

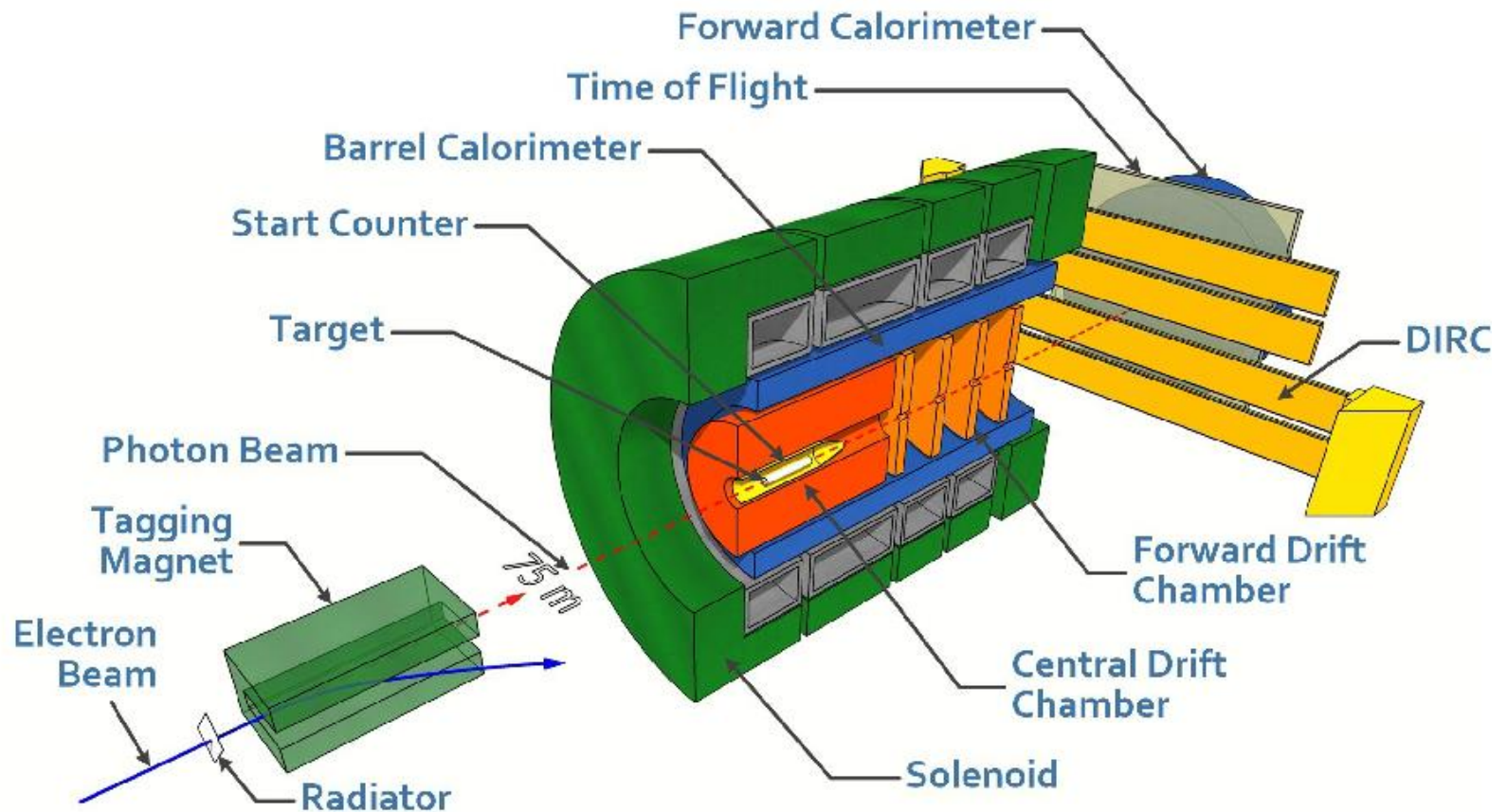
# ***JLAB $\eta$ Factory Experiment in Hall D***

***A. Somov, Jefferson Lab***

***for the GlueX collaboration***

***APS meeting, April 20, 2021***

# GlueX Detector in Hall D



- Beam of photons (linear polarization)
- Optimized to detect multi-particle final states

# Experiments with the GlueX detector

GlueX experiment: search for mesons with exotic quantum numbers; a study of meson and baryon decays to strange final states

2016 – present  
collected 30 % ... of data

*(see talks by M. Khachatryan and J.Stevens)*

A precision measurement of the  $\eta$  radiative decay width via the Primakoff effect

**Calorimeter  
prototype**

Spring 2019 (30 % of data)  
Scheduled in fall 2021

*(see talk by A. Smith and T.Hague)*

Measuring the charged pion polarizability

Scheduled for 2022

Studying short range correlations with real photon beams at GlueX

Scheduled in fall 2021

## Upgrade Forward Calorimeter

Eta decays with emphasis on rare neutral modes:  
The JLab Eta Factory experiment (JEF)

