

# Round-up of October 2012 Project-X Research Program Activity

- **October 11<sup>th</sup>-13<sup>th</sup>:**  
Community Planning Meeting October, Fermilab
- **October 15<sup>th</sup>:**  
Interaction with the Fermilab PAC, Fermilab
- **October 17<sup>th</sup>-19<sup>th</sup>:**  
Muon Spin Rotation (MuSR) forum, Fermilab
- **October 26<sup>th</sup>:**  
Muon Physics Symposium, Pyeongchang SK.

R. Tschirhart  
Nov 16<sup>th</sup> 2012

# Interaction with the Fermilab PAC\*

## **Project X Charge:**

“The PX Stage 1 physics case continues to be refined. We ask the PAC to comment on the plans for understanding and articulating the physics case in preparation for the “Snowmass 2013” meeting.”

## **Associated Charges:**

“The laboratory has also received two EOI’s:

EOI: NNbarX (Kamyshkov)

EOI: Proton EDM (Semertzidis)

These initiatives are seeking support for R&D that will enable them to eventually prepare a full proposal. We ask the PAC to comment, for each EOI, on whether the science goals are compelling, and on the scope and appropriateness of the proposed R&D.”

\* [http://www.fnal.gov/directorate/program\\_planning/Oct2012Public/PAC%20Agenda%20October%202012.htm](http://www.fnal.gov/directorate/program_planning/Oct2012Public/PAC%20Agenda%20October%202012.htm)

## Fermilab PAC feedback:

- Nothing formal yet....in discussions...
- Reaction to Phase-1: Is there a power staging plan to 1 MW?
- Continue to work closely with DOE NP

# Since PXPS: Interaction with the LBNE Reconfiguration enterprise\*

## Physics Opportunities with Stage 1 of Project X

Wolfgang Altmannshofer, Marcela Carena, Patrick Fox, Stuart Henderson,  
Stephen Holmes, Young-Kee Kim, Joachim Kopp, Andreas Kronfeld,  
Joseph Lykken, Chris Quigg, and Robert Tschirhart

August 2012

\* [http://www.fnal.gov/directorate/lbne\\_reconfiguration/](http://www.fnal.gov/directorate/lbne_reconfiguration/)

## Since PXPS: Interaction with the European Strategy for Particle Physics\*

- “Opportunities for Collaboration at Fermilab: Input to the European Strategy for Particle Physics, 2012”  
Submitted by P. Oddone
- “Opportunities for Collaboration in the Design and Development of the Project-X Accelerator Complex and Research Program.”  
Submitted by S. Holmes & R. T.
- “Americas: Vision, Status & Strategy”  
Presented by A. Lankford.

\*(<http://espp2012.ifj.edu.pl/>)

## Project X – Overview

**Unique facility with a 3 MW at 3 GeV continuous-wave (CW) linac.**

**Principal characteristics:**

- **Increases Fermilab low-energy proton flux by x100  
with flexible timing patterns, ideal for rare decay experiments**
- **Experiments run simultaneously at 3 GeV, 8 GeV, & 60-120 GeV at high power**
- **Delivers 2+ MW to LBNE**
- **Design consistent with serving as front end for neu factory or muon collider**

**Capable of a rich physics menu  
with neutrinos, kaons, muons, nuclei**

**Centerpiece of a world-leading Intensity Frontier program**

**R&D in progress**

## Project X – Phased approach

Project X can be broken down into 3 phases, each about 1/3 of the cost.

- **Phase 1: Up to 1 GeV**  
Retires old linac, increases neutrino flux x1.7, enhances existing Mu2e by x10, starts EDM, nuclear-physics and nuclear-materials studies
- **Phase 2: Up to 3 GeV**  
Starts powerful Intensity Frontier experiments with kaons and feeds short baseline neutrino programs
- **Phase 3: Up to 8 GeV**  
Multiplies power to LBNE by x3, multiplies power at 8 GeV several fold for short baseline neutrino program

First phase could be 2<sup>nd</sup> phase of LBNE.

