The CKM Experiment:

Beam and Detector Challenges

- Physics Motivation
- SCRF & Beamline
- Detector Layout
- Detector R&D
- Conclusion

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Research Techniques Seminar
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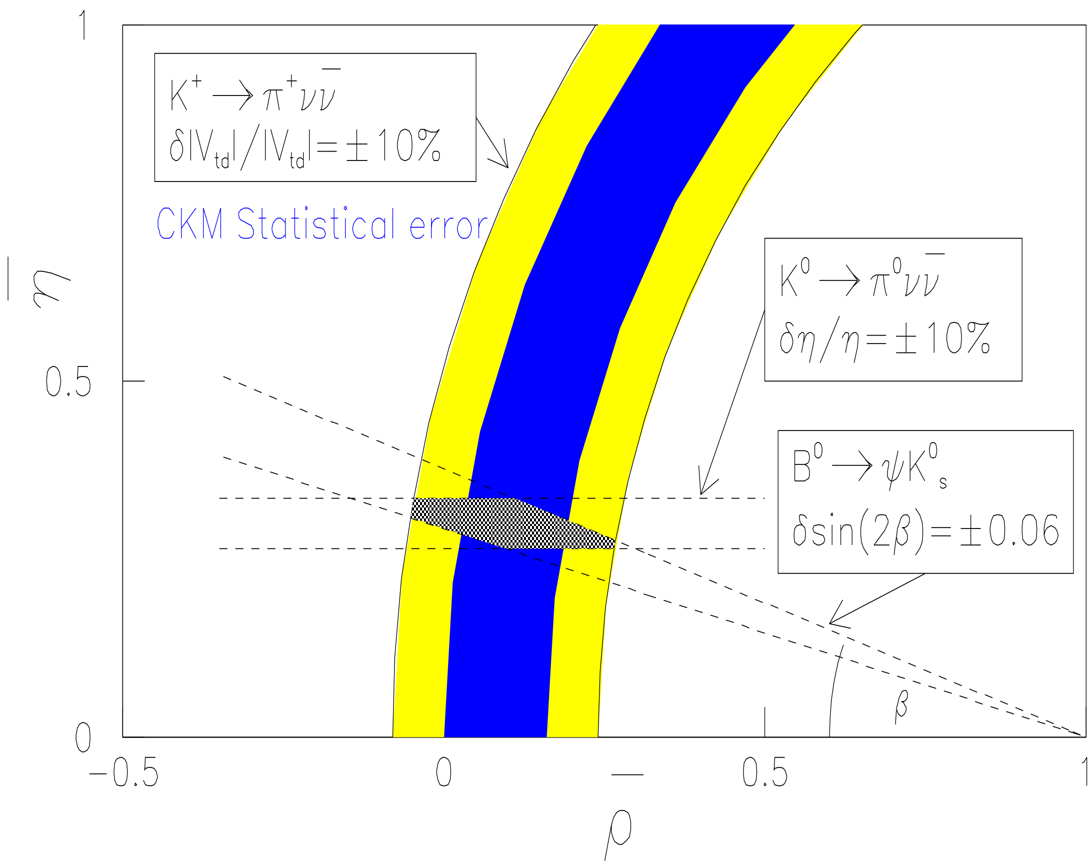
The Unitarity Triangle

Is the CKM matrix the only source of CP violation?



Each constraint on the (ρ,η) plane is a discovery opportunity

$K^+ \to \pi^+ \nu\bar{\nu}$

$$\mathbf{Br}(K^+ \to \pi^+\nu\nu) =$$

(Buchalla & Buras)

$$\kappa_+\{[\,\mathcal{I}(V_{td}V_{ts}^*)\,\mathbf{X}(M_t/M_W)\,]^2$$ *CPV top loops*

$$+[\,\mathcal{R}(V_{td}V_{ts}^*)\,\mathbf{X}(M_t/M_W)$$ *CPC top loops*

$$+\mathcal{R}(V_{cd}V_{cs}^*)\,\mathbf{P}(M_t,\alpha_s(\mu))\,]^2\}$$

Charm contribution; P known to $\pm$5%

$$\kappa_+ = 0.901\,\frac{3\alpha^2\,\mathbf{Br}(K^+\to\pi^0 e^+\nu)}{2\pi^2 \sin^4\theta_W \sin^2\theta_C}$$

Known to $\pm$2.5%

Charm contribution adds ~3% error in Br for any given $\mathcal{I}(V_{td}V_{ts}^*)$

With current V_{CKM} values

$$\mathbf{Br}(K^+ \to \pi^+\nu\bar{\nu}) = (8.2 \pm 3.2)\times 10^{-11}$$

Experimental Status

- BNL E787 reports 1 clean event
  - $Br(K^+ \to \pi^+ \nu \bar{\nu}) = 1.5^{+3.4}_{-1.2} \times 10^{-10}$
- BNL E949 (upgrade of E787) expects to see 5 - 10 events
  - Approved by BNL to run in 2001
- CKM plans to see 100 events
  - Approved for R&D
  - "…the core of a 120GeV fixed-target program"
  - PAC to revisit FT 120 program spring 2001
- BNL / FNAL collaboration