2023  
Run in parallel with GlueX

# JEF Physics Program

Update table

Mode	Branching Ratio	Physics Highlight	Photons
priority:			
$\pi^0 2\gamma$	Upgrade the Forward Calorimeter		4
$\gamma + B$	beyond SM	leptophobic dark boson	4
$3\pi^0$	$(32.6 \pm 0.2)\%$	$m_u - m_d$	6
$\pi^+ \pi^- \pi^0$	$(22.7 \pm 0.3)\%$	$m_u - m_d$ , CV	2
$3\gamma$	$< 1.6 \times 10^{-5}$	CV, CPV	3
ancillary:			
$4\gamma$	$< 2.8 \times 10^{-4}$	$< 10^{-11}$ [112]	4
$2\pi^0$	$< 3.5 \times 10^{-4}$	CPV, PV	4
$2\pi^0 \gamma$	$< 5 \times 10^{-4}$	CV, CPV	5
$3\pi^0 \gamma$	$< 6 \times 10^{-5}$	CV, CPV	6
$4\pi^0$	$< 6.9 \times 10^{-7}$	CPV, PV	8
$\pi^0 \gamma$	$< 9 \times 10^{-5}$	CV, Ang. Mom. viol.	3
normalization:			
$2\gamma$	$(39.3 \pm 0.2)\%$		2

Main physics goal:

1. Probe interplay of VMD & scalar resonances in ChPT to calculate  $O(p^6)$  LEC's in the chiral Lagrangian
2. Search for dark matter
3. Directly constrain CVPC new physics
4. Constrain the light quark mass ratio

# Impact of $\eta \rightarrow \pi^0 \gamma \gamma$ measurements on ChPT

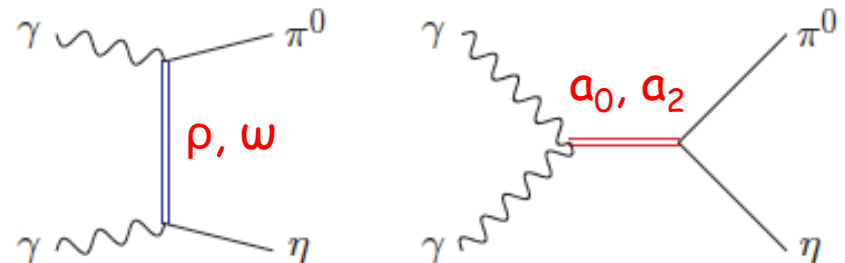
- Unique probe for the high order ChPT: the major contributions to  $\eta \rightarrow \pi^0 \gamma \gamma$  are **two  $O(p^6)$  counter-terms** in the chiral Lagrangian

L. Ametller, J. Bijnens, and F. Cornet, Phys. Lett., B276, 185 (1992)

- Study contribution of scalar resonances in calculation of  **$O(p^6)$  low-energy constants (LEC)** in the chiral Lagrangian
- Shape of Dalitz distribution is sensitive to the role of scalar resonances

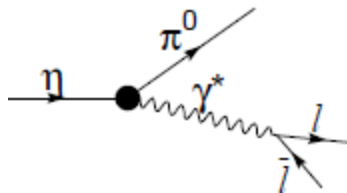
Higher order LEC's are dominated by resonances

Gasser, Leutwyler 84; Ecker, Gasser, Pich, de Rafael 1989; Donoghue, Ramirez, Valencia 1989

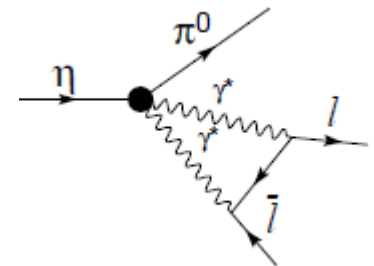


- A cross-check of LEC's with different processes

C and CP violating



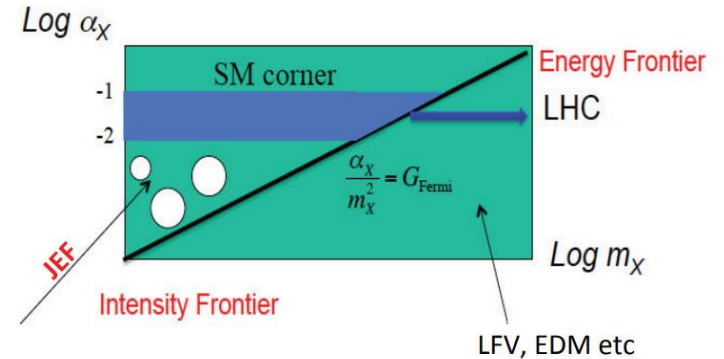
C and CP conserving background



J.N. Ng, et al., Phys. Rev., D46, 5034 (1992)

# Dark Matter Search in $\eta$ Decays

Search for dark matter in sub-GeV range:



Vector

leptophobic vector boson  $B$ :

$$\begin{aligned} \eta, \eta' &\rightarrow \gamma B & B &\rightarrow \pi^0 \gamma & (0.14 < m_B < 0.62 \text{ GeV}) \\ & & B &\rightarrow \pi^+ \pi^- \pi^0 & (0.62 < m_B < 1.0 \text{ GeV}) \end{aligned}$$

dark photon:

$$\eta, \eta' \rightarrow A' \gamma \rightarrow e^+ e^- \gamma$$

Scalar

$$\begin{aligned} \eta, \eta' &\rightarrow \pi^0 S & S &\rightarrow \pi^0 \gamma \gamma, \quad \pi^0 e^+ e^- & (m_S < 2 m_\pi) \\ & & S &\rightarrow 3 \pi & (m_S > 2 m_\pi) \end{aligned}$$

Light pseudoscalar (axion-like particle)

