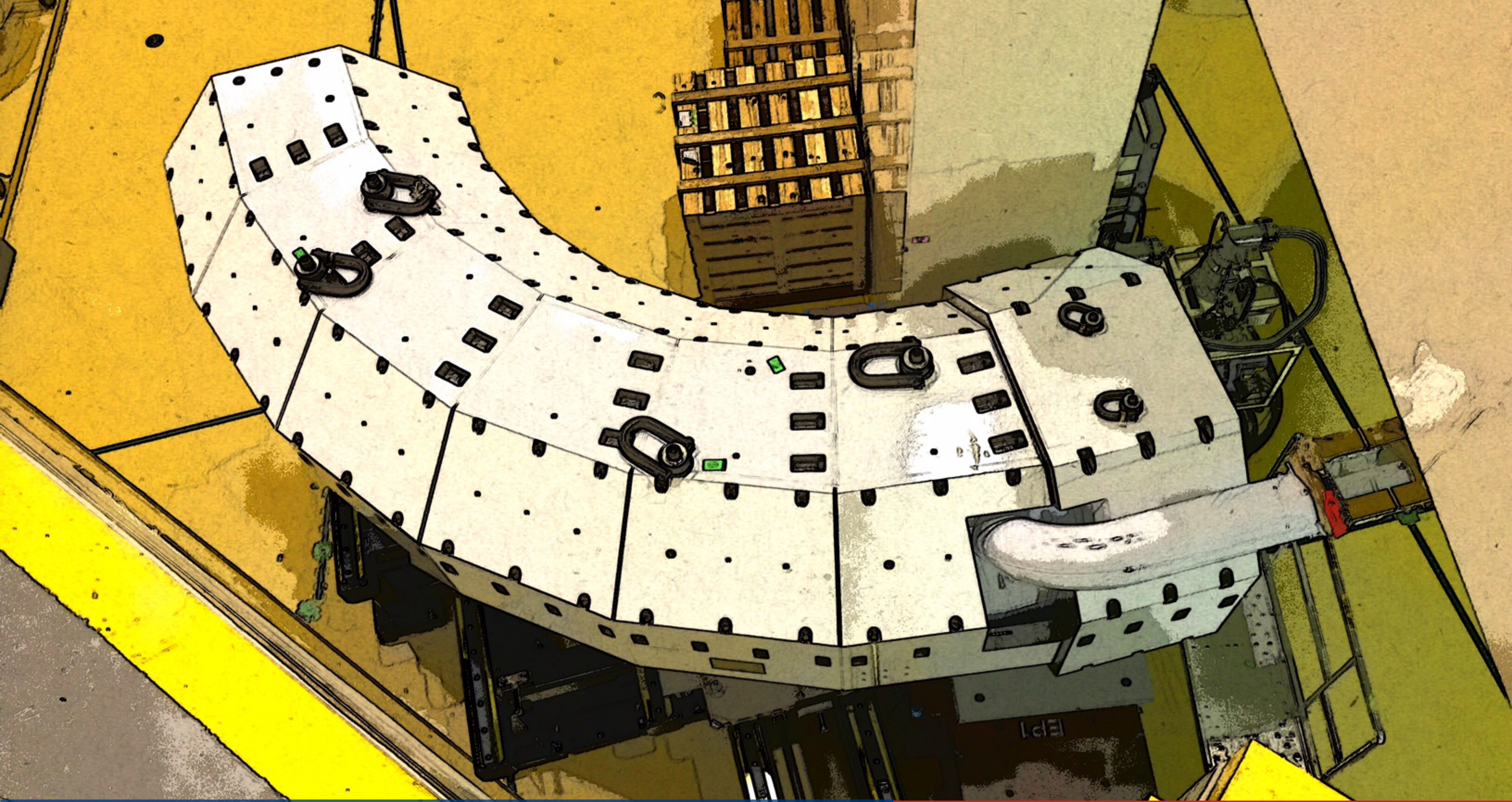

Extinction Measurement of J-PARC MR with 8 GeV Proton Beam for the New Muon-to-Electron Conversion Search Experiment — COMET

10TH INTERNATIONAL PARTICLE ACCELERATOR CONFERENCE

19 - 24 MAY 2019

Hosted by ANSTO's Australian Synchrotron at the Melbourne Convention & Exhibition Centre

IPAC19

Hajime NISHIGUCHI, ***KEK · J-PARC***

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&
Search for *Muon-to-Electron* Conv.
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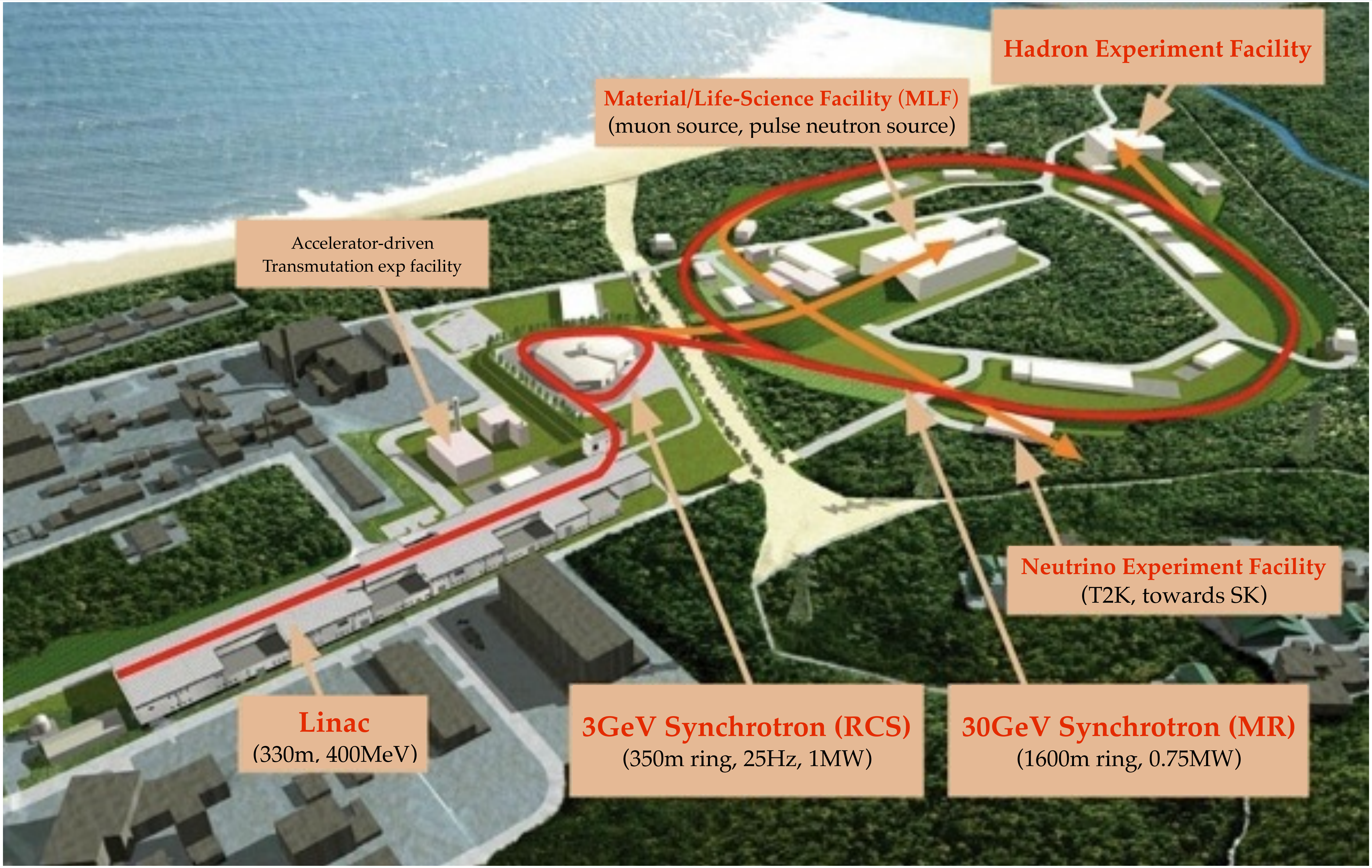
J-PARC

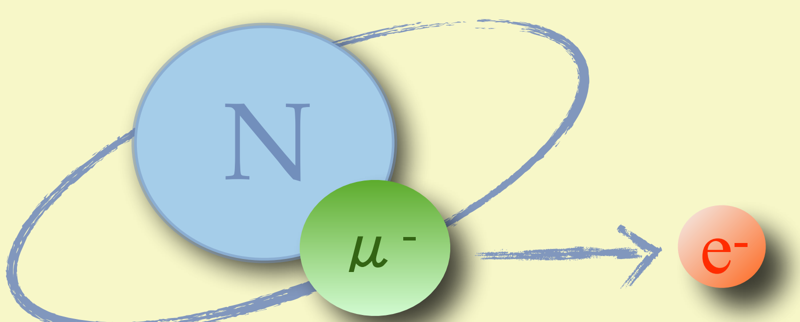


Hadron Experiment Facility
Material/Life-Science Facility (MLF)
(muon source, pulse neutron source)
Accelerator-driven
Transmutation exp facility
Neutrino Experiment Facility
(T2K, towards SK)
Linac
(330m, 400MeV)
3GeV Synchrotron (RCS)
(350m ring, 25Hz, 1MW)
30GeV Synchrotron (MR)
(1600m ring, 0.75MW)

Muon-to-Electron Conversion : "$\mu^{-}N \rightarrow e^{-}N$"

- **Try to Probe New Physics via "*Lepton Flavour Violation*"**
- **Among "Quark", "Neutrino" = Known as Flavour violated**
- **"Charged Lepton Flavour Violation (cLFV)" = Never Observed so far**
  - Very sensitive to the TeV-scale new physics beyond Standard Model
    → **Complementary** and **Competitive** to the **Energy Frontier (LHC *etc.*)**

