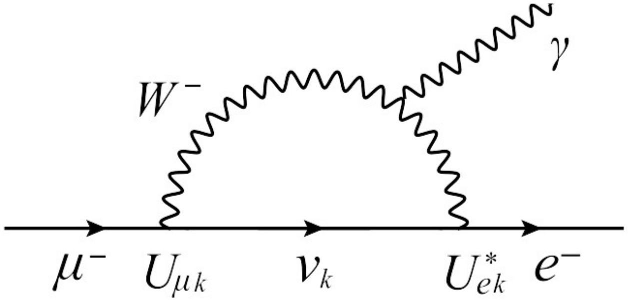
A Two-Stage Approach in the Search for μ-e Conversion with COMET

Andrew Edmonds (UCL)
on behalf of the COMET collaboration

Charged Lepton Flavour Violation

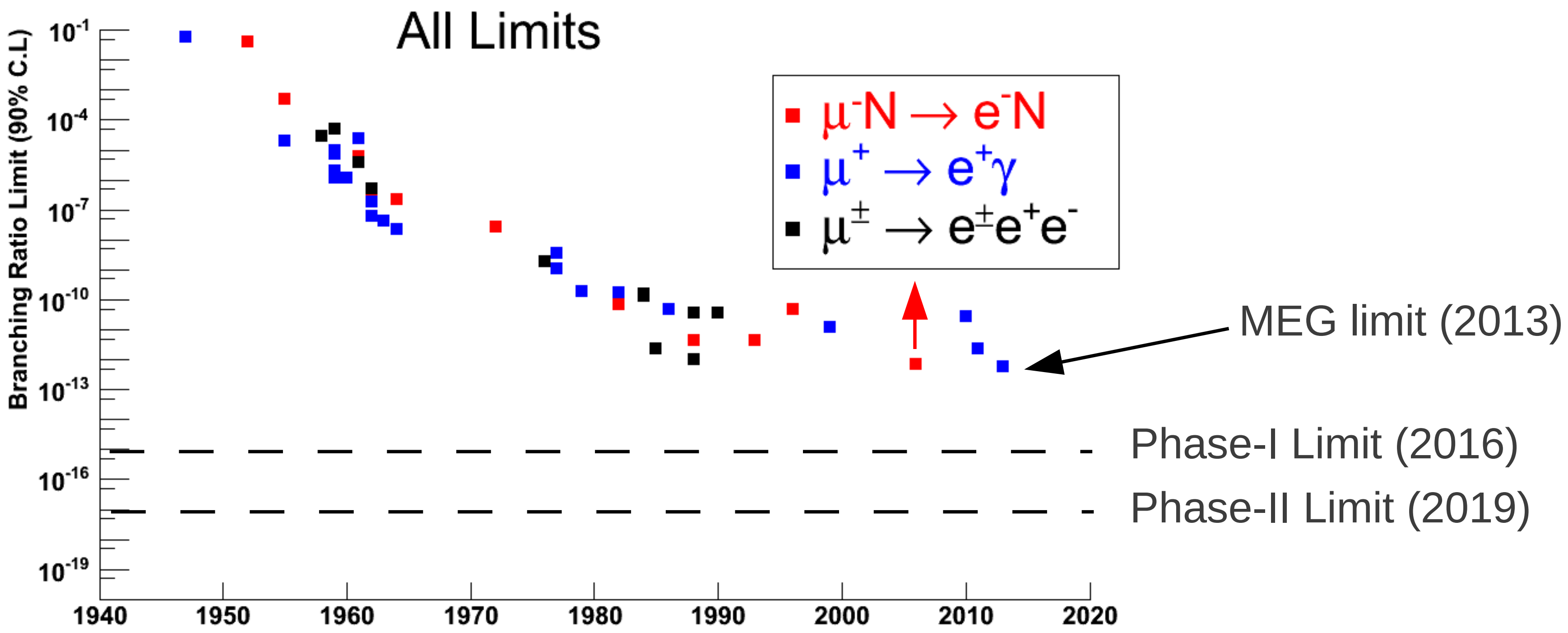
- Know that lepton flavour isn't conserved in neutrino oscillations
- CLFV has not been observed
- SM prediction of CLFV is $O(10^{-54})$
  - Therefore, if observed at any higher rate, it will be clear evidence of physics BSM



Standard Model Feynman diagram of the process $\mu \rightarrow e\gamma$

Current Limits

- COMET limits in relation to historical limits



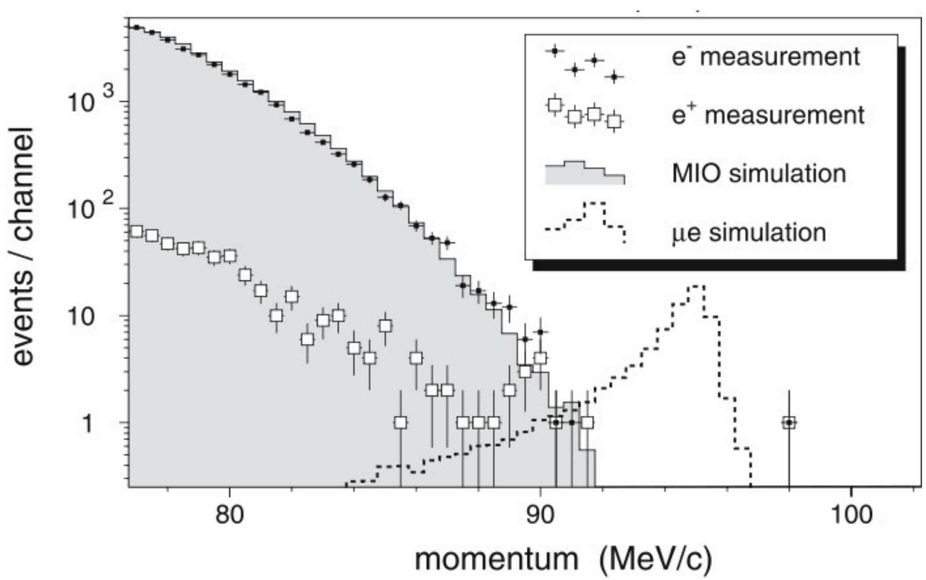
μ-e Conversion

- COMET will be searching for the charged lepton flavour violating process

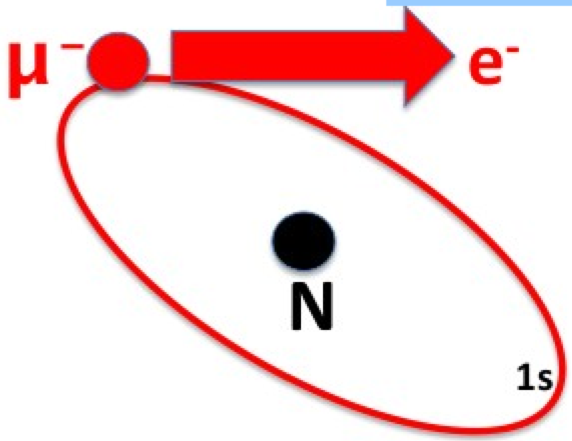
$$\mu^- + N(Z,A) \rightarrow e^- + N(Z,A)$$

in Al with a single event sensitivity (S.E.S) of 3×10^{-17}
(Current limit: S.E.S(μ^-Au → e^-Au) O(10^{-13}))

Signal is electron of E = 105 MeV



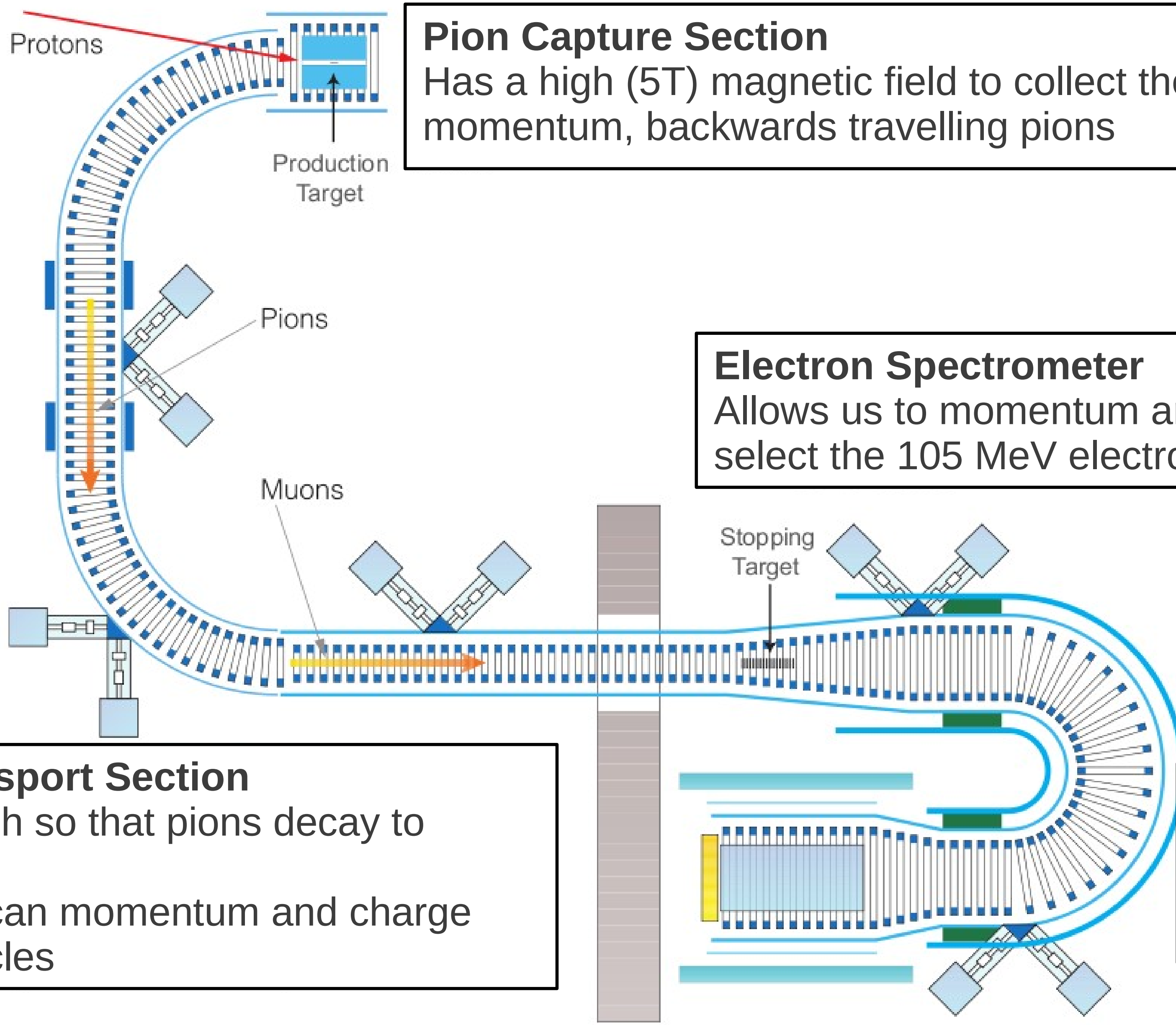
SINDRUM results of search for μ-e conversion in gold



Cartoon of μ-e conversion

Starting in 2019
S.E.S = 3 x 10^{-17}

COMET (Phase-II)



Pion Capture Section
Has a high (5T) magnetic field to collect the low momentum, backwards travelling pions

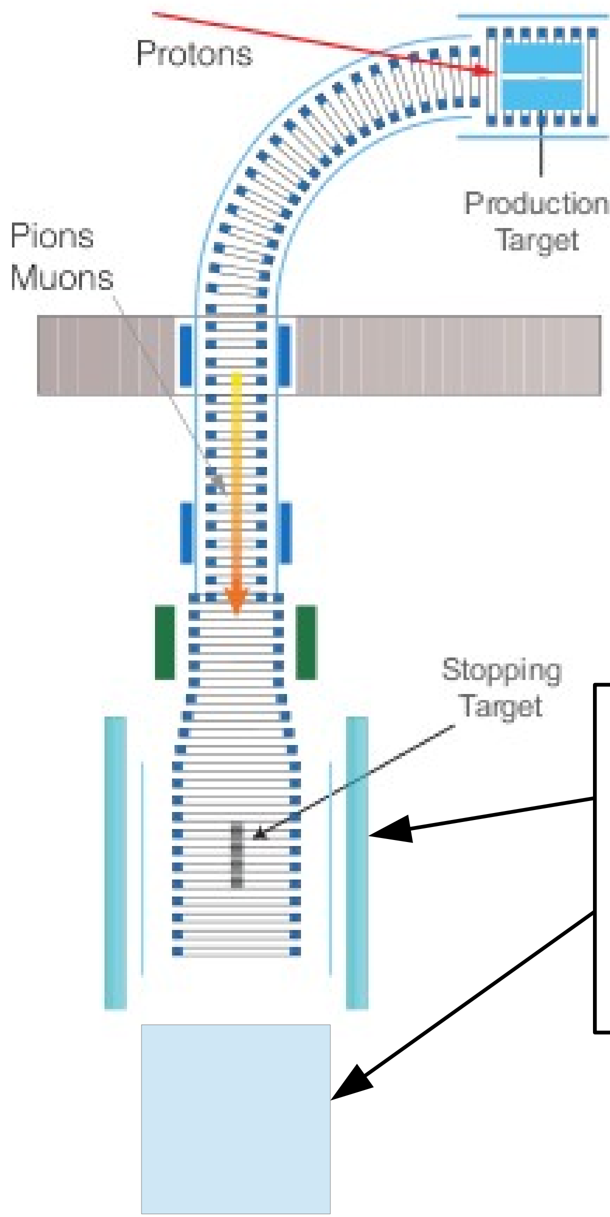
Electron Spectrometer
Allows us to momentum and charge select the 105 MeV electrons

