Detectors for proton beam-dump experiments

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Community Summer Study

Intensity Frontier: New Light Weakly-Coupled Particles

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Outline

Motivation.

Proton beam –dump examples.

One example of using existing detectors.

A design for a new detector.

Three goals for this meeting.

Why look to existing neutrino Near Detectors (at first).

- Design
  - Aimed for energy and direction reconstruction of protons, neutrons, muons, electrons, and photons.
- Precedent
  - There have been observed significant unexplained electron/photon-like excesses in both neutrino and anti-neutrino mode.
- Investment
  - Significant effort by the Intensity Frontier projects for high POT and event readout (timing ~nsec)
- Geometry
  - makes them sensitive to heavy (> MeV) subluminal particles.

NLWCp from proton beam-dumps

- Each model each usually predicts specific processes producing NLWCp in the target/ beam-dumb and specific signatures.
- The most prominent signatures in a detector can be:
  - Elastic scattering on nucleons .
    - ALPs, Light-DM.
  - Particle decay on flight into di-leptons within the detector.
    - Axions, ALPs, other Hidden Sector particles, etc.
  - Single photons, di-muons.
    - Heavy neutrinos.

For references see the Project-X book from FNAL:
http://theory.fnal.gov/people/ask/PX-book/pxps-part2-for-docdb.pdf

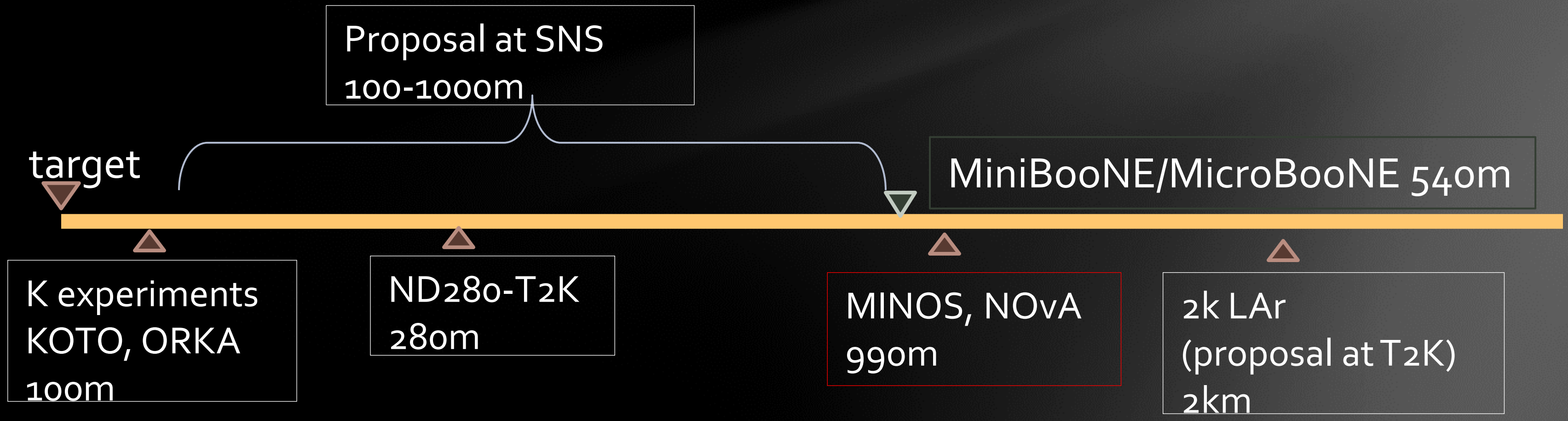
Example of using existing Near Detectors

Large number of protons on target (10^{21} POT per year).

Exotic particle flux is very forward collimated and remains constant with distance from the target (for the range of these near detectors).

Fair distance from the target

- Backgrounds from neutrino interactions are low ($\sim 1/R^2$),



Low energy proton accelerator sources

1 GeV Program of Project X	Stage 1		Stage 2	
	120	**60**	**120**	**60**
Beam Power	984	984	980	980
Protons per second	6.2×10^{15}	6.2×10^{15}	6.2×10^{15}	6.2×10^{15}
Pulse length	CW	CW	CW	CW
Bunch spacing**	Programmable		Programmable	
Bunch length (FWHM)	.04	.04	.04	.04

SNS

Spallation Neutrino Source

Proton beam energy – 1.0 → 1.4 GeV

Intensity - 9.6 · 10^{15} protons/sec

Pulse duration - 380ns(FWHM)

