EUROPEAN PHYSICAL SOCIETY HEP2015

Conference on High Energy Physics 2015

22-29 July 2015, Vienna, Austria

COMET experiment:

— A search for muon-to-electron conversion at J-PARC —

Hajime NISHIGUCHI, *KEK*

On behalf of the COMET collaboration

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1. COMET overview

- physics motivation, event signature and backgrounds

2. COMET features

- experimental principle, muon beam, detectors

3. COMET status & prospects

- strategy, R&Ds, construction status

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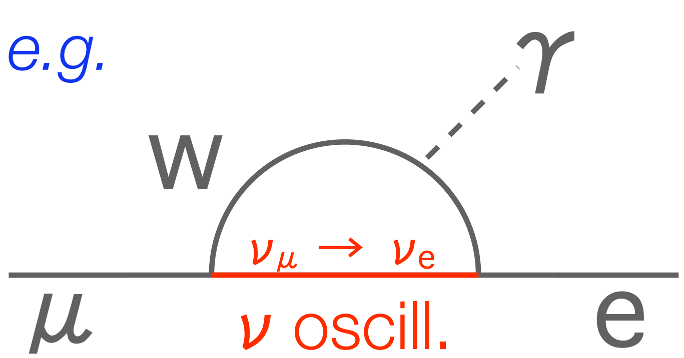
Why charged LFV is so attractive ?

Why ? : Quark/Neutrino Flavour Mixing = ☺ / Charged LFV = ☹ ?

SM + simple ν Oscillation

- charged LFV is possible



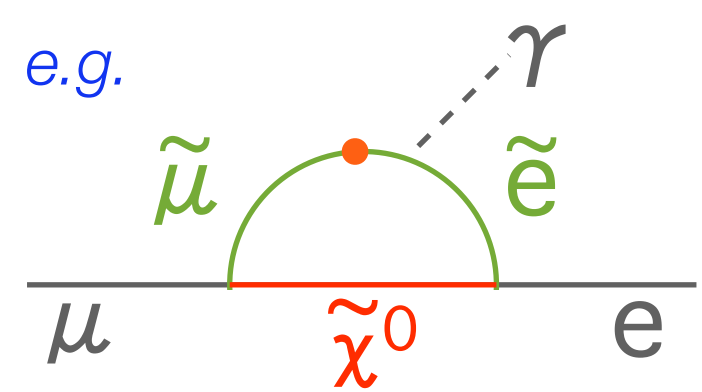
- but extremely rare

$$\mathcal{B}(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi} \sum_i \left| U^*_{\mu i} U_{ei} \frac{m^2_{\nu i}}{m^2_W} \right|^2$$

- B($\mu \rightarrow e\gamma$) $\lesssim 10^{-50}$!!!

beyond SM (SUSY-GUT *etc.*)

- charged LFV is largely enhanced



- still rare but observable level

$$\mathcal{B}(\mu \rightarrow e\gamma) \simeq \frac{\alpha^3 \pi \theta^2_{\tilde{e}\tilde{\mu}}}{G_F^2 \tilde{m}^4}$$

- B($\mu \rightarrow e\gamma$) = $10^{-15} \sim 10^{-11}$!!!

Why charged LFV is so attractive ?

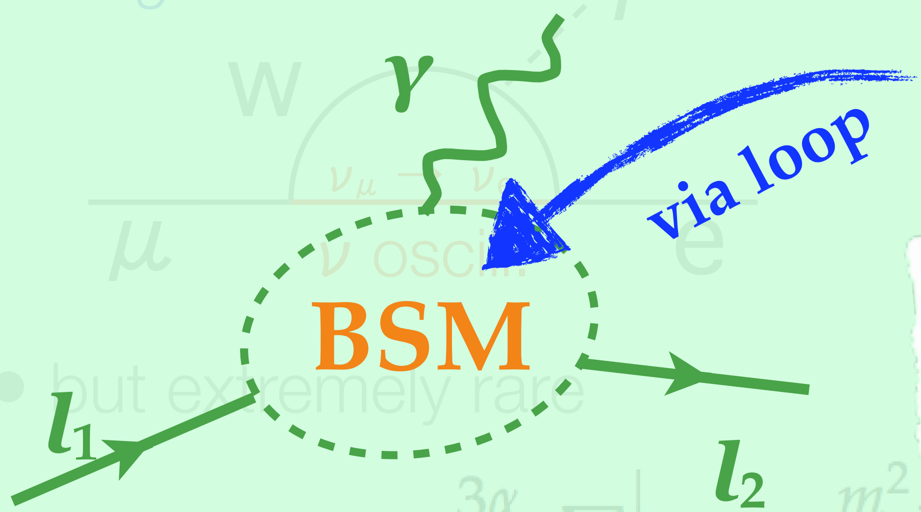
Why ? : Quark/Neutrino Flavour Mixing = ☺ / Charged LFV = ☹ ?

SM + simple ν Oscillation

beyond SM (SUSY-GUT *etc.*)

“charged LFV” = “NEW PHYSICS”

TeV-scale New Physics



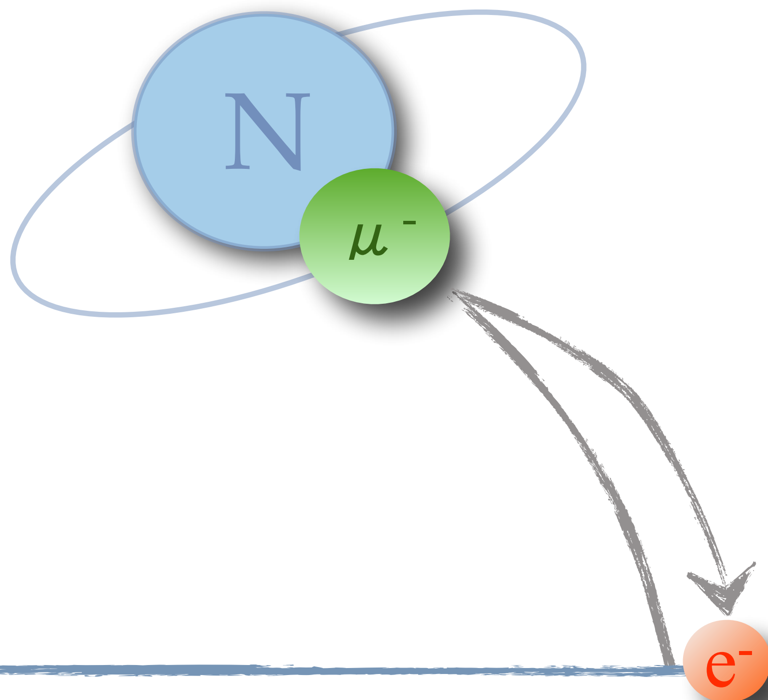
competitive & complementary to LHC !

- B($\mu \to e\gamma$) ≲ 10^{-50} !!!

- B($\mu \to e\gamma$) = 10^{-15} ~ 10^{-11} !!!

What is the muon-to-electron conversion ?

- *1S* state in a muonic atom



Muon Decay in Orbit (DIO)

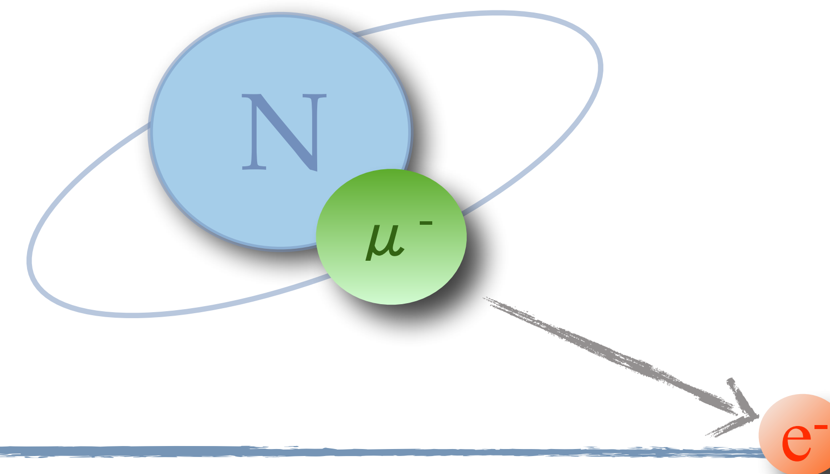
$$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$$

or

Nuclear Muon Capture

$$\mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z-1)$$

- If μ-e Conversion is Occurred ...



Neutrino-less Muon Nuclear Capture

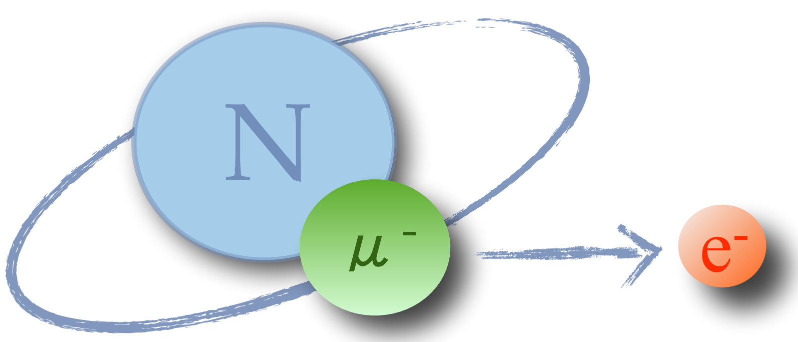
$$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$$

- Branching Ratio is Determined by

$$\mathcal{B}(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

Experimental signature and Backgrounds

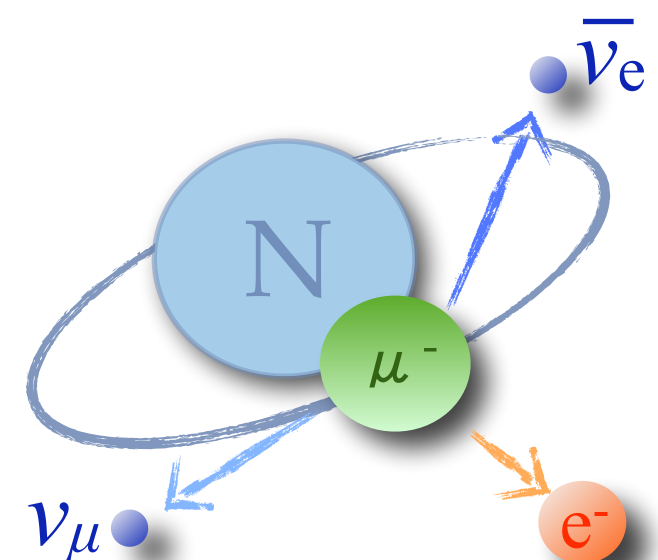
- **Signal**



- ***$E_e = m_\mu - B_\mu$ ~ 105MeV***
- Coherent Process ($Z_{ini}=Z_{end}$)

Signal : Single Mono-Energetic Electron
Sensitivity : Limited by Beam Quality
- **Wait until Pion decays**
- **Pulsed Beam is the BEST**

- **Backgrounds**
  - **Radiative Muon Capture**
  - **Radiative Pion Capture**
  - **Electrons from Muon DIF**
  - **Muon Decay in Orbit (DIO)**



  - Cosmic Rays, *etc.*

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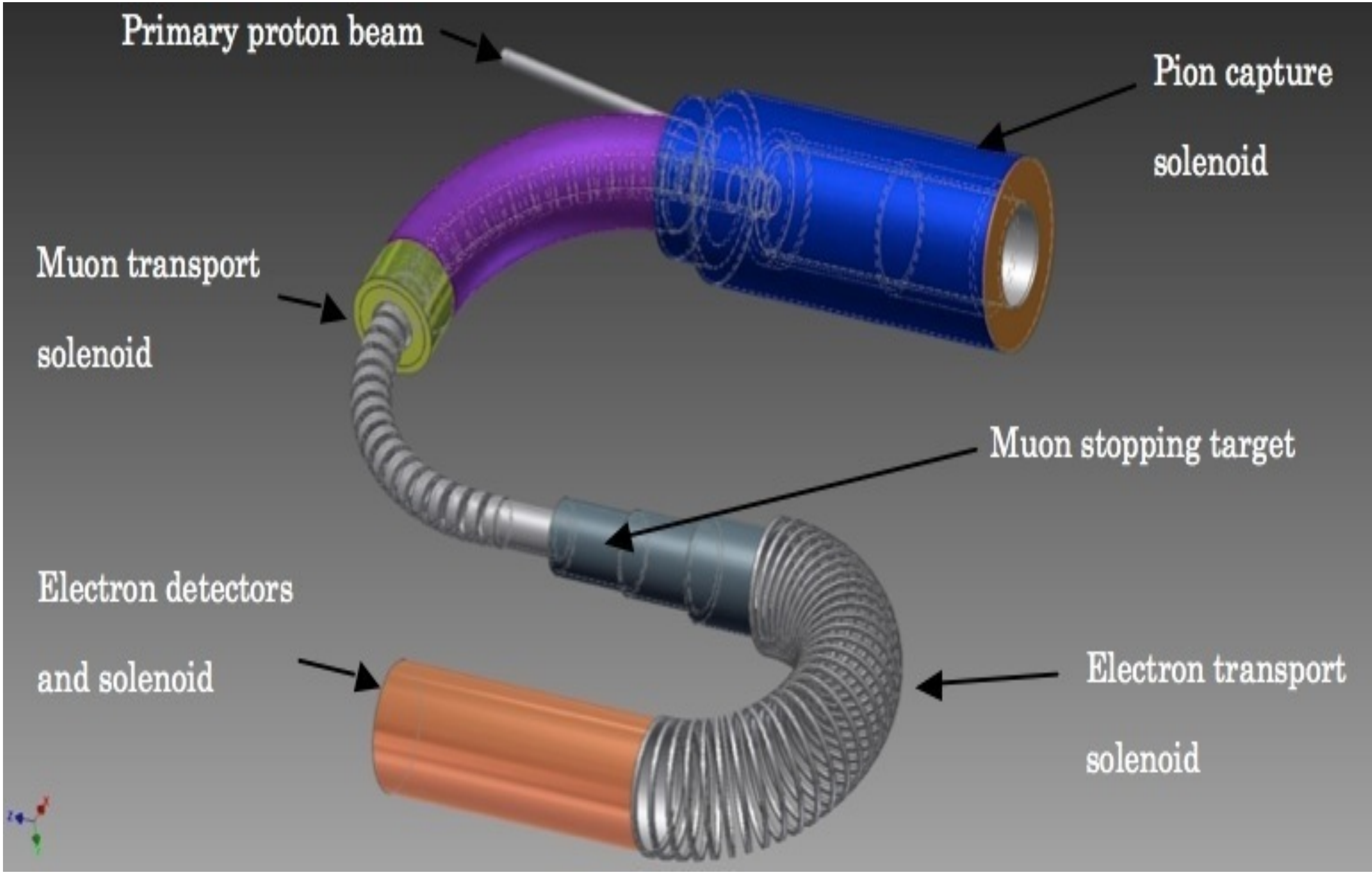
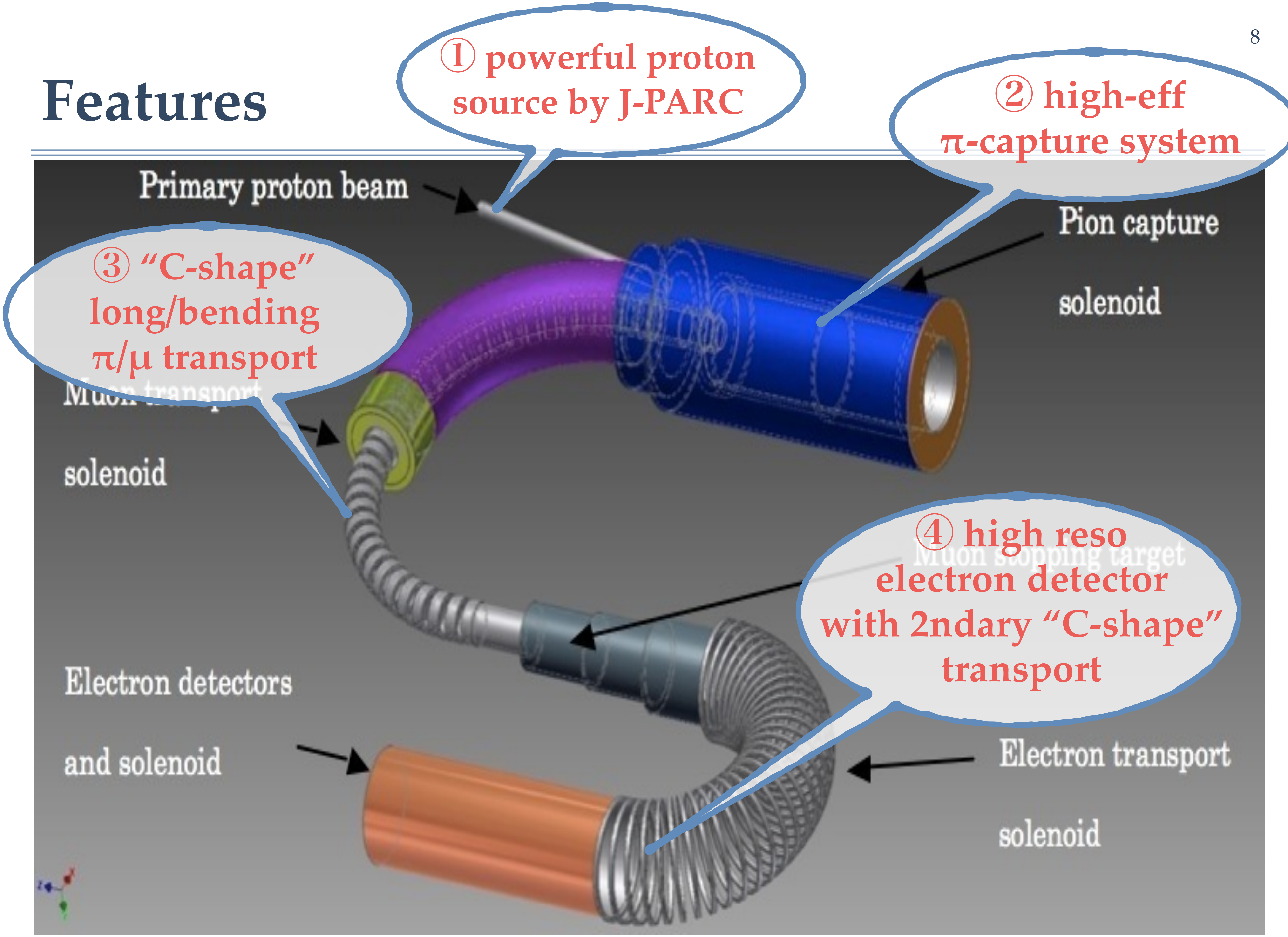
Features



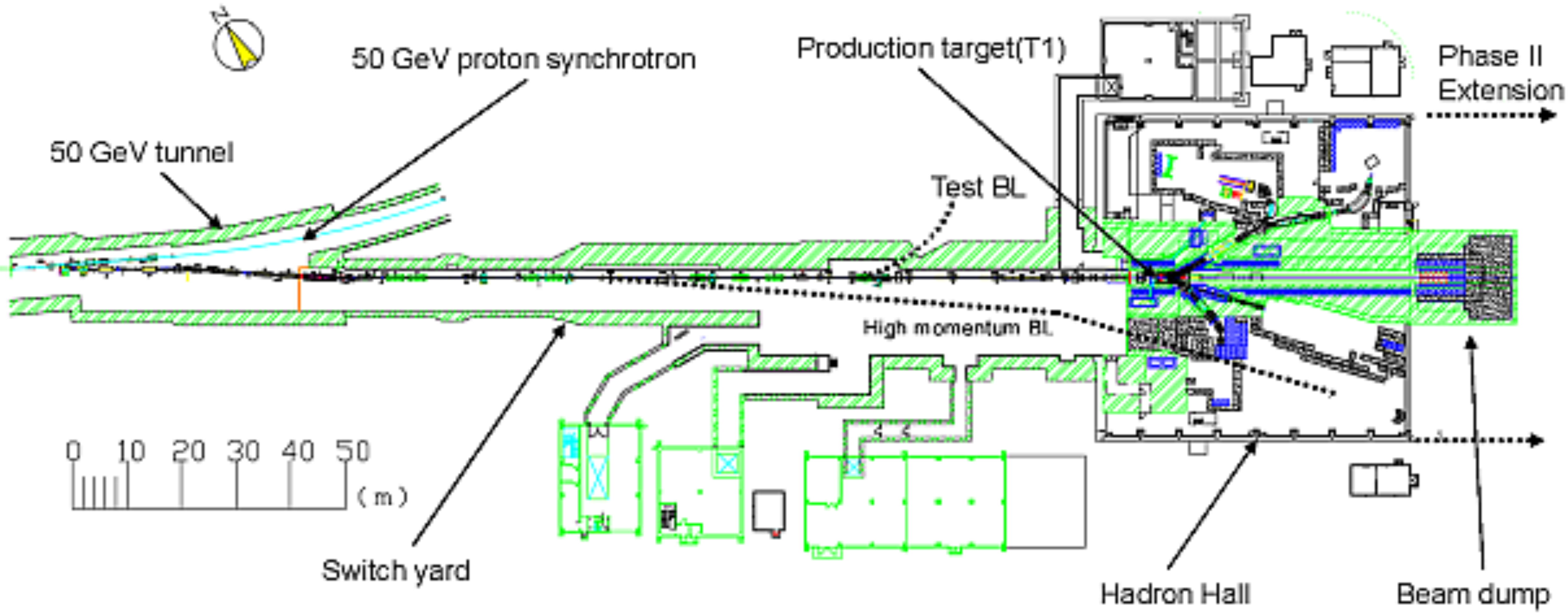
Primary proton beam
Pion capture
solenoid
Muon transport
solenoid
Muon stopping target
Electron detectors
and solenoid
Electron transport
solenoid

Features


① powerful proton source by J-PARC
② high-eff π-capture system
③ "C-shape" long/bending π/μ transport
④ high reso electron detector with 2ndary "C-shape" transport
Primary proton beam
Pion capture solenoid
Muon transport solenoid
Muon stopping target
Electron detectors and solenoid
Electron transport solenoid

① powerful proton source at J-PARC

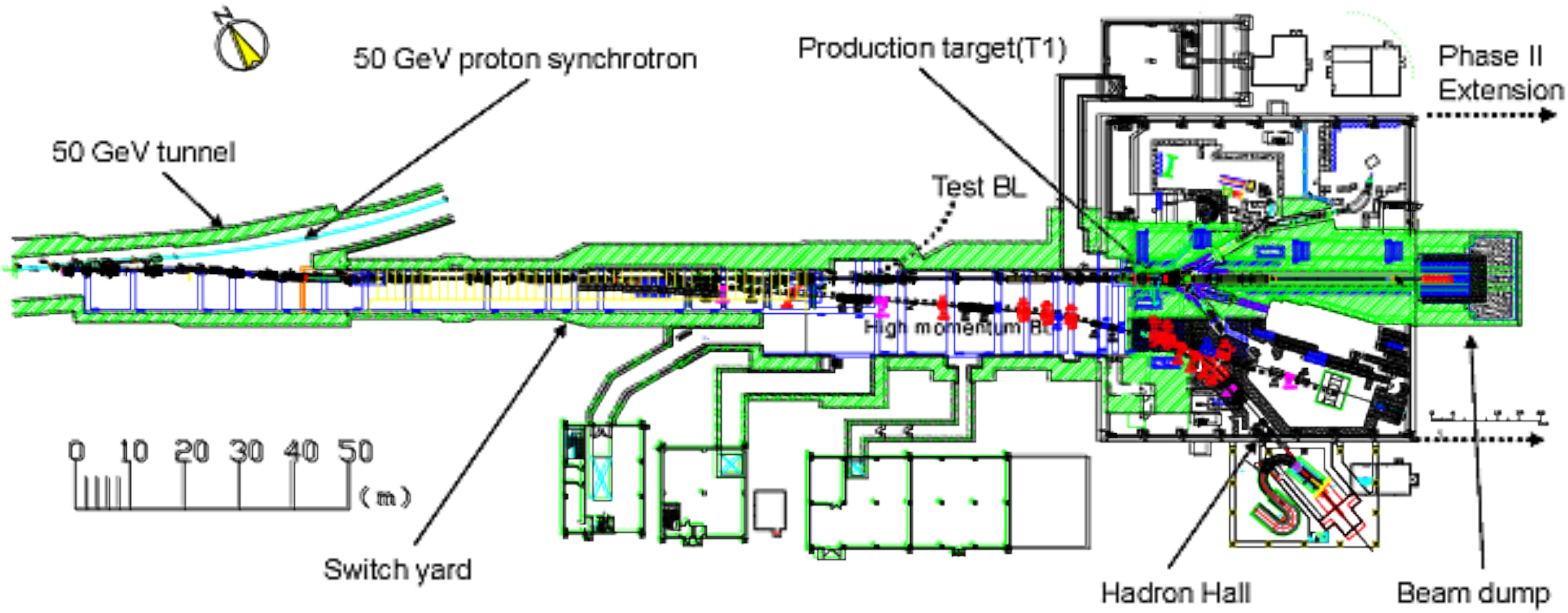
COMET beam-line at J-PARC HD



- Hadron Experimental Facility is currently under modification to have more beam lines; High-p beam line & the COMET beam line.

