CPM-2012 • Fermilab • October 11-13, 2012

Baryon Number Violation search

On behalf of BNV subgroup
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IF4: BARYON NUMBER VIOLATION

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Two major experimental topics:
- Nucleon decay
- Neutron antineutron oscillation

One running experiment:
- Super-Kamiokande

A few proposed experiments:
- Hyper-Kamiokande
- LBNO
- LBNE
- LAGUNA
- NNbarX

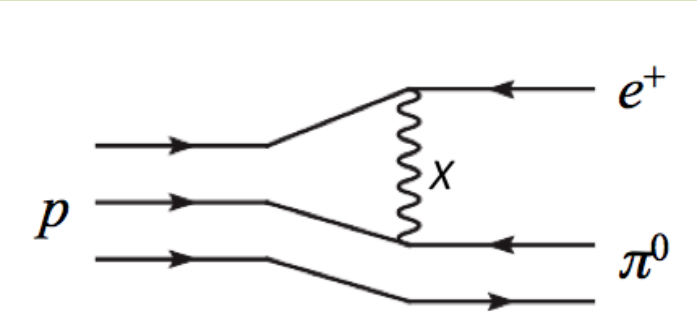
Connections:
- NAF1: Non-Accelerator Facilities
- IF3: Neutrinos
- PX: for n-nbar
- Theoretically to Cosmic Frontier

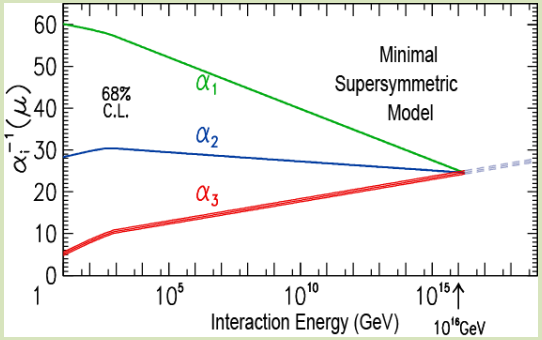
Theoretical Community:
- Well established

See also Ed Kearns talk at NNN-2012
https://indico.fnal.gov/contributionDisplay.py?contribId=50&confId=5755

Scientific Significance of Baryon Number

- Fundamental but unexplained conservation law.
- Nucleon decay predicted by GUTs at 10^{15} GeV scale
- Neutron-antineutron oscillation sensitive to new physics at lower scales (> TeV)
- Possible connections to SUSY
- Deep connections with other physics:
  cosmology, inflation, BAU, neutrino mass.
- Even if no signal is detected,
  experimental limits constrain theoretical options.





E. Kearns
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Relevant Meetings – Recent and Future

Workshop on Baryon & Lepton Number Violation

2007 - Berkeley	http://inpa.lbl.gov/BLNV/blnv.htm
2009 – Wisconsin	http://www.physics.wisc.edu/groups/particle-theory/LBV09-July18.htm
2011 – Tennessee	http://www.phys.utk.edu/blv2011/
April 2013 – Heidelberg	

Next Generation Nucleon Decay and Neutrino Detectors (NNN)

2010 – Toyama	http://www-sk.icrr.u-tokyo.ac.jp/NNN10/
2011 – Zurich	http://neutrino.ethz.ch/NNN11/Welcome.html
2012 – Fermilab	http://conferences.fnal.gov/nnn12/
(October 2013 – Tokyo)	

Also…

2012 – Project X Workshop	https://indico.fnal.gov/conferenceDisplay.py?ovw=True&confId=5276

Baryon number violation in Standard Model

B is a global symmetry of Standard Model classically

Nonperturbative weak interaction effects lead to B violation at quantum level

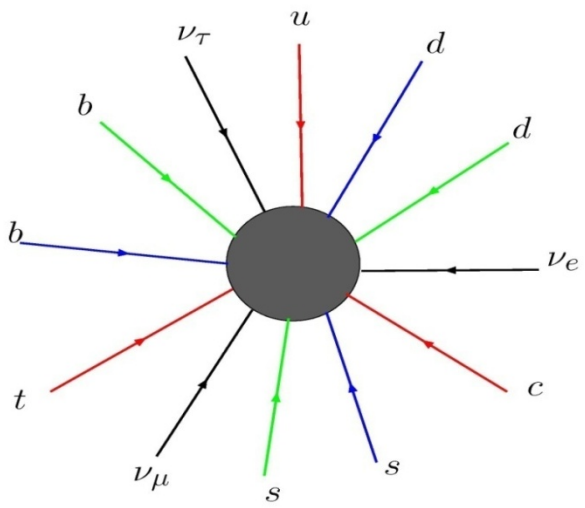
't Hooft (1976)

