

# Search for a new dark boson in meson decays



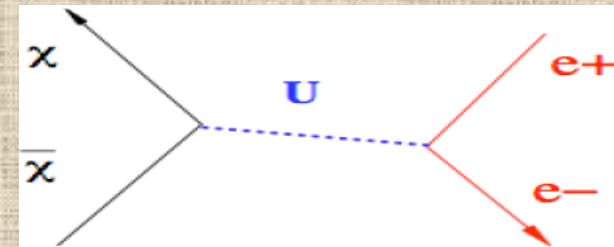
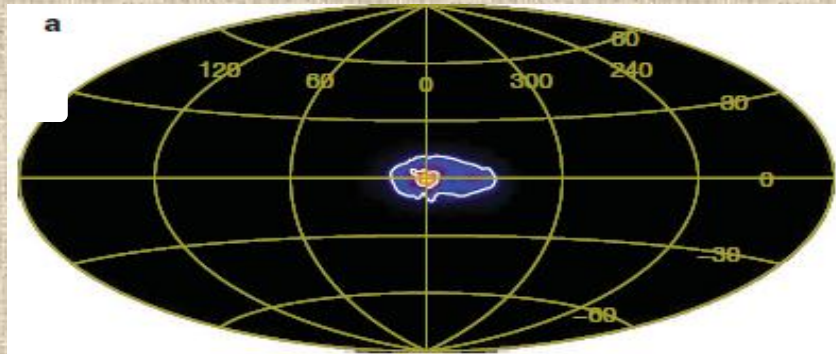
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UPPSALA  
UNIVERSITET

# New boson hypothesis

- Hardly explainable astrophysical observations
  - $e^+$  and/or  $e^-$  excess observed (PAMELA, ATIC, HESS)
  - 511 keV gamma-ray signal from the Galactic center: SPI-INTEGRAL [Nature, Vol 451,10/01/2008]



[Nucl. Phys. B683 219 (2004)]

- Annihilation of dark matter via U boson (Fayet,Boehm)
- KTeV collaboration has measured: [Phys.Rev.D 75,012005, 2007]

$$\text{BR} (\pi^0 \rightarrow e^+e^-) = (7.49 \pm 0.29 \pm 0.25) \cdot 10^{-8}$$

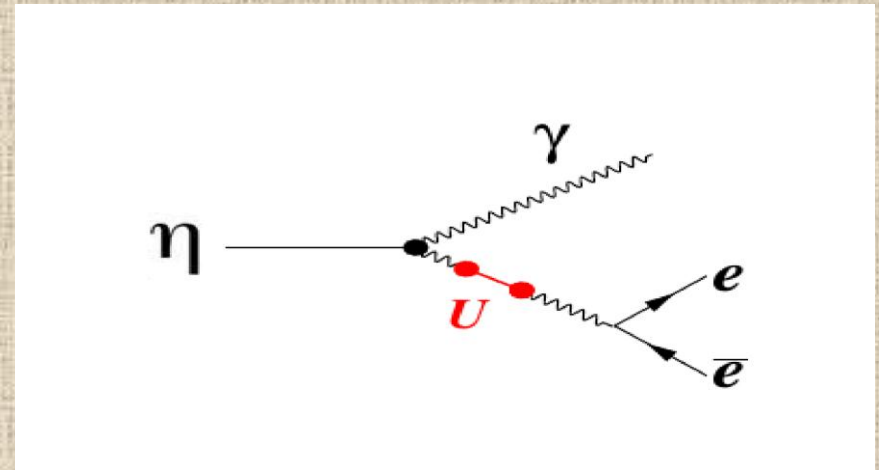
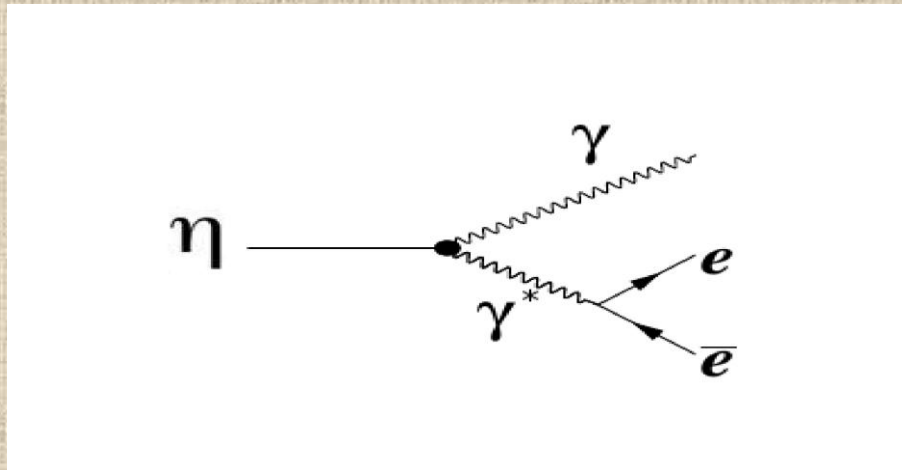
which exceeds SM based theoretical predictions (Dorokhov et al.) by  $3.3\sigma$

[Phys. Rev. D **75**, 114007]

[arXiv:0704.3498]

# New models beyond the SM

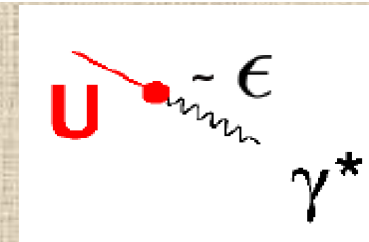
- Vector boson (dark photon):
  - Possible signature in Dalitz decays of mesons



Other interesting channels:

$$\eta \rightarrow \gamma U (\rightarrow \pi^0 \gamma)$$

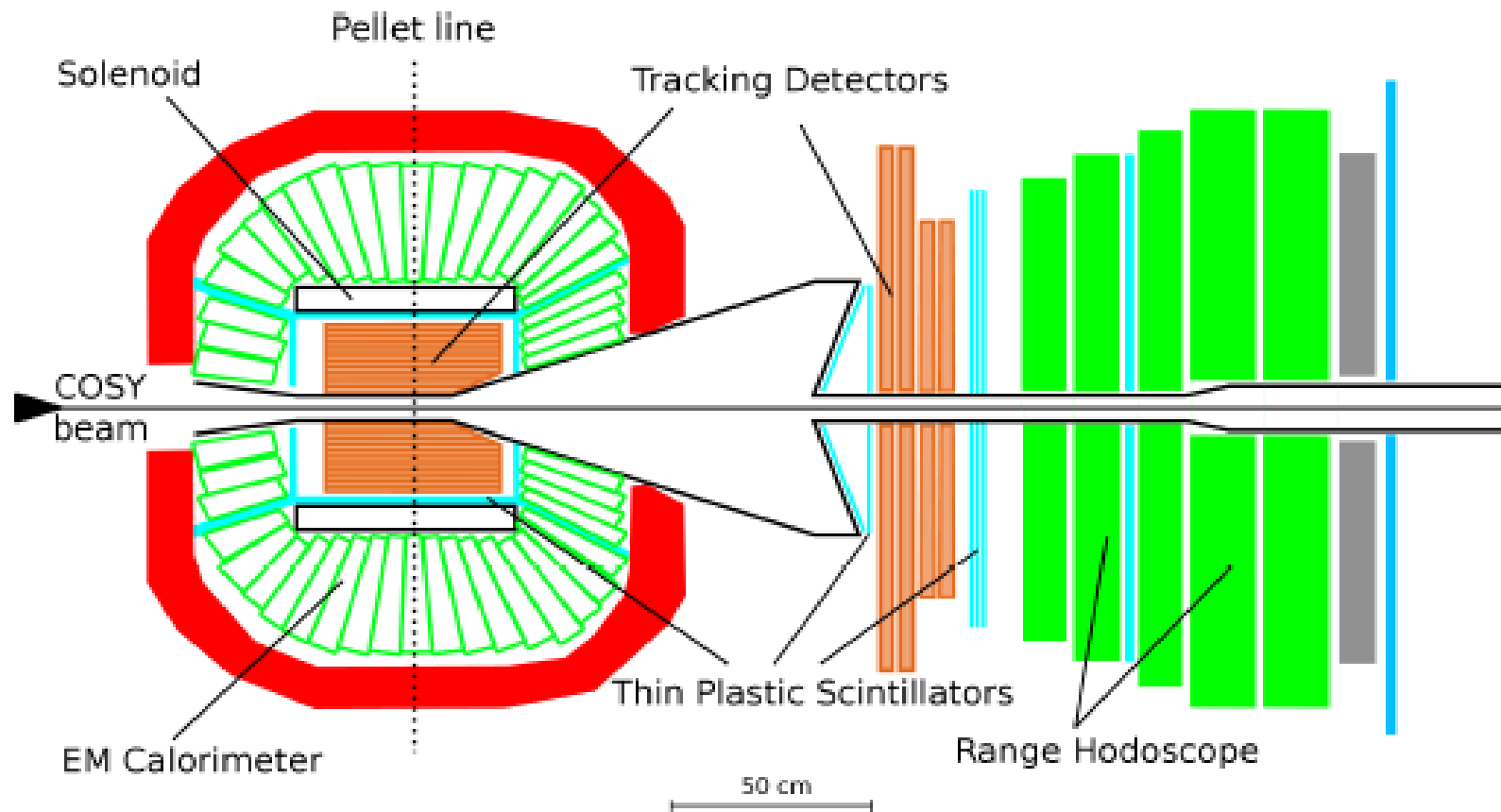
$$\eta \rightarrow \pi^0 U (\rightarrow e^+ e^-)$$



