U boson search in $e^+e^- \to \mu^+\mu^-\gamma$ process at KLOE

Francesca Curciarello
University of Messina, INFN Sez. Catania
(For the KLOE-KLOE2 Collaboration)

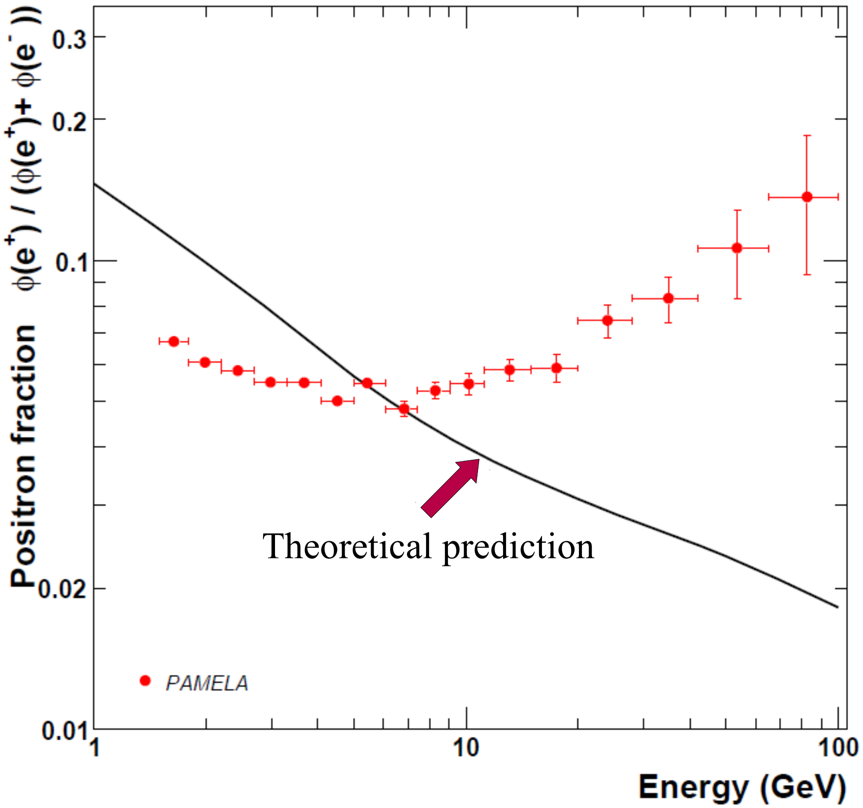
Dark Forces at Accelerators, LNF-Frascati, October 16th-19th, 2012

Outline

- Radiative Events at $e^+ e^-$ Colliders
- DAΦNE Complex and KLOE Detector
- $e^+e^-\rightarrow\mu^+\mu^-\gamma$ Data Analysis: based on KLOE Analysis fot the $\sigma_{\pi\pi\gamma}$ measurement
  - -Event Selection
  - -Background Subtraction Procedure
  - -Data/MC Comparison
- ε^2 Upper limit extraction in the region 600÷1000 MeV
- Future Perspectives and Conclusions

Motivations: Astrophysical Evidences

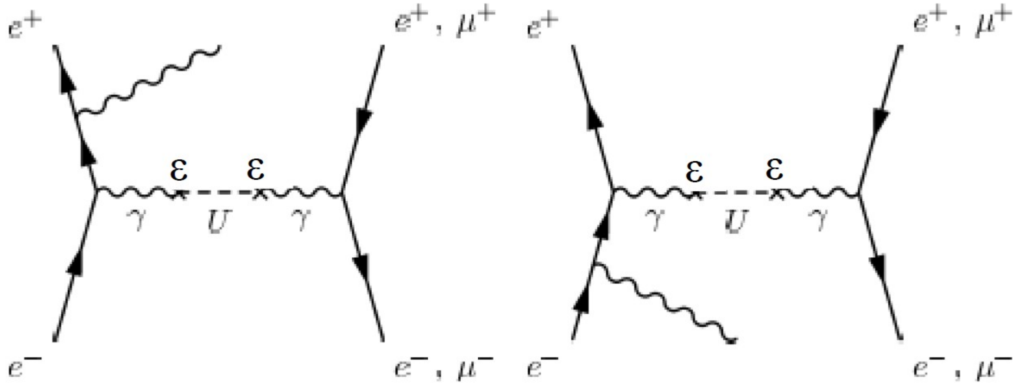
-e^+/e^- excess in the cosmic ray flux and the absence of a similar effect in proton/anti-proton observations by **PAMELA**
-511 KeV gamma ray signal form galactic center by **INTEGRAL satellite**
-total e^+/e^- flux measured by **ATIC**, **HESS**, **Fermi**
-**DAMA/LIBRA** annual modulation signal



All these observations could be explained if one assume that a dark matter gauge boson, mediator of an unknown dark force with $m_U < 2m_p$, exists.

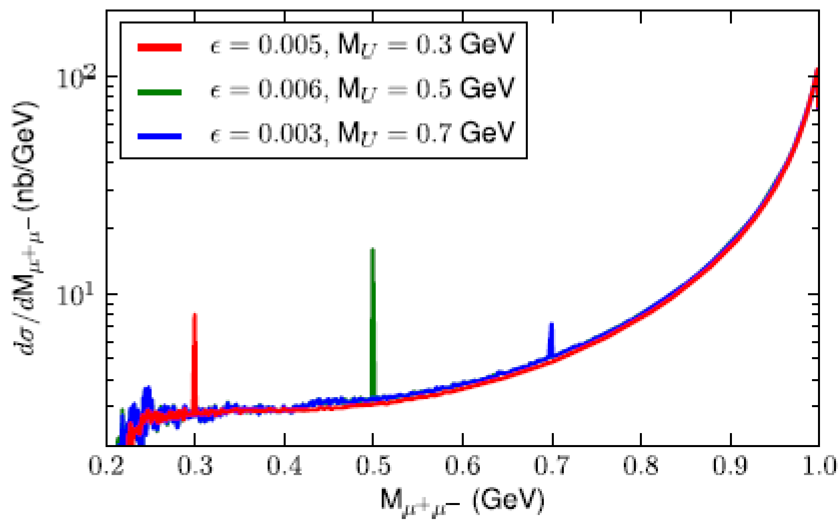
High luminosity e^+ e^- Colliders Experiments at GeV scale can be a direct probe of Dark Forces.

At flavor factories a particular clean channel is the production of the U boson plus a photon with the consequent decay of the boson in a leptons pairs: $\mathbf{e^+ e^- \rightarrow U\gamma \rightarrow l^+ l^- \gamma, l= e,\mu}$



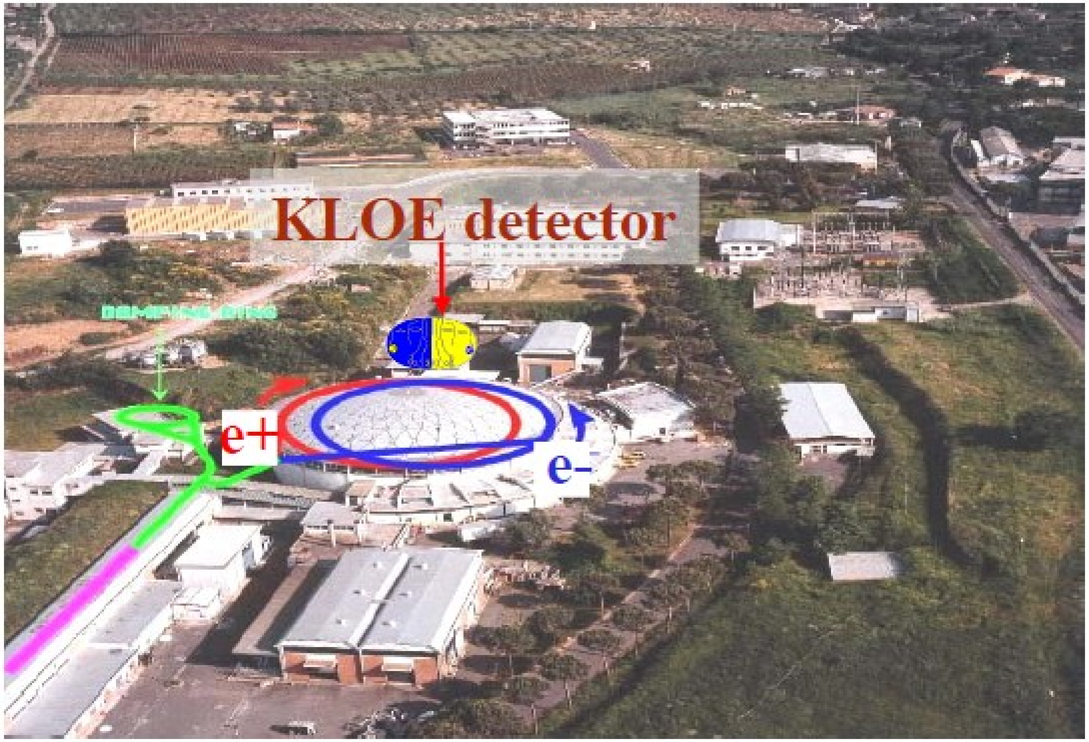
The expected U boson signal should have the shape of a **narrow Breit-Wigner peak in the invariant mass distribution of the leptons pair**

Sensitivity to the kinetic mixing parameter in the range $\varepsilon \sim 10^{-3}$-10^{-2} for a M_U up to a few GeV

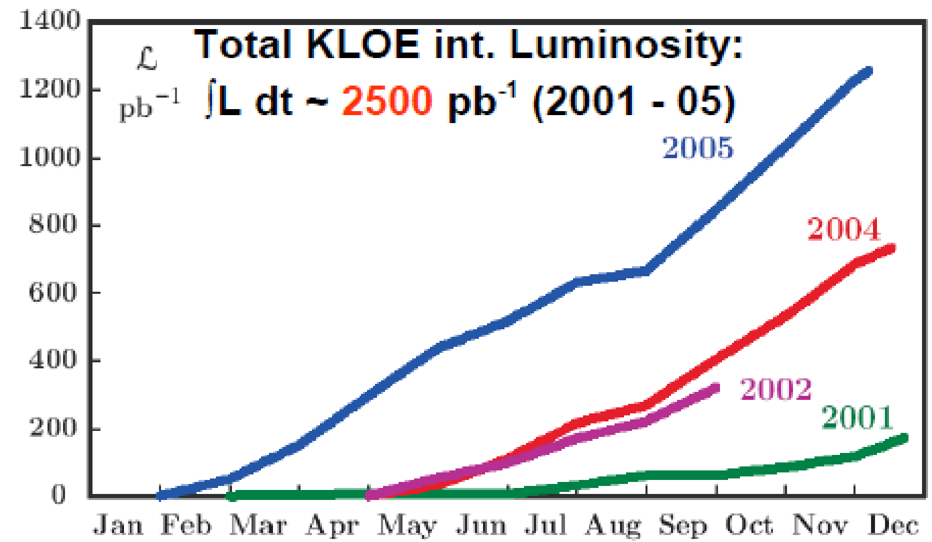


Barzè, L. et al.: *Radiative Events as a Probe of Dark Forces at GeV–Scale e^+e^- Colliders.* Eur. Phys. J., **C71**, 2011, p. 1680–1688.

DAΦNE: The Φ- Factory



Integrated Luminosity



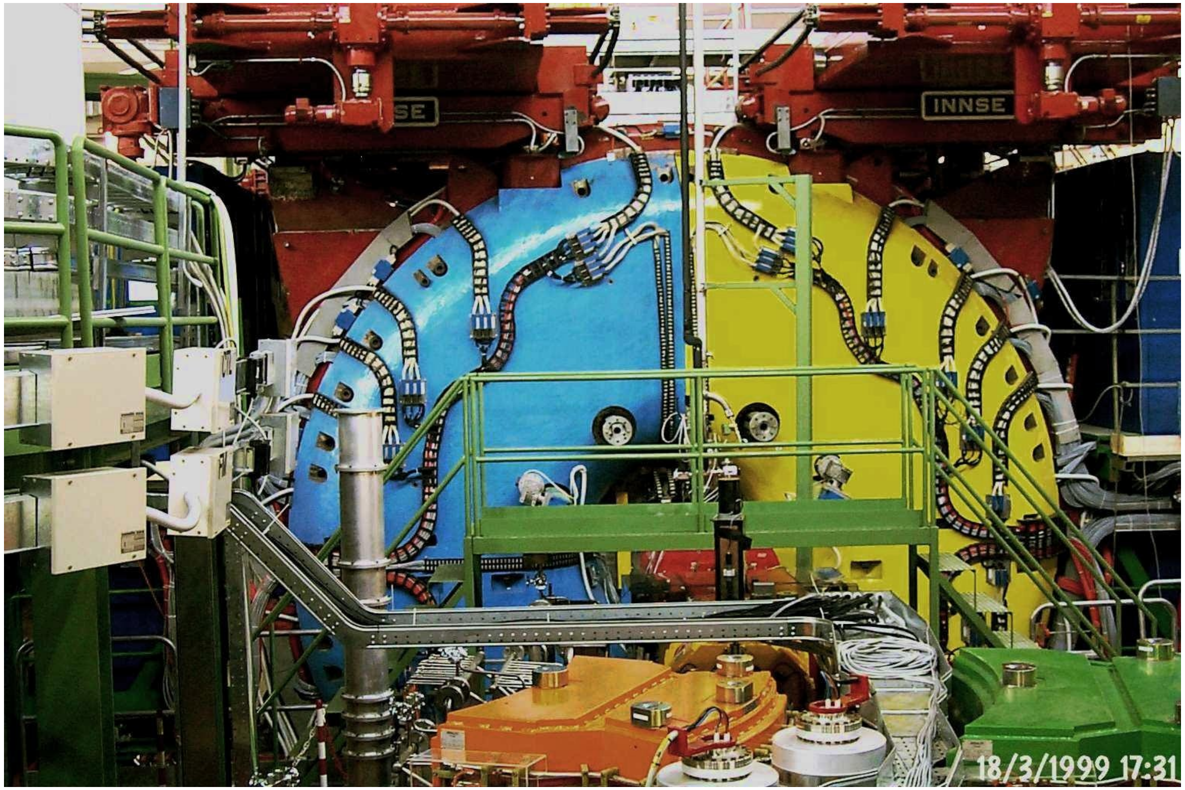
Peak Luminosity Lpeak= $1.5 \cdot 10^{32} cm^{-2}s^{-1}$

DAΦNE is a $e^+ e^-$ Colliders with a $\sqrt{s} = m_\Phi = 1.0195$ GeV, at LNF Frascati.