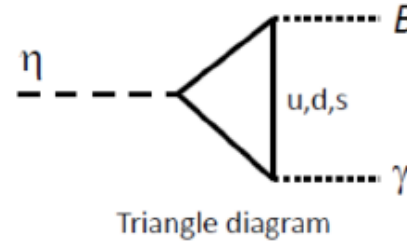
$$\eta, \eta' \rightarrow \pi \pi \gamma \gamma, \quad \pi \pi e^+ e^-$$

# Search for B-boson in $\eta$ decay

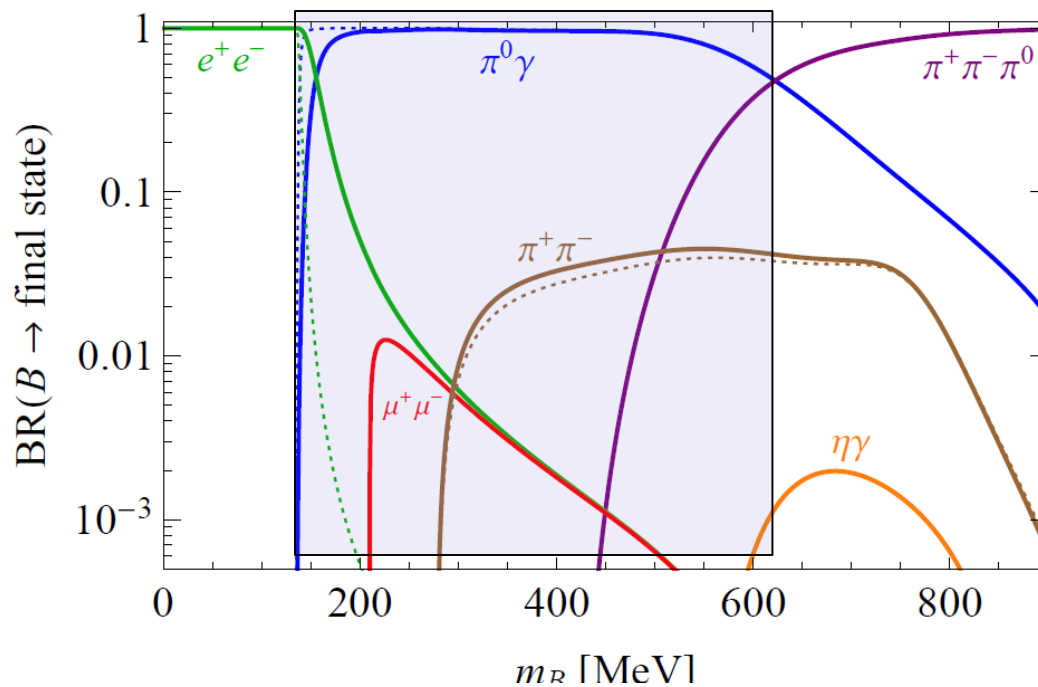
B production:

A.E. Nelson, N. Tetradis, Phys. Lett., B221, 80 (1989)

$\eta \rightarrow B\gamma$  decay ( $m_B < m_\eta$ )

