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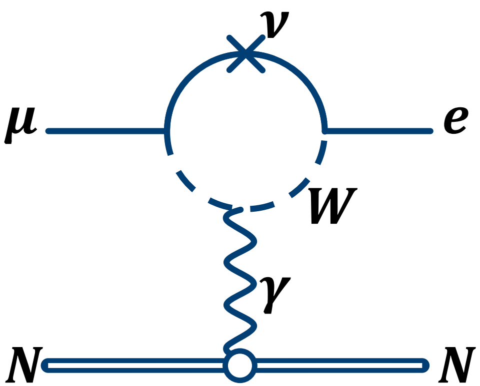
The COMET experiment

Phill Litchfield
on behalf of the collaboration

$\mu - e$ conversion [Recap]

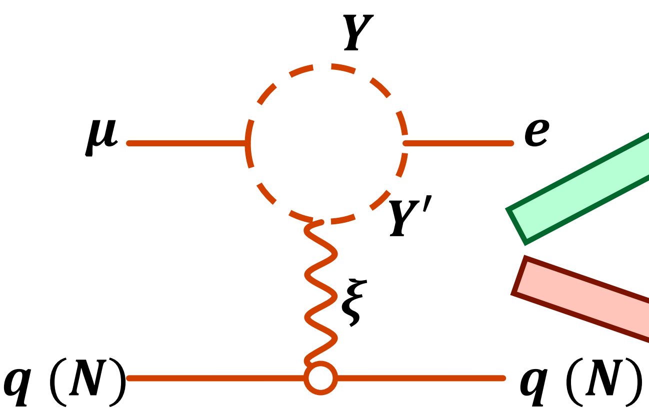
μ to e conversion



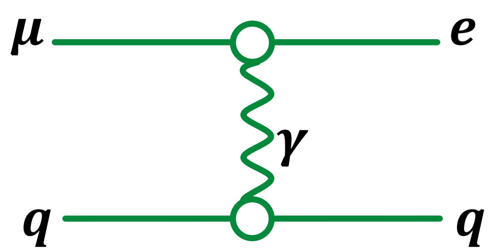
SM $\mu - e$ conversion

In the **SM** $\mu N \to eN$ is supressed by $\mathrm{O}(10^{-54})$ because of the mass disparity between the W and neutrino.

This is 'accidental'; **new physics** scenarios typically give CLFV much higher than SM.

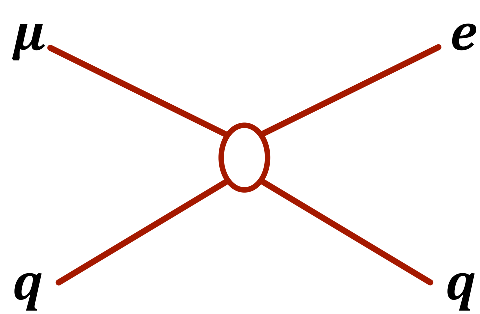


NP $\mu - e$ conversion



Dipole coupling

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



Four-fermion coupling

$$\mathcal{L}_{\mathbf{4}} \sim \frac{1}{\Lambda^2}\, \bar{\mu}\gamma_\mu e \cdot \bar{q}\gamma_\mu q$$

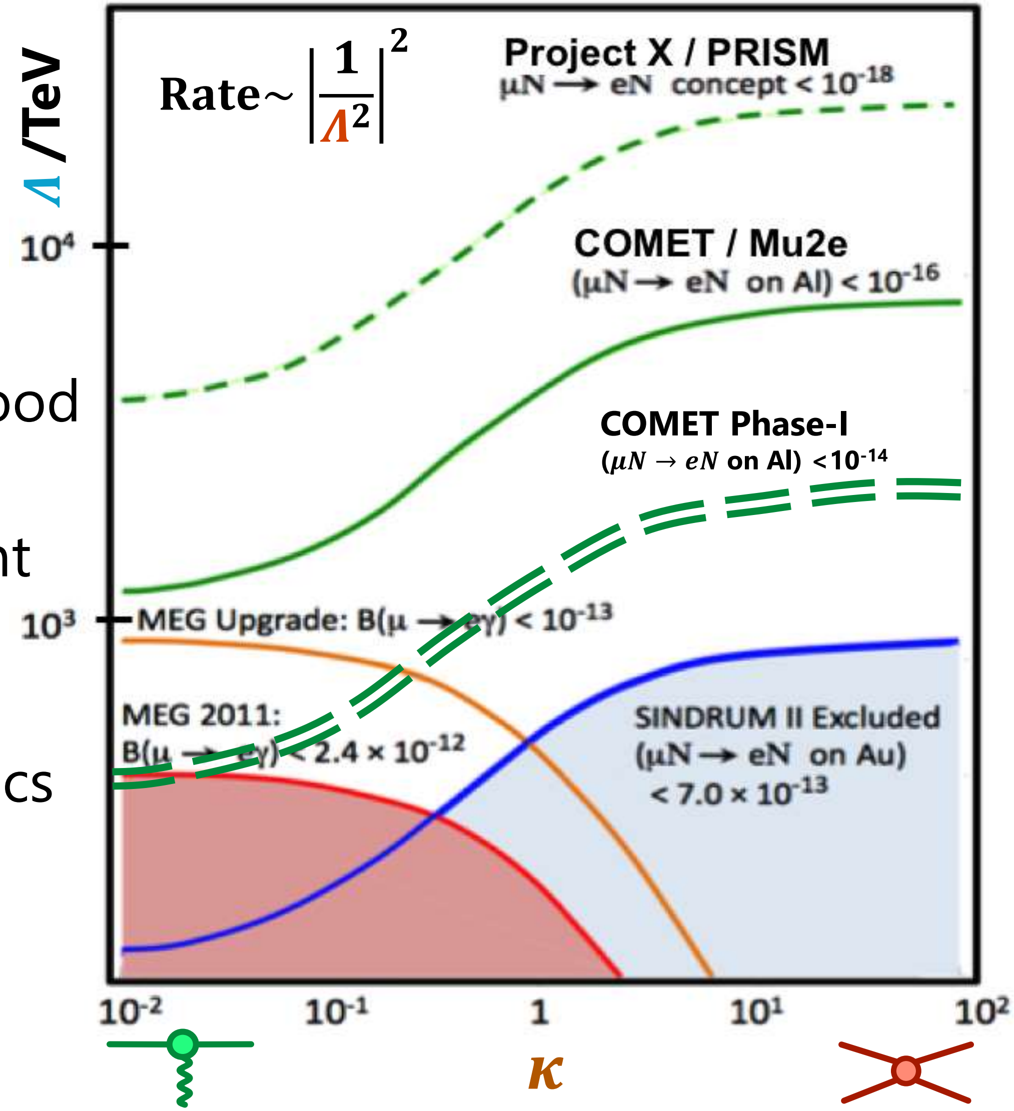
$$\mathcal{L} = \frac{1}{1+\kappa}\mathcal{L}_d + \frac{\kappa}{1+\kappa}\mathcal{L}_4$$

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-I

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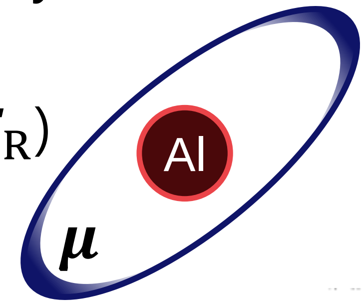
Muon decays

Muons allowed stop in suitable target.

