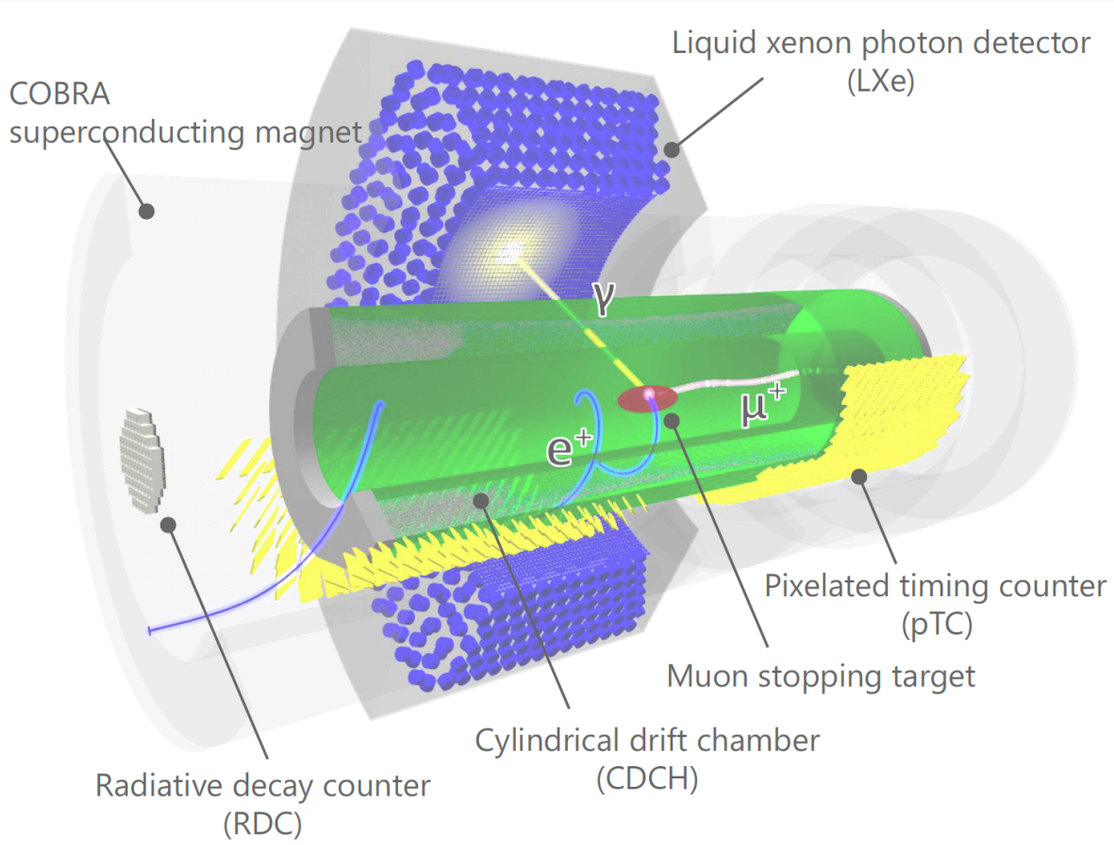
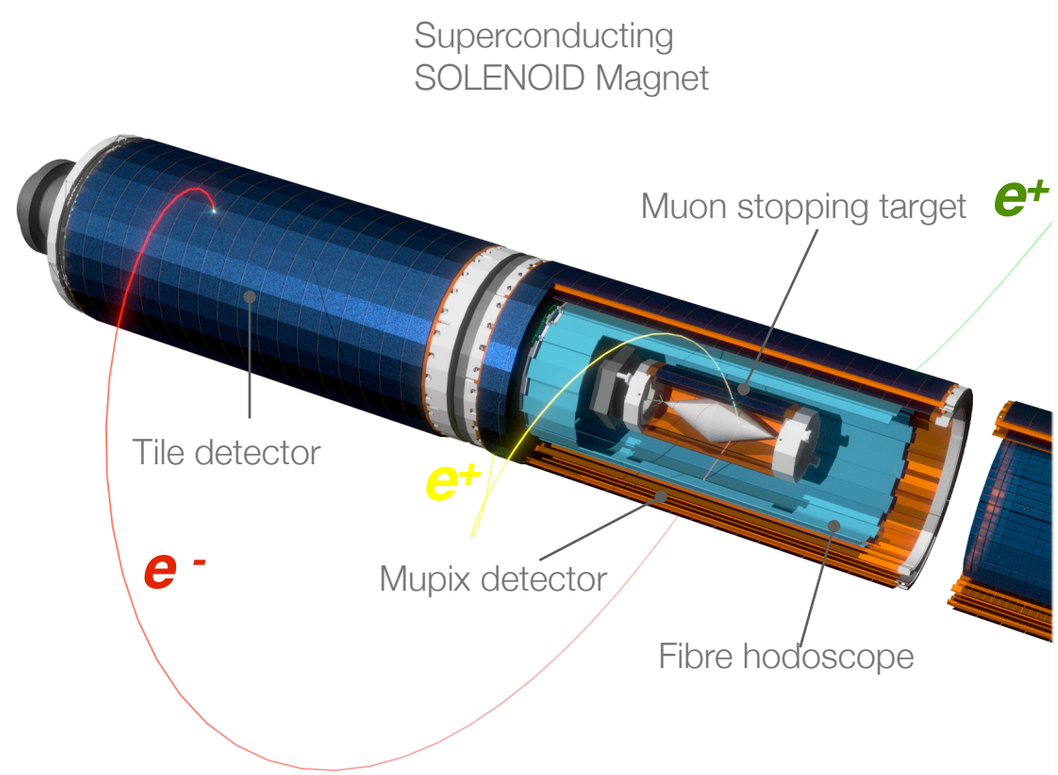
PAUL SCHERRER INSTITUT

Experimental status and prospects for mu->e experiments

Angela Papa, PSI
December 18-19, 2017
Impact of B->mu mu on New Physics Searches Workshop, PSI





Content

- Charged Lepton Flavour Violation (cLFV) search:
  The motivation

- The Most Intense DC and Pulsed Muon Beams in the World:
  Present and future prospects

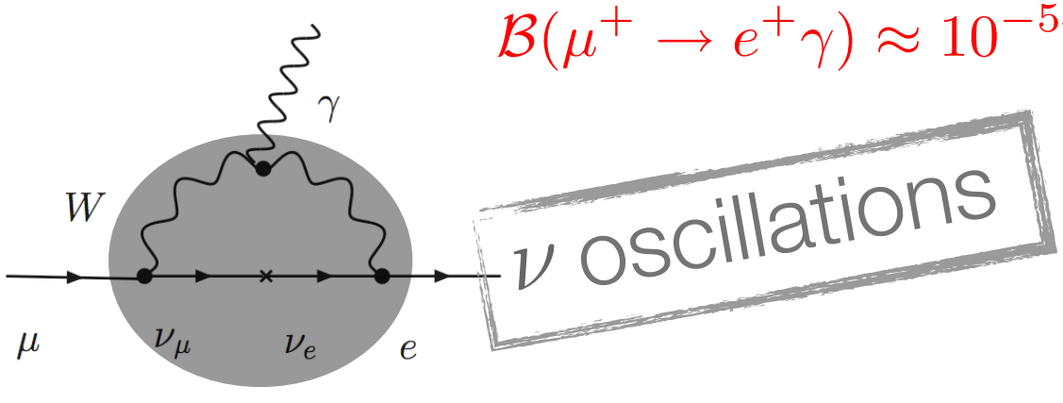
- cLFV with the MEG/MEGII and Mu3e at PSI:
  The $\mu^+ \to e^+\gamma$ and the $\mu^+ \to e^+e^+e^-$ searches

- cLFV with the Mu2e at FERMILAB and COMET at JPARC:
  The $\mu^- N \to e^- N$ search

Charged lepton flavour violation search: Motivation

SM with massive neutrinos (Dirac)

$\mathcal{B}(\mu^+ \to e^+\gamma) \approx 10^{-54}$

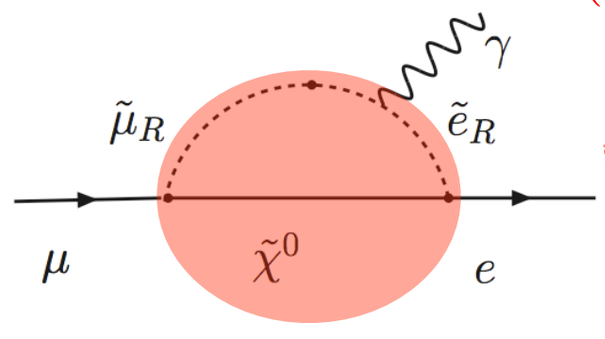


ν oscillations

too small to access experimentally

BSM

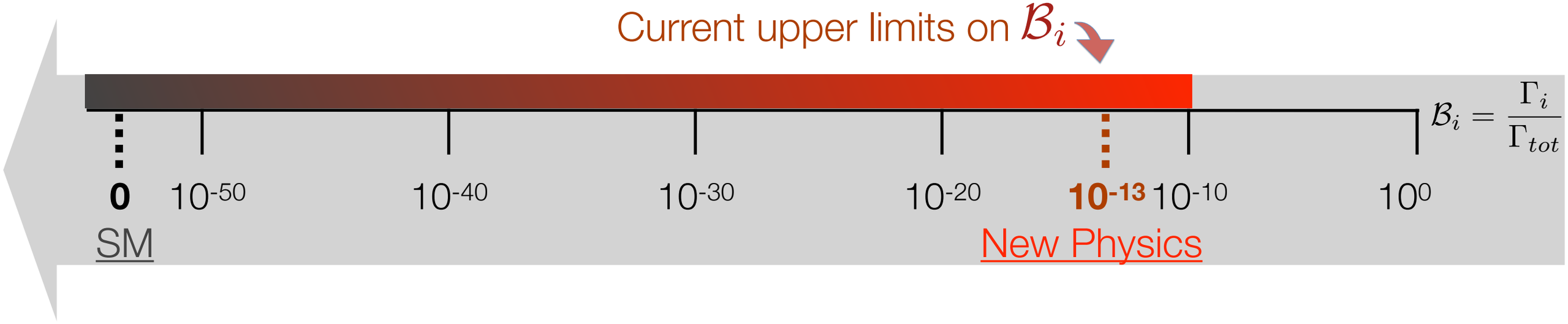
$\mathcal{B}(\mu^+ \to e^+\gamma) \gg 10^{-54}$



New particles

an experimental evidence:
a clear signature of New Physics NP
(SM background FREE)

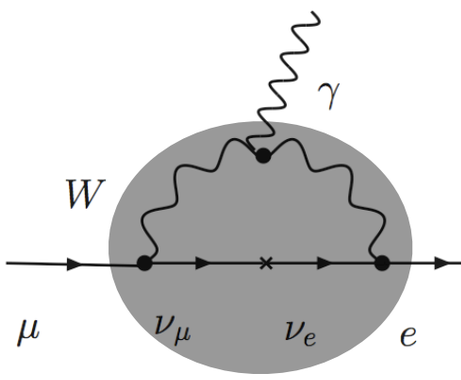
Current upper limits on $\mathcal{B}_i$



Charged lepton flavour violation search: Motivation

SM with massive neutrinos (Dirac)

$\mathcal{B}(\mu^+ \to e^+\gamma) \approx 10^{-54}$

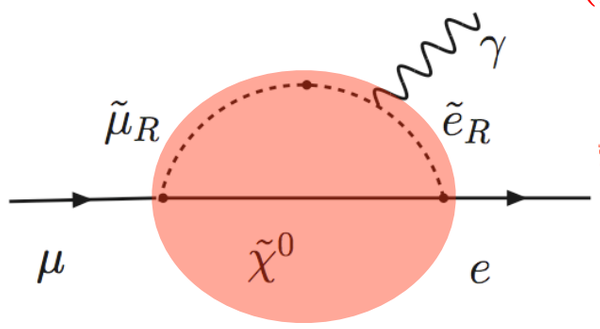


ν oscillations

too small to access experimentally

BSM

$\mathcal{B}(\mu^+ \to e^+\gamma) \gg 10^{-54}$

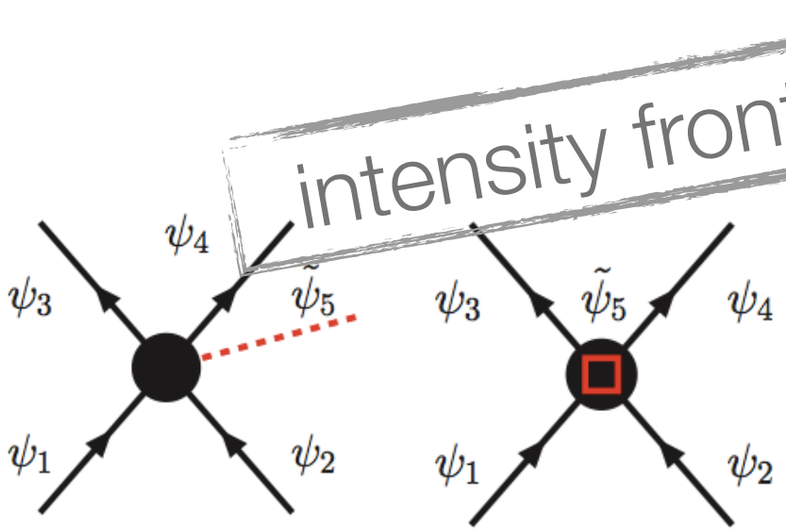


New particles

an experimental evidence:
a clear signature of New Physics NP
(SM background FREE)

to unveil behind SM physics
via virtual particles

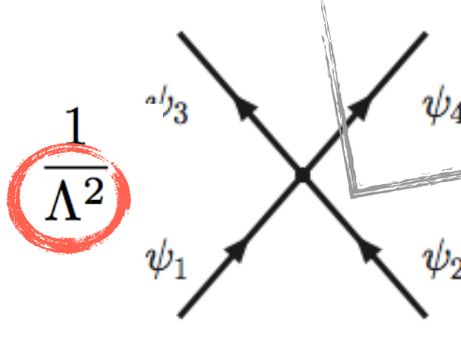
intensity frontier



to probe otherwise unreachable and
unexploited new physics energy scale

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{d>4} \frac{c_n^{(d)}}{\Lambda^{d-4}} \mathcal{O}^{(d)}$$

high energy probe

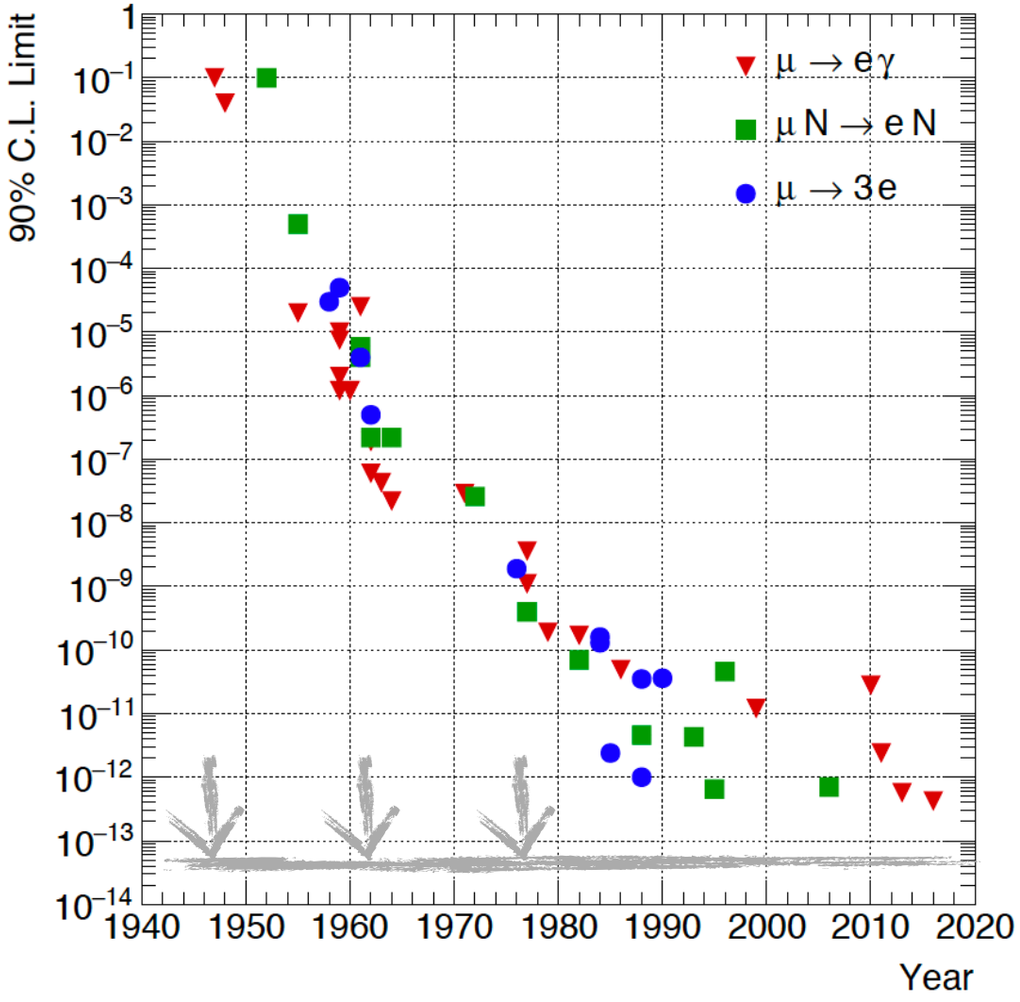


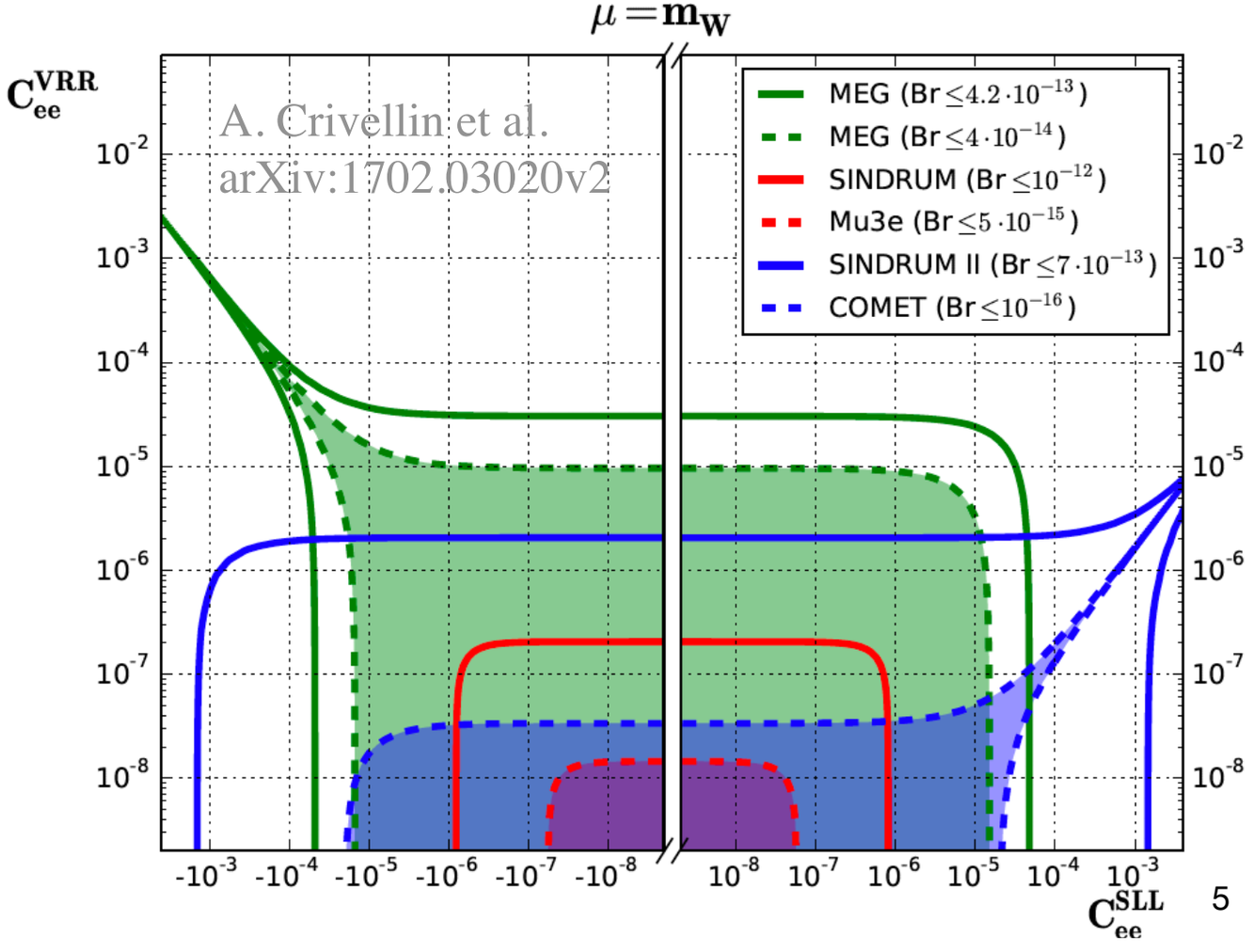
cLFV searches with muons: Status and prospects

- In the near future impressive sensitivities:

	Current upper limit	Future sensitivity
$\mu \to e\gamma$	4.2 x 10^{-13}	~ 4 x 10^{-14}
$\mu \to eee$	1.0 x 10^{-12}	~1.0 x 10^{-16}
$\mu N \to eN'$	7.0 x 10^{-13}	< 10^{-16}

- Strong complementarities among channels: The only way to reveal the mechanism responsible for cLFV



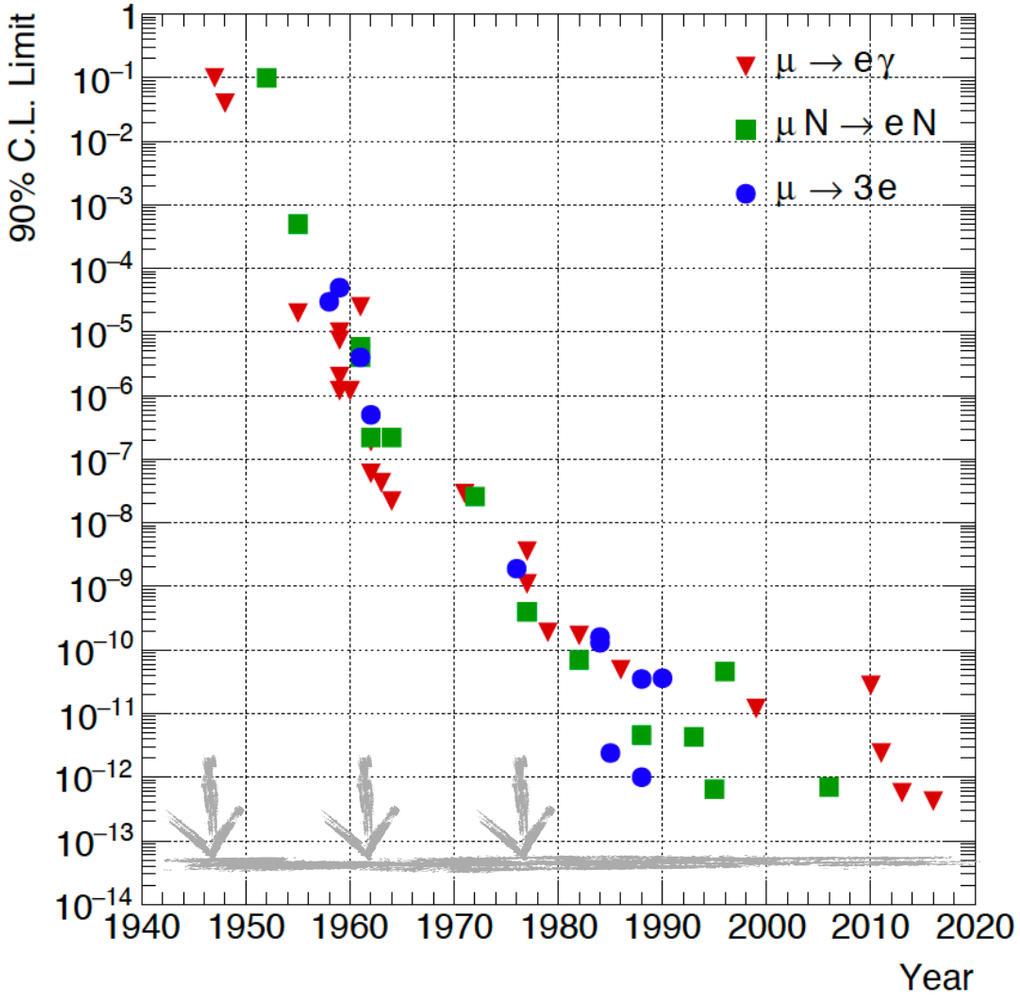


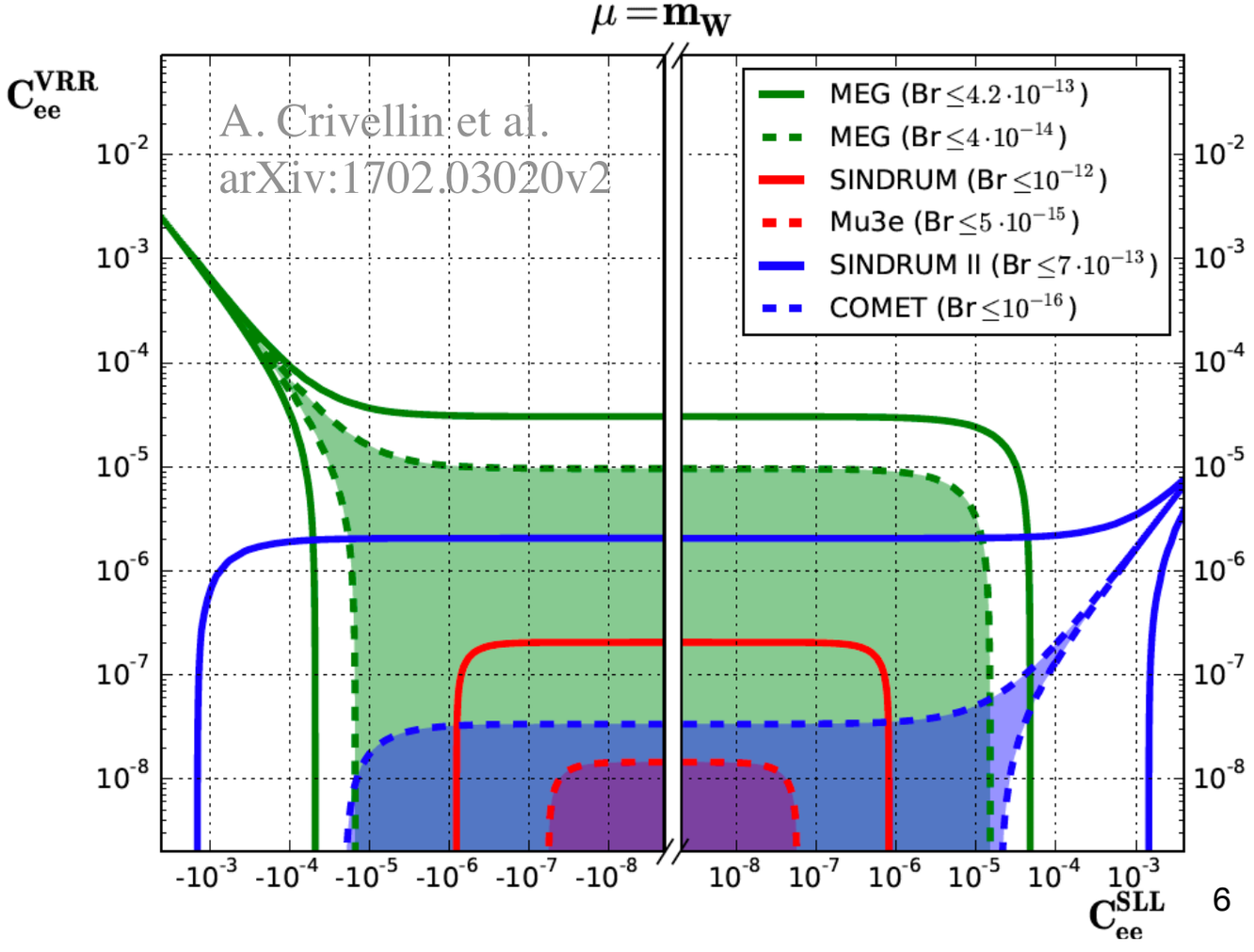
cLFV searches with muons: Status and prospects

- In the near future impressive sensitivities: **Set at PSI**

	Current upper limit	Future sensitivity
$\mu \to e\gamma$	4.2 x 10^{-13}	~ 4 x 10^{-14}
$\mu \to eee$	1.0 x 10^{-12}	~1.0 x 10^{-16}
$\mu N \to eN'$	7.0 x 10^{-13}	< 10^{-16}

- Strong complementarities among channels: The only way to reveal the mechanism responsible for cLFV





Beam features vs experiment requirements

- Dedicated beam lines for high precision and high sensitive SM test/BSM probe at the world's highest beam intensities

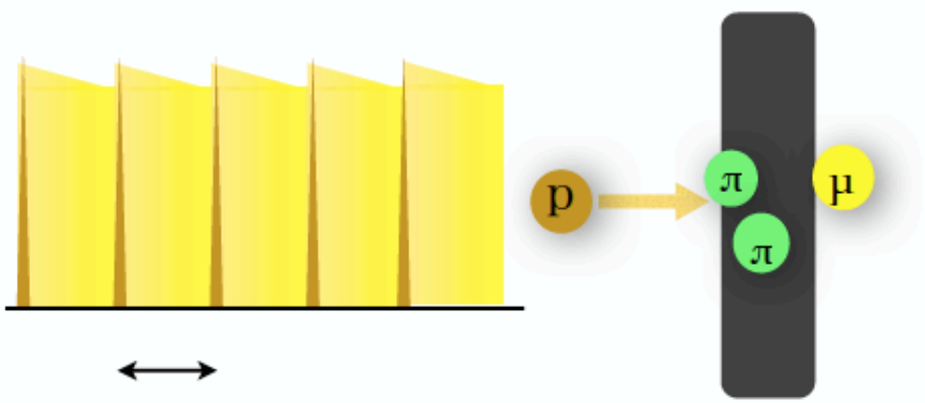
$I_{beam} \sim 10^8 - 10^{10}$ μ/s

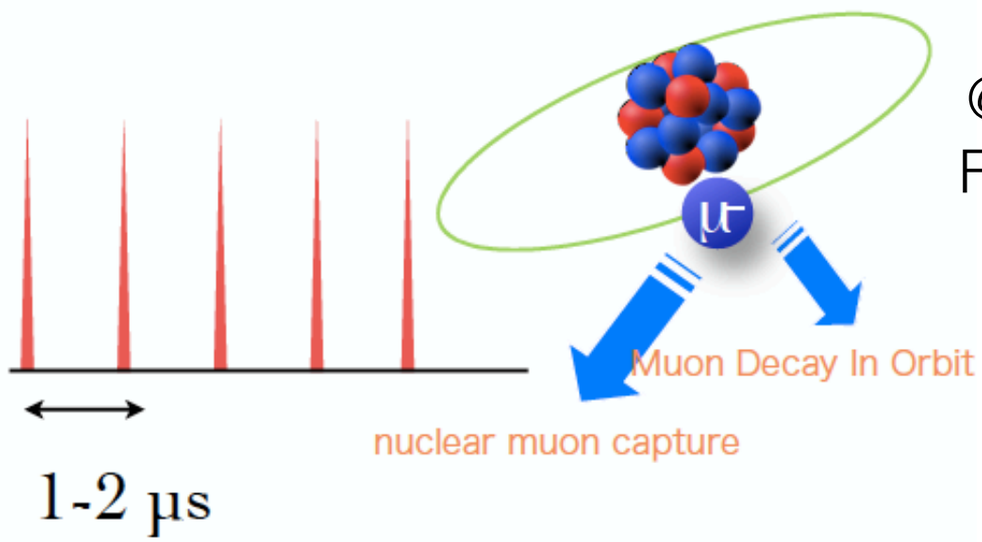
DC or Pulsed?

