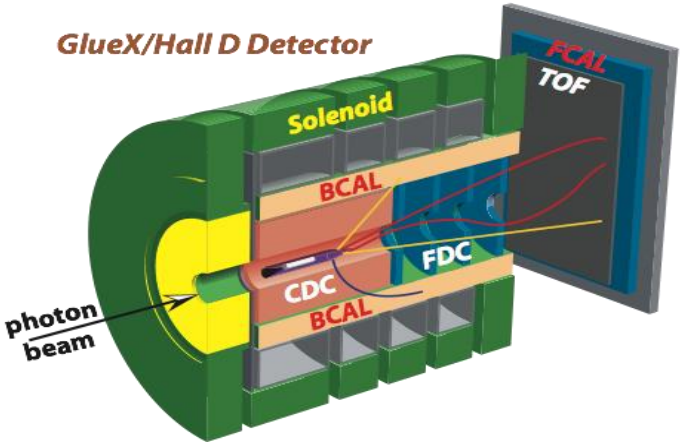


Jefferson Lab

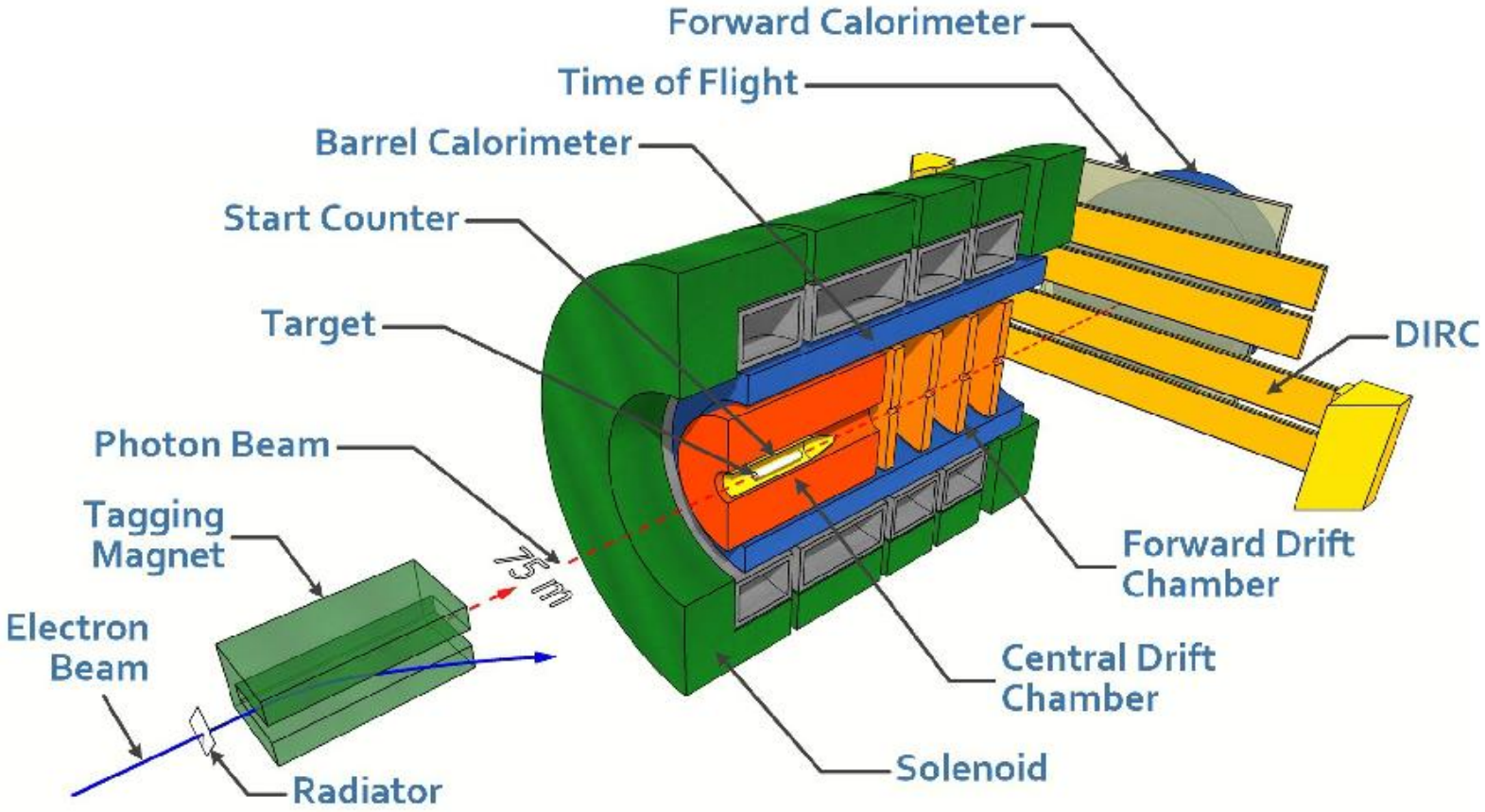
JLAB η Factory Experiment in Hall D

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 η 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

