

# **Status and Prospect of Extinction for Muon Experiments (at J-PARC)**

Y. Fujii

KEK IPNS

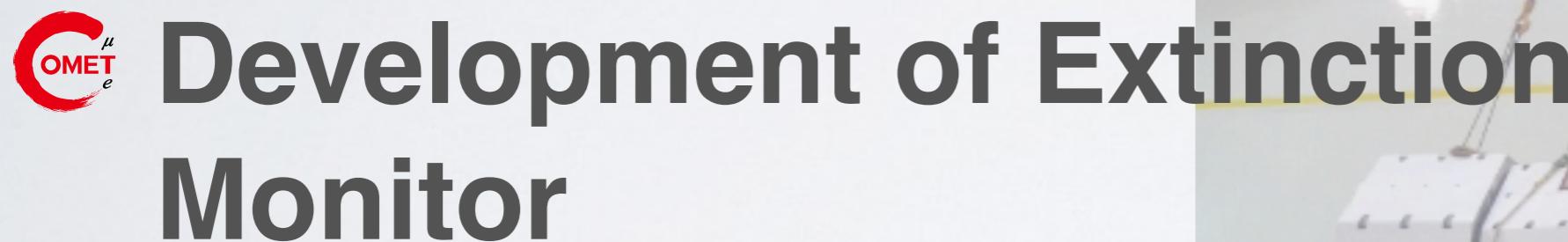
6th December 2016  
HINT2016 @J-PARC



# Outline

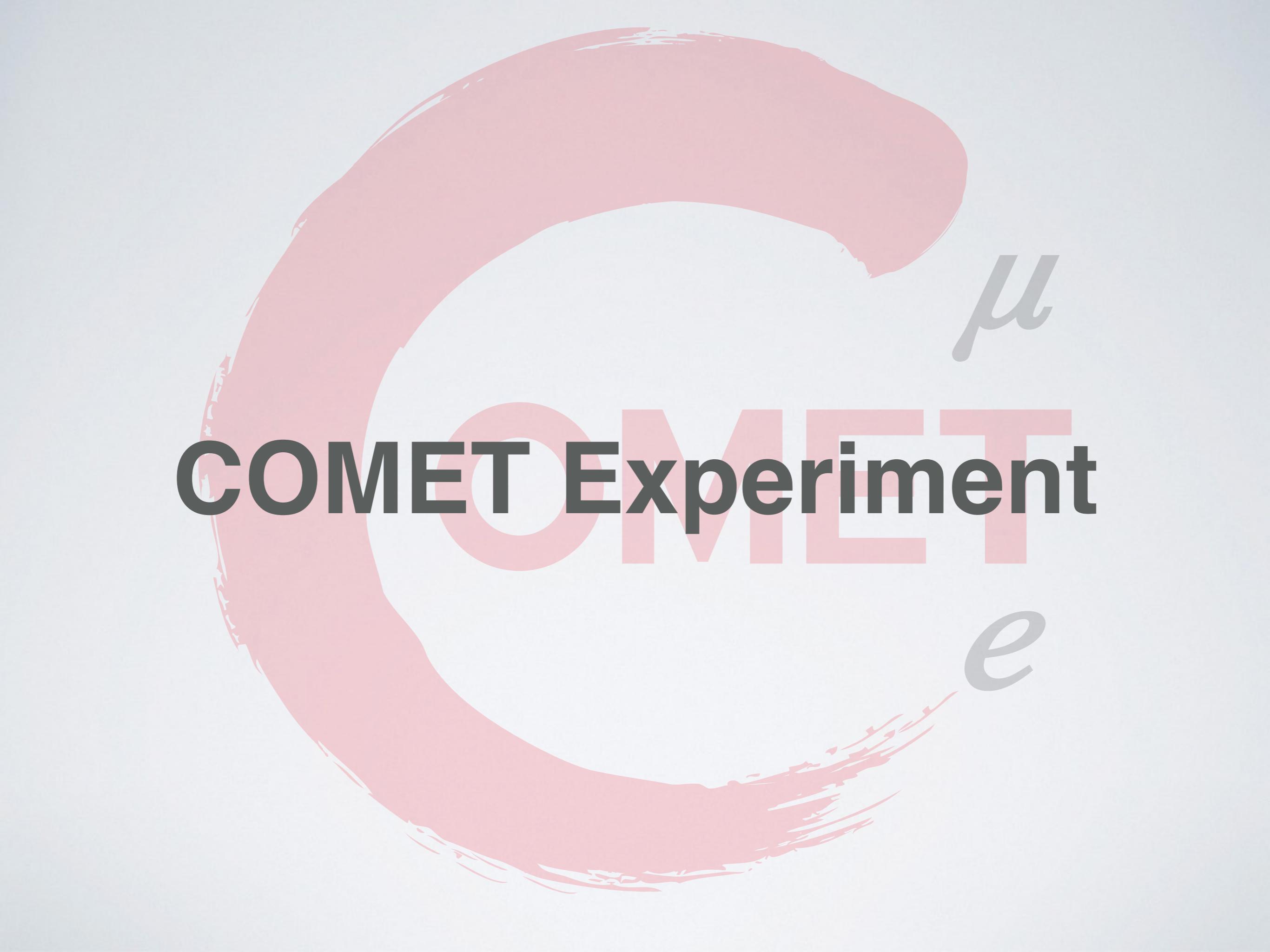
 COMET Experiment

 Extinction Measurements

 Development of Extinction Monitor

 Summary





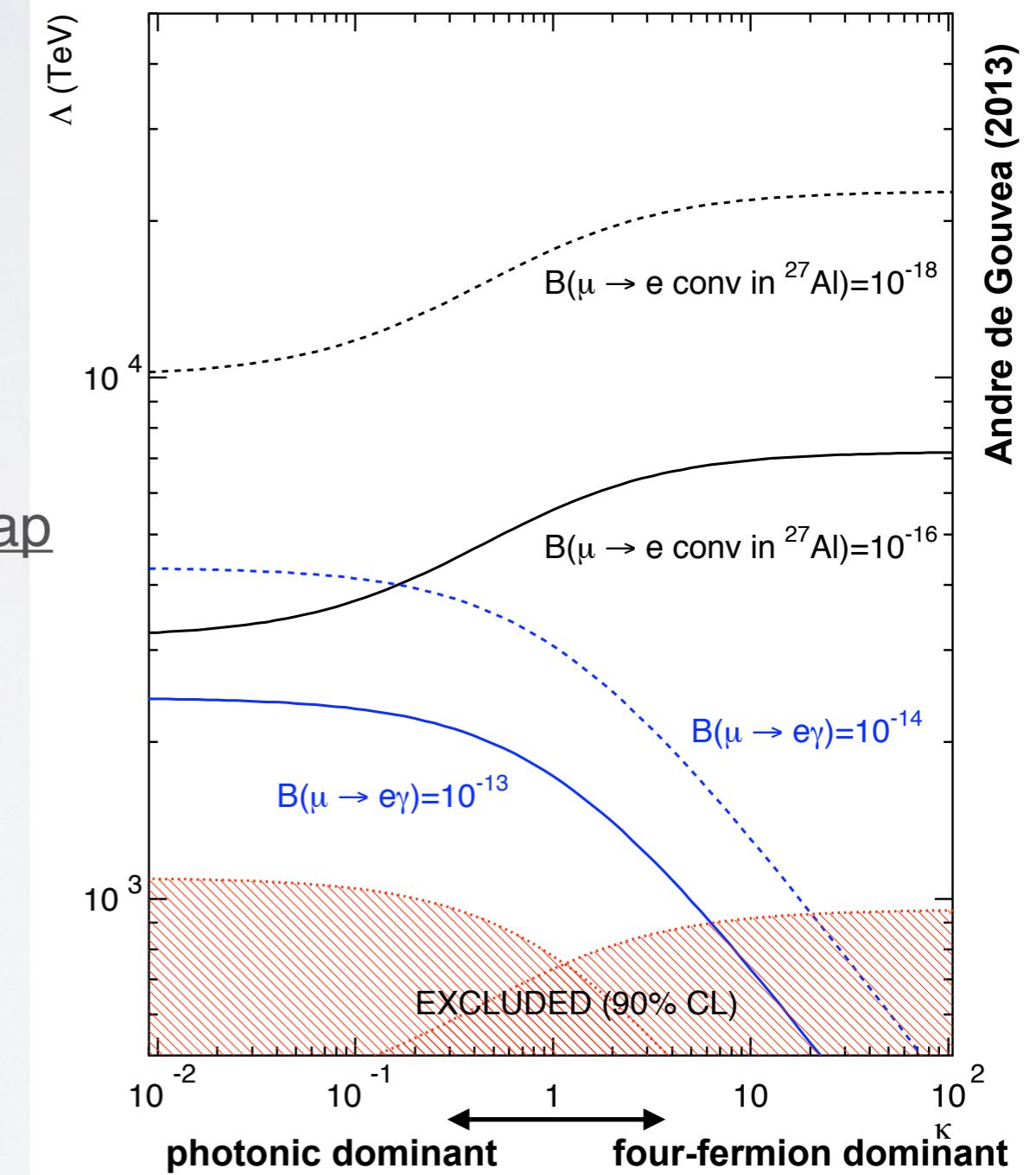
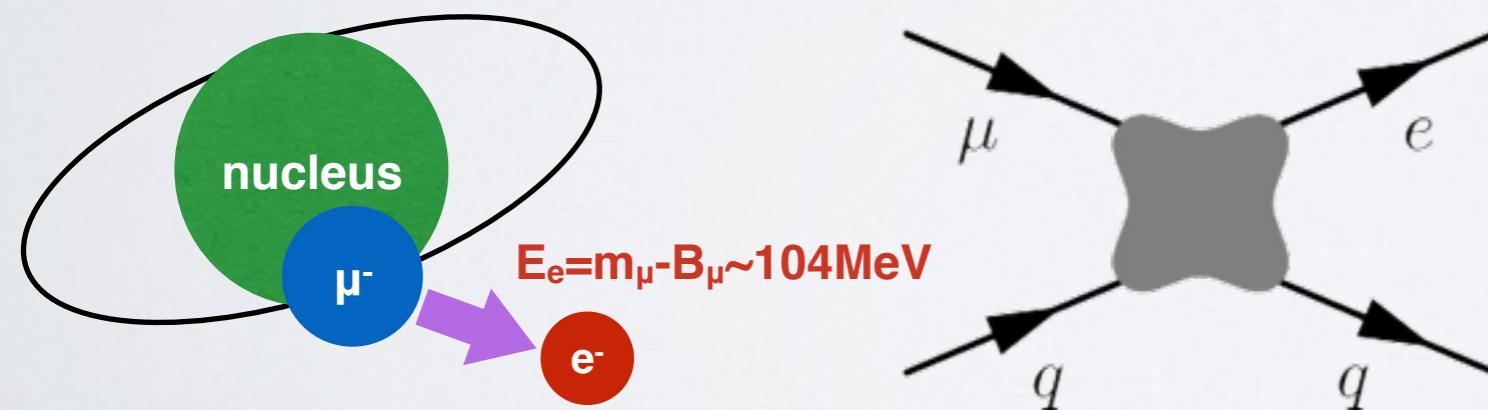
# COMETExperiment

$\mu$

$e$

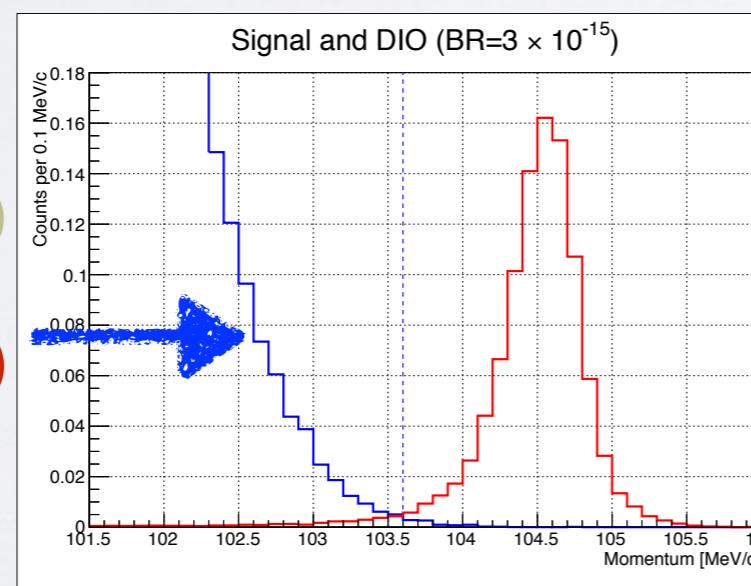
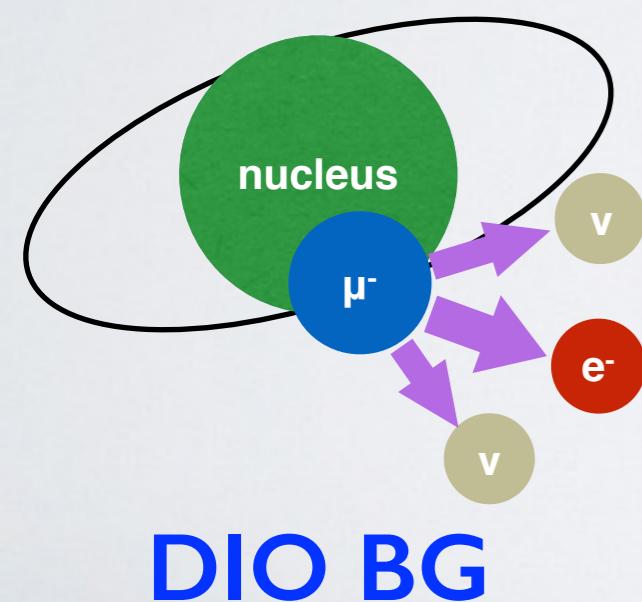
# $\mu$ -e Conversion

- Charged Lepton Flavor Violation (**CLFV**) process
- SM+ $\nu$ -oscillation: Negligible BR  $\sim \mathcal{O}(10^{-54})$
- BSM e.g. SUSY-GUT: **Sizable BR**  $\sim \mathcal{O}(10^{-15})$ 
  - Discovery  $\rightarrow$  Clear Evidence of NP**
  - LHC and other CLFV searches(e.g.  $\mu \rightarrow e\gamma$ ) are complimentary
- Current upper limit:  $7 \times 10^{-13}$  in Au (SINDRUM-II)
- Simple signal kinematics  $\rightarrow$  No accidental overlap