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



'Normal' decays are backgrounds

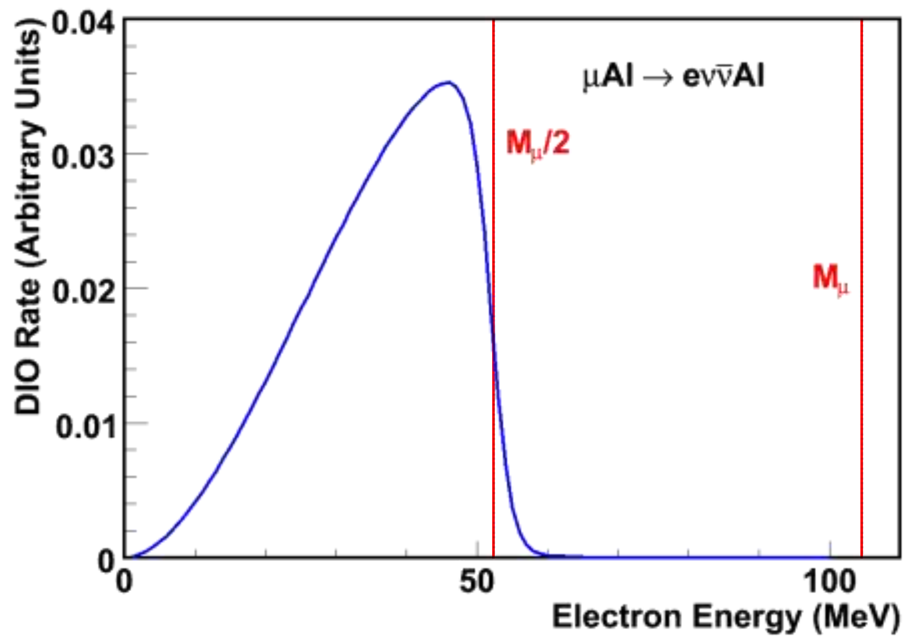
- Nuclear muon capture:

$$\mu N(Z) \to \nu N(Z-1)$$

- **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 $m_\mu - B_{1s}^{\mu} - E_{\mathrm{R}}$

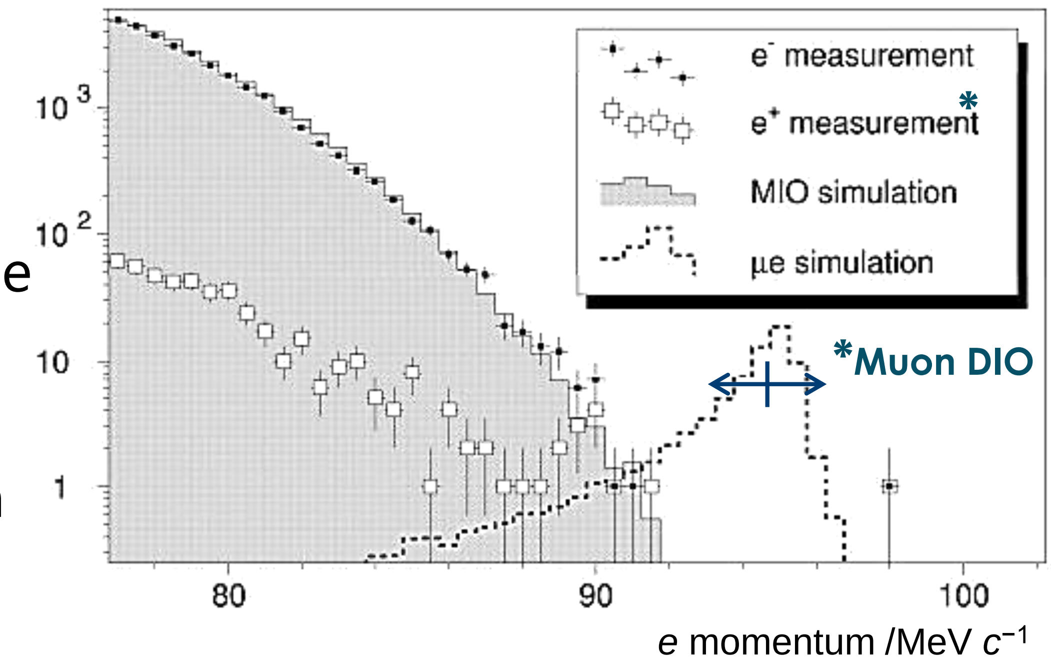


Backgrounds

Three main background processes:

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

Results from SINDRUM-II (BR <7×10^{-13} @ 90%CL)

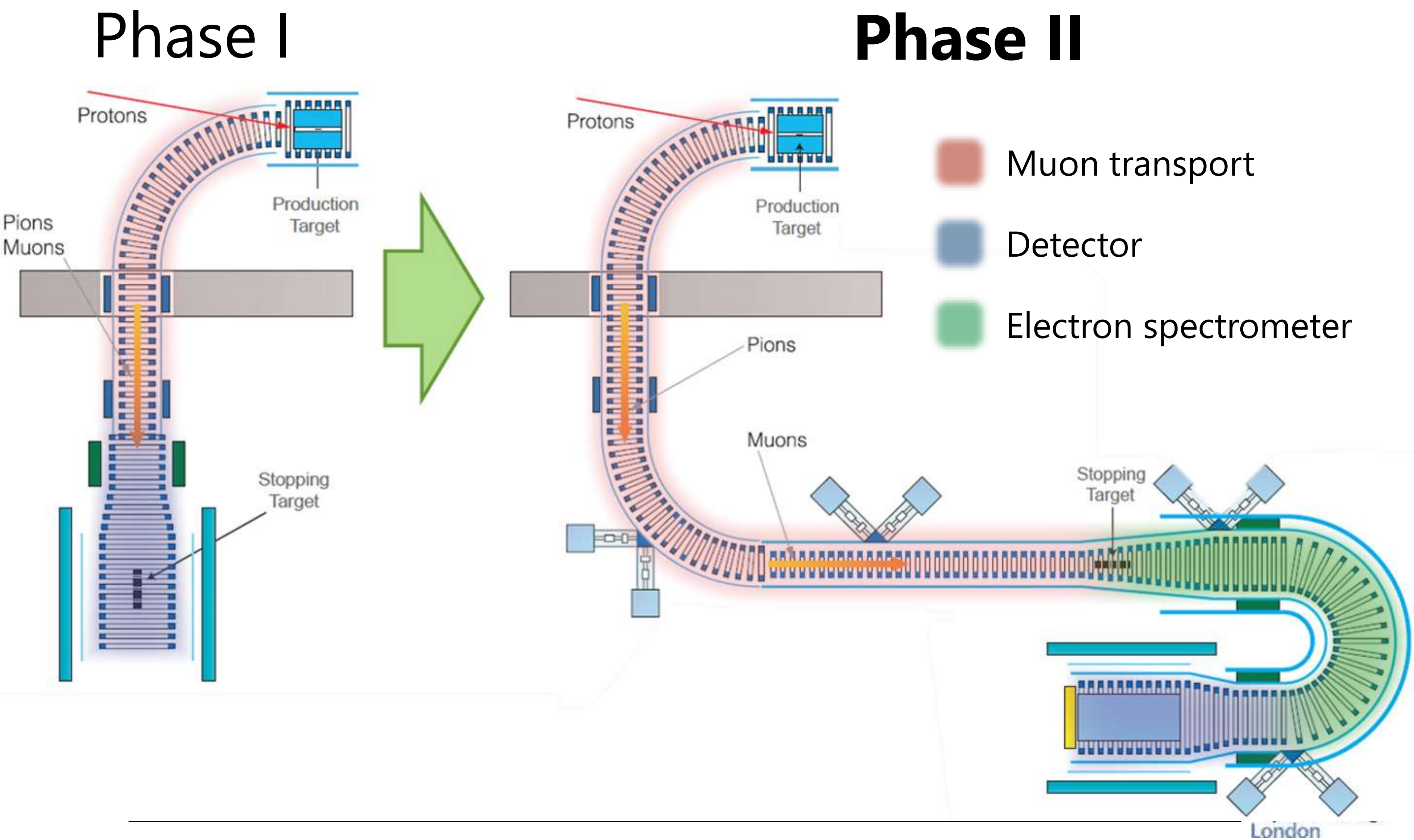


- **Decay in flight**:
  Electrons from energetic free muons can be boosted to 105MeV.
  - Use momentum selection in muon transport