- Realized by putting a Lambertson magnet and extending the experimental hall.

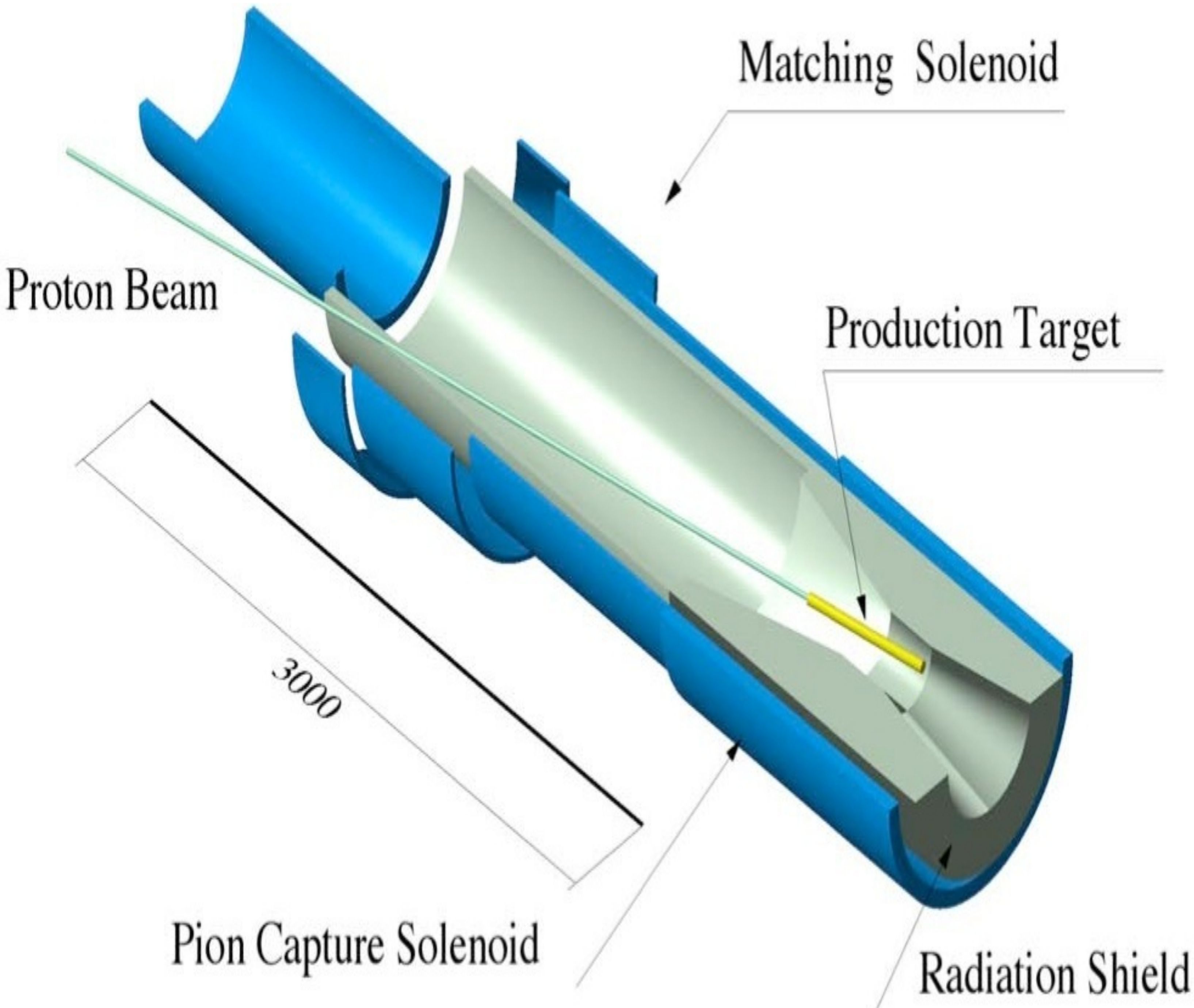
COMET beam-line at J-PARC HD



- Hadron Experimental Facility is currently under modification to have more beam lines; High-p beam line & the COMET beam line.

- Realized by putting a Lambertson magnet and extending the experimental hall.

② High efficiency π-capture system



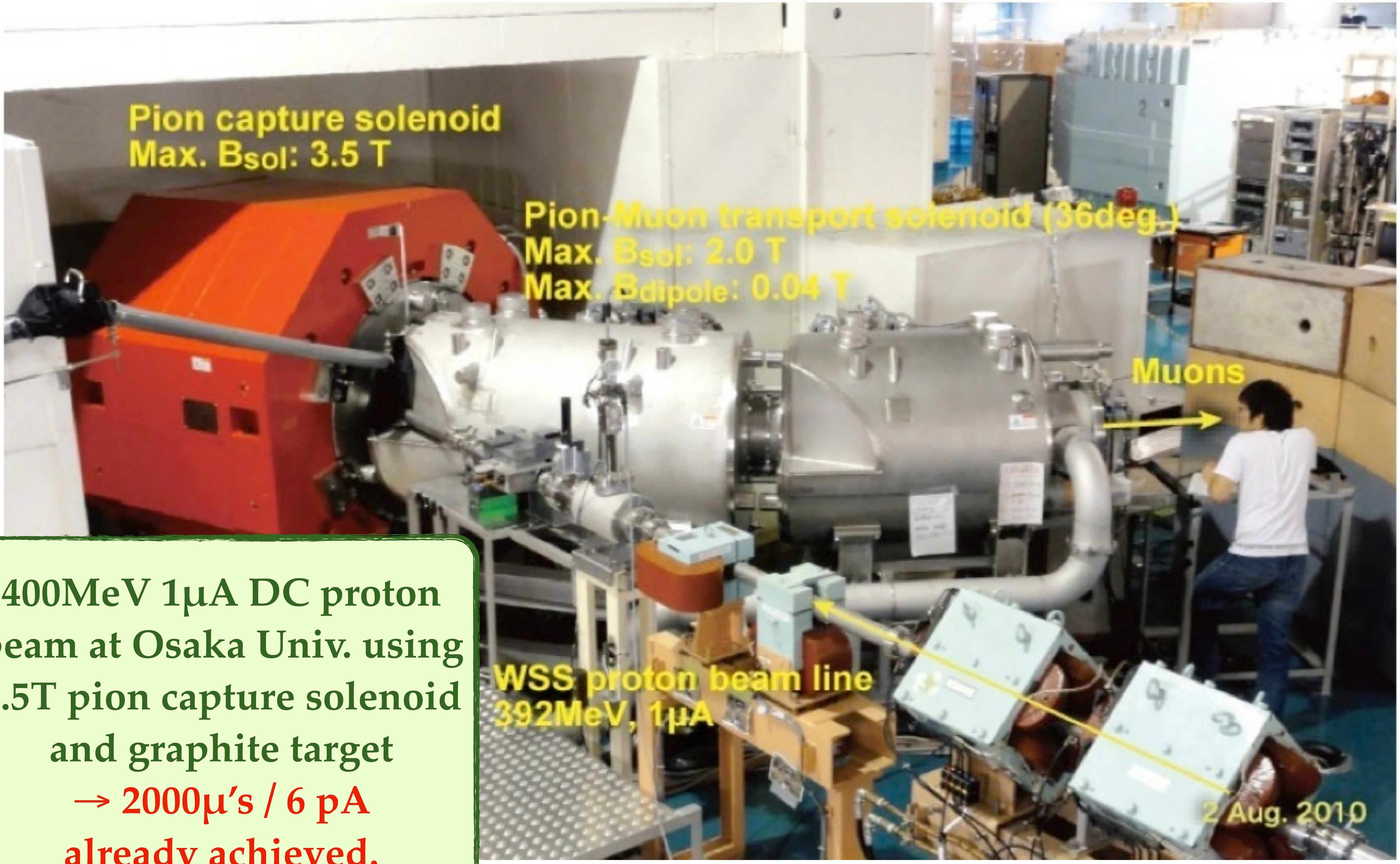
- Large muon yield by Large Solid Angle
  - Powerful Solenoid
  - Surround p target

$$P_T(\mathrm{GeV}/c) = 0.3 \times B(\mathrm{T}) \times \left[\frac{R(m)}{2}\right]$$

B=5T, R=0.2 → P_T=150MeV/c

- Super-conducting solenoidal magnet
  - 5T
  - 30 cm thick W shield.
- Issue : Heat Load

Demonstration of high-eff. capture solenoid



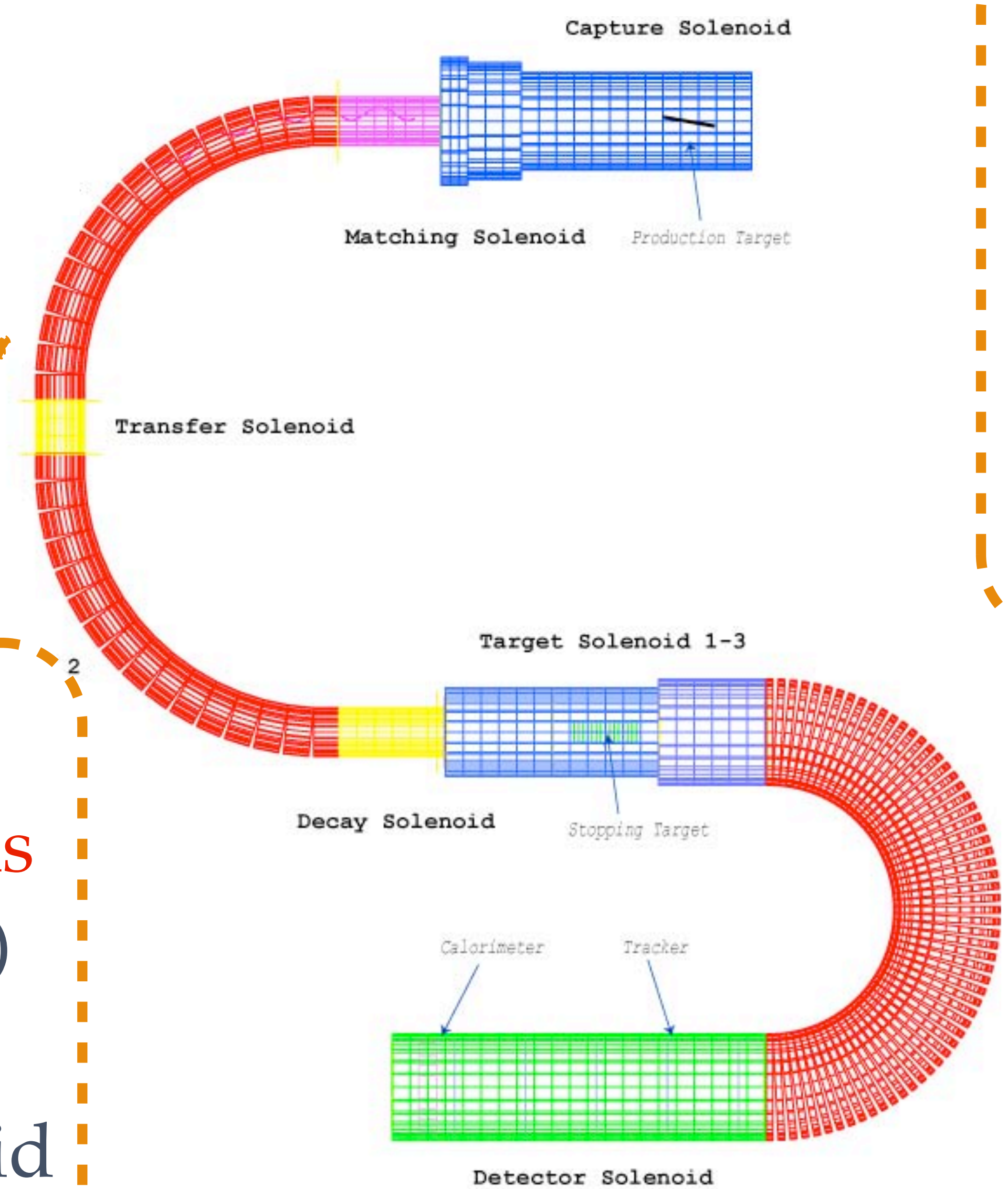
400MeV 1μA DC proton beam at Osaka Univ. using 3.5T pion capture solenoid and graphite target

→ 2000μ's / 6 pA already achieved.

③ "C-shaped" Long/Bending π/μ transport

- Utilize C-shape long/bending magnet to reject background particles.

B_{max}=3.5T



Select high-p **e**$^-$ (& reject low-p **BGs.**) using **C-shaped "transport"** solenoid

Select low-p muons (& reject high-p μ) using **C-shaped "transport"** solenoid

B_{max}=1T

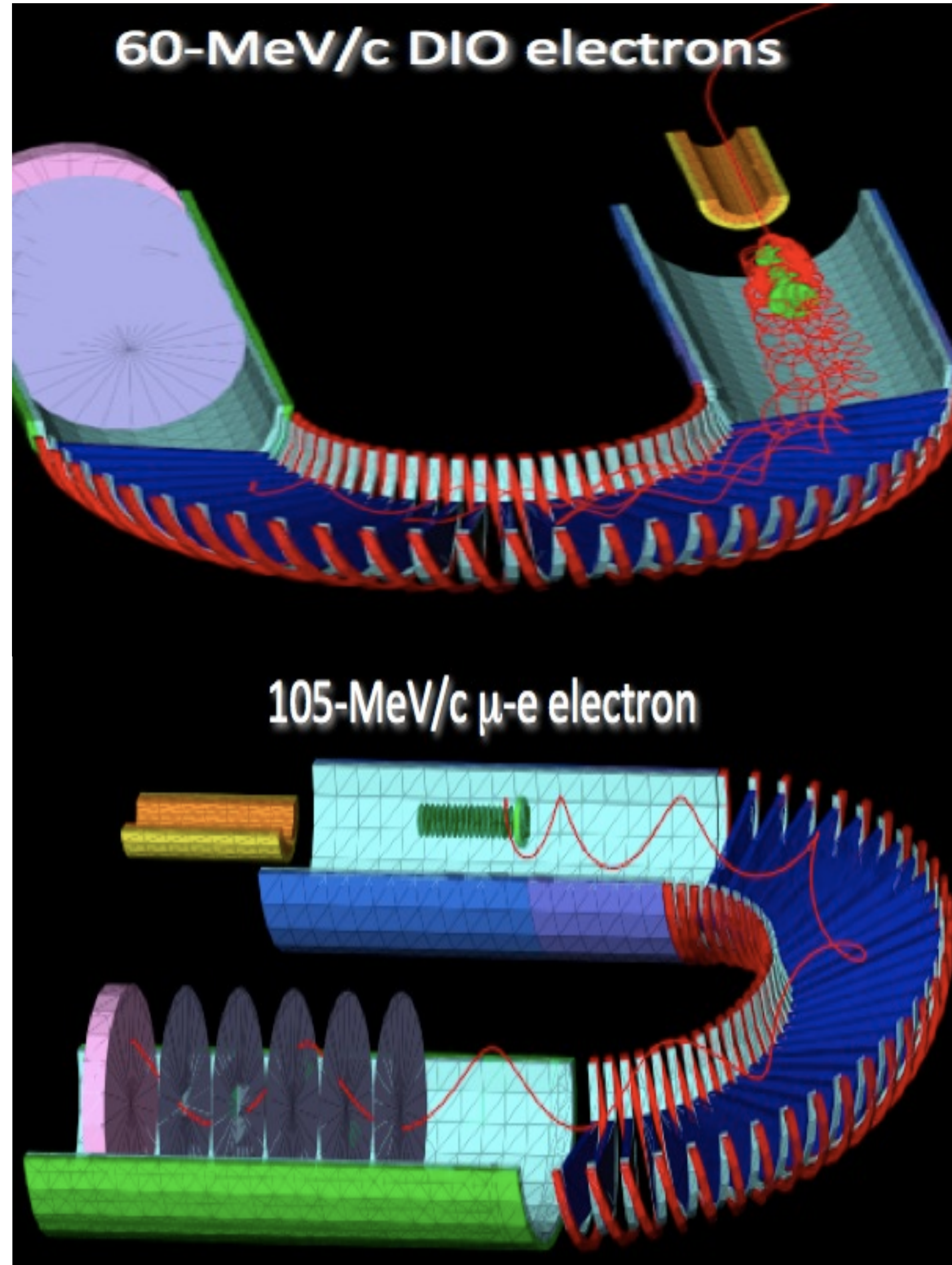
Secondary-bending for detector system

- Torus drift for rejecting low energy DIO electrons.

$$D(m) = \frac{1}{0.3 \times B(T)} \times \frac{s}{R} \times \frac{P_L^2 + \frac{1}{2}P_T^2}{P_L}$$

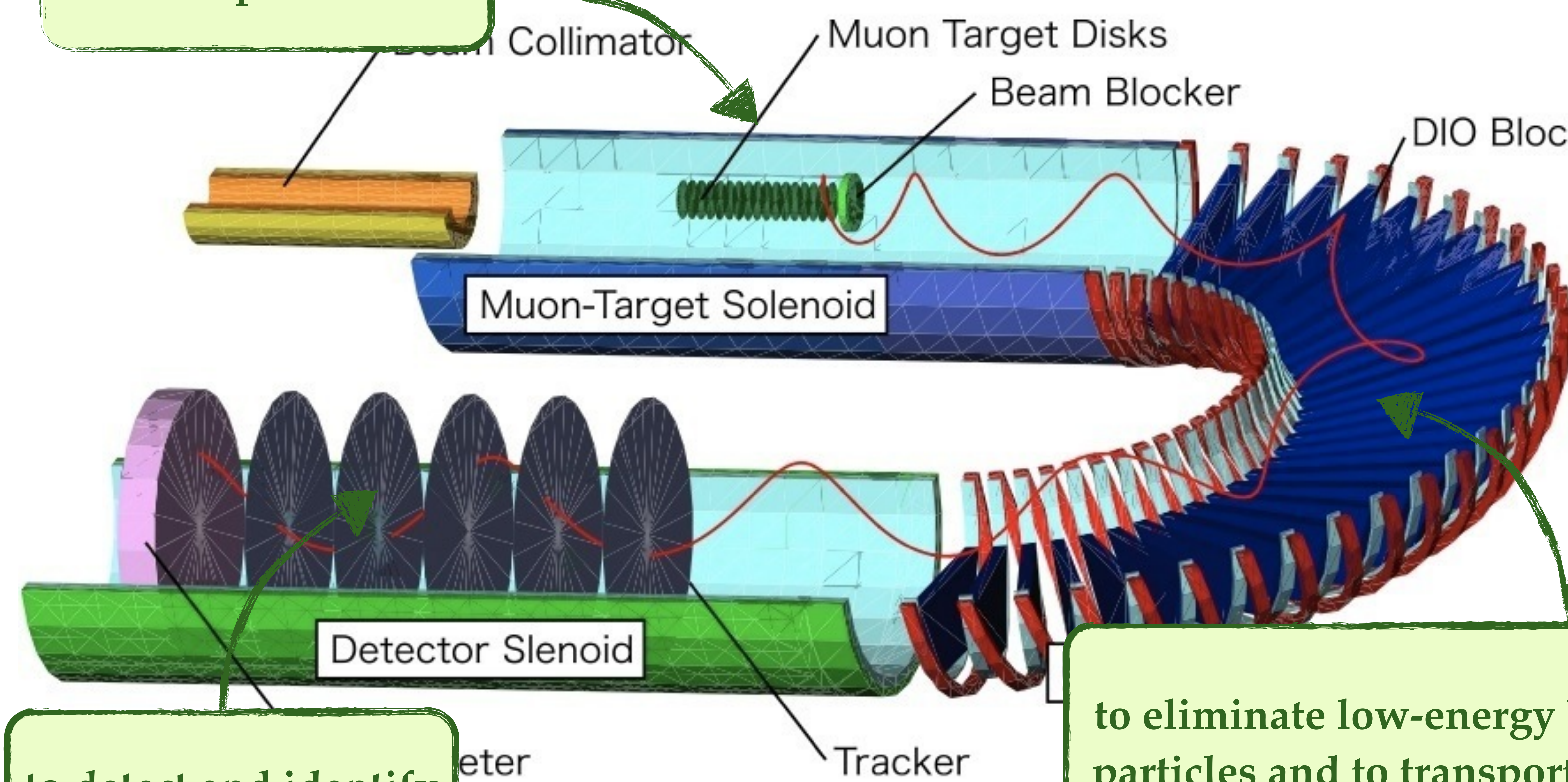
- Rejection Power : ~10^{-6}

- Good Acceptance for signal electrons (w/o including event selection and trigger acceptance)
  - ~20%



④ High resolution electron detector

to stop muons

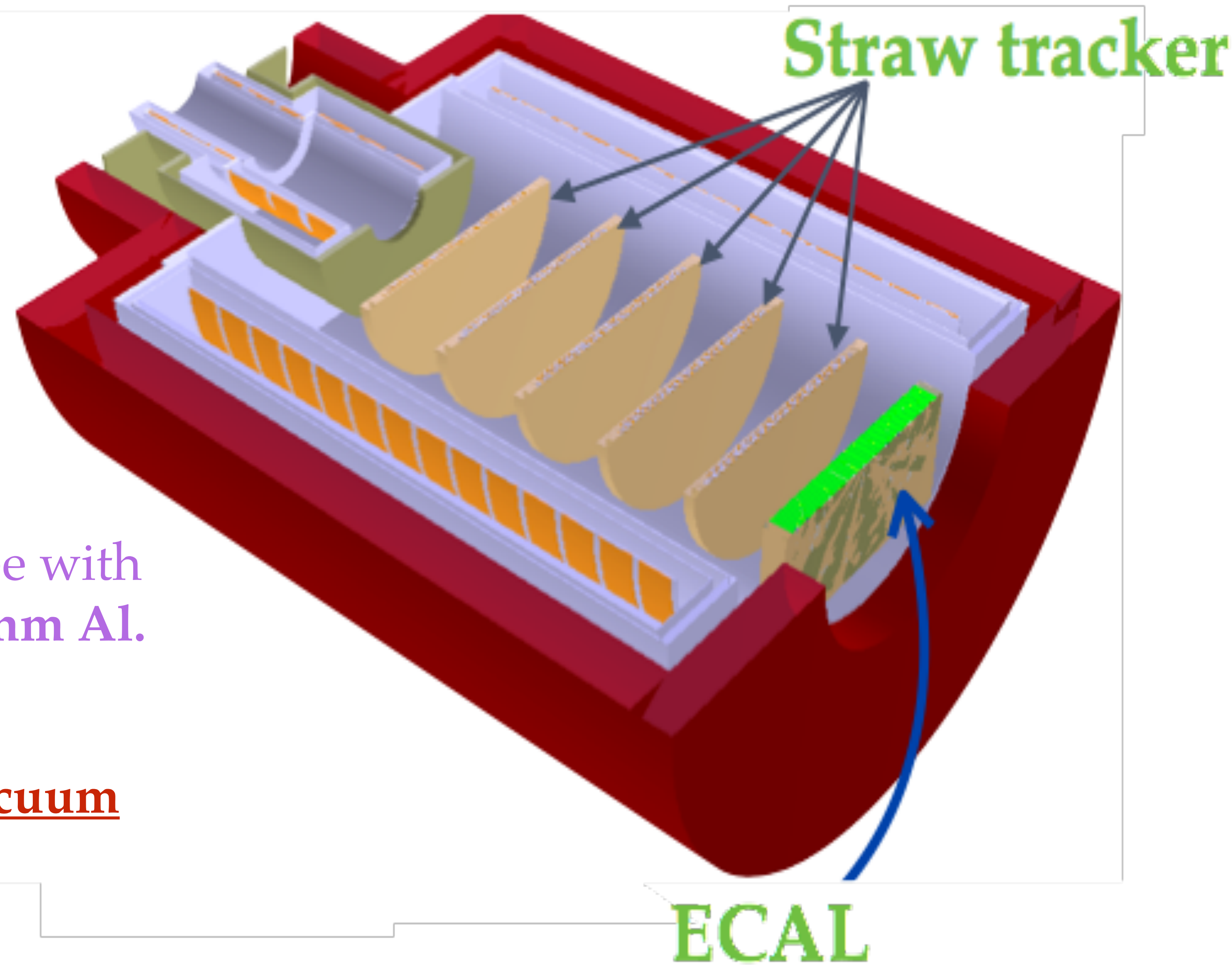


to detect and identify 100 MeV electrons

to eliminate low-energy beam particles and to transport only ~100 MeV electrons

Electron Detector (Tracker + Calorimeter)

