Status Report on the CKM Project

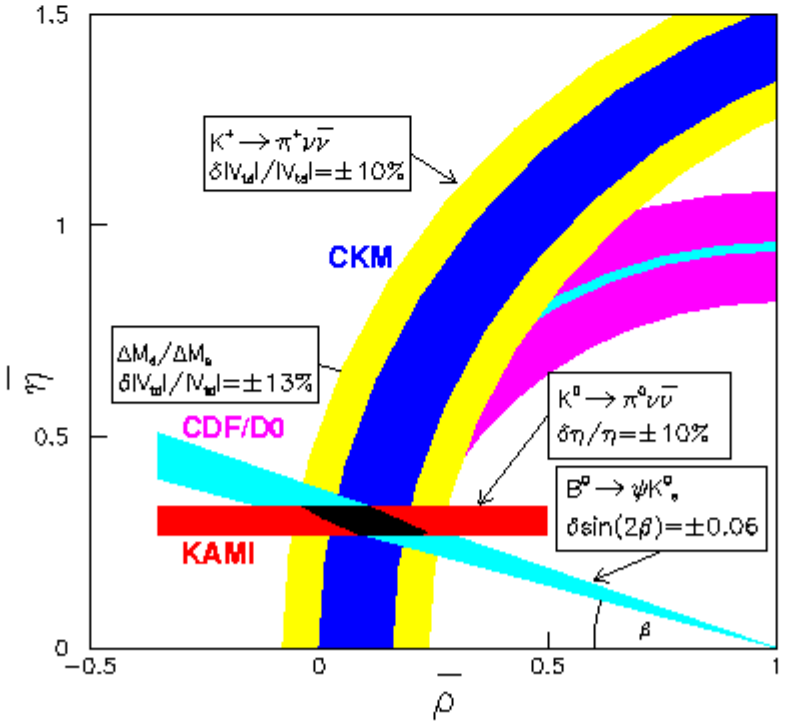
R. Tschirhart, Fermilab
Representing the CKM Collaboration

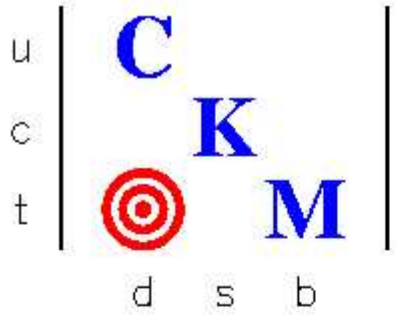
April 14th, 2000

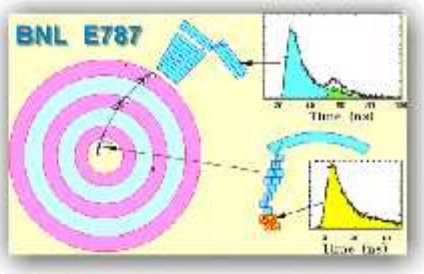
- The Physics.
- A slide show on progress and developments since our last presentation in May of '99.
- What we need from you and the lab to present a technical proposal in April of 2001.

The Physics...

- Measurement of the ultra-rare process $K^+ \to \pi^+ \nu \bar{\nu}$ provides clean access to the CP-violating parameters of the Standard Model.
- This process is expected to occur with a branching fraction of $(8 \pm 3 \times 10^{-11})$, and one clear candidate event has been observed by BNL-E787 with a branching fraction of $(15^{+34}_{-12} \times 10^{-11})$.
- The CKM experiment proposes to measure this process with a sensitivity of 1×10^{-12}.





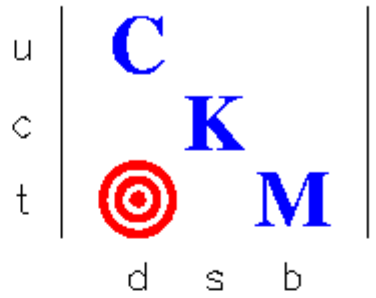


$K^+ \to \pi^+ \nu\overline{\nu}$: E949 & CKM

... the two experiments are stages of a program for studying $K^+ \to \pi^+ \nu\overline{\nu}$, which will eventually reach a sensitivity comparable to the theoretical accuracy at which this process can be calculated in the Standard Model. Stage one would be E949, which seeks to reach a sensitivity of $\sim 10^{-11}$/event and stage two would be CKM, which seeks to reach a sensitivity an order of magnitude beyond this level.

- Collaboration begun in summer of 1999
- E949 approved 8/99
- plans for integration of FNAL TDC's into E949 underway (2/00)
- system tests planned for 9/00
- BNL represented at CKM collaboration meeting 9/99
- BNL active in biweekly CKM video meetings
- BNL contribution to PV system under development
- E949
  - FNAL TDC's to instrument the range stack
  - manpower/expertise
- CKM
  - BNL is collaborating on the Photon Veto
  - manpower/expertise

BROOKHAVEN
NATIONAL LABORATORY



Charged Kaons at the Main Injector

March 10, 2000

A Proposal for a Precision Measurement of the Decay $K^+ \to \pi^+\nu\overline{\nu}$ and Other Rare K^+ Processes at Fermilab Using the Main Injector