The DAΦNE Accelerator Complex consists of **a linear accelerator, a damping ring**, nearly 180 m of **transfer lines**, **two storage rings** that intersect at two points, **a beam test area** (BTF) and **three syncrotron light lines.**

KLOE Detector

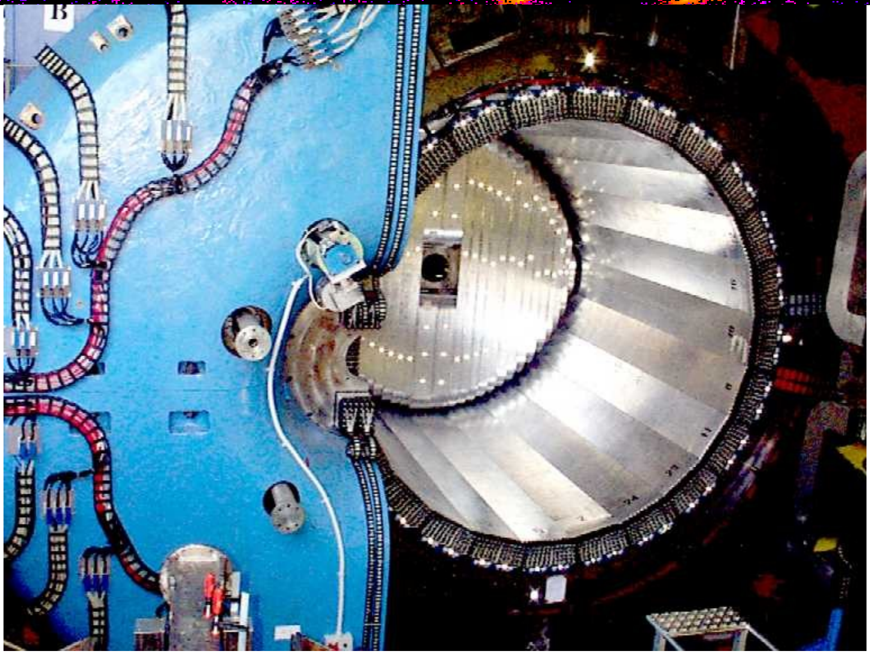
The **KLOE detector** is made up of a large cylindrical drift chamber **(DC)**, surrounded by a lead scintillating fiber electromagnetic calorimeter **(EMC)**. A superconducting coil around the EMC provides a **0.52 T magnetic field.**



EMC: measurement of **photon energies** and **impact point**, accurate measurement of the **time of arrival of particles.**

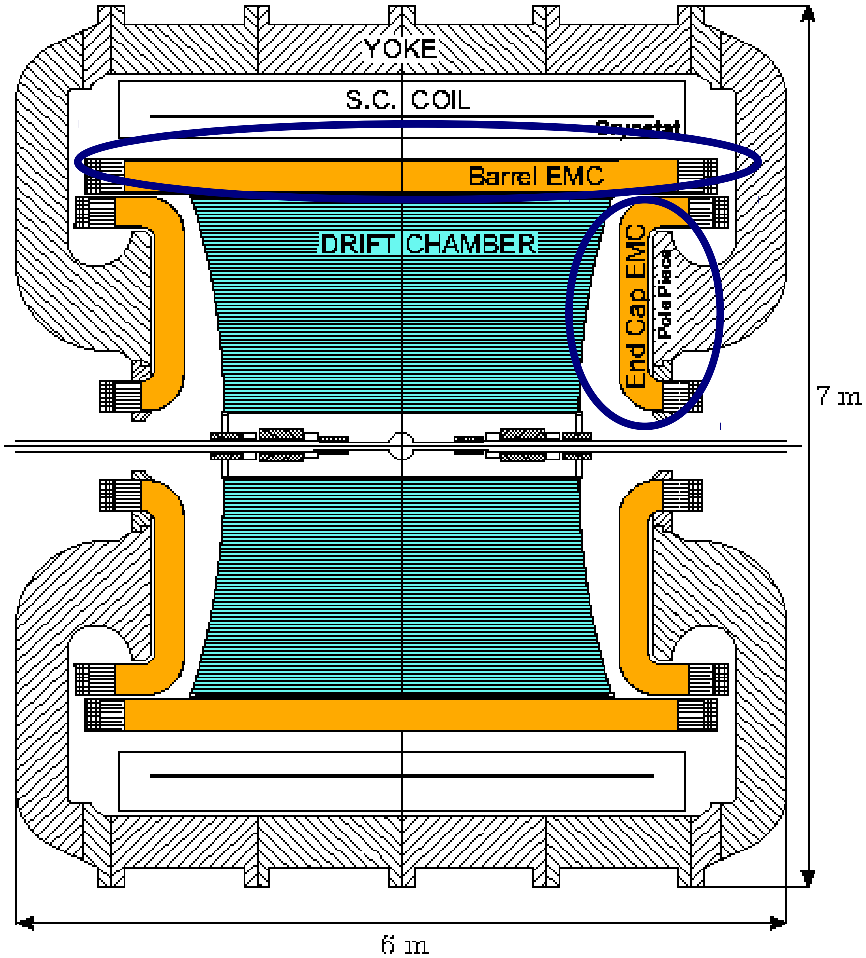
DC: **tracking** of the particles and reaction **vertex reconstruction**

KLOE Detector: EMC



Barrel + 2 end-caps: Pb/scintillating fiber
4880 PM

Beam line



End-caps C-shaped to minimize dead zones:
98% coverage of full solid angle

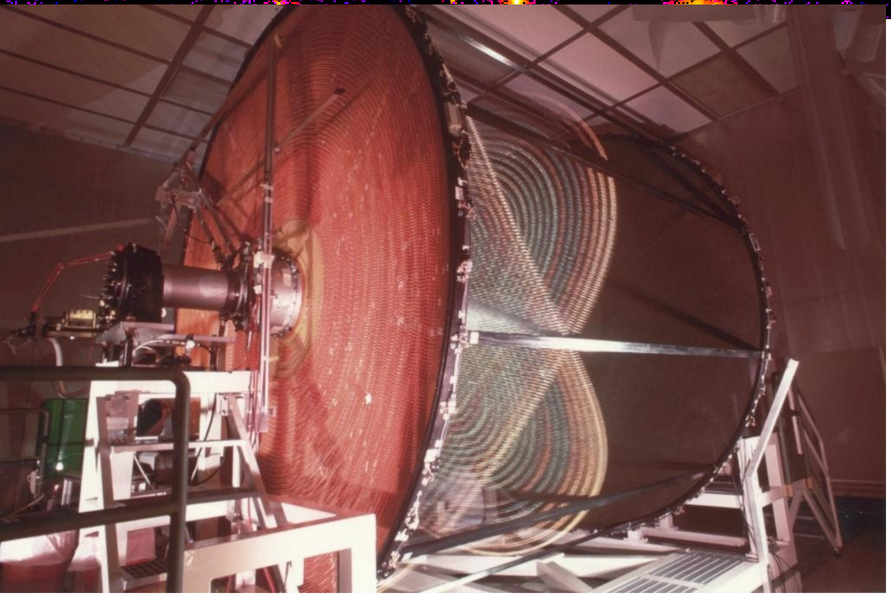
$$\sigma_E/E = 5.7\% / \sqrt{E(\mathrm{GeV})}$$

$$\sigma_T = 54\ \mathrm{ps} / \sqrt{E(\mathrm{GeV})} \oplus 100\ \mathrm{ps}$$

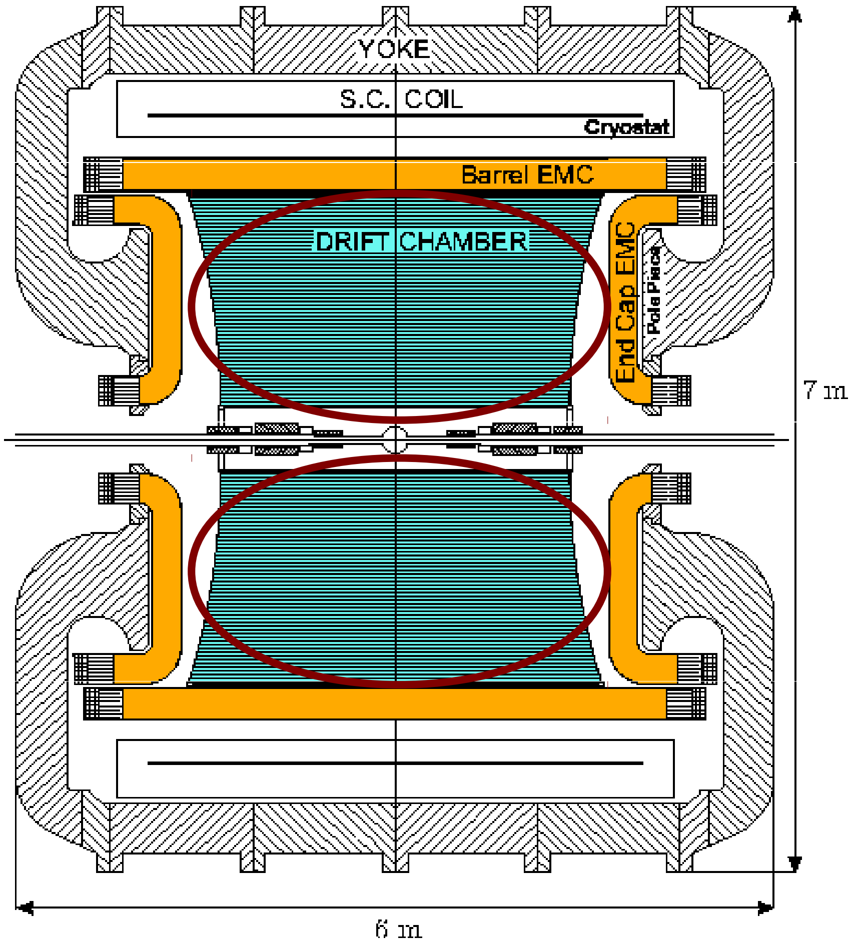
(Bunch length contribution subtracted from constant term)

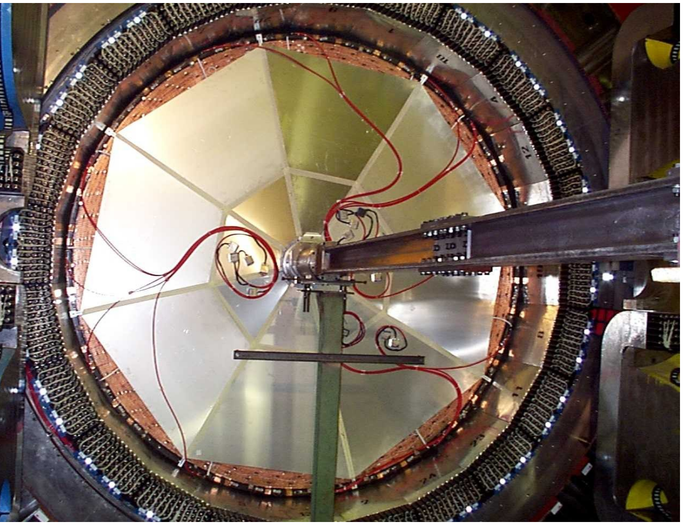
excellent time resolution

KLOE Detector: DC



All-stereo geometry, 4m diameter, 3m long
fiber epoxy composite, **12,000 sense wires**
Filled with gas mixture:90% He 10% C_4H_{10}





$\boldsymbol{\sigma}_{xy}$~150μm, $\boldsymbol{\sigma}_z$ = 2mm
$\boldsymbol{\sigma}_{p_\perp}/\mathbf{p}_\perp$ better then 0.4%
for large angle tracks
(40°≤θ ≤140°)
vertex resolution = ~3mm

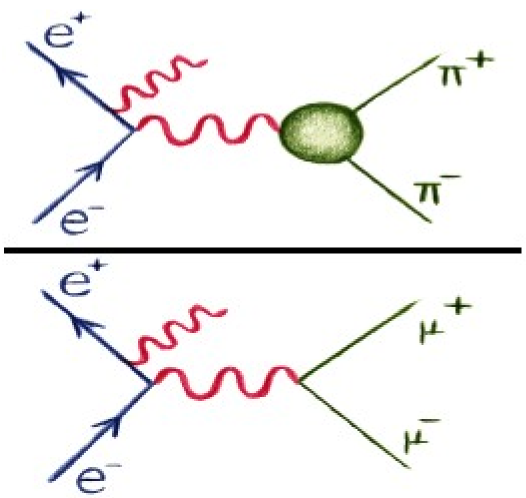
Excellent momentum resolution

$|F_\pi|^2$ KLOE Measurement from $\pi\pi\gamma/\mu\mu\gamma$

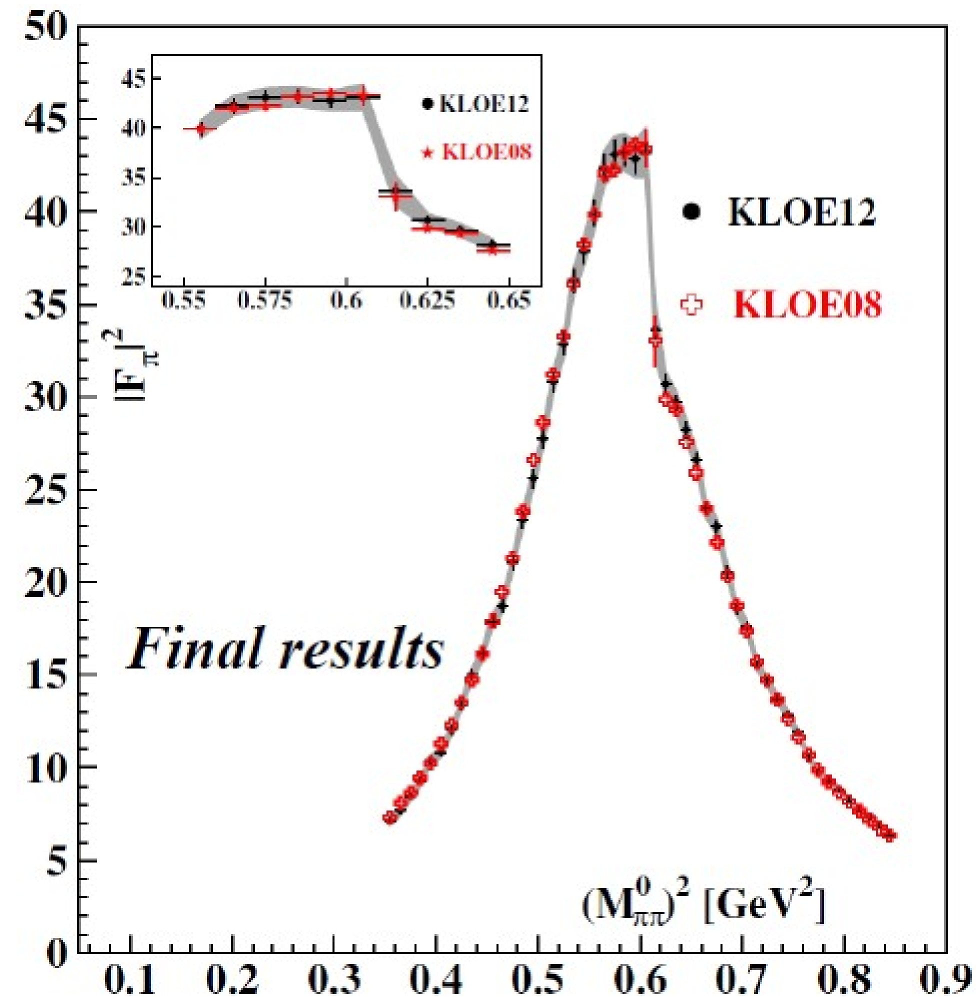
Measure of $|F_\pi|^2$ by the bin by bin ratio of pions over muons yields

