The Abdus Salam
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1951-4

Workshop on the original of P, CP and T Violation

2 - 5 July 2008

The Time Reversal Experiment with Kaons (TREK) at J-PARC

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Workshop on the Origins of P, CP and T Violation, ICTP, Trieste, Italy, July 2-5, 2008

The Time Reversal Experiment with Kaons (TREK) at J-PARC

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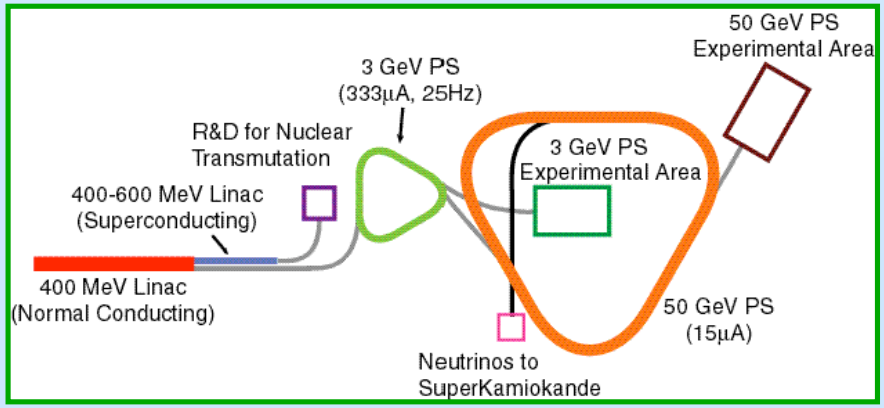
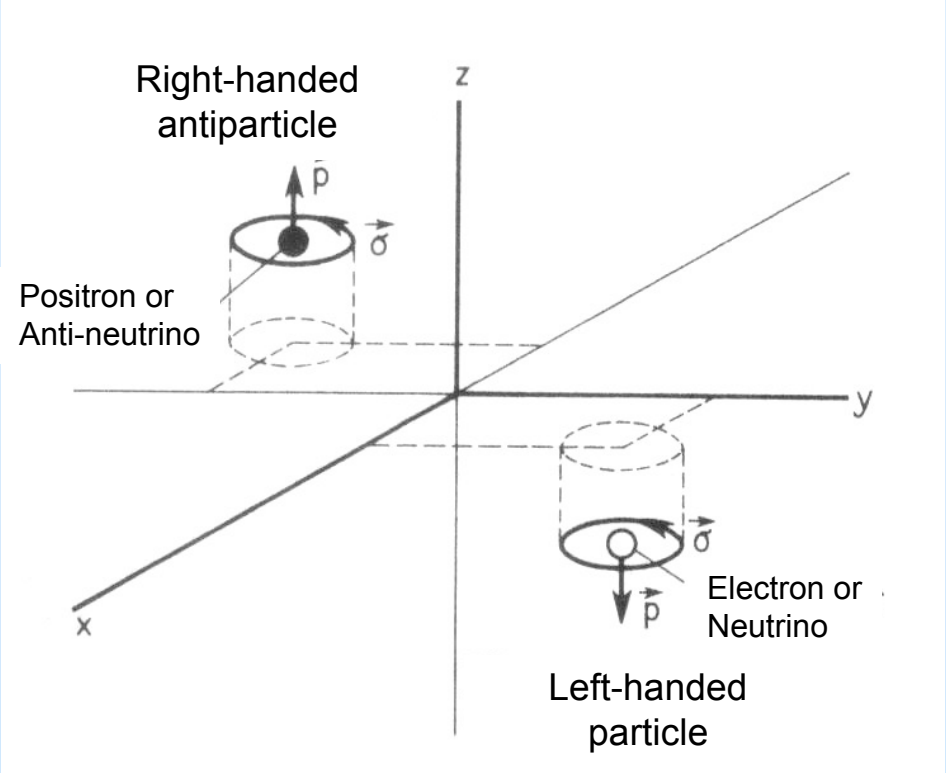


T-violation in stopped-kaon decays

- Introduction: $\not{CP}$, $\not{T}$ (P_T)
- E-246 experiment at KEK
  - Principle of experiment
  - Present detector configuration
- Proposed experiment TREK/E06 at J-PARC
  - Detector upgrade
  - Sensitivity
- Schedule

C, P, and T

Before 1956:
All of nature's laws invariant under
- **C**harge conjugation
- **P**arity
- **T**ime reversal



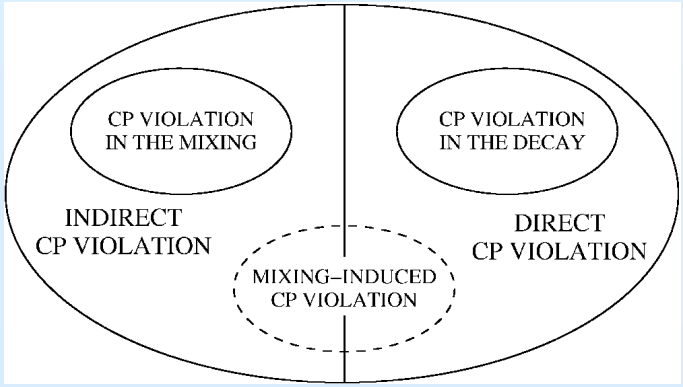
1956
- Parity violated in beta decay
- Combination C+P good symmetry
- T good, CPT good

1964 until today
- Parity violated in weak interaction
- CP violated in neutral K and B weak decays
- CPT good
- All observed CP violation allowed within SM through flavor mixing (CKM)
- Matter/Antimatter asymmetry lacks explanation (Sakharov)

Search for New Physics beyond the SM!

Direct CP violation and New Physics

- Focus on observables with SM≈0



- Electric dipole moments
  suppressed to 3rd order loop in SM
  n-EDM covers same parameter space as ~~CP~~ in neutral mesons (hadronic)

~~T~~ and ~~P~~ $\xrightarrow{CPT}$ ~~CP~~

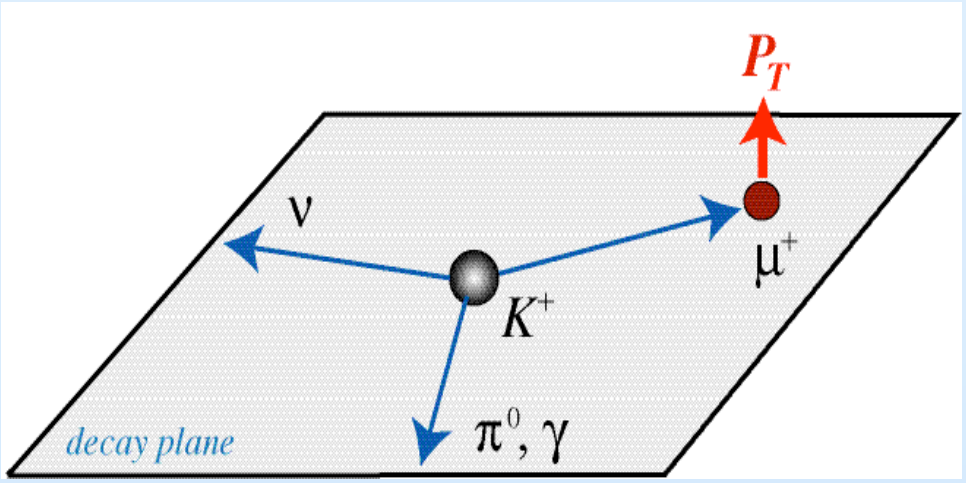
SM: $d_n < 10^{-31}$ ecm
Exp.: $d_n < 3 \cdot 10^{-26}$ ecm
Proposed: $d_n < 9 \cdot 10^{-28}$ ecm

- Charged mesons: Transverse polarization P_T in semileptonic decays
  $K^+ \rightarrow \mu^+\pi^0\nu$ ("$K_{\mu 3}$", BR=3.27%)
  $K^+ \rightarrow \mu^+\gamma\nu$ ("$K_{\mu 2\gamma}$", BR=0.55%)
  J.J. Sakurai PR109 (1958) 980

~~T~~ $\xrightarrow{CPT}$ ~~CP~~

SM: $P_T < 10^{-7}$ (10^{-5})
Exp.: $P_T < 5 \cdot 10^{-3}$ (90%CL)
Proposed: $P_T < 2 \cdot 10^{-4}$ (90%CL)