Repetition rate - 60Hz

Total power – 1.0 → 3 MW

Liquid Mercury target

Medium and High Energy sources

FNAL BOOSTER

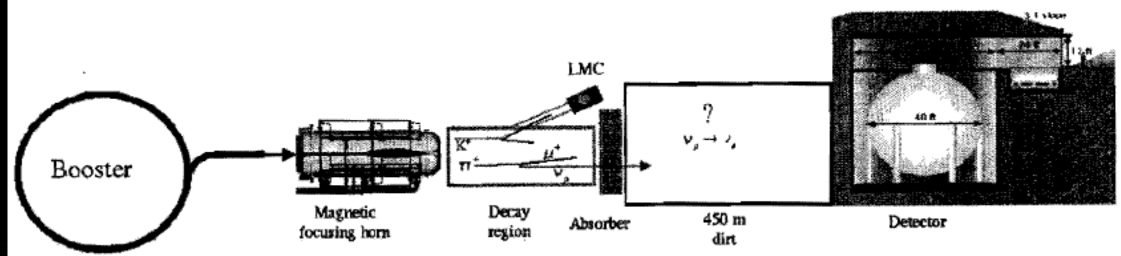
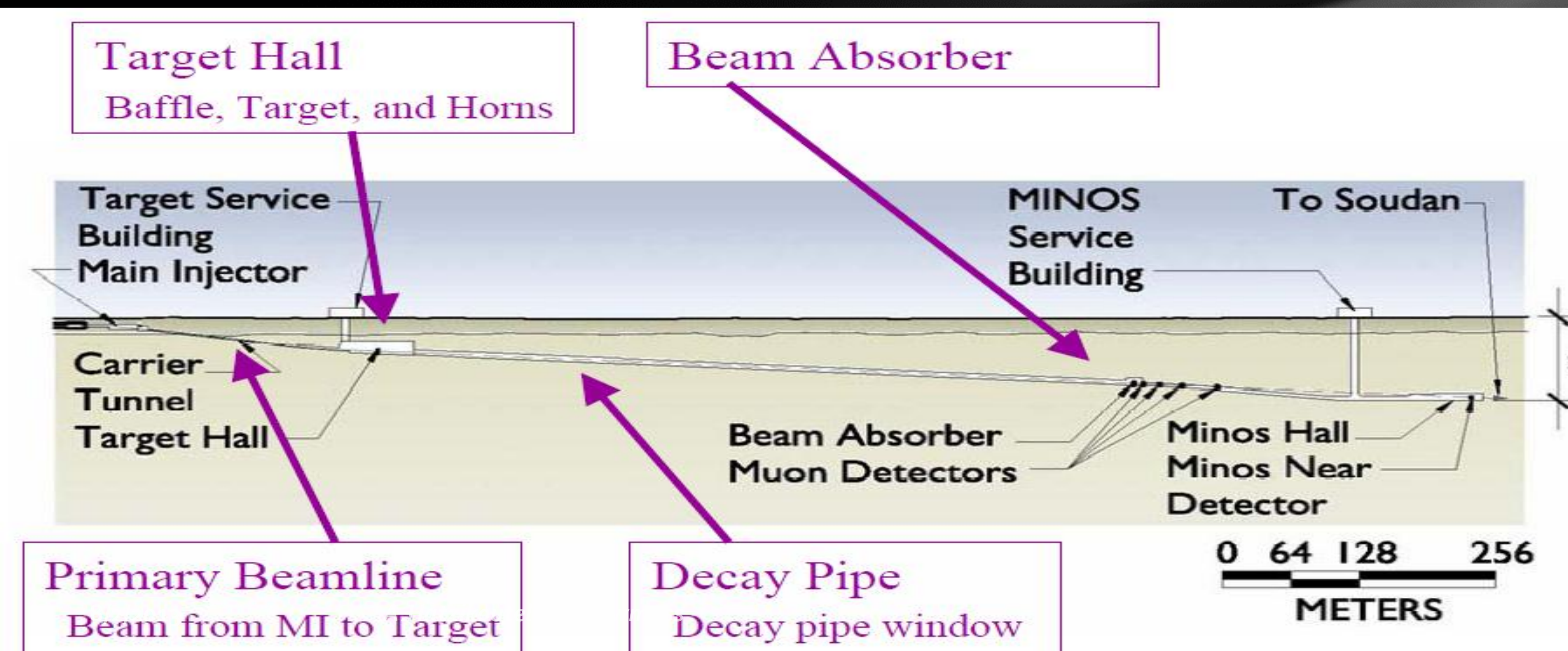
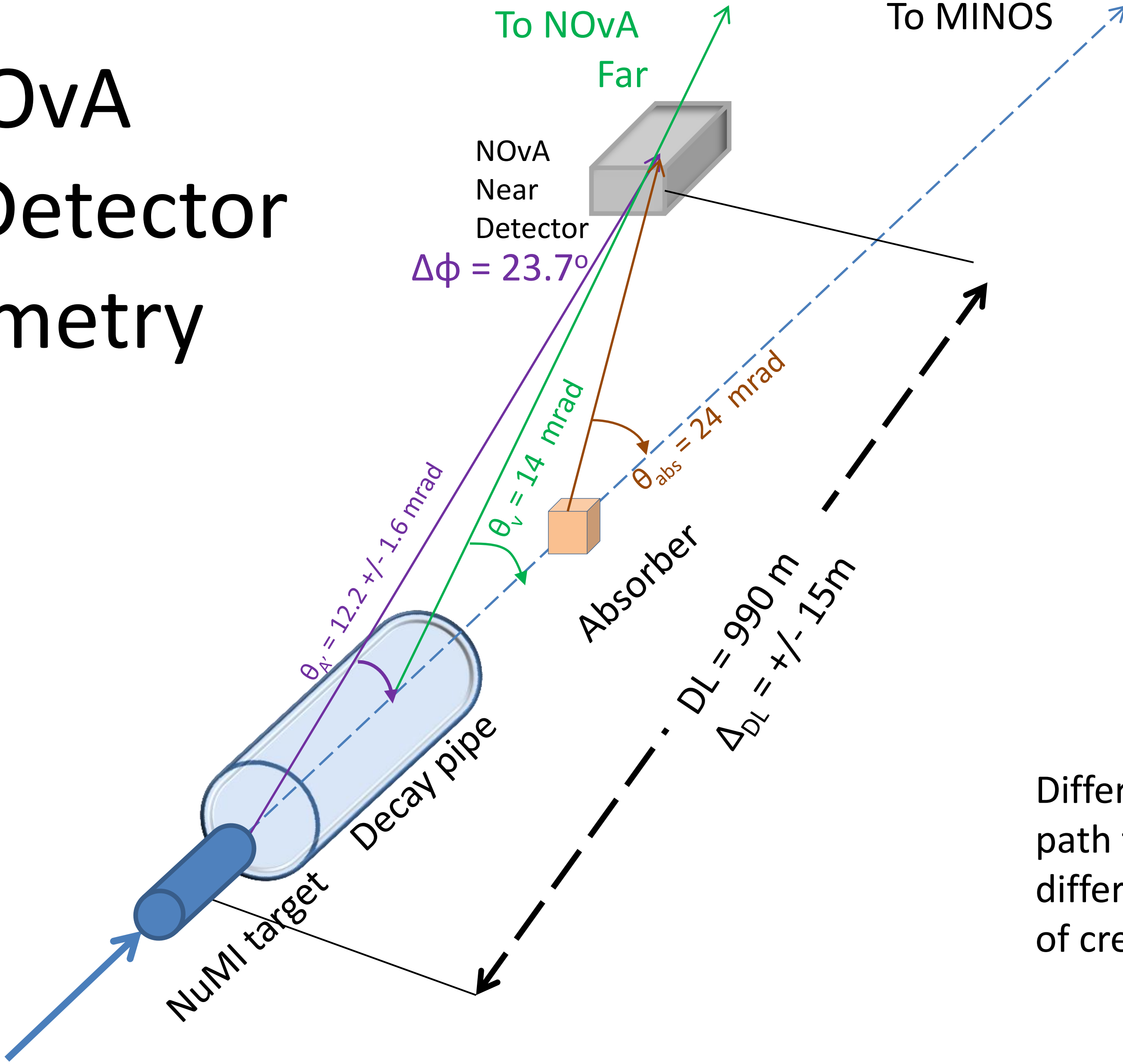


