The MUSE experiment

Technical Overview

Guy Ron (for the MUSE collaboration)
Hebrew University of Jerusalem

MUSE is not your garden variety scattering experiment

Low beam flux

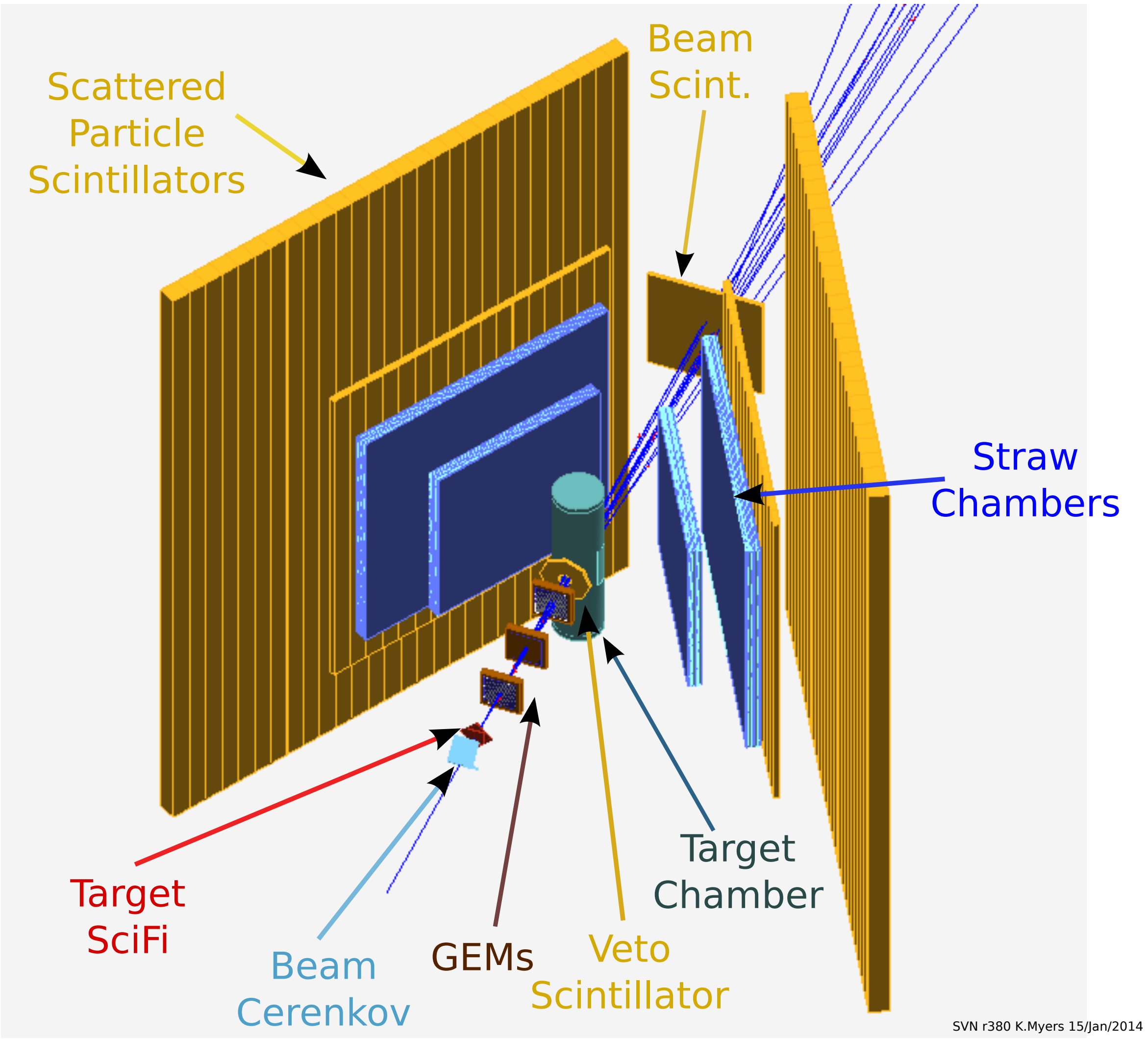
- Large angle, non-magnetic detectors.

Secondary beam (large emittance)

- Tracking of beam particles to target.

Mixed beam

- Identification of beam particle in trigger.



Experiment Overview

PSI πM1 channel

≈115, 153, 210 MeV/c mixed beams of $e^{\pm}$, $\mu^{\pm}$ and $\pi^{\pm}$

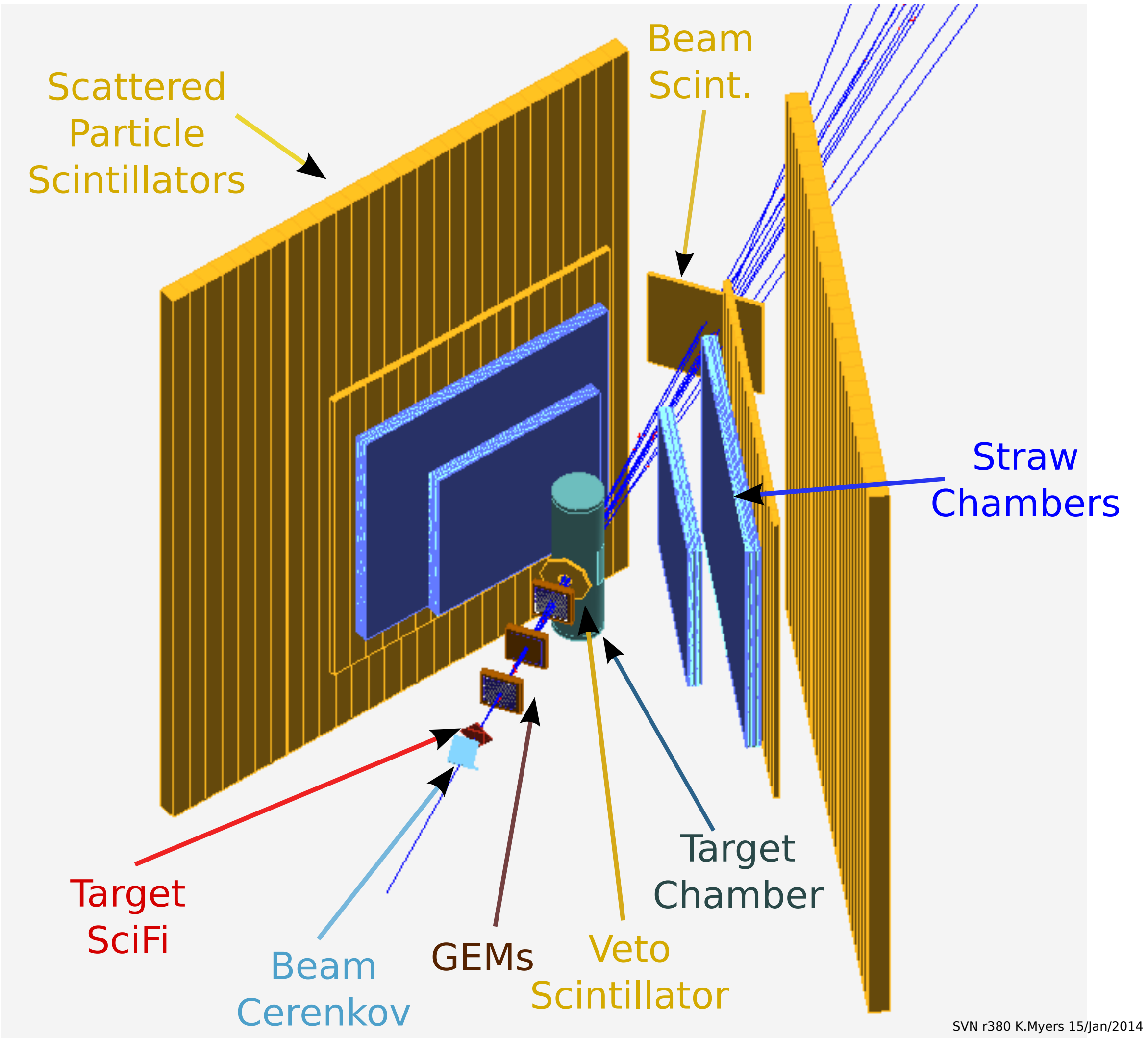
$\theta \approx 20^{o} - 100^{o}$

$Q^2 \approx 0.002 - 0.07$ GeV^2

About 5 MHz total beam flux, ≈2-15% μ's, 10-98% e's, 0-80% π's

Beam monitored with SciFi, beam Cerenkov, GEMs

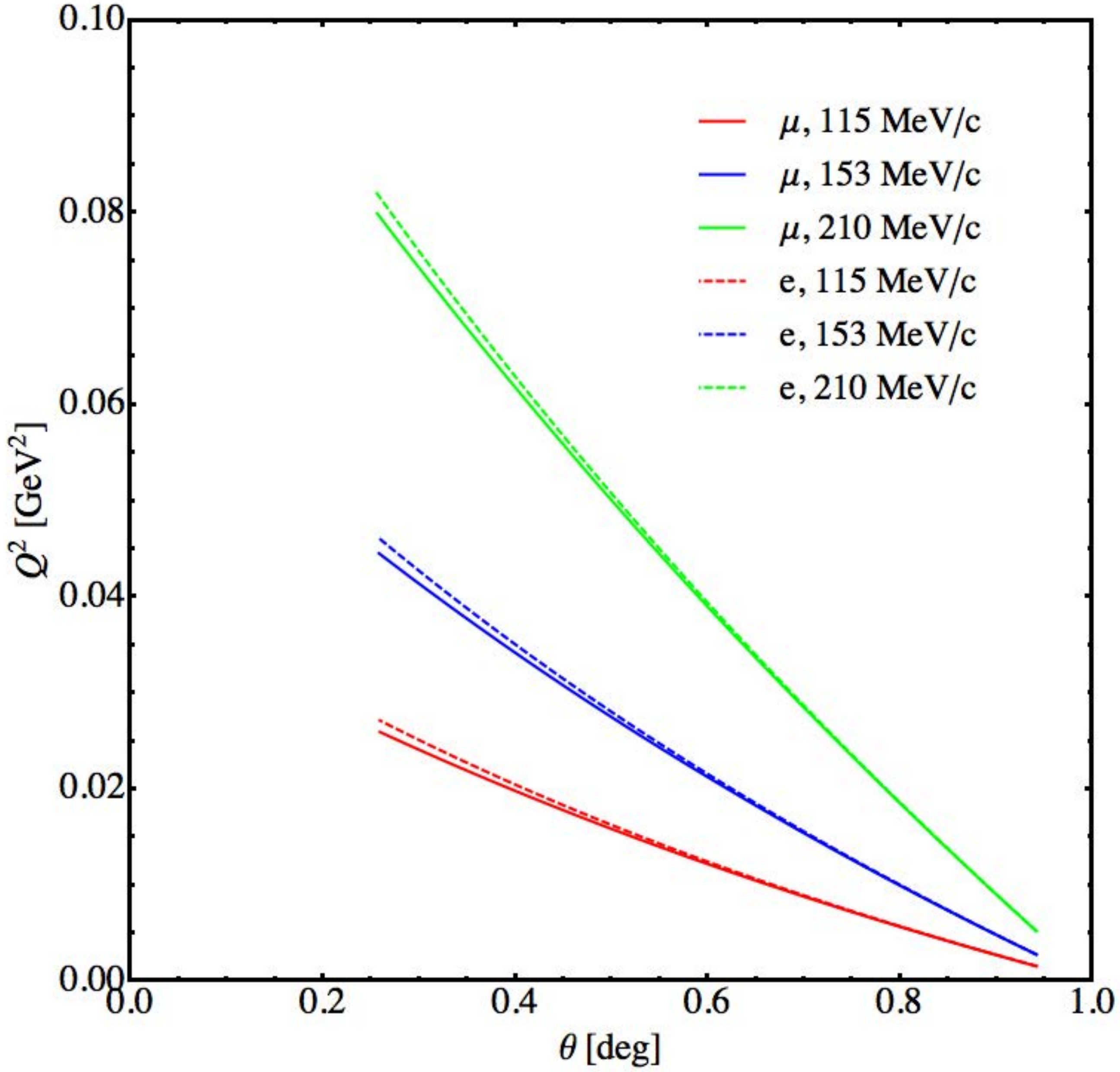
Scattered particles detected with straw chambers and scintillators