Muon Transport Section
Long enough so that pions decay to muons
Curved so can momentum and charge select particles

Detector
Straw tube tracker and ECAL

Starting in 2016
S.E.S = 3×10^{-15}

COMET (Phase-I)

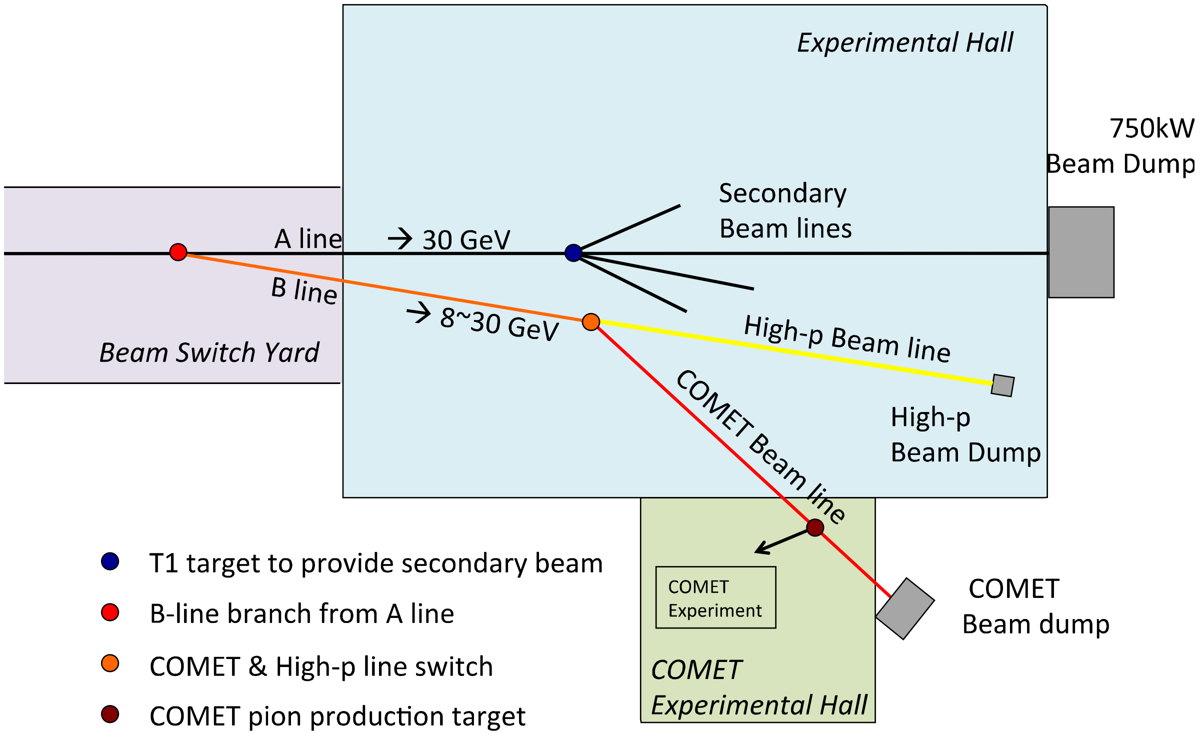


Phase-I Aims
Search for μ-e conversion process with a S.E.S of 3×10^{-15}
Study the backgrounds for Phase-II

Phase-I Detector
A cylindrical drift chamber (CDC) for the μ-e conversion search
A prototype ECAL and straw tube tracker for the background studies

Beamline Construction

- Funding from KEK for new beam lines
  - Will be completed in spring 2015



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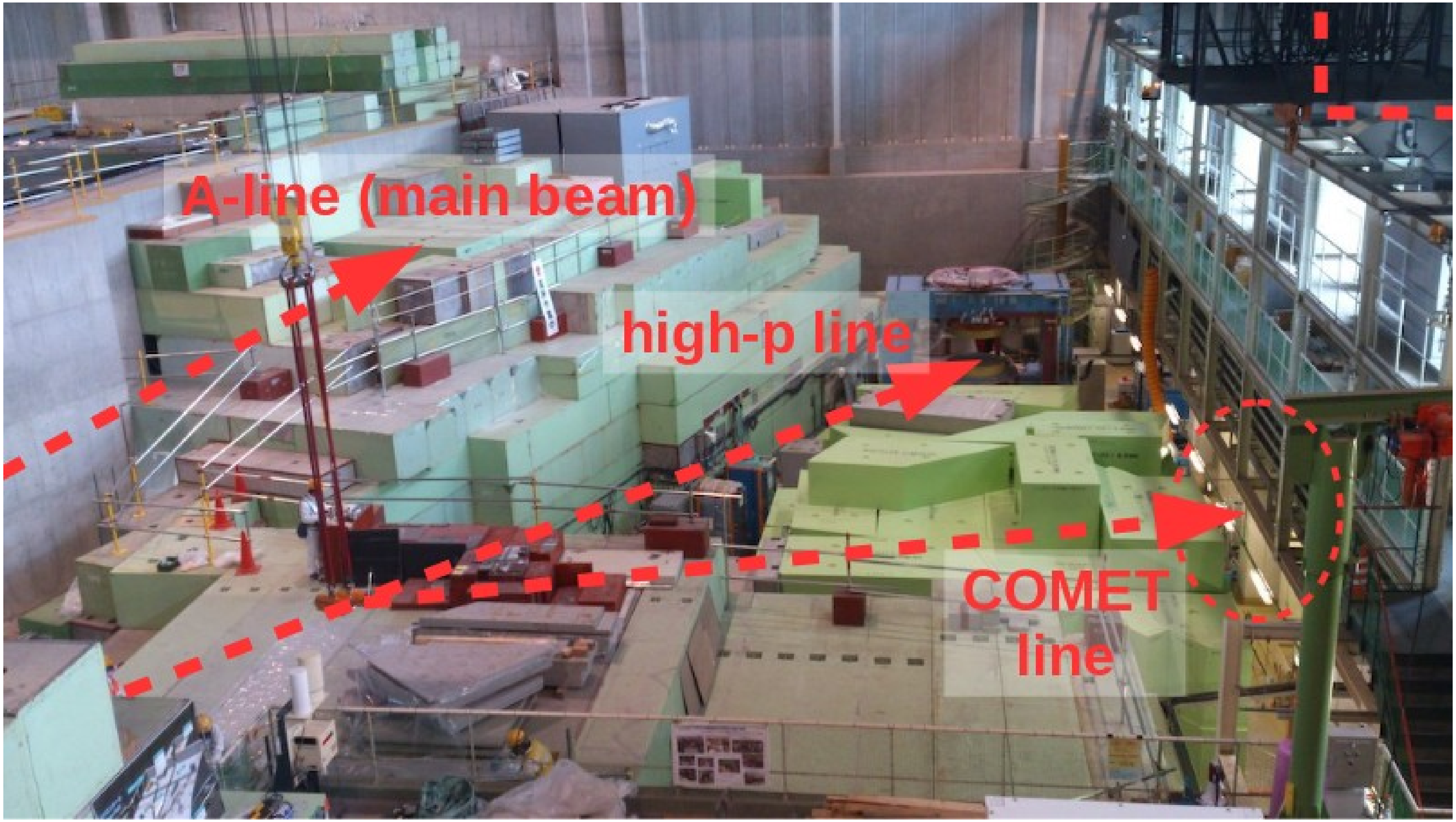
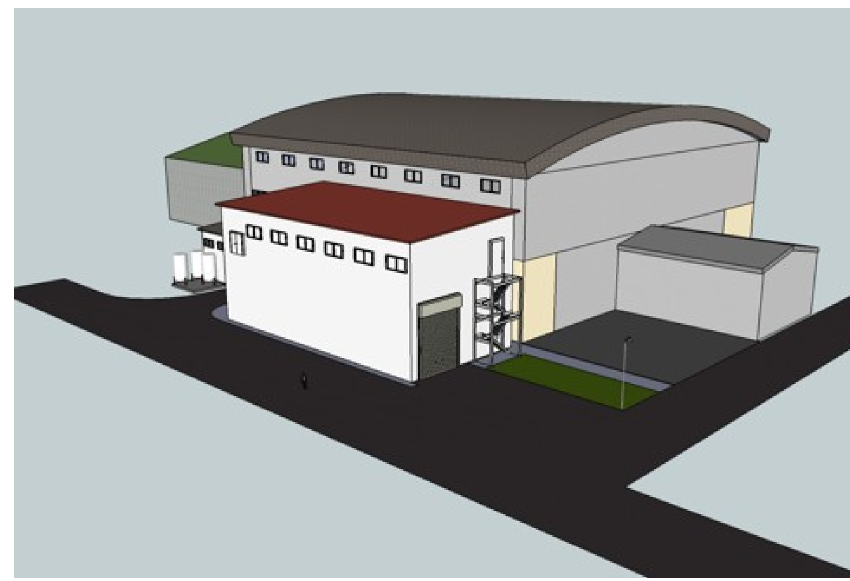


