

# Search for a new dark (U) boson in WASA-at-COSY experiment



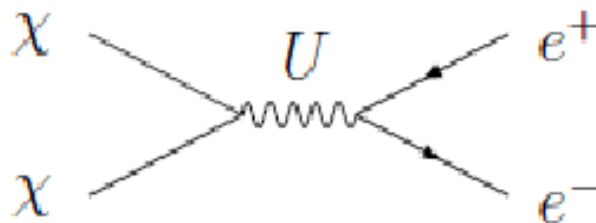
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UPPSALA  
UNIVERSITET

# New boson hypothesis

- Hardly explainable astrophysical observations
  - 511 keV gamma-ray signal from the Galactic center:  
SPI-INTEGRAL [arXiv:astro-ph/0309484]
  - Annihilation of dark matter via U boson (Fayet)



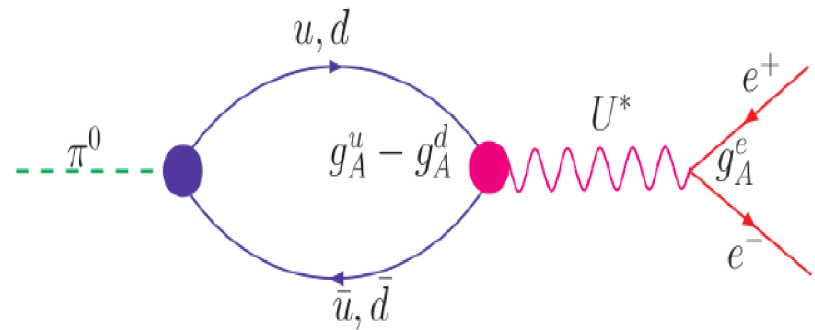
[arXiv:hep-ph/0607094]

- KTeV collaboration:  $\text{BR}(\pi^0 \rightarrow e^+e^-) = (7.49 \pm 0.29 \pm 0.25) \cdot 10^{-8}$  which exceeds theoretical predictions (Dorokhov et al.) by  $3.3\sigma$  [arXiv:0704.3498]

# New models beyond the SM

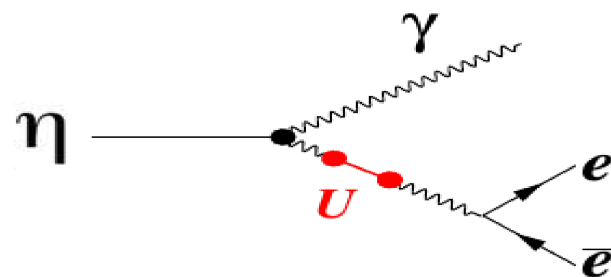
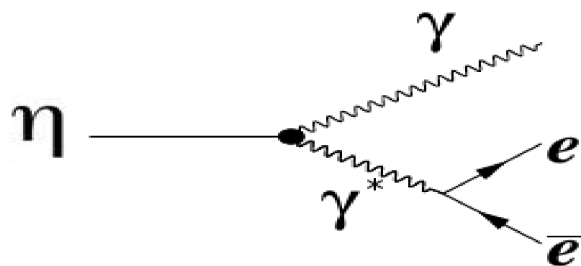
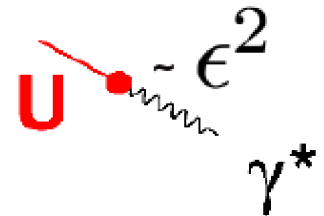
- Scalar boson:

- Signature in very rare meson decays



- Vector boson (dark photon):

- Signature in Dalitz decays of mesons



# WASA-at-COSY experiment

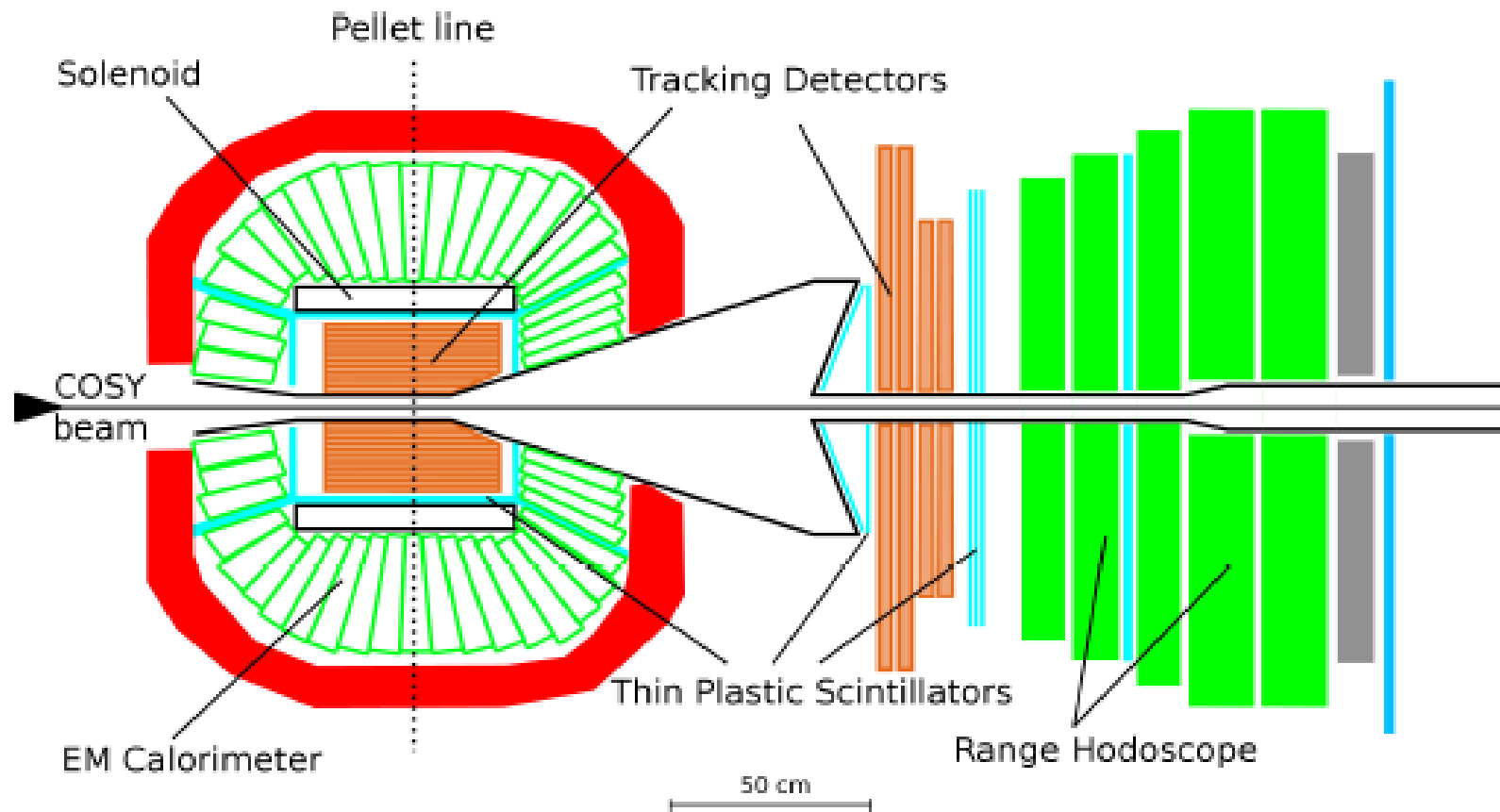
- **Wide Angle Shower Apparatus**
- **Cooler Synchrotron** located at Forschungszentrum Jülich
- Designed to study light meson production and decays in hadronic interactions
- p/d beams up to 3.7 GeV/c (stochastic and e<sup>-</sup> cooling)
- High density p/d pellet target
- Internal experiment
- Up to 10<sup>32</sup> cm<sup>-2</sup> s<sup>-1</sup> luminosity



