Targets for high-intensity muon sources for cLFV experiments

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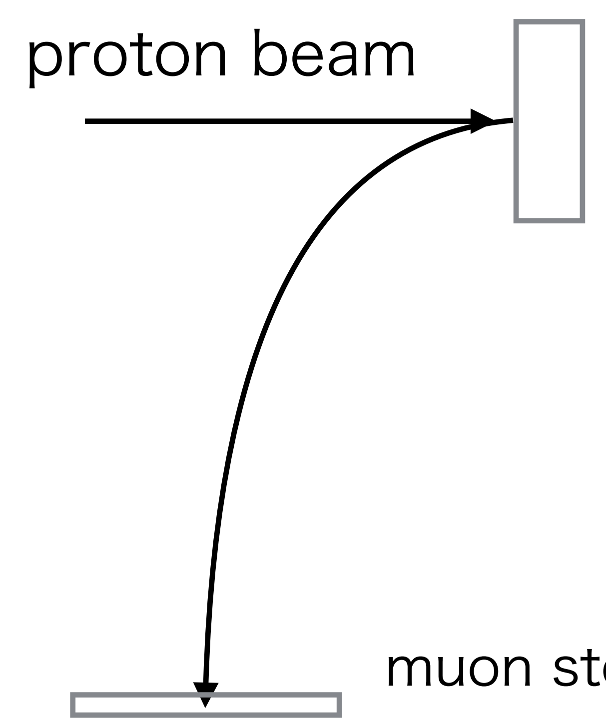
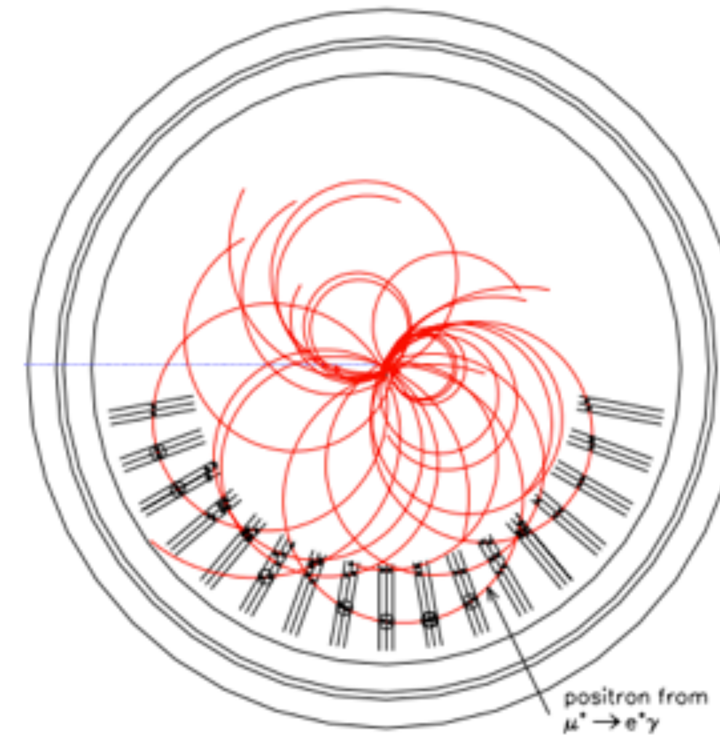
Outline

- Requirements from cLFV search experiments
  - $\mu \to e \gamma$ & $\mu \to eee$
  - μ-e conversation
  - Target material, shape, and cooling
- Muon transport

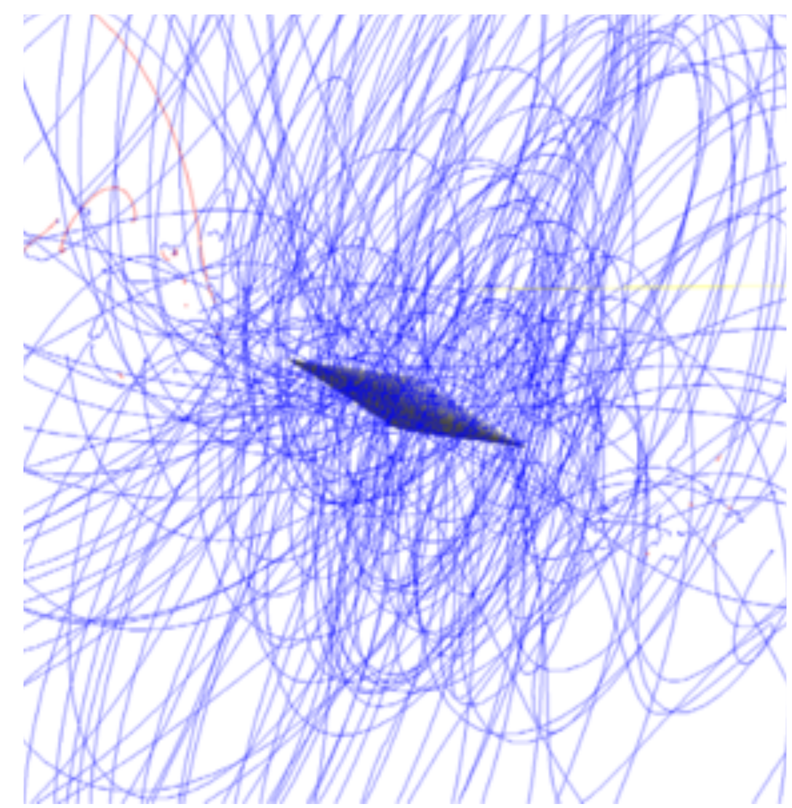


Muon cLFV Search Experiments

$\mu \rightarrow e\gamma$ & $\mu \rightarrow eee$

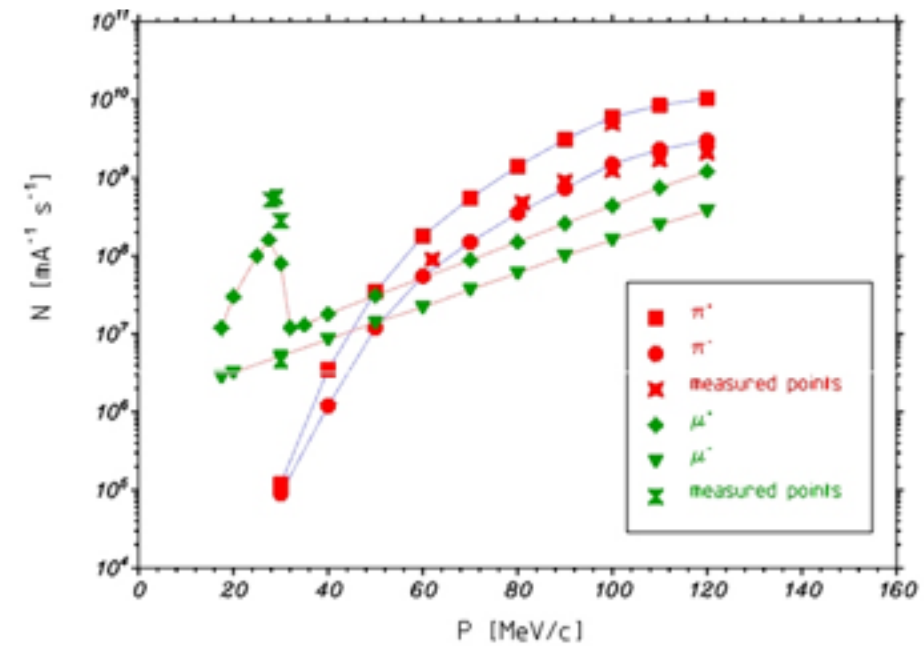


- Muons to be stopped on a target
  - target should be as thin as possible (100-200 μm) to suppress the multiple scattering effect on the decay particles
- Coincidence in the final state
  - $\mu \rightarrow e\gamma$
  - $\mu \rightarrow eee$
  - Multi-layer stopping target is not preferred for the purpose of vertex finding



Requirements from Experiments

- Confidence-Type experiments ($\mu \to e\gamma$ & $\mu \to eee$) requires muon beam with minimum momentum spread at low energy
  - Surface muon is best
  - Target should be optimized to produce the surface muon beam
  - Only positive muon
- Muon beam time structor
  - determined by the proton beam time structure



