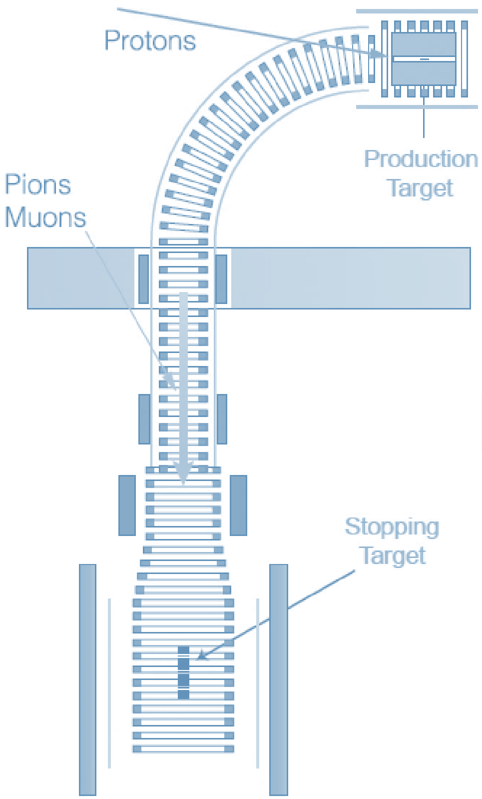
Kometen kommer: Progress towards COMET Phase-I

-Phill Litchfield

Outline



Recap of $\mu \rightarrow e$ conversion

Phase-I and Phase-II

‘Frontend’ components

- Production target
- Capture solenoid

Phase-I Detectors

- Cylindrical Detector

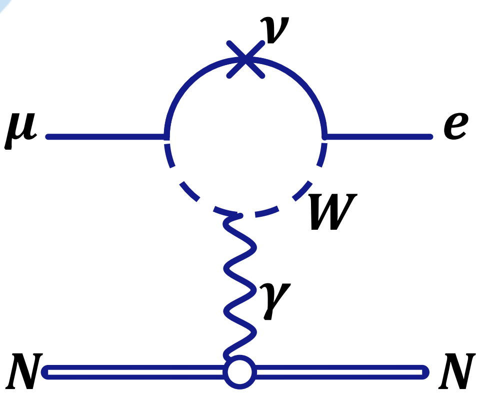
Facility Progress

- Beamline developments

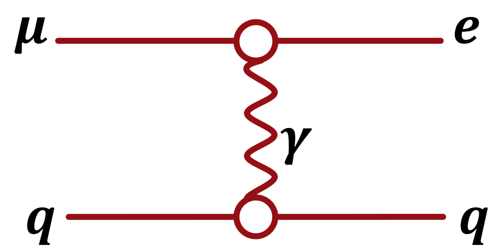
μ to e conversion

In the **SM** $\mu N \to eN$ is heavily supressed because of the mass disparity between the W and neutrino.

In **new physics** scenarios this does not usually apply, and other diagrams typically give CLFV much higher than the SM.

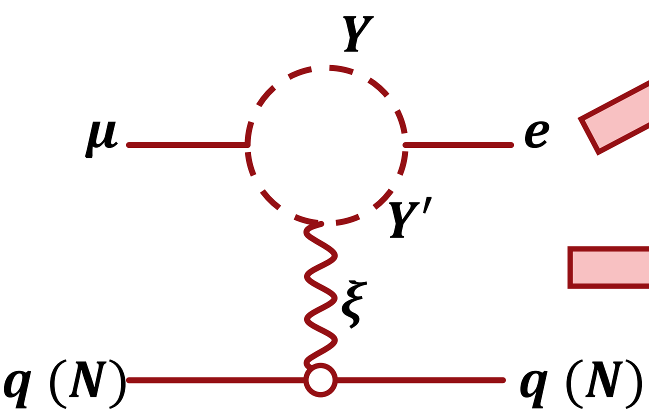


SM $\mu - e$ conversion

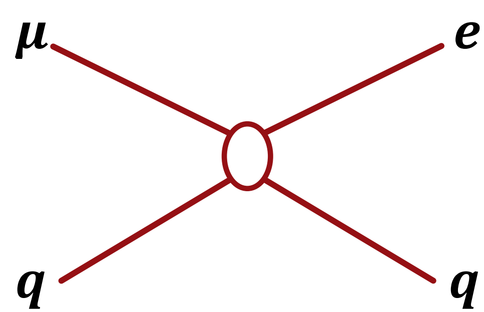


Dipole coupling

$$\mathcal{L}_{\mathrm{d}} \sim \frac{m_\mu}{\Lambda^2}\, \bar{\mu}\sigma_{\mu\nu}e \cdot F^{\mu\nu}$$



NP $\mu - e$ conversion



Four-fermion coupling

$$\mathcal{L}_4 \sim \frac{1}{\Lambda^2}\, \bar{\mu}\gamma_\mu e \cdot \bar{q}\gamma_\mu q$$

A giant leap…

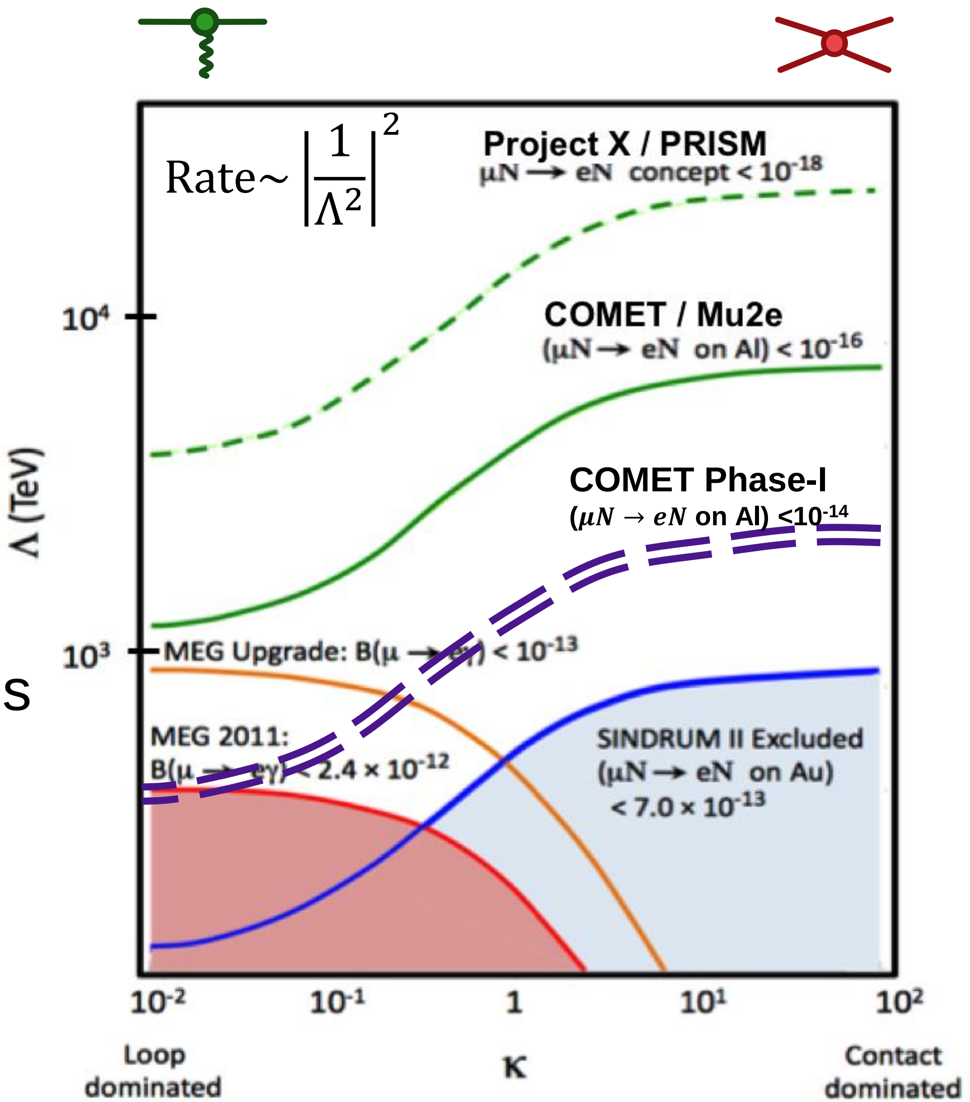
For the full COMET experiment sensitivity improvement over SINDRUM-II is **4 orders of magnitude.**

MC of background processes [especially '*tails*'] may not be good enough for optimal design

- Intermediate-scale experiment can measure background sources and inform design.
- Can still do competitive physics with a smaller apparatus

Include in COMET programme:

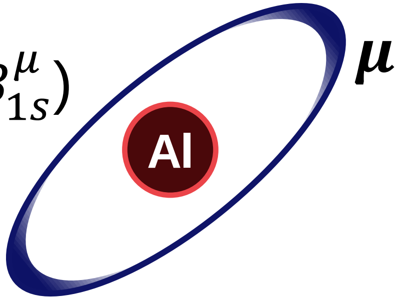
***COMET* Phase-1**



$\mu N \to eN$ and other muon decays

Muons allowed stop in suitable target.