$$\mathcal{O}_{\text{eff}} = c\left(\frac{1}{m_W}\right)^{14} e^{\frac{-2\pi}{\alpha_2}} \prod_{i=1}^{3} (\epsilon^{\alpha\beta\gamma} Q^i_{\alpha L} Q^i_{\beta L} Q^i_{\gamma L} L^i_L)$$

$$\Delta B = \Delta L = 3$$

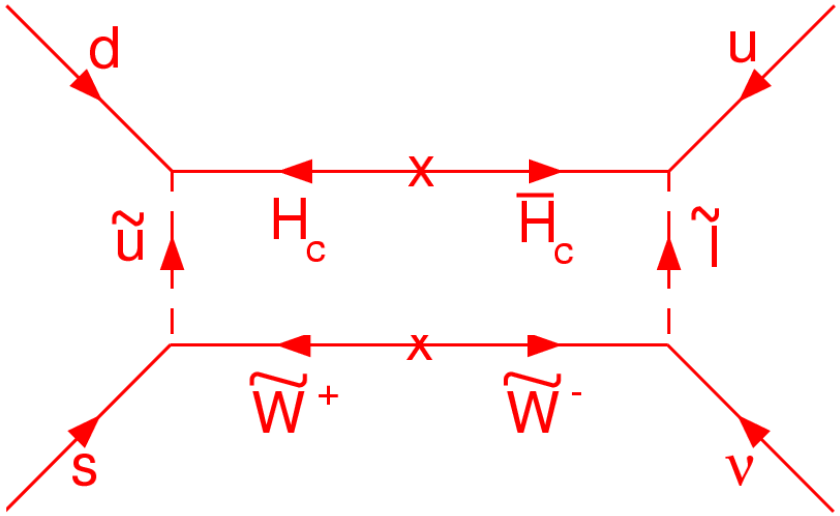
Eg: $ppn \to e^+ e^+ \overline{\nu}$

$$\text{Rate} \propto \left| e^{-\frac{2\pi}{\alpha_2}} \right|^2 \sim 10^{-165}$$



Although rate is very small, there is no fundamental reason believe in B conservation

SUSY GUT nucleon decay



Sakai, Yanagida (1982)

Weinberg (1982)

$$\Gamma^{-1}_{d=5}(p \to \bar{\nu} K^+) \simeq 1.2{\cdot}10^{31}\,\text{yrs} \times \left(\frac{0.012\,\text{GeV}^3}{\beta_H}\right)^2 \left(\frac{7}{\bar{A}^{\alpha}_S}\right)^2 \left(\frac{1.25}{R_L}\right)^2$$

$$\times \left(\frac{M_T}{2{\cdot}10^{16}\text{GeV}}\right)^2 \left(\frac{m_{\tilde{q}}}{1.5\,\text{TeV}}\right)^4 \left(\frac{190\,\text{GeV}}{M_{\tilde{W}}}\right)^2 ,$$

Generally problematic in minimal SUSY $SU(5)$

Murayama, Pierce (2002)

$\tau(\exp) > 6.7 \times 10^{32} yr$

Bajc, Perez, Senjanovic (2002)

Nucleon Lifetime in a Realistic SUSY SU(5)

$\Gamma^{-1}_{d=5}(p \to \bar{\nu} K^+)$	$4 \cdot 10^{33}$ yrs.
$\Gamma^{-1}_{d=5}(n \to \bar{\nu} K^0)$	$2 \cdot 10^{33}$ yrs.
$\Gamma^{-1}_{d=5}(p \to \mu^+ K^0)$	$1.0 \cdot 10^{34}$ yrs.
$\Gamma^{-1}_{d=5}(p \to \mu^+ \pi^0)$	$1.8 \cdot 10^{34}$ yrs.
$\Gamma^{-1}_{d=5}(p \to \bar{\nu} \pi^+)$	$7.3 \cdot 10^{33}$ yrs.
$\Gamma^{-1}_{d=5}(n \to \bar{\nu} \pi^0)$	$1.5 \cdot 10^{34}$ yrs.

