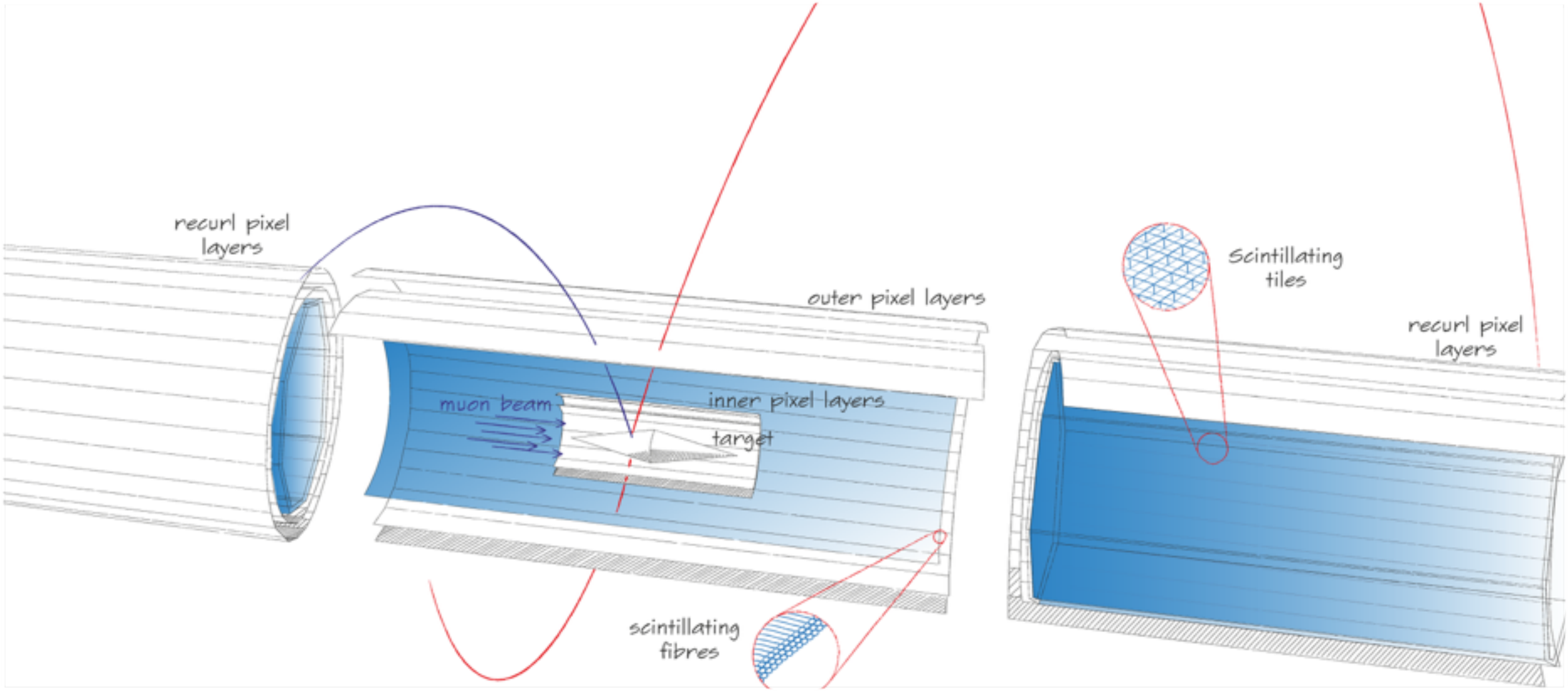


Christian Graf

14.3.2016

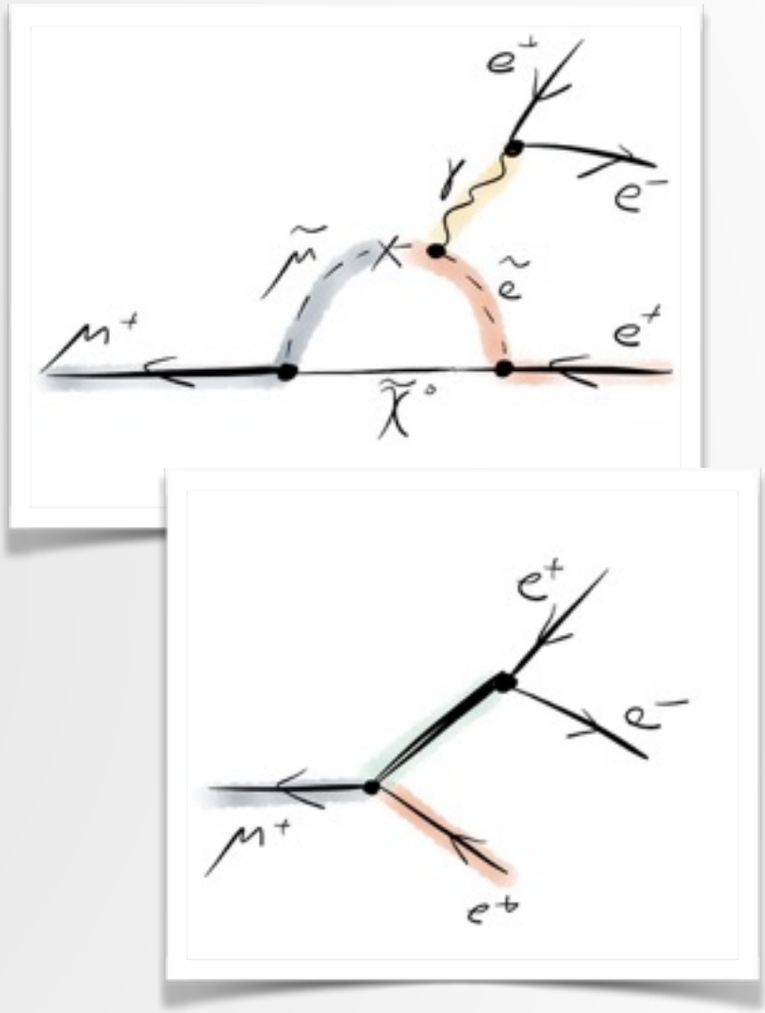
The Mu3e Experiment

A Calibration Scheme for the Mu3e Tile Detector

Master Thesis Presentation
for MPI Munich

The Mu3e Experiment - Goal

μ^- DECAY MODES			Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$e^-\,\overline{\nu}_e\,\nu_\mu$			$\approx 100\%$			53
$e^-\,\overline{\nu}_e\,\nu_\mu\,\gamma$		[d]	(1.4 ± 0.4) %			53
$e^-\,\overline{\nu}_e\,\nu_\mu\,e^+\,e^-$		[e]	$(3.4\pm0.4)\times10^{-5}$			53
Lepton Family number (LF) violating modes						
$e^-\,\nu_e\,\overline{\nu}_\mu$	LF	[f]	<1.2	%	90%	53
$e^-\,\gamma$	LF		<5.7	$\times10^{-13}$	90%	53
$e^-\,e^+\,e^-$	LF		<1.0	$\times10^{-12}$ 10^{-16}	90%	53
$e^-\,2\gamma$	LF		<7.2	$\times10^{-11}$	90%	53



- *Measure the decay $\mu^+ \rightarrow e^+e^+e^-$ with a sensitivity of 10^{-16}*
- Heavily suppressed in the SM by $\sim10^{-50}$

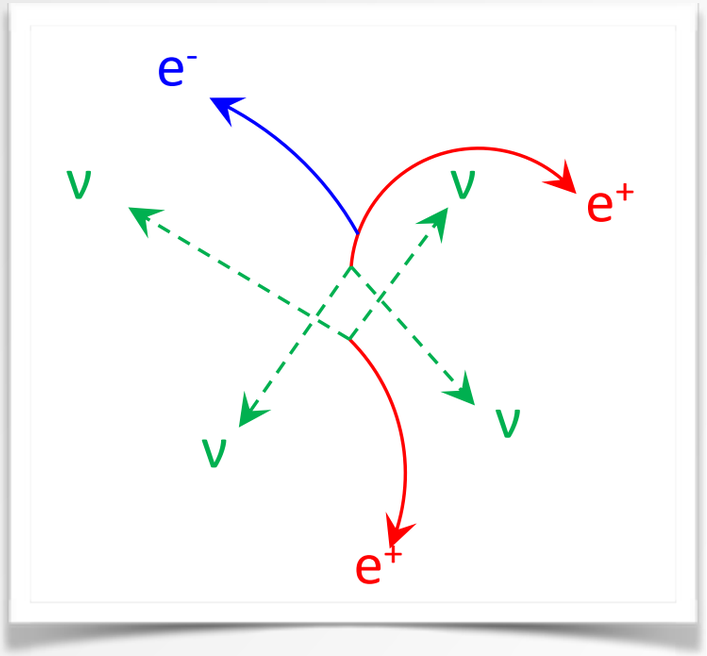
Background

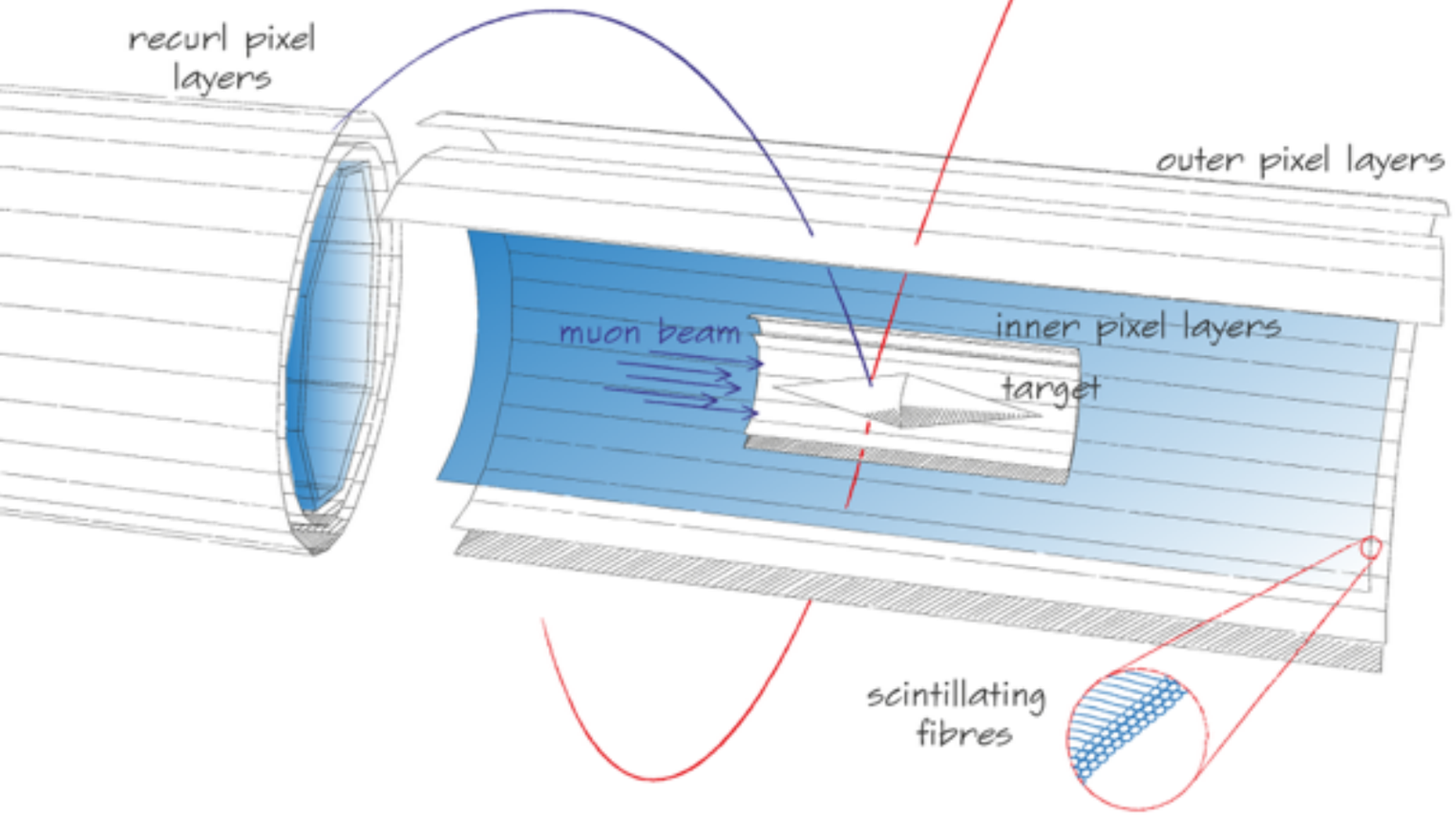
μ^- DECAY MODES		Fraction (Γ_i/Γ)	Con
$e^- \overline{\nu}_e \nu_\mu$		$\approx 100\%$	
$e^- \overline{\nu}_e \nu_\mu \gamma$	[d]	(1.4 ± 0.4) %	
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$	[e]	$(3.4 \pm 0.4) \times 10^{-5}$	

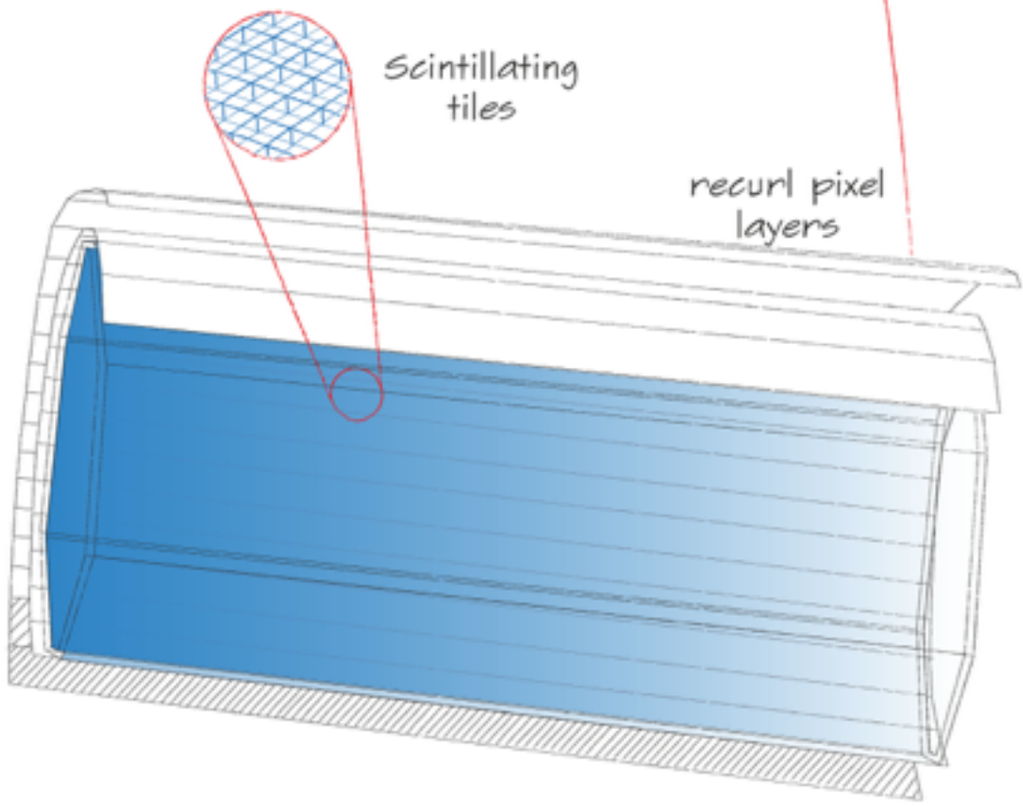
- Total energy of eee should add up to m_μ

- **Irreducible background**: Internal conversion decays
  - Only distinguishable via E_{miss}
  → Excellent momentum resolution needed (~0.5 MeV)

- **Accidental Background**
  - Vertex resolution (< 200μm)
  - Time resolution (< 100ps)

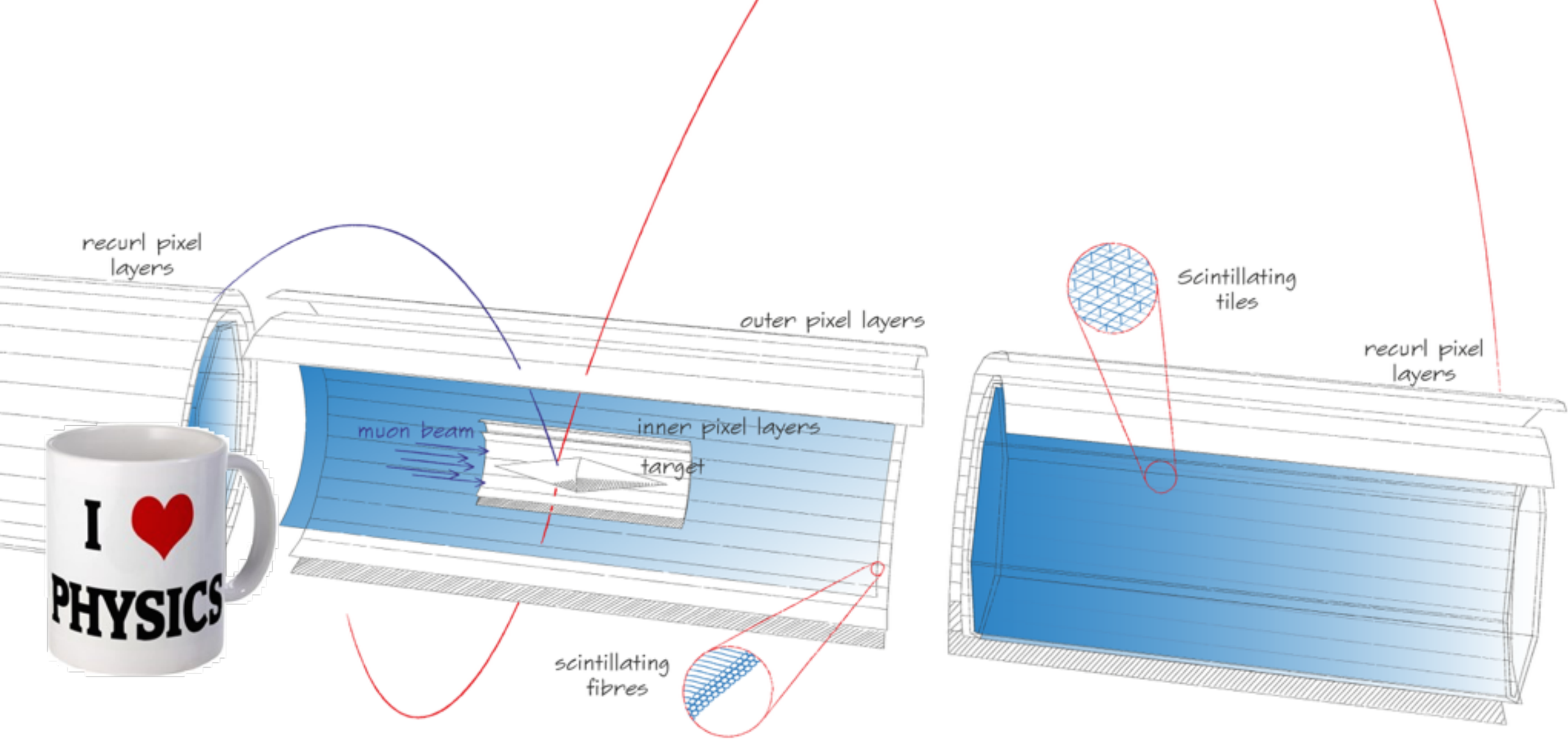






	Rate	Recurl Stations	Sensitivity
Phase 1	1×10^{8}	2	10^{-15}
Phase 2	2×10^{9}	4	10^{-16}

