pm 1.9) \times 10^{-5}$ (*) $Im(x_+) = (0.2 \pm 2.2) \times 10^{-3}$ (*)	$\pm 4 \times 10^{-3}$
$\pi^+\pi^-$ $\pi^+\pi^-$		Δm	$(5.288 \pm 0.043) \times 10^9\ s^{-1}$	$\pm 0.05 \times 10^9\ s^{-1}$

$K_L \to \pi^0\pi^0$ measurement

- KLOE was designed to study the CP violation into the $\overline{K}K$ system through Re(ε'/ε) measurement.
- To reduce systematic errors we measure the double ratio:

$$\frac{\Gamma(K_S \to \pi^+\pi^-)\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_L \to \pi^+\pi^-)\Gamma(K_S \to \pi^0\pi^0)} = 1 - 6\Re\left(\frac{\epsilon'}{\epsilon}\right)$$

- The most important bg source in this measurement is $K_L \to 3\pi^0$;
- QCAL works well on rejecting background losing 1% of signal;
- **QCALT will increase the detection efficiency** and the high granularity will help on **reducing accidental losses**.



η/η' mixing: gluonium content in η'

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KLOE-2

Gluonium content in η' evaluated using Rosner model:

$$R_\phi = \frac{BR(\phi \to \eta'\gamma)}{BR(\phi \to \eta\gamma)} = (4.77 \pm 0.09_{stat} \pm 0.19_{syst}) \times 10^{-3}$$

$$|\eta'\rangle = X_{\eta'} \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + Y_{\eta'} |s\bar{s}\rangle + Z_{\eta'} |glue\rangle$$

$$|\eta\rangle = \cos\varphi_P \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle - \sin\varphi_P |s\bar{s}\rangle$$

$$X_{\eta'} = \cos\phi_G \sin\varphi_P$$

$$Y_{\eta'} = \cos\phi_G \cos\varphi_P$$

$$Z_{\eta'} = \sin\phi_G$$

[Rosner PRD27(1983) 1101]
[Kou PRD63(2001)54027]

Global fit with more free parameters (also Z_N, Z_{NS}, ϕ_V, m_s/m)

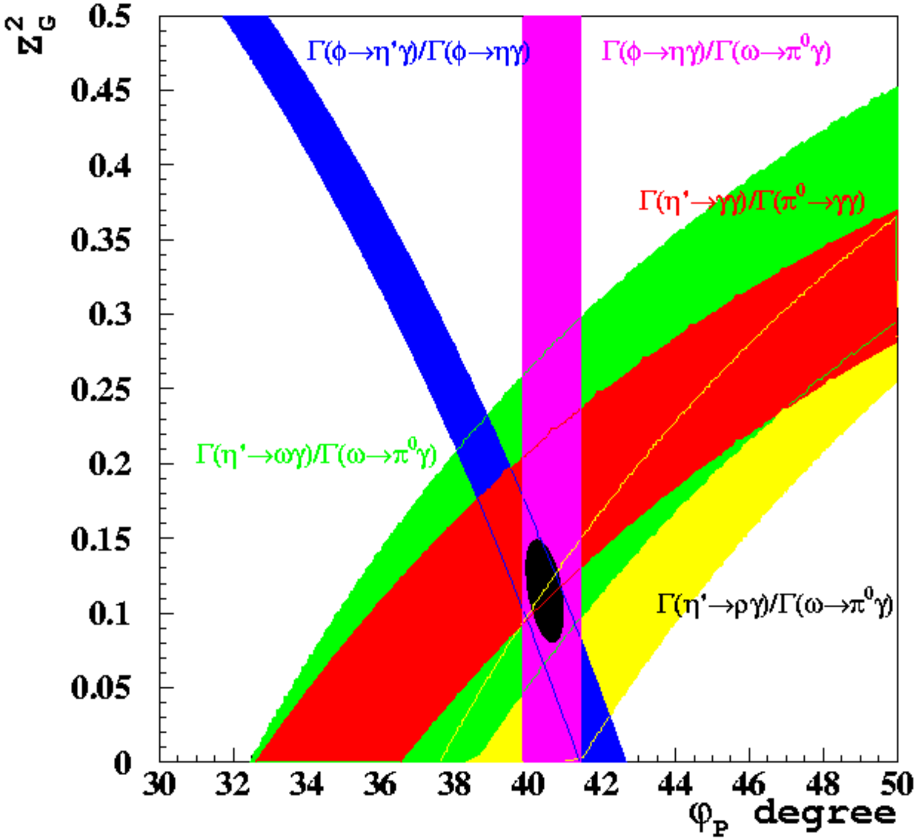
Other SU(3) relations need to be included :

$$\frac{\Gamma(\omega \to \eta\gamma)}{\Gamma(\omega \to \pi^0\gamma)}, \quad \frac{\Gamma(\rho \to \pi^0\gamma)}{\Gamma(\omega \to \pi^0\gamma)}, \quad \frac{\Gamma(\phi \to \eta\gamma)}{\Gamma(\omega \to \pi^0\gamma)}, \quad \frac{\Gamma(\phi \to \pi^0\gamma)}{\Gamma(\omega \to \pi^0\gamma)}, \quad \frac{\Gamma(K^{*+} \to K^+\gamma)}{\Gamma(K^{*0} \to K^0\gamma)}$$

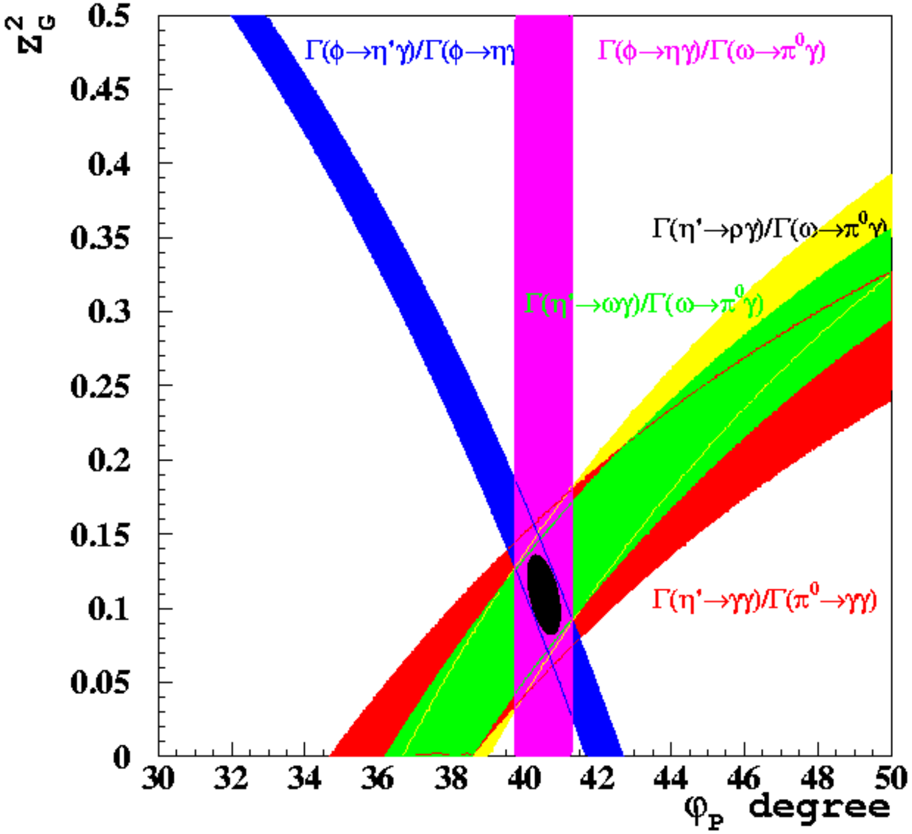
Parameter	Old fit	New fit	New fit (no $P\gamma\gamma$)
$Z^2_{\eta'}$	0.14 ± 0.04	0.105 ± 0.037	0.03 ± 0.06
ϕ_P	(39.7 ± 0.7)°	(40.7 ± 0.7)°	(41.6 ± 0.8)°
Z_{NS}	0.91 ± 0.05	0.866 ± 0.025	0.85 ± 0.03
Z_S	0.89 ± 0.07	0.79 ± 0.05	0.78 ± 0.05
ϕ_V	3.2°	(3.15 ± 0.10)°	(3.16 ± 0.10)°
m_s/m	1.24 ± 0.07	1.24 ± 0.07	1.24 ± 0.07
$P(\chi^2)$	49%	17%	40.7%

