$K_L \to \pi^0 \nu \bar{\nu}$ Experiment at J-PARC

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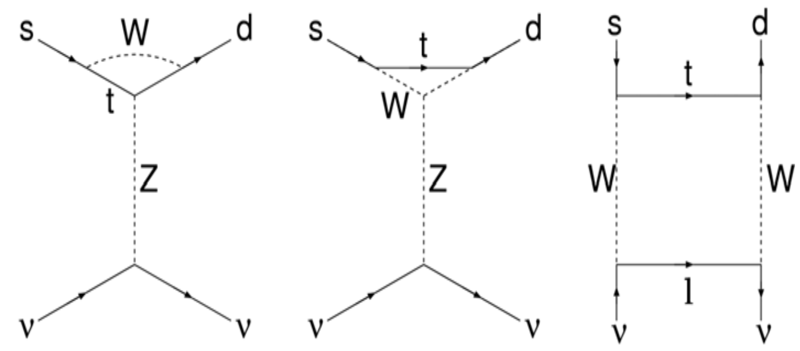
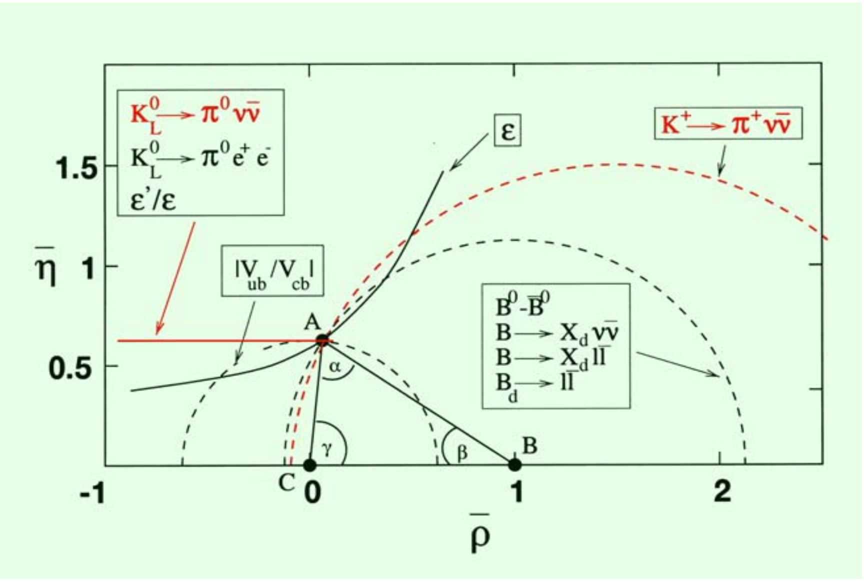
Golden Channel in K Decays

$K_L \to \pi^0 \nu \bar{\nu}$:

- CP violation in FCNC process.
- Clean measurement of $\mathrm{Im}(V_{td}) \sim \eta$.
- Test of the Standard Model
- Clue for new physics
  in comparison with *B* physics.





$$Br(K_L \to \pi^0 \nu \bar{\nu}) = 6\kappa_1 (Im(V_{td} V^*_{ts}))^2 X^2(x_t)$$

$$\sim 1.94 \mathrm{x} 10^{-10} \eta^2 A^4 X^2$$

$$\sim \mathbf{3x10^{-11}}$$

Theoretical uncertainty is small (~1%).

Ligeti

Still Room for Future Progress

- Many interesting decay modes will not be theory limited for a long time

Measurement (in SM)	Theoretical limit	Present error
$B \to \psi K_S \ (\beta)$	$\sim 0.2^\circ$	1.6°
$B \to \phi K_S,\ \eta^{(\prime)} K_S, \ldots\ (\beta)$	$\sim 2^\circ$	$\sim 10^\circ$
$B \to \pi\pi,\ \rho\rho,\ \rho\pi \ (\alpha)$	$\sim 1^\circ$	$\sim 15^\circ$
$B \to DK \ (\gamma)$	$\ll 1^\circ$	$\sim 25^\circ$
$B_s \to \psi\phi \ (\beta_s)$	$\sim 0.2^\circ$	—
$B_s \to D_s K \ (\gamma - 2\beta_s)$	$\ll 1^\circ$	—
$\lvert V_{cb} \rvert$	$\sim 1\%$	$\sim 3\%$
$\lvert V_{ub} \rvert$	$\sim 5\%$	$\sim 15\%$
$B \to X \ell^+ \ell^-$	$\sim 5\%$	$\sim 25\%$
$B \to K^{(*)} \nu\bar{\nu}$	$\sim 5\%$	—
$K^+ \to \pi^+ \nu\bar{\nu}$	$\sim 5\%$	$\sim 70\%$
$K_L \to \pi^0 \nu\bar{\nu}$	$< 1\%$	—

It would require breakthroughs to go significantly below these theory limits

Remains as a Frontier

- Rare decay (Br～10^{-11})
- No definite kinematical constraint.

  $K_L \rightarrow \pi^0 \nu \bar{\nu} \Rightarrow 2\gamma +$ nothing

  Very difficult experiment

- Large BG.

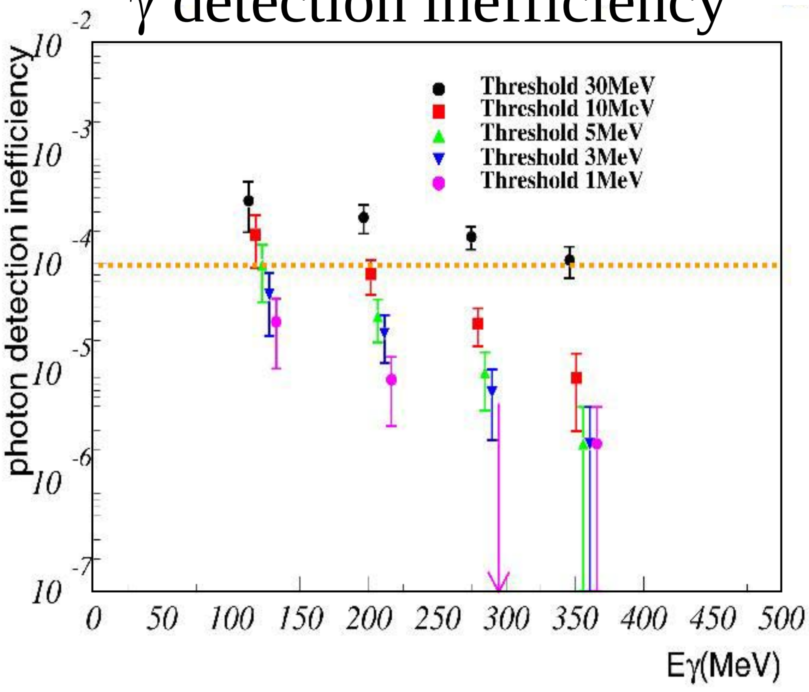
  $K_L \rightarrow 2\pi^0$, 2γ-missing

  (Br ~ 10^{-3})