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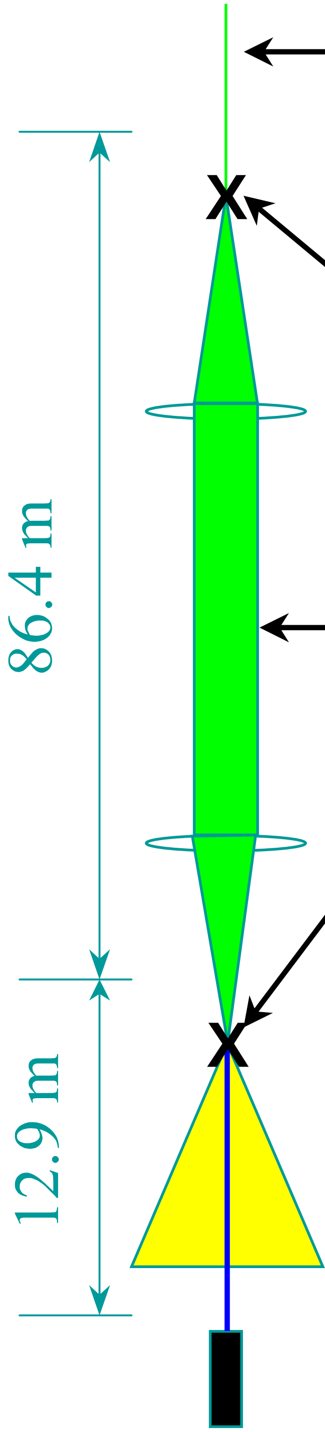
Fermilab

RF separated K^+ beams



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

RF deflection: $A\sin(\omega t)$
A ~ 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^+

2 and 5 cell cavities

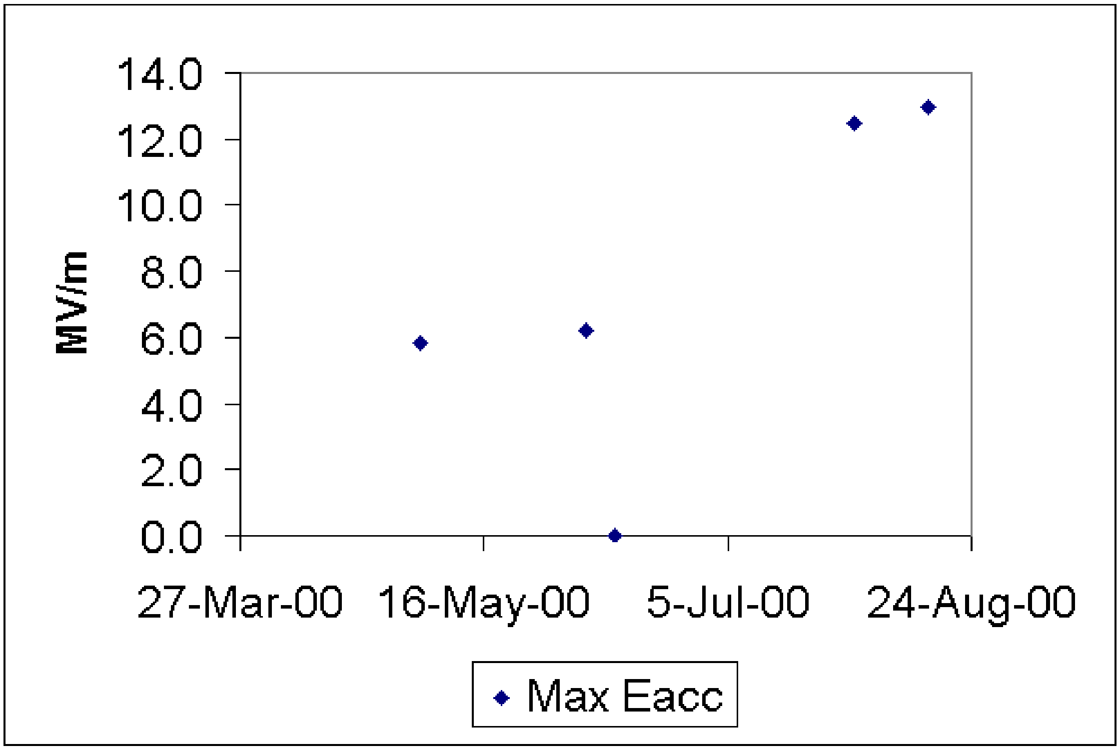
A 2-cell cavity was donated by Cornell to commission our cryogenic test rig

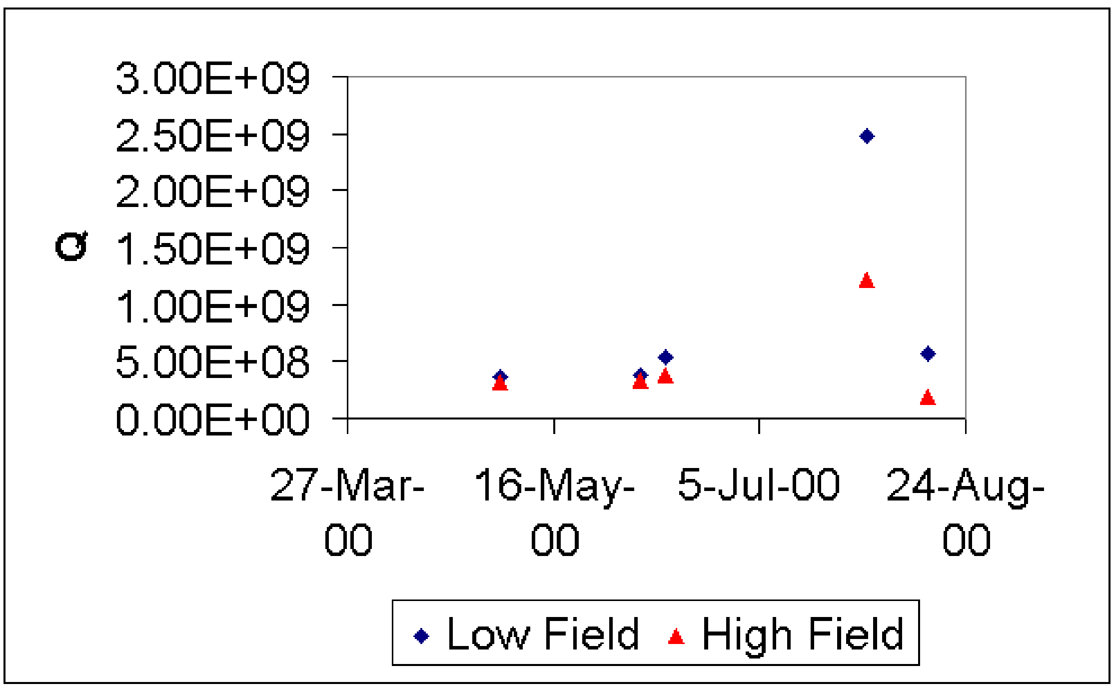
It has since been used for a few studies in surface preparation