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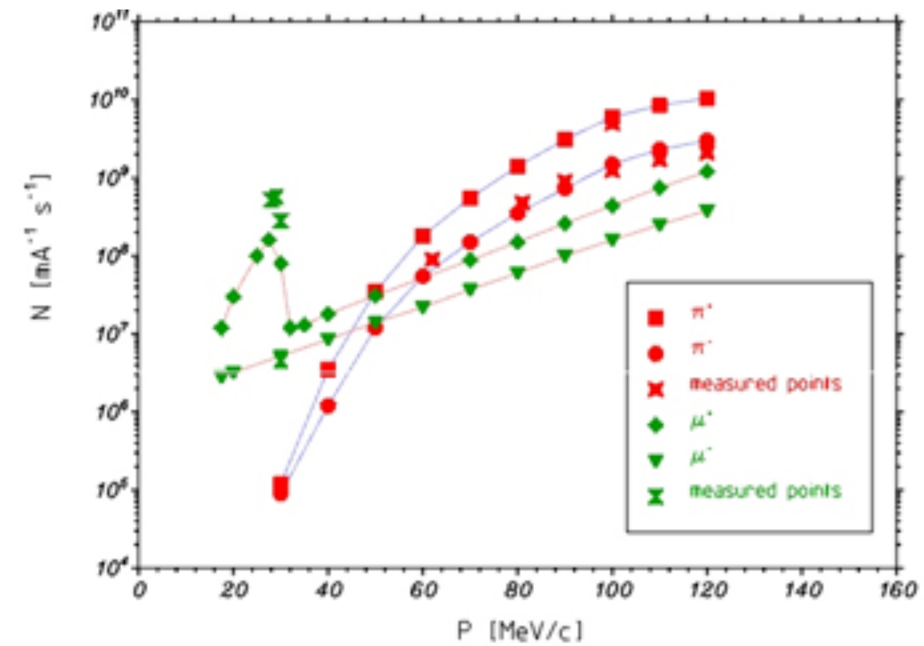
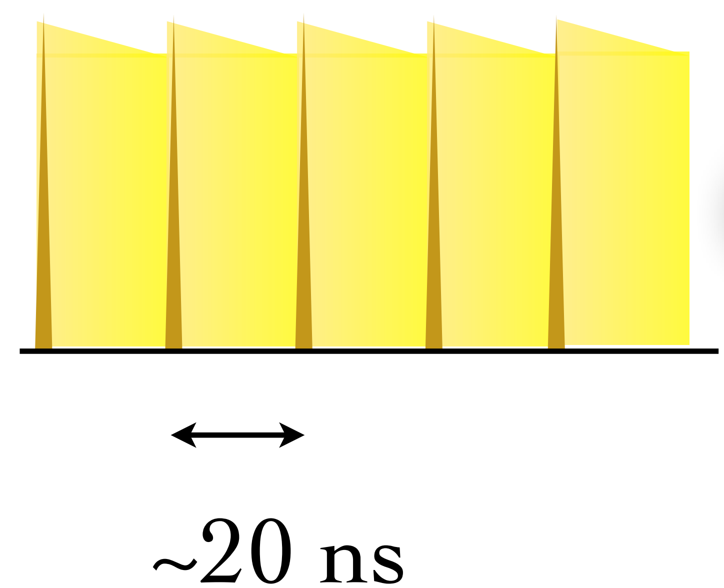
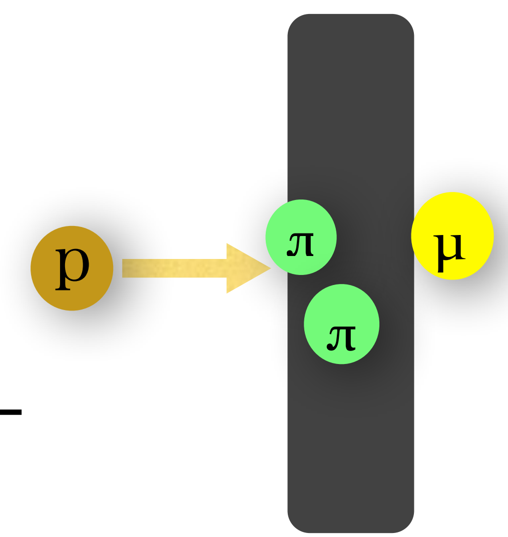


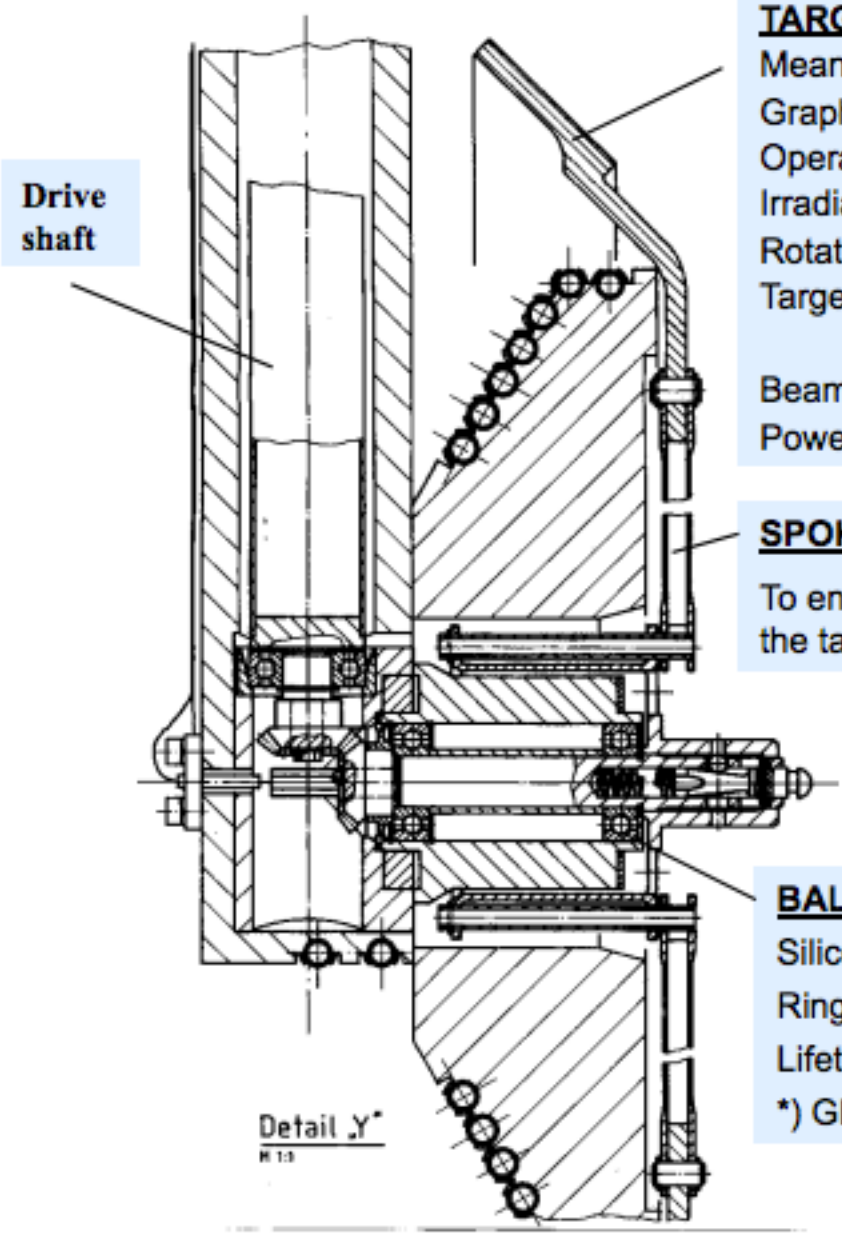




PSI Targe E

- Graphite target
- Radiation cooling

Target-E design



TARGET CONE

Mean diameter:	450 mm
Graphite density:	1.8 g/cm^3
Operating Temperature:	1700 K
Irradiation damage rate:	0.1 dpa/Ah
Rotational Speed:	1 Turn/s
Target thickness:	60 / 40 mm
	10 / 7 g/cm^2
Beam loss:	18 / 12 %
Power deposition:	30 / 20 kW/mA

SPOKES

To enable the thermal expansion of the target cone

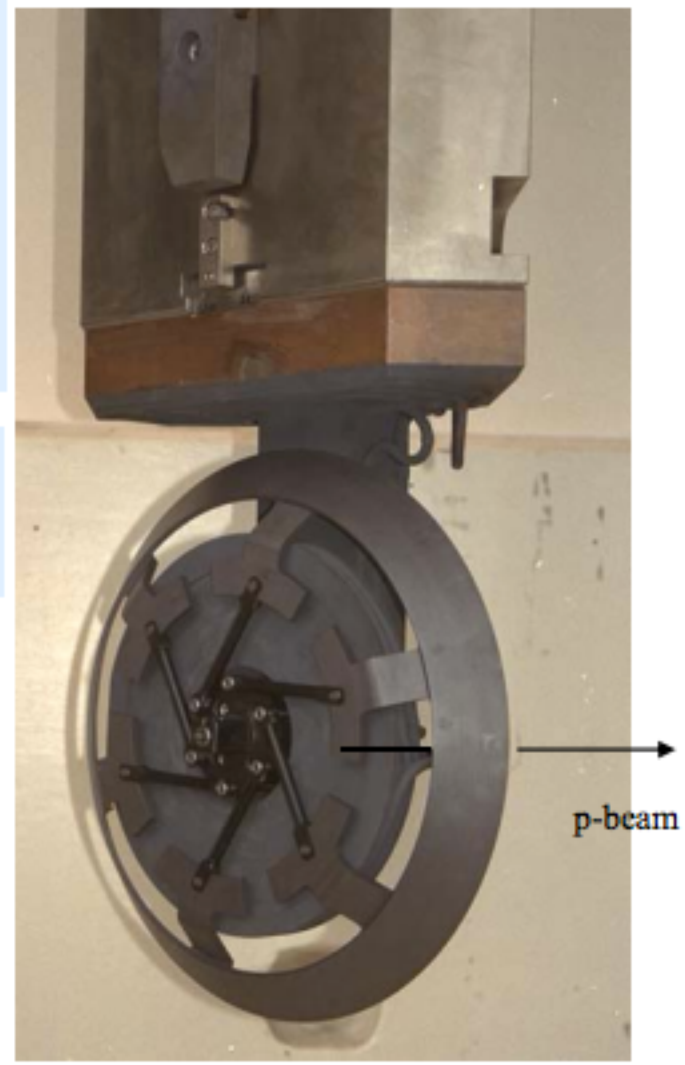
BALL BEARINGS *)

