A Detector for *n-nbar* Oscillations in the NNBarX Experiment: Specifications and Challenges

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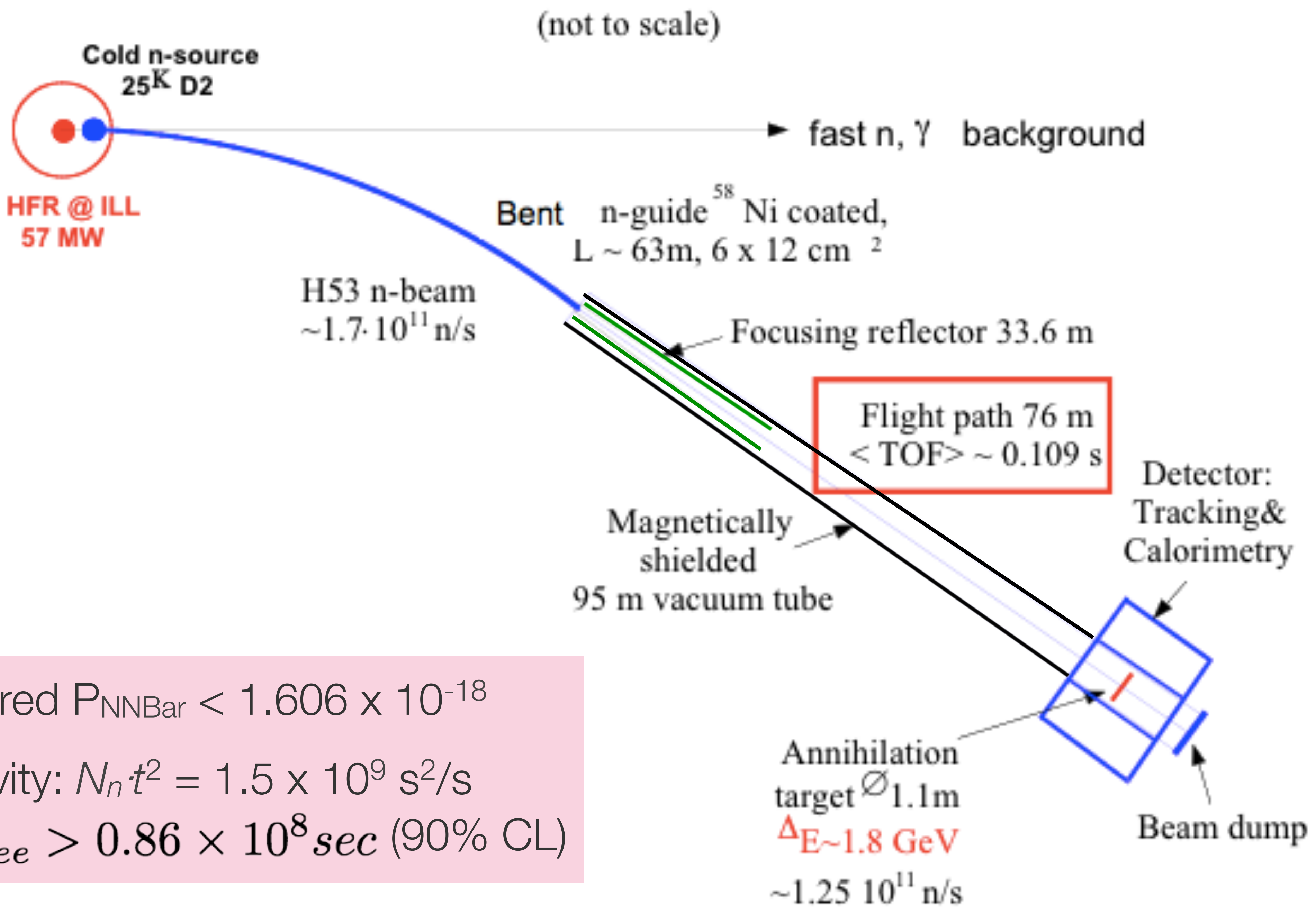
on behalf of the NNBarX Collaboration

Overview

- ILL Detector Review
- NNBarX Goals
- NNBarX Detector Specifications & Considerations
- LANL WNR Test Run
- Path Forward and Summary

ILL Layout

- Free neutron *n-nbar* search experiment in 1989 - 1991 at ILL [1]:



measured $P_{NNBar} < 1.606 \times 10^{-18}$

sensitivity: $N_n t^2 = 1.5 \times 10^9$ s^2/s

$\tau_{n\bar{n},free} > 0.86 \times 10^8 sec$ (90% CL)

ILL Experiment: general background and detector strategies

Backgrounds :

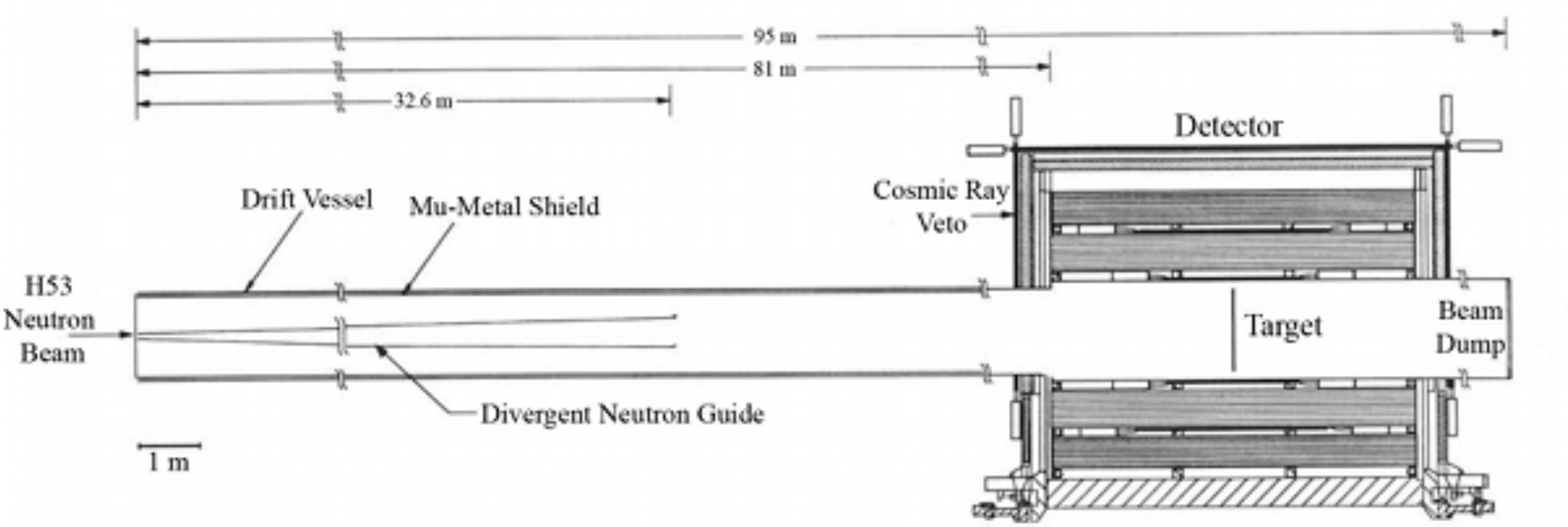
- Bent ^{58}Ni *n*-guides to eliminate γ's & fast *n*'s from reactor
- Complete containment of *n*-beam in propagation region
- 8 rings of ^{10}B-enr. glass in drift vessel (absorb vertically falling *n*'s), ^{6}LiF beam dump

Detector:

- High detection efficiency for annihilation events in target (4-5 pion "star")
- Combine tracking, timing, calorimetry to reject backgrounds

ILL Detector Configuration

- Effective run time = 2.4×10^7 s, $N_{events} = 6.8 \times 10^7$.
- *n-nbar* detection efficiency ($\Delta\Omega/4\pi = 0.94$): 52% ± 2%.
- No background & no candidate events after analysis.