- Rate ≲ 800 kHz
- **Straw-tube tracker to measure electron mom.**
  - 5 stations (super-layers)
  - $\sigma_P < 200$ keV/c
    - 4 planes/ super-layer
    - 5 mm diameter straw-tube with **12 μm thick Mylar & 70 nm Al.**
    - **different for phase-I**
  - **should be operational in vacuum**
  - <200μm spacial resolution



- **Crystal calorimeter for trigger (ECAL)**
  - LYSO crystal + APDs

COMET Collaboration

The COMET Collaboration

R. Akhmetshin[6,28], V. Anishchik[4], M. Aoki[29], R. B. Appleby[8,22], Y. Arimoto[15], Y. Bagaturia[33], Y. Ban[3], W. Bertsche[22], A. Bondar[6,28], S. Canfer[30], S. Chen[25], Y. E. Cheung[25], B. Chiladze[32], D. Clarke[30], M. Danilov[13,23], P. D. Dauncey[11], J. David[20], W. Da Silva[20], C. Densham[30], G. Devidze[32], P. Dornan[11], A. Drutskoy[13,23], V. Duginov[14], A. Edmonds[35], L. Epshteyn[6,27], P. Evtoukhovich[14], G. Fedotovich[6,28], M. Finger[7], M. Finger Jr[7], Y. Fujii[2], Y. Fukao[15], J-F. Genat[20], M. Gersabeck[22], E. Gillies[11], D. Grigoriev[6,27,28], K. Gritsay[14], R. Han[1], K. Hasegawa[15], I. H. Hasim[29], O. Hayashi[29], M. I. Hossain[16], Z. A. Ibrahim[21], Y. Igarashi[15], F. Ignatov[6,28], M. Iio[15], M. Ikeno[15], K. Ishibashi[19], S. Ishimoto[15], T. Itahashi[29], S. Ito[29], T. Iwami[29], Y. Iwashita[17], X. S. Jiang[2], P. Jonsson[11], V. Kalinnikov[14], F. Kapusta[20], H. Katayama[29], K. Kawagoe[19], V. Kazanin[6,28], B. Khazin[§6,28], A. Khvedelidze[14], M. Koike[36], G. A. Kozlov[14], B. Krikler[11], A. Kulikov[14], E. Kulish[14], Y. Kuno[29], Y. Kuriyama[18], Y. Kurochkin[5], A. Kurup[11], B. Lagrange[11,18], M. Lancaster[35], H. B. Li[2], W. G. Li[2], A. Liparteliani[32], R. P. Litchfield[35], P. Loveridge[30], G. Macharashvili[14], Y. Makida[15], Y. Mao[3], O. Markin[13], Y. Matsumoto[29], T. Mibe[15], S. Mihara[15], F. Mohamad Idris[21], K. A. Mohamed Kamal Azmi[21], A. Moiseenko[14], Y. Mori[18], N. Mosulishvili[32], E. Motuk[35], Y. Nakai[19], T. Nakamoto[15], Y. Nakazawa[29], J. Nash[11], M. Nioradze[32], H. Nishiguchi[15], T. Numao[34], J. O'Dell[30], T. Ogitsu[15], K. Oishi[19], K. Okamoto[29], C. Omori[15], T. Ota[31], H. Owen[22], C. Parkes[22], J. Pasternak[11], C. Plostinar[30], V. Ponariadov[4], A. Popov[6,28], V. Rusinov[13,23], A. Ryzhenenkov[6,28], B. Sabirov[14], N. Saito[15], H. Sakamoto[29], P. Sarin[10], K. Sasaki[15], A. Sato[29], J. Sato[31], D. Shemyakin[6,28], N. Shigyo[19], D. Shoukavy[5], M. Slunecka[7], M. Sugano[15], Y. Takubo[15], M. Tanaka[15], C. V. Tao[26], E. Tarkovsky[13,23], Y. Tevzadze[32], N. D. Thong[29], V. Thuan[12], J. Tojo[19], M. Tomasek[9], M. Tomizawa[15], N. H. Tran[29], I. Trek[32], N. M. Truong[29], Z. Tsamalaidze[14], N. Tsverava[14], S. Tygier[22], T. Uchida[15], Y. Uchida[11], K. Ueno[15], S. Umasankar[10], E. Velicheva[14], A. Volkov[14], V. Vrba[9], W. A. T. Wan Abdullah[21], M. Warren[35], M. Wing[35], T. S. Wong[29], C. Wu[2,25], G. Xia[22], H. Yamaguchi[19], A. Yamamoto[15], M. Yamanaka[24], Y. Yang[19], H. Yoshida[29], M. Yoshida[15], Y. Yoshii[15], T. Yoshioka[19], Y. Yuan[2], Y. Yudin[6,28], J. Zhang[2], Y. Zhang[2]

- IBS, KAIST (Korea), CC-IN2P3(France) and Georgian Technical Univ. joined recently
- 179 collaborators (32 institutes, 13 countries), FTE ～30

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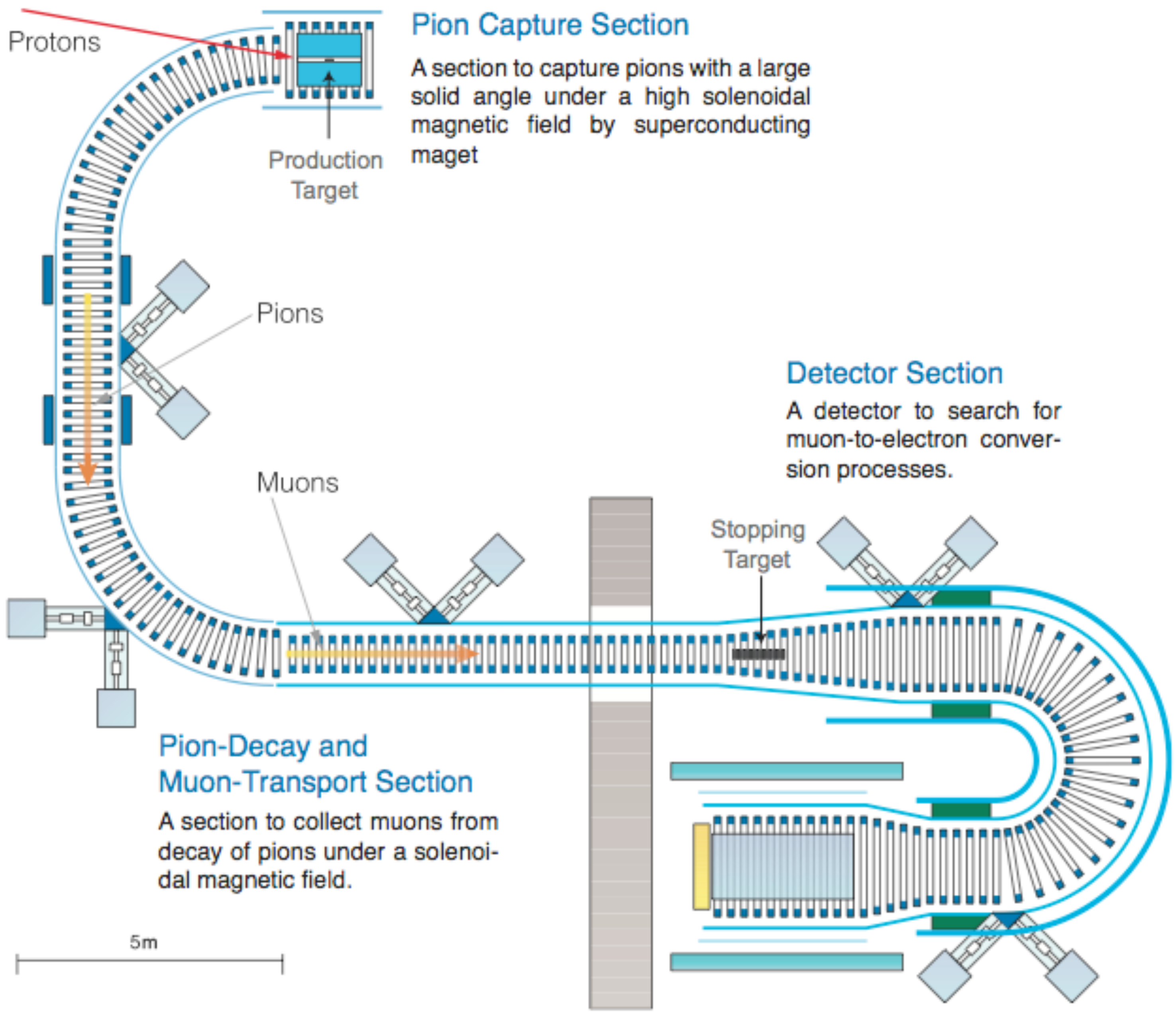
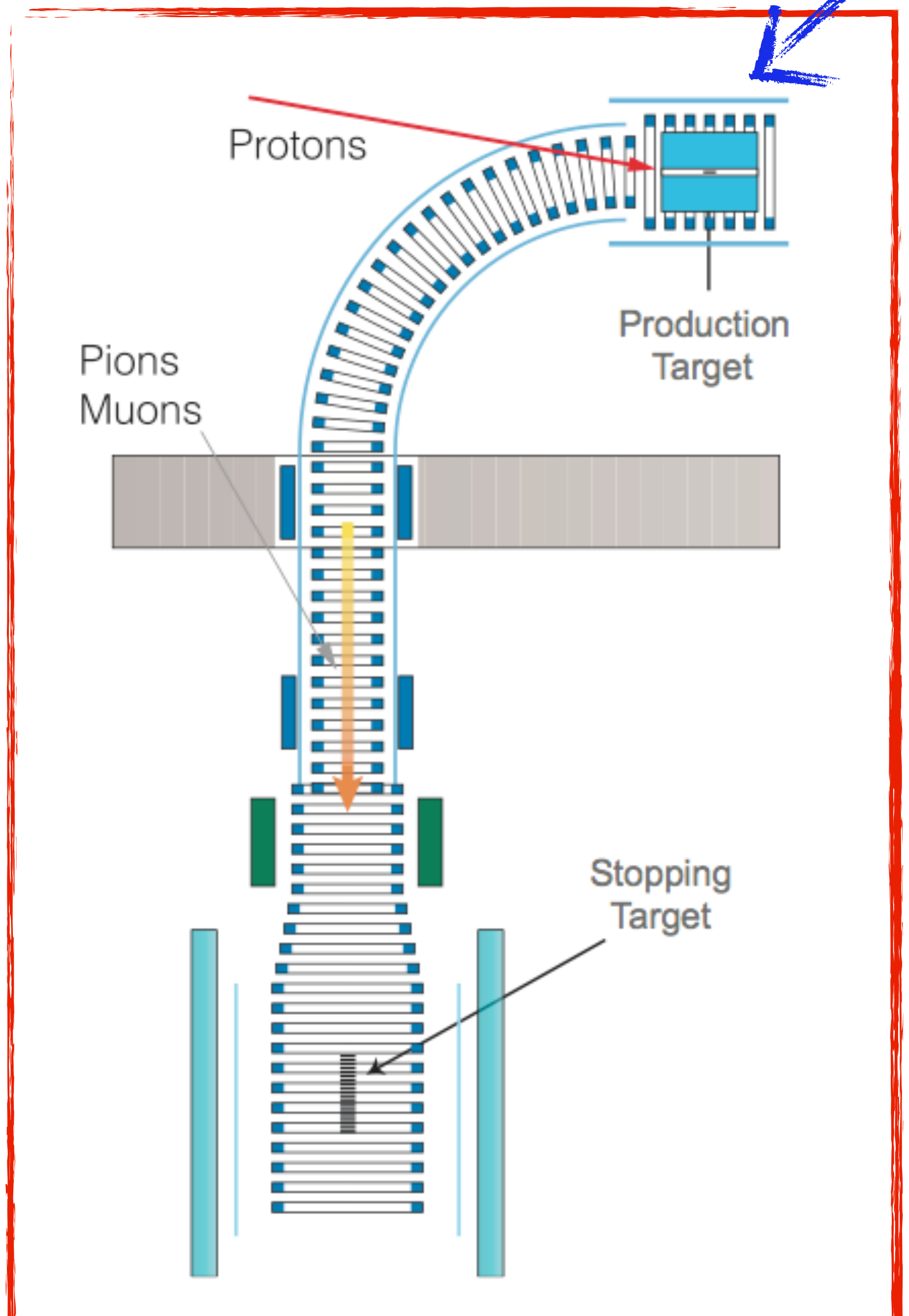
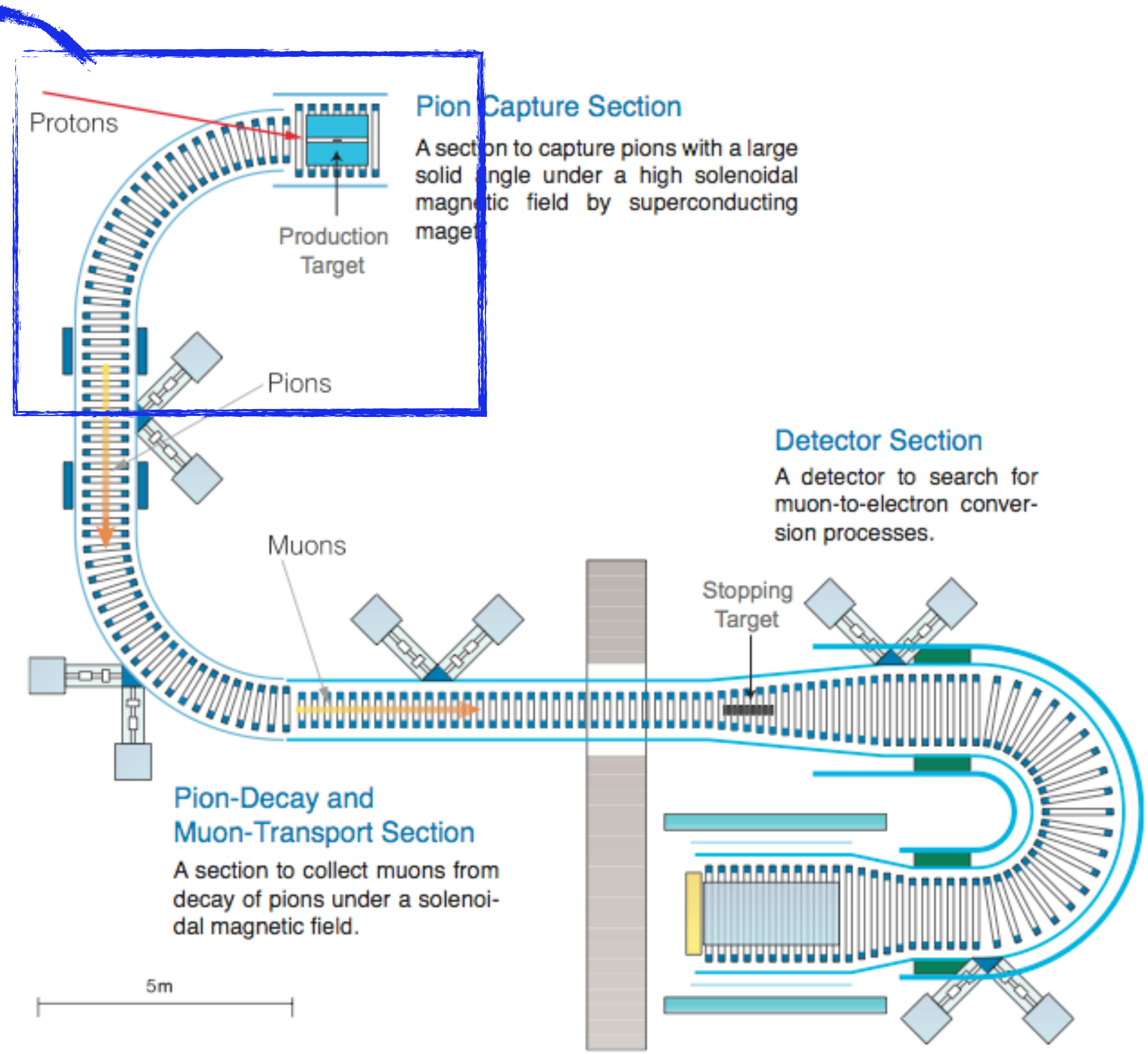
Staged approach



Staged approach



(phase-I)



full COMET (phase-II)

Goal of COMET phase-I

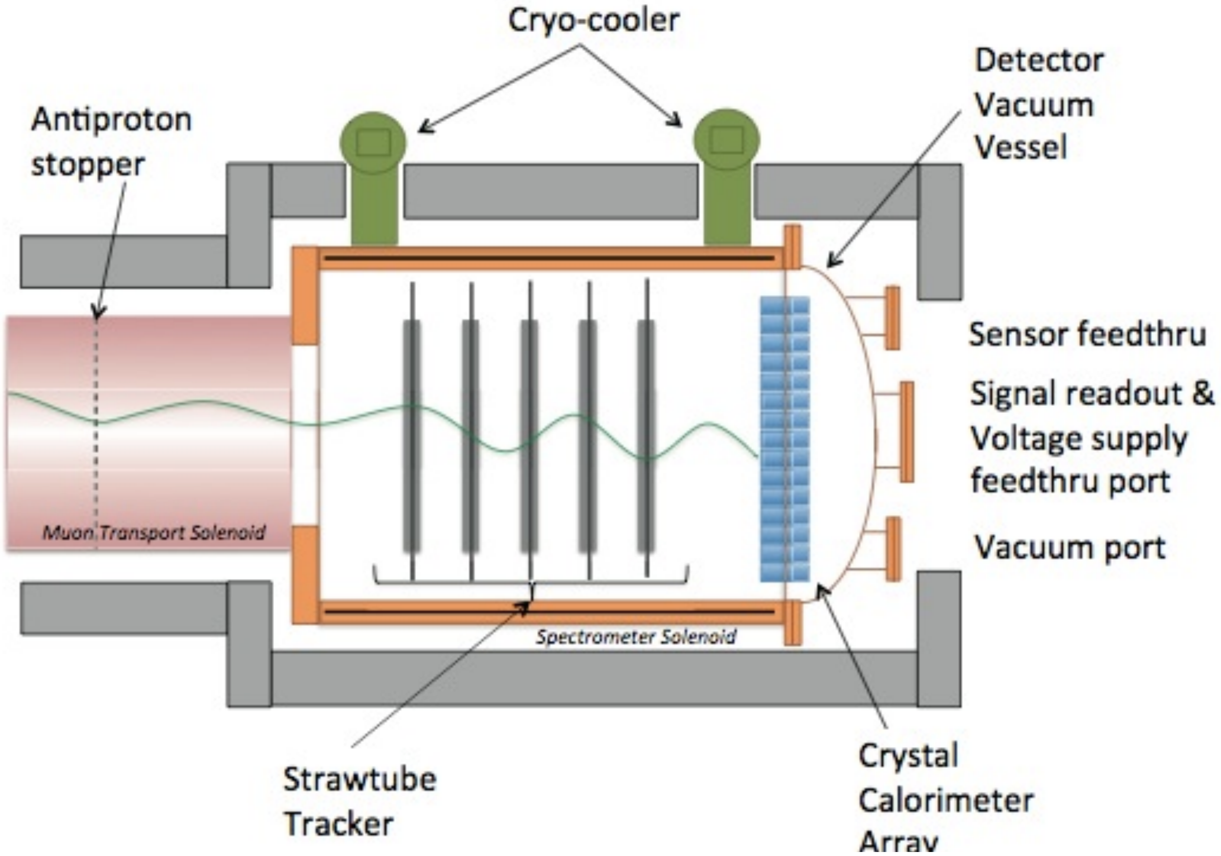
① Background Study for the full COMET (phase-II)

- direct measurement of potential background sources for the full COMET experiment by using the actual COMET beam line

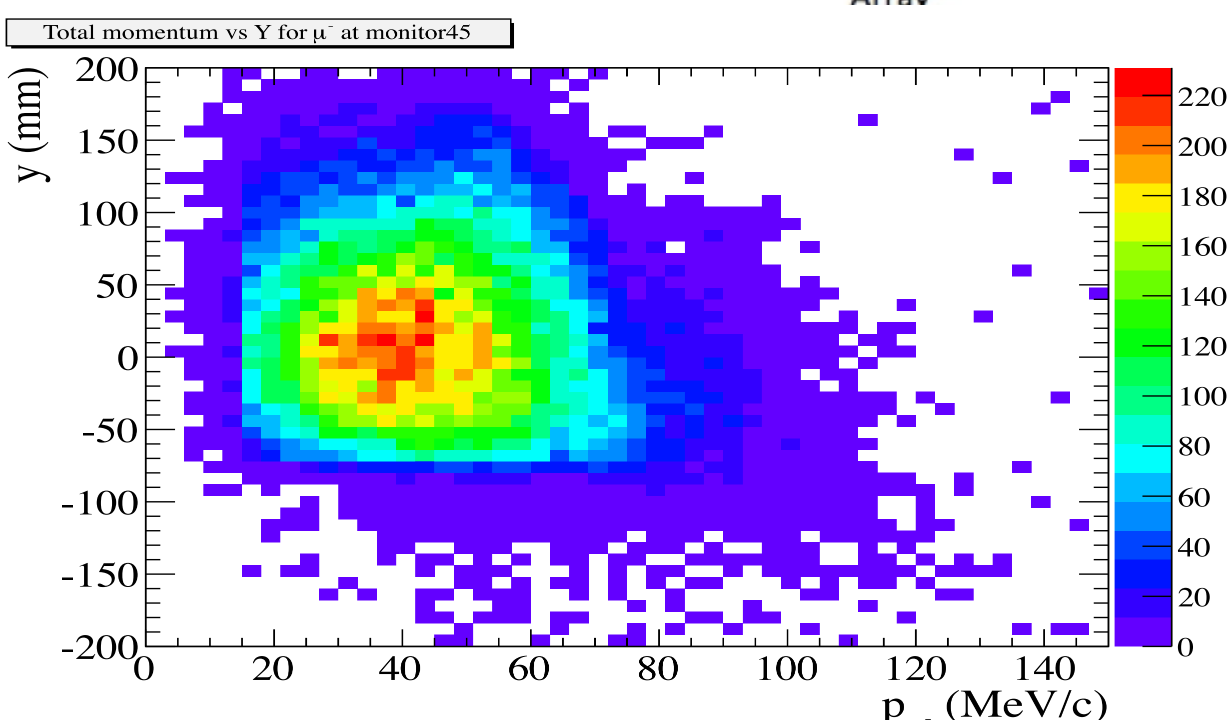
② Search for μ-e Conversion

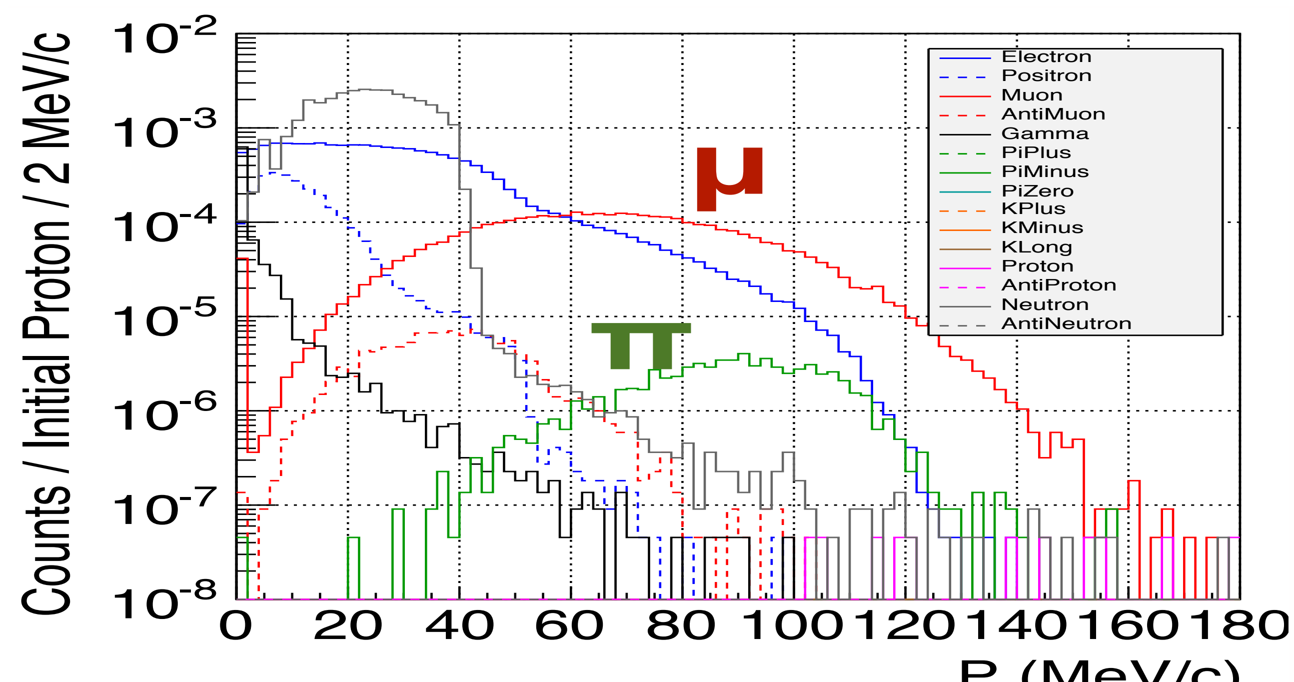
- a search for μ-e Conversion at the intermediate sensitivity which would be 100-times better than the present limit (SINDRUM-II)