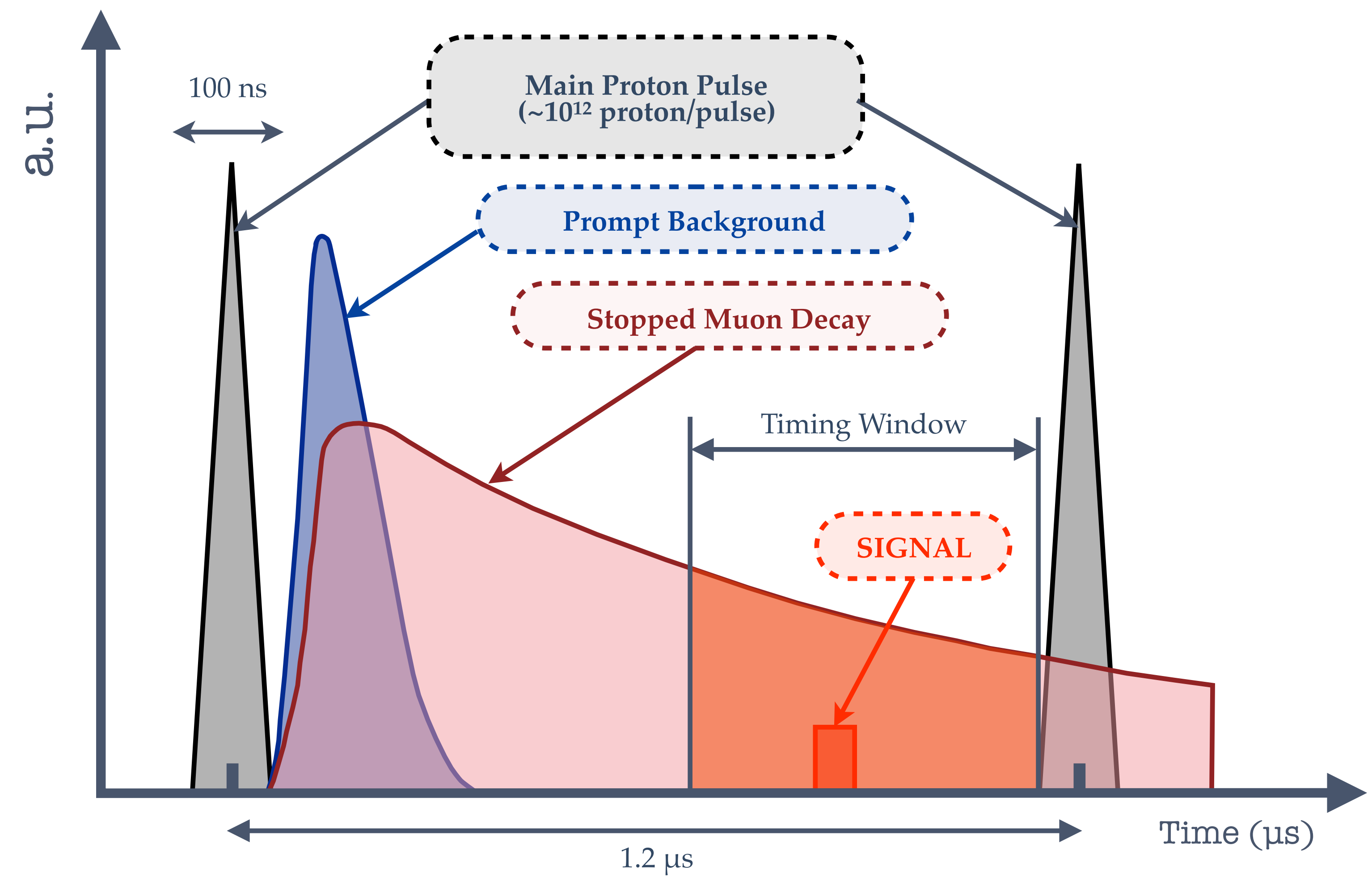
- **"Muon-to-Electron Conversion in Muonic Atom ($\mu^{-}N \rightarrow e^{-}N$)"**
  - **so-called "μ-e Conversion"**
  - **One of the most prominent process of muon LFV**



- **"Signal"**
  - $E_e = m_\mu - B_\mu - E_{recoil}$ **~105 MeV**
- **"Background"**
  - **Beam-related**
  - **Normal muon decay : $E_e^{Michel} = 52.8$ MeV**

Proton-Beam Extinction

- **Dominant Background**
  - Beam-related prompt Background, mainly caused by pion decays
  - Right after the timing of proton bunch
  - Open a DAQ-window right before the next proton bunch
- **Extinction is ESSENTIAL !**



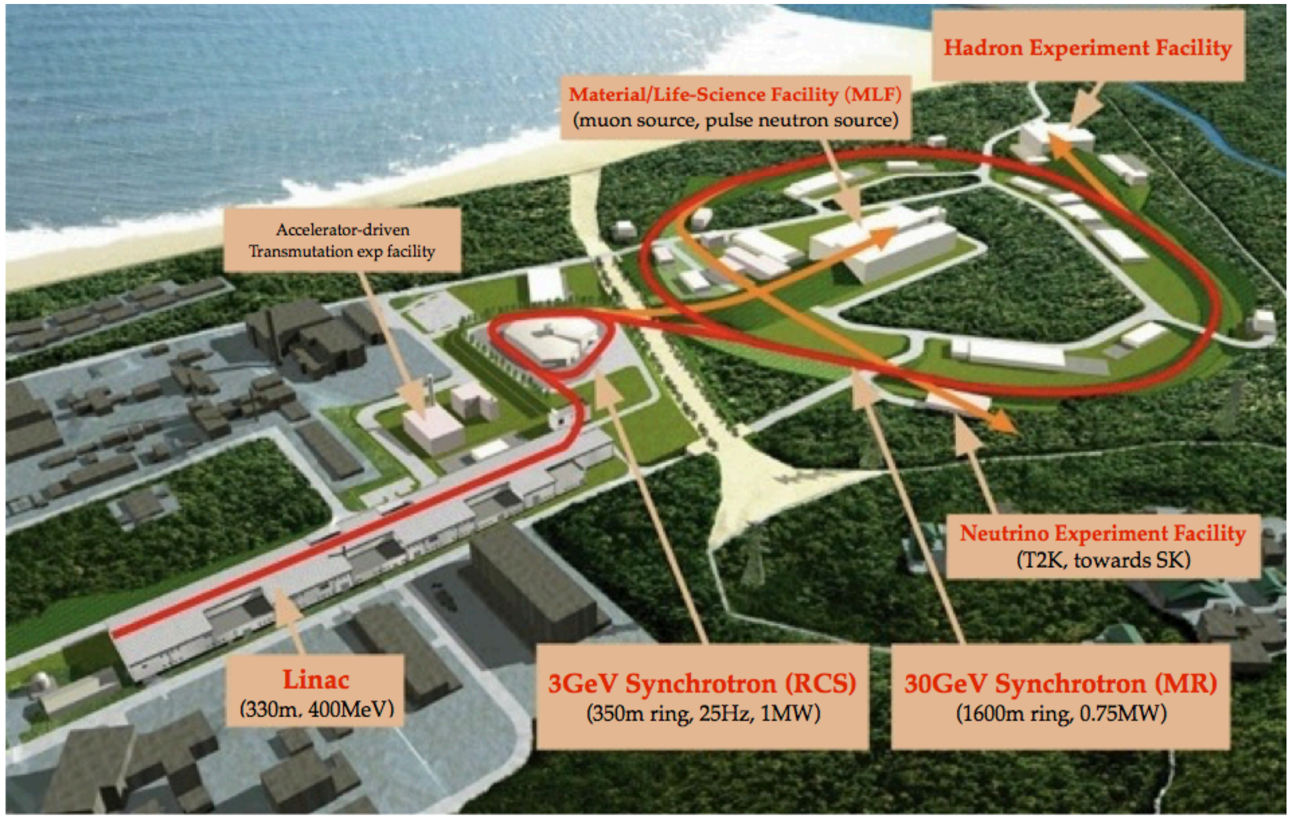
$$\textbf{Extinction} = \frac{\text{\# of leaked proton in between bunches}}{\text{\# of filled protons in main bunches}}$$

Extinction should be <10^{-10} at least to achieve the COMET Goal

(Single Event Sensitivity : 10^{-17})

The COMET Experiment

- **Under Construction at Hadron Experimental Facility of J-PARC**



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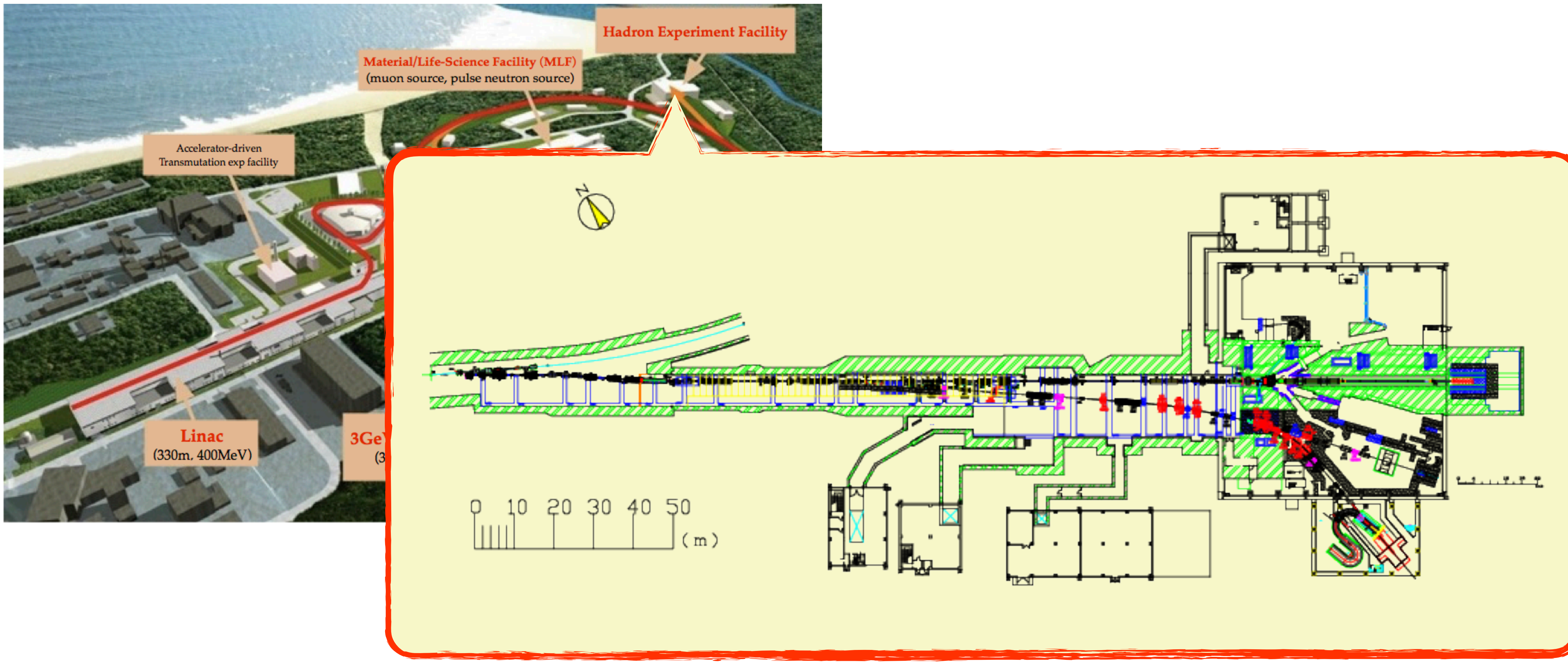

