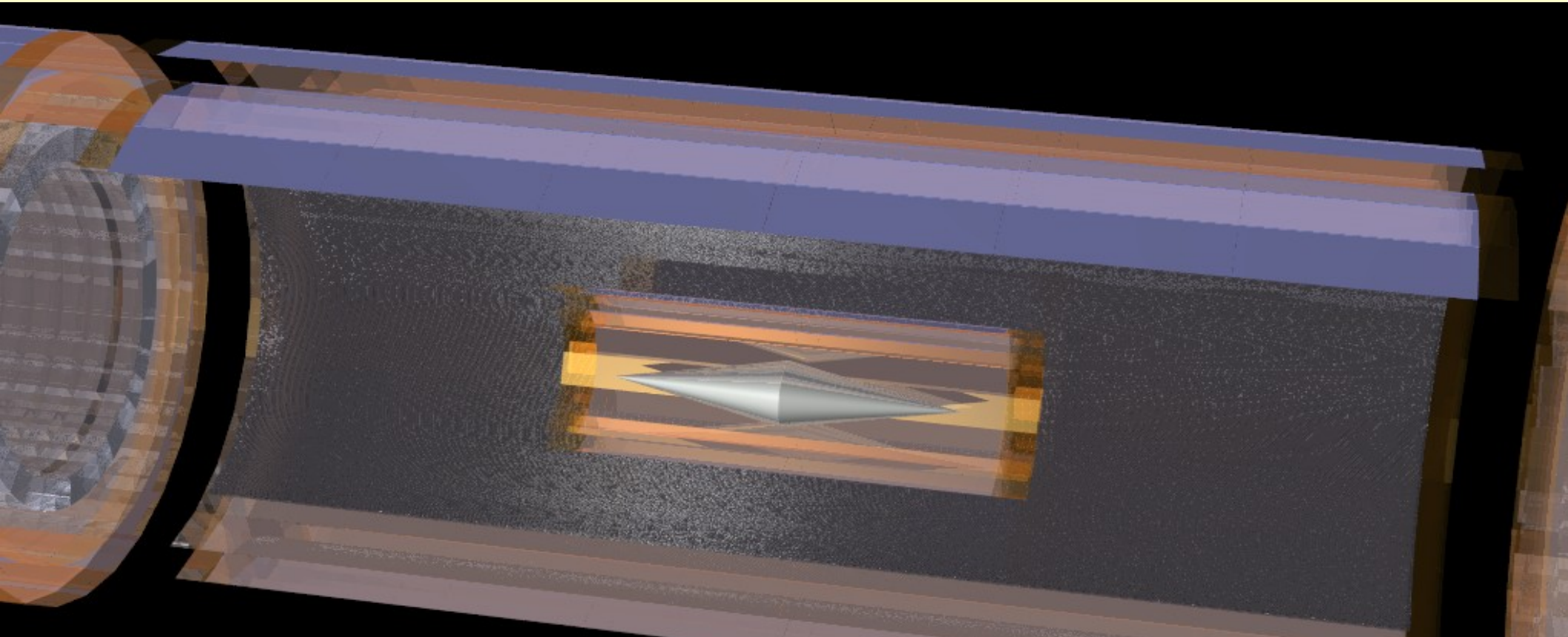
Status of the Mu3e Experiment

Paul Scherrer Institut
Open Users Meeting BV47
Review Meeting
February 8, 2016

André Schöning for the Mu3e Collaboration



Mu3e Collaboration

- Memorandum of Understanding was signed in January 2016
  - University of Geneva (Alessandro Bravar, Giuseppe Iacobucci*)
  - University Heidelberg (Schöning, Schultz-Coulon)
  - Karlsruhe Institute of Technology (Ivan Peric)
  - University Mainz (Niklaus Berger)
  - Paul Scherrer Institute (Stefan Ritt)
  - ETH Zurich (Christoph Grab)

- Engagement of University Zurich group will probably end with retirement of U.Straumann (SciFi)
- *Group of Giuseppe Iacobucci (Geneva) will contribute to Pixel Detector

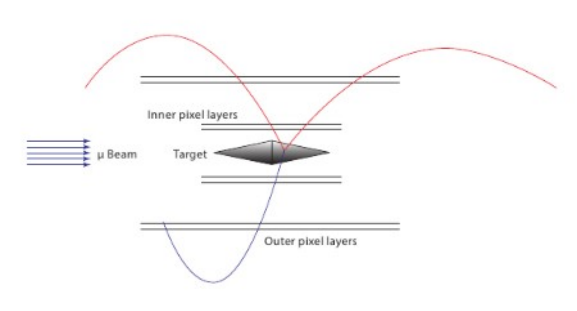
- Liverpool applied for participation (observer status) → funding ?

Mu3e Phase I Detector

Technical Progress:

- Compact Muon Beamline
- Magnet
- Pixel Detector → Frank Meier Aeschbacher
- Scintillating Fibers → Angela Papa
- Scintillating Tiles
- Detector Integration → Dirk Wiedner

