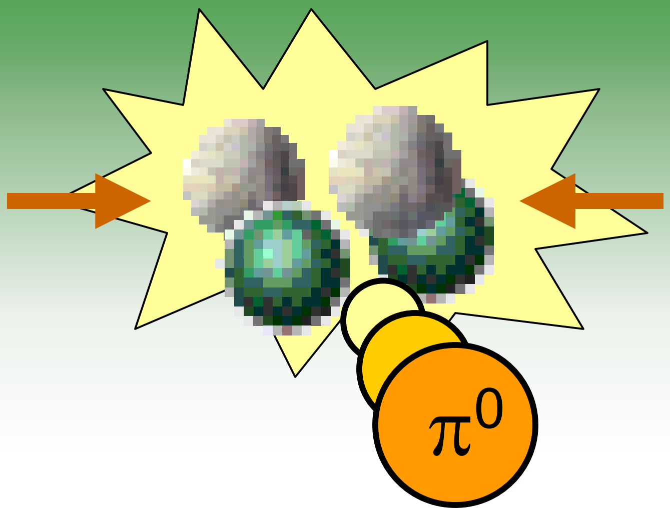
Cooler CSB

Observation of $dd \rightarrow \alpha\pi^0$



Ed Stephenson

Indiana University Cyclotron Facility

CSB–V

Seattle, WA

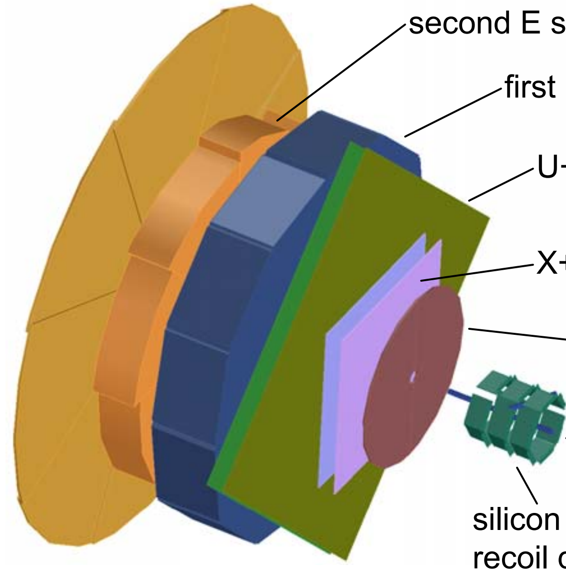
October 20-22,2003

Summary of the analysis

Review of the experiment

CSB – V
SEATTLE, WA
Oct. 20-22, 2003

Status



PRL is out:
91, 142302

CSB summer analysis:

★match GEANT to experiment
(adjust PMT response functions)

rework Pb-glass fit (new routines)
build luminosity simulation
(scintillator non-linearity under study)

No surprises!

Mark Pickar

Long experimental paper
partially written.

d+d elastic scattering:
(use hydrogen target for reference
cross section and analyzing power)

DONE: geometry + efficiency
IN PROCESS:
identify d+d and d+p events
extract deuteron polarization
find good acceptance limits
get σ, iT_{11}, T_{20}, T_{22} data

Paul Pancella

Observation of the Isospin-forbidden $d+d \rightarrow {}^4He+\pi^0$ Reaction near Threshold

$$d + d \Rightarrow {}^4He + \pi^0$$

isospin: 0 0 0 1 —— pion had 3 charge states

CHARGE SYMMETRY says that the physics is unchanged when protons and neutrons are swapped, or when up and down quarks are swapped.

The pion wavefunction is not symmetric under up-down exchange.

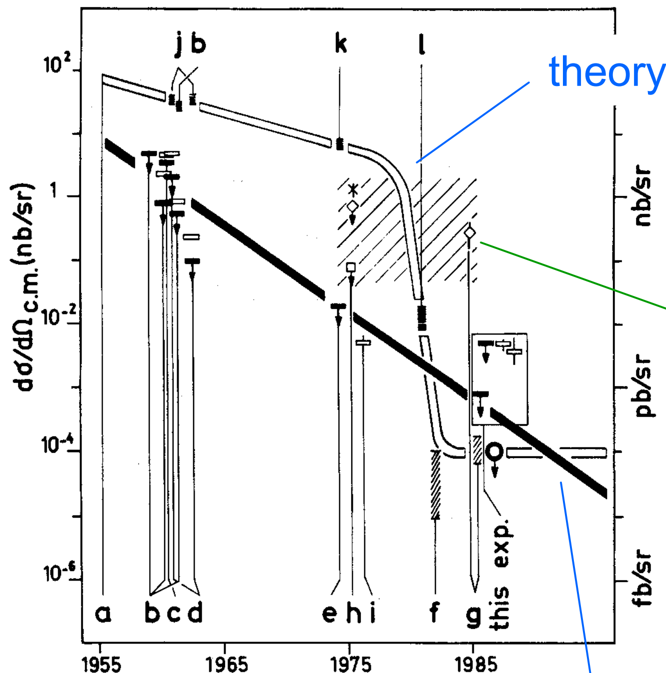
$$\psi = \frac{1}{\sqrt{2}}\left(u\bar{u} - d\bar{d}\right)$$

Deuterons and helium reverse exactly. Thus, an observation of this process is also an observation of <u>charge symmetry breaking</u>.

History of the search for d+d → ^{4}He+π^0

according to J. Banaigs *et al.* PRL 58, 1922 ('87)

Trends in:

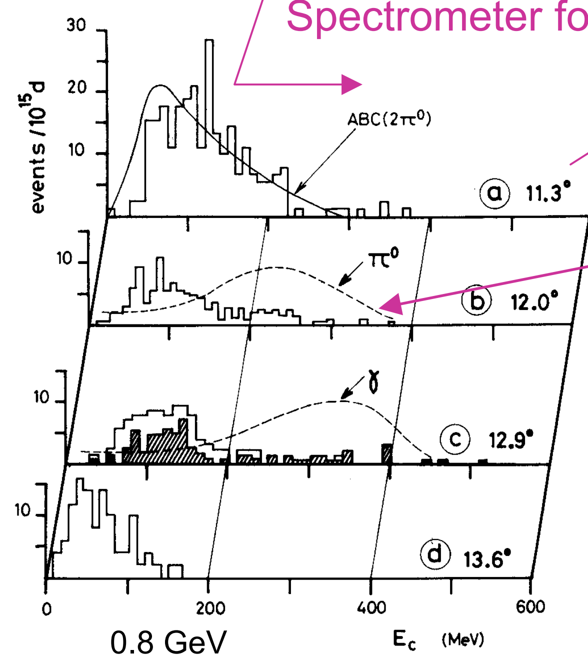


solid: upper limits on ^{4}He+π^0
open: measurements of ^{4}He+γ

Observation of d+d → ^{4}He+X
where X = ω or η

Saturne experiment:
also L. Goldzahl *et al.* NP A533, 675 ('91)

Energies near 1 GeV
(energy) Pb-glass for photons
Spectrometer for ^{4}He (angle)



look for excess events here

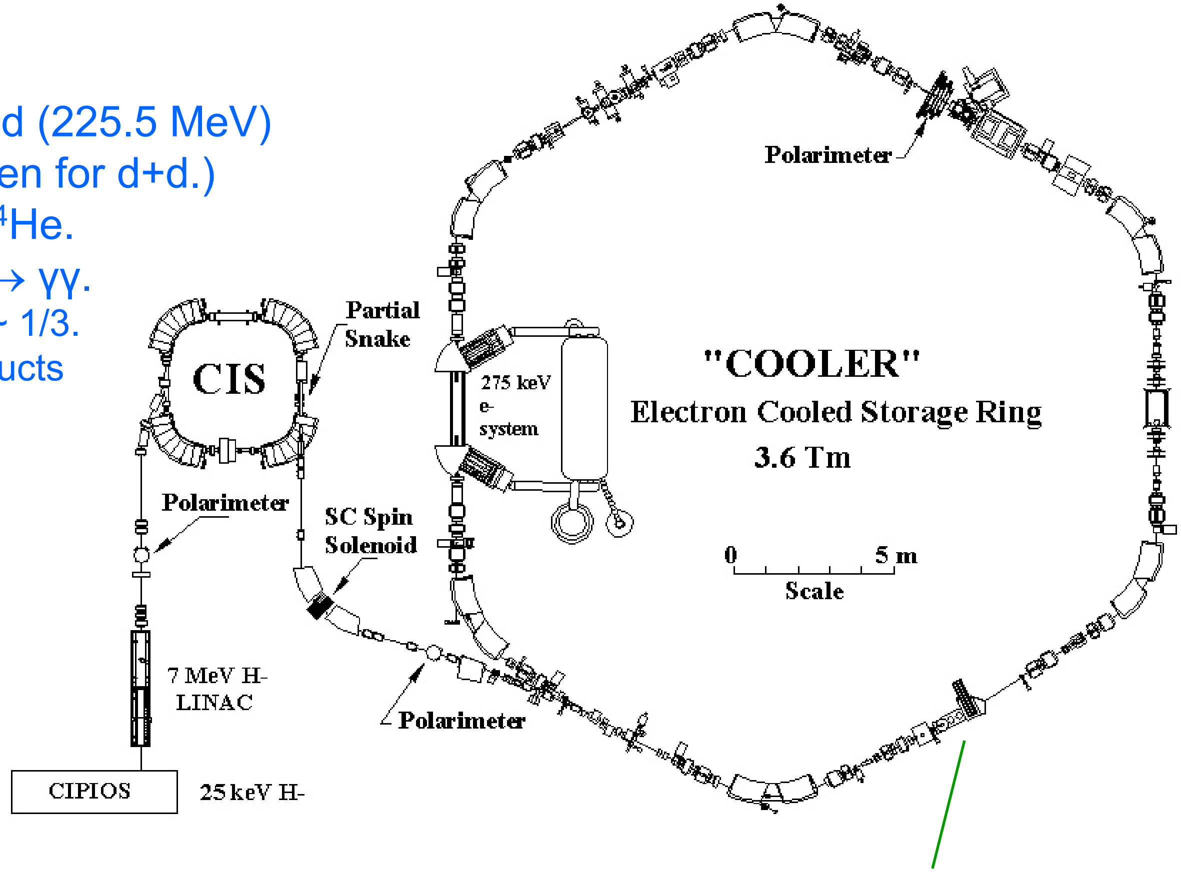
At 1.1 GeV, Goldzahl reports 0.97 ± 0.25 pb/sr for θ_π = 107°

