RSVP Subpanel: Interim Report

HEPAP
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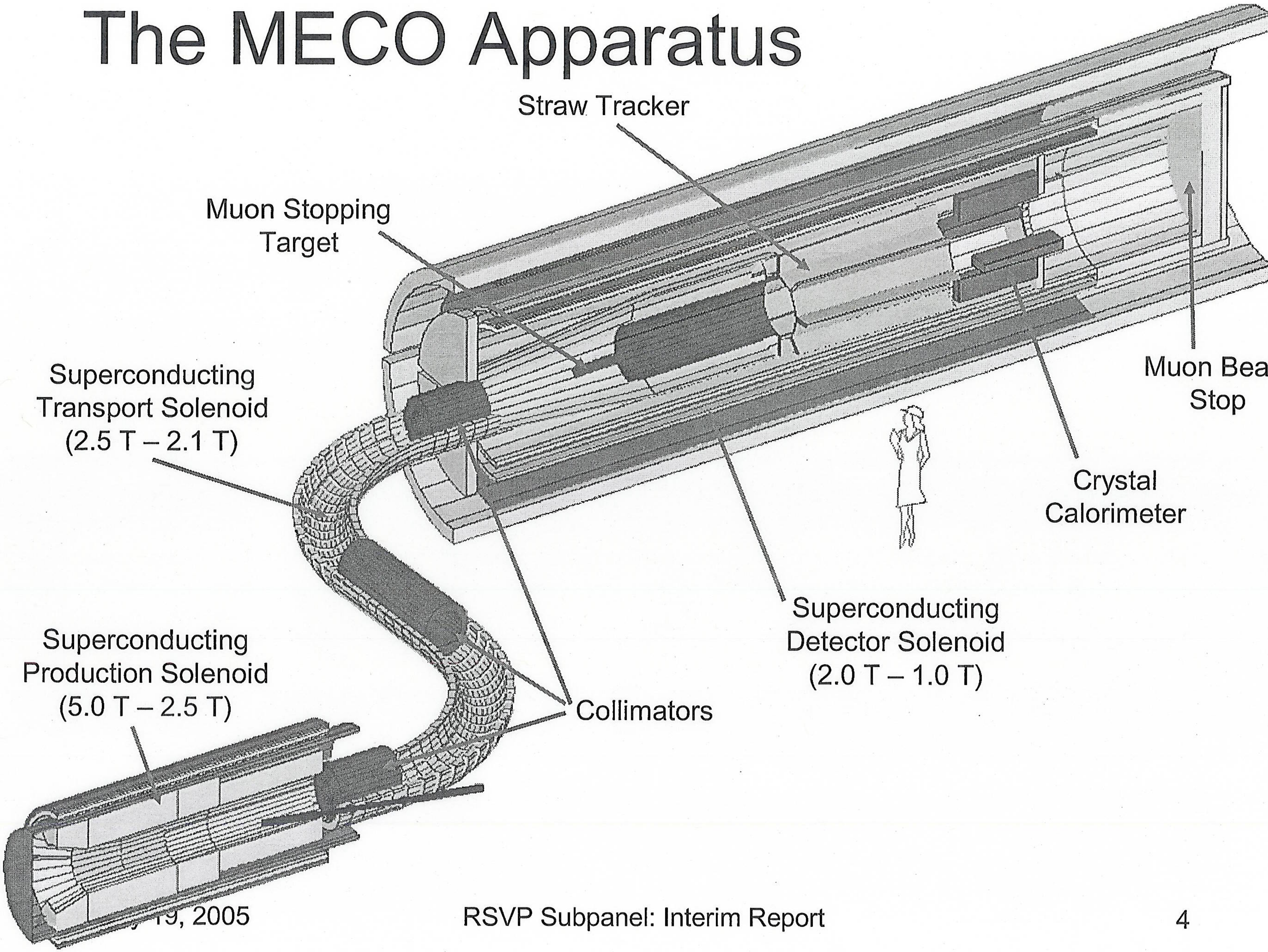
Subpanel Membership

