COMET/PRISM and cLFV

PPAP Community Meeting

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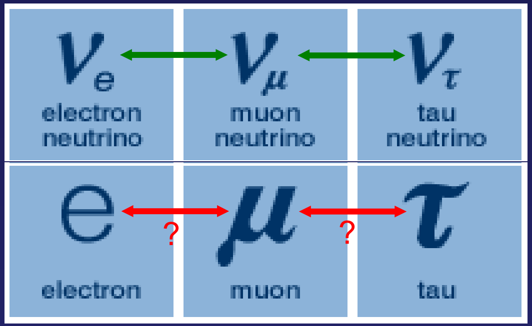
Imperial College London

Introduction

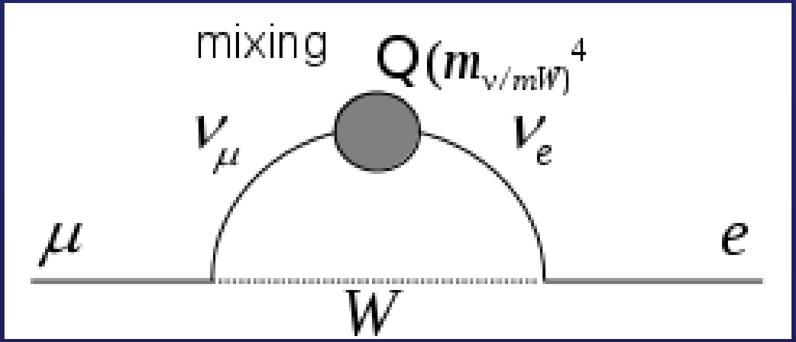
- Physics motivation for charged lepton flavour violation searches.
- Why muon to electron conversion is promising.
- COMET
- PRISM
- On behalf of COMET-UK

Physics Motivation

- Neutrinos in the SM are massless but observation of neutrino oscillations is direct evidence that neutrinos have mass.
  - Proof that neutral lepton flavour number is not conserved.



- Simplest extension to SM to include neutrino mixing.

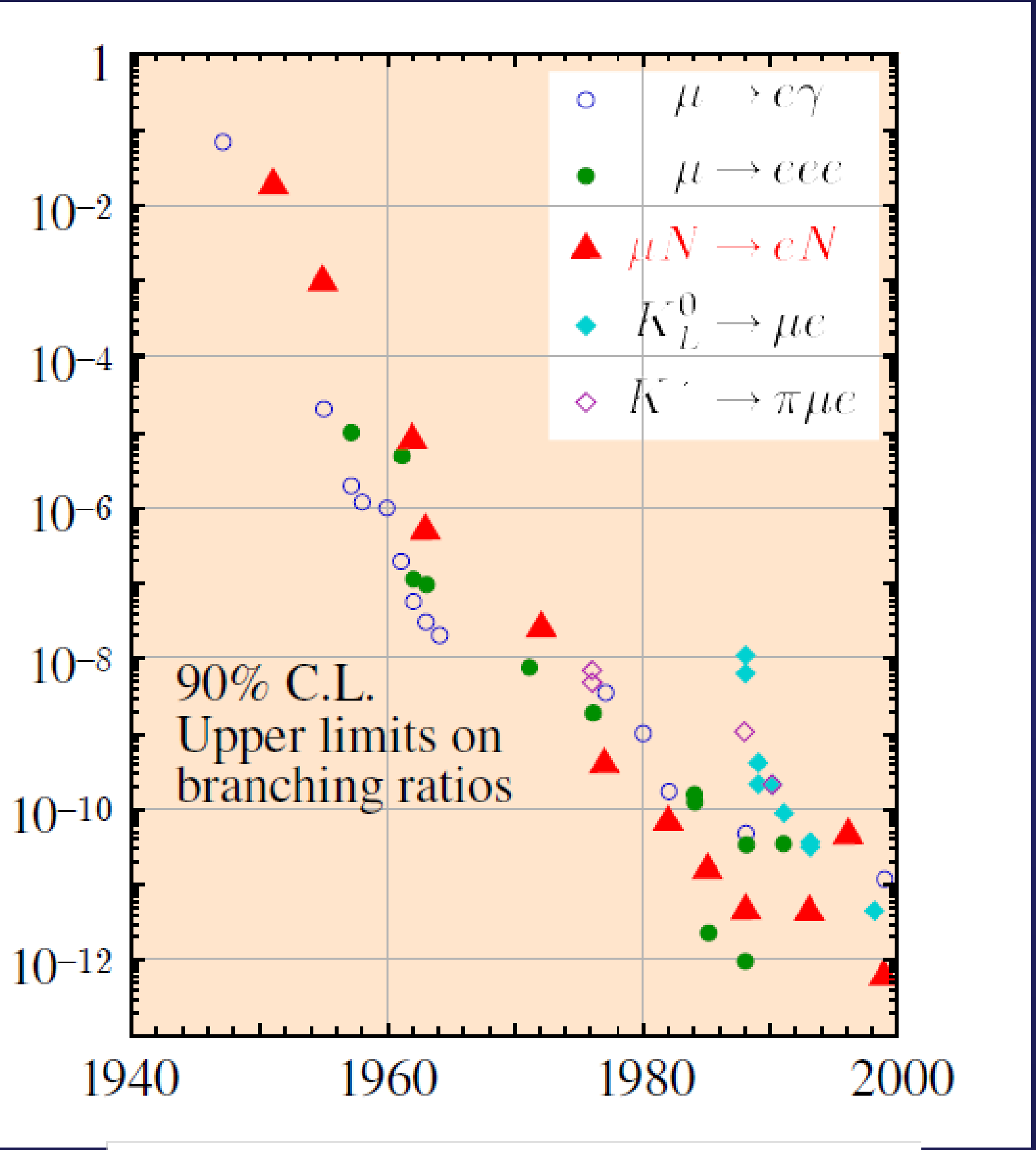


Rate <10^{-52}

- A number of BSM theories predict charged lepton flavour number non-conservation.
  - Rates much higher, e.g. muon to electron conversion could be as large as 10^{-13} – 10^{-15}

cLFV Processes

- Tau based, e.g.
  - $\tau \to \mu \gamma$
  - $\tau \to 3\mu$
  - $\tau \to p \mu \mu$
  - ...
- Muon based, e.g.
  - $\mu^+ \to e^+ \gamma$
  - $\mu^+ \to e^+ e^+ e^-$
  - $\mu^- (A, Z) \to e^- (A, Z)$



First CLFV search by Hincks and Pontecorvo in 1947 for $\mu^+ \to e^+ + \gamma$

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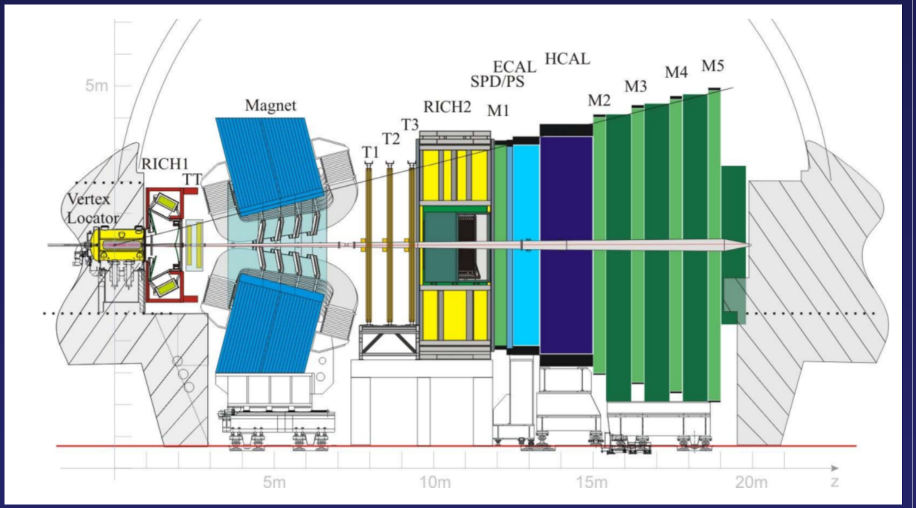
LHCb



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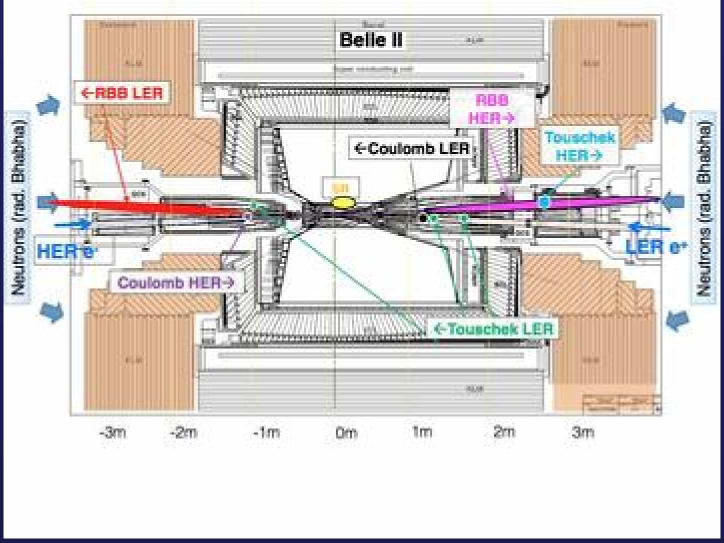
BELLE-II



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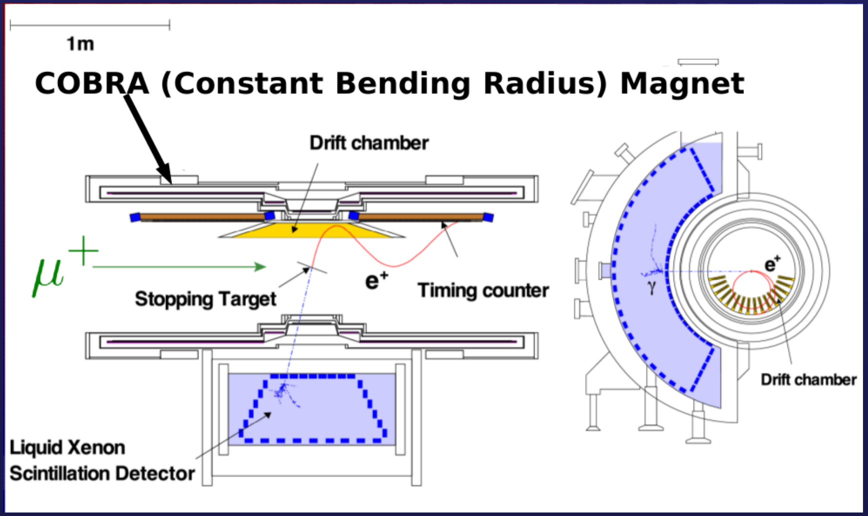
MEG @PSI



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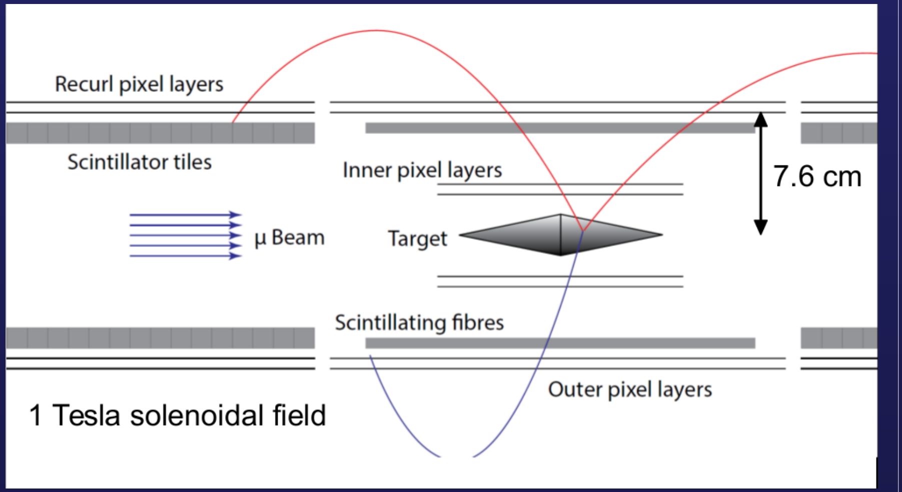
Mu3e @PSI