Pixel Detector
Fibre Detector
Tile Detector



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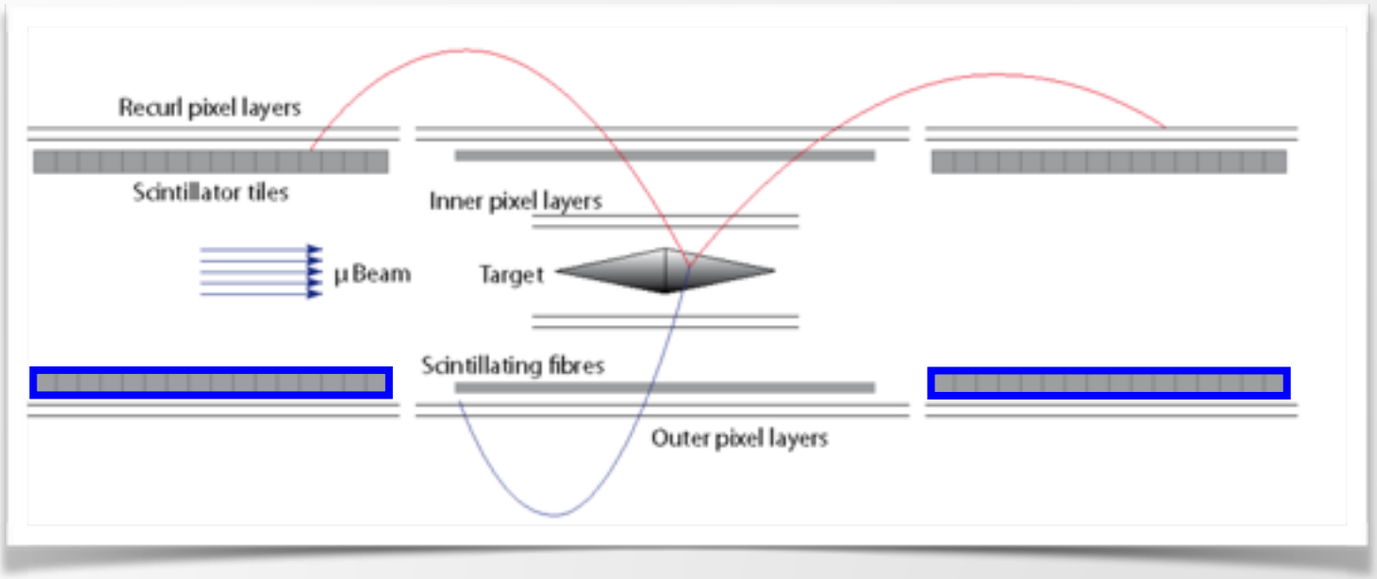
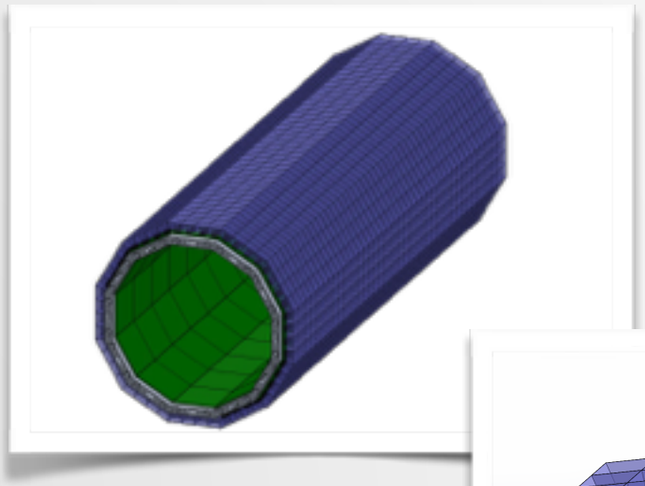
Pixel Detector

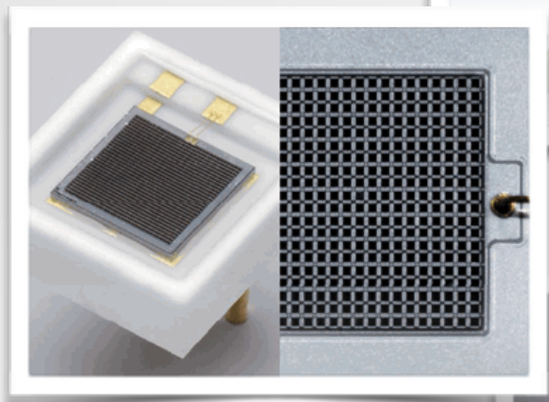
Fibre Detector

Tile Detector

Tile Detector







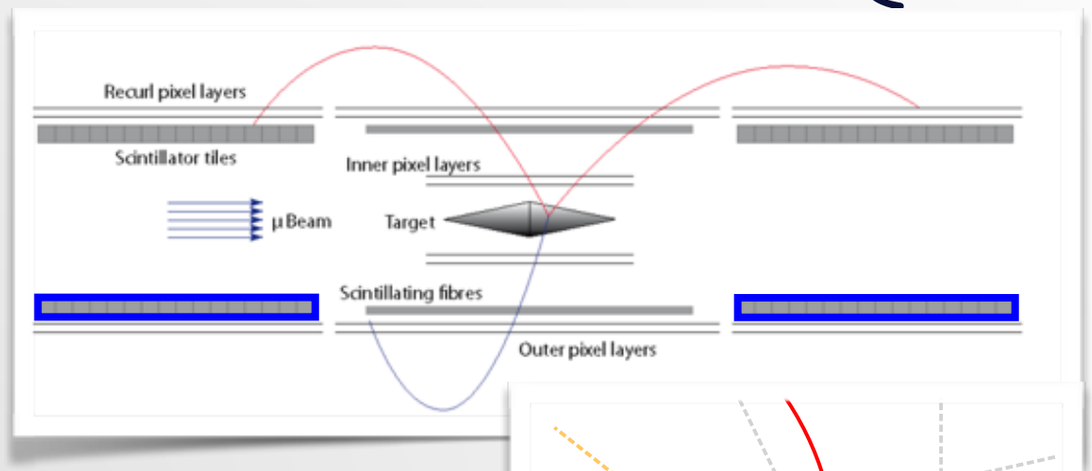
- 3600 tiles (56x60) per station
- Tiles: 6.5mm x 6.0mm x 5.0mm
- Light detected by Silicon Photomultipliers (SiPMs)
- Read-out by STiC, directly under tiles
- Test-beam results time-resolution: ***~60ps***

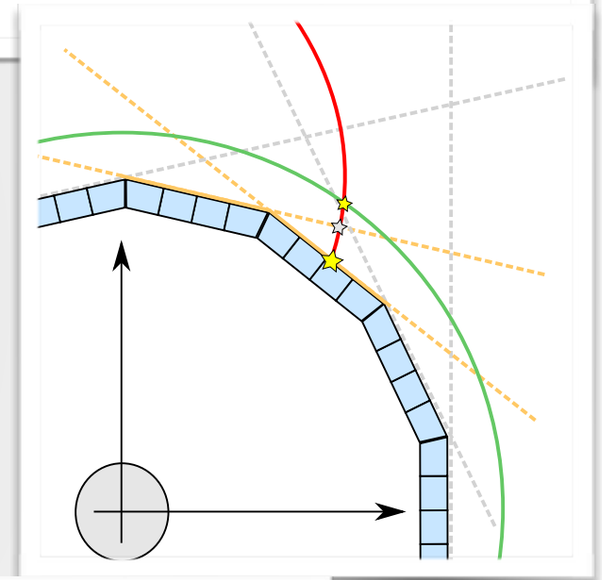
A Calibration Scheme for the Mu3e Tile Detector

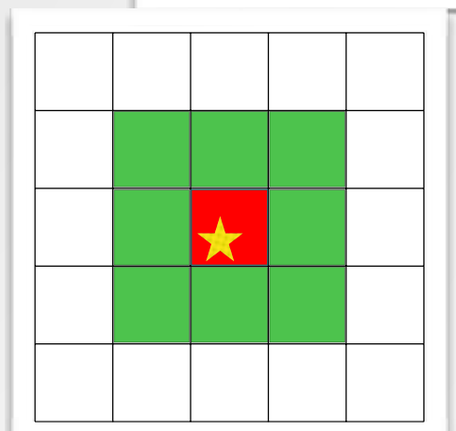
- Track Tile Matching
- Time Calibration of the Tile Detector

Track Tile Matching

- Next step towards full reconstruction:
  Assign time-stamps to tracks
- 1) Propagate track as a helix
- 2) Calculate point of impact on tiles
- 3) Find best suited hit in a certain range

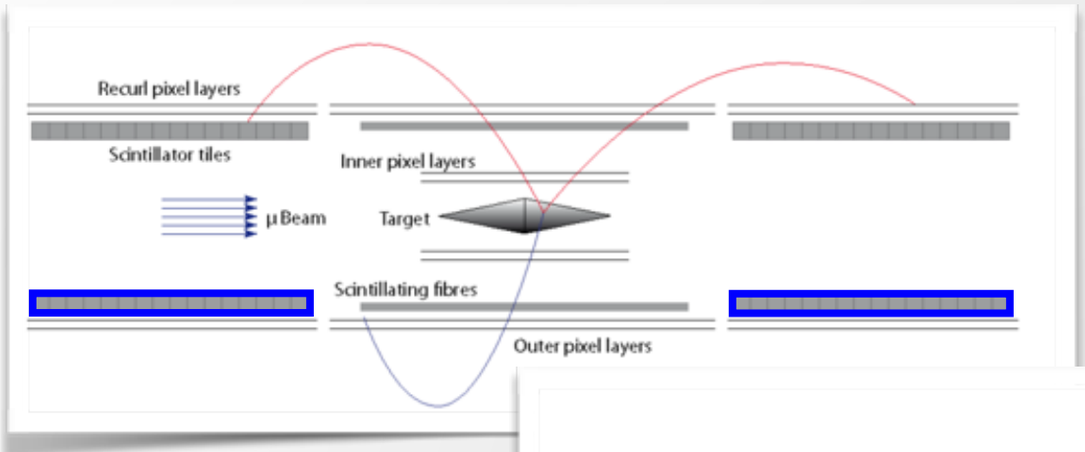


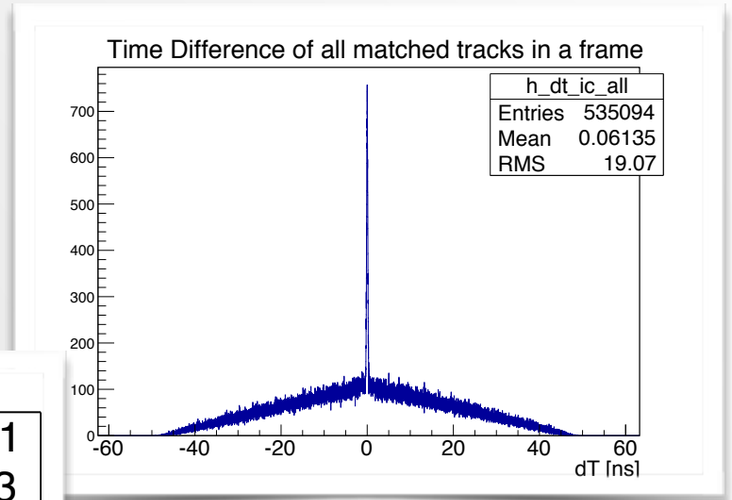


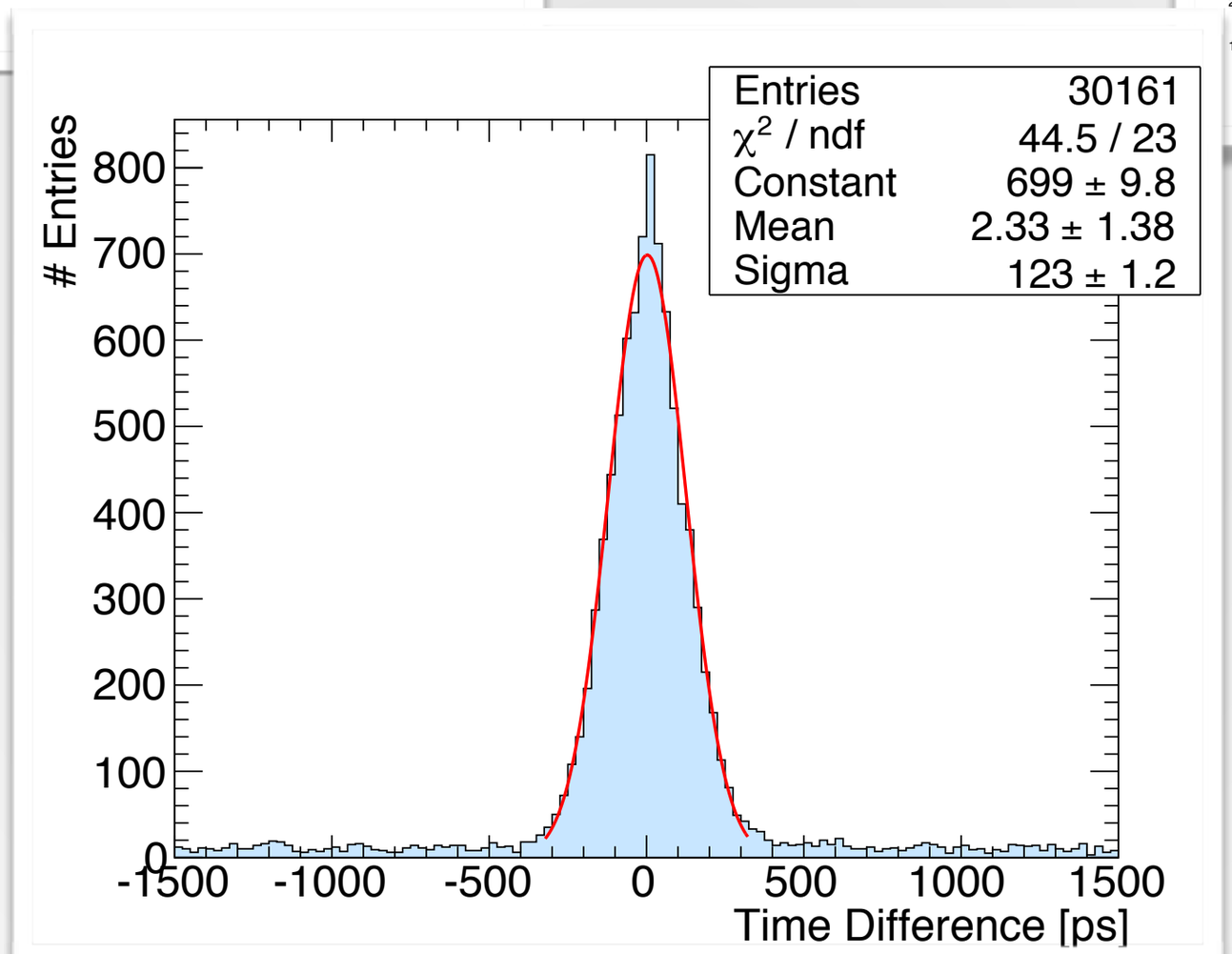


	Phase 1		*Phase 2*	
	Absolute	Relative	Absolute	Relative
Valid tracks	254,169	100.00 %	61,418	100.00 %
Correct matches	253,004	99.54 %	57,539	93.68 %
Unmatchable	924	0.36 %	3,261	5.31 %
Matching error	241	0.10 %	618	1.01 %

Time Resolution of Signal Decays

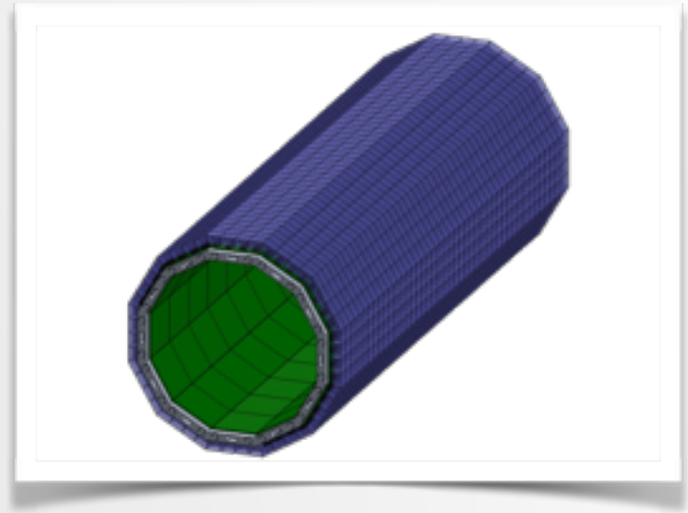




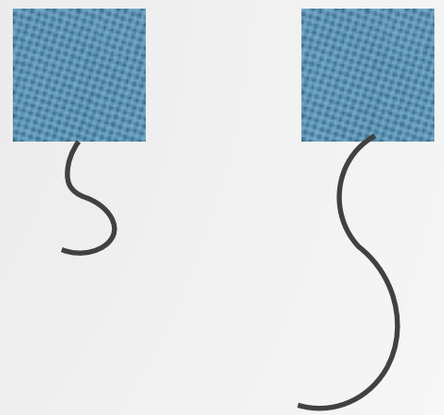


No vertex fit: ~70ps of additional time resolution

Time Calibration of Tile Detector



- Tiles are connected by cables with different lengths
- → signals arrive at different times
- *Time calibration needed of ~10ps in ~10min*
- 1) LED system
- 2) Easier: use muon decays in normal operation