$I_{beam} \sim 10^{11}$ μ/s

- DC beam for coincidence experiments
  - $\mu \to e\gamma$, $\mu \to e\,e\,e$
- Pulse beam for non-coincidence experiments
  - μ-e conversion

@ PSI





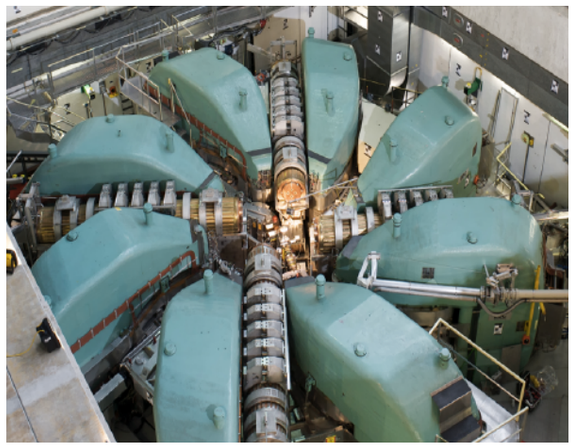
@ JPARC, FERMILAB

The world's most intense continuous muon beam

- τ ideal probe for NP w. r. t. μ
  - Smaller GIM suppression
  - Stronger coupling
  - Many decays
- μ most sensitive probe
  - Huge statistics

- PSI delivers the most intense continuous low momentum muon beam in the world (**Intensity Frontiers**)
- MEG/MEG II/Mu3e beam requirements:
  - Intensity O(10^8 muon/s), low momentum p = 29 MeV/c
  - Small straggling and good identification of the decay

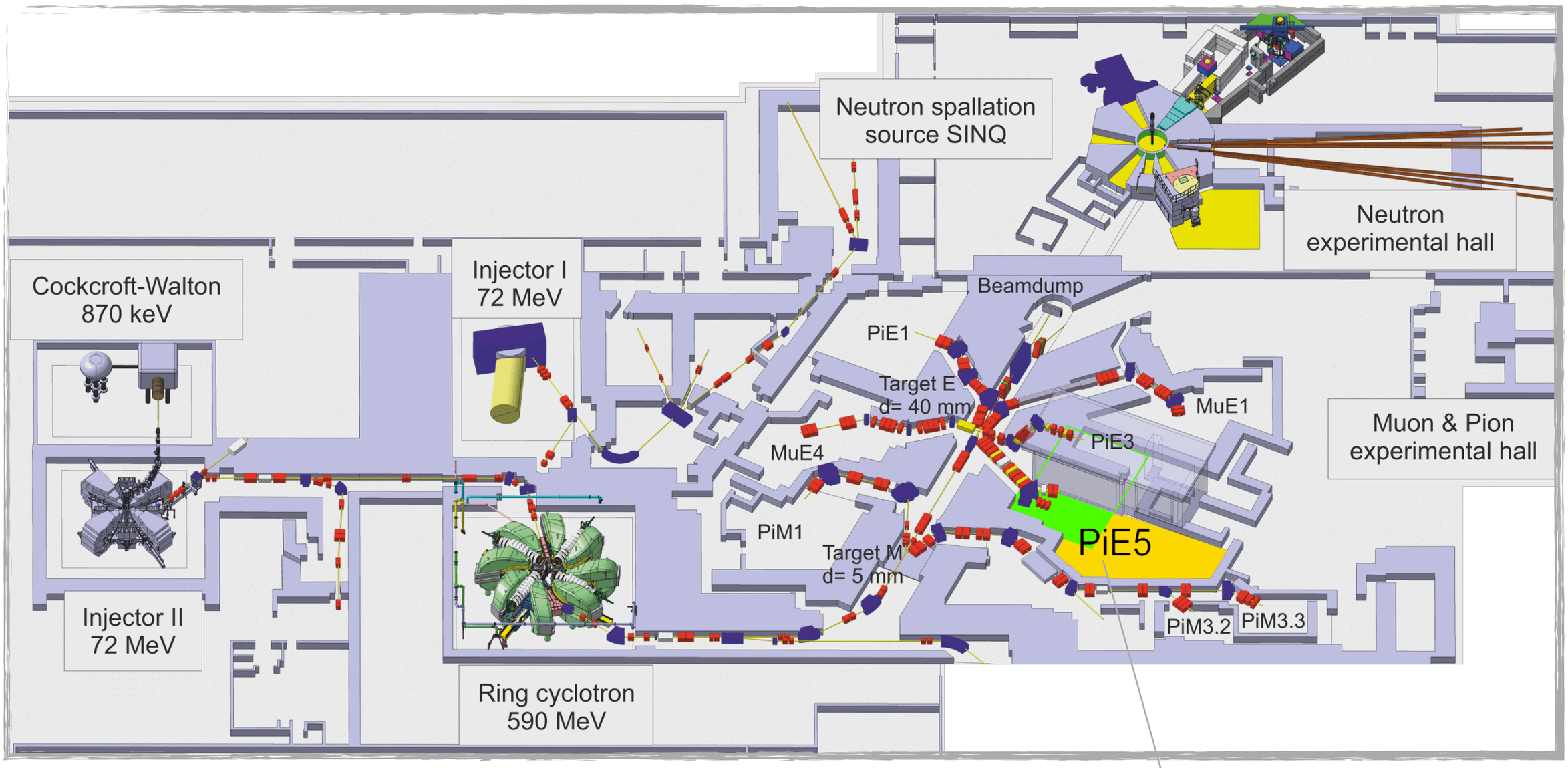
590 MeV proton ring cyclotron
1.4 MW



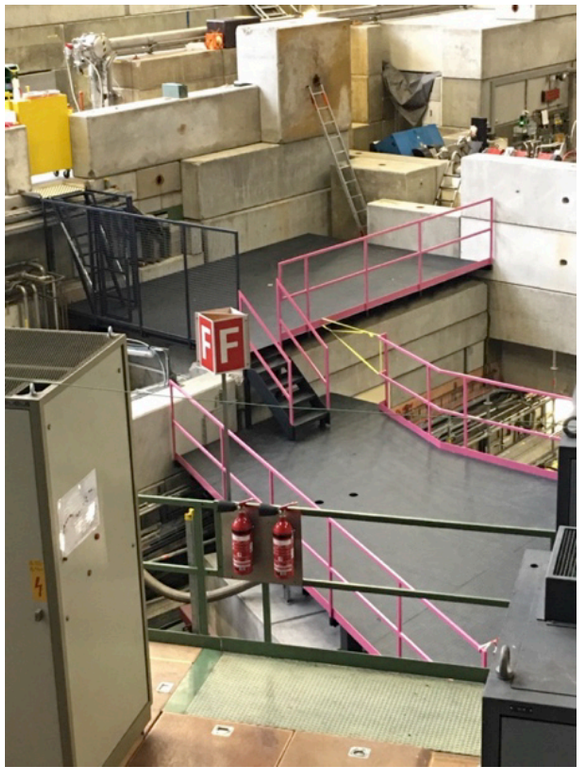
PSI landscape

The world's most intense continuous muon beam

- PSI High Intensity Proton Accelerator experimental areas



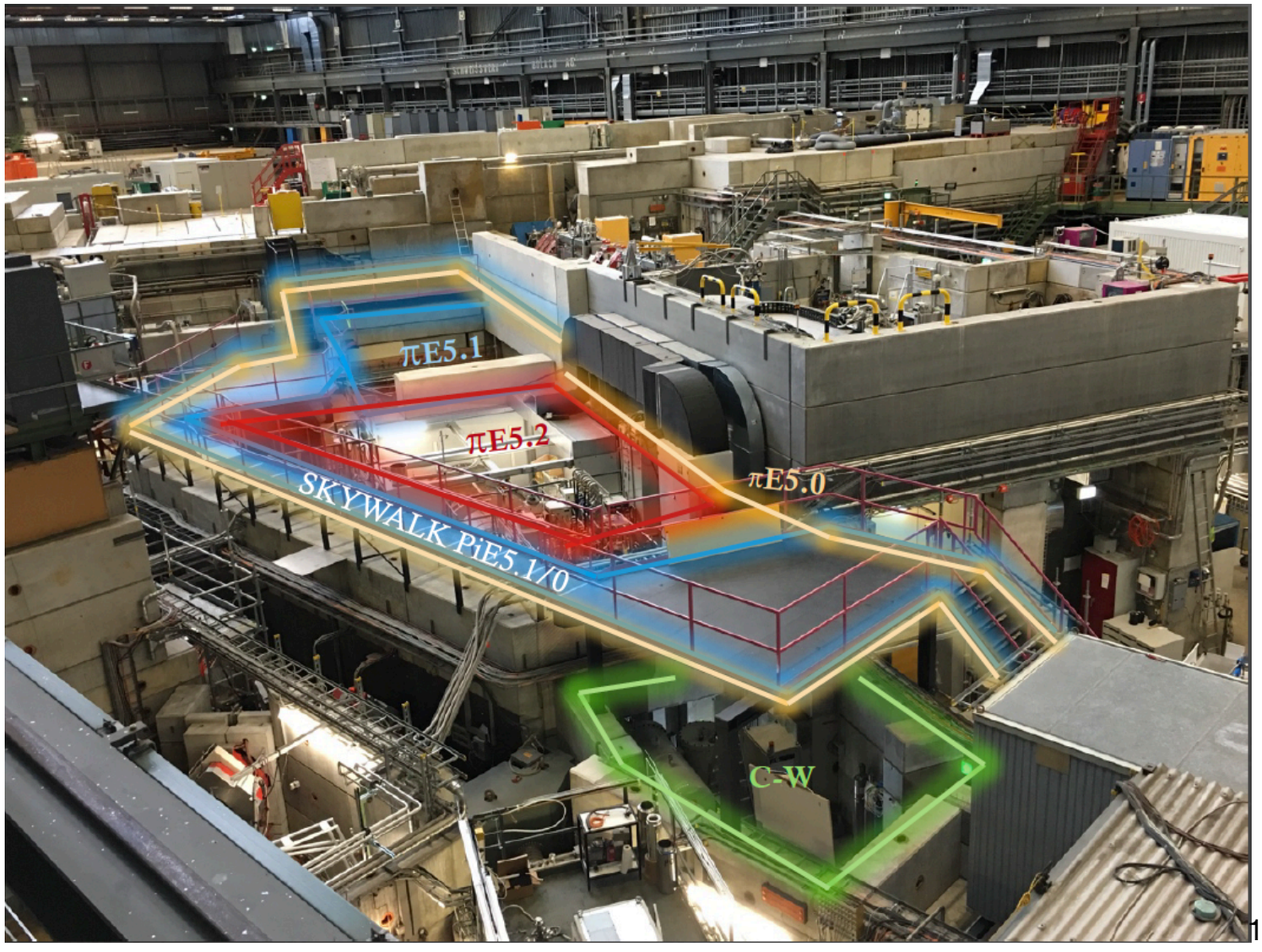
The MEGII and Mu3e experimental area: Pictures



Mu3e extra platforms

New

Overview piE5 area



New

Mu3e control room

The MEGII and Mu3e beam lines

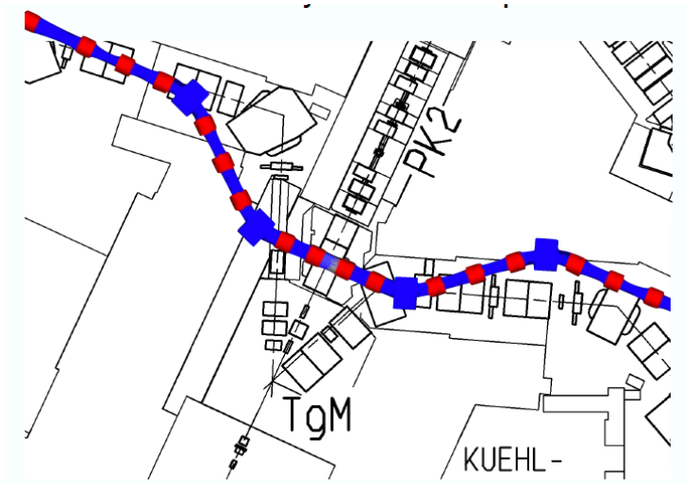
- MEGII and Mu3e (phase I) similar beam requirements:
  - **Intensity O(10^8 muon/s), low momentum p = 28 MeV/c**
  - **Small straggling and good identification of the decay region**
- A dedicated compact muon beam line (CMBL) will serve Mu3e
- Proof-of-Principle: Delivered 8 x 10^7 muon/s during 2016 test beam

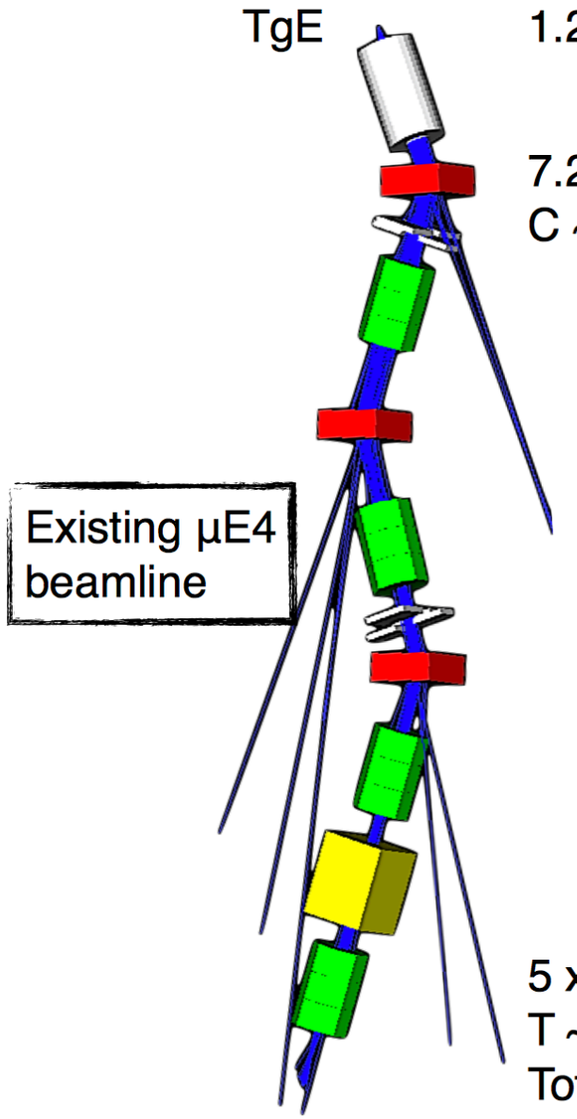
The Mu3e CMBL **New**

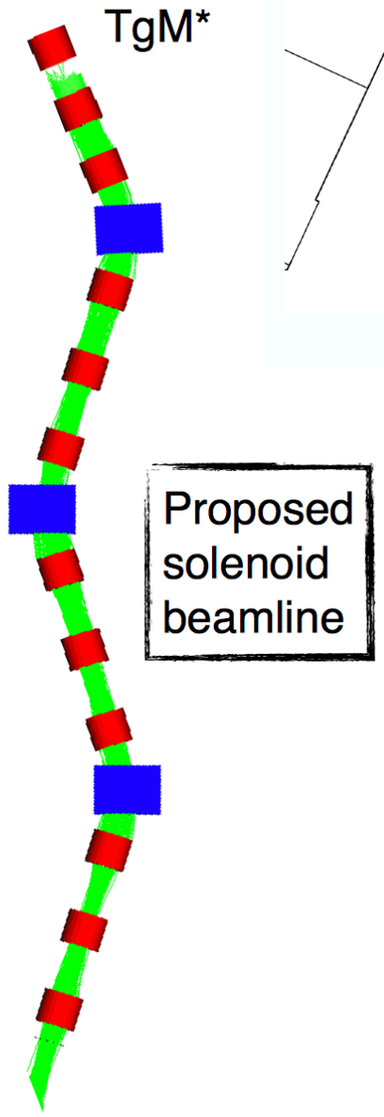
The MEGII BL

The HiMB project at PSI

- Aim: O(**10^{10}** muon/s); Surface (positive) muon beam (**p = 28 MeV/c**); **DC** beam
- Slanted E target test ("towards the new M-target"): planned for **next year**
- Time schedule: **O(2025)**







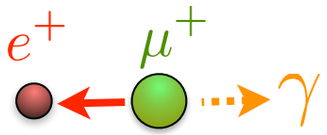
Gain due to high capture and transmission efficiency

A. Baldini et al. (MEG Collaboration),
Eur. Phys. J. C73 (2013) 2365

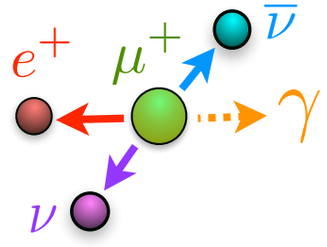
MEG: Signature and experimental setup

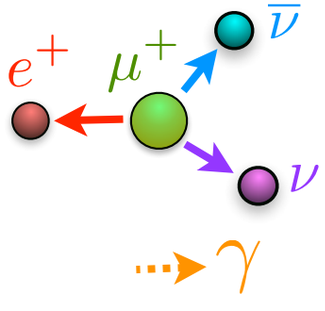
- The MEG experiment aims to search for $\mu^+ \rightarrow e^+ \gamma$ with a sensitivity of $\sim 10^{-13}$ (previous upper limit $BR(\mu^+ \rightarrow e^+ \gamma) \leq 1.2 \times 10^{-11}$ @90 C.L. by MEGA experiment)
- Five observables (E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg}) to characterize $\mu \rightarrow e\gamma$ events

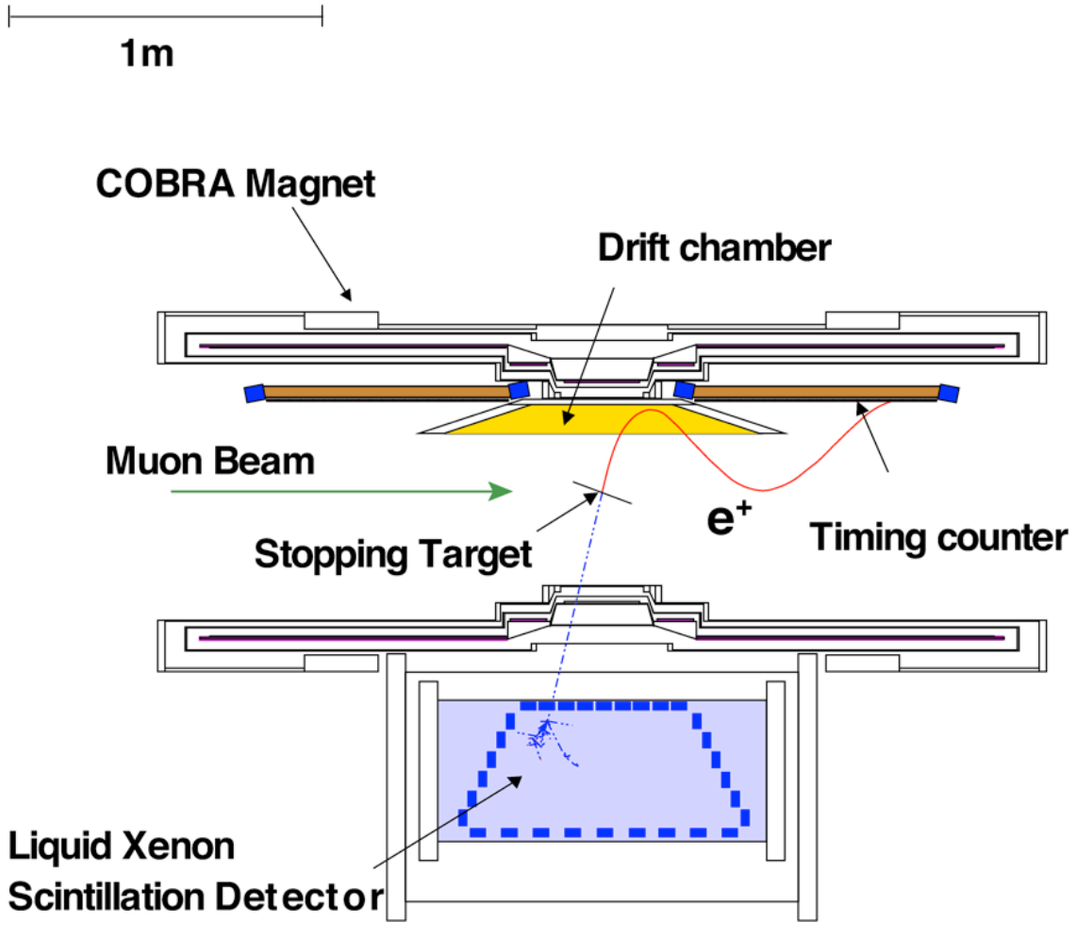
Signature

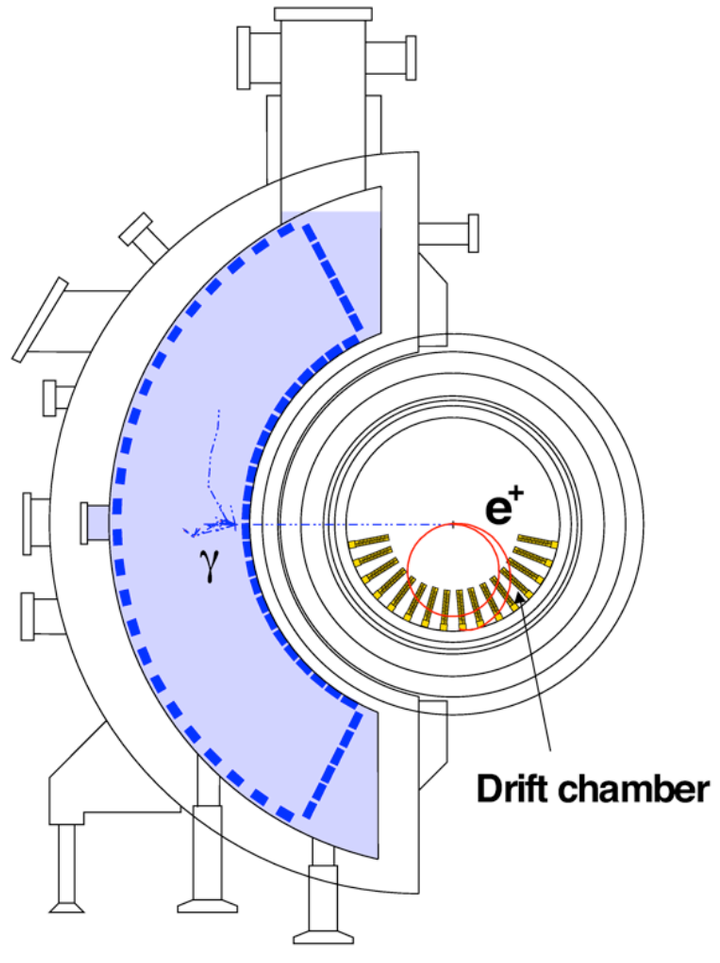


Backgrounds









A. Baldini et al. (MEG Collaboration),
Eur. Phys. J. C76 (2016) no. 8, 434

MEG: The result

Since March 8th 2016

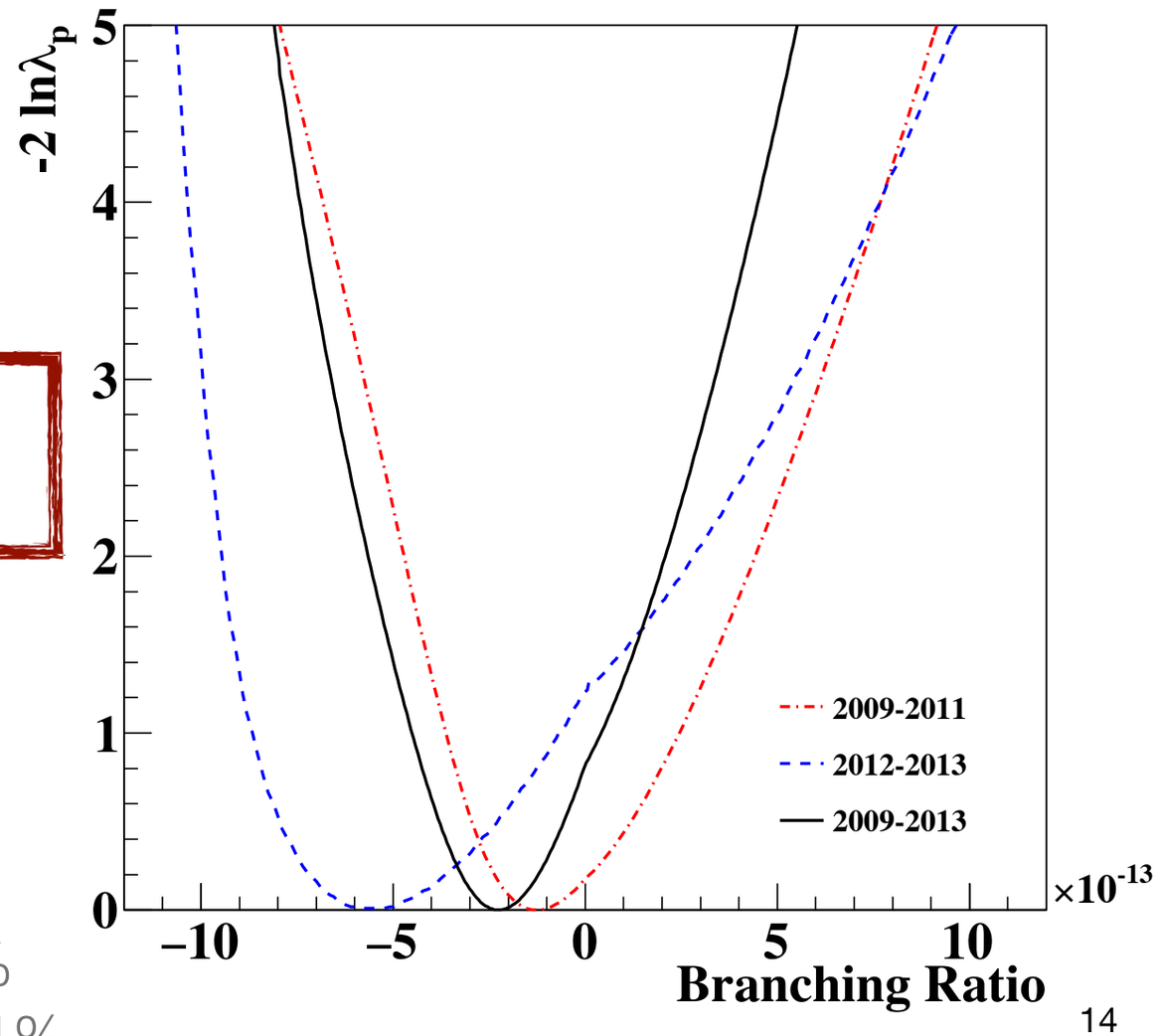
- Confidence interval calculated with Feldman & Cousin approach with profile likelihood ratio ordering
- Profile likelihood ratios as a function of the BR: all consistent with a null-signal hypothesis

Full data sample: 2009-2013
Best fitted branching ratio at 90% C.L.:

$$\mathcal{B}(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$$

From MEGA to MEG:

improvement by a factor ~ 30



Systematic uncertainties: Target “alignment”: 5%
Other sources: < 1%

How the sensitivity can be pushed down?

- More sensitive to the signal...

high statistics

$$SES = \frac{1}{R \times T \times A_g \times \varepsilon(e^+) \times \varepsilon\,(gamma) \times \varepsilon(TRG) \times \varepsilon(sel)}$$

R: Beam rate; T: Acquisition time; A_g: Geometrical acceptance; $\varepsilon(e^+)$: Detector efficiency; $\varepsilon(sel)$: Selection efficiency

- More effective on rejecting the background...

high resolutions

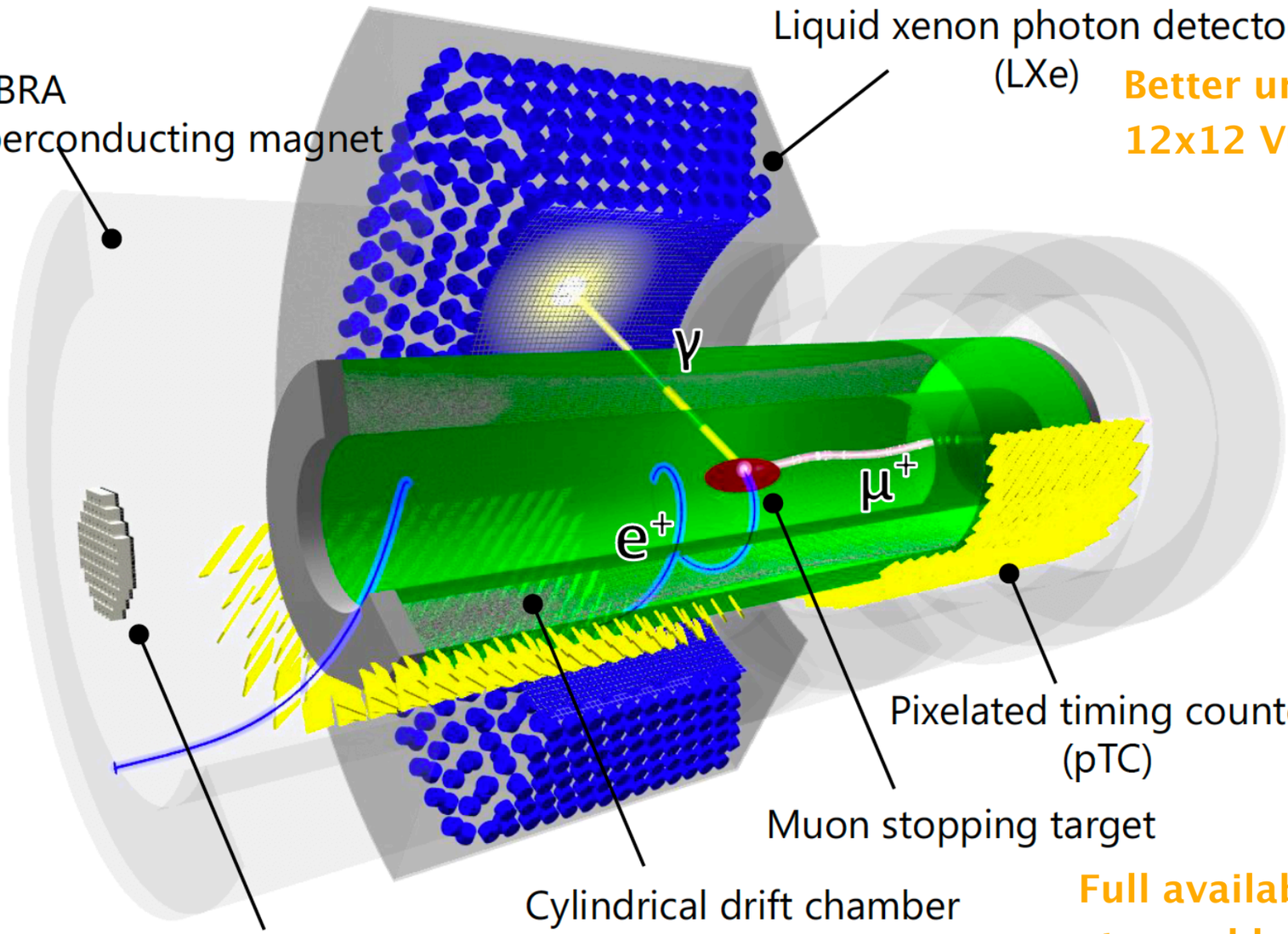
$$B_{acc} \sim R \times \Delta E_e \times (\Delta E_{gamma})^2 \times \Delta T_{egamma} \times (\Delta \Theta_{egamma})^2$$

ΔE_e: Positron Energy resolution; ΔE_{gamma}: Gamma Energy resolution; ΔT_{egamma}: Relative timing resolution; $\Delta \Theta_{egamma}$: Relative angular resolution

The MEGII experiment

New electronics:
Wavedream

~9000 channels at 5GSPS



Better uniformity w/ 12x12 VUV SiPM

x2 Resolution everywhere

x2 Beam Intensity

Updated and new Calibration methods

Quasi mono-chromatic positron beam

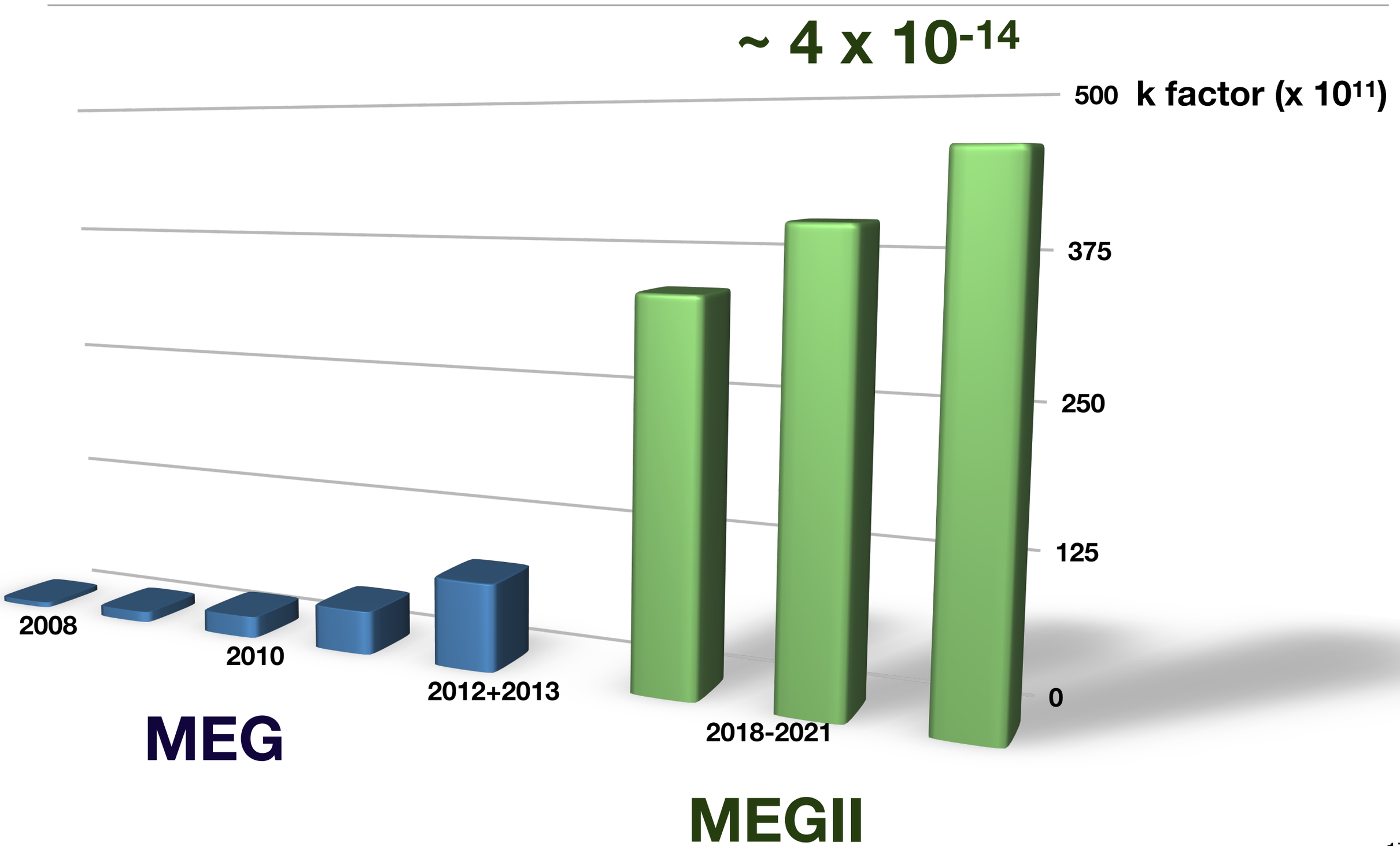
35 ps resolution w/ multiple hits

Background rejection

Single volume He:iC_4H_{10}

Full available stopped beam intensity 7×10^7

Where we will be

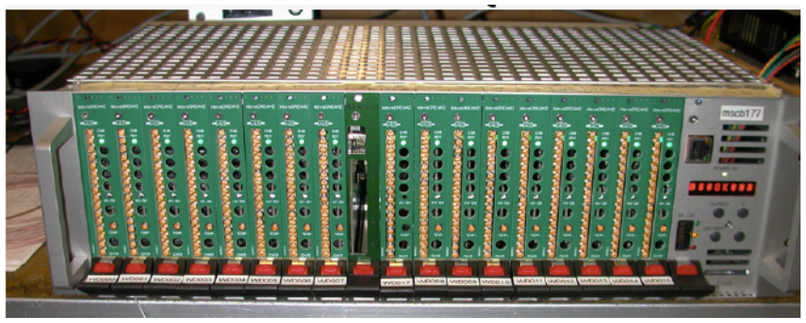


MEGII Status

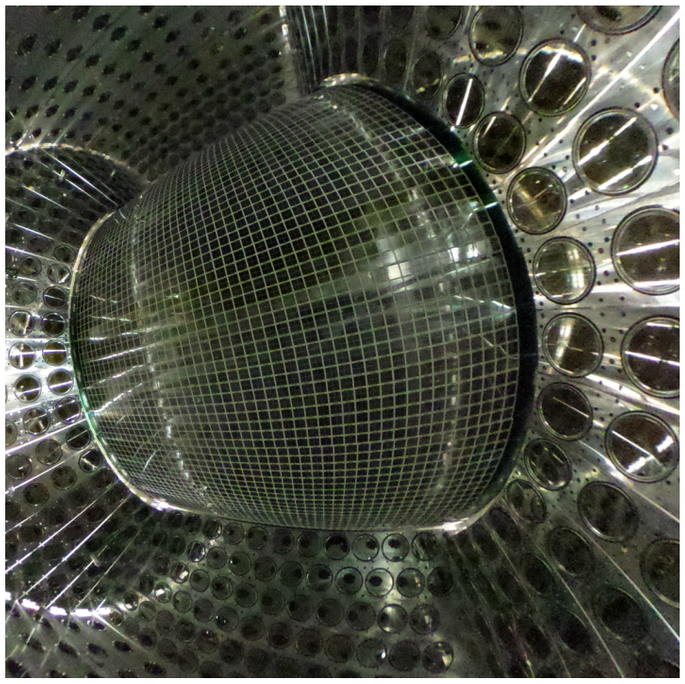
- Pre-engineering runs ongoing. Full engineering run [**2018**] followed by data acquisition