Background measurement

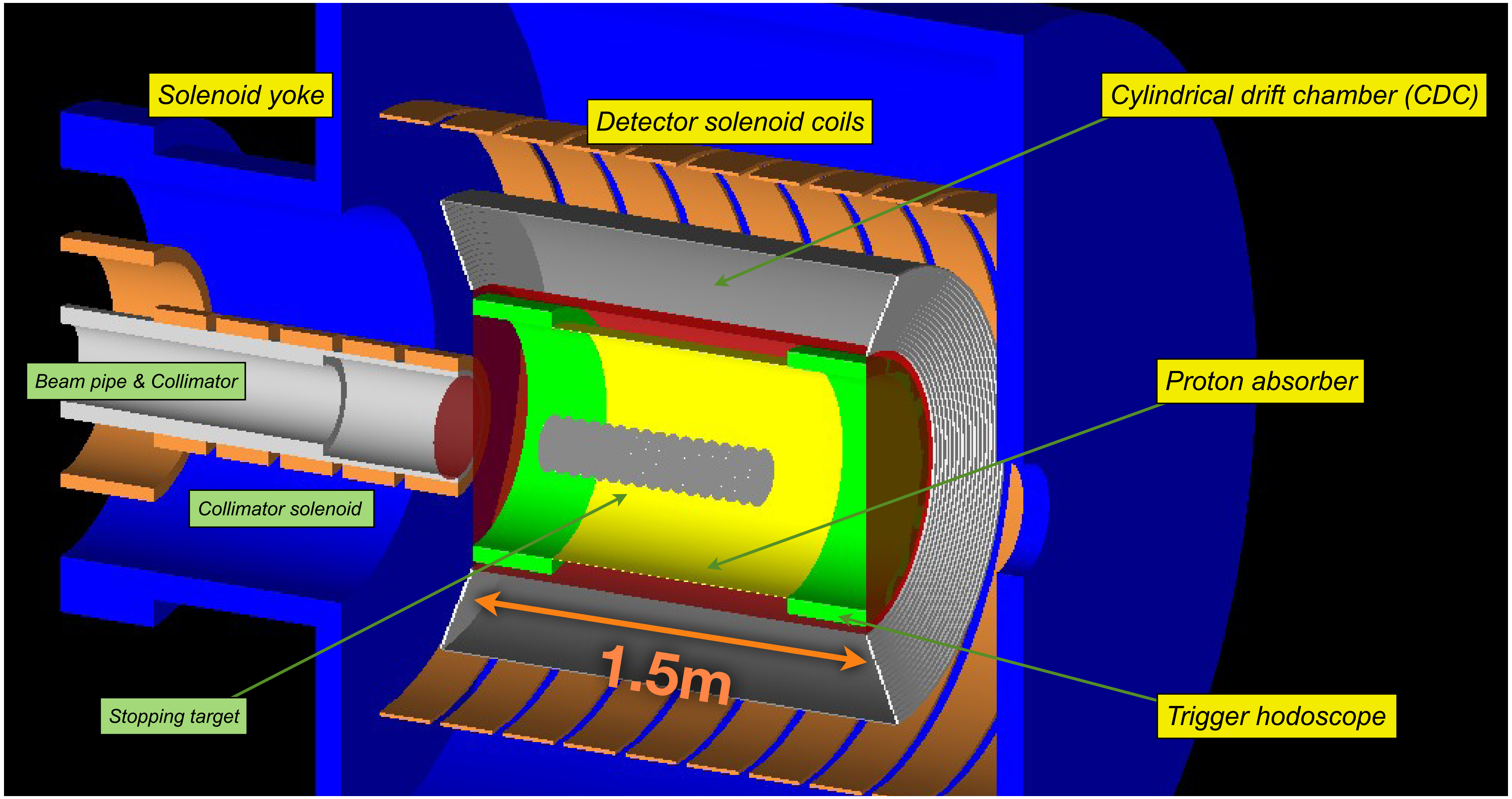


- **Measure almost all particles**
- **Same detector technology for phase-II**
  - SC spectrometer solenoid
  - Straw Tube planner Tracker
  - Crystal Calorimeter
- Particle ID with dE/dx and E/p





Search for $\mu^{-}N \rightarrow e^{-}N$ by the COMET phase-I



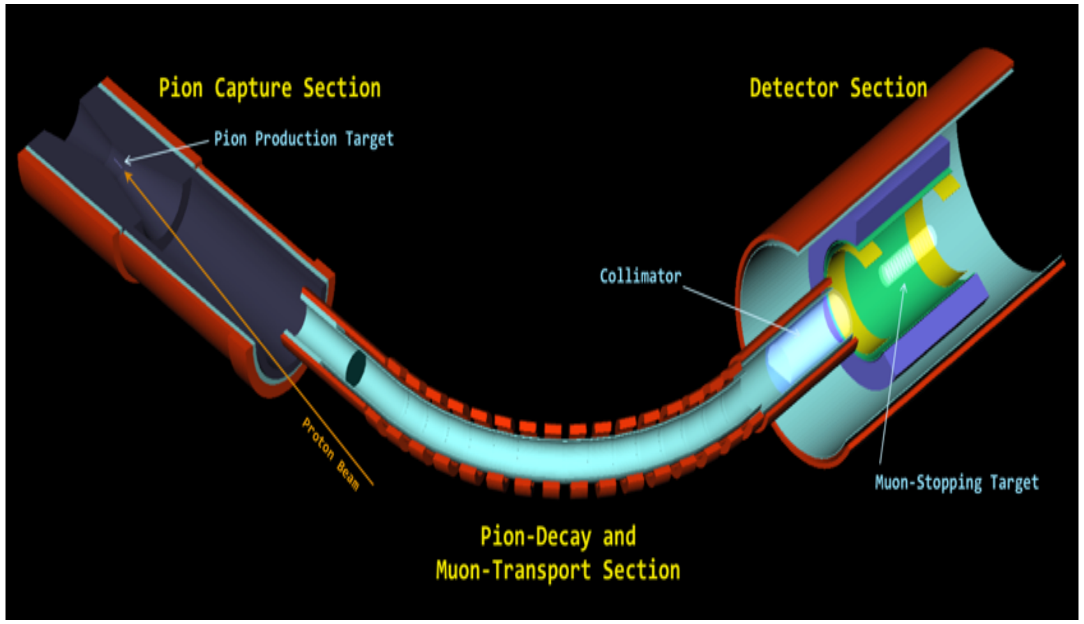
- Dedicated CDC-type tracker → a large bore CDC in a 1T solenoidal magnet
    - all stereo-wire base
    - helium-based low mass gas
- with a combination of trig. hodoscope (Cherenkov radiator + plastic scinti.)

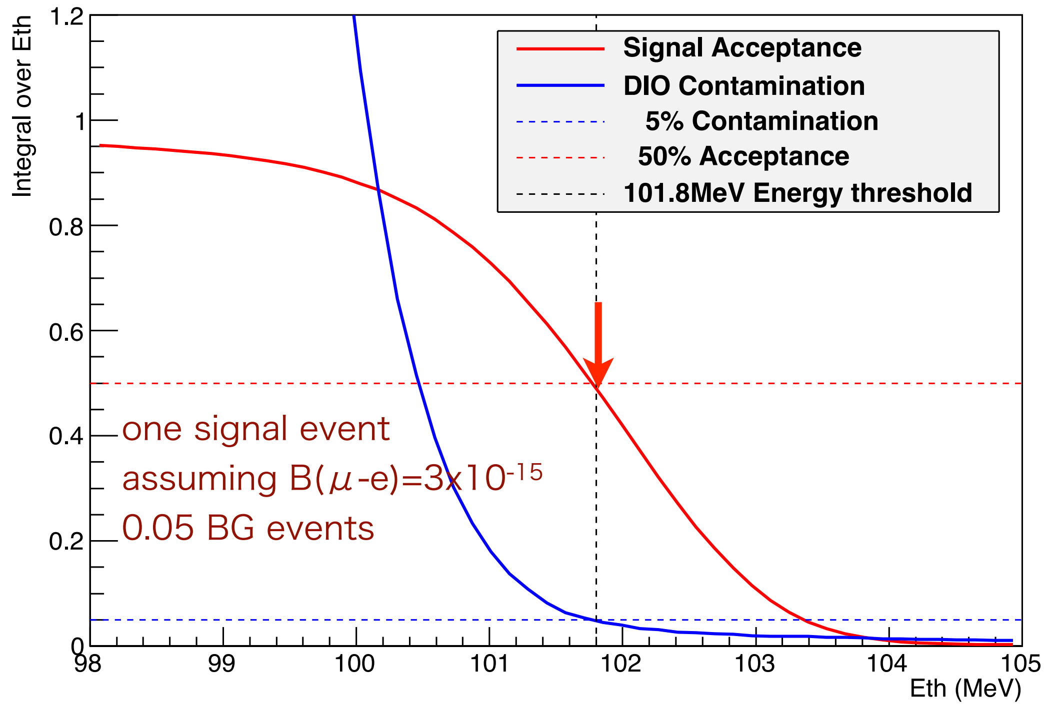
Physics Sensitivity for COMET phase-I

- 8GeV, 3.2kW proton beam is assumed
  - 2.5×10^{12} protons/sec
  - $<10^{-9}$ of extinction is supposed, at least
- 110 days (9.5×10^{6} sec) running time
- Expected single event sensitivity

$$\mathcal{B}(\mu^- + \mathrm{Al} \to \mathrm{e}^- + \mathrm{Al}) = \frac{1}{N_\mu^{stop} \cdot f_{cap} \cdot \mathcal{A}_{\mu-e}}$$

  - $\mathcal{B}(\mu^- + \mathrm{Al} \to \mathrm{e}^- + \mathrm{Al}) = 3.1\times10^{-15}$
- Upper limit at 90% C.L.
  - $\mathcal{B}(\mu^- + \mathrm{Al} \to \mathrm{e}^- + \mathrm{Al}) < 7.0\times10^{-15}$
  - *cf.* present limit $< 7\times10^{-13}$ (SINDRUM-II)



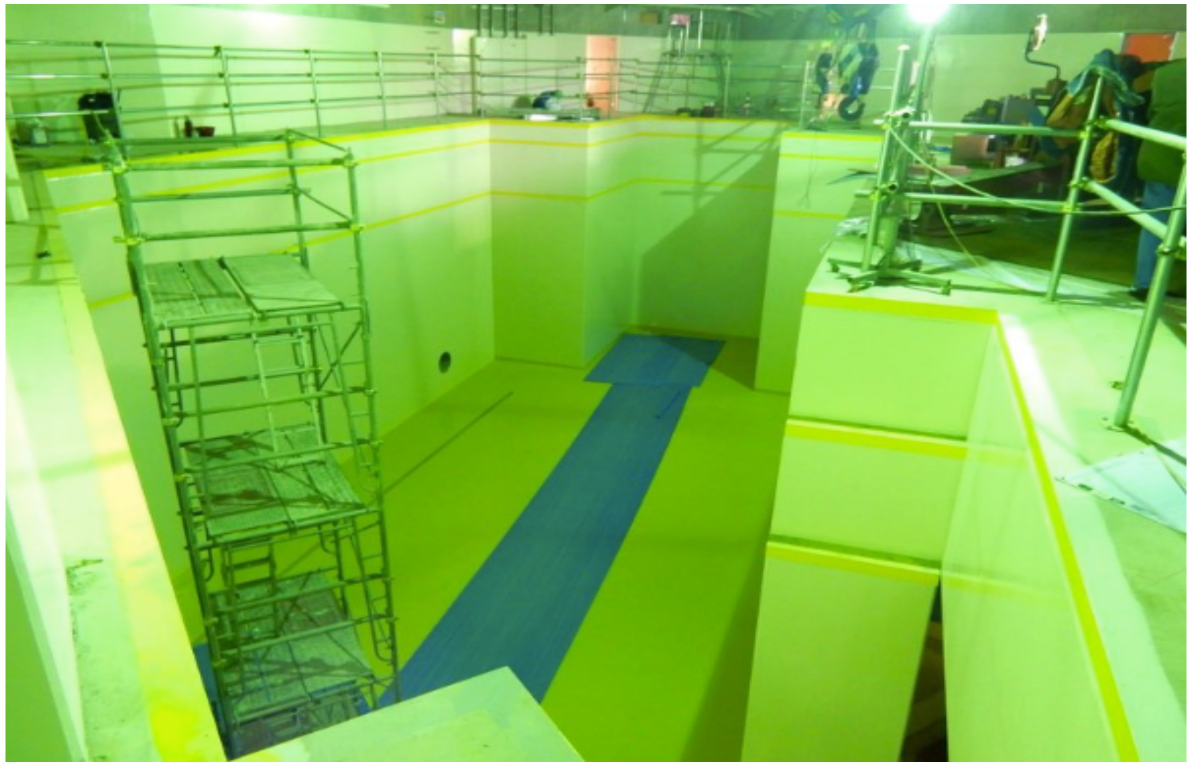


Facility Construction

- Construction of the COMET building has been already completed.
- Underground structure, beam line construction is ongoing.

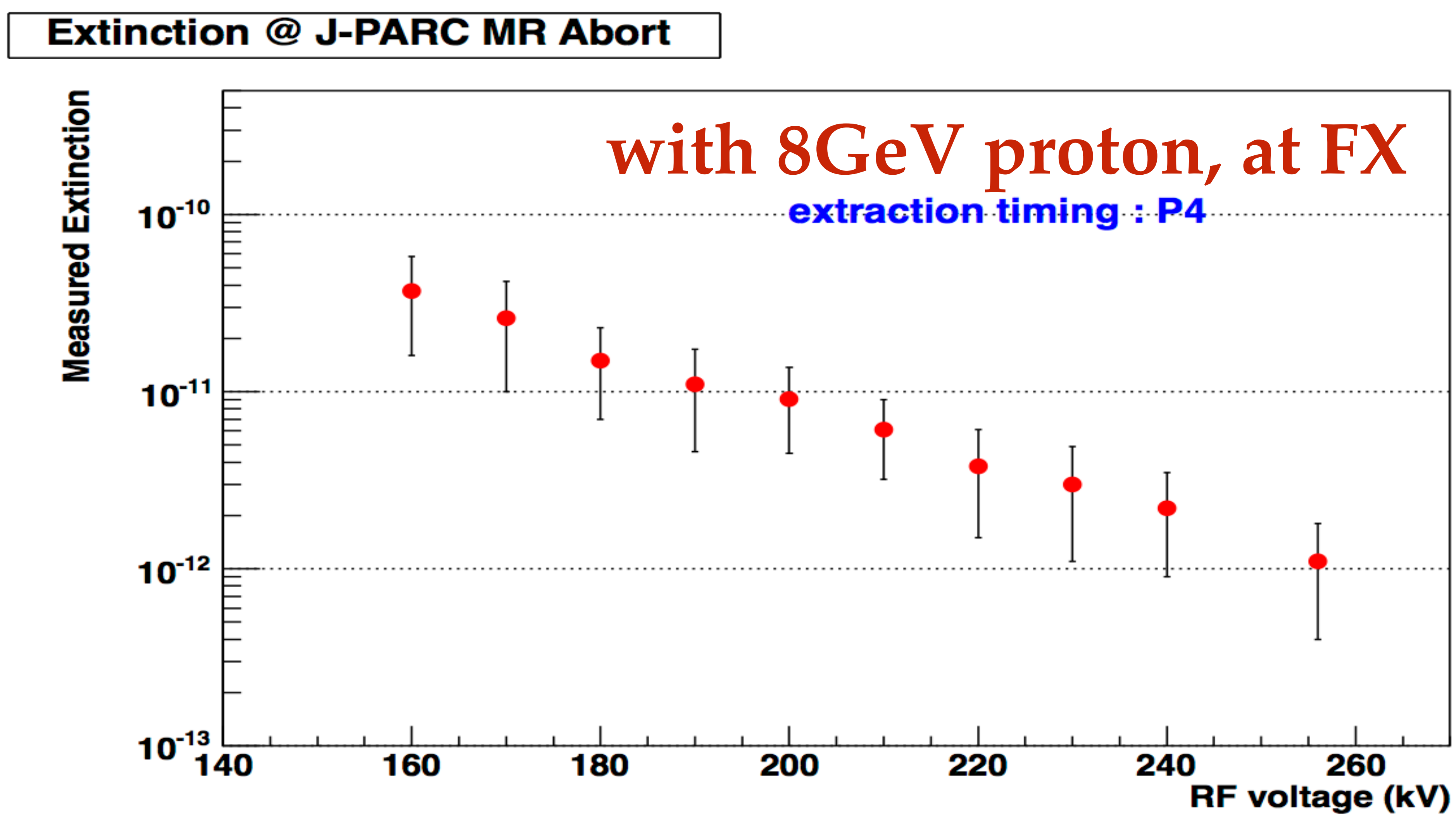
Beam line construction

- **Main part of pion/muon transport solenoid is already installed**



Accelerator-preparation status for COMET

- 8 GeV operation with 3.2kW has been already tested/tuned.
- Extinction studies already involved J-PARC accelerator group.
- Miss kick injection method; Special Thanks to J-PARC Accelerator group
  - Fail injection in purpose to make the completely empty bucket

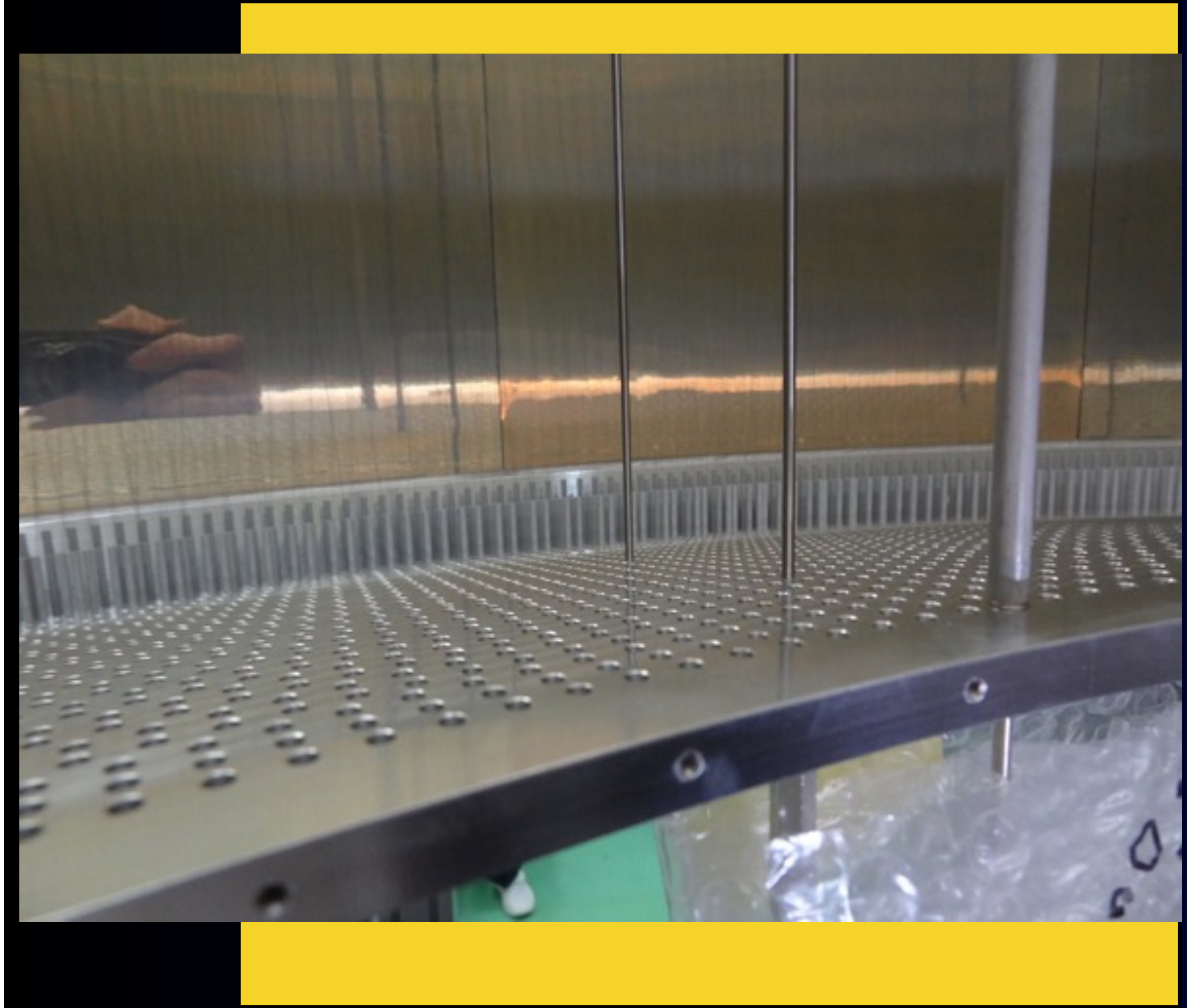


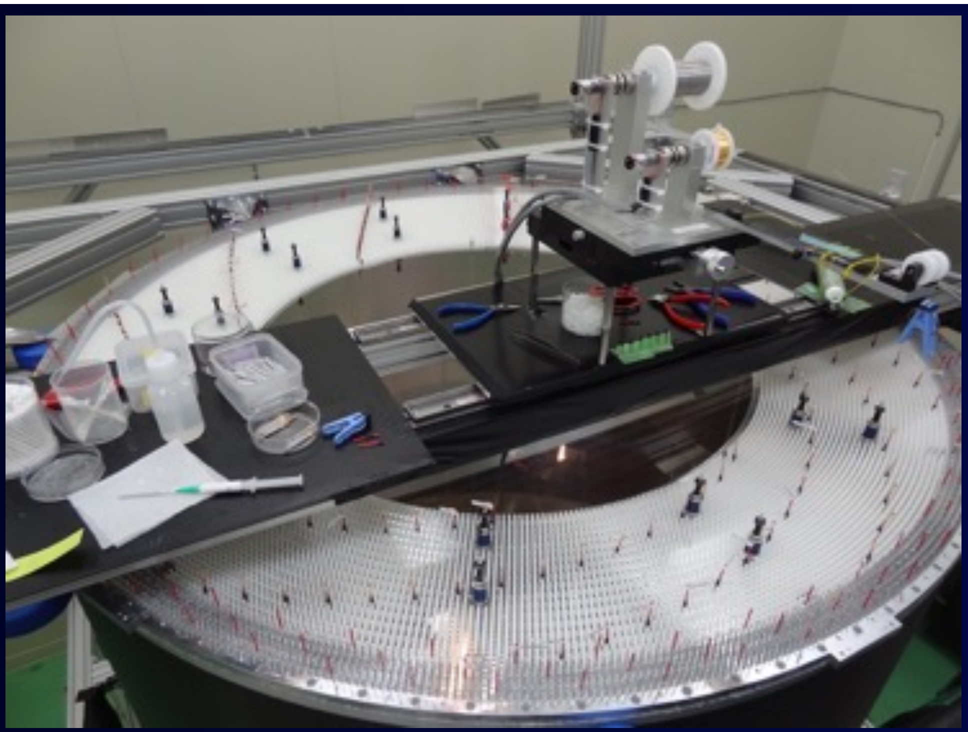
- Obtained best extinction = $O(10^{-12})$!!, Good enough for COMET !!

