LEPS upgrade and LEPS2

RCNP　M. Yosoi

- Upgrade works @LEPS in the past few years and near future
- LEPS2 – new project (→Maeda-san’s talk in detail)

WS on New Hadrons with Various Flavors @Nagoya 2008/12/06

Why GeV photon beam for study the quark hadron physics?

- Wave length: $\lambda\!\!\!^{-} < 1$ fm (typical hadron size)
- Photon interaction is simpler than hadron interactions
- $J^{PC} = 1^{--}$: the same as vector mesons (ρ, ω, ϕ,…)

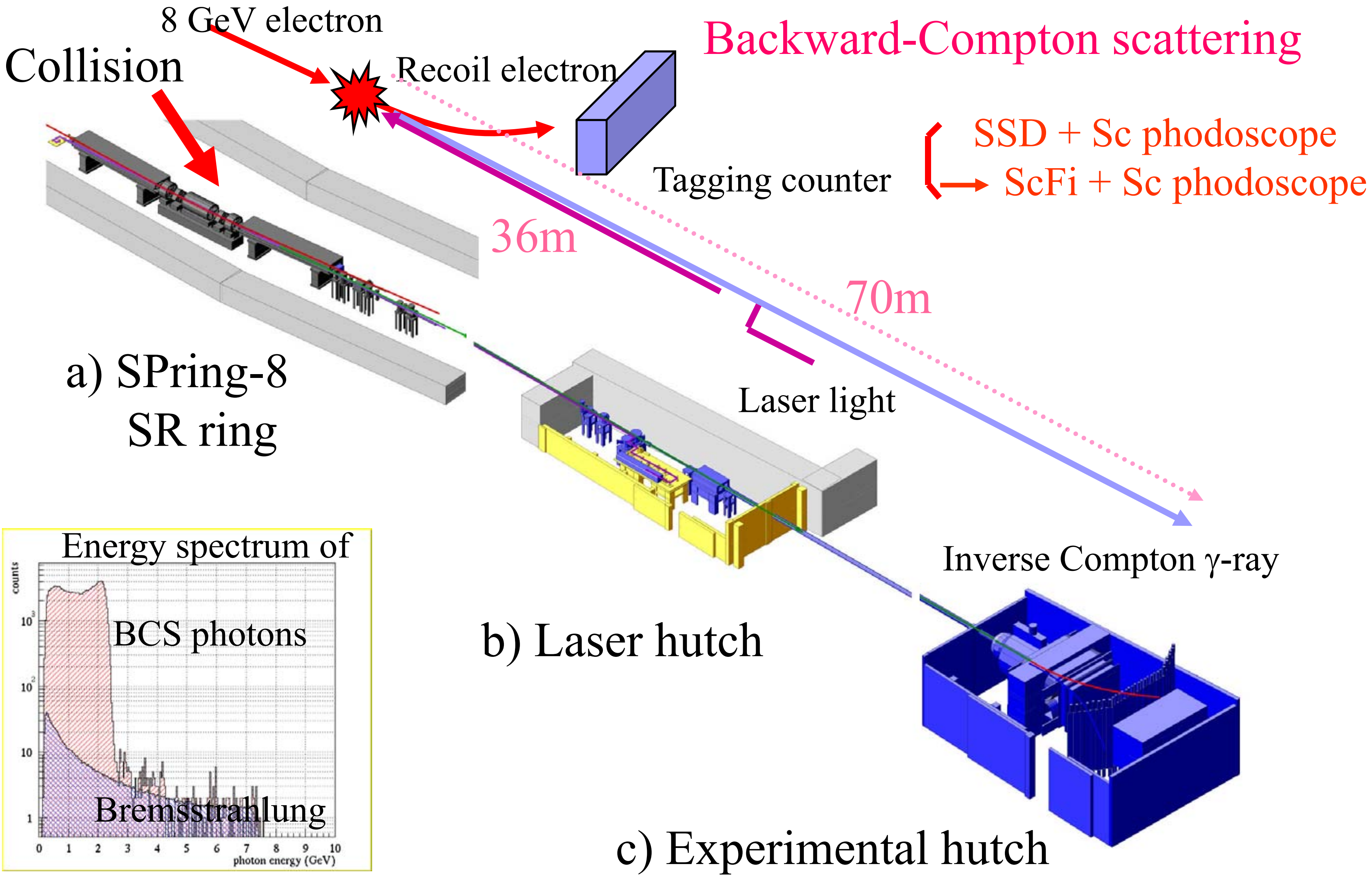
  Contain a large fraction of $s\bar{s}$ and

  the same amount of quark and anti-quark
- Isospin: both I=0 and I=1 components
- When beam is linearly polarized, it can be used as a parity filter

- Disadvantage: low interaction rates

  $\Delta q = \Delta\omega$ (c.f. (e,e'))

Schematic view of the LEPS facility



8 GeV electron

Collision

Recoil electron

Backward-Compton scattering

Tagging counter

SSD + Sc phodoscope

ScFi + Sc phodoscope

36m

70m

Laser light

a) SPring-8 SR ring

b) Laser hutch

Inverse Compton γ-ray

c) Experimental hutch

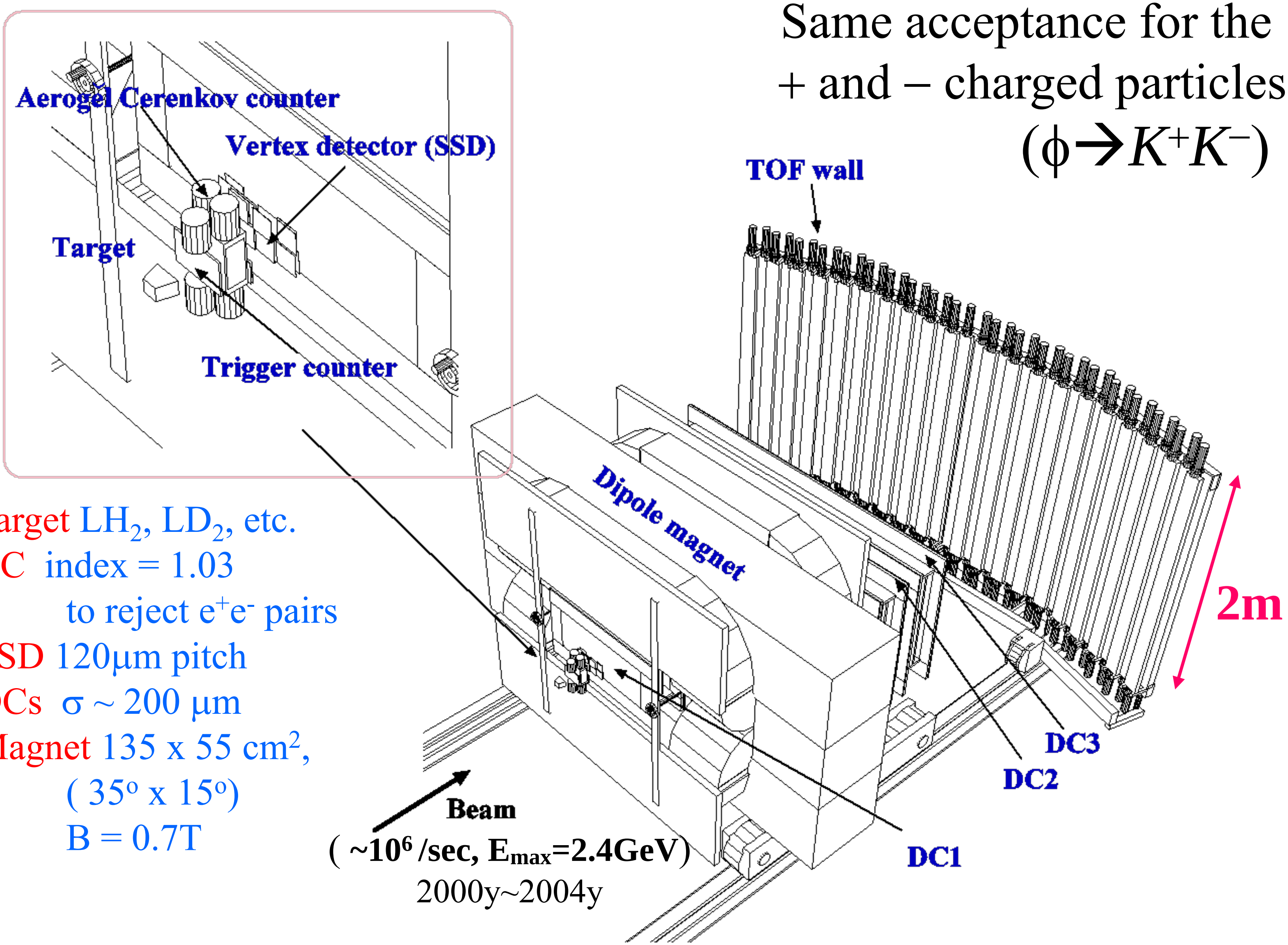
Energy spectrum of

BCS photons

Bremsstrahlung

LEPS forward spectrometer

Same acceptance for the
+ and – charged particles
($\phi \rightarrow K^+K^-$)



(~10^6 /sec, E_{max}=2.4GeV)
2000y~2004y

- Target LH_2, LD_2, etc.
- AC index = 1.03
  to reject e^+e^- pairs
- SSD 120μm pitch
- DCs σ ~ 200 μm
- Magnet 135 x 55 cm^2,
  (35^o x 15^o)
  B = 0.7T

Upgrade items @LEPS

- Beam
  - Intensity --- $1x10^6$ /sec → $2x10^6$ /sec→ more
  - Energy --- $E_{max} = 2.4$ GeV → $E_{max} = 3$ GeV
  - Stability
- Detector
  - Acceptance --- FWD spectrometer → FWD+Side-way
  - DAQ
- Target
  - Polarized target LH$_2$, LD$_2$ → polarized HD

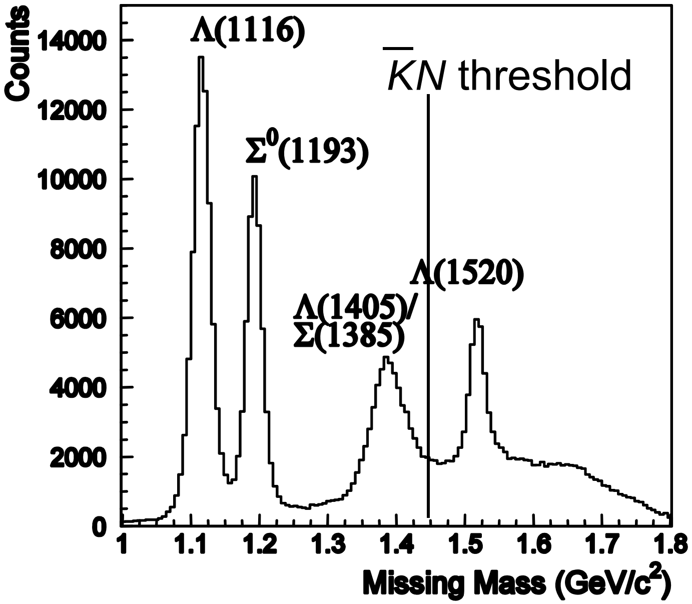
I will Skip the DAQ and polrized HD in my talk. Their developments are going on and recently some progress has been made.

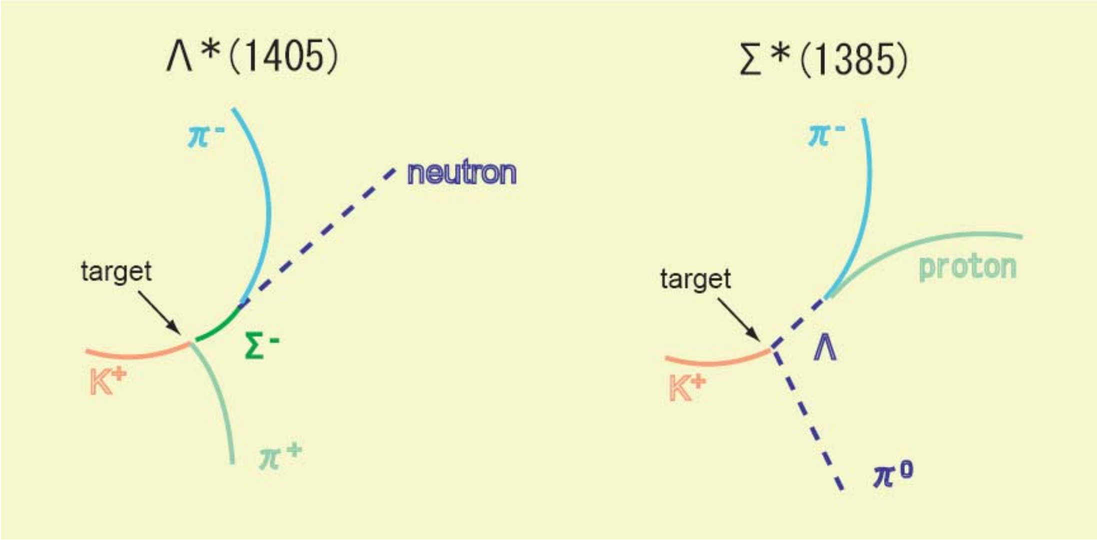
1st upgrade (2004): Time Projection Chamber (TPC) was introduced for the study of $\Lambda(1405)$

missing mass spectrum can not separate Λ(1405) and Σ(1385)
→ detect decay products and distinguish two resonances

$$\gamma p \rightarrow K^+\Lambda(1405) \rightarrow K^+\Sigma^\pm\pi^\mp \rightarrow K^+n\pi^+\pi^-$$

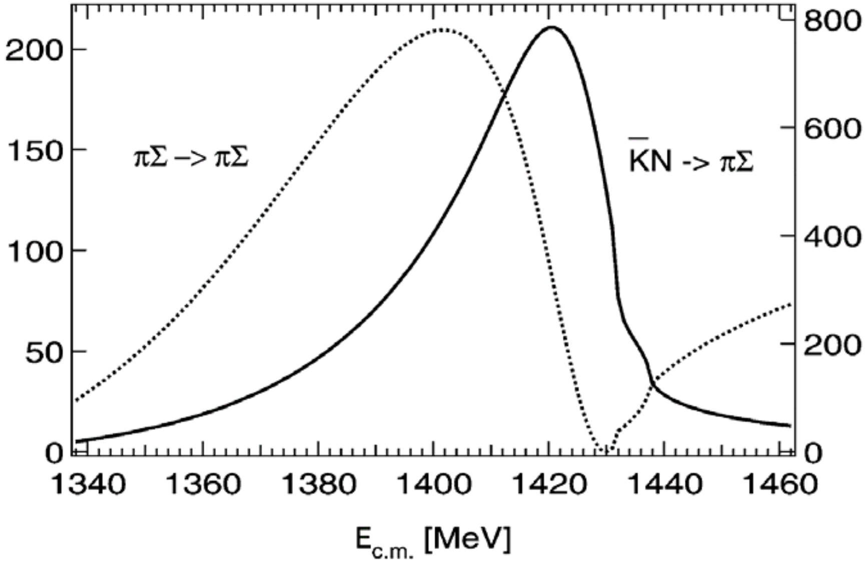
$$\gamma p \rightarrow K^+\Sigma(1385)^0 \rightarrow K^+\Lambda\pi^0 \rightarrow K^+p\pi^-\pi^0$$



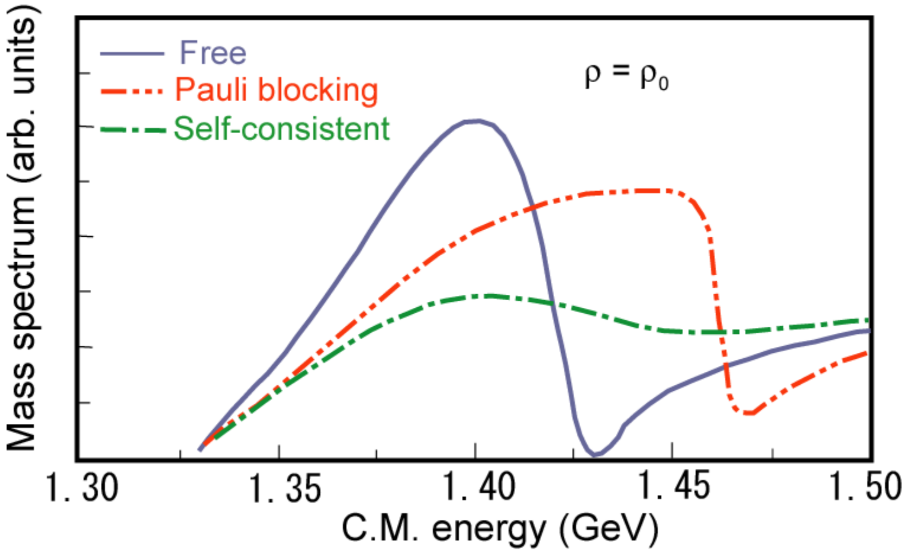


$\Lambda(1405)$

- Long-standing question: 3q state or meson-baryon resonance?
  Large energy difference between $\Lambda(1520)$ $3/2^-$ and $\Lambda(1405)$ $1/2^-$ →~~3q~~
- Line shape is reproduced as the mseon-baryon molecule in Chiral Unitary model.
  → predict the medium modification of its width in nucleus.
- 2-poles of $\pi\Sigma$ and $\bar{K}N$? Pole position of $\bar{K}N$ is especially important for kaonic nuclei (bound *Kpp* state) and *K*-condensation in neutron star.