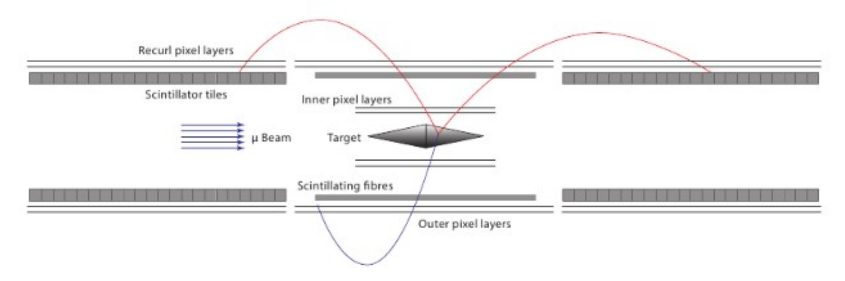
Phase IA:
rate ≤ 10^7 muons/s



only central Pixel Detector

- minimal setup
- add timing detectors if available

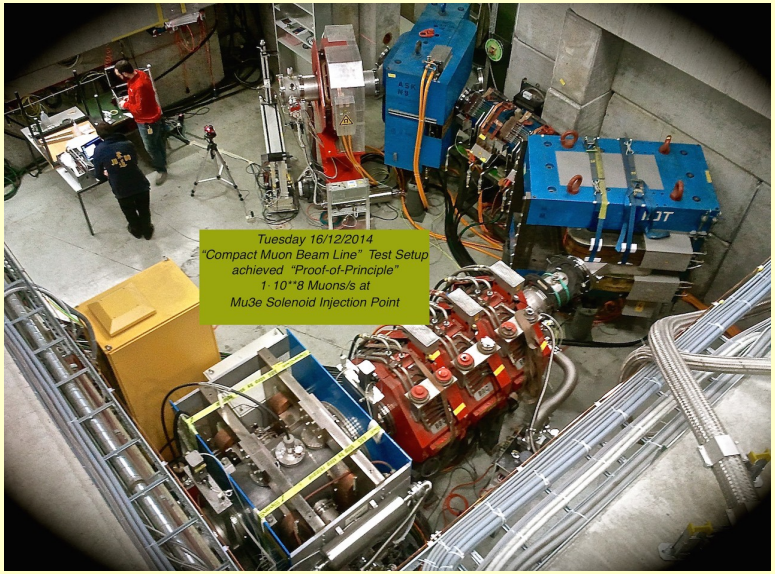
Phase IB:
rate ~ 10^8 muons/s

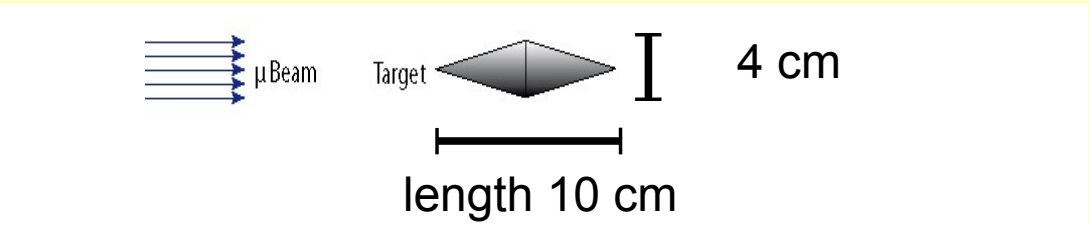


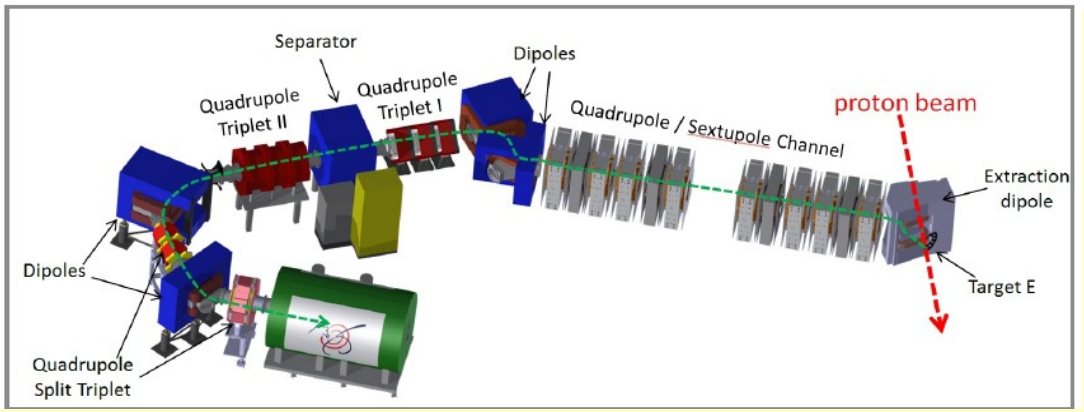
+ Inner Recurl Detectors
+ Timing Detectors

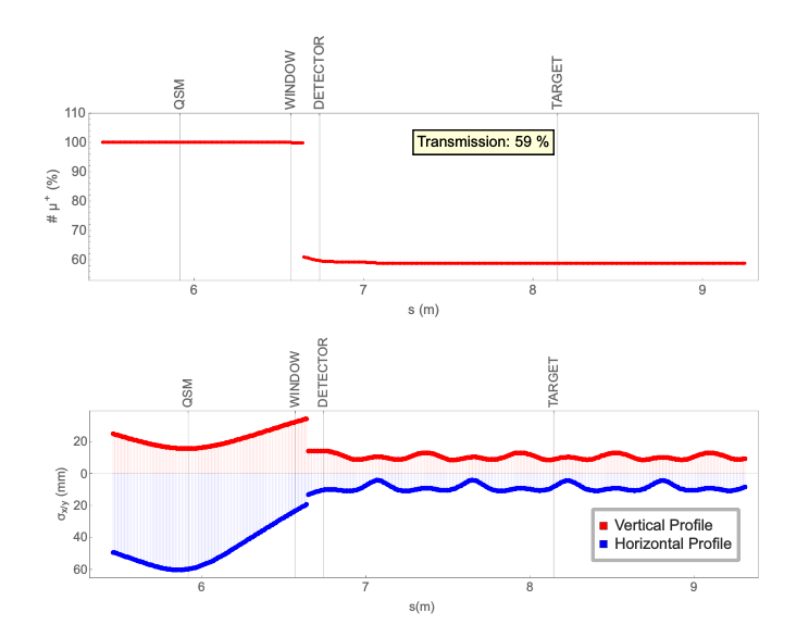
Compact Muon Beamline

- piE5 measurements in 2014: 10^8 muons/s
- measurements in 2015: $7 \cdot 10^7$ muons/s (-30%)
  - ➔ difference due to wrongly specified scanner size
- with improved beamline elements now expect
  - → 10^8 muons/s @ 2.2mA (focus)
- calculated target stopping rate
  - → $5 \cdot 10^7$ muons/s @ 2.2mA (target)
- rate is compromise of several boundary conditions