Figure 1: A schematic drawing of the MiniBooNE experiment.

FNAL NuMI



NOvA Near Detector geometry

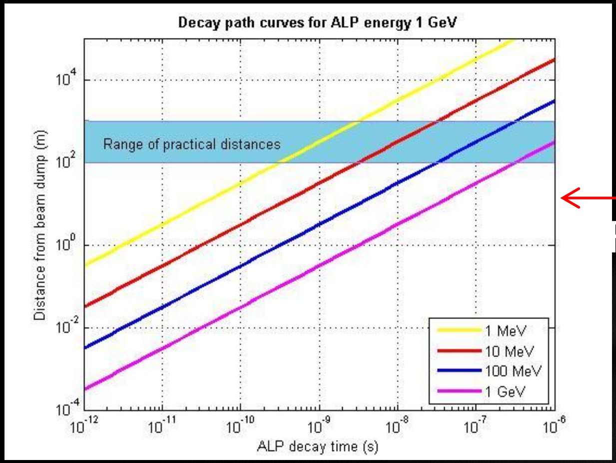


Protons
E_p = 120 GeV
10^{15}bunch,
2.2 sec cycle

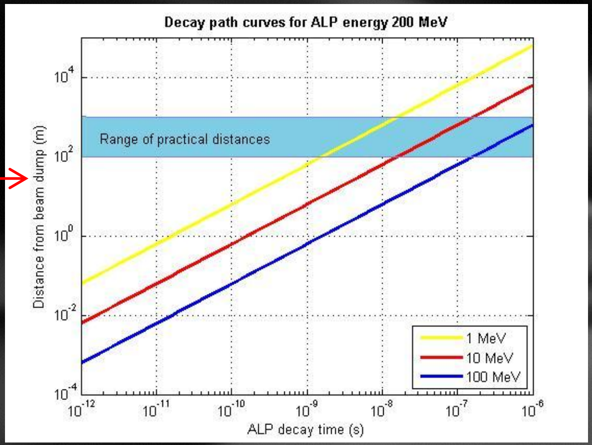
Different decay path for different points of creation