Silicon nitride balls

Rings and cage silver coated

Lifetime 2 y

*) GMN, Nürnberg, Germany



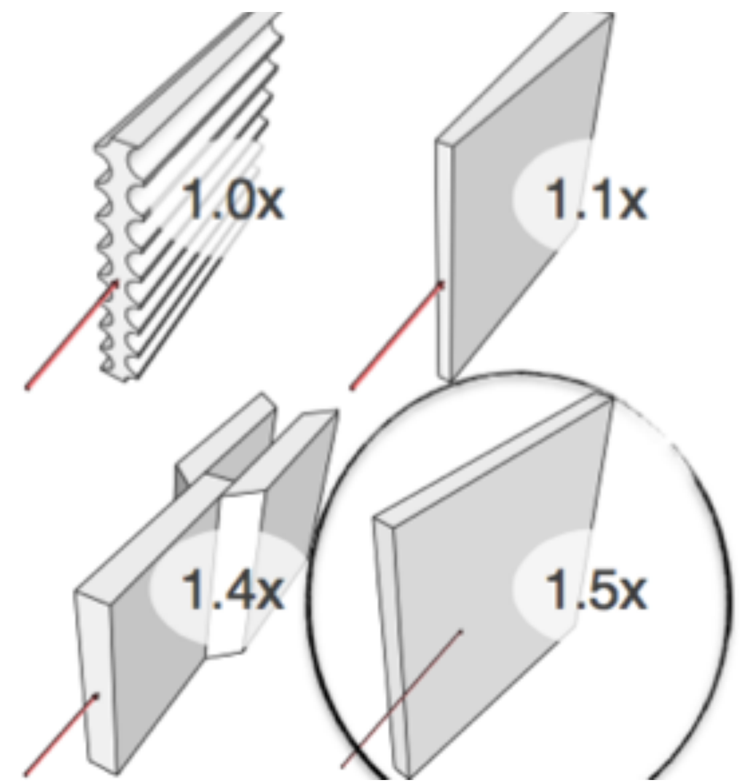
Mike Seidel

Target Performance

- Standard target configuration is good enough
- R&D to improve muon stopping efficiency
  - Muon cooling
  - Angela Papa's presentation "MuCool at PSI"

Surface muon rates in μ+/s for TgE geometry of different lengths

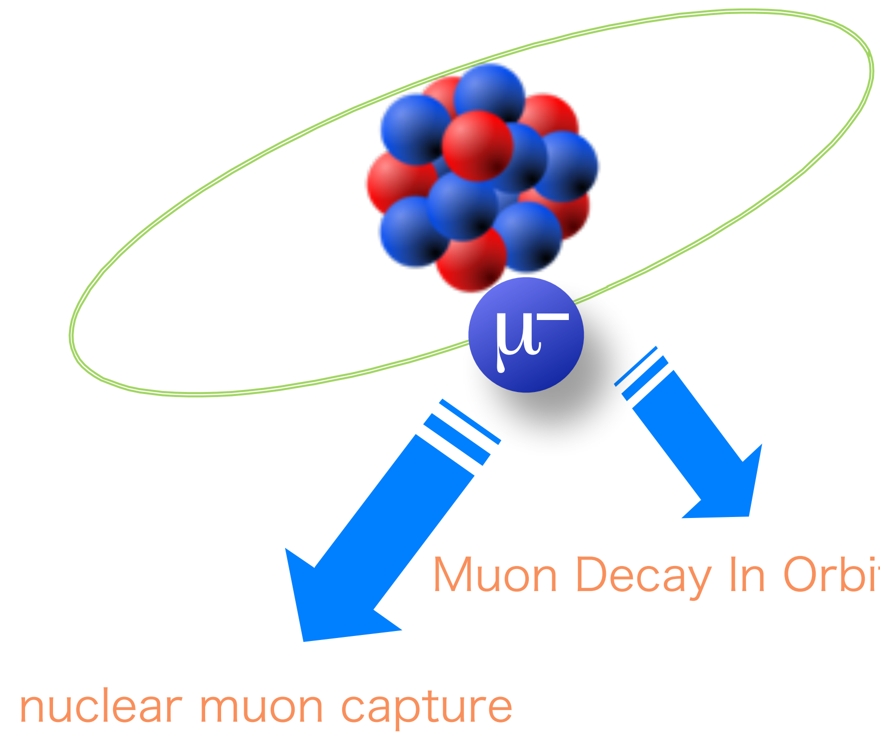
Length	Upstream	Downstream	Side
10	1.4×10^{10}	9.0×10^{9}	1.8×10^{10}
20	1.6×10^{10}	1.2×10^{10}	5.1×10^{10}
30	1.9×10^{10}	1.1×10^{10}	8.5×10^{10}
40	1.8×10^{10}	1.1×10^{10}	1.2×10^{11}
60	1.8×10^{10}	1.2×10^{10}	2.1×10^{11}