$10^{-3} \rightarrow 10^{-11}$: 10^{-8} of reduction

$\Rightarrow (10^{-4})^2$ of γ inefficiency

γ detection inefficiency

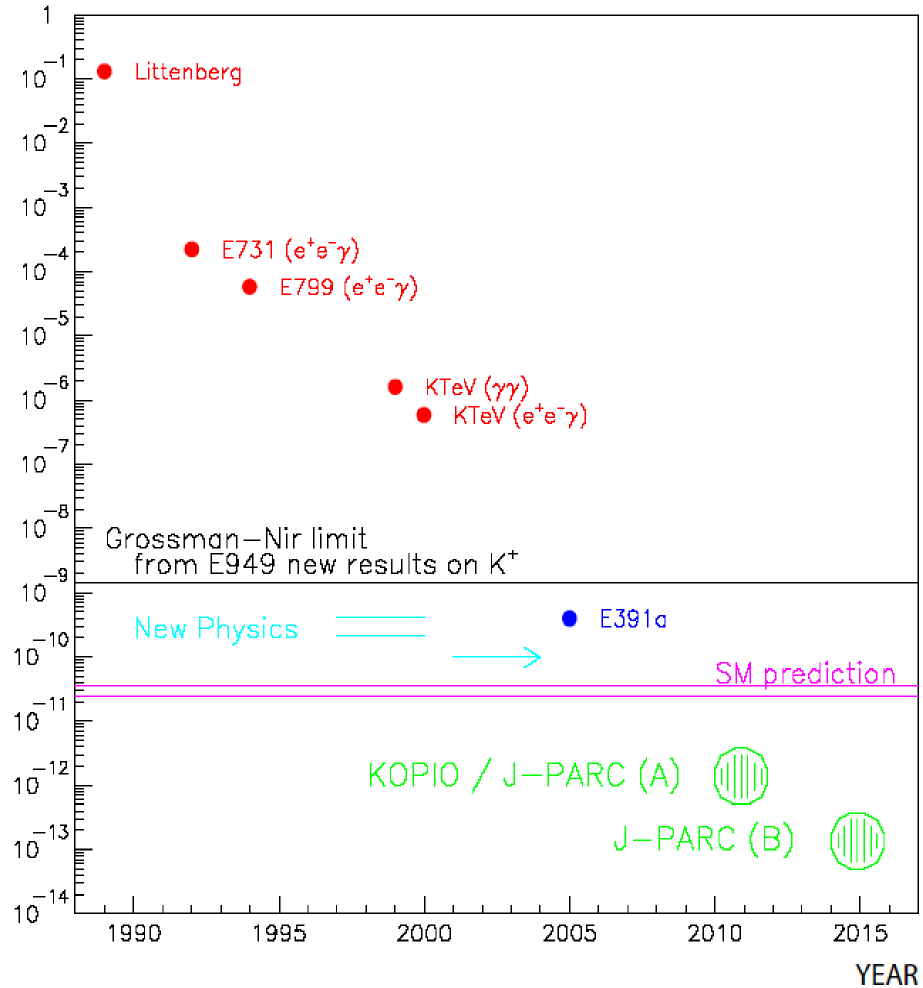


Two Concepts for the Experiment

- KOPIO : Kinematical constraint as much as possible to reduce backgrounds.
  - TOF by bunched-beam, angular measurement of γ,
  - Acceptance is not so high.
  - Low momentum $K_L \rightarrow \gamma$ inefficiency
- **E391a, J-PARC** : **Simply observe 2γ + nothing.**
  - High acceptance.
  - High momentum $K_L \rightarrow$ Better γ inefficiency

Goal

- Present experimental limit
  - Br ~ 5.9 x 10^{-7} (KTeV)
- KEK PS-E391a : ~ 10^{-10}



Goal :

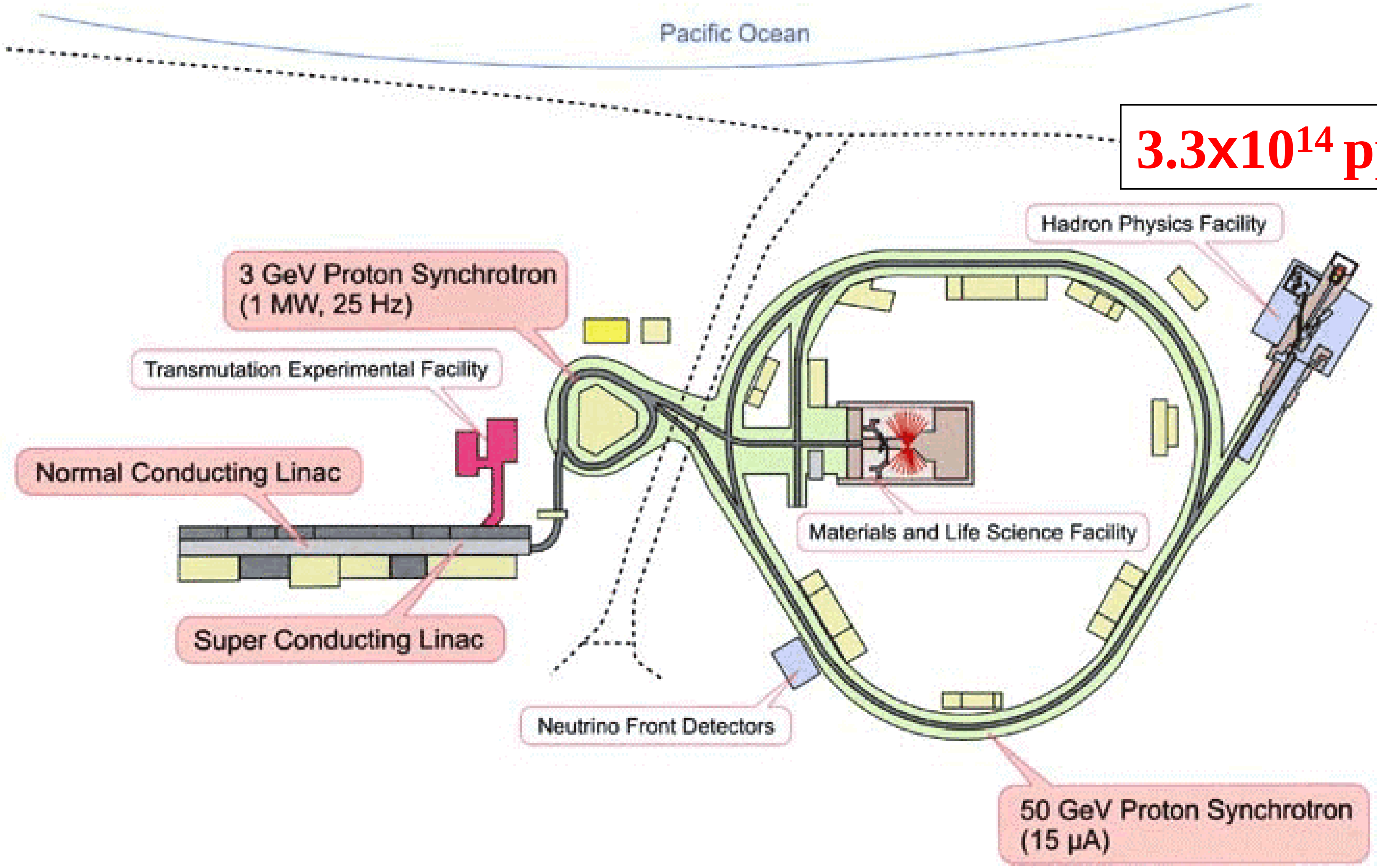
- < **10^{-13}** of the sensitivity
- > **100** SM events
- $\Delta\eta/\eta < 5\%$

⇒ **High-intensity machine** is necessary.

