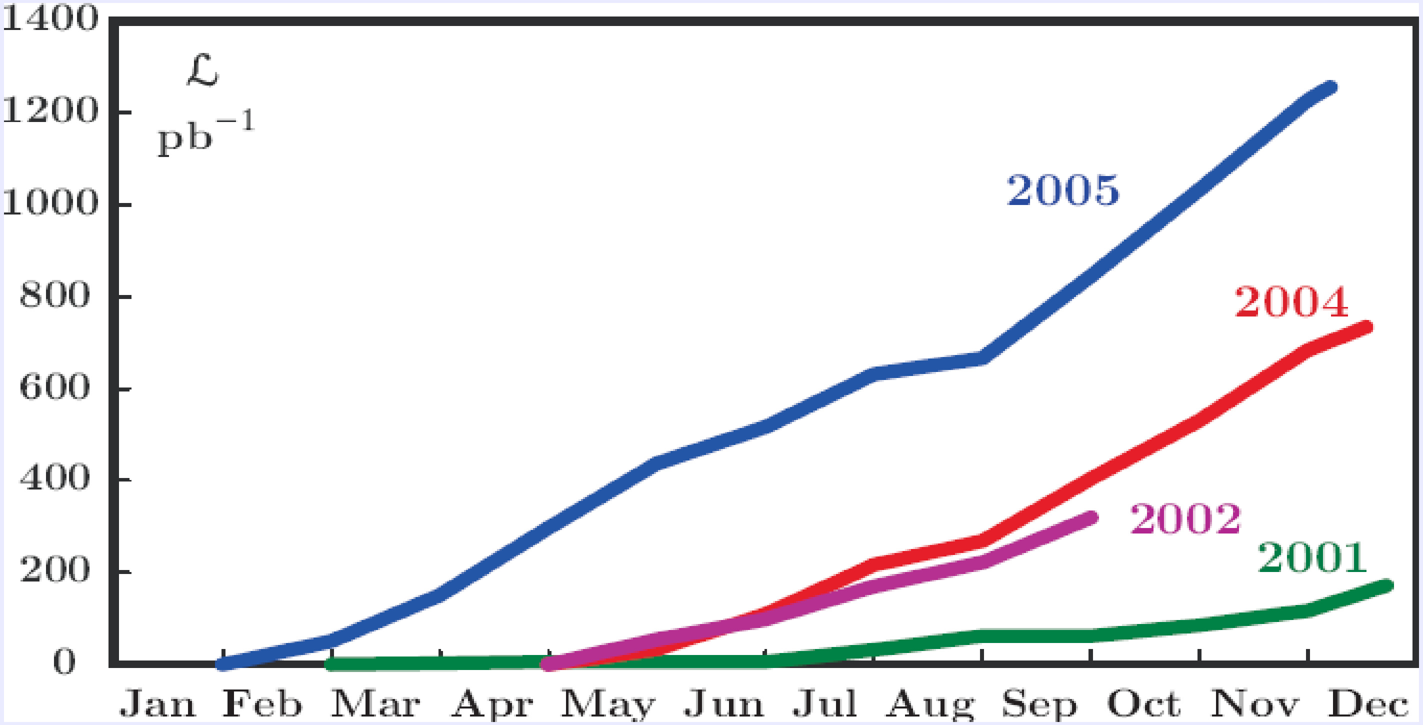
Frascati, June 7, 2010

The KLOE-2 project

Layout

- Status Report on KLOE/2 at DAϕNE
- The most recent physics result
- The KLOE-2 programme
- Conclusions

KLOE data taking



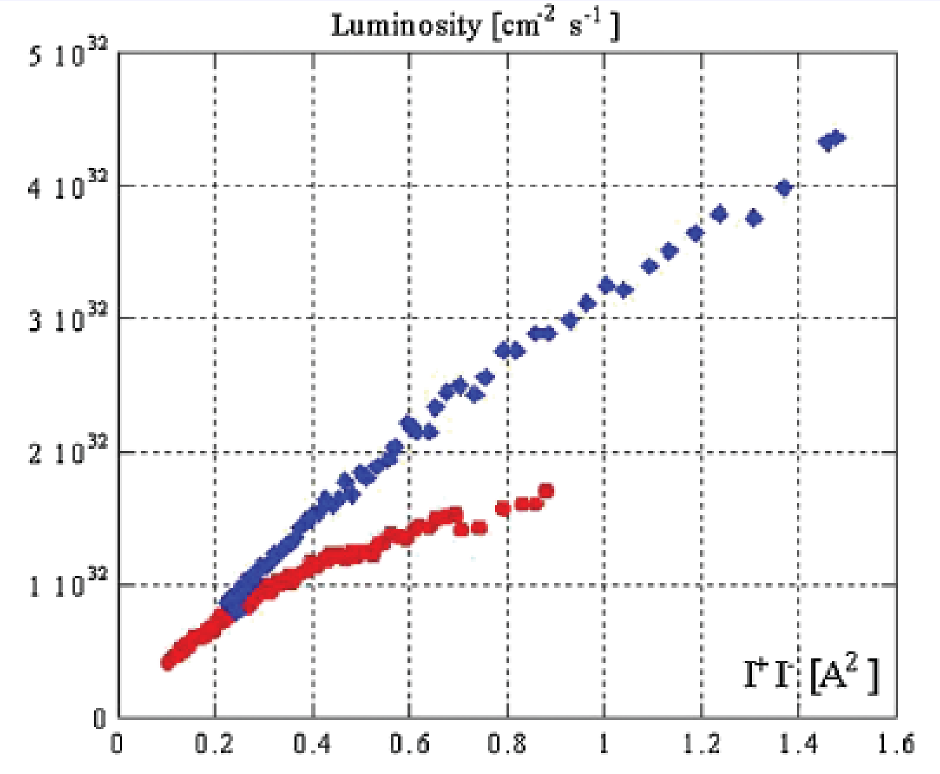
Integrated luminosity:
2005: 1256 pb^{-1}
2004: 734 pb^{-1}
2002: 320 pb^{-1}
2001: 172 pb^{-1}

- A total of 2.5 fb^{-1} of integrated luminosity at the ϕ peak collected
- About 250 pb^{-1} collected at 1 GeV for physics in the continuum

DAΦNE Upgrade

A new collision scheme worked out with
- large crossing angle
- reduced beam size at the crossing point
- sextupole pairs for crab-waist configuration of beam interaction

A factor of 3 in the peak luminosity achieved with the same circulating currents as in the past



Works at DAϕNE for the run with KLOE-2

Performance still limited in November 2009 by:

- *maximum positron current*
- *beam lifetime*
- *hardware reliability*

	DAΦNE upgrade SIDDHARTA	DAΦNE KLOE	DAΦNE FINUDA
L_{peak} [$cm^{-2}s^{-1}$]	$4.53 \cdot 10^{32}$	$1.5 \cdot 10^{32}$	$1.6 \cdot 10^{32}$
$L_{\int day}$ [pb^{-1}]	14.98	9.8	9.4
$L_{\int 1\ hour}$ [pb^{-1}]	1.033	0.44	0.5
I^{-}_{MAX} in collision [A]	1.52	1.4	1.5
I^{+}_{MAX} in collision [A]	1.0	1.2	1.1
$N_{bunches}$	105	111	106

Status Report on DAFNE upgrade at EuCARD, April 2010

EuCARD

The first run of the upgraded DAϕNE was ended in November 2009

Interaction region revised for the compensation of the KLOE magnetic field

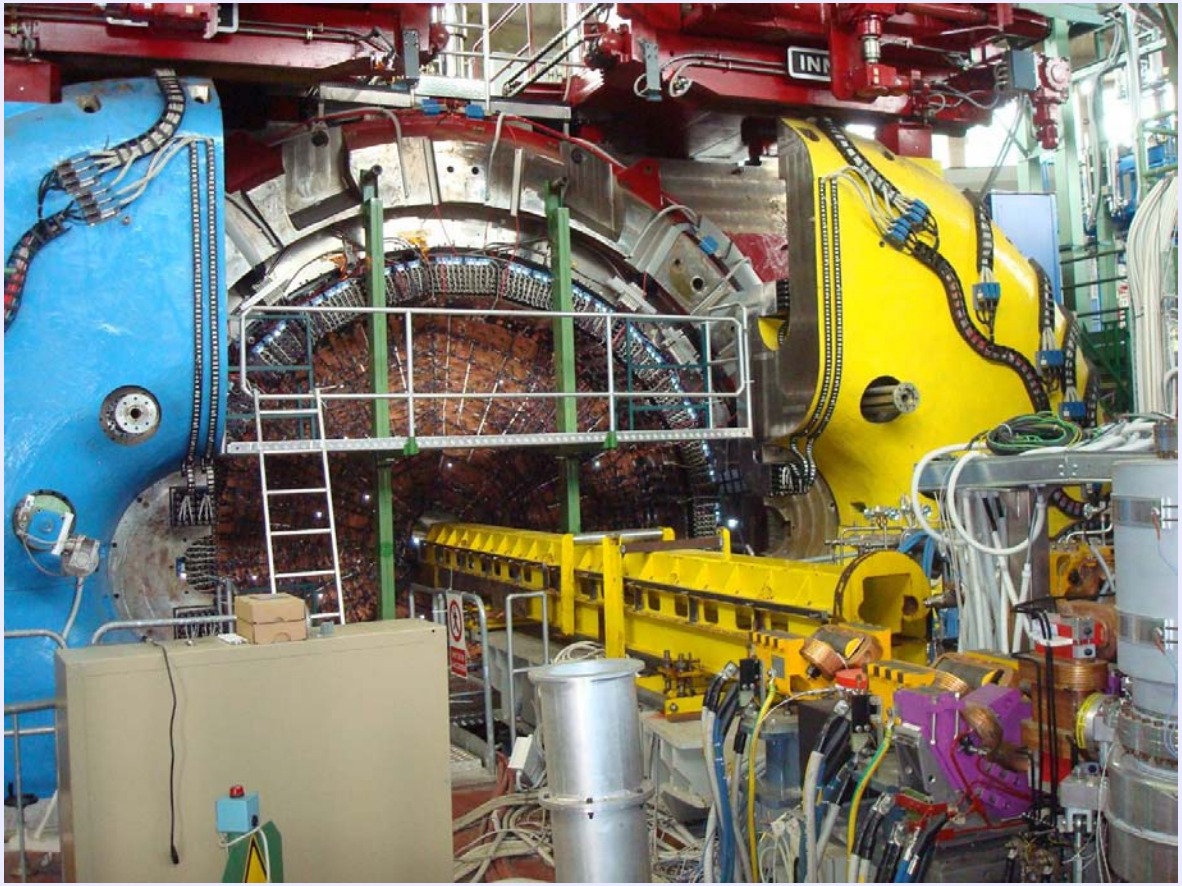
Several maintanance and upgrade works done to overcome the collider limitations

clearing electrodes installed in the positron machines to prevent electron-cloud formation

LINAC: new positron gun , new accelaring section to be installed in September

Other elements modified: wiggler, kickers, control system, cryogenic plant, scrapers

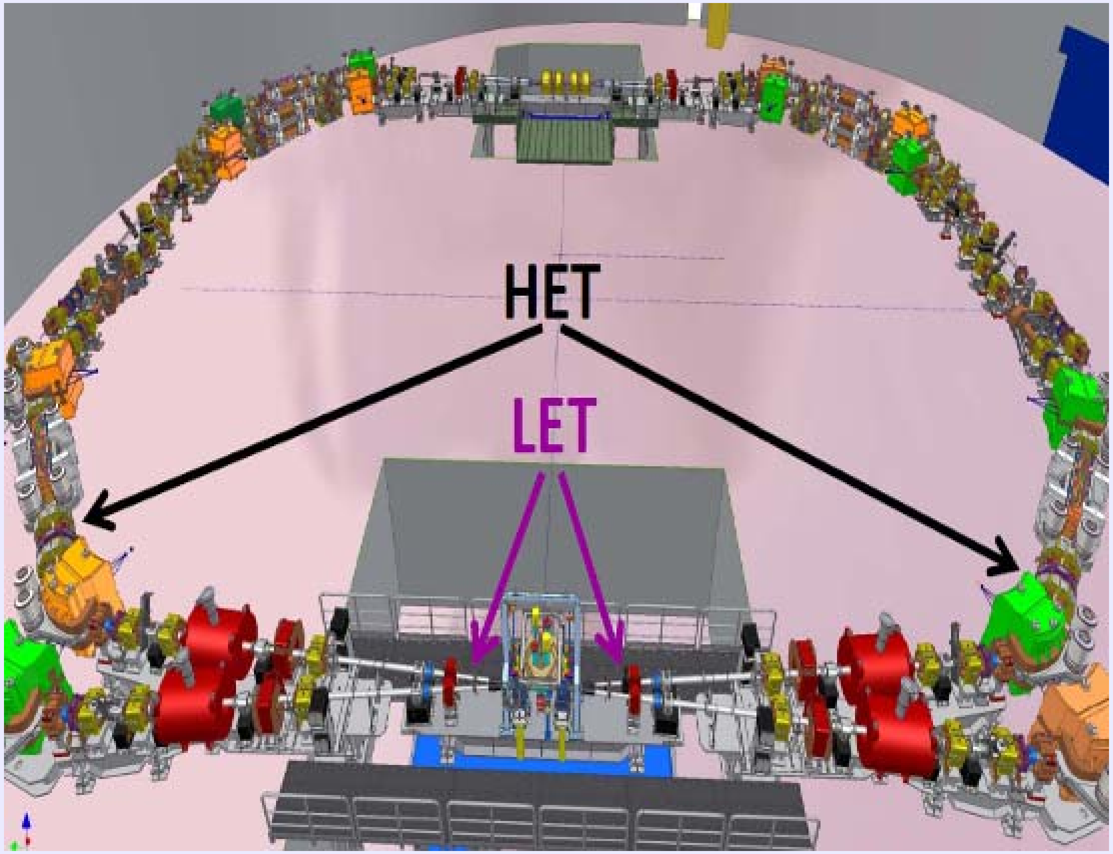
Project status and planning



- The machine commissioning starts by the end of June
- Three-months period scheduled for major tuning of the operation
- Data taking planning as a function of the measured performance
- Upgrade of the LINAC by the end of 2010
- Upgrade of the KLOE detector by the end of 2011

The taggers for $\gamma\gamma$ physics

Detector upgrade for first KLOE-2 run (≈5 fb^{-1} in 1 year):
2+2 detector stations for leptons in $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$



LET: E_l=160-230 MeV

- **Inside KLOE detector**
- **LYSO+SiPM**
- **σ_E<10% for E>150 MeV**

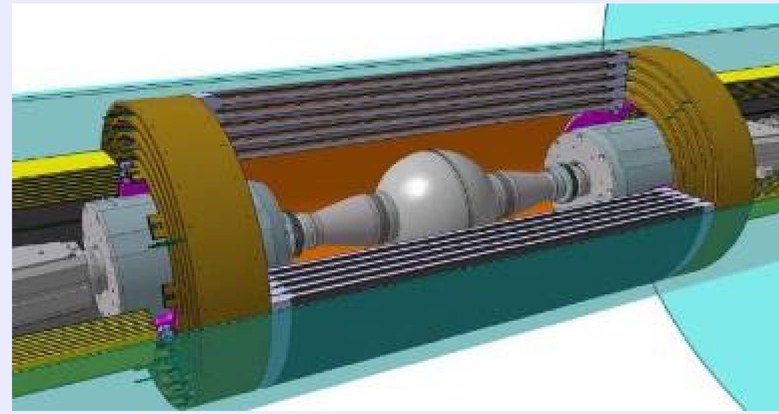
HET: E_l > 400 MeV

- **11 m from IP**
- **Scintillators + PMTs**
- **$\sigma_E \sim 2.5$ MeV**
- **$\sigma_T \sim 200$ ps**

Detector upgrades

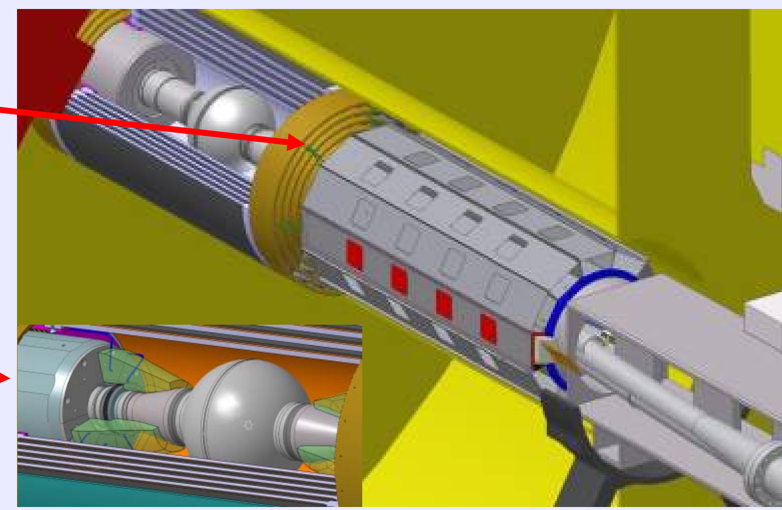
Major detector upgrades (late 2011) for second KLOE-2 run:

INNER TRACKER



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

QCALT



- **W + scintillator tiles + SiPM/WLS**
- **QUADS instrumentation for K_L decays**

CCAL

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

Physics issues

KLOE published several results mostly contributing to

- SM test in the flavor sector through precise measurements of
  - Vus
  - $BR(K \to e\nu)/BR(K \to \mu\nu)$

- CPT and quantum mechanics tests with the analysis of the
  - interference pattern of neutral kaons
  - Ks semileptonic decays
  - unitary (Bell-Steinberger) relation

