Status Report on Rare K Decays
- Experiment -

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Rare K Decays

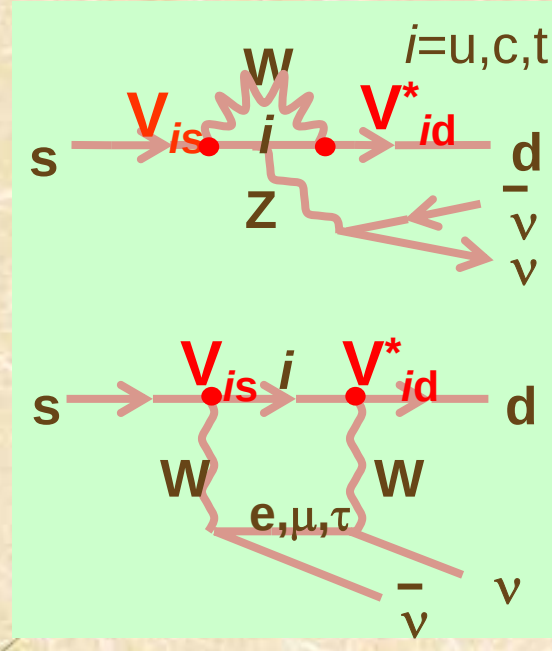
Considering the program,

I will concentrate on

$K \rightarrow \pi\nu\nu$ experiments

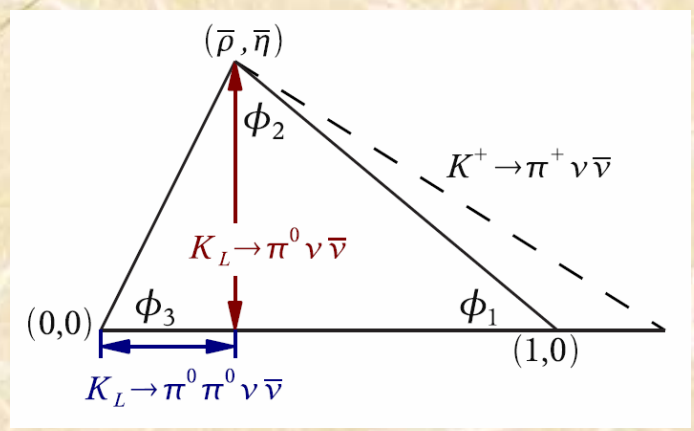
K→πνν in the Standard Model

- Feature
  - Z penguin and Box diagram
  - Top in the loop, Sensitive to V_{td}
  - Small theoretical uncertainty



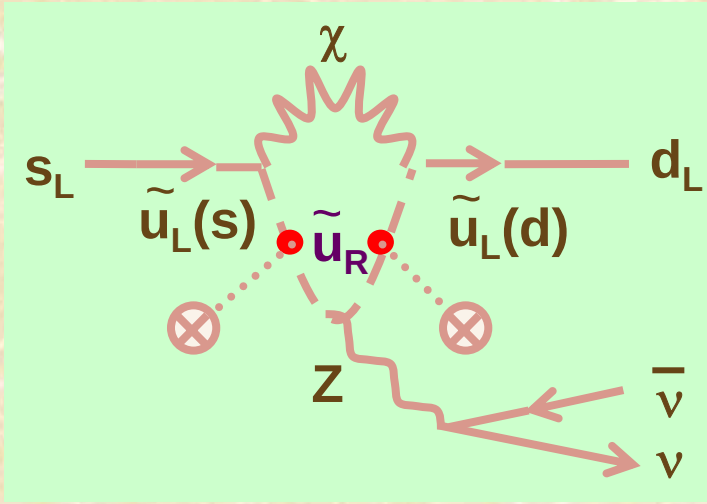
$$B(K^+ \to \pi^+ \nu\nu) \approx 1.0\times10^{-10} A^4 \left(\eta^2 + (\rho_0 - \rho)^2\right)$$
$$= (8.0 \pm 1.1)\times10^{-11}$$

$$B(K_L \to \pi^0 \nu\nu) = 2.2\times10^{-10} \left(\frac{\mathrm{Im}(V_{ts}^* V_{td})}{\lambda^5} X(x_t) \right)^2$$
$$= (2.8 \pm 0.4)\times10^{-11}$$



$K \to \pi\nu\nu$ beyond the SM

- Minimal Flavor Violation
  - Flavor symmetry breaking occurs at very high energy and mediated via Yukawa coupling
  - Small deviation from SM
- Beyond MFV
  - New source of Flavor symmetry breaking at TeV scale



Status of $K^+ \rightarrow \pi^+ \nu\nu$ experiments

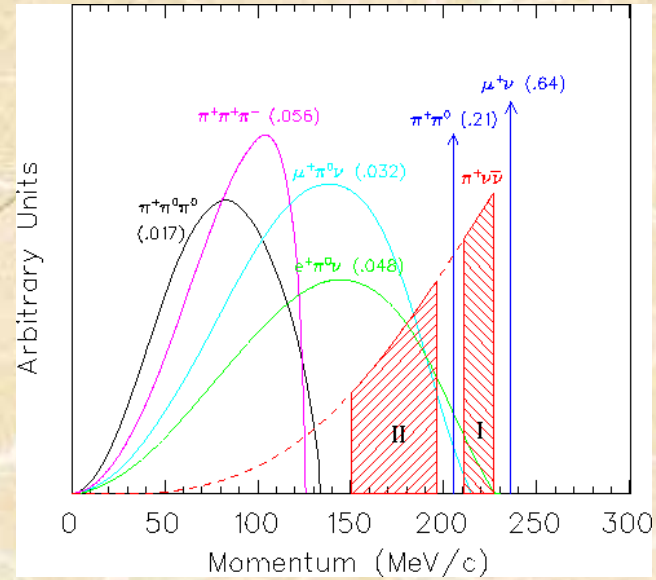
- Current (Run finished)
  - E787 / E949 at BNL
- Future
  - P326 at CERN

- Current $K^+ \rightarrow \pi^+ \nu\nu$ experiment -

BNL E787 / E949

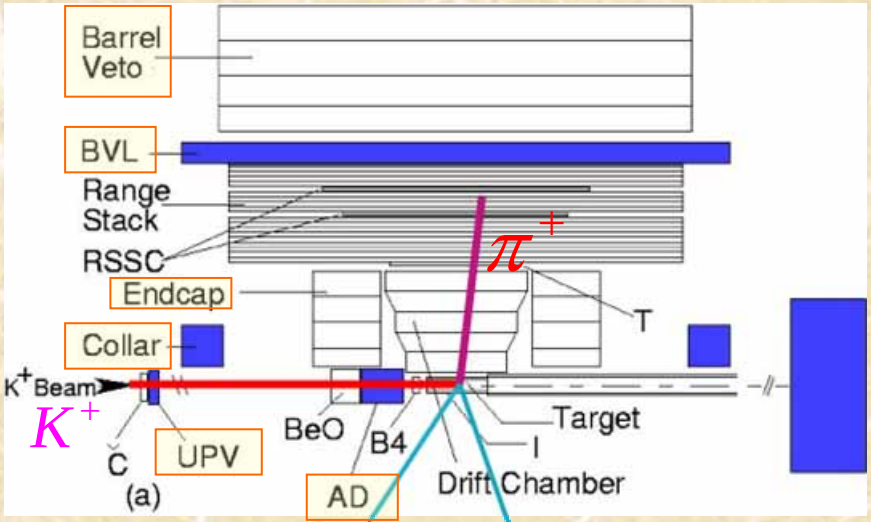
- Event signature of $K^+ \rightarrow \pi^+ \nu\nu$
  = K^+ comes in, only π^+ comes out
- Basic concepts
  - Stopped K^+ experiment
  - Measure full kinematics of π^+
    Energy (E) / Momentum (P) / Range (R)
  - PID by recording π-μ-e decay chain
  - Hermetic photon veto detectors

Momentum in K^+ rest frame
(= in Lab frame)

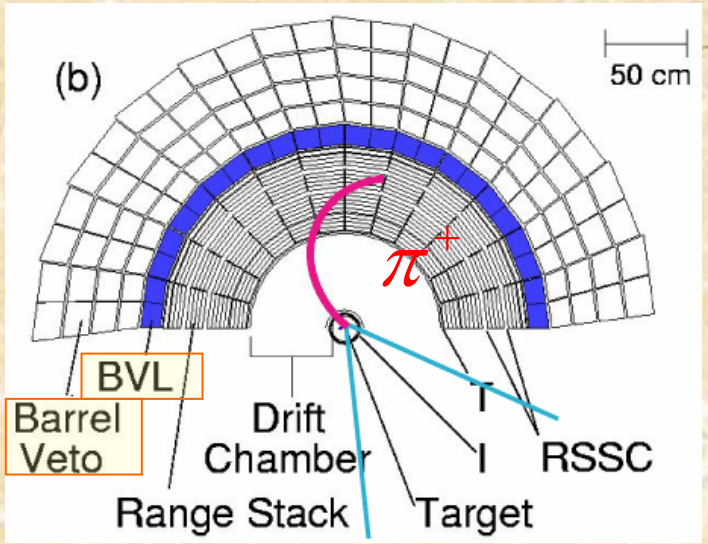


- Current $K^+ \rightarrow \pi^+ \nu\nu$ experiment -

E949 Detector



Side view (cutaway)

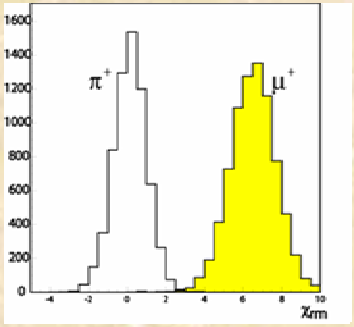


End view (top half)