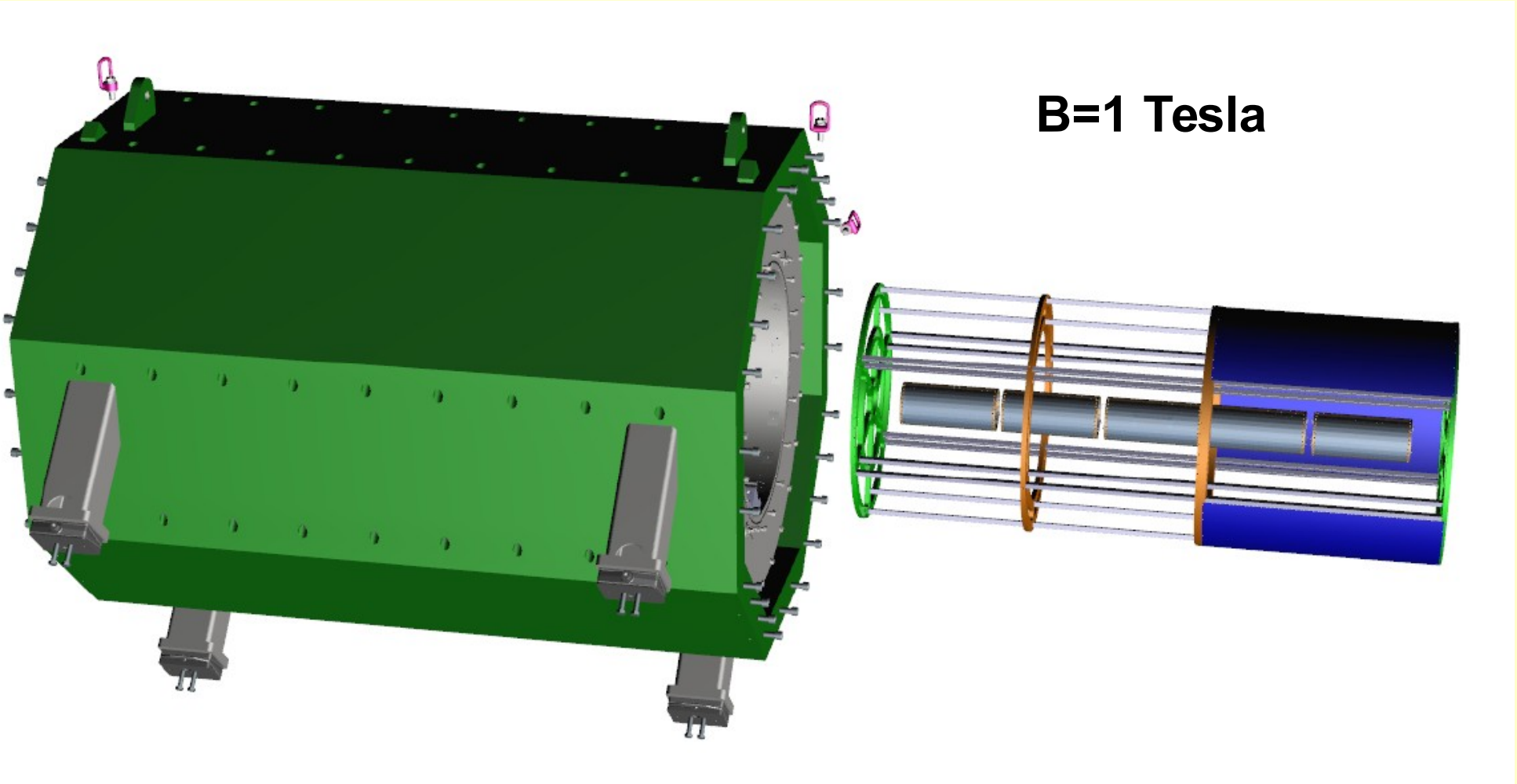






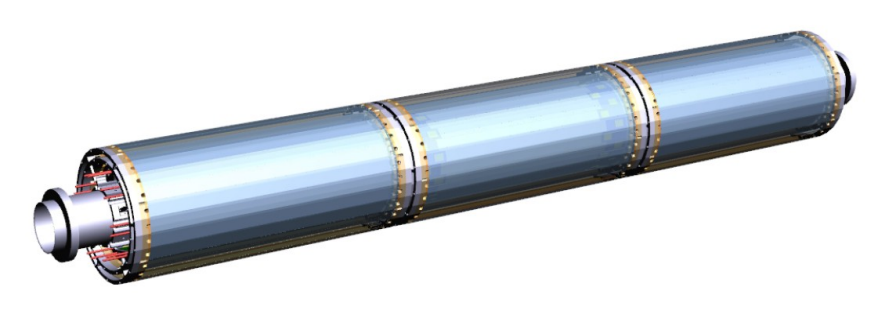
➔ More details in backup

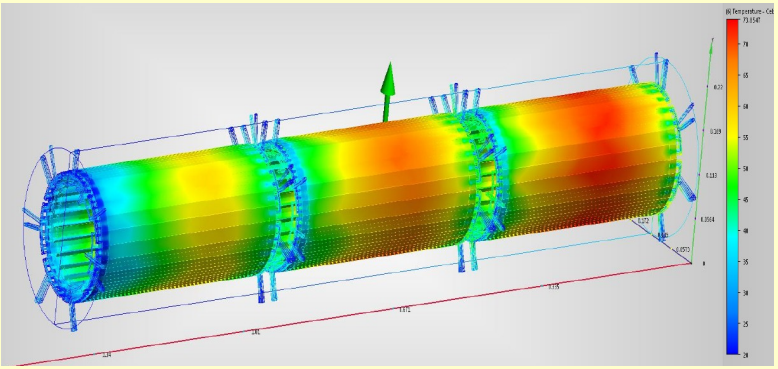
Mu3e Magnet



- Superconducting magnet produced by DANFYSIK (Denmark)
- Magnet Technical Design in December 2015
- Currently being produced → delivery by end of 2016

Pixel Detector → Frank Meier Aeschbacher

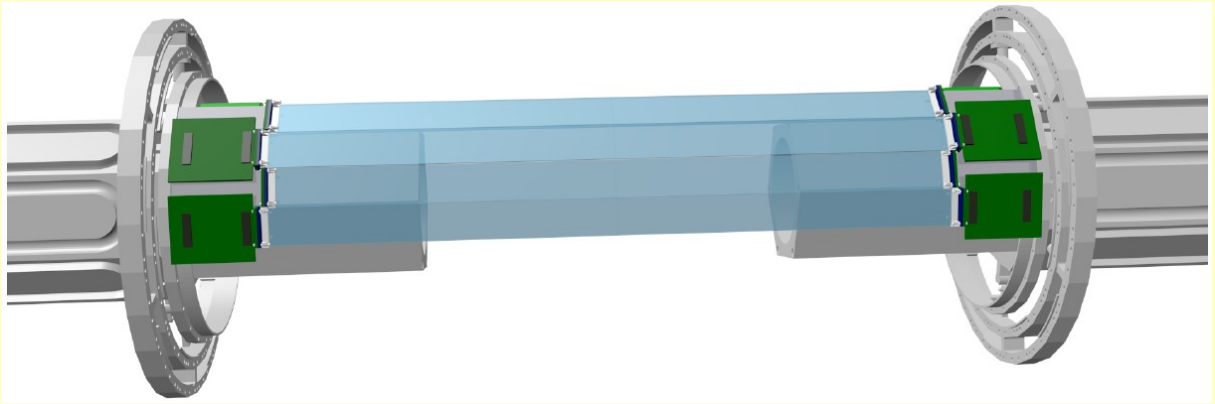




Status

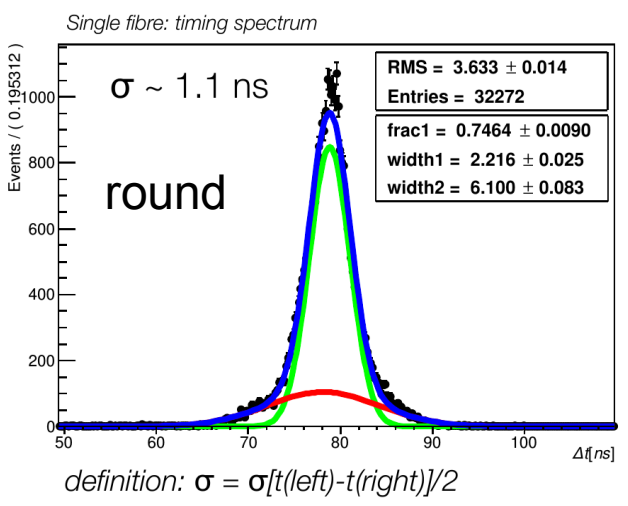
- Mupix7 3x4 mm prototype chip successfully tested in several test beams
  - ➔ all specifactions met!
  - ➔ fast serial readout at 1.25 Gbit/s
  - ➔ no interference of digital readout and signal detection seen so far
  - ➔ some issue with cross talk (~10% of hits) → ideas for improvements
- significant progress on design of modules and flexprints
  → ~1 permille X/X_0 possible with aluminum flexprints
- significant progress concerning He-gas cooling and vibration measurements
  → Dirk Wiedner (detector integration)
- ready for large scale chip (Mupix8) but waiting for AMS foundry
  → submission expected for June 2016 (instead of summer 2015)