Transverse muon polarization



- $K^+ \to \pi^0 \mu^+ \nu$ $(K_{\mu 3})$
- Decay at rest
- T-odd correlation

$$P_L = \frac{\vec{\sigma}_\mu \cdot \vec{p}_\mu}{|\vec{p}_\mu|},$$

$$P_N = \frac{\vec{\sigma}_\mu \cdot (\vec{p}_\mu \times (\vec{p}_\pi \times \vec{p}_\mu))}{|\vec{p}_\mu \times (\vec{p}_\pi \times \vec{p}_\mu)|},$$

$$P_T = \frac{\vec{\sigma}_\mu \cdot (\vec{p}_\pi \times \vec{p}_\mu)}{|\vec{p}_\pi \times \vec{p}_\mu|}.$$

$P_T \neq 0 \Rightarrow$ T violation

(CPT theorem) $\Rightarrow$ CP violation

KEK-E246:

P_T = - 0.0017 ± 0.0023(*stat*) ± 0.0011(*sys*)

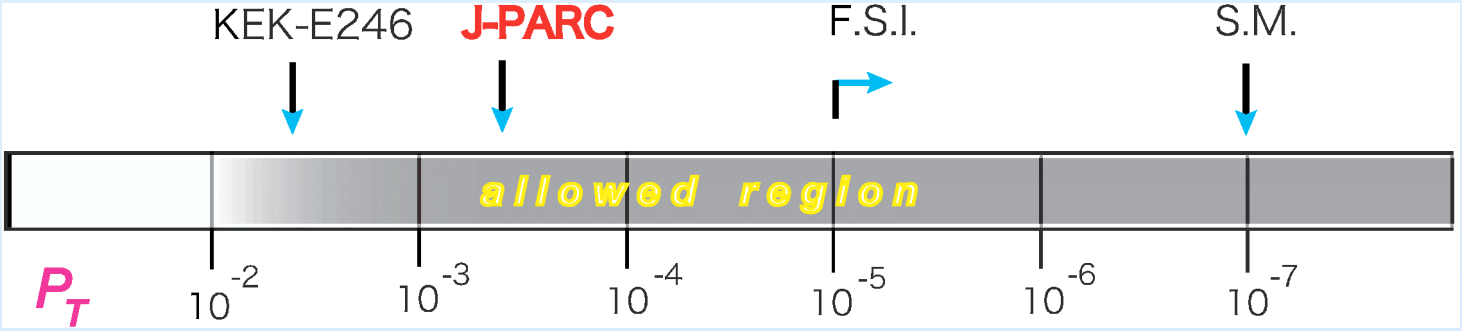
($|P_T|$ < 0.0050 : 90% *C.L.*)

M. Abe et al., PRL83 (1999) 4253

M. Abe et al., PRL93 (2004) 131601

M. Abe et al., PRD72 (2006) 072005

New Physics: Model predictions of P_T



Model	$K^+ \to \pi^0\mu^+\nu$	$K^+ \to \mu^+\nu\gamma$
▪ Standard Model	$<10^{-7}$	$<10^{-7}$
▪ Final State Interactions	$<10^{-5}$	$<10^{-3}$
▪ Multi-Higgs	$\leq 10^{-3}$	$\leq 10^{-3}$
	$P_T(K^+ \to \pi^0\mu^+\nu) \approx 3\, P_T(K^+ \to \mu^+\nu\gamma)$	
▪ SUSY with squarks mixing	$\leq 10^{-3}$	$\leq 10^{-3}$
	$P_T(K^+ \to \pi^0\mu^+\nu) \approx -3\, P_T(K^+ \to \mu^+\nu\gamma)$	
▪ SUSY with *R*-parity breaking	$\leq 4 \times 10^{-4}$	$\leq 3 \times 10^{-4}$
▪ Leptoquark model	$\leq 10^{-2}$	$\leq 5 \times 10^{-3}$
▪ Left-Right symmetric model	0	$< 7 \times 10^{-3}$

New proposal of $P_T(K_{\mu 3})$ at J-PARC

Time Reversal Experiment with Kaons

- **TREK/E06:** Upgrade of E246 setup

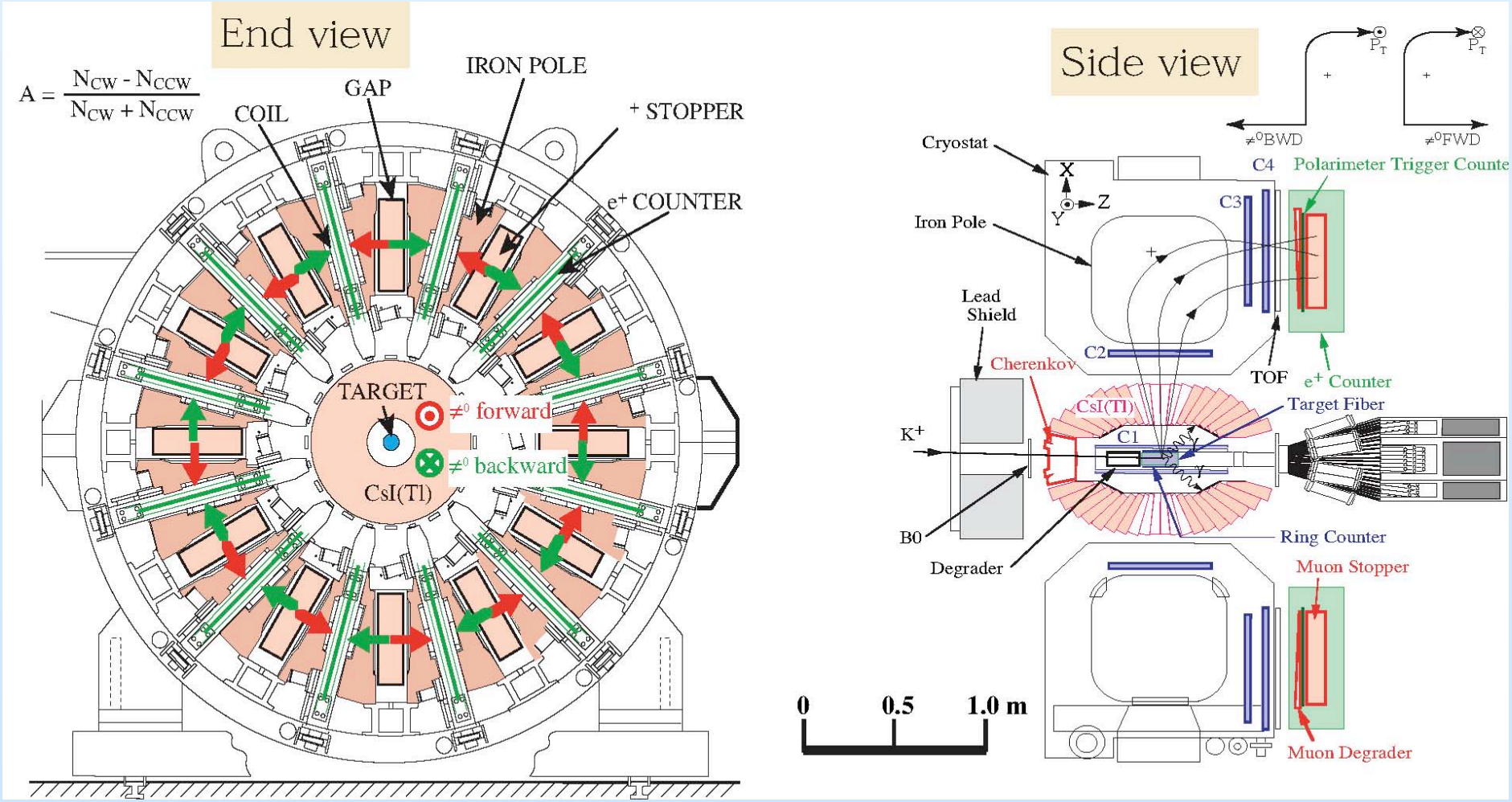
- Reduce systematic errors by factor ~>10
  - alignment with data
  - correction of systematics

  10^{-4}

- Decrease statistical error by factor ~>20
  - 30x higher intensity at J-PARC
  - 10x larger polarimeter acceptance

