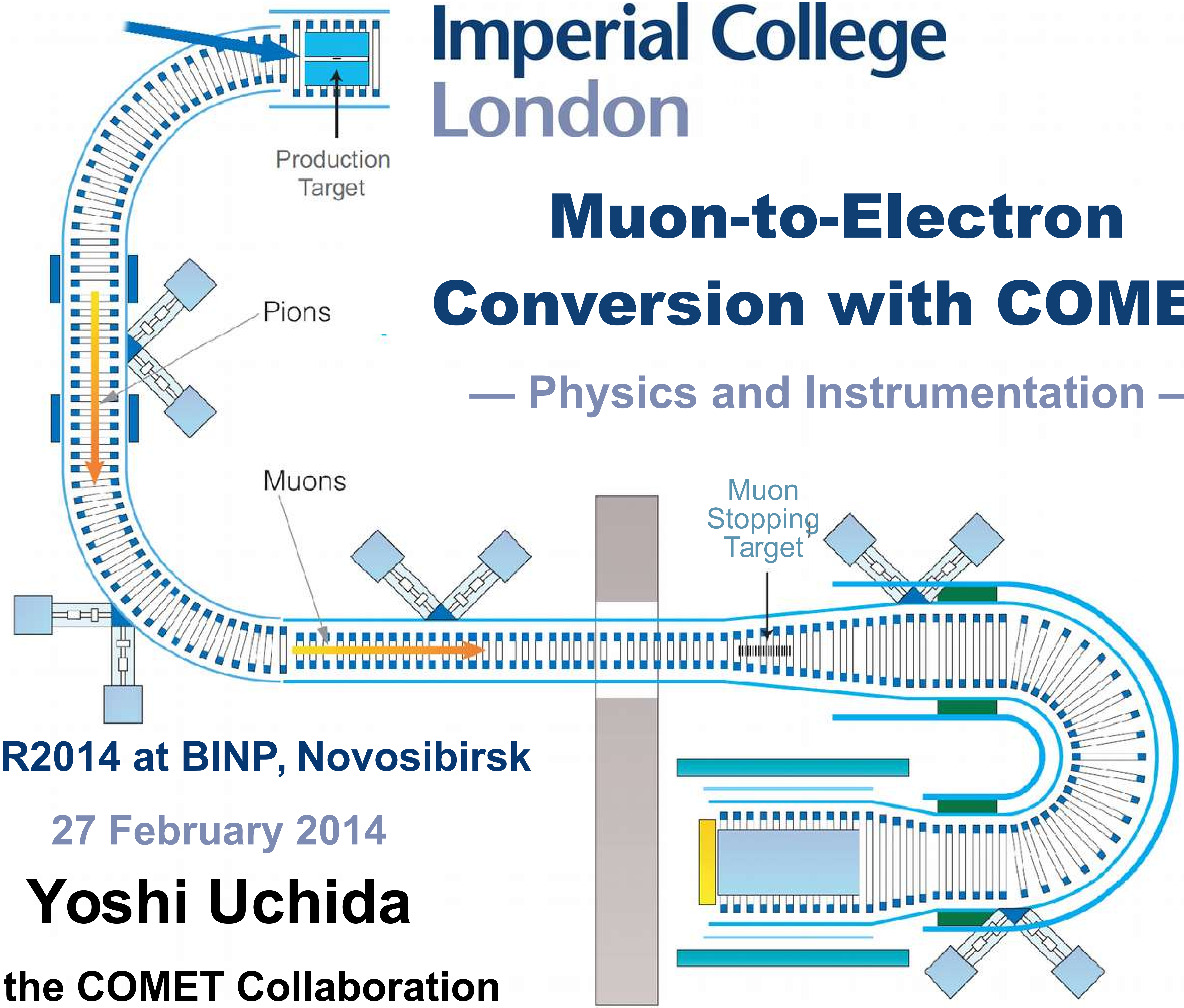
Imperial College
London



Muon-to-Electron Conversion with COMET

— Physics and Instrumentation —

INSTR2014 at BINP, Novosibirsk

27 February 2014

Yoshi Uchida

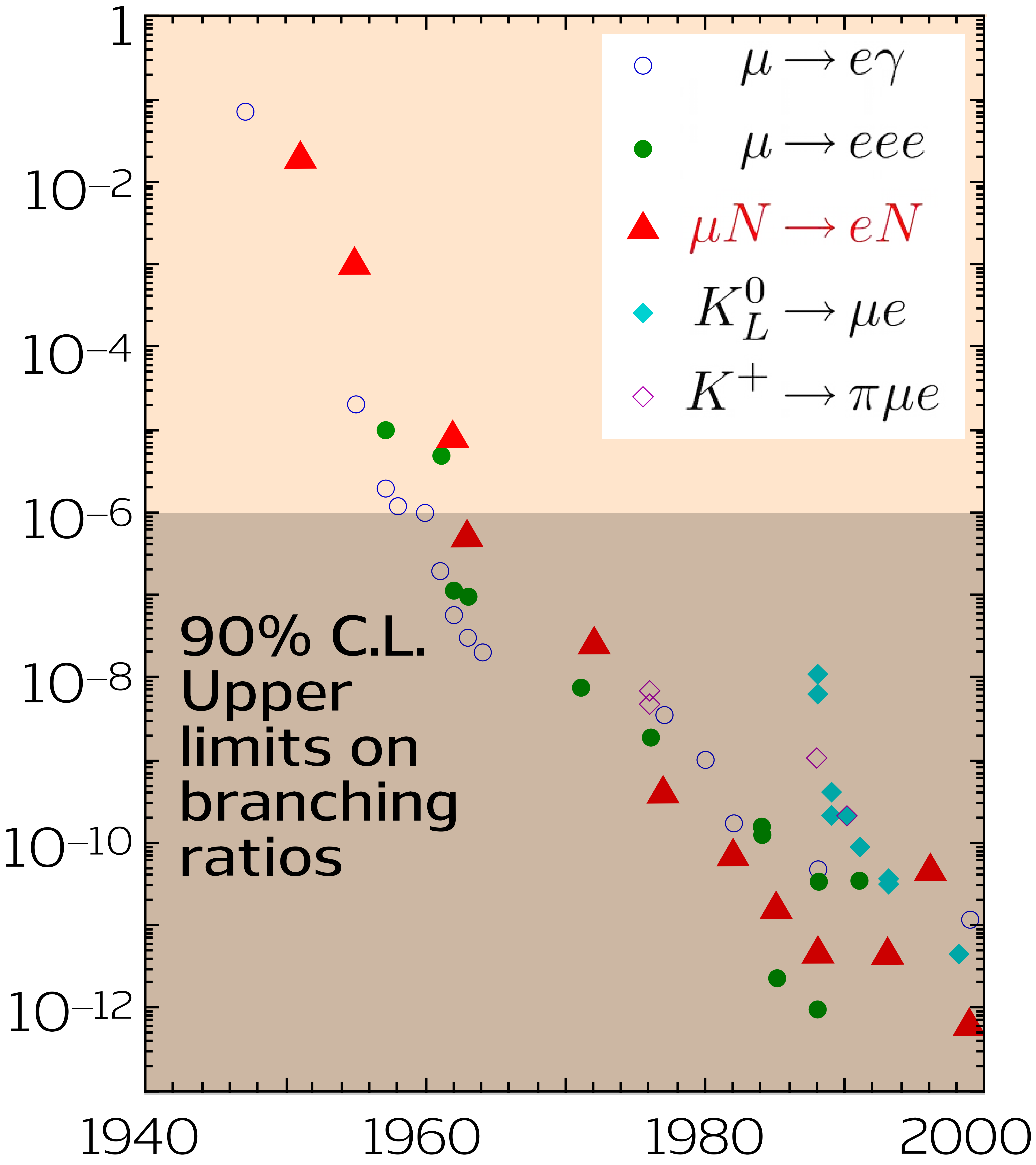
for the COMET Collaboration

- **Muon-to-Electron Conversion**
  - Characteristics
  - Physics reach
- **The Previous Generation**
  - SINDRUM II
- **The Next Generation**
  - COMET & Mu2E
- **COMET Phases I & II**
  - Detectors
  - Outlook

Charged Lepton Flavour Violation

- Experiments in the 1950s and 60s found CLFV is non-existent at O(10^{-6})
- This discovery led to the construction of models where CLFV is excluded **by construction**

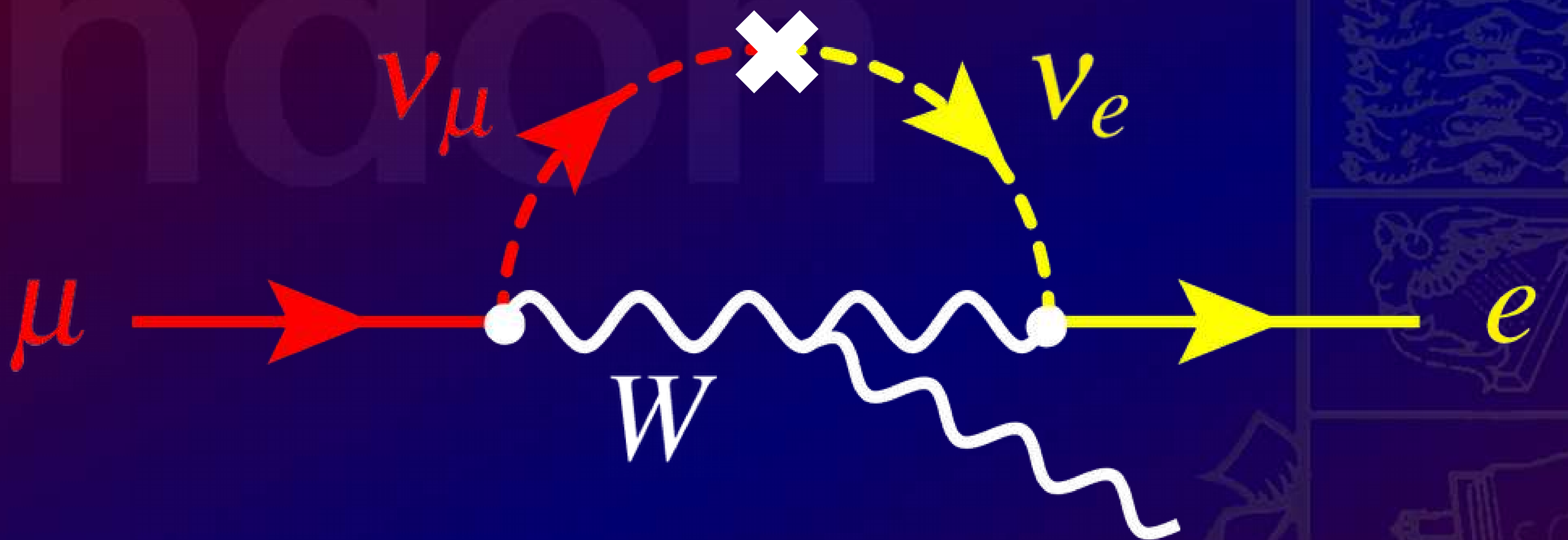
⇒ the Standard Model



90% C.L. Upper limits on branching ratios

Charged Lepton Flavour Violation

- **Beyond-the-Standard Model Physics** can cause CLFV
  - e.g. **massive neutrinos**



  - but CLFV GIM-suppressed to **less than O(10^{-50})**

$$B(\mu \to e + \gamma) = \frac{3\alpha}{32\pi}\left|\sum_\ell V^*_{\mu\ell} V_{e\ell} \frac{m^2_{\nu_\ell}}{m^2_W}\right|^2$$

  - essentially background-free for further new physics
    - no theoretical background uncertainties

Charged Lepton Flavour Violation

- **Beyond-the-Standard Model Physics** can cause CLFV
  - e.g. **massive neutrinos**
    - but CLFV GIM-suppressed to **less than O(10^{-50})**
    - essentially background-free for further new physics
  - without such cancellations, rates can be much larger
  - highly-sensitive probes to BSM physics
  - multiple, complementary channels
    - e.g. for muons:
      - $\mu^+ \rightarrow e^- + \gamma$
      - $\mu^+ \rightarrow e^- + e^+ + e^-$
      - $\mu^- + N \rightarrow e^- + N$

Charged Lepton Flavour Violation

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    - e.g. for muons:
      - $\mu^+ \rightarrow e^- + \gamma$
      - $\mu^+ \rightarrow e^- + e^+ + e^-$
      - $\mu^- + N \rightarrow e^- + N$ (muon-to-electron conversion)

Muon-to-Electron Conversion

- Search for the process

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

muonic atom mono-energetic electron

$(E_e \leq 105 \text{ MeV})$

- Time available after formation of muonic atom:
  up to about **1 microsecond** (Z-dependent)

- $E_e = m_\mu$

  $- E_{\text{bind}} - E_{\text{recoil}}$

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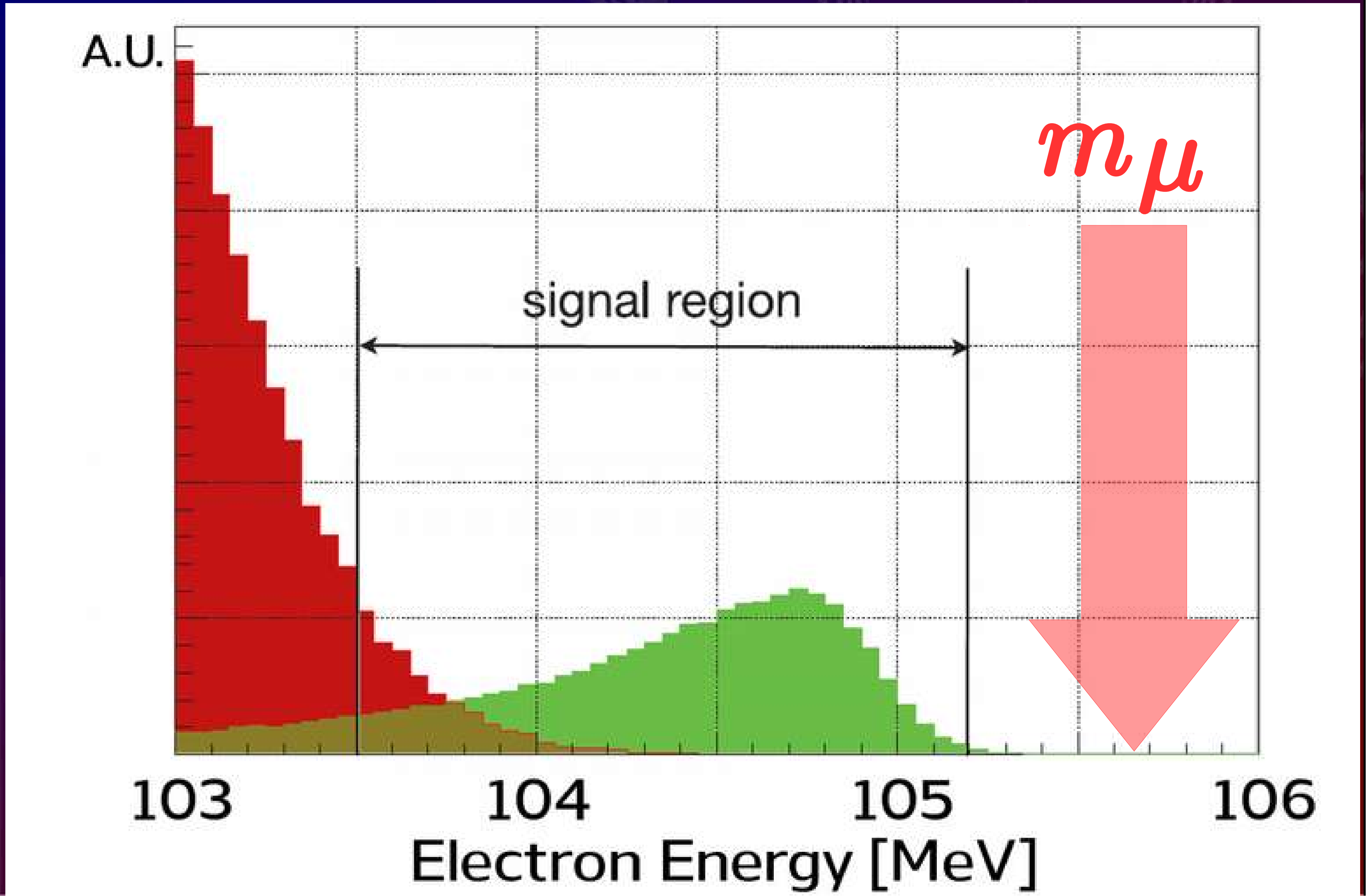
  $- E_{\text{bind}} - E_{\text{recoil}}$

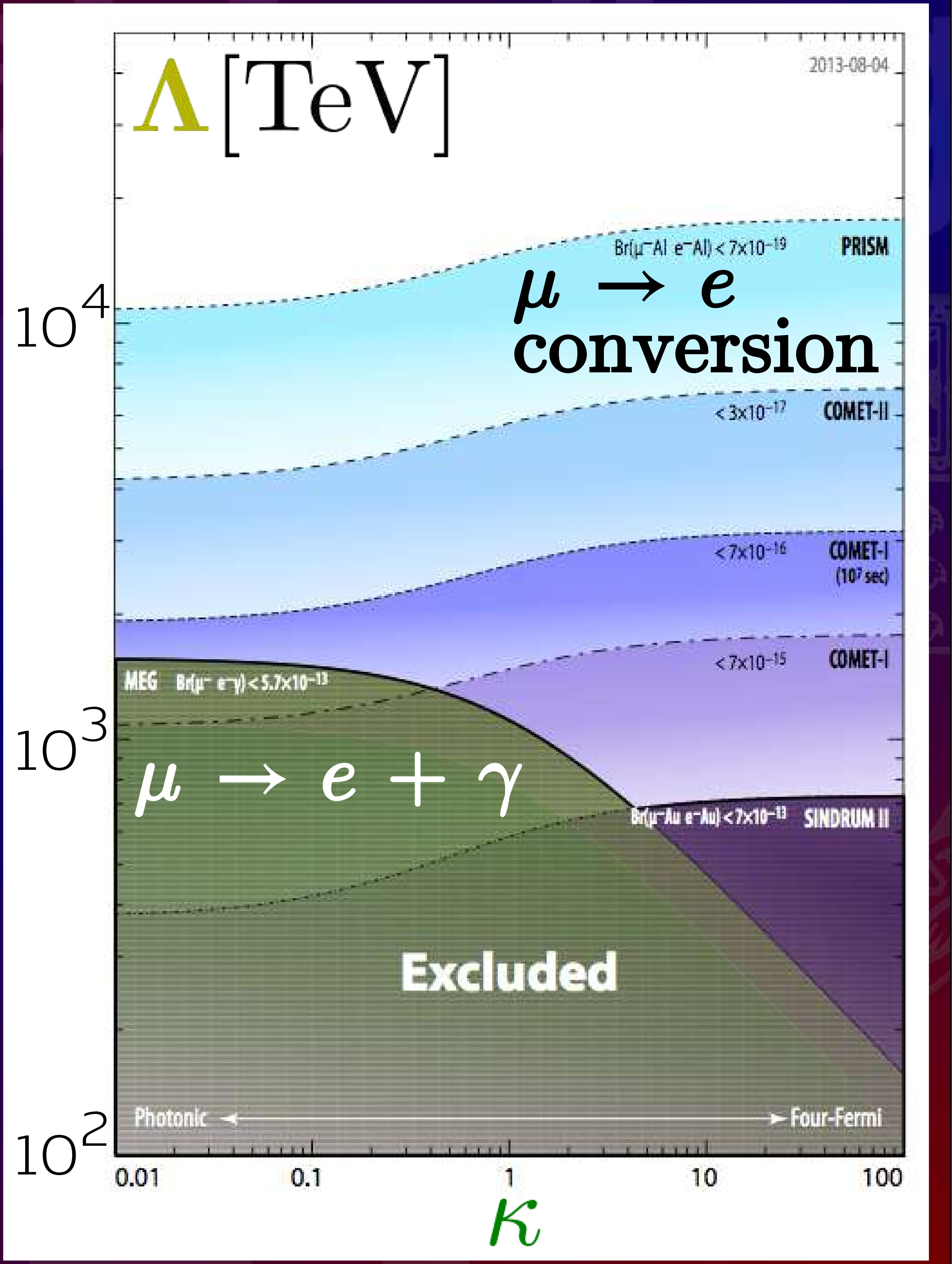
- **observed signal is not a delta-function,** because of detector effects



Muon-to-Electron Conversion

- Complementary to $\mu \rightarrow e + \gamma$
- sensitive to different BSM physics

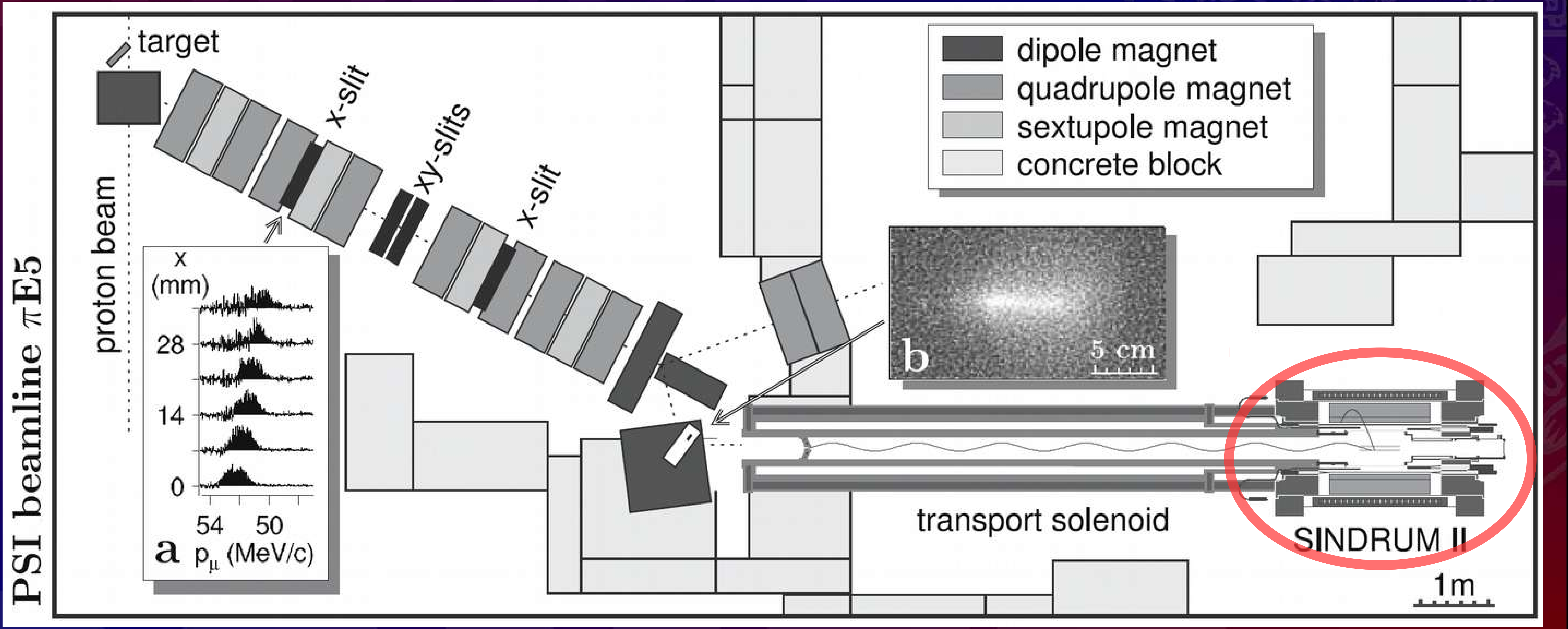
$$\mathcal{L} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_R\sigma^{\mu\nu}e_L F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_L\gamma^\mu e_L)(\bar{q}_L\gamma^\mu q_L)$$



de Gouvea

The Previous Generation: SINDRUM-II

- Data taking at PSI in 2000
- **Continuous beam** (10^7 to 10^8 muons per second)
- Muon-by-muon measurement
- Target material: **Gold (upper limit 7×10^{-13}** at 90% C.L.)



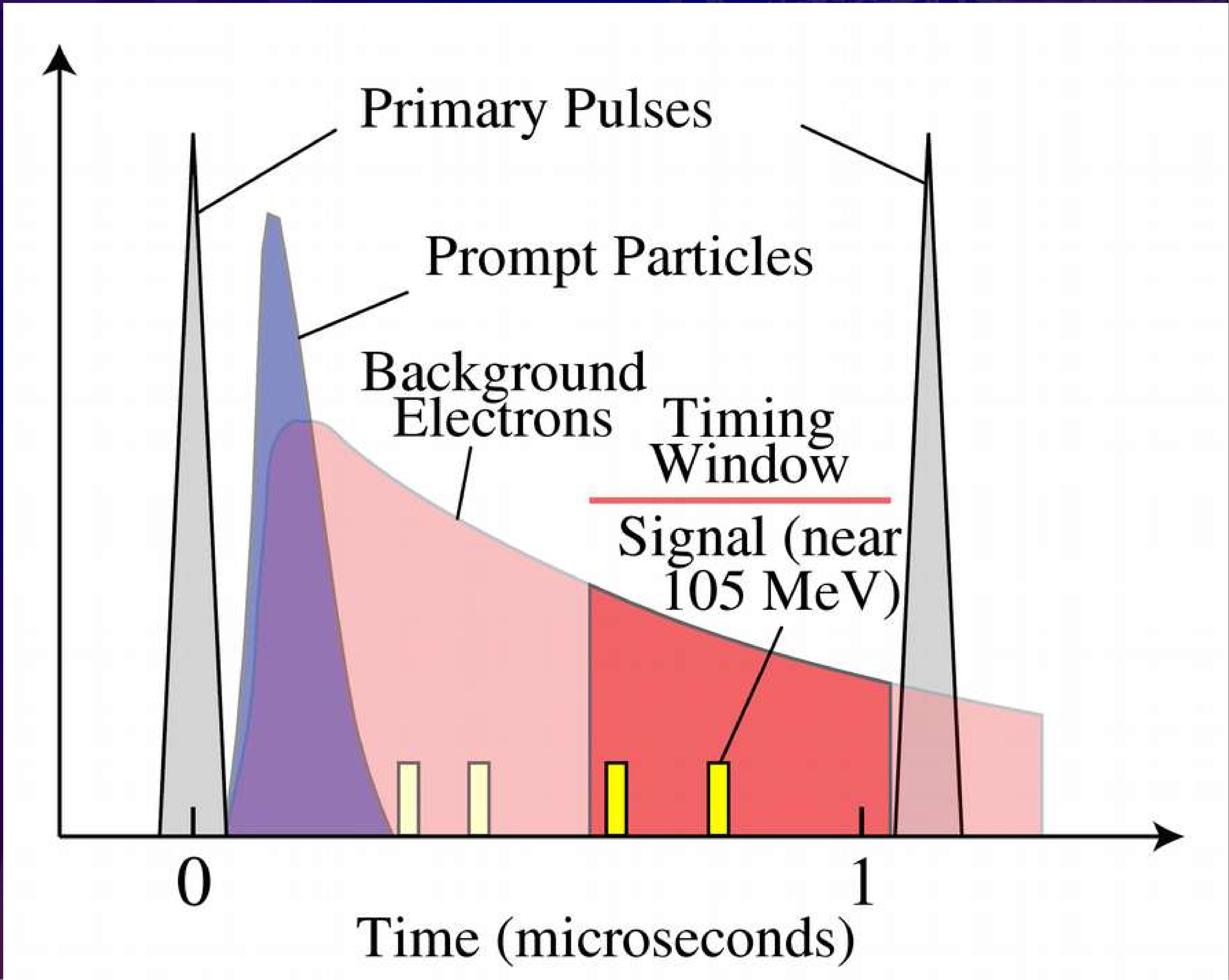
Eur. Phys. J. C 47, 337–346 (2006)

The Next Generation

- Large prompt background when pions and muons are produced
- Signal muon-to-electron conversion occurs with a delay

  ⇒ **Pulse primary beam** to separate prompt backgrounds

  - O(1 μs) between pulses
  - Muonic atom lifetimes vary due to nuclear muon capture
    - Al: 880 ns
    - Ti: 330 ns
    - Au: 73 ns
- New designs contain **built-in background rejection**

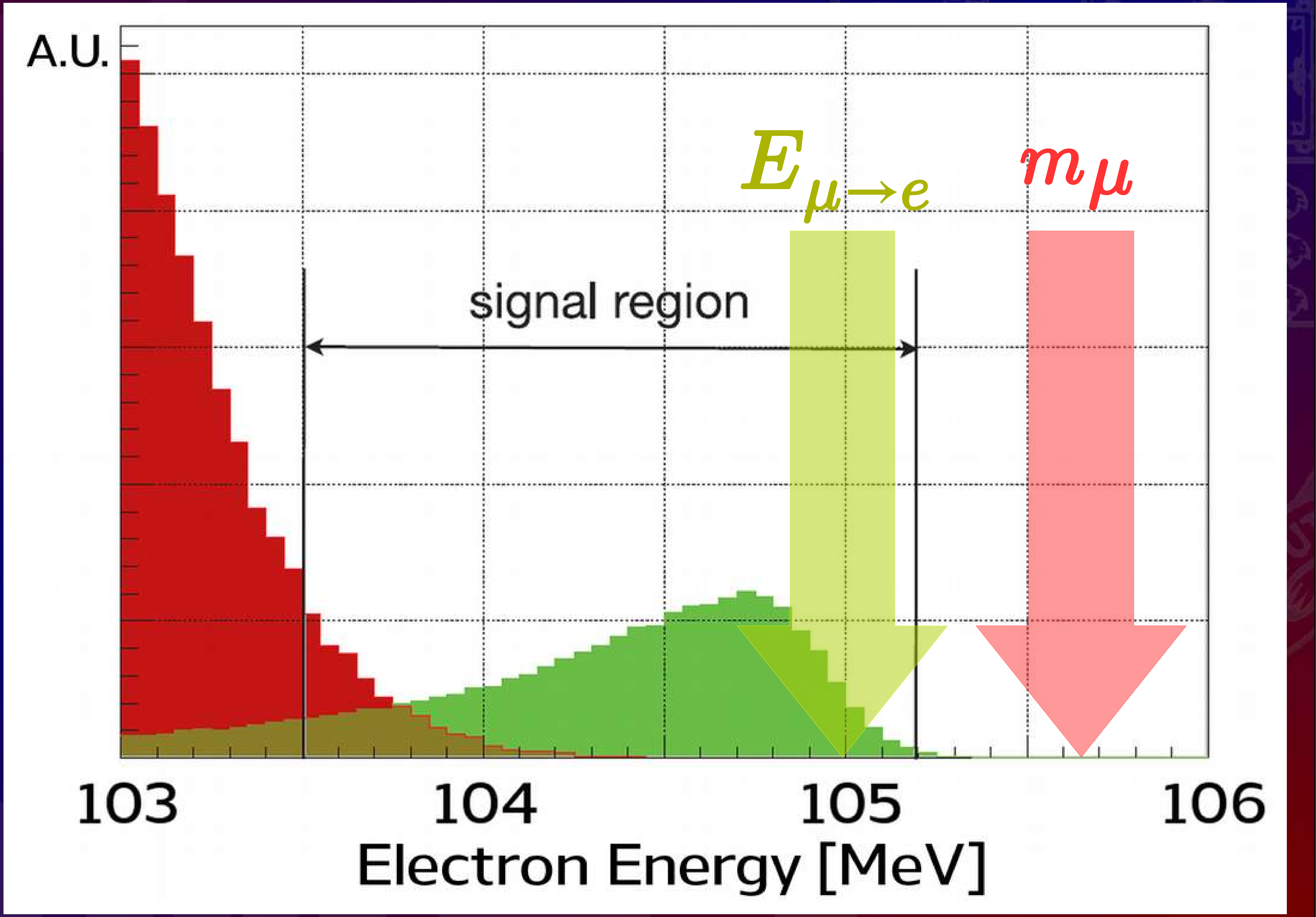


Muon-to-Electron Conversion on Aluminium

$$\mu^- + {}^{27}_{13}\mathrm{Al} \rightarrow e^- + {}^{27}_{13}\mathrm{Al}$$

Single monoenergetic **electron** with $E_e = 104.97$ MeV

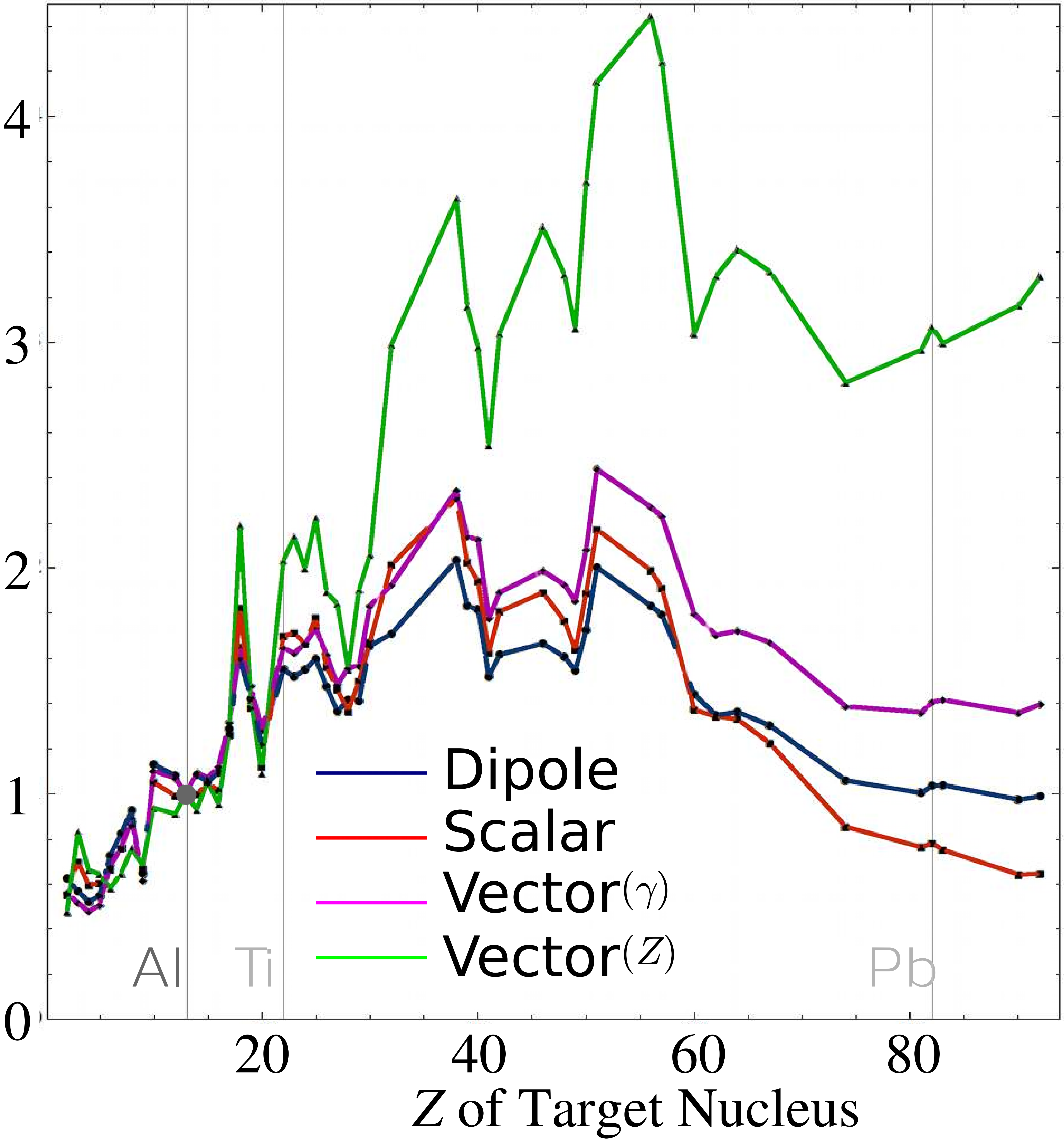
- Ionisation energy loss, straggling
- Resolution effects