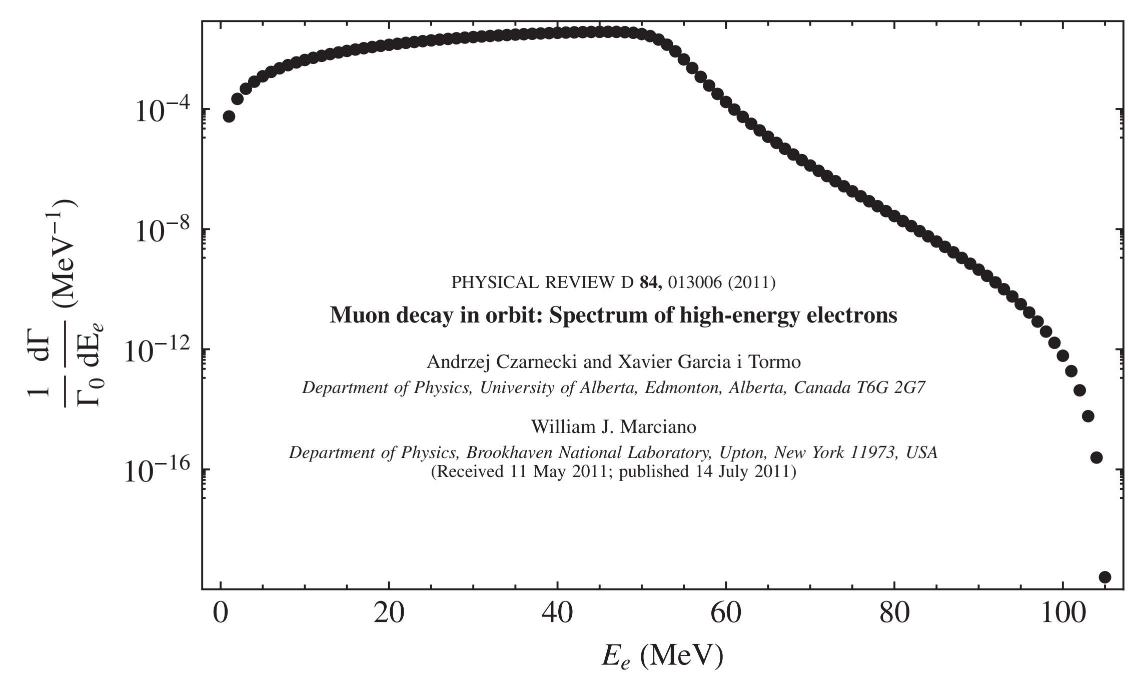


Muon cLFV Experiments

μ-e conversion searches

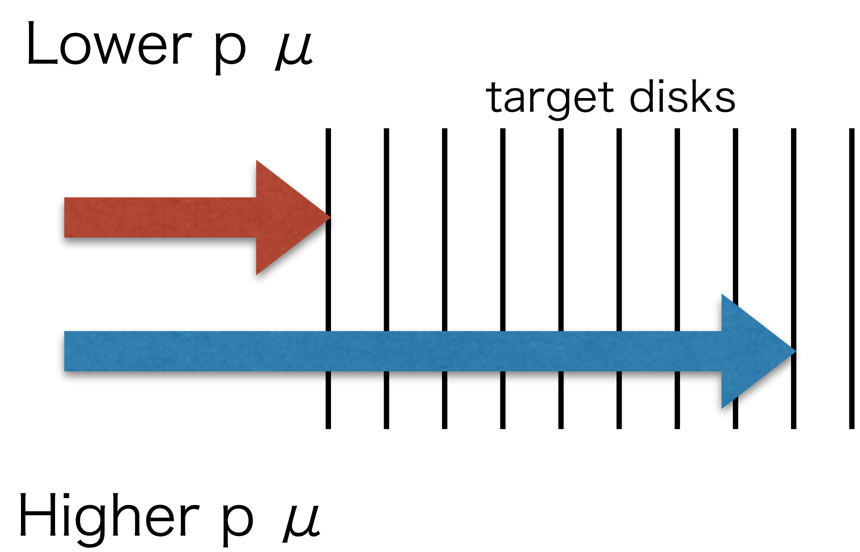
- Muonic atom formation by stopping negative muons in a material
  - Transition to 1S state by emitting X-ray
  - "Decay" or "captured" with a lifetime of ~1μsec
- Signal electron identified with its characteristic energy emitted with a delayed timing
  - $E_e = m_\mu - E_B - E_{recoil} \fallingdotseq 100\text{MeV}$
  - DIO background



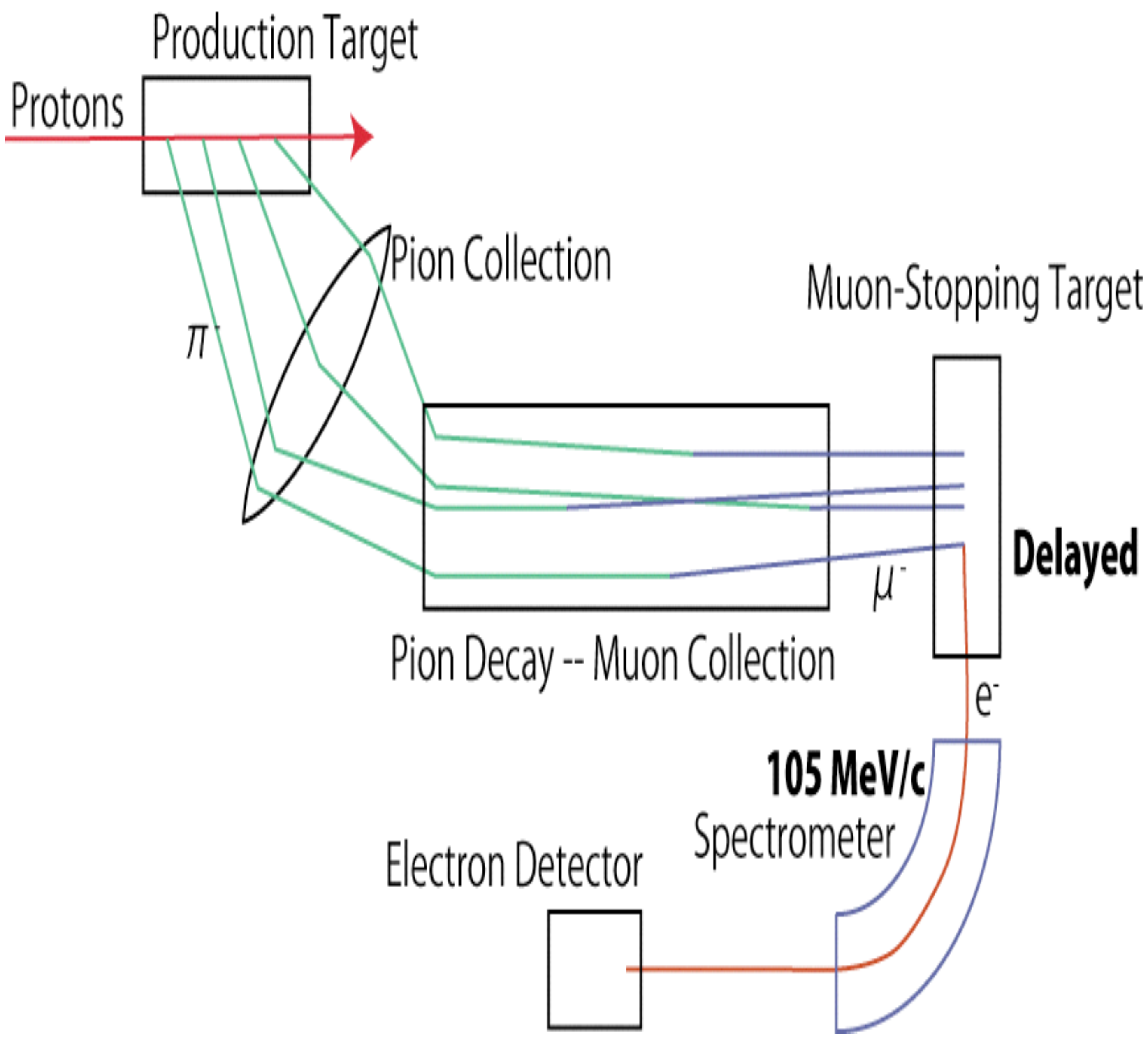


Requirements from μ-e Conversion Experiments

- As many muons as possible
- The muon stopping target should be thin but multi-layer type is acceptable
  - No need of exact vertex finding thanks to one electron in the final state
  - This arrow us to use a larger momentum range of the muon beam
- DeeMe is an exception since they adopt a different method to perform the search