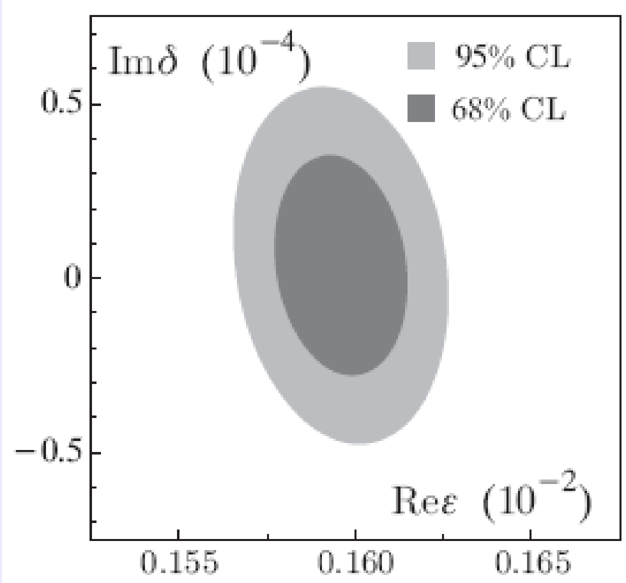
- low-energy QCD

- the study of the light scalar sector

- precision measurement of the di-pion cross section for the calculation of the hadronic contribution to the muon anomaly

From BSR with Ks/KL measurements from KLOE

JHEP 0612 (2006) 011



$Re(\varepsilon) = (159.6 \pm 1.3)\ 10^{-5}$

$Im(\delta) = (0.4 \pm 2.1)\ 10^{-5}$

Recent publications

A Global fit to determine the pseudoscalar mixing angle and the gluonium content of the eta-prime meson	JHEP 0907:105,2009
Study of the a(0)(980) meson via the radiative decay phi ---> eta pi0 gamma with …	PLB 681:5,2009
Measurement of $\sigma(e^+e^- \to \pi^+\pi^-\gamma(\gamma))$ and the dipion contribution to the muon anomaly…	PLB 670:285,2009
Search for the K(S) $\to e^+e^-$ decay with the KLOE detector	PLB 672:203,2009
Precise measurement of $\Gamma(K \to e\,\nu\,(\gamma)) / \Gamma(K \to \mu\,\nu\,(\gamma))$ and study of $K \to e\,\nu\,\gamma$	EPJ C64:627,2009
Search for the decay phi ---> K0 anti-K0 gamma with the KLOE experiment	PLB 679:10,2009
Technical Design Report of the Inner Tracker for the KLOE-2 experiment	arXiv:1002.2572
Technical Design Report of the $\gamma\gamma$ tagger system for the KLOE-2 experiment	LNF:10-14(P)

Submitted:

Physics with the KLOE-2 experiment at the upgraded DAϕNE	arXiv:1003.3868
Measurement of the $\eta \to \pi^0\pi^0\pi^0$ slope parameter α with the KLOE detector	arXiv:1004.1319

Furthermore ...

Paper under review from KLOE referees:

Ks lifetime

Measurement of the pion form factor for $M^2(\pi\pi)$ between 0.1 and 0.85 GeV^2 with the KLOE detector **arXiv:0912.2205**

Ongoing analysis

Update of the results on interferometry

Measurement of the pion form factor for

$M^2(\pi\pi)$ by $\mu\mu(\gamma)$ normalization

Klong lifetime

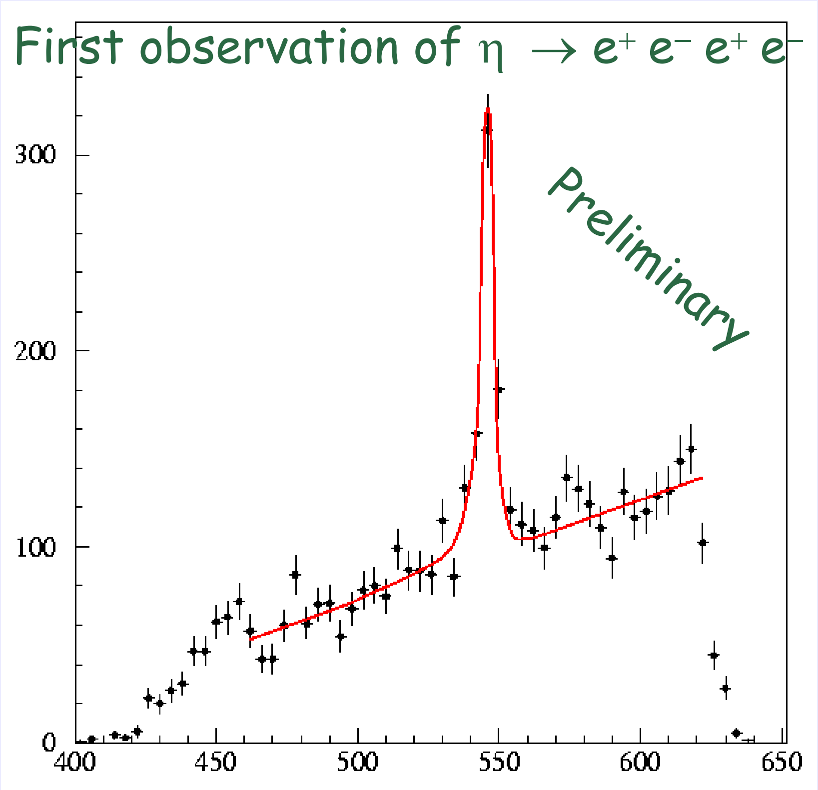
BR($K^\pm \to \pi^\pm \pi^+ \pi^-$) with the update of all BR's

Ks semileptonic decays

$\eta \to e^+ e^- e^+ e^-$

$\eta \to \pi^+ \pi^- \gamma$

$e^+ e^- \to e^+ e^- \eta$, $\quad e^+ e^- \to e^+ e^- \pi^0 \pi^0$



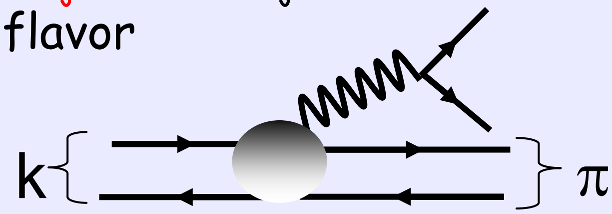
The KLOE-2 physics programme

- The programme, discussed in arXiv:1003.3868 (to be published by EPJC) include the improvement of several KLOE measurements and
  - the study of γ–γ physics based on a sample tagged by a new system for the detection of $e^{\pm}$ from the process $e^+ e^- \rightarrow e^+ e^- X$
  - the search for particles from an hidden sector which could explain the dark matter problem
  - precise measurements of the hadronic cross section near threshold and if the upgrade in energy of the collider is approved in the region from 1.02-2.3 GeV

- List of topics include
  - CKM unitarity and lepton universality
  - CPT symmetry and Quantum Mechanics
  - Low-energy QCD
  - Physics in the continuum: σ_{had}
  - Physics in the continuum: γ–γ processes
  - Hidden WIMP dark matter

CKM unitarity

- CKM unitarity as stated in the SM implies the universality of the couplings of quark and leptons through the assumption $G_{ij} = G\mu \, V_{ij}$ where $\sum_j |Vij|^2 = 1$
- Universality relations: G_{ij} independent from lepton flavor



- New physics contributions through precision measurements of Vus
- KLOE performed a comprehensive, consistent set of measurements: BR's,lifetimes, form factor dependence on Q^2

$$|V_{us}| \times f_+(0) = 0.2163(5) \text{ from KLOE}$$

$K_L e3$	$K_L \mu 3$	$K_S e3$	$K^{\pm} e3$	$K^{\pm} \mu 3$
0.2163(6)	0.2166(6)	0.2155(13)	0.2160(11)	0.2158(14)

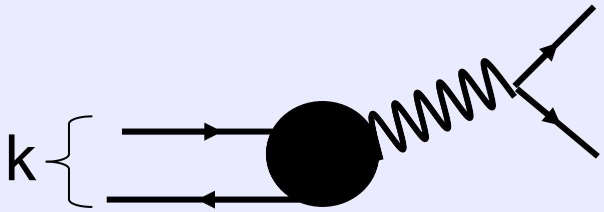
- As a result

$$g_\mu^2/g_e^2 = r_{\mu e} = 1.002(5)$$

- For comparison: $(r_{\mu e})_\pi = 1.0042(33)$; $(r_{\mu e})_\tau = 1.000(4)$

CKM unitarity

- G_{CKM} is also obtained from $K_{\mu 2}$ decays

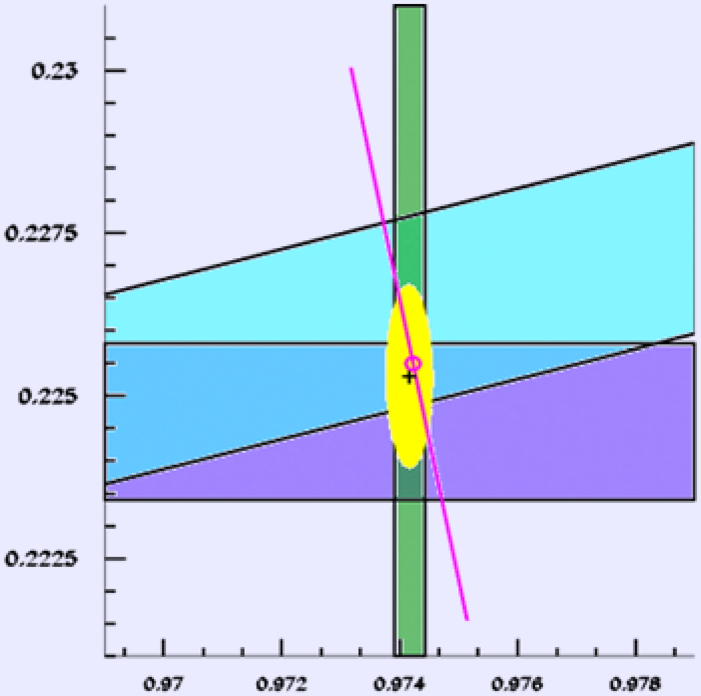


$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K^2}{f_\pi^2} \times \frac{M_K(1-m_\mu^2/M_K^2)^2}{m_\pi(1-m_\mu^2/m_\pi^2)^2} \times 1+\alpha(C_K-C_\pi)$$

- As a result

  $V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$

  is verified at the 6×10^{-4} level



CKM unitarity

- New-physics contributions in the effective Lagrangian of the order v^2/Λ^2
- Strong constraints from FCNC

  $\rightarrow$ new physics encoded by shifts of both G_μ and G_{semil}

  $G_{CKM} = G_\mu (|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2)^{1/2} = G_\mu (1 + \Delta_{semil} - \Delta_\mu)$

  leading to a unitarity-violating term Δ_{CKM}

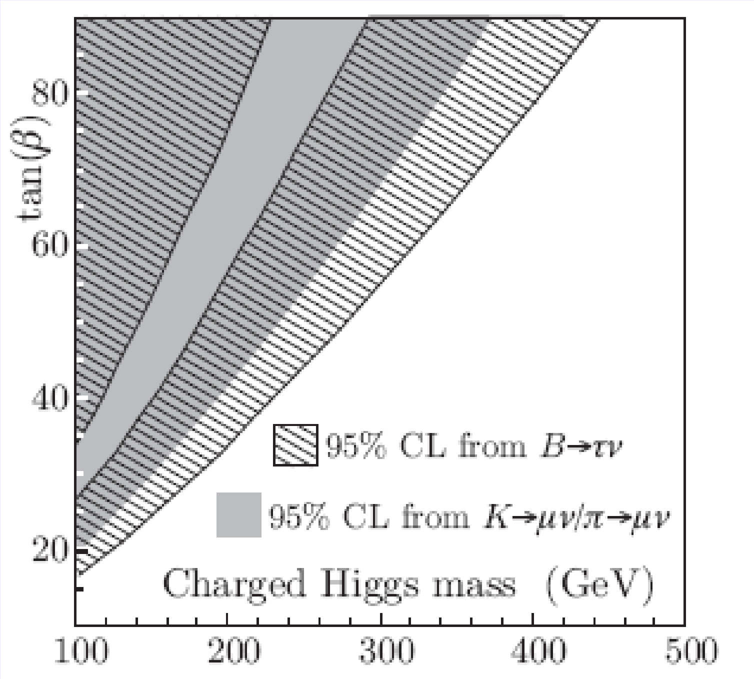
  $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 + \Delta_{CKM}$
- Precision electroweak tests constrains Δ_{CKM} to $-9.5\ 10^{-3} < \Delta_{CKM} < 10^{-4}$
- From leptonic and semileptonic kaon decays $\Delta_{CKM} = -0.0001(6)$

  $\rightarrow$ a probe of the 10 TeV scale

CKM unitarity and lepton universality

- New-physics could affect the helicity-suppressed kaon decays only
  - Vus from semileptonic decays as expected in the SM
  - Vus from leptonic decays smaller than expected
- $R_{\mu 23}$ is used to constrain Higgs-mediated scalar currents

$$R_{\mu 23} = \frac{f_+(0)}{f_k / f_\pi}\left(\frac{|V_{us}|}{|V_{ud}|}\frac{f_k}{f_\pi}\right)_{\mu 2}\frac{|V_{ud}|_{0^+\to 0^+}}{\left(|V_{us}|f_+(0)\right)_{l3}} \approx \left|1 - \frac{m_k^2}{m_{H^+}^2}\frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta}\right|$$

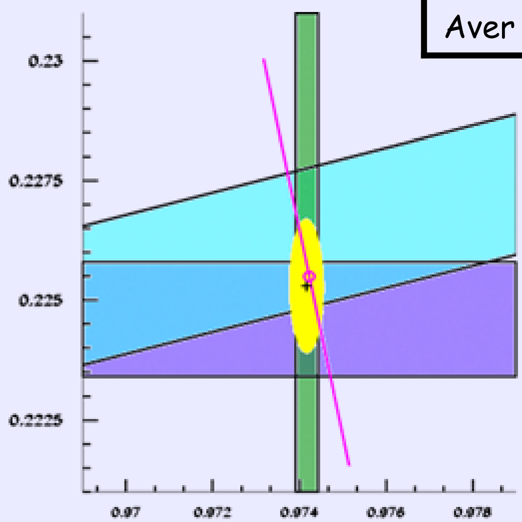


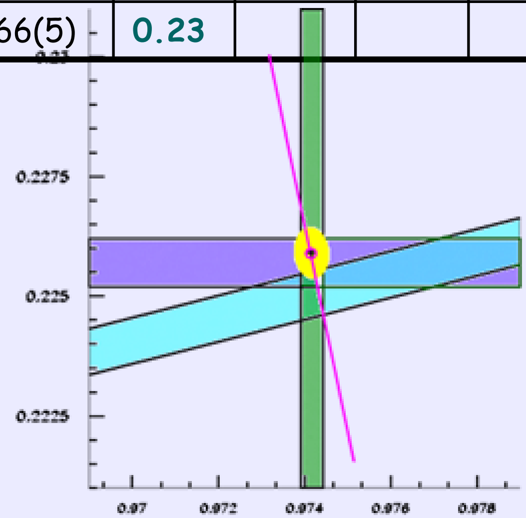
CKM unitarity

To improve on this field both, LQCD calculations, and experimental accuracy must be improved

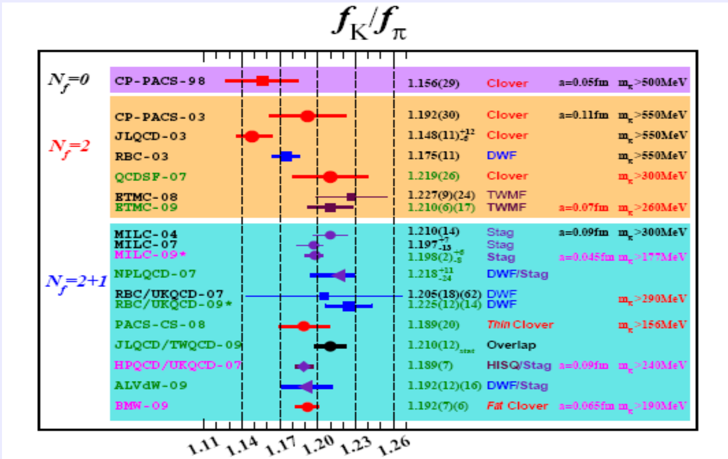
KLOE-2 measurements : semileptonic BR's and lifetimes

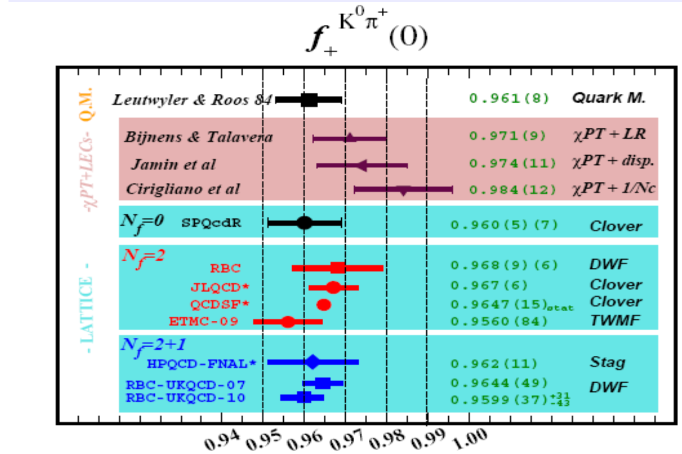
	%err	BR	τ	δ	I_{Kl}	%err	BR	τ	δ	I_{Kl}
$K_L e3$ 0.2163(6)	**0.28**	0.09	0.19	0.15	0.09	**0.24**	0.09	0.13	0.15	0.09
$K_L \mu 3$ 0.2168(7)	**0.30**	0.10	0.18	0.15	0.15	**0.27**	0.10	0.13	0.15	0.15
$K_S e3$ 0.2154(13)	**0.67**	0.65	0.03	0.15	0.09	**0.35**	0.30	0.03	0.15	0.09
$K^{\pm} e3$ 0.2173(8)	**0.39**	0.26	0.09	0.26	0.09	**0.38**	0.25	0.05	0.26	0.09
$K^{\pm} \mu 3$ 0.2176(11)	**0.51**	0.40	0.09	0.26	0.15	**0.41**	0.27	0.05	0.26	0.15
Aver 0.2166(5)	**0.23**					**0.14**				