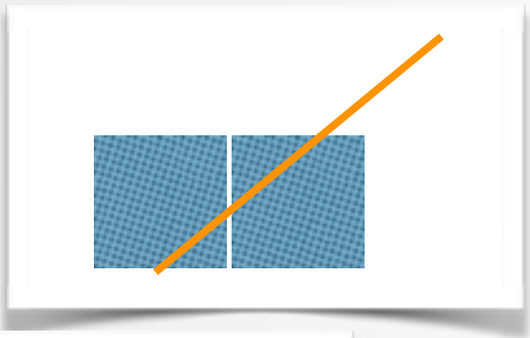


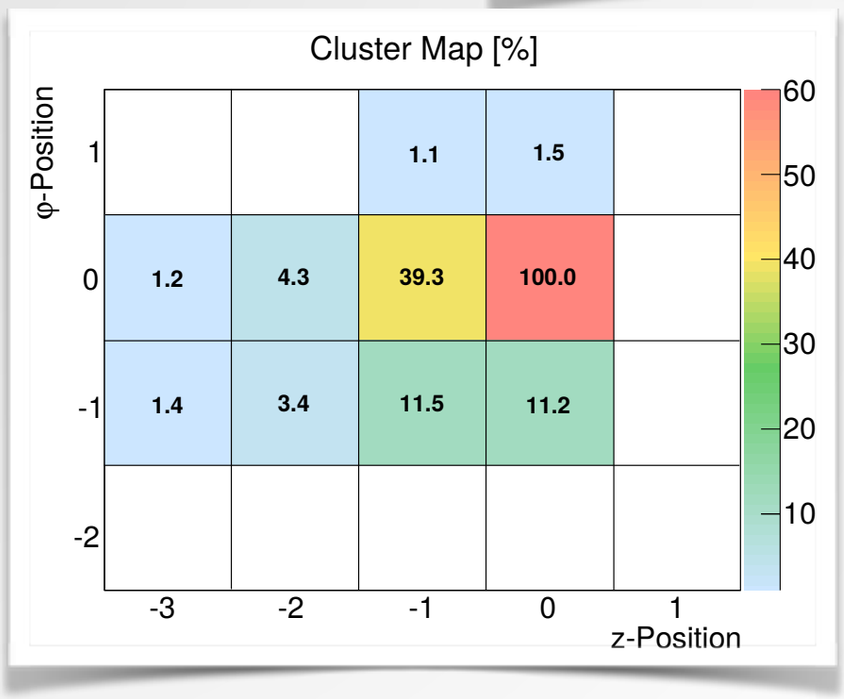
Events for Calibration

- Need events where we exactly know the time difference between several hits
- 1) Internal conversion decays:
  - BR: 3×10^{-5}
  - takes too long!
- 2) Hit Cluster:
  - ~ 50% of particles hit more than one tile

  + high rate

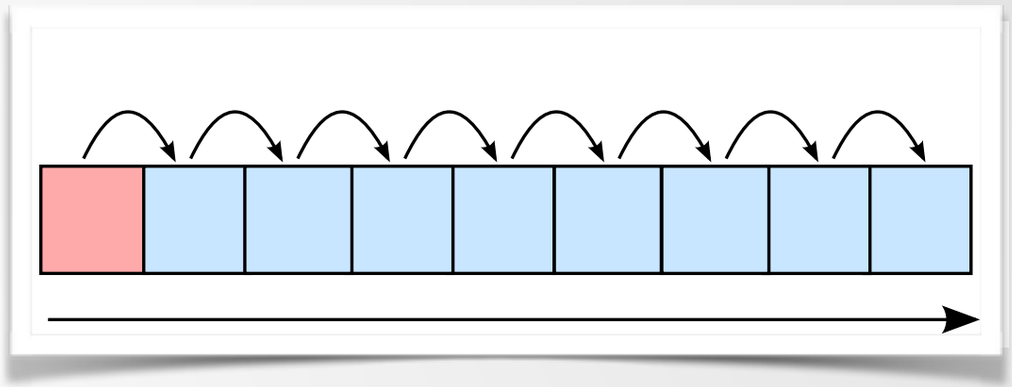
  - calibration just between neighbors



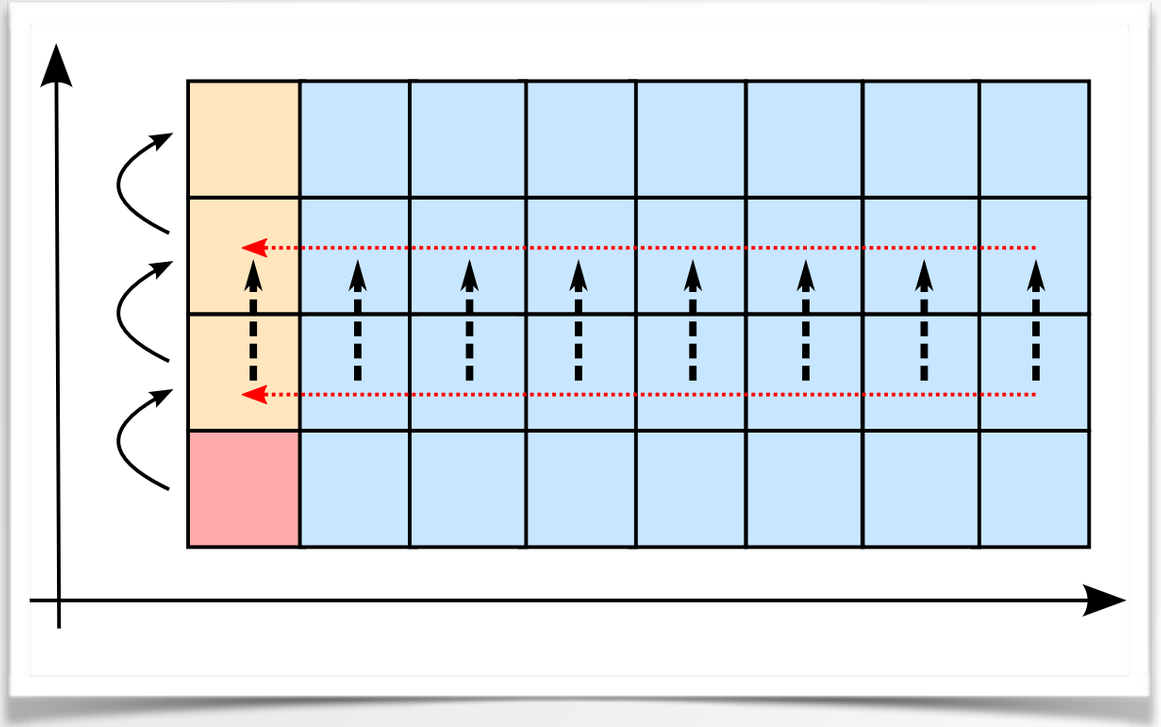


Cluster Calibration

- Calibrate neighbors and propagate through whole detector

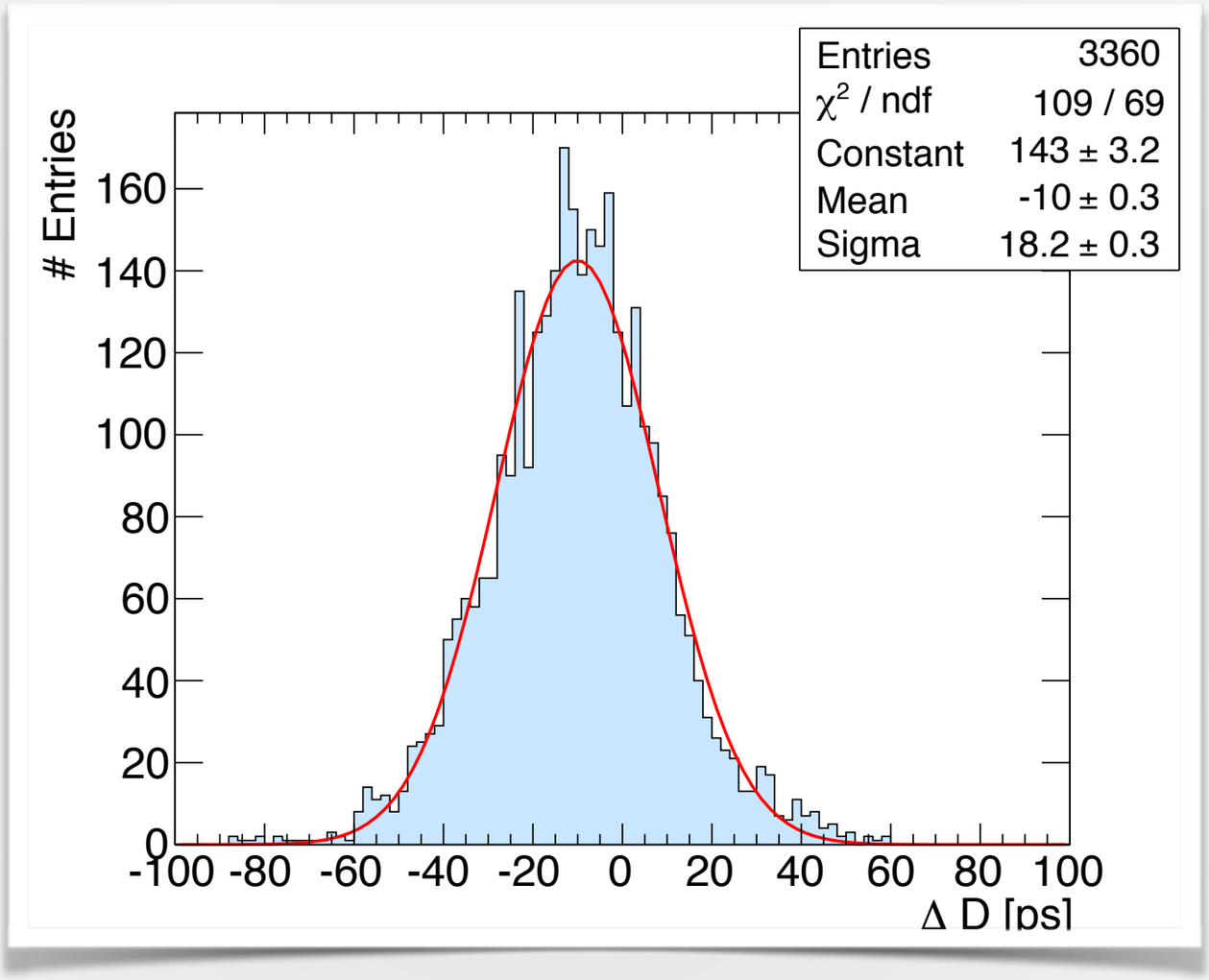


calibrate in z direction



calibrate in ϕ-direction

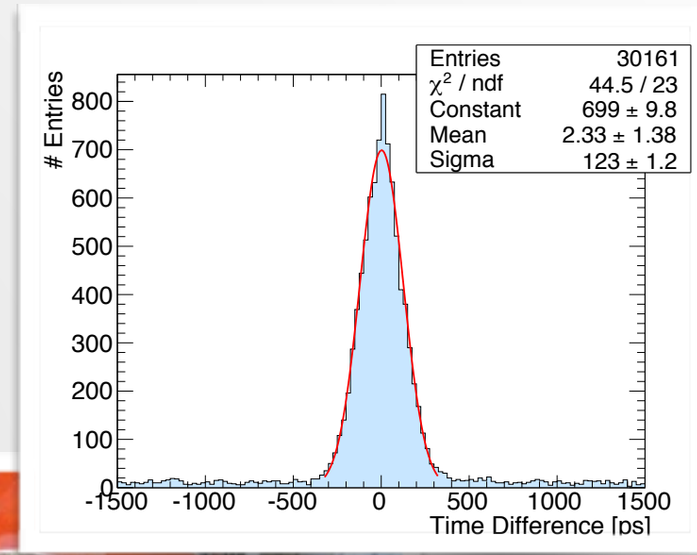
Calibration Results

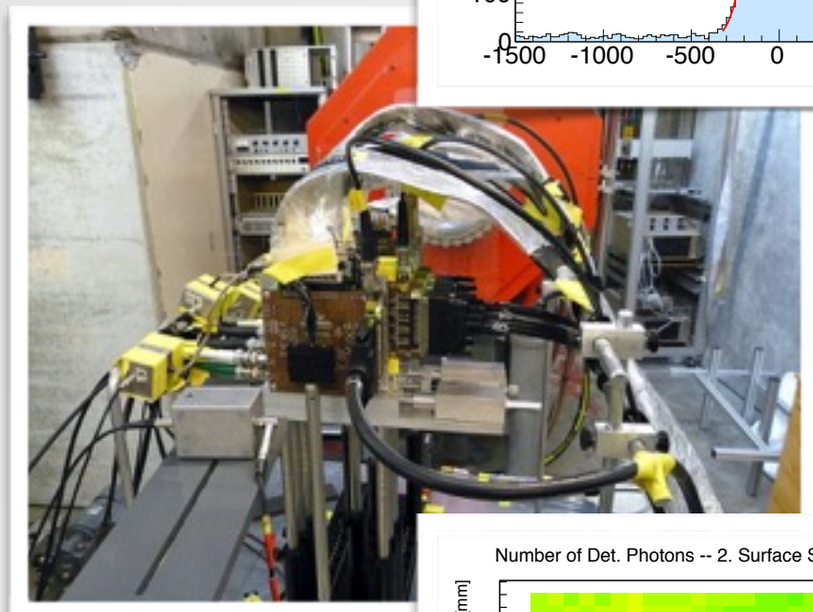


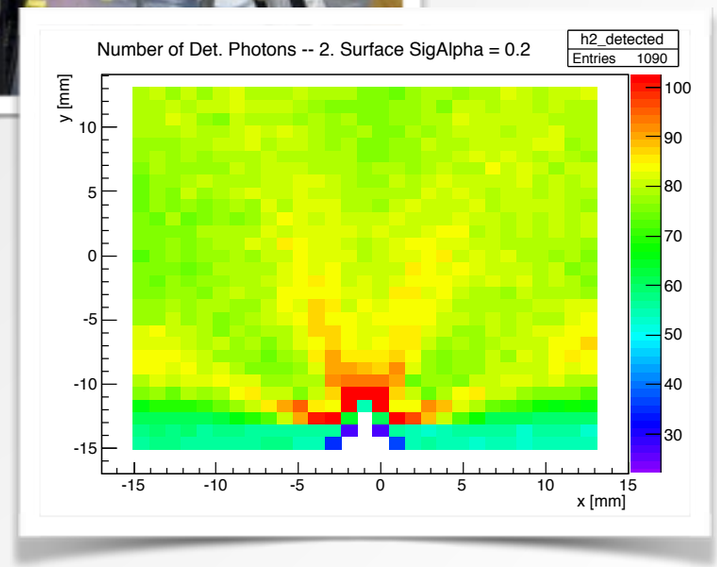
σ(tiles) < 20ps in 50ms of simulated data

Summary

- Track tile matching
- Time calibration with hit clusters
- Dead time measurement
- Two test beam campaigns at PSI
- CALICE: Geant4 tile uniformity studies







Thank you

Backup

Why?