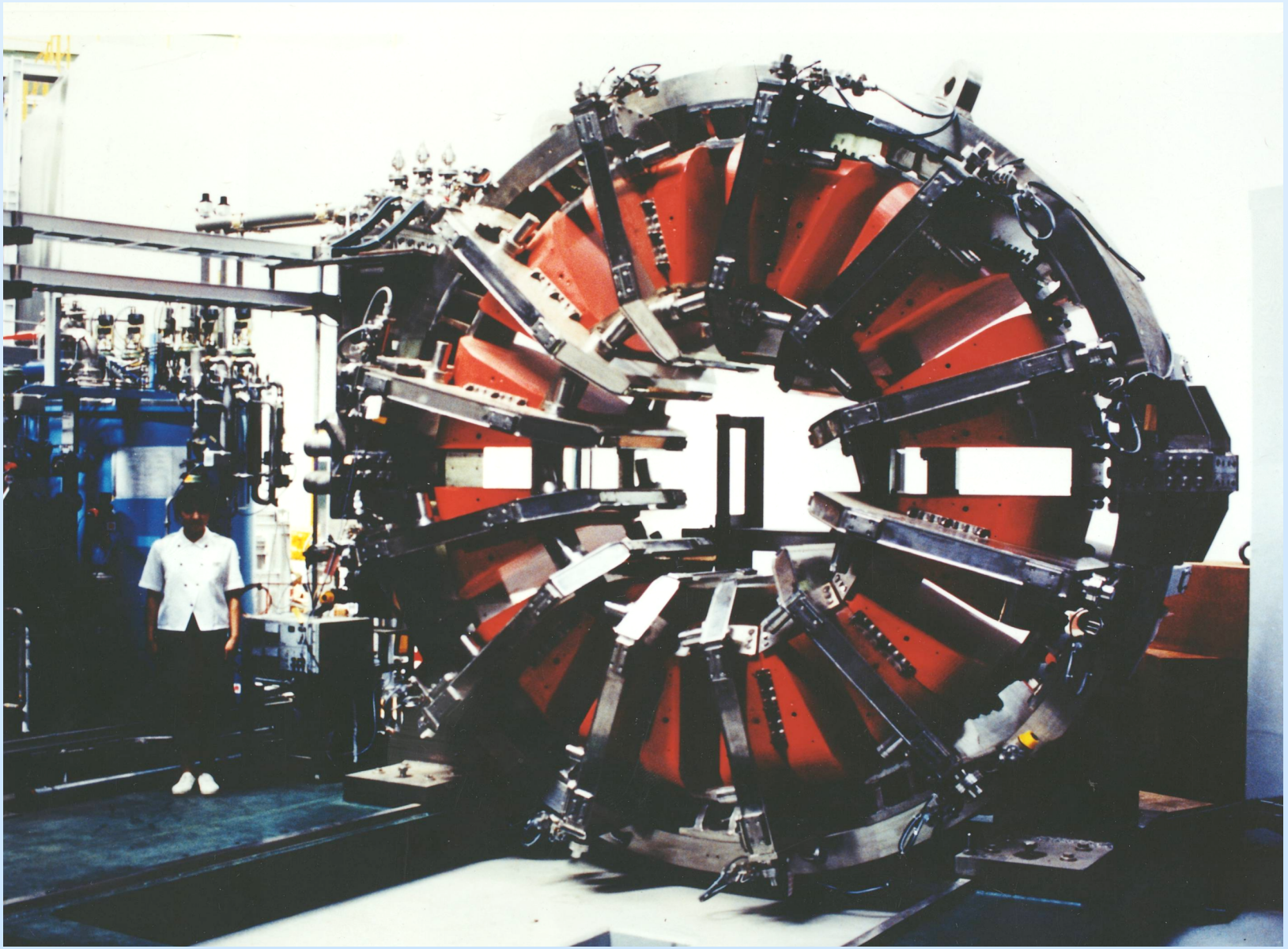
  10^{-4}

KEK-PS E246 experiment: $K^+ \ldots \pi^0 \mu^+ \nu$ ($K_{\mu 3}$)

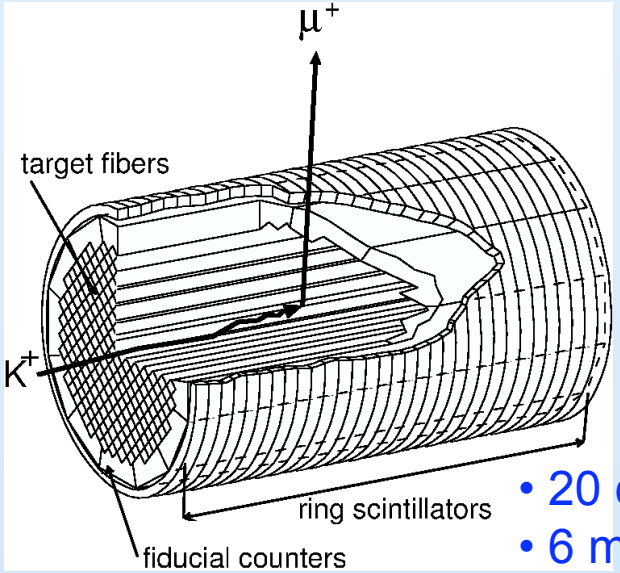


- Stopped K^+ decay at K5
- Superconducting Toroidal Spectrometer

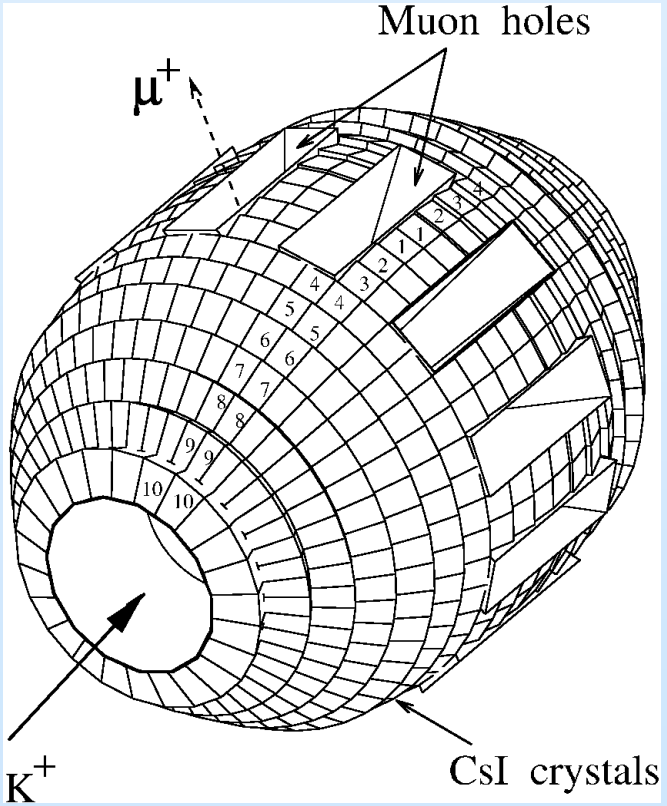
E246: Superconducting toroidal magnet



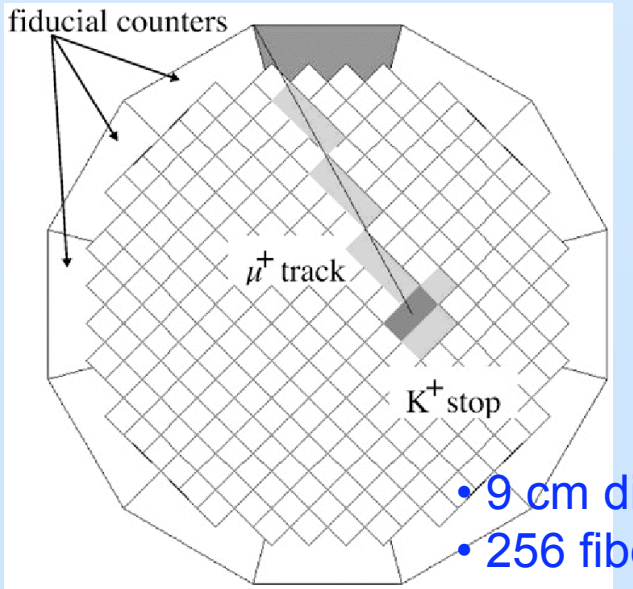
E246: Active target and CsI calorimeter



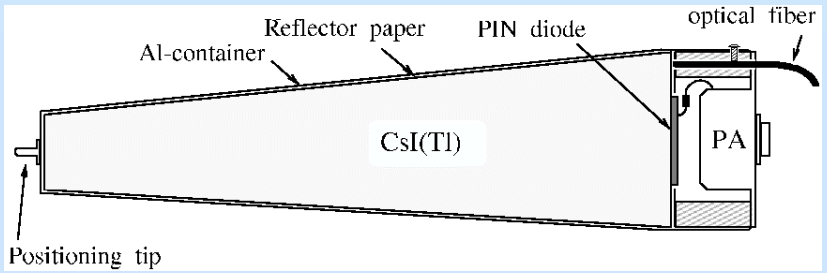
- 768 CsI crystals, 75%4π sr
- 12 muon gaps