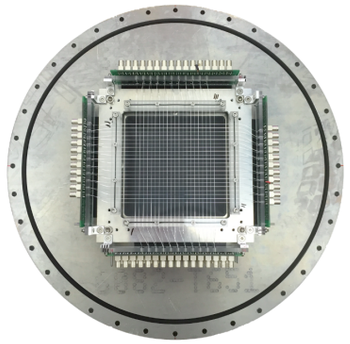
Optimum beam and calibrations: Ready

new DAQ + TRG (**5 Gsample/s**):
Mass production Jan 2018



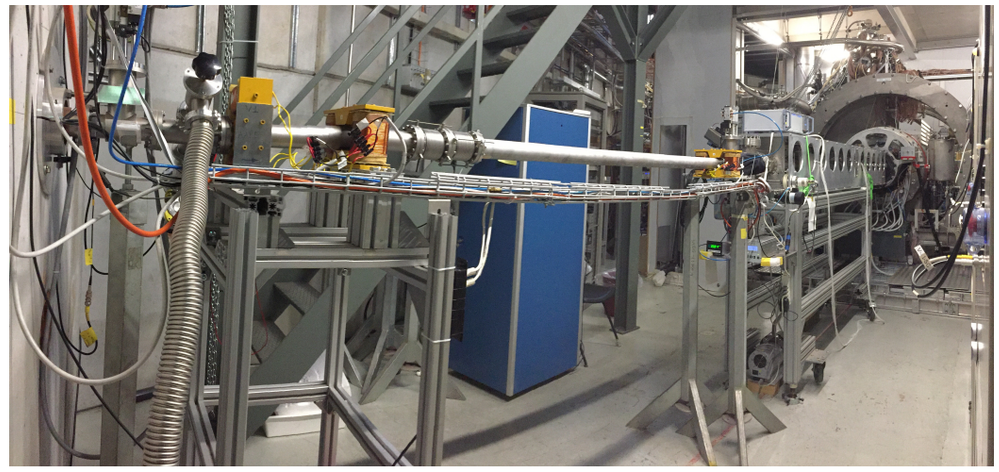
LXe calorimeter (**VUV** MPPC):
Commissioning phase



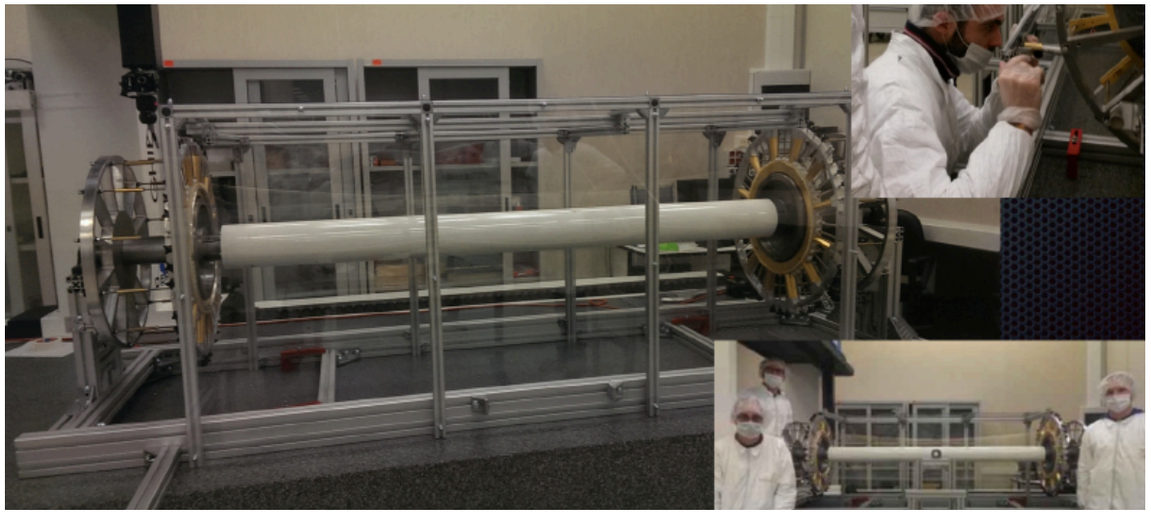


new Beam detector
(**Online profile and rate**):
Ready

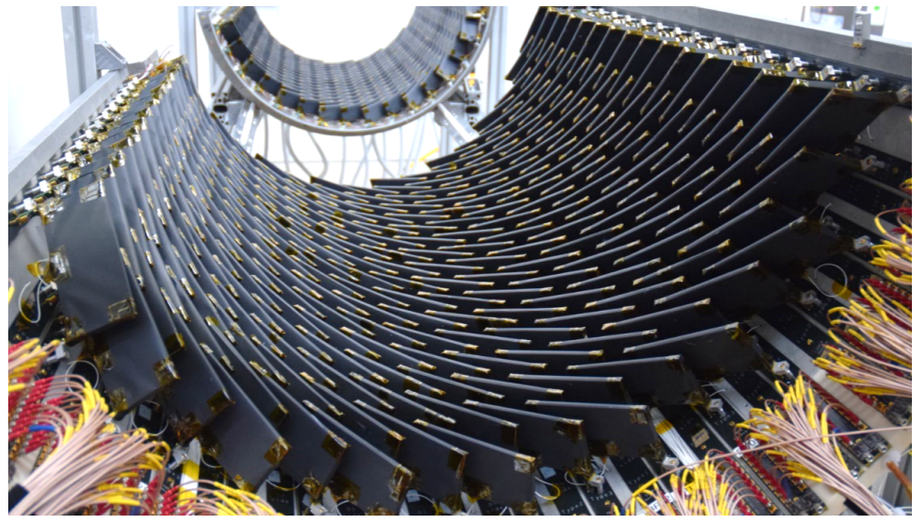
New and upgraded
calibration methods



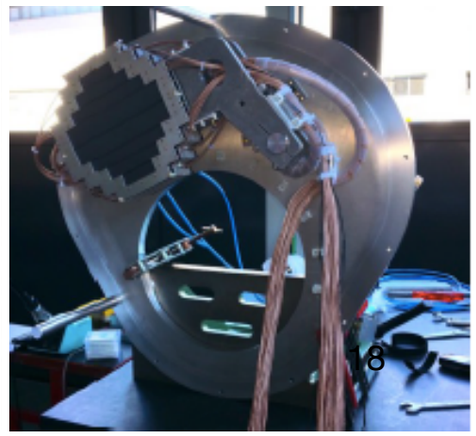
new DCH (**stereo**): in progress (~80%)



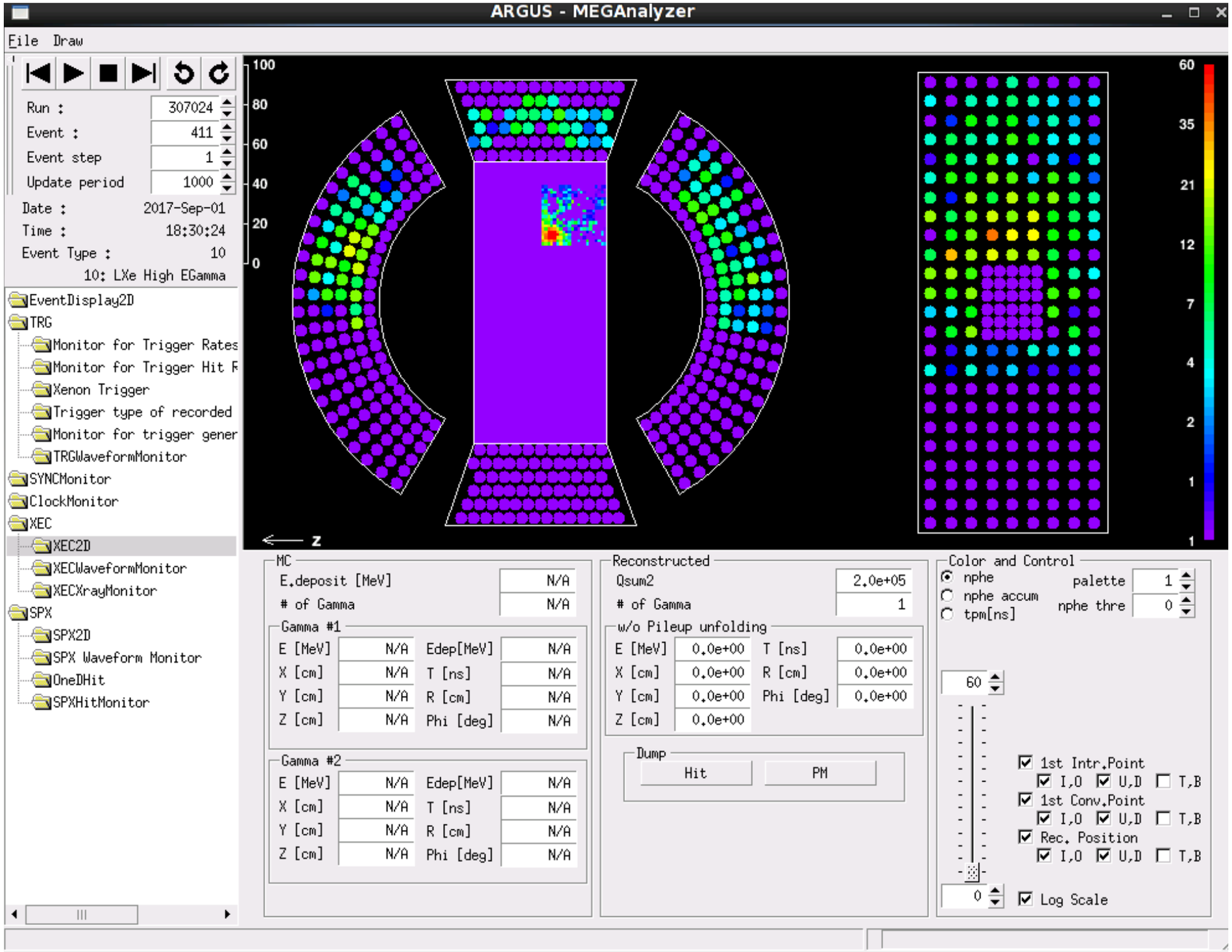
new TC (**multi-hits**): Ready



new AUX detector
(**<< BKG**): Ready



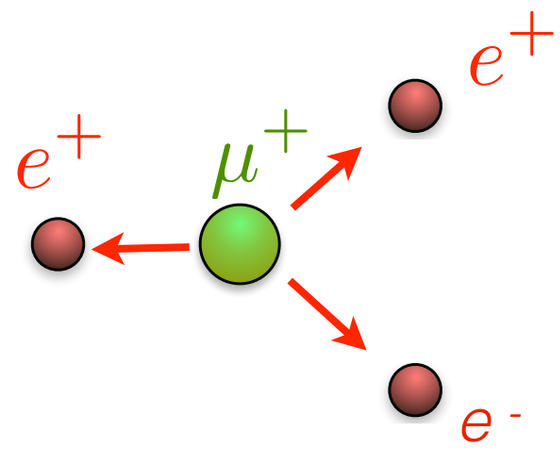
MEGII status: pre-eng 2017



Mu3e: The $\mu^+ \to e^+e^+e^-$ search

- The Mu3e experiment aims to search for μ⁺ → e⁺ e⁺ e⁻ with a sensitivity of ~10^{-15} (Phase I) up to down ~10^{-16} (Phase II). Previous upper limit BR(μ⁺ → e⁺ e⁺ e⁻) ≤ 1 x 10^{-12} @90 C.L. by SINDRUM experiment)
- Observables (E_e, t_e, vertex) to characterize μ→ eee events

Signature

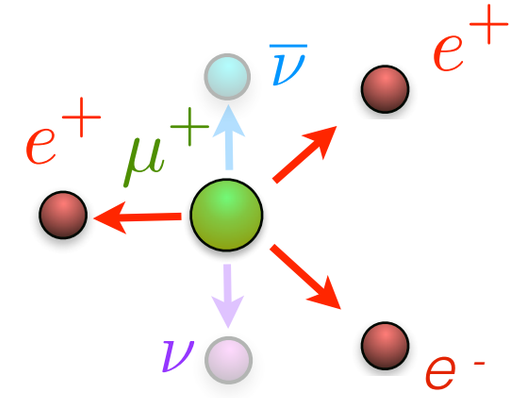


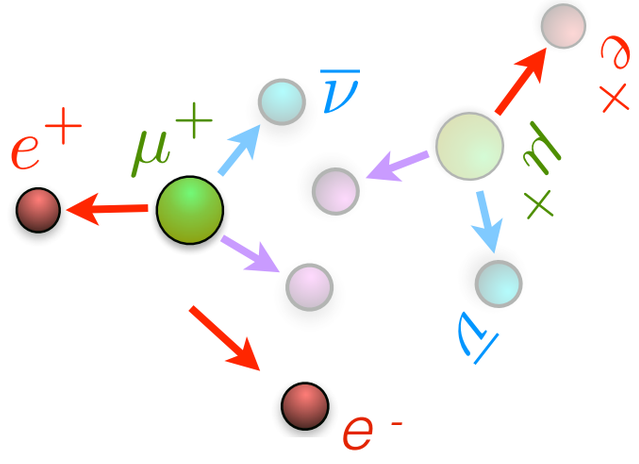
$\Delta t_{eee} = 0$

$\Sigma \vec{p}_e = 0$

$\Sigma E_e = m_\mu$

Background





Mu3e: Requirements

Signal

1. $\mu \rightarrow eee$

- Rare decay search: Intense muon beam O(10*8 muon/s) for phase I

- High occupancy: High detector granularity

- Three charged particles in the final state: allowing for high detector performances vs the case of having neutral particle

Background

1. $\mu \rightarrow eee\nu\nu$

- Missing energy: Excellent momentum resolution

2. $\mu \rightarrow e\nu\nu, \mu \rightarrow e\nu\nu, e^+e^-$

- Coincidence and vertex: High timing and position resolutions

The Mu3e experiment: Schematic 3D

Superconducting solenoid Magnet

Homogeneous field 1T

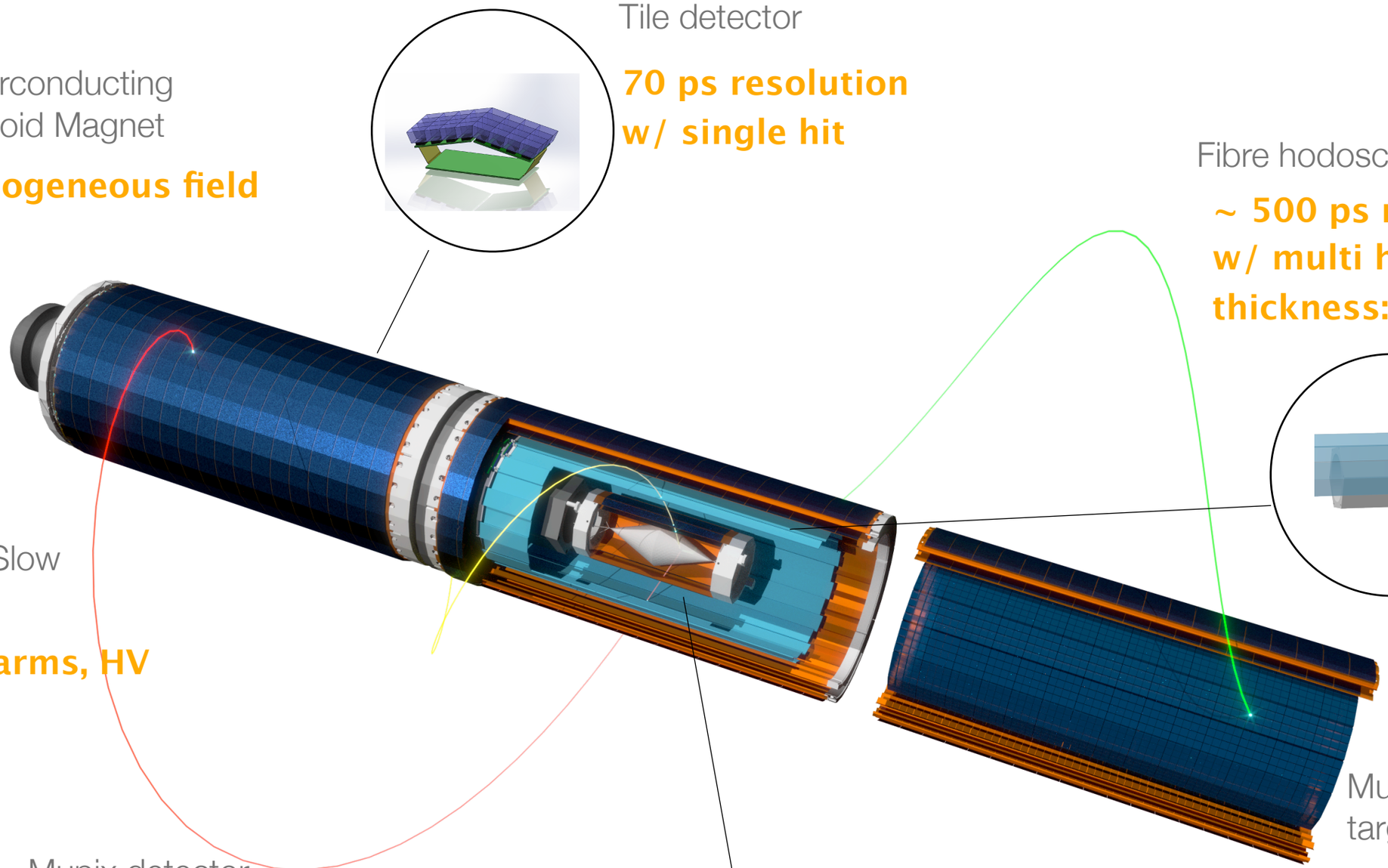
Tile detector

70 ps resolution w/ single hit

Fibre hodoscope

~ 500 ps resolution w/ multi hits

thickness: < 0.3% X_0



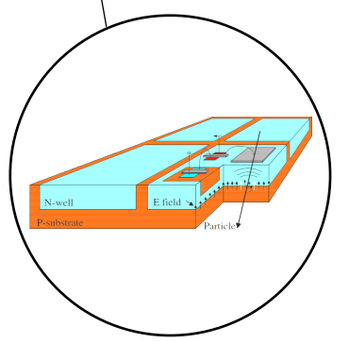
MIDAS DAQ and Slow Control

Run, history, alarms, HV etc.

Mupix detector

Tracking, integrate sensor and readout in the same device: 50 um thick

1 layer: ~ 0.1% X_0



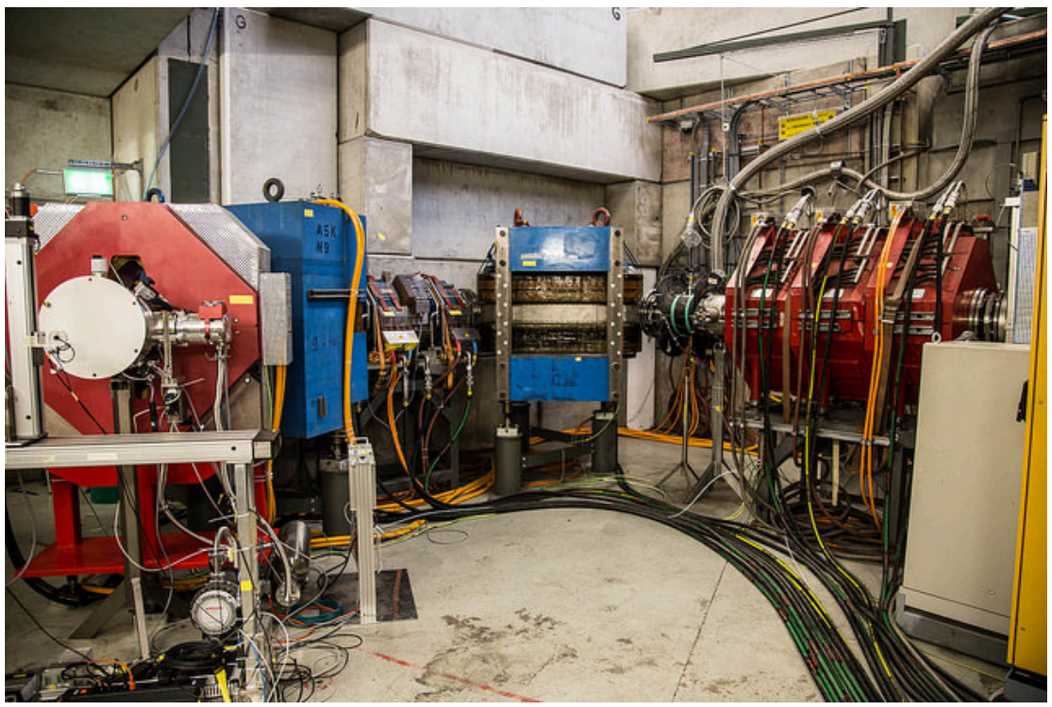
Muon Beam and target

Full available beam intensity O(10^8)

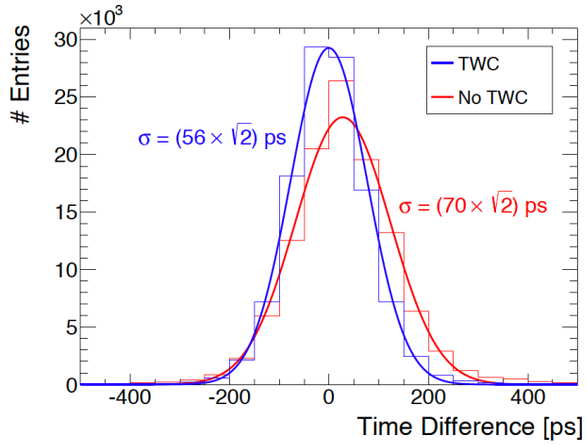
The Mu3e experiment: Status

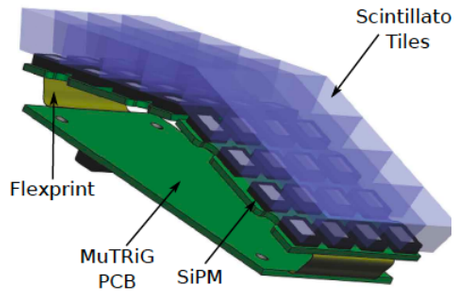
- The Mu3e experiment is completely based on new detector technologies and strongly connected with new beam line projects (HiMB at PSI aiming at 10^10 muon/s)
- The R&D phase for all sub-detectors and beam line has been concluded proving that the expected detector performances can be achieved
- Construction and characterisation of all sub-detector prototype are extensively ongoing
- A pre-engineering run is expected for 2019

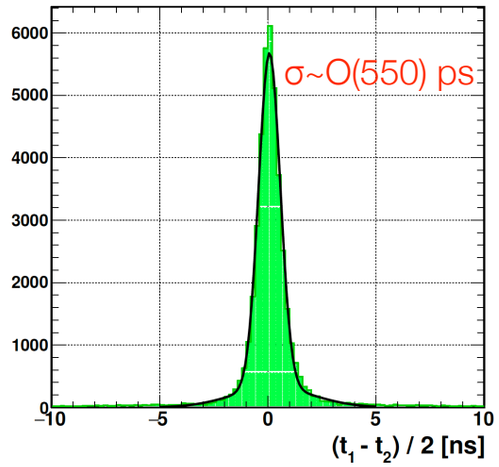
Compact Muon beam line: O(10^8 muon/s)

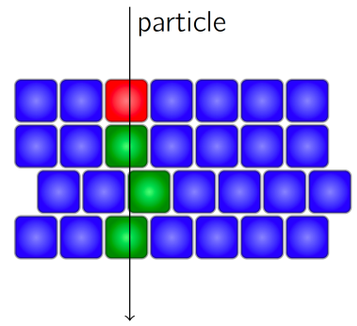


Large MuPix sensor: 2 x 1 cm^2





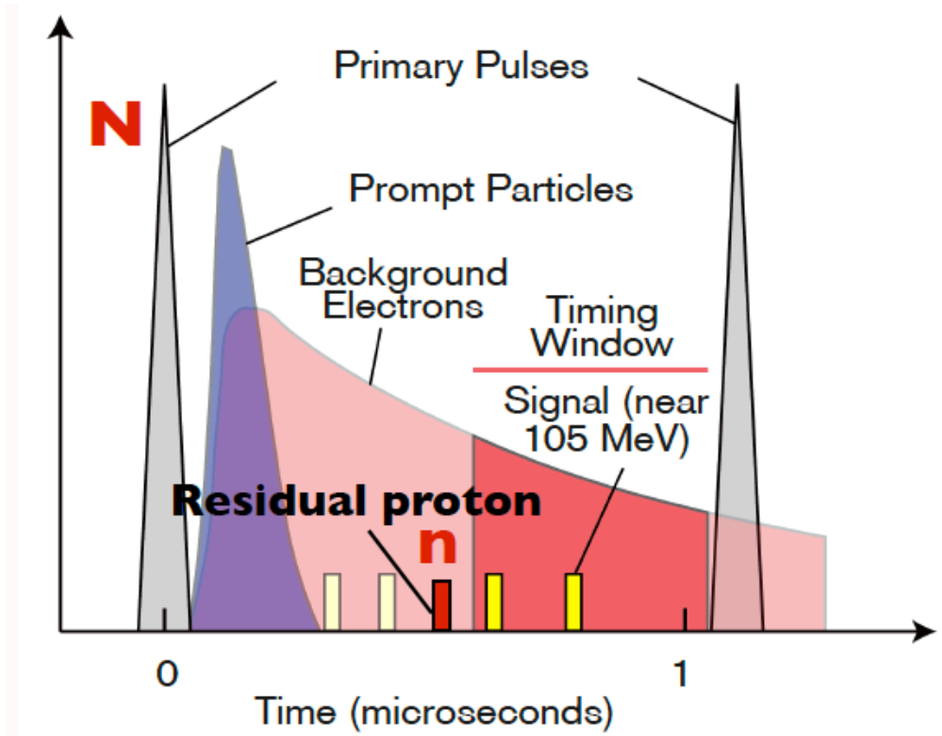


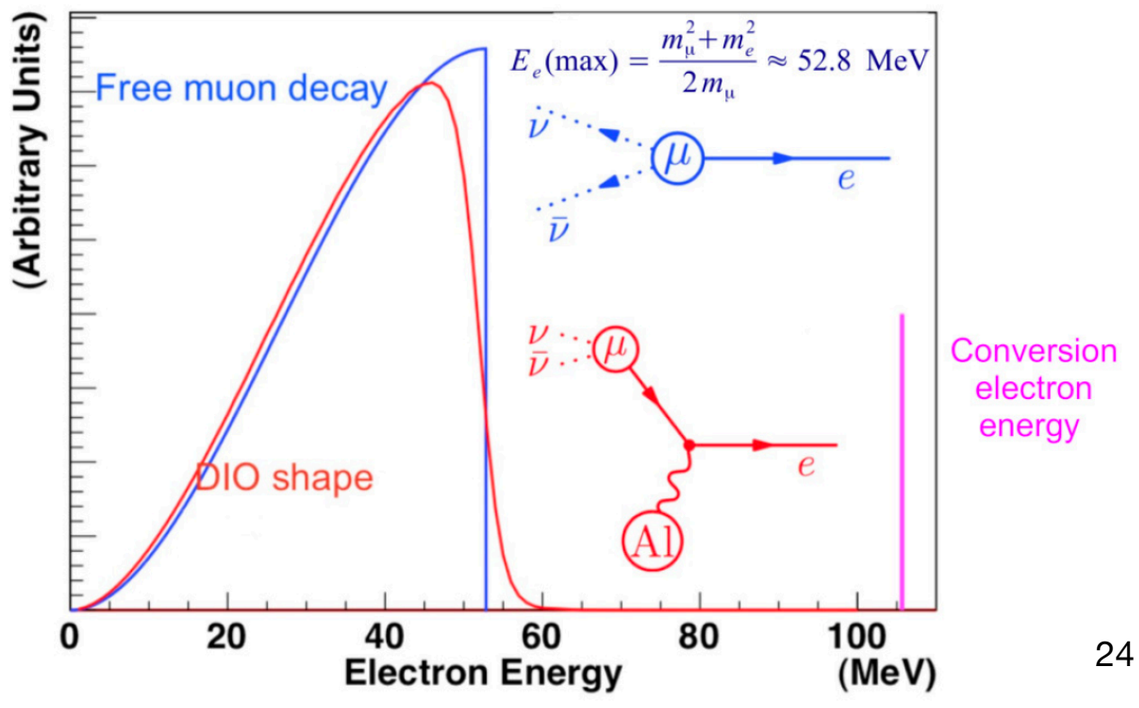


μ⁻ N → e⁻ N experiments

$$R_{\mu e} = \frac{\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)}{\mu^- + A(Z,N) \rightarrow \nu_\mu + A(Z-1,N)}$$

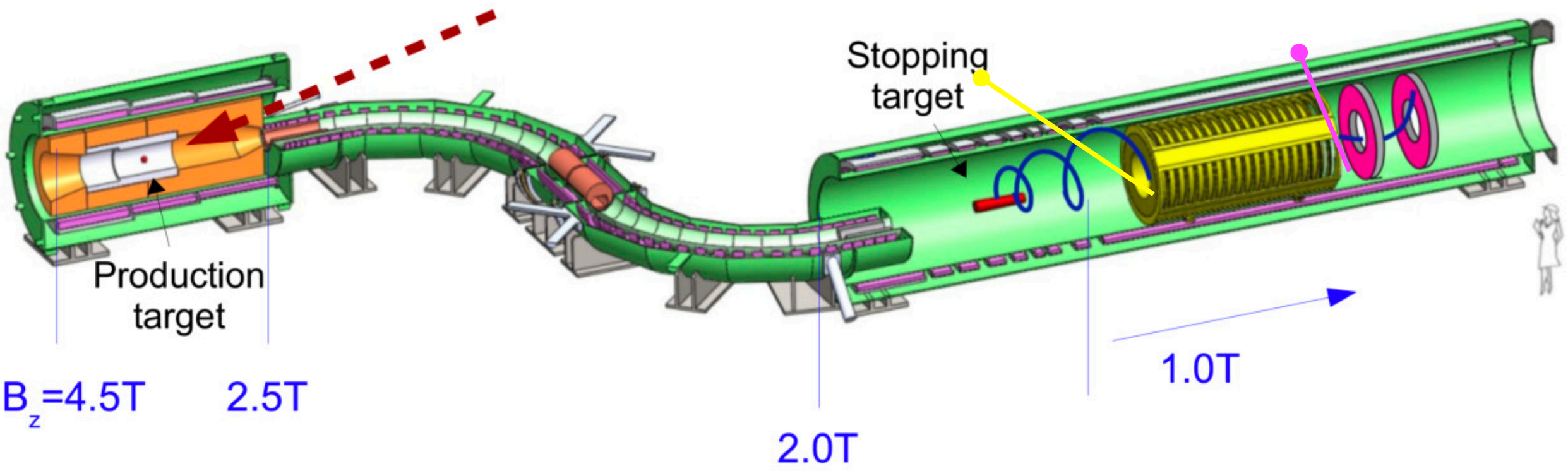
- Signal of mu-e conversion is single mono-energetic electron
- Backgrounds:
  - Beam related, Muon Decay in orbit, Cosmic rays
- Stop a lot of muons! O(10^{18})
- Use timing to reject beam backgrounds (extinction factor 10^{-10})
  - Pulsed proton beam 1.7 μs between pulses
  - Pions decay with 26 ns lifetime
  - Muons capture on Aluminum target with 864 ns lifetime
- Good energy resolution and Particle ID to defeat muon decay in orbit
- Veto Counters to tag Cosmic Rays





The Mu2e experiment

- Three superconducting solenoids: Production, Transport and Detector solenoids
- Muons stop in thin aluminum foils
- High precision straw tracker for momentum measurement
- Electromagnetic calorimeter for PID
- Scintillators for the Veto



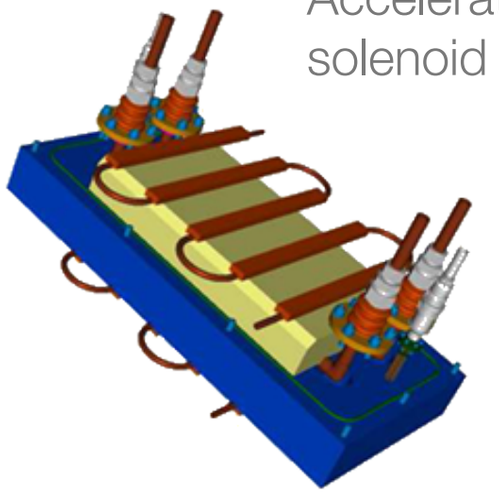
Mu2e status

- 2021: Detector and Beam line commissioning; 2022-2024: Data taking

Building: Completed

Beam line and Solenoids:

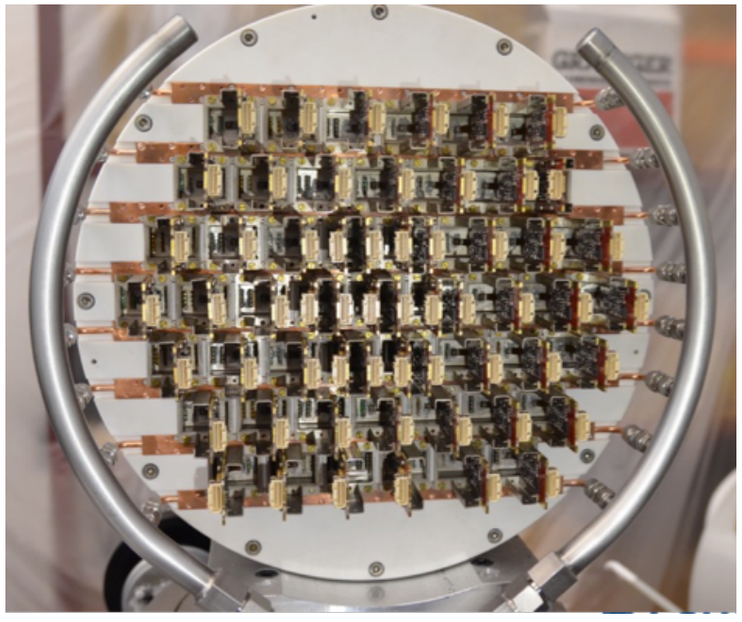
Accelerator work ~50% complete;
solenoid work ~60% complete



