COMET,

An experiment to search for mu-e conversion in a nuclear field

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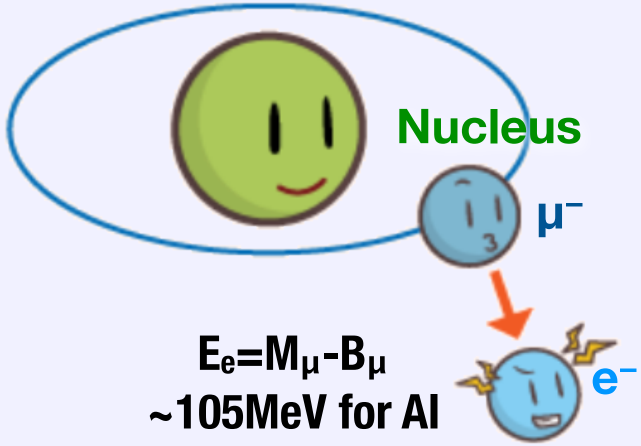
on behalf of COMET collaboration

COMET Collaboration

15 countries, 33 institutes
176 collaborators

Physics Motivation

Muonic atom and μ-e conversion



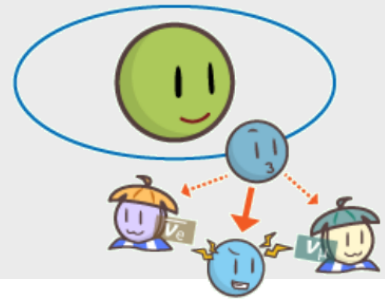
- $\mu^- + (A,Z) \rightarrow e^- + (A, Z)$
- Charged Lepton flavor violating (CLFV) process. Not yet discovered
- Standard Model: Br=0

  SM+ν-oscillation: Br<10^{-54}
- Several BSM predicts Br~10^{-15}
  - Clear Evidence of NP

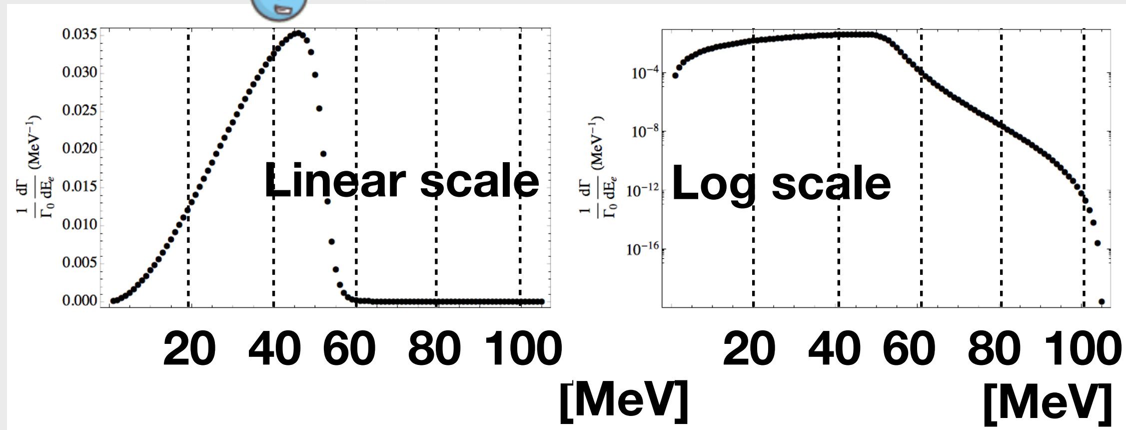
Normal reactions

Decay In Orbit (DIO)

$\mu \rightarrow e\nu\nu$, E_e < 105MeV

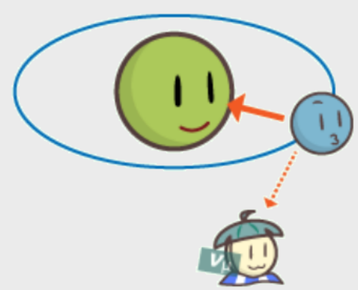


Originally from Czarnecki (2011)



DIO energy spectrum for Al

Muon capture



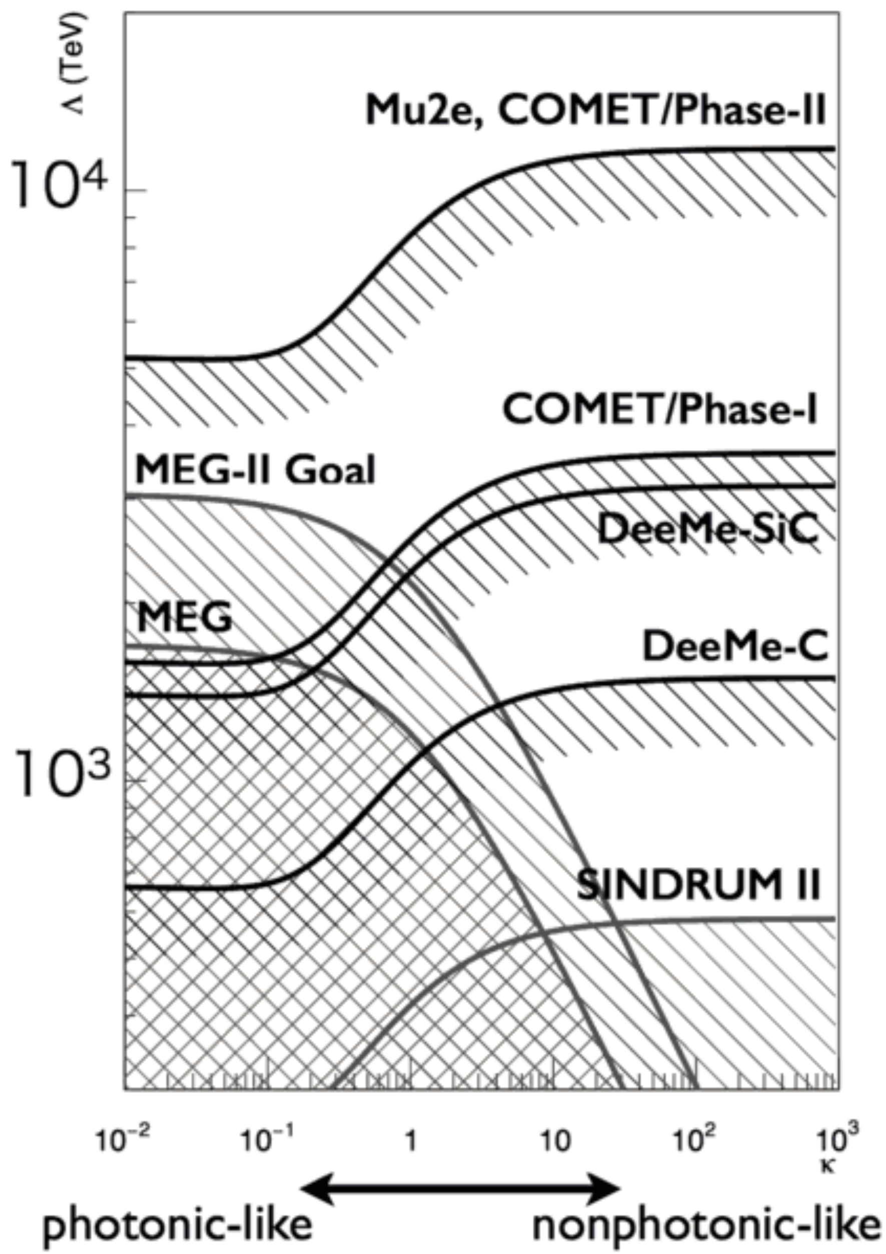
$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z\text{-}1)$