- 20 cm active length
- 6 mm ring counters

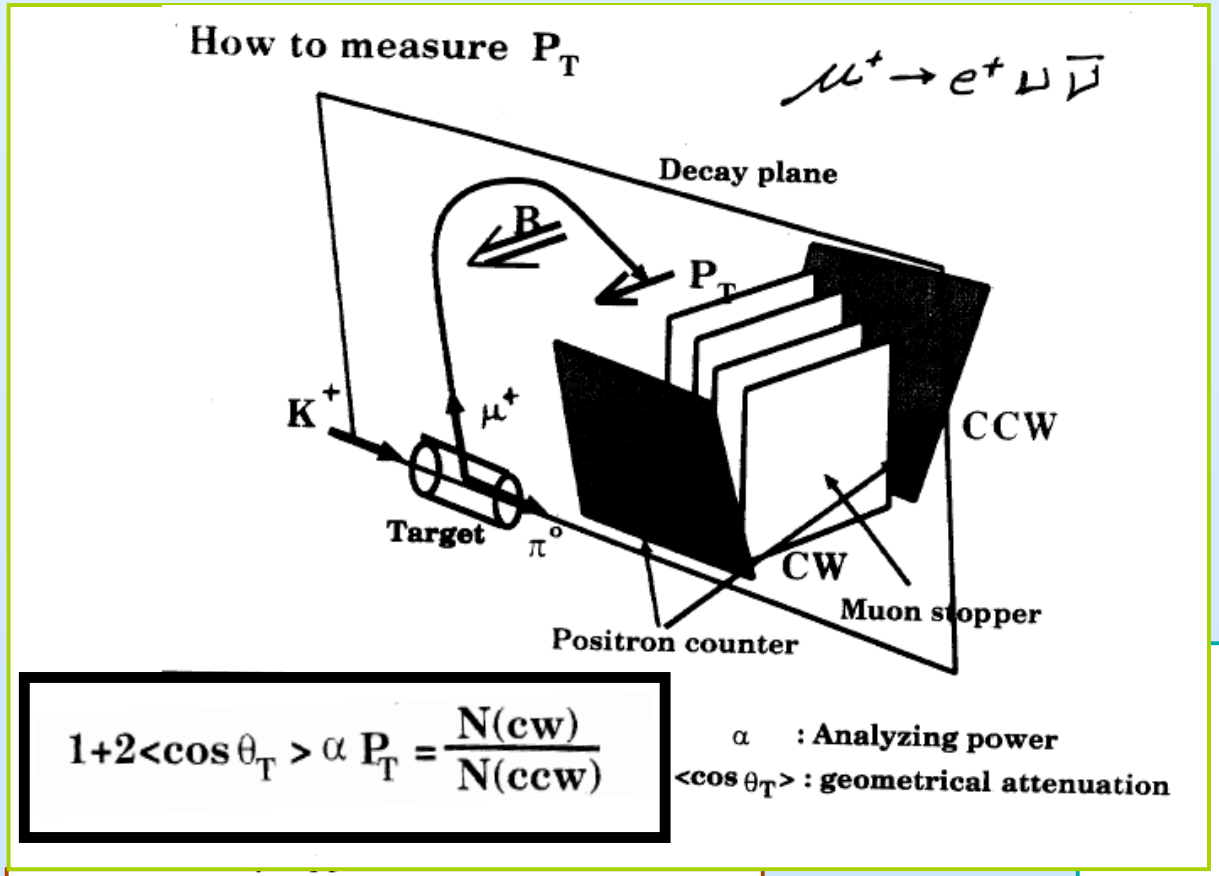


- 25 cm length
- PIN diode readout

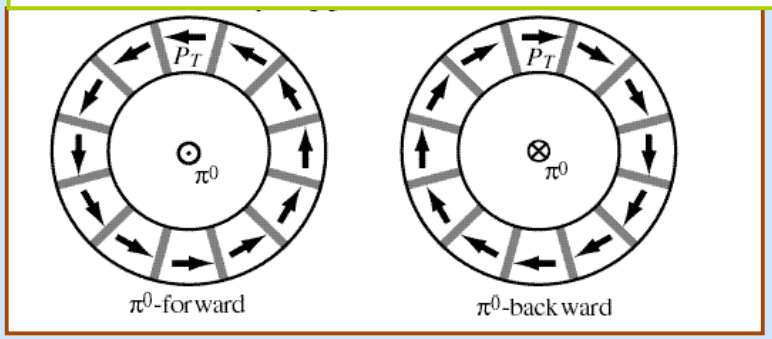


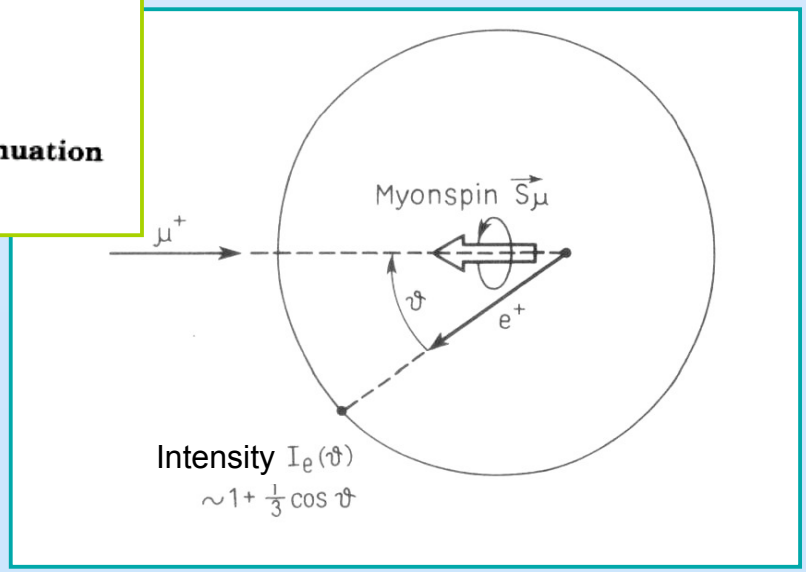
- 9 cm diameter
- 256 fibers 5x5 mm^2

E246: Muon polarimeter



- Muon stopper
- Positron counters
- Toroidal symmetry
- Clockwise/counterclockwise