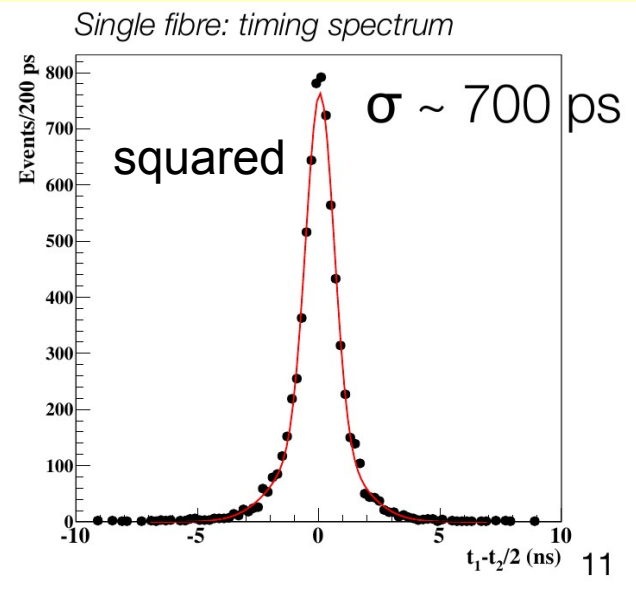
Scintillating Fibers → Angela Papa



- Extensive R&D activities including testbeams in 2015
- Two types of scintillating fibres:
  - round (Kuraray)
  - squared (Saint Gobain)
- Two SiPM options:
  - single SiPMs
  - SiPM array
- Technology decisions to be taken in 2016
- New MuStic for readout expected by end 2016
- CAD designs of system to be finalised

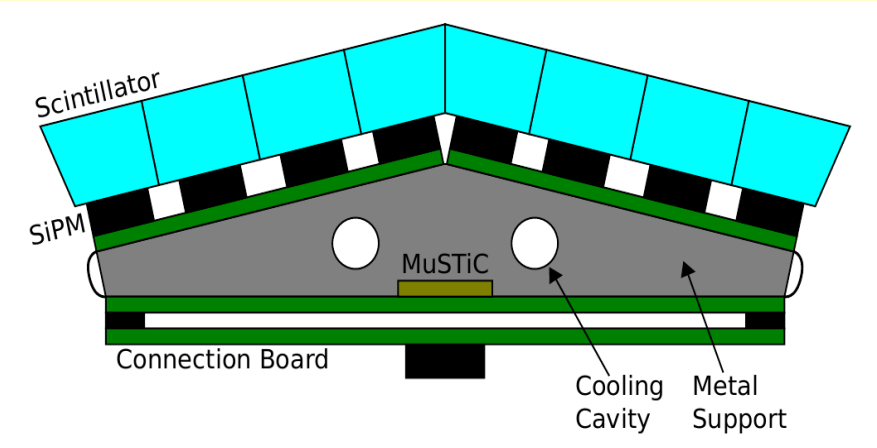
Single fibre time resolutions





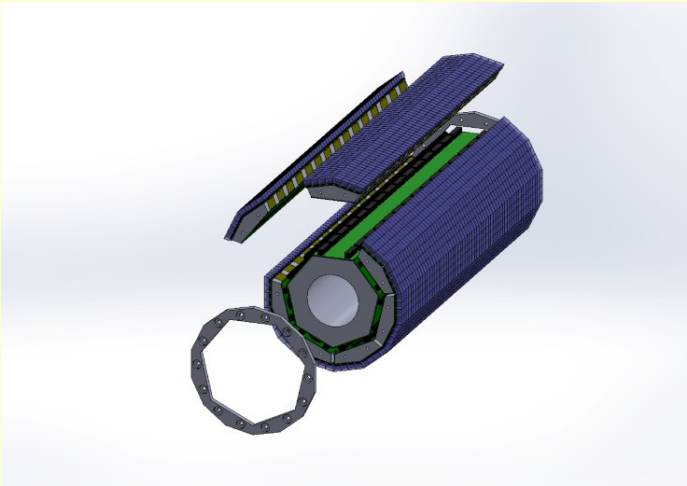
Tile Detector Design

Submodule (32 Ch.)

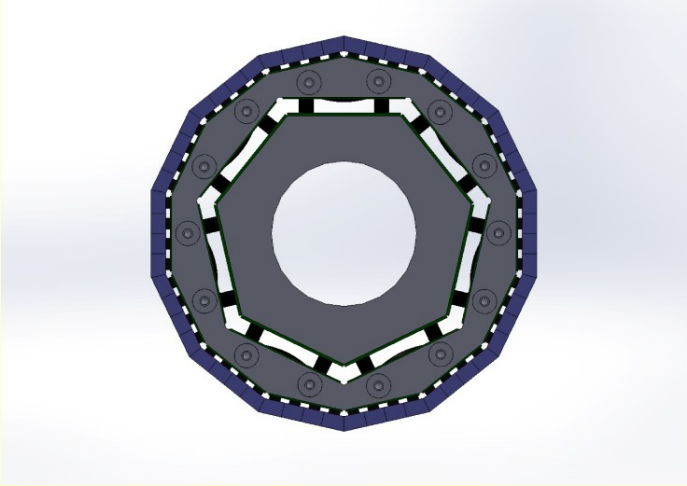


- time resolution: 100 ps
- high efficiency
- dead-time < 200 ns
- data rate: up to 50 kHz per channel

Full Station (3360 Ch.)



(cross section)

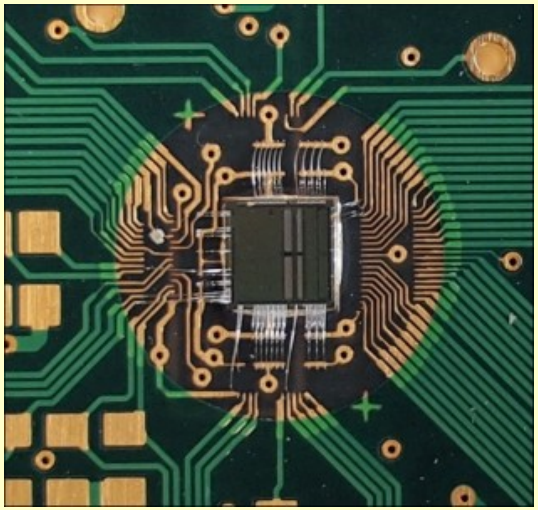


➔**Not much has changed since last review. Technology ready!**

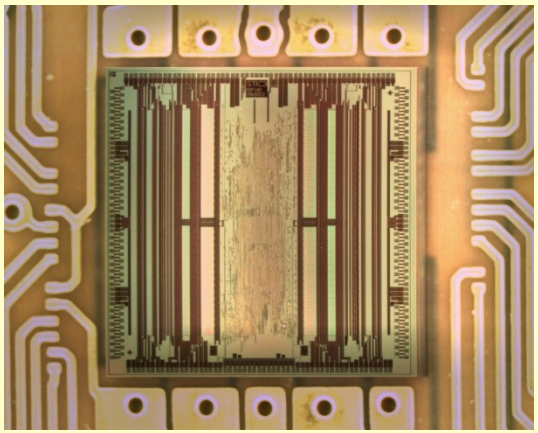
STIC Chip

- STiC 2.0 (16 ch.)
  - Tested in Tile Detector prototype
  - Fulfills time resolution requirement
  - Dead-time sufficient for Phase IB
  - Bug in event reconstruction
  - Event rate limited to 2.5 MHz per chip
- STiC 3.1 (64 ch.)
  - Bugs fixed
  - Running in EndoTOFPET-US Outer Plate
  - Zero pole cancellation circuit → smaller dead-time
  - Event rate limited to 2.5 MHz per chip
- MuSTiC (32 ch. with 1.25 Mhit/ch/s)
  - LVDS serial link test chip delivered January 2016
  - Optimized for Mu3e application
  - Enhanced event rate O(20 MHz) per chip