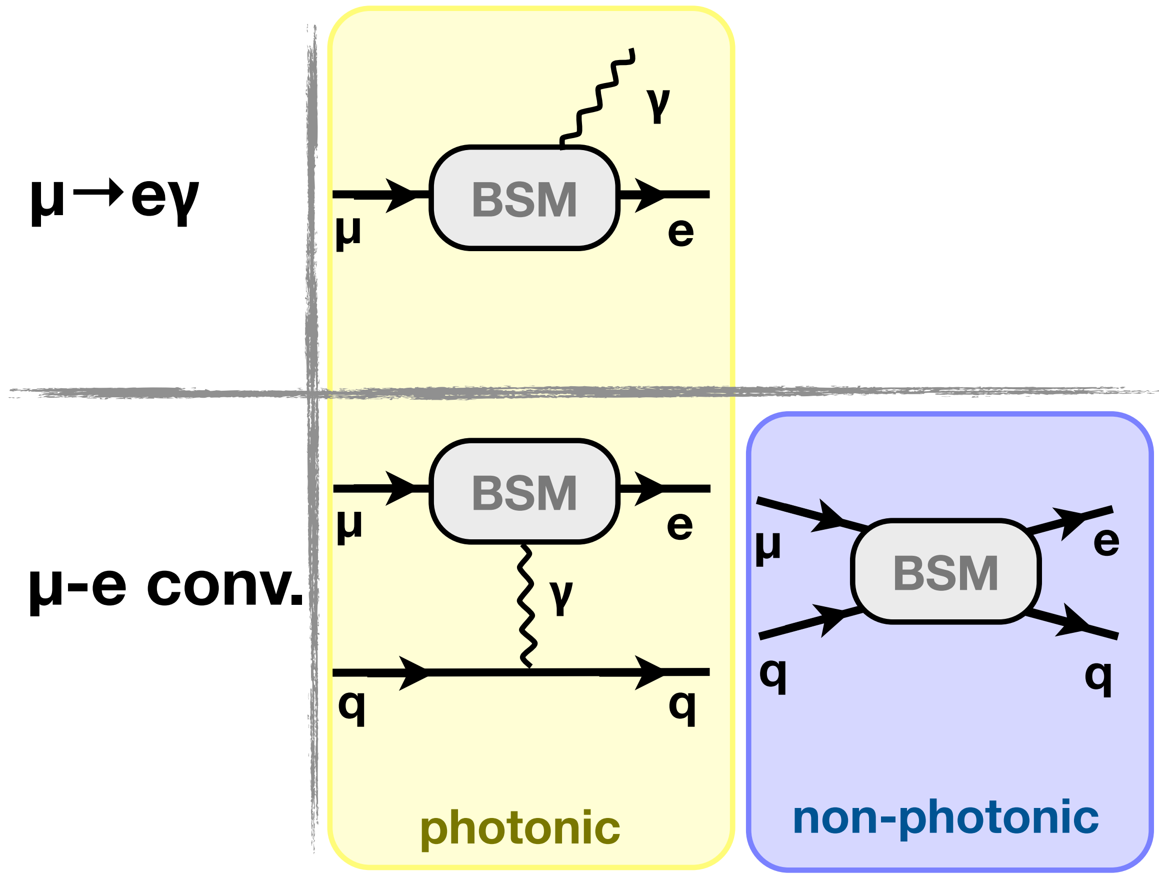
Larger Br for larger Z

Shorten lifetime of muonic atom

μ-e conversion and μ→eγ

originally from Andre de Gouvea (2013)



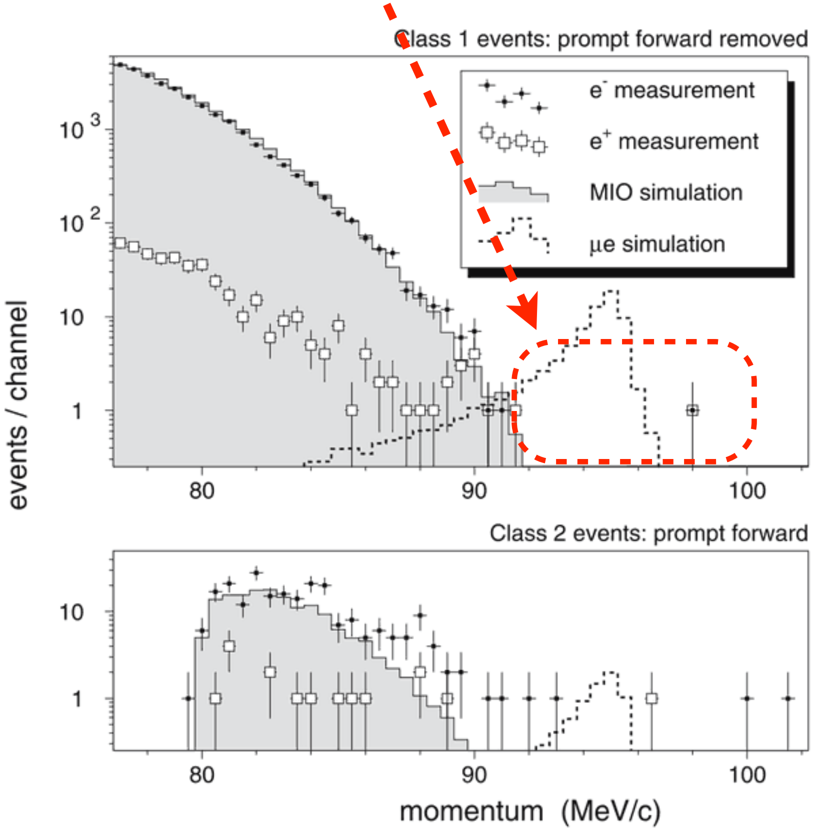


- μ-e conversion search explores > 10^3 TeV
- Complemental to other CLFV (eg. μ→eγ)

COMET Overview

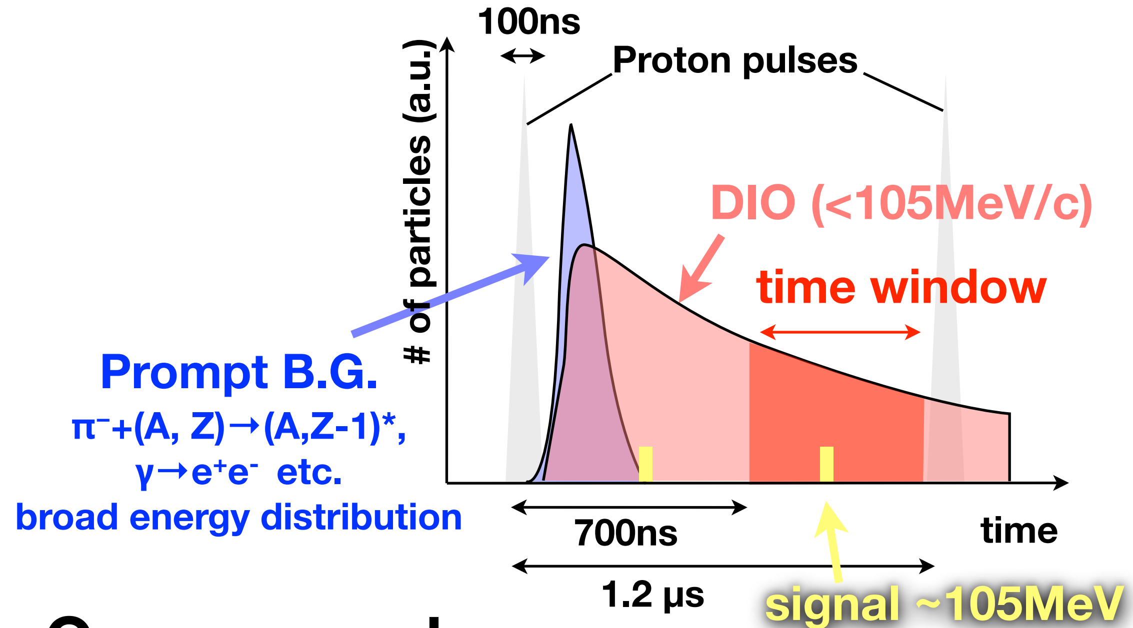
Experiment Strategy

- **SINDRUM II**
  Br(μ-e conv. Au) < 7×10^{-13}
  - **DC beam, heavy nuclei**
  - **O(1) probably beam B.G.**



Eur. Phys. J. C 47, 337–346 (2006)

(E_{signal}=95.56 MeV for Au)