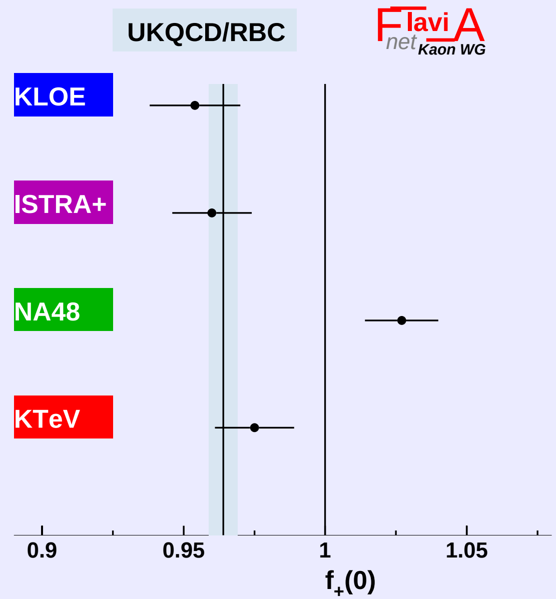


LQCD calculations





- From the dispersion parametrization of the ff dependence from momentum transfer, based on analyticity constraints and CT theorem experimental measurement of the ratio $f_K/f_\pi/f_+(0) = 1.225(14)$



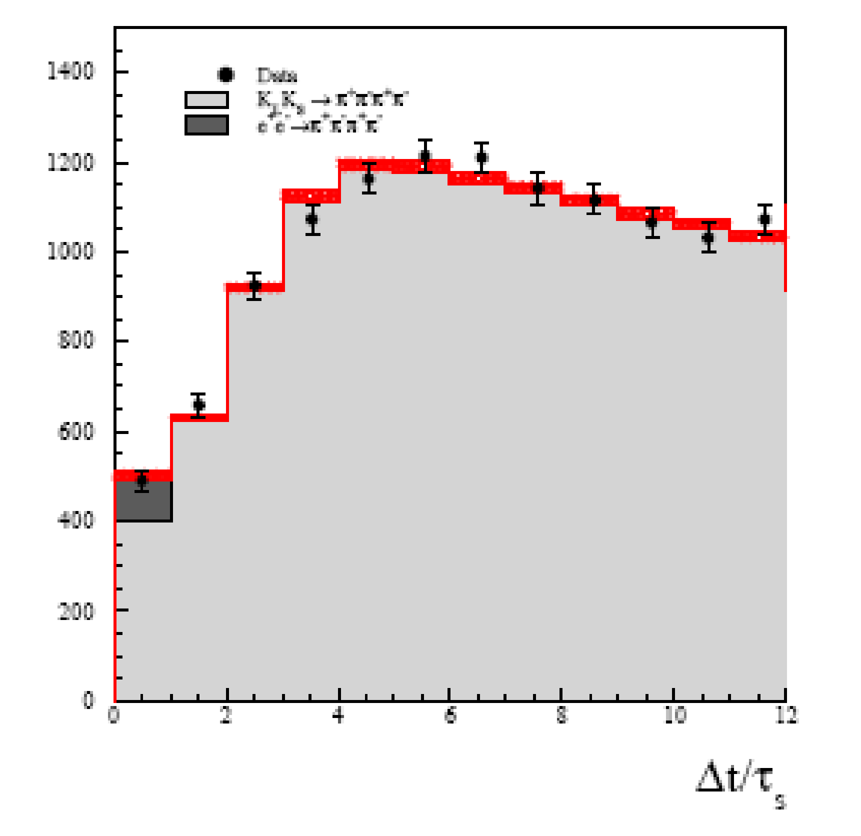
CPT symmetry and QM

- The study of intereference with neutral kaon pairs at the ϕ-factory is a probe of CPT symmetry and QM at the Planck scale
- The sensitivity and variety of the interference phenomena for the unique, special circumstance

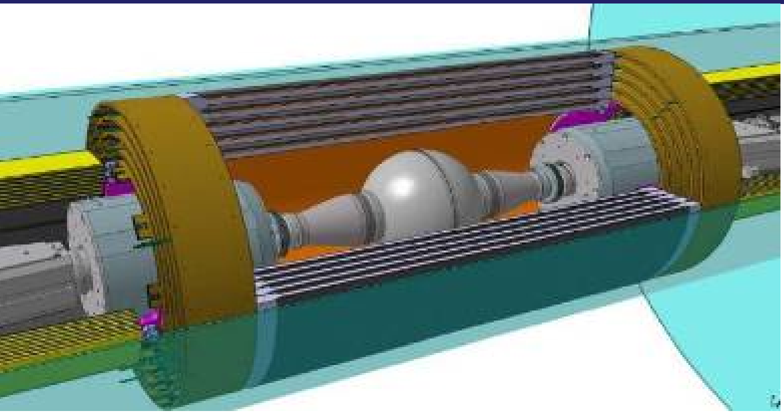
$$\Delta M \sim \tfrac{1}{2}\,\Gamma_s$$

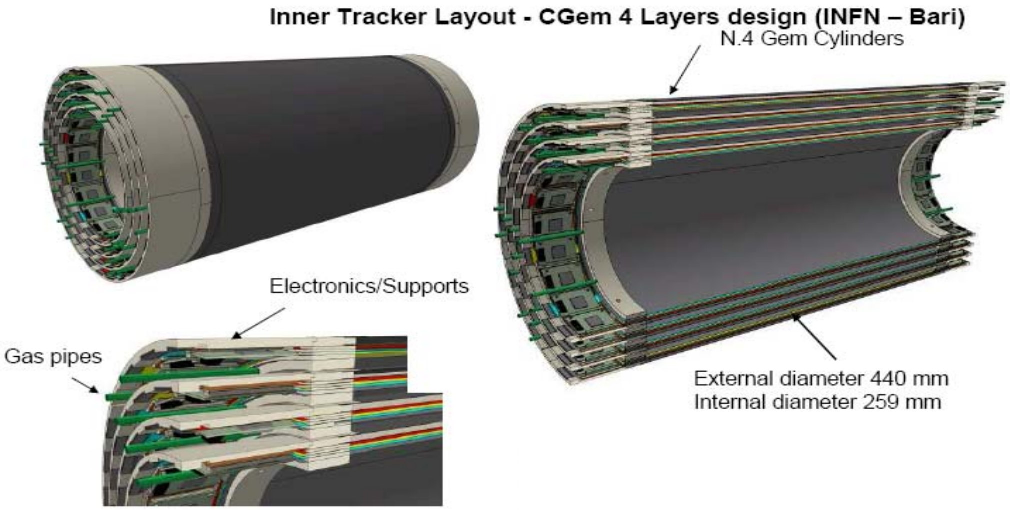
- With KLOE-2 we plan to improve on the vertex resolution with an inner tracker, realized with
- The GEM technology chosen for the super-light material
- The vertex resolution is expected to improve by a factor of 3 in the region of interest

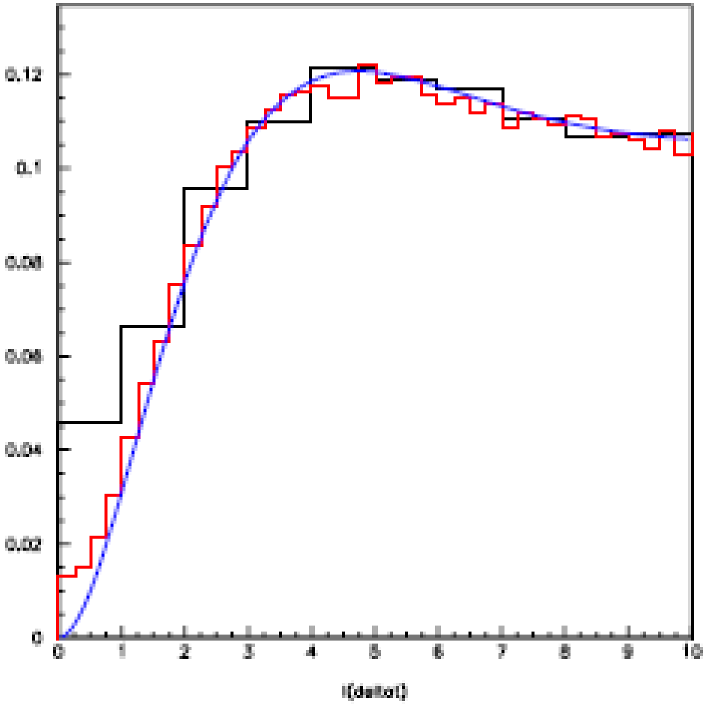
$$I(\pi^+\pi^-,\pi^+\pi^-;\Delta t) \propto e^{-\Gamma_L \Delta t} + e^{-\Gamma_S \Delta t} - 2e^{-\frac{(\Gamma_S+\Gamma_L)}{2}\Delta t}\cos(\Delta m \Delta t) \,,$$



The triple-GEM cylindrical chamber





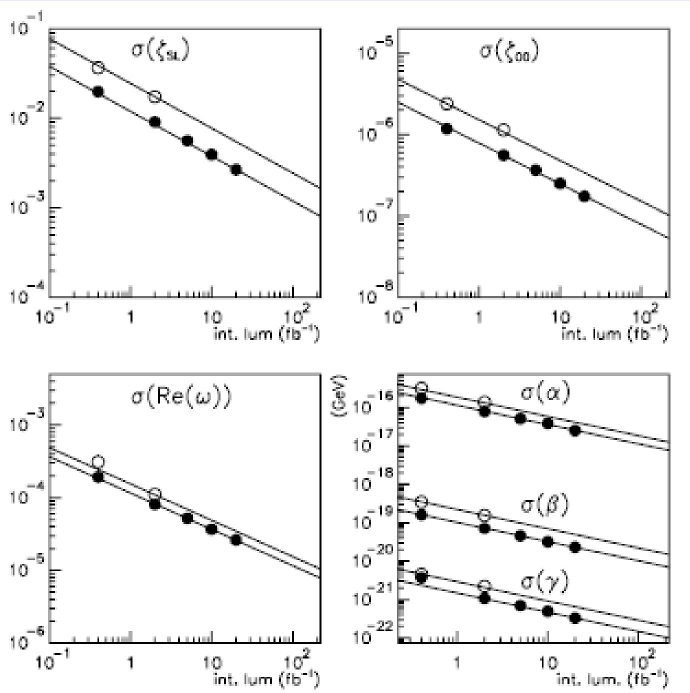


- 4 independent Tracking Layers 700 mm active area
- Inner radius 129.5 mm (limited by $K_L K_S$ interference and Dafne magnets dimensions)
- Outer radius 220 mm (limited by DC dimensions)

Table 2: Material budget for a CGEM layer detector (active area)

Component	times x material (X_0) x quantity	% of X_0
3 GEMs	Copper: 6× 2μm Cu (X_0=14.3mm) ×0.8 Kapton: 3× 50μm kapton (X_0=286mm) ×0.8	0.067 0.042 Total: 0.109
1 Cathode	Copper: 1× 2μm Cu ×1 Kapton: 1× 50μm kapton×1	0.013 0.017 Total: 0.030
1 Readout anode	Copper: 1× 2μm Cu ×0.95 Kapton: 2× 50μm kapton×1	0.013 0.034 Total: 0.047
1 Shielding	Aluminum: 1× 10μm Al(X_0=89mm)×1	Total: 0.011
1 Honeycomb	NOMEX: 1× 3mm Nomex(X_0=13125mm)×1	Total: 0.023
2 CF skins	CF: 2× 250μ CF(X_0=250mm)×1	Total: 0.160
		Total: 0.380

From KLOE to KLOE-2



- Decoherence (loss of total entanglement between kaons) can be traced back to
  - modifications in QM
  - CPT violation

  at the Planck scale from Quantum Gravity

- Sensitivity limited by statistics

f_1	f_2	Parameter	Present best measurement	KLOE-2 (25 fb^{-1})
$K_S \to \pi e \nu$		A_S	$(1.5 \pm 11) \times 10^{-3}$	$\pm 1 \times 10^{-3}$
$\pi^+\pi^-$	$\pi l \nu$	A_L	$(332.2 \pm 5.8 \pm 4.7) \times 10^{-5}$	$\pm 4 \times 10^{-5}$
$\pi^+\pi^-$	$\pi^0\pi^0$	$\mathrm{Re}\frac{\epsilon'}{\epsilon}$	$(1.65 \pm 0.26) \times 10^{-3}$ (PDG)	$\pm 0.3 \times 10^{-3}$
$\pi^+\pi^-$	$\pi^0\pi^0$	$\mathrm{Im}\frac{\epsilon'}{\epsilon}$	$(-1.2 \pm 2.3) \times 10^{-3}$ (PDG)	$\pm 4 \times 10^{-3}$
$\pi^+ l^- \bar{\nu}$	$\pi^- l^+ \nu$	$(\mathrm{Re}\delta + \mathrm{Re}x_-)$	$\mathrm{Re}\delta = (0.25 \pm 0.23) \times 10^{-3}$ (PDG) $\mathrm{Re}x_- = (-4.2 \pm 1.7) \times 10^{-3}$ (PDG)	$\pm 0.3 \times 10^{-3}$
$\pi^+ l^- \bar{\nu}$	$\pi^- l^+ \nu$	$(\mathrm{Im}\delta + \mathrm{Im}x_+)$	$\mathrm{Im}\delta = (-0.6 \pm 1.9) \times 10^{-5}$ (PDG) $\mathrm{Im}x_+ = (0.2 \pm 2.2) \times 10^{-3}$ (PDG)	$\pm 4 \times 10^{-3}$
$\pi^+\pi^-$	$\pi^+\pi^-$	Δm	$5.288 \pm 0.043 \times 10^9 s^{-1}$	$\pm 0.05 \times 10^9 s^{-1}$
$\pi^+\pi^-$	$\pi^+\pi^-$	ζ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 0.2 \times 10^{-2}$
$\pi^+\pi^-$	$\pi^+\pi^-$	$\zeta_{0\bar{0}}$	$(0.1 \pm 1.0) \times 10^{-6}$	$\pm 0.1 \times 10^{-6}$
$\pi^+\pi^-$	$\pi^+\pi^-$	α	$(-0.5 \pm 2.8) \times 10^{-17}$ GeV	$\pm 2 \times 10^{-17}$ GeV
$\pi^+\pi^-$	$\pi^+\pi^-$	β	$(2.5 \pm 2.3) \times 10^{-19}$ GeV	$\pm 0.2 \times 10^{-19}$ GeV
$\pi^+\pi^-$	$\pi^+\pi^-$	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 $\pm 0.2 \times 10^{-21}$ GeV
$\pi^+\pi^-$	$\pi^+\pi^-$	$\mathrm{Re}\omega$	$(-1.6^{+3.0}_{-2.1} \pm 0.4) \times 10^{-4}$	$\pm 3 \times 10^{-5}$
$\pi^+\pi^-$	$\pi^+\pi^-$	$\mathrm{Im}\omega$	$(-1.7^{+3.3}_{-3.0} \pm 1.2) \times 10^{-4}$	$\pm 4 \times 10^{-5}$
$K_{S,L} \to \pi e \nu$		Δa_0	(prelim.: $(0.4 \pm 1.8) \times 10^{-17}$ GeV)	$\pm 2 \times 10^{-18}$ GeV
$\pi^+\pi^-$	$\pi^+\pi^-$	Δa_Z	(prelim.: $(2.4 \pm 9.7) \times 10^{-18}$ GeV)	$\pm 1 \times 10^{-18}$ GeV
$\pi^+\pi^-$	$\pi^+\pi^-$	Δa_X, Δa_Y	(prelim.: $< 9.2 \times 10^{-22}$ GeV)	$\pm 6 \times 10^{-19}$ GeV

- Improvements in the vertex resolution from $1 \to 0.3\ \tau_s$ equivalent to a factor of 3-4 in statistics

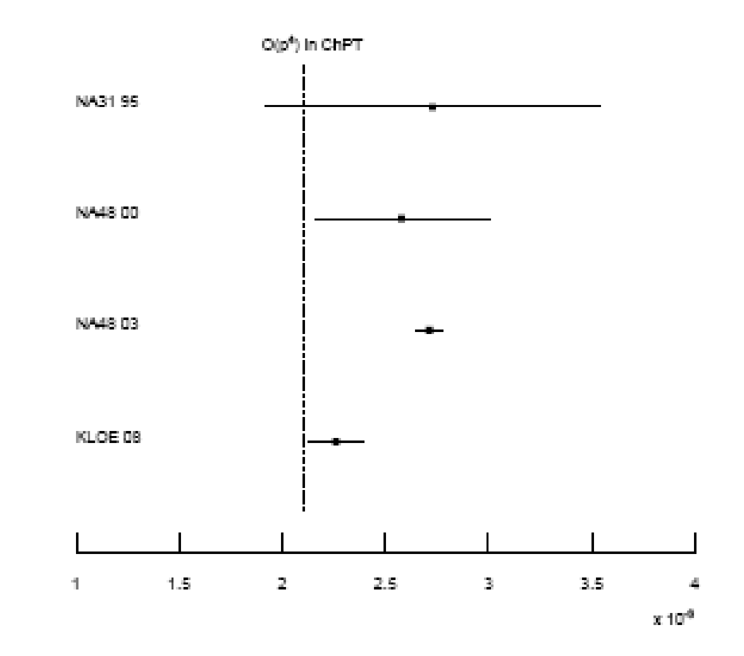
Low-energy QCD

- Kaon and η decays in a clean environment

- The only experiment with Ks pure beams
- KLOE-2 can study kaon channels with BR's to 10^{-9}
- Rare Ks decays; $Ks \to 3\pi, \gamma\gamma, \pi^0\gamma\gamma, \pi^0 l^+l^-, \pi^+\pi^-\gamma, \pi^+\pi^-e^+e^-$