- **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 ▶ Pulsed beam

COMET design and construction

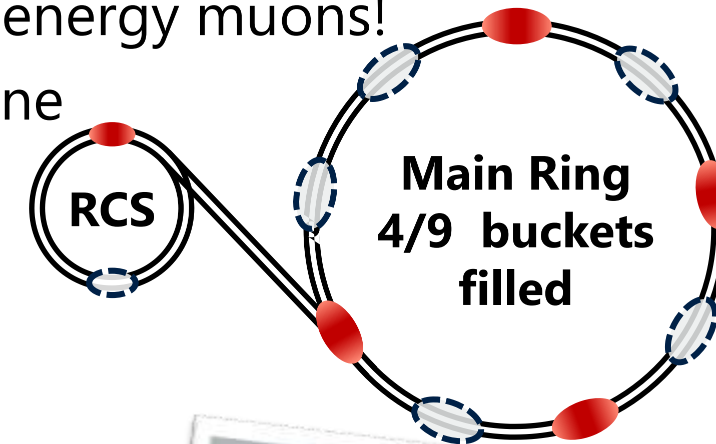
COMET, Phase I and II

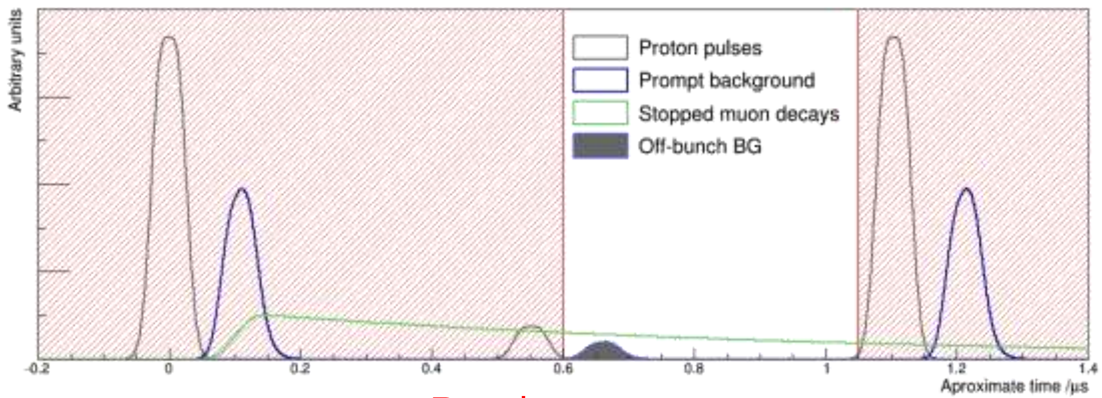


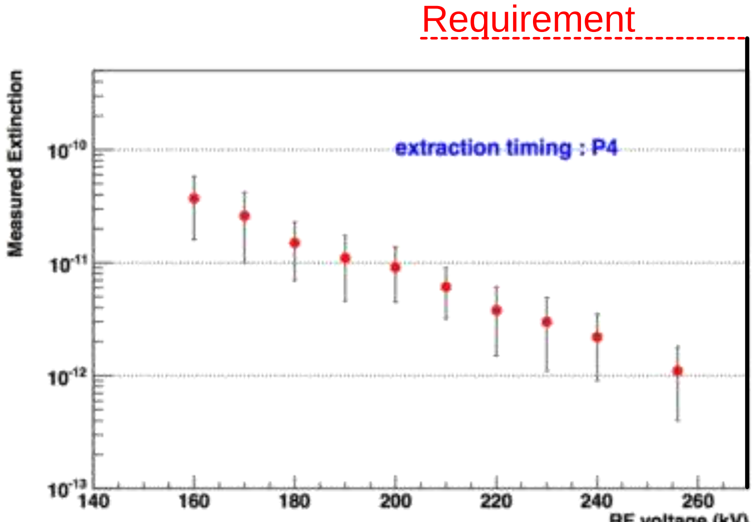
Primary beamline

Main driver of sensitivity: Need lots of low energy muons!

- Use high-power ***pulsed* proton beam** line (8 GeV) with resonant slow extraction

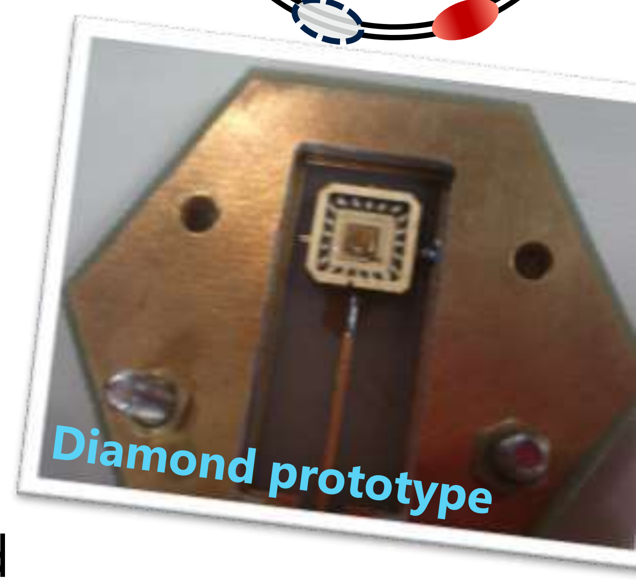




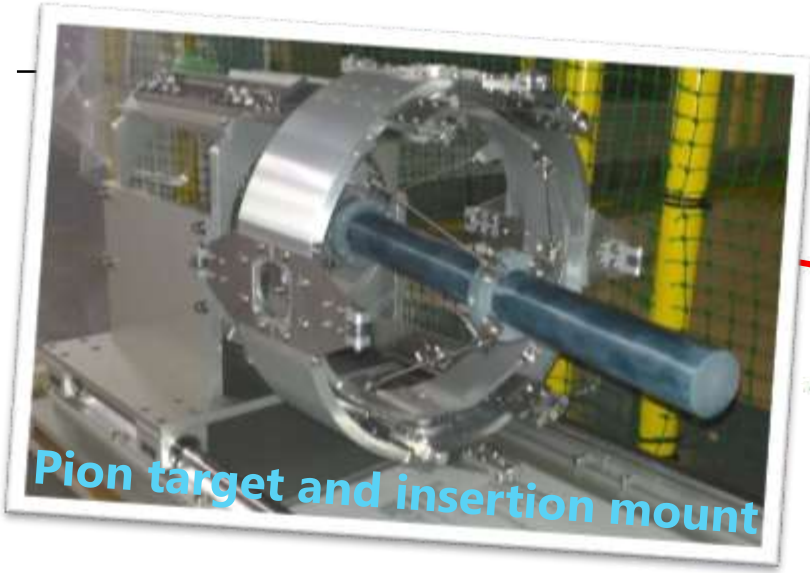


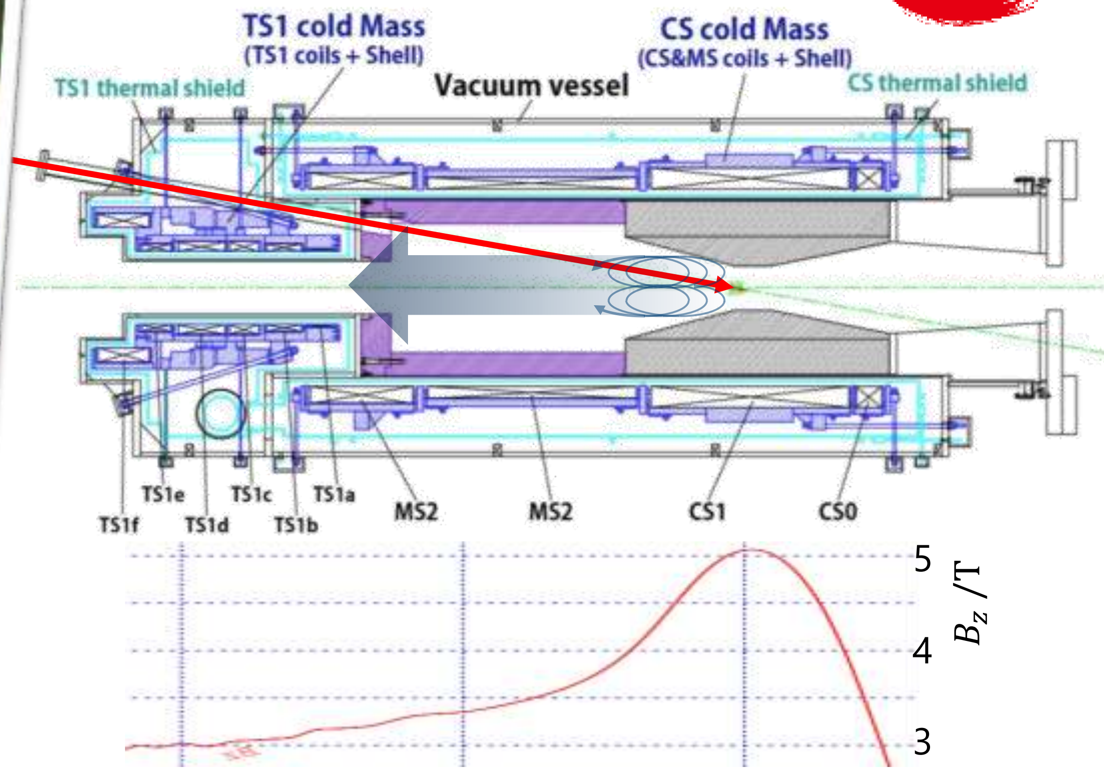
Strict ***extinction*** requirement of $< 10^{-9}$.