# List of participating organizations

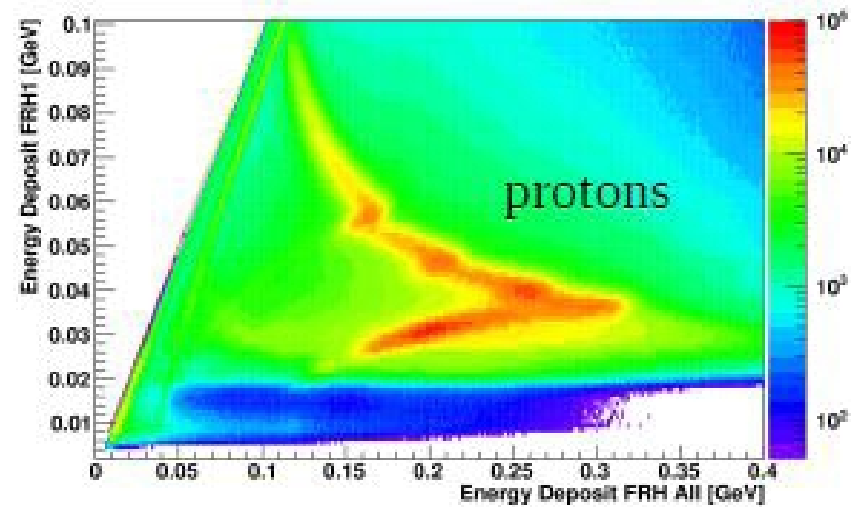
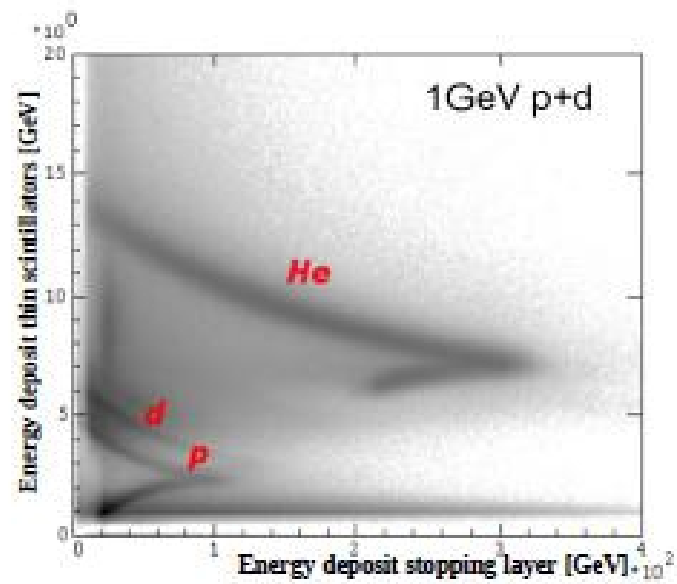
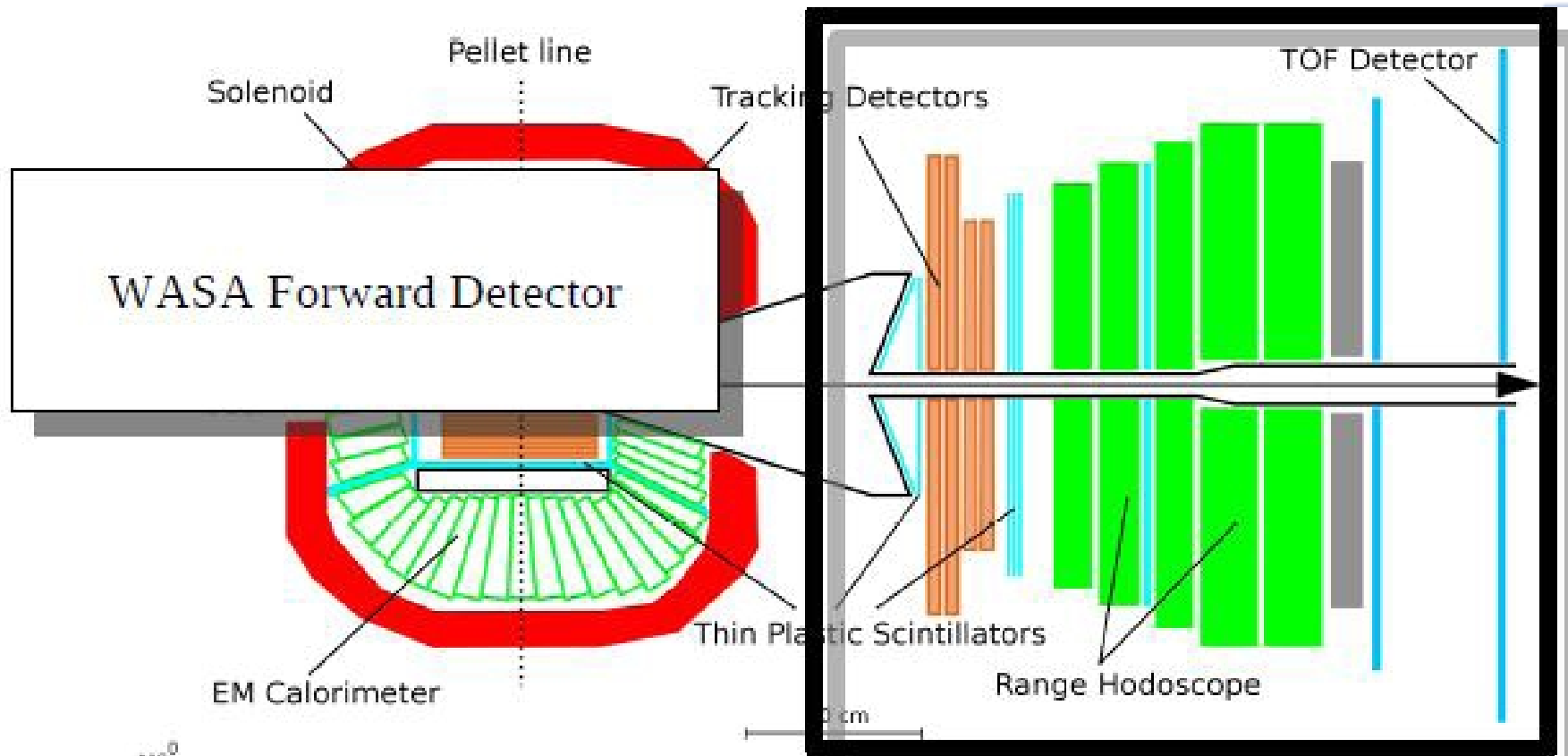
- University of Sofia
- Petersburg Nuclear Physics Institute
- National Centre for Nuclear Research (Warsaw)
- Moscow Engineering Physics Institute
- Indian Institute of Technology Indore
- Indian Institute of Technology Bombay
- Uppsala University
- Joint Institute for Nuclear Research (Dubna)
- Duisburg-Essen University
- Rheinische Friedrich-Whilems University Bonn
- High Energy Accelerator Research Organisation KEK
- Justus Liebig University Giesen
- Hamburg University
- Rhur University Bochum
- Westfälische Wilhelms University Münster
- Forschungszentrum Jülich GmbH
- Warsaw University
- Chinese Academy of Science
- Polish Academy of Science
- Jagiellonian University (Cracow)
- University of Silesia
- State Scientific Center of the Russian Federation
- Bhabha Atomic Research Center (Mumbai)
- Friedrich-Alexander University Erlangen-Nürnberg
- Eberhard Karls University Tübingen
- The Budker Institute of Nuclear Physics

