Threshold Charged Pion Photoproduction

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A Letter-of-Intent submitted to the MAX-lab PAC

π photoproduction

$$\gamma + \mathrm{N} \longrightarrow \mathrm{N} + \pi$$

fundamental process

- uses EM probe (well understood)
- allows predictions of QCD-based theories to be tested
- tests understanding of underlying dynamics in nucleon system

Possible reaction channels:

$$\gamma + p \longrightarrow p + \pi^\circ$$

$$\gamma + n \longrightarrow n + \pi^\circ$$

$$\gamma + p \longrightarrow n + \pi^+$$

$$\gamma + n \longrightarrow p + \pi^-$$

Near Threshold Measurements

pion photoproduction near threshold:

π and N relative angular momentum:

- s-wave ($l = 0$)
- p-wave ($l = 1$)

$$\left(\frac{d\sigma}{d\Omega}\right)_{\rm thr} = \left(\frac{q}{k}\right) \left[|\mathrm{E}_{0^+}|^2 + |p{-}\mathrm{wave}|^2 \right]$$

where:

- q is the π momentum (CMS)
- k is the photon energy (CMS)
- E_{0^+} is the threshold amplitude

At threshold p-waves vanish
so we can examine different aspects of the reaction

- extraction of the E_{0^+} amplitude (at threshold)
- study of the energy dependence (p-waves)

LET Predictions

Classical LET:

- gauge invarience
- PCAC
- current algera

$$E_{0^+}(p\pi^\circ) = \frac{ef}{4\pi m_\pi}\left[-\mu + \frac{\mu^2}{2}(3+\kappa_p) + O(\mu^3)\right]$$

$$E_{0^+}(n\pi^\circ) = \frac{ef}{4\pi m_\pi}\left[\frac{\mu^2}{2}(\kappa_n) + O(\mu^3)\right]$$

$$E_{0^+}(n\pi^+) = \frac{ef\sqrt{2}}{4\pi m_\pi}\left[1 + \frac{3}{2}\mu + O(\mu^2)\right]$$

$$E_{0^+}(p\pi^-) = \frac{ef\sqrt{2}}{4\pi m_\pi}\left[-1 + \frac{1}{2}\mu + O(\mu^2)\right]$$

where:

- f is the πNN coupling constant
- κ is the anomalous magnetic moment
- $\mu = {}^{m_\pi}/_{m_N}$

Chiral Symmetry

Exact . . .

- u & d quarks are massless
- Goldstone boson (pion) has zero mass

Approximate . . .

- u & d quarks have finite but small mas ($\approx$ 10 MeV)
- pion mass ($\approx$ 140 MeV) is small compared with nucleon mass ($\approx$ 1 GeV)

Modern Predictions . . .

- general prediction of χPT
- reliably include higher order terms in μ $\quad ({}^{m_\pi}/_{m_N})$
- calculate p-wave contribution

Predictions

chan	χPT	LET	DR	Recent Experiment Value
$(\pi^\circ p)$	-1.16	-2.3	-1.22 ± 0.16	-1.31 ± 0.08 -1.32 ± 0.11
$(\pi^\circ n)$	$+2.6$	-0.5	$+1.19 \pm 0.16$	———
$(\pi^+ n)$	$+28.2 \pm 0.6$	$+27.6 \pm 0.2$	$+28.0 \pm 0.2$	$+28.2 \pm 0.6$
$(\pi^- p)$	-32.7 ± 0.6	-31.7 ± 0.2	-31.7 ± 0.2	-31.5 ± 0.8

- $\pi^\pm$ channels:
  - χPT corrections are small since the Kroll-Ruderman term is dominant
- π° channels:
  - Kroll-Ruderman term vanishes χPT corrections larger

Recent Data

pion photoproduction experiments
from threshold to 170 MeV (after 1990)

reaction	Ref.	E_γ	θ	data points
$\pi^\circ p$	Be90	147 – 156	8 – 168	55
	Fu96	145 – 169	10 – 170	261
	Sc01	145 – 157	10 – 170	171
	Be97	48 – 169	5 – 175	198
$\pi^+ n$	Ko99	152 – 154	46 – 134	45
$\pi^- p$	Li94	158 – 168	42 – 142	12

- Exists large data set for neutral pion production (from proton)
- Only single modern measurement on each of the charged pion channels
- addition measurements on charged channels would be useful contribution

Proposed Program

A series of 5 measurements

start simple and increase complexity

Allows us to build on previous experience:

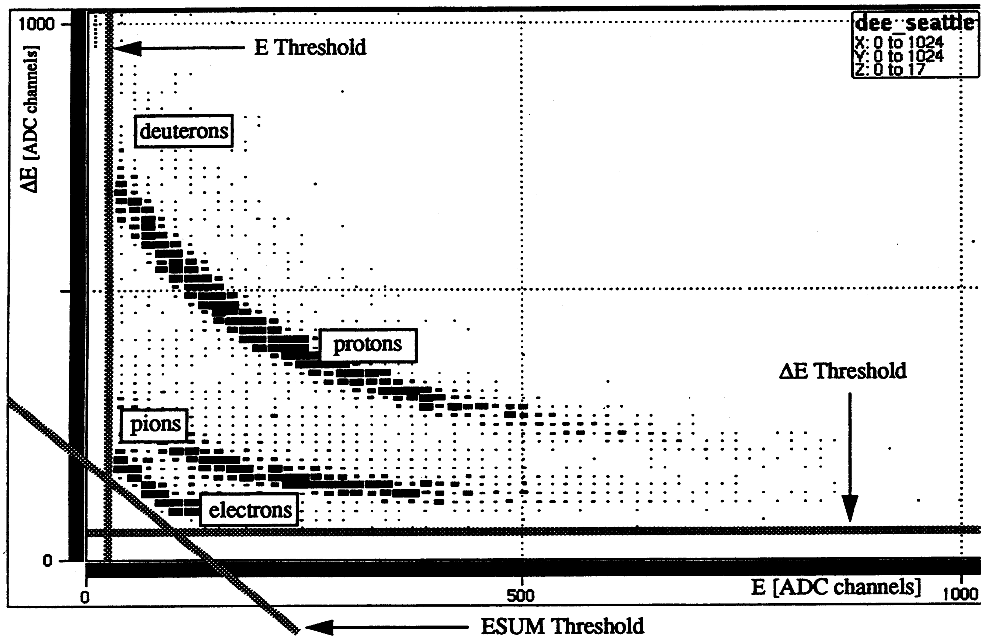
- understand behaviour and performance of accelerator and tagger
  - ∗ tagging efficiency (photon flux normalization)
- test and understand detector systems
  - ∗ overlap in techniques used
- confidence in reliability of each measurement in the series
  - ∗ well understood systematic uncertainties

Proposed Program

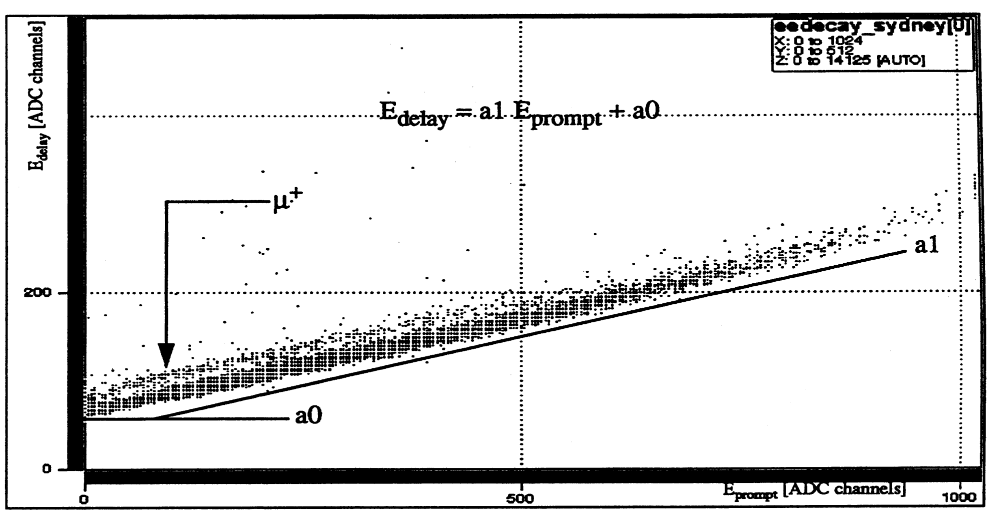
target	details	purpose
C, CH_2	$E_\gamma \sim 160 - 170$ MeV detect π^+	initiate π^+ program solid targets simple detectors
C, CH_2	$E_\gamma \sim 153 - 164$ MeV detect π^+ detect neutron	solid targets test neutron detection confirm neutron efficiency
$l H_2$	$E_\gamma \sim 151 - 161$ MeV detect neutron	precision measurement $p(\gamma, n)\pi^+$
active scint.	$E_\gamma \sim 151 - 161$ MeV detect low-energy π^+ detect neutron	precision measurement $p(\gamma, n)\pi^+$ very close to threshold
active scint. (deut.)	$E_\gamma \sim 151 - 161$ MeV coinc. detect π^- & 129 MeV γ	precision measurement $n(\gamma, p)\pi^-$ very close to threshold