A 5-cell reactor-grade Niobium cavity was assembled to study tooling and electron-beam welding issues

It has since proven useful in studying cavity tuning and other RF related issues

2 cell cavity



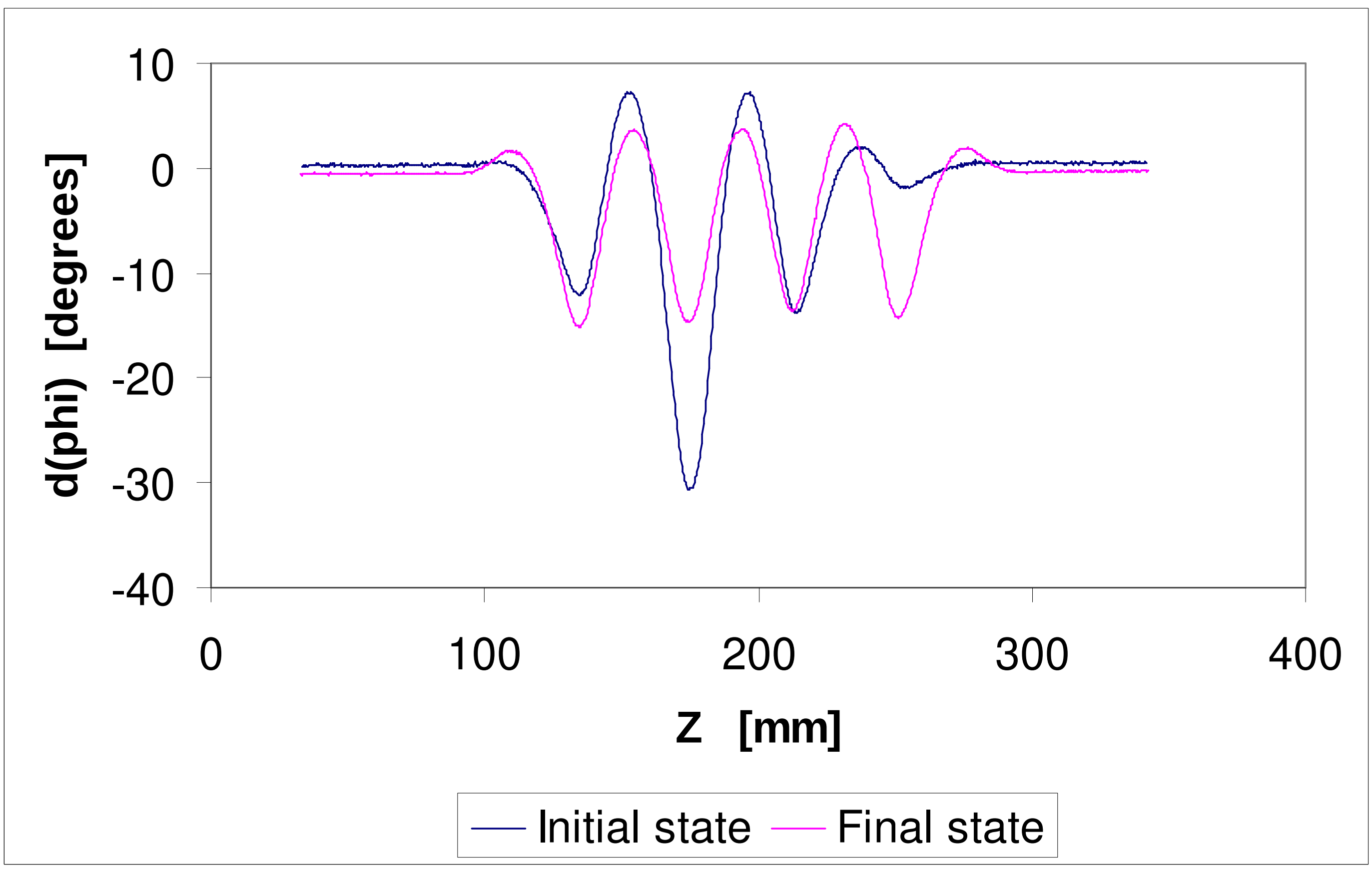


5 cell cavity

Bead pull tests for cell-to-cell uniformity

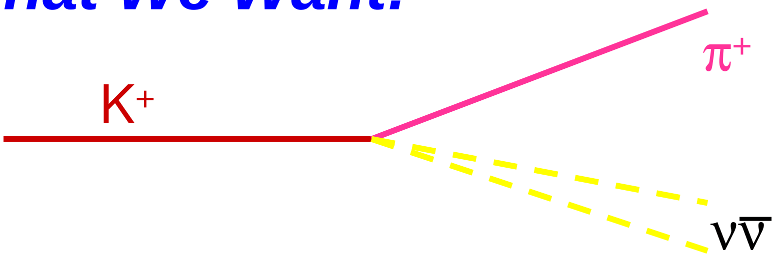
$$\delta f / f = 3/8 \, (\delta v/\mathcal{U}) \, (\mu_0 H^2 - 2\varepsilon_0 E^2)$$