- Lepton flavor violation (LFV) in neutrino sector

- SM forbids charged lepton flavor violation (at tree level)

  → *new physics*

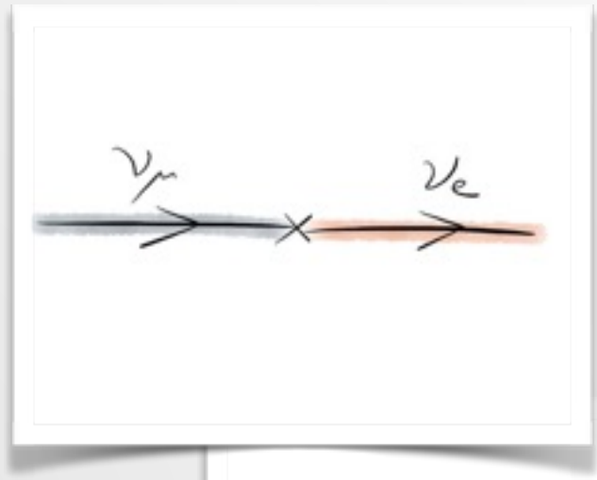
- μ → eee tests on loop and tree diagrams

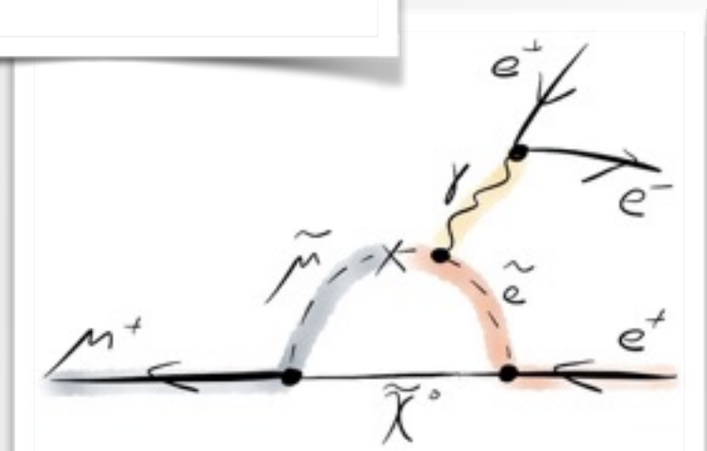
- Loop diagram: SUSY, Little Higgs,

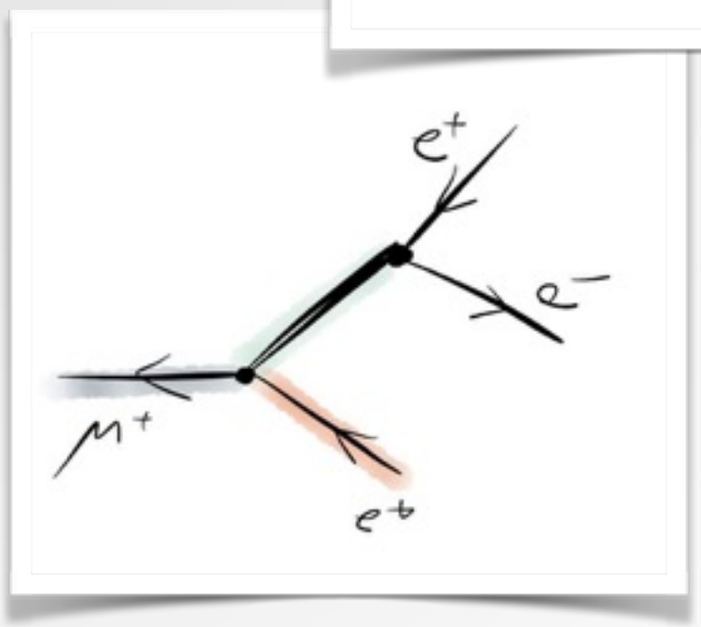
  Seesaw models, Leptoquarks…

- Tree diagram: Z', LFV Higgs,

  Extra Dimensions…

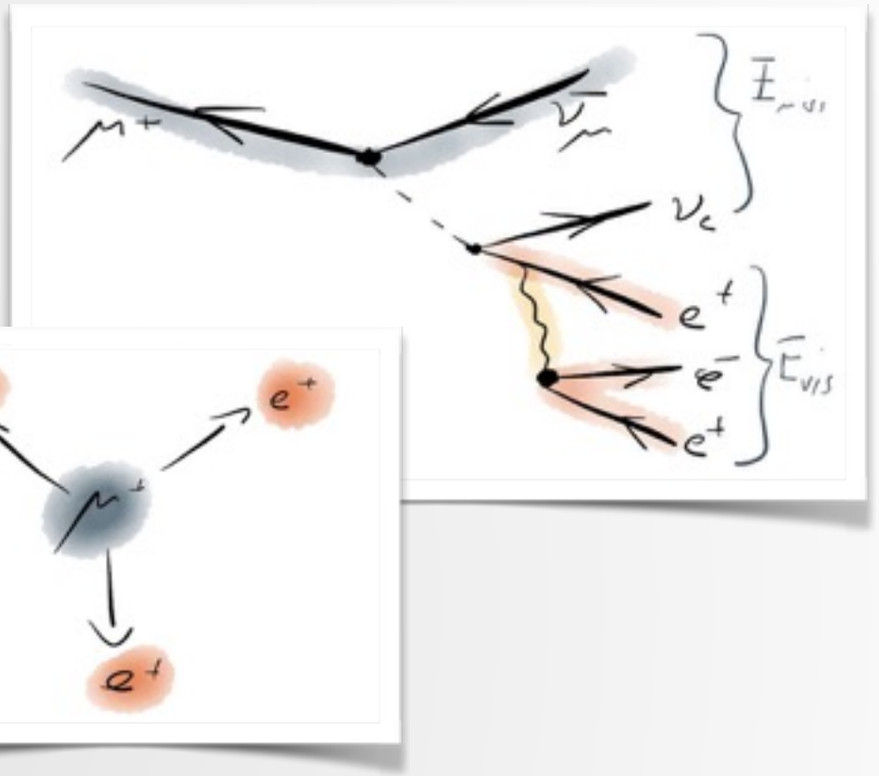


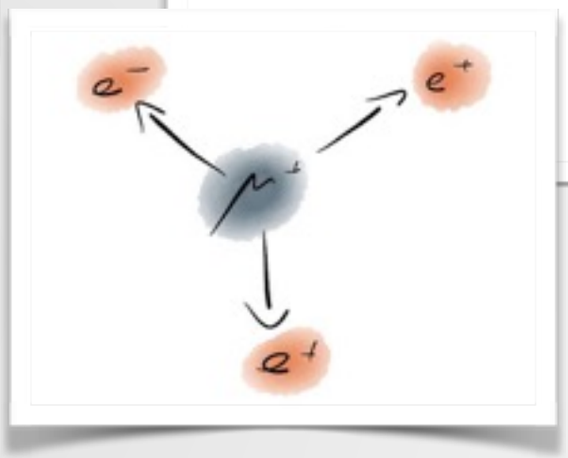




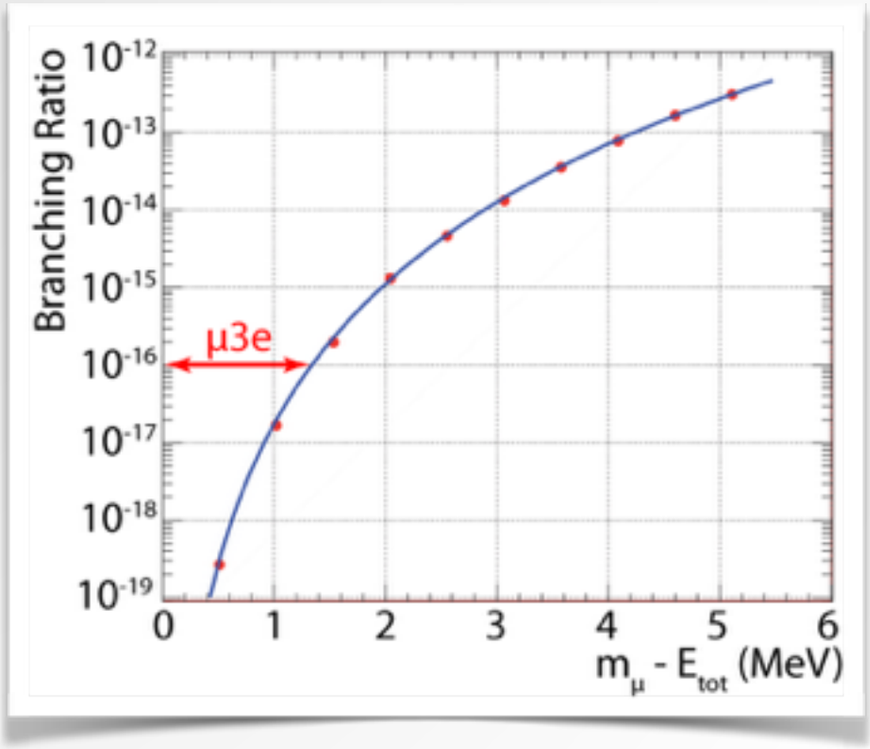
μ Decay - Signal & Background

μ^- DECAY MODES		Fraction (Γ_i/Γ)	Cor
$e^- \overline{\nu}_e \nu_\mu$		$\approx 100\%$	
$e^- \overline{\nu}_e \nu_\mu \gamma$	[d]	(1.4 ± 0.4) %	
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$	[e]	$(3.4 \pm 0.4) \times 10^{-5}$	



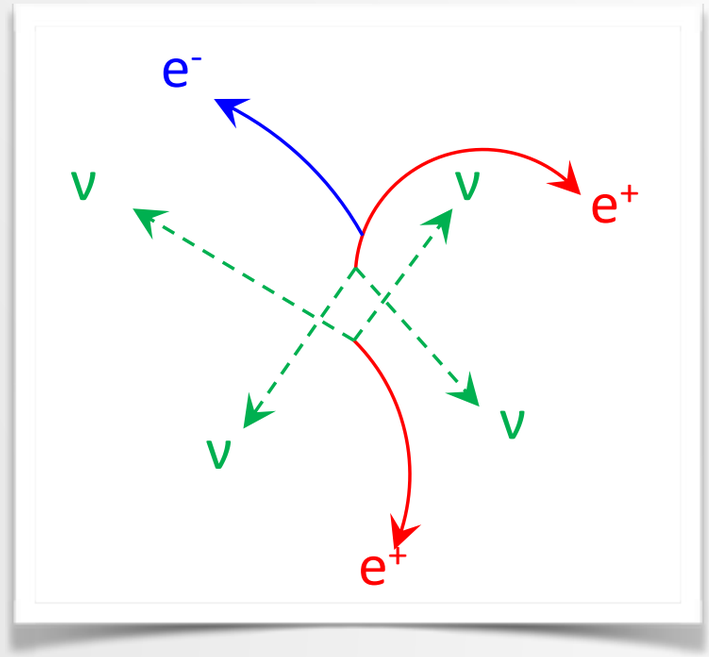


- Total energy of eee should add up to m_μ
- Internal conversion background
- Only distinguishable via E_{miss}
- → *Excellent momentum resolution needed*

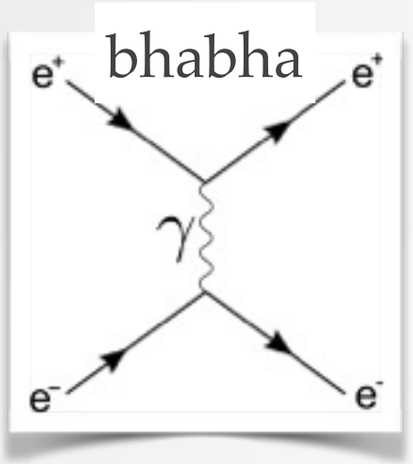


Accidental Background

μ^- DECAY MODES		Fraction (Γ_i/Γ)	Con
$e^-\overline{\nu}_e\nu_\mu$		$\approx 100\%$	
$e^-\overline{\nu}_e\nu_\mu\gamma$	[d]	(1.4 ± 0.4) %	
$e^-\overline{\nu}_e\nu_\mu e^+e^-$	[e]	$(3.4\pm0.4)\times10^{-5}$	

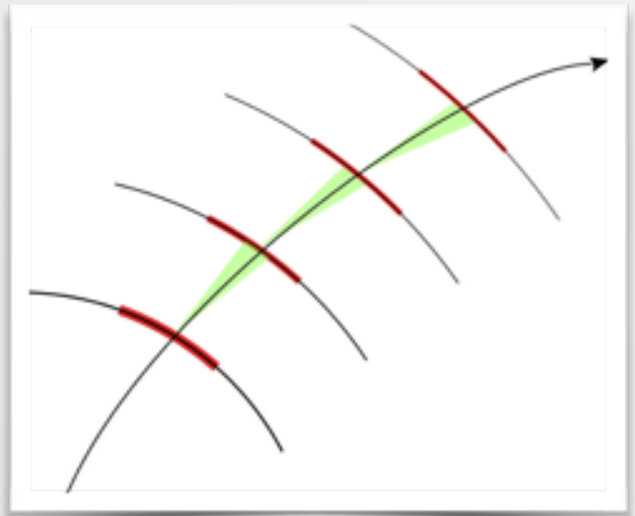


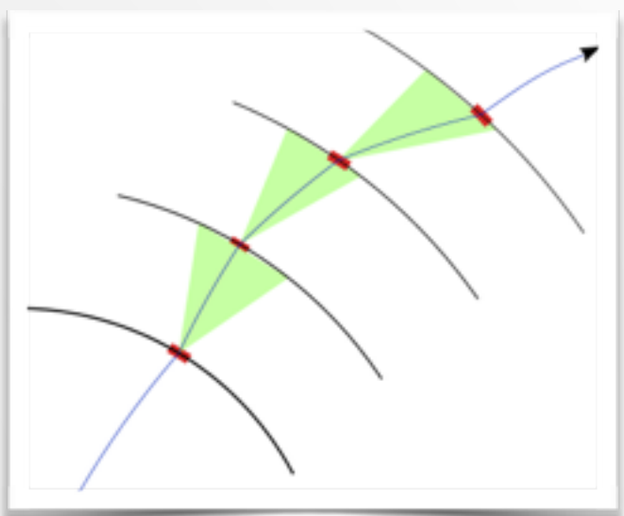
- Overlay of: Michel decays, radiative decays and internal conversion decays
- with processes as:
  Bhabha, compton or misreconstr.
- Dominant: Bhabha + 1 Michel
- ***requires:***
  - momentum resolution
  - vertex resolution (< 200μm)
  - time resolution (< 100ps)



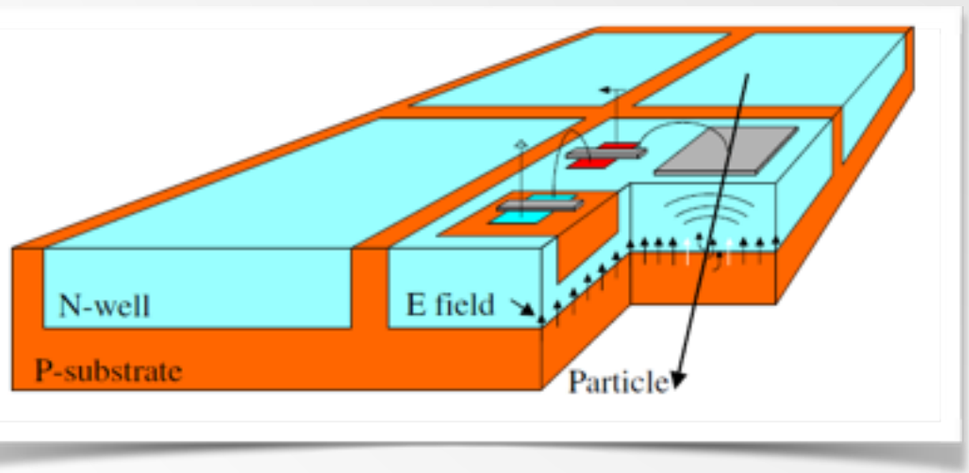
Tracking

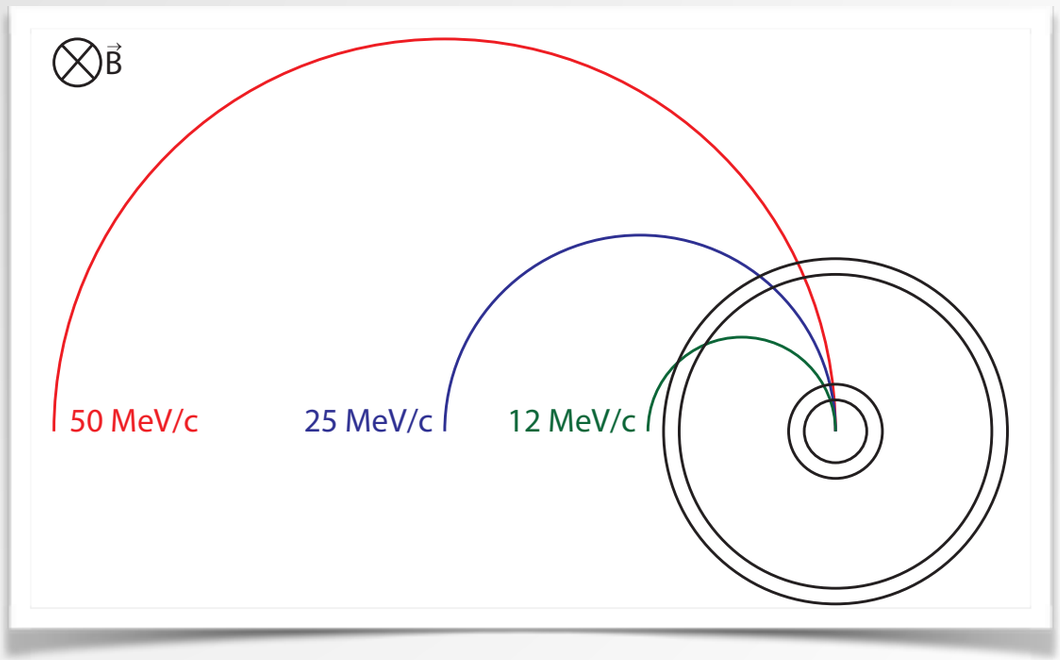
- Pixel tracker for mom. resolution
- Multiple scattering (MS) dominates
  → *low material budget*
- HV-MAPS technology