SUSY $SU(5)$ extended minimally to correct wrong mass relations ($m_s = m_\mu$ and $m_d = m_e$) by adding $5 + \overline{5}$ fermions

Nucleon lifetime cannot exceed 2×10^{34} yrs in this realistic SUSY $SU(5)$ model

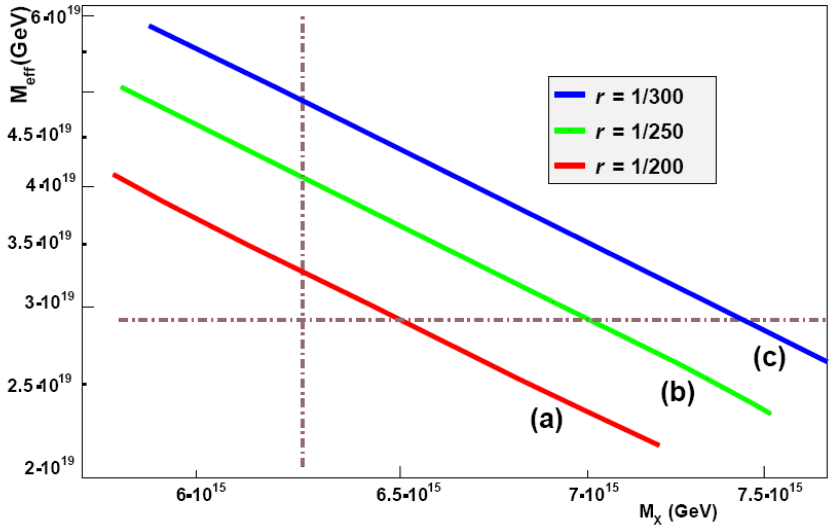
SUSY spectrum ≤ 3 TeV assumed

Babu, Bajc, Tavartkiladze (2012)

Correlation in proton decay in SUSY SO(10) model

$$M_{\rm eff} \simeq 10^{19}{\rm GeV}\cdot\left(\frac{10^{16}{\rm GeV}}{M_X}\right)^3\left(\frac{3}{\tan\beta}\right)\left(\frac{1/100}{r}\right)\frac{\exp[2\pi(\Delta^{(2)}_{2,w}-\Delta^{(2)}_{3,w}-\delta\alpha_3^{-1})]}{2.54\cdot 10^{-2}}\,.$$

$$r\equiv\frac{M_\Sigma}{M_X}\approx\left(\frac{1}{100}-\frac{1}{300}\right)$$



Babu, Pati, Tavartkiladze (2010)

$M_{\rm eff}$ controls $p\to\bar\nu K^+$ and M_X controls $p\to e^+\pi^0$

Suppressing one decay mode enhances the other

Both modes in the observable range

$$\Gamma^{-1}_{d=6}(p\to e^+\pi^0)\lesssim 5.3\times 10^{34}\ {\rm yrs}$$

$$\Gamma^{-1}(p\to\bar\nu K^+)\lesssim(3.1\times 10^{34}\ {\rm yrs})\times\left(\frac{m_{\tilde q}}{1.5\ {\rm TeV}}\right)^4\left(\frac{130\ {\rm GeV}}{m_{\tilde W}}\right)^2\ (3/\tan\beta)^2$$