Measure frequency shift due to bead in cavity by measuring phase shift around resonance



Detection

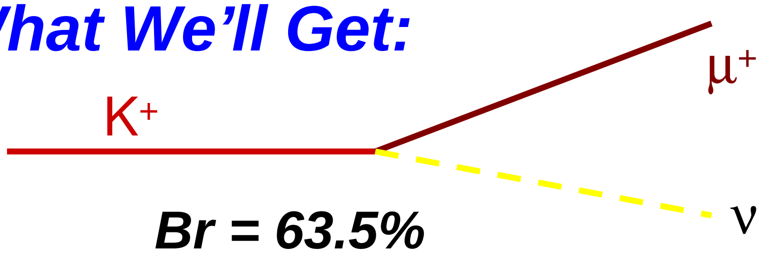
What We Want:



Kinematics

Momentum, direction & position of K^+ and π^+

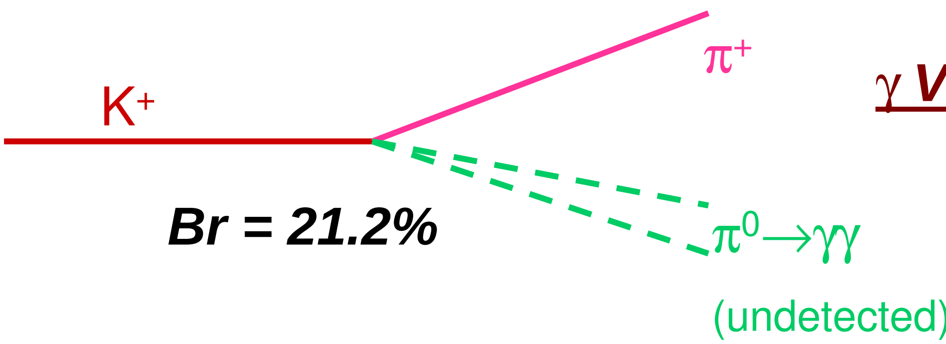
What We'll Get:



μ^+ Veto

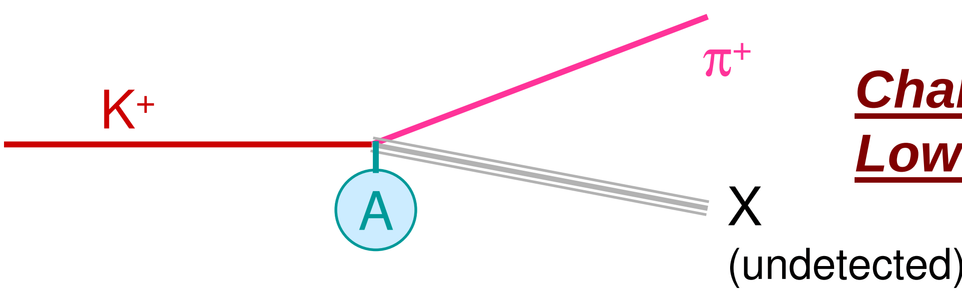
Br = 63.5%

Also $K^+ \rightarrow \mu^+ \nu \gamma$



γ Veto

Br = 21.2%



Charged Veto

Low Material

Upstream Spectrometer and Entrance Tracker

- $\pm$0.5% Momentum resolution
  150μm Position resolution

- Proposal suggested 4 double sided 50μm pitch Si strip detectors

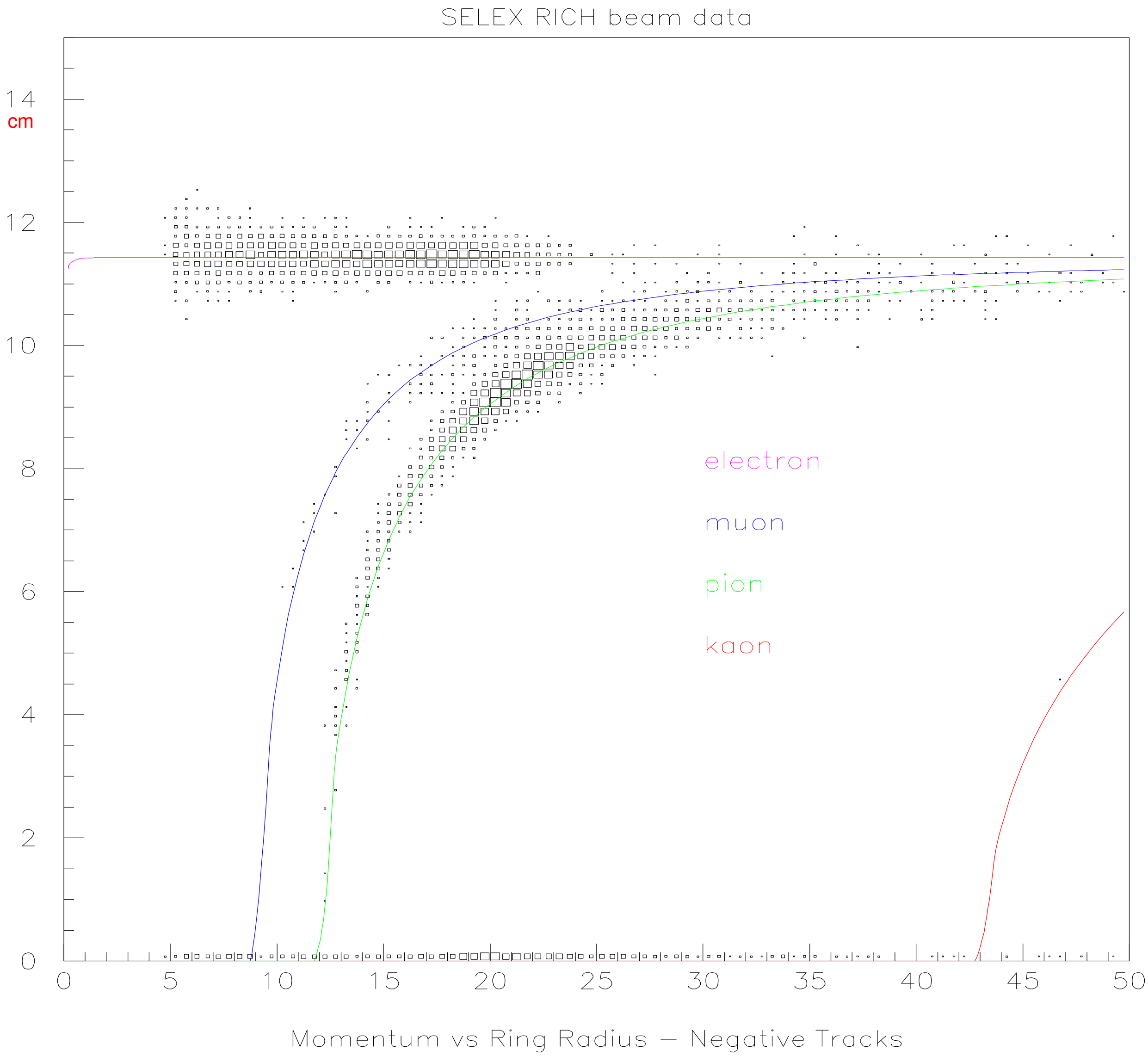
- BTeV pixel detector would reduce tracking ambiguity but introduces 50% more material

