Scientific Case and Perspectives for RSVP

RHIC & AGS Users' Meeting
June 2005

James Miller
Boston University

RSVP: Rare Symmetry Violating Processes

(Proposed NSF funding: Major Research Equipment Facilities Construction Account)

- **MECO** : Muon to Electron COnversion

  An Example of Lepton Flavor Violation (LFV):

$$\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)$$

Current Limit: $R(\mu e) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu_\mu N')} < 6 \times 10^{-13}$

Goal: One event if $R(\mu e) = 2 \times 10^{-17}$

- **KOPIO**: $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ direct CP violation

SM: $B = 3.0 \pm 0.6 \times 10^{-11}$

Current: Limit based on $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ via isospin : $< 1.4 x 10^{-9}$ • [Grossman, Nir]

Goal: ≈ 100 events at SM level, σ(BR)=13%

Outline

–MECO: Theory, Experiment

–KOPIO: Theory, Experiment

(see also talk on KOPIO by M. Sivertz, Friday, 10 am)

–AGS: Upgrades

–RSVP: Management, Cost, Reviews

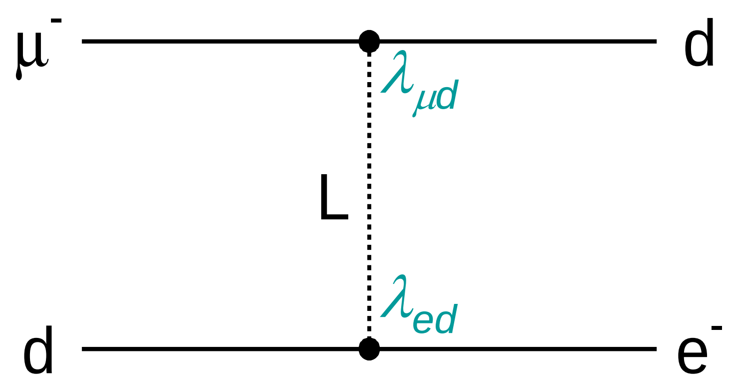
–Conclusions

MECO

- Small effects seen in neutrino oscillations required a modification of SM but the expected effect in conversion process is too small to measure.
- Discovery of $\mu^- N \rightarrow e^- N$ is unambiguous evidence for new physics beyond the Standard Model, in many scenarios at a level that MECO will detect.
- In some cases sensitivity is huge and well beyond direct searches:

$$R(\mu e) \approx 10^{-16} \rightarrow$$

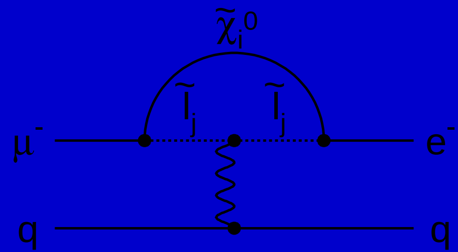
$$M_L = 3000\sqrt{\lambda_{\mu d}\lambda_{ed}}\ \mathrm{TeV}/c^2$$

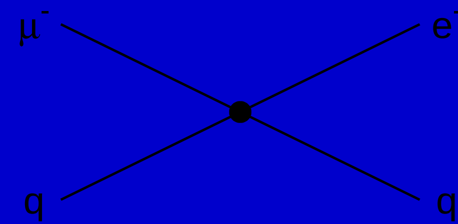


Sensitivity to Different Muon Conversion Mechanisms

Supersymmetry

Predictions at 10^{-15}



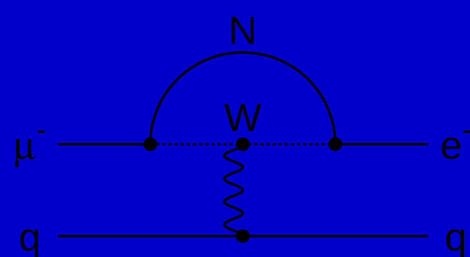


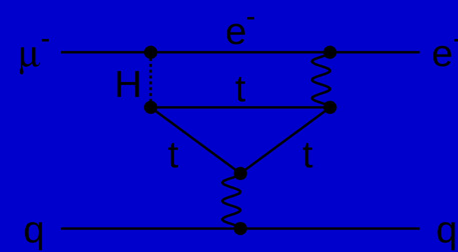
Compositeness

$\Lambda_C = 3000$ TeV

Heavy Neutrinos

$\left|U^*_{\mu N} U_{eN}\right|^2 = 8 \times 10^{-13}$



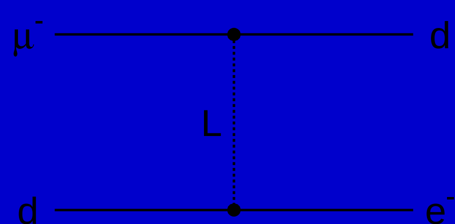


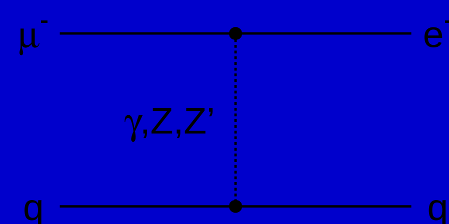
Second Higgs doublet

$g_{H_{\mu e}} = 10^{-4} \times g_{H_{\mu\mu}}$

Leptoquarks

$M_L = 3000\sqrt{\lambda_{\mu d}\lambda_{ed}}$ TeV/c^2





Heavy Z', Anomalous Z coupling

$M_{Z'} = 3000$ TeV/c^2

$B(Z \rightarrow \mu e) < 10^{-17}$

After W. Marciano

MECO: Why $\mu^- N \to e^- N$?

For charged Lepton Flavor Violation:

τ decays : LFV potentially large, but experimental challenges prevent advances at this time.

$\mu \to e\gamma$: more sensitive in the most popular extensions to the Standard Model (which involve photons), but less sensitive for other modes; appears limited experimentally by background considerations to 100-1000 less branching fraction than next generation conversion experiment. MEG(PSI) Phase I: 1 event for $BR(\mu \to e\gamma) = 10^{-13}$

$\mu^- N \to e^- N$: For high precision measurement, beam, detector, necessary muon flux obtainable NOW with current technologies.

Muon to Electron Conversion

- Muons stop in matter and form a muonic atom.
- They cascade down to the 1S state in less than 10^{-16} s.
- They coherently interact with a nucleus (leaving the nucleus in its ground state) and convert to an electron, without emitting neutrinos

$$\Rightarrow E_e = M_\mu - E_{NR} - E_B.$$

- Experimental signature is an electron with E_e=105.1 MeV emerging from an Al stopping target.
- More often, they are captured on the nucleus: $\mu^- N \rightarrow \nu_\mu N(Z-1)$ $[\mu^- p \rightarrow \nu_\mu n]$

or decay in the Coulomb bound orbit: $\mu^- \rightarrow \nu_\mu e^- \bar{\nu}_e$

(τ_μ = 2.2 μs in vacuum, ~0.9 μs in Al)

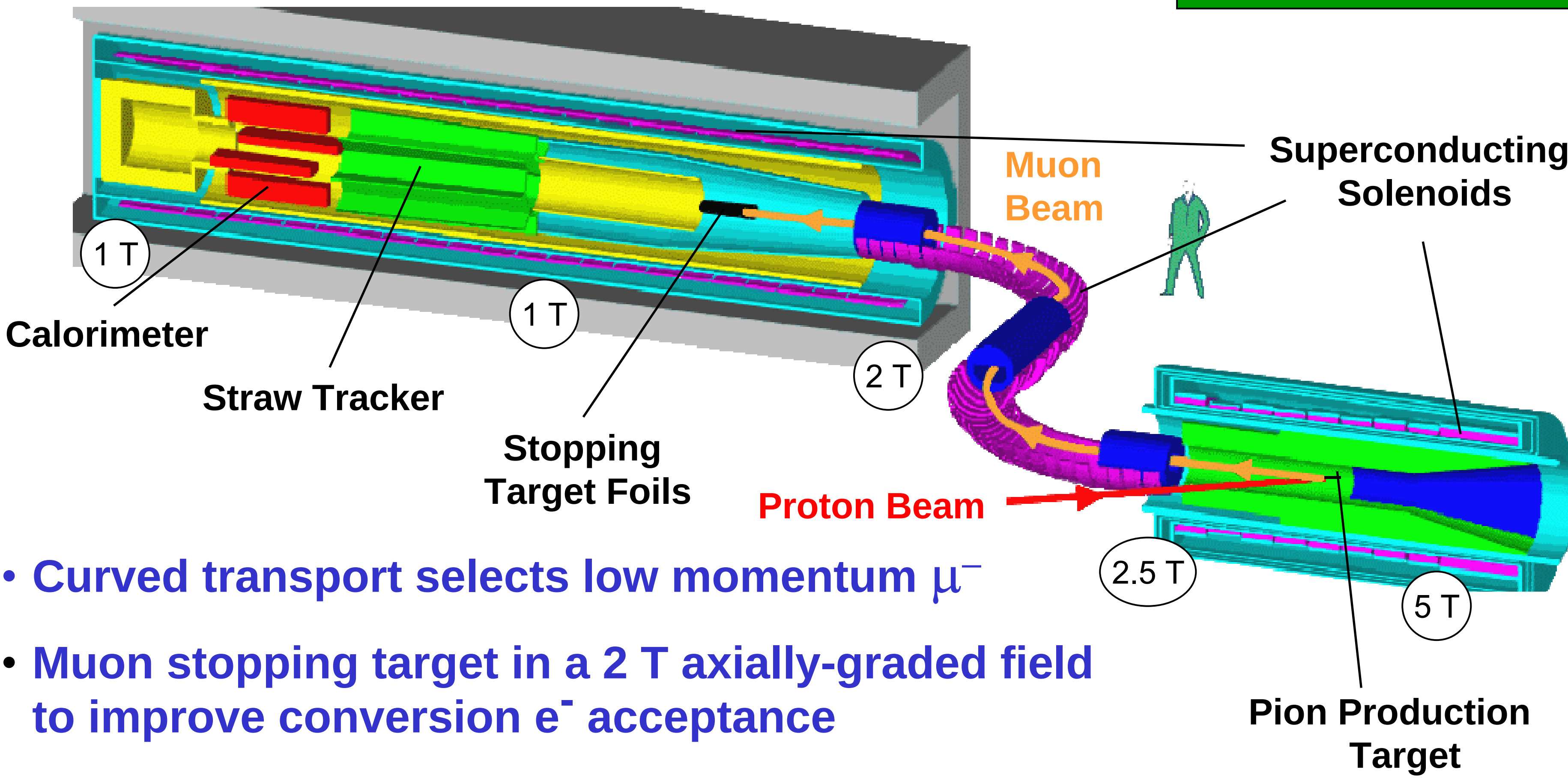
(Reminder: $R_{\mu e} = [\mu^- N \rightarrow e^- N]/[\mu^- N \rightarrow \nu_\mu N(Z-1)]$)

MECO goal is to detect one $\mu^- N \rightarrow e^- N$ if $R_{\mu e}$ is at least 2 X 10^{-17}