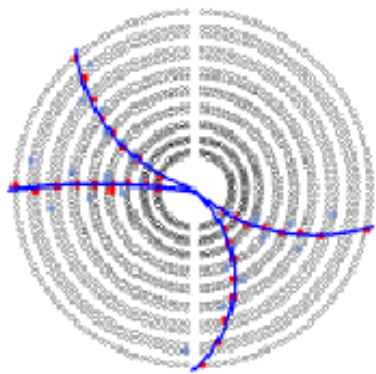
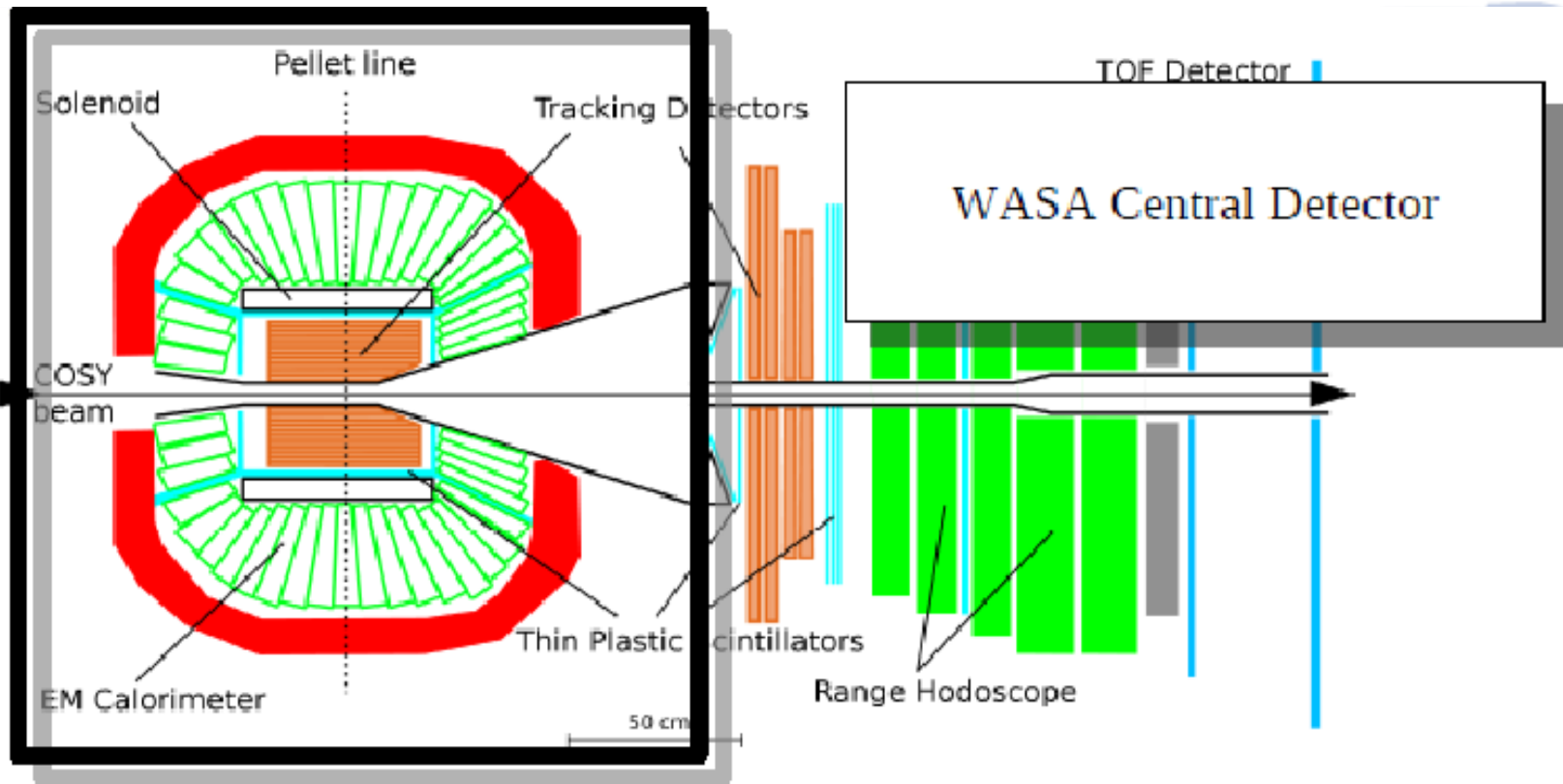
**167 people**



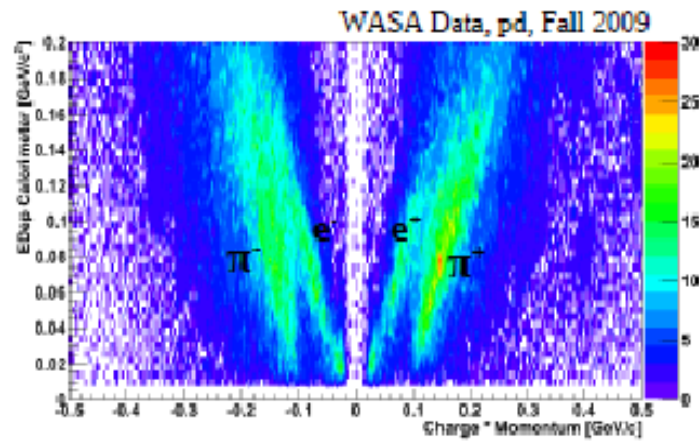
Central Detector:  $20^{\circ}$ - $165^{\circ}$   
polar angle acceptance.  
Measurement of charged  
and neutral decay products

Forward Detector :  $3^{\circ}$ - $18^{\circ}$   
polar angle acceptance.  