CDC

- General Structure is already completed, Wiring just started, Will complete in December

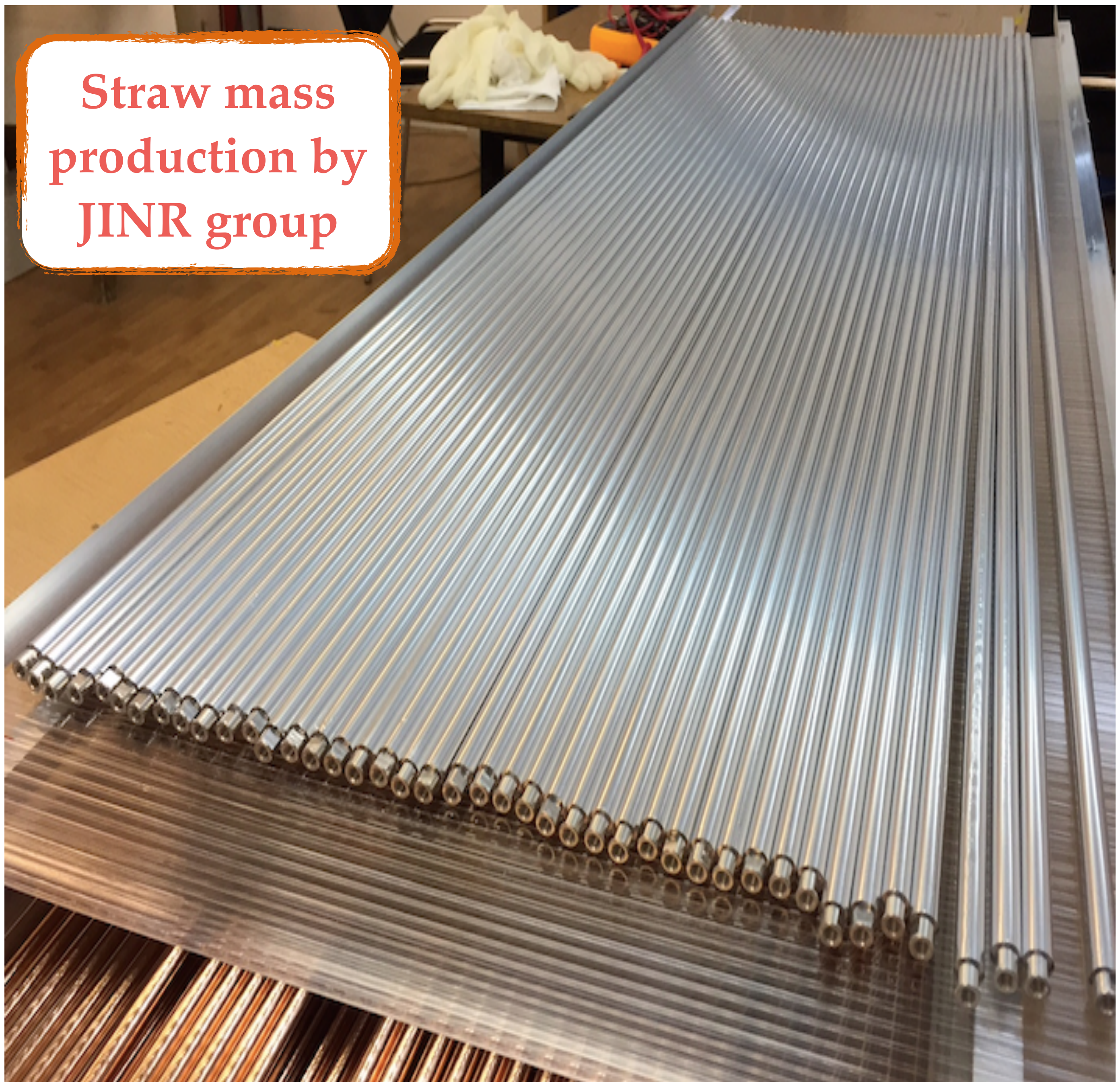
Wire stringing started in May at the Fuji hall.

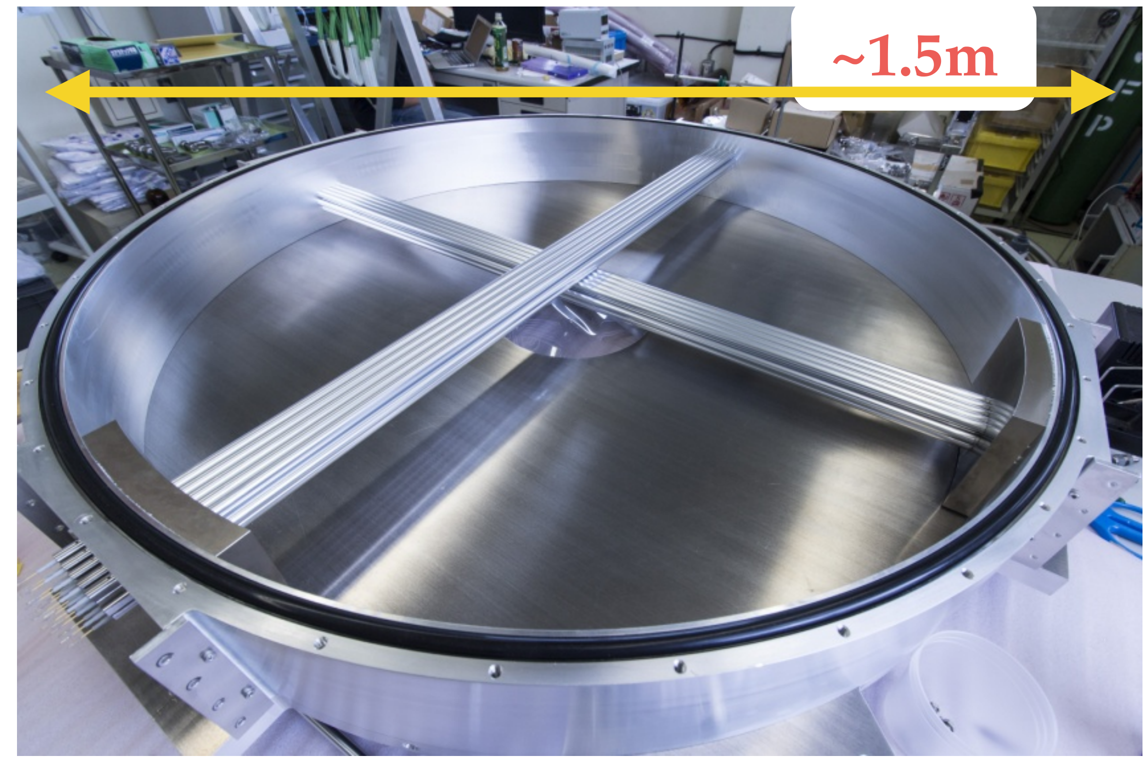


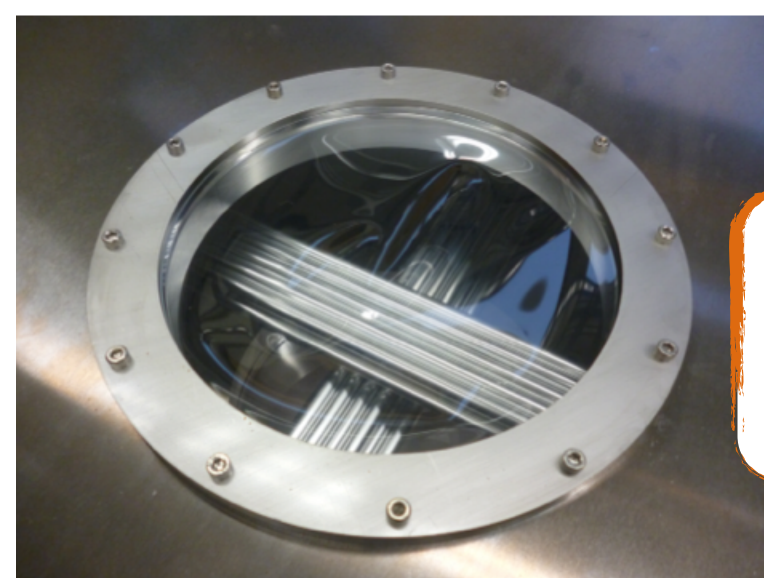


Straw Tracker

- Straw Mass Production is ongoing with a strong help from JINR group
- Tracker-stations assembly will be done in 2015-2016

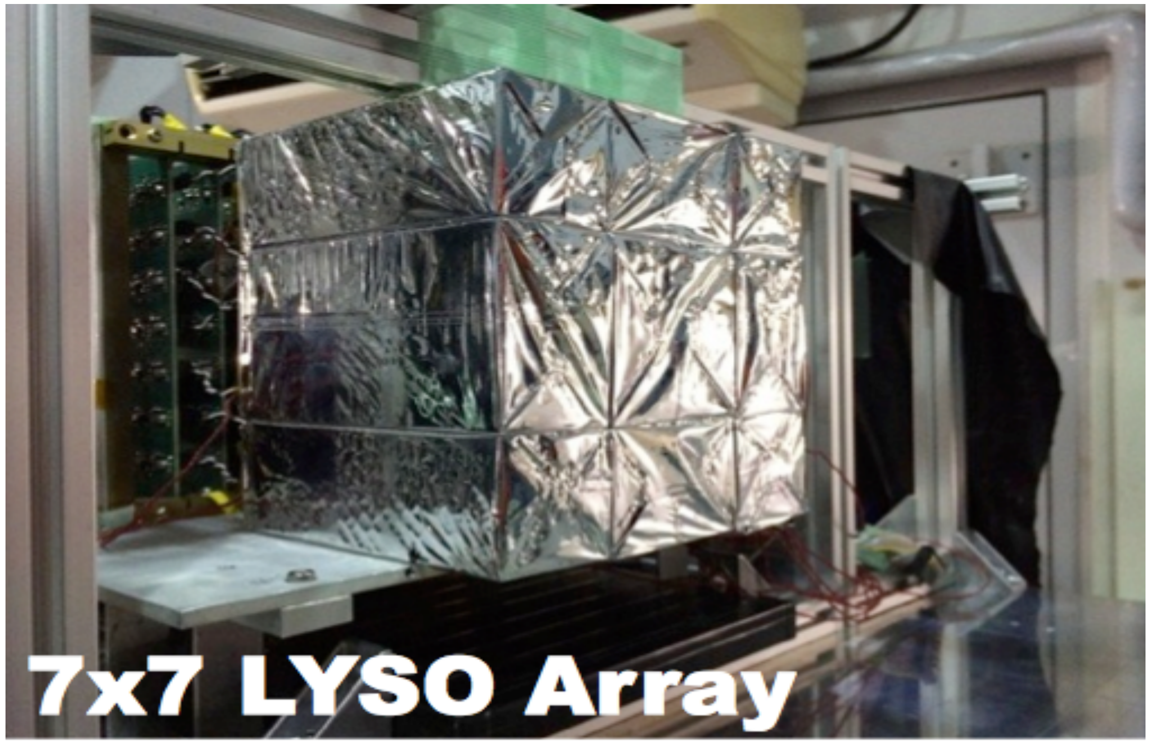


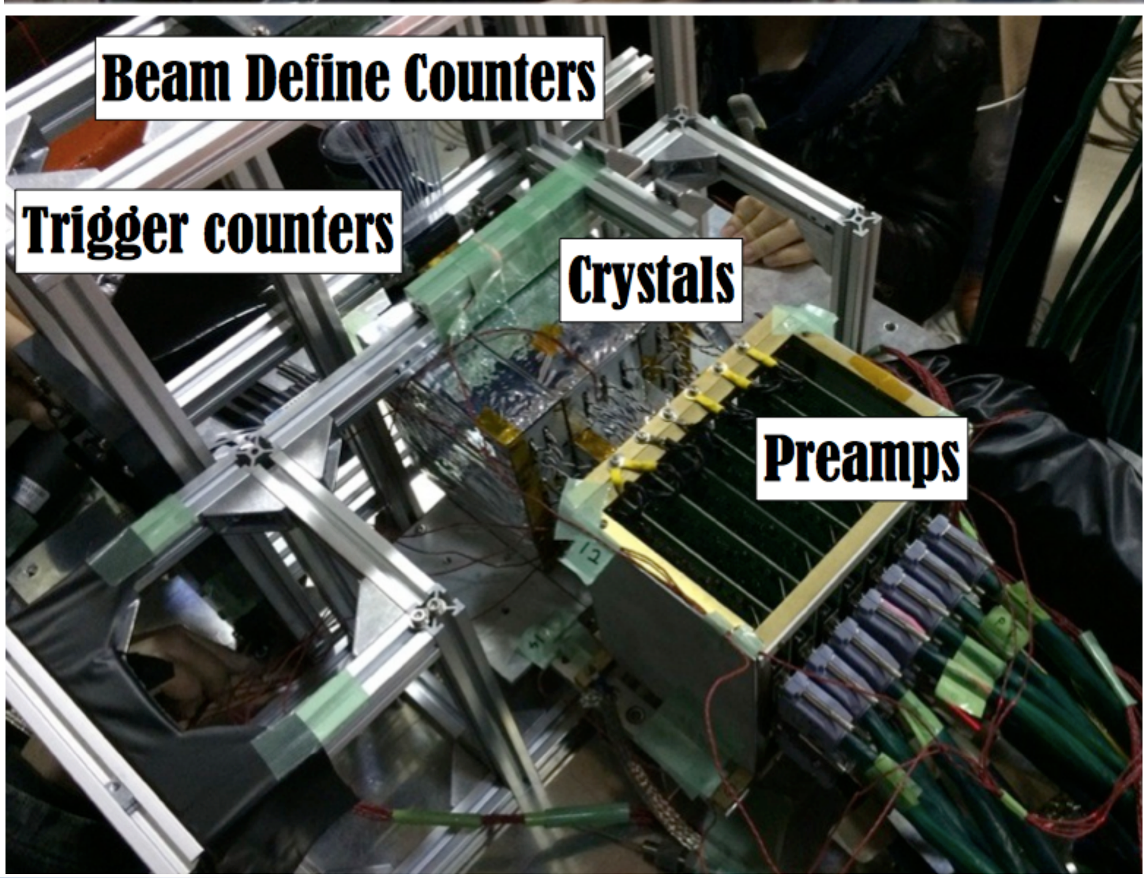




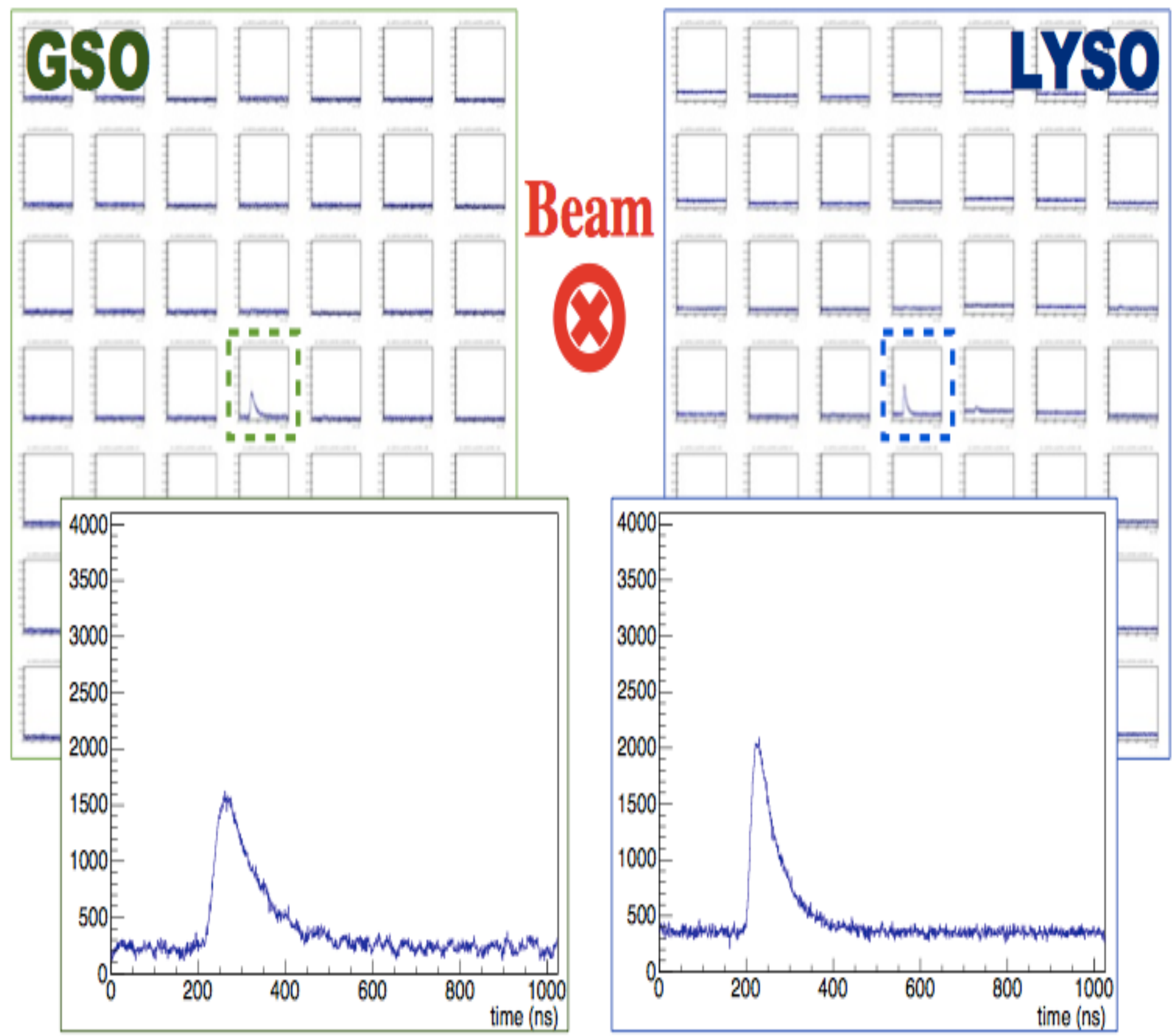
after closed and pumped

ECAL





Event Sample (105 MeV/c runs)



LYSO is clearer than GSO.

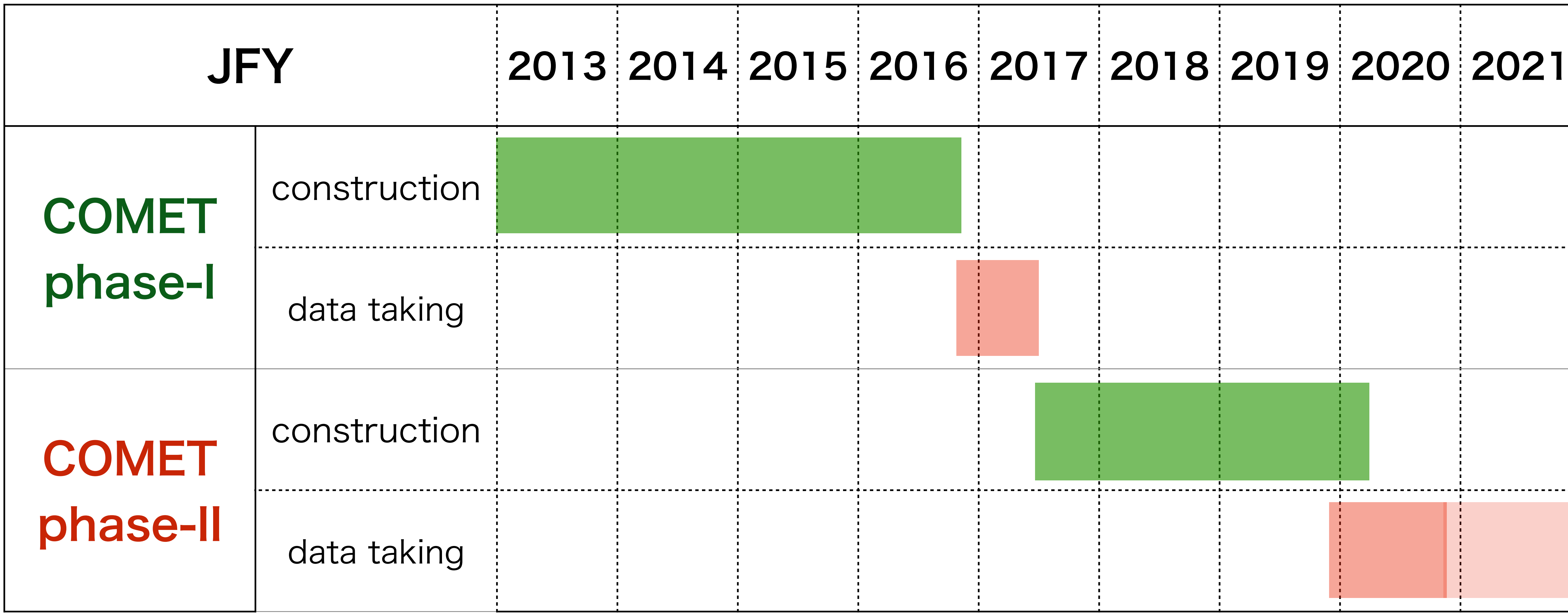
(Amp. gain 1/4 in LYSO runs to compensate light yield difference.)

Summary of COMET phase-I/II

	COMET-Phase-I	COMET-Phase-II
experiment starts (*)	in ~2016	in ~2019
beam power	3.2kW (8GeV,400nA)	56kW (8GeV,7μA)
running time	9.5 x 10^6 (sec)	2.0 x 10^7 (sec)
# of protons	2.4 x 10^(19)	8.5 x 10^(20)
# of muon stops	1.2 x 10^(16)	2.0 x 10^(18)
muon rate	5.8 x 10^9	1.0 x 10^(11)
# of muon stops / proton	0.00052	0.00052
# of BG	0.02	0.3
S.E.S.	3.1 x 10^(-15)	2.6 x 10^(-17)
U.L. (90%CL.)	7.0 x 10^(-15)	6.0 x 10^(-17)

* including the engineering run

General Schedule for Phase-I and Phase-II



COMET Phase-I
- **2016~**
- **S.E.S. ~ 3×10^{-15}**
- **for 9.5×10^{6} sec**
- **with 3.2kW proton beam**

COMET Phase-II
- **2019~**
- **S.E.S. ~ 3×10^{-17}**
- **for 2×10^{7} sec**
- **with 56kW proton beam**

Summary

- The COMET is a search experiment for $\mu^- N \rightarrow e^- N$ at J-PARC with an excellent sensitivity of $O(-17)$ which is four orders of magnitudes better than the present limit.
- The COMET experiment employs the staged approach
  - In Phase-I, 'beam measurement' and '$\mu^- N \rightarrow e^- N$ search with an intermediate sensitivity'.
  - Phase-II = 'Full COMET sensitivity'
- Construction for COMET Phase-I beam-line is fully supported by KEK/J-PARC as a first priority project for the J-PARC facility upgrade.
- We're ready for the COMET Experiment phase-I.

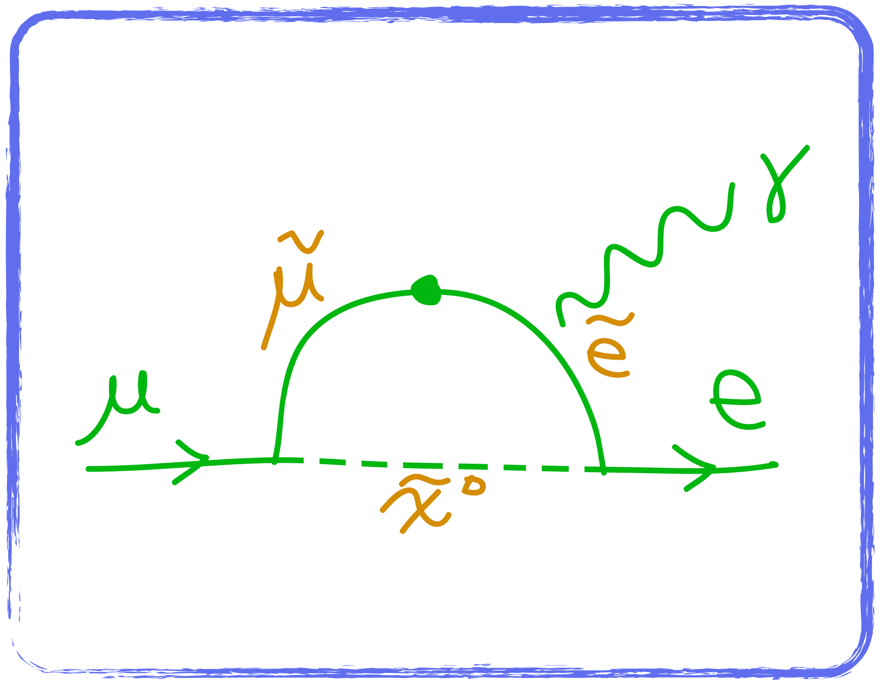
- Thank you !!!

appendices

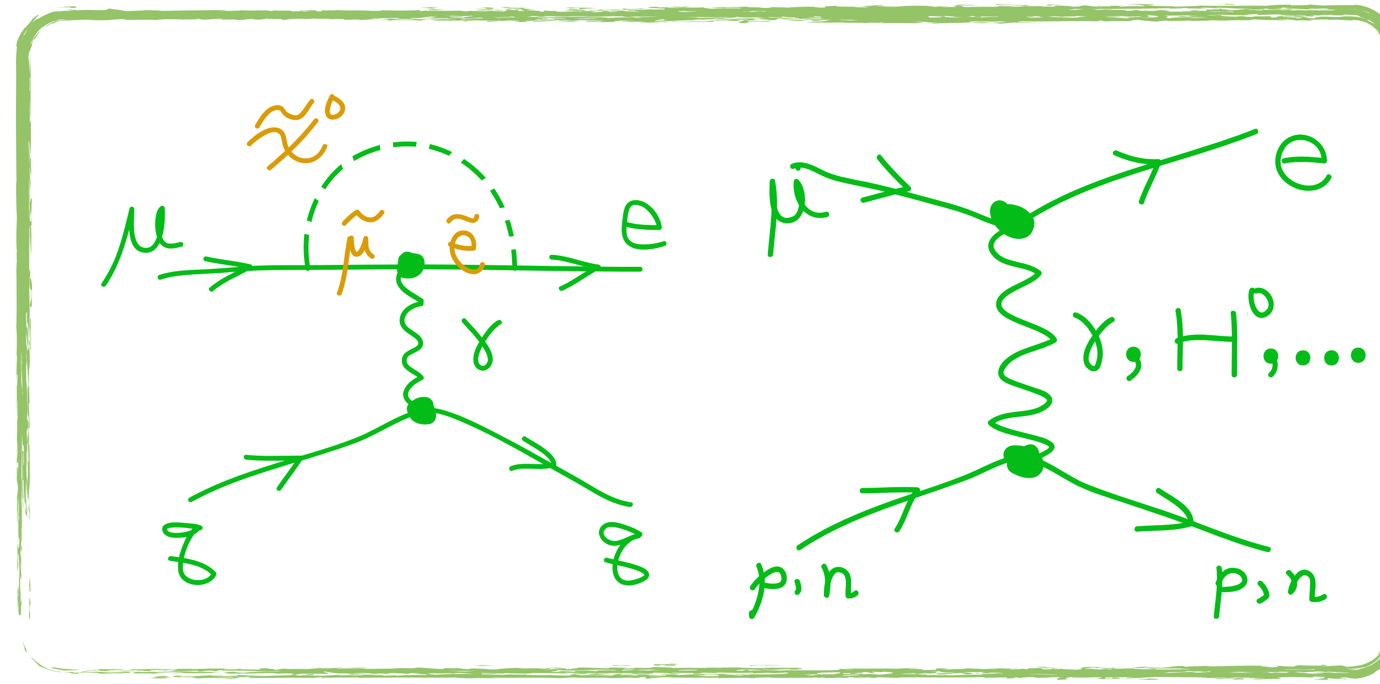
"$\mu \rightarrow e\gamma$" *vs.* "$\mu N \rightarrow eN$"

Physics
Point of view

- **Sensitivity for "photonic" and "non-photonic" processes is different.**



vs.