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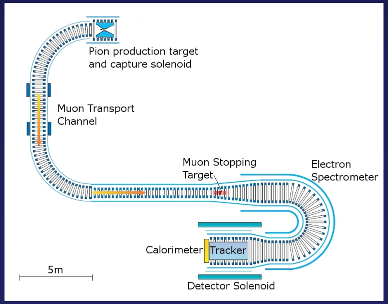
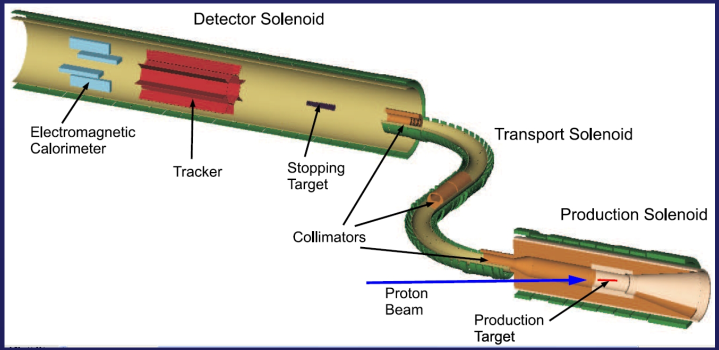
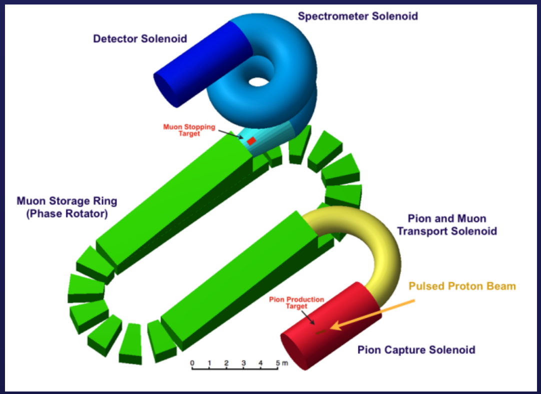
COMET @J-PARC



Mu2e @FNAL

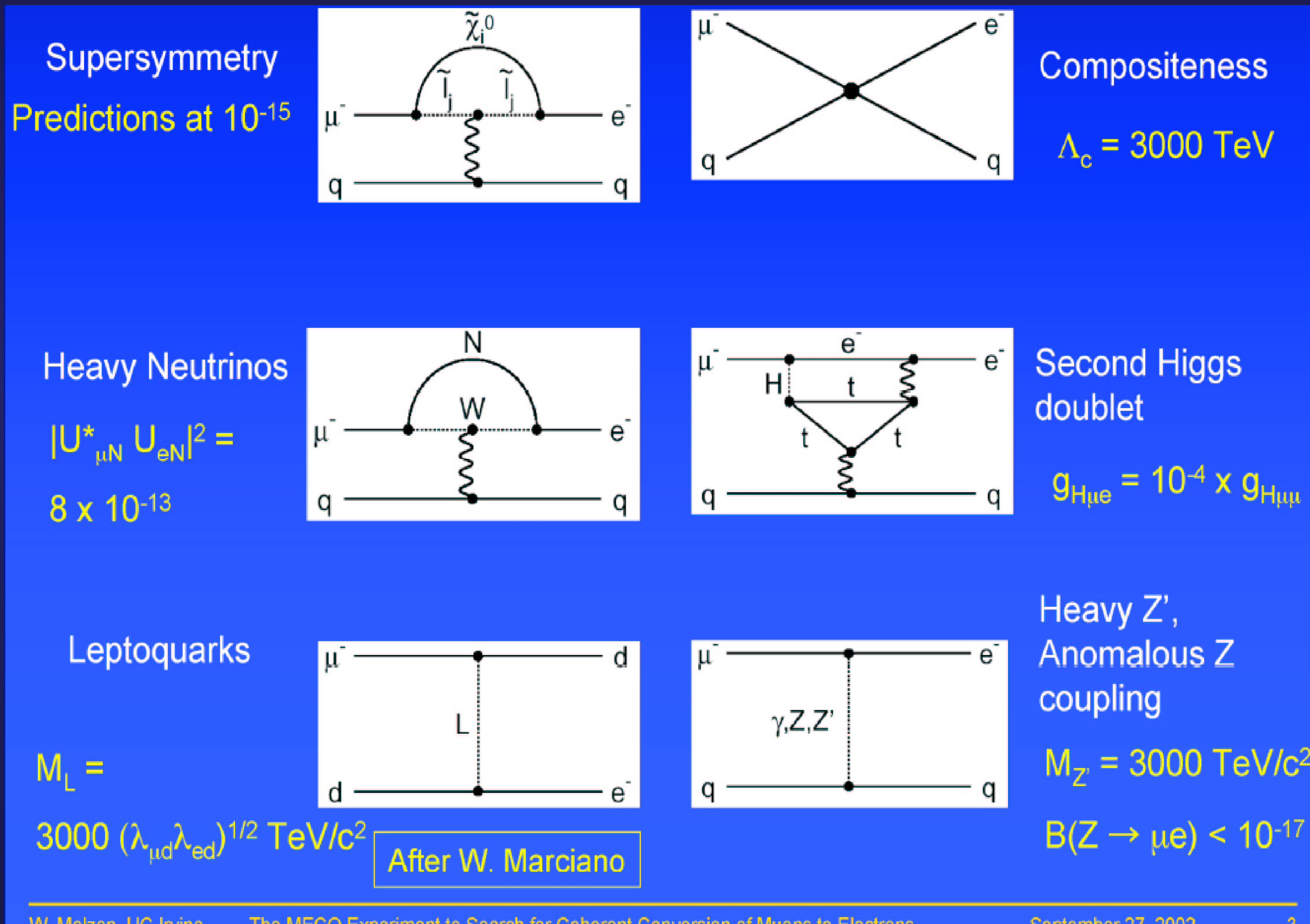


PRISM



Muon to Electron Conversion

- Many BSM models give predictions 10^{-13}-10^{-15}.



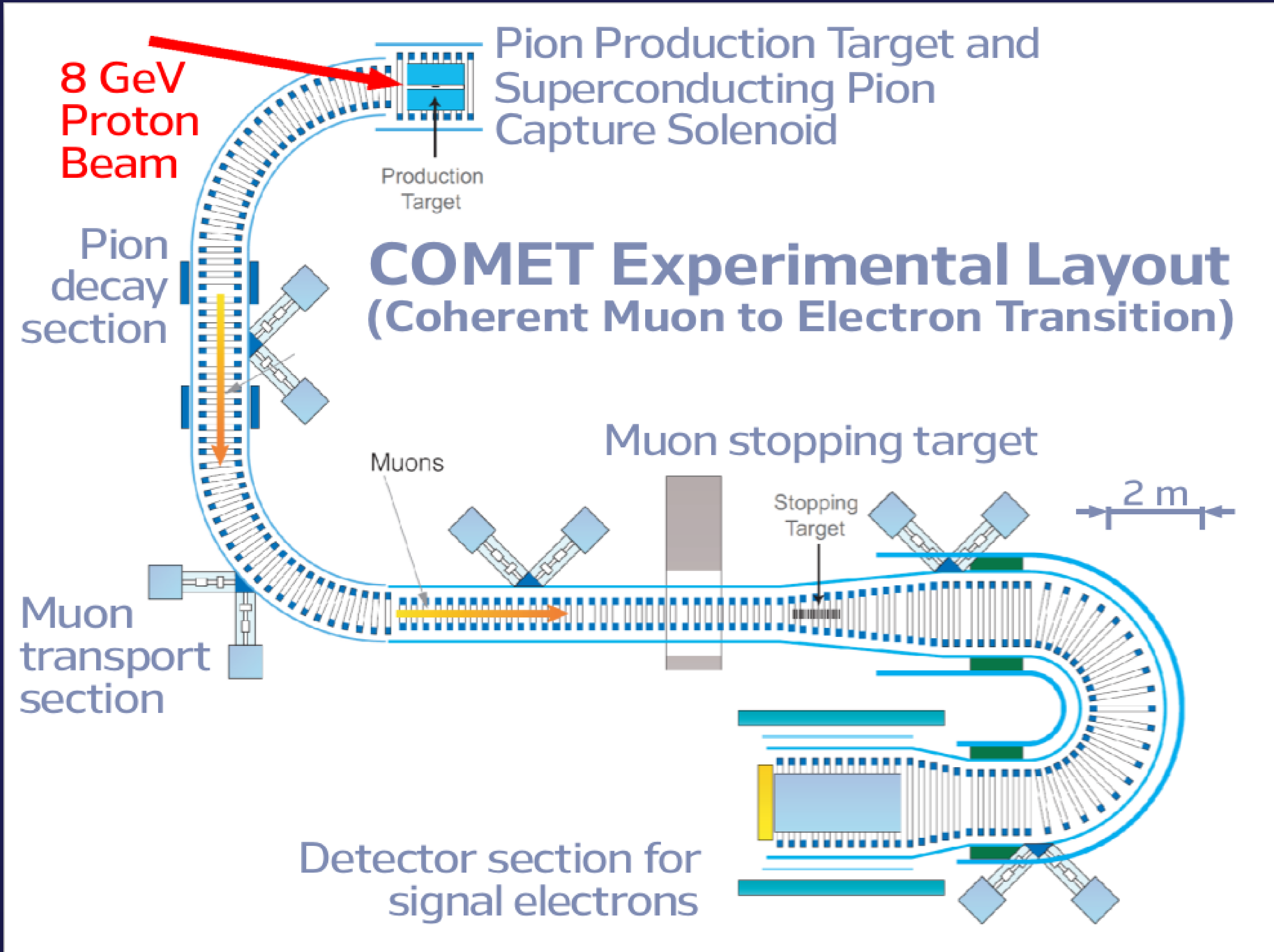
Muon to Electron Conversion

- Many BSM models give predictions 10^{-13}-10^{-15}.
  - Current limit by SINDRUM II $7x10^{-13}$
- Developments in accelerator concepts allows significantly higher intensity muon beams.
- Expected $>10^{4}$ improvement in sensitivity utilising current accelerator technology.
  - COMET and Mu2e.
- Expected $>10^{6}$ improvement in sensitivity utilising future accelerator technology.
  - PRISM.

COMET Status

- Currently under construction.
  - Proton beam line magnets being installed.
  - Experimental hall being excavated.
  - Superconducting magnets being manufactured.
  - Drift chamber construction started, tracker and ECAL designs being finalised.
- Phase-I data in JFY 2015/16.
- Next flagship experiment for J-PARC.
  - Included in the Japanese Research Masterplan.
- Strong recommendation for muon physics in P5.