Jido et. al NPA725 (2003)

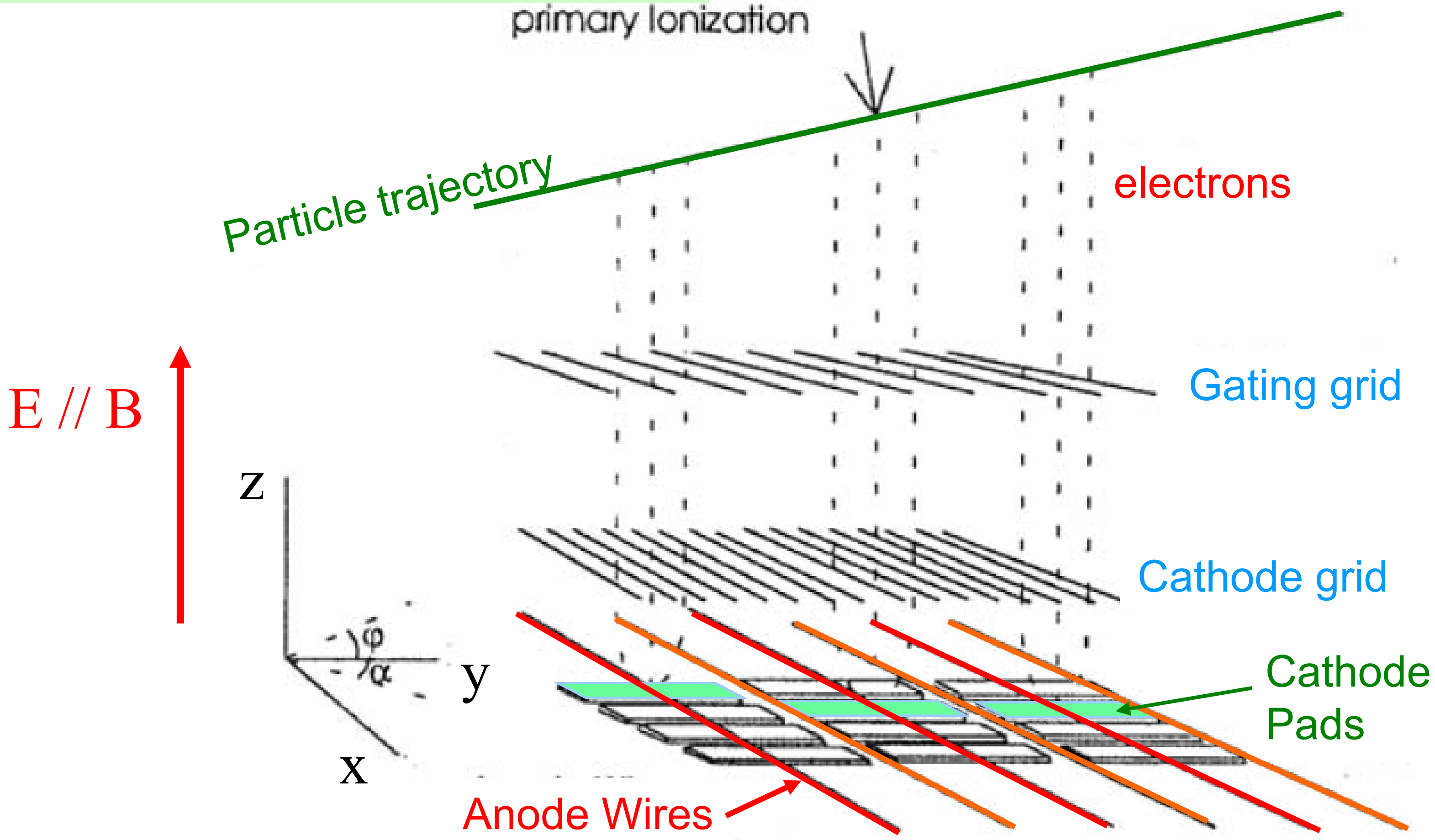


Nacher et al., PLB455 (1999)

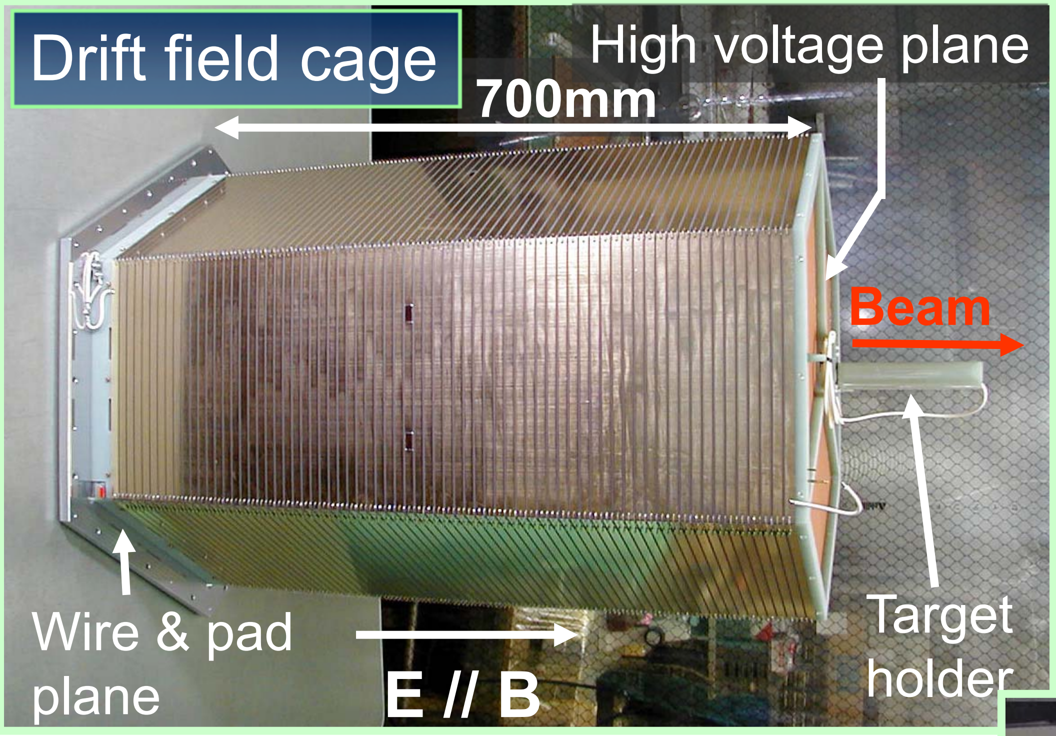
Time Projection Chamber

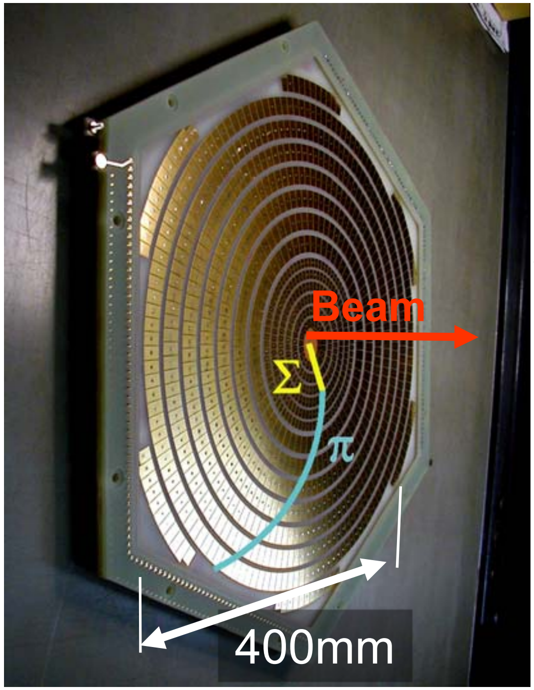
3-dimentional position information
pad-plane → x-y position
drift time → z position
dE/dX, momentum → PID

No thick materials for opposite side of the pad plane, i.e., forward region. (CDC needs wire support frames)



TPC





Pad design

Cathode pads : 1055

Anode wires : 95

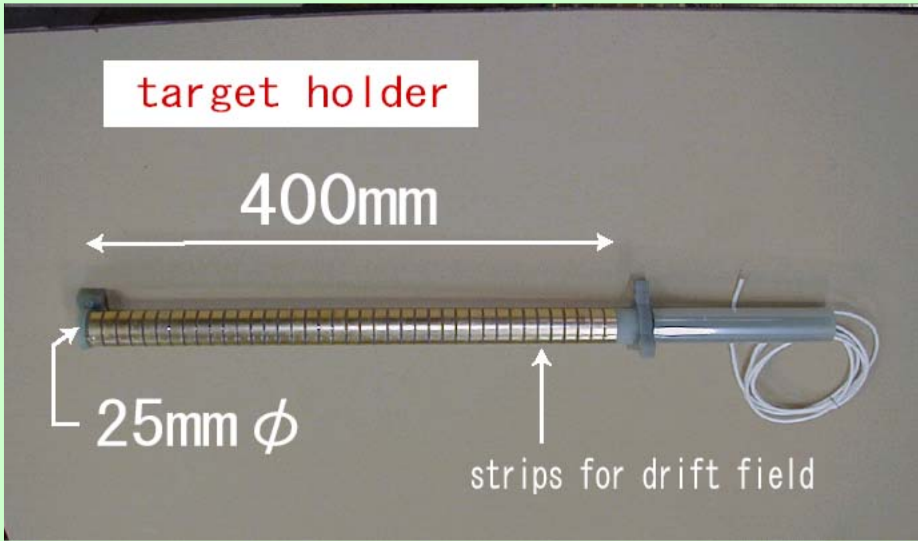
Resolution

Drift direction : 800 μm

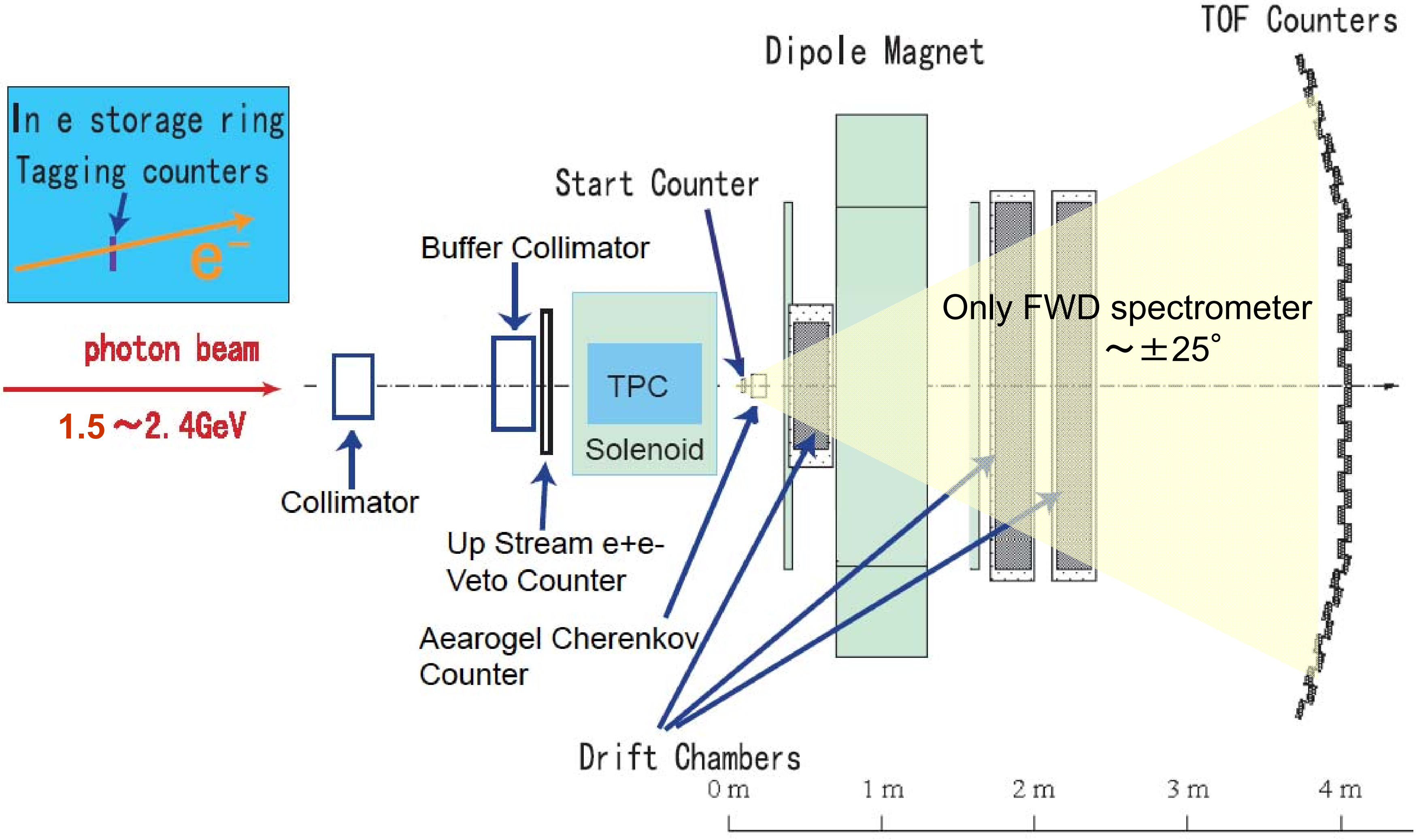
Pad plane : 400 μm

Active volume (cylindrical shape)
700 mm in length
400 mm in diameter

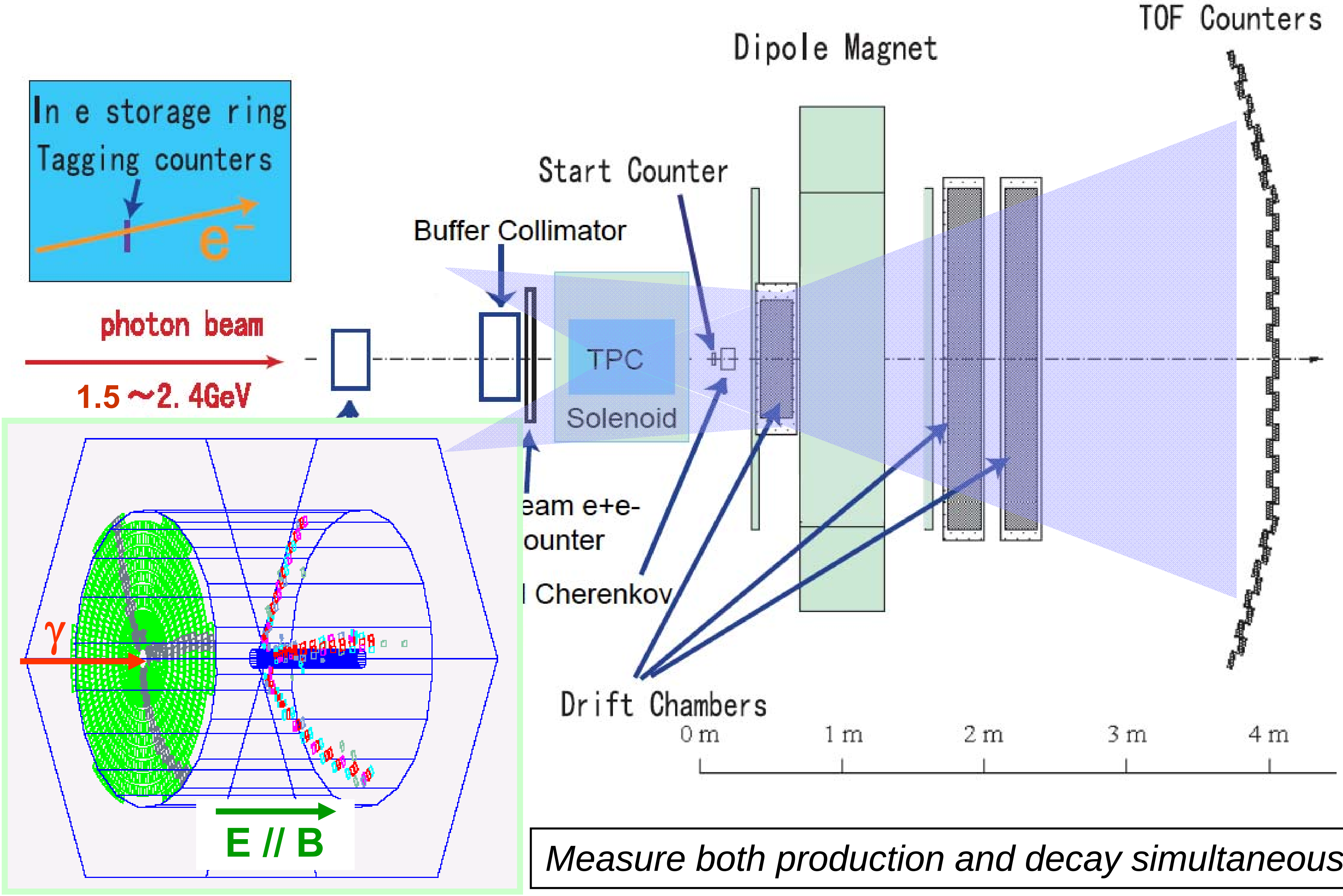
A Solid Target (CH2 or C) is put inside the TPC for detecting Σ decay point, if possible.



