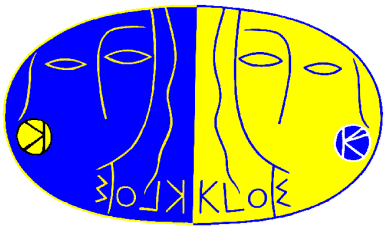
Dark Forces searches at the LNF
Present and Future



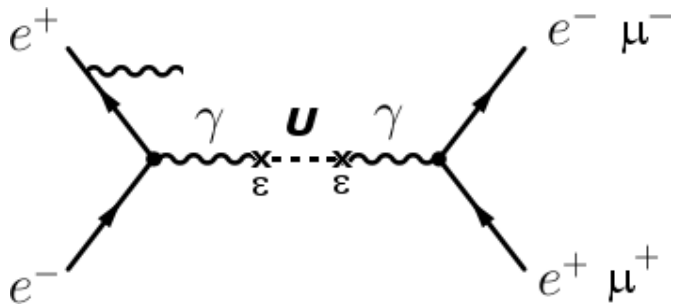
Elena Perez del Rio
On behalf of the KLOE-2 collaboration

AXIONS – One day workshop
INFN-LNF, Frascati
1st July 2016

Probing the dark sector – Why?

- Astrophysical observations
  - e^+/e^- excess in cosmic ray flux (PAMELA)
  - Total e^+/e^- flux (ATIC, Hess, Fermi)
  - Positron spectrum in primary cosmic rays (AMS)
  - 511 keV gamma ray signal from the galactic center (INTEGRAL)
  - DAMA/LIBRA annual modulation
  - Low energy spectrum of nuclear recoil dark matter candidate (CoGeNT)
- Particle physics puzzles
  - g-2 muon anomaly
- All could be explained by introducing a new low energy gauge interaction mediated by a neutral light mass vector particle, usually named the U boson, with a small kinetic mixing ε ($<10^{-3}$) with SM
- Dark vector boson U which mixes with photon:

$$\mathcal{L}_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$

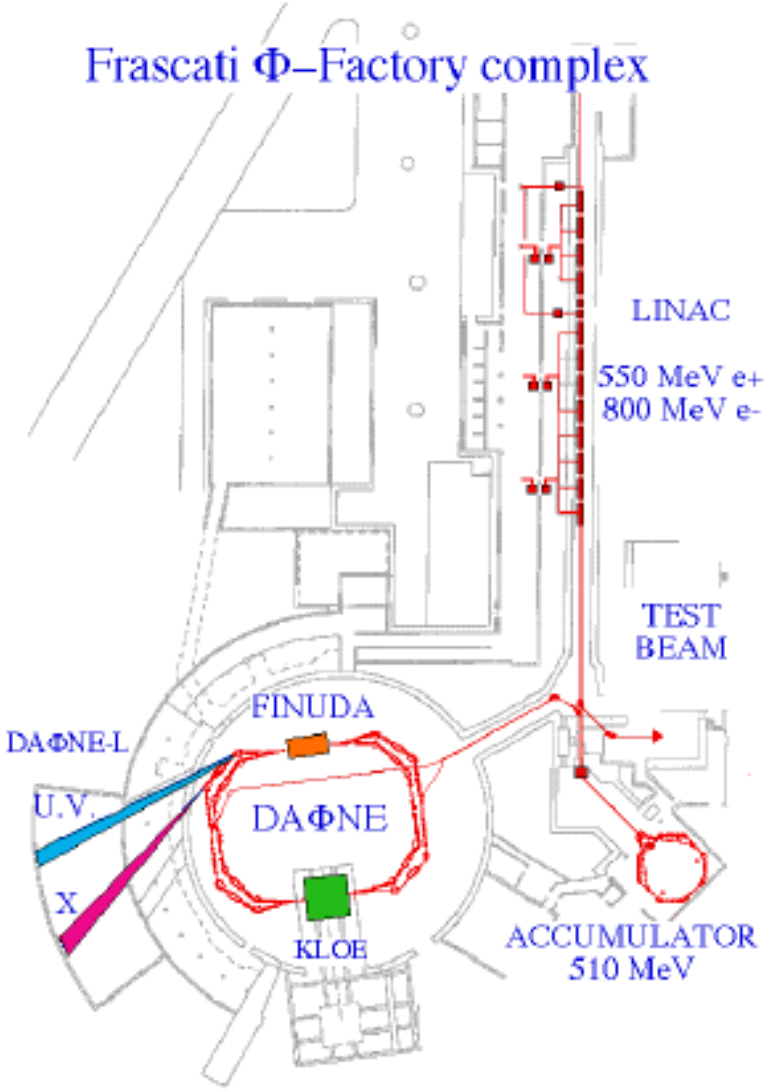


Probing the dark sector

- Experimental searches for Dark Forces can be achieved at:
  - e+e- colliders
    - Rare meson decays
    - Continuum
  - Beam dump and fixed target experiments

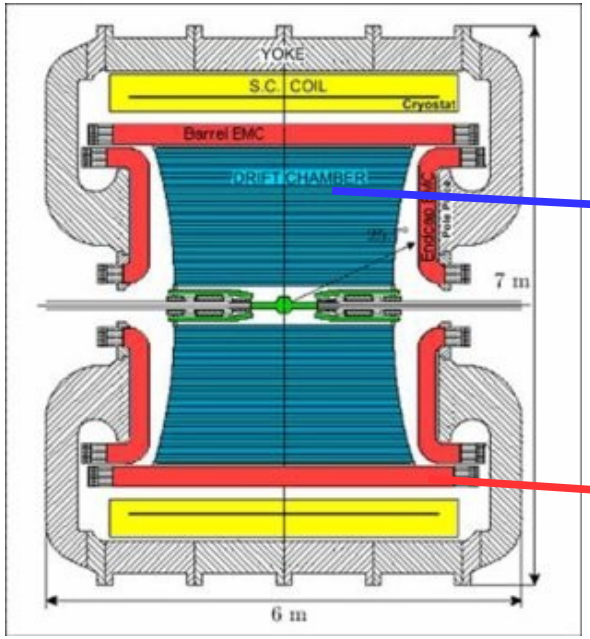
- KLOE/KLOE-2 is in a very good position to probe the dark sector at GeV scale:
  - It operates at DAFNE exactly at √s ~ 1 GeV
  - Most of the interesting dark process cross sections at e+e- colliders scale with 1/s: a factor ~ 100 wrt B factories, compensating for the integrated luminosity
  - Is a Φ factory → unique environment to study rare meson decays

DAΦNE
(Double Annular Φ Factory for Nice Experiments)



- Running period: 1999 – 2006
- $e^+ e^-$ collider $\sqrt{s} = M_\varphi = 1019.4$ MeV
- 2 interaction regions
- $e^+ e^-$ separated rings
- 105 + 105 bunches spaced by 2.7 ns
- $I^-_{peak} \sim 2.4$ A and $I^+_{peak} \sim 1.5$ A

KLOE
(K LOng Experiment)

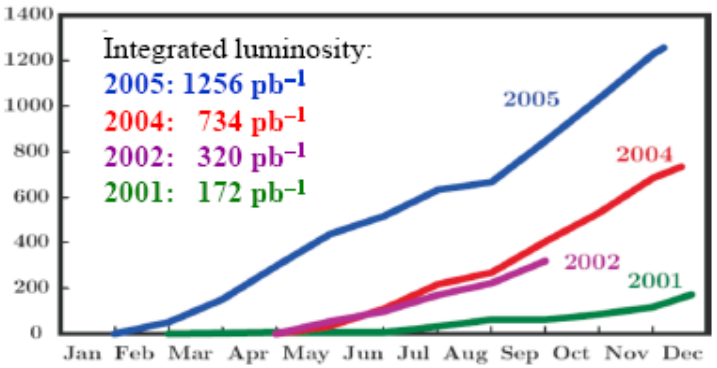


Magnetic field B = 0.52 T

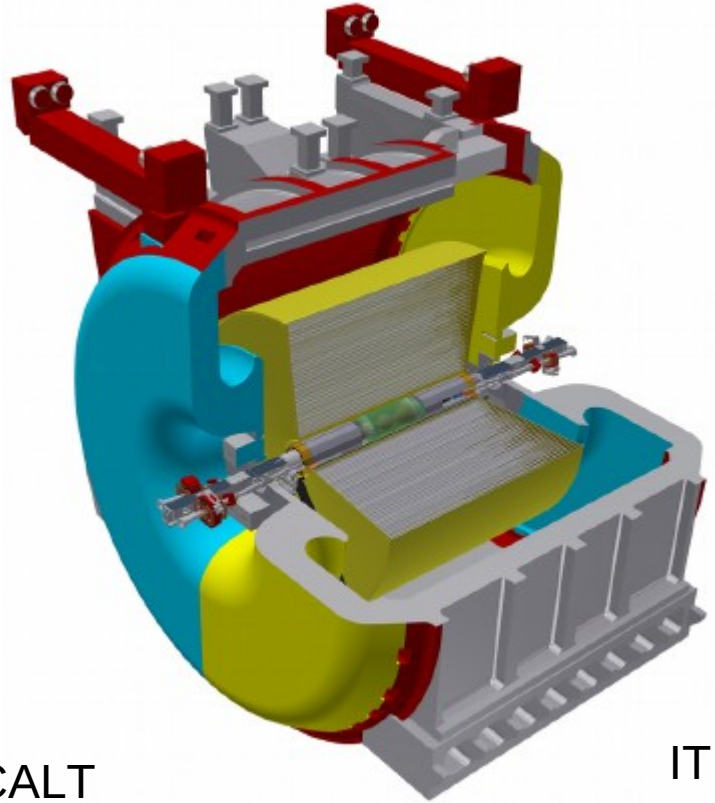
- Low-mass gas mixture 90% Helium + 10% isobutane
- $\delta p_\perp / p_\perp < 0.4\%$ ($\theta > 45°$)
- $\sigma_{xy} \approx 150$ μm ; $\sigma_z \approx 2$ mm
- 12582 sense wires
- Stereo geometry
- 4m diameter, 3.3m long

- 98% full solid angle coverage
- $\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$
- $\sigma_T = 57 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 100 \text{ ps}$
- Barrel + 2 end-caps:
  - Pb/scintillating fiber read out by 4880 PMTs

- KLOE data taking campaign ended in 2006
- 2.5 fb^{-1} acquired at $\sqrt{s}=M_\varphi$
- ~ 260 pb^{-1} off-peak

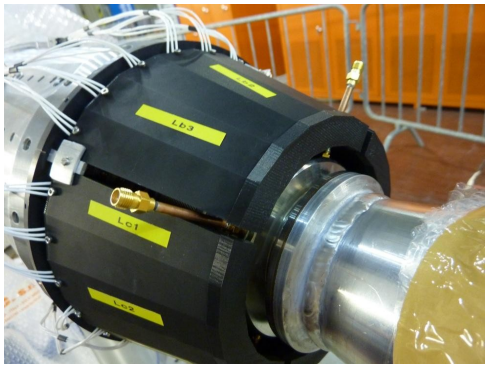


KLOE-2 Upgrade

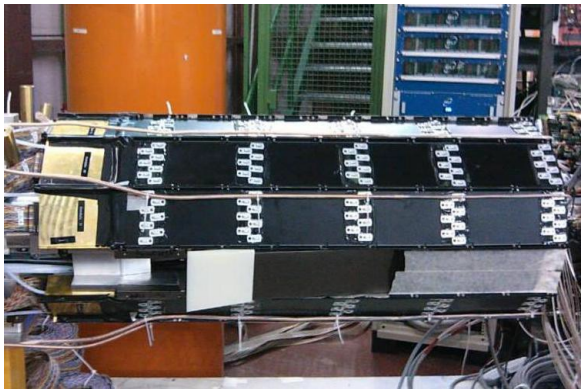


- CCALT (lyso-cristals) & QCALT (scintillator tiles and fibers with SiPM read-out)
  - 2 new calorimeters
  - Improvement acceptance at low polar angles
  - QUADS instrumentation for K_L decays
- Inner Tracker (IT)
  - 4 layers of triple Cylindrical-GEM
  - To improve vertex resolution at the IP
  - Larger acceptance for low p_t track acceptance

