Measurement of the π^0 Lifetime: QCD Axial Anomaly and Chiral Corrections

Chiral Dynamics 2009
July, 2009

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PrimEx Collaboration

- spontaneous chiral symmetry breaking $\Rightarrow$ pions
- $\pi^0 \rightarrow \gamma\,\gamma$: axial anomaly, chiral corrections ~m_d-m_u
- previous experiments
- PrimEx experiment at Jefferson Lab
- conclusions

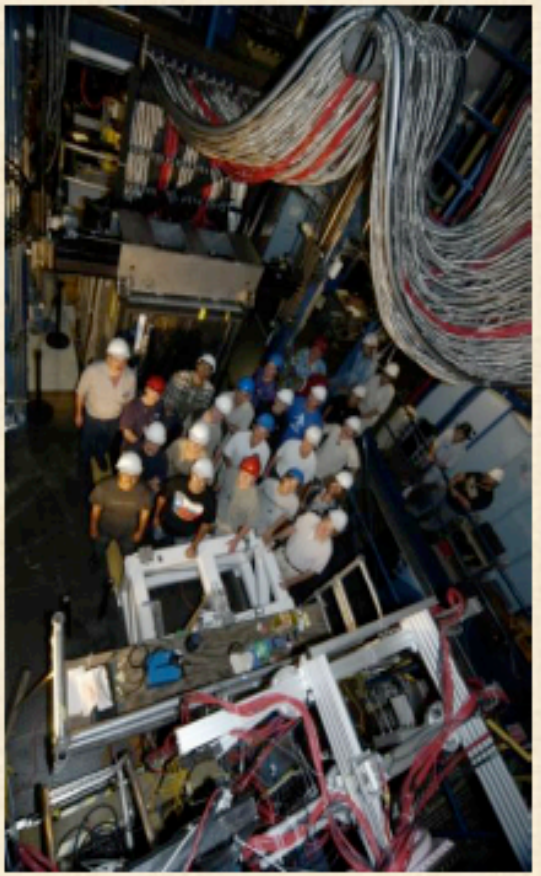
- we present our new results for the $\pi^0 \rightarrow \gamma\gamma$ rate

- this represents an effort of over 10 years

- we undertook this difficult experiment because the process and the rate predictions are closely connected to the symmetry structure of QCD

PrimEx Collaboration

Arizona State University, Tempe, AZ, Catholic University of America, Washington, DC, Chinese Institute of Atomic Energy, Beijing, China, Eastern Kentucky University, Richmond, KY, George Washington University, Washington, DC, Hampton University, Hampton, VA, Institute for High Energy Physics, Chinese Academy of Sciences, Beijing, China, Institute for High Energy Physics, Protvino, Moscow region, Russia, Institute for Theoretical and Experimental Physics, Moscow, Russia, Kharkov Institute of Physics and Technology, Kharkov, Ukraine, Massachusetts Institute of Technology, Cambridge, MA, Moscow Engineering Physics Institute, Moscow, Russia, Norfolk State University, Norfolk, VA, North Carolina A&T State University, Greensboro, NC, North Carolina Central University, Durham, NC, Thomas Jefferson National Accelerator Facility, Newport News, VA, Tomsk Polytechnic University, Tomsk, Russia, Idaho State University, Pocatello, ID, University of Illinois, Urbana, IL, University of Kentucky, Lexington, KY, University of Massachusetts, Amherst, MA, University of North Carolina at Wilmington, Wilmington, NC, University of Virginia, Charlottesville, VA, Yerevan Physics Institute, Yerevan, Armenia



Ph.D. students, postdocs

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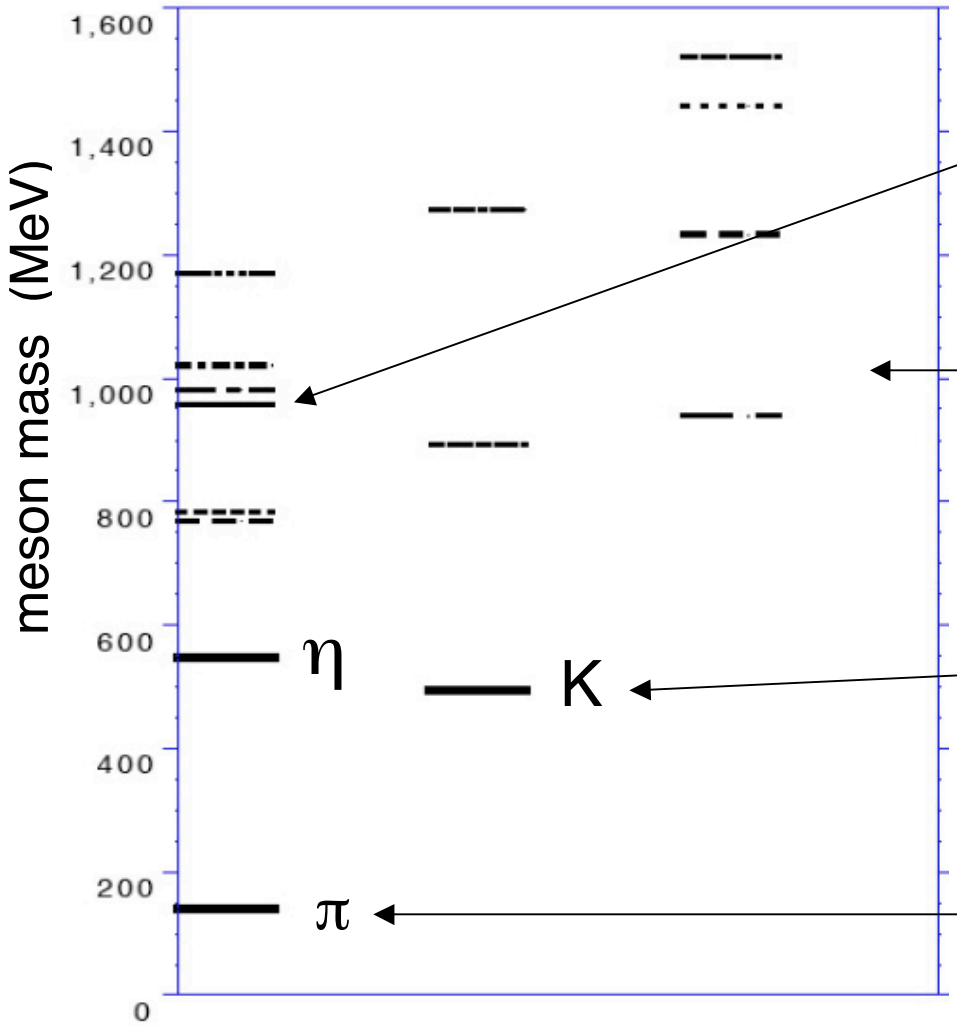
QCD mass gap:chiral symmetry breaking



large η' mass due to gluon axial anomaly

$\Lambda_\chi \approx 1$ GeV

$m_s \approx 140$ MeV

$m_\pi^2 = B(m_u + m_d) \to 0$

$m_u \approx 5$ MeV, $m_d \approx 9$ MeV

Opportunity to perform a precision π^0 lifetime measurement

- π^0 is the lightest hadron

  spontaneous chiral symmetry hiding:
  $m(\pi) \approx 140$ MeV

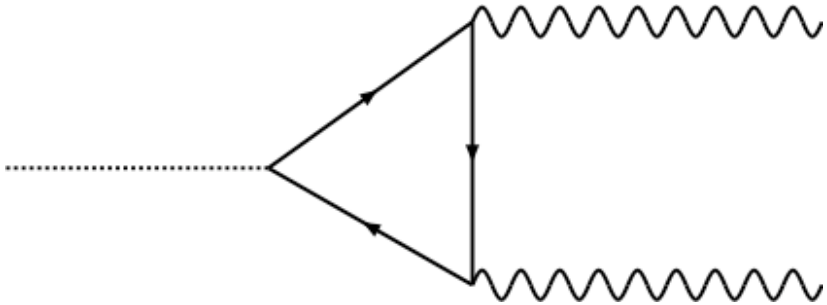
- EM: $m(\pi^{\pm}) - m(\pi^0) = 4.6$ MeV

- EM decay $\pi^0 \rightarrow \gamma\ \gamma$ (BR $= 98.8 \pm 0.032\%$)

  axial anomaly dominant

History: π^0 Lifetime Theory

- PCAC predicts $A_{\pi\gamma\gamma} = 0$ in the chiral limit
- 1968 Adler, Bell, Jackiw discover the axial anomaly