Vision of BV importance

Y. Kamyshkov

- Observation of violation of Baryon number is one of the pillars of the modern Cosmology and Particle Physics
  - it is required for explanation of Matter-Antimatter asymmetry or BAU (Sakharov)
  - it follows from the inflation (Dolgov, Zeldovich)
  - it is motivated by GUT models (Giorgi, Glashow, Pati, Salam, ...)
- (B – L) must be violated (Kuzmin, Rubakov, Shaposhnikov)
  $\rightarrow$ idea of Leptogenesis with $\Delta L = 2$ (Fukugita, Yanagida)
  Majorana nature of ν's should experimentally demonstrate $\Delta L = 2$, i.e. (B – L)V, however experimental prove of Leptogenesis will be hardly possible.
- Most of the Proton decay searches with $\Delta B = 1$ motivated by GUT or SUSY-GUT models are conserving (B – L). "Proton decay is not a prediction of baryogenesis" (Yanagida).
- Alternative search is $n \rightarrow \overline{n}$ transformation with $\Delta B = 2$ and (B – L)V
- All theoretical models with $\Delta B = 1$ and $\Delta B = 2$ at high-energy scale have difficulties when passing through electroweak period due to sphaleron mechanism.
  $\rightarrow$ Interesting class of models with baryogenesis below EW scale (Babu …).
  These models predict new scalars at LHC and observable $n \rightarrow \overline{n}$.

$Scales\ \ of\ \ n \to \bar{n}\ \ (B-L)V$

Left-Right symmetric GUT

Non-SUSY model

$n\bar{n}$

$n\bar{n}$

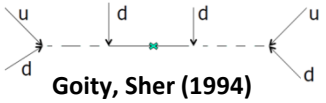
Supersymmetric Seesaw for m_ν

B–L , L–R

SUSY GUT PDK

Plank scale

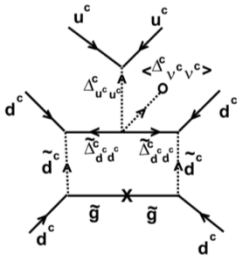
$10^{00}\ 10^{01}\ 10^{02}\ 10^{03}\ 10^{04}\ 10^{05}\ 10^{06}\ 10^{07}\ 10^{08}\ 10^{09}\ 10^{10}\ 10^{11}\ 10^{12}\ 10^{13}\ 10^{14}\ 10^{15}\ 10^{16}\ 10^{17}\ 10^{18}\ 10^{19}\ 10^{20}\ GeV$ υ_{B-L}



Goity, Sher (1994)

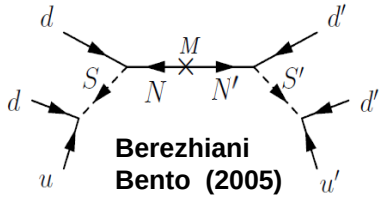
$\propto \upsilon_{B-L}^{-5}$

Mohapatra & Marshak (1980)



$\propto \upsilon_{B-L}^{-2} \cdot \upsilon_{WK}^{-3}$

Dutta-Mimura-Mohapatra (2005)



Berezhiani Bento (2005)

Connected with observable effects at LHC

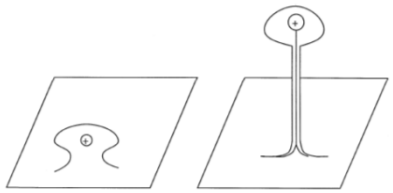
Baryogenesis at TeV scale

Berezhiani et al (2005)
Babu et al (2006)
Dolgov et al (2006)

Low QG models

LHC

$n\bar{n}$



Dvali & Gabadadze (1999)

$10^{00}\ 10^{01}\ 10^{02}\ 10^{03}\ 10^{04}\ 10^{05}\ 10^{06}\ 10^{07}\ 10^{08}\ 10^{09}\ 10^{10}\ 10^{11}\ 10^{12}\ GeV$

Experimental motivation!
large increase of sensitivity:
factor of ×1,000 is possible
compared to existing limit

Expression of Interest

Search for Neutron-Antineutron Transformation at Fermilab

The NNbarX Collaboration

K. Ganezer, B. Hartfiel, J. Hill
California State University, Dominguez Hills

S. Brice, N. Mokhov, E. Ramberg, A. Soha, R. Tschirhart
Fermi National Accelerator Laboratory

D. Baxter, C-Y. Liu, M. Snow, Z. Tang, R. Van Kooten
Indiana University, Bloomington

A. Roy
Inter University Accelerator Centre, New Delhi, India

W. Korsch
University of Kentucky, Lexington

G. Muhrer, A. Saunders
Los Alamos National Laboratory

H. Shimizu
Nagoya University, Japan

P. Mumm
National Institute of Standards

A. Hawari, R. Pattie, D. G. Phillips II, B. Wehring, A. R. Young
North Carolina State University, Raleigh

T. W. Burgess, J. A. Crabtree, V. B. Graves, P. Ferguson, F. Gallmeier
Oak Ridge National Laboratory, Spallation Neutron Source