Results presented by G.Mandaglio @TAU2012

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



High precision measure

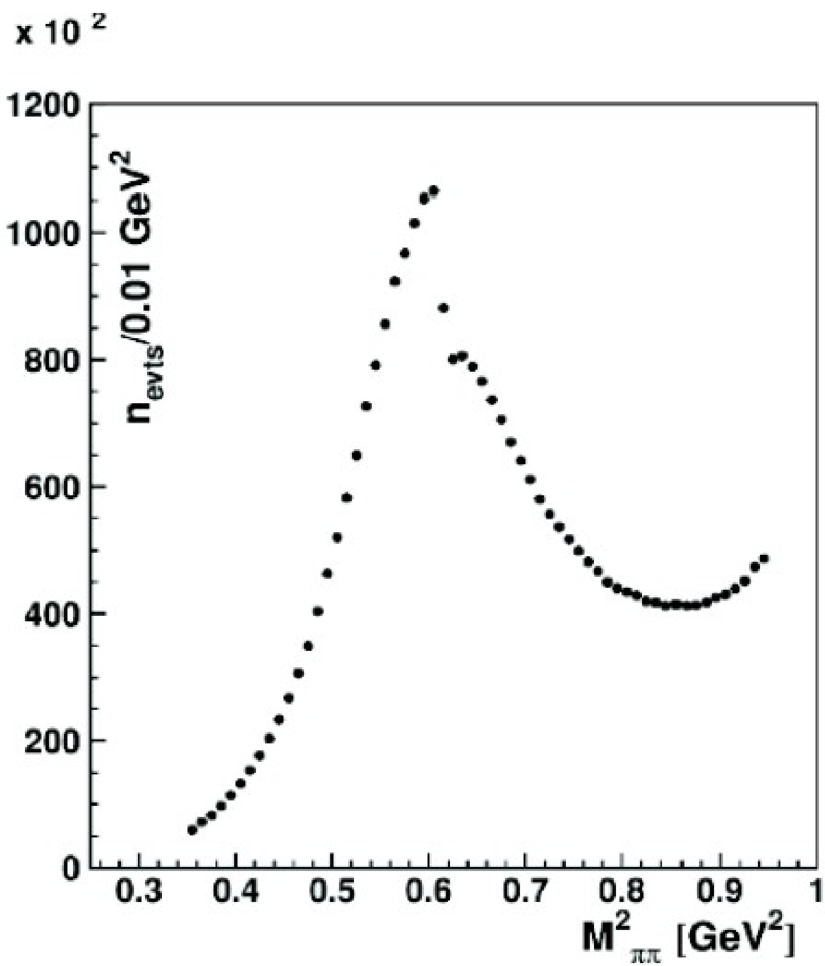


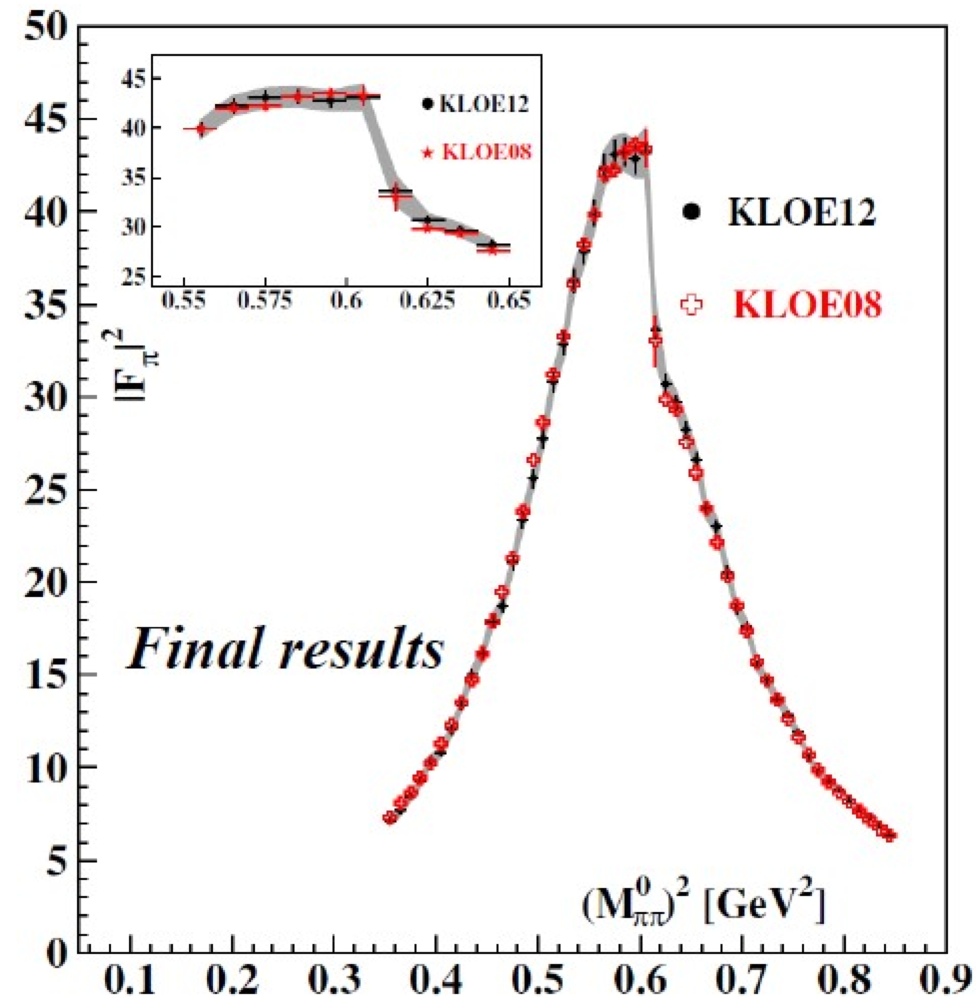
KLOE12: $a_\mu^{\pi\pi}(0.35\text{-}0.95\ \text{GeV}^2) = (385.1 \pm 1.1\text{stat} \pm 4.4\text{sys} \pm 1.2\text{theo}) \cdot 10^{-10}$

$|F_\pi|^2$ KLOE Measurement from $\pi\pi\gamma/\mu\mu\gamma$

Measure of $|F_\pi|^2$ by the bin by bin ratio of pions over muons yields

Results presented by G.Mandaglio @TAU2012





KLOE12: $a_\mu^{\pi\pi}(0.35\text{-}0.95\ \mathrm{GeV}^2) = (385.1 \pm 1.1\mathrm{stat} \pm 4.4\mathrm{sys} \pm 1.2\mathrm{theo}) \cdot 10^{-10}$

$e^+e^- \to \mu^+\mu^-\gamma$ Data Analysis: SA Event Selection

-Statistics: 240 pb^{-1} data taken on 2002.

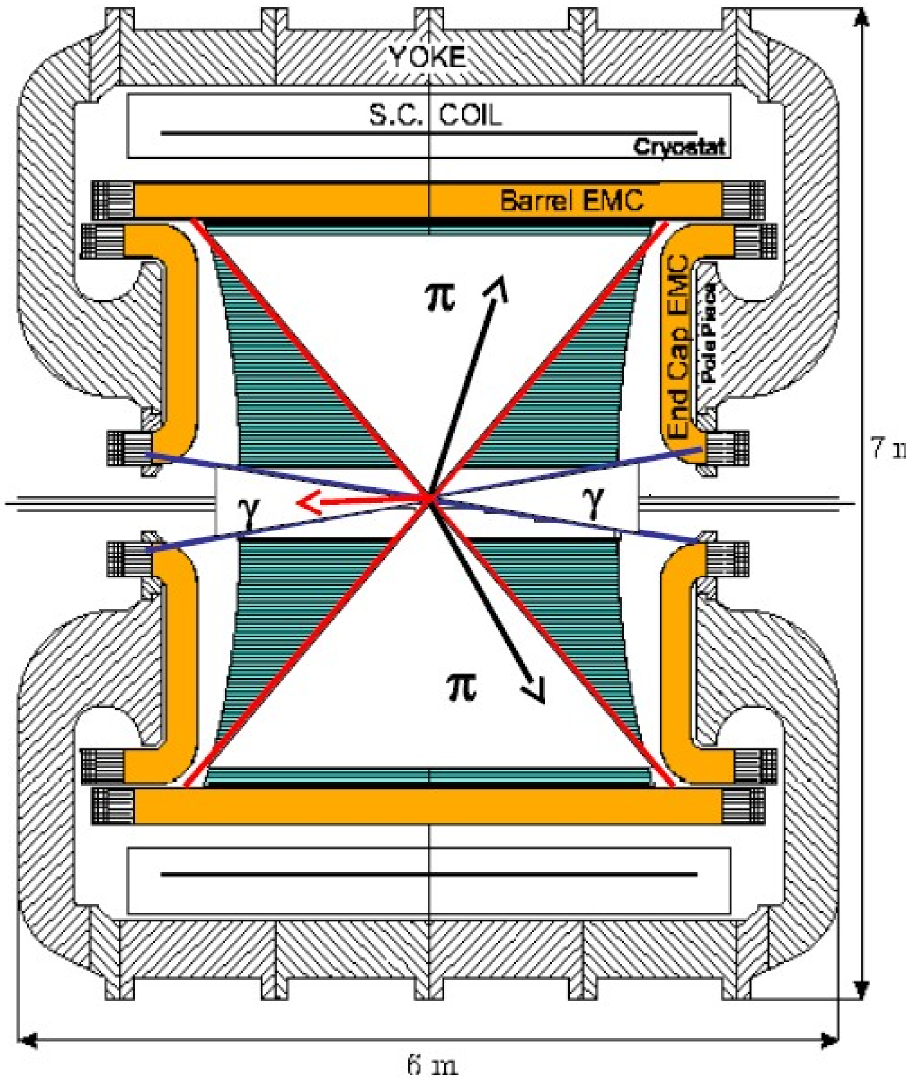
-undetected photon emitted at small angle (θ_γ<15°, θ_γ>165°)

- two charged tracks with 50°<θ_μ<130° .

-high statistics signal

- significant reduction of Φ resonant and FSR radiative processes backgrounds.

$$\text{kinematics}: \vec{p}_\gamma = \vec{p}_{miss} = -(\vec{p}_1 + \vec{p}_2)$$



$e^+e^- \to \mu^+\mu^-\gamma$ Data Analysis: Event Selection

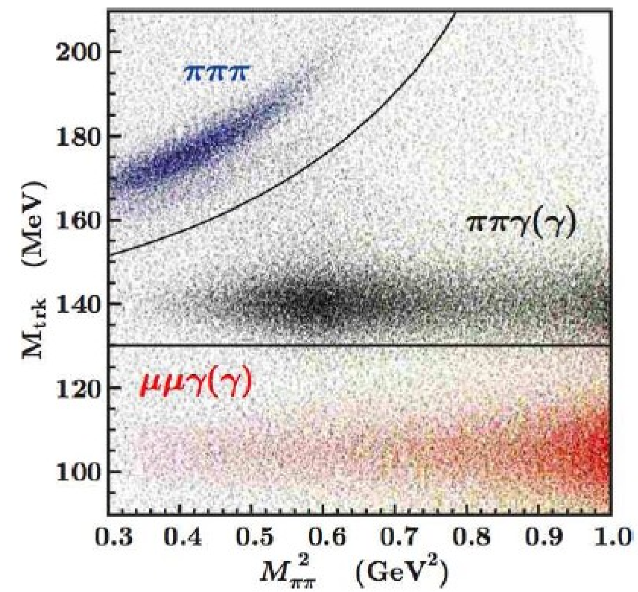
background contributes coming from:

$e^+e^- \to e^+e^-\gamma(\gamma)$

$e^+e^- \to \pi^+\pi^-\gamma(\gamma)$

$\varphi \to \pi^+\pi^-\pi^0$

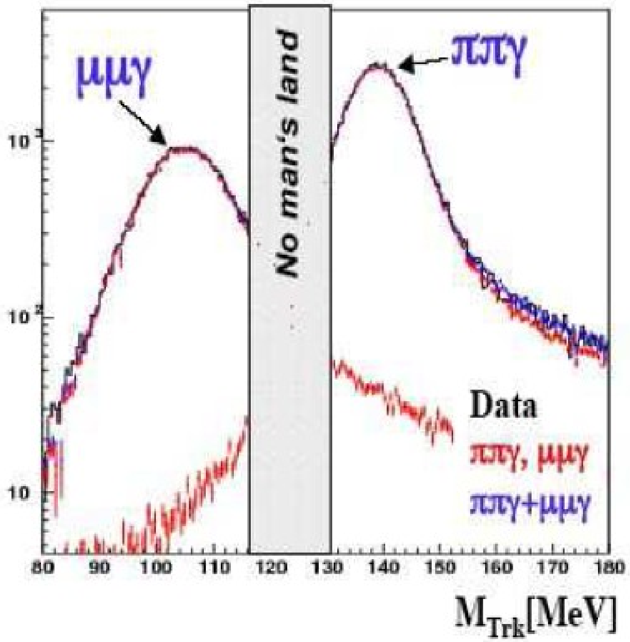
Removed using kinematical cuts in the M_{TRK}-$M^2_{\pi\pi}$ plane.