π^+ Identification
in plastic scintillator

ΔE-E to seperate π events from proton and electrons



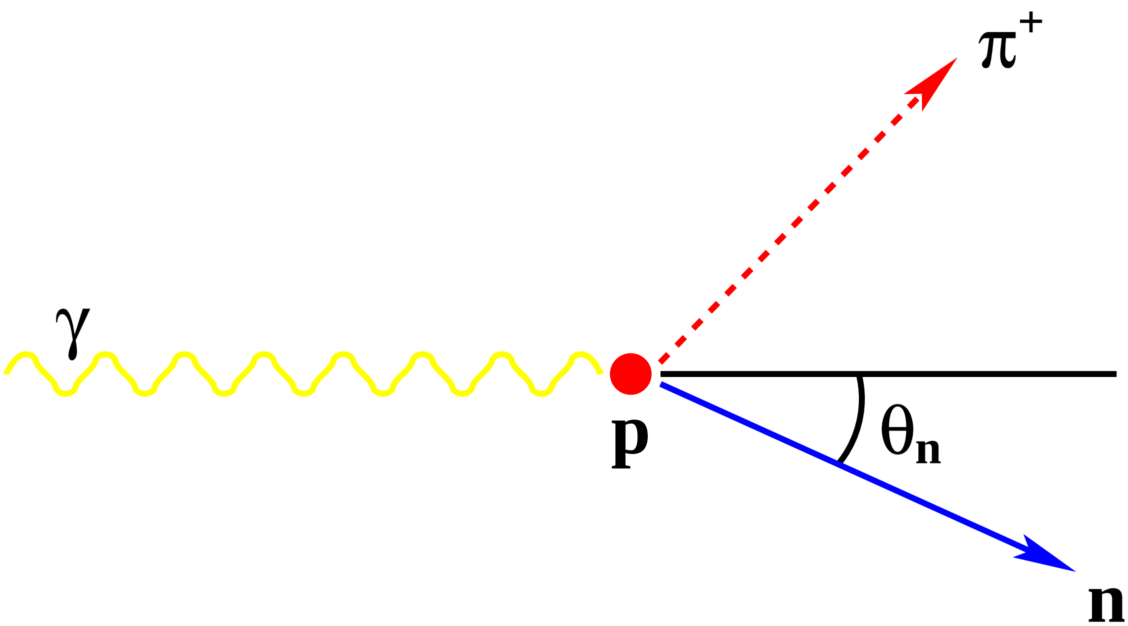
identify π^+ events using $\pi^+ \rightarrow \mu^+_{4.12\,\mathrm{MeV}} + \nu_\mu$ decay



$$\gamma + p \longrightarrow n + \pi^+$$

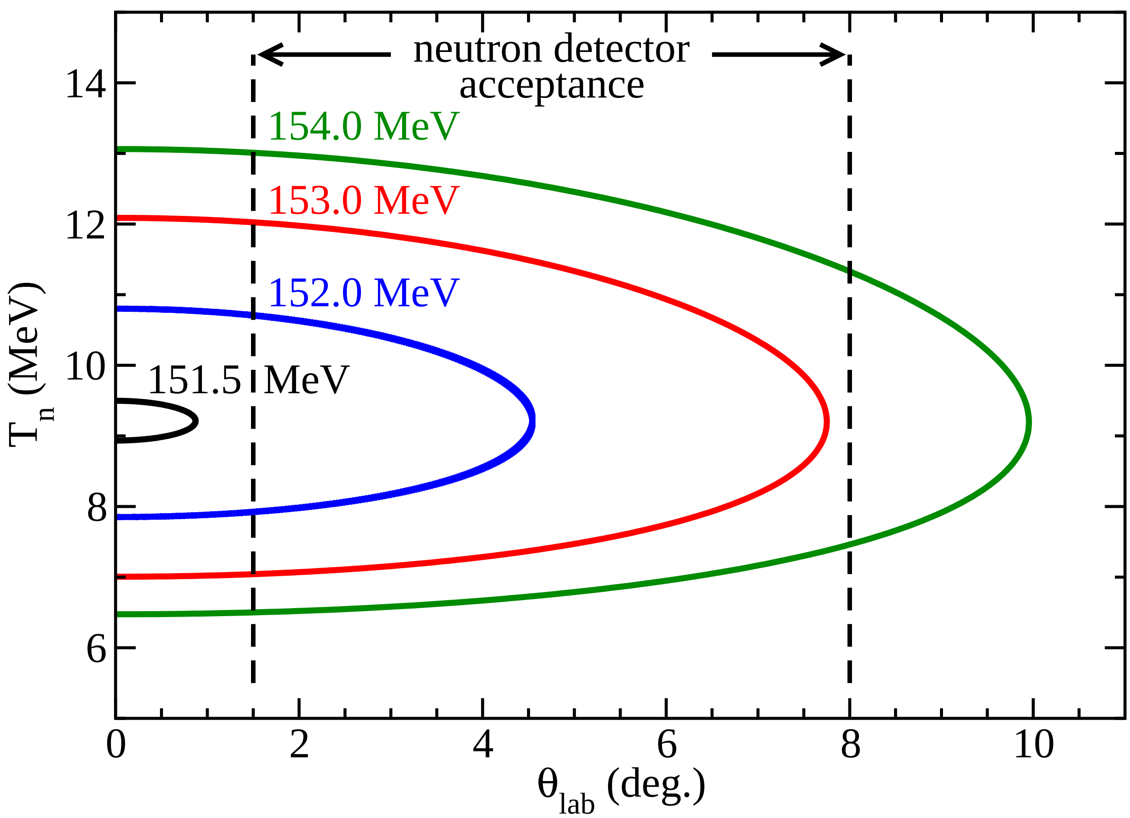
near threshold

π^+photoproduction kinematics



- π^+ has very low energy
- neutron energy well above zero
  confined to a small forward cone
- look for this forward going neutron in liquid scintillator neutron detector