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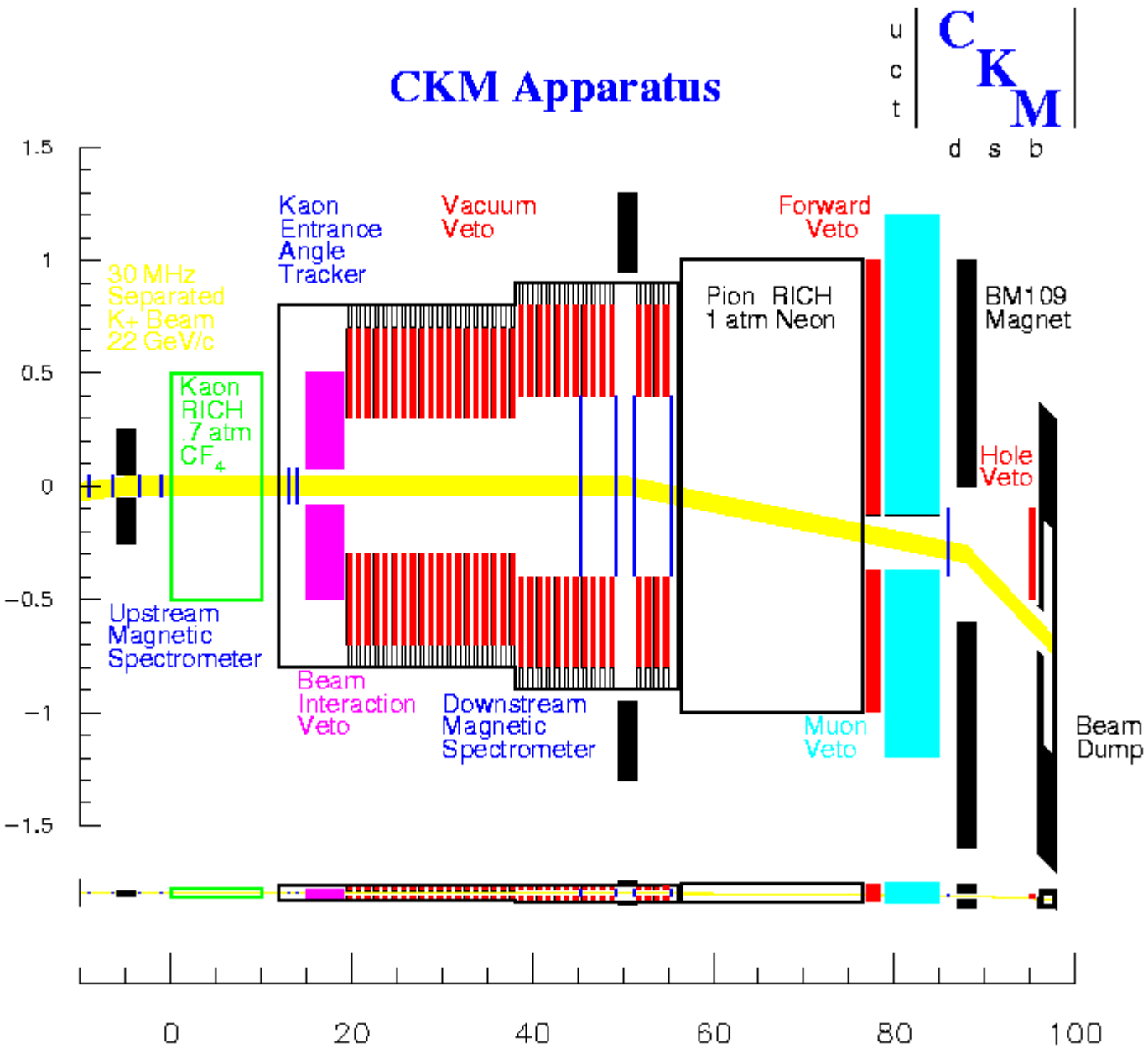
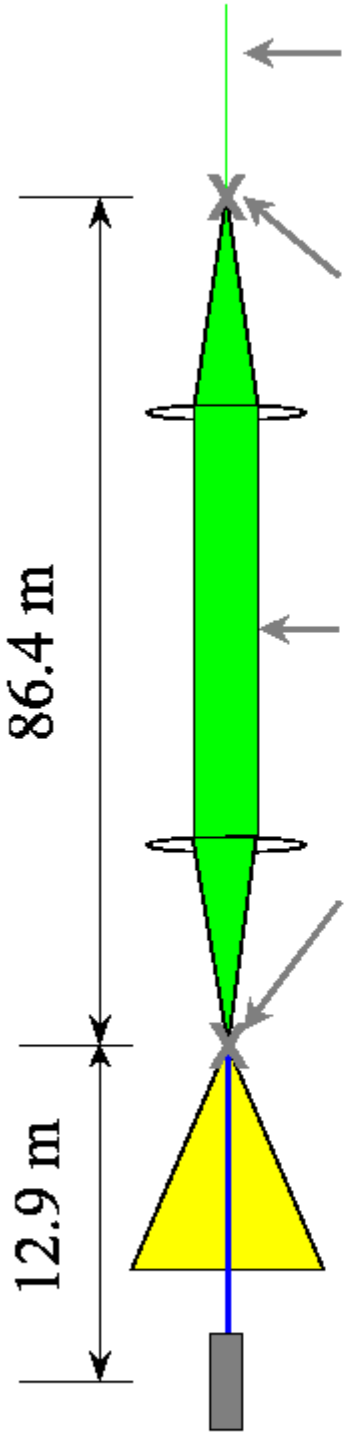

CKM Apparatus
u
c
t
C K M
d s b
30 MHz
Separated
K+ Beam
22 GeV/c
Kaon
RICH
.7 atm
CF_4
Kaon
Entrance
Angle
Tracker
Vacuum
Veto
Pion RICH
1 atm Neon
Forward
Veto
BM109
Magnet
Hole
Veto
Upstream
Magnetic
Spectrometer
Beam
Interaction
Veto
Downstream
Magnetic
Spectrometer
Muon
Veto
Beam
Dump
1.5
1
0.5
0
−0.5
−1
−1.5
0
20
40
60
80
100

RF separated K^+ beams



Initial momentum-selected beam $\Delta P/P \sim 2\%$

RF deflection: $A\sin(\omega t)$
$A \sim 15$ MeV/c

Transport L = (integer)$\beta_\pi c/f$
Δt then integer multiple of $2\pi\omega$ for π^+