Relative dependences of the muon-to-electron conversion branching ratio on the target nucleus

for different models of New Physics interactions

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



Relative dependences of the muon-to-electron conversion branching ratio on the target nucleus

for different models of New Physics interactions

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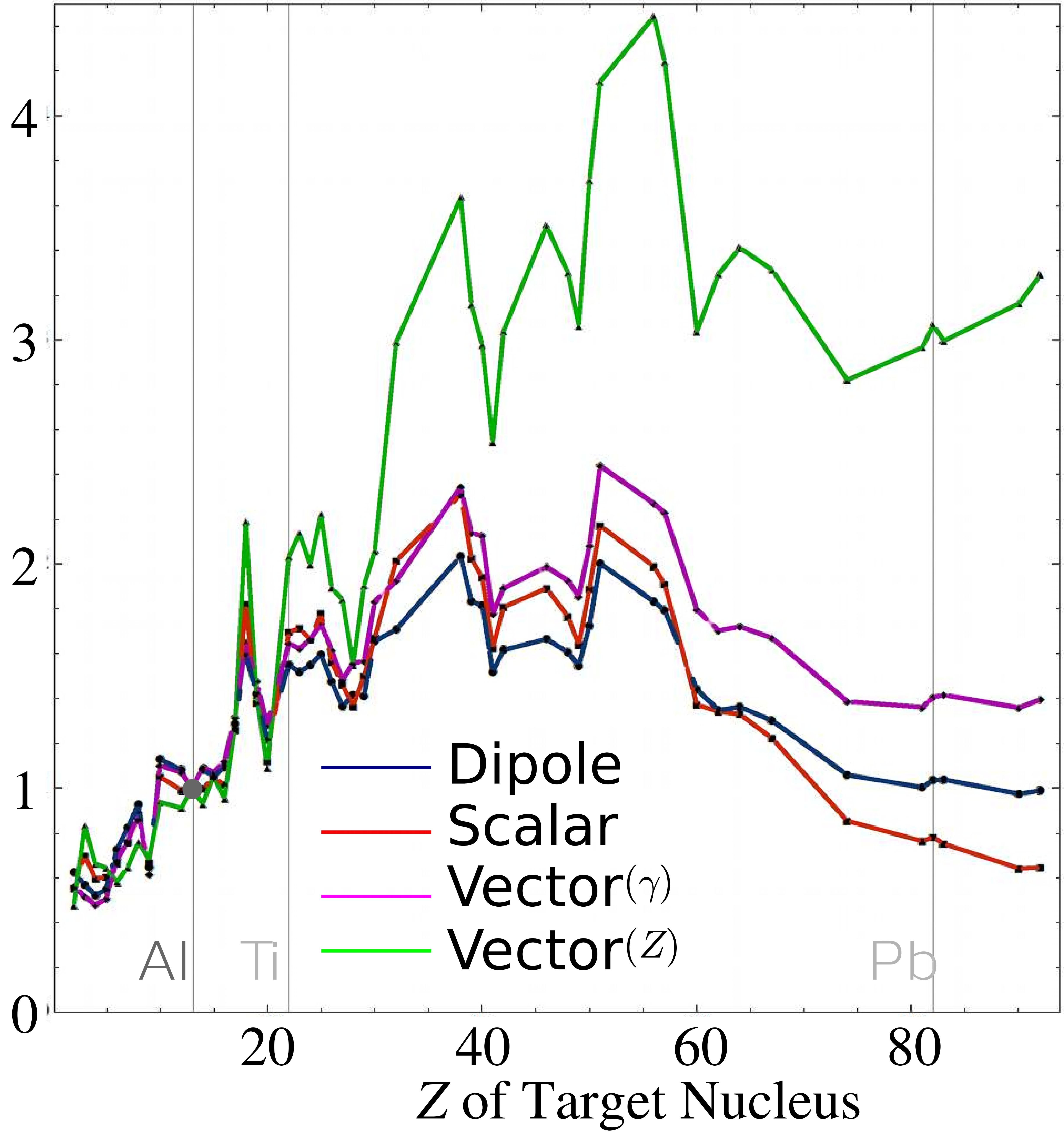
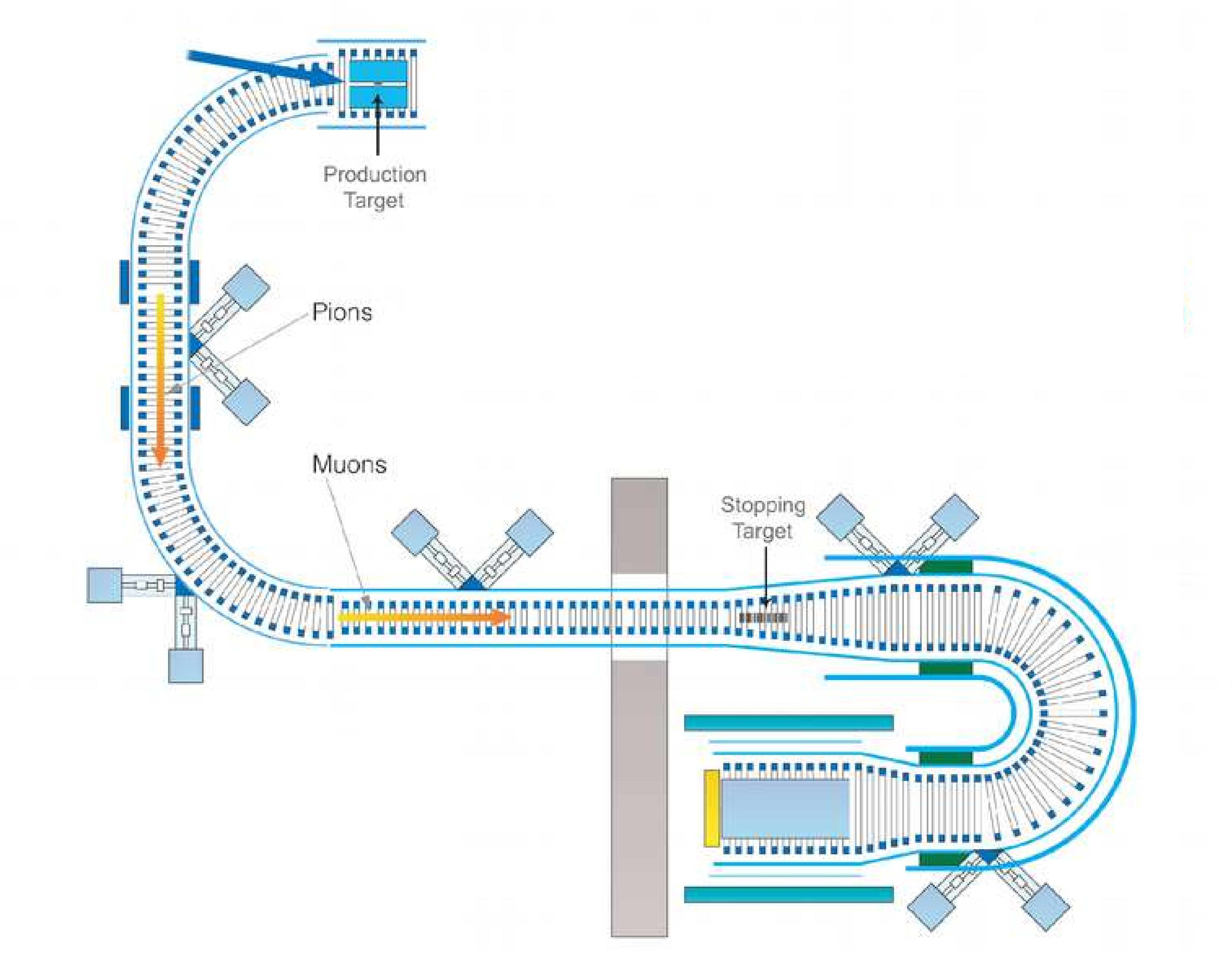
($\mu \to e\gamma$ is sensitive to the **Dipole** interaction)



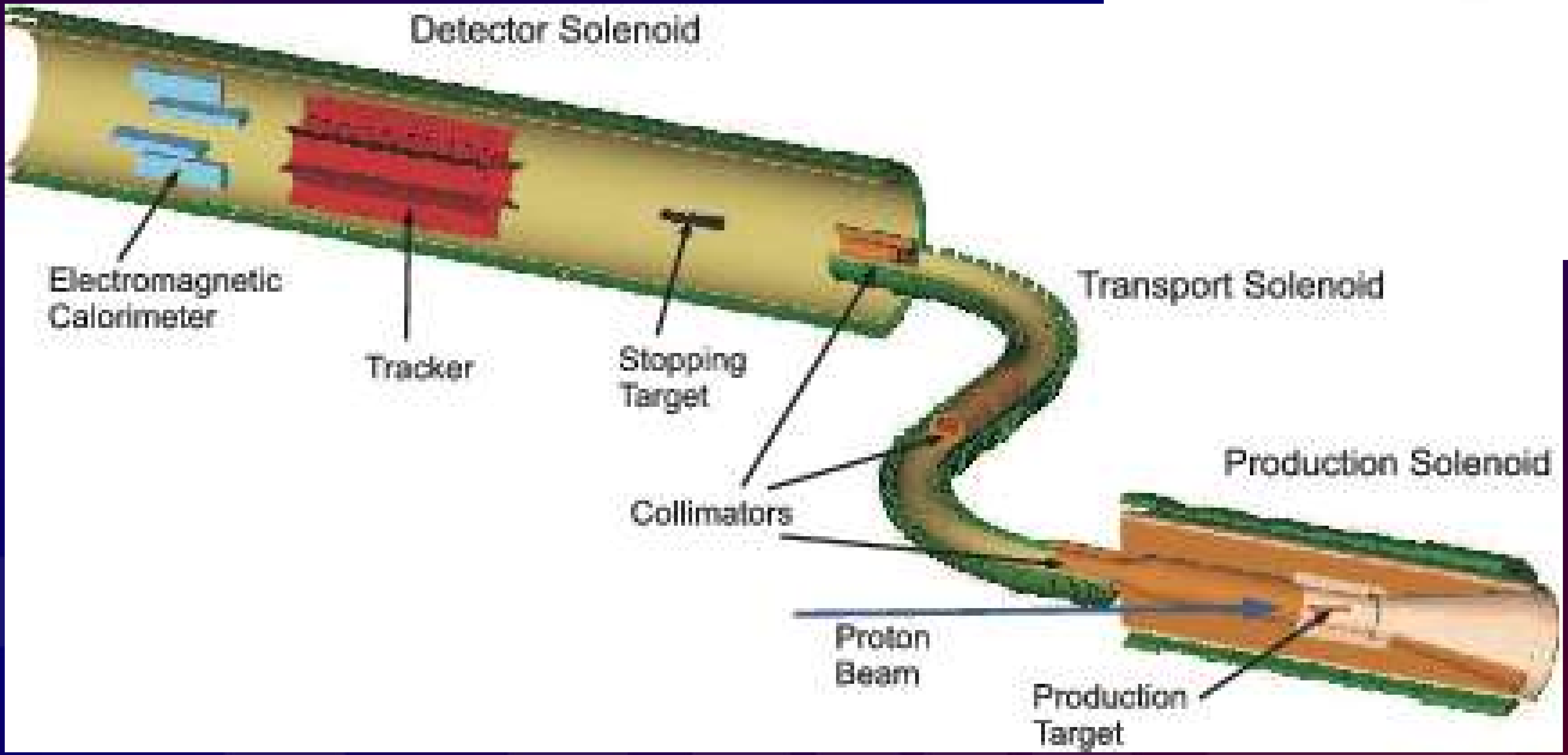
The Next Generation

COMET
at J-PARC



Original concept:
R. Djilkibaev &
V. Lobashev (1989)

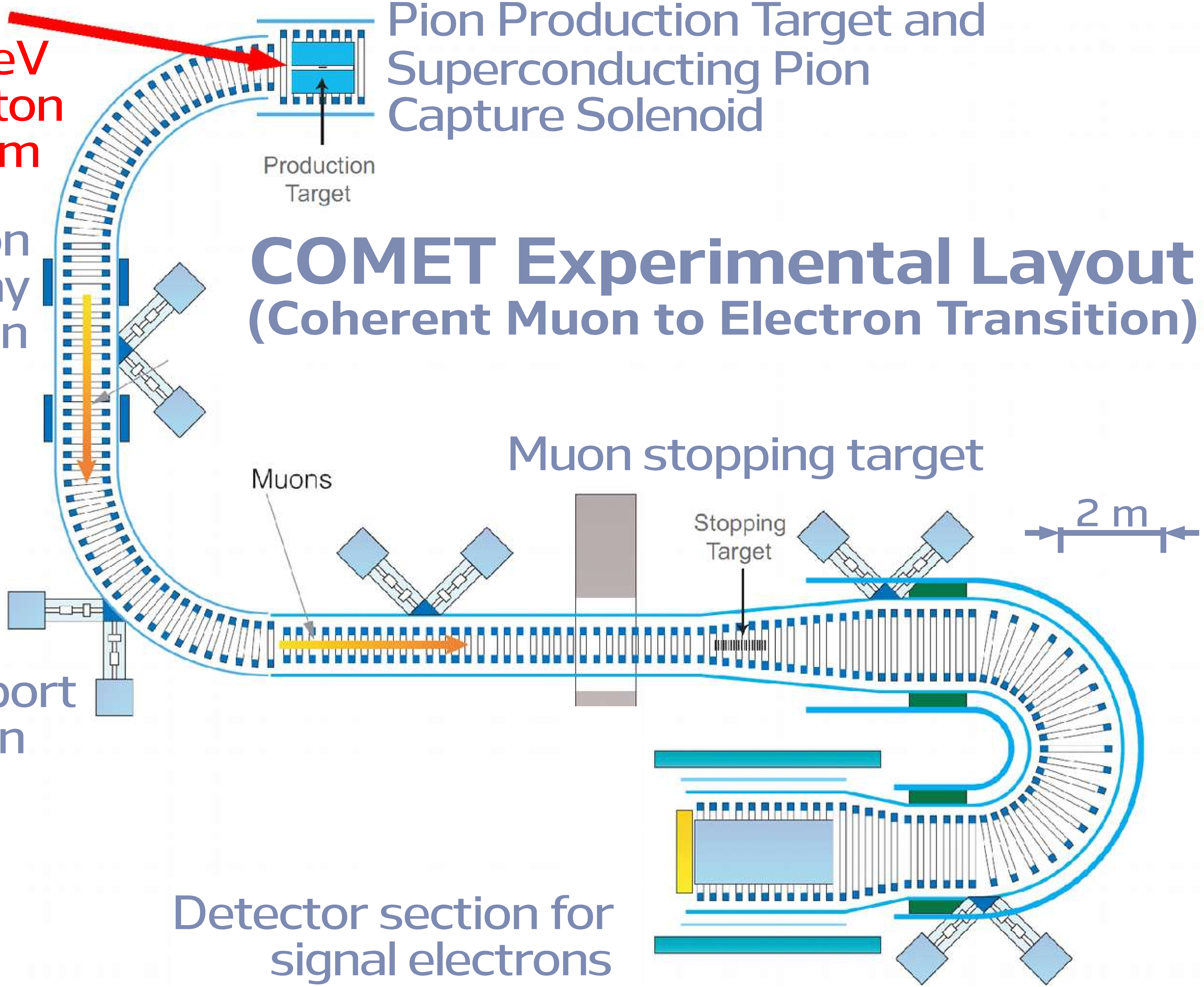
Mu2E
at Fermilab



c.f. Mu2E talk
Tuesday 25th
(D. Hitlin)

COMET Experimental Layout

(Coherent Muon to Electron Transition)



8 GeV Proton Beam

Pion Production Target and Superconducting Pion Capture Solenoid

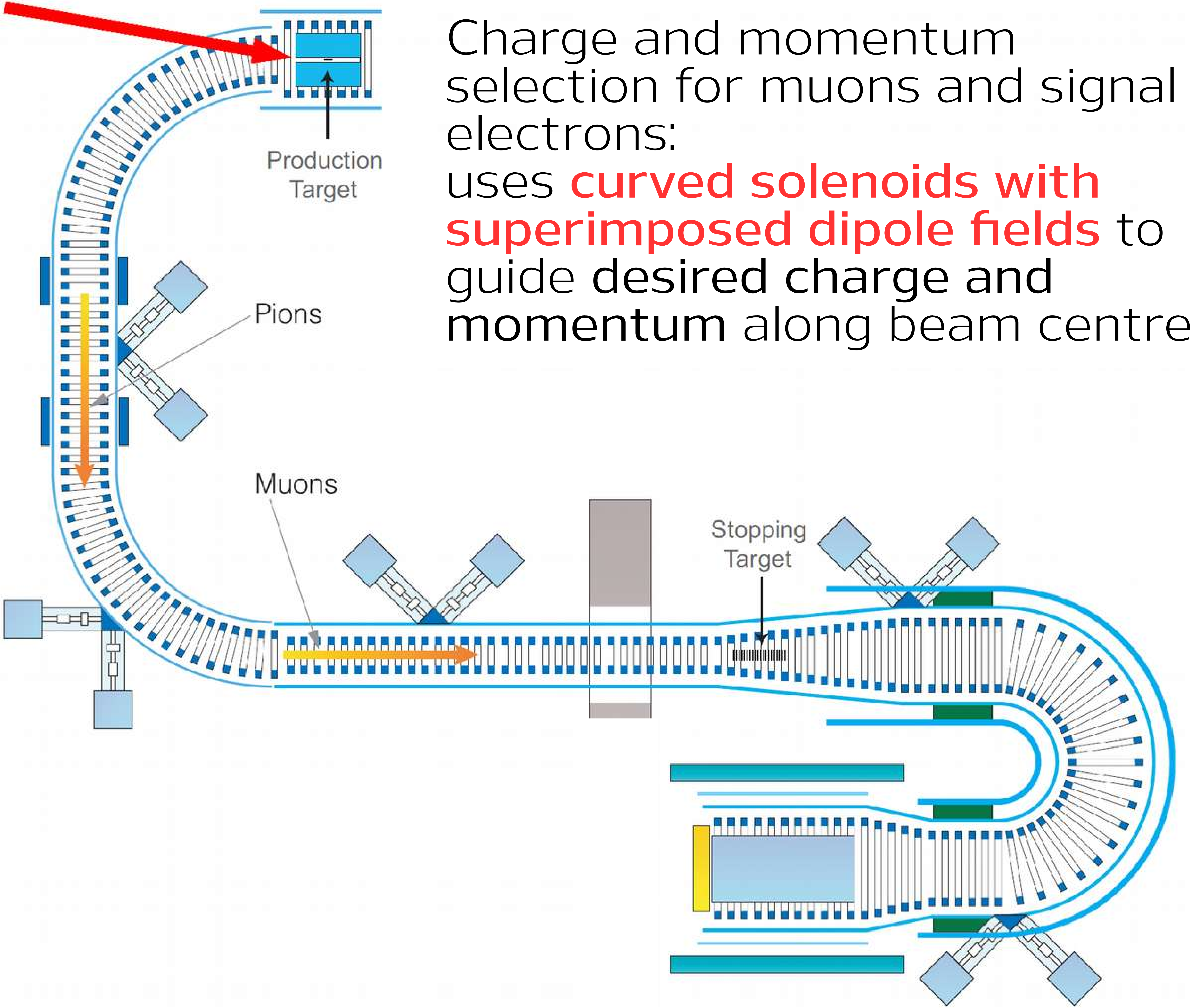
Pion decay section

Muon stopping target

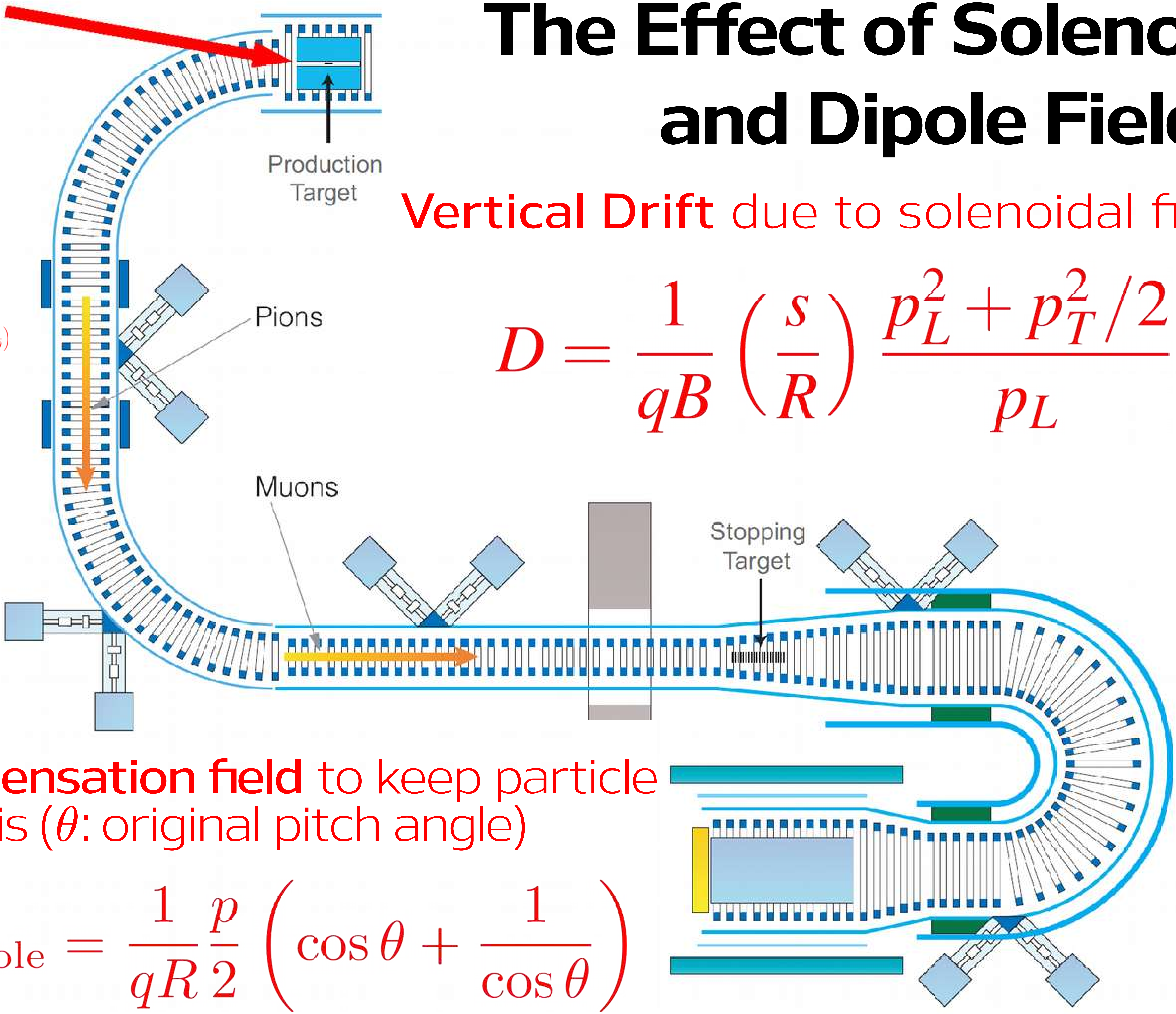
Muon transport section

Detector section for signal electrons

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



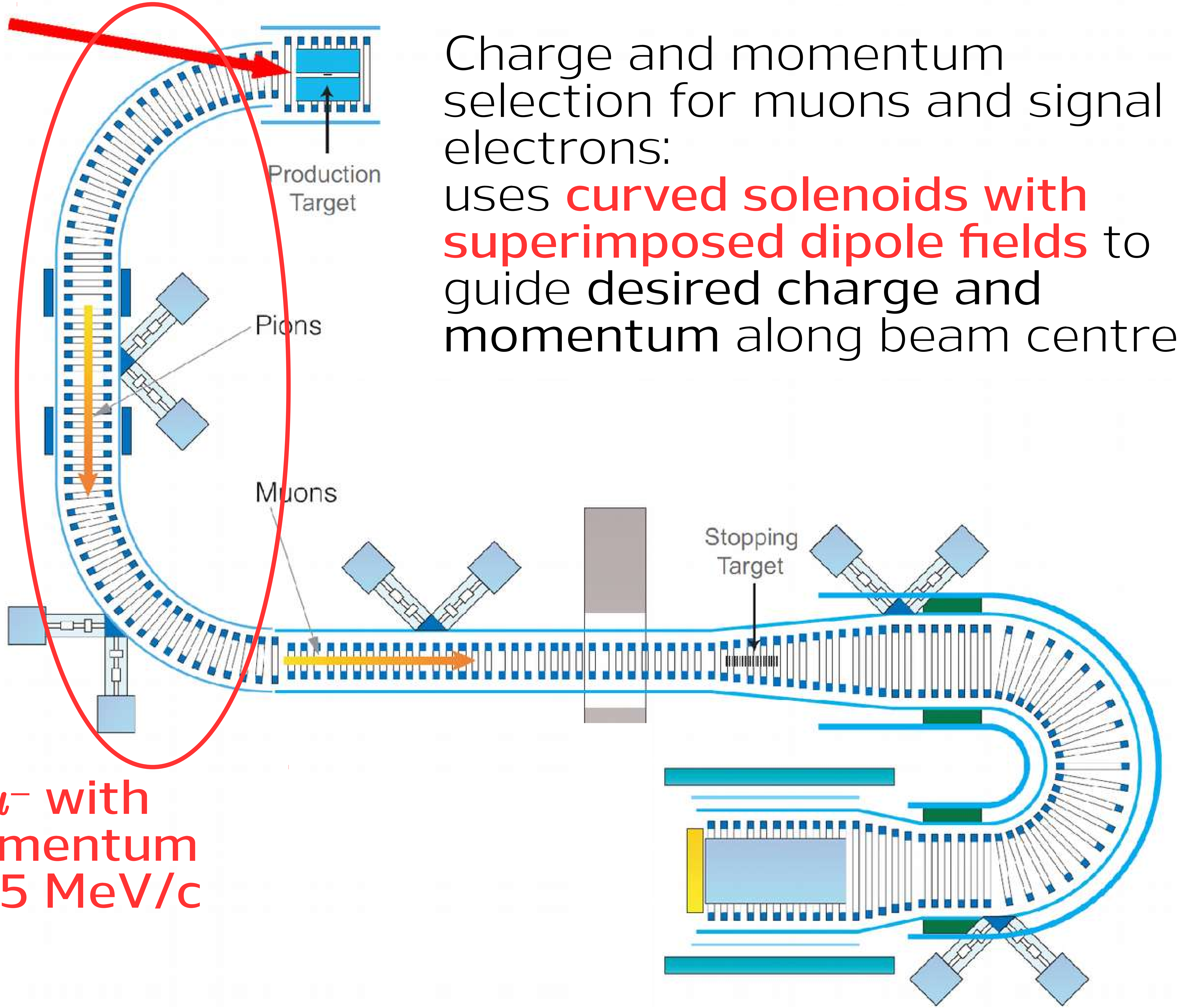
$B_{\text{dipole}} = \frac{1}{qR}\frac{p}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$

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)

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



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

μ^- with momentum < 75 MeV/c

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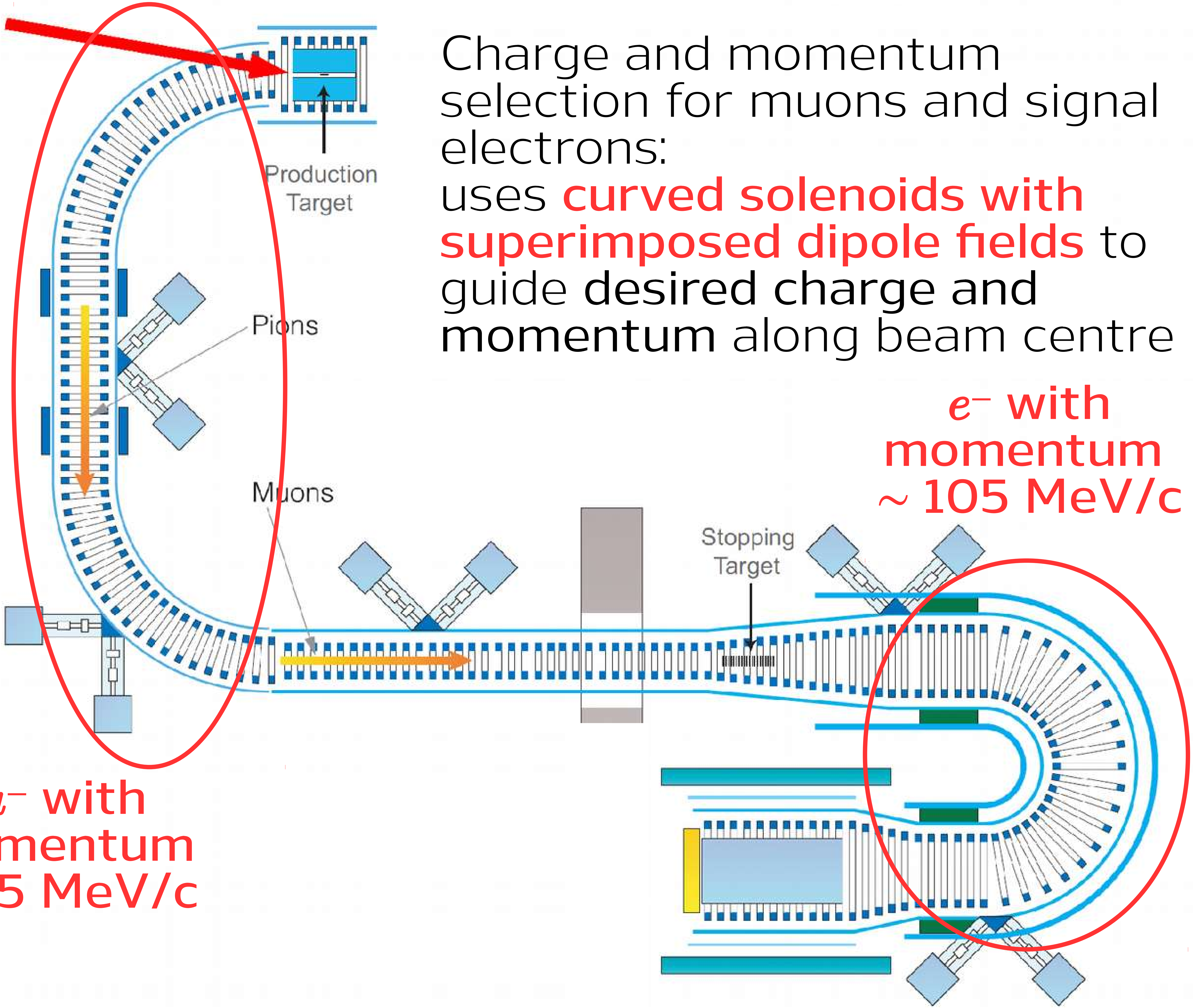
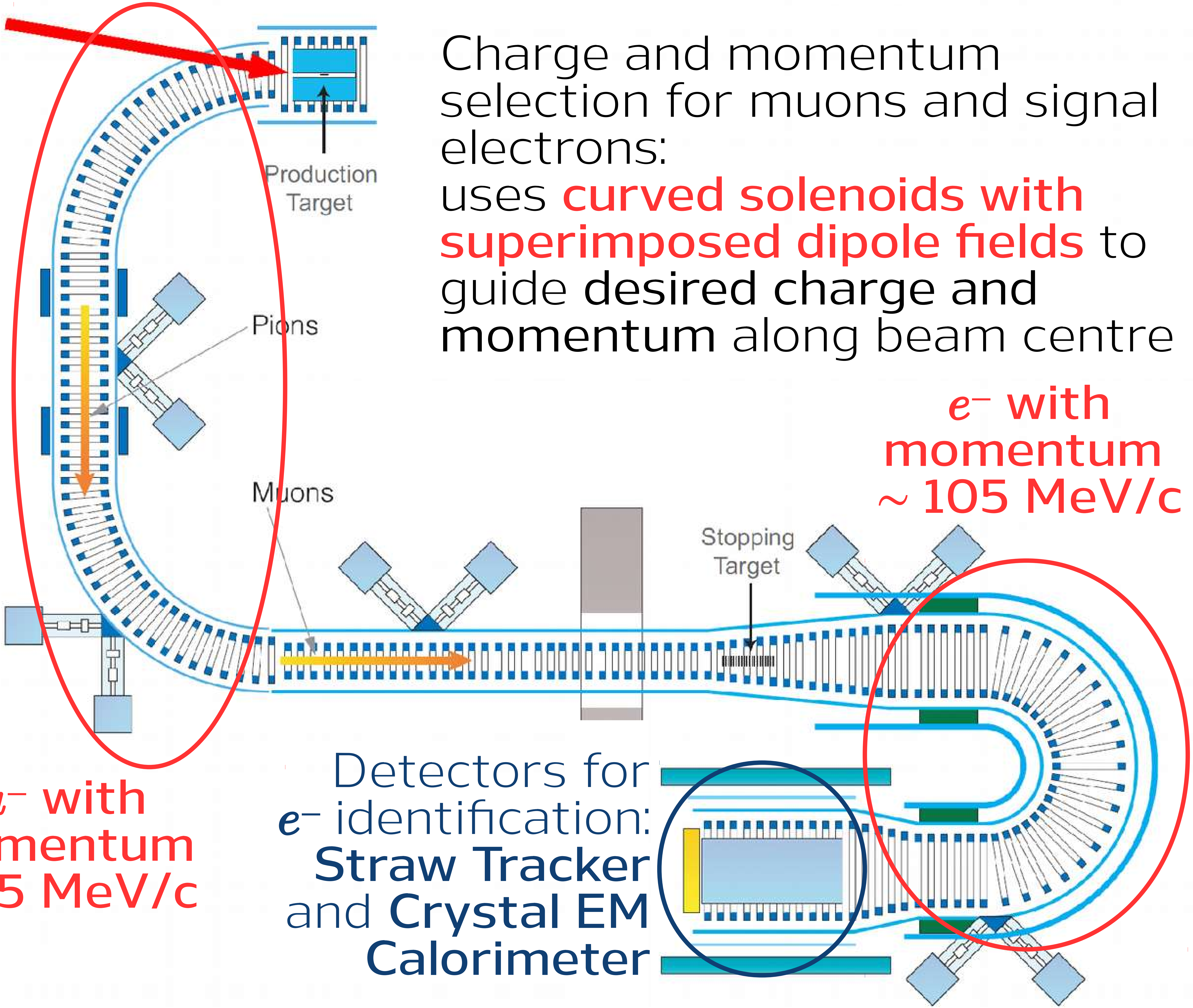


e^- with momentum $\sim$ 105 MeV/c

μ^- with momentum $<$ 75 MeV/c



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

e^- with momentum ~ 105 MeV/c

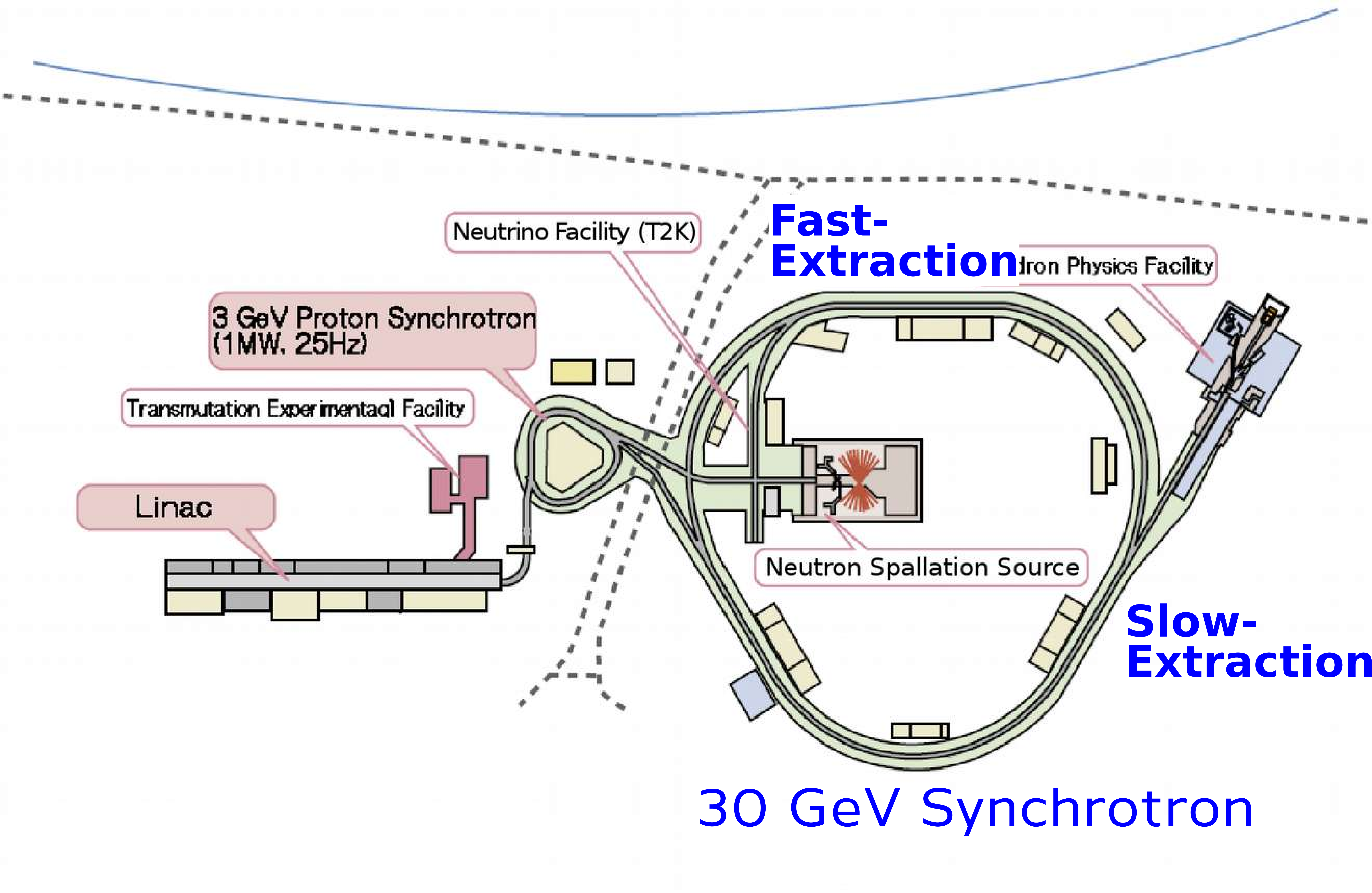
μ^- with momentum < 75 MeV/c

Detectors for
e^- identification:
Straw Tracker
and **Crystal EM Calorimeter**

J-PARC

J-PARC

J-PARC


Neutrino Facility (T2K)
Fast-Extraction
dron Physics Facility
3 GeV Proton Synchrotron (1MW, 25Hz)
Transmutation Experimentaql Facility
Linac
Neutron Spallation Source
Slow-Extraction
30 GeV Synchrotron