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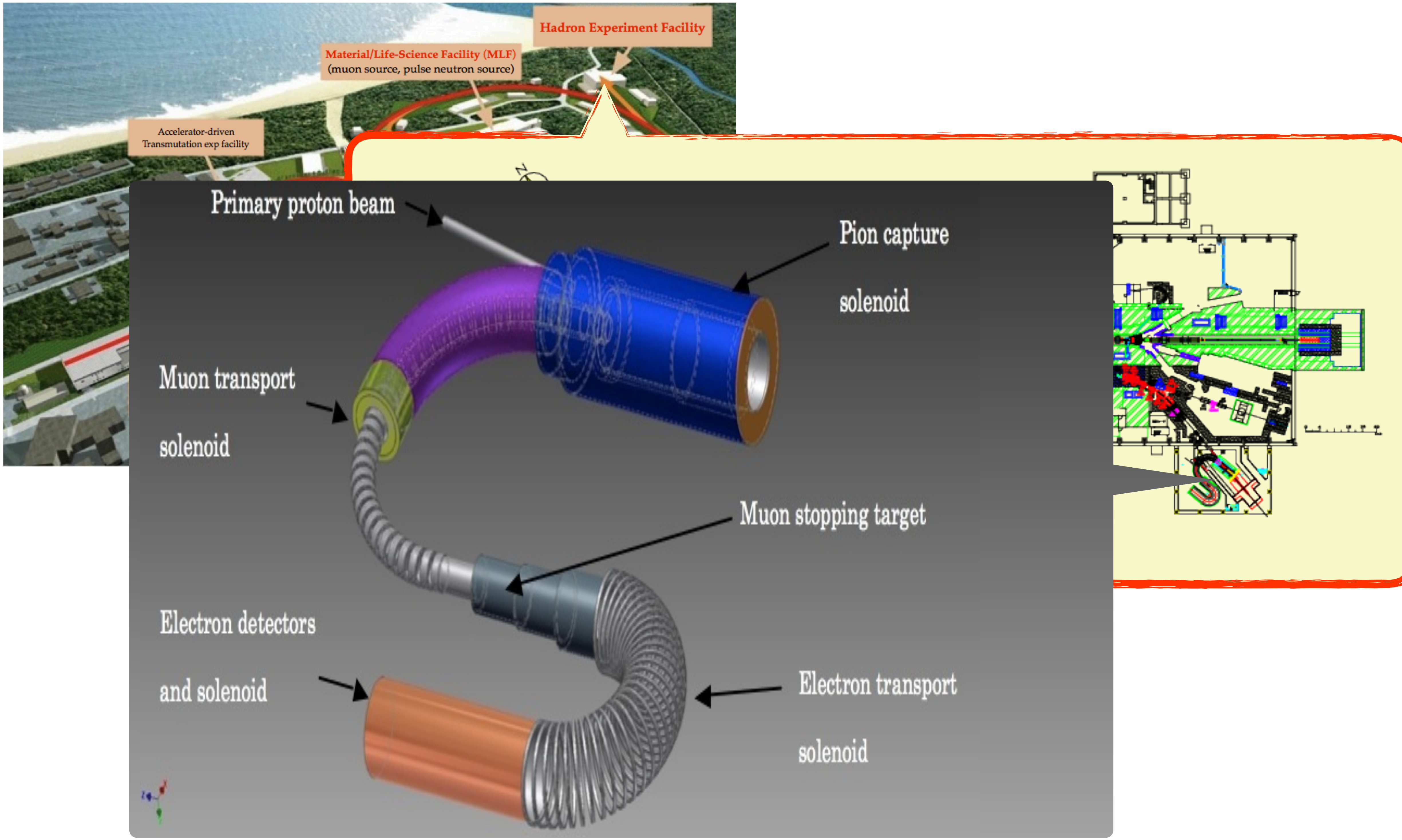

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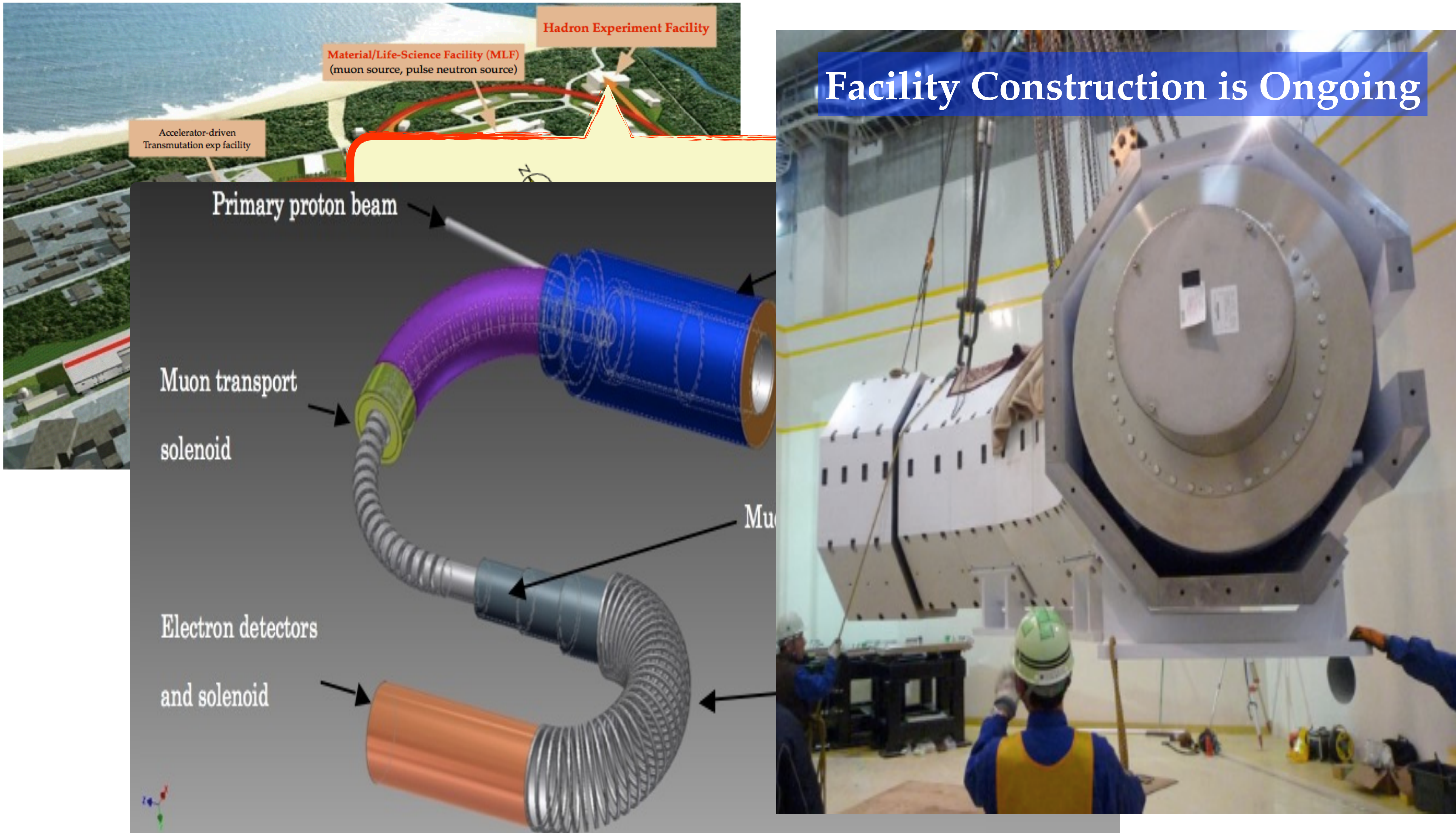


Customized Operation

of

J-PARC MR

for

The COMET Experiment

Requirements

- **Three major (and essential) requirements;**

Proton Energy = 8 GeV

Normally, 30GeV

To avoid anti-proton background

Tomizawa, *et.al.* WEPMP010

Bunch Separation >1 μsec

Normally, 0.6 μsec

Need to wait for Mu life $\tau_{\text{Muonic Al}} = 0.8$ μsec

Extinction < 10^{-10}

Normally, Nobody takes care…

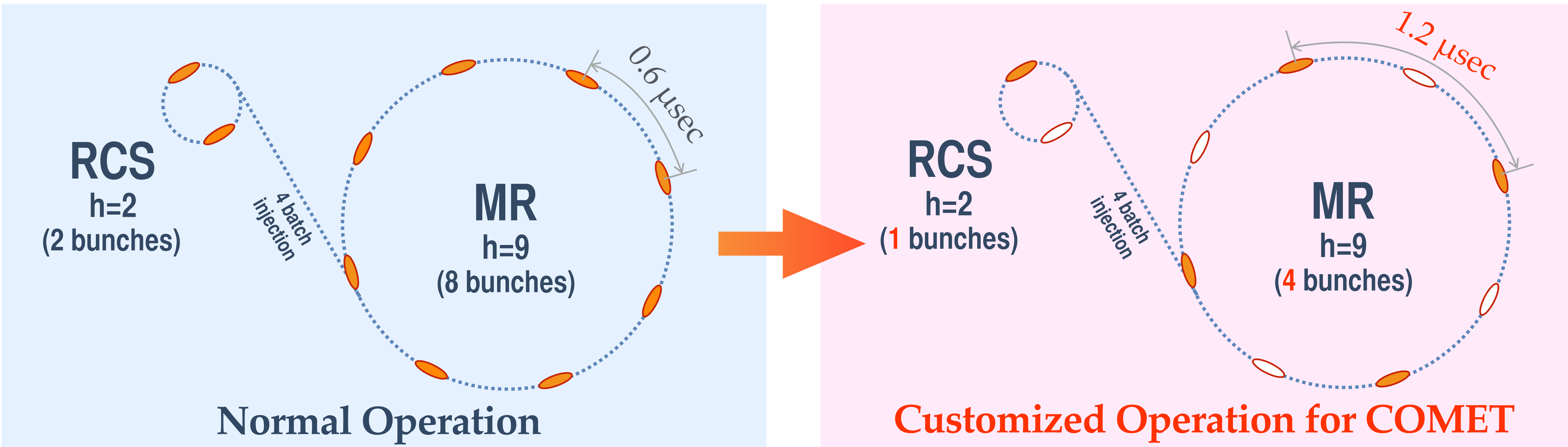
Essential to achieve the COMET Sensitivity

Main Topic

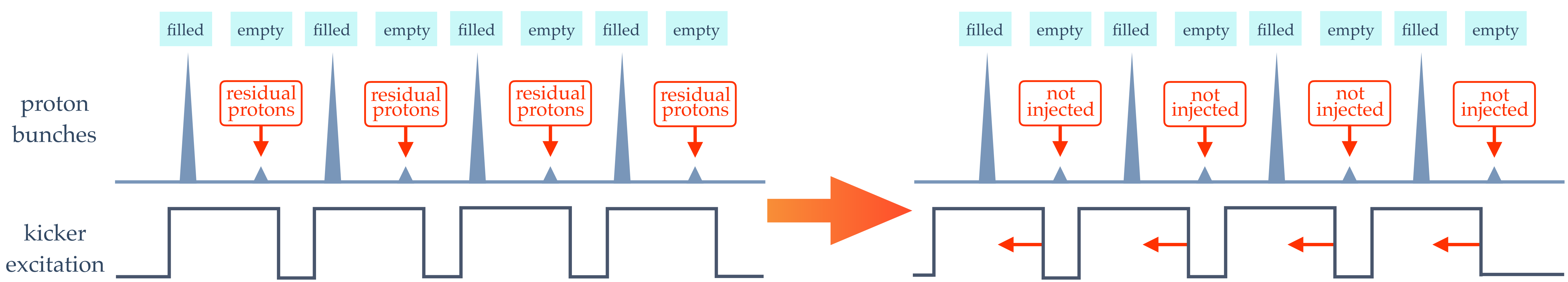
- Several other requirements, too. : **Bunched Slow Extraction**, **56kW** Operation …

How to realize ?

