Production and application of high-intensity low-energy muon beams - recent development

K. Ishida (RIKEN/KEK)

Muon applications

- μCF at RIKEN-RAL

Muon beams

- Large Omage, Dai Omega, RIKEN-RAL II

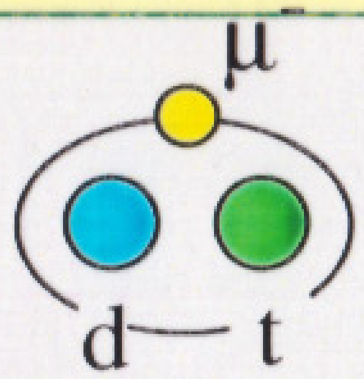
Muon Applications (examples at RIKEN-RAL and KEK-MSL)

- μSR (muon spin rotation, relaxation, resonance)
  - High Tc, magnetism, semiconductor, chemistry ...
- μCF (muon catalyzed fusion)

- Muon life time τ_μ = 2.2 μs (50 τ_μ =100μs)

- FFAG time structure (1-10kHz) is preferable for many muon applications
- FFAG coupling with efficient muon collection would give ideal muon beam

Muon Catalyzed Fusion



Principle of μCF

muon works as catalysis
by forming dtμ molecule

Macroscopic parameters determining the efficiency

Cycling rate: λ_c (vs λ_0)

Muon loss per cycle: W

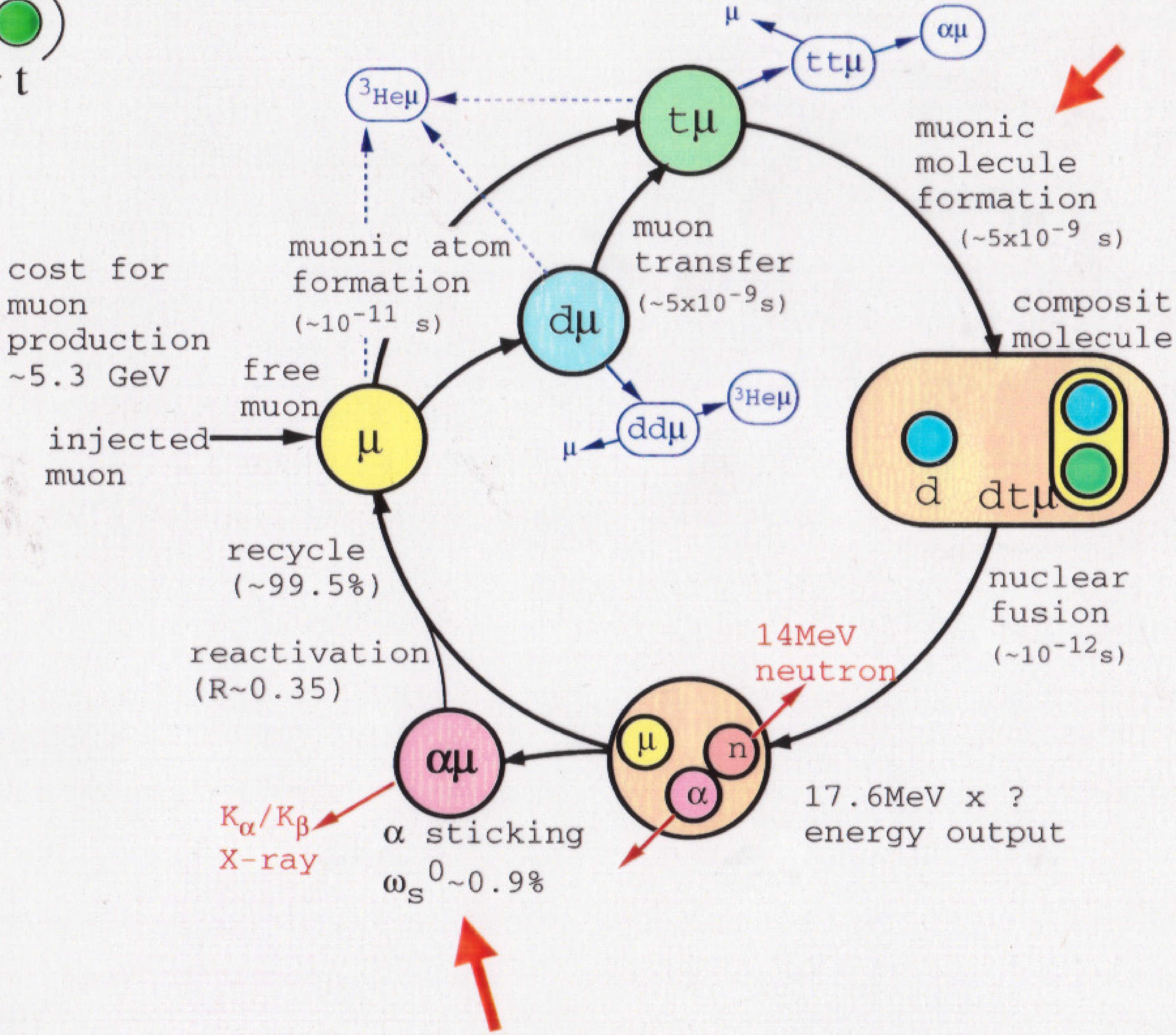
$Yn = \phi \lambda c / \lambda n$

$= 1 / [(\lambda_0 / \phi \lambda_c) + W]$

Key processes

dtμ formation

muon to alpha sticking



Muon catalyzed fusion experiments at RIKEN-RAL

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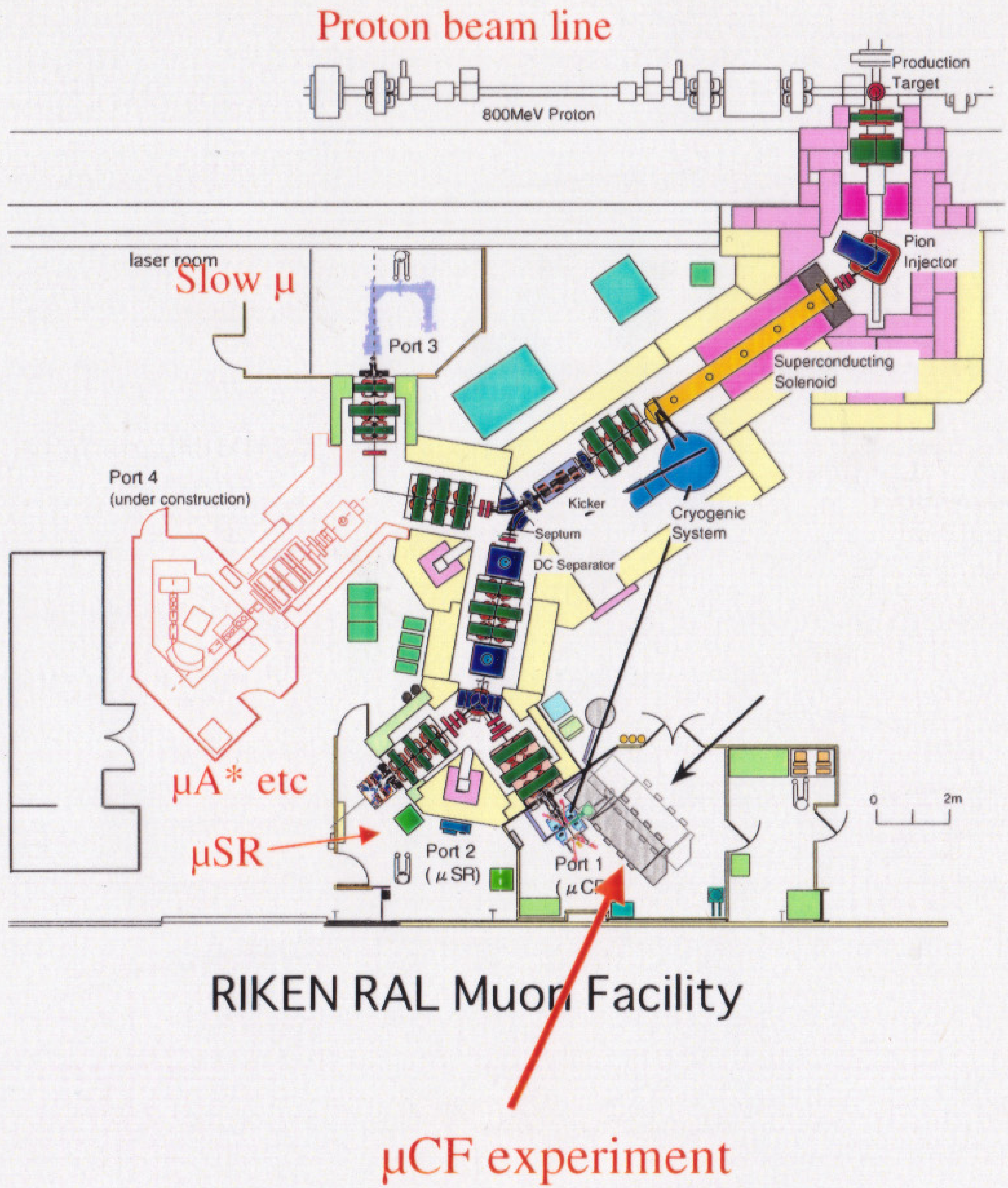
T. Matsuzaki, Y. Matsuda,
N. Kawamura, S.N. Nakamura,
M. Kato, H. Sugai, M. Tanase,
K. Kudo, N. Takeda, G.H. Eaton
(RIKEN / KEK / Tohoku /
JAERI /ETL / RAL)