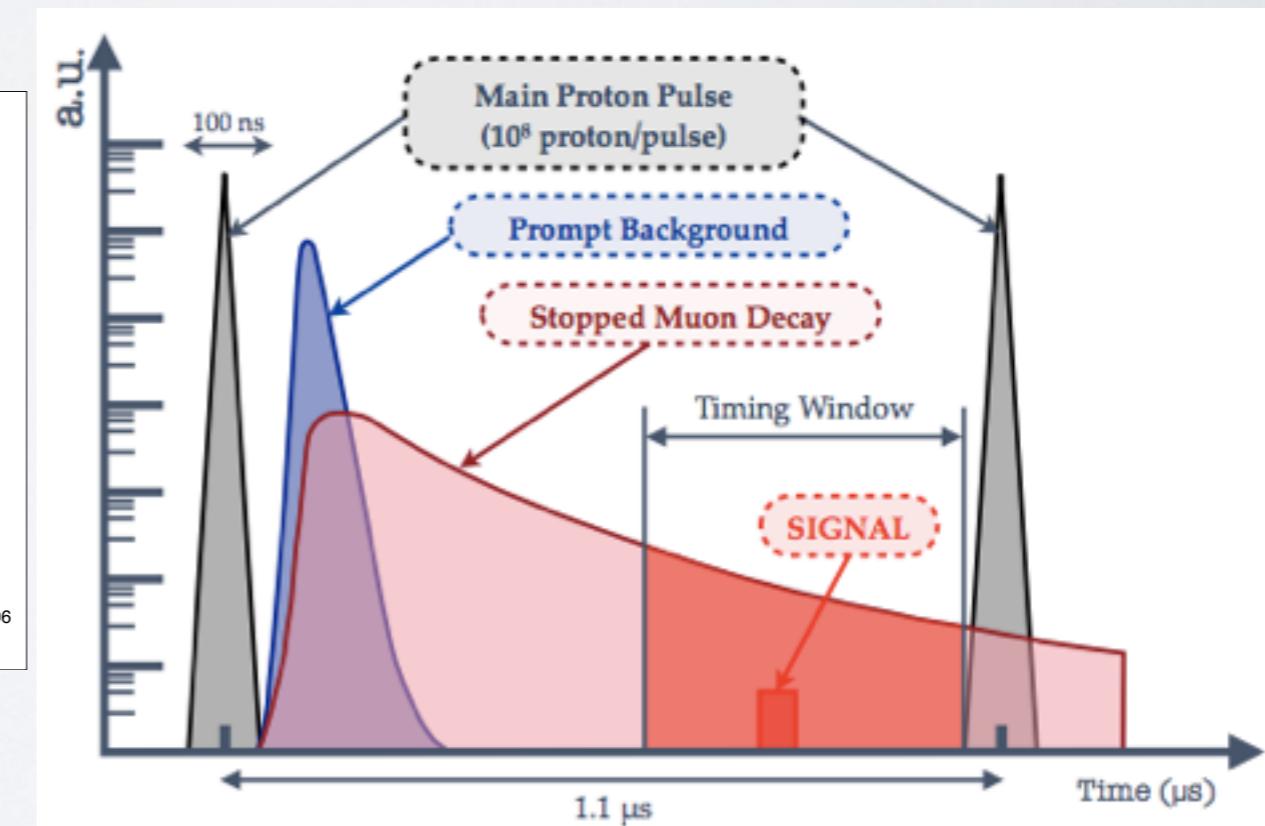


# Requirements

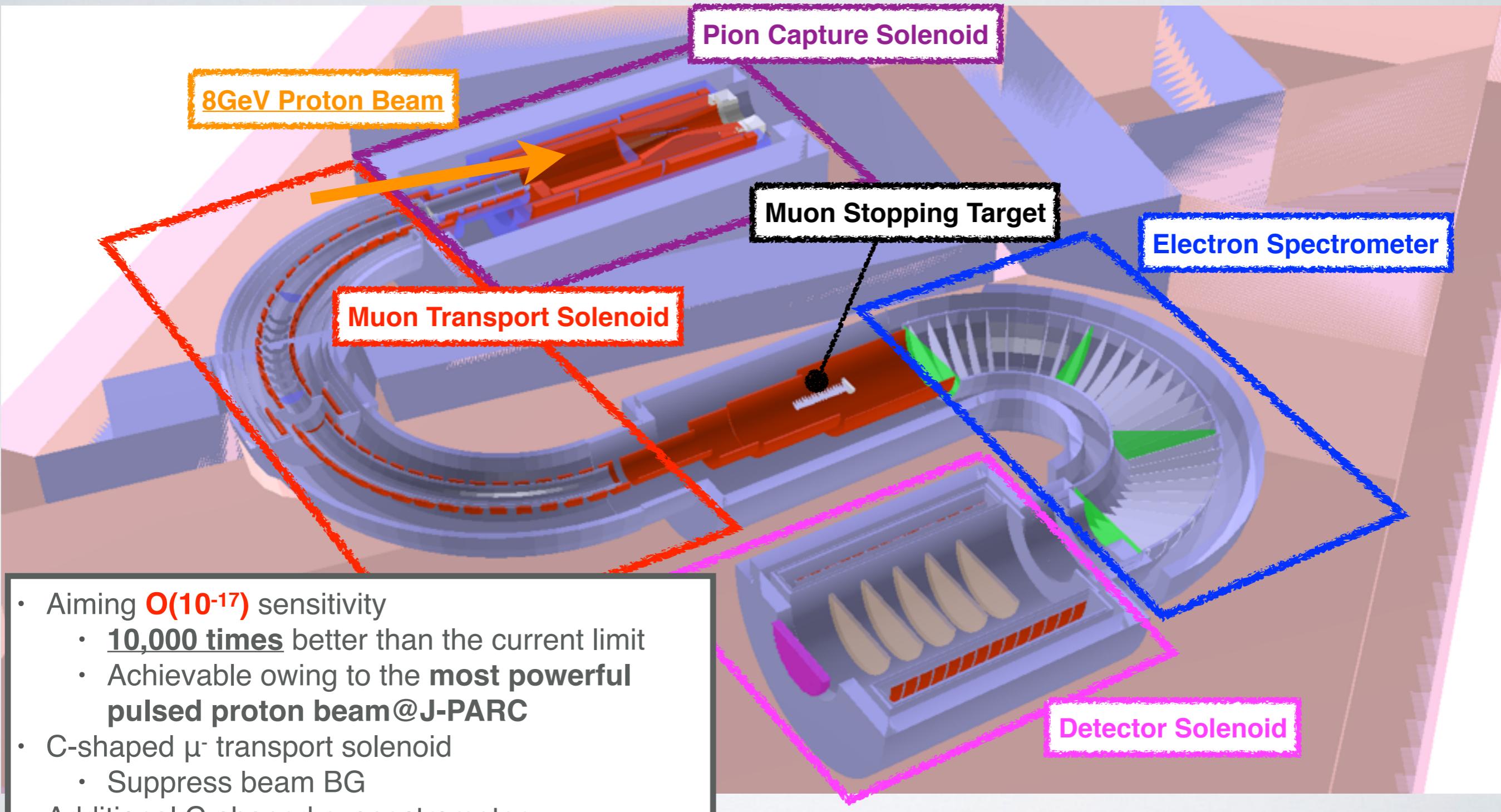
- **High Statistics:** Total stopped muons  $>10^{18}$
- **Low physics BG (Decay In Orbit: DIO)**
  - Excellent Momentum Resolution:  $<200$  keV/c
  - Spectrometer with low mass materials
- **Low Beam BG ( $\sim 100$  MeV/c electrons)**
  - Long pion to muon transportation line:  $O(10m)$
  - Pulsed beam: 1-2  $\mu$ s interval,  $\sim 100$  ns pulse width (e.g.  $\tau_{\mu e} \sim 0.88 \mu$ s in Al)
  - Good extinction factor(  $\equiv (\# \text{of residuals}) / (\# \text{of protons in a pulse})$  ):  $< 10^{-10}$