η/η' mixing: from KLOE to KLOE-2

KLOE: global fit result



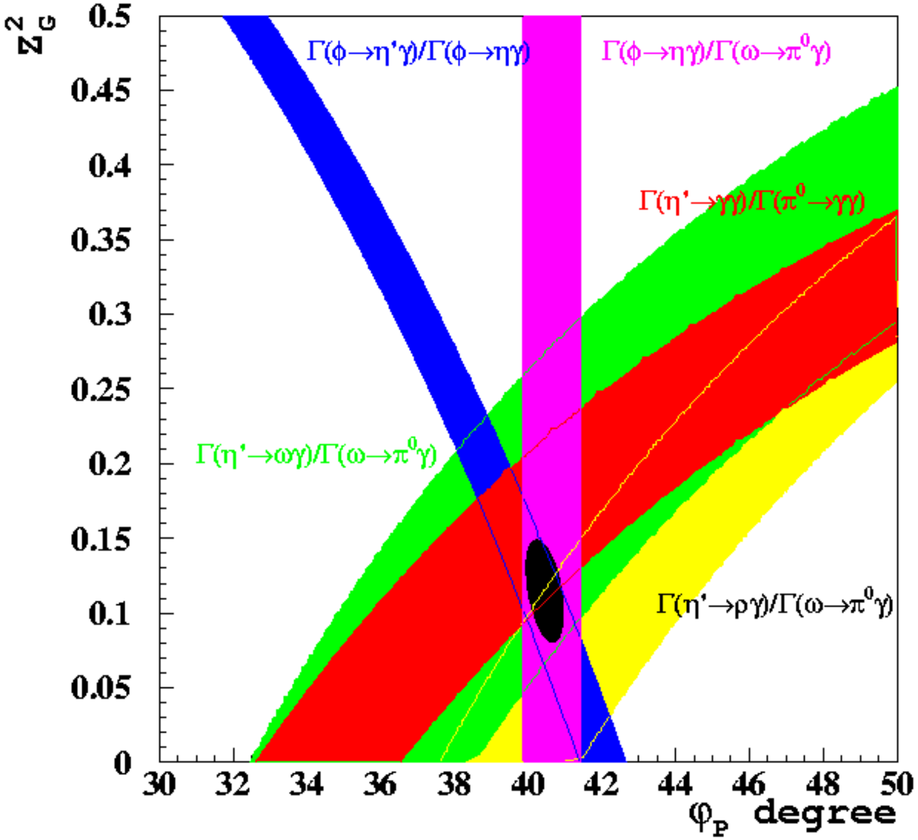
KLOE-2 expectation measuring η' BRs with 1% accuracy



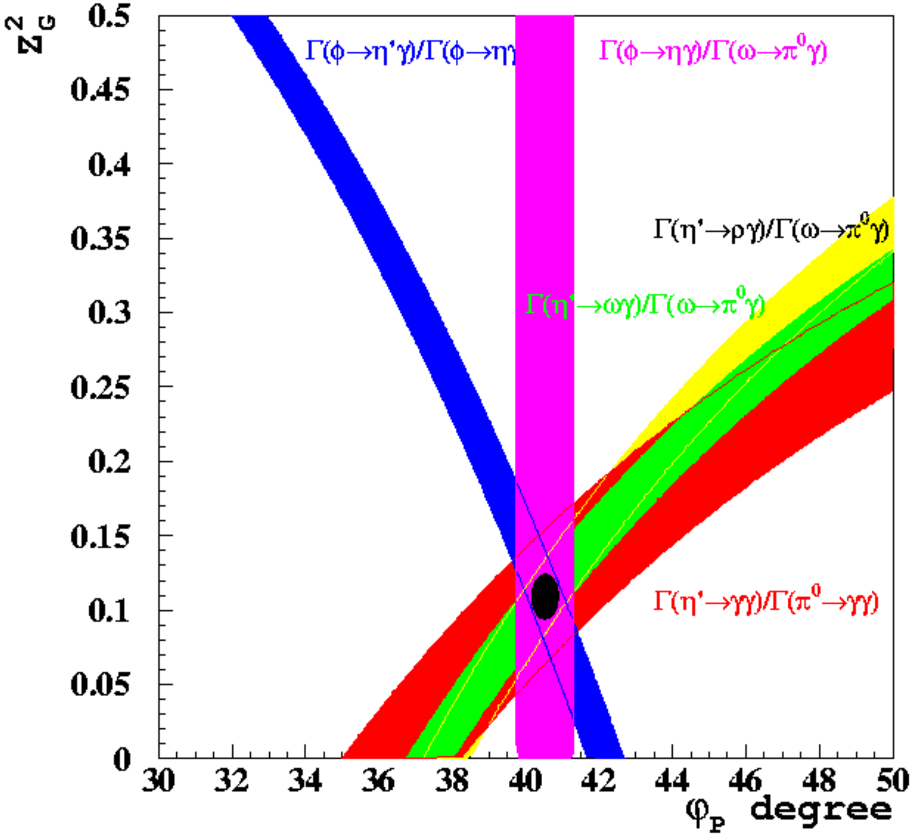
Sensitivity to the gluonium also without the $\eta'\to\gamma\gamma$ decay

η/η' mixing: from KLOE to KLOE-2

KLOE: global fit result



KLOE-2 expectation measuring also η' width with 1.4% accuracy



Run at $\sqrt{s} \geq 1.2$ GeV required

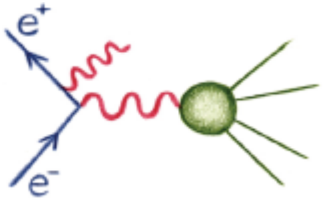
$\sigma(e^+e^- \to$hadr.) below 1 GeV

KLOE-2

- $\sim 3\,\sigma$ discrepancy between $a_\mu^{SM} - a_\mu^{exp}$ [$a_\mu = (g_\mu-2)/2$]
- $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$ → main contribution to the uncertainty on a_μ^{SM}

$$\boxed{a_\mu^{\text{had, LO}} = 1\Big/(4\pi^3)\int_{4m_\pi^2}^{\infty} \sigma(e^+e^- \to \text{hadr.})K(s)ds \quad ; \quad K(s) \sim 1/s}$$