RIKEN-RAL Muon(1994~)

Intense pulsed muon beam
(70ns width, 50 Hz)
800MeV x 200μA proton
20~150MeV/c μ+/μ- muon



RIKEN RAL Muon Facility

μCF Experiment at RIKEN-RAL

Use of strong pulsed muon beam

Tritium handling facility 1c.c. D/T

Detectors with calibration (fusion neutrons, X-rays)

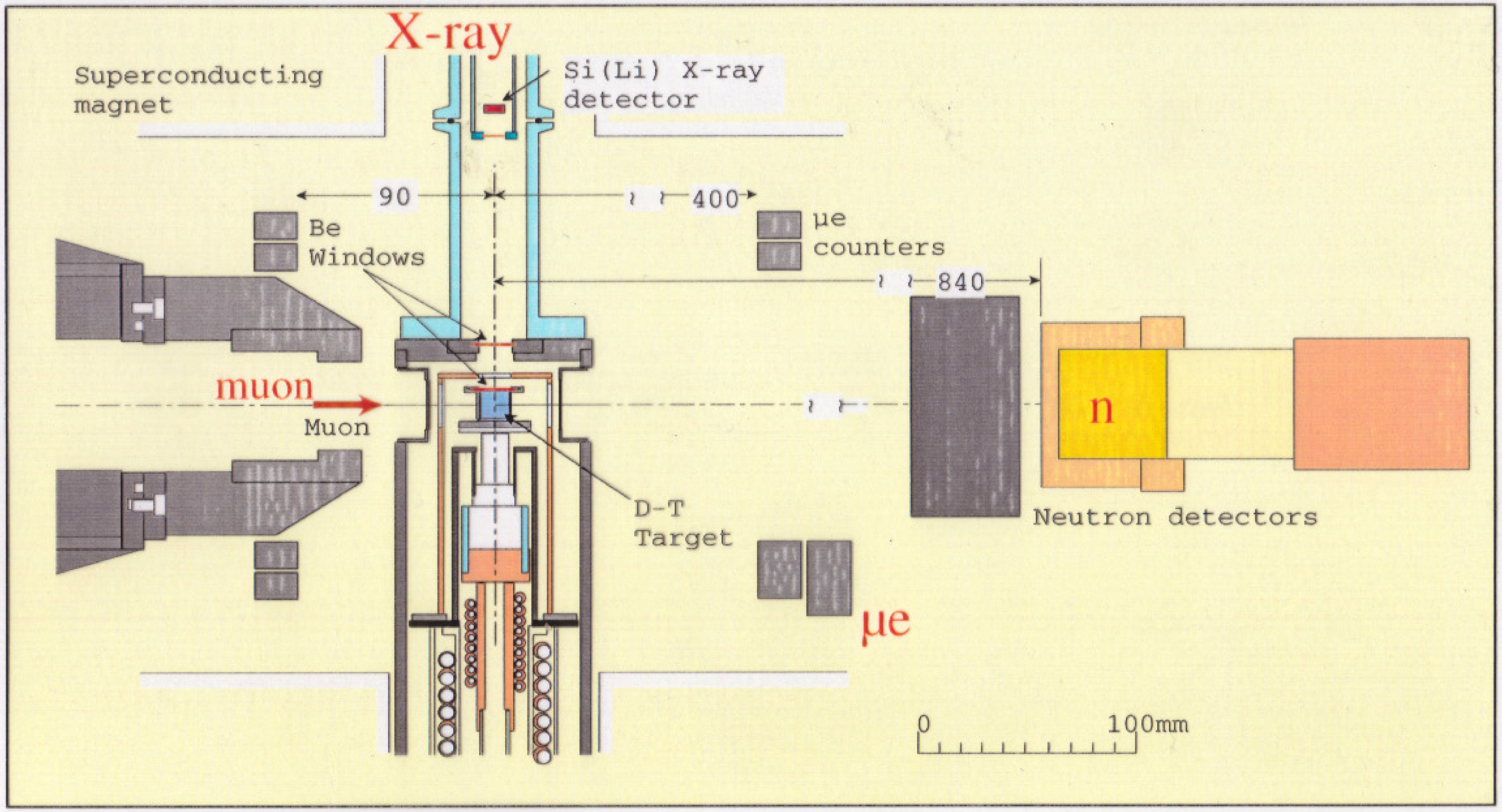
Stopping muon number(μe decay and μBe X-ray)

Determine basic parameters and find the condition for improving efficiency

λc, W, X-ray emission

→ α sticking probability and other loss processes

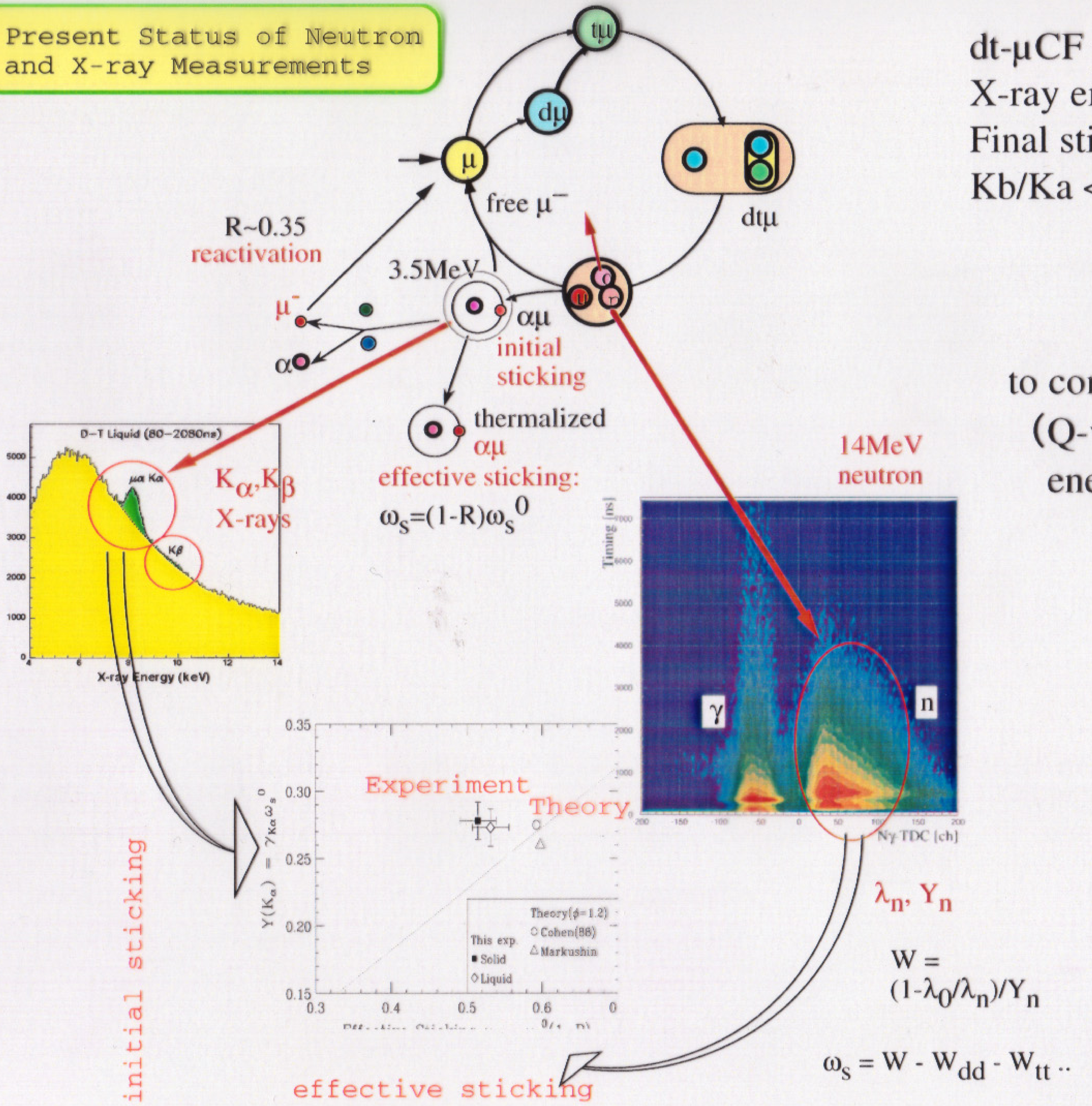
reaction rates (dtμ formation rate, muon transfer etc)



10^4/s μ^- stops

10^6/s fusion neutrons

Present Status of Neutron and X-ray Measurements



dt-μCF present status

X-ray emission ~ calc.

Final sticking < calc

Kb/Ka << calc.

to compare with ddμ, ttμ (Q-value、 α recoil energy)

Energy balance in μCF

~150 fusions per muon ~2.5 GeV { ~30 years of intensive study theory and experiments still many surprising phenomena

Vs Proton energy per muon ~5 GeV (calculation)

In Realistically, at present

10^4 muon stop/s from 10^{15} proton/s

(3 μW from 200kW)

Efforts for narrowing the gap have to be done!