Decision on when to start later in decade.

# U.S. at the Intensity Frontier - Summary

**Vision:** Implement comprehensive program to understand **neutrino mixing**.  
Deliver much improved limits (measurements?) of **charged lepton mixing**  
and **hidden sector phenomena**

## **Status:**

### **Neutrinos**

Broad, world-class neutrino program already in progress at Fermilab  
New facilities are under construction for near term

### Planned program of **major projects:**

long baseline neutrino experiment – **LBNE** (CD-1 planned by end 2012)

lepton number violation experiment – **Mu2e** (CD-1 approved July 2012)

muon anomalous magnet moment experiment – **g-2**

R&D for next generation multi-MW proton accelerator – **Project X**

## **Strategy:**

**Devote Fermilab accelerator complex to advantage of worldwide community**

**Develop LBNE to its full potential:** underground, detector mass, flux

**Construct Project X** to feed rich, world-leading IF program w/ nu's, mu's, K's

# PX Stage 1 Physics Case: Preparations for Snowmass

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[http://www.snowmass2013.org/  
Minnesota](http://www.snowmass2013.org/Minnesota)



# SNOWMASS WORKING GROUPS

- Energy Frontier
- Intensity Frontier
- Cosmic Frontier
- Frontier Capabilities
- Instrumentation Frontier
- Computing Frontier
- Education and Outreach



## Intensity Frontier group charge:

Conveners: JoAnne Hewett (SLAC),  
Harry Weerts (Argonne)

The Intensity Frontier working group is charged with summarizing the current state of knowledge and identifying the most promising future opportunities at the intensity frontier. Topics are described under the working groups.



# Frontier Capabilities Group

Conveners: William Barletta (MIT), Murdock Gilchriese (LBNL)

Frontier Facilities will assess the existing and proposed capabilities of two distinct classes of experimental capabilities for high energy physics broadly understood, namely, those provided by accelerator-based facilities and those provided by detector facilities distinct from accelerators. We expect the evaluations to be performed with two principal groups that will operate independently: Accelerator Facilities and Non-accelerator Facilities.

## Stage-1 Accelerator Resources:

- Promotes the Main Injector (MI) to a Mega-Watt class machine for neutrinos, and increases the potential beam power for other medium power MI experiments (e.g. ORKA, nu-STORM).
- Unshackles the  $\mu \rightarrow e$  (Mu2e) experiment from the Booster complex: Potentially increases sensitivity of Mu2e by  $\times 10$  -  $\times 100$  with 1-GeV CW drive beam.
- High power spallation target optimized for ultra-cold neutron and atomic-edm particle physics experiments and neutron  $\leftrightarrow$  anti-neutron oscillation experiments.
- Capability to drive polarized protons to a proton-edm experiment.
- Increases the available integrated 8 GeV power for other experiments (e.g. short-baseline neutrinos) from the Booster complex by liberating Mu2e.

# CP violation research opportunities with Stage-1:

- Neutrinos: 70% increase in LBNE statistics.
- Proton-EDM,  $\times 10^6$  reach, *new capability*
- Muon-EDM,  $\times 10^4$  reach, *new capability*
- Neutron EDM,  $\times 10^2$ - $10^3$  reach
- Atomic EDMs.  $\times 10^3$ - $10^4$  reach, goal of surpassing Hg!