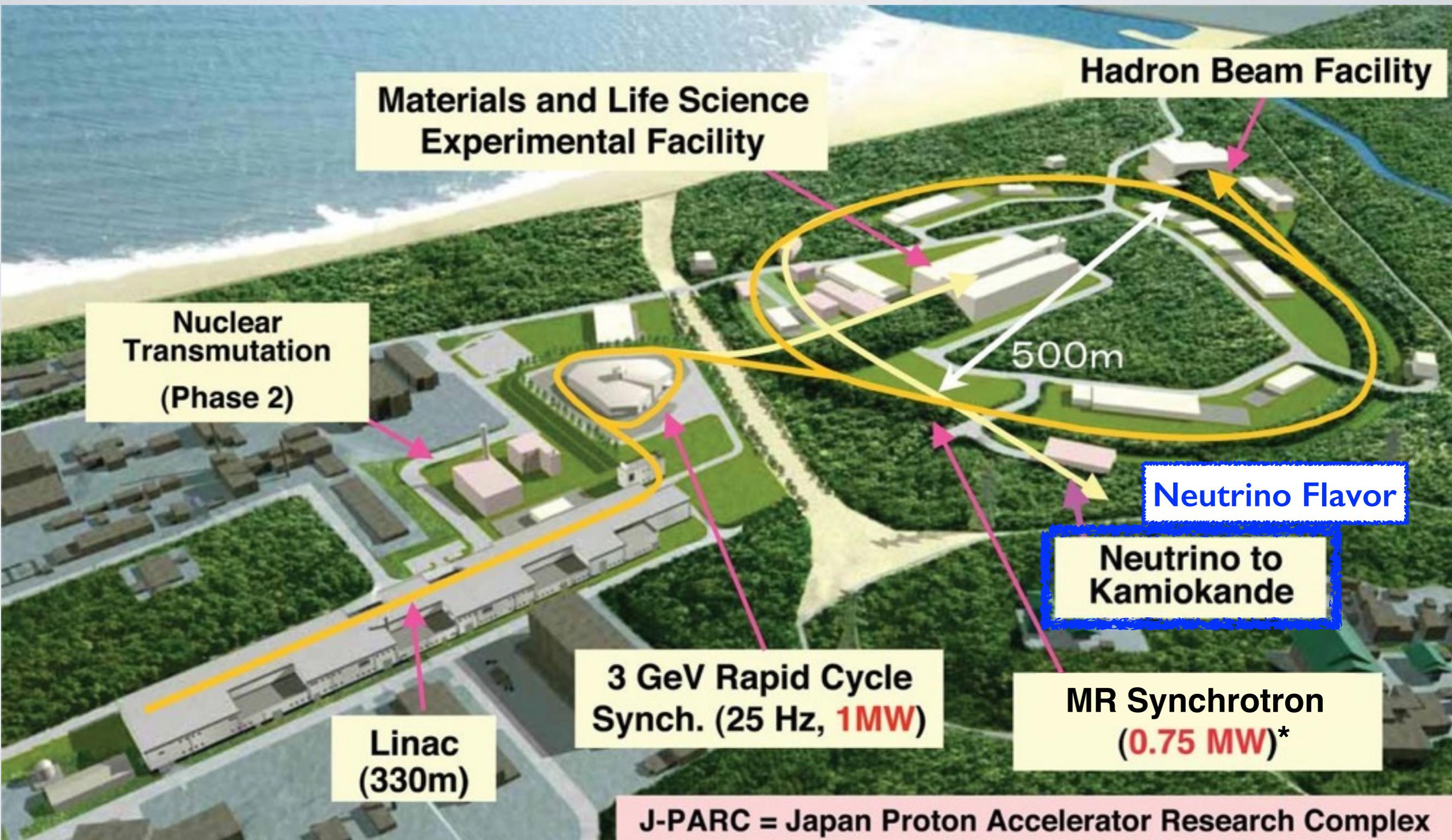
Signal



# COMET Experiment



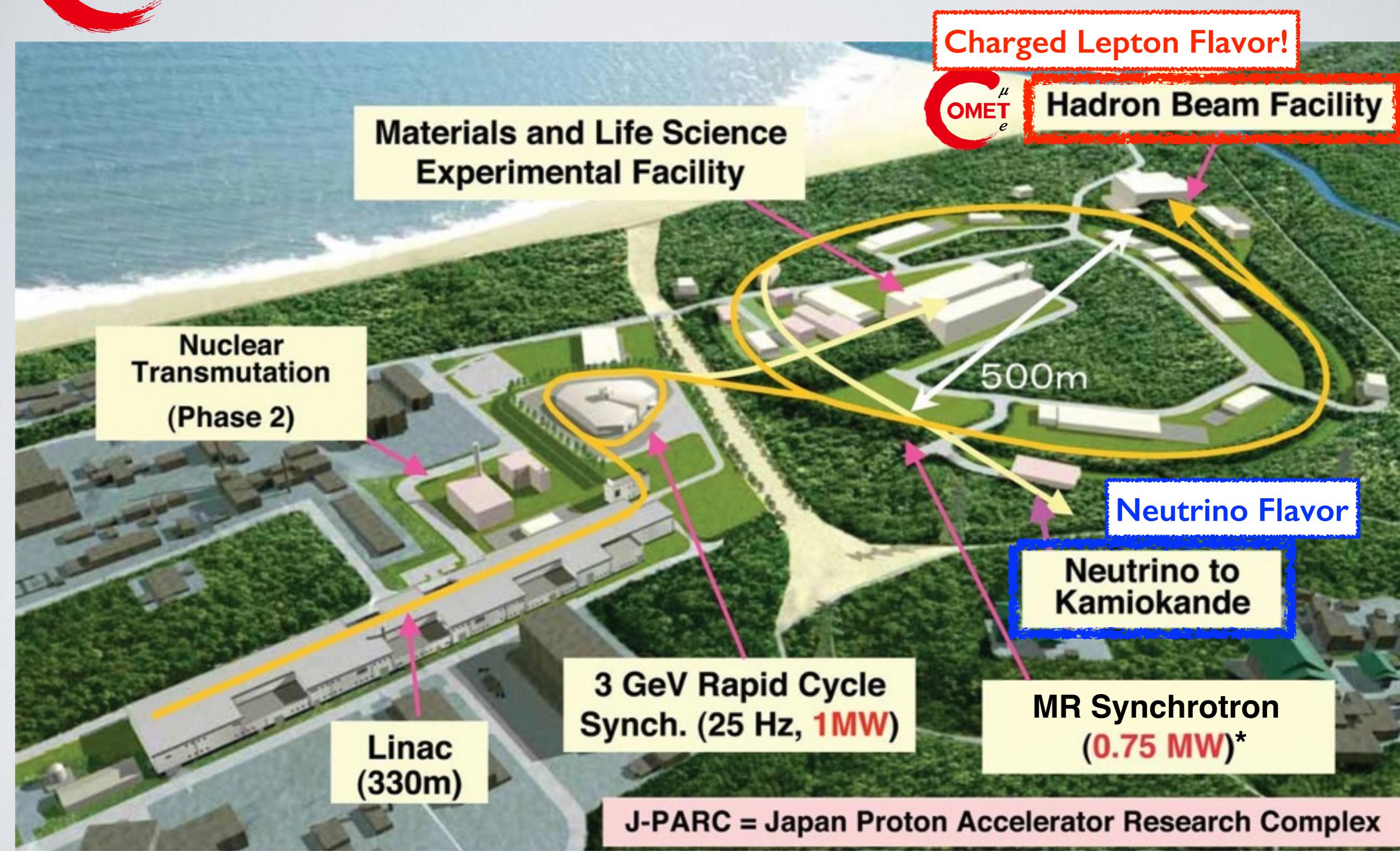
# J-PARC



Joint Project between KEK and JAEA

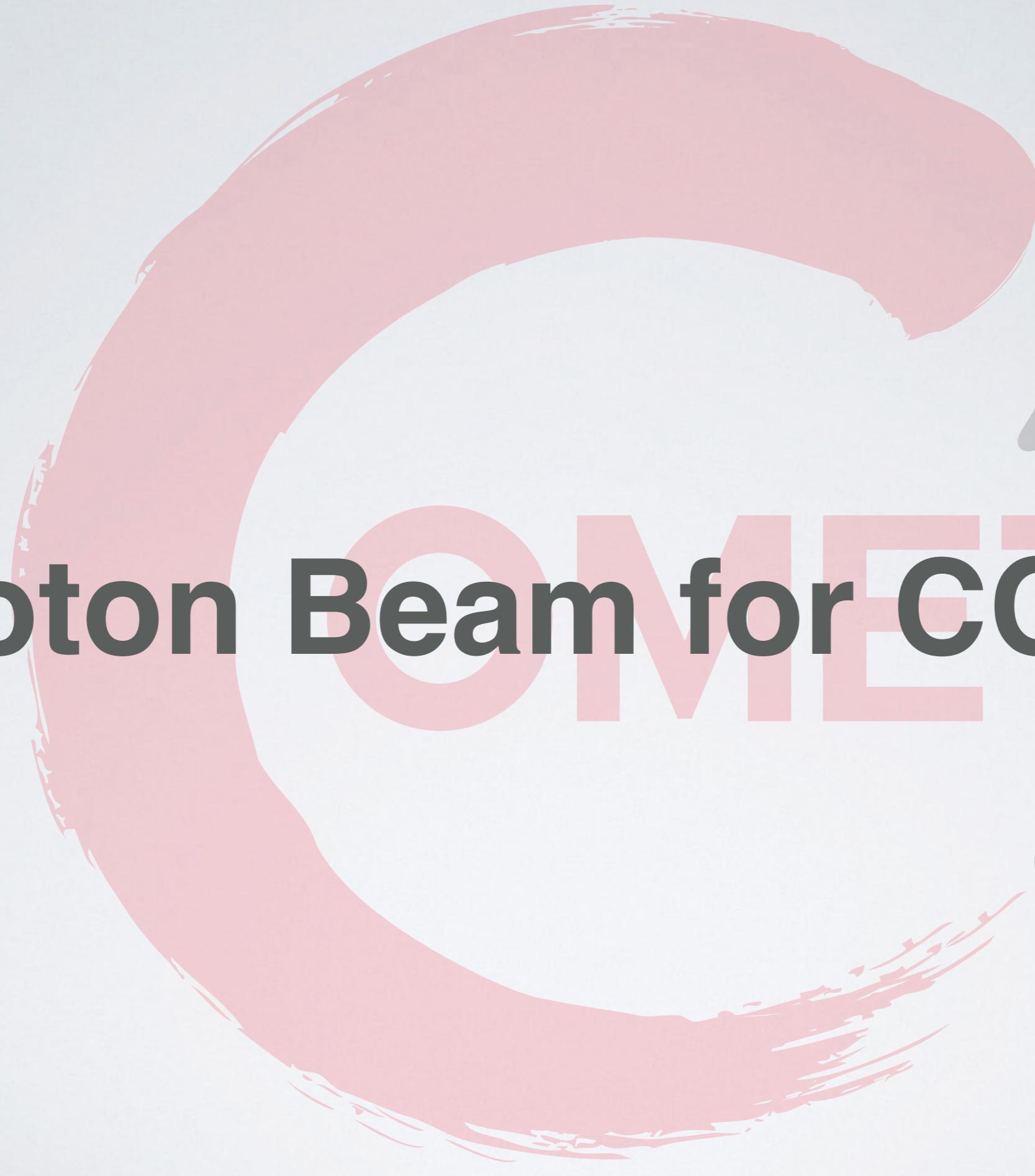
\*design value

# COMET@J-PARC



Joint Project between KEK and JAEA

\*design value

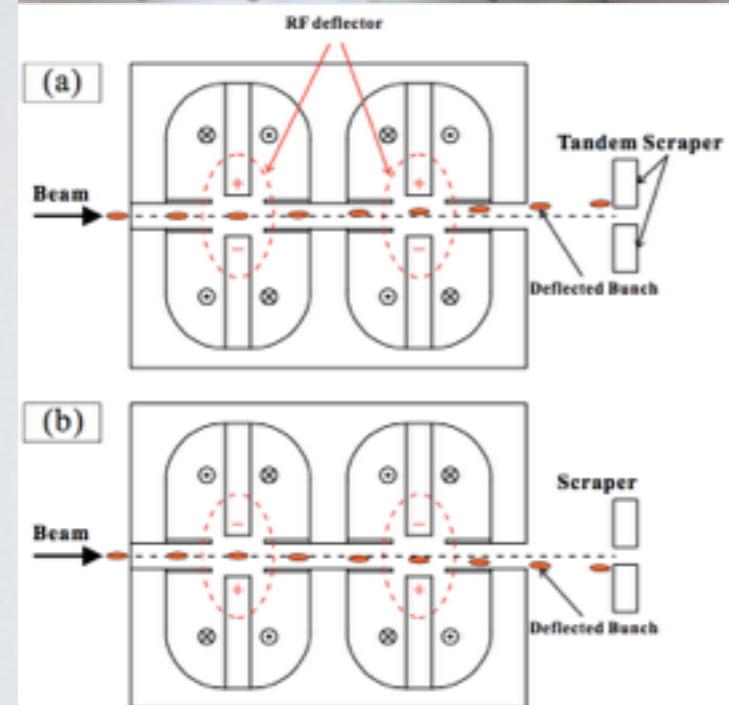
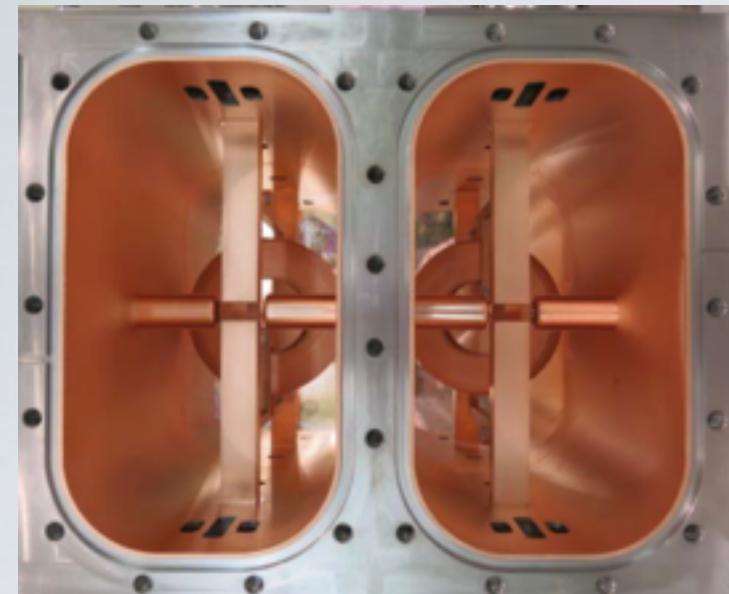


# Proton Beam for **ME** COMET

$\mu$

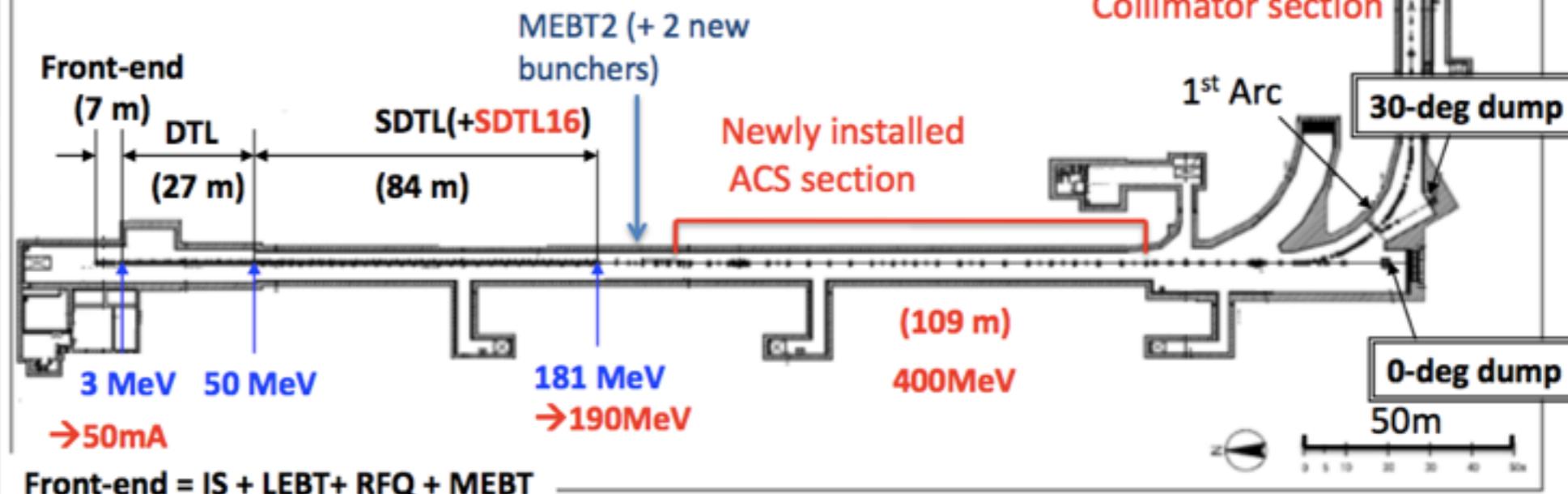
$e$

# Linac



J-PARC linac consists of

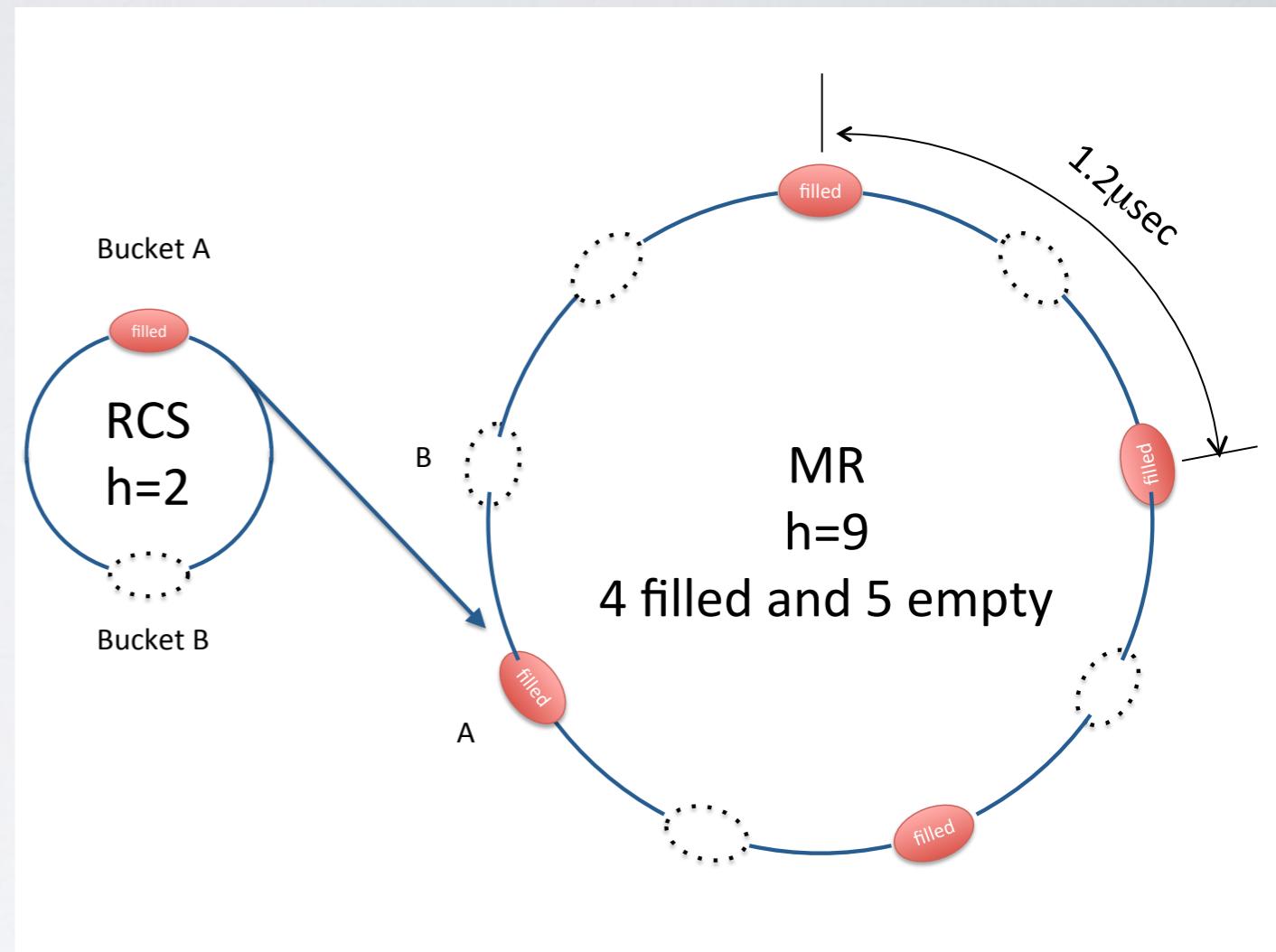
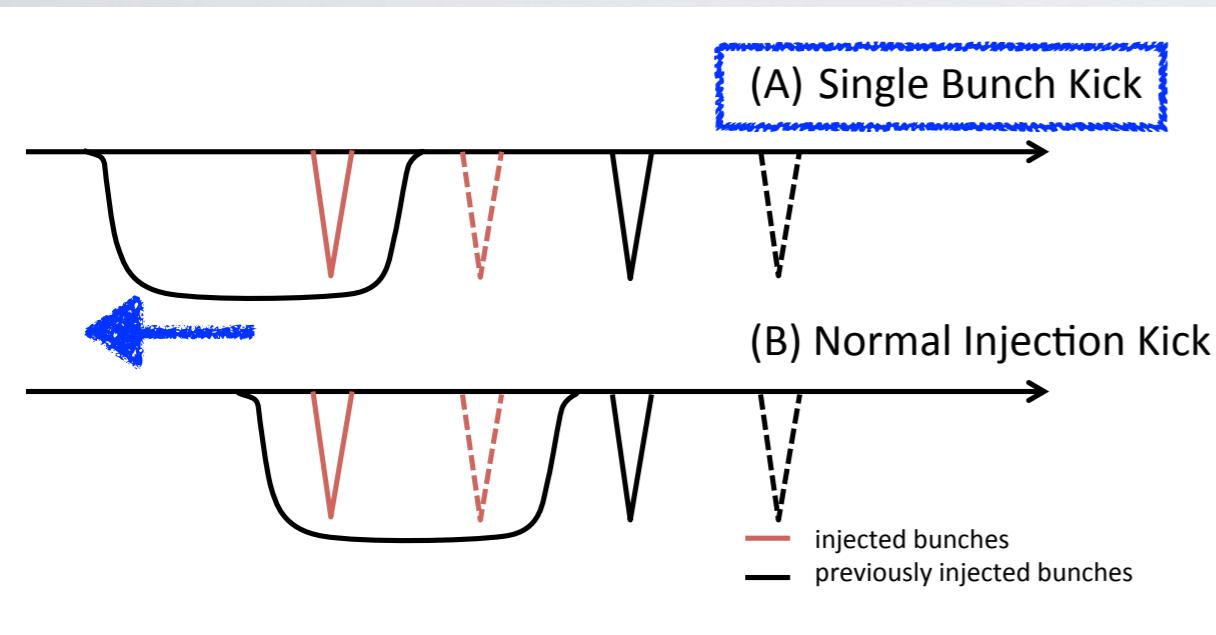
- 50-keV negative hydrogen ion source → **New ion source**
- 3-MeV RFQ
- 50-MeV DTL (Drift Tube Linac)
- SDTL (Separate-type DTL) 181-MeV → **190MeV**
- **400 MeV ACS (Annular Coupled Structure Linac)**



Y.Liu @ ICFA mini-workshop 2015

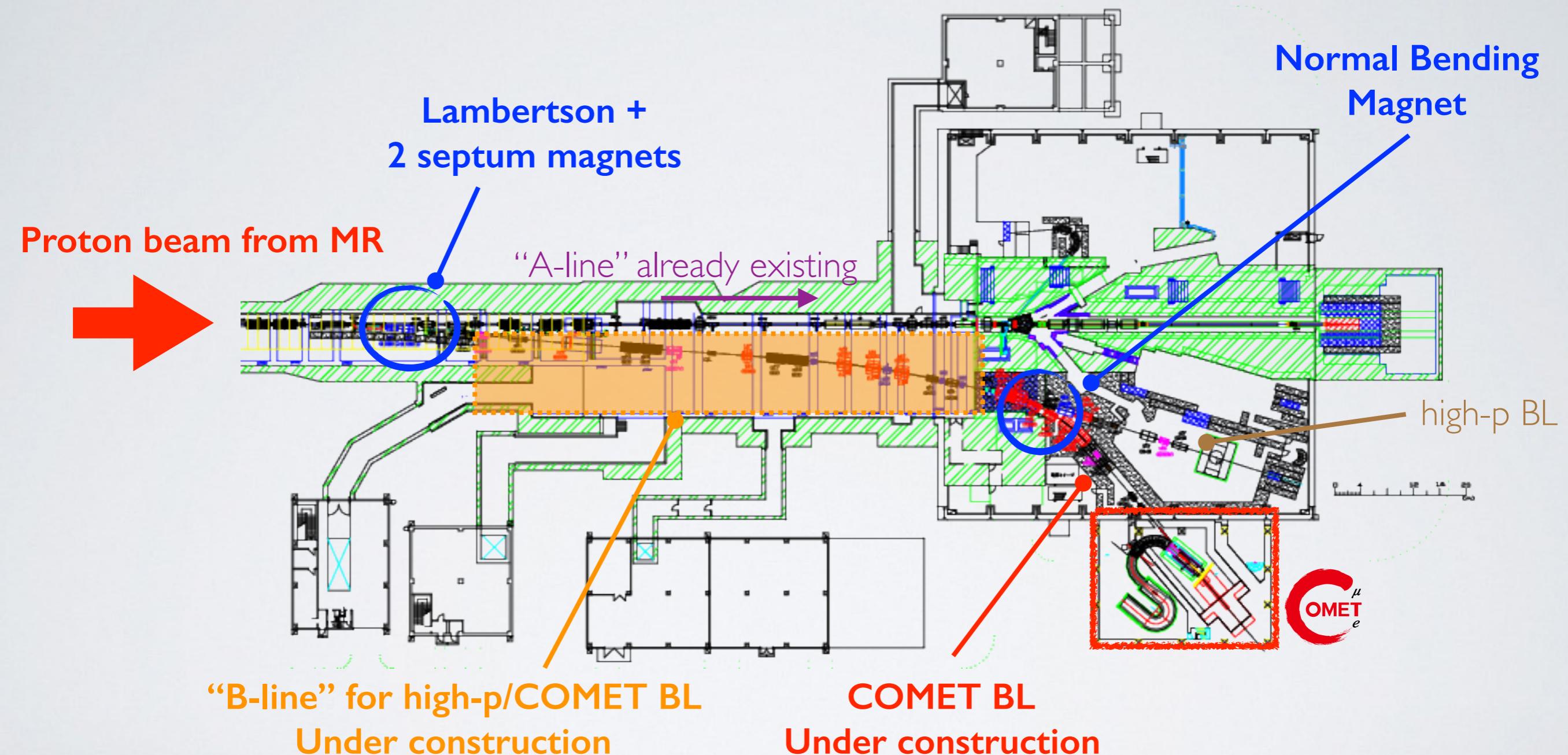
- Linac accelerates protons up to 400MeV to inject them into RCS
- Send protons only to one bucket out of two in RCS 25Hz cycling
  - Realized by using RF chopper and scraper placed after RFQ → **Improved in 2014**