Decay Path sensitivity at different target/ beam dumps

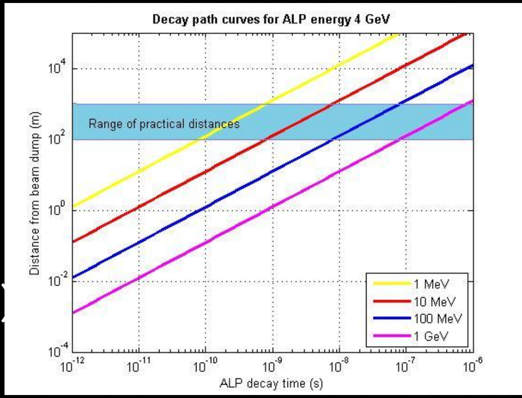
Examples at an 1 GEV accelerator source



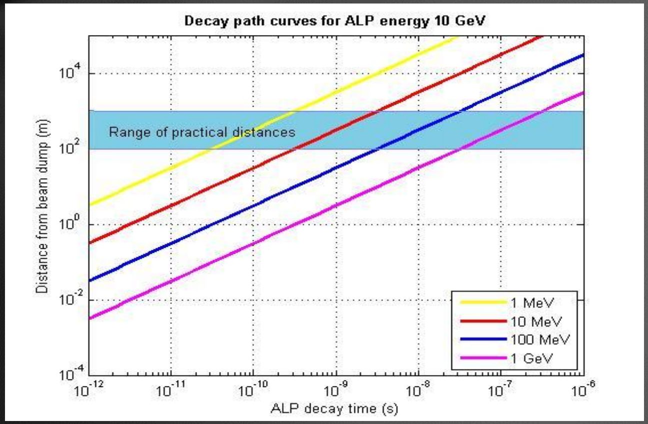
ORNL SNS
FNAL Project-X



Examples at >4 GeV source (FNAL Booster ?)



Examples from a source >10 GeV (FNAL NuMI ?)



Decay path measured from the point of creation : in the target, decay pipe, final absorber, etc

Model independent measurement at NOvA ND

$$N_{A'\to e^+ + e^-}(M_{A'}) = \int F_{lux} * \left(1 - e^{-\frac{P_{ath} * M_{A'}}{\tau_{A'} \quad P}}\right) * \epsilon_{\frac{pair}{eff}} A_{ccept}\, dP_{ath}\, d\Omega$$

Number of pairs

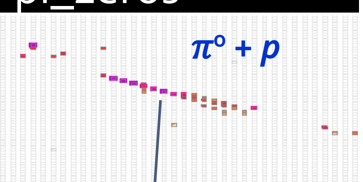
Flux of A′ from the target

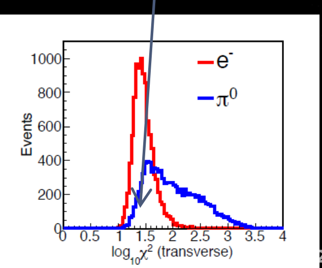
Momentum and Decay path distributions, from Mass, and lifetime of an A′

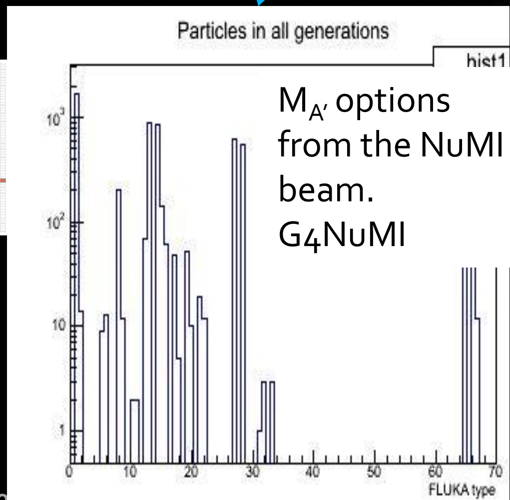
Pair detection efficiency from calibration/ reconstruction, and detector acceptance from dimensions and position.

Limits from physical choices of the experiment

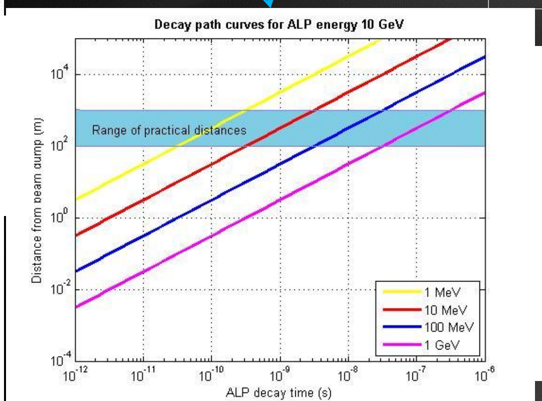
Background: pairs from unrecognized pi_zeros

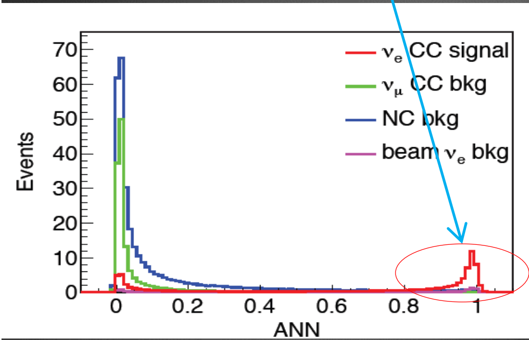






$M_{A'}$ options from the NuMI beam. G4NuMI





Decay-path scans: Movable detectors

Fully active scintillator bar based.