Setup of TPC experiment



Setup of TPC experiment



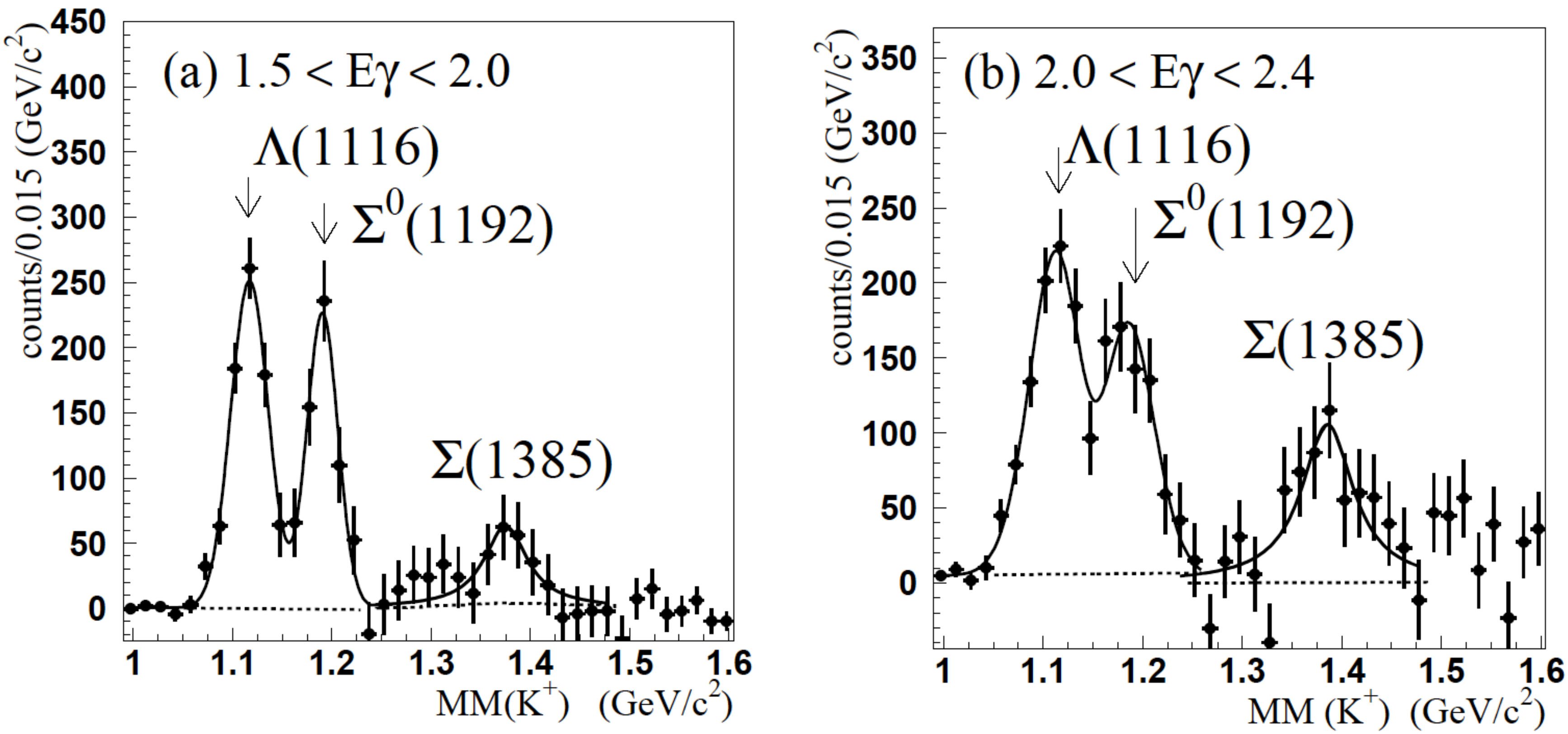
Measure both production and decay simultaneously !

Spectrum of Σ(1385) in 2 Eγ bins [CH_2-C]

spectrometer TPC

$$\gamma\, p \rightarrow K^+\, \Sigma(1385) \rightarrow K^+ \Lambda\, \pi^0 \rightarrow \boxed{K^+}\,\boxed{p\pi^-}\,\pi^0$$

Missing mass



Spectrum of Λ(1405) in 2 Eγ bins [CH_2-C]

● data

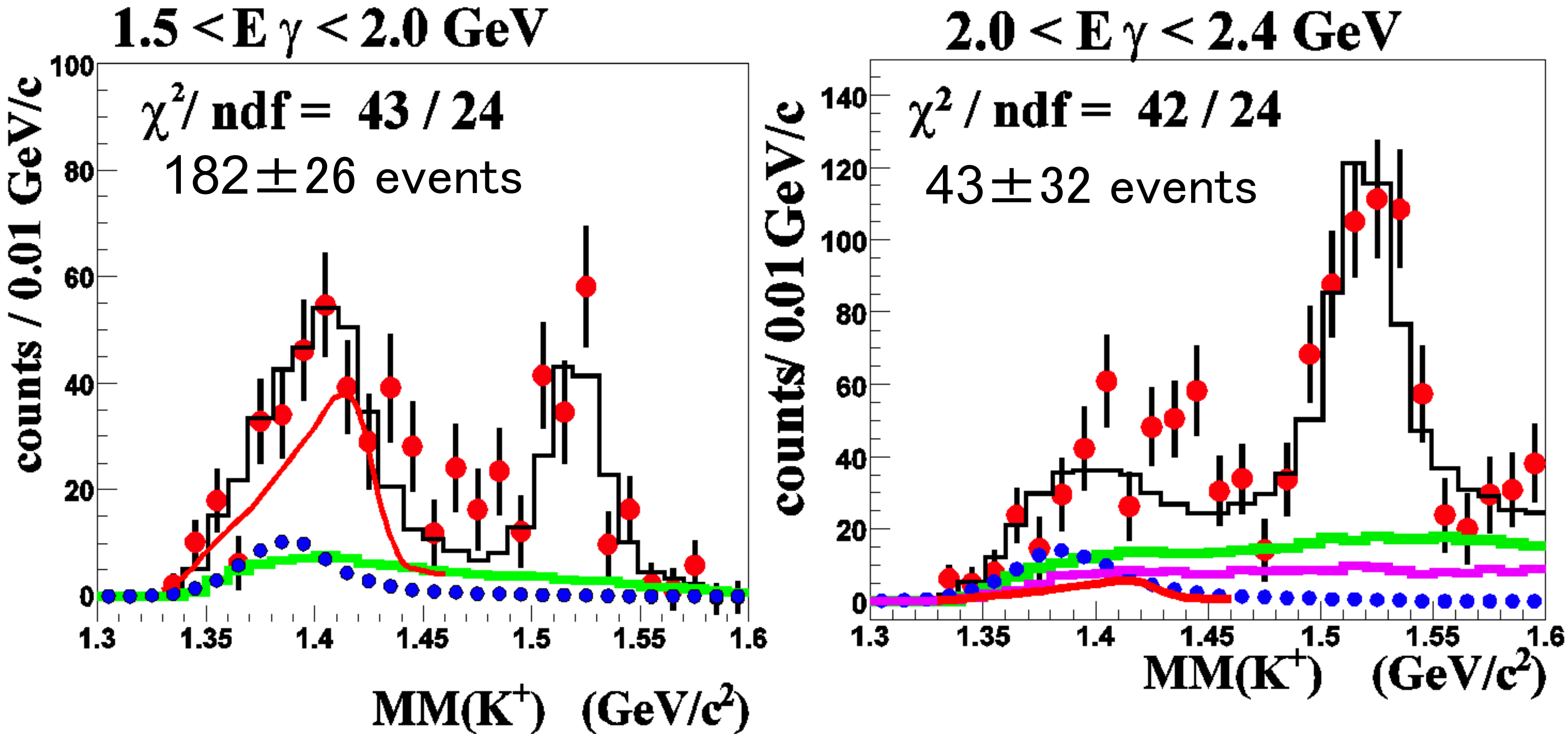
● Σ(1385) ($\Lambda\pi^0$ mode)

▬ Σπ phase space

▬ K*(892)Σ^+

▬ theoretical model

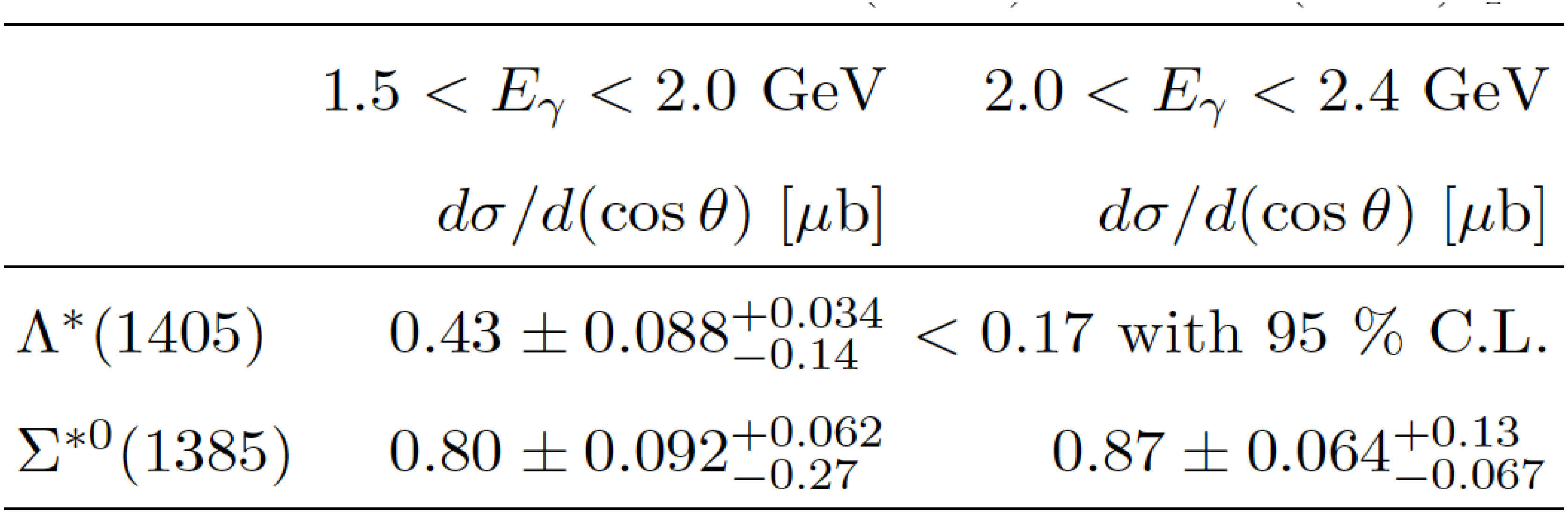
Λ*/Σ* = 0.54 ± 0.17 (1.5<Eγ<2.0)
0.074 ± 0.076(2<Eγ<2.4)



Absolute value of the differential cross section

Using the ratio of $\Lambda(1405)/\Sigma(1385)$,
the absolute value is obtained using LH2 data.

$0.8<\cos\theta_{kCM}<1$



	$1.5 < E_\gamma < 2.0$ GeV	$2.0 < E_\gamma < 2.4$ GeV
	$d\sigma/d(\cos\theta)$ [μb]	$d\sigma/d(\cos\theta)$ [μb]
$\Lambda^*(1405)$	$0.43 \pm 0.088^{+0.034}_{-0.14}$	< 0.17 with 95 % C.L.
$\Sigma^{*0}(1385)$	$0.80 \pm 0.092^{+0.062}_{-0.27}$	$0.87 \pm 0.064^{+0.13}_{-0.067}$

t	$-0.45<t<-0.12$ GeV^2	$-0.37<t<-0.08$ GeV^2

The production cross section of L(1405) decreases in higher photon energy region. It suggests the difference of production mechanism and/or their internal structures.

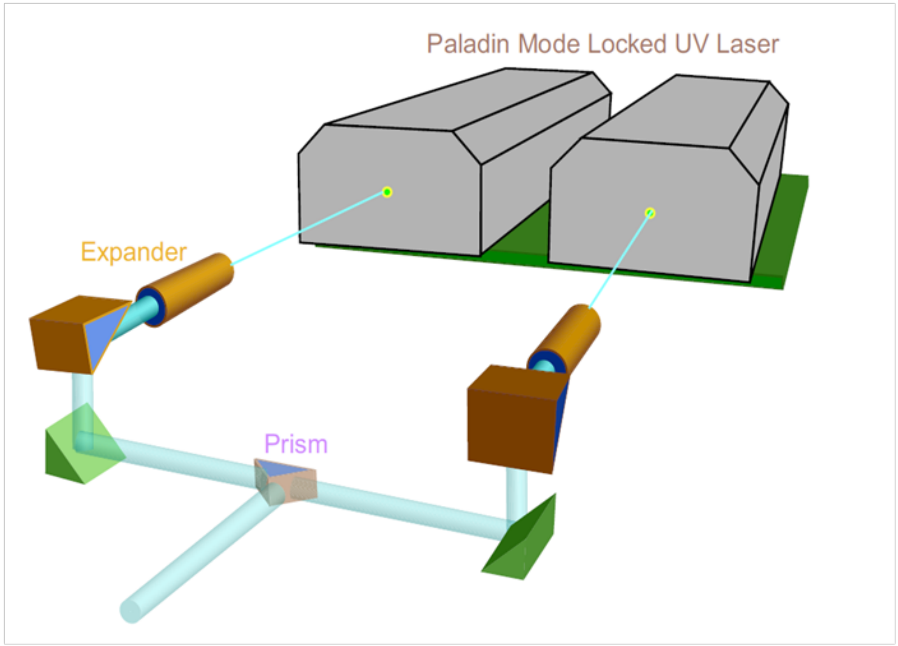
Niiyama et al. PRC78,035202(2008)

2nd upgrade: Multi-laser Injection (2006)

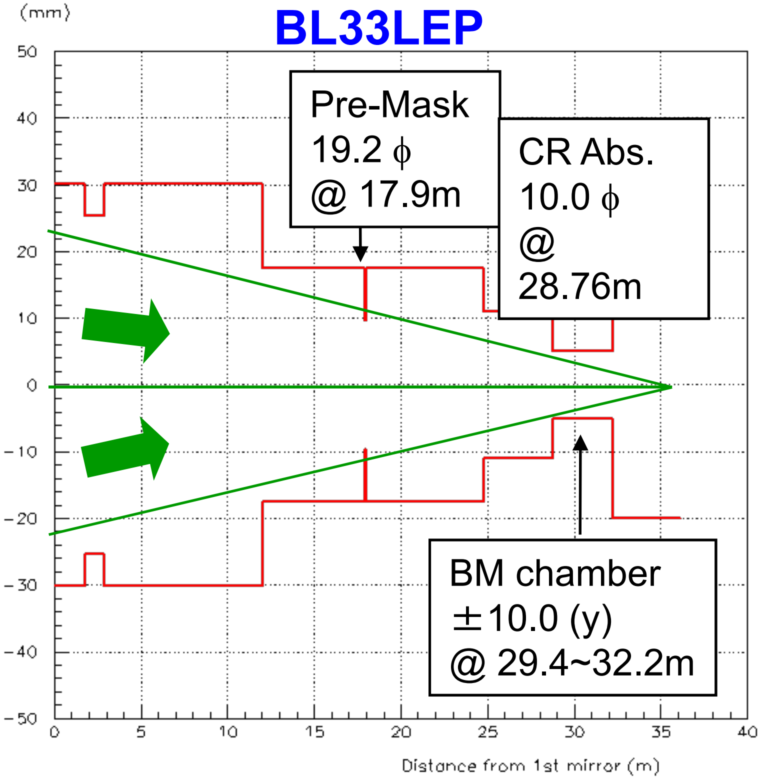
-351nm Ar laser (6.5W CW) was replaced by 355nm solid-state laser :
(1) quasi-CW (80 MHz, 8W) (2) no interference

- 2-laser injection has been installed at BL33LEP ⇒ ~2 Mcps
- But aperture of BL33LEP is narrow. [Only 20 mm / laser is allowed.]