The Coherent Muon to Electron Transition (COMET) Experiment



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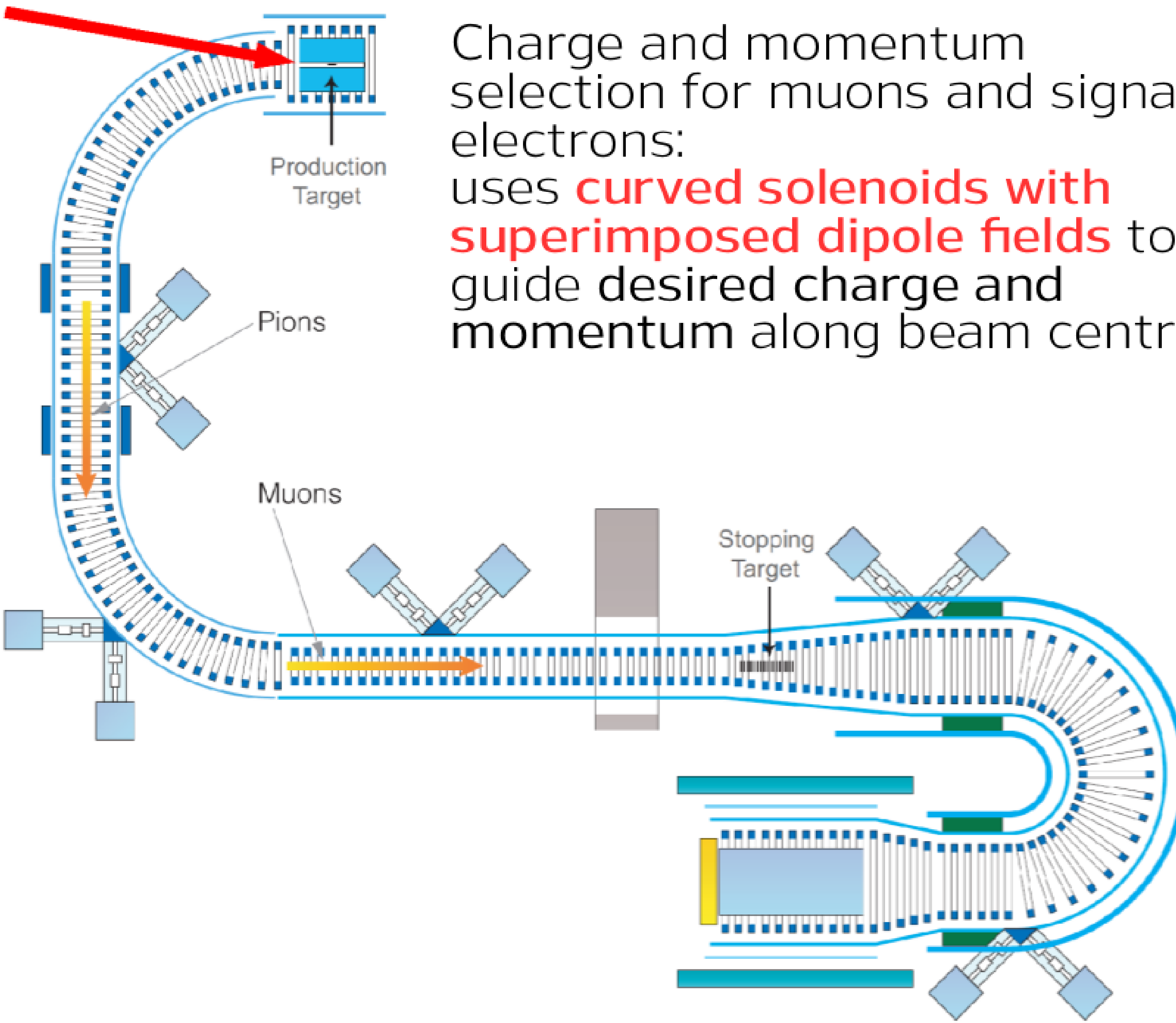
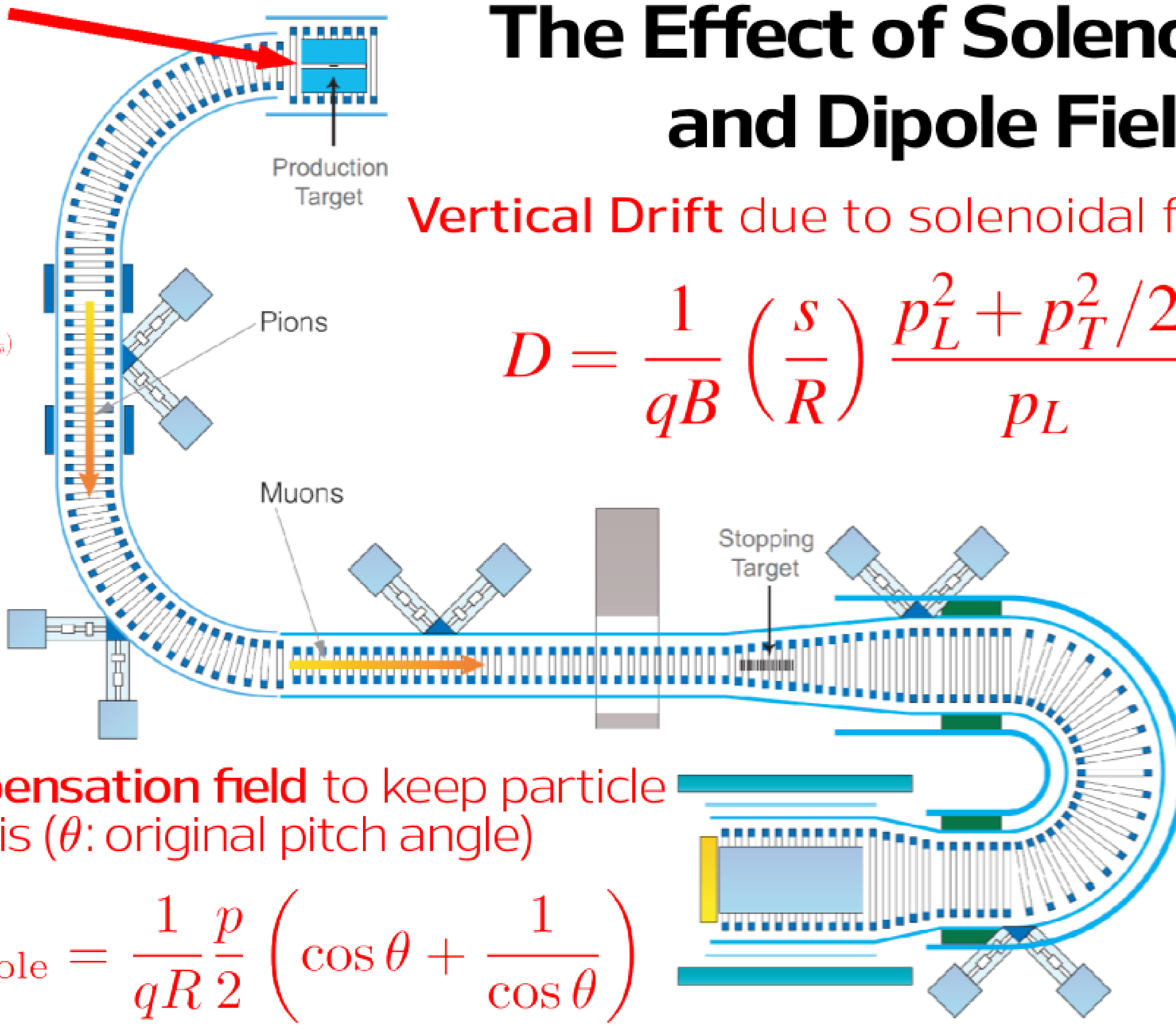


Charge and momentum selection for muons and signal electrons:
uses **curved solenoids with superimposed dipole fields** to guide **desired charge and momentum** along beam centre

The Effect of Solenoid and Dipole Fields



Vertical Drift due to solenoidal field:

$$D = \frac{1}{qB}\left(\frac{s}{R}\right)\frac{p_L^2 + p_T^2/2}{p_L}$$

Compensation field to keep particle on-axis (θ: original pitch angle)

$$B_{\text{dipole}} = \frac{1}{qR}\frac{p}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

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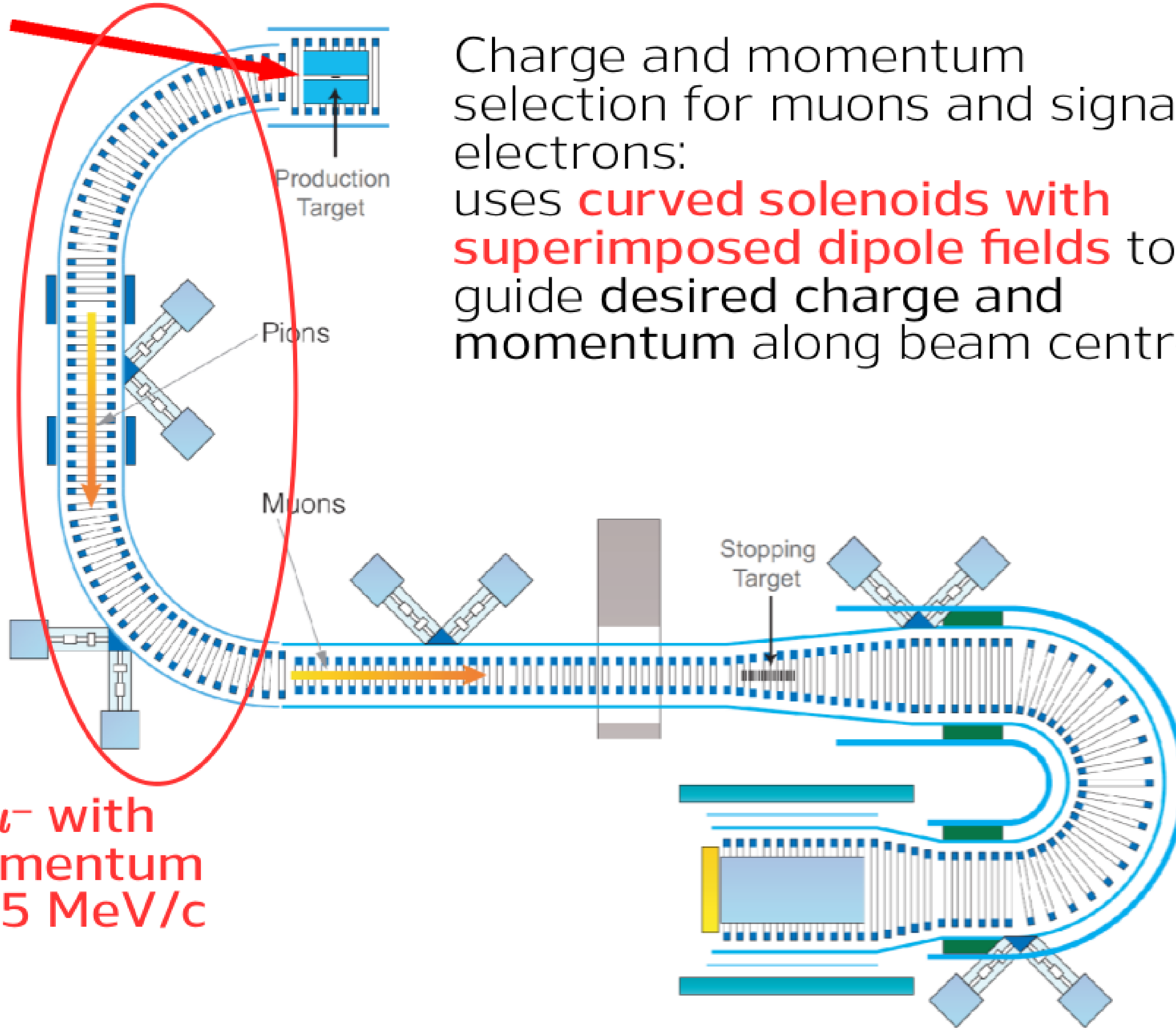

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μ^- with momentum < 75 MeV/c

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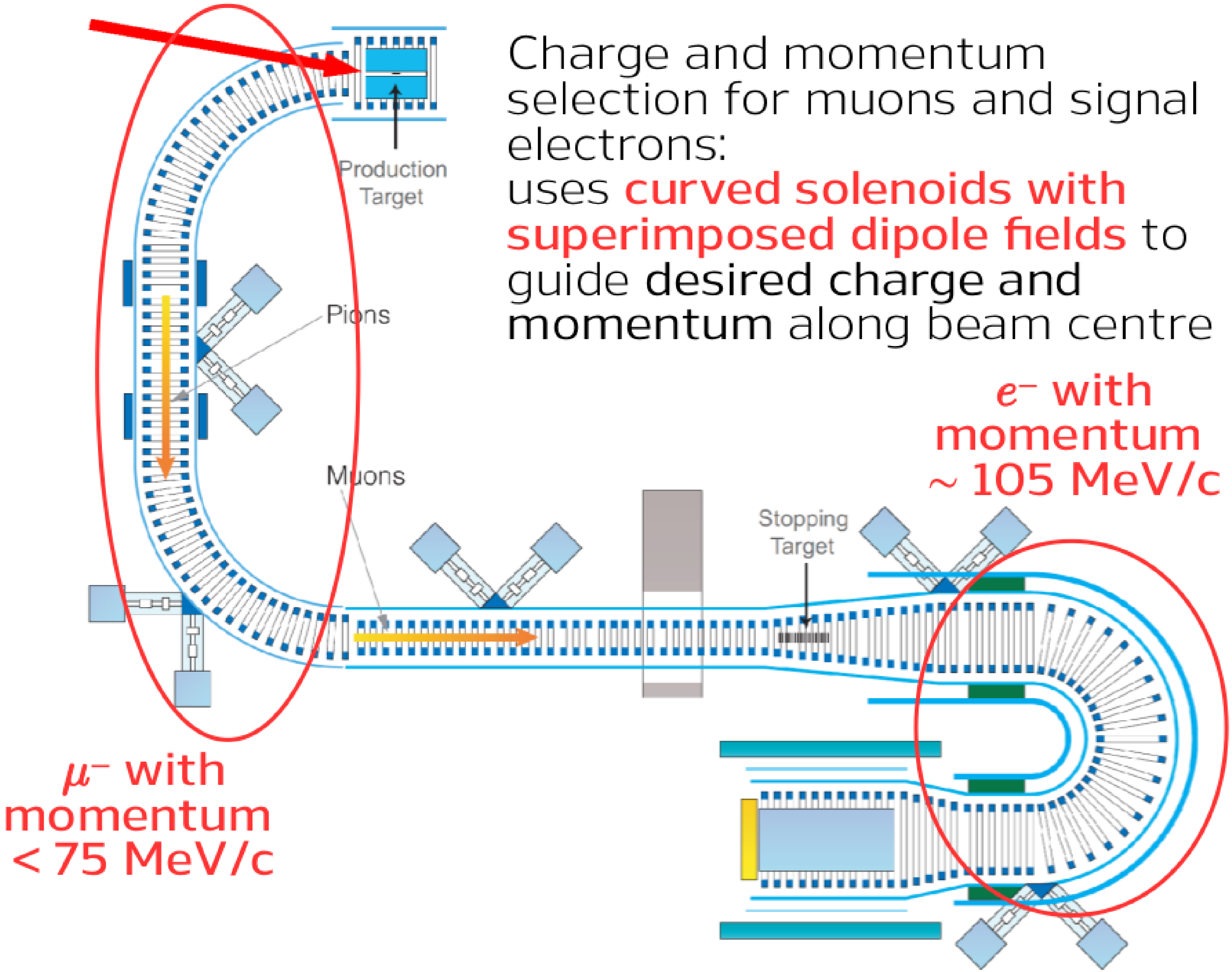