Example: SciBar= 15k bars, 1x2cm² x 3m,1mm WLS fibers, 64 layers.

Example of cost from SciNOvA report $ 2M and 23 month construction.

For a truck-able system on the surface an extra active cosmic veto is necessary.

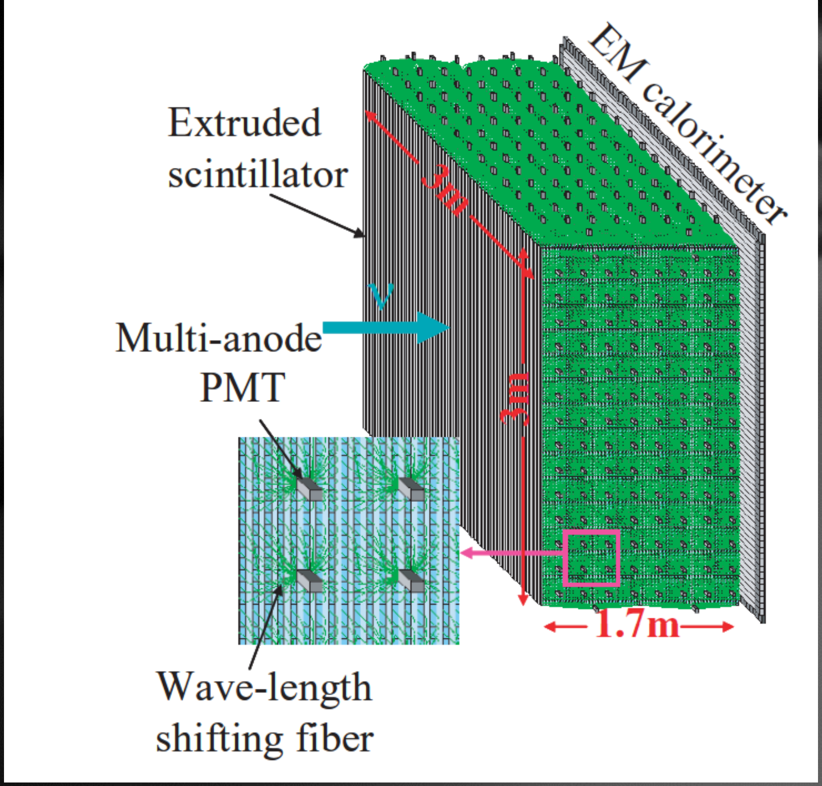
Limitation in weight.

- Can be divided to platforms
  - (1 detector +1 electronics)

Much wider decay-path scans.

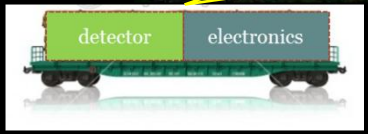
- Covers wider ranges of the parameter phase-space.

SciBar from K2K exp.



Movable detector at the ORNL SNS

Workshop on Neutrinos at the Spallation Neutron Source
May 3-4, 2012 at Oak Ridge National Laboratory
arXiv:1211.5199



Rails can carry a detector as big as a container, larger acceptance options. Permanent arrangement may not be problem (different state, and different funding source than the FNAL)

Detector design

High granularity fully active

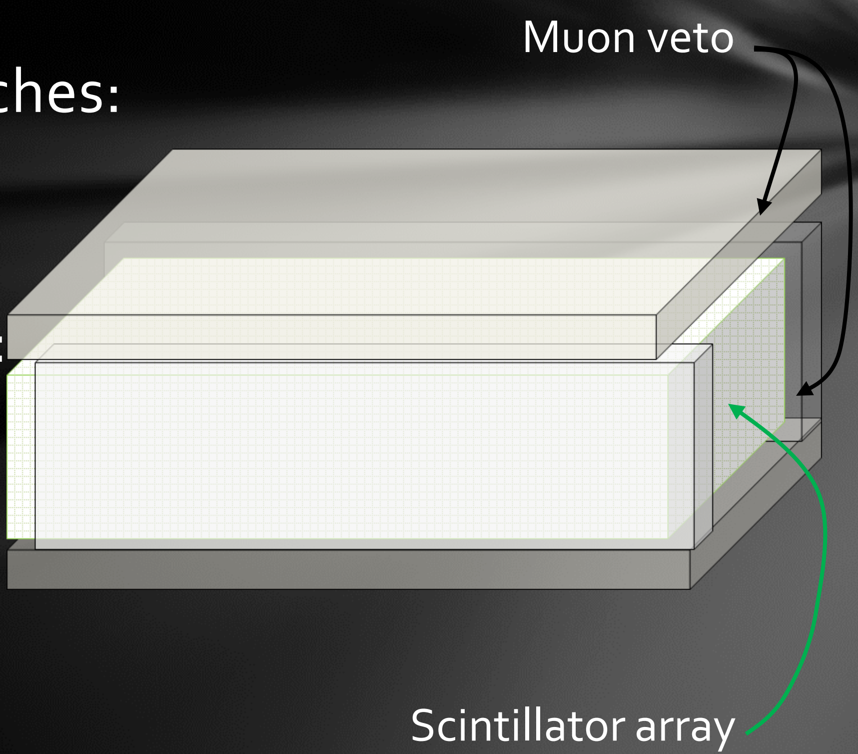
- Examples:
  - SciBar from K2K
  - Pi0Det or FDG from T2K ND280 project.