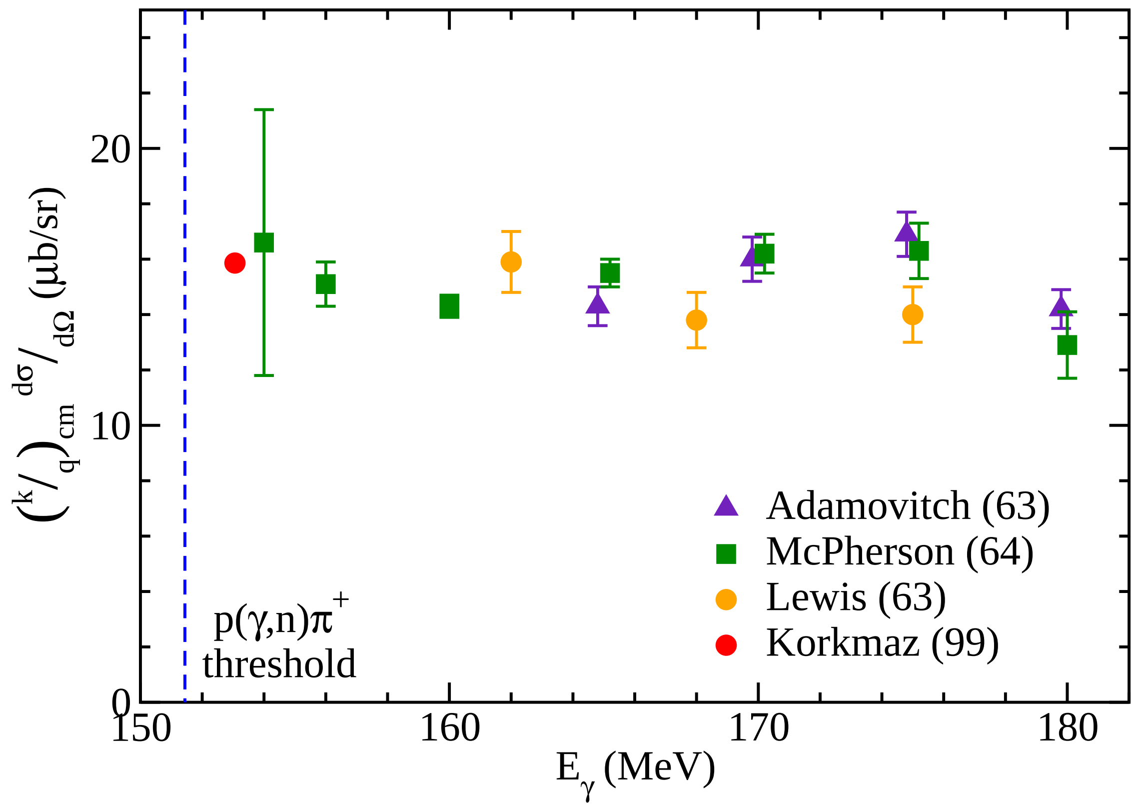
Reaction Kinematics



SAL measurements (Korkmaz *et. al.*)

- array of 84 liquid scintillator detectors in forward direction, around photon beam direction
  - covered from about 1° to 8°
- good acceptance near threshold from about 0.5 to 2 MeV above threshold

Existing Data



most recent measurement:

Korkmaz *et al,* at SAL

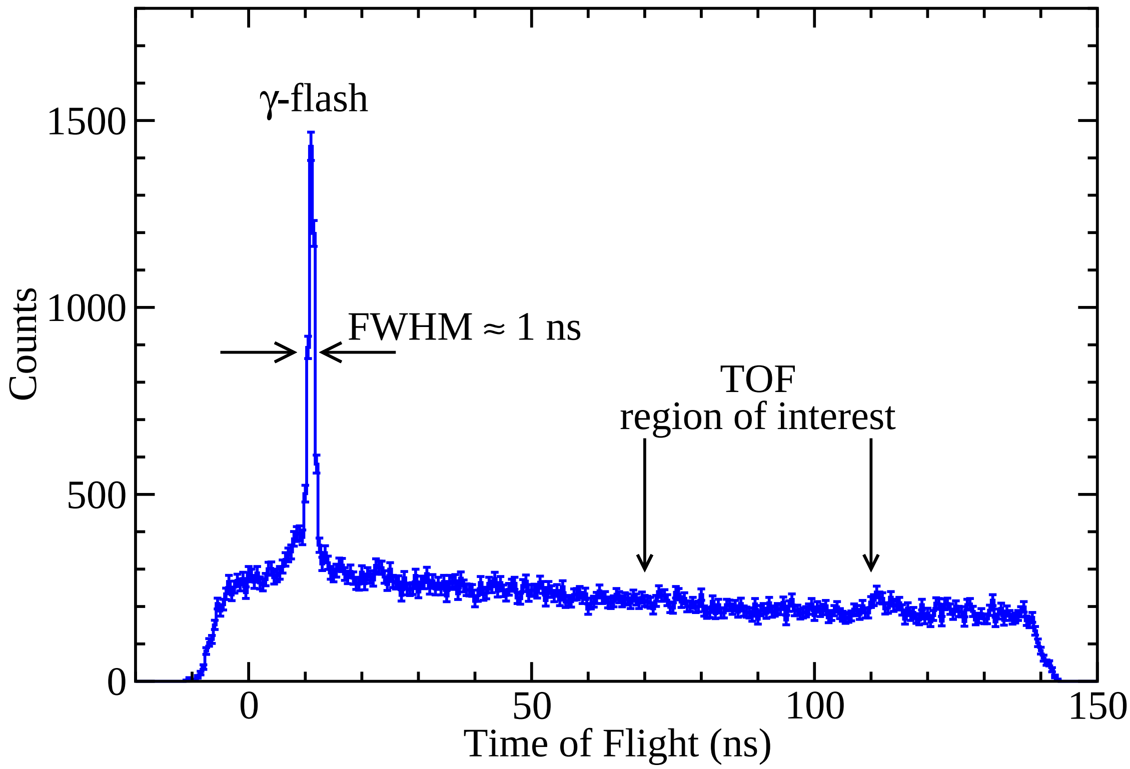
- much closer to threshold than earlier work
- small uncertainties