Facility Construction

- Work under way on the facility construction

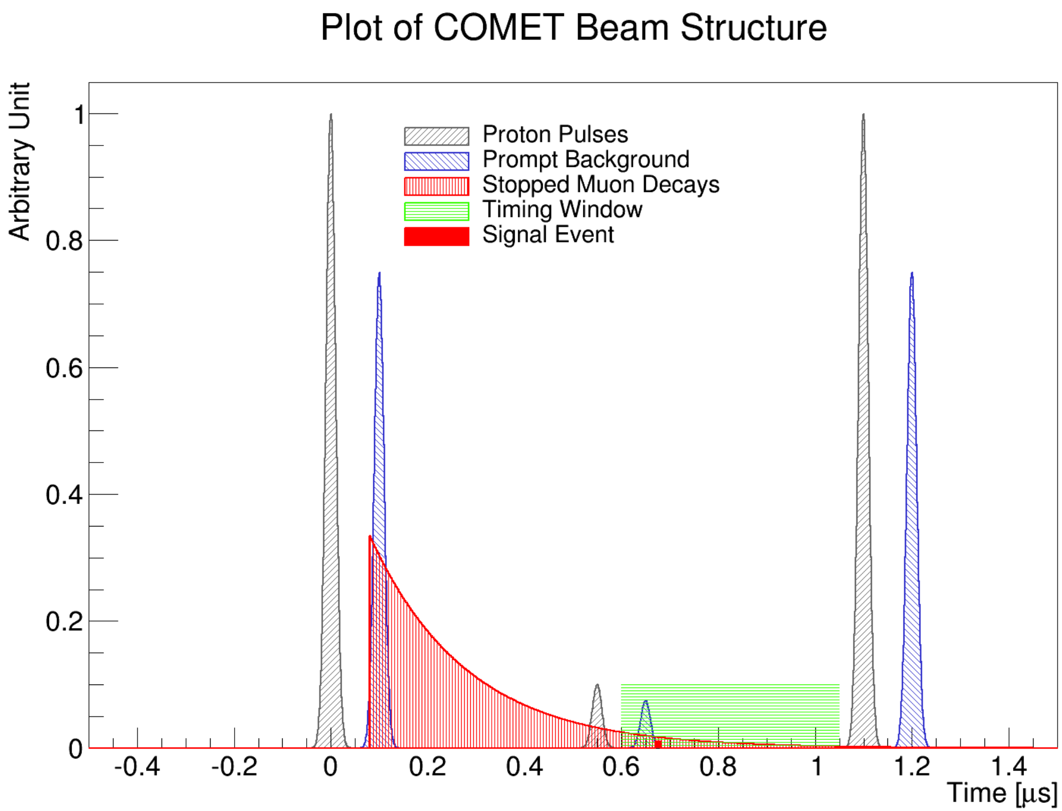
Excavation Started 4th June



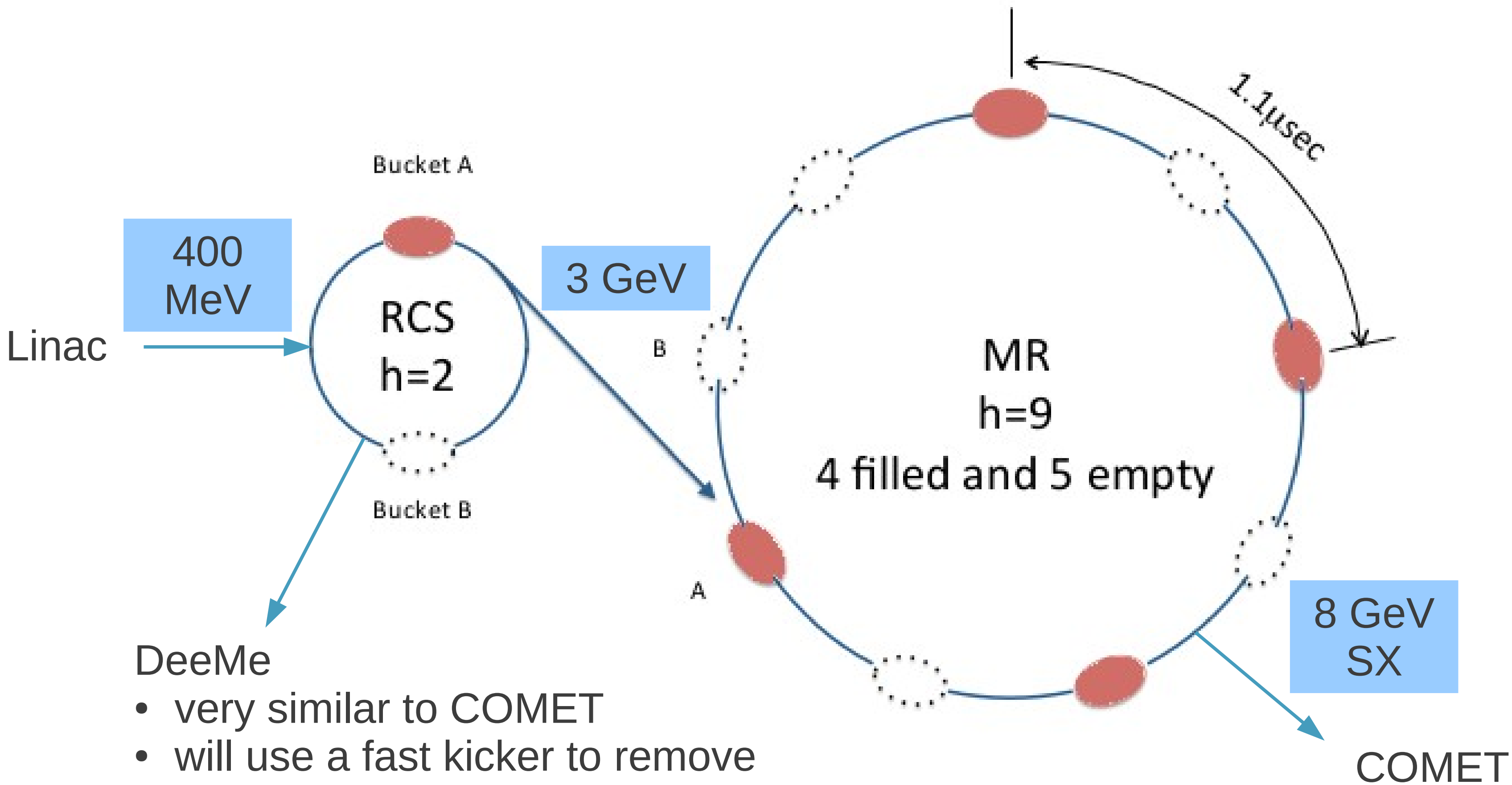
COMET Building

Proton Beam

- Energy: 8 GeV
- Power: 3.2 kW / 56 kW (Phase-I/Phase-II)
- Pulsed
  - Allows us to measure in a timing window and reduce beam-related backgrounds



Proton Beam Acceleration

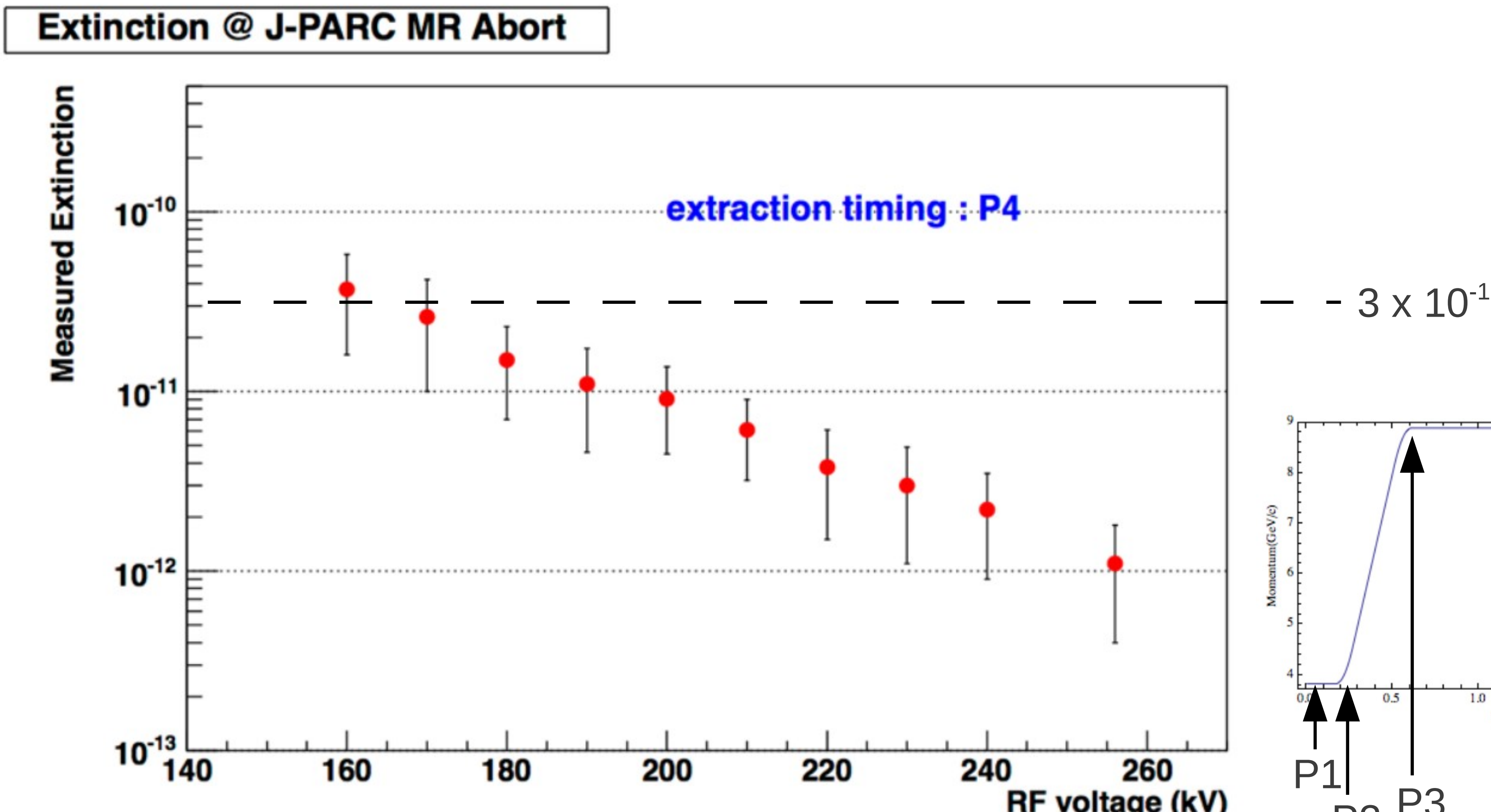


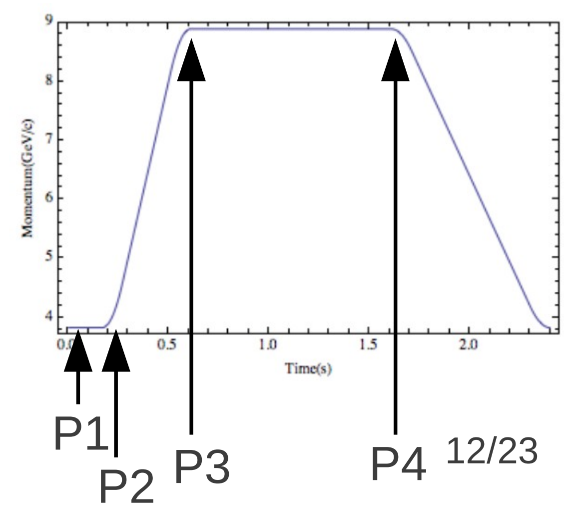
DeeMe

- very similar to COMET
- will use a fast kicker to remove background
- SiC target
- aiming for S.E.S of 2×10^{-14} in 2015

Proton Beam Extinction

- New single bunch kick injection method successfully demonstrated at 8 GeV in May 2014 at J-PARC





Background Estimates

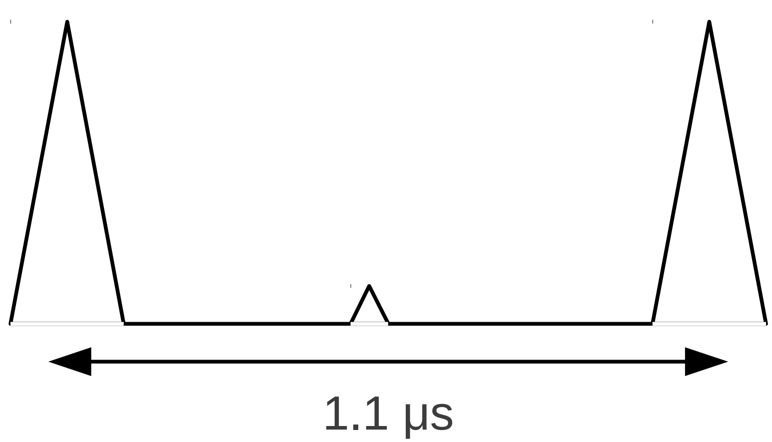
- For Phase-I, we expect 0.03 background events per signal event for BR 3×10^{-15} and 30 days running

Background	Expected Number of Events
Decay In Orbit (DIO)	0.01
Radiative Pion Capture (RPC)	0.01*
All others	0.01