- $\sigma(e^+e^- \to$hadr.) below 1 GeV is dominated by $e^+e^- \to \pi^+\pi^-$
- ϕ - factory: fixed $\sqrt{s} \Rightarrow$ Initial State Radiation method



$$\boxed{s \cdot \frac{d\sigma(e^+e^- \to \pi^+\pi^- + \gamma)}{ds_\pi} = \sigma(e^+e^- \to \pi^+\pi^-)\, H(s, s_\pi)}$$

- Two different analyses: (1) photon emitted at Small Angle (S.A. analysis) [PLB606(2005)12, PLB670(2009)285]

  (2) photon emitted at Large Angle (L.A. analysis) [arXiv:1006:5313, submitted to PLB]

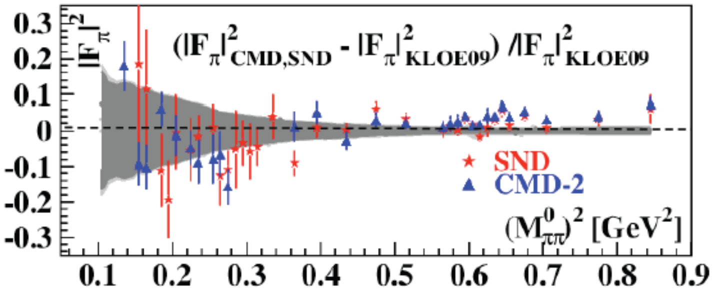
Result on L.A. analysis

KLOE-2

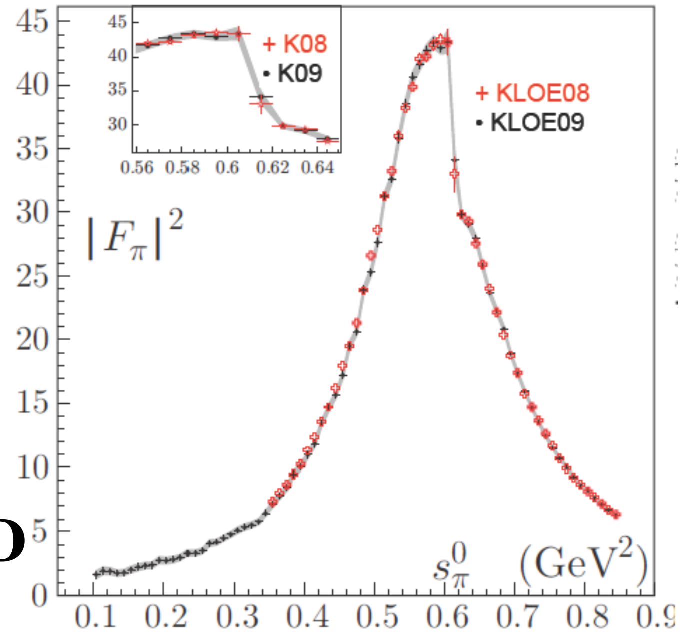
- Good agreement between S.A. (KLOE08) and L.A. (KLOE09) analyses

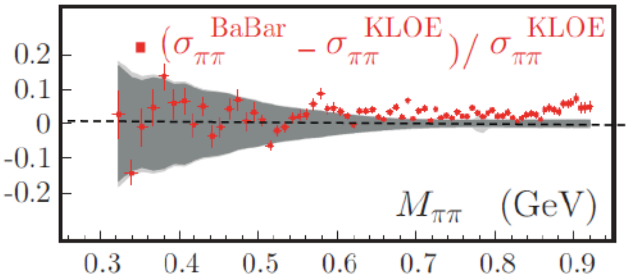
$a_\mu^{\pi\pi}(0.1-0.85\ \mathrm{GeV}^2)=(478.5 \pm 2.0_{stat} \pm 4.8_{sys} \pm 2.9_{theo}) \times$

[arXiv:1006.5313, submitted to PLB]

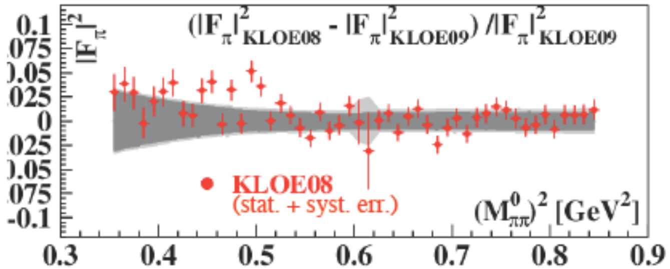


Agreement with CMD-2 and SND





Above 0.6 GeV BaBar higher by 2 – 3%



(Grey band = L.A. error)

- 3.2 σ discrepancy a_μ^{SM} - a_μ^{exp} confirmed

42

27

$\Delta a_\mu^{\pi\pi}$ for different exp.:

$\Delta a_\mu^{\pi\pi}(0.35\text{-}0.85\,\text{GeV}^2)$:

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3}\int_{x_1}^{x_2} \sigma^{\text{had}}(s)K(s)\,ds$$

KLOE08 (small angle) $a_\mu^{\pi\pi} = (379.6 \pm 0.4_{stat} \pm 2.4_{sys} \pm 2.2_{theo}) \cdot 10^{-10}$

KLOE09 (large angle) $a_\mu^{\pi\pi} = (376.6 \pm 0.9_{stat} \pm 2.4_{sys} \pm 2.1_{theo}) \cdot 10^{-10}$

0.2% 0.6% 0.6%

$\Delta a_\mu^{\pi\pi}(0.152\text{-}0.270\,\text{GeV}^2)$:

KLOE09 (large angle) $a_\mu^{\pi\pi} = (48.1 \pm 1.2_{stat} \pm 1.2_{sys} \pm 0.4_{theo}) \cdot 10^{-10}$

CMD-2 $a_\mu^{\pi\pi} = (46.2 \pm 1.0_{stat} \pm 0.3_{sys}) \cdot 10^{-10}$

$\Delta a_\mu^{\pi\pi}(0.397\text{-}0.918\,\text{GeV}^2)$:

KLOE08 (small angle) $a_\mu^{\pi\pi} = (356.7 \pm 0.4_{stat} \pm 3.1_{sys}) \cdot 10^{-10}$

CMD-2 $a_\mu^{\pi\pi} = (361.5 \pm 1.7_{stat} \pm 2.9_{sys}) \cdot 10^{-10}$

SND $a_\mu^{\pi\pi} = (361.0 \pm 2.0_{stat} \pm 4.7_{sys}) \cdot 10^{-10}$

BaBar $a_\mu^{\pi\pi} = (365.2 \pm 1.9_{stat} \pm 1.9_{sys}) \cdot 10^{-10}$

Impact of DAFNE-2 on $(g-2)_\mu$

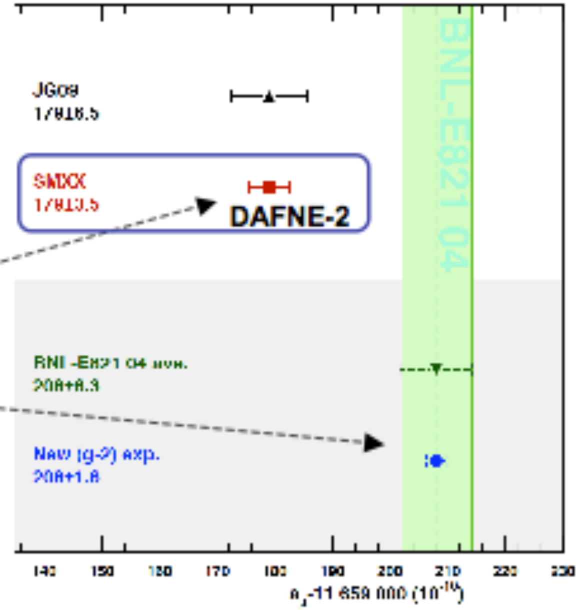
$a_\mu^{exp} - a_\mu^{theo,SM} = (27.7 \pm 8.4) 10^{-10}$ (3.3σ) [Eidelman, TAU08]