Features of MECO

- **1000–fold increase in μ beam intensity over existing facilities**
  - **High Z target for improved pion production**
  - **Axially-graded 5 T solenoidal field to maximize pion capture**

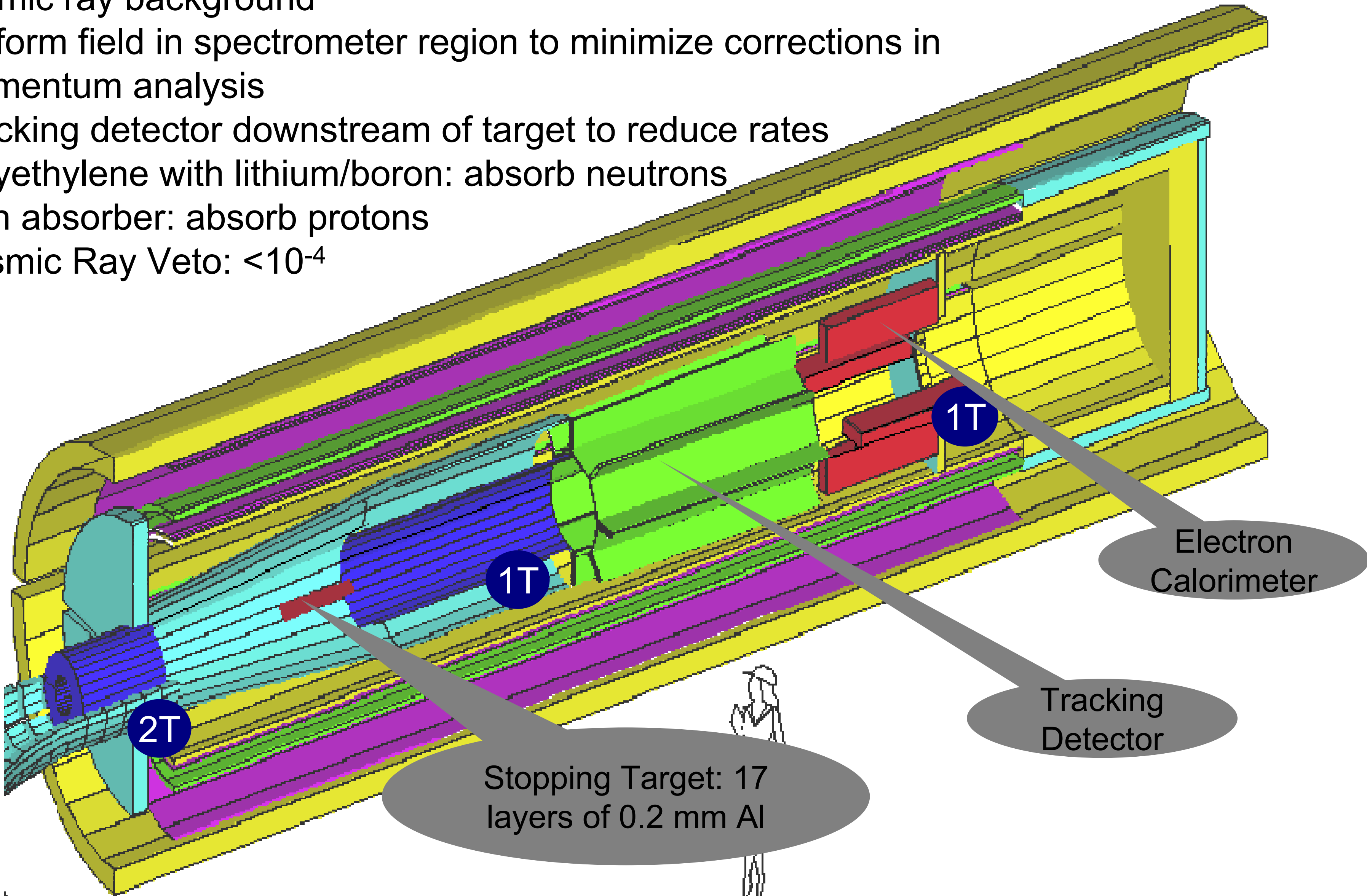
Cosmic Ray Shield (scintillator veto) not shown



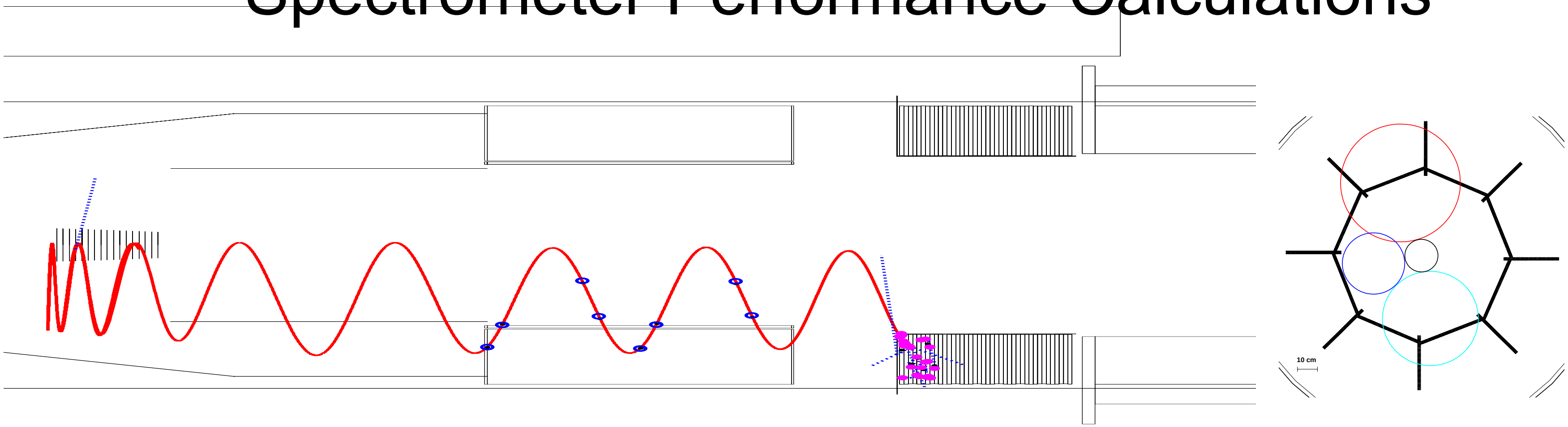
- **Curved transport selects low momentum μ^-**
- **Muon stopping target in a 2 T axially-graded field to improve conversion e^- acceptance**
- **High rate capability e^- detectors in a constant 1 T field**

Stopping Target and Experiment in Detector Solenoid

- Graded field in front section to increase acceptance and reduce cosmic ray background
- Uniform field in spectrometer region to minimize corrections in momentum analysis
- Tracking detector downstream of target to reduce rates
- Polyethylene with lithium/boron: absorb neutrons
- Thin absorber: absorb protons
- Cosmic Ray Veto: $<10^{-4}$