⇒ Larger aperture will give more efficient transmission
and allow additional laser injections. → LEPS2

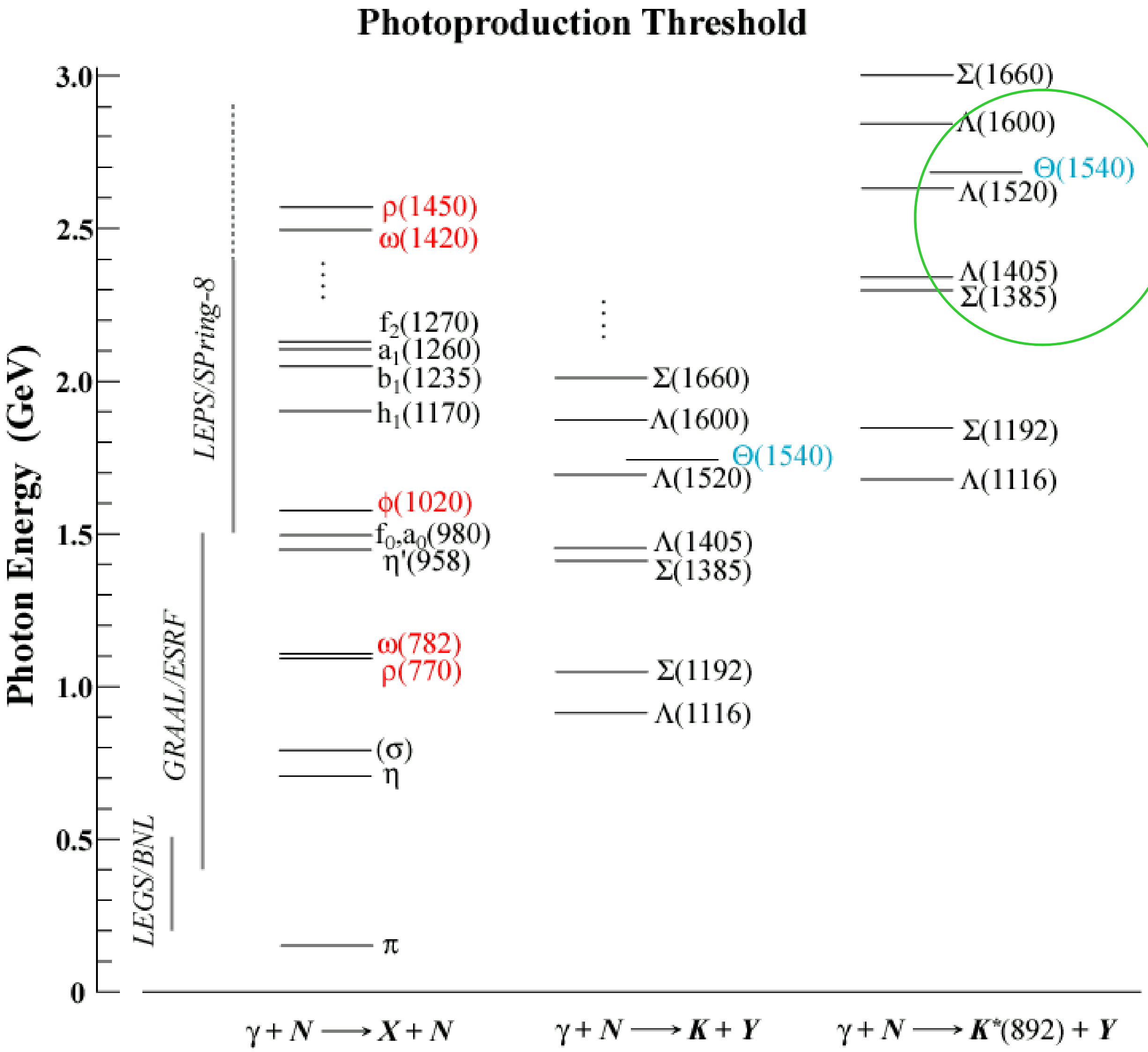


Used in 2006-2007 run for the Θ^+ study with higher statistics



3rd upgrade: Energy up with deep-UV laser

(E_{max}=2.96 GeV @ 257nm Ar laser)



2005: test exp. for ω mesic nucleus

2006:
$\gamma + p \rightarrow K^{*0} + \Sigma^{+}$

But the intensity is still low <1.8x10^5.

Very unstable due to the fast deterioration of the optical system.

4th upgrade: new TPC for the cryo-targets (2008~)

Physics motivation

$$\vec{\gamma} + p \rightarrow \Theta^{+} + \overline{K}^{*0} \quad (K^{*} \rightarrow K\pi)$$

$$\vec{\gamma} + n \rightarrow \Theta^{+} + K^{*-}$$

$$\vec{\gamma} + p \rightarrow \Theta^{+} + K^{-(+)} + \pi^{+(-)}$$

$$\vec{\gamma} + A \rightarrow \text{backward}\ \phi\ \text{production}$$

$$\vec{\gamma} + p \rightarrow \Lambda^{*}(1405) + K^{*+} \qquad \text{etc.}$$

→

new TPC (NTPC)
2.96 GeV γ
new LH_2,LD_2 target

Decay asymmetry of K*
→ sensitive to the parity of exchange particle(s)

information of both missing masses and invariant masses

new TPC design

Strong boundary condition : use it with the LEPS solenoid (60 cmϕ bore)

- **TPC-I**

  decay vertex for Σ

  → no inner bore (diameter of target pipe: 25mmϕ)

  Anode wire : one direction, Pad raw : circular, two sizes

  → large position-dependent σ_{xy} (300μm to ~800μm)

  LH_2, LD_2, LHe: impossible

- **new TPC**

  inner bore size :~100mmϕ for LH_2,LD_2,LHe target

  hexagonal shape

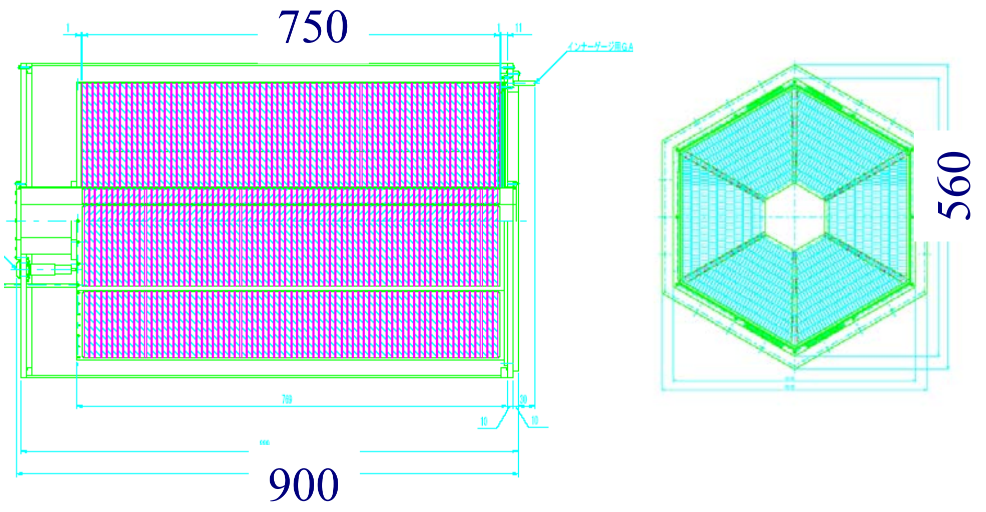
  → small dead region for the wire-supporting

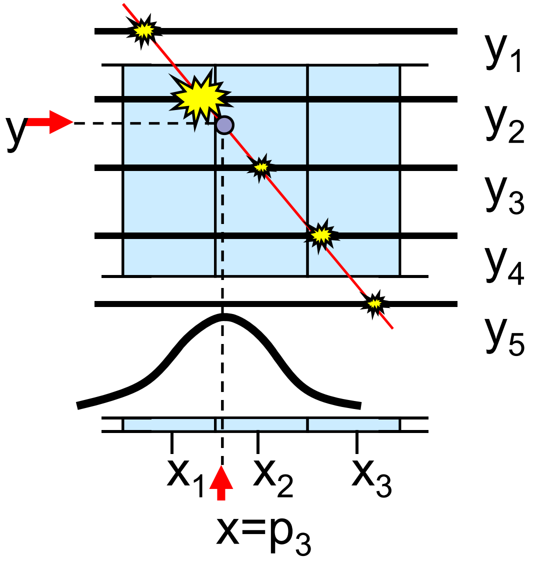
  → need better σ_{xy} for good *Δp/p* (*L_T* is small !)

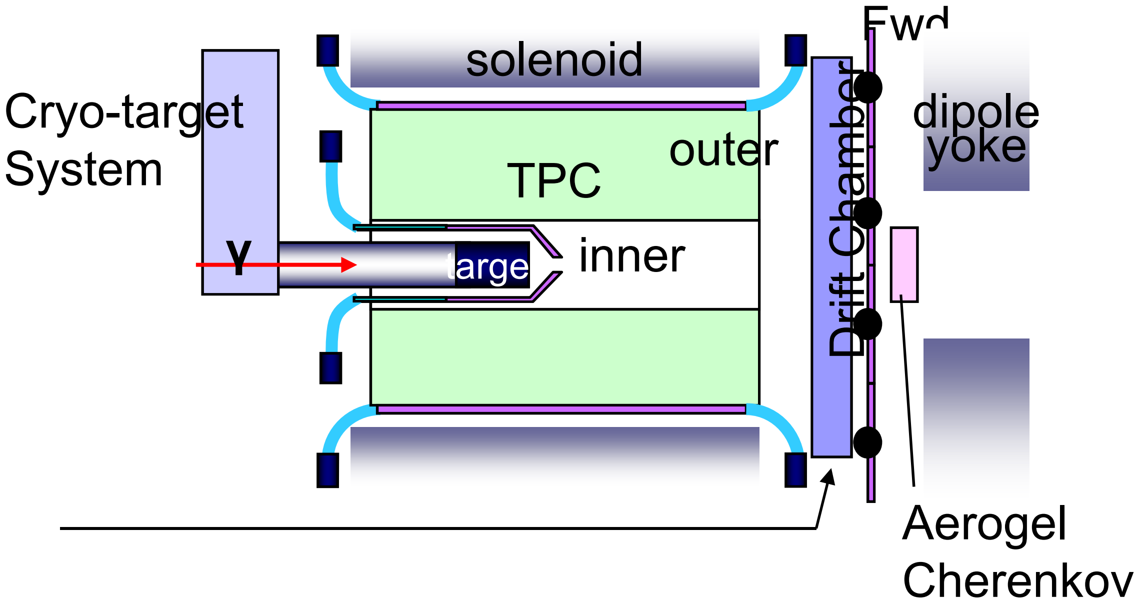
$$\frac{\Delta p_t}{p_t} \approx \frac{\sigma_{xy} p_t}{0.3BL_T^2}\sqrt{\frac{720}{N+4}} \approx 5.4\% \quad @\sigma_{xy} = 200\,\mu\mathrm{m},\ p_t = 0.5\,\mathrm{GeV/c}$$

New TPC

- LEPS new TPC
  - Inner bore for the cryo-target
  - determine y-position by using anode wire information





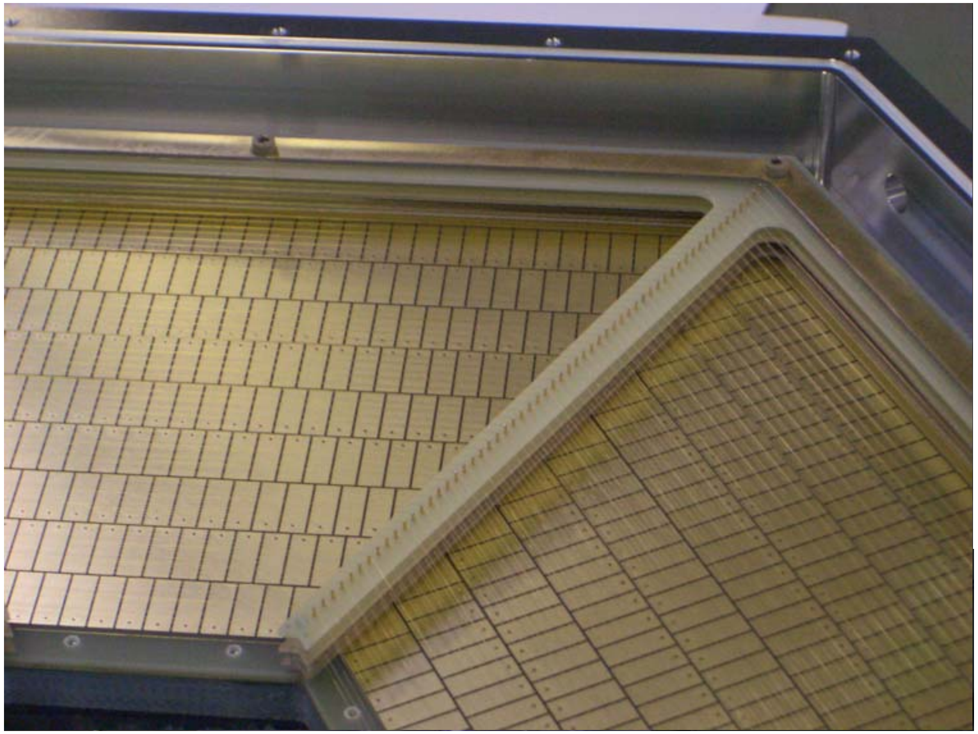


- Add a DC covering the Forward region

New Time Projection Chamber

- Pad size : **5.1mm x 14.5mm** space : **0.5mm** 9 layers **225 pads** / sector (total **1350 pads**)
- Wire anode wire: 27 x 2 (upper half & lower half) = 54 wires
  Spacing of anode and potential wires: **2.5mm**
  Distance from the pad plane = **4mm**

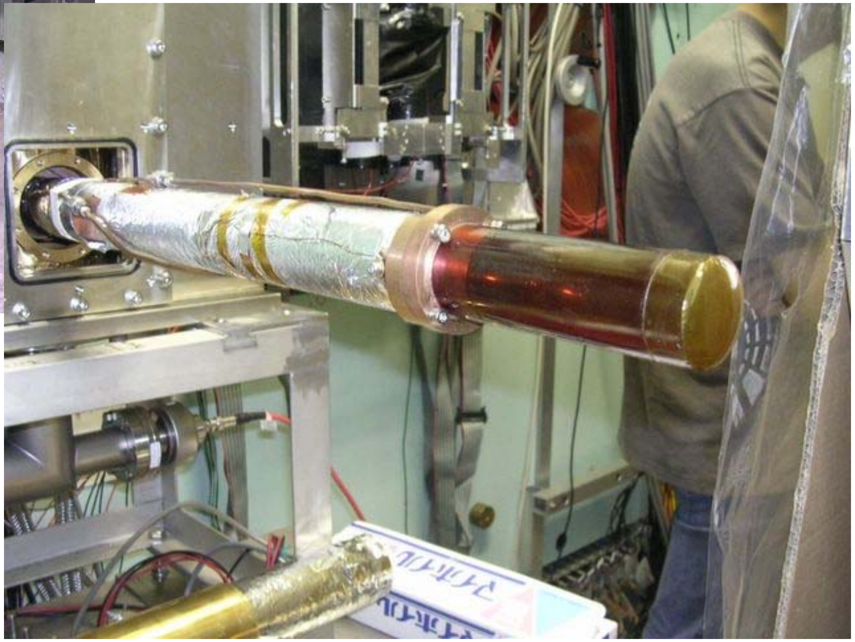
  3-plane structure of gate wires, shield wires, and anode/potential wires