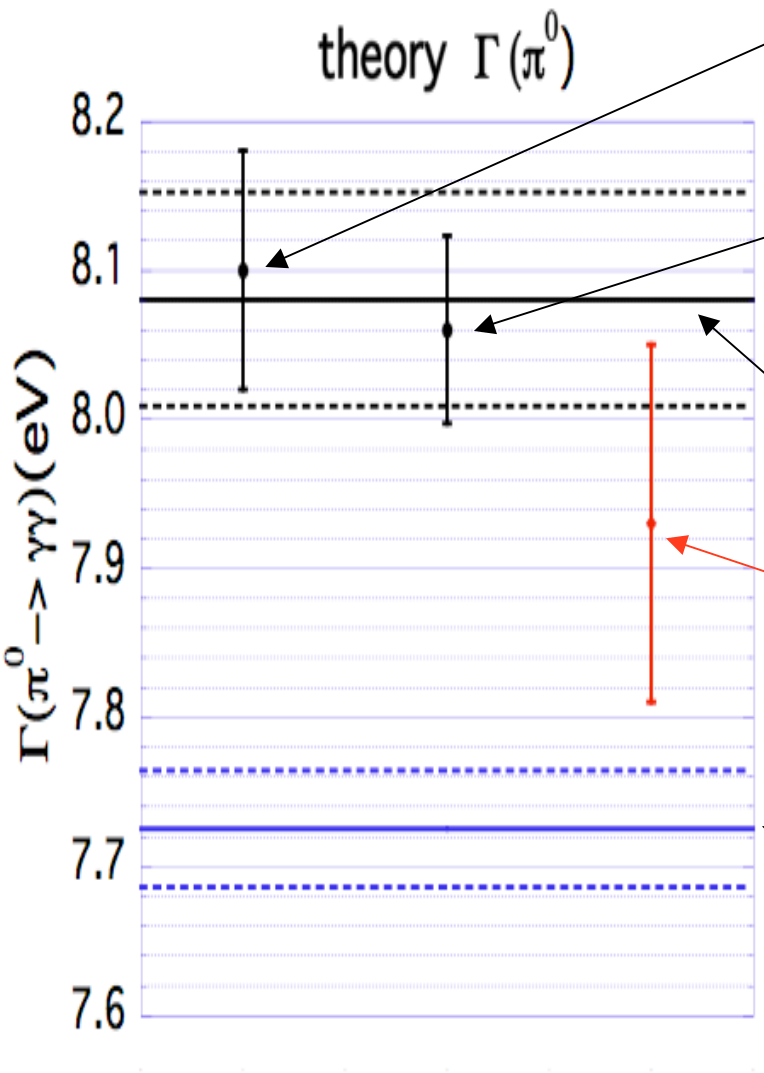


- $A_{\pi\gamma\gamma} = \alpha / \pi F_\pi$

$\Gamma(\pi^0 \rightarrow \gamma\,\gamma) = (m_\pi^3/64\pi)A_{\pi\gamma\gamma}^2 = 7.725$ eV ± 0.5%

$\tau(\pi^0) = 0.807 \cdot 10^{-16}$ sec

$c\,\tau(\pi^0) = 0.0253\ \mu$



ChPT: Goity, AB, Holstein:
$O(p^6)$, $O(p^4 \bullet 1/Nc)$: π,η,η'

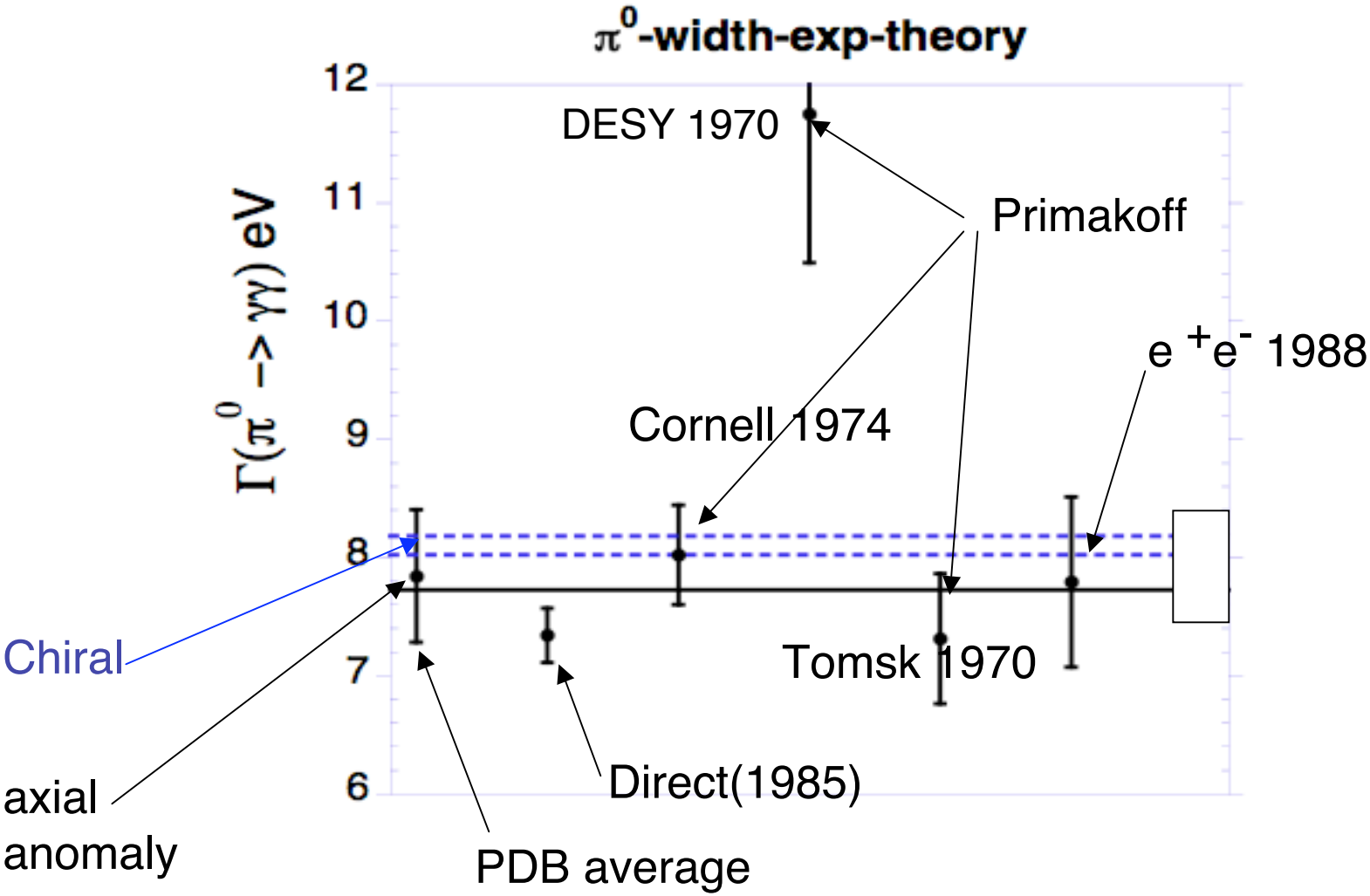
ChPT: Ananathanarayan, Moussallam, $O(p^4\, e^2)$: π,η,η'

ChPT average(LEC errors)

Sum rules: Ioffe, Oganiesian: π,η

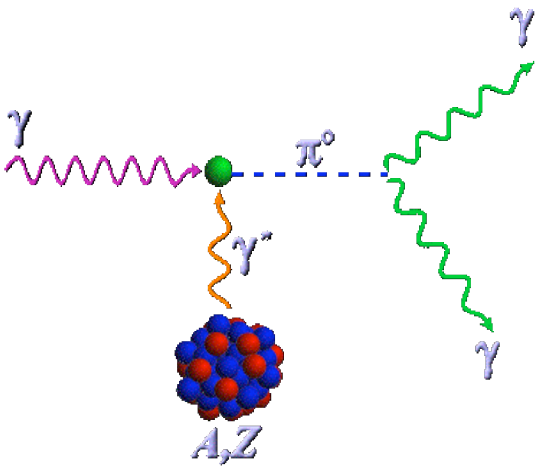
Anomaly, $O(p^4)$
0.3% exp. error in F_π