Event Identification
Neutrals Time-of-Flight

$\gamma + p \rightarrow n + \pi^+$: E_n = 5 – 16 MeV

TOF = 70 – 110 ns

(at 3 metre for SAL027 array)



- γ-flash used to determine zero for TOF
- timing resolution < 1 ns for each of tagger and neutron detector
- requires careful calibration of tagger channel TDCs

Analysis

Large background

due to accidental coincidence between
tagger and neutron detector

- large coincidence resolving time (40 ns)
  due to range of neutron *time-of-flight*
- neutron background – $X(\gamma, n)$
- photon background

reduce photon contamination

- use Pulse Shape Discrimination techniques
  to distinguish between neutrons and photons

final background subtraction

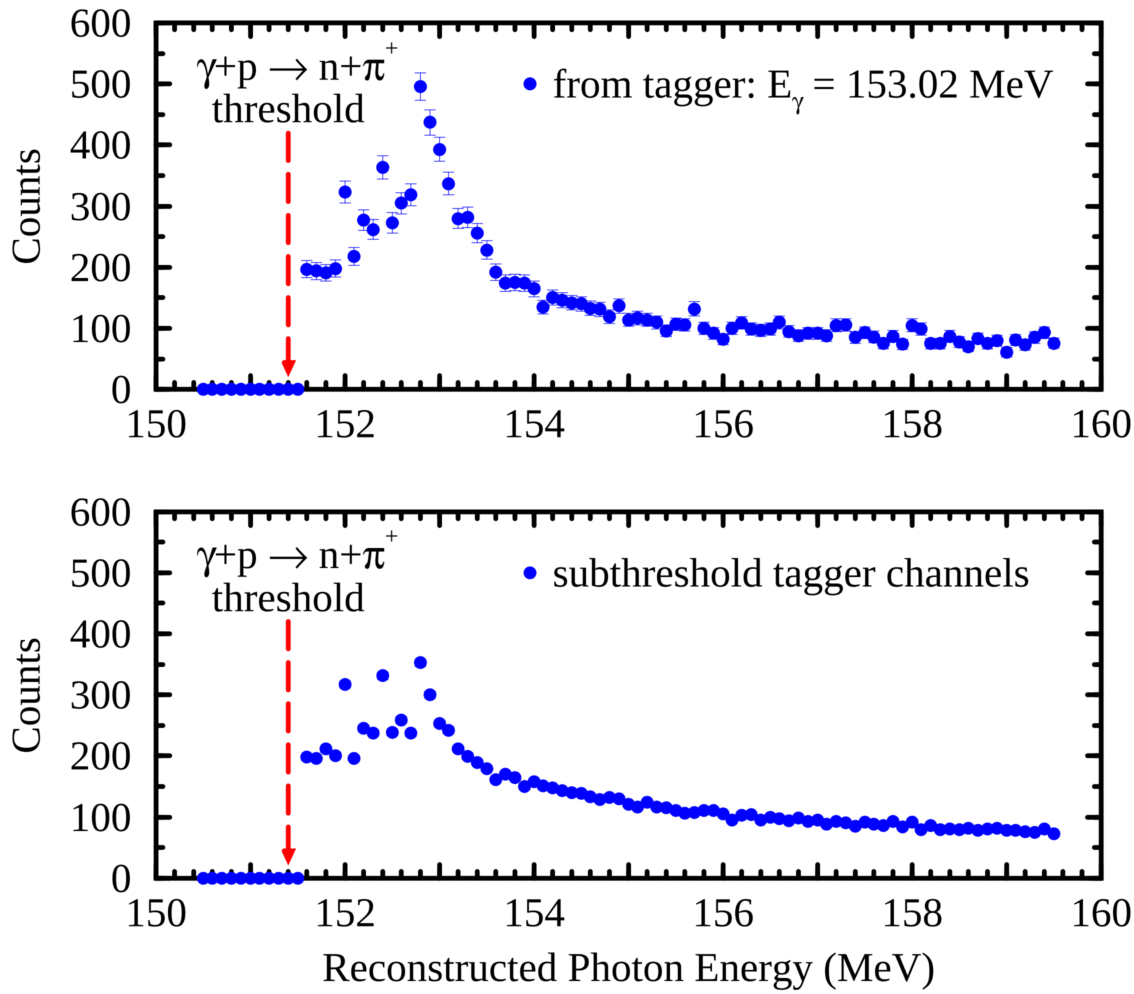
- based on events from sub-threshold tagger channels
  - ∗ no true events
  - ∗ assume background shape
    is same above threshold