- Also looking at high rate PWCs
  a la HyperCP

K^+, π^+ RICHs

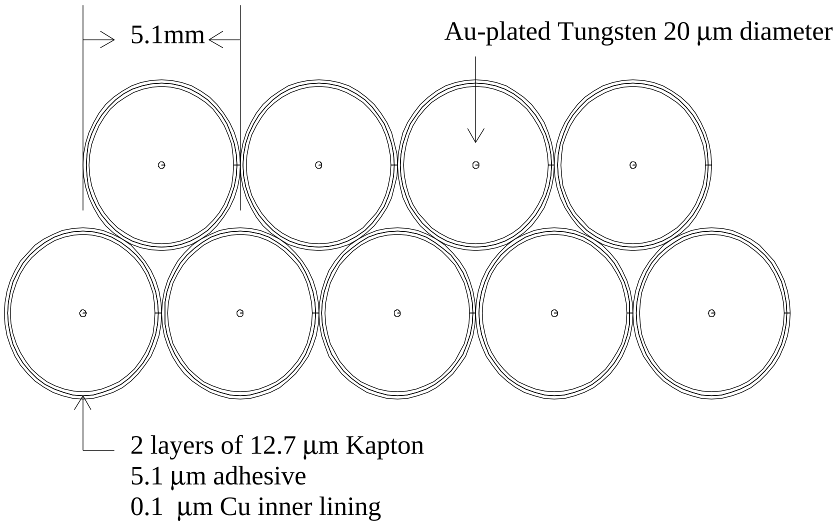
- 22GeV beam gives K^+ velocity resolution to $\pm$0.5%
- K^+ RICH is 10m long CF_4 (or N_2) radiator with ~10 detected photons
- π+ velocity resolution to <2.0%
- π^+ RICH is 20m long Ne radiator with 3000 PMTs
- Challenges include:
  - Need 0_2 contamination at $\mathcal{O}(10^{-6})$
  - Low mass mirrors
  - High rate (~1MHz) photomultiplier tubes
  - Gaussian tails in resolution to 5 orders of magnitude
- Drawing heavily on the SELEX experience

SELEX *RICH*



SELEX RICH beam data
cm
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
electron
muon
pion
kaon
Momentum vs Ring Radius – Negative Tracks