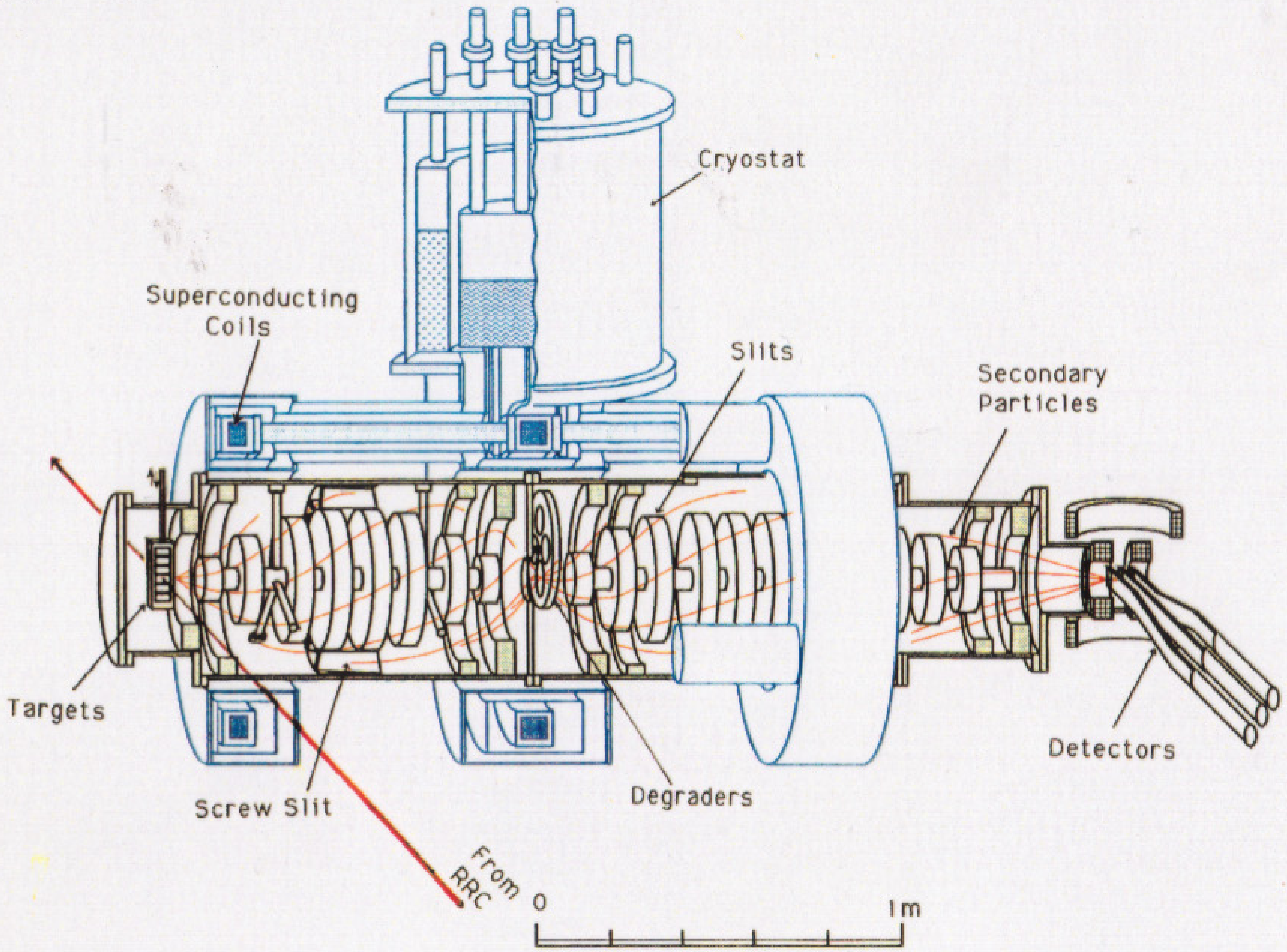
Muon beam production

- Conventional Method Q+B
  - Increase proportional to proton beam power
    - KEK, PSI, TRIUMF, RIKEN-RAL, and JHF-M
    - Typically $\Delta\Omega < 50$msr、 $\Delta p/p < 5\%$
- Recent movement
  - Requirement for tremendous improvement of muon collection efficiency
    - $\Delta\Omega = 1\sim4\pi$ sr, $\Delta p/p \sim 50\%$
    - Large Ω, Dai Omega, RIKEN RAL II, …
      - Muon beam for versatile applications (μCF, μSR, analysis etc)
    - MECO, Muon collider, Neutrino factory, μCF neutron source
      - Dedicated for rare decay, muon acceleration, μCF application,
  - Bright muon beams (cooling)
    - Positive muon : rare gas solid degrader (PSI), thermal Mu ionization(KEK, RIKEN)
    - Ionozation Cooling, Phase Space Rotation

High acceptance muon collection

Large solid-angle collection of surface muons by "Large Ω"
with axi-symmetric magnetic field (RIKEN) (1987-1992)

- Sub-threshold pion production by heavy-ions (^{14}N 135 MeV/u) and its decay
- Superconducting coil triplet, maximum axial field 0.8 Tesla
- $\Delta\Omega$=0.6 sr, $\Delta p/p$ ~4%



Super-super Muon Channel for RIEKN-RAL II: design

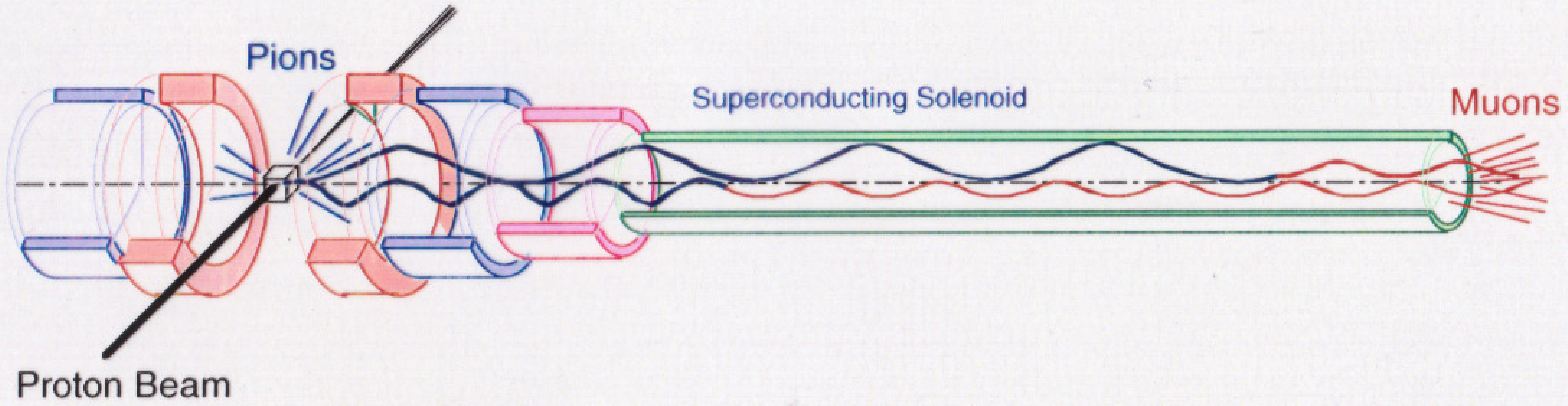
K. Nagamine, K. Ishida, T. Matsuzaki, I. Watanabe, Y. Matsuda (RIKEN-RAL)