- η decays: $\pi^0\gamma\gamma, \pi^+\pi^-e^+e^-$, eeee
- η' decays: improvement of the BR's to 1%
- $\phi \to \eta ee, \eta\mu\mu$ interesting also for the dark-force searches
- $\phi \to KsKs\gamma$

BR($Ks \to \gamma\gamma$)



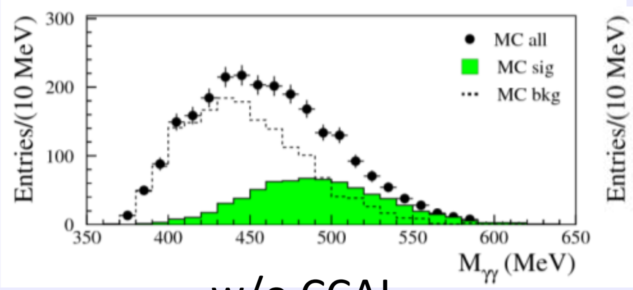
CCALT

2 small barrels of 24 crystals
each with length 10-13 cm and transversal area from 1.5x1.5cm2 to 2x2cm2

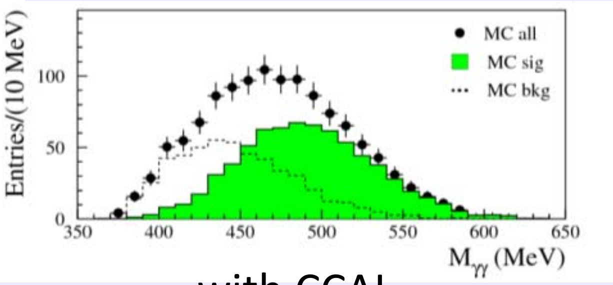
The angular acceptance is extended to 10°

Ks →γγ

Ks →$\pi^0\pi^0$

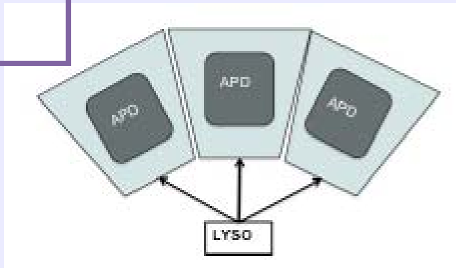


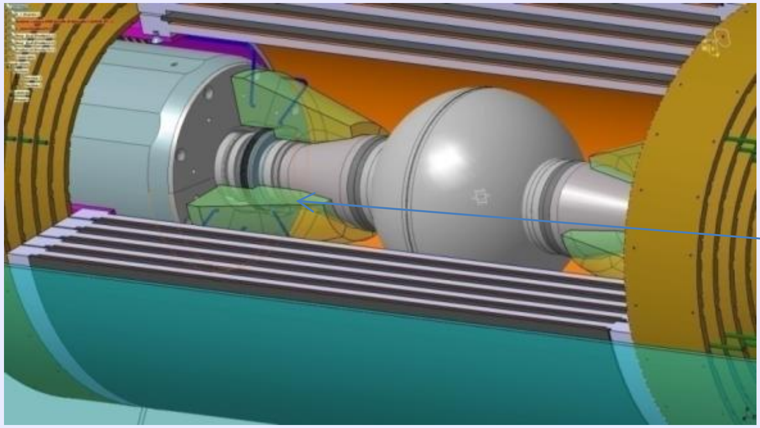
w/o CCAL



with CCAL

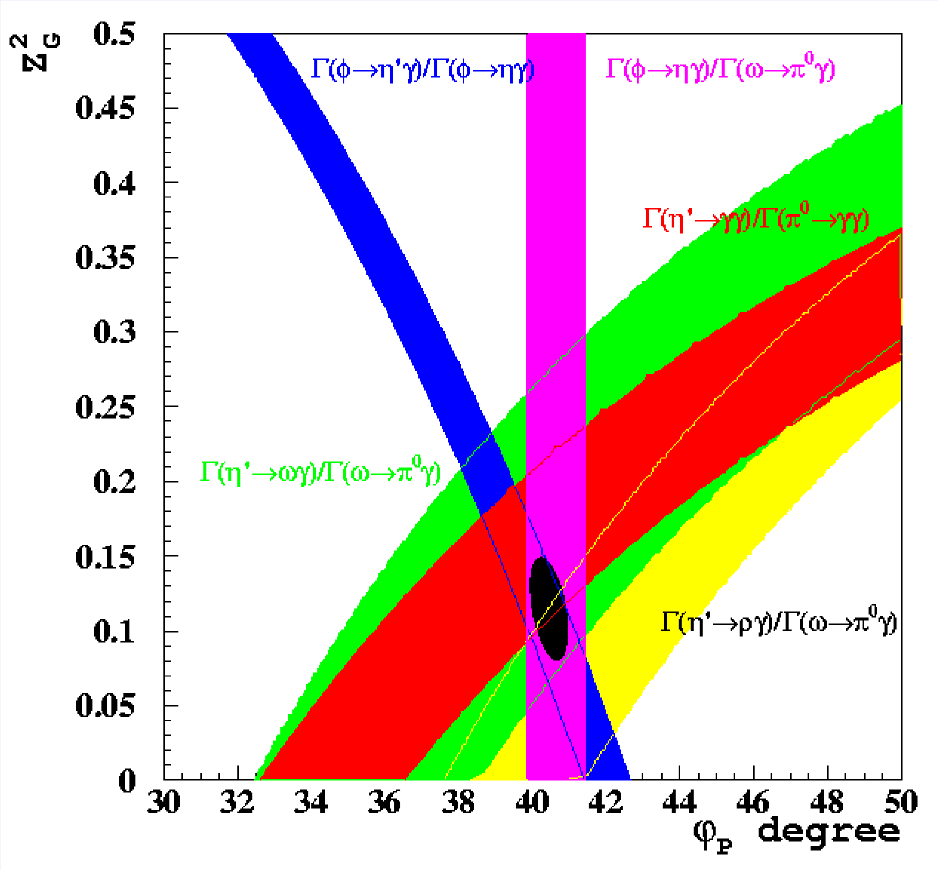
Dodecagonal Barrel



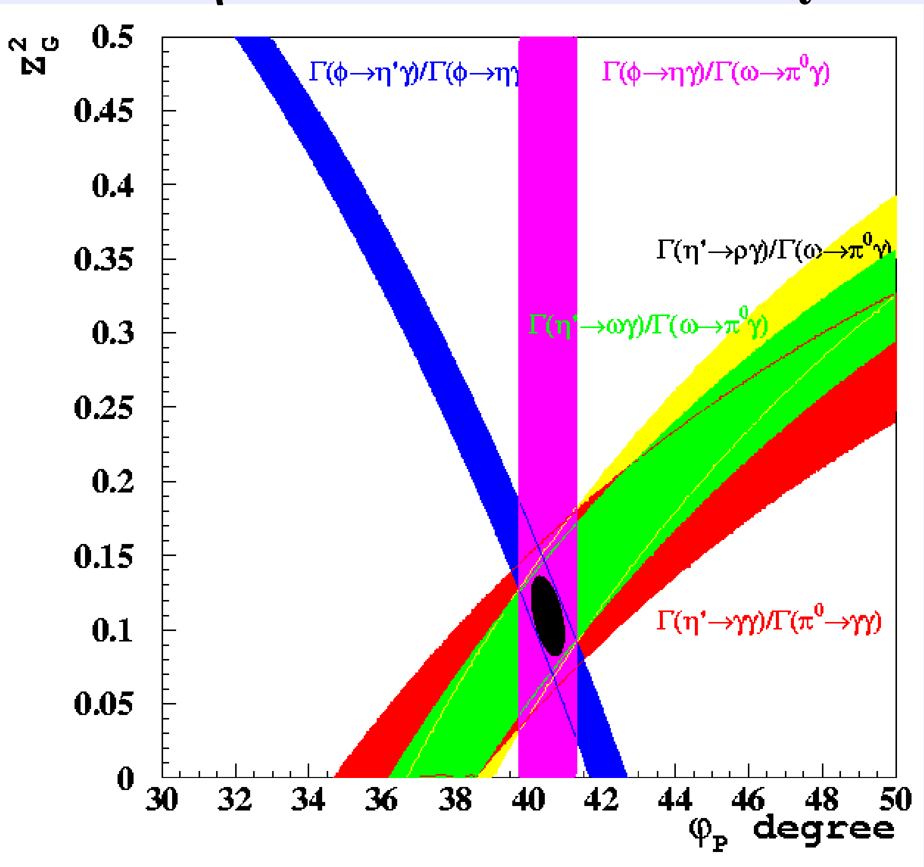


η - η ' - G mixing

KLOE: global fit result



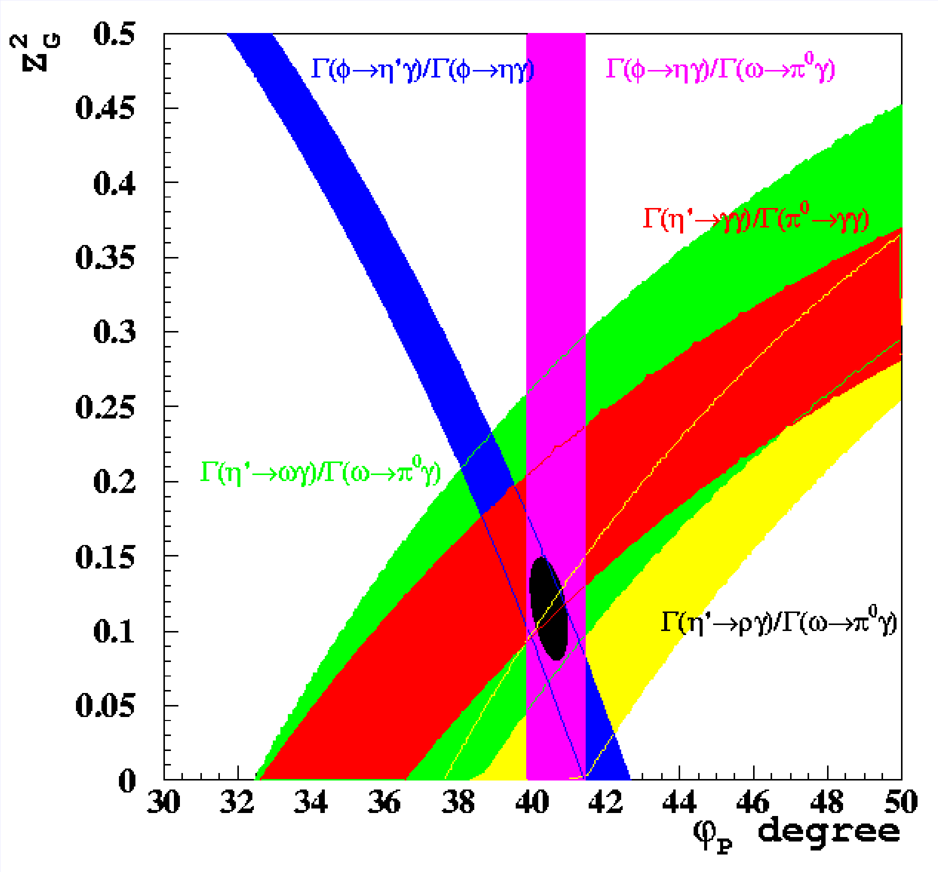
KLOE-2 expectation measuring η' BRs with 1% accuracy



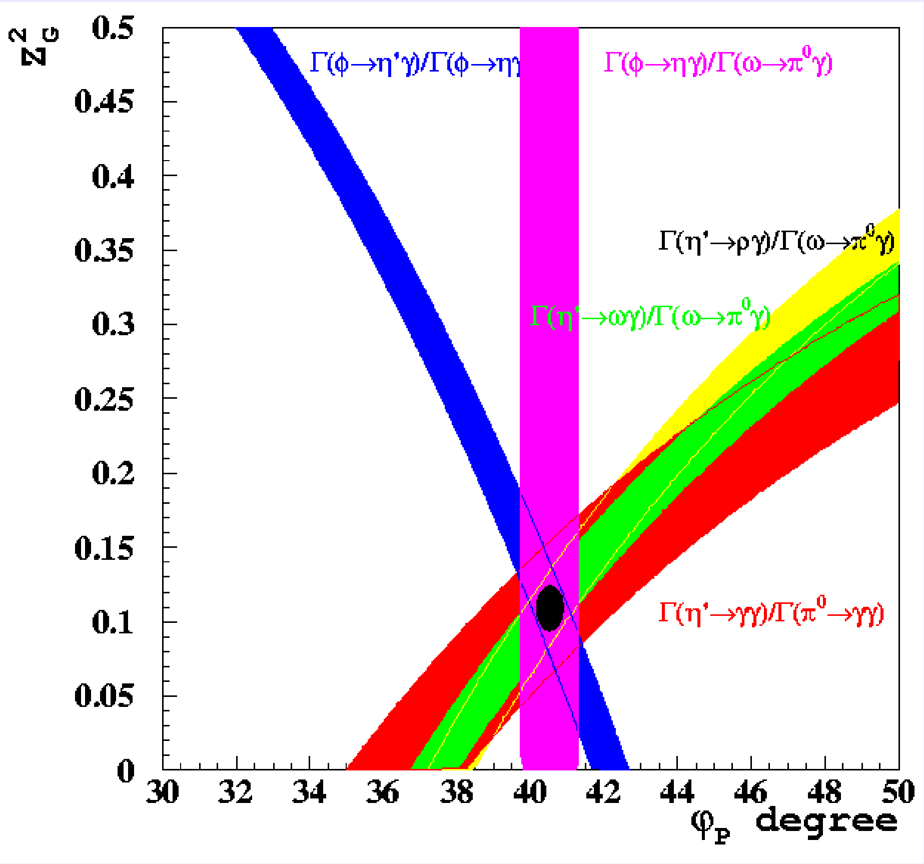
Sensitivity to the gluonium also without the η'→γγ decay

η - η ' - G mixing: from KLOE to KLOE-2

KLOE: global fit result

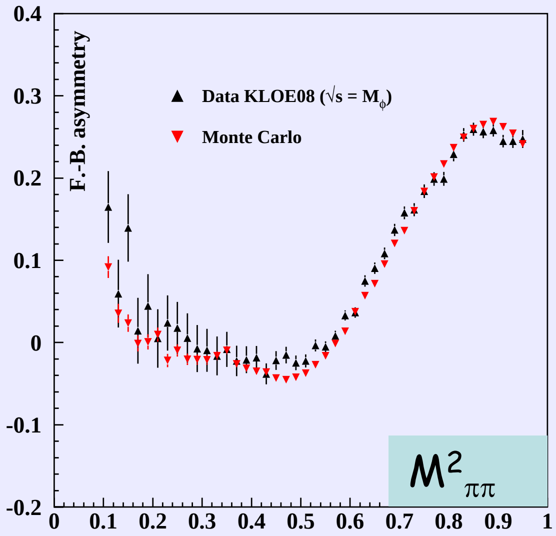


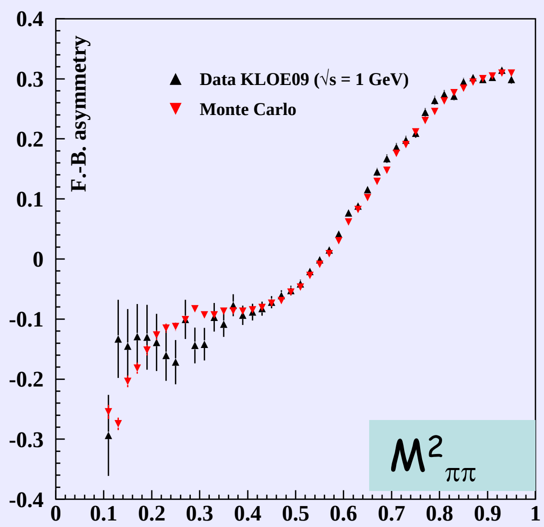
KLOE-2 expectation measuring also η' width with 1.4% accuracy



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

Physics in the continuum: hadronic cross-section





Hadronic cross section at low energy to obtain hadronic contributions to

$(g-2)_\mu$

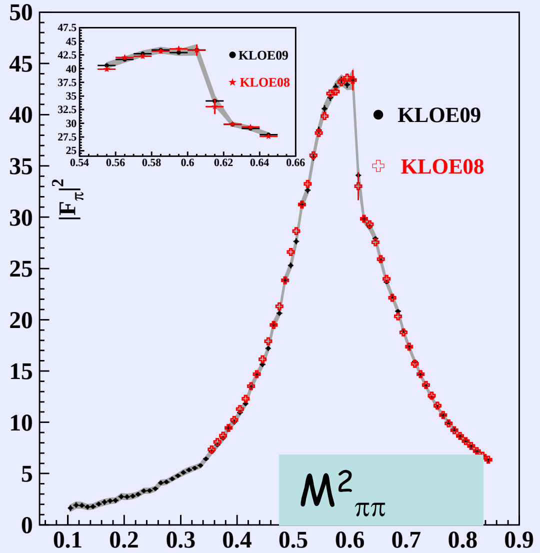
$\alpha(M_Z)$

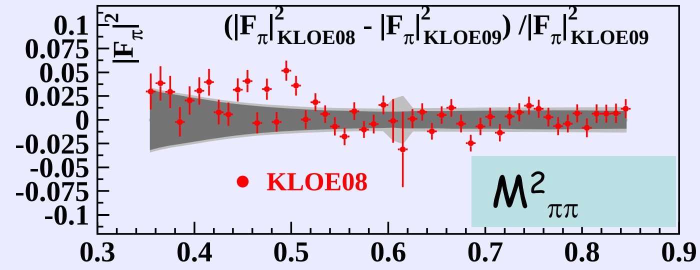
Independent measurements of $\pi\pi\gamma$ cross section with