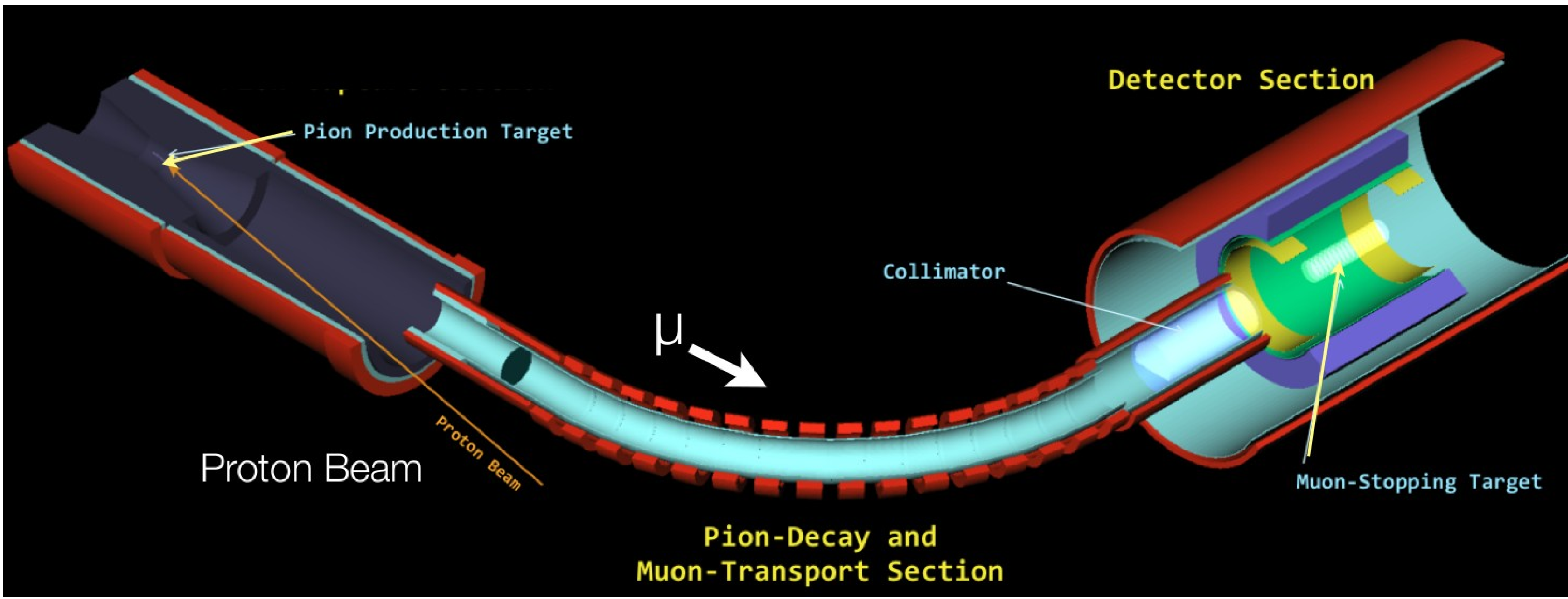
Detector (DIO) → Detector

Accelerator (RPC) → Accelerator

* Assuming proton beam extinction factor of 3×10^{-11}



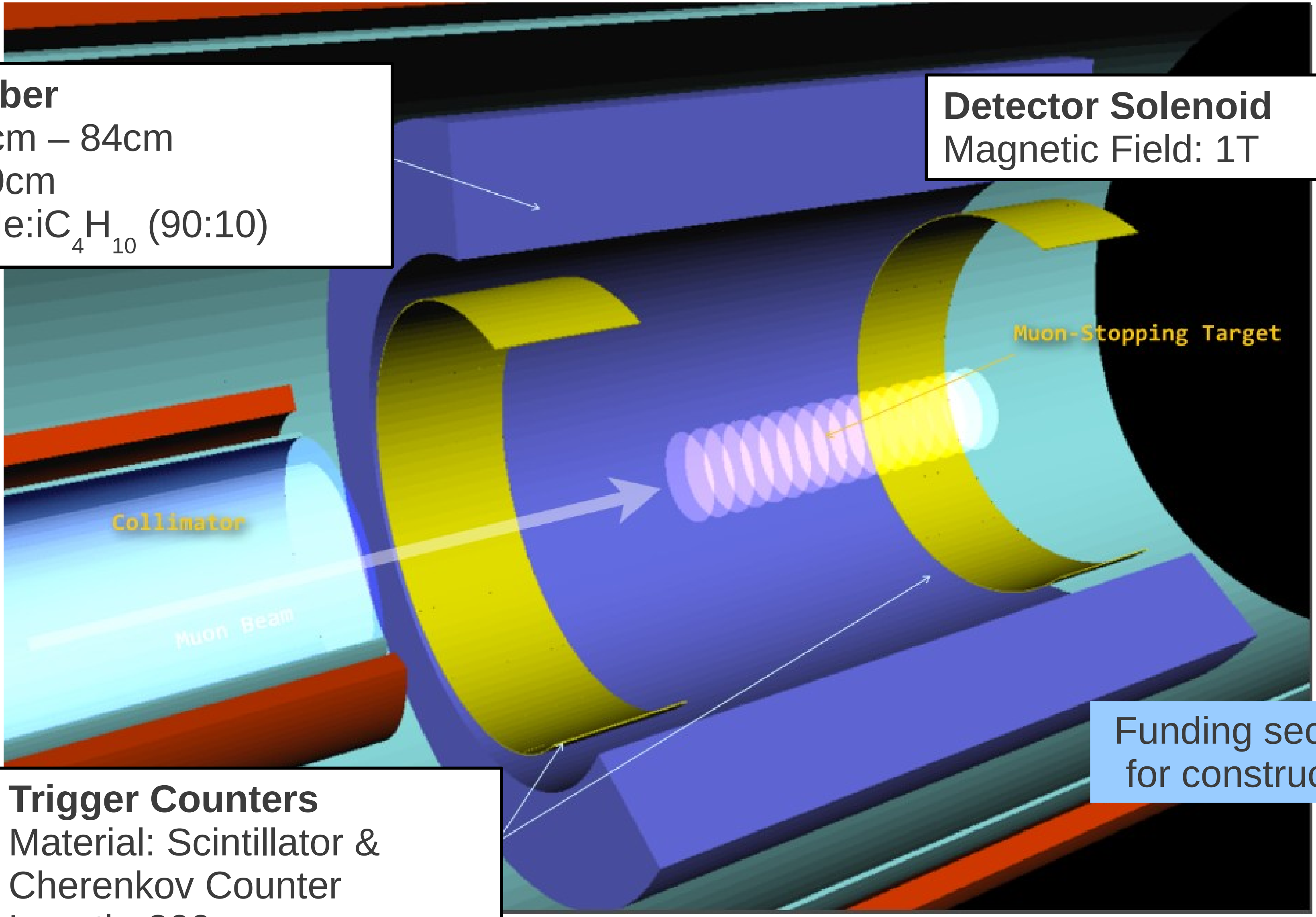
COMET Detectors



Cylindrical Drift Chamber

Drift Chamber
Radius: 55cm – 84cm
Length: 150cm
Drift Gas: He:iC_4H_{10} (90:10)

Detector Solenoid
Magnetic Field: 1T



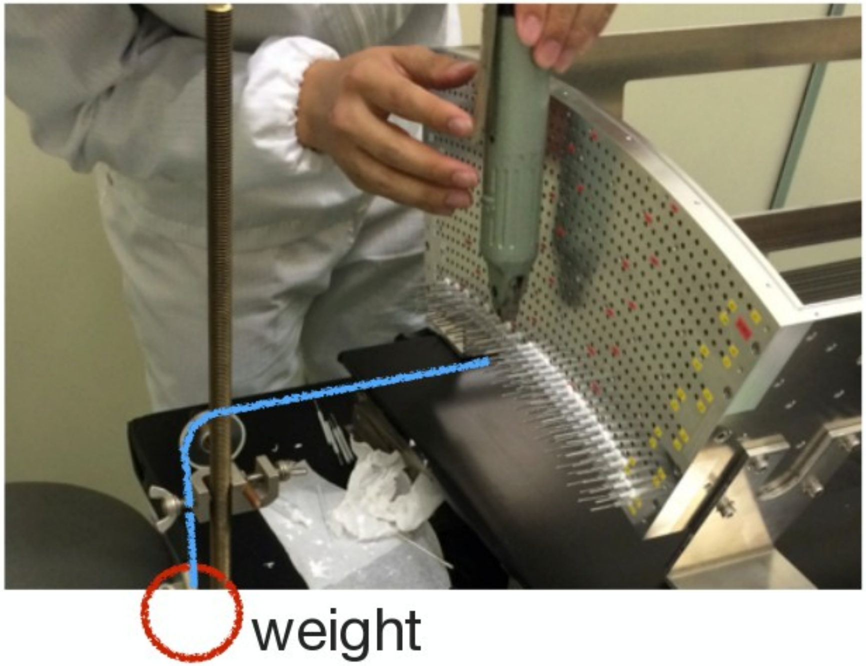
Funding secured for construction

Trigger Counters
Material: Scintillator & Cherenkov Counter
Length: 300mm
Thickness: 35mm

Cylindrical Drift Chamber

- Requirements
  - Gas gain: > 10^5
  - Position resolution (x, y): < 150 μm
  - Position resolution (z): < 2mm
  - Reduce multiple scattering for good momentum resolution
- Cosmic ray tests performed on prototype at Osaka and KEK

Wiring @KEK



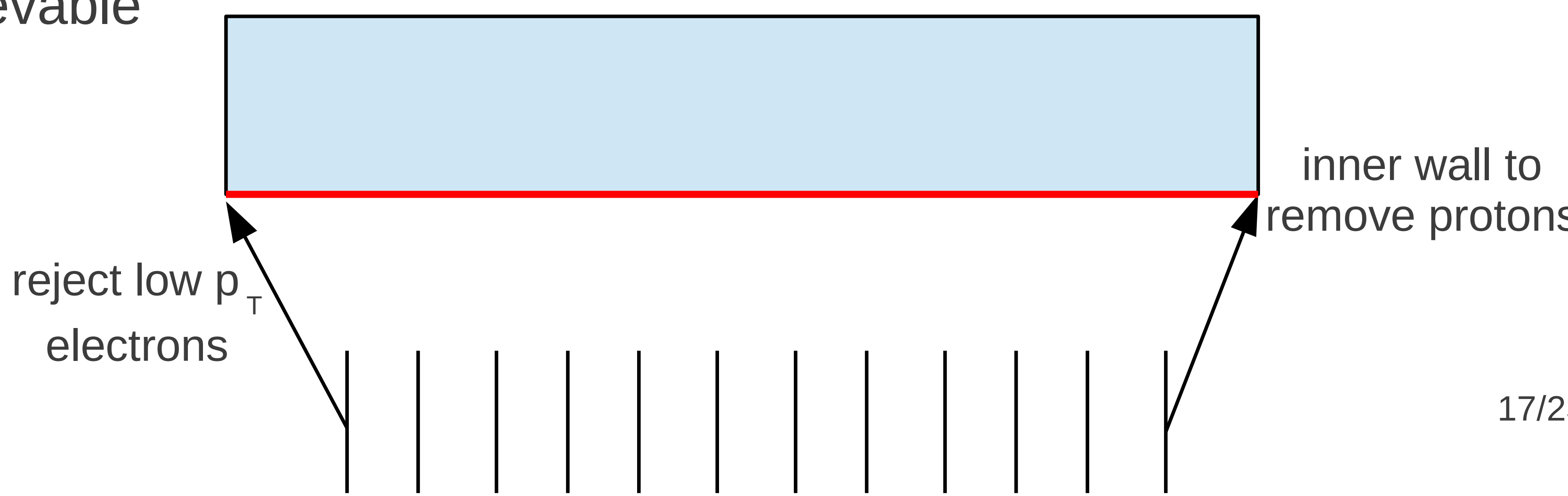
Cylindrical Drift Chamber

- But proton emission from muon capture greatly increases the detector rates

Source	Optimisation	Rate / wite
DIO electrons	Minimum radius 55cm	270 Hz
Protons after muon capture*	Inner wall (CFRP) thickness 0.5mm	40kHz

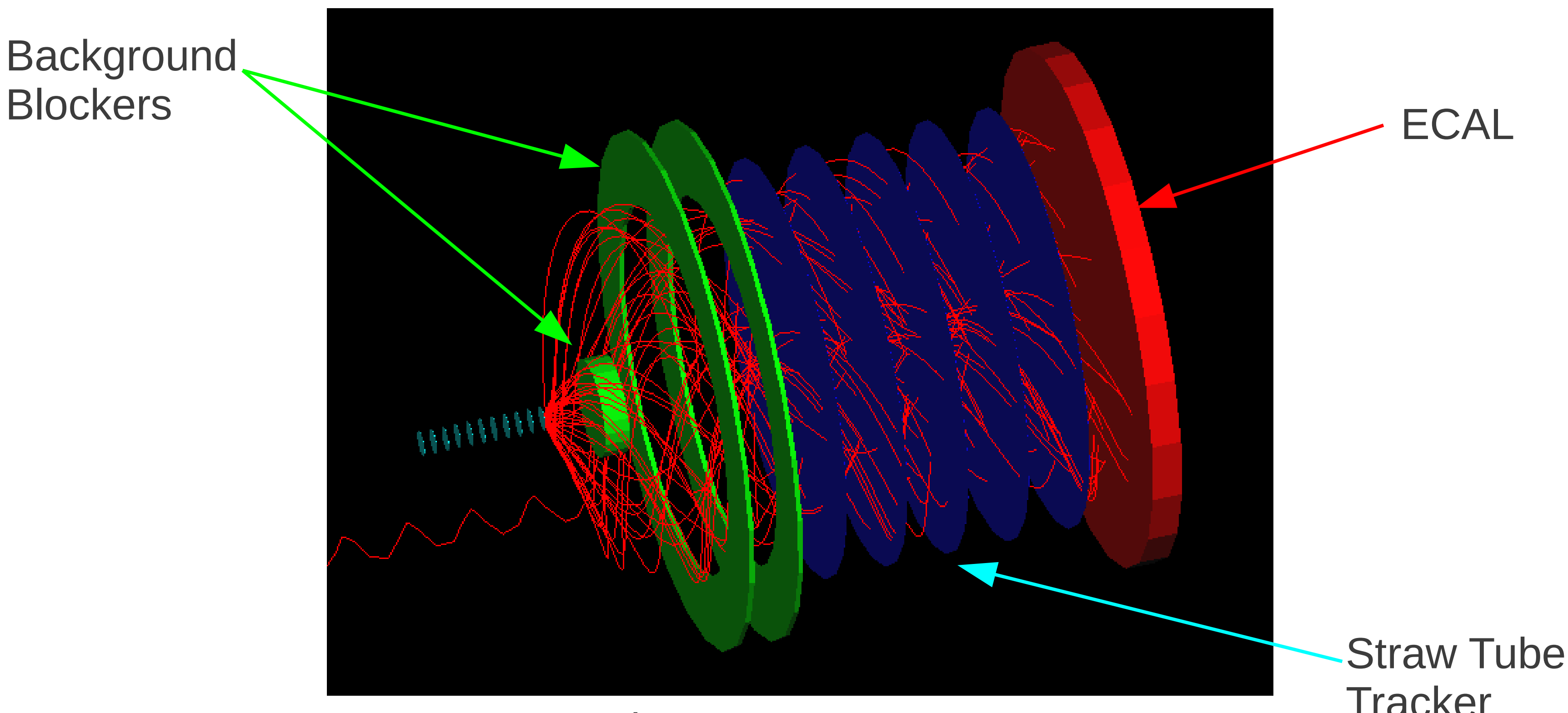
* Assume 15% per capture

- Current simulation shows a resolution will be 200 keV/c is achievable



Final Phase-II Detector

- The final Phase-II detector will consist of a straw tube tracker and an electromagnetic calorimeter
- Phase-I will develop prototypes of these