2nd RF deflection *e.g.* 180° out of phase: $-A\sin(\omega t+\omega\Delta t)$

For π^+, no net deflection

For K^+, deflection is

$2A \sin(n\beta_K c/2f) \bullet \cos(wt+ n\beta_K c/2f)$

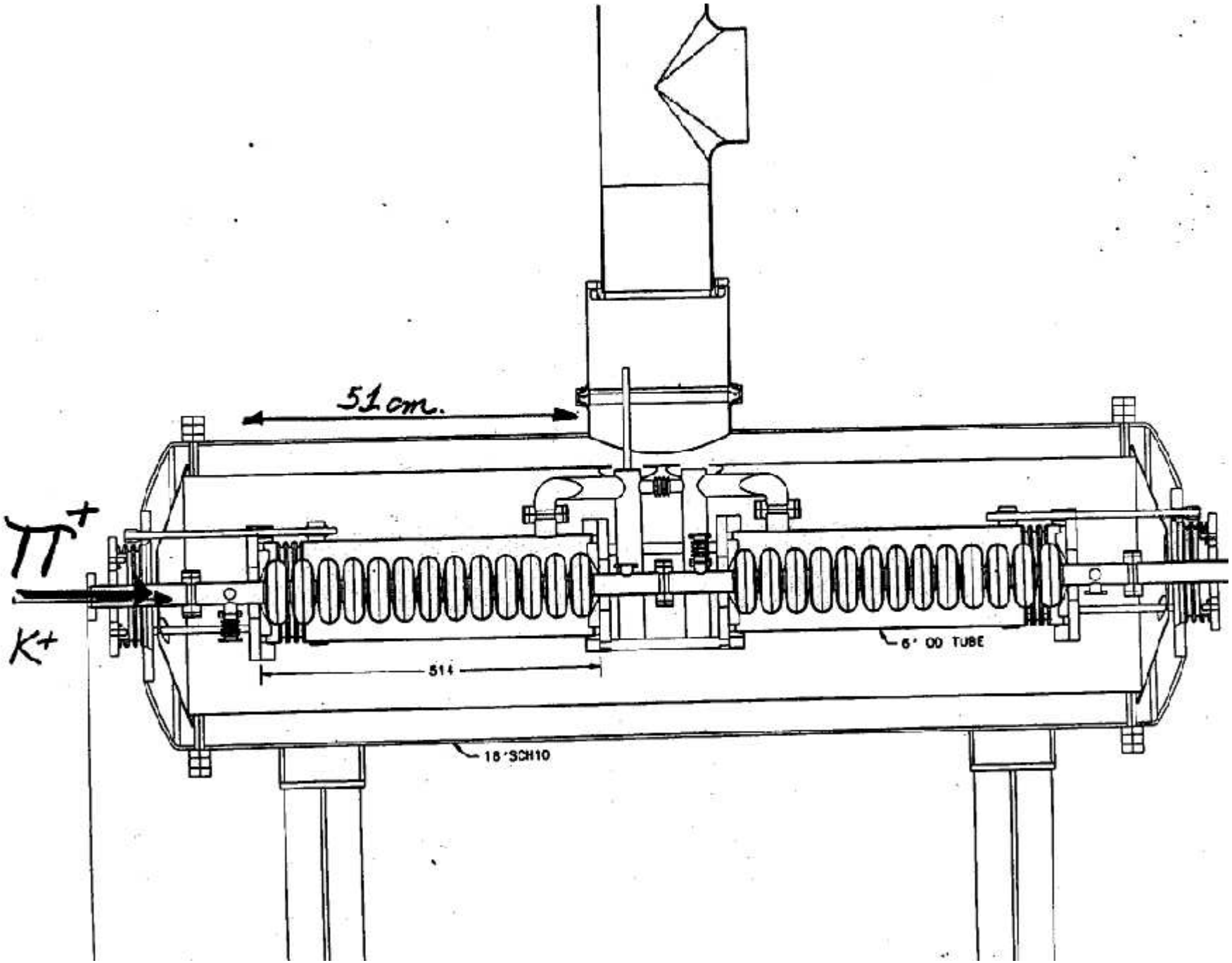
Stop π^+ with beam plug, collect K^+

Recent Progress / Plans

- Bead pull apparatus recommissioned
- RF properties of Aluminum models extensively measured and confirmed with MAFIA
- 5-cell Niobium cavity assembled (tooling, electron-beam welding issues)
- Vertical dewar assembled with RF, cryo instrumentation, known good cavity from Cornell
- 1st cooldown this week with Cornell cavity
- Polarize and tune 5-cell cavity, *perhaps* test it when cold
- Full 13-cell prototype as recommended by Tigner review panel
  - Mechanical, cryogenic and electrical engineering/design for horizontal cryostat, high-power RF system

Preliminary Parameters

- 3.9 GHz, TM_{110} π mode
  - 15mm iris radius
  - 47mm equator radius
  - 38mm cell length
- 26 cells per meter
- 5 MeV/c per meter $P_{\perp}$ kick
- E_{peak}= 22MV/m B_{peak}= 0.1T
- Stored energy 0.92 J/m
- Q: 2.2×10^9 (unloaded)
  6.0×10^7 (loaded)


51 cm.
π+
K+
51¼
6" OD TUBE
18" SCH10

Summary of Current Beam Results

	Required	Achieved in Simulation
K rate per 5E12 ppp	30 MHz	40 MHz
Purity (K/all hadrons)	70%	~90%
Beam Divergence	<0.5 mr	0.5 mr
dp/p	+/-2 %	+/- 2%
RF Kick		30 MeV

Immediate Goals:

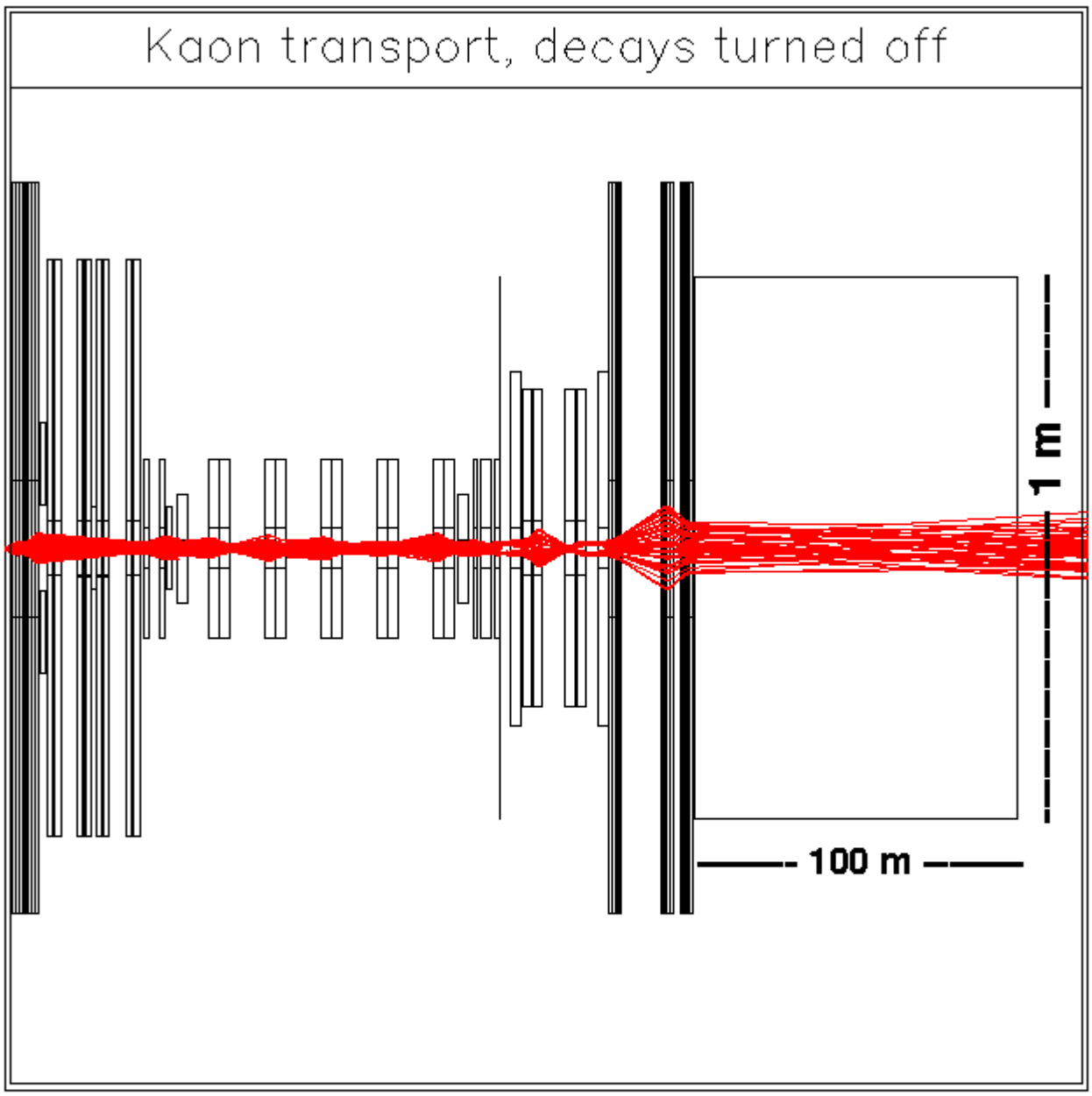
- muon background:
  - optimize clean-up bend
  - investigate shielding requirements
- provide background particles to detector
- target and beam-dump design:
  - investigate energy deposition
  - determine shielding requirements
- study field uniformity and alignment tolerances for magnets and RF cavities