- small-angle photons
- large-angle photons and $s = 1\ GeV^2$ to avoid the badly-known scalar contributions
- with $\pi\pi\gamma$ normalization to $\mu\mu\gamma$ event

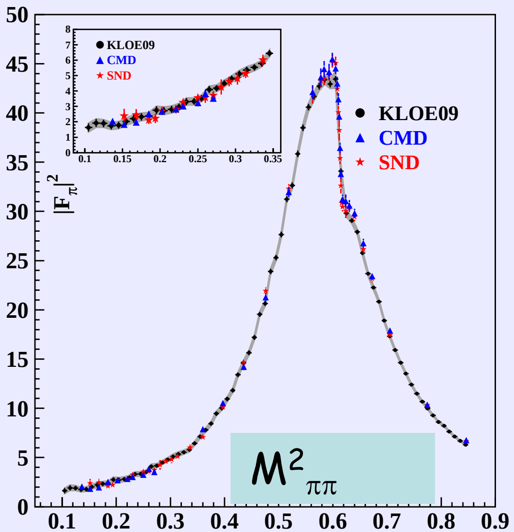
Di-pion cross section as a functions of s using ISR events and the radiator function H(s,s')

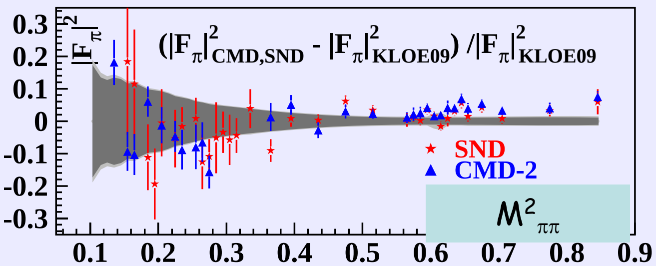
KLOE results



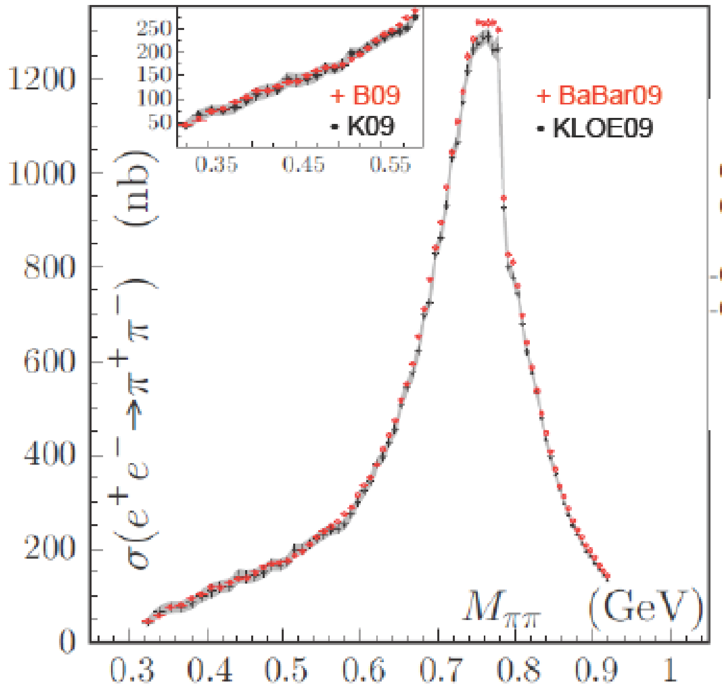


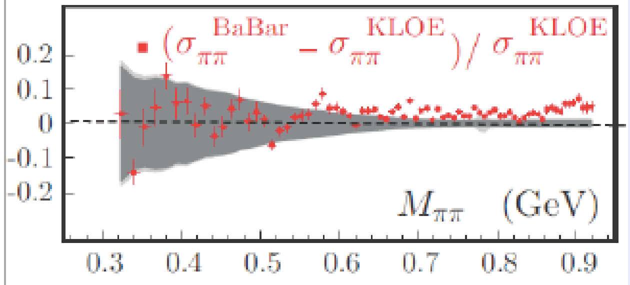
- The most recent result with photons at large angle are from s = 0.1 GeV^2 very near the di-pion threshold
- Results consistent with the analysis of events with photons at small angle





Comparison with BaBar





band: KLOE09 error

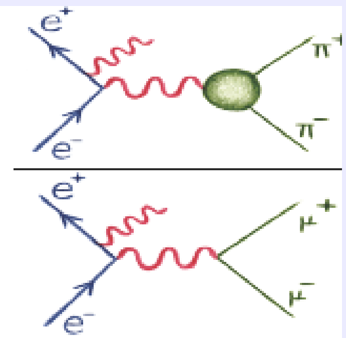
Agreement within errors below 0.6 GeV; BaBar higher by 2-3% above

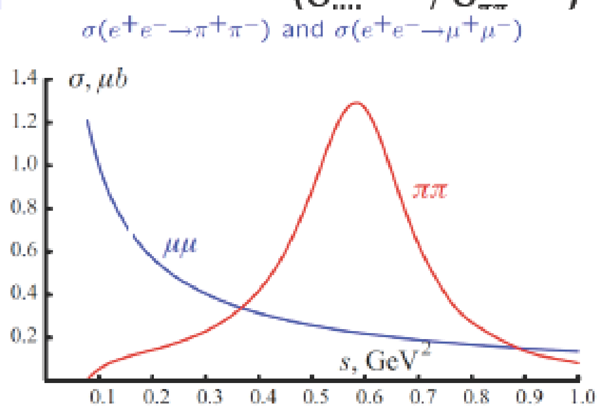
Normalization to $\mu\mu\gamma$

- The measurement does not depend from corrections for vacuum polarization and from the luminosity measurement
- The analysis is well advanced: preliminary results in Summer

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

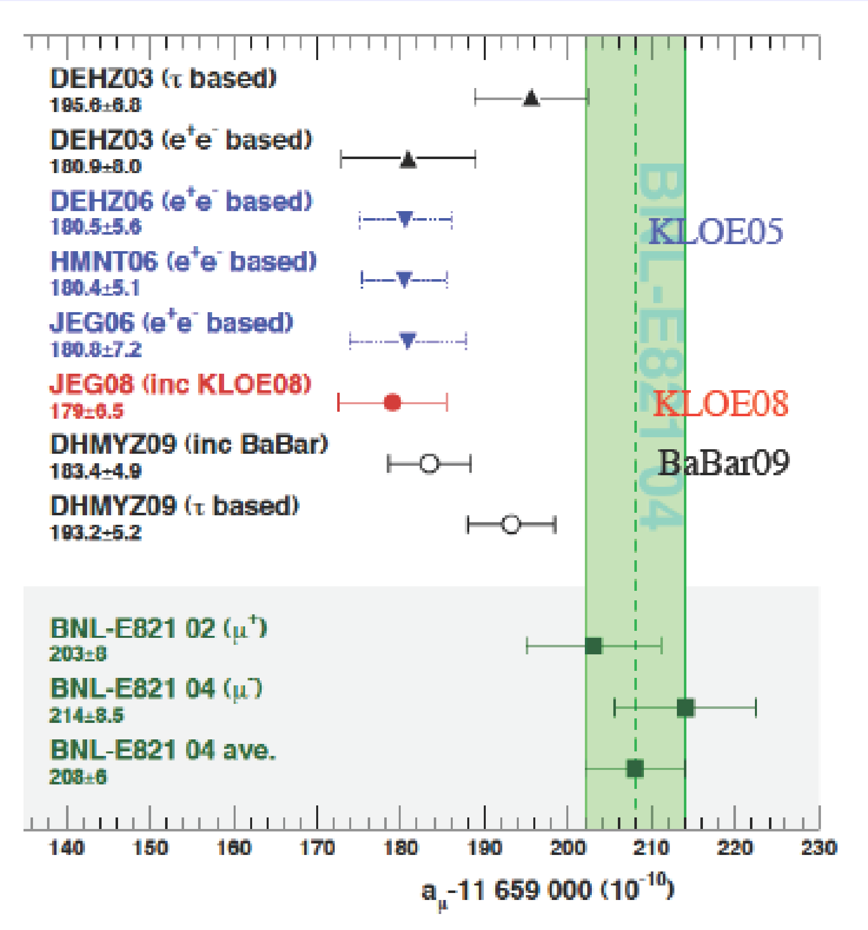
kinematical factor ($\sigma_{....}^{Born} / \sigma_{....}^{Born}$) — meas. quantities





μ-ID in the ρ region to be carefully controlled

The results on $(g-2)_\mu$



KLOE-2 results with photons at large angle not included yet

The 2% discrepancy with BaBar above the ρ peak to be investigated

Next KLOE results with the sample normalized to $\mu\mu\gamma$ can give an answer

Improvement by a factor of 2 in a_μ^{HLO} calls for both, improvements of the di-pion cross section near threshold, and the multi-hadronic cross sectio in the [1-2.5] GeV region

Hadronic contribution to α_{em}

G.Isidori

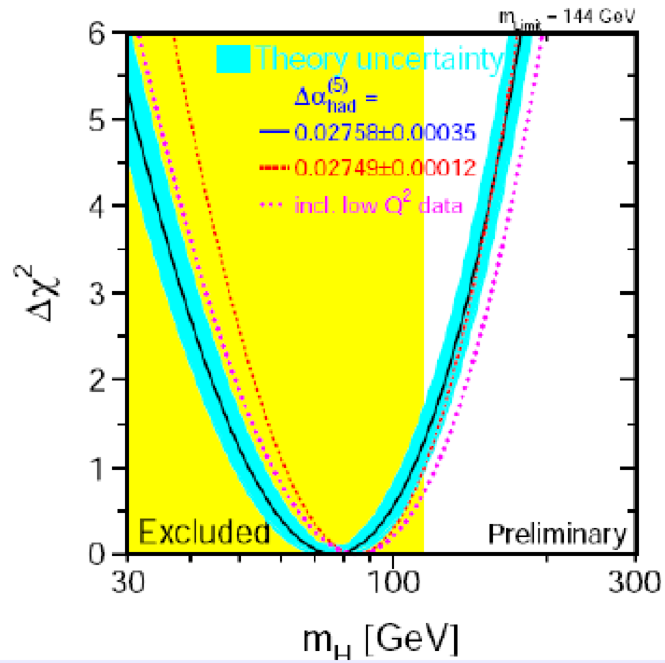
While $\alpha_{em}(m_e)$ is known with an incredible precision [~3×10^{-9} !], the error on $\alpha_{em}(M_Z)$ - the effective coupling relevant at the electroweak scale- is much larger because of hadronic uncertainties:

$$\frac{\Delta\alpha_{em}(M_Z)}{\alpha_{em}(M_Z)} \sim (1\text{-}4)\times10^{-4}$$

Significant source of uncertainty →
(given the precision reached on other e.w. fundamental couplings)

$$\frac{\delta G_\mu}{G_\mu} \sim 8.6\times10^{-6}$$

$$\frac{\delta M_Z}{M_Z} \sim 2.4\times10^{-5}$$



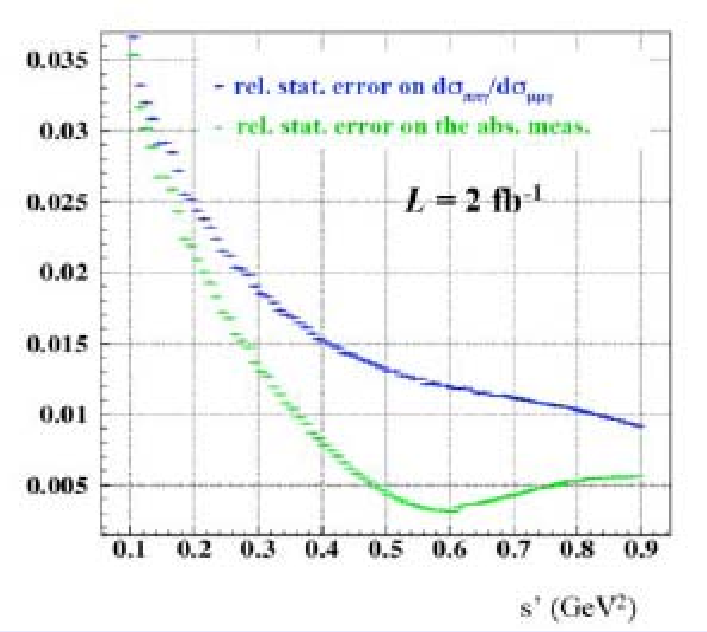
A reduction of the uncertainty on σ_{had} @ ($1 < \sqrt{s} < 2$) GeV from 5% to 1% needed to have

$\delta\alpha_{em}/\alpha_{em} \cong \delta G_\mu/G_\mu \cong \delta M_Z/M_Z \cong O(10^{-5})$

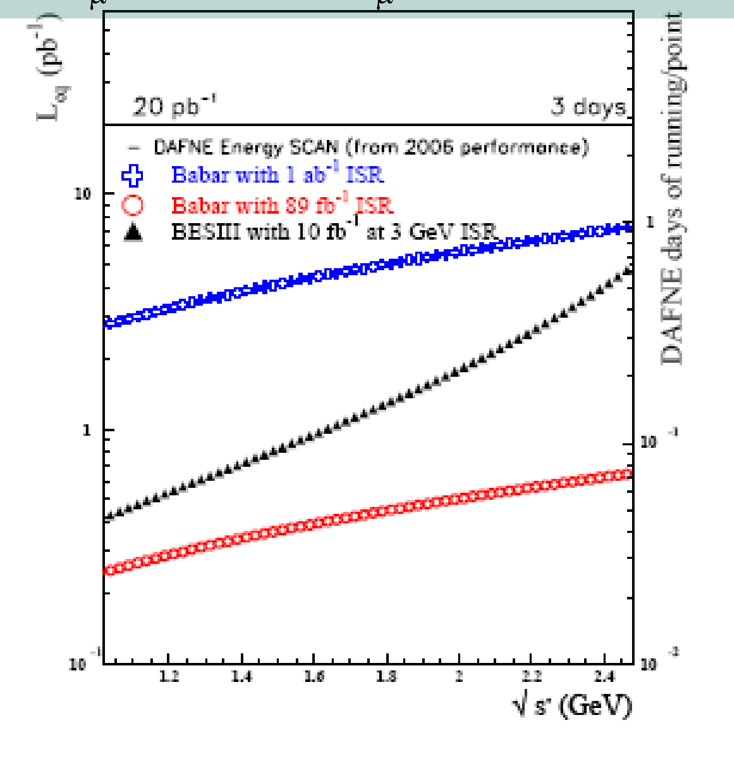
Data taking proposal at KLOE-2

The 0.7% uncertainty in σ_{had} at $\sqrt{s}<1$ GeV can be reduced to 0.4% with O(fb-1) off-peak integrated luminosity at DAFNE

Reduction of the uncertainty on σ_{had} @ ($1 < \sqrt{s} < 2$) GeV from 5% to 2% is also needed to have $\delta a_\mu^{had,LO} \cong \delta a_\mu^{had,LBL}$ and $\delta a_\mu^{SM} \cong 4.2\ 10^{-10}$