Mode	Branching Ratio	Physics Highlight	Photons
priority:			
$\pi^0 2\gamma$			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
3γ	$< 1.6 \times 10^{-5}$	CV, CPV	3
ancillary:			
4γ	$< 2.8 \times 10^{-4}$	$< 10^{-11}$ [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:			
2γ	$(39.3 \pm 0.2)\%$	anomaly, η-η' mixing PR12-10-011	2

Upgrade the Forward Calorimeter

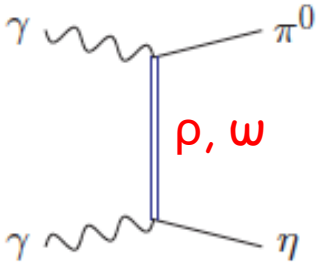
Main physics topics:

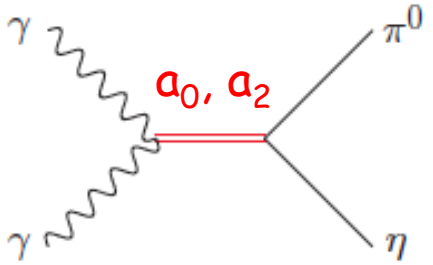
1. Test of low-energy QCD
2. Search for dark matter
3. Directly constrain CVPC new physics
4. Constrain the light quark mass ratio

Impact of $\eta \to \pi^0\gamma\gamma$ measurements on Chiral Perturbation Theory

- Unique probe for the high order ChPT: L. Ametller, et.al, Phys. Lett., B276, 185 (1992)
  - contribution from two $O(p^6)$ counter-terms in the chiral Lagrangian
- 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

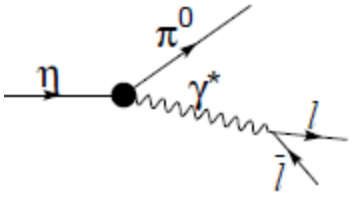
Higher order LEC's are dominated by resonances
Gasser, Leutwyler 84; Ecler, Gasser, Pich, de Rafael 1989; Donoghue, Ramirez, Valencia 1989



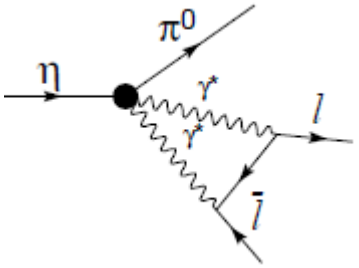


- A cross-check of LEC's with different processes

C and CP violating



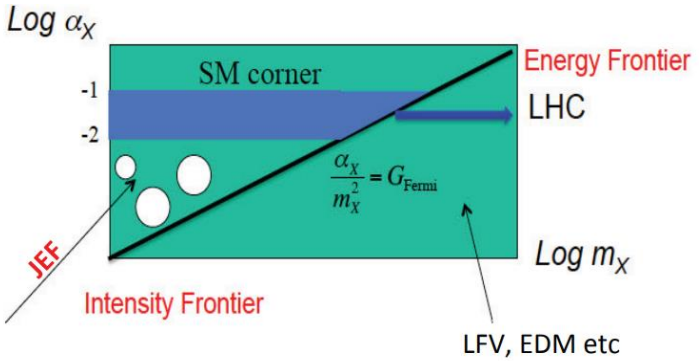
C and CP conserving background



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

Dark Matter Search in η Decays

Search for dark matter in sub-GeV range:



Vector

leptophobic vector boson B:

$\eta, \eta' \to \gamma B$ $\quad B \to \pi^0 \gamma$ $\quad (0.14 < m_B < 0.62$ GeV)

$B \to \pi^+ \pi^- \pi^0$ $\quad (0.62 < m_B < 1.0$ GeV)

dark photon:

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

Scalar

$\eta, \eta' \to \pi^0 S$ $\quad S \to \pi^0 \gamma \gamma, \quad \pi^0 e^+ e^-$ $\quad (m_S < 2 m_\pi)$

$S \to 3\pi$ $\quad (m_S > 2 m_\pi)$

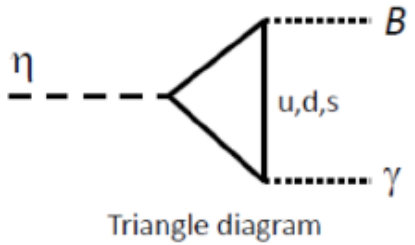
Light pseudoscalar (axion-like particle)