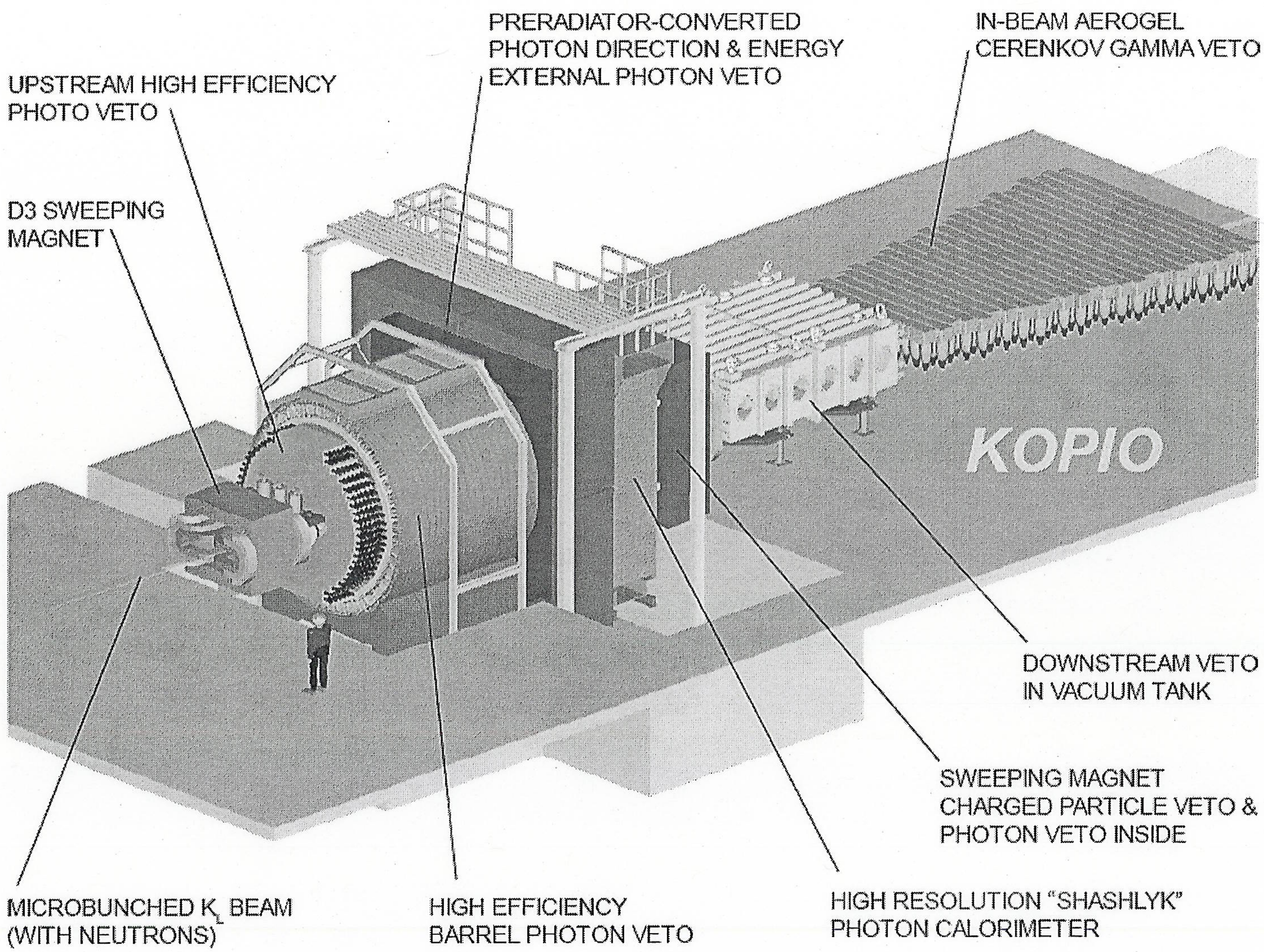
- G. Baym (Illinois)
- R. Cahn (LBNL)
- C. Callan (Princeton)
- B. Grinstein (UCSD)
- J. Hewett (SLAC)
- H. Prosper (FSU)
- J. Ritchie (UT)
- N. Roe (LBNL)
- A. Seiden (UCSC)
- A.J.S. Smith (Princeton)
- F. Wilczek (MIT)
- M. Wise (Caltech)

Charge to Subpanel

- Evaluate the science value of MECO in the context of the US investment in elementary particle physics, <u>assuming</u> three cases, achieving sensitivities of 10^{-17}, 10^{-16}, and 10^{-15}.
- Evaluate the science value of KOPIO in the context of the US investment in elementary particle physics, <u>assuming</u> two cases, observation of 10 events and 100 events (at the rate predicted by the standard model).
- Place the science value of each in the context of the US elementary particle physics program, broadly defined, recognizing the fiscal environment and the impact on other potential investments at NSF and DOE. How has this context changed since 1999, when the proposal was submitted?
- Place the scientific value of each in the context of the international elementary particle physics program and assess any potential overlap or complementarity with work being planned elsewhere. How has this context changed since 1999?