$8.4 = \sim 5_{HLO} \oplus \sim 3_{HLbL} \oplus 6_{BNL}$

4 $\quad 2.6_{DAFNE\text{-}2}$ $\quad 2.5$ $\quad 1.6_{NEW\ G\text{-}2}$

7-8σ

(if 27.7 will remain the same)



$\delta a_\mu^{HLO} = 5.3 = 3.3(\sqrt{s}<1\,GeV) \oplus 3.9(1<\sqrt{s}<2\,GeV) \oplus 1.2(\sqrt{s}>2\,GeV)$

$\delta a_\mu^{HLO} \rightarrow \mathbf{2.6} = 1.9\ (\sqrt{s}<1\,GeV) \oplus \mathbf{1.3\ (\sqrt{s}<1\,GeV)} \oplus 1.2(\sqrt{s}>2\,GeV)$

This means:

$\delta\sigma_{HAD} \sim 0.4\%\ \sqrt{s}<1\,GeV$ (instead of 0.7% as now) *With ISR at 1 GeV*

$\delta\sigma_{HAD} \sim 2\%\ 1<\sqrt{s}<2\,GeV$ (instead of 6% as now) *With Energy Scan 1-2 GeV*

Search for $\gamma\gamma \to \sigma \to \pi\pi$

Long debate about the experimental evidence of the $\sigma(600)$ meson

- Pole in ππ scattering with vacuum quantum numbers ($J^{PC}=0^{++}$)

  $$m_\sigma = 441^{+16}_{-8}\,\mathrm{MeV}, \Gamma_\sigma = 544^{+24}_{-18}\,\mathrm{MeV}$$ [PRL96(2006)132001]

- Evidence for $\pi^+\pi^-$ bound state (E791, CLEO, BES) from Dalitz plot analyses
- Values of mass and width with large uncertainties
- **Indirect evidence in the $e^+e^-\to\pi^0\pi^0\gamma$ Dalitz plot analysis @ KLOE**

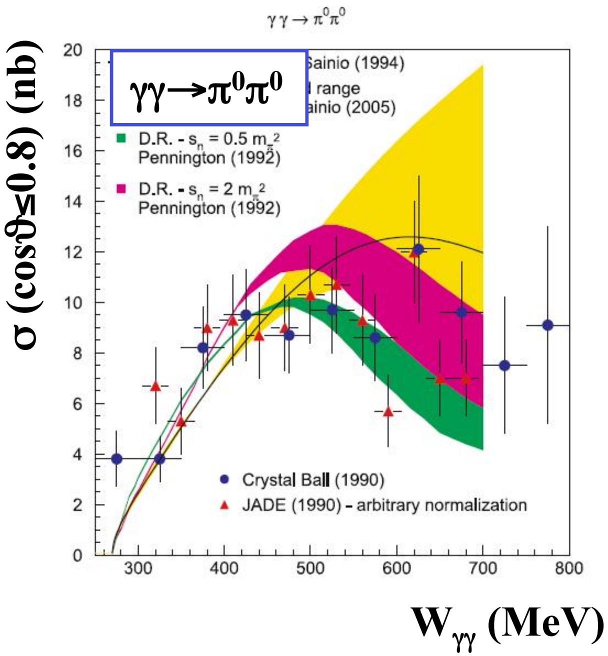
$e^+e^-\to e^+e^-\pi\pi$

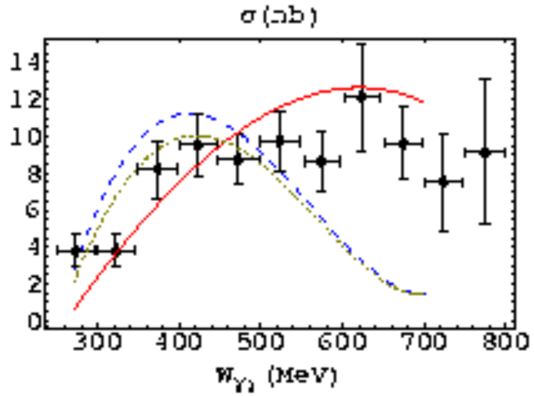
$\pi^0\pi^0 \Rightarrow$ golden channel for sigma search

$\pi^+\pi^-$: large background from:

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

$e^+e^-\to \pi^+\pi^-\gamma^*\to \pi^+\pi^-e^+e^-$





Resonant contribution
$\gamma\gamma\to\sigma\to\pi^0\pi^0$
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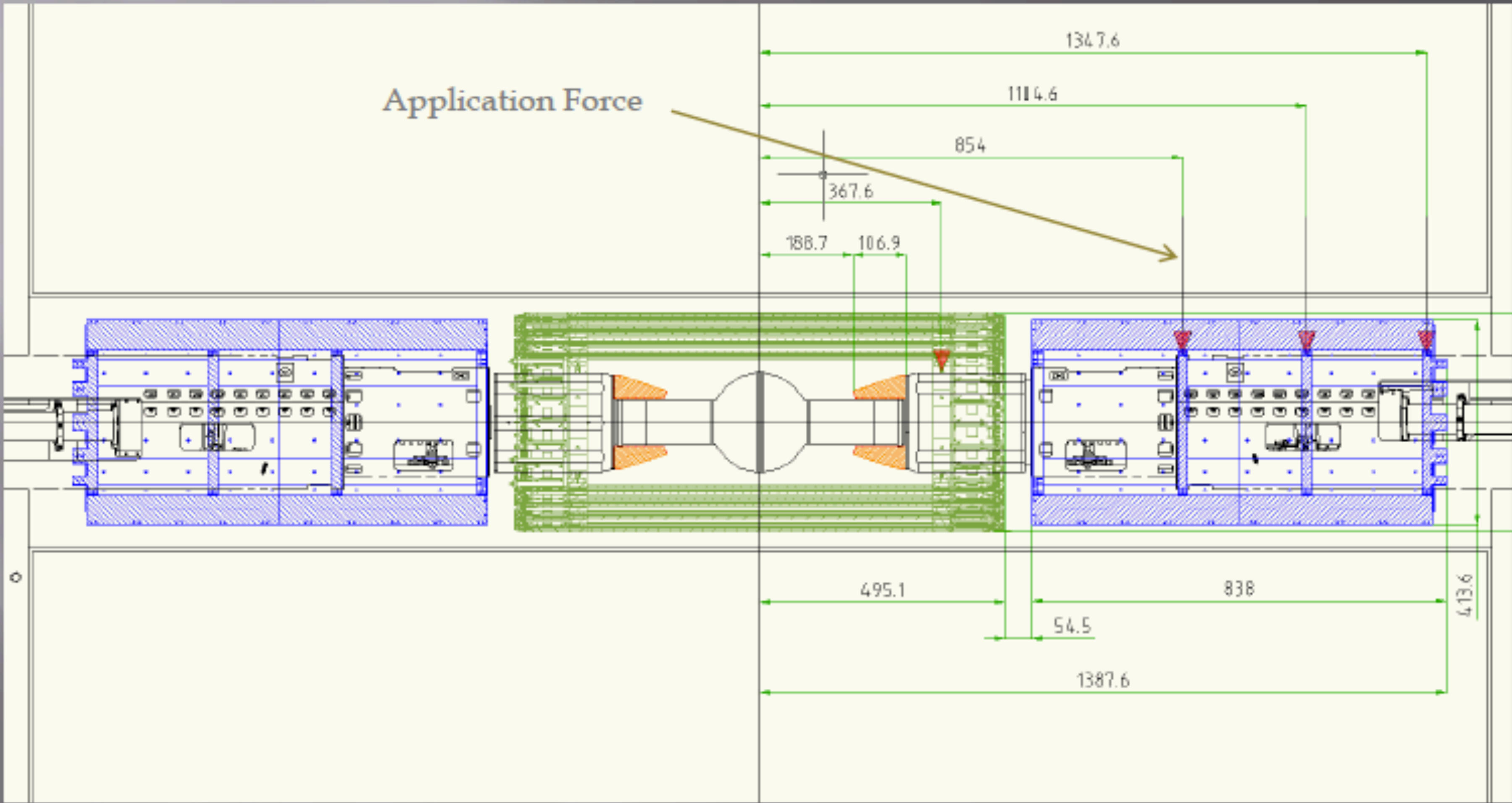
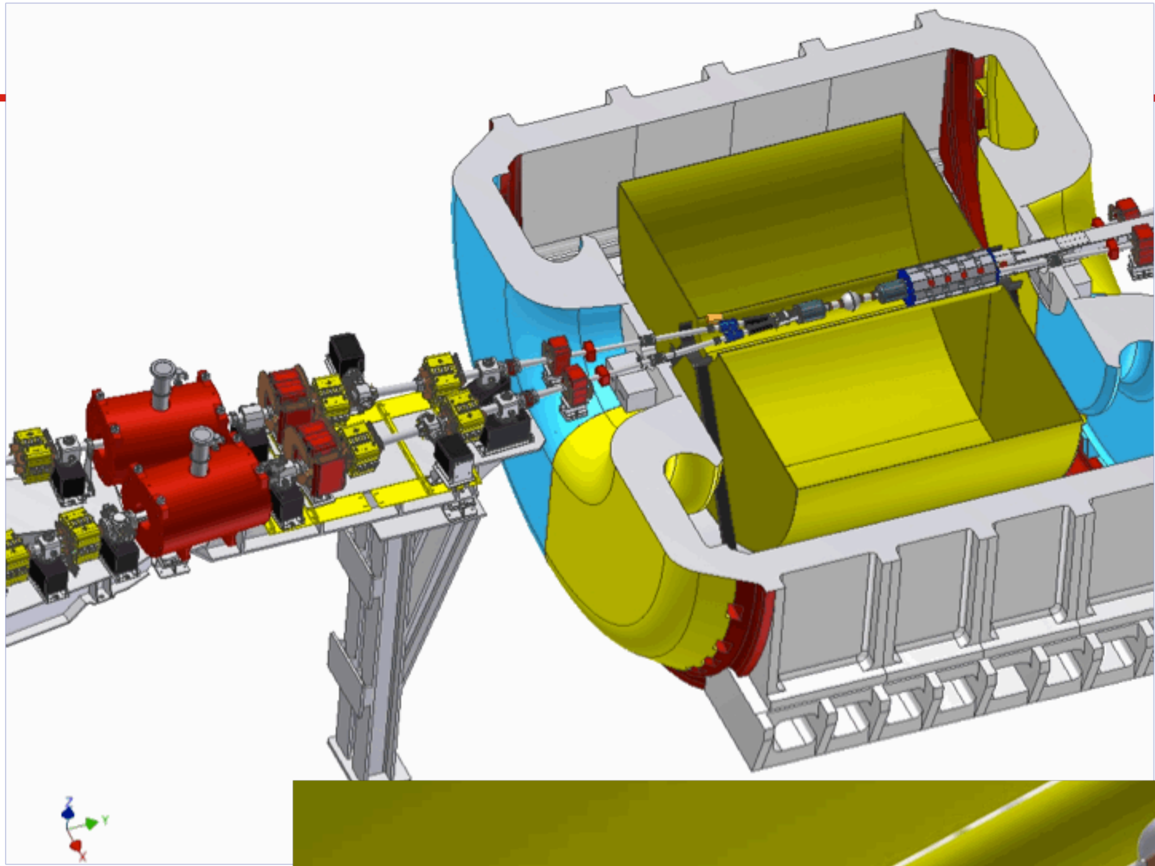
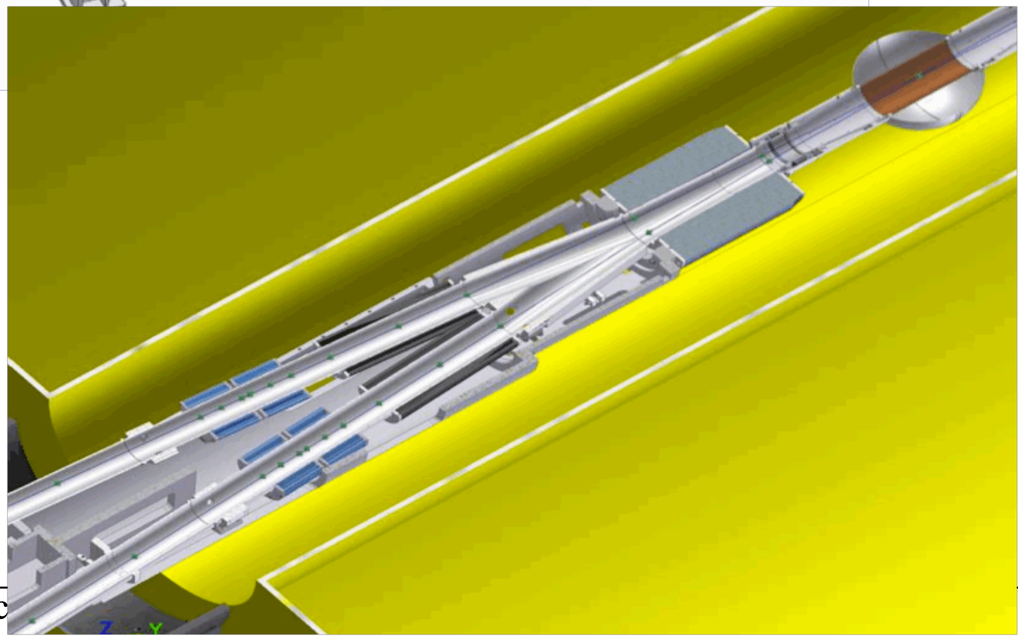
OCCUPANCY OF THE DETECTORS