Beam Extinction

- Inter-bunch beam extinction critical to suppress prompt backgrounds
  - relative extinction factor of **3×10^{-11}** required
  - measurements with existing 30 GeV synchrotron indicate that this is achievable
    - must be verified for 8 GeV slow extraction

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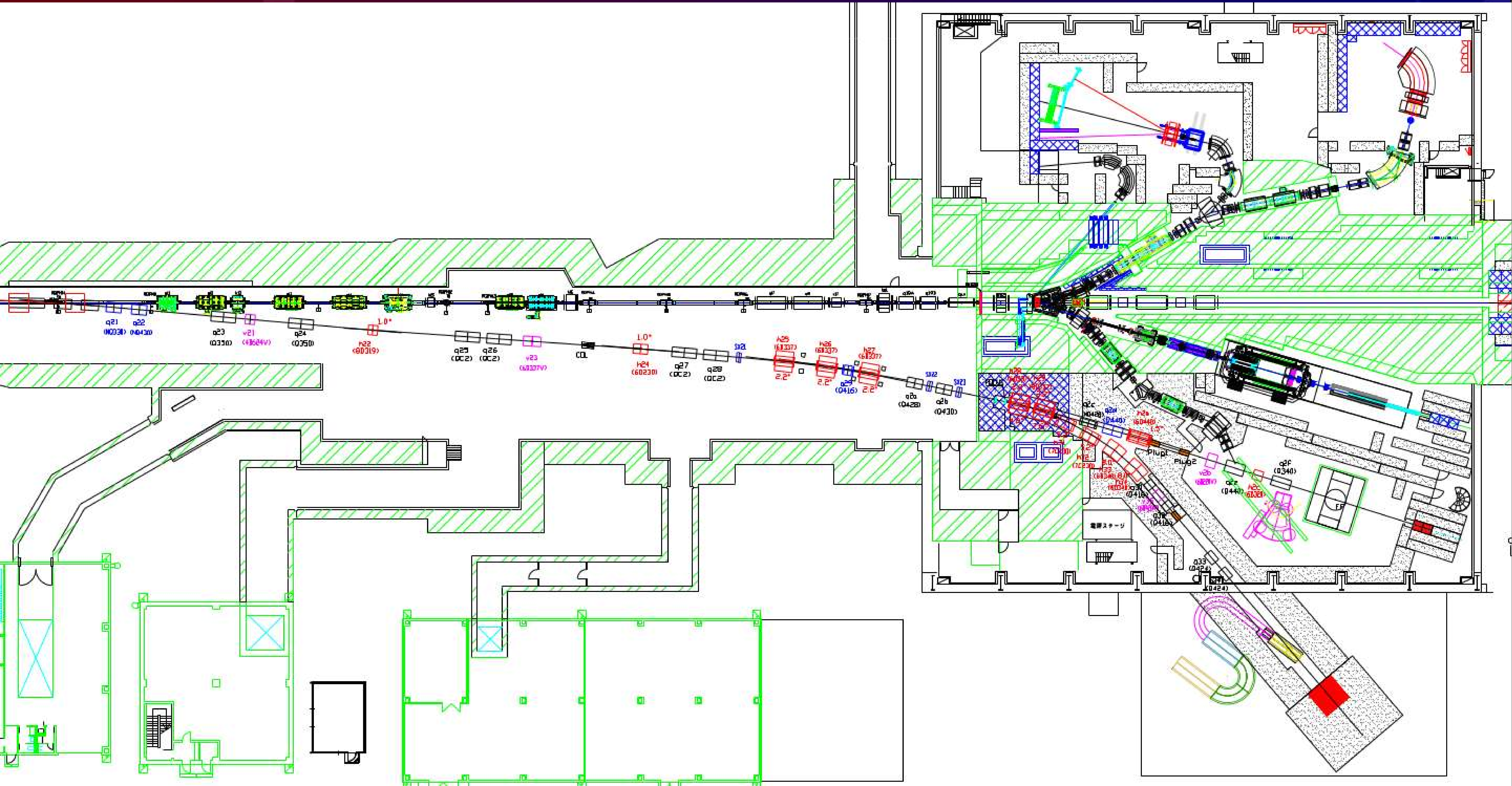
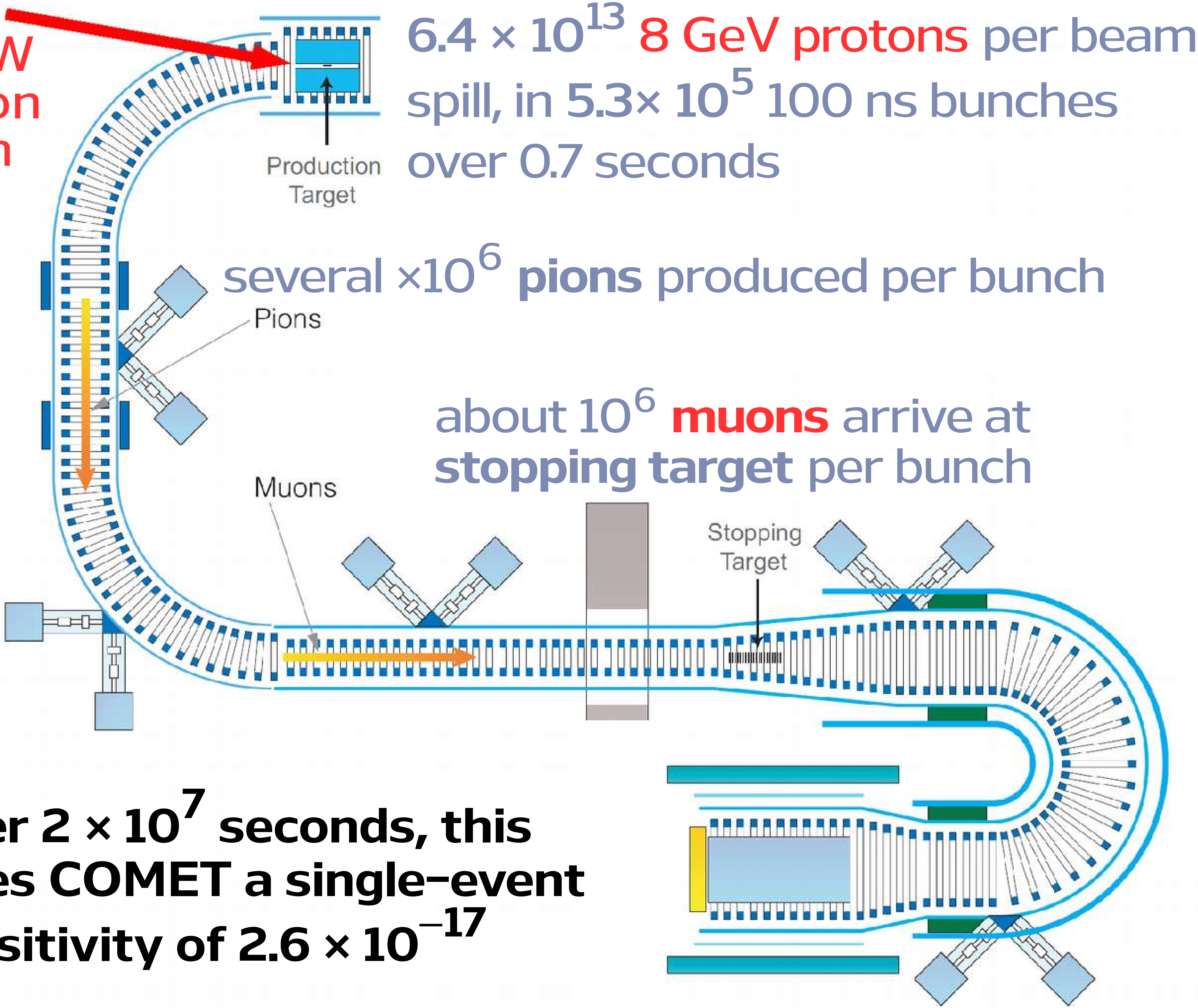
INSTR2014, Budker Institute Novosibirsk February 2014

J-PARC Hadron Hall Beam Lines





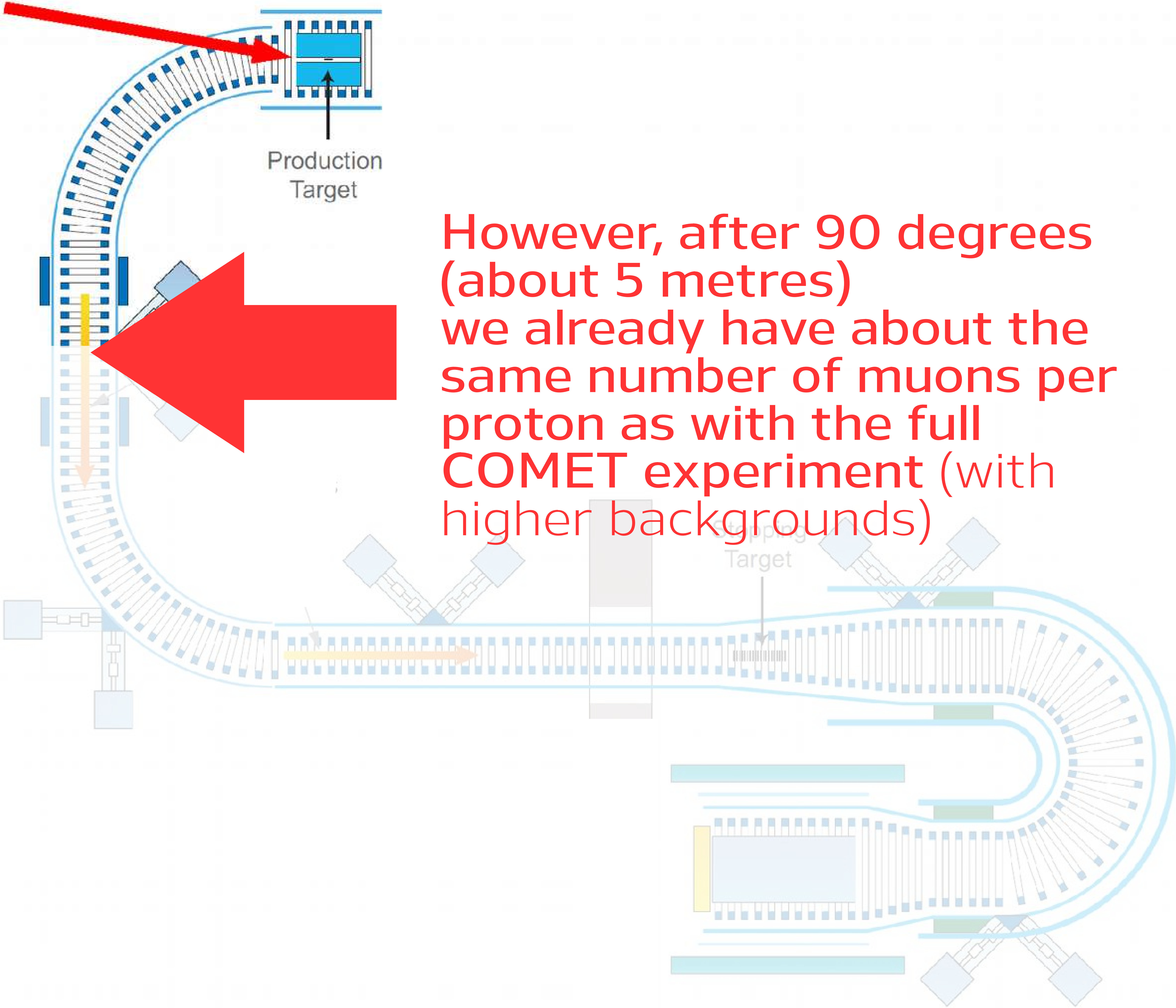
56 kW proton beam

6.4×10^{13} 8 GeV protons per beam spill, in 5.3×10^{5} 100 ns bunches over 0.7 seconds

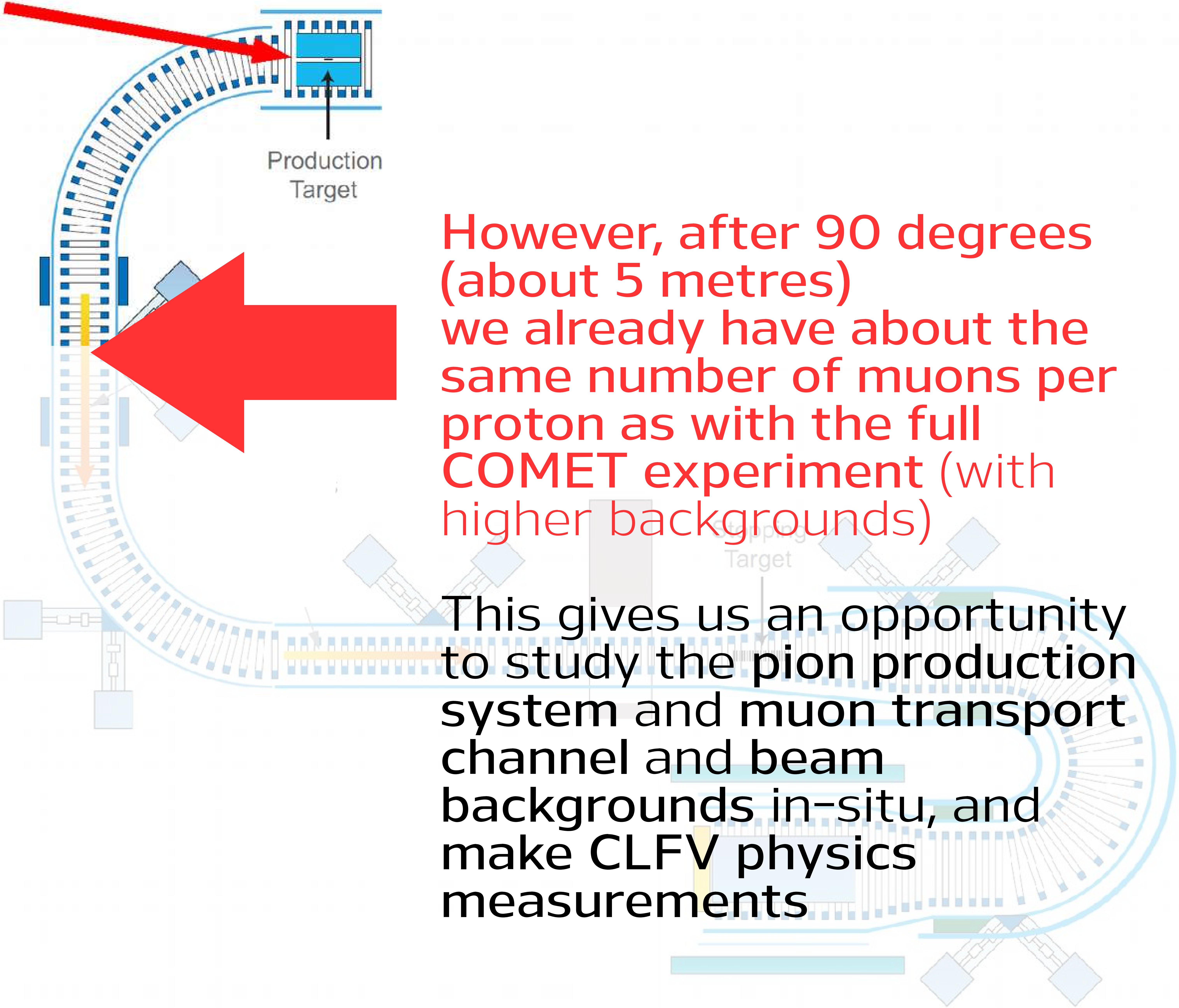
several $\times 10^{6}$ **pions** produced per bunch

about 10^{6} **muons** arrive at **stopping target** per bunch

Over 2×10^{7} seconds, this gives COMET a single-event sensitivity of 2.6×10^{-17}



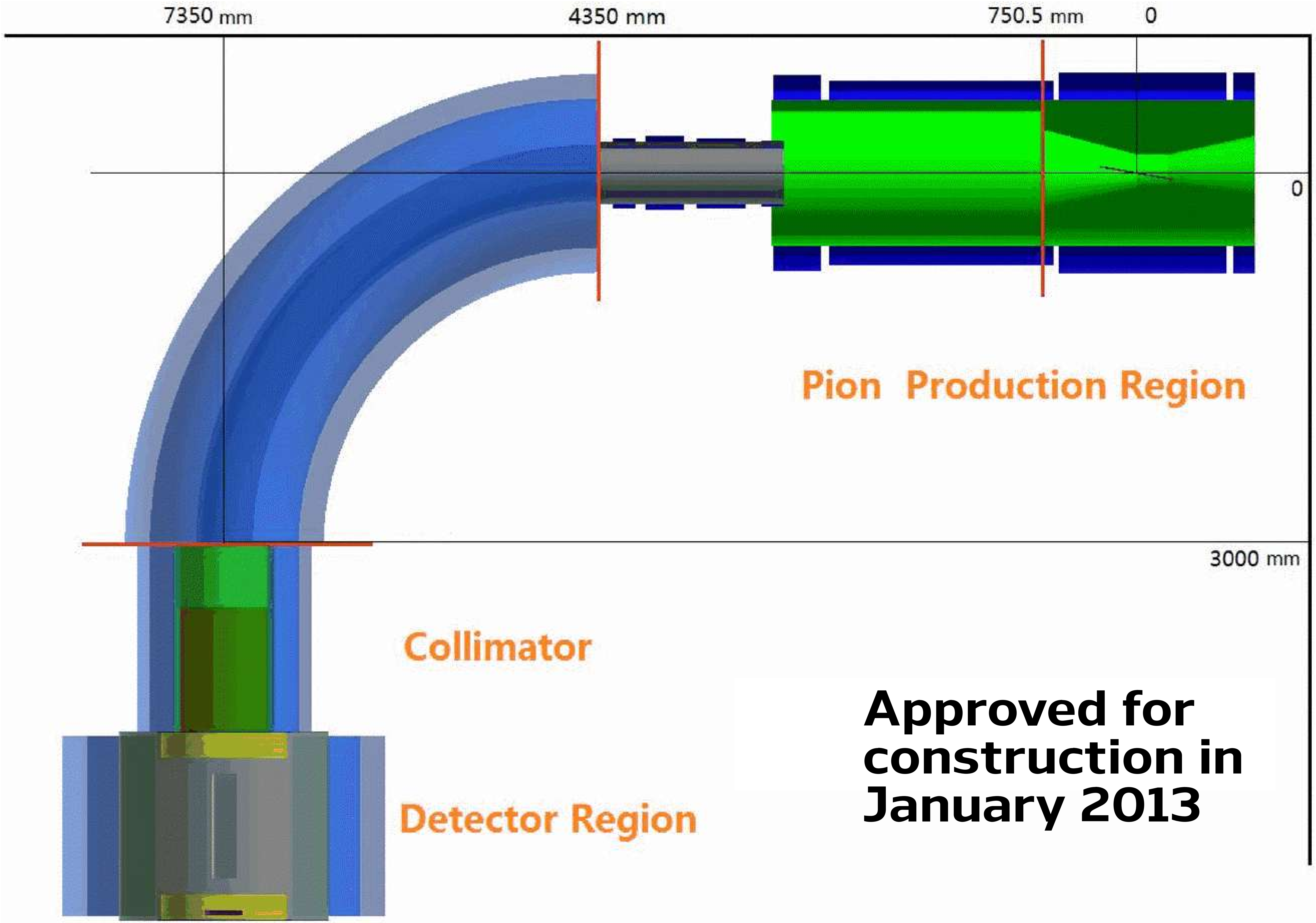
However, after 90 degrees (about 5 metres) we already have about the same number of muons per proton as with the full **COMET experiment** (with higher backgrounds)



However, after 90 degrees (about 5 metres) we already have about the same number of muons per proton as with the full COMET experiment (with higher backgrounds)

This gives us an opportunity to study the **pion production system** and **muon transport channel** and **beam backgrounds in-situ, and make CLFV physics measurements**

COMET Phase-I



Approved for construction in January 2013

COMET Phase-I

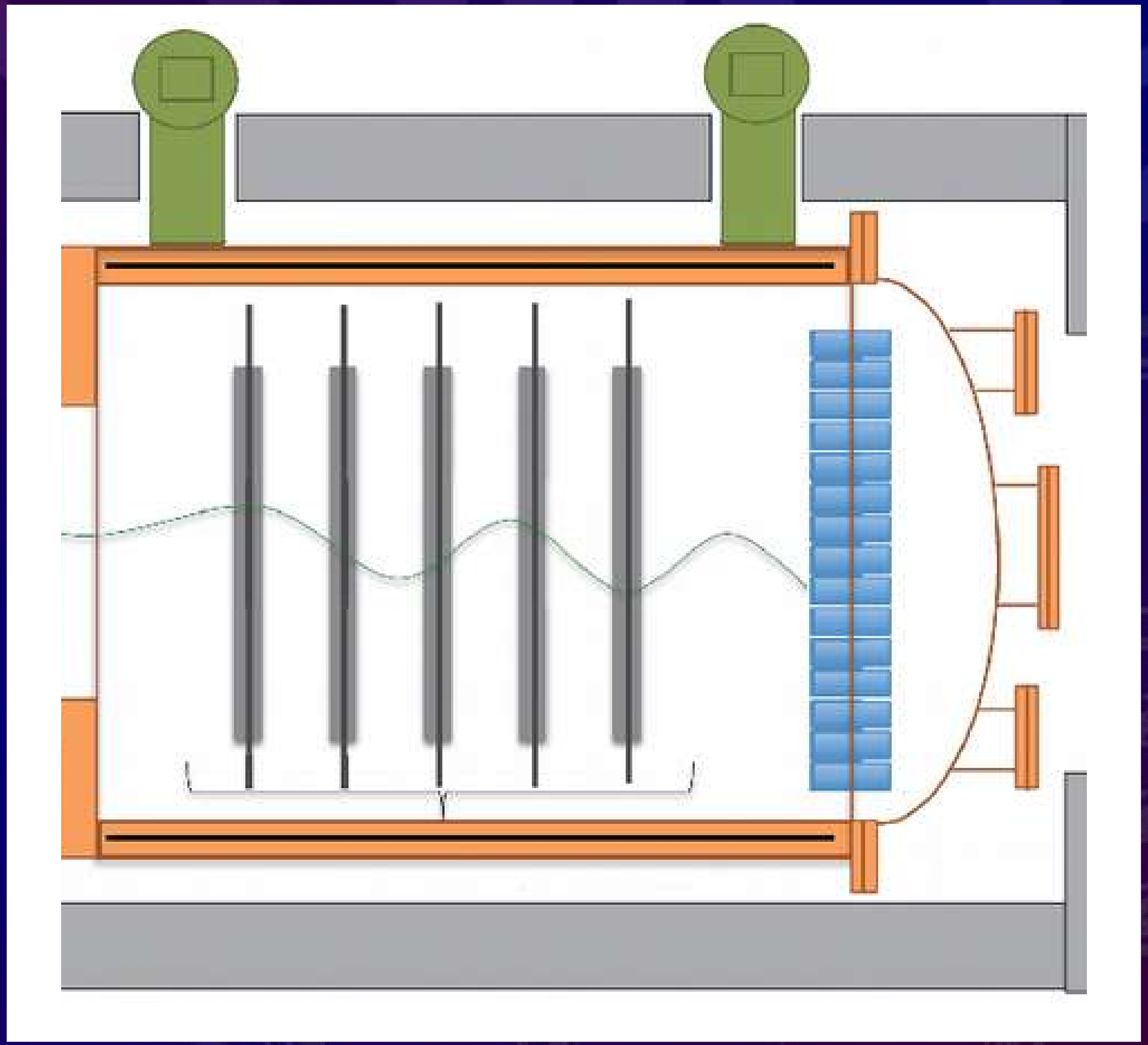
- **Muon-to-electron conversion** at 100 times the sensitivity of SINDRUM-II
- Can also search for:
  - $\mu^- + N(A, Z) \rightarrow e^+ + N'(A, Z\text{–}2)$
  - $\mu^- + e^- + N \rightarrow e^- + e^- + N$

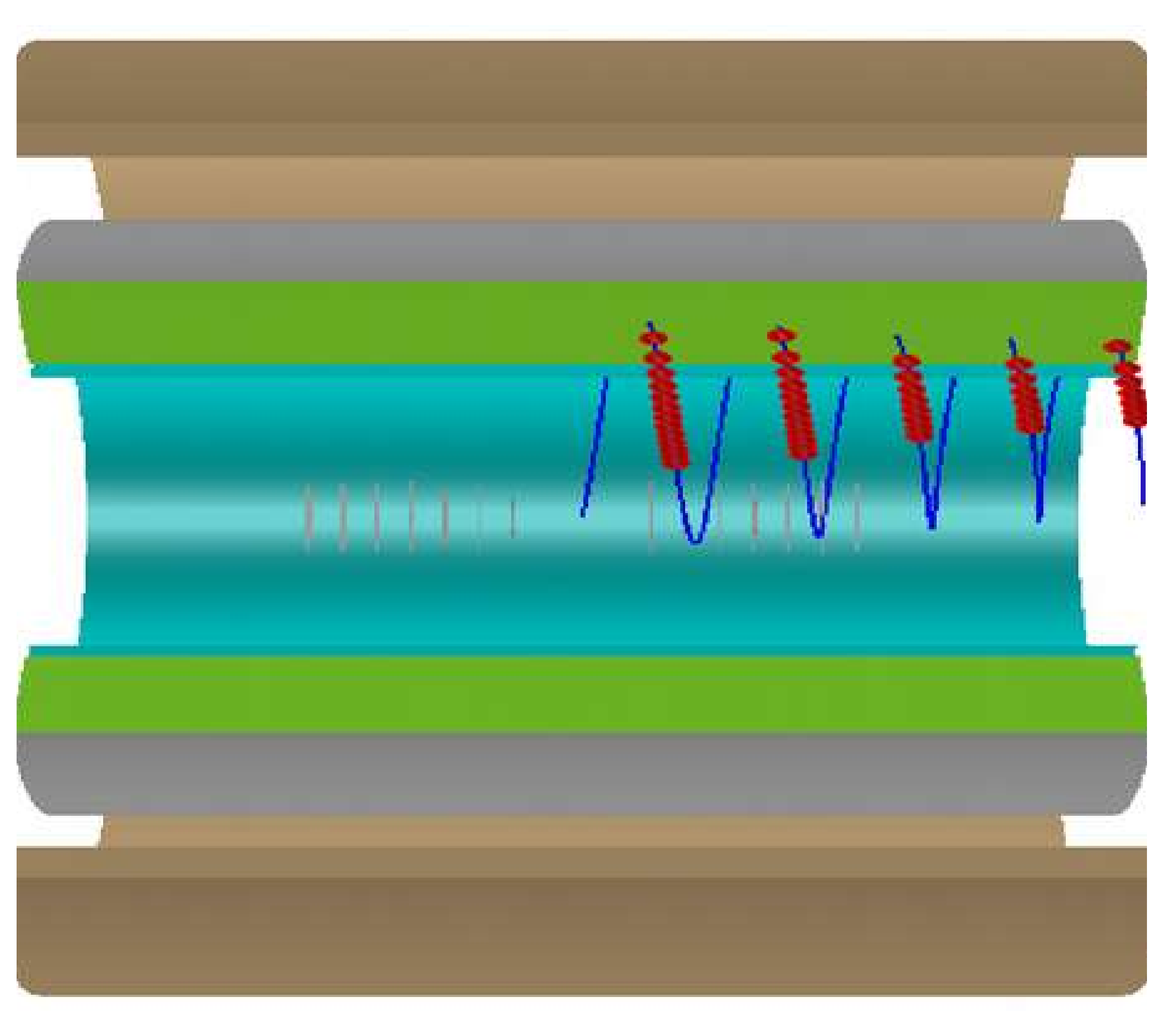
  etc
- Running at about **5% of the intensity of Phase-II**
- Allows us to **study the beam line and backgrounds in-situ** to prepare for Phase-II

COMET Phase-I Detector Systems

StrEcal (Straw-Tracker & ECAL)

- for **beam line studies and particle flux** measurements
- “COMET Phase-II-style” detector
  - Comprehensive PID and momentum & energy measurements





CyDet (Cylindrical Drift Chamber & Triggering Hodoscopes)

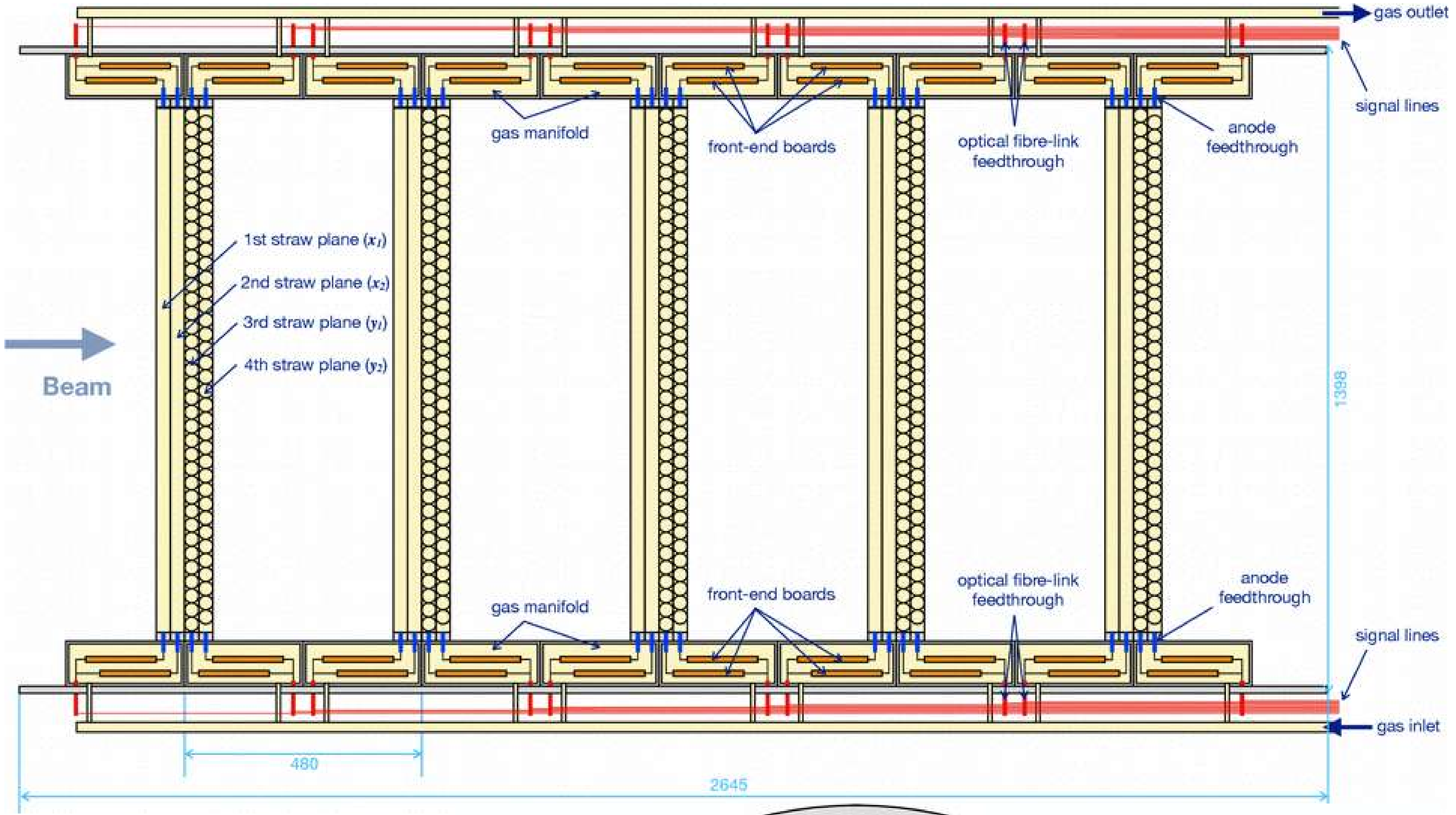
- for **lepton flavour violation** measurements
- **“SINDRUM II-style”** detector
- Geometric acceptance only for particles from μ-stopping target with $p > 75$ MeV/c