ILL Detector Configuration

ILL Target [2,3]: 130 μm thick.

$$\sigma_{annihilation} \sim 4\text{Kb}$$
$$\sigma_{nC,capture} \sim 4\text{mb}$$

ILL Scintillator Counters [4,5]:

$$\sigma_{TOF} \sim 600\text{ps}$$

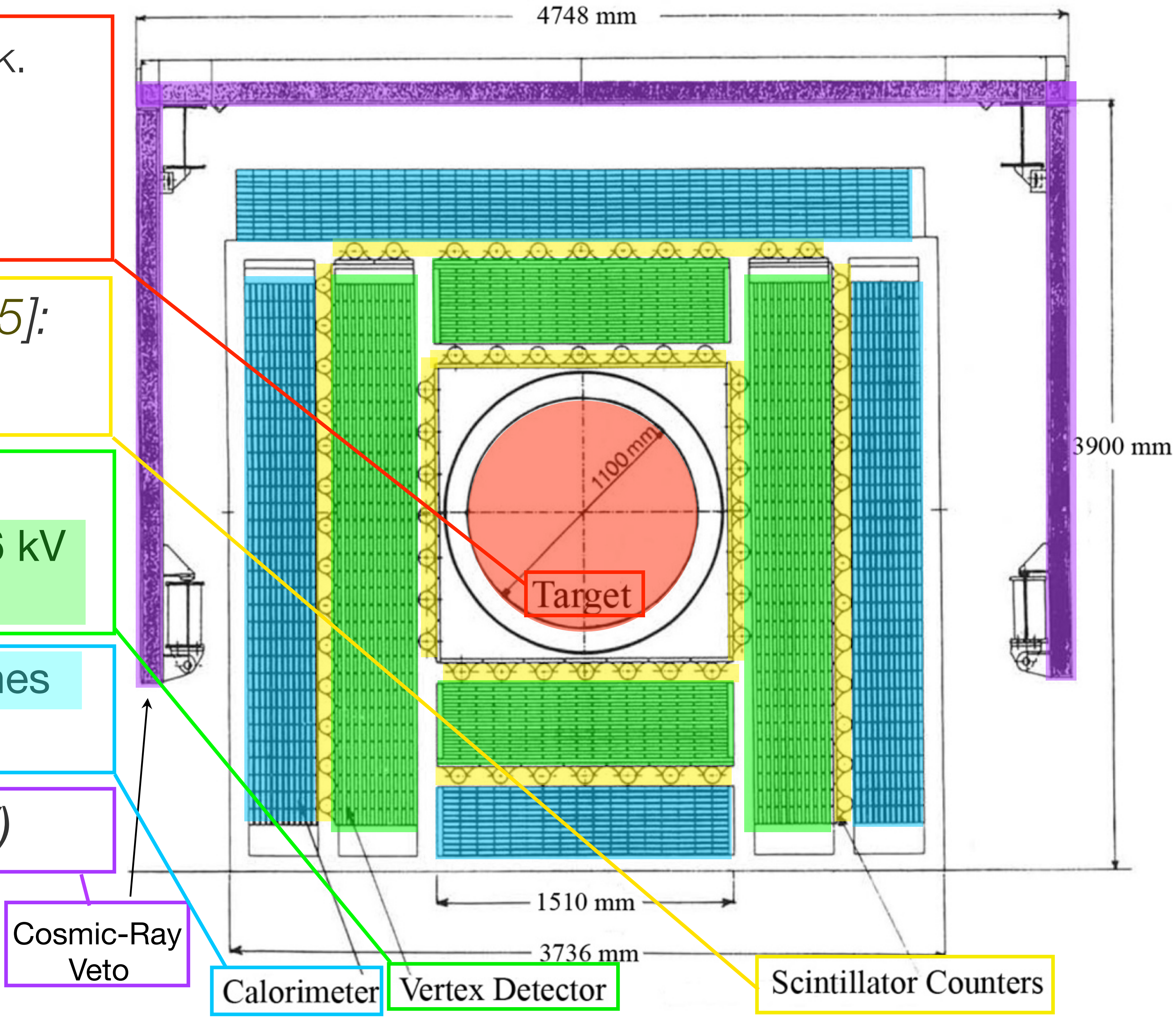
ILL Vertex Detector [6]:

10 LST planes operated at 4.6 kV
Vertex = ±4 cm; $\rho = 0.3\text{g/cm}^3$

ILL Calorimeter: 12 LST planes interleaved w/Pb & Al plates.

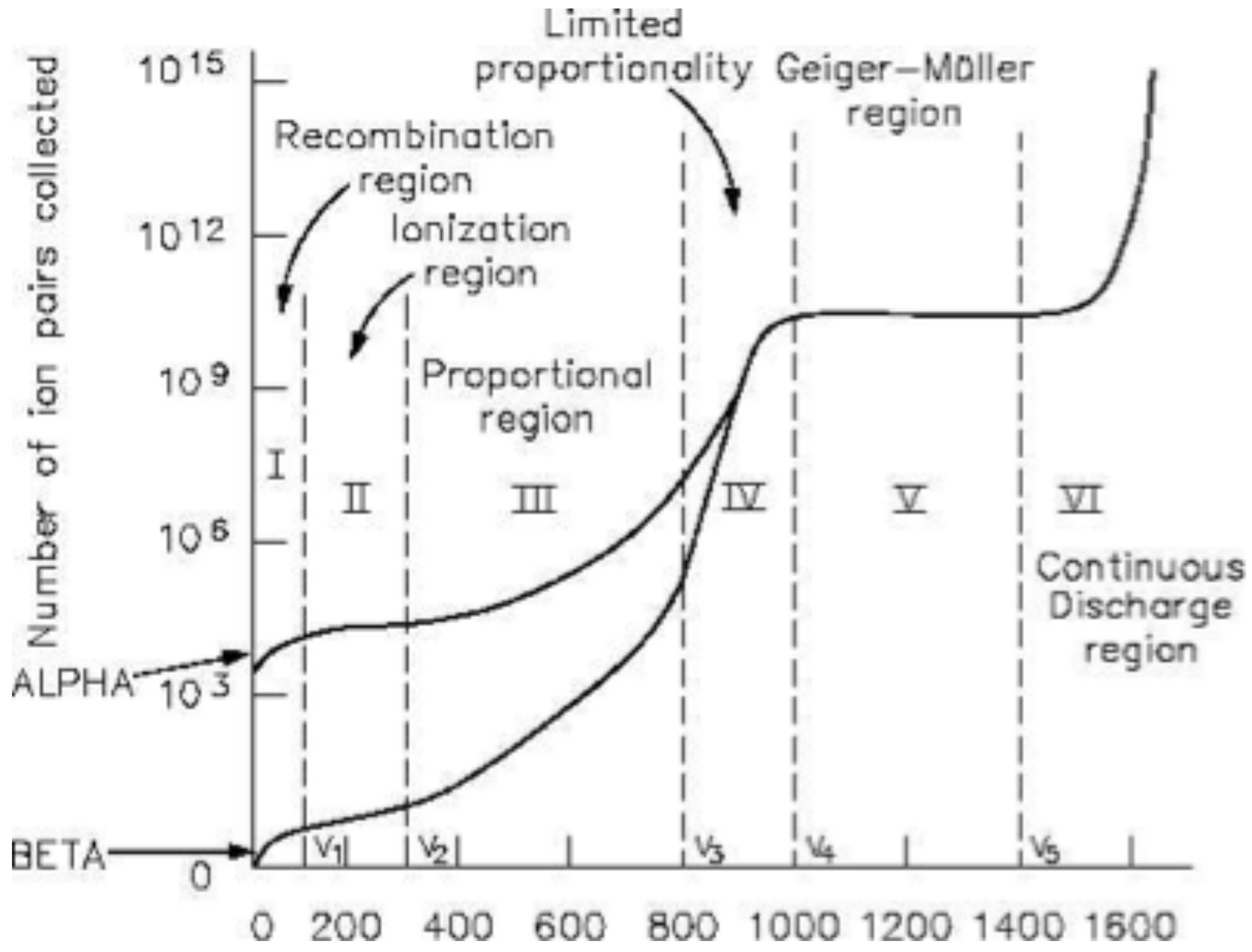
ILL Cosmic-Ray Veto (CRV)

6.0x10^4 electronics chnls.



LST Characteristics

- One application of the limited streamer tube (LST) is the Iarocci tube [6,7].



- conducting cathode surface.

- equiv. to single wire drift chamber.

- Long (recent) history of usage in large experiments to detect muons: *CLEO* [8], *OPAL* [9,10], *ZEUS* [11], *D0* [12,13,14], *BaBar* [15].

ILL Triggers, Cuts, Acceptance

1 MHz raw triggers due to capture gammas…

Trigger Requirement	Trigger Rate (Hz)
1) Coinc. Of Inner & Outer SC (same det. quad.) in anticoinc. w/CRV.	2000
2) Cond. 1) + 1 track in same vtx. det. quad. as SC coinc.	800
3) Cond. 2) + 1 SC hit (diff. quad.) + 2nd track (in vtx. det. or calor.)	6
4) Cond. 3) + ≥ 120 hits in LST det. (> ~400 MeV)	4

A little over ½ due to spurious, γ-induced triggers
rest essentially due to cosmics

$\varepsilon_{trig} = 77\%$

SW Filter Requirement	Data Acceptance	MC Acceptance
2.0 GeV > E_{vis} > (0.87 ± 0.17) GeV, $R_{orig} \leq 80$ cm	10.0%	85.0%
TOF: $T_{SC,OUT} - T_{SC,IN} < 5$ ns	16.4%	96.0%
Vertex: $R_{orig} \leq 60$ cm, $\|z\| < 32$ cm, $\theta_{track} > 170^o$	1.2%	89.0%
Total	0.018%	72.0%

ε_{filter}

ILL Triggers, Cuts, Acceptance

N_{events} surviving SW Filter: 1.2x10^4

Analysis Requirement	Remaining Events
Incorrectly reconstructed vtx. (visual inspection)	403
Charged CR	335
$R_{orig} \leq 55$ cm, $\lvert z \rvert \leq 15$ cm	5
$E_{vis} > 800$ MeV	2
$y_{vb} > -60$ cm	0