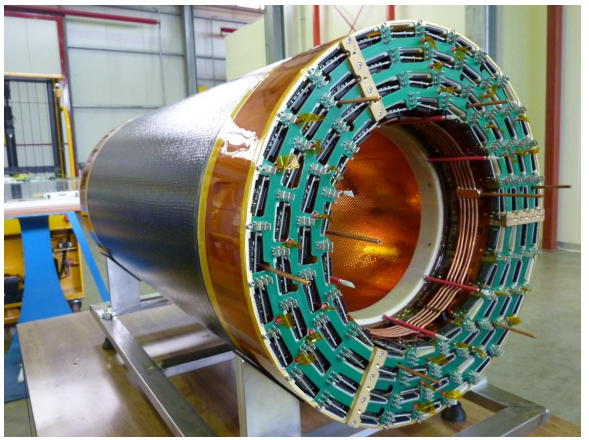
CCALT



QCALT

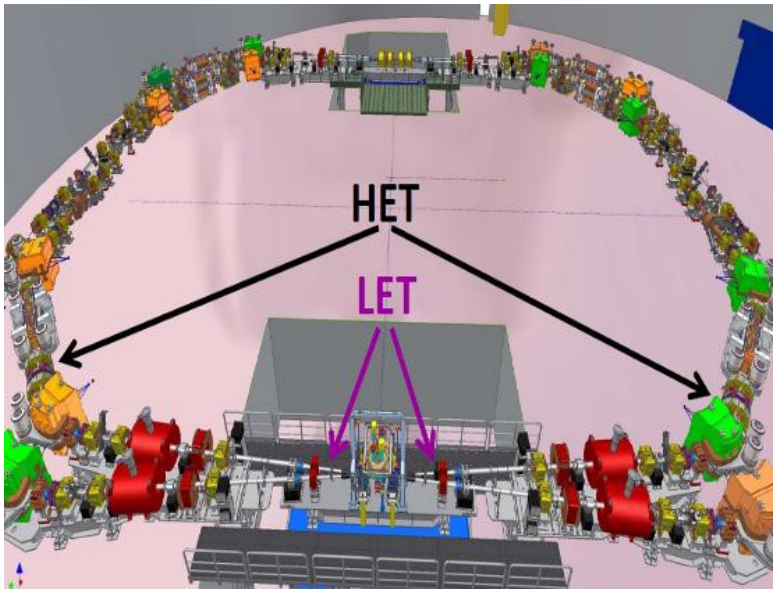


IT

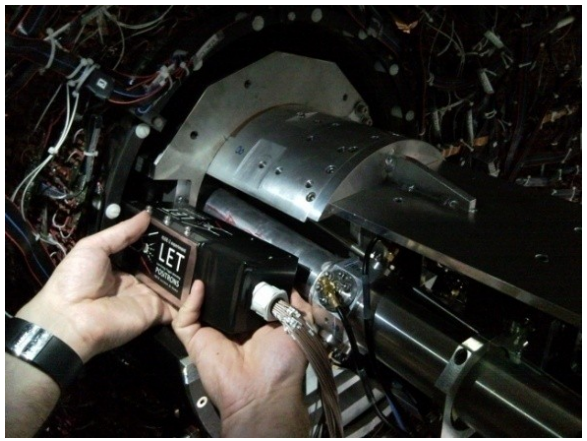


KLOE-2 Upgrade

- LET & HET
  - 2+2 e+e- tagger stations for γγ-physics
  - High Energy Taggers (HET)
    - Scintillator + PMT
    - 11 m from IP
    - E > 400 MeV
  - Low Energy Taggers (LET)
    - E = 160 – 230 MeV
    - Inside KLOE detector
    - LYSO with SiPM read-out

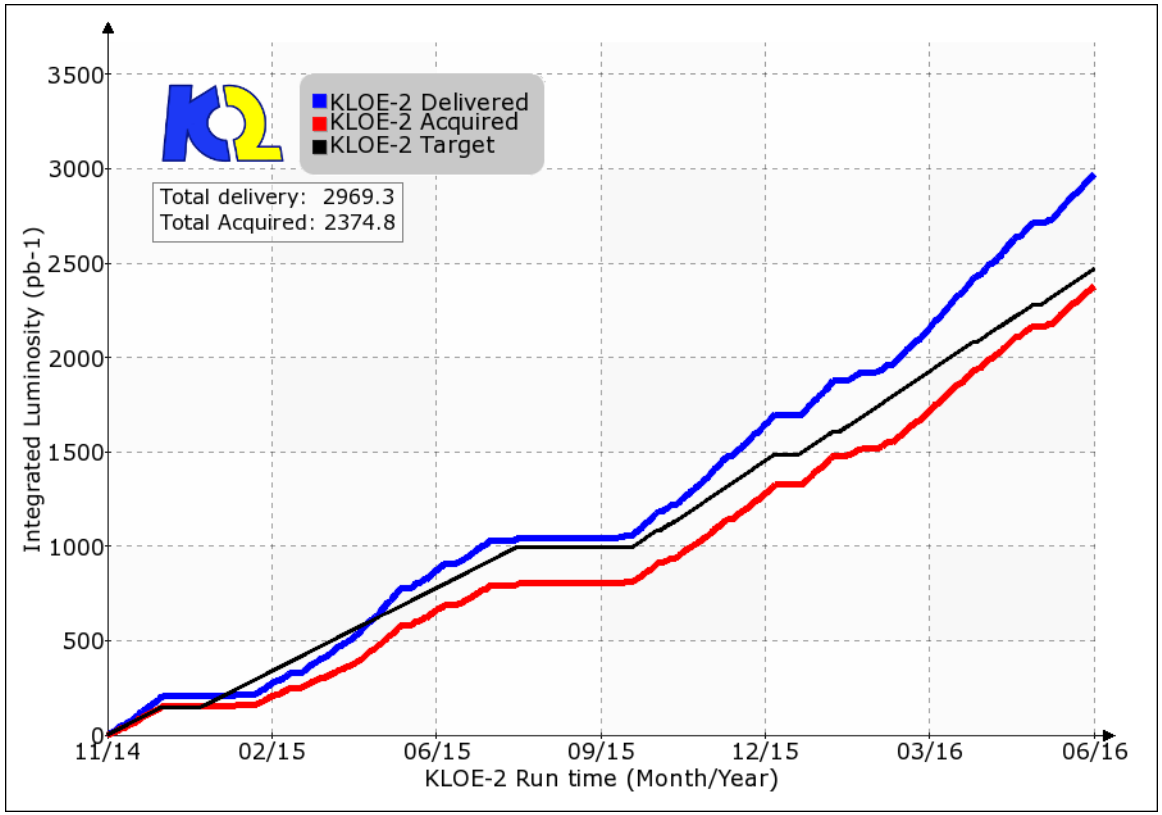


LET



HET

KLOE-2 Upgrade



Best performance

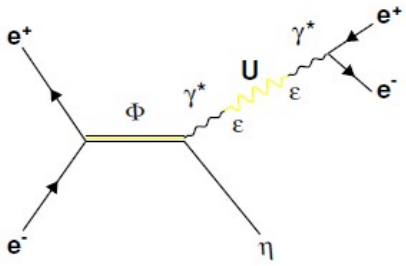
Max instantaneous: 2.21x1032cm^{-2}s^{-1}
Max hourly: 651.0 nb^{-1}
Max daily delivery: 13.4 pb^{-1}
Max daily acquired: 11.0 pb^{-1}
Max weekly delivered: 76.3 pb^{-1}
Max weekly acquired: 62.9 pb^{-1}

- KLOE-2 new data taking campaign started on November 2014
- It aims to collect more than 5 fb^{-1} within the next 2 years
- New detectors fully operative
- More than 2.3 fb^{-1} already collected

KLOE Dark Searches Summary

- KLOE searches:
  - Decay of the φ meson into a U boson + pseudoscalar η
    - $\varphi \rightarrow \eta U$ with $U \rightarrow e^+ e^-$ Phys. Lett B 706 (2012) 251-255 Phys. Lett B 720 (2013) 111-115
  - Associated Uγ production
    - $e^+ e^- \rightarrow U\gamma$ with $U \rightarrow \mu^+ \mu^-$ Phys. Lett B 736 (2014) 459-464
    - $e^+ e^- \rightarrow U\gamma$ with $U \rightarrow e^+ e^-$ Phys.Lett. B750 (2015) 633
    - $e^+ e^- \rightarrow U\gamma$ with $U \rightarrow \pi^+ \pi^-$ Phys.Lett. B757 (2016) 356-361
  - Higgsstrahlung process, in the $mh' < mU$ scenario, with an invisible Higgs
    - $e^+ e^- \rightarrow Uh'$ with $h' \rightarrow$ invisible Phys.Lett. B747 (2015) 365-372

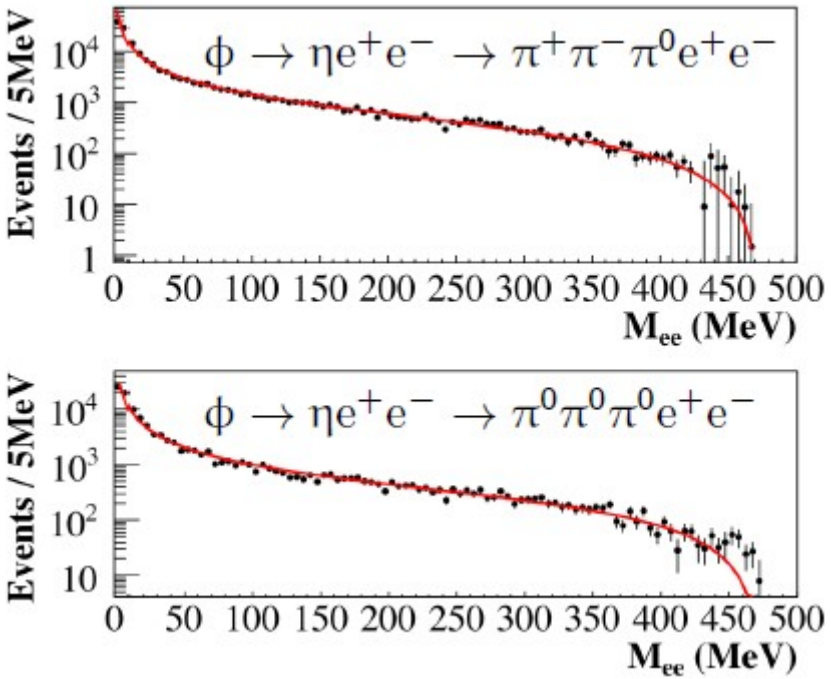
$\Phi \rightarrow \eta U$ with $U \rightarrow e^+e^-$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ / $\pi^0\pi^0\pi^0$



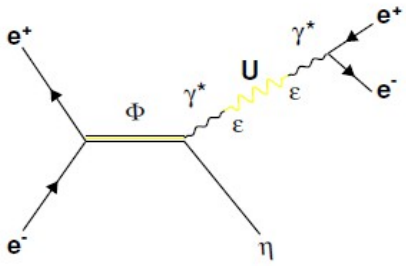
Phys. Lett B 706 (2012) 251-255
Phys. Lett B 720 (2013) 111-115

- $\varphi \rightarrow \eta e^+e^-$ irreducible background
- Simulated with a Vector Meson Dominance parameterization
- Combined analysis
  - $\eta \rightarrow \pi^+\pi^-\pi^0$
    - ~ 13000 events and 2% background
  - $\eta \rightarrow \pi^0\pi^0\pi^0$
    - ~ 31000 events and 3% background
    - Phys. Lett B 720 (2013) 111-115

Di-electron mass spectrum



$\Phi \rightarrow \eta U$ with $U \rightarrow e^+e^-$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ / $\pi^0\pi^0\pi^0$



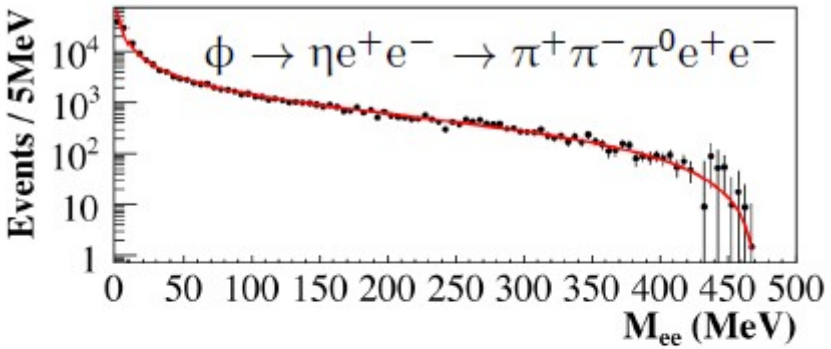
Phys. Lett B 706 (2012) 251-255
Phys. Lett B 720 (2013) 111-115

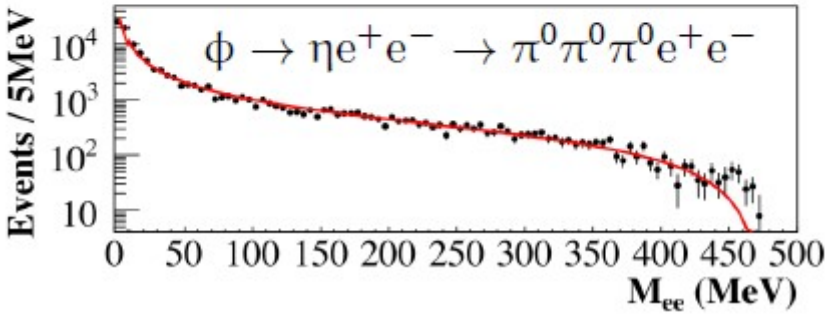
- UP limit with CLs
- $\varphi \rightarrow \eta e^+e^-$ background from fit to the sidebands.
- $\varepsilon = \alpha_D/\alpha_{EM}$ derived assuming the relation:

$$\sigma(\varphi \rightarrow \eta U) \sim \epsilon^2 |F_{\eta\varphi}(m_U^2)|^2 \sigma(\varphi \rightarrow \eta\gamma)$$