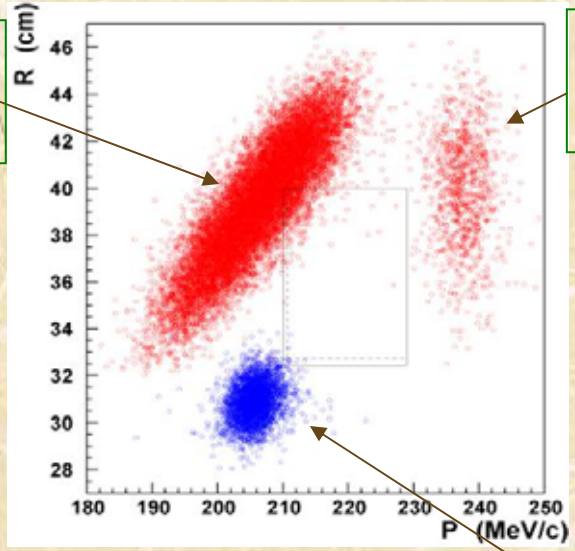
- Active target (scintillation fibers) to stop K^+
- Chamber and the magnetic field to measure π^+ momentum
- 19 layers of scintillators ("Range Stack") to measure E and R
- Waveform digitizer to record π-μ-e decay chain in RS counter
- Photon vetoes surrounding 4π (BV / BVL / Endcap / …)

E949 Evaluation of Backgrounds

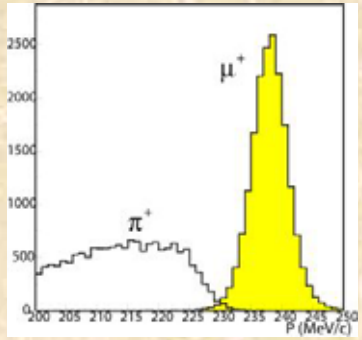
$K^+ \rightarrow \mu^+ \nu\gamma$, …
χ_{rm} and NN function



$\chi_{rm}=(R_{meas}-R_{expect})/\sigma_R$



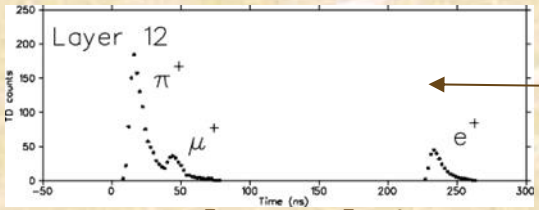
$K^+ \rightarrow \mu^+ \nu$, but short range
P and NN function



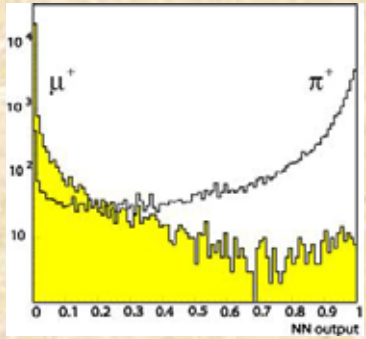
P for π and μ

$K^+ \rightarrow \pi^+ \pi^0$
P(E,R) and Photon veto

PV rejection ~10^{-6}
when 80% acceptance



π-μ-e decay chain
in the π stopping RS



Neural Net function for π and μ

BG level evaluated
as functions of cut positions

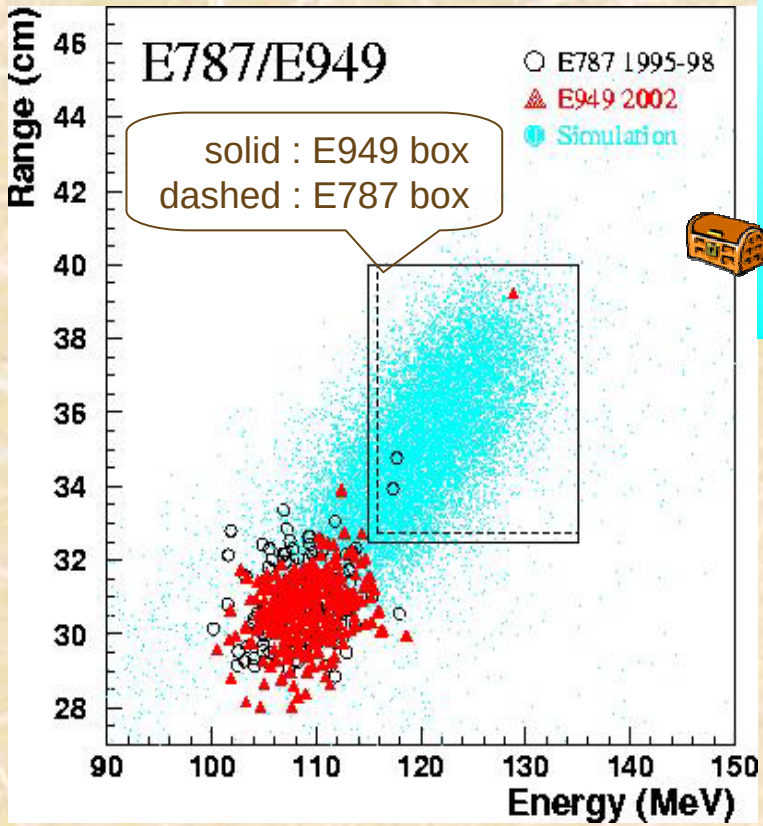
E787 / E949 Result

- Range vs Energy after all the cuts
- 3 candidates observed
  - ▲ **E949** ○ E787
  - ● Simulation
- Combined E787 / E949

$$Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$$

  - E949 alone

$$Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = 0.96^{+4.09}_{-0.47} \times 10^{-10}$$



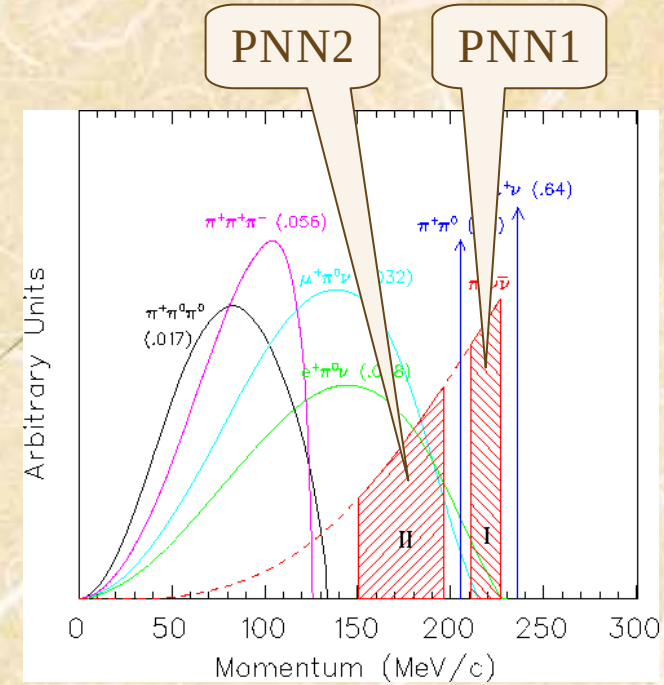
-1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12

A factor of 2 larger than SM prediction ? Need more statistics !!

- Current $K^+ \rightarrow \pi^+ \nu\nu$ experiment -

E949 Status

- PNN1 analysis finished PRL93(2004)031801
- PNN2 ($140 < P_\pi < 199$) on analysis
  - Simultaneously taken with PNN1
  - Goal: S/N ~ 1
    - 1/10 in E787 PRD70(2004)037102
    - Dominant backgrounds from $K\pi 2$, π^+ scattered in the target
    - PV upgrade (BVL, Beam PV) in E949 helps the BG rejection
  - Will be completed in < 1 year

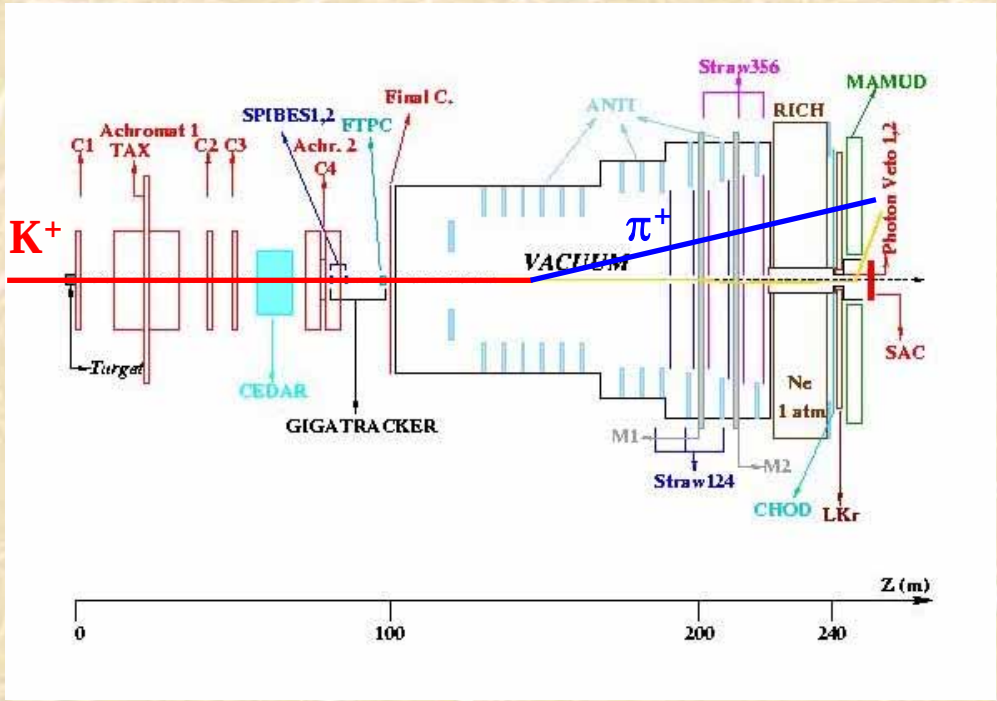


- Future $K^+ \rightarrow \pi^+ \nu\nu$ experiment -

P326 at CERN

Details in Talk
in "Future Directions" session

- Based on NA48 detector
- Decay in flight
- For BG rejection …
  - K^+ tracking in 1GHz
  - PID(π/μ) by RICH
  - High E π^0, low ineff.
  - Missing mass cut
- 80 SM events in 2 years