Design Goal of RIKEN-RAL II Super-super Muon Channel

Enhance RIKEN-RAL beam intensity by x100 for the same beam size

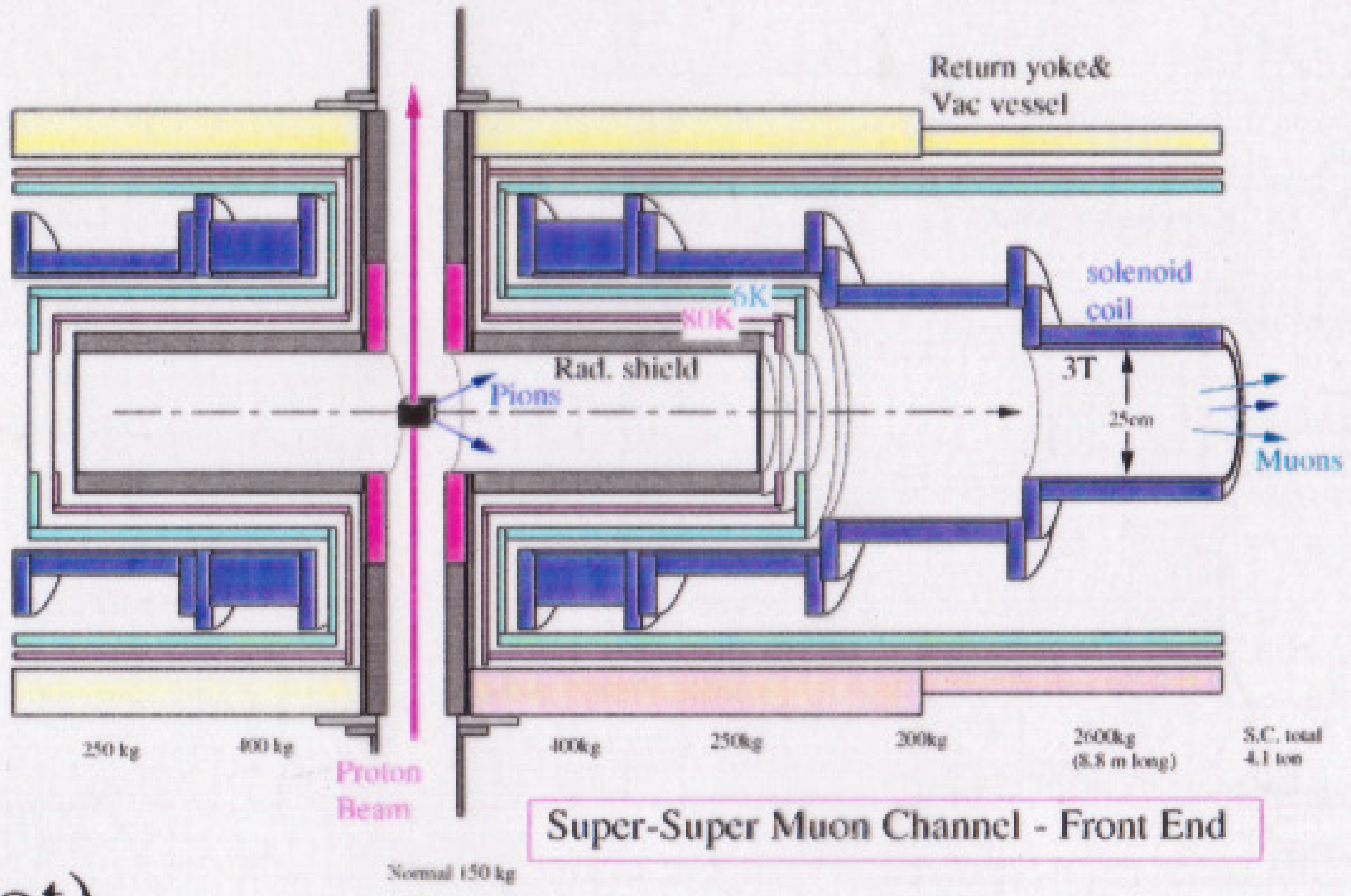
Possibility of super high-intensity beam (~10^{10}/s)

for dedicated experiments



Super-super Muon Channel for RIKEN-RAL II

- Basic Parameter
  - 3 GeV, 200 μA proton beam
  - 1cm thick carbon target
  - 90 degree pion
  - 4T max, 20cm Bore, 10m Solenoid
- Yield Estimate
  - Optimization for 60 MeV/c muon
  - μ^- beam at solenoid exit~ 2 x 10^{11} /s
  - Selected μ^- beam ~8 x 10^7 /s
- Technical Design (preliminary)
  - First coil heating ~ 0.15 mW/g(1.5mW/g spot)
  - Total 4K Heat Load ~600W



Super-Super Muon Channel - Front End

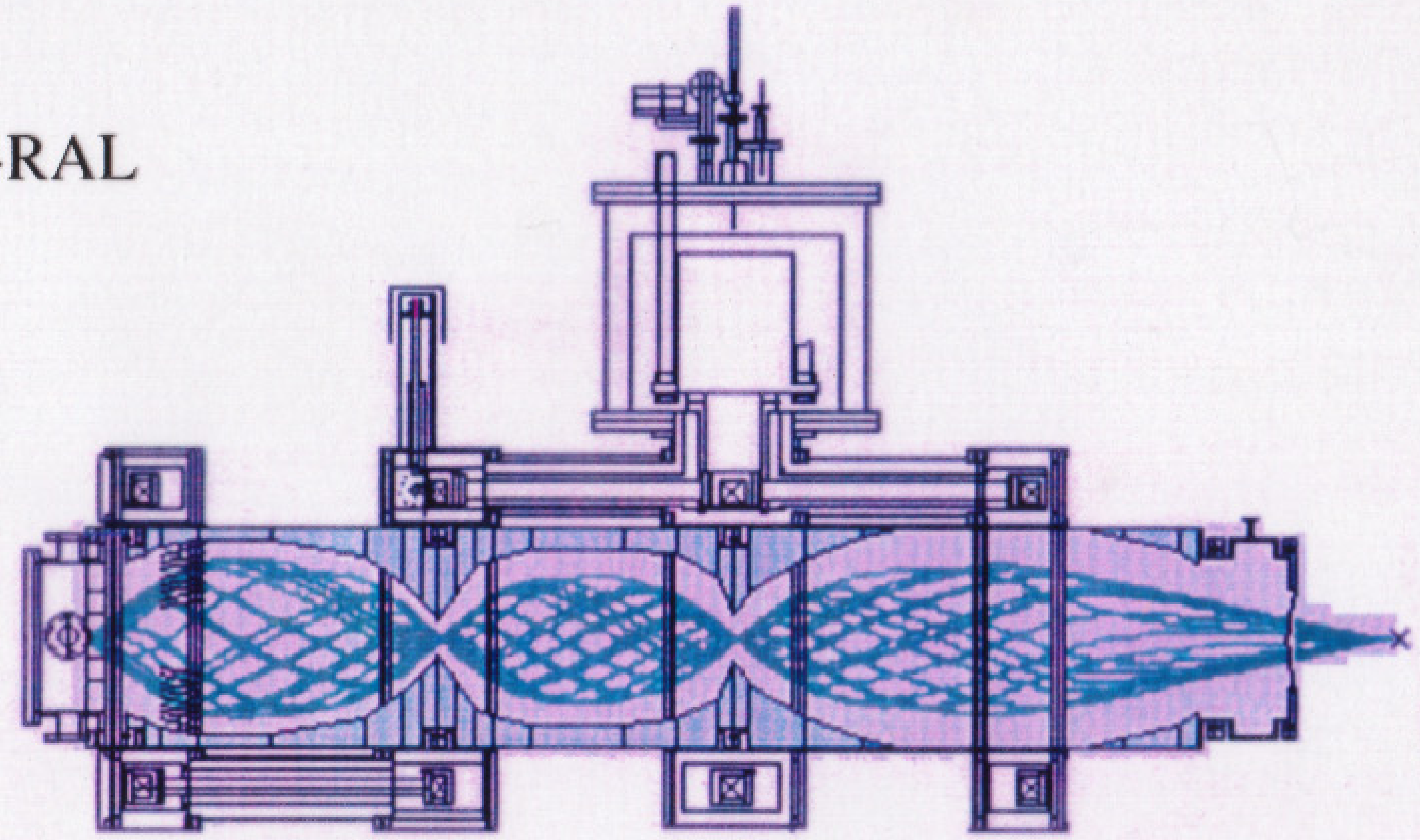
Upgrading "Large Omega"

K. Nagamine, K. Shimomura, H. Miyadera, K. Nishiyama,
Y. Miyake, K. Fukuchi, S. Makimura, K. Ishida

KEK-MSL

Upgrade from "Large Omega" to "Dai Omega" (2000~)

- Recycle "Large Ω" coil
  - Add front coil with polyimide insulation
  - Triplet coil -> Quartet coil
- Installation at KEK Booster proton beam
  - 500 MeV, 6 μA
  - High-intensity surface muon beam will be extracted
    - Total intensity is expected to
    - become comparable to RIKEN-RAL



