Dark photon searches with the KLOE detector

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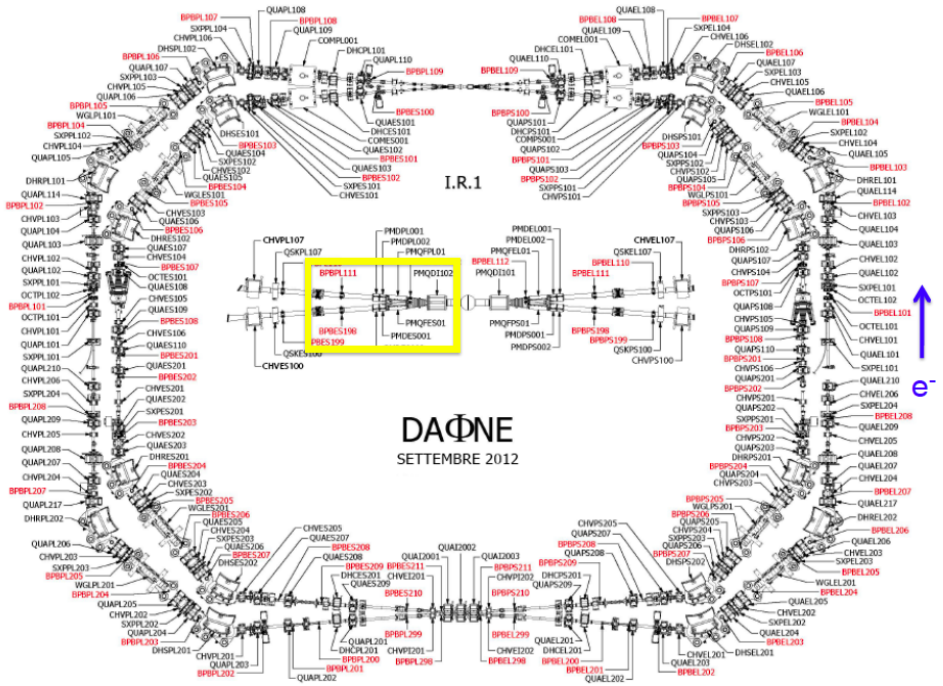
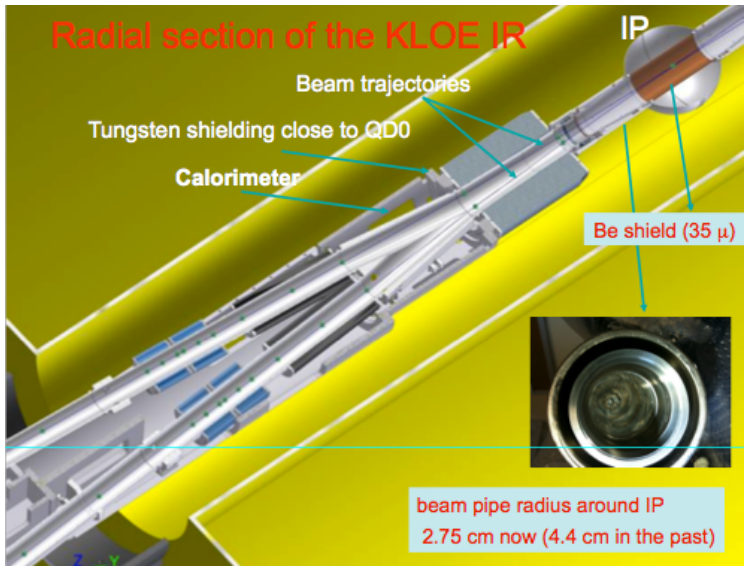
DAΦNE, the Frascati ϕ factory





- Most of the infrastructures of the Frascati accelerator complex have been consolidated for a physics run with KLOE-2
- Beam interaction region upgraded
- Commissioning in progress
- The goal is to collect $O(10)$ fb^{-1} in 2-3 years

The KLOE detector

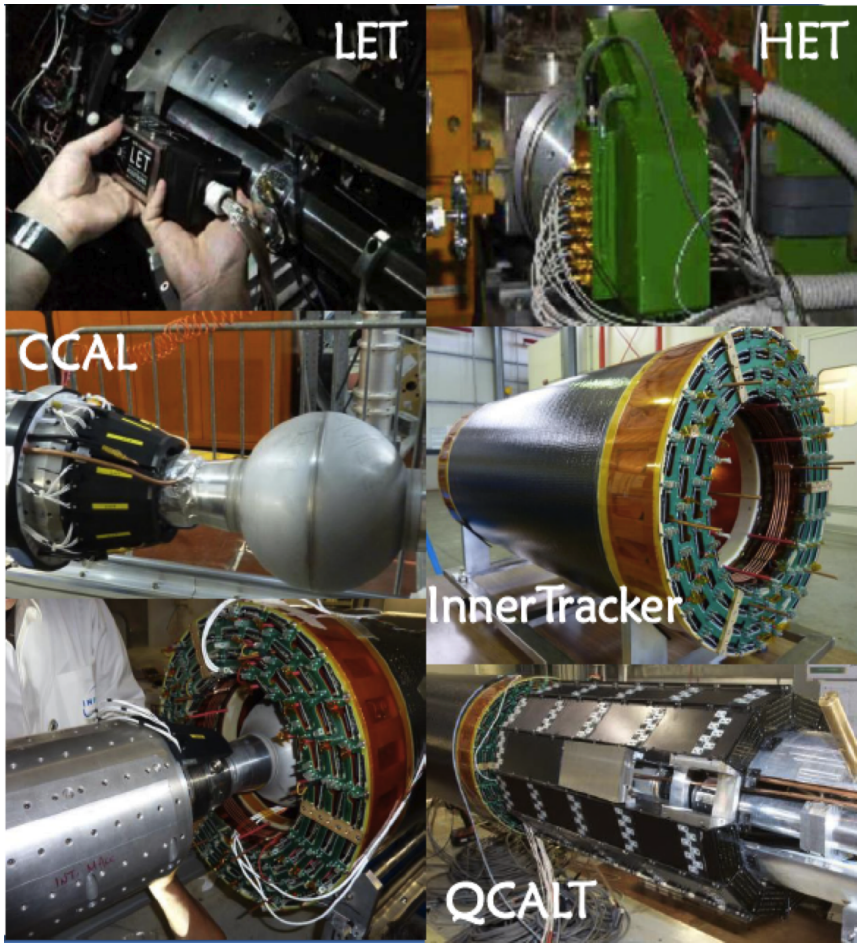
- Big Drift chamber operating with He-rich(90%) mixture, with stereo wires and carbon-fiber structure, $\sigma_{P_T} < 0.4\cdot\%\ P_T\ (\theta > 45^\circ)$
- Hermetic sampling calorimeter with lead, scintillating fibers, C-shaped end-caps for full coverage, $\sigma_t \sim \frac{57}{\sqrt{E(GeV)}} \oplus 100$ ps
- Loose trigger conditions insure maximal acceptance for any event topology for a wide physics program,