Beam monitored with diamond detector



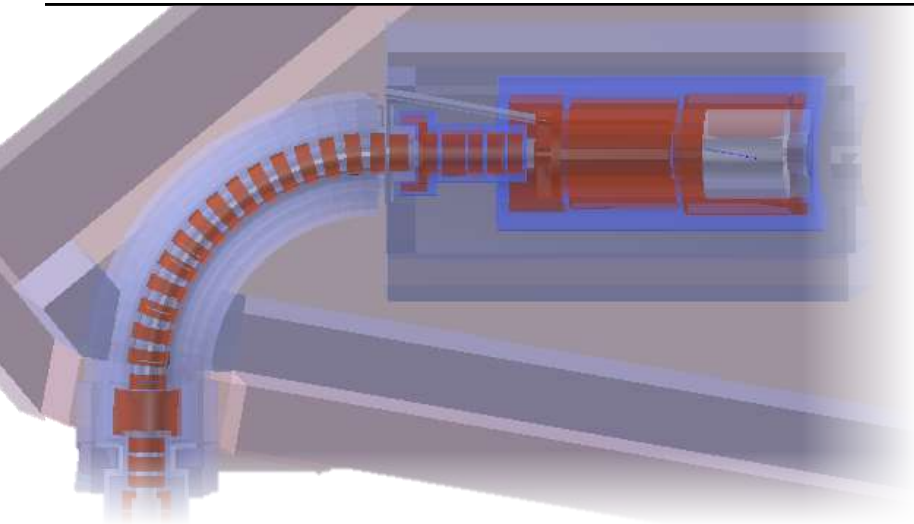
Muon source

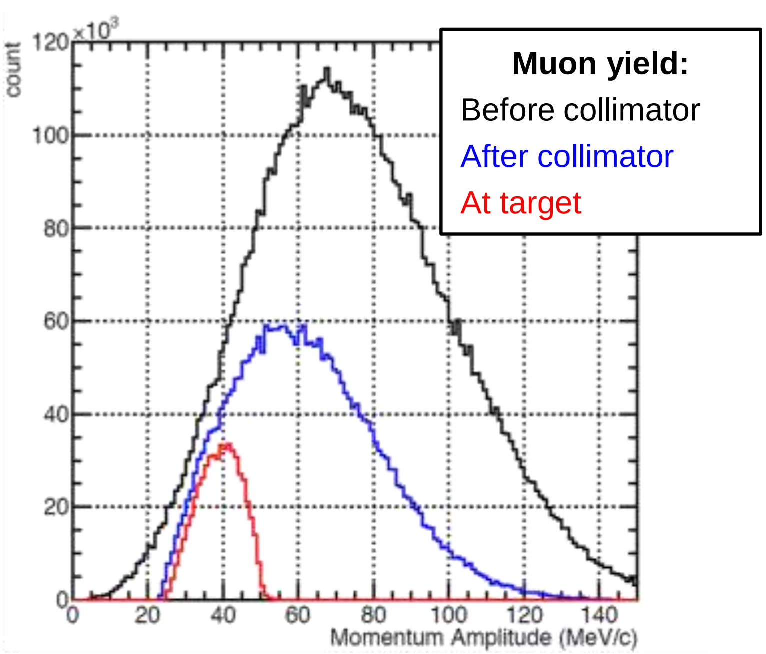




- Collect ***backward*-going pions** with capture solenoid
- Maximise field at target to give larger solid angle aperture
- Pions decay to muons en-route to stopping target.
- Many neutrons produced, requires careful shielding. The curved transport line helps to eliminate direct line-of sight.

Muon transport



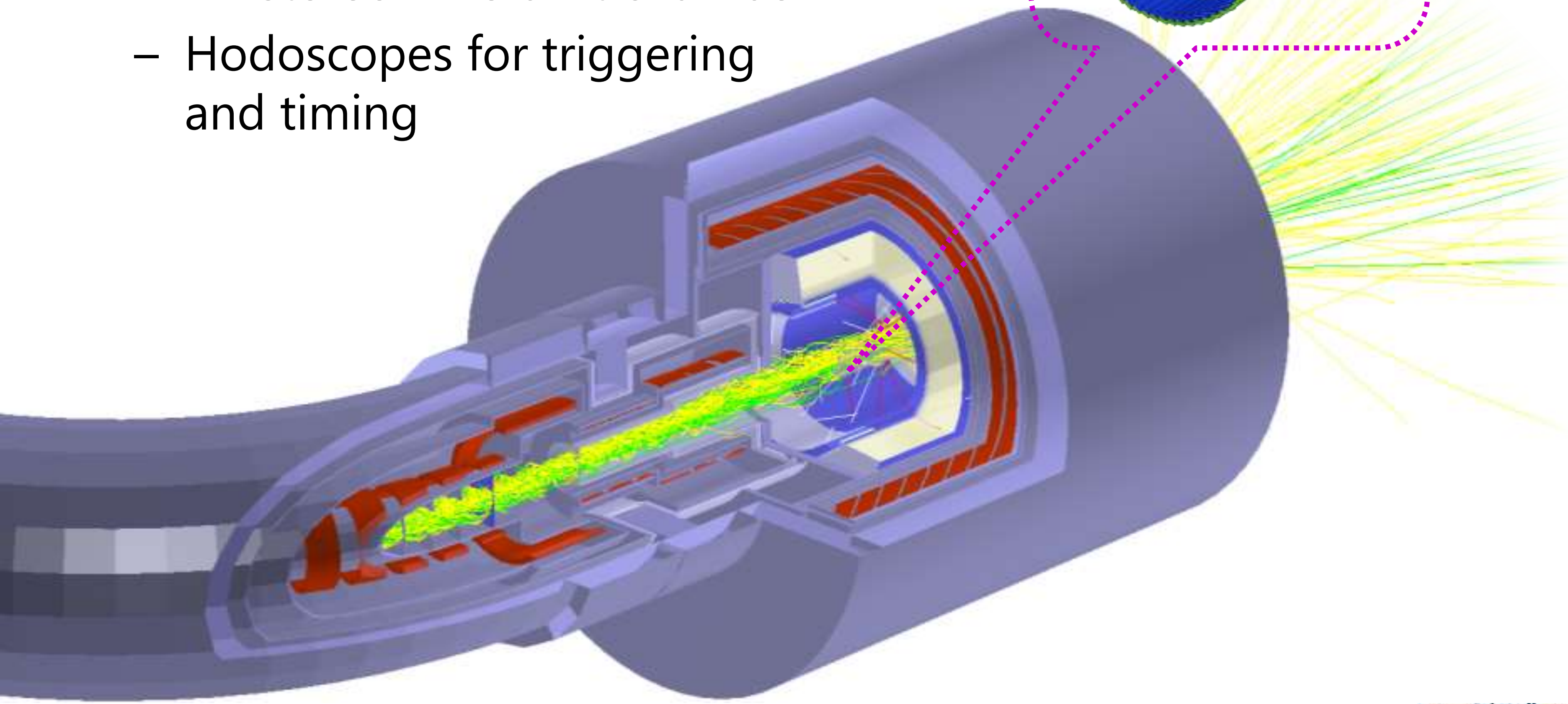


Muon transport is a curved solenoid:

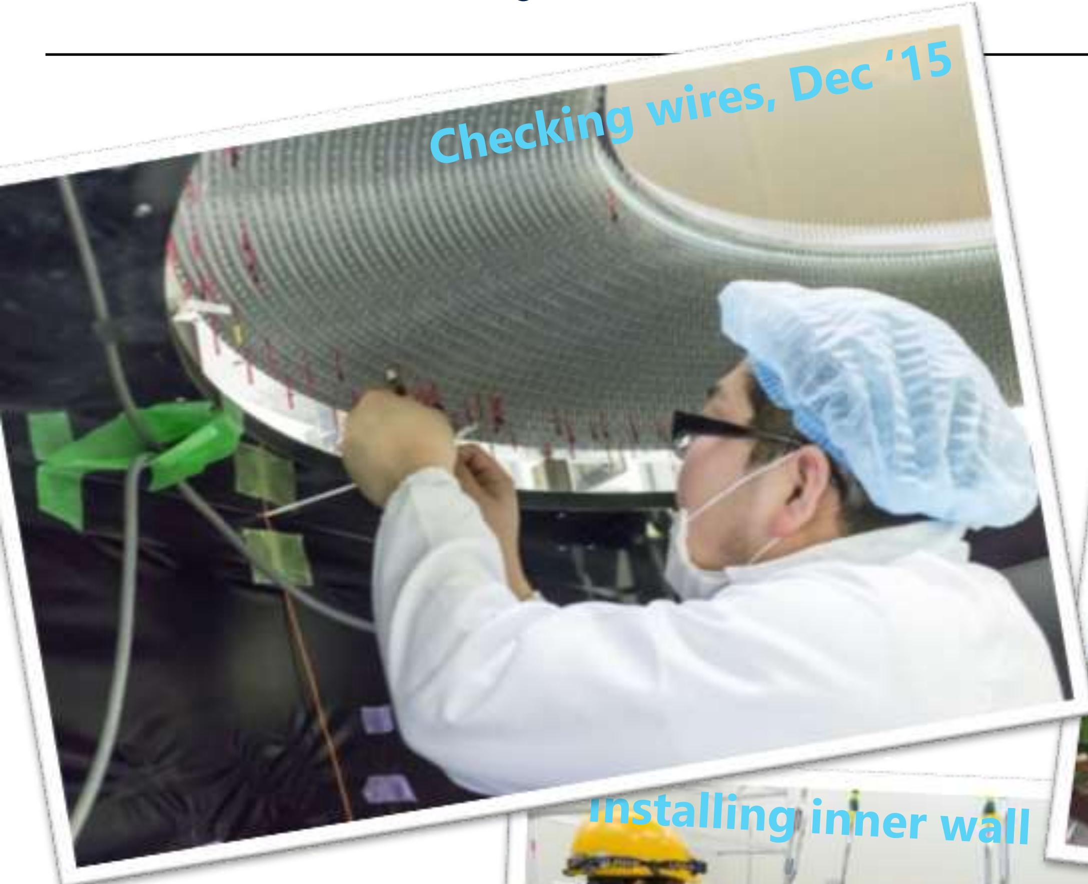
- Particles are channelled in **spiral paths [solenoid]**, which naturally tend **up/down [curvature]** depending on *p* and charge
- Dipole keeps desired lower-*p* muons on level trajectory
- Gives charge and momentum selection, which is enhanced by using a collimator.
- Eliminates high-*p* muons (which won't stop) & other particles.
- Eliminates line-of-sight from production target

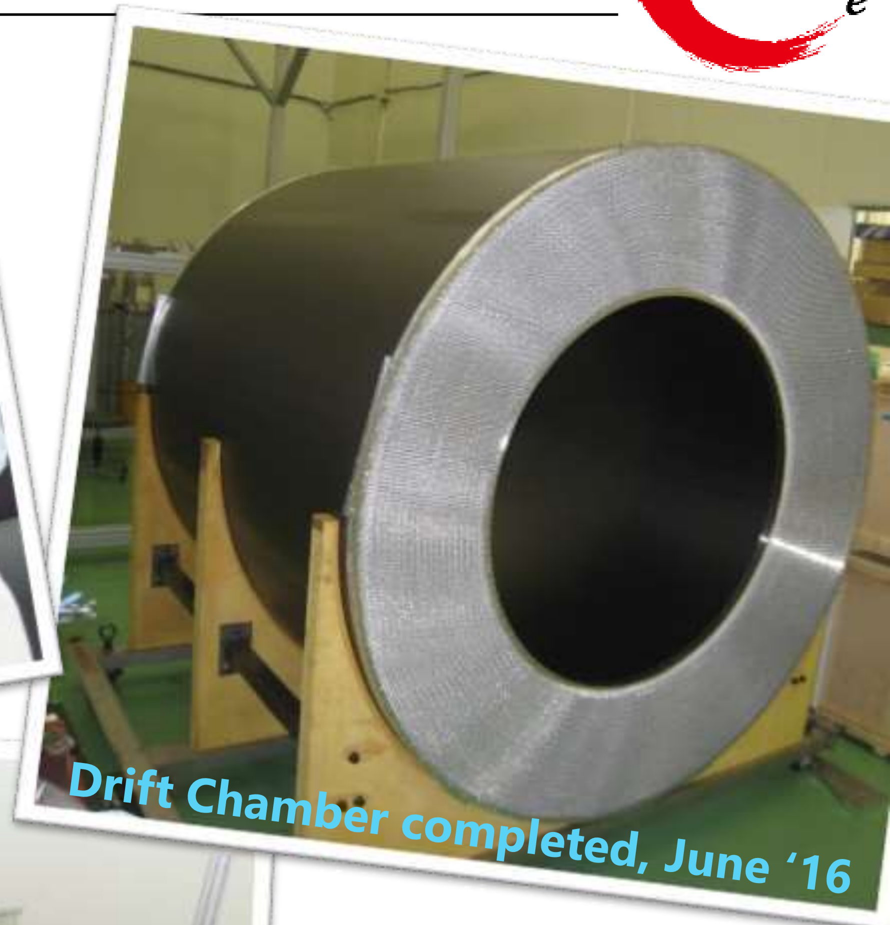
Phase I detector (CyDet)

- Aluminium stopping target at centre.
- Particle flux in central region is still very high → **Cy**lindrical **Det**ector system:
  - All-stereo-wire drift chamber
  - Hodoscopes for triggering and timing



