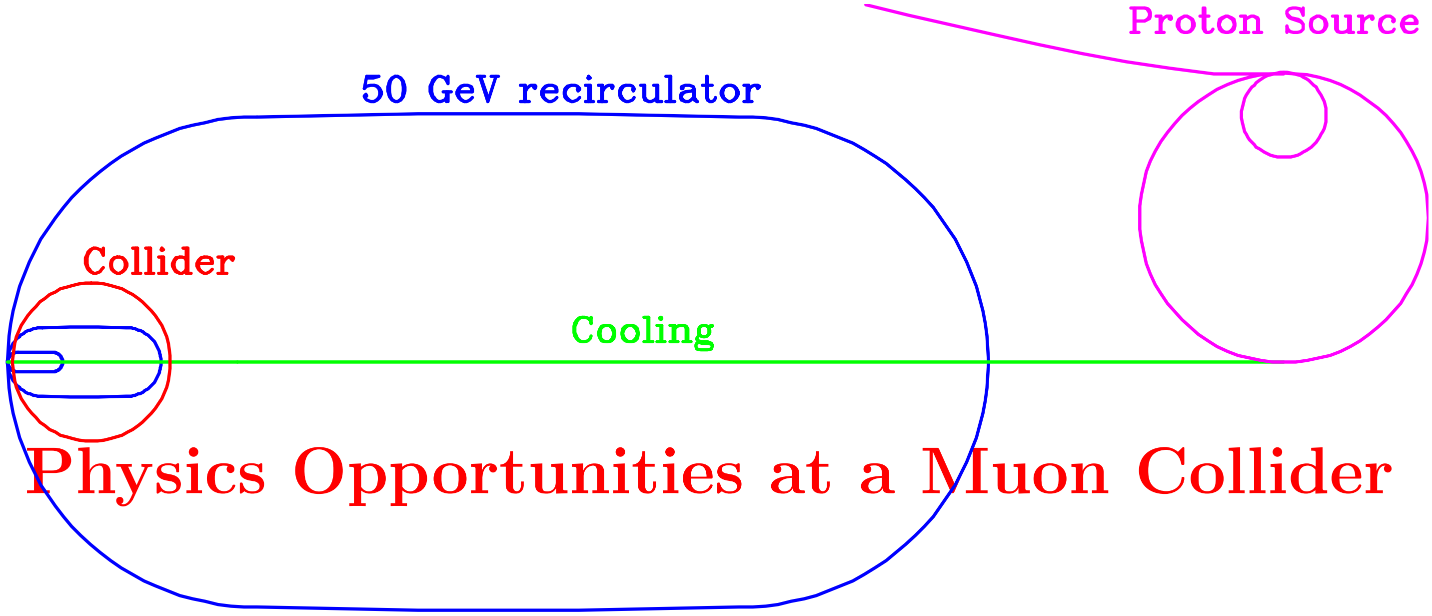


Physics Opportunities at a Muon Collider

Kirk T. McDonald

Princeton U.

mcdonald@puphep.princeton.edu

January 7, 1999

DPF'99 Session 11B: Future Accelerator Projects

Muon Collider main page:

http://www.cap.bnl.gov/mumu/mu_home_page.html

Muon Collider R&D Status Report:

http://www.cap.bnl.gov/mumu/status_report.html

Princeton Muon Collider page:

http://puhep1.princeton.edu/mumu/

AIP Conference Proceedings, Vols. 352, 372, 435 & 441

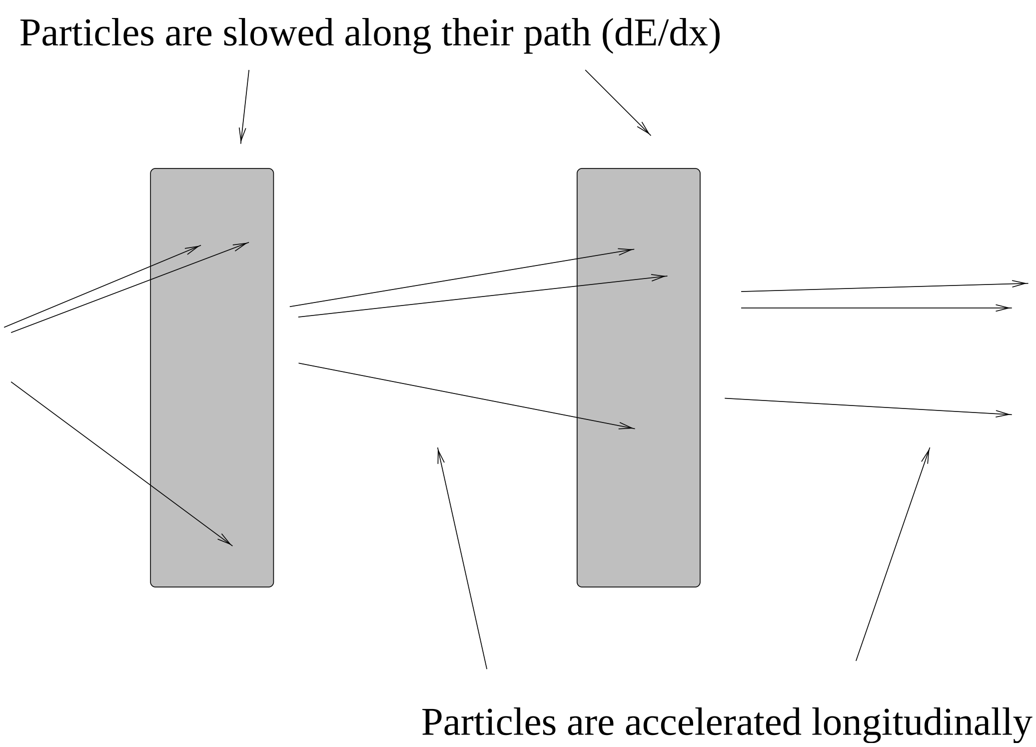
I Want to Believe...

- That elementary particle physics will prosper for a 2nd century with laboratory experiments based on innovative particle sources.
- That a full range of new phenomena will be investigated:
  - Neutrino mass $\Rightarrow$ a 2nd 3×3 (or larger?) mixing matrix.
  - Precision studies of Higgs bosons.
  - A rich supersymmetric sector.
  - ... And more ....
- That our investment in future accelerators will result in more cost-effective technology, that is capable of extension to 10's of TeV of constituent CoM energy.
- That a **Muon Collider** is the best option to accomplish the above.

Ionization Cooling

(An Idea So Simple It Might Just Work)

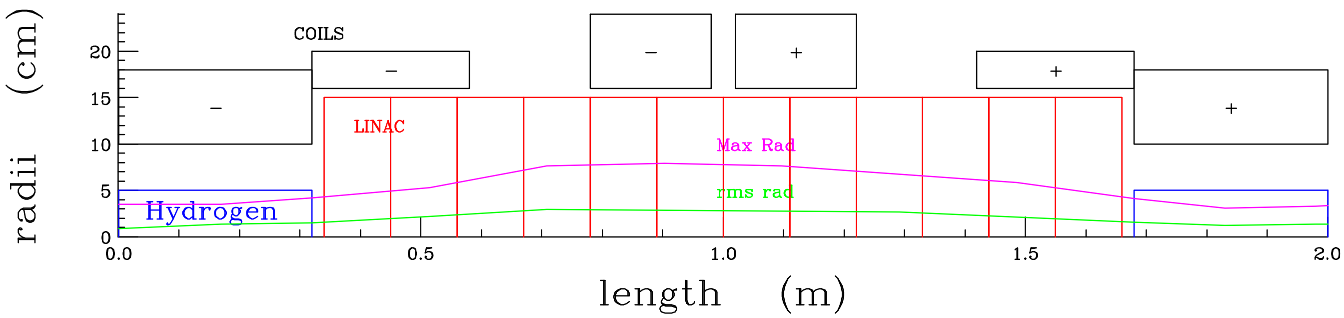
- Ionization: takes momentum away.
- RF acceleration: puts momentum back along z axis.
- $\Rightarrow$ Transverse "cooling".



- Origin: G.K. O'Neill, Phys. Rev. **102**, 1418 (1956).
- But won't work for electrons or protons.
- So use muons: Balbekov, Budker, Skrinsky, late 1960's.