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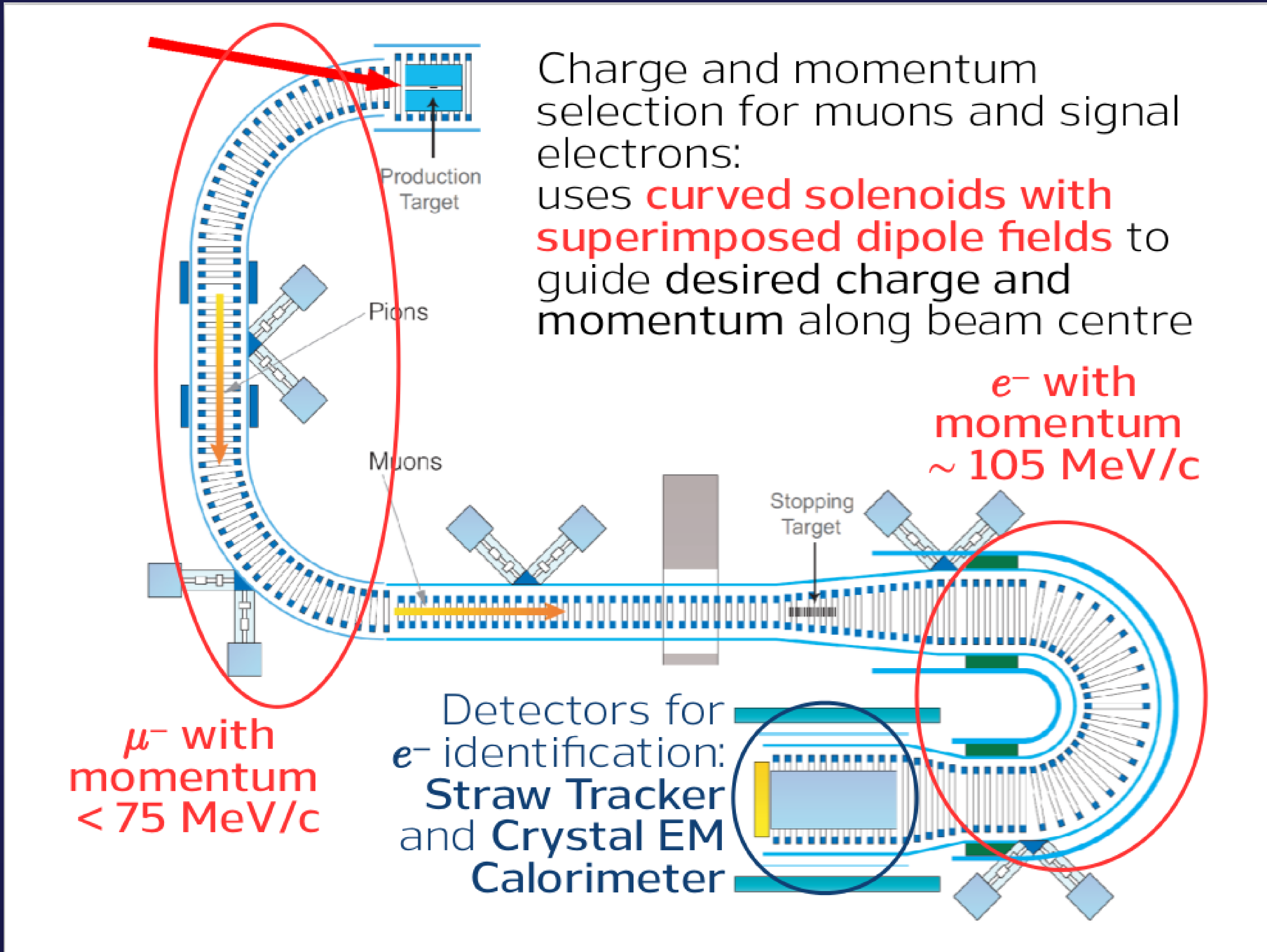

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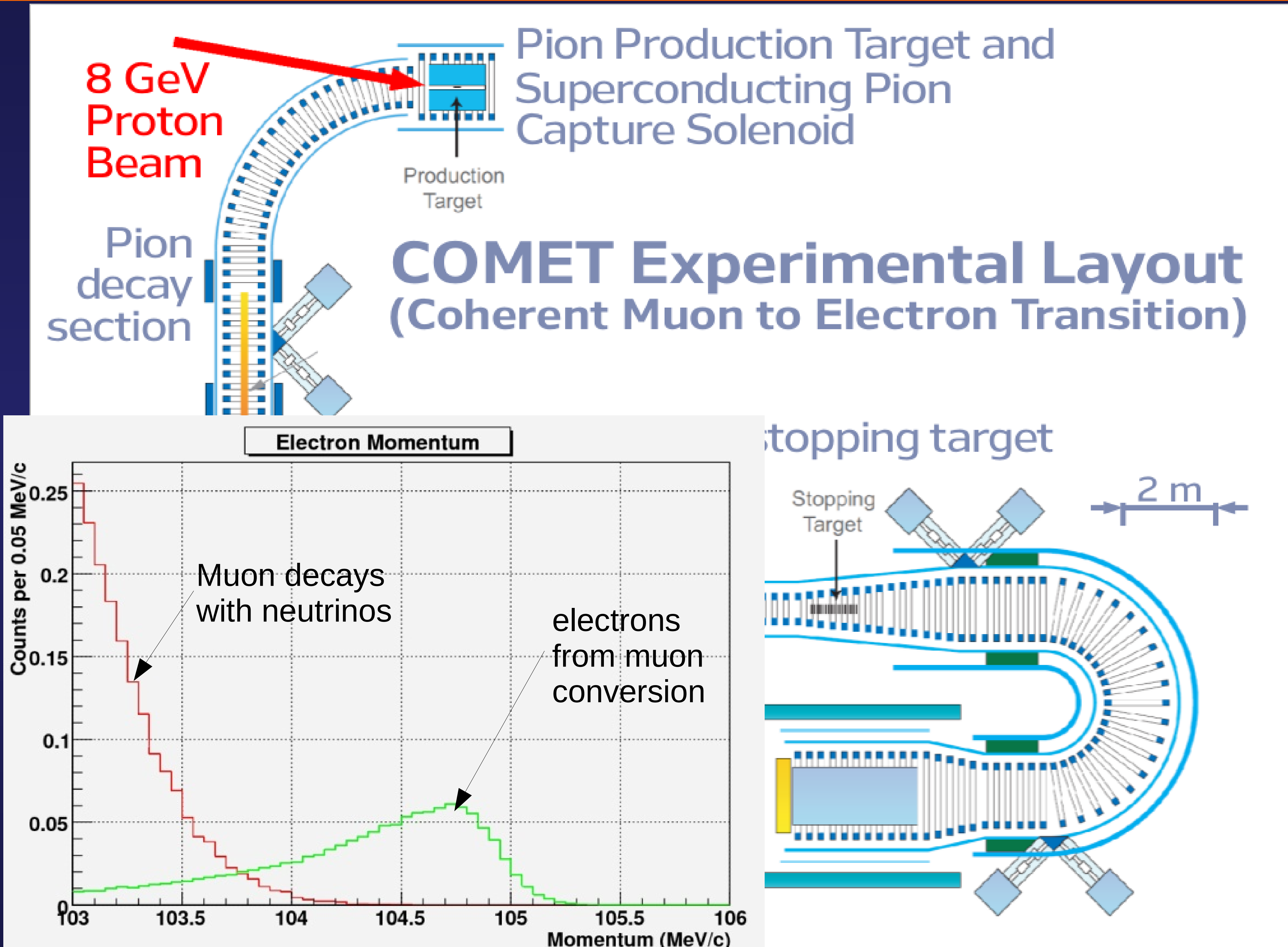
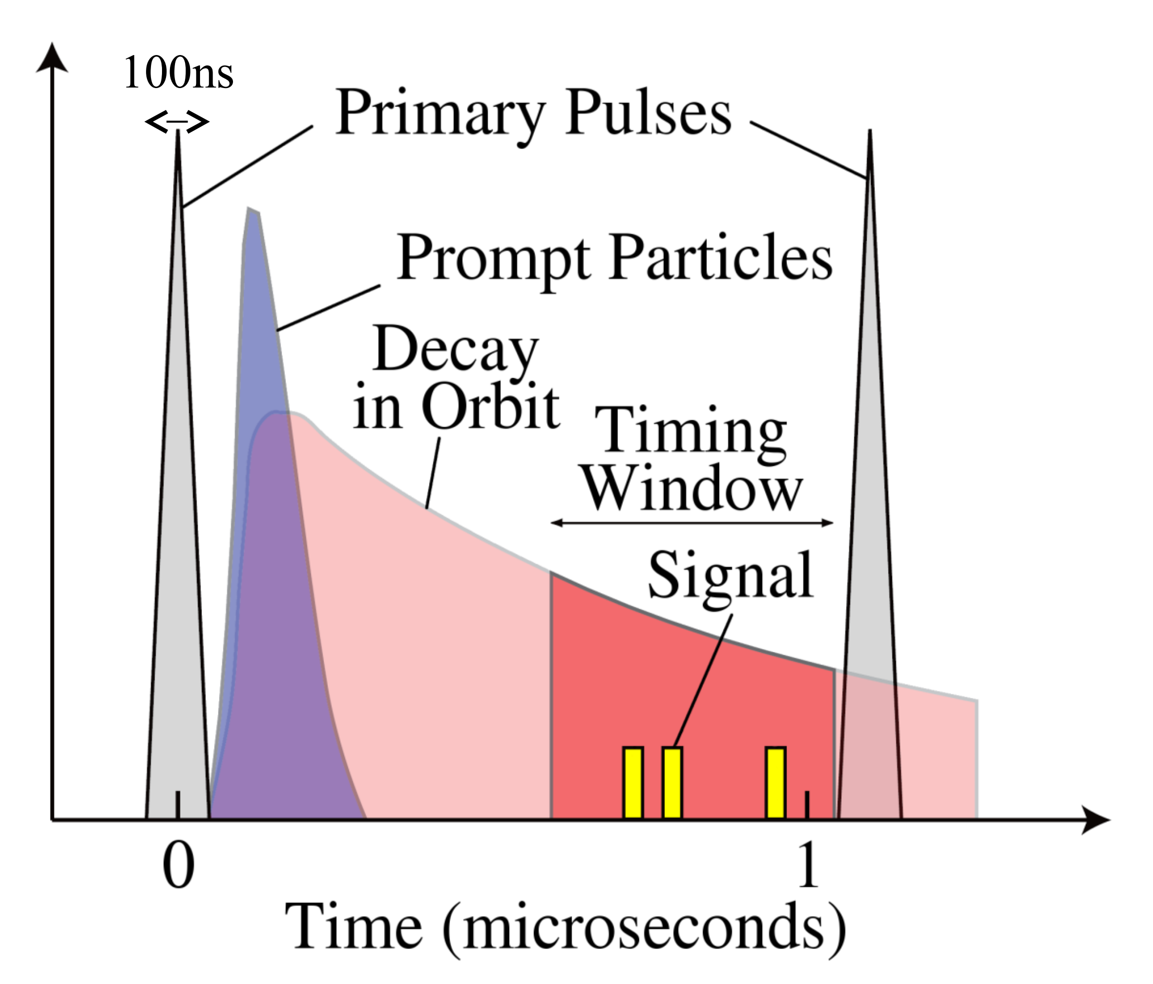
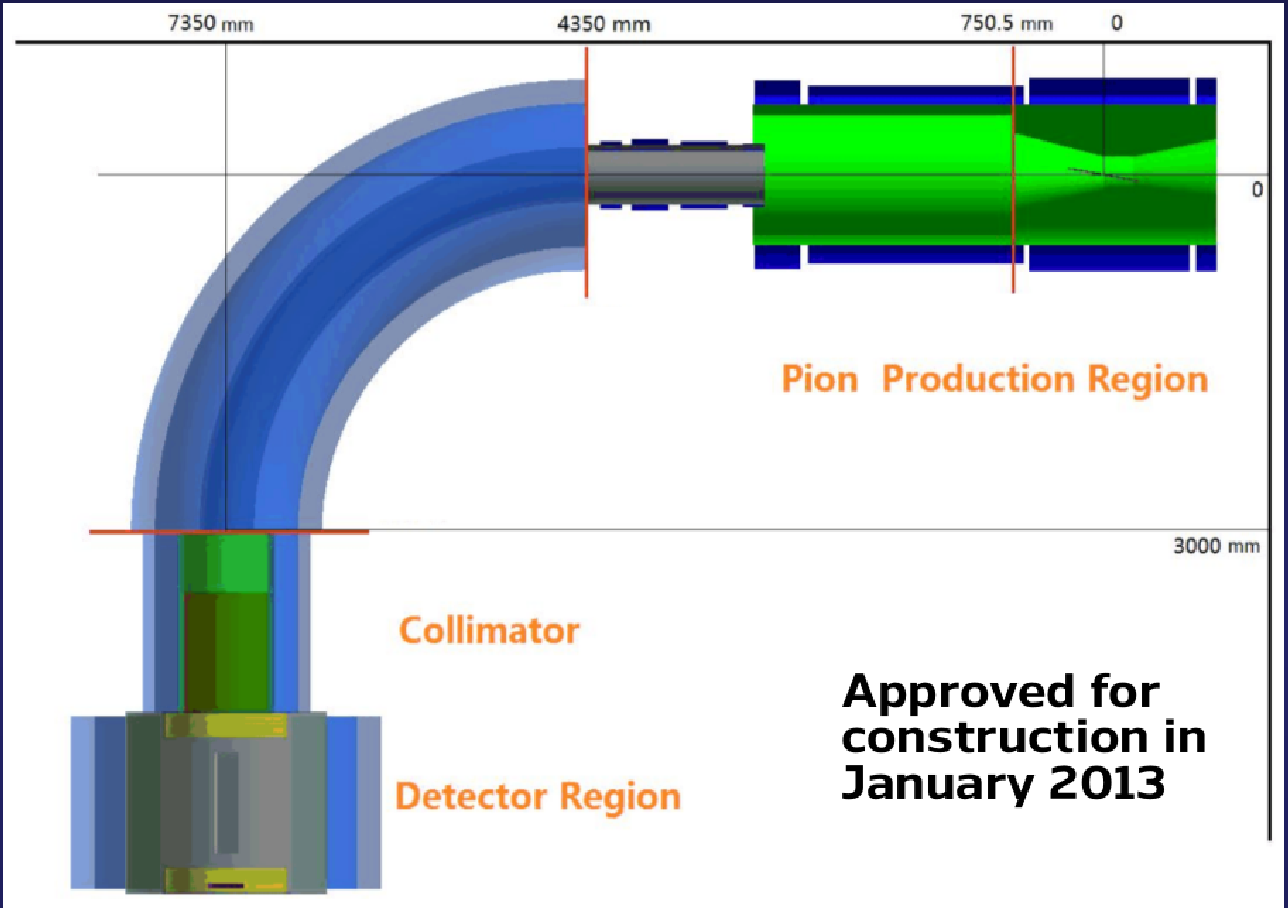