# WASA-at-COSY experiment

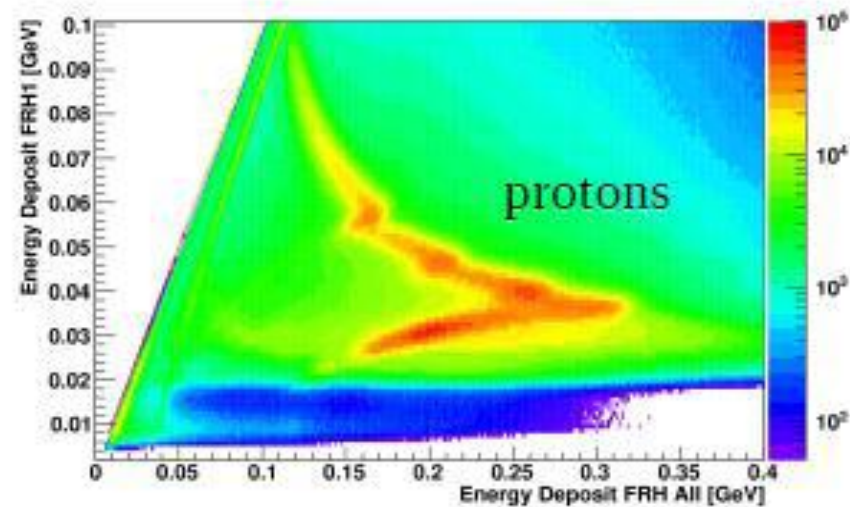
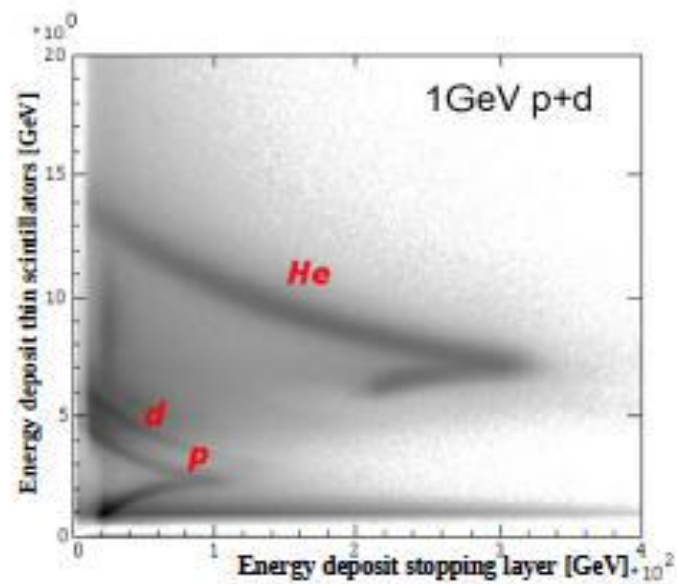
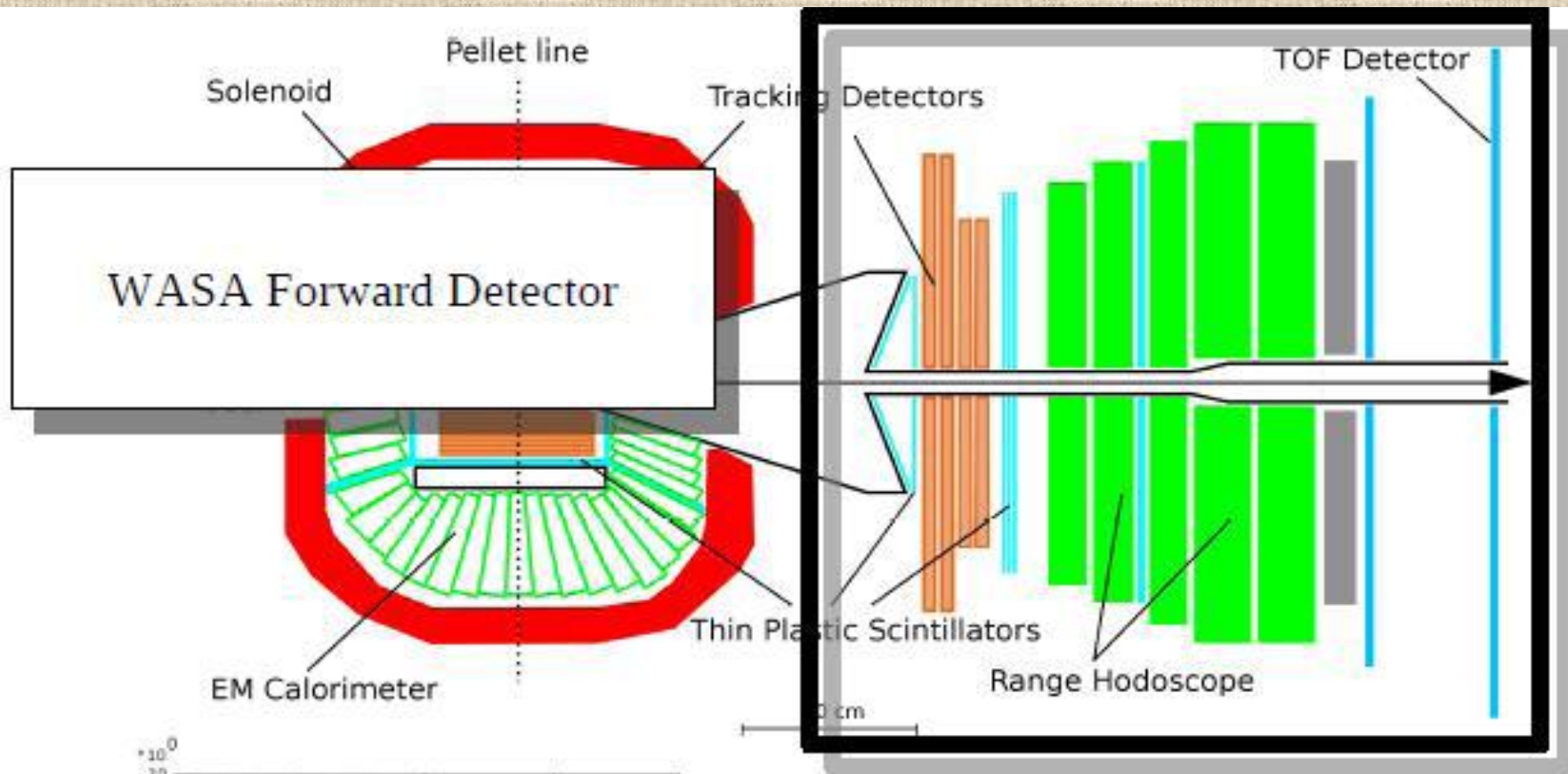
- **Wide Angle Shower Apparatus**
- **Cooler Synchrotron** located at Forschungszentrum Jülich
- Designed to study light meson production and decays in hadronic interactions
- p/d beams up to 3.7 GeV/c (stochastic and  $e^-$  cooling)
- High density p/d pellet target
- Internal experiment

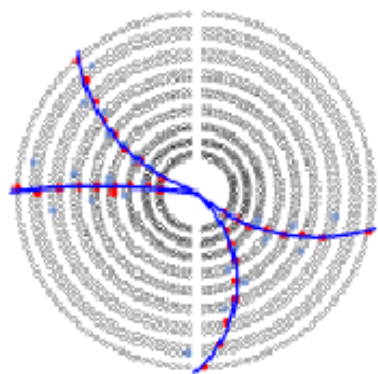
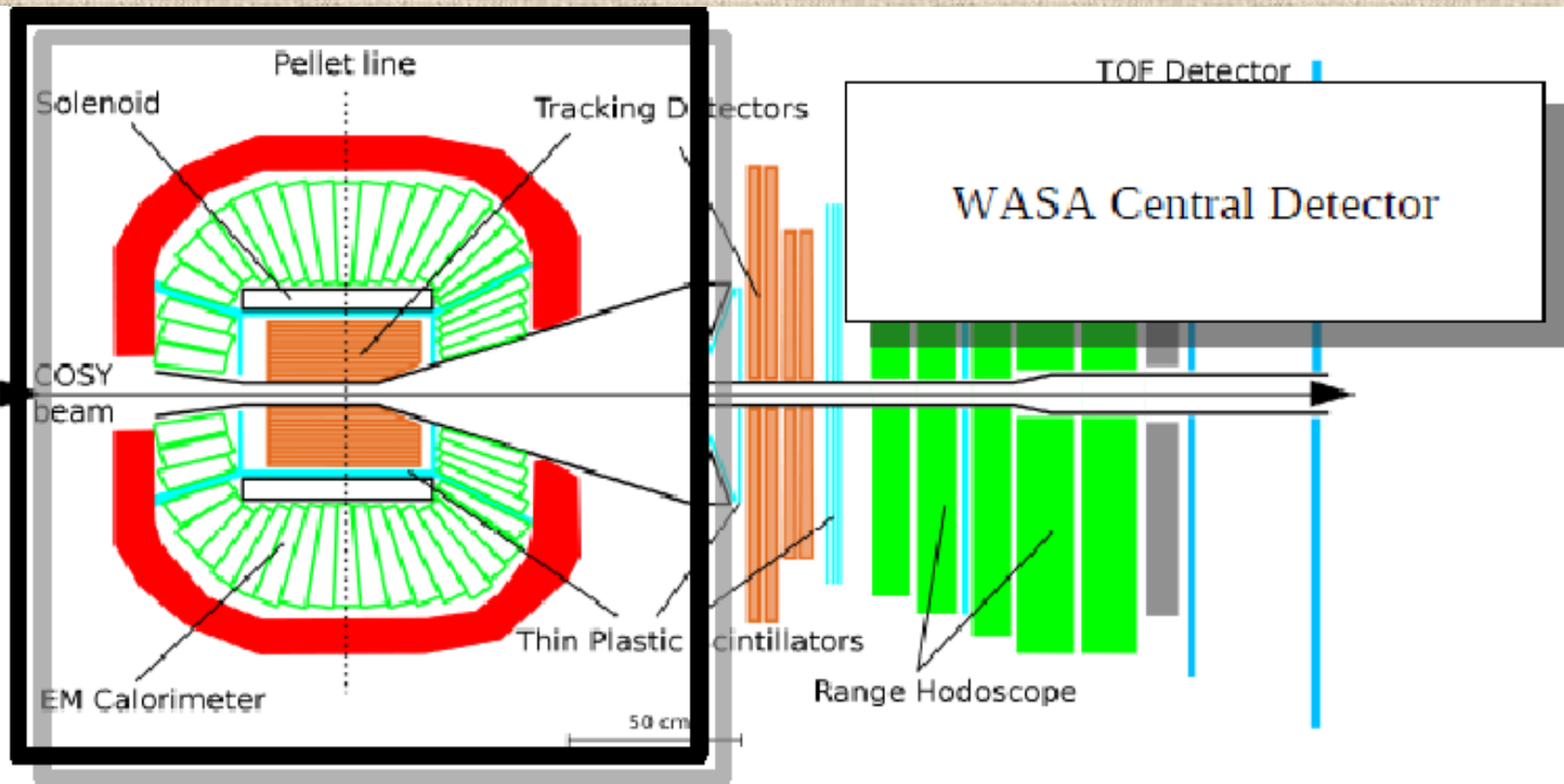