M_{TRK} defined by 4-momentum conservation assuming 2 charged particles of the same mass and 1 γ in the final state.

$$\left(\sqrt{s}-\sqrt{|p_+|^2+M^2_{TRK}}-\sqrt{|p_-|^2+M^2_{TRK}}\right)^2-(p_+ + p_-)^2=0$$

cut on variable M_{TRK} to reduce $\pi\pi\gamma$ tail contamination in the $\mu\mu\gamma$ M_{TRK} region, by requiring:



M_{TRK}<115 MeV for muons

M_{TRK}>130 MeV for pions

The systematic uncertainty on the muons cross section is about 1%

Data corrected by Trig, Track and PID efficiencies.

Background Subtraction

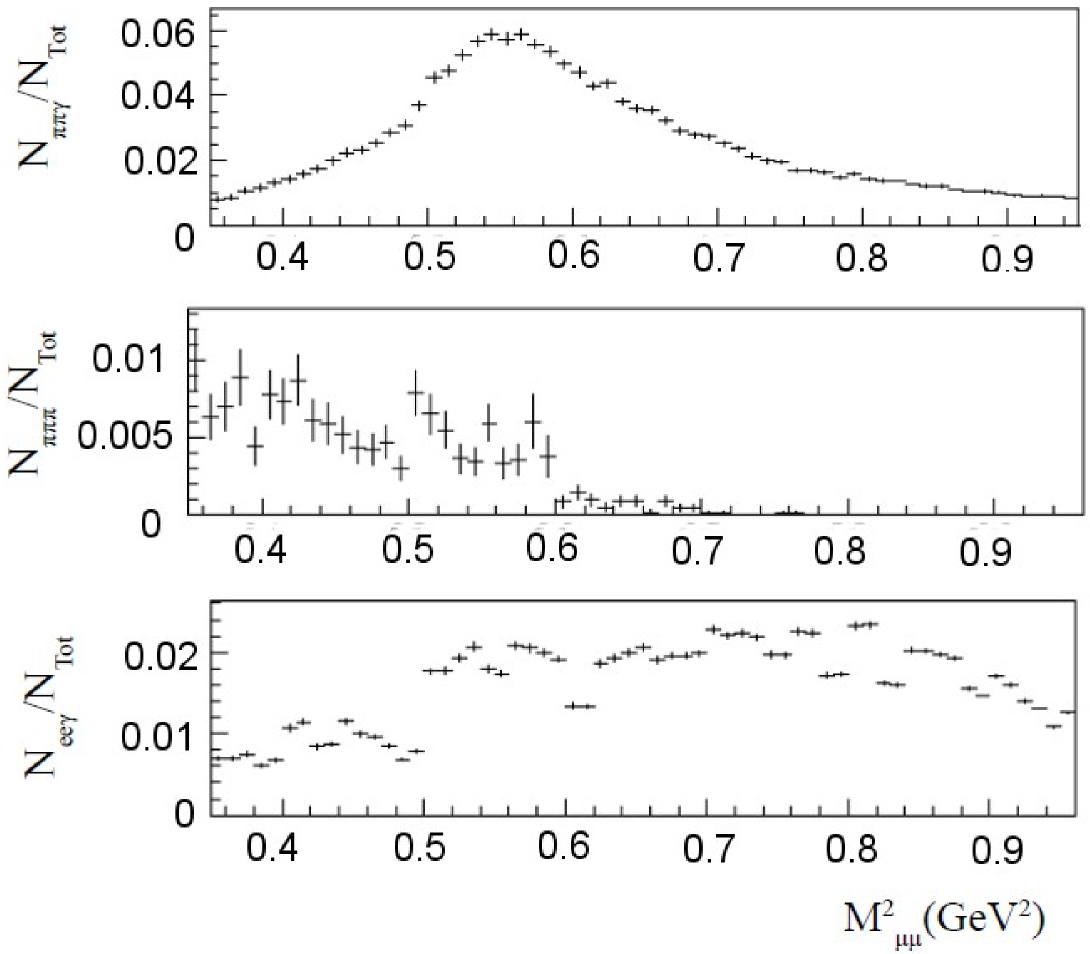
Three main background components:

- **$e^+ e^- \gamma(\gamma)$**
- **$\pi^+ \pi^- \gamma(\gamma)$**
- **$\pi^+ \pi^- \pi^0$**

-Backgrounds contributions obtained for 32 $M^2_{\mu\mu}$ slices of 0.02GeV^2 between 0.32 and 0.96 GeV^2

-$e^+ e^- \gamma$, $\pi^+ \pi^- \gamma$ and 3π distribution taken byMC

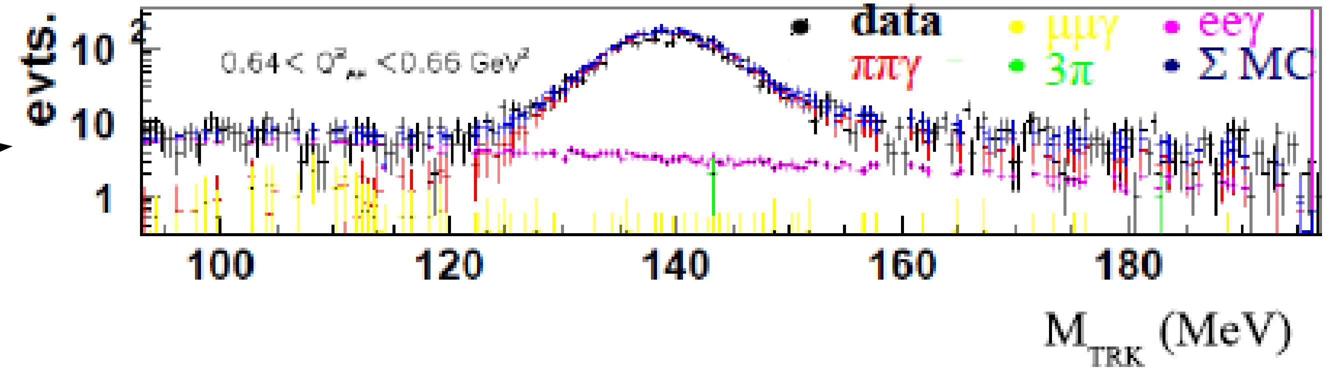
- tuning of $\pi^+ \pi^- \pi^0$ M_{TRK} tail correction applied.



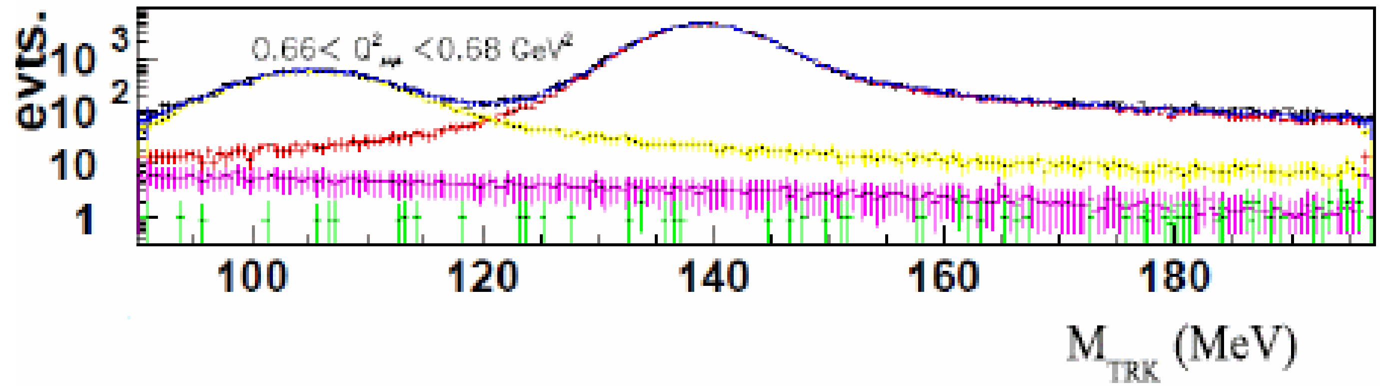
Background Subtraction

Two steps:

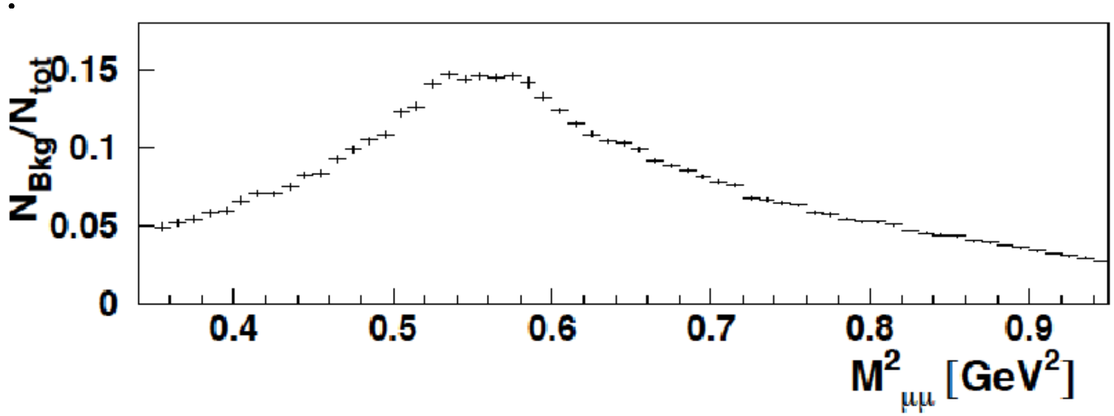
eeγ weights



ππγ,3π weights



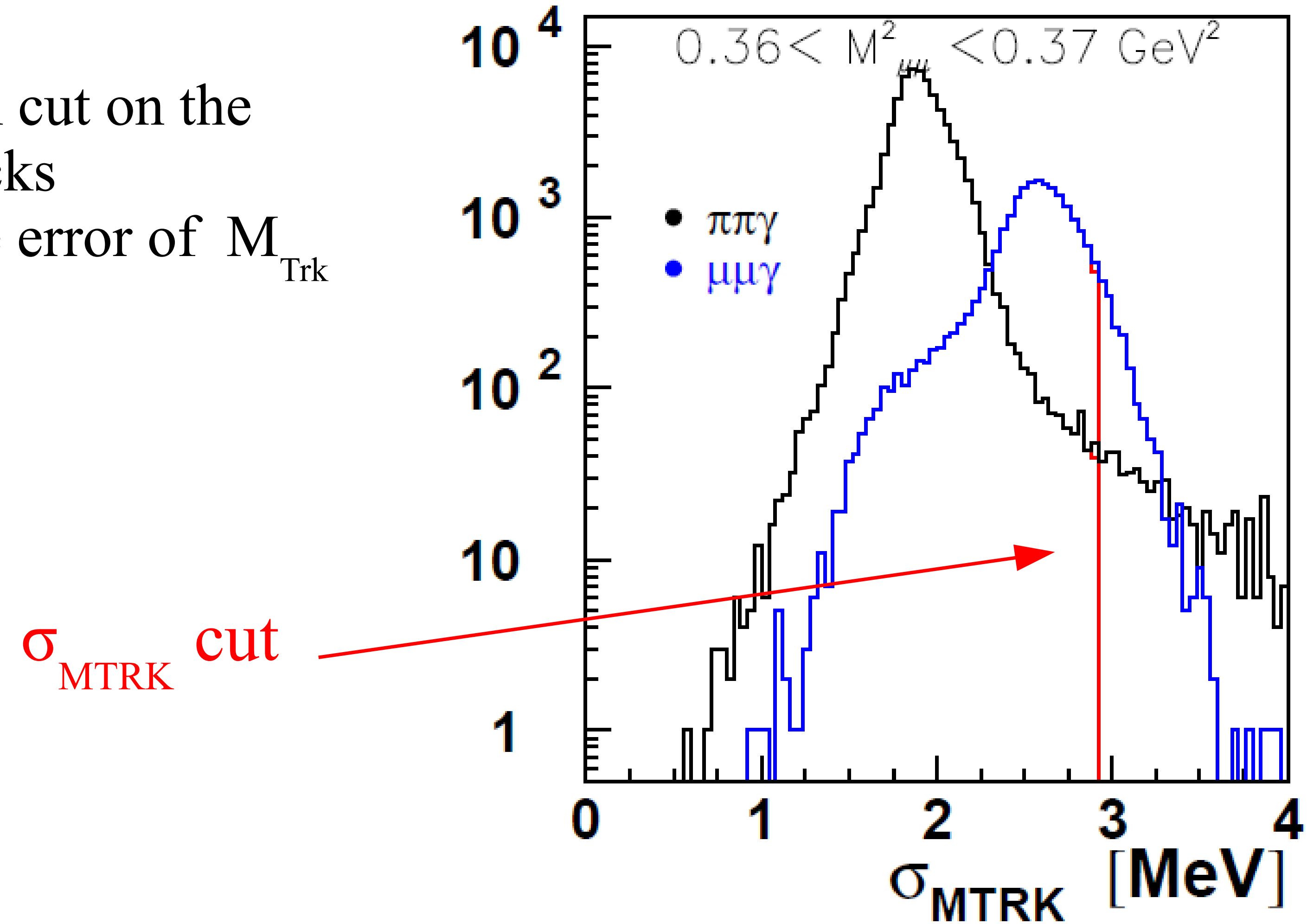
.



The resulting ratio Background spectrum, was fitted and transformed by function of GeV^2 to GeV and then subtracted to data.

