Results from the E391a Experiment at KEK

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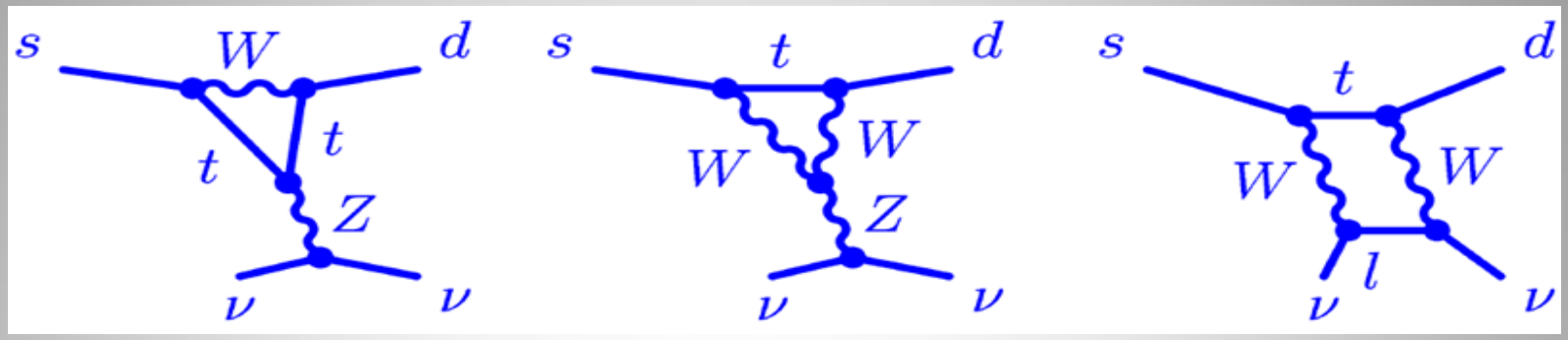
$K_L \rightarrow \pi^0\nu\nu$ Decay



CP Violating FCNC Process

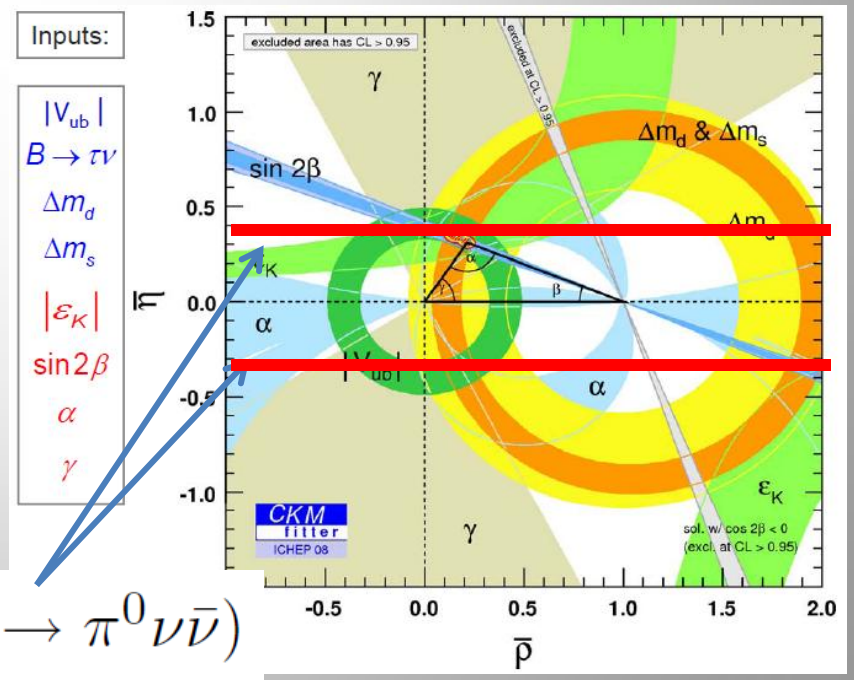
$$Br(K_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \cdot \left(\frac{\mathrm{Im}\lambda_t}{\lambda^5} X(x_t)\right)^2$$

$$\kappa_L = \frac{r_{K_L}}{r_{K^+}} \frac{\tau(K_L)}{\tau(K^+)} \kappa_+ = 1.80 \cdot 10^{-10}$$

$(2.49 \pm 0.39) \times 10^{-11}$

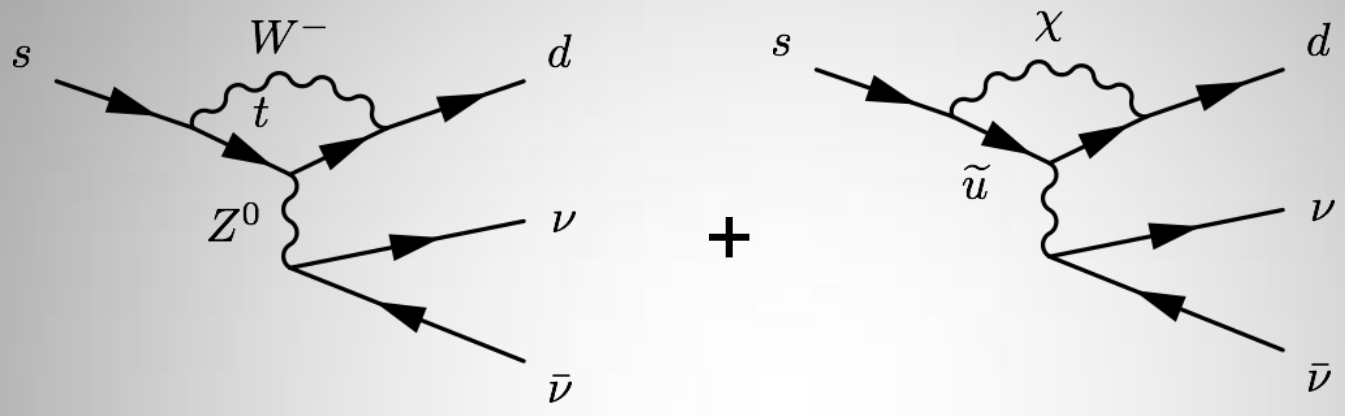
(F. Mescia and C. Smith, PRD76, 074017(2007))

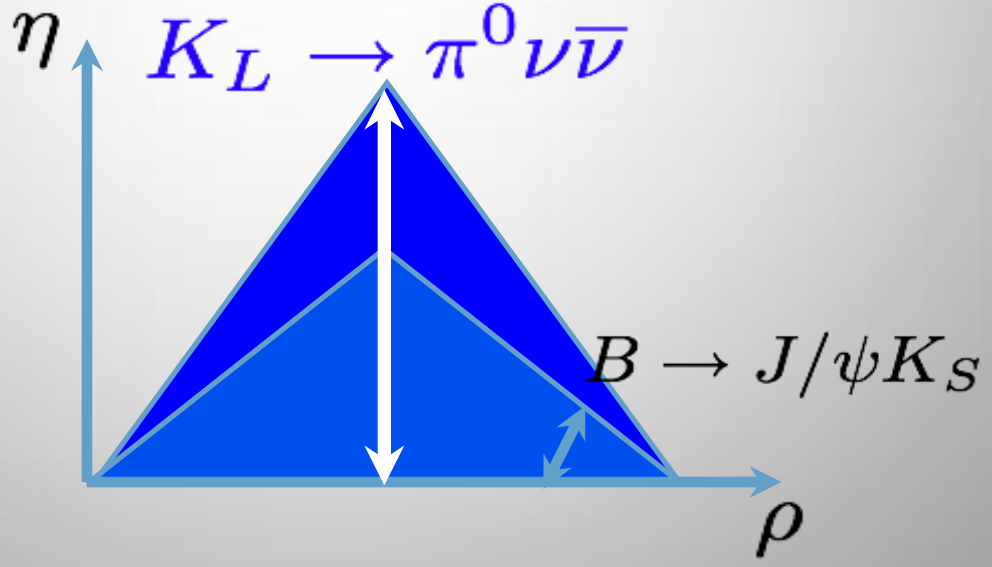
1-2 % error to evaluate the BR.