$\varepsilon_{analysis} = 95\%$

$\varepsilon_{trig} \bullet \varepsilon_{filter} \bullet \varepsilon_{analysis} = (52 \pm 2)\%$ [1]

Final cuts correspond to: $E_{thresh} >$ ~800 MeV, at least 1 charged particle track, at least two "tracks", vertex reconstructs to target

NNBarX

- Adapt detector to cold neutron source driven by 1 MW spallation target with very large increase in flux due to concentrating optics
- Goal: 0 background events, ε > .5 for annihilation events
- Challenges:
  - Fast backgrounds possibly present (pulse structure)
  - Larger CN fluxes may increase capture gamma rates
  - Affordability

NNBarX Strategy

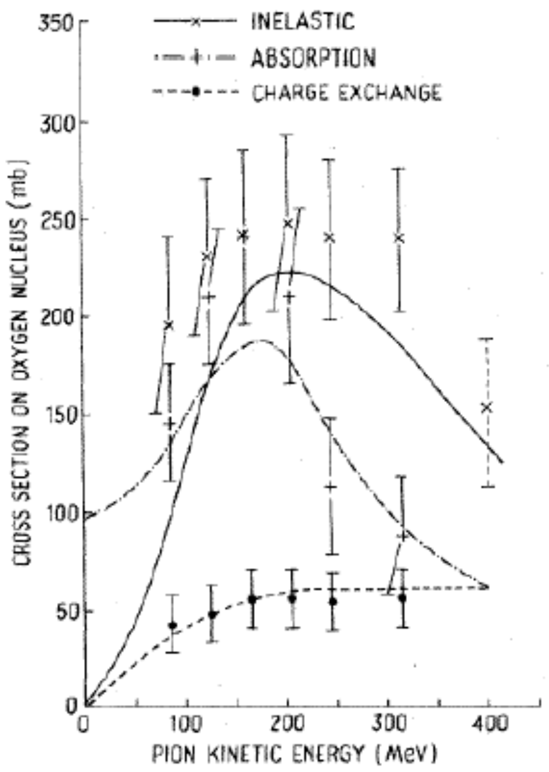
- Scale successful ILL geometry to larger beam and target size required for NNbarX
- Identify promising technologies for tracker and calorimeter, signal is ~5 π's from common vtx. (w/~200 MeV K.E. each), similar requirements to stopped kaon experiments (see E949)
- Evaluate candidate geometries with target performance specifications
  - Annhilation events, ε > 0.5
  - Improved vertex reconstruction (± 1 cm)

NNBarX Annih. Event Simulation

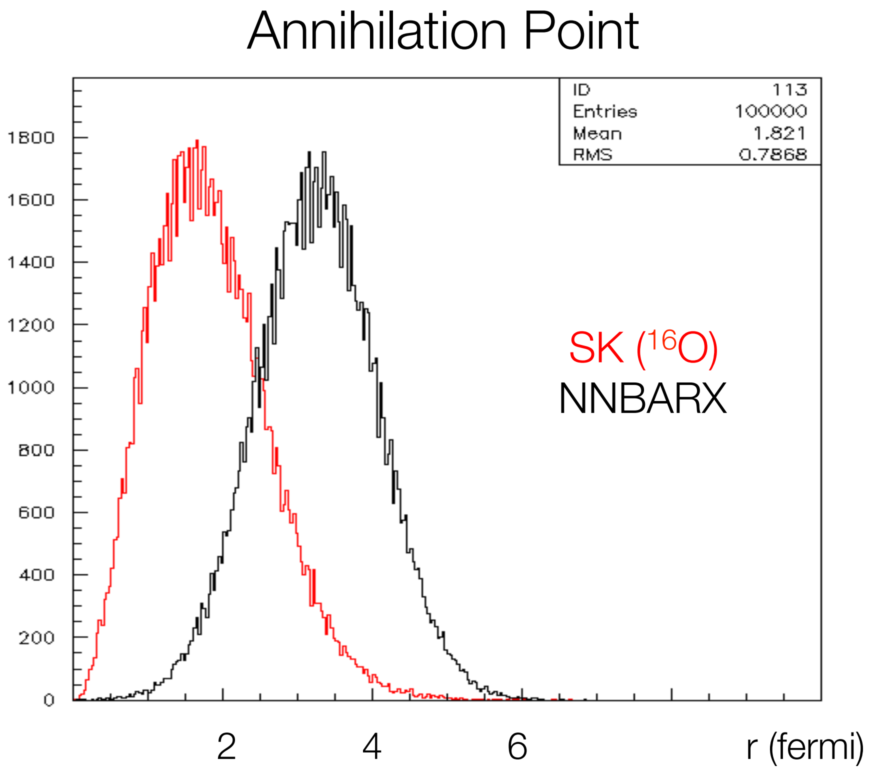
Branching Fractions

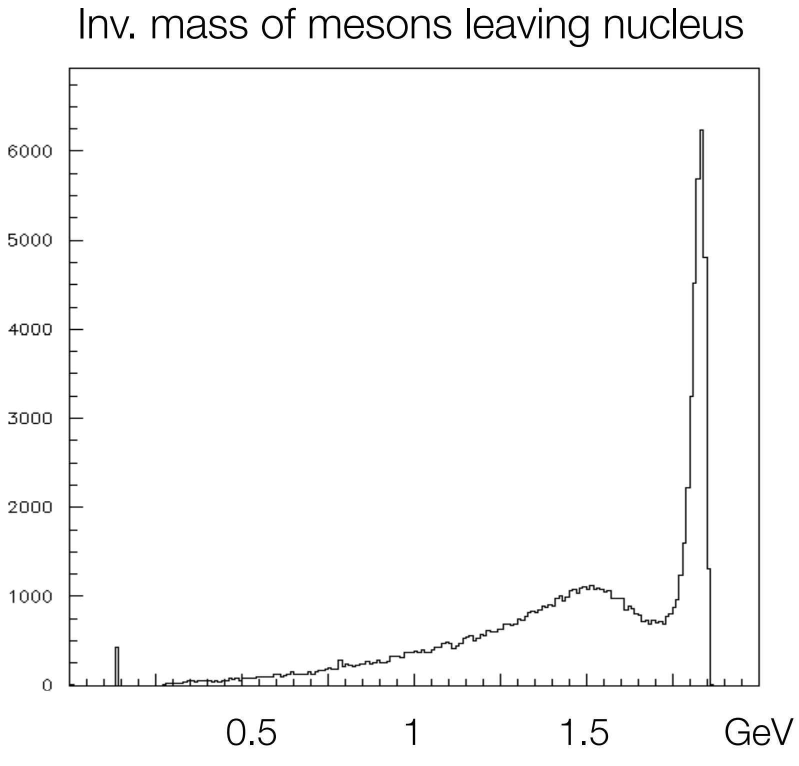
$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1%	$\pi^+\pi^-$	2%
$\pi^+2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	10%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	22%	$\pi^+\pi^-2\pi^0$	11%
$2\pi^+\pi^-2\pi^0$	36%	$\pi^+\pi^-3\pi^0$	28%
$2\pi^+\pi^-2\omega$	16%	$2\pi^+2\pi^-$	7%
$3\pi^+2\pi^-\pi^0$	7%	$2\pi^+2\pi^-\pi^0$	24%
		$\pi^+\pi^-\omega$	10%
		$2\pi^+2\pi^-2\pi^0$	10%

X-sections rescaled for ^{12}C



Annih. event generator based on IMB expt. code
(K. Ganezer, B. Hartfiel, CSUDH)


Annihilation Point


Inv. mass of mesons leaving nucleus

Fast Backgrounds

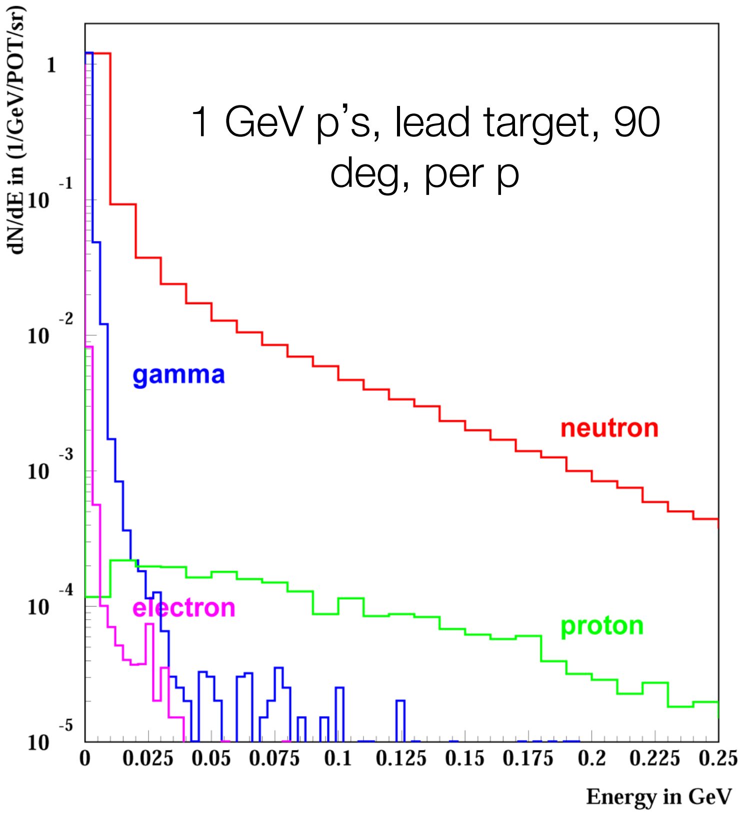
- Beam for Project X: quasi-CW 1 GeV

  Quasi-continuous production of fast *n*’s, protons and γ’s.