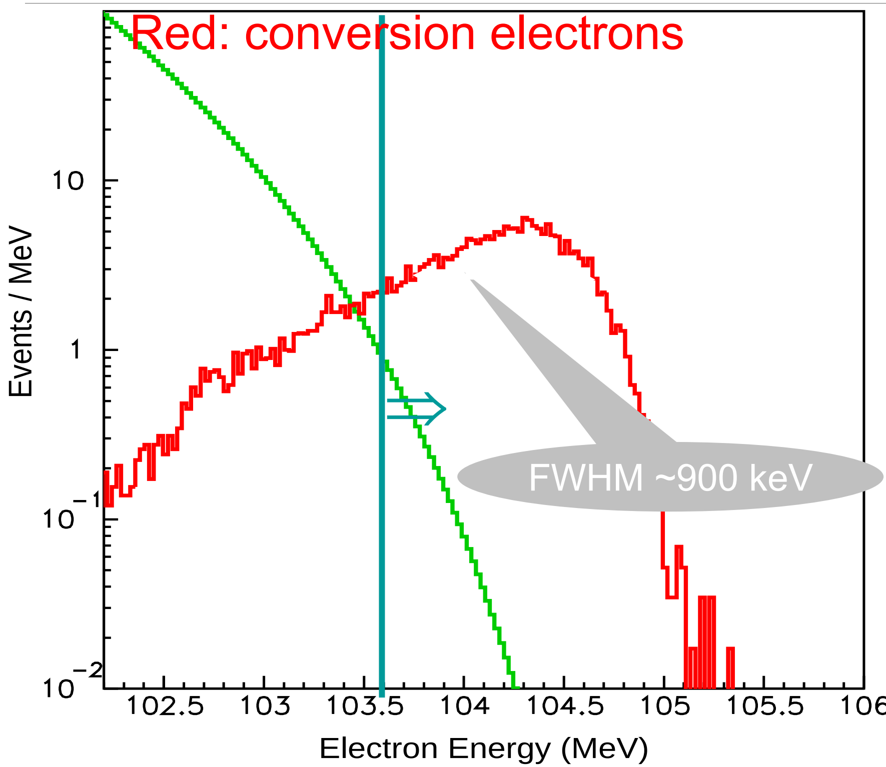


Spectrometer Performance Calculations



Green: muon decay in orbit

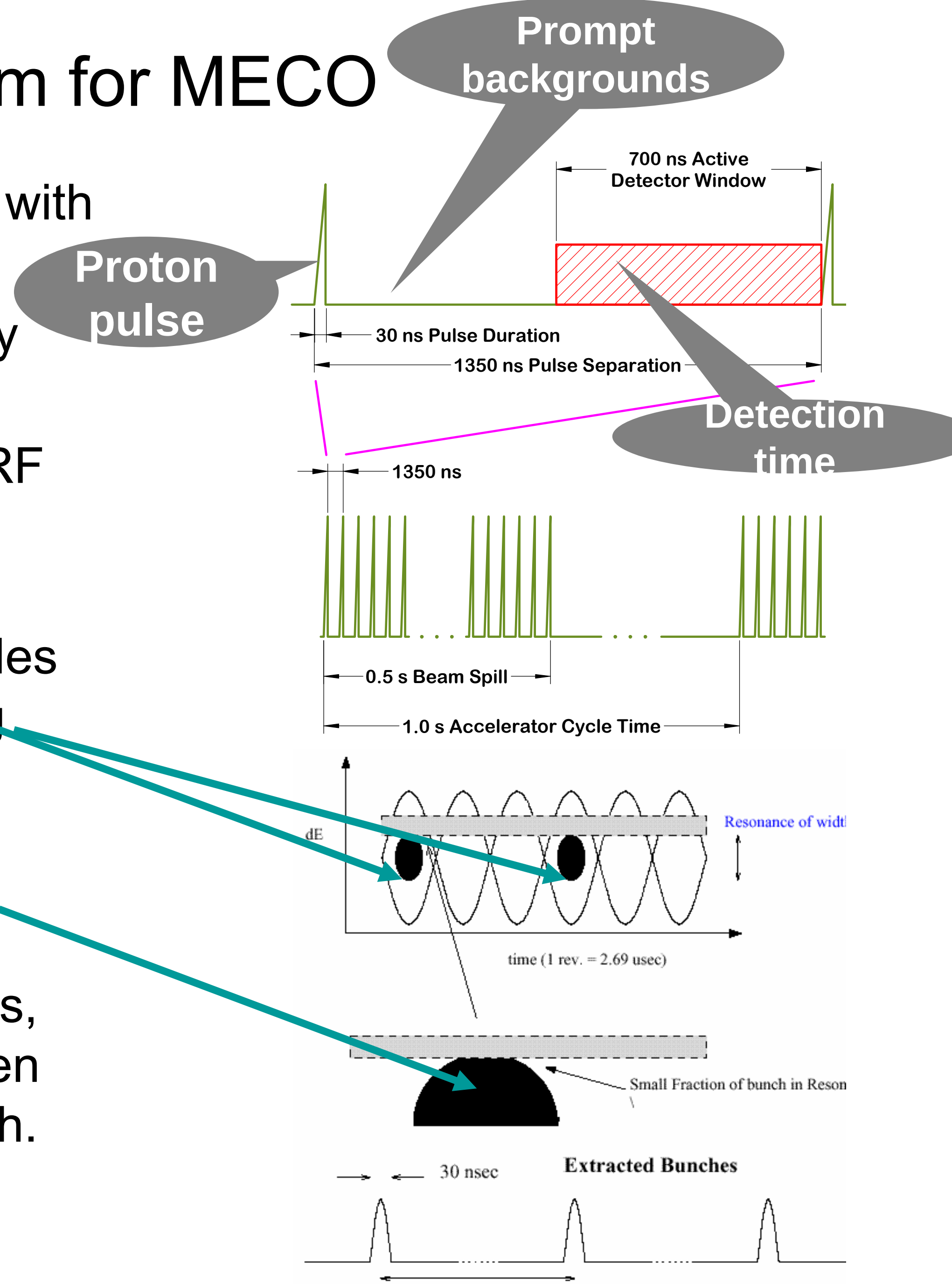
Red: conversion electrons



- Performance calculated using Monte Carlo simulation of all physical effects
- Resolution dominated by multiple scattering in tracker and energy loss in target
- Resolution function of spectrometer convolved with theoretical calculation of muon decay in orbit to get expected background.
- Geometrical acceptance ~50% (60°-120°)
- *Alternate transverse geometry has similarly good tracking performance with sophisticated fitting.*

AGS Pulsed Proton Beam for MECO

- Machine will operate at 7.5 GeV with 2×10^{13} protons/second
- Cycle time of 1.0 s with 50% duty factor
- Revolution time = 2.7 μs with 6 RF buckets in which protons can be trapped and accelerated
- Fill 2 RF buckets on opposite sides of ring for 1.35 μs pulse spacing
- 1 $\times10^{13}$ protons / RF bucket
- Resonant extraction of bunched beam
- To eliminate prompt backgrounds, we require < 10^{-9} protons between bunches for each proton in bunch. We call this the beam extinction.



Expected Signal Sensitivity in MECO

Factors affecting the Signal Rate	Expectations
Running time (s)	1.9×10^{7}
Proton flux (Hz) (50% duty factor, 740 kHz μpulse)	2×10^{13}
μ entering transport solenoid / incident proton	0.0043
μ stopping probability	0.58
μ capture probability	0.60
Fraction of μ capture in detection time window	0.49
Electron trigger efficiency	0.90
Geometrical acceptance, fitting and selection criteria efficiency	0.19
Detected events for $R_{\mu e} = 10^{-16}$	5.0

Current running assumptions:

- 6 year RSVP running period, 2011-2016
- KOPIO and MECO sharing running time equally, alternate years
- Average net 90 hours per week in shared mode with RHIC
- Average 25 productive running weeks per year (17 weeks in 2011/2012)

Total: about 5700 hours of beam time for each experiment

Muon to Electron COnversion (MECO) Experiment

- <u>Boston University</u>
  - **<u>I. Logashenko</u>**, J. Miller, B. L. Roberts
- <u>Brookhaven National Laboratory</u>
  - M. Brennan, K. Brown, L. Jia, W. Marciano, W. Morse, P. Pile, Y. Semertzidis, P. Yamin
- <u>University of California, Berkeley</u>
  - Y. Kolomensky
- <u>University of California, Irvine</u>
  - **<u>C. Chen</u>**, M. Hebert, **<u>P. Huwe</u>**, W. Molzon, **<u>J. Popp</u>**, V. Tumakov
- <u>University of Houston</u>
  - **<u>Y. Cui</u>, <u>N. Elkhayari</u>**, E. V. Hungerford, **<u>N. Klantarians</u>,** K. A. Lan, B. Mayes, L. Pinsky, J. Wilson
- <u>University of Massachusetts, Amherst</u>
  - K. Kumar

<u>Institute for Nuclear Research, Moscow</u>

V. M. Lobashev, V. Matushka

<u>New York University</u>

R. M. Djilkibaev, A. Mincer, P. Nemethy

<u>Osaka University</u>

M. Aoki, Y. Kuno, A. Sato

<u>Syracuse University</u>

R. Holmes, P. Souder

<u>University of Virginia</u>

C. Dukes, K. Nelson, **<u>A. Norman</u>**

<u>The College of William and Mary</u>

M. Eckhause, J. Kane, R. Welsh

KOPIO: $K_L \to \pi^0 \nu \bar{\nu}$

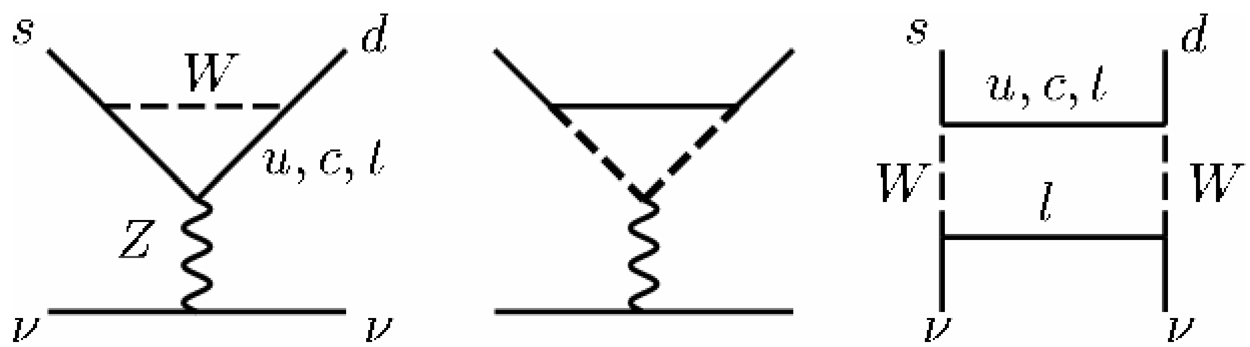
SM

- Suppression by CKM hierarchy
- No tree level contributions
- Dominated by short distance physics
- Precise determination of CKM parameters
- Dominated by direct CP violation in amplitude (K-K mixing effects negligible)

BSM

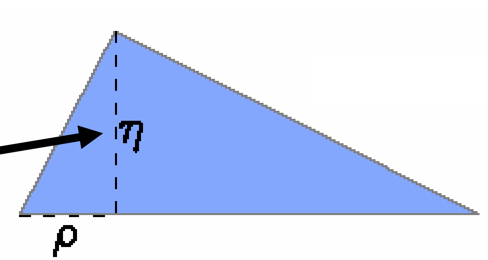
- Highly sensitive to new physics
- Still dominated by short distance physics, direct CP violation
- Unique access to new CP phases

$K_L \to \pi^0 \bar{\nu}\nu$ in the Standard Model



Hadronic m.e. from Ke3

$BR = (1.558 \pm 0.025) \times 10^{-3} \bullet (1 \pm 1.3\sigma_m/m_t) \bullet (\mathrm{Im}\,\lambda_t)^2$



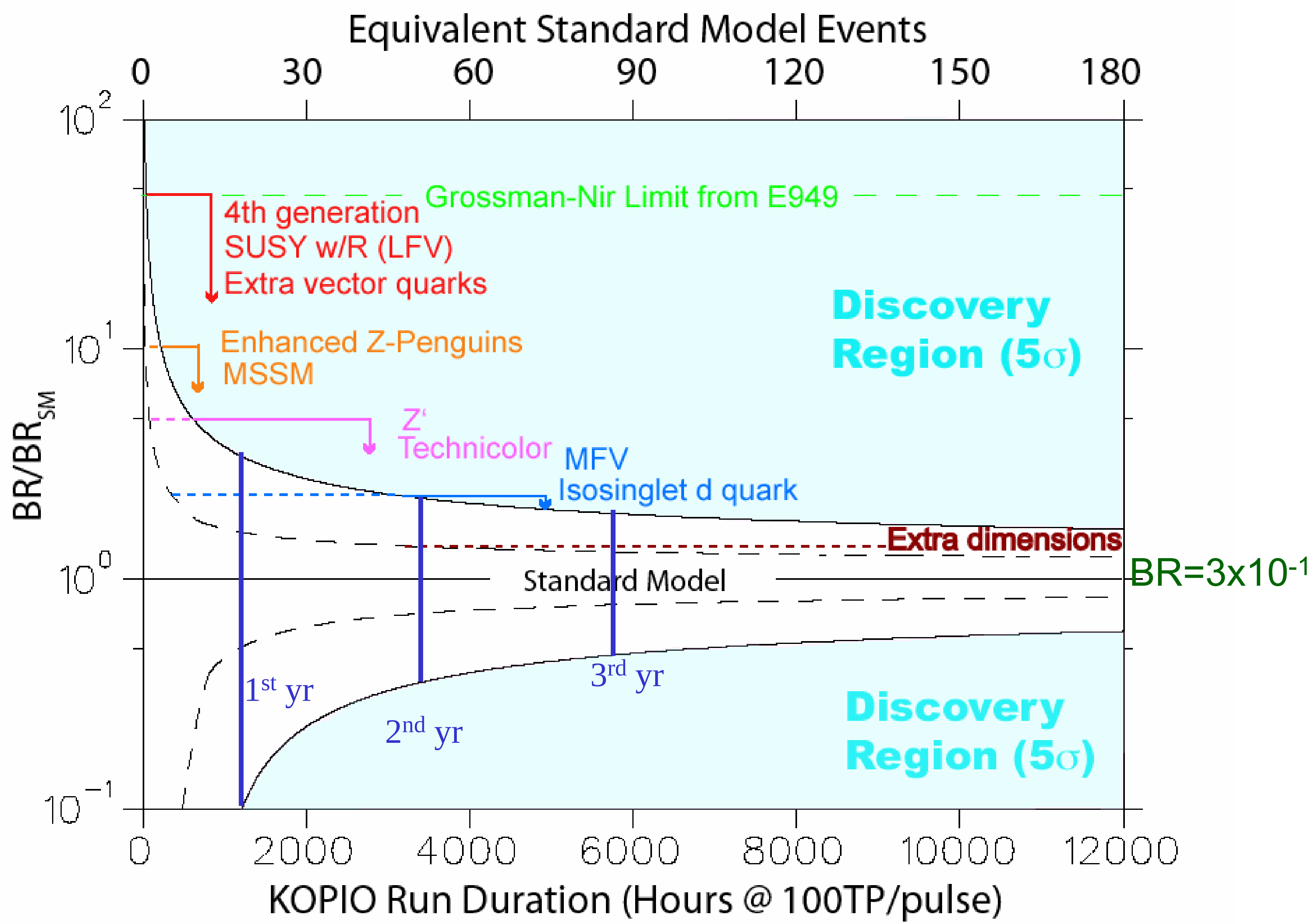
< 2% intrinsic theoretical uncertainty

uncertainty due to that on m_t

$$BR = 4.1 \times 10^{-10} A^4 \eta^2 = (3.0 \pm 0.6) \times 10^{-11}$$

$\sigma(BR)$=13% leads to $\sigma(\eta)$=7.5%

Discovering/Constraining New Physics



Experiments Seeking $K_L^0 \to \pi^0 \nu \bar{\nu}$

Limit based on $K^+ \to \pi^+ \nu \bar{\nu}$ via isospin : $< 1.4 x 10^{-9}$ • [Grossman, Nir]