Status of $K_L \rightarrow \pi^0 \nu\nu$ experiments

- Current (Run finished)
  - E391a at KEK
- Future
  - JPARC-K (P-14)

- Current $K_L \rightarrow \pi^0\nu\nu$ experiment -

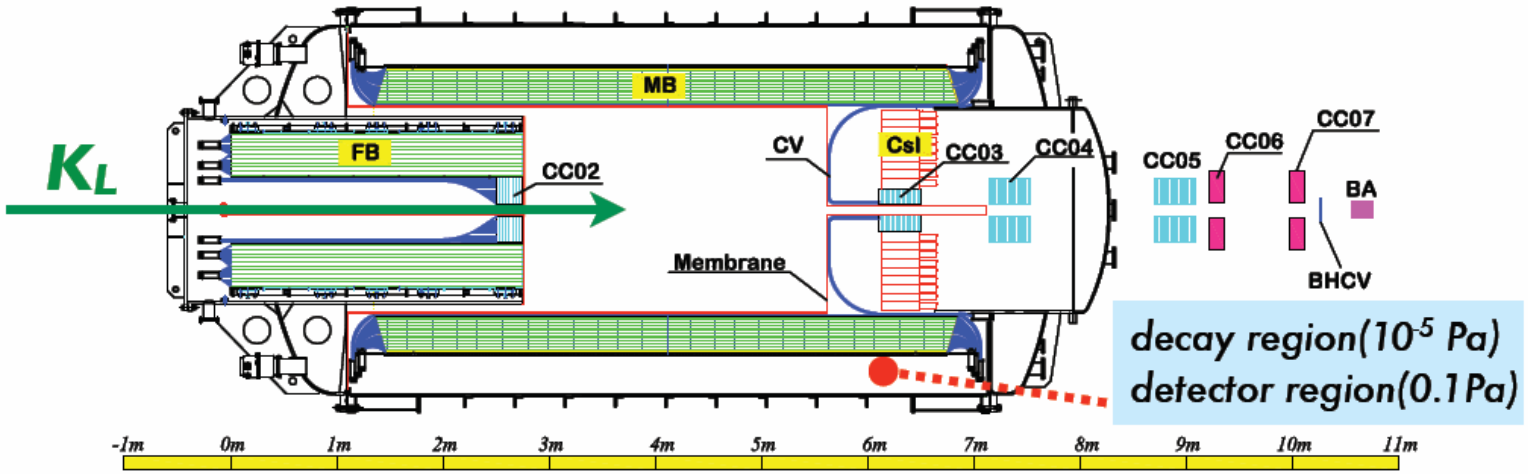
KEK E391a

detect 2γ ($\pi^0 \rightarrow \gamma\gamma$) + require no other particles

w/ new ideas (1,2,3)

1. Hermetic photon veto

- suppress bkg. involving extra particles (ex. $K_L \rightarrow 2\pi^0$, ~~2γ~~)



2. clean/narrow beam

- 8cm @ 16 m from target (calorimeter)

3. vacuum decay region

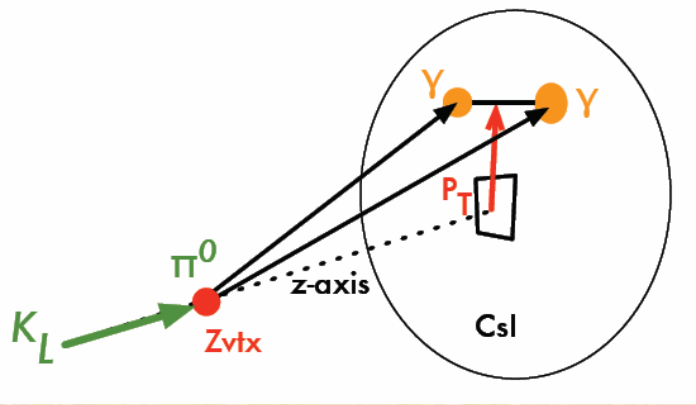
- suppress neutron interactions w/ residual gas

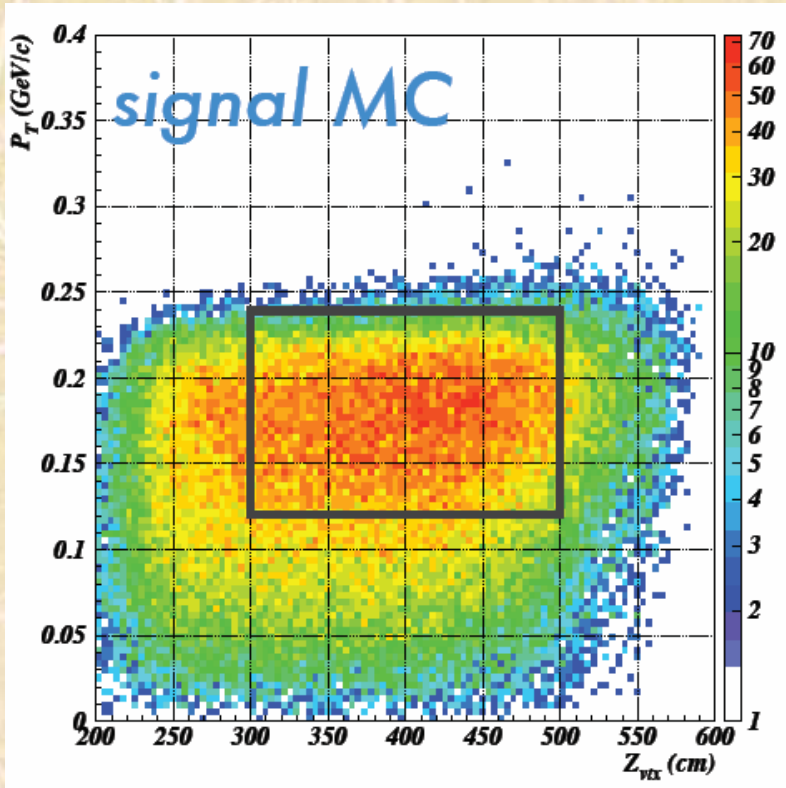
KEK E391a Dataset

- Run I Feb 04 - Jul 04
  - Membrane problem (described later)
- Run II Mar 05 - Apr 05
  - Fix membrane problem
- Run III Nov 05 - Dec 05
  - New BA (in-beam PV: PWO+Quartz sandwich)

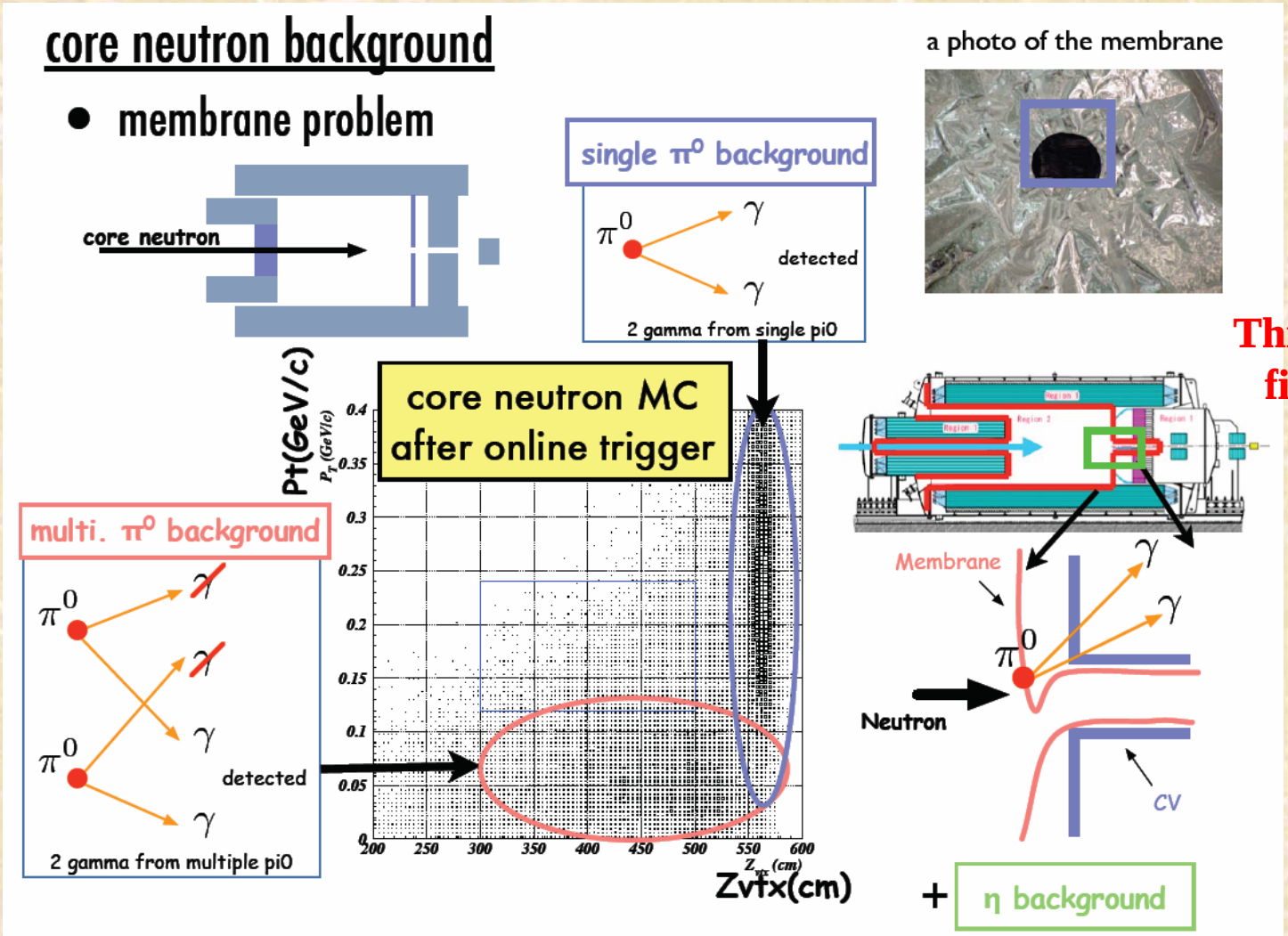
E391a Analysis

- Event Reconstruction
  - Find 2 clusters
  - Reconstruct Z vertex assuming $M(2\gamma)=M(\pi^0)$
  - Calculate P_T