But Dobrokhotov *et al.* PRL 83, 5246 ('99) say this could be ^{4}He+γ+γ (isospin-allowed double radiative capture)

We must separate this background!

PLAN

Search just above threshold (225.5 MeV)
- (No other π channel open for d+d.)
- Capture forward-going ^{4}He.
- Pb-glass arrays for $\pi^0 \rightarrow \gamma\gamma$.
  - Efficiency on two sides ~ 1/3.
  - Insensitive to other products
    - (γ_{beam} = 0.51)



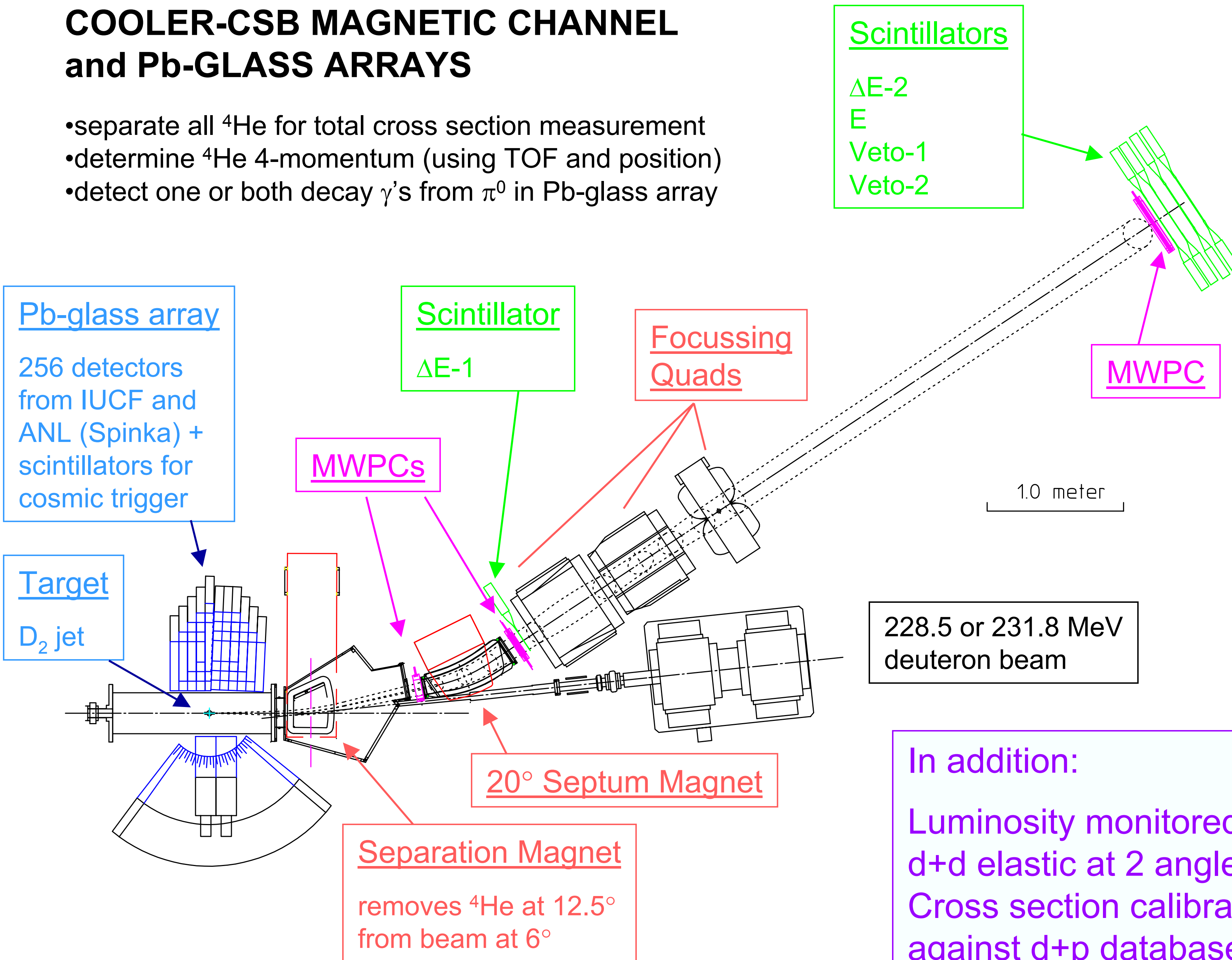
Target density = 3.1 x 10^{15}
Stored current = 1.4 mA
Luminosity = 2.7 x 10^{31} /cm^2/s

Expected rate ~ 5 /day

6° bend in Cooler straight section
- Target upstream, surrounded by Pb-glass
- Magnetic channel to catch ^{4}He (~100 MeV)
- Reconstruct kinematics from channel
  - time of flight and position.
  - (Pb-glass energy and angle too uncertain for π^0 reconstruction. $\alpha\gamma\gamma$ looks the same.)

COOLER-CSB MAGNETIC CHANNEL and Pb-GLASS ARRAYS

- separate all ^{4}He for total cross section measurement
- determine ^{4}He 4-momentum (using TOF and position)
- detect one or both decay γ's from π^0 in Pb-glass array

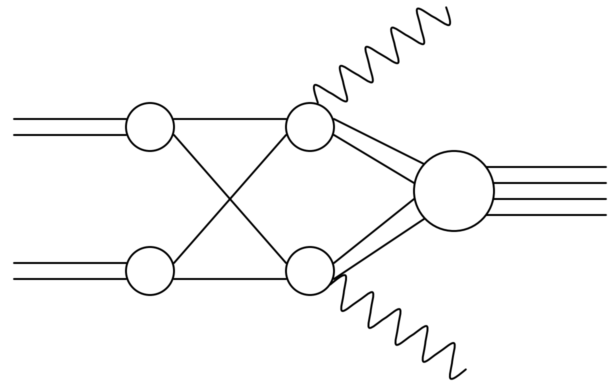


In addition:

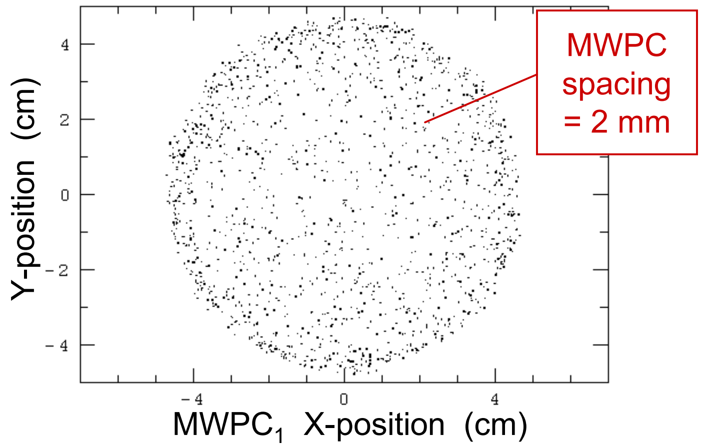
Luminosity monitored by d+d elastic at 2 angles. Cross section calibrated against d+p database.