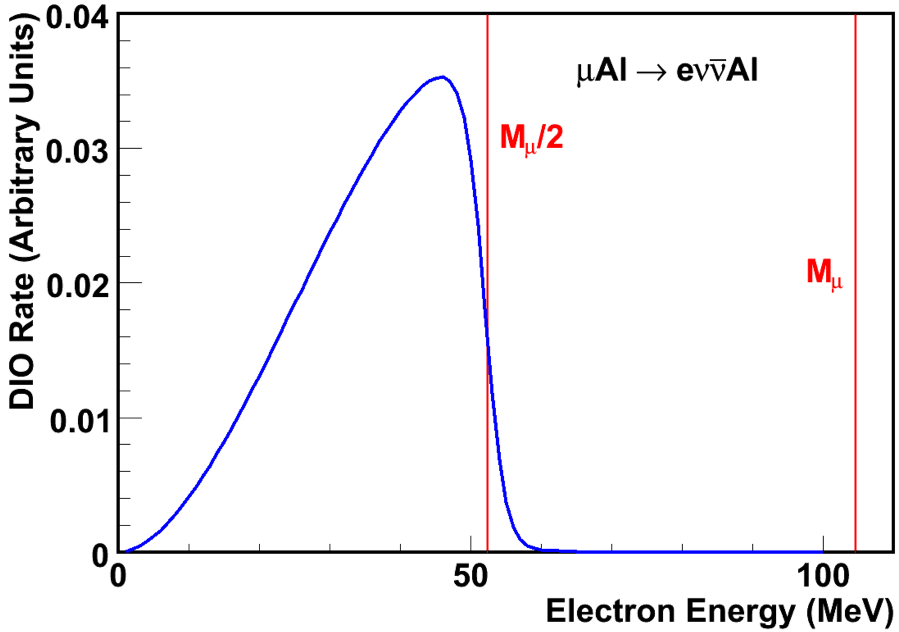
- Initially **Aluminium**, but other materials under study.
- Conversion from 1s orbital: $\mu N \to eN$ gives a ***mono-energetic electron*** at 105MeV ($\approx m_\mu - B^\mu_{1s}$)



'Normal' decays are backgrounds

- Nuclear muon capture: $\mu N(Z) \to \nu N(Z-1)$
- **Decay in Orbit [DIO]:**
  $\boldsymbol{\mu N \to e\nu\bar{\nu}N}$

  For a free muon, cuts off at $\frac{1}{2}m_\mu$, but bound state has a small tail up to m_μ



Backgrounds

See friday talk (Sato)

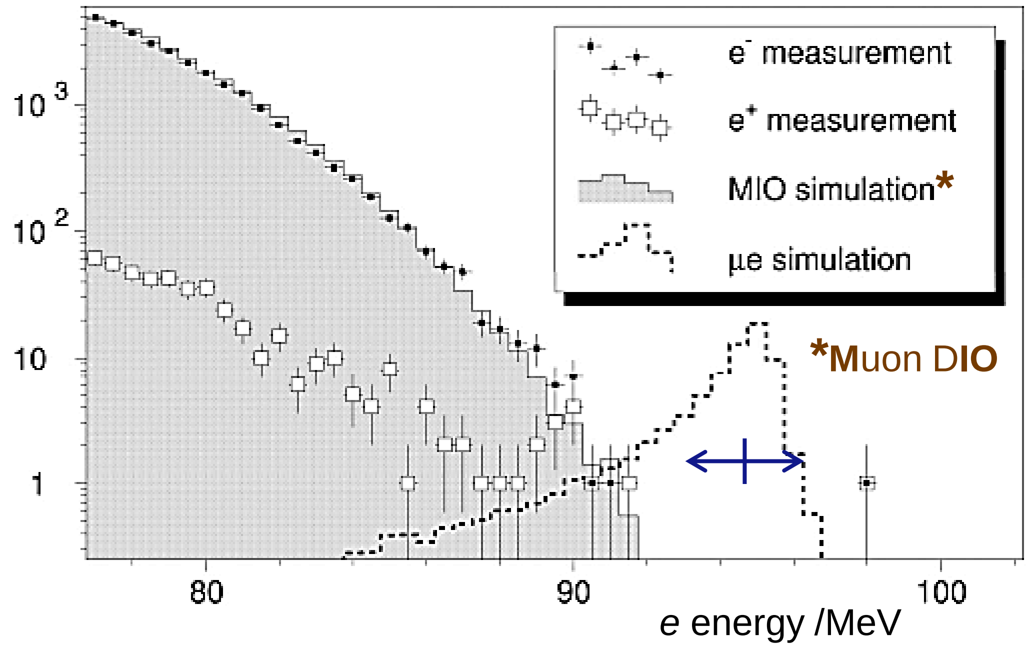
Three main background processes:

- **Decay in orbit**, as before ▶
  Energy resolution!

- **Decay in flight**:
  Electrons from energetic free muons can be boosted to 105MeV.
  - Use momentum selection in muon transport

See friday talk (Kurup)