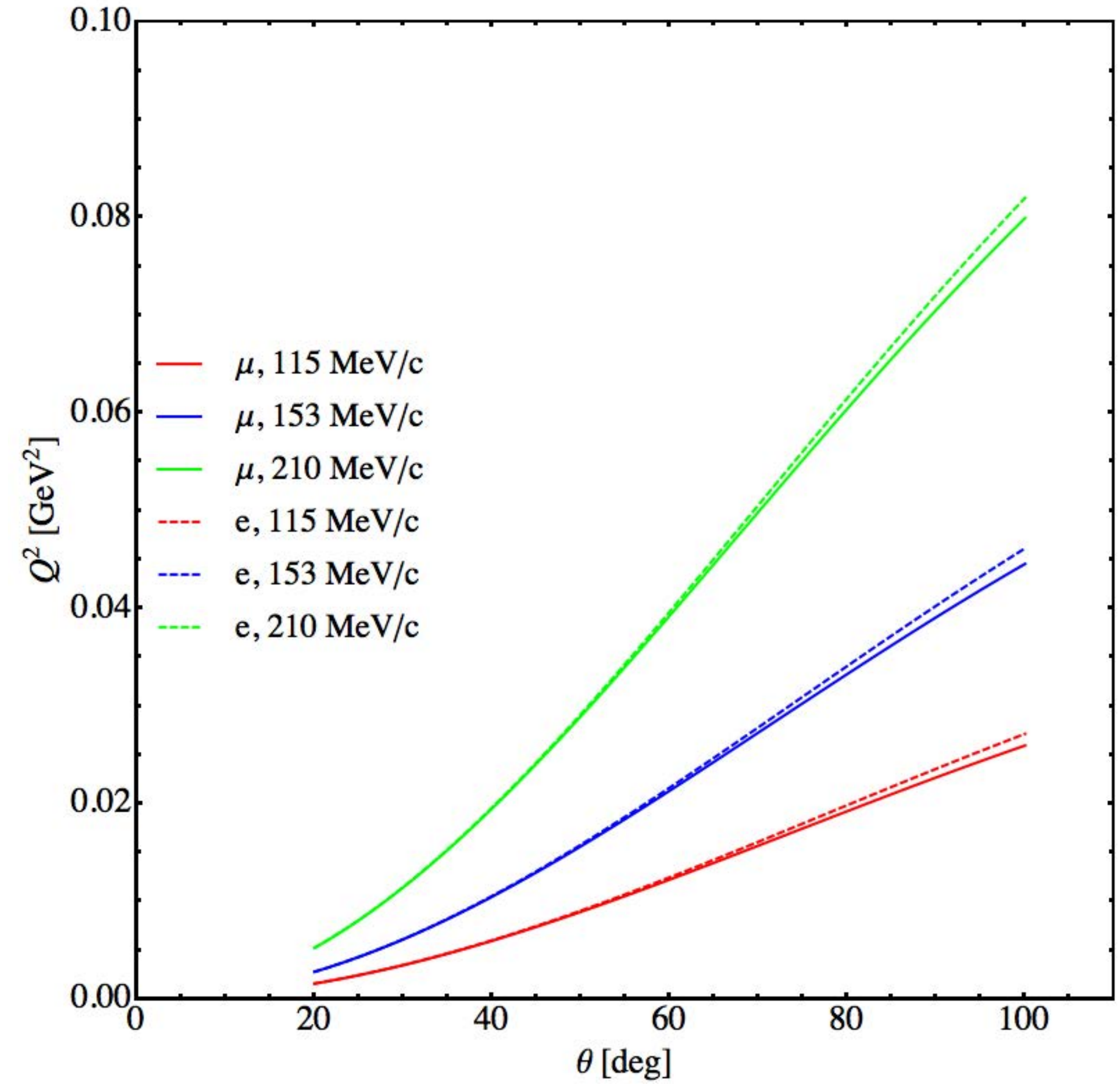


Not run like a normal cross section experiment - 7-8 orders of magnitude lower luminosity.

But there are some benefits: count every beam particle, no beam heating of target, low rates in detectors, ...

Experiment Overview





$\theta \approx 20^o - 100^o$

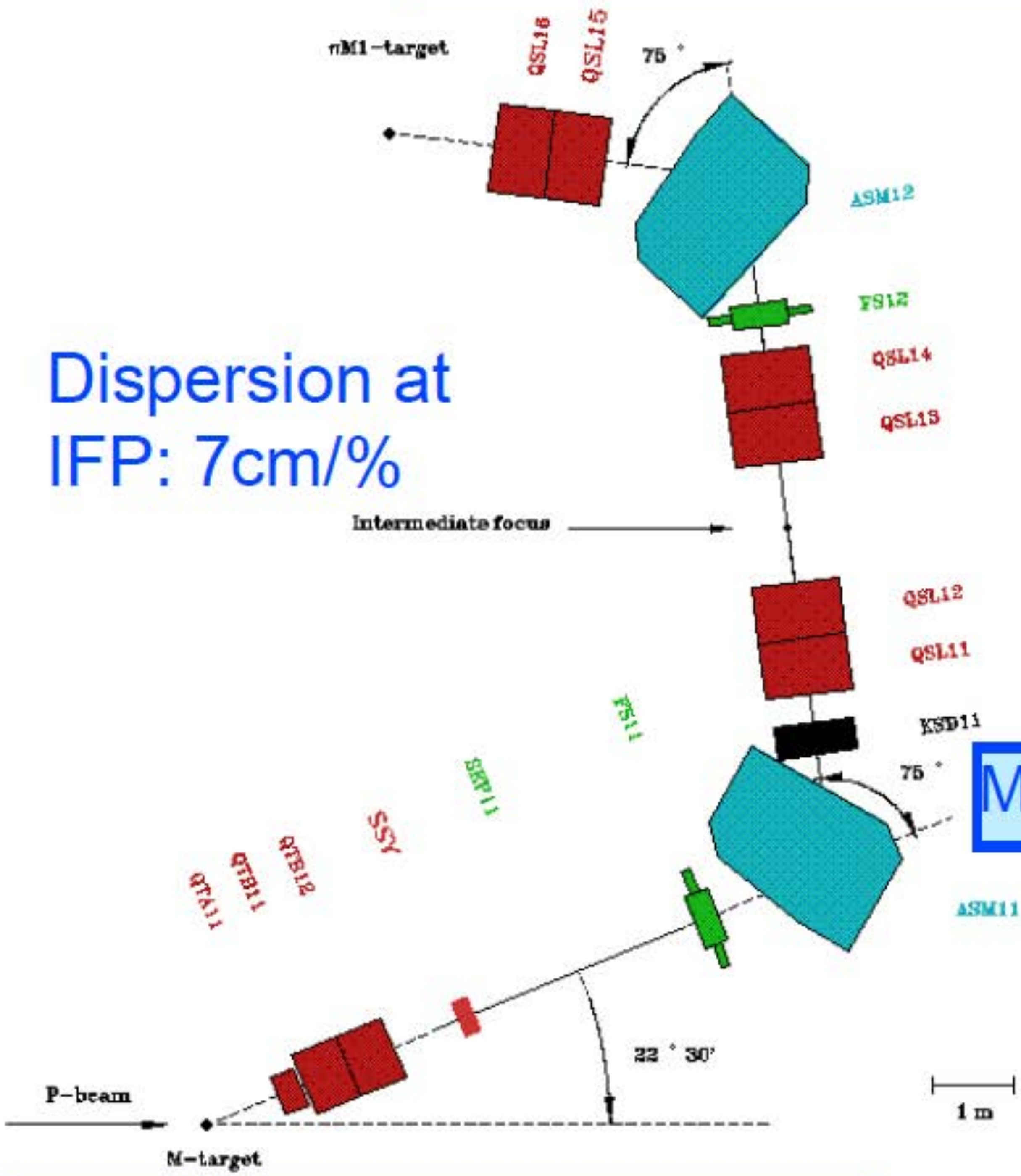
$Q^2 \approx 0.0015 - 0.08$ GeV^2

$\varepsilon \approx 0.256 - 0.94$

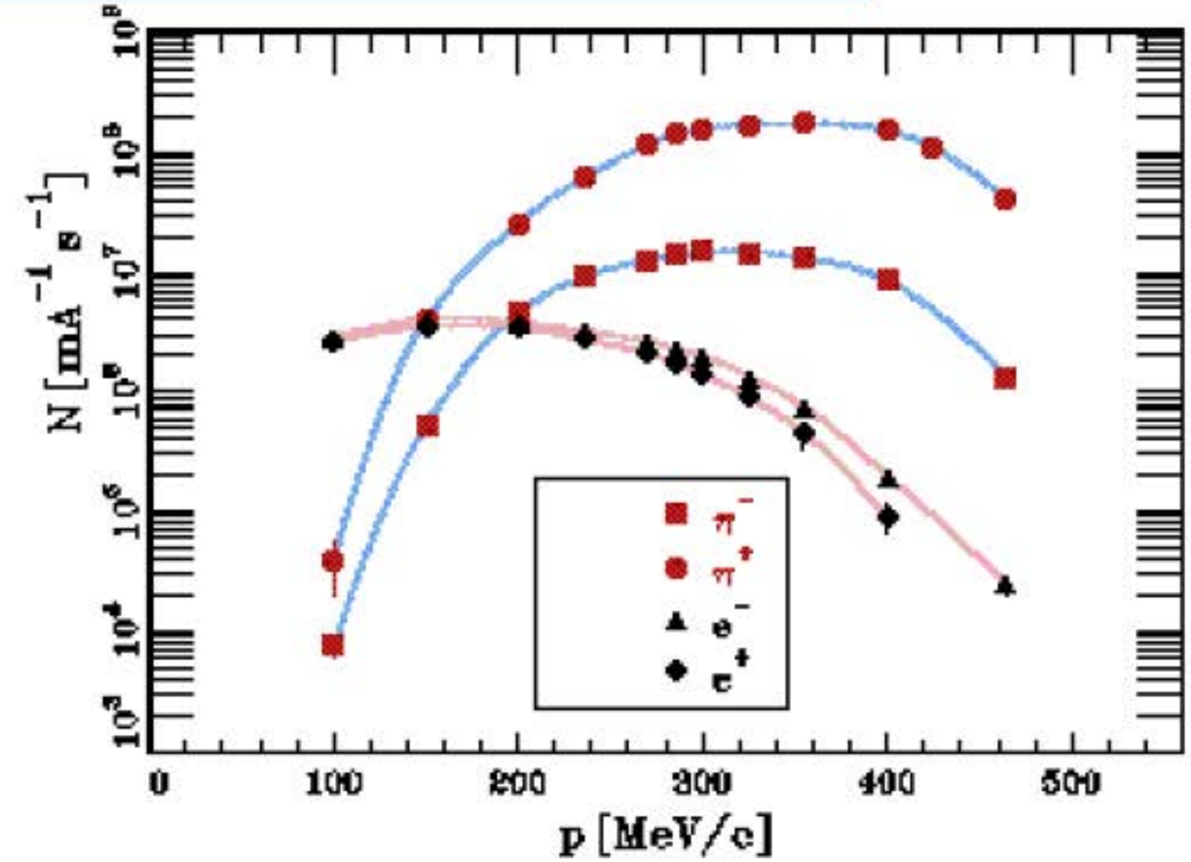
Essentially same coverage for all beam particles.

PSI πM1 Channel Characteristics

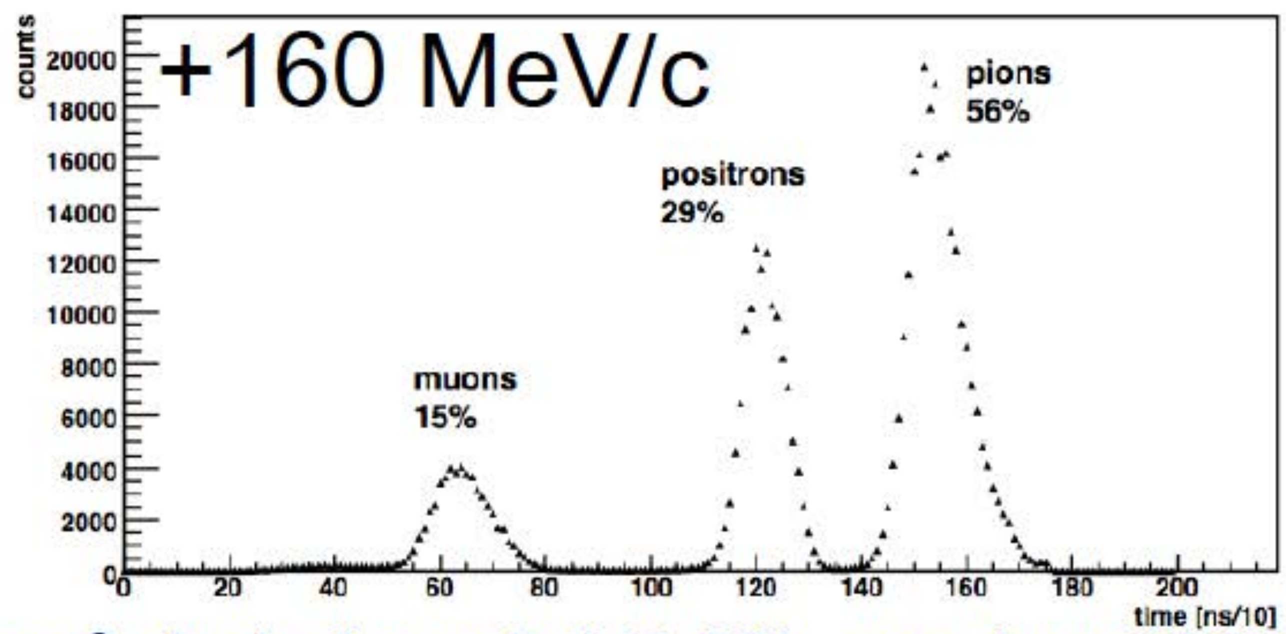
≈100 - 500 MeV/c mixed beam of μ's + e's + π's



Dispersion at IFP: 7cm/%



Momentum acceptance: 3% resolution: 0.1%



Beam spot (nominal): 1.5 cm X x 1 cm Y, 35 mr X' x 75 mr Y'

Spots from 0.7x0.9 cm^2 up to 16x10 cm^2, Δp/p from 0.1-3.0%, used previously.