- Cold neutron beam has mean velocity of roughly 600 m/s

Two scenarios:

1. Beam on always
   - max. CN flux
   - max. fast backgrounds
2. Pulsed beam – e.g 1 ms on, 1 ms off
   - CN flux x 0.5
   - No fast backgrounds



1 GeV p’s, lead target, 90 deg, per p

S. Striganov (FNAL)

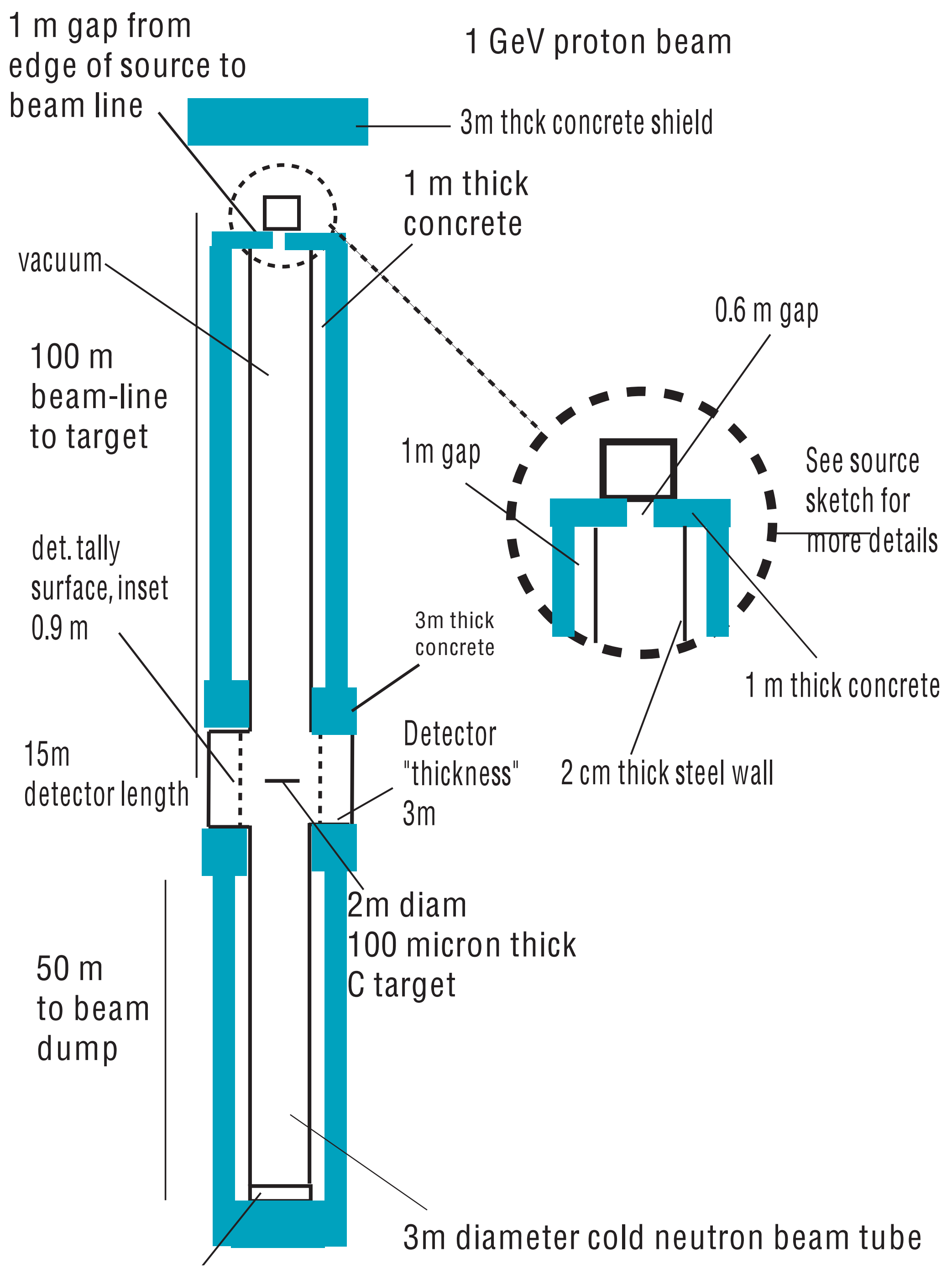
NNBarX Layout

Default geometry will suppress fast backgrounds using passive shielding wherever possible

Tracker detector selection favors gas counters (with minimal hydrocarbons) to suppress sensitivity to fast n's

evaluate detector response to fast n's!

Experiment design and simulation requires integrated treatment of CN source, beamline and detector to model backgrounds



MCNPX and GEANT simulations in progress

NNBarX Det. Candidate Tech.

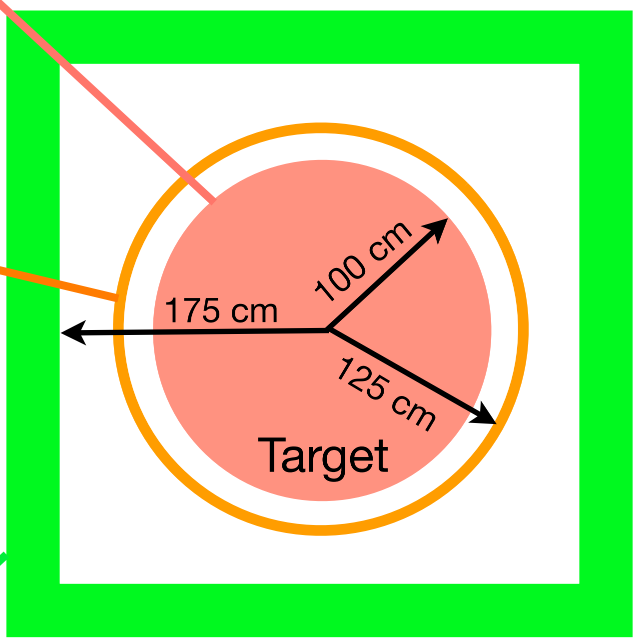
Annihilation Target: 100 **μm** thick ^{12}C disk control ^{1}H to < 0.1% (reduce gen. of capture γ's)

Vacuum Region: mag. shielded low *Z* wall (for low (n,γ) x-section & reduces mult-scattering)

Inner Lining: need to reduce gen. of γ's by captured *n*'s (^{6}LiF or similar)

Tracker: annih. vtx. Reconst. *rms* ≤ 1 cm Solid angle coverage of min. ~20° – 160°

Possibilities: straw tubes, range stack MWPC's, polystyrene scintillating bars



NNBarX Det. Candidate Tech.

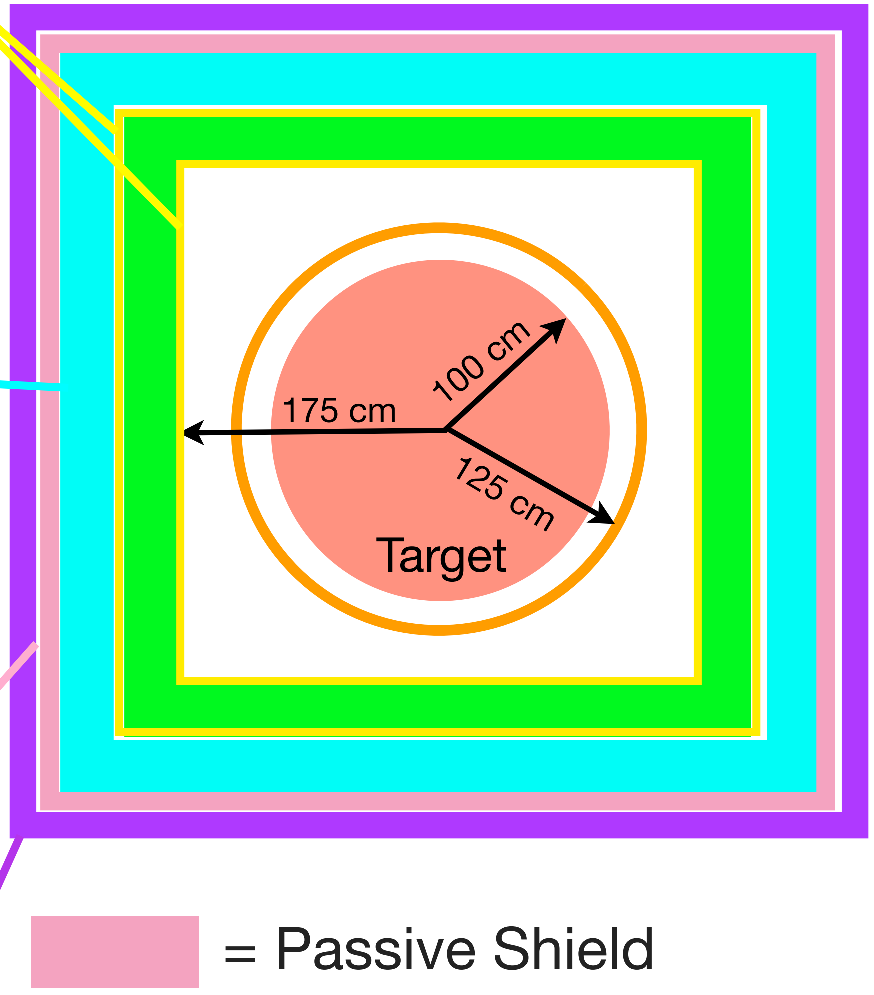
TOF System: 2 layers of fast detectors
Before and after Tracker
Discriminate betw. CR’s and annih.-like tracks