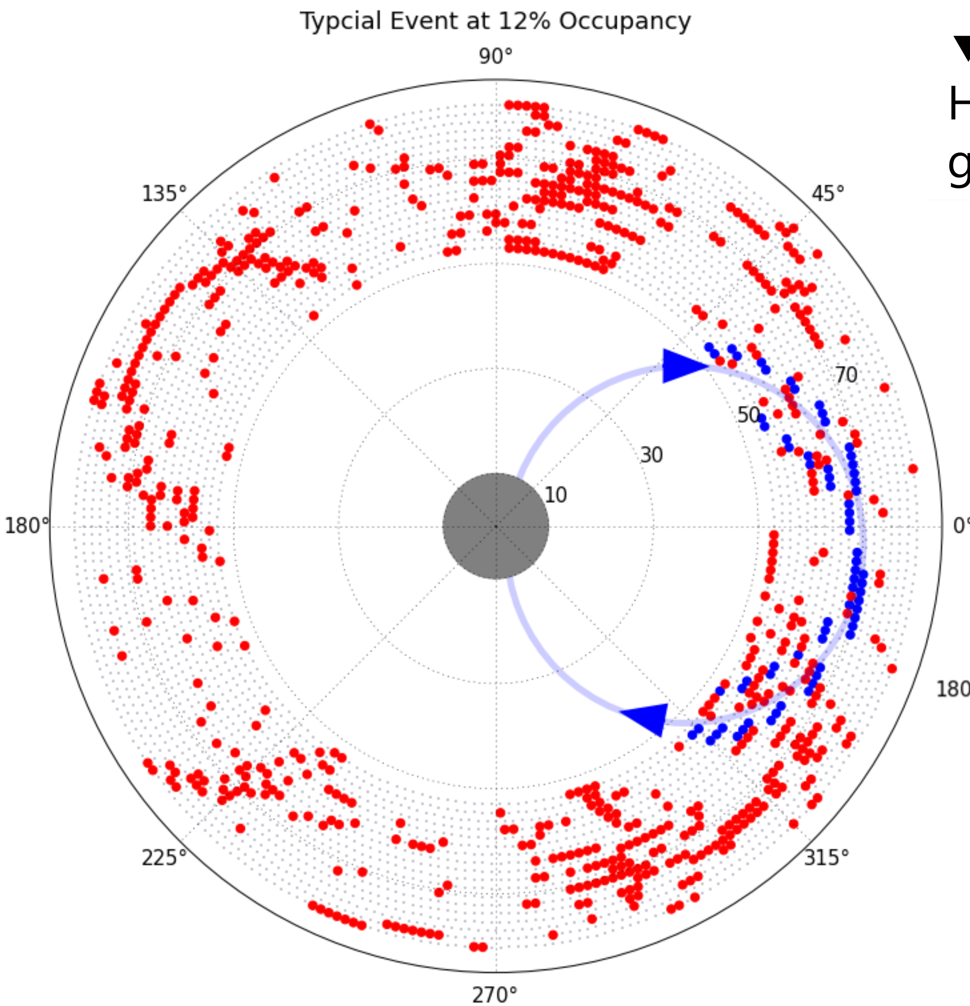
CyDet construction



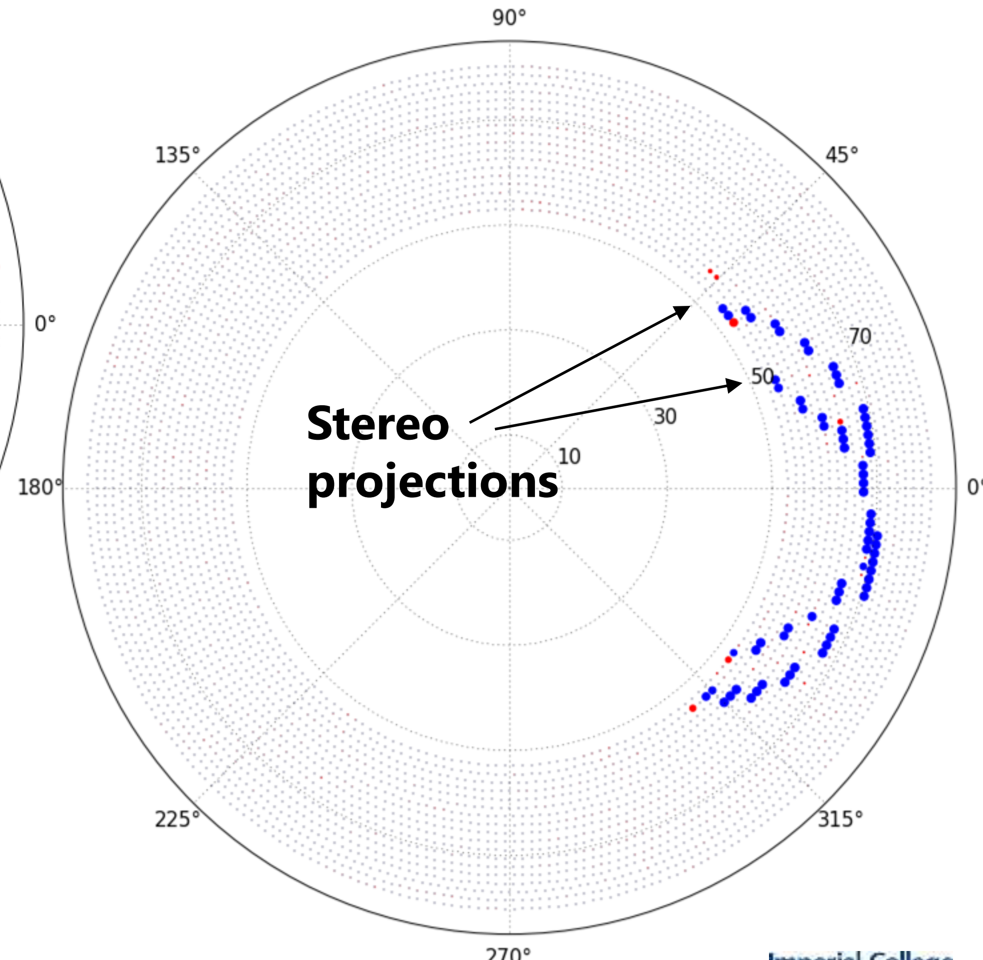


CyDet reconstruction

▼ **Signal** tracks picked out using Hough transform based discriminator, then given to Kalman filter for reconstruction.



▲ Most **background** hits are rejected based only on timing & local features



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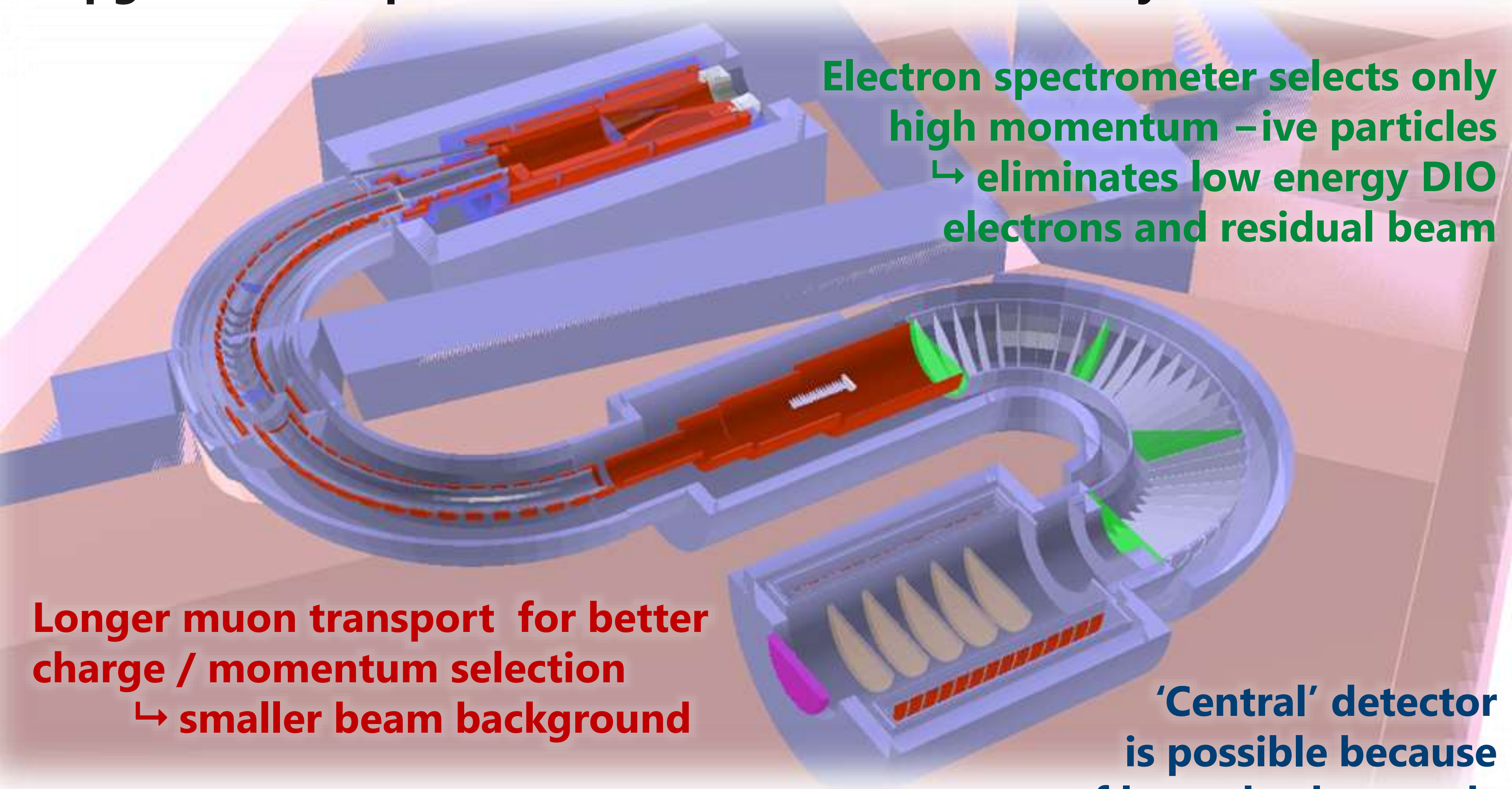
COMET Phase II