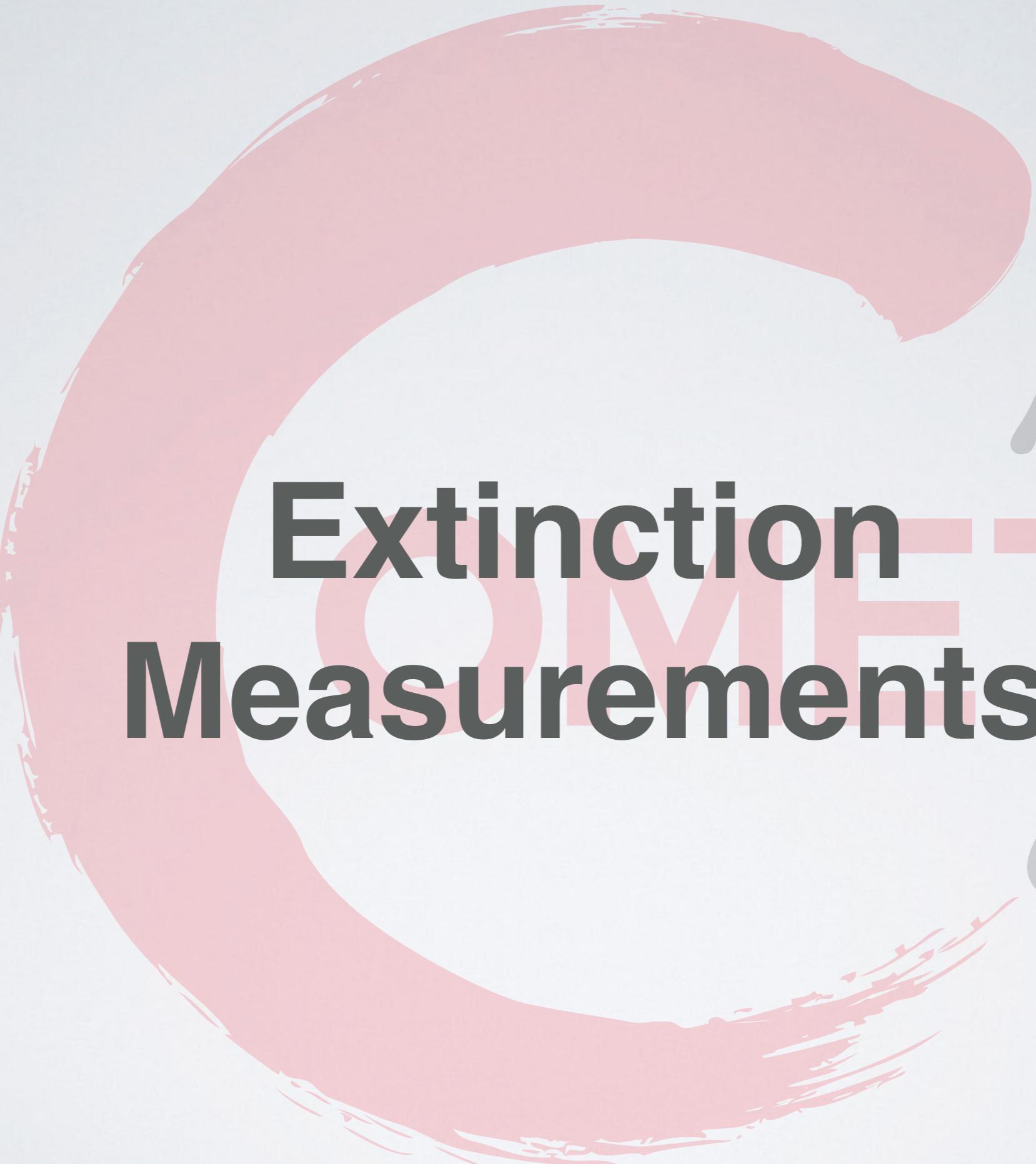
# RCS & MR Operation



- Dedicated operation mode (Bunched Slow Extraction: **BSX**) will be adopted for COMET
  - →Fast Extraction(**FX**) for v/MLF, Slow Extraction(**SX**) for hadron
- A 1.2(1.7) $\mu$ s of the bunch interval can be realized by filling 3(4) buckets out of 9
- Extinction is too large  $\sim O(10^{-7})$  if we use only RF chopper in Linac
  - New method called “**Single Bunch Kicking**” to highly suppress the extinction factor
  - Shift the timing of injection kicker → Already tested, details will be shown later

# Hadron Hall





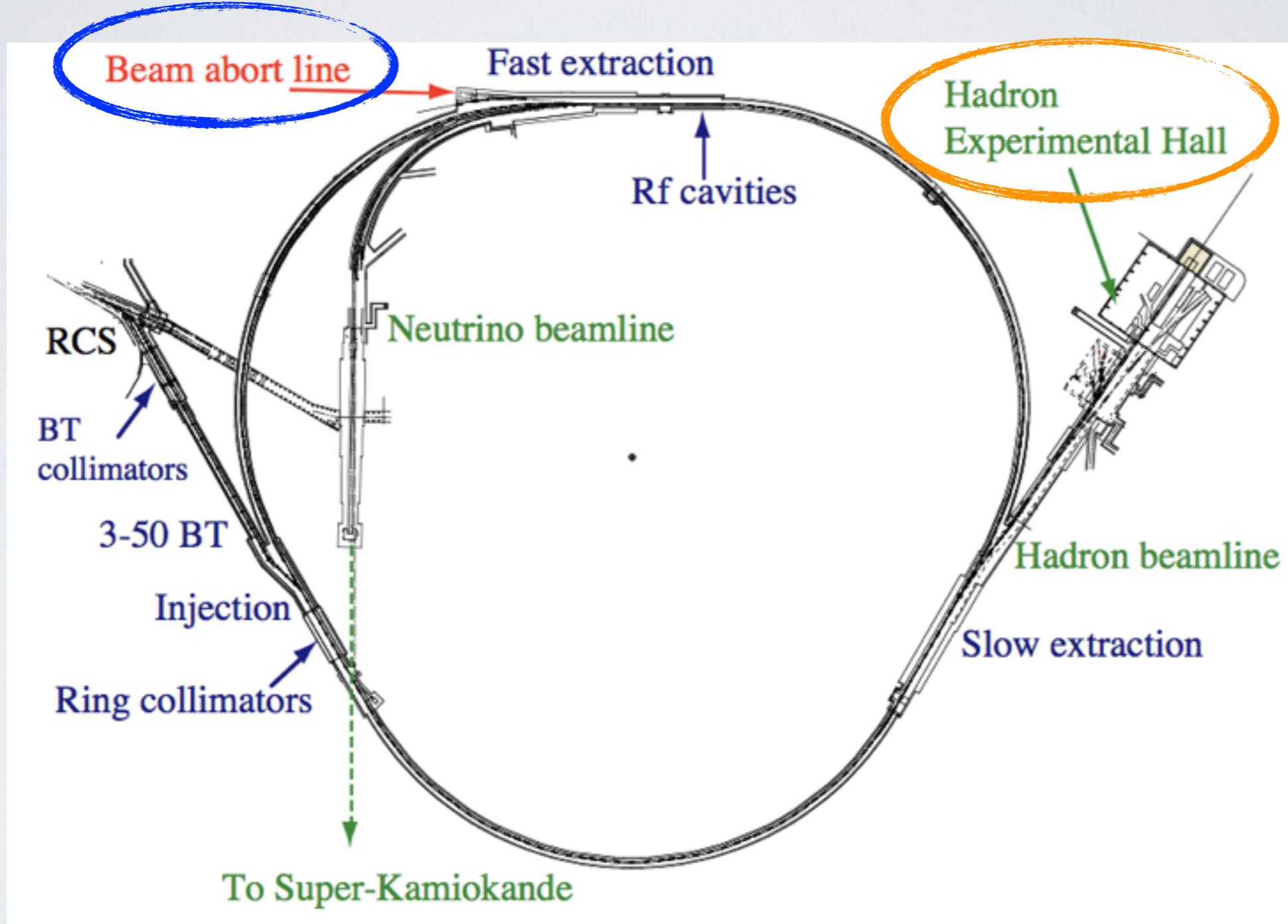
# Extinction Measurements



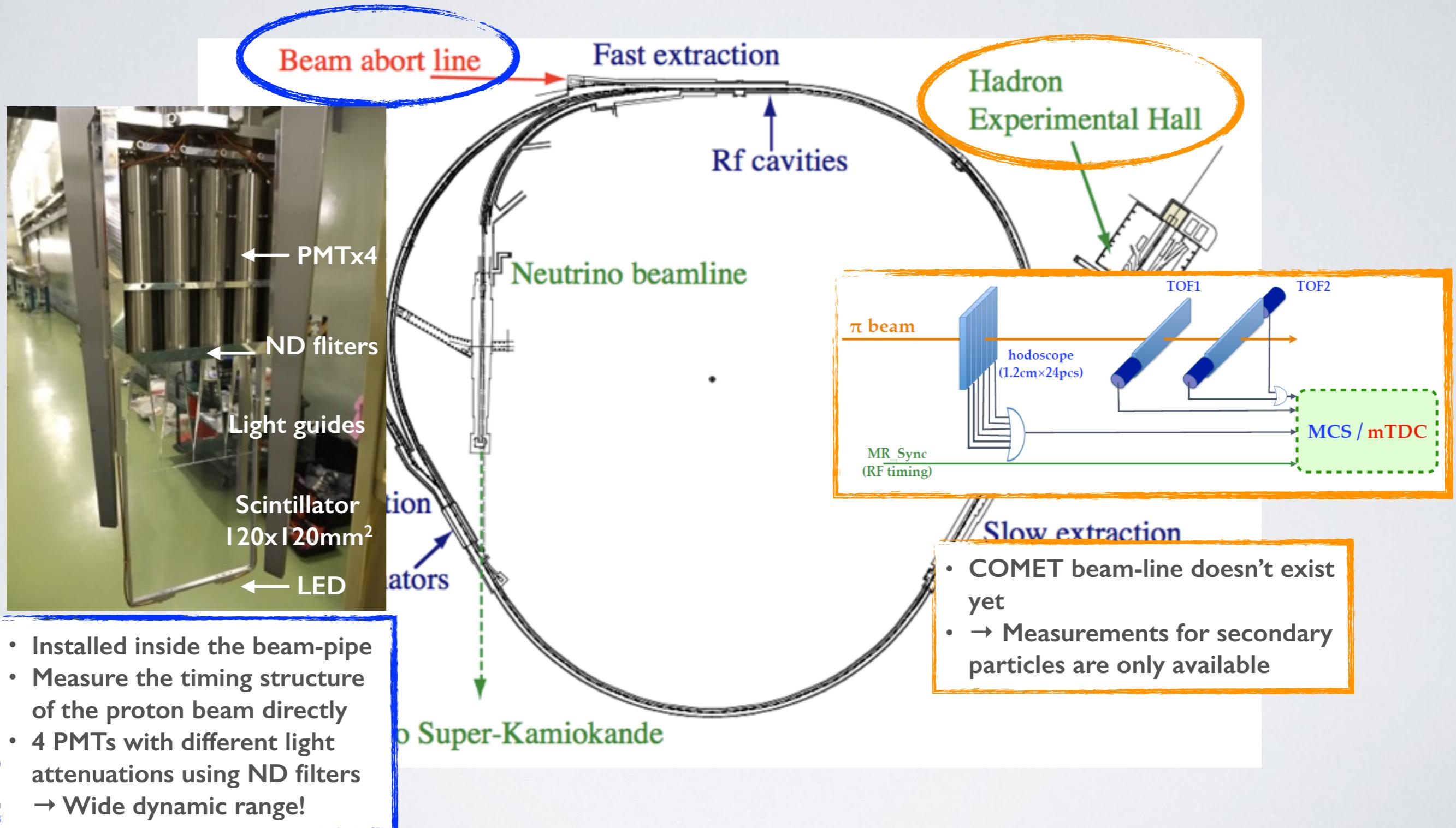
$\mu$

$e$

# Available Measurements



# Available Measurements



## 1. Extinction Measurement in Dec. 2010

- 30GeV operation with FX
- Measure the raw extinction factor

## 2. Extinction Measurement in June 2012

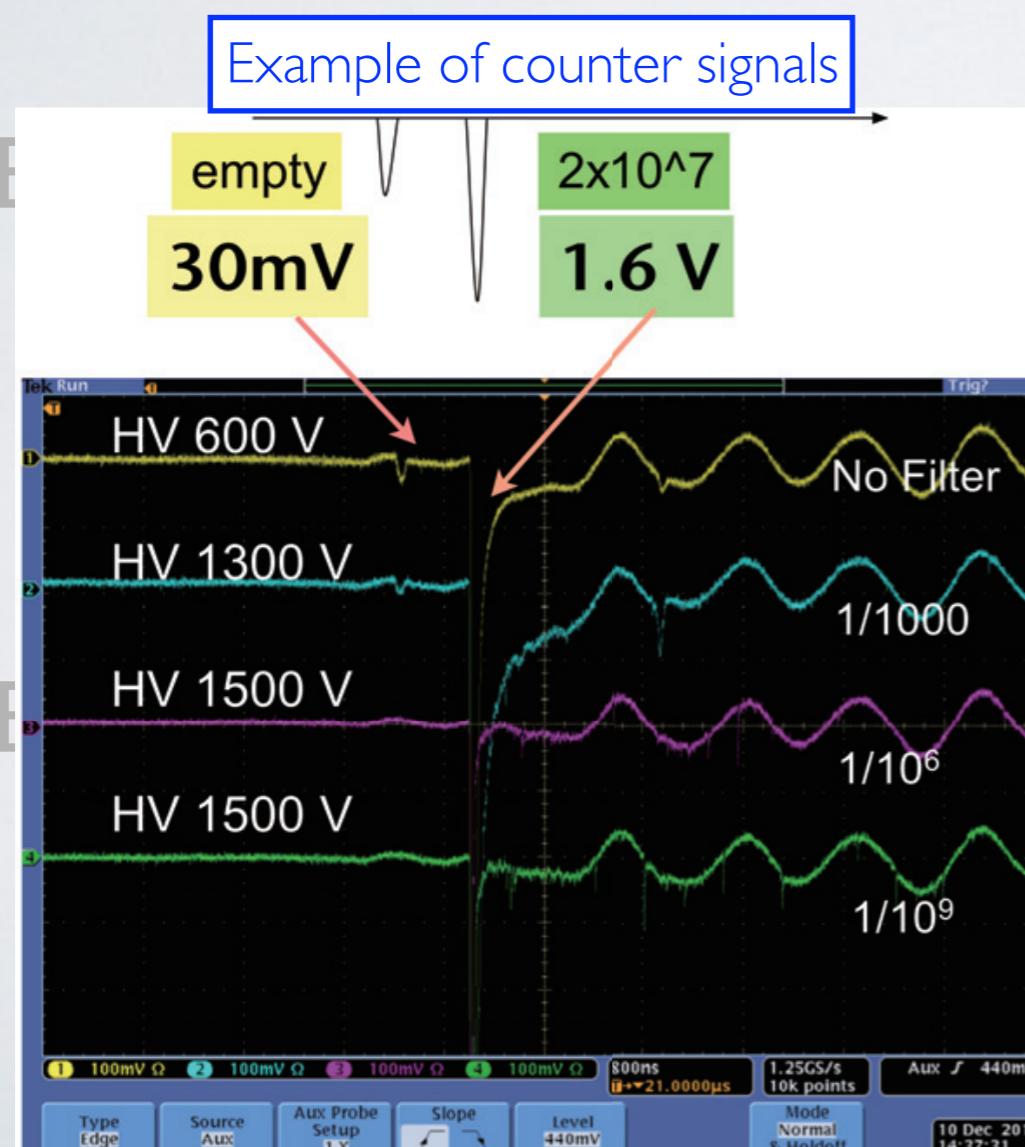
- 30GeV operation with FX
- “Single Bunch Kicking” method was newly introduced

## 3. Extinction Measurement in May 2014

- 8GeV operation with FX
- “Single Bunch Kicking” method was confirmed

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- 30GeV operation with FX
- Measure the raw extinction factor



in June 2012

FX

" me

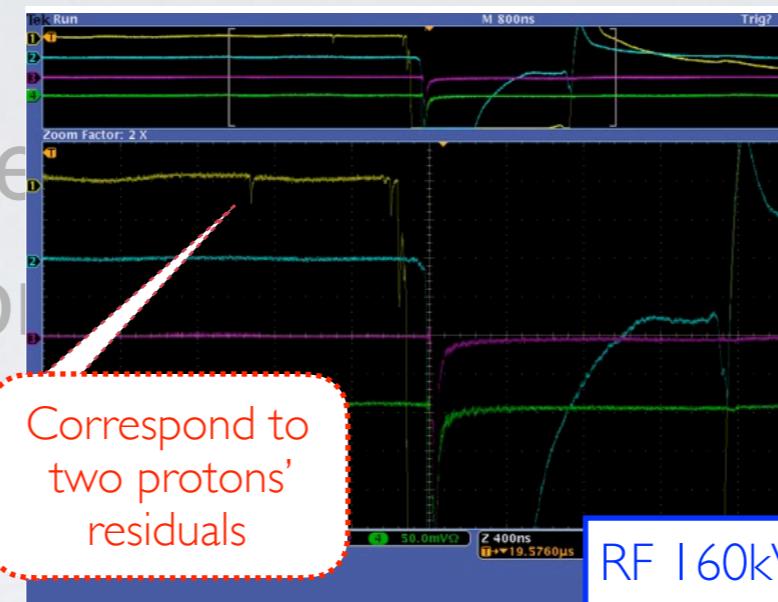
in M

FX

" method was confirmed

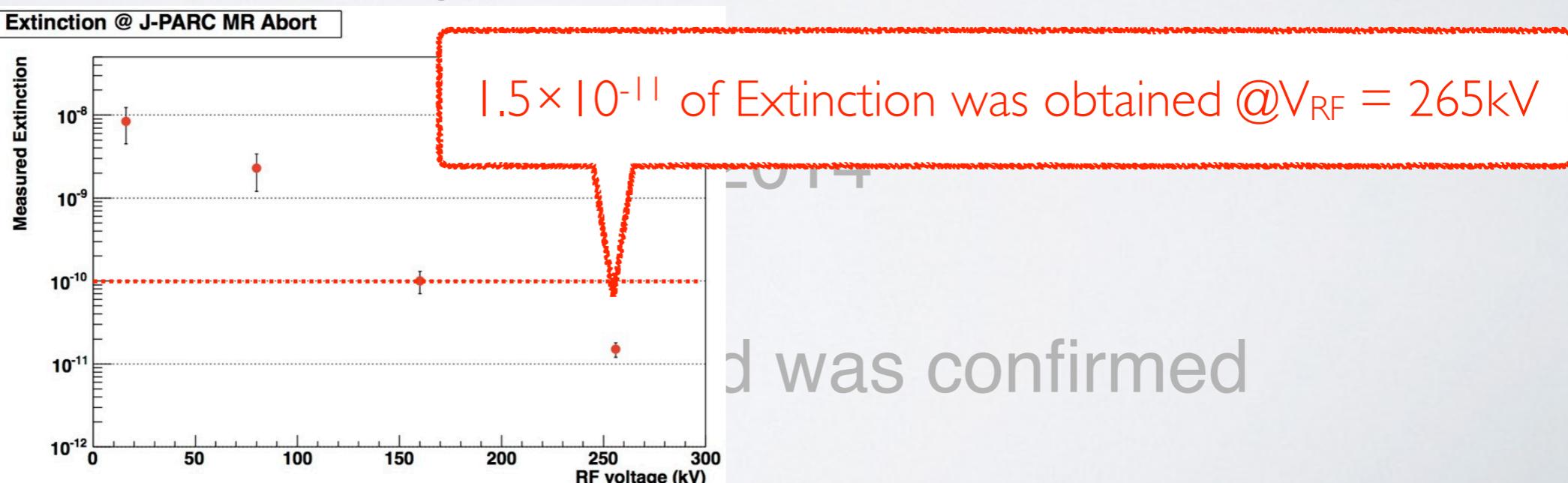
By taking into account the gain difference, extinction factor is calculated to be  $O(10^{-7})$   
→ Need 1,000 suppression!