Measurement of forward-  
scattered hadrons

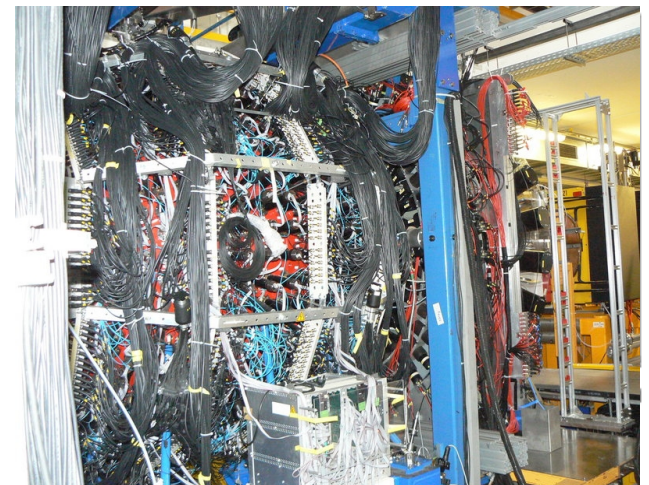




Tracking (Mini-Drift Chamber)



Particle Identification



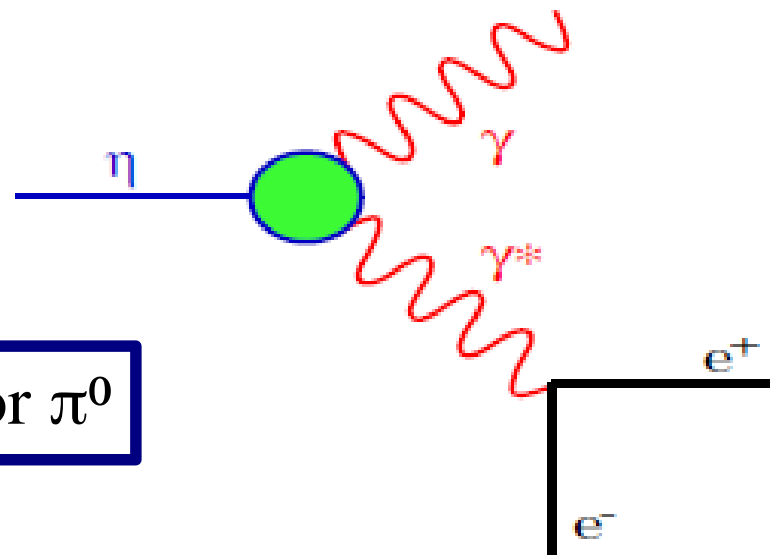


# Search for a new boson in meson Dalitz decays

- Dalitz decays of mesons
  - $\eta/\pi^0 \rightarrow \gamma U (\rightarrow e^+e^-)$  has the same topology as the Dalitz decay!