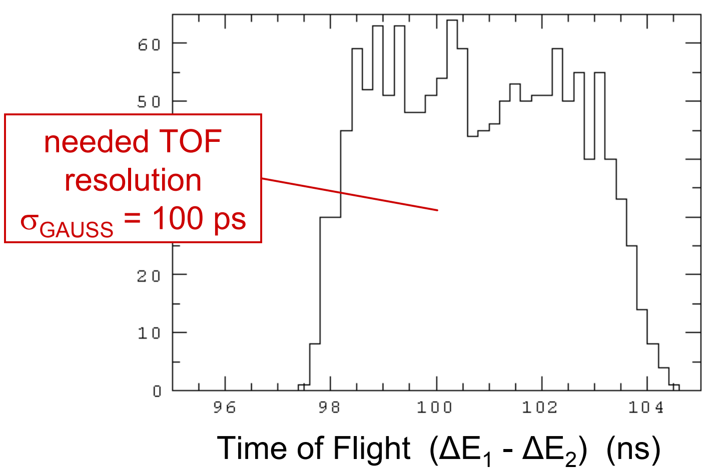
SEPARATION OF $\alpha\pi^0$ AND $\alpha\gamma\gamma$ EVENTS

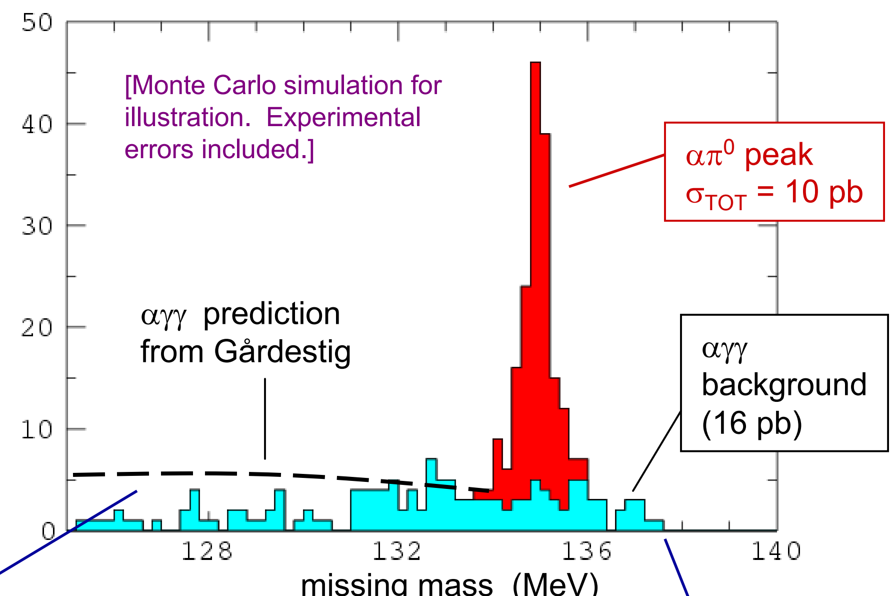
Calculate missing mass from the four-momentum measured in the magnetic channel alone, using TOF for z-axis momentum and MWPC X and Y for transverse momentum.



Major physics background is from double radiative capture.







Difference is due to acceptance of channel. Acceptance widths are:
- angle = 70 mr (H and V)
- momentum = 10%

Cutoff controlled by available energy above threshold.

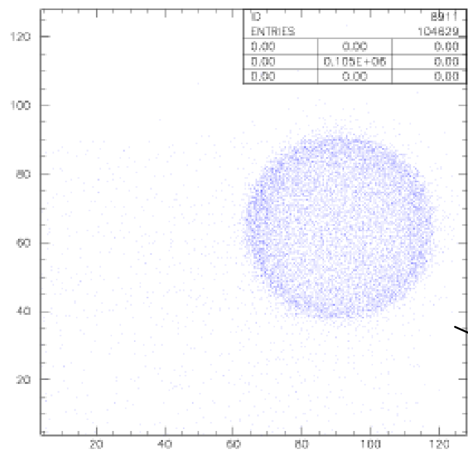
COMMISSIONING THE SYSTEM using p+d $\rightarrow$ $^{3}He+\pi^{0}$ at 199.4 MeV

^{3}He events readily identified by channel scintillators.

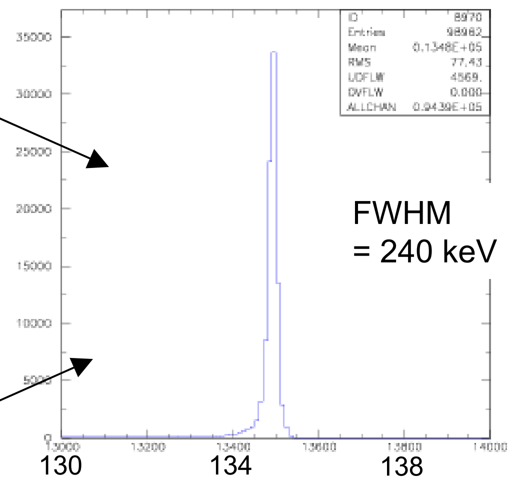
It is important to identify loss mechanisms.

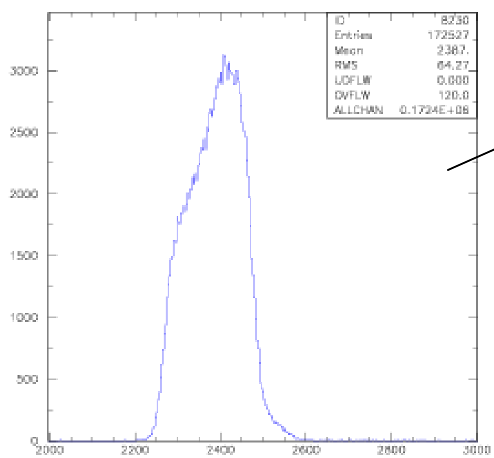
Pb-glass energy sums nearest neighbors.

Recoil cone on first MWPC



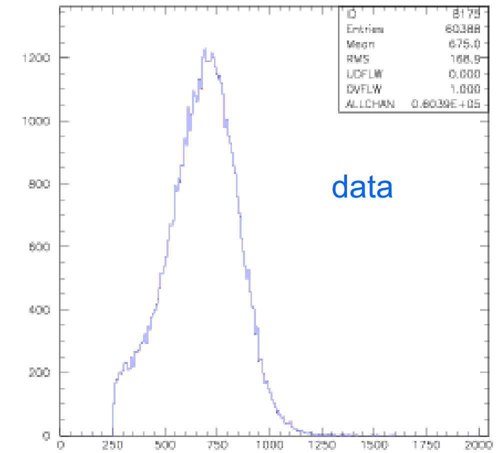
Construction of missing mass from TOF and position on MWPC.

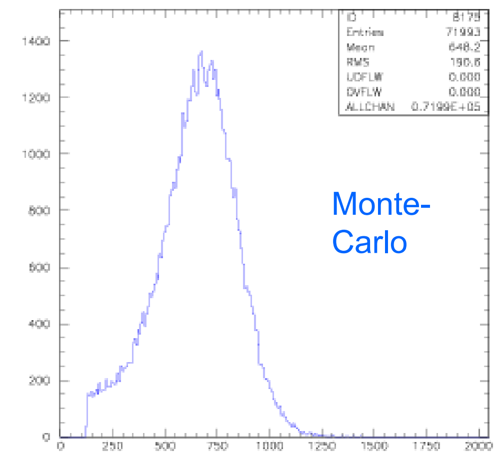




Channel time of flight

NOTE: Main losses in channel from random veto, multiple scattering, and MWPC multiple hits.

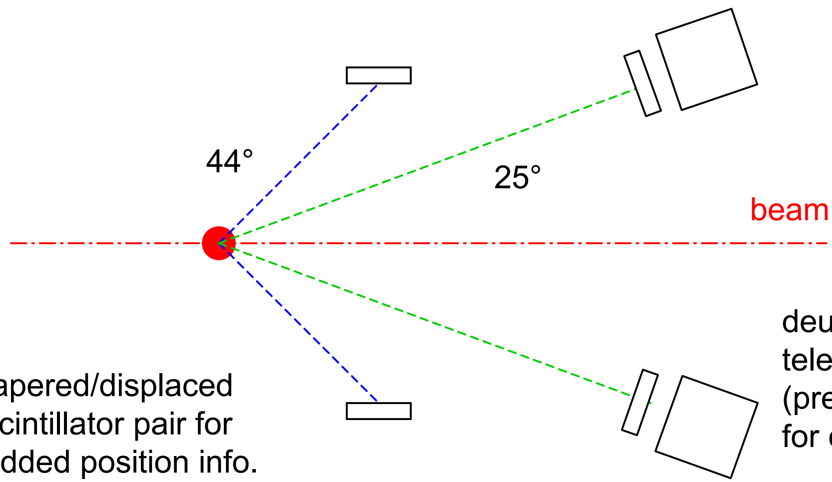




Response matched to GEANT model. Efficiency (~ 1/3) known to 3%.