  EPJ C68(2010)619
- Integrated luminosity of 2.5 fb^{-1} with 2002 and 2004-2005 runs

- 250 pb^{-1} collected at 1 GeV for physics in the continuum

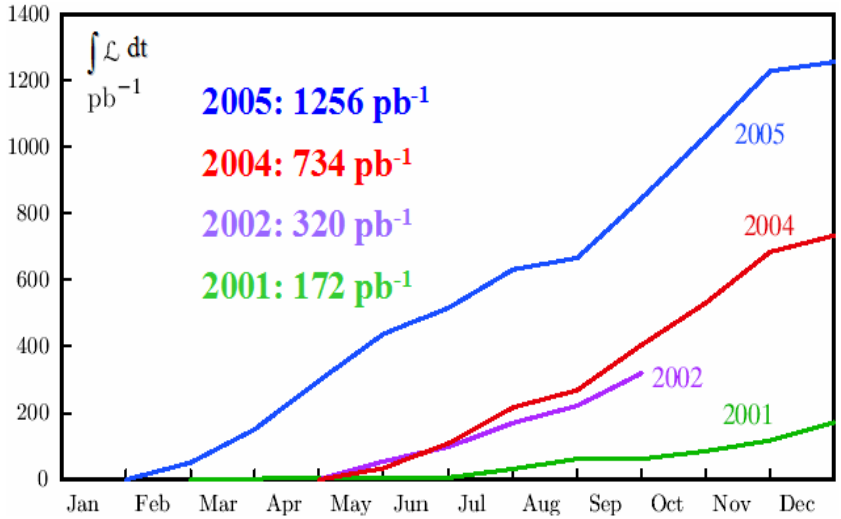
The detector upgrades

- Two different stations of γ–γ taggers, for the detection of e^+ and e^- in the high-energy (HET) and low-energy (LET) windows : $E_e > 400$ MeV and $130 < E_e < 300$ MeV.
- The Inner Tracker is the first cylindrical 3-GEM chamber ever built
- CCALT is a LYSO-crystal calorimeter to detect low-angle photons
- QCALT is a sampling calorimeter to instrument the final focusing region



Physics

- Data collected in 2002 and 2004-2006 are being used for precision measurements in various fields.
- Recently-finalized physics analyses include:



CPT tests studying the interference of neutral kaon pairs PLB 730(2014)89

The $K^+ \to \pi^+\pi^-\pi^0$ decays arXiv:1407.2028

Transition form factors $F_{\phi\eta}$ and $F_{\phi\pi^0}$ arXiv:1409.4582

The η radiative width JHEP 1301(2013)119

Isospin violating decays: $\eta \to \pi^+\pi^-\pi^0$

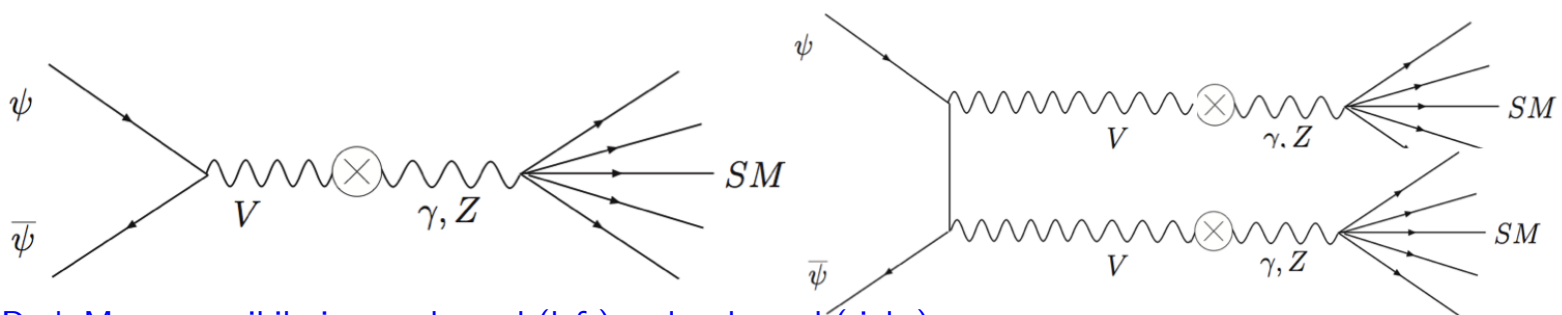
The hadronic cross section to improve on $(g-2)_\mu$ PLB 720(2013)336

Dark photon searches PLB 736(2014)459

Kinetic mixing

– New gauge field $U_S(1)$ advocated for explaining dark matter
– The SM allows few interactions with the secluded sector
– Such portals comprise couplings with the Higgs sector, to right–handed neutrinos and to photon/Z through the kinetic mixing with $U_Y(1)$, $\epsilon F^S_{\mu\nu} F^Y_{\mu\nu}$ B. Batell et al. PRD 79(2009)115008
– Kinetic mixing can be studied at ϕ and B–factories by a rich experimental program of dark photon (U–boson) searches
– Minimally suppressed (by ϵ^2) channels are

- pair annihilation: $e^+e^- \rightarrow U\gamma$; $e^+e^- \rightarrow U\ P(\pi^0\eta...)$
- higgs'-strahlung: $e^+e^- \rightarrow U\ h'$