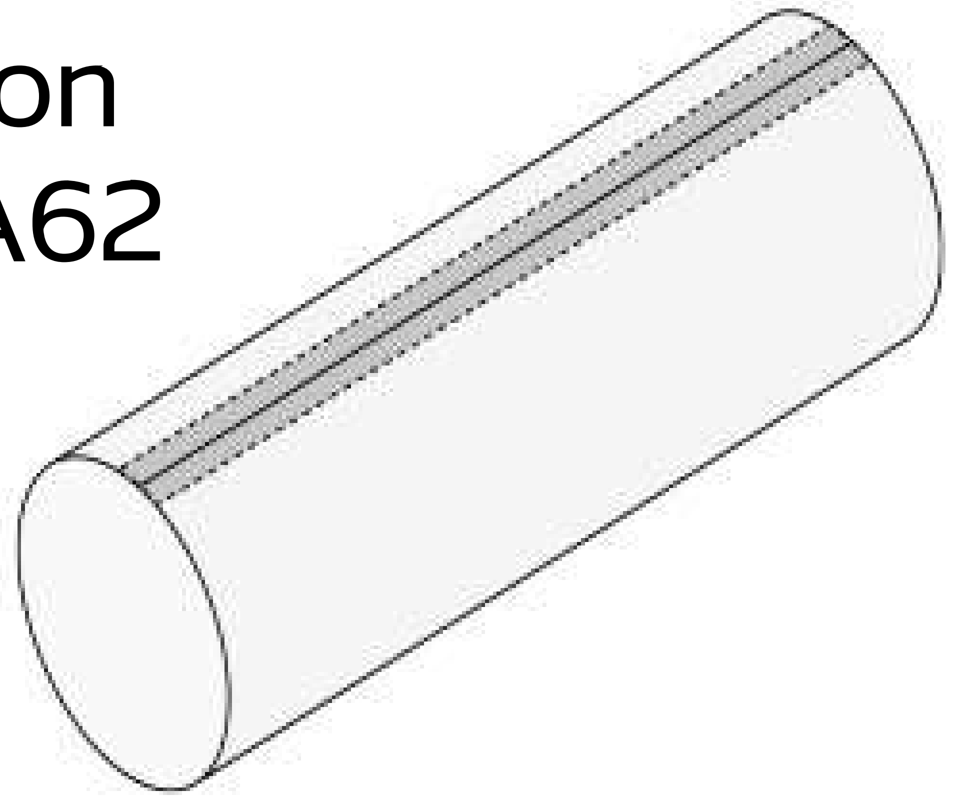
The StrECAL

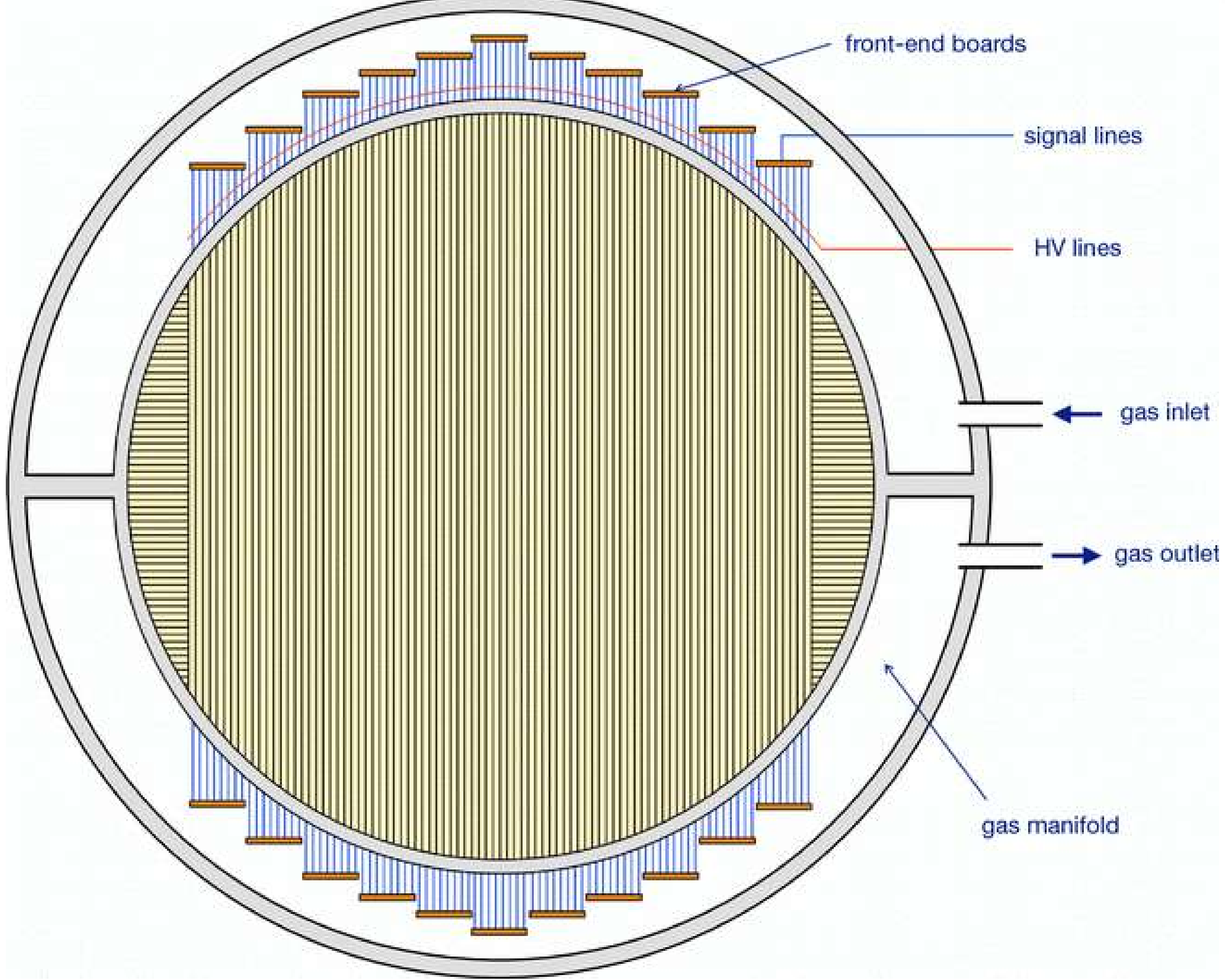
- An important goal of Phase-I is **to study the pion & muon production beam line's performance so we can learn from this as we continue to Phase-II**
  - large uncertainties in
    - **low-momentum pion production** in the backwards direction
  - **particle interactions that cause backgrounds**
- **The Straw Tracker + ECAL combination will measure particle fluxes at the 90-degree point**
  - to be fed back into beam line models and Geant4 simulations
- Also important to **use Phase-I as a test bed for Phase-II detectors**
  - similar detector technologies used to help make design decisions

StrECAL: Straw Tracker

- Five modules
- Situated in vacuum
- Positioning (distance between each module) undergoing optimisation
- Straight-adhesion seam construction method from NA62 design
- Same 9.75 mm diameter as NA62

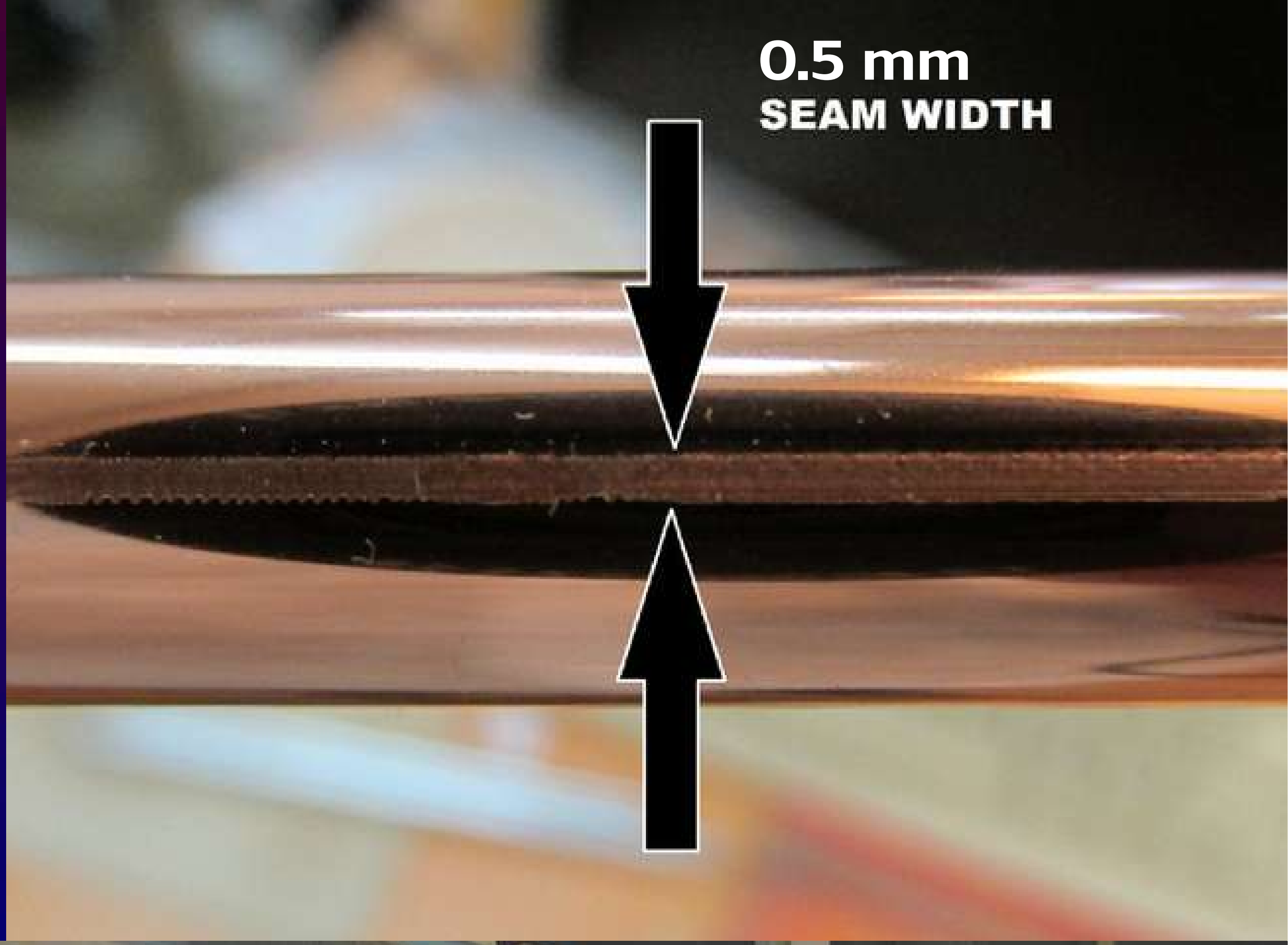






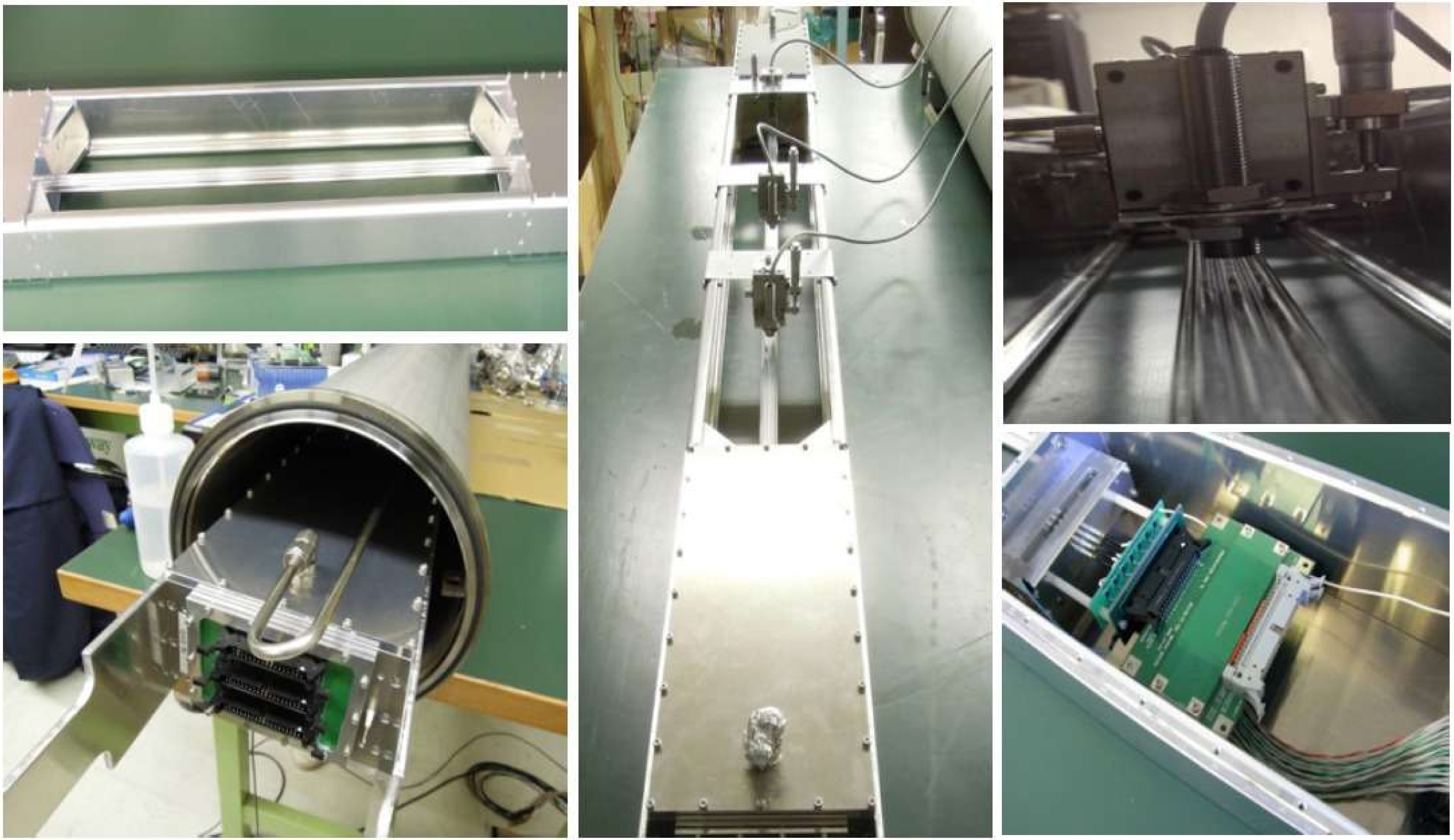
Straw R&D

- Design based on NA62 straws
  - to take advantage of existing expertise & tooling
  - ultrasonic welding
    - 500 μm seam
  - 9.75 mm diameter
  - 30 μm Mylar, 50 nm Al coating
- Diameter larger than originally envisaged:
  - **Need to reduce straw mass**
  - **R&D ongoing**
    - 20 μm Mylar, 70 nm Al
    - 12 μm Mylar, 70 nm Al



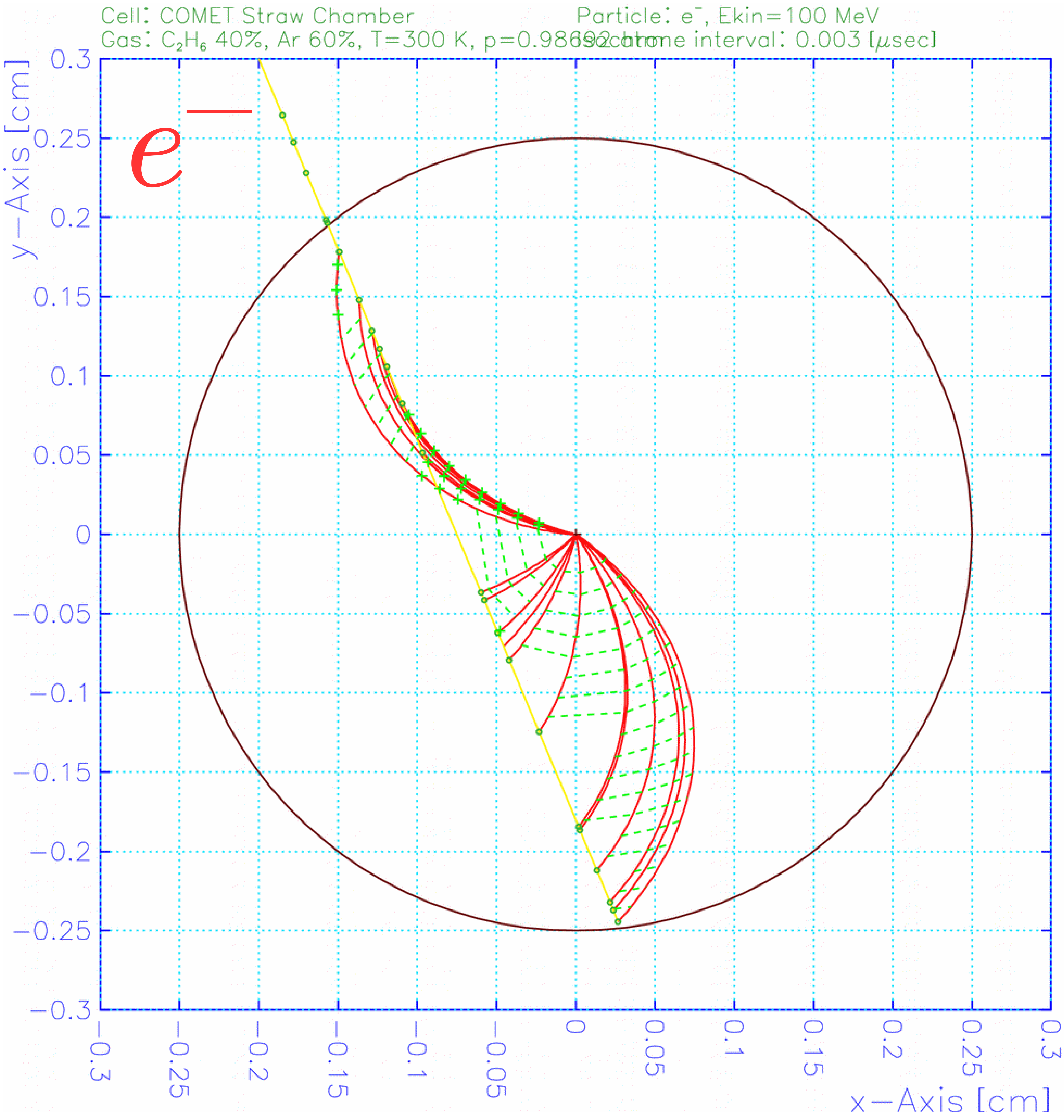

NA62 Straw-tube lab
JINR

Straw Tube Tests in Vacuum



(these photos from tests for previous design of tube)

Straw Tracker: Garfield Simulations



$E_e = 100$ MeV

Gas: **C_2H_6 40%**

Ar 60%

T = 300 K

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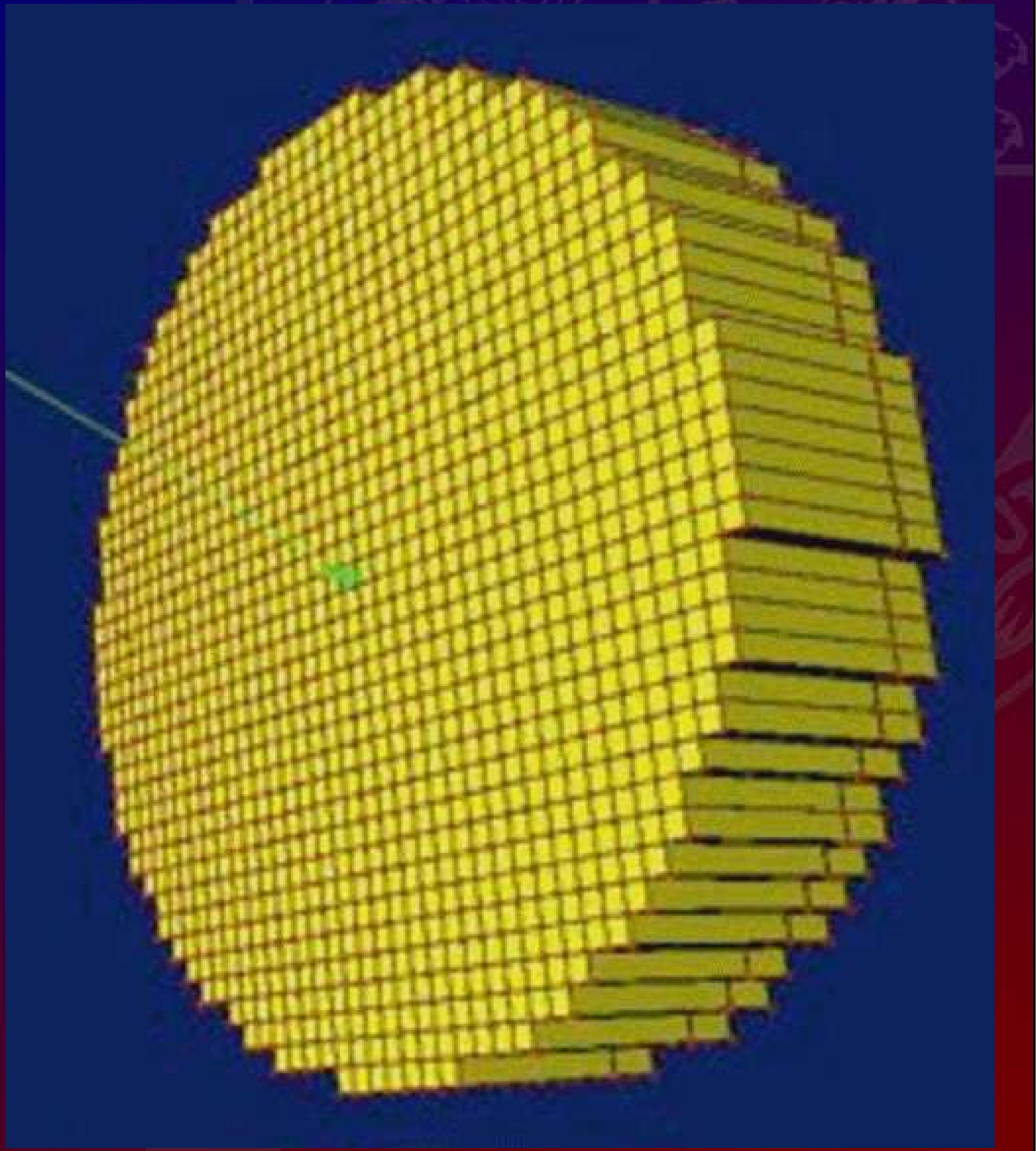
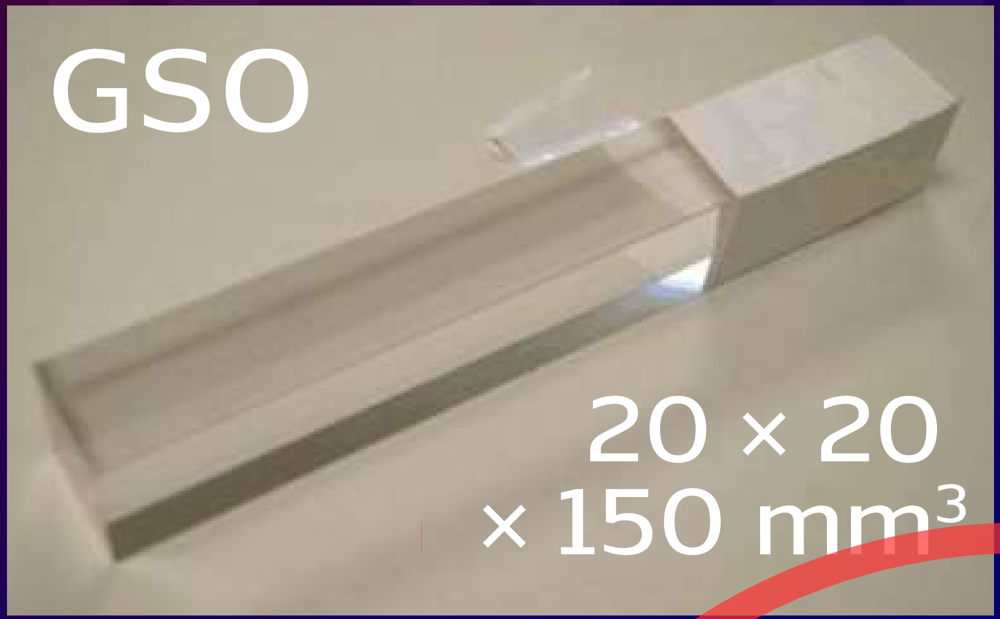
StrECAL: Crystal Calorimeter

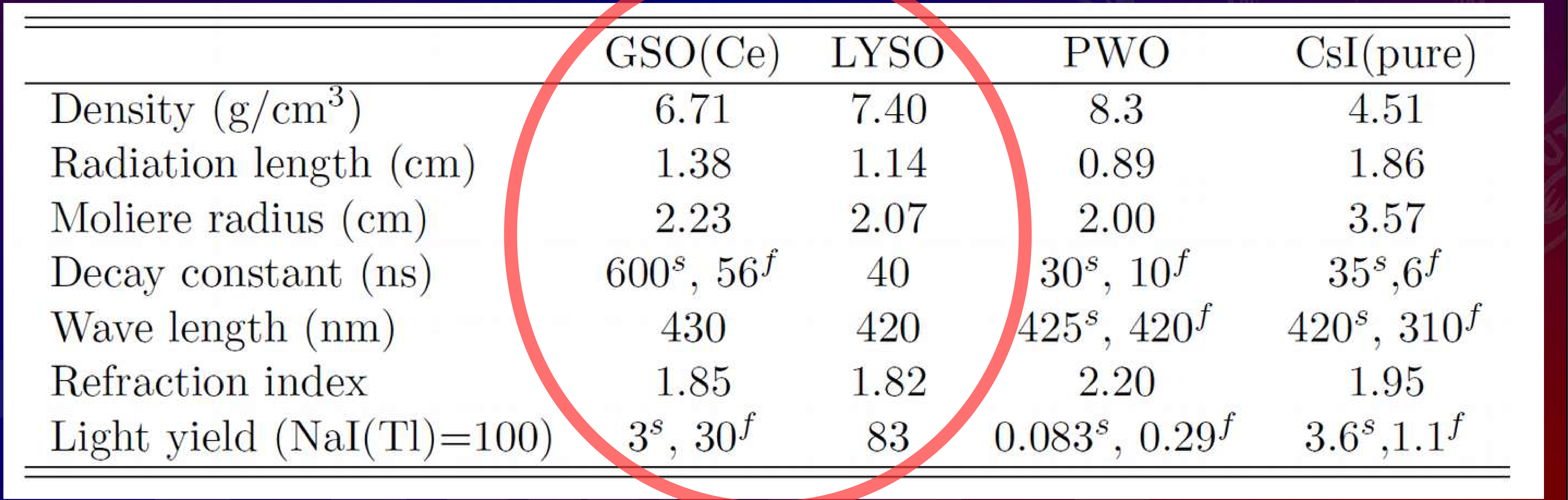
- Requirements:
  - electron energy resolution at 100 MeV: **< 5 %**
  - cluster postion resolution: **< 1 cm**
  - timing response: **< 100 ns**
  - operation in 1 Tesla field
- Solution
  - highly-segmented scintillating crystal calorimeter
    - high light yield and fast response
  - APD read-out



Crystal ECAL

- Undergoing beam tests to decide crystal type
- APD readout
- R&D ongoing at groups including Kyushu, KEK, Osaka & BINP



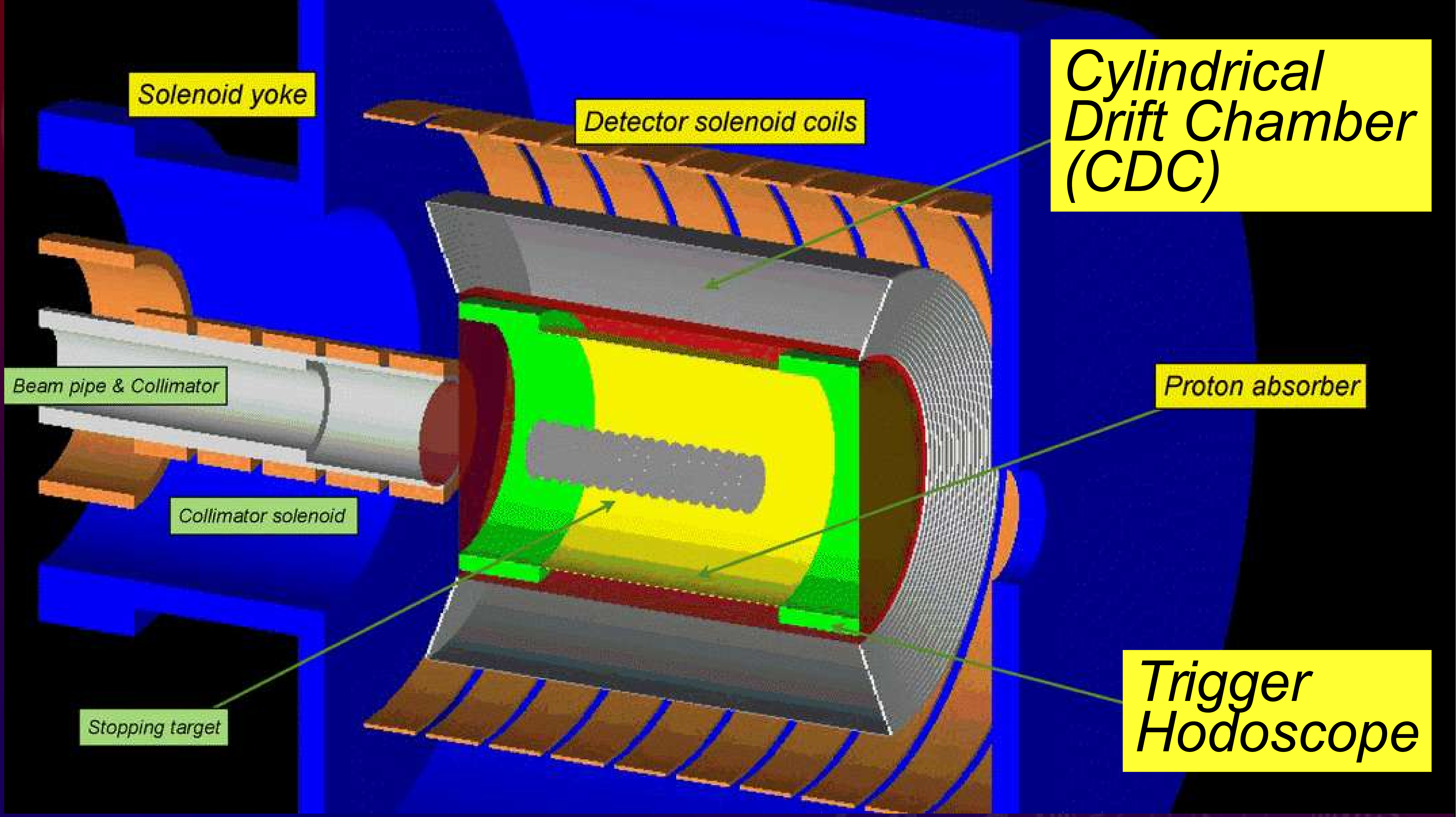


	GSO(Ce)	LYSO	PWO	CsI(pure)
Density (g/cm^3)	6.71	7.40	8.3	4.51
Radiation length (cm)	1.38	1.14	0.89	1.86
Moliere radius (cm)	2.23	2.07	2.00	3.57
Decay constant (ns)	600^s, 56^f	40	30^s, 10^f	35^s,6^f
Wave length (nm)	430	420	425^s, 420^f	420^s, 310^f
Refraction index	1.85	1.82	2.20	1.95
Light yield (NaI(Tl)=100)	3^s, 30^f	83	0.083^s, 0.29^f	3.6^s,1.1^f

CyDet: Requirements

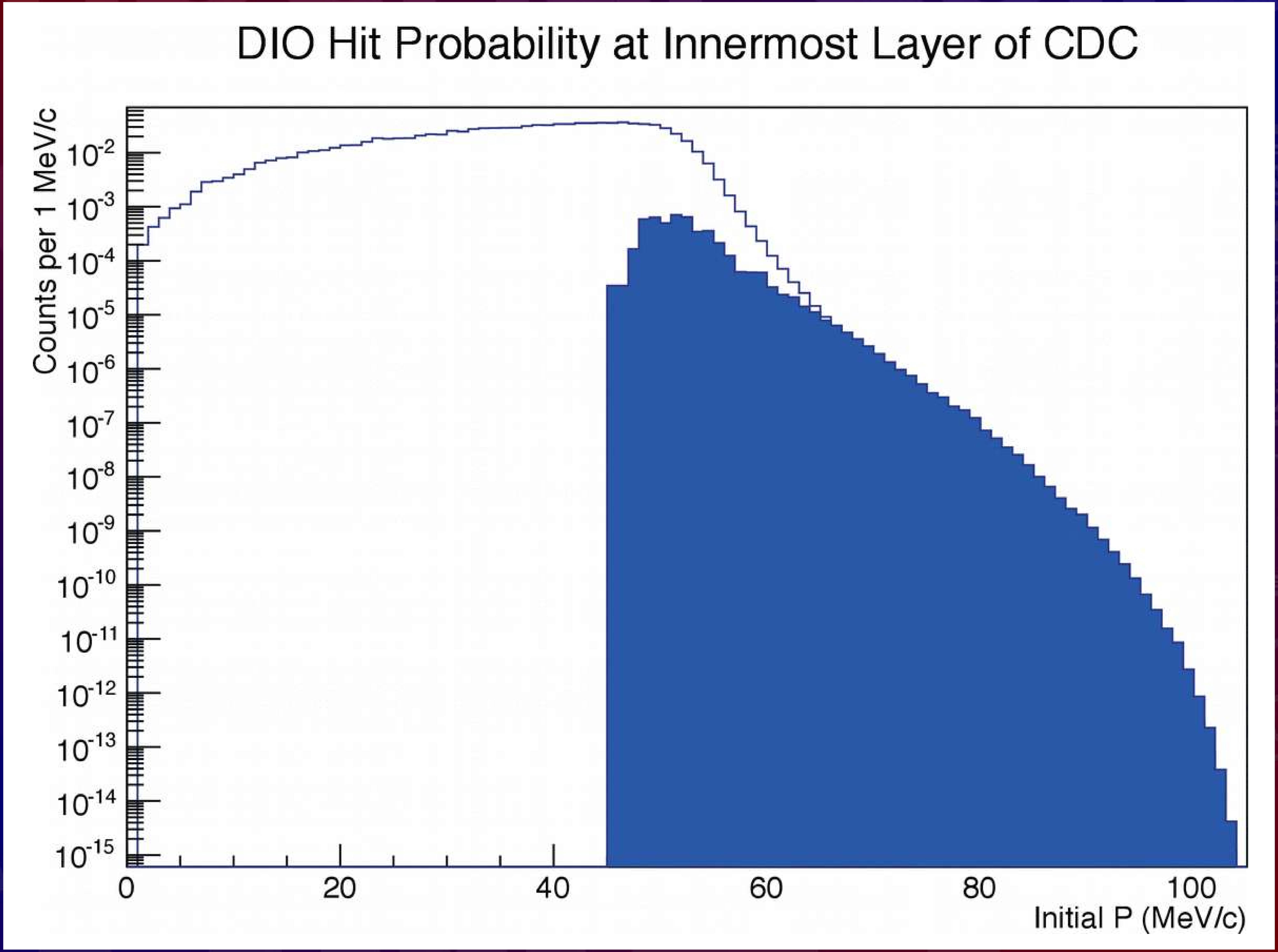
- Observes **particles emitted from muons stopped in Aluminium** target
- Needs to **identify 105 MeV/c e^-** and **reject most background** (mainly lower energy e^- from muon decay-in-orbit)
  - **good momentum resolution** to maintain signal peak
    - **low detector mass**
- Must **avoid intense prompt beam flash**
- Should **suppress false trigger rates: e.g.:**
  - integrated **proton absorber** (largest source of background from muon captures)
  - trigger should incorporate **electron PID**

CyDet



- Cylindrical Drift Chamber in a 1 Tesla solenoidal field, surrounding a target made of several thin Aluminium disks, in which the beam muons stop and form muonic atoms
  - geometric p_T cut-off for background rejection
  - prompt beam pulse avoids active detector components
- Scintillator & Cherenkov Hodoscope to allow triggering on electrons above the transverse momentum threshold
- Makes use of Belle II Central Drift Chamber experience & construction facilities at KEK
- Undergoing detailed design optimisation