Upgrade the experiment for 100× better sensitivity

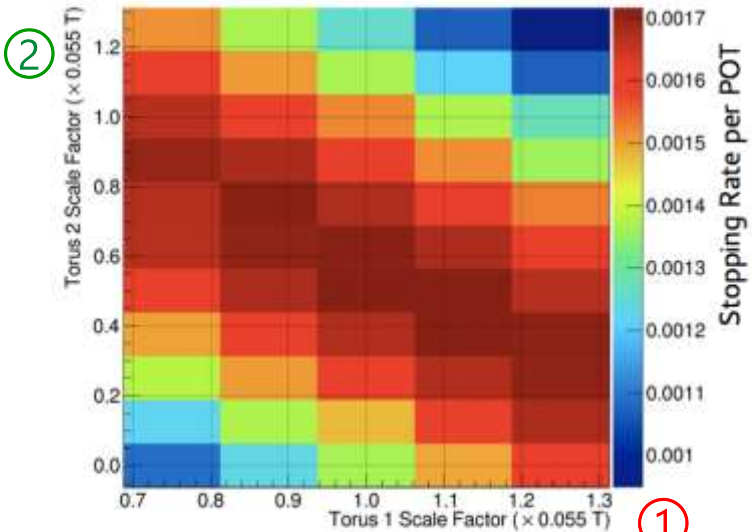


Electron spectrometer selects only high momentum −ive particles
↳ eliminates low energy DIO electrons and residual beam

Longer muon transport for better charge / momentum selection
↳ smaller beam background

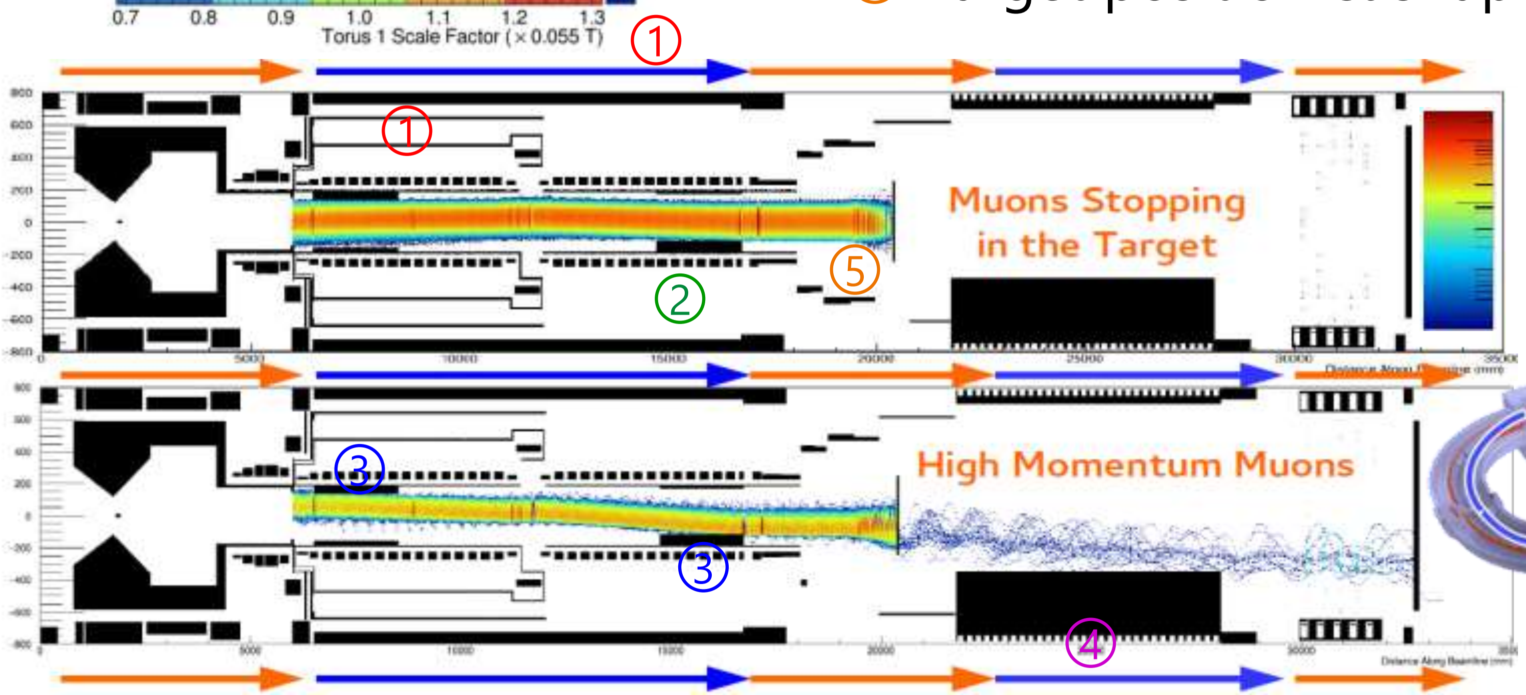
‘Central’ detector is possible because of lower backgrounds

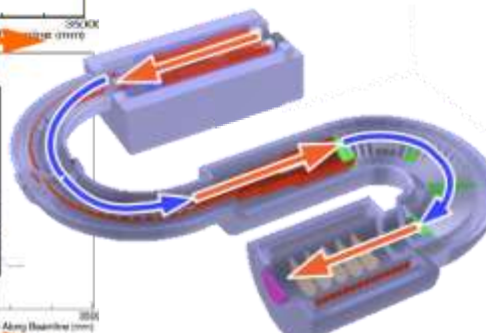
Phase II beamline optimisation



In parallel with Phase I construction, Phase II design is being optimised using integrated COMET simulation. Examples:

- ① ② Correcting dipole field strength
- ③ ④ Collimator positions
- ⑤ Target position & shape





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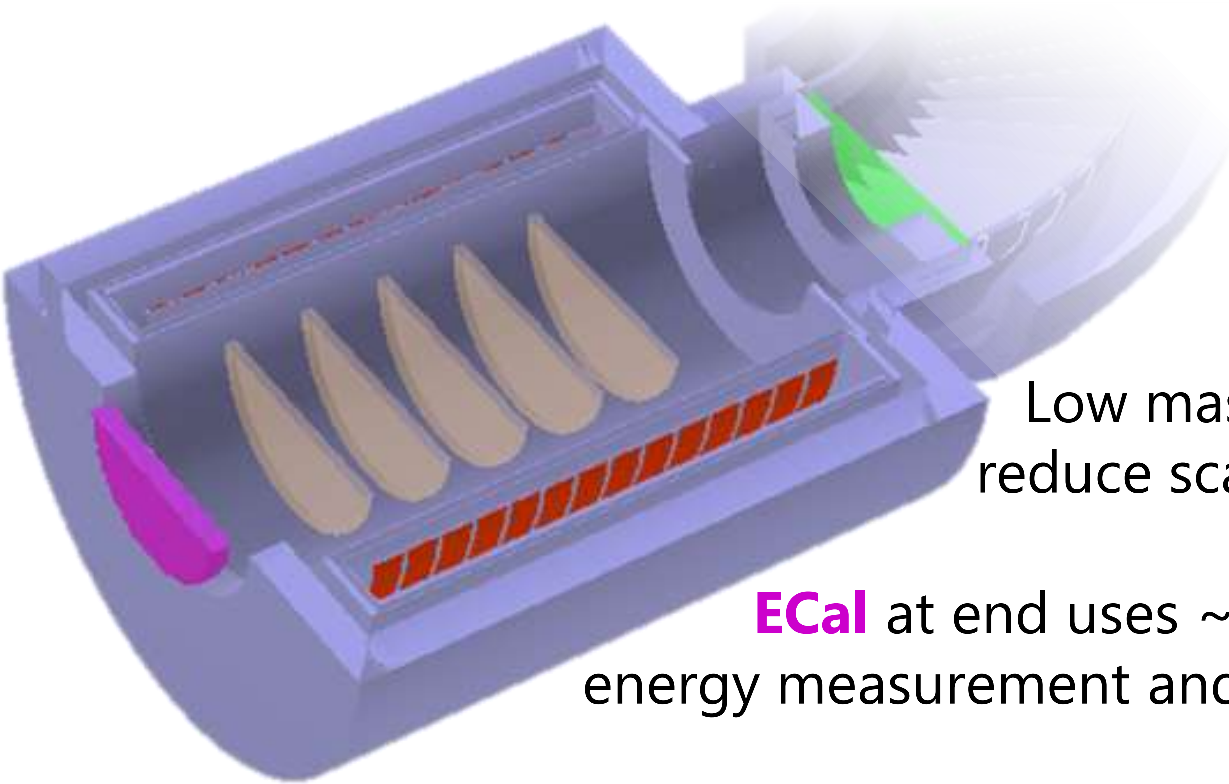
Phase II detectors