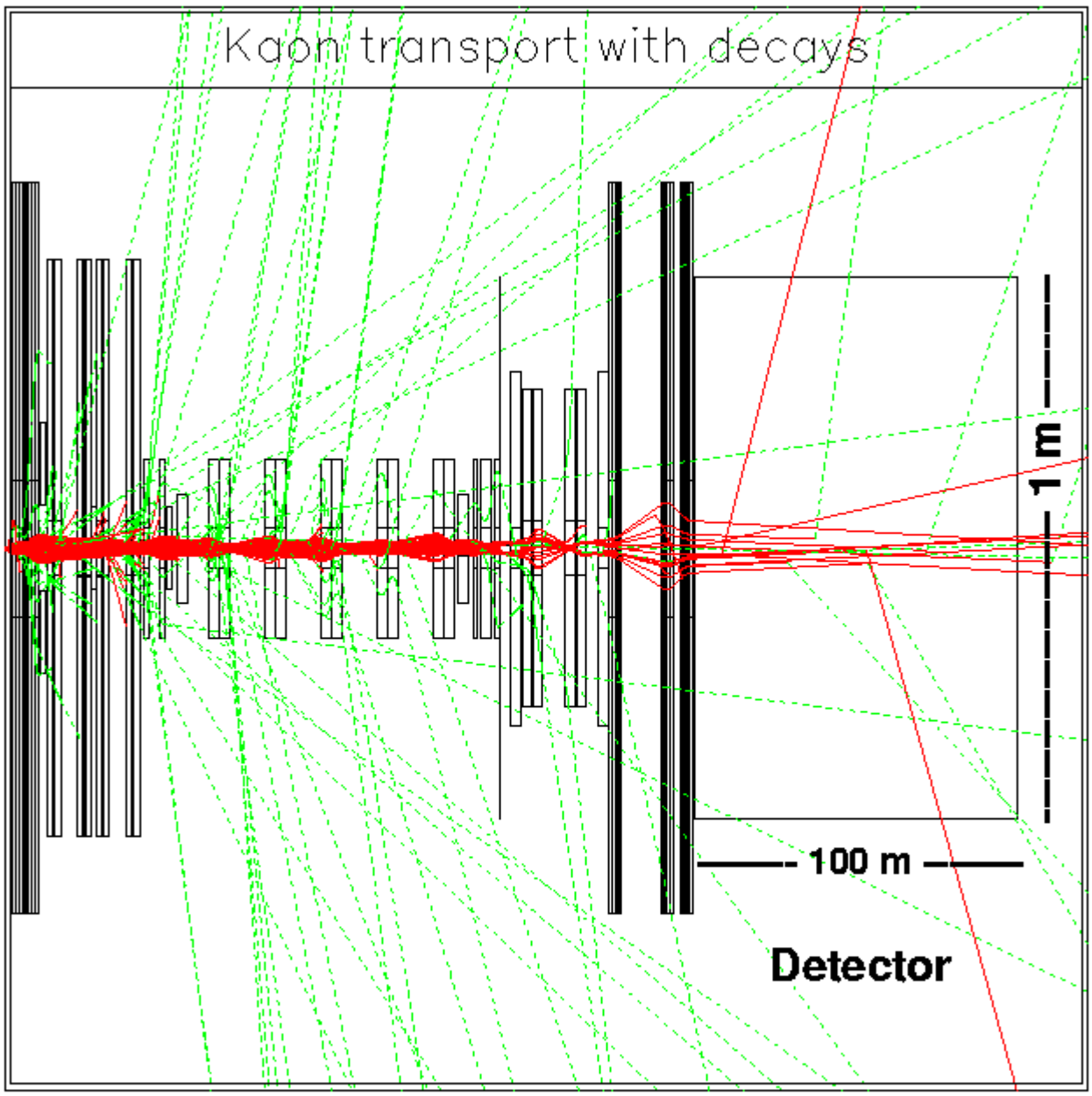
Development of Simulation Tools:

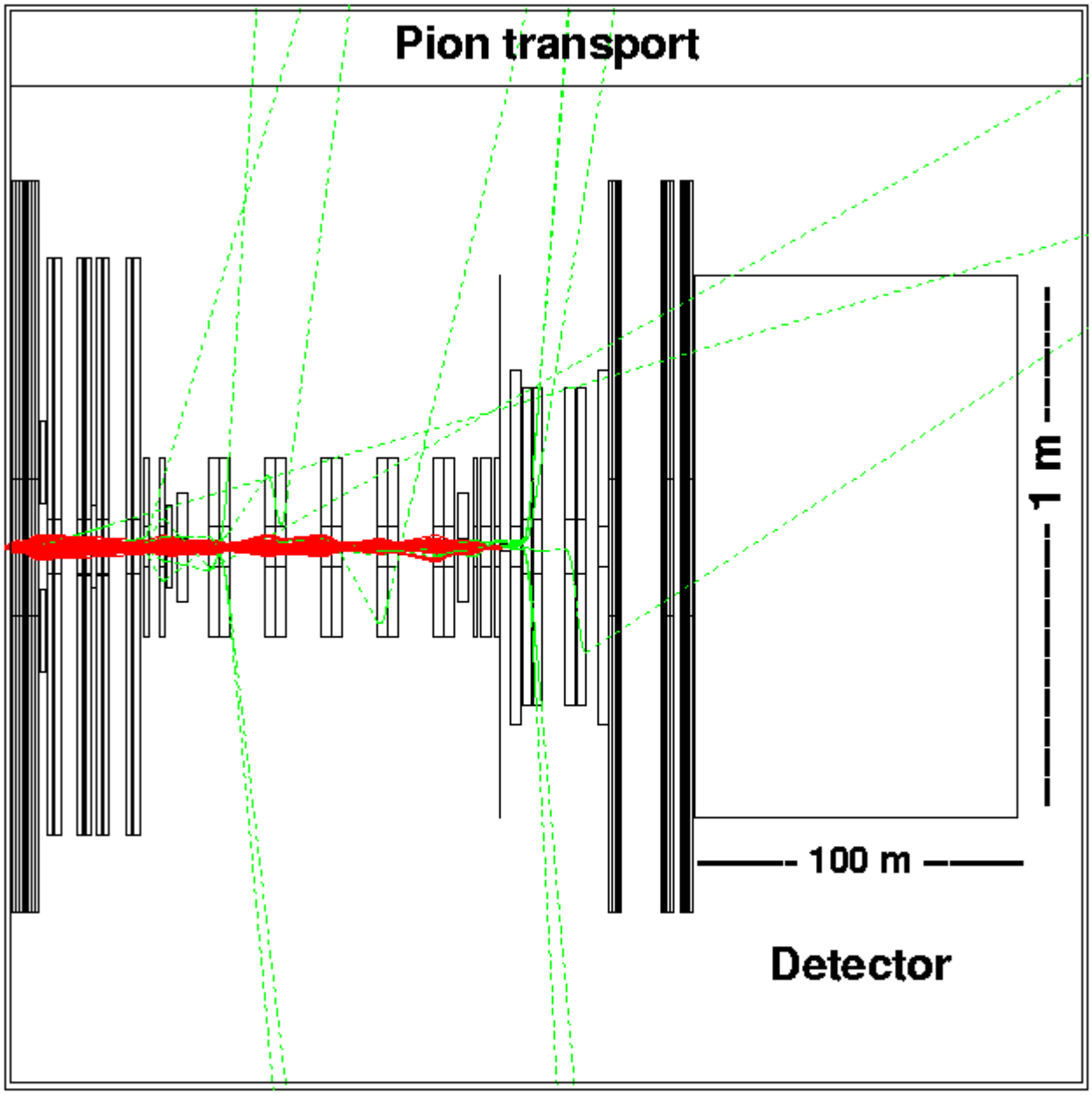
- ray tracing program (TURTLE modified to include RF cavities)
- beam purity and background (GEANT model of beamline)
- hand-off rays to experiment (GEANT)
- radiation shielding (MARS)