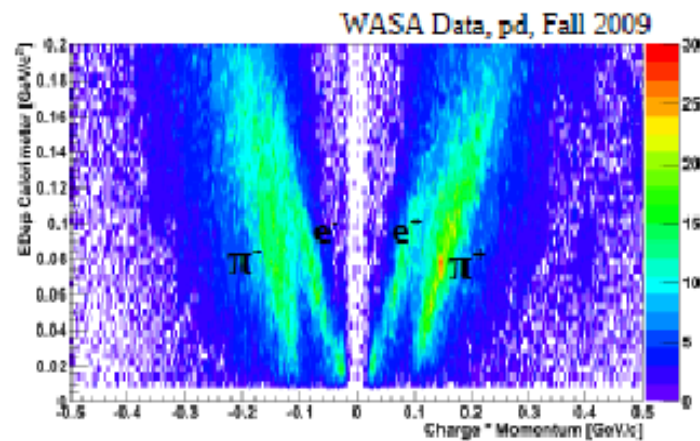
Central Detector:  $20^{\circ}$ - $165^{\circ}$   
polar angle acceptance.  
Measurement of charged  
and neutral decay products

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

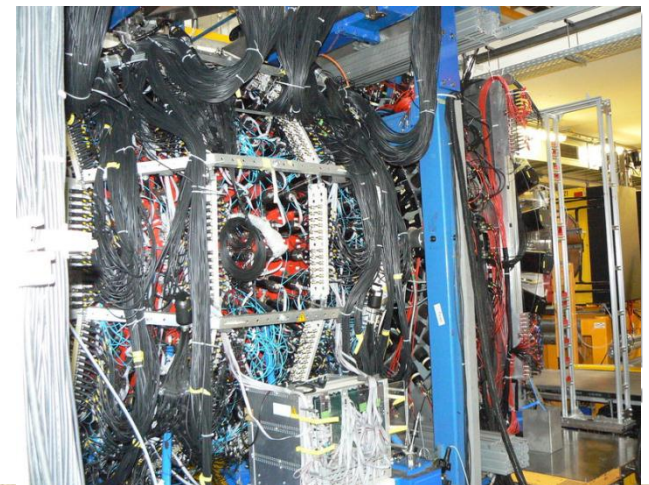




Tracking (Mini-Drift Chamber)

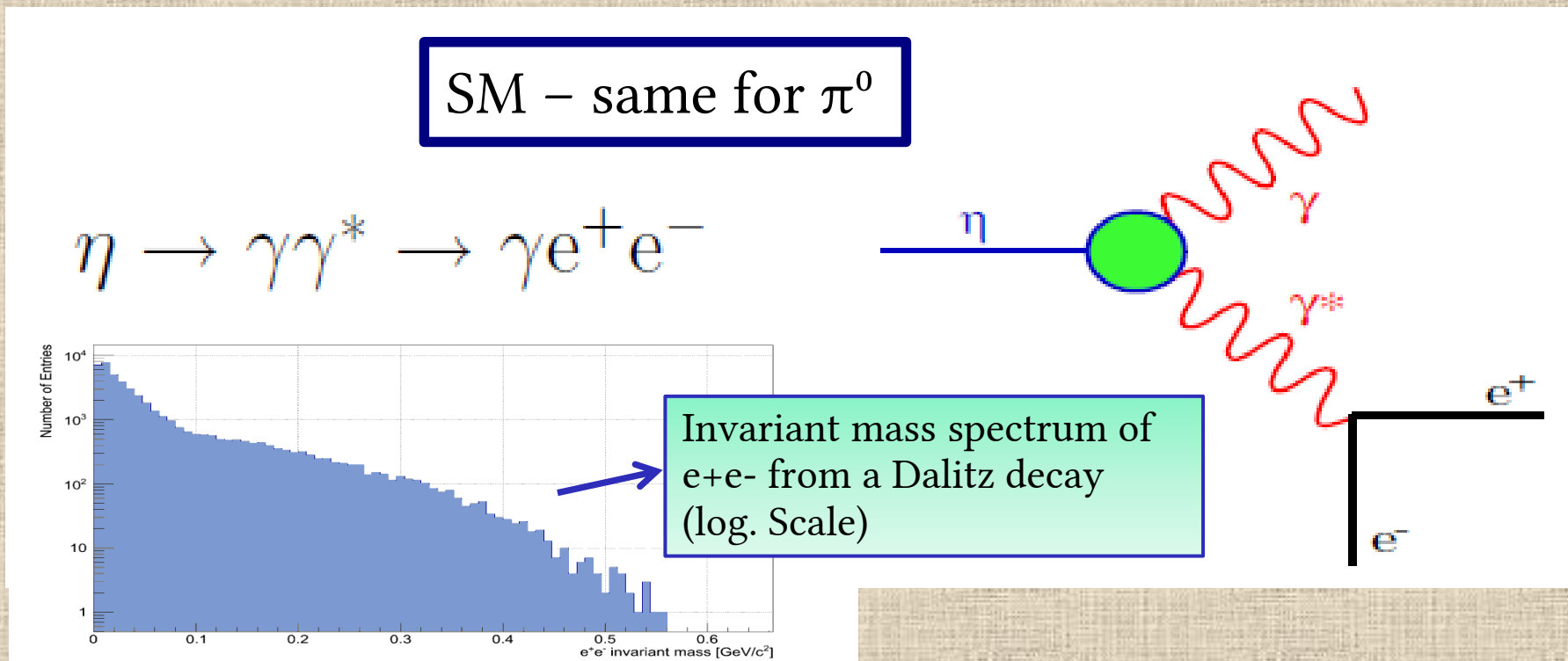


Particle Identification



# Search for a new boson in meson Dalitz decays

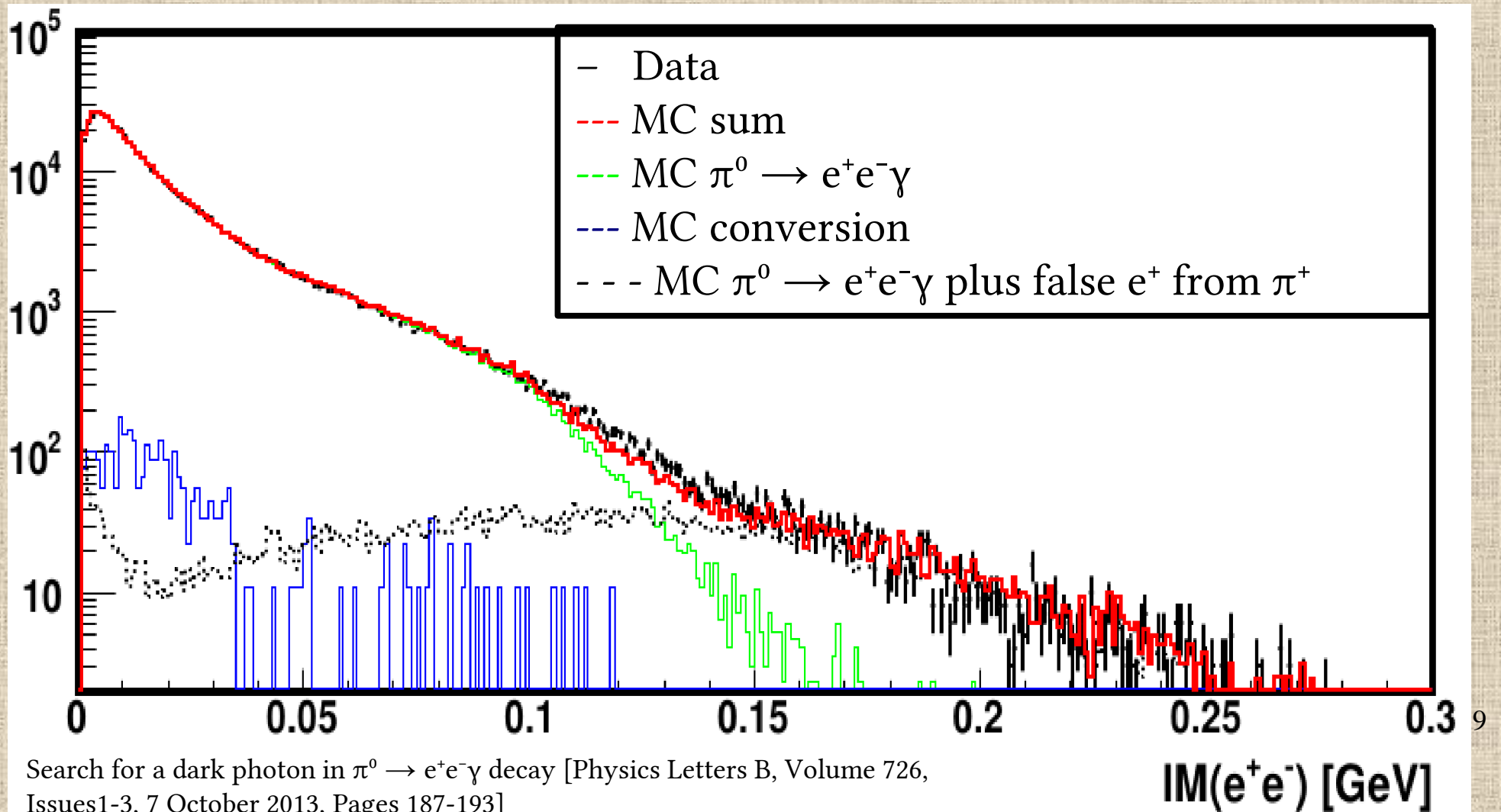
- Dalitz decays of mesons
  - $\eta/\pi^0 \rightarrow \gamma U (\rightarrow e^+e^-)$  has the same topology as the Dalitz decay!