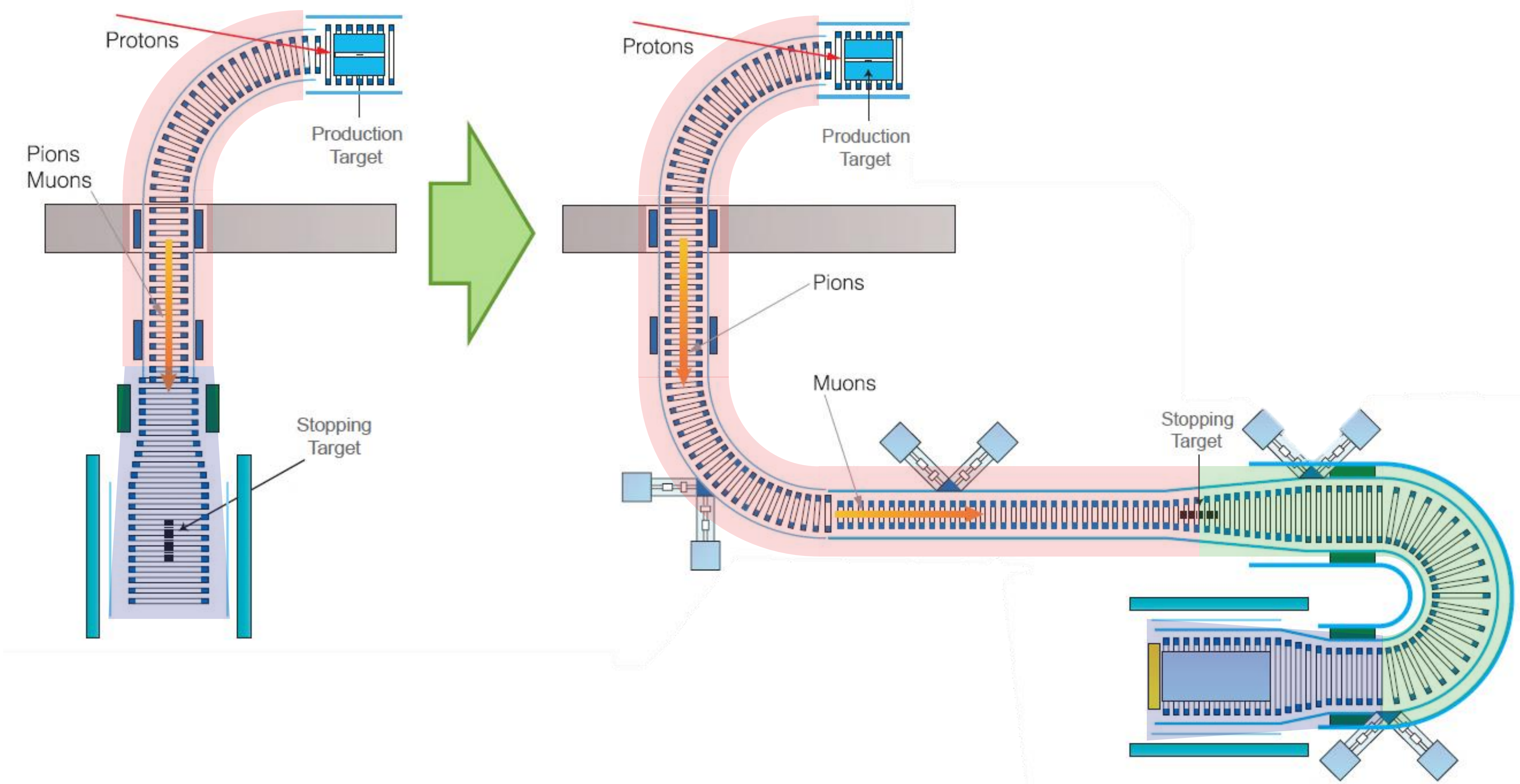
Results from SINDRUM-II



- **Beam backgrounds**:
  Significant number of prompt e^- and π^- produced by beam. Can eliminate this with timing *if* we have reliably beam-free time windows.

COMET phases

Phase I **Phase II**



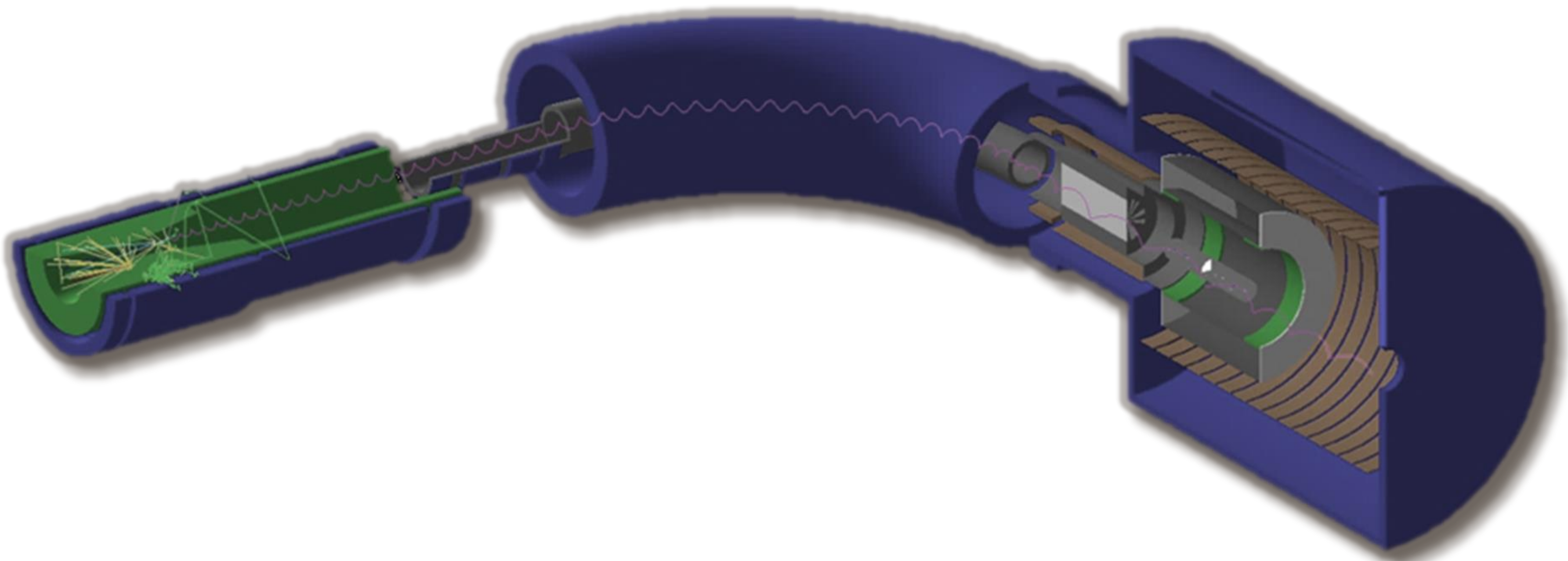
Phase I

Capture solenoid and first 90° of muon transport will be reused for COMET Phase II.

- See A.K. talk for more on muon transport
- **Production target** and **capture solenoid** covered here

Stopping target is 17×0.2mm Al discs (100mm radius), and is surrounded by a **tracking chamber** for physics measurement.

- Not going to cover detector solenoid in any detail

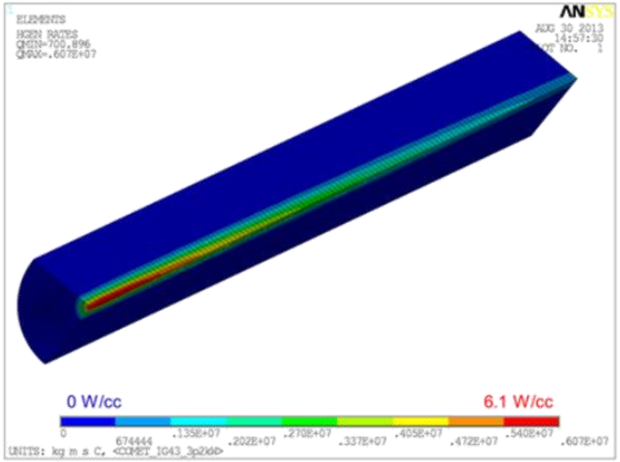


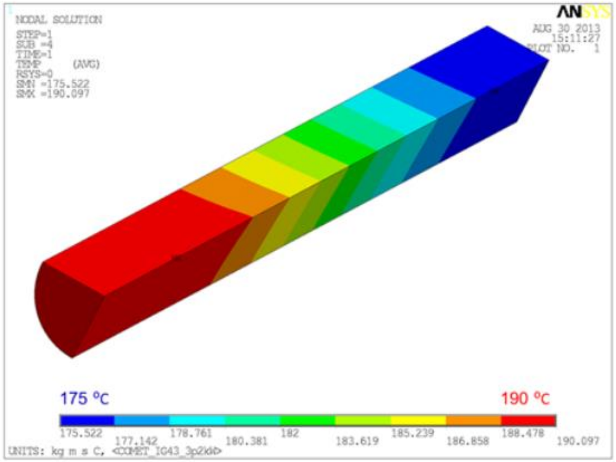
Production target

In Phase-I we will use a 60cm × 2cm dia. graphite (IG-43) target.

Higher Z is better for pion production, but **graphite** is a ‘safer’ choice:

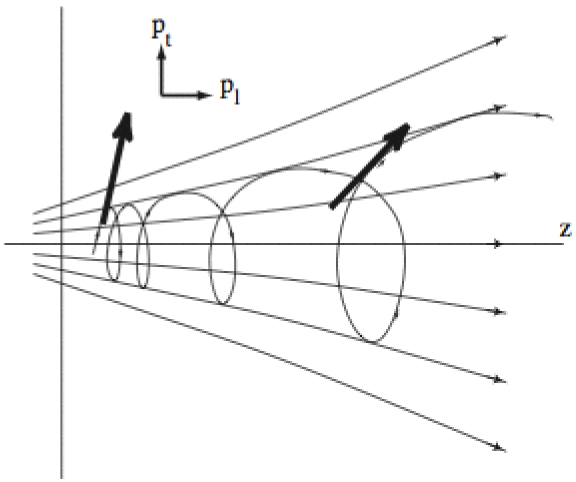
- IG-43 is used for T2K target (FX, >200kW beam) so is known to be capable of handling our beam.
- Lower irradiation of target and shield makes removal and storage safer in case of replacement in Phase-II
- At Phase-I power, radiative cooling is sufficient for this target.