Currently:

- good (~1 mm / 100 m) agreement between TURTLE and GEANT
- able to integrate beamline and detector using GEANT
- initial estimate of shielding for target pile using MARS


Kaon transport, decays turned off
1 m
100 m

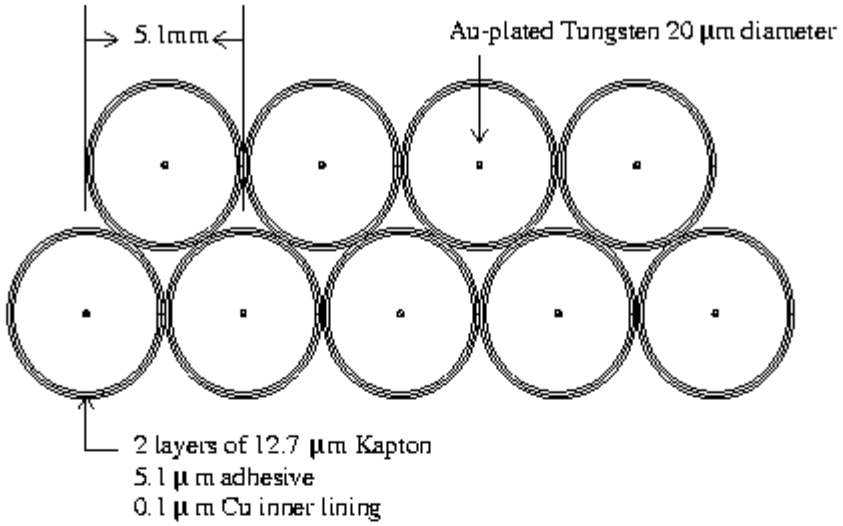

Kaon transport with decays
1 m
100 m
Detector


Pion transport
1 m
100 m
Detector

Beamline Simulation Developments

- At the time of the proposal (April '98):
  - Shared beamline (CKM and CPT).
  - Designed by J. Doornbos (CPT, Triumf).
  - 10 MV/meter
  - 5.8 GHz cavities.
  - 30-60 MeV/c of transverse RF kick.
- Currently:
  - 5 MV/meter.
  - 3.9 GHz cavities.
  - RF design reviewed and blessed by Tigner panel.
  - 30-40 MeV/c of transverse RF kick.
  - Developing in-house expertise.
  - Acheives baseline CKM requirements.

Straw Tracking System



5-8 straw layers per chamber (X,Y,U,V)
4×10^{-4} X_0 per layer
150μm hit resolution per layer
25 nsec charge collection time
Operation in vacuum decay volume

Achievements

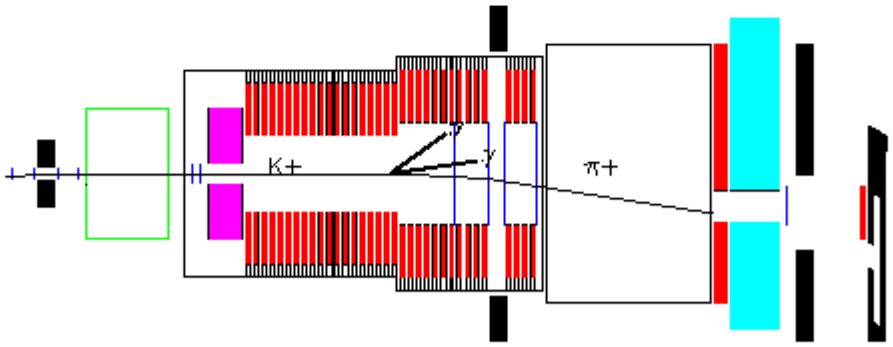
Studied straw mechanical properties at 1-1.5 atm. overpressure
GEANT simulations of scattering in straws
Acquiring an instrumented BNL-871 straw chamber from Brookhaven

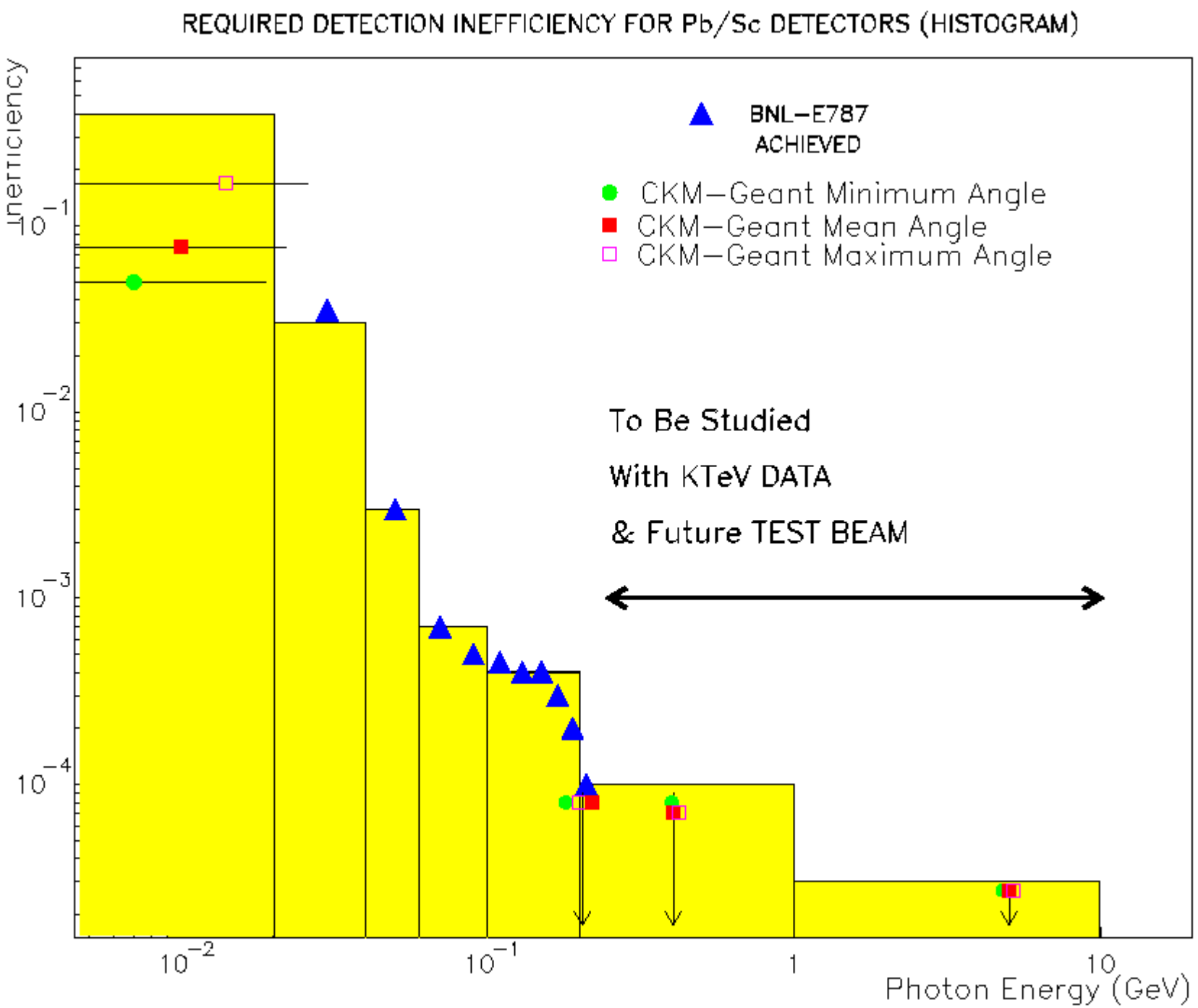
Goals

Commission BNL-871 straw chamber to study signal gains/shapes
Measure leak rate of straws
Mechanical design of frame
Engineered cost estimate