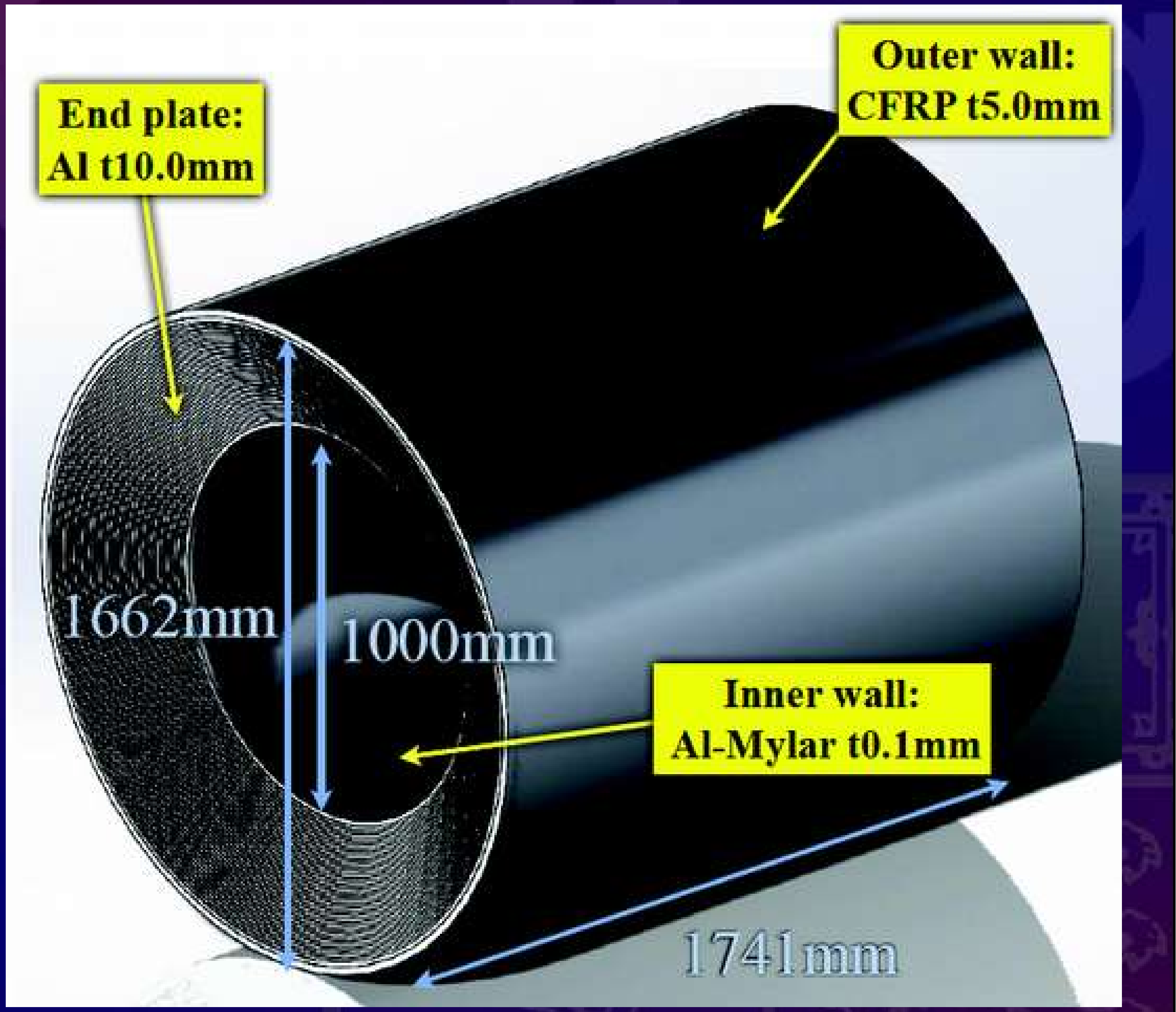
Cylindrical Drift Chamber

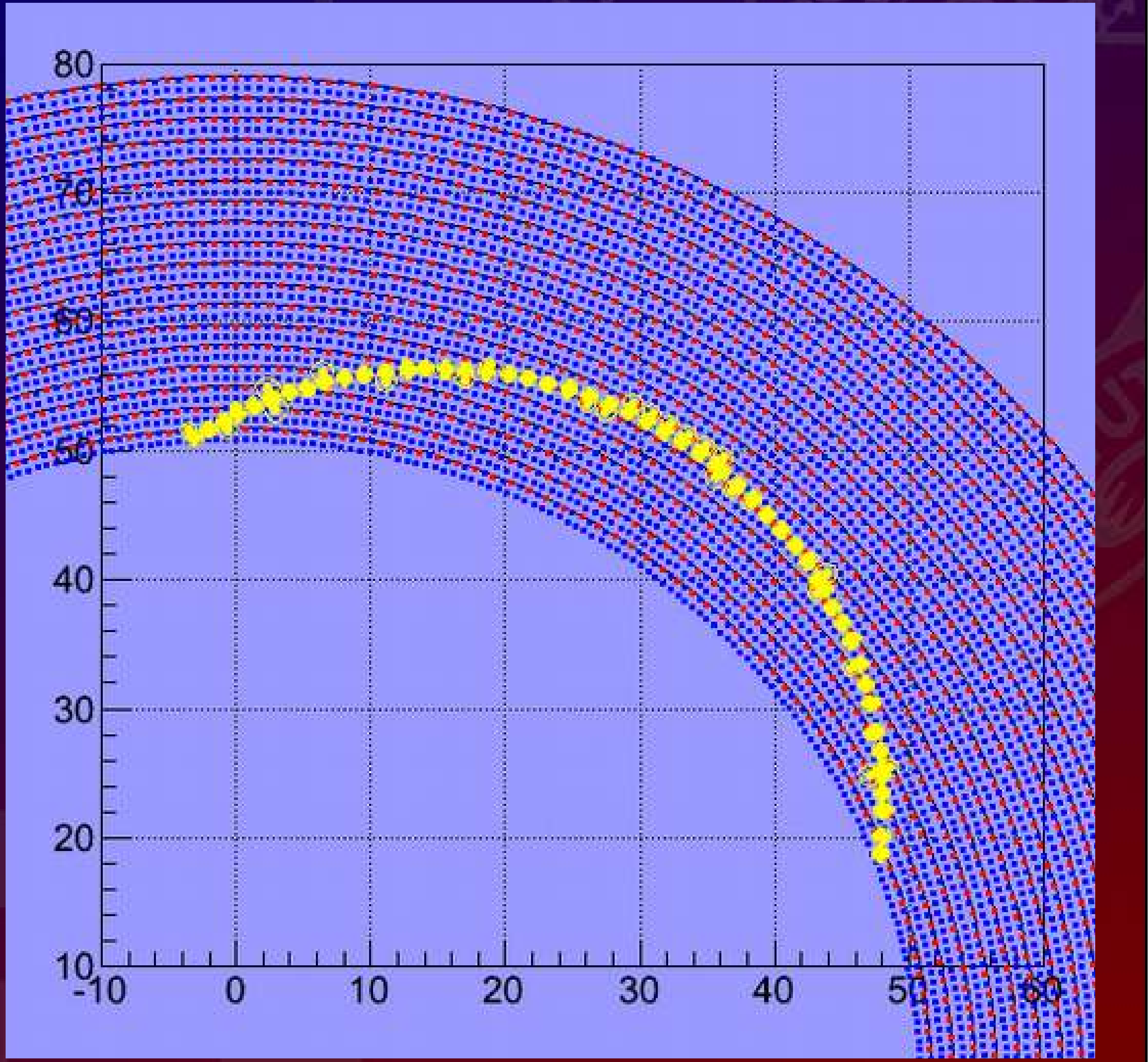


Cylindrical Drift Chamber

Current design **(being optimised)**:

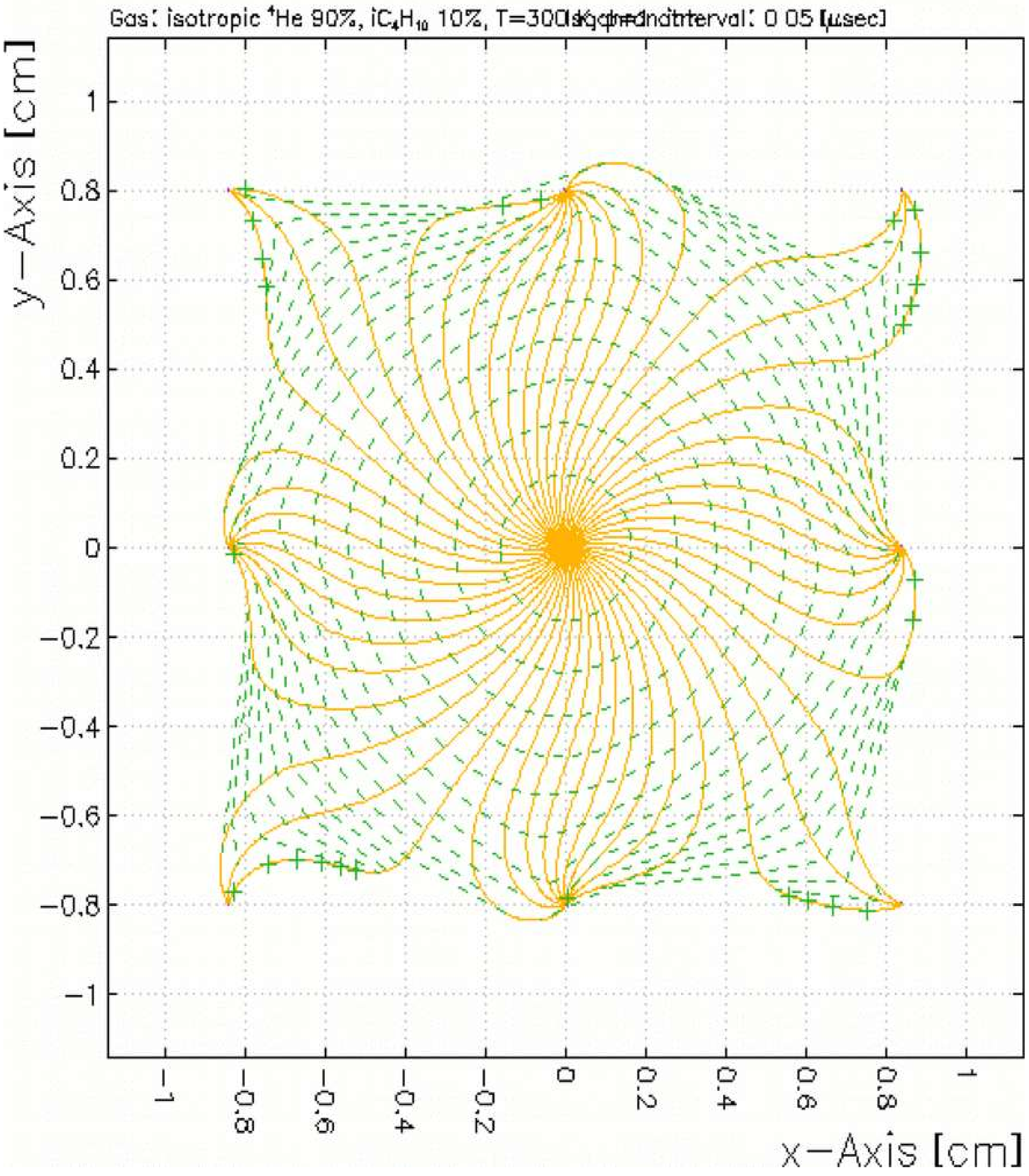
  - **all-stereo wire configuration**
    (based on KLOE CDC)
  - **20 sense layers**
  - about 20,000 wires in total
  - at 50 g tension
- Square cells
  - 16.8 mm (w) × 16.0 mm (h)
- Anode wires:
  - ø30 micron Gold-plated Tungsten
  - HV at +1.7 kV
- Field wires:
  - ø80 micron Aluminium
  - at ground
- He : Isobutane (90 : 10)





Cylindrical Drift Chamber

- Garfield drift simultions



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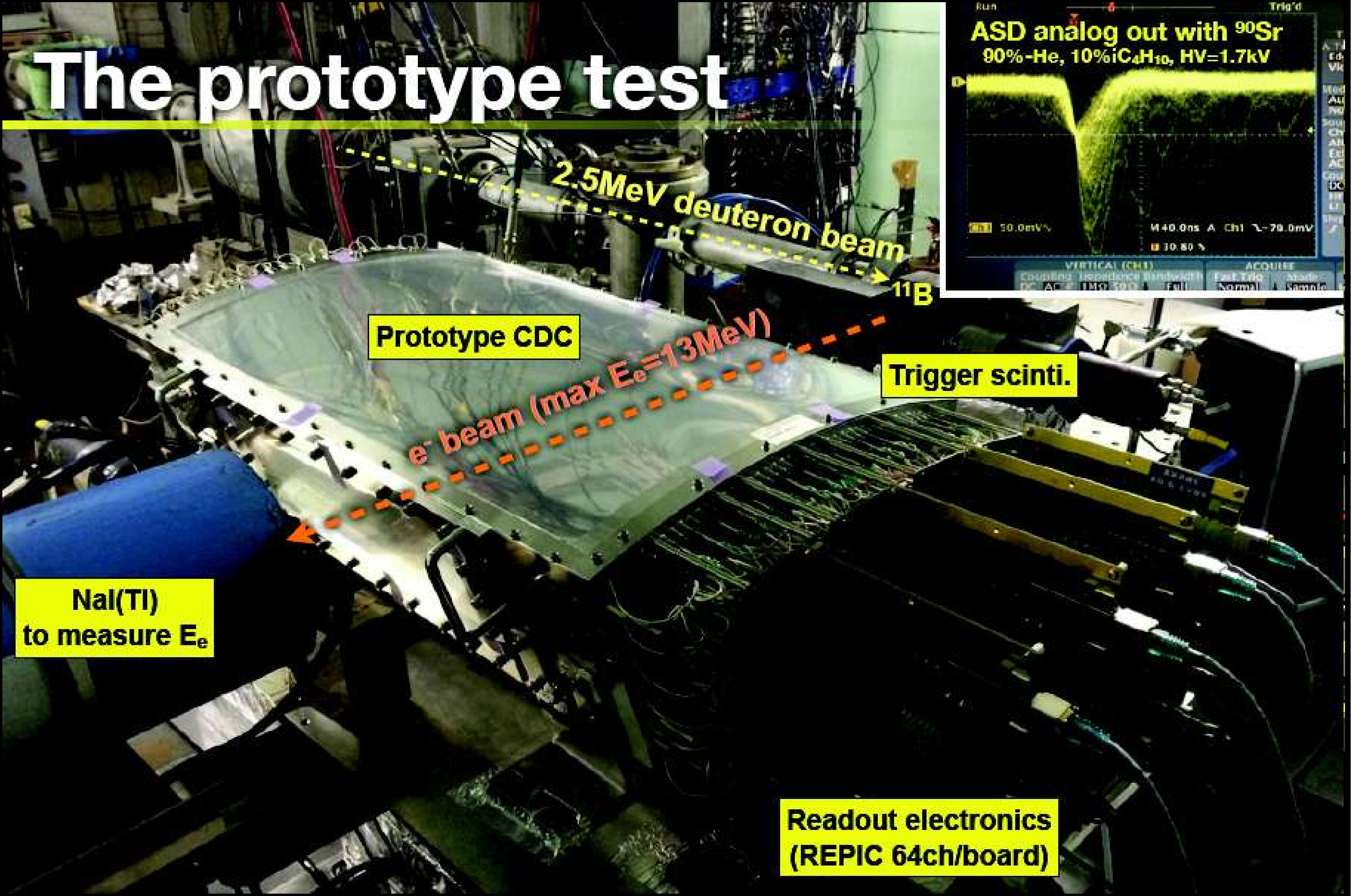
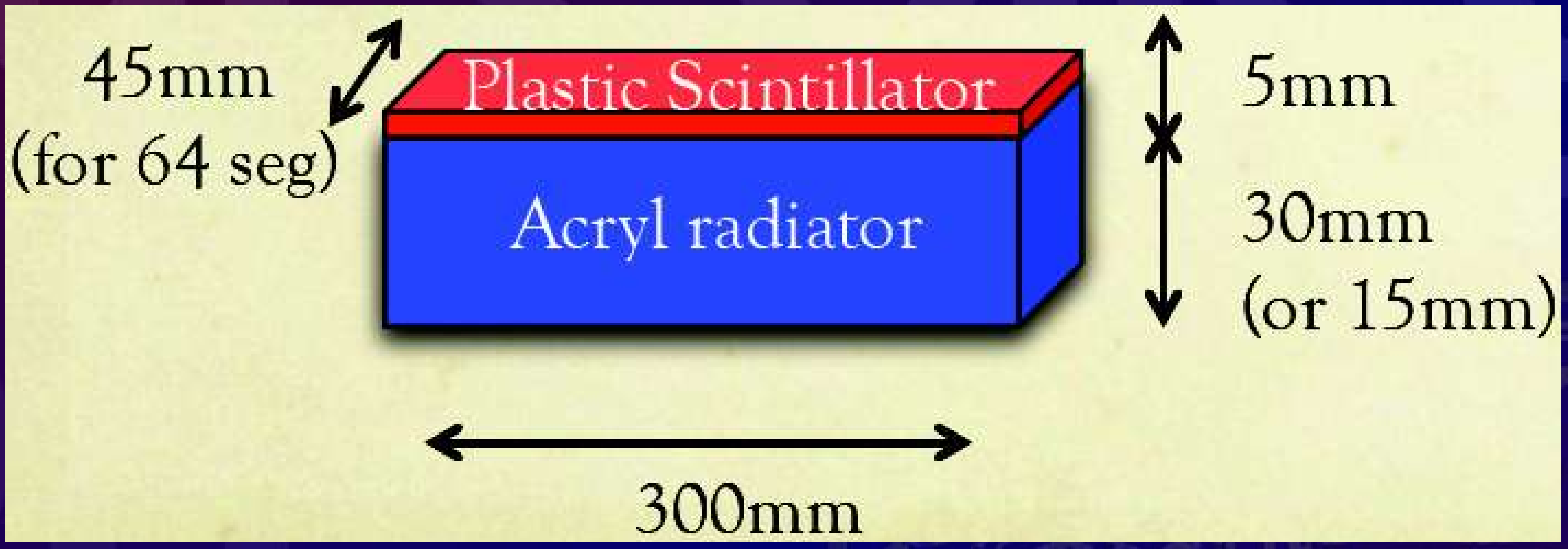
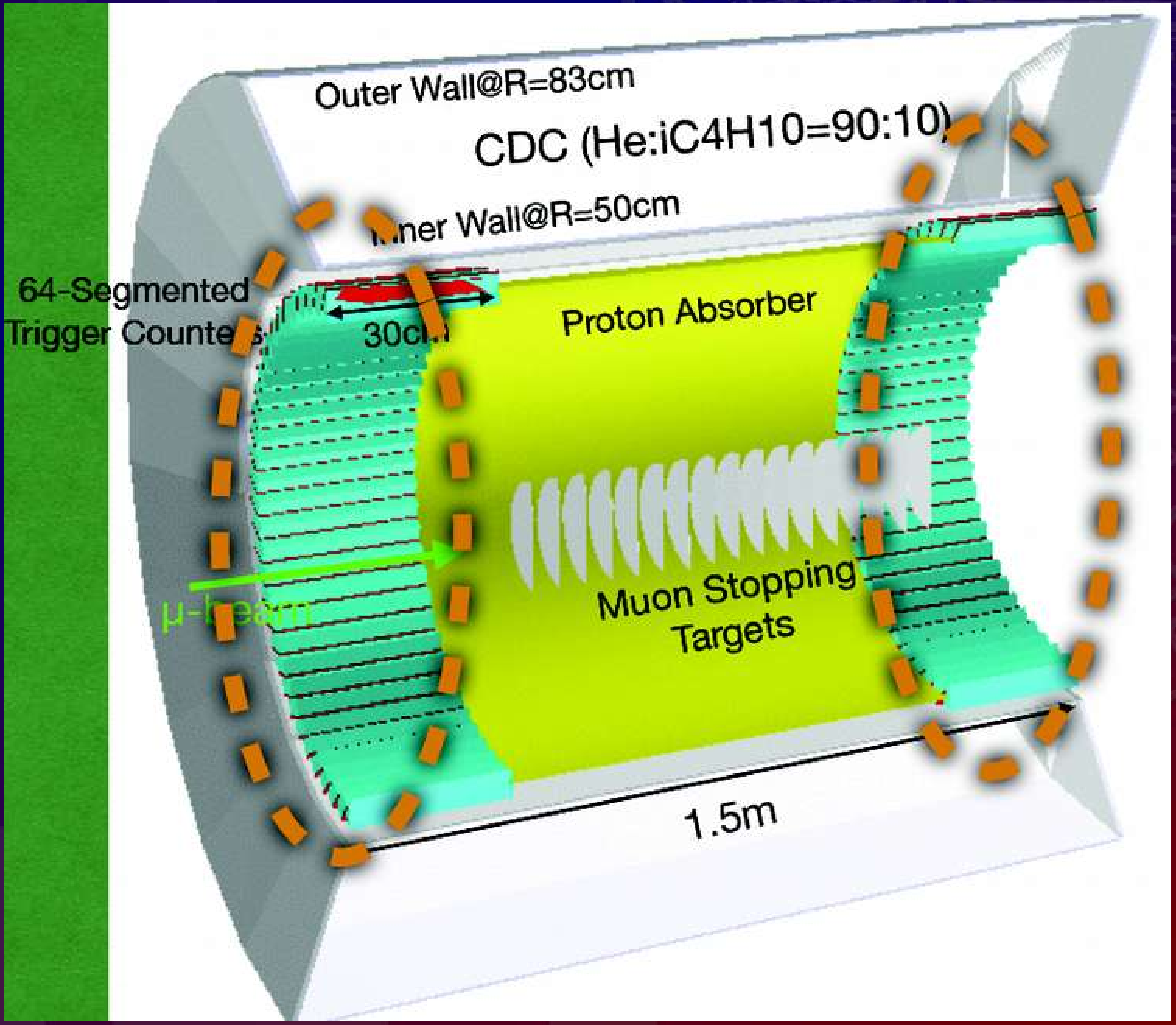
The prototype test



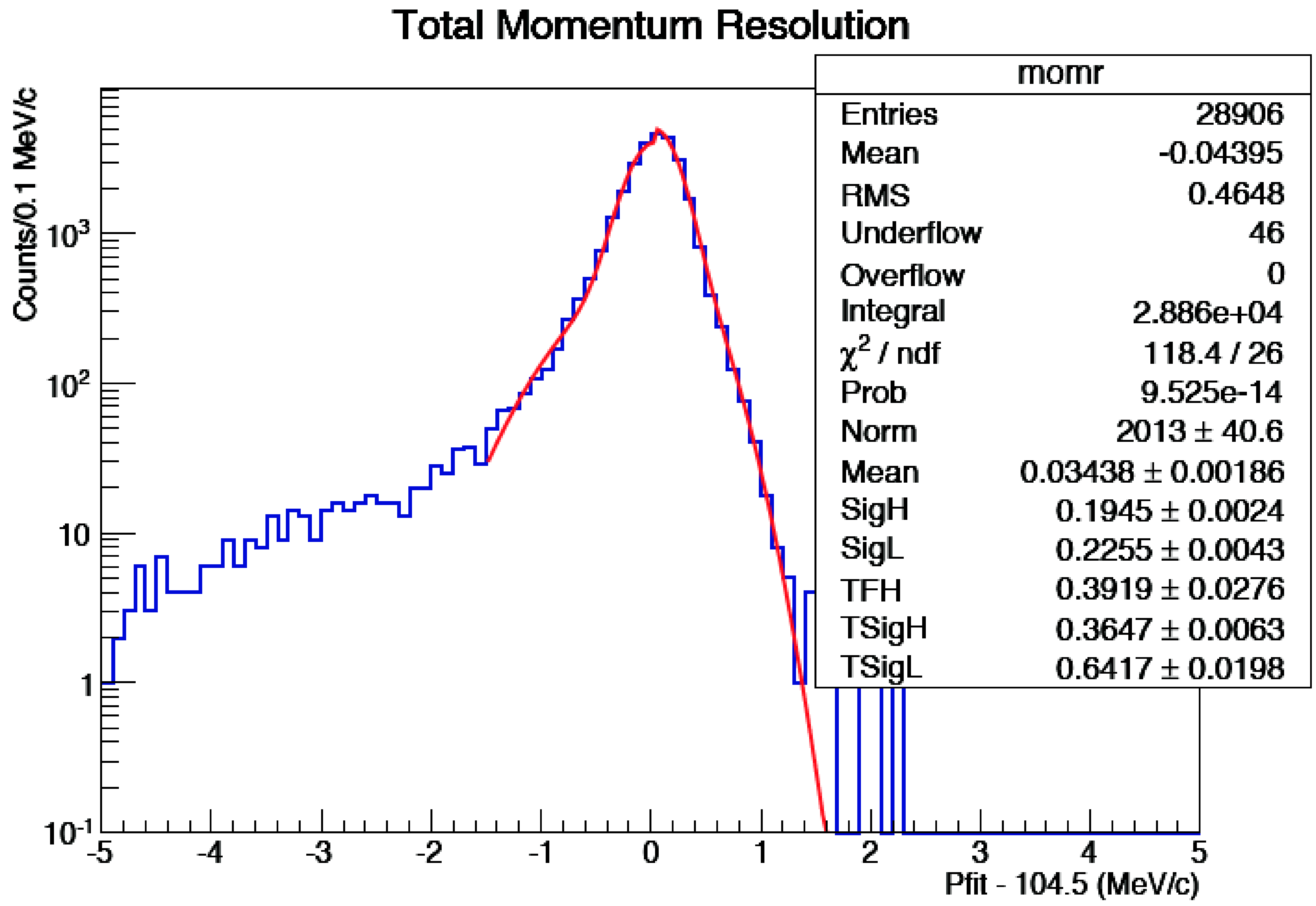
CyDet: Triggering Hodoscope

- Cherenkov counters
  - Acrylic radiator
    - $n = 1.49$
  - Hamamatsu MPPCs
    - $12 \times 12\ \text{mm}^2$
- Scintillators
  - Ultra-fast plastic scintillator
    - $n = 1.58$
  - Hamamatsu MPPCs
    - $3 \times 3\ \text{mm}^2$
- Reflectors
  - 3M ESR (Vikuiti enhanced specular reflector)
  - Teflon





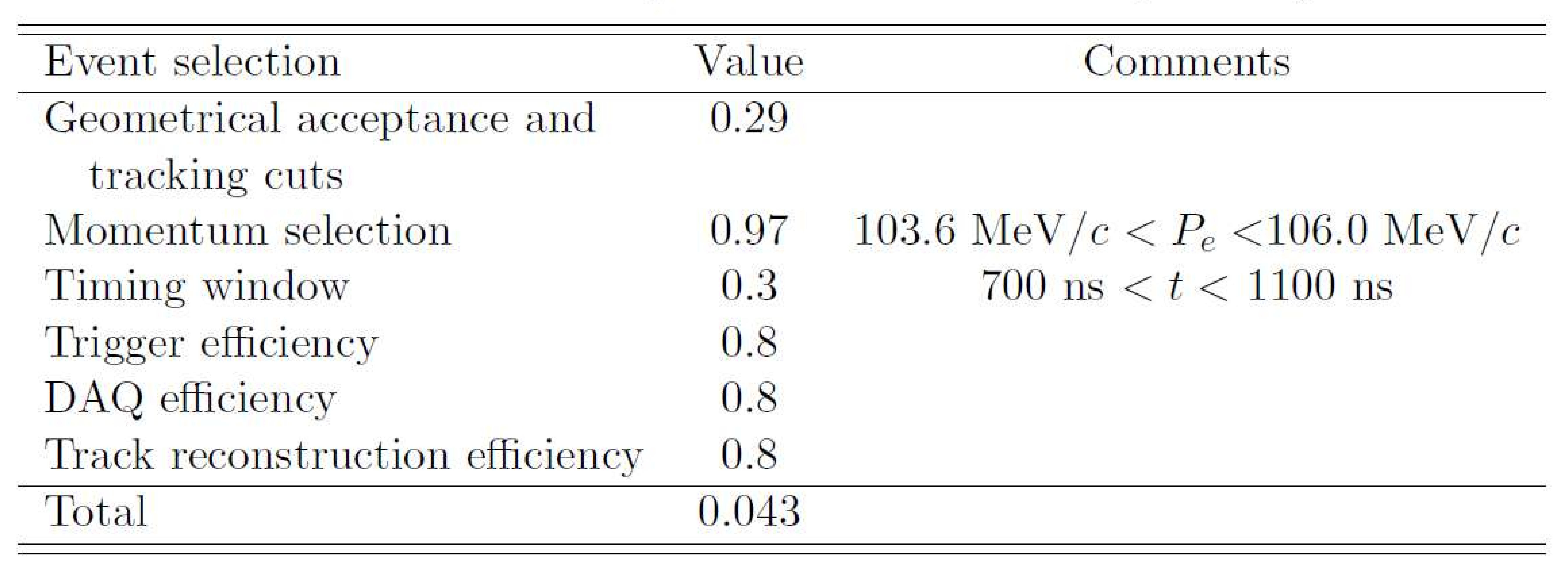
CyDet Resolution (Simulated/Preliminary)



σ of the core Gaussian at the high momentum side `SigH`	195 keV/c
σ of the core Gaussian at the high momentum side `SigL`	226 keV/c
Fraction in the tail distribution `TFH`	39%
σ of the tail Gaussian at the high momentum side `TSigH`	365 keV/c
σ of the tail Gaussian at the low momentum side `TSigL`	642 keV/c

CyDet: $\mu \rightarrow e$ Conversion Performance

- Signal electron efficiency

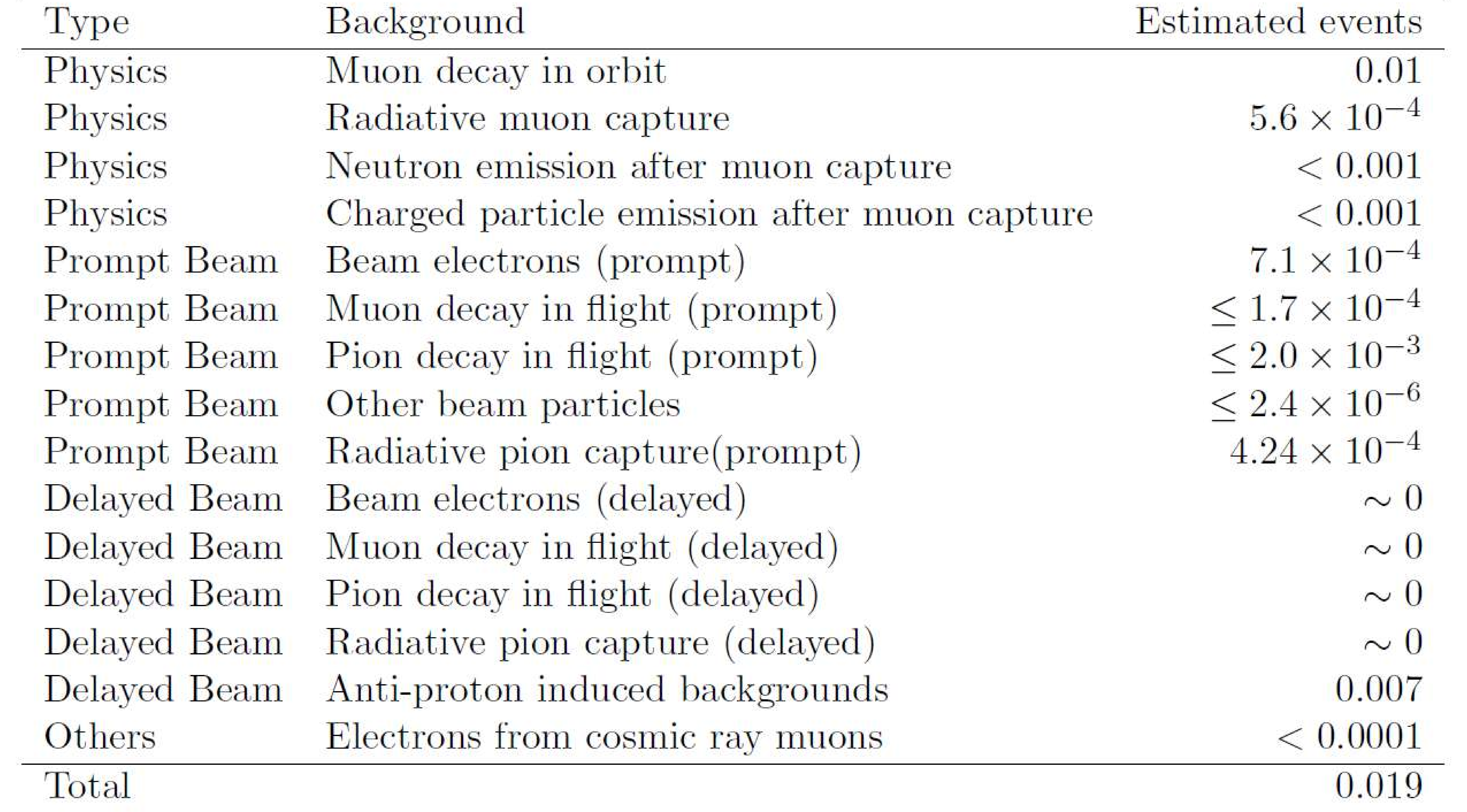


Event selection	Value	Comments
Geometrical acceptance and tracking cuts	0.29	
Momentum selection	0.97	$103.6\ \mathrm{MeV}/c < P_e < 106.0\ \mathrm{MeV}/c$
Timing window	0.3	$700\ \mathrm{ns} < t < 1100\ \mathrm{ns}$
Trigger efficiency	0.8	
DAQ efficiency	0.8	
Track reconstruction efficiency	0.8	
Total	0.043	

- This gives a single-event-sensitivity of 3.1×10^{-15} with the CyDet after 90 days of Phase-I running

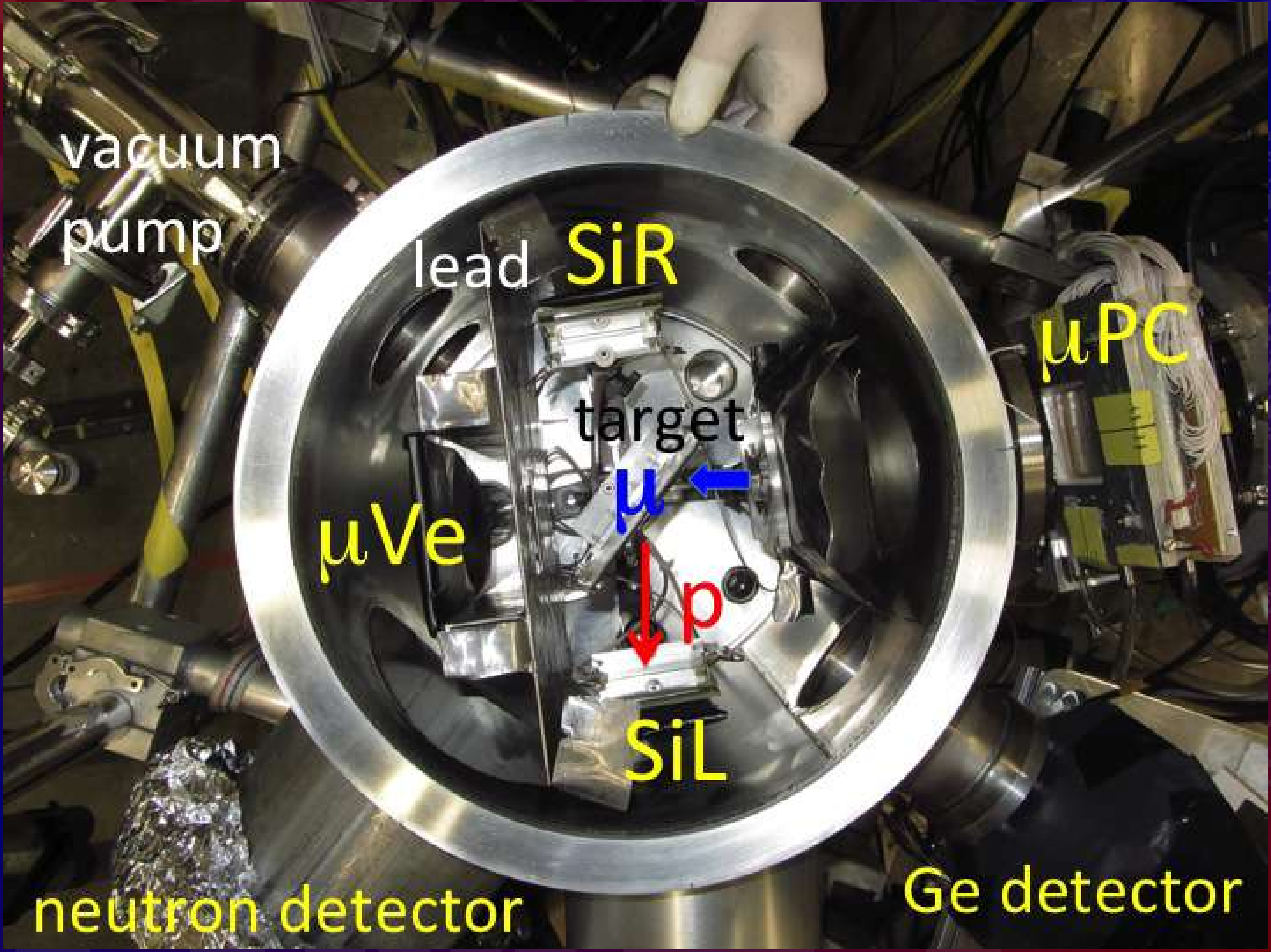
CyDet: $\mu \rightarrow e$ Conversion Performance