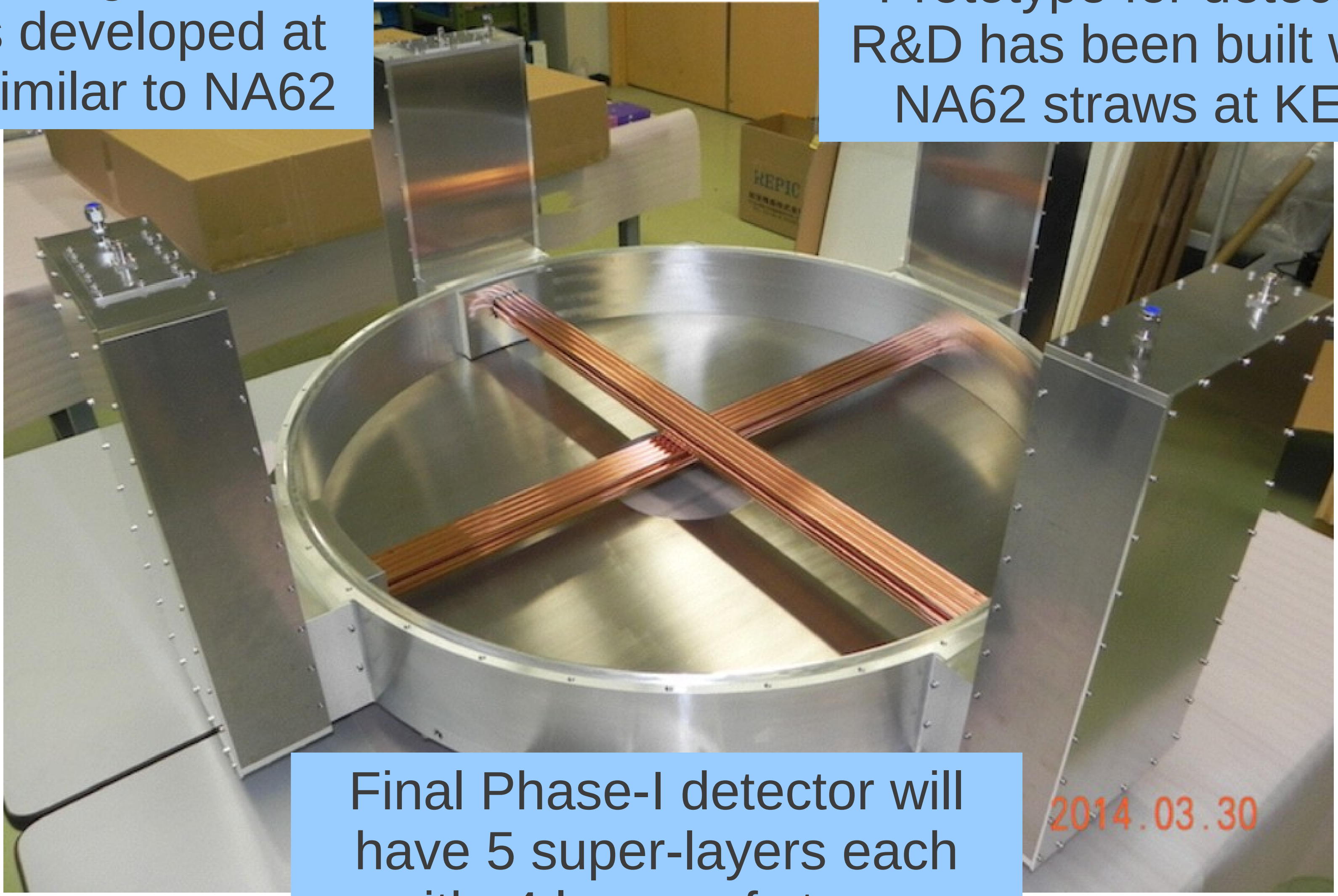


Phase-I Detector

Straw Tube Tracker

Proposing to use straws developed at JINR similar to NA62

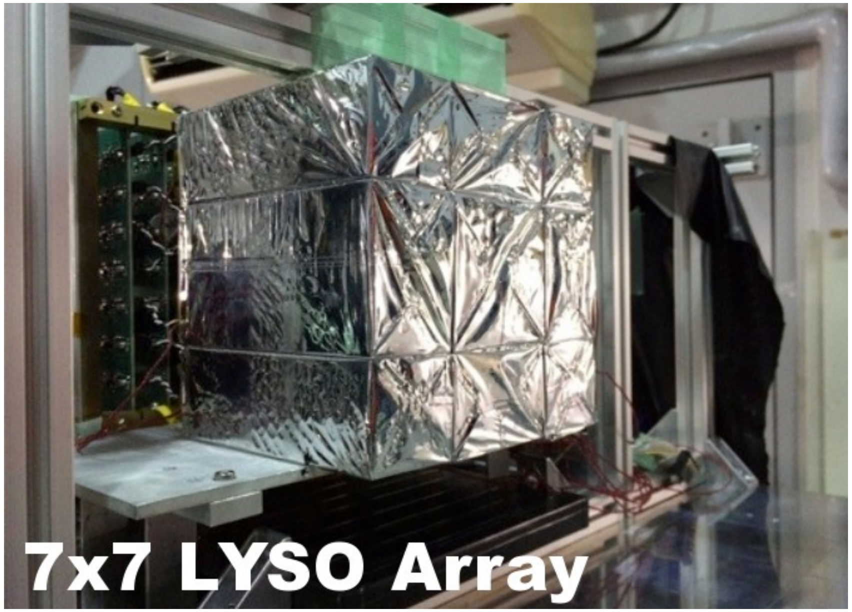
Prototype for detector R&D has been built with NA62 straws at KEK

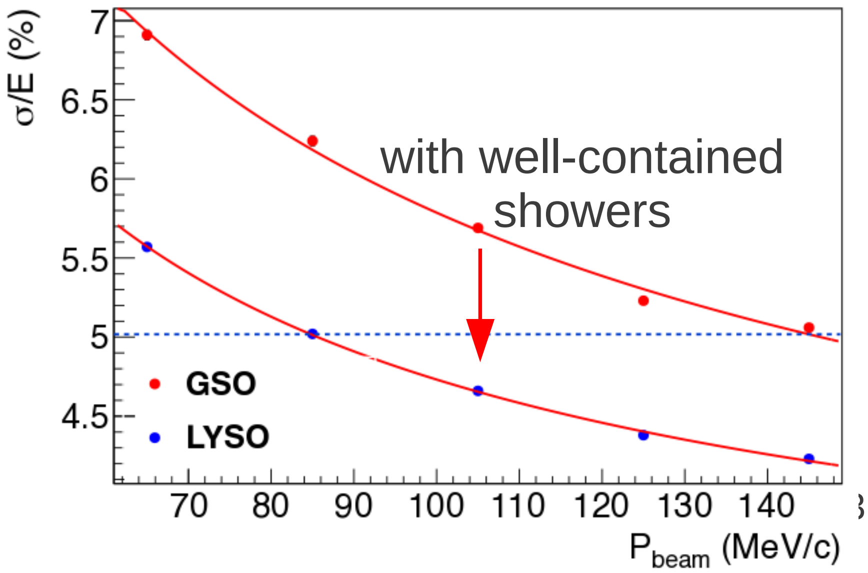


Final Phase-I detector will have 5 super-layers each with 4 layers of straws

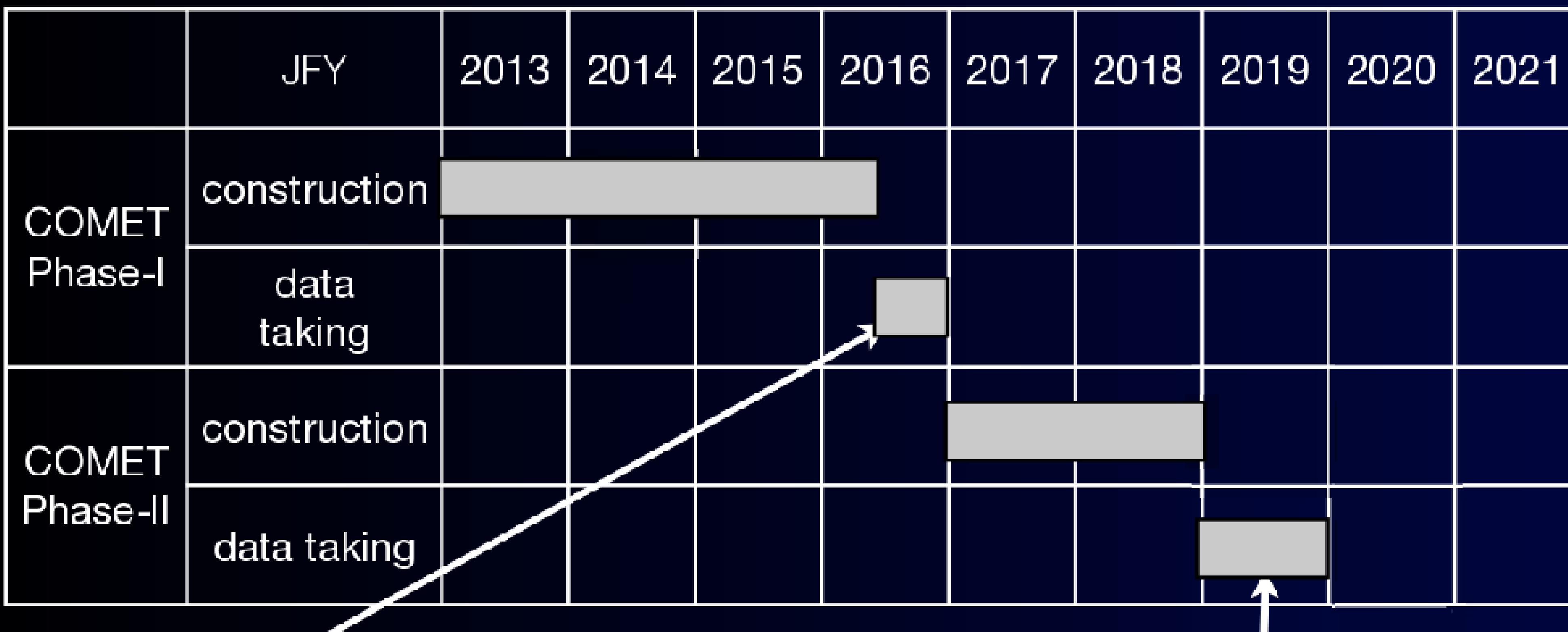
Electromagnetic Calorimeter

- Requirements
  - Resolution: <5% at 105 MeV/c
  - Trigger Rate: <5 kHz
  - Spatial resolution: <1.5 cm
  - Response: <100 ns
- Two candidate crystals
  - GSO and LYSO
- Beam test at Tohoku University (March 2014)





Timeline



COMET Phase-I :
2016 ~
S.E.S. ~ 3×10^{-15}
(for 1~3 months
with 3,2 kW proton beam)

Mu2e :
2019
S.E.S: 2.5×10^{-17}
(for ~3 years
with 8kW
proton beam)

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

Conclusion

- COMET will be searching for μ-e conversion in Al in two stages
  - Phase-I (2016): S.E.S = 3×10^{-15}
  - Phase-II (2020): S.E.S = 3×10^{-17}
- Construction has begun

Thanks for Listening

Any Questions?

Back Up

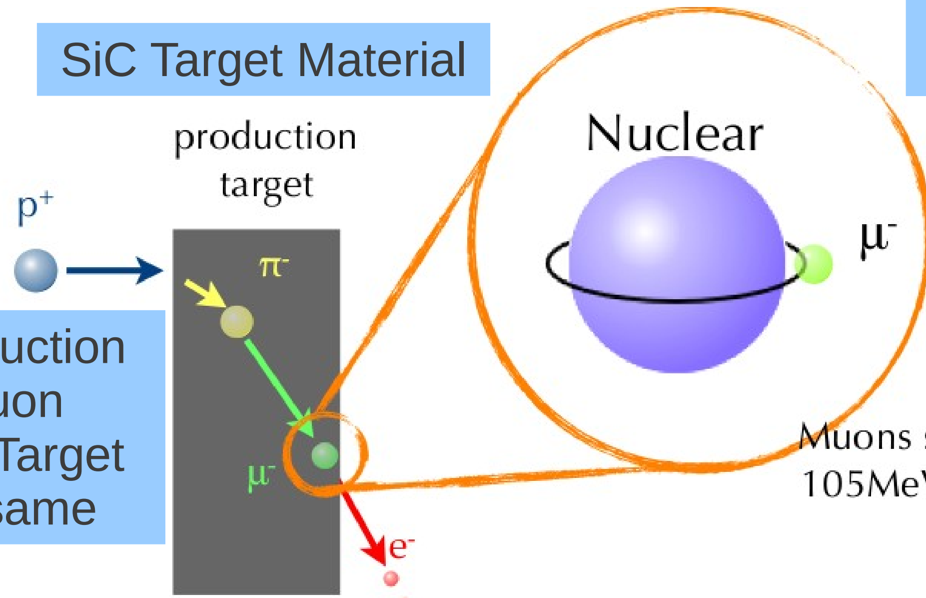
Starting in 2015
S.E.S = 2 x 10^{-14}

DeeMe

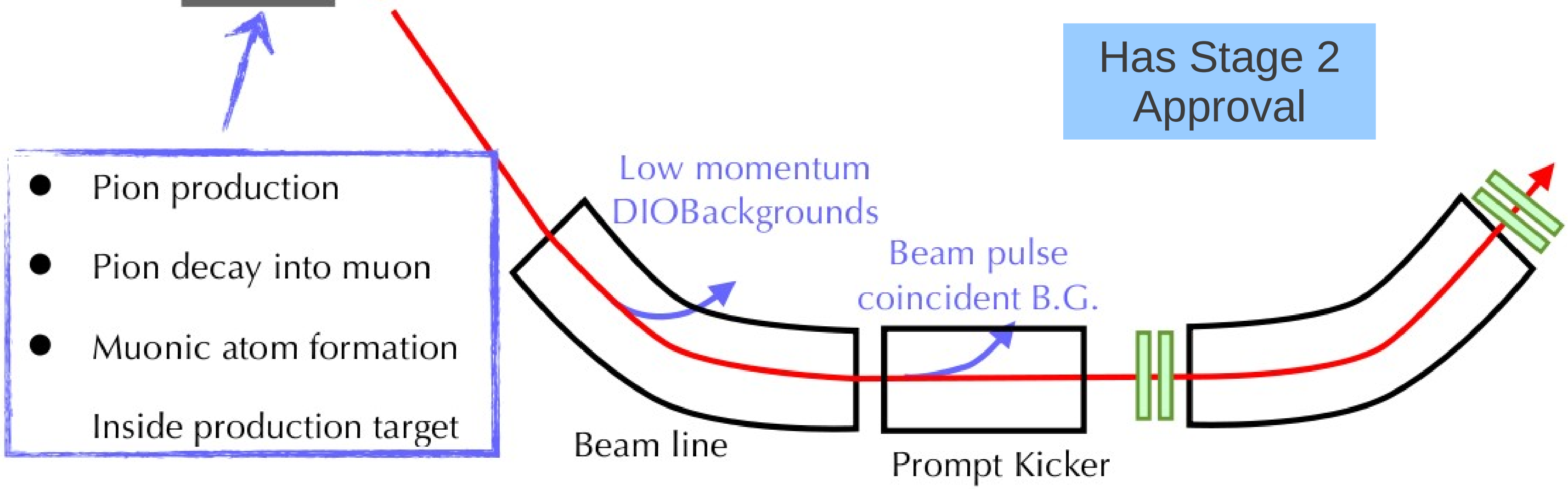
SiC Target Material

Being built at J-PARC

Pion Production and Muon Stopping Target are the same



Muons stopped near the surface may emit 105MeV signal mu-e conversion electron (Surface muon analogy)