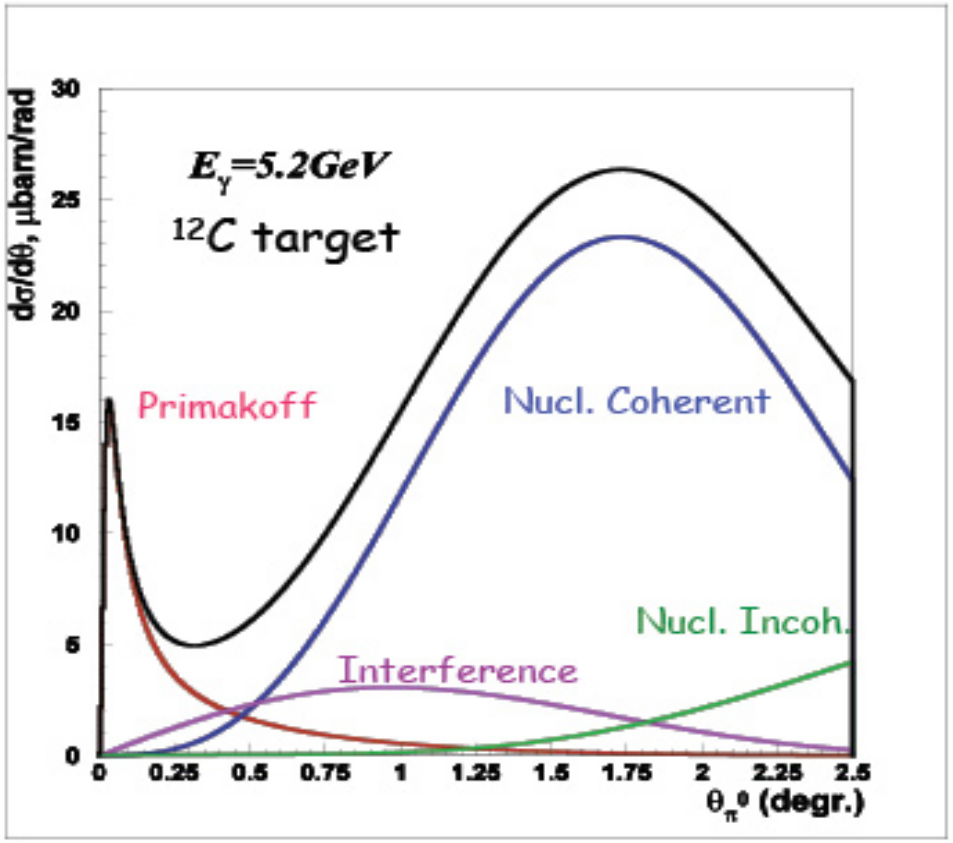
Previous exp. results



$\sigma(\gamma A \rightarrow \pi^0 X)$

Primakoff + nuclear





$\sigma_{prim}(\theta_\pi) \propto \Gamma_{\gamma\gamma} Z^2 \; E_\gamma^4 \sin^2(\theta_\pi)/Q^4$ Q= mom.trans.

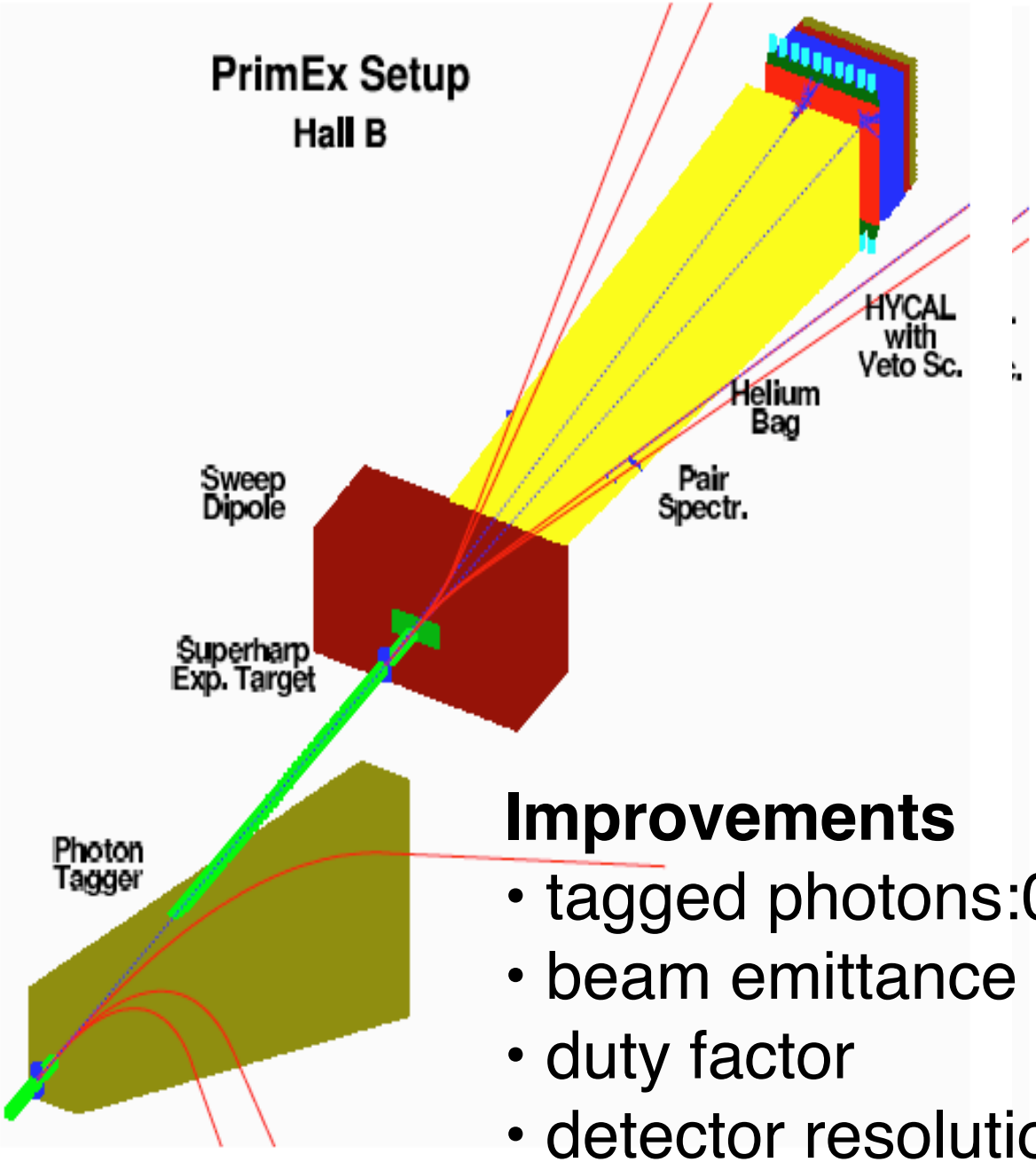
$\sigma(\theta_\pi) = | A_{prim} + e^{i\phi} A_{nc}|^2 + \sigma_{incoherent}$

fit data with 4 parameters; $\Gamma_{\gamma\gamma}$, ϕ,

scale factors for nuclear coherent and incoherent

EXPERIMENTAL SETUP

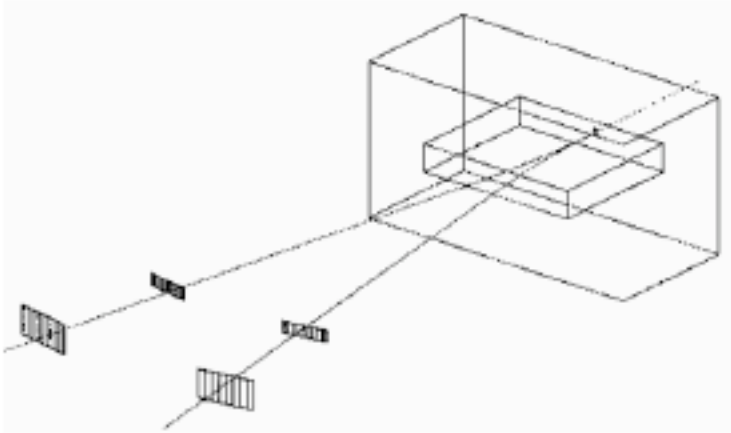
- DATA TAKING FALL 2004
- C, Pb TARGETS
- JLAB HALL B PHOTON TAGGING FACILITY - HIGH INTENSITY, HIGH RESOLUTION DEVICE
- STATE-OF-THE-ART CALORIMETRY - HyCal
- PAIR SPECTROMETER



Improvements

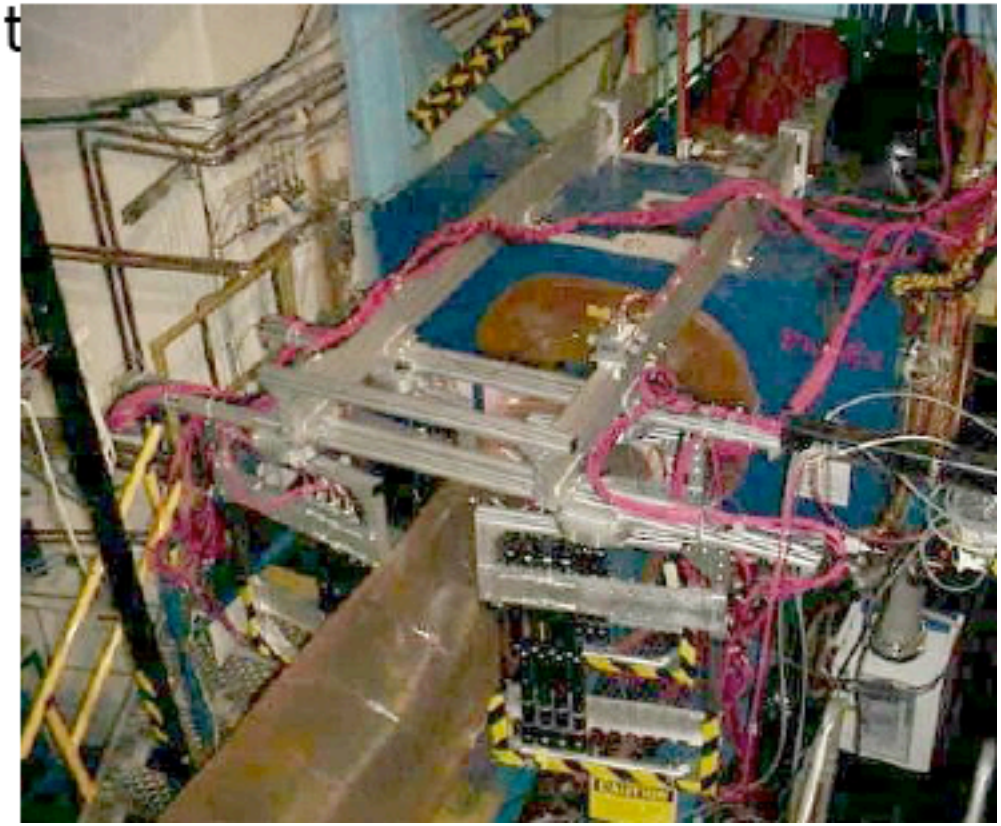
- tagged photons:0.1%
- beam emittance
- duty factor
- detector resolution