Adaptation for use in NLWCp searches:

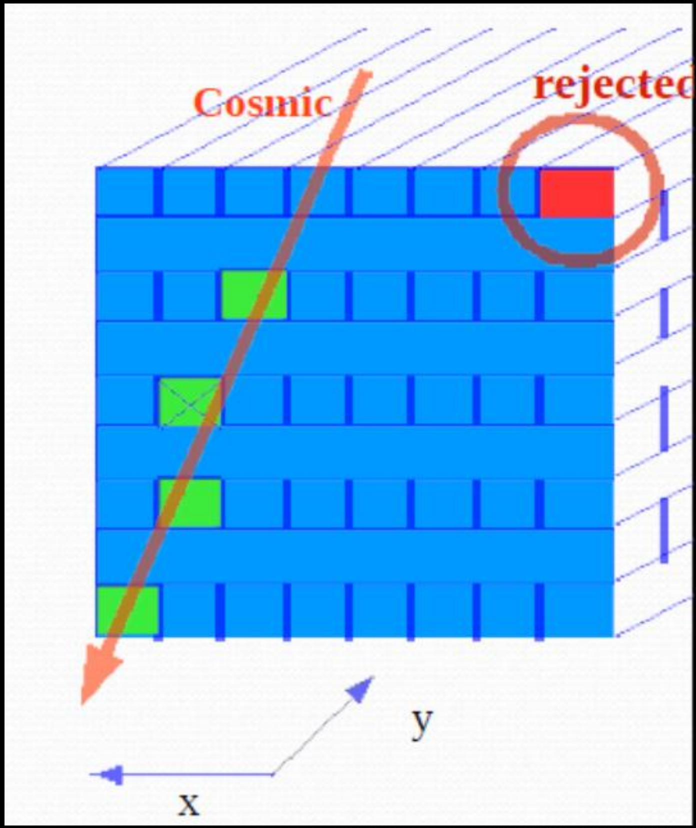
- 1x2 cm x 2m bars
- Double the depth to 120 layers.
- Added active veto, covering all 6 sides.

Leveraging from exiting proposals:

- Designs
  - SciBar@FNAL, hep-ex/0601022 of 2006.
  - SciNOvA P-1003, FNAL PAC 11/2010.
- Proven technologies.
  - Readout with SiPMs as in ND280.
  - DAQ & Slow controls as in MicroBooNE.
  - Analysis methodology from NOvA-NDUG.