Extinction was measured with single bunch kicking by changing RF voltage



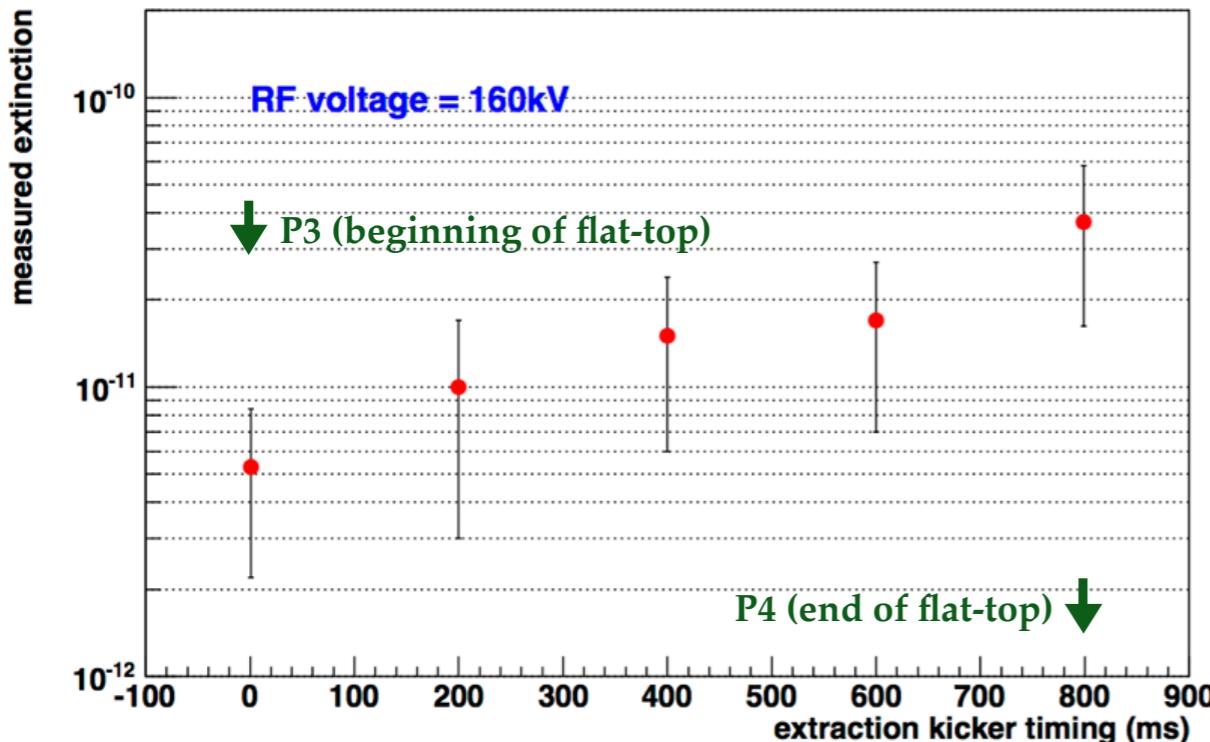
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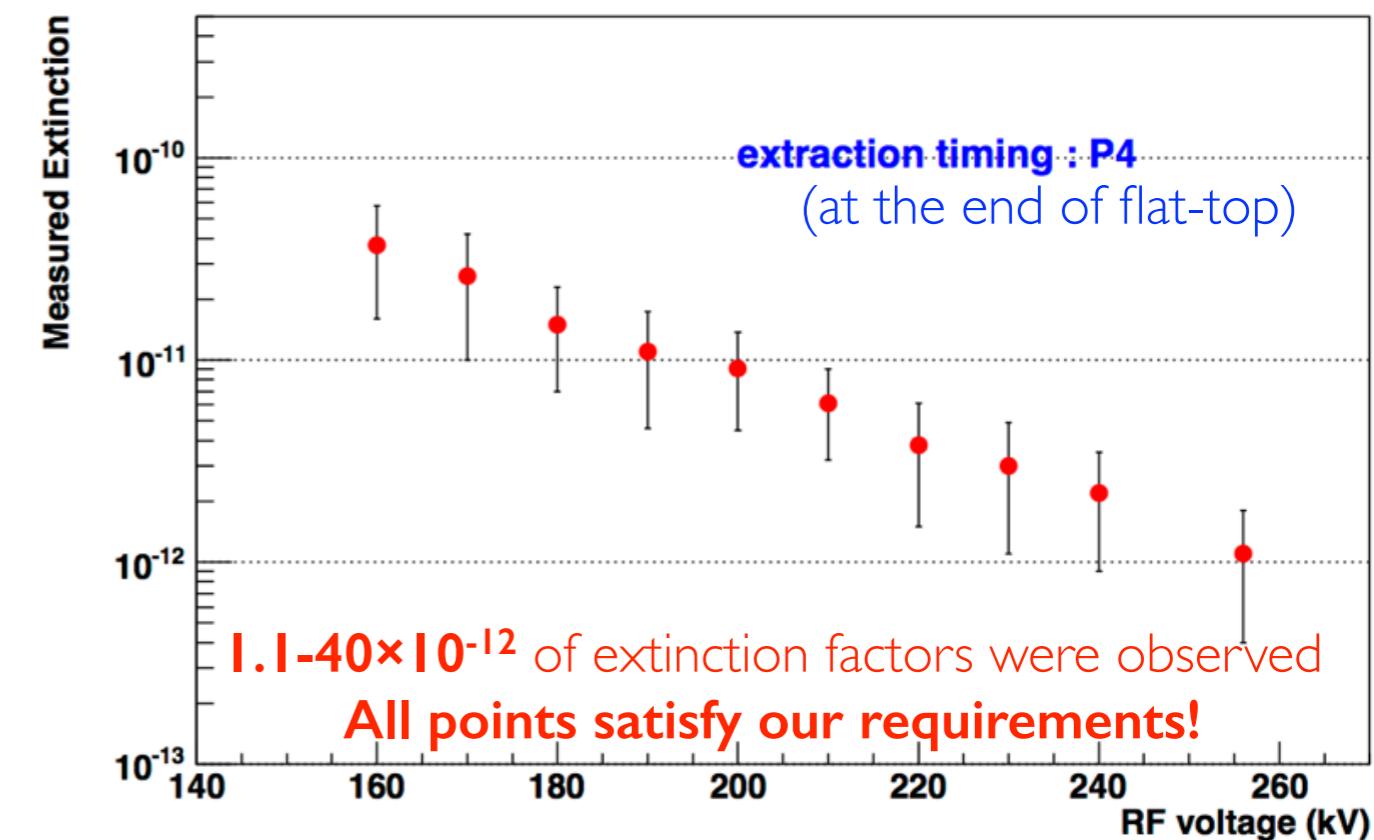


## 1. Extinction Measurement in April 2014

Extinction @ J-PARC MR Abort



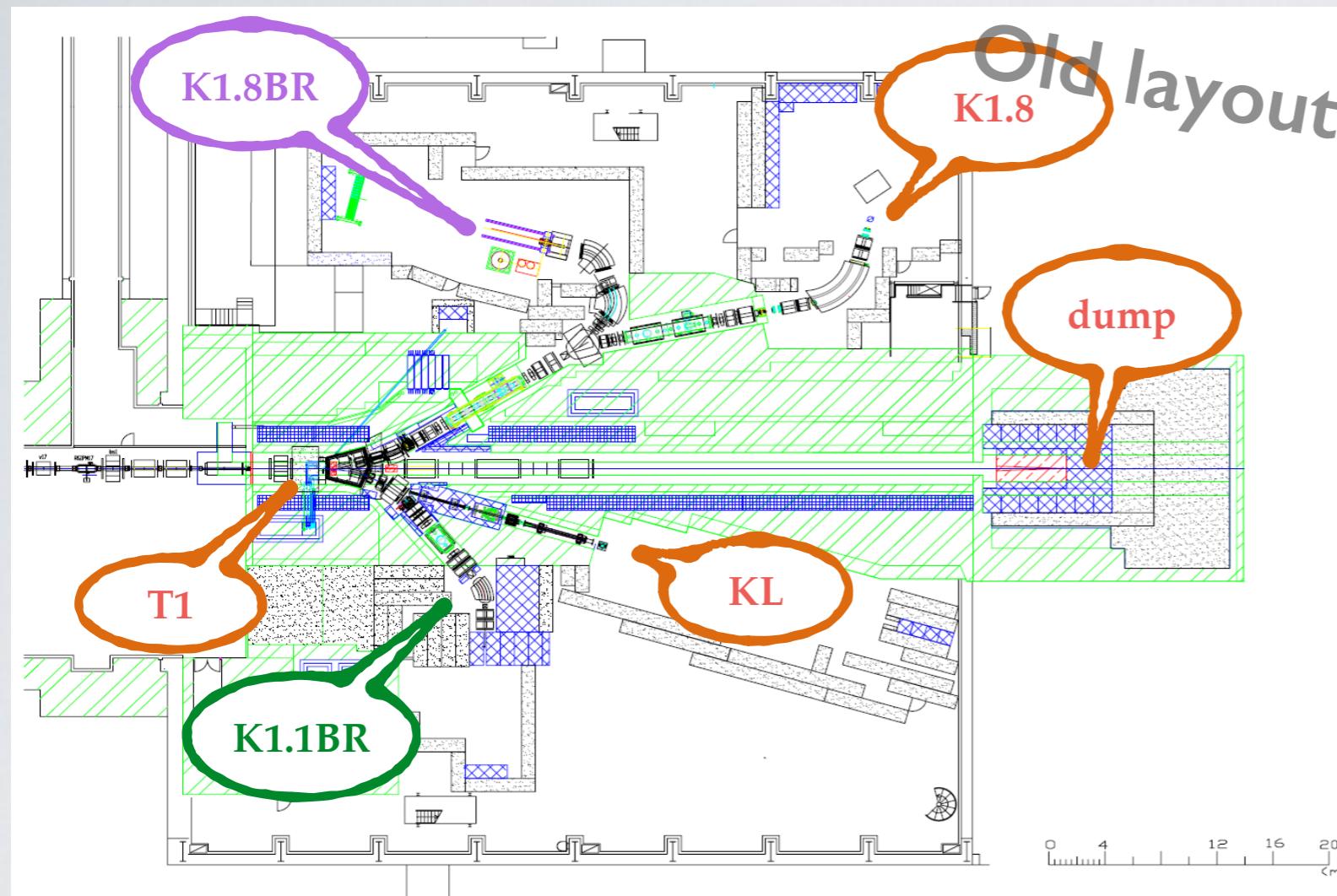
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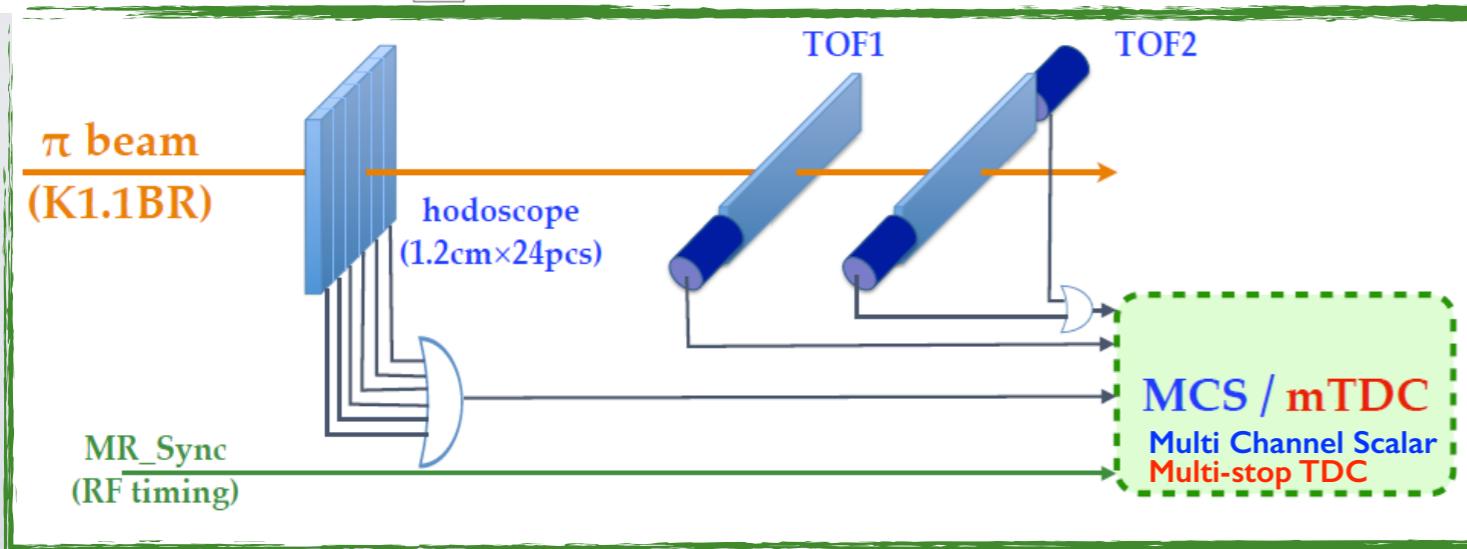
## 3. Extinction Measurement in May 2014

