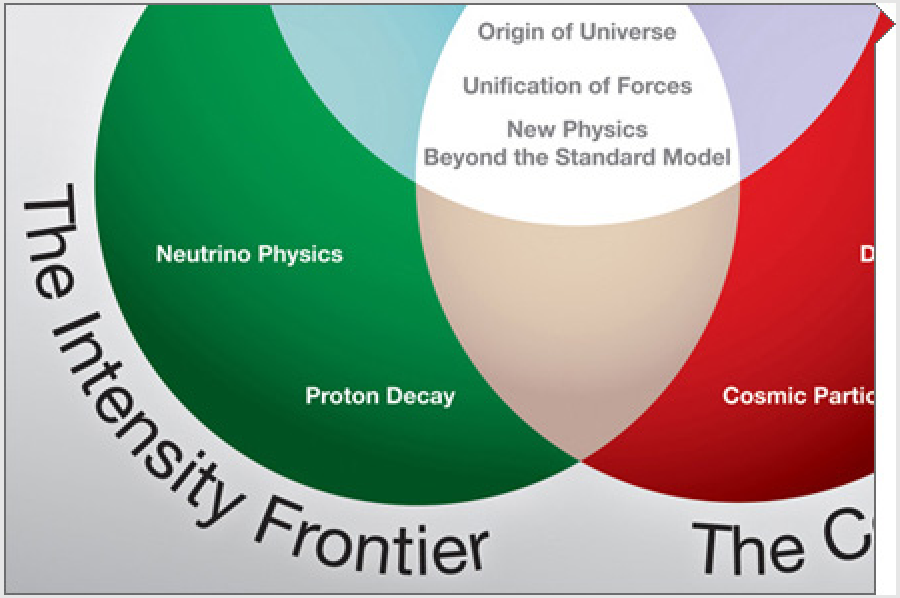
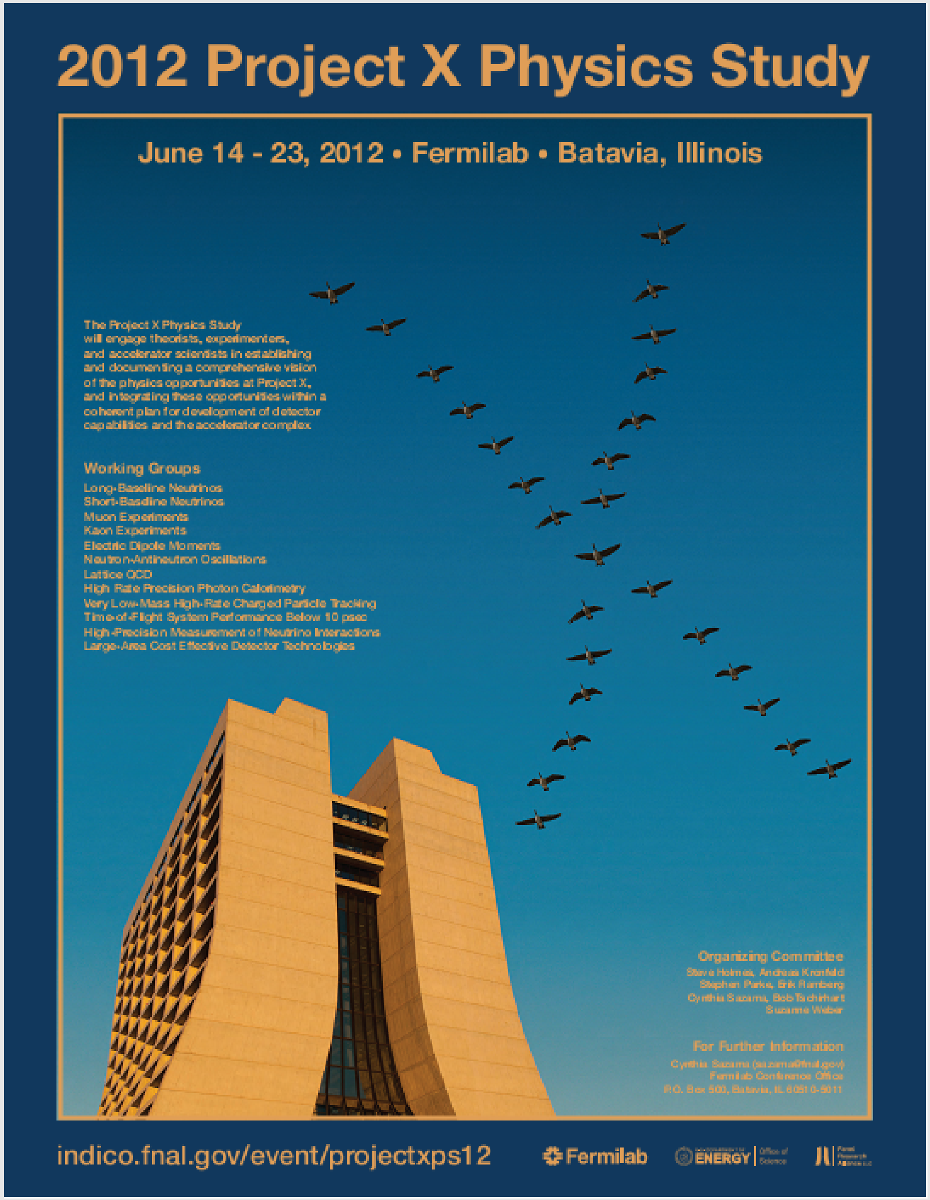
PXPS workshop: nu detectors WG summary

Outline:
- physics
- detector development
- nu source design





R. Tayloe, Indiana U.
PXPS workshop
FNAL, 6/12

Neutrino Physics at Project X

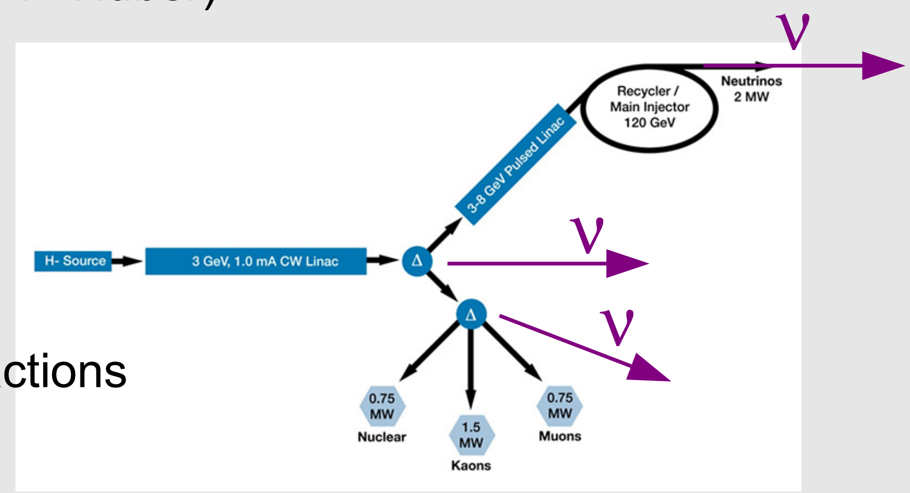
- short-, long-baseline oscillations (covered by P. Huber)

- supernova detection

- nu interactions/cross sections
  - "low-energy":
    - π DAR source, ~10-50MeV
    - ν elastic coherent, νN supernova interactions
  - "med-energy":
    - π DIF source, ~0.1-2.0 GeV
    - 2N correlations, deltas, nu pi coherent prod, etc
  - "hi-energy":
    - π DIF source, ~1.0-10GeV

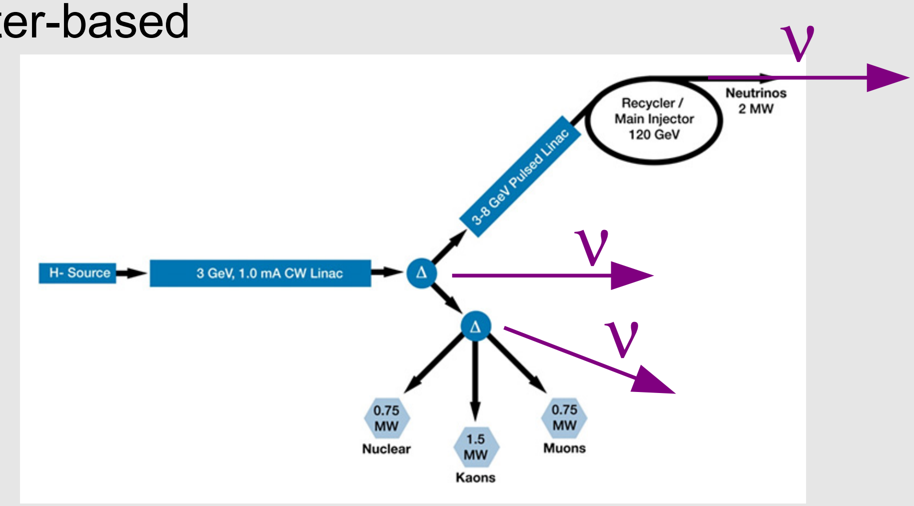
- nu-e elastic for nu mag moments, sin2thew, flux monitoring

- "exotica"
  - dark sector searches
  - non-standard interactions (covered by P. Huber)



Enabling... Neutrino Physics at Project X

Detectors:
- scintillators:
  - new (non-PC mixtures), metal loading, water-based
  - physics techniques with these
  - readout methods, new configurations
- liq-AR (liq noble gases)
  - studies of ionization, light, etc
  - readout techniques, new configs
- others
  - emulsion

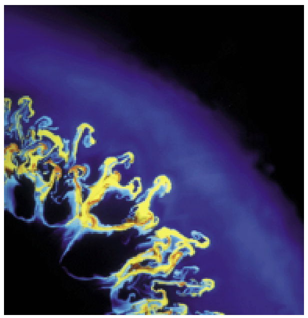


nu sources:
- DAR source for ~50Mev nu
  - from 1,3,or 8 GeV
  - target design
  - time structure, buncher ring requirement
- DIF source from 1,3,8,60,120 GeV for 0.5-10GeV nu
  - target design
  - time structure, buncher ring requirement
- DAR kaon source
- "nu-factory" type

Supernova Physics at Project X

- Most large neutrino detectors (≈> 1kT) are candidate SN ν detectors and could provide important info for next supernova event.

What We Can Learn

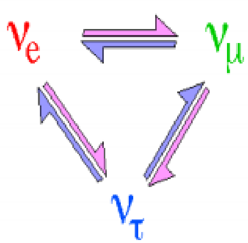


CORE COLLAPSE PHYSICS

- explosion mechanism
- proto nstar cooling, quark matter
- black hole formation
- accretion disks
- nucleosynthesis

from flavor, energy, time structure of burst

NEUTRINO/OTHER PARTICLE PHYSICS



- ν absolute mass (not competitive)
- ν mixing from spectra: flavor conversion in SN/Earth
  (' θ_{13} the lucky and patient way')
- other ν properties: sterile ν's, magnetic moment,...
- axions, extra dimensions, FCNC, ...

+ EARLY ALERT

Kate Scholberg, Duke University

Supernova Physics at Project X

Many detection options exist in detectors of all types...