5 full planes (baseline design) of **straw tubes** for tracking

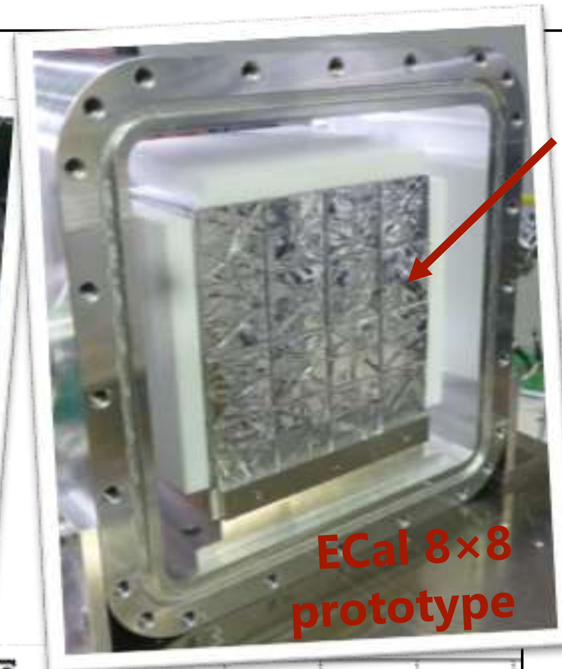
Low mass straw design to reduce scattering.

ECal at end uses ~2000 LYSO crystals for energy measurement and triggering.

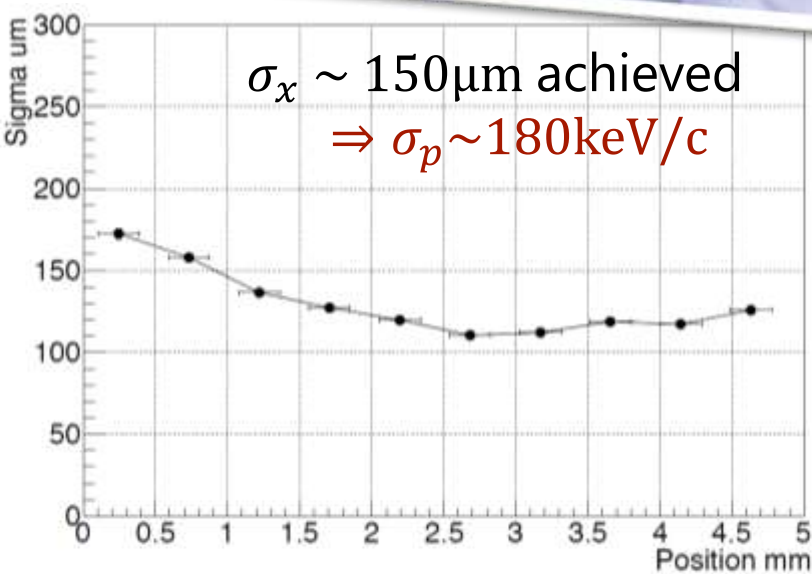
Prototype version detector in development for Phase I, can be installed in place of CyDet.

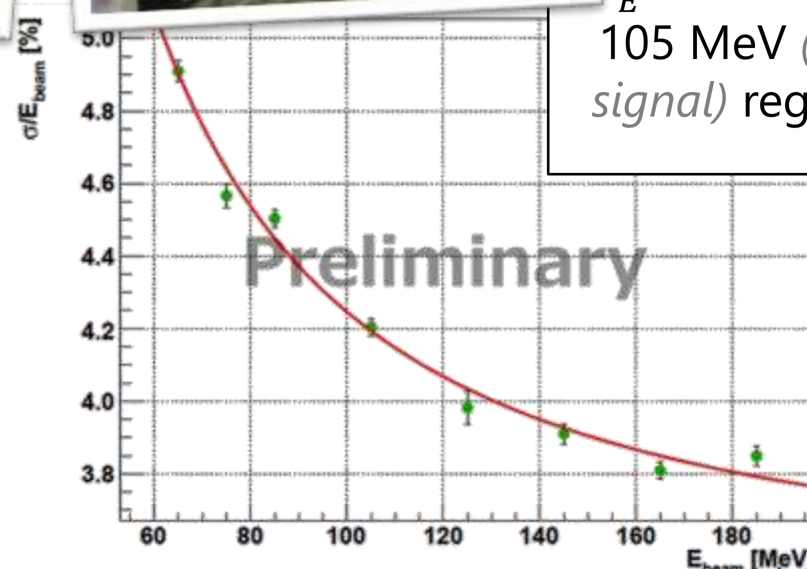
- Test design (e.g. new straw weld for lower mass) and readout
- Study particle content of secondary beamline to improve MC prediction (esp. for Phase II analysis)

ECal & Straw testing



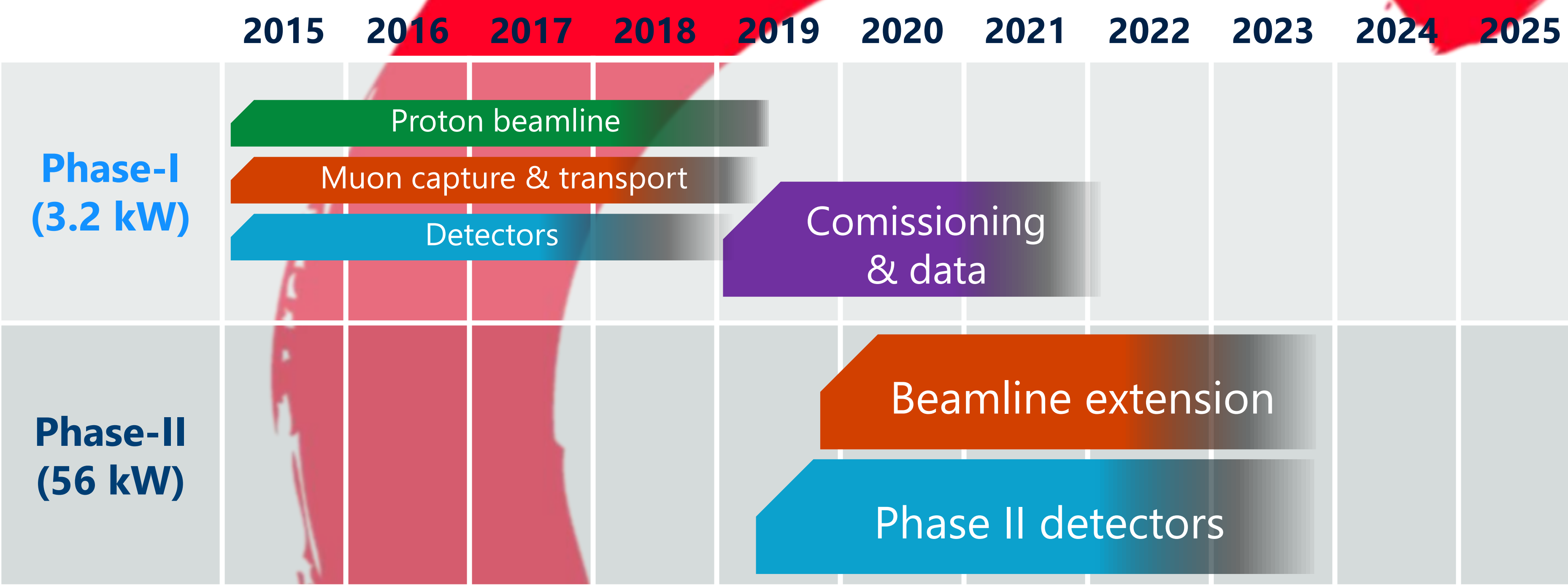
4 ECal crystals in Teflon + Al-mylar wrapping





$\frac{\sigma_E}{E} \sim 4.2\%$ in 105 MeV *(i.e. signal)* region

Summary [Timeline]



Current limit [SINDRUM-II]: 7×10^{-13} **90% U.L.**

~2018: Start COMET Phase I; goal $\mathbf{3 \times 10^{-15}}$ **S.E.S.** (~ 5 mo)

COMET Phase II goal $\mathbf{3 \times 10^{-17}}$ **S.E.S.** (~ 1 year)

Phase I of experiment coming together rapidly!