	$\mu \rightarrow e\gamma$	$\mu N \rightarrow eN$
photonic (*eg*. SUSY-base models, *etc*.)	**YES** (on-shell)	**YES** (off-shell)
non-photonic (*eg*. Extra-D, Little-Higgs, *etc*.)	**NO**	**YES !!**

***eg*. SUSY-based case, B($\mu \rightarrow e\gamma$)/B($\mu N \rightarrow eN$) ~ O(100) (depends on N)**

"$\mu \to e\gamma$" *vs.* "$\mu N \to eN$"

Experimental
Point of view

	$\mu \to e\gamma$	$\mu N \to eN$
Dominant B.G.	Accidental	Beam related
Challenge	Detector Performance	Beam Quality
Suitable Muon Source	DC Muon Beam	Pulsed Muon Beam
Beam Intensity	(almost) Limited	No Limitation

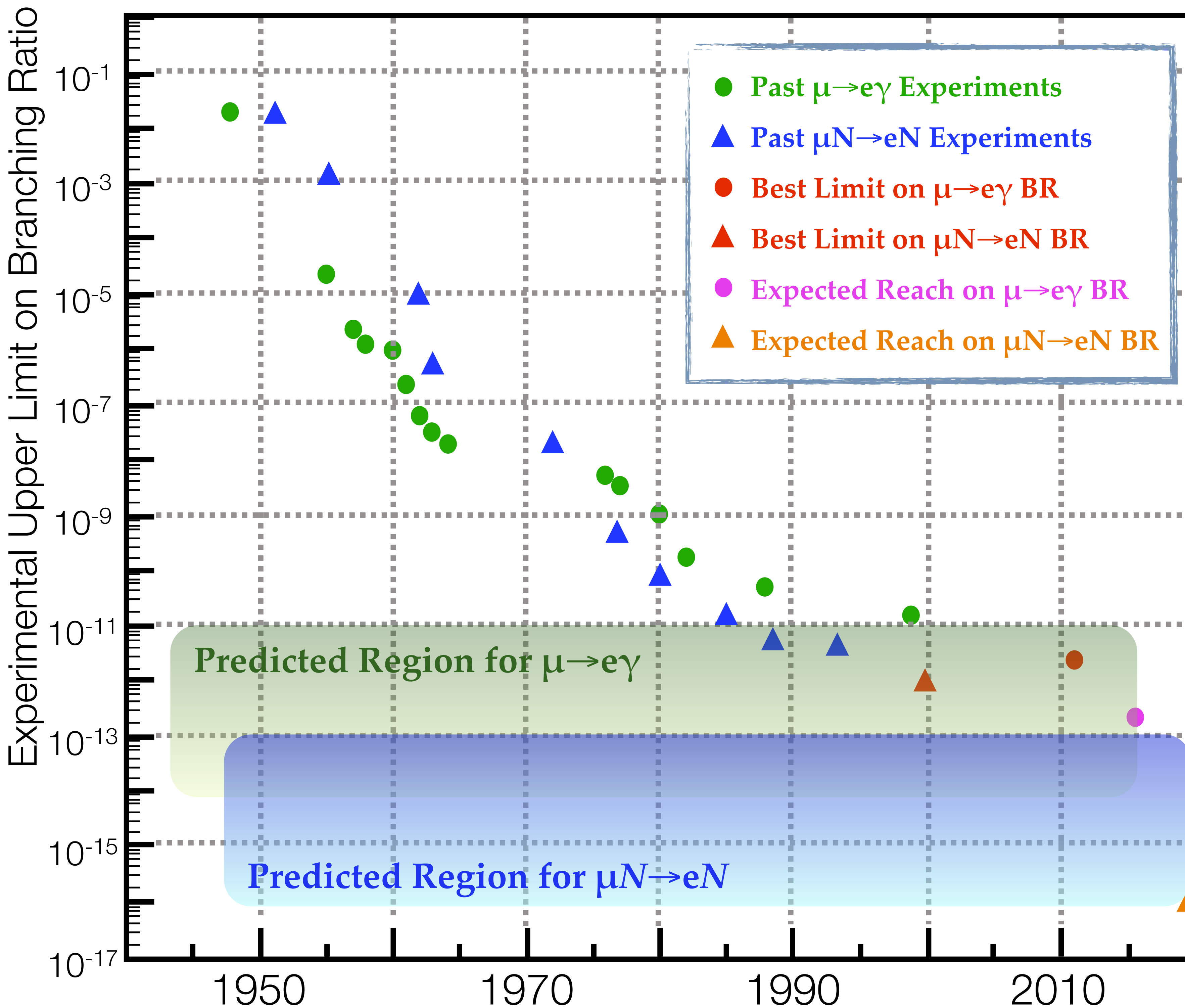
- **$\mu \to e\gamma$** : accidental B.G. ∝ (rate)2
  - MEG (and its upgrade) may be the final experiment

discovery

- **$\mu N \to eN$** : Required Beam is recently / finally achievable
  - Once we get a required beam, **$\mu N \to eN$** experiment might be a next experiment after the MEG.

measurement

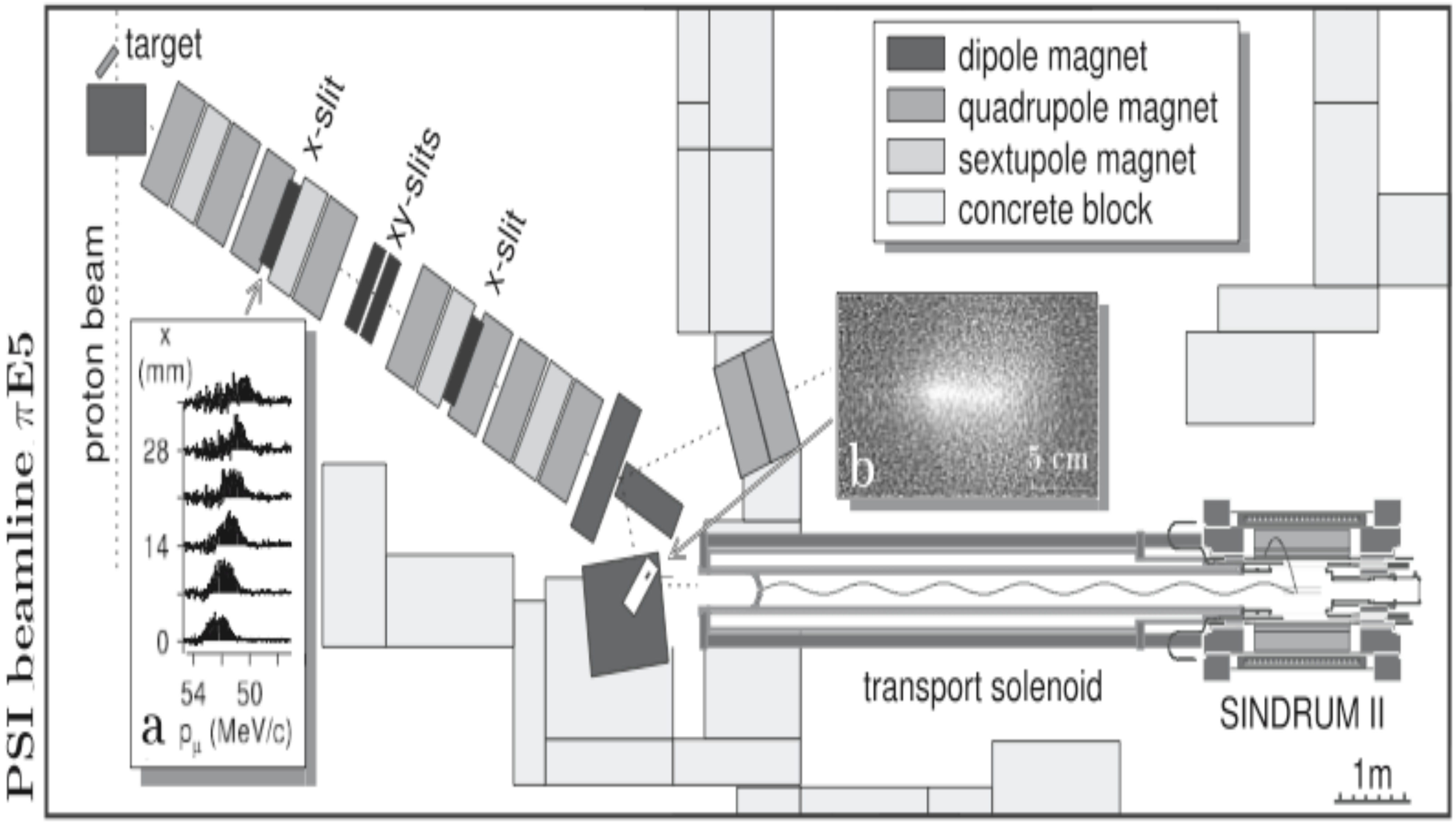
History of muon LFV search experiment



- Long Tradition on the **μ→eγ / μN→eN** Search Experiment
- Started right after the muon discovery
- **μ→eγ** has already entered the predicted region !!
- **μN→eN** is sitting at just in front of the predicted region !!
- **NOW VERY VERY ATTRACTIVE !!!!!**

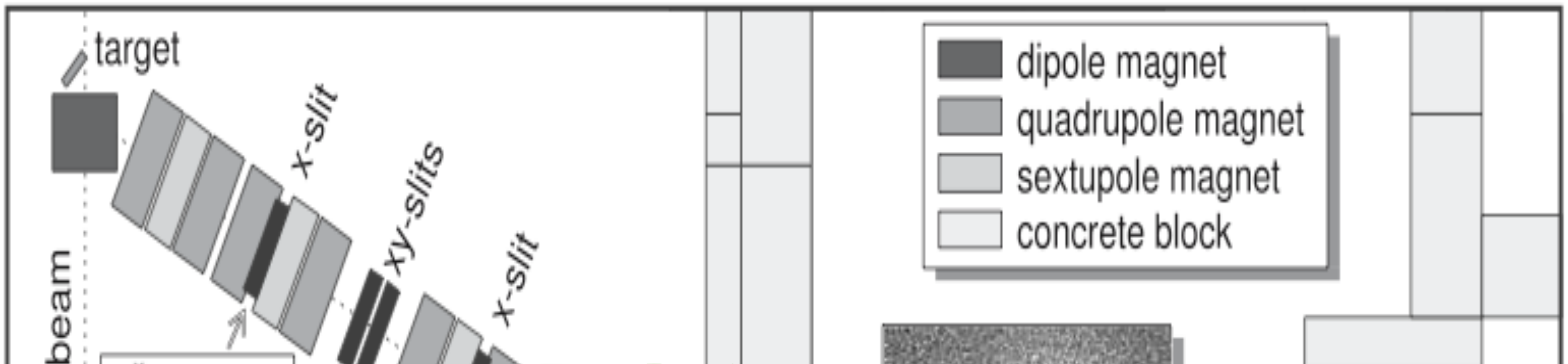
Present best limit on $\mathcal{BR}(\mu N \to eN)$

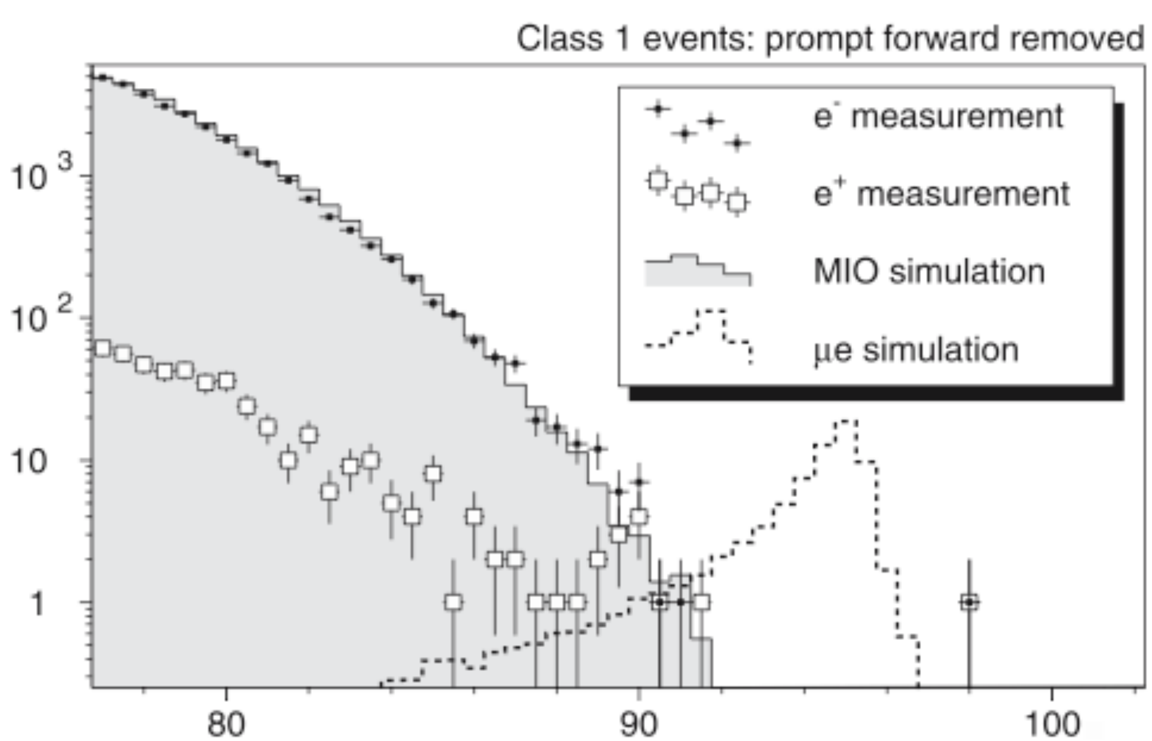
- SINDRUM-II experiment (1989-1993, PSI)



Present best limit on $\mathcal{BR}(\mu N \to eN)$

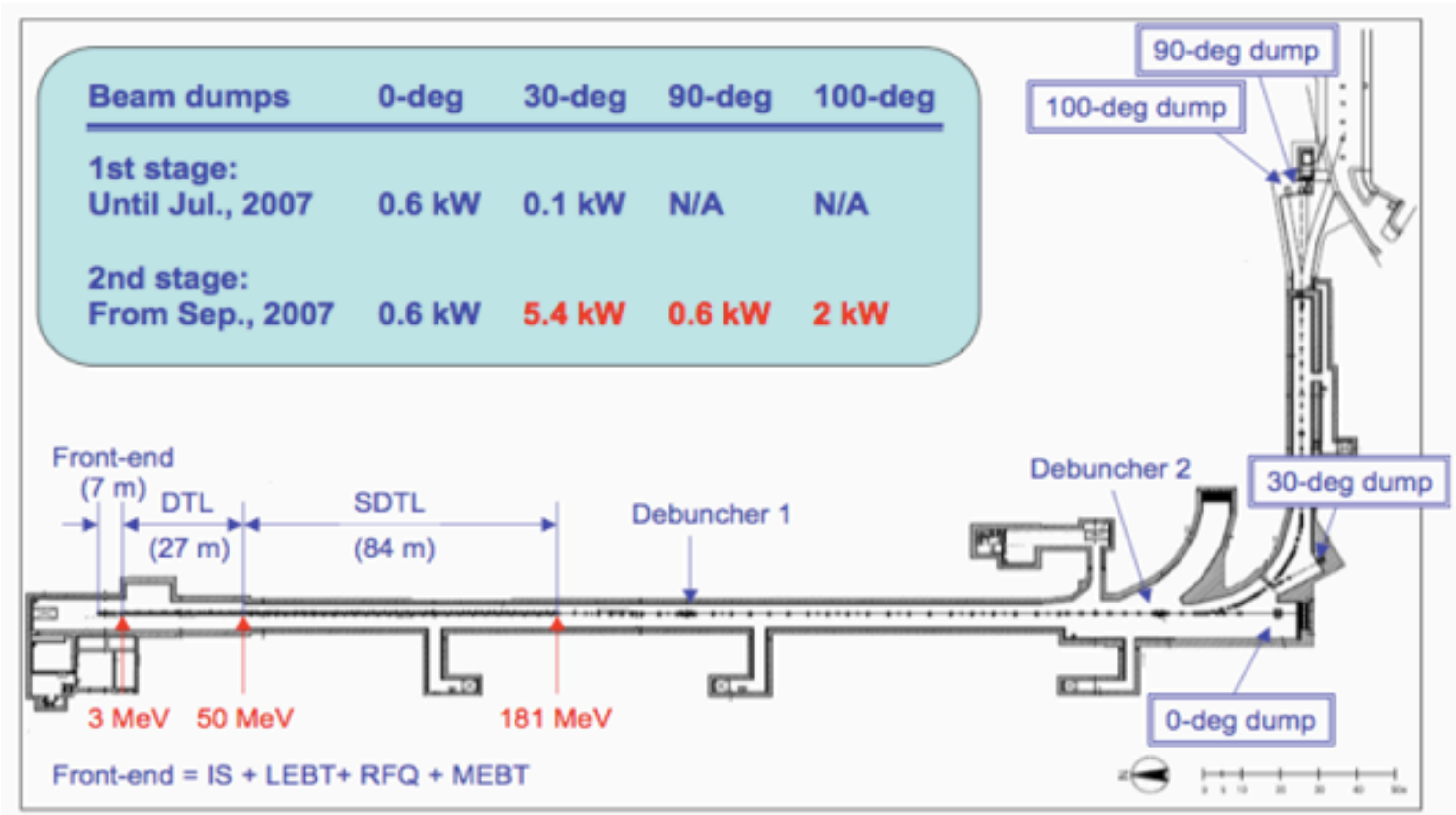
- SINDRUM-II experiment (1989-1993, PSI)



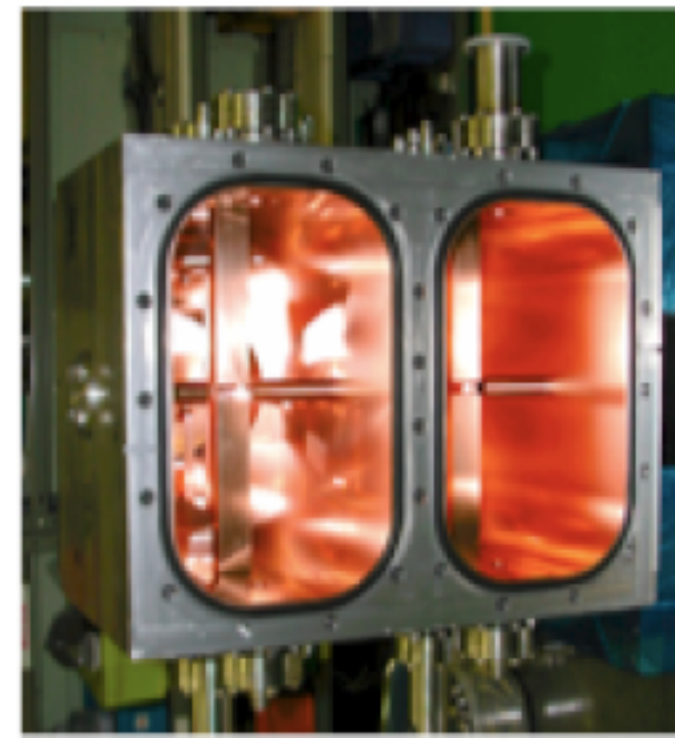


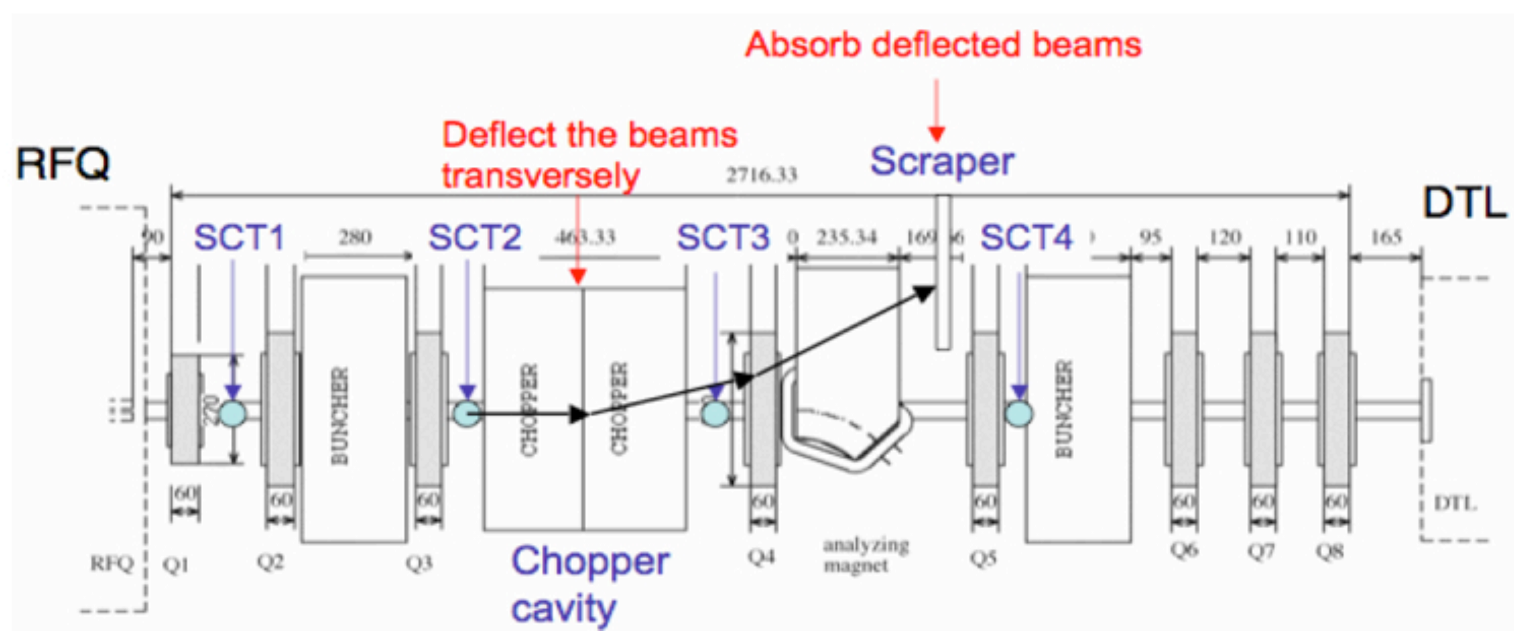
- **DC muon beam with veto counter**
- **Results:**
  - **$\mathcal{B}(\mu^- Ti \to e^- Ti) < 6.1\times10^{-13}$ (1993)**
  - **$\mathcal{B}(\mu^- Au \to e^- Au) < 7\times10^{-13}$ (2000)**
- **Limited by Significant BG Rate**