High-Intensity Machine : J-PARC

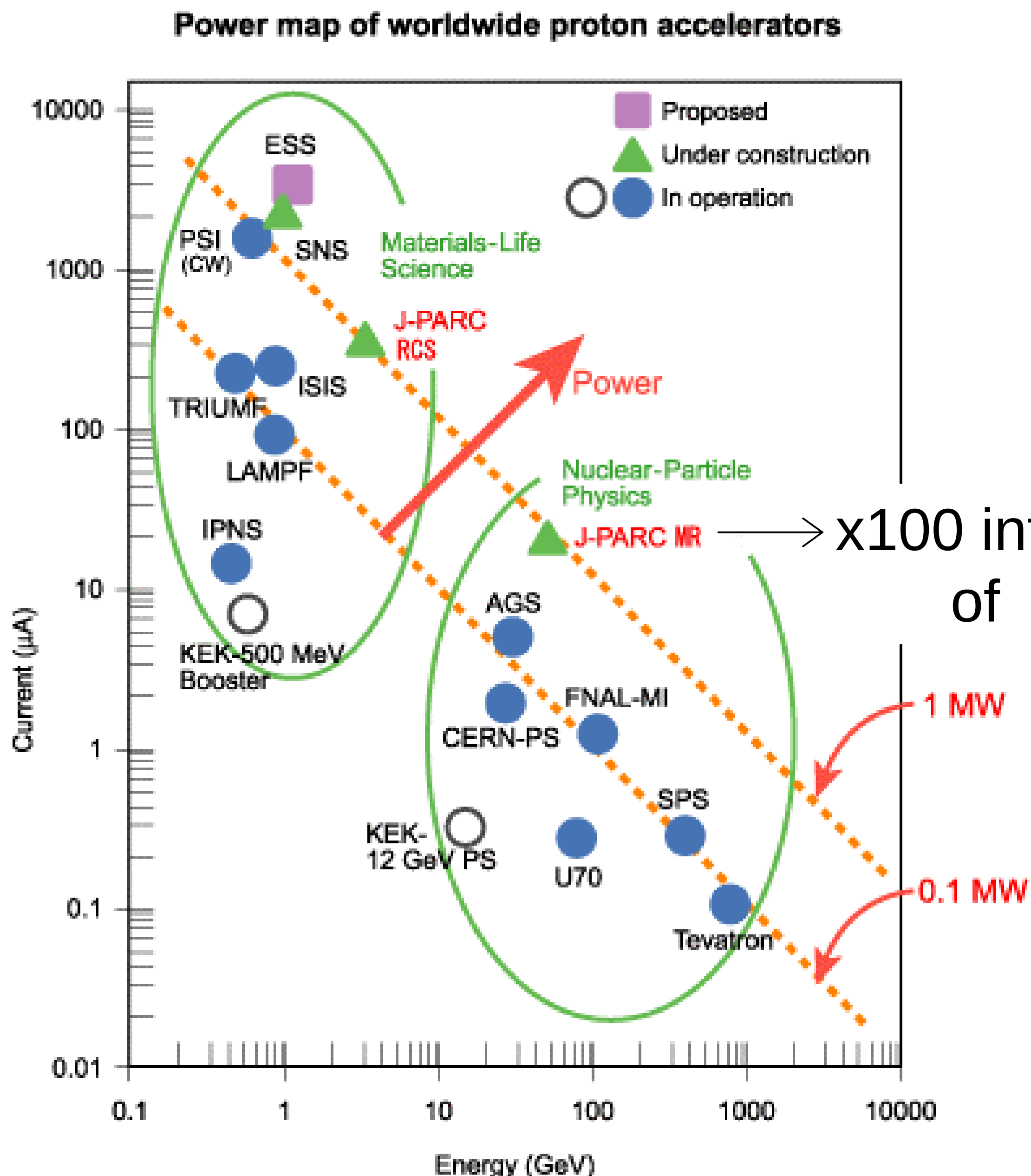
J-PARC : Accelerator Complex @Tokai

Accelerator Layouts



3.3×10^{14} ppp

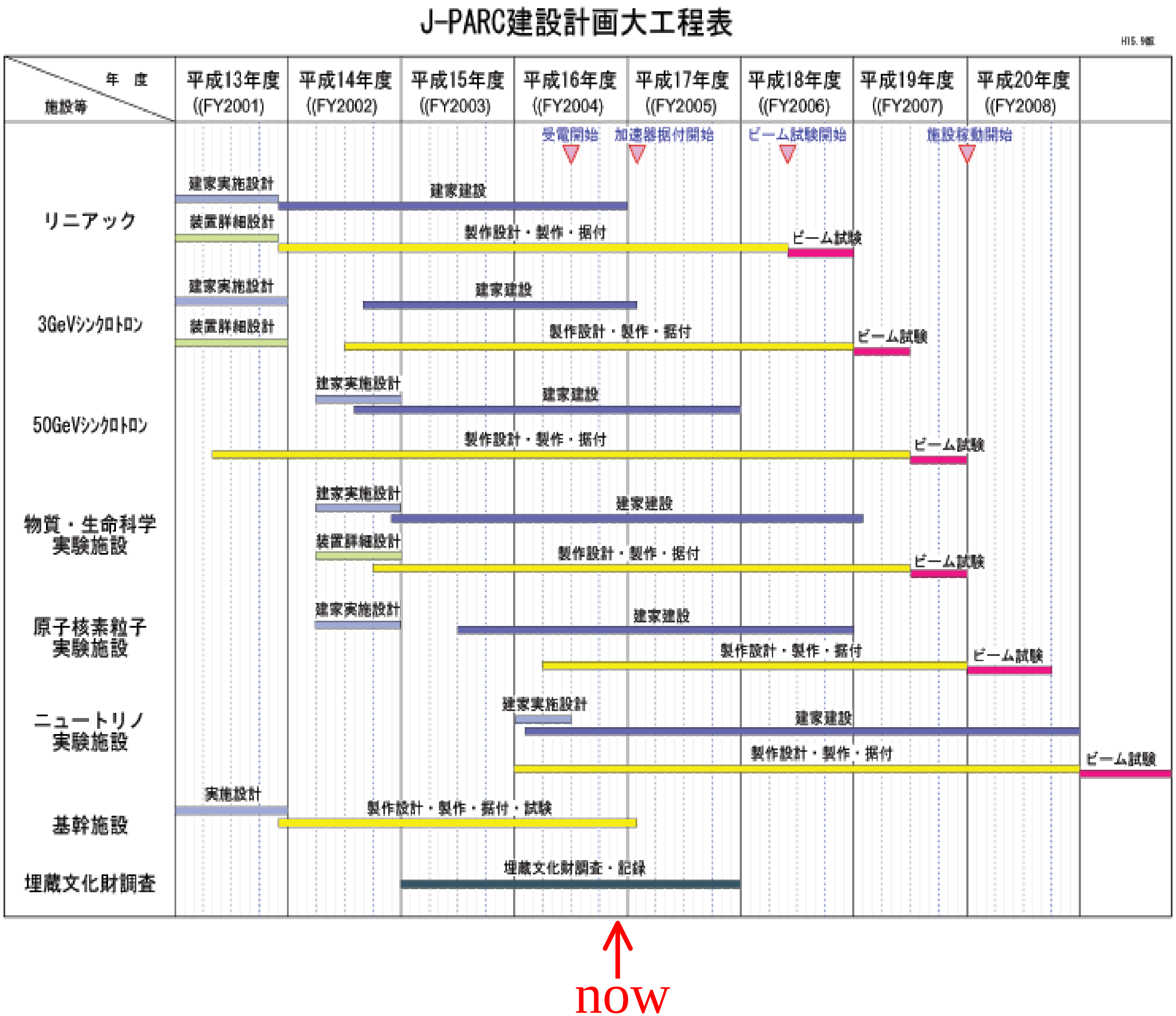
Proton accelerator in the world



x100 intensity
of KEK-PS

Schedule

Feb. 2005

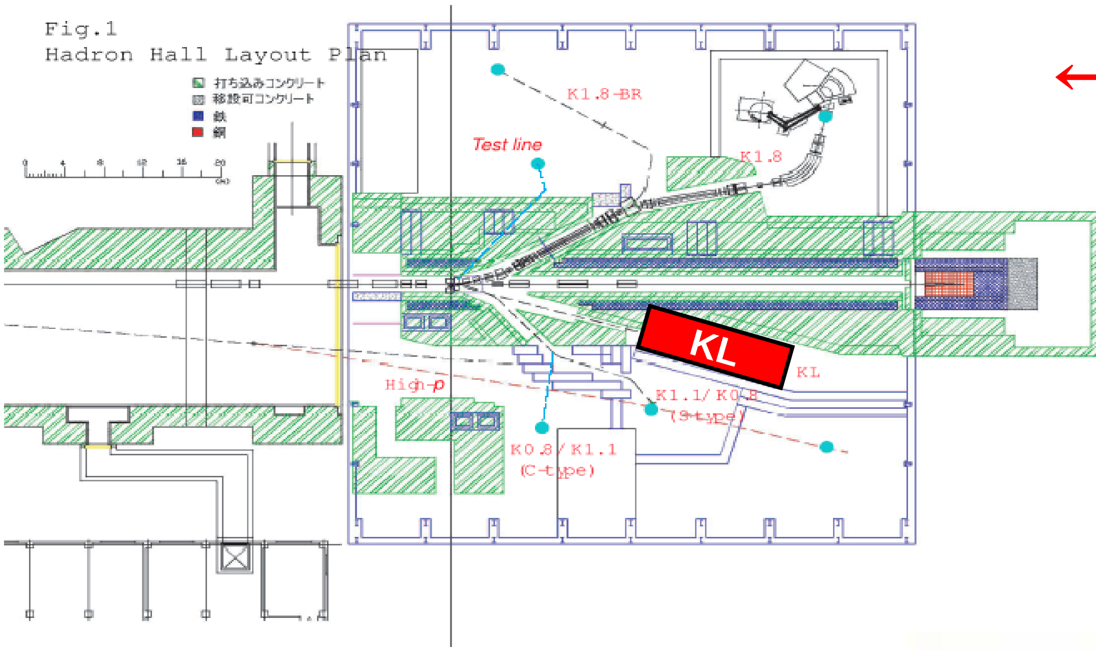


Linac

3GeV RCS

50GeV MR

Hadron Hall Layout Plan