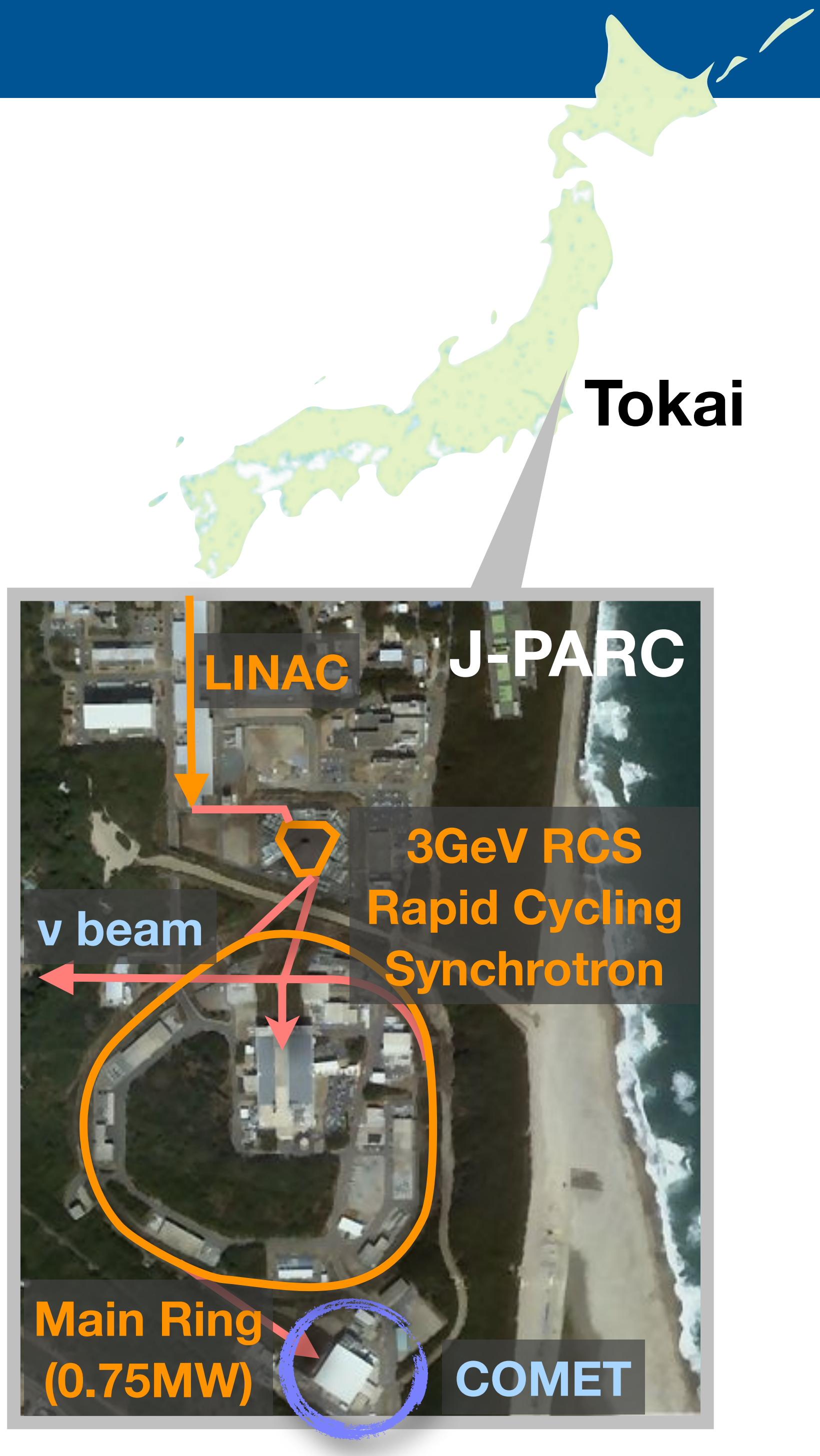


Our approach

- **Pulsed beam, delayed signal window, light but not too light nucleus (COMET selects Al)**
  - **Heavier nucleus, larger overlap with muon wave function, but shorter lifetime ($\tau_{(Au)}$~0.07μs, $\tau_{(Al)}$~0.9μs)**
- **Need more intense beam**

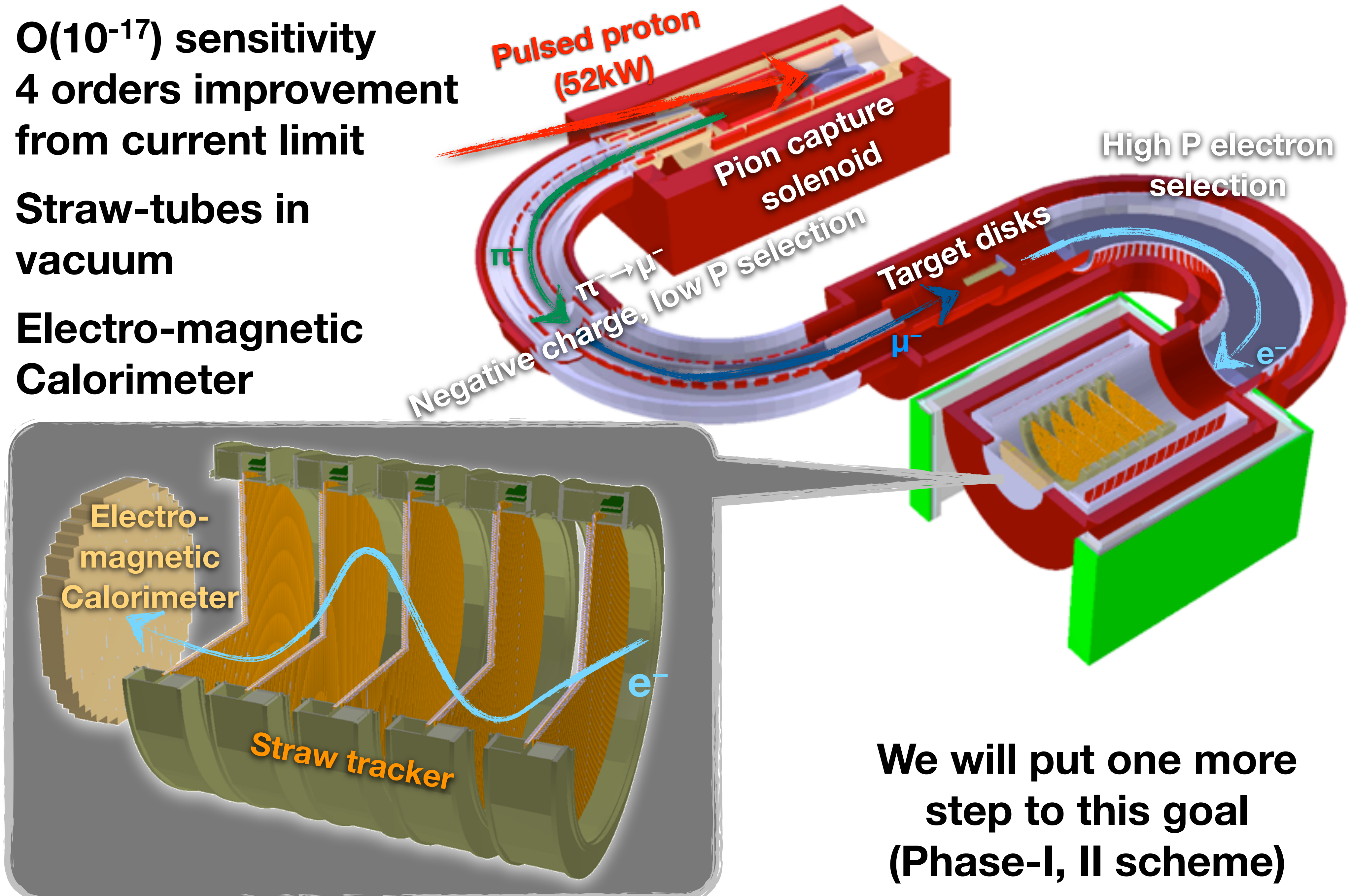
Experiment site

- High statistics: > 10^{18} muons stopped on target
  - High power 8 GeV, 1.2 μs repetition proton beam at J-PARC
    3.2 (56) kW for Phase-I (Phase-II)
- Good extinction factor : (off-timing proton)/(proton in bunch) << 10^{-9} (our requirement)



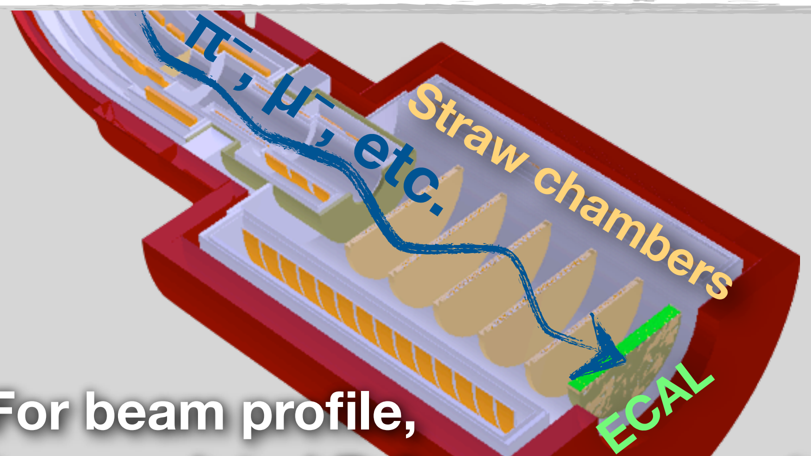
COMET (Phase-II)

- O(10^{-17}) sensitivity
  4 orders improvement from current limit
- Straw-tubes in vacuum
- Electro-magnetic Calorimeter

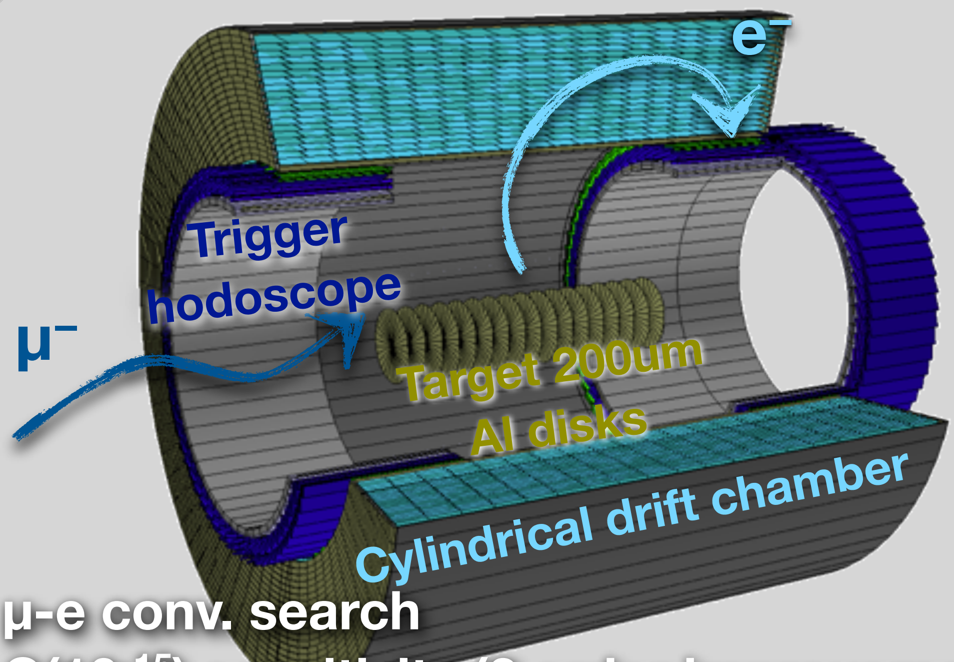


We will put one more step to this goal (Phase-I, II scheme)