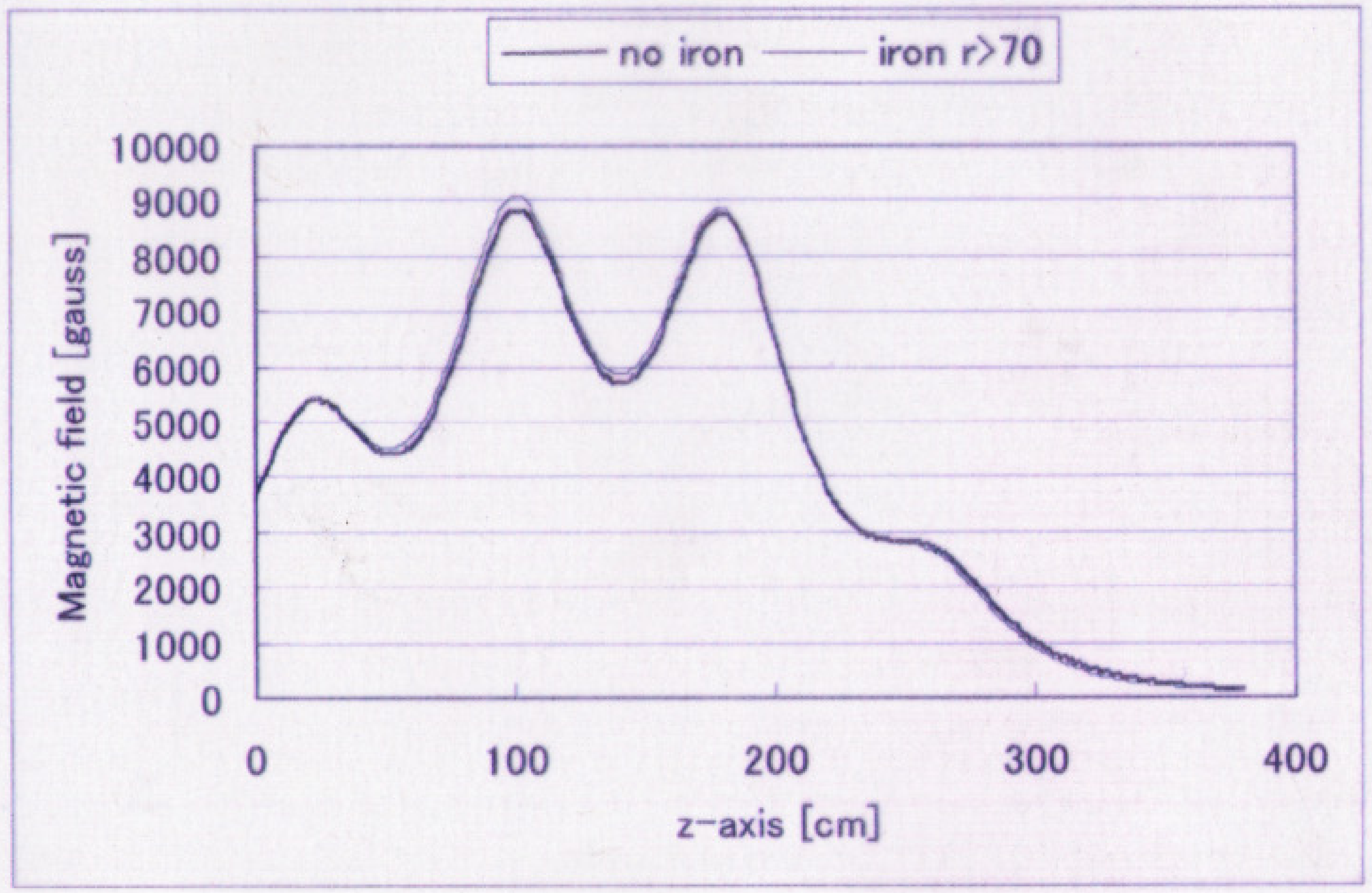
Dai Omega: beam design

Field calculation by TOSCA

- Effect of surrounding iron shield

Beam calculation

- Maximum solid angle acceptance at designed momentum ~ 1400 msr
- Momentum acceptance ~ 5%



Dai Omega: design considerations

Realization of radiation shield concept etc

R&D for future use at high-intensity proton accelerators

Magnetic Force

Calculations with TOSCA (H. Miyadera)