The MECO Apparatus




UPSTREAM HIGH EFFICIENCY
PHOTO VETO
D3 SWEEPING
MAGNET
PRERADIATOR-CONVERTED
PHOTON DIRECTION & ENERGY
EXTERNAL PHOTON VETO
IN-BEAM AEROGEL
CERENKOV GAMMA VETO
KOPIO
DOWNSTREAM VETO
IN VACUUM TANK
SWEEPING MAGNET
CHARGED PARTICLE VETO &
PHOTON VETO INSIDE
HIGH RESOLUTION "SHASHLYK"
PHOTON CALORIMETER
HIGH EFFICIENCY
BARREL PHOTON VETO
MICROBUNCHED K_L BEAM
(WITH NEUTRONS)

Value

The strength of both RSVP experiments is their ability to find new physics by detecting a signal differing significantly from Standard Model expectations. Such a discovery would be revolutionary. This scientific value is unchanged since the RSVP MRE was approved in 1999.

Value..

- MECO is sensitive to lepton-flavor violation in both the $\mu \rightarrow e\, \gamma$ interaction and in more exotic interactions, such as those directly mediated by lepto-quarks.

...Value

- KOPIO's measurement of $K_L^0 \rightarrow \pi^0\nu\nu$ is sensitive to new CP-violating interactions. While KOPIO would not add much to our knowledge of the CKM parameters (η will be known to better than 5% by 2015 from B_d and B_s mixing, relying on lattice calculations for a ratio of hadronic matrix elements), it will probe new physics at the TeV scale in models with minimal flavor violation. In the context of other models, KOPIO is sensitive to even higher mass scales.

MECO Goal

MECO needs to make a substantial improvement over the current μ-to-e conversion limit of 6×10^{-13} in titanium, equivalent to 3×10^{-13} in aluminum.

It also needs to be able to cover the domain of the planned $\mu \rightarrow e\,\gamma$ experiment MEG, which would reach the equivalent of 2.6×10^{-16} if μ-to-e conversion occurs through the same mechanism as $\mu \rightarrow e\,\gamma$.

A minimum single-event sensitivity of 10^{-16} is required, consistent with the MECO goal of 2×10^{-17} allowing for somewhat larger backgrounds and/or less than perfect detector performance. A sensitivity of 10^{-15} is not an adequate level for MECO.

KOPIO Goal

A goal of 100 events for KOPIO for the Standard Model rate is appropriate. With a signal-to-background ratio of 2, this would give a 5-σ statistical effect for an intrinsic rate 75% greater than the Standard Model prediction. The 100-event level would be achieved with 6000 hours of running at the expected performance. A sensitivity of 10 events for KOPIO with the Standard Model rate is not an adequate goal.

Competition

Proposals for other experiments with similar goals exist for both KOPIO and MECO, but these proposals are not as well developed and in any case the timescale for RSVP would allow it to reach its goals first. There are also proposals for related experiments, which in general are complementary.

Competition...

- There is a Letter-of-Intent for an experiment (PRIME) at the PRISM muon facility at JPARC, to measure μ-to-e conversion with a sensitivity goal of 10^{-18}.

- There is a Letter-of-Intent for an experiment to measure $K_L^0 \to \pi^0 \nu\nu$ at JPARC with a goal of 100 events. There is a pilot experiment, E931a, at 12 GeV PS at KEK, with a sensitivity of about 10^{-10}.

- The MEG experiment at PSI could find evidence for a $\mu e \gamma$ coupling before MECO. Such a discovery would provide additional motivation for MECO.

Competition...

- There are proposed $K^+ \rightarrow \pi^+ \nu\nu$ experiments at CERN and KEK. This channel is sensitive to new contributions from both CP-violating and CP-conserving interactions, whereas the K_L^0 decay mode is sensitive only to CP-violating interactions. However, the neutral decay mode has the advantages of smaller theoretical uncertainties and greater sensitivity to new CP-violating physics, due to the smaller Standard Model amplitude. If the charged K experiments were to find evidence for new physics, it would increase interest in the KOPIO result.

Context

In recent years we have learned that neutrinos have mass and large mixing angles, violating (neutral)-lepton-flavor conservation. B-meson decays violate CP and the best-measured modes conform to the predictions of the CKM model. No direct sign of a Higgs boson has been seen, but electroweak measurements indicate it should have a low mass. The nature of dark matter remains a mystery, as does that of the newly discovered dark energy.