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

Search for B-boson in η decay

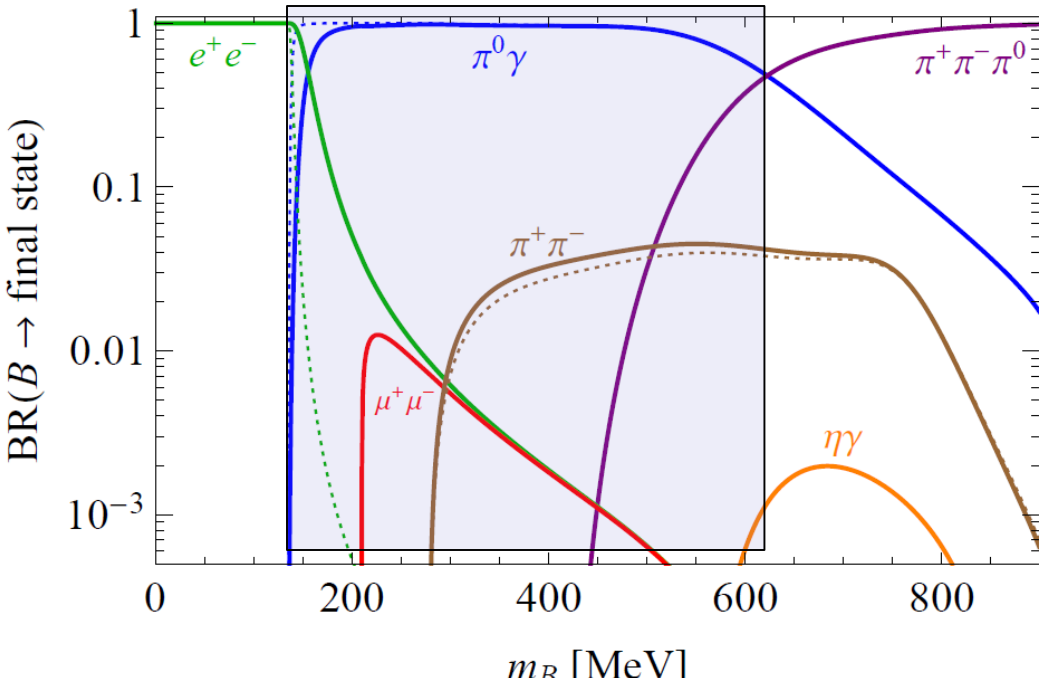
B production: A.E. Nelson, N. Tetradis, Phys. Lett., B221, 80 (1989)