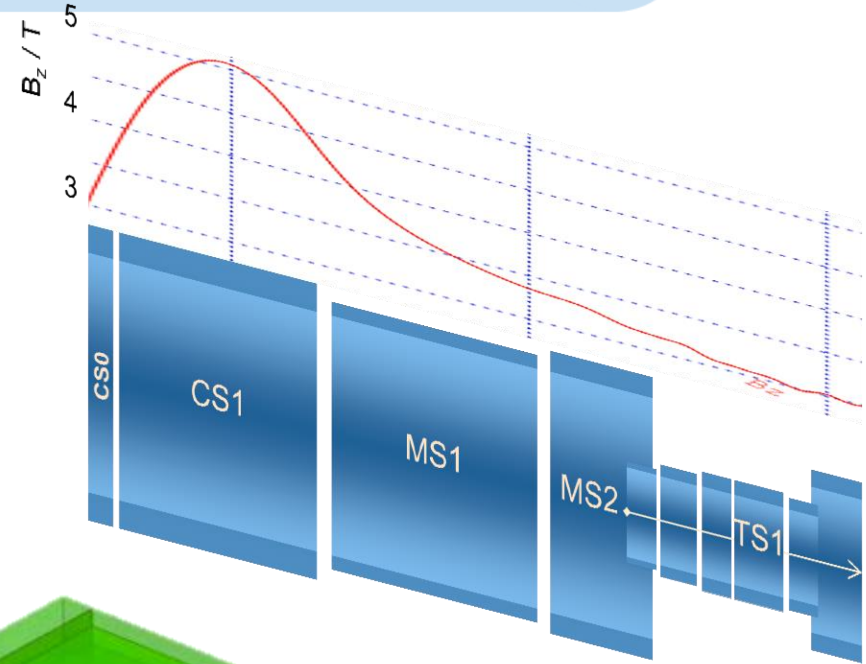


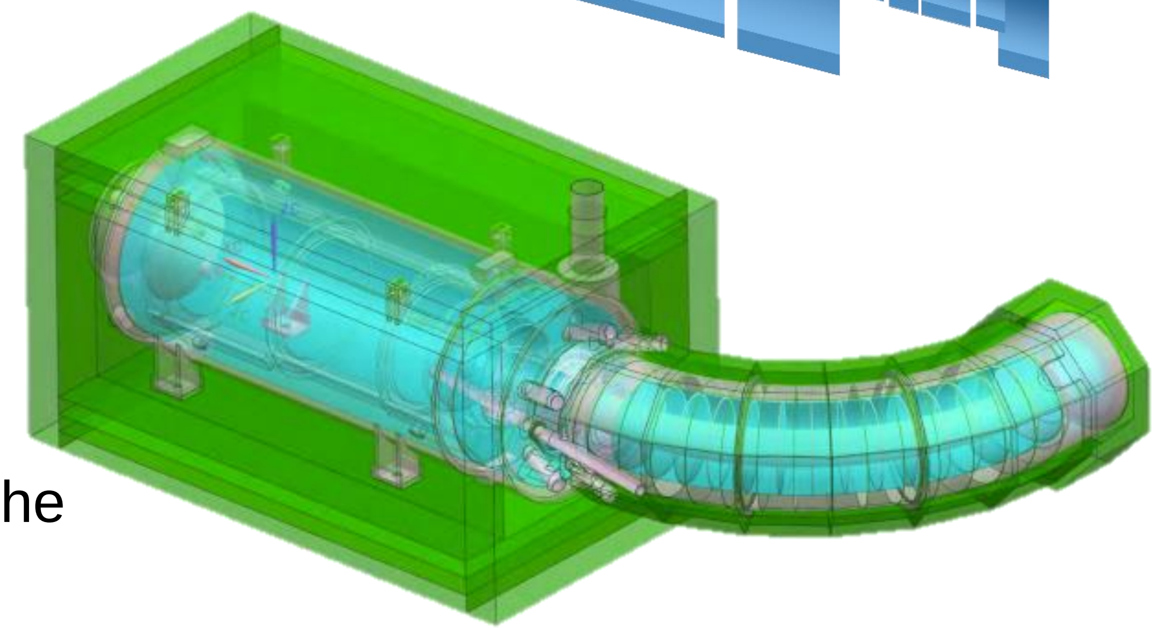


Capture Solenoid

Comet needs *low energy* pions so collect from **back and sides** of target.



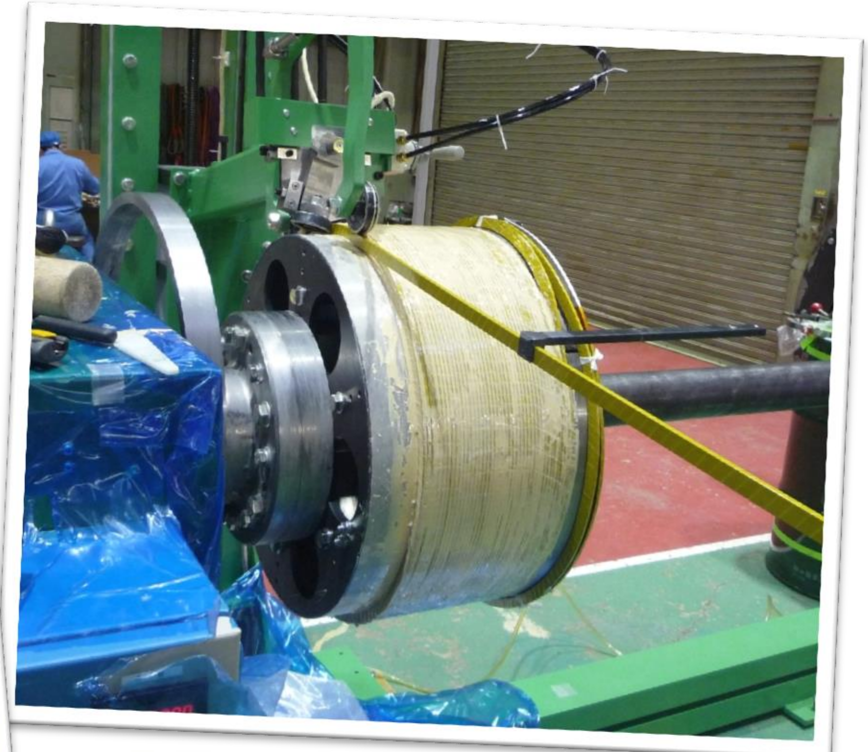


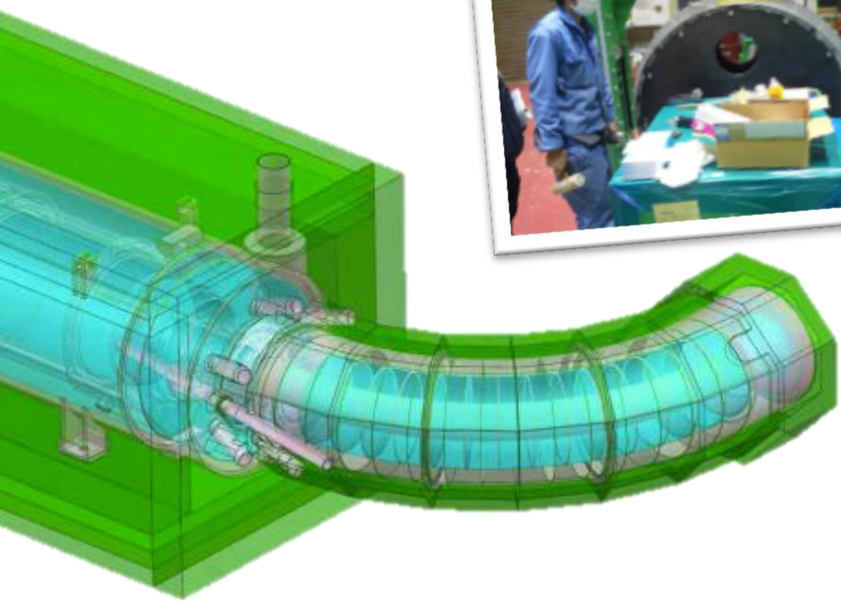


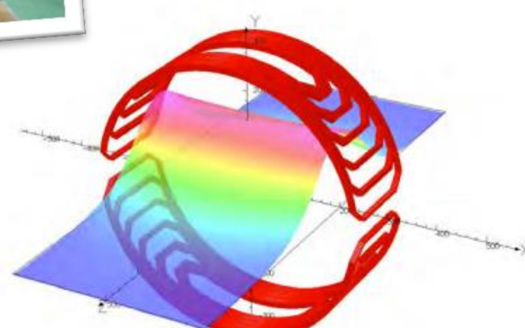
Gradient field converts transverse momentum into longitudinal momentum.