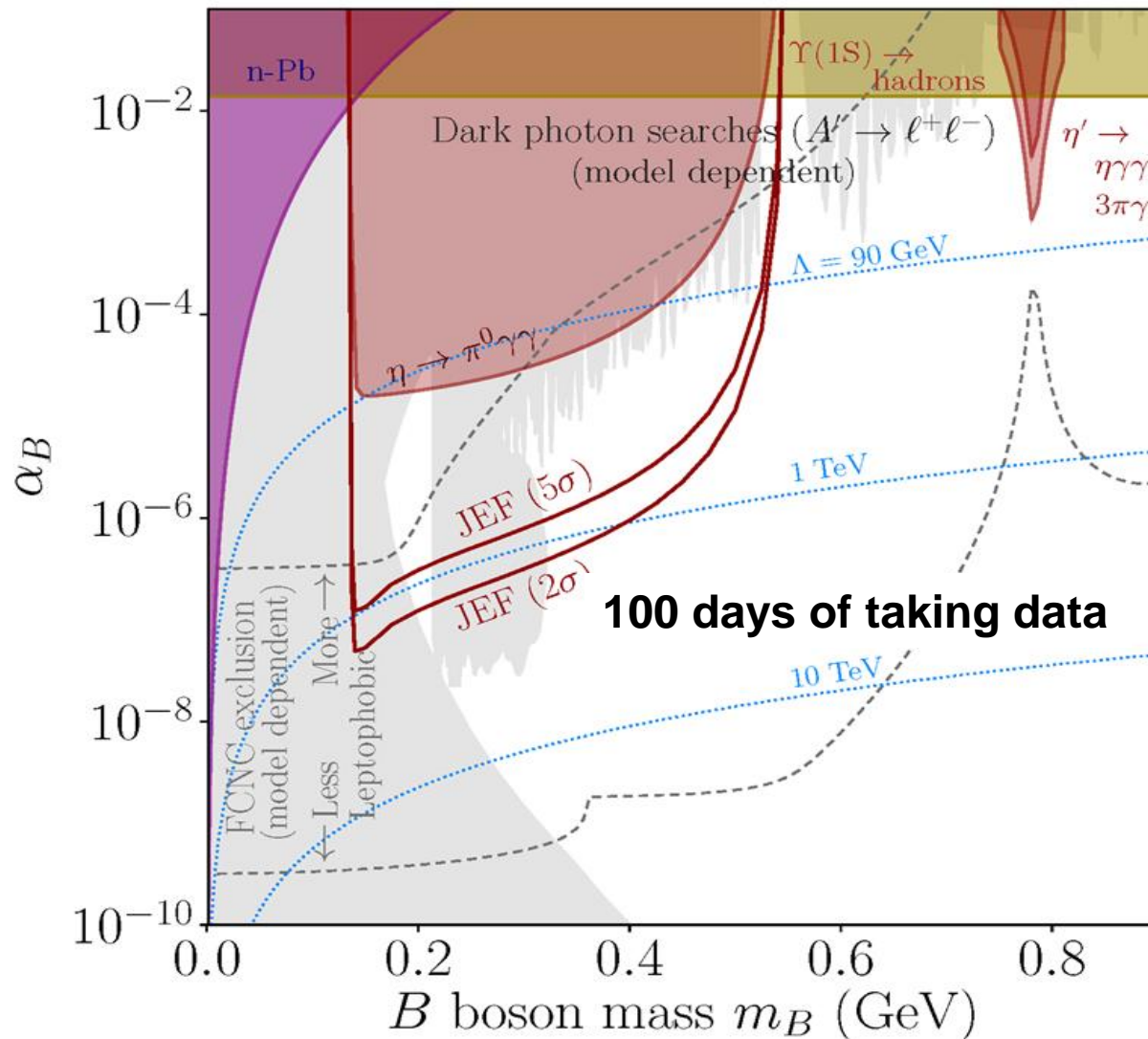


B decay:  $B \rightarrow \pi^0 \gamma$  in 140-600 MeV mass range



S. Tulin, Phys.Rev., D89, 14008 (2014)

# JEF Experimental Reach ( $\eta \rightarrow B\gamma \rightarrow \pi^0\gamma\gamma$ )

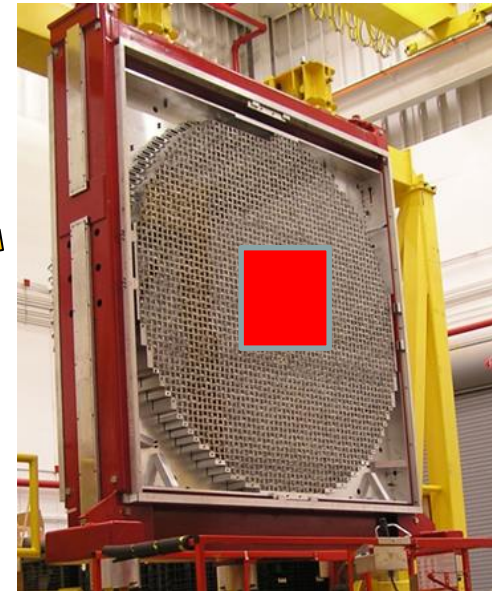
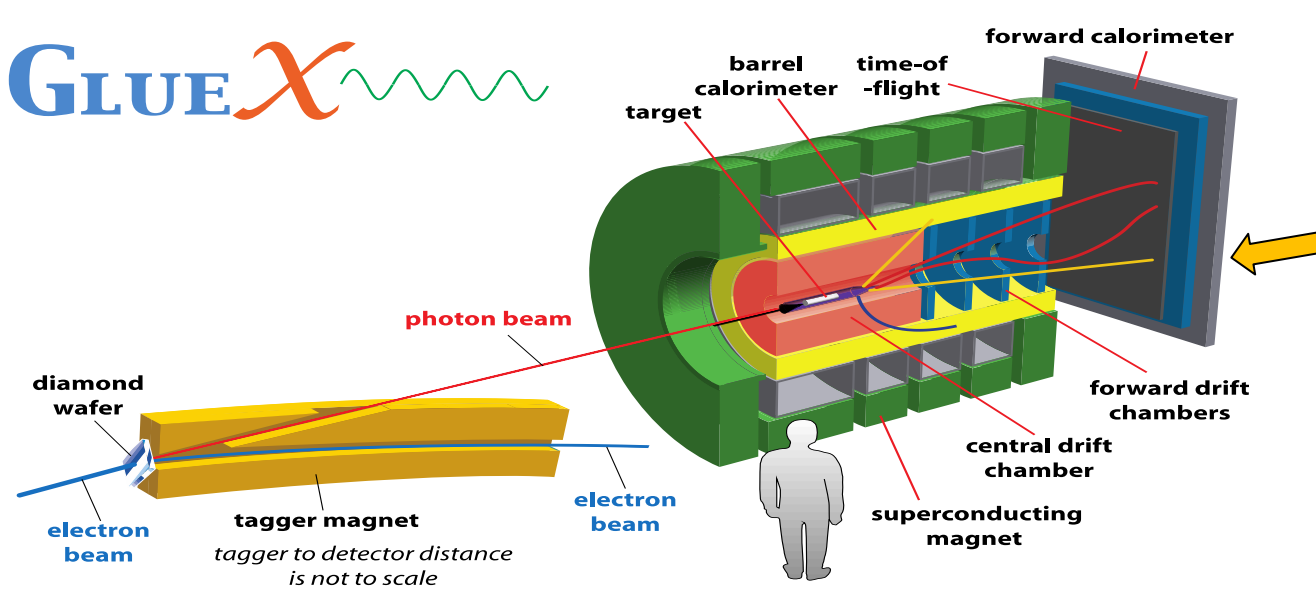