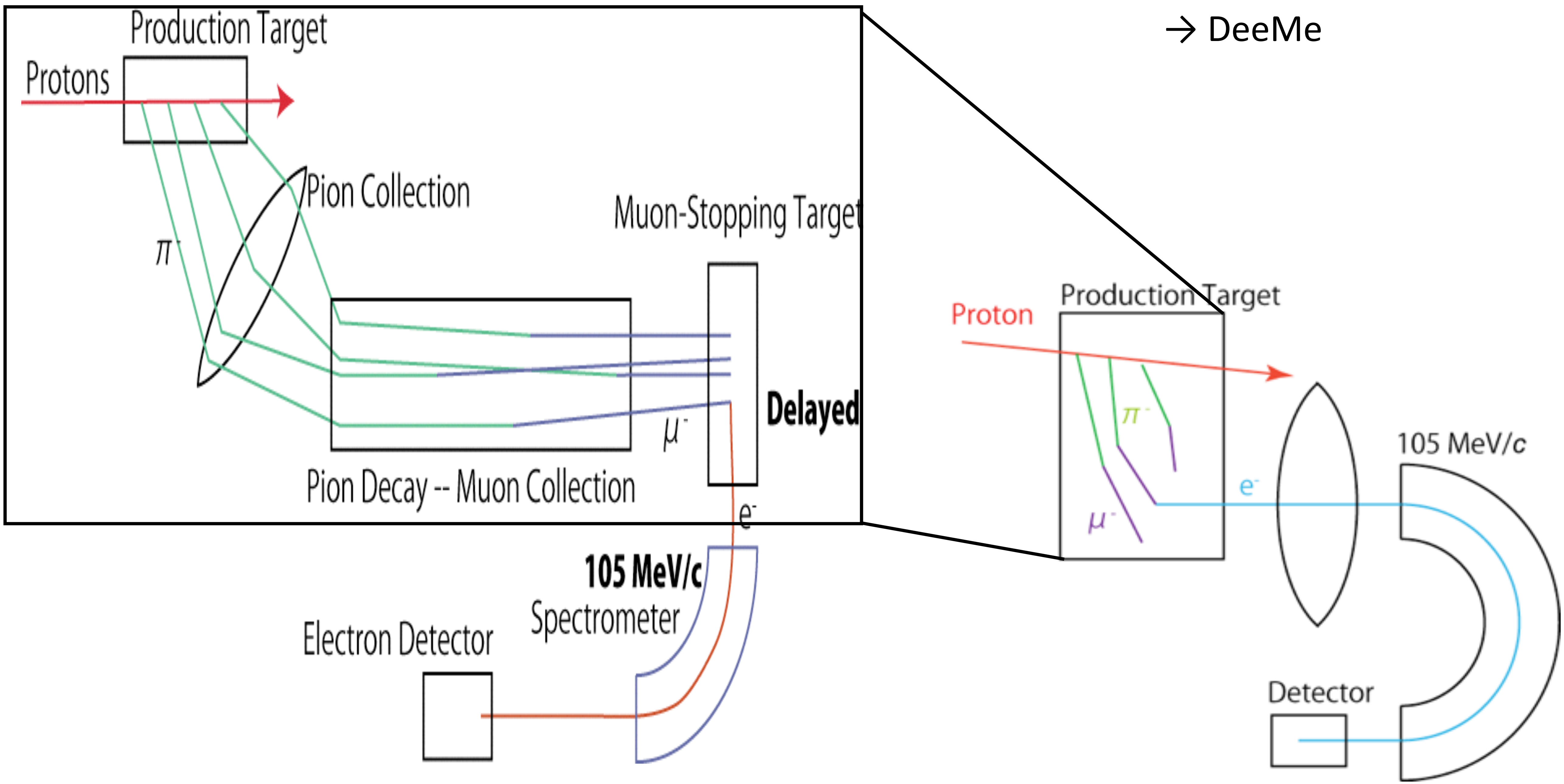


Principle of DeeMe



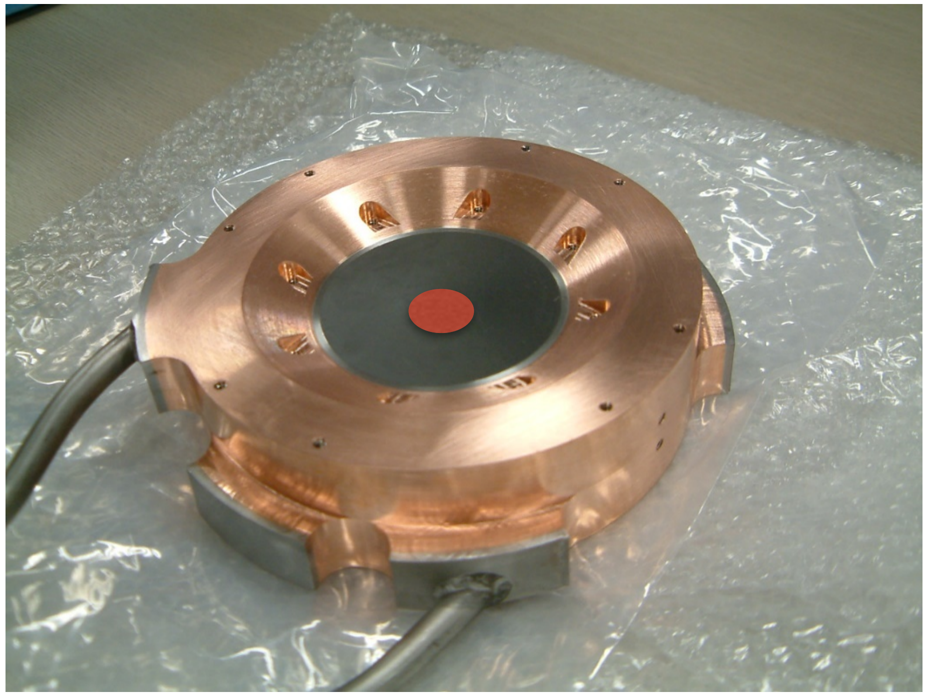
Principle of DeeMe

→ DeeMe



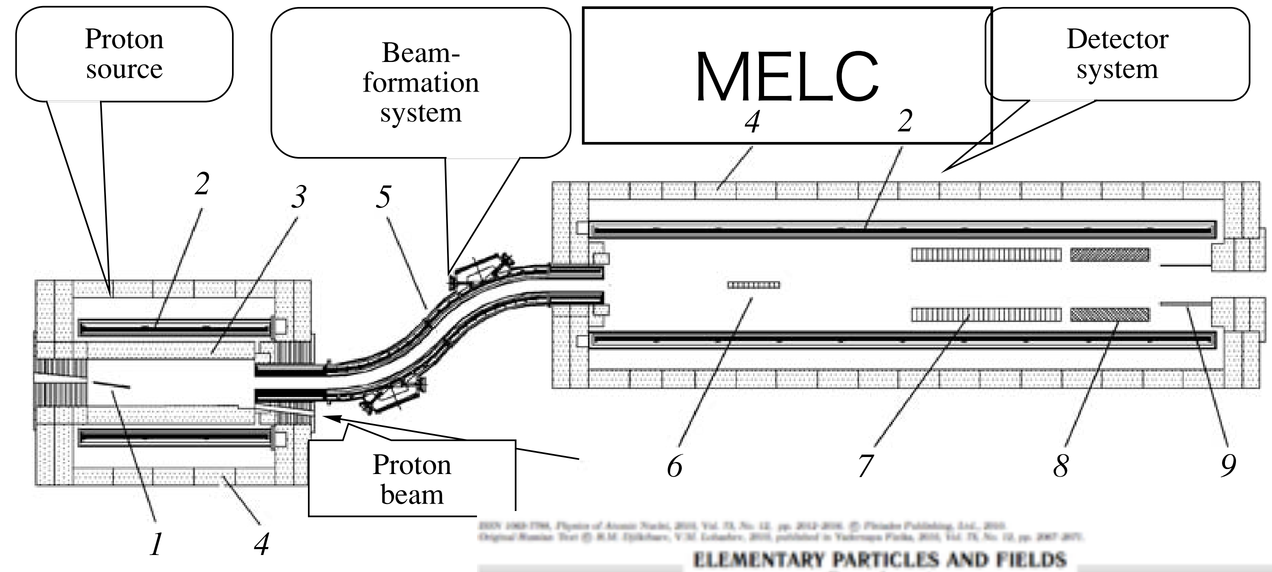
J-PARC MLF Target

- Shunske Makimura's presentation for more details
- Fixed target (Polycrystalline graphite) had been used in the period from 2009 to 2014, Water cooling & thermal conduction
- Rotating target operational from 2014. Radiation cooling
- **R&D of SiC as a future option** → **more muon (for all muon users)** & **another material for muonic atom formation (for DeeMe)**
- Beam size 16mm in 2σ



COMET & mu2e

- Both employ MELC idea
- Pion production target in the gradient magnetic field
- Collect low-momentum pions/muons emitted backward
- Target can be thick along the beam direction
  - ~3x σ_{beam} in the orthogonal direction
- Rotating scheme cannot be used
  - Active cooling
  - Radiation cooling (doing nothing)