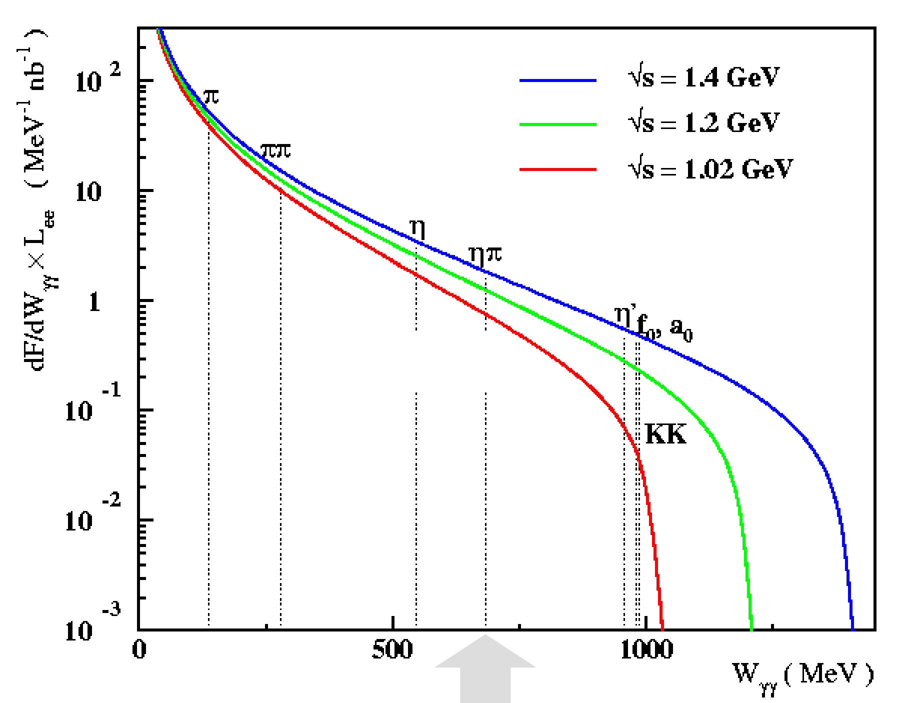


Di-pion production threshold:
Run at $s \leq 1$ GeV^2



Direct scan above 1 GeV
with DAφNE upgrade in energy

Physics in the continuum: $\gamma\gamma$ physics



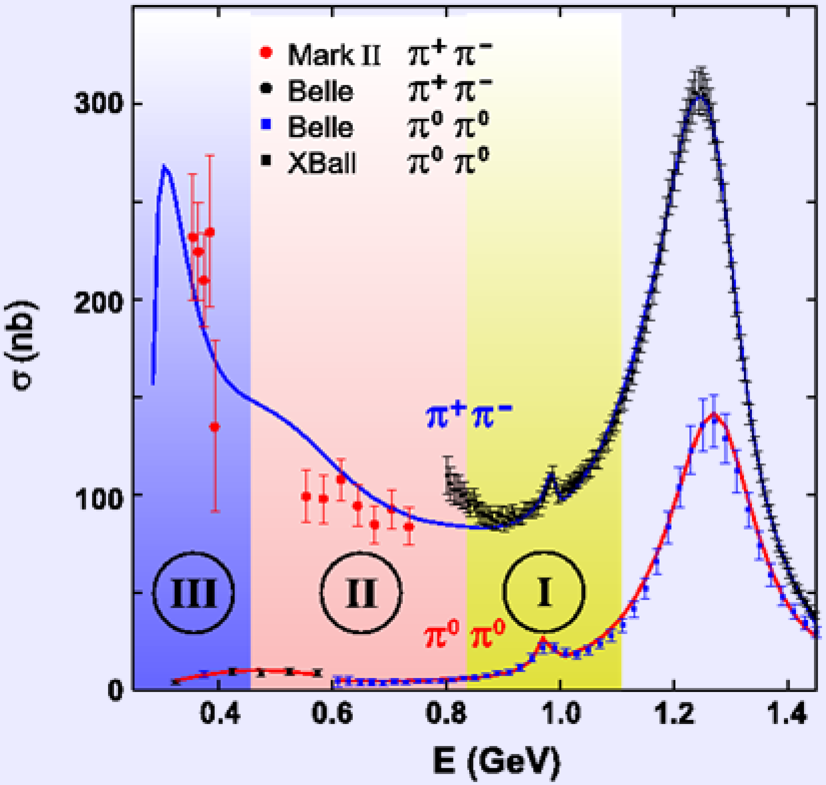
$L_{int} = 1\ fb^{-1}$

$\sqrt{s}$ (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

Meson $\gamma\gamma$ widths

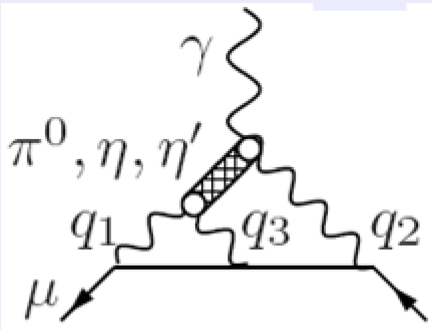
Pseudoscalar FF and contribution to LbL

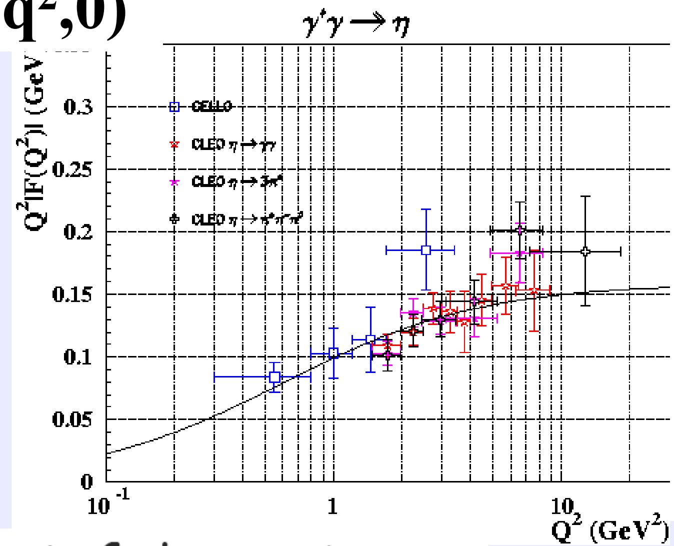
Scalar study via $\pi\pi$ spectrum

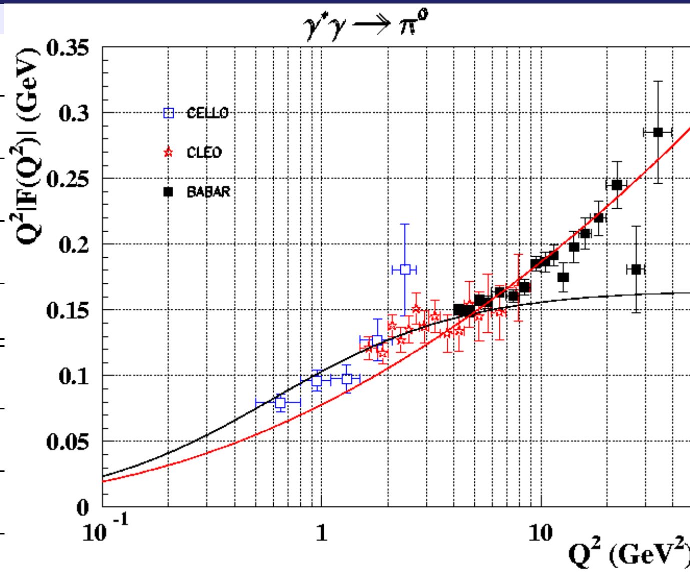


Pseudoscalar ff and LbL

$\gamma^*\gamma \rightarrow P$ ⇒ $F(P^2, q^2, 0)$

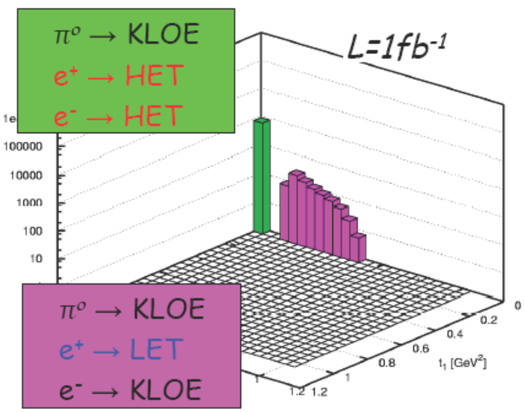






studies with **EKHARA Monte Carlo** generator

($e^+e^- \rightarrow e^+e^-\pi^0$ added in a new version)



Preliminary

- Henryk Czyz (Katowice)
- Sergiy Ivashyn (Katowice, Kharkov)

http://prac.us.edu.pl/~ekhara

Tagged sample needed for background reduction

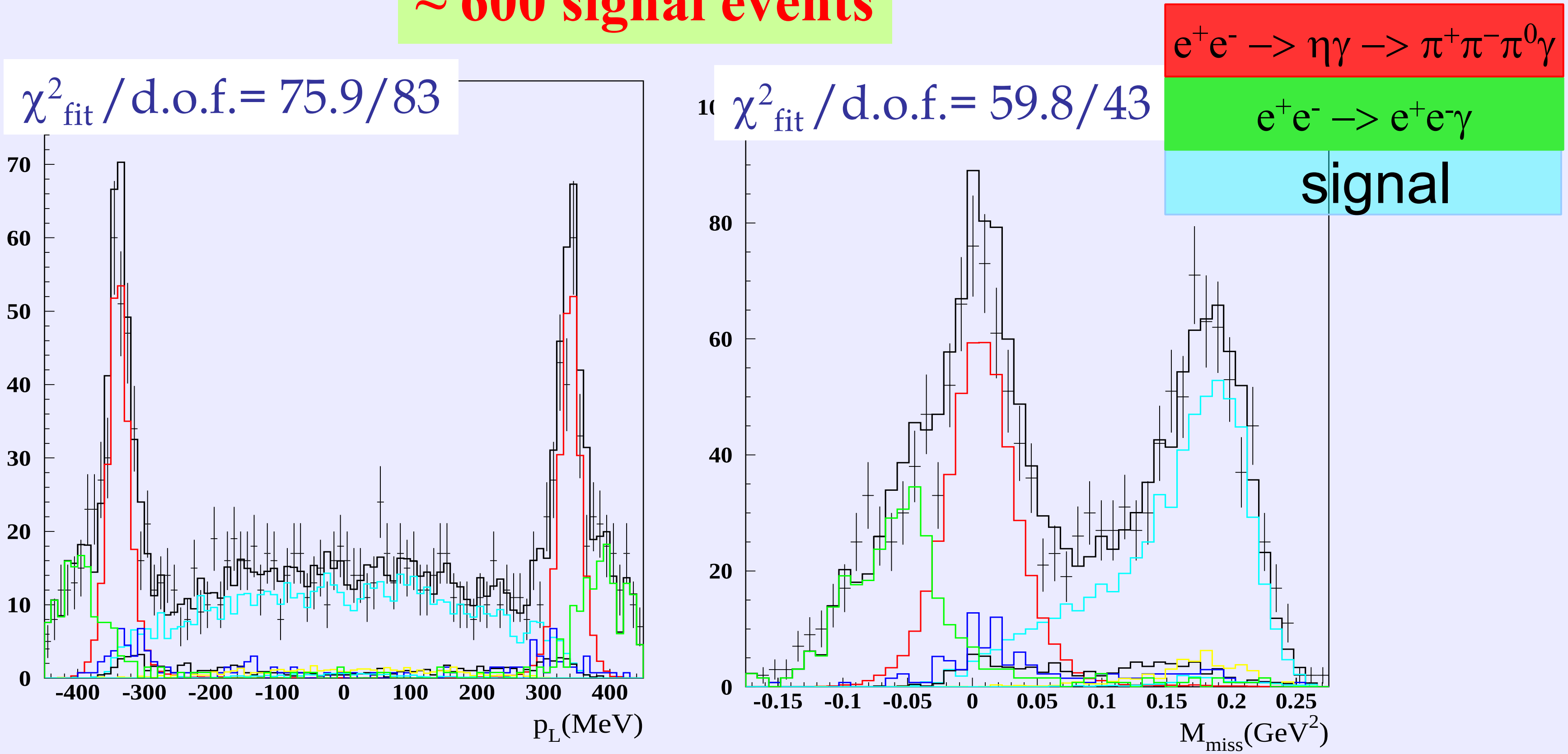
Ongoing studies at KLOE on the off-peak sample

$\gamma\gamma\to\eta$ from KLOE data at 1 GeV

PRELIMINARY

Fit to p_L and M_{miss}^2 with signal and background shapes

~ 600 signal events



- ❖ Extraction of $\sigma(e^+e^-\to e^+e^-\eta)$ and $\Gamma_{\gamma\gamma}$ in progress
- ❖ Statistical accuracy on $\Gamma_{\gamma\gamma}$ comparable with existing measurements

Dark forces

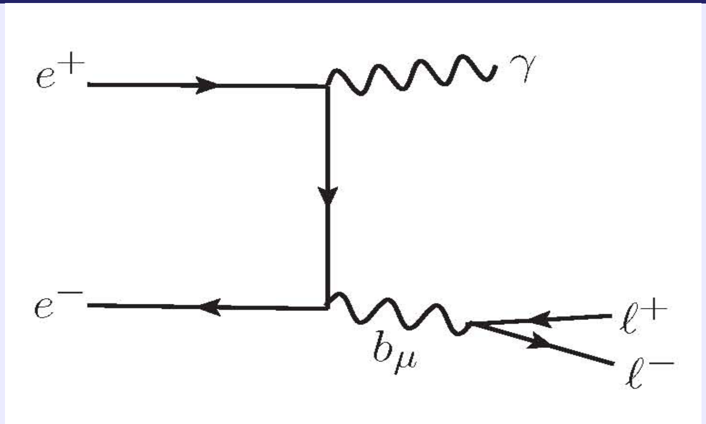
Recent puzzling astrophysical observations (PAMELA, ATIC, INTEGRAL, DAMA) can be interpreted by postulating the existence of some secluded gauge sector with at least one low ($\mathcal{O}$(1 GeV)) mass force mediator ("*U*" boson)

The secluded sector can be used to explain the dark matter puzzle. Hence the nickname of "dark forces"

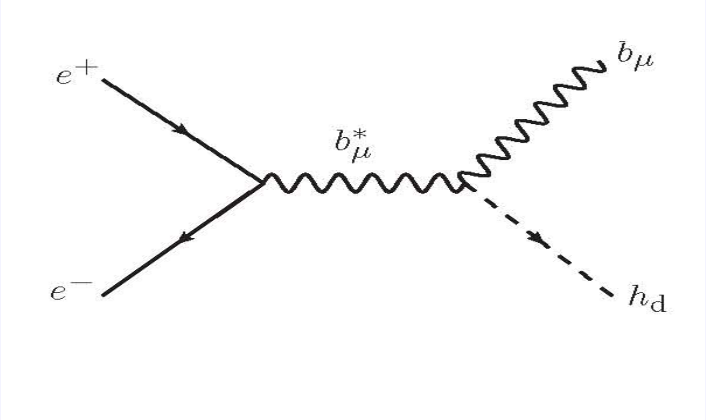
Standard Model particles are weakly coupled with the secluded ones through a kinetic mixing mechanism with a strenght ε that can be of order up to 10^{-2} – 10^{-3}

The cross sections of these processes scale typically as 1/s, thus their observation at lower energy colliders is in principle favourite wrt higher energies ones, as long as kinematically allowed.

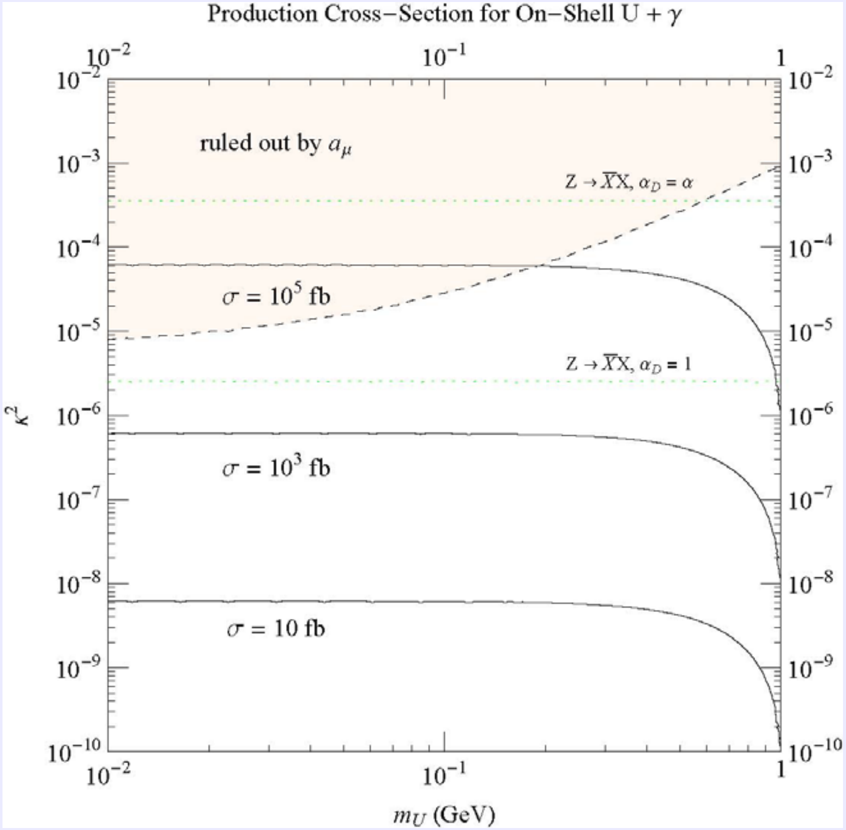
Processes to search for



"Dark photon" (*U* boson) resonant production in $e^+e^- \to l^+l^-\gamma$ events



" Higgs'-strahlung" in $e^+e^- \to l^+l^-$ + missing energy events



On shell *U* boson production

U-boson in meson decays

Radiative decay channels wth one photon replaced by one *U* meson and BR ~ε^2 $BR(\rightarrow \gamma X)$

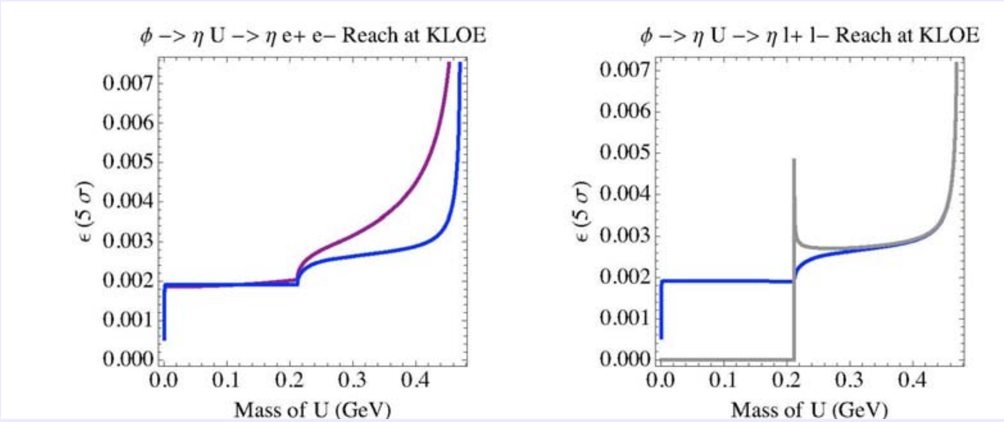
For $BR(\rightarrow \gamma X)$ ~10^{-2} ~10^9 mesons are needed to reach a sensitivity to $\varepsilon \sim 10^{-3}$