Straw Tube Tracker

Cosmic Ray Veto module

Calorimeter Crystal Test

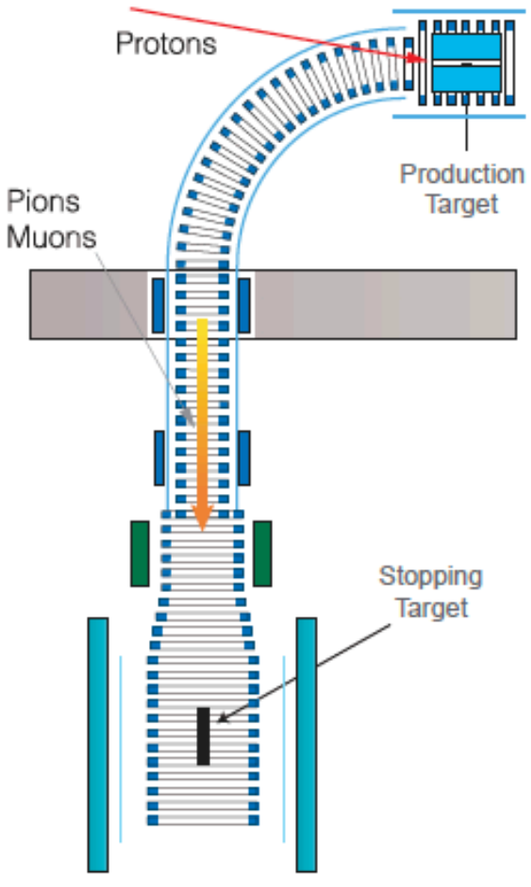


Detectors:
Pre-production versions have been fabricated and successfully tested

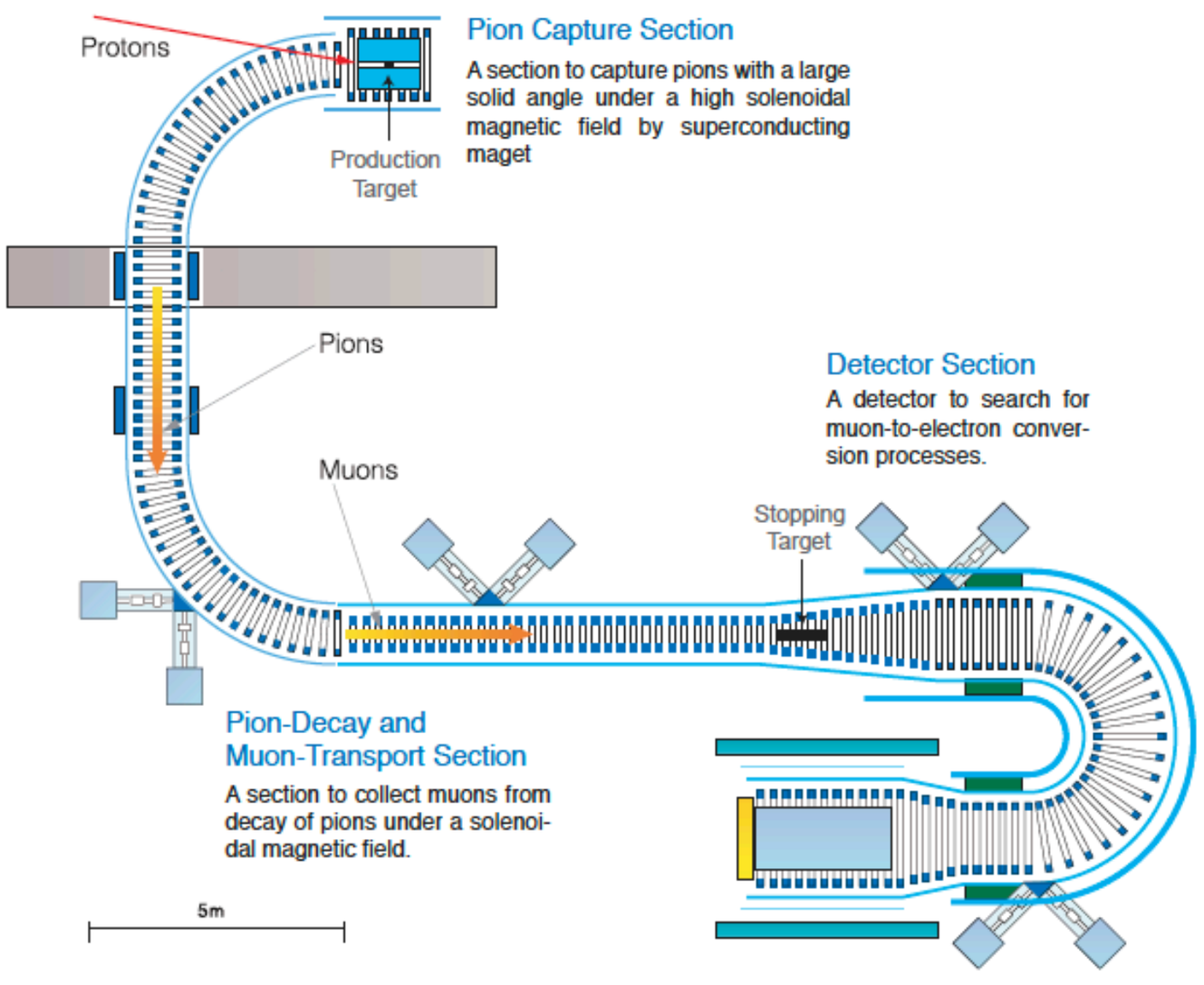
The COMET experiment

- Stage phase approach: ultimate sensitivity with phase II [Data taking in: 2021/2022]

COMET Phase-I



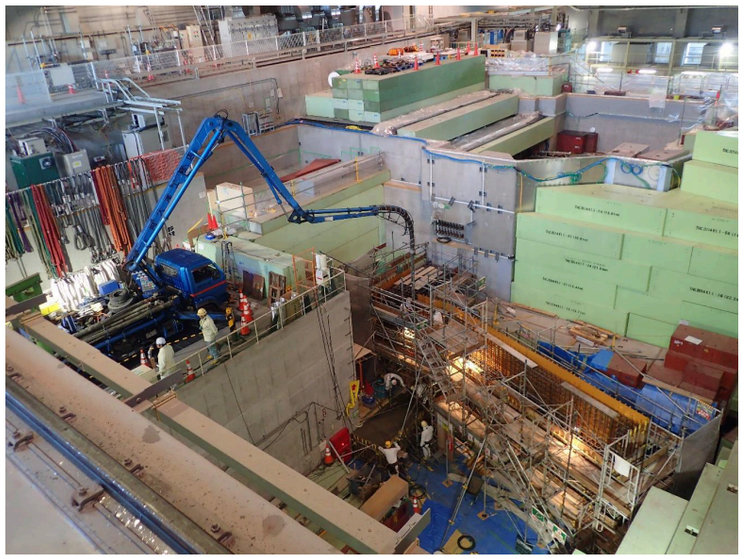
COMET Phase-II



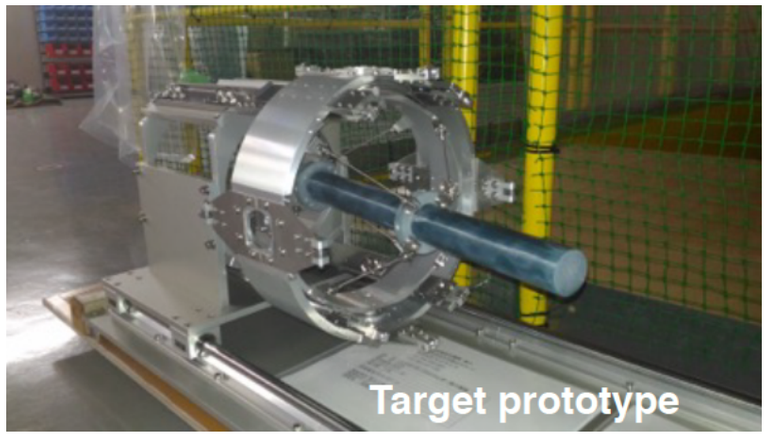
COMET Status

- Stage phase approach: phase I. CR data **STARTED** [August 2017]. Data taking from **2019**!

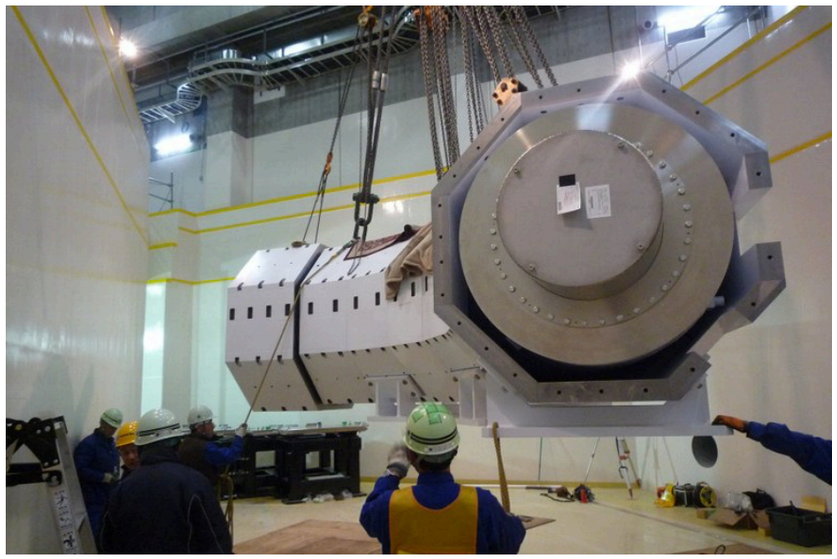
Proton beam line: under construction



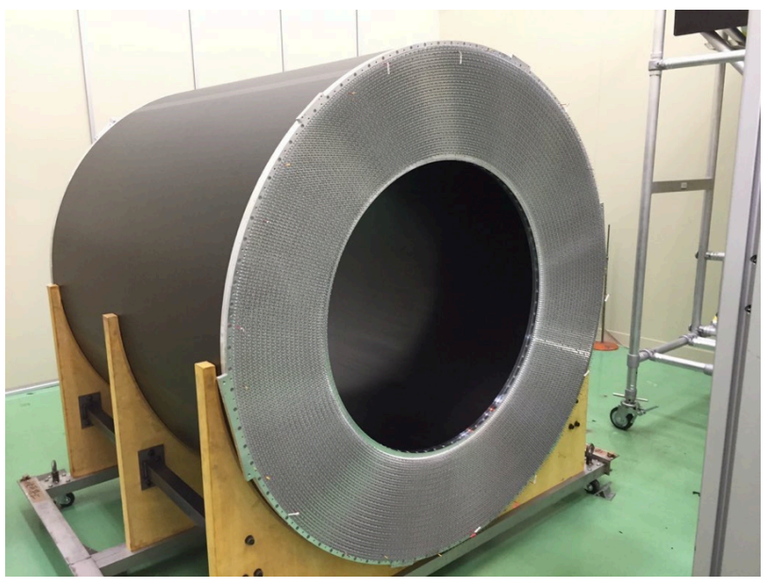
Pion capture Solenoid: DS ready, US under construction



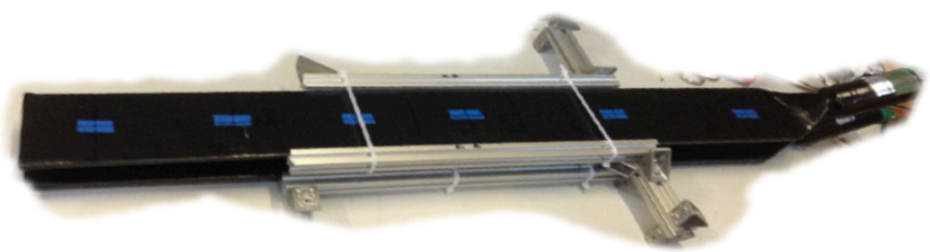
Transport Solenoid: Ready



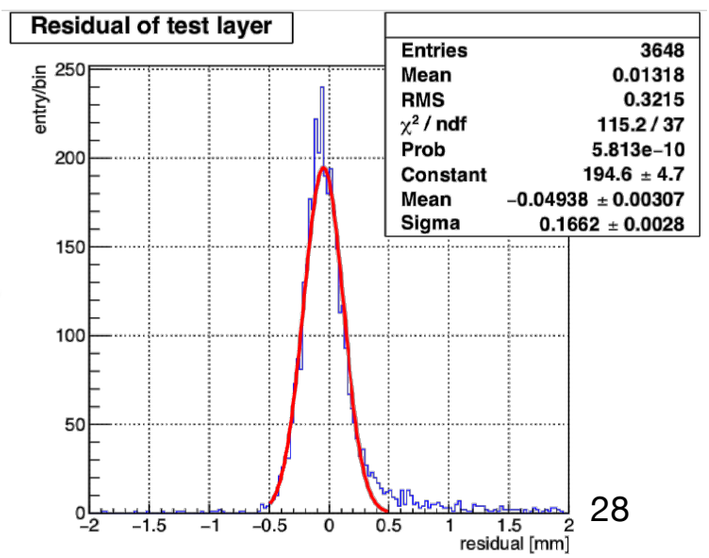
Cylindrical Drift Chamber: Ready



Trigger scintillators + Cerenkov detector: Ready



Trigger/DAQ/Analysis: in very good shape



Outlooks

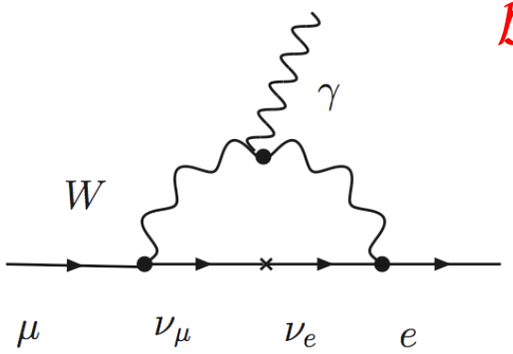
- The MEG experiment has set a new upper limit for the branching ratio of **$B(\mu^+ \to e^+ \gamma) < 4.2 \times 10^{-13}$** at 90% C.L. An upgrade of the apparatus is ongoing: MEGII is expect to start next year the full engineering run followed by a physics run aiming at a sensitivity **down to 4×10^{-14}**
- The Mu3e experiment **aim at a sensitivity of $SES(\mu^+ \to e^+ e^+ e^-) \sim 10^{-15}$** (phase I) down to **few x 10^{-16}** (via the **HiMB** at PSI aiming at 10^10muon/s). The R&D phase proved that the expected detector performances can be achieved. Construction and characterisation of all sub-detector prototype are extensively ongoing
- The Mu2e preparation **is advancing**: Infrastructures, beam line under construction; detector prototypes delivering the requested performances for a final sensitivity **$SES(\mu^- N \to e^- N) < 10^{-16}$**
- The COMET phase I is expected **to have the full eng. run next year** followed by the physics run

- **cLFV remains one of the most exiting place where to search for new physics**

Backup

cLFV evidence: A clear signature of New Physics

SM with massive neutrinos (Dirac)

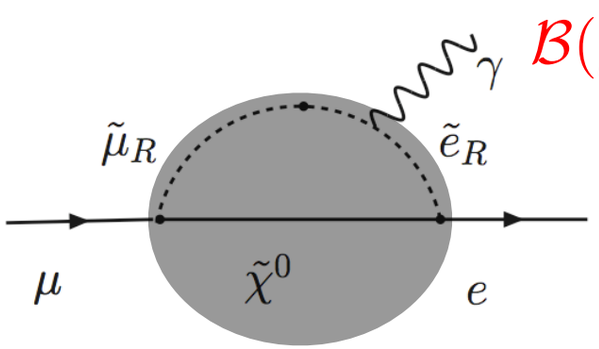


$$\mathcal{B}(\mu^+ \to e^+\gamma) \approx 10^{-54}$$

ν oscillations

too small to access experimentally

i.e. SU(5) SUSY-GUT or SO(10) SUSY-GUT

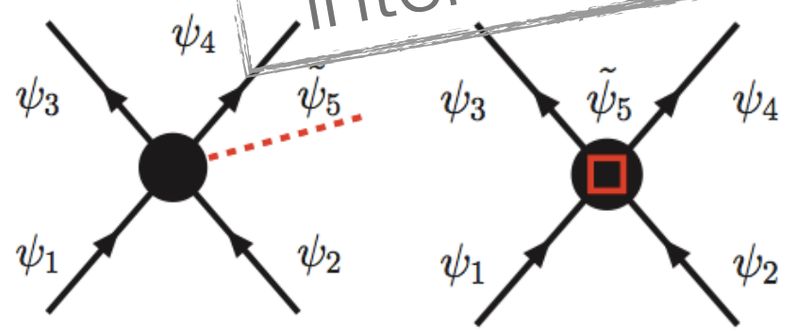


$$\mathcal{B}(\mu^+ \to e^+\gamma) \gg 10^{-54}$$

an experimental evidence:
a clear signature of New Physics NP
(SM background FREE)

to unveil behind SM physics
via virtual particles

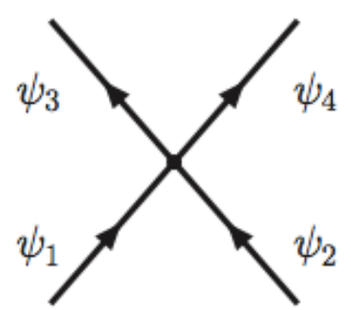
intensity frontier



to probe otherwise unreachable and
unexploited new physics energy scale

high energy probe

$$\mathcal{L}_{eff} = \mathcal{L}_{\mathcal{SM}} + \sum_{d>4} \frac{c_n^{(d)}}{\Lambda^{d-4}} \mathcal{O}^{(d)}$$

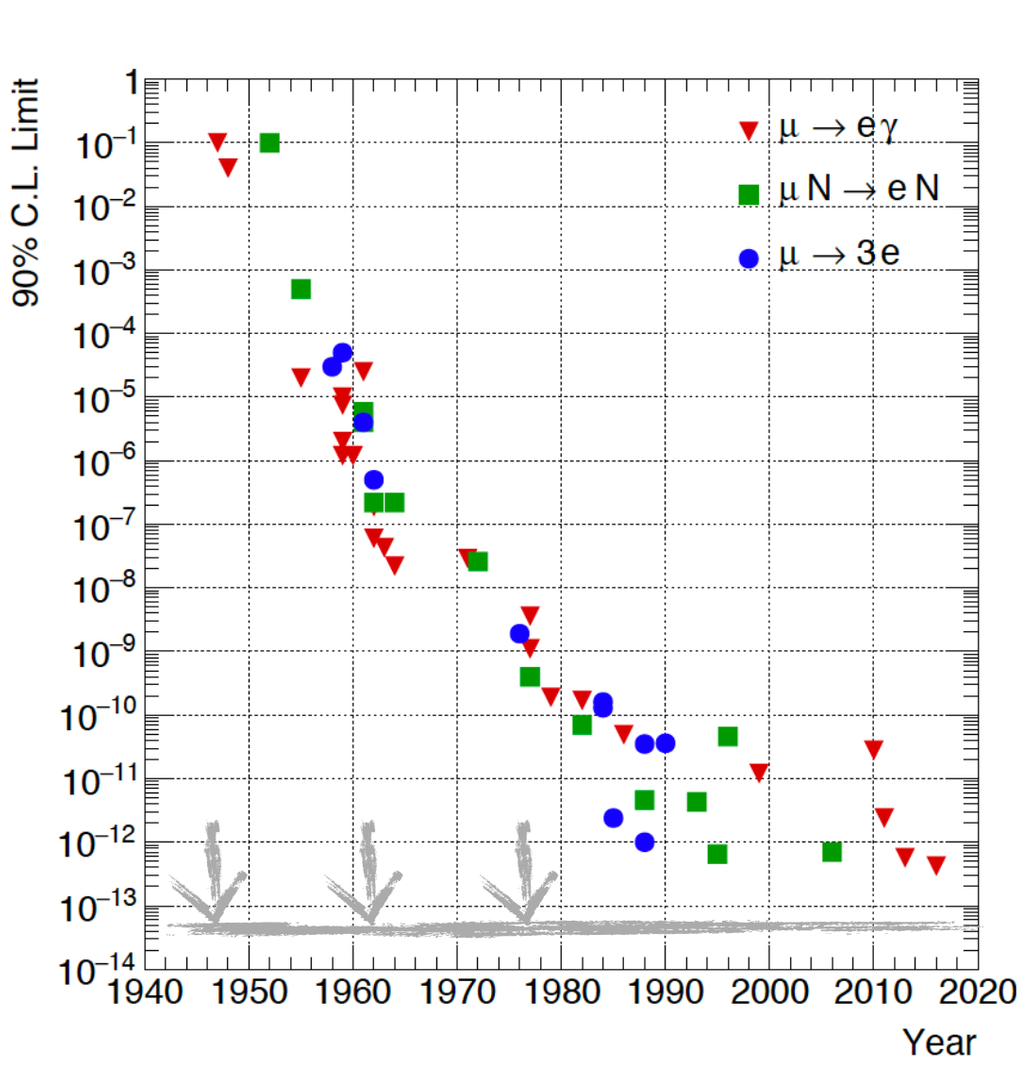


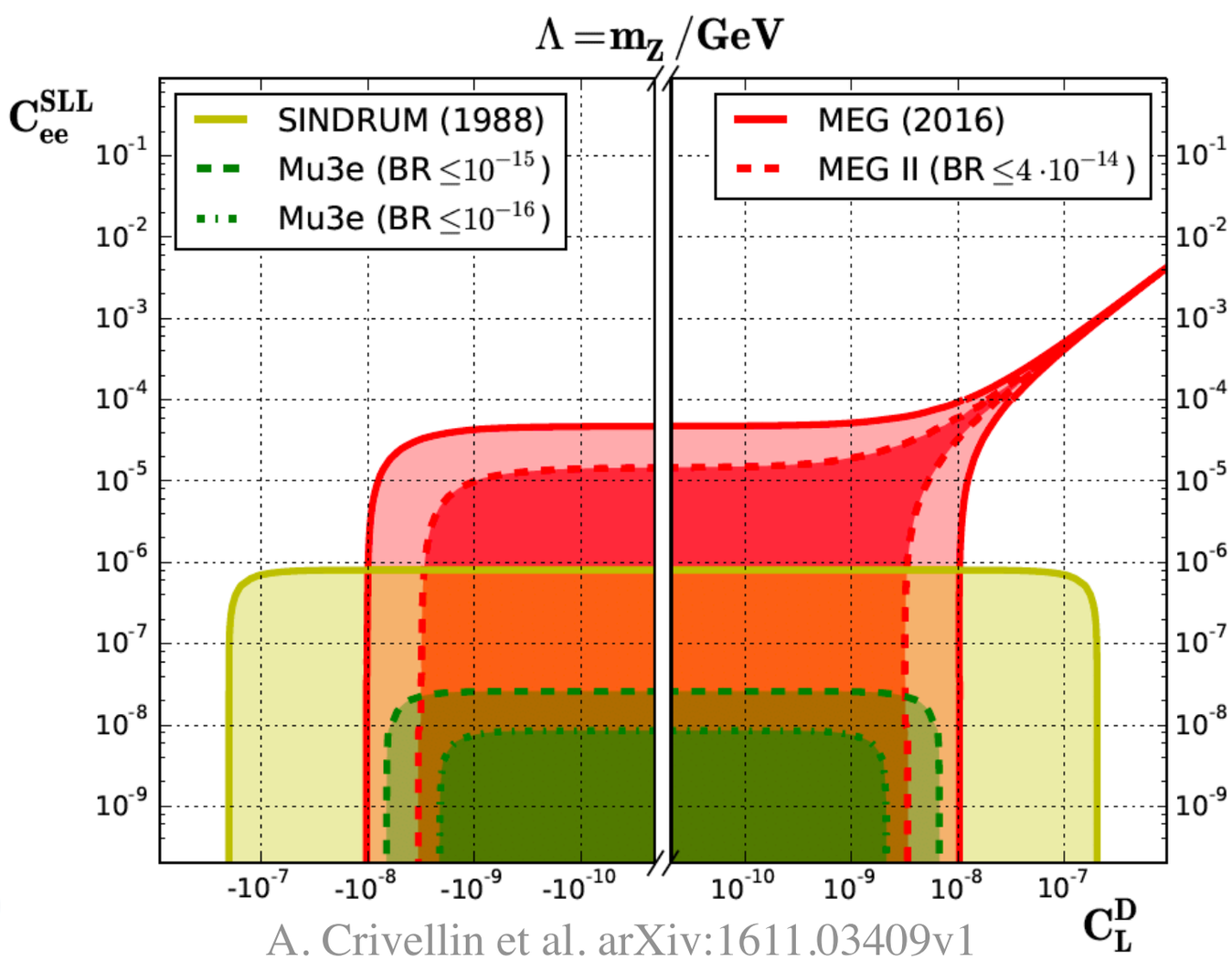
$$\frac{1}{\Lambda^2}$$

cLFV searches with muons: Status and prospects

- In the near future impressive sensitivities: BR($\mu \rightarrow e\gamma$) < 4 10^{-14} ; BR($\mu \rightarrow eee$) < 5 10^{-15}; CR($\mu N \rightarrow eN'$) < 10^{-16}

- Strong complementarities among channels: The only way to reveal the mechanism responsible for cLFV

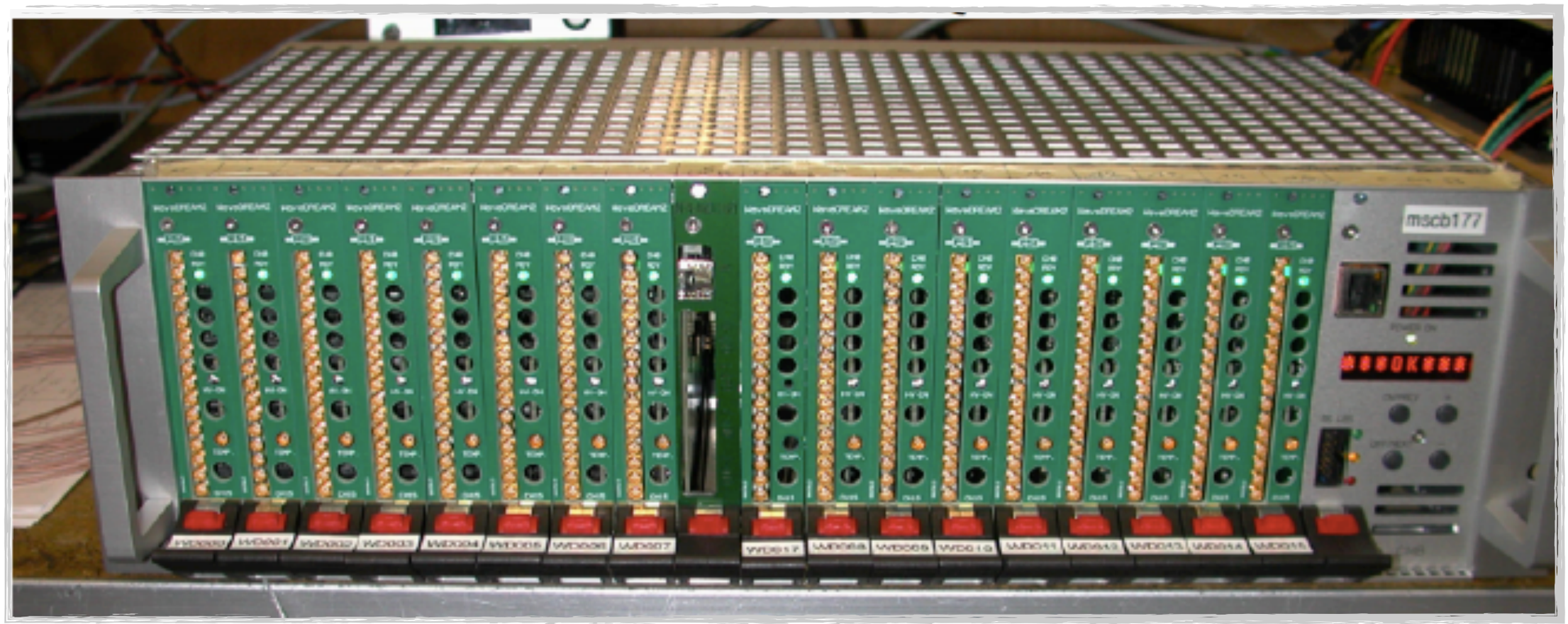




A. Crivellin et al. arXiv:1611.03409v1

MEGII: The new electronic - DAQ and Trigger

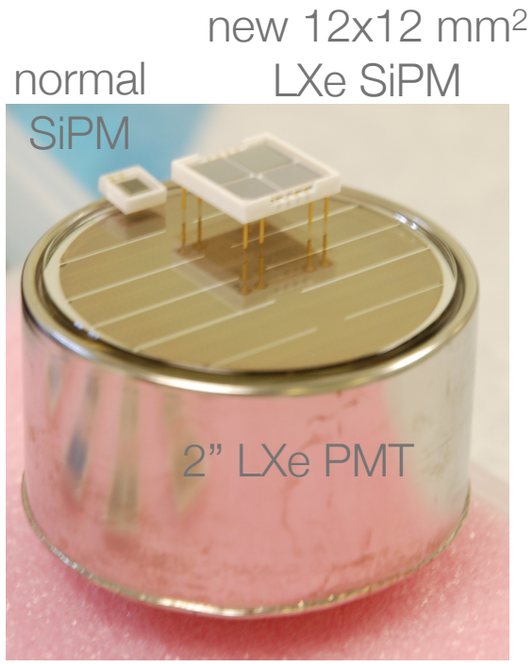
- DAQ and Trigger
  - ~9000 channels (5 GSPS)
  - Bias voltage, preamplifiers and shaping included for SiPMs
- 256 channels (1 crate) abundant tested during the 2016 pre-engineering run; >1000 channels available for the incoming 2017 pre-engineering run
- Trigger electronics and several trigger algorithms included and successfully delivered for the test beams/engineering runs



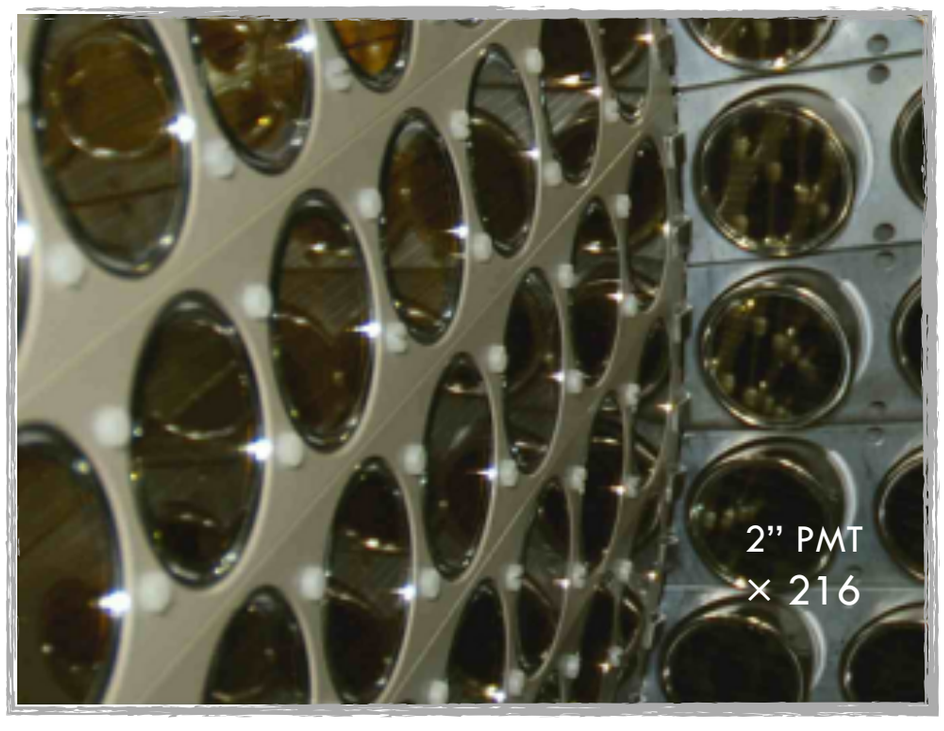
MEGII: The upgraded LXe calorimeter

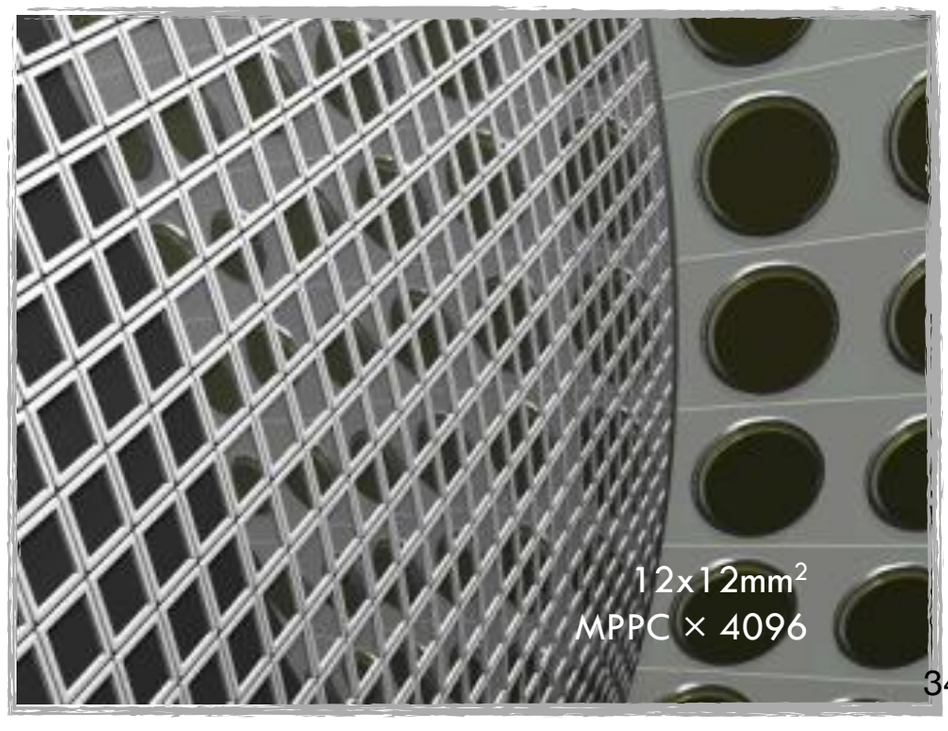
- Increased uniformity/resolutions
- Increased pile-up rejection capability
- Increased acceptance and detection efficiency
- Assembly: Completed
- Detector filled with LXe
- Purification: Ongoing
- Monitoring and calibrations with sources: Started

New



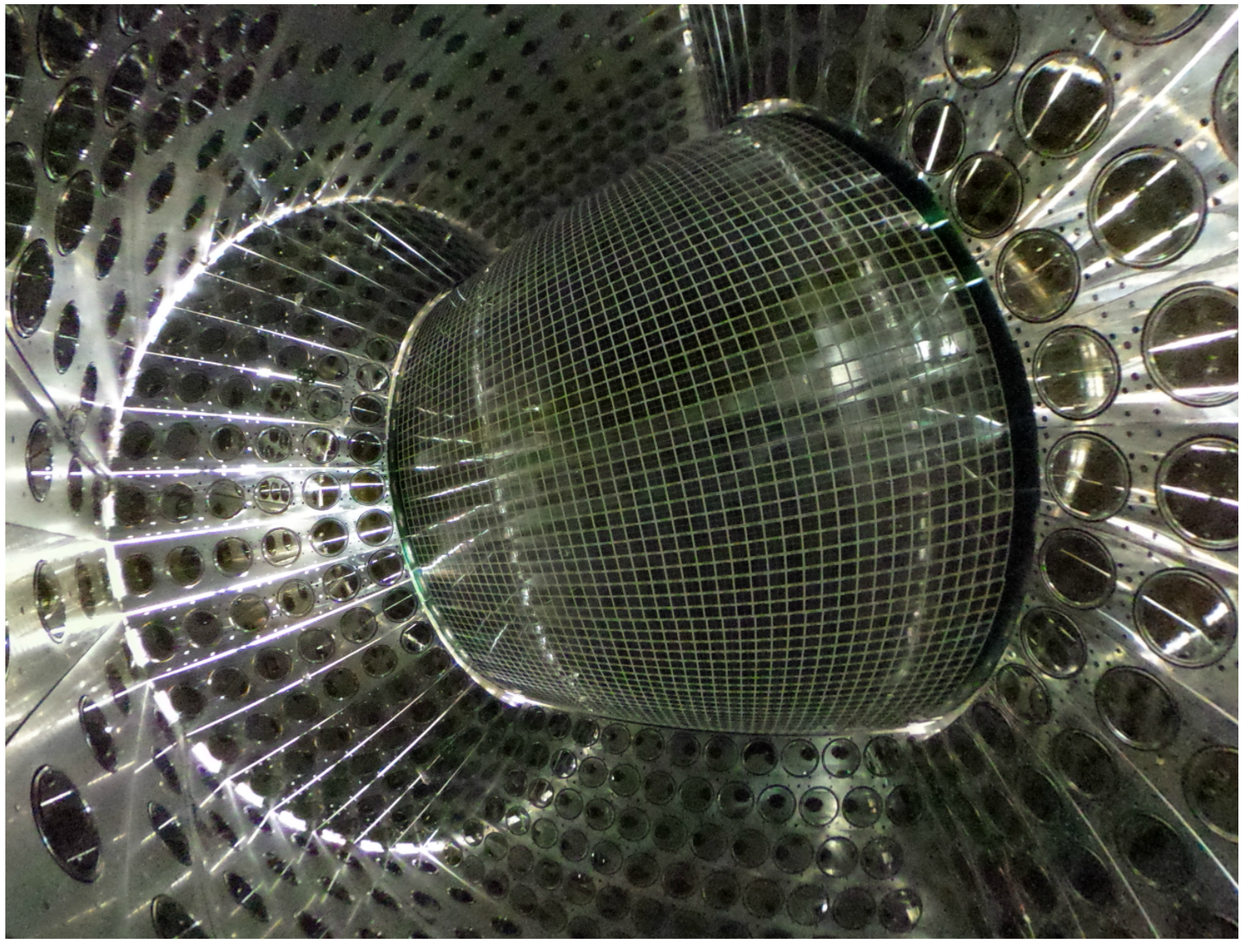
	MEG	MEGII
u [mm]	5	2.4
v [mm]	5	2.2
w [mm]	6	3.1
E [w<2cm]	2.4%	1.1%
E [w>2cm]	1.7%	1.0%
t [ps]	67	60



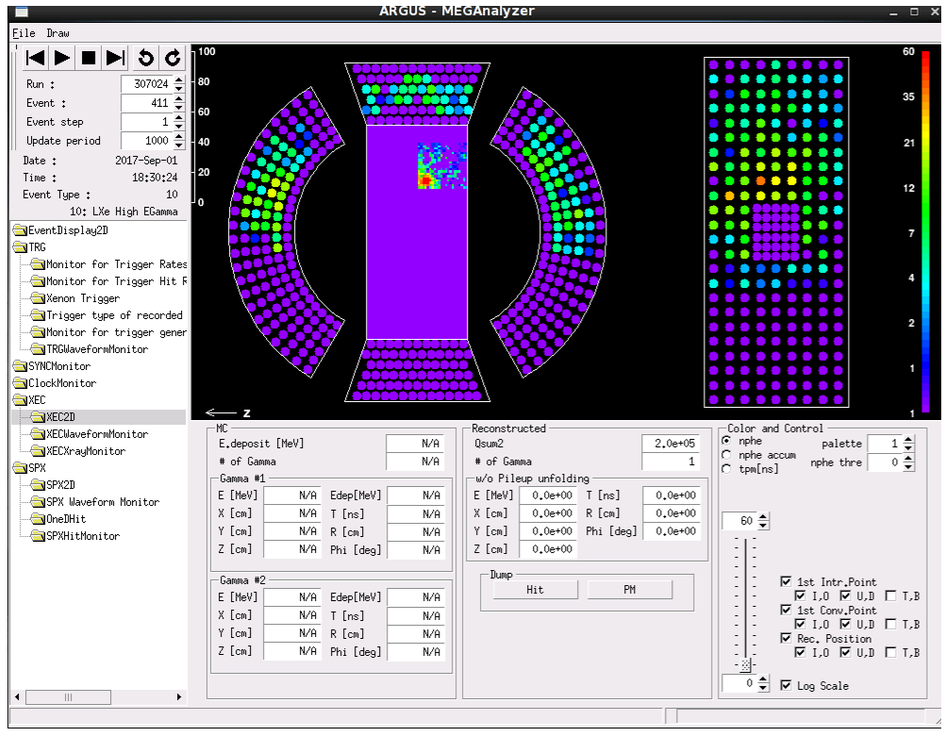


MEGII: The upgraded LXe calorimeter

Detector commissioning started !