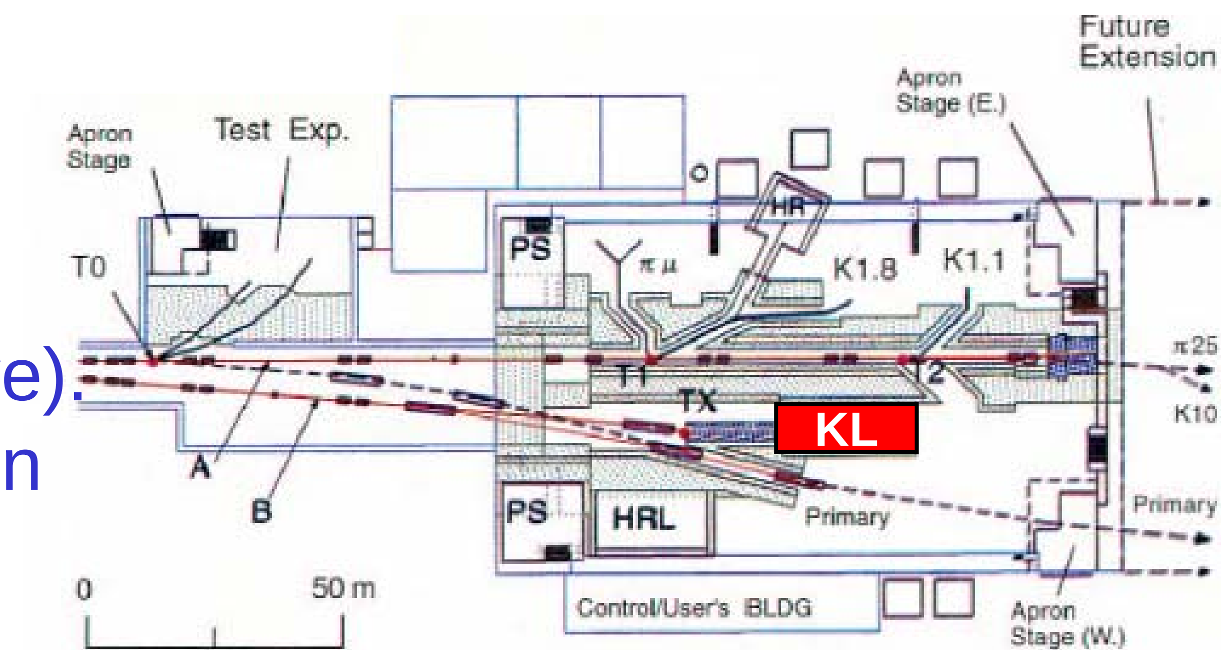


← Phase 1

- A-line only
- T1-target only
- Shared beam
- Not optimum for K_L exp.

Phase 2 →

- B-line (exclusive).
- Optimum design for K_L exp.



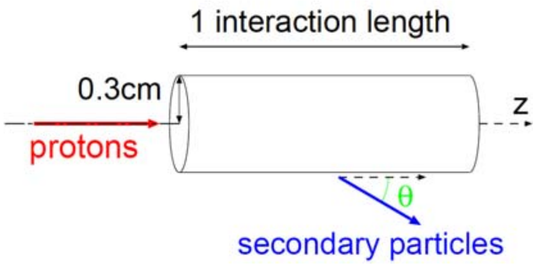
Concept for J-PARC K_L experiment

What we need

- Many signal events
  - K_L flux
    - proton flux, energy, targeting angle, beam size,
  - High acceptance