S. Banerjee, S. Bhattacharya, S. Chattopadhyay
Saha Institute of Nuclear Physics, Kolkata, India

D. Lousteau
Scientific Investigation and Development, Knoxville, TN

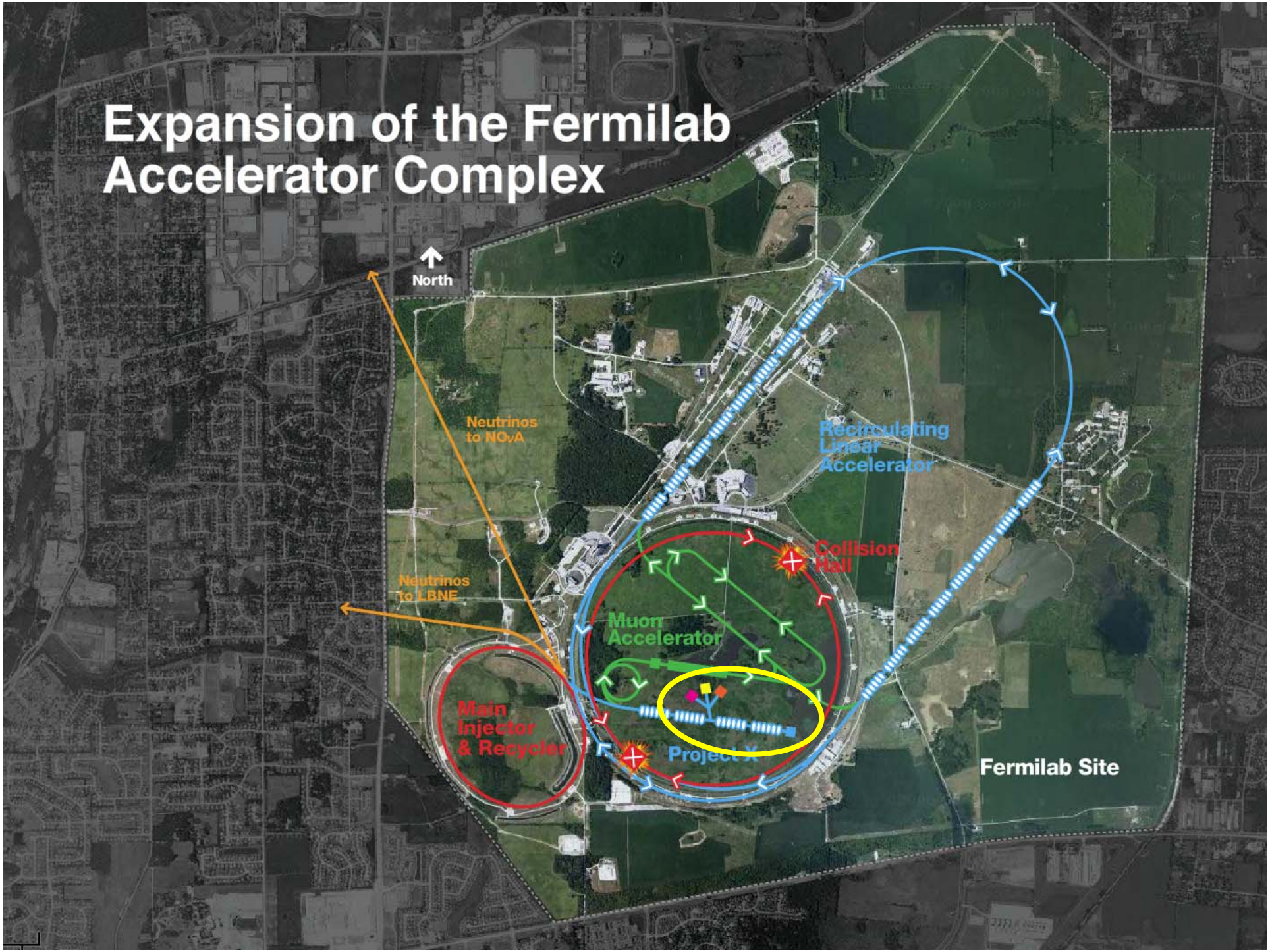
A. Serebrov
St. Petersburg Nuclear Physics Institute, Russia