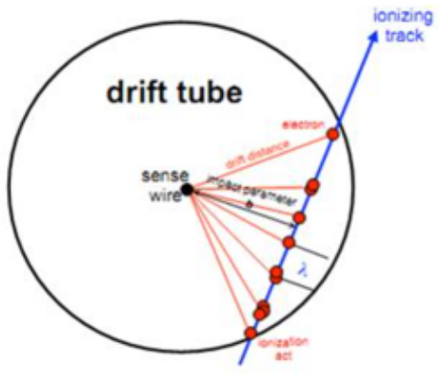


New



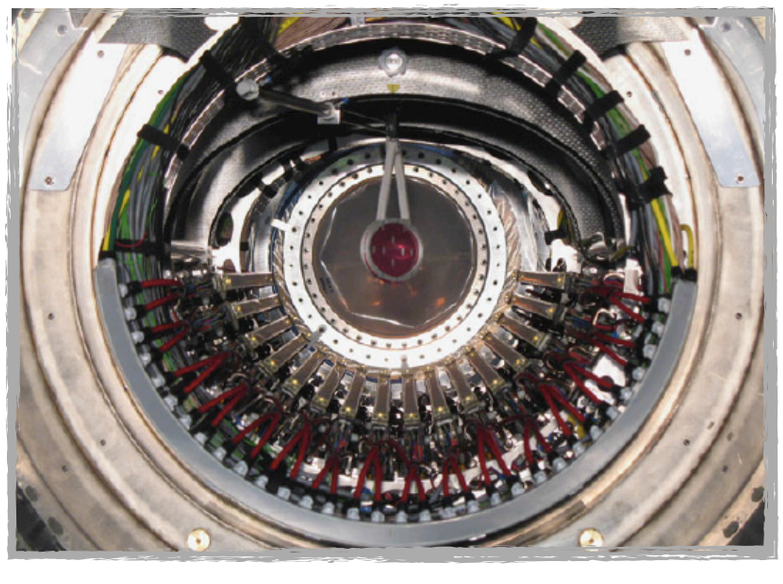
MEGII: The new single volume chamber

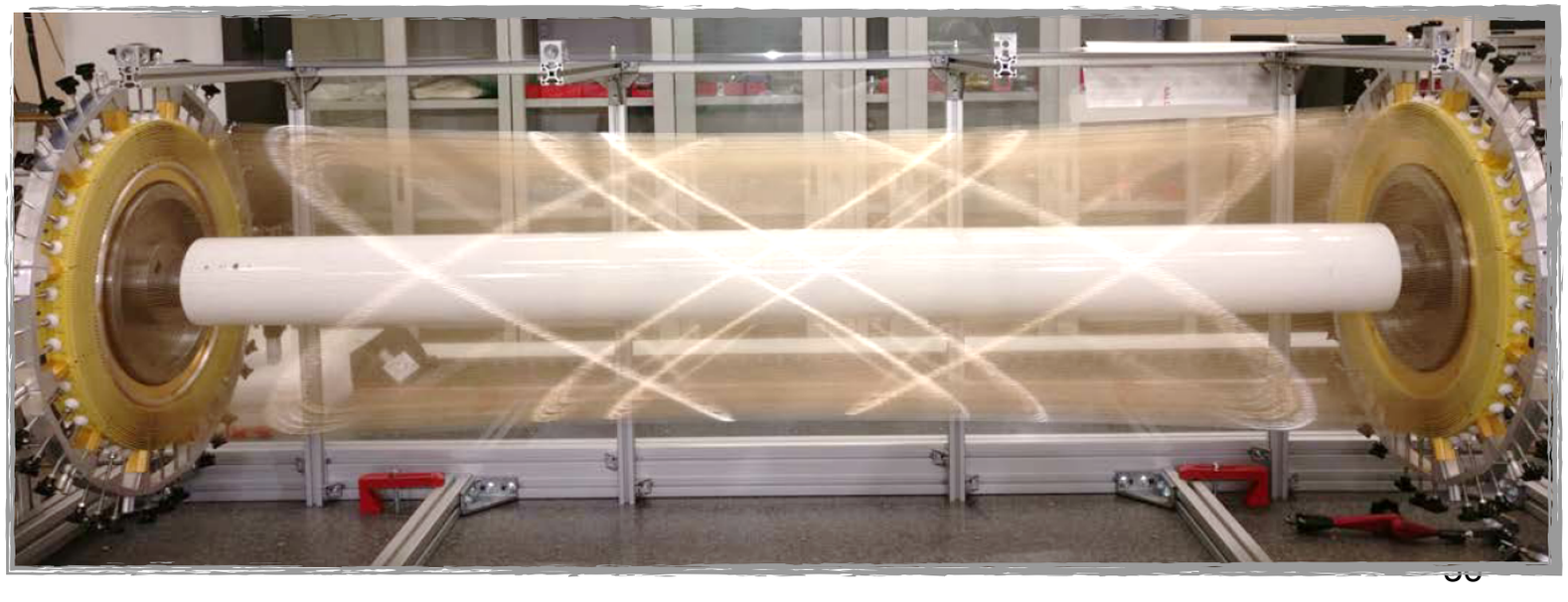
- Improved hit resolution: σ_r ~< 120 um (210 um)
- High granularity/Increased number of hits per track/cluster timing technique
- Less material (helium: isobutane = 90:10, 1.6×10^{-3} X_0)
- High transparency towards the TC
- Assembly: ~ 70% (wiring ~ 80%)



	MEG	MEGII
p [keV]	306	80
θ [mrad]	9.4	6.3
ϕ [mrad]	8.7	5.0
ϵ [%]*	40	70

(*) It includes also the matching with the Timing Counter





MEGII: The new single volume chamber

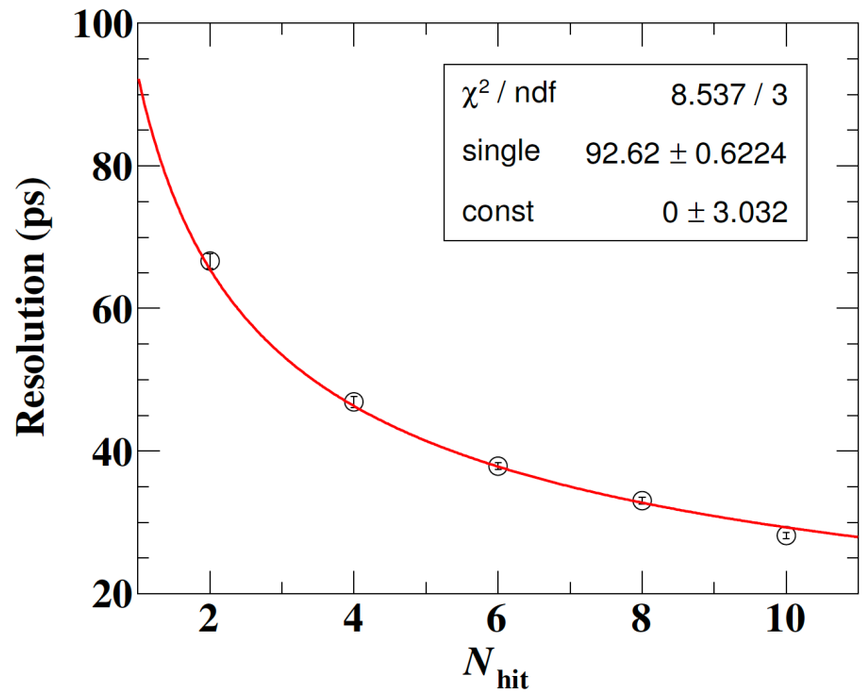
New

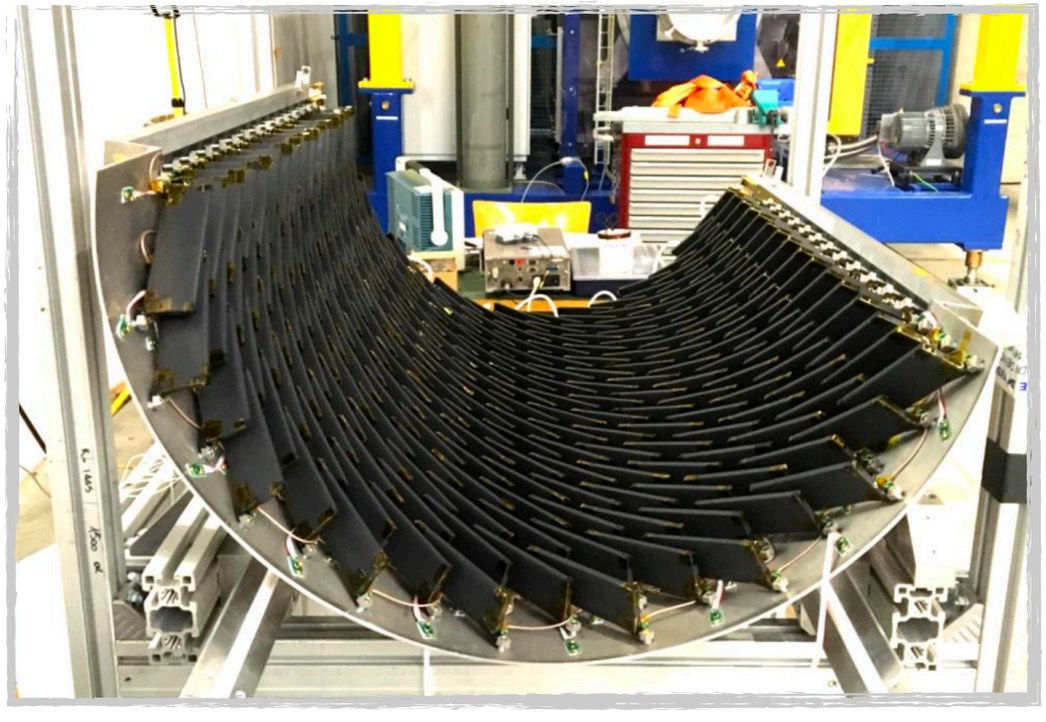
DCH Mock-up Ready!

MEGII: the pixelized Timing Counter

- Higher granularity: 2 x 256 of BC422 scintillator plates (120 x 40 (or 50) x 5 mm^3) readout by AdvanSiD SiPM ASD-NUM3S-P-50-High-Gain
- Improved timing resolution: from 70 ps to 35 ps (multi-hits)
- Less multiple scattering and pile-up
- Assembly: Completed **New**
- Expected detector performances confirmed with data

Pilot run 2016

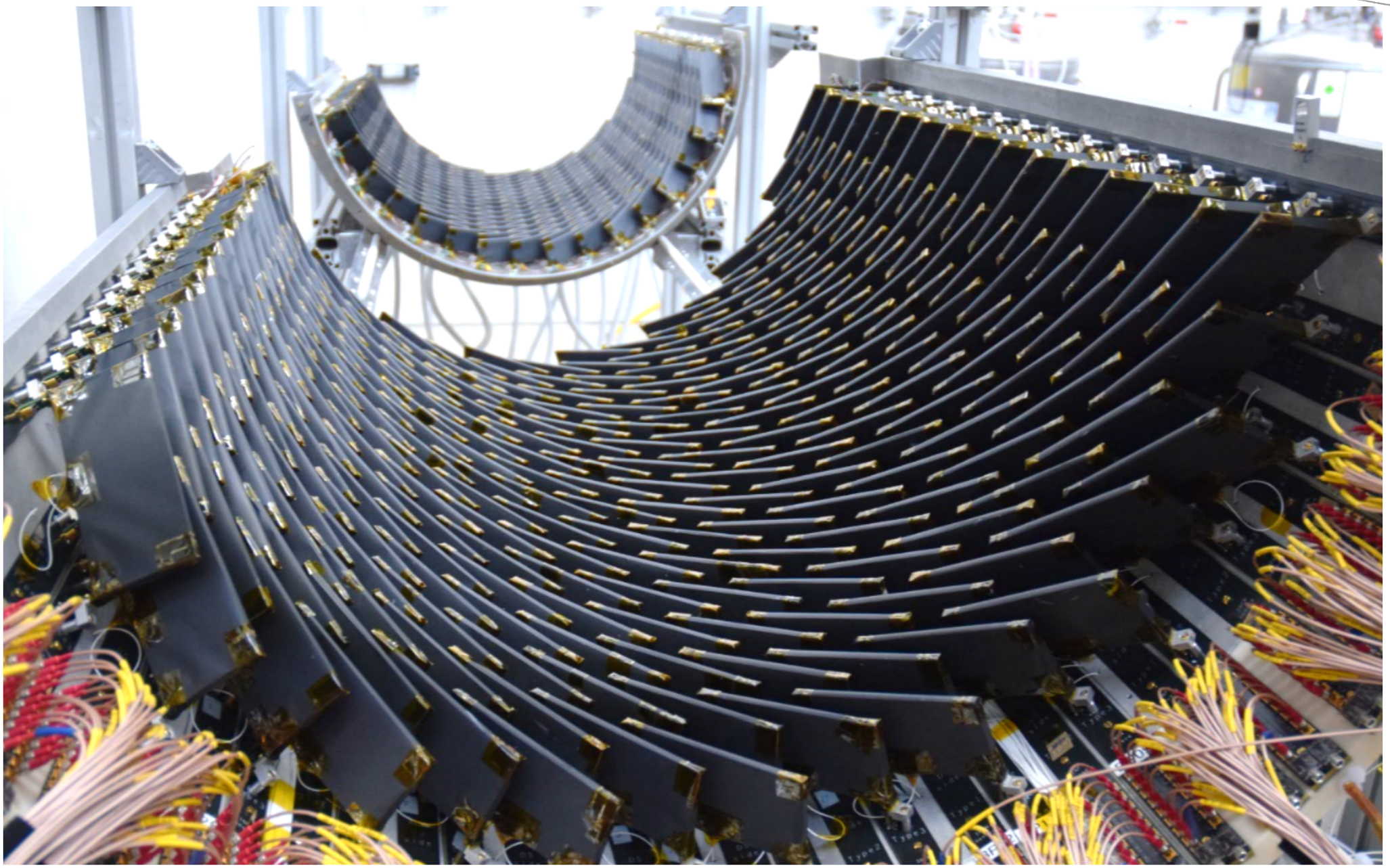




MEGII: the pixelized Timing Counter

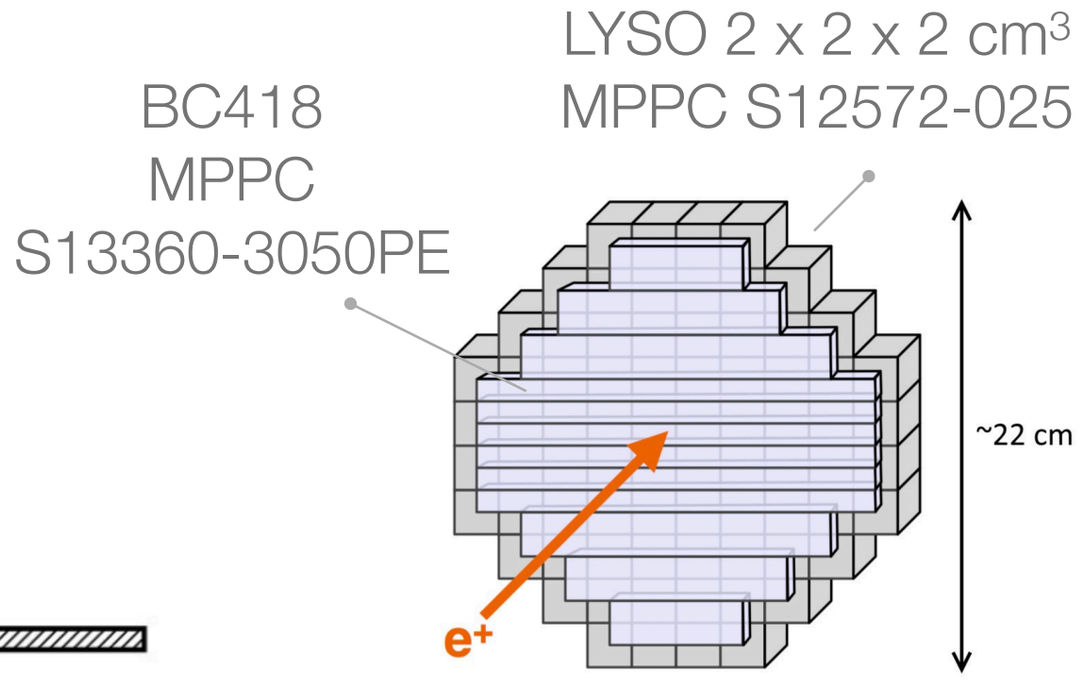
Ready to be inserted inside Cobra !

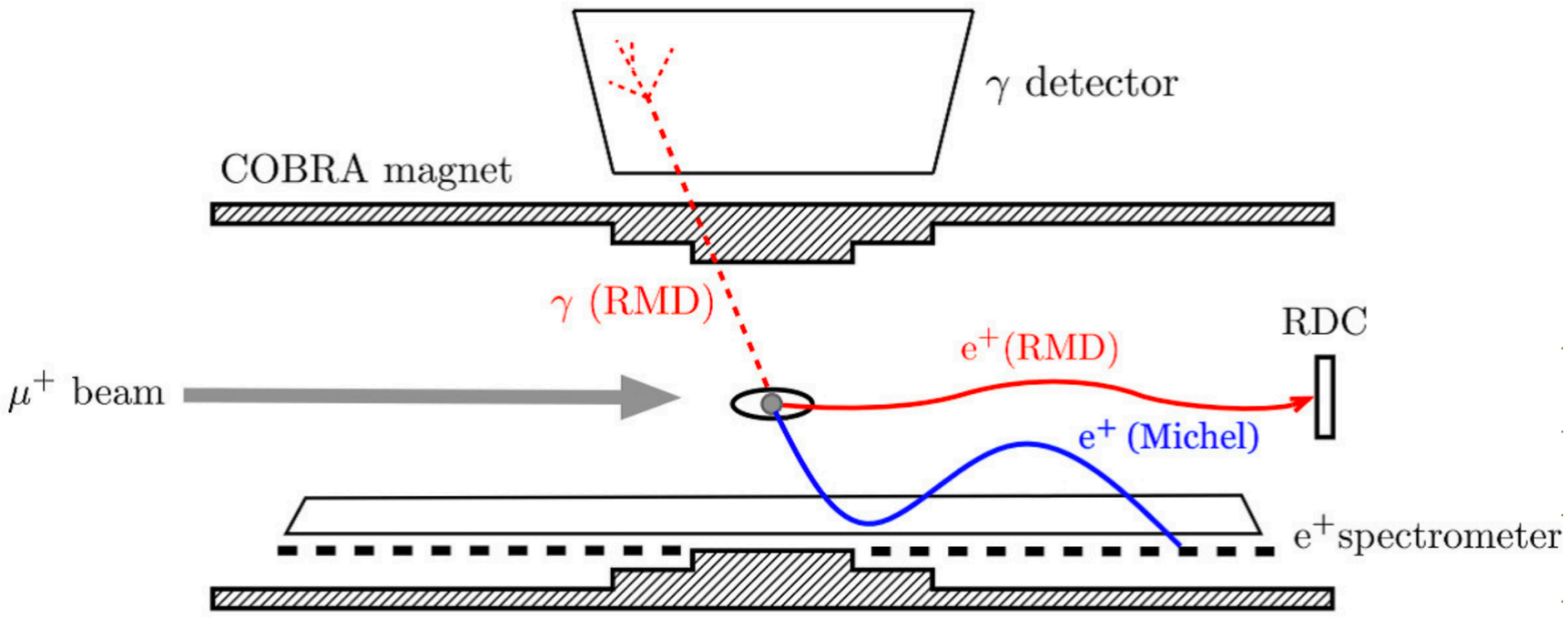
New

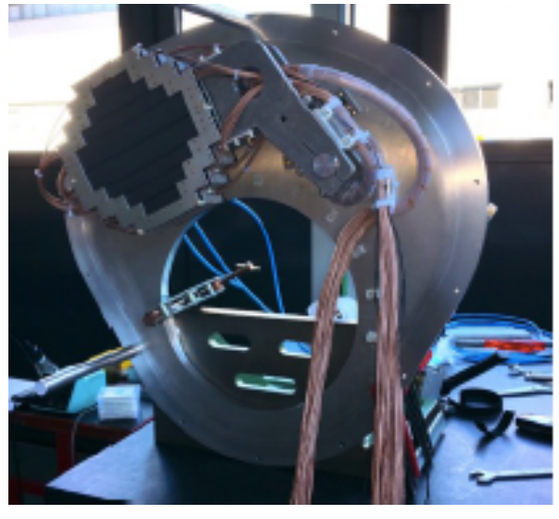


MEGII: The Radiative Decay Counter

- Added a new auxiliary detector for background rejection purpose. Impact into the experiment: Improved sensitivity by 20%
- Commissioning during the 2016 pre-engineering run
- Status: Ready



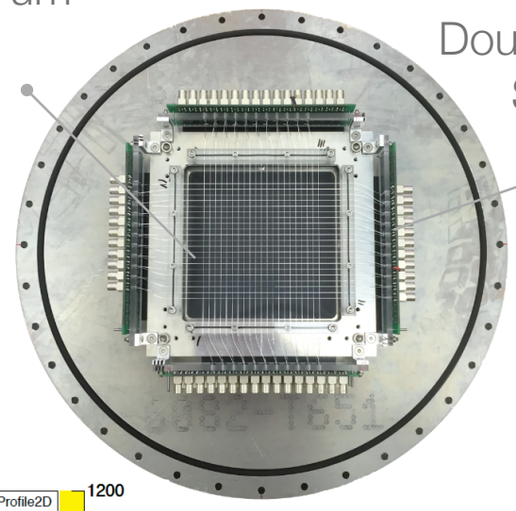




MEGII: new calibration methods and upgrades

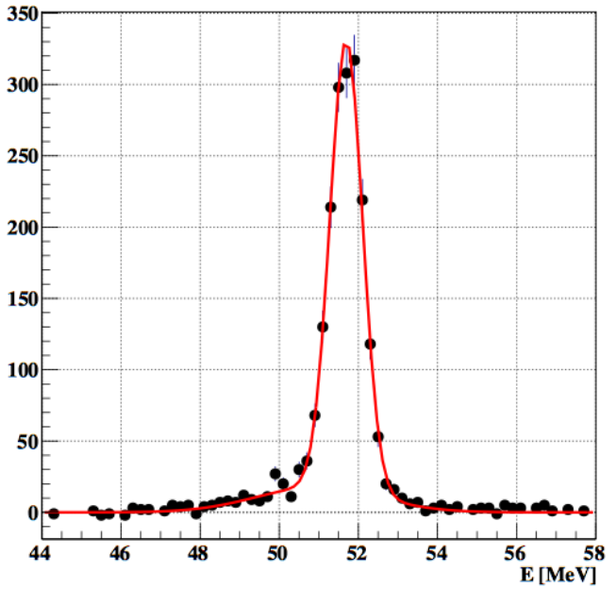
- CEX reaction: $p(\pi^-, \pi^0)n$, $\pi^0 \rightarrow \gamma\gamma$
- 1MV Cockcroft-Walton accelerator
- Pulsed D-D Neutron generator
- NEW: Mott scattered positron beam to fully exploit the new spectrometer
- NEW: SciFi beam monitoring. Not invasive, ID particle identification, vacuum compatible, working in magnetic field, online beam monitor (beam rate and profile)
- NEW: Luminophore (CsI(Tl) on Lavsan/Mylar equivalent) to measure the beam properties at the Cobra center
- NEW: LXe X-ray survey
- NEW: Laser system for the pTC

MC BCF12 250 x 250 um^2 scintillating fibers



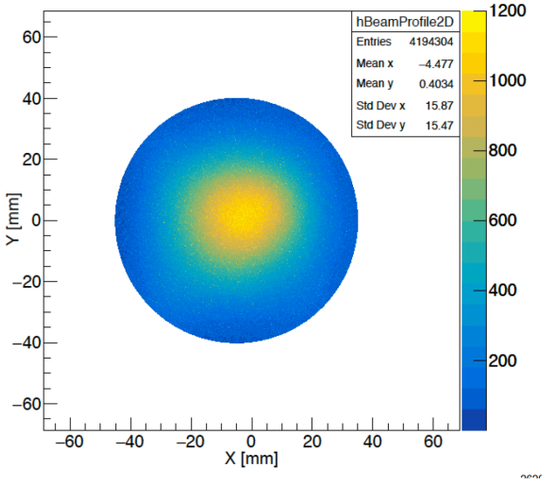
Double readout: MPPC S13360-3050C

Monochromatic e-line

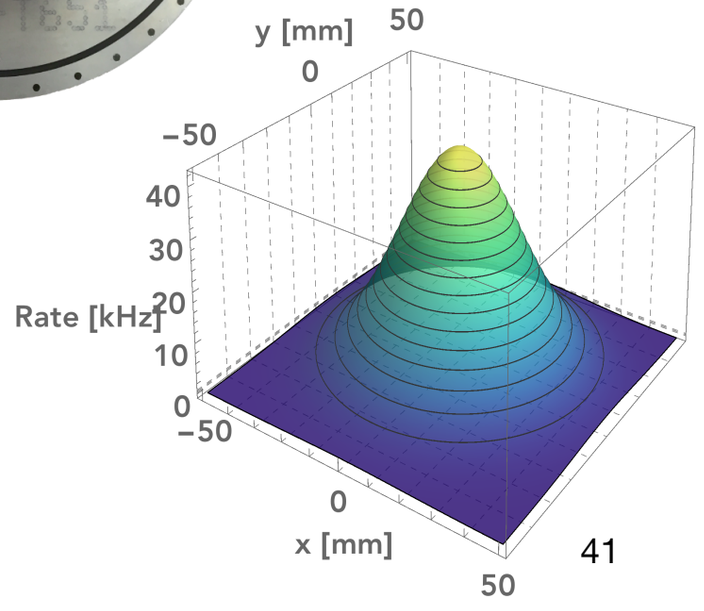


pTC's laser

Luminophore



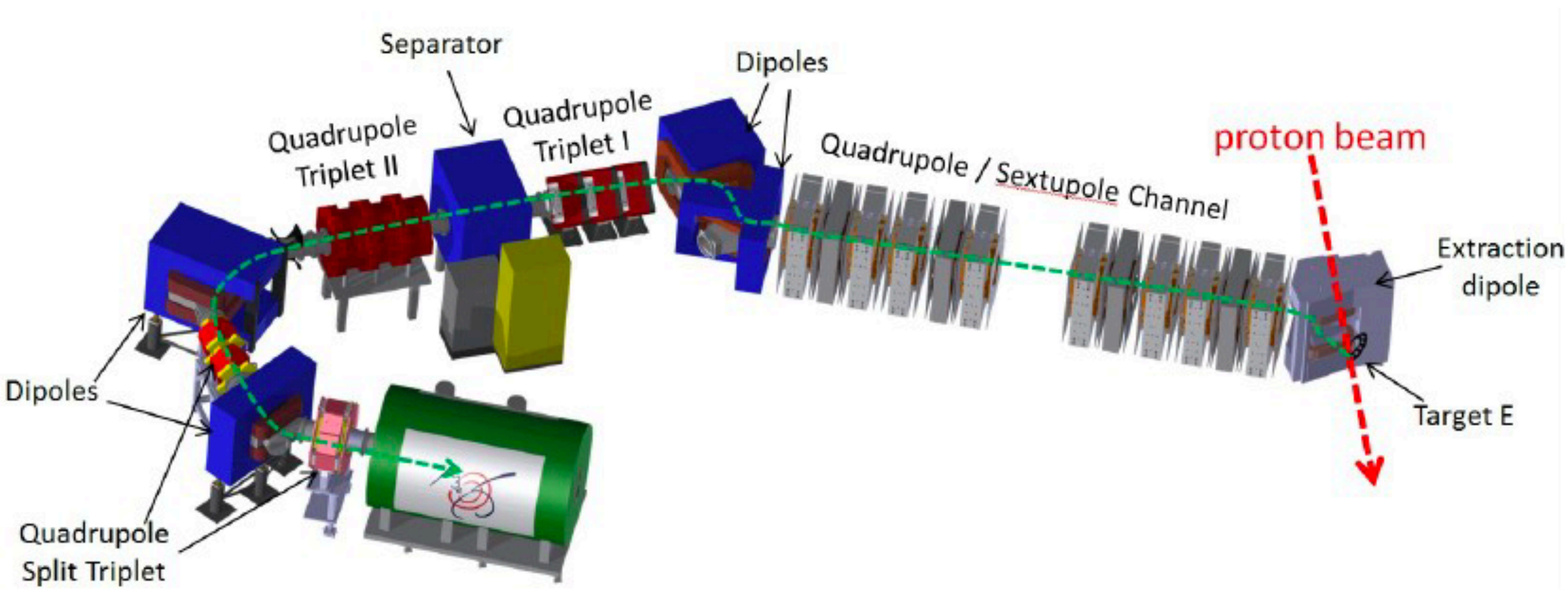
SciFi



The compact beam line

- A dedicated compact muon beam line (CMBL) will serve Mu3e
- Aim: To deliver O(10^8) muon/s