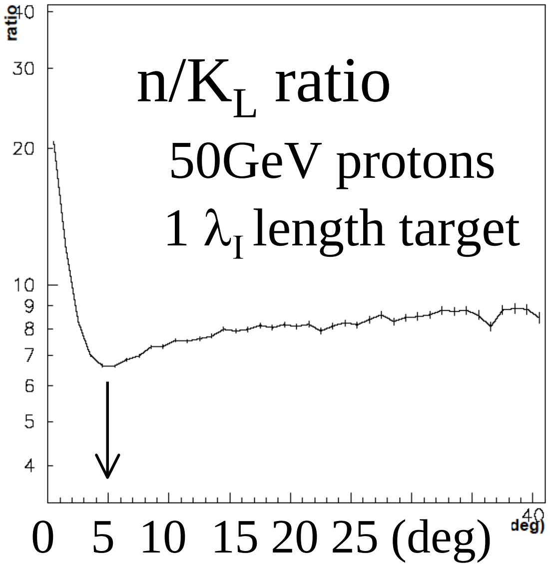
- Less background events
  - Veto efficiencies
  - $K_L \to \pi^0 \pi^0$
  - Neutrons
  - $\Lambda \to n\pi^0$

K_L flux



(MC study)

- 50 GeV protons on 1 λ_I length of target.
  - 5° extraction to minimize n/K_L ratio.
    → $<p_{KL}>$ ~ 5.8 GeV/c.
- 50m of Neutral beamline :
  - 1 μstr of solid angle (7cmϕ at detector)



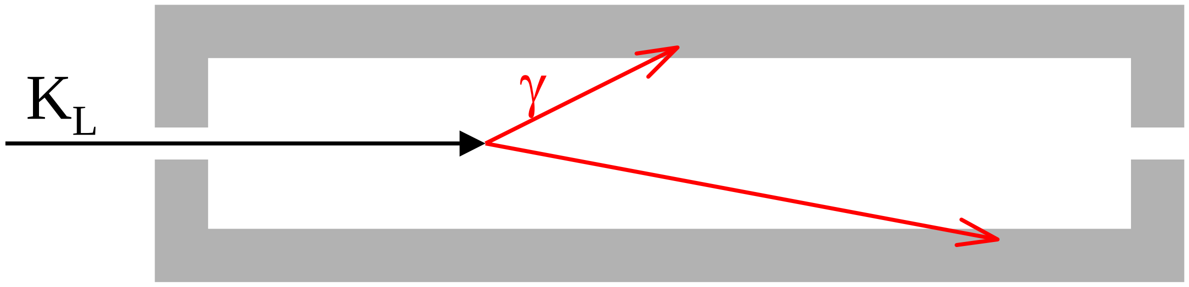
3.3 x10^{14} ppp for 3 years (3x10^7 sec)

⇒ ~5x10^{14} K_L @ detector

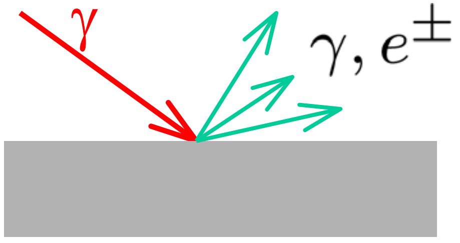
- 30 GeV protons ⇒ ~60% of K_L yield
- A-line (30GeV, 16deg extraction, T1 target, 7cmϕbeam) ⇒ ~7 % of K_L yield.

High acceptance

- Geometrical acceptance
  - Long pipe-like calorimeter (e.g. 15m-long)



- Less accidental vetoing
- Less self vetoing
  - Shower leakage kills the signal event.

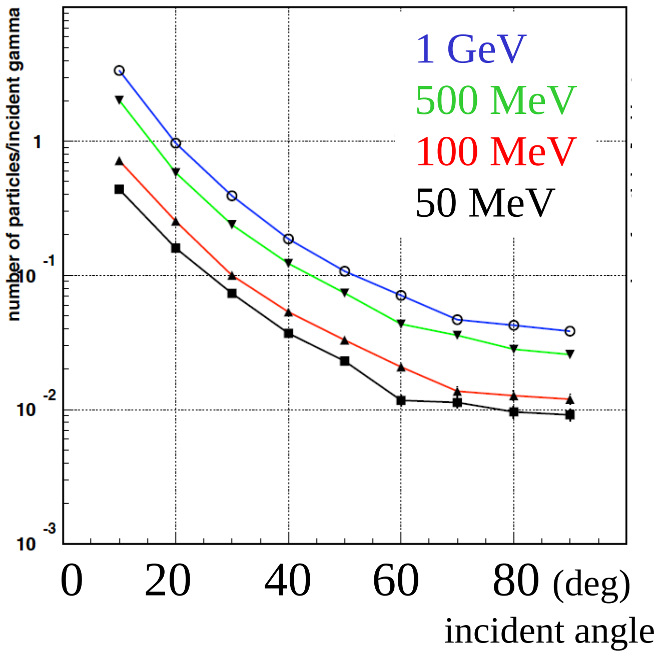


Shower-leakage effect

- Shallow incident angle
  → Larger # of leakage

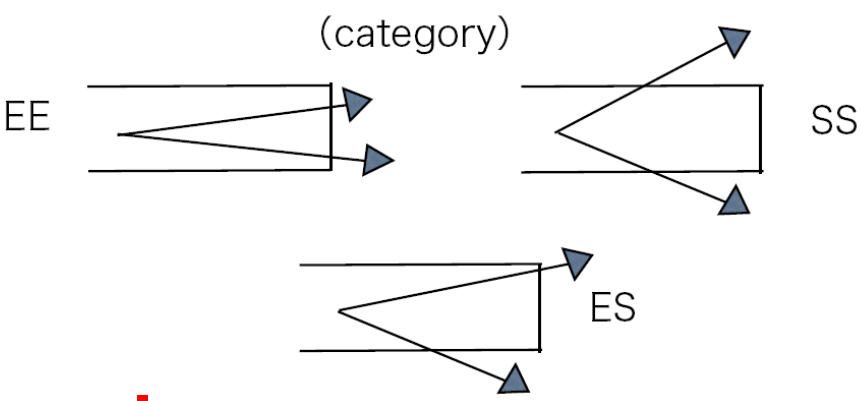
↓

# of leakage / incident γ



# of recon'd event / decay (MC)

	Shower leakage	No leakage
EE	6%	7%
SS	2%	9%
ES	4%	12%
Total	12%	28%



Side detector kills many signals.

For high acceptance ..

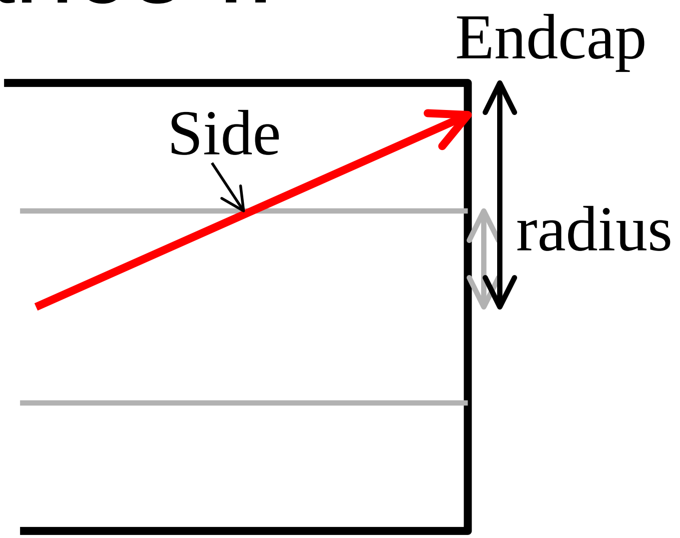
- Larger-radius detector
  → More hits to Endcap