Cut on σ_{MTRK}

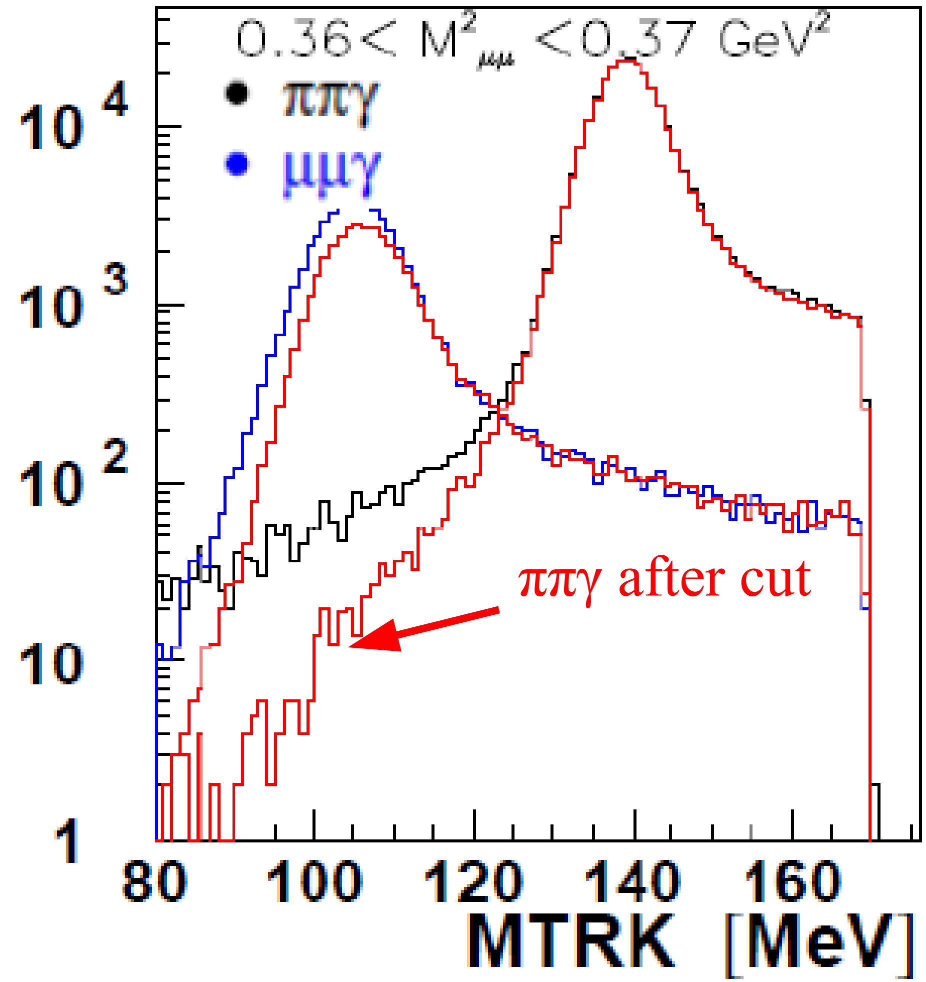
continuous function cut on the quality of fitted tracks parametrized by the error of M_{Trk}



Cut on σ_{MTRK}

— $\pi\pi\gamma$ M_{TRK} tail before σ_{MTRK} cut

— $\pi\pi\gamma$ M_{TRK} tail after σ_{MTRK} cut



Effect of the cut:
- significant reduction of $\pi\pi\gamma$ contamination in the $M^2_{\mu\mu}$ region.
- improvement of π/μ separation

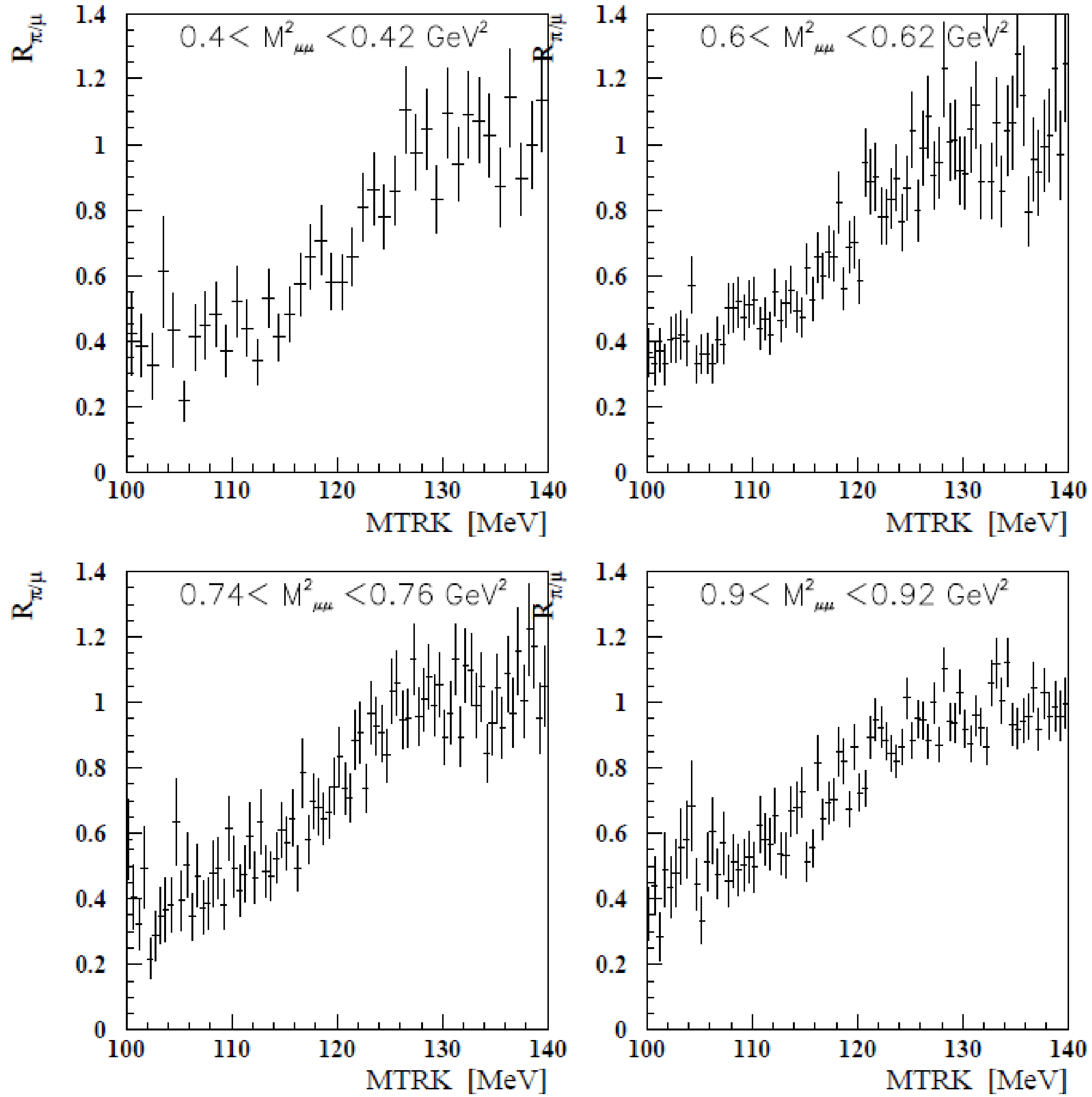
Quality Factor $R_{\pi/\mu}$

Crosscheck of the goodness of the cut: Quality Factor $R_{\pi/\mu}$.

$R_{\pi/\mu}$<1 means the cut is efficient

$$R_{\pi/\mu} = \frac{r_{\pi/\mu(\text{after cut})}}{r_{\pi/\mu(\text{before cut})}}$$

$$r_{\pi/\mu} = \frac{N_{\pi\pi\gamma}}{N_{\mu\mu\gamma}}$$



Reduction of the $\pi\pi\gamma$ fractional background in the $\mu\mu\gamma$ M_{TRK} region of a factor >2

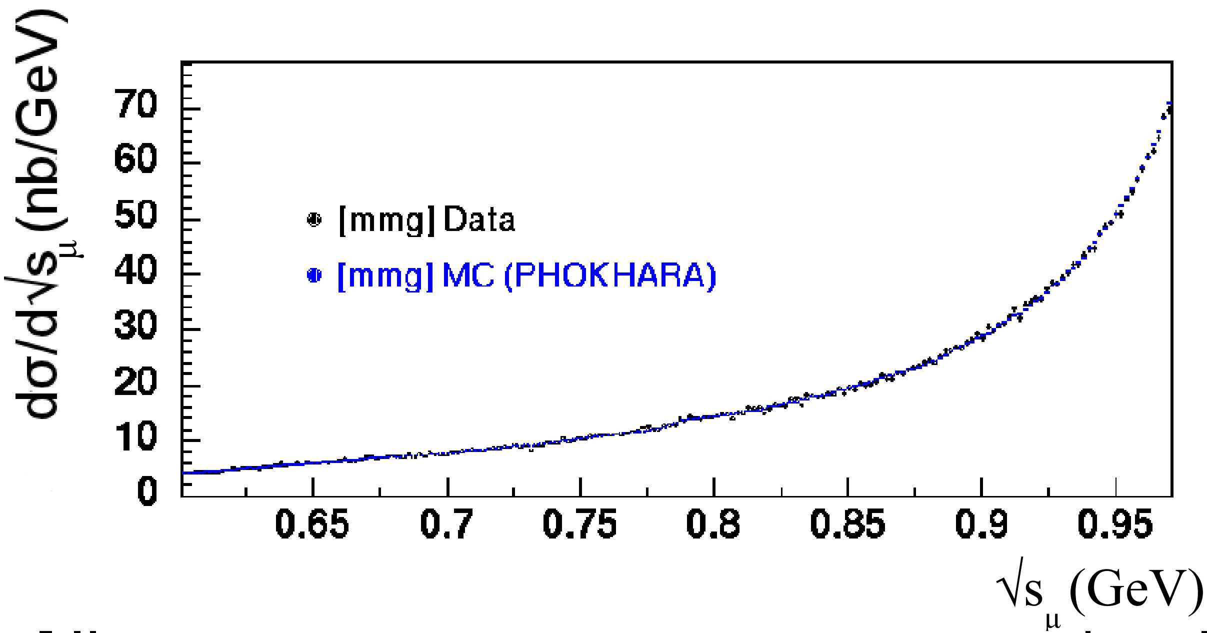
Efficiency of the cut ~70%

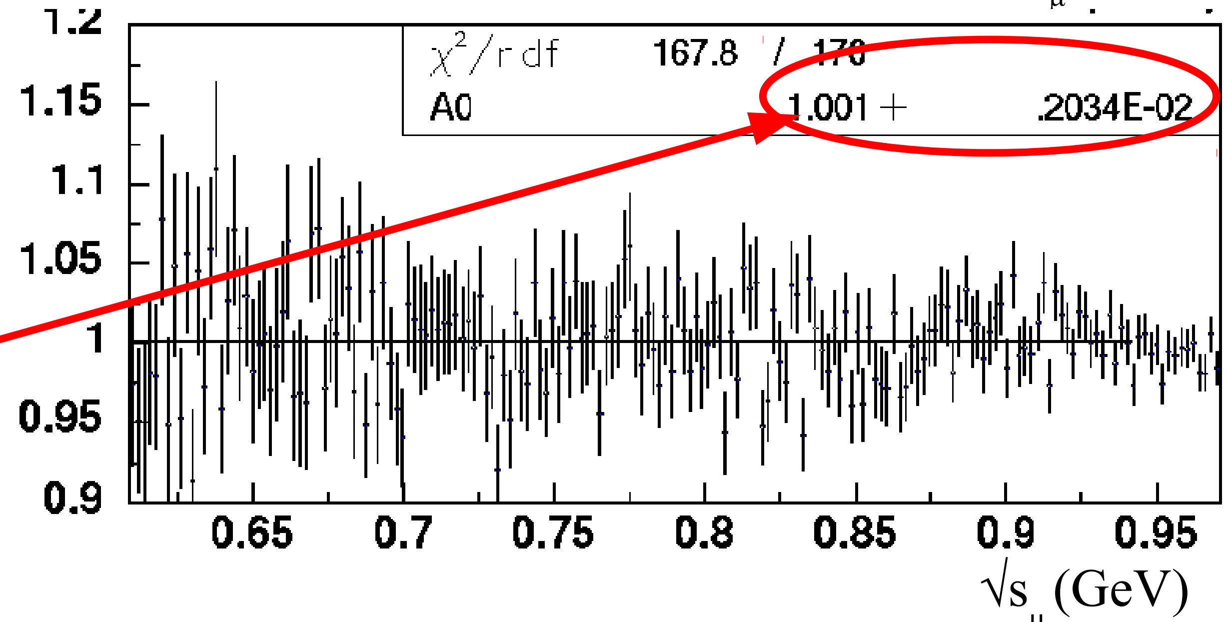
Data/MC Comparison

$$\frac{d\sigma^{obs}_{\mu\mu\gamma(\gamma)}}{dM_{\mu\mu}} = \frac{\Delta N^{osb} - \Delta N^{bckg}}{dM_{\mu\mu}} \cdot \frac{1}{\epsilon_{sel}} \cdot \frac{1}{\int L\,dt}$$

-μμγ absolute cross section obtained by subtracting residual backgrounds and dividing it for efficiencies (track and trig) and luminosity, σ_{MTRK} cut included.

-comparison of the computed cross section with the NLO QED prediction of PHOKHARA.