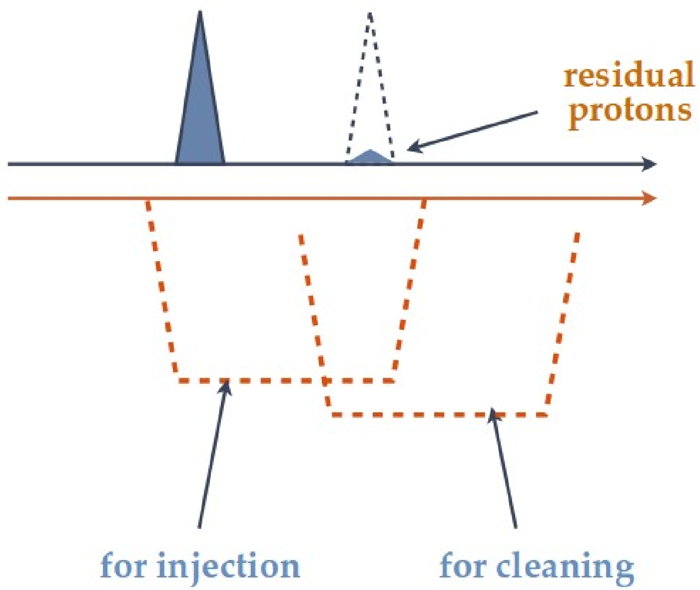


Has Stage 2 Approval

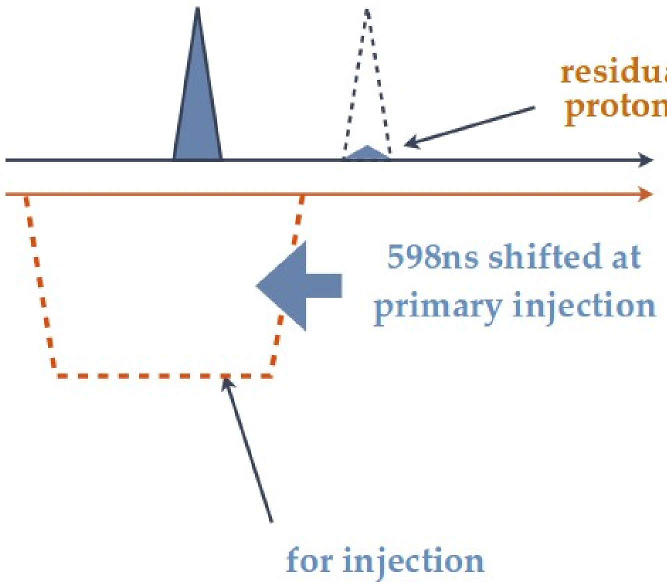
Proton Beam Extinction

- Plan to use a novel kick injection method such that residual protons don't enter MR

Double Kick Injection

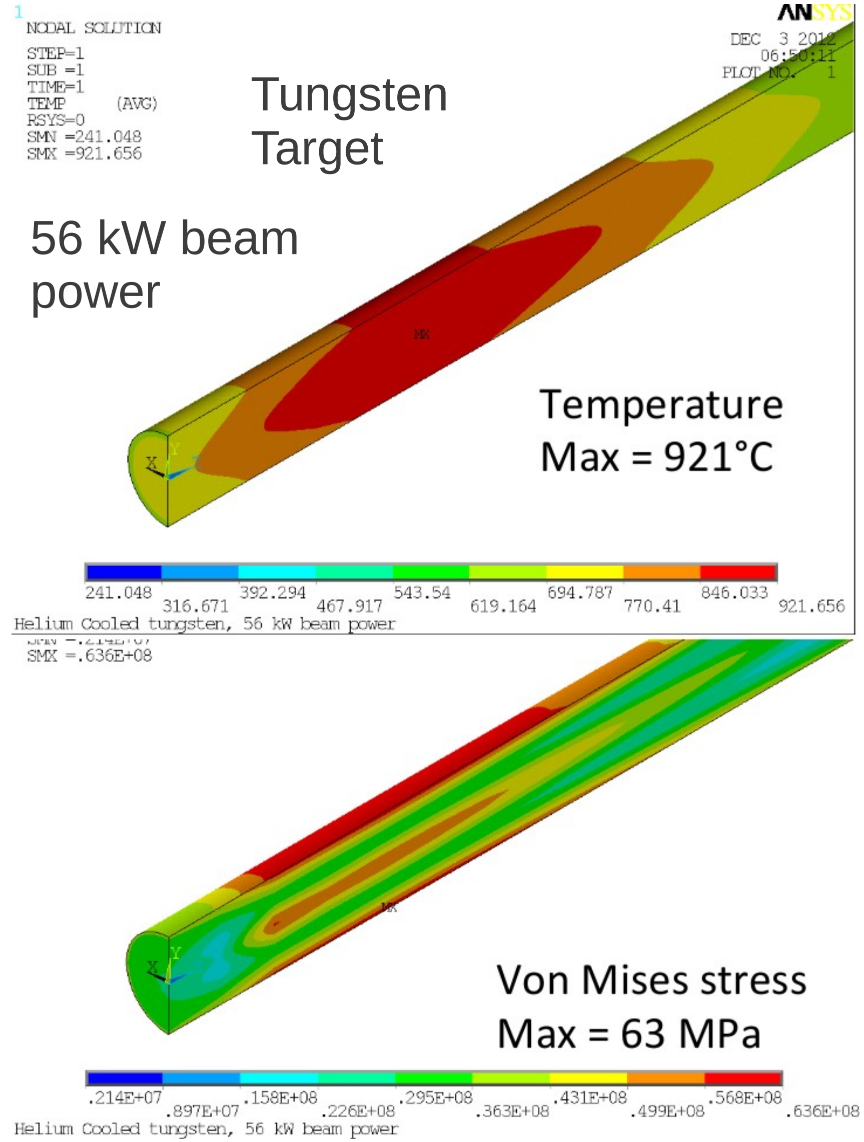


Single Bunch Kick Injection

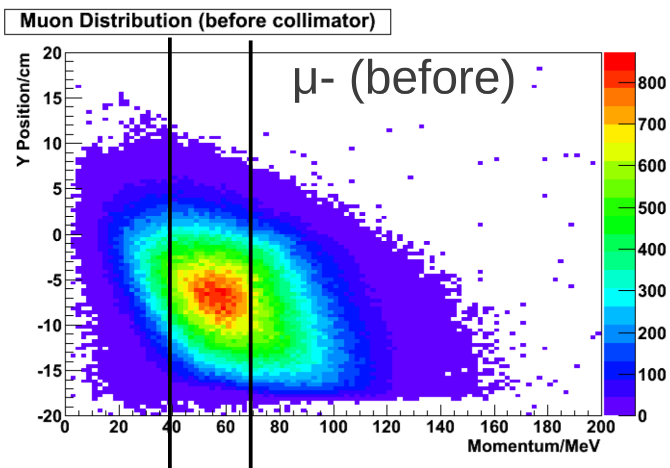


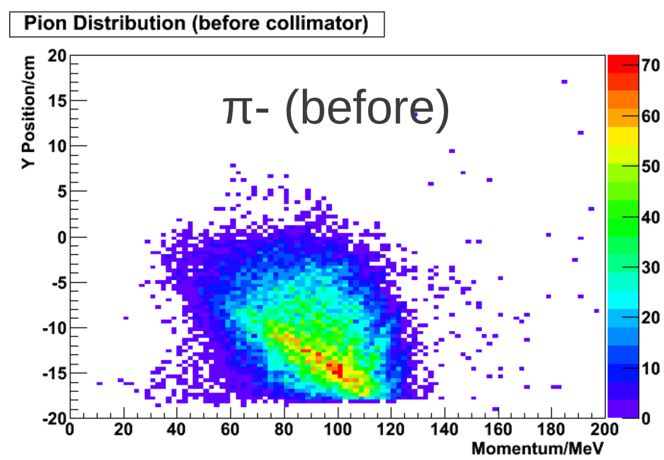
Pion Production Target

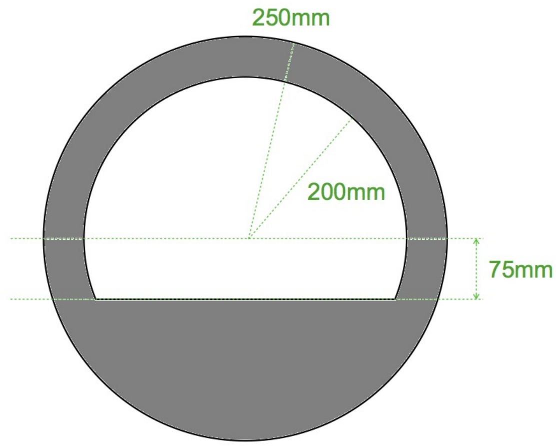
- For Phase-I will use a graphite target
  - 4cm diameter, 60 cm length
  - Radiation cooling
- For Phase-II will move to a tungsten target
  - Greater pion yield
  - Requires helium cooling