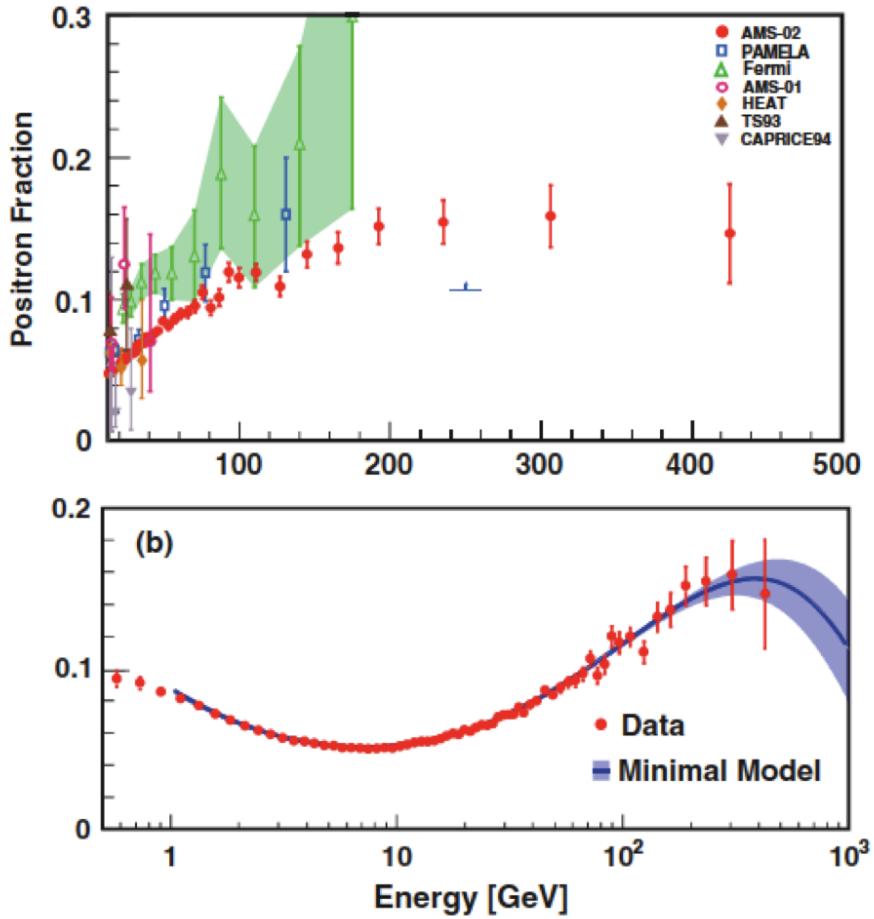


Dark Matter annihilation: s-channel (left) and t-channel (right)

– Cosmic ray positron fraction increases with the energy
– The effect was measured by HEAT, PAMELA, Fermi, AMS
– It requires another e^+ source besides the high–energy cosmic ray interactions with interstellar medium
– If the additional source is DM annihilation, $\sigma_{DMannihi}$ should be larger than for primordial–relic WIMPS
– The existence of a dark force could enhance the cross section at the right level Arkani–Hamed et al. PR D79(2009)015014
– Dark force could also explain other astroparticle measurements from DAMA/LIBRA, COGENT, ATIC and WMAP

Cosmic rays: positron fraction

AMS Collab. PRL 113(2014)121101



- The KLOE program in this field includes several analyses
- Search for the U–boson resonance in the $\eta e^+ e^-$ final state
- Search for the U–boson resonance in the $\mu^+ \mu^- \gamma$ final state
- Search for the U–boson resonance in the $e^+ e^- \gamma$ final state
- Search for associated U-h' production in the $\mu^+ \mu^-$ + missing energy final state (invisible h' expected for $M_{h'} < M_U$)
- Further searches feasible at the ϕ–factory to treat dark photon decays to hadrons studying $\phi \to \eta U \to \eta \pi^0 \gamma$ and $\phi \to \eta \gamma \to (U(\to \pi^0 \gamma)\gamma)\gamma$ final states S. Tulin PRD 89(2014)114008

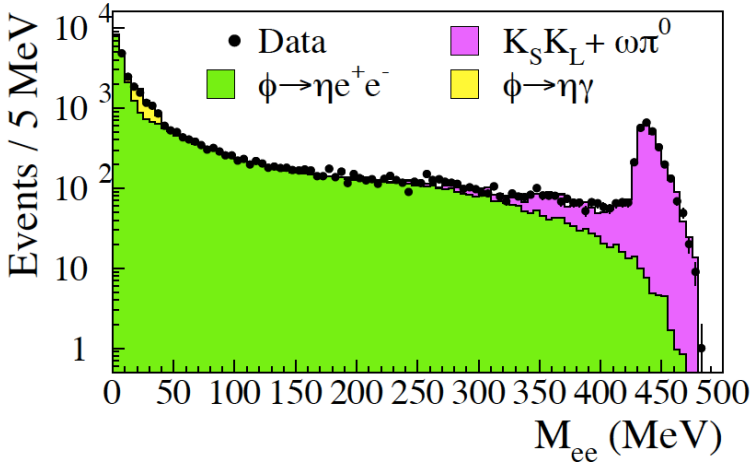
Data selection

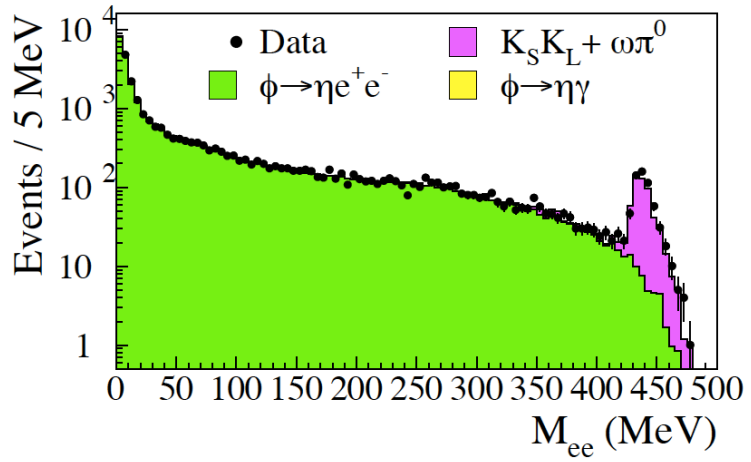
– From a sample of $\sim 6 \times 10^9$ ϕ mesons (1.7 fb^{-1}) we selected the $\phi \to \eta e^+e^-$ Dalitz decays with $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^0\pi^0\pi^0$