A stringent constraint  
on the leptophobic  
B-boson in  
140 - 550 MeV range



# GlueX Calorimeter Upgrade

FCAL

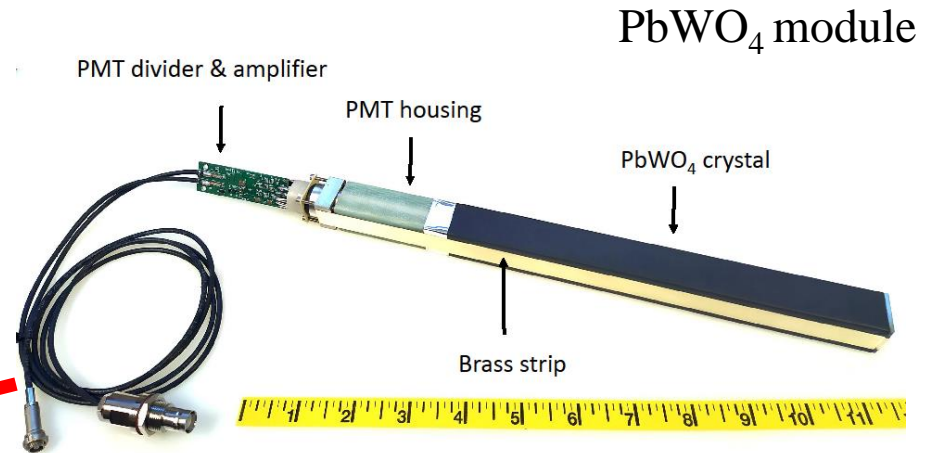
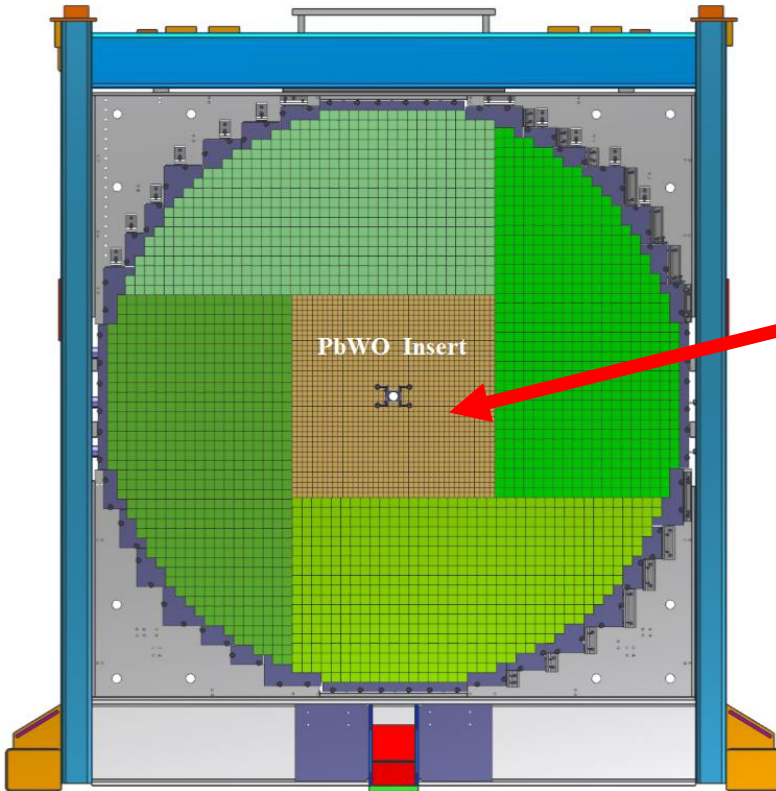


- Upgrade the inner part of the lead glass Forward Calorimeter with the  $\text{PbWO}_4$  crystals (**FCAL-II**)

- improve reconstruction of photons in forward direction
- improve reconstruction of rare  $\eta \rightarrow \pi^0 \gamma \gamma$  decay modes

# Calorimeter Upgrade

Forward Calorimeter



- Install an array of 40 x 40 PbWO<sub>4</sub> modules in the inner part of the FCAL (replace lead glass modules)