Straw Tracking System



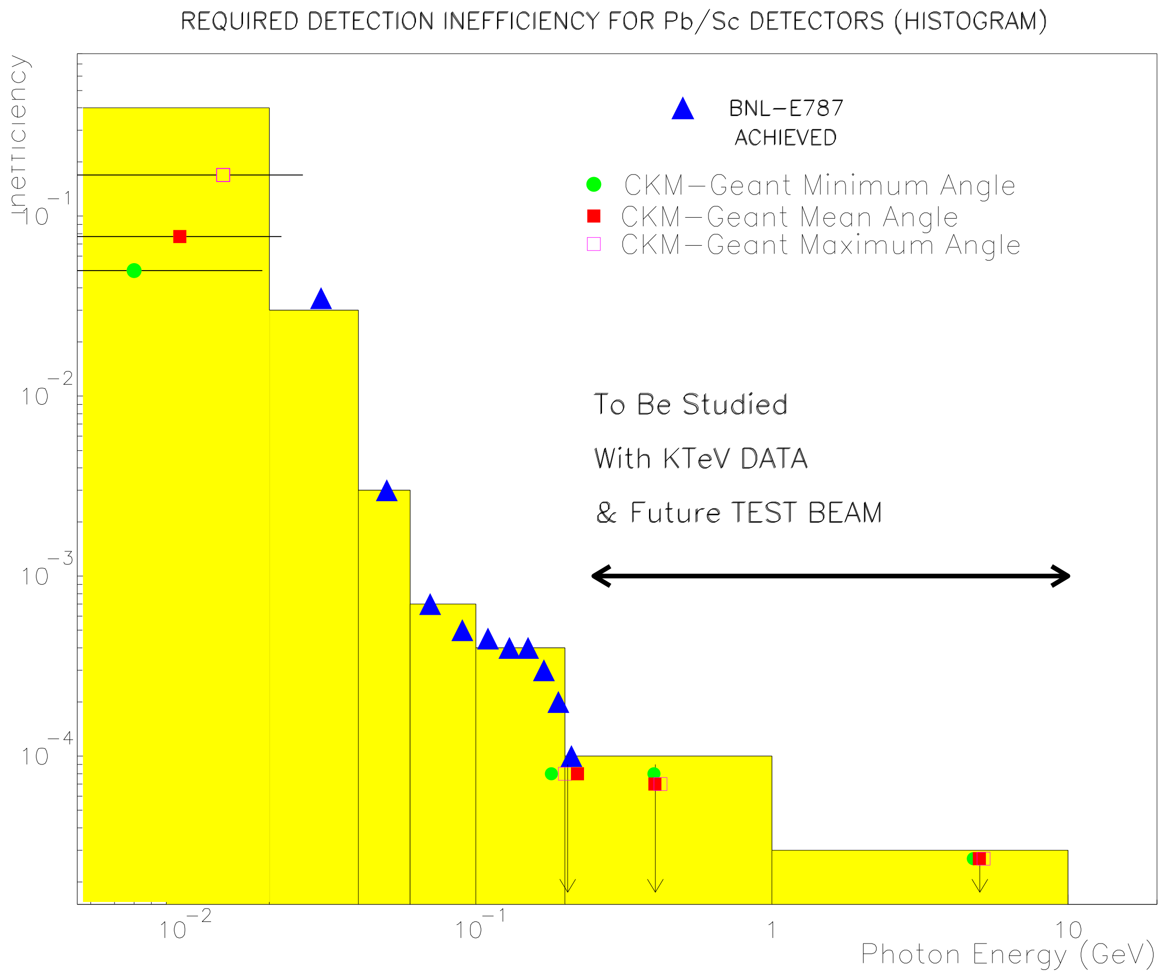
5-8 straw layers per chamber (X,Y,U,V)
4×10^{-4} X_0 per layer
150 µm hit resolution per layer
25 nsec charge collection time
Chamber gain reduced in beam region
Operation in vacuum decay volume

- **Studied mechanical properties at ~1 atm overpressure; now testing under vacuum**
- **GEANT simulations of scattering**
- **Commissioning BNL-871 straw chamber for study of signal gains/shapes.**
- **Measuring leak rate of straws**
- **Need overall design, assembly procedure, cost estimate**

Material for Tracker

Straw tubes, 5-layer	0.0021 X_0
Straw tubes, 8-layer	0.0034 X_0
KTeV Drift Chamber	0.0011 X_0
+ vacuum window, gap	0.0032 X_0
500µm Fibers, 4 layers	0.0057 X_0
835µm Fibers, 4 layers	0.0095 X_0
300µm Silicon	0.0032 X_0
BTeV Silicon Pixel layer	0.0089 X_0