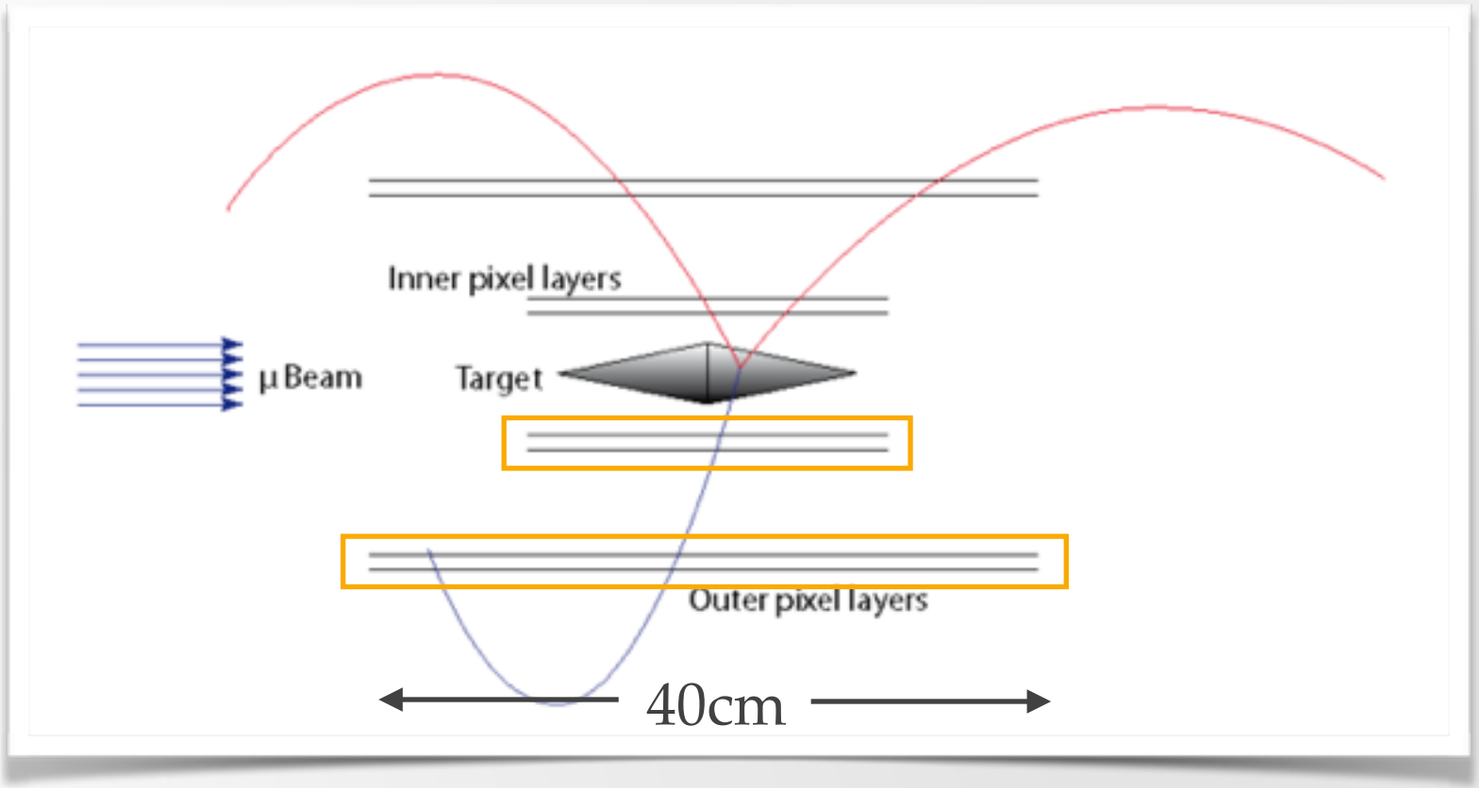


- Use recurler & high acceptance
  → *small, long tube design*





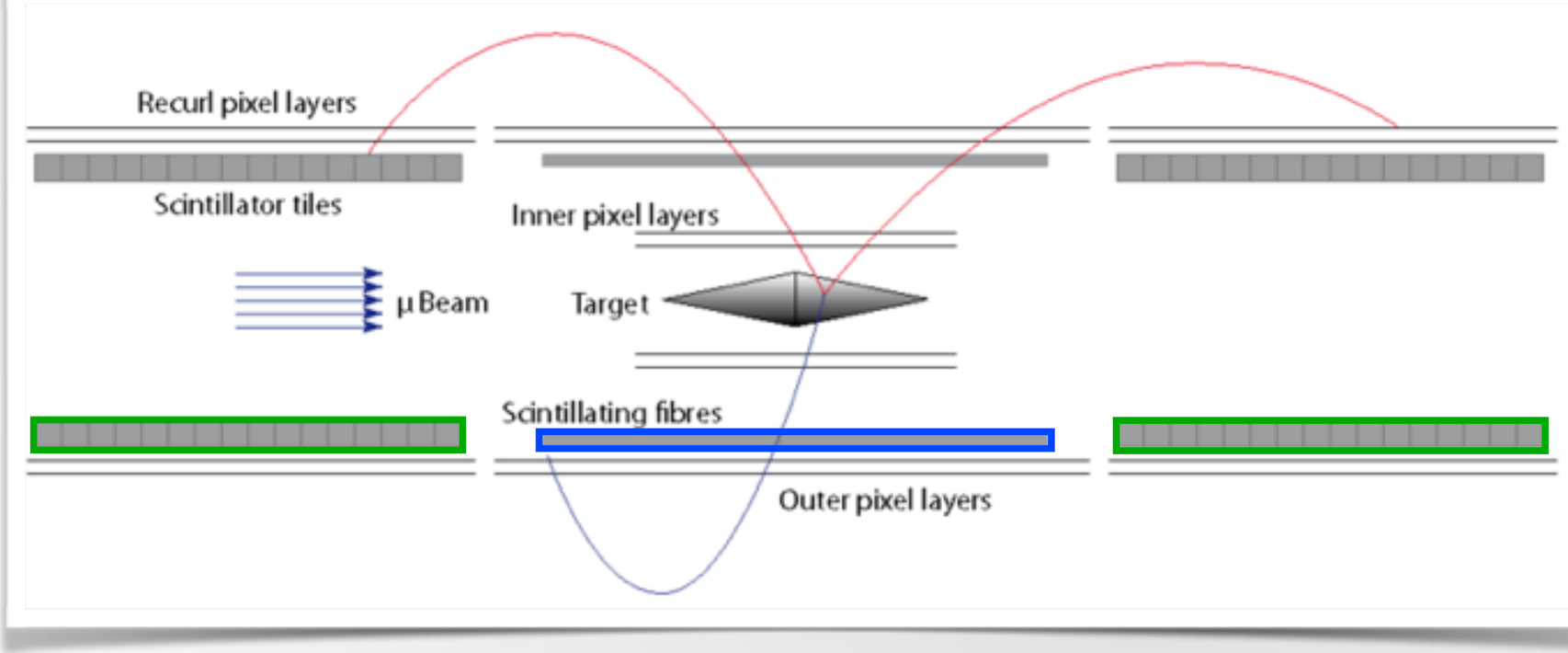
The Detector: Phase Ia



Rate	2×10^{7}
Sensitivity	10^{-14}

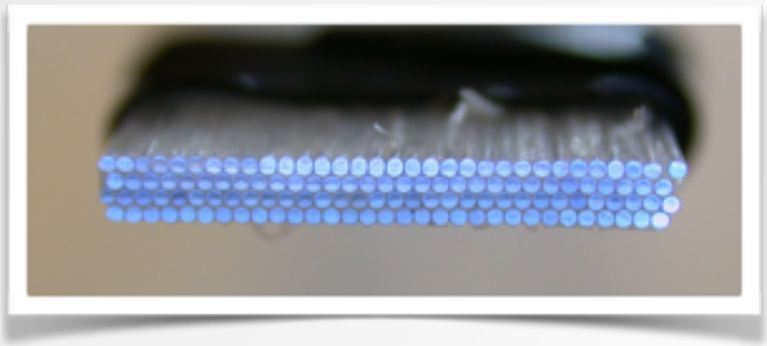
- Minimal configuration — 4 layers of HV-MAPS (thinned to ~50μm)
- Glued on kapton foil, self-supporting
- Momentum resolution: 0.5 MeV

The Detector: Phase Ib



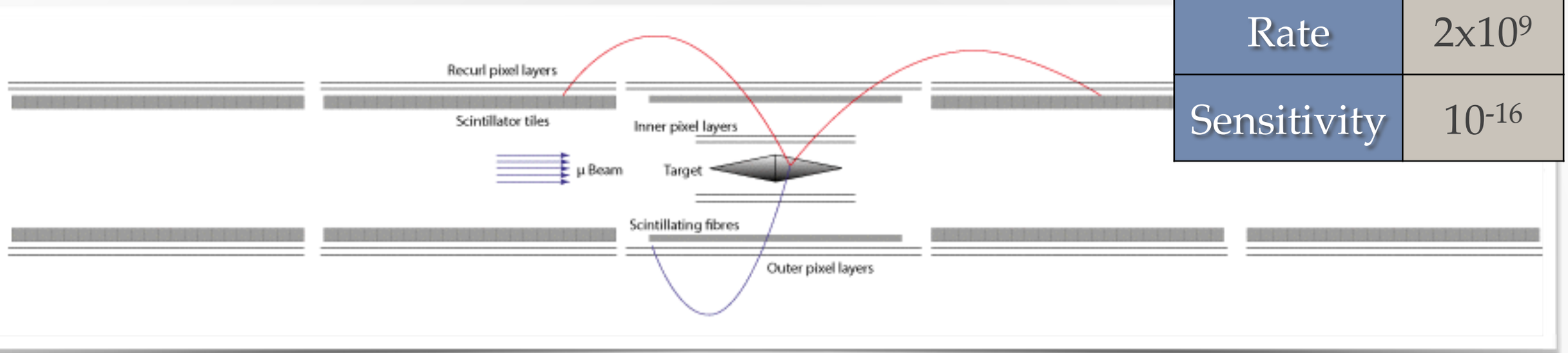
Rate	1×10^{8}
Sensitivity	10^{-15}

- Adding **sci. fibres** in central station + recurl stations with **sci. tiles**
- Combined with Silicon Photomultipliers
- Time resolution fibres: ~1ns, tiles: ~100ps
- *Limited by statistics*



3-5 layers of 250μm fibres

The Detector: Phase II

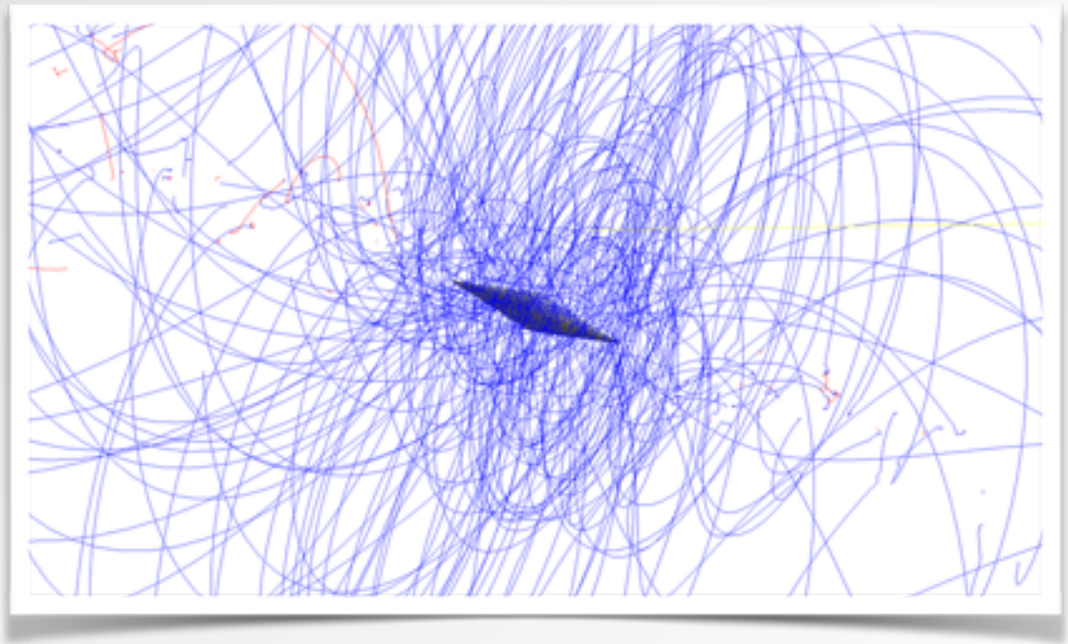


Rate	2×10^{9}
Sensitivity	10^{-16}

- Higher rate at a possible new beam-line
- Size matters: add two more recurl stations

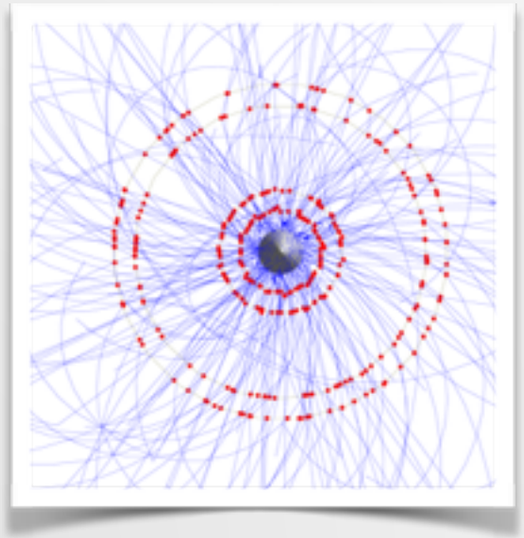
Simulation

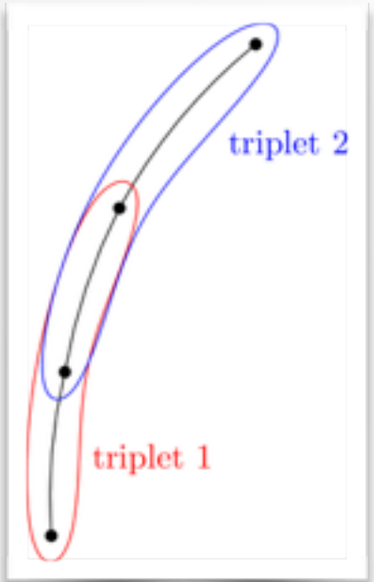
- Full detector simulation in Geant4:
- Optimize geometry
- Analysis with truth data:
  - e. g. Background estimation
- *Reconstruction development*
  - Vertex fit
  - Track fitting
  - Track-Tile matching
  - Track-Fibre matching



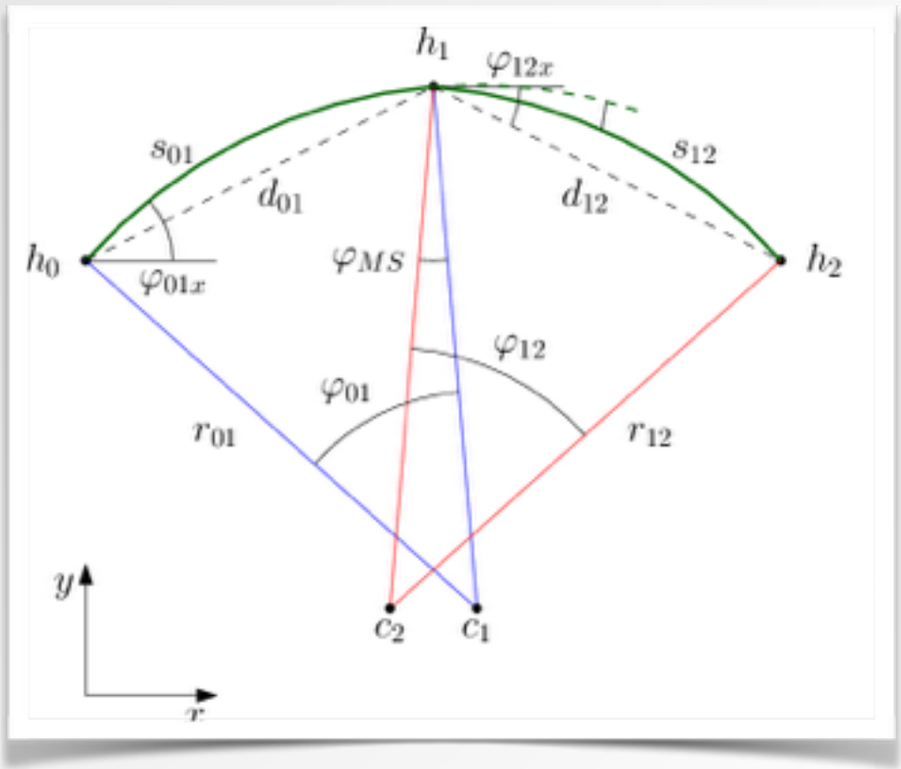
Track Fitting

- No hardware trigger, read out everything
- Reconstruct every event on an online filter farm
- → has to be fast!

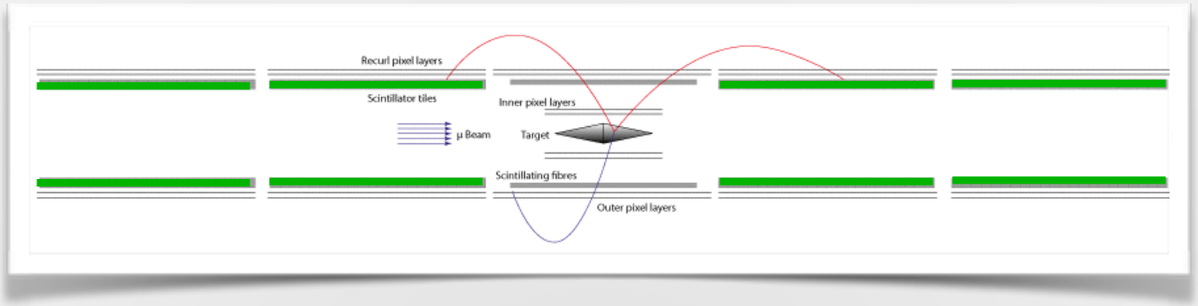


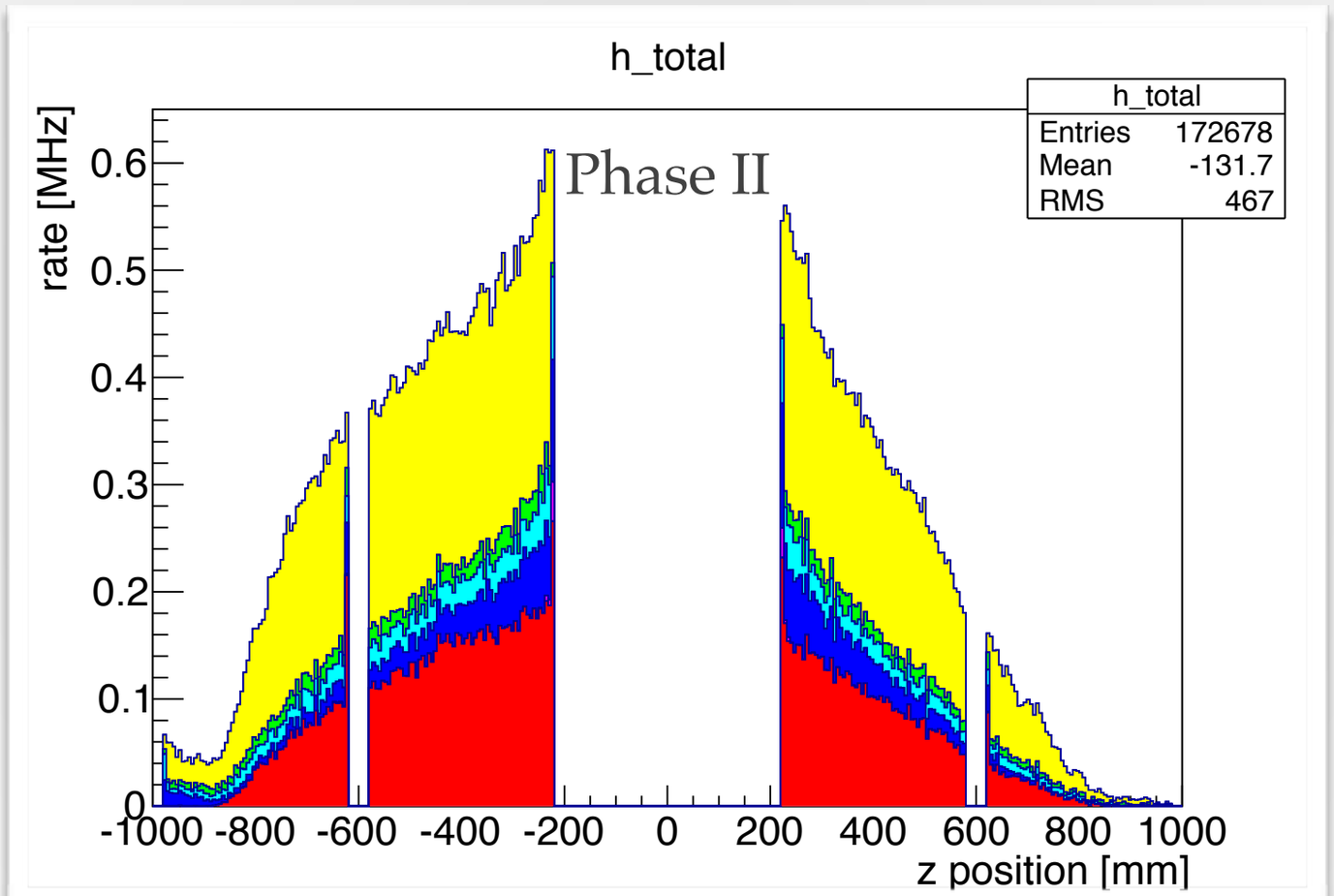


- Multiple scattering fit
- Describe track as a sequence of triplets
- MS in middle hit of triplet
- Track = weighted mean of triplets