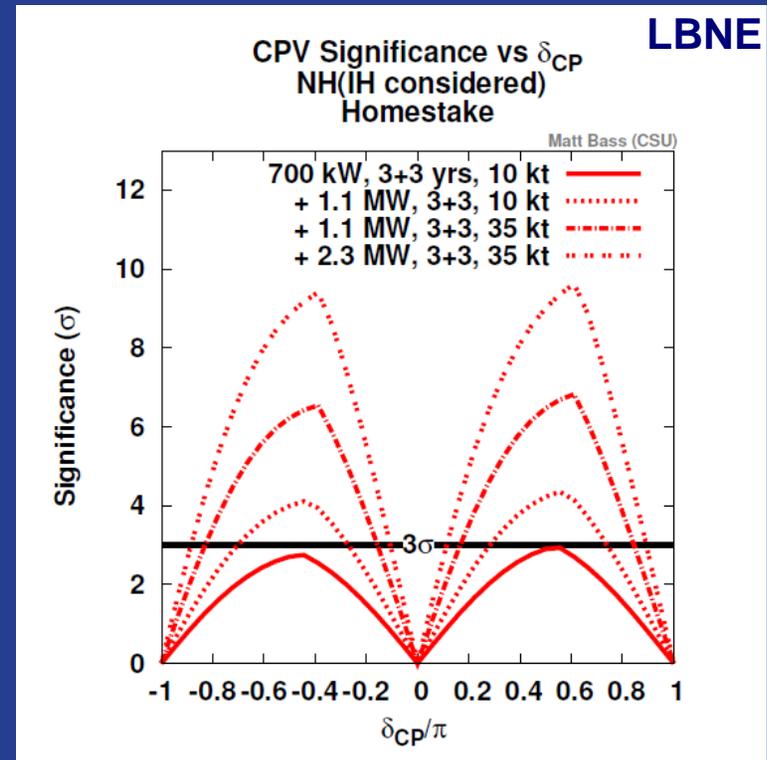


Table 2: SM predictions and current and expected limits on selected examples of EDMs.

EDMs	SM	current limit	Project X
electron	$\sim 10^{-38} e \text{ cm}$	$1.0 \times 10^{-27} e \text{ cm}$	$\sim 10^{-30} e \text{ cm}$
muon	$\sim 10^{-35} e \text{ cm}$	$1.1 \times 10^{-19} e \text{ cm}$	$\sim 10^{-23} e \text{ cm}$
neutron	$\sim 10^{-31} e \text{ cm}$	$2.9 \times 10^{-26} e \text{ cm}$	$\sim 10^{-29} e \text{ cm}$
proton	$\sim 10^{-31} e \text{ cm}$	$6.5 \times 10^{-23} e \text{ cm}$	$\sim 10^{-29} e \text{ cm}$
nuclei	$\sim 10^{-33} e \text{ cm}$ ( $^{199}\text{Hg}$ )	$3.1 \times 10^{-29} e \text{ cm}$ ( $^{199}\text{Hg}$ )	$\sim 10^{-29} e \text{ cm}$ ( $^{225}\text{Ra}$ )

Stage-1

# EDM Research Worldwide...

## ■ Neutrons

~200

- @ILL
- @ILL,@PNPI
- @PSI
- @FRM-2
- @RCNP,@TRIUMF
- @SNS
- @J-PARC

## ■ Molecules

~50

- YbF@Imperial
- PbO@Yale
- ThO@Harvard
- HfF+@JILA
- WC@UMich
- PbF@Oklahoma

Rough estimate of numbers of researchers, in total  
~500 (with some overlap)

## ■ Atoms

~100

- Hg@UWash
- Xe@Princeton
- Xe@TokyoTech
- Xe@TUM
- Xe@Mainz
- Cs@Penn
- Cs@Texas
- Fr@RCNP/CYRIC
- Rn@TRIUMF
- Ra@ANL
- Ra@KVI
- Yb@Kyoto