L. G. Landsberg, Physics Reports, 128 (6), p.301-376, Nov 1985

$$\eta \rightarrow \gamma \gamma^* \rightarrow \gamma e^+ e^-$$



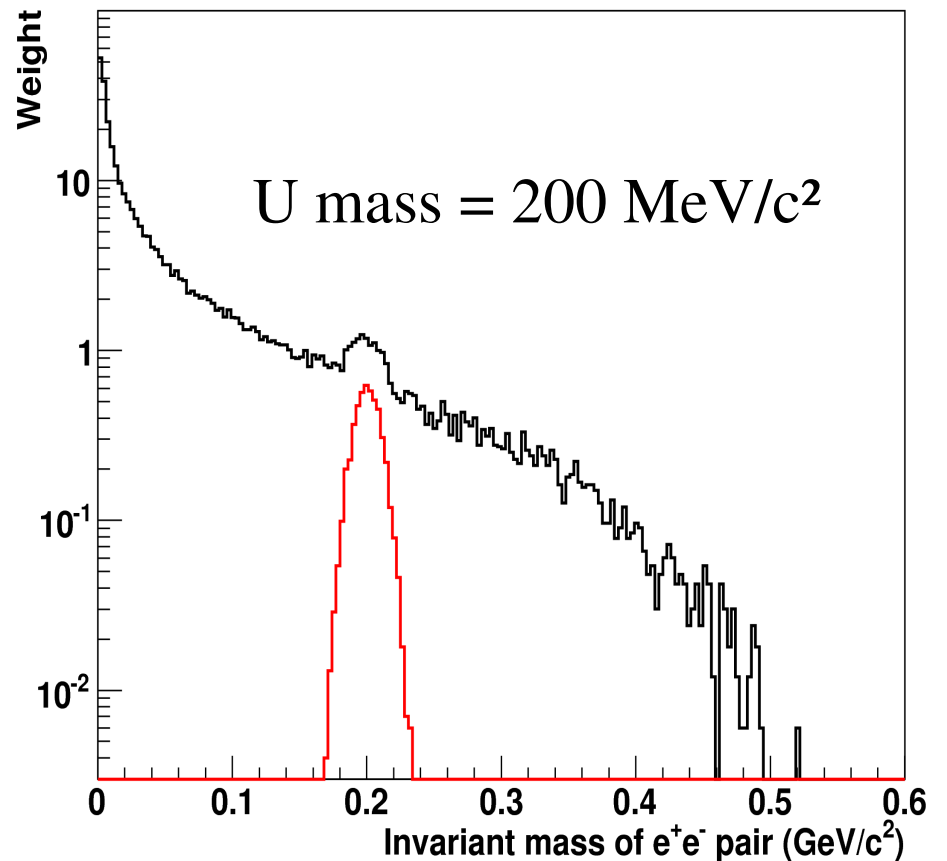
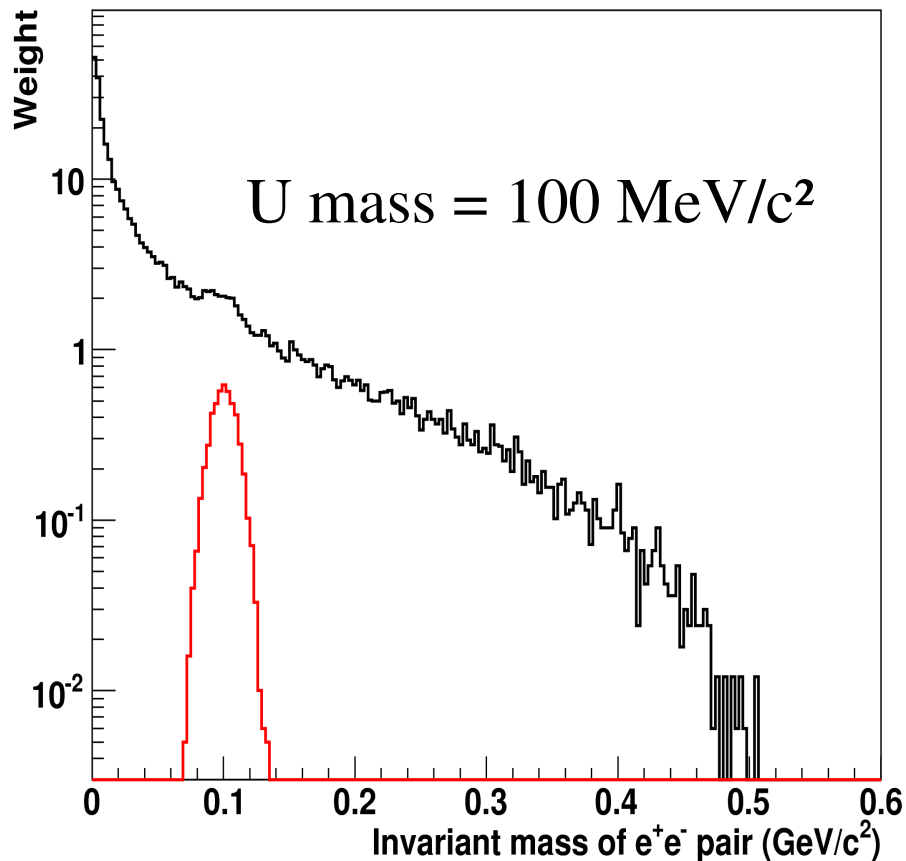
SM – same for  $\pi^0$