Proton Beam and Backgrounds

- Proton beam requires specific pulse structure to reduce backgrounds.
- Cleanliness quantified by extinction factor.
  - Require 10^{-9}.
  - Important to measure this.
- Understanding background modes is the key.
  - Decay in orbit.
  - Prompt beam related.
    - Decay in flight.
    - Radiative capture.
  - Scattered electrons.
  - Cosmic rays.
  - Neutrons.



COMET Phase-I

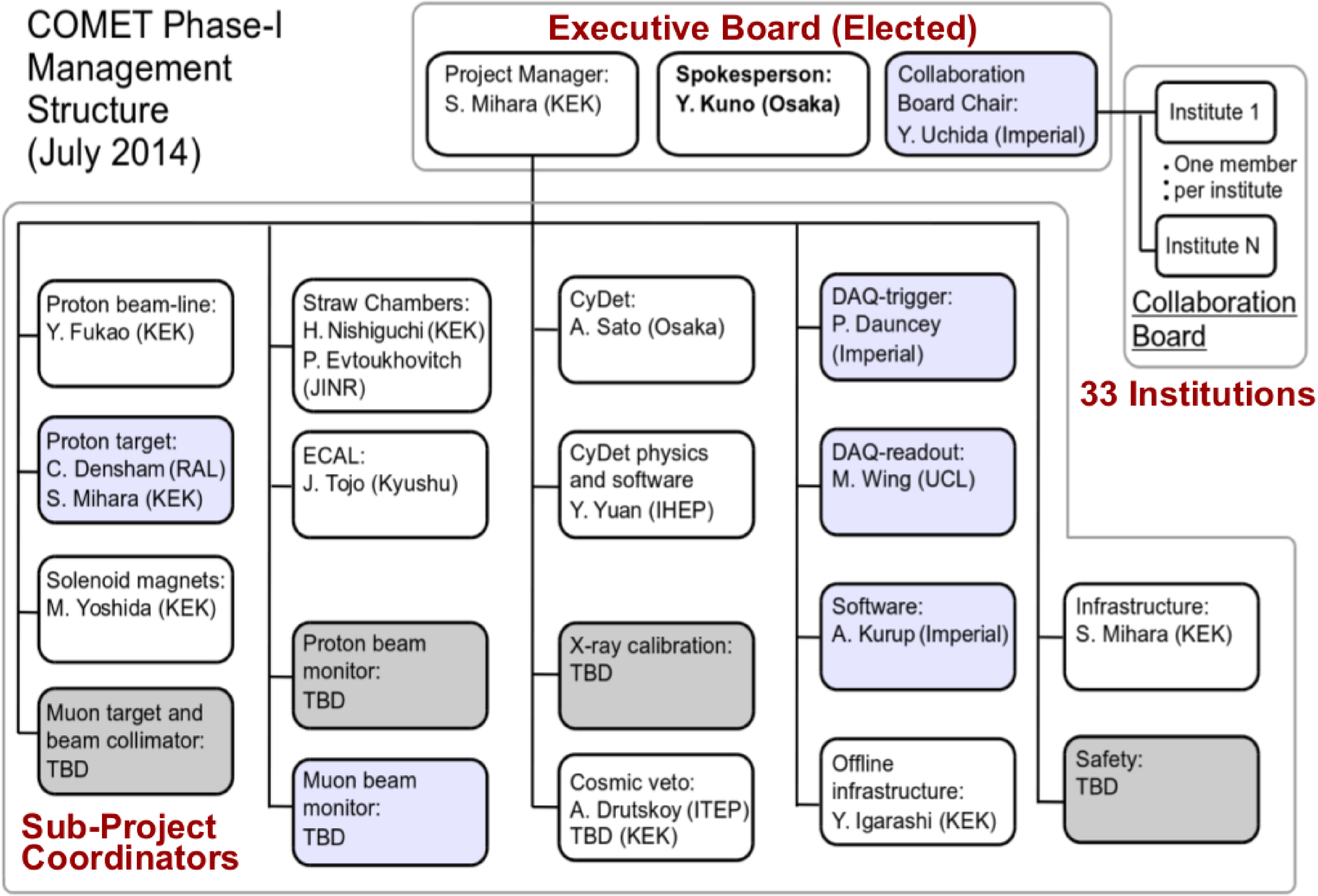


- Several advantages to staging.
  - Allows measurement of backgrounds.
  - Test beam line and detector technology.
- Sensitivity 100 times better than World's best limit.
  - 5% of the proton beam intensity of Phase-II and 90 days running.

COMET-UK Background

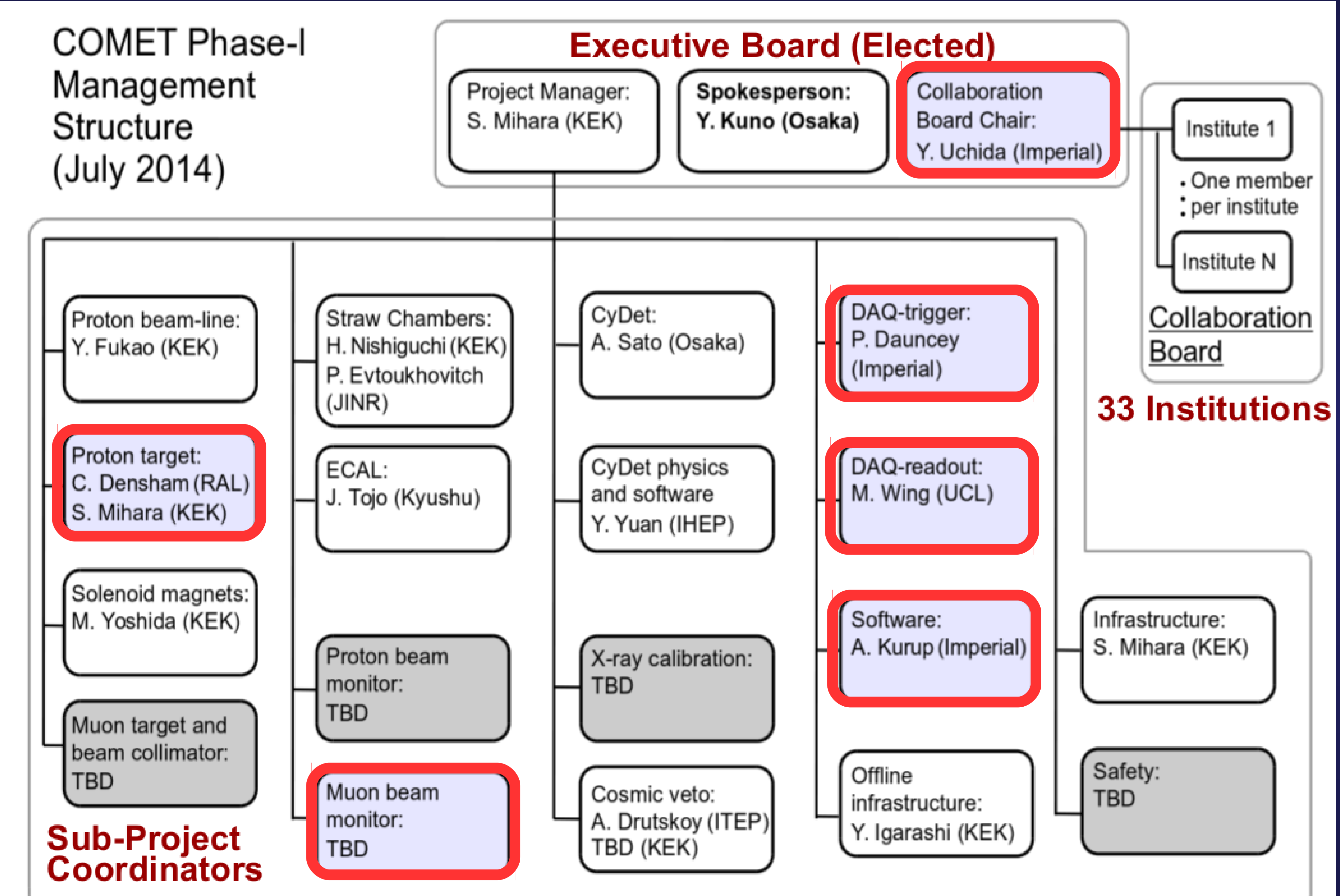
- Participated in COMET since first collaboration meeting (2008).
  - Imperial College, Manchester/Cockcroft, RAL, UCL.
- UK involvement instrumental in the preparation of the COMET CDR, the Phase-I EOI, LOI and TDR, which culminated in approval of Phase-I.
- SoI submitted in 2012.
- Consolidated Grant funding from PPGP.
- In 2013, submitted to STFC a three-year proposal (2014–17) for participation in COMET Phase-I.
  - PPRP recommended it but was not approved by Science Board due to lack of funds.
- Continued participation through other means.
  - Consolidated Grant, fellowships, University funds, bridging funds and PhD studentships.
- Targeting full participation in Phase-II including R&D.