Table 1 Summary of relevant interactions for current and near-future detectors

KS, arXiv:1205.6003

Channel	Observable(s)[a]	Interactions[b]
$\nu_x + e^- \rightarrow \nu_x + e^-$	C	17/10
$\bar{\nu}_e + p \rightarrow e^+ + n$	C, N, A	278/165
$\nu_x + p \rightarrow \nu_x + p$	C	682/351
$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N^{(*)}$	C, N, G	3/9
$\bar{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B^{(*)}$	C, N, G, A	6/8
$\nu_x + {}^{12}C \rightarrow \nu_x + {}^{12}C^*$	G, N	68/25
$\nu_e + {}^{16}O \rightarrow e^- + {}^{16}F^{(*)}$	C, N, G	1/4
$\bar{\nu}_e + {}^{16}O \rightarrow e^+ + {}^{16}N^{(*)}$	C, N, G	7/5
$\nu_x + {}^{16}O \rightarrow \nu_x + {}^{16}O^*$	G, N	50/12
$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$	C, G	67/83
$\bar{\nu}_e + {}^{40}Ar \rightarrow e^+ + {}^{40}Cl^*$	C, A, G	5/4
$\nu_e + {}^{208}Pb \rightarrow e^- + {}^{208}Bi^*$	N	144/228
$\nu_x + {}^{208}Pb \rightarrow \nu_x + {}^{208}Pb^*$	N	150/55
$\nu_x + A \rightarrow \nu_x + A$	C	9,408/4,974

(Livermore/GKVM)

C: energy loss of a charged particle
N: neutrons
A: annihilation gammas
G: de-excitation gammas

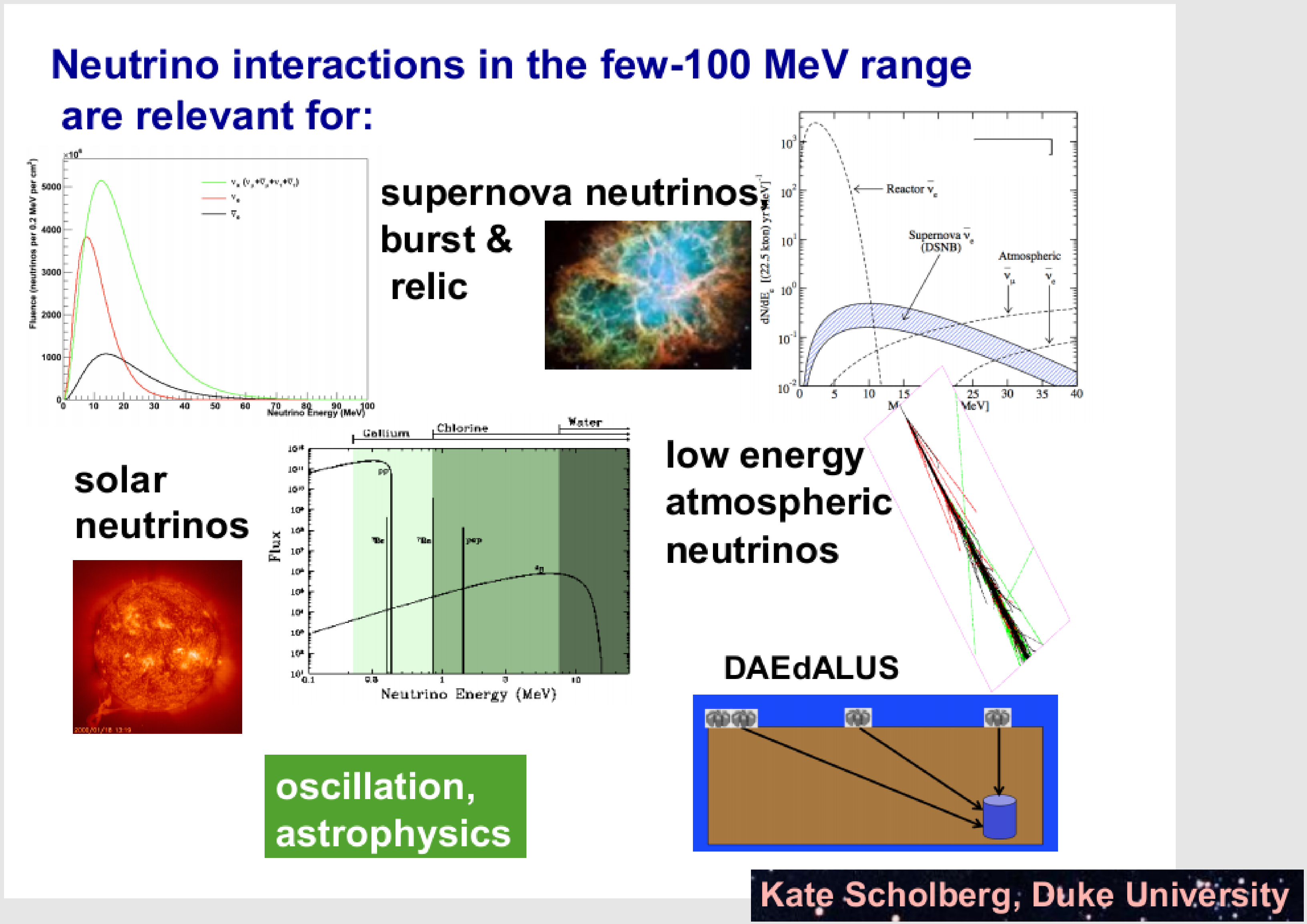
Kate Scholberg, Duke University

Requires:
- large detector
- dedicated triggers
- (for some channels) calibration in additional experiments...

Neutrino Interaction Physics at Project X

"low-E" (~50MeV) neutrino physics:

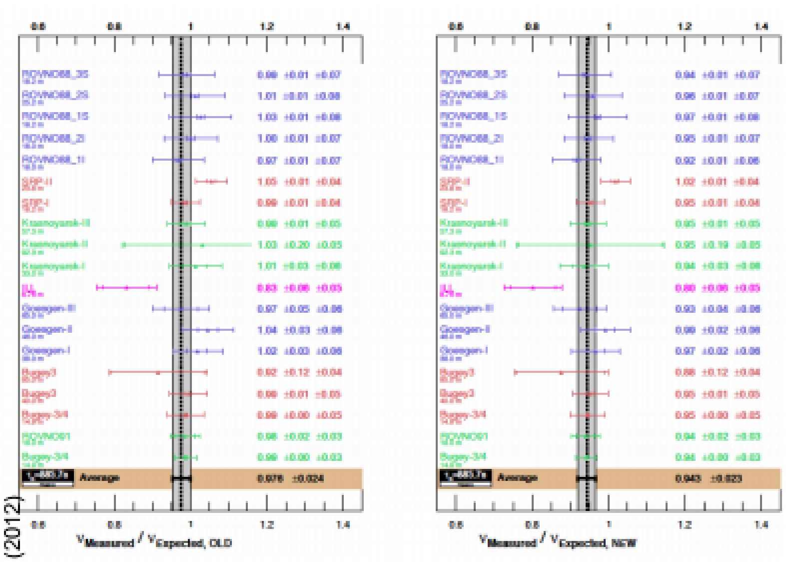
- important both for fundamental physics as well as support for oscillations and SN experiments



Neutrino Interaction Physics at Project X

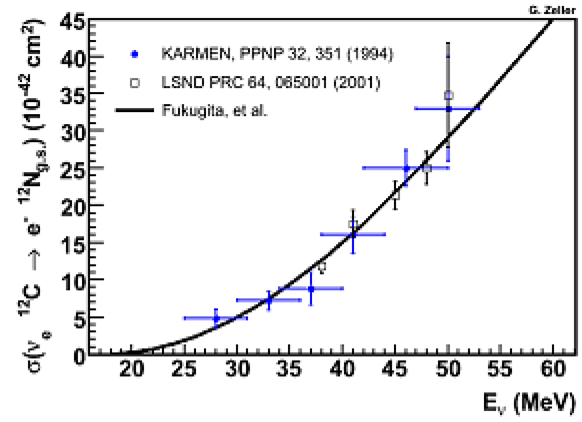
CC Low Energy Physics

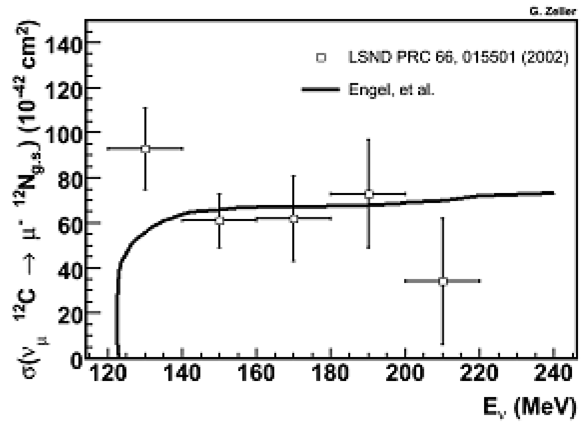
- CC: $\nu_{e,\,\mu} + {}^{12}C_{gs} \rightarrow (e^-, \mu^-) + {}^{12}N_{gs}$
- CC: $\nu_{e,\,\mu} + {}^{12}C_{gs} \rightarrow (e^-, \mu^-) + {}^{12}N^*$
- CC: anti-$\nu_e + p \rightarrow e^+ + n$



J. Formaggio and G. Zeller, RMP, to be published (2012)

World reactor data, L ≤ 100 m





UF UNIVERSITY of FLORIDA The Foundation for The Gator Nation

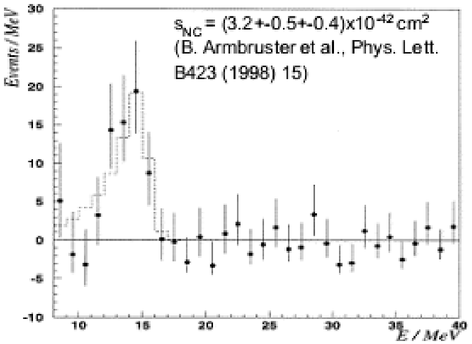
H. Ray

6

Neutrino Interaction Physics at Project X

NC Low Energy Physics

- NC
  - $\nu_x + {}^{12}C_{gs} \rightarrow \nu_x + {}^{12}C^*$, anti-$\nu_x + {}^{12}C_{gs} \rightarrow$ anti-$\nu_x + {}^{12}C^*$
    - Super-allowed, produces distinctive 15.11 MeV de-excitation photon
    - ν_μ only measured by KARMEN, 20% total error, half due to stats
    - Anti-ν_μ only measured by KARMEN, 10% total error, half due to stats
    - **Sterile neutrino search!!!**



  - $\nu_e + e^- \rightarrow \nu_e + e^-$
    - Precision measurement of $\sin^2\theta_W$
  - $\nu_x + A \rightarrow \nu_x + A^*$
    - Coherent scattering, impt for SN, **never observed** due to low recoil E (O tens of keV)

UF UNIVERSITY of FLORIDA The Foundation for The Gator Nation H. Ray 7

Requires:
- O(1kt) scintillation, liquid noble gas detectors
- π DAR source, O(1MW)
- low duty factor beam, <1E-3, likely buncher ring required

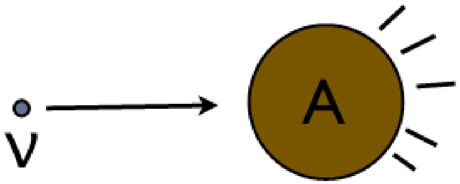
Neutrino Interaction Physics at Project X

"low-E" (~50MeV) neutrino physics:

- coherent ν - A elastic scattering

Why is coherent neutrino-nucleus scattering interesting?