The Details are Delicate

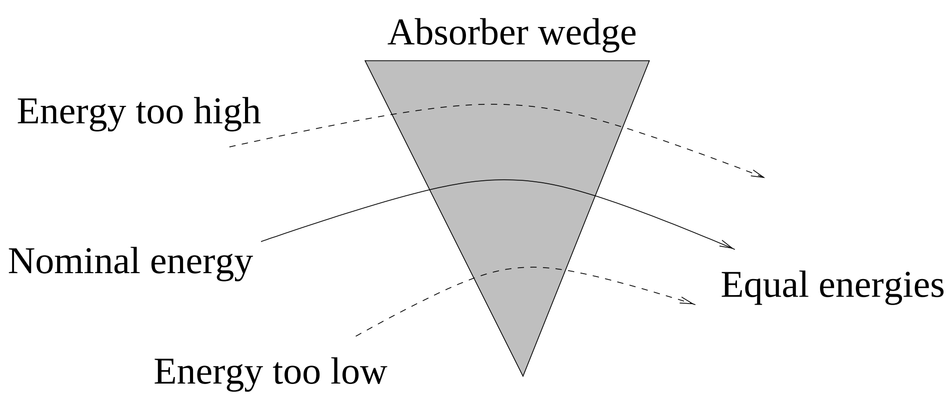
Use channel of LH_2 absorbers, rf cavities and alternating solenoids (to avoid buildup of angular momentum).



The Energy Spread Rises due to "Straggling"

$\Rightarrow$ Must exchange longitudinal and transverse emittance frequently to avoid beam loss due to bunch spreading.

Can reduce energy spread by a wedge absorber at a momentum dispersion point:



What is a Muon Collider?