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



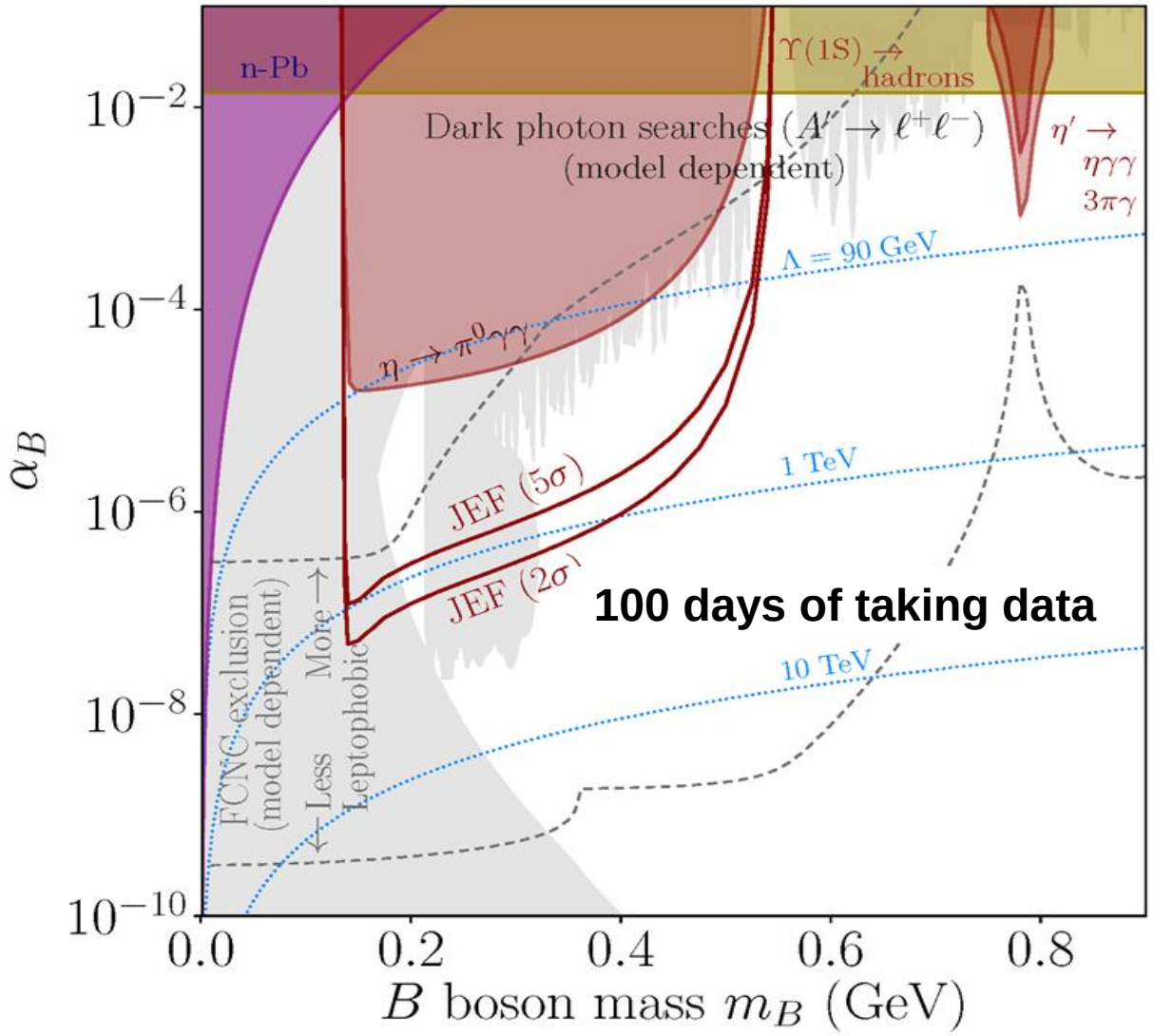
Triangle diagram

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



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

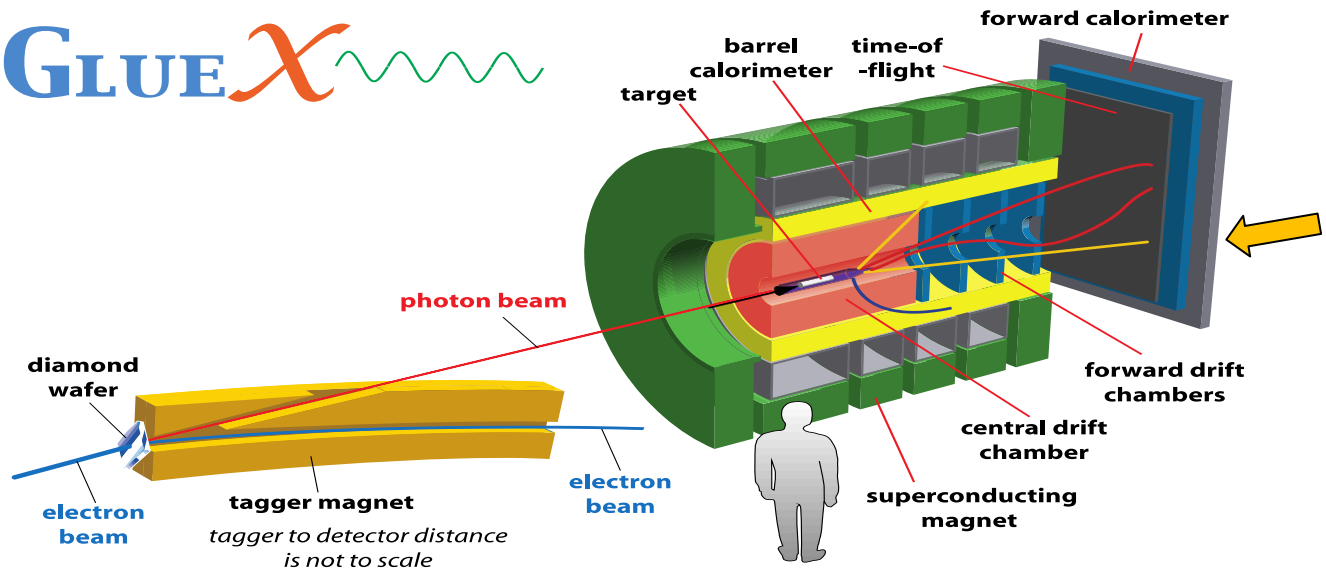
JEF Experimental Reach ($\eta \rightarrow B\gamma \rightarrow \pi^0\gamma\gamma$)