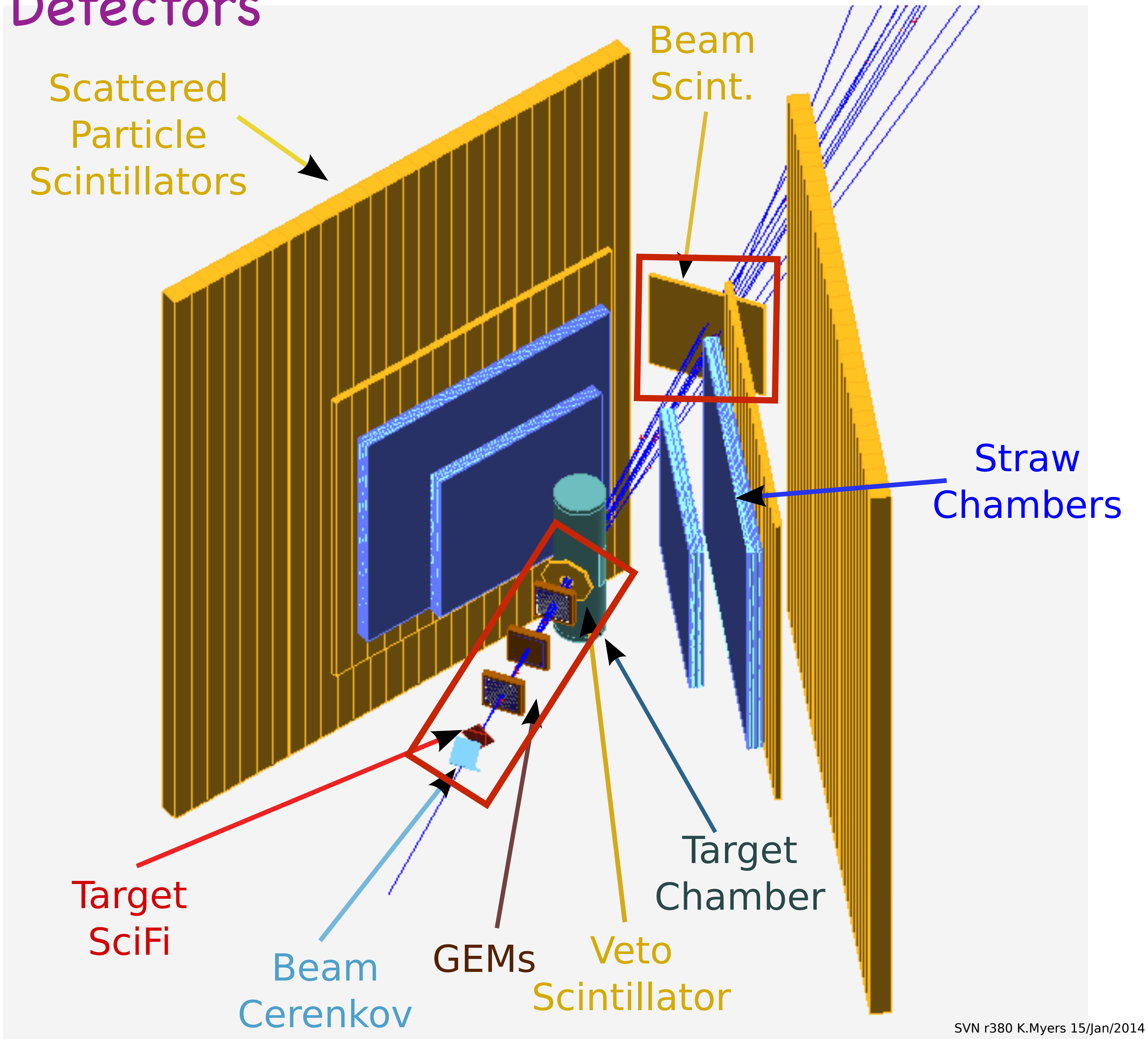
MUSE Design Choices

- Minimal R&D.
- Use existing designs as much as possible.
- Reuse equipment whenever possible.
- Maximal cost reduction.
- Modular construction (can run dress rehearsal with fewer components).

Performance Requirements

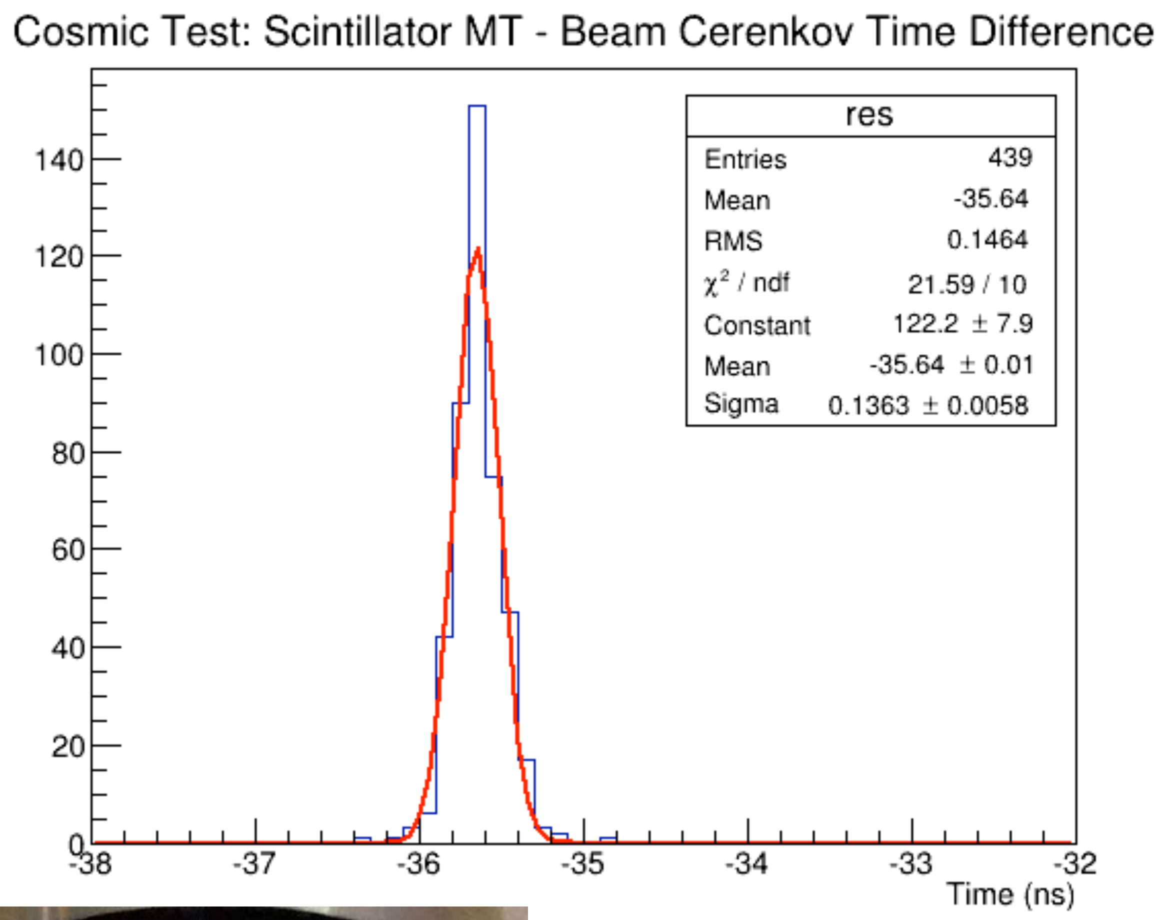
- Angle reconstruction to few mr (limited by multiple scattering).
- Reduce multiple scattering as much as possible.
- Mostly timing used for PID - O(50ps) time resolution.
- 99% or better online π rejection.

Beamline Detectors

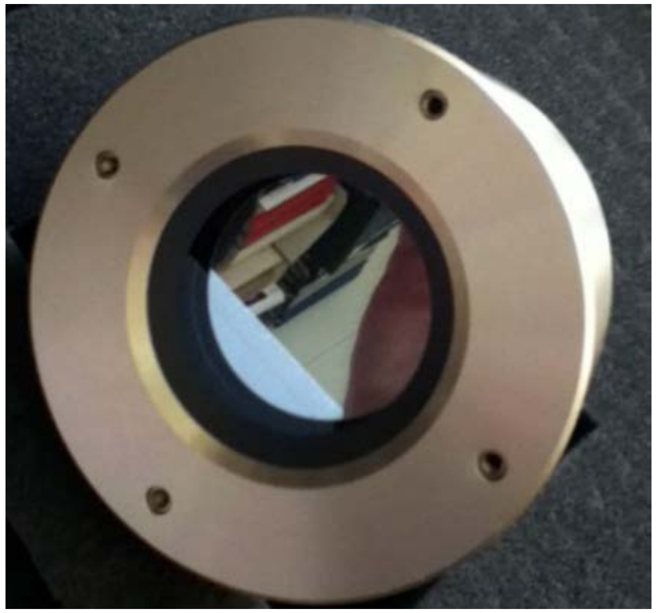


Detectors - beam Cerenkov

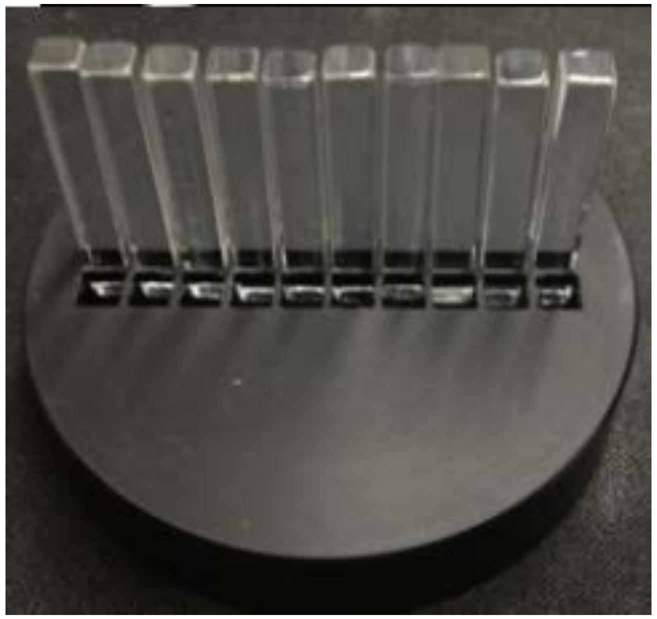
- Improve timing at target.
- Muon decay event rejection.
- 140ps achieved with cosmics (~110ps from geometrical).
- Estimate 25-50ps resolution can be reached.
- Crystals placed at Cernekov angle -> better timing from prompt photons.
- Fast MCP-PMT photon detection.
- Likely to use Sapphire/Plastic.