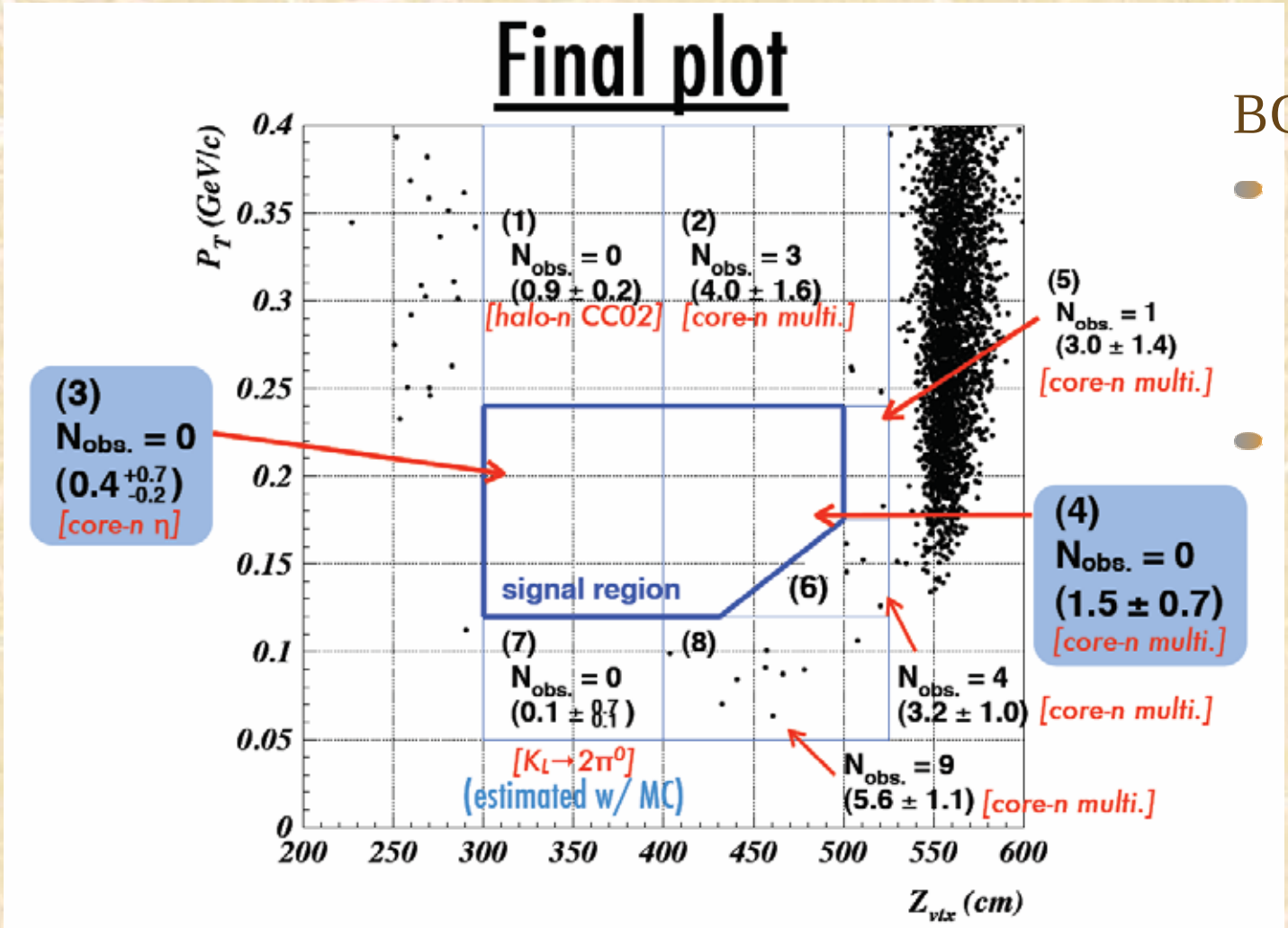


E391a Background in Run I



- Current $K_L \rightarrow \pi^0 \nu\nu$ experiment -

E391a Result (Run I 1week)

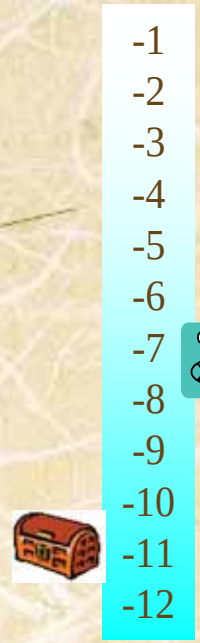


BG Estimation

- Core n multi π^0
  → Bifurcation
  (PV cut / EH cut)
- Halo n CC02
  → Z tail from
  "π^0 run"
  (put Al in beam)

E391a Result (Run I 1week)

- $S.E.S = [9.11 \pm 0.20_{(stat.)} \pm 0.64_{(syst.)}] \times 10^{-8}$
  - Dominant systematic error
    - Data/MC mismatch in $E_{MainBarrel}$ (4.2%)
    - Data/MC mismatch in shower shape in CsI (4%)



- **BR < 2.1 x 10^{-7} (90% C.L.)**

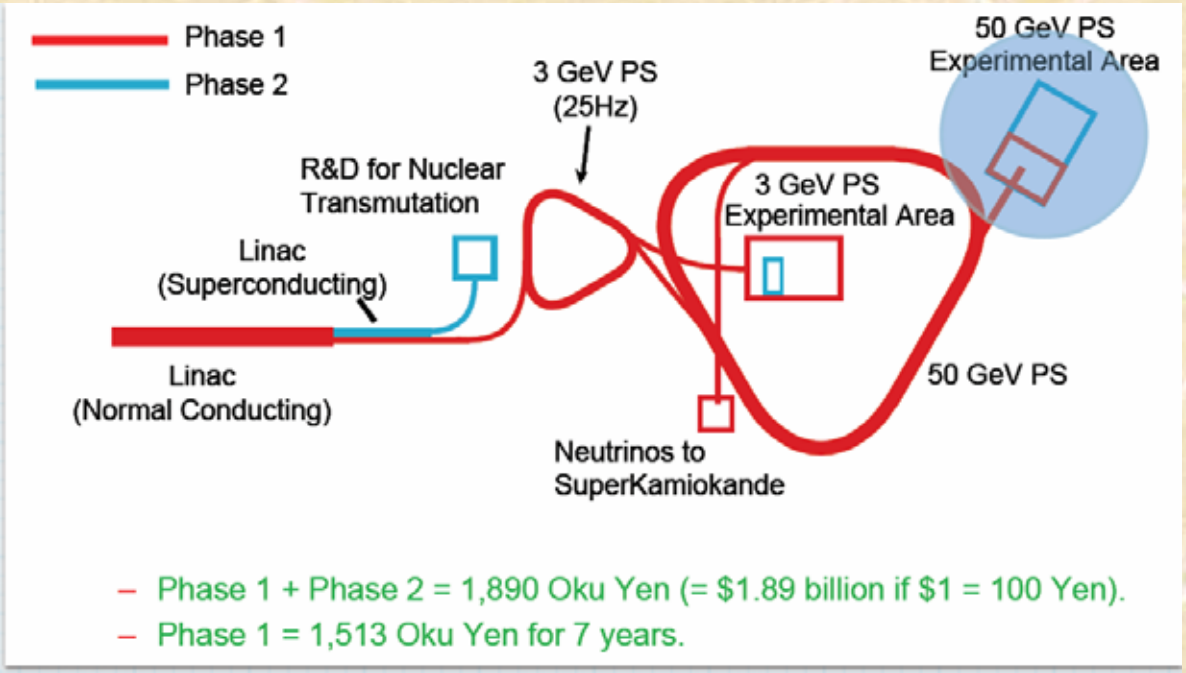
  A little bit updated from Kaon2005 by analysis refinement
  - 2.8 times improvement of current limit

E391a Status

- Run I
  - Finish 1 week data sample → will submit to PRL
  - Process under going for Run I full period
- Run II / III (Blind analysis)
  - Glance at 1 week sample, improvement confirmed
  - 1/3 of Run II sample now being studied
  - Will open the box by the end of 2006 ? (Hopefully)
  - Finish full analysis by the end of 2007 ? (Hopefully)

J-PARC K experiment

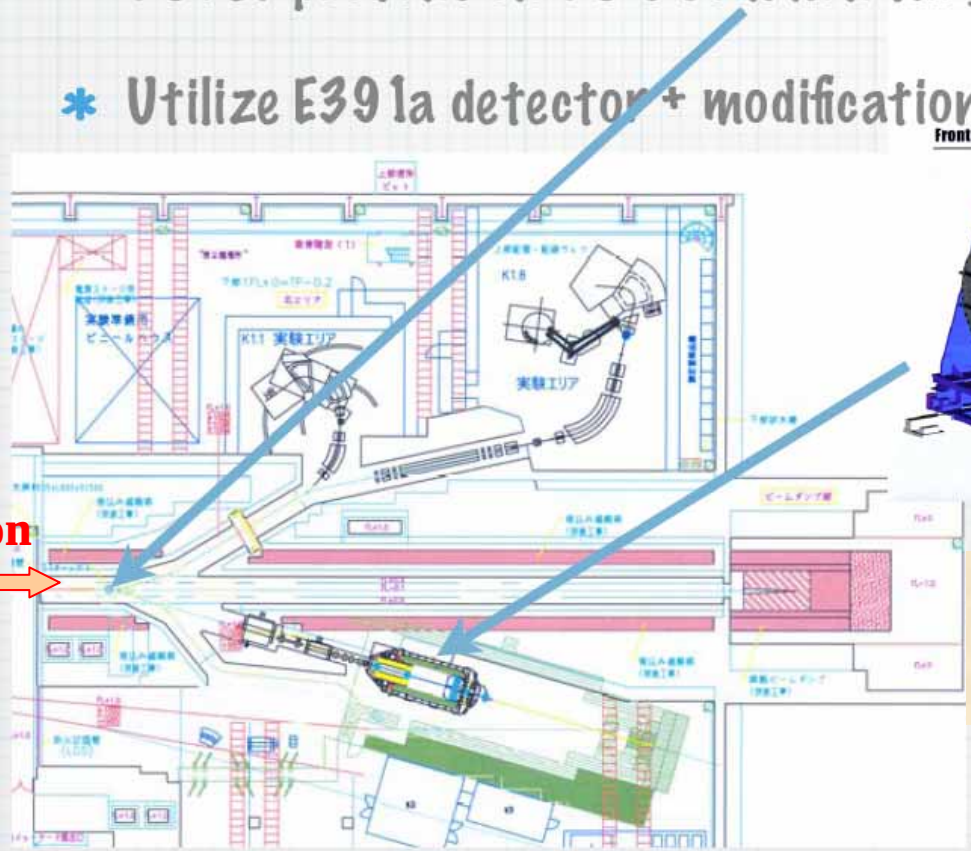
- J-PARC = Japan Proton Accelerator Research Complex
- Now under construction at Tokai-site
- High intensity PS
  - 30 / 50 GeV
  - 3×10^{14} ppp
  - 3.4 sec cycle
- First beam in 2008