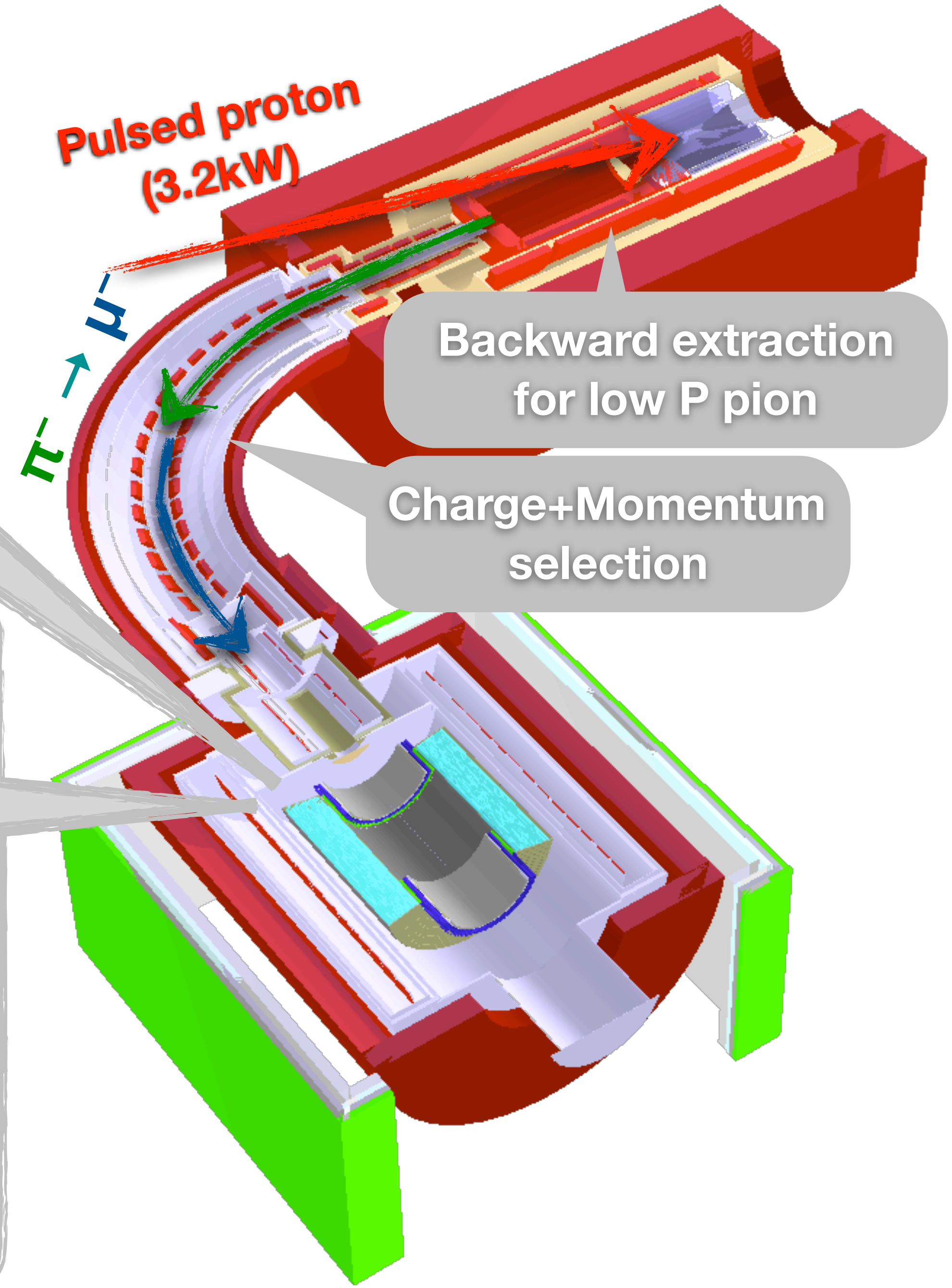
Phase-I with 2 kinds of detectors



For beam profile,
beam related B.G. measurement
Validation of Phase-II detector



μ-e conv. search
$O(10^{-15})$ sensitivity (2 order improvement)



Background estimation (Phase-I)

Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	
	All (*) Combined	≤ 0.0038
	Radiative pion capture	0.0028
	Neutrons	$\sim 10^{-9}$
Delayed Beam	Beam electrons	~ 0
	Muon decay in flight	~ 0
	Pion decay in flight	~ 0
	Radiative pion capture	~ 0
	Anti-proton induced backgrounds	0.0012
Others	Cosmic rays†	< 0.01
Total		0.032

† This estimate is currently limited by computing resources.

Phase-I Sensitivity

$$\text{S.E.S} = \frac{1}{N_\mu \times f_{cap} \times f_{gnd} \times A_{\mu e}} = 3 \times 10^{-15}$$

($< 7 \times 10^{-15}$, 90%C.L. with 0.032 B.G.)

$N_\mu = 1.5 \times 10^{16}$: # of muon stop on target disks

muon yield : 4.7×10^{-4} muons / one proton hit on target

3.2kW and 1.26×10^{7} sec operation (~146 days)

$f_{cap} = 0.61$: Fraction (muon capture) / (muon stop on target)

$f_{gnd} = 0.9$: Fraction of nucleus is not excited by μ-e conv.

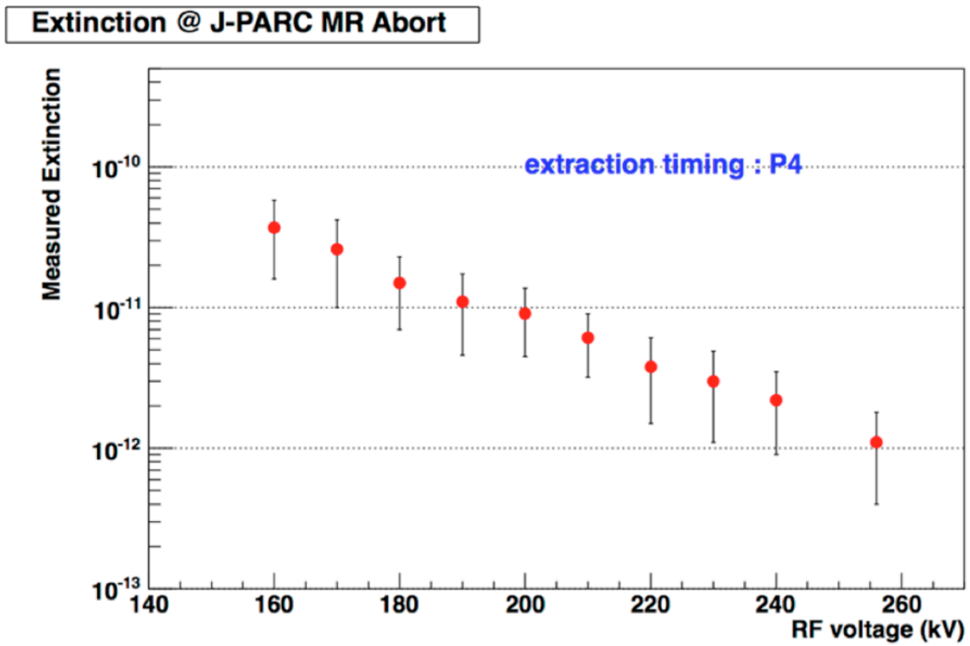
$A_{\mu e} = 0.041$: Total acceptance for μ-e electron