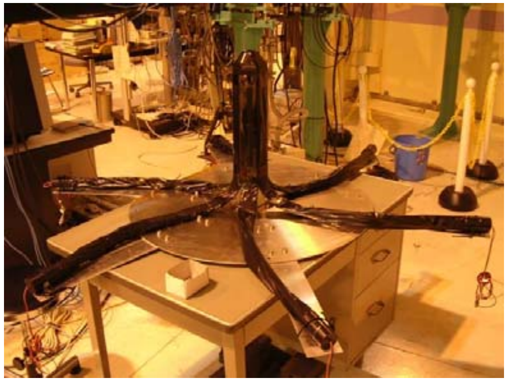
Liquid Cryo-Target System

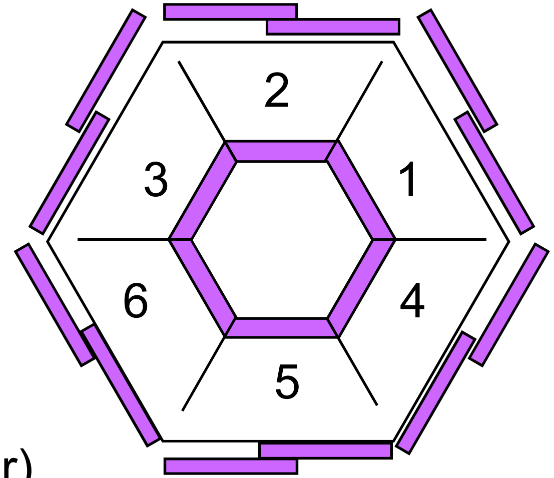
- target cell
  - Kapton film
  - length 150mm
  - diameter 40mmϕ

CFRP cap
(carbon fiber)



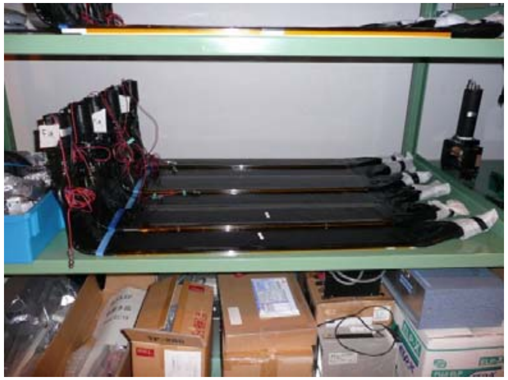
Trigger Counters





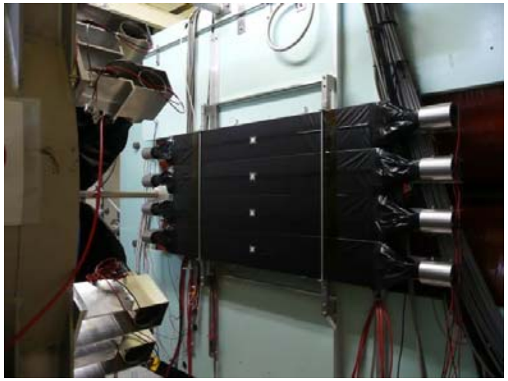
inner scintillator

- 6 counters (1 for each sector)
- PMT: one side
- thickness: 3mm



outer scintillator

- 12 counters (2 for each sector)
- PMT: both sides
- thickness: 5mm
- time resolution = ~150ps



forward scintillator

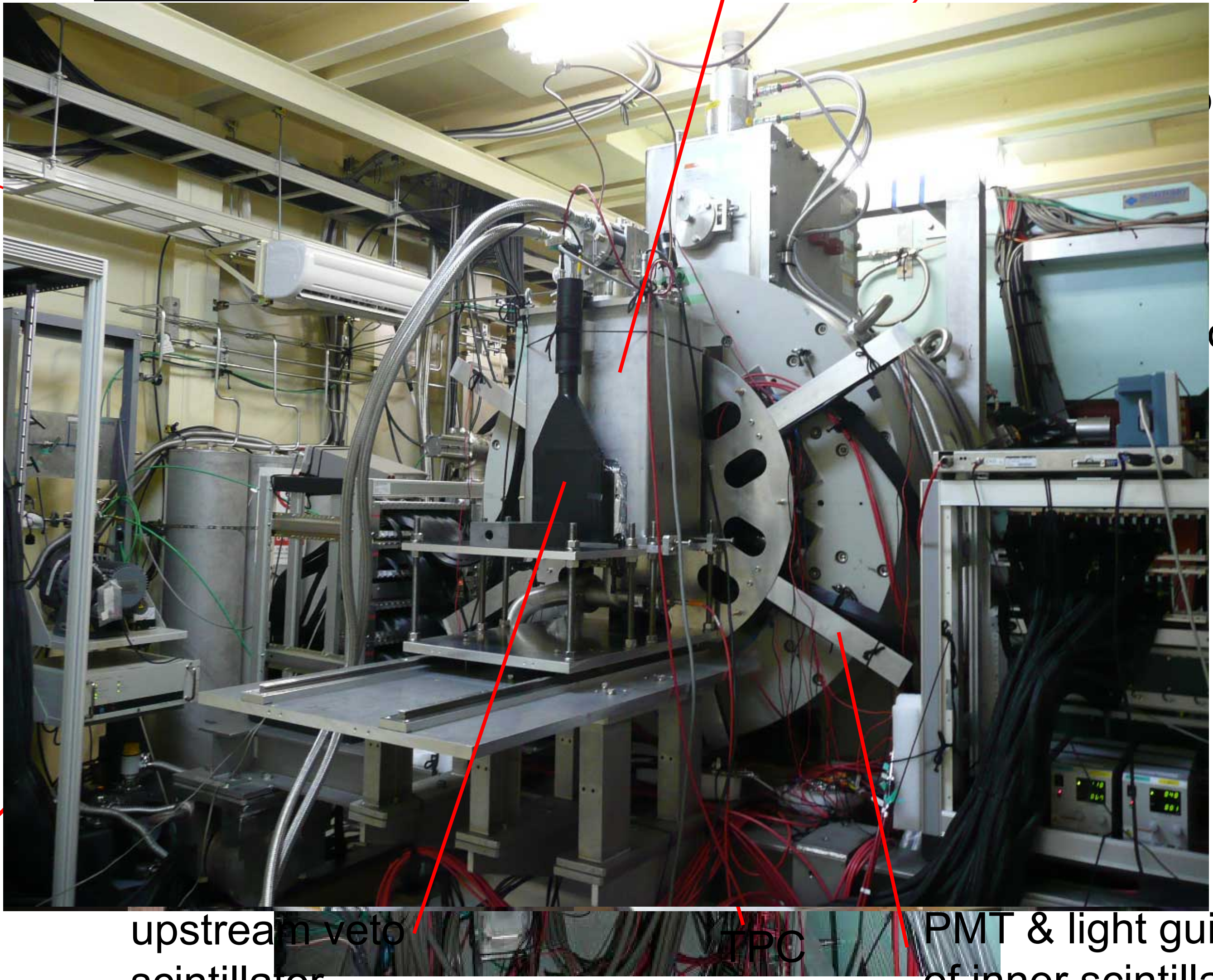
- 4 counters
- PMT: both sides
- thickness: 10mm
- time resolution = ~100ps

Set up

Before target install

After target install

Downstream side



liquid target system

PMT of outer scintillator

ole

d scintillator

dipole

outer

solenoid

upstream veto scintillator

TPC

chamber

PMT & light guide of inner scintillator

Summary of LEPS upgrade

- LEPS@Spring-8 has been successfully operated since 2000.Dec for the study of the quark nuclear physics. We have continuously tried to upgrade the LEPS, just after the LEPS experiment was started.
- Beam intensity has been increased (1×10^6 → 2×10^6 /sec) by means of two laser injection for the 2.4 GeV beam.
- Bean energy has been upgraded using the 257nm deep-UV laser. But the intensity is still low and unstable.
- Two TPCs have been constructed to enlarge the side-way acceptance.

(One is for the inner solid target and the other is for the cryo-liquid target.)

Momentum resolution and PI capability are limited by detector size

→ LEPS2

- The first 10-year contract with Spring-8 has been finished.

→ extend the LEPS next 6 years.

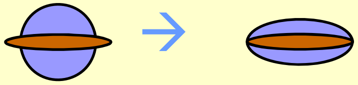
higher intensity (8W →16W for 355nm, 2-laser injection for 257nm), stable operation of 3 GeV beam, speed up of DAQ system, and use of the polarized target.

LEPS new beam line (LEPS2)

- Beam upgrade:

Intensity --- High power laser, Multi laser(x4)

--- Laser elliptic focus



2x10^{6} → 10^{7} /sec for 2.4 GeV

2x10^{5} → 10^{6} /sec for 3 GeV

Energy --- Laser with short λ , re-injected Soft X-ray+BCS (2nd stage),

→ up to ~7.5 GeV

- Detector upgrade: (reaction process & decay process)

Scale & --- General-purpose large 4π detector

Flexibility Coincidence measurement of charged particles and neutral particles (photons) ← BNL/E949 detector

DAQ --- High speed for the minimum bias trigger

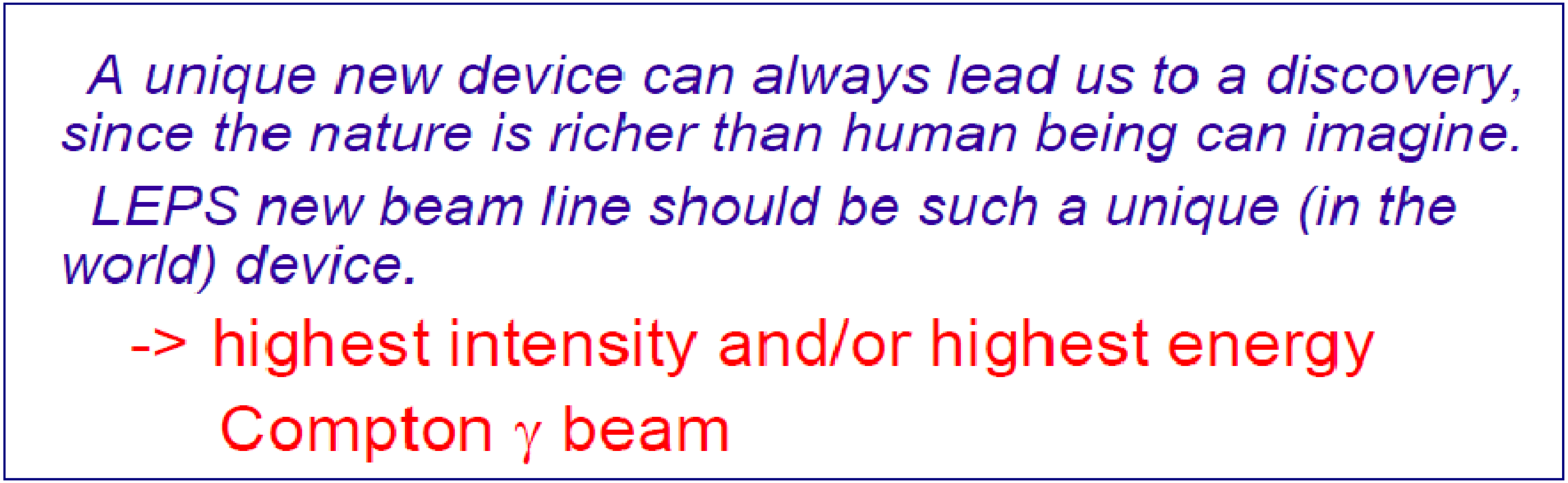
- Physics: Multi-quark (>3)

Workshop on LEPS2 (2005/7, 2007/1)

Virtual laboratory http://www.hadron.jp

What to measure ?

Imai-san's comment in the workshop



A unique new device can always lead us to a discovery, since the nature is richer than human being can imagine.

LEPS new beam line should be such a unique (in the world) device.

-> highest intensity and/or highest energy

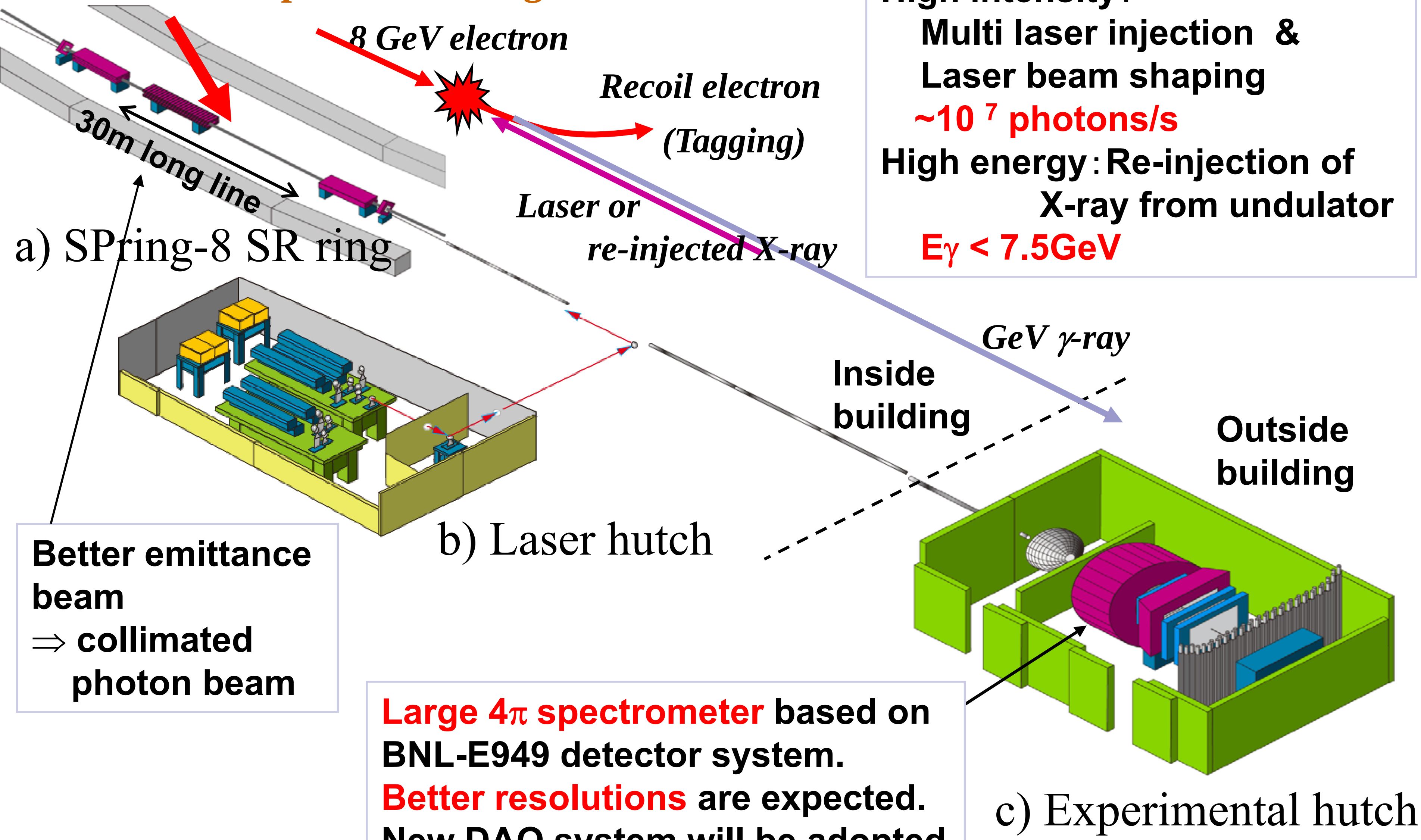
Compton γ beam

- High priority

→ Further confirmation of the Θ^+ with high statistics, wide energy range, and large acceptance.