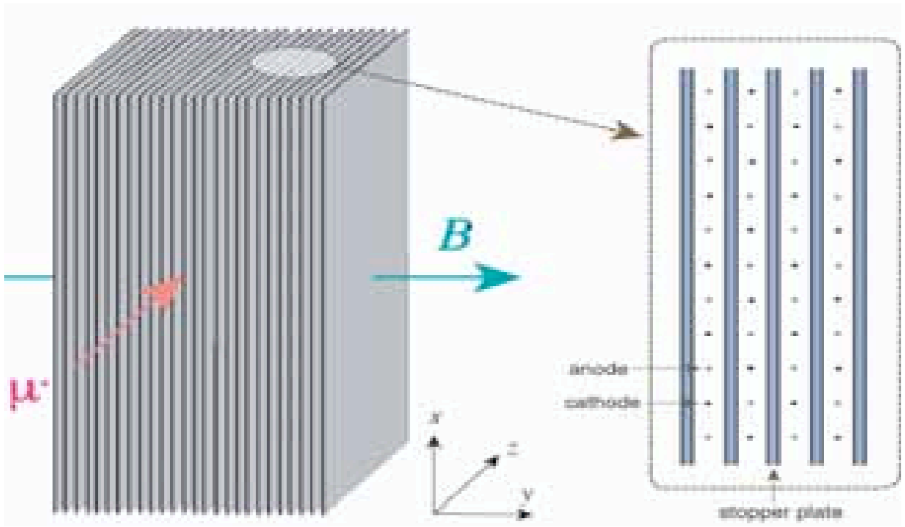


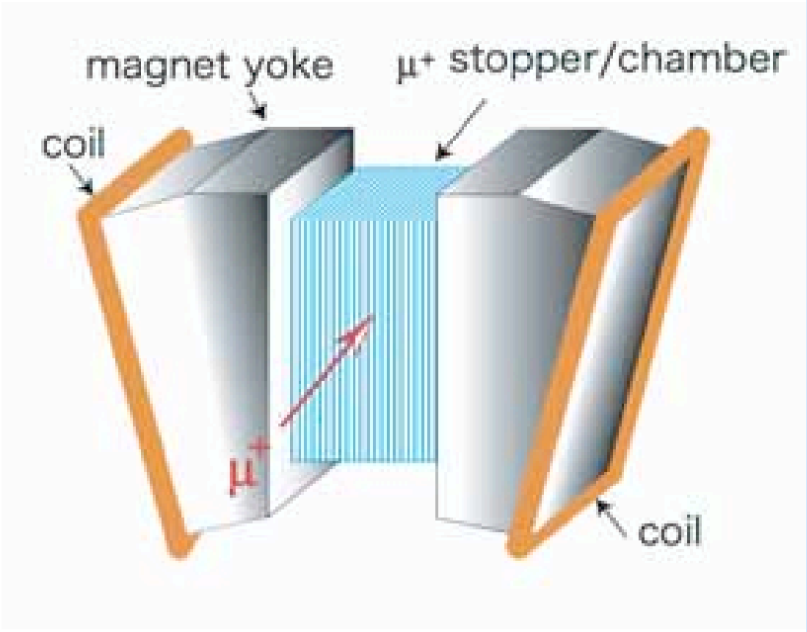


Upgrade proposal

- Charged tracking:
  - Addition of a new element C1 between C2 and TGT/RNG
  - Replacement of previous C1 chamber by cylindrical GEM
  - Finer segmentation of TGT fiber; use of helium bags
    Readout: MPPC (SiPMT) or MA-PMT
- π^0 detection:
  - New, faster readout of CsI(Tl): APD, MAPD
  - Operation of wave form analysis by FADC
- Muon polarimeter :
  - Active polarimeter
  - New magnet with a parallel field

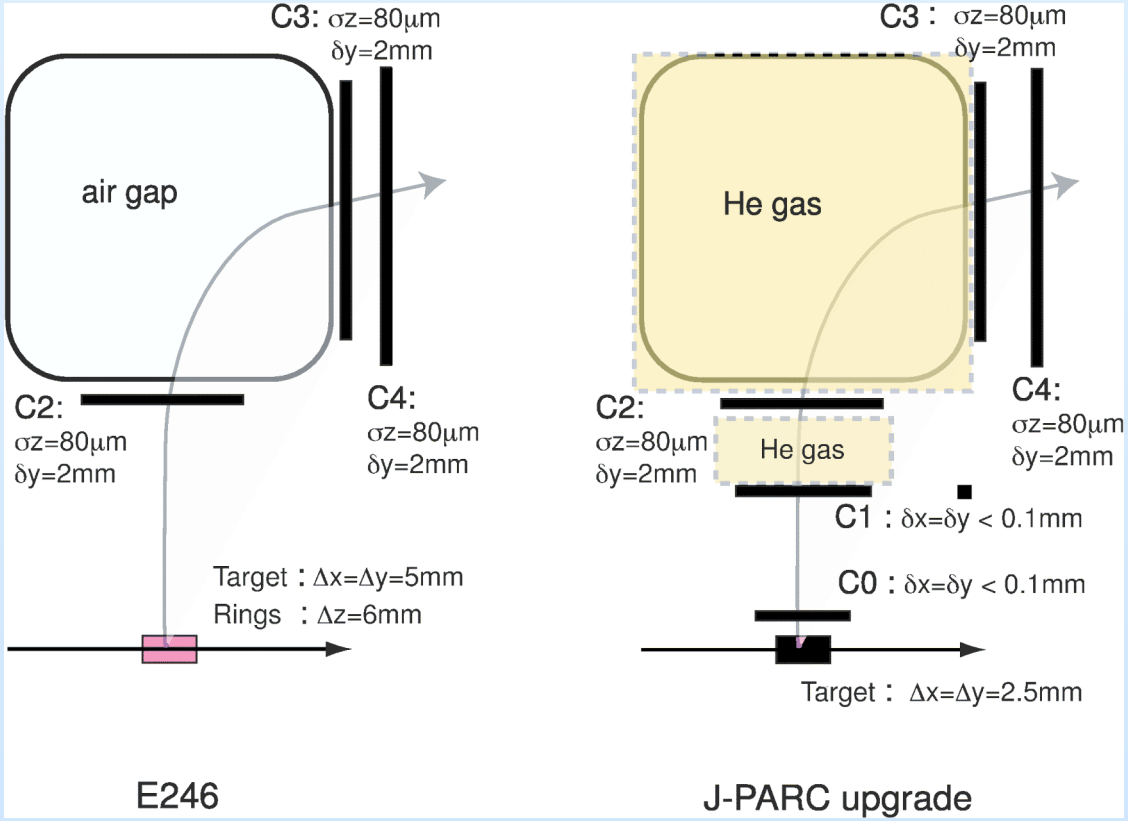
Active Muon Polarimeter



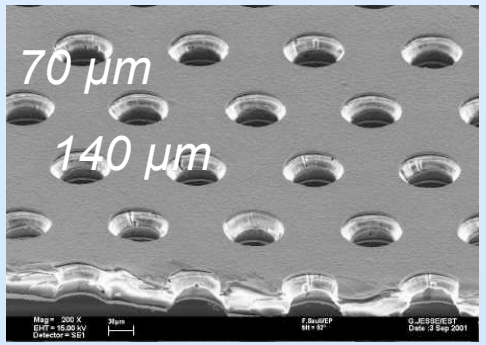


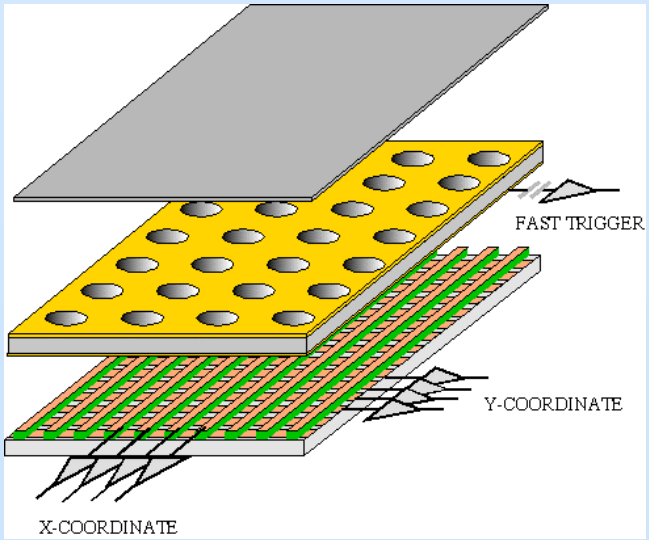
- 10 times more acceptance
- Full angular acceptance for positrons
- Improved field alignment

TREK/E06 Tracking Upgrade



GEM technology:
In collaboration with Jefferson Lab, Hampton U. and MIT





- **Planar GEMs (C1)**
  between CsI and C2
- **Cylindrical GEM (C0)**
  in replacement of former C1