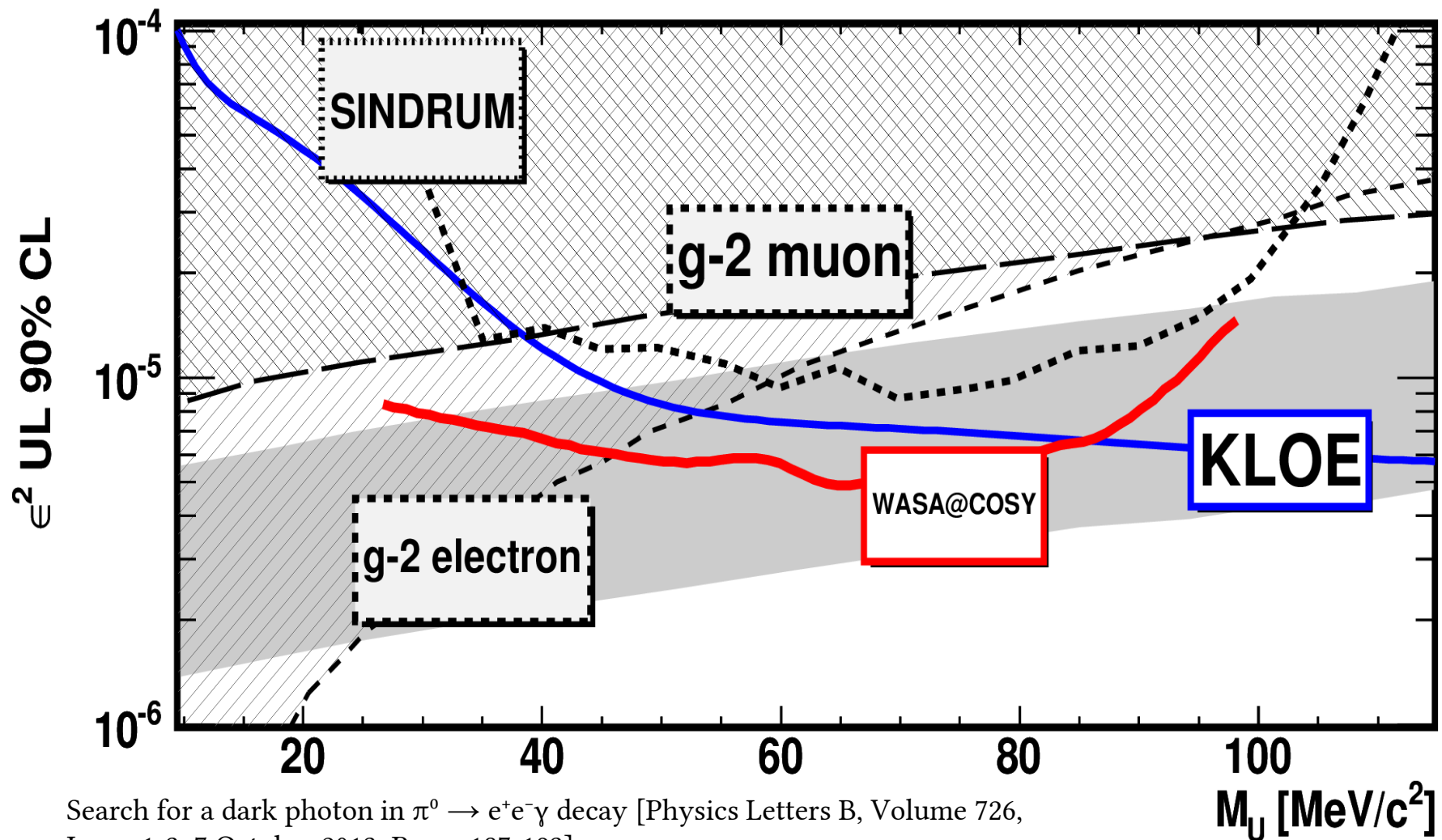


# Data: $\pi^0$ Dalitz decay

- Huge statistics collected  $\sim 5 \cdot 10^5$  of  $\pi^0 \rightarrow e^+e^-\gamma$
- Good agreement between data and simulations achieved



# 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 [Physics Letters B, Volume 726, Issues 1-3, 7 October 2013, Pages 187-193]

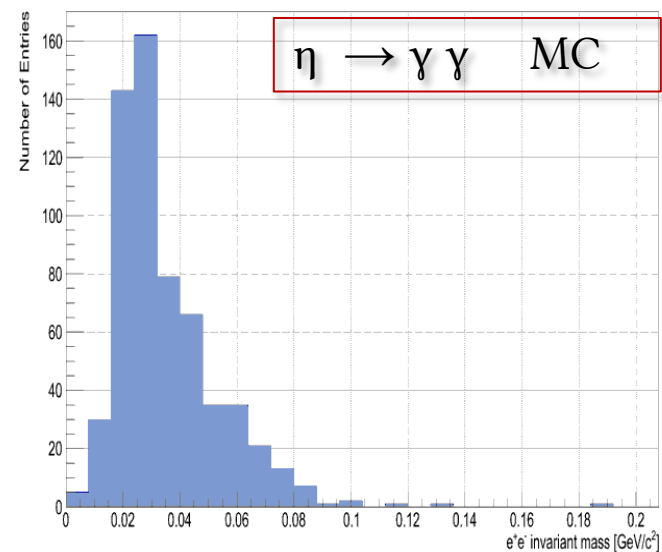
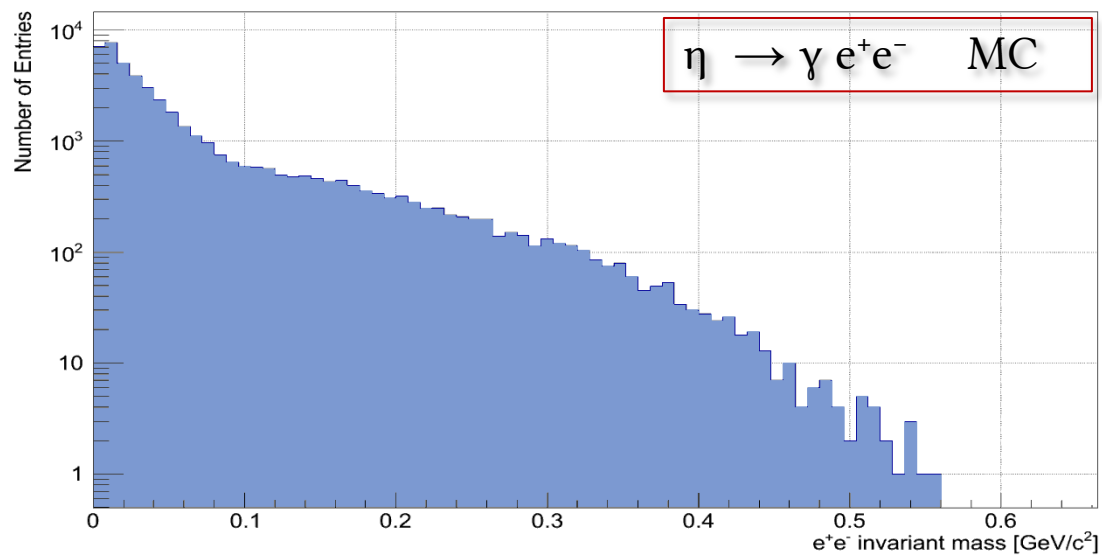
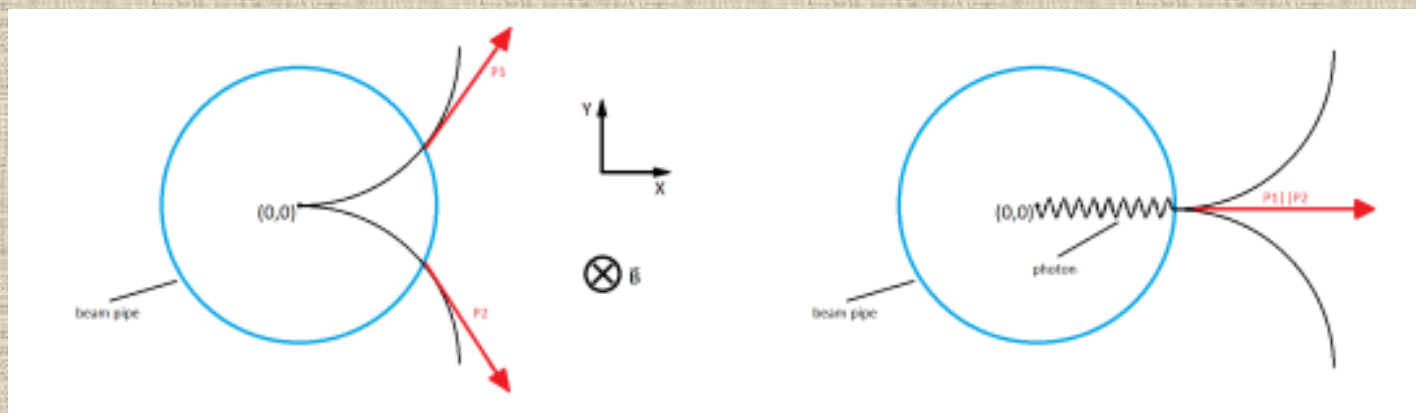
# Data: $\eta$ Dalitz decay

- $2.5 \cdot 10^8$   $\eta$  mesons produced in pp @ 1.4 GeV
  - ↳ Data collected in the beamtime period : January - March 2012
- up to higher  $IM(e^+e^-)$  than in  $\pi^0 \rightarrow e^+e^-\gamma$  case
- Hardware event selection - trigger (two clusters in CD above threshold and two tracks in FD)
- Software event selection – “preselection” and cuts
  - First step : rough conditions (charges, multiplicities etc...)
  - Second step :  
“cuts” = imposed selection criteria to maximize signal/background ratio