Background Subtraction

Use reaction kinematics

- determine E_n using TOF
- reconstruct photon energy

  assuming 2-body kinematics
- compare with E_γ known from tagger

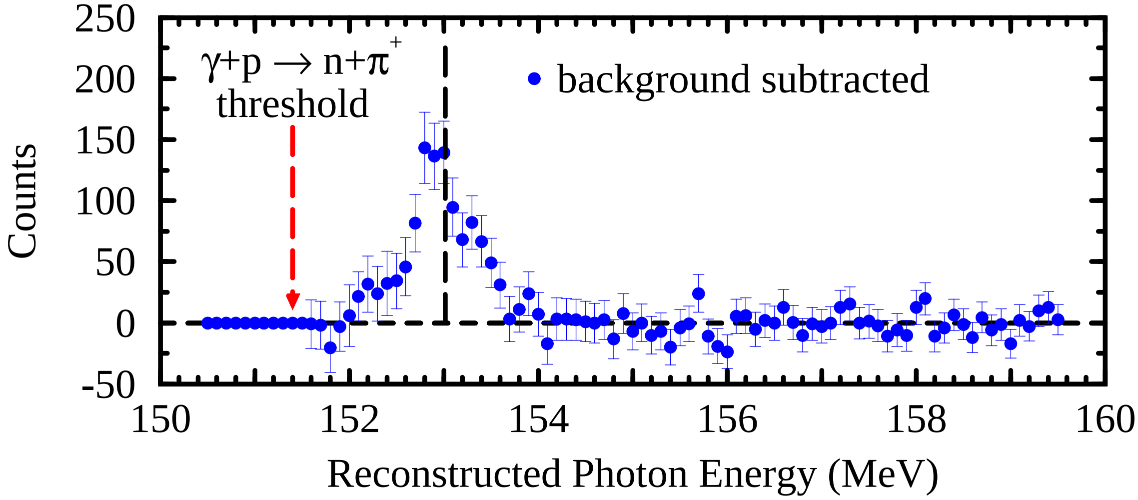


$$\text{background scaling} = \frac{\text{tagger scaler}}{\Sigma(\text{sub-threshold tagger scalers})}$$

Final Yields

after background subtraction

- energy of reconstructed peak agrees with tagger energy (shown by black dashed line)
- events away from peak are flat and consistent with zero

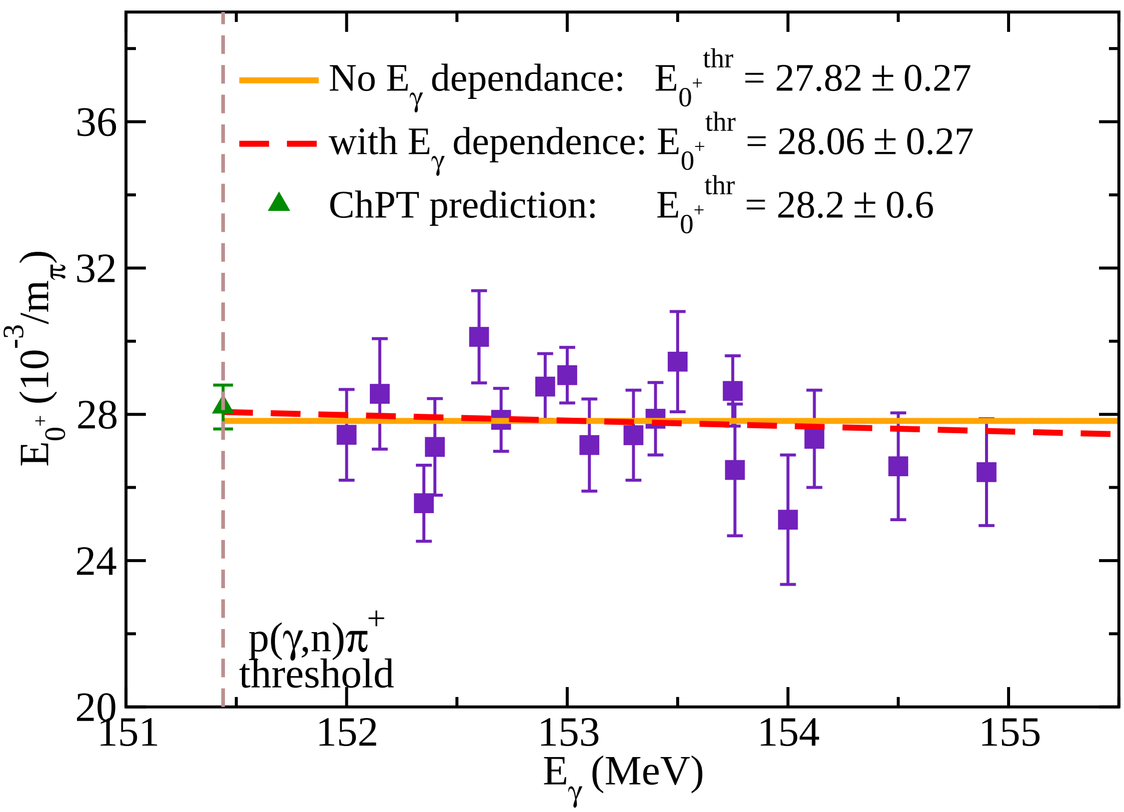


gives confidence in final yields

Modern Results

Korkmaz *et al.* (SAL)