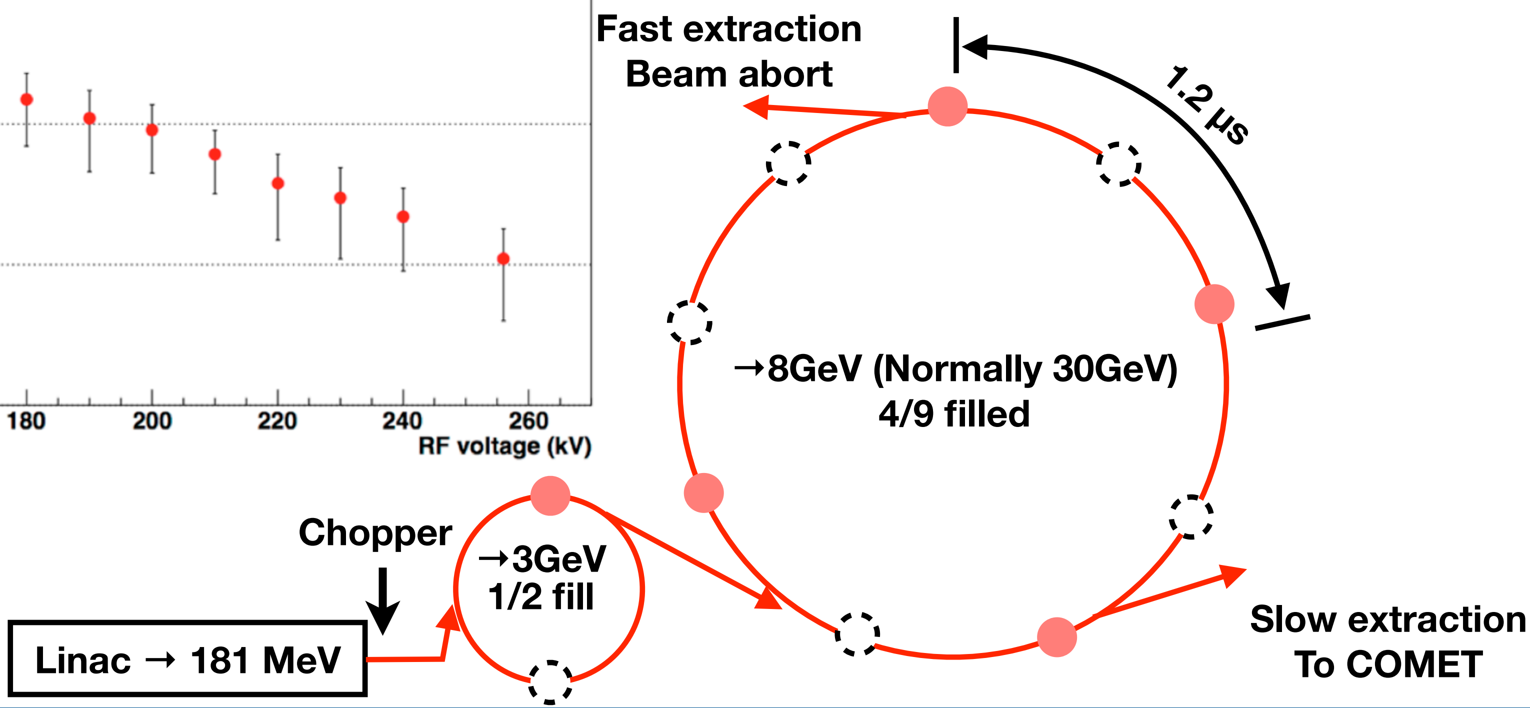
Event selection	Value	Comments
Online event selection efficiency	0.9	Section 16.1.3
DAQ efficiency	0.9	
Track finding efficiency	0.99	Section 13.5.1
Geometrical acceptance + Track quality cuts	0.18	
Momentum window ($\varepsilon_{\mathrm{mom}}$)	0.93	103.6 MeV/c < P_e <106.0 MeV/c
Timing window ($\varepsilon_{\mathrm{time}}$)	0.3	700 ns < t < 1170 ns
Total	0.041	

Preparation Status

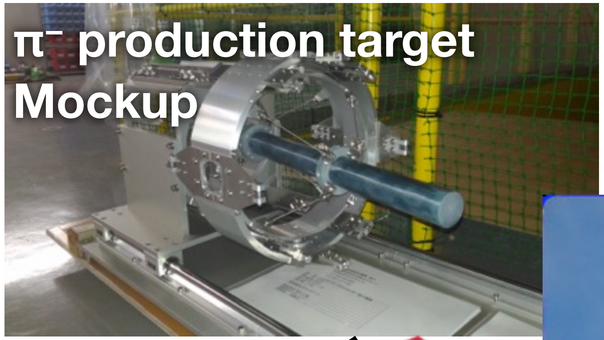
COMET Beam mode

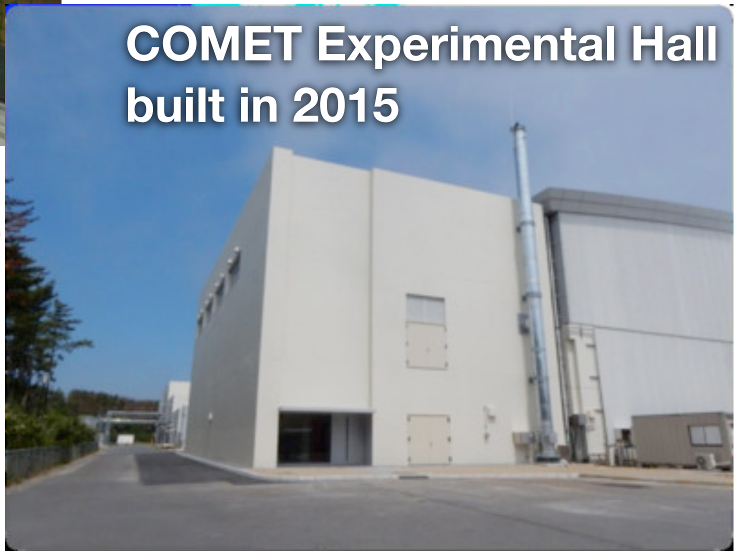
- **COMET beam mode operation is already tested**
- **Extinction: (off-timing proton)/(proton in bunch)**
  - **Requirement: 10^{-9} for 10^{-17} sensitivity**
  - **Measured 1×10^{-12} @ FX with 8 GeV COMET operation. To be measured with slow extraction.**