- 8GeV operation with FX
- “Single Bunch Kicking” method was confirmed

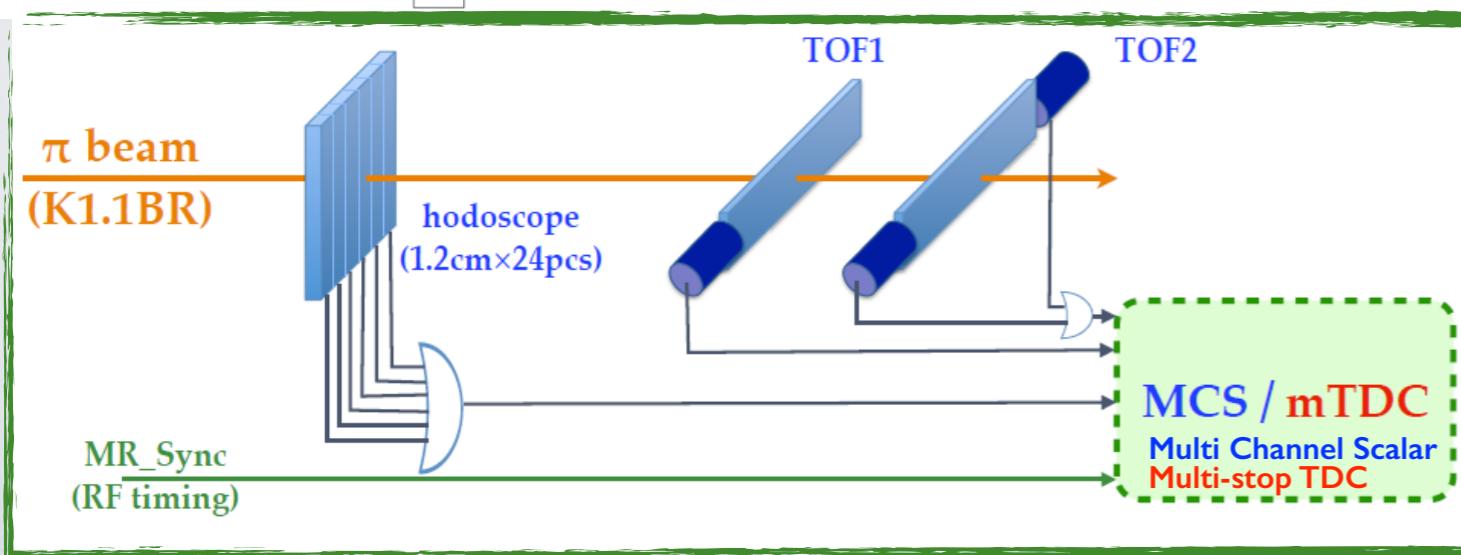
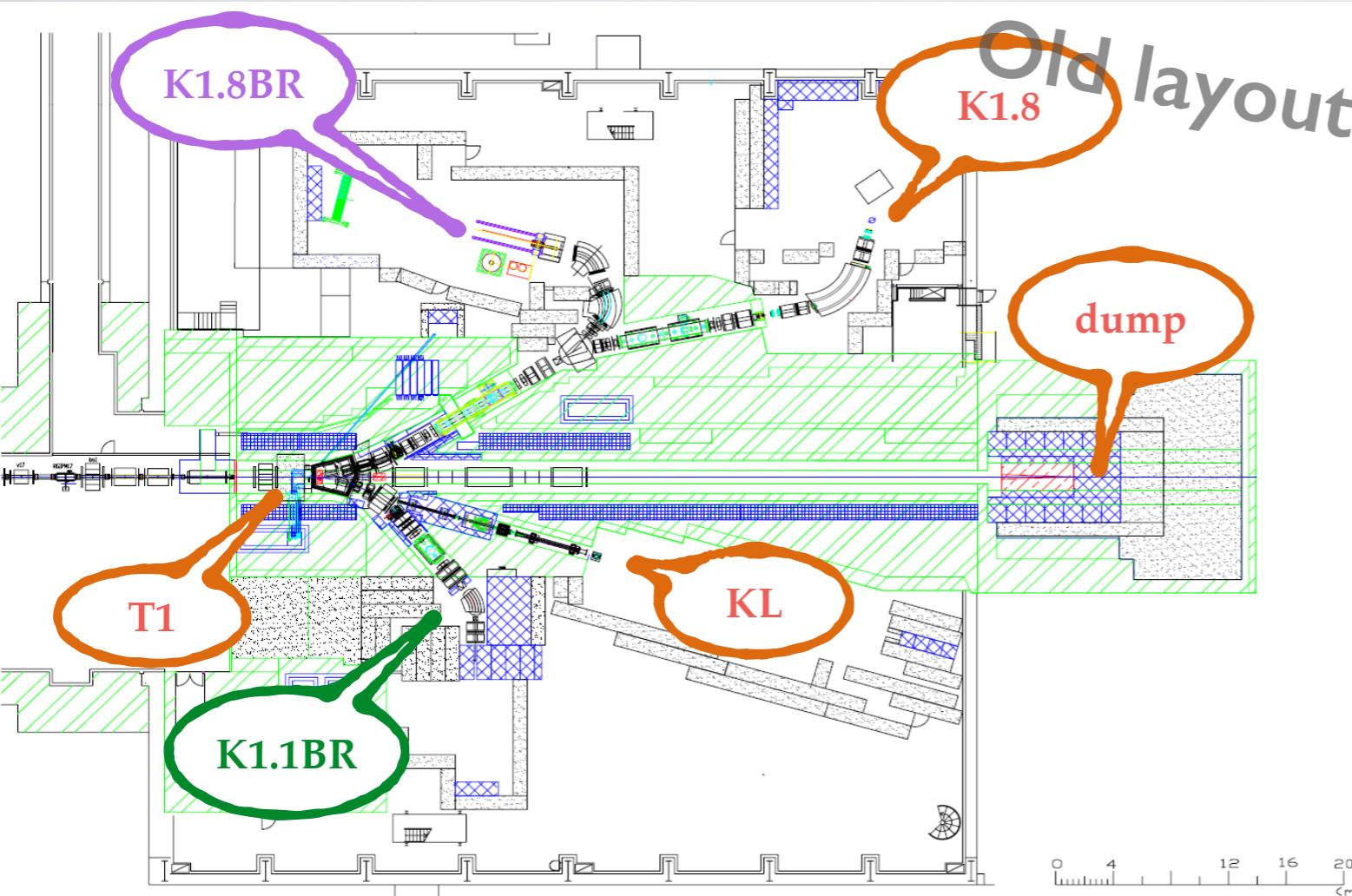
## Extinction Measurements @Hadron Hall



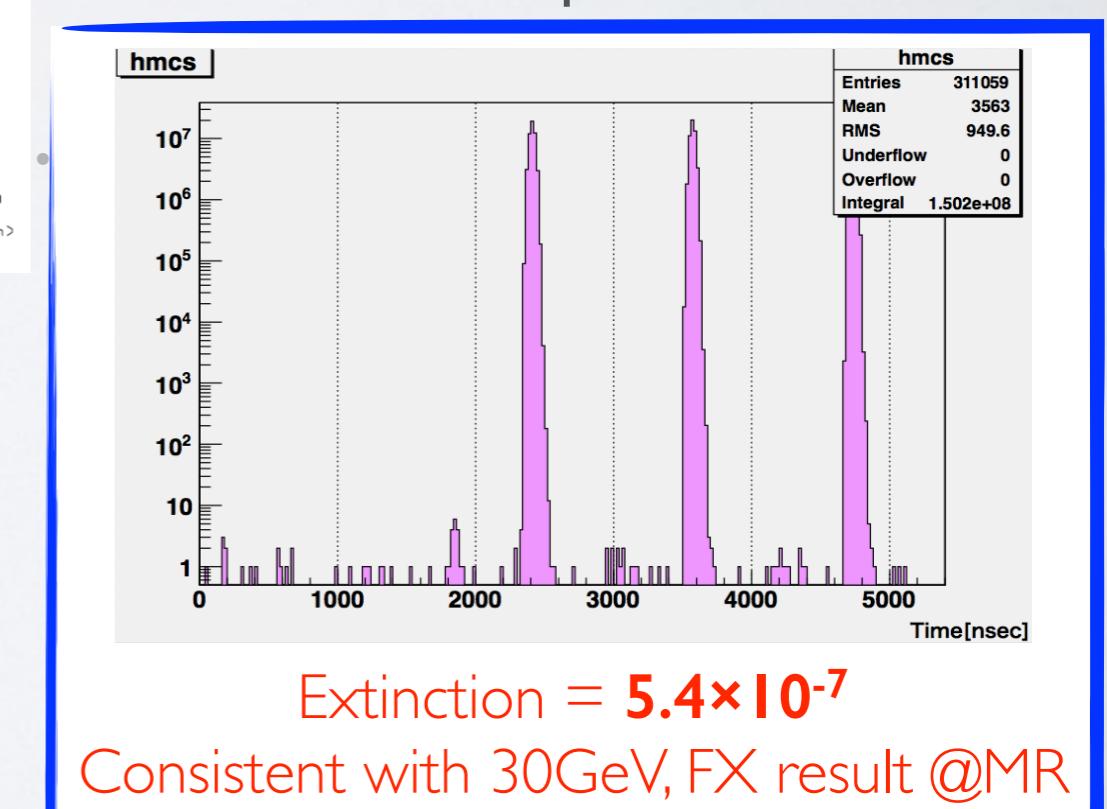
- The 1st extinction measurement was performed
  - in Oct. 2010
  - @K1.1BR (already dismantled...)
  - 30GeV BSX
  - Measure the raw extinction factor by counting #of high momentum pions
- 2nd one is in preparation
  - will be done in 2017
  - @K1.8BR (most probably)
  - 8GeV BSX
  - Measure the extinction factor with “Single Bunch Kicking” method



# Extinction Measurements @Hadron Hall



- The 1st extinction measurement was performed
  - in Oct. 2010
  - @K1.1BR (already dismantled...)
  - 30GeV BSX
  - Measure the raw extinction factor by counting #of high momentum pions



# Measurement Status

		Proton Energy	30 GeV	8 GeV
Extraction Mode				
FX	Without Single Bunch Kicking	$\sim \mathcal{O}(10^{-7})$		Not yet
	With Single Bunch Kicking	$1.5 \times 10^{-11}$		$1.1 \times 10^{-12}$
BSX	Without Single Bunch Kicking	$5.4 \times 10^{-7}$		Not yet
	With Single Bunch Kicking	Not yet		Not yet

Will be measured in Spring 2017 !



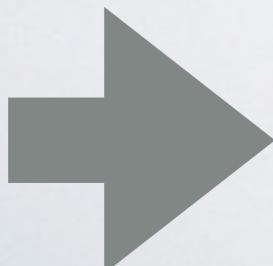
# Development of Extinction Monitor

$\mu$

$e$

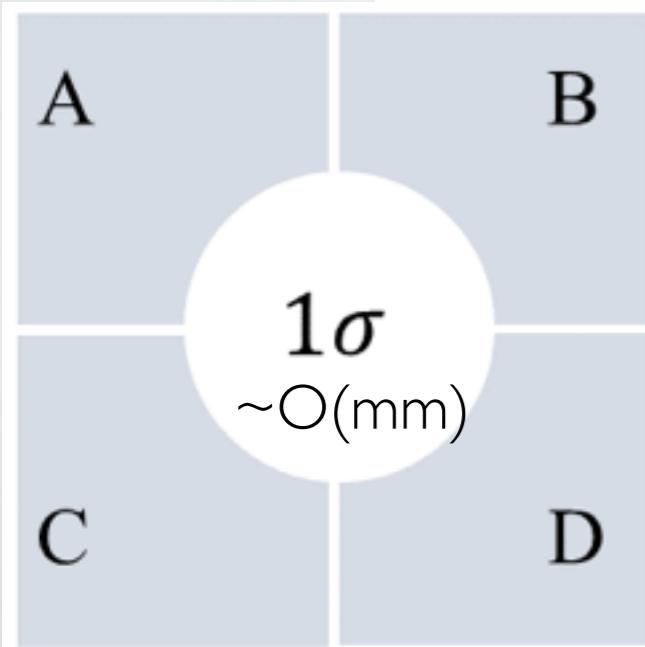
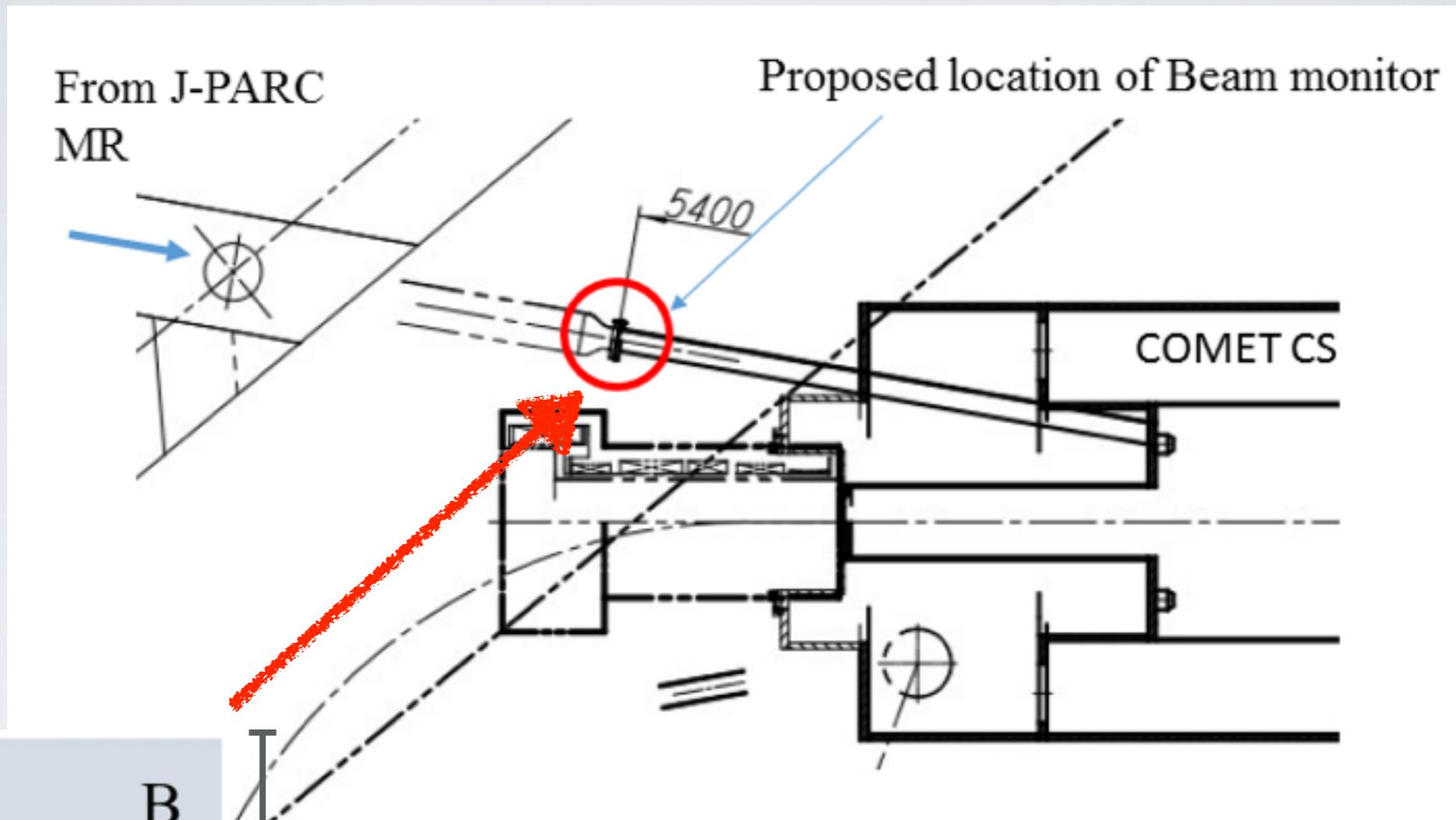
# Extinction Monitor in COMET

- We are aiming to measure the extinction during the COMET physics measurement
  - To ensure that extinction factor is low enough
  - Beam profile could be measured as well
- Ordinary detectors e.g. scintillator cannot be used:
  - Radiation hardness,  **$2.5 \times 10^{12}$  protons/sec** (in COMET Phase-I)
  - Too massive to perform the long-term operation inside the beam-line
  - Single MIP signal cannot be seen due to the saturation caused by prompt burst
- **Diamond(= new generation semiconductor) detector is a strong candidate!**
  - **High radiation tolerance** →  $O(1\text{MGy})$  for gamma,  $O(10^{15} \text{n/cm}^2)$  for neutron
  - Can be very thin  **$O(100\text{um})$**
  - Fast time response →  **$O(1\text{ns})$**  rise & drift time
  - Extremely low thermal noise, etc...