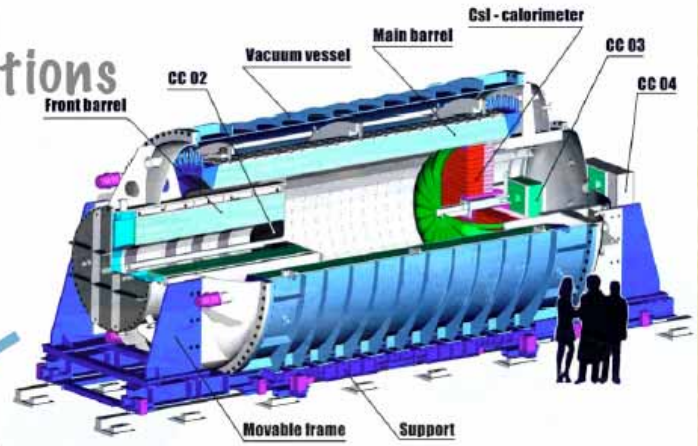


- Future $K_L \rightarrow \pi^0 \nu\nu$ experiment -

J-PARC K experiment : Step1

* 30GeV protons on 30° Common target
* Utilize E391a detector + modifications

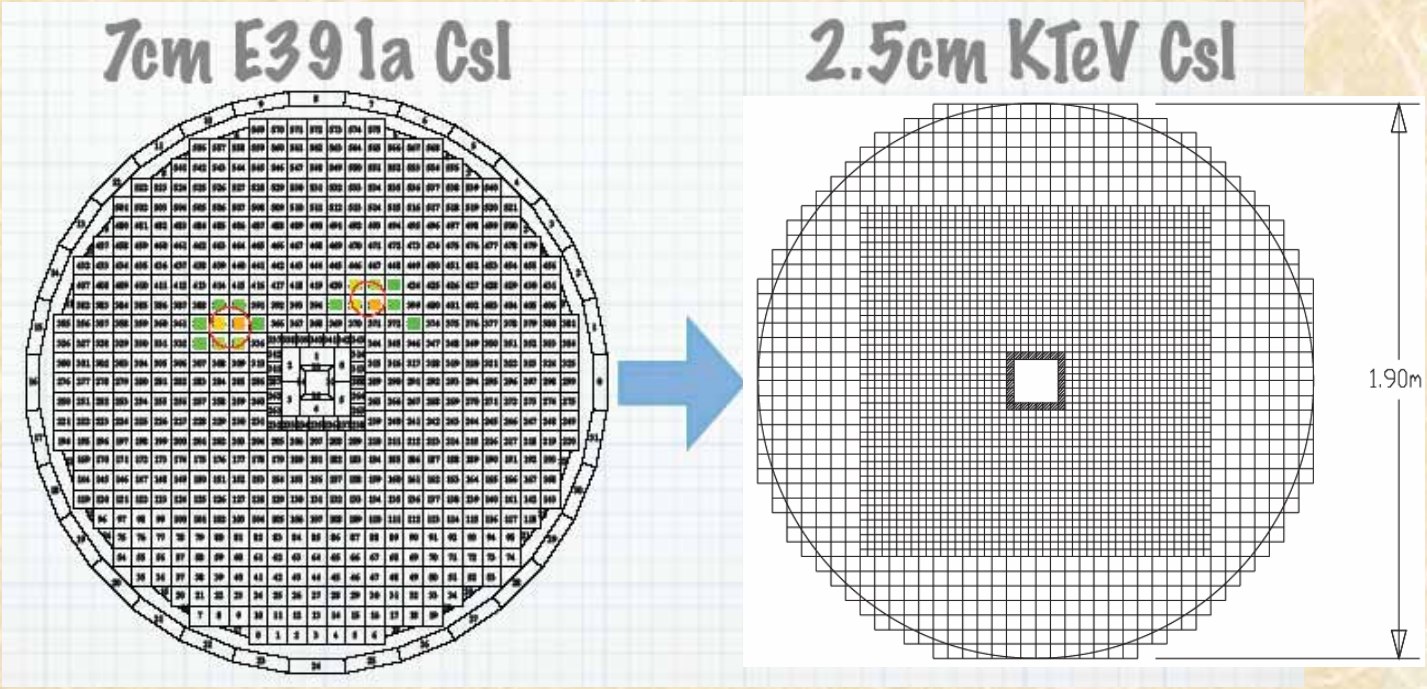




- 16 degree production angle
- Pencil beam with 9 μstr

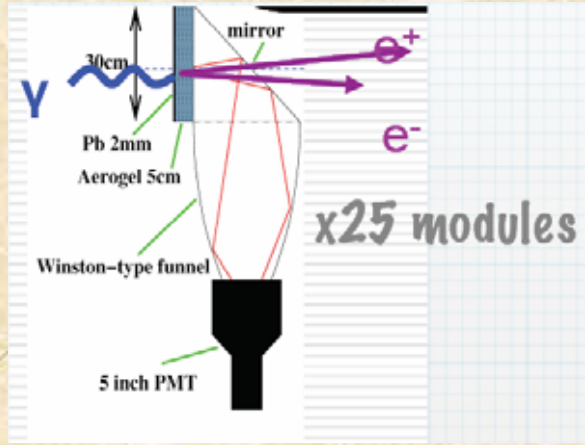
J-PARC K : Detector upgrade

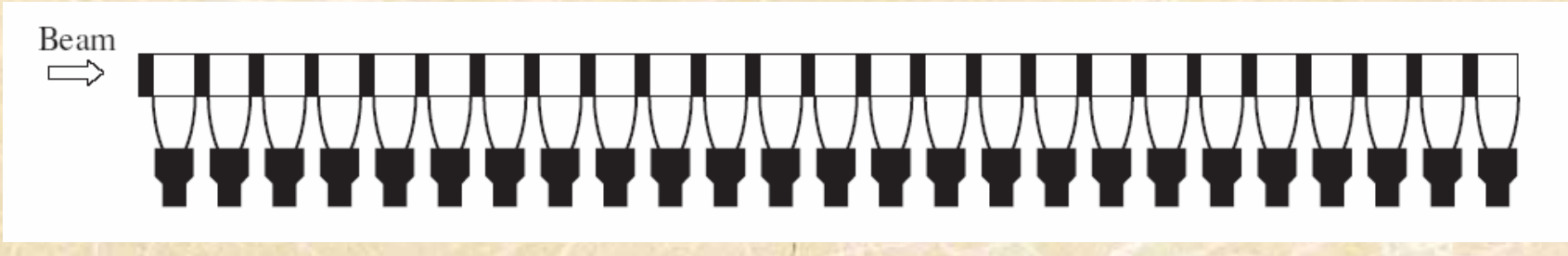
- Calorimeter : use KTeV CsI (KEK and FNAL under negotiation)
  - More radiation length, reduce shower leakage
  - Better segmentation (7cm → 2.5cm), reduce fused photons



J-PARC K : Detector upgrade

- In-beam photon veto detector
  KOPIO-type Lead-Aerogel "sparse" sandwich
  - Less sensitive to beam neutron
    - Efficiency $<10^{-3}$ for En=1GeV
      (cf) neutron rate: ~0.5GHz, En>0.1GeV





J-PARC K : Goal and Time-line

- In Step1, observe ~5 SM events, with S/N=1.4
  - 3 years run, 2010-2012
  - Acceptance loss, estimated from E391a experience
- In Step2, collect >100 SM events
  with new detector, and dedicated beam line

- Proposal Submitted in April, 2006 (J-PARC P-14)
- First J-PARC PAC in last weekend

Summary (I)

- $K \rightarrow \pi\nu\nu$ among Rare K experiments
  - Unitarity triangle via K decays
  - Explore physics beyond the SM

- $K^+ \rightarrow \pi^+\nu\nu$
  - 3 candidate events observed by BNL E787 / E949
    - BR = $1.47\ ^{+1.30}_{-0.89} \times 10^{-10}$
  - New experiment at CERN : P326
    - Aims to observe ~100 events

Summary (II)