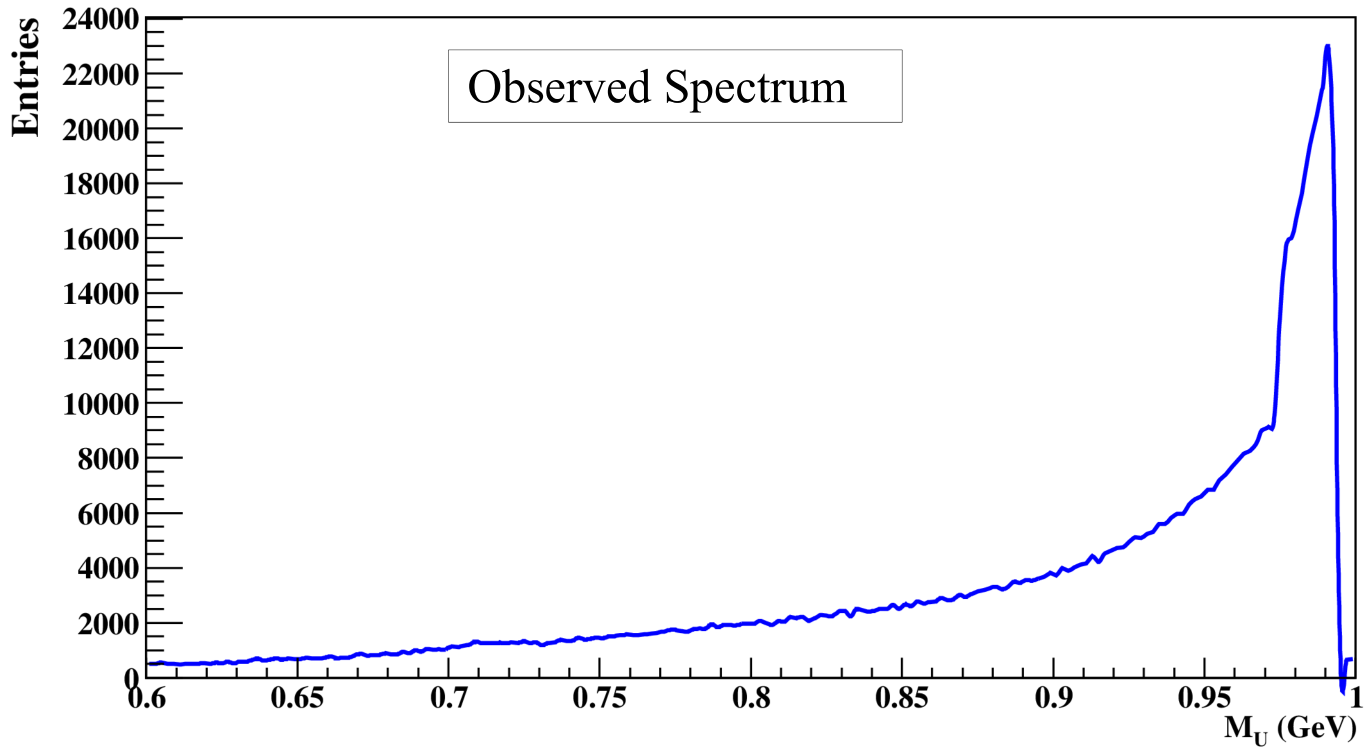
Excellent Data/MC agreement

Exclusion Plot for Number of Events

-Observed spectrum and MC prediction by Phokara as input of Tlimit procedure (data and predicted background respectively)

-each spectra divided in slices of 0.002 GeV (our binning factor)

-each M_U sub-sample used to compute, by Tlimit Root Class (CLS technique), the exclusion plot of number of events

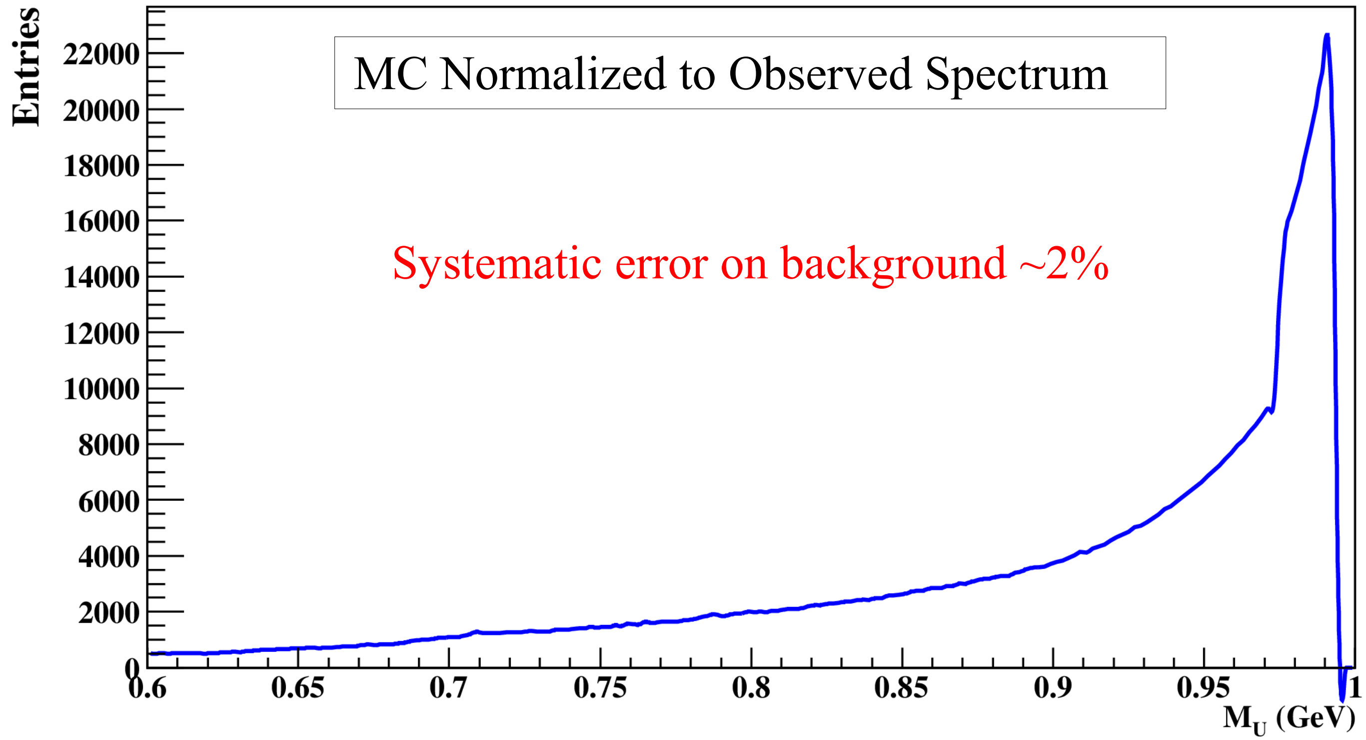


Exclusion Plot for Number of Events

-Observed spectrum and MC prediction by Phokara as input of Tlimit procedure (data and predicted background respectively)

-each spectra divided in slices of 0.002 GeV (our binning factor)

-each M_U sub-sample used to compute, by Tlimit Root Class (CLS technique), the exclusion plot of number of events

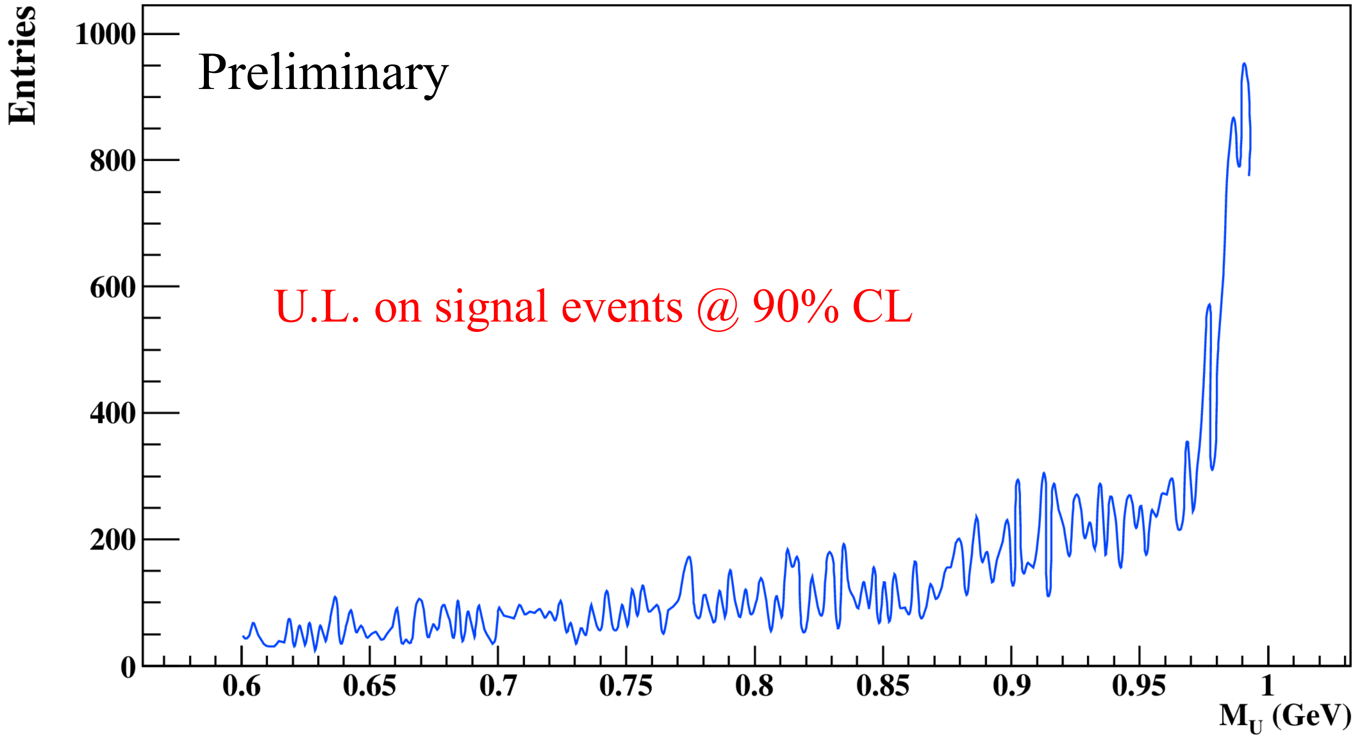


Exclusion Plot for Number of Events

-Observed spectrum and MC prediction by Phokara as input of Tlimit procedure (data and predicted background respectively)

-each spectra divided in slices of 0.002 GeV (our binning factor)

-each M_U sub-sample used to compute, by Tlimit Root Class (CLS technique), the exclusion plot of number of events



ε^2 Upper limit extraction in the region 600÷1000 MeV

$$\varepsilon^2 = \frac{N_{CLS}/(\epsilon_{eff} \cdot L)}{H \cdot I}$$

N_{CLS} = #entries of signal hypothesis of ROOT Tlimit procedure

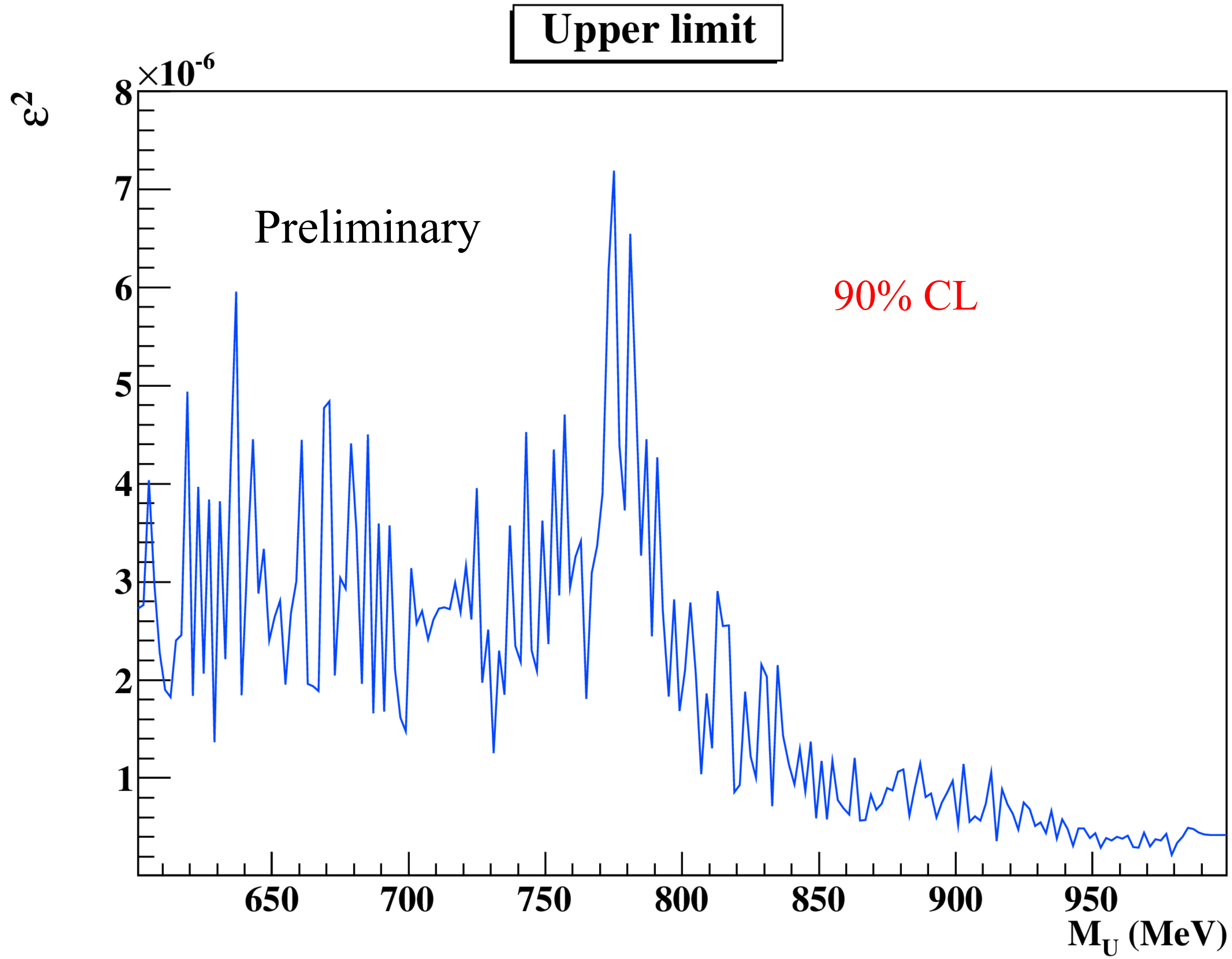
ϵ_{eff} = acceptance
$(0° < \theta_\gamma < 180°\ 0° < \theta_\mu < 180°)$
+ eff. corrections

$$H = \frac{d\sigma_{\mu\mu\gamma}/d\sqrt{s_\mu}}{\sigma(e^+e^- \to \mu^+\mu^-, s)}$$