$Br(K_L \to \pi^0 \nu\bar{\nu})$

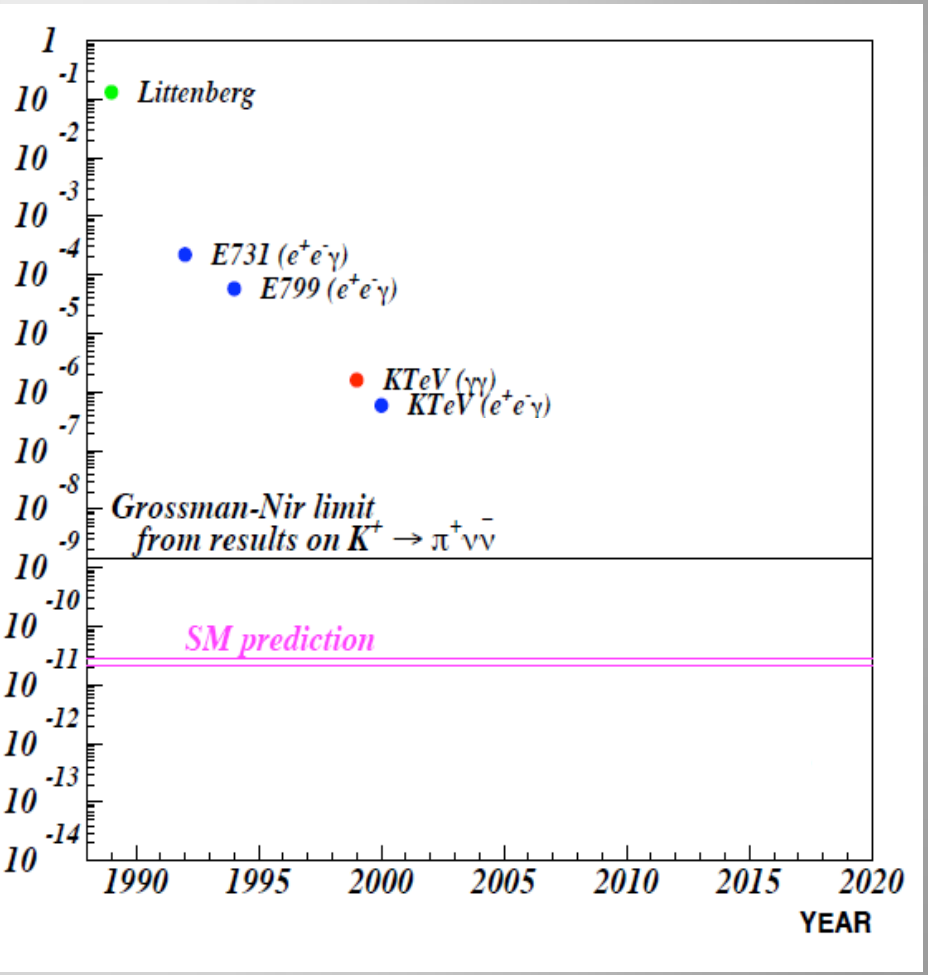
New physics contribution



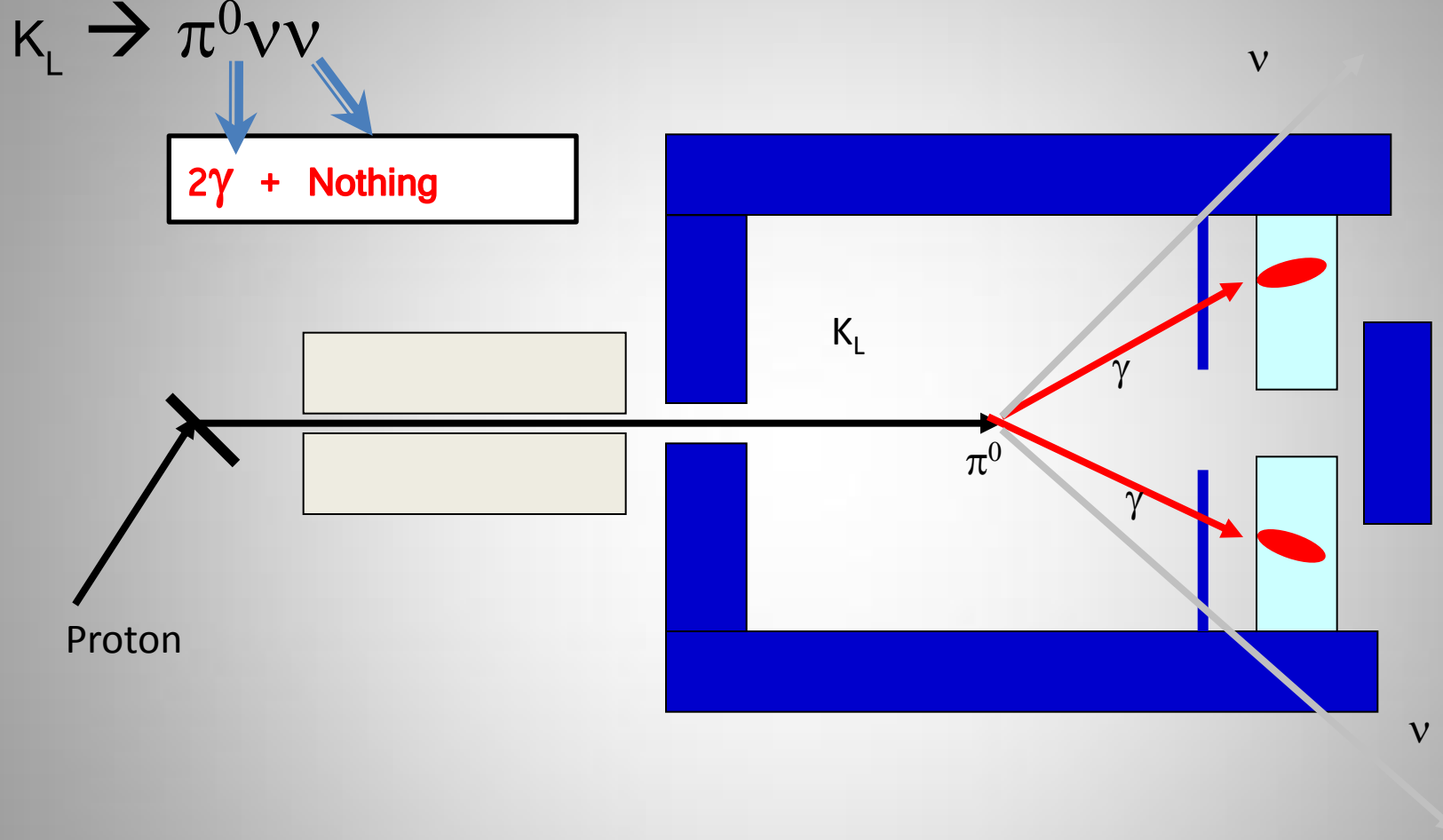


Experimental Study

- $K_L \rightarrow \pi^0\nu\nu$
  - Single π^o detection
- $\pi^o \rightarrow e^+e^-\gamma$
  - Decay vertex with tracking
  - Br($\pi^o \rightarrow e^+e^-\gamma$) ~ 1%
- $\pi^o \rightarrow \gamma\gamma$
  - Br($\pi^o \rightarrow \gamma\gamma$) ~ 99%
  - Weak kinematical constraint
  - Needs a dedicated experiment
- E391a
  - Establish an experimental method for precise meas.