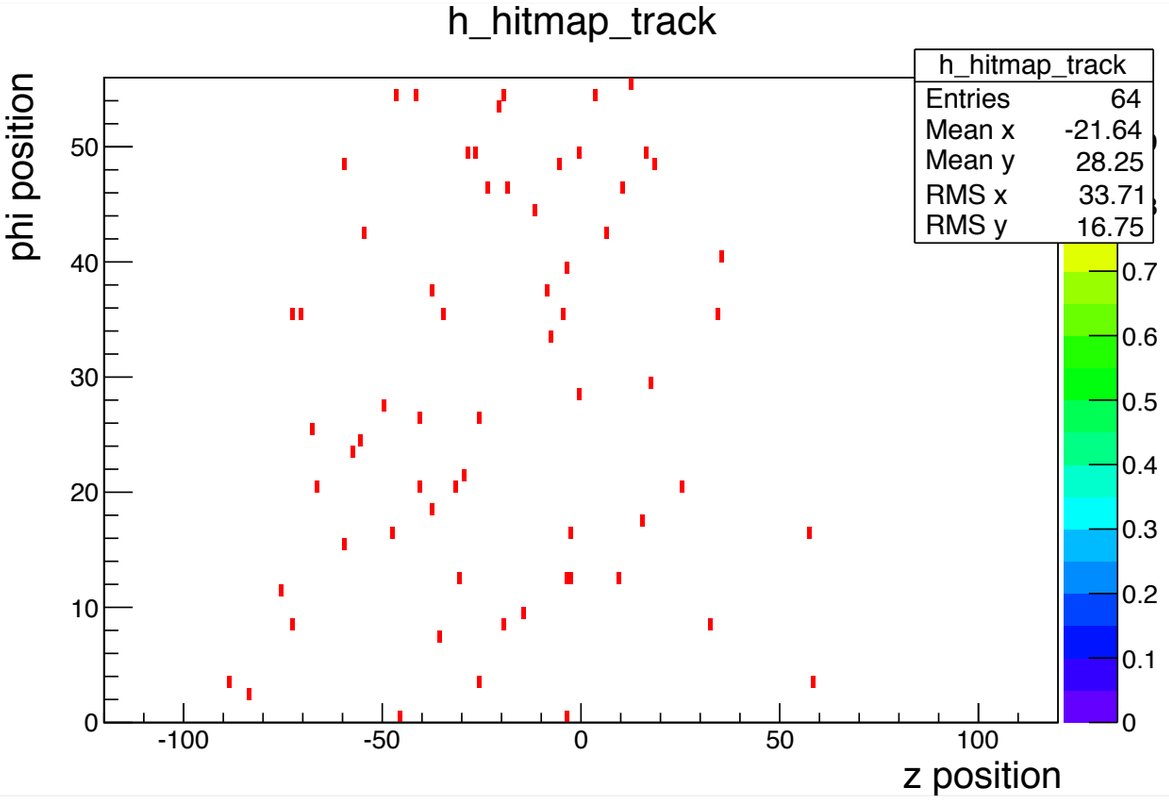
Tile Detector Studies

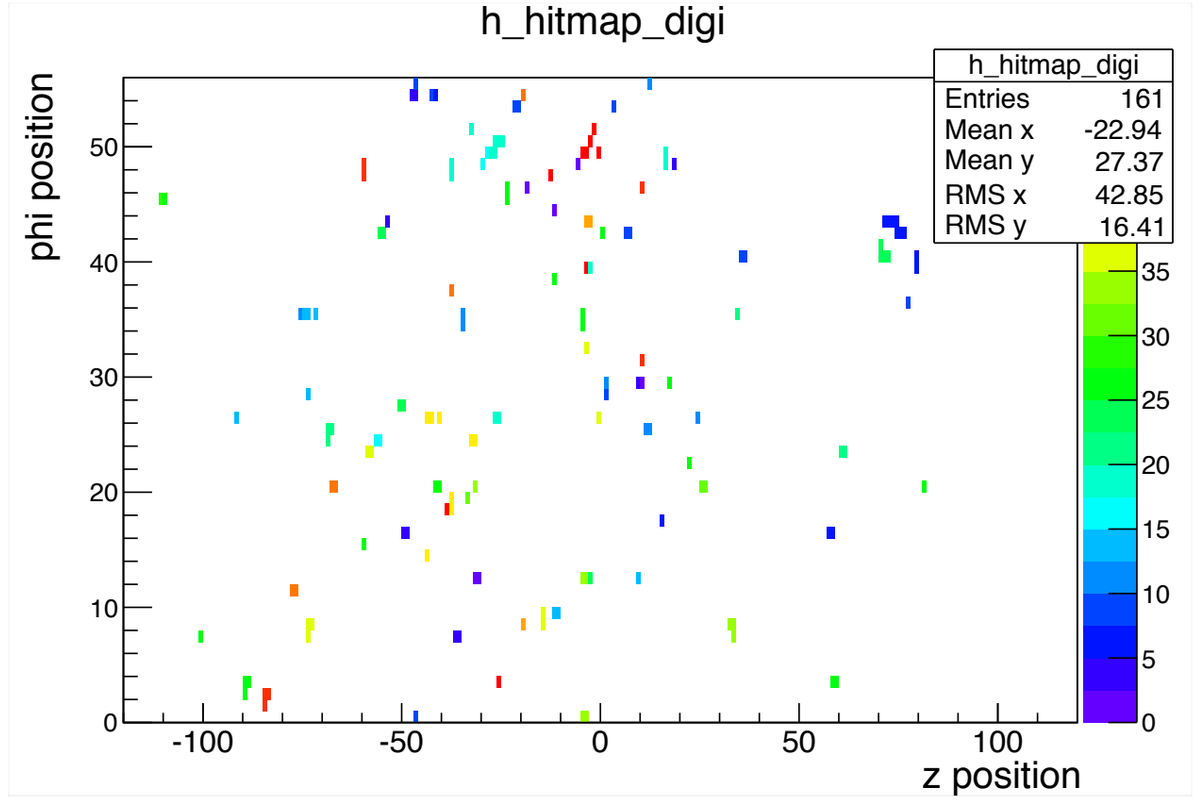




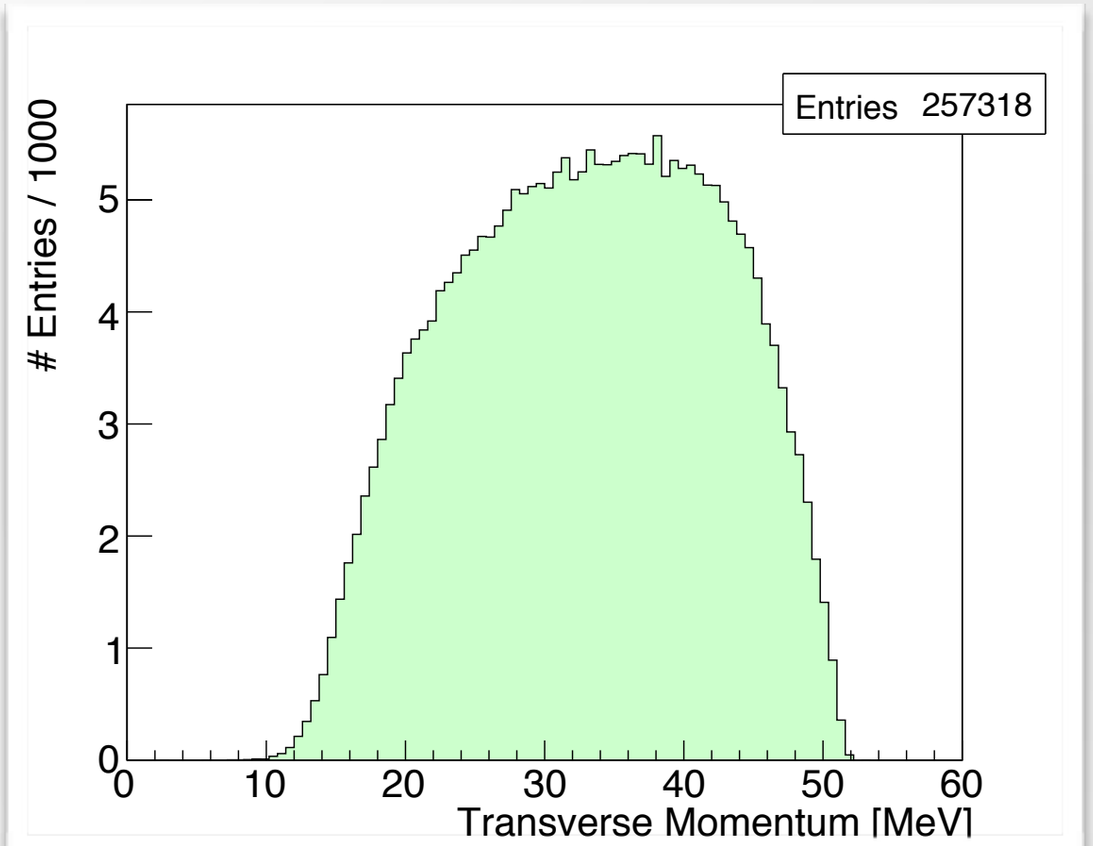
Tile Detector Studies

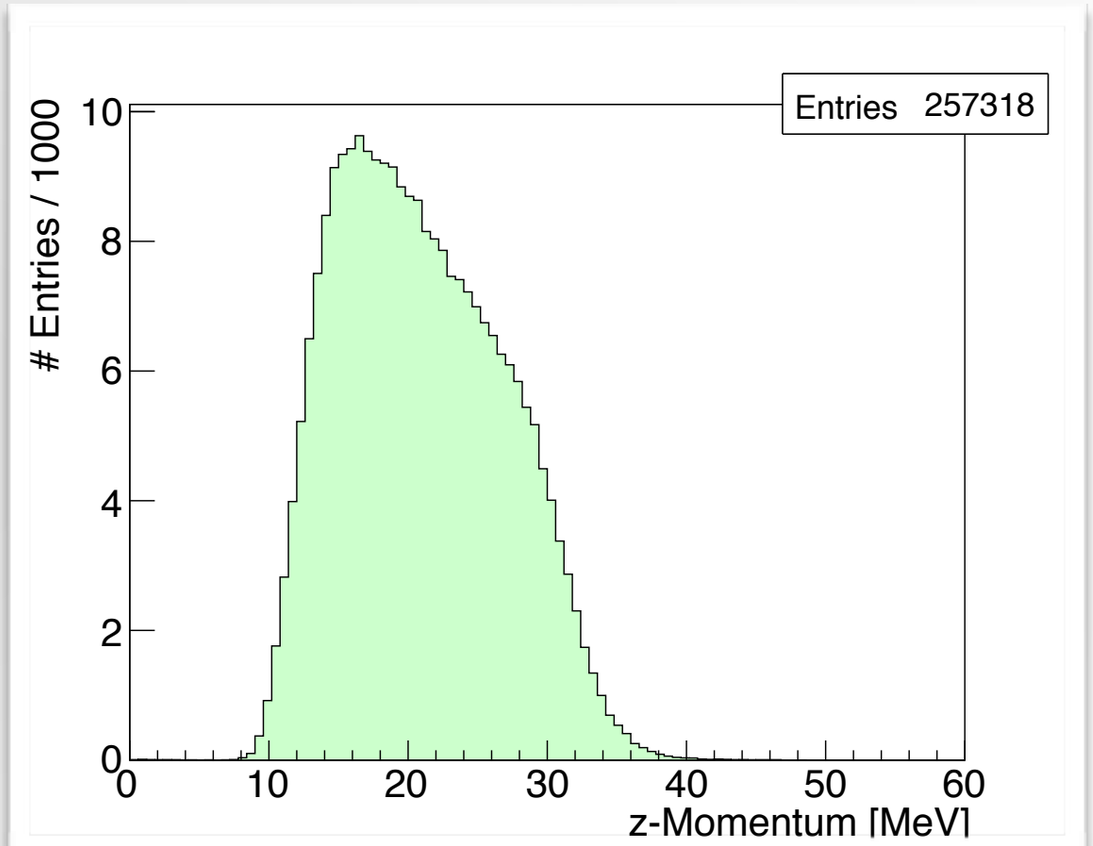
Phase II



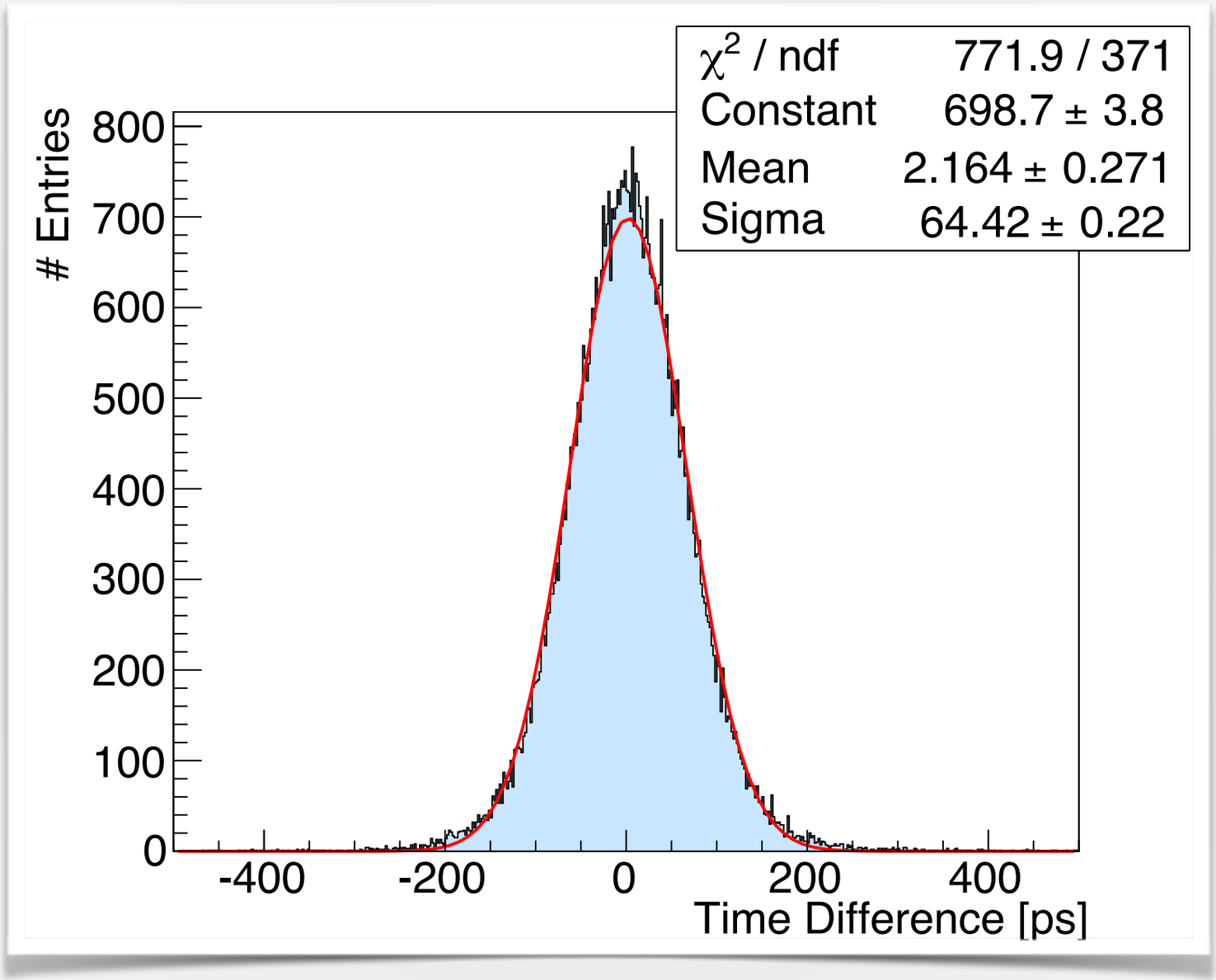


Kinematics of Particles Hitting the Tile Detector