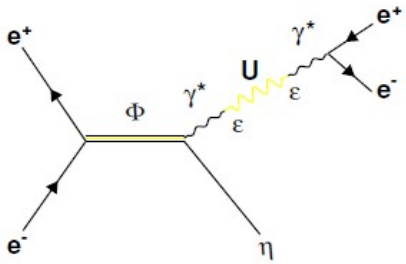
from *[Reece-Wang, JHEP0907:051 (2009)]*

Di-electron mass spectrum





$\Phi \rightarrow \eta U$ with $U \rightarrow e^+e^-$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ / $\pi^0\pi^0\pi^0$



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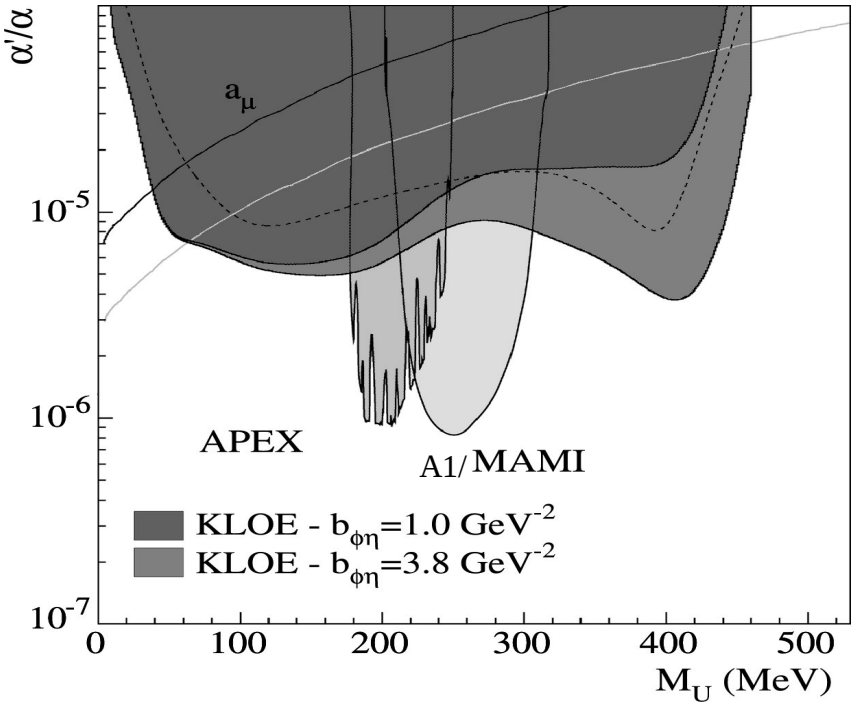


- No clear signal → Upper limit evaluation with CLs
  - $\varphi \rightarrow \eta e^+e^-$ background from fit to the sidebands.
- $\varepsilon = \alpha_D/\alpha_{EM}$ derived assuming the relation:

$$\sigma(\varphi \rightarrow \eta U) \sim \epsilon^2 |F_{\eta\varphi}(m_U^2)|^2 \sigma(\varphi \rightarrow \eta\gamma)$$

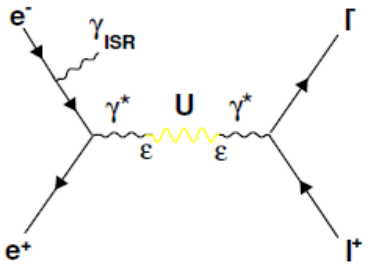
from *[Reece-Wang, JHEP0907:051 (2009)]*

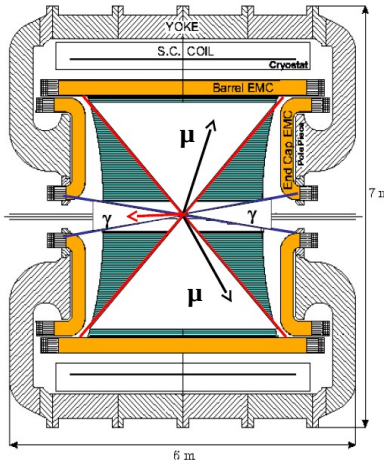
Slope factor from KLOE $b_{\Phi\eta} \sim 1.28$ GeV^{-2} *PLB 742(2015)*

Exclusion limit compared with:
- APEX *PRL 107 (2011)*
- A1/MAMI *PRL 106 (2011)*

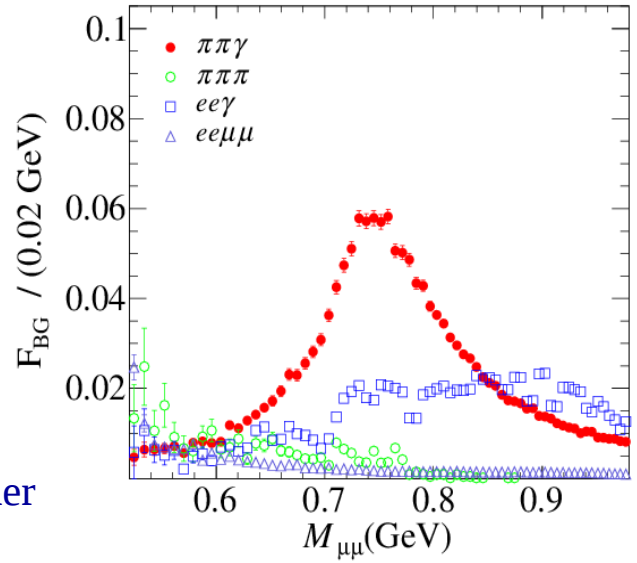
at the moment of the KLOE publication

$e^+e^- \rightarrow U\gamma$ with $U \rightarrow \mu^+\mu^-$

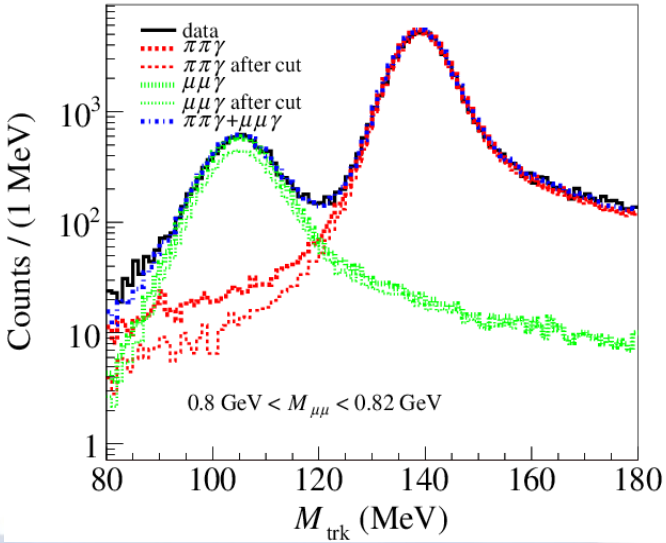




Phys. Lett B 736 (2014) 459-464



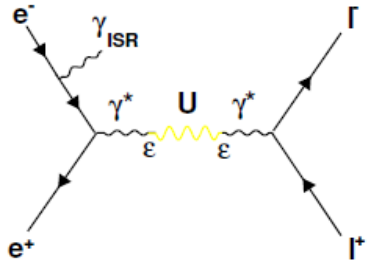
- Two opposite charged tracks within a cylinder around IP
- $50^o < \theta\mu < 130^o$
- Undetected photon $\theta\gamma < 15^o$, $>165^o$
- High statistics ISR
- Strong suppression of FSR and $\varphi \rightarrow \pi^+\pi^-\pi^0$
- Good μ / π separation with M_{trk} and σ_{Mtrk}
  - M_{trk} = track mass assuming two equal mass charged particles and 1 γ in the final state



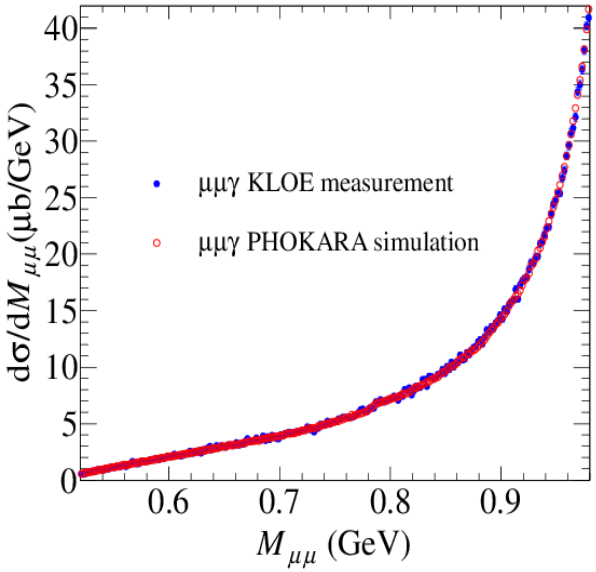
$e^+e^- \rightarrow U\gamma$ with $U \rightarrow \mu^+\mu^-$

Phys. Lett B 736 (2014) 459-464

- Main sources of background
  - e+ e- → $\pi^+ \pi^- \gamma(\gamma)$
  - e+ e- → $e^+ e^- \gamma(\gamma)$
  - $\varphi \rightarrow \pi^+ \pi^- \pi^0$
- UL evaluated from raw spectra with Cls technique. Total sys. uncertainty approx. 2%.



Di-muon mass spectrum



Results based on only 240 pb^{-1}

Using the 2.5 fb^{-1} full KLOE data set improves the sensitivity by a factor ~ 3

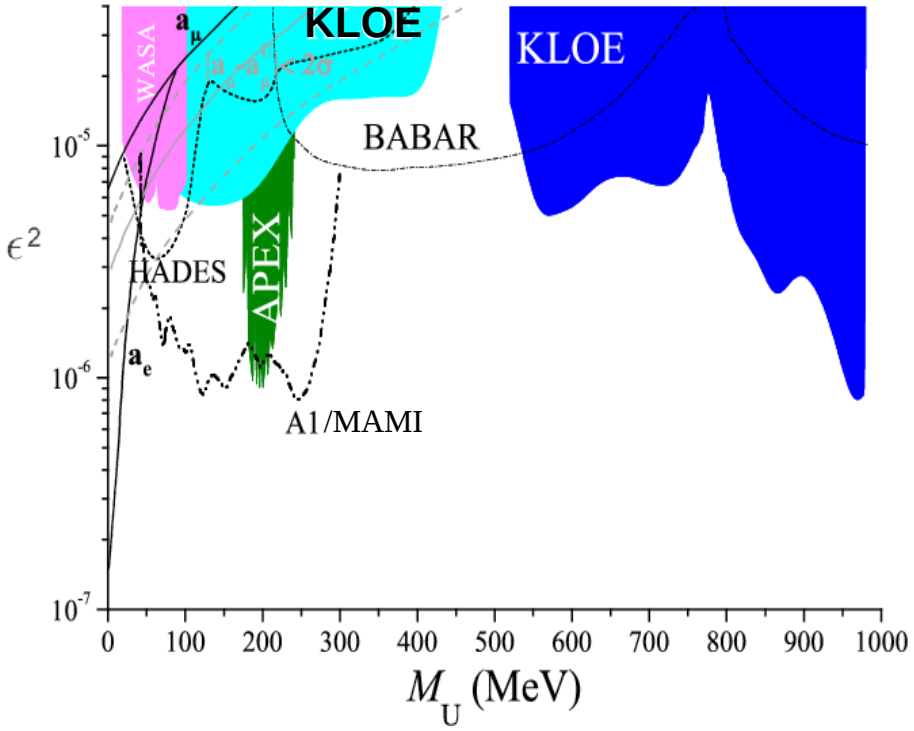
A further factor of 2 in sensitivity expected from KLOE-2 experiment

$e^+e^- \rightarrow U\gamma$ with $U \rightarrow \mu^+\mu^-$

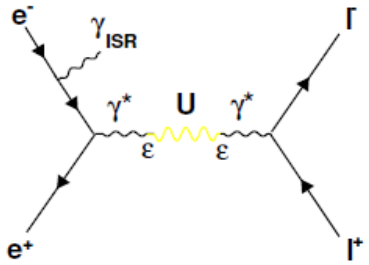
Phys. Lett B 736 (2014) 459-464

- UL on ε^2 compared to
  - BABAR Phys. Rev. Lett. 113 201801 (2014)
  - WASA PLB 726 (2013)
  - HADES PLB 731 (2014)
  - APEX PRL 107 (2011)
  - A1/MAMI Phys. Rev. Lett. 112 (2014)