Calorimeter: stop all annih. products here
Solid angle coverage of min. ~20° – 160°

MINERvA-like wavelength shifting fibers
w/scintillating bars (+SiPM/PMT) [16]

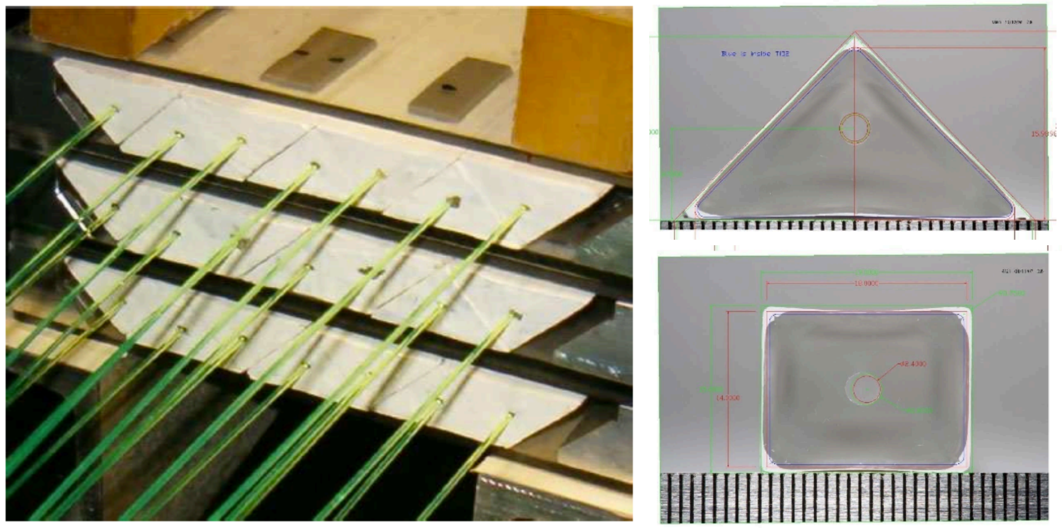
Passive Shield: veto neutral CR’s
prevent autoveto of *nbar*-annih. events

Cosmic-Ray Veto: identify all CR bkgd
MINOS-like scintillator supermodules [17]
(8m L x 15m W, 95–97% efficiency)



NNBarX Scintillator Candidates

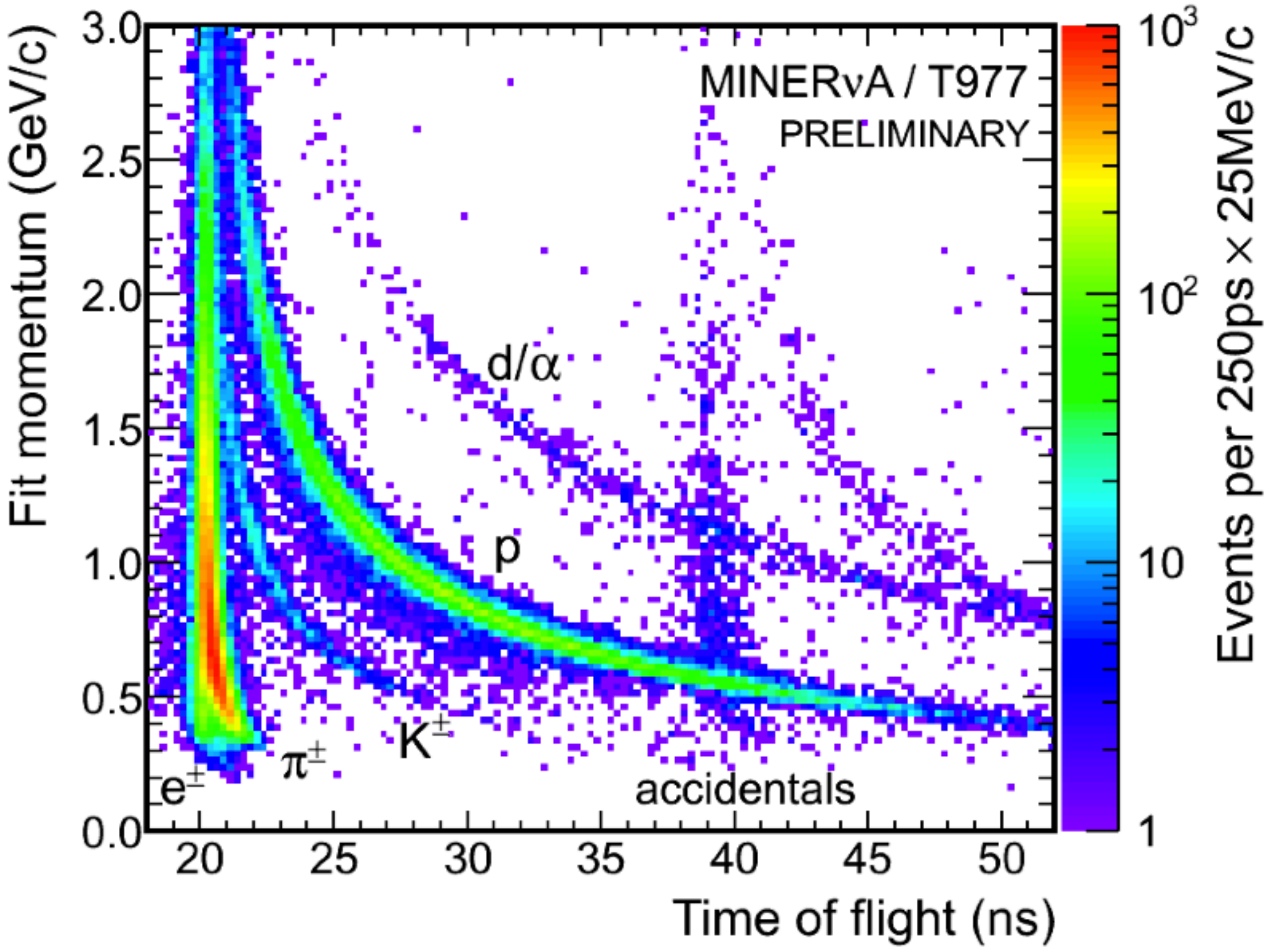
MINERVA Extruded Scintillator
(Affordable & Produced at FNAL)



MINERvA images credit: E. Ramberg (FNAL)

PMT or SiPM

Content of Tertiary Beam from TOF System –
MINERVA T977 Test Beam Experiment Data



Need to consider add'l alternatives.