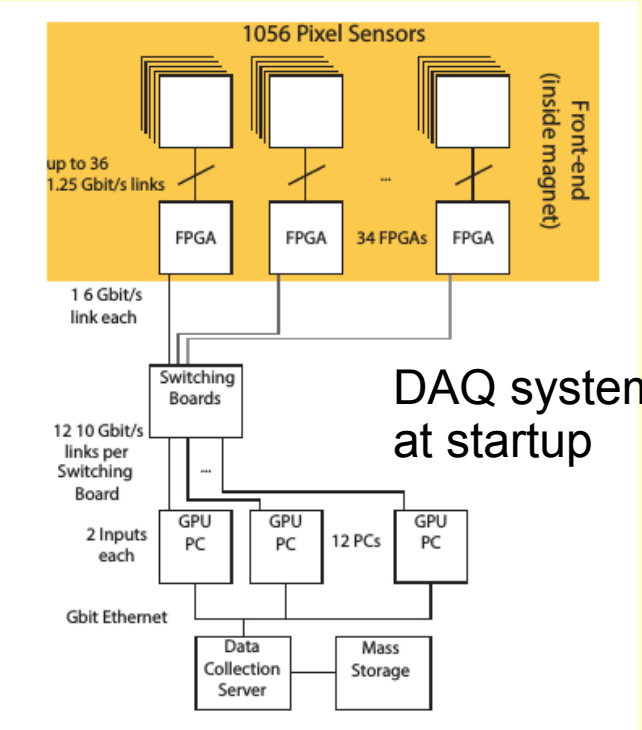
STiC 2.0



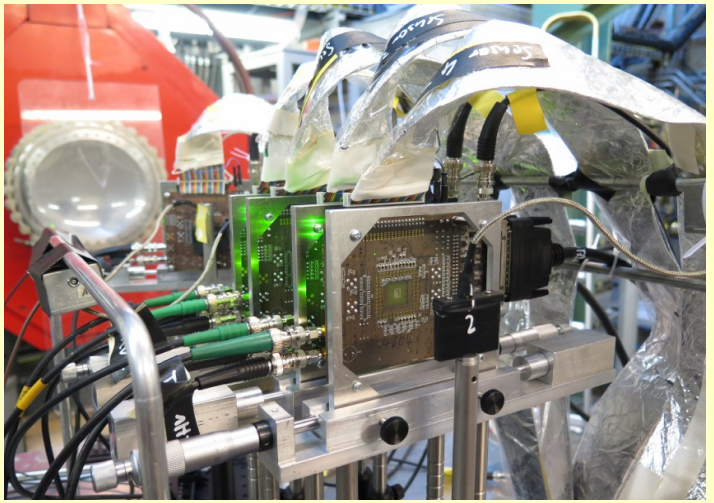
STiC 3.1



Readout + Online Reconstruction



DAQ system at startup

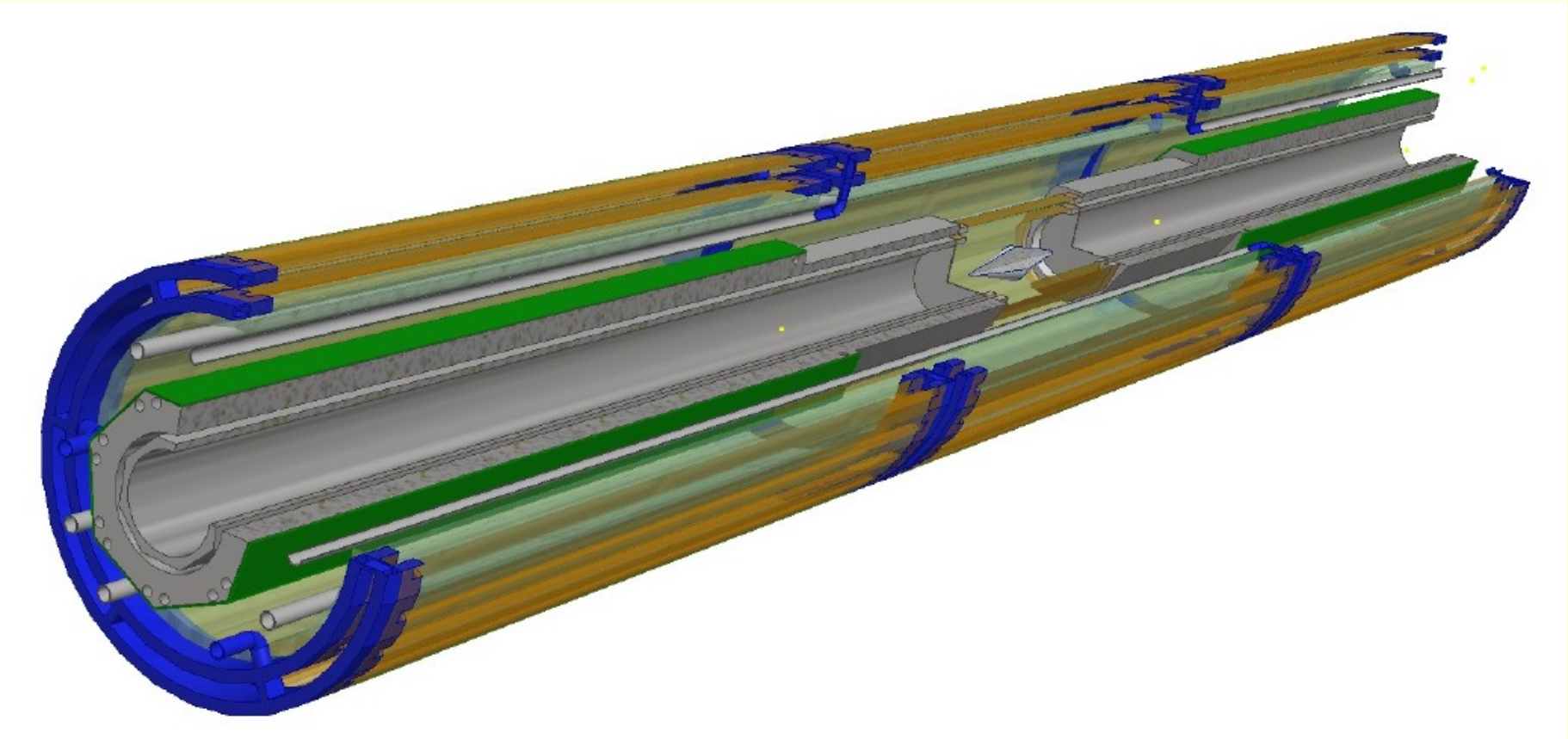


- Lots of experience from test-beam campaigns at CERN, PSI, DESY, Mainz
- Vertical slice with 4 pixel layers running!