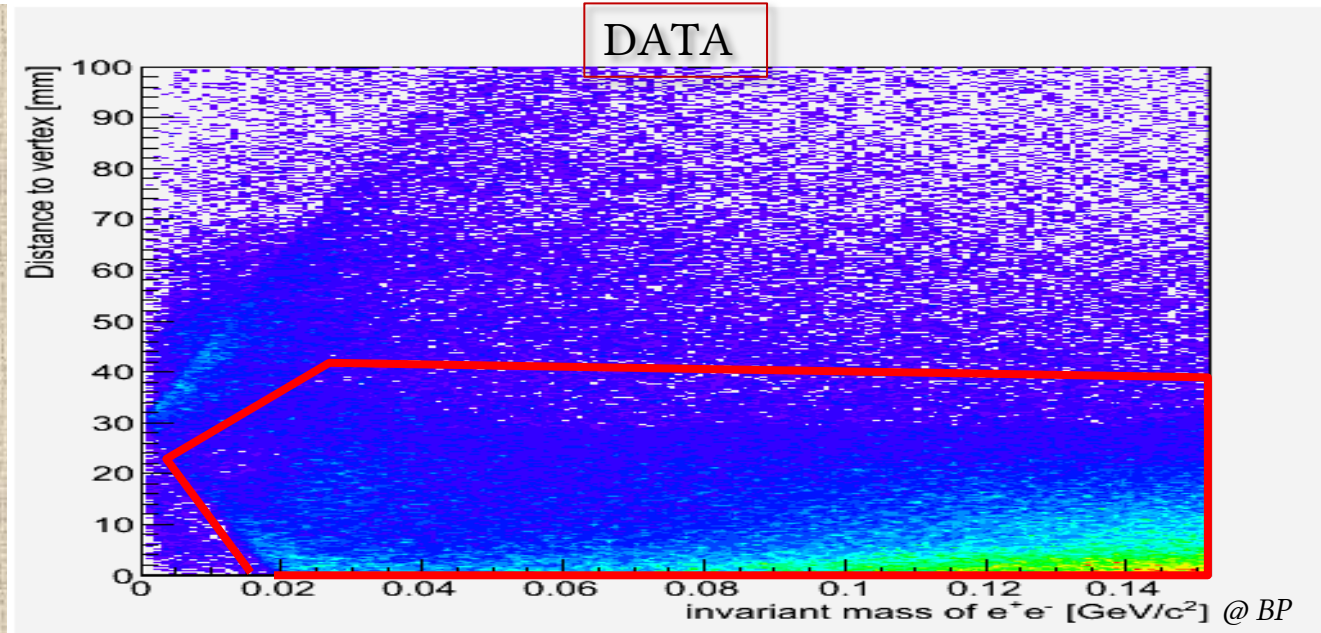
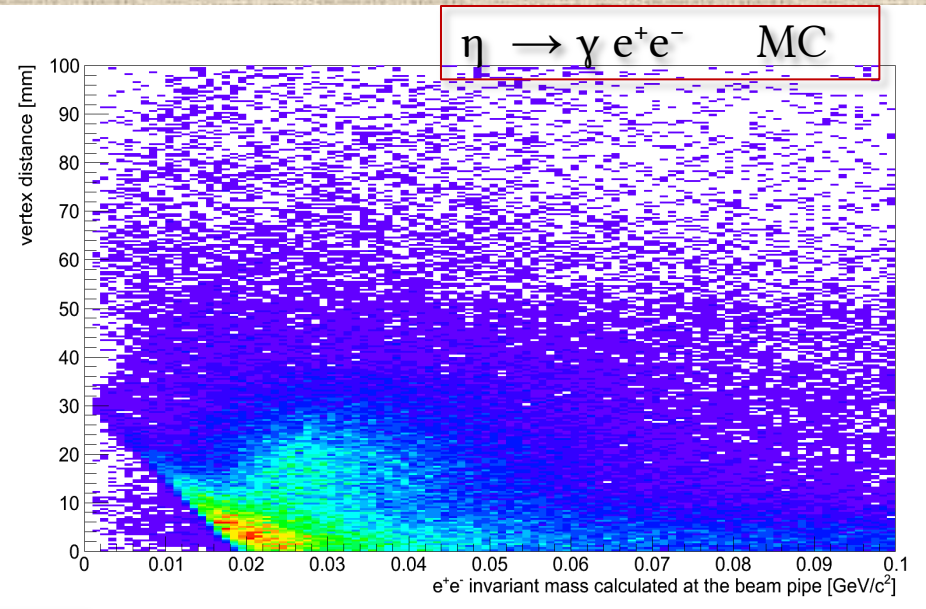
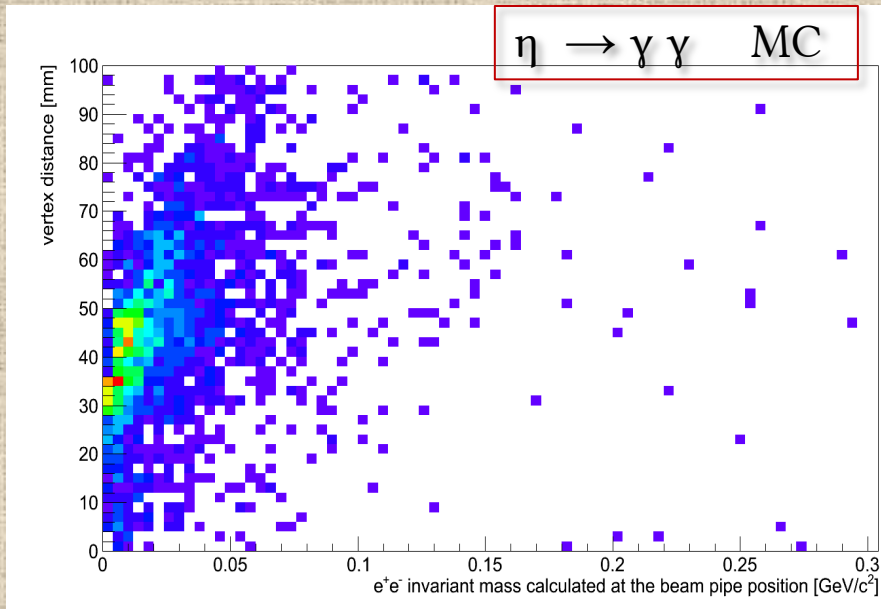


# Background: photon pair production (conversion)

## Invariant mass of $e^+e^-$ spectra

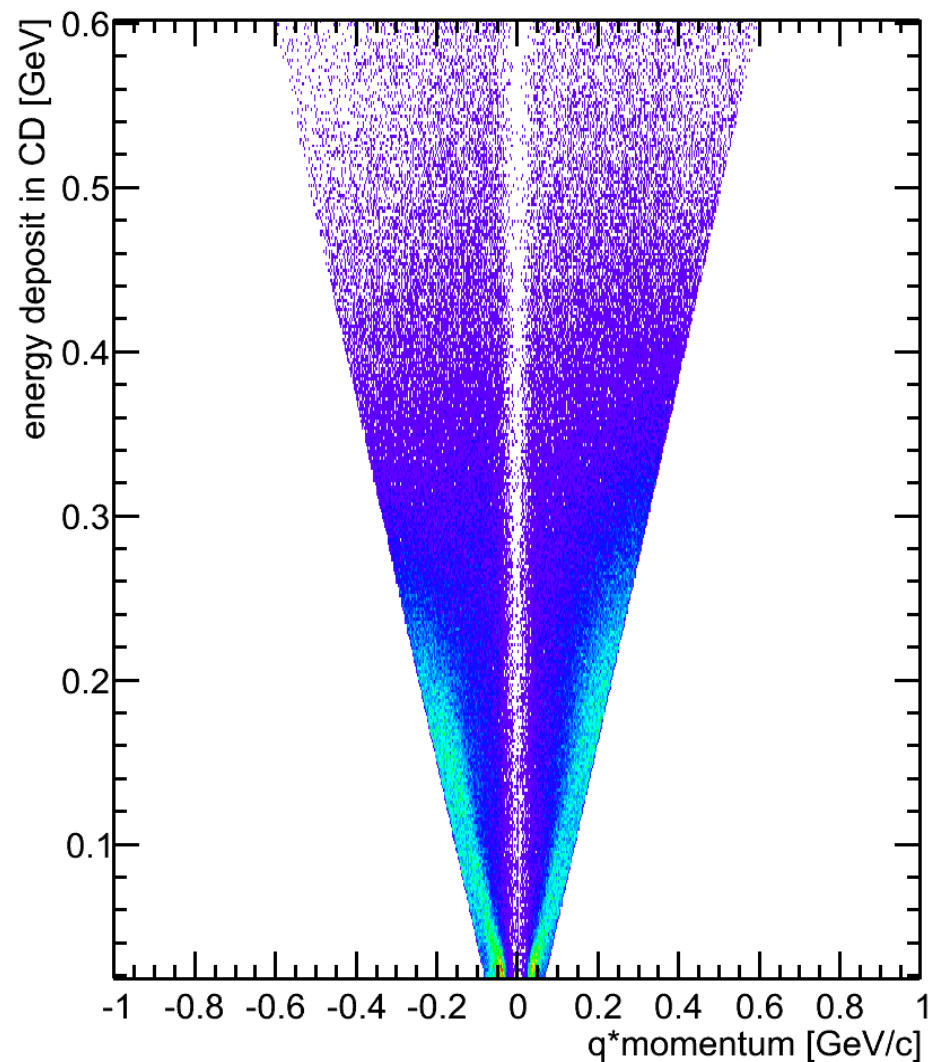
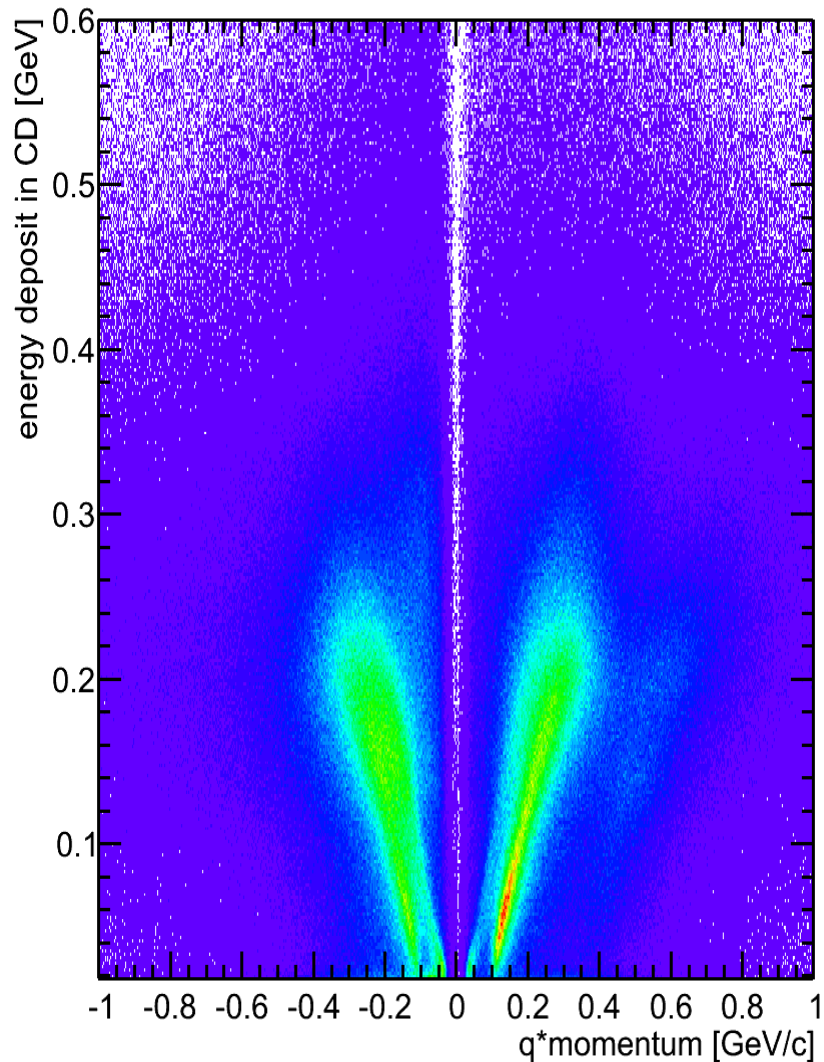