– Event selection requires two opposite–charge particles from the interaction region and 6 prompt clusters in the calorimeter, or 2 clusters and 2 opposite–charge particles, with invariant mass compatible with the η mass

– The contamination from $\phi \to \eta\gamma$ with photon conversion on the beam pipe or DC wall is suppressed by cuts on M_{ee} and on the PCA to BP and DCW

– $\sim 3.0 \times 10^4$ (1.3×10^4) events are selected in the neutral (charged) η decay channels with contamination at 3(2)% level





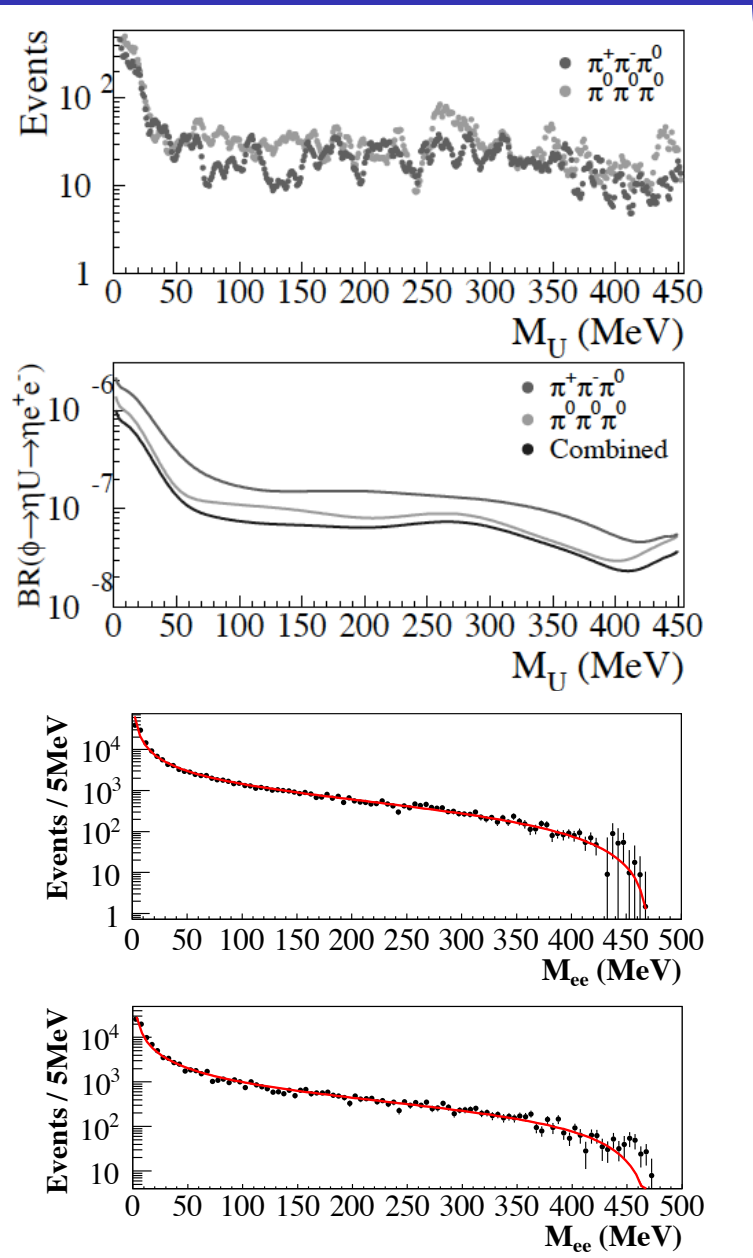
M_{ee} distribution

– Residual background is obtained from a fit to data using MC–predicted shapes

– After background subtraction consistent M_{ee} distributions from events with neutral and charged η decay are obtained

– Dark photon search is performed in 5 MeV bins from 5–450 MeV independently for neutral and charged η decays

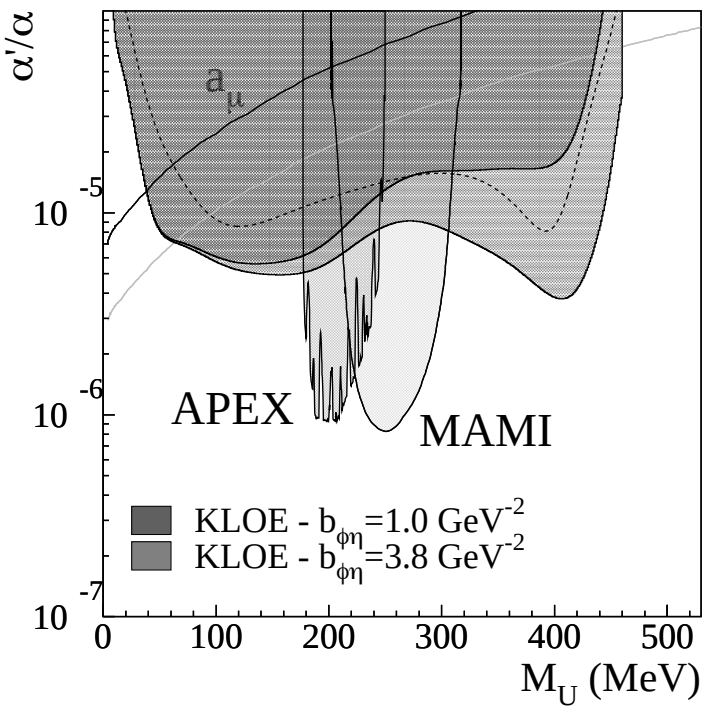
– Combined CLs upper limits from the two samples are obtained



Results

PLB B720(2013)111

No evidence for signal in a 4.3 10^4 ηe^+e^- sample $\to$
we obtain an excluded region at 90% C.L. in the ϵ^2–M_U plane
Upper limits on kinetic mixing parameter $\epsilon^2 \leq 8\ 10^{-6}$ are obtained in the M_U range from 50-210 MeV