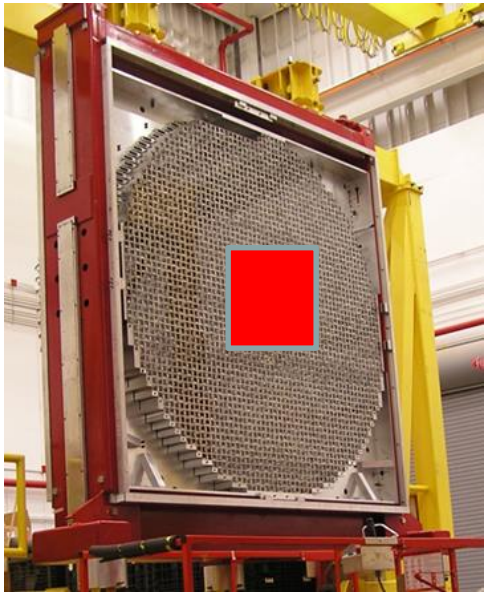


A stringent constraint on the leptophobic B-boson in 140 - 550 MeV range

GlueX Calorimeter Upgrade

FCAL



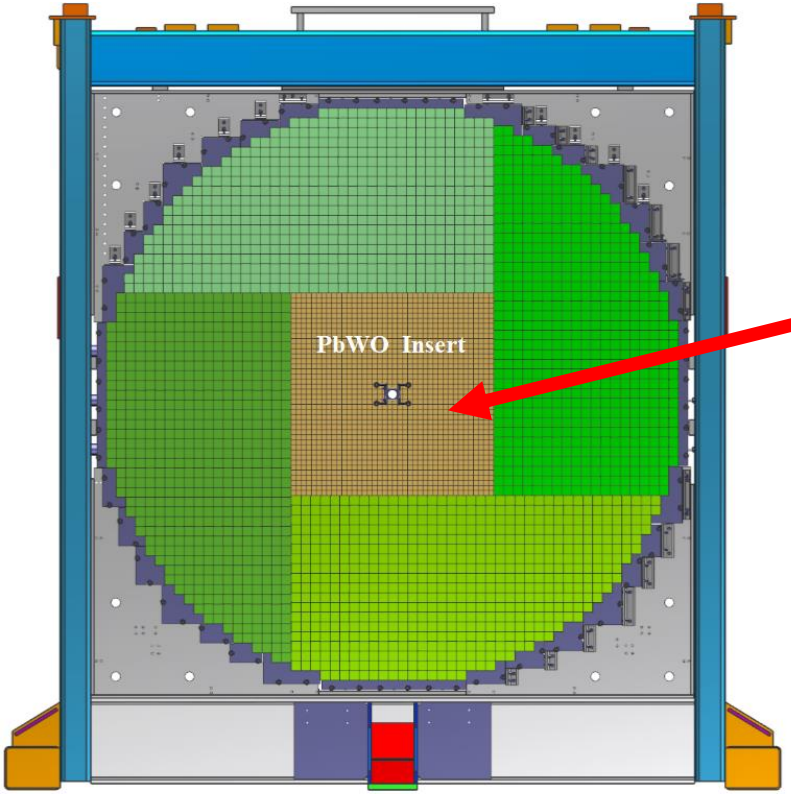


- Upgrade the inner part of the lead glass Forward Calorimeter with the $PbWO_4$ crystals (**FCAL-II**)

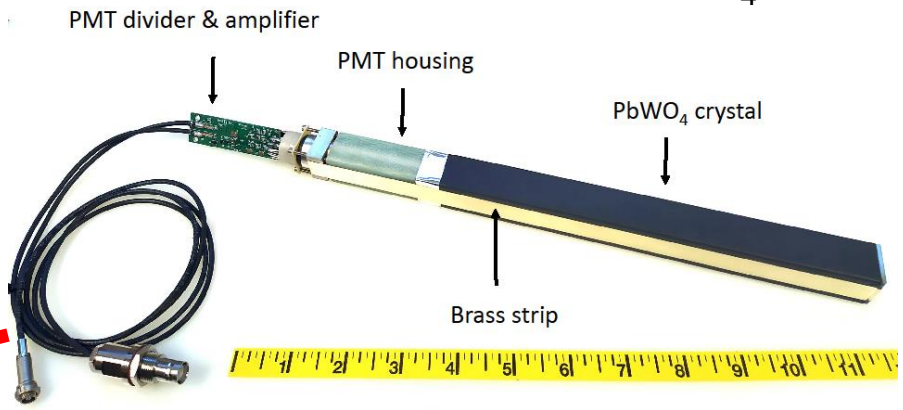
  - improve reconstruction of photons in forward direction
  - improve reconstruction of rare η decay modes such as $\eta \rightarrow \pi^0 \gamma \gamma$

Calorimeter Upgrade

Forward Calorimeter



$PbWO_4$ module



- Install an array of 40 x 40 $PbWO_4$ modules in the inner part of the FCAL
  (replace lead glass modules)