# Conversion cut

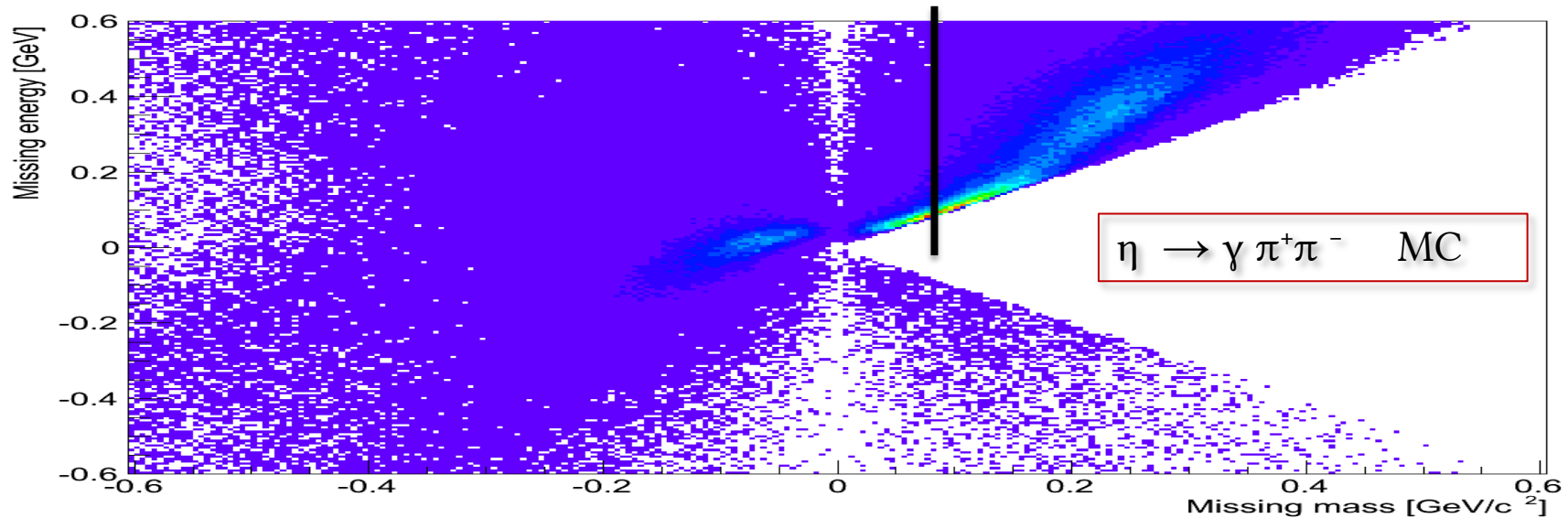
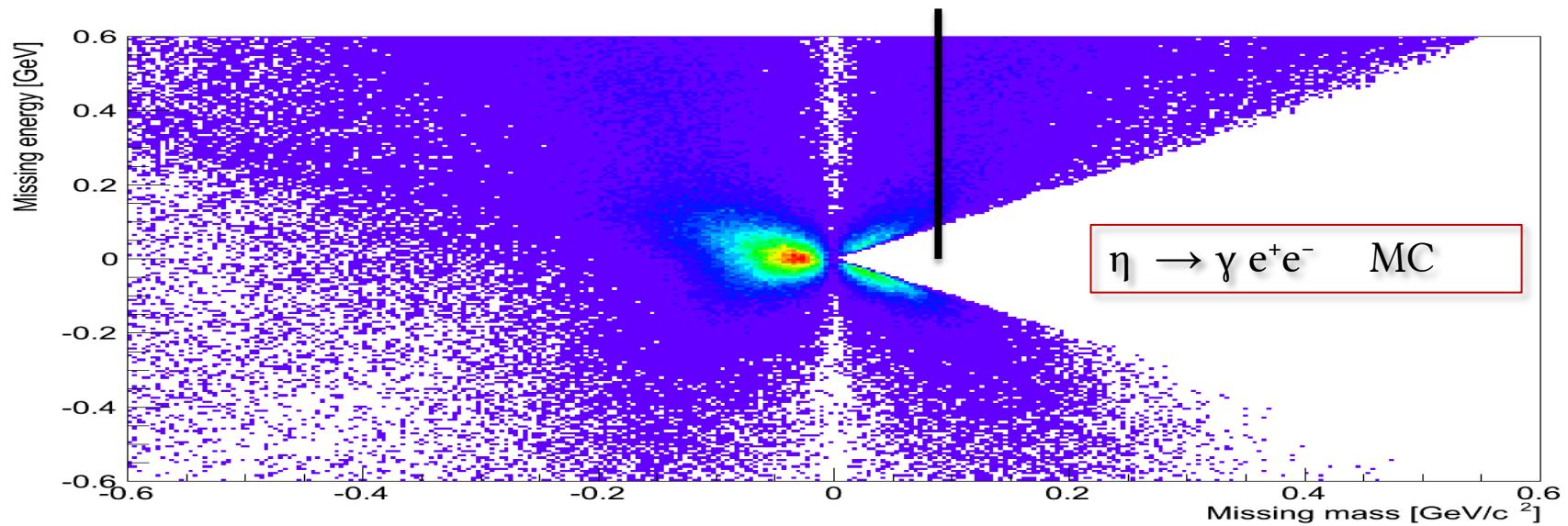


# Identification plot cut: $\pi^+\pi^-$ vs $e^+e^-$

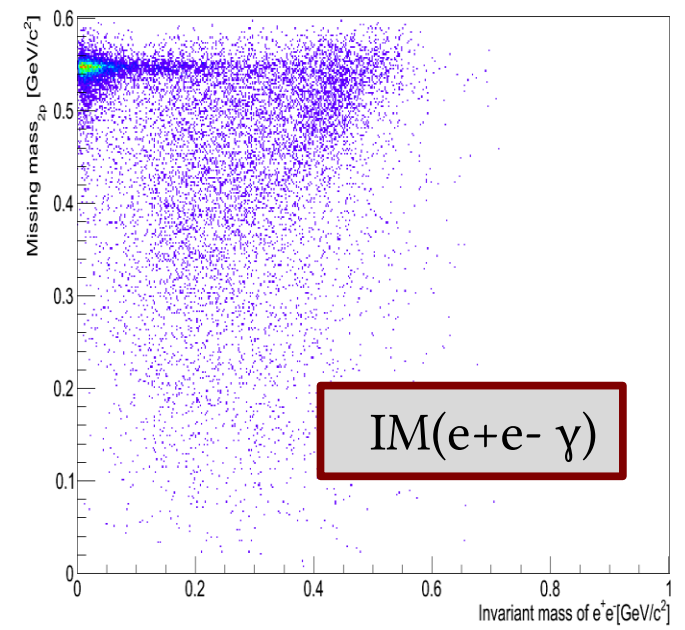
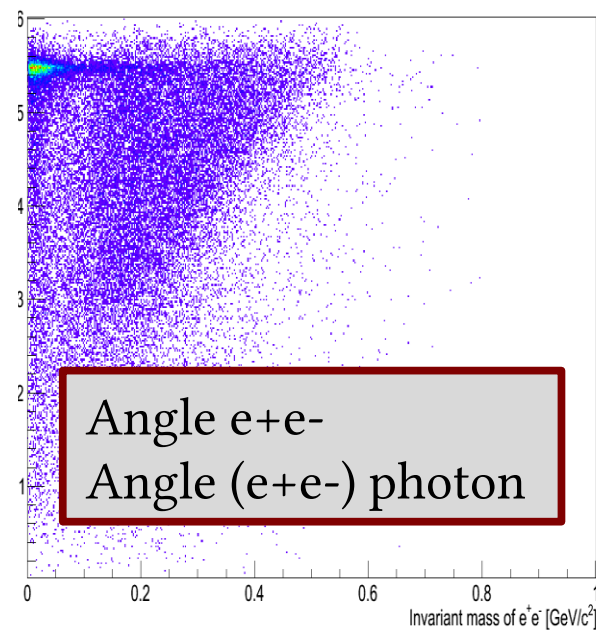
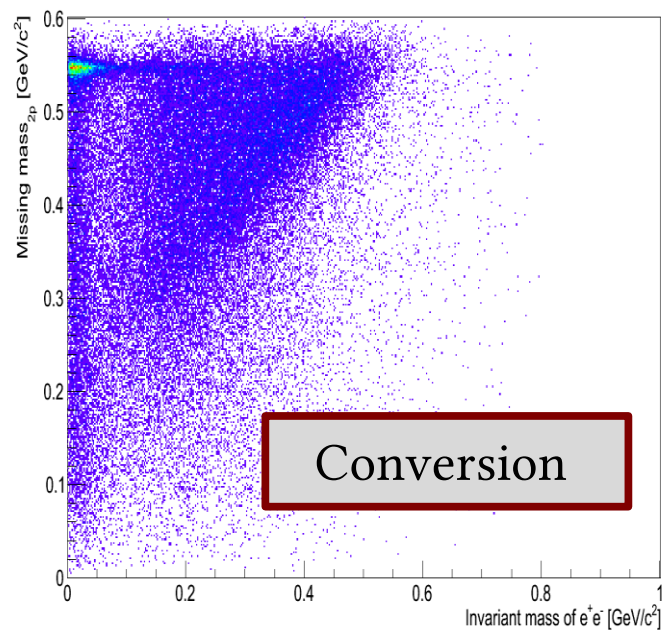
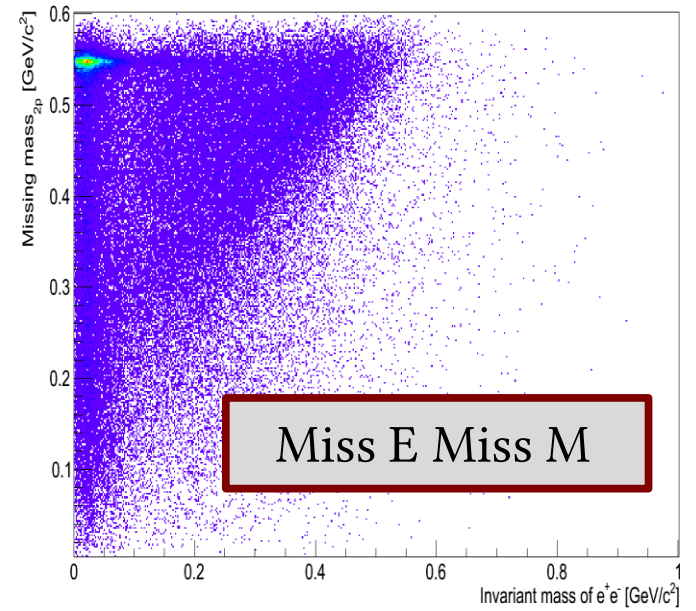
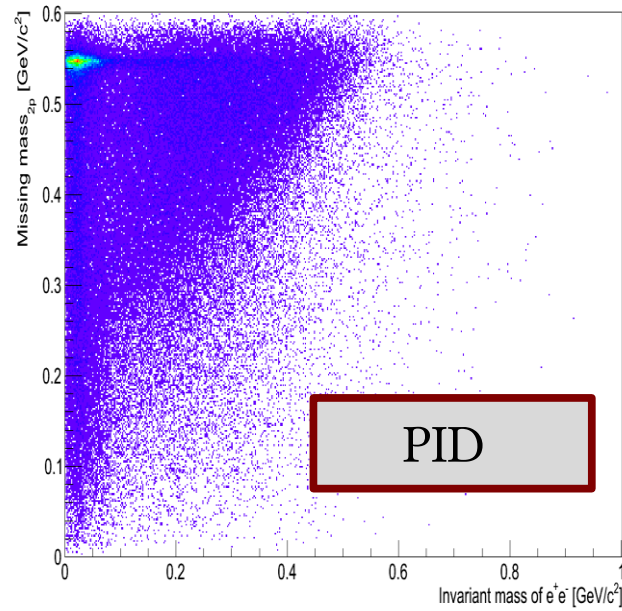
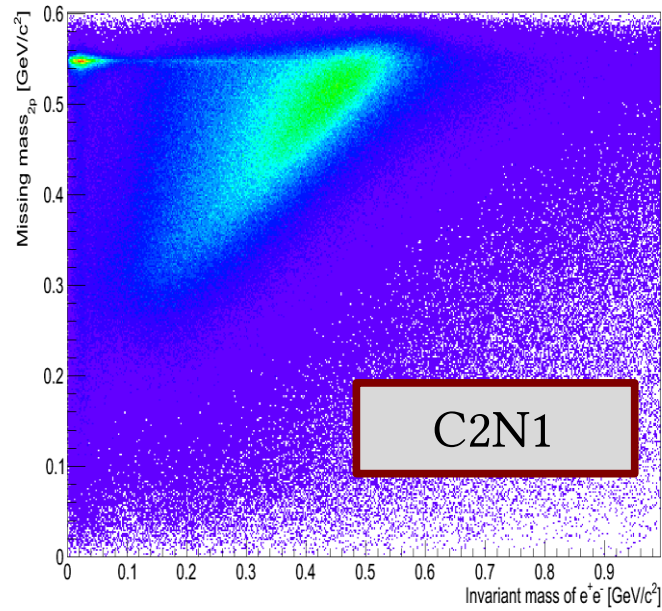
Energy deposit vs momentum\*sign(charge)