Linac Choper at J-PARC



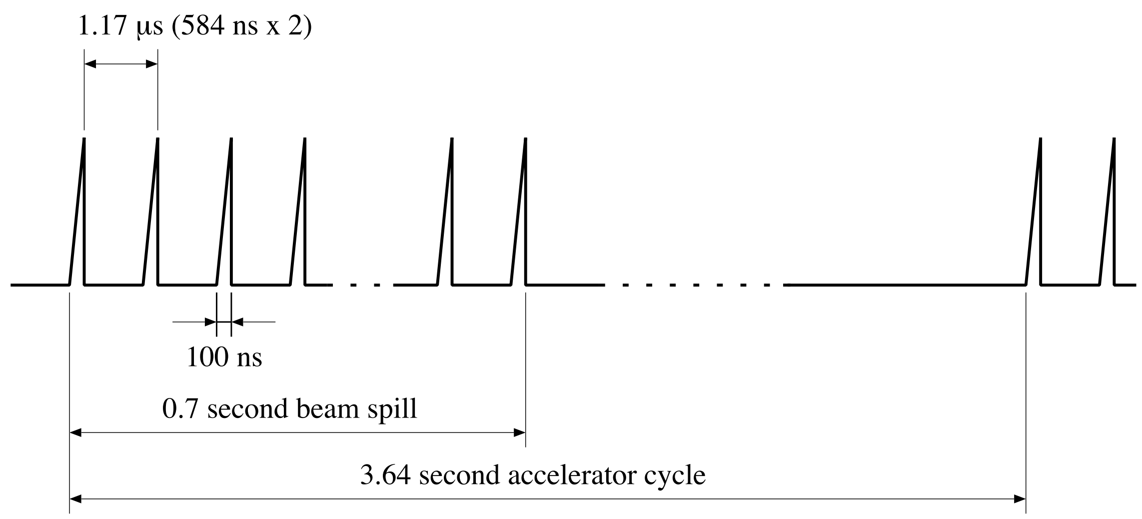
Two Cavities

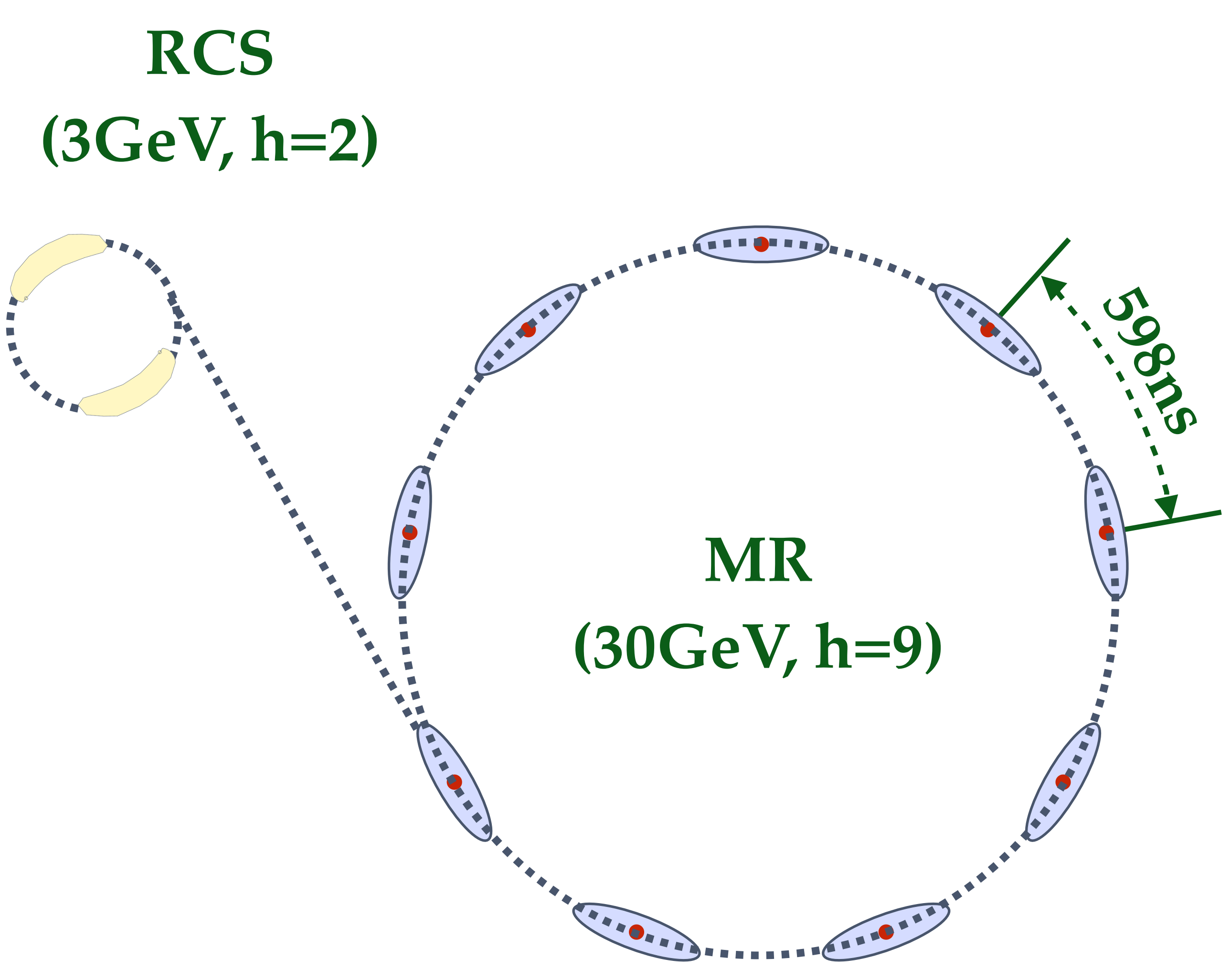




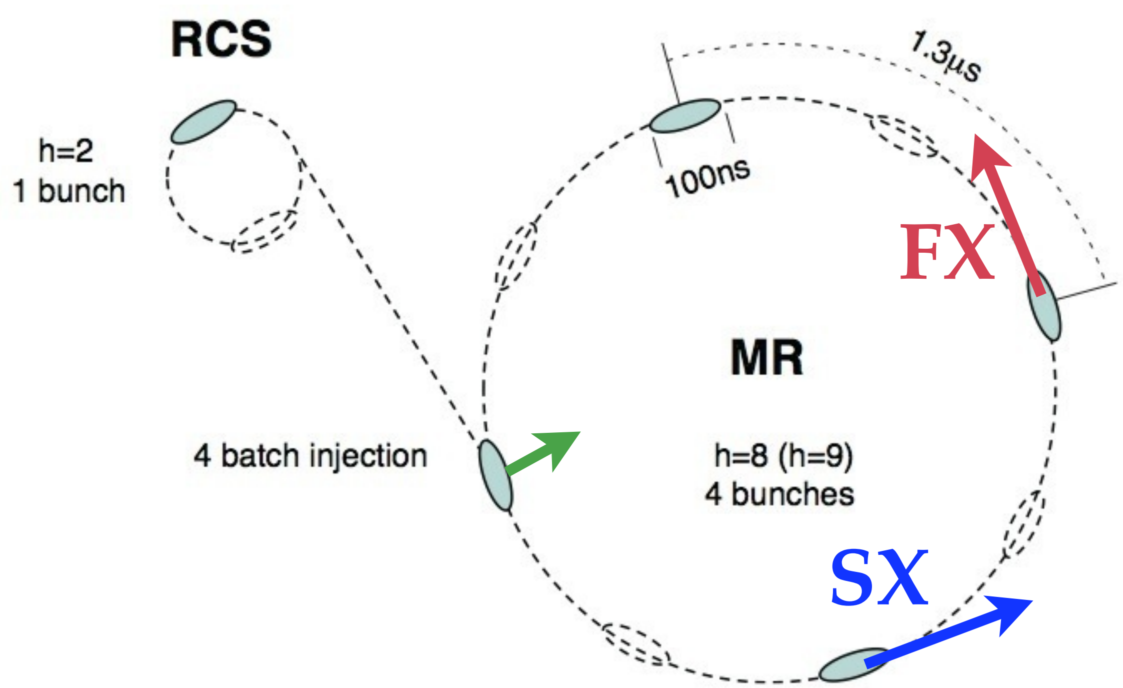
Proton beam at J-PARC

- A pulsed proton beam is needed to reject beam-related prompt BG
- Time structure required to be;
  - Pulse separation ~1μs or more (muonic atom lifetime)
  - Narrow pulse width ~ 100ns

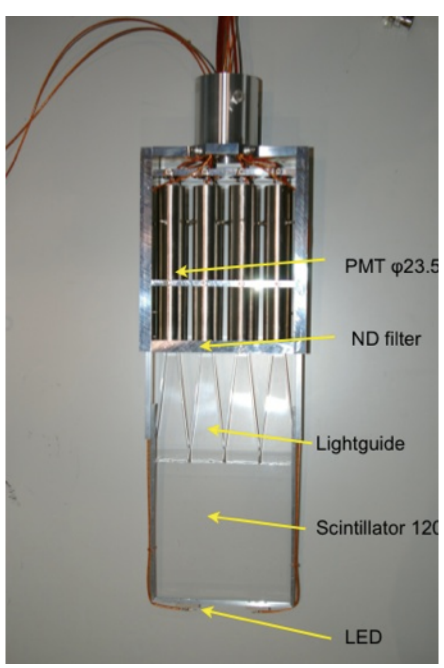




Extinction measurement at J-PARC

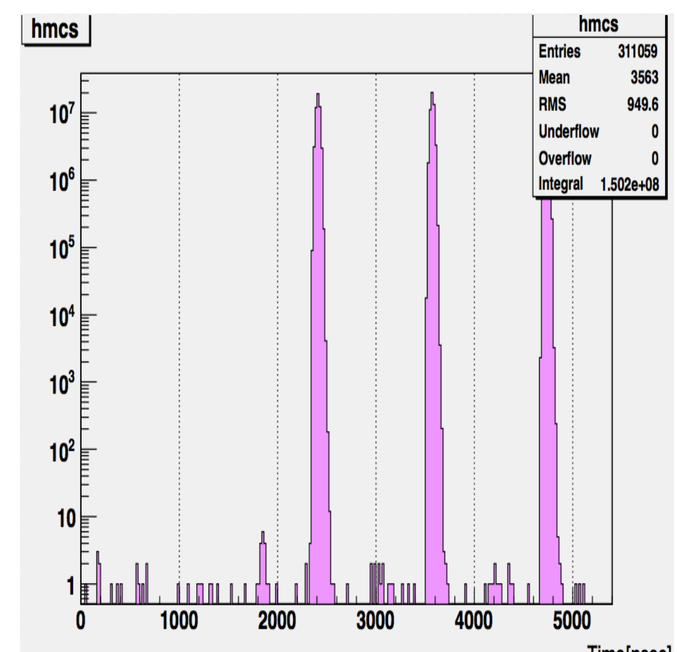


- **Extinction** = "# of residual proton" / "# of main proton", **should be < 10^{-10} !!!**
- **Should be realized with the COMET operation mode;**
  - **8GeV (56kW), bunched slow extraction**

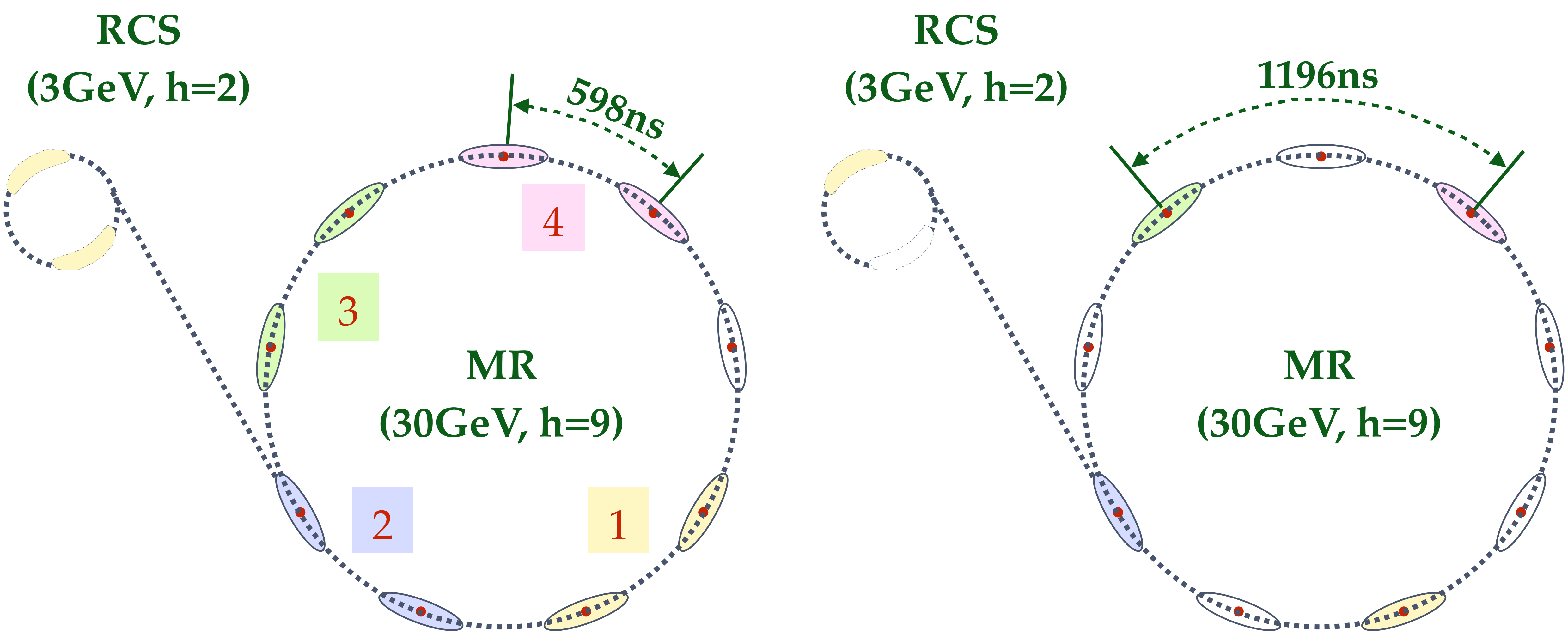


- Abort monitor
  - dynamic R ~ 10^{12} counts
- Direct measurement
  - 2010-Dec., @ FX abort line
  - Result:
    - Ext. <~ O(-7)

- Beam counter at secondary beam line
- Direct measurement
  - 2010-Oct., @ SX
  - Result:
    - **Ext. < 5.4×10^{-7}**
- Consistent with measurement at abort.



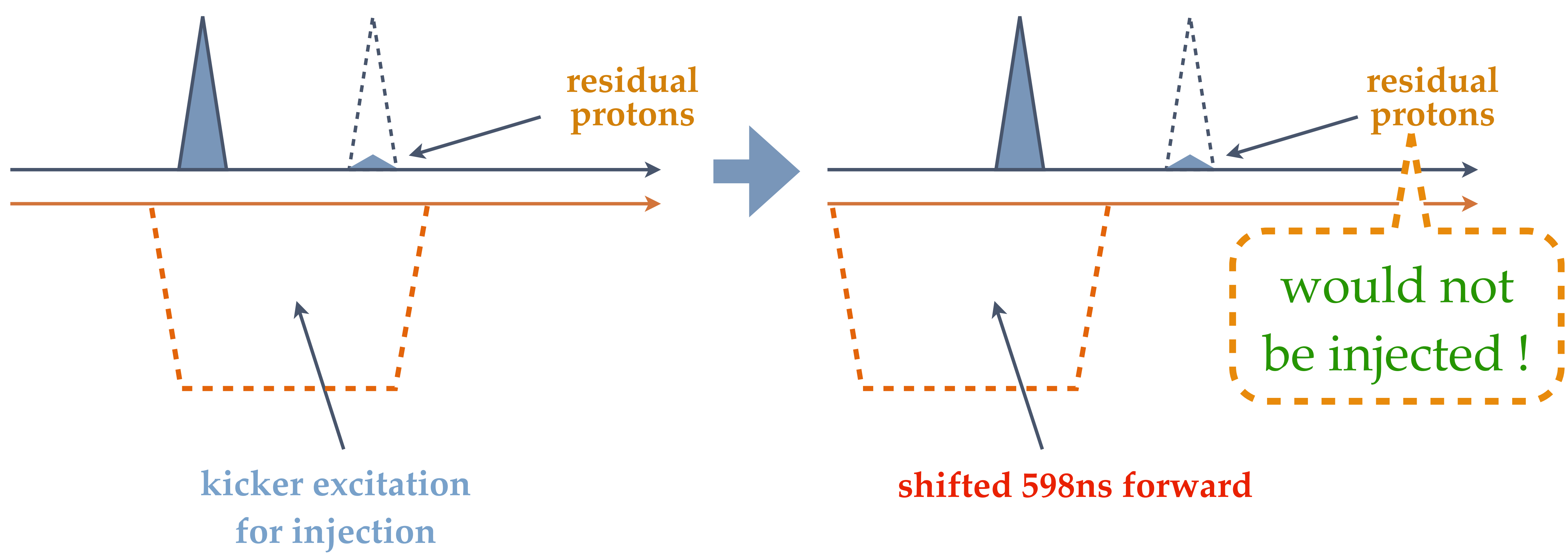
Proton beam at J-PARC



【Normal Operation】　　【COMET Operation】

Miss-kick method

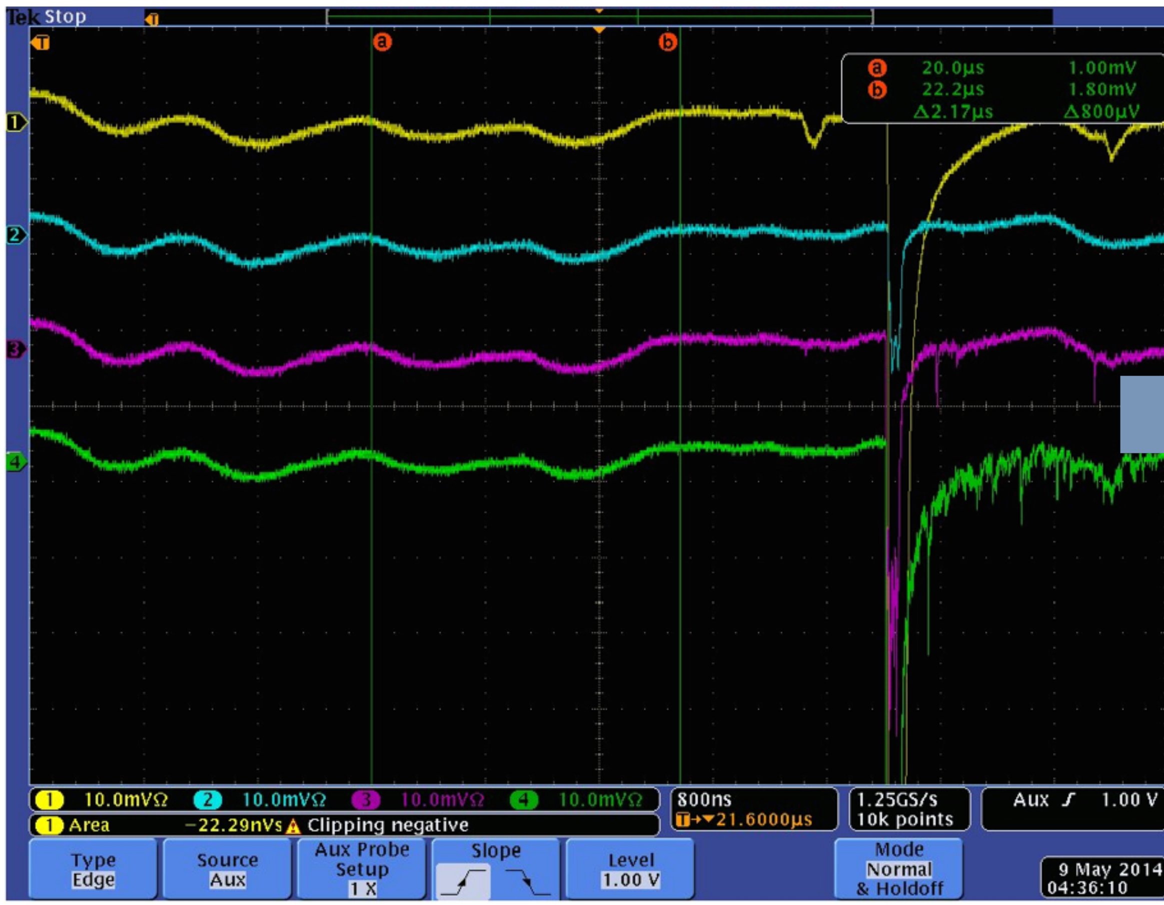
- <u>Miss kick injection method</u>; Special Thanks to J-PARC Accelerator group

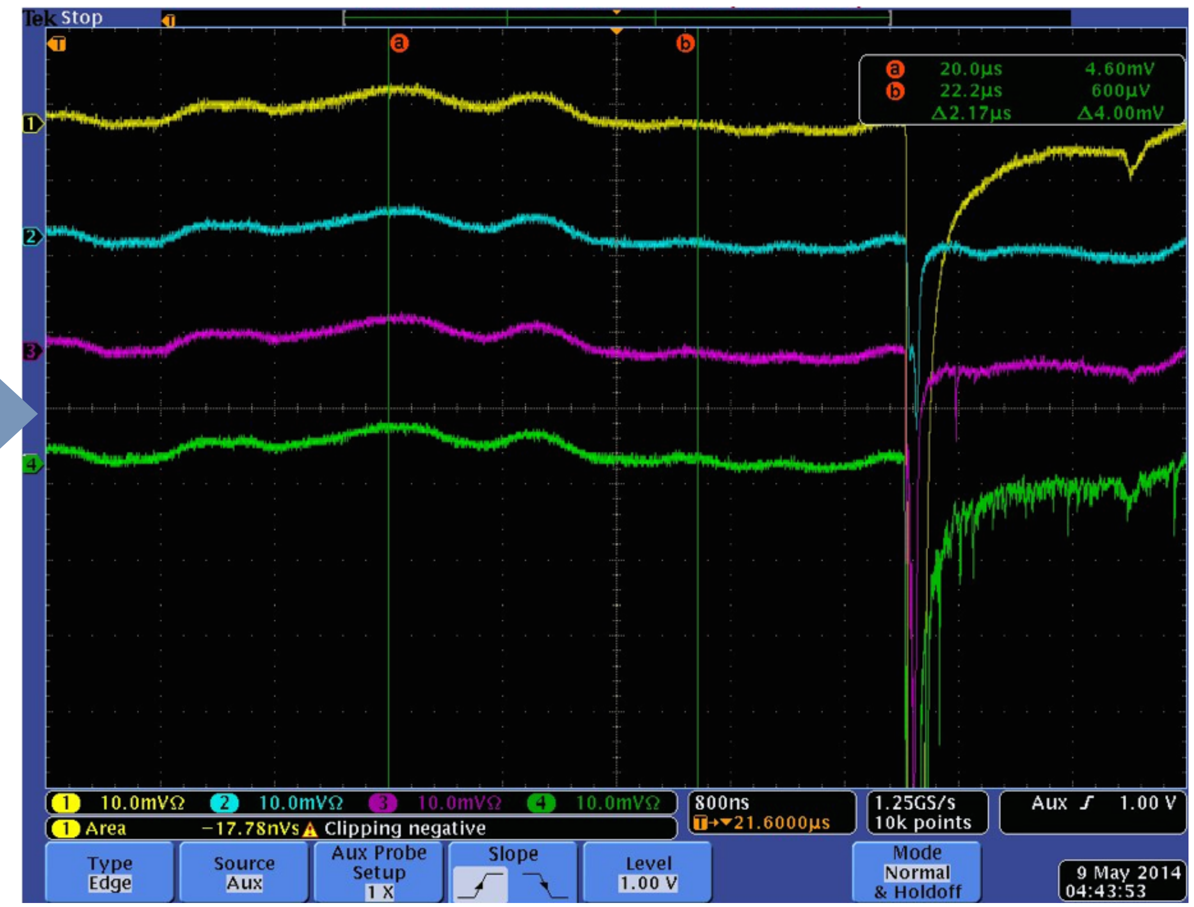


- By **shifting the kicker timing** 598ns forward/backward, residual protons are originally **not injected** into MR.
- **Completely empty bucket should be realized !**

Miss-kick Demonstration

- **Miss-kick methode was successfully demonstrated**





before miss-kick **after miss-kick**

- **This was done w/o acceleration…**

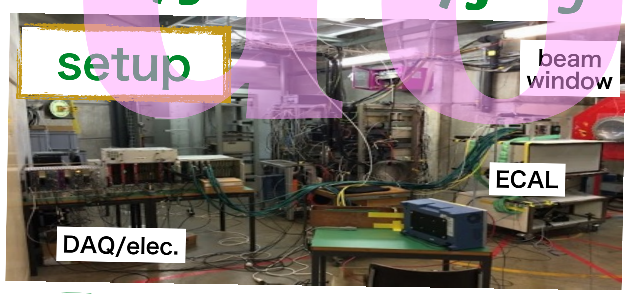
Test Beam Campaign 2015

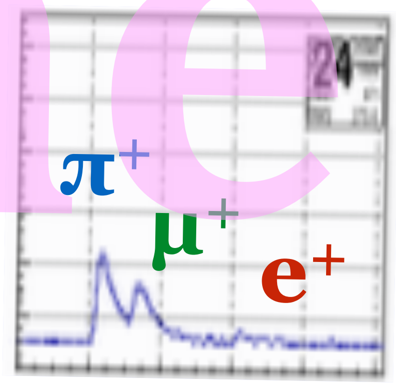
Five test-beam experiments are planned in 2015 towards finalising the setups for the COMET phase-I.