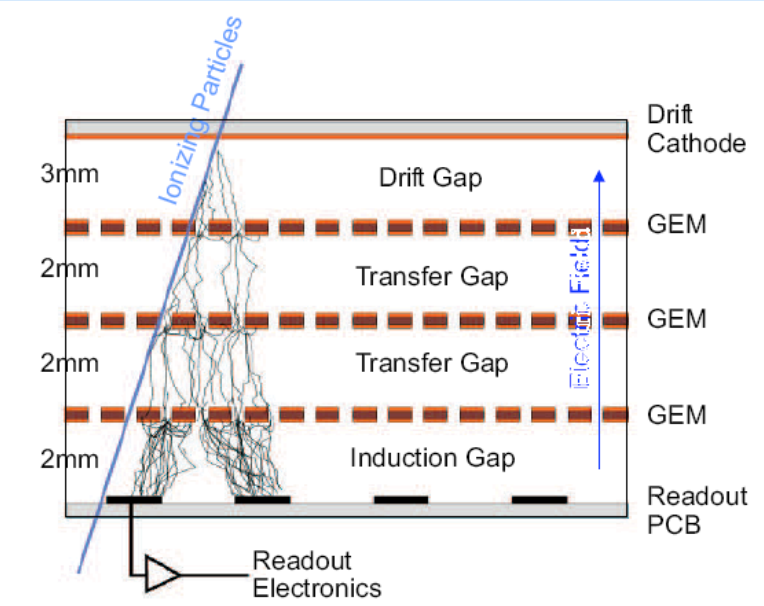
Principle of GEM Detectors

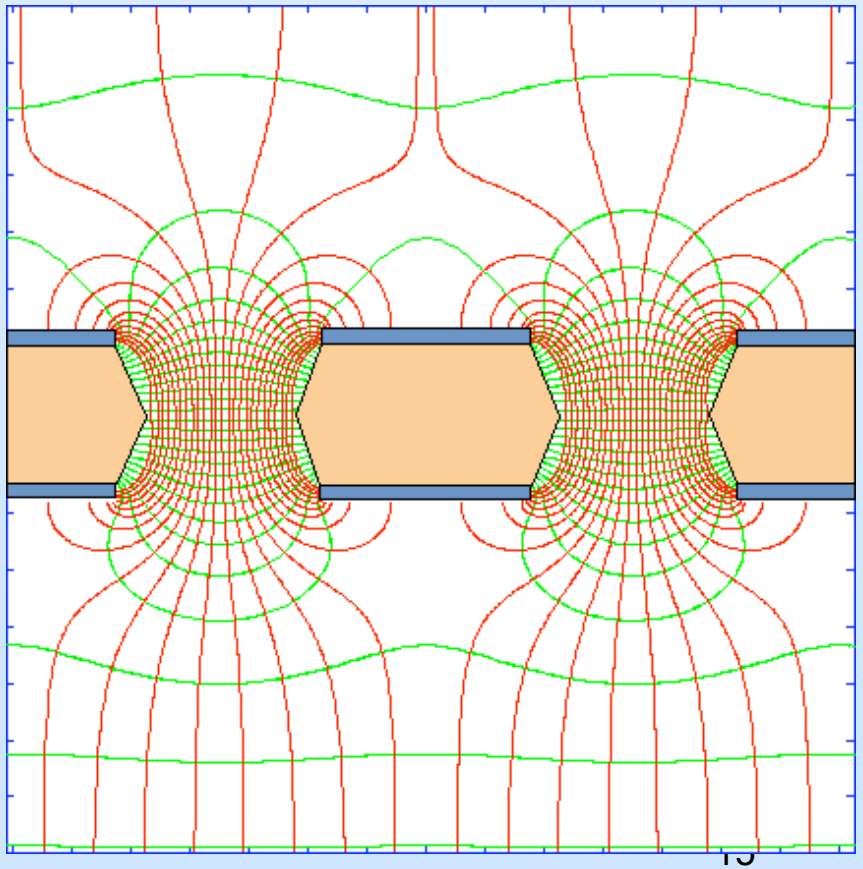
- GEM = Gas Electron Multiplier

  introduced by F. Sauli in mid 90's, F. Sauli et al., NIMA 386 (1997) 531

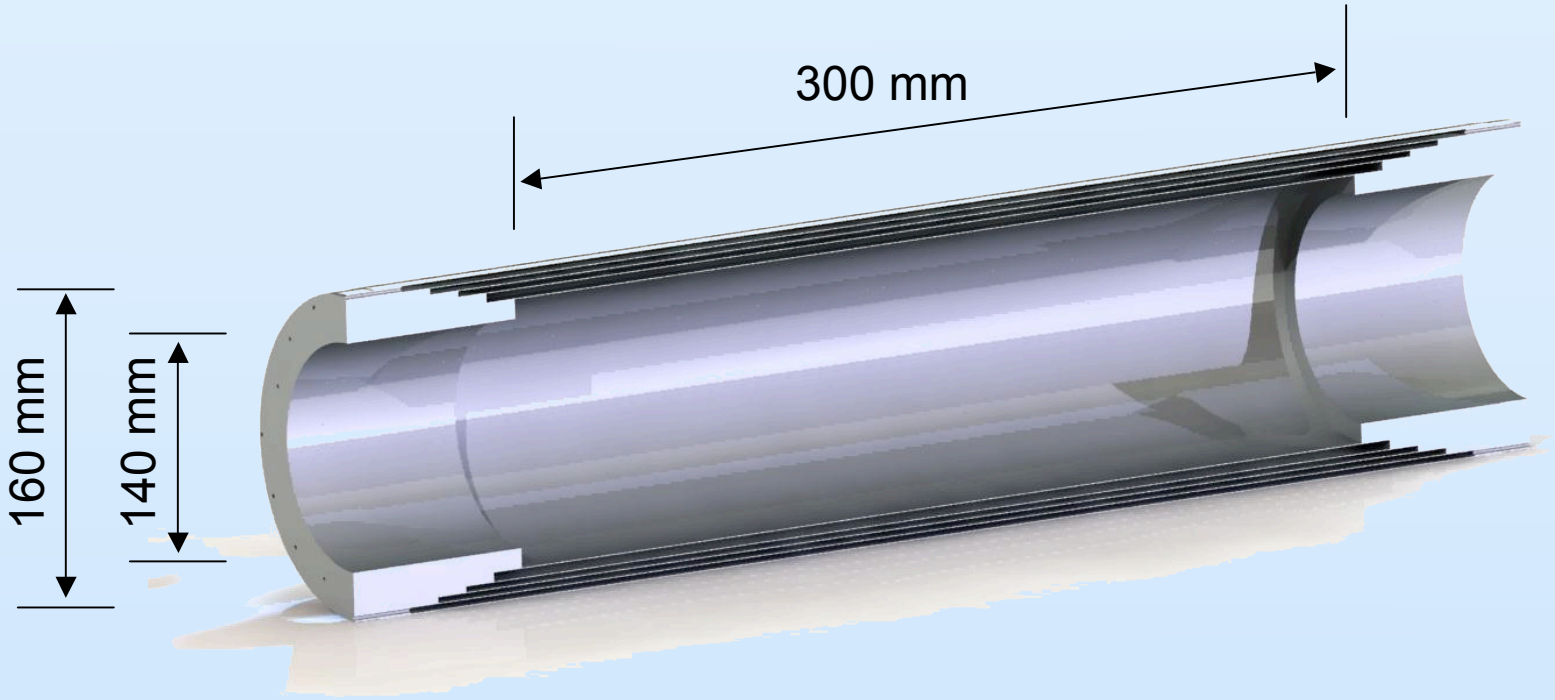
- Copper layer-sandwiched kapton foil with chemically etched micro-hole pattern

  ⇨ gas amplification in the hole





C0 Cylindrical GEM for TREK

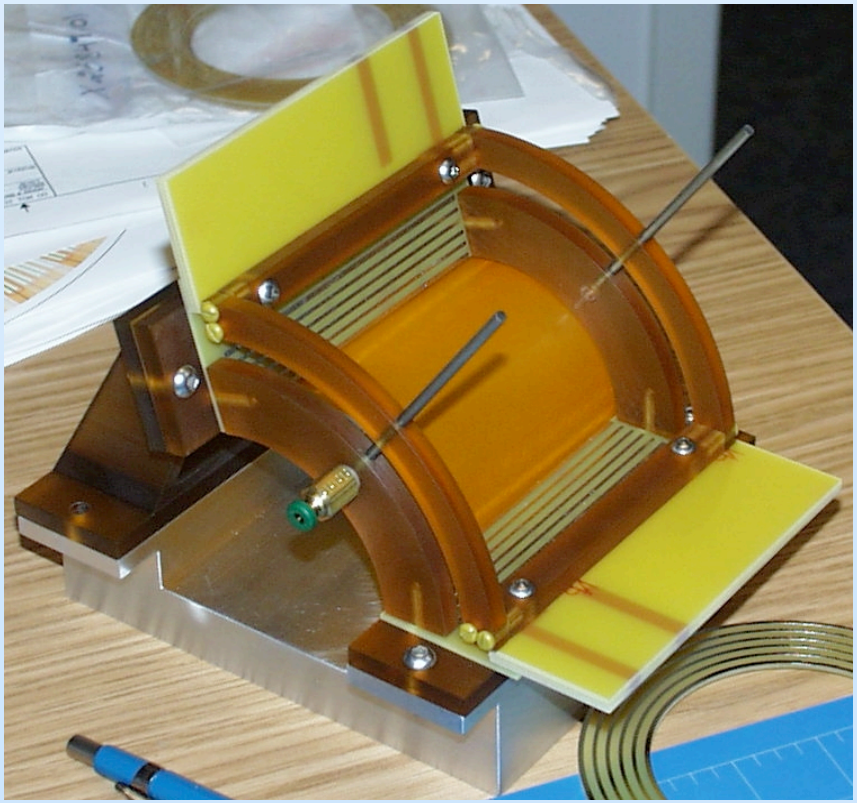


- Vertex tracking near target, $\delta < 0.1$ mm
- Very high rate capability > 1 kHz/mm^2
- Radiation-hardness >> 10^7/mm^2