- How to realize **Longer Bunch Separation**



- How to realize **Excellent Extinction**



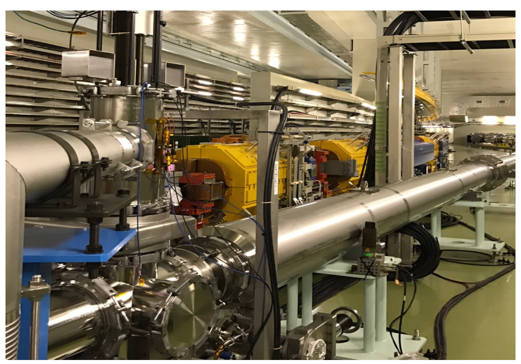
- 4 batch injection = 4 times kicker excitation
- **Initial Extinction** = ***O*(-6)** due to "Chopper Inefficiency"
- Shift the kicker timing by half a period forward
- "Single Bunch Kicking" → **Perfect Extinction !!**

How to measure an extinction ?

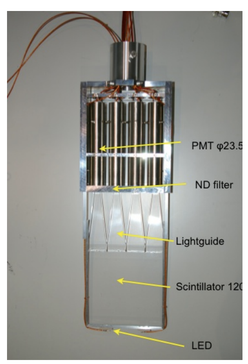
- Two extraction ports of MR → Two occasions to measure an extinction

Fast Extraction (FX)

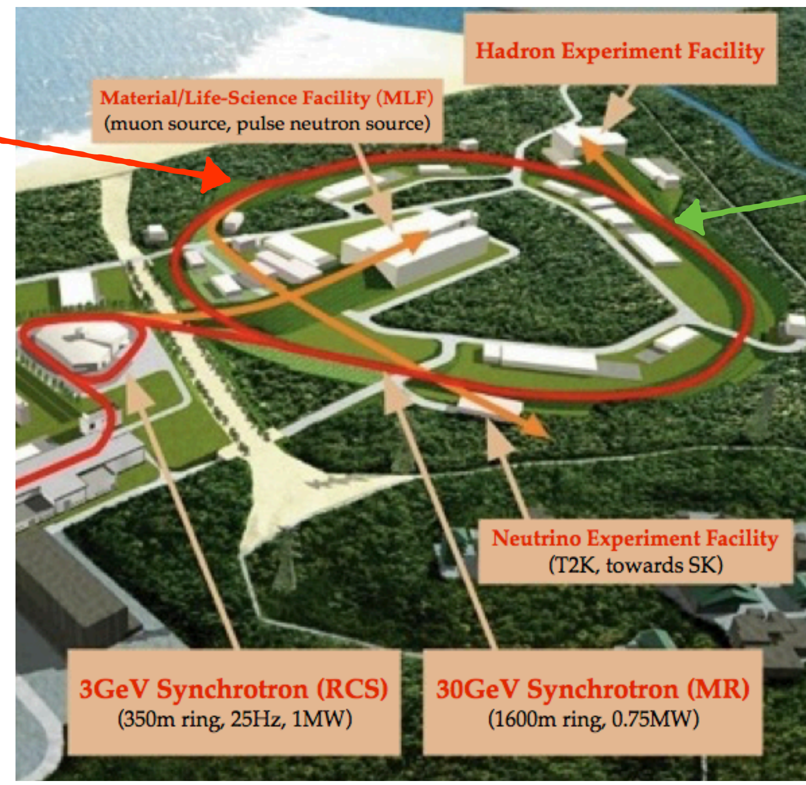
- Towards Neutrino Beam line
- Possible to measure an extinction at Abort Line



【MR Abort Line】

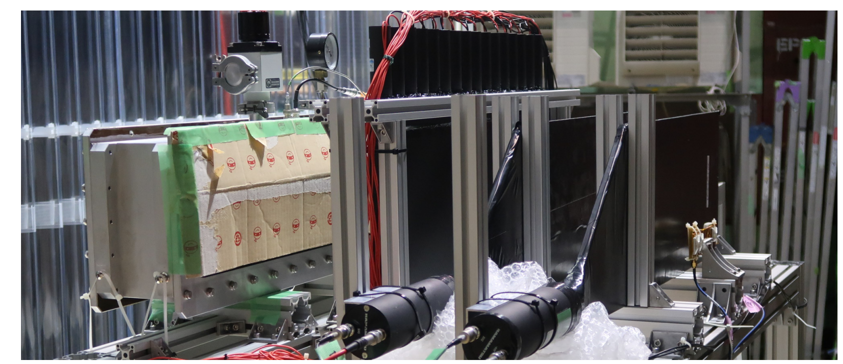


【Abort Monitor】



Slow Extraction (SX)

- Towards Hadron Exp. Facility
- Possible to measure an extinction at Secondary Beam



【Hodoscopes in Secondary Beam Line】

FX – PROS
- Measurable by Single Shot → Can be measured quickly
- Understand within MR

FX – CONS
- Not compatible w/ continuous beam operation
- Not precise with limited stat.

Both Occasions have Advantages/Disadvantages

Both Measurements are Necessary !!!

SX – PROS
- Can investigate an effect of SX
- Same as final COMET configuration with Bunched-SX

SX – CONS
- Measurable by 2ndary Beam → Need a certain beam time
- Need a special DAQ to count all 2ndary particles

Results

of

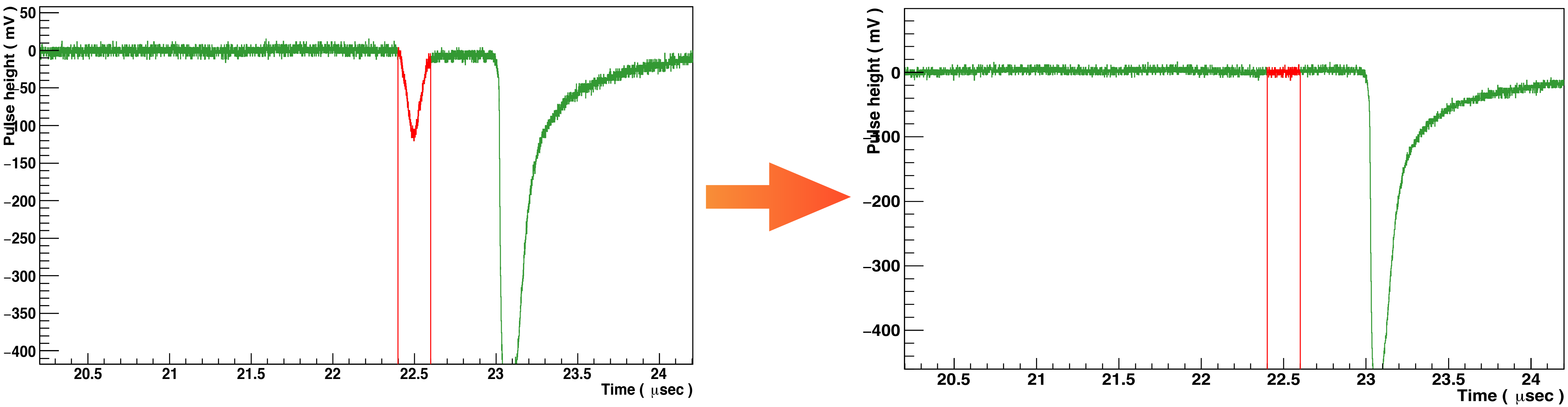
Extinction Measurement

and

It's Improvement

Extinction at MR Abort with FX beam -1-

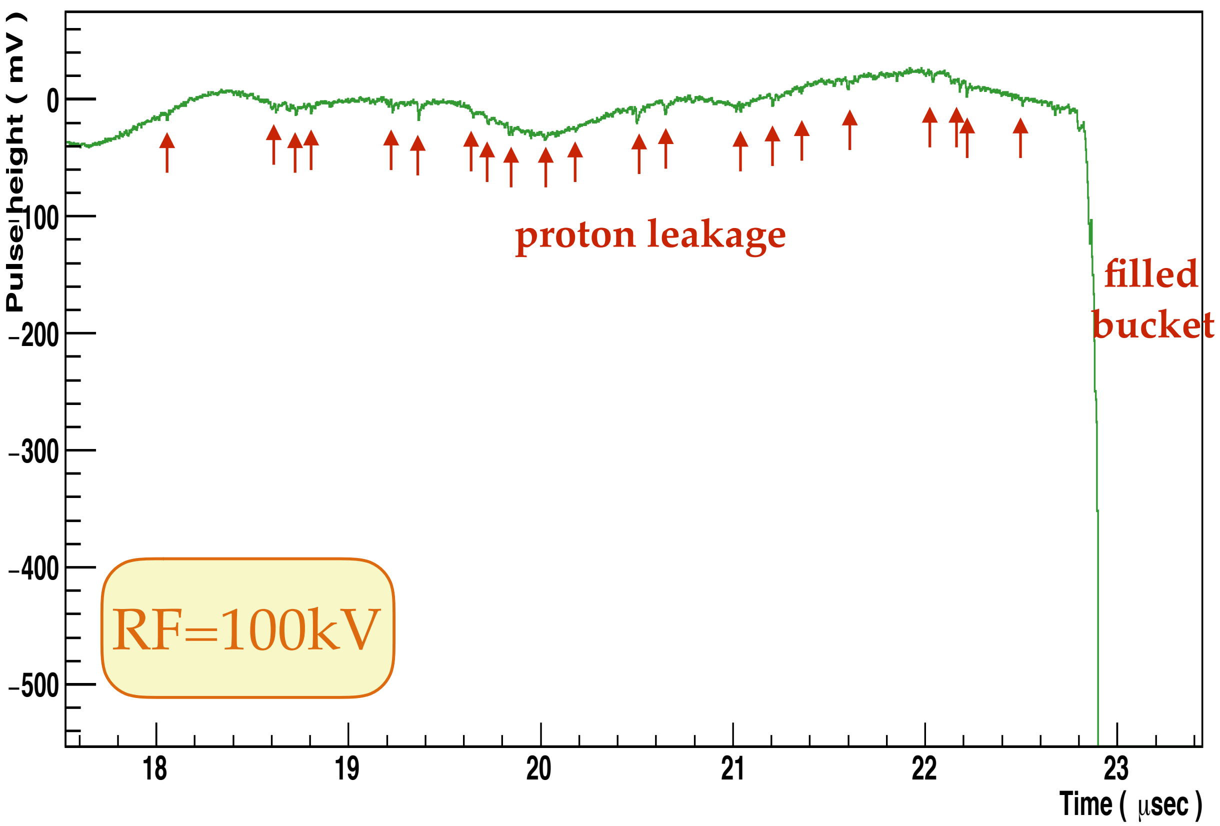
- **Demonstration of Single Bunch Kicking**