Next Milestones

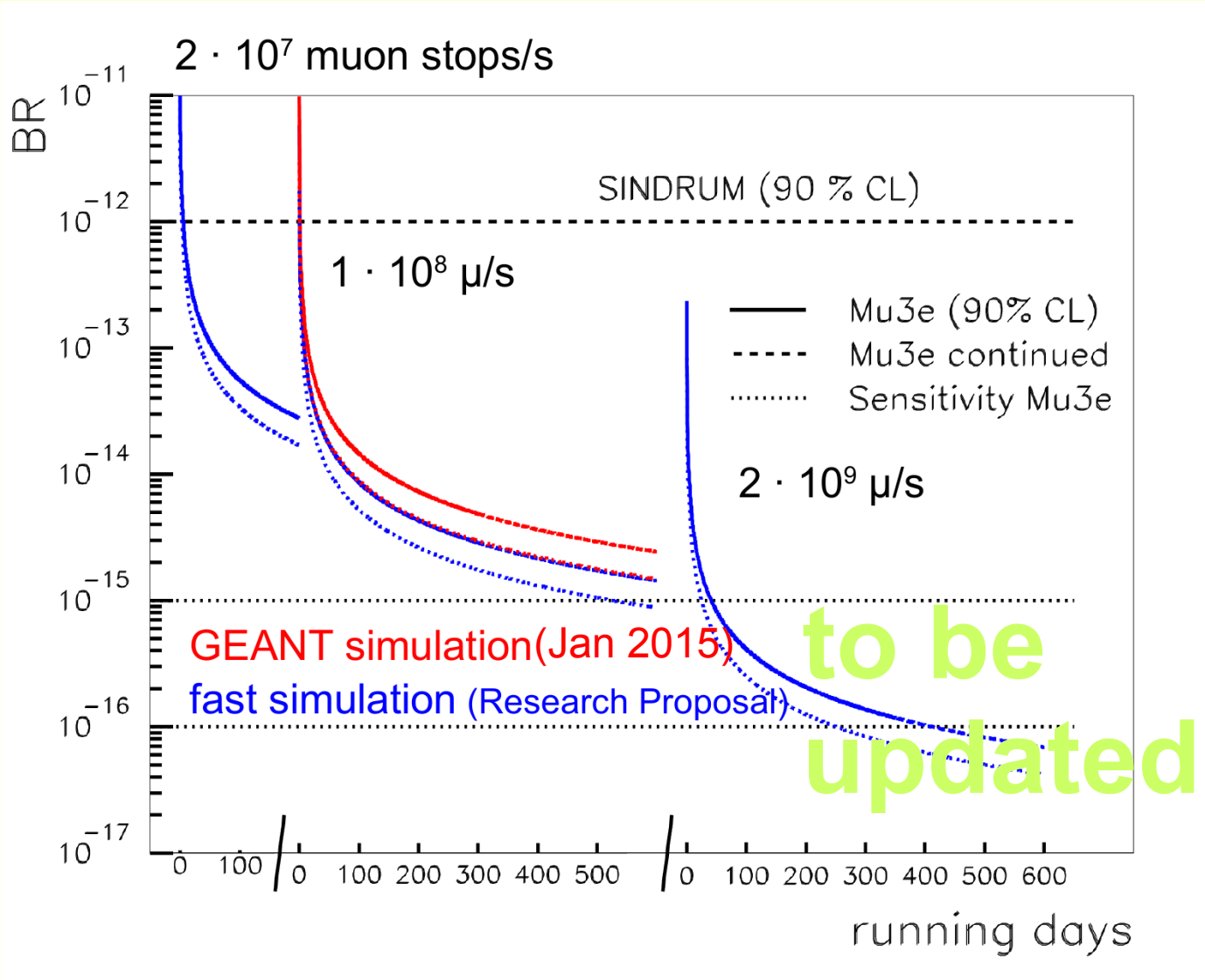
- Develop, produce and test the final small front end board.
- Acquire and test the switching board.
- Run the full selection algorithm on a GPU.
- Integrate the readout chain and the selection algorithms.
- Integrate the farm PCs with the MIDAS DAQ system.
- Scale readout system to full phase I capability.

Detector Integration → Dirk Wiedner



- Detailed CAD drawings of most sub-detectors
- Target region and integration of scintillating fiber detector is most critical because of spatial constraints
- Gaps between barrel modules unavoidable → acceptance reduced
- But no show stoppers so far!

Sensitivity Projection (BVR 46)



- Detailed full simulation studies ongoing → TDR
- Simulation + Reconstruction Software in very good shape in general

Mu3e Costs

estimated: **Item**	**Costs in kCHF**	**Costs in kEUR**
Solenoidal Magnet		1695
Pixel Detector		660
Scintillating Fiber Detector	300	
Scintillating Tile Detector		290
Detector Readout and Filter Farm		550
Slow Control	100	
Infrastructure Area&Experiment	336 (being evaluated)	
Mechanics, Cooling and Target	12	200
Beamline & Infrastructure	2017	
Computing Costs	150	
Data Storage	100	
Sum	**3015**	**3395**

Including 20% contingency and PSI in-kind contributions of about ~1500 kCHF

Mu3e Funding

- MU3E Magnet Großgeräteforschungsantrag (BMBF/DFG): ~950 k€ for (2015)
- Appointment Funds (A.S.): ~750 k€
- Mu3e Magnet (ETH Zurich): 100 kCHF (2014)
- Development of HV-MAPS Pixel Detector for Mu3e (DFG):
  ~450 k€ for Pixel R&D (2015-2017)
- Development of SciFi Tracker and HV-MAPS R&D (SNF): pending
- Young investigator group for N.Berger (DFG Emmy Noether program 2012-2017)

Planned funding applications:

- Research Unit (DFG) for German Mu3e groups:
  ~3000 k€ for construction + operation

BMBF=Federal Ministry of Education and Research
DFG=Deutsche Forschungsgesellschaft
SNF=Swiss National Science Foundation

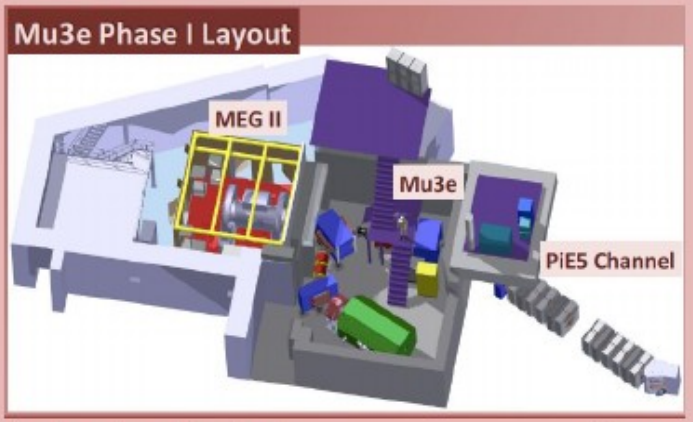
Reviews and Technical Design Report

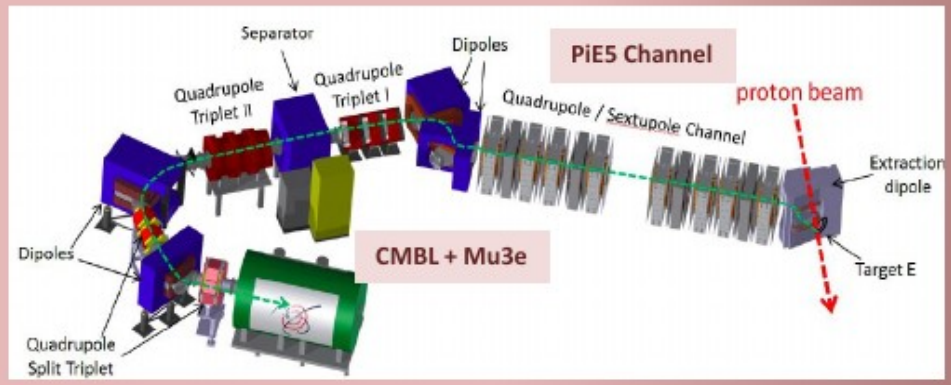
- Prepared ~240 pages Mu3e internal Status Report end of 2015 (→ summary of all Mu3e R&D activities of all areas)
- Plan to prepare TDR after BV47 meeting
- However, HV-MAPS R&D will take until end of 2016 due to delay in Mupix8 submission
- Rest of experiment will be ready for review by spring 2016