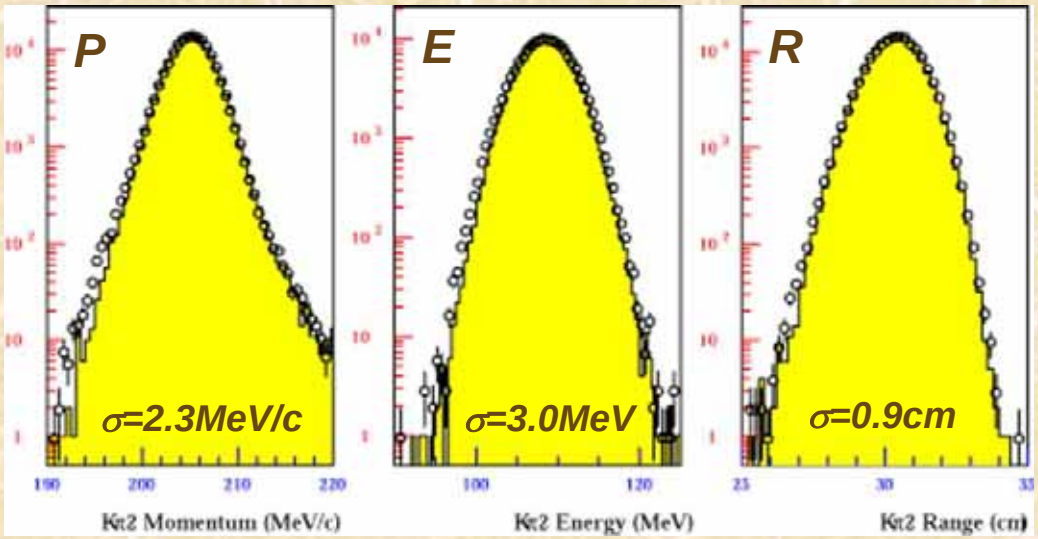
- $K_L \rightarrow \pi^0 \nu\nu$
  - First dedicated experiment KEK E391a successfully finished
    - On analysis
    - Sensitivity $< 10^{-8}$ expected
  - Proposal to JPARC : P-14
    - Step1 for discovery, with E391a detector : ~ 5 SM events
    - Step2 for precise measurement : >100 SM events

Extras

E949 Detector Performance

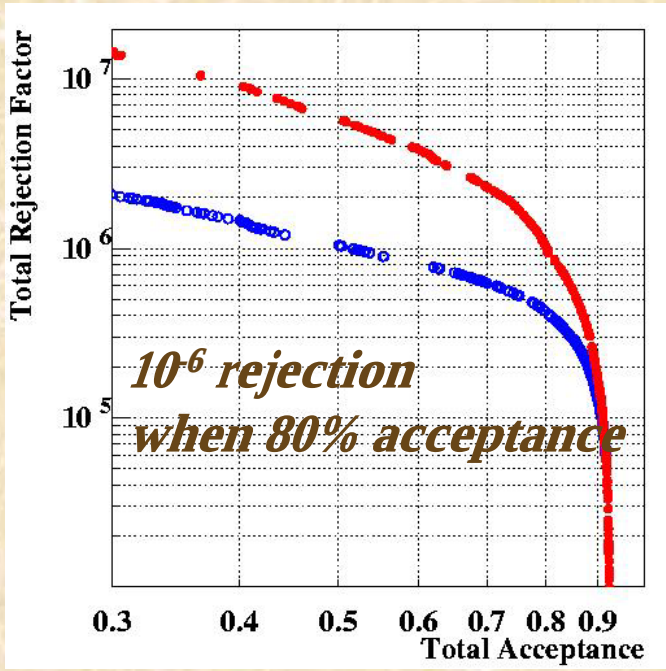
Kp2 momentum, energy and range

E949 (yellow histogram) and E787 (circle)



Kp2 Rejection by PV

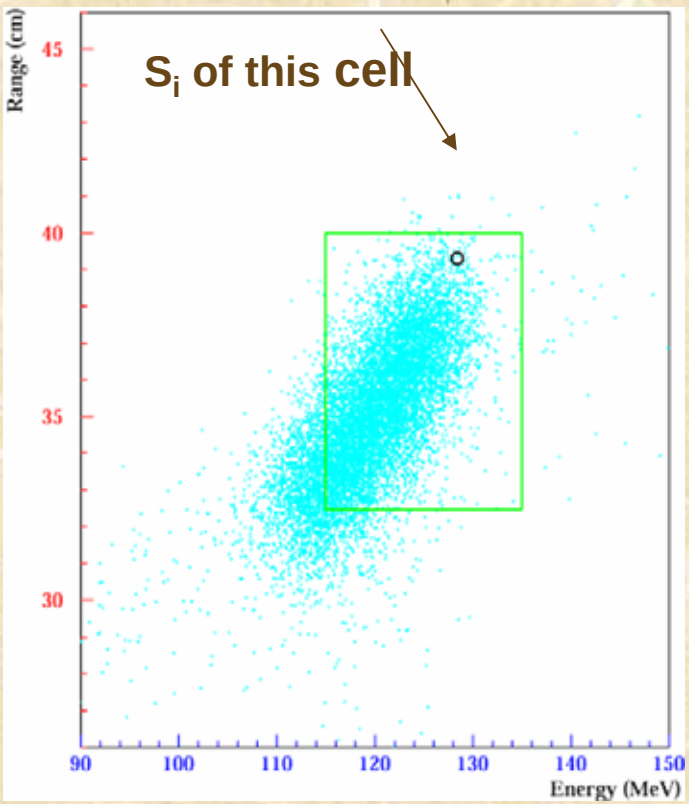
E949 (red) and E787 (blue)

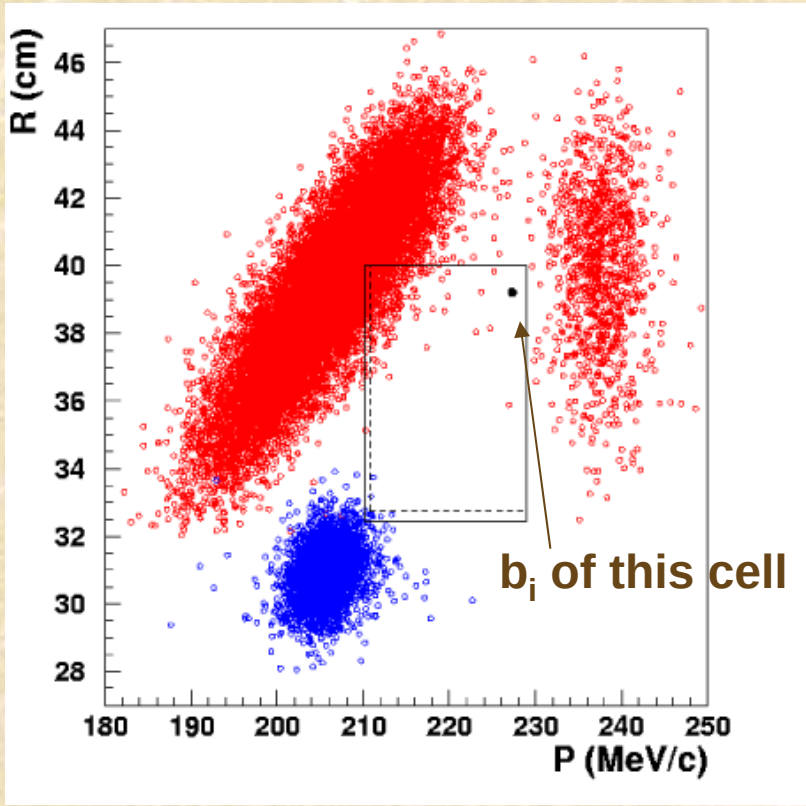


- Current $K^+ \rightarrow \pi^+ \nu\nu$ experiment -

S_i and b_i for E949 candidate cell

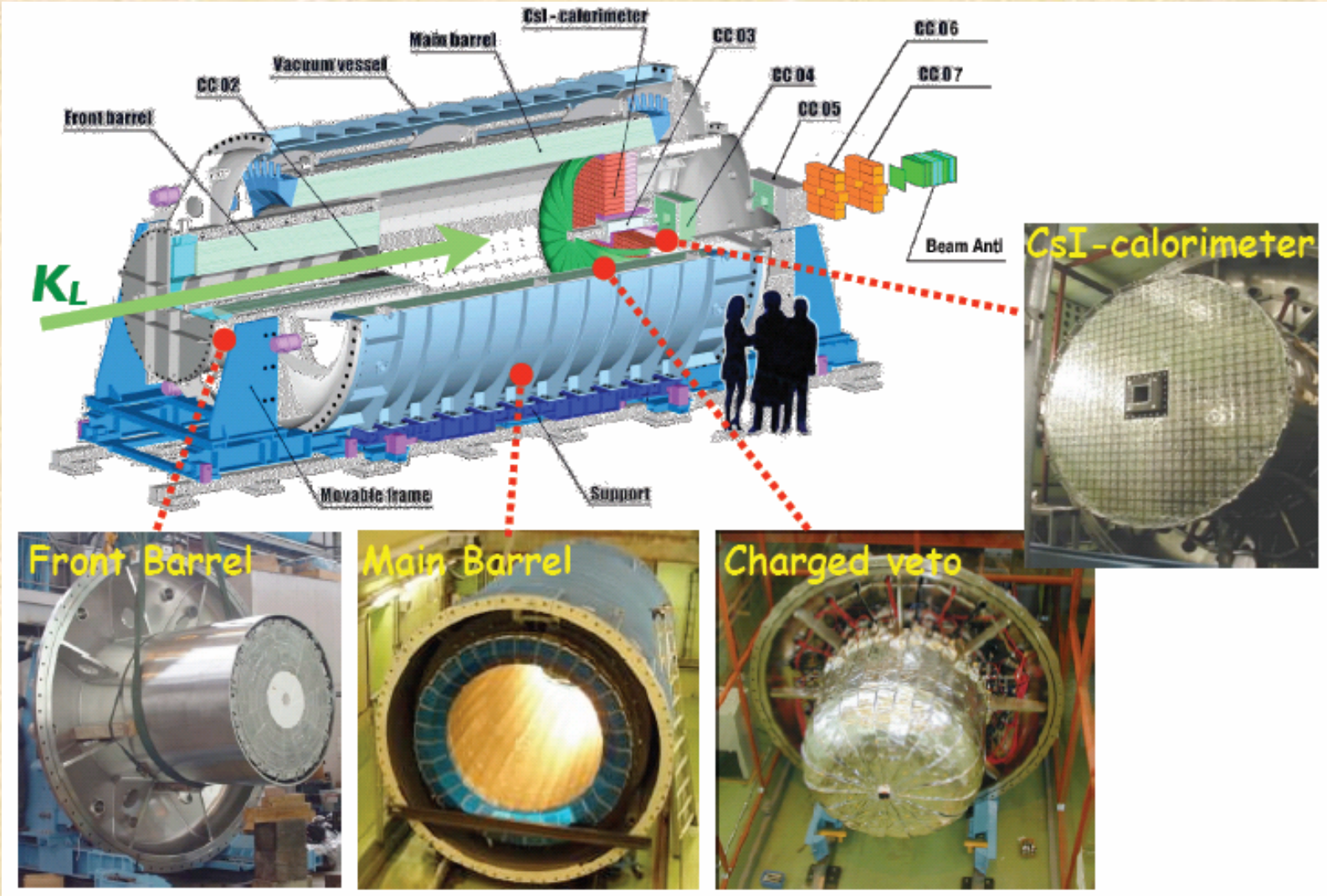
- Signal $S_i = 5.3 \times 10^{-5}$, with $BR(K^+ \rightarrow \pi^+ \nu\nu) = 1.47 \times 10^{-10}$
- Background $b_i = 5.7 \times 10^{-5}$ ➔ $W_i = S_i / b_i = 0.9$