Fz(axial)~1500N, Fy(vertical)~3600N

Use non-magnetic shield SUS and Pb for R<70cm

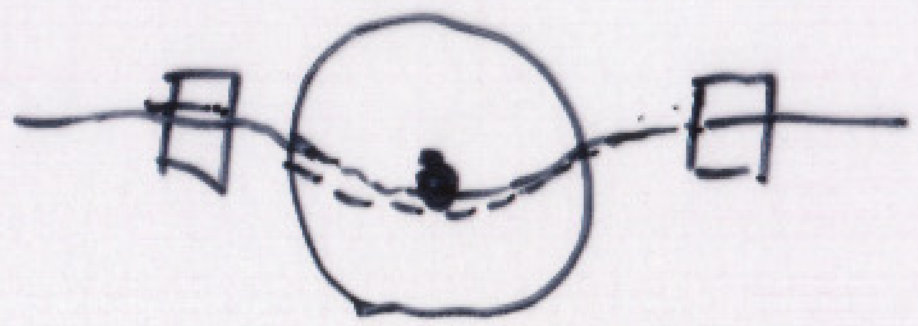
Proton beam deflection & correction

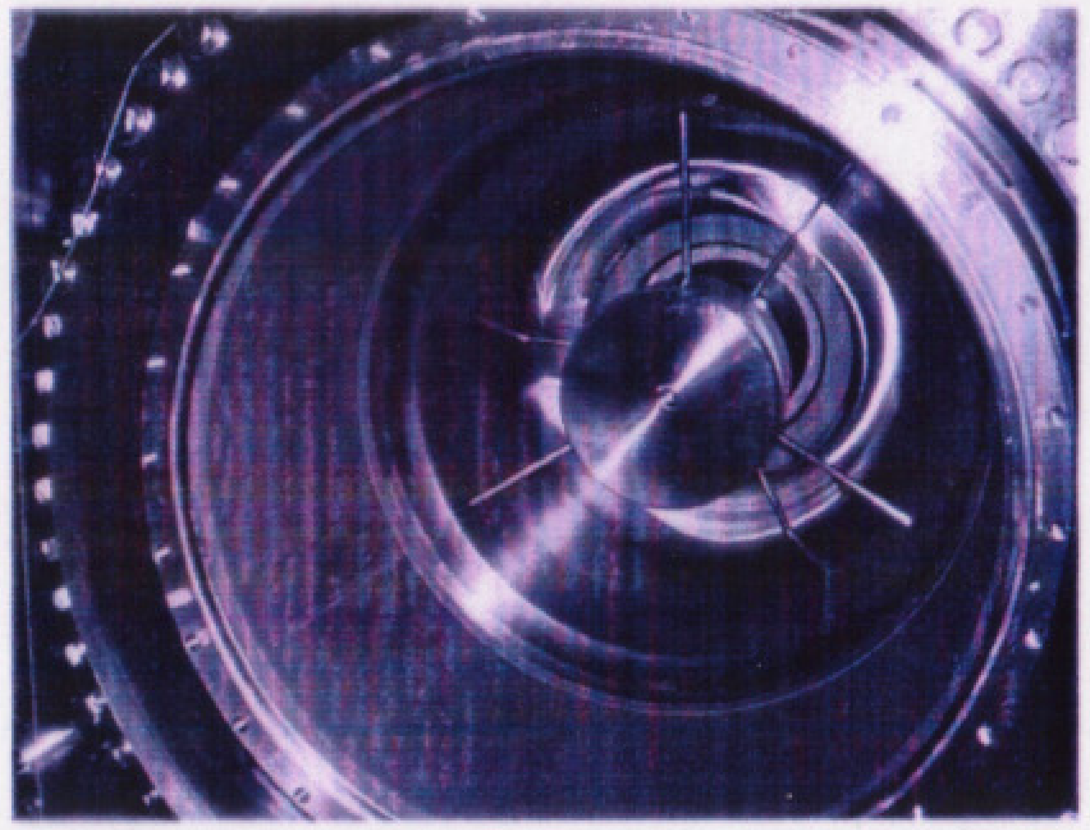
Proton beam correction magnet

Dai Omega set 3cm

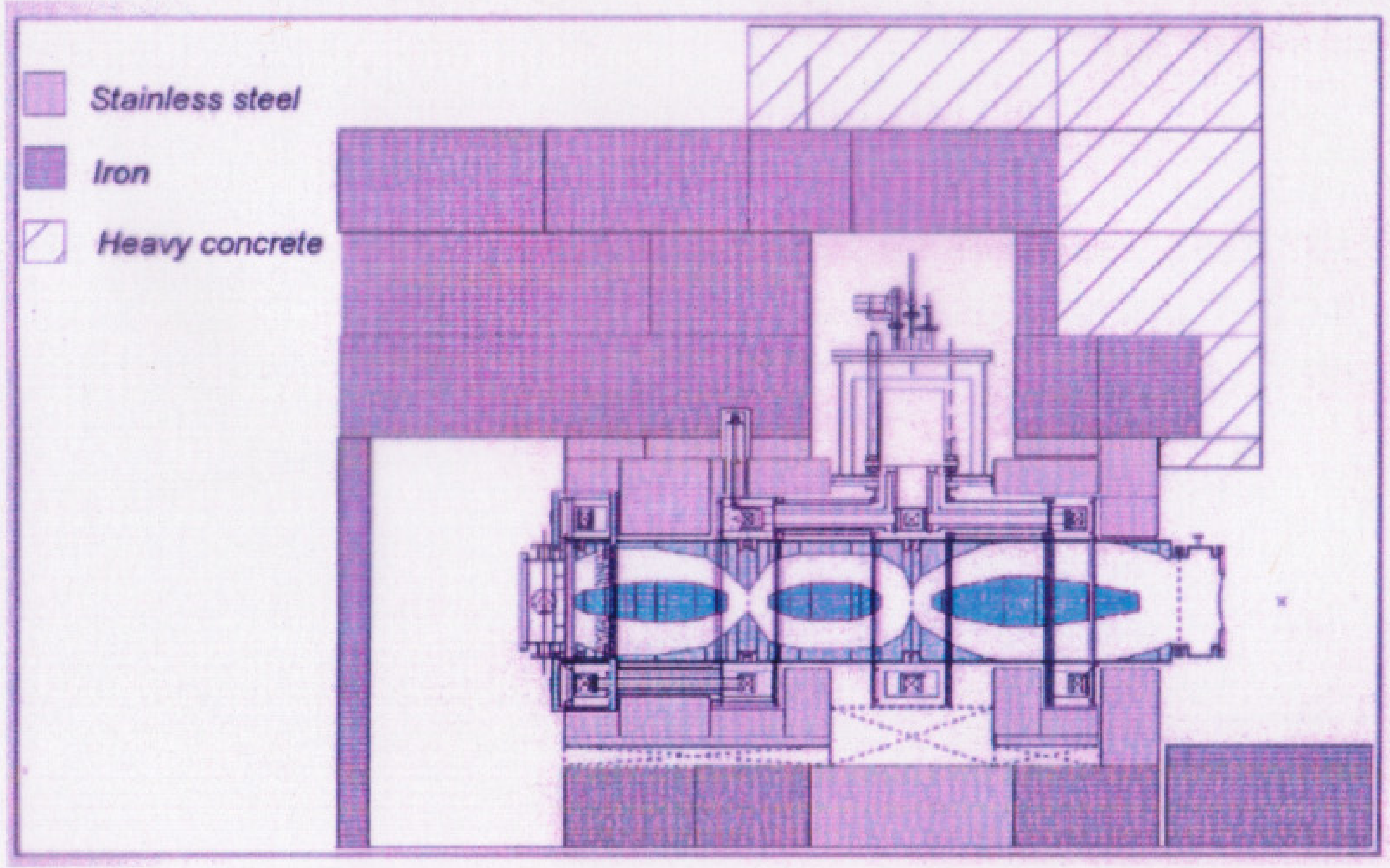
below beamline

$4mm^t$ C target



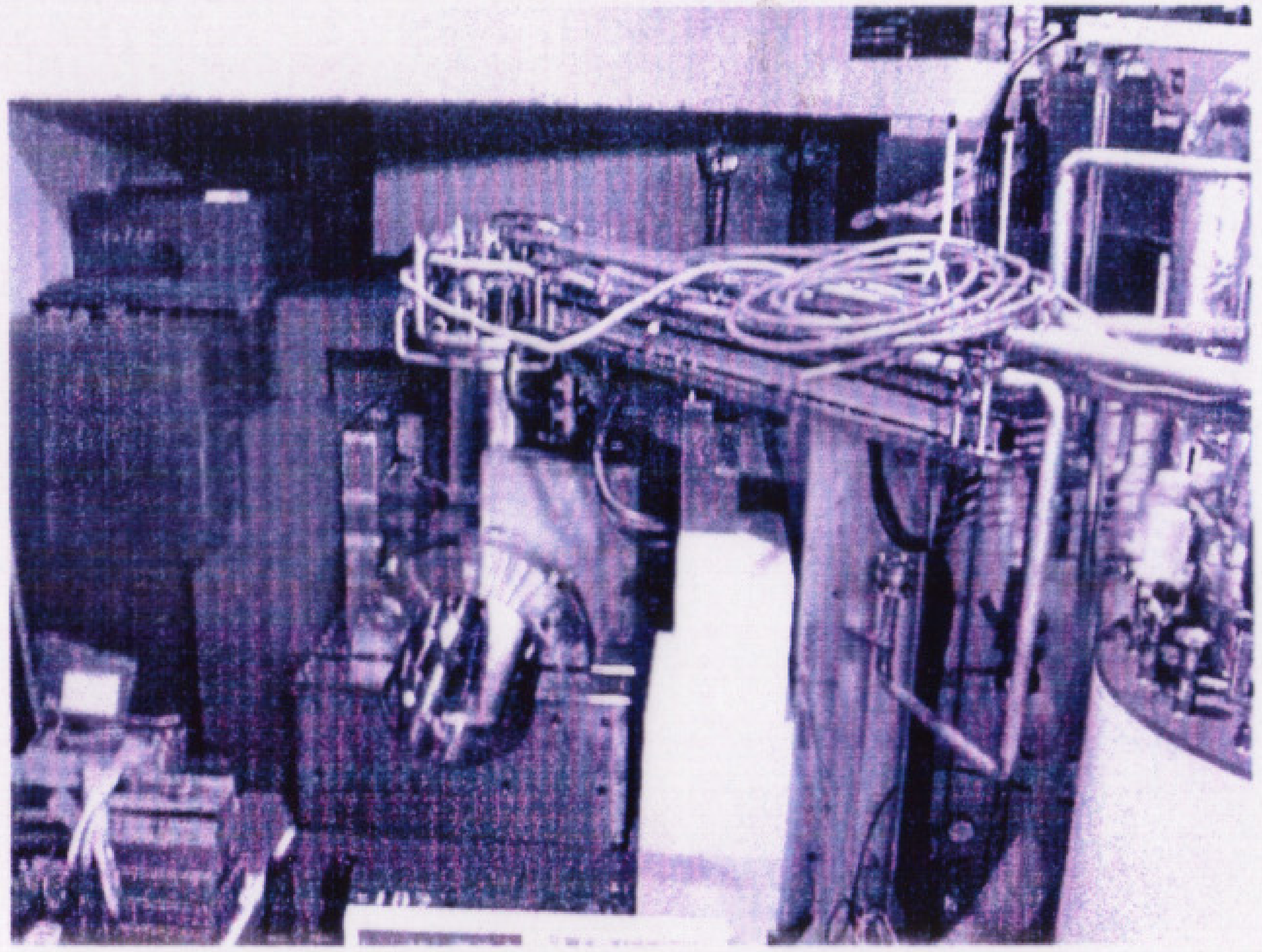


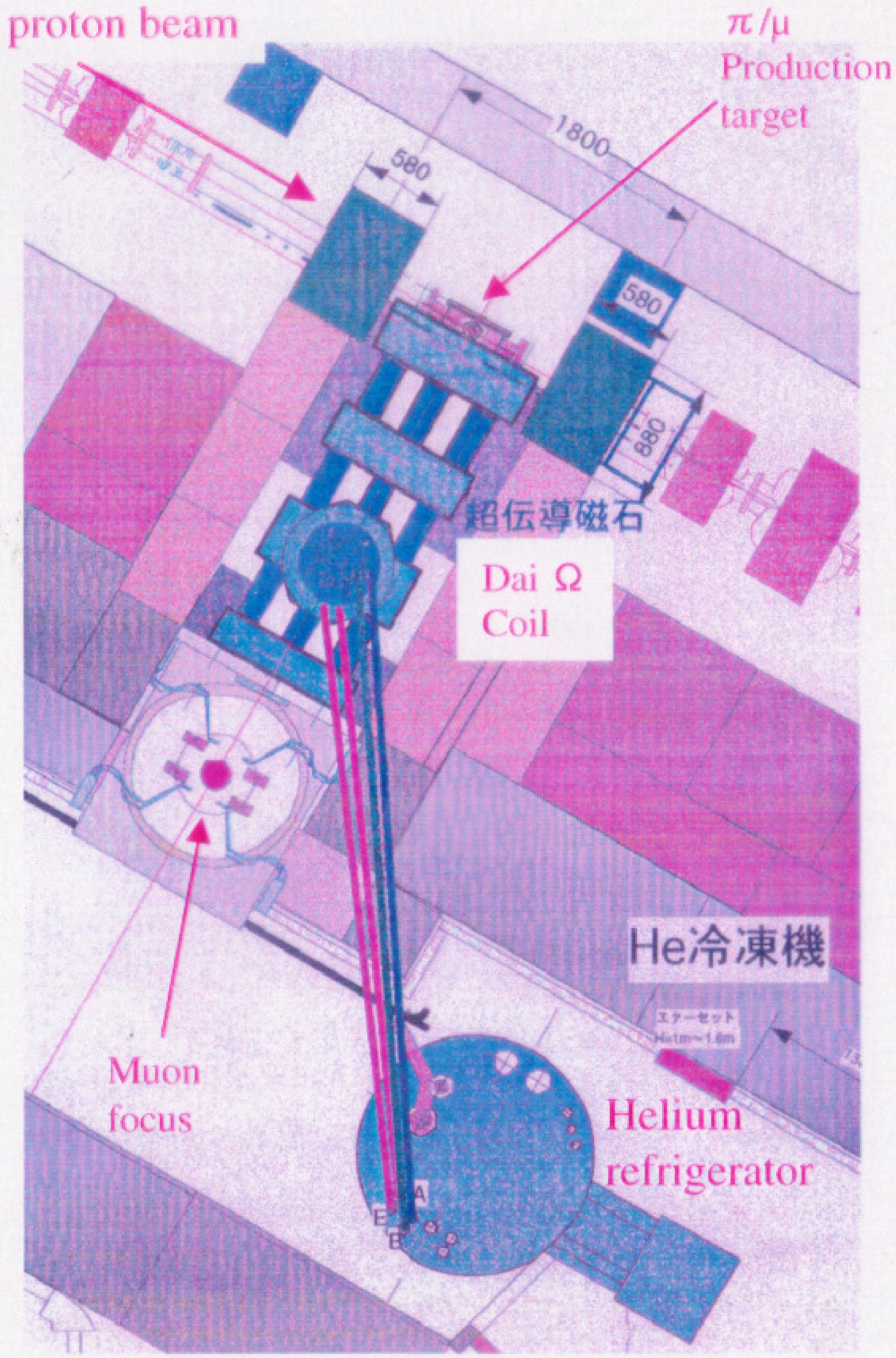
Inside beam duct



Dai Omega: installation

- Sep 2001
  - Completion of installation and field test
- Dec 2001
  - First Beam : CCD camera
- Jan-Feb 2002
  - Beam test & yield, S/N estimation