Experimental Method



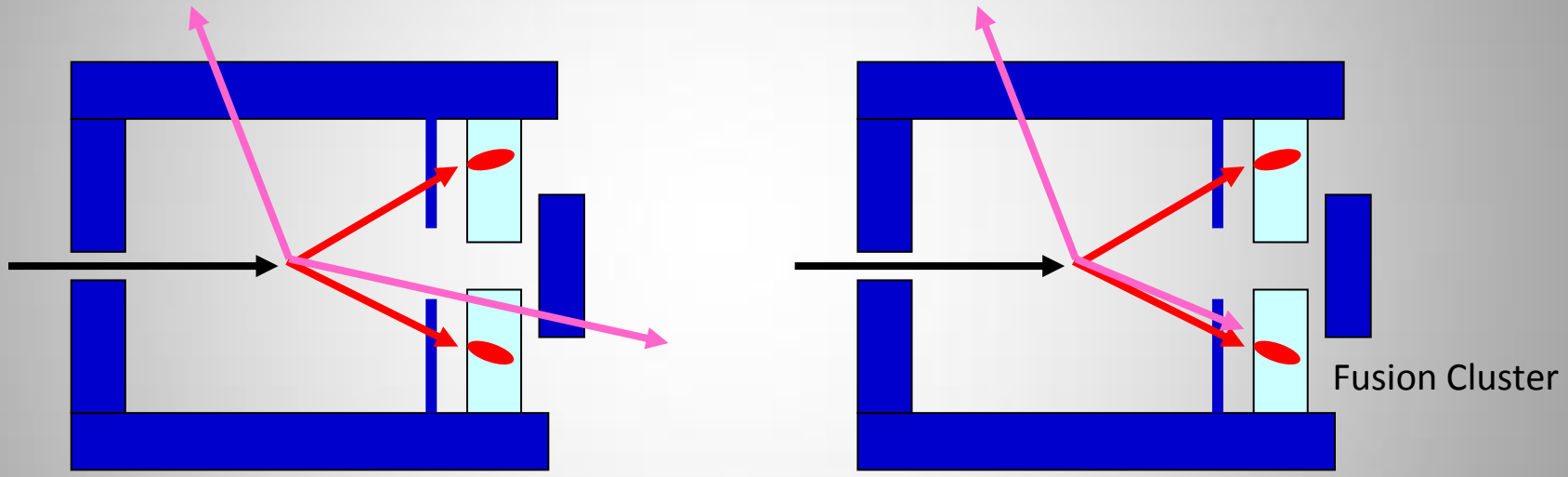
Pencil Beam + Hermetic Veto System

Experimental feature

- Extremely suppressed process (O (-11))
- Weak kinematical constraints
  - Backgrounds rejection is the main subject
- Any single π^0 generation would be background.
  - KL decays.
  - Neutrons; n+A$\rightarrow\pi^0$+n+A
- To confirm Nothing.
  - Detector system having high detection efficiency.
- Multi-particle rejection.
  - Monitoring channels (Kpi3, Kpi2, K$\gamma\gamma$).