The primary consequences for RSVP of these developments are an increased interest in lepton-flavor violation and a decreased opportunity for KOPIO to contribute to the determination of CKM parameters.

Context...

RSVP is complementary to LHC: discoveries at LHC would likely increase interest in RSVP. If LHC sees only a single Standard-Model Higgs, there would still be interest in RSVP experiments since their sensitivity extends beyond the reach of LHC.

Context...

The U.S. domestic experimental program in high energy physics is shrinking dramatically with the cancellation of CKM and BTeV and the scheduled completions for BaBar (2008), CESR (2008), and the Tevatron collider (2009). RSVP represents a major fraction of the anticipated accelerator-based program in the U.S.

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.

...Context

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.

Comparisons

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 experiments designed to measure θ_{13} in neutrino oscillations, the search for neutrinoless double beta decay, and a future cryogenic cold-dark-matter search.

Comparisons

- The angle θ_{13} in neutrino oscillations is both a fundamental parameter of the Standard Model and a crucial input for future neutrino experiments. It could be beyond the reach of the proposed experiments, resulting only in upper limits.

- The cosmological evidence for dark matter is overwhelming, but we don't know if future cryogenic dark-matter searches will be sensitive enough to detect it. These experiments are complementary to the LHC, which may find particle candidates for the dark matter.

- Whether neutrinos are their own antiparticles is an important fundamental question, with implications for both cosmology and particle physics, but answering it may be beyond the scope of the proposed neutrinoless double beta decay experiments.

Comparisons

- KOPIO and MECO share with the three comparison experiments the capability to affect dramatically our understanding of fundamental interactions.

- The three comparison experiments are responses to specific discoveries: dark matter, neutrino masses, and neutrino mixing. KOPIO and MECO are well-motivated searches for physics beyond the Standard Model, “long-shots” with potentially high pay-offs.

Limiting Cost

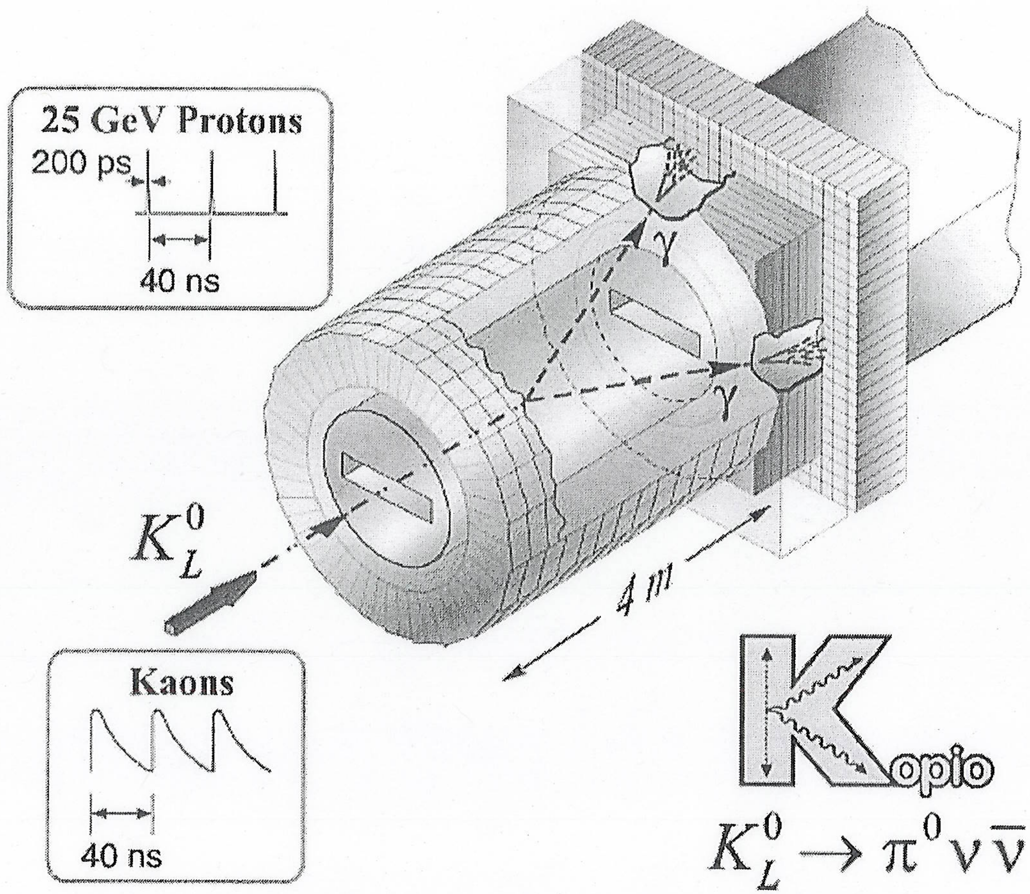
We assume that NSF will bear only the incremental cost of running the AGS for RSVP. The opportunities provided by RSVP would not justify the full cost of running the AGS.