- Effectively increases the solid angle aperture into the transport solenoid.

Coil winding (TS1)







Compensating dipoles

Cooling and shielding

A 5T solenoid is (unsurprisingly?) superconducting.

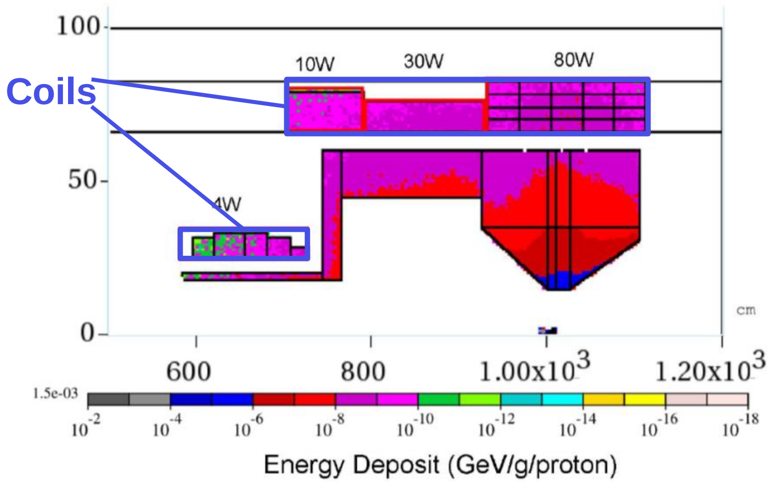
- And therefore cryogenically cooled…

But there is a high power beam hitting a target in the middle!

- Phase I: this heating is estimated up to 30W
- Phase II: heating can be 120W [c.f. other sources ~15W]

Shielding is needed, for radiation and thermal heating.

- Copper and tungsten shield
- Cooled with water
- Will probably need upgrade for Phase II, gets very (radioactively) hot.



Non-trivial engineering challenge!

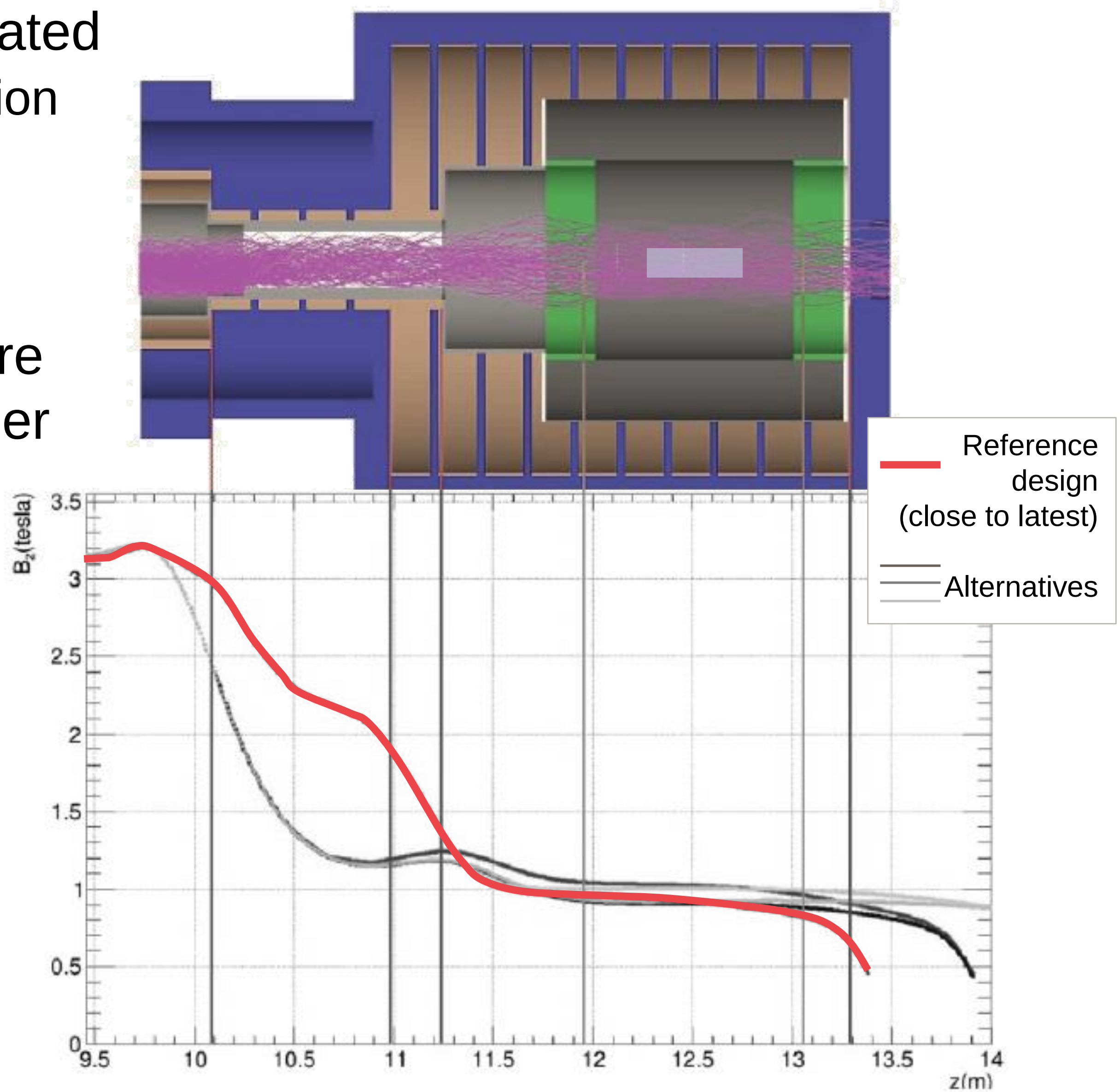
Phase-I Detector

Phase-I will have a dedicated detector for $\mu \to e$ conversion measurements.

Because of the charged particle tracks in the centre channel, a co-axial cylinder geometry is used.
↳ **CyDet**

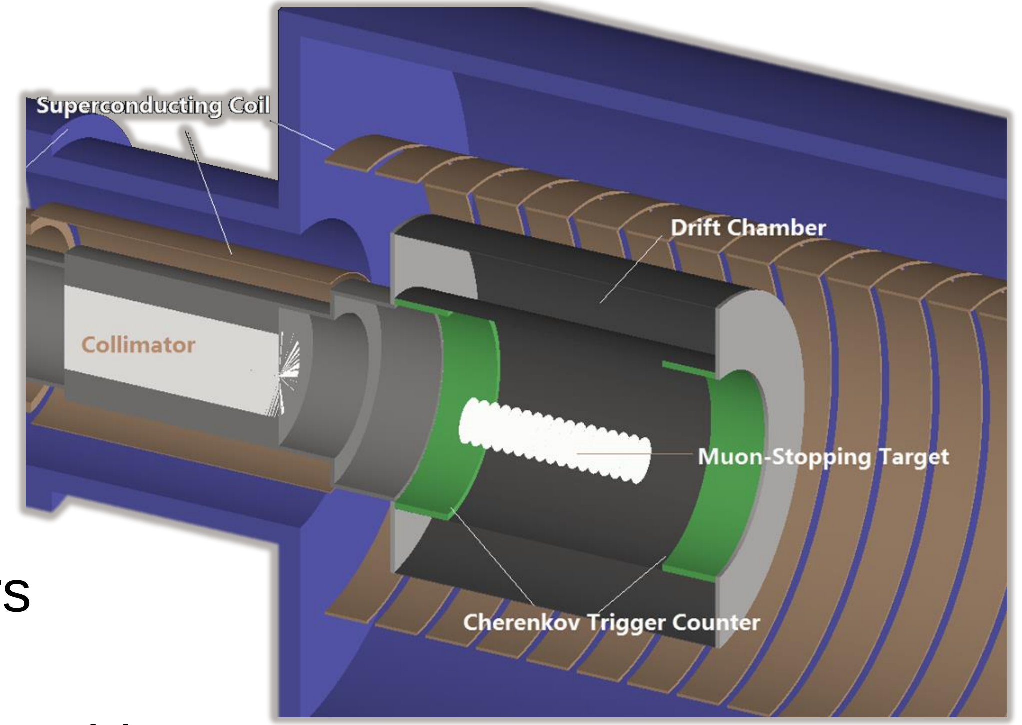
The detector and capture target will sit within a 1T solenoid field.