NNBarX Tracker Candidates

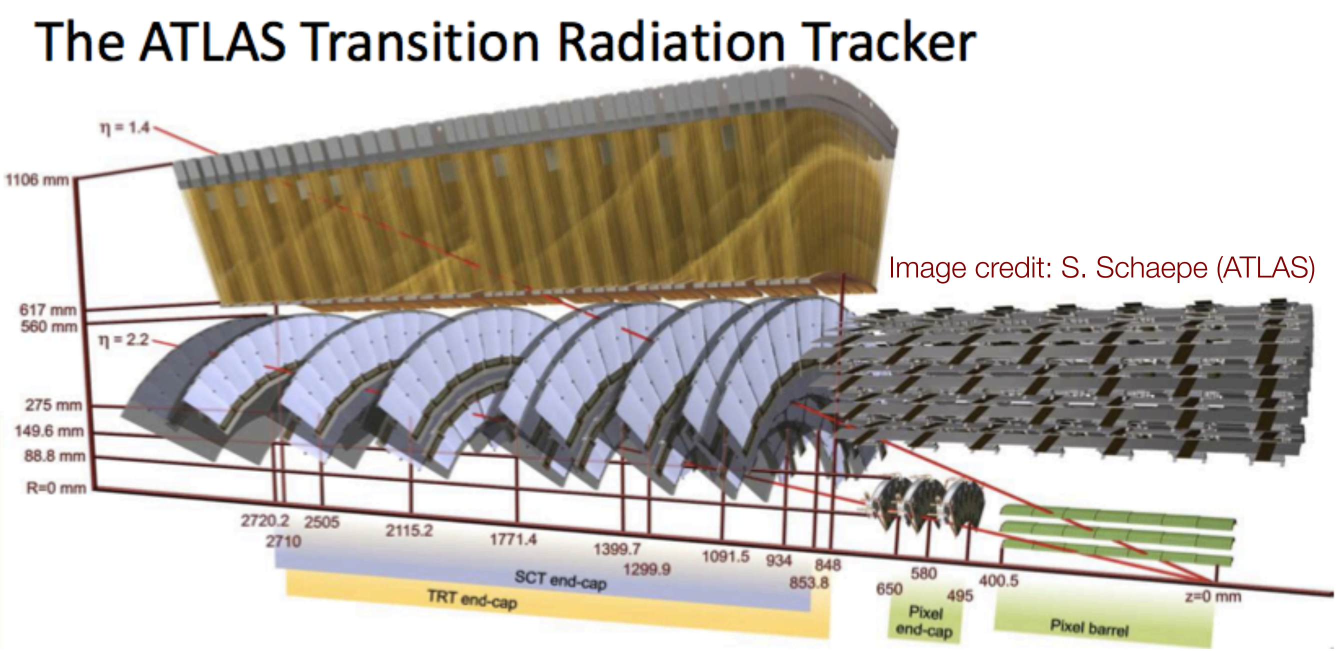
- Straw tube array in barrel and end-cap configuration (ala ATLAS).

- ATLAS TRT – hit precision: ~130 μm, ε ~ 94%, [18].

- Straw tube fill gas options need to be identified and tested.

Other Options

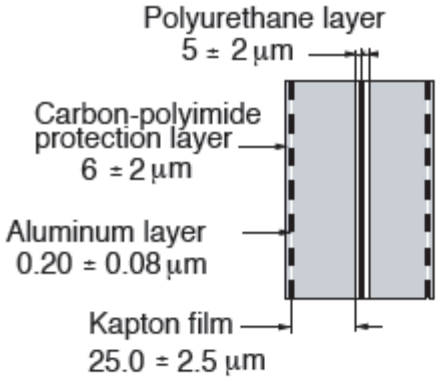
- Range stack MWPC's., polystyrene scintillating bars.

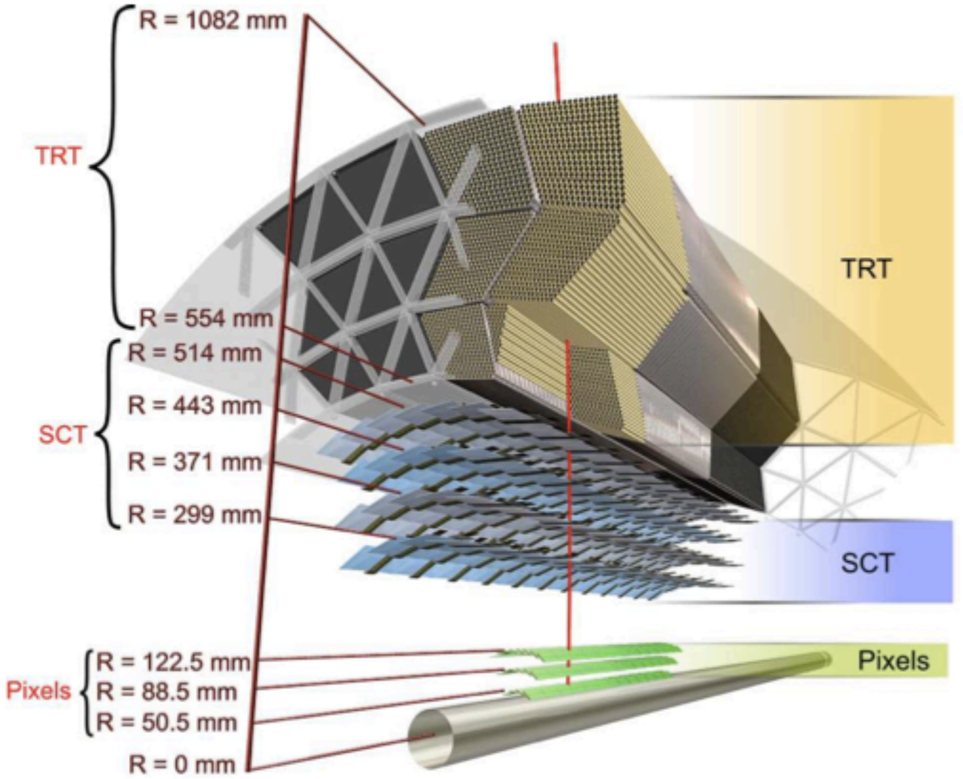


The ATLAS Transition Radiation Tracker

Image credit: S. Schaepe (ATLAS)

Straw Tube Schematic





TRT Assembly at Indiana University

R&D Program: WNR Tests

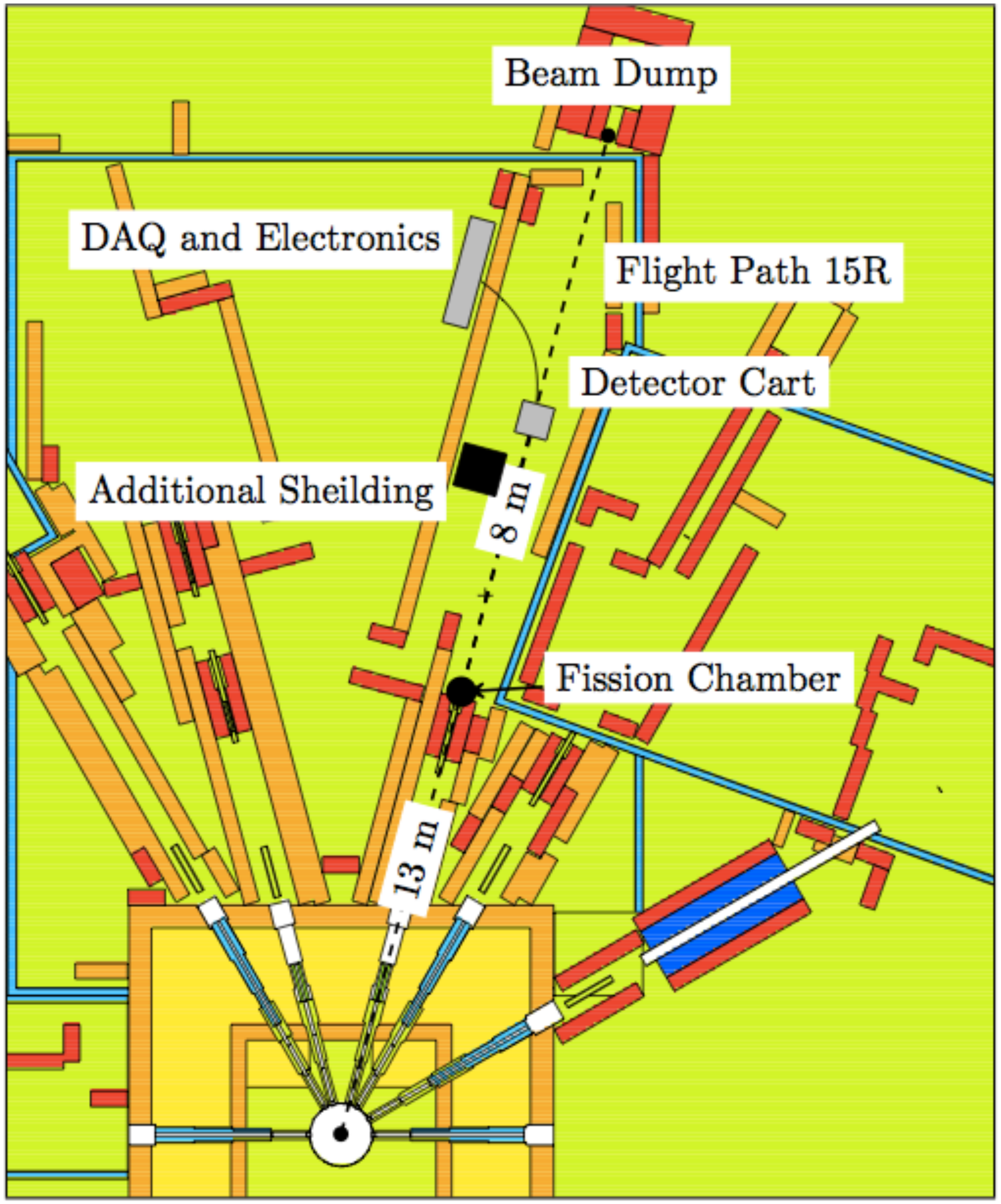
Goal: evaluate response of specific gas and plastic scintillators to fast neutrons (few MeV < E_n < 800 MeV)