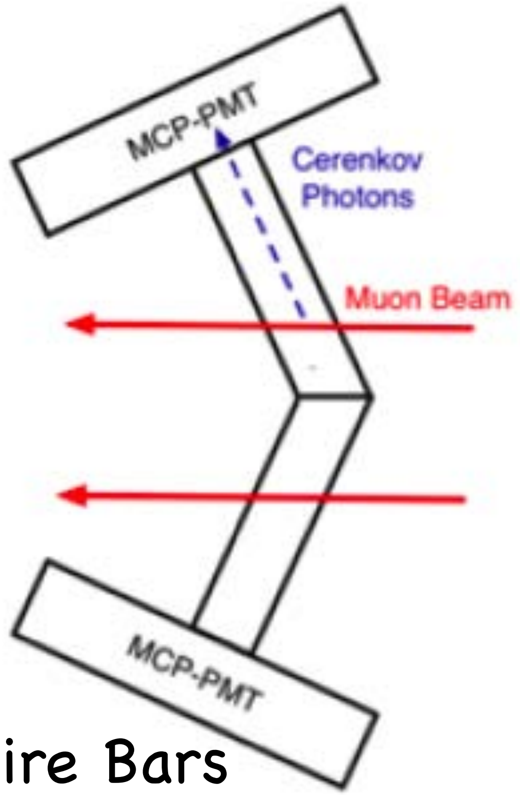


MCP-PMT



Quartz Bars

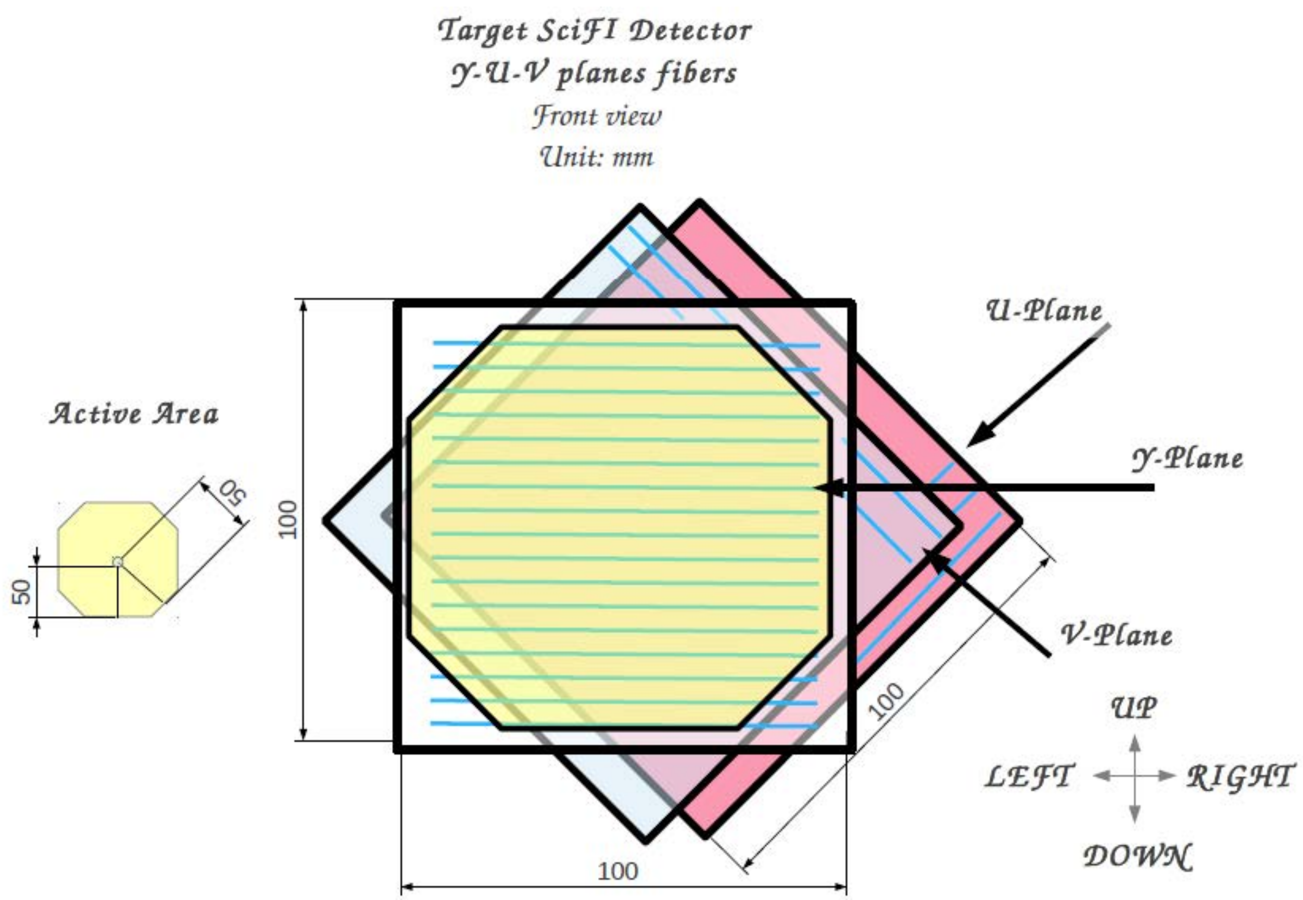




Sapphire Bars

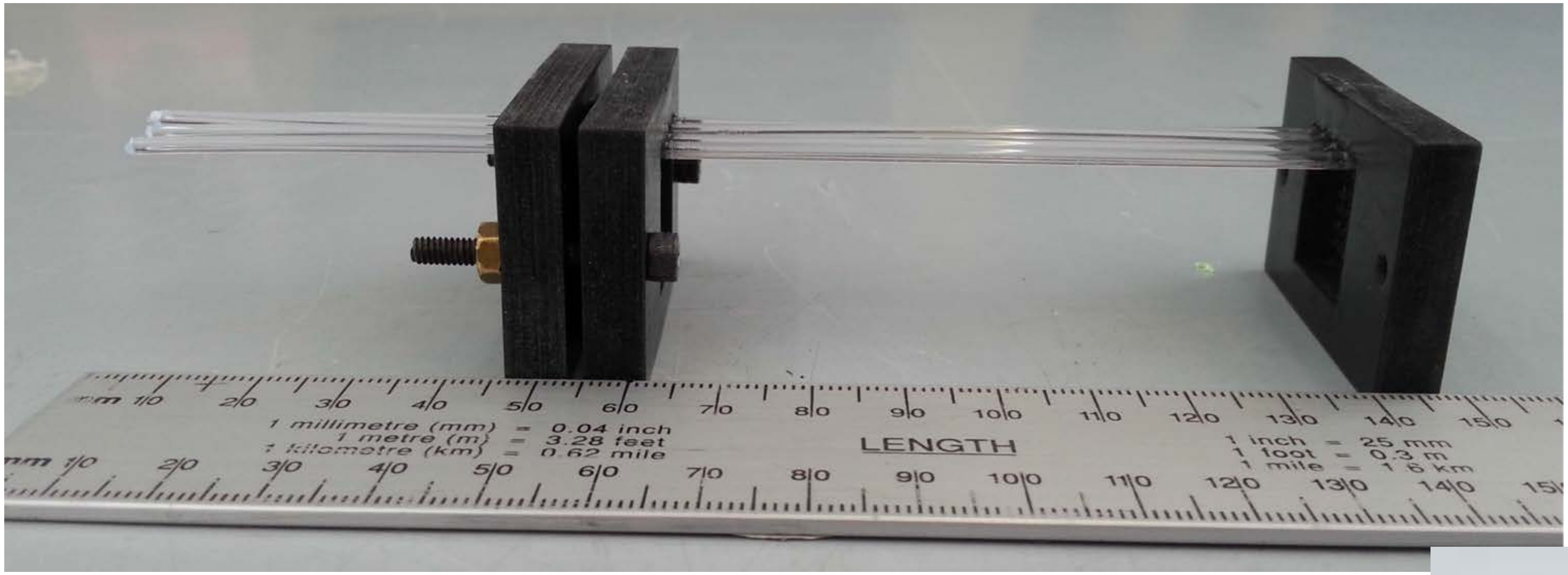
Detectors - SciFis

- One scintillating fiber array near target
- Precise timing at target, less precise than Cerenkov, but with higher segmentation and rate capability
- RF to target TOF for beam PID
- Provide GEM trigger, spatial info for multi-hit / multi-track selection, to identify triggering track
- 3 SciFi planes + walk correction gives ~300ps timing resolution.



- YUV plane arrangement
- 40 2mm circular fibers / plane
- Double sided readout with maPMT
- Multiplexed to reduce channel cross-talk