- This process has never been detected
- Differences from Standard Model prediction could be a sign of new physics
- Non-standard neutrino interactions
- Supernova process and burst/diffuse neutrino detection
- Weak mixing angle
- Neutron radius
- Sensitivity to sterile neutrino(s)



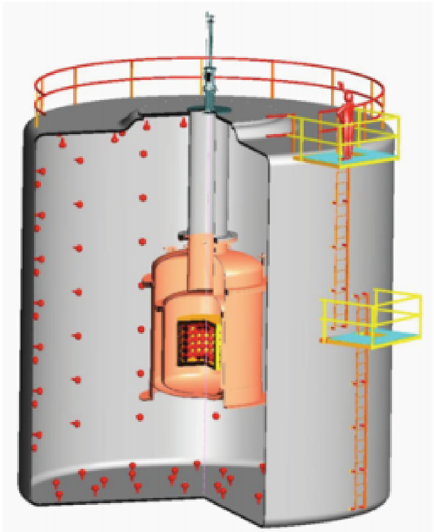
Joshua Spitz MIT

Neutrino Interaction Physics at Project X

"low-E" (~50MeV) neutrino physics:
- coherent ν - A elastic scattering

Coherent neutrino detection at Fermilab

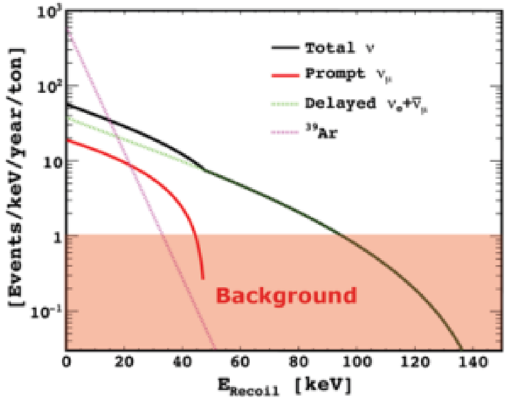
A ton-scale LAr detector may perform the first ever observation of the coherent-NCvAS at Fermilab



Envisioned experimental setup

Thanks to J.Yoo for plots and information!

- There is a decay-at-rest neutrino component to the Booster Neutrino Beam, dominating at far-off-axis.
- A WIMP-detector-like single-phase Ar-based device could collect ~200 events/ton/yr at 20 m from the target.



Event rate 20 m from BNB target

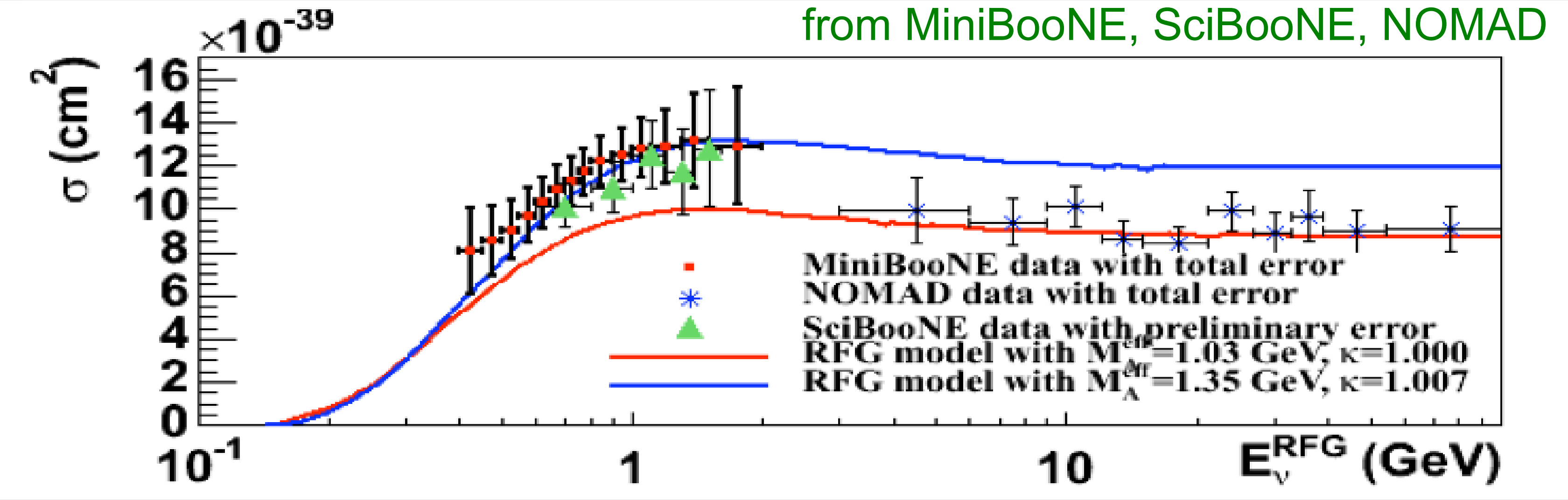
Requires:
- O(1ton) liquid noble Argon detector
- π DAR source, O(1MW)
- neutron background mitigation
- low duty factor beam, <1E-3, likely buncher ring required

Neutrino Interaction Physics at Project X

"med-E" (0.1-2GeV) neutrino physics:

- many interesting topics recently addressed by MiniBooNE, SciBooNE
    - multi-nucleon correlations in nuclei

ν CCQE total cross section measurement
from MiniBooNE, SciBooNE, NOMAD



- coherent production of pions, photons from nuclei
- "strange"-spin of nucleus, Δs

- Some topics are being addressed by MINERvA,T2K with results appearing now/soon
- However ultimate resolution and understanding across all nuclei likely to require additional experiments in ProjectX era.

Neutrino Interaction Physics at Project X

"med-E" (0.1-2GeV) neutrino physics:

- multi-nucleon correlations in nuclei
- coherent production of pions, photons from nuclei
- "strange"-spin of nucleus, Δs

Requires:

- scintillator/Cerenkov/liquid Argon detectors
- higher power (100kW) 8GeV DIF source
- possibly 3GeV (1MW) DIF source, lowish duty factor
- H/D targets to disentangle nuclear effects

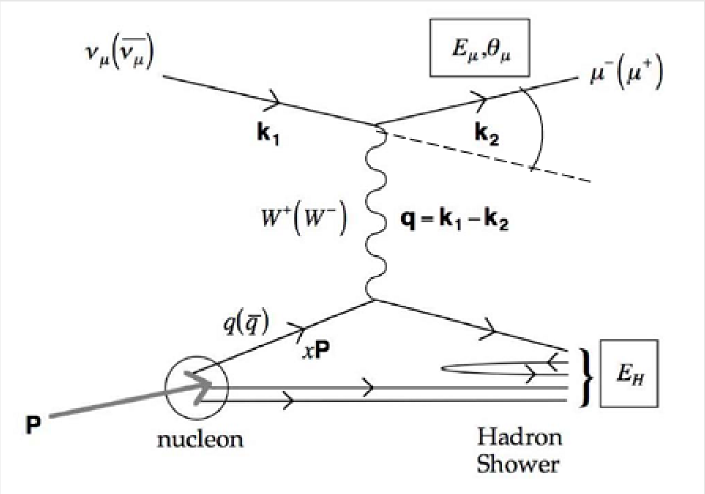
Neutrino Interaction Physics at Project X

"high-E" (>2GeV) neutrino physics:
- currently being addressed by MINERvA

Neutrino DIS Motivation

- Unlike charged lepton scattering, nuclear effects in neutrino scattering have not been directly measured, not well constrained by global fits
- Reasons nuclear effects could be different in neutrino DIS
  - Presence of Axial-Vector current
  - Different nuclear effects for valence and sea quarks, possibly different shadowing for xF_3 vs F_2?
- Neutrinos have the ability to directly probe the flavor of the nucleon partons
  - ν interacts with u-bar, d, c-bar, s, ν-bar interacts with u, d-bar, c, s-bar
  - Measuring charm production with ν, ν-bar probes the s, s-bar content within a nucleon
  - $xF_3(\nu) - xF_3(\nu\text{-bar}) = 2[(s + s\text{-bar}) - (c + c\text{-bar})]$, information on heavy quark content

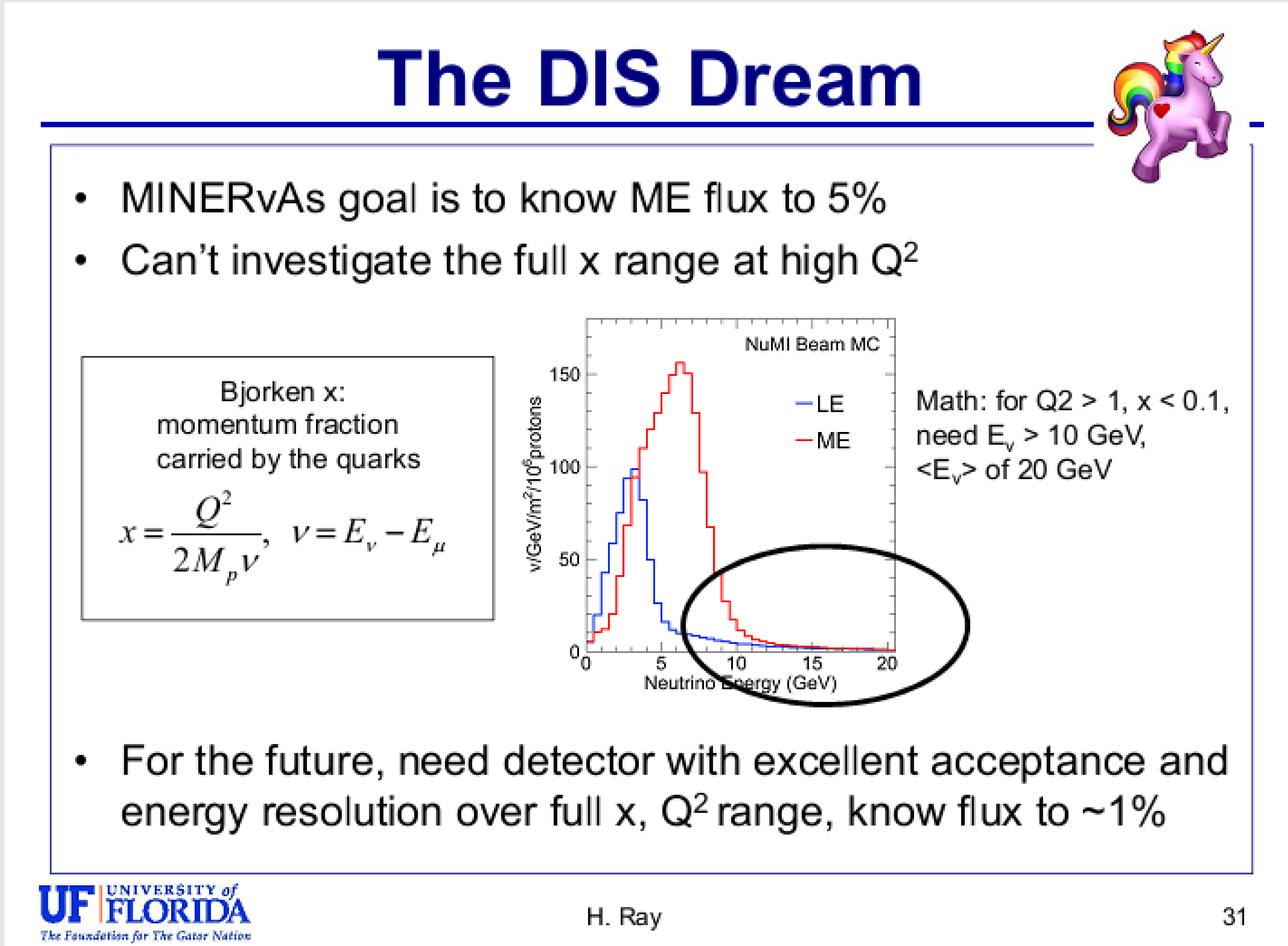
UNIVERSITY of FLORIDA The Foundation for The Gator Nation H. Ray 6



- These topics are being addressed by MINERvA, results appearing..
- however more work needed in ProjectX era....