# Two methods to look for a new boson

- $\eta/\pi^0 \rightarrow \gamma U \rightarrow \gamma e^+e^-$ 
  - If U decays inside the detector:  $e^+e^-$  invariant mass or  $\gamma$  energy
  - If U escapes the detector:  $\gamma$  energy in CMS
- We need to make some assumptions about the boson lifetime (also about its coupling to leptons and its decay width)

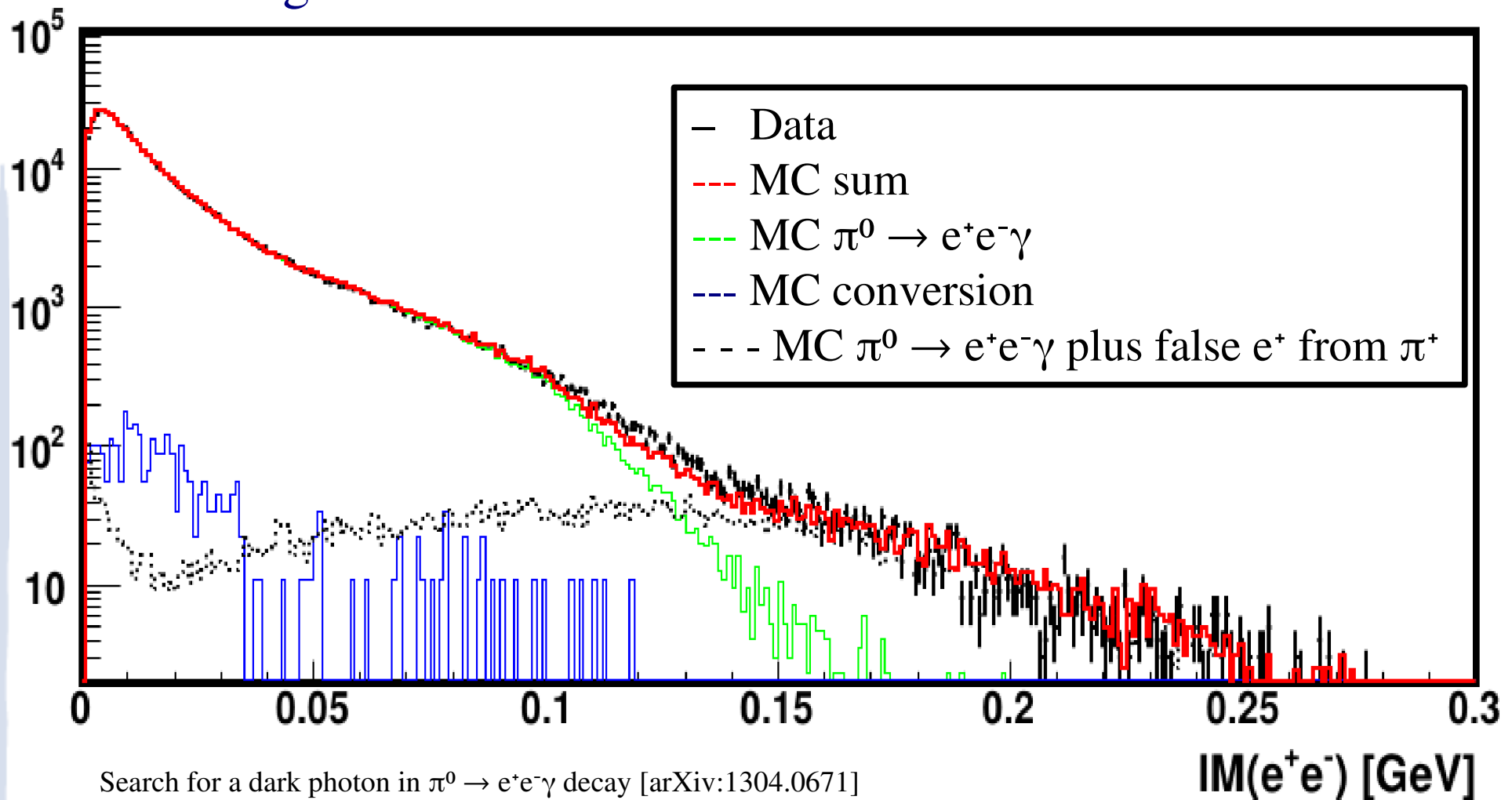
# Simulation

- $\text{BR}(\eta \rightarrow \gamma U) = 10^{-4}$ ,  $\text{BR}(U \rightarrow e^+e^-) = 1$
- $U$  width  $\sim 24$  MeV