At DAFNE 3×10^9 ϕ / fb^{-1} are produced. The channel to look at is $\Phi \rightarrow \eta U$

The η meson can be identified through its 3π or $\gamma\gamma$ decays

A study on the potentials of KLOE, using present statistics, was done by Reece and Wang (*arXiv:0904.1743*)

The conclusion of the work is that KLOE(2) can be sensitive to mixing parameters down to $\varepsilon \sim 10^{-3}$



U-boson associated to η decays

Reece and Wang *arXiv:0904.1743*

$X \to YU$	n_X	$m_X - m_Y$ (MeV)	BR$(X \to Y + \gamma)$	BR$(X \to Y + \ell^+\ell^-)$	$\epsilon \leq$
$\eta \to \gamma U$	$n_\eta \sim 10^7$	547	$2 \times 39.8\%$	6×10^{-4}	2×10^{-3}
$\omega \to \pi^0 U$	$n_\omega \sim 10^7$	648	8.9%	7.7×10^{-4}	5×10^{-3}
$\phi \to \eta U$	$n_\phi \sim 10^{10}$	472	1.3%	1.15×10^{-4}	1×10^{-3}
$K_L^0 \to \gamma U$	$n_{K_L^0} \sim 10^{11}$	497	$2 \times (5.5 \times 10^{-4})$	9.5×10^{-6}	2×10^{-3}
$K^+ \to \pi^+ U$	$n_{K^+} \sim 10^{10}$	354	-	2.88×10^{-7}	7×10^{-3}
$K^+ \to \mu^+ \nu U$	$n_{K^+} \sim 10^{10}$	392	6.2×10^{-3}	7×10^{-8a}	2×10^{-3}
$K^+ \to e^+ \nu U$	$n_{K^+} \sim 10^{10}$	496	1.5×10^{-5}	2.5×10^{-8}	7×10^{-3}

Ongoing analysis on KLOE data

First milestones at KLOE-2

- The KLOE-2 analysis board worked out the milestone to focus the efforts of the collaboration

  - $\gamma\gamma$ physics : measurement of the acceptance vs Q^2

  - $\phi \to \eta\, e^+ e^-$: measurement of the form factor
  - $\eta' \to \eta\, \pi^+ \pi^-$: measurement of the $M_{\pi\pi}$ distribution
  - $\phi \to Ks\, Ks\, \gamma$: improved upper limit, first evidence of the decay

  - Exclusion plot for $e^+ e^- \to U\gamma \to l^+ l^- \gamma$,
    $e^+ e^- \to \eta U \to \eta\, l^+ l^-$
    $e^+ e^- \to h\, \gamma \to X_{Miss}\, l^+ l^-$

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

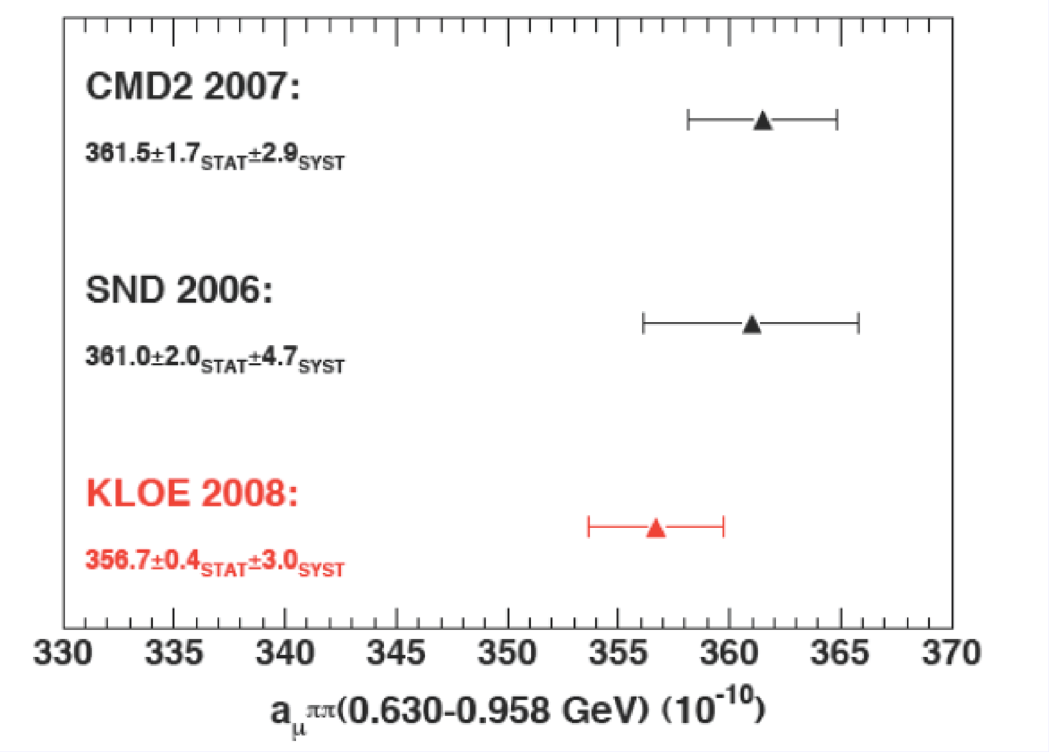
Conclusions

- KLOE has been able to address many topics of fundamental physics with precision measurements in kaon physics, η/η' decays, low-mass scalars, and hadronic cross section
- The physics programme will continue at KLOE-2 which is ready for data taking at the upgraded DAϕNE

- Machine commissioning by the end of June
- A tagger system for $\gamma\gamma$ events has been installed
- The construction of the
  - inner tracker for improving on vertex reconstruction at the IR and
  - calorimeters to instrument the quadrupole region and to detect small-angle photons

  has been started to be ready for installation by September, 2011

Spares



CMD2 2007:
361.5±1.7STAT±2.9SYST
SND 2006:
361.0±2.0STAT±4.7SYST
KLOE 2008:
356.7±0.4STAT±3.0SYST
330
335
340
345
350
355
360
365
370
aμππ(0.630-0.958 GeV) (10-10)

Hadronic contribution to $(g\text{-}2)_\mu$

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

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

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%

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

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

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

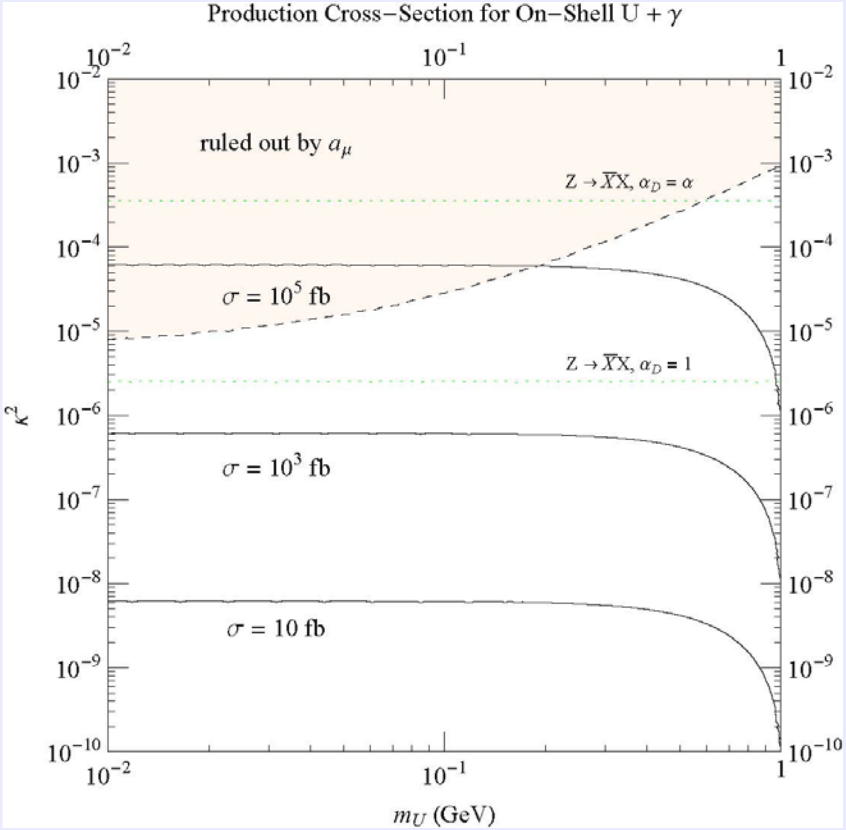
KLOE08 (small angle): $a_\mu^{\pi\pi} = (356.7 \pm 0.4_{stat} \pm 3.1_{sys}) \cdot 10^{-10}$

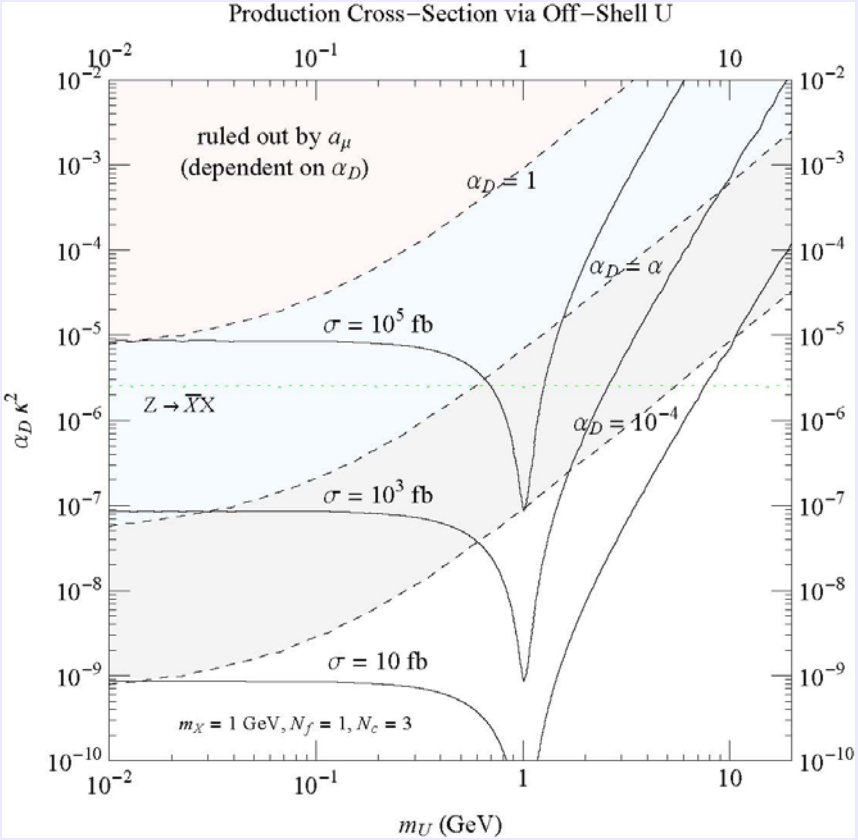
CMD-2: $a_\mu^{\pi\pi} = (361.5 \pm 1.7_{stat} \pm 2.9_{sys}) \cdot 10^{-10}$

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

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

Cross section





On shell *U* boson production

Multilepton events

η - η ' - G mixing

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

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Gluonium content in η' evaluated using Rosner model:

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

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

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

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

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

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

SU(3) relations between decay modes:

$$\frac{\Gamma(\eta' \to \rho\gamma)}{\Gamma(\omega \to \pi^0\gamma)} = C_{M2} Z_{NS} \left(\sin(\varphi_G)\cos(\varphi_P)\right)^2$$

$$R_\phi = \cot^2(\varphi_P)\cos^2(\varphi_G)\left(1 - C_V \frac{Z_{NS}}{Z_N} \frac{1}{\sin(2\varphi_P)}\right)^2 \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

$$\frac{\Gamma(\eta' \to \gamma\gamma)}{\Gamma(\pi^0 \to \gamma\gamma)} = C_{M1} \left(5\cos(\varphi_G)\sin(\varphi_P) + \sqrt{2}\frac{f_q}{f_s}\cos(\varphi_G)\cos(\varphi_P)\right)^2$$

$$\frac{\Gamma(\eta' \to \omega\gamma)}{\Gamma(\omega \to \pi^0\gamma)} = C_{M3} \left(Z_{NS}\sin(\varphi_G)\cos(\varphi_P) + 2C_V Z_S \sin(\varphi_G)\sin(\varphi_P)\right)^2$$

Gluonium content extracted using Z_N, Z_{NS} evaluated assuming $Z^2_{\eta'}=0$:

[Bramon et al., EPJC 7 (1999) ; PLB 503 (2001)]

$\varphi_P = (39.7 \pm 0.7)°$

$Z^2_{\eta'} = 0.14 \pm 0.04$

$P(\chi^2) = 49\%$

η - η ' - G mixing

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

Other SU(3) relations :

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

Parameter	Old fit	New fit	New fit (no Pγγ)
Z🗎♒o	0.14 ± 0.04	0.105 ± 0.037	0.03 ± 0.06
ϕ_Π	(39.7 ± 0.7)°	(40.7 ± 0.7)°	(41.6 ± 0.8)°
$Z_{N\Sigma}$	0.91 ± 0.05	0.866 ± 0.025	0.85 ± 0.03
Z_Σ	0.89 ± 0.07	0.79 ± 0.05	0.78 ± 0.05
ϕ_ς	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%

- **Gluonium content @ ~3σ level confirmed**
- **Forcing $Z_{\eta'}$ =0** : $\phi_P = (41.6\pm0.5)°$ **with** $P(\chi^2)=1\%$
- **Discrepancy with Escribano-Nadal** ($Z_{\eta'} = 0.04 \pm 0.09$, $\phi_P = (41.4\pm1.3)°$ [JHEP05(2007)006] **due to Pγγ transitions**

$\eta - \eta' - G$ mixing

Gluonium content of the η' obtained from the KLOE measurements of ϕ radiative decays into η-η' (but not only …)

A recent work, by Chen et al., PRD79:014024(2009), obtains from the KLOE result, a glueball mass of 1.4±0.1 GeV

somewhat in contrast with the glueball mass from improved staggered fermions confirming the results of … calculations of M_G>2.1 GeV

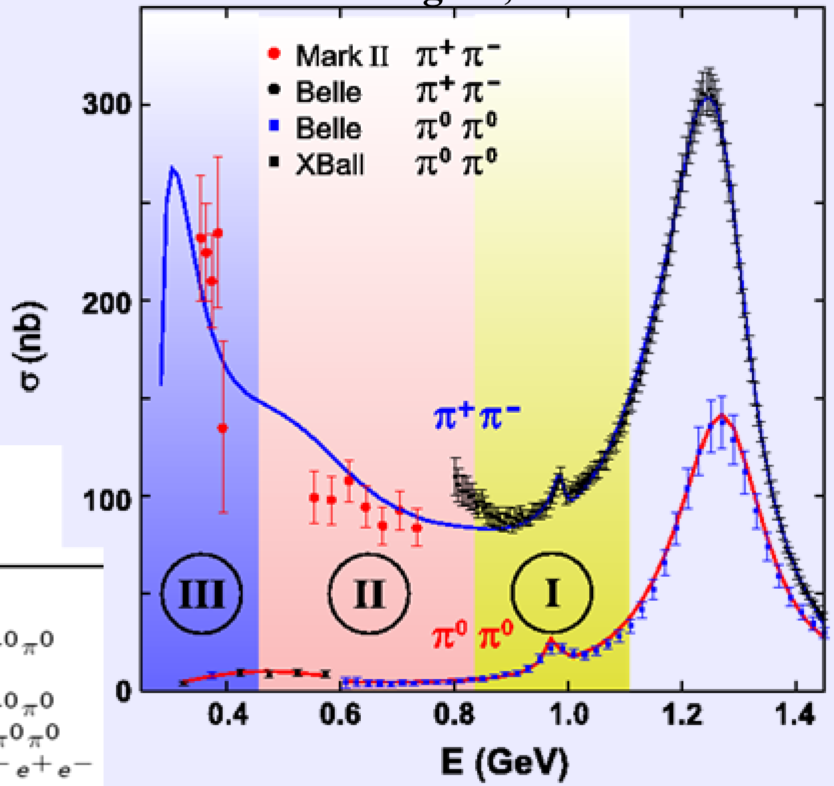
Search for $\gamma\gamma \rightarrow \sigma \rightarrow \pi\pi$

- Long debate about the experimental evidence of the σ(600) meson
- 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 $e^+e^- \rightarrow \pi^0\pi^0\gamma$ Dalitz plot analysis @ KLOE**

Only process to measure directly the $\sigma\gamma\gamma$ coupling → infer structure

$\pi^0\pi^0$ preferred w.r.t. $\pi^+\pi^-$ due to smaller background contamination