π^+photoproduction



Lund Measurement

A new measurement of $p(\gamma, n)\pi^+$ detecting the recoil neutron

- θ_n second data set to compare with earlier SAL measurement
  - different systematics
  - comparable or better statistics
- measure neutron angular distributions to higher photon energies
  - information on energy evolution of p-waves

Pushing closer to threshold

recoil neutron detection:

- θ_n depends on E_γ
- for E_γ very close to threshold, θ_n also small
  - ∗ neutron too close to photon beam to detect

to get even closer to threshold
have to detect outgoing π^+

- this is low-energy so cannot exit a reasonable thickness target
- need to use target itself to detect the π^+
- active scintillator target

H in scintillator forms proton target

Active Target

New set of problems:

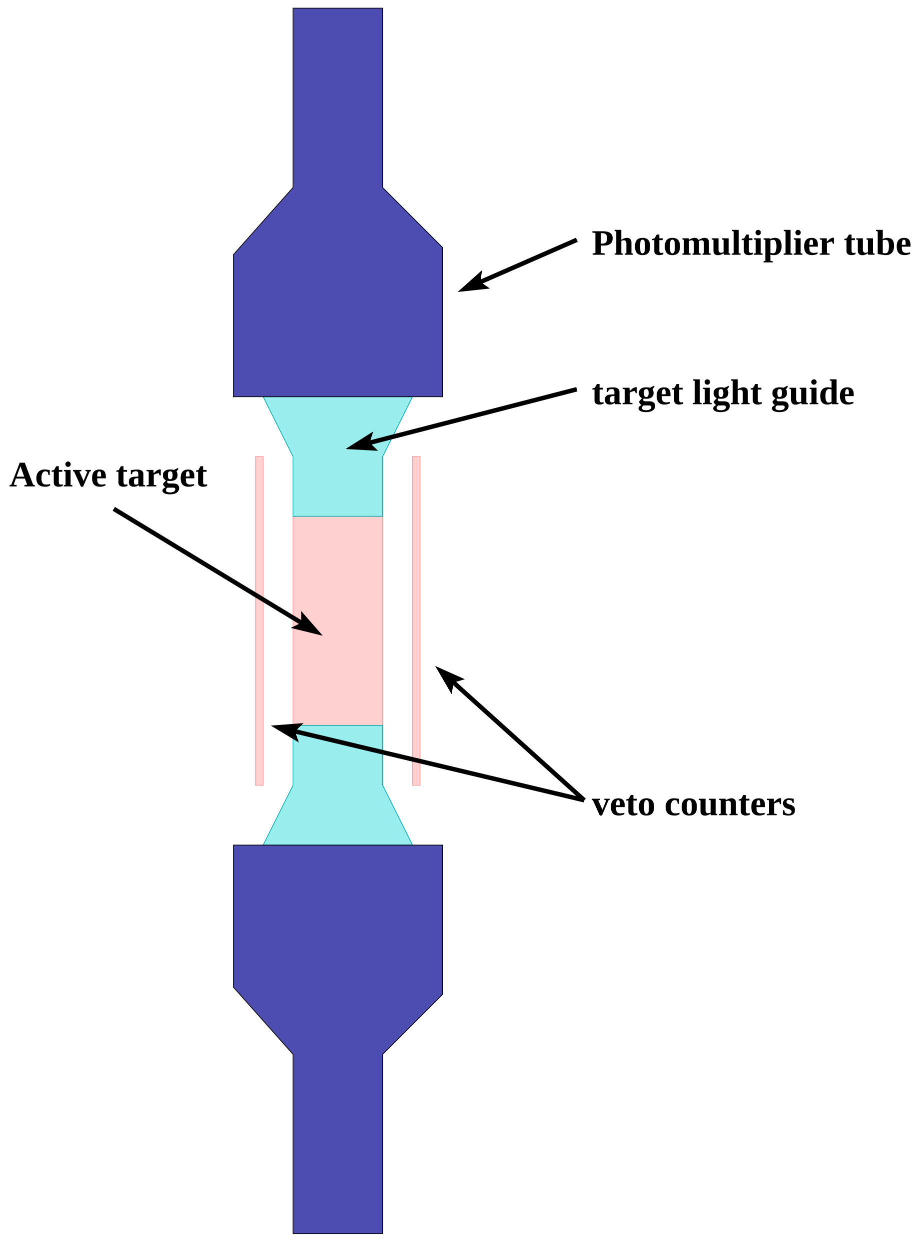
- other photoreactions on C in target
- EM process between photon beam and target
  - compton scatting, pair production