- KTEV (FNAL) result: $B(K_L^0 \to \pi^0 \nu \bar{\nu}) < 5.9 x 10^{-7}$ (90%CL)
- KEK E391a: $10^{-10} - 10^{-9}$??
- KOPIO (BNL): Single event Sensitivity $< 10^{-12}$

Discovery (5σ) for $B("K_L^0 \to \pi^0 \nu \bar{\nu}") > 5x10^{-11}$

or >100 "SM" events

(Recall: SM prediction is $B=3x10^{-11}$)

KOPIO Challenge

- $B(KL \rightarrow \pi^0 \nu\nu) \sim 3 \times 10^{-11}$;
  need huge flux of K's -> high rates
- All particles are neutral…
- Weak kinematic signature (2 particles missing)
- Backgrounds with $\pi 0$ up to 10^{10} times larger BR
- Veto inefficiency on extra particles must be very low
- Neutrons dominate the beam
  - make $\pi 0$ off residual gas – require high vacuum
  - halo must be very small
  - hermeticity requires photon veto in the beam
- Need convincing measurement of background

$K_L^0 \to \pi^0 \nu\bar{\nu}$ Measurement

Background suppression factor needed: 10^{10}

Primary Backgrounds

Mode	Branching Ratio
$K_L^0 \to \pi^0\pi^0$	0.93×10^{-3}
$K_L^0 \to \pi^- e^+ \nu \gamma$	0.36×10^{-2}
$K_L^0 \to \pi^+\pi^-\pi^0$	0.1255
$K_L^0 \to \pi^0\pi^0\pi^0$	0.2105
Others	

KOPIO Technique

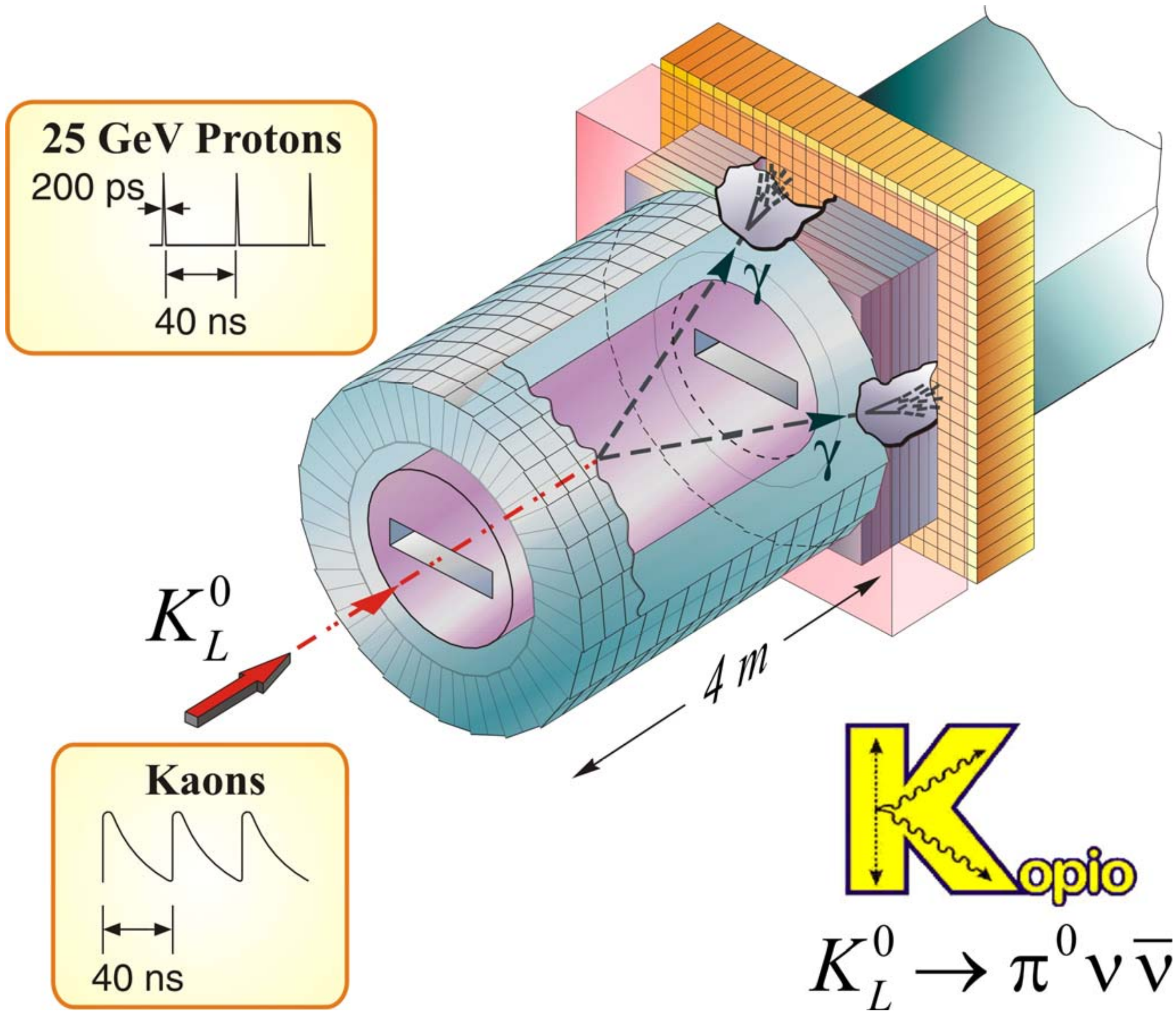
- High intensity micro-bunched 25 GeV proton beam from AGS

  Width: $\sigma = 200$ ps   Spacing: 40 ns

- 100×10^{12} protons per 5 s spill, 7 s total cycle
- 0.1% interbunch extinction
- Measure everything: energy, position, angle, time: with pulsed beam get K_L velocity
- Eliminate extra charged particles or photons

  π^0 veto inefficiency $< 10^{-8}$

KOPIO Detector Concept



KOPIO Collaboration

6 countries 19 institutions 80 scientists 10 Grad students

Arizona State University J.R. Comfort, *J. Figgins*

Brookhaven National Laboratory D. Beavis, I-H. Chiang, A. Etkin, J.W. Glenn, A. Hanson, D. Jaffe, D. Lazarus, K. Li, L. Littenberg, G. Redlinger, C. Scarlett, M. Sivertz, R. Strand

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IHEP, Protvino G.Britvich, V. Burtovoy, S.Chernichenko, L, Landsberg, A. Lednev, V. Obraztsov, R.Rogalev, V.Semenov, M. Shapkin, I.Shein, A.Soldatov, N.Tyurin, V.Vassil'chenko, D. Vavilov, A.Yanovich

INR, Moscow A. Ivashkin, *D.Ishuk*, M. Khabibullin, A. Khotjanzev, Y. Kudenko, A. Levchenko, O. Mineev, N. Yershov and *A.Vasiljev*.

INFN-University of Perugia G. Anzivino, P. Cenci, *E. Imbergamo*, A. Nappi, M. Valdata

KEK M. Kobayashi

Kyoto University of Education R. Takashima

Kyoto University *K. Misouchi, H. Morii*, T. Nomura, N. Sasao, *T. Sumida*

Virginia Polytechnic Institute & State University M. Blecher, *N. Graham*, A. Hatzikoutelis

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University of Montreal J.-P. Martin

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TRIUMF P. Amaudruz, M. Barnes, E. Blackmore, J. Doornbos, P. Gumplinger, R. Henderson, N. Khan, A. Mitra, T. Numao, R. Poutissou, F. Retiere, A. Sher, G. Wait

University of British Columbia D. Bryman, M. Hasinoff, *J. Ives*

Tsinghua University S. Chen

University of Virginia E. Frlez, D. Pocanic

University of Zurich P. Robmann, P. Trüol, A. van der Schaaf, *S. Scheu*

Yale University G. Atoyan, S.K. Dhawan, V. Issakov, H. Kaspar, A. Poblaguev, M.E. Zeller

Summary of AGS Requirements (1)