Calibrating the luminosity of the IUCF Cooler

PLAN: Monitor with d+d elastic. Measure ratio of d+d cross section to d+p (known) with molecular HD target.



deuteron telescope (present only for calibration)

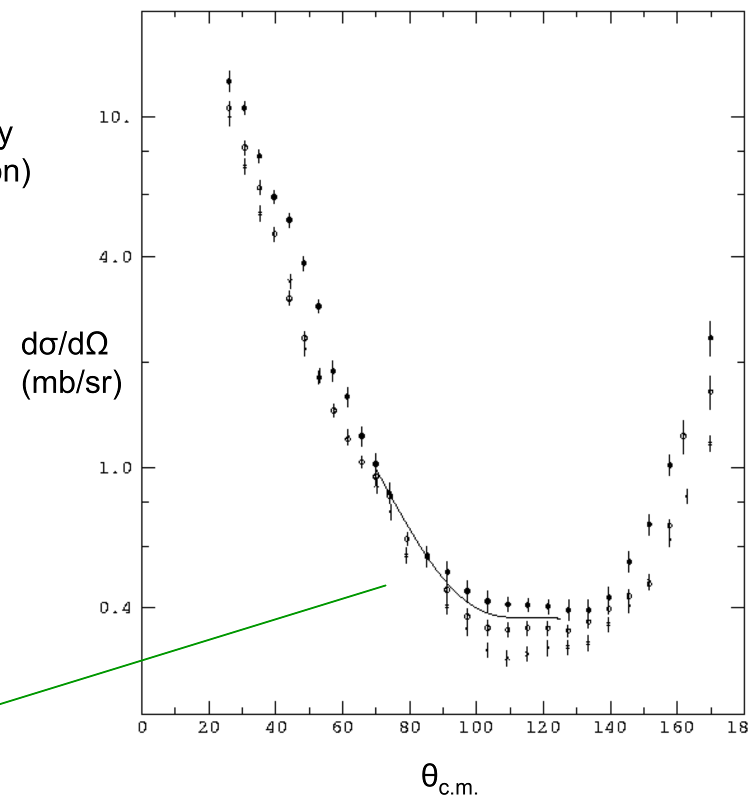
tapered/displaced scintillator pair for added position info.

NOTE:
Target distribution monitored using position sensitive silicon detector looking at recoil deuterons from small-angle scattering.
Detector acceptance determined using Monte-Carlo simulations.

Reference d+p cross sections: thesis of Karsten Ermisch, KVI, Groningen ('03).

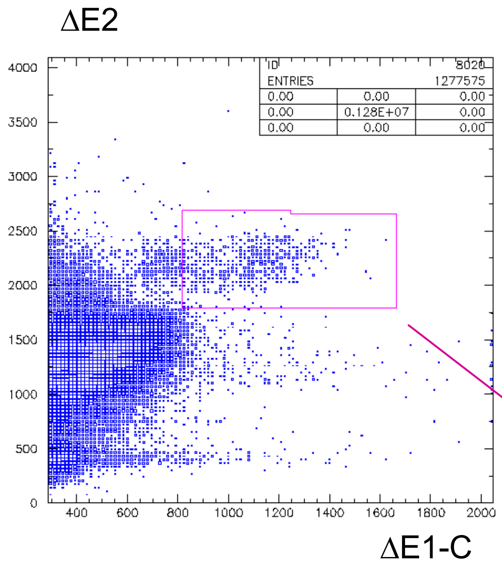
dot = 108 MeV
circle = 120 MeV
X = 135 MeV

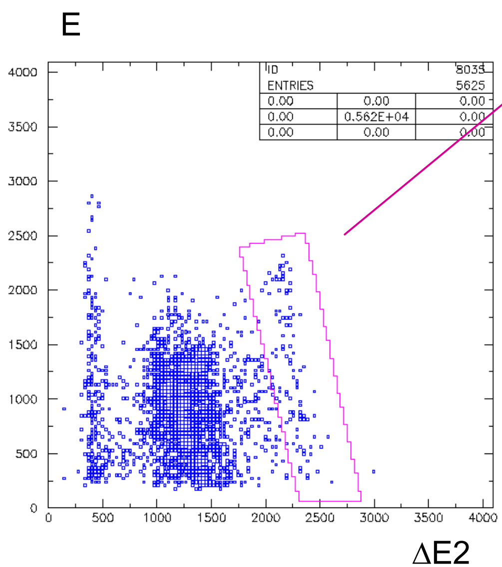
line = adopted cross section



INDENTIFICATION OF ^{4}He IN THE CHANNEL

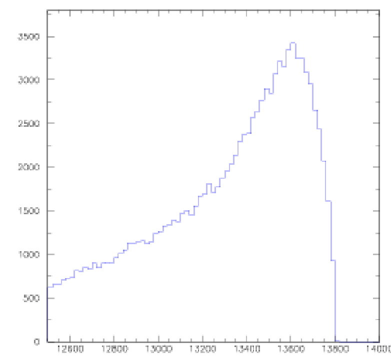
[online spectra for 5-hour run]





Proton rate from breakup ~ 10^5 /s.
Handle this with:
- veto longer range protons
- set timing to miss most protons
- reduce MWPC voltage to keep Z=1 tracks below threshold
- divide ΔE-1 into four quadrants

Set windows around ^{4}He group.
Rate still 10^3 too high.

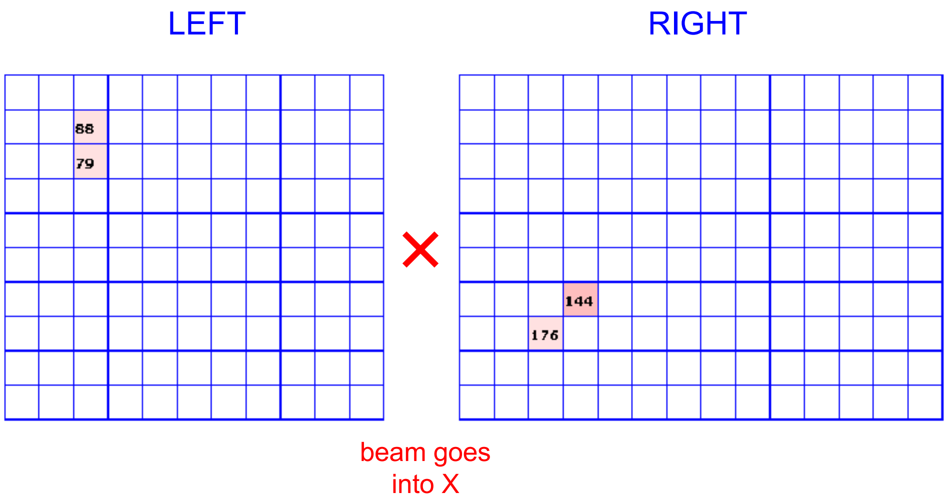


The ^{4}He flux, most likely from (d,α) reactions, is smooth in momentum and angle. It represents the part of phase space sampled by the channel.

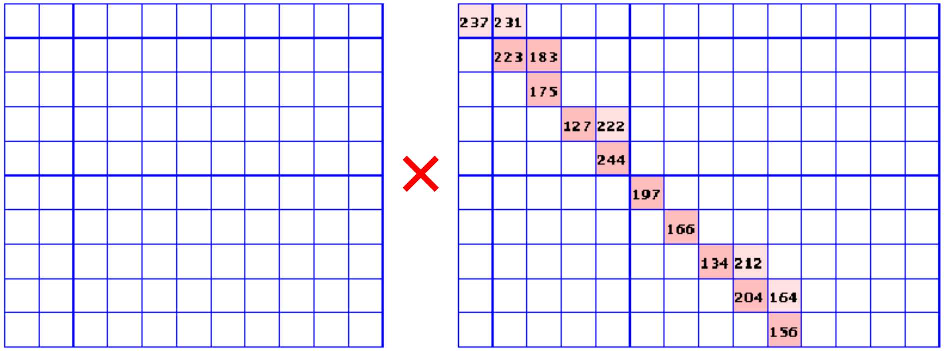
We absolutely need coincidence with the Pb-glass (decay γ) to extract any signal at all.