  - 2 cm x 2 cm x 20 cm $PbWO_4$
  - 4 cm x 4 cm x 45 cm lead glass

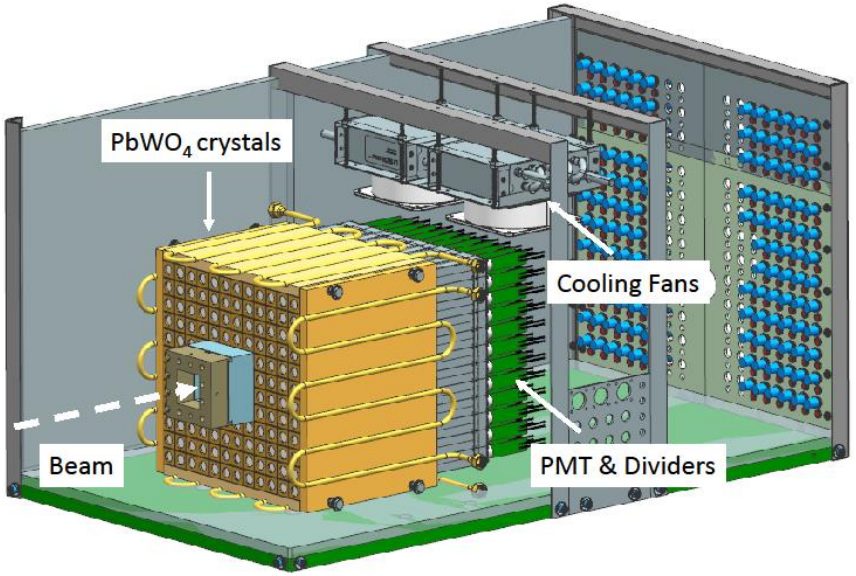
- A factor of 4 better detector granularity
  - significantly improve shower separation

- Improves the energy and position resolution by about a factor of 2

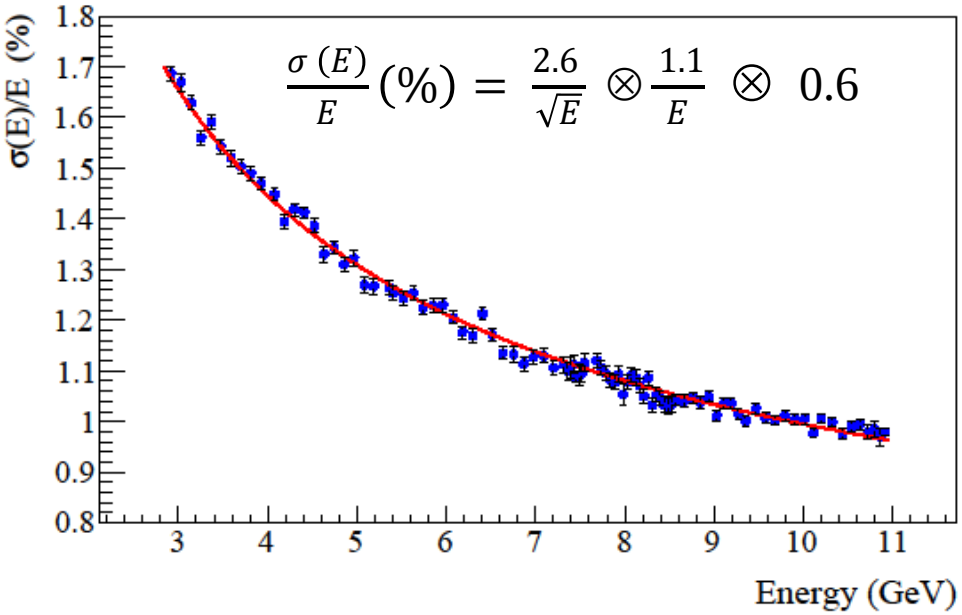
Calorimeter Upgrade

- 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 η 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 $PbWO_4$ 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

Backup Slides

Search for B boson

- Dark leptophobic B-boson

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

- 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 $m_B < m_p$ region is strongly constrained by long-range forces search exp. ; the $m_B > 50 GeV$ has been investigated by the collider experiments

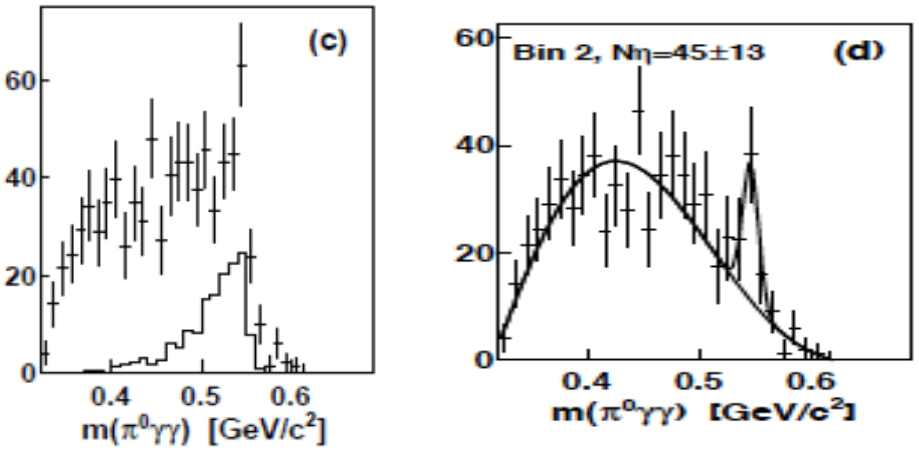
- GeV-scale domain is poorly constrained

discovery opportunity!