Pair Spectrometer

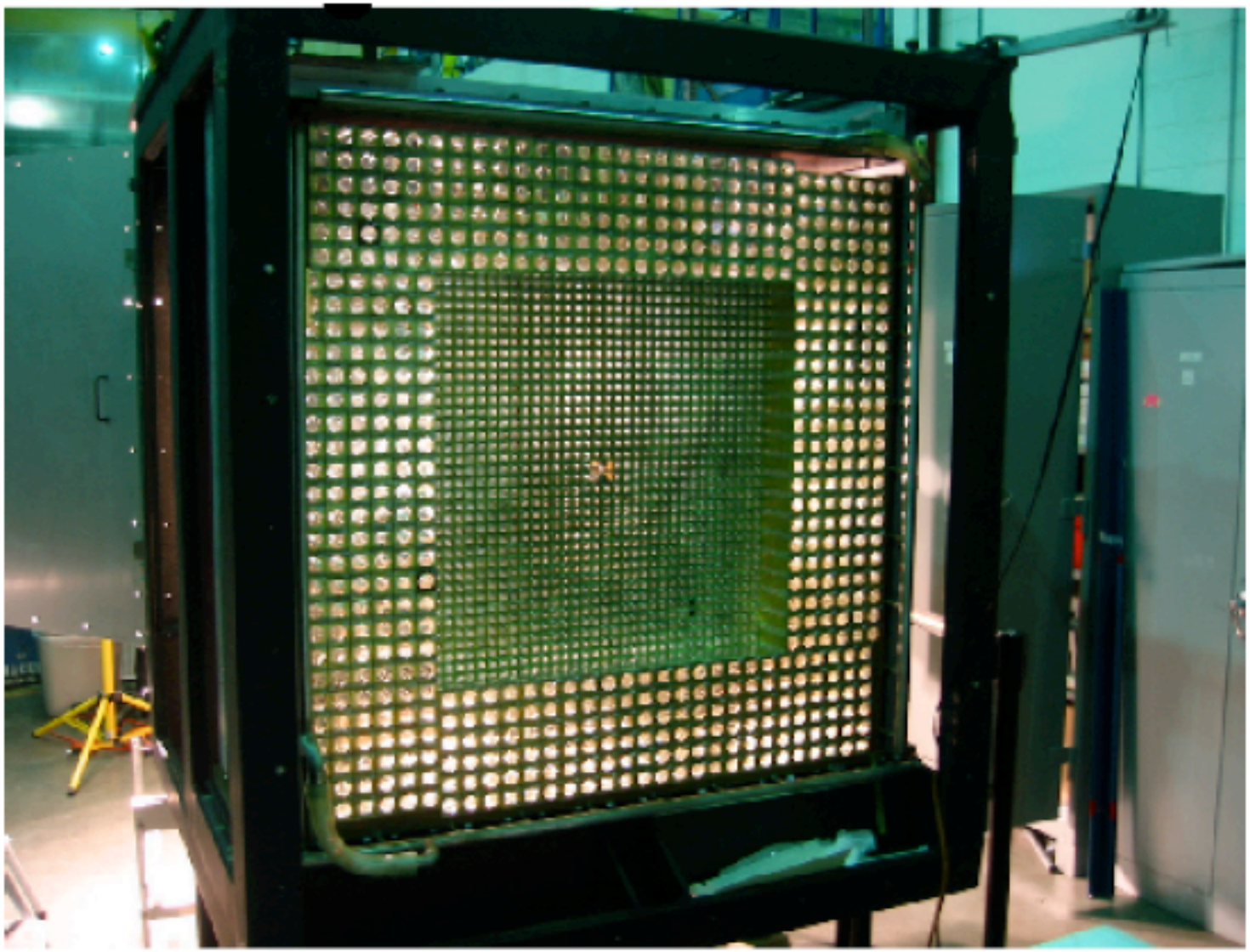


- relative photon flux monitor:

  by detecting e^+e^- pairs from beam during the experiment



- Combination of:
  - 16 KGxM dipole magnet
  - 2 telescopes of 2x8 scintillating detectors



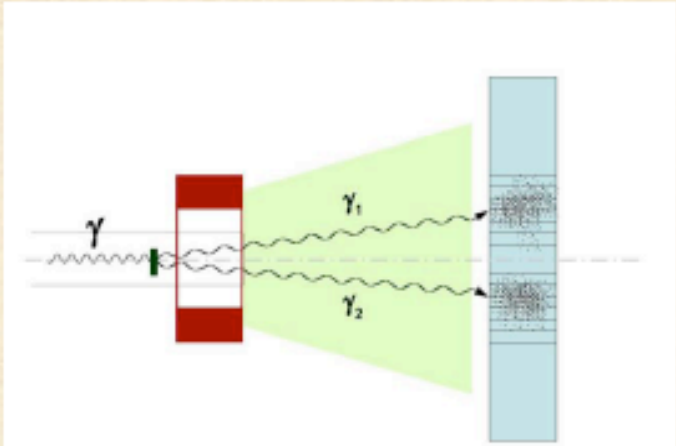
π^0 analysis

We measure:

incident photon: energy and time

π^0 decay photons:

energies, coordinates and time



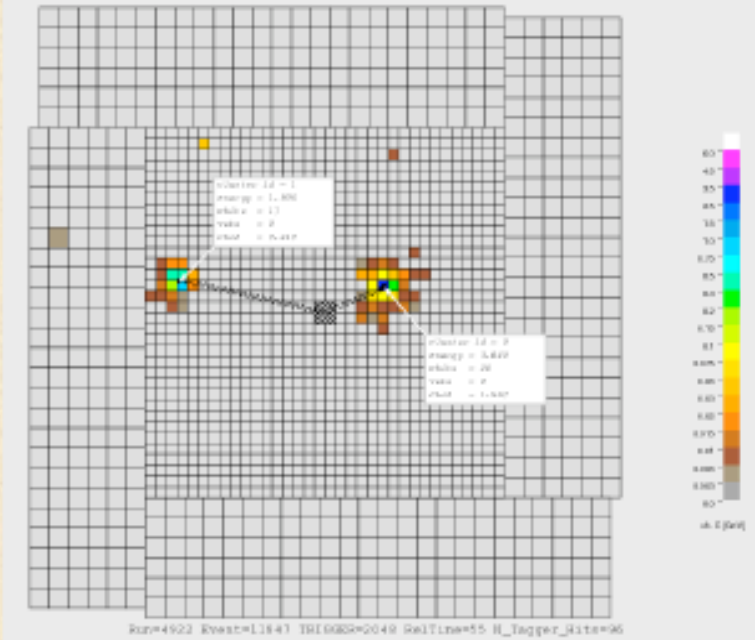
Schematic view of π^0 event

Kinematical constraints:

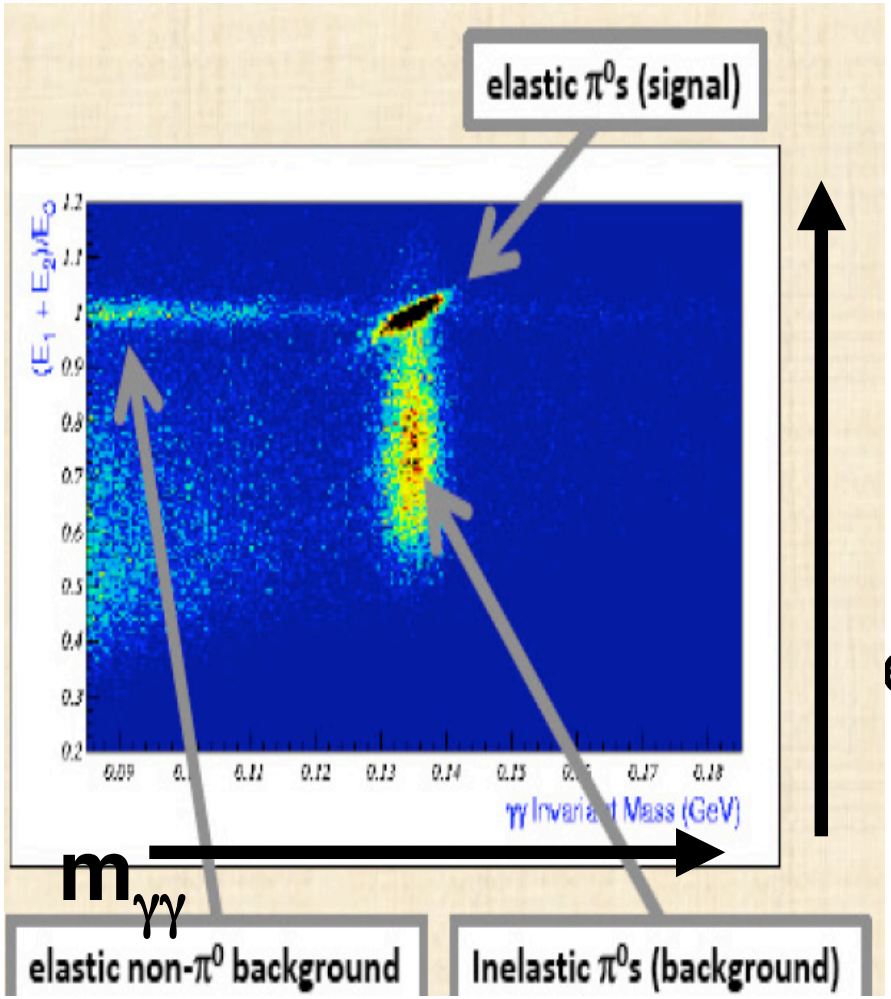
Conservation of energy;