Technique: use known absolute n spectrum for pulsed beam at LANSCE WNR facility to measure efficiency (and timing) vs. energy

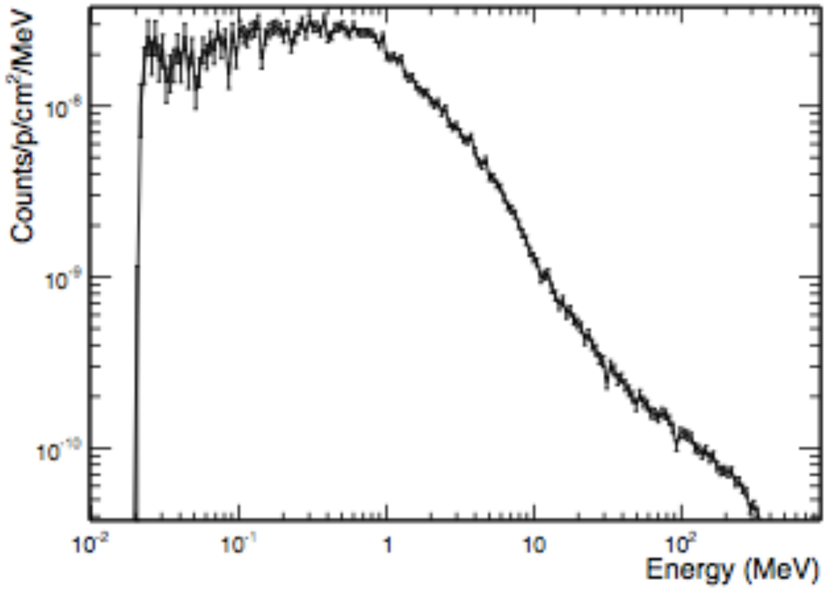
Detectors: Atlas straw tubes (delayed till fall)
fission foil detector
carbon fiber gas proportional counters
plastic scintillator