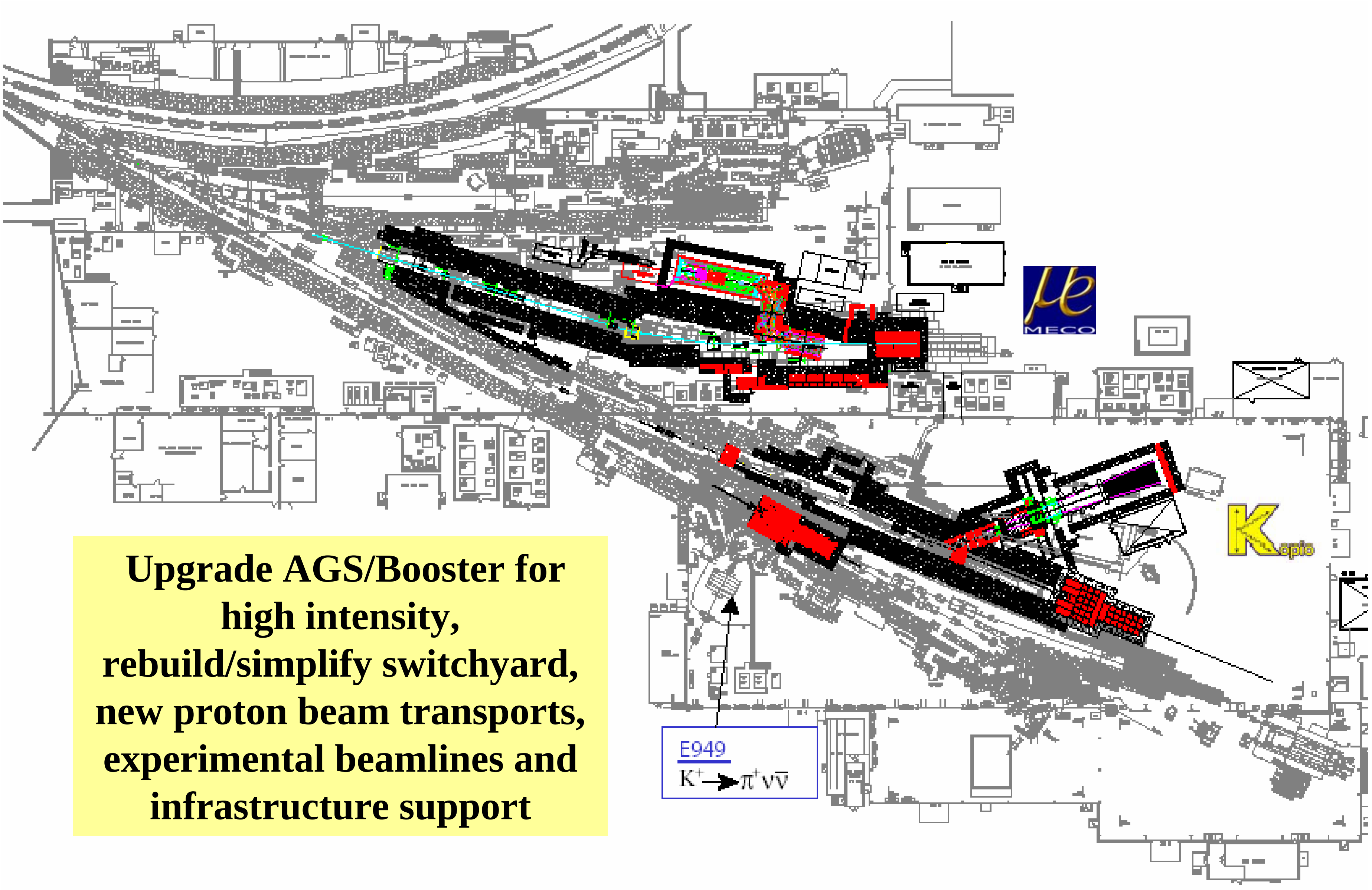
- KOPIO(B line): 25.5 GeV proton beam, 100 TP slow extracted beam/spill, 200 ps bunches spaced at 40 ns, 4.9 s extraction, 7 s total cycle period.
  - -Need 10^{-3} extinction
    - 25 MHz and 100 MHz RF cavities in AGS ring
- MECO(A line): 7.5 GeV proton, 20 TP/spill, 2 buckets filled in ring, separated by 1.35 μs, 0.5 s extraction, 1 s total cycle period.
  - -Need 10^{-9} extinction
    - AC dipole + Strip line kicker in AGS ring
    - RF Modulated Magnet sweeper in beam line

Summary of AGS Requirements (2)

RSVP Operations at high intensity must meet stringent radiation safety requirements, have high reliability, and not impact RHIC operations.

- Cap on AGS to control tritium in ground water
- Additional shielding of components
- Upgrades to the Booster and AGS for high intensity
- Replacement of aging parts subject to fail w/additional radiation load; spare coils for magnets

AGS Upgrades for RSVP

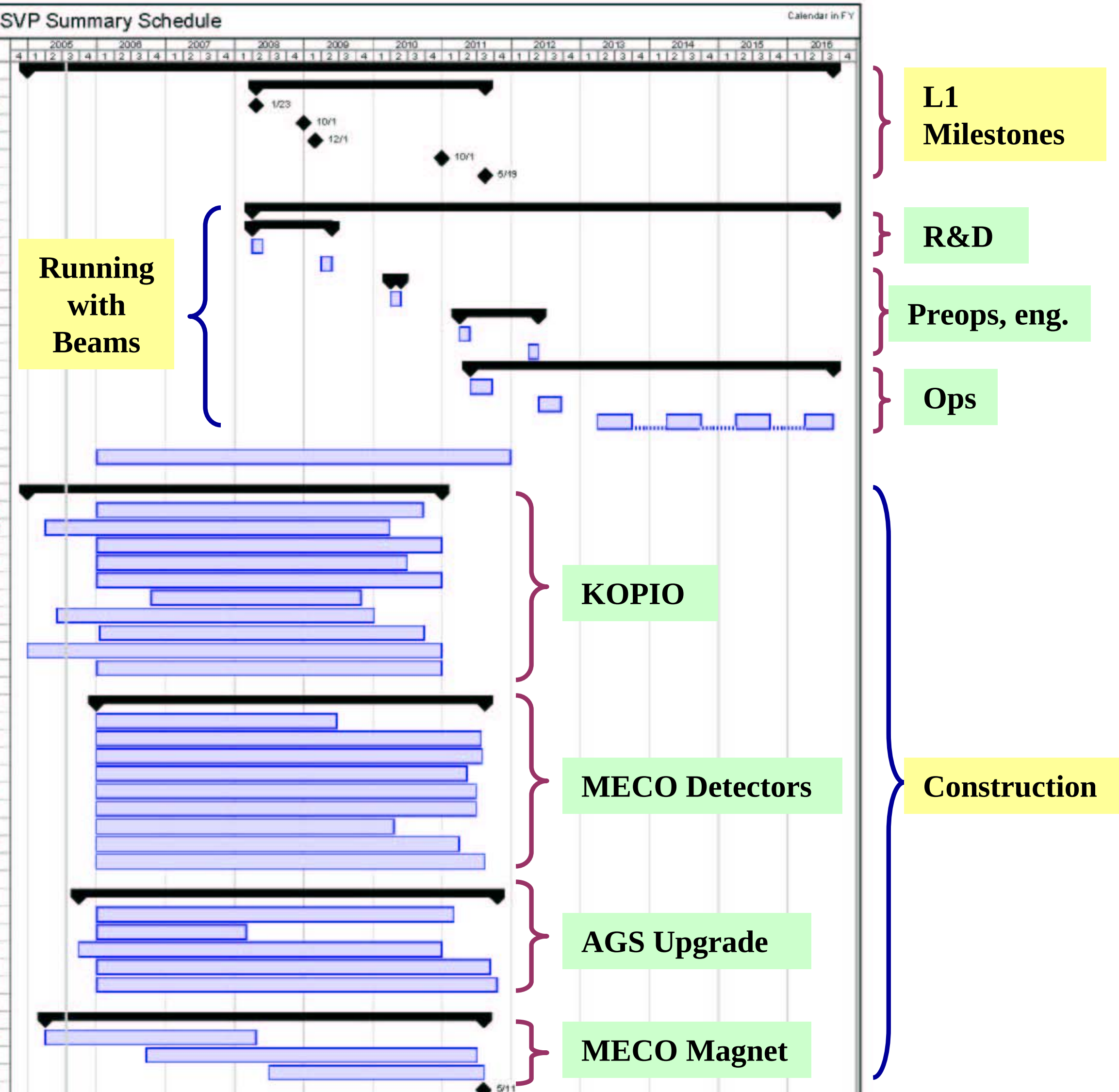


Upgrade AGS/Booster for high intensity, rebuild/simplify switchyard, new proton beam transports, experimental beamlines and infrastructure support

RSVP Summary Schedule

RSVP Summary Schedule

ID	WBS	Task Name	Start	Finish
1	1	RSVP	Fri 10/1/04	Wed 6/1/16
2		Level One Milestones	Wed 1/23/08	Thu 5/19/11
3		All Solenoid Procurements Placed	Wed 1/23/08	Wed 1/23/08
4		MECO A Line Ready for Tests	Wed 10/1/08	Wed 10/1/08
5		KOPIO Neutral Beam Line Complete	Mon 12/1/08	Mon 12/1/08
6		KOPIO Experiment Ready for Beam	Fri 10/1/10	Fri 10/1/10
7		MECO Experiment Ready for Beam	Thu 5/19/11	Thu 5/19/11
8				
9		RSVP Beam Running	Wed 1/2/08	Wed 6/1/16
10		Beam & Detector R&D	Wed 1/2/08	Thu 2/26/09
11		FY08	Wed 1/2/08	Tue 2/26/08
12		FY09	Fri 1/2/09	Thu 2/26/09
13		Beam Pre-operations	Mon 1/4/10	Fri 2/26/10
14		FY10	Mon 1/4/10	Fri 2/26/10
15		Engineering & Commissioning	Mon 1/3/11	Fri 2/24/12
16		FY11 (KOPIO)	Mon 1/3/11	Fri 2/25/11
17		FY12 (MECO)	Mon 1/2/12	Fri 2/24/12
18		Operations, Data-taking	Mon 2/28/11	Wed 6/1/16
19		FY11 (KOPIO)	Mon 2/28/11	Fri 6/24/11
20		FY12 (MECO)	Mon 2/27/12	Fri 6/22/12
21		FY13 - FY16 (KOPIO & MECO alternate)	Wed 1/2/13	Wed 6/1/16
22				
23	1.1	RSVP PO	Mon 10/3/05	Fri 9/30/11
24				
25	1.2	KOPIO	Fri 10/1/04	Fri 10/1/10
26	1.2.1	Vacuum Subsystem	Mon 10/3/05	Wed 6/23/10
27	1.2.2	Preradiator	Mon 1/3/05	Wed 12/30/09
28	1.2.3	Calorimeter System	Mon 10/3/05	Fri 10/1/10
29	1.2.4	Charged Particle Veto	Mon 10/3/05	Wed 3/31/10
30	1.2.5	Photon Veto	Mon 10/3/05	Fri 10/1/10
31	1.2.6	Catcher	Mon 7/17/06	Thu 7/30/09
32	1.2.7	Trigger	Mon 3/7/05	Wed 10/7/09
33	1.2.8	DAQ	Mon 10/17/05	Thu 7/1/10
34	1.2.9	Off-line Computing	Fri 10/1/04	Fri 10/1/10
35	1.2.10	Systems Integration	Mon 10/3/05	Fri 10/1/10
36				
37	1.3	MECO	Sat 10/1/05	Mon 5/16/11
38	1.3.1	Extinction	Sat 10/1/05	Tue 3/24/09
39	1.3.2	Production Target and Shield	Sat 10/1/05	Mon 4/25/11
40	1.3.3	Muon Beamline	Sat 10/1/05	Mon 5/2/11
41	1.3.4	Straw Tracker	Sat 10/1/05	Thu 2/10/11
42	1.3.5	Electron Calorimeter	Sat 10/1/05	Thu 3/31/11
43	1.3.6	Cosmic Ray Shield	Sat 10/1/05	Thu 3/31/11
44	1.3.7	Trigger and DAQ	Sat 10/1/05	Fri 1/22/10
45	1.3.8	Simulations and Offline Analysis	Sat 10/1/05	Fri 12/31/10
46	1.3.9	Integration and Installation	Sat 10/1/05	Mon 5/16/11
47				
48	1.4	AGS Upgrade Project	Fri 7/1/05	Wed 7/20/11
49	1.4.1	Booster/AGS Modifications	Mon 10/3/05	Fri 12/3/10
50	1.4.2	Switchyard	Mon 10/3/05	Mon 12/3/07
51	1.4.3	KOPIO	Fri 7/1/05	Thu 9/30/10
52	1.4.4	MECO	Mon 10/3/05	Mon 6/13/11
53	1.4.5	AGS Project Office	Mon 10/3/05	Wed 7/20/11
54				
55	1.5	Solenoids	Tue 1/4/05	Wed 5/11/11
56	1.5.1	Magnet system final design	Tue 1/4/05	Wed 1/23/08
57	1.5.2	Magnet system fabrication	Wed 6/21/06	Tue 4/5/11
58	1.5.3	Magnet system installation	Tue 4/1/08	Wed 5/11/11
59	1.5.4	Magnet commissioning complete	Wed 5/11/11	Wed 5/11/11