- Mu3e Collaboration therefore proposes:
  - ➔ Review of Experiment by June 2016 based on Preliminary TDR
  - ➔ Review of HV-MAPS8 design before submission (June 2016)
  - ➔ Final Mu3e Review including Mupix8 results at BV48 (2017)

Backup

Beam Line Status

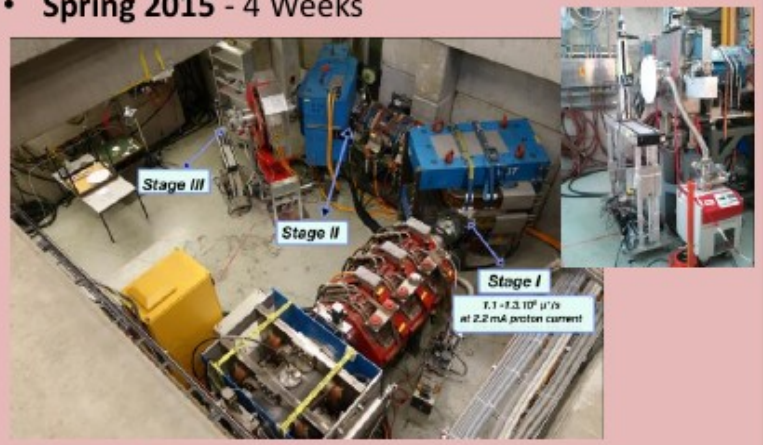




Test Commissioning Periods

(with not all elements optimized)

- **End 2014** – 4 Weeks (reported last Review)
- **Spring 2015** - 4 Weeks



- Staged approach
- "Proof-of-Principle" achieved Dec. 2014
- Reported 10^8 μ^+/s at 2.2 mA at Stage III
- Spring 2015 run showed rates must be modified (found borrowed detector size wrongly specified) -->Rates 70%!

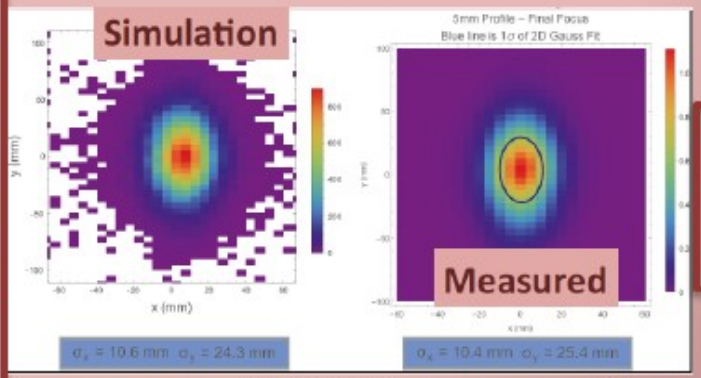
Stage I
R_μ = 1.14·10^8 μ^+/s at 2.2 mA proton Current
σ_x ~ 23 mm, σ_y ~ 15 mm
e^+/μ^+ ratio = 7/1 (Wien-filter OFF)
μ-e Separation = 5.7 σ_μ 85 mm peak-to-peak (Wien-filter ON)

Stage III
R_μ = 7•10^7 μ^+/s at 2.2 mA proton Current
σ_x ~ 10.4 mm, σ_y ~ 25.4 mm

Comparison of Measurement & Simulation

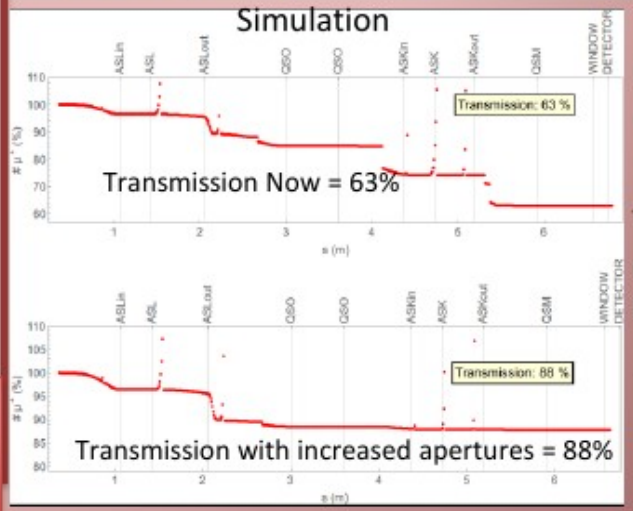
Very good agreement achieved: measured transmission 61% simulated 63% with current non-optimal apertures

from simulation Improvements Possible



Widening of vacuum chamber apertures & dipole gaps ASL41, ASK41 Results in Transmission Factor 88% giving an expected

Stage III Rate of 1·10^8 μ^+/s at 2.2mA



Currently expected Stopping Rate
(predominantly determined by inner Si-detector & target size -> compromise between: occupancy, granularity & n° Channels)

Target size 19 mm radius -> 41% beam lost on entry to inner beam-pipe

Expected Stopping Rate 5·10^7 μ^+/s at 2.2mA

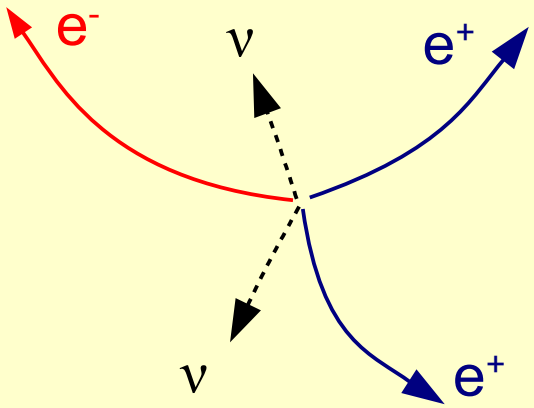
-> optimization of central detector beam region & further transmission improvements under study