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

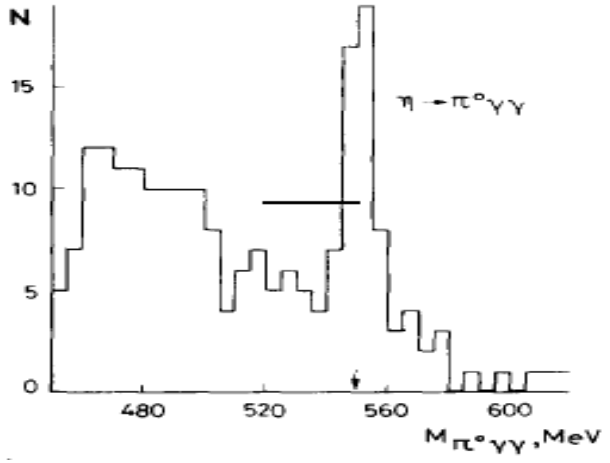
A2 at MAMI (Phys.Rev. C90, 025206,2014)

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



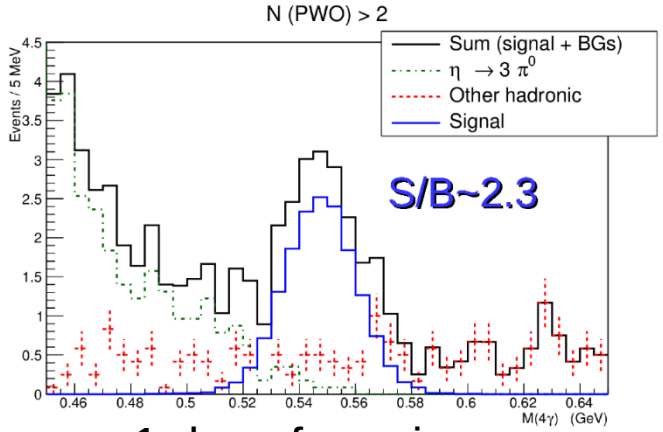
GAMS (Z. Phys. C25,225, 1985)

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



JEF (proposed)