L=239.29 pb^{-1}

$$I = \int_i \sigma_U^{\mu\mu} ds_i \quad s = M_U^2 \quad s_i = \text{bin}$$

$$\sigma_U^{\mu\mu} = \sigma(e^+e^- \to U \to \mu^+\mu^-, s)$$



ε^2 Upper limit extraction in the region 600÷1000 MeV

$$\varepsilon^2 = \frac{N_{CLS}/(\epsilon_{eff} \cdot L)}{H \cdot I}$$

N_{CLS} = #entries of signal hypothesis of ROOT Tlimit procedure

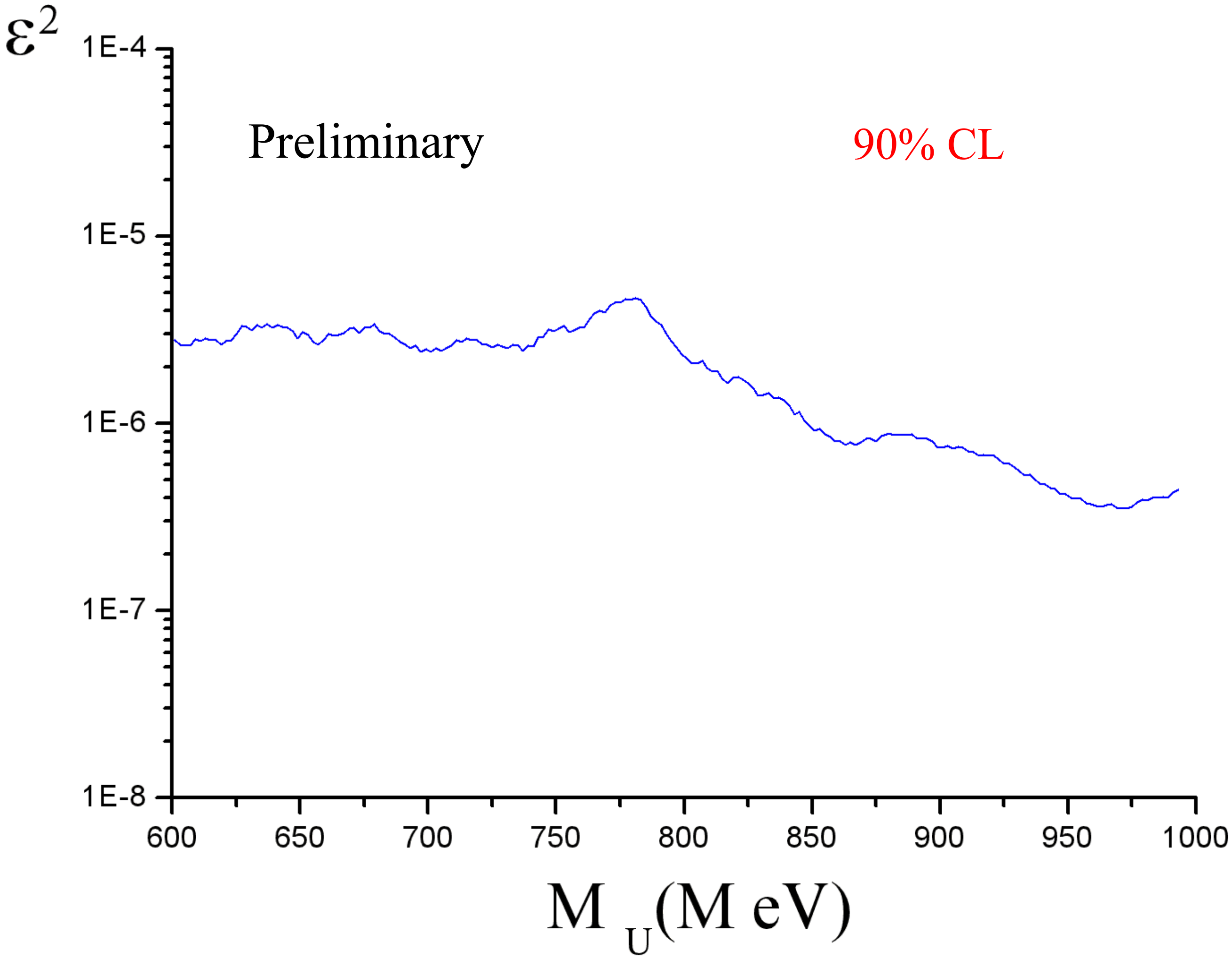
$$\epsilon_{eff} = \text{acceptance}$$
$$(0° < \theta_\gamma < 180°\ 0° < \theta_\mu < 180°)$$
$$+ \text{eff. corrections}$$

$$H = \frac{d\sigma_{\mu\mu\gamma}/d\sqrt{s_\mu}}{\sigma(e^+e^- \to \mu^+\mu^-, s)}$$

$L = 239.29\ pb^{-1}$

$$I = \int_i \sigma_U^{\mu\mu} ds_i \quad s = M_U^2 \quad s_i = \text{bin}$$

$$\sigma_U^{\mu\mu} = \sigma(e^+e^- \to U \to \mu^+\mu^-, s)$$



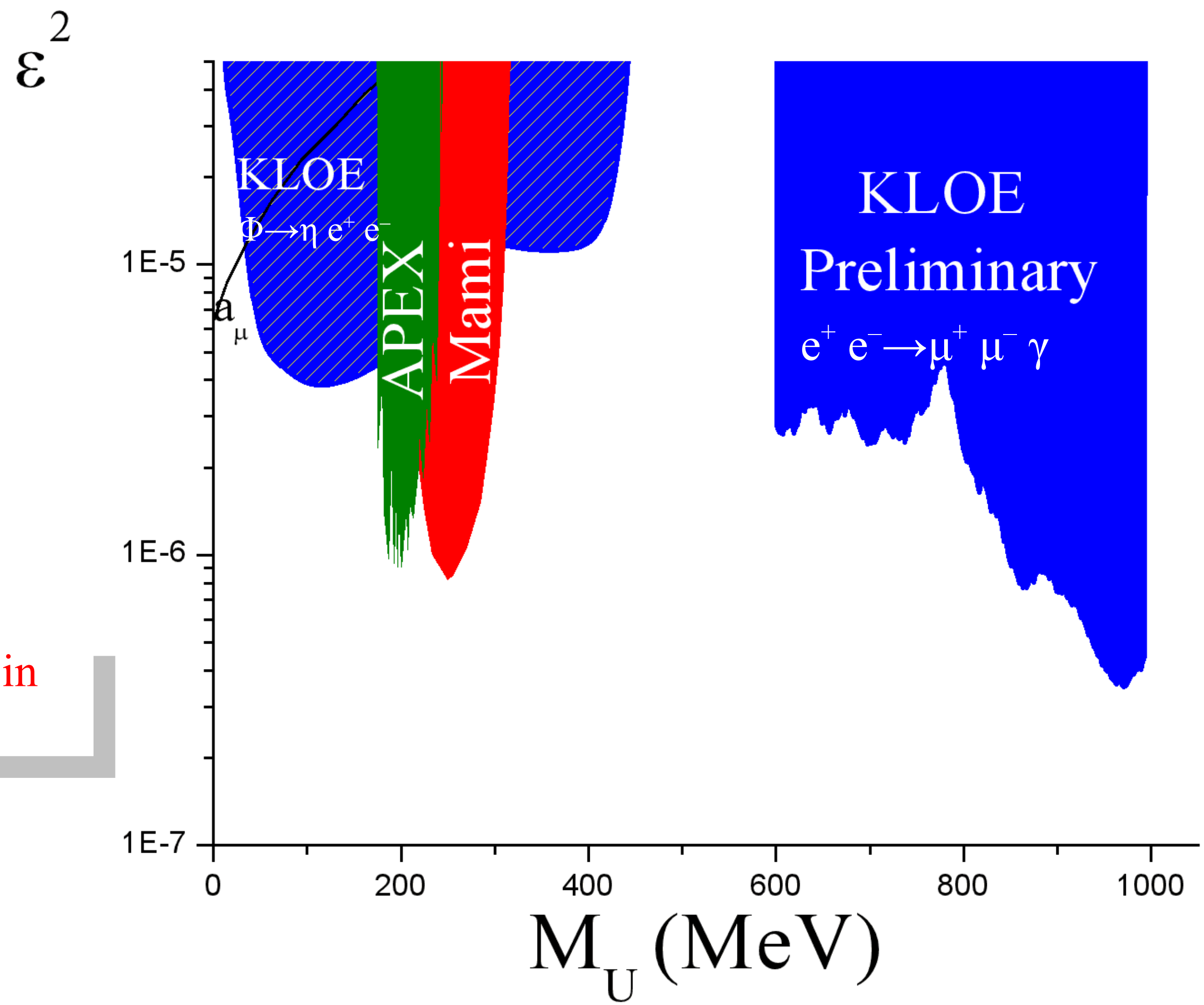
ε^2 Upper limit extraction in the region 600÷1000 MeV

[KLOE] AarXiv:1210.3927, submitted to PLB

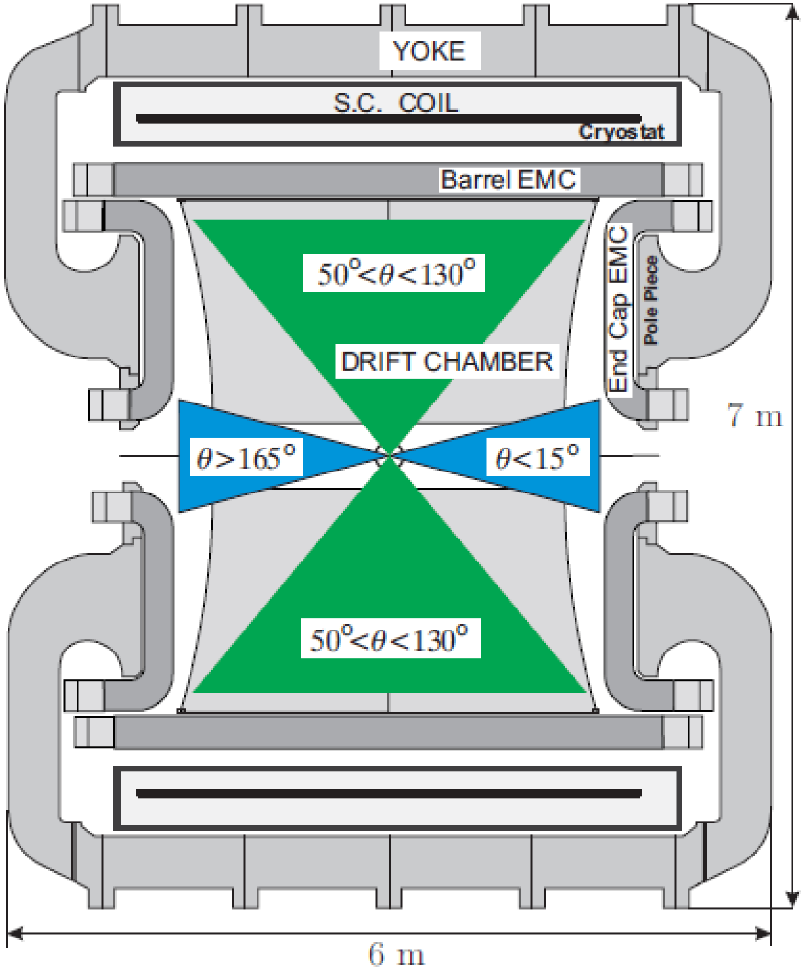
[Mami] H.. Merkel et al., Physic. Rev. Lett. 106, 2011.

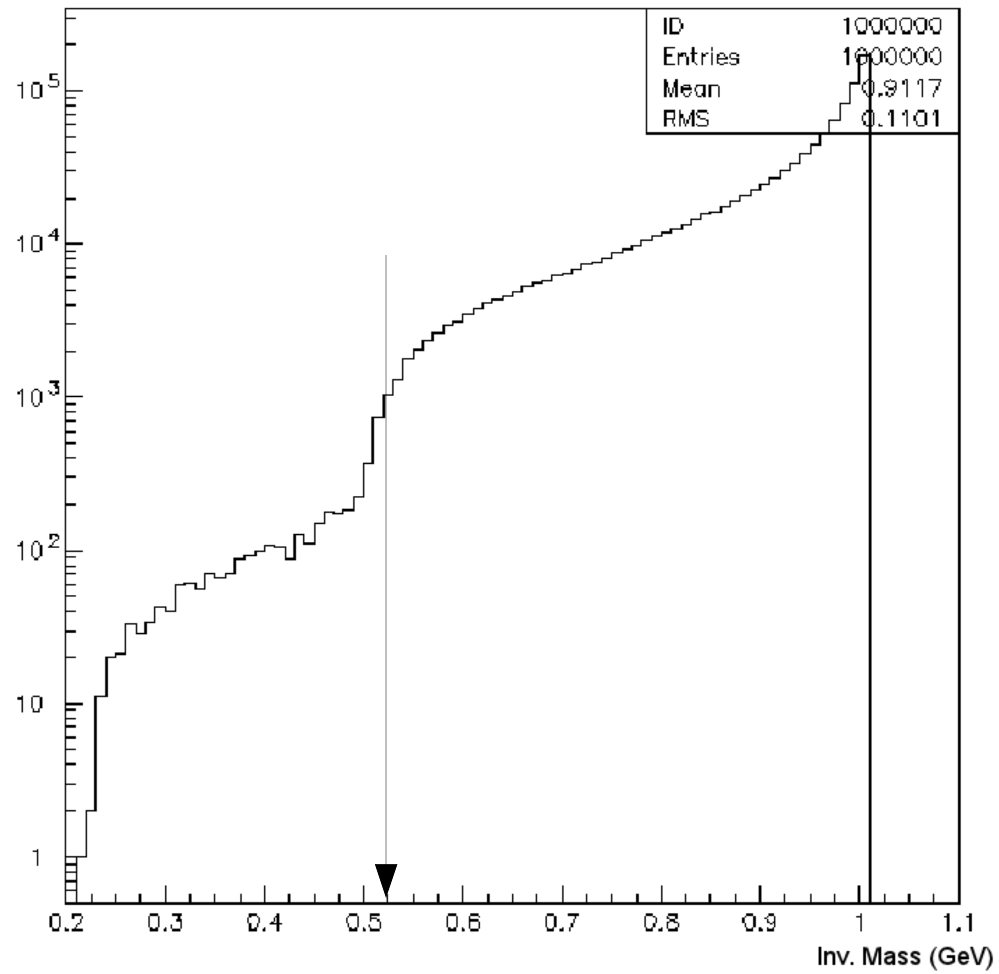
[Apex] S. Abrahamyan et al., Phisical Rev. Lett., 107 , 2011.