PID demonstrations at PSI

done

* PID among π/μ/e beam by waveform difference in LYSO signal
* 28/June-05/July





Proton emission measur.

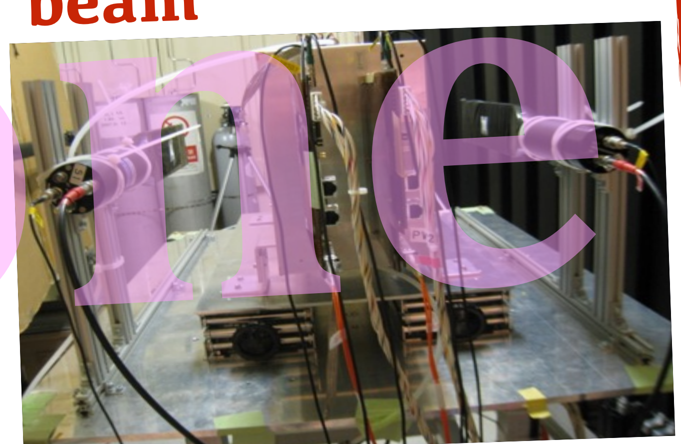
done

* After muon capture
* AlCap experiment at PSI

CDC performance at Spring8

done

* tracker test by e⁻ beam
* 09-12/July



Straw Tracker Test

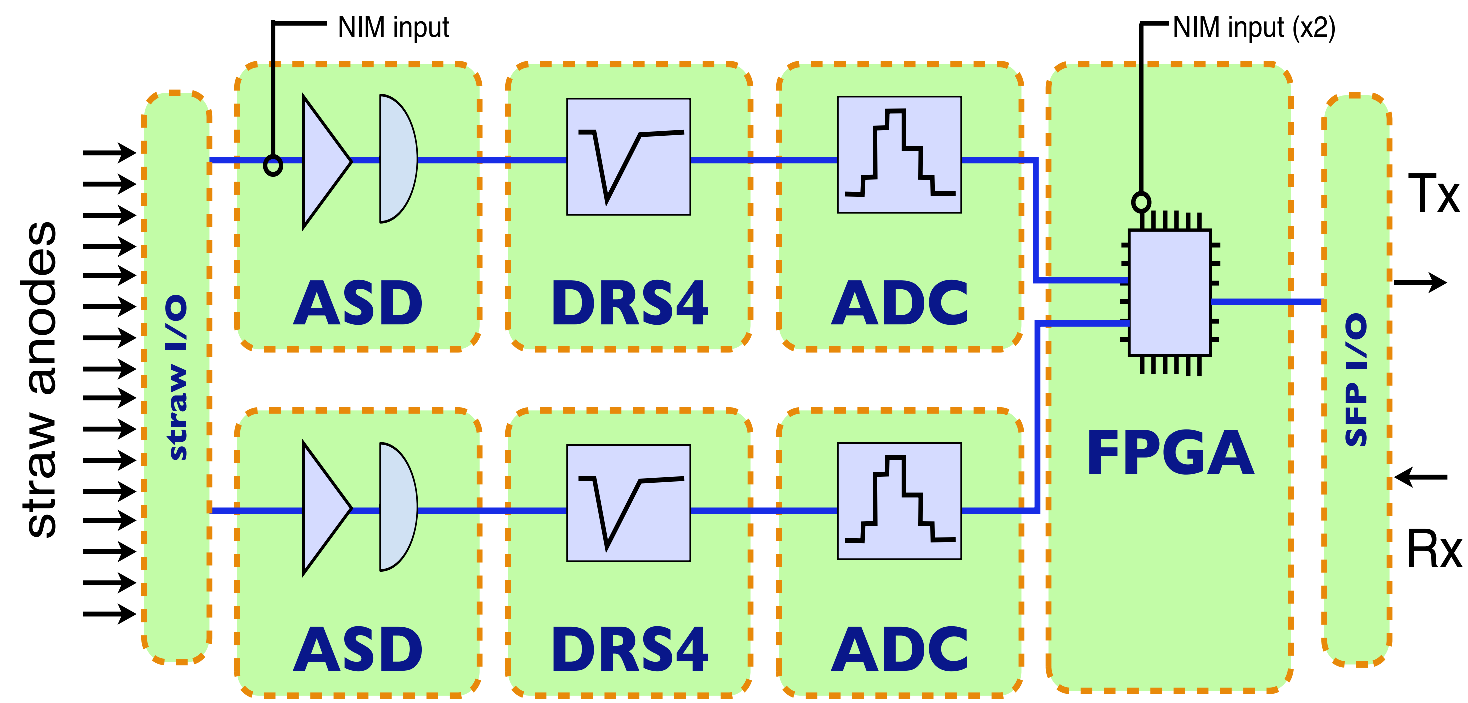
* 105MeV e⁻ beam @ Tohoku Univ
* To be done in late half in 2015
* Performance studies

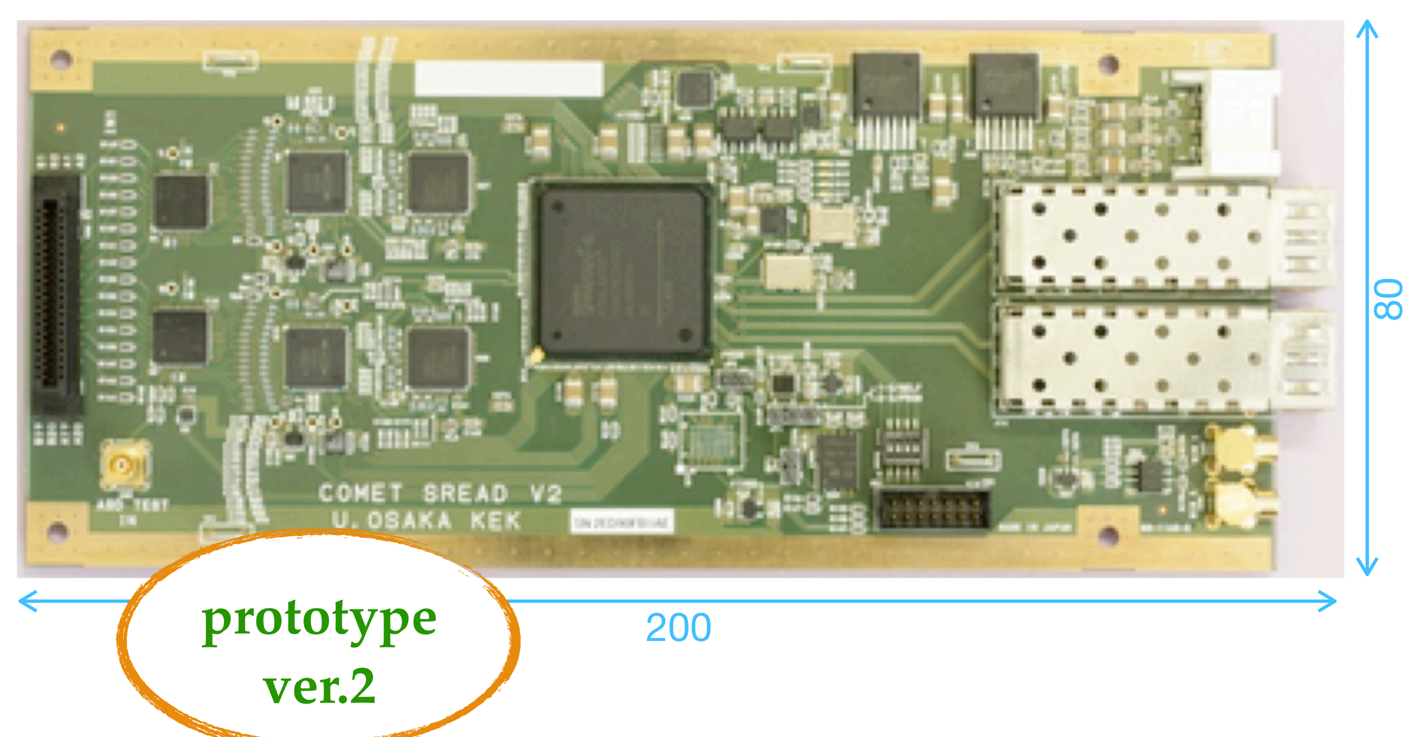
StrECAL Test

* 105MeV e⁻ beam @ Tohoku Univ
* Integrated test (Straw+ECAL +Trig+FE)
* To be done in beginning of 2016

Front-end Electronics R&D

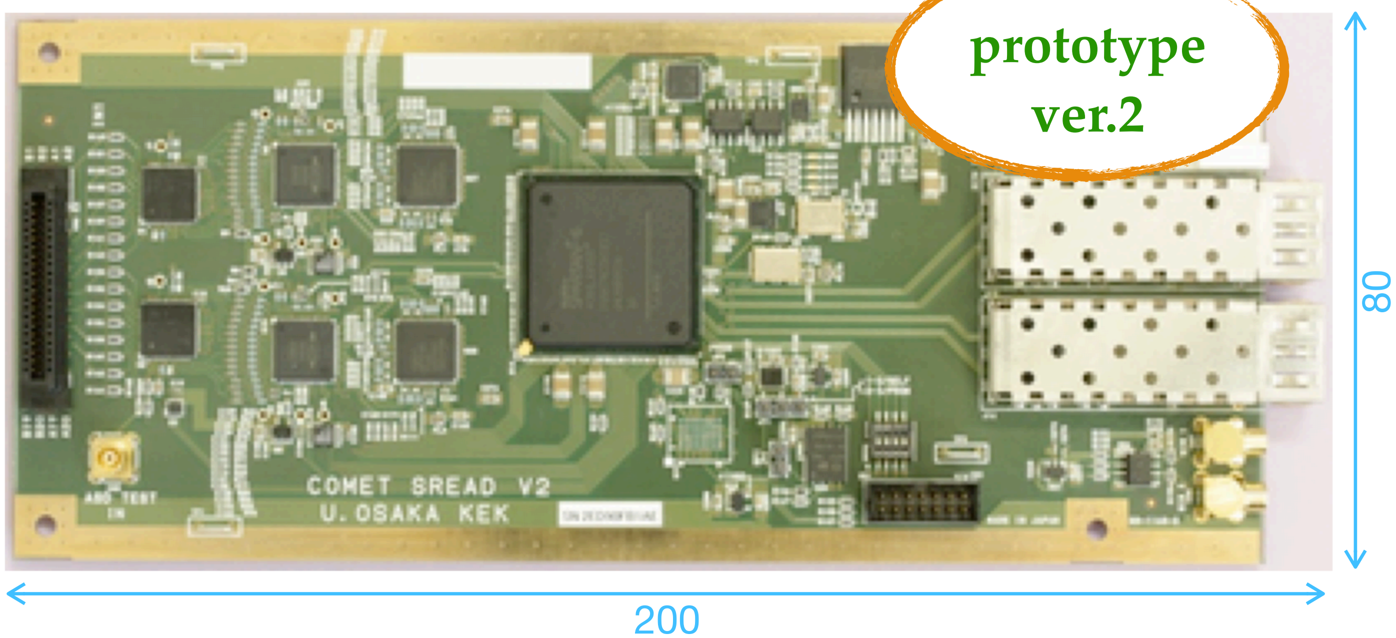
- Own Front-end electronics is under development
- **ROESTI** : **R**ead**O**ut **E**lectronics for **S**traw **T**ube **I**nstrument
  - **power consumption**
  - **# of feedthrough**
  - **space limitation**
  - **pile-up elimination (WF)**
  - picking up a small charge / timing resolution, *etc*.
- Pre-amplification→Pulse shaping, discrimination is done by **ASD** and Waveform digitization is done by **DRS4**, controlled by FPGA-based local bus control system on the board.

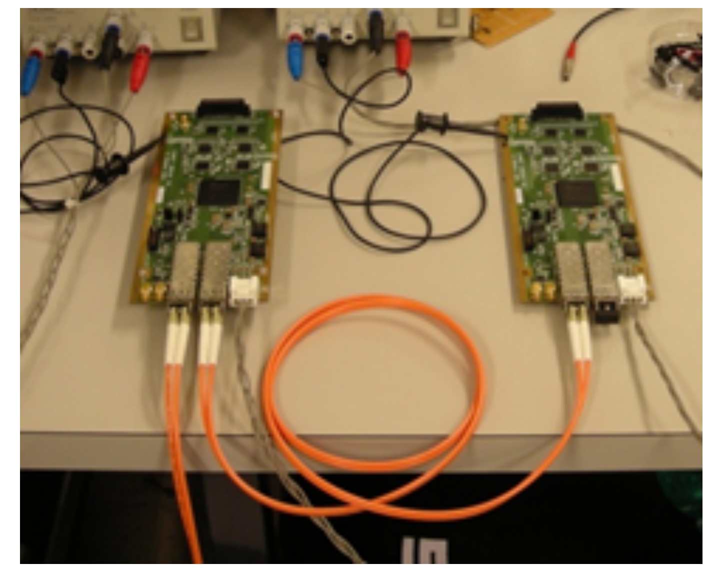


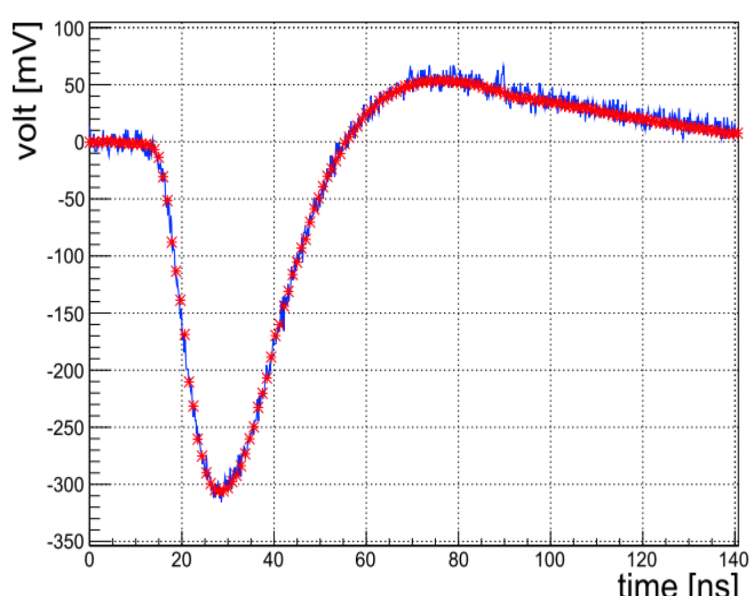


ROESTI prototype

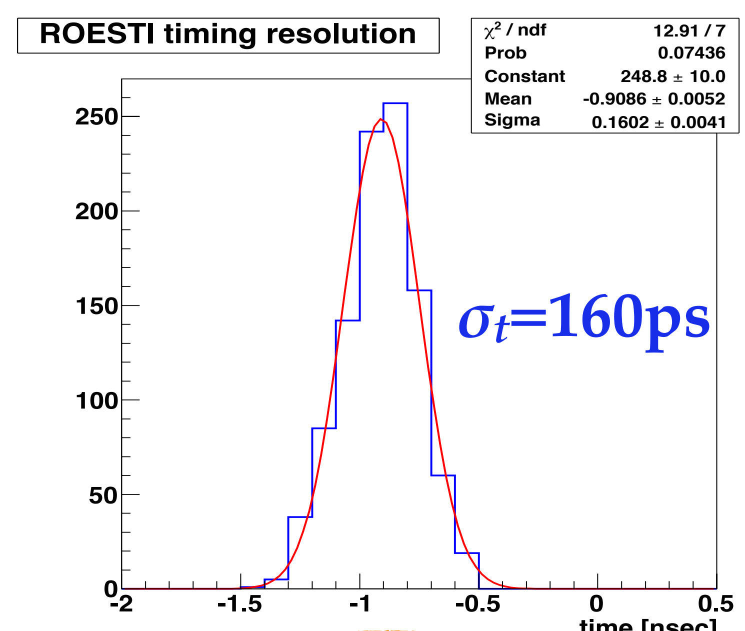
- Two prototypings were done, and ver.3 is under development which will be the final prototype.



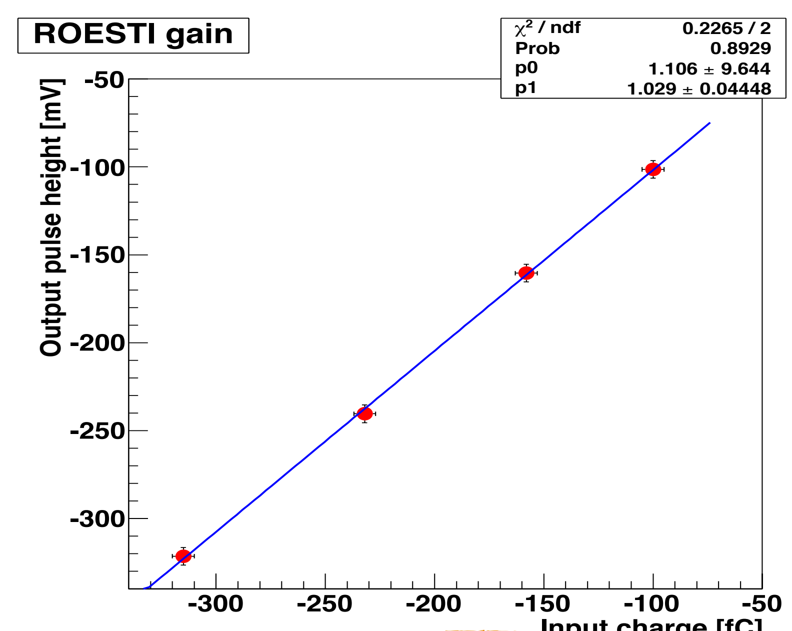




WF output



timing reso.



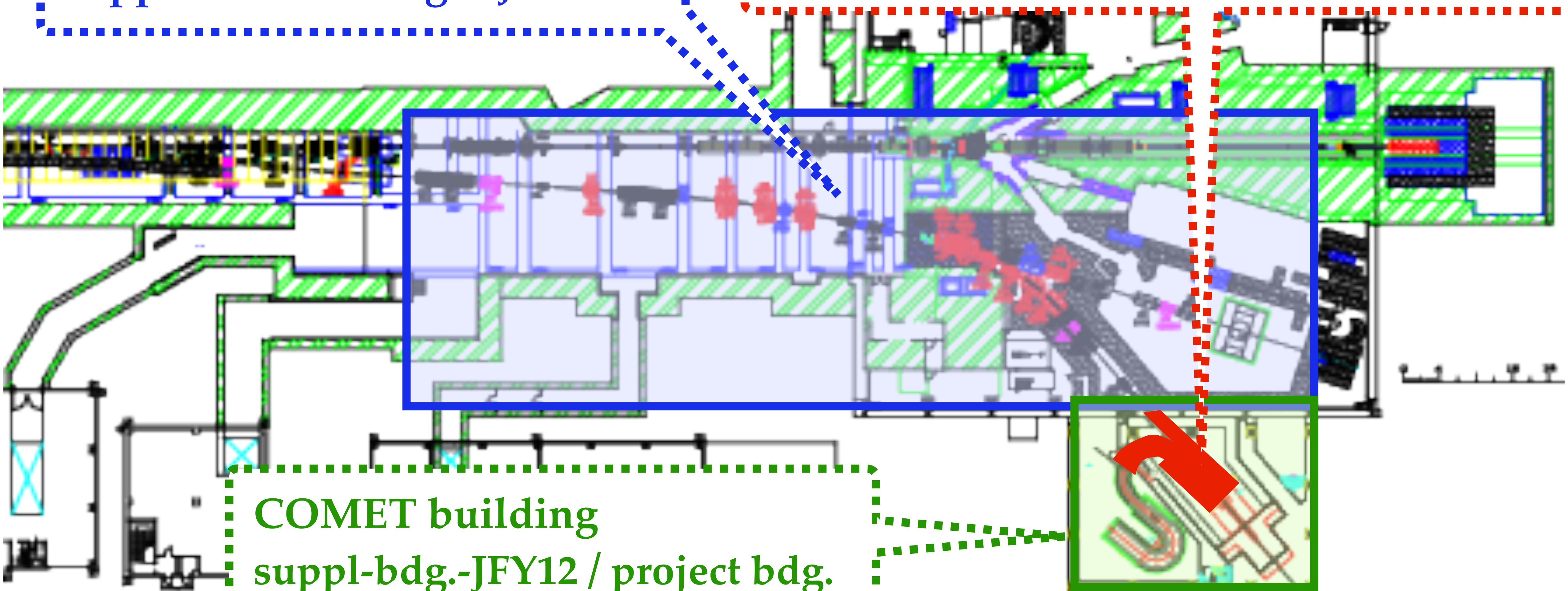
calibration

Funding for Phase-I

- Almost secured…

Detector (CDC+trig.+elec.) + Solenoid
Grant-in-Aid JFY2013-17
Detector (Straw+ECAL+elec.)
Partially secured by another Grant-in-Aid.
Remaining cost would be covered by efforts from other countries, *eg*. UK, JINR, *etc.*

Proton beam-line
supplemental-budget-JFY2012



COMET building
suppl-bdg.-JFY12 / project bdg.

Background list for Phase-I

Intrinsic physics backgrounds		
1	Muon decay in orbit (DIO)	Bound muons decay in a muonic atom
2	Radiative muon capture (external)	$\mu^- + A \to \nu_\mu + A' + \gamma$, followed by $\gamma \to e^- + e^+$
3	Radiative muon capture (internal)	$\mu^- + A \to \nu_\mu + e^+ + e^- + A'$,
4	Neutron emission after after muon capture	$\mu^- + A \to \nu_\mu + A' + n$, and neutrons produce e^-
5	Charged particle emission after muon capture	$\mu^- + A \to \nu_\mu + A' + p$ (or d or α), followed by charged particles produce e^-
Beam related prompt/delayed backgrounds		
6	Radiative pion capture (external)	$\pi^- + A \to \gamma + A'$, $\gamma \to e^- + e^+$
7	Radiative pion capture (internal)	$\pi^- + A \to e^+ + e^- + A'$
8	Beam electrons	e^- scattering off a muon stopping target
9	Muon decay in flight	μ^- decays in flight to produce e^-
10	Pion decay in flight	π^- decays in flight to produce e^-
11	Neutron induced backgrounds	neutrons hit material to produce e^-
12	$\overline{p}$ induced backgrounds	$\overline{p}$ hits material to produce e^-
Other backgrounds		
14	Cosmic-ray induced backgrounds	
15	Room neutron induced backgrounds	
16	False tracking	

Background estimation for Phase-I

Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
Physics	Radiative muon capture	5.6×10^{-4}
Physics	Neutron emission after muon capture	< 0.001
Physics	Charged particle emission after muon capture	< 0.001
Prompt Beam	Beam electrons (prompt)	7.1×10^{-4}
Prompt Beam	Muon decay in flight (prompt)	$\leq 1.7 \times 10^{-4}$
Prompt Beam	Pion decay in flight (prompt)	$\leq 2.0 \times 10^{-3}$
Prompt Beam	Other beam particles	$\leq 2.4 \times 10^{-6}$
Prompt Beam	Radiative pion capture(prompt)	4.24×10^{-4}
Delayed Beam	Beam electrons (delayed)	~ 0
Delayed Beam	Muon decay in flight (delayed)	~ 0
Delayed Beam	Pion decay in flight (delayed)	~ 0
Delayed Beam	Radiative pion capture (delayed)	~ 0
Delayed Beam	Anti-proton induced backgrounds	0.007
Others	Electrons from cosmic ray muons	< 0.0001
Total		0.019