Pennington, arXiv:0906.1072



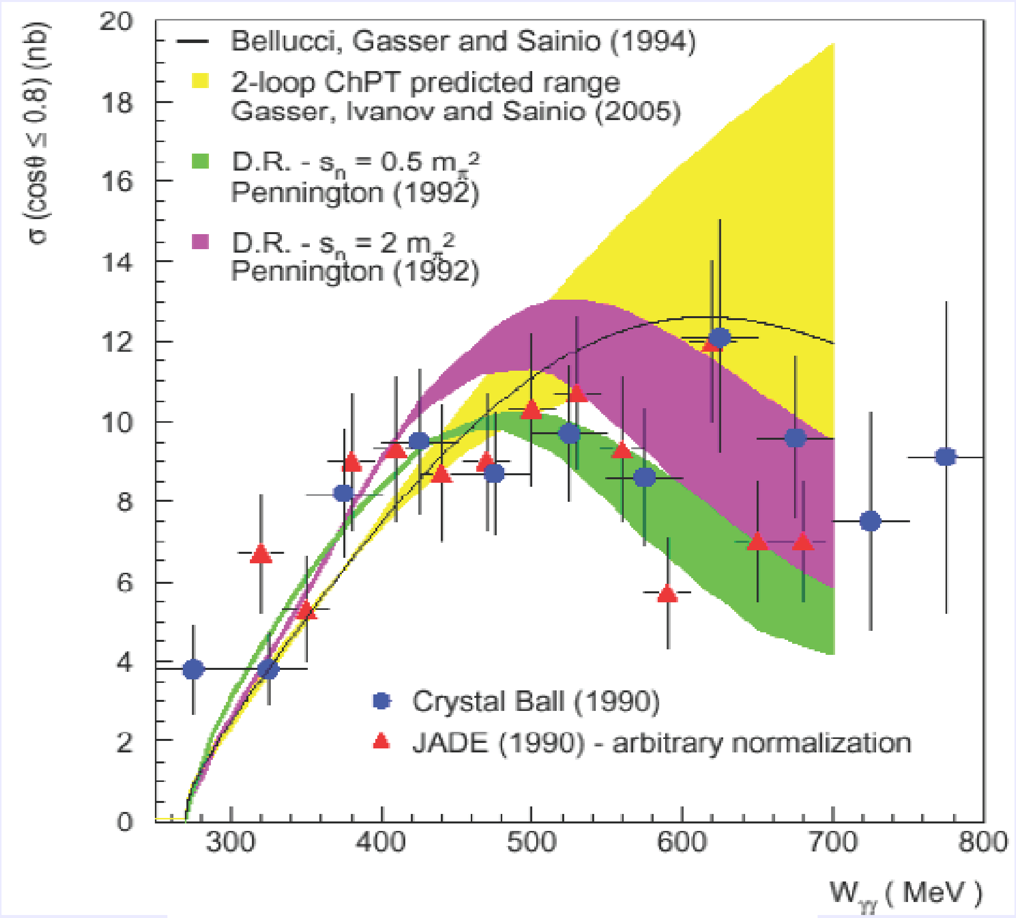
$f_0(600)$ PARTIAL WIDTHS

Γ(γγ)

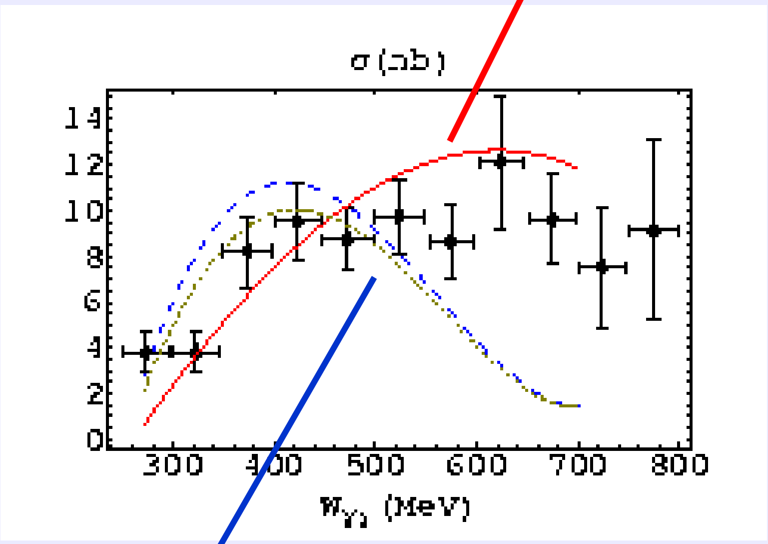
VALUE (keV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.2±0.4	[48] BERNABEU	08	RVUE	
3.9±0.6	[49] MENNESSIER	08	RVUE	$\gamma\gamma \rightarrow \pi^+\pi^-, \pi^0\pi^0$
4.1±0.3	[50] PENNINGTON	06	RVUE	$\gamma\gamma \rightarrow \pi^0\pi^0$
3.8±1.5	[51,52] BOGLIONE	99	RVUE	$\gamma\gamma \rightarrow \pi^+\pi^-, \pi^0\pi^0$
5.4±2.3	[51] MORGAN	90	RVUE	$\gamma\gamma \rightarrow \pi^+\pi^-, \pi^0\pi^0$
10 ±6	COURAU	86	DM1	$e^+e^- \rightarrow \pi^+\pi^-e^+e^-$

$\gamma\gamma \to \pi^0\pi^0$ at low energies

Cleanest channel to assess existence and nature of the ♦ meson



ChPT



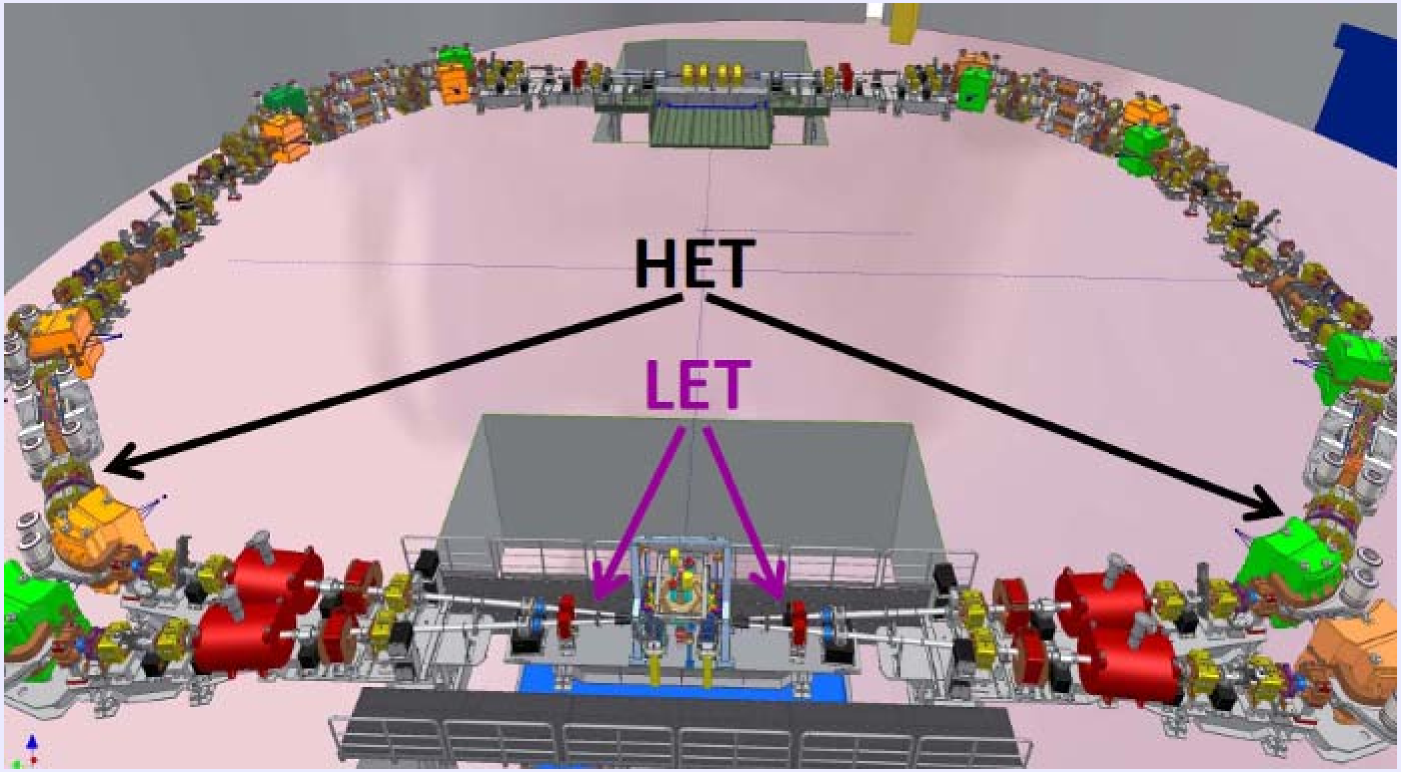
Resonant contribution

♑♑→♦→□□□□

[Nguyen, Piccinini, Polosa, EPJC 47 (2006) 65]

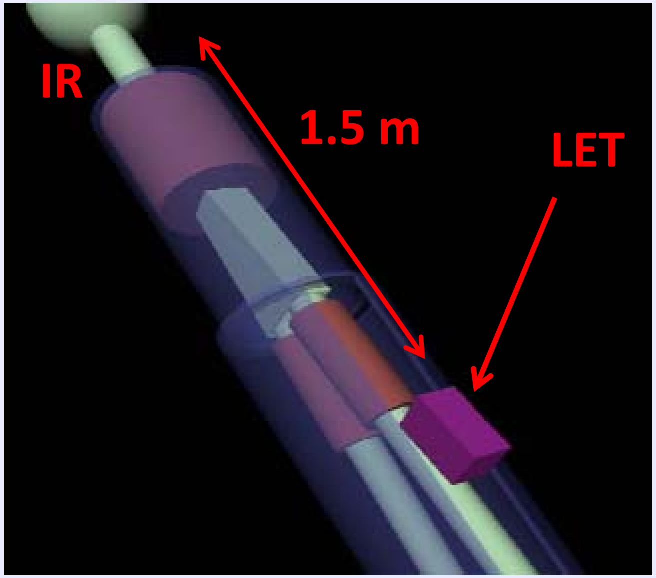
Tagger per la fisica $\gamma\gamma$

- **LET (Low Energy Taggers)** are LYSO calorimeters placed inside KLOE
- **HET (High Energy Taggers)** are scintillator hodoscopes placed at 11m on the beam line



Low-energy (e) tagger - LET

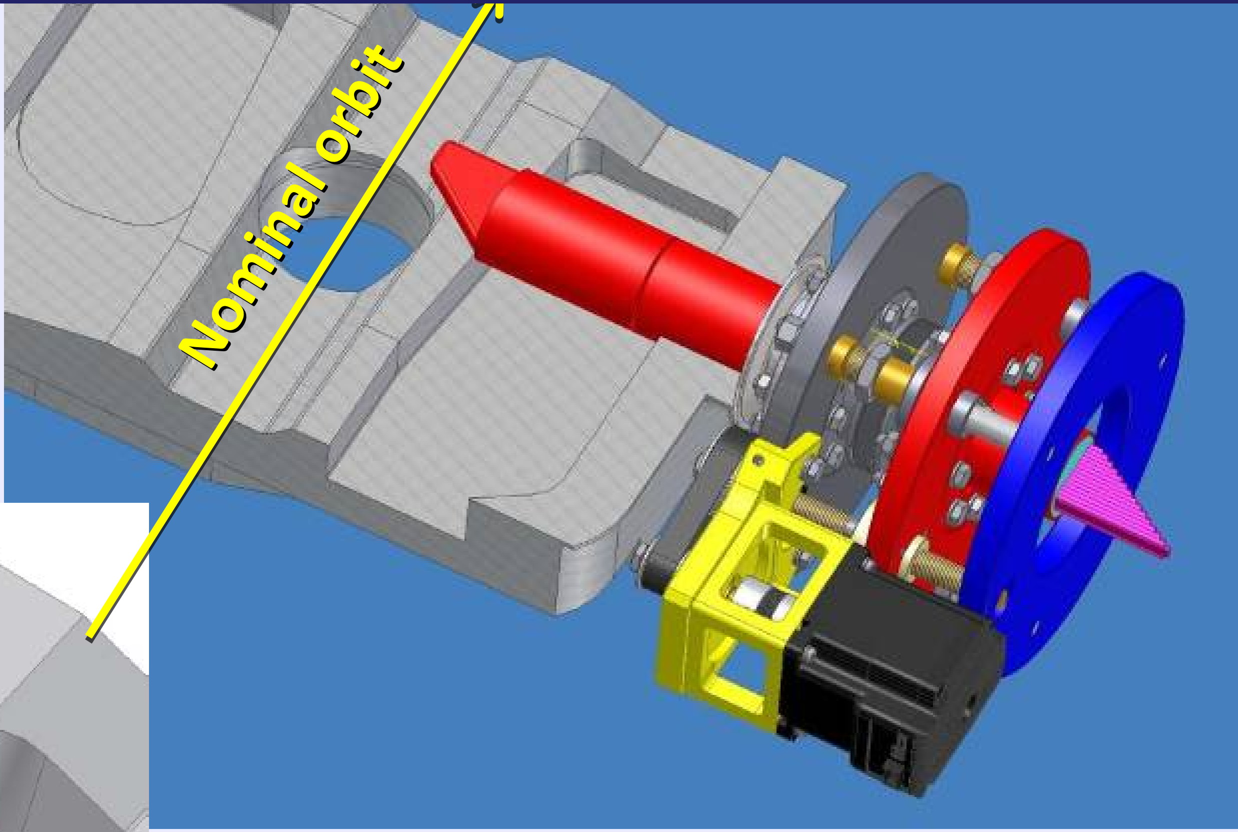
The detector is composed by a LYSO crystal matrix with SiPM readout

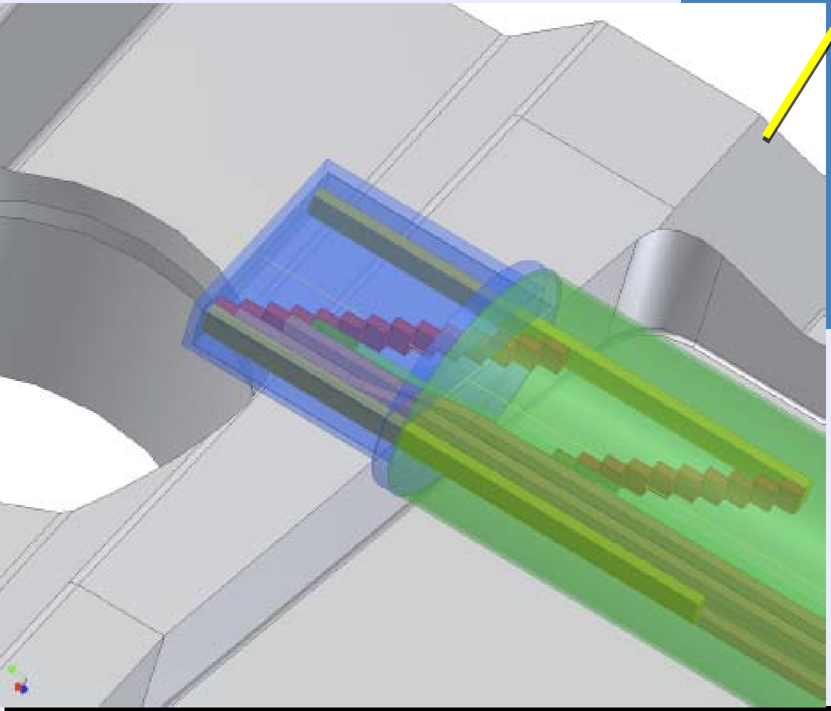


130-230 MeV/c electrons are tagged in this position

High-energy (e) tagger - HET

The hodoscope is composed by two rows of **15 3x5x6 mm^3 scintillators** + 2 3x5x120 mm^3 scintillators for coincidence to be inserted in the DAFNE beam-pipe with a dedicated **motorized driver**



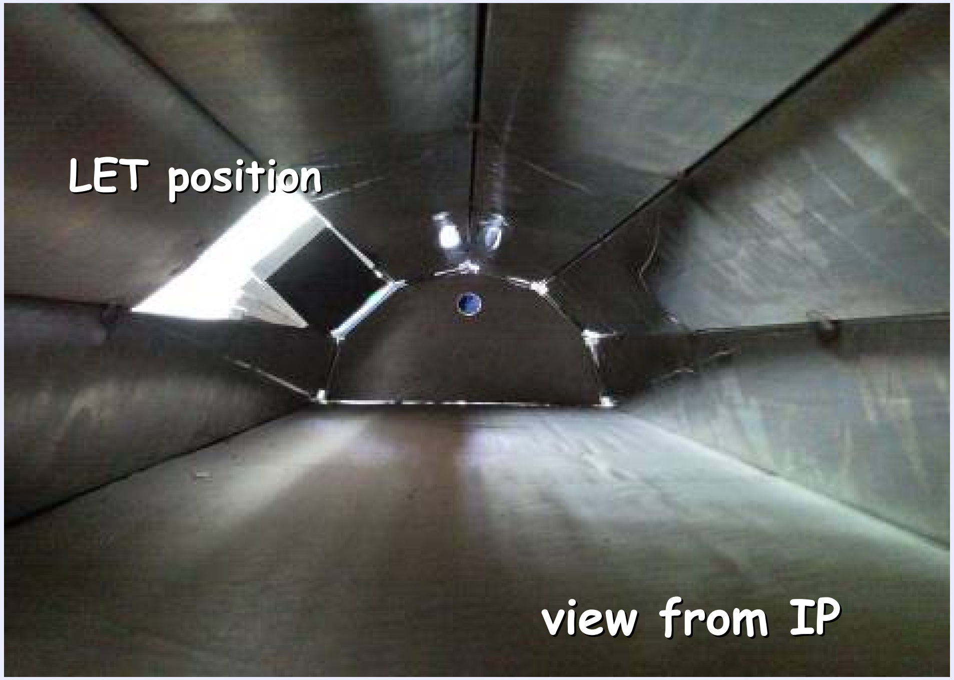


Le stazioni di tagging - HET

I pozzetti per l'installazione del rivelatore sono su DAFNE.
Il sistema di movimentazione è pronto

Alla partenza di DAFNE verranno inserite due strip di scintillatori per controllare i livelli di radiazione

Le stazioni di tagging - LET



La struttura modulare disegnata per QCALTcon gli schermi in Pb e la slitta per l'installazione del LET è stata realizzata in officina a Frascati

LET e FEE pronti per l'installazione

L'inserimento di beam pipe e LET in corso