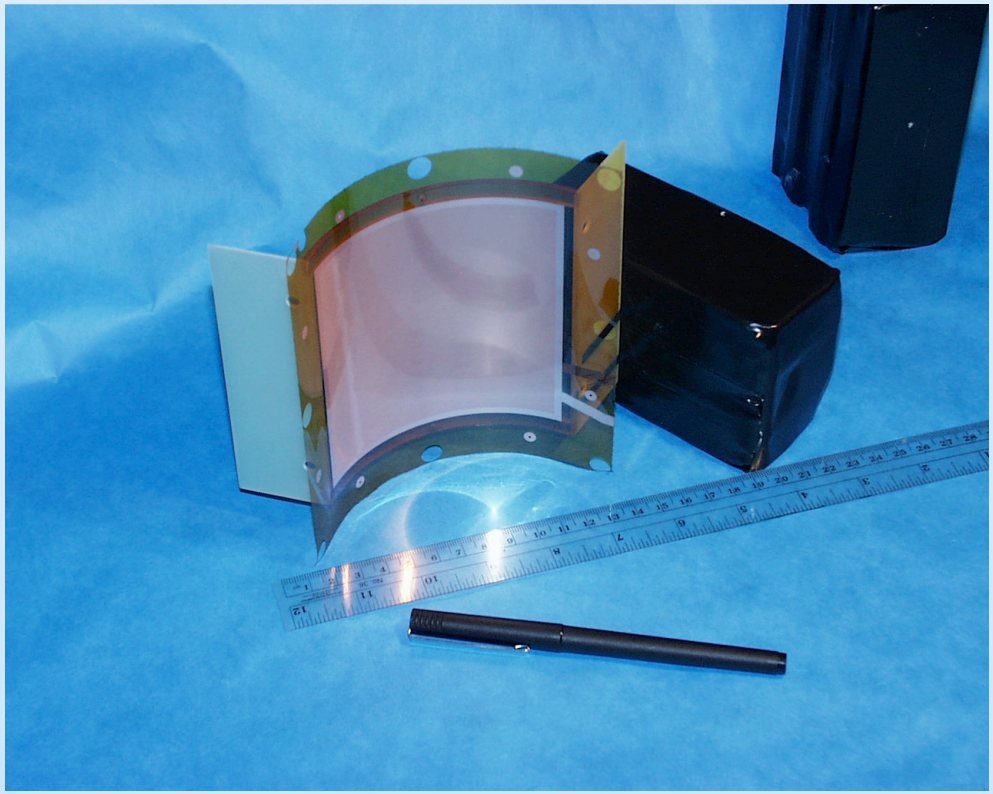
Jlab/BoNuS: First cylindrical GEM

Barely off-shell Nuclear Structure

Prototype

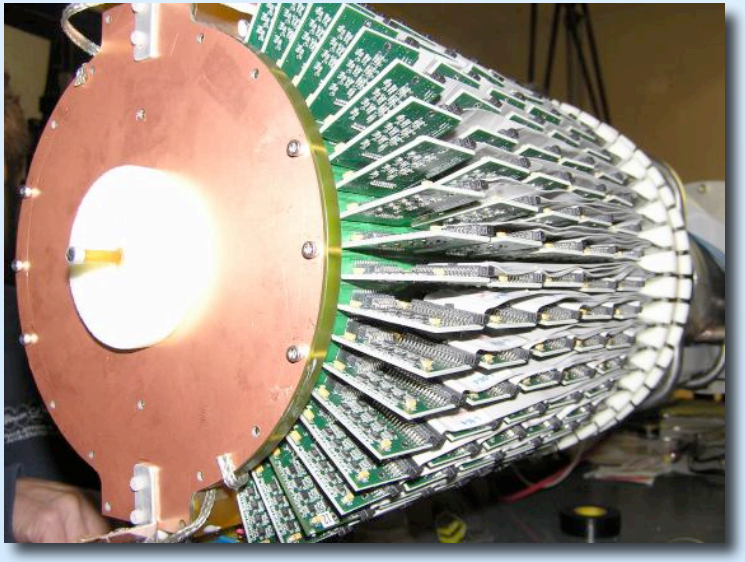


Curved GEM foil



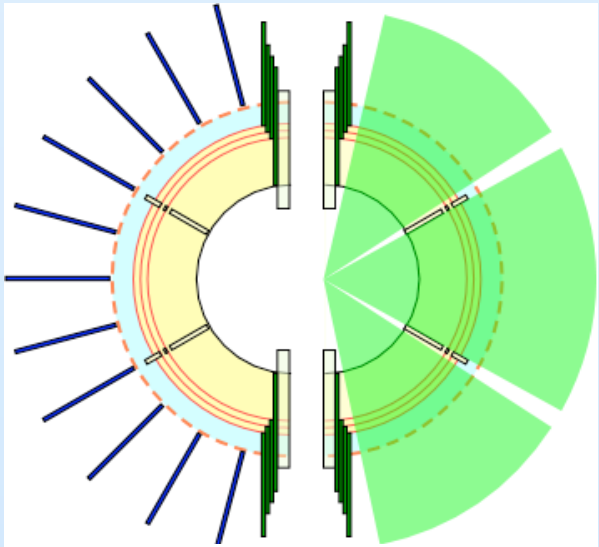
TREK/E06 GEM will have potential applications at Jefferson Lab

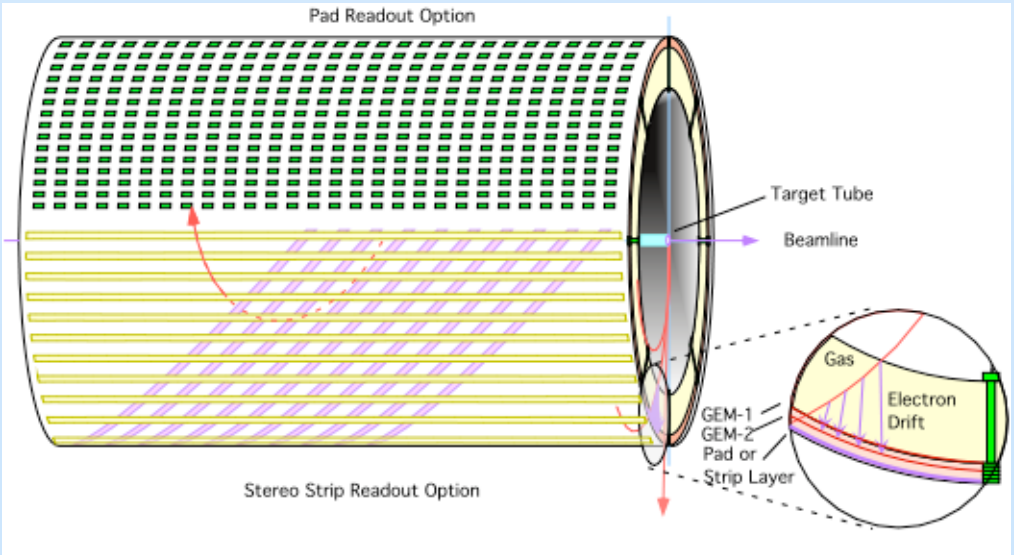
BoNuS

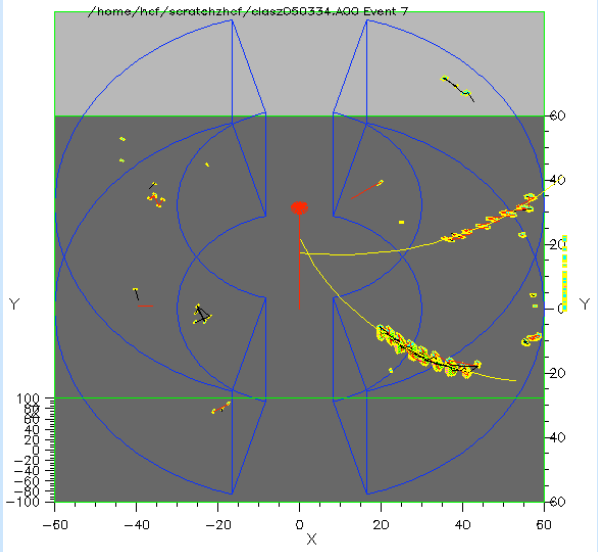


- Radial TPC
  (8-12 cm in./out. diameter
  20cm active length)
- Ran in CLAS
  end of 2005
- Further development
  planned for Jlab-12 GeV