RSVP Timeline: Overview

- 10/96 – BNL Scientific Approval for KOPIO
- 10/97 – BNL Scientific Approval for MECO
- 11/99 – Submission of RSVP to NSF as MRE candidate
- 07/00 – NSF External Cost Verification Review
- 10/00 – NSF National Science Board authorizes RSVP for inclusion in President's Budget "for funding in FY02 or later"
- 06/01 – NSF External Panel Review (science, cost, technical, management)
- 2001 – HEPAP Subpanel endorses physics goals of RSVP
- 03/02 – NSF External Panel Review (R&D progress, budgets, roadmap)
- 01/04 – DOE (Lehman) Review of RSVP impact on RHIC operations
- 02/04 – NSF proposes RSVP to Congress for FY2006 funding as MREFC
- 08/04 – DOE/NSF Interagency MoU signed regarding RSVP
- 09/04 – NSF creates RSVP Project Office, W. Willis, Project Director
- 12/04 – Congress appropriates $15M MREFC & construction start for FY05
- 02/05 – President's Budget requests $42M FY06 MREFC RSVP funding
- 03/05 – HEPAP Subpanel on RSVP science value convened, R. Cahn, LBL, Chair
- 04/05 – Baseline Review conducted, S. Wojcicki, Stanford, Chair

RSVP Cost Summary (AY$)

- Detector and AGS construction:
  - TOTAL: $266,711k
  - [$188,950k + $85,760k (47.4%) Contingency]
- Pre-operations and engineering:
  - Pre-operations: $4,934k
  - Engineering & commissioning: $10,504k
  - TOTAL: $15,438k
- Total MREFC = $282,149k
- Beam and detector R&D, operations and D&D:
  - Beam and detector R&D: $9,497k$
  - Operations: $116,892k (assumes healthy RHIC)
  - Decommissioning & Decontamination: $19,600k
- Total R&RA = $145,989k

Timeline
(RSVP Recent 1)

Milestone	Date	Status, Comments
Discussion of Baseline Expectations, Timeline with Experiments	September 13, 2004	Completed
MECO Magnet Review	Sun-Tue, Oct 10-12, 2004	Held at Columbia U., MOG, Tom Taylor (CERN), Chair
AGS Review	Thu-Fri, Nov 4-5, 2004	Held at BNL, Ray Larsen (SLAC), Chair
Internal discussion of resource-loaded schedules (RLS) for all projects	Thu, Dec 9, 2004	Held at BNL – Project Office, NSF PM, & experiments
Simulations & Backgrounds Review	Tue-Thu, Jan 11-13, 2005	Held at NYU, Jack Ritchie (UTexas), Chair
Initial review of RLS for all projects	Tue-Thu, Jan 18-20, 2005	Reviewed by LOG, Tom Kirk (BNL), Chair

RSVP Recent Timeline (2)

Milestone	Date	Status, Comments
All-Hands Baseline Preparation Kickoff	Feb 17, 2005	Focus projects on spring ’05 baselining
HEPAP subpanel on RSVP science value convened	March, 2005	R. Cahn, LBL, Chair
Preliminary Baseline Review (Project Office)	Wed-Fri, April 6-8, 2005	Held at BNL, E. Temple (FNAL), Chair
NSF Baseline Review	Wed-Fri, April 20-22, 2005	Held at BNL, S. Wojcicki (Stanford), Chair
Submission of RSVP Project Plan to NSF	June 2005	Package includes initial report from HEPAP subpanel
NSB Decision on RSVP Startup	August 2005	

This intensive series of reviews represents initial preparatory phase toward achieving a project baseline

Excerpts of Conclusions of HEPAP Sub-panel on RSVP Science Value

(April 2005; Chair: Bob Cahn)

•"*The real strength of both RSVP experiments is their ability to find new physics by detecting a signal differing significantly from SM expectations*. *Such a discovery would be revolutionary."*

•"RSVP is complementary to LHC: discoveries at LHC would likely increase interest in RSVP."

• "With resources after 2009 increasingly concentrated in LHC and (we hope) ILC, there is need for more modest-sized experiments for a balanced program and for increased opportunities for students."

• "While the B factories and LHCb are positioned to cover B physics thoroughly, the completion of the search for new phenomena in flavor physics requires that both the charged and neutral rare K-decay experiments be completed to the level expected in the Standard Model"

•The physics/cost advantage of RSVP depends on the reduced running costs of parallel running with RHIC.

HEPAP Sub-panel: Comparison with Other Physics Efforts

"To characterize the importance of MECO and KOPIO, we compare them to three existing/proposed experiments of generally comparable cost ($100- 300 M): reactor or accelerator θ_{13}, neutrinoless double beta decay, a future cold-dark-matter search.

- θ_{13} is a parameter that we know is there and whose measurement is crucial (but which could be beyond the reach of proposed experiments).
- Dark matter is there but we don't know if the future dark-matter search would detect it.
- The Majorana nature of neutrinos is a fundamental question but answering it may be beyond proposed neutrinoless double β decay experiments.
- MECO searches for physics beyond the Standard Model. It is a "long-shot" experiment, but with a potentially huge pay-off.
- KOPIO is sensitive to new physics and is also a "long shot" with high payoff.
- KOPIO and MECO share with the three comparison experiments *the capability to dramatically affect the course of high energy physics*.
- The three comparison experiments are responses to the evidence for dark matter, neutrino masses, and neutrino mixing. KOPIO and MECO are exploratory."

Baseline Review Recommendations

(April 20-22, 2005; Chair: Stan Wojcicki)

–State of readiness:

"(For) AGS modifications and the MECO solenoid, significant engineering design has already been done. A number of the detector subsystems, on the other hand, are still in rather early phases of development…but not on critical path…" (due to intentional allocation of scarce funds) (Temple review: RSVP is between a conceptual design and a detailed design.)

–Technical Design:

"…the technical design of the experiments and associated accelerator infrastructure is well matched to the stated physics goals. ..no show stoppers."

"Areas of concern: MECO extinction, KOPIO neutron halo, performance of detectors in beam, testing of detectors and AGS beams in real rate conditions."

–Schedule:

"The tight schedule being proposed may be one of the most significant contributors to the cost risk. The technical challenges…may well cause slippage of the start of data taking by a year or more. ..a float of roughly this duration should be built in into the construction and operation schedule."

Baseline Review Recommendations(2)

Construction Cost:

“ …We feel comfortable that no large cost elements are missing.”

“ The Panel thus feels that the Project’s estimate of total MREFC cost of $282M in then-year dollars (including pre-operations and commissioning) could be adequate…”

Other recommendations:

-Perform contingency analysis for operations (risk of changing regulations or of unanticipated findings- 25% too low)

-Increase contingency for the Project Office from 11% to 20%

-Documented agreements among NSF, DOE, BNL, RSVP Project Office…

(NSF project at a DOE lab is a new idea)

Conclusion from the Report of the Baseline Review

(April 20-22, 2005; Chair: Stan Wojcicki)

"To conclude, the Panel believes that the RSVP physics program addresses frontier physics questions that are not likely to be addressed elsewhere on this time scale. Furthermore, the construction and initial operation would occur in a time frame when few other particle physics activities will be going on in US. Thus it would make a major contribution to the health of the field in US. The proposed experimental arrangements appear well suited towards addressing the physics goals and we see no major show-stoppers. There are a number of technical challenges but they do not seem to be fundamental; no new inventions are required to achieve the proposed goals. The experiments are very difficult, however, and achievement of the proposed sensitivity is not certain. The management team in place is experienced and a management structure is being developed that should significantly improve the probability of success. Because of the long range nature of the program, there has to be a commitment on the part of US funding agencies to support it for at least a decade. There are cost risks to NSF arising principally from technical uncertainties that might affect the length of operation required to reach science goals and from the uncertainty in the extent of DOE support for AGS operations in the future."

Conclusions

KOPIO and MECO:

–Science is compelling and ‘must do’- confirmed by esteemed panel of experts

–Challenging experiments, but baseline shown to be solid- no ‘show stoppers’

–Results of Baseline and HEPAP reviews are being considered now at NSF, who will forward the case to the National Science Board soon.

–The NSB will make final decision on RSVP in their August meeting.

–Room for new collaborators on both experiments!