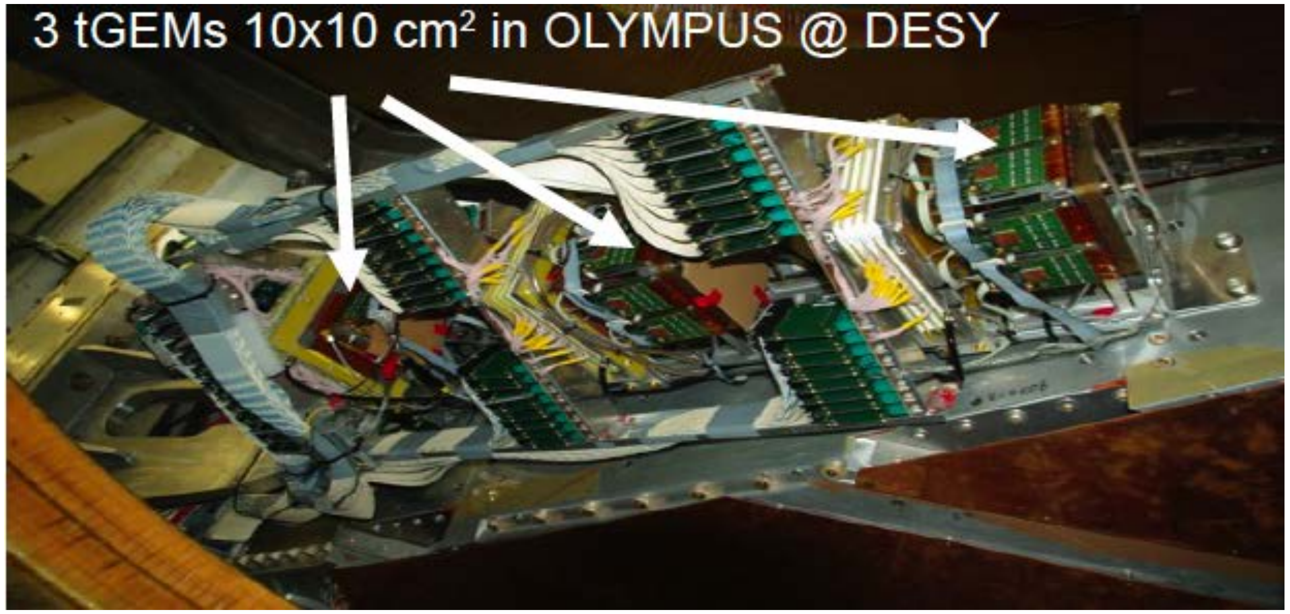
Detectors - SciFis

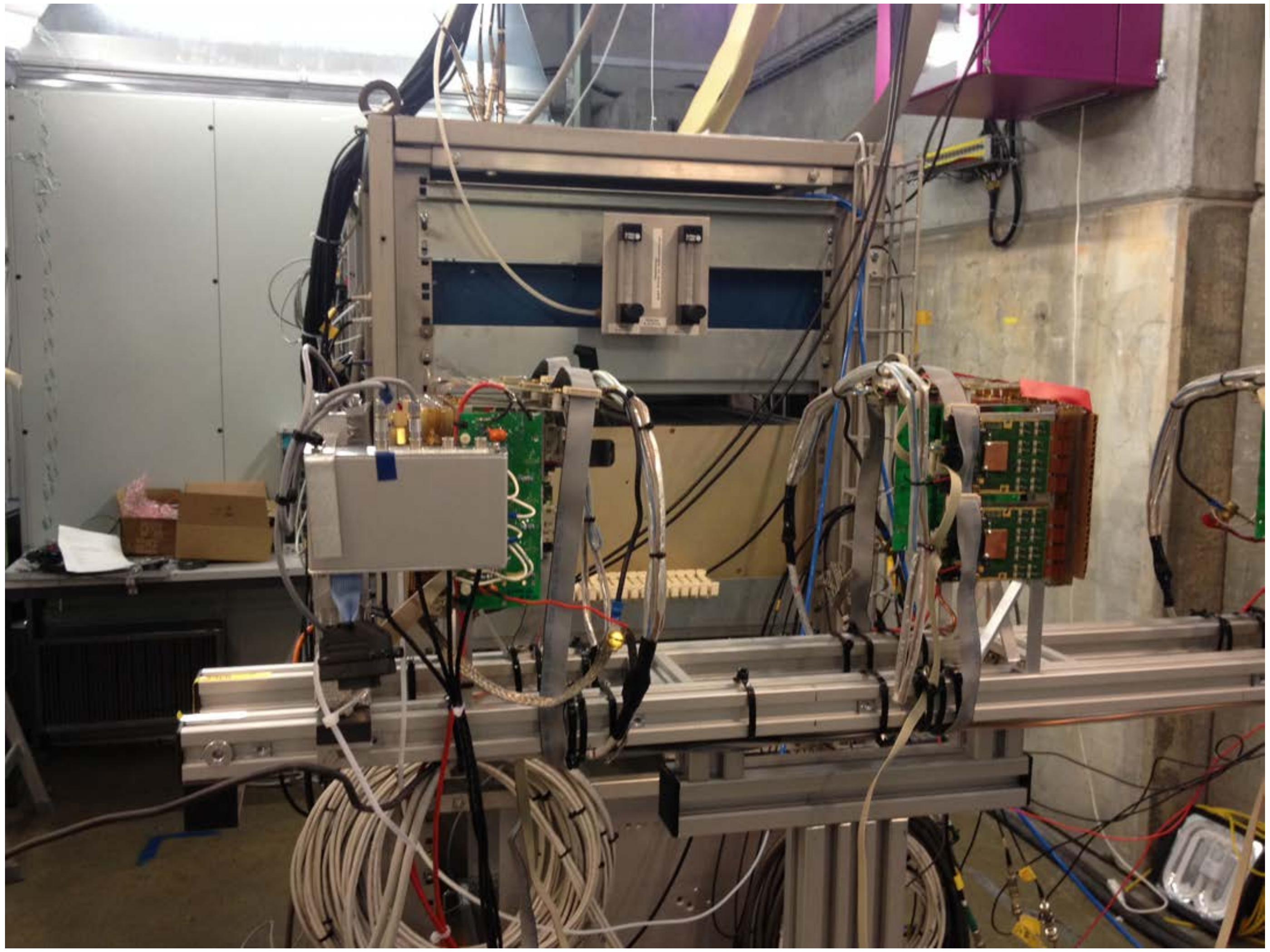


Prototyping at Tel Aviv

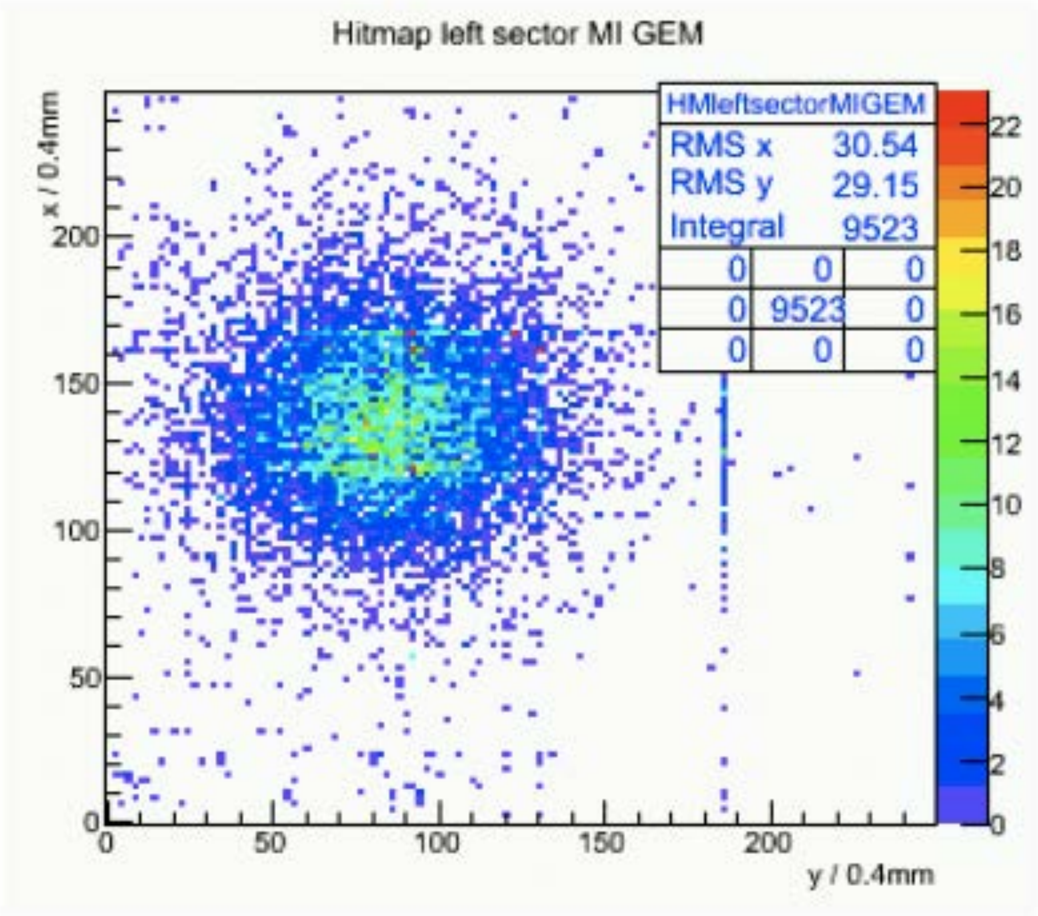
Detectors - GEMs

- Determine trajectory for scattering angle and Q^2.
- 70um Spatial resolution.
- Third GEM rejects ghost tracks.
- Existing detector repurposed from OLYMPUS experiment @ DESY.





GEMs installed @PSI



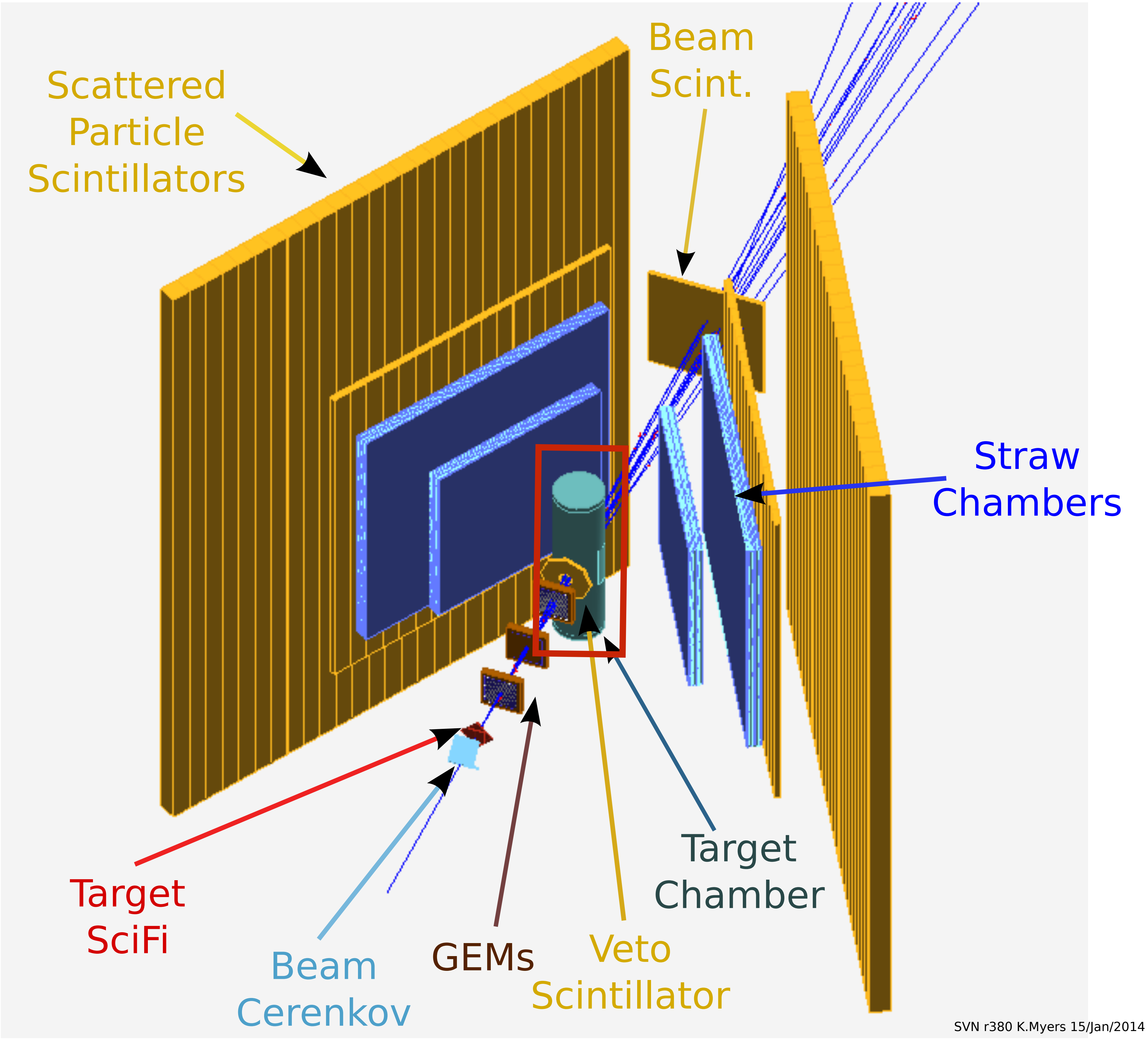
Detectors - Veto

- 8 Segment annular detector around target entrance window.
- Discriminate against muon decay events.

Detectors - Beam line Scintillators

- Beam flux normalization.
- Veto to remove Møller electrons.

Target


Scattered
Particle
Scintillators
Beam
Scint.
Straw
Chambers
Target
Chamber
Target
SciFi
Beam
Cerenkov
GEMs
Veto
Scintillator
SVN r380 K.Myers 15/Jan/2014

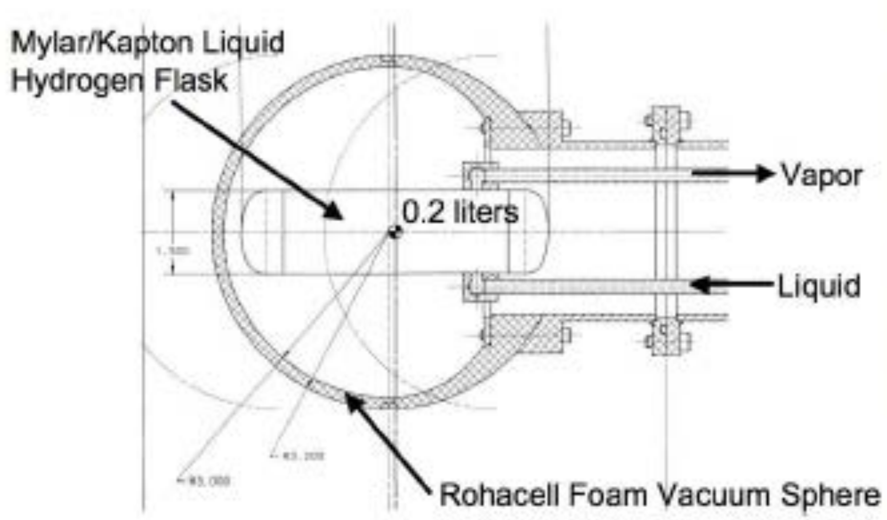
Target

LH$_2$ target cell

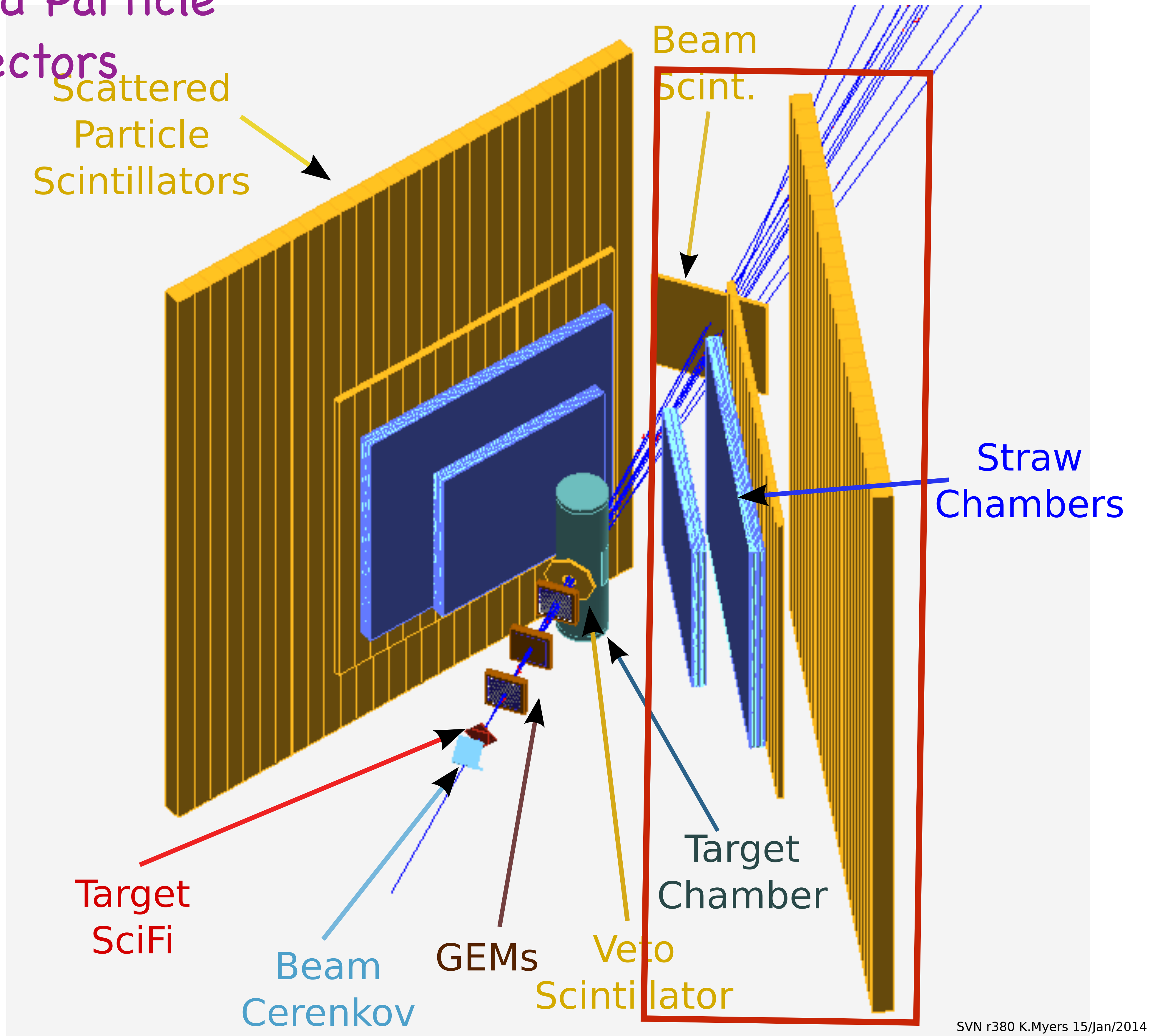
- Thin windows to limit backgrounds
- Small enough to limit multiple scattering
- Big enough so all but tails of beam go through cryogen, not side walls.
- Current plan - 4 cm wide x 8 cm high x 4 cm long.