KL background

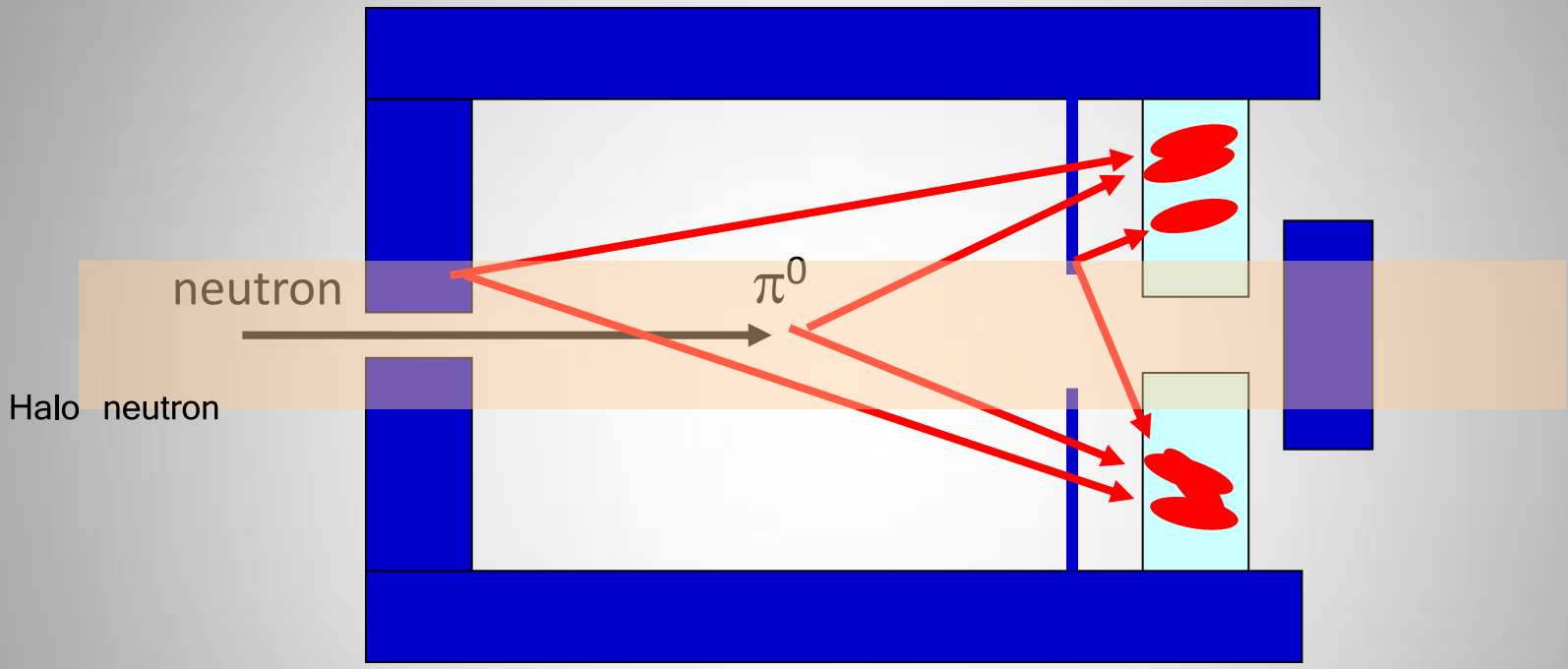
$K_L \rightarrow \pi^0\pi^0$



Hermetic veto system with high detection efficiency

Fine segmented Calorimeter for correct γ-counting

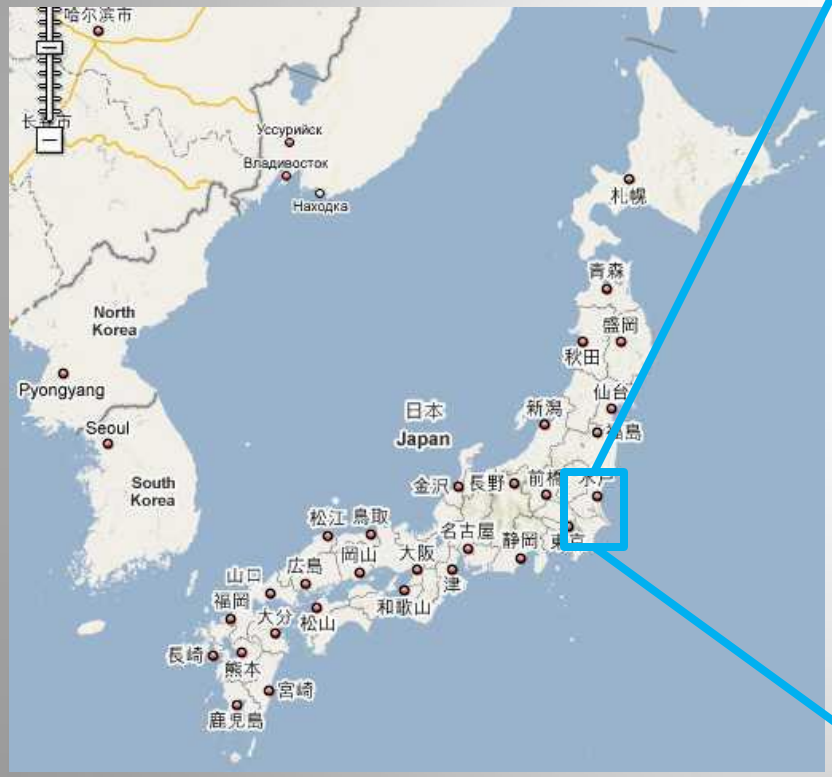
Neutron Background

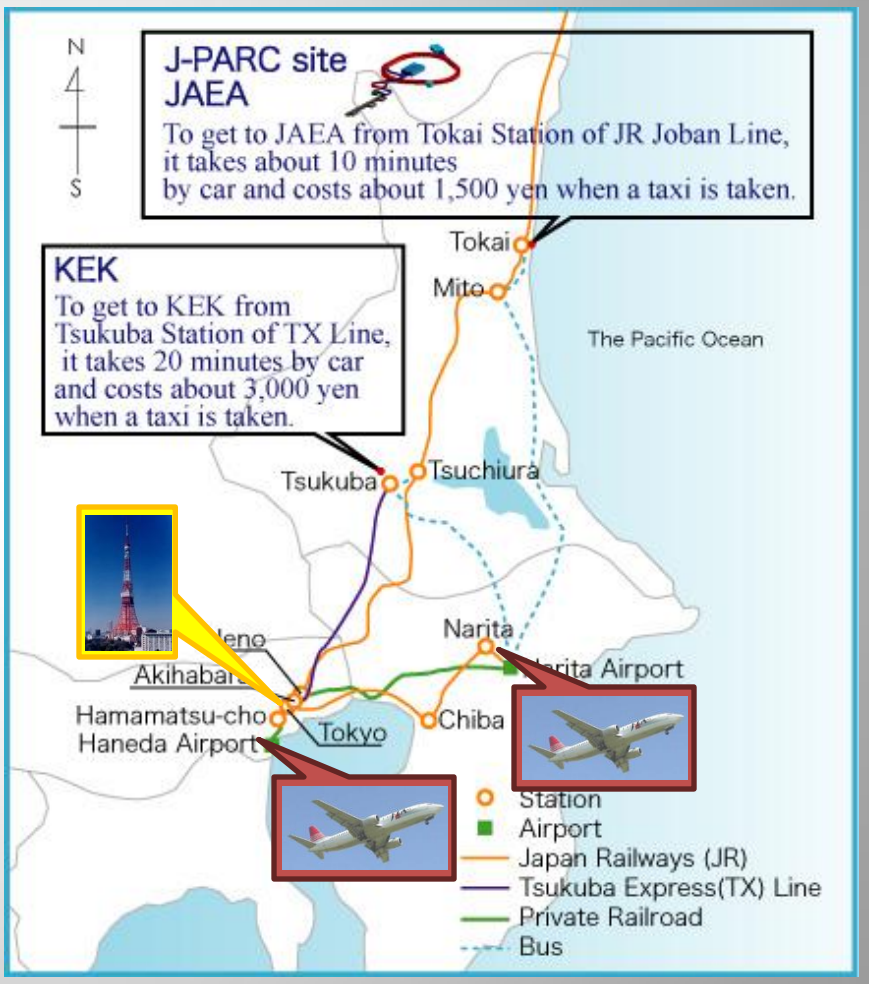


Evacuating decay region

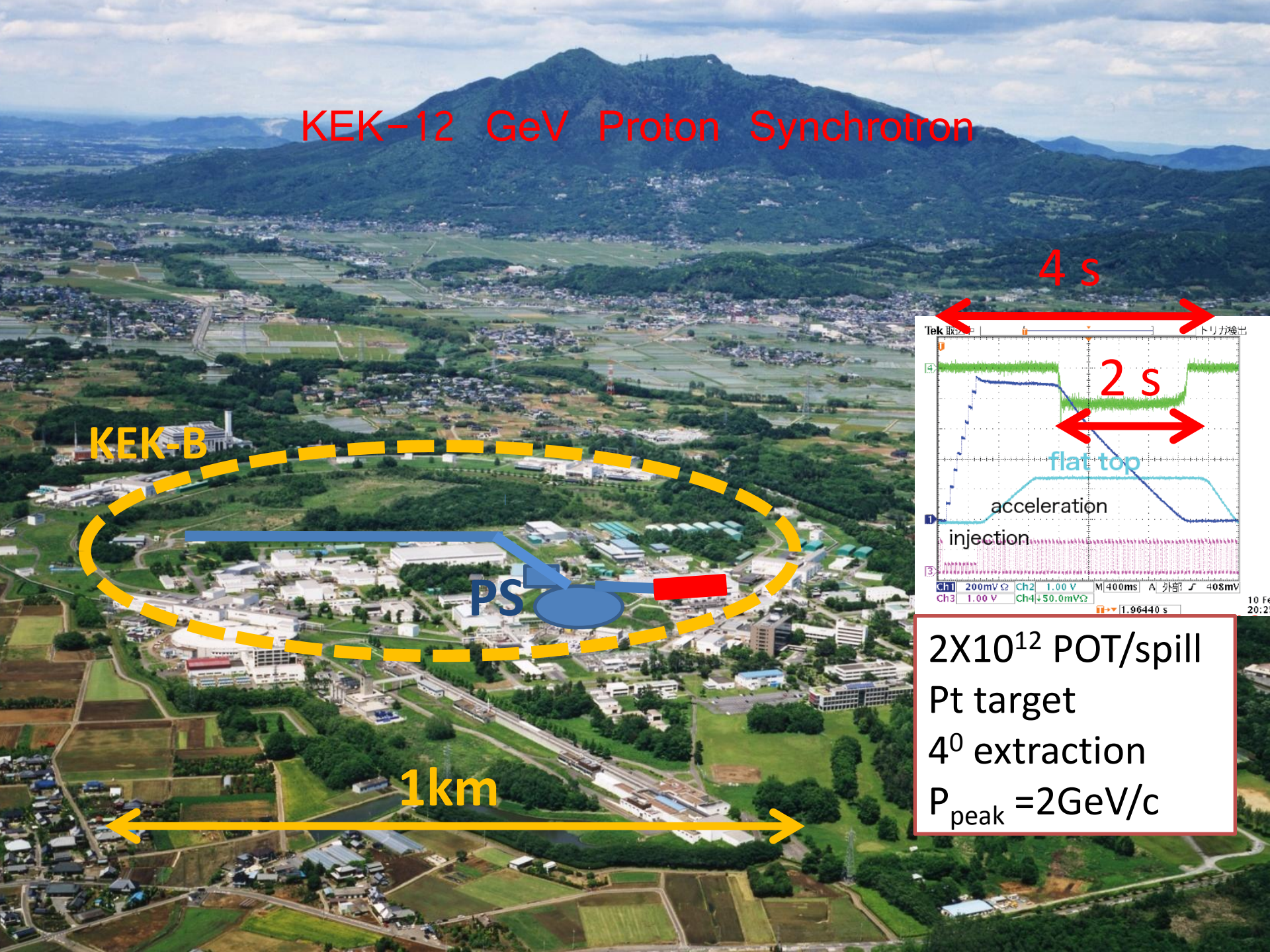
Suppressing halo neutron

E391a @ KEK-PS


哈尔滨市
Уссурийск
Владивосток
Находка
札幌
North Korea
Pyongyang
Seoul
South Korea
日本
Japan
青森
盛岡
秋田
仙台
新潟
金沢
長野
名古屋
静岡
松江
鳥取
岡山
大阪
広島
山口
福岡
大分
松山
和歌山
長崎
熊本
宮崎
鹿児島