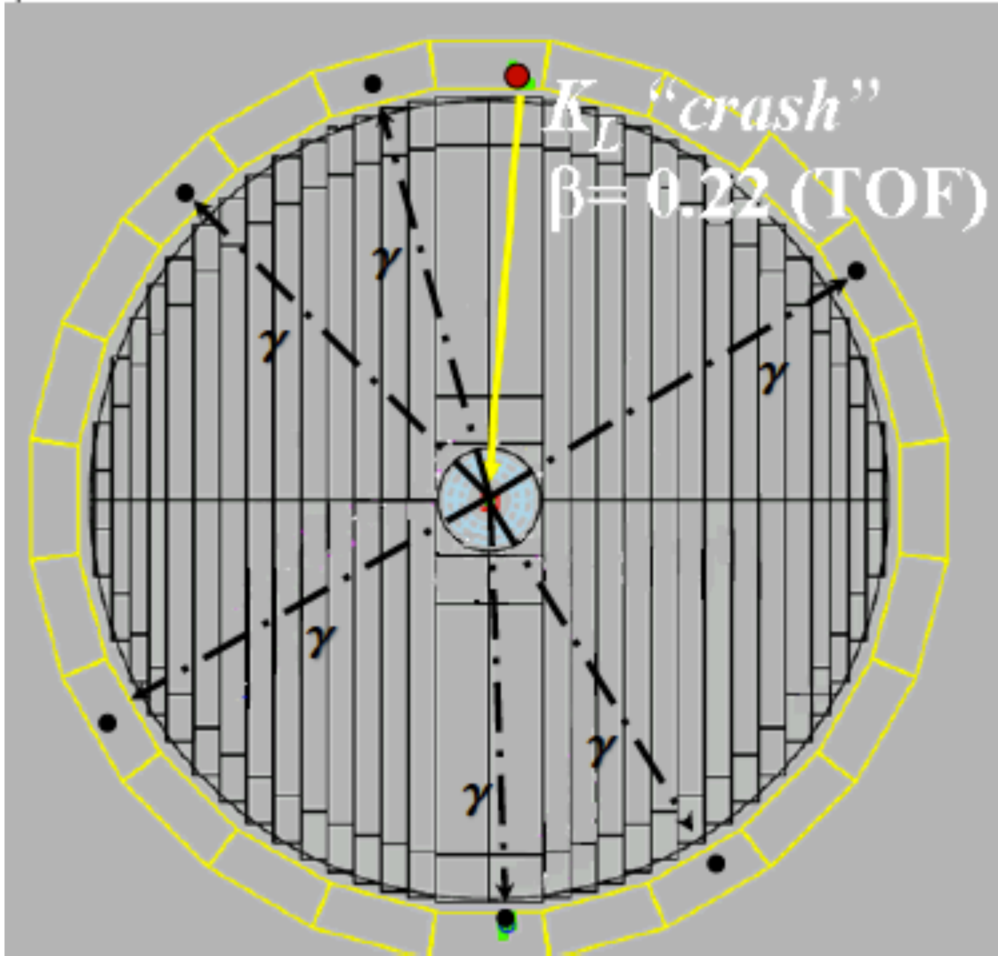
- The space available and the occupancy for any detectors is defined;
- Also the interference between the detectors and BP is verified;
- Some change could be done during the design;
- Any change have to be noticed to the integration group;

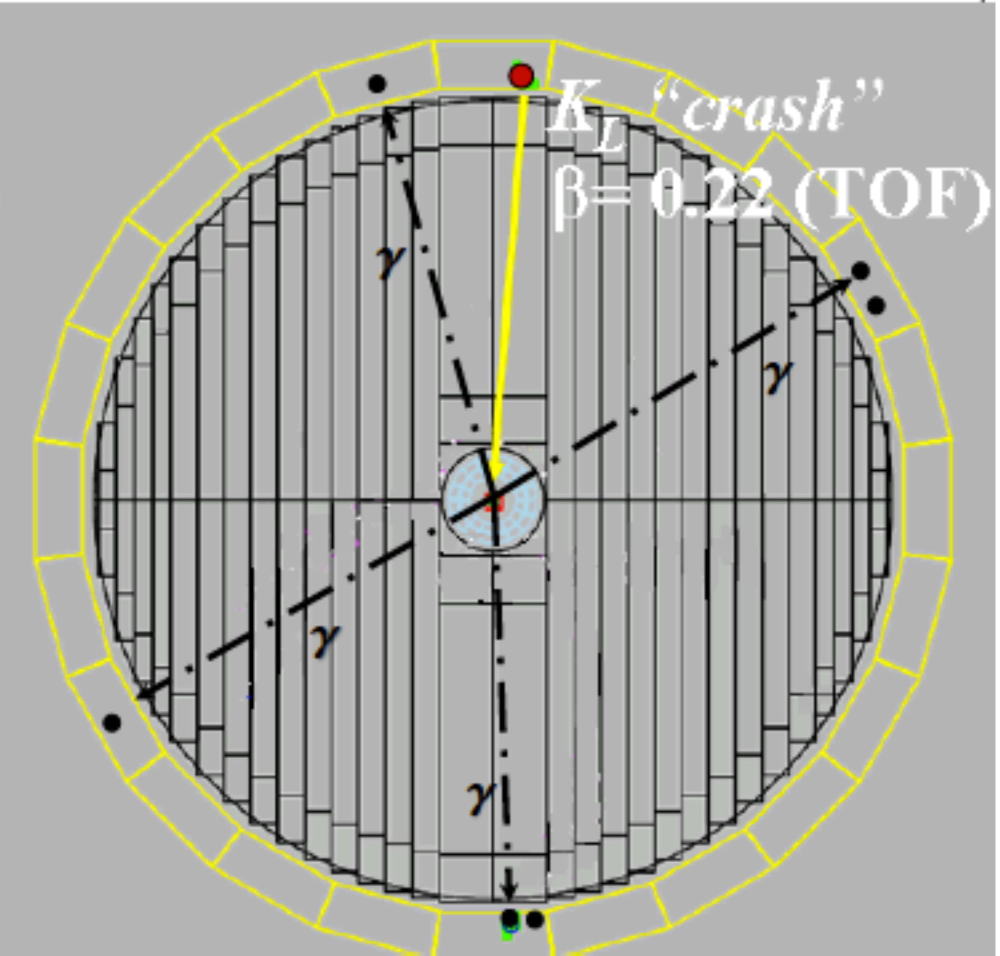






Introduction





$K_S \rightarrow 3\pi^0 \rightarrow 6\gamma$

$K_S \rightarrow 2\,\pi^0$ + accidental/splitted clusters
$K_L \rightarrow 3\,\pi$, $K_S \rightarrow \pi^+\pi^-$ (fake K_L crash)

Kaons: Ks semielectronic decays

KLOE-2

Sensitivity to CPT violating effects through charge asymmetry

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

If $A_S \neq A_L$, CPT violation in mixing and/or decay with $\Delta S \neq \Delta Q$