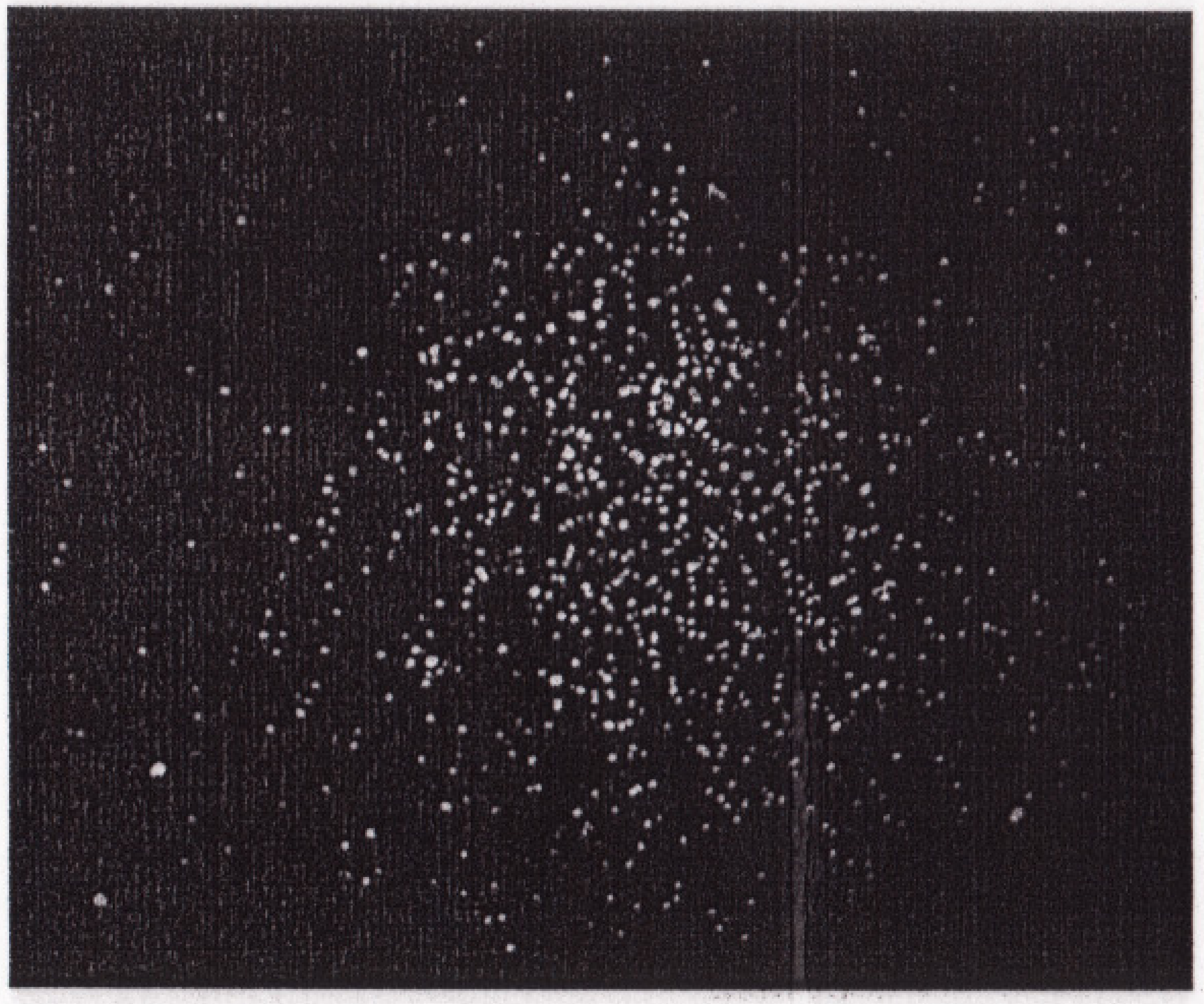


Dai Omega: beam test

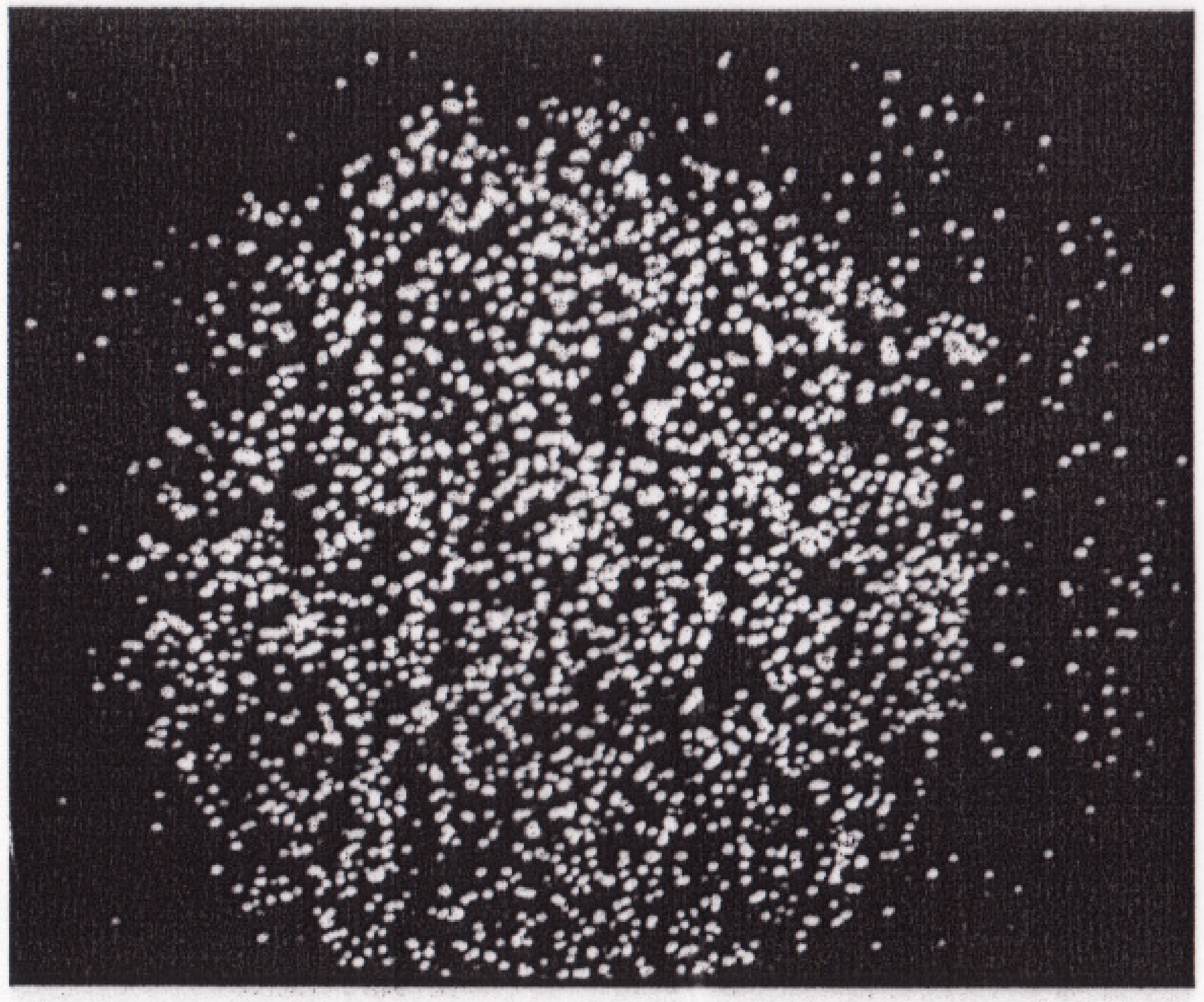
CCD camera in the beam

(flashing in synchronous to the proton beam pulse)

(9cm ϕ sensitive area)



π Port of KEK-MSL
(conventional surface μ+)