# Missing energy vs Missing Mass cut



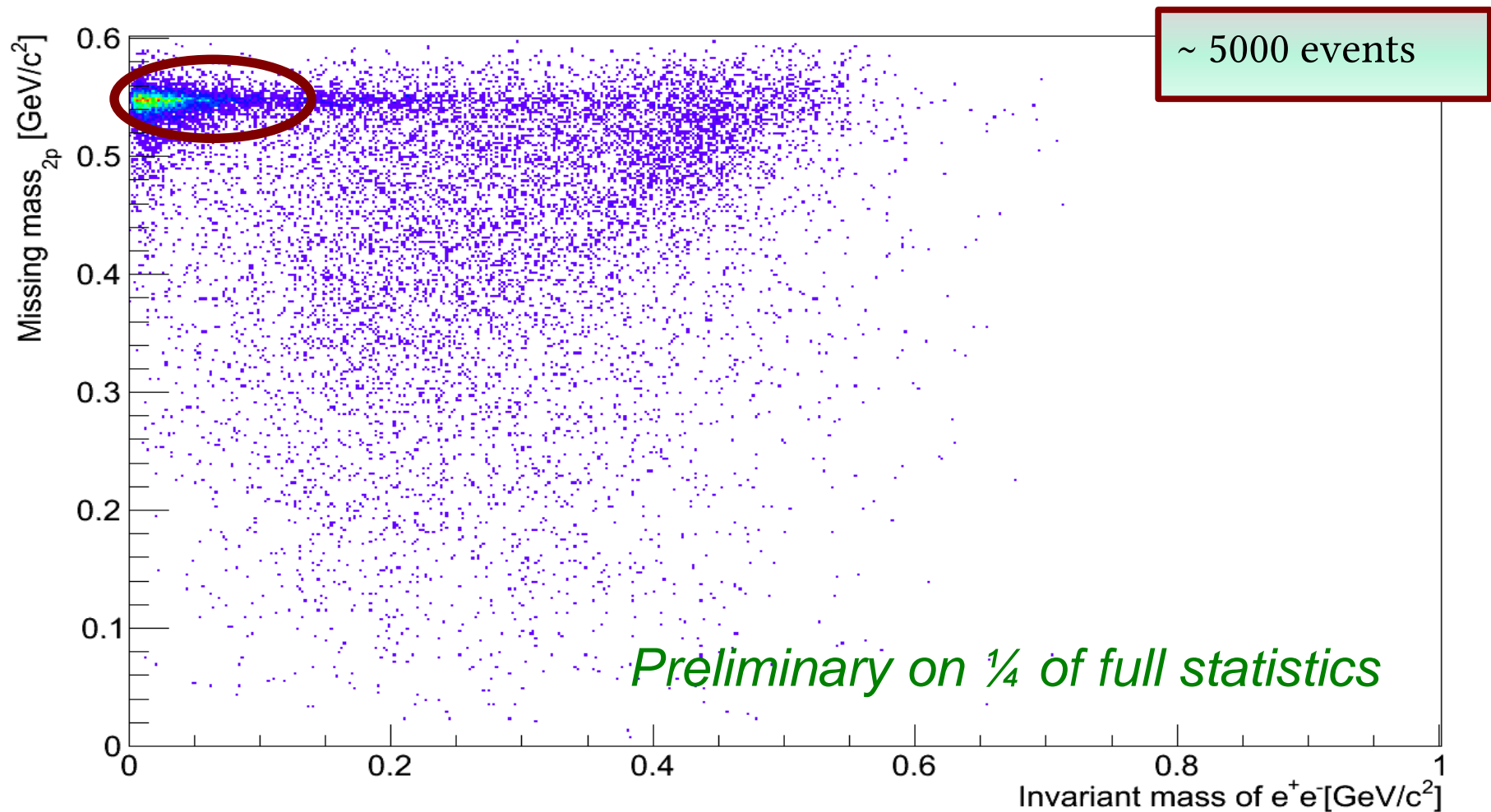
# Missing mass of two protons vs invariant mass of $e^+e^-$ pair - CUTS





# Data: $\eta$ Dalitz decay

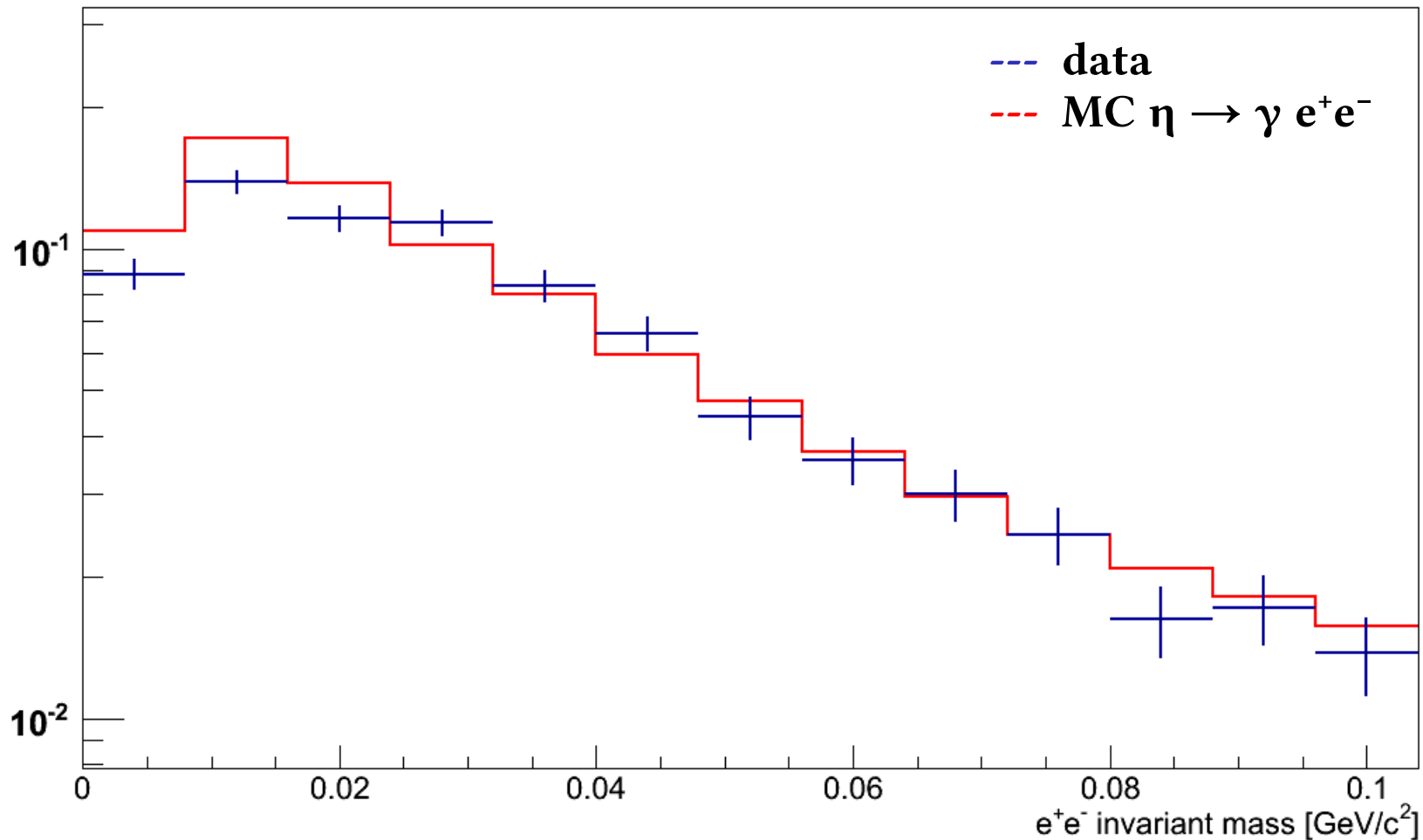
- Data analysis in progress
- $2.5 \cdot 10^8$   $\eta$  mesons produced in pp @ 1.4 GeV