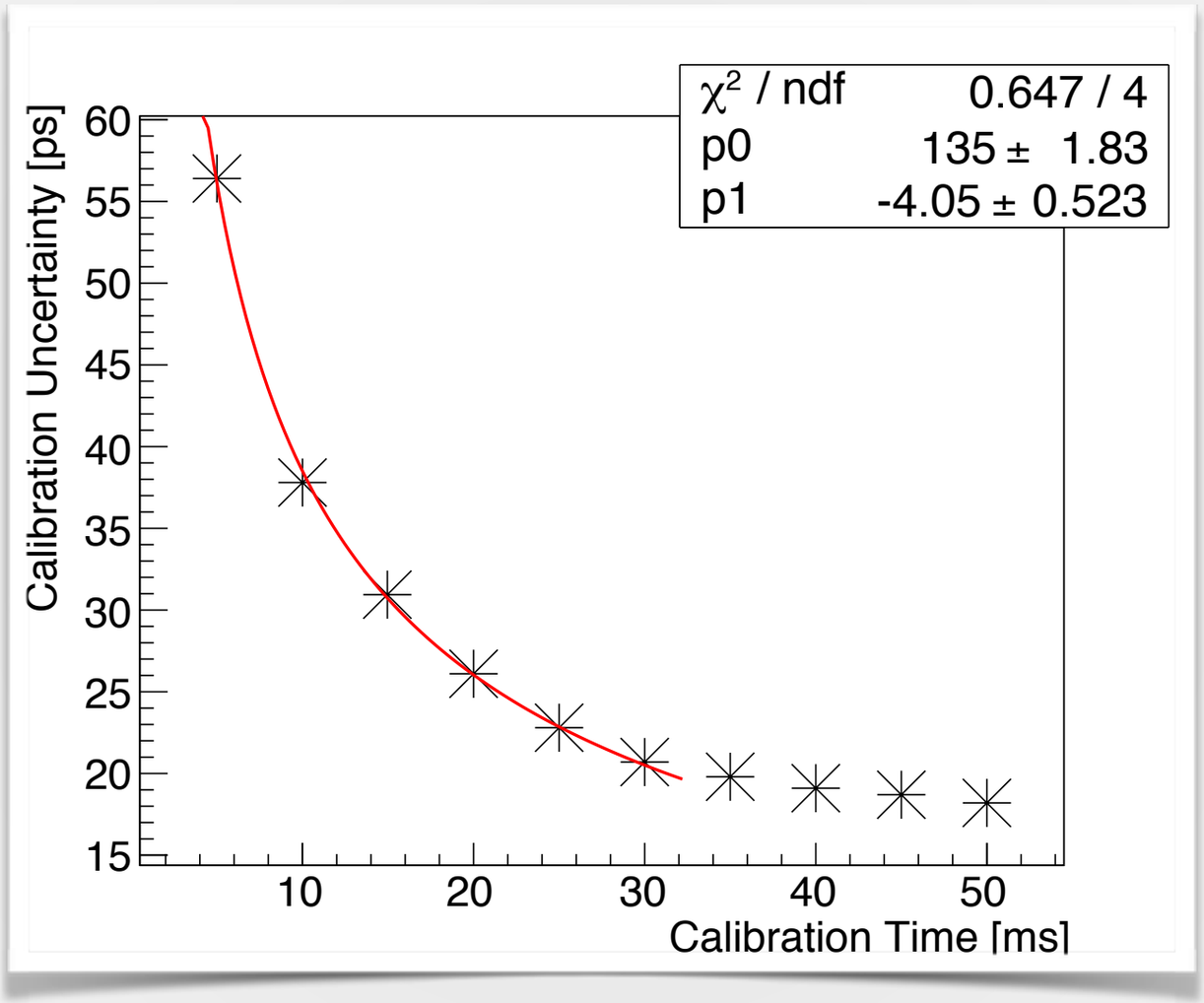


Track Tile Matching Resolution



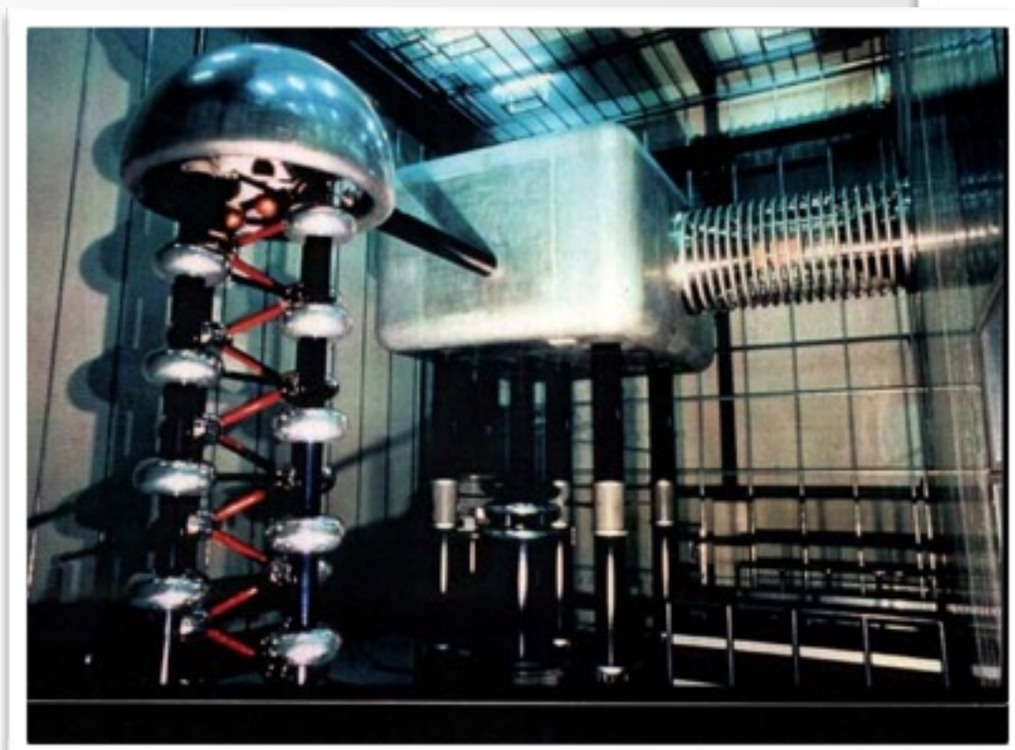
Phase 2

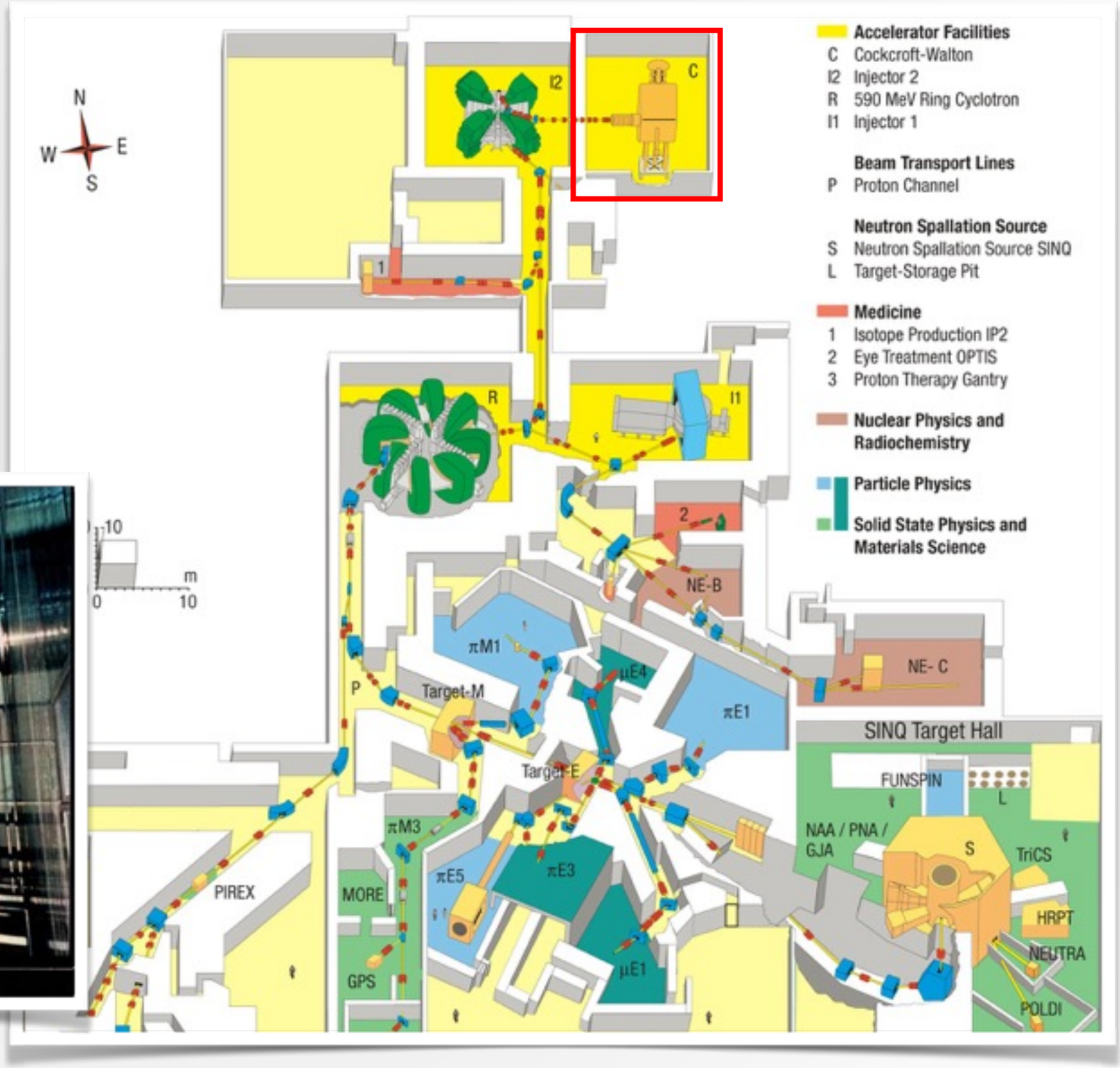
Calibration Precision over n



Beam Infrastructure

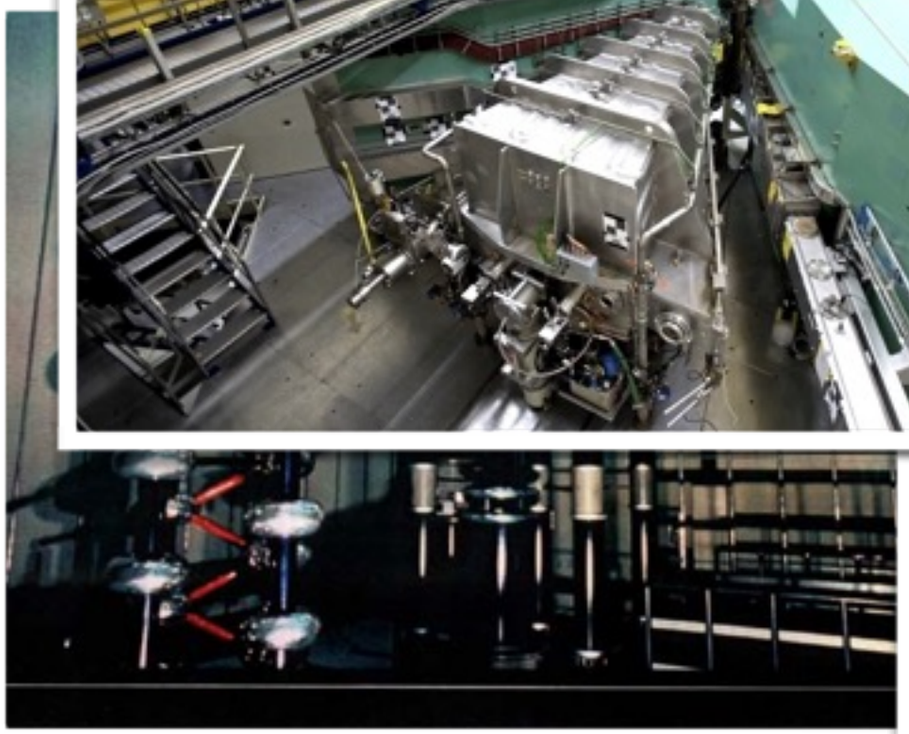
- Cockcroft-Walton:
- accelerates hydrogen atoms to 870 keV