$\mu\mu\gamma$ selection

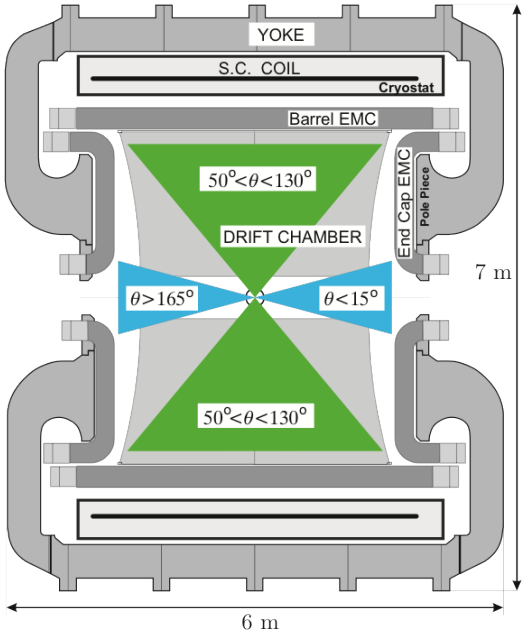
– Event selection requires two opposite–charge particles at large angle ($|\cos(\theta)| \leq 0.64$) and one undetected photon at small angle ($|\cos(\theta)| \geq 0.96$)

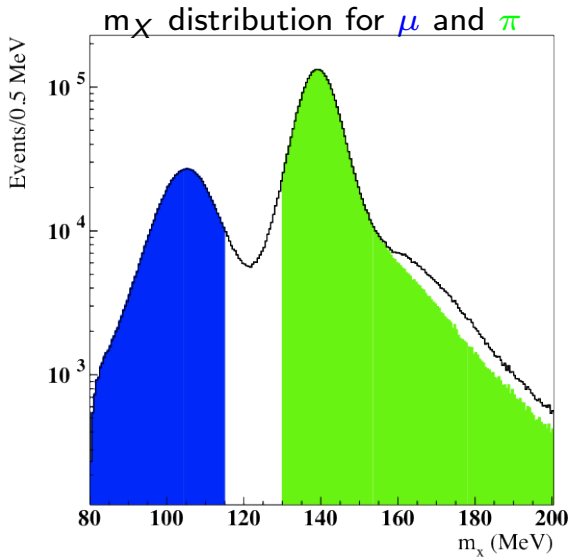
– eeγ, $\mu\mu\gamma$ and $\pi\pi\gamma$ samples separated by

- kinematical constraints giving m_X

$$E - \sqrt{p_+^2 + m_X^2} - \sqrt{p_-^2 + m_X^2} = |\vec{P} - \vec{p}_+ + \vec{p}_-|$$

- PID based on time–of–flight and energy deposit in the calorimeter
- additional track–quality cut to improve on μ/π separation



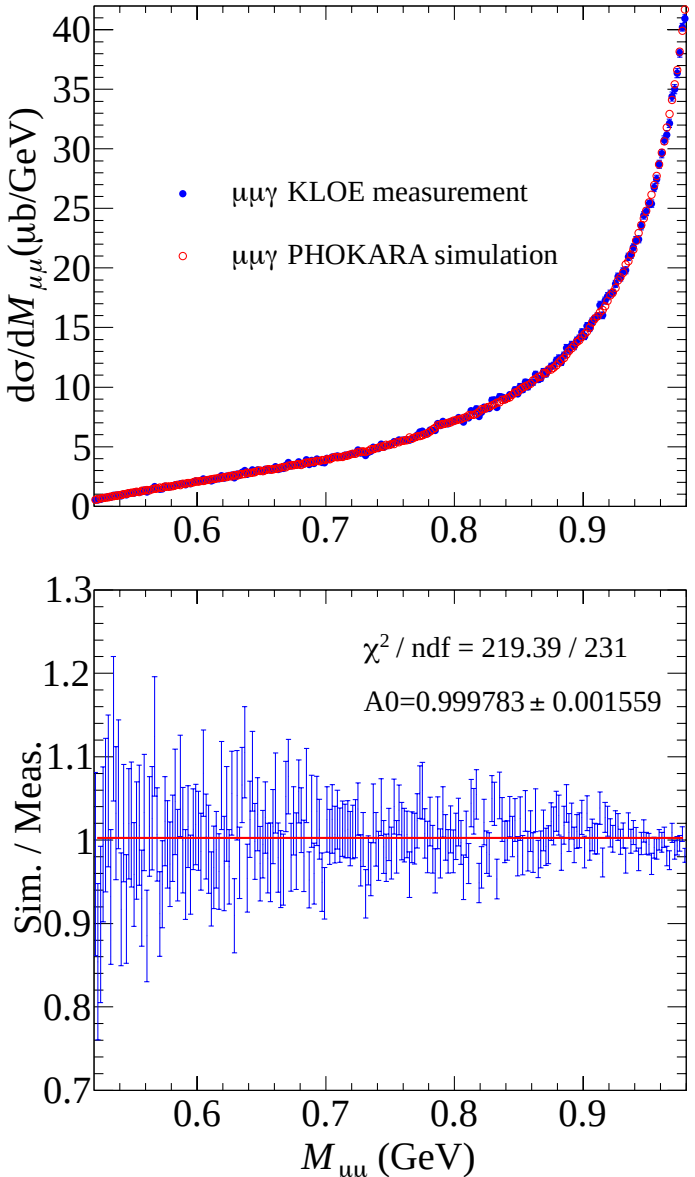


$\mu\mu\gamma$ spectrum

– Residual background is obtained from a fit to data using MC–predicted shapes for $\pi\pi\gamma$,$\pi\pi\pi^0$,$ee\gamma$ and $ee\mu\mu$ contributions to m_X distribution

– After background subtraction $M_{\mu\mu}$ distribution is in agreement within 1% with predictions from the NLO $\mu\mu\gamma$ generator Phokhara S. Actis et al. EPJ C66(2010)585