Muon Transport

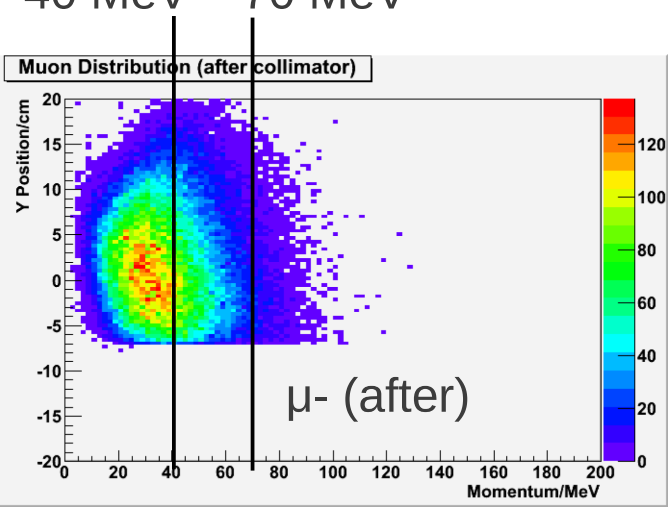


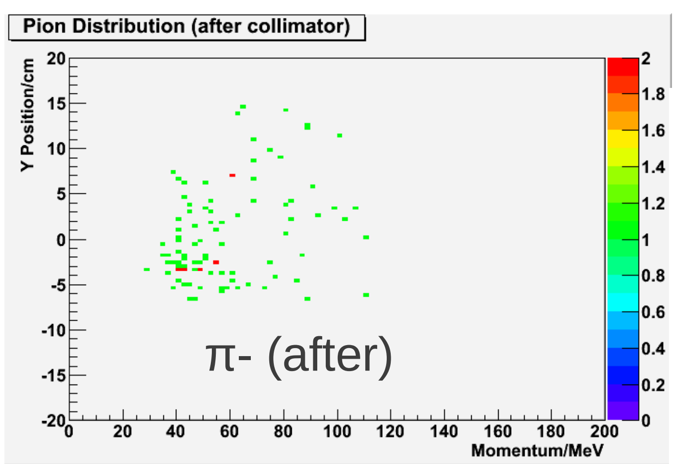


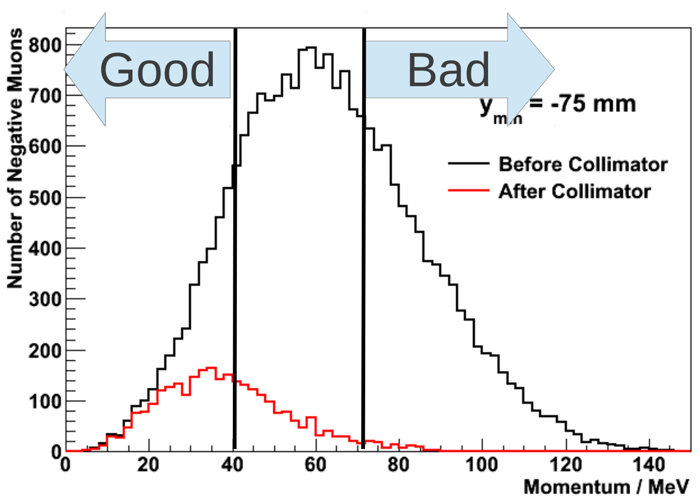


40 MeV 70 MeV

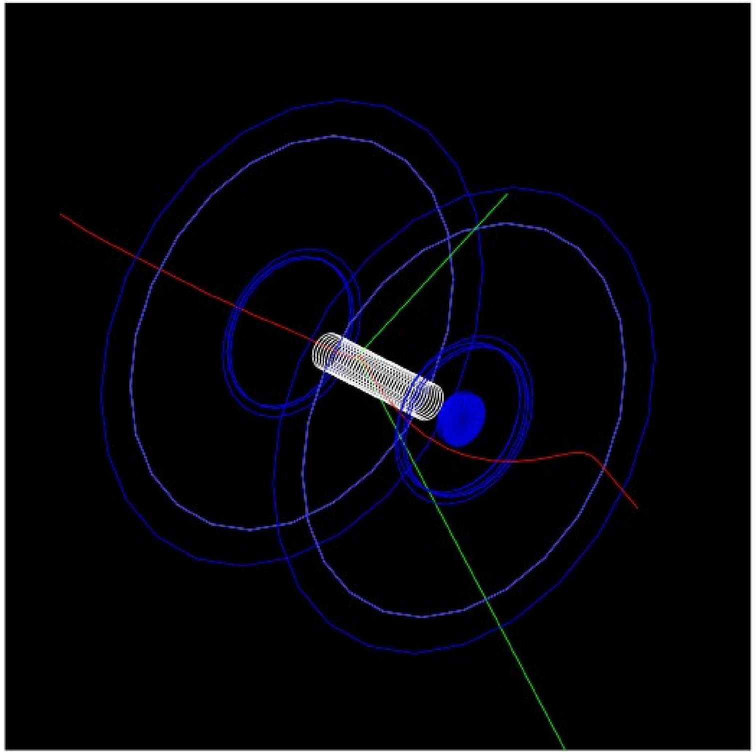
Shape of Collimator

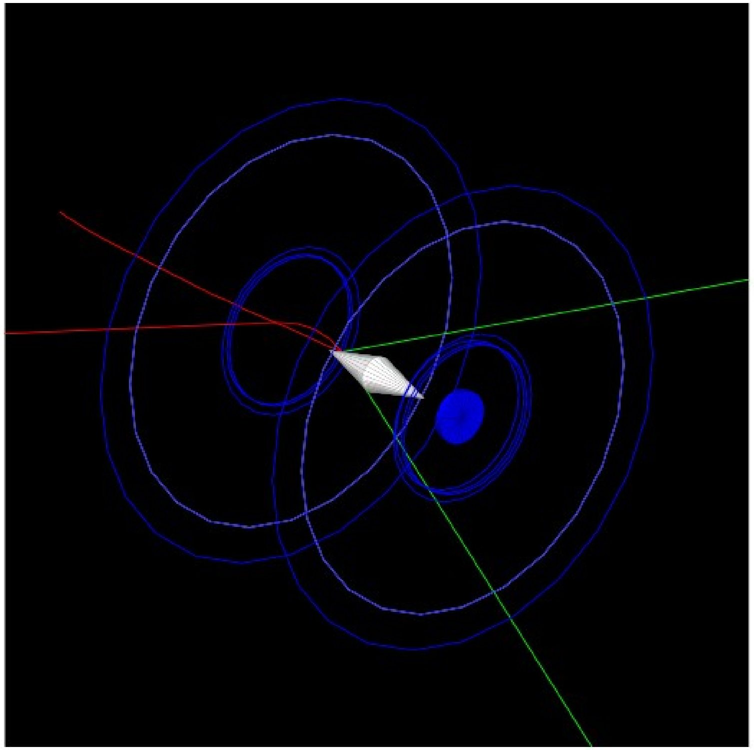






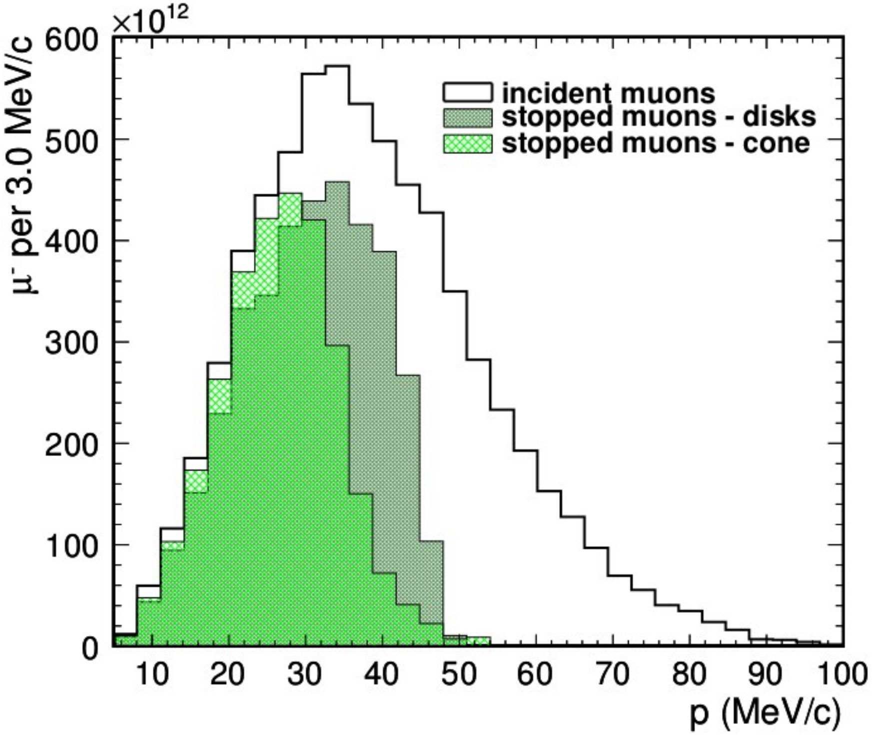
Stopping Target



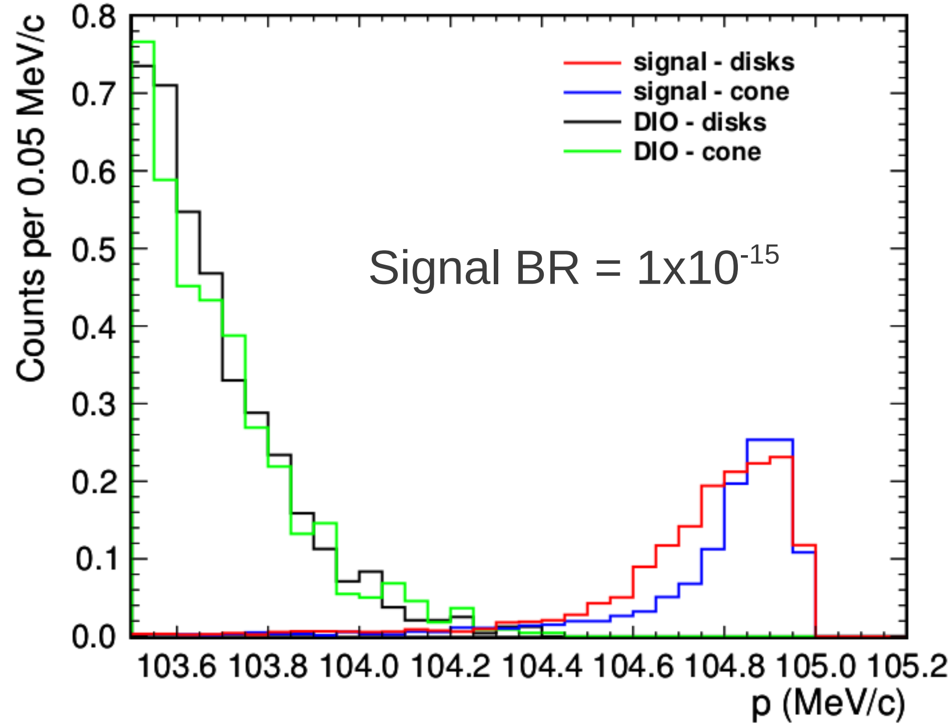


- Currently 17 Al disks but also looked at double cone
- Radius: 10 cm, Thickness: 200 μm, Length: 80 cm

Stopping Target



Plot of stopped muon momentum distribution



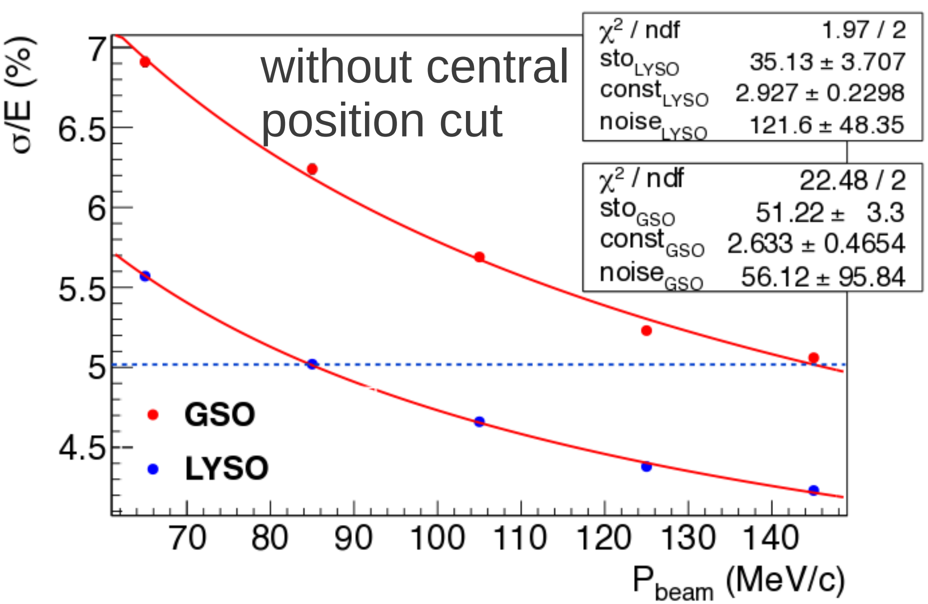
Plot of signal shape

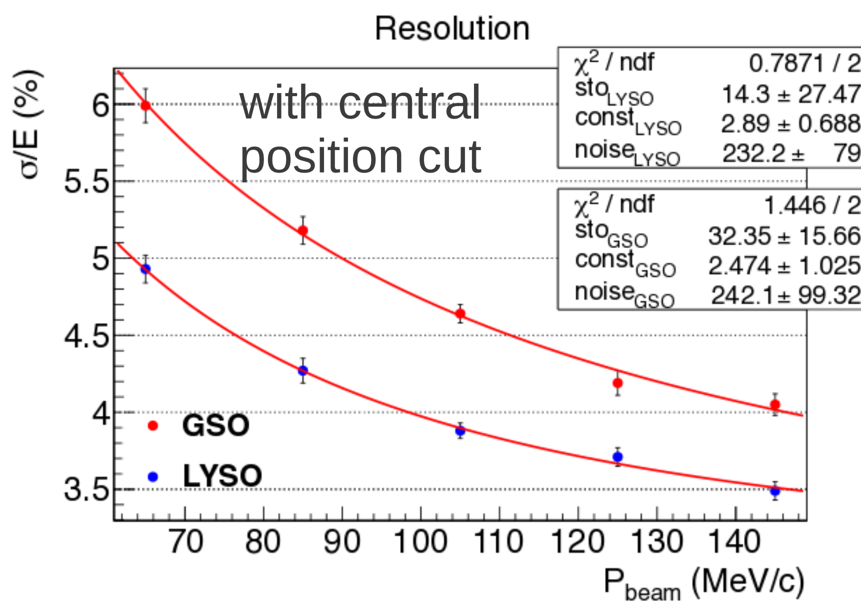
Stopping Target	Stopping Efficiency
Disks	0.66
Cone	0.42

Stopping Target	# Events (p > 104.4 MeV)
Disks	1.14
Cone	1.45

Electromagnetic Calorimeter

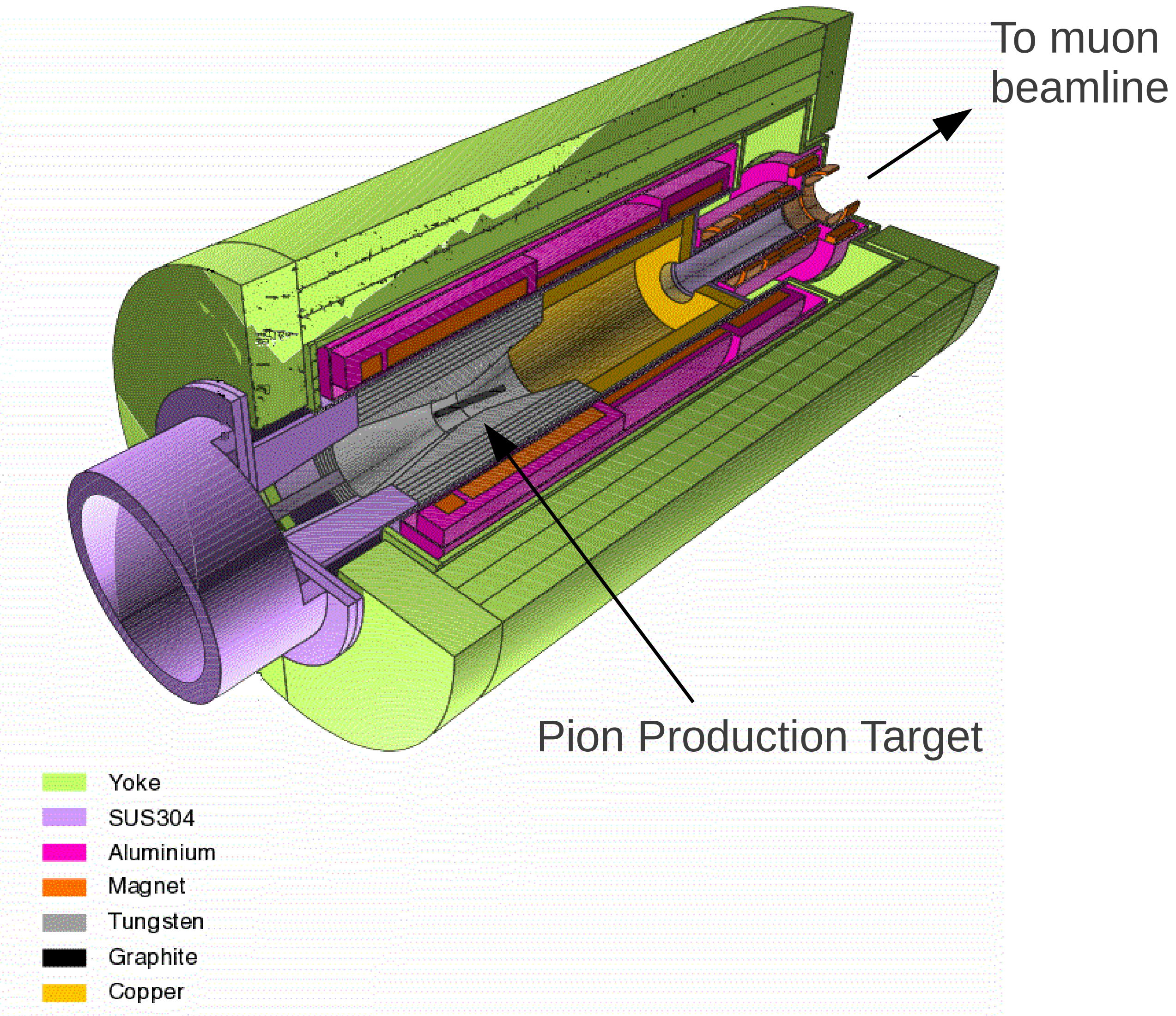
- Beam test at Tohoku University (March 2014)
  - Used both GSO and LYSO crystals
  - 7x7 crystal array
  - Measured the resolution at 65, 85, 105, 125 and 145 MeV/c