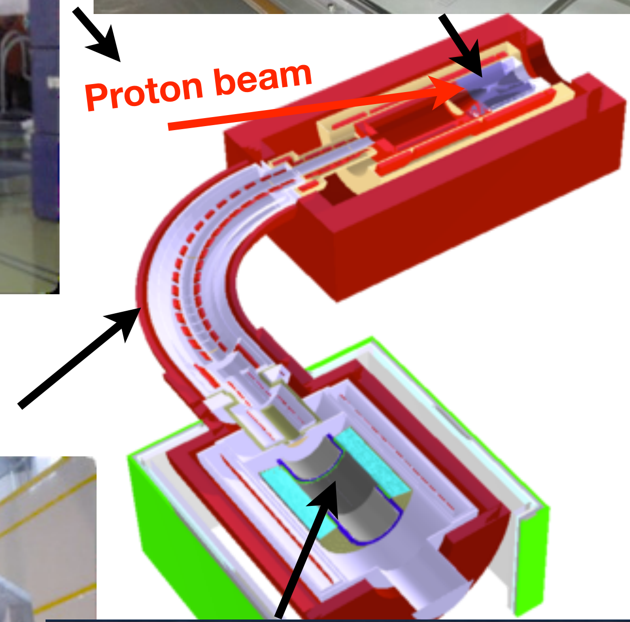


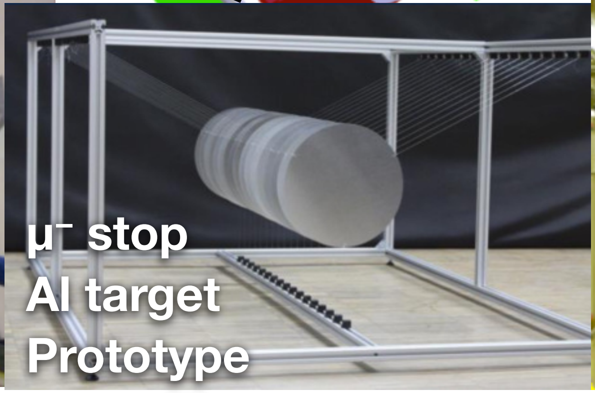


Facility, beamline elements



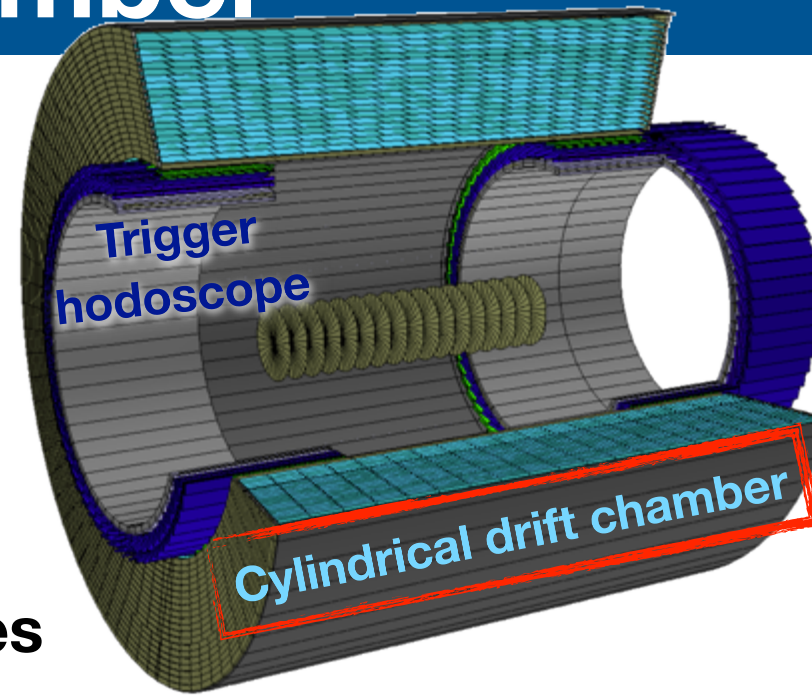


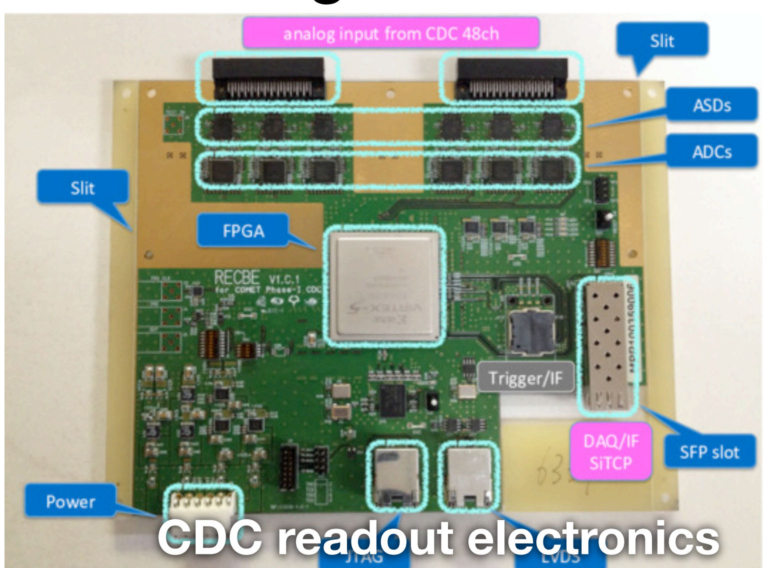




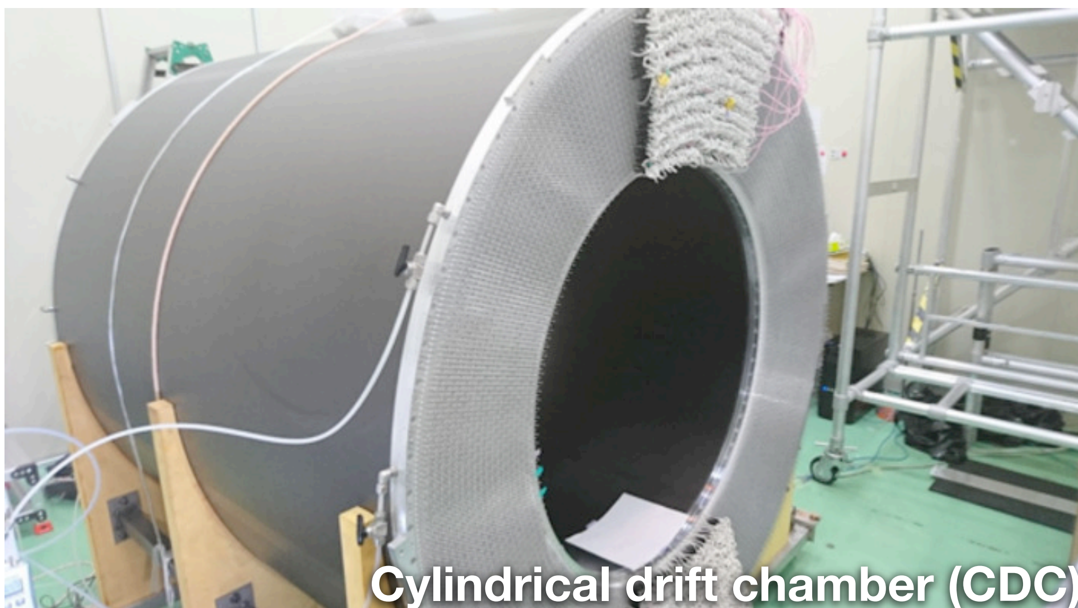
Cylindrical drift chamber

- Final detector constructed (June 2016)
  - Position resolution < 200um (cosmic-ray measurement w/o B)
  - Momentum resolution 195keV/c by simulation
  - 20 layer stereo wires ~15,000 field wires, ~5,000 sense wires
  - radius: 496 to 840mm (Accept >60MeV/c)
  - He based gas mixture



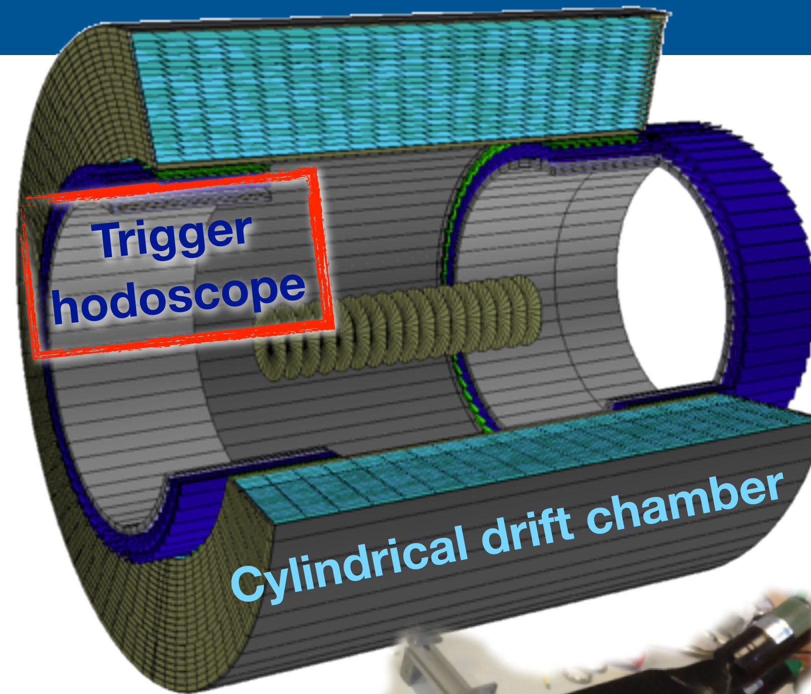


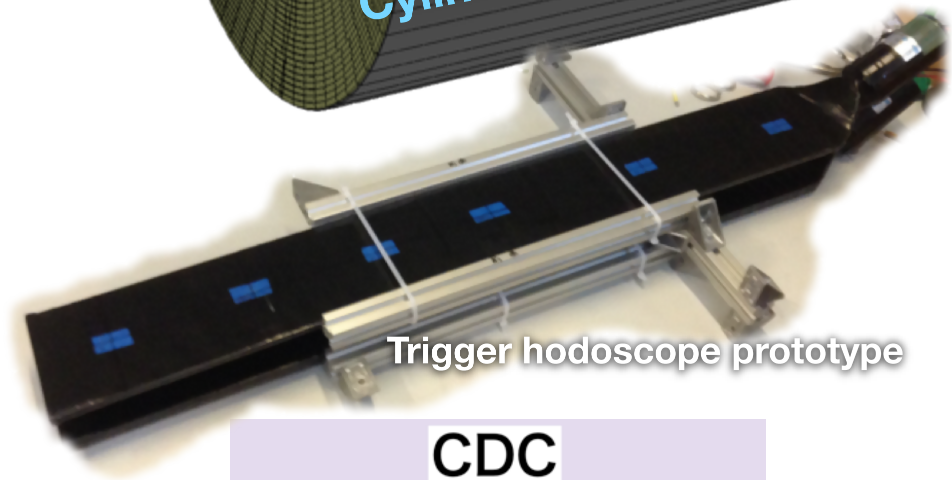
CDC readout electronics

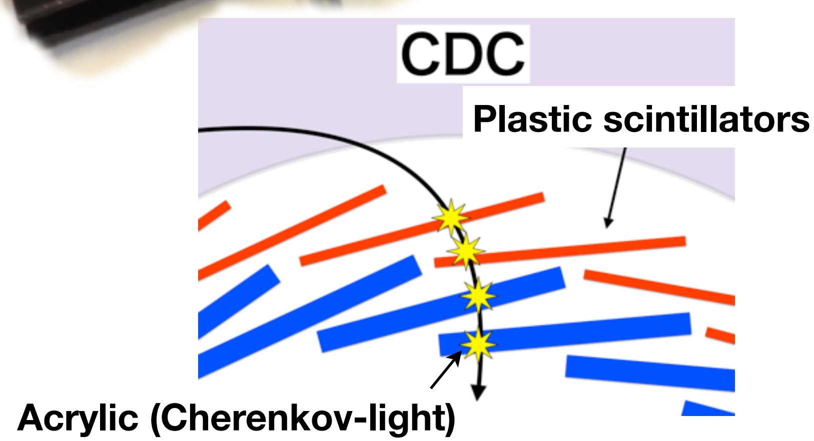

Cylindrical drift chamber (CDC)