Determine the spin and parity of Θ^+

Schematic view of the LEPS2 facility



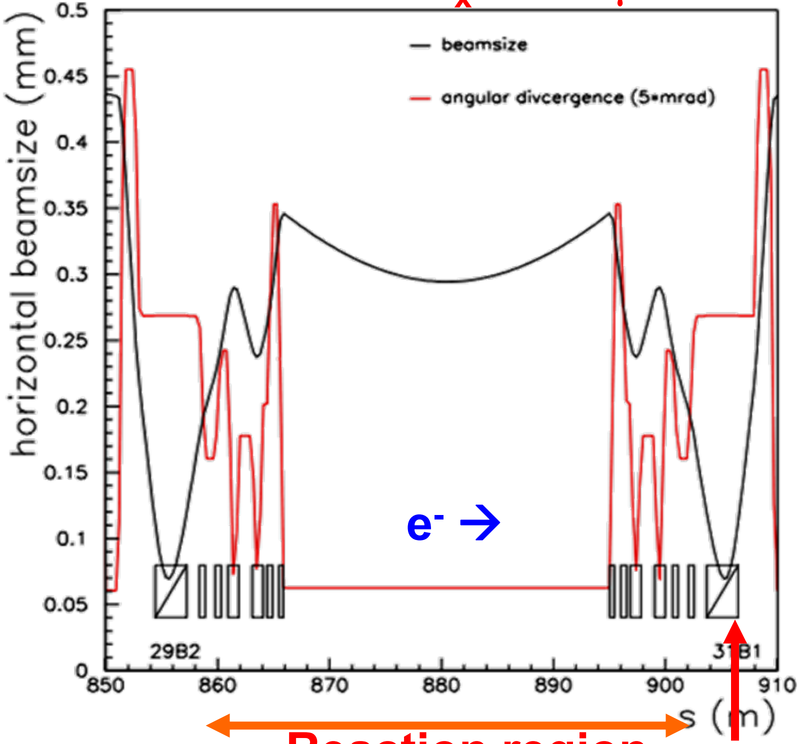
High intensity:
Multi laser injection &
Laser beam shaping
~10 ^{7} photons/s
High energy: Re-injection of
X-ray from undulator
E_γ < 7.5GeV

Better emittance beam
⇒ collimated photon beam

Large 4π spectrometer based on BNL-E949 detector system.
Better resolutions are expected.
New DAQ system will be adopted

Divergence of LEP beam

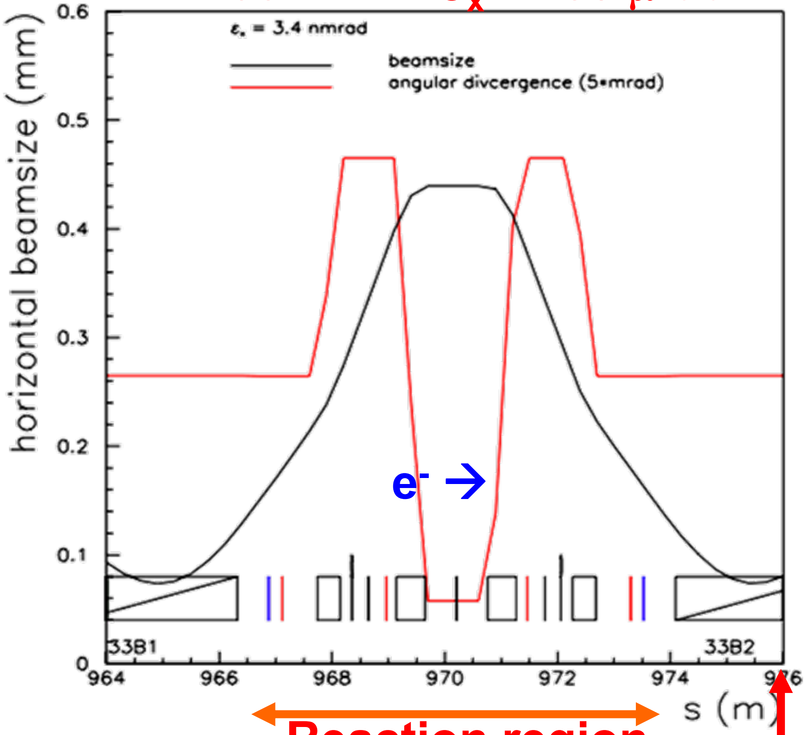
BL31ID $\langle\sigma_{x'}\rangle=14\ \mu\text{rad.}$



Reaction region (30m)

Tagging point

BL33B2 $\langle\sigma_{x'}\rangle=58\ \mu\text{rad.}$

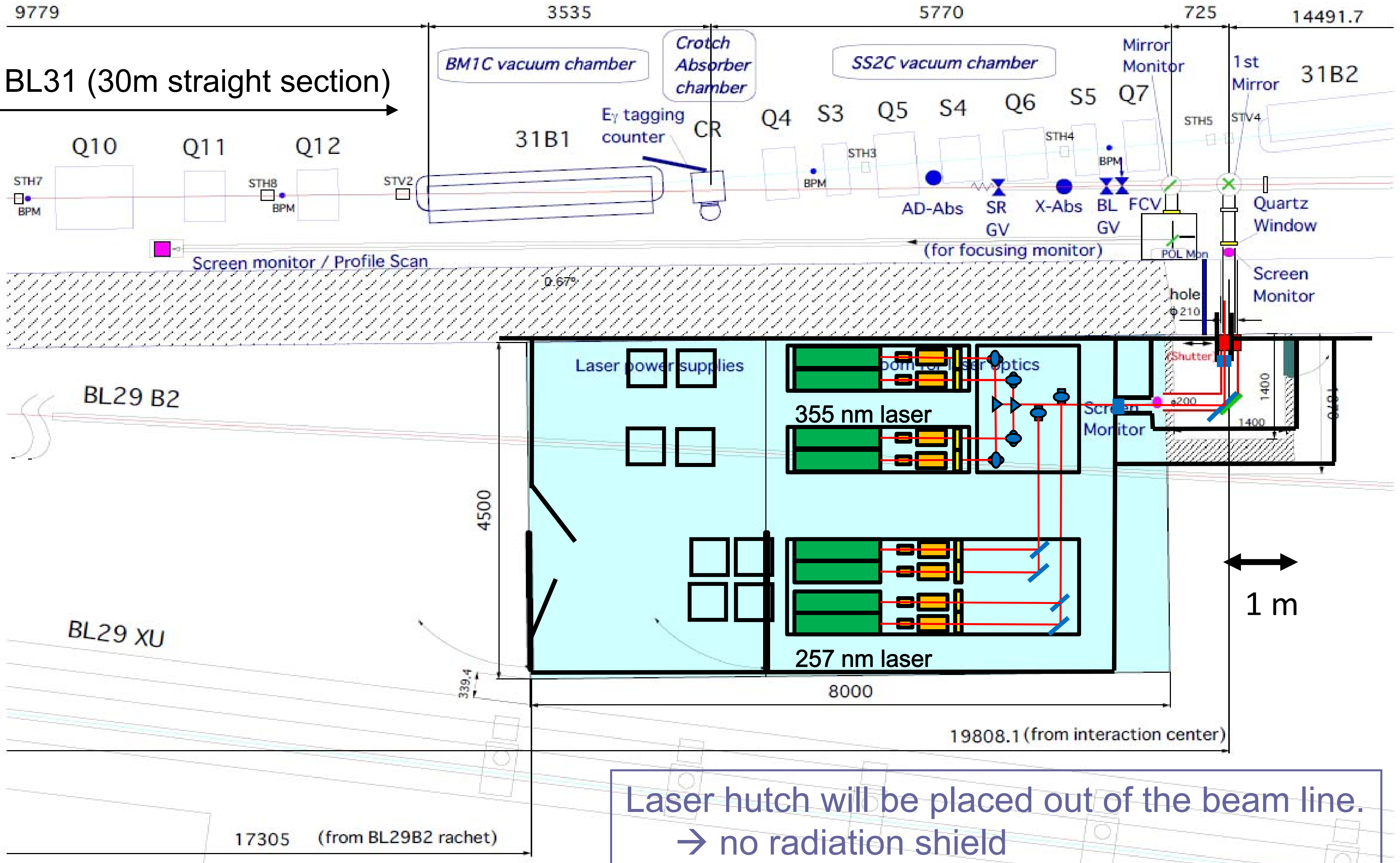


Reaction region (7.8m)

Tagging point

Better divergence → Better tagging resolution
Smaller beam size at the target

Laser hutch for new beam line

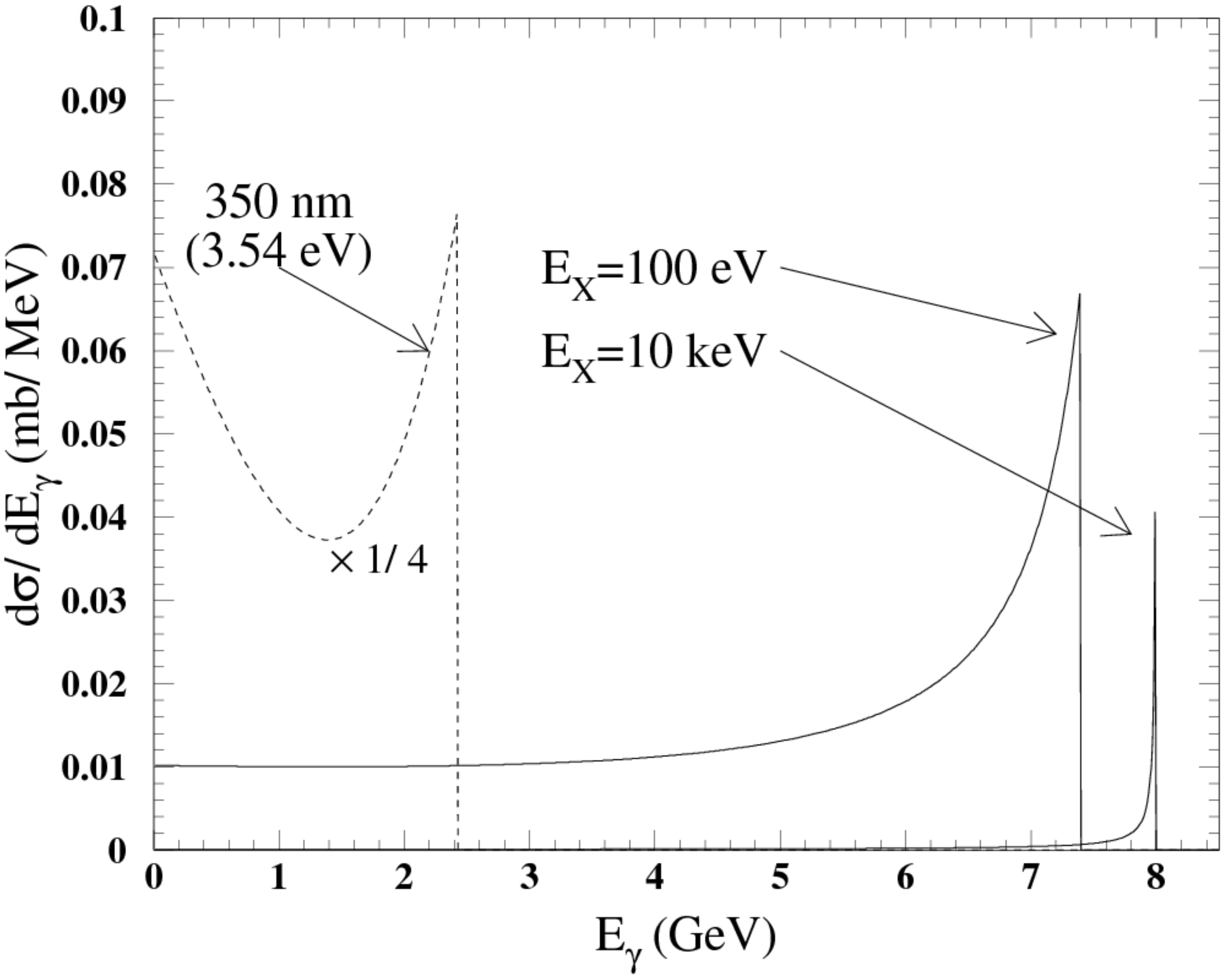


Laser hutch will be placed out of the beam line.

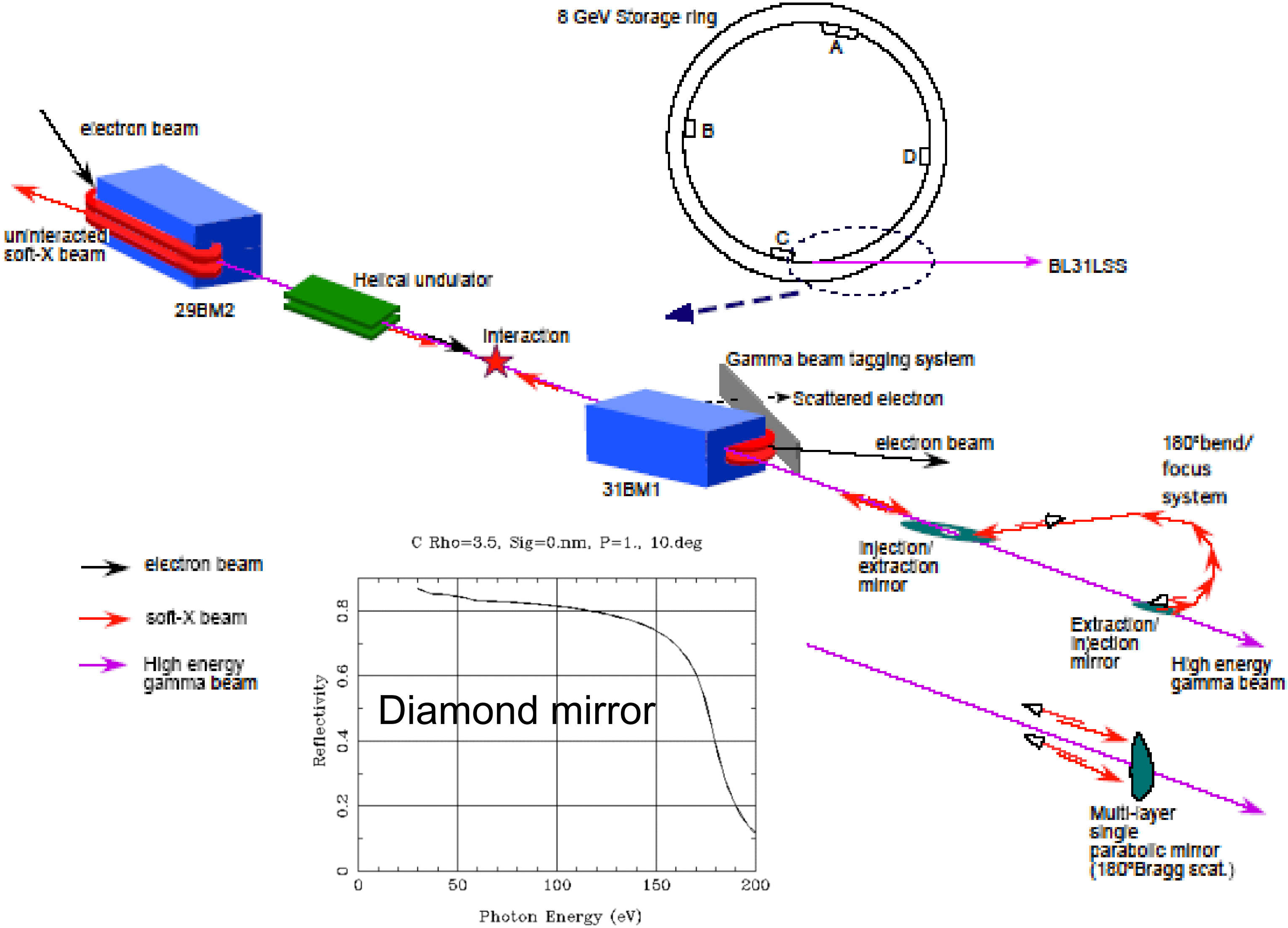
→ no radiation shield

→ close to the collision point

High Energy Backward Compton Photons

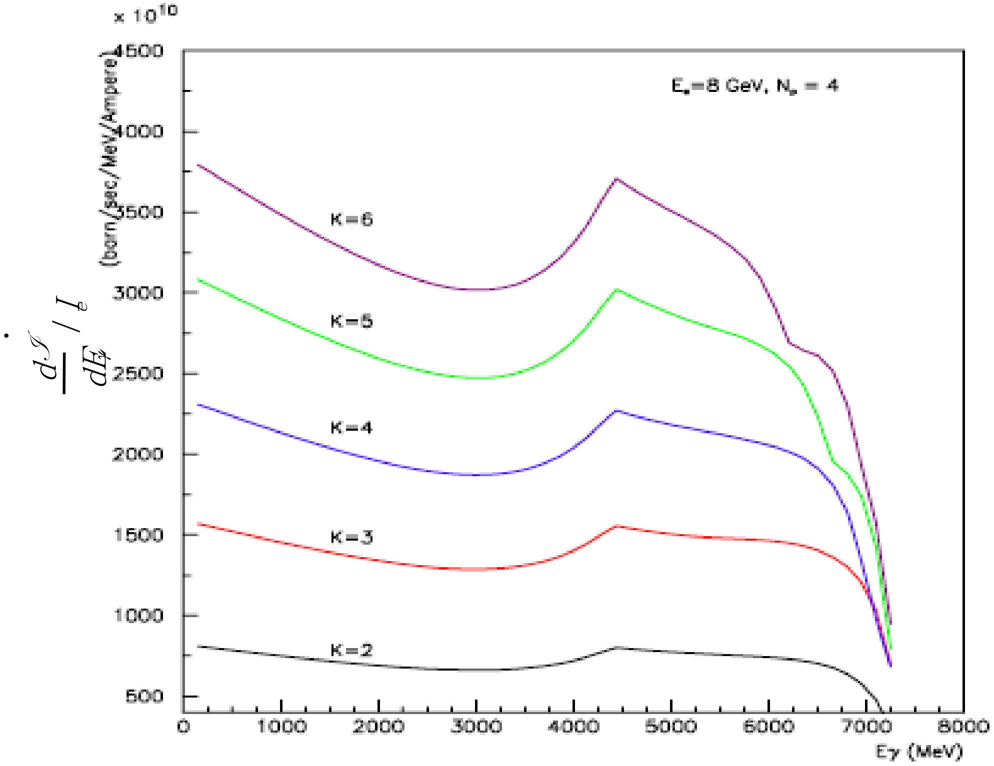


Backward Compton Scattering of X-ray for Ultra High Energy LEP



Energy Spectrum of High Energy γ

$$\frac{d\dot{\mathscr{I}}}{dE_\gamma} = \int_{\omega_1}^{\omega_2} d\omega \frac{d\sigma}{dE_\gamma}(\omega)\,\frac{d\dot{N}_{ph}}{d\omega}$$