ELEMENTARY PARTICLES AND FIELDS
Experiment

Search for Lepton-Flavor-Violating Rare Muon Processes

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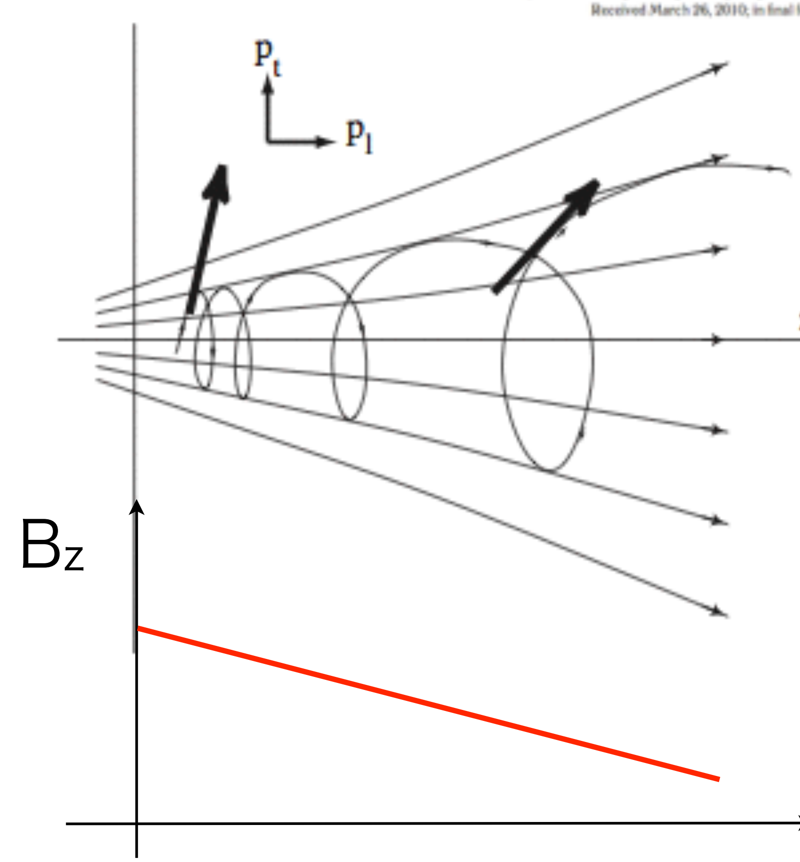
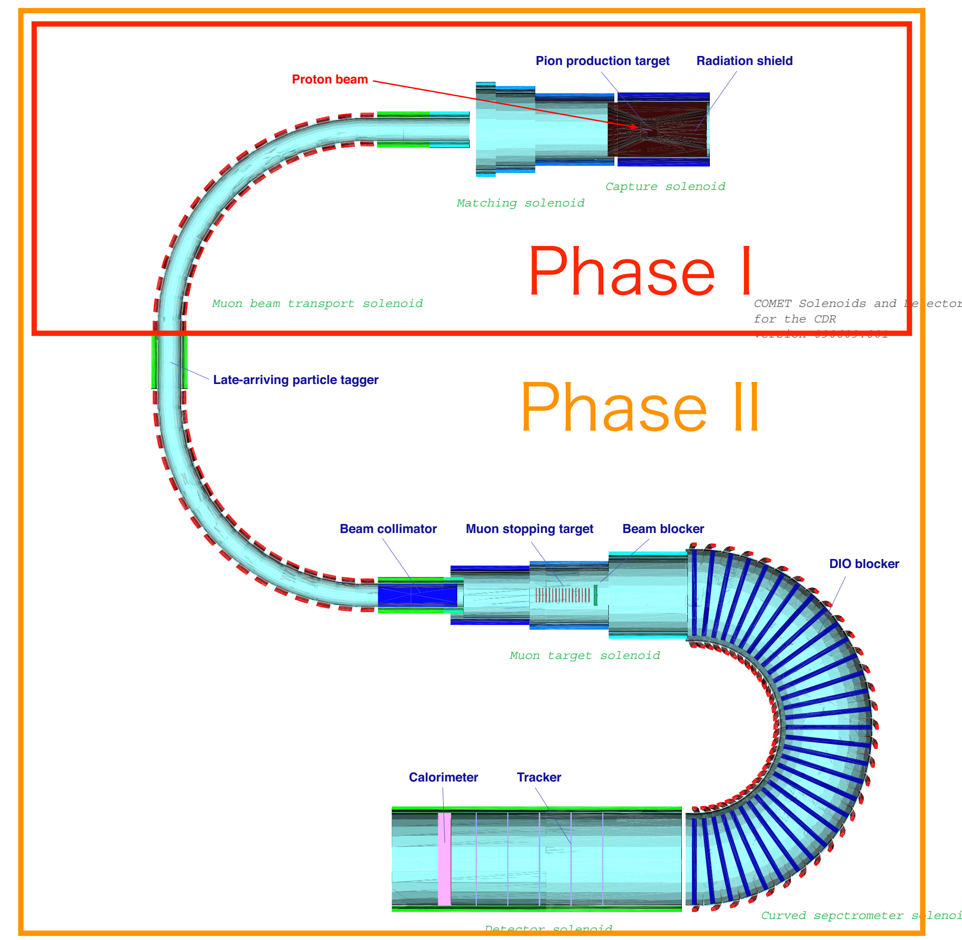
Received March 26, 2010; in final form, July 12, 2010



COMET
Phase I & Phase　II

- See Y. Yuan's presentation for more details of the setup and physics goal
- Phase-I sensitivity < 10^{-14}
  - The pion production target should be simple and robust to start the experiment timely
- Phase-II sensitivity < 10^{-16}
  - more time for R&D to achieve higher muon production efficiency
  - Metal target with active cooling
    - mu2e target R&D