$$A_S - A_L = 4(\Re\delta + \Re x_-)$$

Sensitivity to CP violation in mixing $A_S \simeq 2\Re\epsilon$

Test of $\Delta S = \Delta Q$ rule using $\Gamma(K_S \to \pi e \nu)$

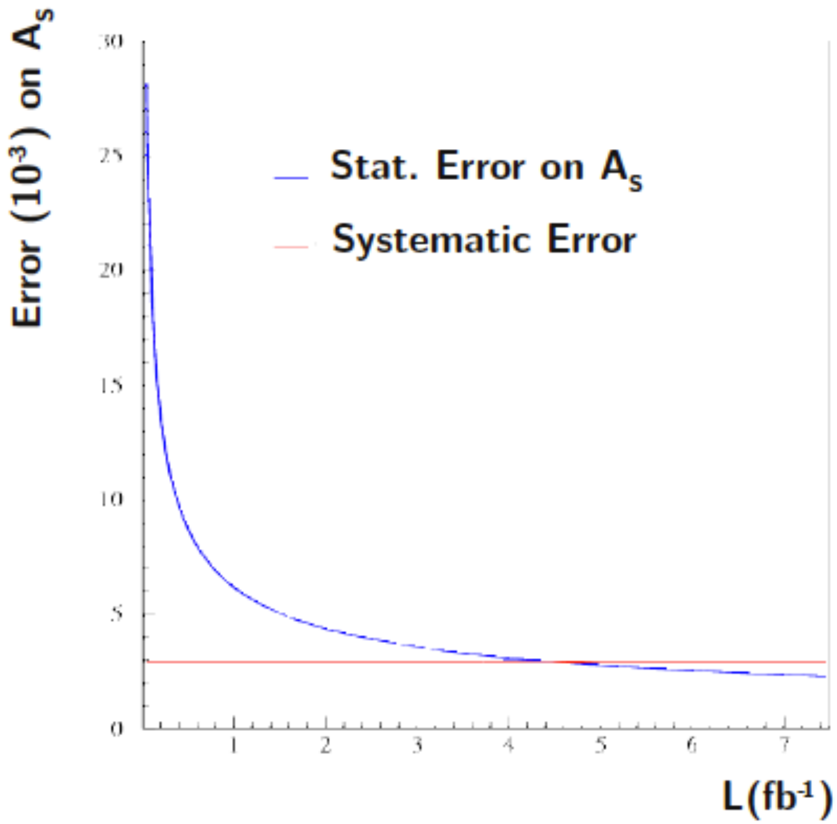
$$1 + 4\Re x_+ = \Gamma(K_S \to \pi e \nu)/\Gamma(K_L \to \pi e \nu)$$

Can extract $|V_{us}|$ via measurement of BR($K_S \to \pi e \nu$)

A_S = [$\Gamma(K^0_S \to \pi^- e^+ \nu_e)$ - $\Gamma(K^0_S \to \pi^+ e^- \bar{\nu}_e)$] / SUM

Such asymmetry violates *CP*. If *CPT* is assumed then $A_S = 2\,\mathrm{Re}(\epsilon)$.

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*	*TECN*
1.5± 9.6±2.9	13k	AMBROSINO 06E	KLOE



- ❖KLOE with 400 pb-1 → stat. limited.
- ❖ in progress now with 1.8 fb-1, bkg reduction with new n.network technique
- ❖ O(5 fb-1) stat. error compares with existing systematics.

Perspectives for the next KLOE run

KLOE-2

- Conditioning of both rings with high current beams to improve vacuum conditions and minimize beam size growth and backgrounds in KLOE → in progress
- Closed orbit correction and beam functions optimization
- Horizontal-vertical coupling minimization (~ 0.3% now)
- Optimization of beam-beam interaction and luminosity
- Optimization of beam collimation with the scrapers to minimize background in KLOE also during injection

Start of KLOE data taking foreseen for mid January

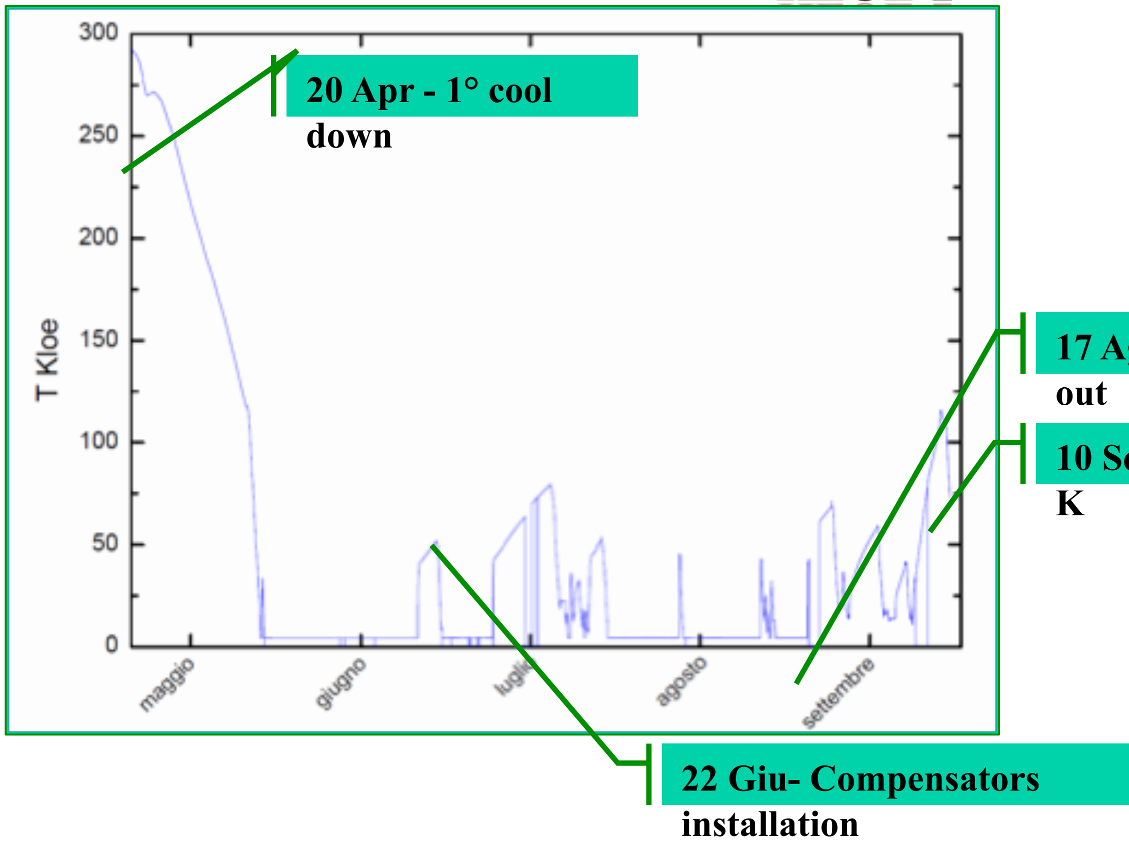
KLOE magnet: the cool down history

✧ between July 27th and August 12th there are 3 fridge-out events (turbine low T, cooling water interruption and compressed air lack)

✧on August 23rd new cool-down start but 3 days after stops again due to maintenance of the lab electric power distribution system

✧on August 30th cool-down is resumed, but the coil temperature does not go below 15 K° and for the first time an excessive cooling of the screens is observed

✧on September 10th it is decided to warm-up the magnet to 110 K° and clean the cooling lines



✧ On September 24th WEKA (ex Oxford) contacted: few interventions on valves performed. Not successfull. Steve Harrison (responsible for the Oxford of KLOE magnet) arrives on Oct the 4th and suggests to perform a series of tests at 110 K° and then warm-up the magnet at room temperature and perform additional tests.

✧ on October 25th cool-down starts again and on November 14th the magnet is cold again (after the fastest cool-down of his history,16 days) and energized.