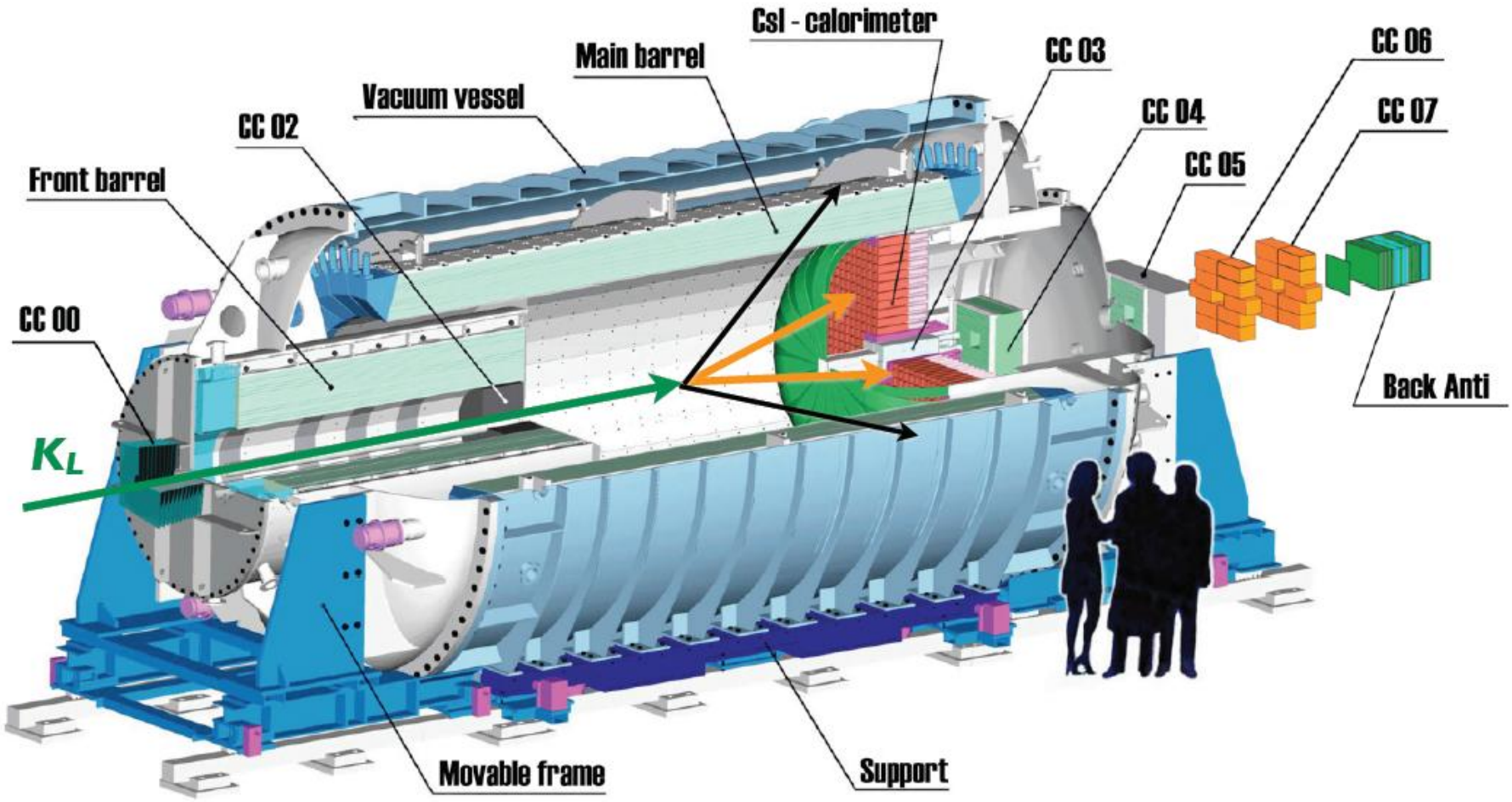

N
S
J-PARC site
JAEA
To get to JAEA from Tokai Station of JR Joban Line, it takes about 10 minutes by car and costs about 1,500 yen when a taxi is taken.
KEK
To get to KEK from Tsukuba Station of TX Line, it takes 20 minutes by car and costs about 3,000 yen when a taxi is taken.
Tokai
Mito
The Pacific Ocean
Tsukuba
Tsuchiura
Narita
Narita Airport
Akihabara
Hamamatsu-cho
Haneda Airport
Tokyo
Chiba
Station
Airport
Japan Railways (JR)
Tsukuba Express(TX) Line
Private Railroad
Bus

KEK−12 GeV Proton Synchrotron



$2X10^{12}$ POT/spill
Pt target
4^0 extraction
P_{peak} =2GeV/c

The E391a Detector



Run	Run period	POT
Run-1	Feb.–Jun. 2004	2.1×10^{18}
Run-2	Feb.–Apr. 2005	1.4×10^{18}
Run-3	Oct.–Dec. 2005	1.1×10^{18}

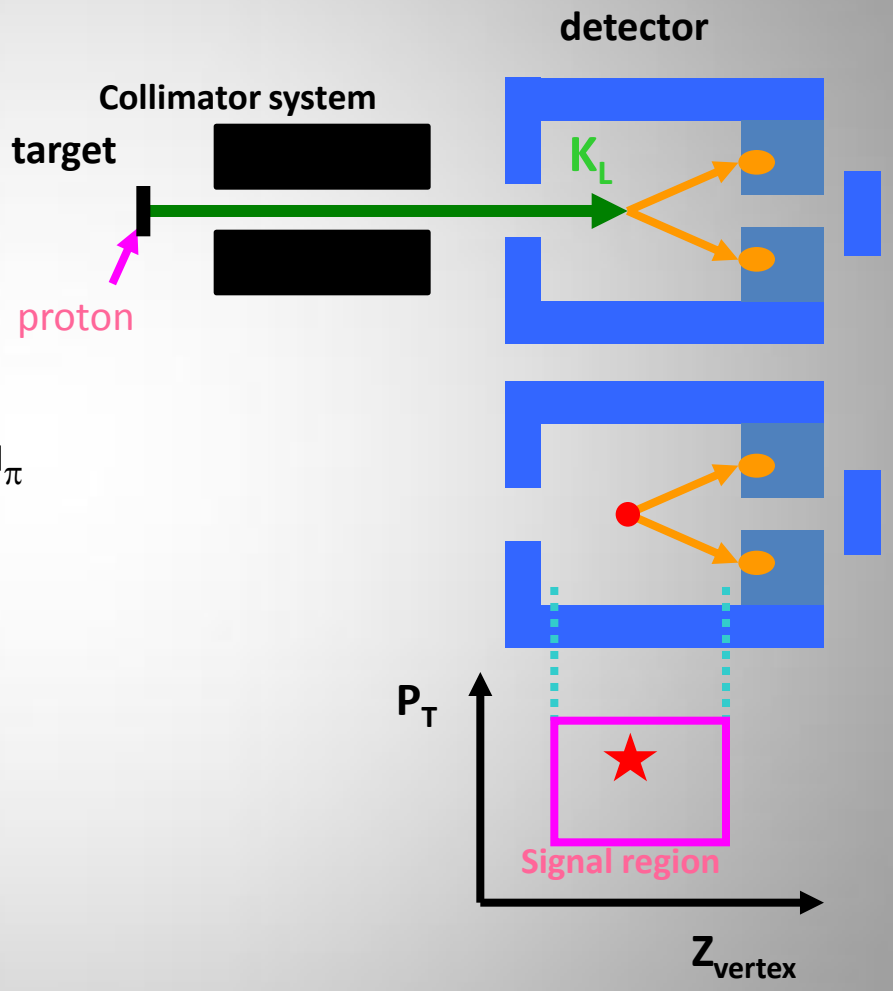
→ PRD 74,051105(R) (2006)

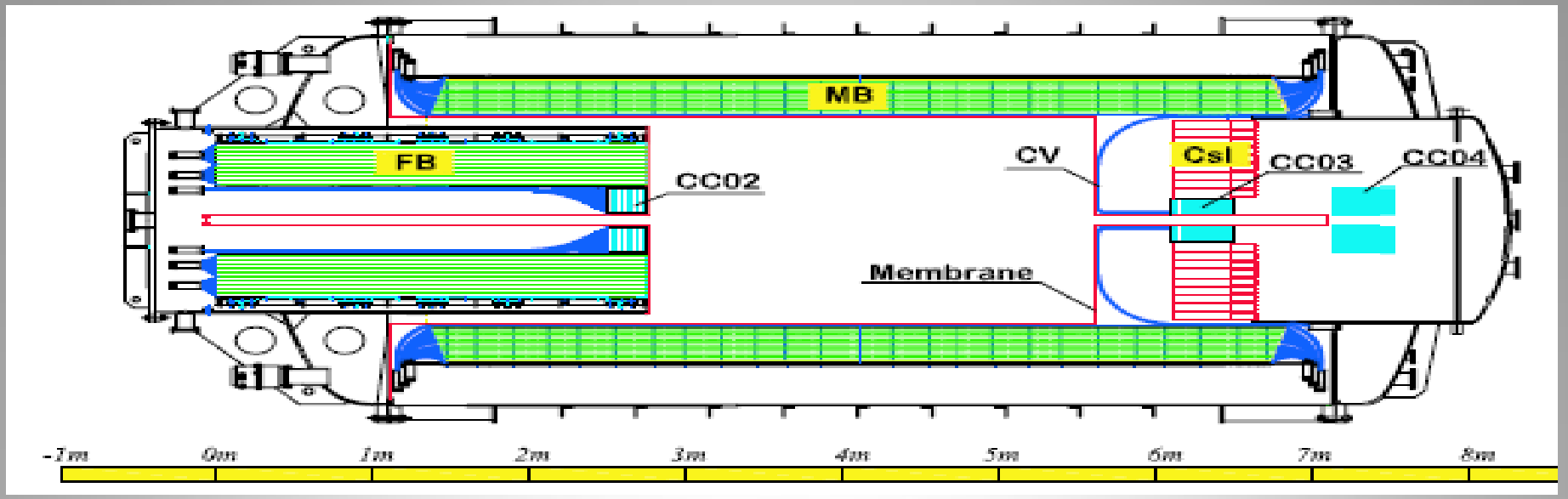
→ PRL 100,201802 (2008)