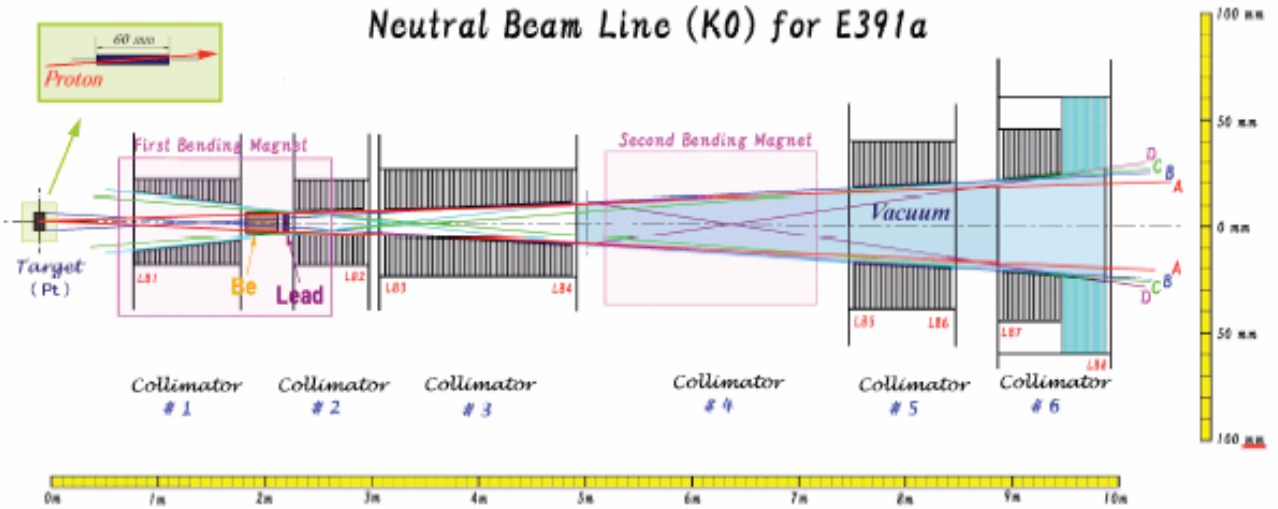


- Current $K_L \rightarrow \pi^0 \nu\nu$ experiment -

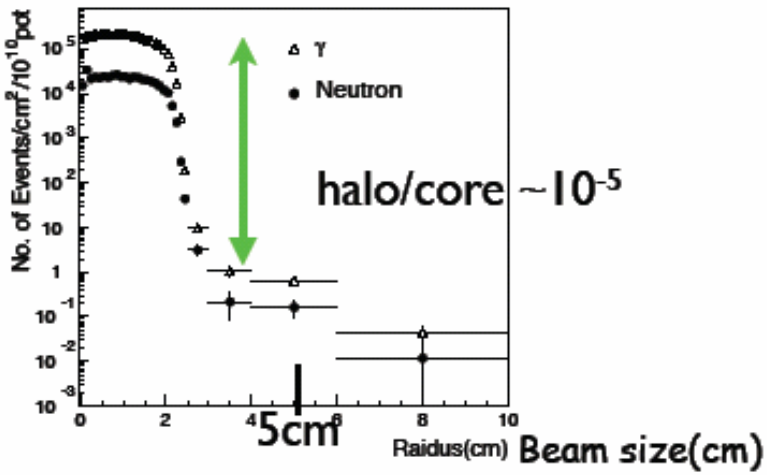
E391a Detector Pictures



E391a "Pencil" Beam



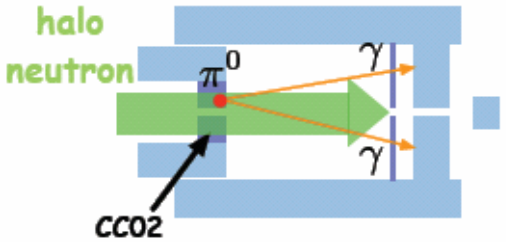
- Pt target
- 6 collimators + sweeping magnets
- 11 m



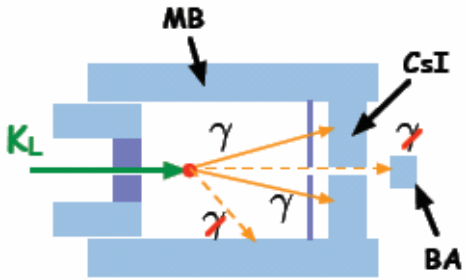
E391a Background in Run I

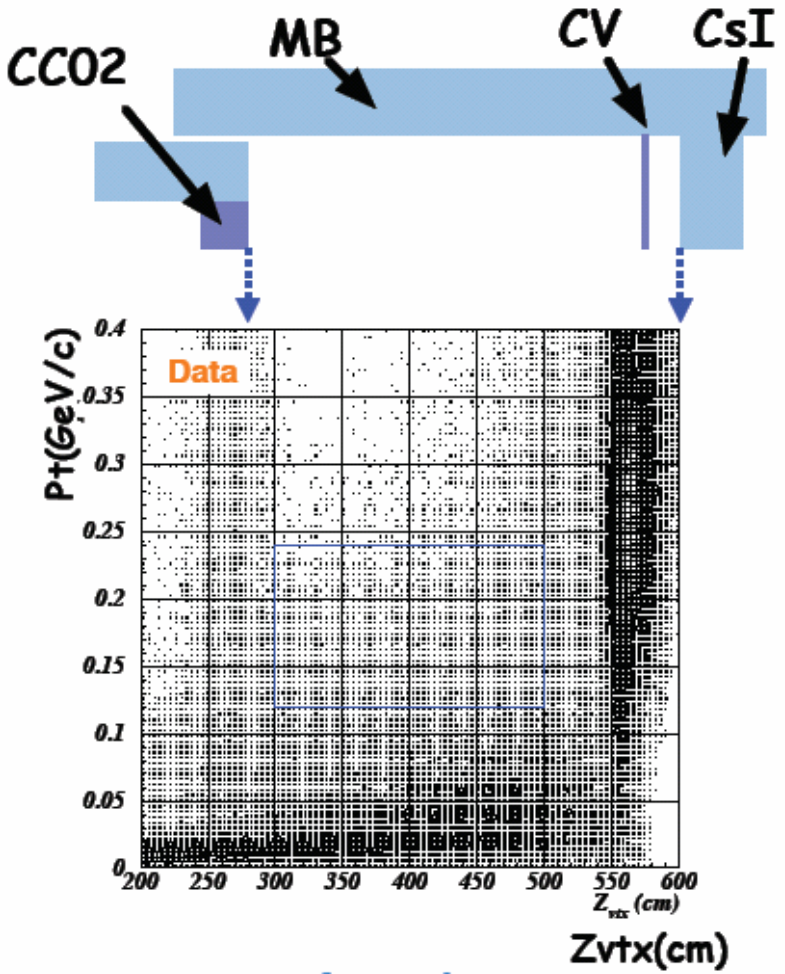
- Background

1. core neutron
2. halo neutron ($n+X \rightarrow \pi^0+X'$)