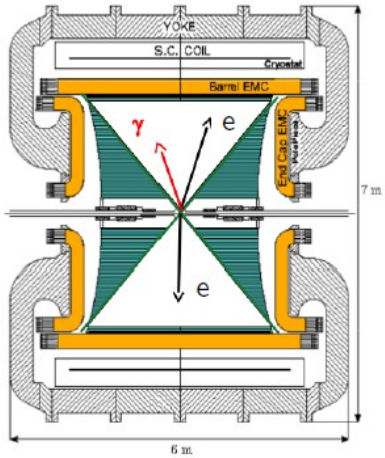
At the moment of the KLOE publication



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



Phys.Lett. B750 (2015) 633

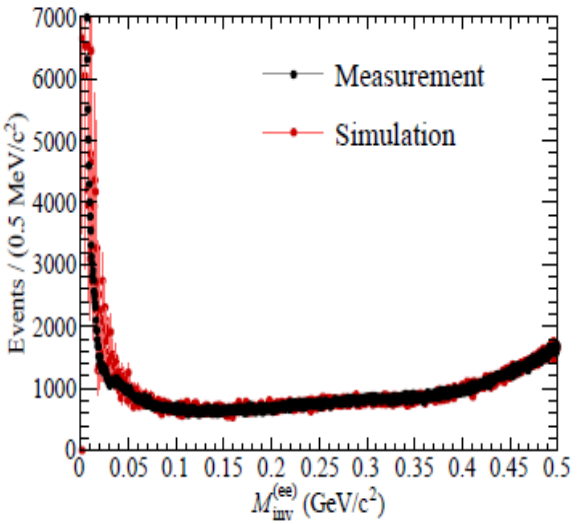


- Two opposite charged tracks within a cylinder around IP
- $55^o < \theta_e < 125^o$
- detected photon $50^o < \theta_\gamma < 130^o$
- M_{trk} variable to separate electrons from muons and pions
- High statistics radiative Bhabha in KLOE
- Approx per mil level background contamination or even better

Babayaga-NLO simulation (with weighted events)
Background estimated from data

No peak observed → UL CLS technique

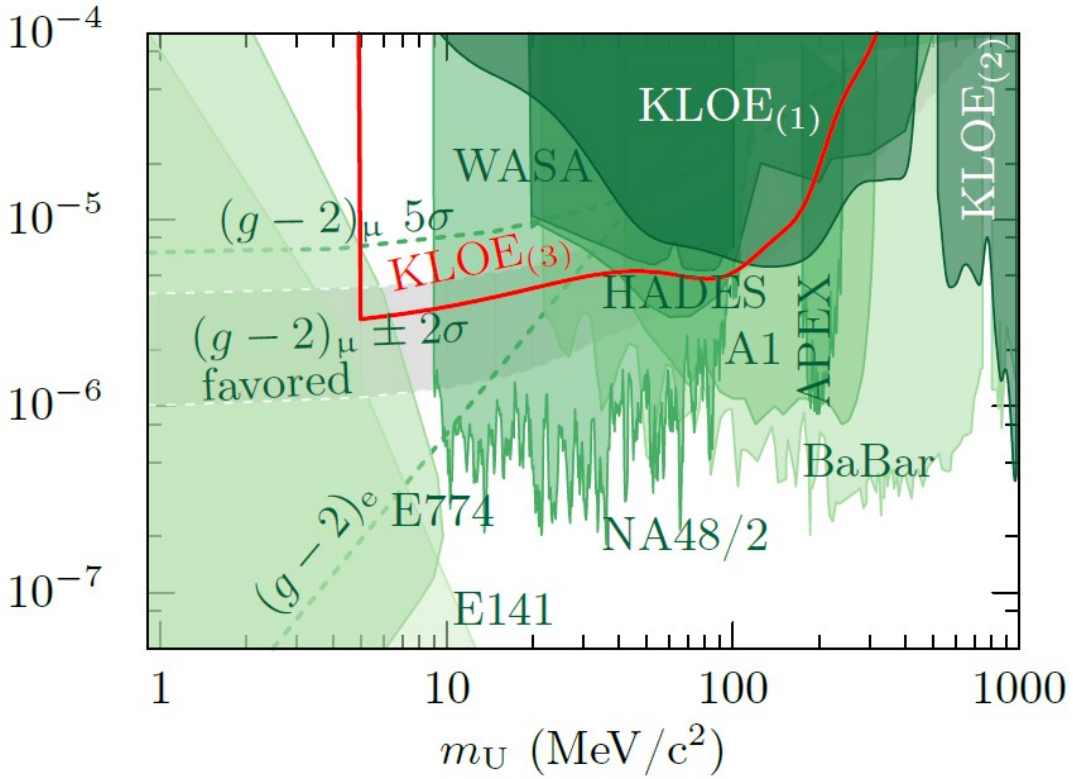
Di-electron mass spectrum



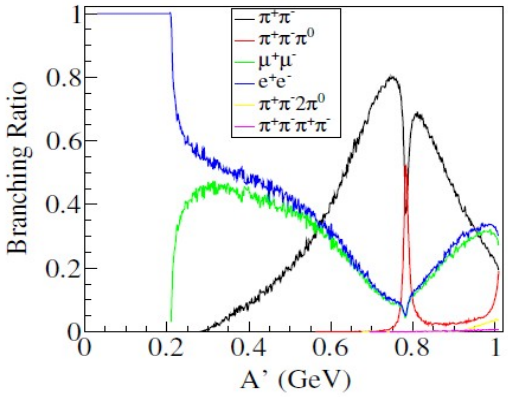
$e^+e^- \rightarrow U\gamma$ with $U \rightarrow e^+e^-$

Phys.Lett. B750 (2015) 633

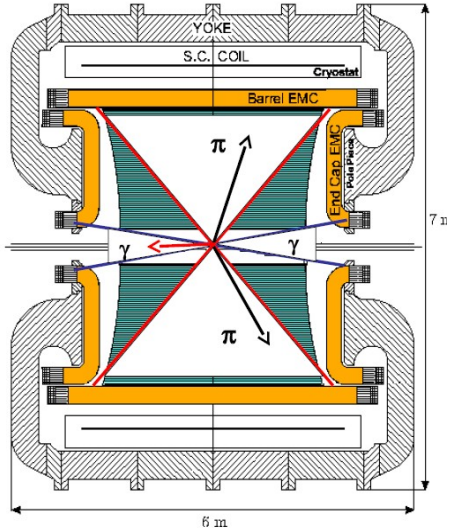
- UL on ε^2 compared to
-
  - KLOE
  - BABAR Phys. Rev. Lett. 113 201801 (2014)
  - WASA PLB 726 (2013)
  - HADES PLB 731 (2014)
  - APEX PRL 107 (2011)
  - A1/MAMI Phys. Rev. Lett. 112 (2014)
  - NA48/2 PLB 746 (2015)



$e^+e^- \rightarrow U\gamma$ with $U \rightarrow \pi^+\pi^-$



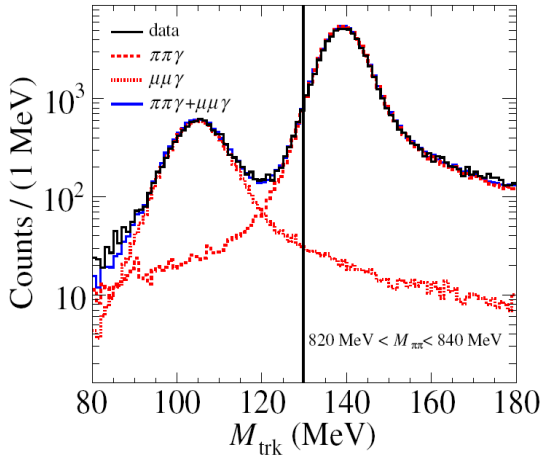
Phys.Lett. B757 (2016) 356-361



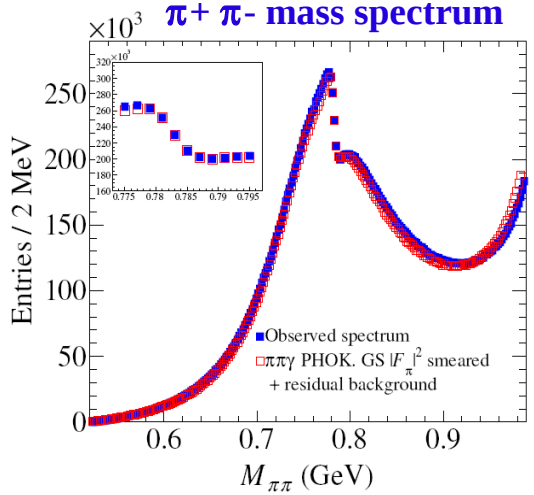
two opposite sign charged tracks $50° < \theta_\pi < 130°$

undetected small angle photon $\theta\gamma < 15°$, $\theta\gamma > 165°$

π/μ separation



π+ π- mass spectrum

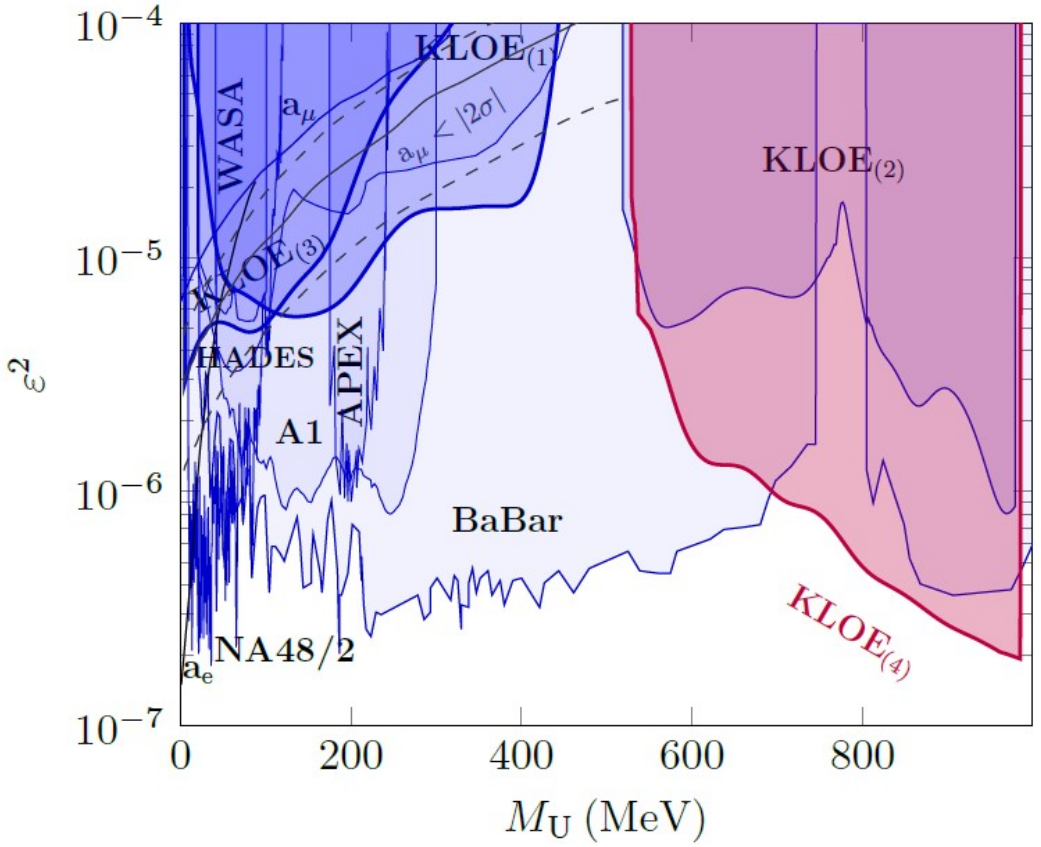


L=1.93 fb^{-1}

$e^+e^- \rightarrow U\gamma$ with $U \rightarrow \pi^+\pi^-$

- KLOE
  - (1) Dalitz decay *PLB 720 (2013)*
  - (2) $U \rightarrow \mu^+\mu^-$ *PLB 736 (2014)*
  - (3) $U \rightarrow e^+e^-$ *PLB 750 (2015)*
  - (4) $U \rightarrow \pi^+\pi^-$ *PLB 757 (2016)*
- BABAR *PRL 113 201801 (2014)*
- WASA *PLB 726 (2013)*
- HADES *PLB 731 (2014)*
- APEX *PRL 107 (2011)*
- A1/MAMI *PRL 112 (2014)*
- NA48/2 *PLB 746 (2015)*

Phys.Lett. B757 (2016) 356-361



Higgsstrahlung process

Phys.Lett. B747 (2015) 365-372

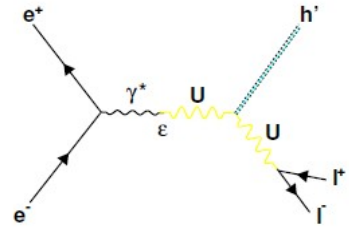
Two different scenarios:

- $m_{h'} > 2m_U$

with decays: $e^+e^- \rightarrow Uh'$ with $h' \rightarrow UUU$ thus 6l, 2π+4l, 6π in the final state

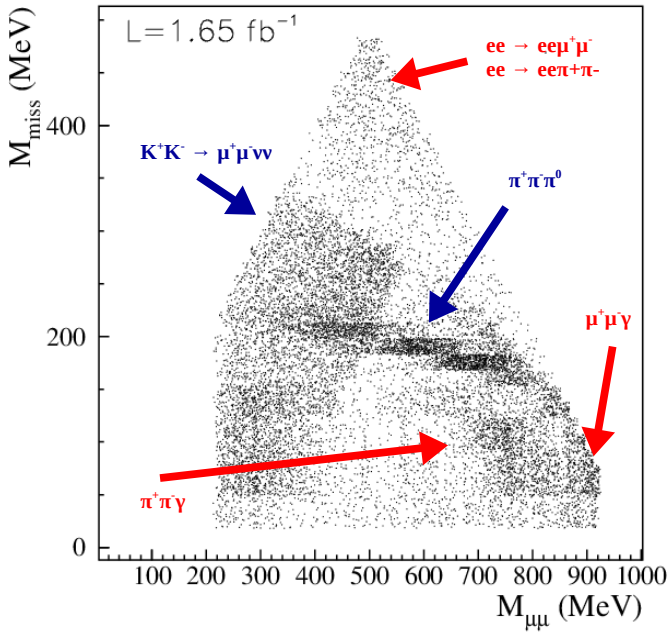
- $m_{h'} < 2m_U$

where h' is "invisible"