Low momentum particles do not reach the detector

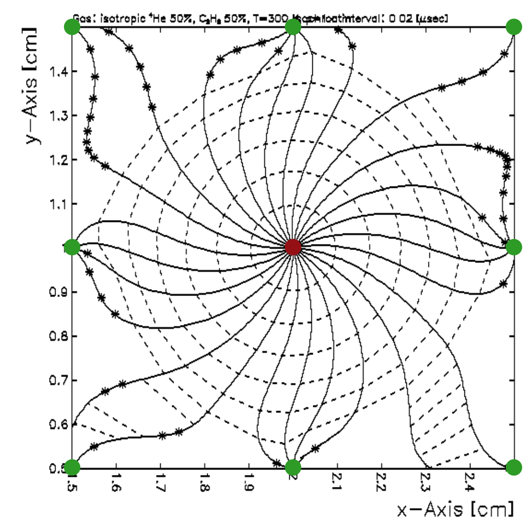


CyDet

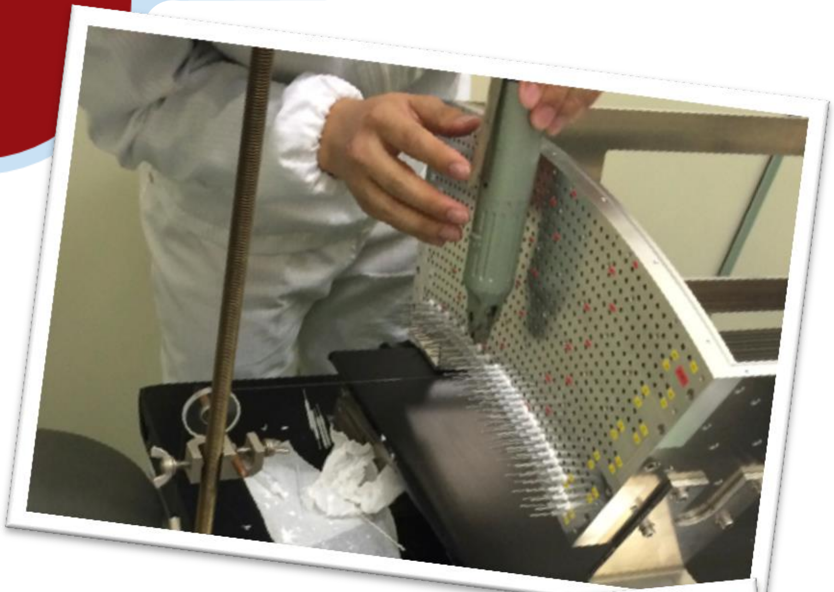
The main part of the detector is a coaxial **drift chamber**

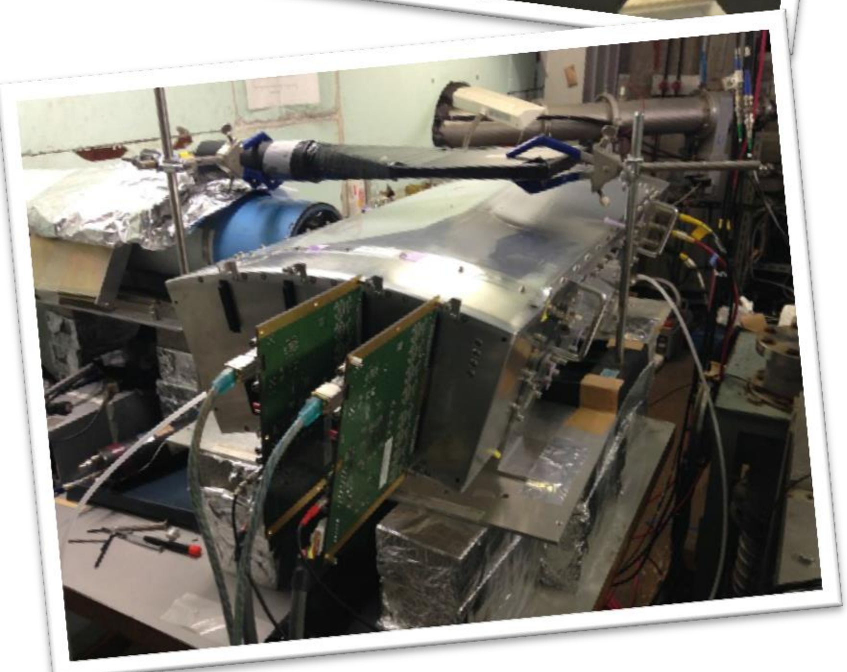


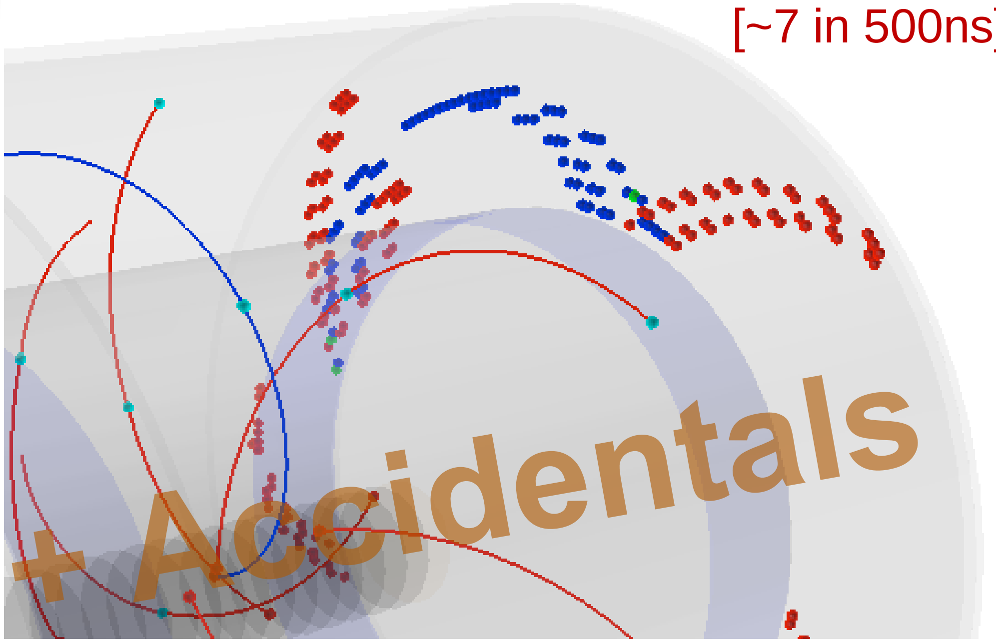
- Helium-based gas mixture to reduce multiple scattering.
  - Resolution ~ 200 keV
- z measurement by stereo layers
- Large inner radius to reduce DIO hit rate
  - Dim: 150cm × 84cm(outer) // 50cm(inner)
- 19 concentric sense layers
- Triggering from **hodoscopes** at ends