3. $K_L \rightarrow 2\pi^0$, 2γ missing

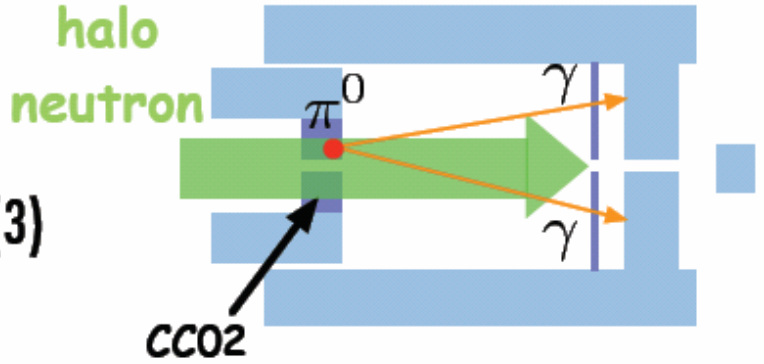


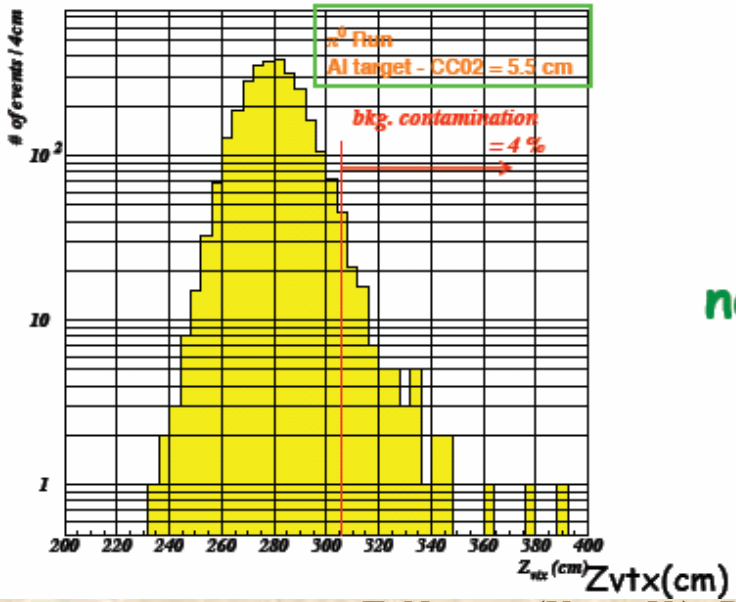


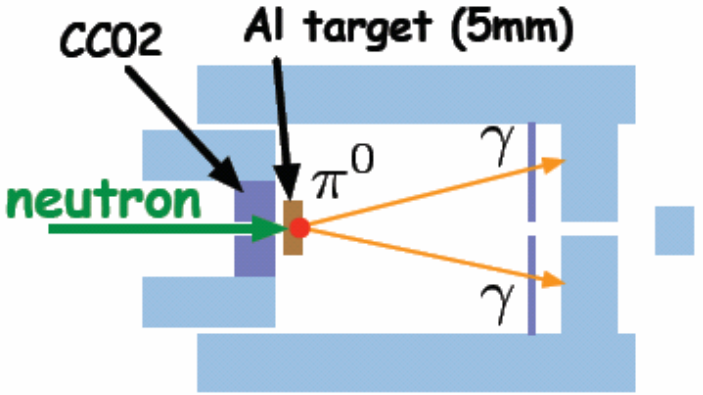
Data after online trigger

E391a Halo Neutron BG

- Halo neutron background
  - "$\pi\pi^0$ run" w/ Al target in the beam
  - $N_{bkg} = 0.04 \pm 0.04$ in region (3)
  - $N_{bkg} = 0.9 \pm 0.2$ in region (1)

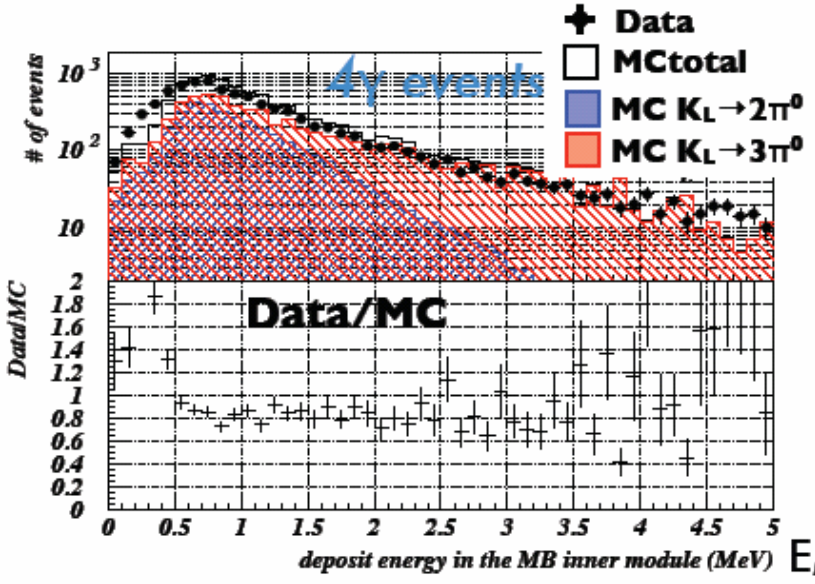


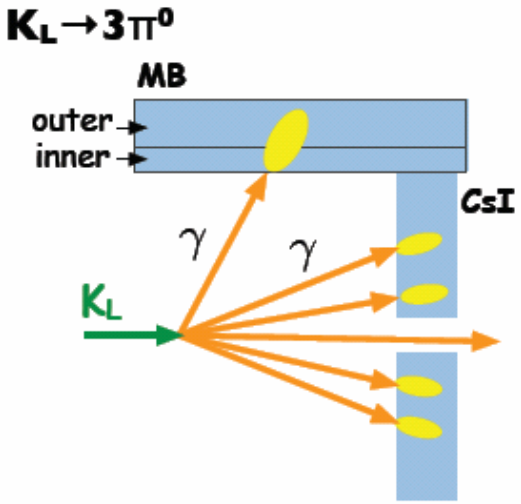


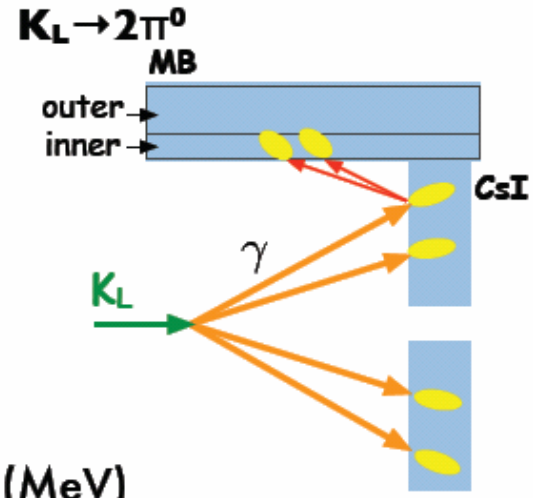


E391a Photon Veto

- Hermetic Photon veto : MB
  - thr. = 1.0 MeV (inner), 0.5 MeV(outer)
  - $K_L \rightarrow 3\pi^0, 2\gamma$ x 0.26 (data)
  - $K_L \rightarrow \pi^0\nu\nu$ efficiency 60% (MC)
    - "shower-splash-back" from CsI

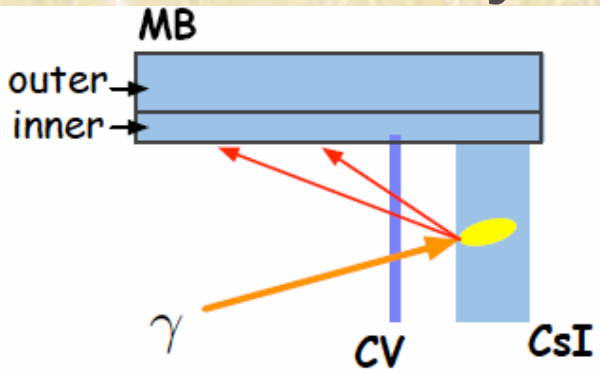


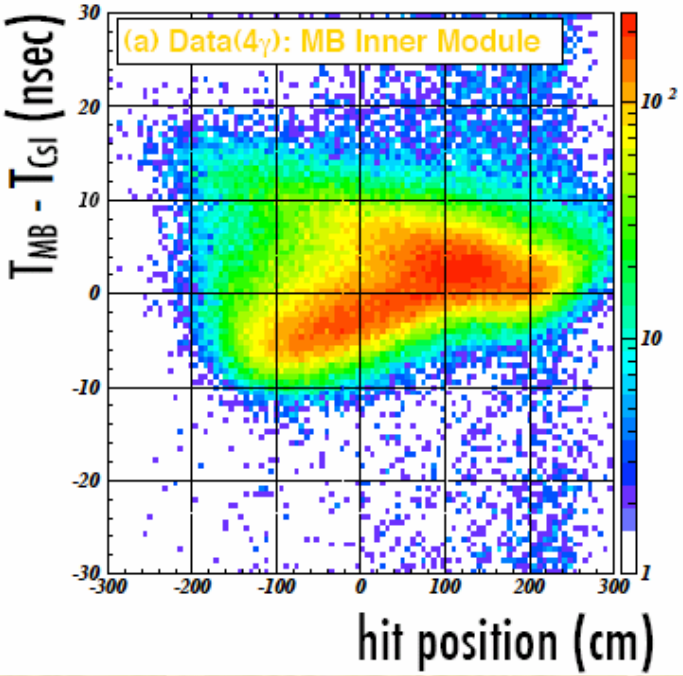


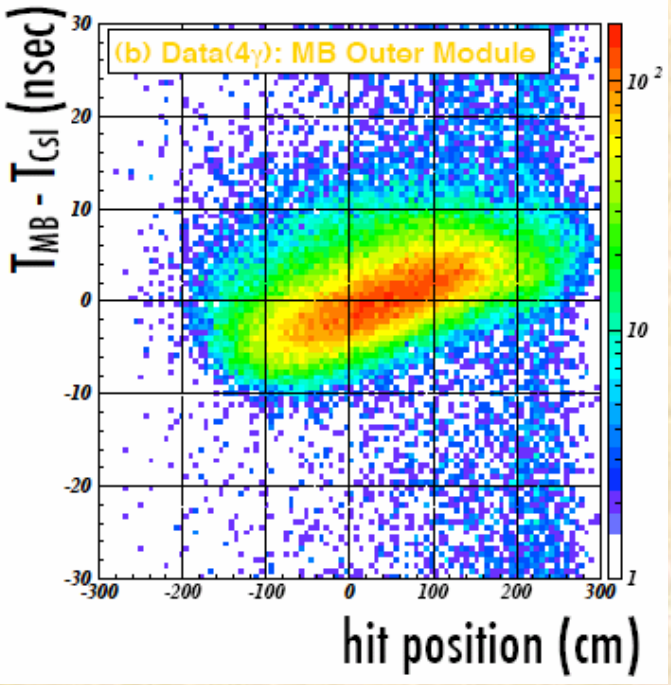


E391a Acceptance Loss by PV

- "shower-splash-back" from CsI
- hit position vs ΔT (= $T_{MB} - T_{CsI}$)







E391a Acceptance

Acceptance

$A_{sig} = [0.657 \pm 0.016] \times 10^{-2}$ ← *cut efficiencies estimated with Data and MC*

- largest signal loss caused by "photon veto cut" (MB: 40% loss, BA: 35% loss)

of K_L decays

- w/ $K_L \rightarrow 2\pi^0$ decays

$$N_{decay} = [1.67 \pm 0.04_{(\text{stat.})}] \times 10^9$$

- cross check

PDG: [4.455±0.023] x 10^{-3}

$$\frac{\Gamma_{00}}{\Gamma_{000}} = [4.16 \pm 0.09_{(\text{stat.})} \pm 0.04_{(\text{MC stat.})}] \times 10^{-3}$$

7% diff. ← the mismatch Data/MC in E_{MB}