- Life time of the dark Higgs boson
- $\varepsilon = 10^{-3}$
- $\alpha_D = \alpha_{em}$
- $m_{h',U} \sim 100$ MeV

- $\tau > 5\ \mu s \rightarrow \beta\gamma c\tau > 100$ m → h' would be invisible up to $\varepsilon \sim 10^{-2}$ to 10^{-1} depending on $m_{h'}$

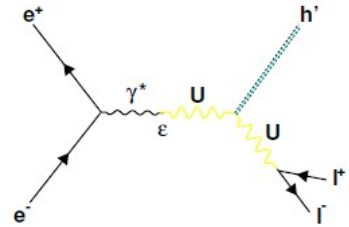


Final state: 2 muons + missing energy → peak in the M_{miss} vs $M_{\mu\mu}$ distribution

Higgsstrahlung process

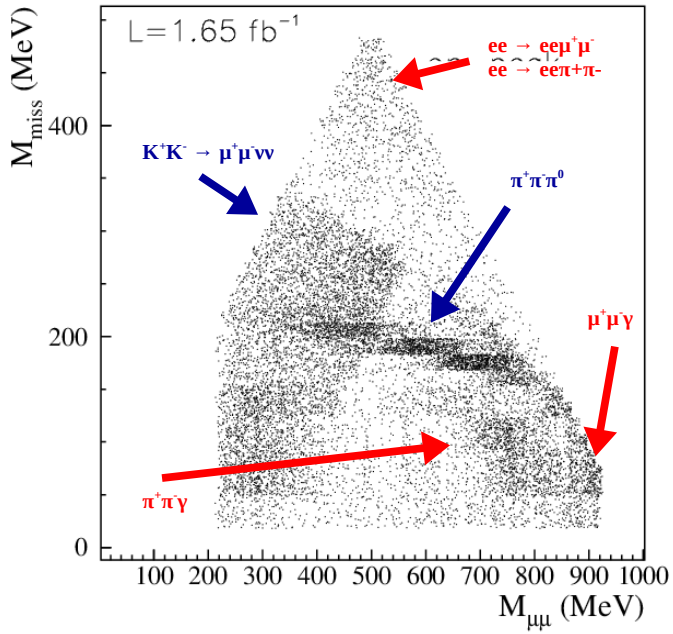
Phys.Lett. B747 (2015) 365-372

Final state: 2 muons + missing energy → enhancement in the M_{miss} vs $M_{\mu\mu}$ distribution



• Binning chosen such that 90-95% of signal would be in one bin

• Sliding 5x5 bin matrix (excluding the central bin used to checked the presence of a possible signal) used to determine background MC scale factors

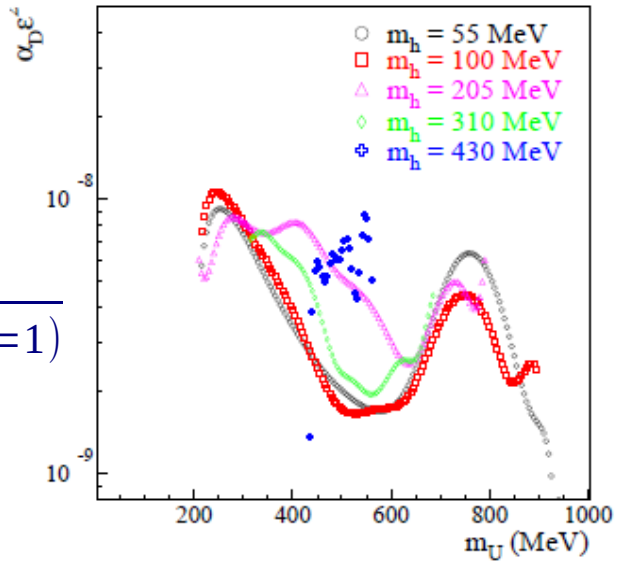


Higgsstrahlung process

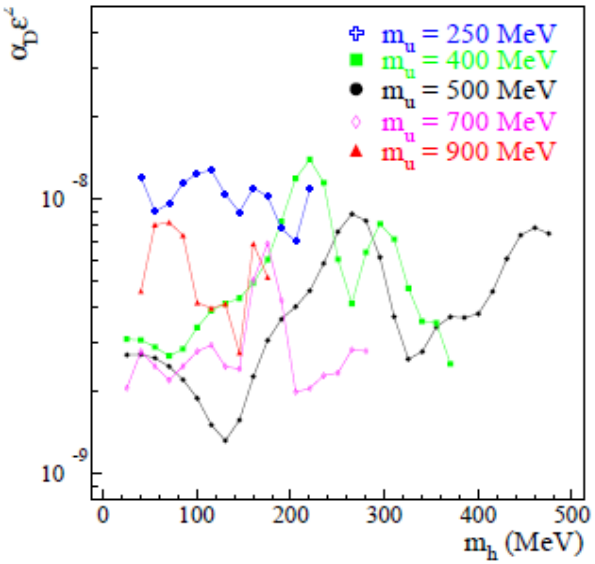
Phys.Lett. B747 (2015) 365-372

Combined results on- and off- peak data

$$\alpha_D \epsilon^2 = \frac{N_{90}}{\epsilon_{eff}} \frac{1}{L_{integrated} \cdot \sigma(\alpha_D \epsilon^2 = 1)}$$



Limit on $\alpha_D\varepsilon^2$ vs m_U at 90% CL

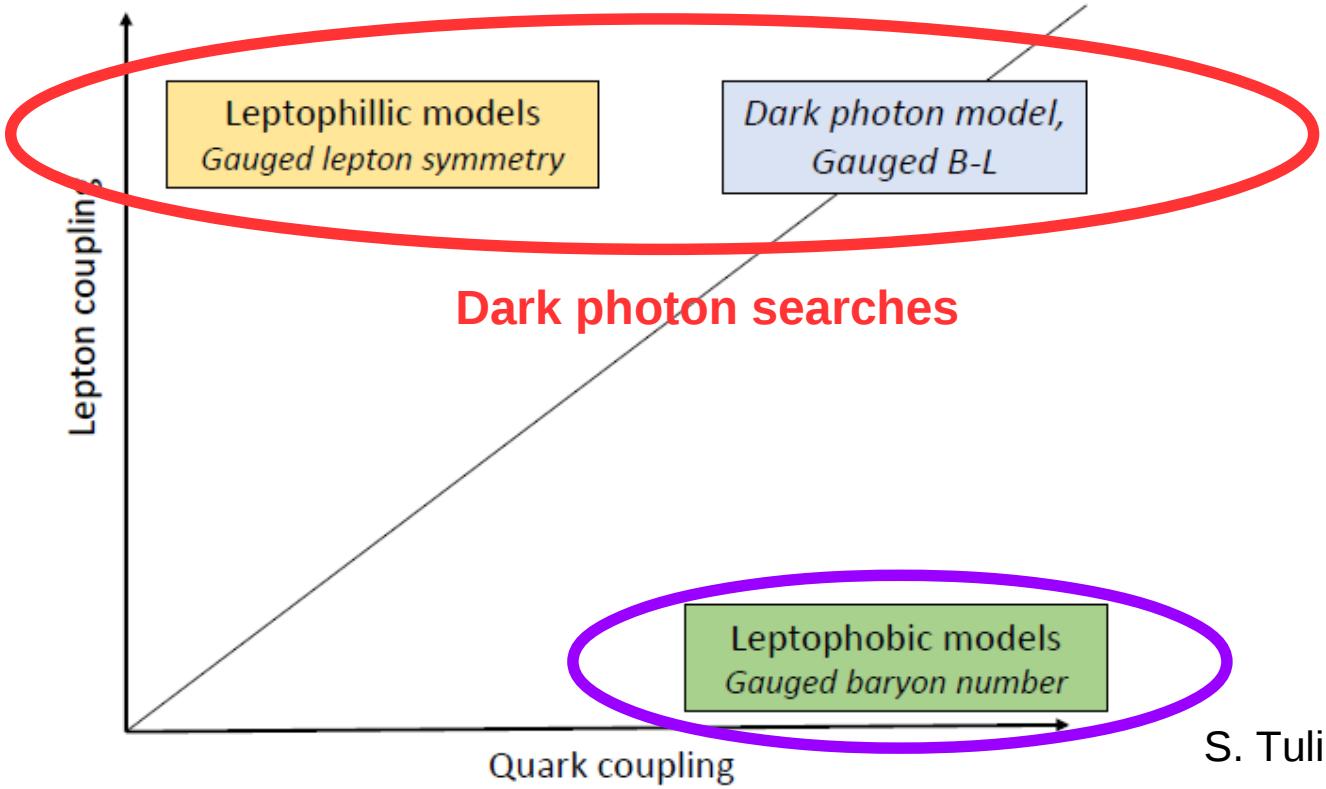


Limit on $\alpha_D\varepsilon^2$ vs $m_{h'}$ at 90% CL

Limits ~ 10^{-8} - 10^{-9} in $\alpha_D\varepsilon^2$ (translate in 10^{-3} to some 10^{-4} in ε if $\alpha_D = \alpha_{em}$)

New GeV-scale forces

- U searches don't cover all possible scenarios
- Room for new gauge boson searches



S. Tulin

Also a 3rd axis with invisible decays (neutrinos, light dark matter)

Leptophobic Dark Matter mediator search with KLOE-2

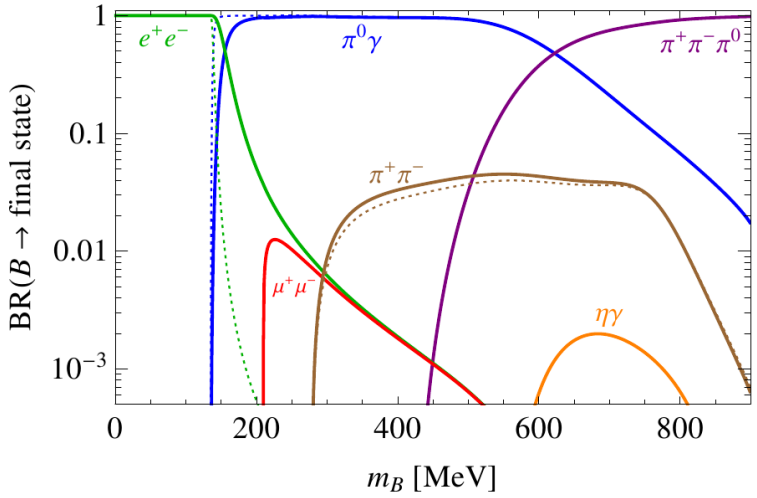
- B boson couples mainly to quarks
- Most basic model → coupling to baryon number

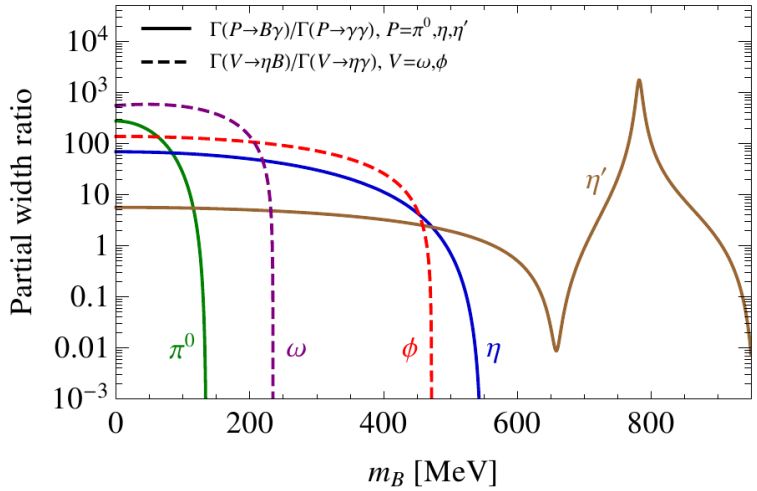
S. Tulin (Phys. Rev. D 89, 114008 (2014))

$$\mathscr{L} = \frac{g_B}{3}\,\bar{q}\gamma^\mu q B_\mu$$

$$g_B \lesssim 10^{-2} \times (m_B/100\ \text{MeV})$$

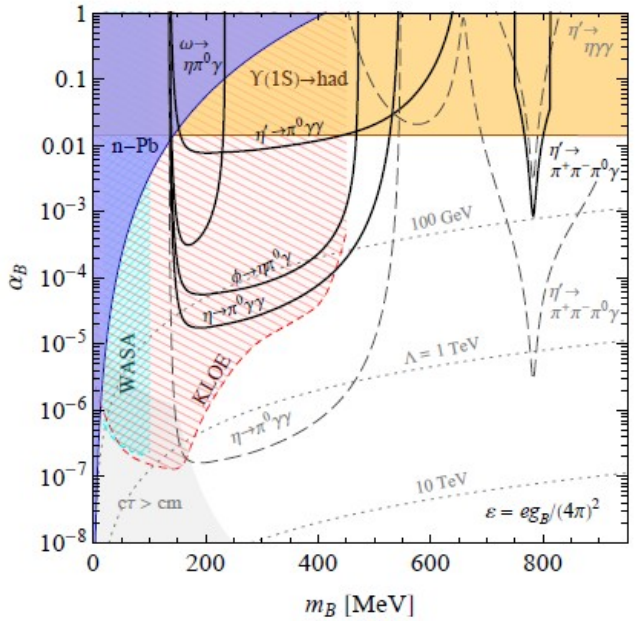
$$\alpha_B = \frac{g_B^2}{4\pi} \lesssim 10^{-5} \times (m_B/100\,\text{MeV})^2$$





Decay → / Production ↓	$B \to e^+e^-$ $m_B \sim 1-140$ MeV	$B \to \pi^0\gamma$ 140–620 MeV	$B \to \pi^+\pi^-\pi^0$ 620–1000 MeV	$B \to \eta\gamma$
$\pi^0 \to B\gamma$	$\pi^0 \to e^+e^-\gamma$	...	...	...
$\eta \to B\gamma$	$\eta \to e^+e^-\gamma$	$\eta \to \pi^0\gamma\gamma$	...	...
$\eta' \to B\gamma$	$\eta' \to e^+e^-\gamma$	$\eta' \to \pi^0\gamma\gamma$	$\eta' \to \pi^+\pi^-\pi^0\gamma$	$\eta' \to \eta\gamma\gamma$
$\omega \to \eta B$	$\omega \to \eta e^+e^-$	$\omega \to \eta\pi^0\gamma$	...	...
$\phi \to \eta B$	$\phi \to \eta e^+e^-$	$\phi \to \eta\pi^0\gamma$	...	