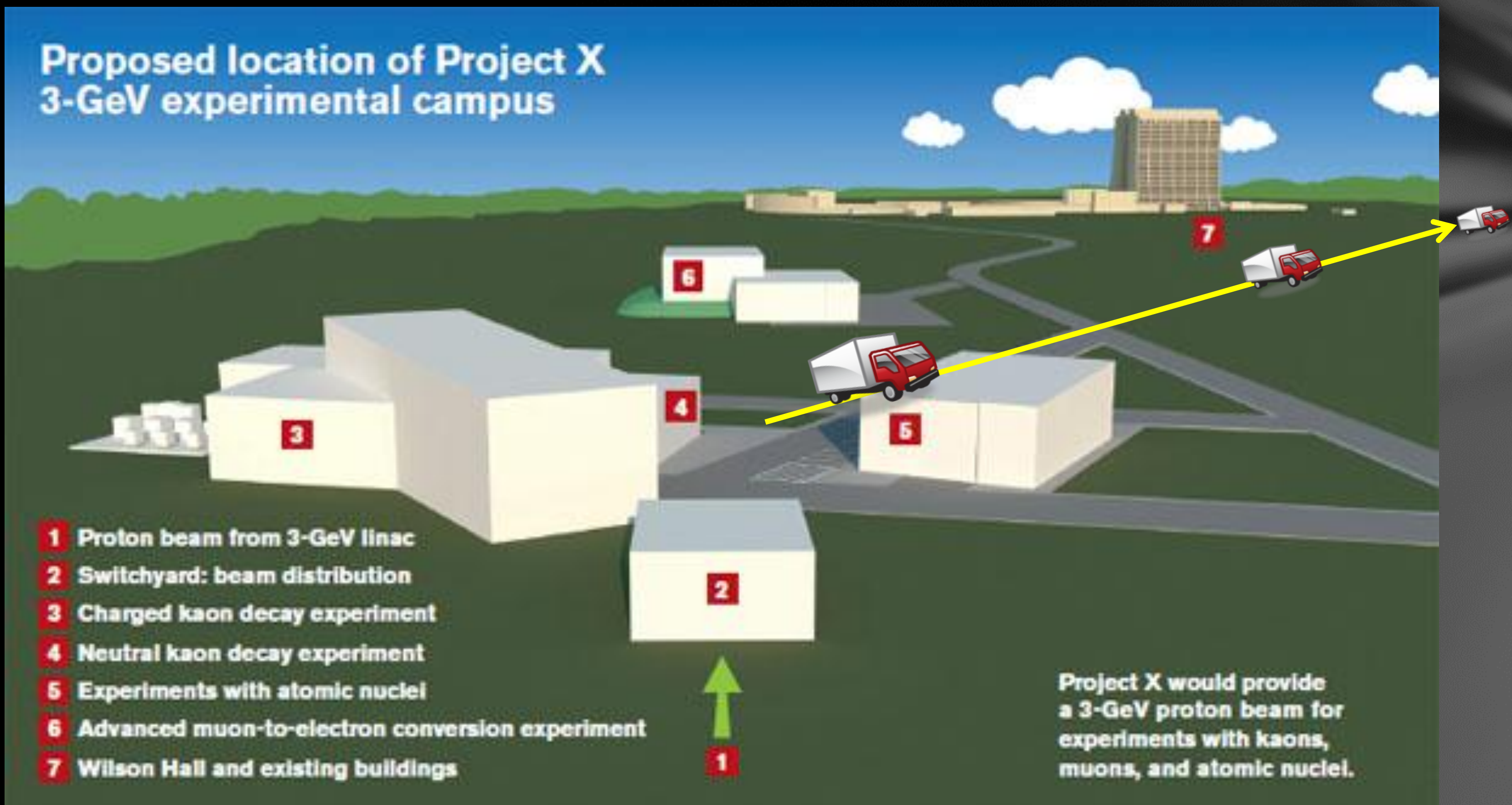


Active muon veto design.



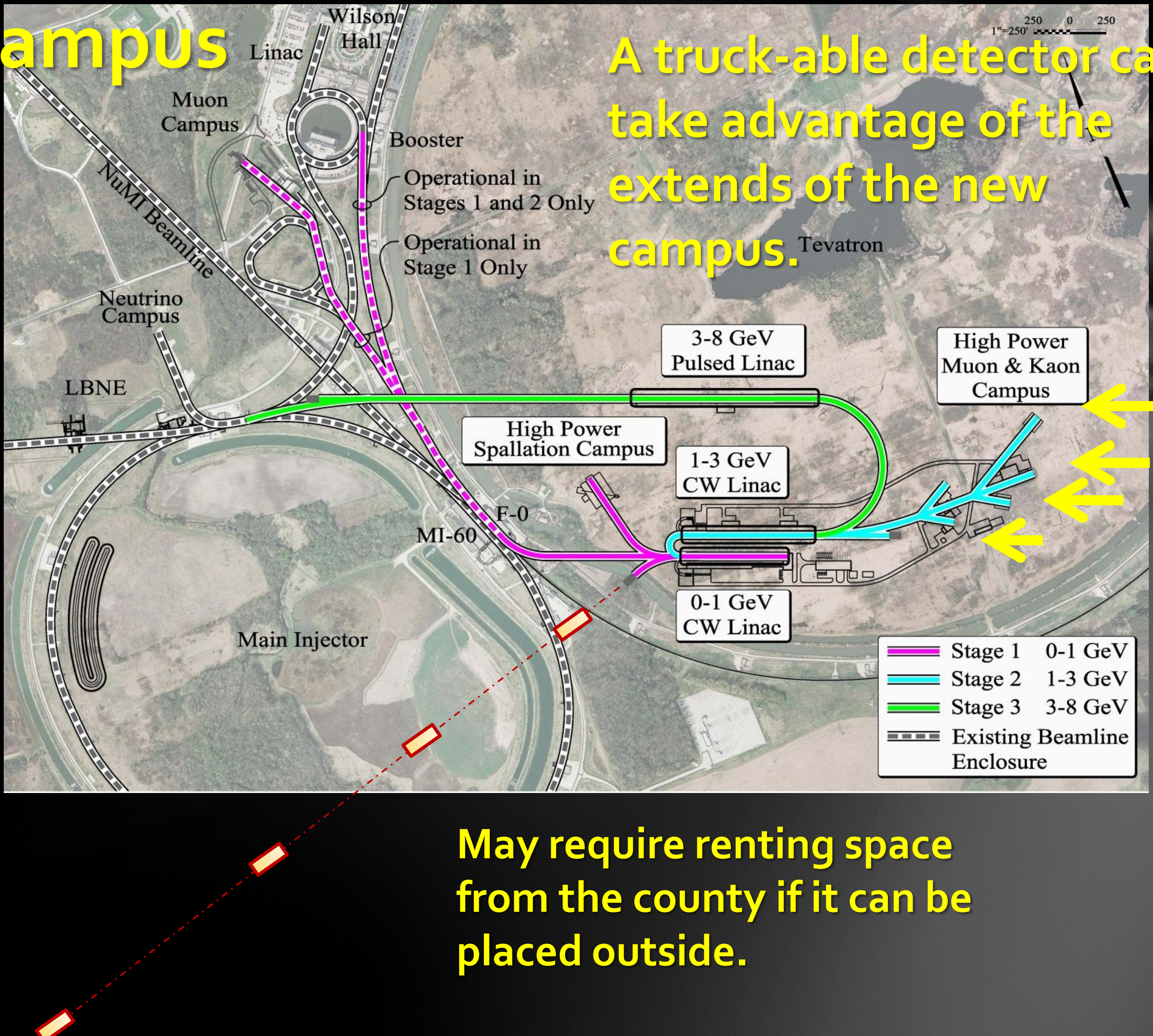
Scintillator based/ 2x4 cm^2/ 6-10 layers/ X-Y orientation.
Covers large areas economically.
Proven technique to id cosmic tracks within 1mm.
Readout by the same method as DAQ system.