CKM Photon Veto Design Strategy

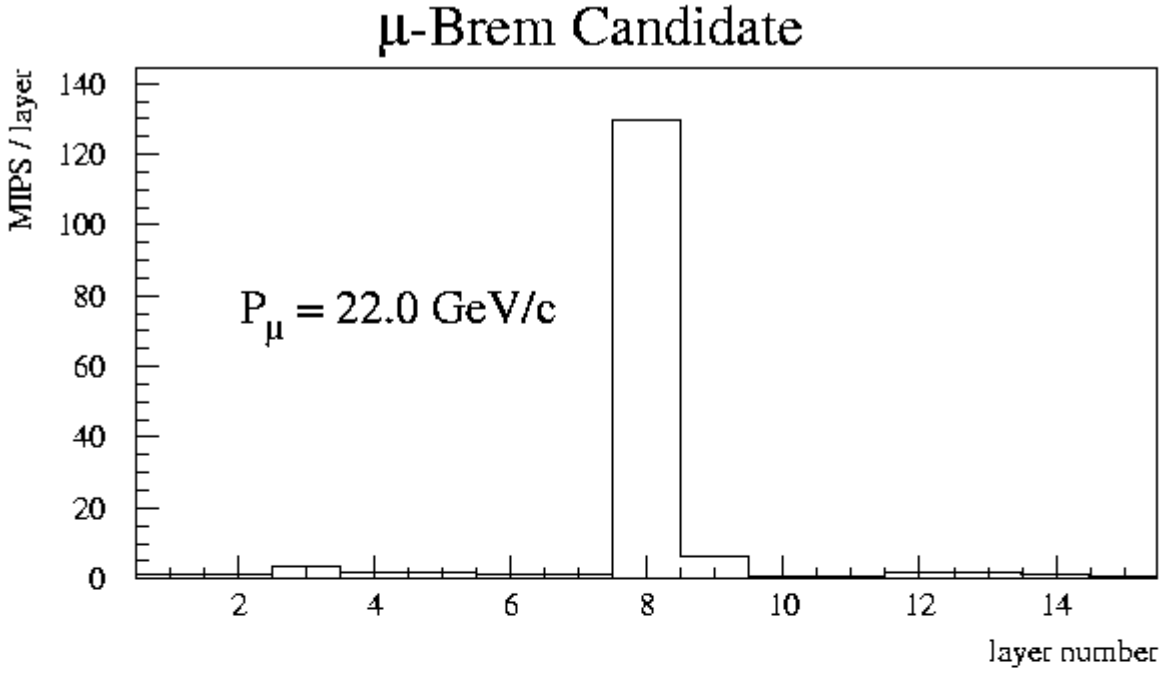
- The design assumes the demonstrated performance of the BNL-E787 (1mm Pb/5mm Scint) system for vetoing low energy (20 MeV-200 MeV) photons.
- Benchmark the high energy performance of the design with studies of electrons (1-10 GeV) on Pb/Scint KTeV veto structures. A special KTeV data set was collected in the '99 Fixed Target run that serves as a laboratory for these studies.
- Base the engineering of the vacuum decay-volume veto system on the proven success of the KTeV vacuum veto system.

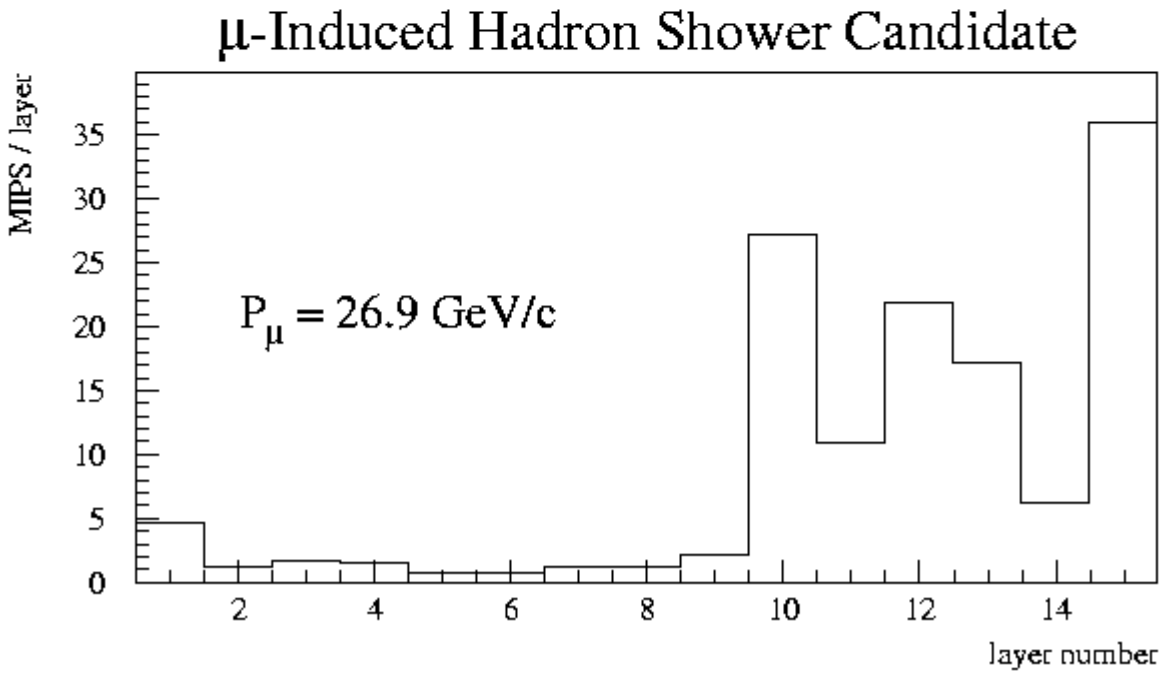



REQUIRED DETECTION INEFFICIENCY FOR Pb/Sc DETECTORS (HISTOGRAM)
Inefficiency
10^{-1}
10^{-2}
10^{-3}
10^{-4}
BNL–E787
ACHIEVED
CKM–Geant Minimum Angle
CKM–Geant Mean Angle
CKM–Geant Maximum Angle
To Be Studied
With KTeV DATA
& Future TEST BEAM
10^{-2}
10^{-1}
1
10
Photon Energy (GeV)