COMET Management Structure



(also UK leadership of **Internal Review Panel, CDR/TDR Editorial boards & Speakers Bureau**)

COMET Management Structure



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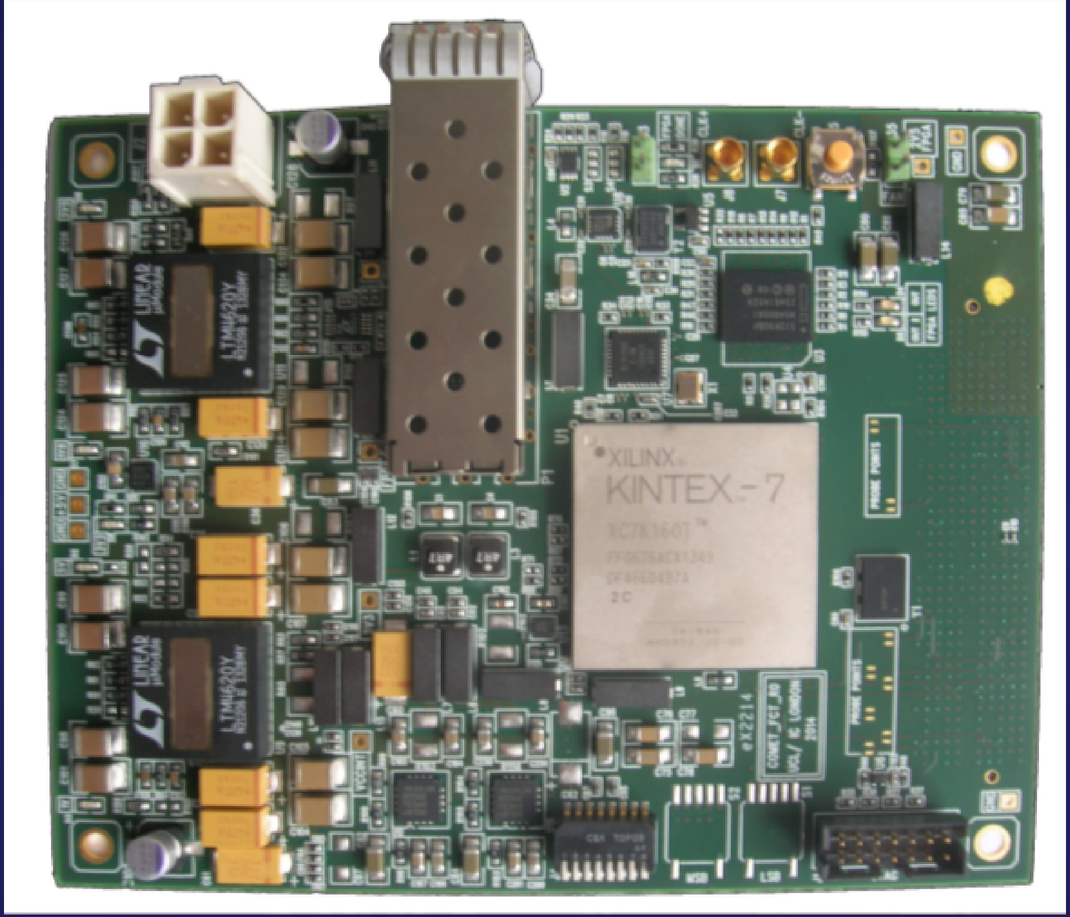
COMET-UK:Physics and Software

- UK leads the COMET Software and Analysis groups.
- COMET software adapted from T2K ND280 software.
  - Exploiting UK leadership in ND280 software (online and offline).
- Software and analysis methods need to be fully established before data-taking.
- Other regions contribute fully to software effort, but transfer of software leadership is not feasible.
- Combining RA effort with PhD and undergraduate student effort to meet obligations.
- Critical for COMET that CG effort continues into full exploitation stage for Phase-I.

COMET-UK: Fast Control & DAQ

- Full system designed by UK for Phase-I physics use and serves as critical Phase-II R&D.

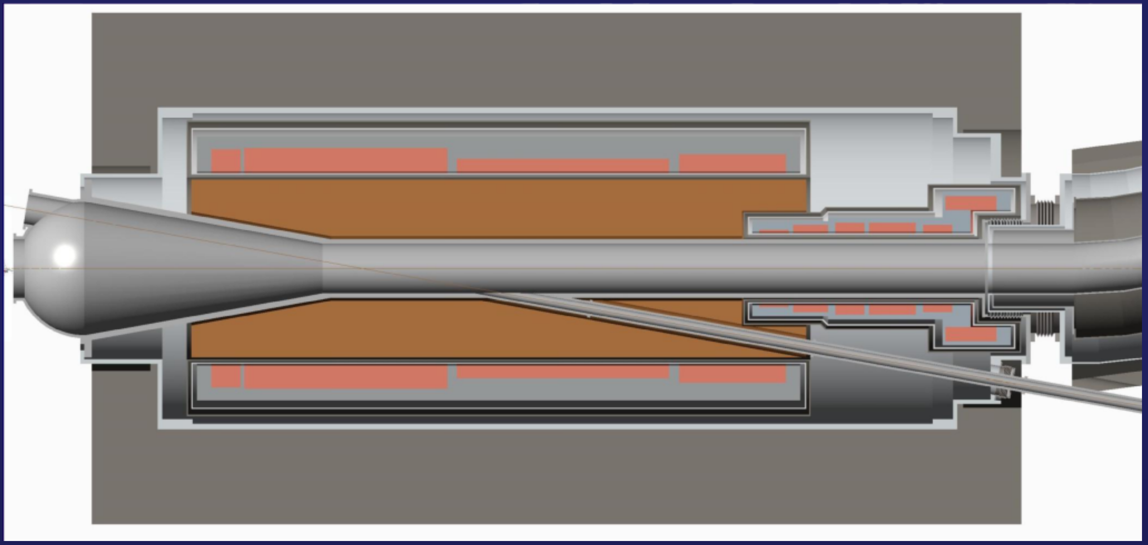


- Produced FCT boards.
- Central processing to use FC7 boards designed in UK for CMS Upgrade.
- Need new dedicated RA effort for software and debugging.
- Now transferring trigger work and most hardware and subdetector-specific obligations to international partners.
- But FC & DAQ central deployment and debugging effort must remain UK-led if further delays are to be avoided.

COMET-UK: Beam Line

- RAL TD high-power targets group ideally positioned for proton beam target and infrastructure work required by COMET.
  - Strong synergies with other ongoing work.
  - Highly-valued contributions to T2K at J-PARC.

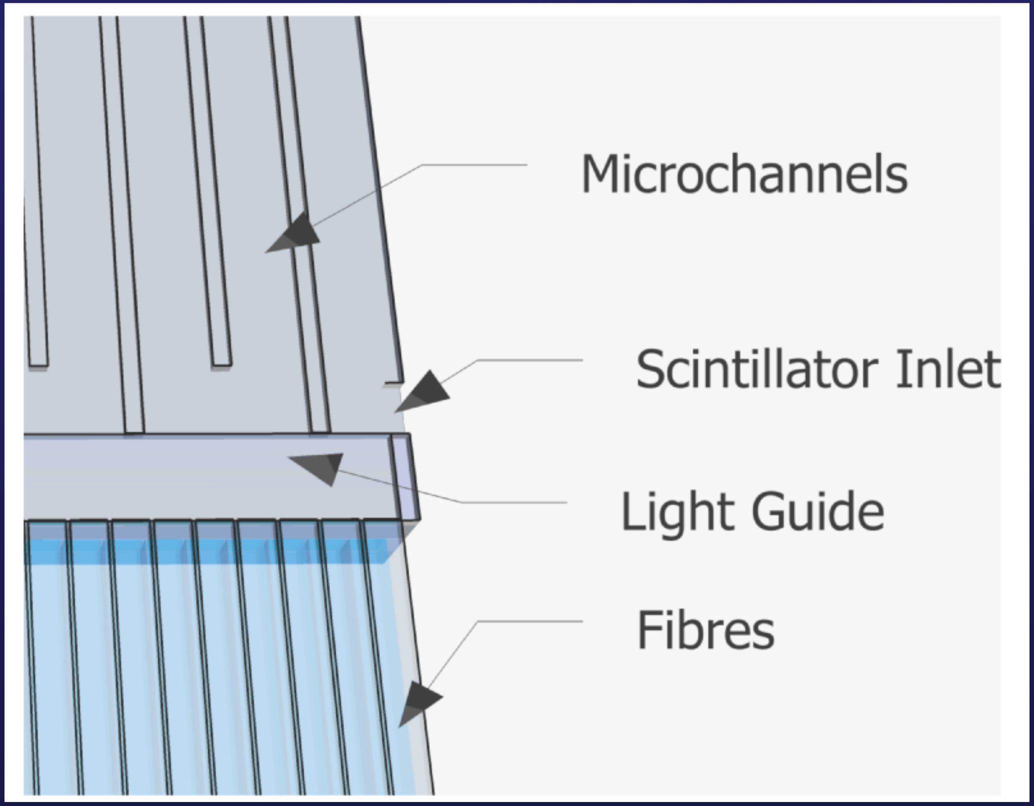
- Contributed to significant design decisions.
  - New choice of target material for Phase-I.
  - Common shielding design for Phase-I and Phase-II.
  - Remote handling and infrastructure layout.



- Input is recognised as critically important by KEK/J-PARC.
- Now providing conceptual designs for Phase-I instead of full technical designs and target hardware.

COMET-UK: Beam Monitoring

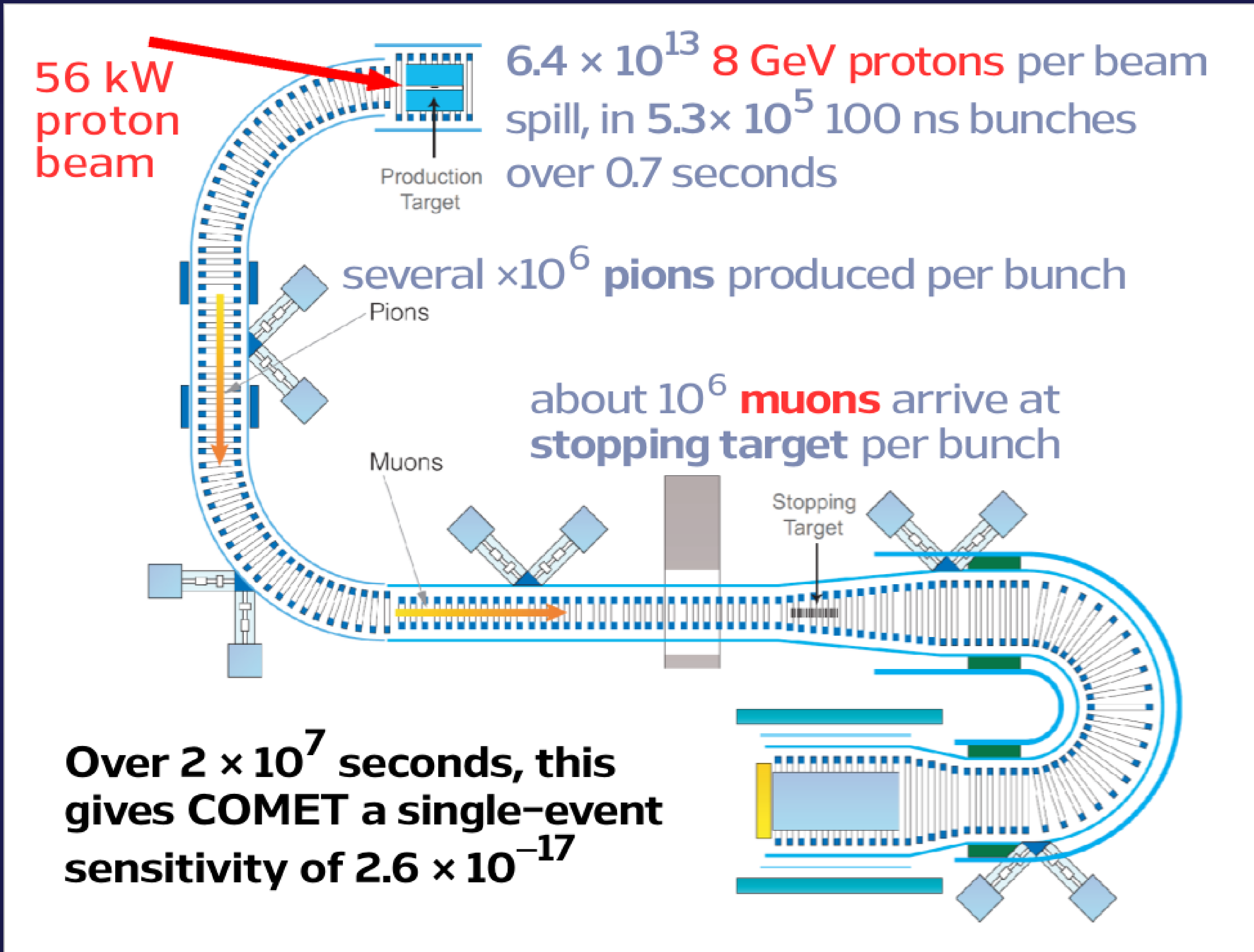
- Monitoring of high-intensity beams is critical.
  - Large emittance muon beams are particularly challenging.
  - Highlighted by International External Review panel (Jan 2014) as needing addressing by the collaboration.
- Perform R&D using Phase-I, while contributing to physics (i.e. background characterisation).
- Pursuing novel silicon micro-channel liquid scintillator technology.
  - Led by Manchester group.
  - Seeking funding in UK and Europe.
- Utilising UK strengths in accelerator and detector technologies.