Drift chamber progress







▲ Event display showing event projection

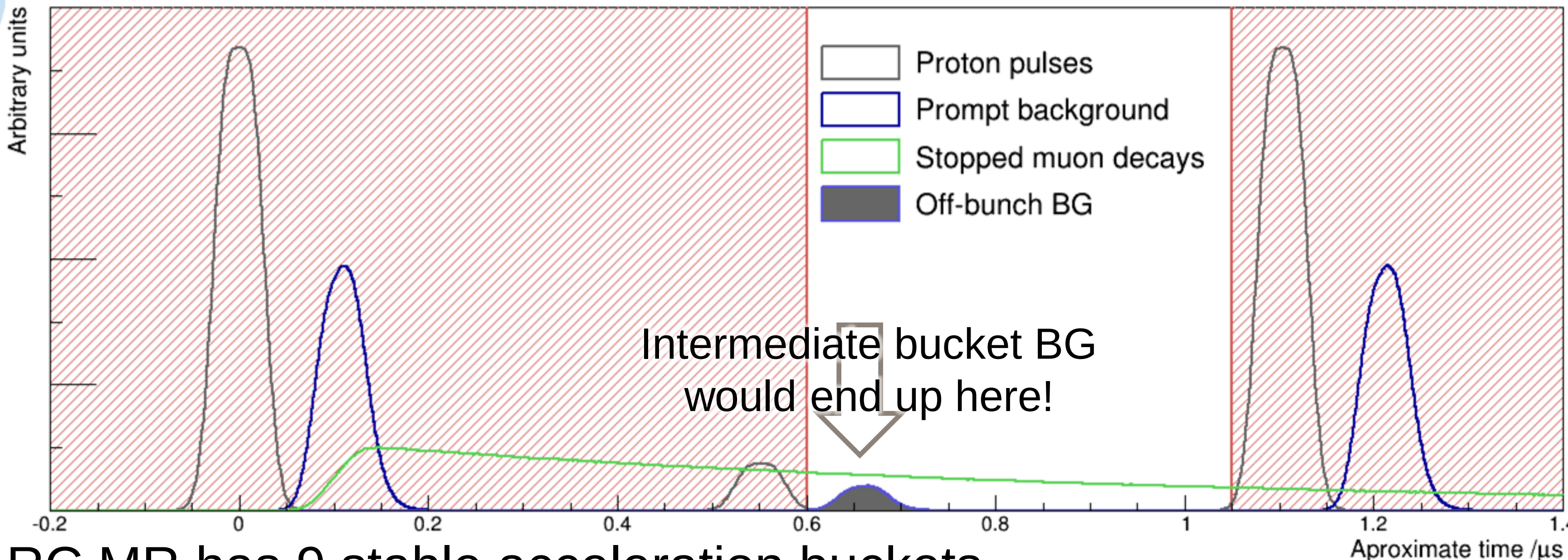
◄ Stringing wires and CR test of prototype section

Facility construction

◀ Magnets laid-out for beam switchyard

◀ COMET hall construction proceeding well

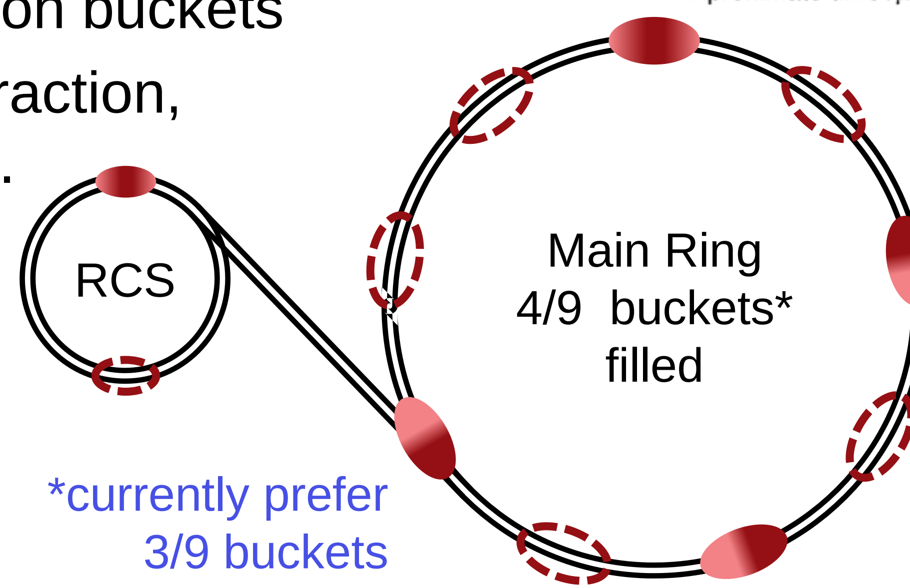
Beam extinction



J-PARC MR has 9 stable acceleration buckets

- Need to maintain RF during extraction, so that bunch structure remains.
- If RF is not strong enough, protons will 'leak' into empty buckets.

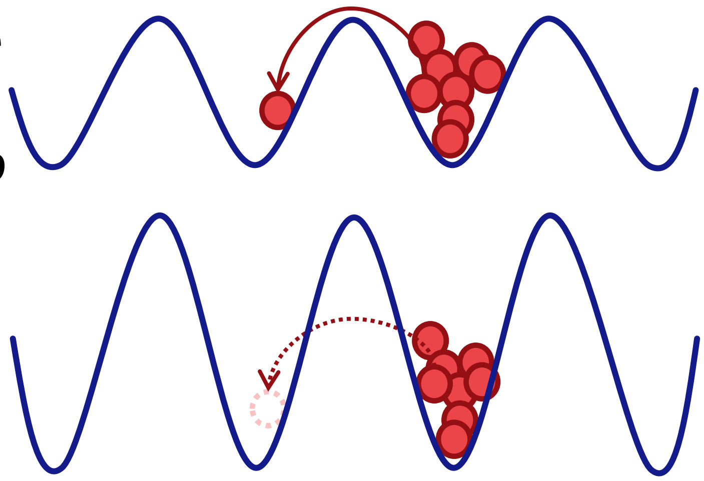
Signal process is rare so even a small leak is a major background



Extinction measurement

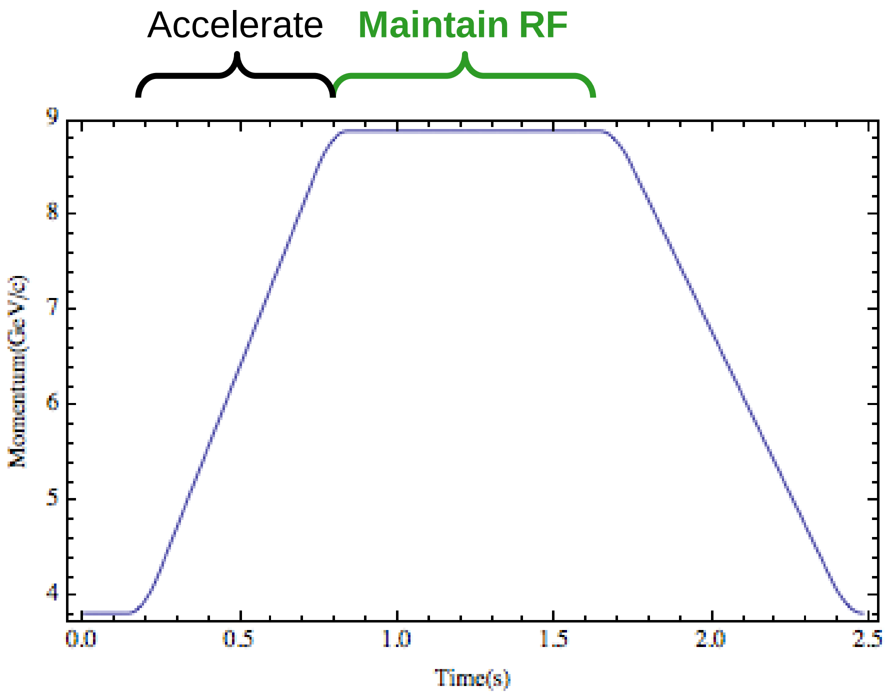
COMET design requires that we can achieve an extinction:

$$E = \frac{N_{Empty}}{N_{Filled}} < \mathbf{10^{-9}}$$



Extinction can be improved by increasing RF voltage, but this heats the cavities.

(And there is a limit…)