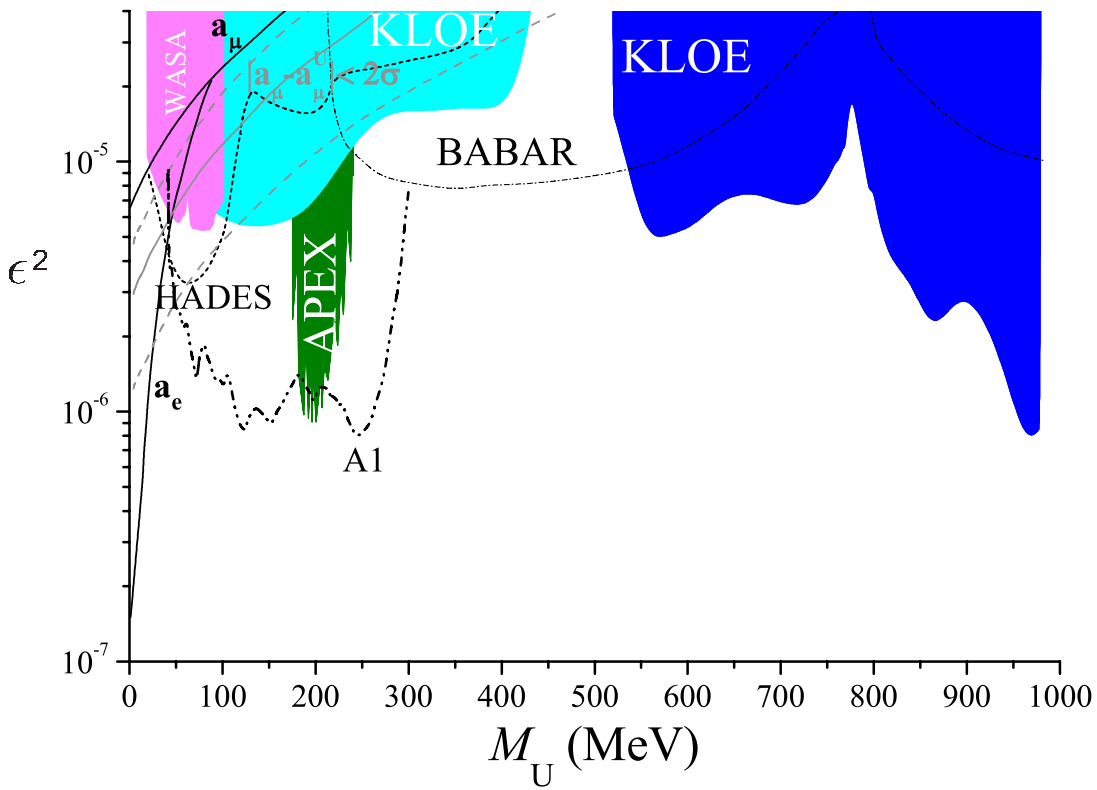
– Dark photon search is performed in 2 MeV bins from 520–980 MeV using the CLs technique



Results

PLB 736(2014)459

No evidence for signal in a 5.35 10^5 $\mu\mu\gamma$ sample $\to$
we obtain an excluded region at 90% C.L. in the ϵ^2–M_U plane
with M_U from 520-980 MeV and upper limits on
kinetic mixing parameter ϵ^2 from 8.6 10^{-7} to 1.6 10^{-5}



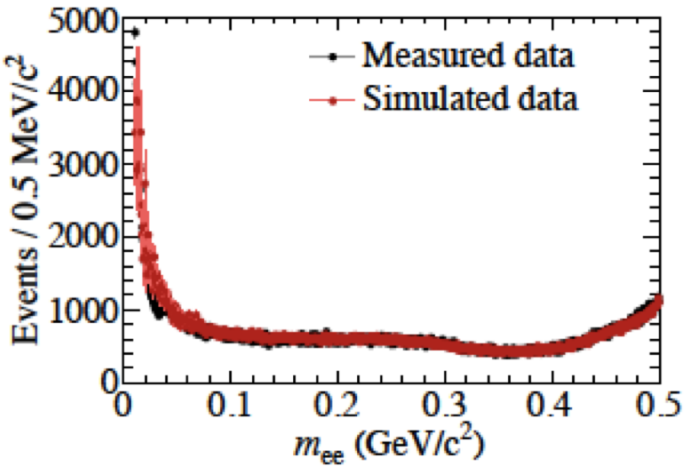
$ee\gamma$ selection

– Event selection requires two opposite–charge particles and one photon cluster at large angle ($|\cos(\theta)| \leq 0.57$)

– eeγ, $\mu\mu\gamma$ and $\pi\pi\gamma$ samples separated by same kinematical constraints as in the $\mu\mu\gamma$ analysis

– Residual background consists of $\mu\mu\gamma$, $\pi\pi\gamma$, $\pi^+\pi^-\pi^0$ and of $e^+e^- \to \gamma\gamma$ processes with photon convertion on the BP or DCW

– All of the background contributions have been evaluated by MC and are less than 1%

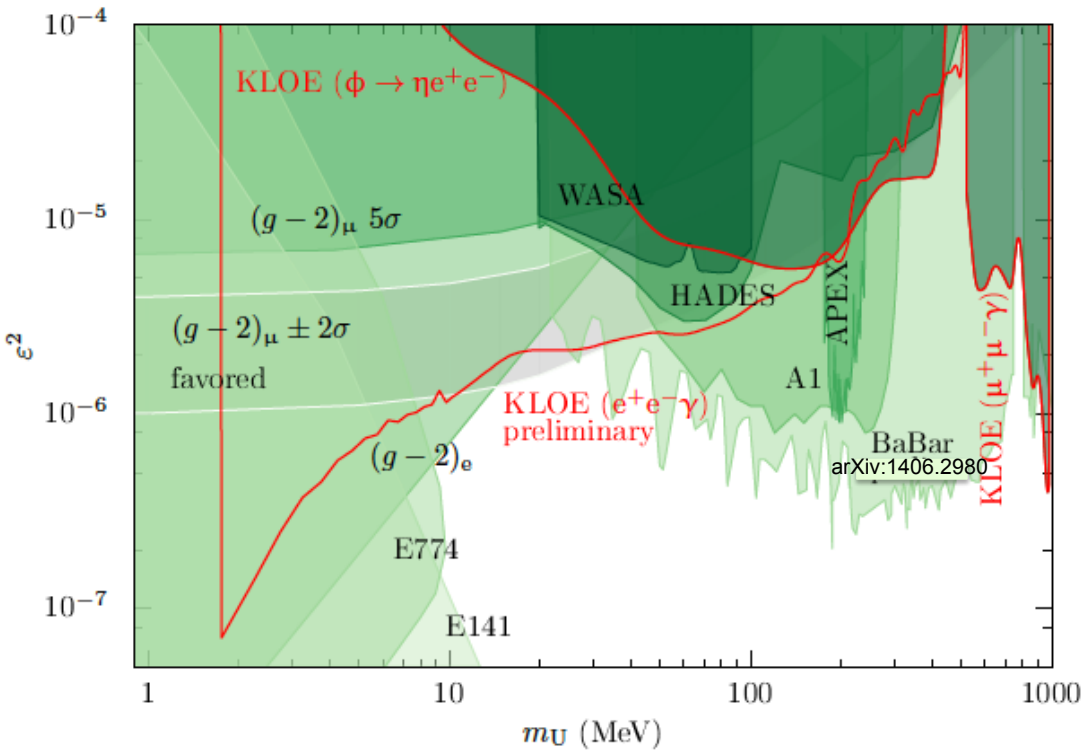


– The M_{ee} spectrum is in agreement with the MC expectation using Bhabhayaga generator EPJ C71(2011)1680