Neutrino Interaction Physics at Project X

"high-E" (>2GeV) neutrino physics:



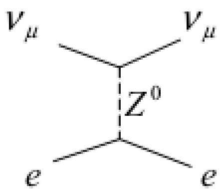
Requires:
- high-resolution tracking detectors
- 60-120 GeV DIF source or perhaps "nu-factory" -like source

Neutrino Interaction Physics at Project X

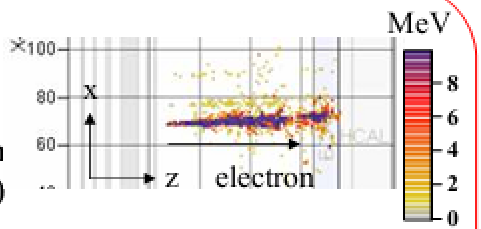
nu e elastic scattering:
- neutrino flux calibration
- nu magnetic moment
- weak mixing angle at low Q2

$$\nu_\mu + e \rightarrow \nu_\mu + e$$

$$\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e$$



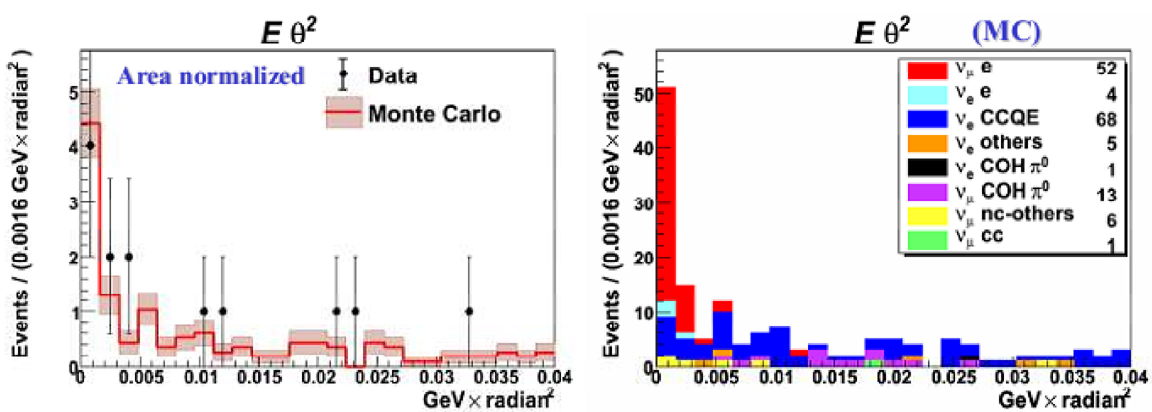
Very clean physics channel but it has tiny cross section. (~1/2000 to neutrin nucleon scattering)



- Well known pure leptonic process is used to get ν_μ flux information
- ν_μ scattering off on light electron has small center of mass energy, so it can have only small momentum transfer, Q^2 , which produces very forward electron final state

Jaewon Park
University of Rochester

Small Sample Result



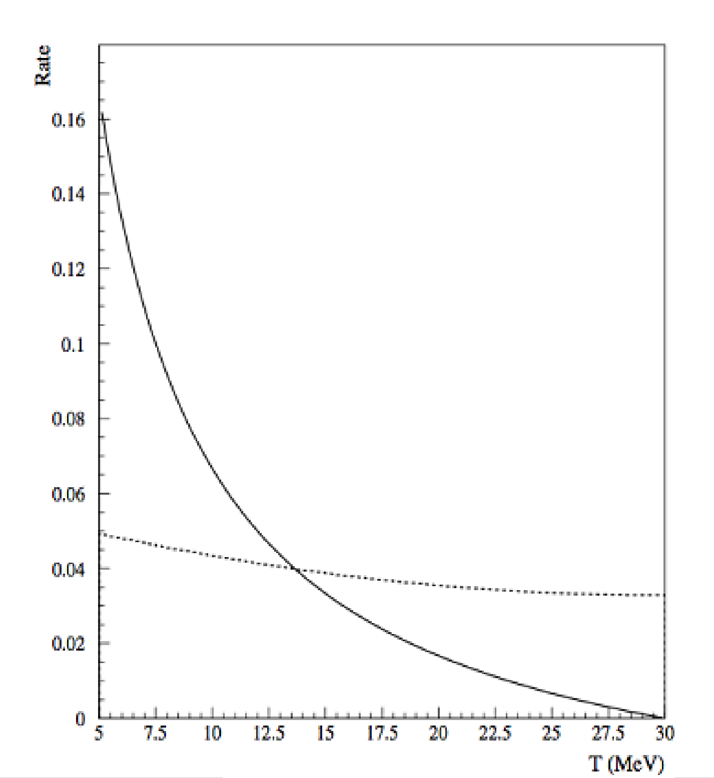
sample of MINERvA data:
- promising, yet low-stats
- estimate 8.6% stat error on nu e,
- more powerful with MINERvA med-E beam
- higher stats with Project X beams

Neutrino Interaction Physics at Project X

nu e elastic scattering:
- neutrino flux calibration
- nu magnetic moment
- weak mixing angle at low Q2

- Present limit for ν_μ is $6.8*10^{-10}$ Bohr Magnetons. LSND PRD 63,112001
- Present limit for ν_e is $0.5*10^{-10}$ Bohr Magnetons. Borexino PRL 101, 091302

- At low electron energy, T_e, the magnetic moment cross section is given by $d\sigma^M/dT_e = f^2*2.5*10^{-25}\ cm^2/T_e$ for $T_e << E_\nu$ where f = magnetic moment in electron Bohr magnetons
- Because of $1/T_e$ factor want to look at as low an electron energy as possible



Richard Imlay
University of Virginia

- Project X beams will allow improvement on numu limit (to ~1E-10 Bohr magnetons)

Neutrino Interaction Physics at Project X

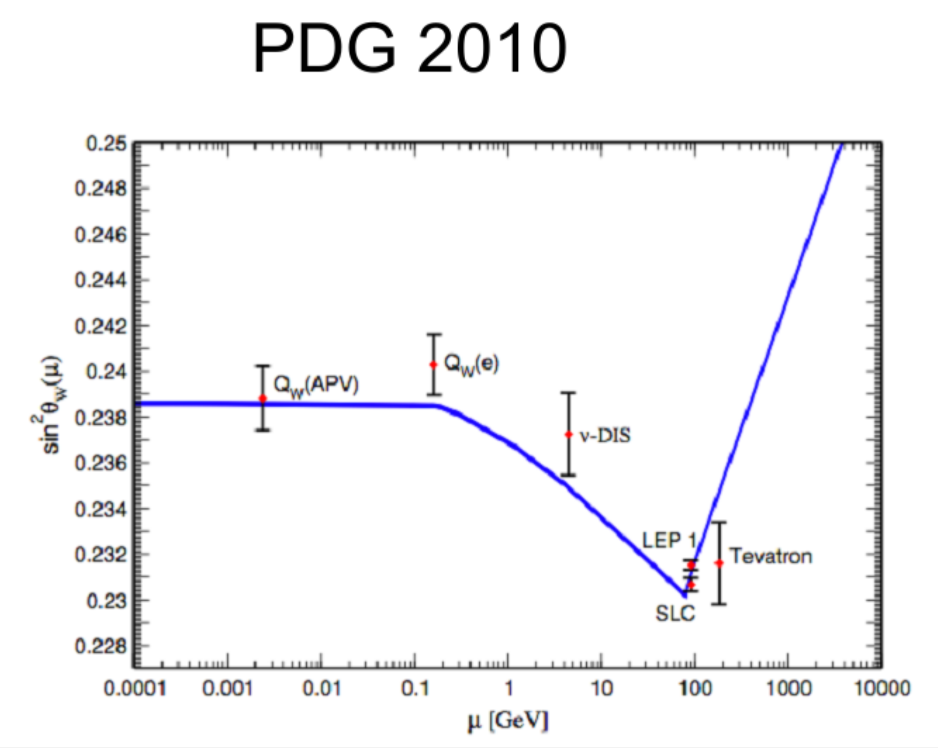
nu e elastic scattering:
- neutrino flux calibration
- nu magnetic moment
- weak mixing angle at low Q2

- Running with Q^2 of $\sin^2\theta_w$.
- Present low Q^2 limit ~0.5% from parity violation asymmetry experiment.

- Use Project X π DAR beam

- Get mostly ν_e and $\nu_\mu$bar from μ^+ decay with 2.2 μs lifetime and ν_μ from π^+ decay with 26 ns lifetime.
- The ratio $R = \sigma(\nu_\mu e)/[\sigma(\nu_e e) + \sigma(\nu_\mu \text{bar-}e)]$ $=(0.75-3\sin^2\theta_w+4\sin^4\theta_w)/(1+2\sin^2\theta_w+8\sin^4\theta_w)$

Richard Imlay
University of Virginia

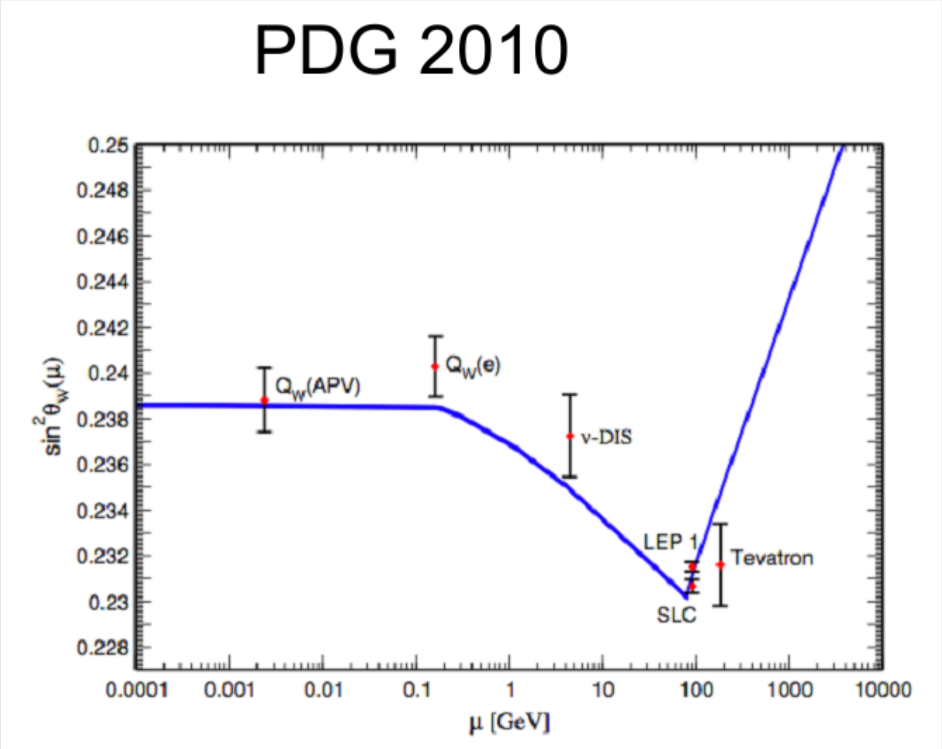


- See J.Phys. G. Nucl. Part.Phys. 29(2003) 2647-2664 for design for SNS
- Measure R to 2-3% for 600 ns spill and $\sin^2\theta_w$ to 1 to 2% in oil or water detector.
- Might do factor of 2 better with 200 ns spill.