**Suitable for COMET Extinction measurement**  
**Even direct proton measurement might be available!**

# Diamond Detector

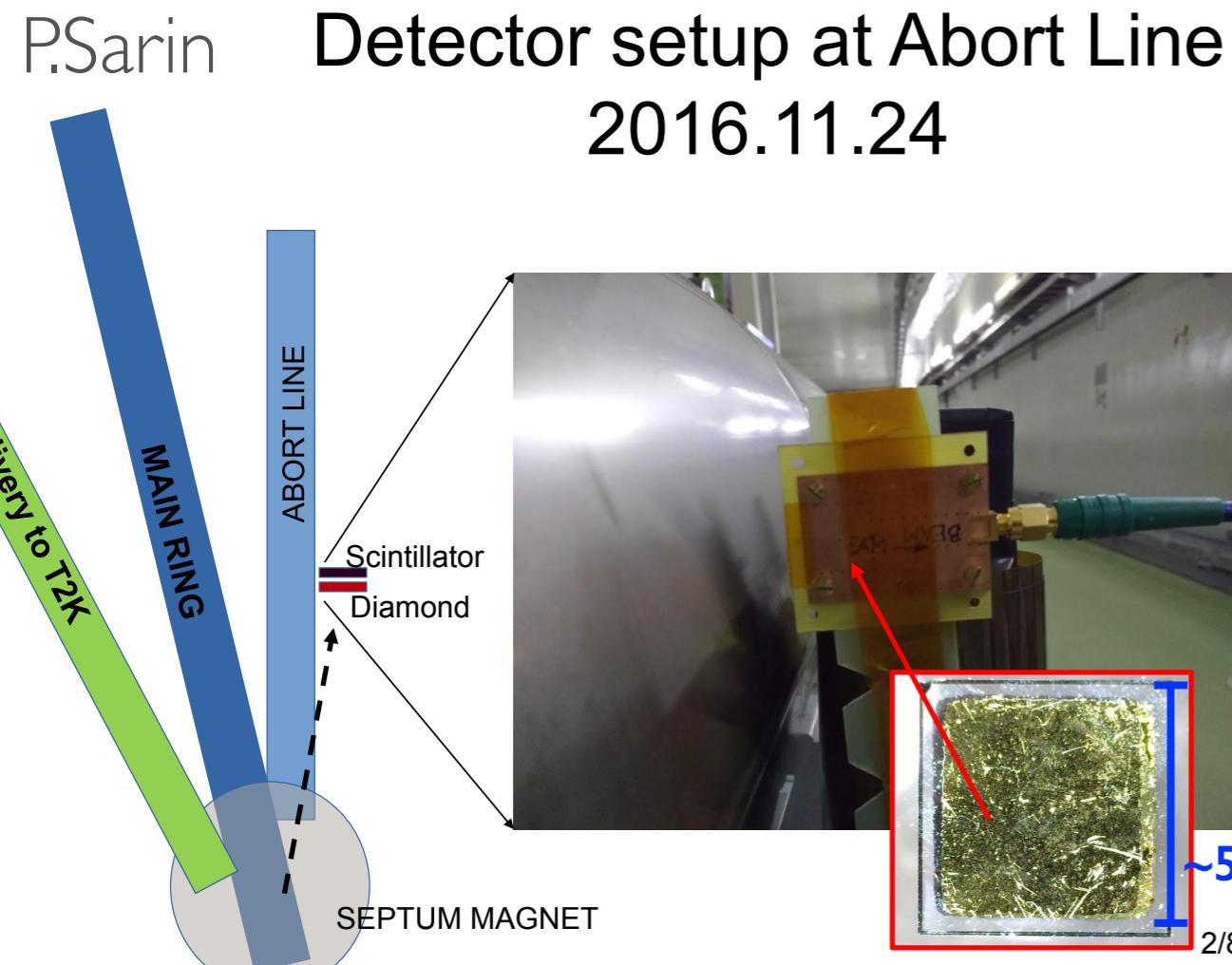


~1-2cm

**x-y position can be measured by looking  
difference of signals among 4 crystals with a  
few mm position resolution**

# R&D Status

- Several samples are being tested in collaborating with our Indian collaborator
  - Vendors: IIA, Element-6 (,Hokkaido Univ.)
  - Type of crystals: polycrystalline diamond(pCVD) or single (scCVD)
- Recently we successfully observed secondary particles by installing the prototype diamond detector beside the MR abort

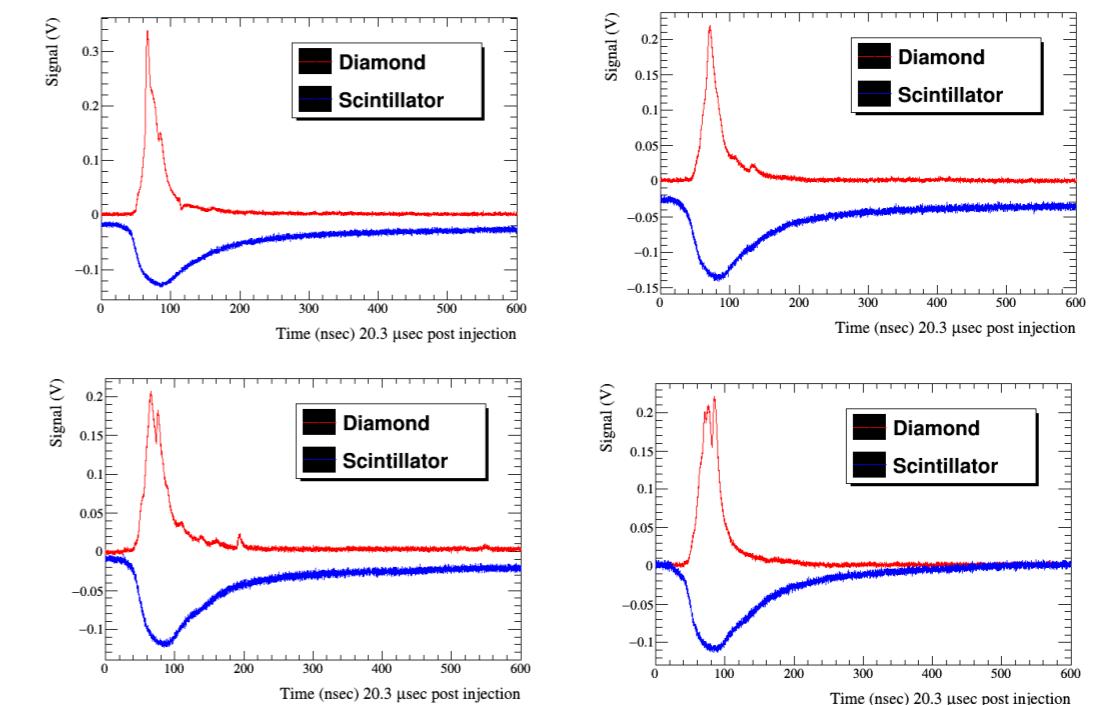


PSarin

## Detector response plots

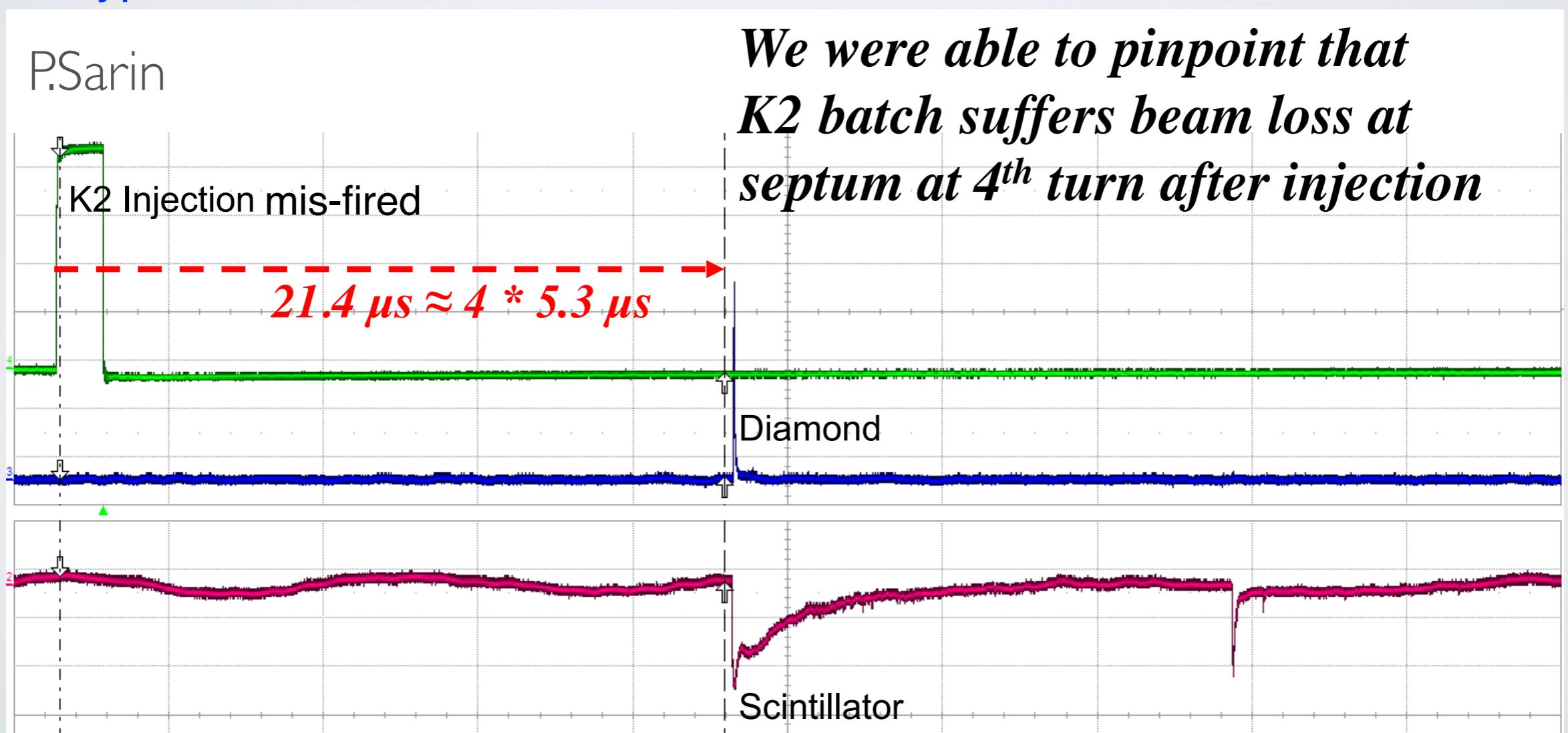
Single crystal diamond, 7mm x 7mm @ -200V bias  
Scintillator @ -400V bias

Halo of secondary's detected from each bunch. One bunch =  $5 * 10^{13}$  protons



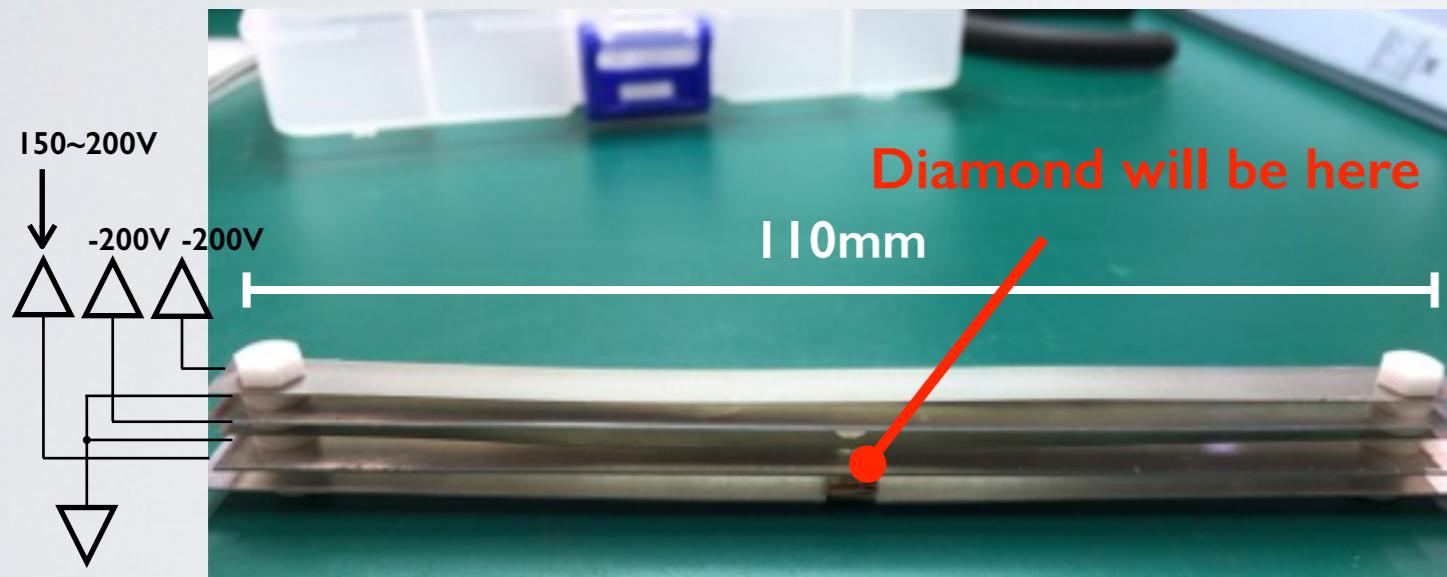
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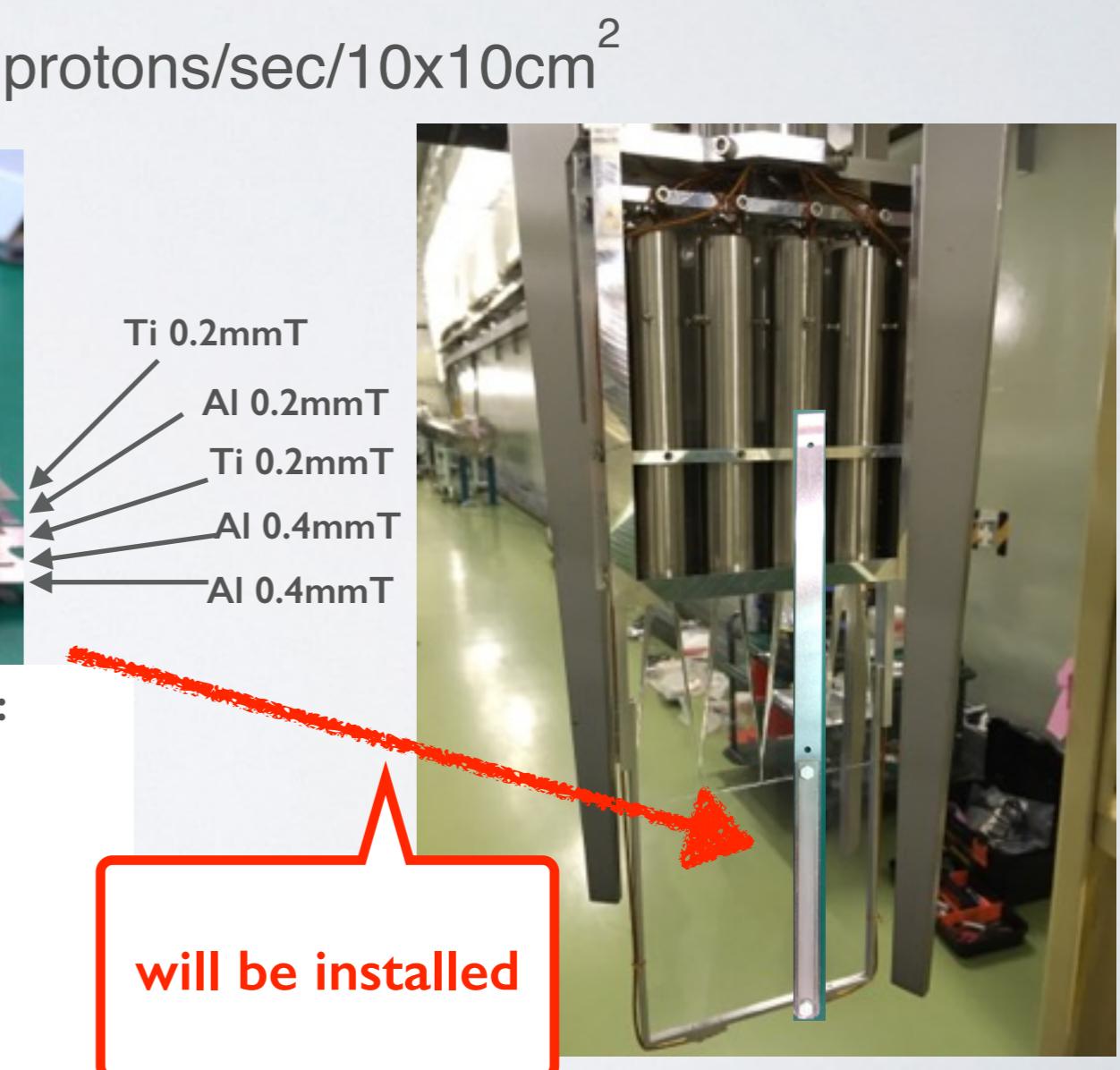
# R&D Status

- Next step
  - → Direct measurement of proton beam @MR abort
- Requirements
  - Vacuum compatible detector system
  - Very high radiation environment →  $10^{12}$  protons/sec/10x10cm<sup>2</sup>



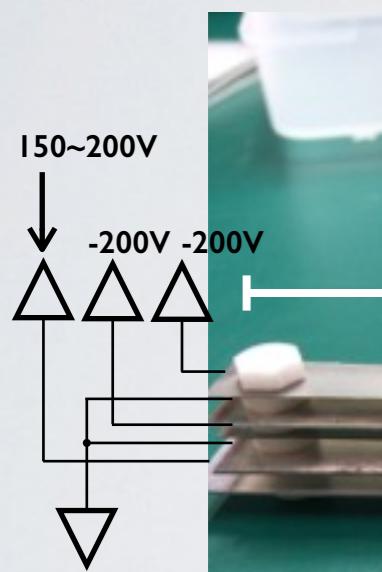
Small frame to mount the diamond detector composed of:

- One signal layer to be biased
- Two Al layers for grounding
  - one is in between Ti layers
- Two Ti reference layers
  - to measure #of protons using secondary emission
  - one layer has 3mmΦ hole