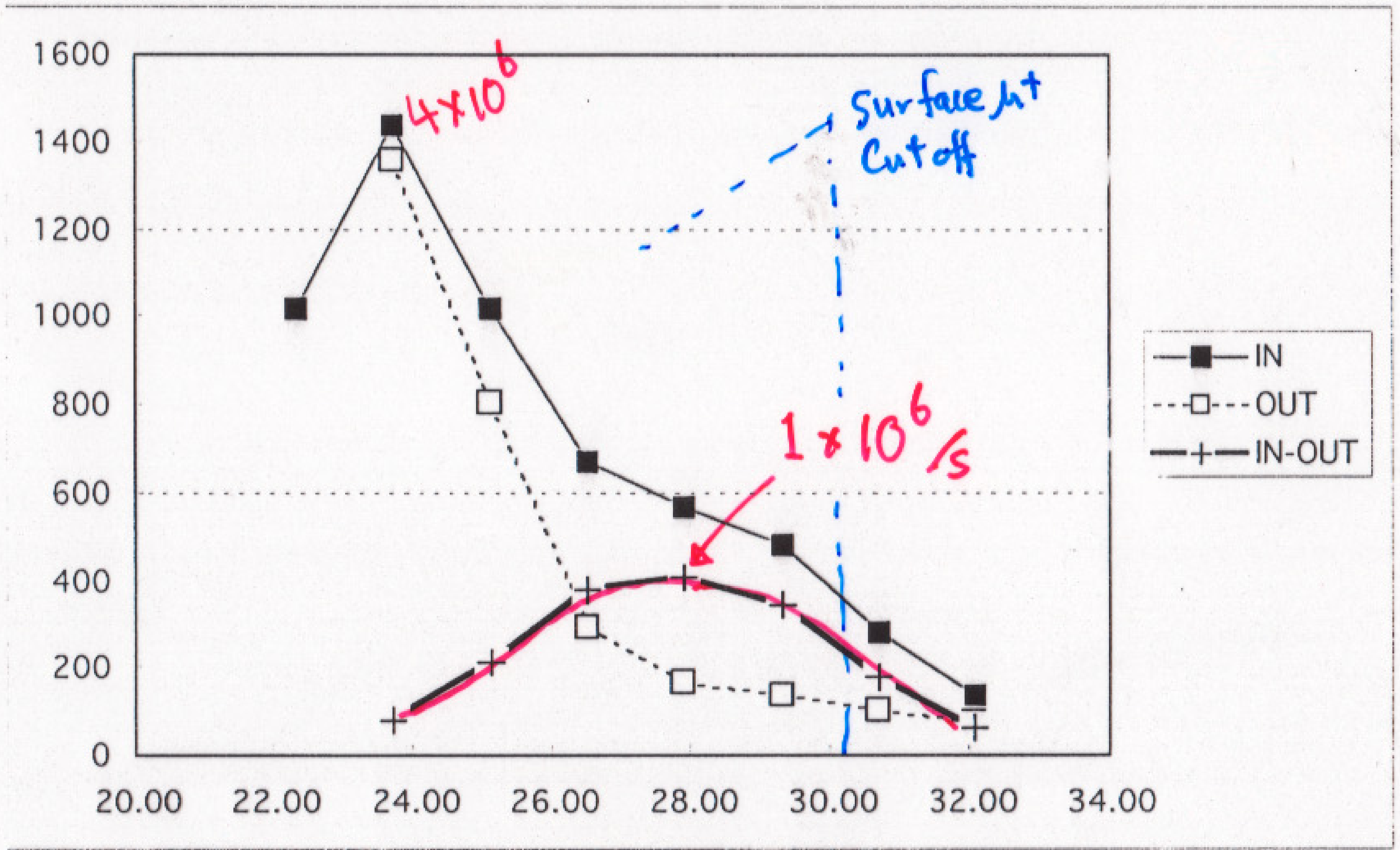


Dai Omega

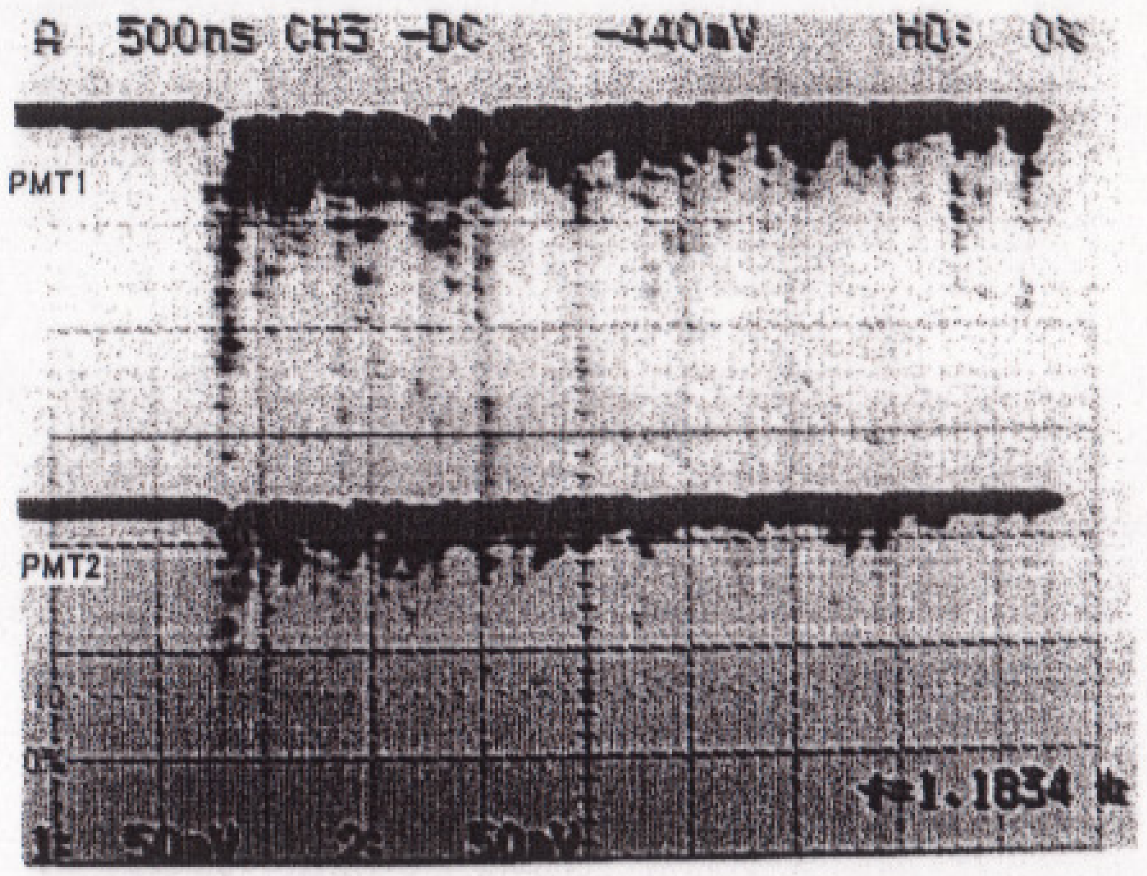
Dai Omega: beam test

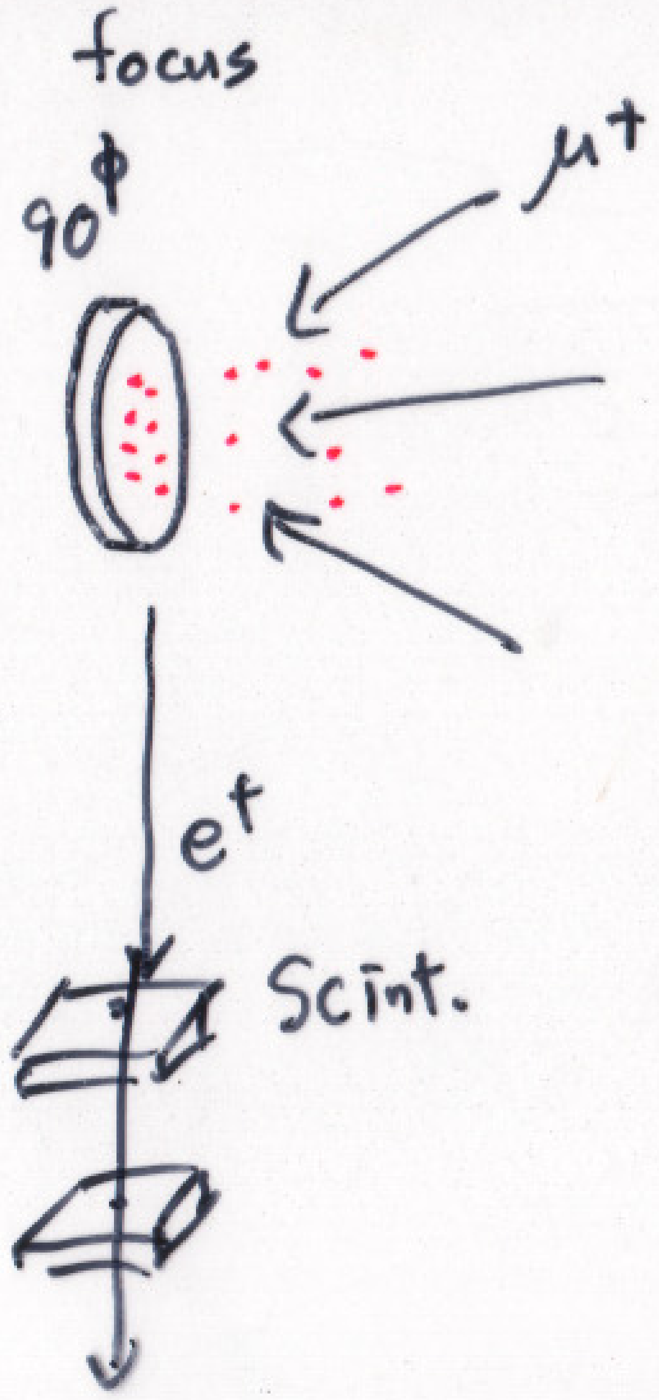
Momentum dependence: stopping target IN-OUT

(3-Feb run)



Design central momentum [MeV/c]





Dai Omega: to be done

Tuning in progress

Coil 1 ~4, C-mag

- Beam size measurement

Background suppression

- Radiation shield improvement
  - Inner plugs, Lead walls
- Detection system
  - Telescope coincidence counters works
  - Single counters ?
- e+ removal
  - Pulsed electric field using TOF

Usage
- μSR
- source for secondary μ beam
  - ultra slow μ^+, thermal Mu

Summary

High acceptance muon collection is an important step for higher intensity muon beam

- design work is in progress for μ^+/μ^-
- a system "Dai Omega" for surface muon beam was constructed and is under testing