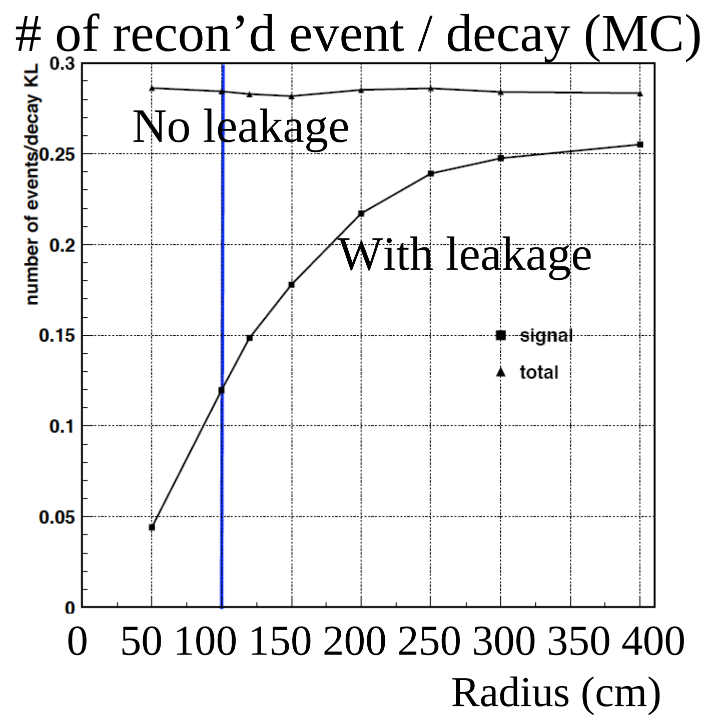
↓

Less leakage

↓

Better acceptance

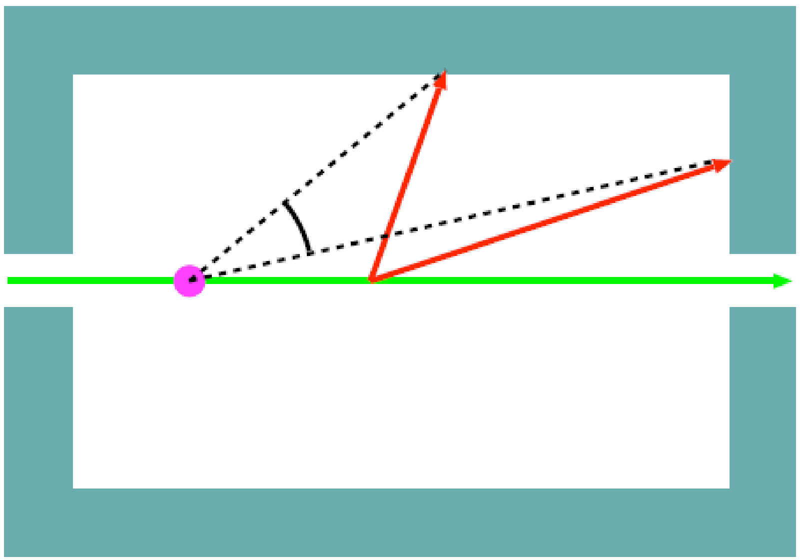


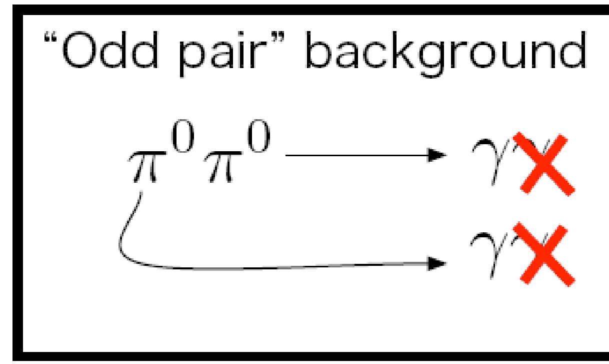


Larger-radius might be better.