The CMBL

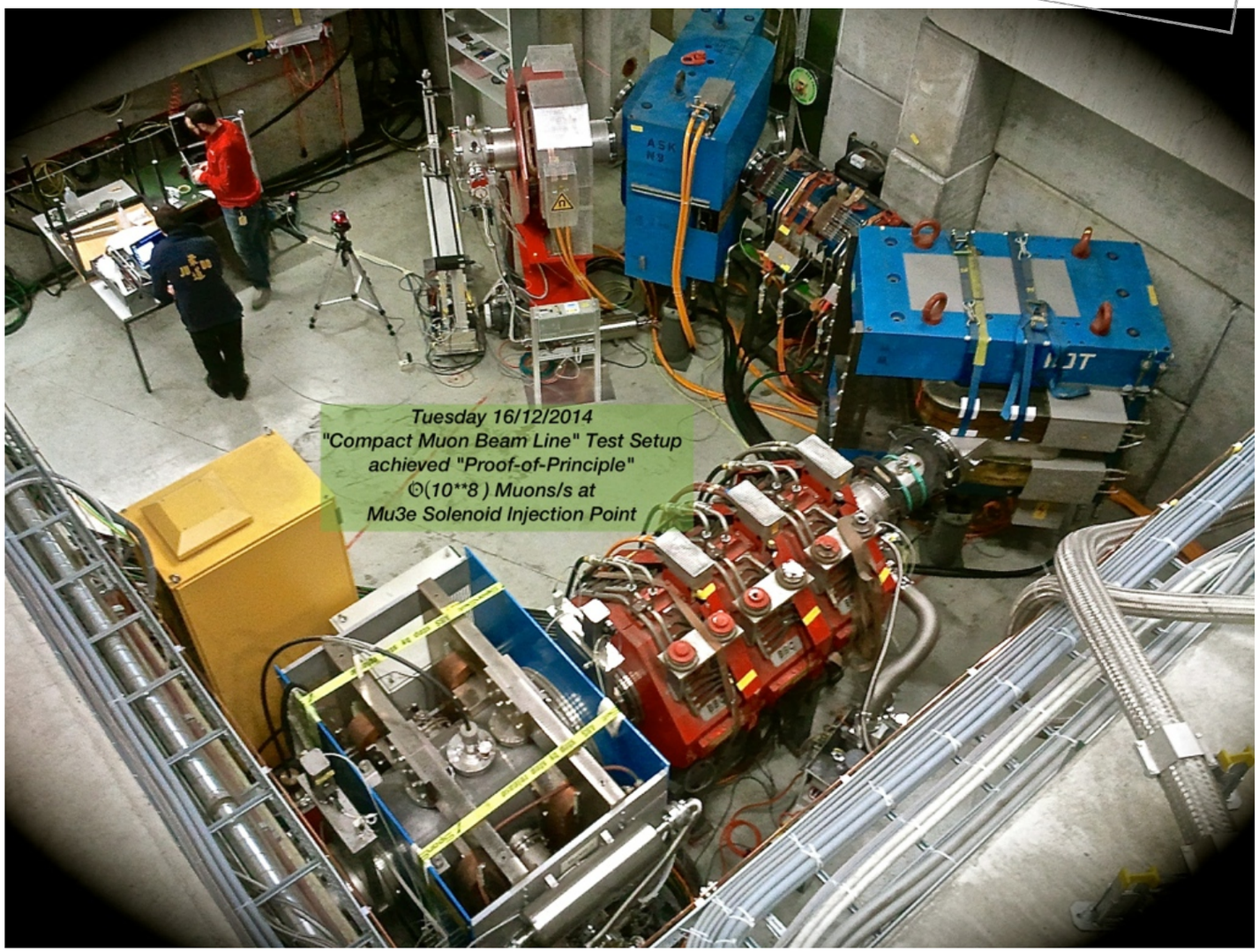


The compact beam line: Results

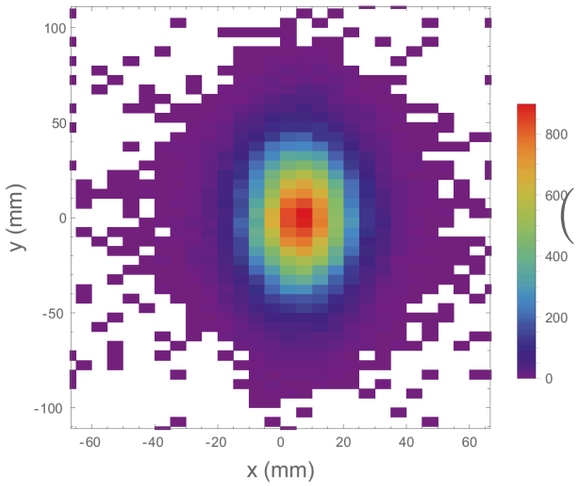
- A dedicated compact muon beam line (CMBL) will serve Mu3e
- Proof-of-Principle: Delivered 8.4 10^7 muon/s during 2016 test beam

The CMBL

New

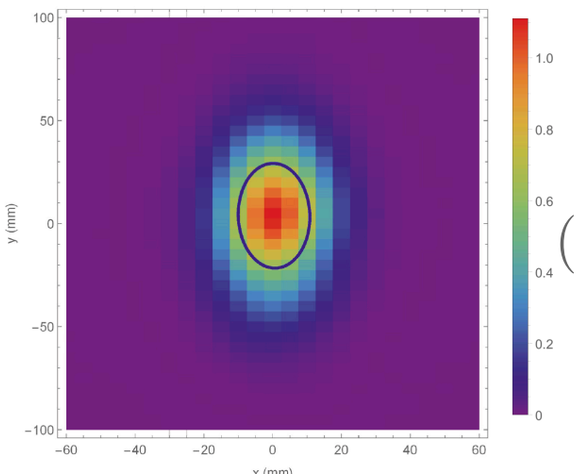


Beam at the injection Mu3e solenoid point



Simulation

$$(\sigma_x, \sigma_y) = (10.6, 24.3)[\text{mm}]$$

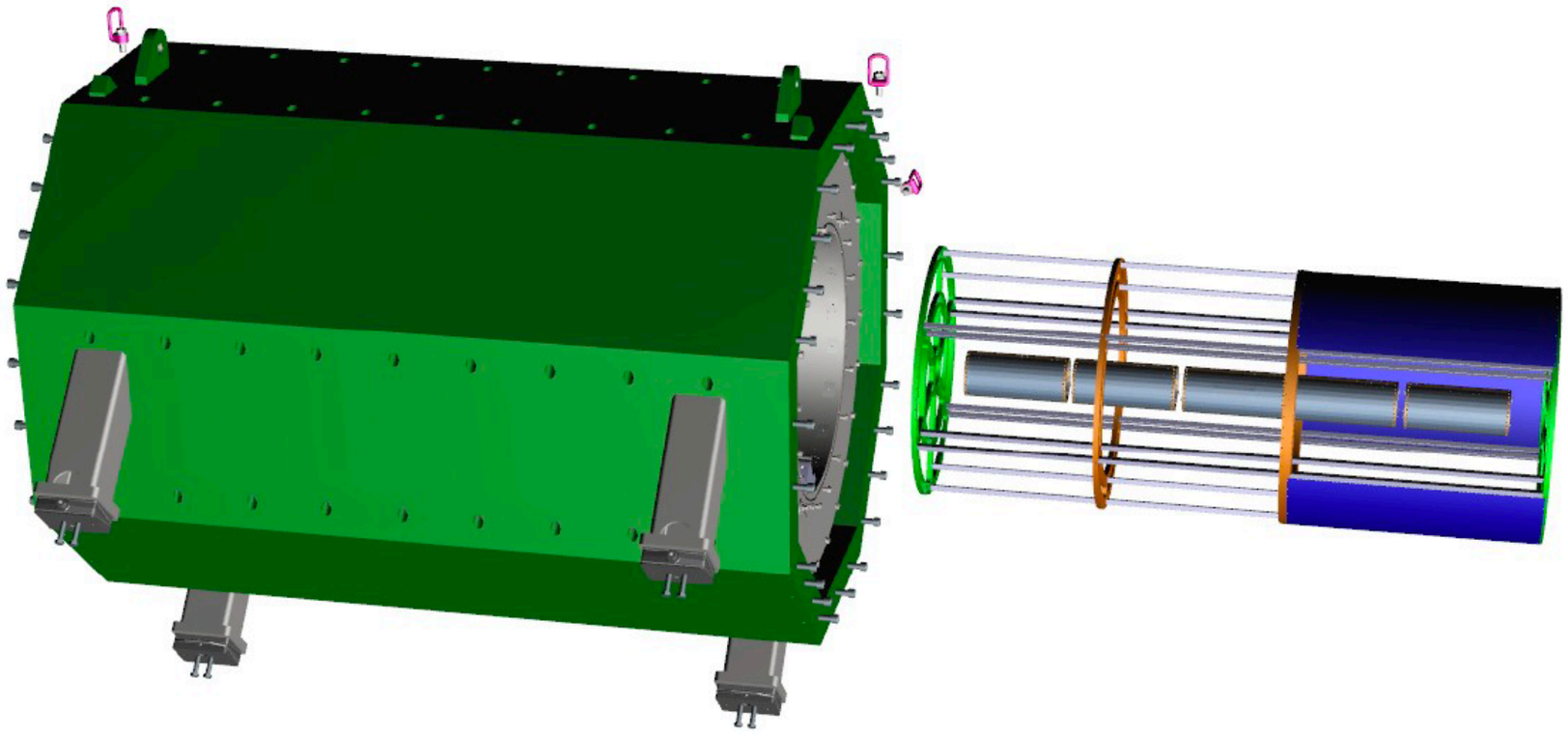


Data

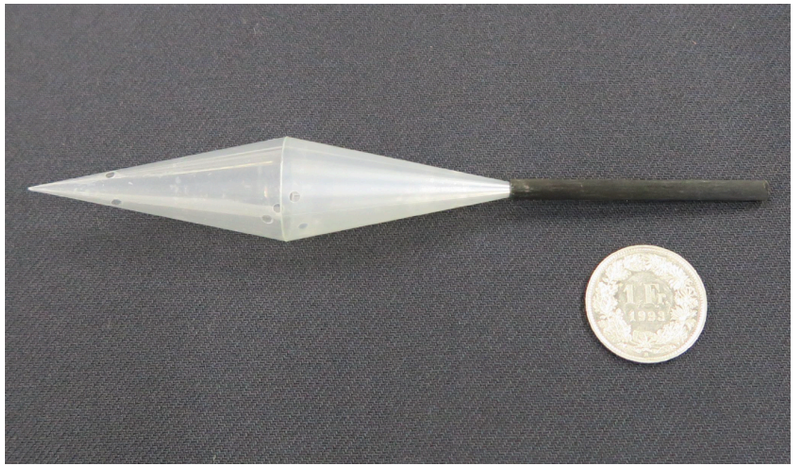
$$(\sigma_x, \sigma_y) = (10.4, 25.4)[\text{mm}]$$

Target and magnet: Status

- Target: Mylar double hollow cone (L = 100 mm, R = 19 mm), Stopping efficiency: ~ 83%, Vertex separation ability (tracking) < 200 um
- Magnet: Delivery including the commissioning of the magnet at PSI originally foreseen for December 2016. Contract cancel in January 2017
- Current status: In contact several companies. New delivering date: beginning 2019

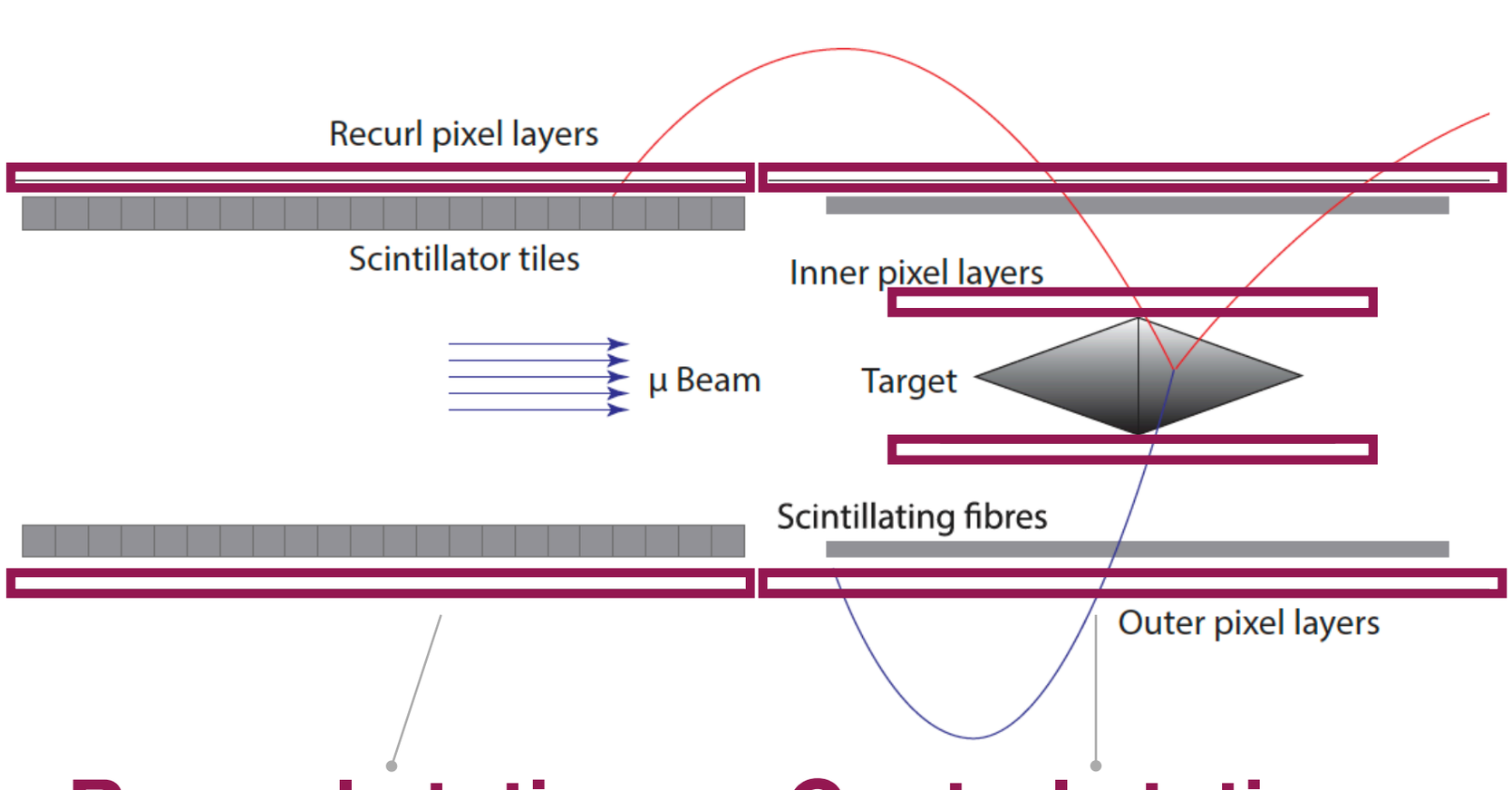


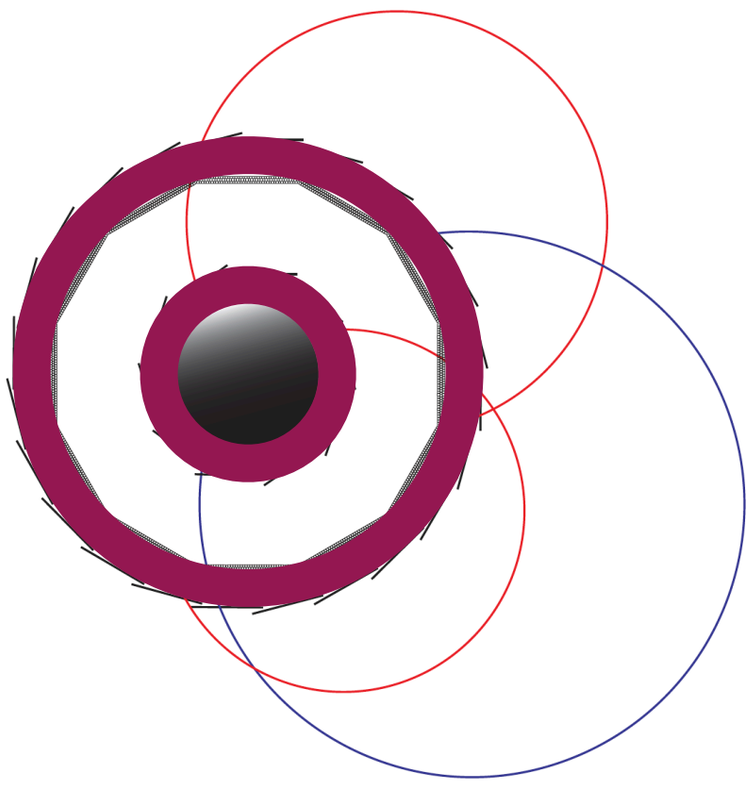
Target prototype



The pixel tracker: Overview

- Central tracker: Four layers; Re-curl tracker: Two layers
- Minimum material budget: Tracking in the scattering dominated regime
- Momentum resolution: < 0.5 MeV/c over a large phase space; Geometrical acceptance: ~ 70%; X/X_0 per layer: ~ 0.011%



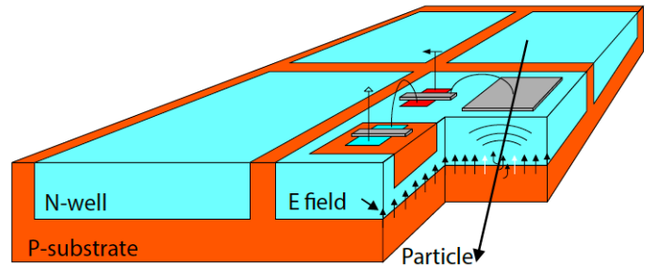


Re-curl stations **Central stations**

The pixel tracker: The MuPix prototypes

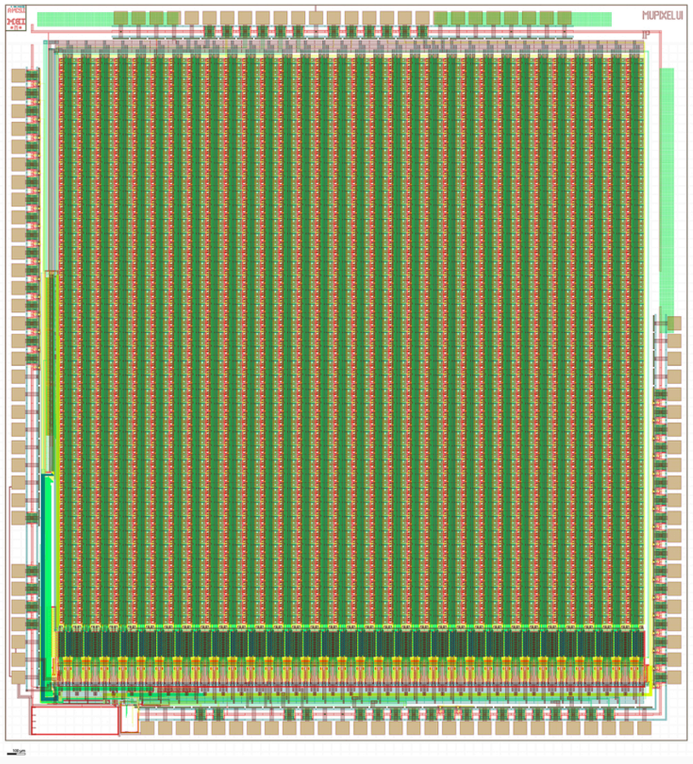
Ivan Peric, Nucl.Instrum.Meth. A582 (2007) 876-885

- Based on HV- MAP: Pixel dimension: 80 x 80 μm^2 , Thickness: 50 µm , Time resolution: < 20 ns, Active area chip: 20 x 20 mm^2 , Efficiency: > 99 %, Power consumption : < 350 mW/cm^2
- MuPix 7: The first small-scale prototype which includes all Mu3e functionalities

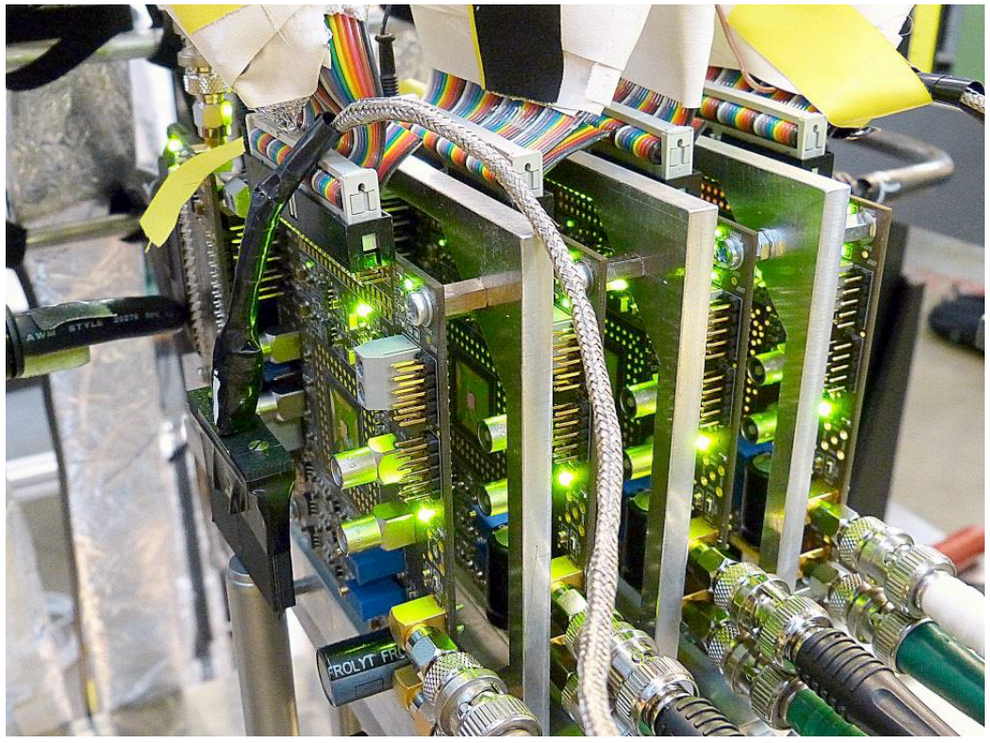


Prototype	Active Area [mm^2]
MuPix1	1.77
MuPix2	1.77
MuPix3	9.42
MuPix4	9.42
MuPix6	10.55
MuPix7	10.55

MuPix7



Extensively tested along beams



The pixel tracker: Current and future plan

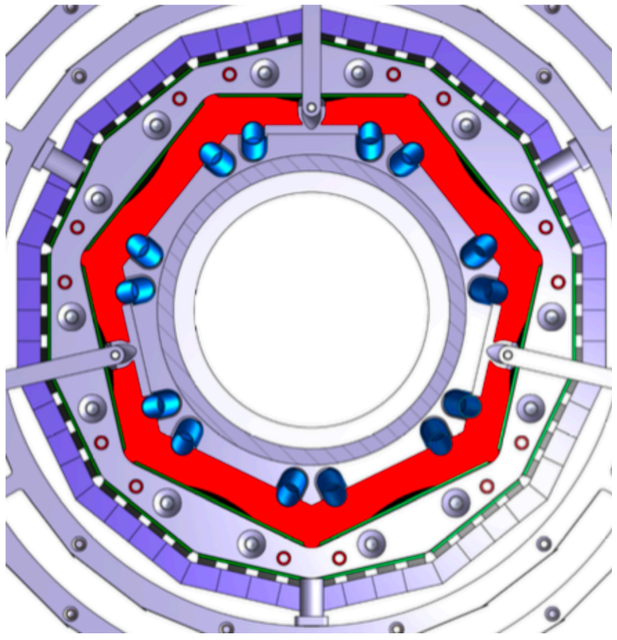
- After an extensive test beam campaign, achieved milestones
  - A fully functional HV-MAPS chip, 3x3 mm^2, Operation at high rates: 300 kHz at PSI; up to 1 MHz at SPS
  - Crosstalk on setup under control, on chip seen. Mitigation plan exists (MuPix8), Routinely operated systems of up to 8 chips in test beams reliably
  - Data processing of one telescope at full rate on GPU demonstrated

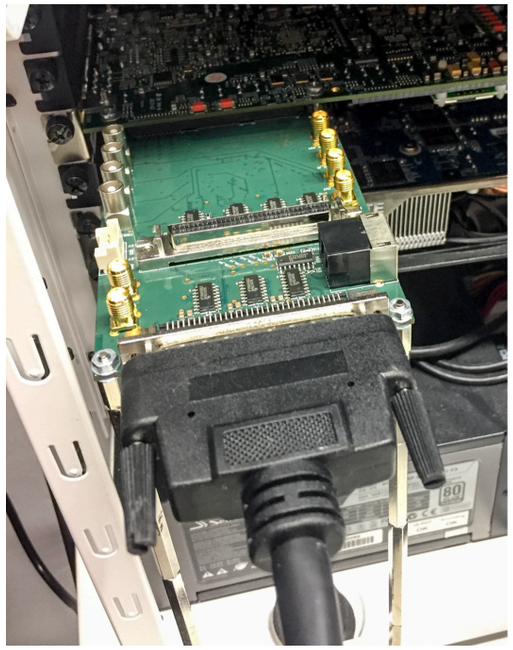
- Next steps
  - MuPix 8, the first large area prototype: from O(10) mm^2 to 160 mm^2 : Ready !
  - MuPix 9, small test chip for: Slow Control, voltage regulators and other test circuits; Submission is happening right now
  - MuPix 10, the final version for Mu3e: Active area from 160 mm^2 to 380 mm^2

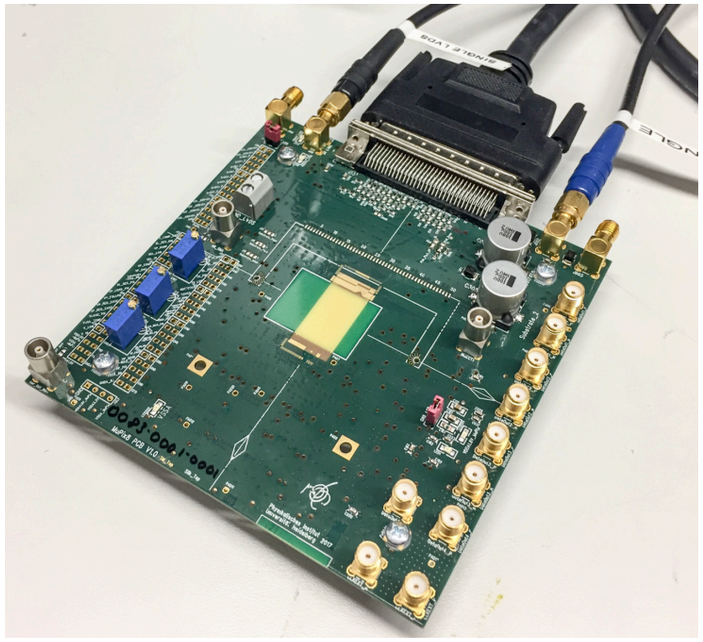
New

MuPix8

New

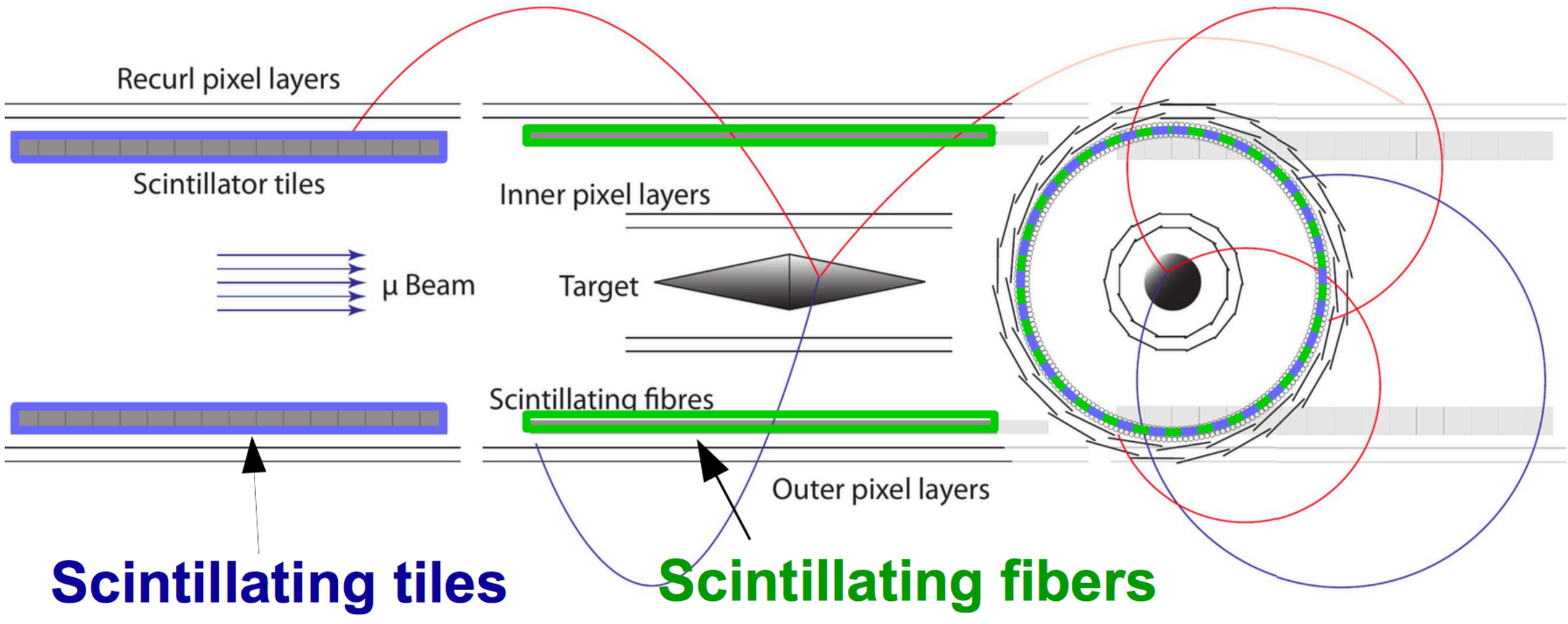






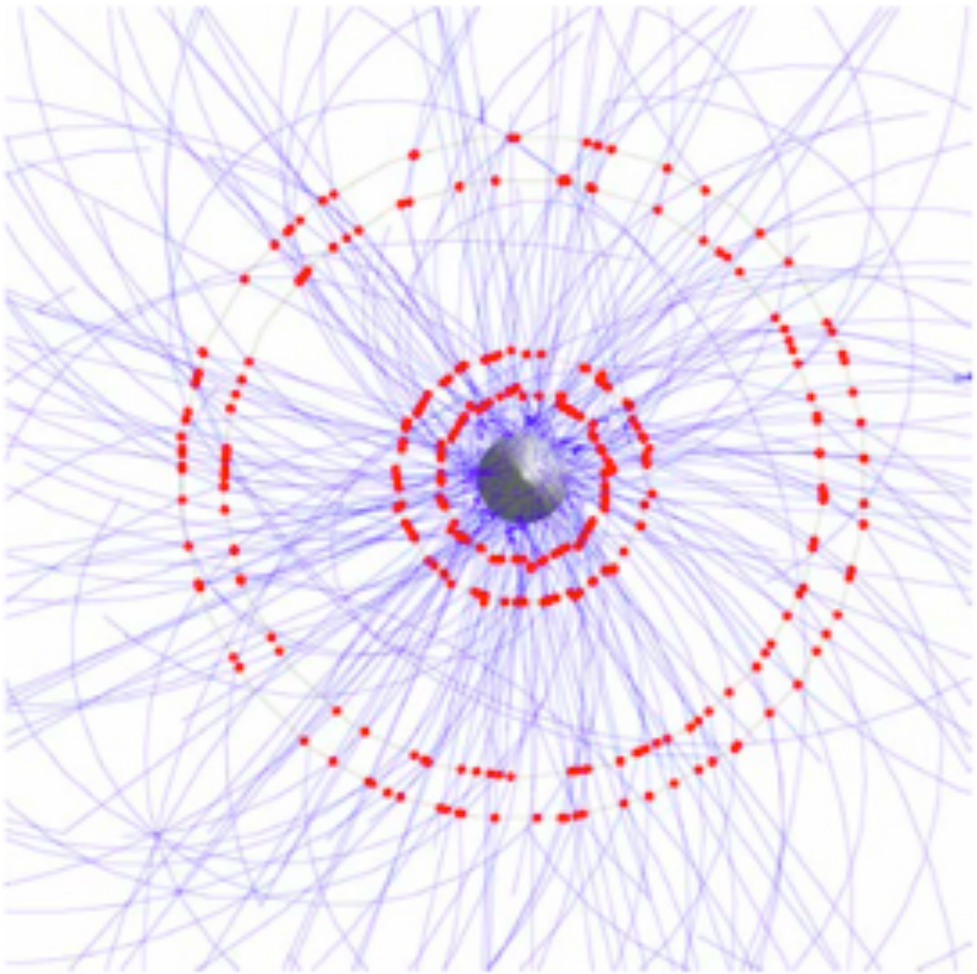
The timing detectors: Fibers and tiles

- Precise timing measurement: Critical to reduce the accidental BGs
  - Scintillating fibers (SciFi) O(1 ns), full detection efficiency (>99%)
  - Scintillating tiles O(100 ps), full detection efficiency (>99%)

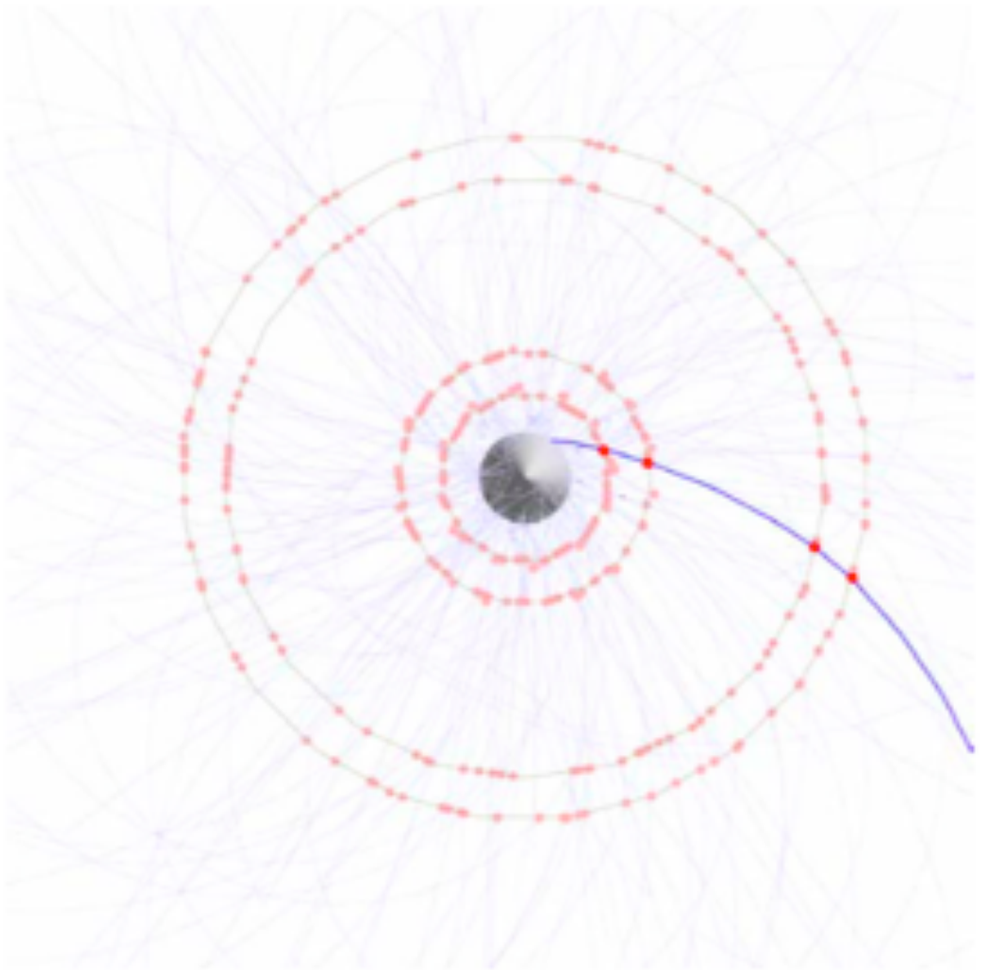


The timing detectors: Fibers and tiles

- Precise timing measurement: Critical to reduce the accidental BGs
    - Scintillating fibers (SciFi) O(1 ns), full detection efficiency (>99%)
    - Scintillating tiles O(100 ps), full detection efficiency (>99%)