Leptophobic Dark Matter mediator search with KLOE-2



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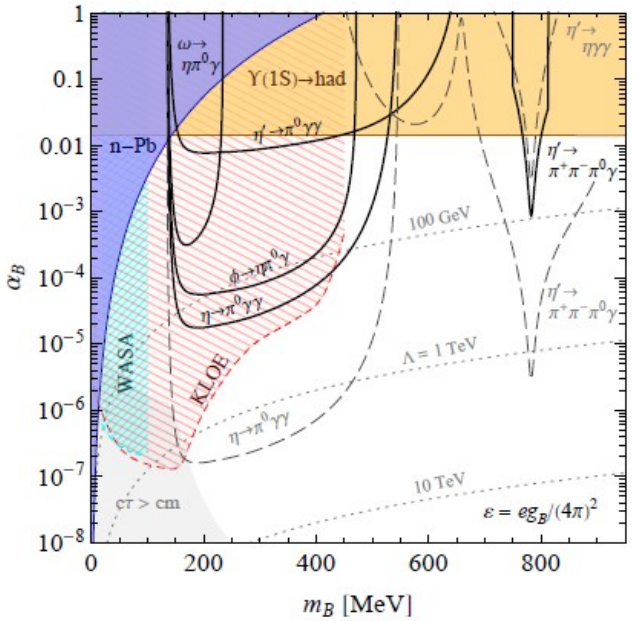
$$\alpha_B = \frac{g_B^2}{4\pi} \lesssim 10^{-5} \times (m_B/100\,\text{MeV})^2$$

- KLOE searches for B → $\pi^0\gamma$
  - Φ → η B
  - η → Bγ

KLOE searches

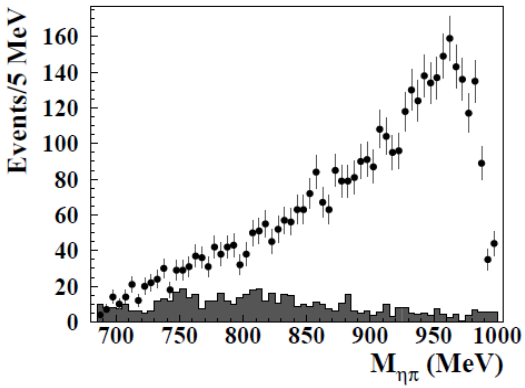
Decay → / Production ↓	$B \to e^+e^-$ $m_B \sim 1-140$ MeV	$B \to \pi^0\gamma$ 140–620 MeV	$B \to \pi^+\pi^-\pi^0$ 620–1000 MeV	$B \to \eta\gamma$
$\pi^0 \to B\gamma$	$\pi^0 \to e^+e^-\gamma$	...	...	...
$\eta \to B\gamma$	$\eta \to e^+e^-\gamma$	$\eta \to \pi^0\gamma\gamma$	...	...
$\eta' \to B\gamma$	$\eta' \to e^+e^-\gamma$	$\eta' \to \pi^0\gamma\gamma$	$\eta' \to \pi^+\pi^-\pi^0\gamma$	$\eta' \to \eta\gamma\gamma$
$\omega \to \eta B$	$\omega \to \eta e^+e^-$	$\omega \to \eta\pi^0\gamma$	...	...
$\phi \to \eta B$	$\phi \to \eta e^+e^-$	$\phi \to \eta\pi^0\gamma$	...	

Leptophobic Dark Matter mediator search with KLOE-2



S. Tulin (Phys. Rev. D 89, 114008 (2014))

- $\Phi \rightarrow \eta B$ with $B \rightarrow \pi^0\gamma$ already under study with full KLOE statistics
  - Channel used for a0(980) scalar meson
- Look for resonance in $\pi^0\gamma$ invariant mass
- 2001/2002 data analysis
  - ~ 13000 Φ events after background subtraction
- KLOE-2 with 5 fb^{-1} improvement of a factor of ~3 in $\pi^0\gamma$ invariant mass sensitivity for the upper limit calculation
  - Considerable systematic improvement due to background rejection with CCALT +QCALT
    - Acceptance increased for θ from 21° to 8°

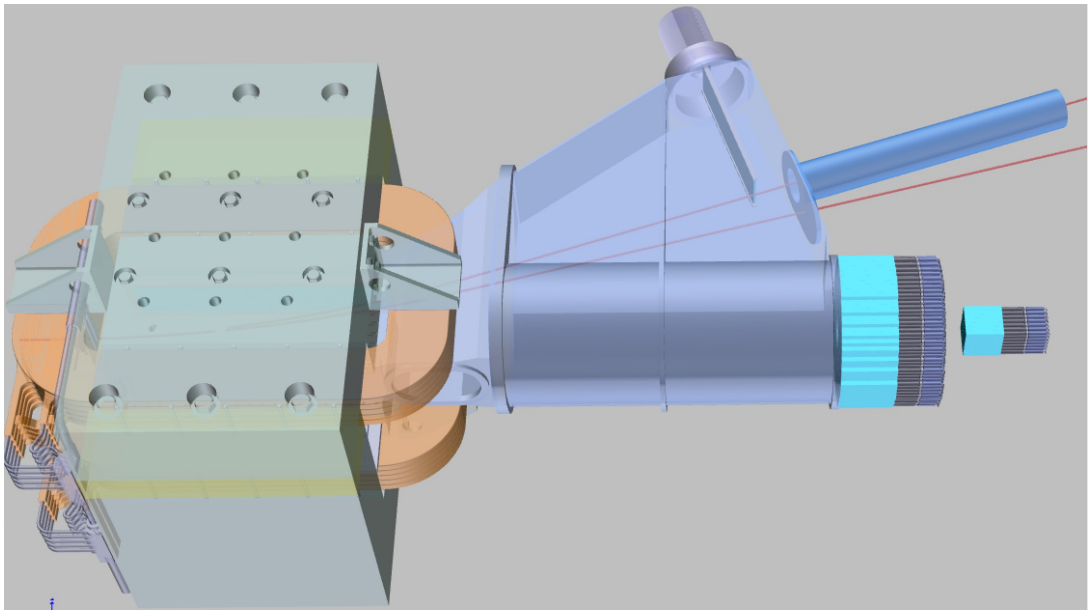


Phys. Lett. B 681 (2009) 5-13

KLOE searches

Decay → / Production ↓	$B \rightarrow e^+e^-$ $m_B \sim 1-140$ MeV	$B \rightarrow \pi^0\gamma$ 140–620 MeV	$B \rightarrow \pi^+\pi^-\pi^0$ 620–1000 MeV	$B \rightarrow \eta\gamma$
$\pi^0 \rightarrow B\gamma$	$\pi^0 \rightarrow e^+e^-\gamma$	...	...	...
$\eta \rightarrow B\gamma$	$\eta \rightarrow e^+e^-\gamma$	$\eta \rightarrow \pi^0\gamma\gamma$	...	...
$\eta' \rightarrow B\gamma$	$\eta' \rightarrow e^+e^-\gamma$	$\eta' \rightarrow \pi^0\gamma\gamma$	$\eta' \rightarrow \pi^+\pi^-\pi^0\gamma$	$\eta' \rightarrow \eta\gamma\gamma$
$\omega \rightarrow \eta B$	$\omega \rightarrow \eta e^+e^-$	$\omega \rightarrow \eta\pi^0\gamma$	...	...
$\phi \rightarrow \eta B$	$\phi \rightarrow \eta e^+e^-$	$\phi \rightarrow \eta\pi^0\gamma$	...	

Future searches at LNF
PADME



Positron Annihilation into Dark Matter mediator Experiment

M. Raggi and V. Kozhuharov, Advances in High Energy Physics Vol. 2014 ID 959802

- A' can be produced in e+ collision on target by:
  - Bremsstrahlung: $e+N \rightarrow e+NA'$
  - Annihilation: $e+e- \rightarrow gA'$
  - Meson decays

→

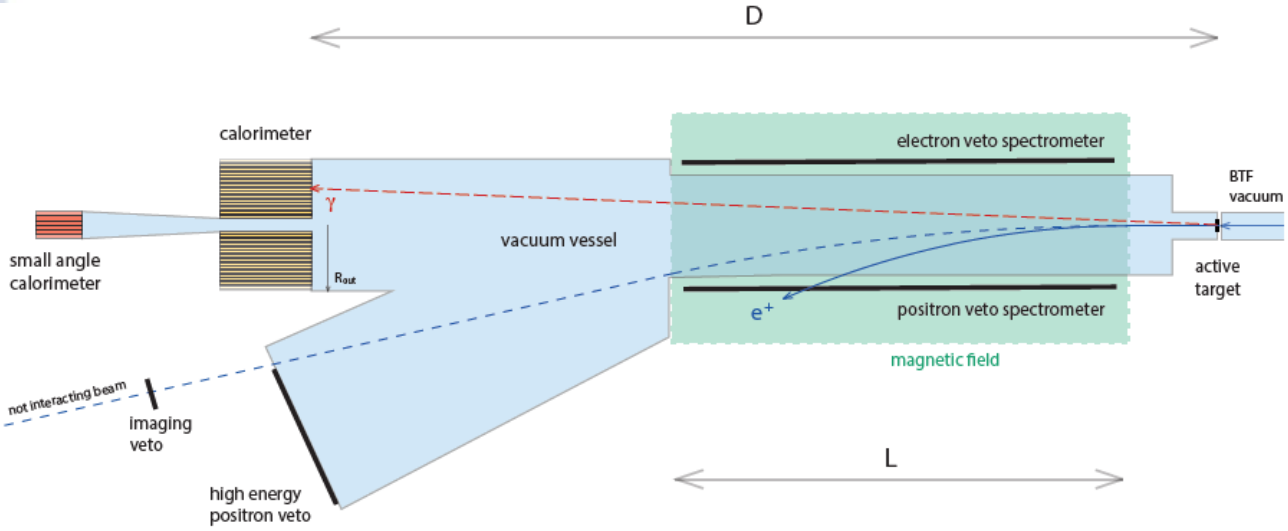
If any dark matter particle c with $2M_X < M_{A'}$ exists

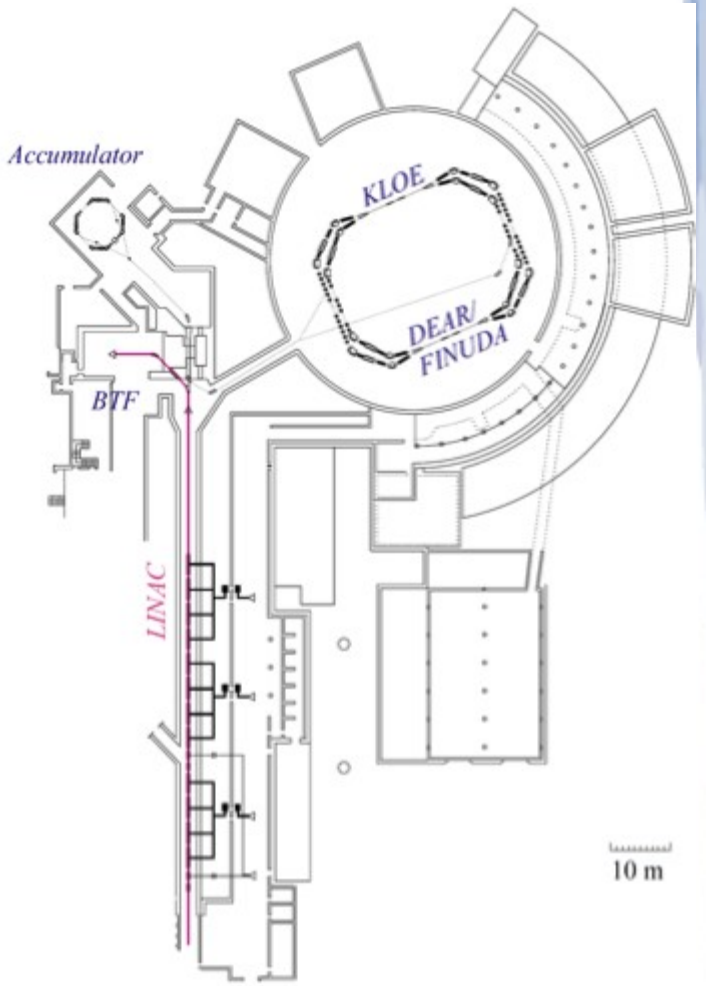
- A' will dominantly decay into pure DM
- BR(l^+l^-) suppressed by factor
- $A' \rightarrow XX \sim 1$. These are the so called decays to "invisible"

$$\frac{\sigma(e^+e^- \to U\gamma)}{\sigma(e^+e^- \to \gamma\gamma)} = \frac{N(U\gamma)}{N(\gamma\gamma)} * \frac{Acc(\gamma\gamma)}{Acc(U\gamma)} = \epsilon^2 * \delta, \qquad \delta(M_{A'}) = \sigma(A'\gamma)/\sigma(\gamma\gamma)$$