Low power system

- LN$_2$ baffles reduce heating.
- Snow prevention using baffles + extra space.

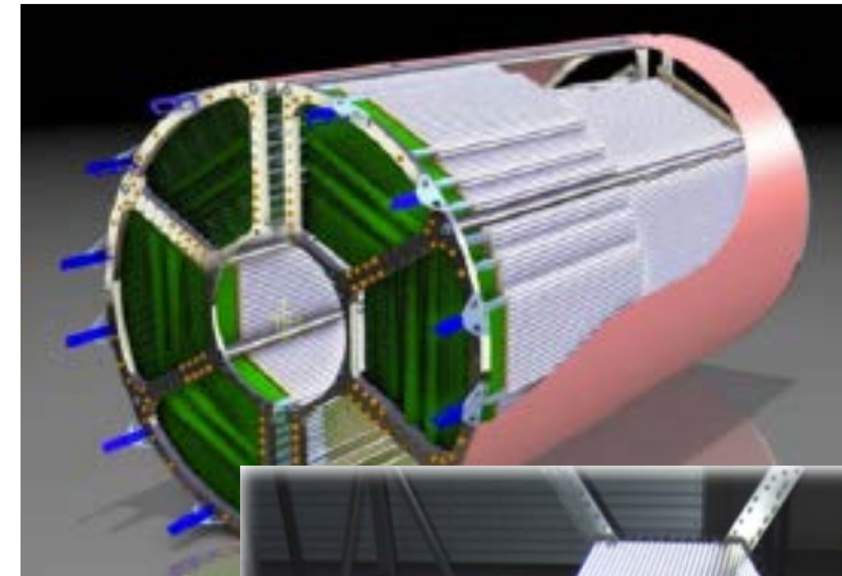


Scattered Particle Detectors

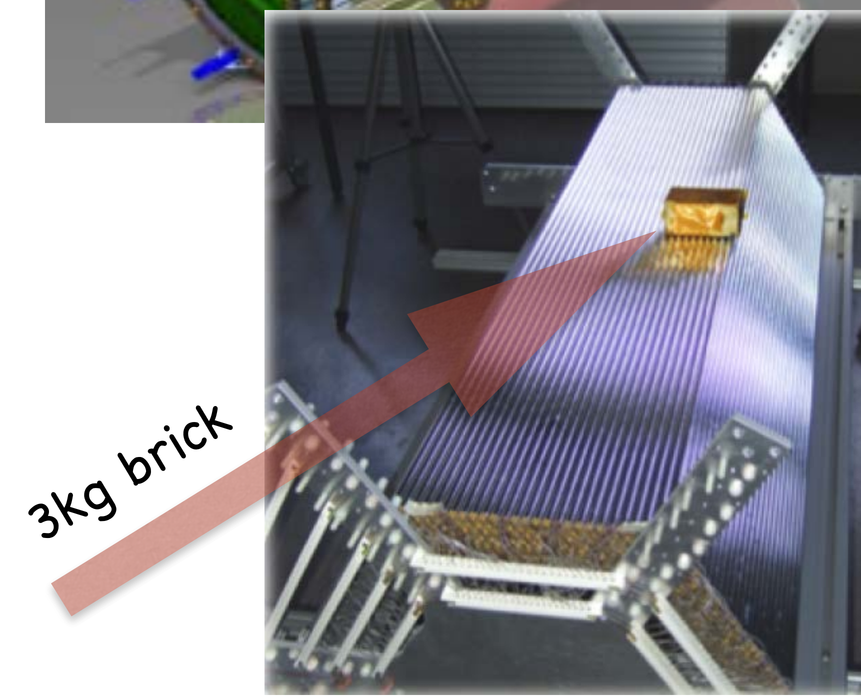


Straw Tube Tracker

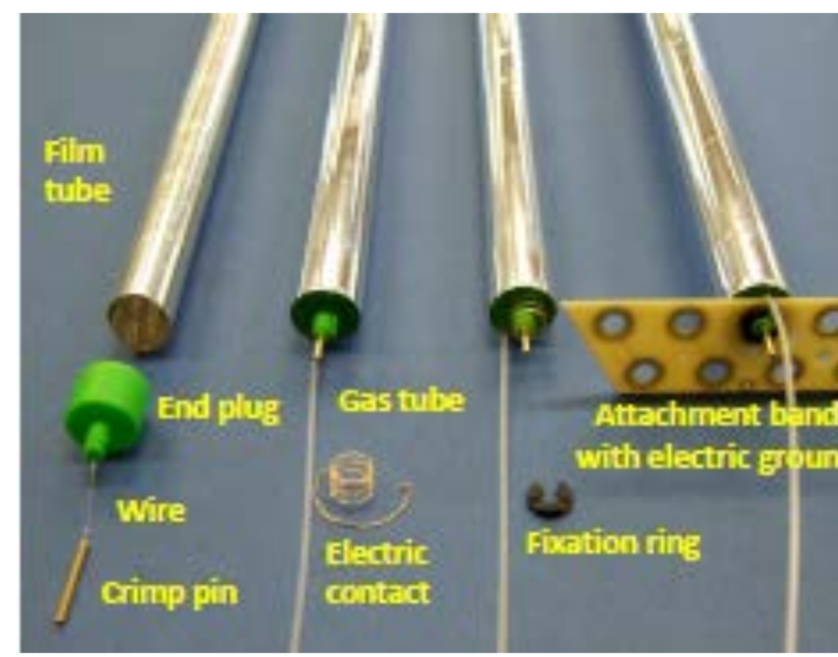
PANDA STT



- Based on ~1.5m long straws (1cm diameter).
- Close packed straws, w/ minimal gaps.
- ~30um thick straws -> low material budget.
- Mechanical stability provided by over-pressuring straws to ~2bar - allows significantly lower material budget.



Element	Material	X[mm]	X_0 [cm]	X/X_0
Film Tube	Mylar, 27 μm	0.085	28.7	3.0×10^{-4}
Coating	Al, $2\times0.03\,\mu$m	2×10^{-4}	8.9	2.2×10^{-6}
Gas	$Ar/CO_2(10\,\%)$	7.85	6131	1.3×10^{-4}
Wire	W/Re, 20 μm	3×10^{-5}	0.35	8.6×10^{-6}
			$\sum_{straw}$	4.4×10^{-4}



Gas Mixture

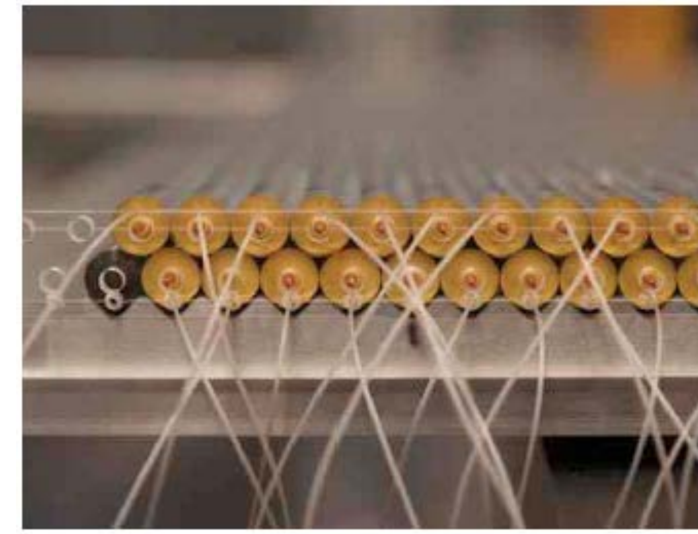
Table 2.2: Properties of different gases and gas mixtures. Z and A are charge and atomic weight, for molecules the total number has to be taken, N_p and N_t are the number of primary and total electrons per cm, respectively, E_x and E_i are the excitation and ionization energy, respectively, W_i is the average energy required to produce one electron-ion pair in the gas, $(dE/dx)_{mip}$ is the most probable energy-loss by a minimum ionizing particle and X_0 is the radiation length. For gas mixtures, the weighted average value has been taken.

Gas or gas mixture	Z	A	E_x [eV]	E_i [eV]	W_i [eV]	dE/dx [keV/cm]	N_p [cm^{-1}]	N_t [cm^{-1}]	X_0 [m]
He	2	4	19.8	24.5	41	0.32	4.2	8	5299
Ar	18	40	11.6	15.7	26	2.44	23	94	110
CO_2	22	44	5.2	13.7	33	3.01	35.5	91	183
i–C_4H_{10}	34	58	6.5	10.6	23	5.93	84	195	169
Ar+10% CO_2	-	-	-	-	26.7	2.5	24.6	93	117
He+10% i–C_4H_{10}	-	-	-	-	39.2	0.88	12.7	26.7	1313
He+20% i–C_4H_{10}	-	-	-	-	37.4	1.44	20.6	45.4	749

- Ar (90%)/CO2(10%) mixture selected - achieves design goals.
- Non toxic/non flammable - easy to deal with.
- Achieved ~150um resolution and better than 8kHz/cm.

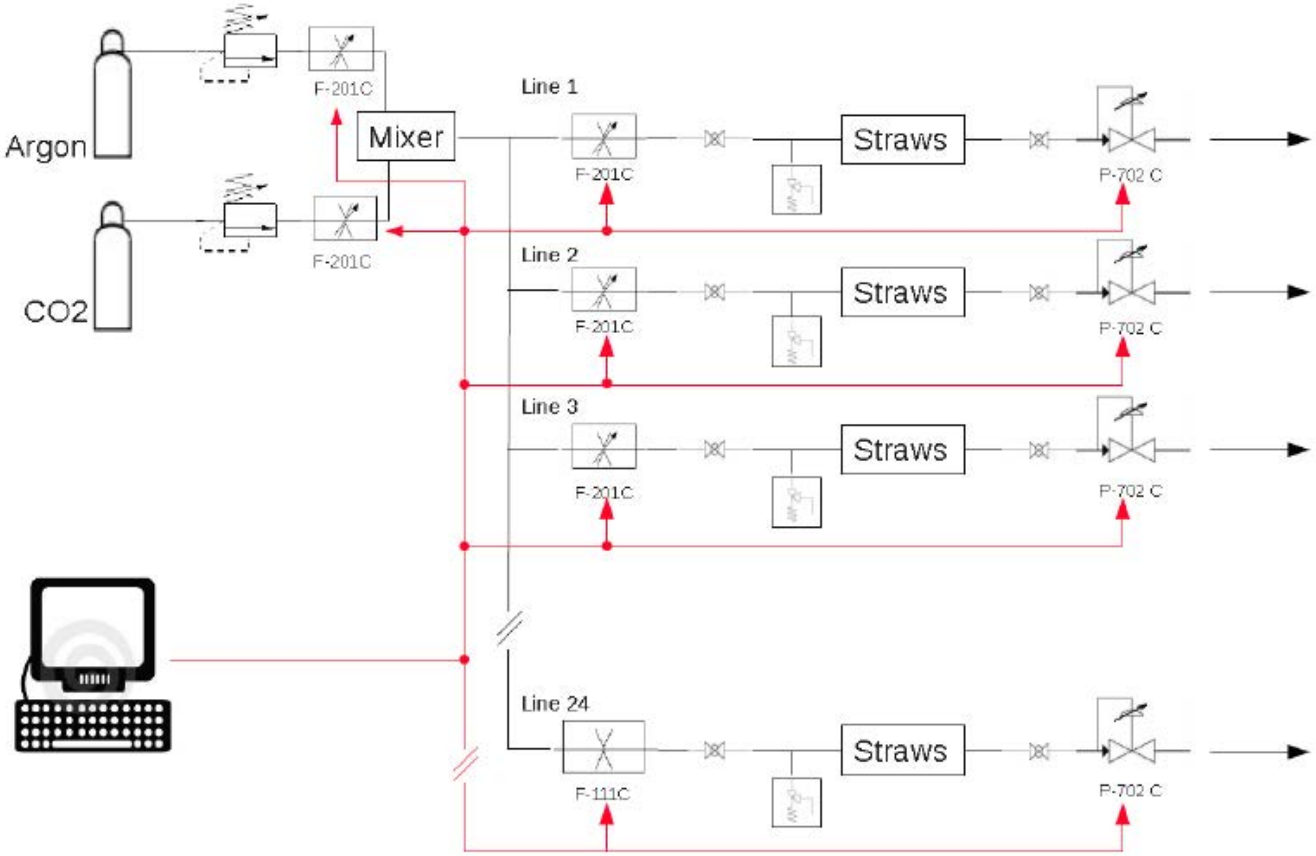
Construction Procedure

- Wires:
  - Straws cut to length.
  - End caps glued and 1 wire end crimped.
  - 12h glue hardening.
  - Wire stretched w/ 50g weight and pressure raised (2bar).
  - 2nd wire end crimped.
- Straw planes:
  - Straws placed on jig.
  - Each monolayer glued @ predefined points.
  - Additional layers stacked on first layer.
  - Final arrangement clamped in place.
- Procedure designed to allow straws/wires to be positioned at the 25um level.