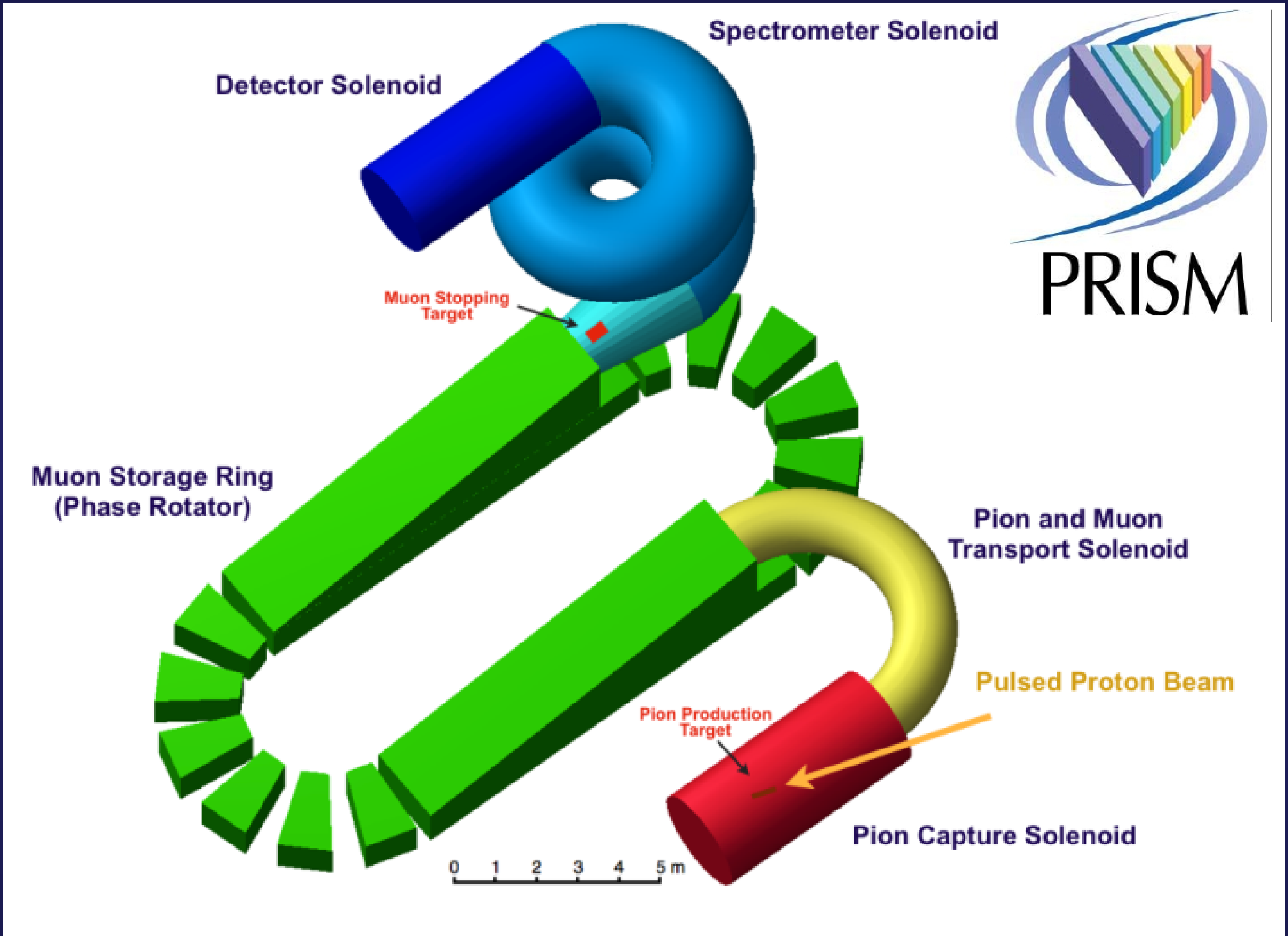
COMET-UK: AlCap Experiment

- Joint experiment at PSI between COMET and Mu2E collaborations.
- Important measurements for high-intensity muon physics.
  - (Z-dependent particle emission from muonic atoms).
- First run in December 2013.
- Strong UK involvement (Imperial & UCL).
- Physics publications expected later this year and UK PhD theses.
- Further data-taking with enhanced set-up and continued physics exploitation planned for 2015.

COMET Phase-II



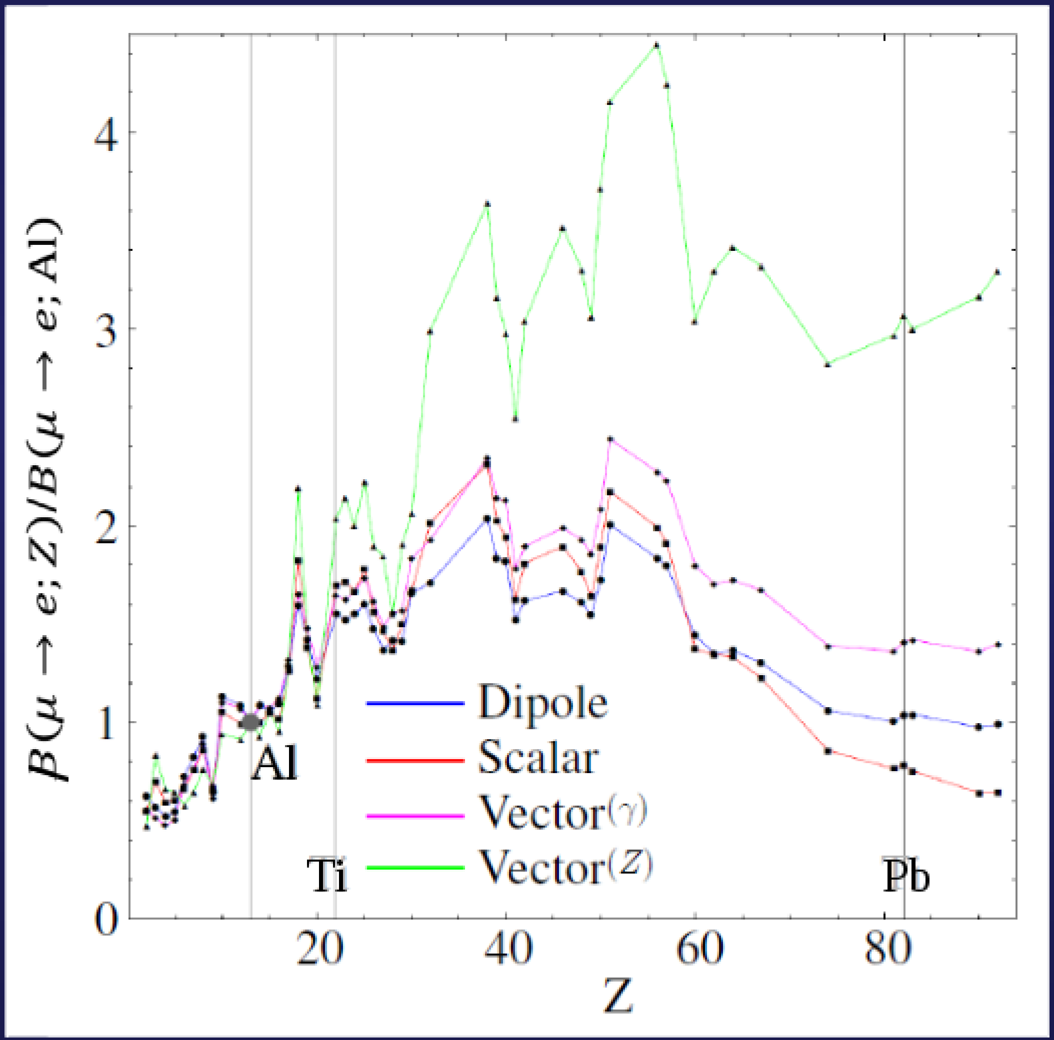
Phase Rotated Intense Source of Muons (PRISM)



- PRISM task force led by Jaroslaw Pasternak, Imperial College London.

PRISM

- Sensitivity down to 10^{-19}.
- Branching ratio as a function of Z.

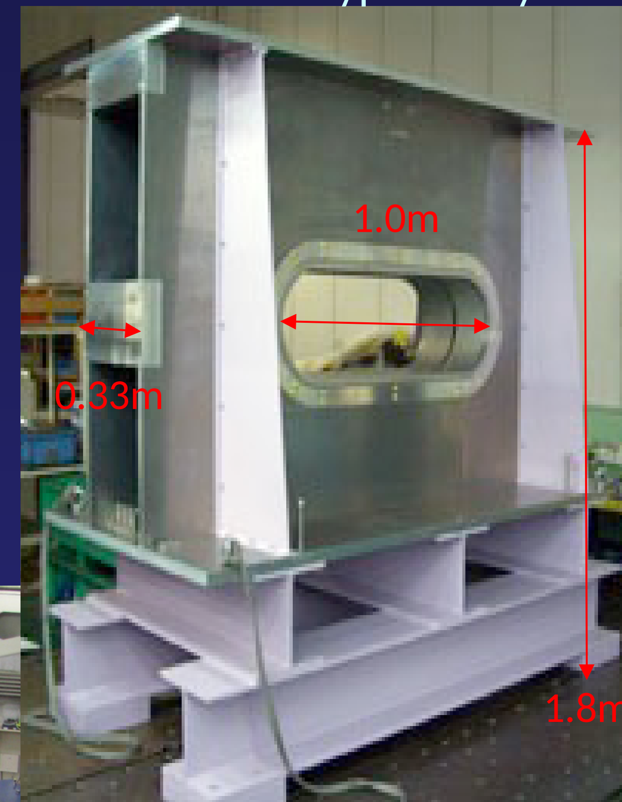


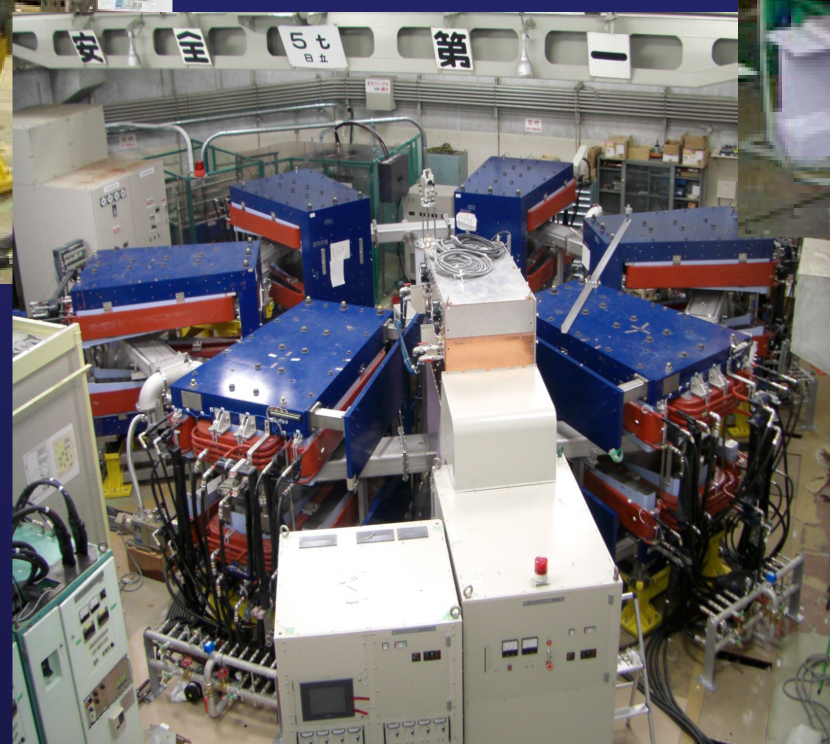
Cirigliano, Kitano, Okada and Tuzon, arXiv:0904.0957.