- Expected backgrounds for 90 days of Phase-I running

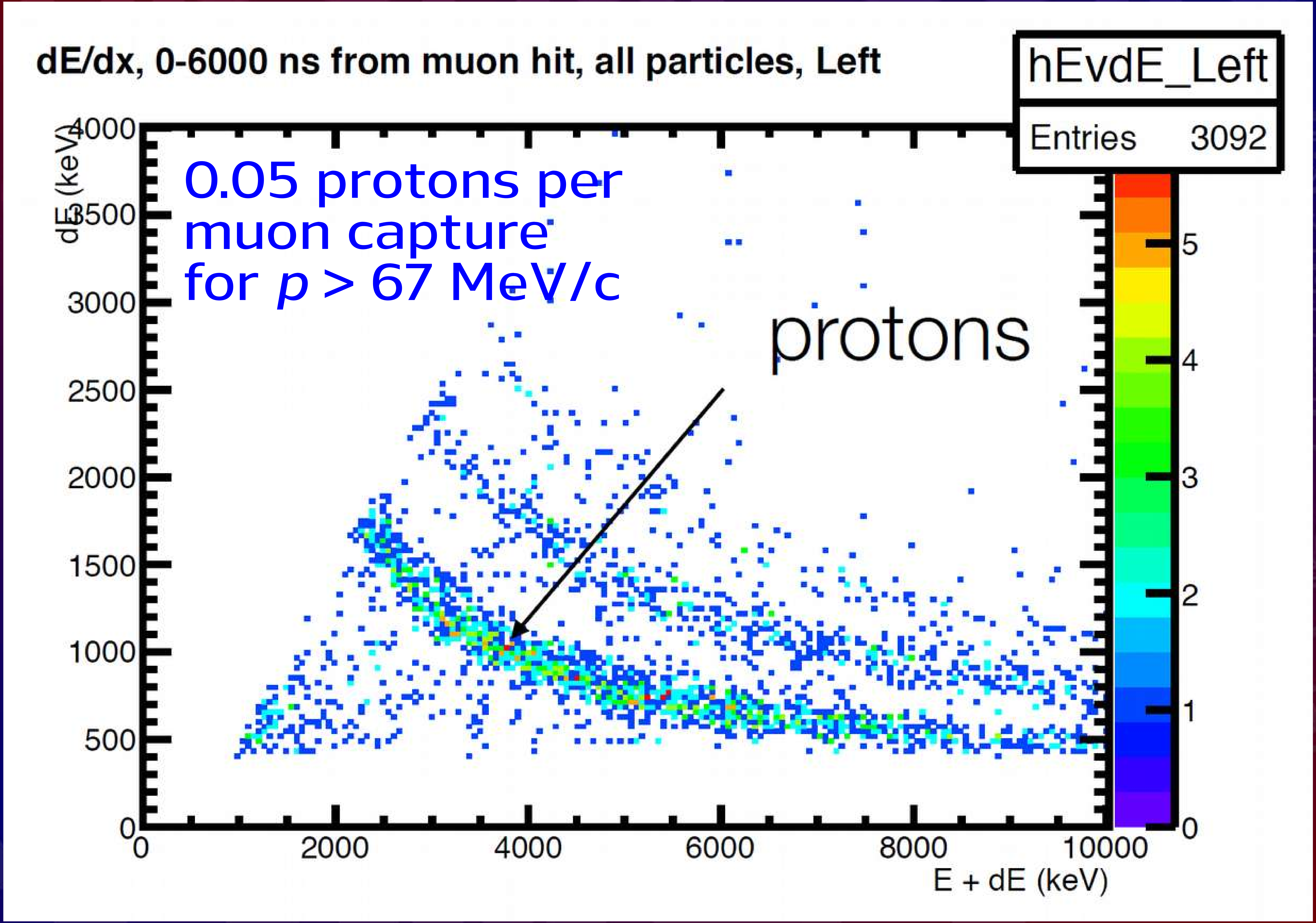


Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
Physics	Radiative muon capture	5.6×10^{-4}
Physics	Neutron emission after muon capture	< 0.001
Physics	Charged particle emission after muon capture	< 0.001
Prompt Beam	Beam electrons (prompt)	7.1×10^{-4}
Prompt Beam	Muon decay in flight (prompt)	$\leq 1.7 \times 10^{-4}$
Prompt Beam	Pion decay in flight (prompt)	$\leq 2.0 \times 10^{-3}$
Prompt Beam	Other beam particles	$\leq 2.4 \times 10^{-6}$
Prompt Beam	Radiative pion capture(prompt)	4.24×10^{-4}
Delayed Beam	Beam electrons (delayed)	~ 0
Delayed Beam	Muon decay in flight (delayed)	~ 0
Delayed Beam	Pion decay in flight (delayed)	~ 0
Delayed Beam	Radiative pion capture (delayed)	~ 0
Delayed Beam	Anti-proton induced backgrounds	0.007
Others	Electrons from cosmic ray muons	< 0.0001
Total		0.019

AlCap Experiment at PSI



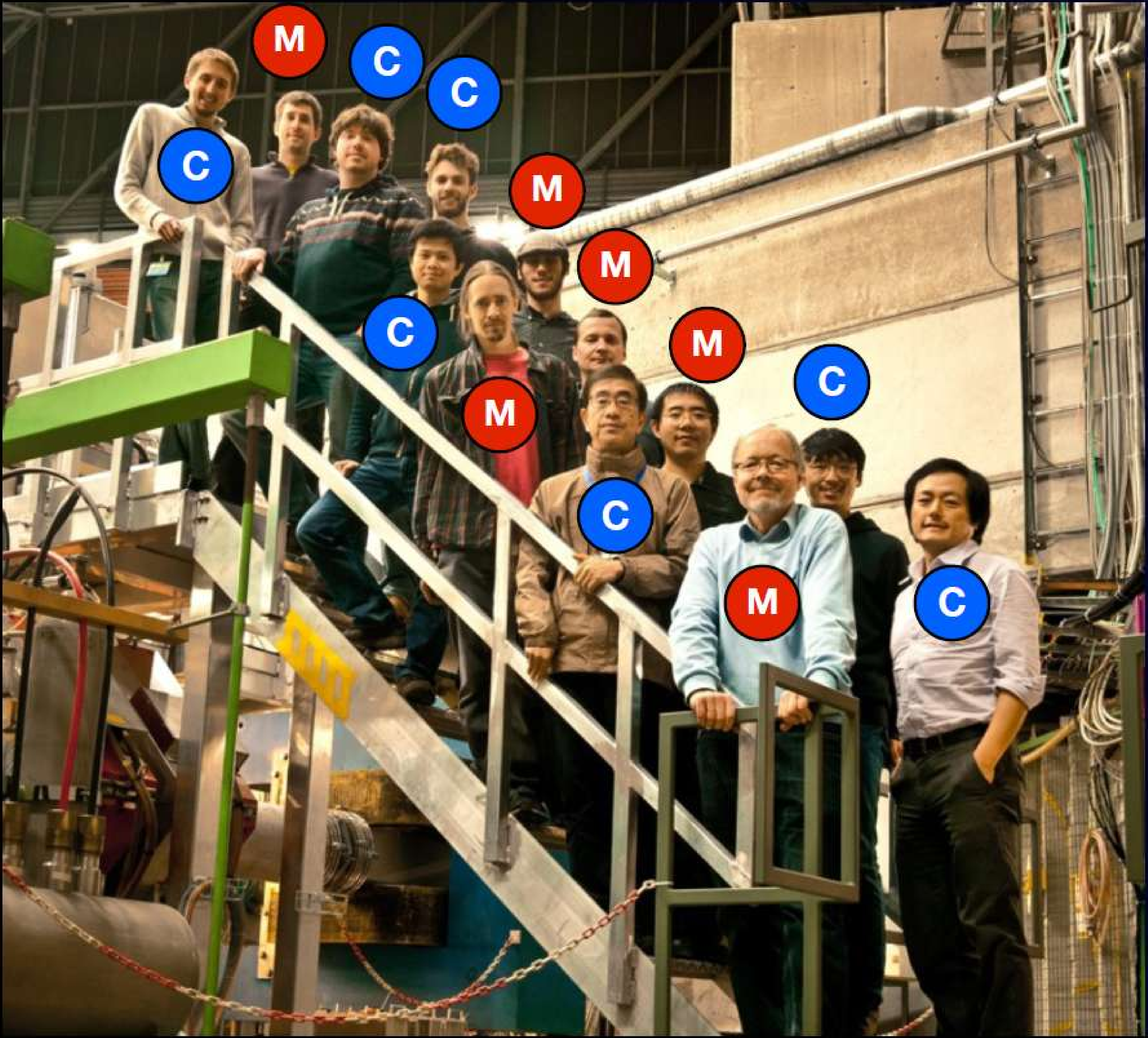
AlCap Experiment PSI (Preliminary)



0.05 protons per muon capture for $p > 67$ MeV/c

AlCap@PSI

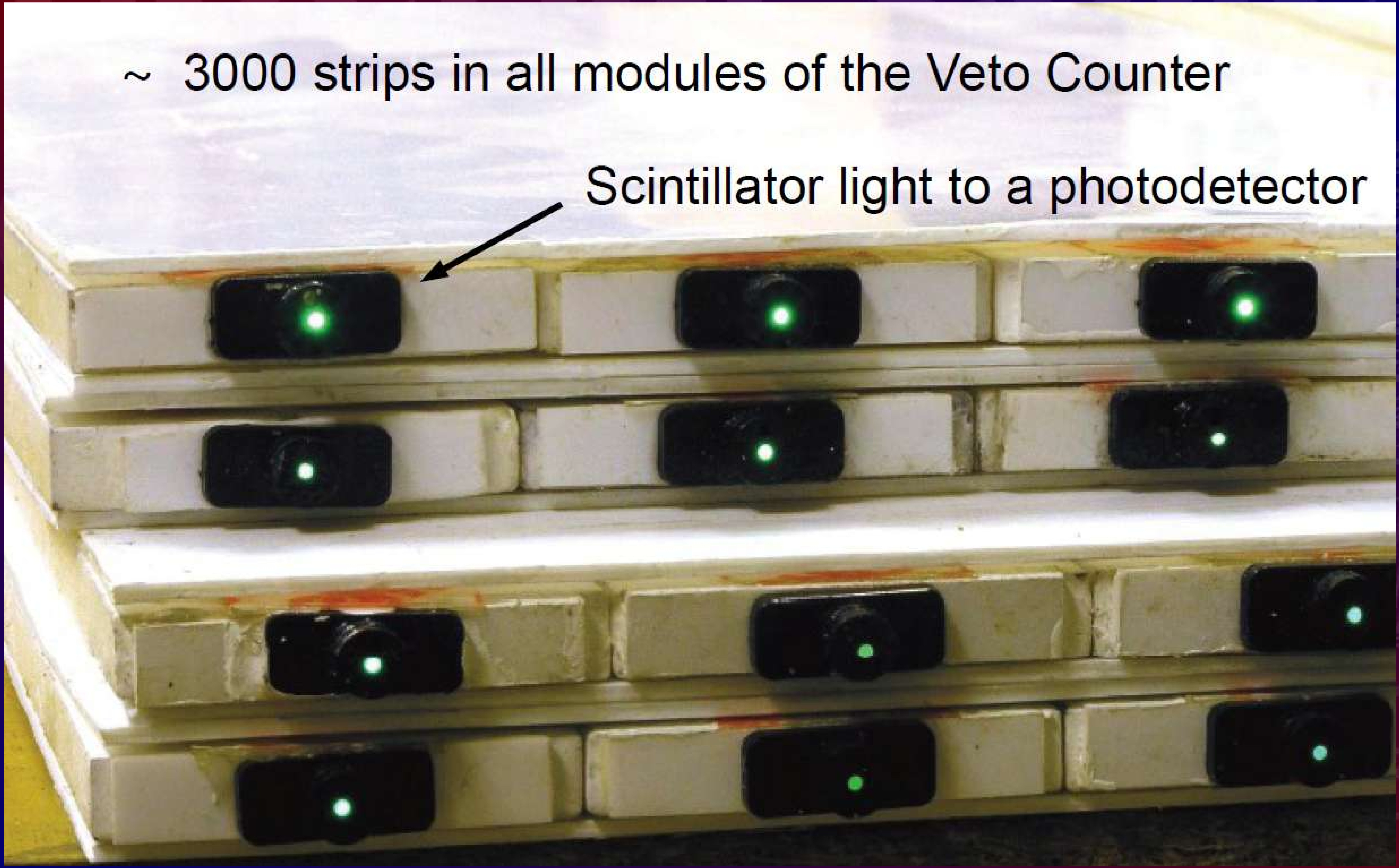
Dec. 13



C COMET

M Mu2e

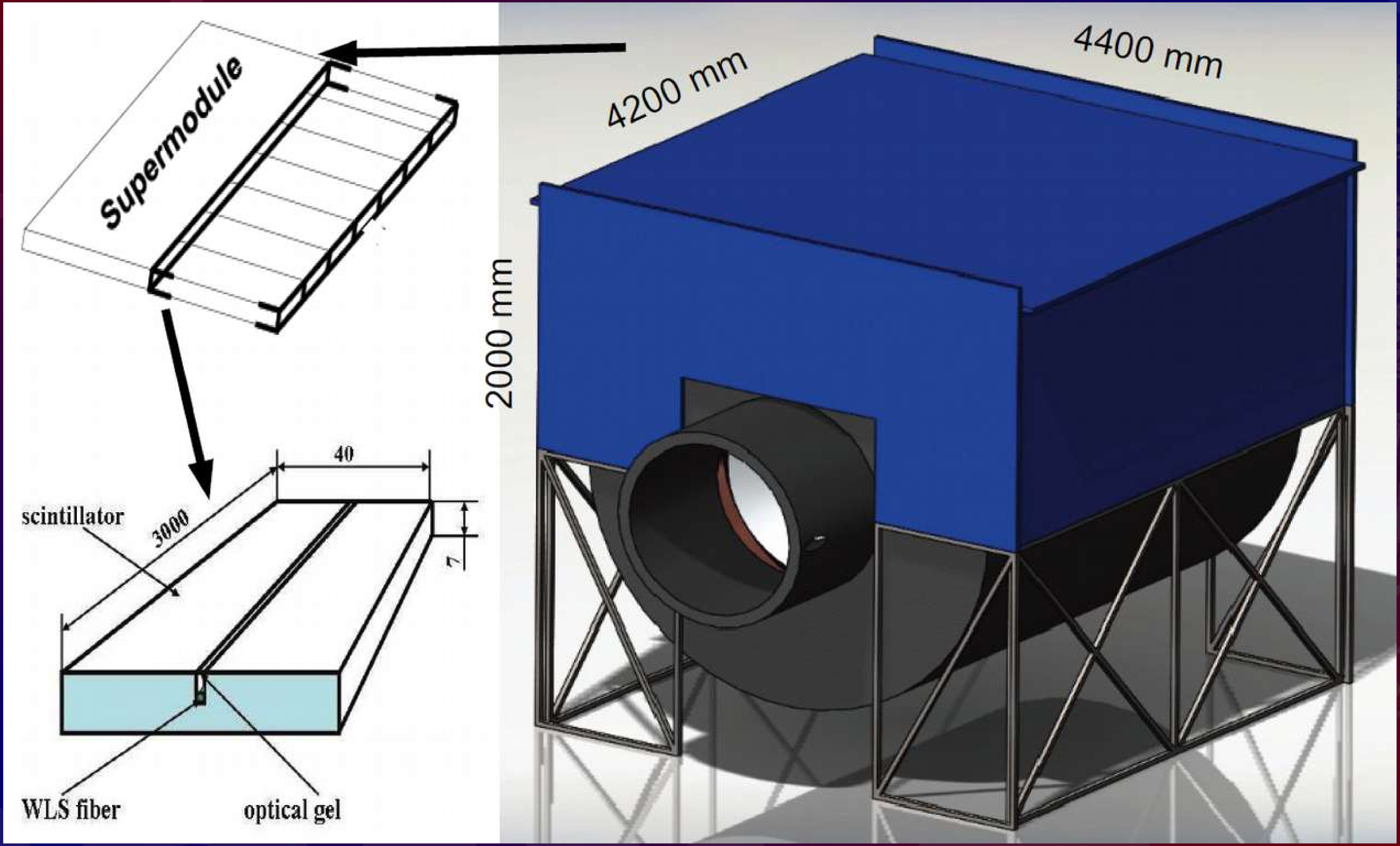
Cosmic Ray Veto



Studies at ITEP, based on Belle II KLM detector endcap construction experience

Cosmic Ray Veto

Four layers of scintillator strip bars



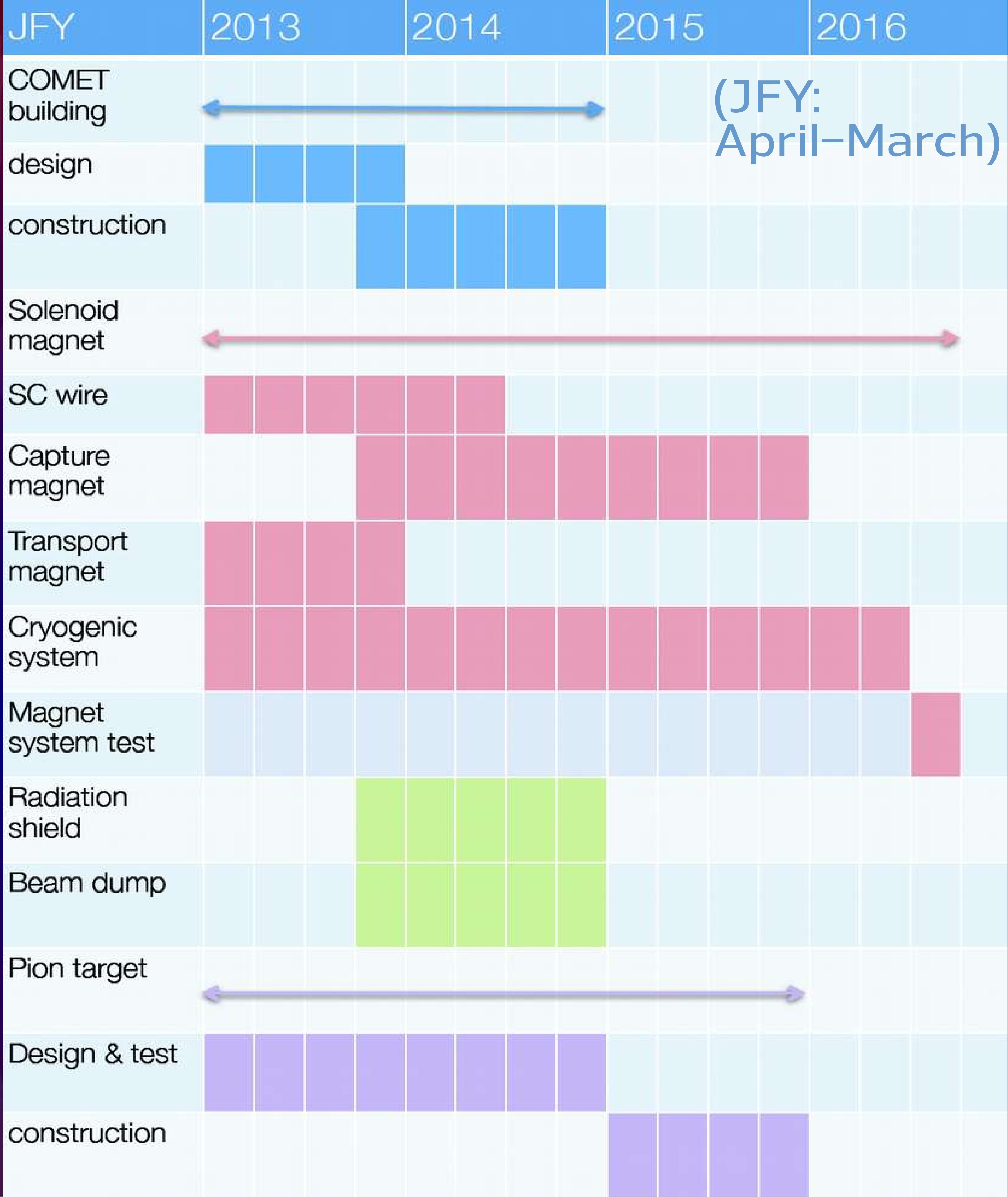
to provide rejection of cosmic rays at the 10^{-4} level

COMET Phase-I Facility Construction Schedule

Detectors being built to be ready by 2016

Recently reviewed by an external panel of international experts

Currently working on implementing the panel's recommendations



(JFY: April–March)

JFY	2013				2014				2015				2016			
COMET building	←	—	—	—	—	—	—	→								
design	🟦	🟦	🟦	🟦												
construction				🟦	🟦	🟦	🟦	🟦								
Solenoid magnet	←	—	—	—	—	—	—	—	—	—	—	—	—	—	→	
SC wire	🟥	🟥	🟥	🟥	🟥	🟥										
Capture magnet				🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥				
Transport magnet	🟥	🟥	🟥	🟥												
Cryogenic system	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		
Magnet system test															🟥	
Radiation shield				🟩	🟩	🟩	🟩	🟩								
Beam dump				🟩	🟩	🟩	🟩	🟩								
Pion target	←	—	—	—	—	—	—	—	—	—	—	→				
Design & test	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪								
construction									🟪	🟪	🟪	🟪				

The COMET Collaboration

143 participants from 31 institutes in 12 countries

Canada **TRIUMF**, Vancouver, **University of British Columbia**, Vancouver

China Institute of High Energy Physics (**IHEP**), Beijing, **Nanjing University**

Czech Republic **Charles University**, Prague, **Czech Technical University**, Prague

France **Laboratory of Nuclear and High Energy Physics** (**LPNHE**), CNRS-IN2P3 and University Pierre and Marie Curie (UPMC), Paris

Georgia **Ilia State University** (ISU), Tbilisi, Institute of High Energy Physics of I. Javakhishvili State University (**HEPI TSU**), Tbilisi

India **Indian Institute of Technology**, Bombay

Japan High Energy Accelerator Research Organization (**KEK**), Tsukuba, Institute for Chemical Research, **Kyoto University**, **Kyoto University Research Reactor Institute**, **Kyushu University**, Fukuoka, **Nagoya University**, Nagoya, **Osaka University**, **Saitama University**, **Utsunomiya University**

Malaysia **University Technology Malaysia**, Johor, **University of Malaya**, Kuala Lumpur

Russia Budker Institute of Nuclear Physics (**BINP**), Novosibirsk, Institute for Theoretical and Experimental Physics (**ITEP**), Moscow, Joint Institute for Nuclear Research (**JINR**), Dubna, Moscow Physical Engineering Institute, **National University**, **Novosibirsk State Technical University**, **Novosibirsk State University**

Saudi Arabia **King Abdulaziz University**

United Kingdom **Imperial College London**, **University College London**, **University of Manchester**, STFC **Rutherford Appleton Laboratory**

Vietnam College of Natural Science, **National Vietnam University**, Ho Chi Minh City, **Institute for Nuclear Science and Technology**, Hanoi

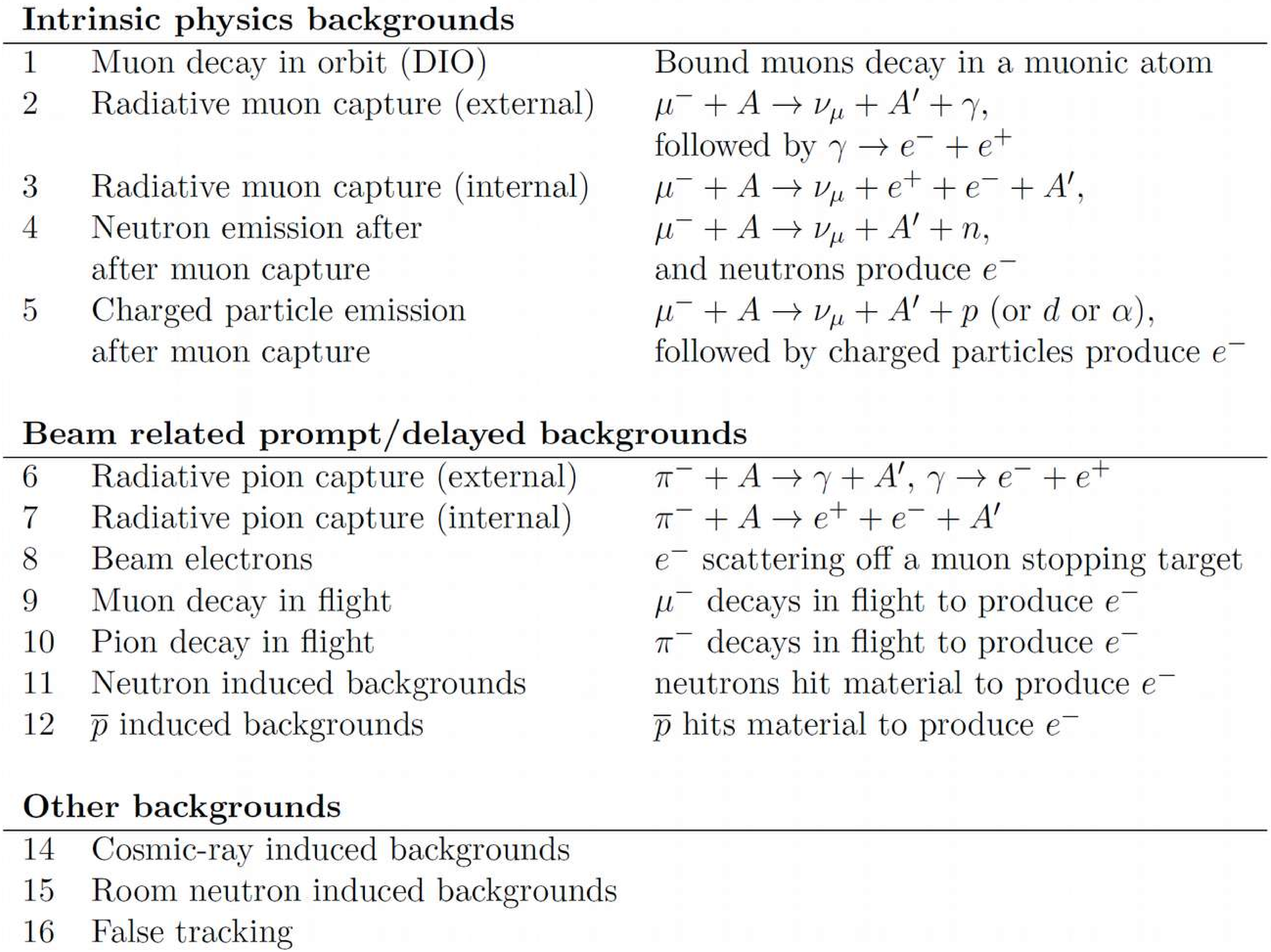
Conclusions

- Charged Lepton Flavour Violation is one of the most sensitive probes to physics beyond the Standard Model
- Muon-to-electron conversion offers a huge potential increase in sensitivity
- COMET is a next-generation muon-to-electron conversion experiment being built at J-PARC
- A staged construction scenario is being implemented, in which Phase-I allows us to study the novel pion production and muon transport system and make CLFV measurements
- The instrumentation concepts are fixed:
  - **StrECAL: straw-tracker and crystal ECAL for beam and background measurements**
  - **CyDet: drift chamber and triggering hodoscope for CLFV measurements**
- Design optimisations are ongoing

Yoshi.Uchida@imperial.ac.uk – COMET

I could not find **CLFV** in Northern California....

Summary of Backgrounds



Intrinsic physics backgrounds

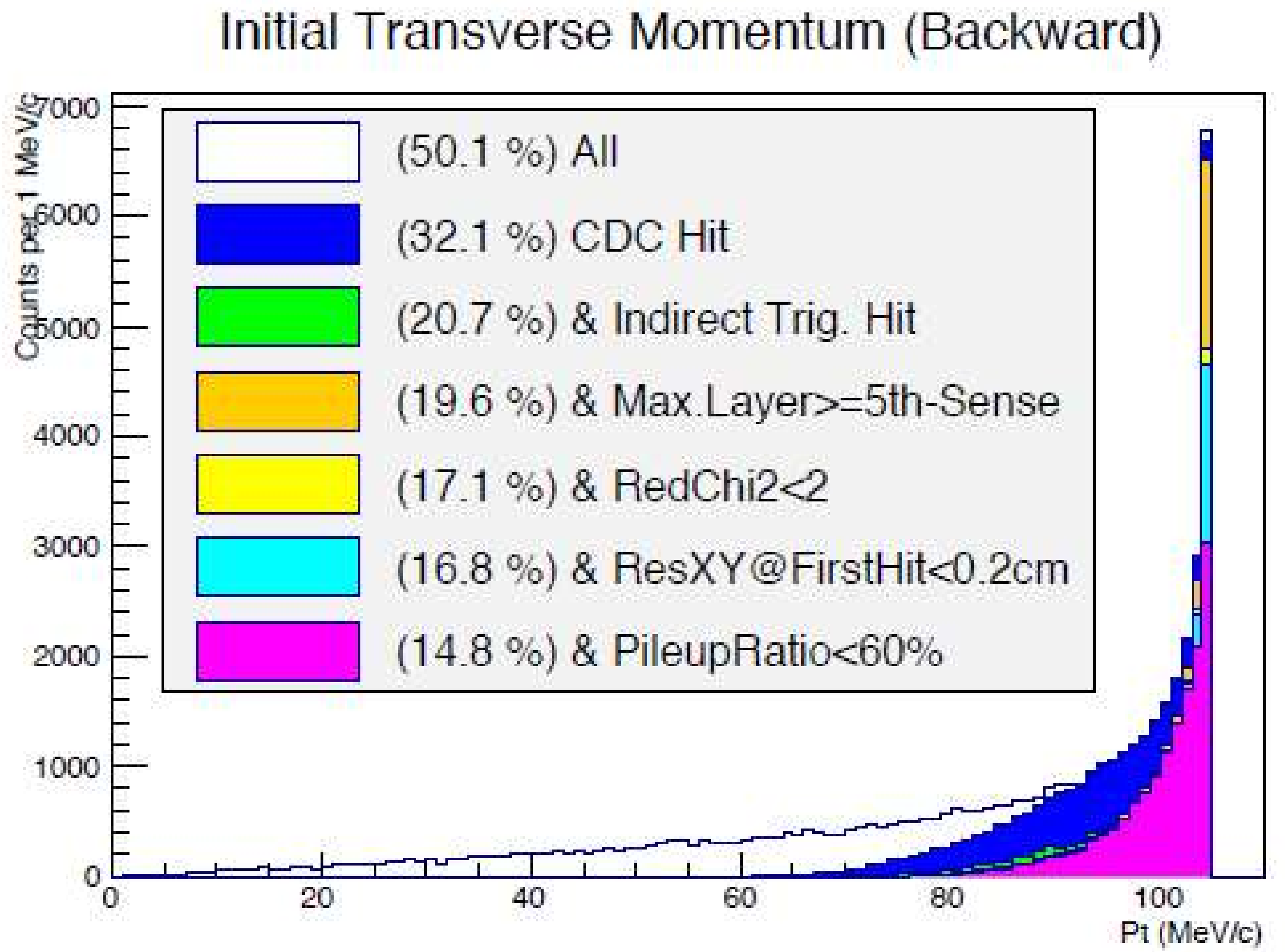
1	Muon decay in orbit (DIO)	Bound muons decay in a muonic atom
2	Radiative muon capture (external)	$\mu^- + A \to \nu_\mu + A' + \gamma$, followed by $\gamma \to e^- + e^+$
3	Radiative muon capture (internal)	$\mu^- + A \to \nu_\mu + e^+ + e^- + A'$,
4	Neutron emission after after muon capture	$\mu^- + A \to \nu_\mu + A' + n$, and neutrons produce e^-
5	Charged particle emission after muon capture	$\mu^- + A \to \nu_\mu + A' + p$ (or d or α), followed by charged particles produce e^-

Beam related prompt/delayed backgrounds

6	Radiative pion capture (external)	$\pi^- + A \to \gamma + A'$, $\gamma \to e^- + e^+$
7	Radiative pion capture (internal)	$\pi^- + A \to e^+ + e^- + A'$
8	Beam electrons	e^- scattering off a muon stopping target
9	Muon decay in flight	μ^- decays in flight to produce e^-
10	Pion decay in flight	π^- decays in flight to produce e^-
11	Neutron induced backgrounds	neutrons hit material to produce e^-
12	$\overline{p}$ induced backgrounds	$\overline{p}$ hits material to produce e^-