Background

- $K_L \to \pi^0\pi^0$, 2γ-missing

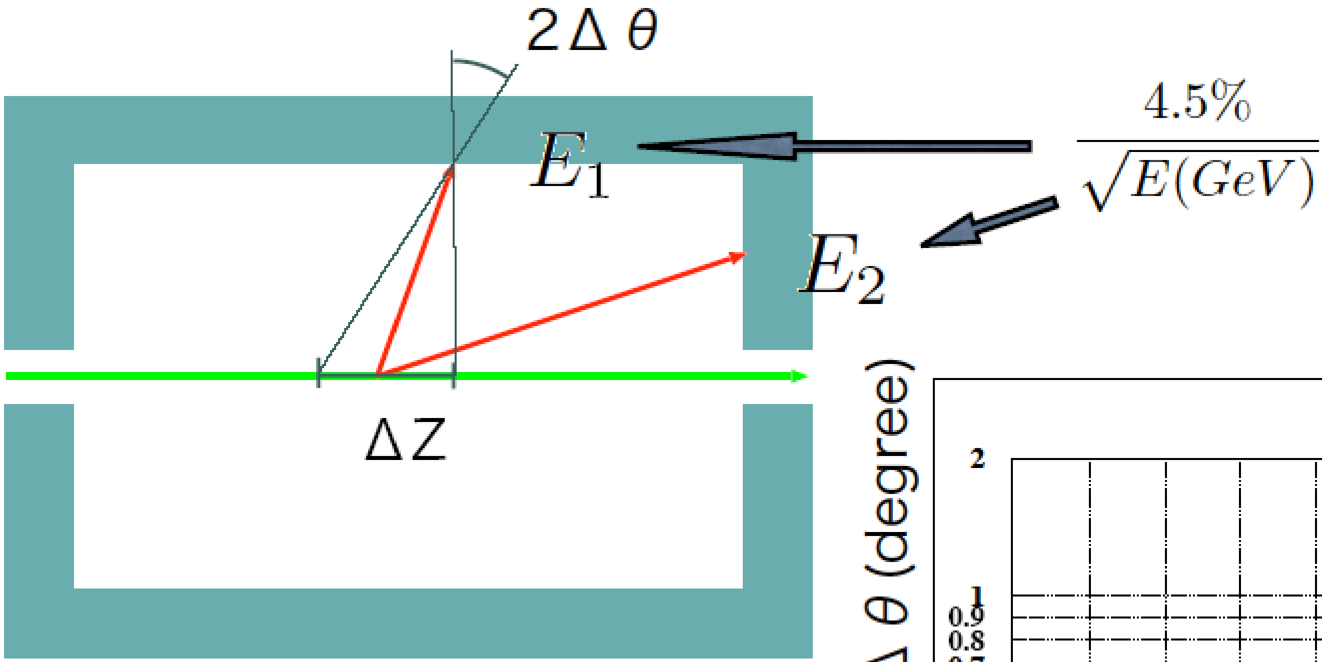




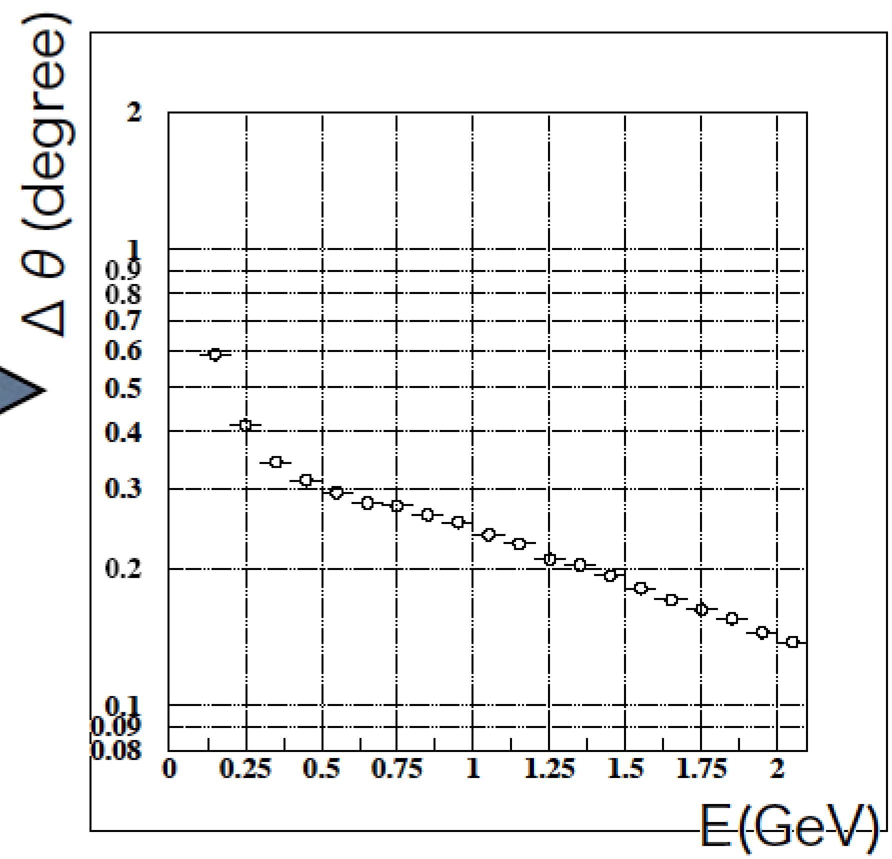
"Odd pair" background であれば再構築された崩壊点と本当の崩壊点は必ずしも一致しない

検出器で入射γの角度を測ることができれば、"Odd pair" background を減らすことができる

Required angle resolution

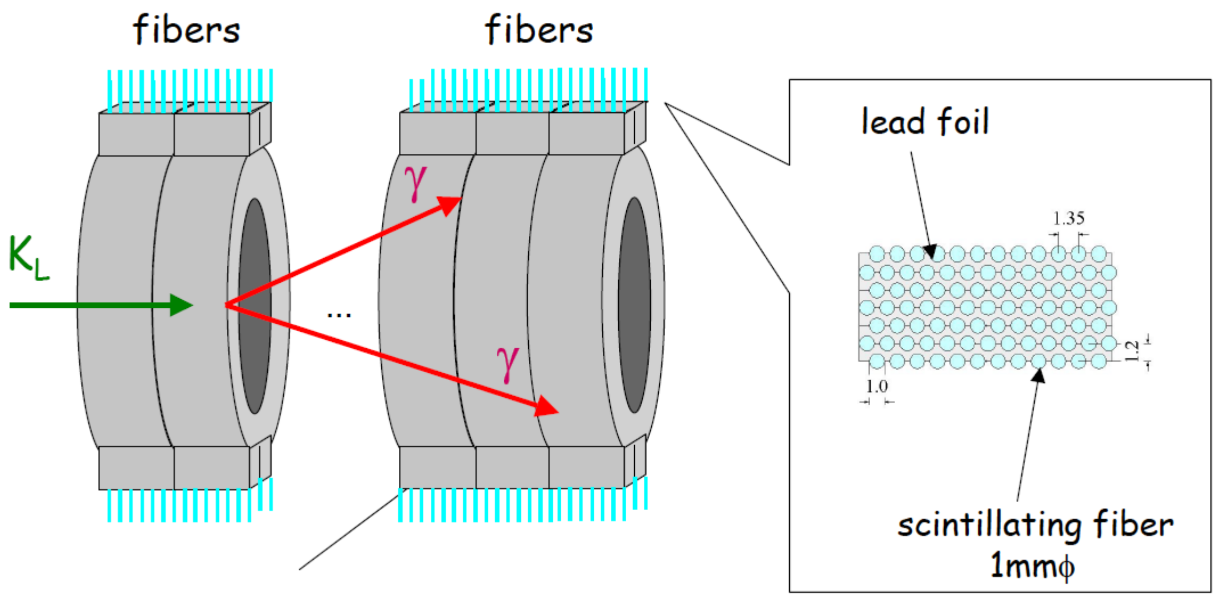


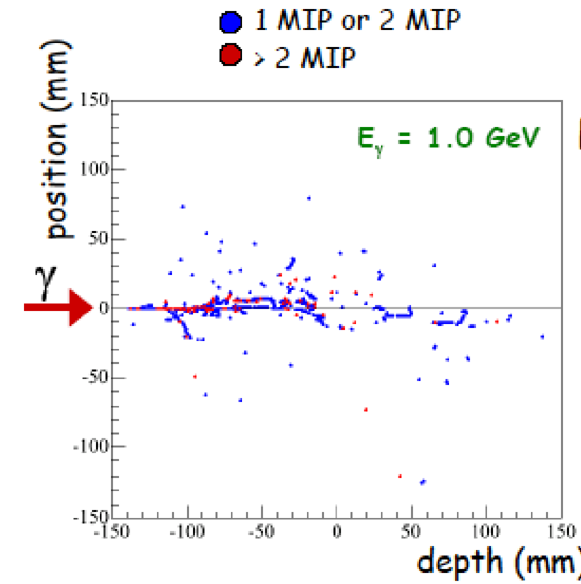
Δ θ vs E



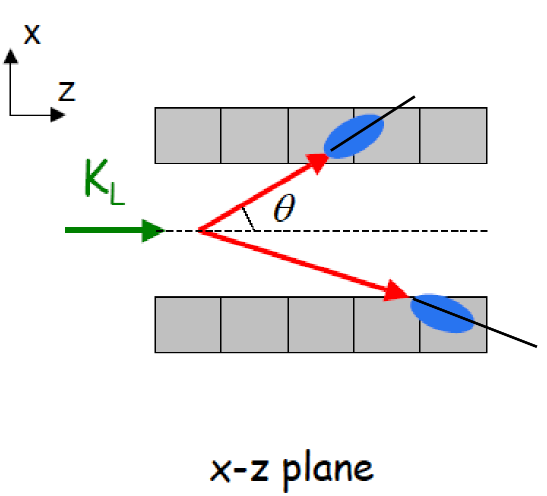
1GeV:0.25degree

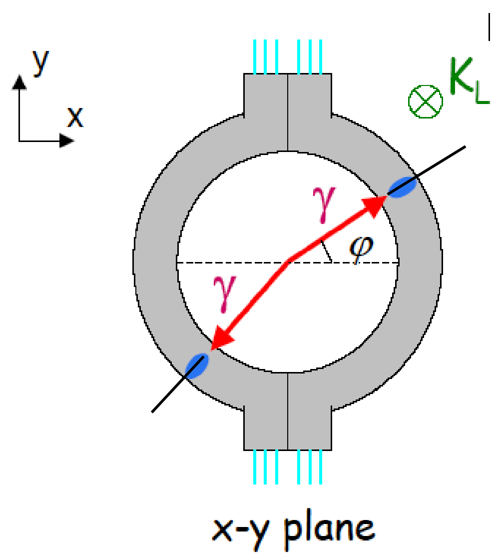
Detector for photon-angle measurement





Weight of 1 unit : ~ 1,800 kg
30cm(thick) x 30cm(length) x 100cm(diameter)