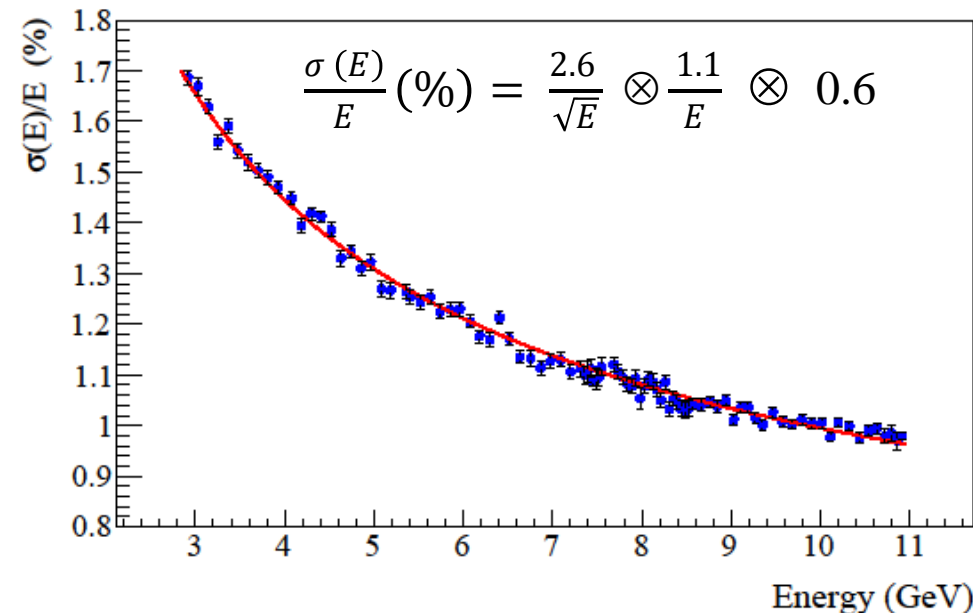
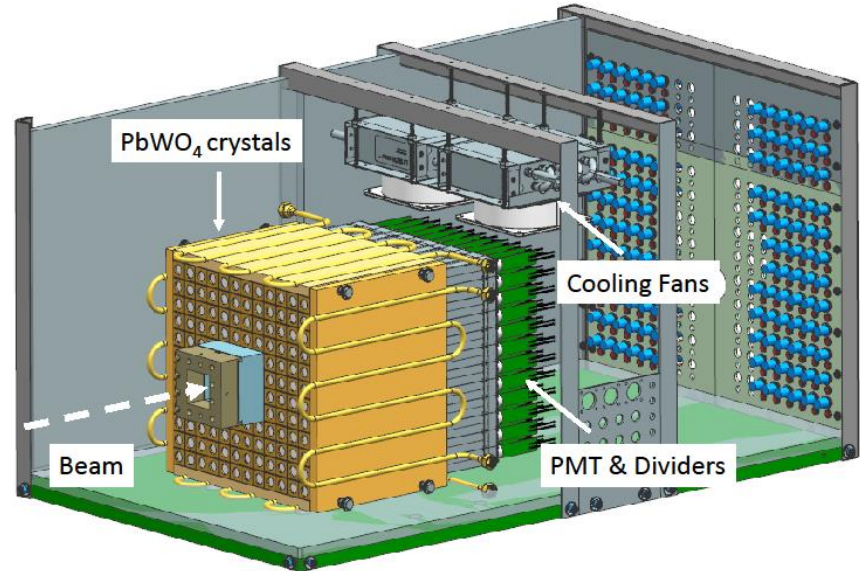
- 2 cm x 2 cm x 20 cm PbWO<sub>4</sub>
- 4 cm x 4 cm x 45 cm lead glass

- A factor of 4 better detector granularity
  - significantly improve shower separation
- Improves the energy and position resolution by about a factor of 2

# Calorimeter Upgrade

- Beam test of calorimeter prototype
  - 12 x 12 modules
  - used as a Compton calorimeter in PrimEx (see A. Smith talk)

Energy resolution



- Fabrication of FCAL2 modules in progress
- Installation in Hall D: 2023

# Summary

- The new JEF experiment in Hall D will extend the physics potential of the GlueX detector. The JEF physics program spans from the study of rare decays of  $\eta$  mesons to the dark matter searches in the sub-GeV mass region.
- The experiment requires upgrade of the lead glass GlueX forward calorimeter with high-granularity, high-resolution  $\text{PbWO}_4$  crystals
- The new calorimeter will be installed in Hall D in 2023

*GlueX acknowledges the support of several funding agencies and computing facilities: [gluex.org/thanks](http://gluex.org/thanks)*

# **Backup Slides**

# Search for B boson

- Dark leptophobic B-boson

$$L = \frac{1}{3} g_B \bar{q} \gamma^\mu q B_\mu + \dots$$

- Arises from a new gauge baryon symmetry  $U(1)_B$

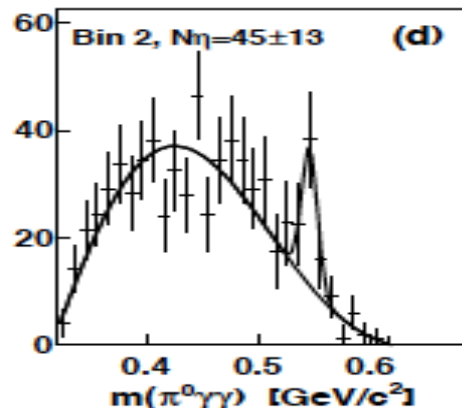
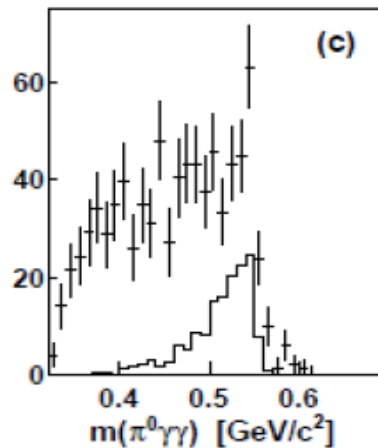
Early studies by Lee and Yang, Phys.Rev.,98 (1955) 1501; Okun, Yad.Fiz., 10 (1969) 358,

- Unified genesis of baryonic and dark matter
- the  $m_B < m_\rho$  region is strongly constrained by long-range forces search exp. ; the  $m_B > 50 GeV$  has been investigated by the collider experiments
- GeV-scale domain is poorly constrained  
discovery opportunity!