Neutrino Interaction Physics at Project X

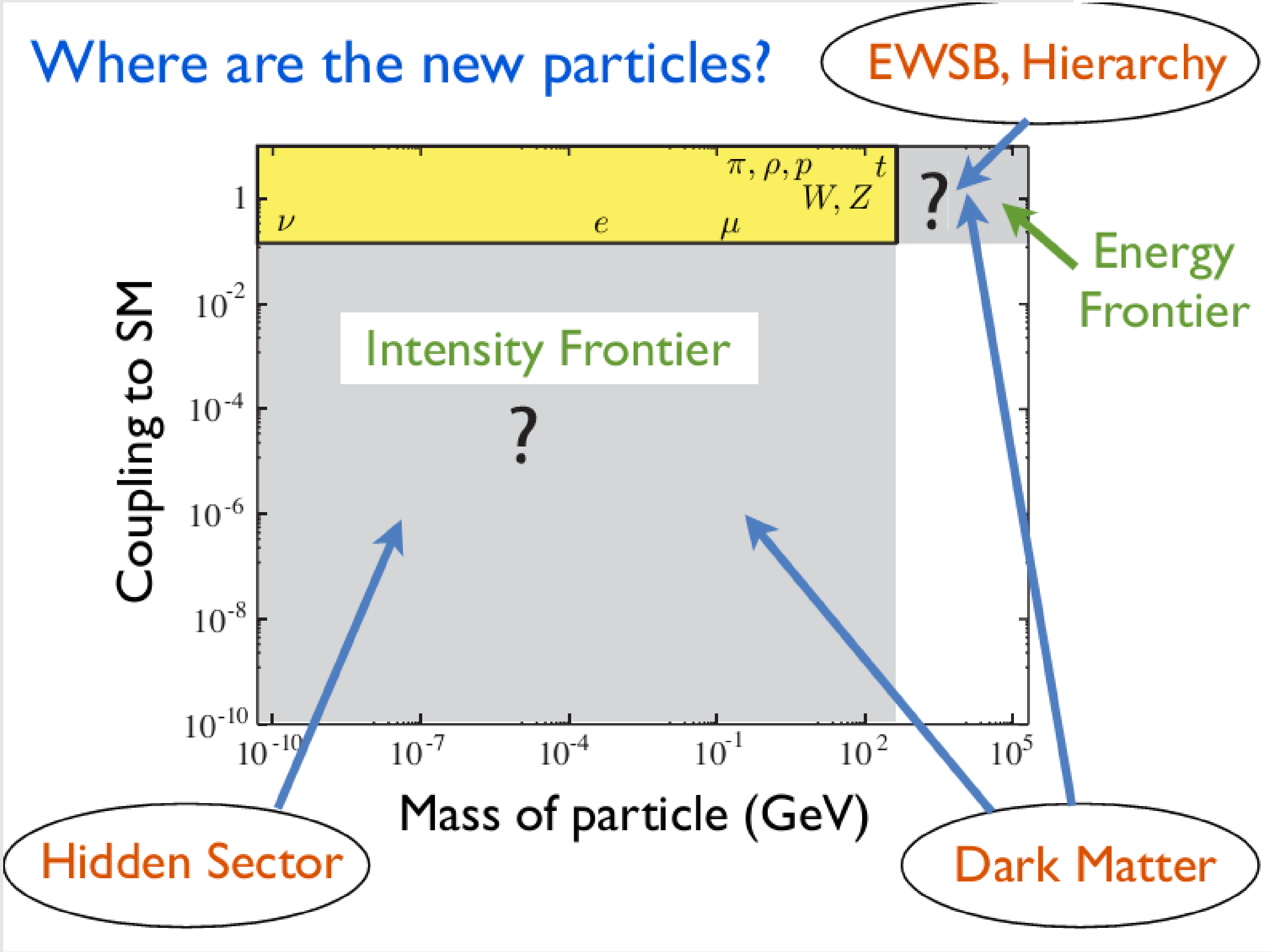
nu e elastic scattering:
- nu magnetic moment
- weak mixing angle at low Q2

Requires:
- tracking detector
- π DAR source, O(1MW)
- lowish duty factor beam, <10% ?



Dark Sector Physics at Project X

Brian Batell
University of Chicago



Dark Sector Physics at Project X

Brian Batell
University of Chicago

Dark matter beam

BB, Pospelov, Ritz

Dark matter produced in decay of light mediator

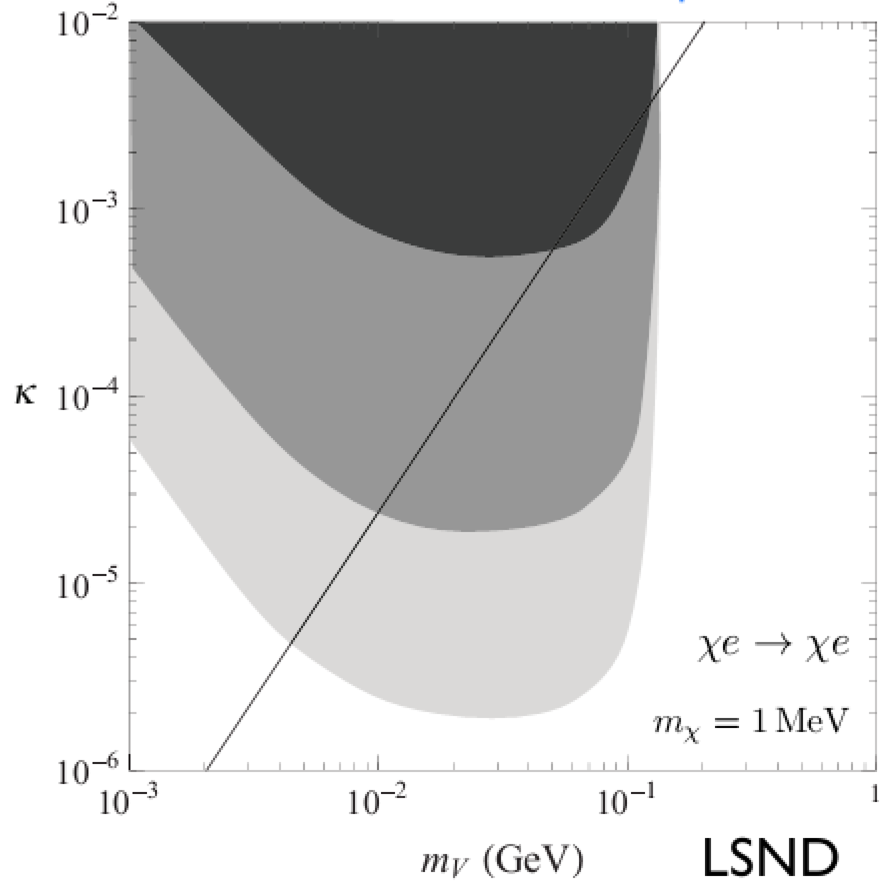
$$\pi_0, \eta \to \gamma V$$

$$V \to \bar{\chi}\chi$$

Neutral current-like event:

$$\chi e \to \chi e$$

$$\chi N \to \chi N$$



Requires:
- scintillator/Cerenkov/liquid Argon detectors
- higher power (100kW) 8GeV DIF source

Neutrino Detector Development at Project X

Detector development work required for Project X
- scintillators:
  - new (non-PC mixtures), metal loading (n-capture), water-based
  - higher segmentation
  - readout methods, new configurations
- liq-Ar (liq noble gases)
  - studies of ionization, light, etc
  - readout techniques, new configs
- others
  - emulsion
- detector techiques
  - nu beam wrong-sign contribution
  - flux normalization

Neutrino Detector Development at Project X

Detector development work required for Project X
- scintillators:
  - new (non-PC mixtures)

Table 1
The chemical properties and physical performance of selected LS

first identified by SNO+

	LS[a]						
	PC	PCH	DIN	PXE	LAB	MO	DD
Molecular formula	C_9H_{12}	$C_{12}H_{16}$	$C_{16}H_{20}$	$C_{16}H_{18}$	$C_{18}H_{30}$[b]	C_nH_{2n+2}[c]	$C_{12}H_{26}$
Can Gd be loaded into the LS?	Yes	Yes	Yes	Yes[d]	Yes	No	No
Density (g/ml)	0.89	0.95	0.96	0.99	0.86	0.85	0.75
$abs_{430,before purification}$	0.008	0.072	0.040	0.044	0.001	0.002	0.001
$abs_{430,after purification}$	0.002	0.001	0.023	0.022	~0.000	0.001	~0.000
Purification method[e]	v.d.	c.e.	c.e.	c.e.	c.e.	c.e.	c.e.
Index of refraction[f]	1.504	1.526	1.565	1.565	1.482	1.461	1.422
S%[g]	1	0.46	0.87	0.87	0.98	n.a.	n.a.
H-atoms per c.c. ($\times 10^{22}$)	5.35	3.72	5.45	4.34	6.31	8.05	4.77
Flash point (°C)	48	99	>140	145	130	215	71

[a]See the text in Section 3.4 for the chemical names of these organic compounds.
[b]With alkyl side chain containing 12 carbon atoms.
[c]$n \approx 30$ [17].
[d]Only stable for few months.
[e]v.d. = vacuum distillation; c.e. = column extraction with solid Al_2O_3.
[f]Optical index of refraction at 20 °C, except DIN at 25 °C (cited from Material Safety Data Sheets and Ullmann's Encyclopedia of Industrial Chemistry, 5th ed., vol. A, Wiley, November 1991).
[g]Scintillation yield normalized to 100% PC; n.a. = non-aromatic compounds which do not scintillate.

M. Yeh et al. / Nuclear Instruments and Methods in Physics Research A 578 (2007) 329–339

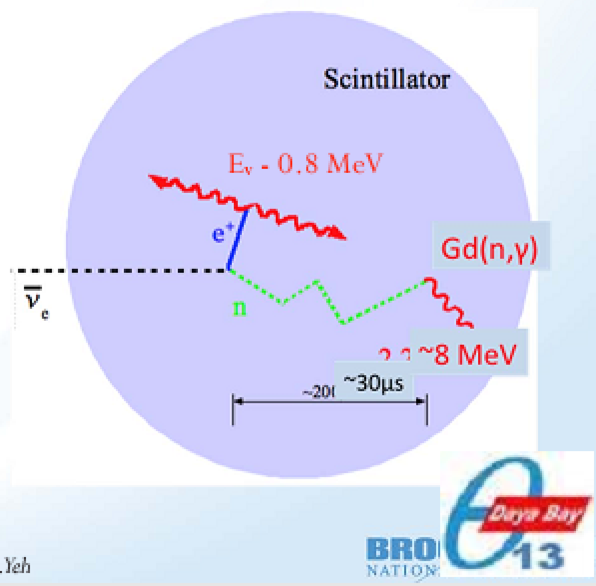
Brookhaven Science Associates — *PX workshop M.Yeh* — BROOKHAVEN NATIONAL LABORATORY

Neutrino Detector Development at Project X

Detector development work required for Project X
- scintillators:
    - metal loading (n-capture), water-based