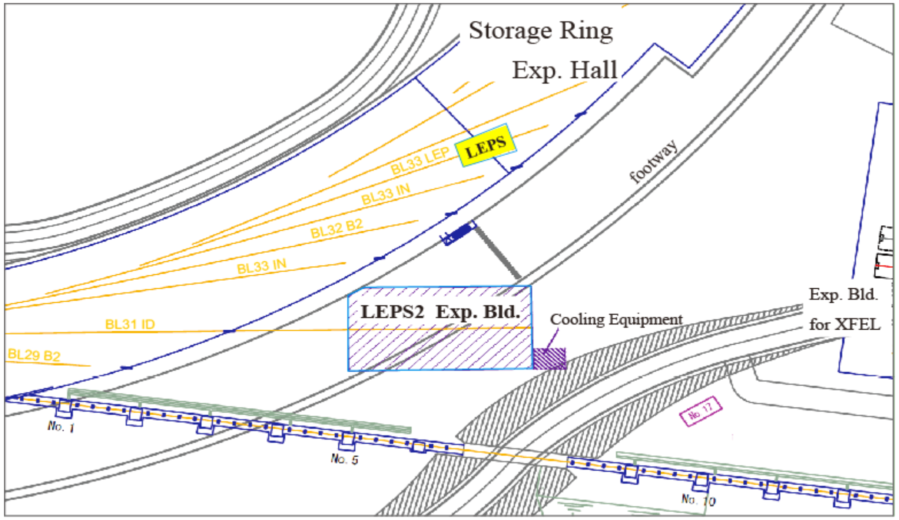


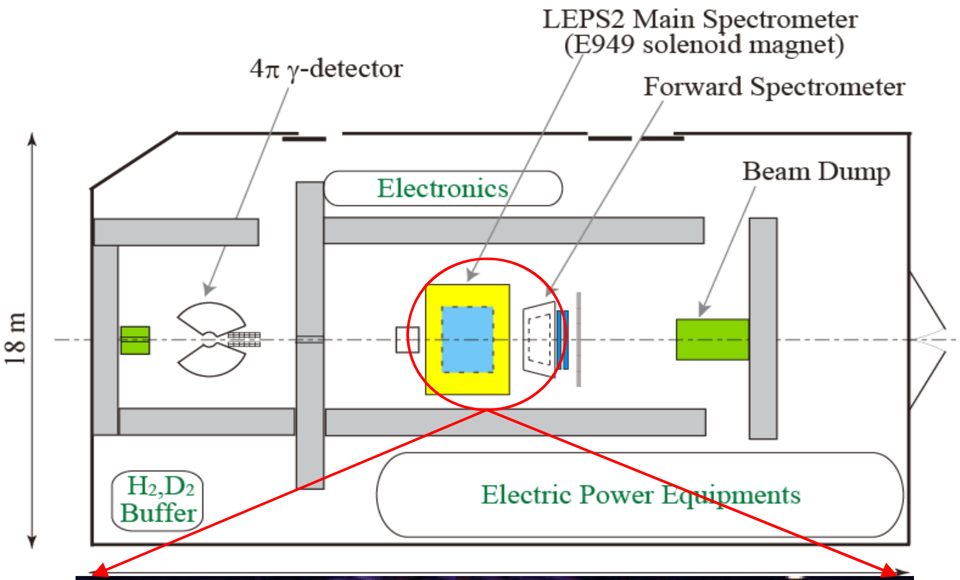
Estimated LEP Intensity

$$\dot{N}_\gamma = 2\times10^5 / \text{s}$$

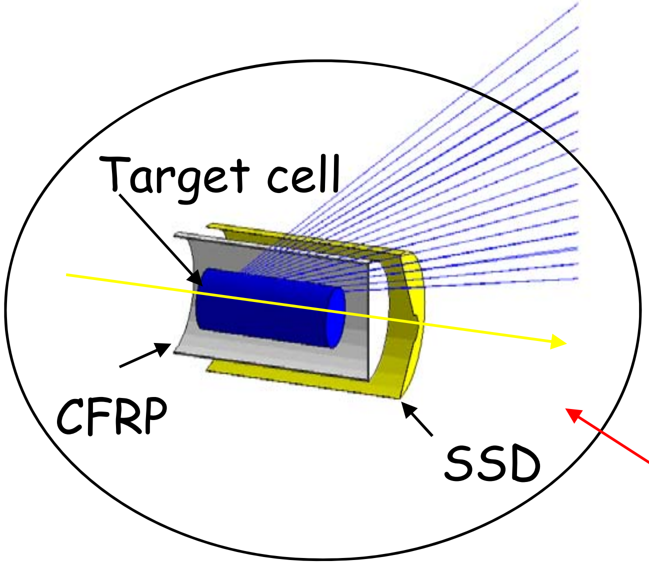
Need R&D study for the mirror, especially its radiation hardness.

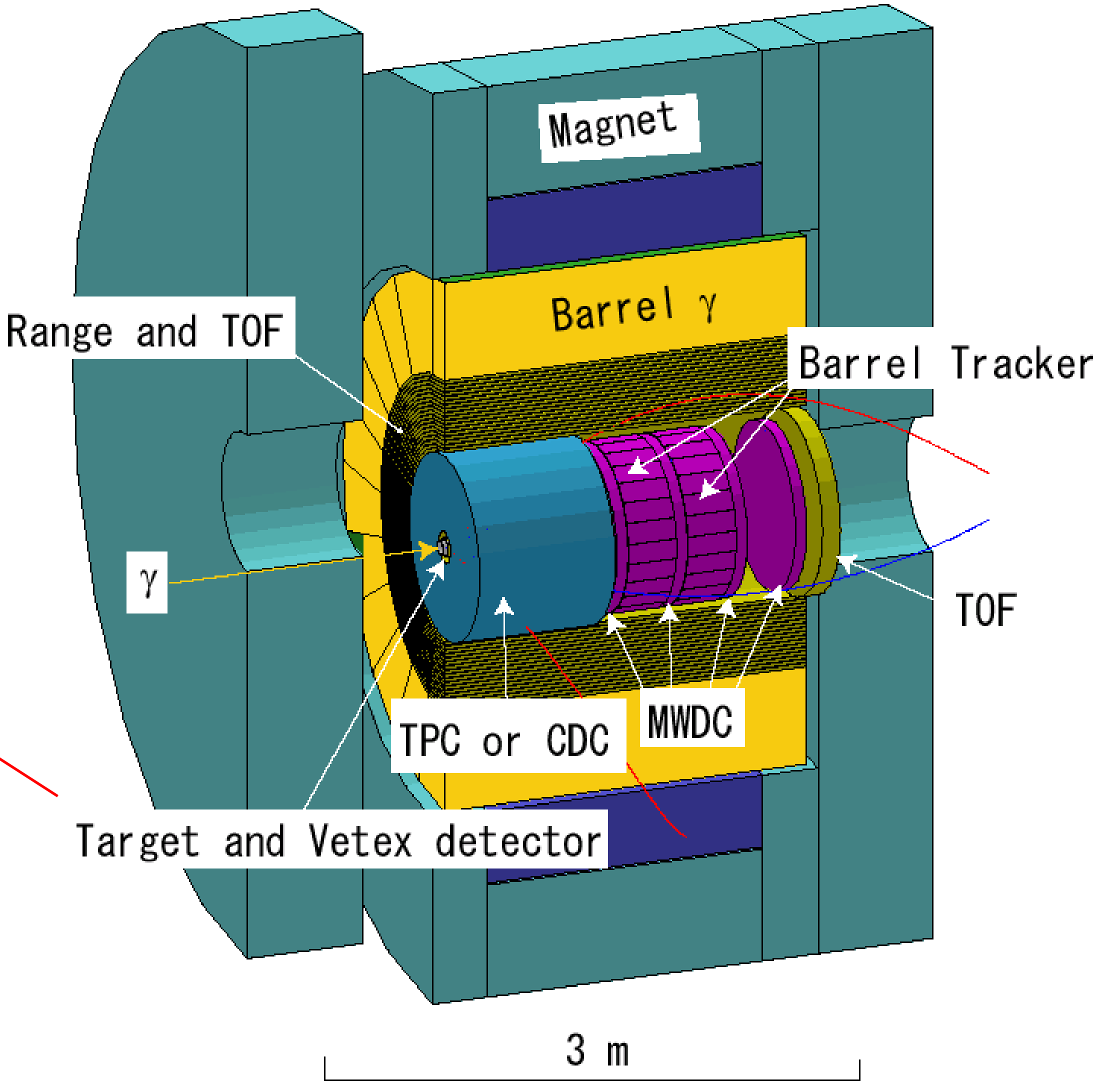
Experimental building for LEPS2





Detector Setup





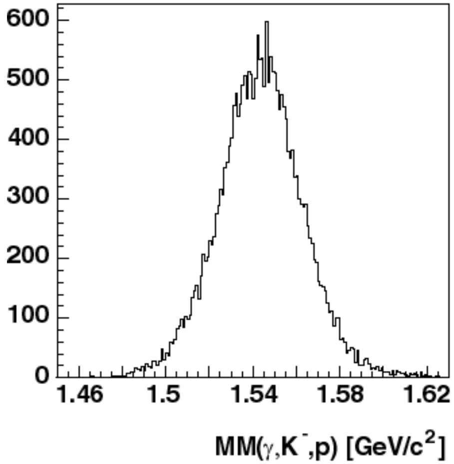
$\gamma\, d \to \Lambda(1520)\Theta^+$

$\gamma d \to \Lambda(1520)\ \Theta^+$

$\quad\quad \hookrightarrow K^- p$

Missing Mass

$\Delta M(\Theta^+)=17\ \mathrm{MeV}/c^2$

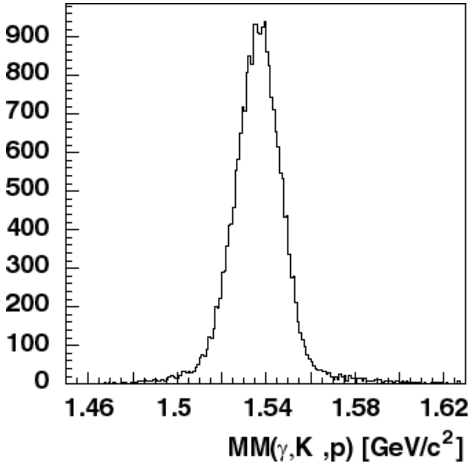


$\gamma d \to \Lambda(1520)\ \Theta^+$

$\quad\quad \hookrightarrow K^- p \quad \hookrightarrow K^+ n$

+ Kinematical fit

$\Delta M(\Theta^+)=10\ \mathrm{MeV}/c^2$

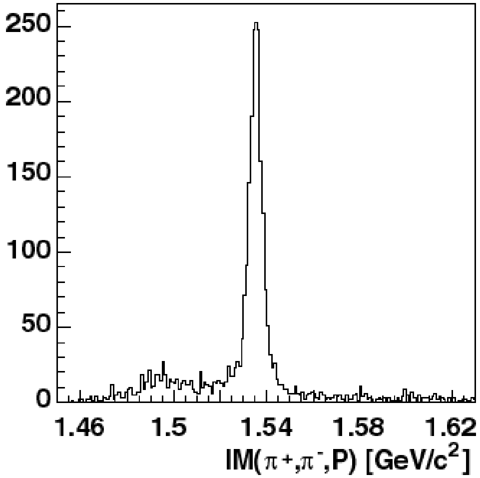


$\gamma d \to \Lambda(1520)\ \Theta^+$

$\quad\quad \hookrightarrow K^- p \quad \hookrightarrow K_s\, p$

Invariant Mass

$\Delta M(\Theta^+)=3\ \mathrm{MeV}/c^2$



Status of the LEPS2 project

- 2005.6: Discussion for the LEPS2 beamline was started.
- 2005.7: First workshop was held at RCNP
  → Both physics and technical issues.
- 2005.12: Basic agreement for the movement of the E949 detector was made with BNL and associated laboratories.
- Numerical consideration for getting the high energy γ beam by re-injection of X-ray has been performed. → Need R&D for the mirror.
- Test of the LRNB method for the high intensity LEP
  → The same intensity as the normal Gauss beam
- 2006.4:Test of the two laser injection → succeed !
- Disassembling work for E949 detector
- Discuss detector design, modification of beamline etc.
- 2007.1: Second workshop @RCNP
- 2008.1: Change the plan of the laser hutch place.
- 2008.11: Loan agreement for the E949 detector

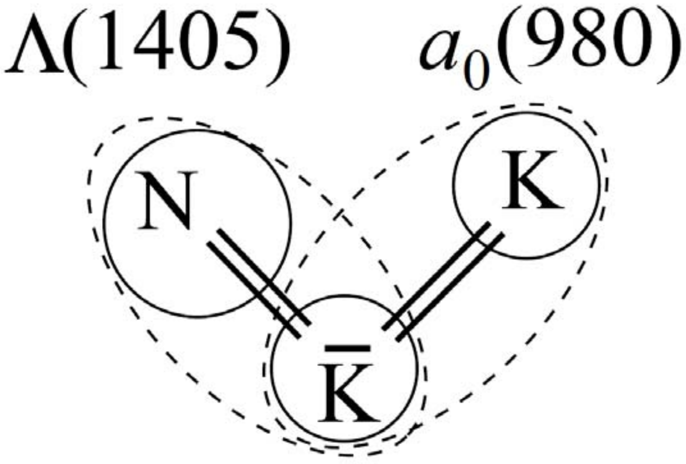
- LOI to Spring-8: 2006.12 Hearing → Approved. BL31 was assigned.
- Budget request: 2007FY,2008FY from RCNP → X

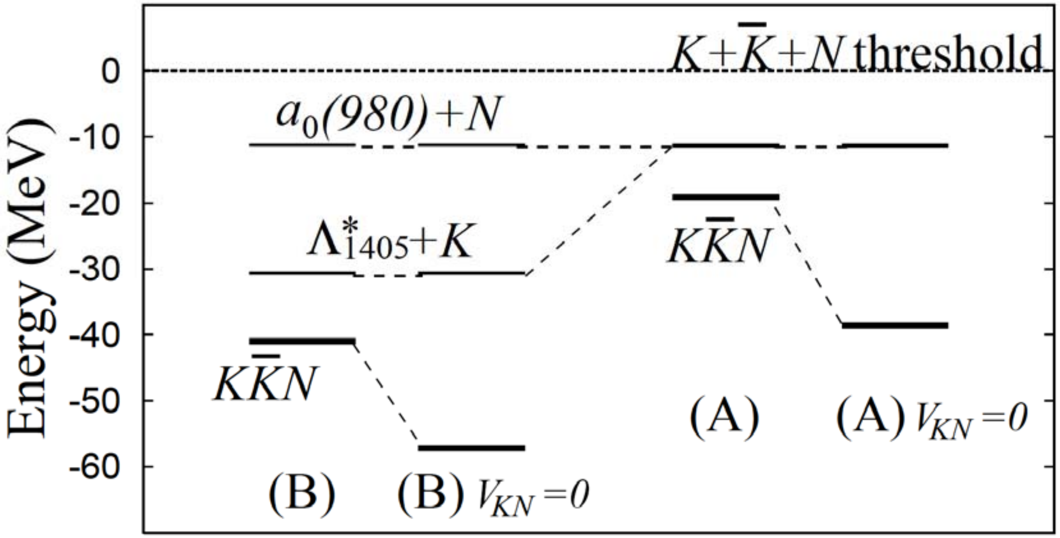
Backup

Differential cross section of Λ(1405) production

Interesting idea by Jido and En’yo :
KKN bound state.   (PRC78,035203(2008))

M ~ below KKN threshold (1930 MeV)
Γ ~ 90 MeV

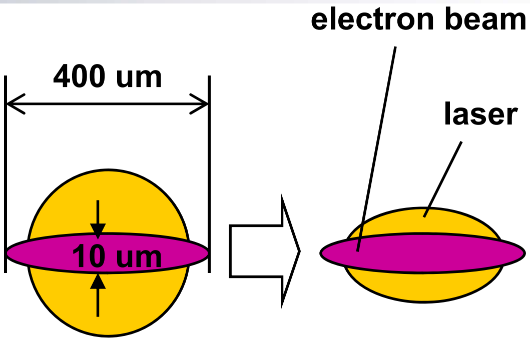


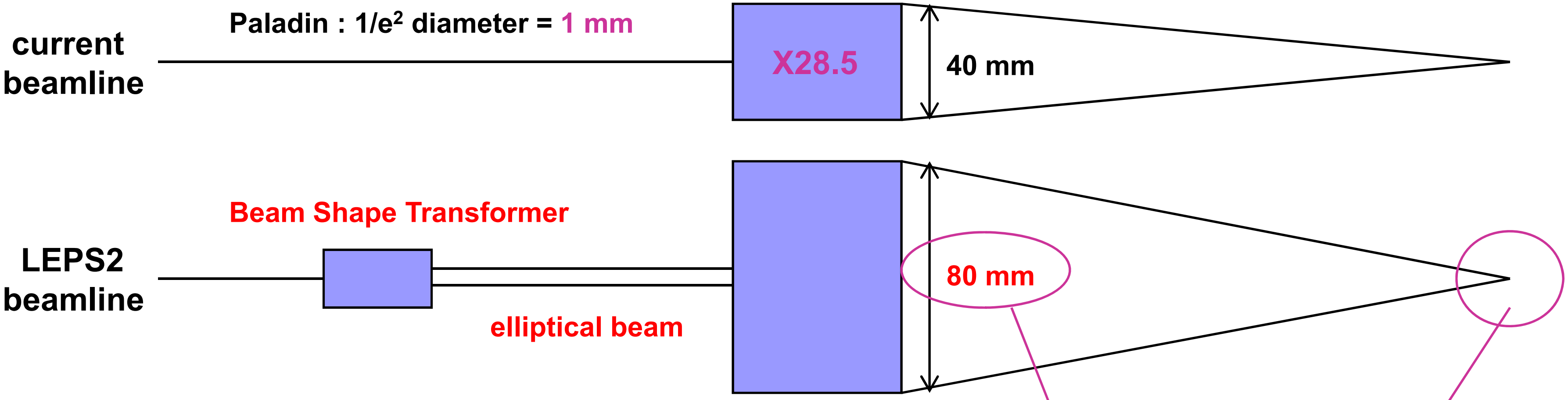


Need more statistics experimentally !