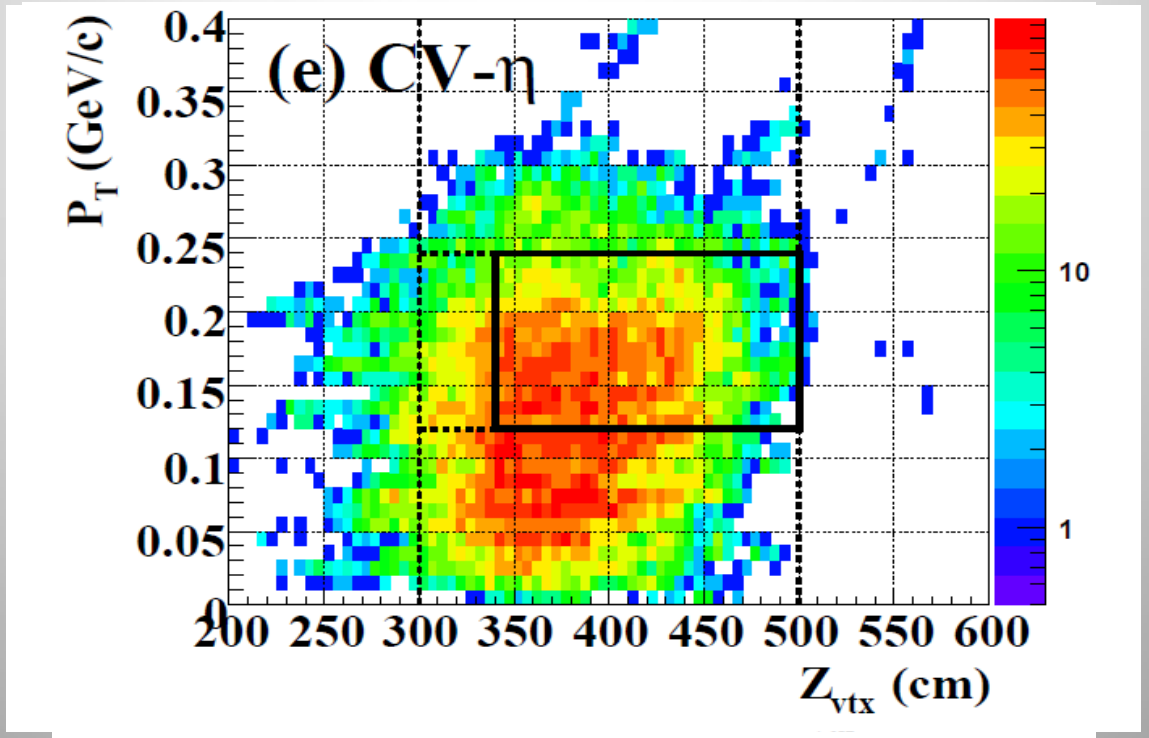
→ PRD 81,072004 (2010)

Analysis Flow

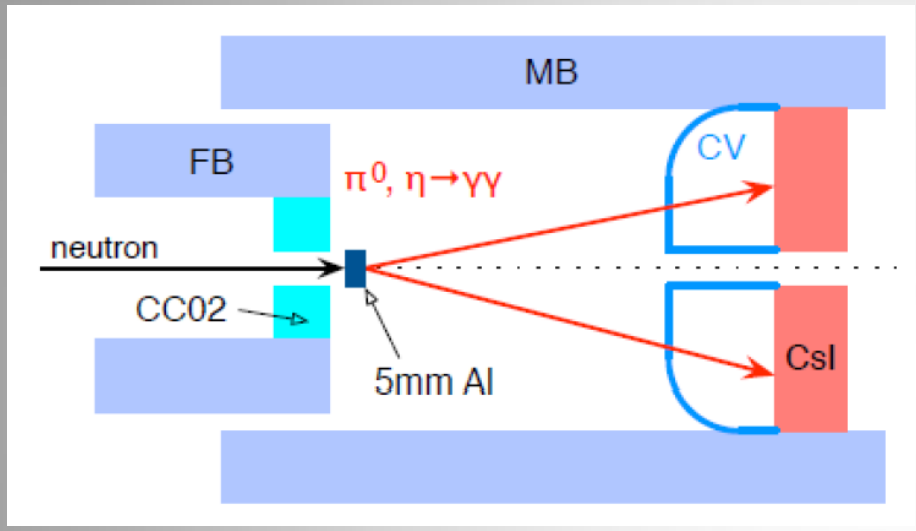
1. Require 2 photons
2. Measure the photon energies and positions
3. Reconstruct the π^0 decay vertex on the beam line assuming $M_{2\gamma} = M_\pi$
4. Calculate π^0 transverse momentum (P_T)
5. Require Nothing with tight vetoing
6. Two clusters have consistent shape of photon's EM shower for rec. π^0
7. Require high P_T and the vertex in the fiducial region

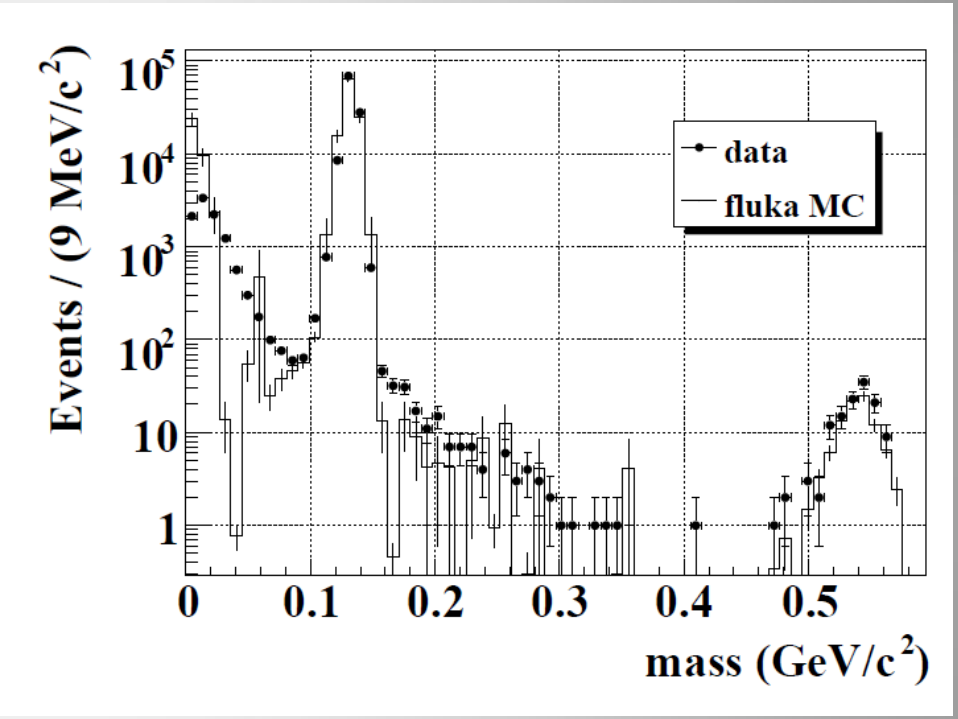



MB
FB
CC02
CV
CsI
CC03
CC04
Membrane
-1m
0m
1m
2m
3m
4m
5m
6m
7m
8m


(e) CV-η
P_T (GeV/c)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
200 250 300 350 400 450 500 550 600
Z_{vtx} (cm)
10
1