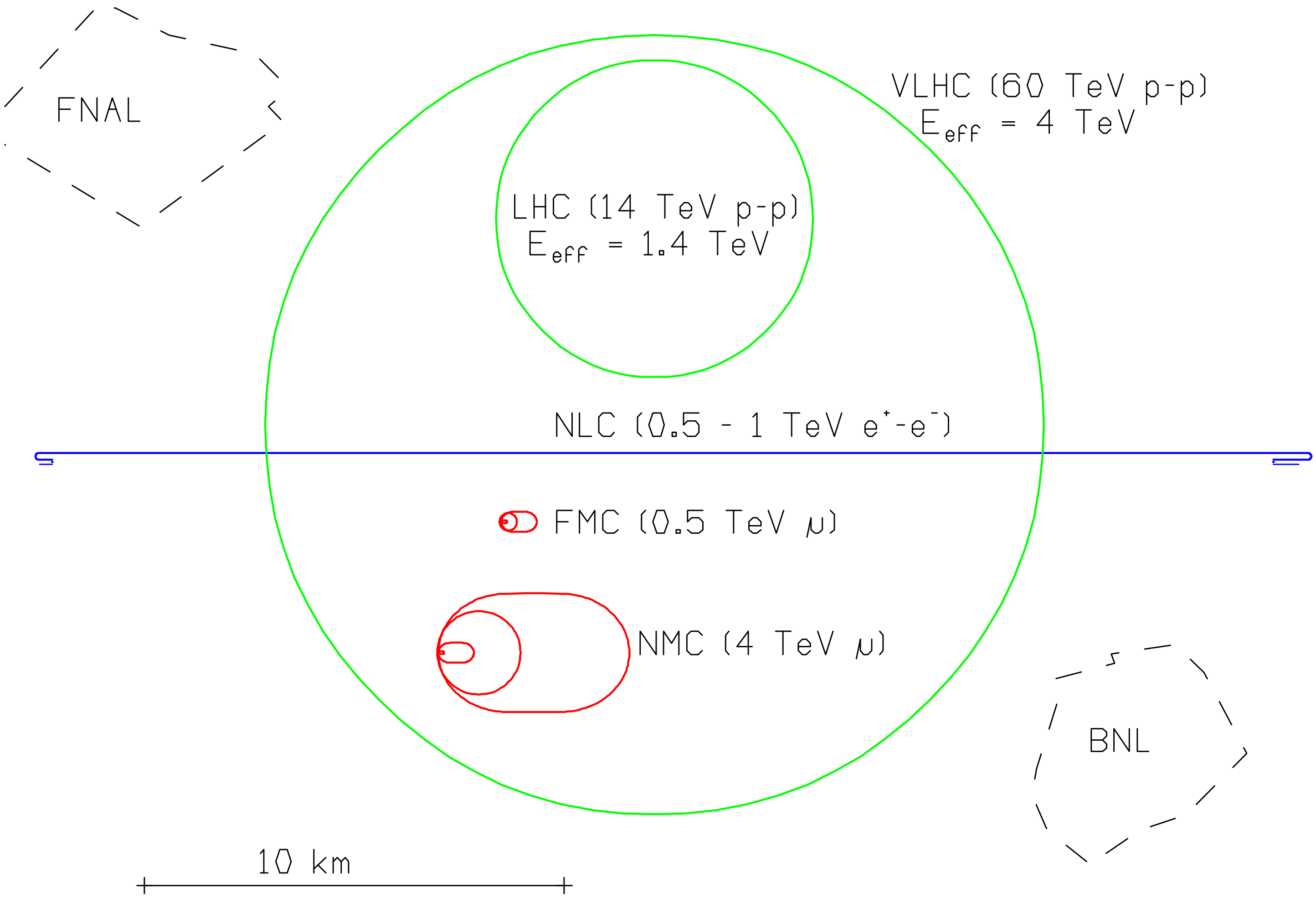
An accelerator complex in which

- Muons (both μ^+ and μ^-) are collected from pion decay following a pN interaction.
- Muon phase volume is reduced by 10^6 by ionization cooling.
- The cooled muons are accelerated and then stored in a ring.
- $\mu^+\mu^-$ collisions are observed over the useful muon life of ≈ 1000 turns at any energy.
- Intense neutrino beams and spallation neutron beams are available as byproducts.

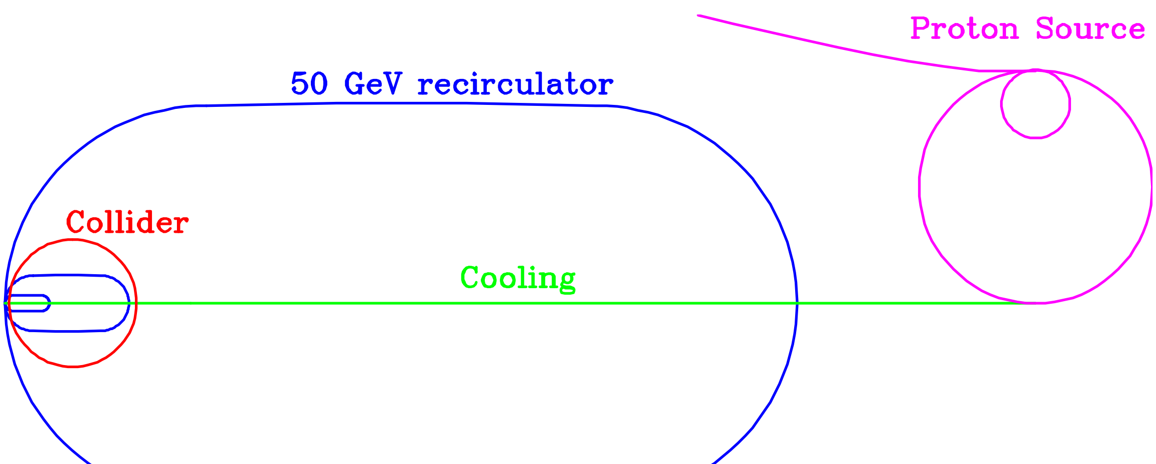
Muons decay: $\mu \to e\nu \qquad \Rightarrow$

- Must cool muons quickly (stochastic cooling won't do).
- Detector backgrounds at LHC level.
- Potential personnel hazard from ν interactions.