* pictures and more from M. Raggi

Future searches at LNF
PADME



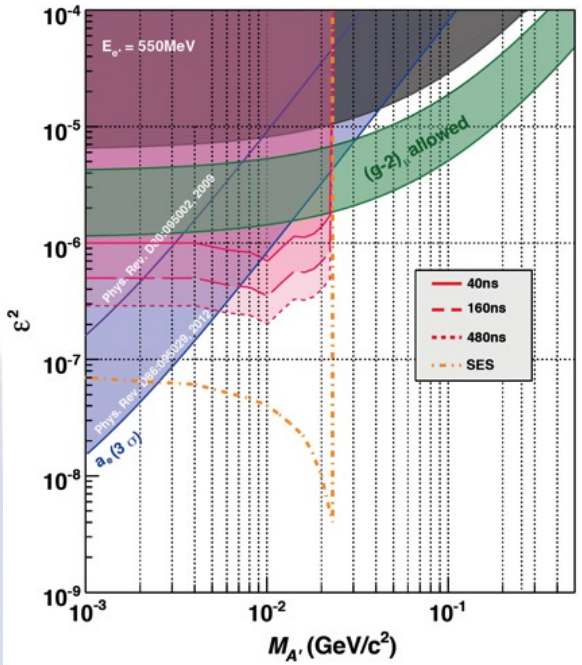


Search for the process: e+e- → γ A' on target e- at rest electrons

Beam: 6000 e+ on target per 40 ns bunch, at 50 bunch/s (10^{13} e+/year)
Main detector components:

- Active target, thin: 50-100mm diamond (Time, N_{e-}, beam position and spot size)
- Charged particles plastic scintillators veto system ~1m length
- Conventional magnet, B≈0.6T but large gap for gaining acceptance
- Cylindrical BGO crystal EM calorimeter
- Measures: time, energy and direction of photons
- Compute the $M_{miss}^2 = (P4_{e-} + P4_{beam} - P4_{\gamma})^2$
- P4e- =(0,0,0,m_e) and $P4_{beam}$ =(0,0,550,sqrt($550^2 + m_e^2$))
- Veto additional charged particles and photons

Future searches at LNF
PADME



Search of A' → invisible

PADME 2 years of data taking at 50% efficiency with bunch length of 40 ns

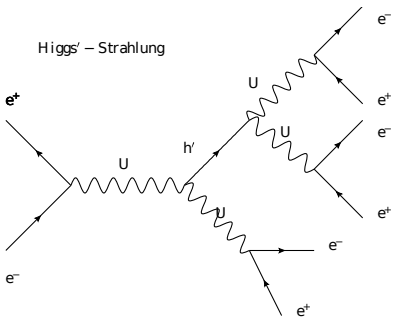
PADME can explore in a ***model-independent way the*** favored by $(g\text{-}2)_\mu$ band up to $M^2_{A'} = 2m_e E_{e+}$

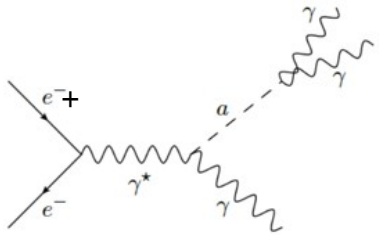
E_{e+}=550 MeV: $M_{A'} < 23.7$ MeV/c^2

E_{e+}=1 GeV: $M_{A'} < 32$ MeV/c^2

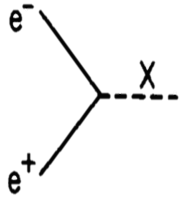
Search of dark higgs production e+e- → A' h' with h' → A'A'

$2M_{A'} < M_{h'}$ dominant A'h'->A'A'A'->6 leptons

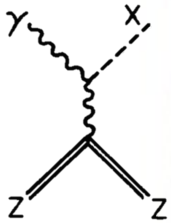


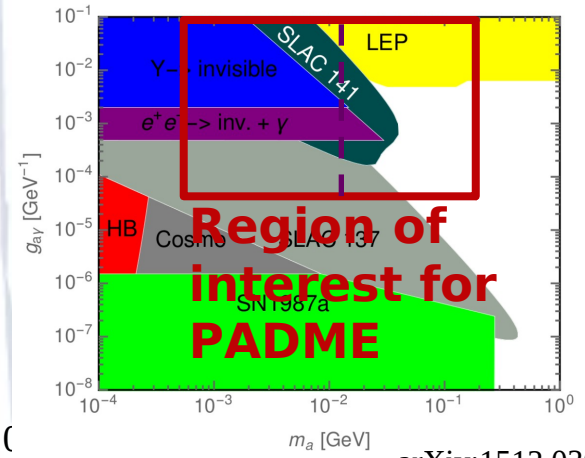


Annihilation

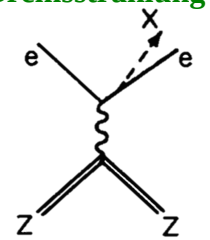


Primakoff





Bremsstrahlung



ALP physics at PADME

- PADME can search for long living ALPs by looking for $1\gamma + M^2_{miss}$ final states
- In the visible final state a->γγ all production mechanisms can be explored extending the mass range in the region of ~100MeV The observables at PADME will be: eγγ or γγγ

arXiv:1512.03069

Conclusions

- KLOE has extensively contributed to the U boson searches with (up to now) six different analysis:
  - $\varphi \rightarrow \eta U$ with $U \rightarrow e^+ e^-$ Phys. Lett B 706 (2012) 251-255 Phys. Lett B 720 (2013) 111-115
  - $e^+ e^- \rightarrow U\gamma$ with $U \rightarrow \mu^+ \mu^-$ Phys. Lett B 736 (2014) 459-464
  - $e^+ e^- \rightarrow Uh'$ with $h' \rightarrow$ invisible Phys.Lett. B747 (2015) 365-372
  - $e^+ e^- \rightarrow U\gamma$ with $U \rightarrow e^+ e^-$ Phys.Lett. B750 (2015) 633
  - $e^+ e^- \rightarrow U\gamma$ with $U \rightarrow \pi^+ \pi^-$ Phys.Lett. B757 (2016) 356-361
- Setting limits on ε^2 in the mass range $5\ \text{MeV} < m_U < 980\ \text{MeV}$
- As well as on $\alpha_D \varepsilon^2$ in the mass range $2m_\mu < m_U < 1000\ \text{MeV}$
- The increased DAϕNE-2 delivered luminosity and the presence of the new detectors in KLOE-2 are expected to improve these limits by a factor ~2 or better .
- LNF future searches with new experiments to be run in the recent future → PADME
- PADME experiment aims at the first search for A' with the missing mass technique
  - The technique is model independent and could be used to constrain non dark photon models as well
- PADME can also cover new channels, searching for ALPs and dark Higgs

BACKUP SLIDES

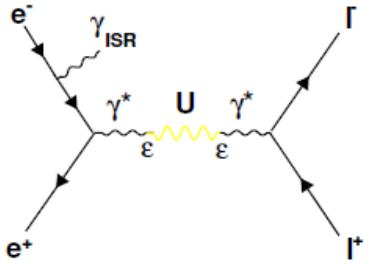
New hidden-forces

- Astrophysical observations
  - e^+/e^- excess in cosmic ray flux (PAMELA)
  - Total e^+/e^- flux (ATIC, Hess, Fermi)
  - Positron spectrum in primary cosmic rays (AMS)
  - 511 keV gamma ray signal from the galactic center (INTEGRAL)
  - DAMA/LIBRA annual modulation
  - Low energy spectrum of nuclear recoil dark matter candidate (CoGeNT)
- Particle physics puzzles
  - g-2 muon anomaly

$e^+e^- \rightarrow U\gamma$ with $U \rightarrow e^+e^-$

Phys.Lett. B750 (2015) 633

- CLs



$$\epsilon^2 = \frac{\alpha'}{\alpha} = \frac{N_{CLs}}{\epsilon_{eff}} \frac{1}{H \cdot I \cdot L_{integrated}}$$

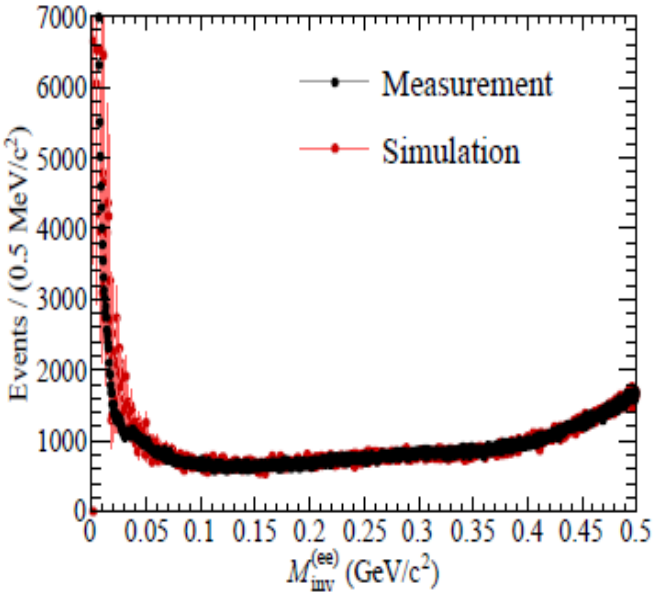
N_{CLs} = number of U boson signal events excluded at 90% C.L.

$$H = \frac{d\,\sigma_{ee\gamma}/dM_{ee}}{\sigma(ee \rightarrow ee, M)}$$

$$I = \int \sigma_U \, dM_U$$

$$L_{integrated} = 1.54\ fb^{-1}$$

Di-electron mass spectrum



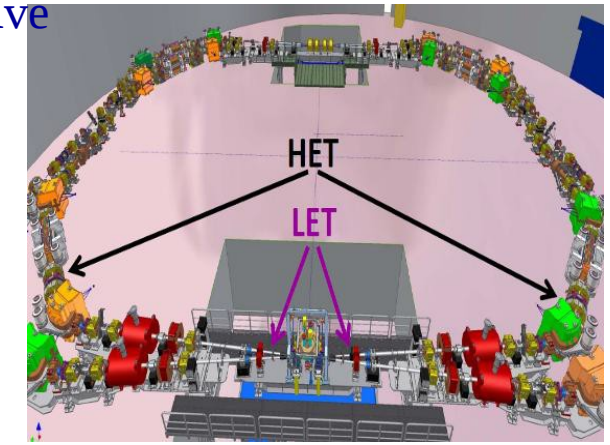
KLOE-2 Upgrade

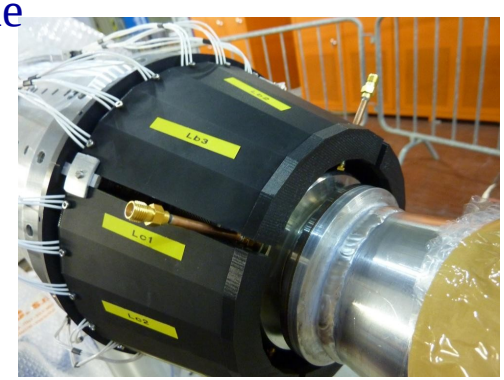
•KLOE-2 new data taking campaign started on November 2015

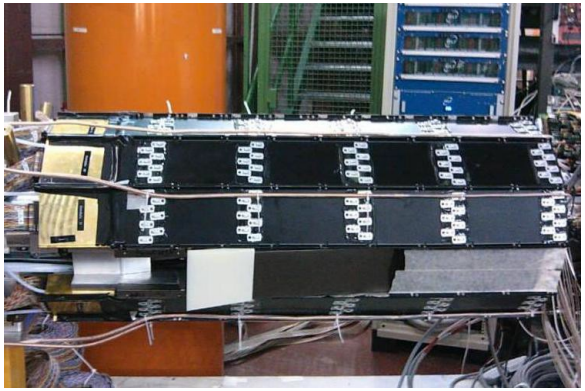
•It will collect more than 5 fb^{-1} within the next 3 years