# Data: $\eta$ Dalitz decay

$e^+e^-$  invariant mass [ $\text{GeV}/c^2$ ]

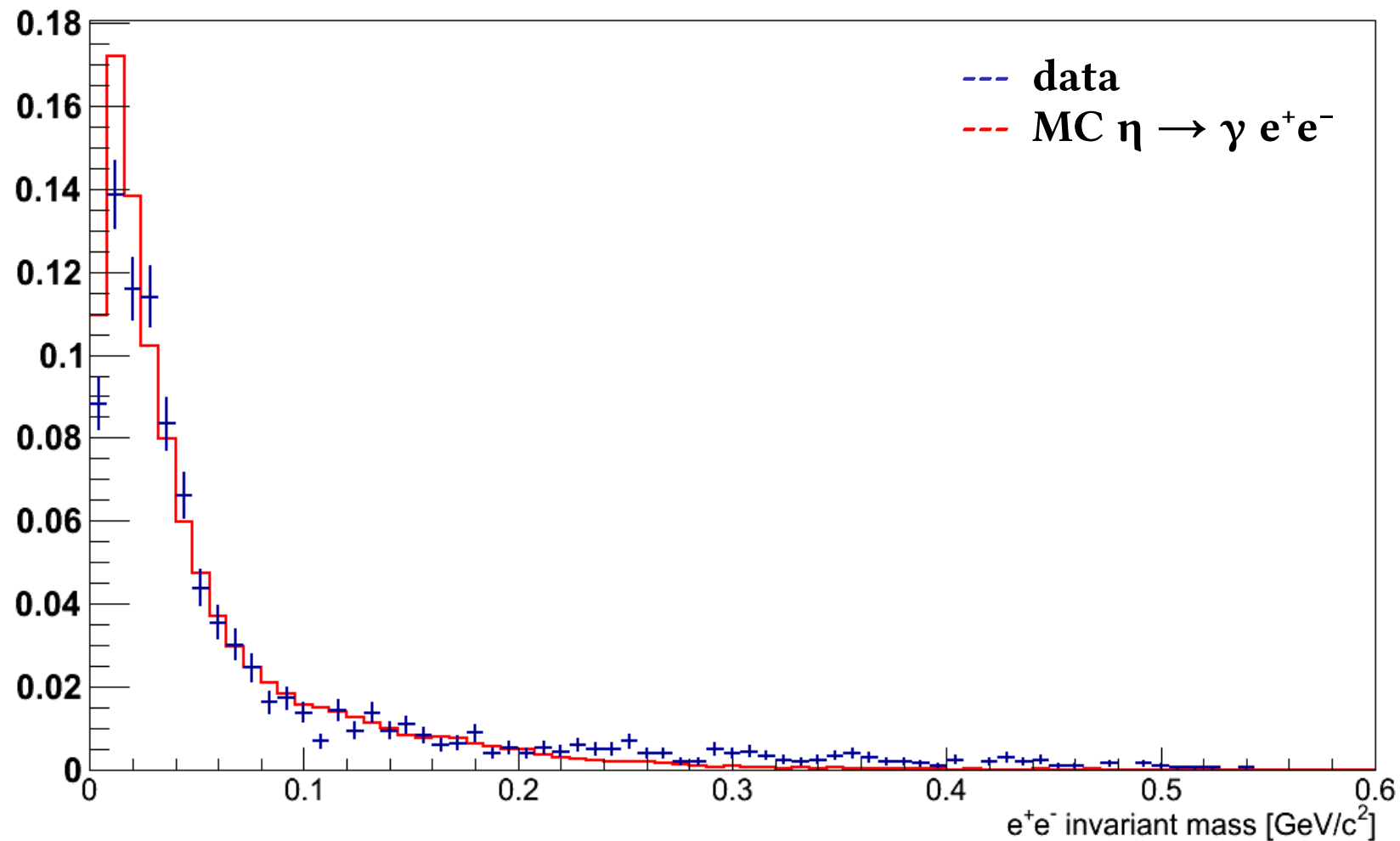
*Preliminary*



# Data: $\eta$ Dalitz decay

$e^+e^-$  invariant mass [ $\text{GeV}/c^2$ ]

*Preliminary*

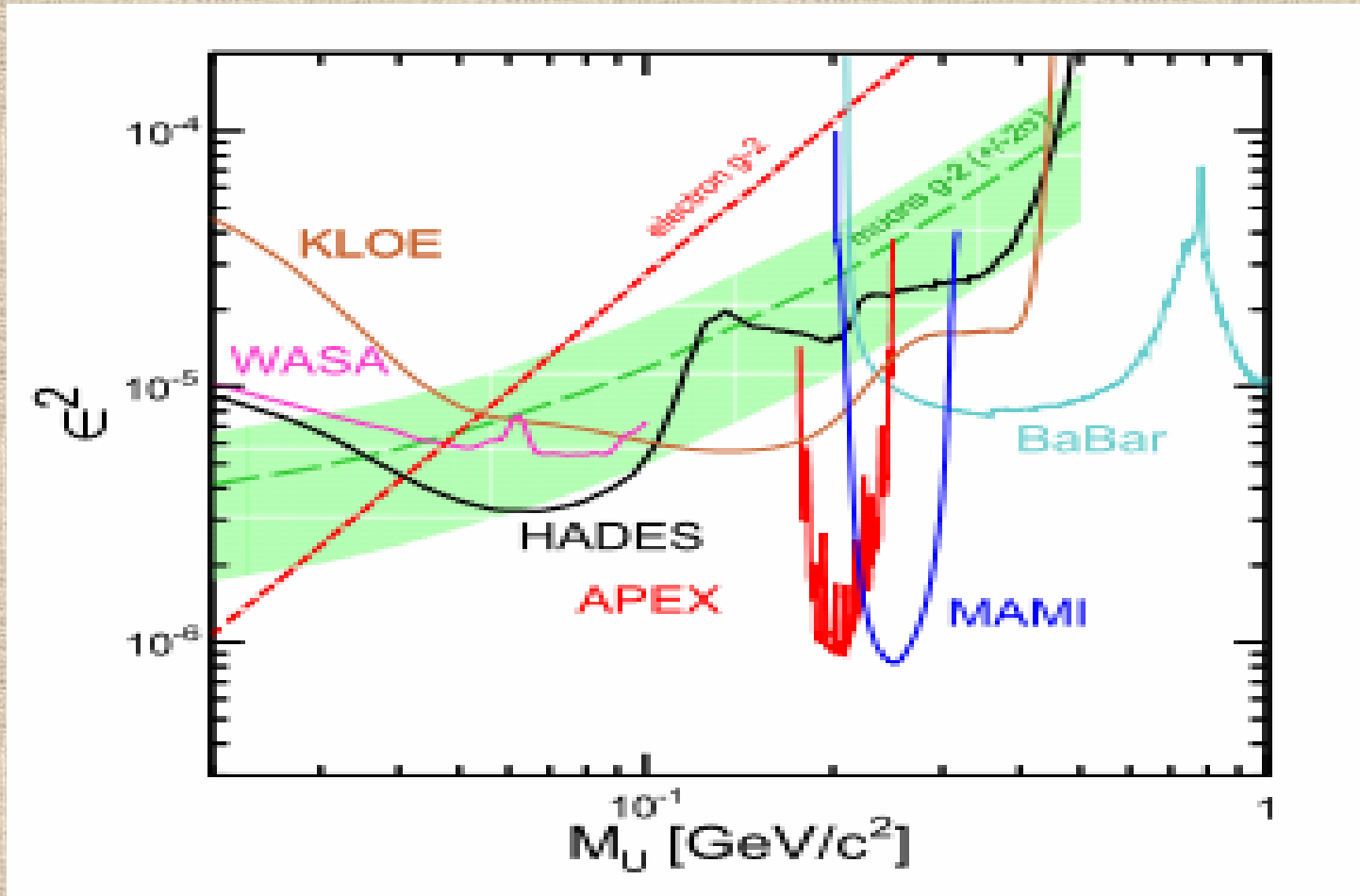


# Data: $\eta$ Dalitz decay

- We expect around 20 000  $\eta$  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	$p d \rightarrow {}^3\text{He} \eta$	
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	$e^+ e^- \rightarrow \phi \rightarrow \eta \gamma$	

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



# Summary and outlook

- Upper limit established by WASA-at-COSY collaboration in  $\pi^0$  Dalitz decay for dark photon-photon coupling parameter:  $\epsilon^2 < 5 \cdot 10^{-6}$  @ 90% C.L.
- Upper limit established by WASA-at-COSY collaboration in  $\eta \rightarrow e^+e^-$  decay:  
$$\text{BR}(\eta \rightarrow e^+e^-) < 4.6 \cdot 10^{-6} \text{ @ CL } 90\%$$
- Analysis of  $\eta$  Dalitz channel in progress based on  $\sim 2.5 \cdot 10^8$   $\eta$  mesons produced in pp collisions @ 1.4 GeV
- Possible analysis of other channels:
  - $\eta \rightarrow e^+e^-$        $\eta \rightarrow \pi^0 e^+e^-$        $\eta \rightarrow \pi^0 \gamma \gamma$

THANK YOU  
FOR YOUR  
ATTENTION

# Simulation

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