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

$$n + {}^{A}\mathrm{Gd} \rightarrow {}^{A+1}\mathrm{Gd} + \gamma's$$

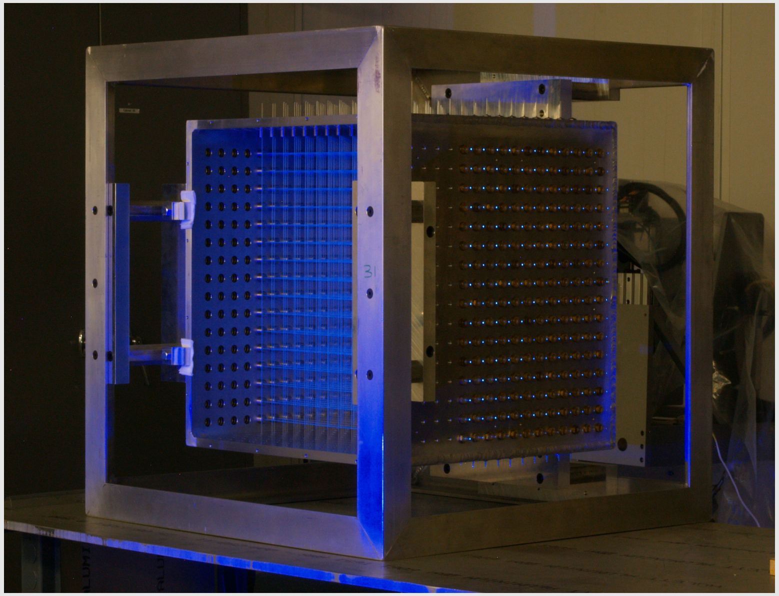


Option-3: Water-based Liquid Scintillator

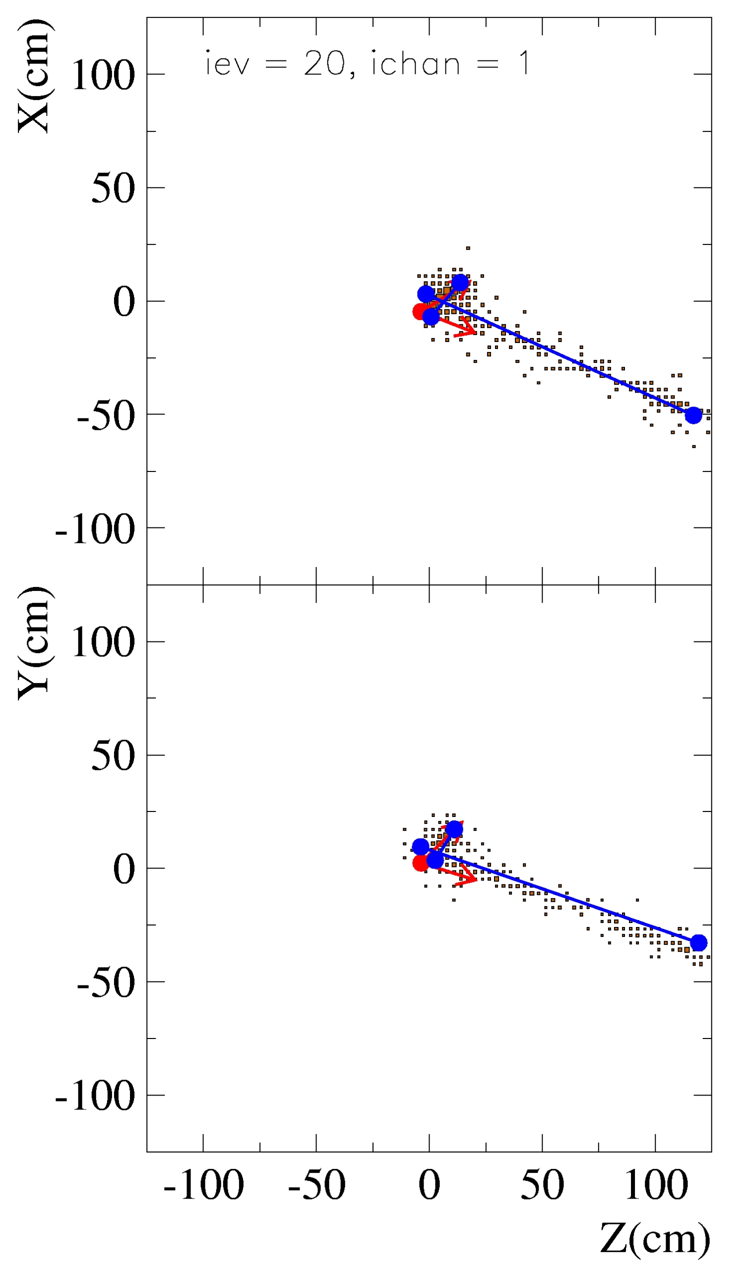
- *Cost-saving for larger detector (see talk in cost-effective detector session)*
- *Clean Cerenkov cone with scintillation at few hundreds of photons per MeV (tunable)*
- *Fast pulse and long attenuation length with minimum ES&H concerns*
- *A new technology ready to use:*
    - *Excellent detection medium for proton decay; and other physics*
    - *Easy to be handled for large detector*
    - *Gd-soluable*
    - *A economic large veto solvent*

Neutrino Detector Development at Project X

Detector development work required for Project X
- scintillators:
  - higher segmentation

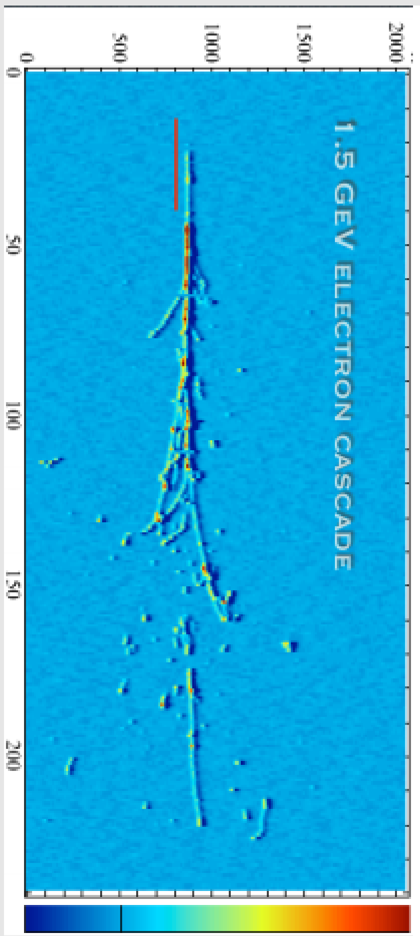


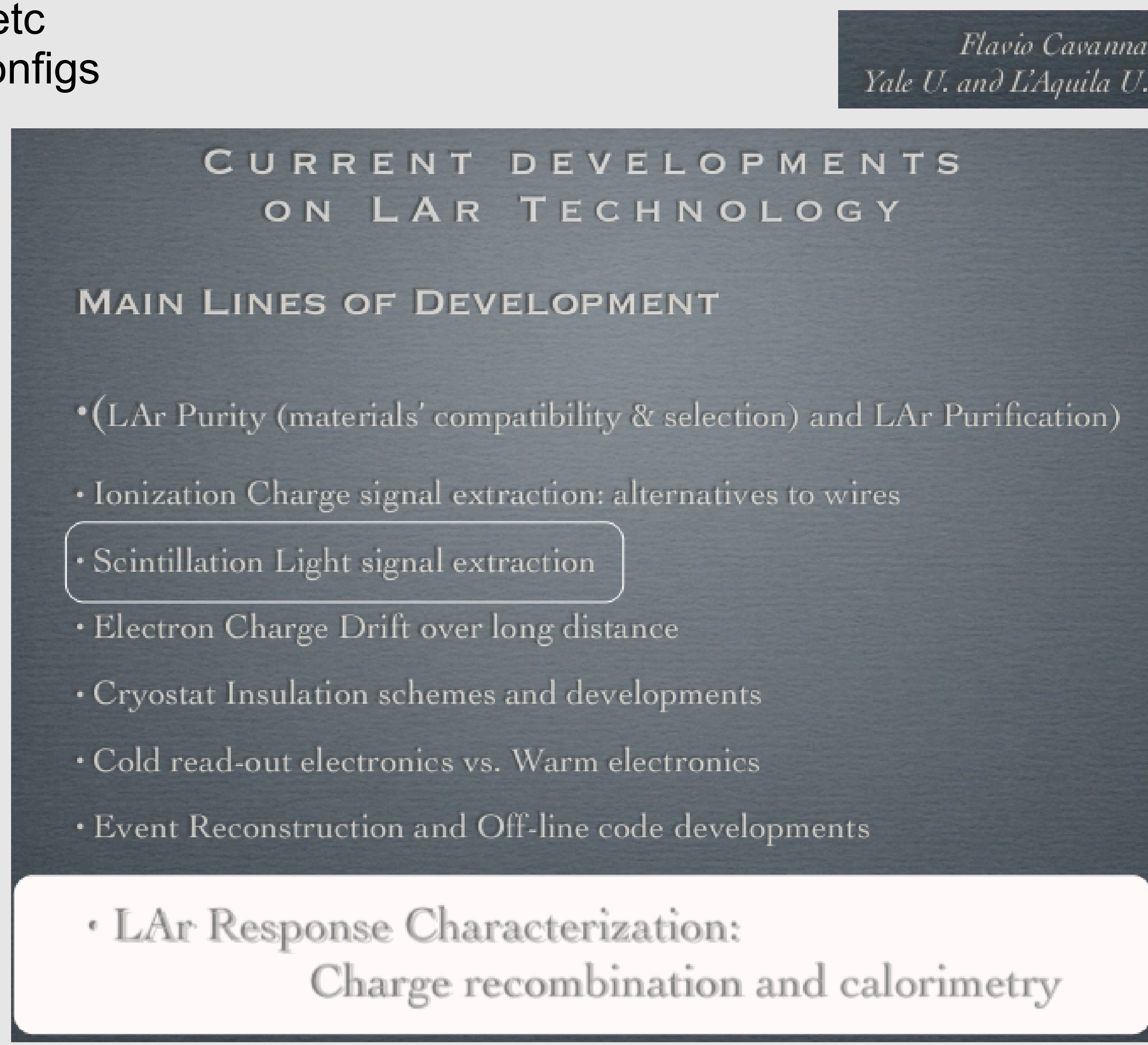
scibath detector, Indiana U.