Other backgrounds

14	Cosmic-ray induced backgrounds
15	Room neutron induced backgrounds
16	False tracking



Event selection	Value
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Momentum selection	0.97
Timing window	0.3
Trigger efficiency	0.8
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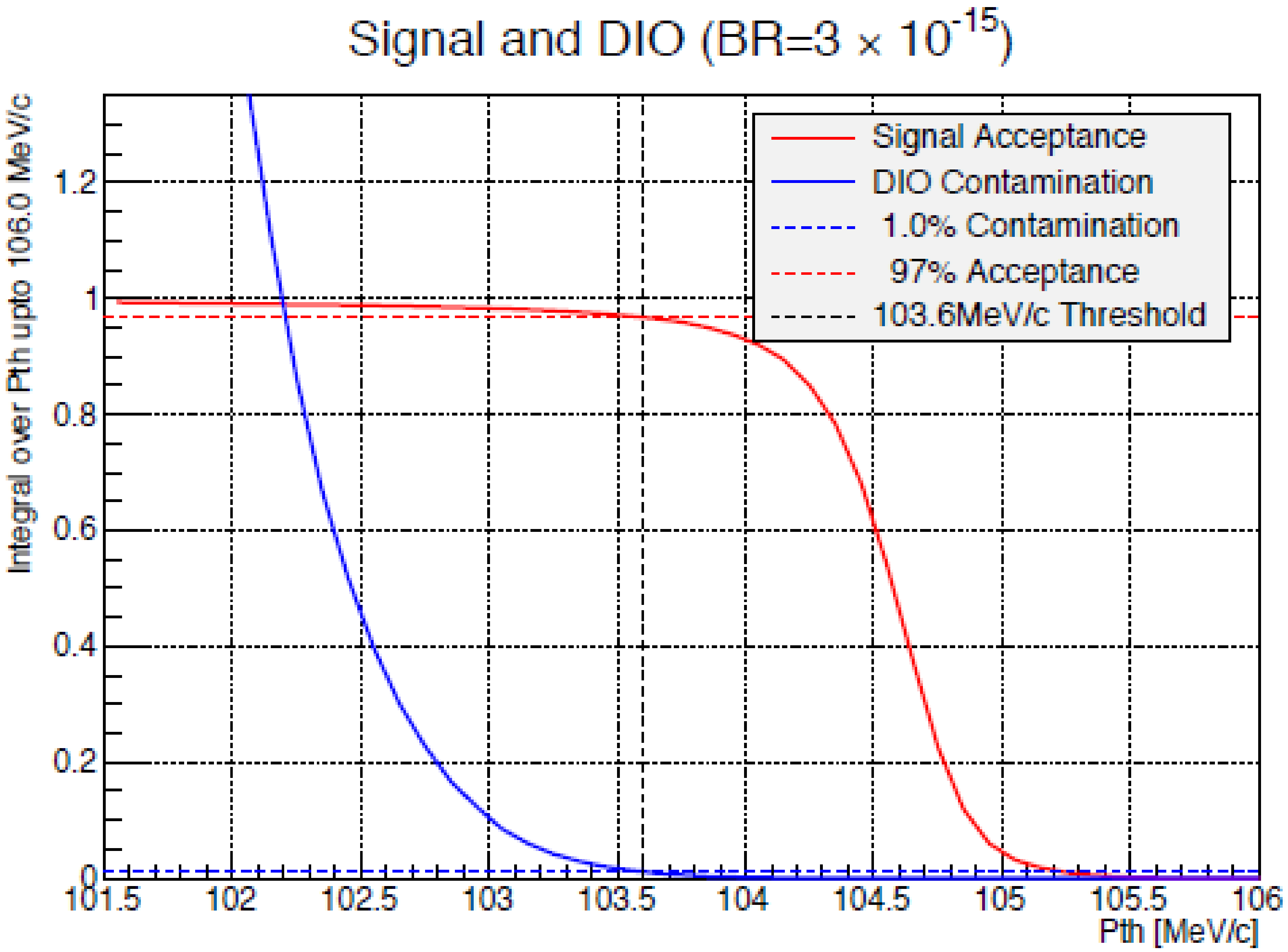
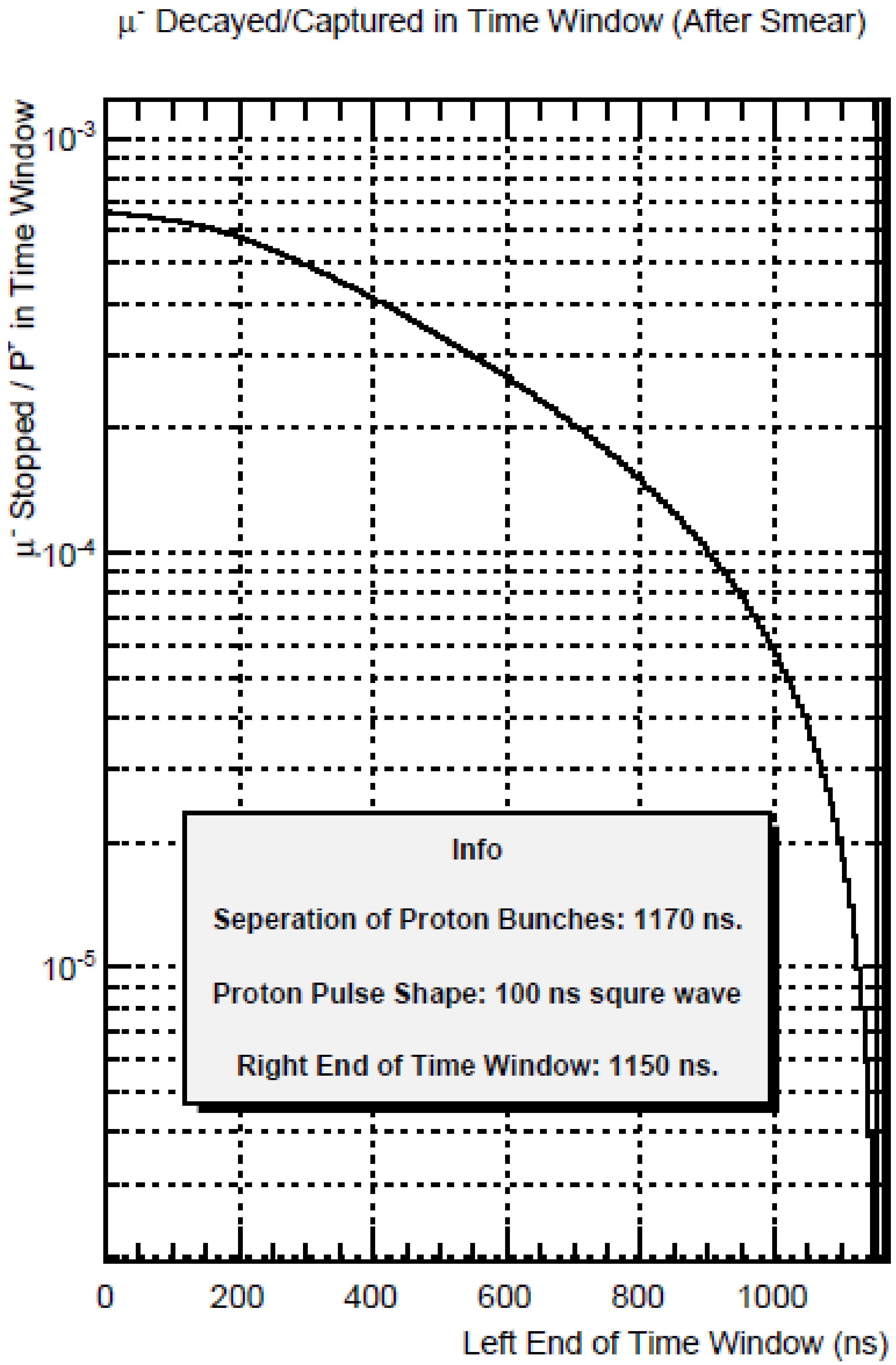
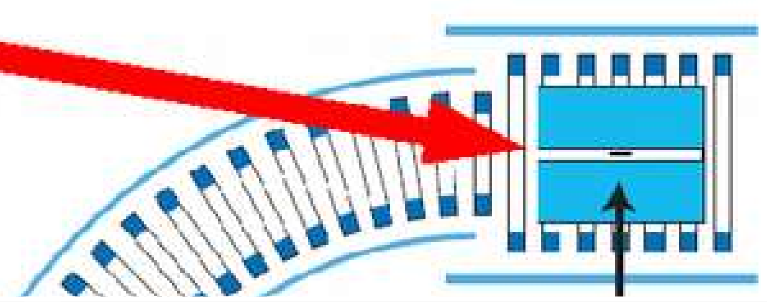
Track reconstruction efficiency	0.8

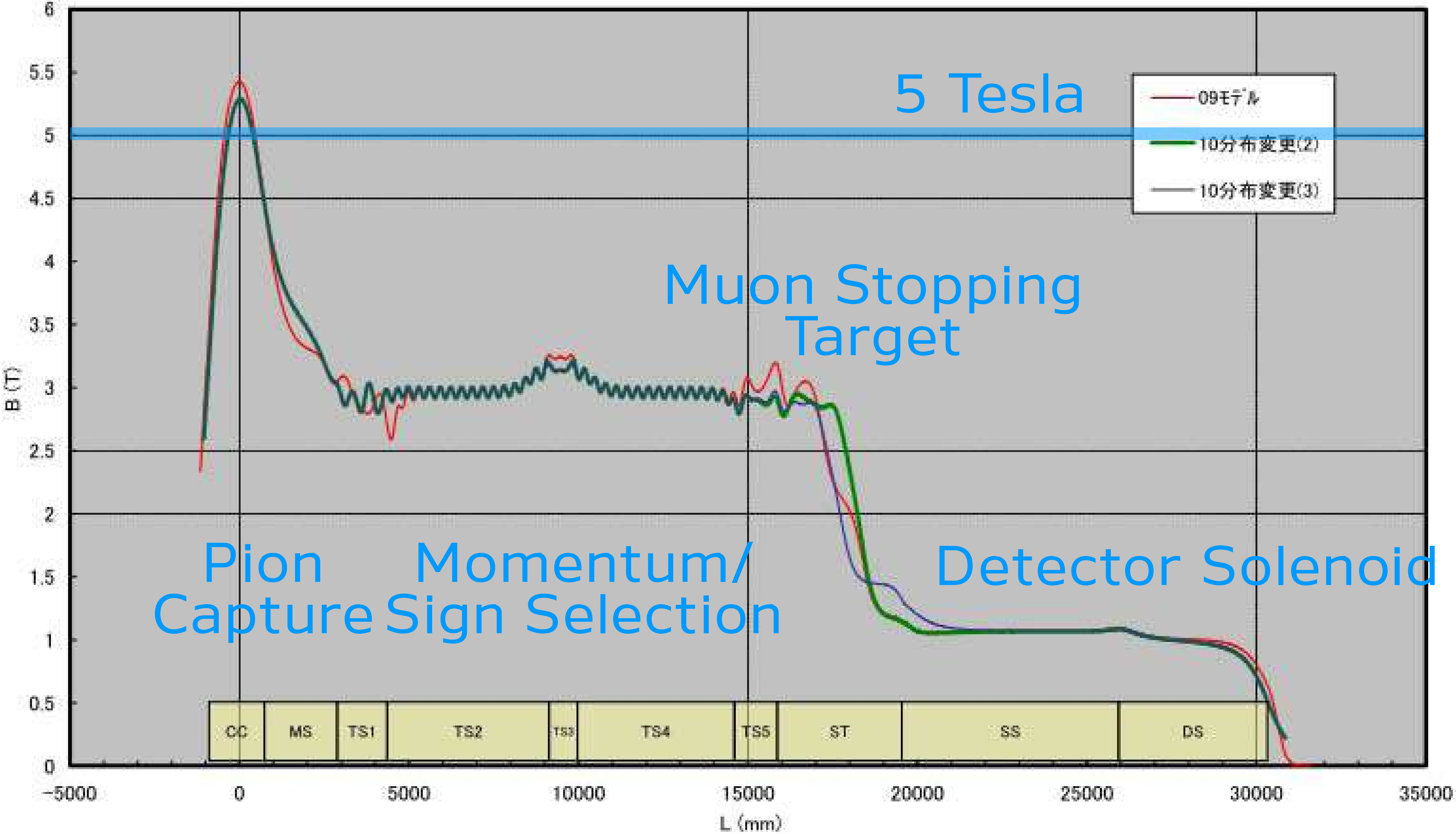




8 GeV
Proton



Pion Production Target and
Superconducting Pion
Capture



5 Tesla

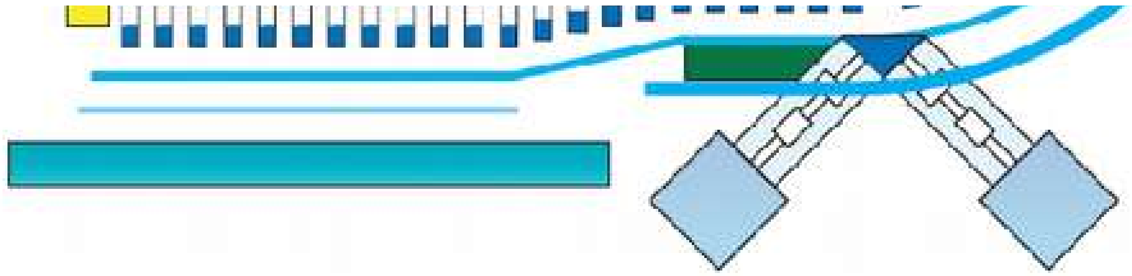
Muon Stopping
Target

Pion
Capture

Momentum/
Sign Selection

Detector Solenoid

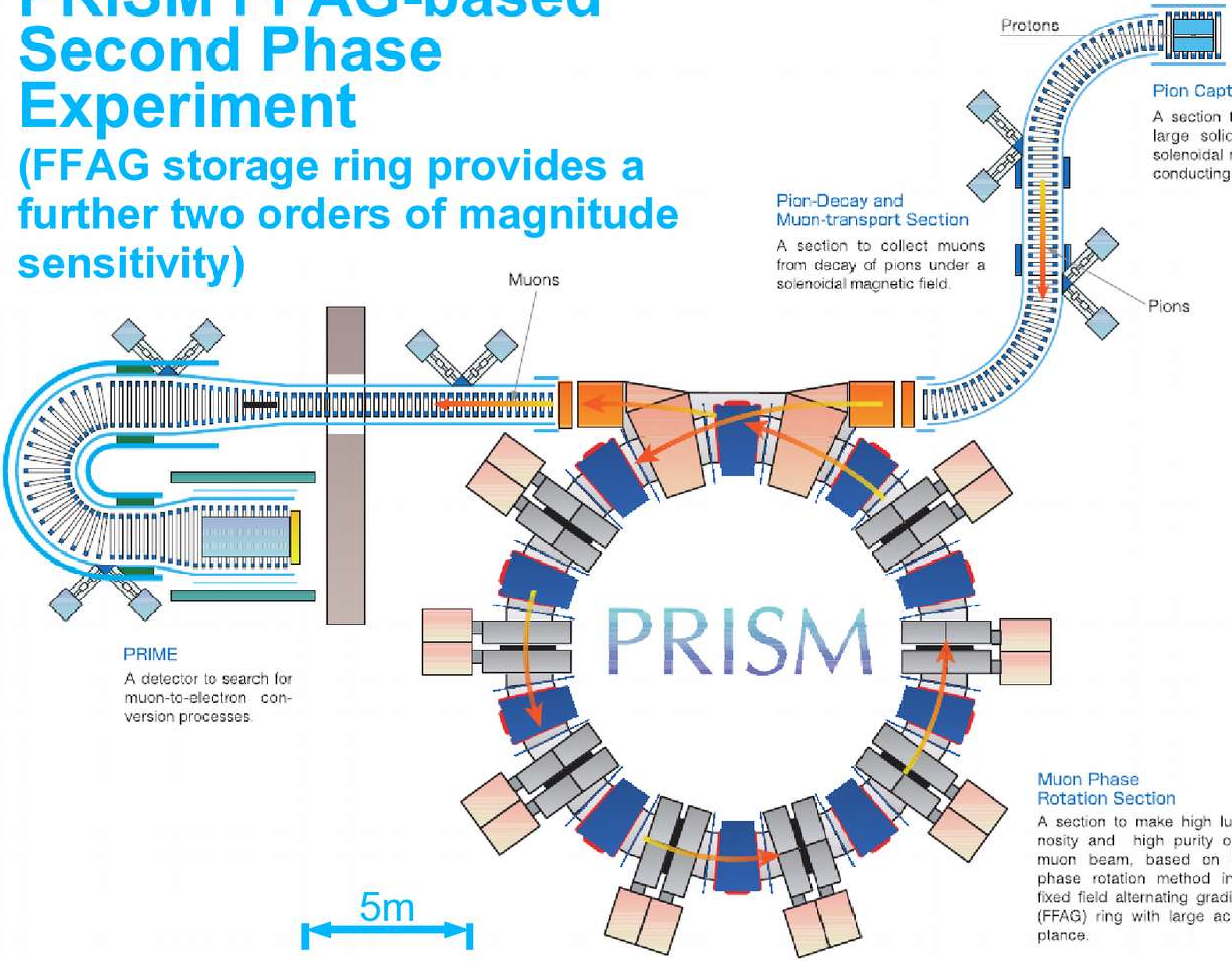
Detector section
for signal electrons



MuSIC Facility at RCNP, Osaka

PRISM FFAG-based Second Phase Experiment

(FFAG storage ring provides a further two orders of magnitude sensitivity)



Pion Capture Section

A section to capture pions with a large solid angle under a high solenoidal magnetic field by superconducting magnet.

Pion-Decay and Muon-transport Section

A section to collect muons from decay of pions under a solenoidal magnetic field.

PRIME

A detector to search for muon-to-electron conversion processes.

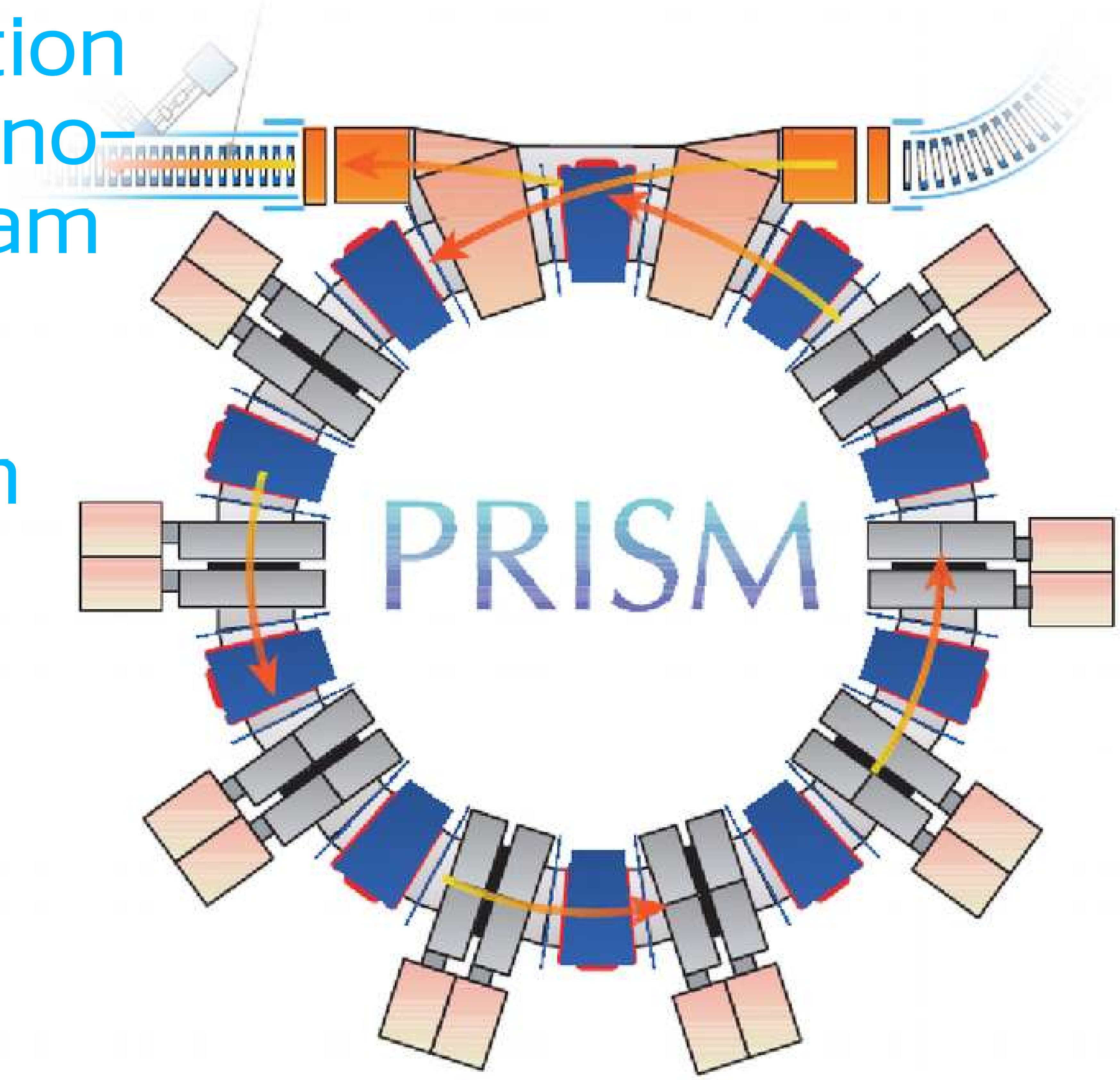
Muon Phase Rotation Section

A section to make high luminosity and high purity of a muon beam, based on the phase rotation method in a fixed field alternating gradient (FFAG) ring with large acceptance.

PRISM/FFAG

Muon Storage Ring

- high acceptance
  H: 40000 mm mrad
  V: 6500 mm mrad
- phase-rotation produces mono-energetic beam
- 8 turns gives a 150 m path length



PRISM/FFAG

Muon Storage Ring

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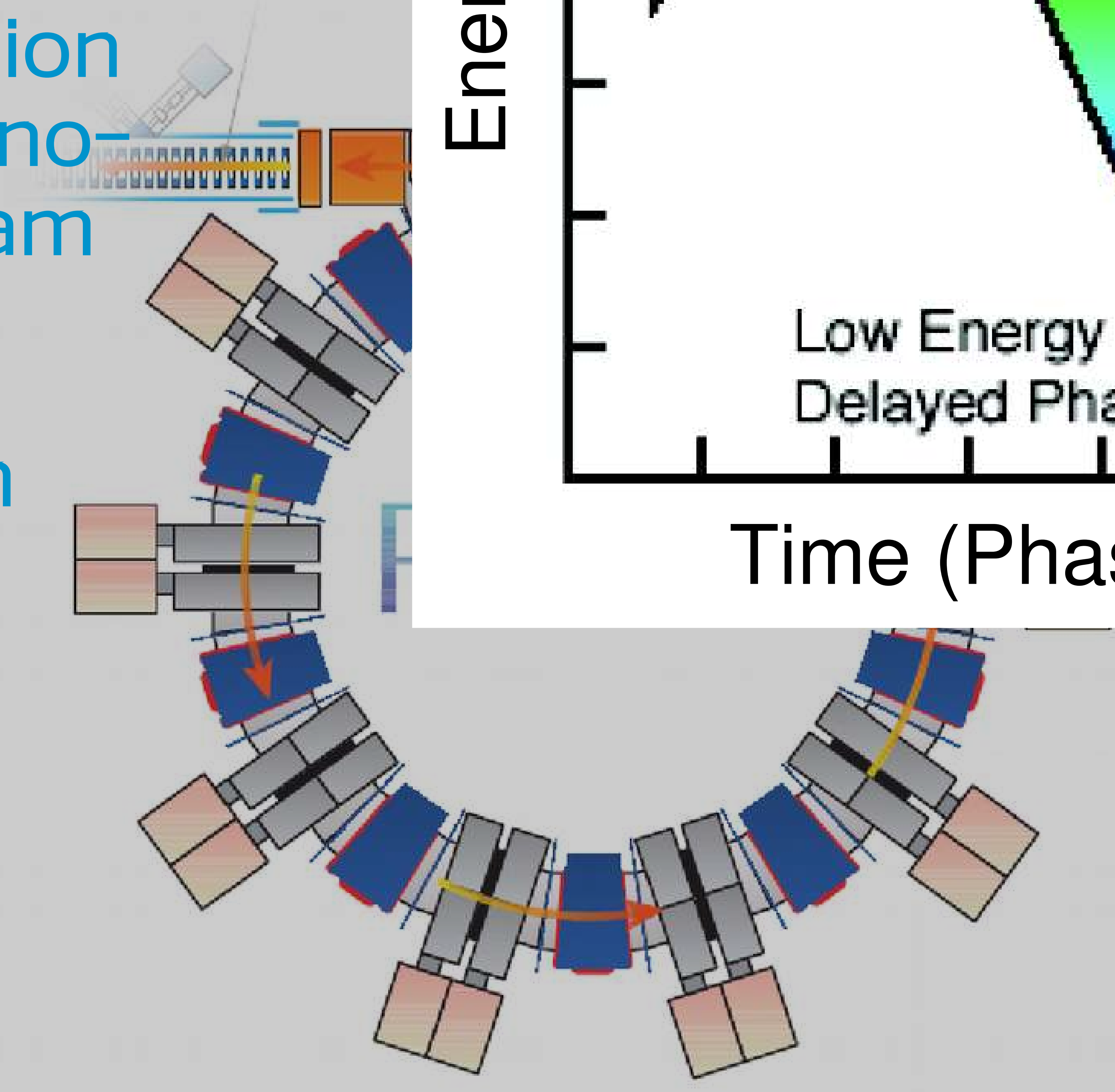
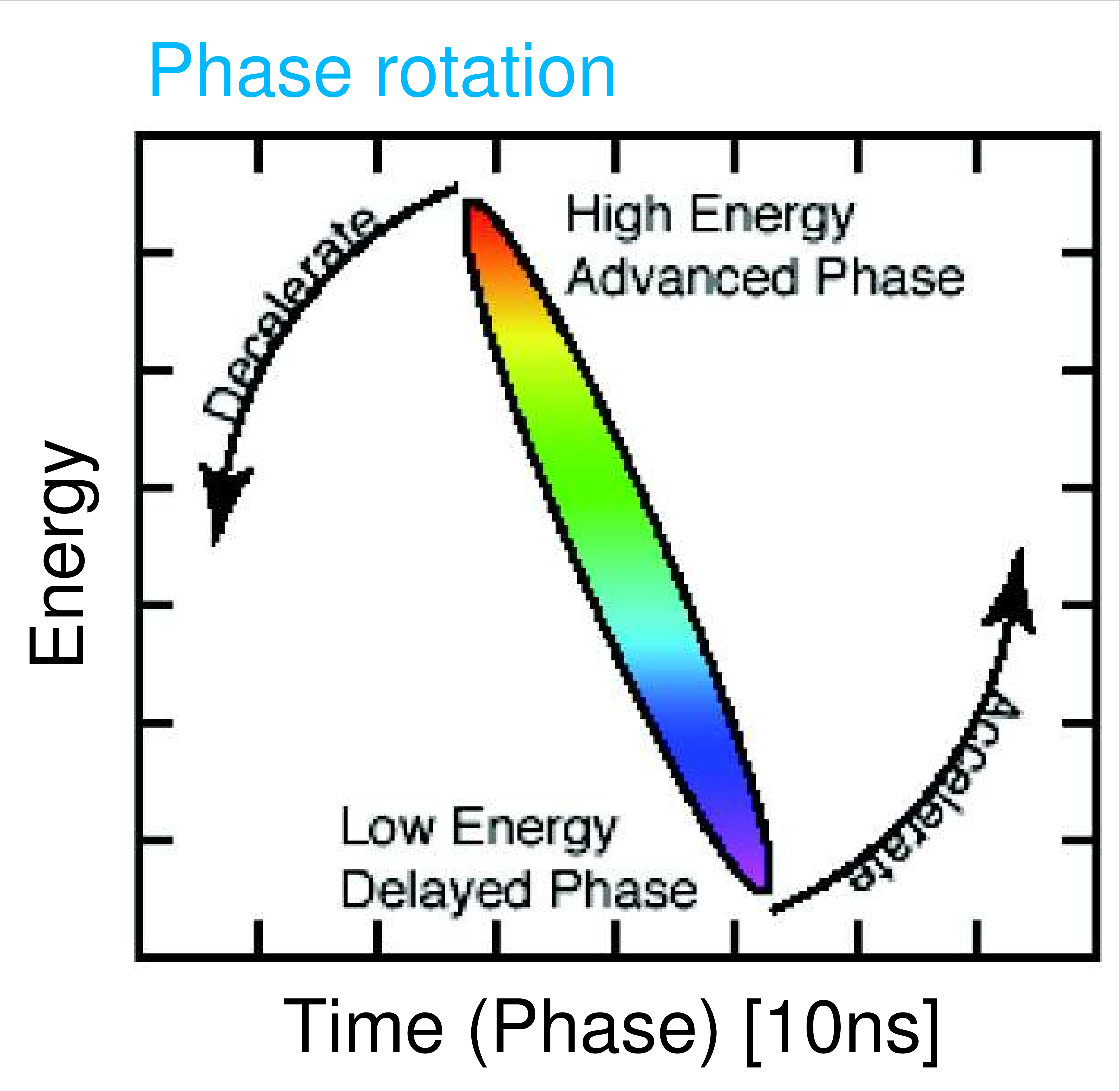




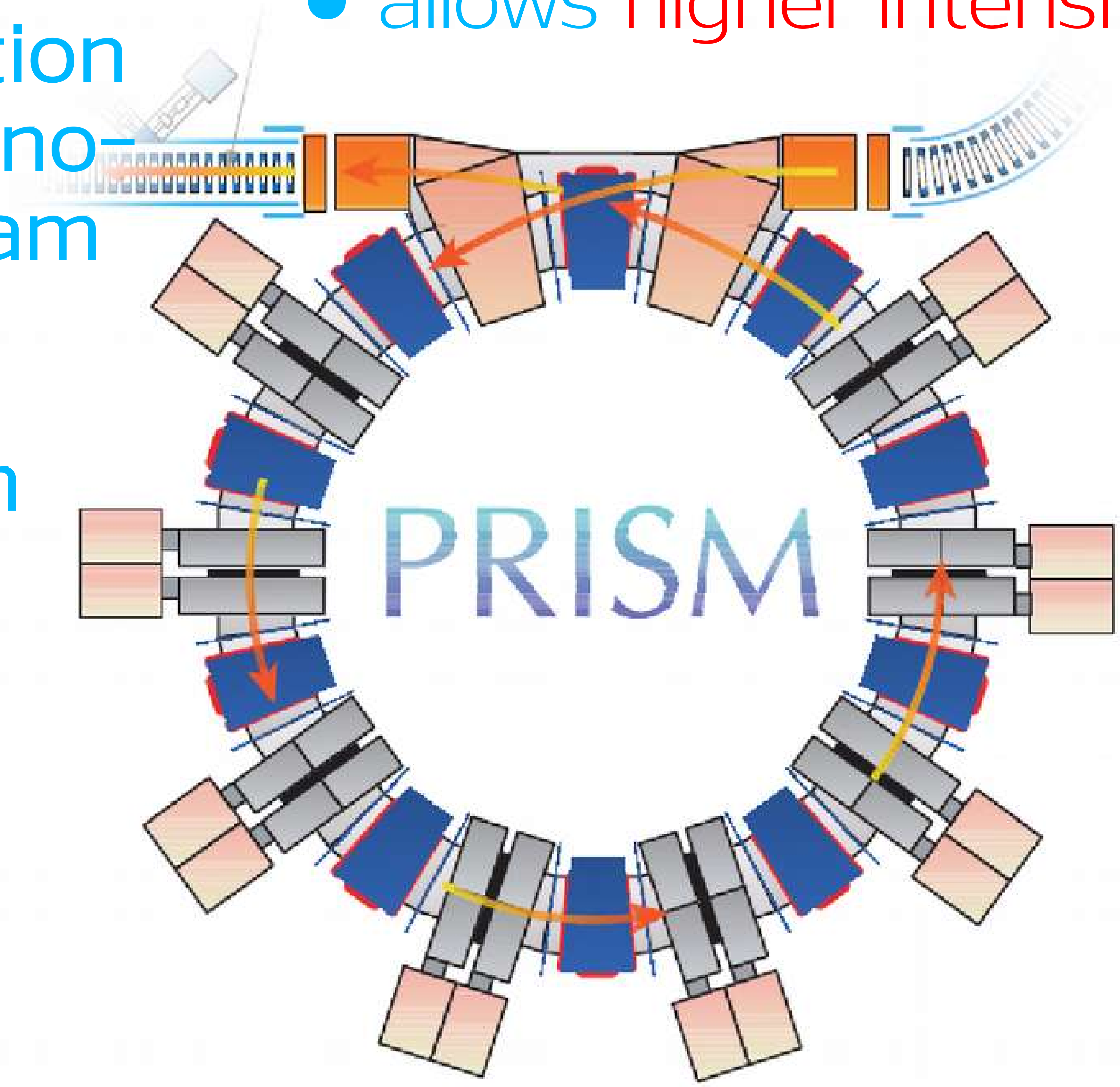
PRISM/FFAG

Muon Storage Ring

- high acceptance
  H: 40000 mm mrad
  V: 6500 mm mrad
- phase-rotation produces mono-energetic beam
- 8 turns gives a 150 m path length

Benefits:

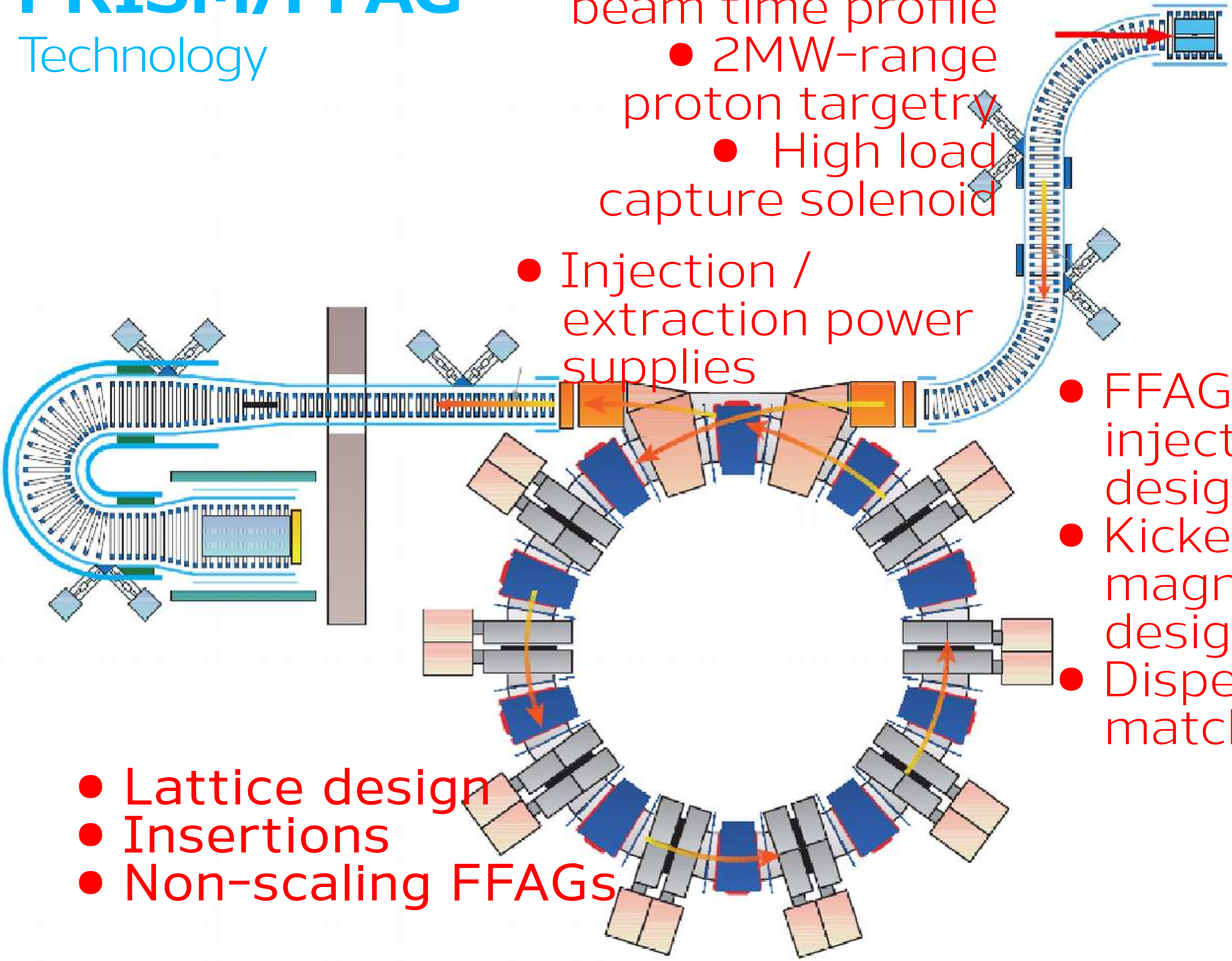
- narrow momentum spread allows for thinner, optimised stopping target
  long path length makes residual pions negligible (<10^{20})
- muon beam inter-bucket extinction
- allows higher intensity running



- lower duty cycle to reduce cosmic backgrounds
- stopping target materials with larger *Z*

PRISM/FFAG

Technology



- 10 ns proton beam time profile
- 2MW-range proton targetry
- High load capture solenoid
- Injection / extraction power supplies
- FFAG beam injection design
- Kicker magnet design
- Dispersion matching
- Lattice design
- Insertions
- Non-scaling FFAGs