- Requires novel accelerator technology.

PRISM R&D

PRISM Prototype Cavity





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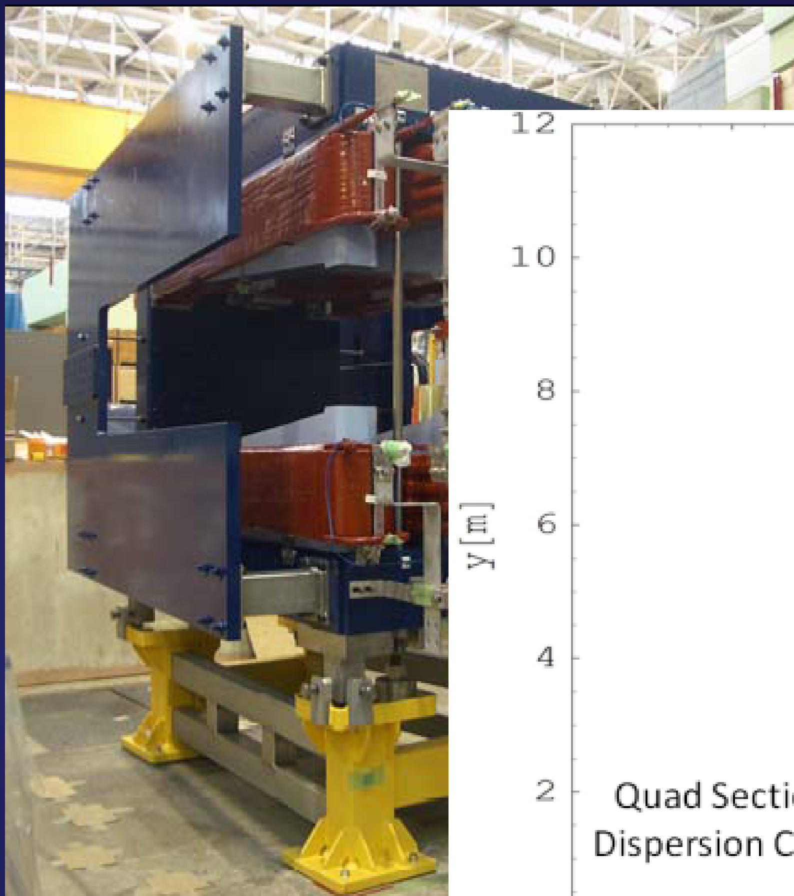

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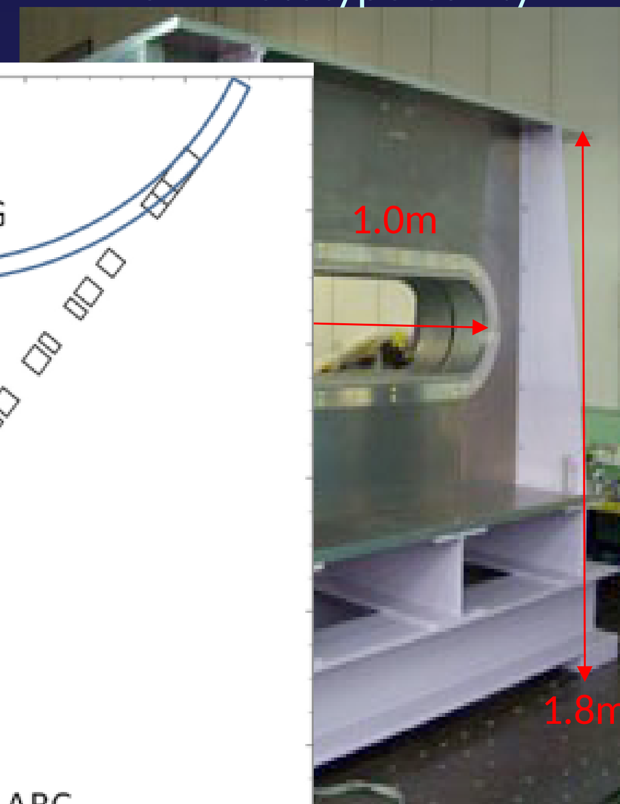
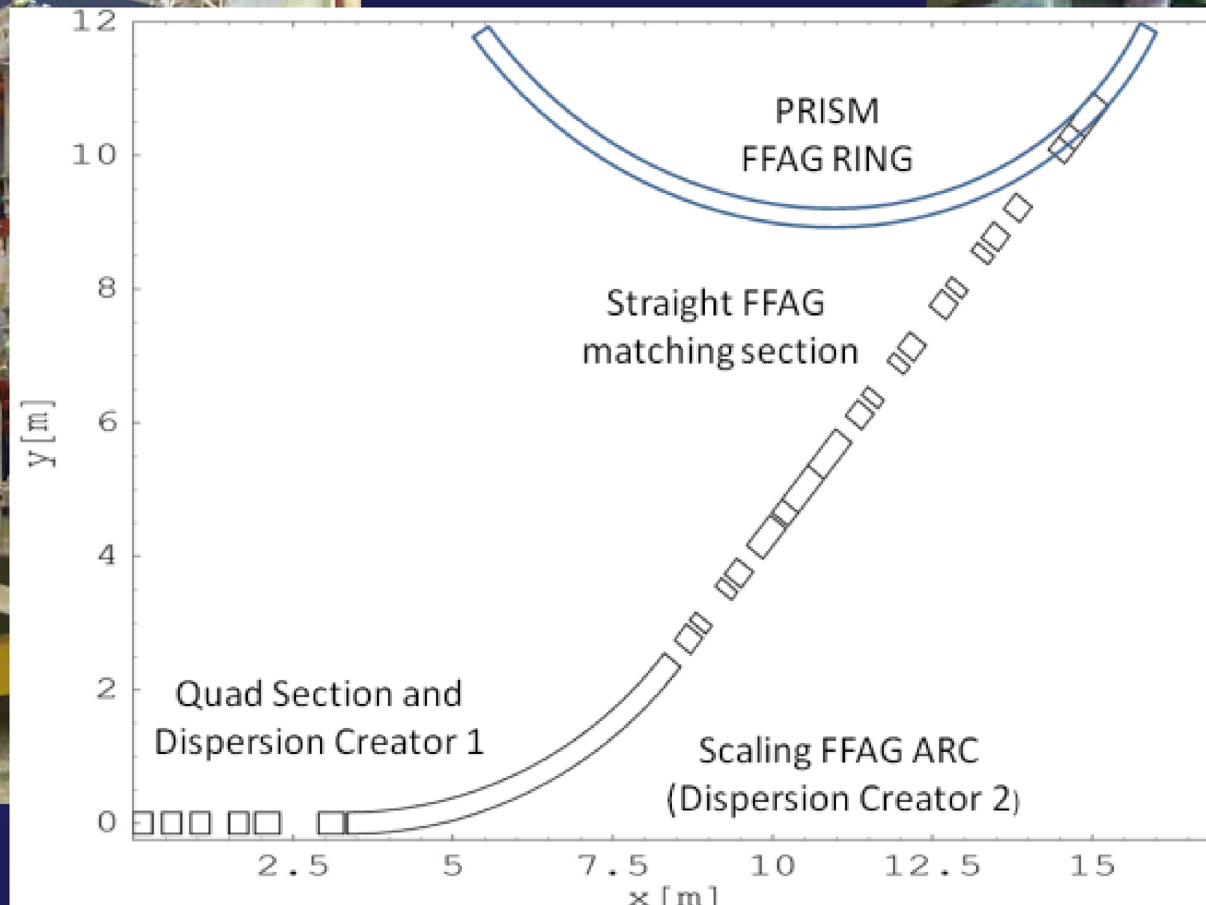
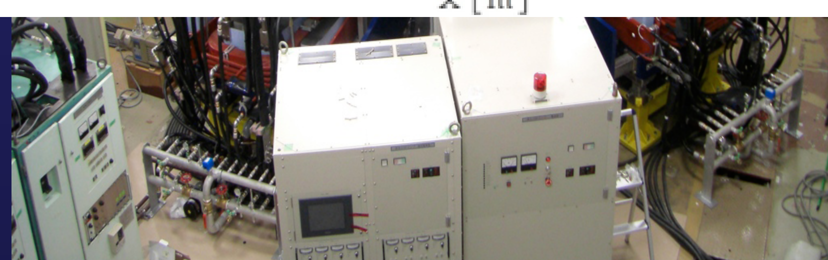






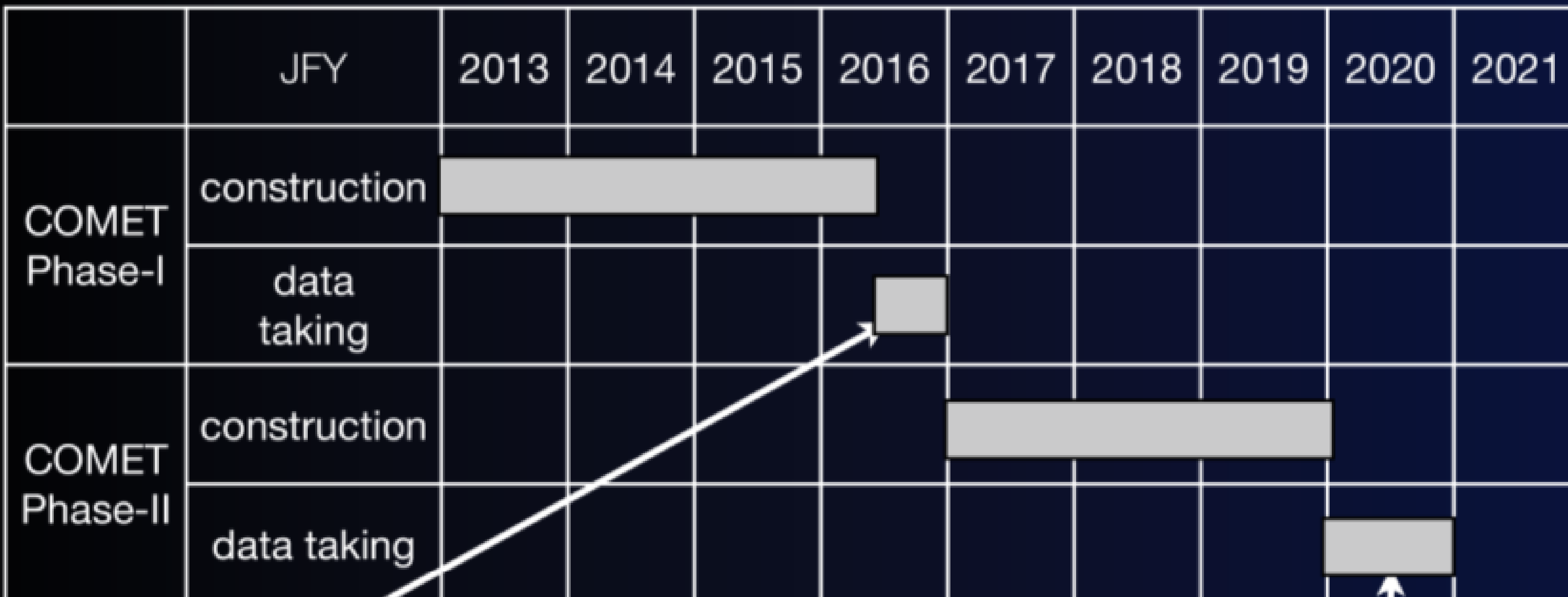
- Accelerator challenges being addressed by PRISM task force.

Summary

- Physics case for muon to electron is strong.
  - > 10^4 to 10^6 improvement in sensitivity.
  - Strong discovery potential.
- COMET is happening!
  - Commissioning runs / physics data in 2015/16.
- Continuing our strong involvement in driving COMET Phase-I forward.
  - Fully exploit investment for physics from Phase-I.
- Targeting major participation in COMET Phase-II.

Backup slides

Schedule of COMET Phase-I and Phase-II



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

COMET Phase-II :
2020~
S.E.S. ~ 3×10^{-17}
(for 2×10^{7} sec
with 56 kW proton beam)

Mu2E Schedule (from May 2013)