Neutrino Detector Development at Project X

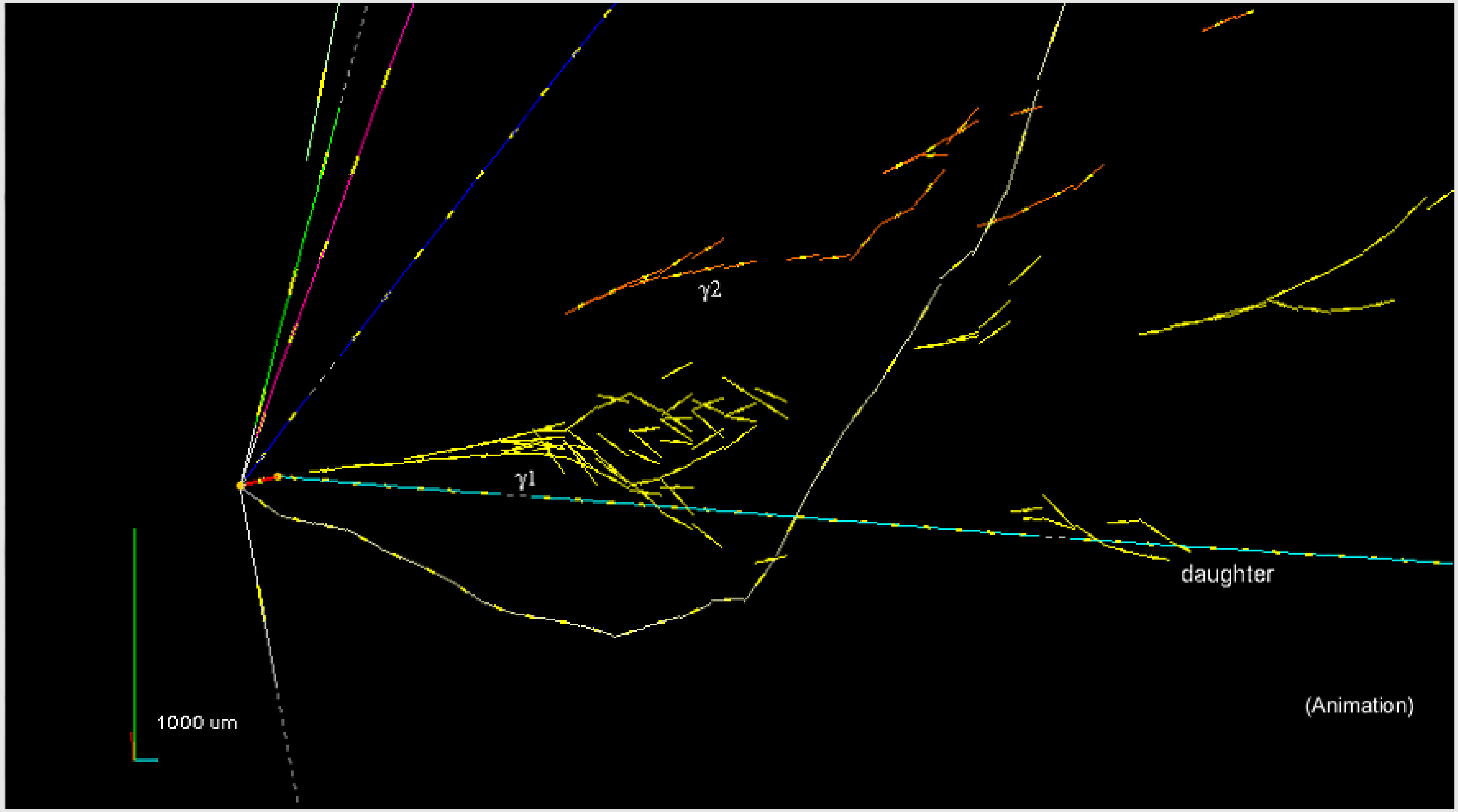
Detector development work required for Project X
- liq-Ar (liq noble gases)
  - studies of ionization, light, etc
  - readout techniques, new configs





Neutrino Detector Development at Project X

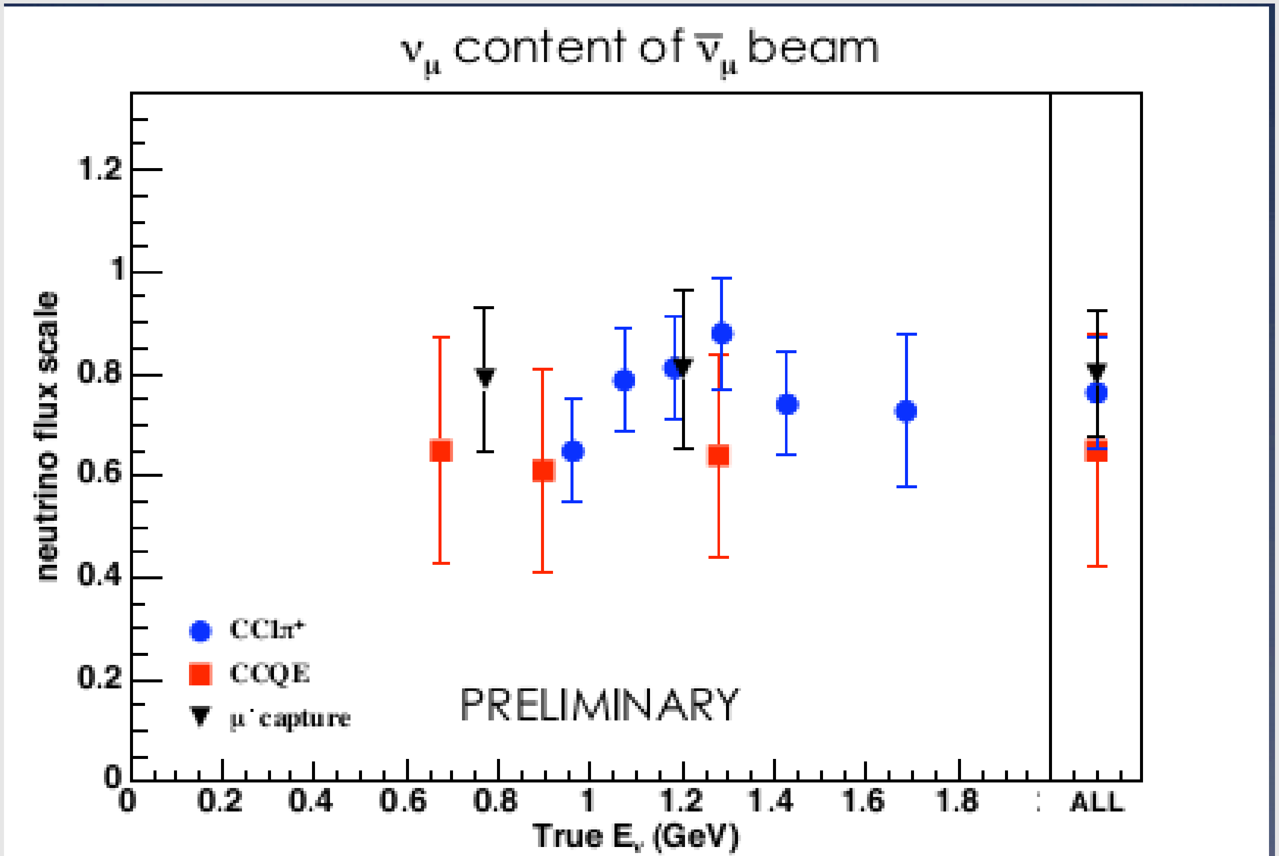
Detector development work required for Project X
- others
  - emulsion



Adam Para,

Neutrino Detector Development at Project X

Detector development work required for Project X
- detector techiques
  - nu beam wrong-sign contribution

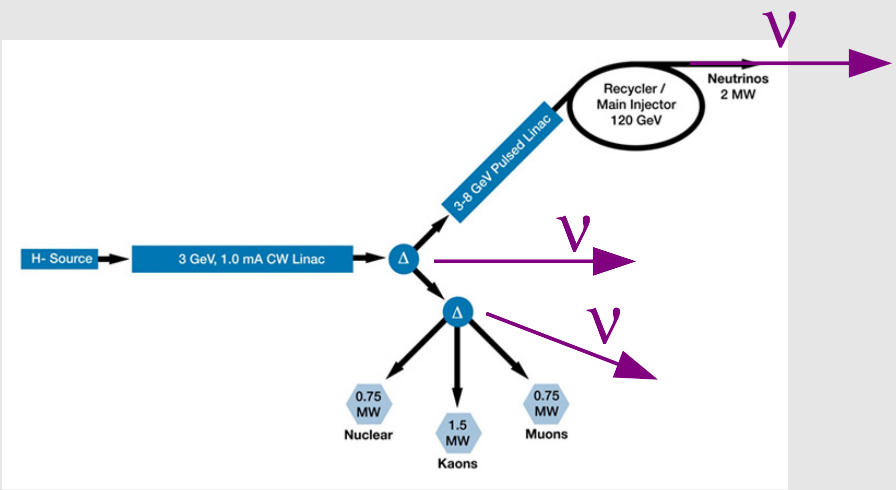


Joe Grange
University of Florida

Neutrino Detector Development at Project X

nu sources and parameters to consider:

- DAR source for ~50Mev nu
  - from 1,3,or 8 GeV
  - target design
  - time structure, buncher ring requirement
- DIF source from for 0.5-10GeV nu
  - from 3,8,60,120 GeV
  - target design
  - time structure, buncher ring requirement
- DAR K+ source
- "nu-factory" type



Program:	Onset of NOvA operations in 2013	Stage-1: 1 GeV CW Linac driving Booster & Muon, n/edm programs	Stage-2: Upgrade to 3 GeV CW Linac	Stage-3: Project X RDR	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
		← Project X Campaign →			
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2450 kW	2450-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-42 kW* + 0-90 kW**	0-84 kW*	0-172 kW*	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	0-172 kW*	1000 kW
1-3 GeV Muon program, e.g. Mu2e-2	-----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1870 kW	1870 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
# Programs:	4	8	8	8	8
Total max power:	735 kW	2222 kW	4284 kW	6492 kW	11870kW

* Operating point in range depends on MI energy for neutrinos.
** Operating point in range depends on MI injector slow-spill duty factor (df) for kaon program.

Neutrino Detector Development at Project X

nu sources to consider:

- DAR source for ~50Mev nu
    - competition with SNS, JPARC makes staging important
- from 1,3,or 8 GeV?
    - DAR from 8 GeV may happen earlier, increased 8GeV power can provide incremental gains
    - 1,3 GeV, ~1MW would be world-class DAR source, but will it be timely?
    - time structure, buncher ring for ~1E-4 duty factor required for most physics id'd
- target design
    - best if optimized for nu, but may not be crucial
    - multiple functions (n-production, etc)

Project X Campaign

Program:	Onset of NOvA operations in 2013	Stage-1: 1 GeV CW Linac driving Booster & Muon, n/edm programs	Stage-2: Upgrade to 3 GeV CW Linac	Stage-3: Project X RDR	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2450 kW	2450-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-42 kW* + 0-90 kW**	0-84 kW*	0-172 kW*	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	0-172 kW*	1000 kW
1-3 GeV Muon program, e.g. Mu2e-2	----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1870 kW	1870 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
# Programs:	4	8	8	8	8
Total max power:	735 kW	2222 kW	4284 kW	6492 kW	11870kW

* Operating point in range depends on MI energy for neutrinos.

** Operating point in range depends on MI injector slow-spill duty factor (df) for kaon program.

Neutrino Detector Development at Project X

nu sources to consider:
- DAR source for ~50Mev nu

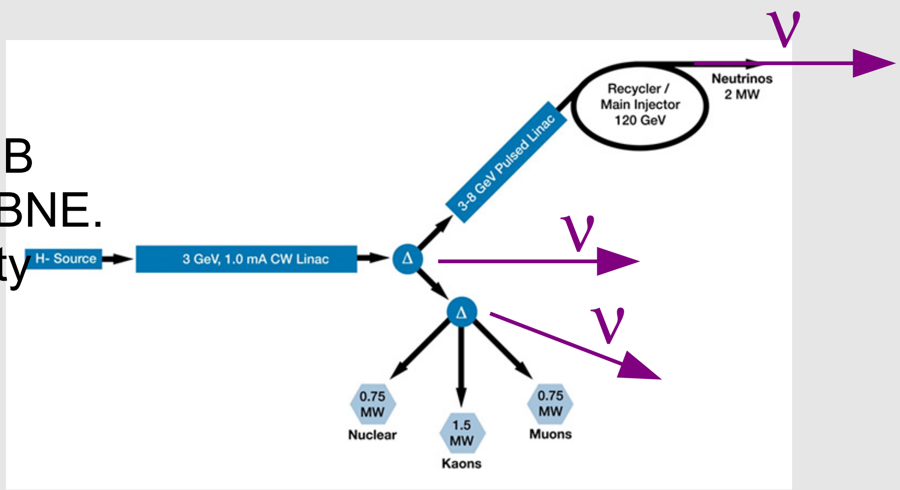
Project X targets

Fritz DeJongh

- A chance to design for detector close in?
- 1 MW, 1 GeV
- 1 MHz, 10 nsec beam width
- Can reduce duty cycle only by removing pulses, proportionally reducing power
- If enough motivation to justify expense:
  - Compressor ring
  - Full absorption target
    - More advice from Tennessee colleagues: Target is cheaper if it doesn't have to be a spallation source.
- As we improve our understanding, we can look at targets being build for other uses and see if any are suitable.