Footprints

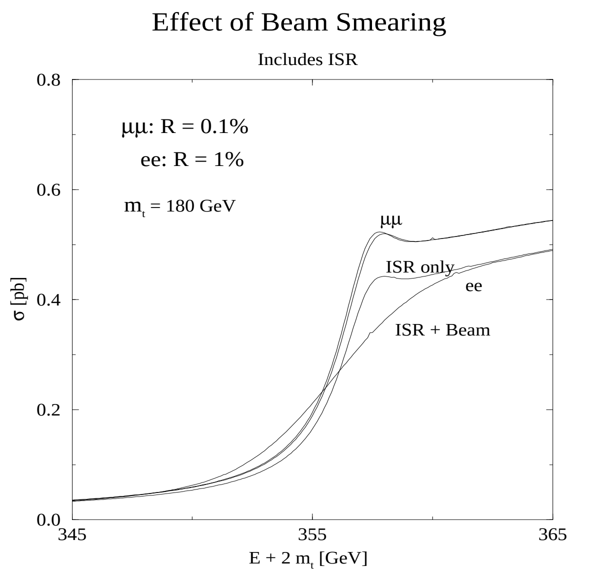


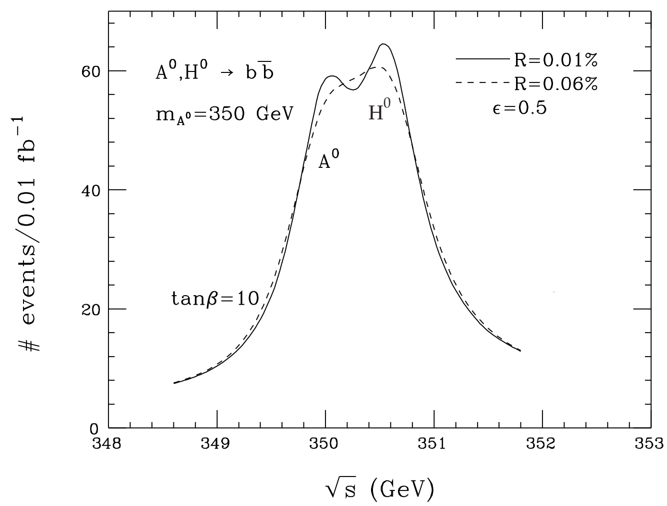
A First Muon Collider to study light-Higgs production:



The Case for a Muon Collider

- More affordable than an e^+e^- collider at the TeV (LHC) scale.
- More affordable than either a hadron or an e^+e^- collider for (effective) energies beyond the LHC.
- Precision initial state superior even to e^+e^-.





- Initial machine could produce light Higgs via s-channel:

  Higgs coupling to μ is $(m_\mu/m_e)^2 \approx 40,000\times$ that to e.

  Beam energy resolution at a muon collider $< 10^{-5}$,

  $\Rightarrow$ Measure Higgs width.

  Add rings to 3 TeV later.

- Neutrino beams from μ decay about 10^4 hotter than present.

Future Frontier Facilities

(A Personal Assessment)

- Hadron collider (LHC, SSC): $\approx$ \$100k/m [magnets].

  $\approx$ 2 km per TeV of CM energy.

  Ex: LHC has 14-TeV CM energy, 27 km ring, $\approx$ \$3B.

- Linear e^+e^- collider (SLAC, NLC(?)): $\approx$ \$200k/m [rf].

  $\approx$ 20 km per TeV of CM energy;

  But a lepton collider needs only $\approx 1/10$ the CM energy

  to have equivalent physics reach to a hadron collider.

  Ex: NLC, 1.5-TeV CM energy, 30 km long, $\approx$ \$6B (?).

- Muon collider: $\approx$ \$1B for source/cooler + \$100k/m for rings

  Well-defined leptonic initial state.

  $m_\mu/m_e \approx 200 \Rightarrow$ Little beam radiation.

  $\Rightarrow$ Can use storage rings.

  $\Rightarrow$ Smaller footprint.

  Technology: closer to hadron colliders.

  $\approx$ 6 km of ring per TeV of CM energy.

  Ex: 3-TeV muon collider $\approx$ \$3B (?).