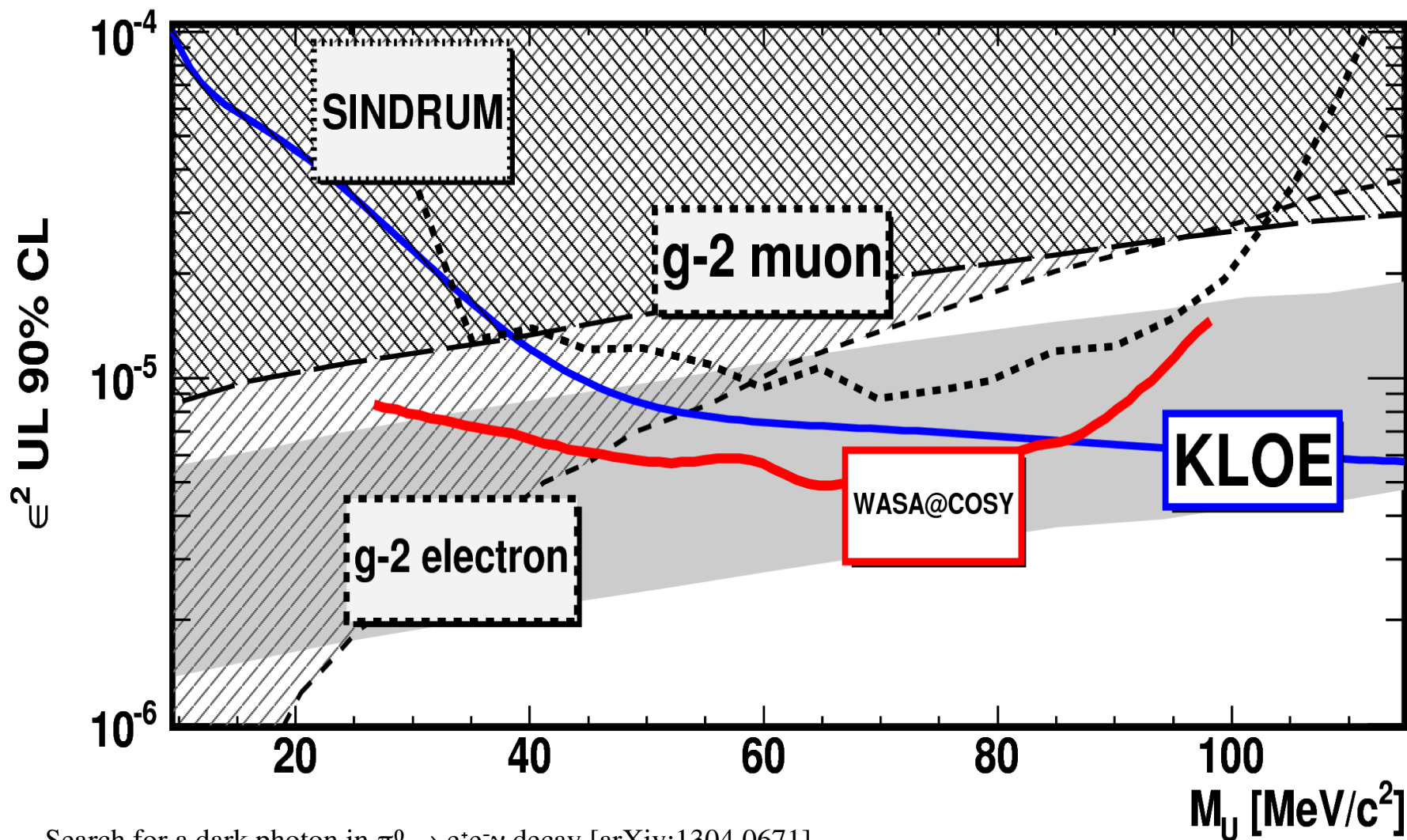
# Data: $\pi^0$ Dalitz decay

- Huge statistics collected
- Good agreement between data and simulations achieved



Search for a dark photon in  $\pi^0 \rightarrow e^+e^-\gamma$  decay [arXiv:1304.0671]  
Carl-Oscar Gullström talk at MesonNet 2013 Prague:  
<http://www-ucjf.troja.mff.cuni.cz/mesonnet13/talks/Gullstrom.pdf>

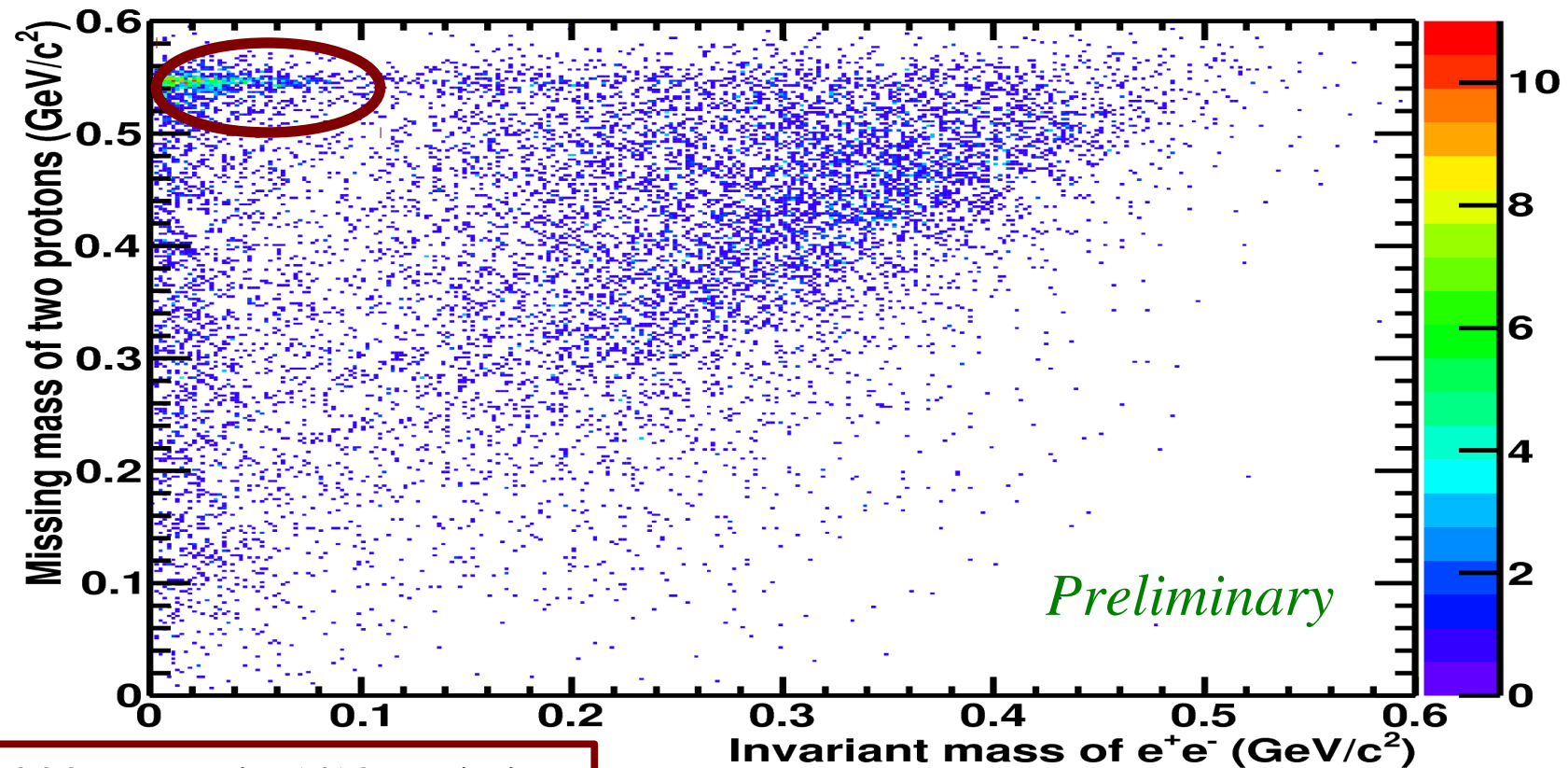
# Exclusion plot for the coupling parameter $\epsilon^2$ vs Mass of Dark Boson