M. Bergevin
University of California, Davis

L. Castellanos, C. Coppola, T. Gabriel, G. Greene, T. Handler,
L. Heilbronn, Y. Kamyshkov*, A. Ruggles, S. Spanier, L. Townsend, U. Al-Binni
University of Tennessee, Knoxville

P. Das, A. Ray, A.K. Sikdar
Variable Energy Cyclotron Centre, Kolkata, India

- Will be presented to Fermilab PAC on October 15, 2012 as an Experiment for Project X


Expansion of the Fermilab Accelerator Complex
North
Neutrinos to NOvA
Neutrinos to LBNE
Recirculating Linear Accelerator
Collision Hall
Muon Accelerator
Main Injector & Recycler
Project X
Fermilab Site

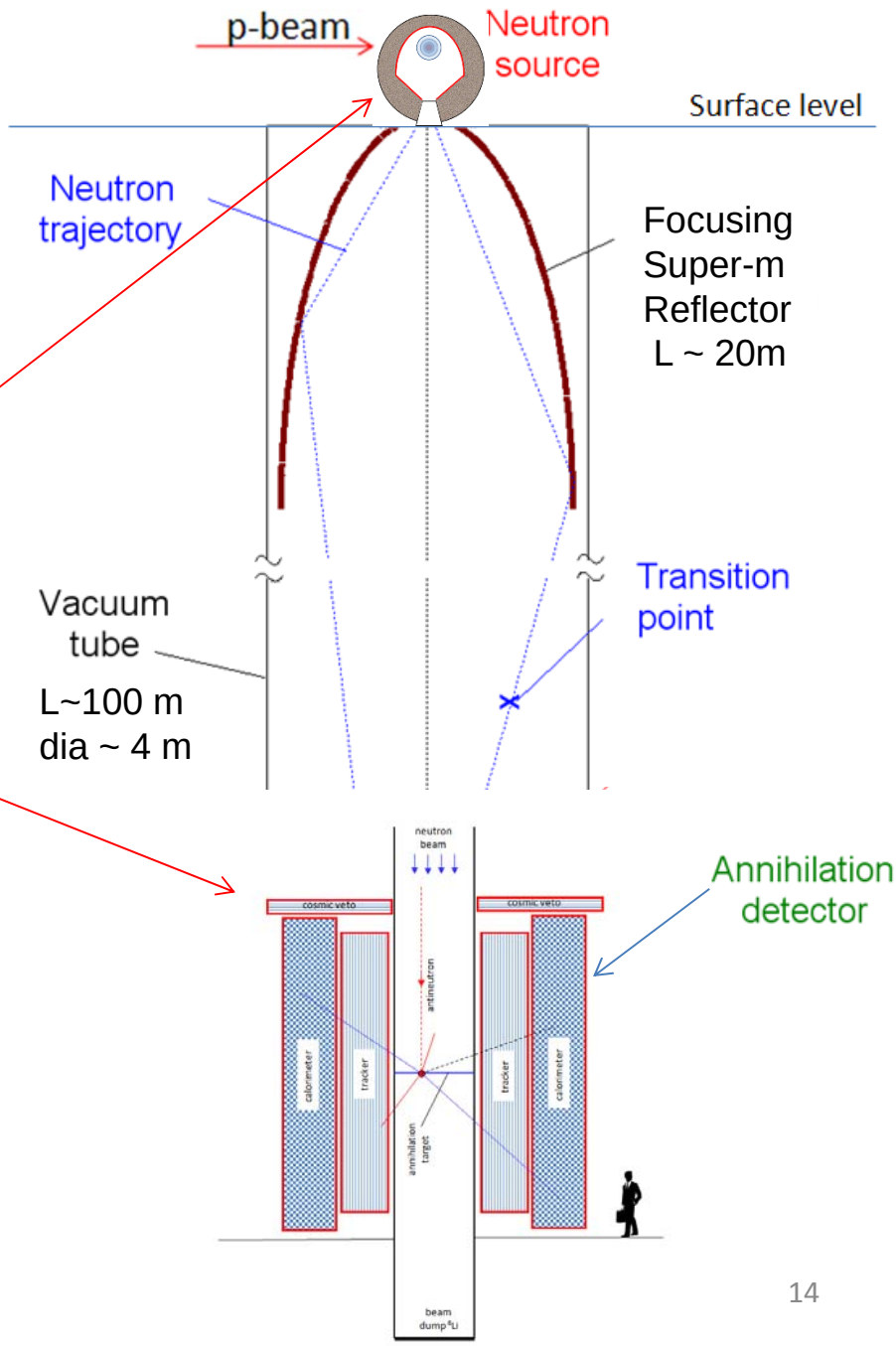
How the major improvement in N-Nbar sensitivity can be made?