## ■ Ions-Muons

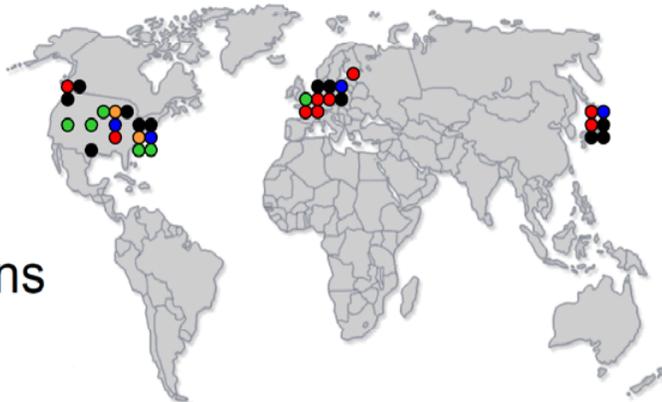
~200

- @BNL
- @FZJ
- @FNAL
- @JPARC

## ■ Solids

~10

- GGG@Indiana
- ferroelectrics@Yale



Courtesy Klaus Kirch  
CIPANP 2012

## Neutrino research opportunities with Stage-1:

- 70% increase in LBNE statistics for hierarchy, precision oscillation measurements.
- 70% increase in statistics for short baseline experiments driven by the Main Injector (e.g. nuSTORM).
- x3 increase in 8 GeV beam power for short baseline experiments.

## Baryon number violation research opportunities with Stage-1

- $n$ - $\bar{n}$  oscillations with free neutron techniques, sensitivity reach beyond Super-K which is background limited.

# Rare Processes Research Probing far Beyond the TeV scale with Stage-1

- x10 improvement in  $\mu \rightarrow 2e$  sensitivity.  
Platform for next generation rare muon decay experiments such as  $\mu \rightarrow 3e$ .
- x100 improvement in  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  sensitivity, many other rare  $K^+$  modes.

Process	Current	ORKA	Comment
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	7 events	1000 events	
$K^+ \rightarrow \pi^+ X^0$	$< 0.73 \times 10^{-10}$ at 90% CL	$< 2 \times 10^{-12}$	$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is a background
$K^+ \rightarrow \pi^+ \pi^0 \nu \bar{\nu}$	$< 4.3 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \rightarrow \pi^+ \pi^0 X^0$	$\lesssim 4 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \rightarrow \pi^+ \gamma$	$< 2.3 \times 10^{-9}$	$< 6.4 \times 10^{-12}$	
$K^+ \rightarrow \mu^+ \nu_{heavy}$	$< 2-10 \times 10^{-8}$	$< 1 \times 10^{-10}$	$150 \text{ MeV} < m_\nu < 270 \text{ MeV}$
$K^+ \rightarrow \mu^+ \nu_\mu \nu \bar{\nu}$	$< 6 \times 10^{-6}$	$< 6 \times 10^{-7}$	
$K^+ \rightarrow \pi^+ \gamma \gamma$	293 events	200,000 events	
$\Gamma(Ke2)/\Gamma(K\mu2)$	$\pm 0.5\%$	$\pm 0.1\%$	
$\pi^0 \rightarrow \nu \bar{\nu}$	$< 2.7 \times 10^{-7}$	$< 4-50 \times 10^{-9}$	depending on technique
$\pi^0 \rightarrow \gamma X^0$	$< 5 \times 10^{-4}$	$< 2 \times 10^{-5}$	

## Broader Impacts Research with Stage-1

- Energy applications: Material studies, transmutation science, accelerator reliability. DOE SC/NE workshop early 2013.
- Materials science with muon Spin Rotation (muSR): very-low energy ( $<4$  MeV) stopping  $\mu^+$  that are sensitive probes of the magnetic properties of materials. Several facilities world-wide, no US facilities. Project X muSR forum October 17<sup>th</sup>-19<sup>th</sup>.

## CSS 2013 Engagement Plan: Accelerator Reference Design Report

- Accelerator Reference Design Report (RDR) will be prepared for distribution to the community in at the Fermilab Users Meeting June 12<sup>th</sup> 2013. The RDR will include:
  - Staging plan, capability of each stage.
  - Some information on cost drivers and scaling.

# CSS 2013 Engagement Plan: Research Program Report

- Research program opportunities report will be prepared for distribution to the community at the Fermilab Users Meeting June 12th 2013. This report will include:
  - Experimental concepts and physics reach opportunities of each stage.
  - Will evolve from existing white papers, work at the Project X Physics Study, a URA funded theory study group and PX/CSS Intensity Frontier meetings in late April 2013.