2012 test at 30 GeV demonstrated this is possible for RF > 120kV,

But study time at 8 GeV not allocated until this year…

Extinction measurement

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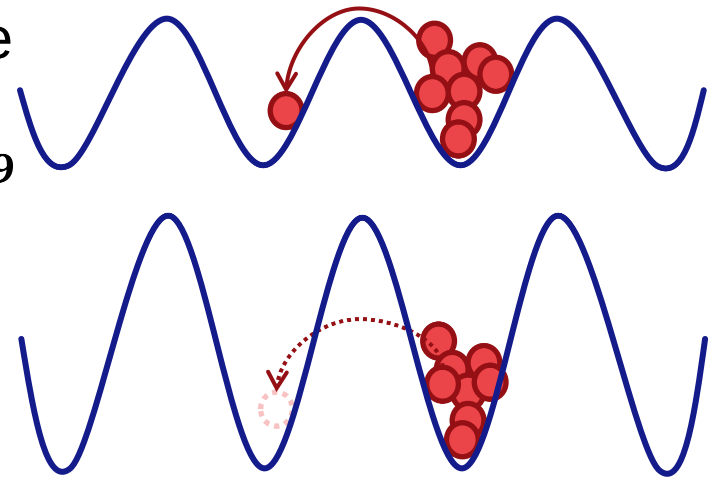
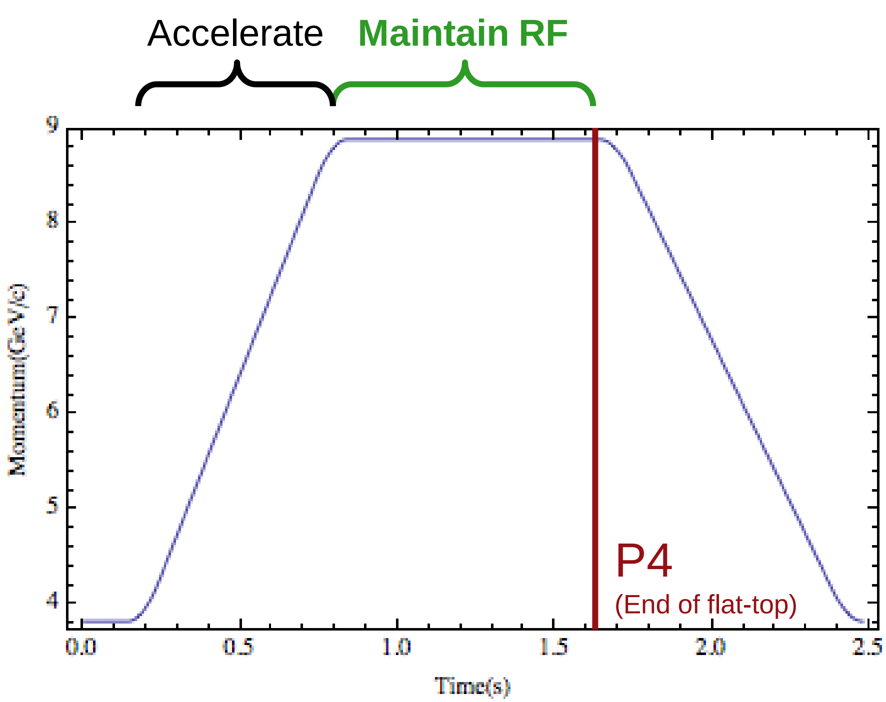
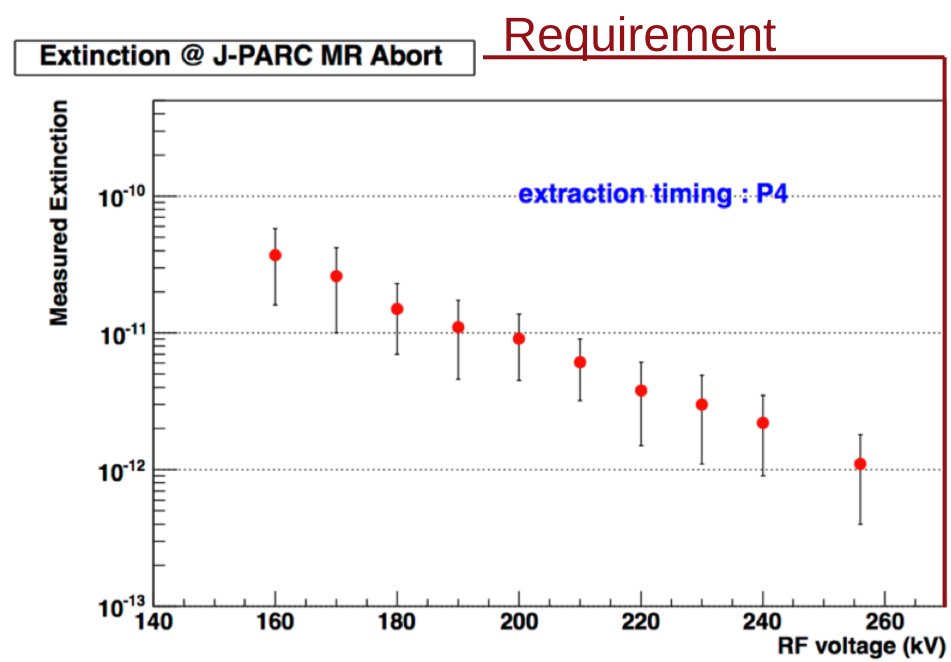


Result was excellent! Even low RF voltage provides the required extinction





Summary

- **Phase I of COMET is taking shape!**
  - Facility construction progressing quickly.
  - Magnet coils also in construction.
  - CyDet prototype assembled and tested.

- **Beam extinction requirements met comfortably!**
  - Accelerator should be fully capable of (fairly demanding) use cycle.

- **Phase-I projected to be ready in 2016.**
  - Short (few month) run should improve sensitivity by 2 orders of magnitude over previous experiment (S.E.S. of $\mathbf{3 \times 10^{-15}}$)
  - Will also aid understanding of backgrounds [AS talk] for Phase II [AK talk], so stay tuned for tomorrow's session.

日本語：「ムーミンだにのすいせい」[The comet of Moomin Valley]

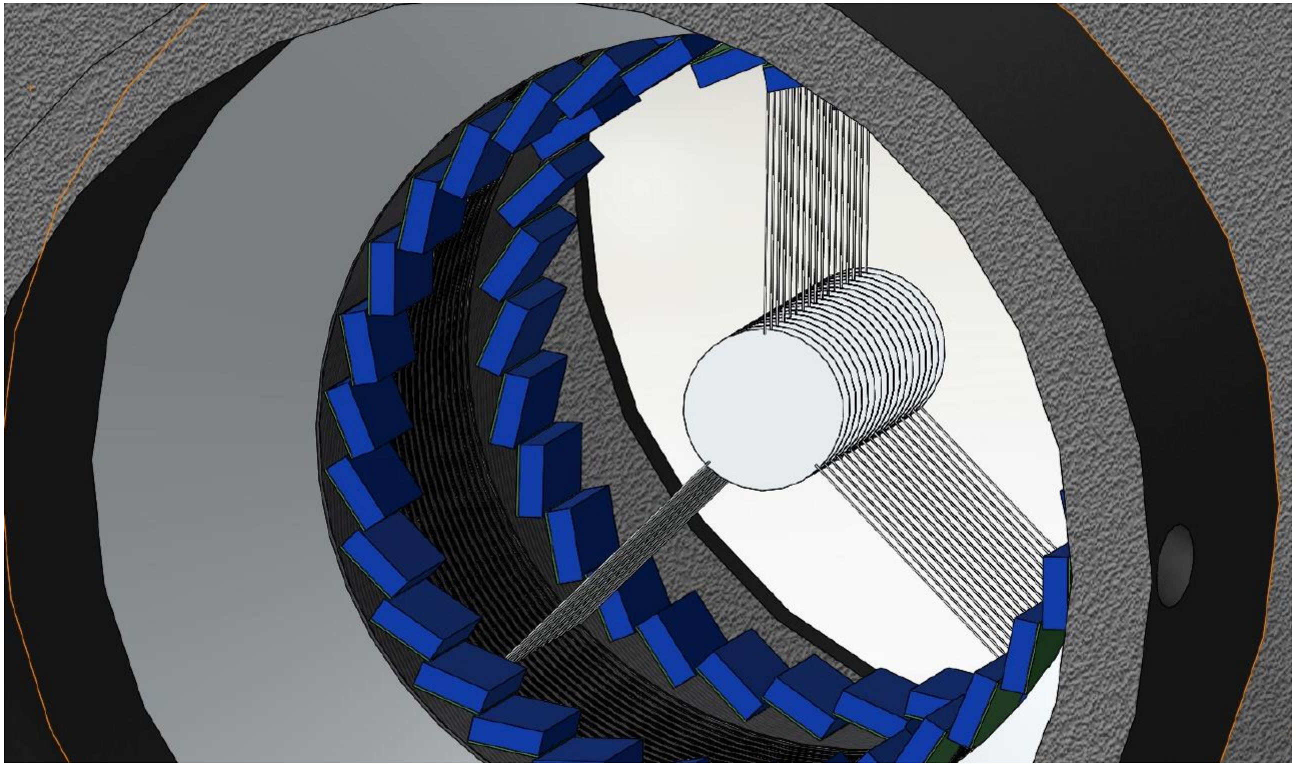
Suomi: “Muumi ja punainen pyrstötähti” [Moomin and the comet chase]

English: Comet in Moominland

Phase I capture target details

Material	Al
Radius	100 mm
Thickness	200 µm
Nº Disks	17
Spacing	50 mm
Total thickness	3.4 mm
Total length	0.8 m

- Target may be changed for Phase 2



Extinction vs timing