Pb-glass Hit Patterns

$\pi^0 \rightarrow \gamma\gamma$ from p+d $\rightarrow$ ^{3}He+π^0



cosmic ray muon

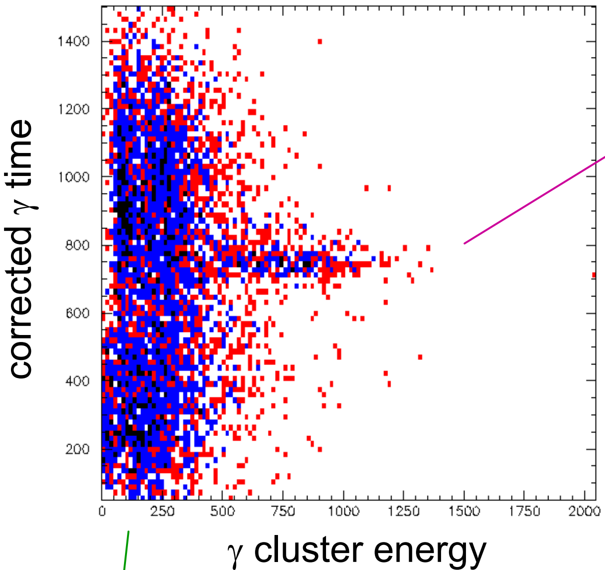


color scale: red > pink > blue

SINGLE AND DOUBLE GAMMA SIGNALS

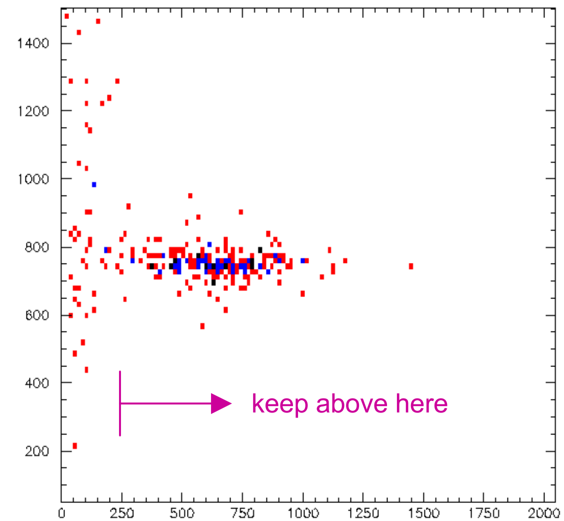
data for all of July run

Beam left-side array



A single γ may be difficult to extract.

But select on the similar locus on the other side of the beam, and the signal becomes clean.



We will require two γ's.

Many γ's come from beam halo hitting downstream septum.

List of requirements:

> correct PID position in channel scintillator energy

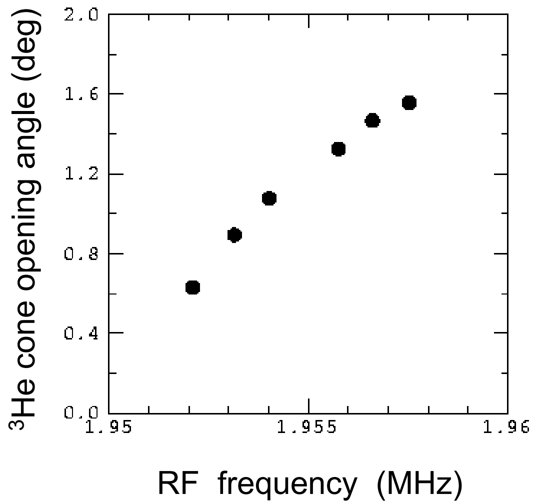
> correct range of TOF values

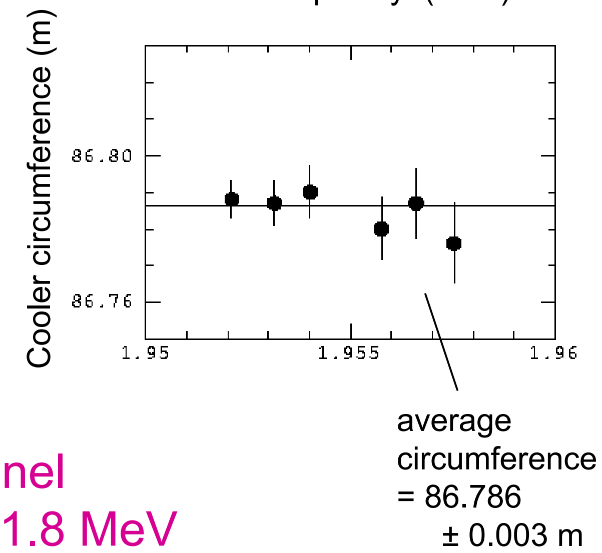
> correct Pb-glass cluster energies and corrected times

OTHER ITEMS

Stuff you have to get right!

Energy of Cooler beam known from ring circumference and RF frequency (~ 16 keV)





Calculation of He momentum depends on good model of energy loss in channel. This is also needed to set channel magnets.

Calculation of time of flight required knowing the time offsets for each scintillator PMT and tracking changes through the experiment. Final adjustments were made in replay.

Run plan:

- started in June at 228.5 MeV to keep cone in channel
- during 1-week break decided to raise energy to 231.8 MeV
  - demonstrate that peak stayed at pion mass
  - provide two cross sections to check energy dependence

(Limits were luminosity, rate handling, available time.)

Time Stability Problem

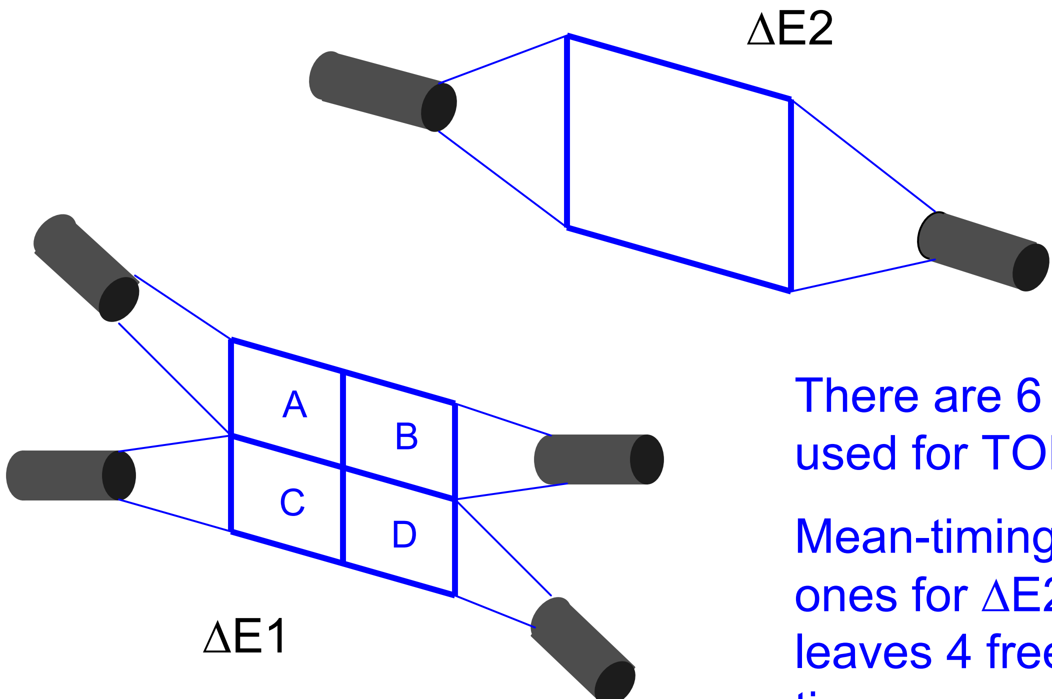
For good resolution, we need FWHM ~ 0.2 ns.

PMT signal transit time drifts and occasionally jumps as the tube ages, responding to heat.

Timing is affected when people change PMT voltage or swap other equipment.

This is also connected to missing mass reconstruction errors arising from 6° magnet dispersion, pulse height, and position effects.

A narrow peak helps π^0 separation statistically.

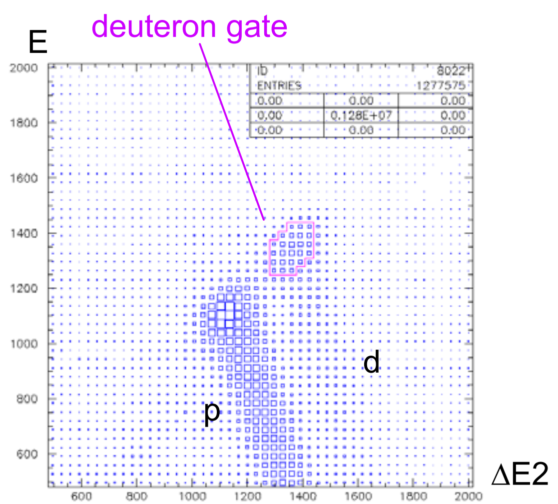


There are 6 PMTs used for TOF.

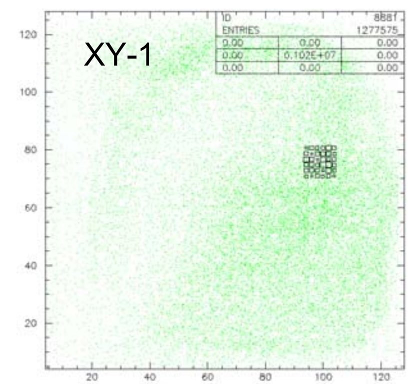
Mean-timing the ones for ΔE2 leaves 4 free time parameters.