Backup Slides

Features of the MECO Experiment (Molzon)

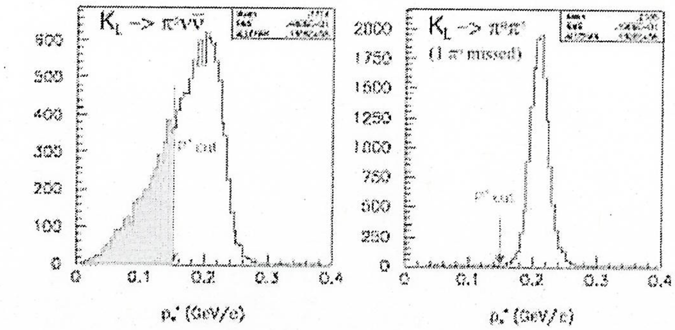
- 1000 fold increase in muon intensity using an idea from MELC at MMF
  - High Z target for improved pion production
  - Graded solenoidal field to maximize pion capture
  - Produce $\approx 10^{-2}$ m-/p at 8 GeV (SINDRUM2 $\approx 10^{-8}$, MELC $\approx 10^{-4}$, Muon Collider ≈ 0.3)
  - Muon transport in curved solenoid suppressing high momentum negatives and all positives and neutrals (new for MECO)
- Pulsed beam to eliminate prompt backgrounds following PSI method (A. Badertscher, et al. 1981)
  - Beam pulse duration $<< t_m$
  - Pulse separation $\approx t_m$
  - Large duty cycle (50%)
  - Extinction between pulses $< 10^{-9}$
- Improved Detector Resolution and Rate Capability
  - Detector in graded solenoid field for improved acceptance, rate handling, background rejection following MELC concept
  - Spectrometer with nearly axial components and very high resolution (new for MECO)

KOPIO Concepts



Concepts

Kaon Center of Mass Measurements



- Maximize micro-bunched beam from the AGS
- Measure everything! (Energy, Position, Angle, Time)
- Eliminate extra charged particles or ***photons***
  - * KOPIO: π^0 inefficiency $< 10^{-8}$
- Suppress backgrounds
  - * Predict backgrounds *from data*: dual cuts
  - * Use "Blind analysis" techniques
  - * Test predictions "outside-the-box"
- Weight candidate events with S/N likelihood function

Nominal Beam Parameters

Proton Beam:

100 Tp/spill (Upgraded from present 70 Tp)

~5.5 s spill, 2.3 s interspill period

25 MHz micro-buching frequency

Bunch width 200ps

Interbunch extinction 10^{-3}

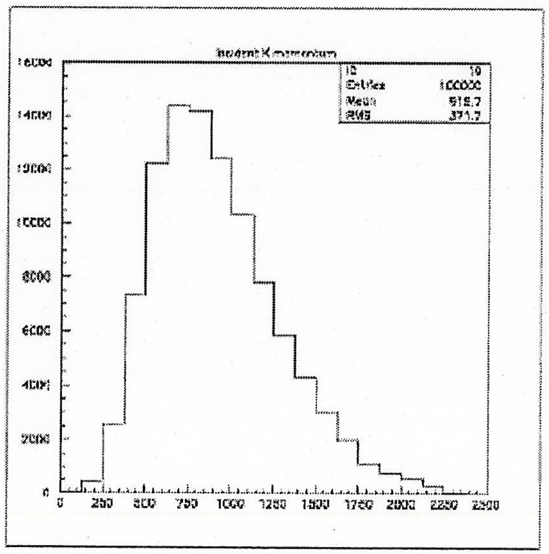
"Kaon Beam":