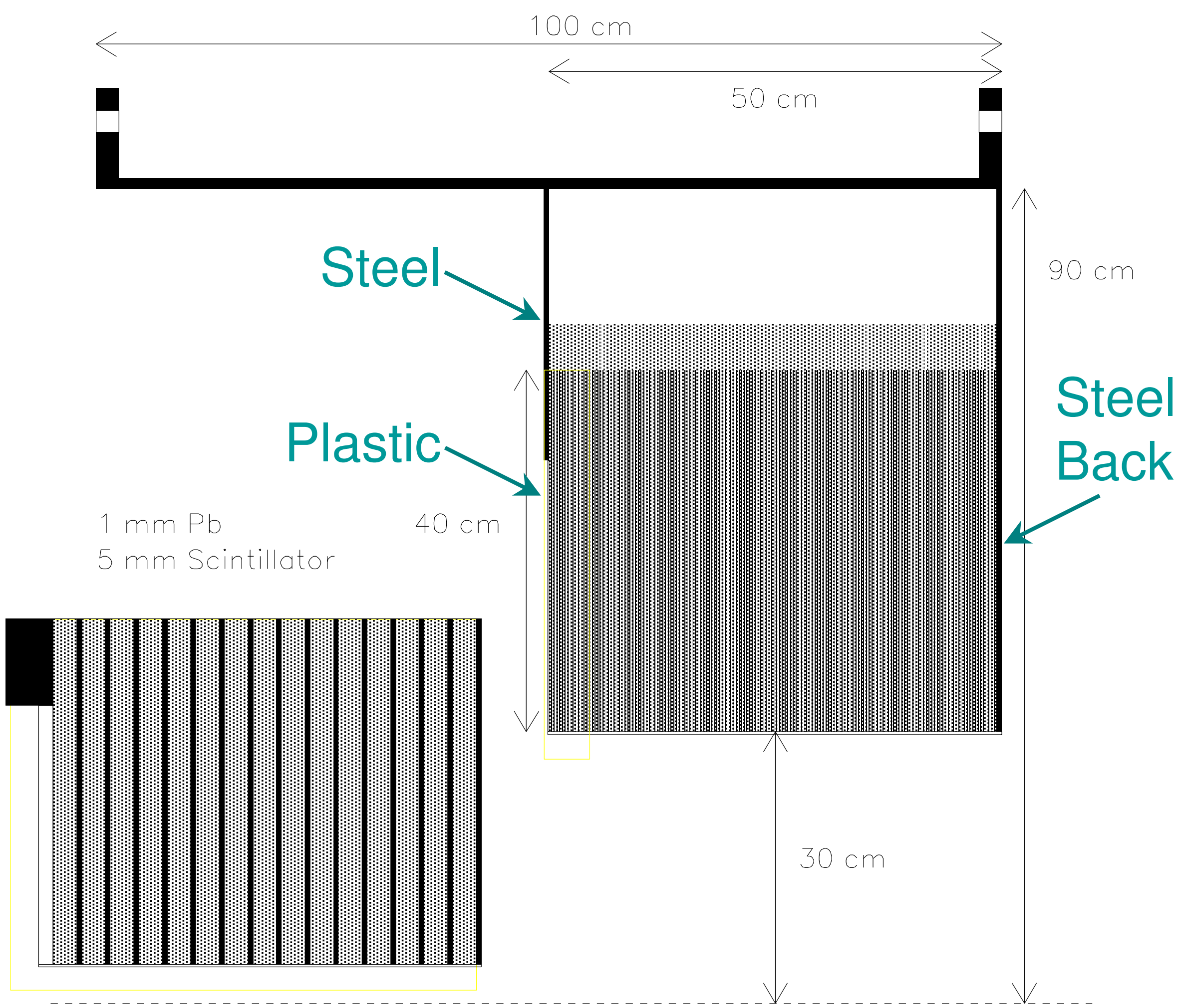
Photon Veto System



Design assumes the demonstrated performance of BNL-E787 system (1mm Pb / 5mm Scintillator) for vetoing low energy (20 - 200 MeV) photons

10x10x50 cm *Prototype now under construction in Lab 6*

Photon Veto System



~4600 lb per module
34 modules total

μ^+ *Veto*

Need to reject 14-20GeV μ^+ from $K^+_{\mu 2}$ decays at $\mathcal{O}(10^{-5})$ level

What could make a μ^+ fake a π^+ ?

- μ^+ **bremsstrahlung**
- $\mu^+ \rightarrow e^+ \nu \bar{\nu}$
- **DIS**

GEANT says we can get to $\mathcal{O}(10^{-5})$ level

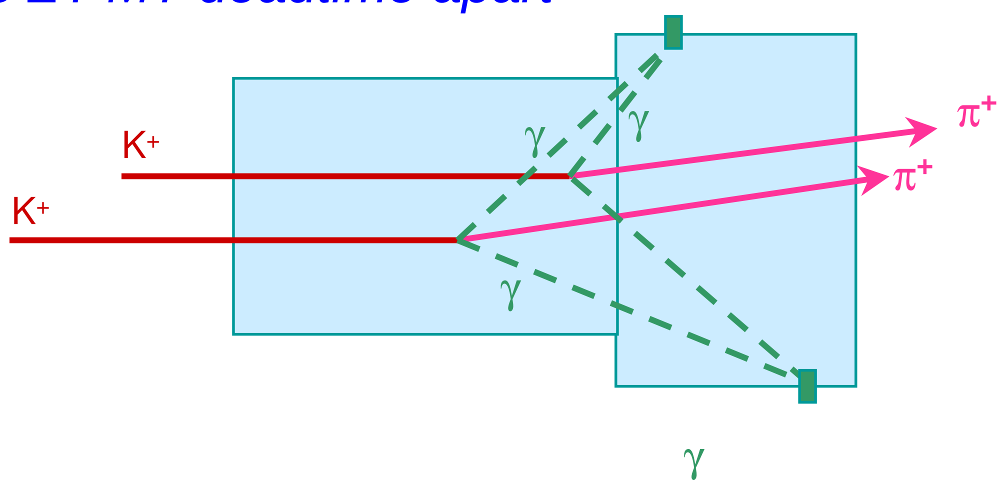
Thanks to KaMI collaboration, have test beam data with 16 layer Uranium / Scintillator

Need test of full-length prototype planned for IHEP(Protvino) with pure μ^+ beam and measurement of both incident and scattered μ^+ momentum

Electronics

- **44MHz debunched beam ⇒ need continuous deadtimeless digitization**
- **TDC every channel, QDC on many**
- **Recent history of activity in detector is important**