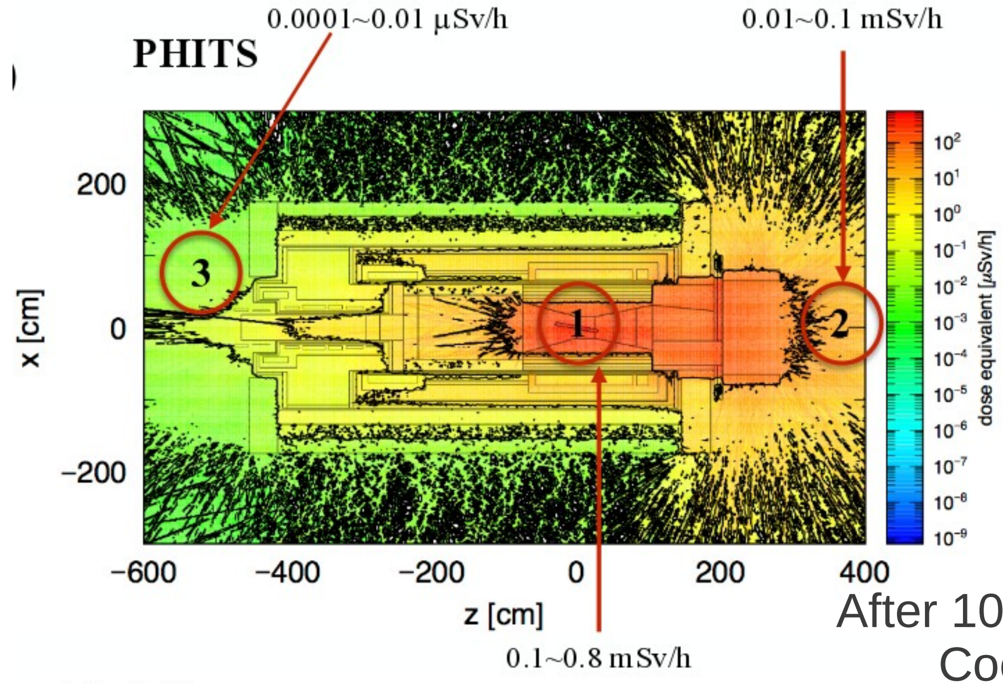
Pion Capture Solenoid

- Current design of the pion capture system

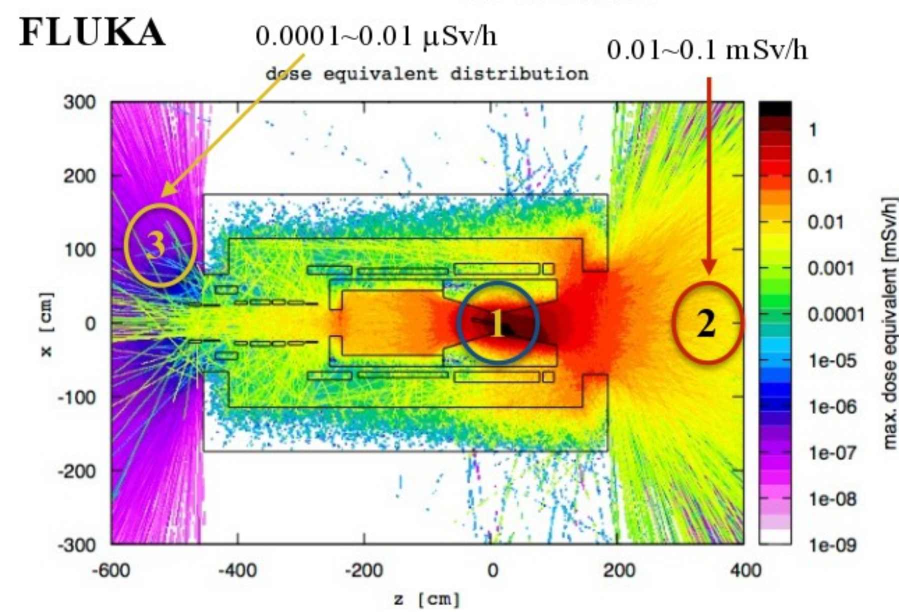


Neutron Backgrounds

- Regulations
  - < 25 μSv/h at 1F
  - < 11 mSv/h in underground soil
- Performed calculation with PHITS and FLUKA for Pion Capture Solenoid
  - MARS to be done

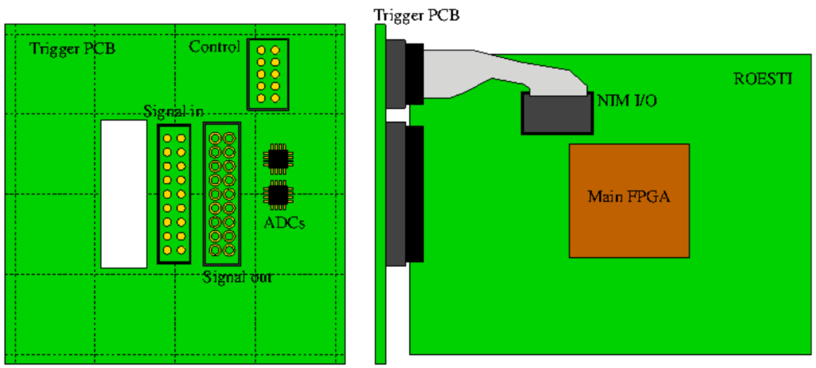


After 10 Month Cooldown



DAQ & Trigger

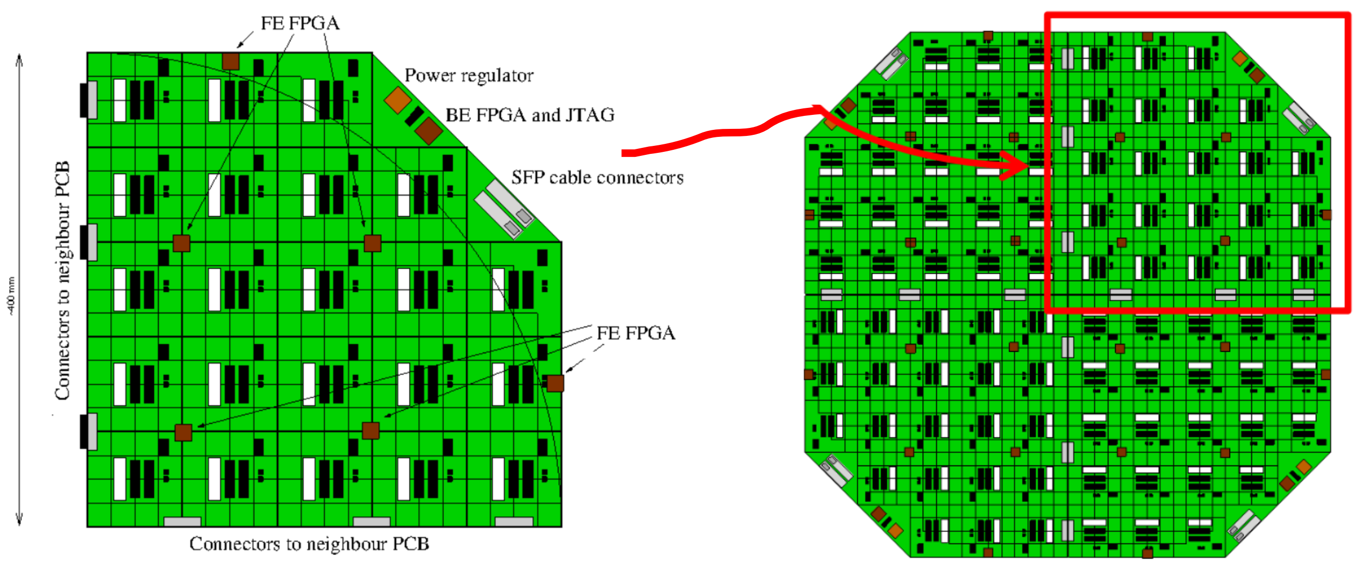
- The basic unit will be a 4x4 crystal array with a single trigger board which can scale up to the full ECAL



Left: Basic Unit

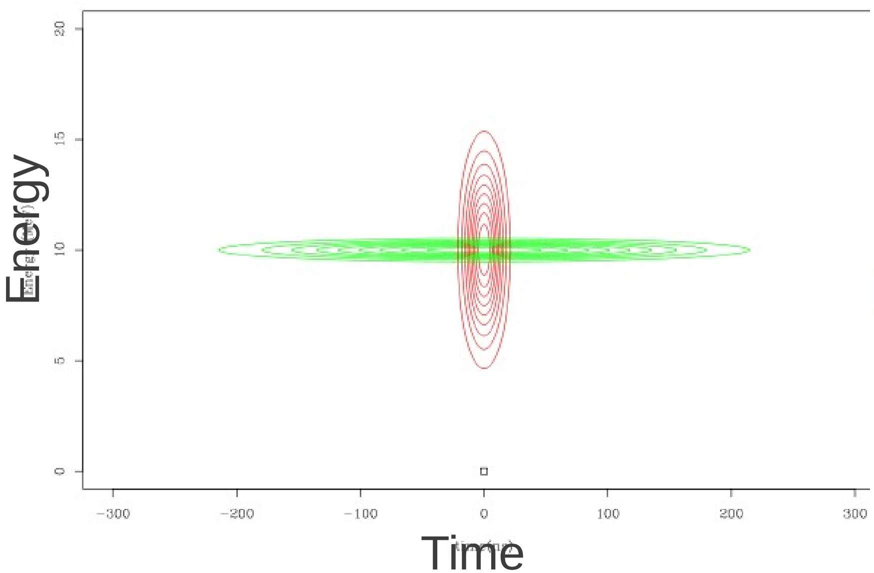
Below: Full scale with modular quadrants

For 1316 crystals

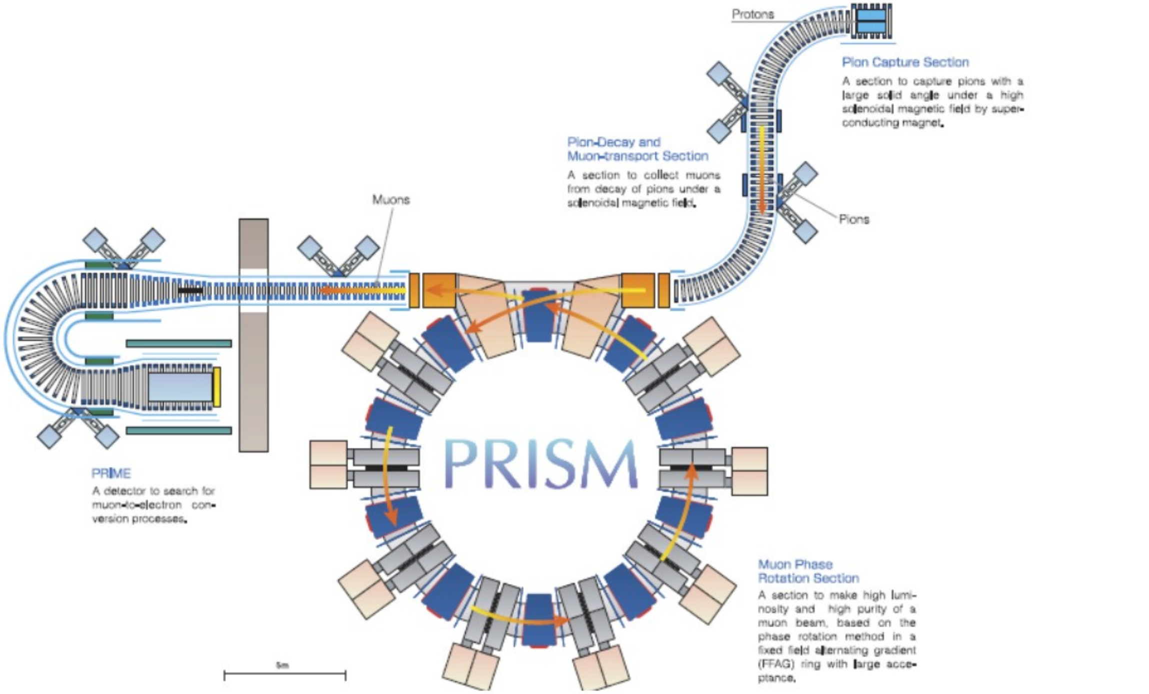


PRISM/PRIME

- To get down to 10^{-18} and beyond PRISM/PRIME propose to use an FFAG ring
- This gives the muon beam a small momentum width which allows the use of one target disk



Before phase rotation (red)
After phase rotation (green)



Background Estimation

- Here are the estimates for our backgrounds for Phase-I
  - Two main backgrounds are DIO and RPC

Background	estimated events
Muon decay in orbit	0.01
Radiative muon capture	< 0.001
Neutron emission after muon capture	< 0.001
Charged particle emission after muon capture	< 0.001
Radiative pion capture	0.0096^{*}
Beam electrons Muon decay in flight Pion decay in flight	$< 0.00048^{*}$
Neutron induced background	$\sim 0^{*}$
Delayed radiative pion capture	0.002
Anti-proton induced backgrounds	0.007
Electrons from cosmic ray muons	< 0.0002
Total	0.03