# Measurements of $\eta \rightarrow \pi^0 \gamma \gamma$

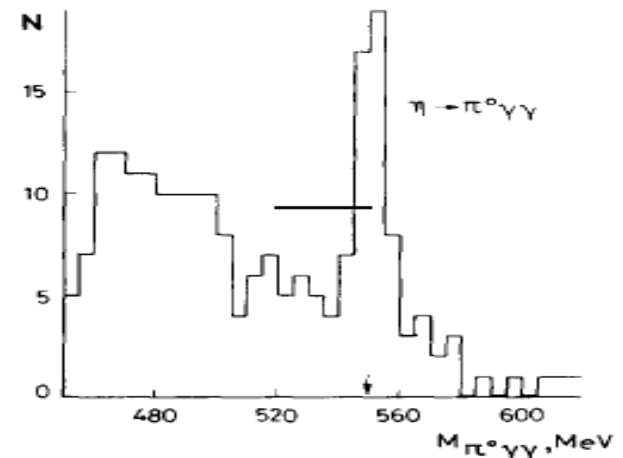
**A2 at MAMI** (Phys.Rev. C90, 025206,2014)

$\gamma p \rightarrow \eta p$  ( $E_\gamma = 1.5$  GeV)



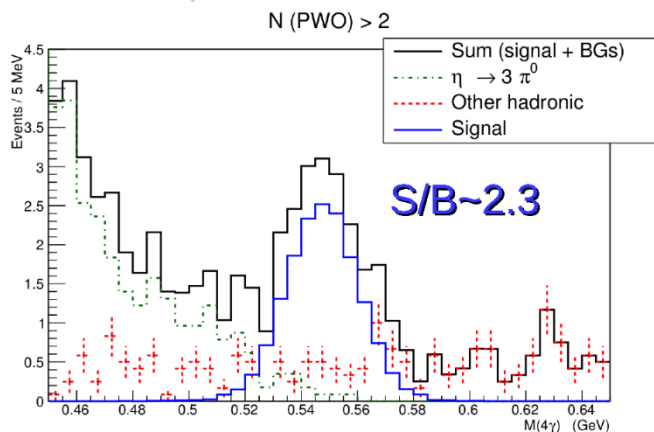
**GAMS** (Z. Phys. C25,225, 1985)

$\pi p \rightarrow \eta p$  ( $E_\pi = 30$  GeV)



**JEF** (proposed)

$\gamma p \rightarrow \eta p$  ( $E_\gamma = 9-11.7$  GeV)