WNR Tests - Layout

LANL WNR-15R Beamline



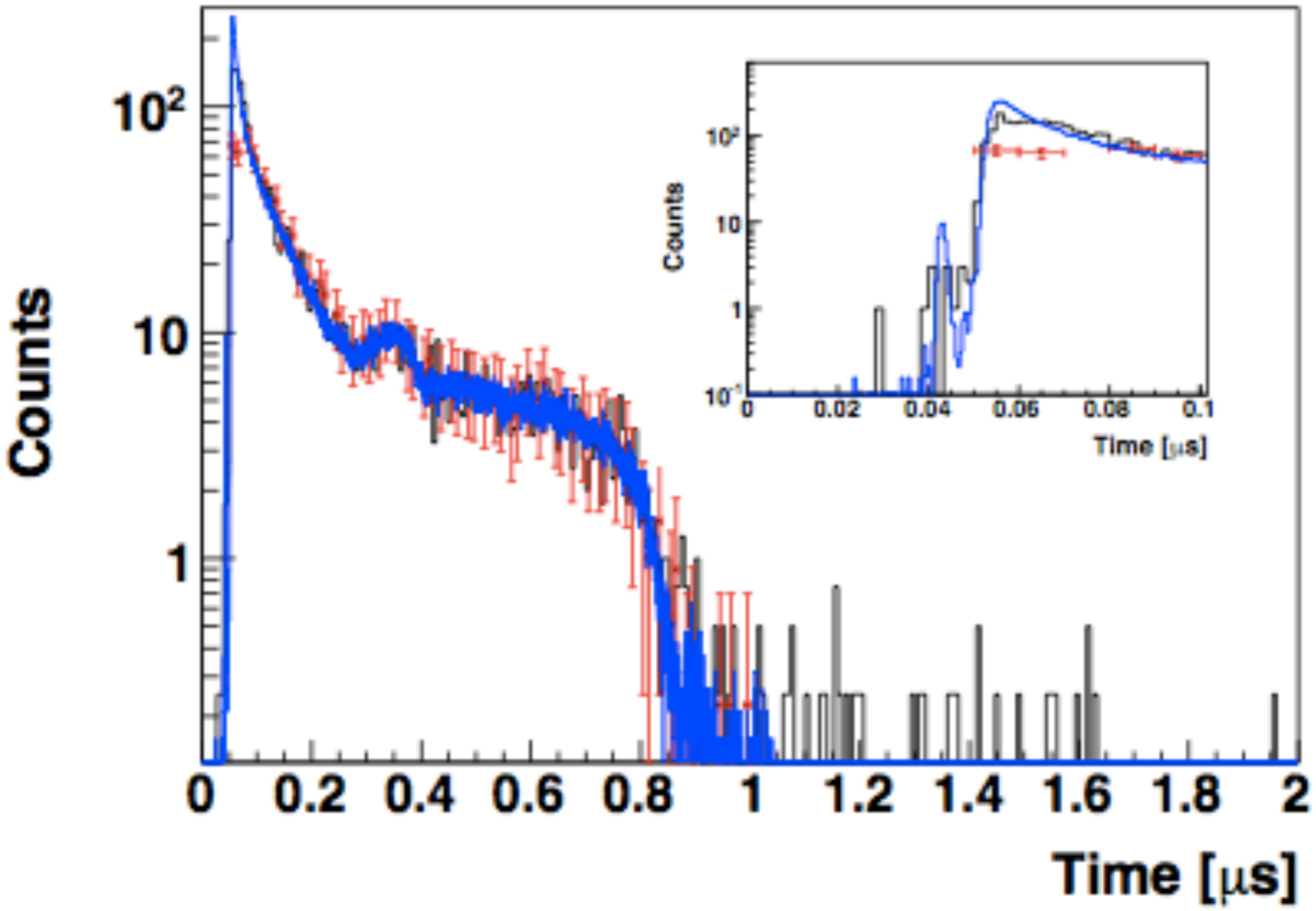
Predicted *n*-flux 20m from target



Interested in these energies

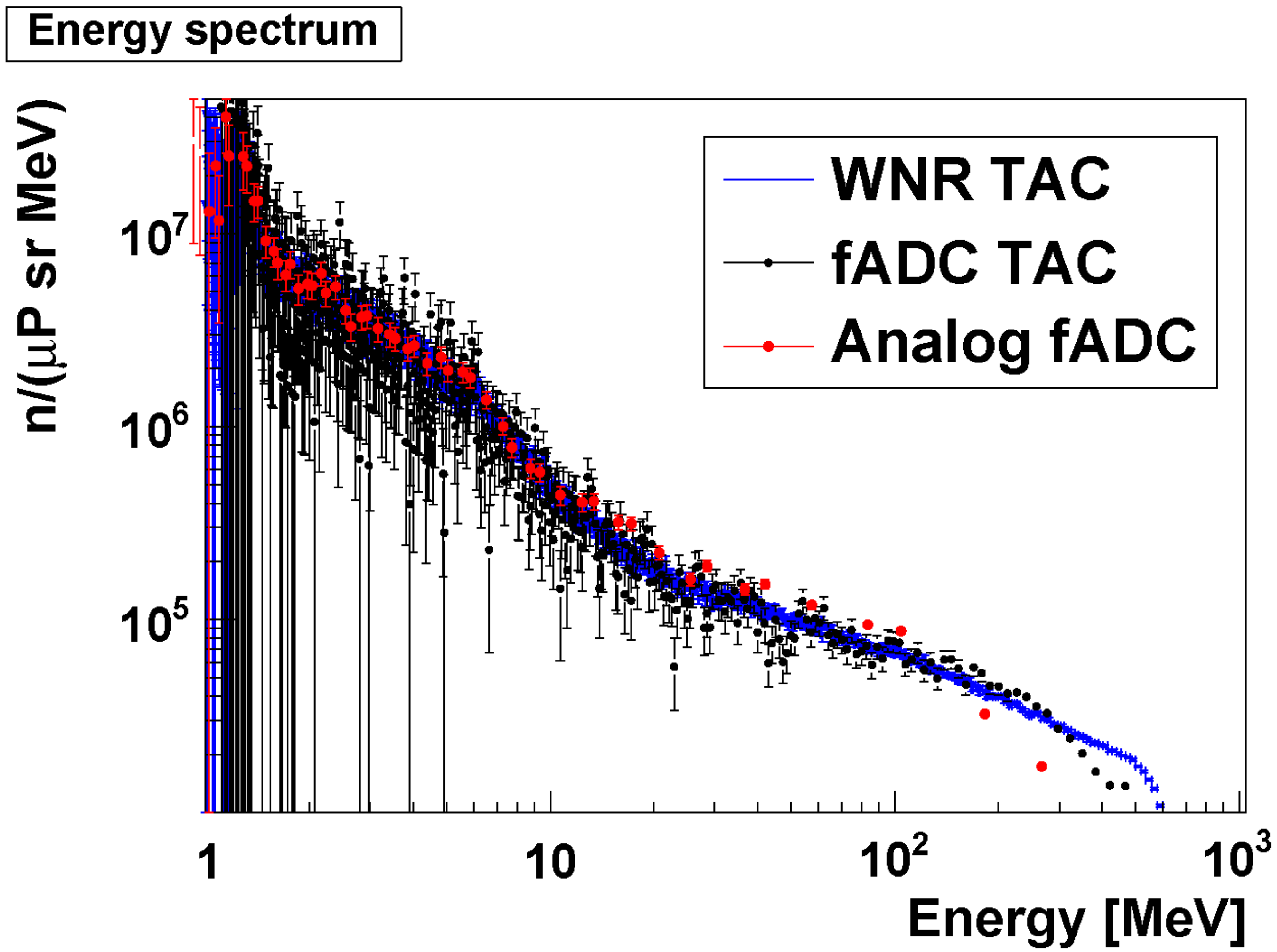
WNR Tests - Fission Foil

Fission Chamber TOF Spectra

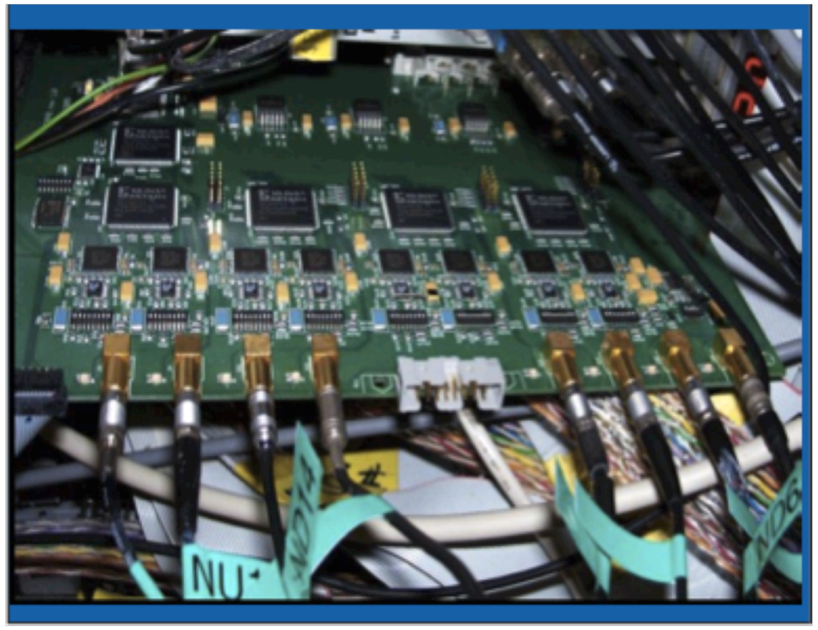


Absolute spectrum derived from fission foil detector mainted by LANL

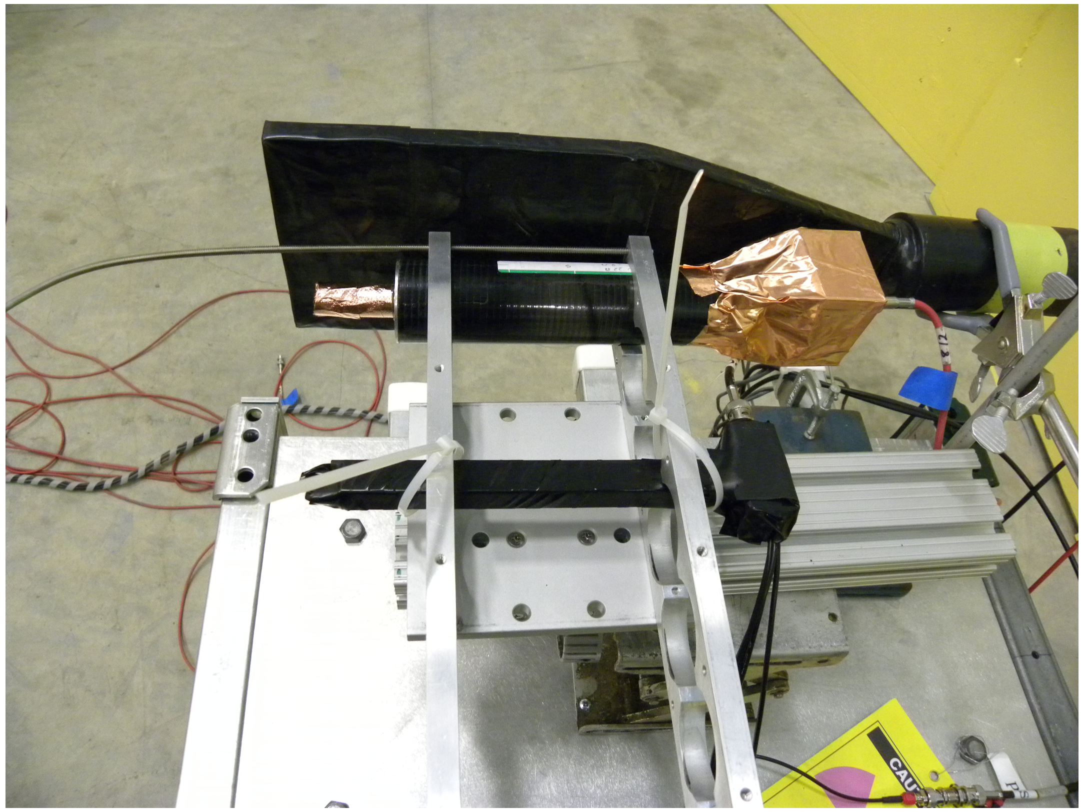
First results – Fission foil energy spectrum

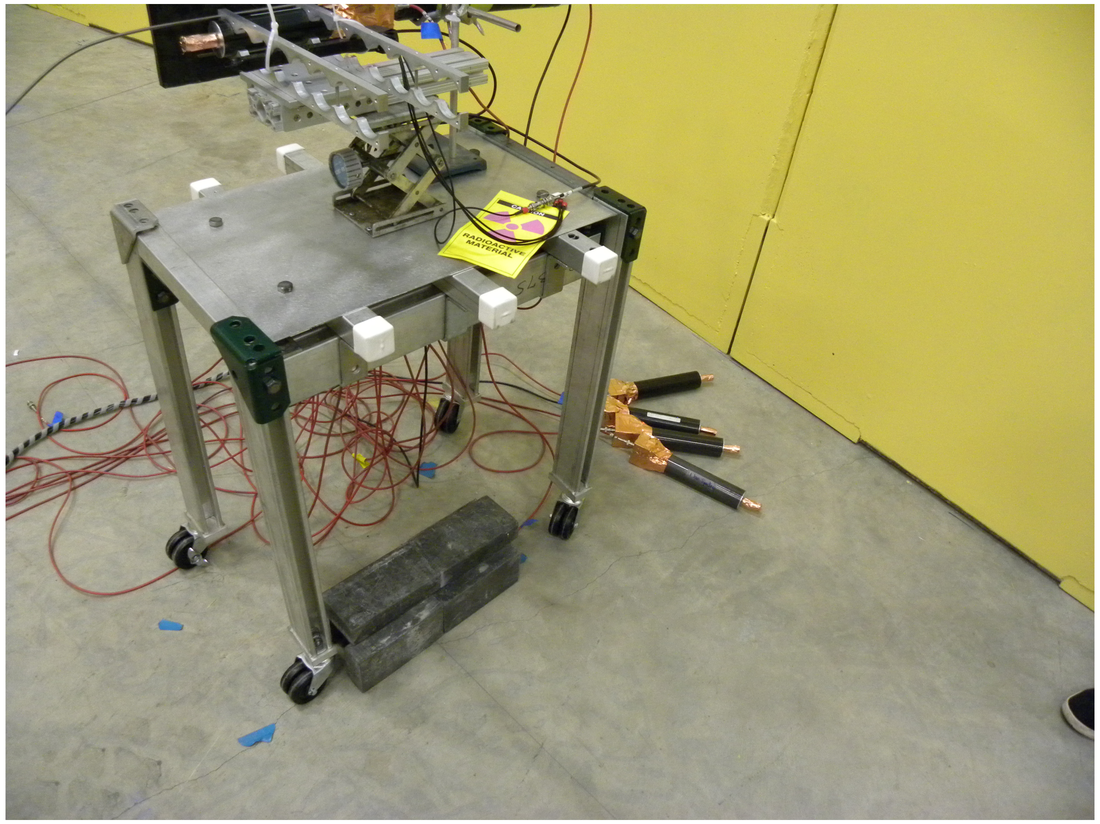


250 MHz 8-chnl 12-bit fADC



WNR Tests - Gas Tubes & Prep





Path Forward

Short term:

Complete WNR analysis

Create baseline detector model

- Preliminary evaluation of efficiency for annhilation vertex and backgrounds
- Cost model

Longer term:

Systematically evaluate detector technologies

Optimize background strategy

Need input and collaborators!

Summary

- ILL experiment provides excellent proof-of-principle for a zero background experiment

- Optimizing the physics reach of the NNbarX experiment will require careful assessment of background rejection requirements for spallation target

- New technologies provide cost-effective and exciting options to explore!

Collaboration

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