Dafne parameters

KLOE-2

	DAΦNE FINUDA	DAΦNE Upgrade
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm x mrad)	0.34	0.20
β_x^* (cm)	170	20
σ_x^* (mm)	0.76	0.20
$\Phi_{Piwinski}$	0.36	2.5
β_y^* (cm)	1.70	0.65
σ_y^* (μm)	5.4 (low current)	2.6
Coupling, %	0.5	0.5
I_{bunch} (mA)	13	13
N_{bunch}	110	110
σ_z (mm)	22	20
L ($cm^{-2}s^{-1}$) x10^{32}	1.6	5

$\left.\right\}$ Larger Piwinski angle

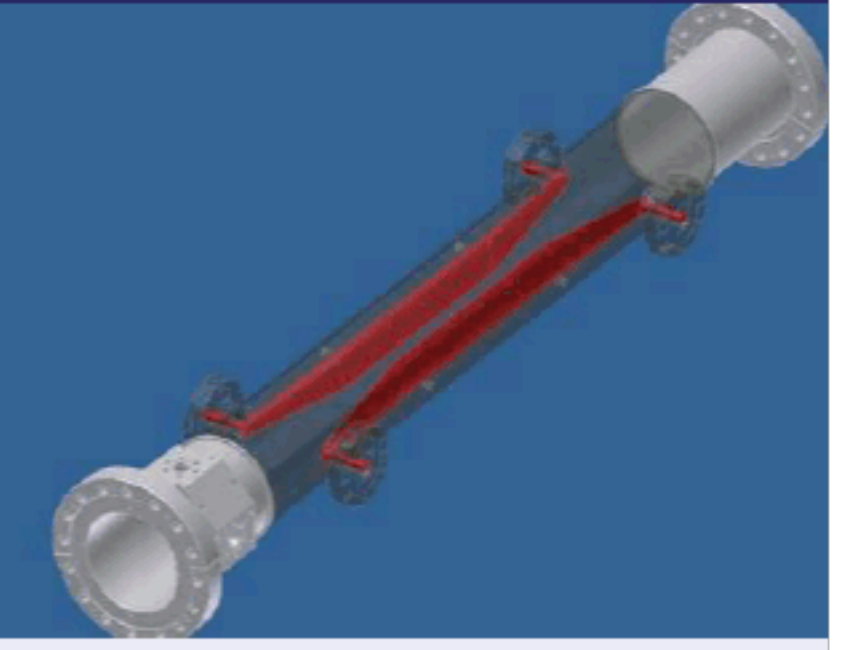
$\left.\right\}$ Lower vertical beta

$\left.\right\}$ Already achieved

Kicker

A new kicker has been designed to be used for both

- transverse horizontal feedback in the e+ ring
- beam dump (less detector trips and radiation level)



kick strength improved by a factor ≈3 *(with the same amplifier power).*

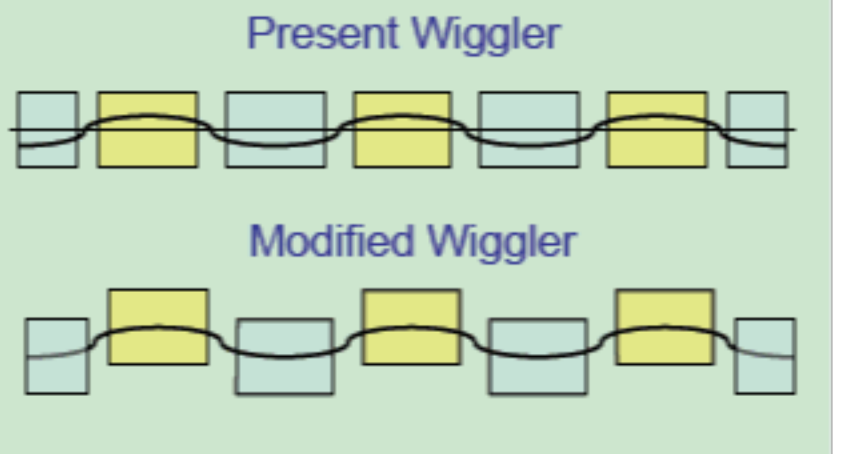
- *longer strip-line (x2)*
- *smaller separation between strip-lines: 88 mm -> 60 mm*
- *new position with higher β*

Wiggler

The 8 wigglers have been modified in order to:

- *enlarge the good-field region*
- *reduce higher order components in the B*
- *increase B_{max} at fixed current*

Improved beam dynamics
longer beam lifetimes
500KW power reduction with same B_{max} (0.5ME/Year)



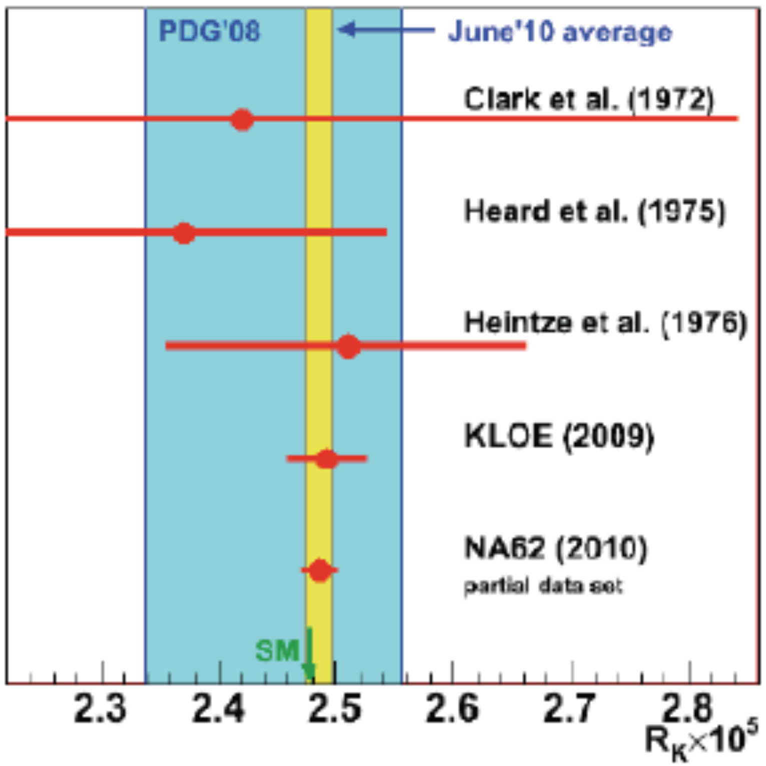
• Using 2.2 fb^{-1} of data acquired at the ϕ peak, KLOE measured:

$$R_K = (2.493 \pm 0.025_{stat} \pm 0.019_{syst}) \times 10^{-5}$$

• KLOE δR_K is dominated by the Ke2 event counting and by the control samples statistics: results can improve with the larger data samples foreseen for the oncoming KLOE-2 run.

• With same analysis strategy, 25 fb^{-1} translate into 0.6% fractional accuracy on R_K.

• Inner Tracker can allow for better performance on K tracking: higher efficiency of Kl2 event selection.



❖KLOE-2 can significantly improve the accuracy on the measurement of K_L , $K^{\pm}$ lifetimes and K_Se3 branching ratio with respect to present world average with data from the first year of data taking, at KLOE-2/step-0.

❖The present 0.23% fractional uncertainty on |Vus| × f+(0) can be reduced to 0.14% using KLOE present data set together with the KLOE-2/step-0 statistics.

❖Detector upgrades have not been considered in this evaluation

	$f_+(0)V_{us}$
KLOE today (*World Average*)	0.28% (0.23%)
KLOE + Step-0 + WA	0.14%

With $f_+(0)$ @ 0.5% the accuracy on the unitarity relation of the first row is

$$\sigma(1-V_{ud}^2-V_{us}^2) = 6\times10^{-4} \left\{ \begin{array}{l} V_{us} \text{ @ } 0.4\% \text{ from fit} \\ V_{ud} \text{ @ } 0.026\% \end{array} \right.$$

❖ To improve the accuracy on the V_{us} determination and then its contribution to the total uncertainty on the unitarity relation, a more precise estimate of $f_+(0)$ is needed.