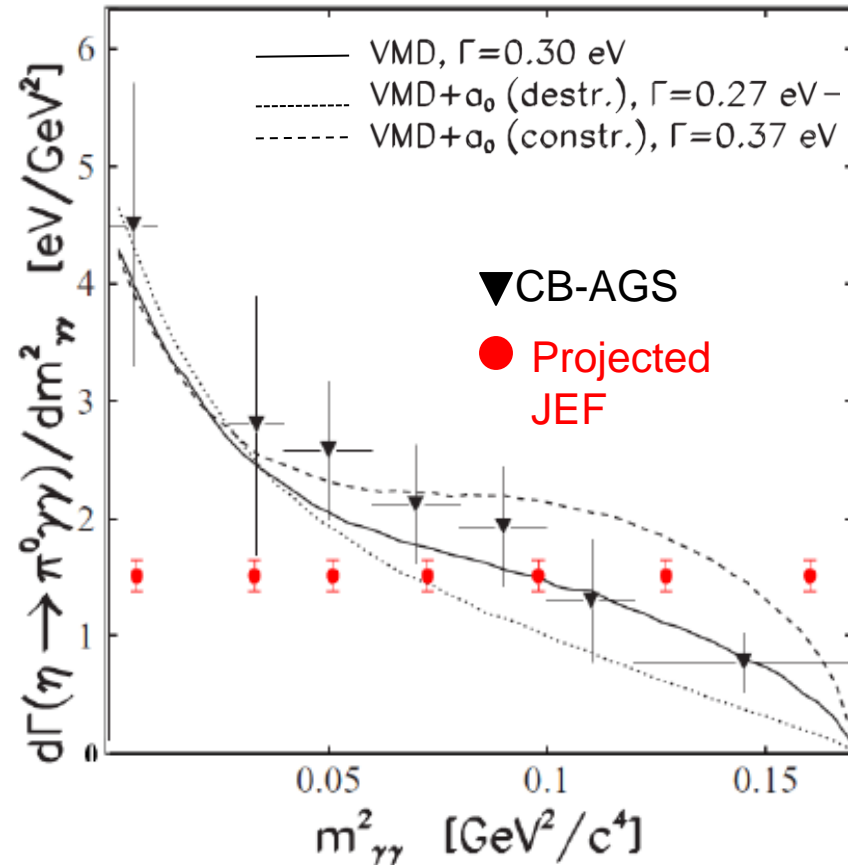
1 day of running

- Smaller background with  $\eta$  energy boost
- Large statistics

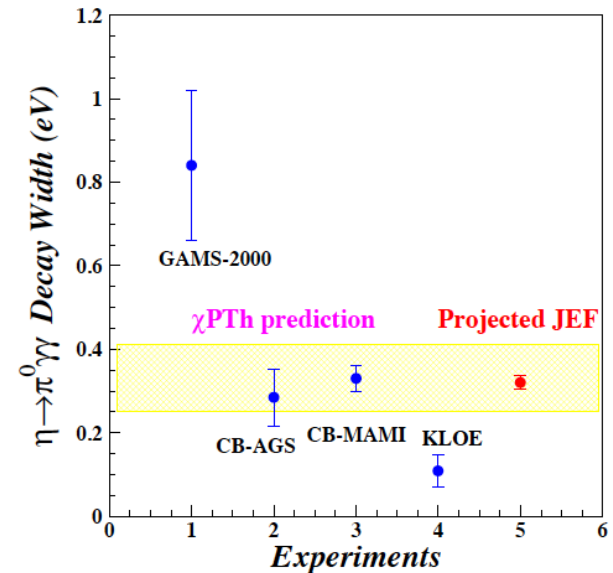
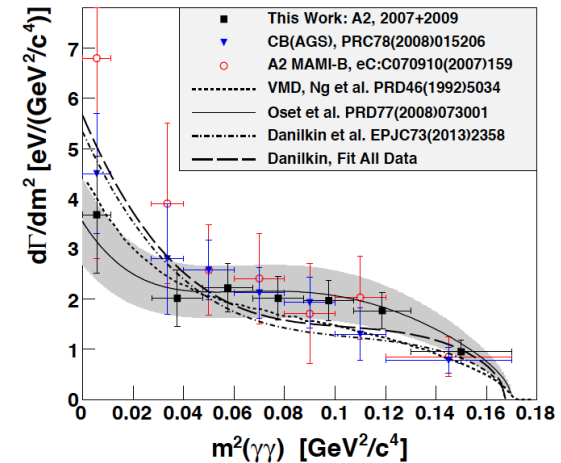
# Projections for $\eta \rightarrow \pi^0 \gamma \gamma$ Decay

Prakhov et al., Phys. Rev. C78, 015206 (2008)

A2 at MAMI arXiv:1405.4904, 2014



Constrain contribution of scalar resonances  
in the calculation of  $O(p^6)$  low-energy constants





# C Invariance

- Maximally violated in the weak force and is well tested
- SM prediction:  
 $\text{BR}(\eta \rightarrow 3\gamma) < 10^{-19}$  via P-violating weak interaction.
- Study constraints on CVPC from EDM
  - no constraints in the presence of a conspiracy or new symmetry; **only the direct searches are unambiguous**



## C Violating $\eta$ neutral decays

Final State	Branching Ratio (upper limit)	Gammas in Final State
$3\gamma$	$< 1.6 \cdot 10^{-5}$	3
$\pi^0\gamma$	$< 9 \cdot 10^{-5}$	
$2\pi^0\gamma$	$< 5 \cdot 10^{-4}$	5
$3\gamma\pi^0$	Nothing published	
$3\pi^0\gamma$	$< 6 \cdot 10^{-5}$	7
$3\gamma 2\pi^0$	Nothing published	

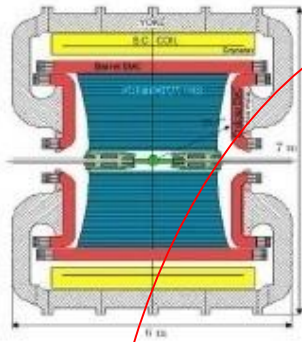
M. Ramsey-Musolf, phys. Rev., D63 (2001);

[talk at the AFCL workshop](#),  
 studies are in progress

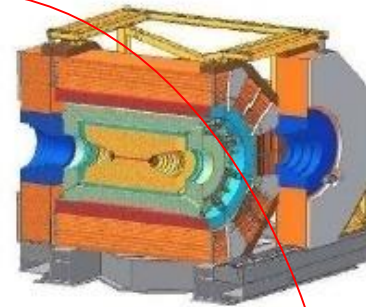
# World competition in $\eta$ decays

$e^+e^-$   
Collider

KLOE-2 at DAΦNE



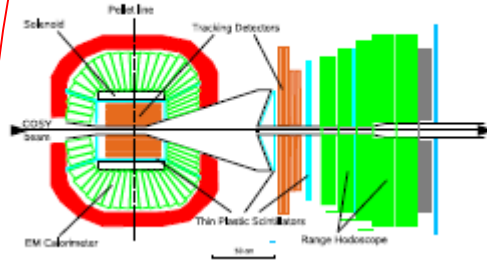
BESIII at BEPCII



Low energy  
 $\eta$ -facilities

Fixed-target

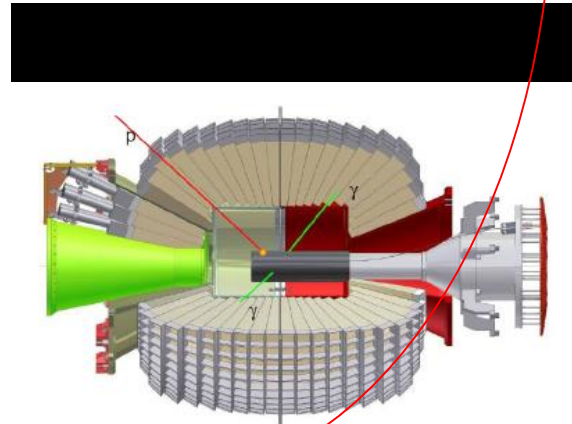
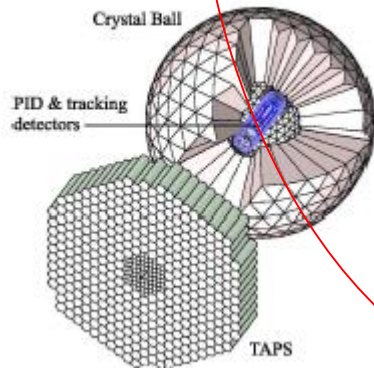
WASA at COSY



hadroproduction

High energy  $\eta$ -  
facility

Crystall Ball at MAMI



photoproduction