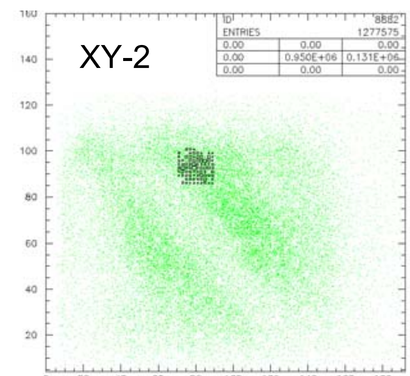
To make run-by-run corrections to TOF, we need a marker.
We use deuterons that stop and the back of the E scintillator.

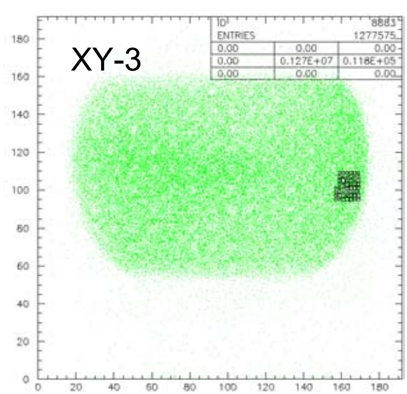
Choose Energy



Choose Trajectory

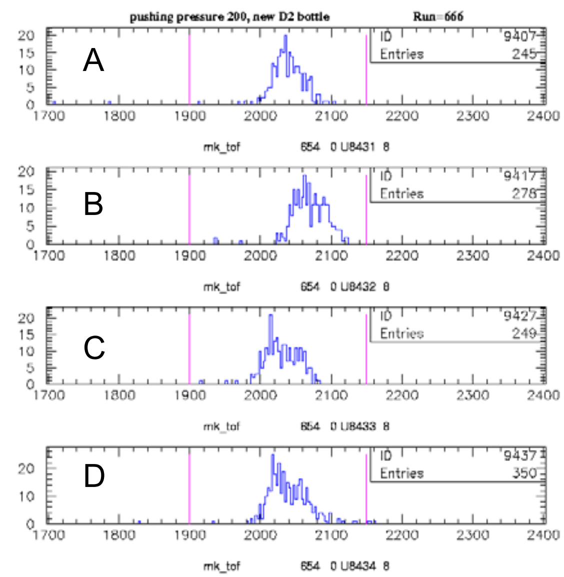




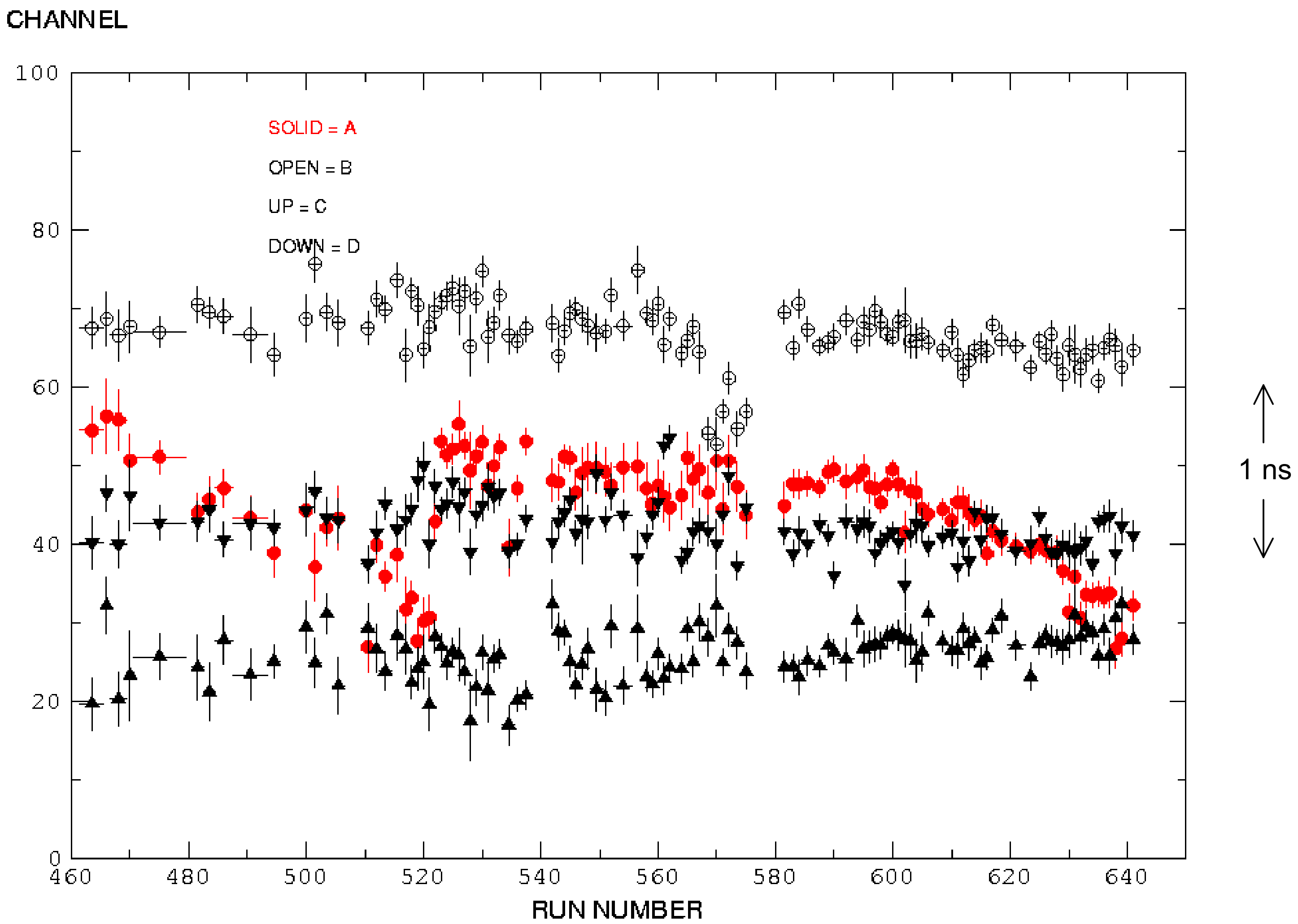


Resulting TOF peaks

ΔE1 scintillator:



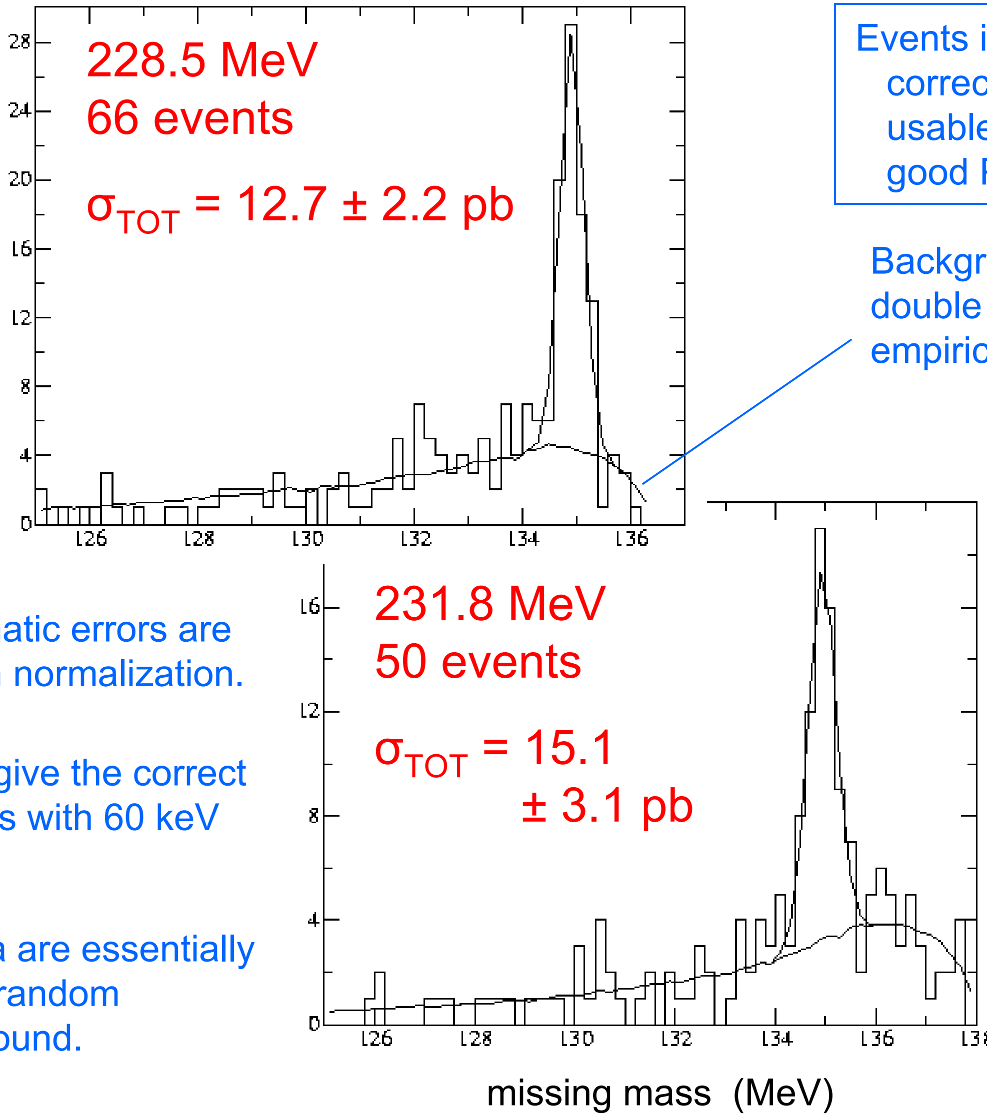
Results for June run:



RESULTS

Events in these spectra must satisfy:
- correct pulse height in channel scintillators
- usable wire chamber signals
- good Pb-glass pulse height and timing

Background shape based on calculated double radiative capture, corrected by empirical channel acceptance using ^{4}He.