Trigger hodoscope

- Acrylic bar (Cherenkov light) identify particle
- Plastic scintillator measures timing and position
- Readout by fine-mesh PMT for operation in magnetic field
- 4 (2×Acrylic & 2×Scintillator) coincidence for trigger
- S/N > 100, σ_{time} < 0.8ns measured

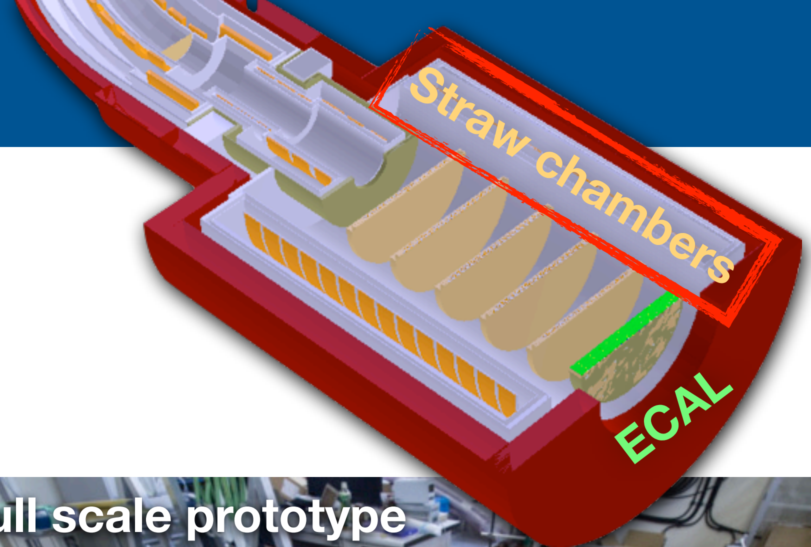


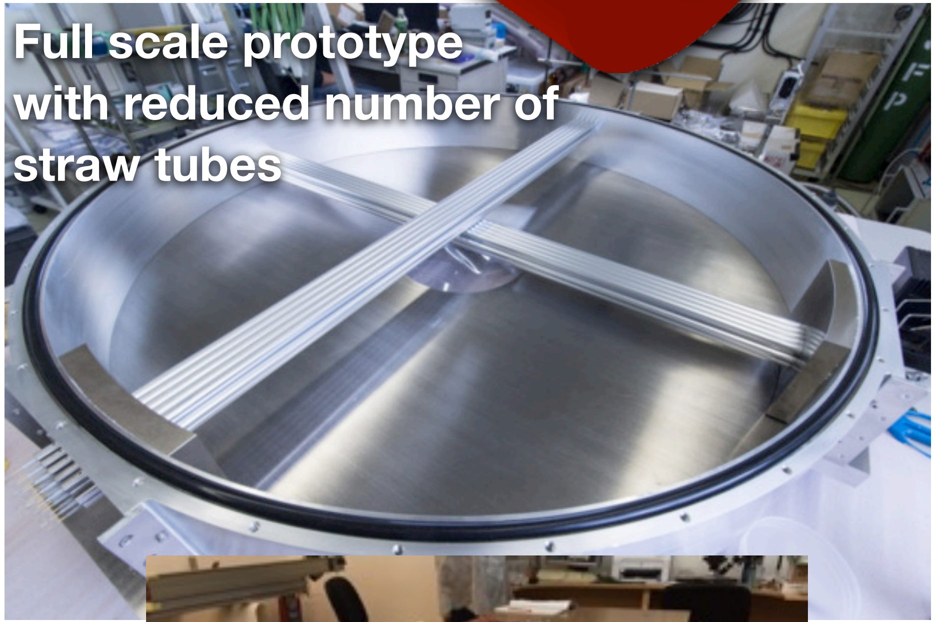




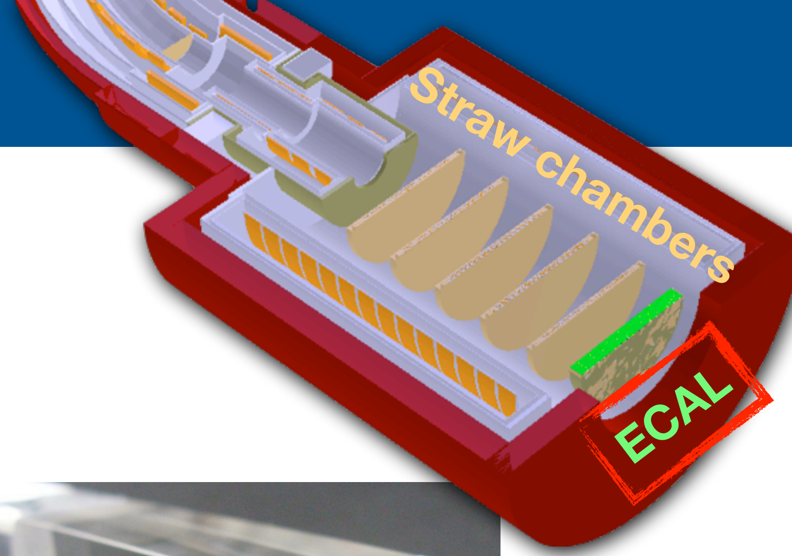
Straw tracker

- Al (70nm) laminated Mylar (20μm) tubes with 9.75mmϕ (15μm thickness, 5mmϕ for Phase-II)
- Ar/Ethane or Ar/CO2
- Position resolution < 200μm measured with prototype (corresponds to σ_P < 200keV)
- Operation in vacuum (<0.1 Pa) achieved with prototype
- Mass production of Phase-I straws completed