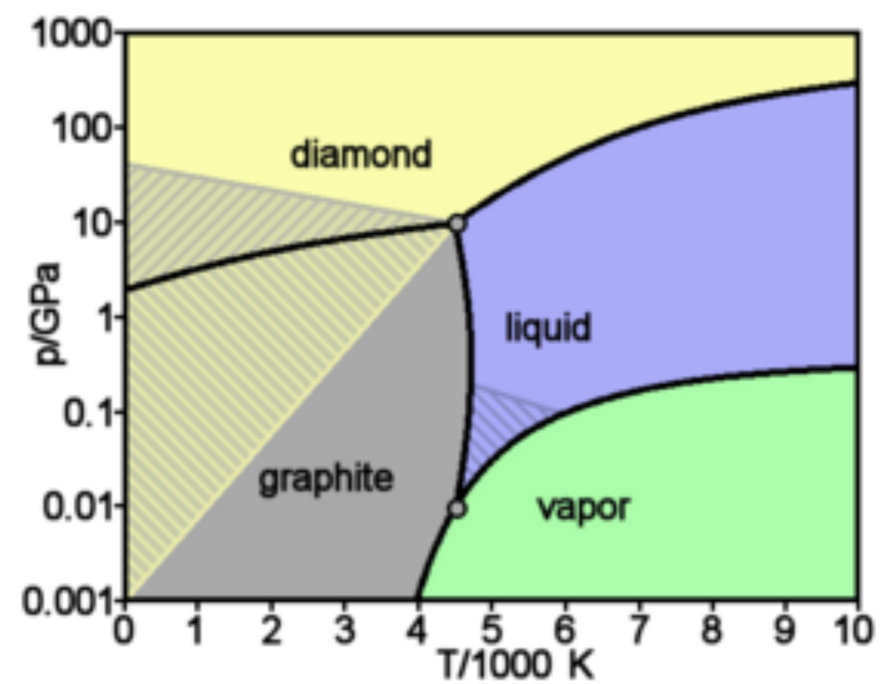


3.2kW in Phase I

56kW in Phase II

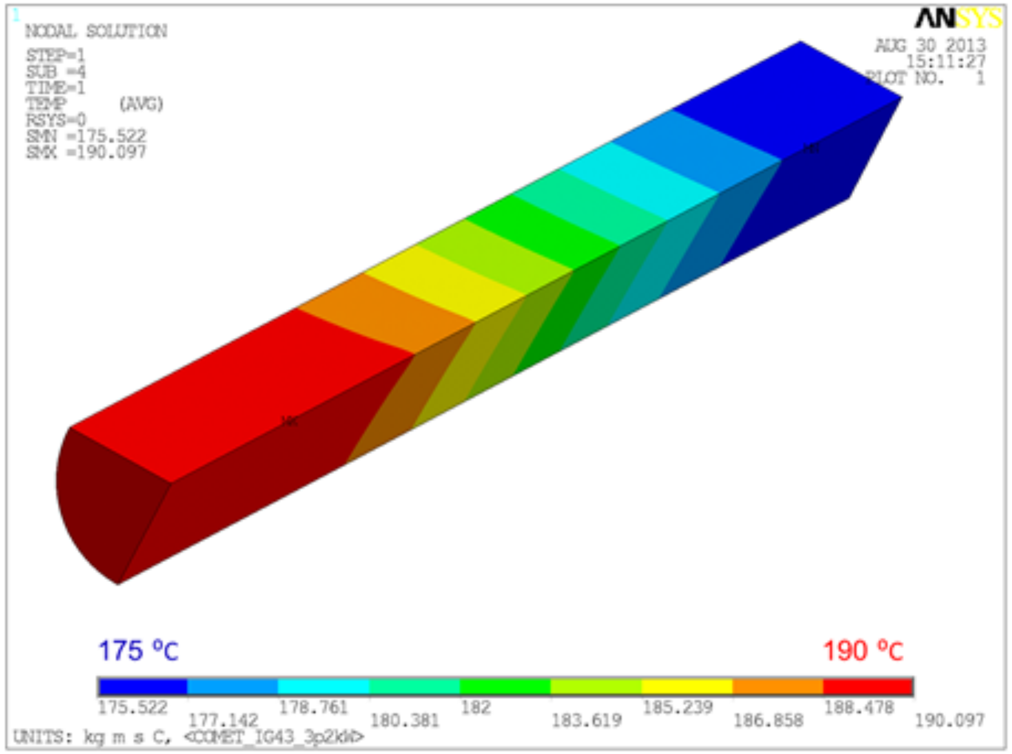
COMET Phase-I Target

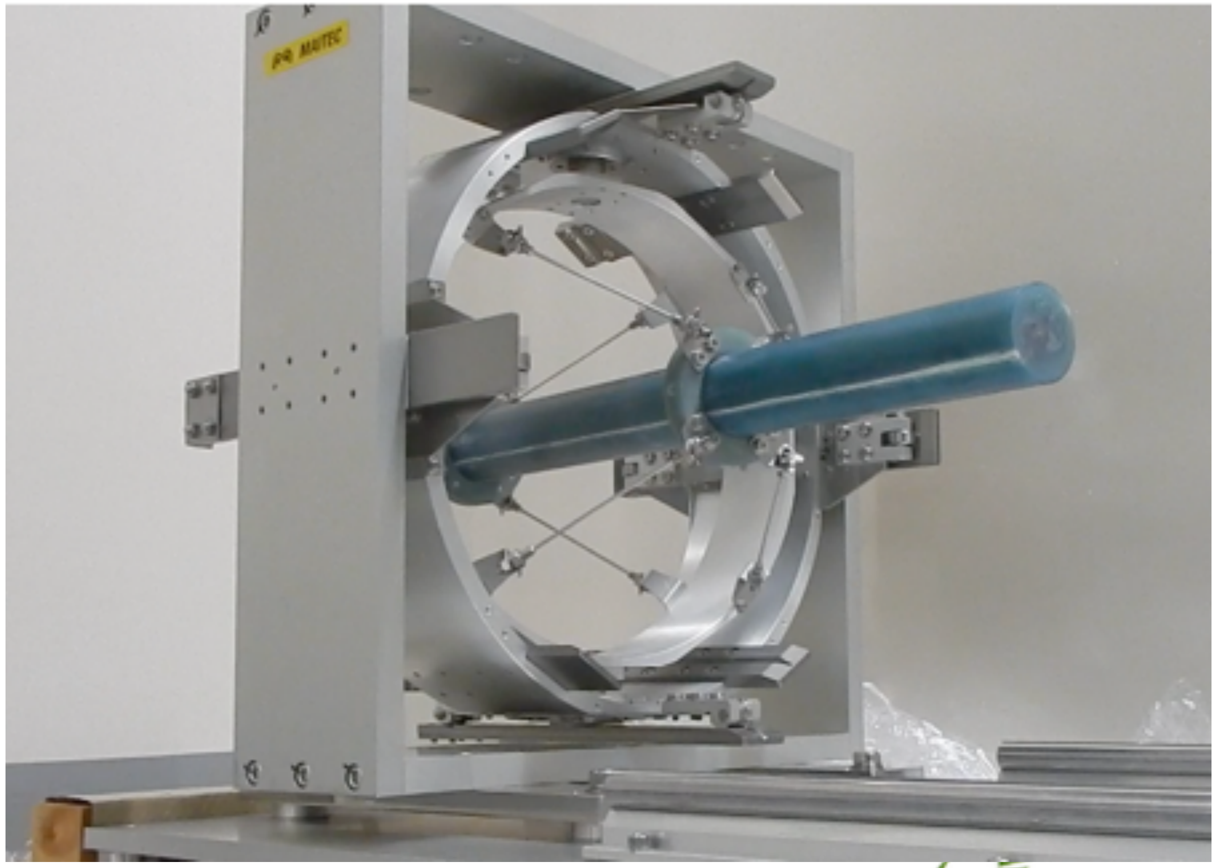
- Accept 8GeV 3.2kW proton beam
- Produce and transport as many low-momentum muons as possible
  - 1-2 interaction length with an optimized diameter
    - Larger diameter reduces pion emission from the target
- Simple & refractory
  - Radiation cooling rather than active cooling using water/gas to simplify the system
- Graphite (IG-43) with 4cm diam. and 60cm length
  - Refractory material and so is tolerant to high temperature operation
  - Experience in T2K



COMET Phase-I Target Design

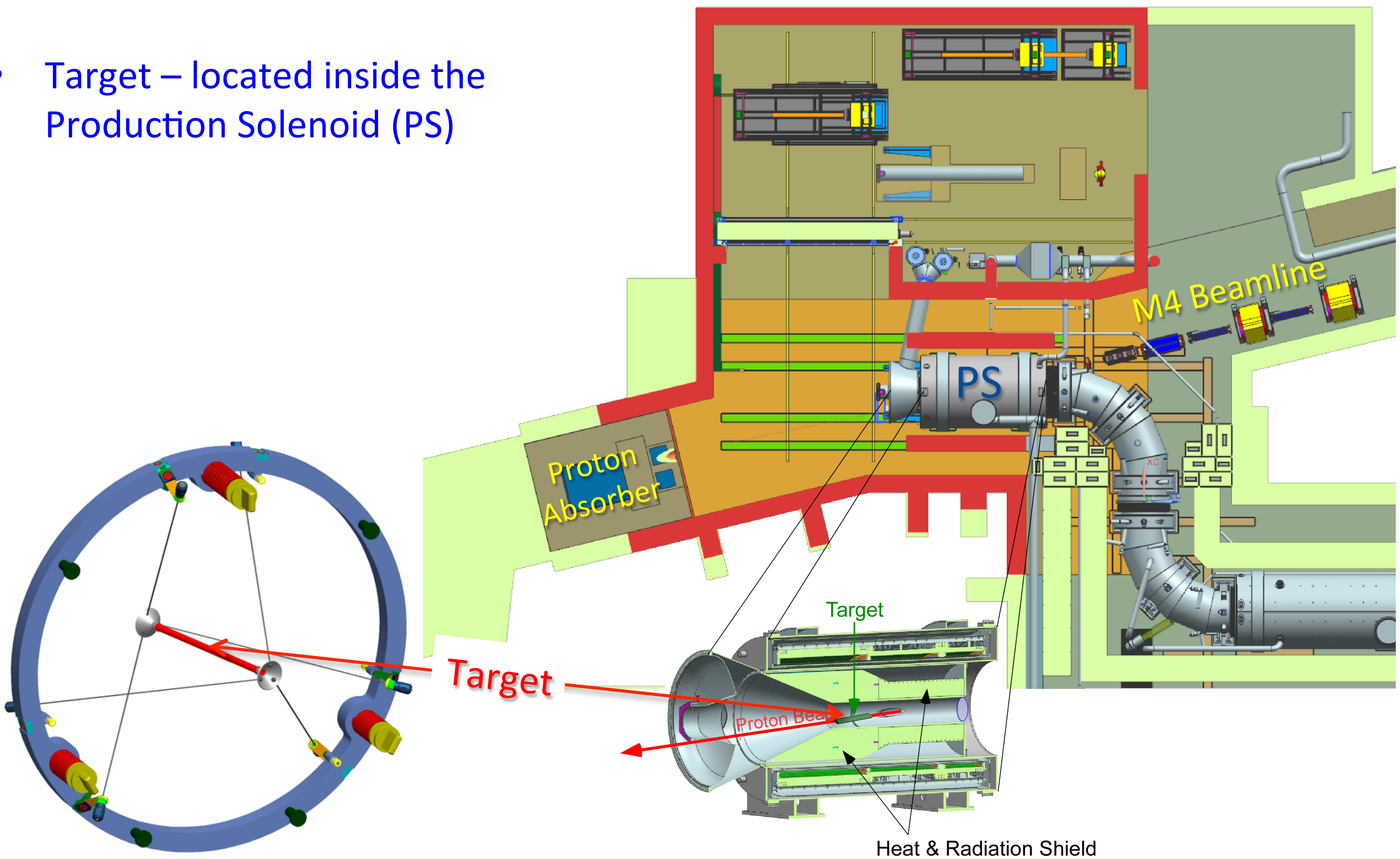
- Radiation cooling
- Support structure for Phase I
  - Same interface with Phase II target support
  - Graphite spoke & Titanium ring
- Target Installation
  - Alignment & Replacement scenario
- Monitor
  - Temperature censor and/or Infrared monitor
- Possibility to use heavier material
  - SiC: 3.22 g/cm^3
  - Preliminary study indicate more then 30% increase of muon stops in COMET Phase-I configuration





COMET Phase-II & mu2e Target Design

- Target – located inside the Production Solenoid (PS)