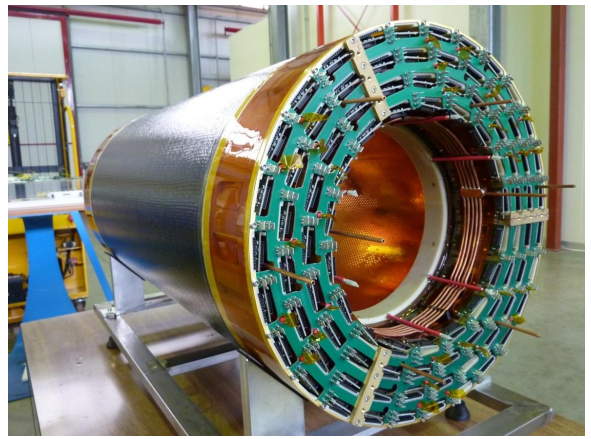
•New detectors fully operative

- LET & HET
  - e+e--taggers for γγ-physics
- CCALT & QCALT
  - 2 new calorimeters (for low angle γs & s from K_L decays)
- IT
  - 4 layers of C-GEM
  - better vertex reconstruction and larger low p_t track acceptance







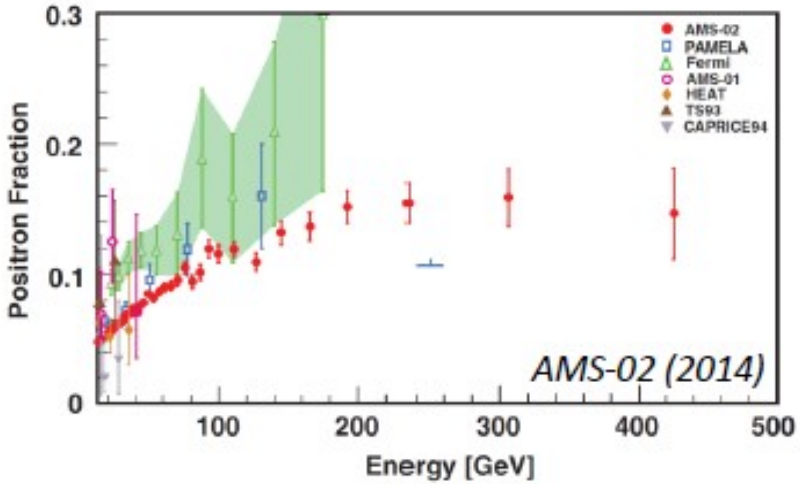


Motivations for new GeV-scale forces

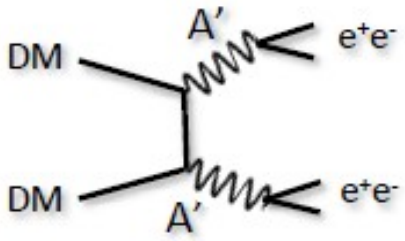
Dark matter indirect detection anomalies

e.g. Pamela/AMS-02 positron excess

Pospelov & Ritz (2008); Arkani-Hamed et al (2008)

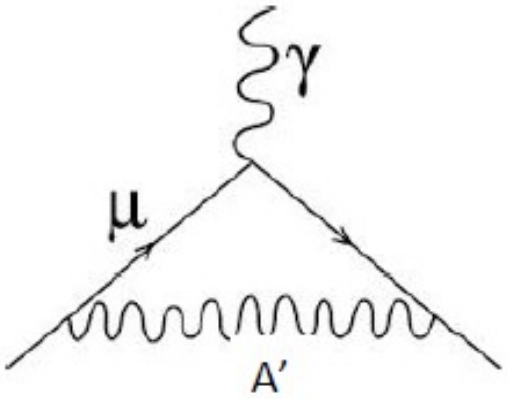


Dark matter annihilation

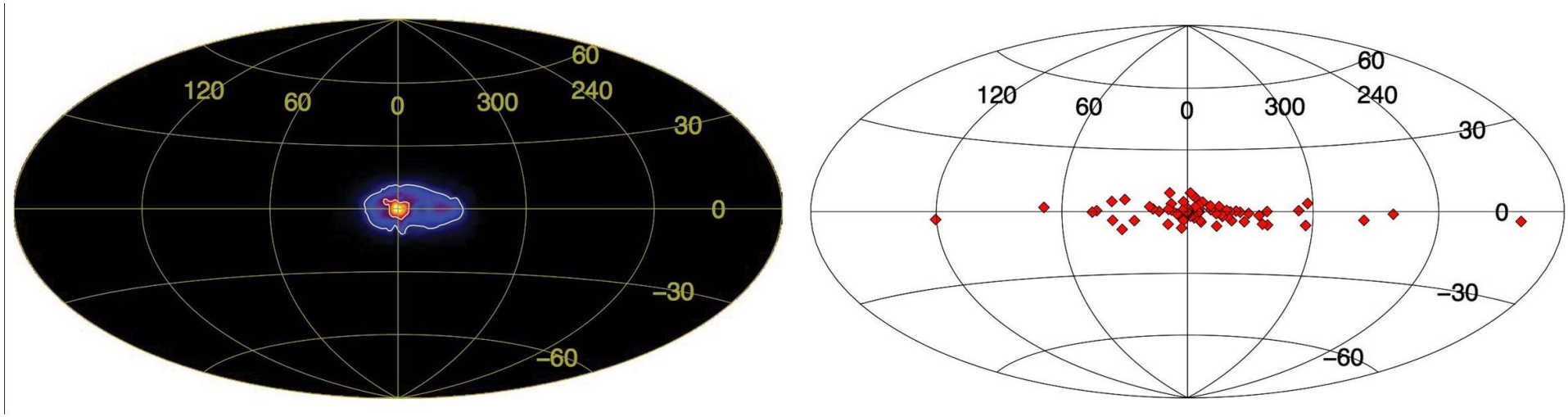


$(g-2)_\mu$ anomaly

Pospelov (2008)



Motivations for new GeV-scale forces



The left-hand panel shows the glow of 511 keV gamma rays coming from the annihilation of electrons by their antimatter counterparts, the positrons of the Milky Way observed by SPI. The map shows the entire sky, with the galactic centre at the middle. The emission can be seen extending towards the right-hand side of the map. The color code shows the intensity of the signal (white more intense). The right-hand panel shows the distribution of hard low mass X-ray binary stars detected by IBIS/ISGRI telescope on board INTEGRAL satellite. This stellar population has a distribution that matches the extent of the 511 keV map.
(Credits: Integral CEA and CESR team)

Motivations for new GeV-scale forces

CoGeNT scattering cross sections with nucleus

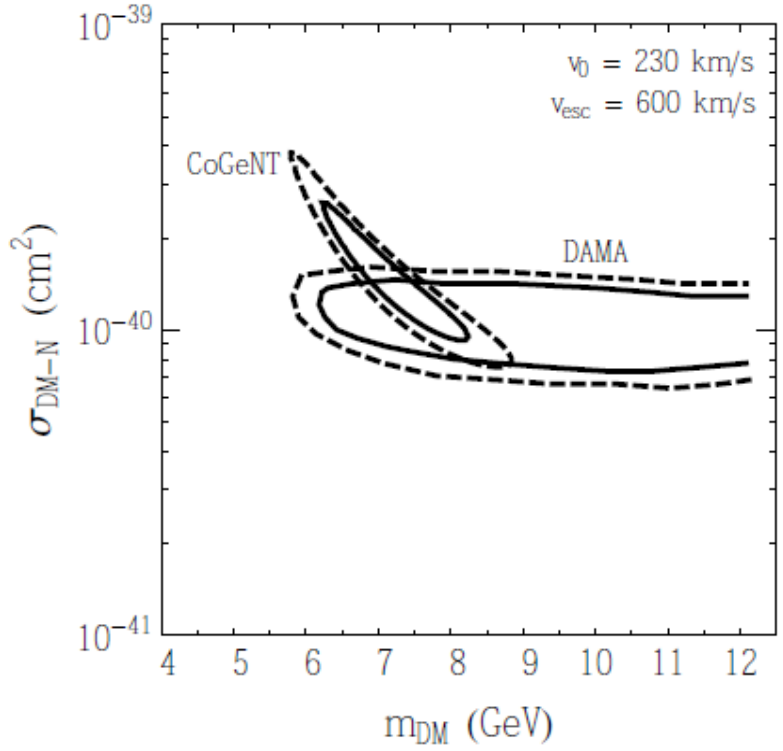


FIG. 6: A comparison of the parameter space favored by the CoGeNT spectrum with that favored by the modulation spectrum reported by DAMA/LIBRA [7]. Good agreement is found, but somewhat large quenching factors for low energy nuclear recoils on sodium are required ($Q_{Na} \sim 0.40-0.45$) [7].

Leptophobic B boson: new force coupling to quarks

- B boson couples mainly to quarks
- Most basic model → coupling to baryon number

$$\mathscr{L} = \frac{g_B}{3}\,\bar{q}\gamma^\mu q B_\mu$$

$$g_B \lesssim 10^{-2} \times (m_B/100\ \mathrm{MeV})$$

$$\alpha_B = \frac{g_B^2}{4\pi} \lesssim 10^{-5} \times (m_B/100\,\mathrm{MeV})^2$$

- Literature:
  - Radjoot (1989), Foot et al (1989), Nelson & Tetradis (1989), He & Rajpoot (1995), Bairley & Davidson (1995), Aranda & Carone (1998), Fileviez Perez & Wise (2010), Graesser et all (2011),Dobrescu & Frugiule (2014), Batell et all (2014), **S. Tulin (Phys. Rev. D 89, 114008 (2014))**
- Discovery signal depends on mass m_B

Leptophobic B boson

- **B boson decays**

S. Tulin ArXiv:1404.4370

KLOE searches

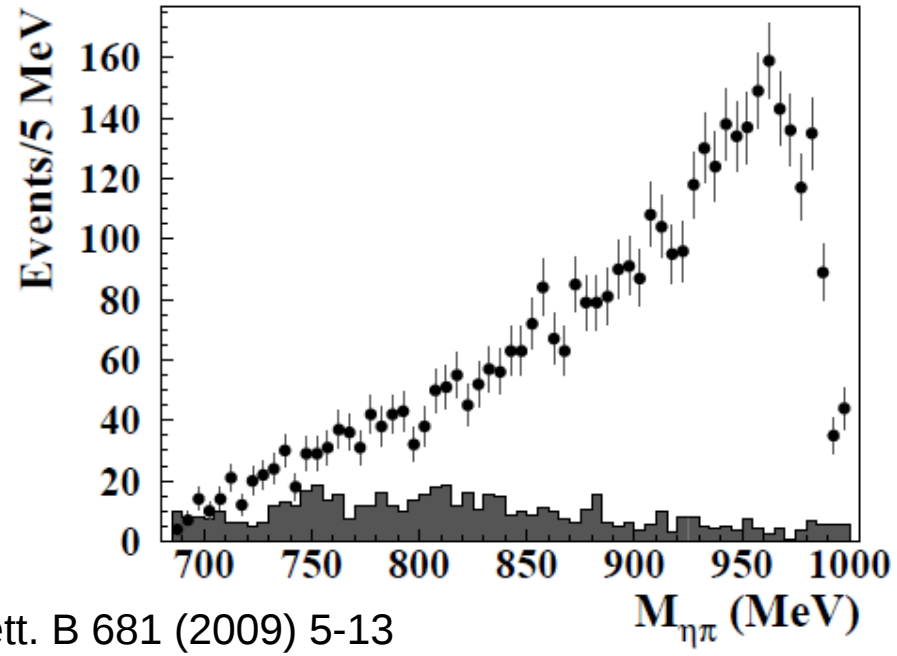
Decay → Production ↓	$B \to e^+e^-$ $m_B \sim 1-140$ MeV	$B \to \pi^0\gamma$ 140–620 MeV	$B \to \pi^+\pi^-\pi^0$ 620–1000 MeV	$B \to \eta\gamma$
$\pi^0 \to B\gamma$	$\pi^0 \to e^+e^-\gamma$	...	...	...
$\eta \to B\gamma$	$\eta \to e^+e^-\gamma$	$\eta \to \pi^0\gamma\gamma$	...	...
$\eta' \to B\gamma$	$\eta' \to e^+e^-\gamma$	$\eta' \to \pi^0\gamma\gamma$	$\eta' \to \pi^+\pi^-\pi^0\gamma$	$\eta' \to \eta\gamma\gamma$
$\omega \to \eta B$	$\omega \to \eta e^+e^-$	$\omega \to \eta\pi^0\gamma$	...	...
$\phi \to \eta B$	$\phi \to \eta e^+e^-$	$\phi \to \eta\pi^0\gamma$	...	

Covered by dark photon searches

New signals

B boson search at KLOE

- $\Phi \rightarrow \eta B$ with $B \rightarrow \pi^0\gamma$
  - Channel used for a0(980) scalar meson
- Look for resonance in $\pi^0\gamma$ invariant mass
- 2001/2002 data analysis
  - ~ 13000 Φ events after background subtraction



Phys. Lett. B 681 (2009) 5-13

Future searches at LNF
PADME