Laser Beam shaping

- Electron beam is horizontally wide.
  ⇒ BCS efficiency will be increased by elliptical laser beam.





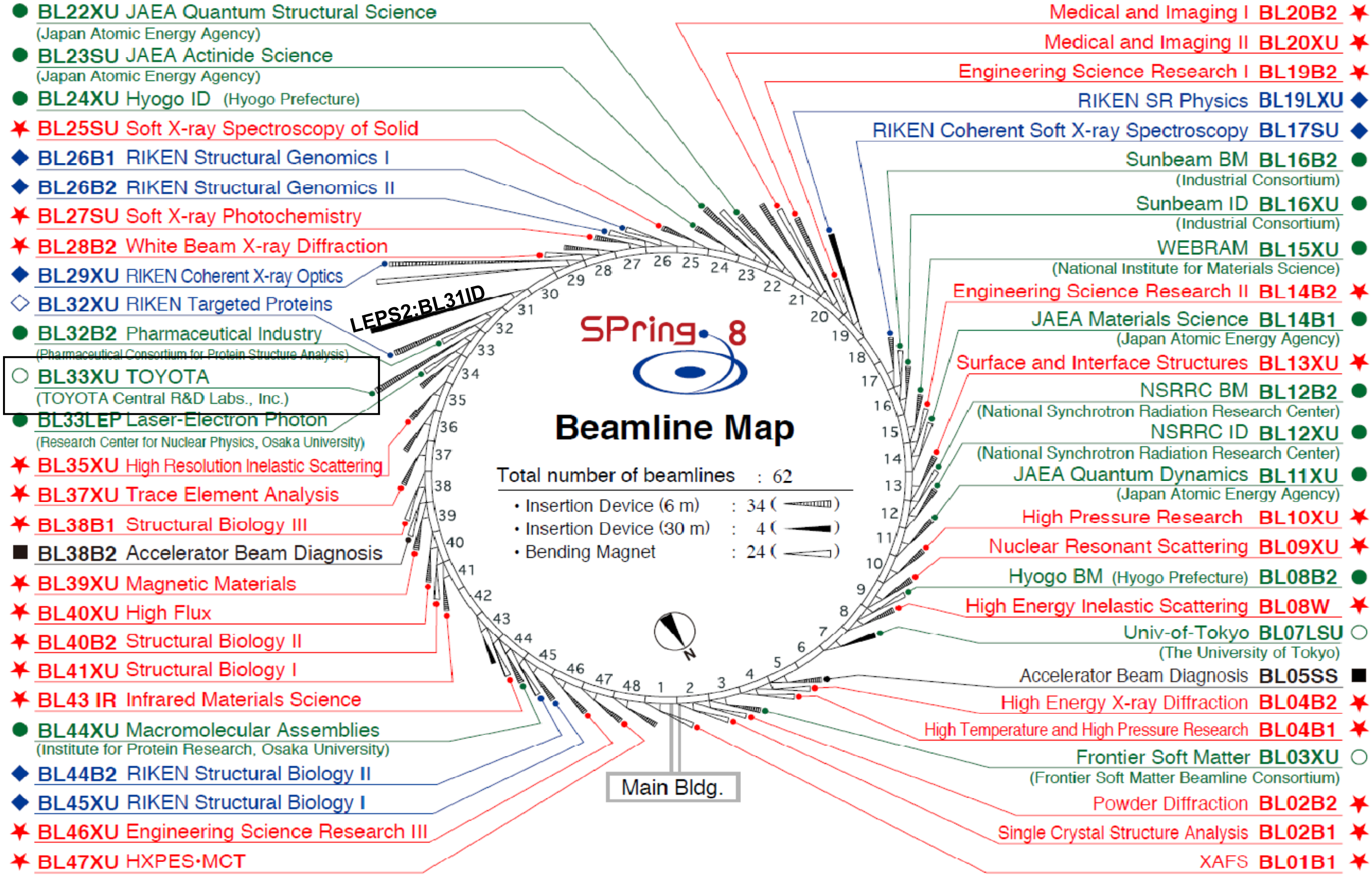
	Beam Shape Transformer x : y	**Expander magnification**
Option (1)	1 mm : 2 mm	x28.5
Option (2)	0.5 mm : 1 mm	x 57

Need twice diameter in vertical direction.

- Both methods are technically available, but option (1) will be easier. (ITOCHU Aero-Tech)

Beam spot at focus point:
Horizontal size = electron beam
Vertical size = 1/2 x horizontal size.
⇒ **Energy density becomes twice.**

Beam line map of Spring-8



● **BL22XU** JAEA Quantum Structural Science
(Japan Atomic Energy Agency)
● **BL23SU** JAEA Actinide Science
(Japan Atomic Energy Agency)
● **BL24XU** Hyogo ID (Hyogo Prefecture)
✶ **BL25SU** Soft X-ray Spectroscopy of Solid
◆ **BL26B1** RIKEN Structural Genomics I
◆ **BL26B2** RIKEN Structural Genomics II
✶ **BL27SU** Soft X-ray Photochemistry
✶ **BL28B2** White Beam X-ray Diffraction
◆ **BL29XU** RIKEN Coherent X-ray Optics
◇ **BL32XU** RIKEN Targeted Proteins
● **BL32B2** Pharmaceutical Industry
(Pharmaceutical Consortium for Protein Structure Analysis)
○ **BL33XU** TOYOTA
(TOYOTA Central R&D Labs., Inc.)
● **BL33LEP** Laser-Electron Photon
(Research Center for Nuclear Physics, Osaka University)
✶ **BL35XU** High Resolution Inelastic Scattering
✶ **BL37XU** Trace Element Analysis
✶ **BL38B1** Structural Biology III
■ **BL38B2** Accelerator Beam Diagnosis
✶ **BL39XU** Magnetic Materials
✶ **BL40XU** High Flux
✶ **BL40B2** Structural Biology II
✶ **BL41XU** Structural Biology I
✶ **BL43 IR** Infrared Materials Science
● **BL44XU** Macromolecular Assemblies
(Institute for Protein Research, Osaka University)
◆ **BL44B2** RIKEN Structural Biology II
◆ **BL45XU** RIKEN Structural Biology I
✶ **BL46XU** Engineering Science Research III
✶ **BL47XU** HXPES·MCT

Medical and Imaging I **BL20B2** ✶
Medical and Imaging II **BL20XU** ✶
Engineering Science Research I **BL19B2** ✶
RIKEN SR Physics **BL19LXU** ◆
RIKEN Coherent Soft X-ray Spectroscopy **BL17SU** ◆
Sunbeam BM **BL16B2** ●
(Industrial Consortium)
Sunbeam ID **BL16XU** ●
(Industrial Consortium)
WEBRAM **BL15XU** ●
(National Institute for Materials Science)
Engineering Science Research II **BL14B2** ✶
JAEA Materials Science **BL14B1** ●
(Japan Atomic Energy Agency)
Surface and Interface Structures **BL13XU** ✶
NSRRC BM **BL12B2** ●
(National Synchrotron Radiation Research Center)
NSRRC ID **BL12XU** ●
(National Synchrotron Radiation Research Center)
JAEA Quantum Dynamics **BL11XU** ●
(Japan Atomic Energy Agency)
High Pressure Research **BL10XU** ✶
Nuclear Resonant Scattering **BL09XU** ✶
Hyogo BM (Hyogo Prefecture) **BL08B2** ●
High Energy Inelastic Scattering **BL08W** ✶
Univ-of-Tokyo **BL07LSU** ○
(The University of Tokyo)
Accelerator Beam Diagnosis **BL05SS** ■
High Energy X-ray Diffraction **BL04B2** ✶
High Temperature and High Pressure Research **BL04B1** ✶
Frontier Soft Matter **BL03XU** ○
(Frontier Soft Matter Beamline Consortium)
Powder Diffraction **BL02B2** ✶
Single Crystal Structure Analysis **BL02B1** ✶
XAFS **BL01B1** ✶

LEPS2:BL31ID

SPring-8

Beamline Map

Total number of beamlines : 62
- Insertion Device (6 m) : 34
- Insertion Device (30 m) : 4
- Bending Magnet : 24

LEPS2 LOI was approved: BL31 was assigned for LEPS2.

Collaboration

- Core institutes

  RCNP

  LNS Tohoku U.

  SPring-8/JASRI Accelerator group

  RIKEN Radiation Laboratory (new !)
- Other LEPS members

  Kyoto U., Osaka U., Konan U., Chiba U., Yamagata U., Miyazaki U., Pusan U.(Korea), Seoul U.(Korea), Academia Sinica (Republic of China),

  Ohio U. (USA), Saskachewan U. (Canada) etc.
- New members

  National Defense Academy, …

  some members from the BNL-E949 experiment

  (domestic and foreign institutes (BNL, TRIUMF,…))

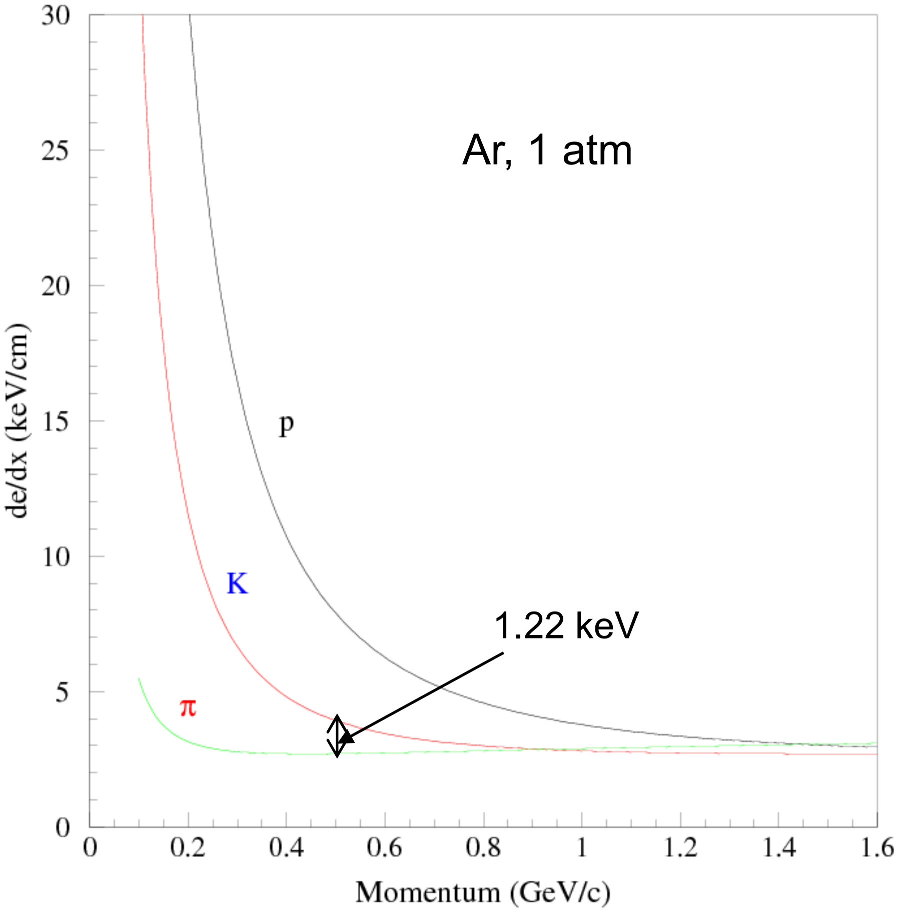
Try to strengthen the collaboration group

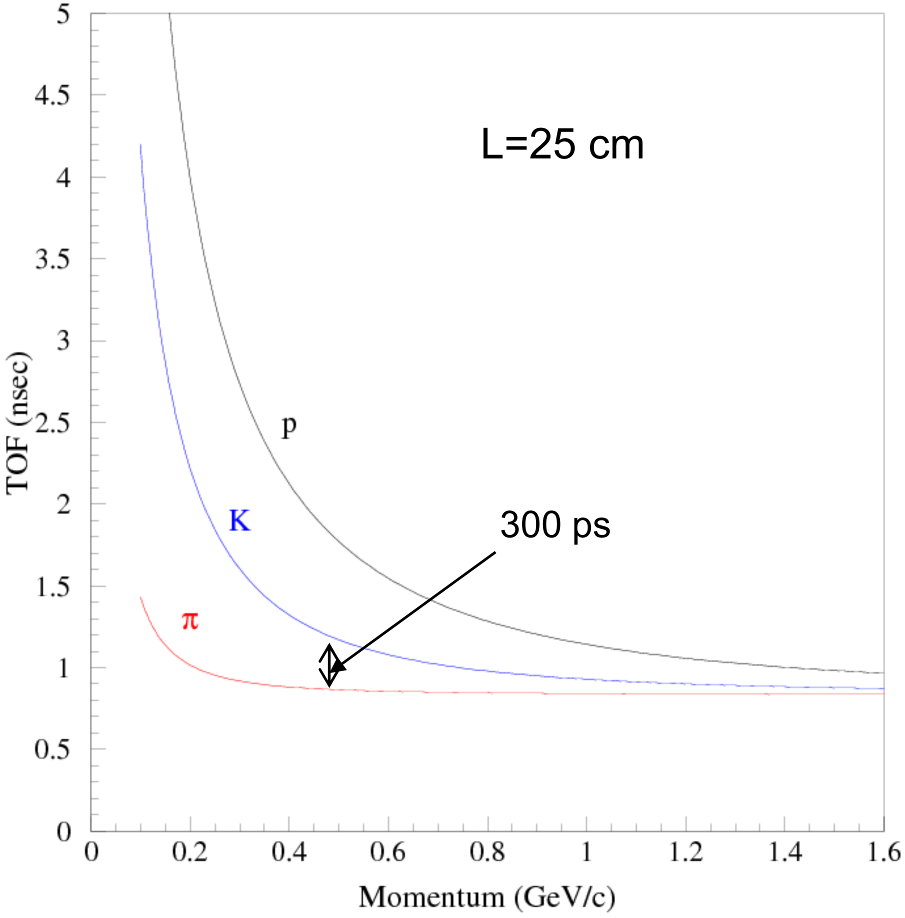
Particle Identification

de/dx vs Momentum and/or TOF vs Momentum

(PI is difficult for higher momentum due to small inner diameter of the solenoid !)

πK 2σ separation at 0.5 GeV/c → σ(TOF)= 150ps or σ(de/dx)/(dedx)=16%





Particle Identification

PID by TPC