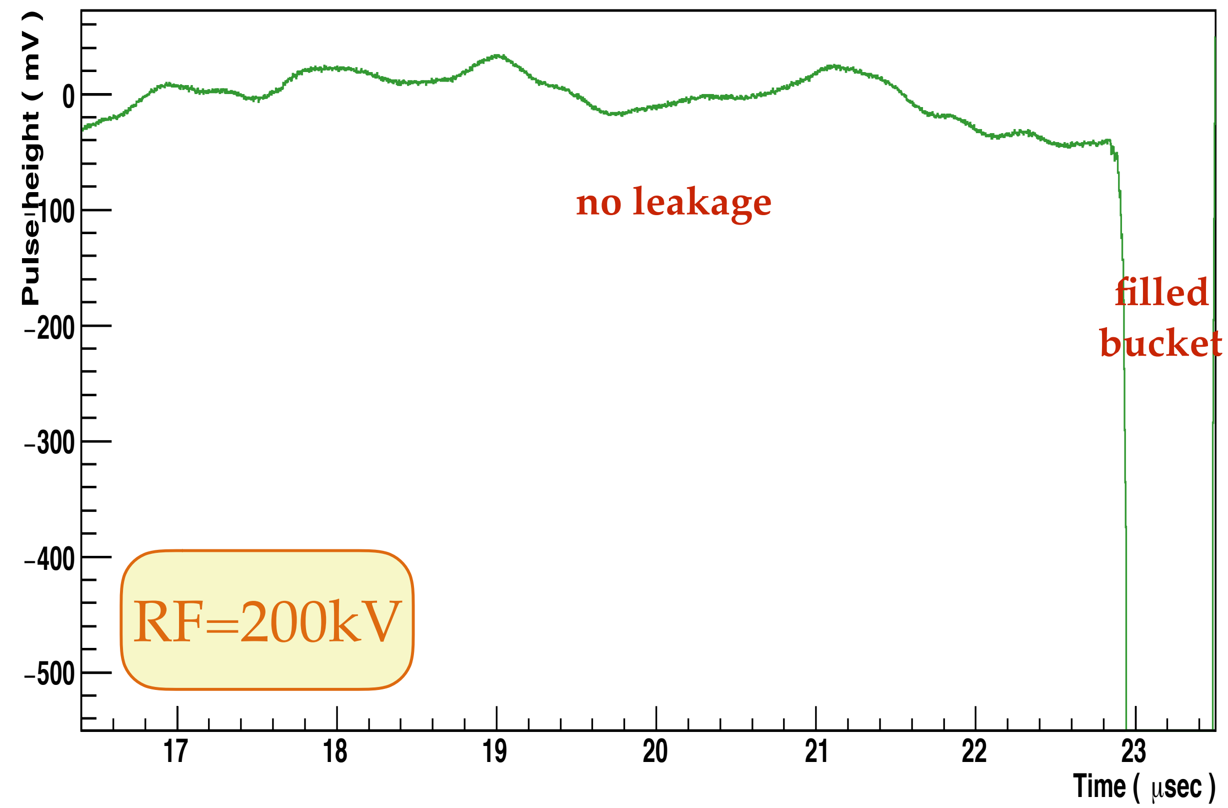


- In order to demonstrate the *"Single Bunch Kicking"* method,
  - Intermediate Intensity Proton (10^9 ppp) was injected
  - Only for the rear bucket of 4th batch (called "***K4_rear***" bucket)
  - Injection Kicker timing was shifted 600 nsec backward
- Abort Monitor showed a successful demonstration of Single Bunch Kicking
  - Before the kicker shift, small amount of residuals are shown in K4_front
  - After the kicker shift, no any protons are appeared in K4_front

Extinction at MR Abort with FX beam -2-

- **Fill the full intensity protons… (COMET Intensity = 1.6×10^{12} ppp)**

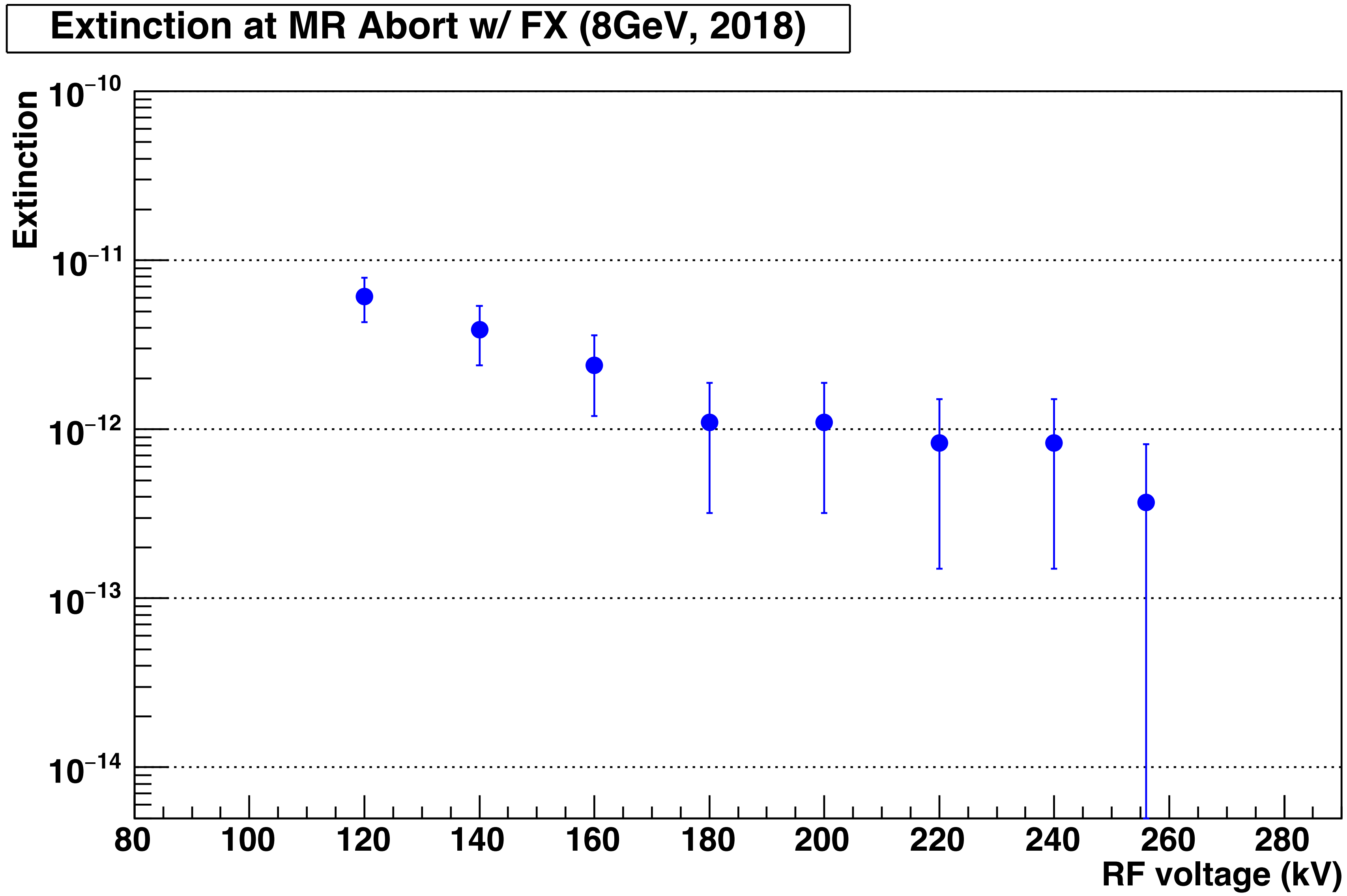




- If the full intensity proton for COMET operation is injected to K4_rear,
  - Some leaked proton signals are appeared even kicker timing is shifted
  - These protons are leaked over the potential wall of K4_rear RF bucket
- These can be avoided by keeping RF voltage high enough even during the flat-top
  - *eg*. Keeping RF of 200kV during the flat top,
  - A perfect extinction was realized !!