– CLs upper limit evaluated on the basis of i) Number of $ee\gamma$ events in each 0.5 MeV bin from a fit to the sidebands and ii) signal simulation taking into account experimental resolutions

Preliminary results

No evidence for signal → we can exclude at 90% C.L. kinetic couplings of the dark sector ϵ^2 above 1–10 10^{-7} for $m_U \leq 10$ MeV and above 1-5$\times 10^{-6}$ from 10–210 MeV



The h'iggs-strahlung processes

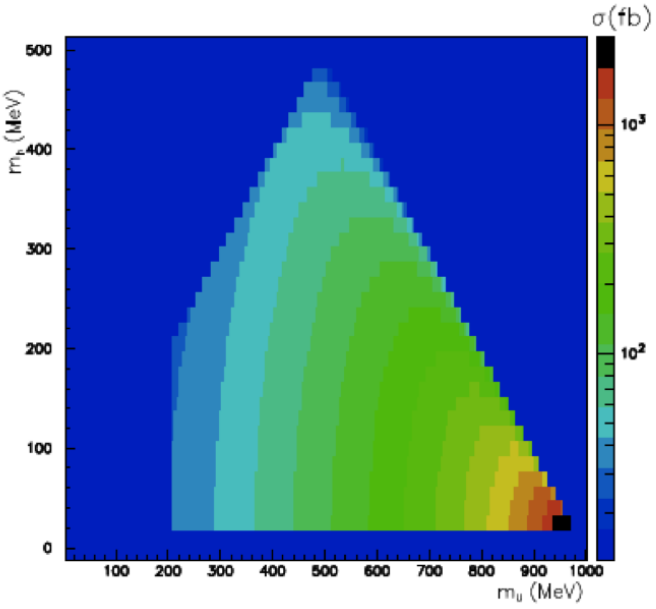
– The h'iggs-strahlung cross section depends $\epsilon^2 \times \alpha_D$, $m_{h'}$ and m_U

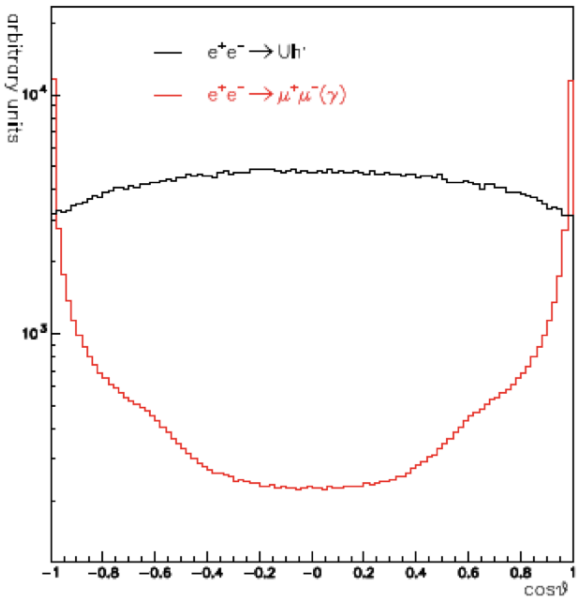
B. Batell et al. PRD79(2009)115008

– h' is expected to be invisible if $m_{h'} \leq 2m_U$ and $\epsilon^2 \times \alpha_D \sim (10^{-4} - 10^{-2})\alpha_{em}$ or smaller ($m_{h'}$–dependent condition)

– Within such scenario KLOE sensitivity on $\alpha_D \times \epsilon^2$ is better than 510^{-9} in most of the $m_{h'}$–m_U plane, $2m_\mu \leq m_U \leq 1$ GeV, $m_{h'} \leq m_U$

– Particle production from the h'iggs-strahlung process is expected at high polar angle thus being separated from QED continuum background





Data analysis

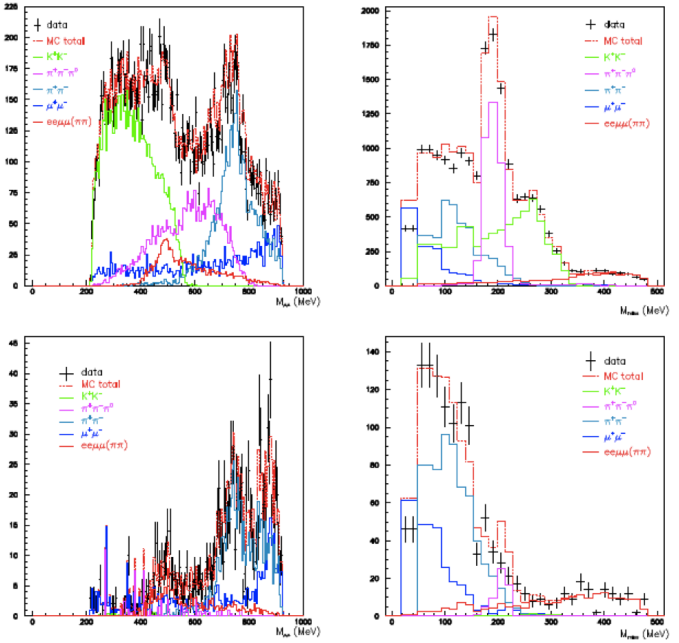
– Event selection requires two opposite–charge particles from the IR with polar angle $|cos(\theta_{1,2})| \leq 0.80$ and $|P_{1,2}| \leq 460$ MeV
Missing momentum, $|\overrightarrow{P}_{miss}| \leq 40$ MeV
PID based on calorimeter clusters to reject e^+e^- pairs