Truck-able detector at FNAL



Positioned in a straight line with the 3GeV beam beyond the beam dump of the muon campus.

Proposed detectors for NLWCP at Project X campus



A truck-able detector can take advantage of the extends of the new campus.

Proposed positions of a NLWCP detector.

May require renting space from the county if it can be placed outside.

Discussion and outlook

Experimental strategy: Economy reasoning favors multi-purpose experiments.

- Small : in particle physics scales (and costs).
- Making a detector mobile can scan various ranges of mass.
  - It improves sensitivity (for each mass, scans lifetime ranges instead of a value).
  - Can be included in smaller grants, built by smaller collaborations.
  - Beam-dump: rarely prime area for competing experiments
    - Can share source (dump) with other experimental efforts/ideas.

Detector design: Tracker /calorimeter combination.

- Popular around neutrino experiments, proven technique.
- Good vertex and mass reconstruction can scan decay vertices closer to the interaction point.
  - Slower /heavier particles. Increase the scanned phase space.

Signature: Di-particle with vertex in the beam-line.

- Electron, muon, or pion pairs depending on the mass and the type.
- Mass reconstruction provides the particle mass.
- Overall measurement is model independent
  - Signal excess gives the coupling strength.
  - Life time and mass are measured independently from each other.

Future technologies expectations

- Detectors for vertex searches (pixel).
  - Fast, radiation hard.
  - Faster DAQ, High-level Triggering.

My Goals for this meeting

- Beam dumps are important.
  - not an “not-important” end but a source for others.
  - if no model exists we get 10e15 pot /min.
    - itf they are there we will see them.
  - The civil engineering of the new machines must include accessibility.
- Technology leveraging.
  - We can create economical detection systems by combining technologies.
  - The neutrino experiment investment in technology and s/w.
- Periodical testing.
  - Every 10 years or
  - when there is a major upgrade to intensity or readout tech.

Extra slides

Light mediators: π^0

$$N_{\frac{signal}{bkgd}} = N_{\pi^0} * BR(\pi^0 \rightarrow \gamma A') * BR(\mathrm{A}' \rightarrow e^+ + e^-) * \epsilon_{\frac{pair}{eff}} * A_{ccept}$$

From beam simulations

This is what it is estimated from the measurement

Detector properties

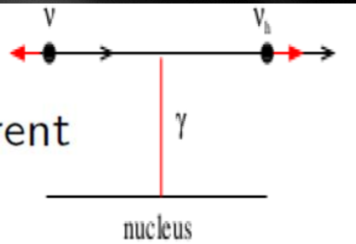
SINDRUM: $M_{A'}$ = 25-120MeV, BR ~10^{-6}

WASA: $M_{A'}$ =30- 90 MeV, BR ~10^{-6}

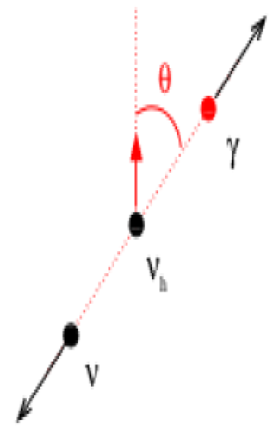
NOMAD : ($M_{A'}$,$P_{A'}$)=(<95MeV, 4GeV)➔ BR ~10^{-15}

Heavy neutrinos in Near detectors

- NOMAD set limits , if the hypothetical single photon has a momentum distribution similar to that of a photon from the coherent π° decay



$$\frac{\sigma(Single, Forward - \gamma)}{\sigma(\nu_\mu A \rightarrow \mu^- X)} < 1.6 \times 10^{-4} (90\% CL)$$



- By using the enhanced flux from NuMI beam and good photon reconstruction we can attempt to try and see how signals for this heavy neutrino can be seen at NOvA ND. We can try and use other decay modes if the heavy neutrino could be of a greater mass, by supplementing with other particle recognition algorithms..

if the mass of $\nu_h > 140 MeV$ then other decay channels are also possible i.e $\nu_\mu ee, \nu_\mu \pi^\circ, \nu_\mu \nu\nu, \mu\pi$.