Extinction at MR Abort with FX beam -3-

- **Result of Extinction Measurement at Abort w/ FX as a function of RF voltage**



Realized Extinction

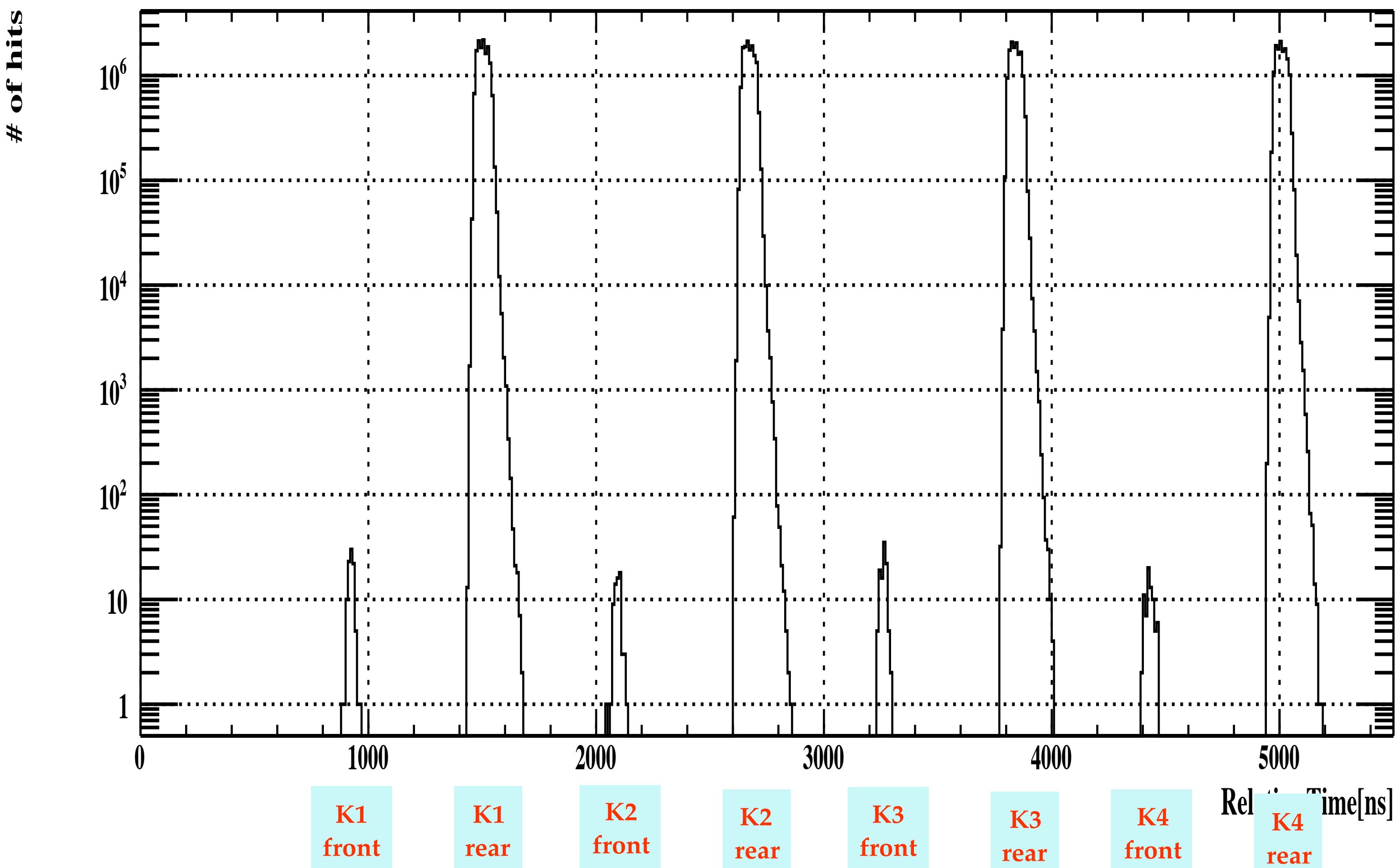
$10^{-11} \sim 10^{-12}$

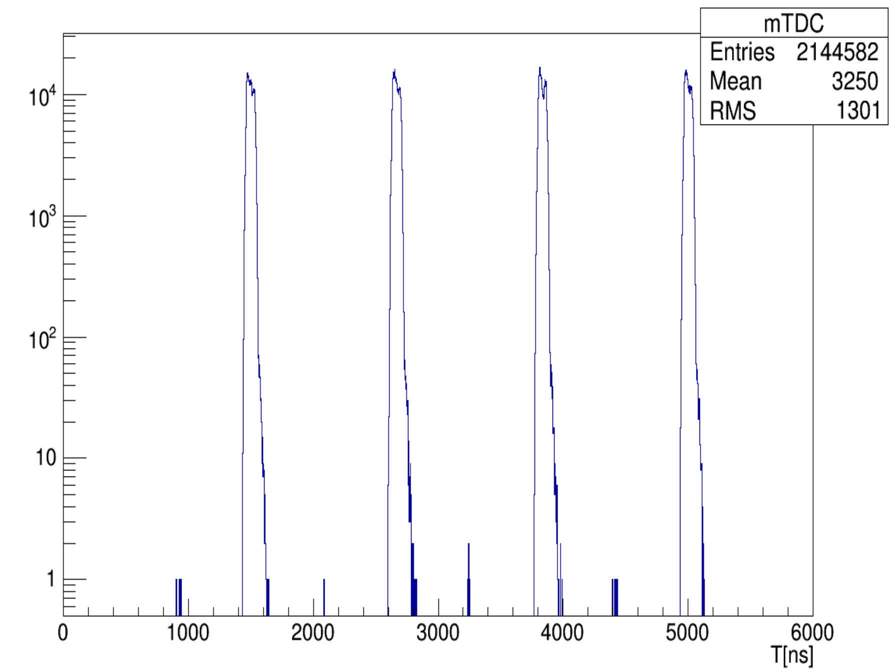
(At Abort w/ FX)

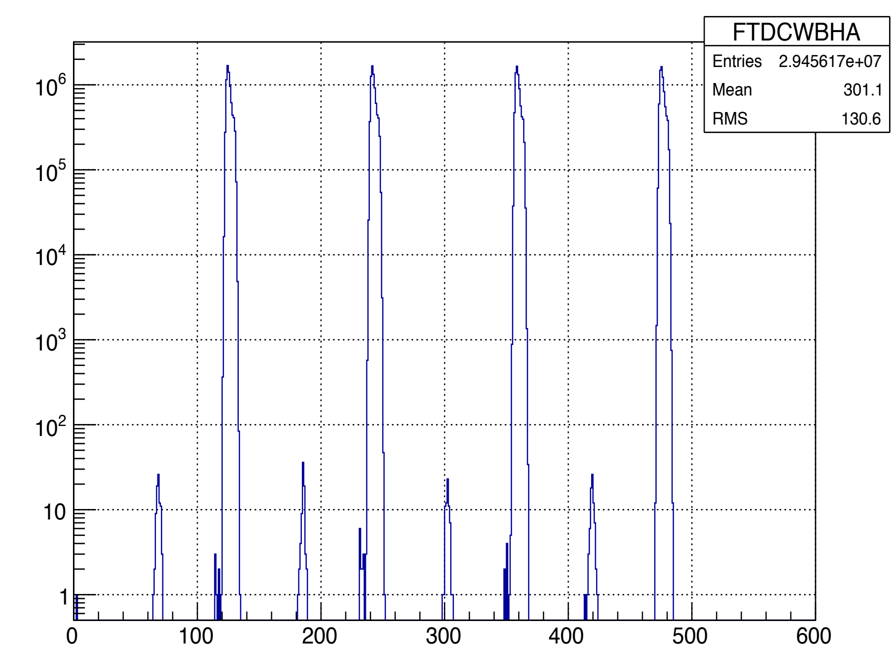
- Extinction can be improved by increasing RF voltage accordingly.
- Inside MR, good enough extinction is achieved by keeping RF high enough during flat-top. However it is mandate to demonstrate it **at Hadron w/ bunched-SX**.

Extinction at "Hadron" with Bunched-SX beam -1-

- **Initial Extinction was measured to check the precision of 3 TDCs**



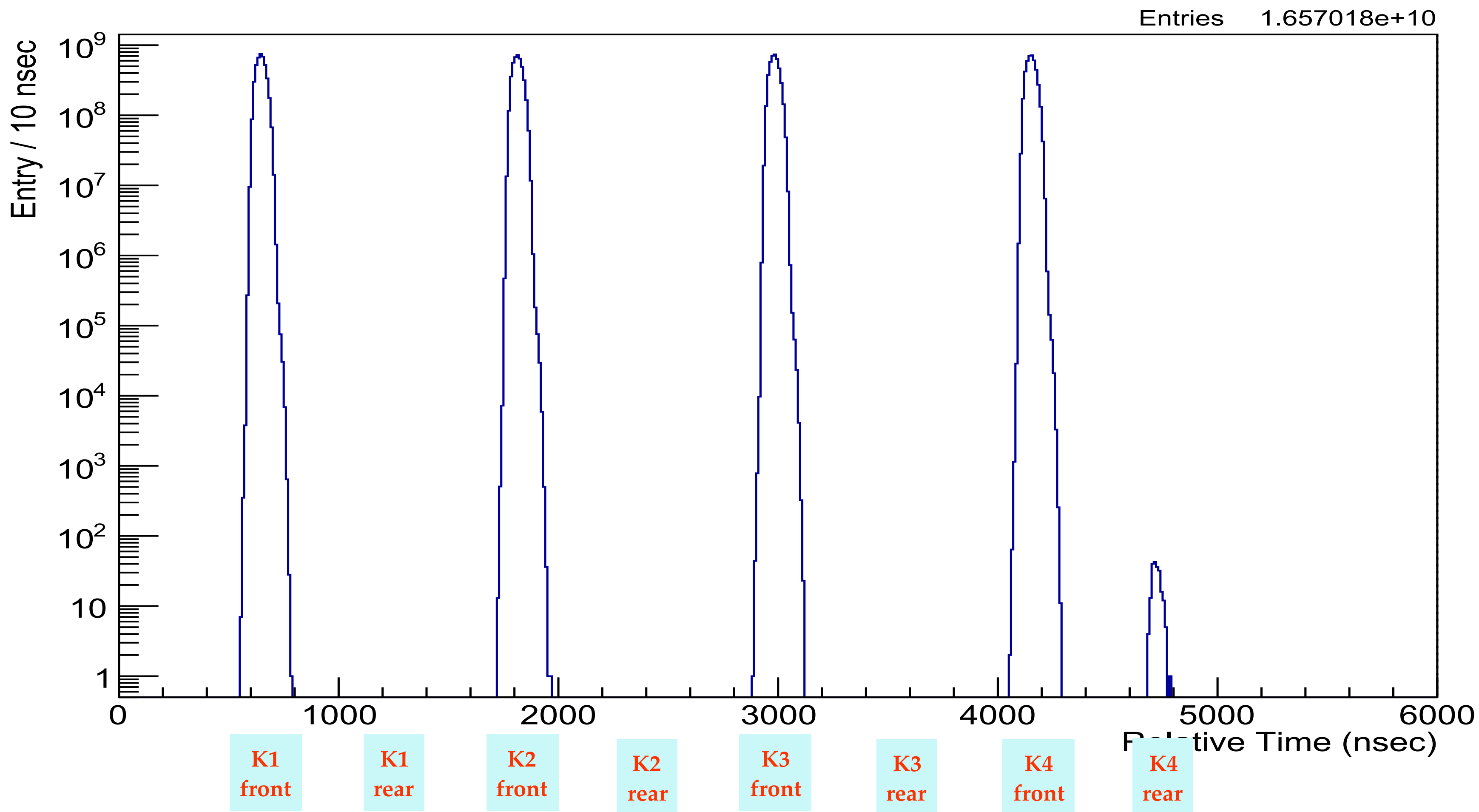




- Rear buckets were filled with protons of COMET intensity, **No kicker shift → Initial Extinction**
- Afraid the inefficiency of DAQ for filled bucket → Redundancy w/ 3 different TDCs → Good agreements
- Measured Initial Extinction = 7~8×10^{-6}, →Consistent with the result from studies w/ FX