$m_{\gamma\gamma}$ invariant mass

Three groups analyzed the data independently



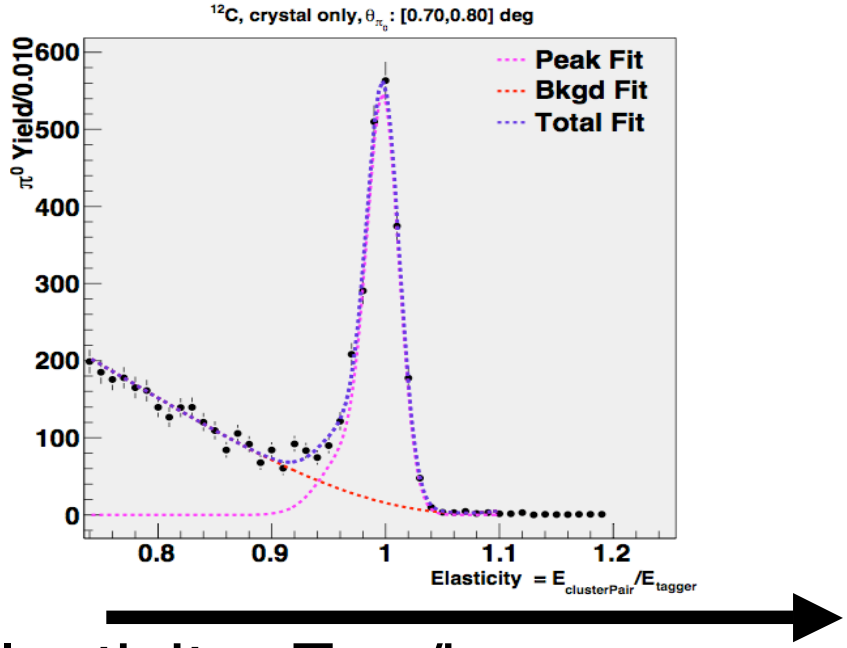
π^0 yield from data



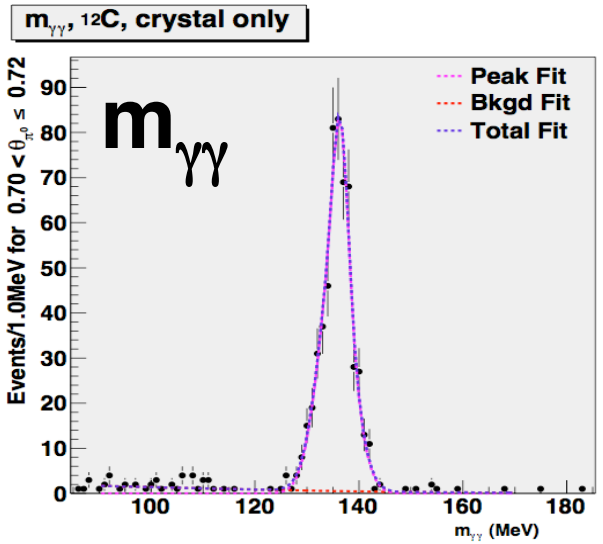
remove inelastic background

find N(π^0) from $m_{\gamma\gamma}$ peak

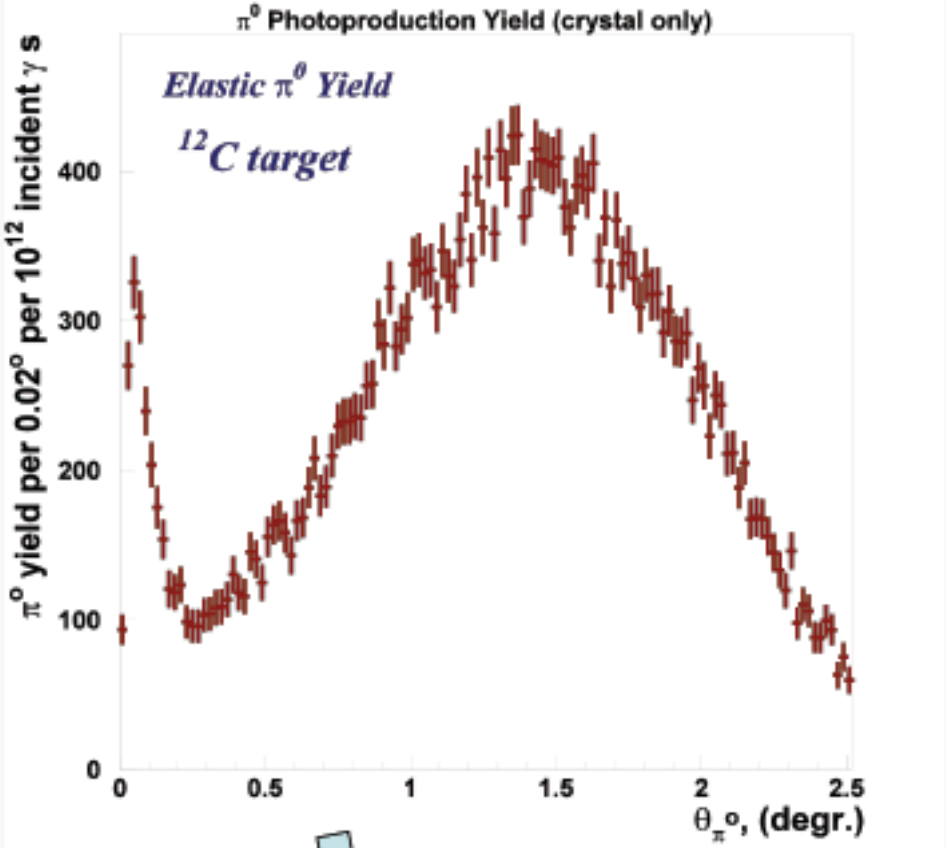
Elasticitv distribution

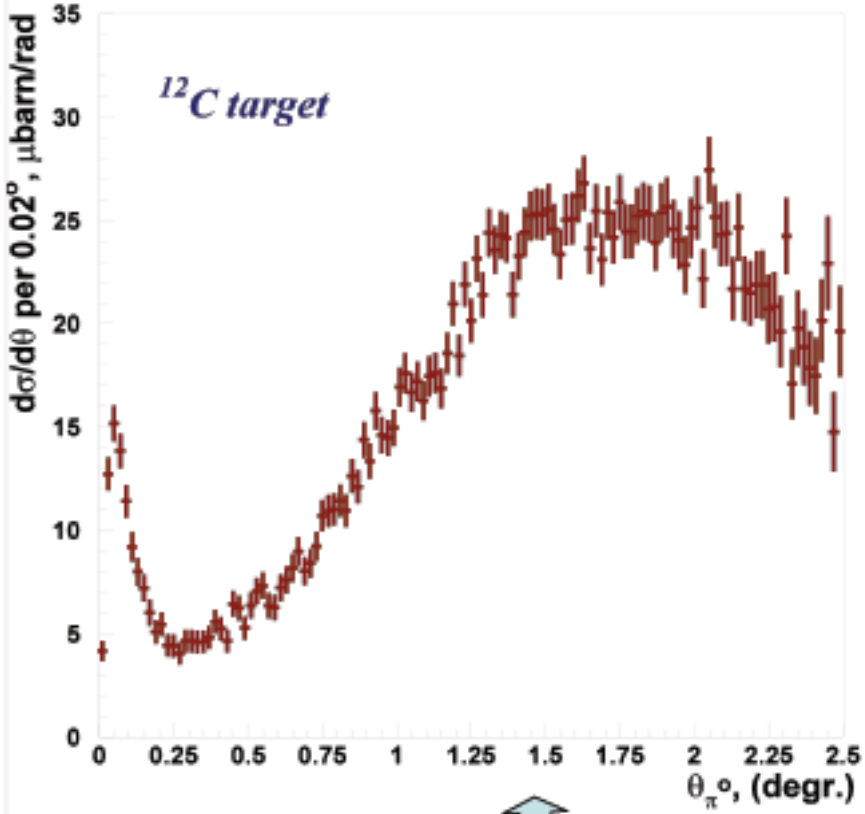


elasticity=E_π/k



Differential Cross section





Experimental Yield per $\Delta\vartheta_\pi$

GEANT:

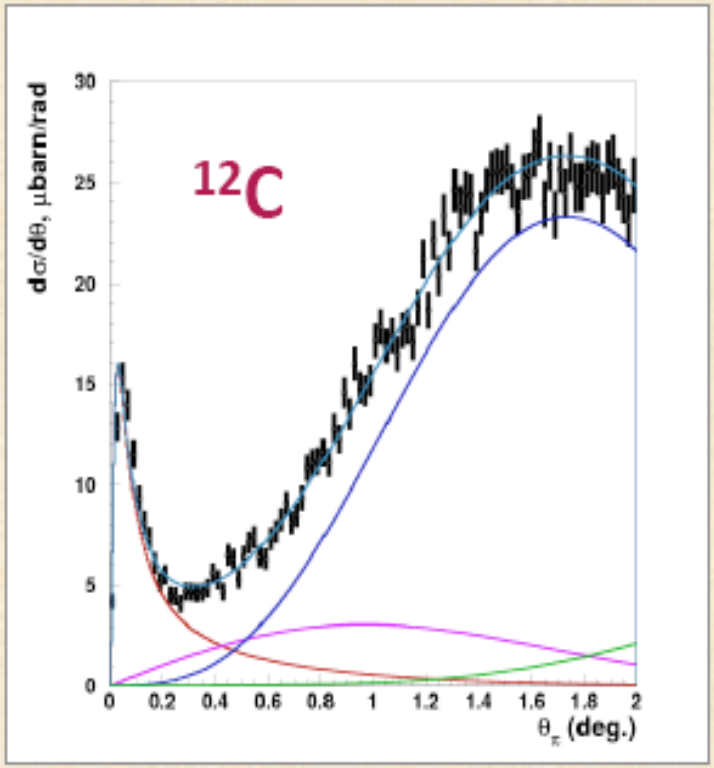
- acceptances;
- efficiencies;
- resolutions;

Diff. cross section

π^0 photoproduction cross section

- π^0 photoproduction cross section has been extracted from elastic π^0 yield using setup acceptance and efficiency