All of these will produce signals in the active target

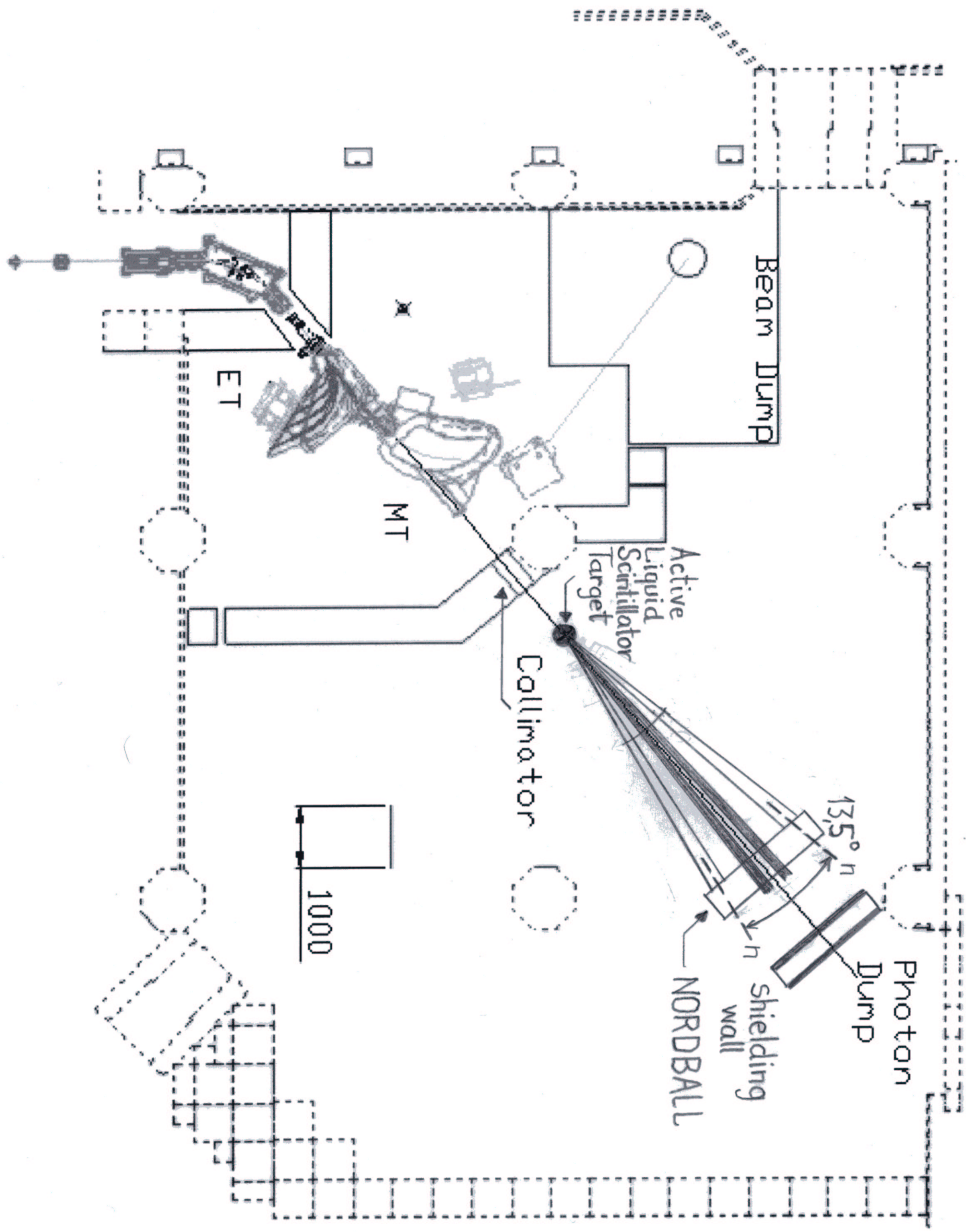
- need to identify signal from π^+
  - PSD techniques to exclude signals from protons or heavier recoils
  - target design may include a veto counter to exclude particles which exit the target
    - (such as electron events produced by the photon beam

Active Target

Draft design:



Active Target Experiment



Development

need Monte-Carlo simulation of target and experiment

- understand backgrounds
- estimate background rates
- test analysis techniques to extract π^+ signal

Active Target

$$\gamma + n \longrightarrow p + \pi^-$$

Use deuterated scintillator

- deuteron as neutron target
  - ∗ look for low-energy proton in target
  - ∗ look for π^- capture in target
    gives 129 MeV photon
    - – look for this in large γ-ray detector
- exclude reactions on C in scintillator
  based on pulse height
  - ∗ these will produce huge signal in scintillator

Conclusion

MAX-lab upgrade

- produce tagged photons at the pion threshold region
- ability to do further precision measurements
  - well understood systematic uncertainties
  - small statistical uncertainties
- investigation of charged pion channels

Opportunity

to contribute to knowledge of

pion photoproduction in the

threshold region.