Extinction at "Hadron" with Bunched-SX beam -2-

- **Result with kicker shift to realize an excellent extinction**



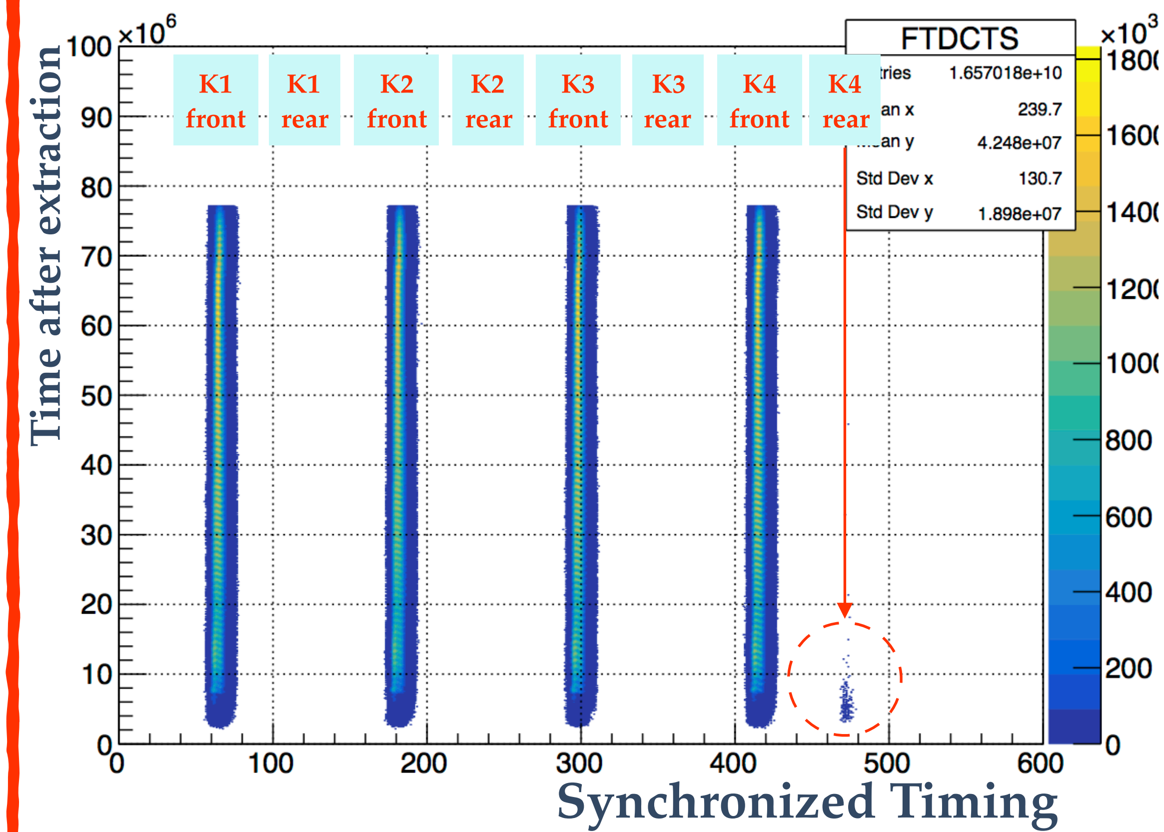
- Front buckets were filled with protons of COMET intensity (1.6×10^{12} ppp) and Injection Kicker was shifted 600 nsec forward
- **Perfect Extinction (= No Leak)** was realized for 3 Injection Batches (K1, K2 and K3)
- But…
  - Small amount of residual protons are shown in K4 rear…

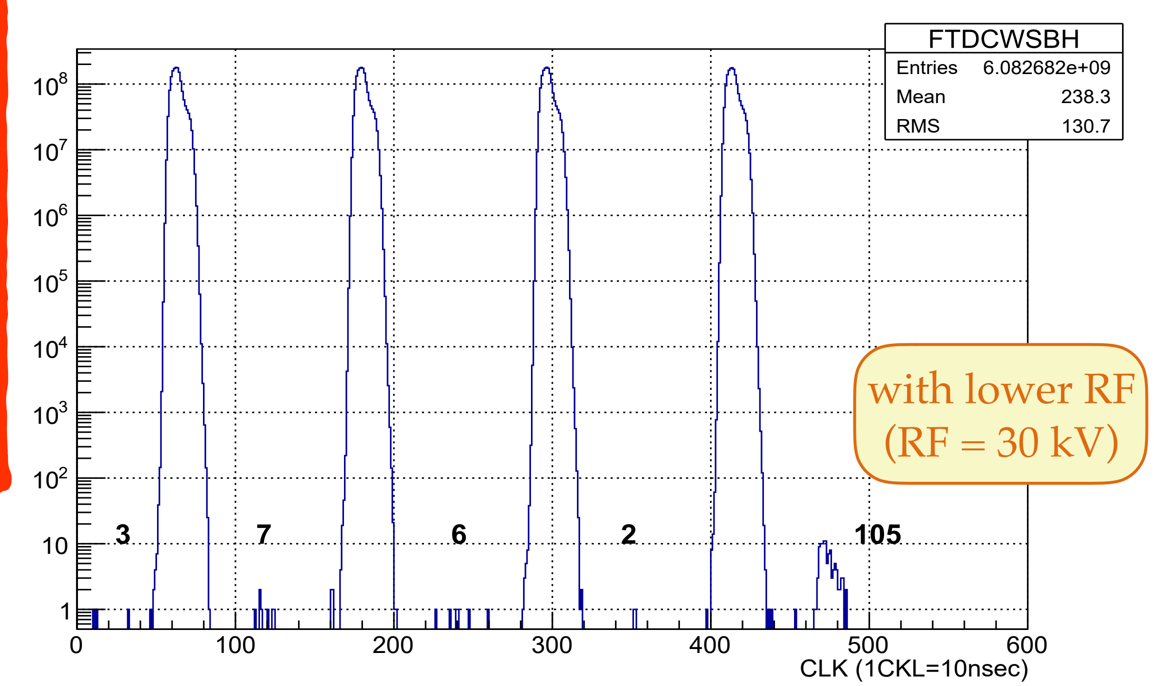
Extinction at "Hadron" with Bunched-SX beam -3-

- **Three feasible Scenarios;**

Scenario "A"	Mask the beginning events (<0.1s within extraction start)	6×10^{-10} Not enough
Scenario "B"	Avoid the 4th Injection (K4) (Use only K1, K2 and K3)	1×10^{-10} Just Matched
Scenario "C"	Solve K4_rear Mystery (Can use all bunch datas)	$<6\times10^{-11}$ Further Improvement

- *Scenario-A* doesn't match with the requirement, but *Scenario-B* can match.
- *Scenario-B* just matches with the requirement, but the beam power would be worsen.
- *Scenario-C* can realize the further improvement → As long as no leakage, experimental sensitivity will improve.





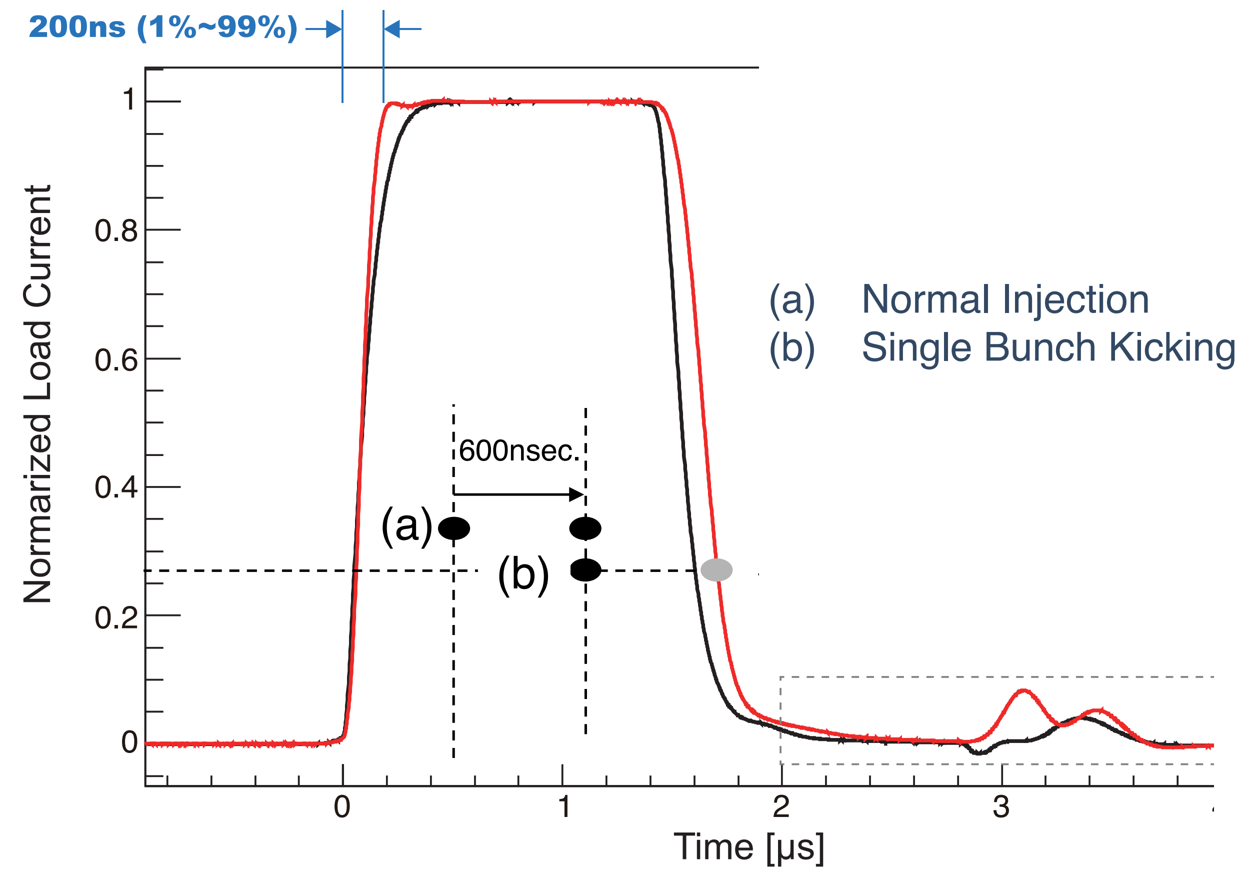
In order to realize ***Scenario-C***, analysis on leaked proton has been carried out carefully.