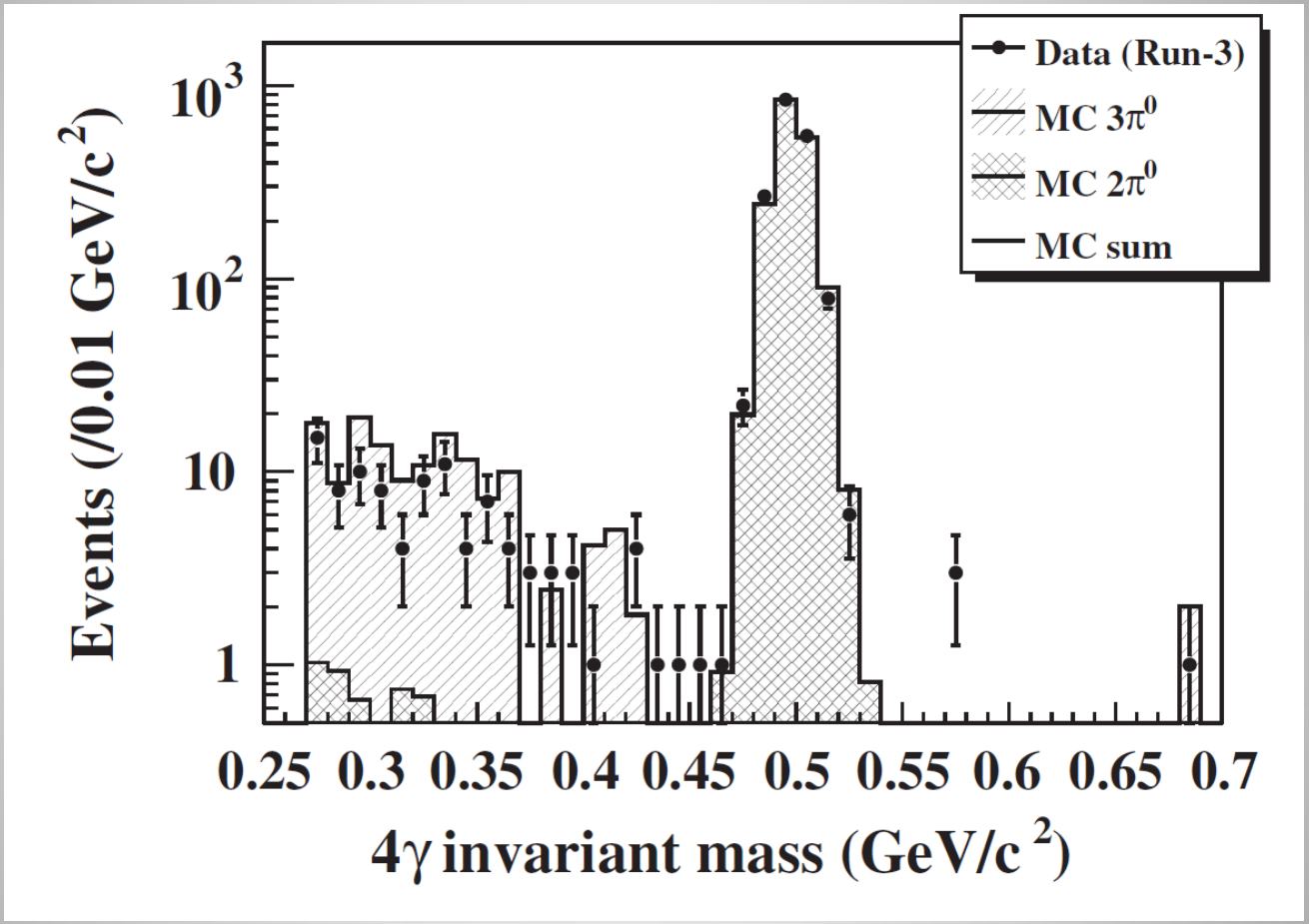
Al target Run





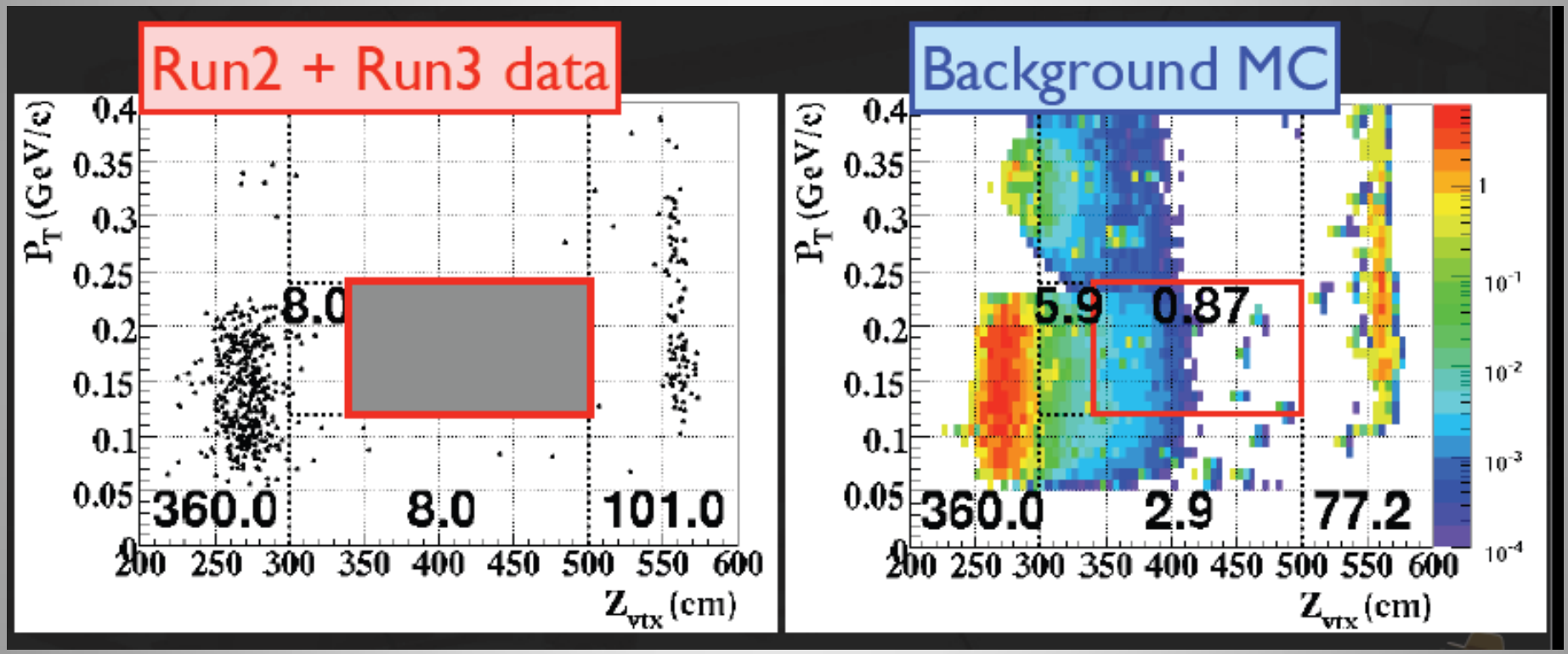
- Reference of neutron interaction
- Used for BG. estimation
- Confirmation of M.C. validity （FLUKA package）

4γ invariant mass



- Normalization of number of KL decays
- Overall check of detection inefficiency for missing photon

M.C. matched data



Summary of B.G.

Background source		Estimated number of BG
Halo neutron BG	CC02-π^0	0.66 ± 0.39
	CV-π^0	<0.36
	CV-η	0.19 ± 0.13
K_L^0 decay BG	$K_L^0 \rightarrow \pi^0\pi^0$	$(2.4 \pm 1.8) \times 10^{-2}$
	$K_L^0 \rightarrow \gamma\gamma$	Negligible
	Charged modes	Negligible ($\mathcal{O}(10^{-4})$)
Other BG	Backward π^0	<0.05
	Residual gas	Negligible ($\mathcal{O}(10^{-4})$)
Total		0.87 ± 0.41

Results

- # of KL decay

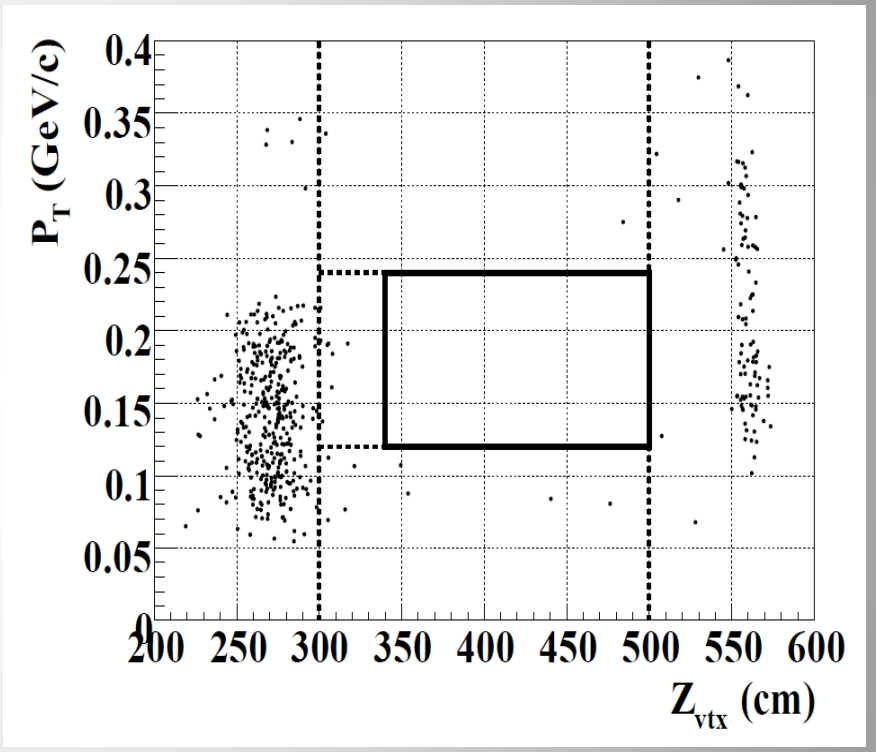
$$(8.70 \pm 0.17_{\text{stat.}} \pm 0.59_{\text{syst.}}) \times 10^9$$

- Signal Acceptance

$$A_{\text{signal}} = (1.06 \pm 0.08)\% \quad \text{(for Run-2)}$$
$$A_{\text{signal}} = (1.01 \pm 0.06)\% \quad \text{(for Run-3)}$$