The Previous Generation: SINDRUM-II

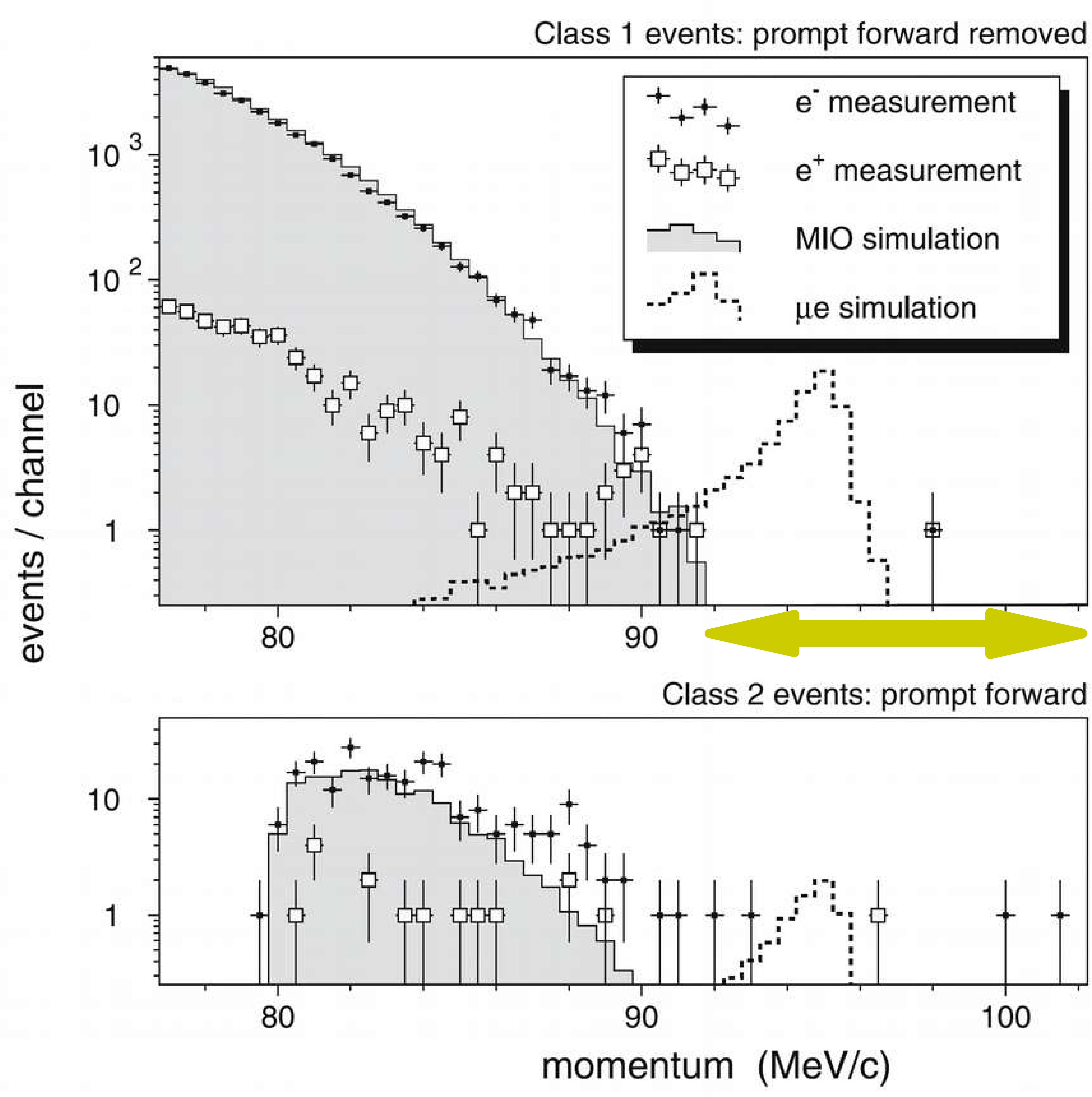
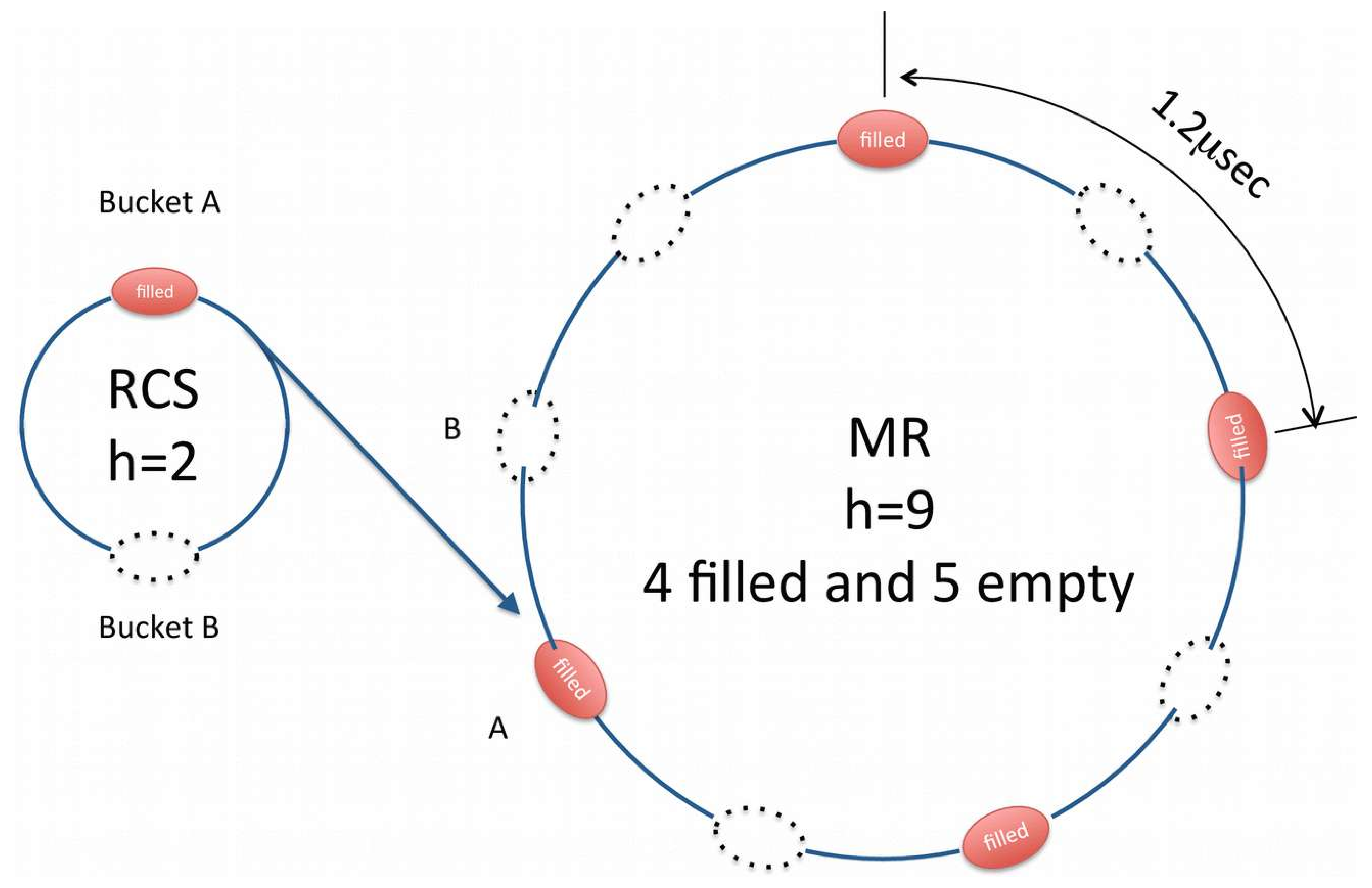


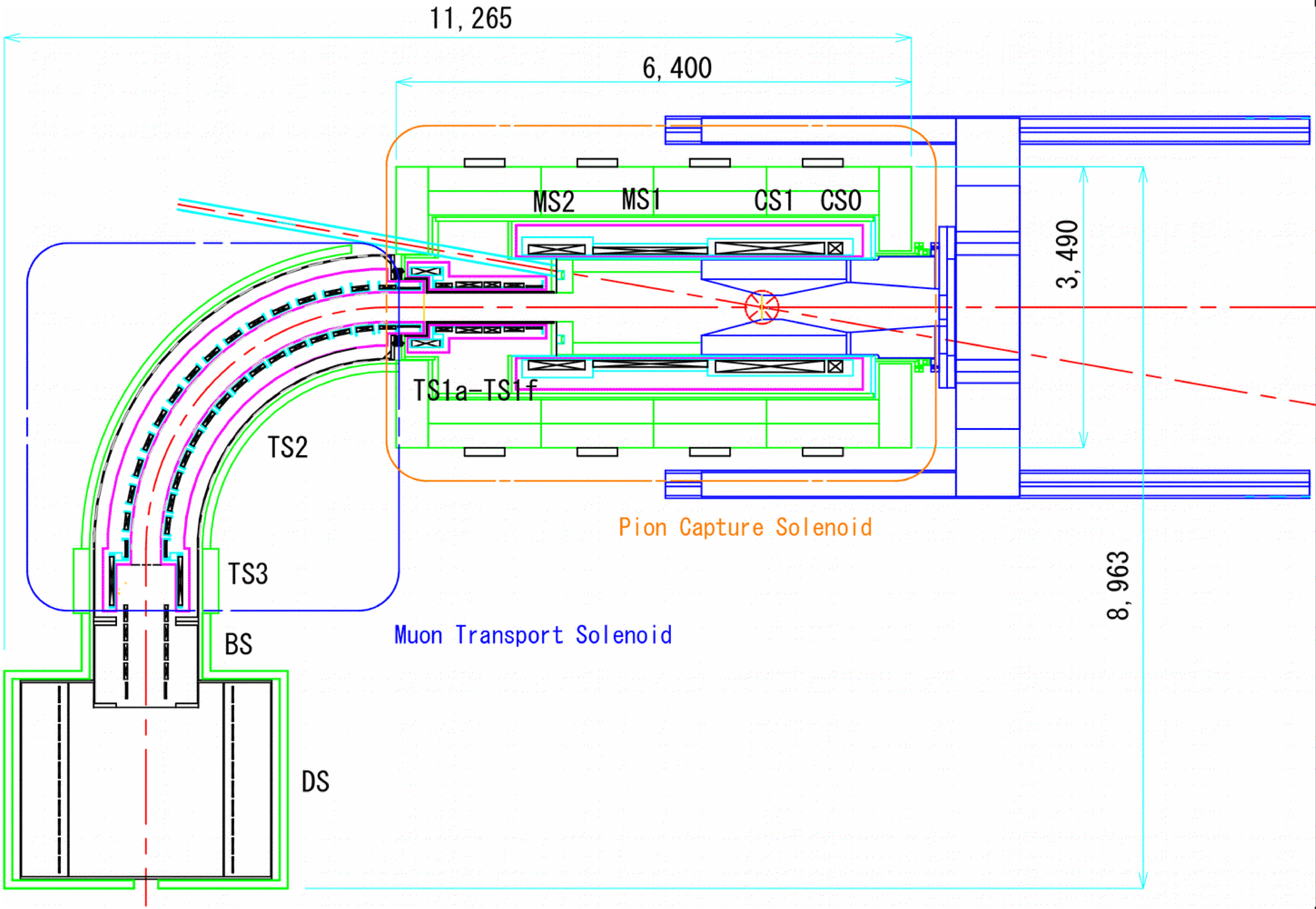
Fig. 11. Momentum distributions of electrons and positrons for the two event classes. Measured distributions are compared with the results of simulations of muon decay in orbit and $\mu - e$ conversion

on Gold
(binding energy 10 MeV)

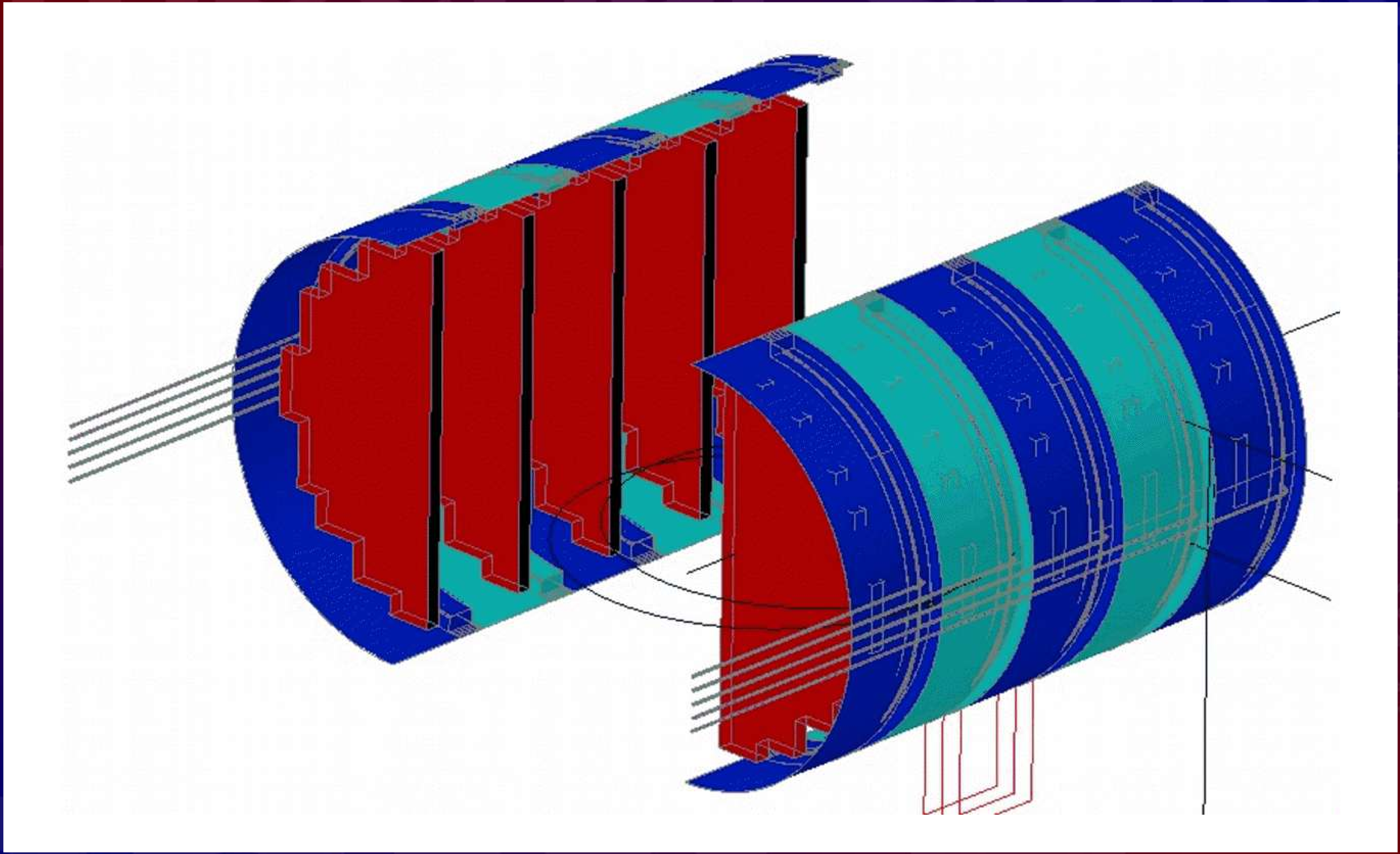
Eur. Phys. J. C 47, 337–346 (2006)

Proton Beam Acceleration Scheme

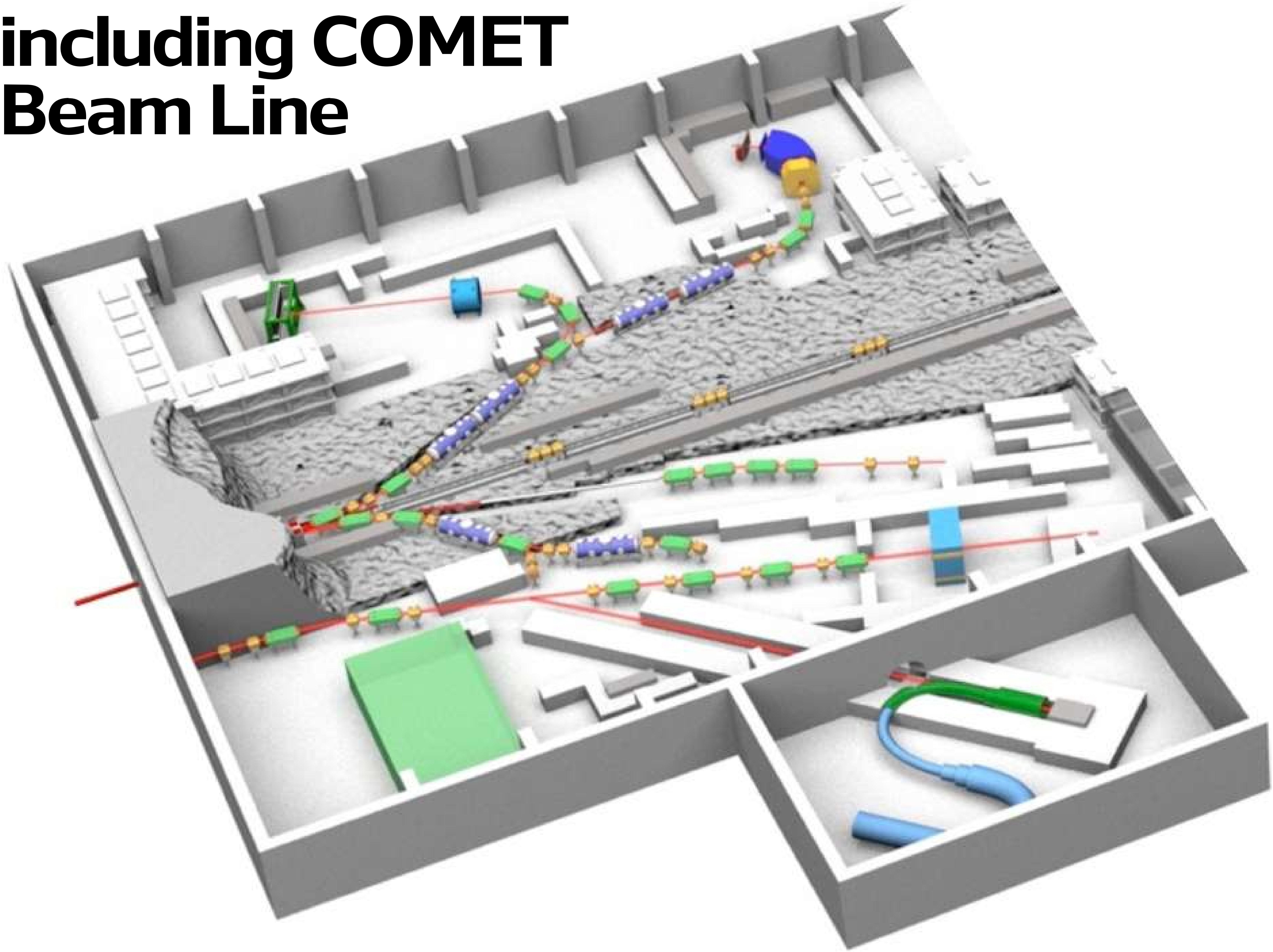



11,265
6,400
MS2
MS1
CS1
CS0
3,490
TS1a-TS1f
TS2
Pion Capture Solenoid
TS3
8,963
BS
Muon Transport Solenoid
DS

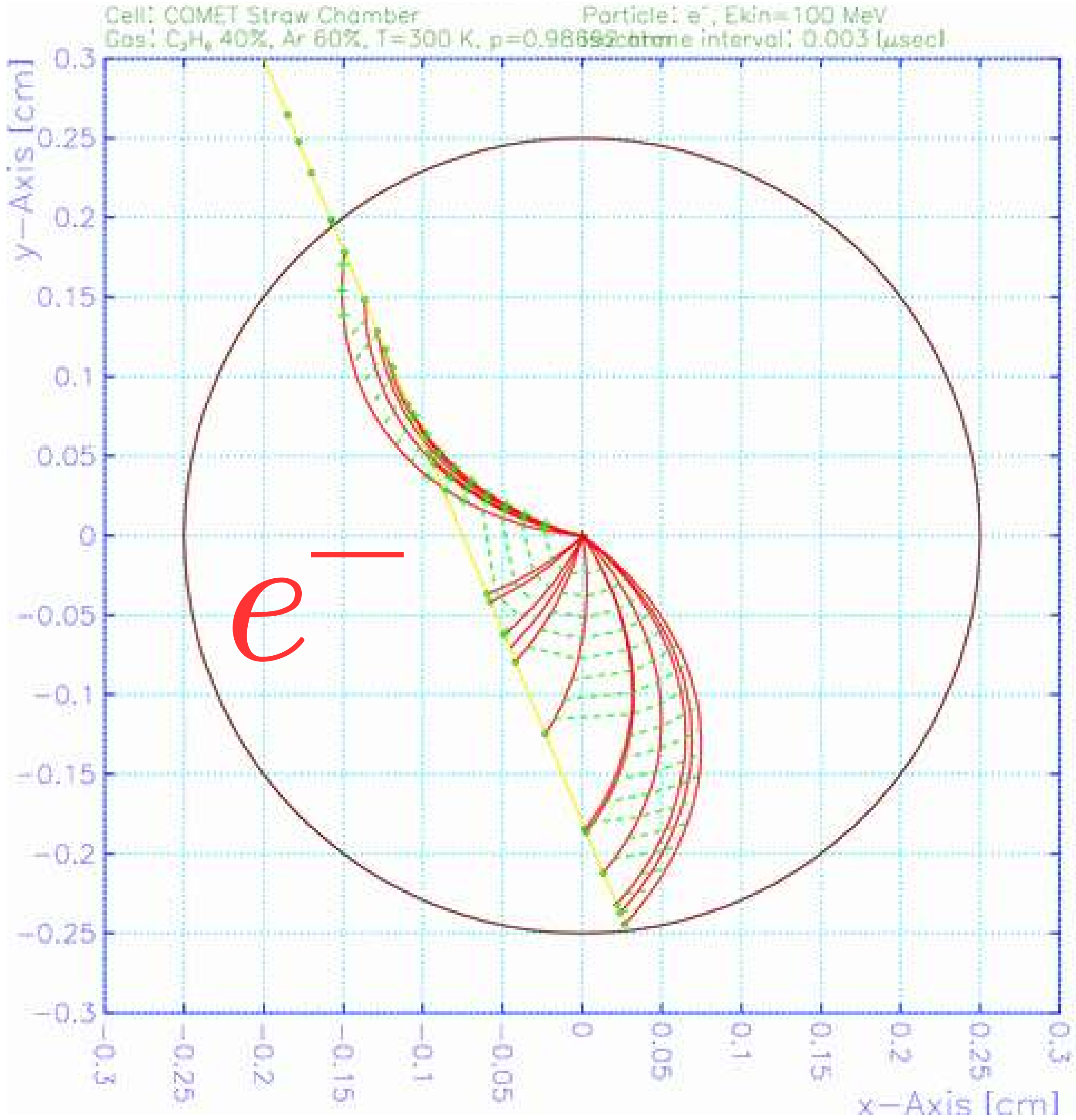
StrECAL: Straw Tracker

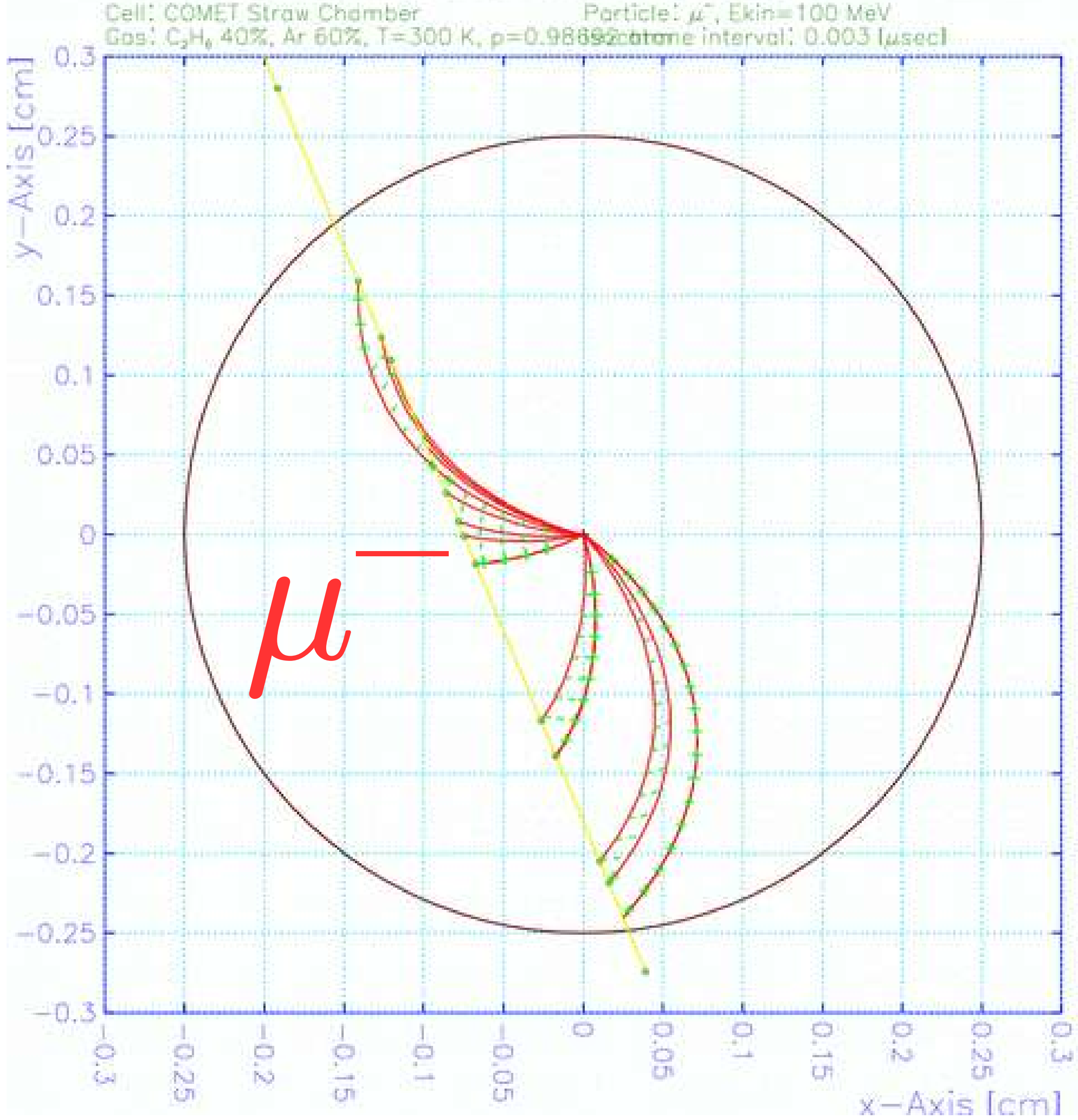


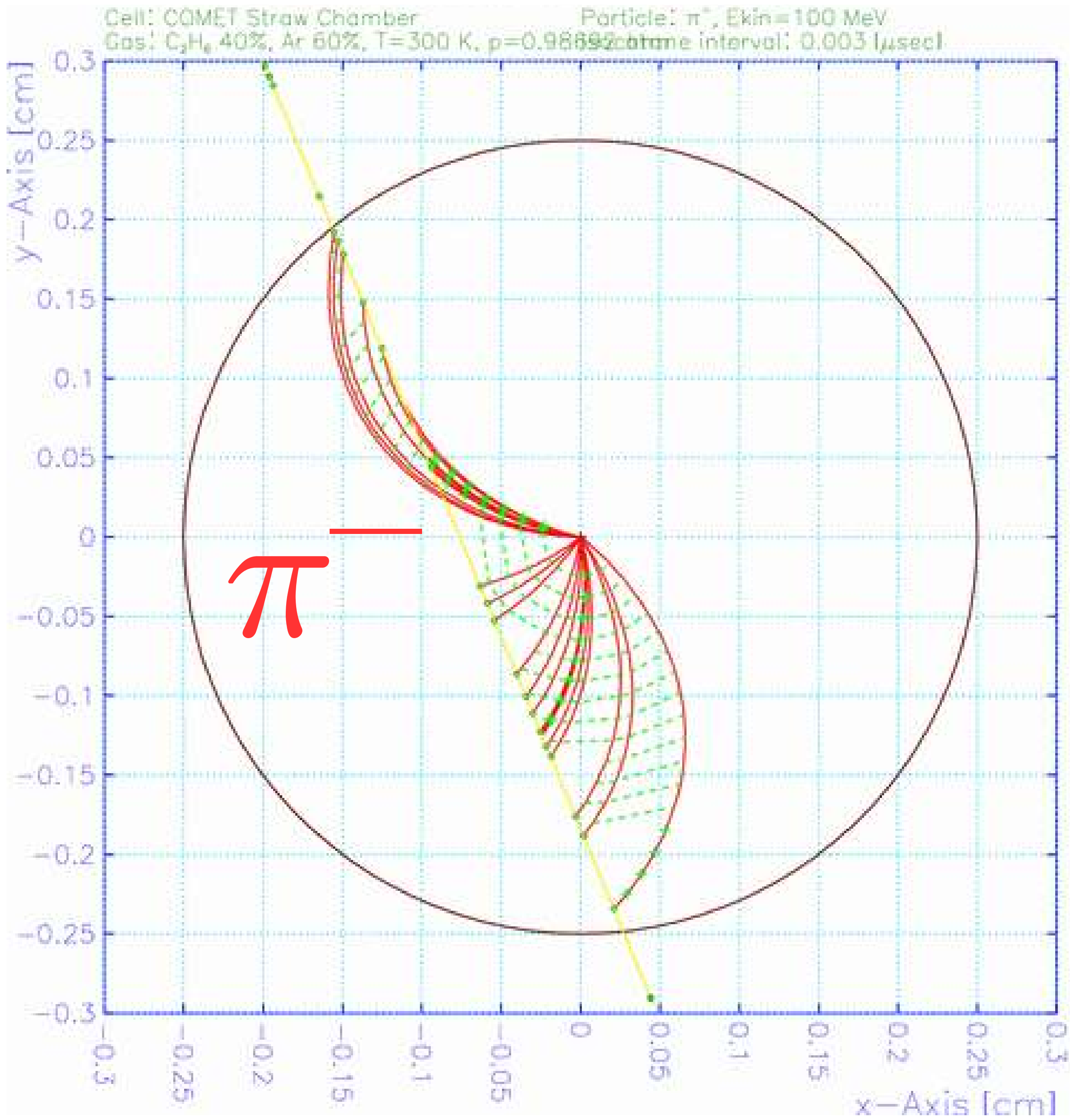
J-PARC Hadron Hall including COMET Beam Line

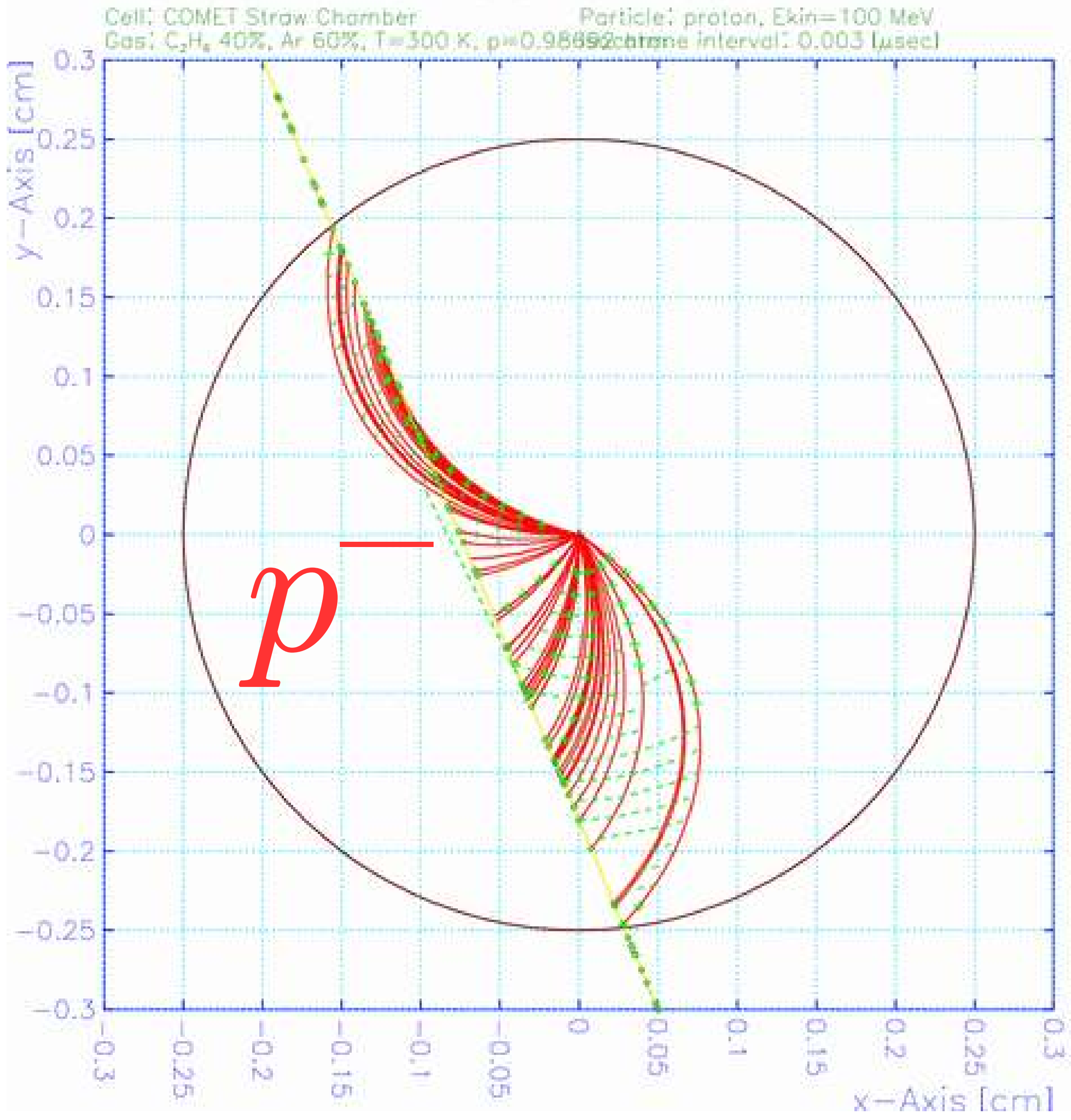


Straw Tracker Garfield Simulations









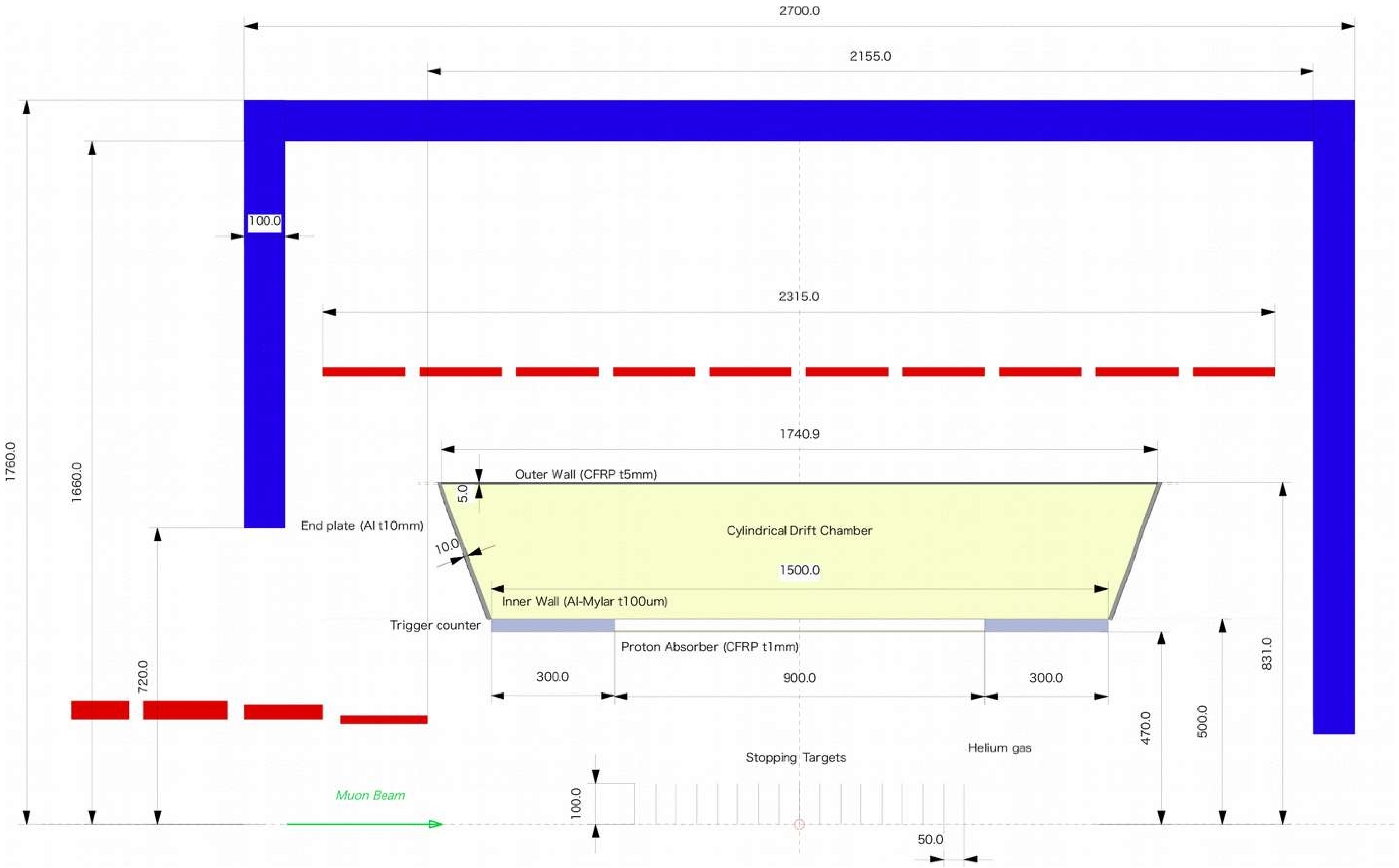
$E_e = 100$ MeV

Gas: C_2H_2 40%

Ar 60%

T = 300 K

COMET Phase-I: CyDet




Comet
AUG
California
CPFC