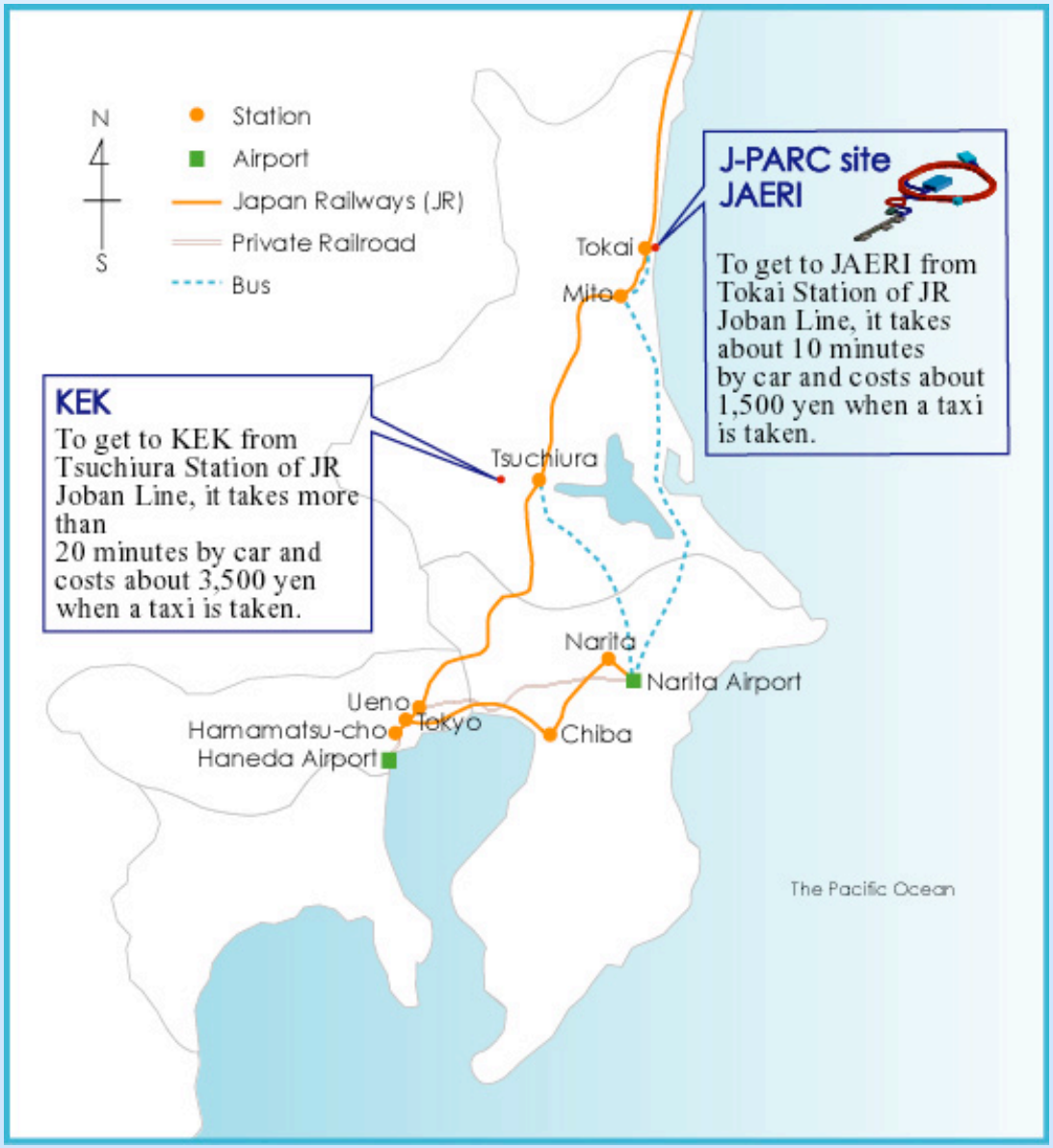
→ Howard Fenker





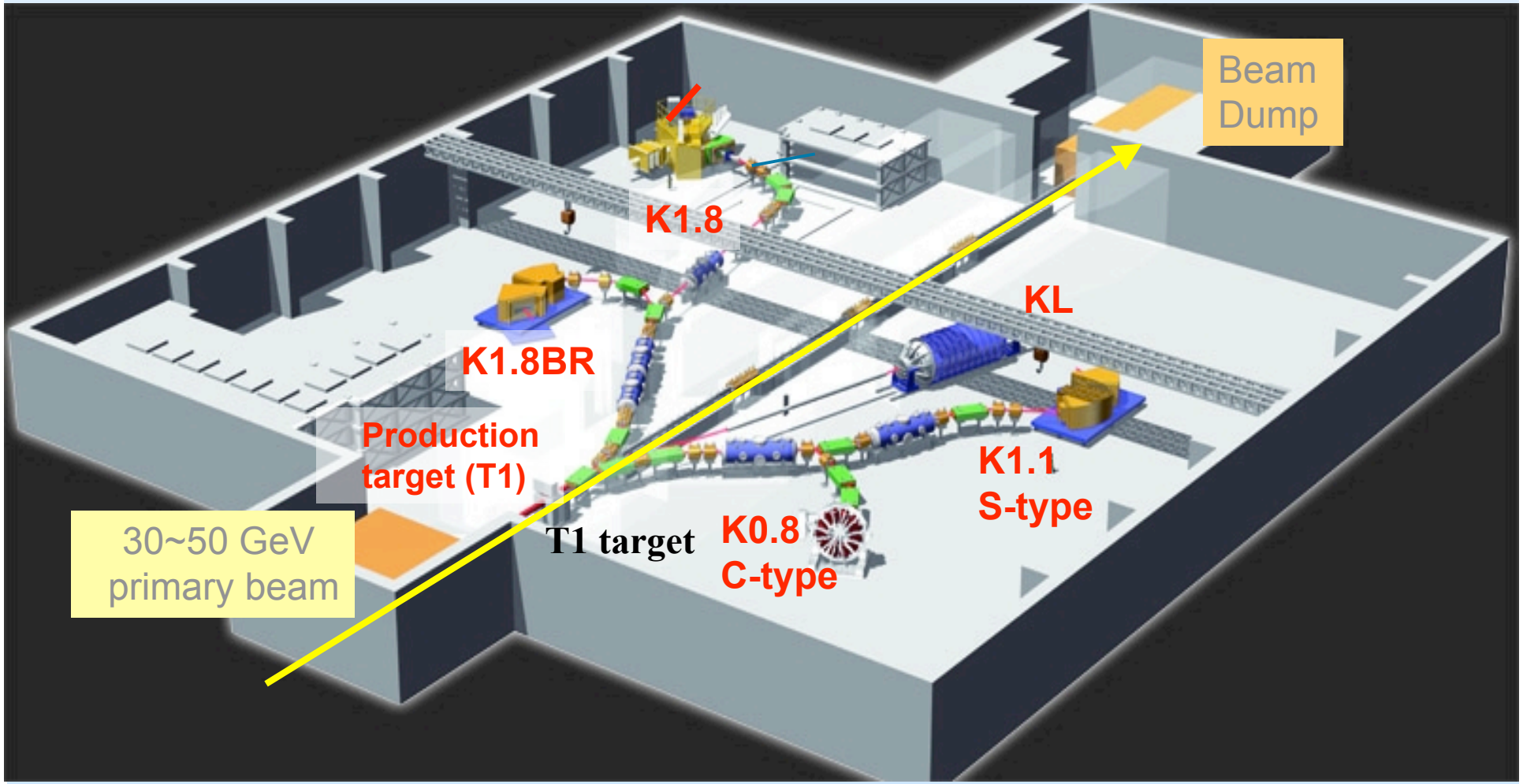


Location of J-PARC




Hadron Experimental Hall
50 GeV
Materials & Life
Experimental Hall
Neutrino
3 GeV
Linac
Sept. 15, 2005

Hadron Experimental Hall



Schedule / Agenda 2013

Feb 2005:	New collaboration formed (Japan, Canada, USA, Russia and Vietnam)
April 2006:	Proposal submission
July 2006:	Review by PAC → “stage-1” (scientific) approval

2007-2009:	R&D and experiment design phase J-Parc PS and HF start operating
2010-2011:	Kaon 0.8 beamline, experiment upgrade and commissioning
2011-2012:	**Start of experiment (1 year)**
2012-2013:	Analysis and results

Summary

- **TREK (E-06) at J-PARC is taking off**

- **Measure T-violating transverse muon polarization in $K_{\mu 3}$ decays**
  - **Large potential for discovery comparable to n-EDM**
  - **Upgrade of existing experimental setup of KEK/E-246**

- **Sensitivity improved by factor 20 to ~10^{-4}**

- **Run in 2011/12**