To be tested in 2016 with a 6-week Requested beam time in PiE5

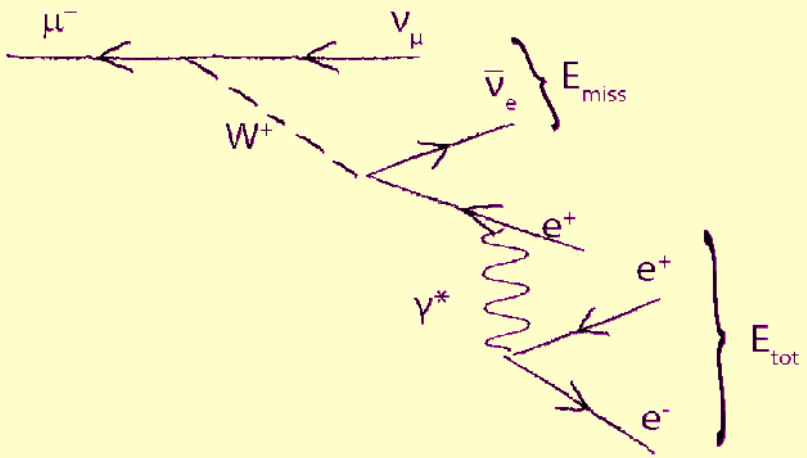
P.-R. Kettle

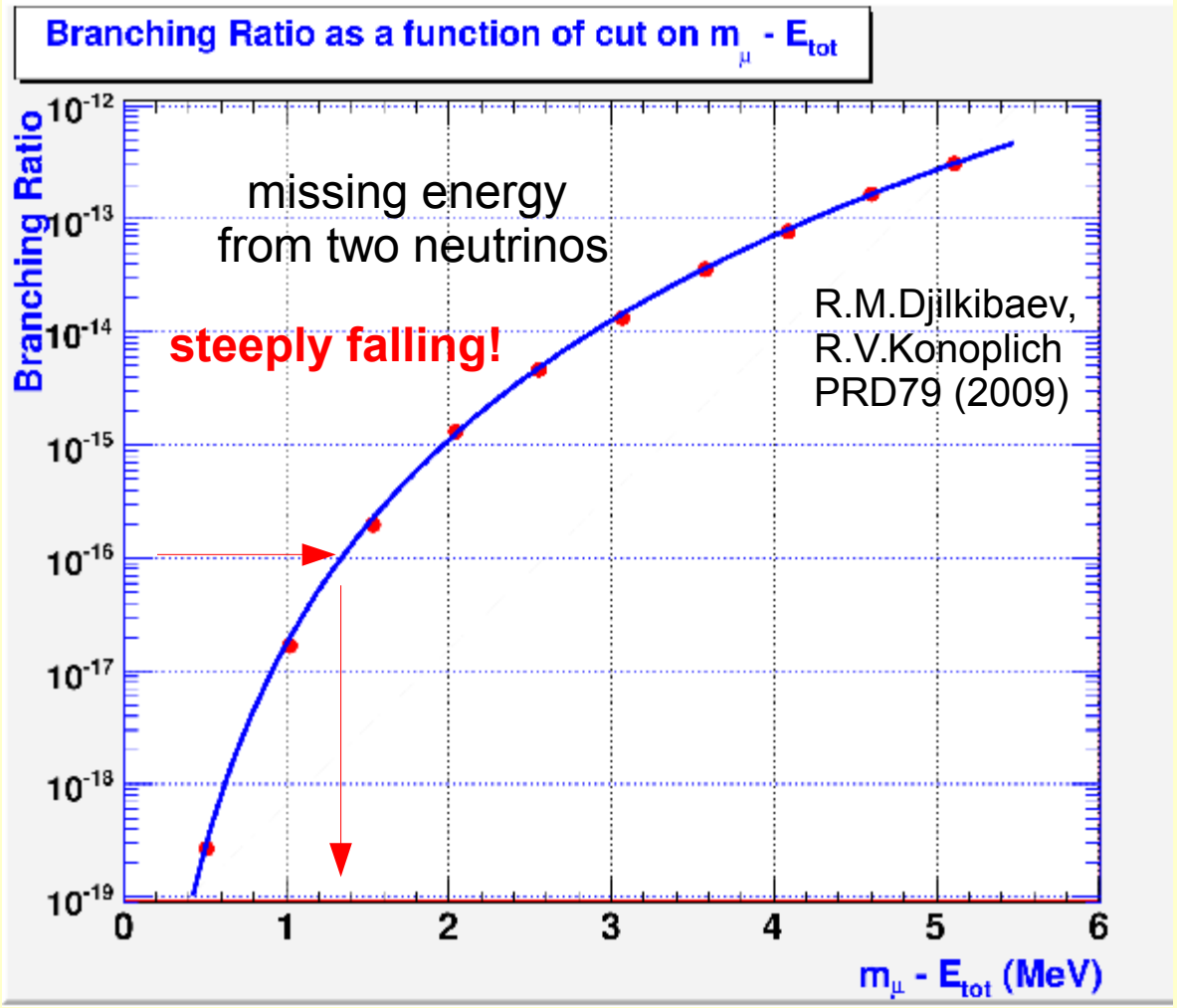
Backgrounds

Irreducible BG: radiative decay with internal conversion



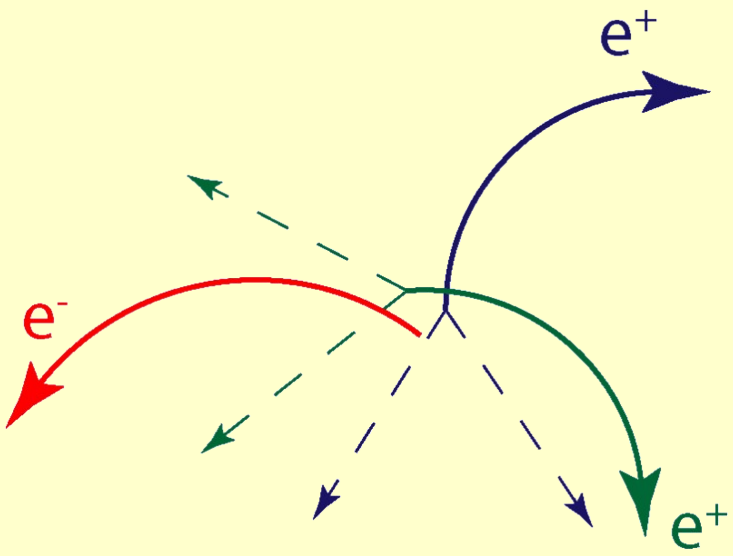
$Br(\mu^+ \rightarrow e^+e^+e^- \nu\nu) = 3.4 \cdot 10^{-5}$

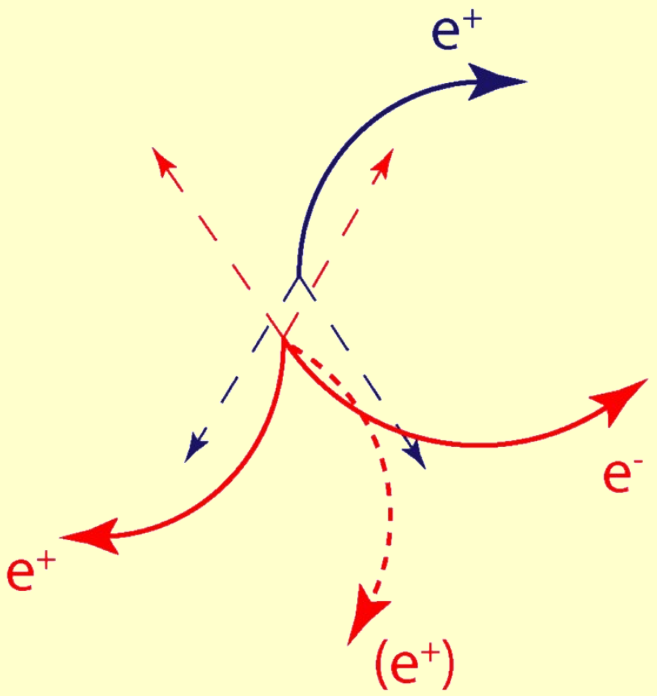




Accidental Backgrounds

- **Overlays** of two ordinary **μ^+ decays** with a (fake) **electron (e^-)**
- Electrons from: **Bhabha** scattering, photon conversion, mis-reconstruction





Need excellent:

- **Vertex resolution**
- **Timing resolution**
- **Kinematic reconstruction**