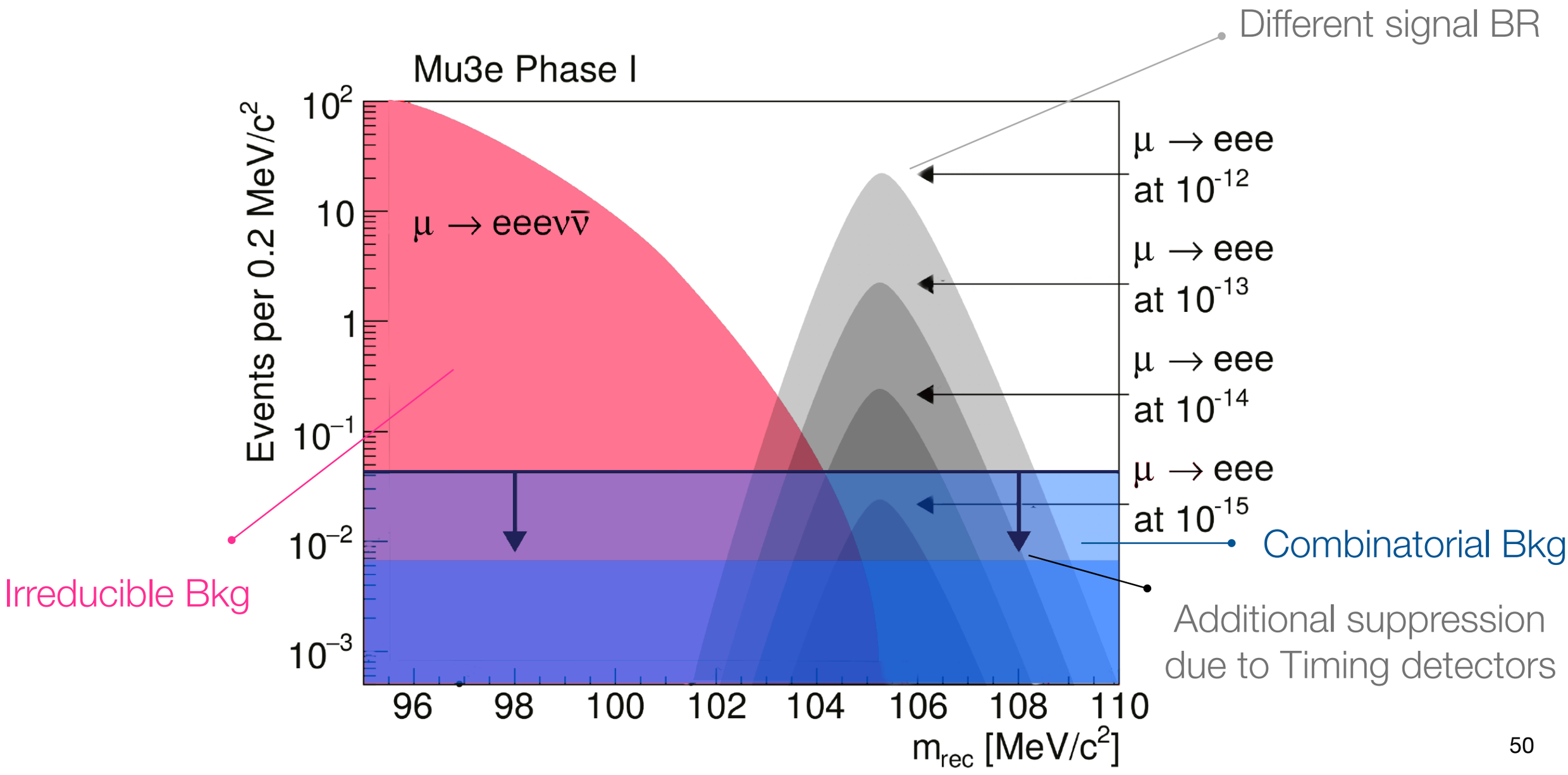
Pixels: O(50 ns)



Scintillating fibres O(1 ns);
Scintillating tiles O(100 ps)

The timing detectors: Impact

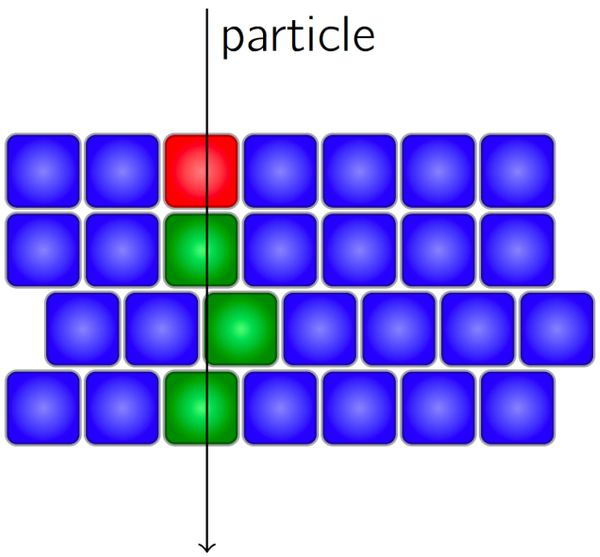
- Precise timing measurement: Critical to reduce the accidental BGs
  - Scintillating fibers (SciFi) O(1 ns), full detection efficiency (>99%)
  - Scintillating tiles O(100 ps), full detection efficiency (>99%)



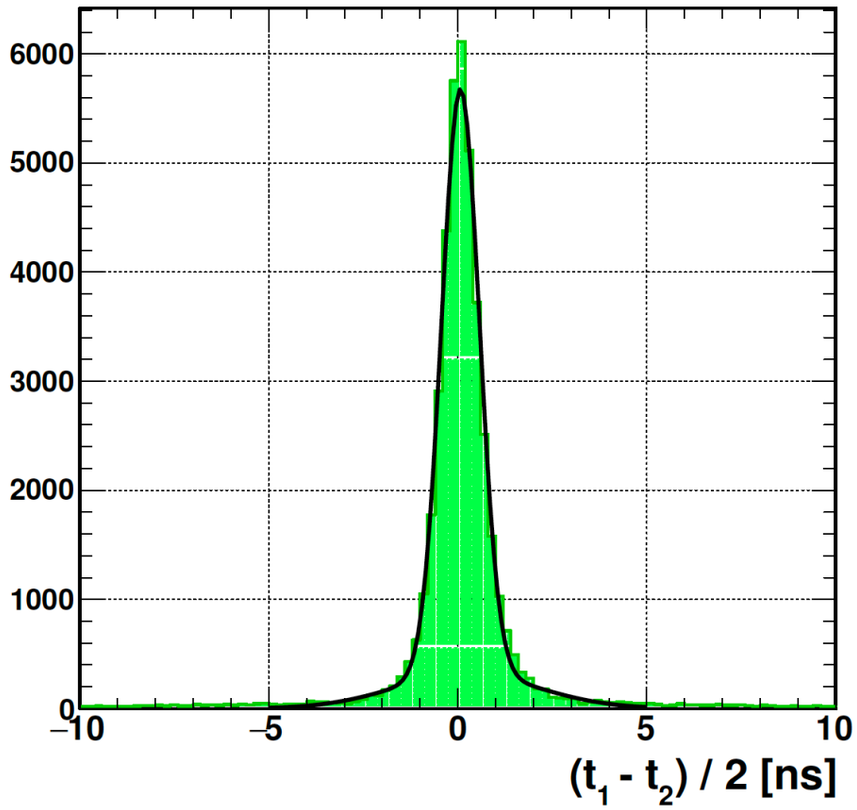
SciFi prototypes: Results

- Confirmed full detection efficiency (> 96 % @ 0.5 thr in Nphe) and timing performances for multi-layer configurations (square and round fibres) with several prototypes: individual and array readout with standalone and prototyping (STiC) DAQ

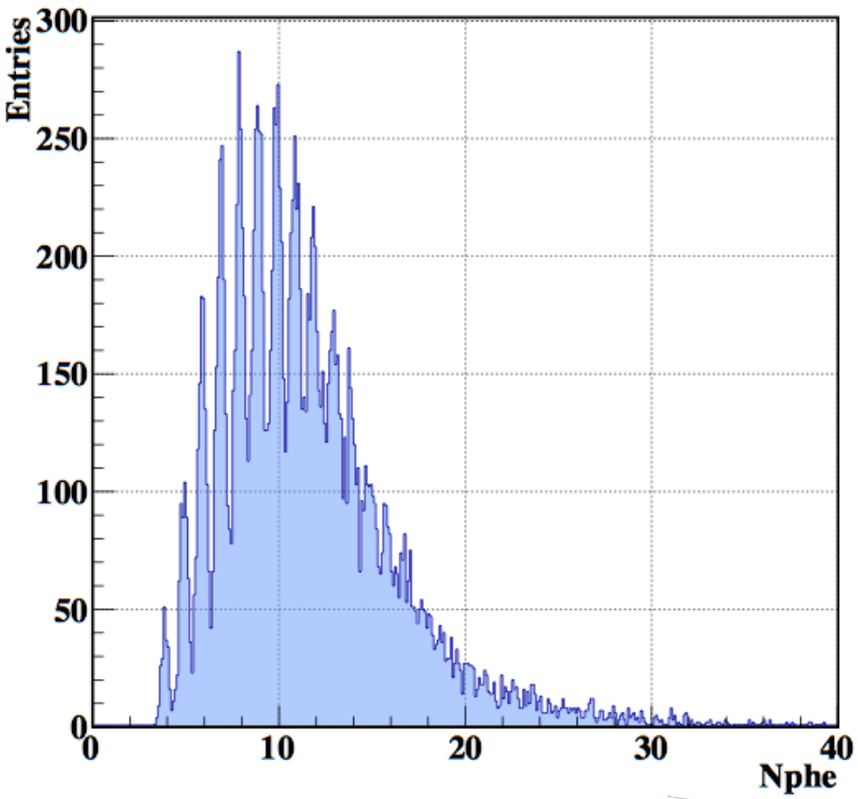
Trigger
offline selection:
hits in 3 layers



3 layer time resolution O(550) ps



3 layer offline array charge collection (thr > 1.5 Nphe)

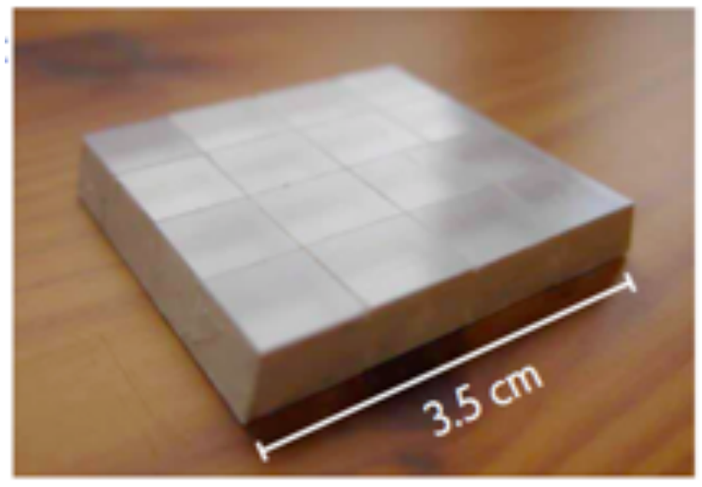


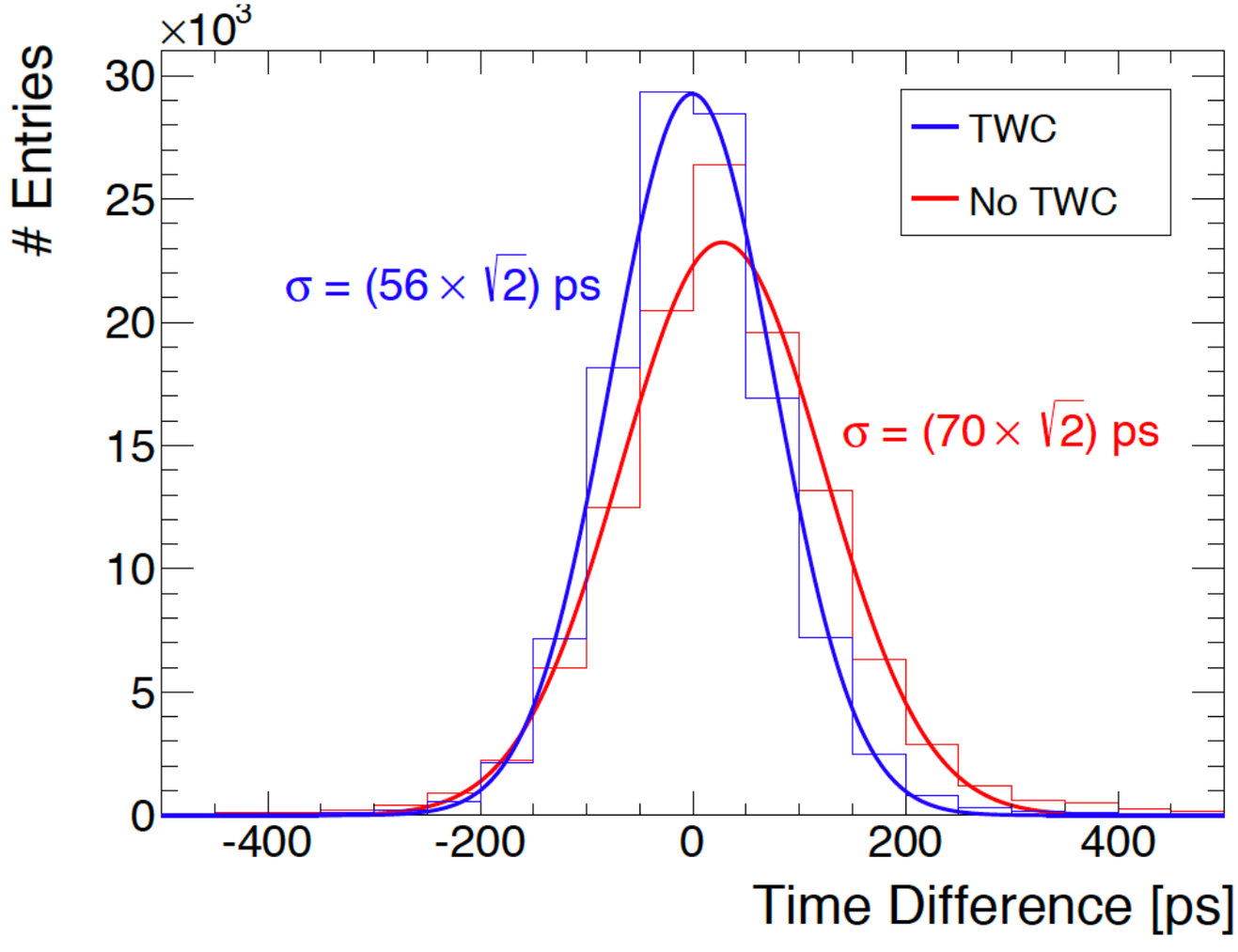
New

Very promising results from summer test beams with also with “new” fibres: SCSF 78 MJ, clear; SCSF 78 MJ, with 20% TiO2; NOL 11, clear; NOL 11, with 20% TiO2; SCSF 81 MJ, with 20% TiO2

Tile Prototype: Results

- Mu3e requirements fulfilled: Full detection efficiency (> 99 %) and timing resolution O (60) ps
- 4 x 4 channel BC408
- 7. 5 x 8. 5 x 5. 0 mm^3
- Hamamatsu S10362-33-050C (3 x 3 mm^2)
- readout with STiC2

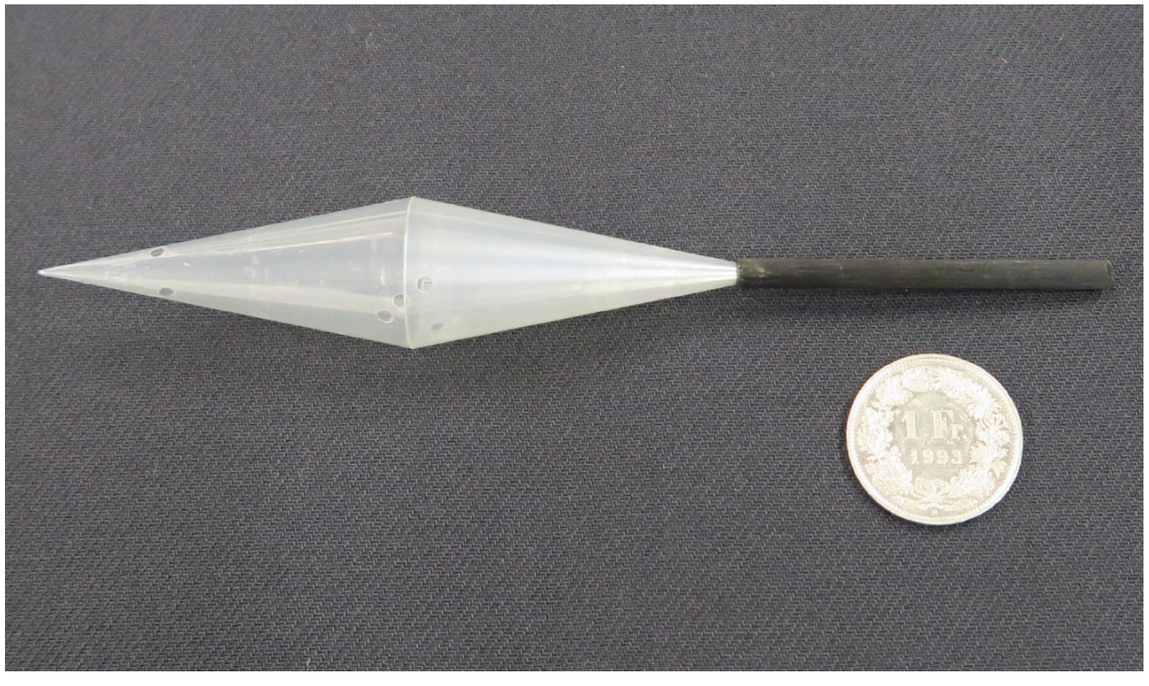




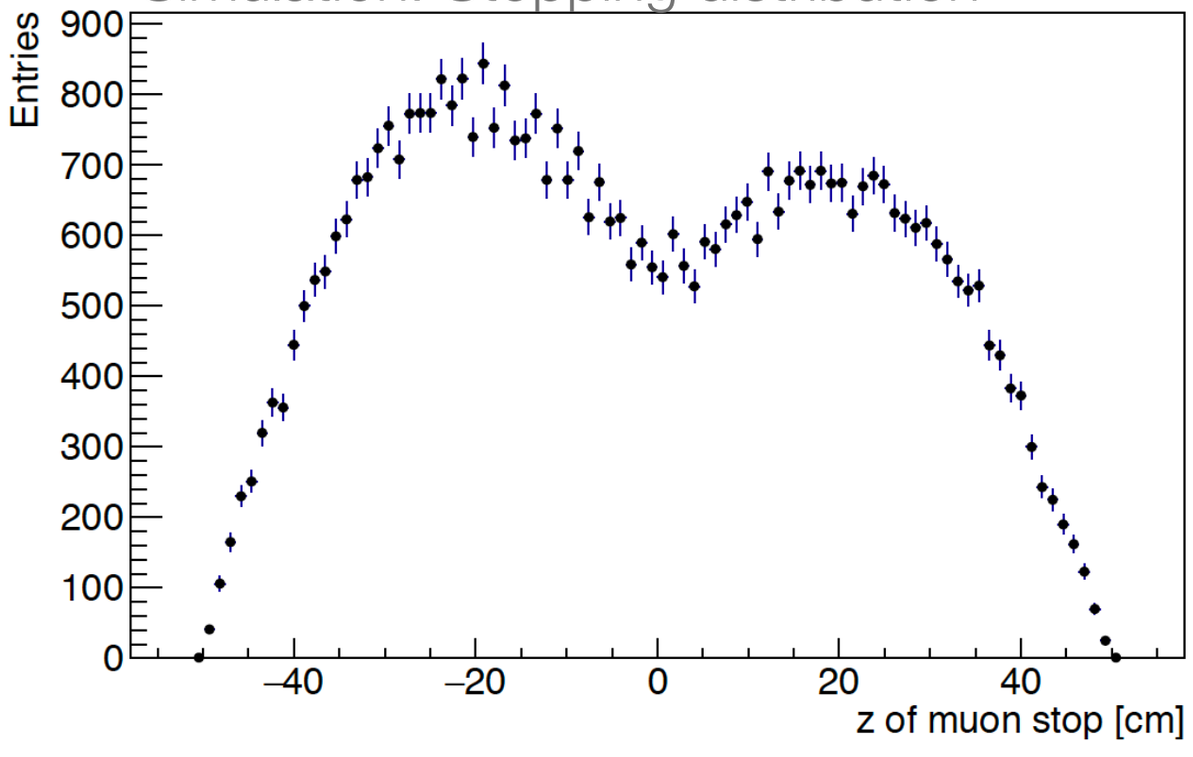
The target

- Mylar double hollow cone
- Large target area (L = 100 mm, R = 19 mm; A ~ XXX mm^2)
- Low material budget: (asymmetric structure: US 75 um, DS 85 um)
- Stopping efficiency: ~ 83%
- Vertex separation ability (tracking) < 200 um

Target prototype



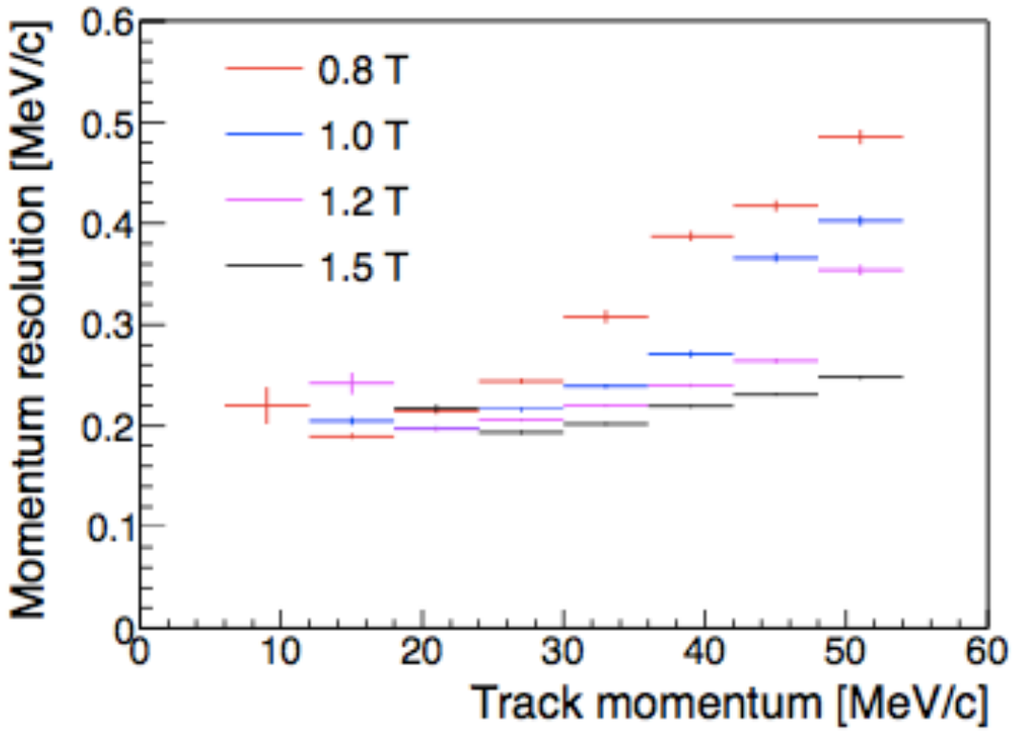
Simulation: Stopping distribution

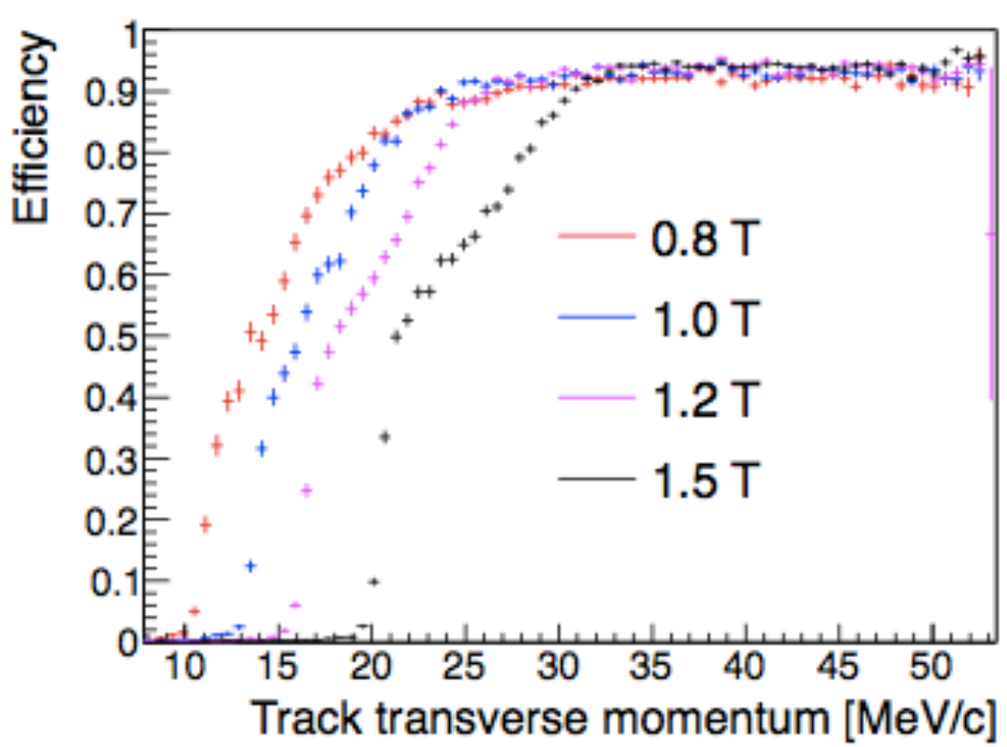


The magnet: The characteristics

- Superconducting Solenoidal magnet: Precise momentum determination, beam transport to the target
- Field Intensity: 1T
- Field description: $dB/B \leq 10^{-4}$
- Field stability: $dB/B(100\ d) \leq 10^{-4}$
- Dimensions: L < 3.2 m, W < 2.0 m, H < 3.5 m

Simulation

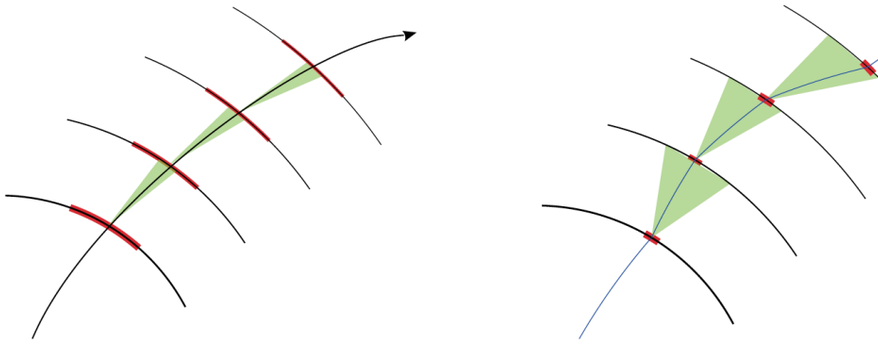




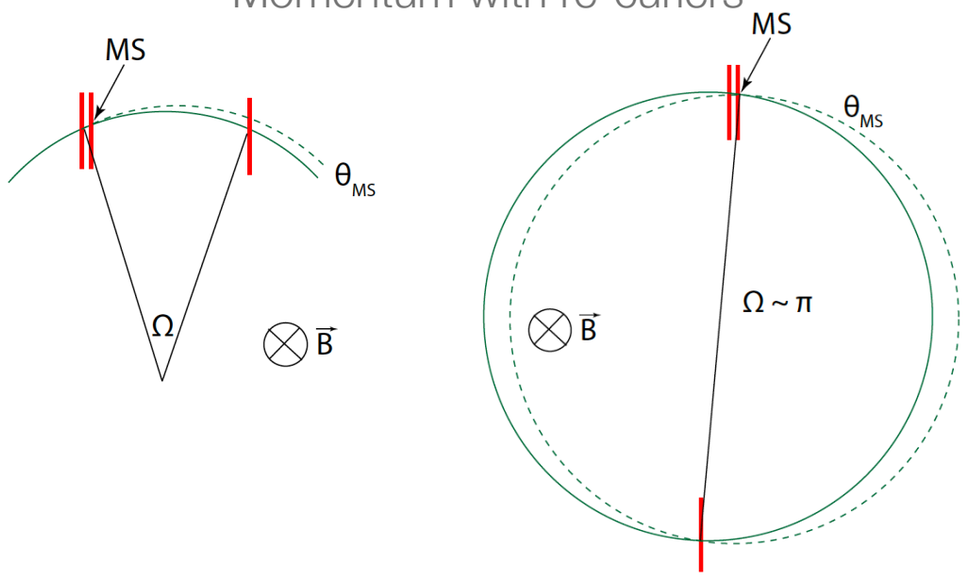
The pixel tracker: The principle

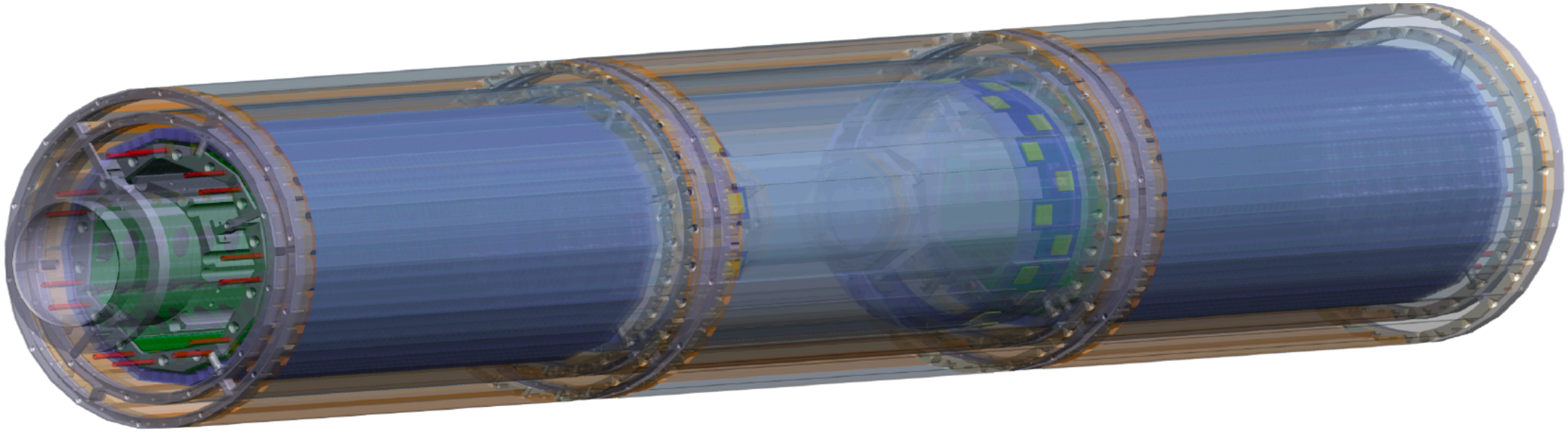
- Central tracker: Four layers; Re-curl tracker: Two layers
- Minimum material budget: Tracking in the scattering dominated regime