U. L. between $2.6 \cdot 10^{-6}$ and $3.5 \cdot 10^{-7}$ in the energy range 600-1000 MeV

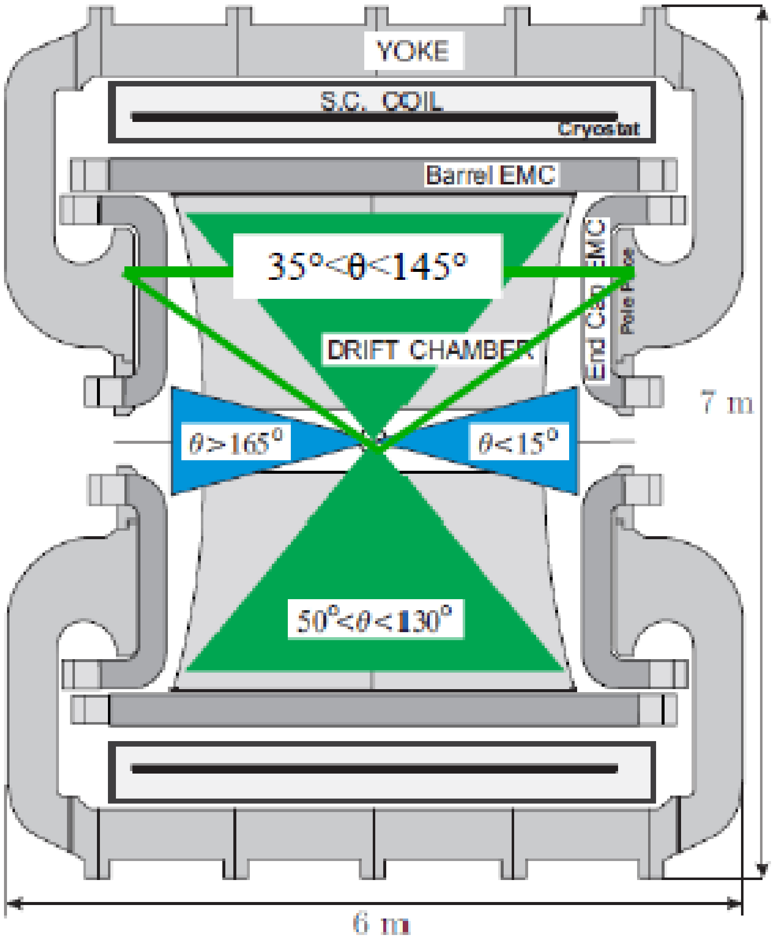


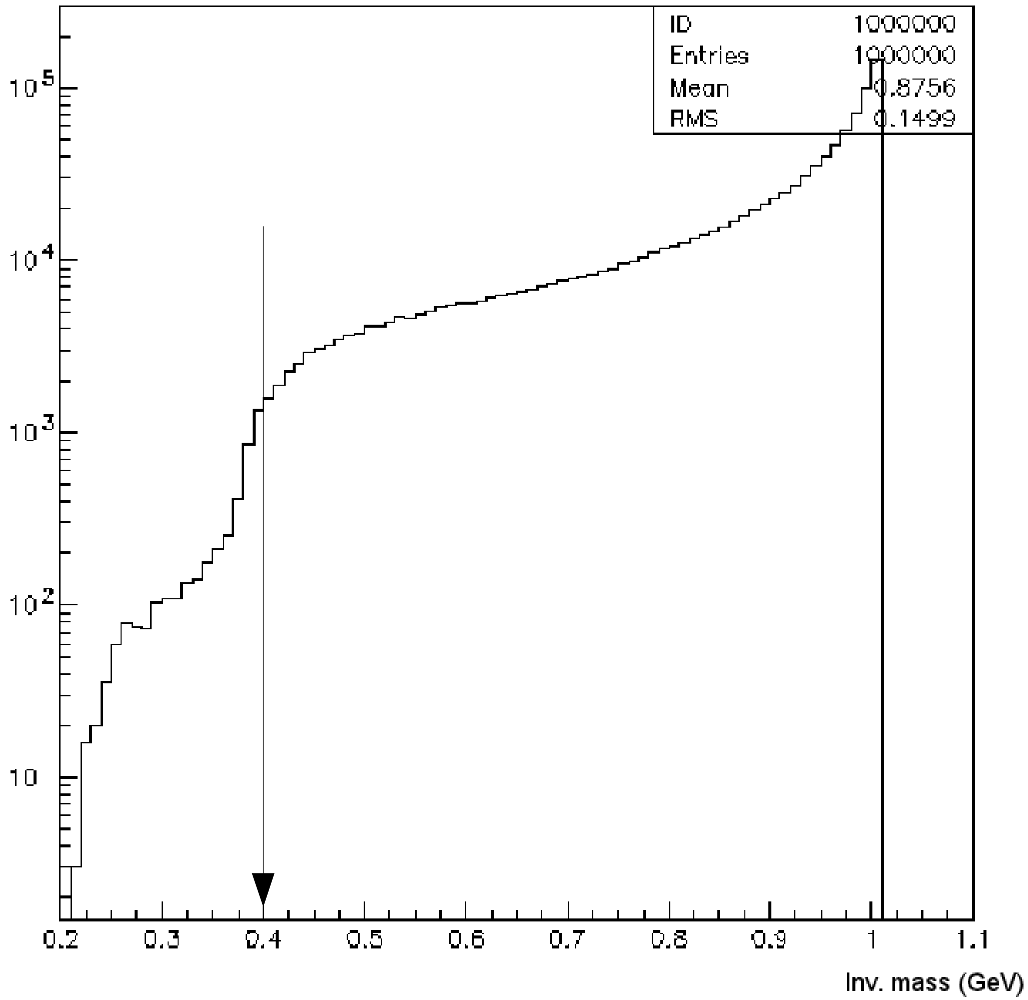
Future Perspectives: muon acceptance extension





Future Perspectives: muon acceptance extension





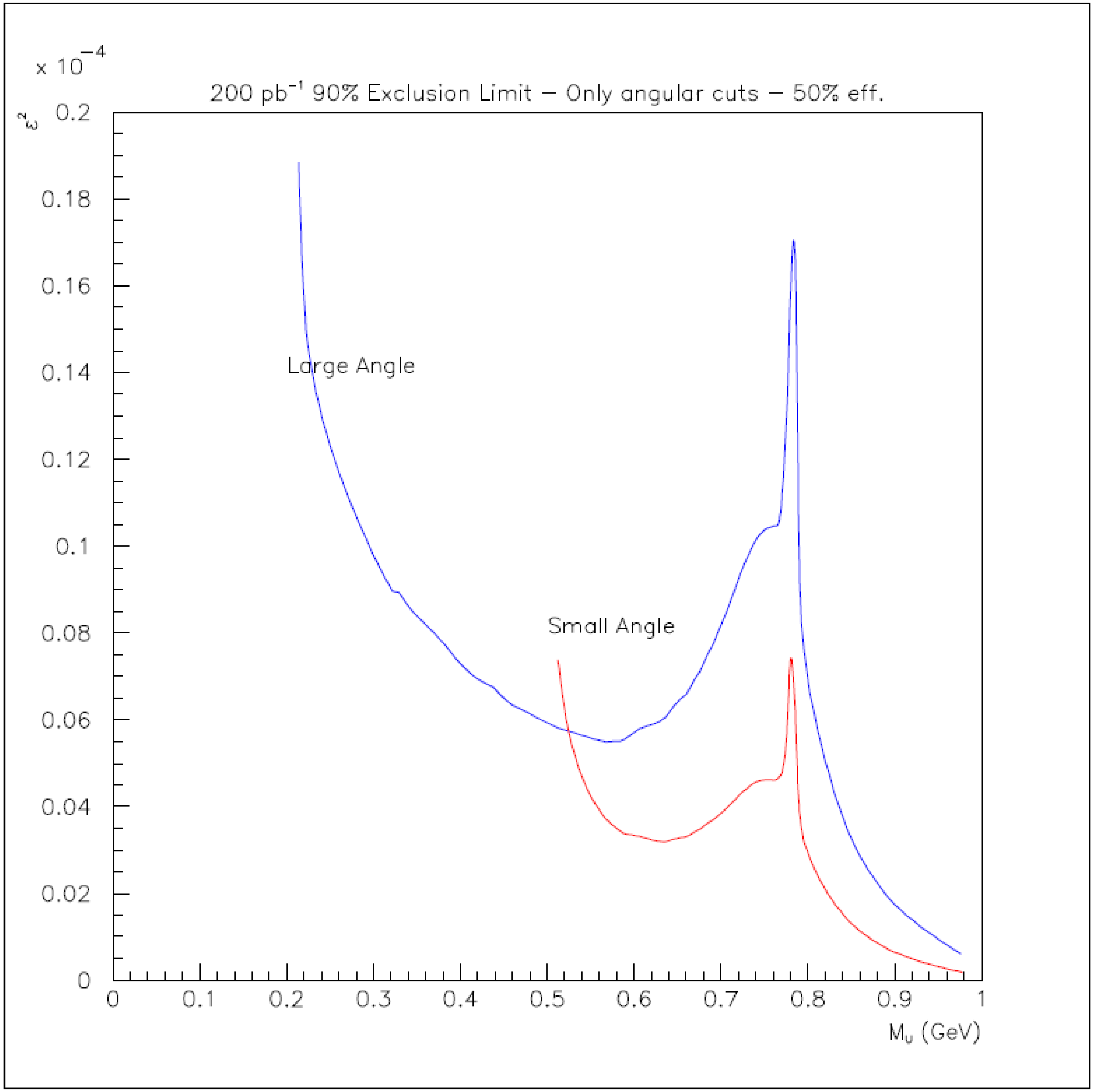
Also θ_γ acceptance extension investigated with no effects on the muon invariant mass distribution.

Future Perspectives

-The result presented is based on ~240 pb^{-1} with the photon at small angle.

-By using the full KLOE statistics (2.5 fb^{-1}), the current sensitivity can be improved by a factor of ~3.

-In addition we can perform the analysis down to the threshold region by using a data sample off-peak (1GeV) to suppress the $\Phi \rightarrow \pi^+ \pi^- \pi^0$ background.



Conclusions

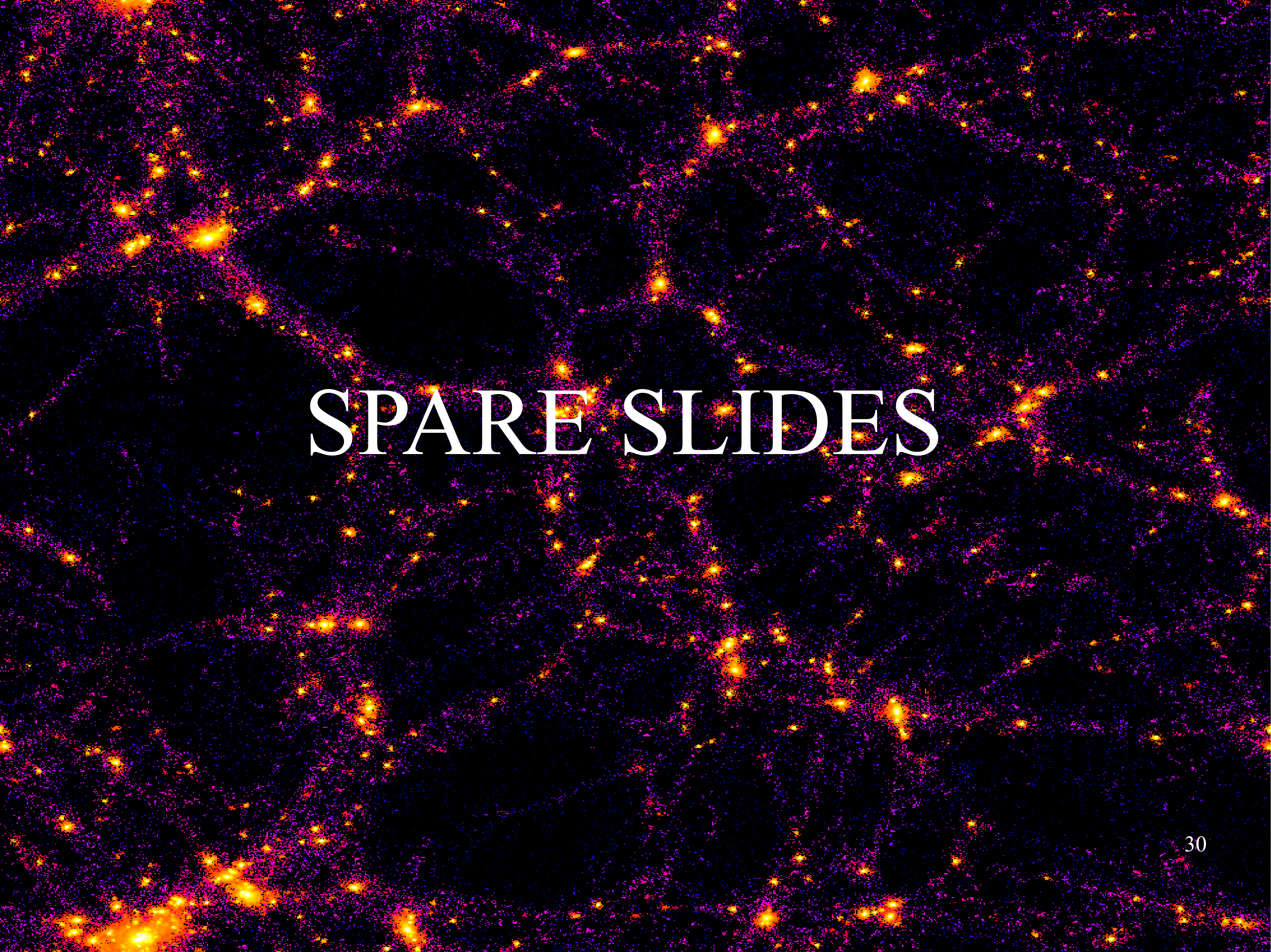
•We used 239.29 pb^{-1} of 2002 KLOE data to search for light vector boson in the $e^+e^- \rightarrow \mu^+\mu^-\gamma$ channel.

•No evidence was found and an U.L. has been extracted on the kinetic mixing parameter ε^2 in the energy range between 600 and 1000 MeV.

•By changing muons acceptance selection and performing the analysis at full statistics and off-peak, we will have the possibility to explore the muons lower invariant mass region.

• Work is in progress to finalize this analysis and submit the result for publication

Thank you!



SPARE SLIDES

Motivations of KLOE collaboration to exclude BaBar UL

-The BaBar Collaboration never performed a direct search of the U boson. The exclusion plot is just an estimate from the search of a light, narrow scalar particle in Υ decays: $\Upsilon(3S) \rightarrow \gamma A_0$

-The analysis is close to the search of $e^+e^- \rightarrow \gamma U$, but obviously acceptance and selection efficiency are different for scalar and vector particles

- The $\mu^+ \mu^-$ background shape from continuum production has been obtained from data taken at Υ(4S), with the assumption that the A_0 is produced in decays and not in QED continuum processes. This is true for the A_0, but not for the vector U boson