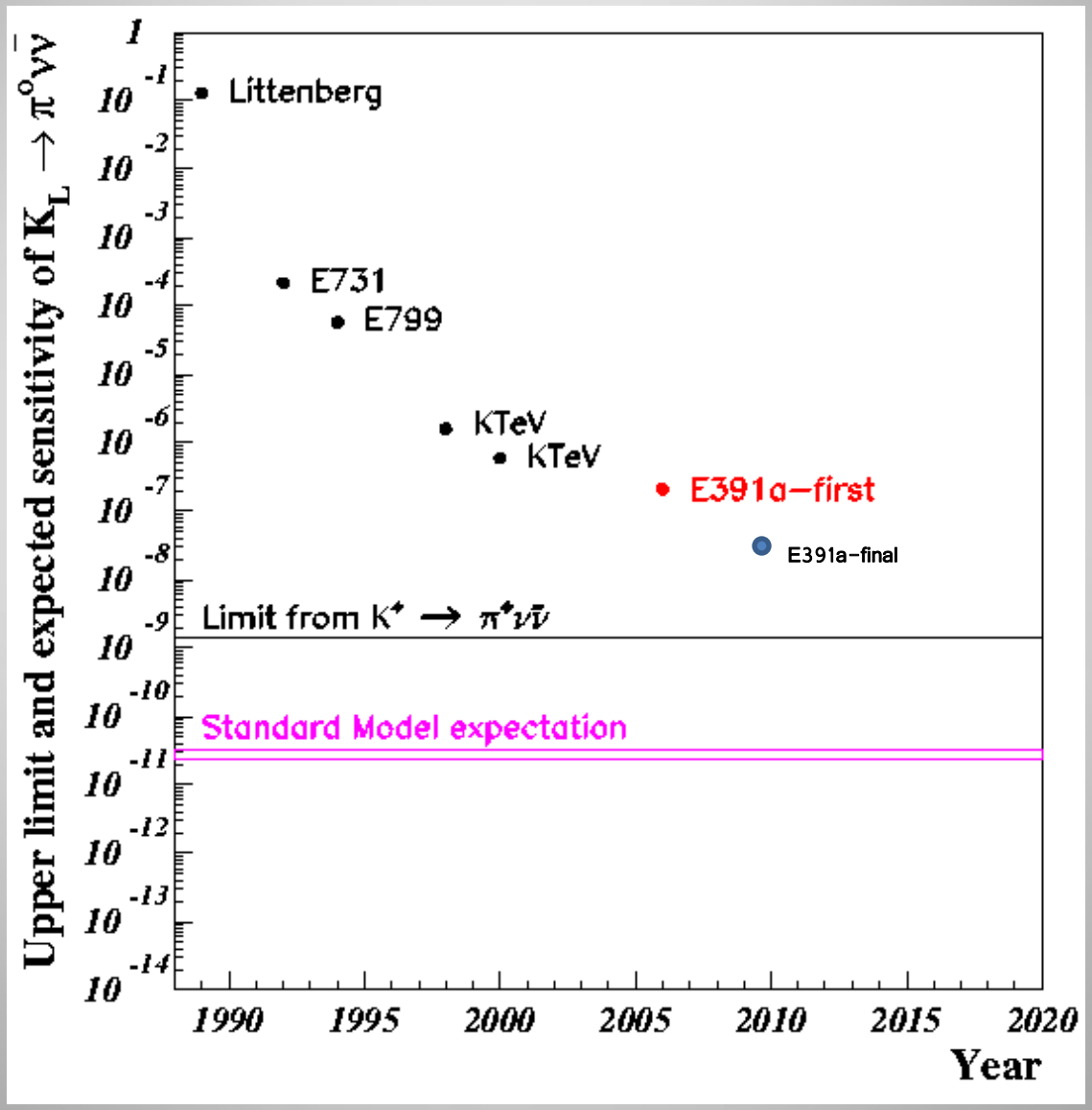
- S.E.S.

$$(1.11 \pm 0.02_{\text{stat.}} \pm 0.10_{\text{syst.}}) \times 10^{-8}$$



$Br(K_L \rightarrow \pi^0\nu\nu) < 2.6X10^{-8}$

Step-by-step


Upper limit and expected sensitivity of $K_L \to \pi^0 \nu\bar{\nu}$
Littenberg
E731
E799
KTeV
KTeV
E391a-first
E391a-final
Limit from $K^+ \to \pi^+ \nu\bar{\nu}$
Standard Model expectation
1990
1995
2000
2005
2010
2015
2020
Year

Summary

- Searching for $K_L \rightarrow \pi^0\nu\nu$ decay is difficult but interesting.
- We need a dedicated experiment.
- E391a allowed us to move forward to the next step with the same way.
- Neutron backgrounds were dominated.
  - We will suppress them down to O(-11)
  - Step-by-step approach

Acceptance

Selections / Reasons	Acceptance
Geometrical acceptance	19.5 %
Veto cuts	47.4 %
Kinematic selections	22.8 %
P_T-Z_{VTX} selection	51.6 %
Accidental activities	92.6 (89.4) %
Total	1.06 (1.01) %

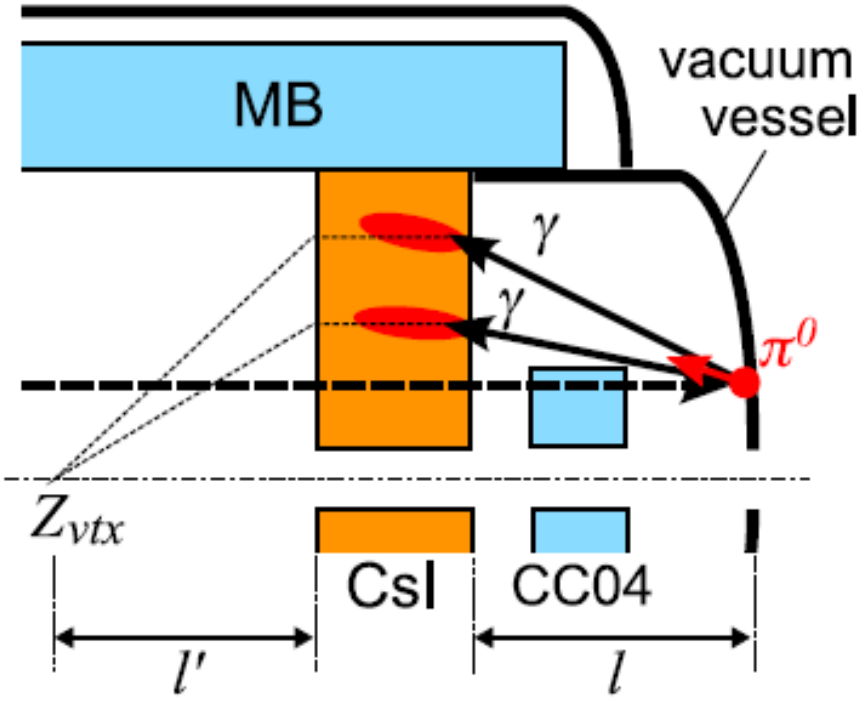


Figure 8.9: Mechanism of backward-going π^0 background.

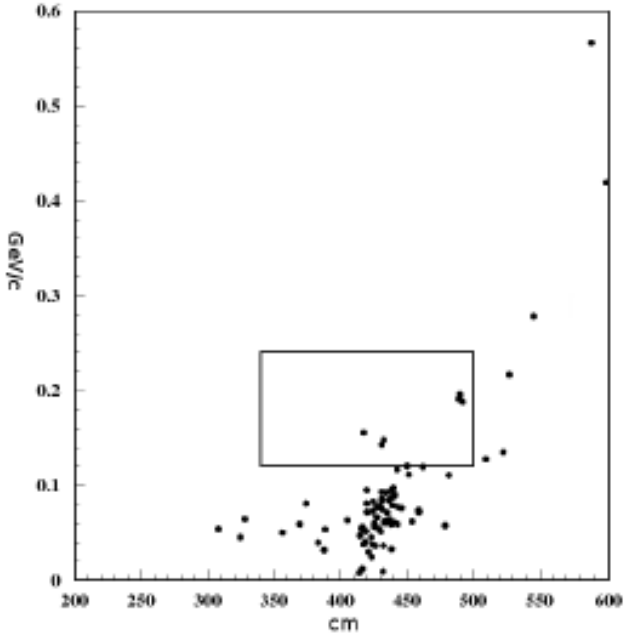


Figure 8.10: P_T vs. Z_{VTX} distributions of the backward-going π^0 background with all veto cuts are imposed.