# CSS 2013 Engagement Plan: Necessary Detector R&D Report

- A report on Detector R&D required to develop the research program opportunities will be prepared for distribution to the community at the Fermilab Users Meeting June 12th 2013. This report will include:
  - R&D necessary for each stage.
  - Coordination with the DPF Coordination Panel for Advanced Detectors (CPAD) and connections to other scientific and technical disciplines. Meetings at ANL in January, Boulder Co. in the spring.

# CSS 2013 Engagement Plan: Broader Impacts Report

- A report on the broader impacts of Project X will be prepared for distribution to the community at the Fermilab Users Meeting June 12th 2013. This report will include:
  - Energy and material irradiation applications working closely with our DOE NE colleagues at ANL, LANL and PNNL and our Indian collaborators.
  - Possibly muon Spin Rotation applications.

## CPM 2012 Feedback

- There will be discussion regarding facilities.
- What the “Capabilities” group wants:

Particle	Energy	Rate	Timing	Purity	Spatial...
Kaons					
Muons					
Neutrinos					
Neutrons					
....					

## Schedule in advance of CSS 2013

- December 2012: Provide table of particle beam requirements to Bill Barletta (CSS2013 capabilities group).
- Broader applications forums and workshops Oct 2012 (muSR, done), January 2013 (Energy & Materials).
- Late April 2013: Meeting at Fermilab to review Project X draft materials for Snowmass. This meeting will be coordinated with an Intensity Frontier CSS 2013 preparatory meeting at ANL.
- June 2013: Post and distribute Project X Snowmass materials at Fermilab Users Meeting June 11<sup>th</sup>-12<sup>th</sup>.