tungsten target with helium cooling

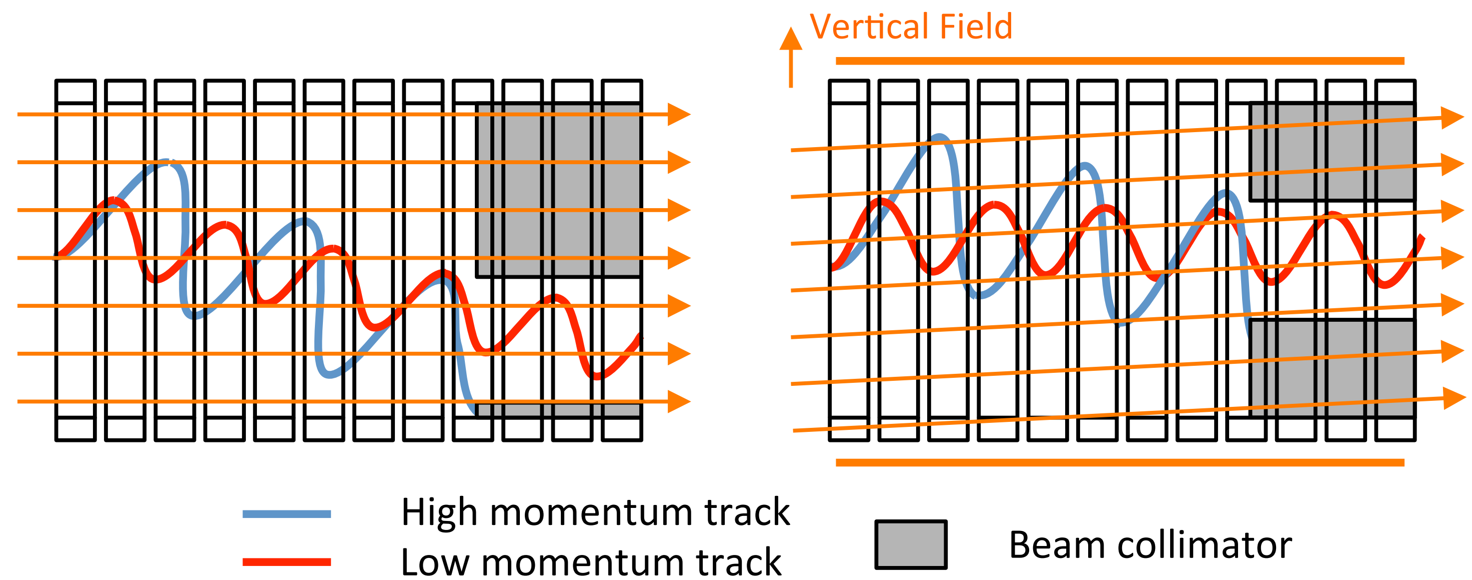
C. Densham

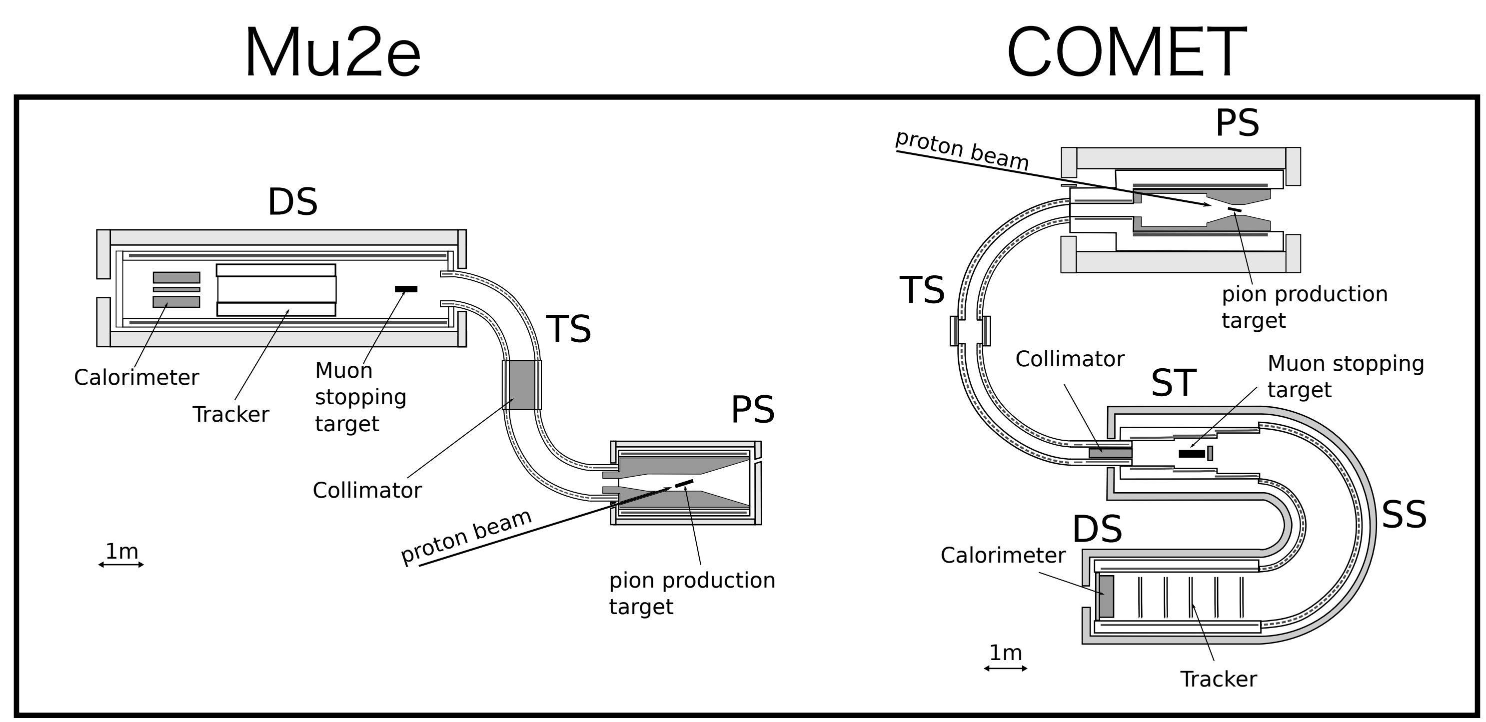
Comments on Muon Transport

- Curved solenoid technology
  - COMET & Mu2e Muon Transport
  - MUSIC (Dai Tomono's presentation on Friday)
- Solenoid beam line study at PSI

Curved Solenoid Muon Transport

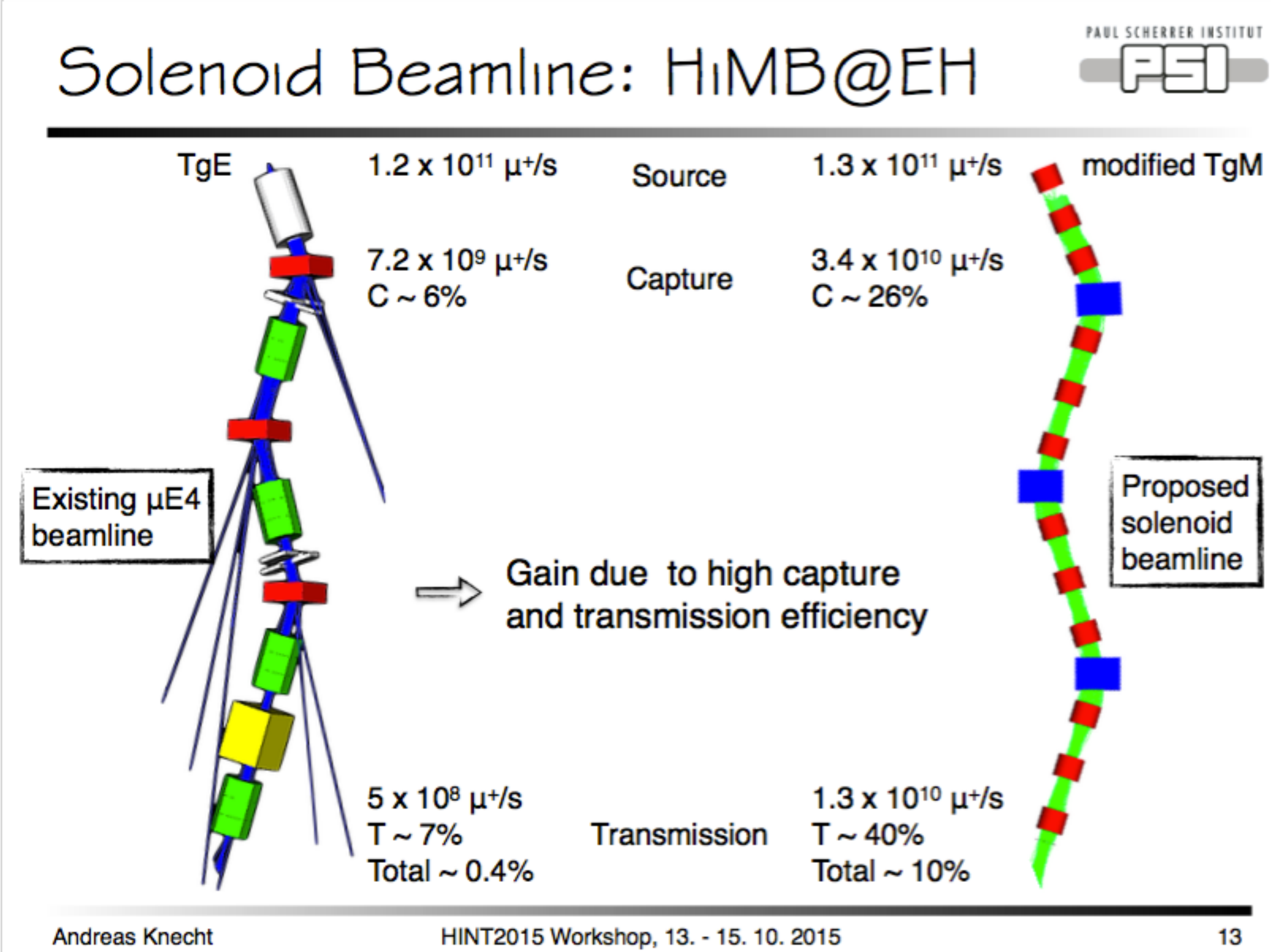
- Center of the charged particle helix drift depending on the charge and momentum
- Momentum & charge selection





COMET Curved Solenoid Installation

Solenoid Beam Line @ PSI



Summary

- Targets for high-intensity muon sources for cLFV experiments
- Graphite target with radiation cooling have been used in many facilities
  - SiC
- Future experiments (mu2e & COMET Phase II) will use metal target to achieve better pion production efficiency
  - Need active cooling
- Muon transport should optimized accordingly