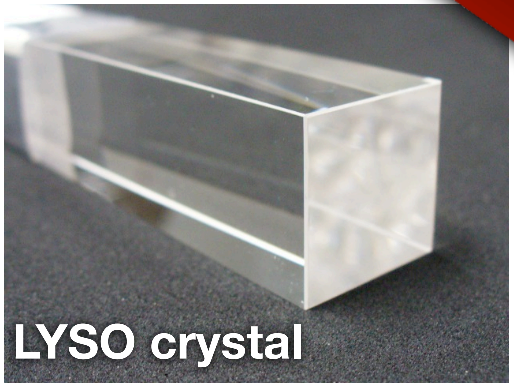


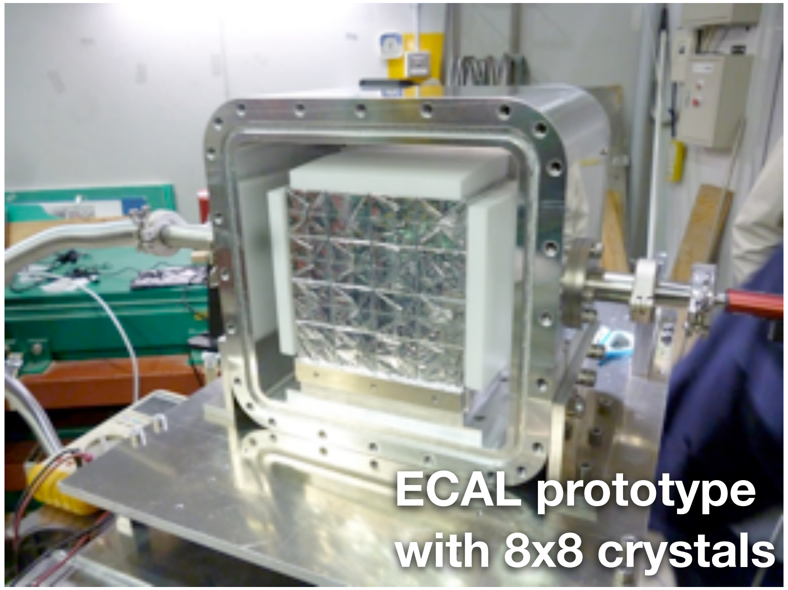


Calorimeter



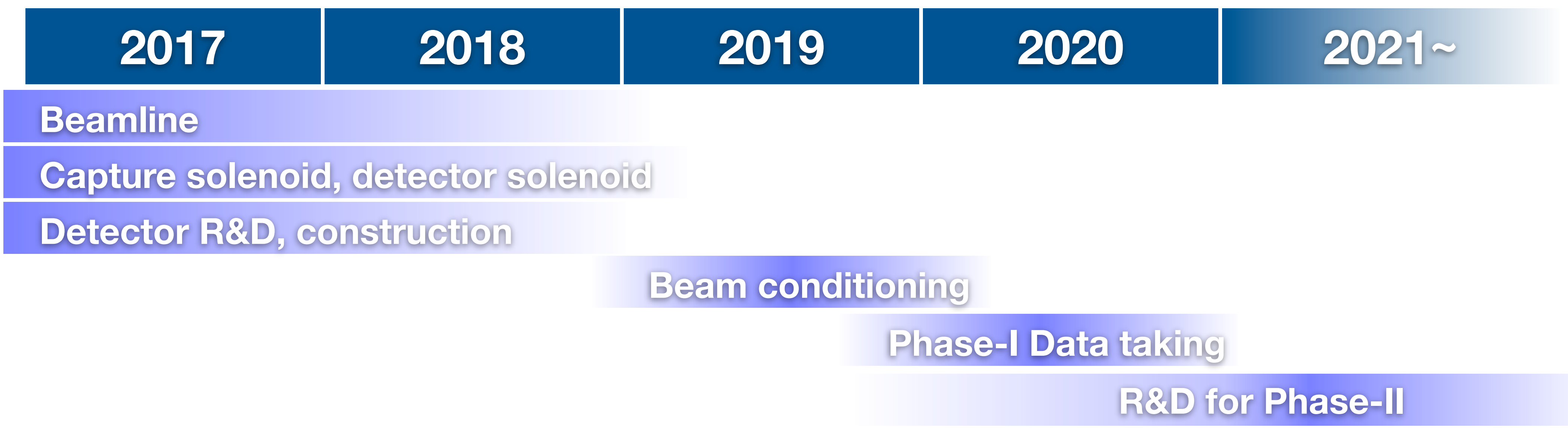
- < 5% Energy resolution is needed for affordable trigger rate
- > 90% Particle identification ($e^-/\mu^-/\pi^-$) with data + MC evaluation
- 2 × 2 × 12 cm^3 LYSO crystals with 10 ×10 mm^2 APD
- Prototype shows
  - Energy resolution: 4.2%
  - Position resolution: 7.7mm
  - Timing resolution: 0.4ns
- ~2000 crystals (covers 1mϕ) will be prepared for Phase-I


LYSO crystal


ECAL prototype with 8x8 crystals

Summary and schedule

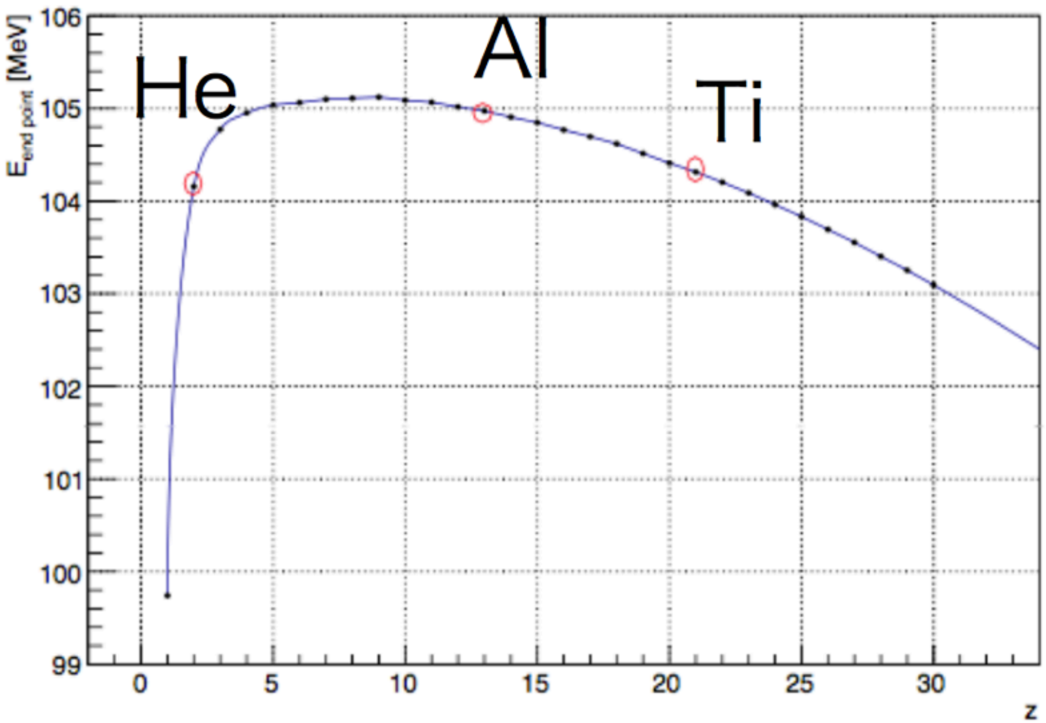
- COMET aims to search for μ-e conversion with sensitivity of $O(10^{-17})$ (Phase-II)
- COMET at first concentrate on Phase-I to
  - Search for μ-e conv. with sensitivity of $O(10^{-15})$
  - Perform a direct measurement of the beam profile and backgrounds
- R&D and construction are progressing



End of slide

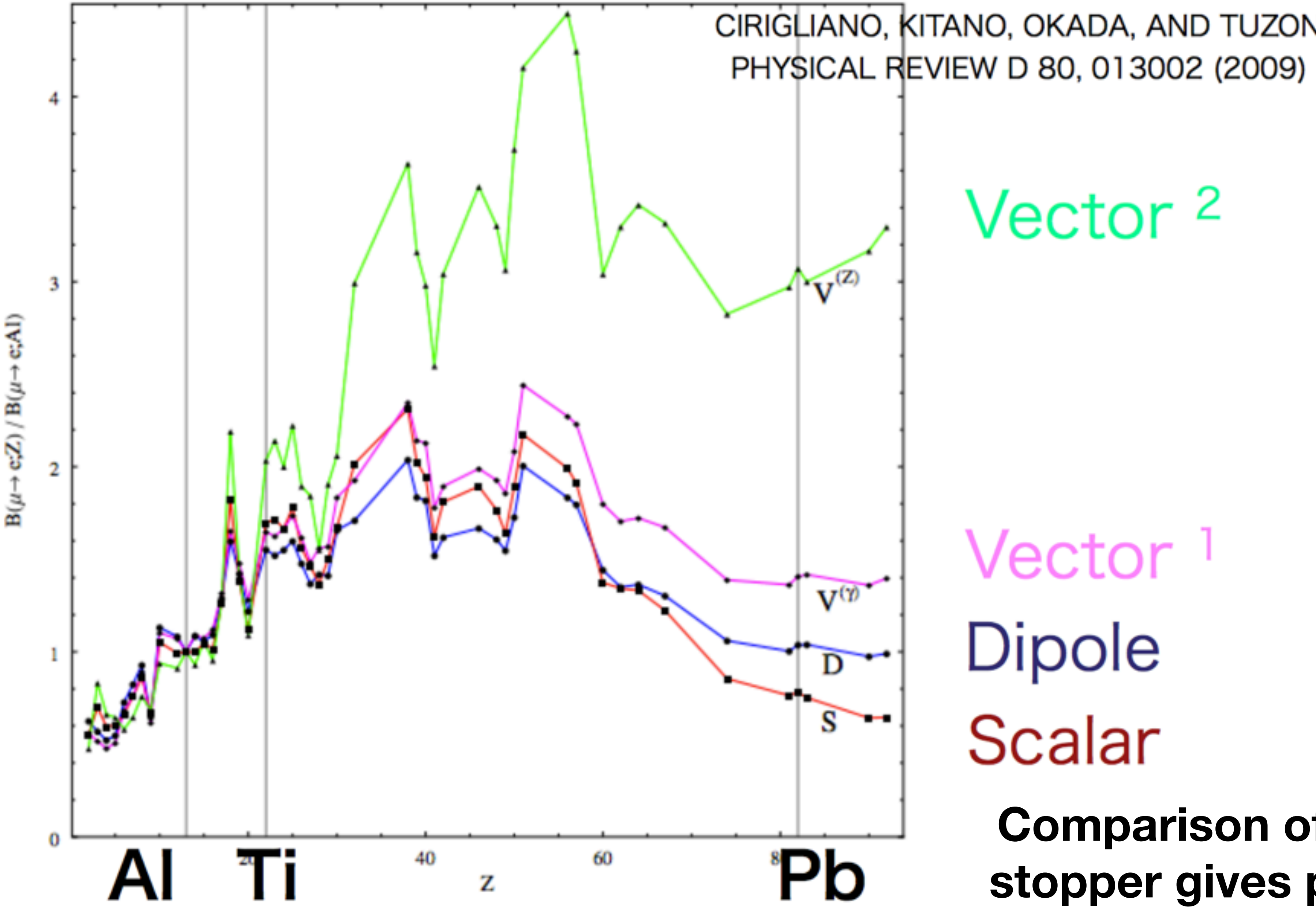
Muon stopping target material

- Heavier Z, smaller signal energy
(larger binding energy)
- Using Al, better to avoid Z=1 to 12,
He is OK to be used around target
- Heavier Z, shorter lifetime due to larger fraction of muon capture



	Al	Ti
lifetime	864 ns	330 ns
time window	0.3	0.2
signal	1	1.5
net	0.3	0.3

Target material vs physics



Comparison of muon stopper gives physics information

- **Diamond detector development for extinction measurement**