E_γ = 5.2GeV



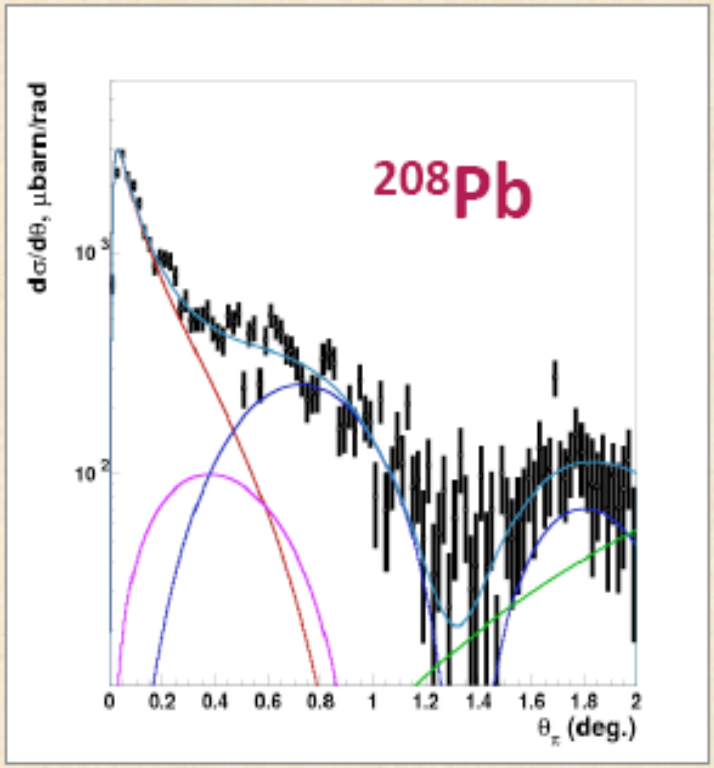
Primakoff

Nuclear coherent

Interference

Incoherent

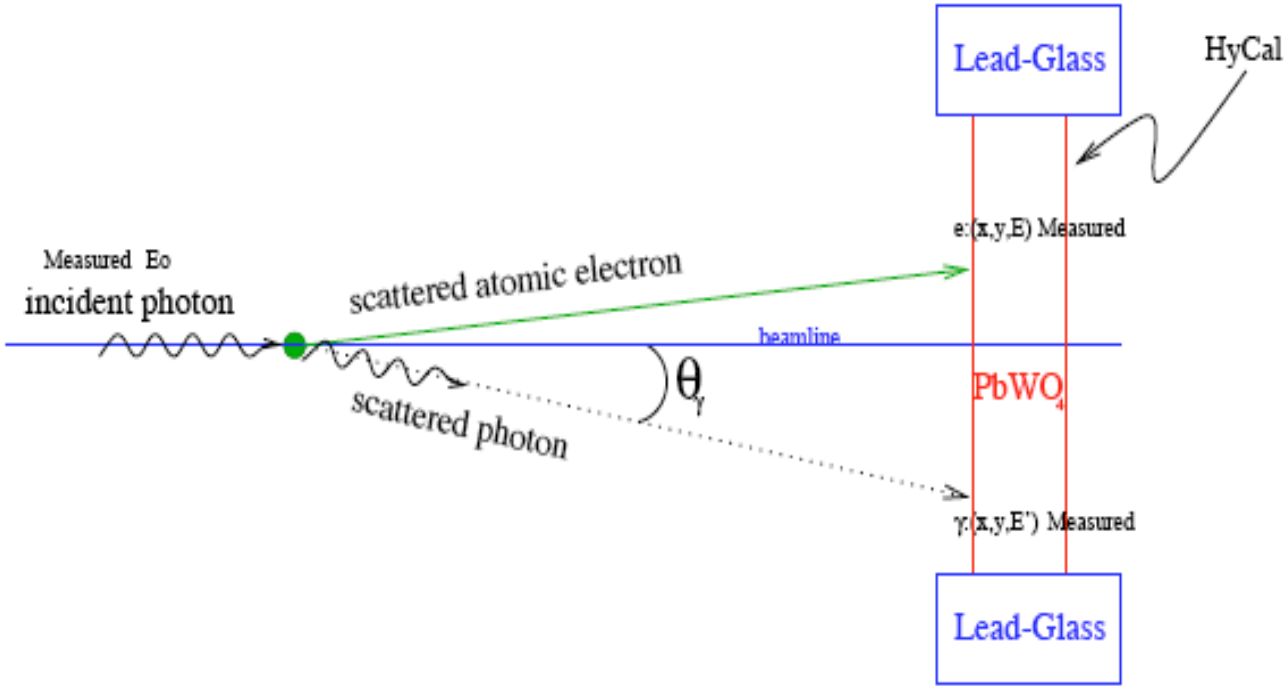
Total



$\Gamma(\pi^0 \rightarrow \gamma\gamma)$ systematic errors

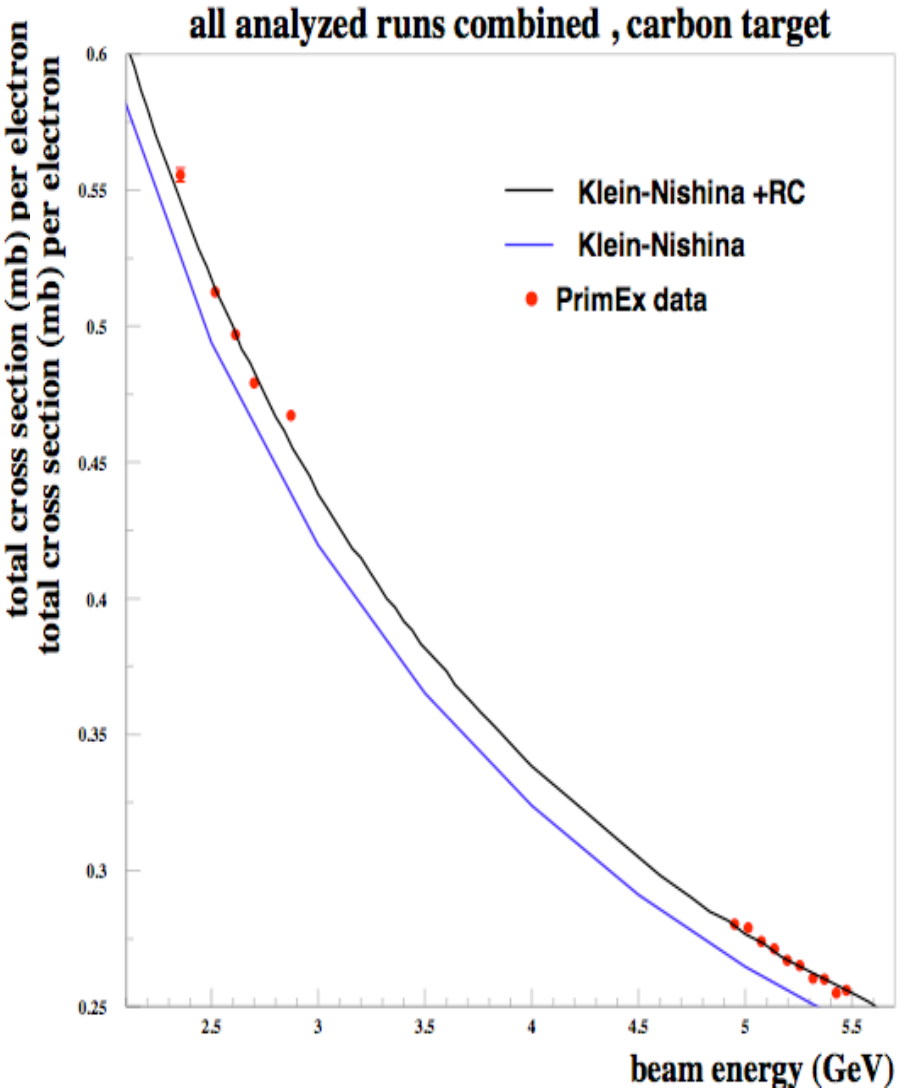
Contributions	Error, [%]
Photon flux	1.0
Target	0.1
Yield extraction	1.6
HYCAL eff.	0.5
Beam parameters	0.4
Trigger eff.	0.1
VETO eff.	0.4
Acceptance	0.3
Model errors (theory)	0.3
Physics background	0.25
Branching ratio	0.03
Total	2.1

COMPTON SCATTERING IN PRIMEX*



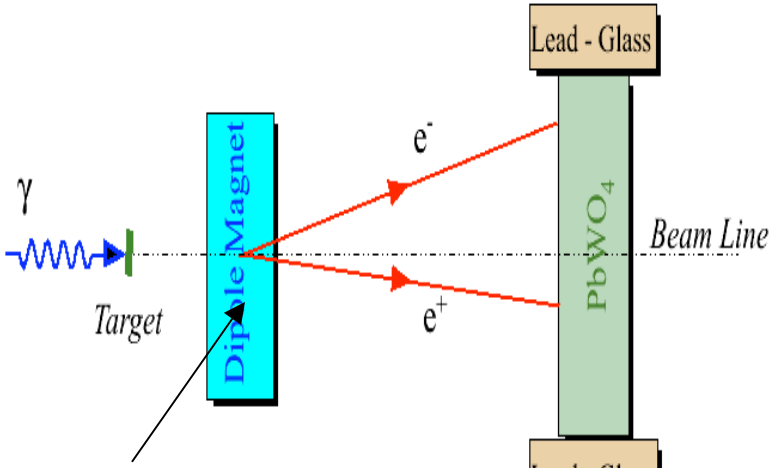
** analysis results from by P. Ambrozewicz, L. Gan, Y. Prok*

Compton Cross Section

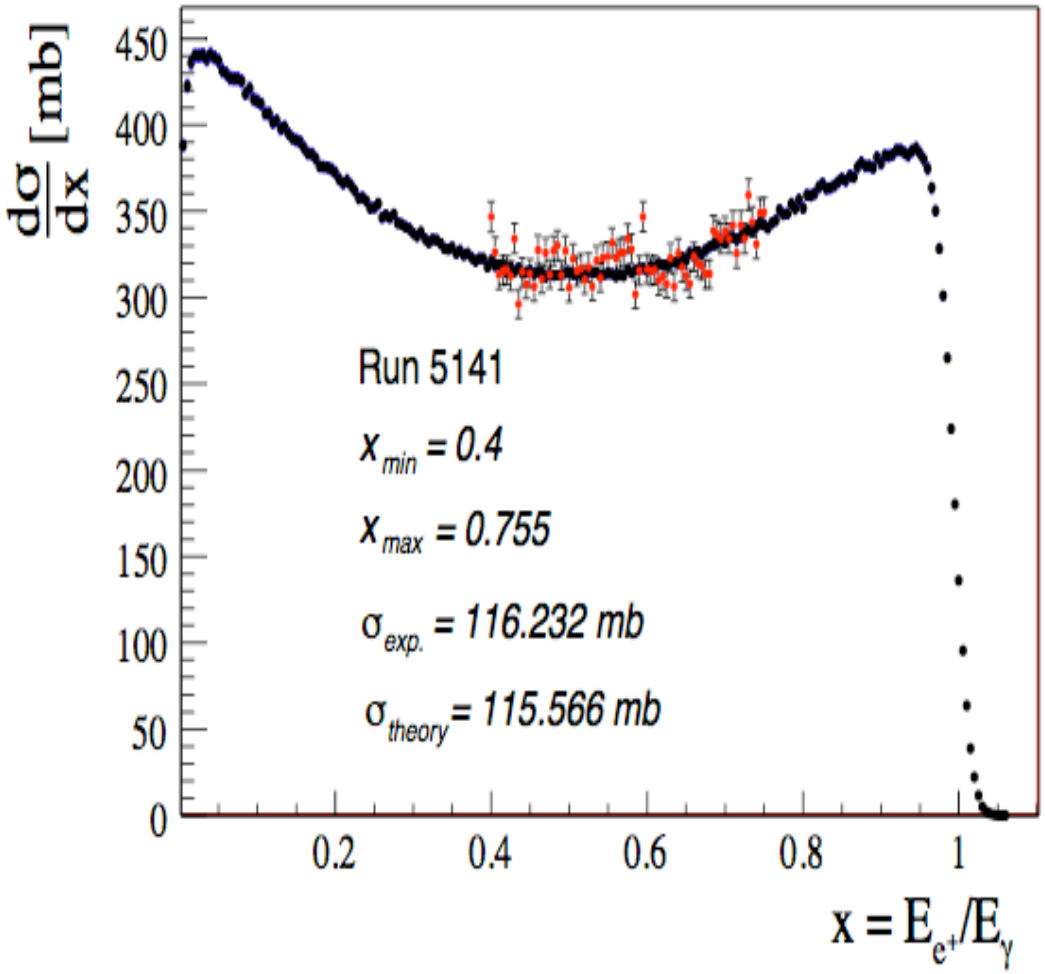


Experiment and theory agree within the 0.6% statistical and ≈1.8% systematic errors