# Project X Spin Rotation Forum\*

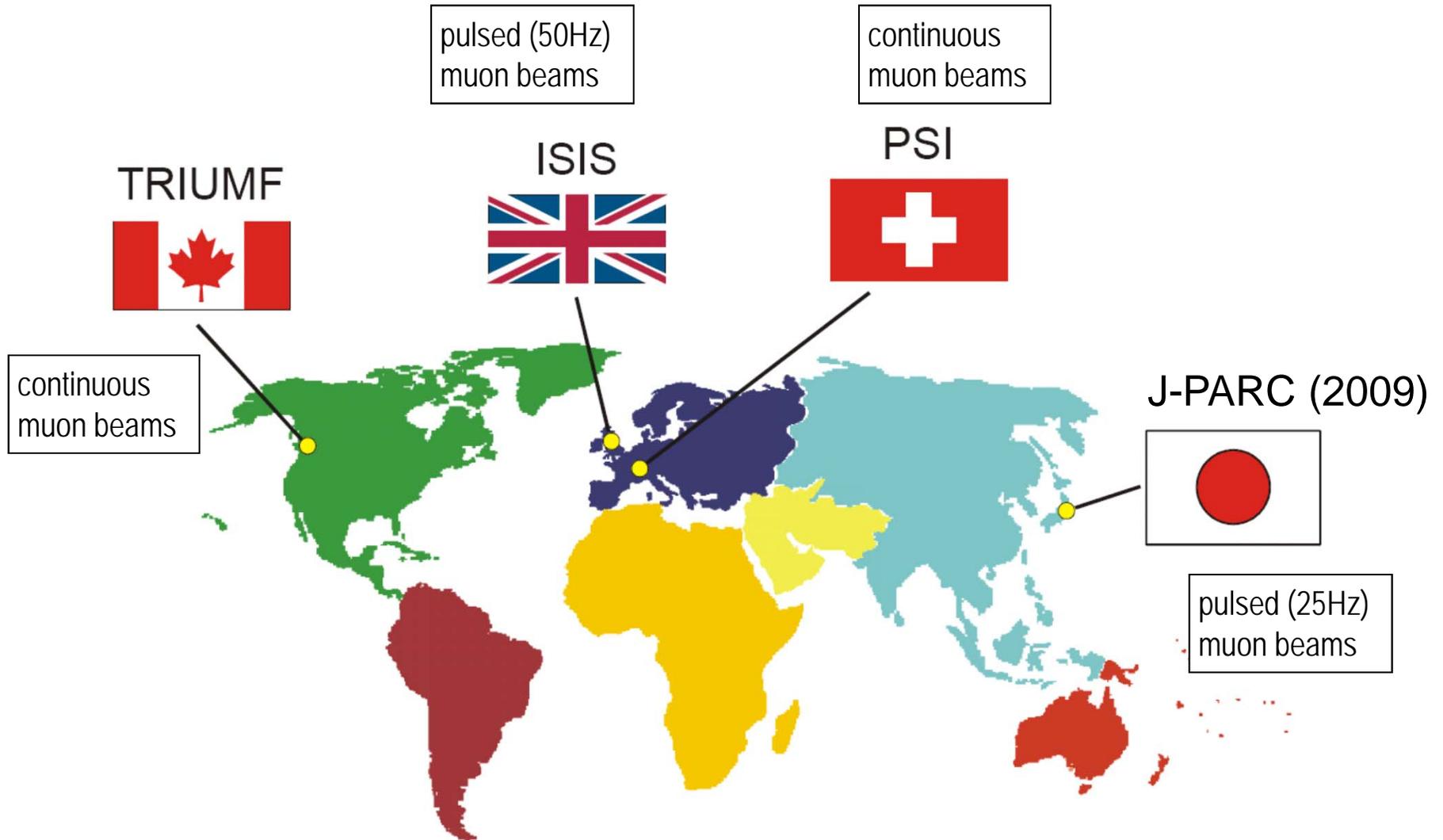


\*<https://indico.fnal.gov/conferenceDisplay.py?confId=6025>

# MuSR Forum Summary

- Current facilities world wide are either continuous beam or low frequency ( $\sim 25$  Hz) pulsed, and are typically oversubscribed by x2-x3.
- There are currently no US facilities, although there are active researchers within the US working elsewhere.
- The “perfect” pulsed facility would be 20-100kHz at high power ( $>100$  kW). No easy solution at hand!
- There is world-wide interest in another facility in the US.

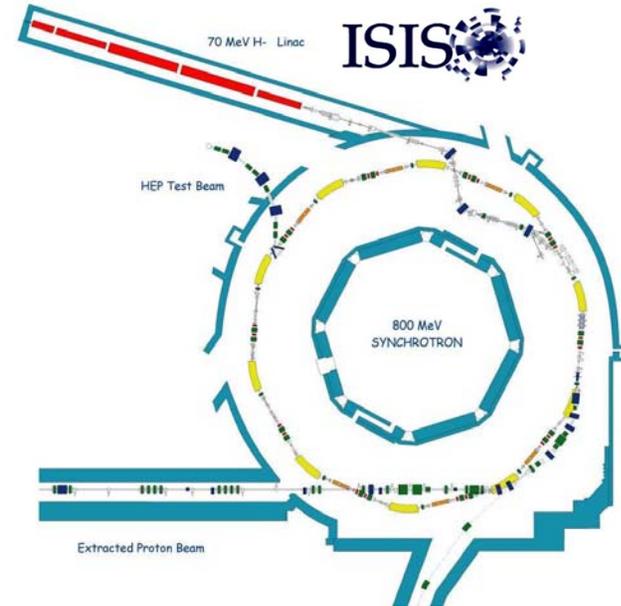
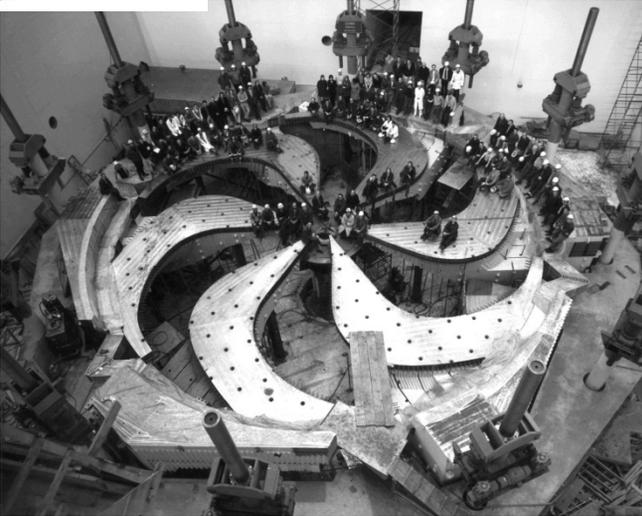
# Muon Research Facilities around the World