Imagine 2 $K^+ \to \pi^+ \pi^0$ events
10ns ≅ PMT deadtime apart

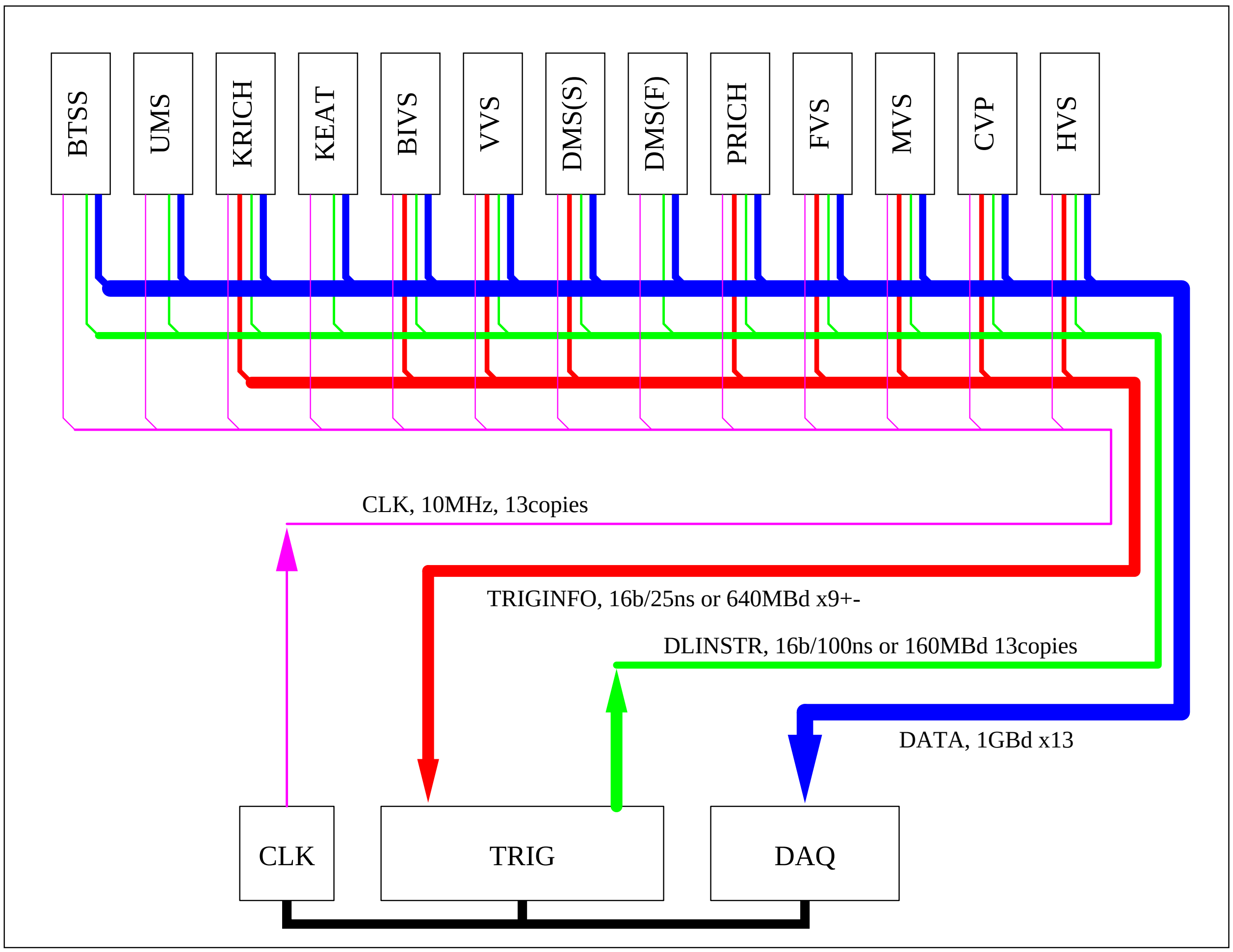


(Branching Ratio)^2 / *(Number of γ veto channels)*^{2}

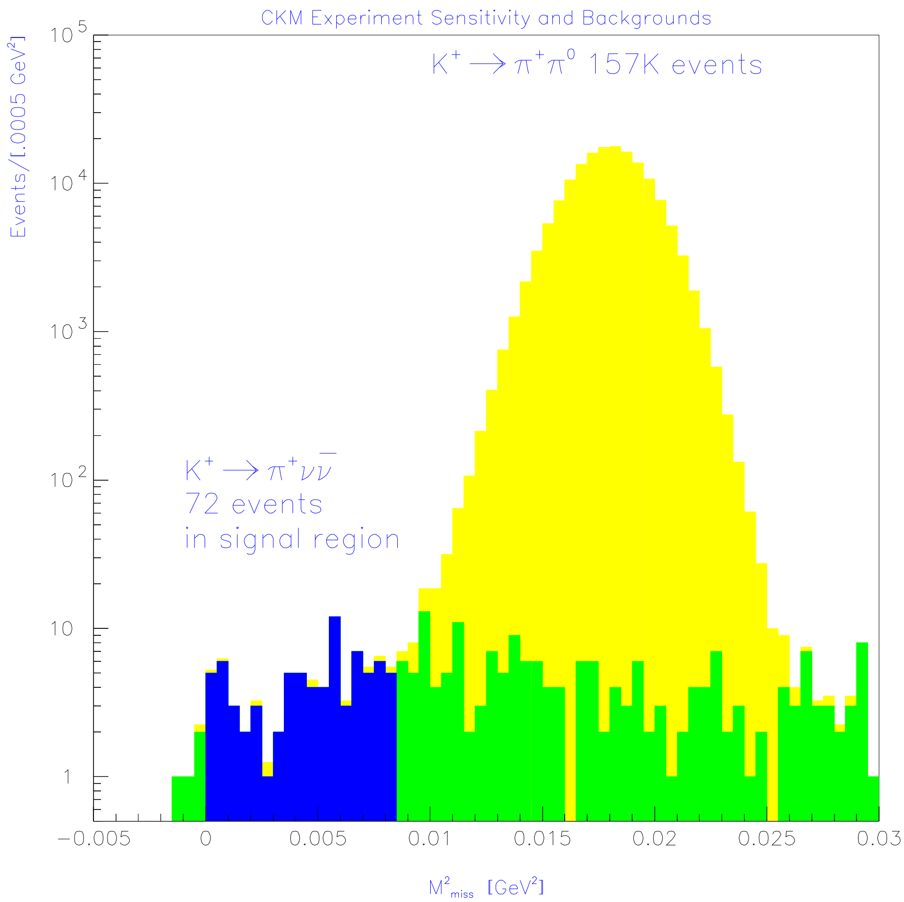
= 2×10^{-8} >> 8×10^{-11} *Br we want to measure*

Electronics Layout

Subdetector – specific modules contain digitization, event history, low level trigger processing



When it all works…



$$M^2_{MISS} = M^2_K(1 - p_\pi/p_K) + m^2_\pi(1 - p_K/p_\pi) - p_\pi p_K \theta^2$$

But a great deal needs to be done to get there…
now recruiting collaborators!

Preliminary Specs

- 3.9 GHz, TM_{110} π mode
  - 15mm iris radius
  - 47mm equator radius
  - 38mm cell length
- 26 cells per meter
- 5 MeV/m $P_{\perp}$ kick; 15 MeV/station
- 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)