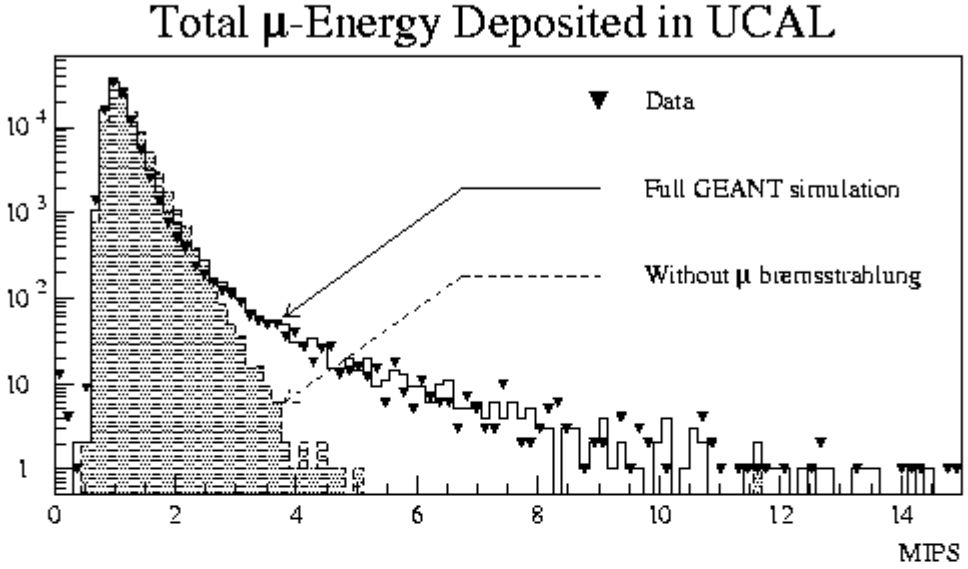
High Stats Study of KAMI Test-beam Muons

- The CKM Muon Veto System must not confuse μ^+'s from $K^+_{\mu 2}$ decays as π^+'s. The required μ/π rejection in the muon system is $\times 100,000$. Is this achievable for $14 - 20$ GeV muons??
- GEANT simulations say yes. Relevant processes that can confuse a high energy μ^+ as a π^+ are:
  - μ-Bremsstrahlung
  - μ-Decay
  - Deep Inelastic Scattering
- Thanks to the support of our KAMI colleagues we are able to test this conjecture. The pure muon source available during the KAMI test-beam together with the hadron beam calorimeter (UCAL) form an excellent laboratory for these studies.


μ-Brem Candidate
MIPS / layer
140
120
100
80
60
40
20
0
P_μ = 22.0 GeV/c
2
4
6
8
10
12
14
layer number


μ-Induced Hadron Shower Candidate
MIPS / layer
35
30
25
20
15
10
5
0
P_μ = 26.9 GeV/c
2
4
6
8
10
12
14
layer number

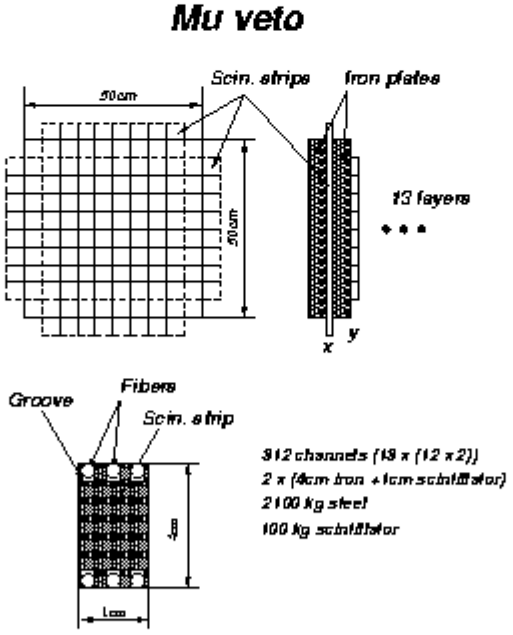
Preliminary Analysis of $10 - 30\ GeV$ Muons.



- Midterm conclusions of this analysis:
  - We have a high statistics sample of CKM-energy muons illuminating a hadron calorimeter similar to that required in CKM.
  - Our GEANT simulations describe the μ-Bremsstrahlung component very well.
  - We are continuing to study a sample of μ-induced hadron showers candidates, that ultimately will limit our abilitly to distinguish μ's from π's.

μ-Veto Beam-test Plans at IHEP(Protvino)

- We are continuing preparations for a full length CKM μ-Veto prototype that will be tested at IHEP(Protvino) later this year with a well controlled test-beam: .
  - A 10-20 GeV/c μ^+ beam with π^+ contamination less than 1×10^{-5}.
  - Measurement of the incident and scattered muon momentum.



RICH – Status April 2000

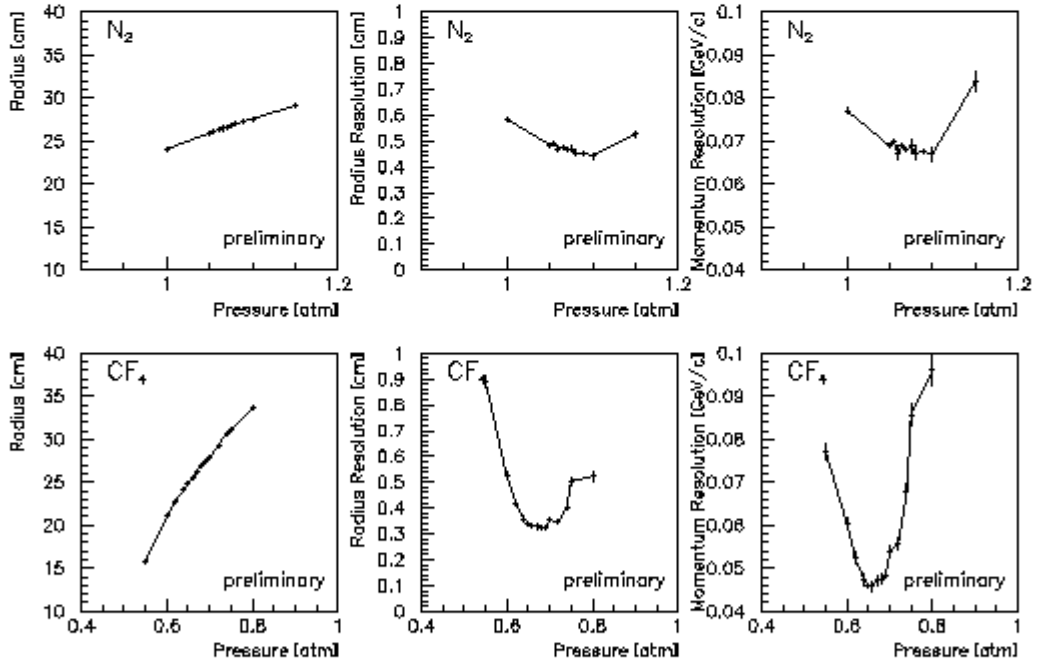
In the last couple of months, we put a full description of both RICH detectors into GEANT, with the goal to simulate the dependence of the momentum resolution as a function of different parameters. For the efficiencies of the photomultipliers, the reflectivity of the mirrors, and the transmission of (quartz-)windows we use values measured in the SELEX RICH. At this moment, we assume a perfect surface of the mirrors in the simulations.

The Pion RICH is envisioned to be a copy of the SELEX RICH, with the only difference being a longer vessel (20 m instead of 10 m), accompanied by a corresponding change in mirror radius to 40 m. We verified (even though we have still to fine tune) that we receive the same number of photons detected and the same resolution as expected from the SELEX RICH, with Neon as radiator gas.