Tracking in the spacial and scattering dominated regime



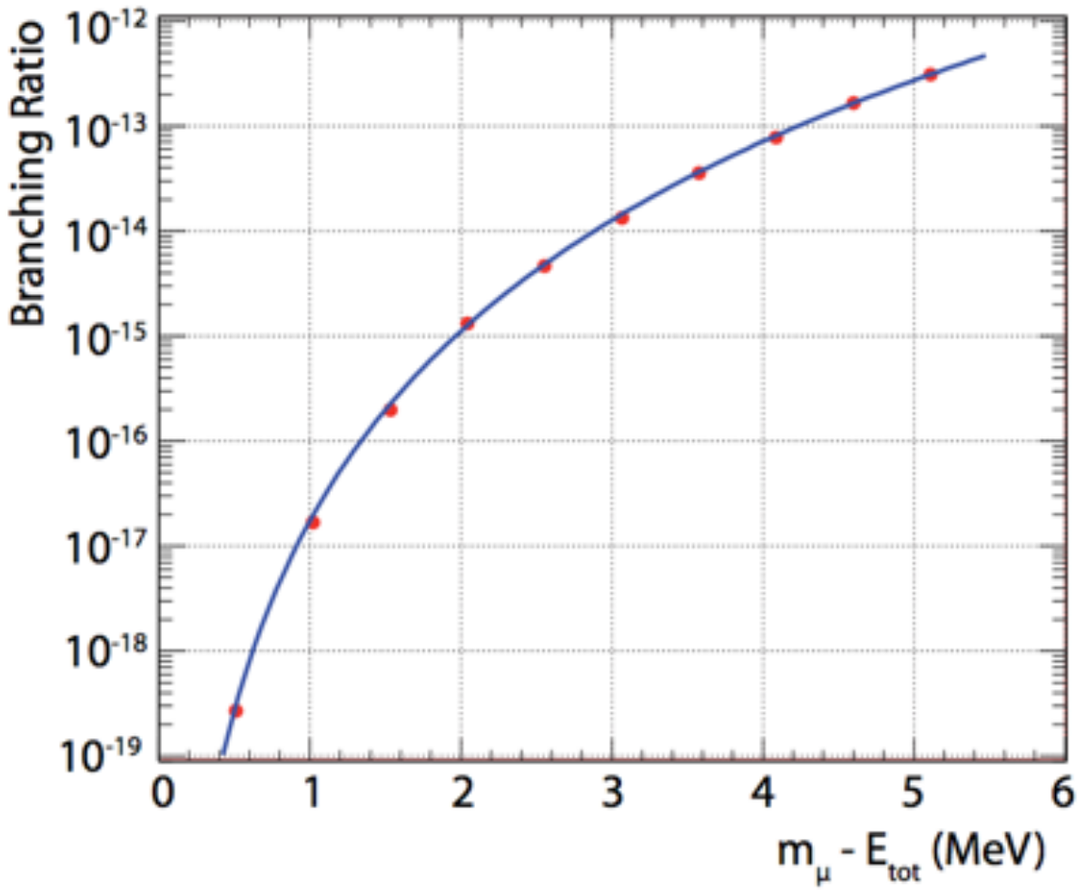
Momentum with re-curlers

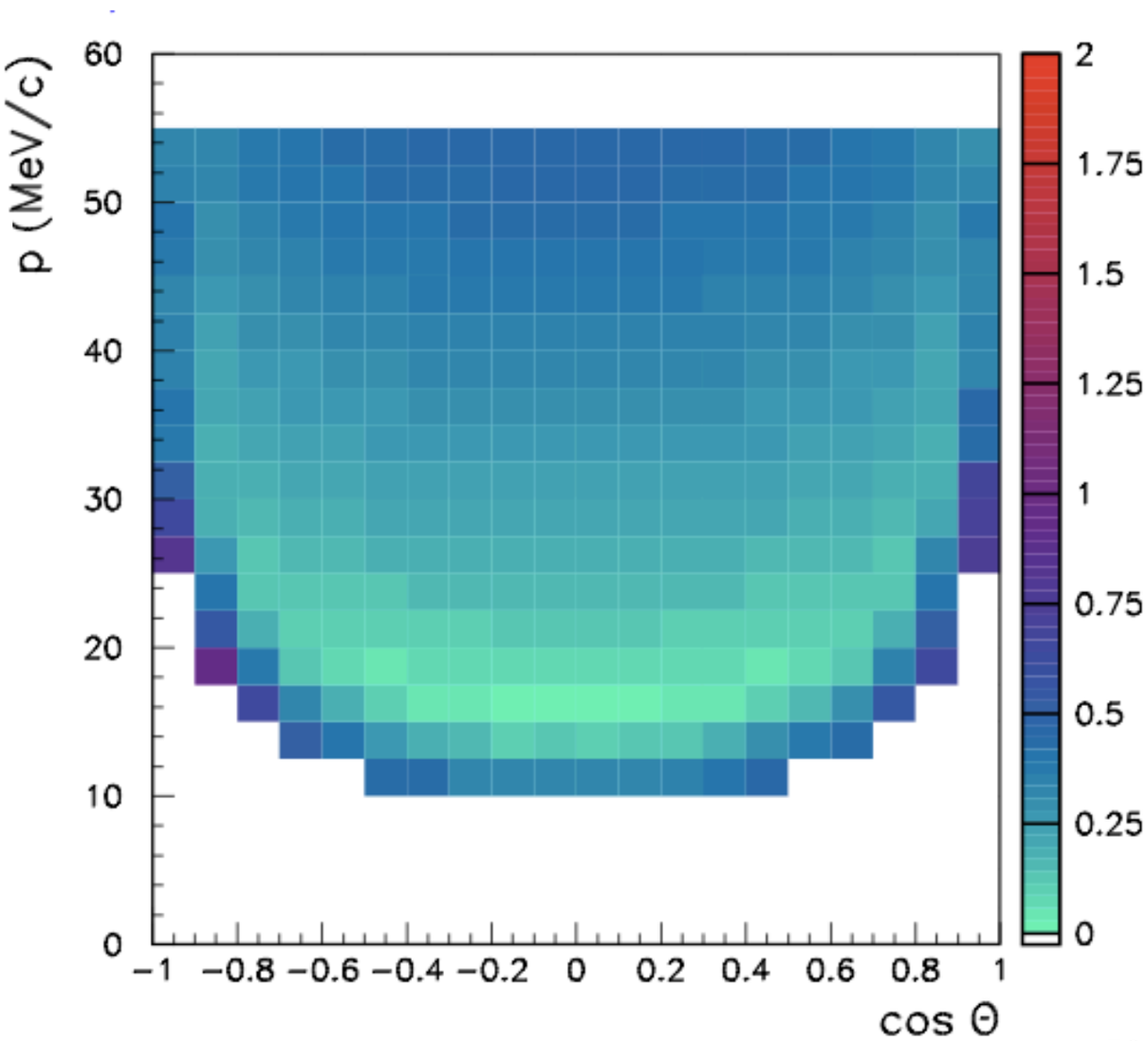




The pixel tracker: The performances

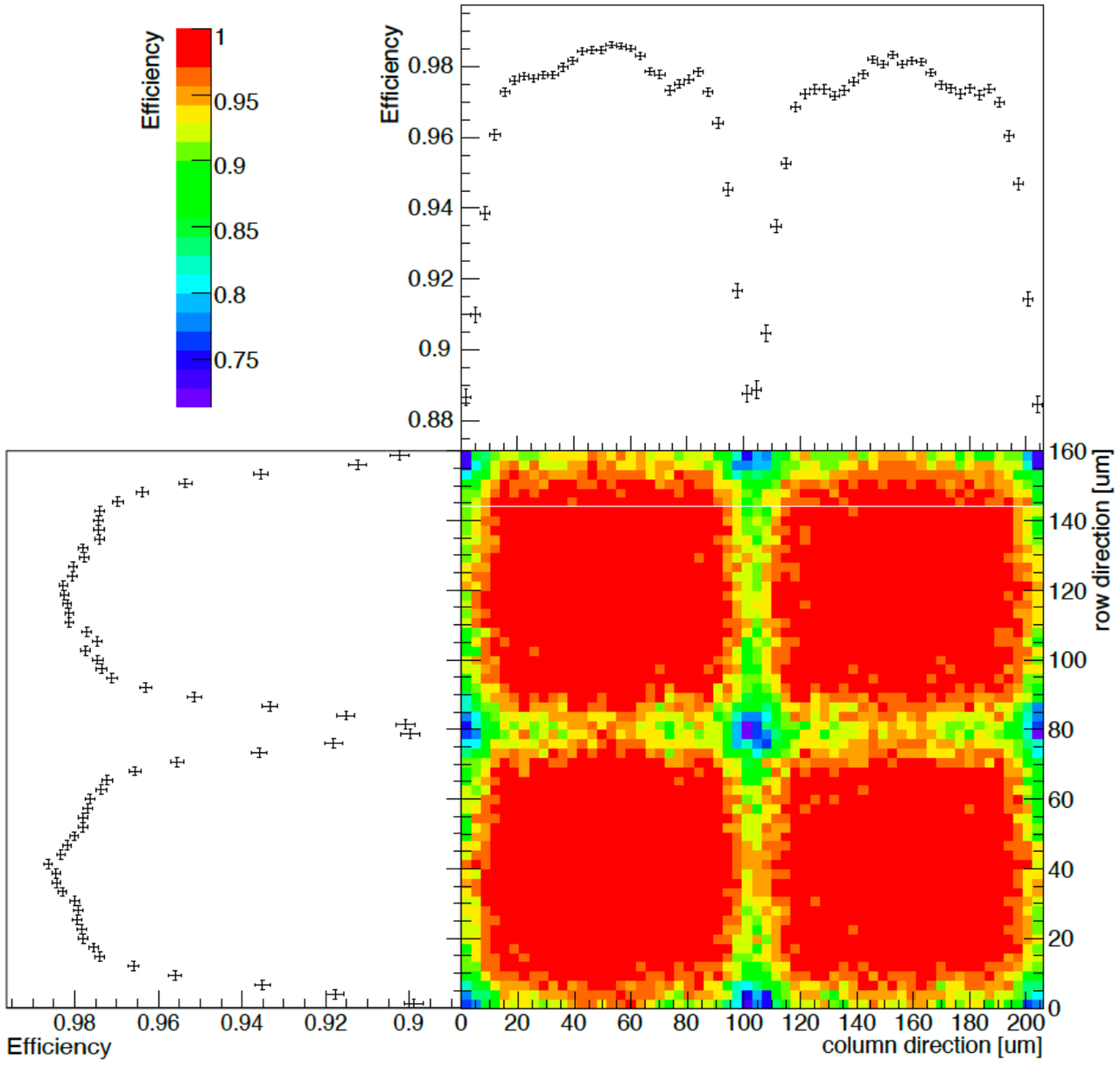
- Momentum resolution: < 0.5 MeV/c over a large phase space
- Geometrical acceptance: ~ 70%
- X/X_0 per layer: ~ 0.011%
- Vertex resolution: < 200 μm





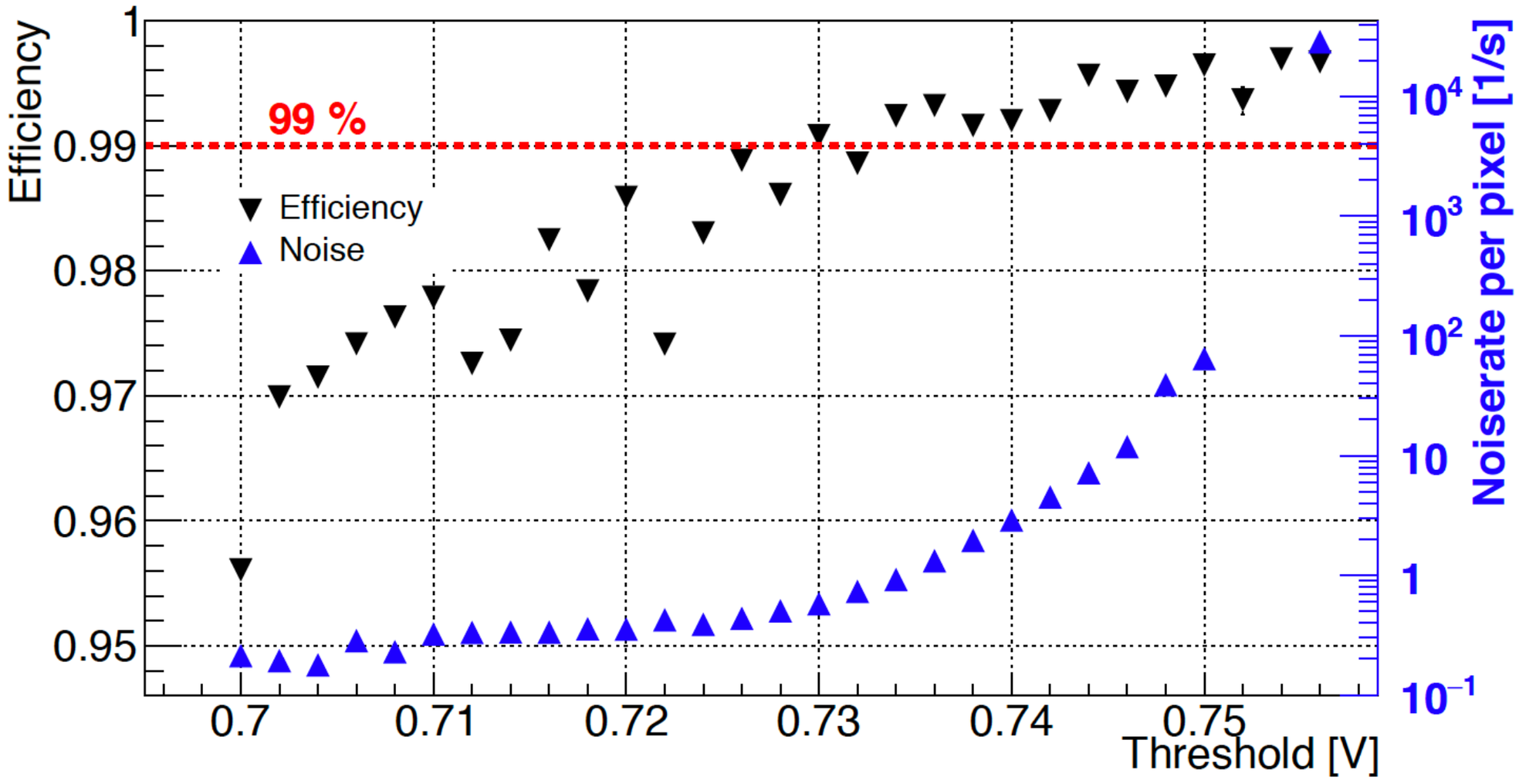
Prototypes: Results

- Hit map efficiency. MuPix7: 2 x 2 pixel array. Bias voltage: -40 V
- 4 GeV electrons

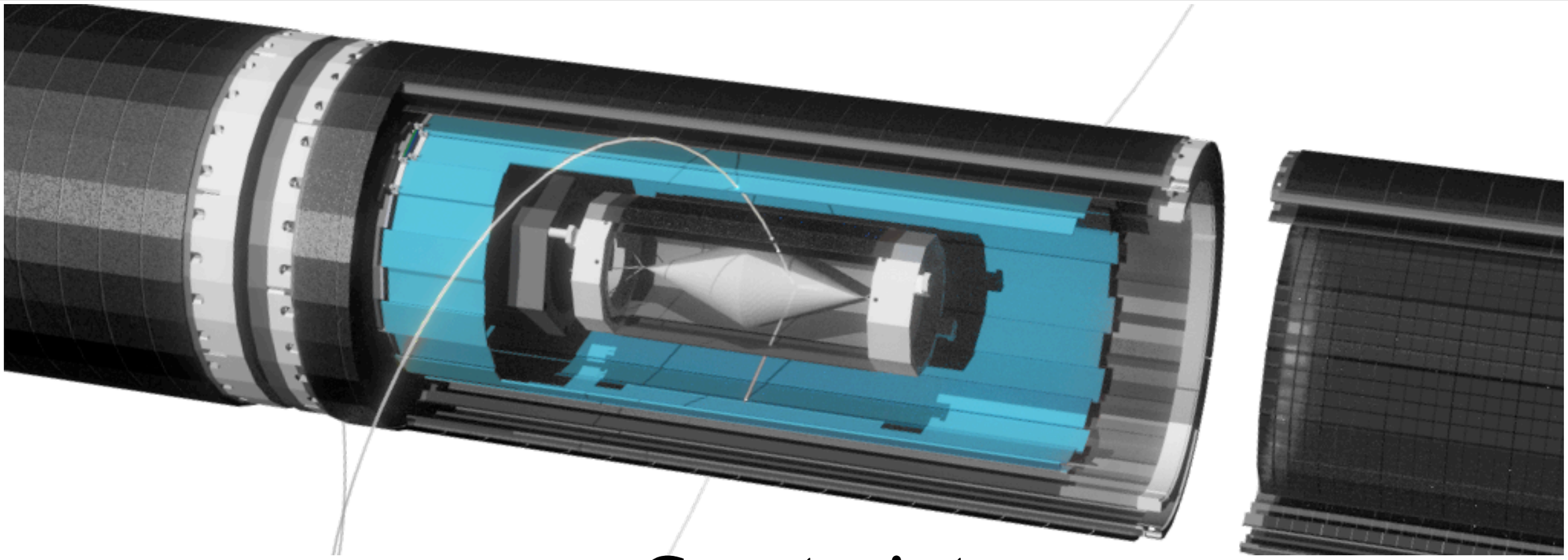


Prototypes: Results

- Hit efficiency and noise as a function of the charge threshold. MuPix7: 2 x 2 pixel array. Bias voltage: -85 V
- 4 GeV electrons



The Fiber detector (SciFi): Overview



Parts

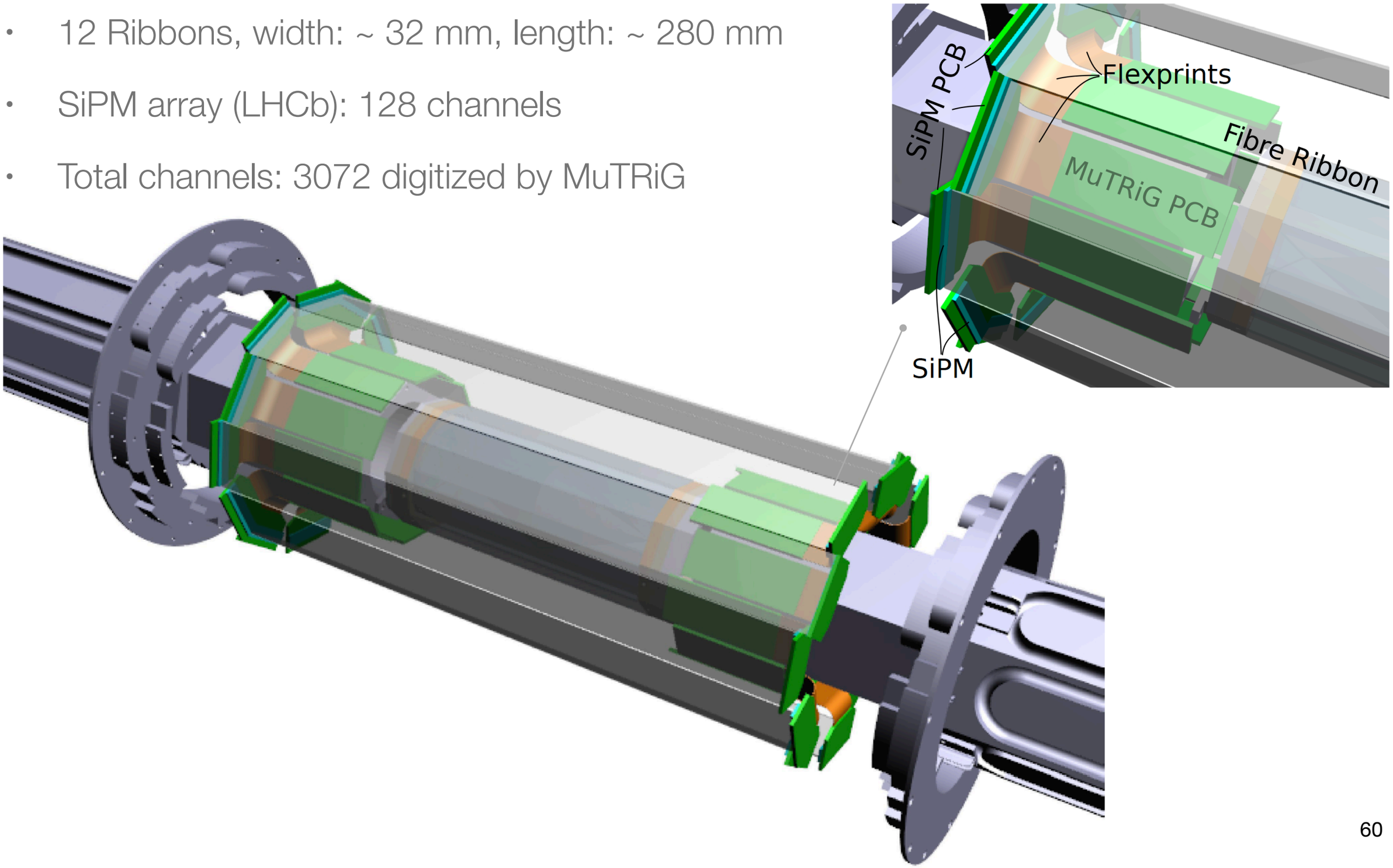
- cylindrical at ~ 6 cm (radius);
- length of 28-30 cm;
- 3 layers of round or square
- multi-clad 250 μm fibres
- fibres grouped onto SiPM array
- MuSTiC readout

Constraints

- high detection efficiency ε > 95%
- time resolution σ < 1 ns
- < 900 μm total thickness
- < 0.4 % X_0
- rate up to 250 KHz/fibre
- very tight space for cables, electronics and cooling

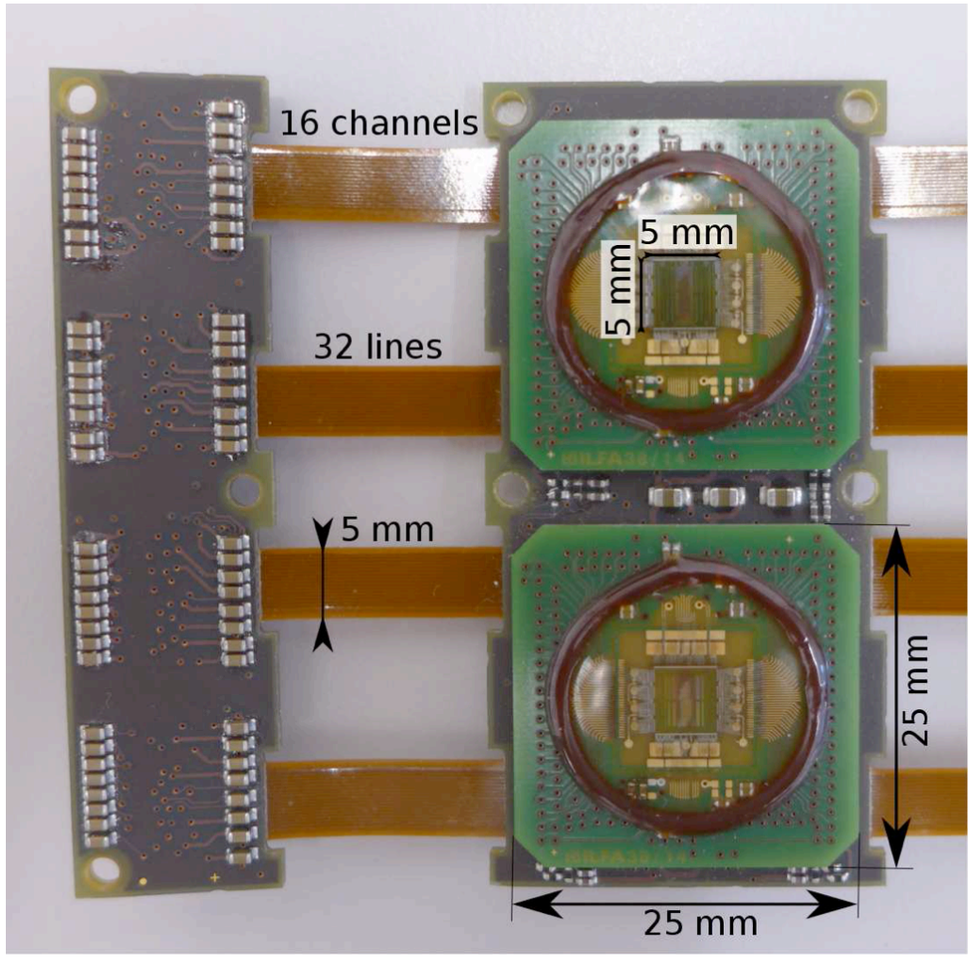
The Fiber detector (SciFi): 3D view

- 12 Ribbons, width: ~ 32 mm, length: ~ 280 mm
- SiPM array (LHCb): 128 channels
- Total channels: 3072 digitized by MuTRiG



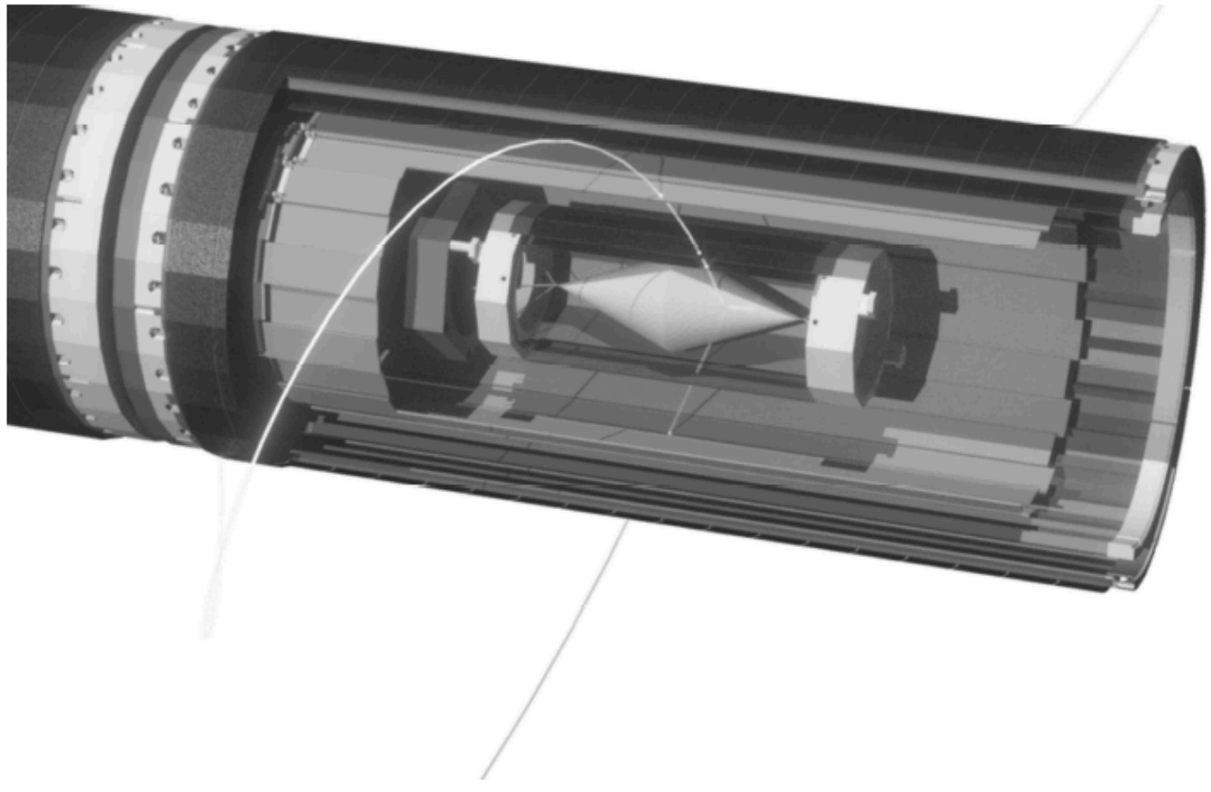
SciFi: Electronics readout, MuTRiG

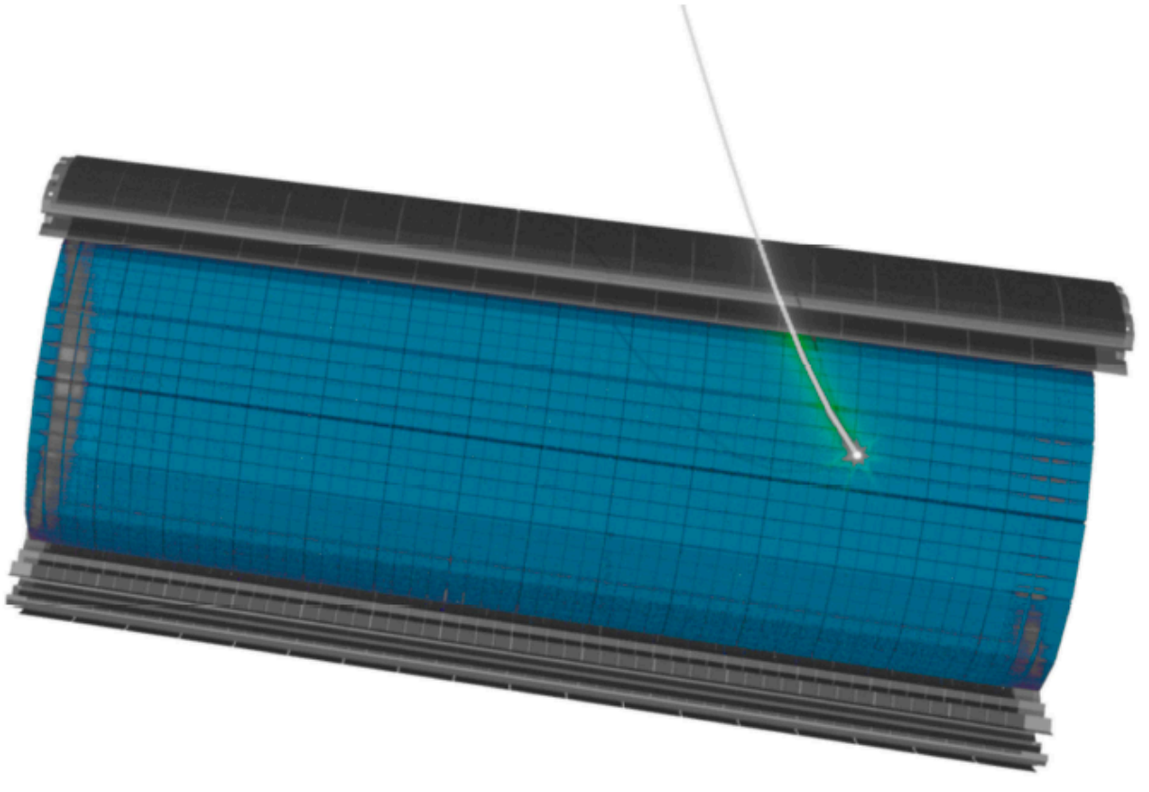
- Requirements:
  - 3072 channels
  - O(1000) kHz/channel
  - < 100 ps time information [charge beneficial, possibly 2nd threshold]
  - very tight space constraints (48 ASICs)



STiC3.1	MuTRiG
Tested	in development ready for summer
64 channels	32 channels
160 Mbit/s links	1250 Mbit/s links
~40 kevents/s	~1200 kevents/s
no charge for fibre signals	possibly 2nd threshold

The Tile detector: Overview





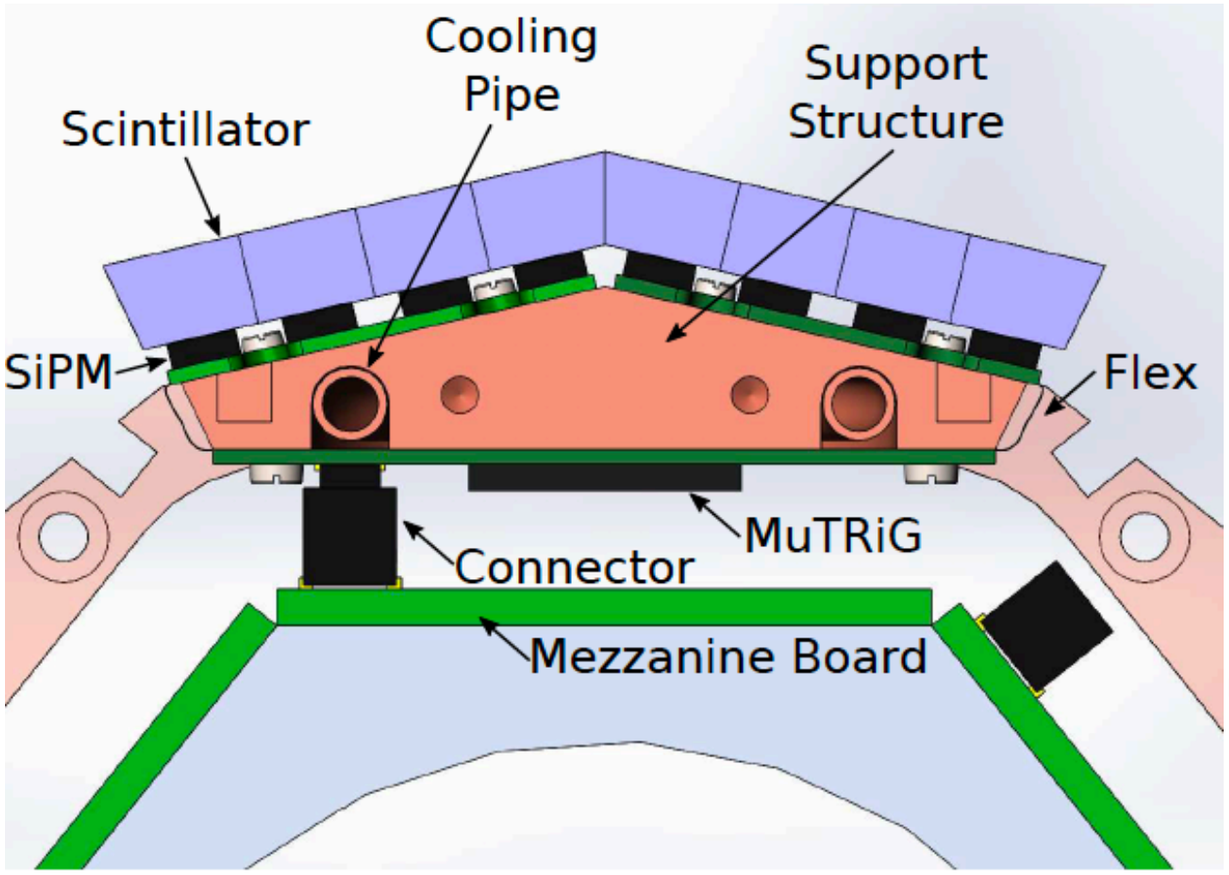
Parts

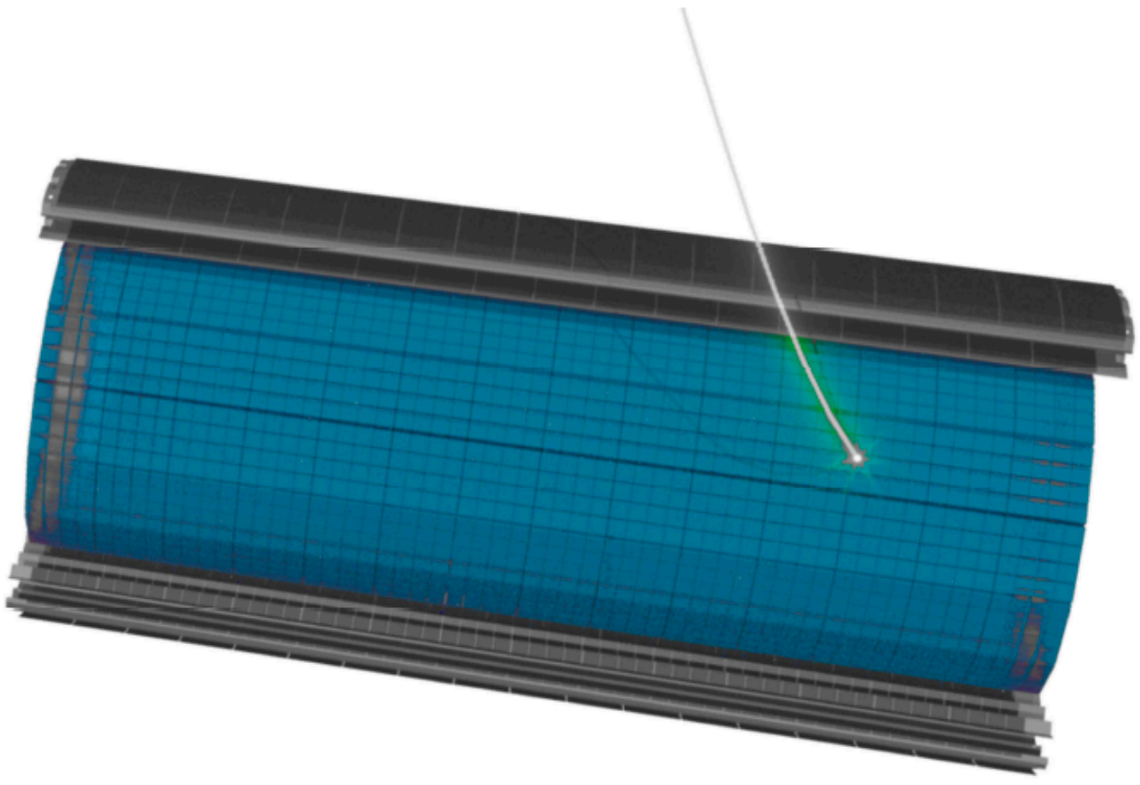
- cylindrical at ~ 6 cm (radius)
- length of 36.4 cm
- 56 x 56 tiles of 6.5 x 6.5 x 5 mm^3
- 3 x 3 mm^2 single SiPM per tile
- Mixed mode ASIC: MuTRiG

Requirements

- high detection efficiency $\varepsilon > 95\%$
- time resolution $\sigma < 100$ ps
- rate up to 50 KHz per tile/channel

The Tile detector: Overview





Parts

- cylindrical at ~ 6 cm (radius)
- length of 36.4 cm
- 56 x 56 tiles of 6.5 x 6.5 x 5 mm^3
- 3 x 3 mm^2 single SiPM per tile
- Mixed mode ASIC: MuTRiG

Requirements

- high detection efficiency $\varepsilon > 95\%$
- time resolution $\sigma < 100$ ps
- rate up to 50 KHz per tile/channel

MuTRiG

MuTRiG commissioning started !

New