Search for a dark photon in  $\pi^0 \rightarrow e^+e^-\gamma$  decay [arXiv:1304.0671]  
Carl-Oscar Gullström talk at MesonNet 2013 Prague:  
<http://www-ucjf.troja.mff.cuni.cz/mesonnet13/talks/Gullstrom.pdf>

# Data: $\eta$ Dalitz decay

- Data analysis in progress
- $2.5 \cdot 10^8$   $\eta$  mesons produced in pp @ 1.4 GeV
- Lower statistics than in  $\pi^0$  case but up to higher masses



~ 900 events in 1/12 statistics

# Data: $\eta$ Dalitz decay

- We expect around 11000  $\eta$  Dalitz events in full data set
- In comparison PDG data are based on the following statistics:

$\Gamma(e^+ e^- \gamma)/\Gamma_{\text{total}}$					$\Gamma_{11}/\Gamma$
<i>VALUE</i> (units $10^{-3}$ )	<i>EVTS</i>	<i>DOCUMENT ID</i>	<i>TECN</i>	<i>COMMENT</i>	
<b>6.9 <math>\pm</math>0.4</b>	<b>OUR FIT</b>	Error includes scale factor of 1.2.			
<b>6.7 <math>\pm</math>0.5</b>	<b>OUR AVERAGE</b>	Error includes scale factor of 1.2.			
6.6 $\pm$ 0.4 $\pm$ 0.4	1345	BERGHAUSER 11	SPEC	$\gamma p \rightarrow p\eta$	
7.8 $\pm$ 0.5 $\pm$ 0.8	435 $\pm$ 31	BERLOWSKI 08	WASA	$pd \rightarrow {}^3\text{He} \eta$	
5.15 $\pm$ 0.62 $\pm$ 0.74	283	ACHASOV 01B	SND	$e^+ e^- \rightarrow \phi \rightarrow \eta\gamma$	
7.10 $\pm$ 0.64 $\pm$ 0.46	323	AKHMETSHIN 01	CMD2	$e^+ e^- \rightarrow \phi \rightarrow \eta\gamma$	

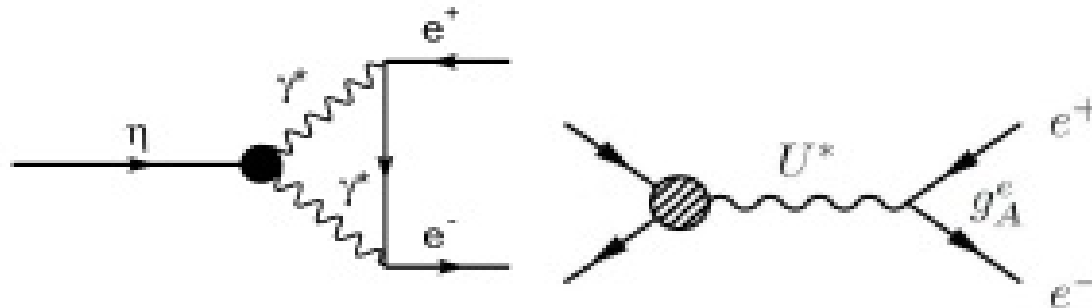
# Rare $\eta \rightarrow e^+e^-$ decay

- Limit on  $\text{BR}(\eta \rightarrow e^+e^-)$  set by M. Berłowski:

$$\text{BR}(\eta \rightarrow e^+e^-) < 4.6 \cdot 10^{-6} \text{ @ CL 90\%}$$

[arXiv:1301.6040]

- Improvement (on an eight times larger statistics) in progress
- Standard model:  $\text{BR} \sim 10^{-9}$





# Summary and outlook

- Upper limit established for dark photon-photon coupling parameter:  $\epsilon^2 < 5 \cdot 10^{-6}$  @ 90% C.L.
- Upper limit established for  $\eta \rightarrow e^+e^-$  decay:  
 $\text{BR}(\eta \rightarrow e^+e^-) < 4.6 \cdot 10^{-6}$  @ CL 90%
- Analysis of  $\eta$  Dalitz channel in progress based on  $\sim 2.5 \cdot 10^8$   $\eta$  mesons produced in pp collisions @ 1.4 GeV