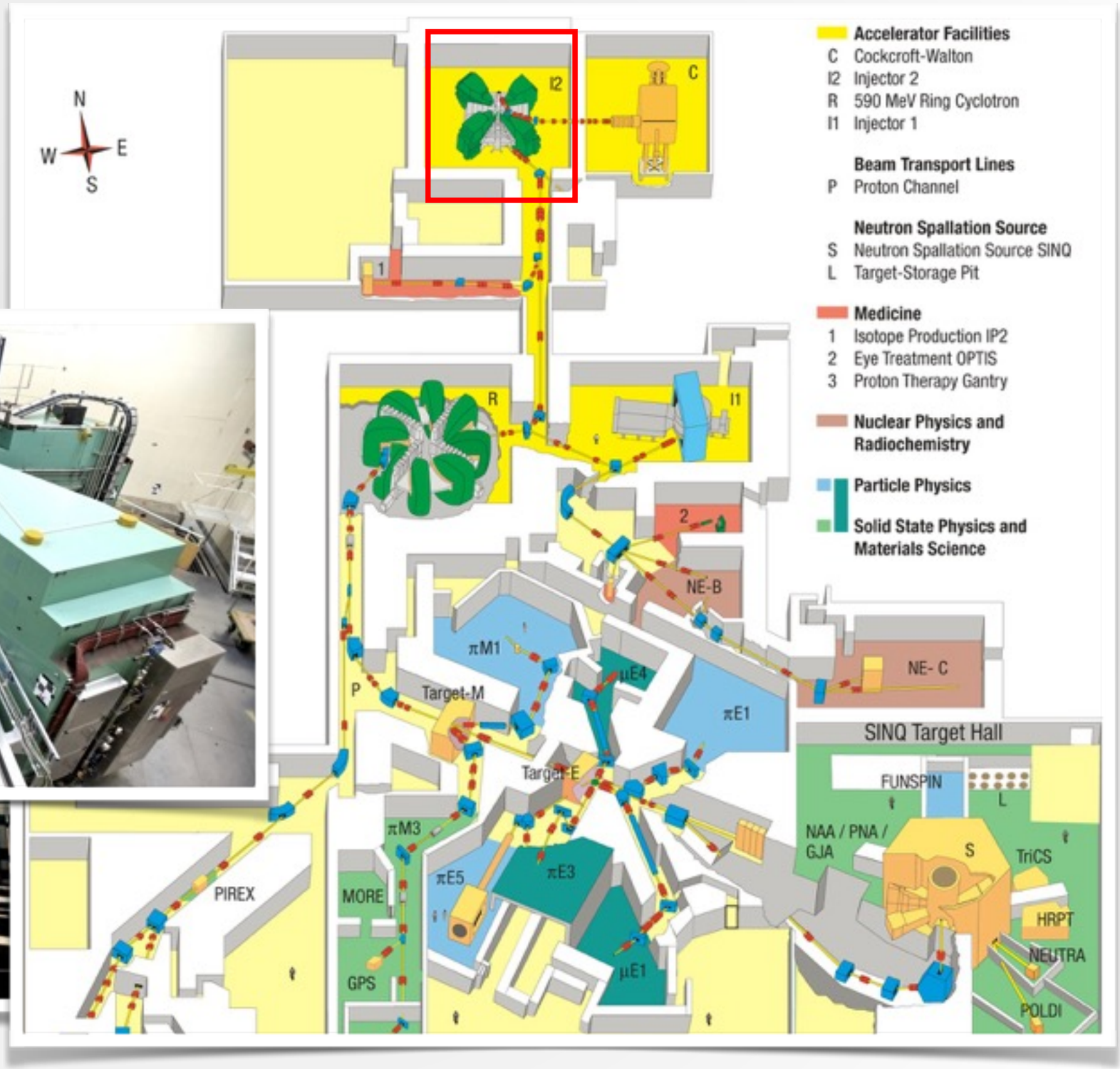




Beam Infrastructure

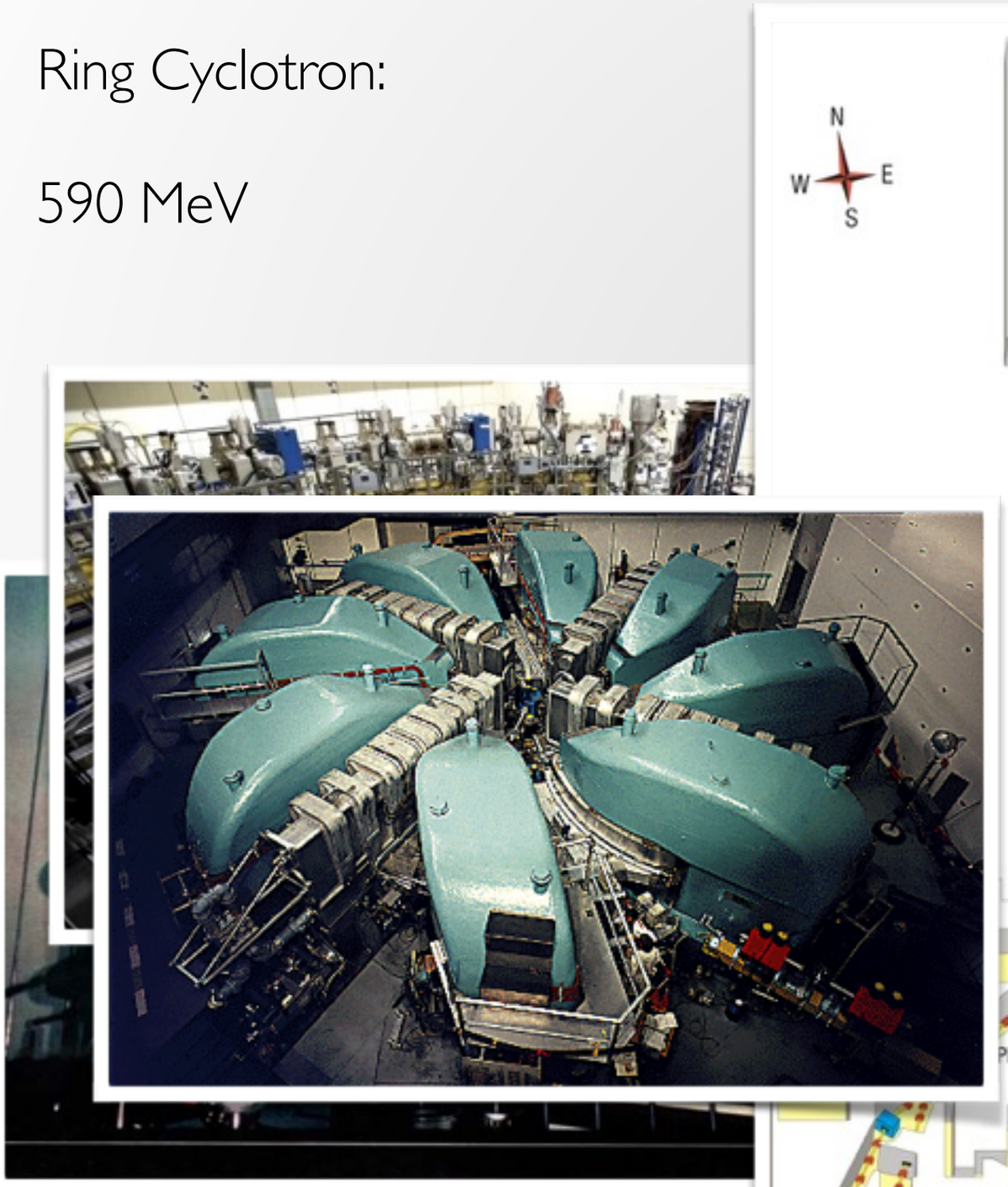
- Injector 2:
- 72 MeV Cyclotron

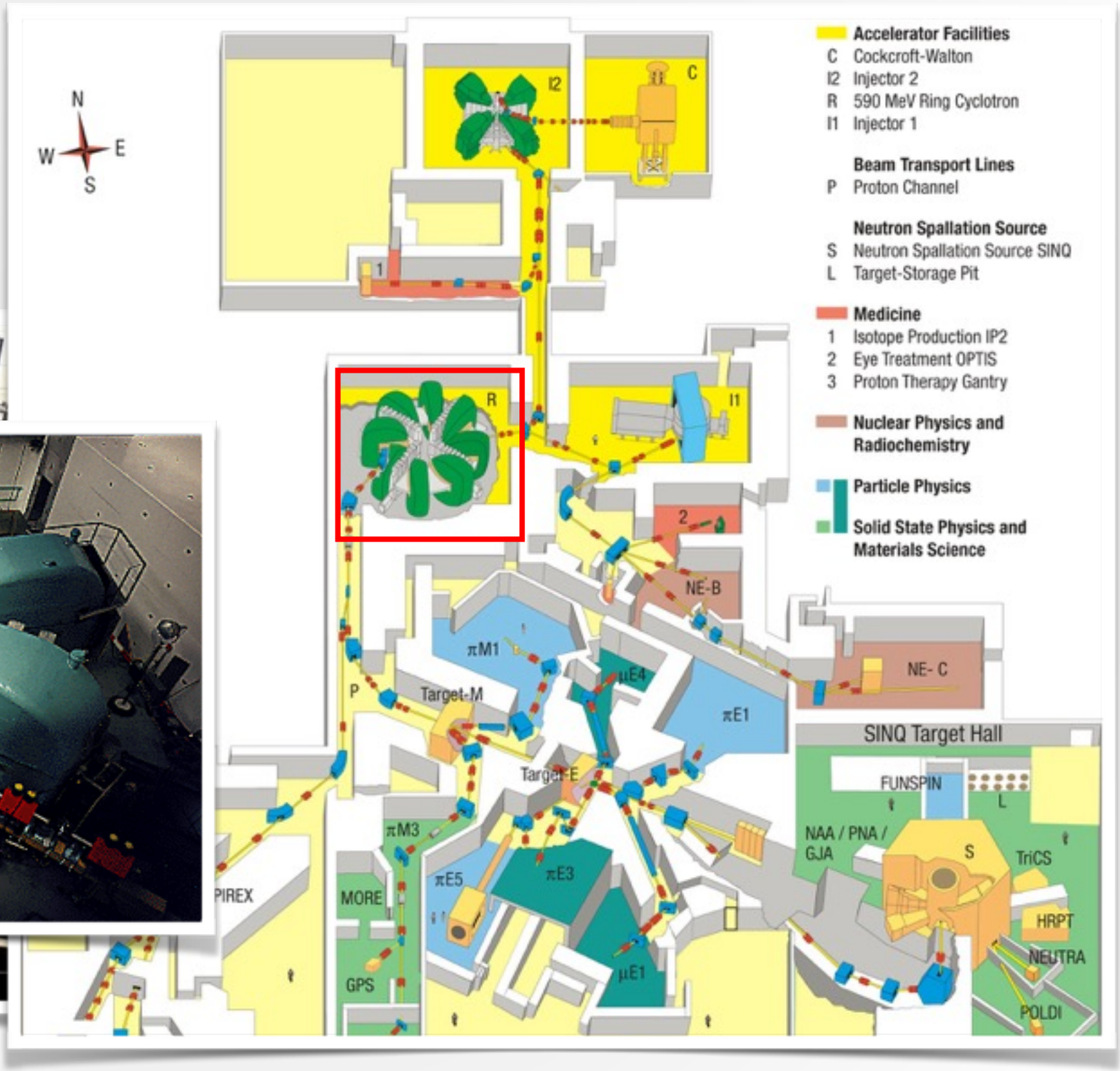




Beam Infrastructure

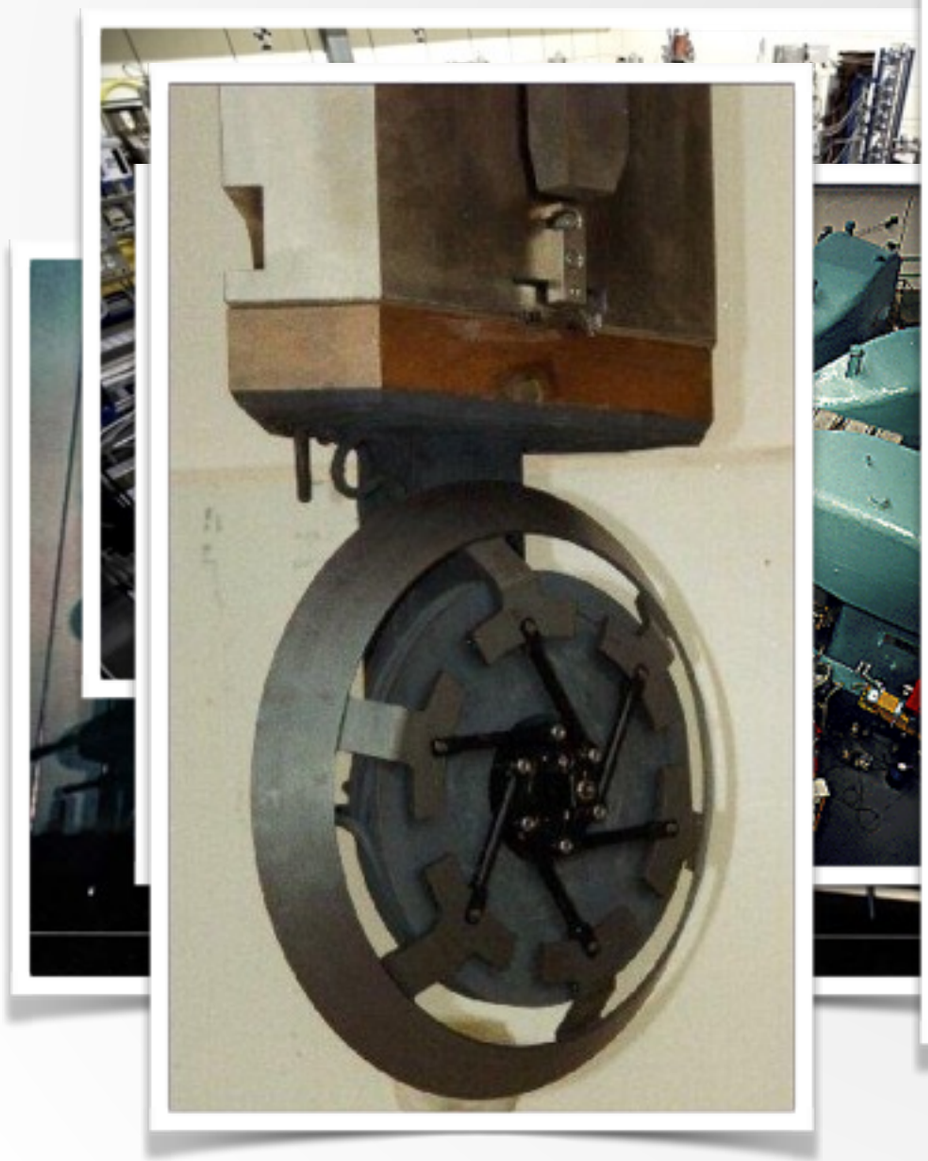
- Ring Cyclotron:
- 590 MeV





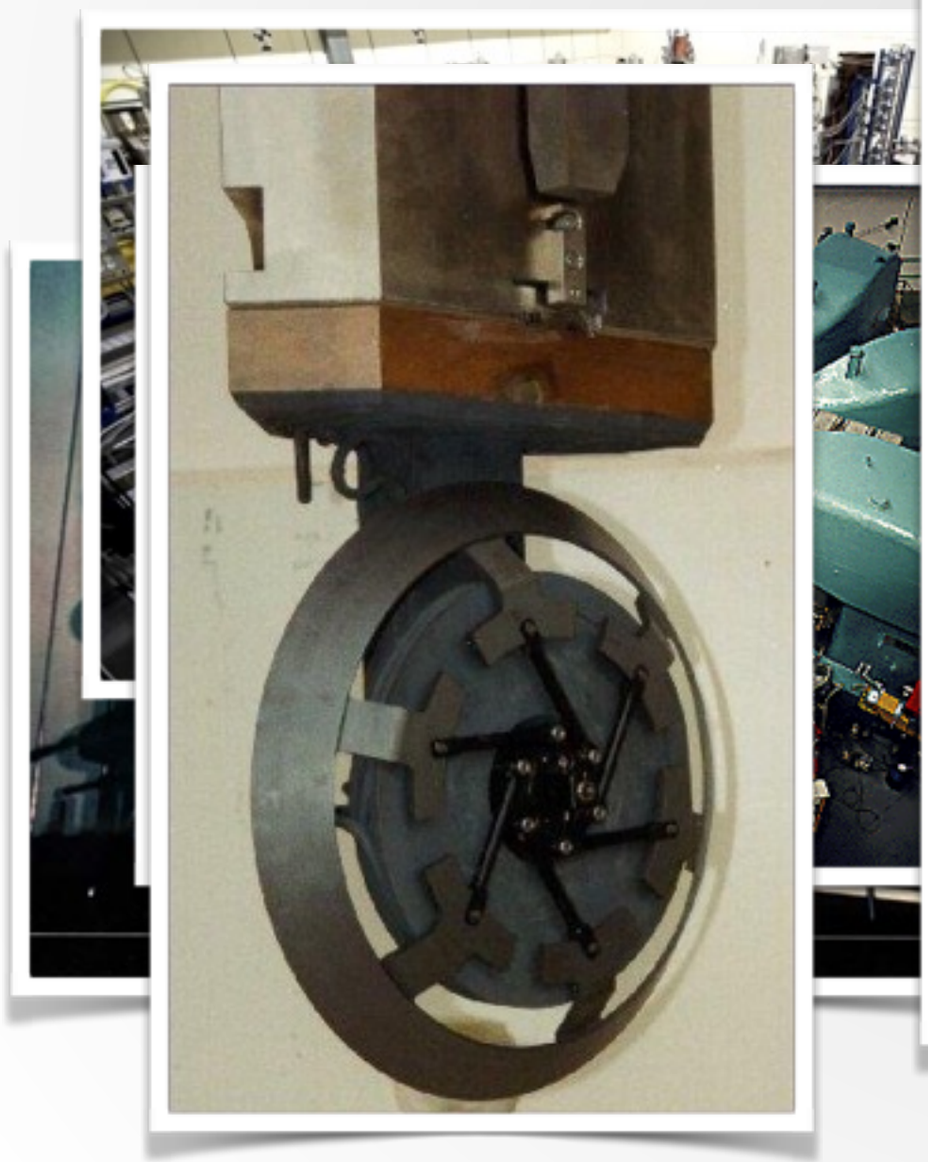
Beam Infrastructure

- Target E (rotating):
- 40mm of graphite
- generates π^+ -> μ^+

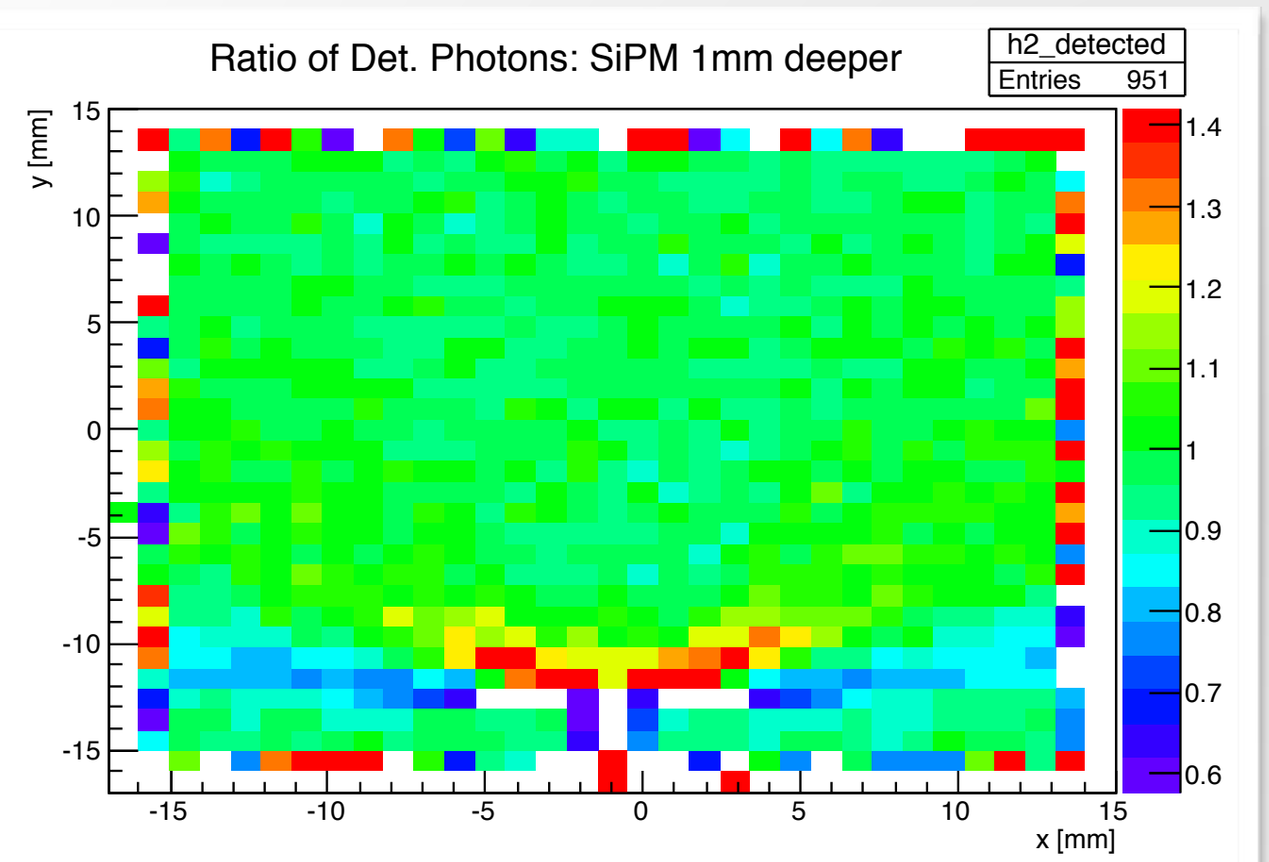


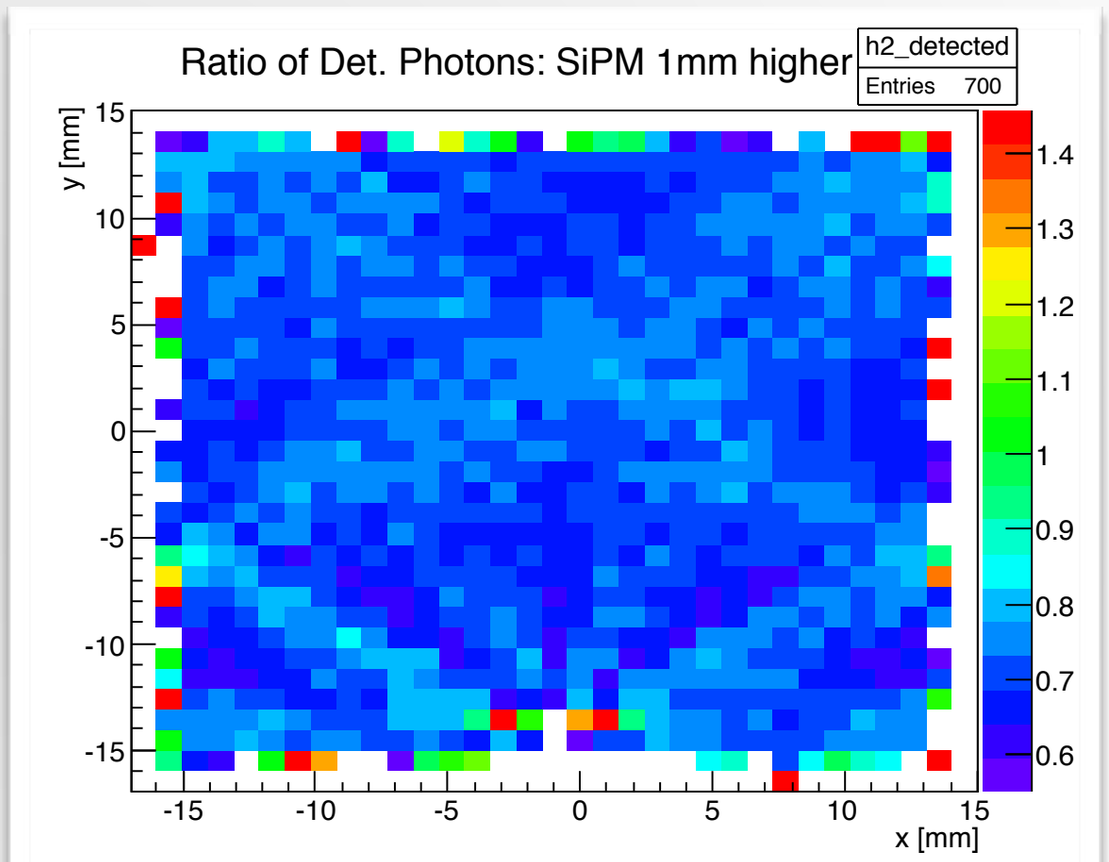
Beam Infrastructure

- SINQ
- new beam line for phase 2



Misplaced SiPM





Thinner Tile