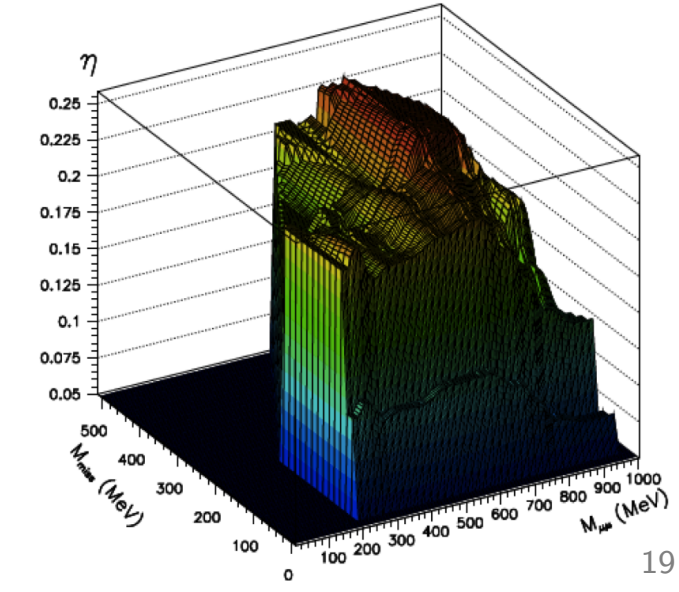
–Analysis on 53 bins in the $m_{h'}$–m_U plane

– Background contributions carefully studied with MC simulation corrected with real data comparisons

– Sample based on data at the ϕ resonance and on off–peak data

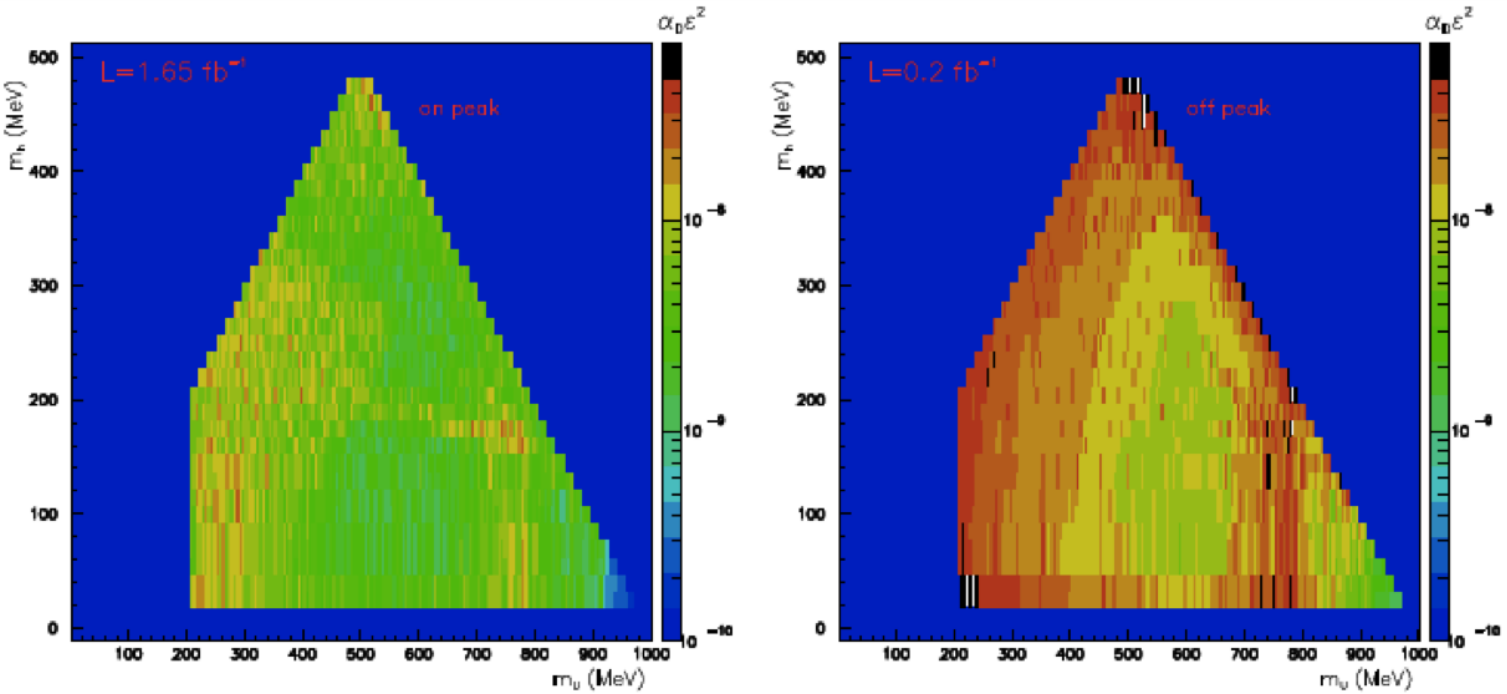
– Analysis efficiency is at the level of 20% on most of the bins, evaluated from MC and controlled on real data samples





Preliminary results

From the analysis of final states with $\mu\mu$ + missing energy using 1.65 fb^{-1} of on–peak data and ~200 pb^{-1} at 1 GeV no evidence for $e^+e^- \to Uh' \to \mu^+\mu^-$ + invisible h' $\to$ we obtain an exclusion plot where $\alpha_D \times \epsilon^2 \geq 5\ 10^{-9}$ is ruled out in most of the $m_{h'}$–m_U plane, $2m_\mu \leq m_U \leq 1$ GeV, $m_{h'} \leq m_U$



Conclusions and Outlook

- The KLOE experiment has recently obtained several results on kaon and hadron physics, and the exclusion plot for dark photon masses from few to 1000 MeV at a level of kinetic mixing parameter ϵ^2 of 1-5 10^{-6}
- The analyses of $e^+e^- \to U\gamma$ in the $e^+e^-\gamma$ final state is in progress together with the search for the h'iggs-strahlung process on a sample of $\mu\mu$+missing energy
- The innermost part of the detector has been upgraded to improve vertex resolution near the IP, to increase the acceptance at low polar angle and to instrument the DAΦNE final focusing region
- The goal is to collect $O(10)$ fb^{-1} in 2-3 years
- New data sample can improve the sensitivity of dark photon searches especially for m$_U$ of $O(10)$ MeV