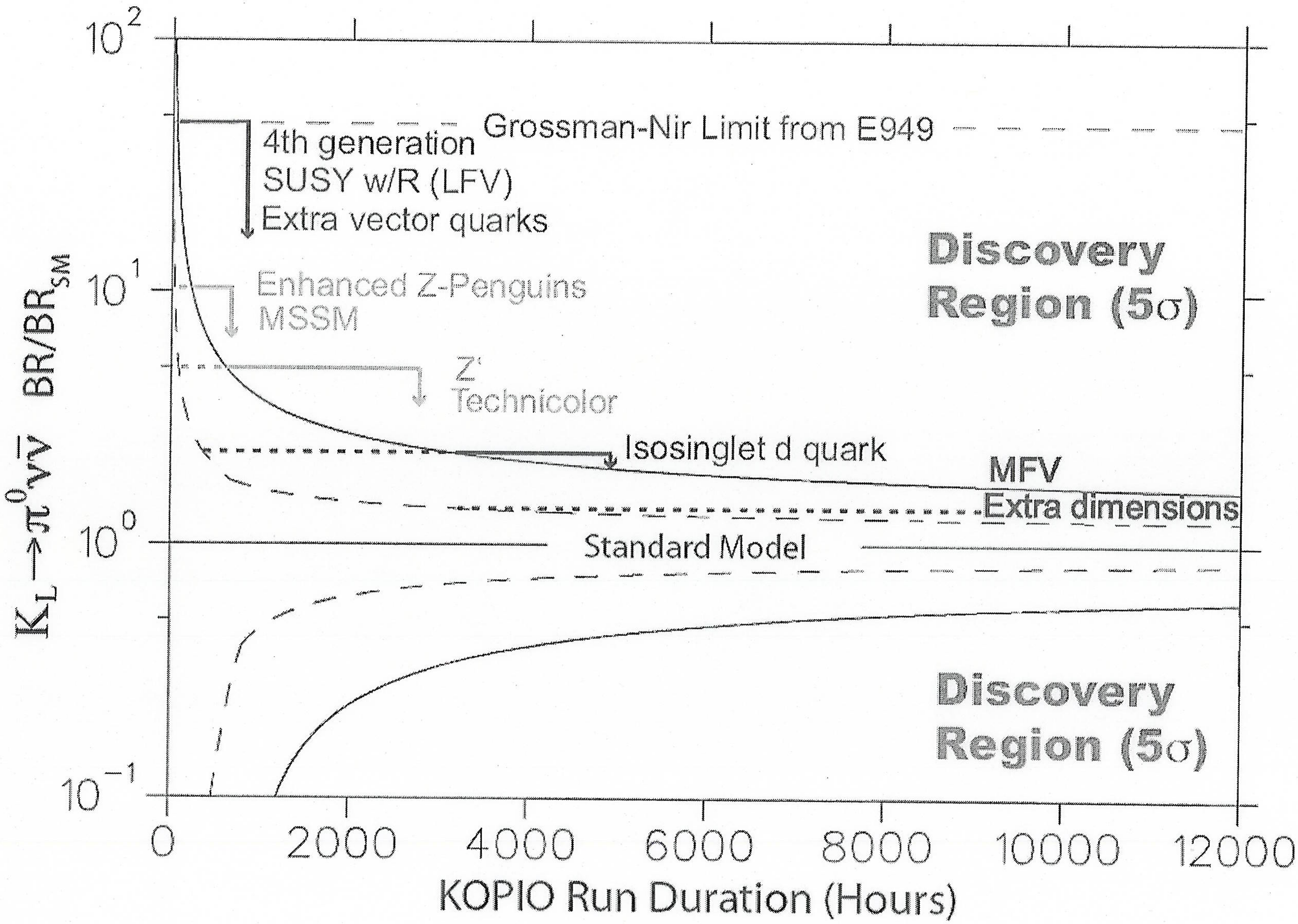
42.5 degree take-off angle

Soft momentum spectrum [0.5,1.5 GeV]

3×10^8 K_L / spill, 8 % decay

10 GHz neutrons





$K_L \rightarrow \pi^0 \nu \bar{\nu}$ BR/BR$_{SM}$
10^2
10^1
10^0
10^{-1}
Grossman-Nir Limit from E949
4th generation
SUSY w/R (LFV)
Extra vector quarks
Enhanced Z-Penguins
MSSM
Z'
Technicolor
Isosinglet d quark
MFV
Extra dimensions
Standard Model
Discovery Region (5σ)
Discovery Region (5σ)
0
2000
4000
6000
8000
10000
12000
KOPIO Run Duration (Hours)