addendum

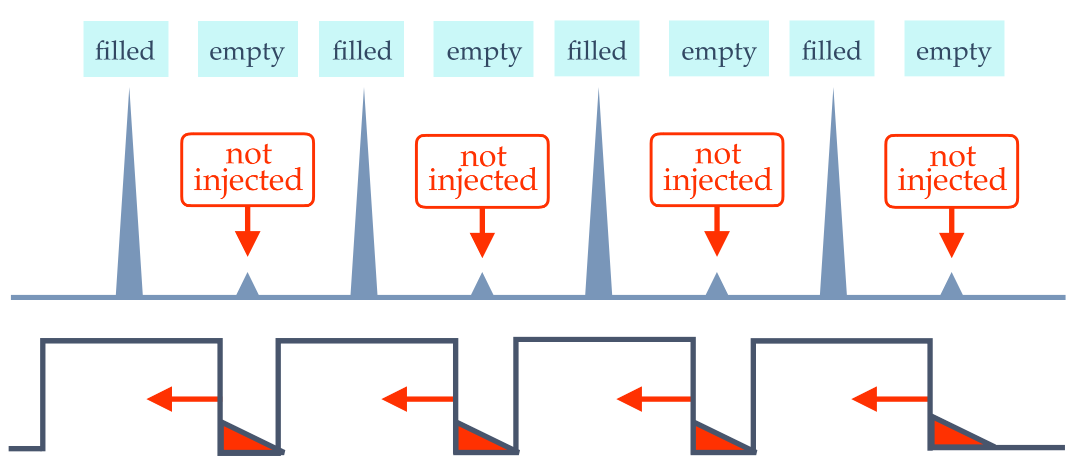
"What does cause K4_rear Mystery" ???

- **Most suspicious assumption:**
  - **Tail of Kicker Excitation ?**
  - **Injection Kicker filed has a small but a certain trailing component**
  - Shift for "Single Bunch Kicking" is half a excitation duration (= 600 nsec)
  - Shift of 600 nsec might be not long enough

    → **Can cause imperfect extinction**



- **Why only K4_rears shows a Mystery ?**
  - Every injection batch has a following injection immediately except for K4
  - Kicker excitation can extinct the residual protons in the prior batch

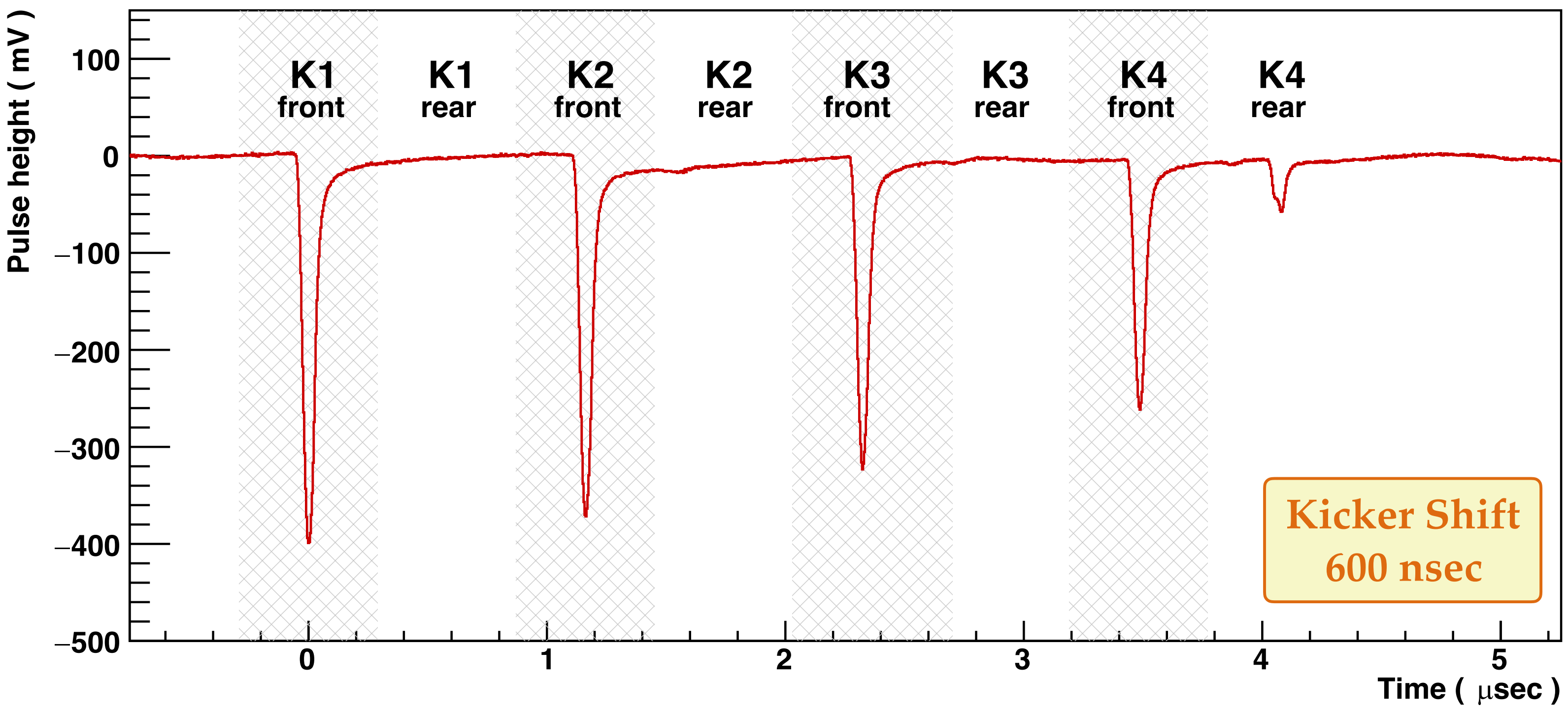


- **Can be tested quickly just shit the kicker timing little more**
- **Following kicker excitation might have a finite effect…**
- **Let's test it by FX !!**

A Quick Test

Preliminary (Feb.2019)

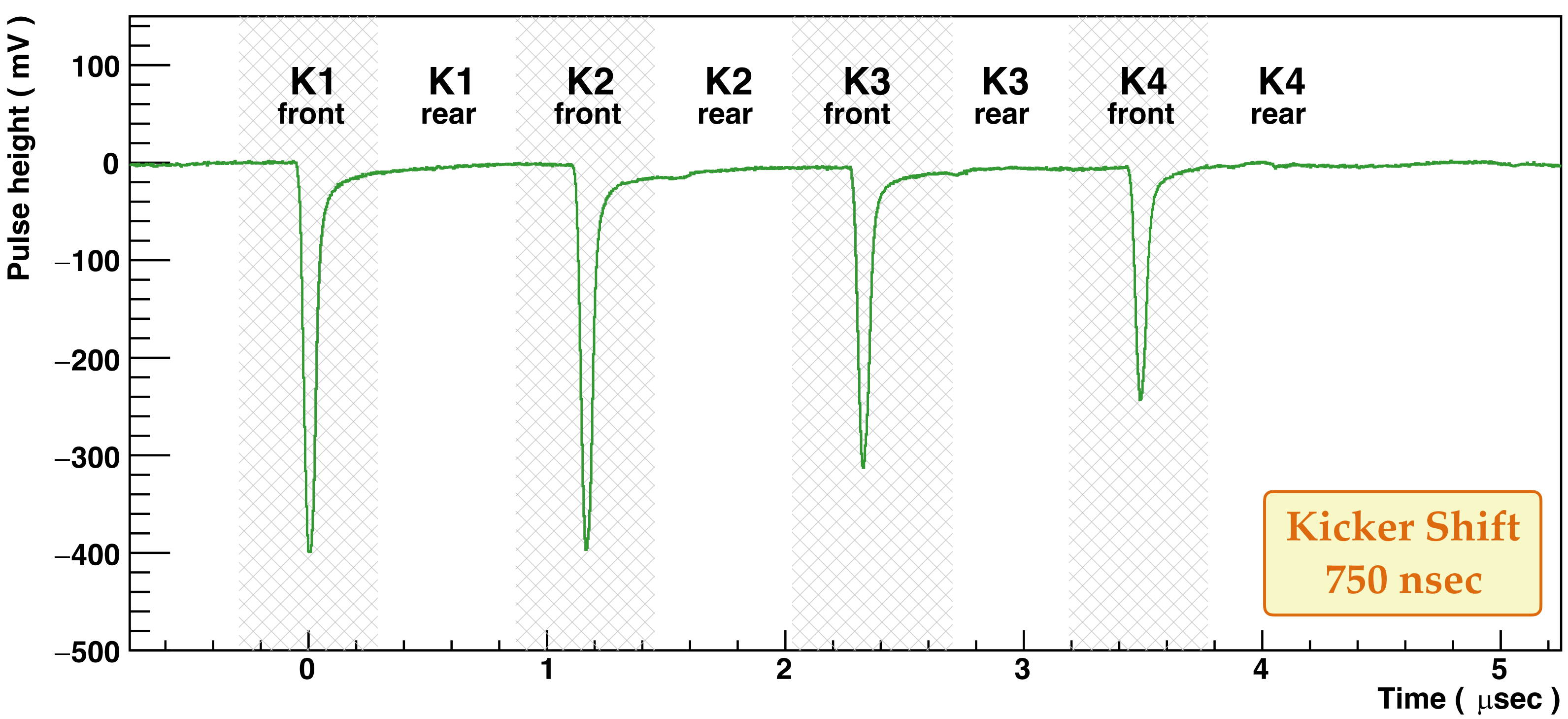
Reproduced



- Filled each front bucket and kicker timing was shifted 600 nsec forward

  ➡ Reproduced !

Solved



- Kicker timing was shifted 150 nsec more

  ➡ Solved !!!

Summary & Prospects

- Proton Extinction is one of the most important parameter for the COMET
  - Extinction should be better than 10^{-10} at least
- Three major requirements on J-PARC MR
  - 8 GeV acceleration instead of 30 GeV
  - 1.2 μsec bunch separation instead of 0.6 μsec
  - 10^{-10} extinction though nobody has taken care…

  } All demonstrated
- Result of extinction studies;
  - Perfect Extinction by K1, K2 and K3, but K4_rear has a tiny amount of residual protons
    - Extinction = 1×10^{-10}, if K4 would be thrown away
    - Extinction < 6×10^{-11}, if K4_rear Mystery would be solved
    - Experimental Sensitivity will be improved accordingly as long as extinction will be improved.
- Most suspicious source of "K4_rear Mystery" was confirmed by a quick test at Abort with FX → Should be demonstrated at Hadron with B-SX

➡ J-PARC MR is READY for COMET