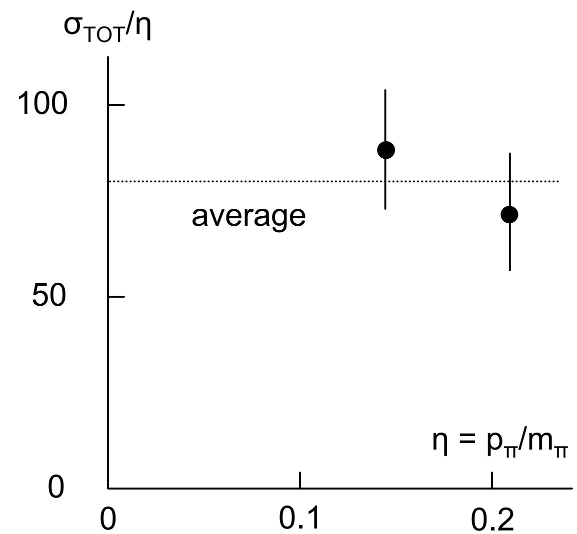


Systematic errors are 6.6% in normalization.

Peaks give the correct π^0 mass with 60 keV error.

Spectra are essentially free of random background.

Cross sections are consistent with S-wave pion production.

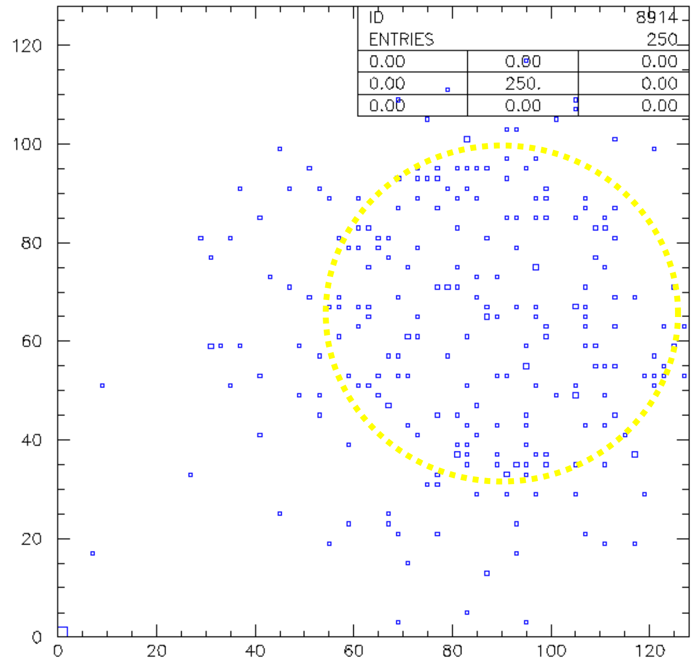


EXISTENCE?

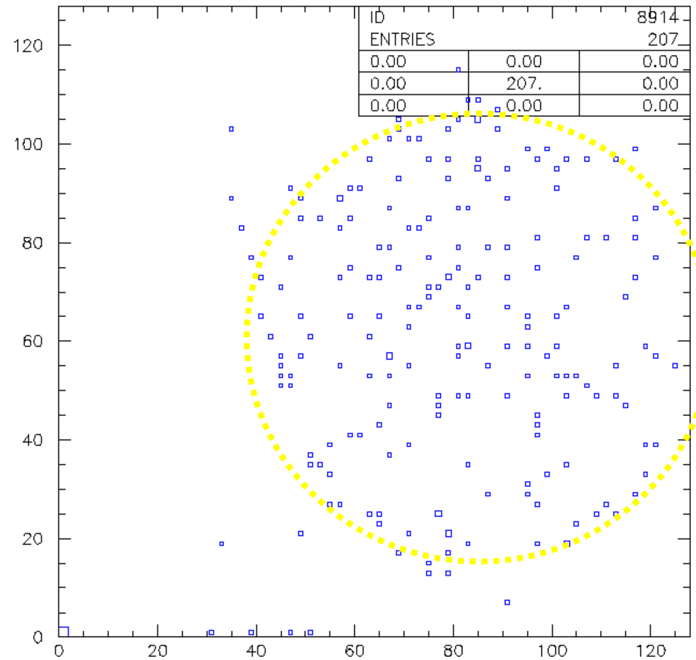
For the candidate events, check to see whether there is any cone.

XY-1 position

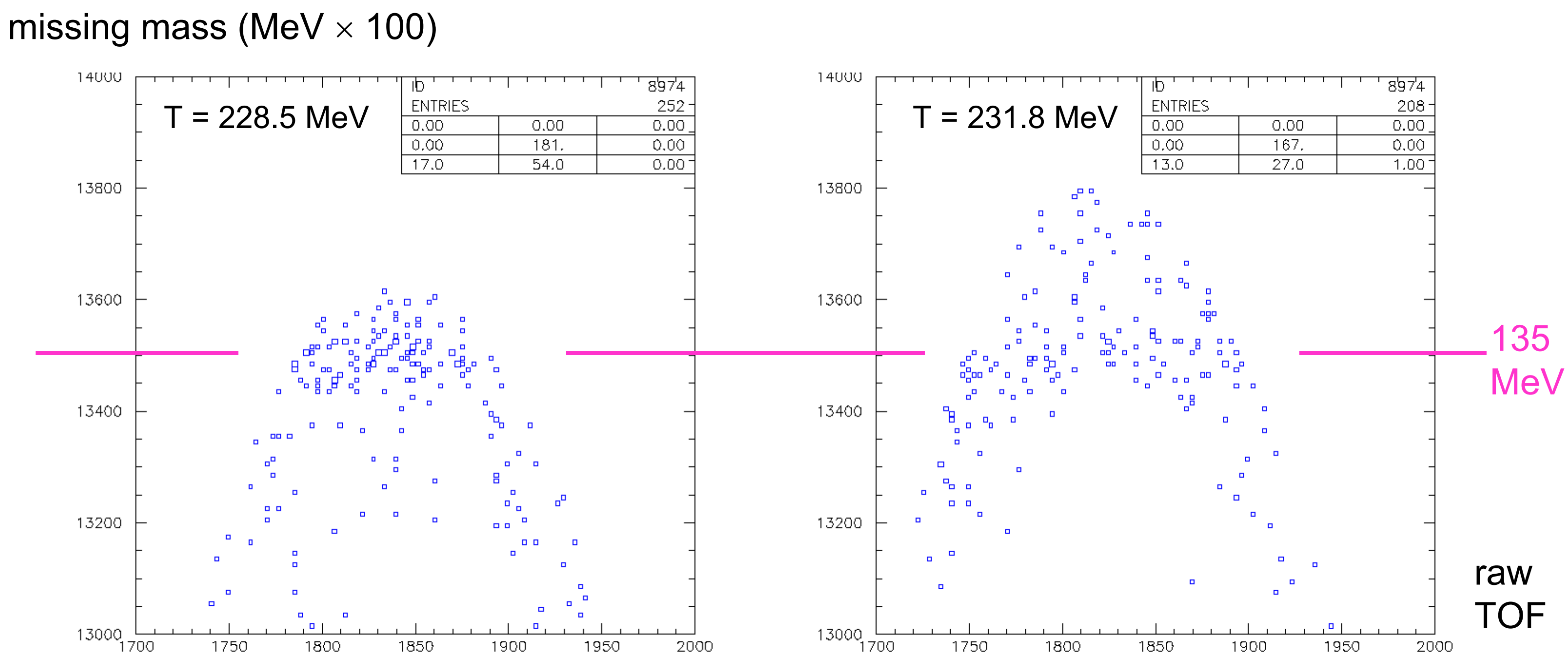
T = 228.5 MeV, θ_{max} = 1.20°



T = 231.8 MeV, θ_{max} = 1.75°



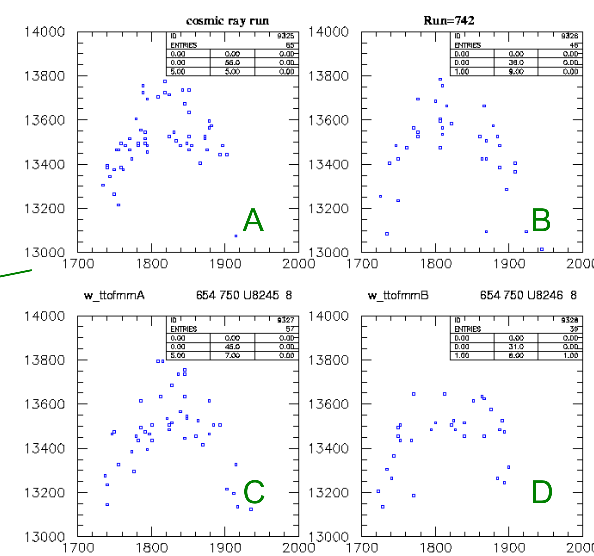
Circles with these centers also minimize the missing mass width.