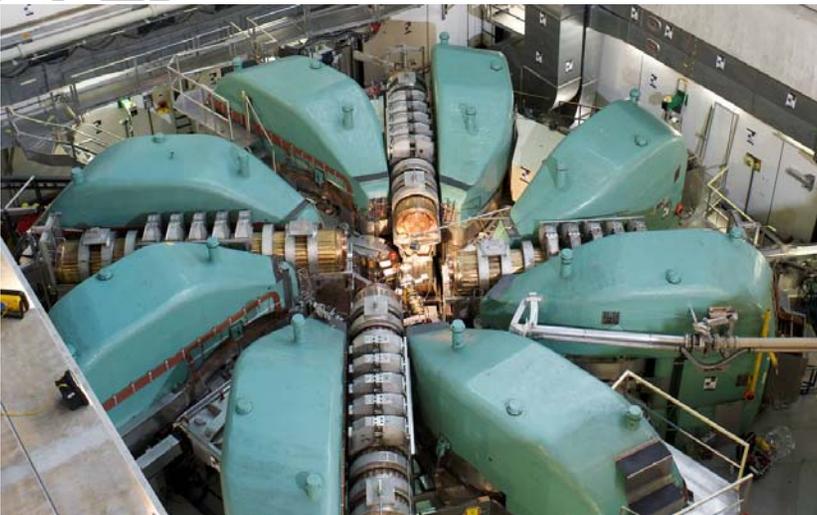
<http://musr.org/intro/musr/muSRBrochure.pdf>

...and their proton drivers:

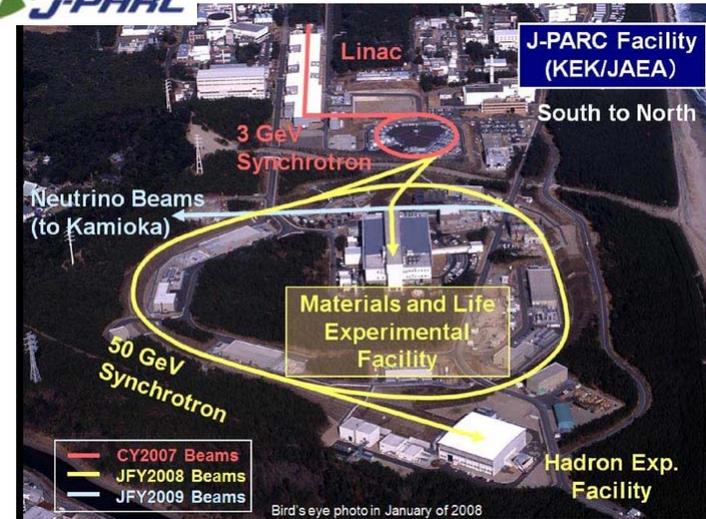
**TRIUMF** Cyclotron (1972)



PAUL SCHERRER INSTITUT  
PSI 590 MeV Ring Cyclotron



J-PARC



## Summary of the Muon Physics Symposium, Pyeongchang SK.

- The RISP/ROAN project is exploring the possibility of a particle physics muon program synergistic with the planned muSR element of the program.
- The facility could have important reach in a next generation muonium oscillation ( $\mu^+e^- \rightarrow \mu^-e^+$ ) and  $\mu \rightarrow 3e$  experiments.
- We will host Korean leads in further developing this program in a small workshop in March at Fermilab.