The Muon Collider Collaboration

Charles M. Ankenbrandt[1], Giorgio Apollinari[2], Muzaffer Atac[1], Bruno Autin[3], Valeri I. Balbekov[1], Vernon D. Barger[4], Odette Benary[5], Scott Berg[6], Michael S. Berger[6], S. Alex Bogacz[7], T. Bolton[8], Shlomo Caspi[9], Christine Celata[9], Yong-Chul Chae[10], David B. Cline[11], John Corlett[9], Lucien Cremaldi[12], H. Thomas Diehl[1], Alexandr Drozhdin[1], Richard C. Fernow[13], David A. Finley[1], Yasuo Fukui[14], Miguel A. Furman[9], Tony Gabriel[15], Juan C. Gallardo[13] Alper A. Garren[11], Stephen H. Geer[1], Ilya F. Ginzburg[16], Michael A. Green[9], John F. Gunion[17], Ramesh Gupta[9], Tao Han[17], Katherine C. Harkay[10], Colin Johnson[3], Carol Johnstone[1], Stephen A. Kahn[13], Bruce J. King[13], Harold G. Kirk[13], Masayukiu Kumada[18], Yoshitaka Kuno[14], Paul LeBrun[1], Kevin Lee[11], Derun Li[9], David Lissauer[13], Laurence S. Littenberg[13], Changguo Lu[19], Alfredo Luccio[13], Kirk T. McDonald[19], Alfred D. McInturff[9], Frederick E. Mills[1], Nikolai V. Mokhov[1], Alfred Moretti[1], David V. Neuffer[1], King-Yuen Ng[1], Robert J. Noble[1], James H. Norem[10,1], Blaine E. Norum[20], Hiromi Okamoto[21], Yasar Onel[22], Robert B. Palmer[13], Zohreh Parsa[13], Jack M. Peterson[9], Yuriy Pischalnikov[11], Milorad Popovic[1], Eric J. Prebys[19], Zubao Qian[1], Rajendran Raja[1], Pavel Rehak[13], Thomas Roser[13], Robert Rossmanith[23], Jack Sandweiss[24], Ronald M. Scanlan[9], Lindsay Schachinger[9], Andrew M. Sessler[9], Quan-Sheng Shu[7], Gregory I. Silvestrov[25], Alexandr N. Skrinsky[25], Panagiotis Spentzouris[1], Ray Stefanski[1], Sergei Striganov[1], Iuliu Stumer[13], Don Summers[12], Valery Tayursky[25], Valeri Tcherniatine[13], Lee C. Teng[10], Alvin V. Tollestrup[1], Yağmur Torun[13,26], Dejan Trbojevic[13], William C. Turner[9], Andy Van Ginneken[1], Tatiana A. Vsevolozhskaya[25], Masayoshi Wake[14], Weishi Wan[1], Haipeng Wang[13], Robert Weggel[13], Erich H. Willen[13], David R. Winn[27], Jonathan S. Wurtele[28], Yongxiang Zhao[13], Max Zolotorev[9]

[1]*Fermi National Laboratory, P. O. Box 500, Batavia, IL 60510*
[2]*Rockefeller University, New York, NY 10021*
[3]*CERN, 1211 Geneva 23, Switzerland*
[4]*Department of Physics, University of Wisconsin, Madison, WI 53706*
[5]*Tel-Aviv University, Ramat-Aviv, Tel-Aviv 69978, Israel*
[6]*Physics Department, Indiana University, Bloomington, IN 47405*
[7]*Jefferson Laboratory, 12000 Jefferson Ave., Newport News, VA 23606*
[8]*Kansas State University, Manhattan, KS 66502-2601*
[9]*Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720*
[10]*Argonne National Laboratory, Argonne, IL 60439*
[11]*University of California Los Angeles, Los Angeles, CA 90095*
[12]*University of Mississippi, Oxford, MS 38677*
[13]*Brookhaven National Laboratory, Upton, NY 11973*
[14]*KEK High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba 305, Japan*
[15]*Oak Ridge National Laboratory, Oak Ridge, TN 37831*
[16]*Institute of Mathematics, Prosp. ac. Koptyug 4, 630090 Novosibirsk, Russia*
[17]*Physics Department, University of California, Davis, CA 95616*
[18]*National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage, Chiba, Japan*
[19]*Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544*
[20]*University of Virginia, 205 McCormick Road, Charlottesville, VA 22901*
[21]*N.S.R.F, Institute for Chemical Research, Kyoto University, Gokanoshou, Uji, Kyoto 611, Japan*
[22]*Physics Department, Van Allen Hall, University of Iowa, Iowa City, IA 52242*
[23]*DESY, Hamburg, Germany*
[24]*Physics Department, Yale University, CT 06520*
[25] *Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia*
[26]*Department of Physics and Astronomy, SUNY, Stony Brook, NY 11790*
[27]*Fairfield University, Fairfield, CT 06430*
[28]*University of California Berkeley, Berkeley, CA 94720*

Spokesperson: R.B. Palmer