QED calibration reaction: pair production



Weak B field

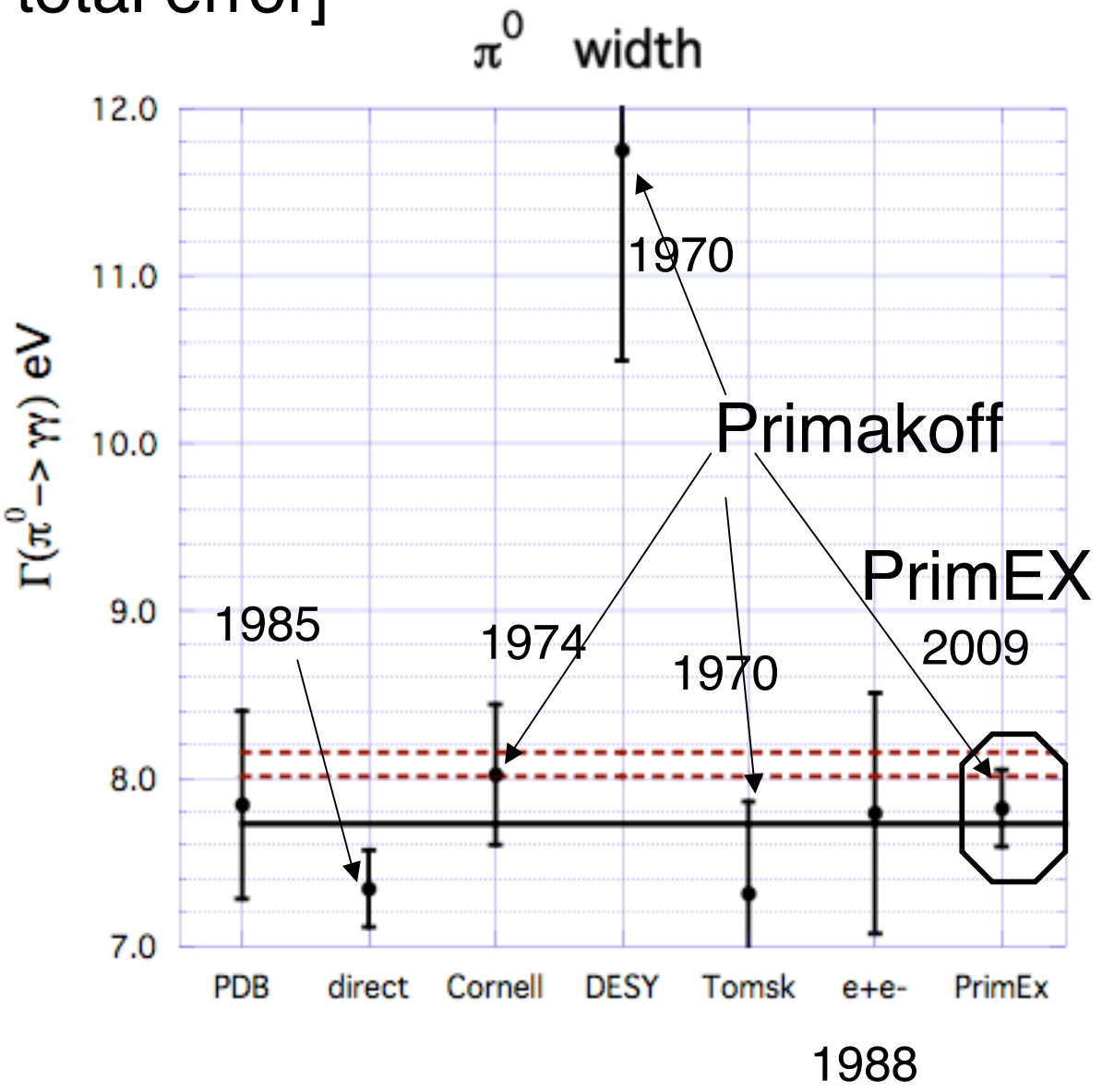


σ_exp and σ_theory agree to better then the systematic error of 1.7%

PrimEx result

$\Gamma(\pi^0 \rightarrow \gamma\,\gamma)$=7.82eV± 2.2%(stat) ± 2.1%(sys)

[3.0% total error]

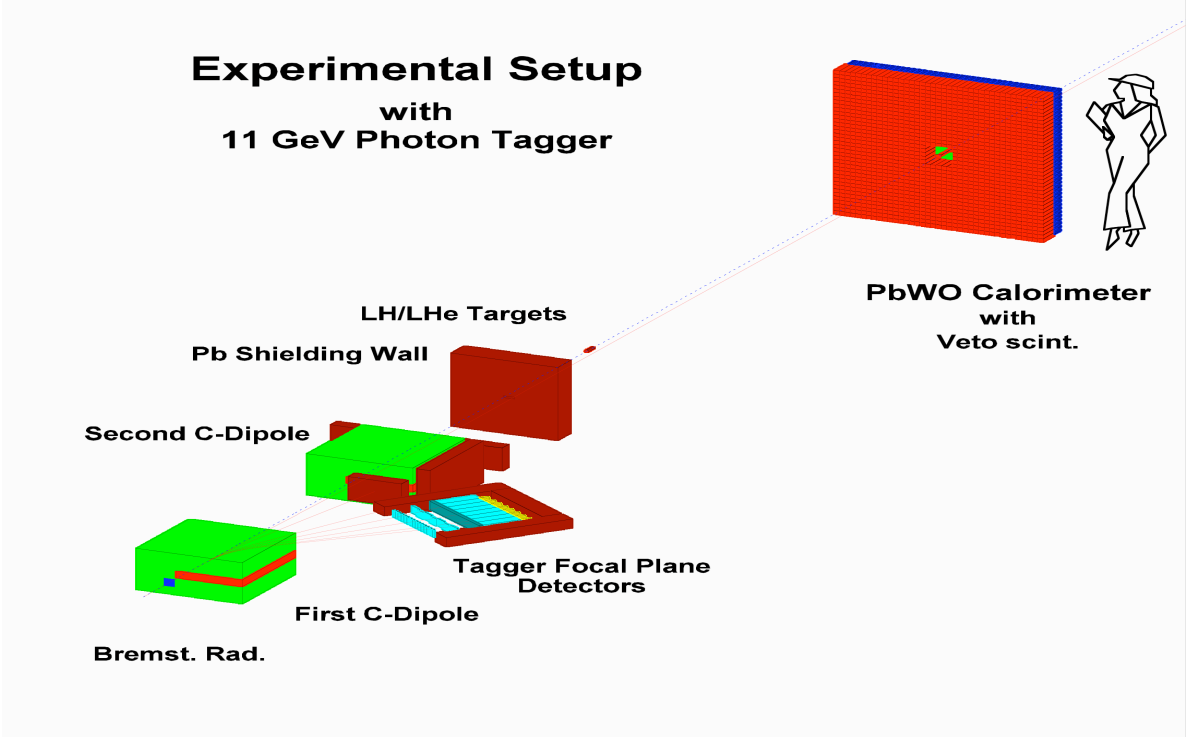


PrimEx Collaboration Future Projects

- 6 GeV: PAC approved run 2 to reduce error by ~50% in the next few years
- 12 GeV program under development:

  $\Gamma(\eta \rightarrow \gamma\gamma), \Gamma(\eta' \rightarrow \gamma\gamma)$

  transition form factors $F_{\gamma\gamma^*}$ at low Q^2(0.001 → 0.5 GeV2)



Conclusions

- We have concluded a modern Primakoff measurement

$$\Gamma(\pi^0 \rightarrow \gamma\,\gamma) = 7.82\text{eV} \pm 2.2\%(\text{stat}) \pm 2.1\%\ (\text{syst})$$

[3.0% total error]

- The systematic error was checked by measurements of the Compton and pair production cross sections to ~ 1.8%

- The results agree with the predictions of the axial anomaly + chiral corrections~m_d-m_u

- Primex 2: to reduce error to ~1.5% in the next few years

- 12 GeV Jlab $\eta \rightarrow \gamma\,\gamma$, $\eta' \rightarrow \gamma\,\gamma$;

transition form factors at low Q^2 $\pi^0, \eta, \eta' \rightarrow \gamma^*\,\gamma$

AB: Outlook: Experiment and Theory

- A modern (~ 1%) e^+e^- experiment is needed!
- preferably for $\pi^0, \eta, \eta' \rightarrow \gamma\gamma$
- reduction of ~1% theoretical error for $\pi^0 \rightarrow \gamma\gamma$

lattice-chiral extrapolation -
calculation of low energy constants?

- QCD predictions for $\eta, \eta' \rightarrow \gamma\gamma$

PrimEx Collaboration

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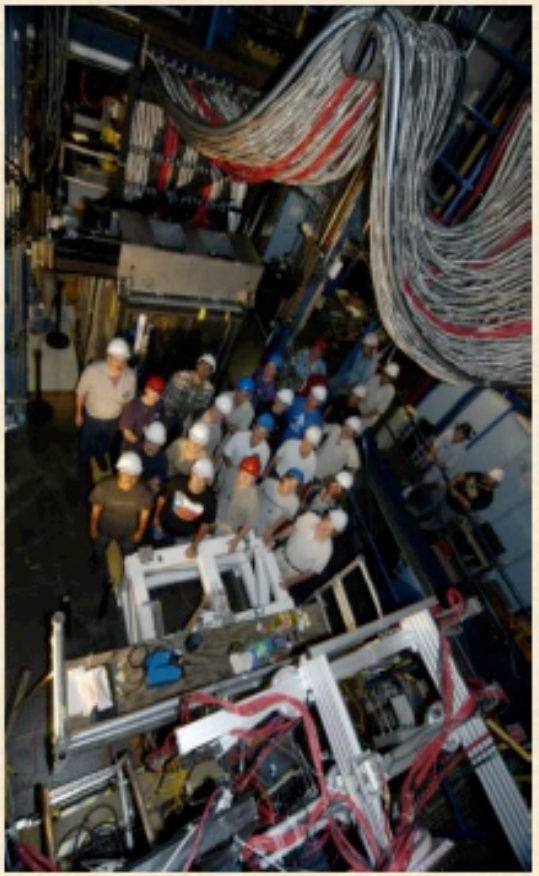

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