# R&D Status

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  - → Direct measurement of proton beam @MR abort
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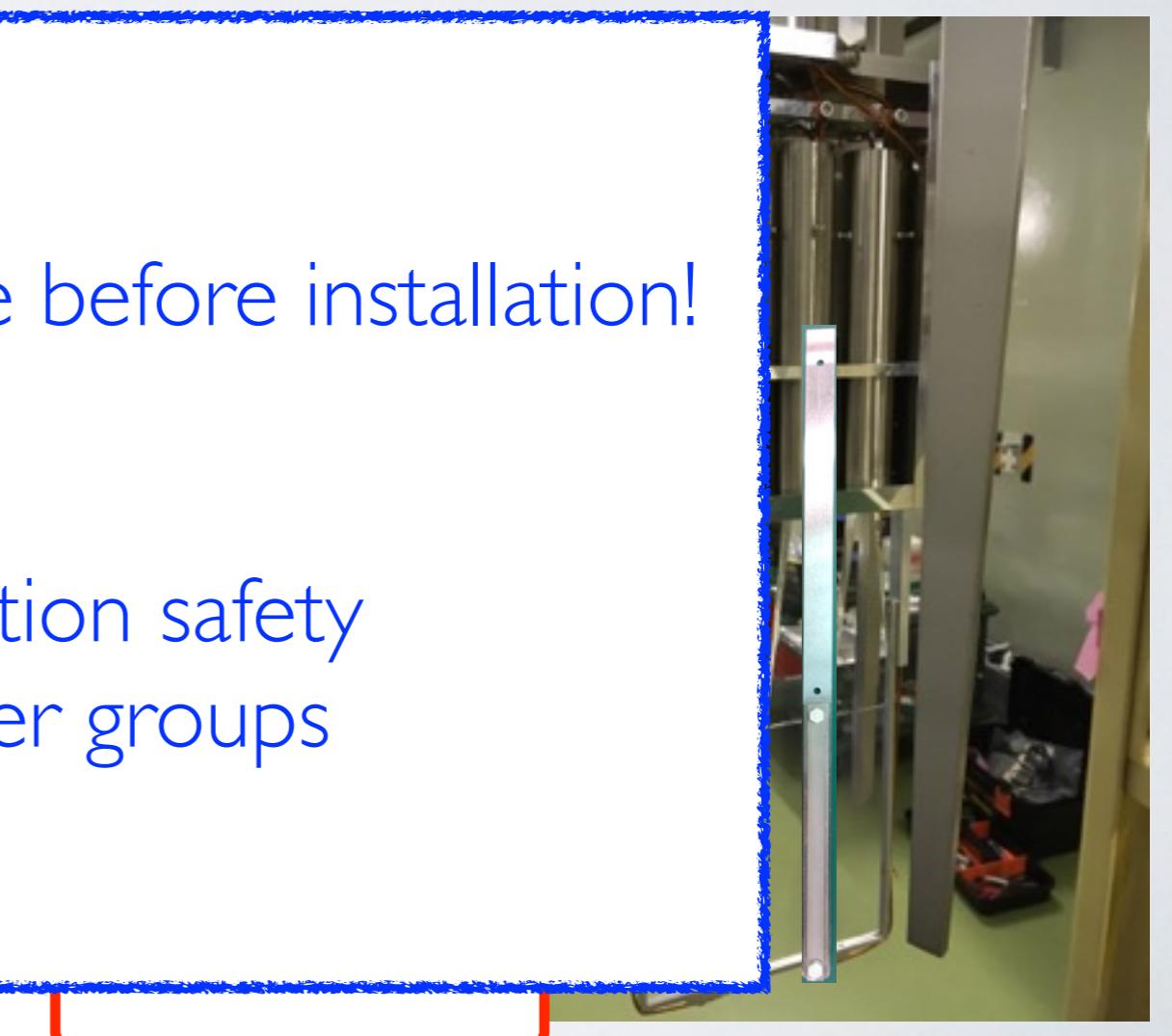


**Small frame**

- One signal
- Two Al layers
  - one is
- Two Ti ret
  - to me
  - one layer has 3mmΦ hole

Many things have to be done before installation!

- Bench test in lab
- Out-gas check in vacuum
- PHITS simulation for radiation safety
- Official approval from other groups





# Summary & Prospects

## MET

$\mu$

$e$

# Summary

- Good “extinction” factor is the most important key for the success of  $\mu$ -e conversion search with a target sensitivity  $O(10^{-17})$  in COMET
- Also important to realize the ultra high quality pulse beam @J-PARC
- “**Single Bunch Kicking**” method gives excellent extinction factor
  - **1.1x10<sup>-12</sup>** of Extinction factor was obtained with 8GeV FX operation @MR
  - **Less than 10<sup>-10</sup>** even in the worst case
- Extinction measurement @Hadron hall is in preparation with 8GeV BSX, “Single bunch kicking”
- Diamond detector will be used as Extinction and beam profile monitor in COMET during the physics measurement
  - First measurement using prototype diamond detector was carried out by detecting secondary particles @MR abort in this year
  - → **Very clear and fast signals were observed!**
  - Development of new prototype to directly measure the proton beam in vacuum is ongoing

# Prospects

- 2017 is very important year for the Extinction measurement and COMET
  - Extinction measurement will be performed @Hadron hall with 8GeV BSX mode in Spring
    - Almost same situ. as in COMET
  - Direct measurement of the most high intense proton beam using Diamond detector will be demonstrated
    - **Scientifically interesting** as well
- When the construction of COMET BL is completed, extinction factor can be measured in the real situ. with Diamond detector
  - will be in 2018?

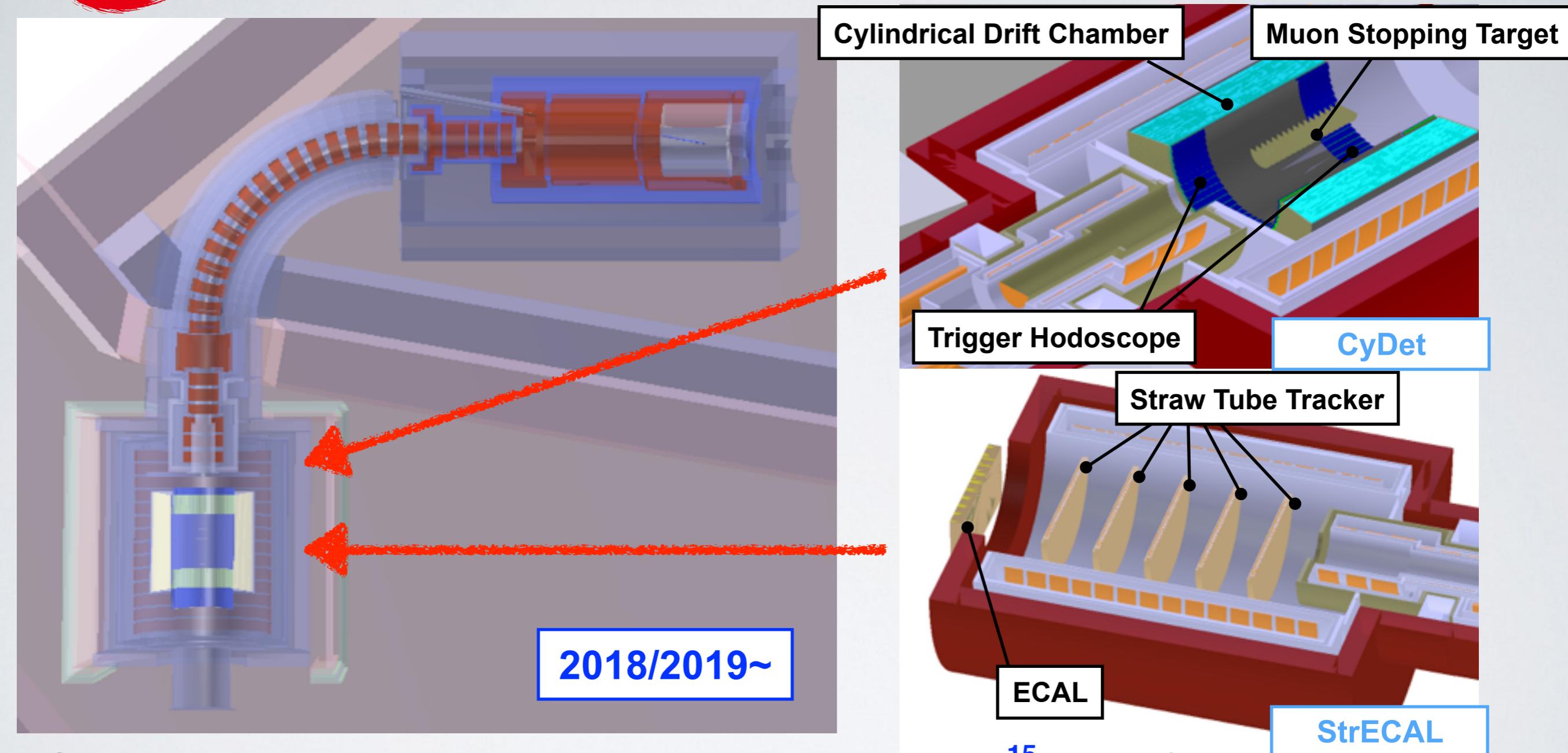


**Backup** MET e

$\mu$

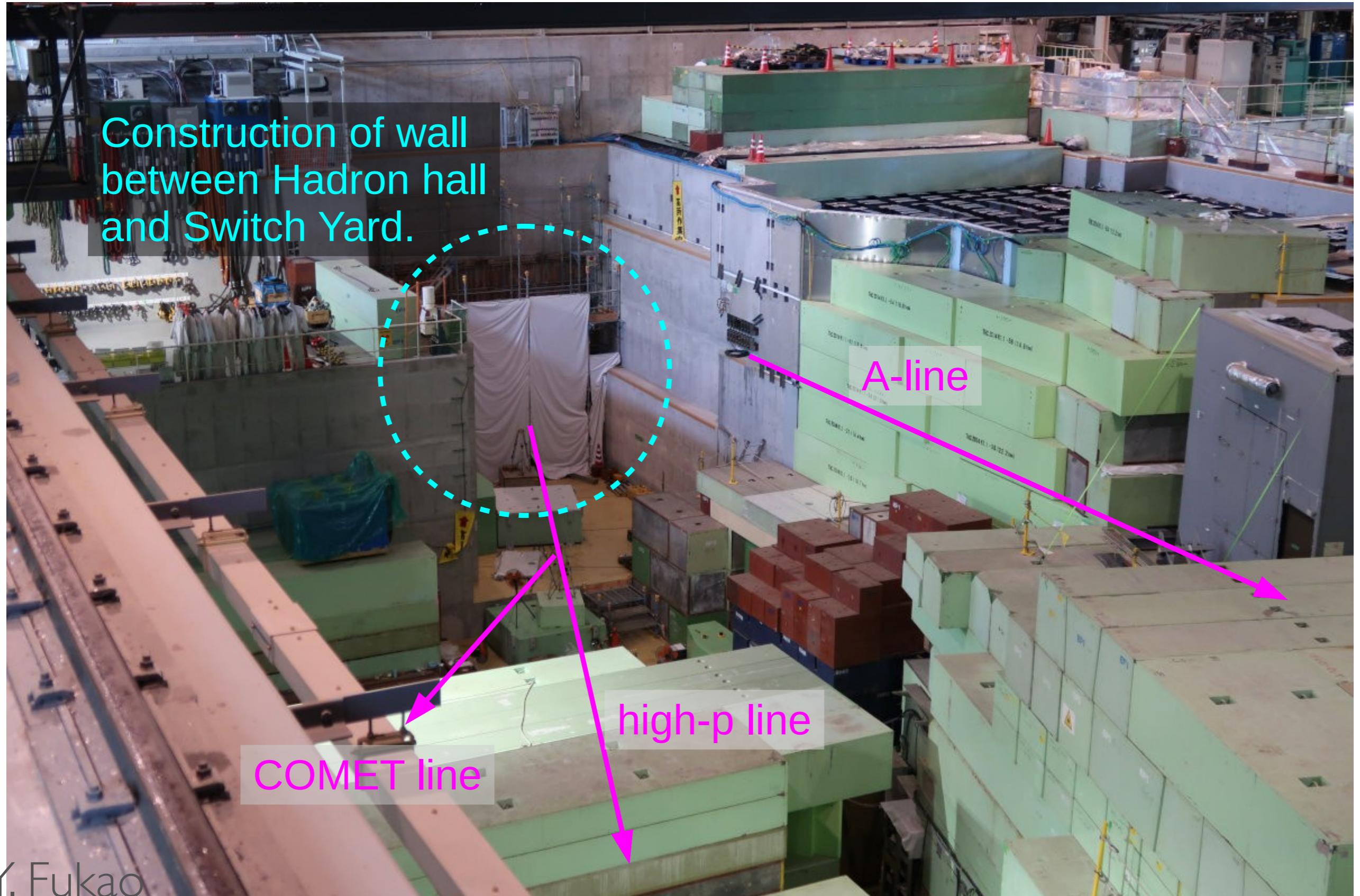
$e$

# COMET Phase-I



- Search for  $\mu$ -e conversion with a sensitivity of  $\sim 3 \times 10^{-15}$  using CyDet
- Direct beam measurement using StrECAL as a Phase-II Prototype Detector
- Both detector systems will suffer from very high hit rate
  - → Trigger rate must be effectively suppressed

# Beamline Construction Status (2)



Y. Fukao

# Production Status of LAM/MS1/2

Lambertson Magnet



They are key component to establish Phase-1 proton beamline.

Fabrication & Field Measurement will be completed by Jan-2015

They will be located in SY in the next summer (2015).

Magnetic Septum 1

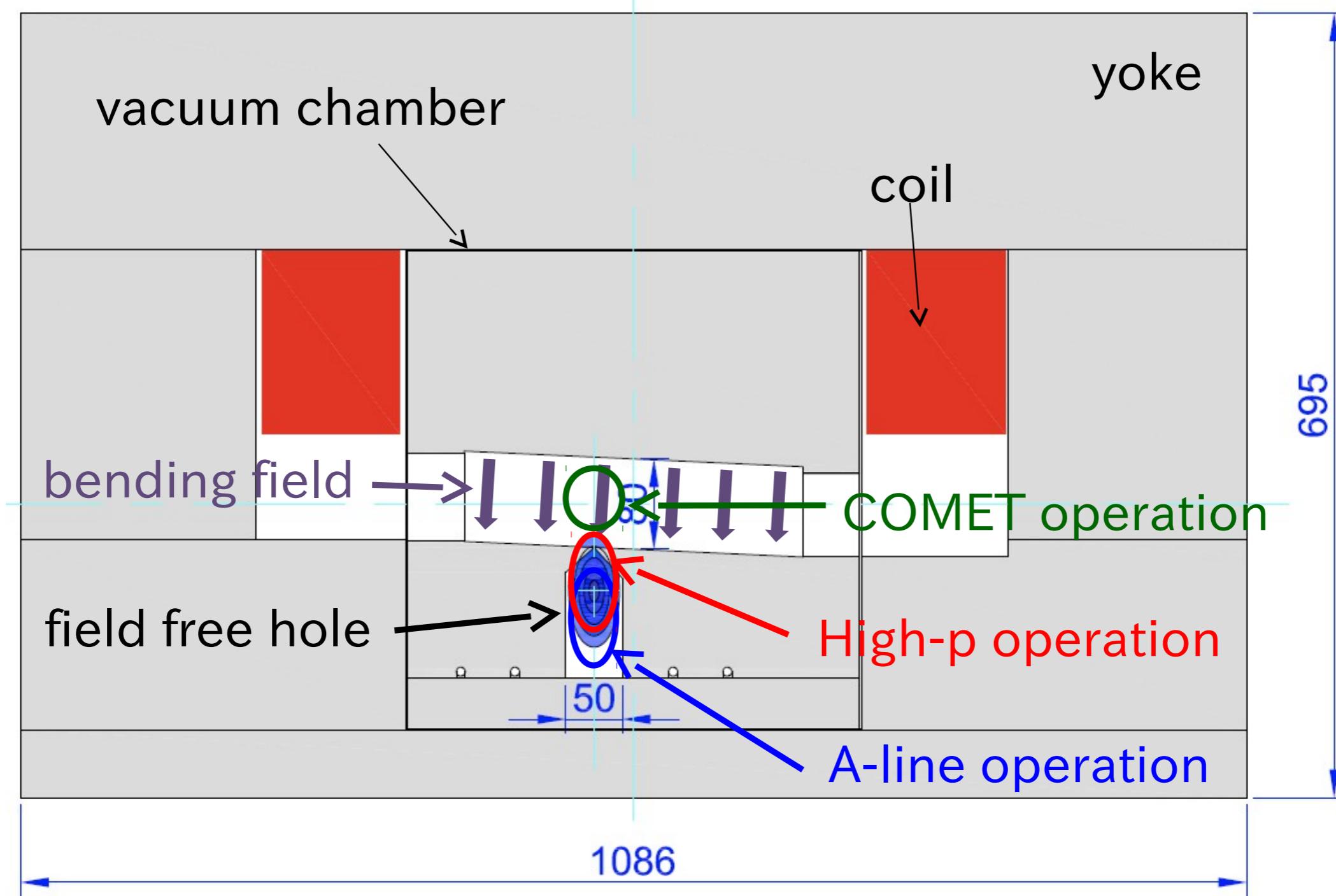


Magnetic Septum 2



Y. Fukao

# Cross Section of Lambertson Magnet



- Manufacturing magnets, including Lambertson and Septum, are ongoing. Installation to SY is ongoing.

Y. Fukao