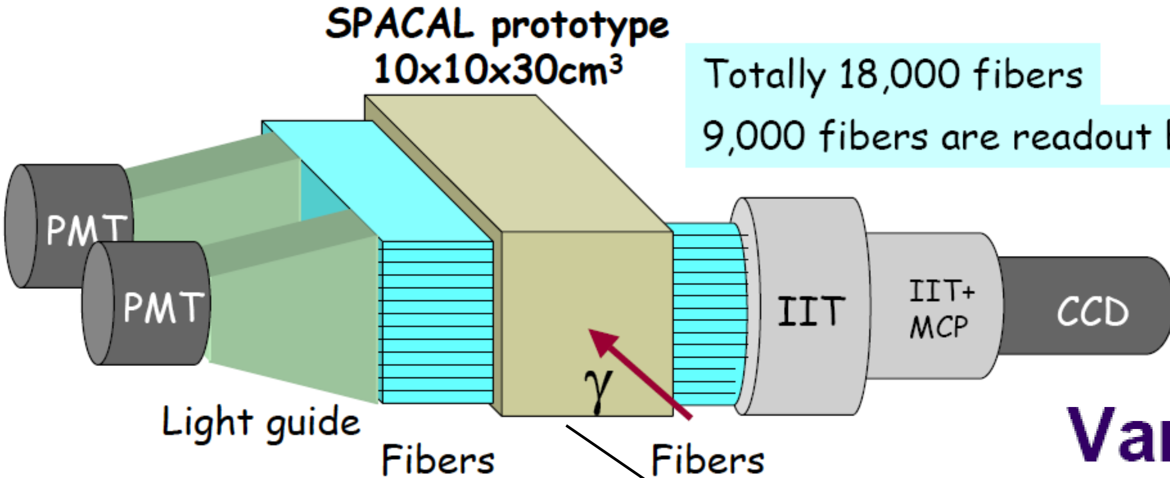




Resolutions

- Energy resolution
  - σ_E/E ~ 5.0% for 1 GeV photon
- Position resolution
  - σ_x ~ 3-4 mm (RMS)
- Angular resolution
  - σ_θ ~ 2-3 deg

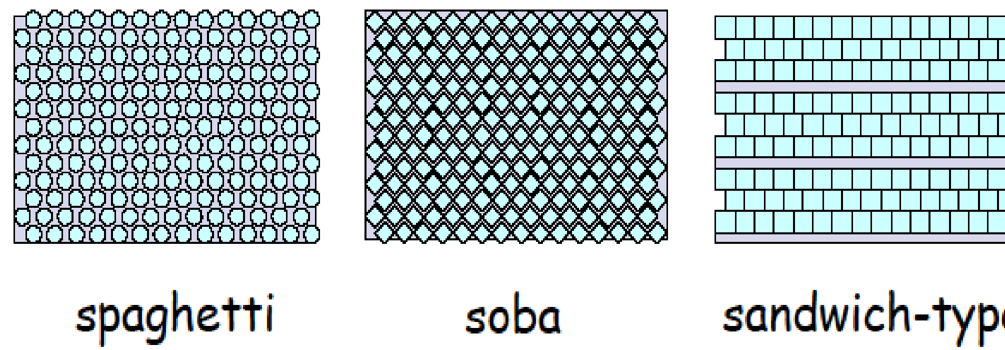
Prototype module



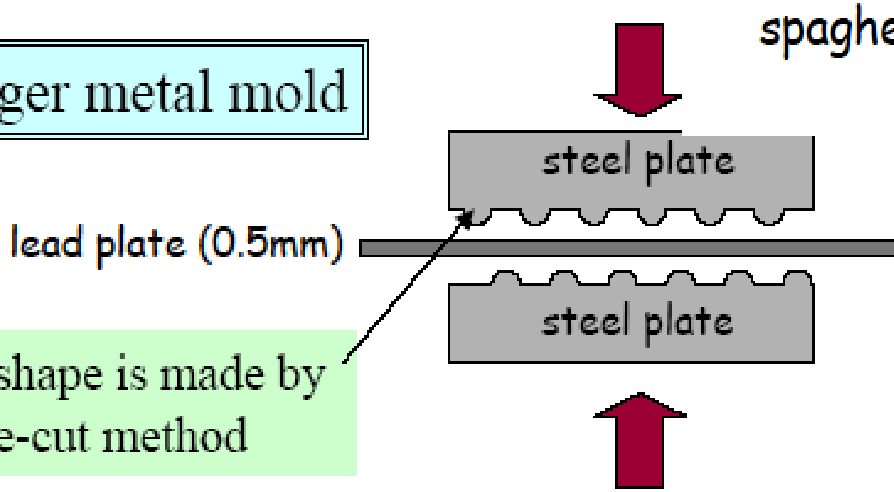
Totally 18,000 fibers

9,000 fibers are readout by a CCD

Various configurations



Stronger metal mold



This shape is made by a wire-cut method

MC study underway.
Beam test in next fiscal year

Sensitivity

- 50 GeV primary protons
- Full intensity (3.3×10^{14} ppp) for 3 years
- 15m-long, 3m-ϕ detector

$\Rightarrow$ S/N = 206/180 ~ 1.1

$\Delta\eta/\eta$ ~ 5%

- With γ angular measurement :
  - Odd-pair BG=1/3, Even :Odd ~ 1:1

BG $\rightarrow$ 70% $\Rightarrow$ S/N ~ 1.6

$\Delta\eta/\eta$ ~ 4%

Other considerations / developments

- PMT development
  - High quantum-efficiency
    - Prism-PMT (NIM A522 (2004) 477)
    - Muiti-alkali Multi-anode-PMT
  - High-rate resistant PMT
    - Cockcroft-Walton-type devider

- Charged Tracker by straw-chamber
  - Useful for calibration by e.g. $K_L \to \pi^+\pi^-\pi^0$.
  - Charged veto

- DAQ
  - Pipeline readouts for ADC/TDC.

Things to study

- Extraction beamline and beam dump for B-line.
- Collimating scheme for neutral beam.
  - How to clean-up the beam halo.
- Neutral beam size
  - Large solid angle → more K_L yield.
  - P_T resolution ?
- …

Step by Step in reality

- Step1 : A-line
  - 30 GeV protons
  - E391a detector + some modifications
  - Good to test new components
  - ~1 SM events

- Step 2 : B-line
  - 30 (or 50) GeV protons
  - Optimum beamline and collimator
  - Fully upgraded detector
  - ~200 SM events, $\Delta\eta/\eta <$ ~5%

Summary

- High-Intensity machine is necessary to measure the golden mode, $K_L \rightarrow \pi^0 \nu \bar{\nu}$.

- Conceptual designing underway.
  - R&D for detectors, PMT, DAQ, …

- B-line at Phase-2 would be needed to achieve our final goal.

  Step by Step in reality is good for the test.

- Full proposal will be prepared within 2005.