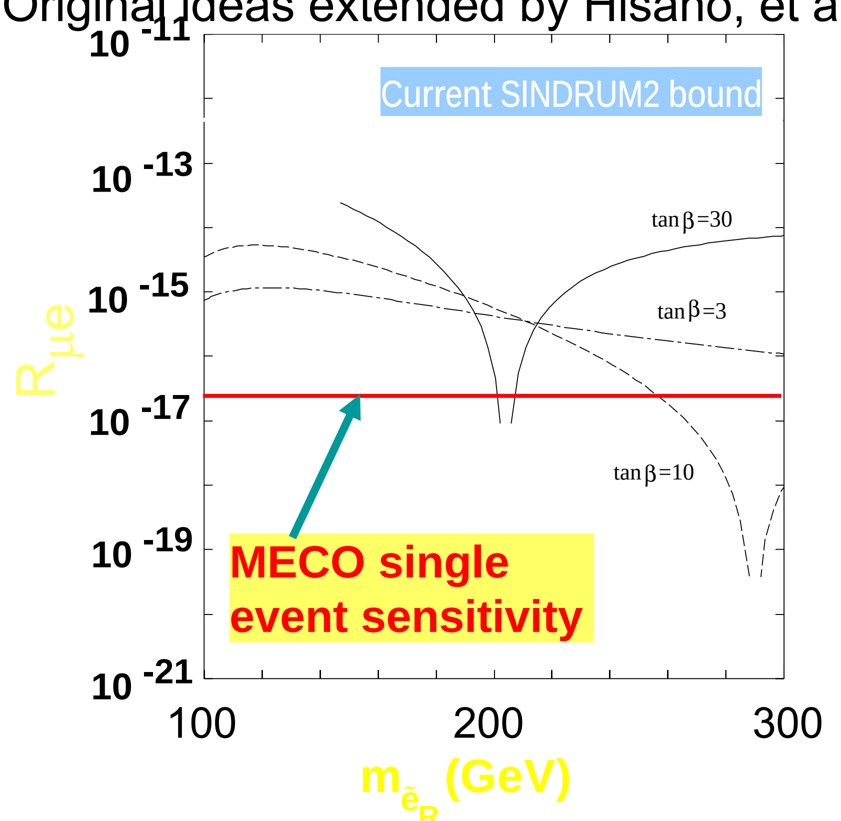
Backup Slides

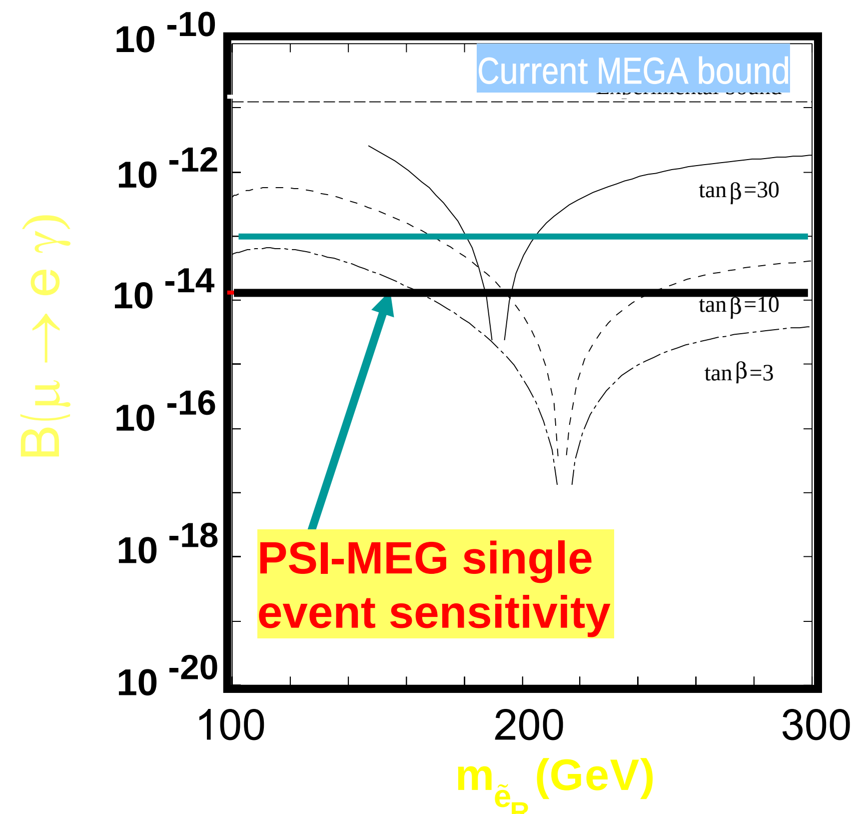
Supersymmetry Predictions for LFV Processes

- From Hall and Barbieri
  - –Large t quark Yukawa couplings imply observable levels of LFV in supersymmetric grand unified models
- Extent of lepton flavor violation in grand unified supersymmetry related to quark mixing

Process	Current Limit	SUSY level
$\mu^- N \rightarrow e^- N$	10^{-12}	10-
$\mu^+ \rightarrow e^+ \gamma$	10^{-11}	10-
$\tau \rightarrow \mu\gamma$	10^{-6}	10^{-9}

- Original ideas extended by Hisano, et al.





Summary of RSVP Beam Costs

	Exp't	Weeks	Cost (Ayk$)
R&D			
FY08	Both	8	4,687.6
FY09	Both	8	4,809.3
TOTAL R&D		**16**	**9,496.9**
Pre-ops & Eng/Comm			
FY10	K0PI0	8	4,934.5
FY11	K0PI0	8	5,378.6
FY12	MECO	8	5,124.9
TOTAL Eng/Comm		**16**	**15,438.0**
Operations			
FY11	K0PI0	17	13,666.2
FY12	MECO	17	13,185.7
FY13	K0PI0	25	22,864.2
FY14	MECO	25	21,462.9
FY15	K0PI0	25	23,600.2
FY16	MECO	25	22,112.9
TOTAL Operations		**134**	**116,892.1**

Operations cycle provides 3.7E20 integrated TP to MECO, 5700 hours running time at 100 TP equivalent for K0PI0. Takes into account losses due to startup times, intensity build up, etc.

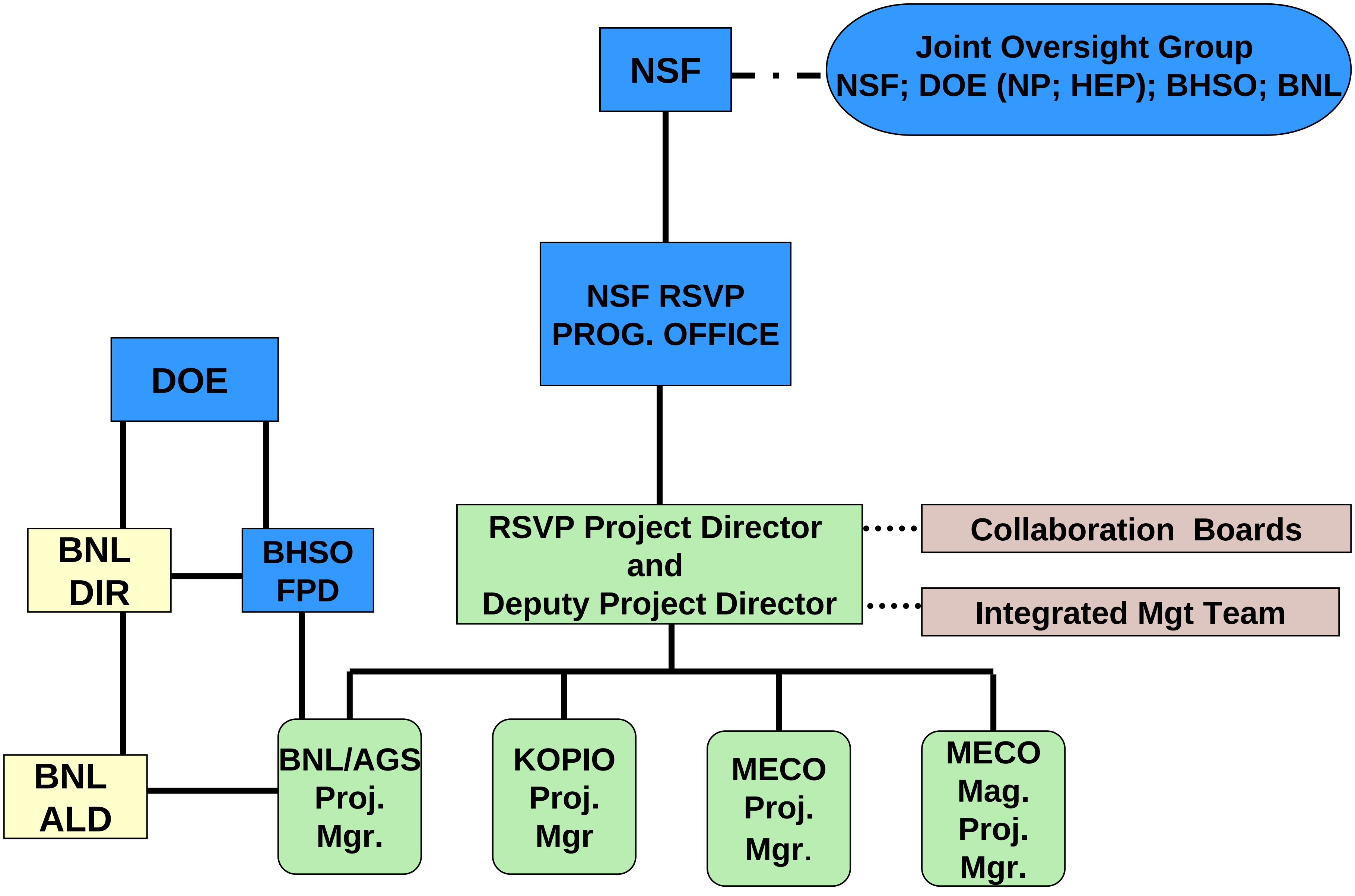
Start of commissioning and operations takes into consideration nominal detector readiness dates.

Total RSVP MREFC Cost (AYk$)

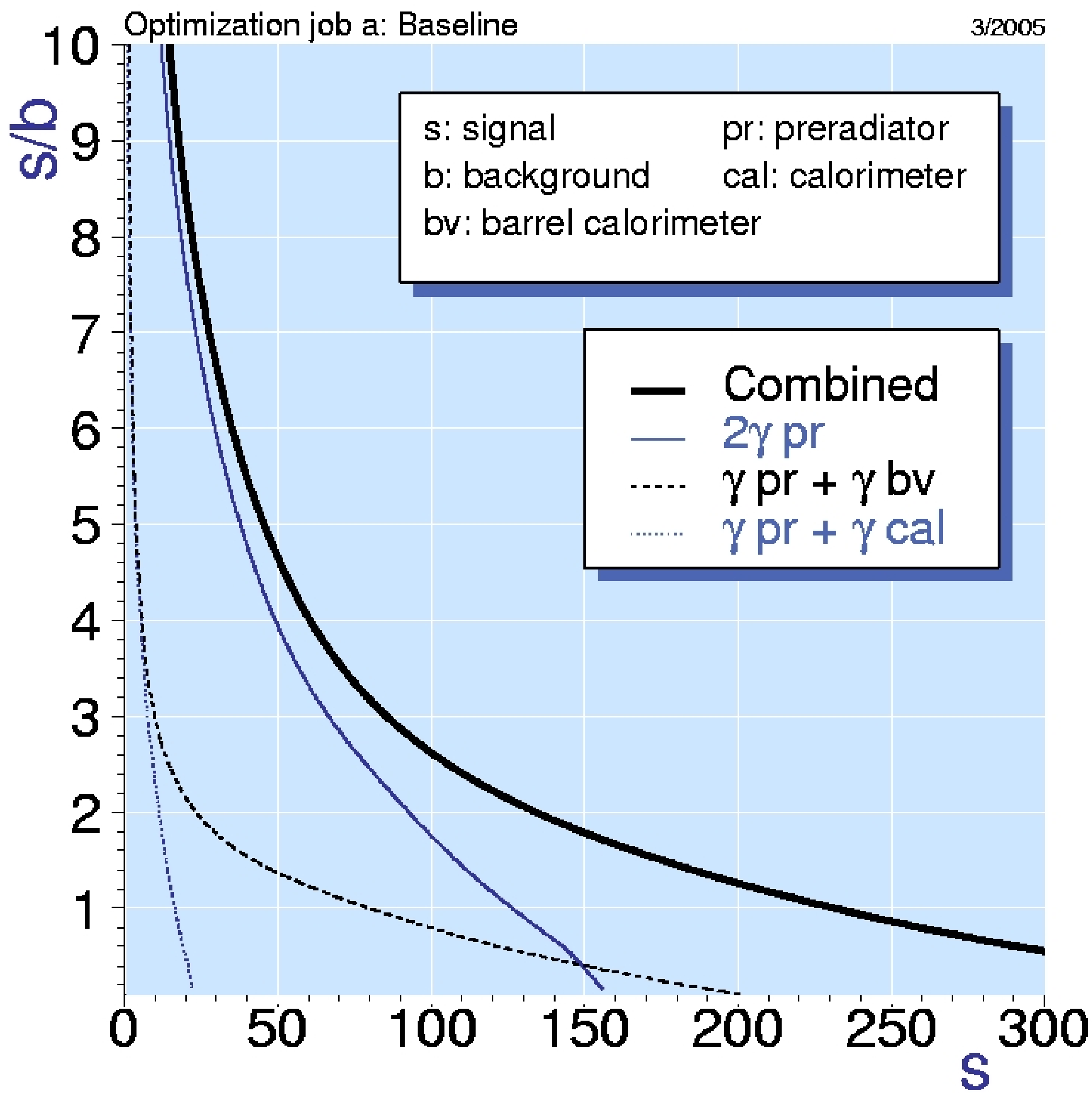
Total RSVP MREFC in AYk$ (NSF Burden)										
	WBS	**FY05**	**FY06**	**FY07**	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**	**Total**
RSVP Project Office	1.1	0.0	3029.2	3107.9	3213.5	3284.3	3369.8	3457.3	0.0	19,462.1
KOPIO	1.2	0.0	7102.3	12377.9	13827.5	7486.1	3526.9	657.7	0.0	44,978.4
MECO Detector	1.3	0.0	4669.1	6952.0	6812.8	2591.7	1478.2	834.7	0.0	23,338.6
AGS	1.4	0.0	9557.0	15284.0	9270.2	5077.8	1875.7	935.3	0.0	42,000.1
MECO Magnet	1.5	0.0	5194.9	9126.6	19484.2	11473.8	4156.0	1733.5	0.0	51,169.0
TOTAL RSVP BASE COST (AYk$)		**0.0**	**29552.5**	**46848.4**	**52608.2**	**29913.8**	**14406.6**	**7618.6**	**0.0**	**180948.1**
Contingency		0.0	7766.2	19978.6	25567.2	21314.2	8241.1	2895.1	0.0	85,762.4
Contingency (%)		0.0	26.3	42.6	48.6	71.3	57.2	38.0	0.0	47.4
SUB-TOTAL		**0.0**	**37318.6**	**66827.0**	**78175.5**	**51228.1**	**22647.7**	**10513.7**	**0.0**	**266,710.6**
Pre-operations		0.0	0.0	0.0	0.0	0.0	4934.5	0.0	0.0	4,934.5
Engineering & commissioning		0.0	0.0	0.0	0.0	0.0	0.0	5378.6	5124.9	10,503.5
TOTAL RSVP MREFC (AYk$)		**0.0**	**37,318.6**	**66,827.0**	**78,175.5**	**51,228.1**	**27,582.1**	**15,892.3**	**5,124.9**	**282,148.5**
escalation rate		1	1.0280	1.0547	1.0822	1.1103	1.1392	1.1688	1.1991	