Neutrino Detector Development at Project X

nu sources and parameters to consider:
- DIF source for 0.5-10GeV nu
  - from 3-120 GeV
    - expect much progress pre-projectX from BNB (8GeV), NUMI (120GeV), in NOvA upgrades, LBNE.
    - not clear that new DIF source of same variety called for.. from ProjectX
    - new type of DIF source may be needed
  - time structure, buncher ring requirement
    - likely that low-duty factor required



Project X Campaign

Program:	Onset of NOvA operations in 2013	Stage-1: 1 GeV CW Linac driving Booster & Muon, n/edm programs	Stage-2: Upgrade to 3 GeV CW Linac	Stage-3: Project X RDR	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2450 kW	2450-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-42 kW* + 0-90 kW**	0-84 kW*	0-172 kW*	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	0-172 kW*	1000 kW
1-3 GeV Muon program, e.g. Mu2e-2	-----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1870 kW	1870 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
# Programs:	4	8	8	8	8
Total max power:	735 kW	2222 kW	4284 kW	6492 kW	11870kW

* Operating point in range depends on MI energy for neutrinos.
** Operating point in range depends on MI injector slow-spill duty factor (df) for kaon program.

Neutrino Detector Development at Project X

- nu sources:
  - “nu-factory" type (A. Bross)

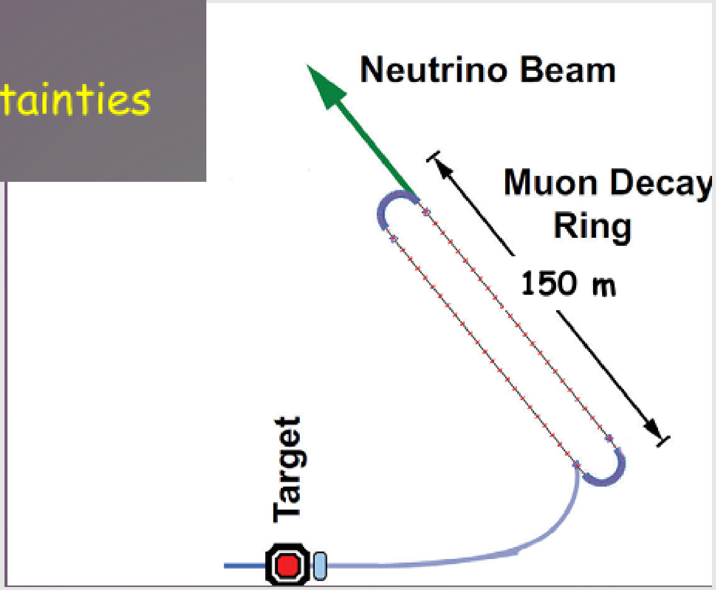
Well-understood neutrino source:

$$\mu^+ \to e^+ \bar{\nu}_\mu \nu_e$$

μ Decay Ring: $$\mu^- \to e^- \nu_\mu \bar{\nu}_e$$

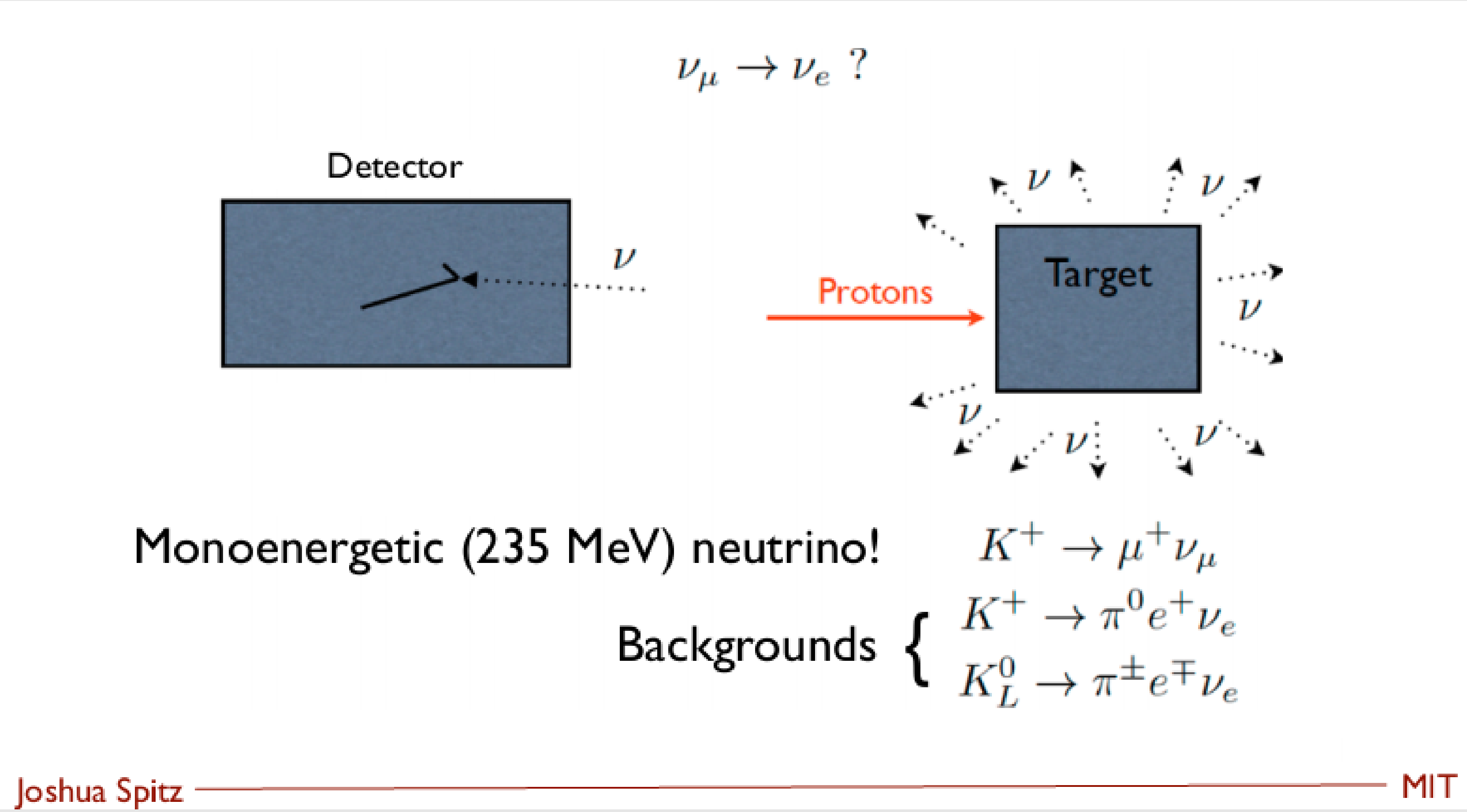
- Flavor content fully known
- “*Near Absolute*” Flux Determination is possible in a storage ring
  - Beam current, polarization, beam divergence monitor, μ_p spectrometer
- Overall, there is tremendous control of systematic uncertainties with a well designed system

νSTORM



Neutrino Detector Development at Project X

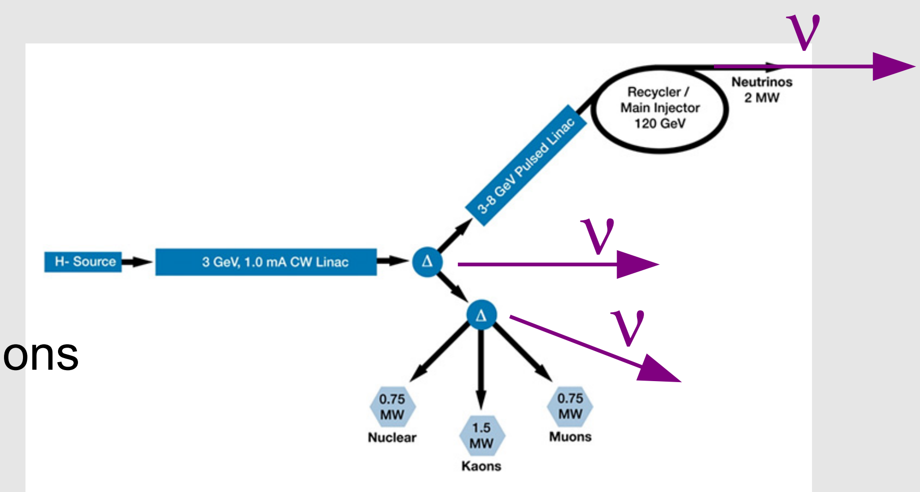
- nu sources:
  - K+ DAR source?
    - requires >3GeV, intense, proton source.
    - O(10%) duty factor may be ok.



Neutrino Physics at Project X

- short-baseline, long baseline oscillations (covered by P. Huber)

- supernova detection



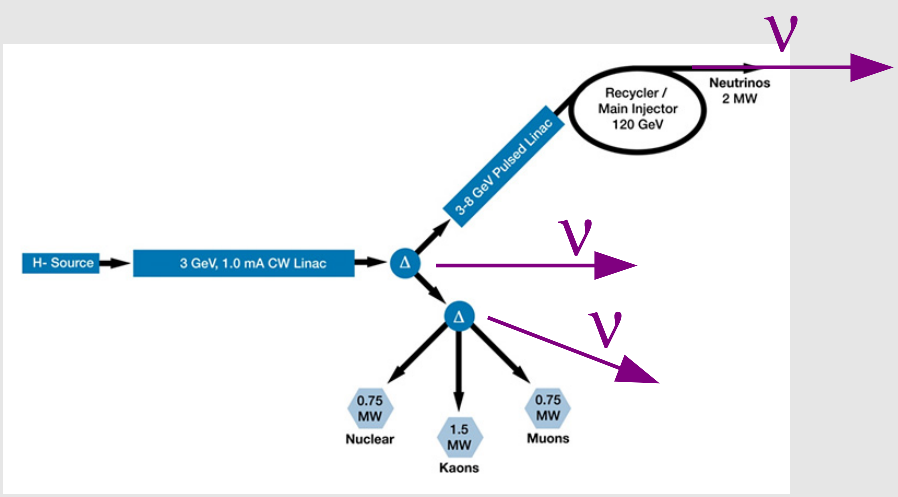
- nu interactions/cross sections
  - "low-energy":
    - π DAR source, ~10-50MeV
    - ν elastic coherent, νN supernova interactions
  - "med-energy":
    - π DIF source, ~0.1-2.0 GeV
    - 2N correlations, deltas, nu pi coherent prod, etc
  - "hi-energy":
    - π DIF source, ~1.0-10GeV

- nu-e elastic for nu mag moments, sin2thew, flux monitoring

- "exotica"
  - dark sector searches
  - non-standard interactions (covered by P. Huber)

Enabling... Neutrino Physics at Project X

- Detectors:
- scintillators:
  - new (non-PC mixtures), metal loading, water-based
  - physics techniques with these
  - readout methods, new configurations
- liq-AR (liq noble gases)
  - studies of ionization, light, etc
  - readout techniques, new configs
- others
  - emulsion



- nu sources:
- DAR source for ~50Mev nu
  - from 1,3,or 8 GeV
  - target design
  - time structure, buncher ring requirement
- DIF source from 3,8,60,120 GeV for 0.5-10GeV nu
  - target design
  - time structure, buncher ring requirement
- DAR kaon source
- "nu-factory" type

Summary

- Project X offers great opportunity for neutrino oscillation, neutrino interaction, non-standard iteraction physics.

- Detector R&D work will be required. Planning underway.

- nu sources from Project X can be world-class. Optimization crucial.