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

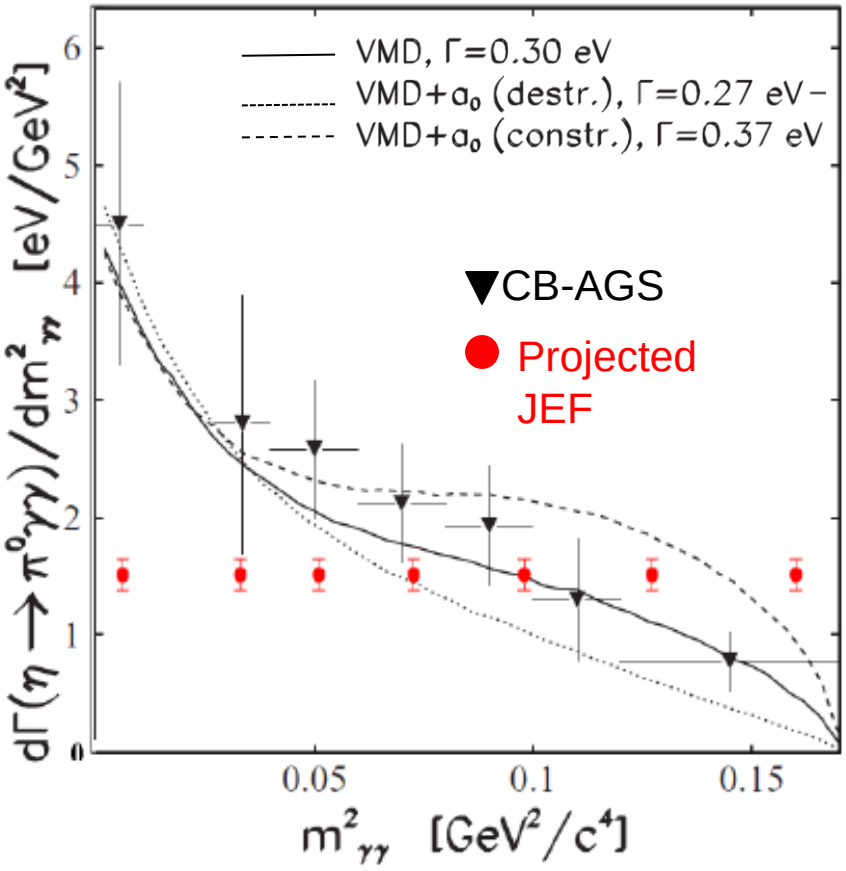


1 day of running

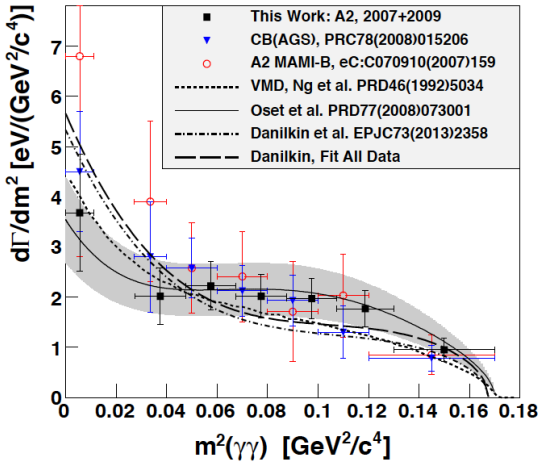
- Smaller background with η energy boost
- Large statistics

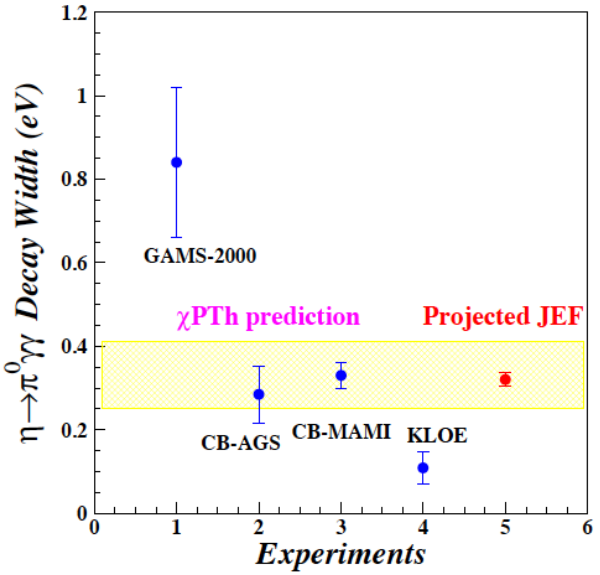
Projections for $\eta \to \pi^0\gamma\gamma$ Decay

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:
  BR(η→3γ) <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

M. Ramsey-Musolf, phys. Rev., D63 (2001);
talk at the AFCI workshop,
studies are in progress

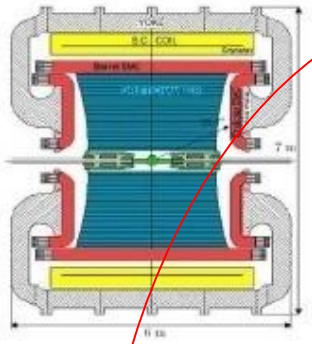
C Violating η neutral decays

Final State	Branching Ratio (upper limit)	Gammas in Final State
3γ	$< 1.6 \cdot 10^{-5}$	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	

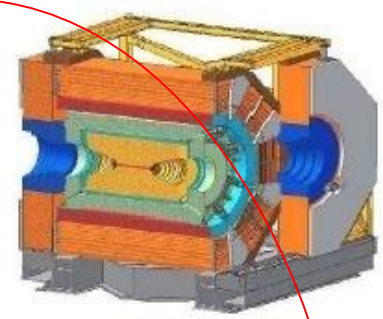
World competition in η decays

e^+e^- Collider

KLOE-2 at DAϕNE



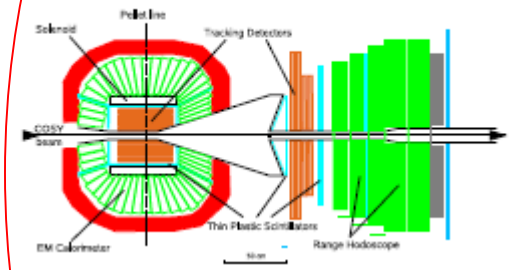
BESIII at BEPCII



Low energy η-facilities

Fixed-target

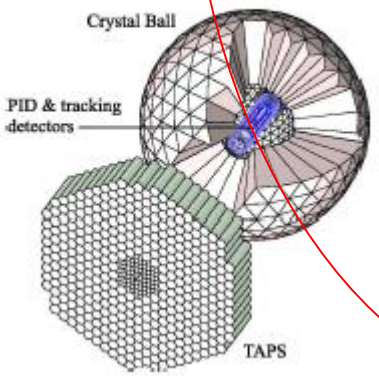
WASA at COSY



hadroproduction

High energy η-facility

Crystall Ball at MAMI



photoproduction