IS IT CORRECT?

The missing mass should be independent of the TOF.

In fact, the time adjustments are made separately for each segment of ΔE1.



Framework from CHIRAL PERTURBATION THEORY

based on symmetries of QCD
uses nucleons (N) and pions (π) in low-momentum expansion

There are two contributions to charge symmetry breaking: (δm_N and $\bar{\delta} m_N$)
U. van Kolck, J.A. Niskanen, and G.A. Miller, PL B 493 (2000) 65

1. difference in the down and up quark masses

$$\mathcal{L}^{(1)}_{\rm qm} = \frac{\delta m_N}{2}\left(N^\dagger \tau_3 N - \frac{2}{DF_\pi^2} N^\dagger \pi_3 \pi\cdot\tau N\right)$$

2. electromagnetic

$$\mathcal{L}^{(-1)}_{hp} = \frac{\bar{\delta} m_N}{2}\left(N^\dagger \tau_3 N + \frac{2}{DF_\pi^2} N^\dagger (\pi_3 \pi\cdot\tau - \pi^2 \tau_3) N\right)$$

contributes to neutron-proton mass difference

contributes to pion production

THESE ARE CONNECTED

NOTE: δm_N and $\bar{\delta} m_N$ are not measures of either the quark mass difference or EM effects, but represent their contribution to the neutron-proton mass difference.

NOTE: There are also indirect contributions through neutron-proton mass difference, pion mixing, etc.

THEORETICAL CHALLENGE (estimates from Anders Gardestig)

Still to be included:
- realistic wavefunctions
  (D-wave, etc.)
- distorted waves (d+d)
- Δ-excitations
- photon loops
- heavy meson exchange

$$d + d \rightarrow {}^4\mathrm{He} + \pi^0$$

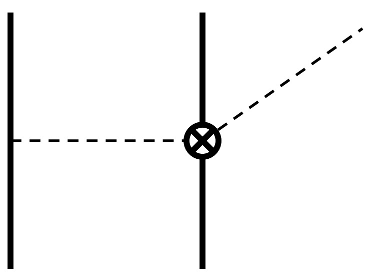
Coulomb isospin mixing

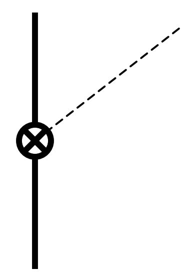
process (operators)

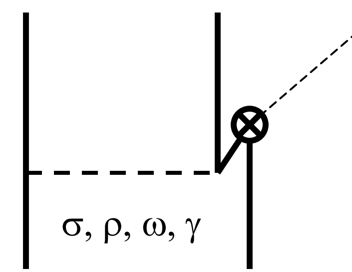
chiral perturbation theory
(pion nucleon scattering)

π – η mixing
(one-body amplitude)

heavy meson
exchange





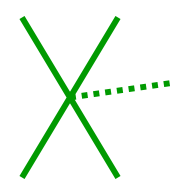


$$\frac{1}{2f_\pi}\left(\delta m_N - \frac{\bar{\delta} m_N}{2}\right) \approx 0.0022$$

$$\frac{g_\eta}{m_\eta^2}\left\langle \pi^0 \middle| H \middle| \eta \right\rangle \approx 0.0035$$

largest
so far

applies to:

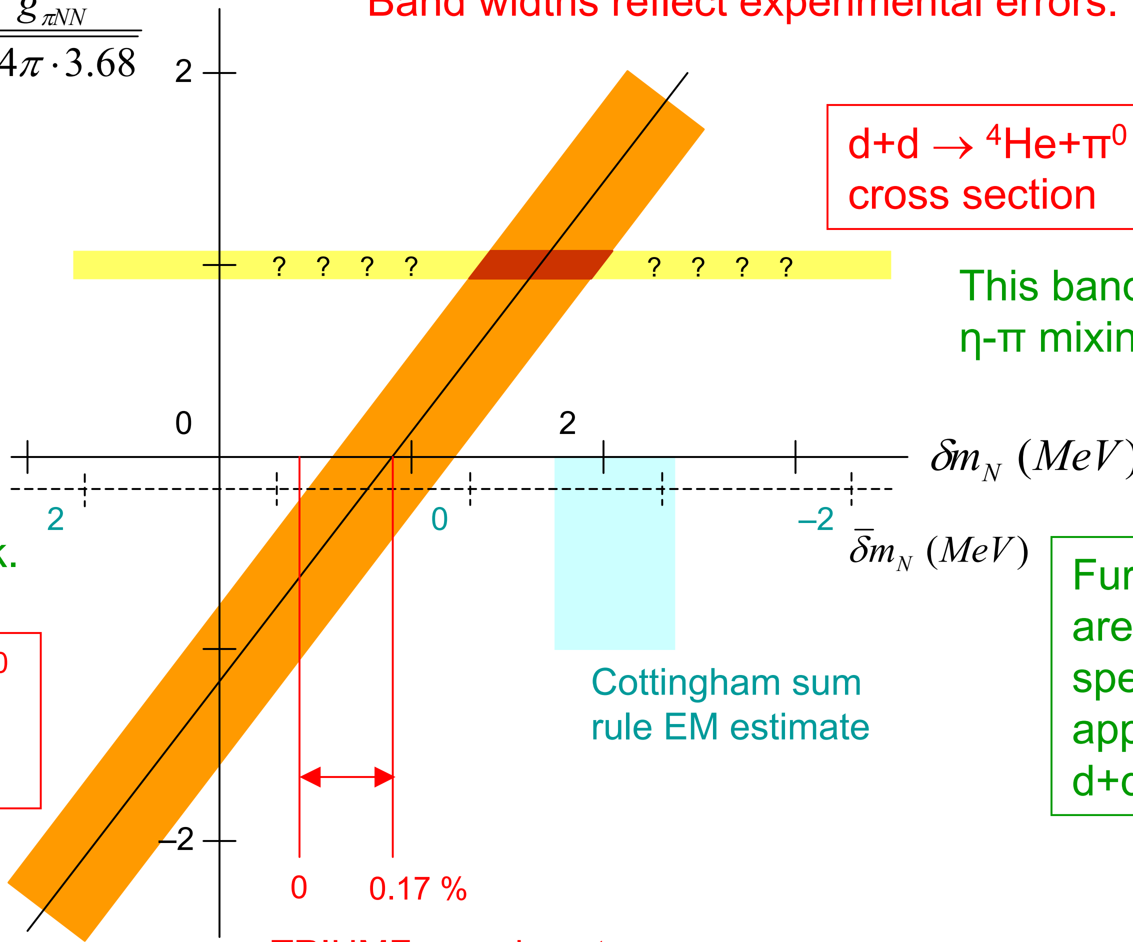


SUMMARY - one possible result

The relationship $\delta m_N + \bar{\delta} m_N = 1.29$ MeV is assumed.
Band widths reflect experimental errors.

$$\frac{\langle \eta | H | \pi \rangle}{-0.0059} \frac{g_{\pi NN}}{\sqrt{4\pi \cdot 3.68}}$$

A value of one means that η-π mixing is unchanged from the calculation of van Kolck.



d+d → ^{4}He+π^0 cross section

This band applies for η-π mixing dominance.

Further calculations are needed to specify the slope appropriate for d+d → ^{4}He+π^0.

n+p → d+π^0 fore-aft asymmetry

Cottingham sum rule EM estimate

TRIUMF experiment measures this gap

Experimental (active):

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Experiment (historical):

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Indiana University Cyclotron Facility, Bloomington, IN 47408

B. Chujko, A. Kuznetsov, V. Medvedev, D. Patalahka, A. Prudkoglyad, and P.A. Semenov, *Institute for High Energy Physics, Protvino, Moscow Region, Russia 142284*

S. Shastry, *State University of New York, Plattsburgh, NY 12901*

spokesperson for CE-82 and letter of intent
post-doc
technical manager
student

Underline did June/July shift work

Theoretical:

Antonio Fonseca, Lisbon

Anders Gardestig, Indiana

Christoph Hanhart, Juelich

Chuck Horowitz, Indiana

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