Sensitivity $N_n \cdot t^2$ improvement factors

- Use many neutrons (optimized spallation source)
- Use slow neutrons: cold, VCN, UCN
- Neutron manipulation by mirror and diffuse reflectors
- Neutron manipulation by gravity
- Sensitivity improvement by factor of >1,000 will be possible at Project X

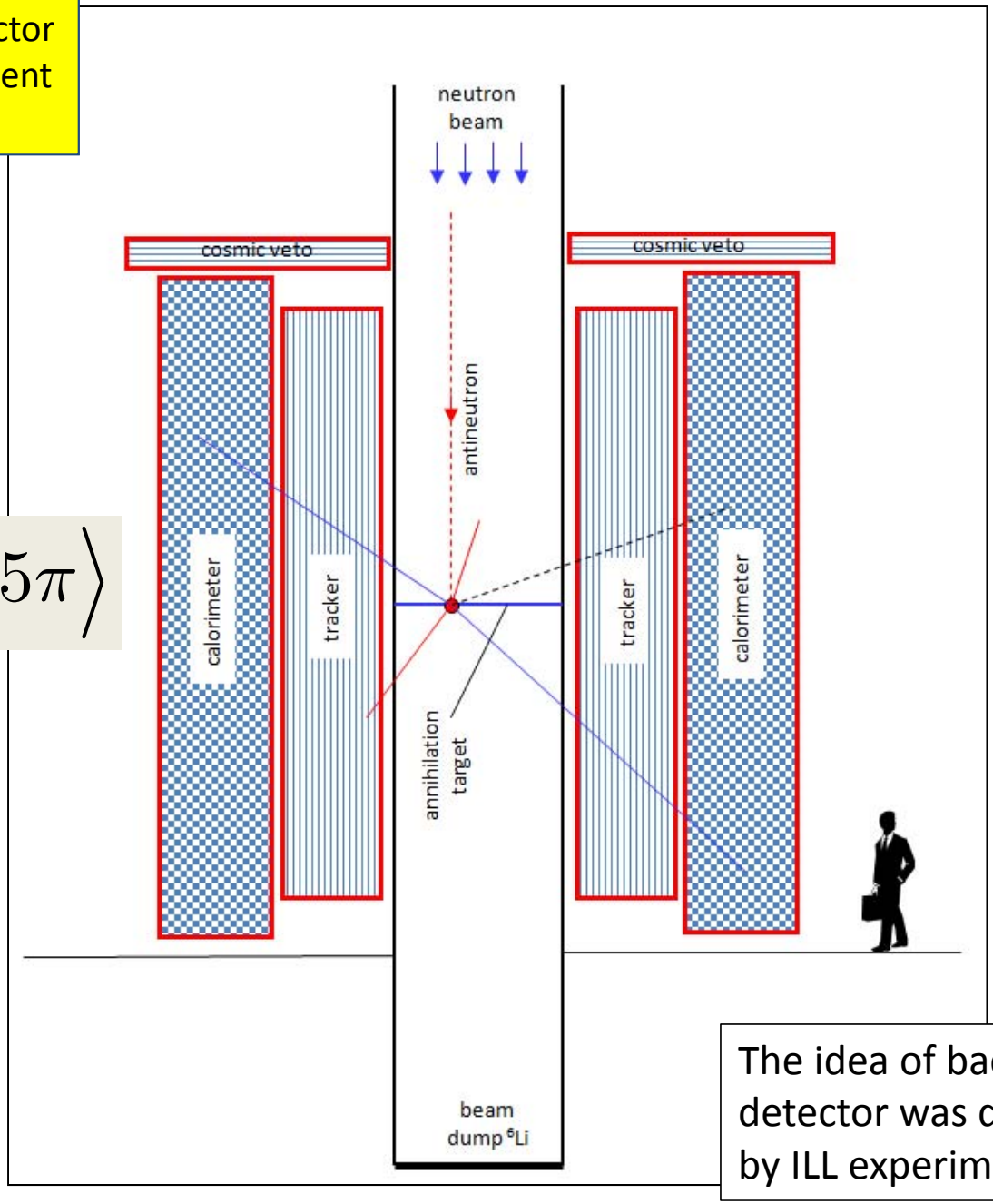
N-Nbar vertical scheme

- New concept of large focusing neutron reflector using super-mirror. Sensitivity increases as ~ L^2
- Dedicated spallation target optimized for cold neutron production
- "Background free" detector: one event = discovery !
- Expected sensitivity > 2,000 ILL units



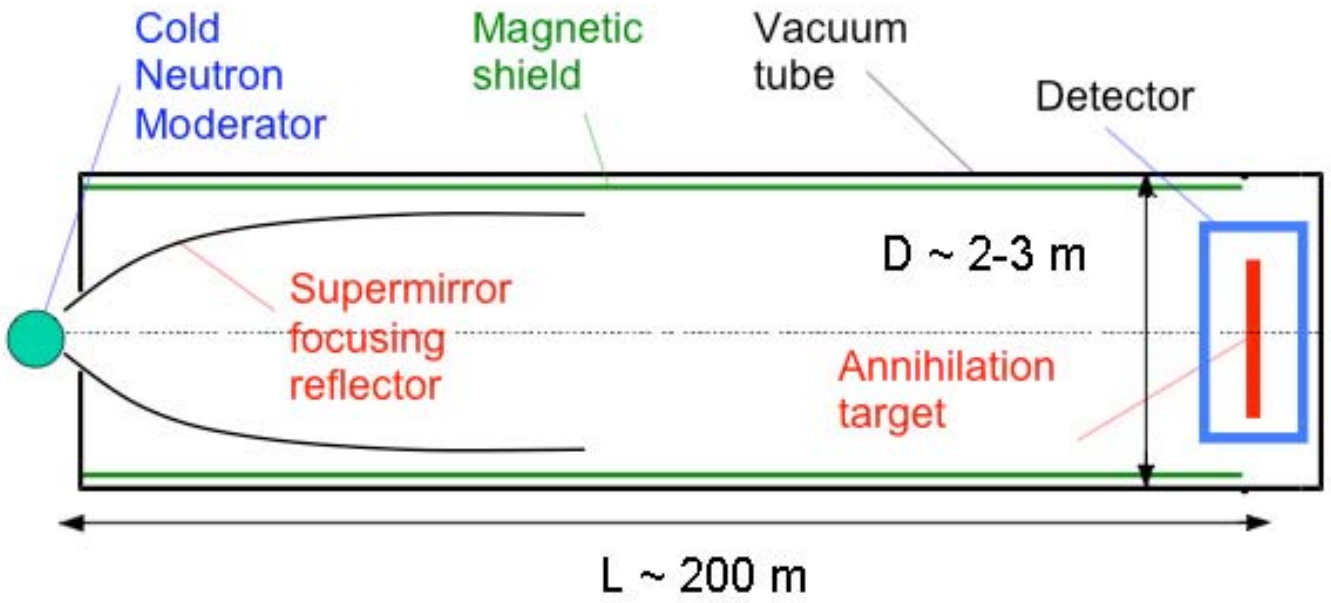
The conceptual scheme of antineutron detector for NNbarX experiment planned at Fermilab

$$\overline{n} + C \rightarrow \langle 5\pi \rangle$$



The idea of backgroundless detector was demonstrated by ILL experiment

Less Expensive Conceptual Horizontal version with Free Neutrons for Project X



What is being done:

- University of Tennessee (optimization of sp. Target, NNbarX, and n-edm expts)

Indiana University (cold moderation, shielding, reflection, detectors + …)
North Carolina State U (annihilation detector configuration and simulations + …)
in collaboration with Fermilab and engineering are proposing an R&D program

- Creation of Collaboration and meetings

- Development of relations with Detector Technologies groups in IF
  (initial interactions were during PXPS in July 2012.