For the Kaon RICH, in the proposal we left the choice of radiator gas open, pending a GEANT simulation. The most obvious choice would be Nitrogen at about 1 atm, with the dis-advantage of having a large chromatic dispersion (dependence of the refractive index as a function of wavelength). CF_4 has a lower dispersion, but is heavier (multiple scattering), but has to be also at lower pressure.

In the figure we show the achieved resolutions at different pressures for both gases. The parameters used in this study are: geometry like in the proposal (vessel length 10 m, double folding the light path with 2 flat mirrors, spherical mirror with 40 m radius, phototubes with 1/2" diameter). All mirrors have realistic reflectivity, but perfect surface. As particle we are using a Kaon with 22 GeV/c momentum, straight down the center of the detector. The difference in resolution of N_2 and CF_4 is due to the different chromatic dispersion.

The resolution at the minimum is in both gases better than 0.5 %, the number given in the proposal, but not all effects affecting resolution are included yet.



In the next few months, we will continue this study: add realistic mirror surfaces, fine tune efficiencies with SELEX data, vary phototube sizes, verify that GEANT is taking into account multiple scattering correctly.

J. Engelfried, A. Morelos, I. Torres, Instituto de Física, Universidad Autónoma de San Luis Potosí

What We Need From the Laboratory

- First off, thanks for the encouragement and support received to date. The growing level of support from the PPD, Beams, and Computing divisions is raising enthusiasm within the lab and the community as a whole.
- But it's not enough...we need significant engineering and technical support to attach a realistic cost estimate to this project. That means:
  - Continued and growing support for development of the SCRF beamline. This is new beamline technology for Fermilab. We *must demonstrate* that we can achieve 5 MV/meter in the RF cavities so that we can can accurately cost these critical elements.
  - Continued and growing support for the development of detector systems so that we can correctly assess what technical risks we face and what the cost drivers are. These concerns are particularly relevant for the Photon Veto Systems and the Vacuum Straw Tracker. These are fun projects, and the technical staff is eager to become involved.

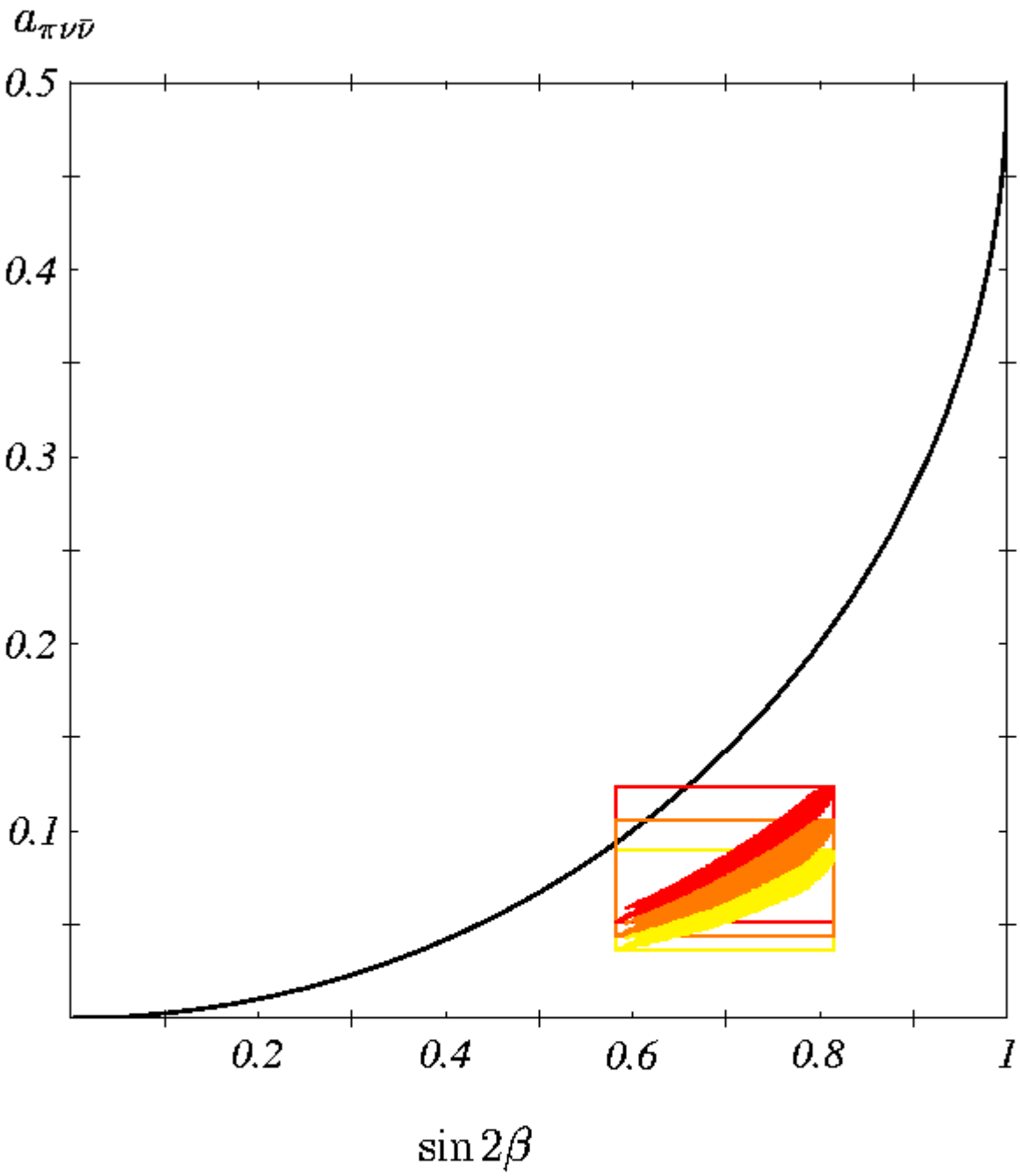


FIG. 3. Relation between $a_{\pi\nu\bar{\nu}}$ and $\sin 2\beta$: The solid curves displays $a_{\pi\nu\bar{\nu}}(\sin 2\beta)$ for $\Delta = 0$. Only in this case there is a one-to-one correspondence between $a_{\pi\nu\bar{\nu}}$ and $\sin 2\beta$. A scan over the presently allowed region for $(\bar{\rho}, \bar{\eta})$ (c.f. Fig. 1) with $\Delta = 0.41$ ($\Delta_{min} = 0.29$, $\Delta_{max} = 0.56$) yields the orange (yellow, red) region in the $\sin 2\beta - a_{\pi\nu\bar{\nu}}$ plane.

Summary

- The physics case for precision measurement of $K \to \pi\nu\bar{\nu}$ continues to grow. Measurement of these rare K decays together with key measurements in the B system can *quantitatively* challenge the Standard Model description of CP violation.

- Taken together BTeV, KAMI, and CKM along with B system results from the collider program form a coherent assault at Fermilab on the sensitivity frontier in flavor physics.

- We are proposing a coherent program to sytematically reach a sensitivity of 1×10^{-12} for $K^+ \to \pi^+\nu\bar{\nu}$ matched to the theoretical uncertainies. We will reach the 1×10^{-11} level at BNL in E949 in the 2001-3 timeframe, to be followed by CKM at Fermilab to reach this goal.

- Continued support is required to successfully complete the CKM R&D project. We expect this to leading to full scientific approval for CKM in a years time.