Gas distribution

- Mixture/Pressure controlled by pressure controllers/gas flow controllers from Bronkhorst inc.
- Gas distribution to individual chambers from single mixing chamber.



MUSE Electronics

- Straws provide low charge signal, suitable for discrimination with front end PADIWA board.
- MUSE will use the standard PADIWA->TRB3 setup that is planned for all timing detectors.
- HV distribution / readout card for the straw chambers will be designed and prototyped @ HUJI e-shop.

MUSE Design

- The tracker design has been modified to accommodate the MUSE requirements.
- Design calls for 2 chambers on each side of the detector.
- 5X/5Y planes per chamber.
- X-planes likely closer to target to allow for better resolution in scattering angle.
- ~3000 straws total.

TABLE VII. Wire chamber parameters including the distance from the pivot, chamber active area and the number of wires.

Chamber	Distance (cm)	Active Area (cm^2)	Number of Straws per chamber
Front	30	60×55	575
Back	45	90×80	850

Scintillators

Scintillator Overview

- Produced by USC based on design for CLAS12 upgrade.
- State-of-the-art production lab @ USC already set up.
- Expect at least 6 bars/week production rate once design is finalized.

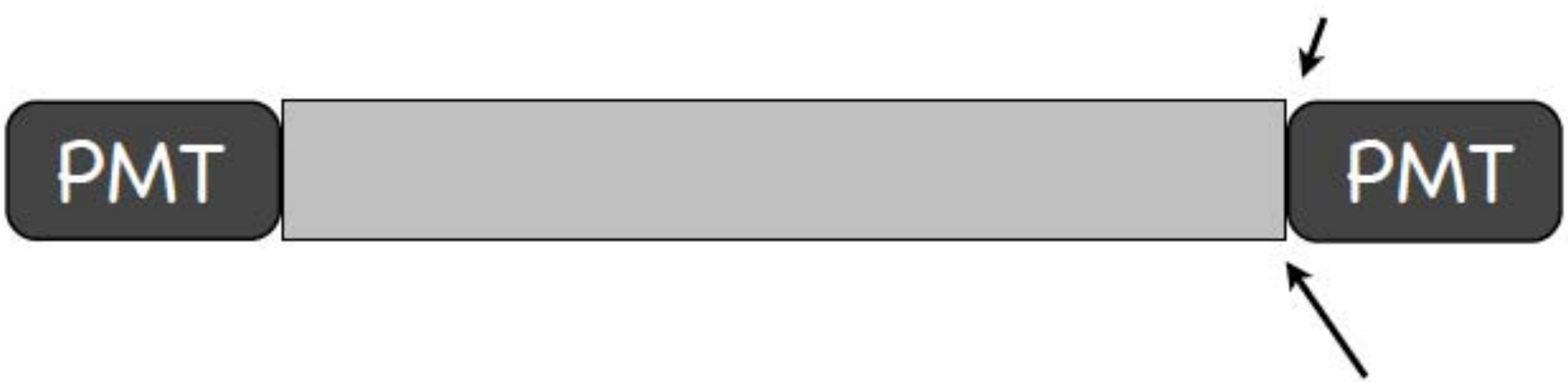
The CLAS12 Scintillator Detector

Scintillators:

BC-404; 6 cm x 6 cm x (50 - 200) cm

PMT: Hamamatsu R9779, d = 51 mm.

(2) No Light guides;
PMT directly glued to SC;
gluing procedure in batches of 6 bars in 'windmill' type setup

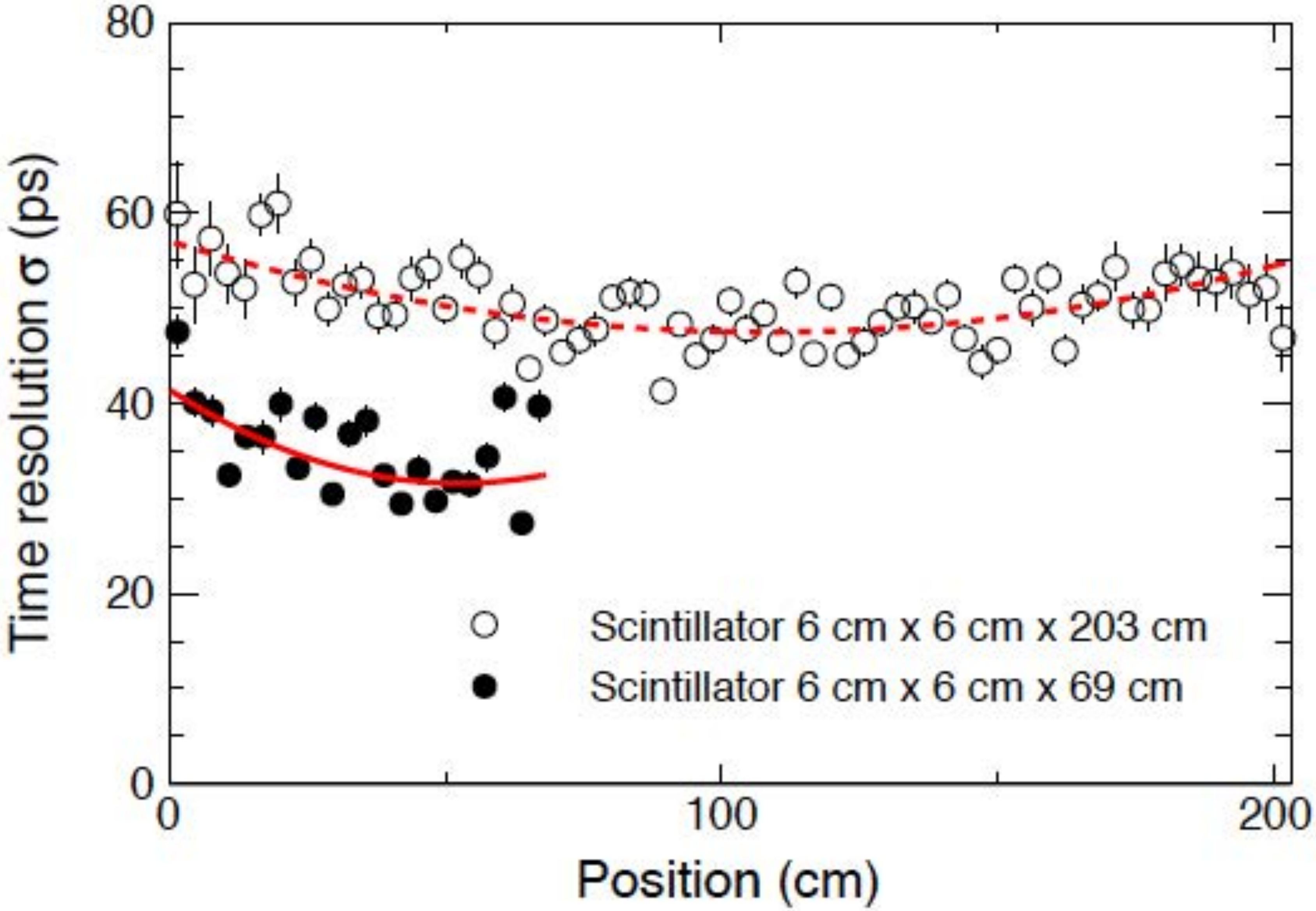


(3) Scintillator wrapped in **Aluminized Mylar**

(4) Light tight **DuPont Tedlar** encases entire counter

(1) Corners masked with black tape

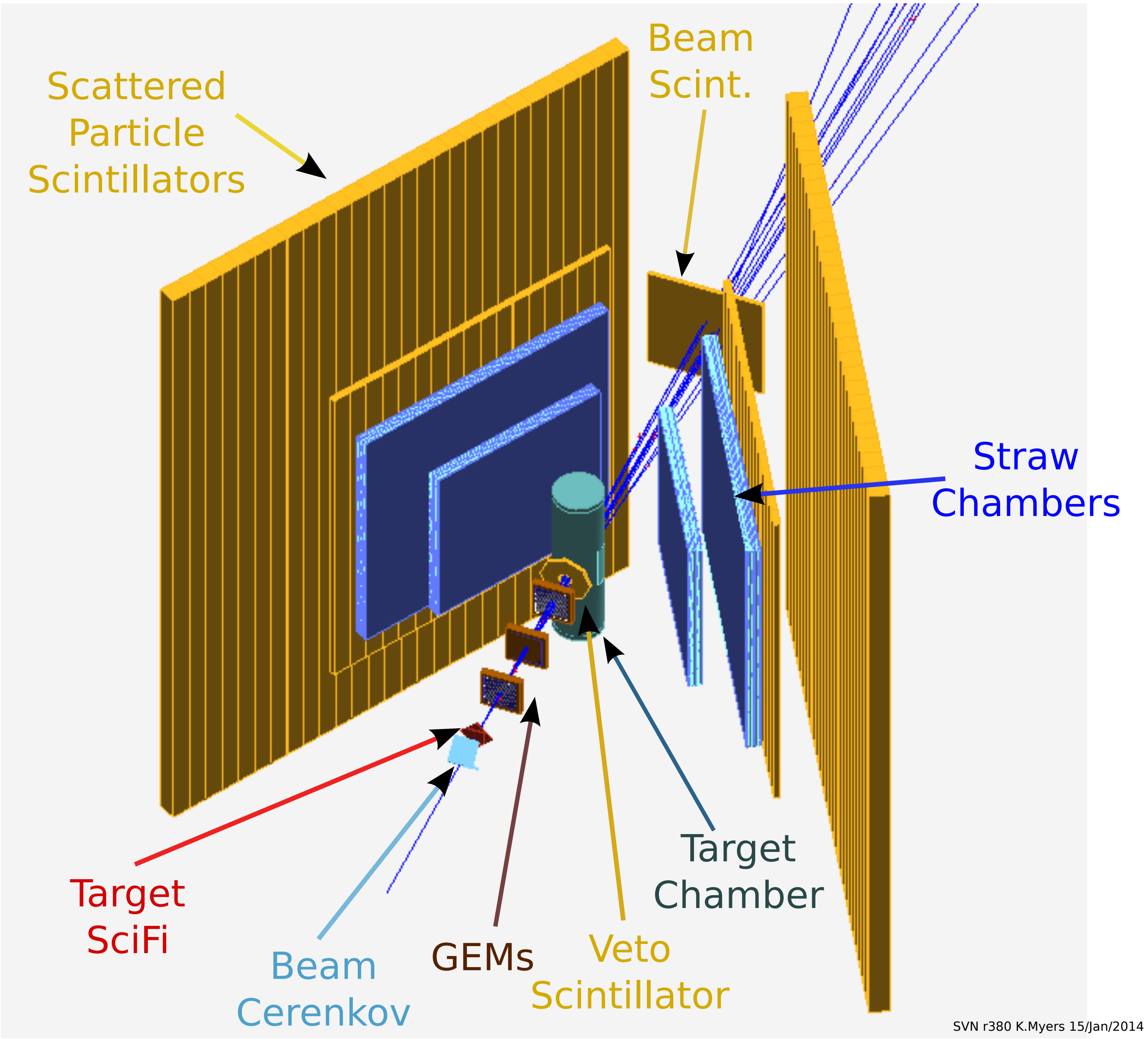
Achieved Time Resolutions



- Time resolution after calibration, event selection, time-walk correction:
  - σ_{avg} = 51 ps for 203-cm bar
  - σ_{avg} = 34 ps for 69-cm bar