- Total MREFC (AY$) = $282.15M
  - Detector Construction: $266.71M
  - Pre-operations, Commissioning: $15.44M
- Total project contingency includes contingency on in-kind contributions
- Includes MREFC only, R&RA not included (beam and detector R&D, operations)

RSVP Organization Oversight



(Events) –



Optimization job a: Baseline
3/2005
s: signal
b: background
bv: barrel calorimeter
pr: preradiator
cal: calorimeter
Combined
2γ pr
γ pr + γ bv
γ pr + γ cal
s/b
10
9
8
7
6
5
4
3
2
1
0
50
100
150
200
250
300
s

Other Backgrounds

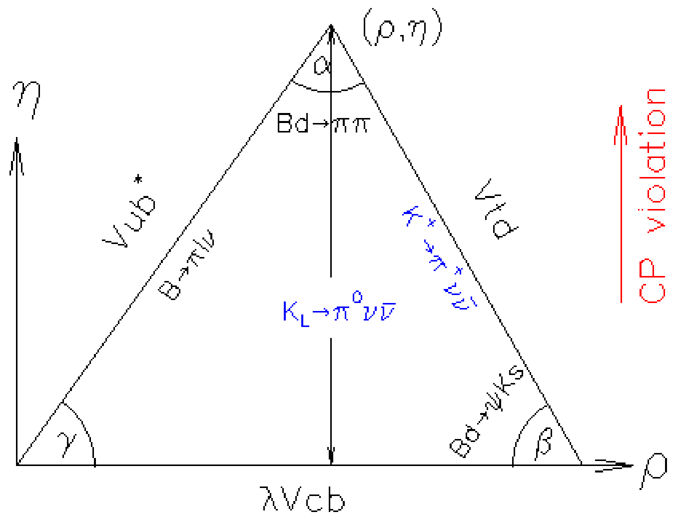
- K^+ contamination of beam: <0.001 of signal rate
- $K_L \to K^+ e^- \nu$, $K^- e^+ \nu$: ~ 0.001 of signal rate
- $nN \to \pi^0 N$: negligible production from residual gas in decay volume if pressure<10^{-6} Torr. Requirements on reconstructed $Z_V(K_L)$ suppress rate from US wall to <0.01 of signal rate
- n: far smaller than neutron background
- Hyperons: <10^{-5} of signal rate
- Fake photons < 0.05 of signal rate assuming ~$10^{-3} \times 10^{-3}$ suppression from (vetoing) $\times$ (γ/n discrimination)
- Two K_L giving single candidate: negligible due to vetoes
- $(K_L \to \pi^\pm X) \times (\pi^\pm \to \pi^0 e^\pm \nu)$: ~0.01 of signal rate
- $K_S \to \pi^0 \pi^0$: $\sim 4 \times 10^{-4}$ of $K_L \to \pi^0 \pi^0$ background rate

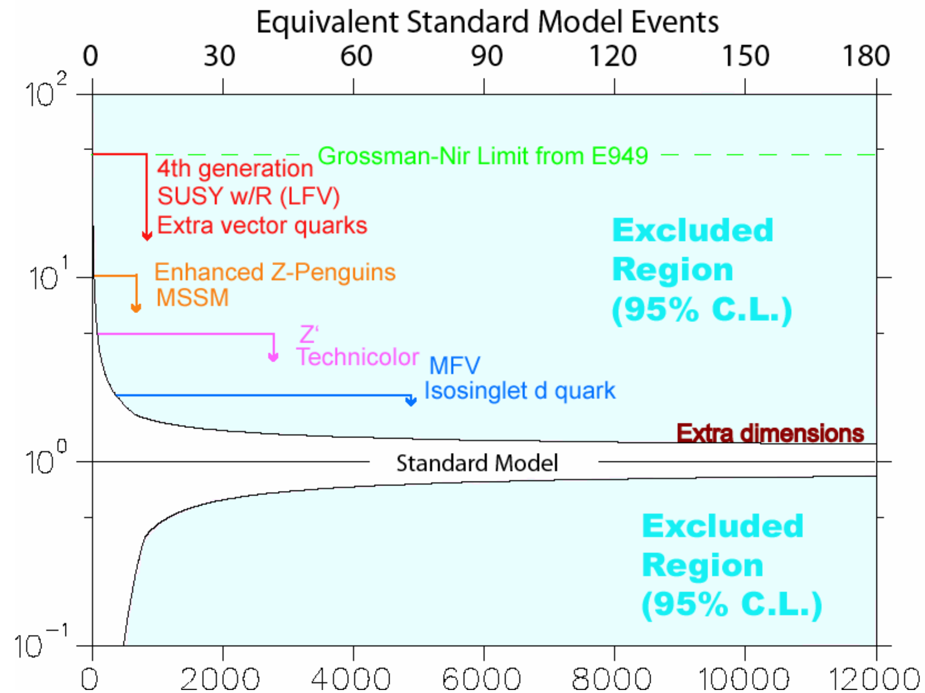
RSVP Beam Operating Scenario

- Beam and detector R&D (R&RA):
  - 8 weeks in each of FY08 and FY09
    - Neutral beam/halo
    - Extinction tests for MECO
    - Beam tests for completed portions of detectors
- Beam Pre-operations (MREFC):
  - 8 weeks in FY10
  - Neutral beam/halo with micro structure
    - 25 MHz cavity installed summer 2009
  - Pushing extinction tests to higher intensity for MECO
  - Beam tests for completed portions of detectors
  - Prepare for engineering/commissioning and operations running
- Engineering and commissioning (MREFC)
  - 8 weeks in FY11 (K0PI0)
  - 8 weeks in FY12 (MECO)
- Operations, data-taking (R&RA):
  - 17 weeks in FY11 (K0PI0) and FY12 (MECO)
  - 25 weeks in FY13-16 (alternating K0PI0, MECO)

Funding categories follow NSF guidance

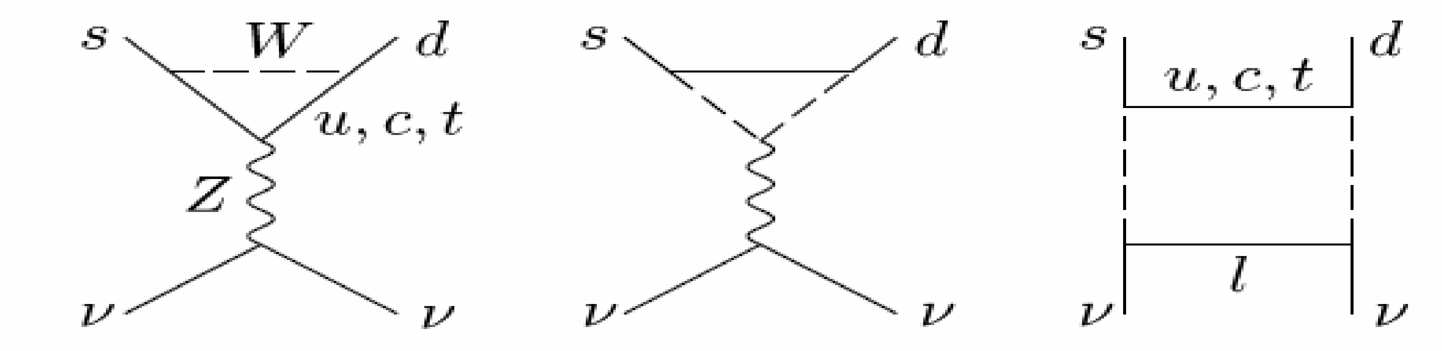
KOPIO Physics Program





- Anticipate 10% measurement of $B(K_L \to \pi^0 \nu\nu) \sim 3\times10^{-11}$
  - 5% measurement of area of unitarity triangle (unique)
- Early running provides sensitive probe of non-SM physics

$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ in the SM



Standard Model (*Buras*): $\operatorname{Im}\lambda_t = \operatorname{Im}V_{ts}^{*}V_{td} = \eta A^2 \lambda^5$

$$B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) = 1.8\,x10^{-10} \left(\frac{\operatorname{Im}\lambda_t}{\lambda^5} X(x_t) \right)^2$$

$$\approx 4.1\,x10^{-10} A^4 \eta^2 = 3.0 \pm 0.6\,x10^{-11}$$

$$B(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \approx 1.0\,x10^{-10} A^4 \left[\eta^2 + \left(\rho_0 - \rho \right)^2 \right] = 7.8 \pm 1.2\,x10^{-11}$$