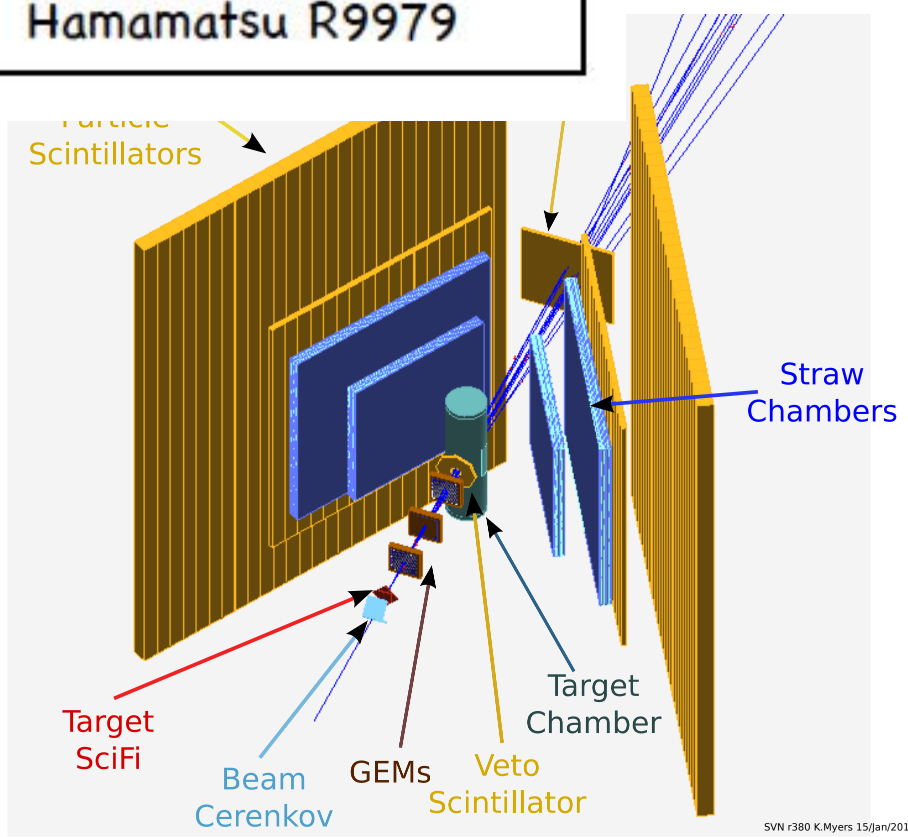
Scintillator Overview

- Vertically oriented bars, covering the full acceptance (20-100 deg) - in 2 walls.
- Back wall increased in size to account for multiple scattering.



Scintillator Overview

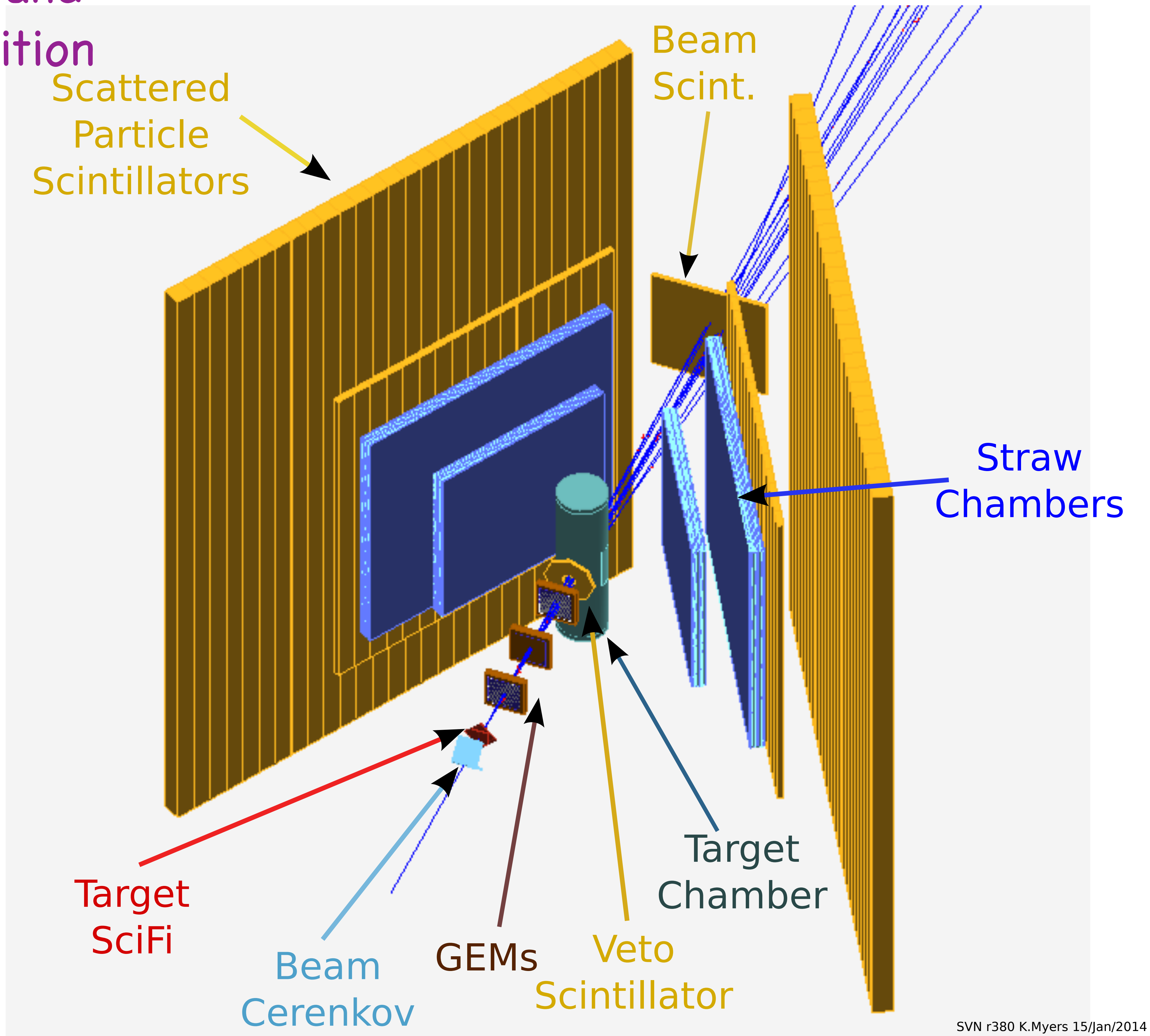
	Front wall	Back wall
Number of scintillator bars	17	27
Scintillator cross section	6 cm x 2 cm	6 cm x 6 cm
Scintillator length	103 cm	163 cm
Target to front-face distance	50 cm	73 cm
Gap between scintillator bars	0.02 cm	0.02 cm
Scintillation material	BC-404	BC-404
Photomultiplier	Hamamatsu R9779	Hamamatsu R9979



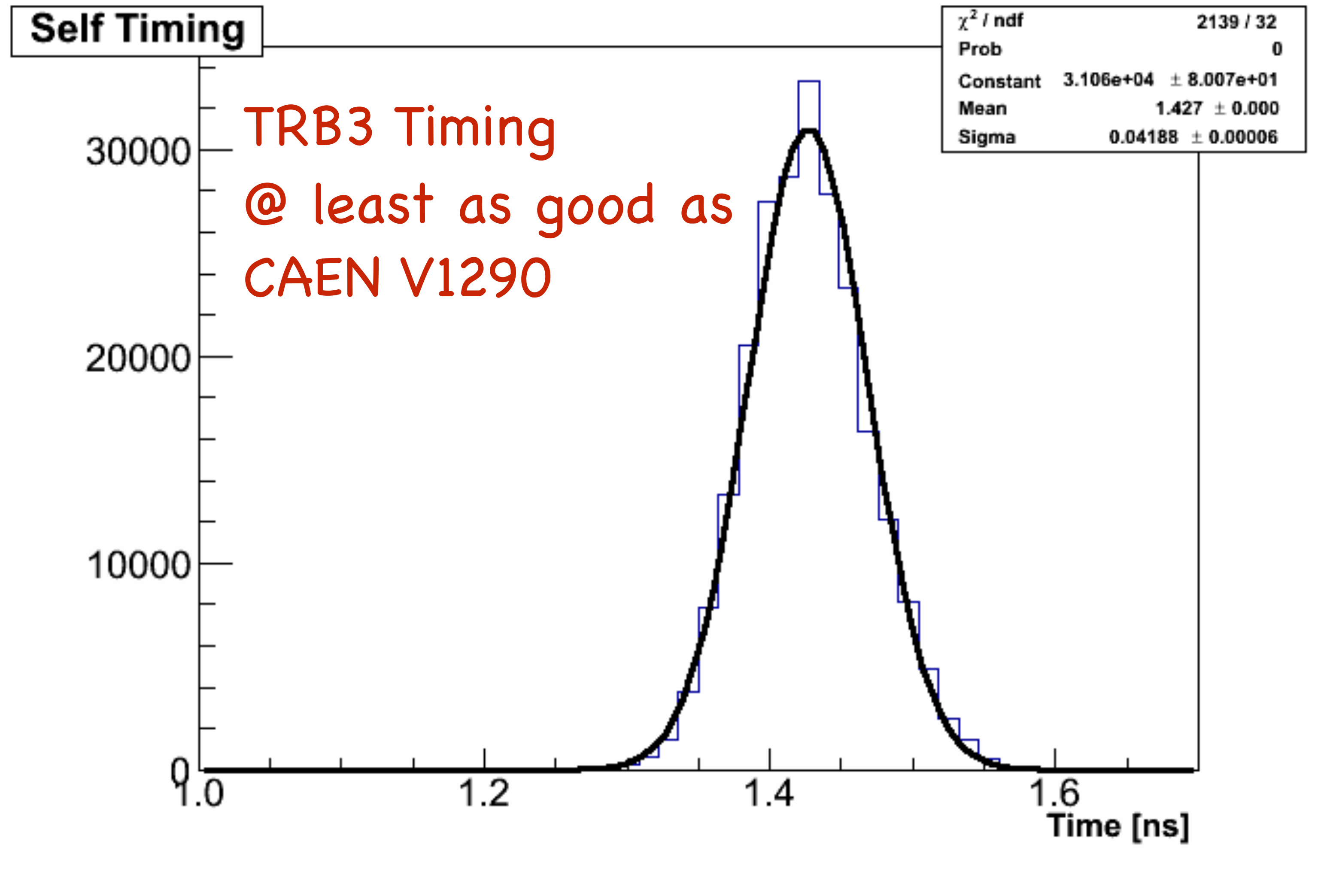
Scintillator Readout

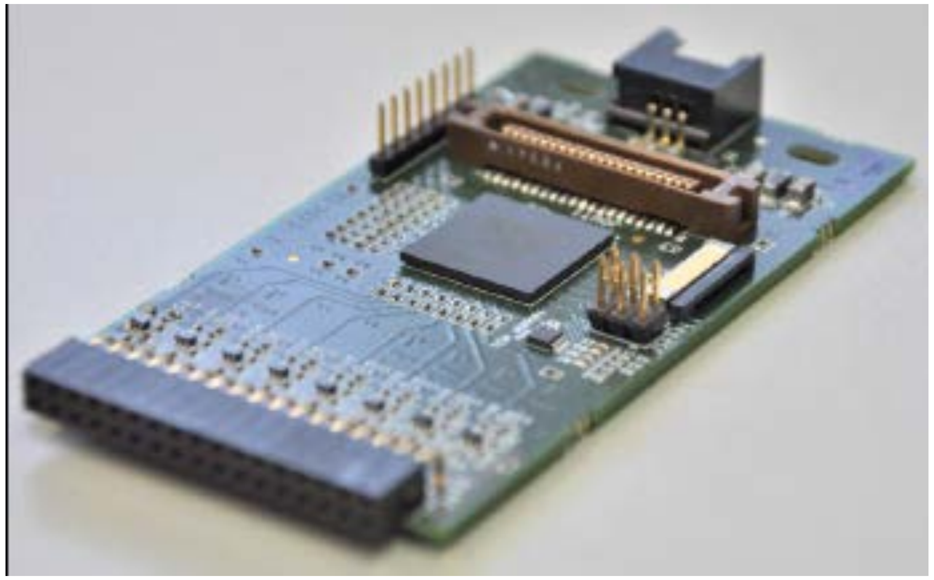
- R9779 PMTs with double output last dynode + anode.
- Dynode (slower) output readout into QDC.
- Anode (fast) readout fed directly into PADIWA for discrimination and TDC.
- Time-walk correction based on QDC.
- Scintillator efficiency better than 99%.

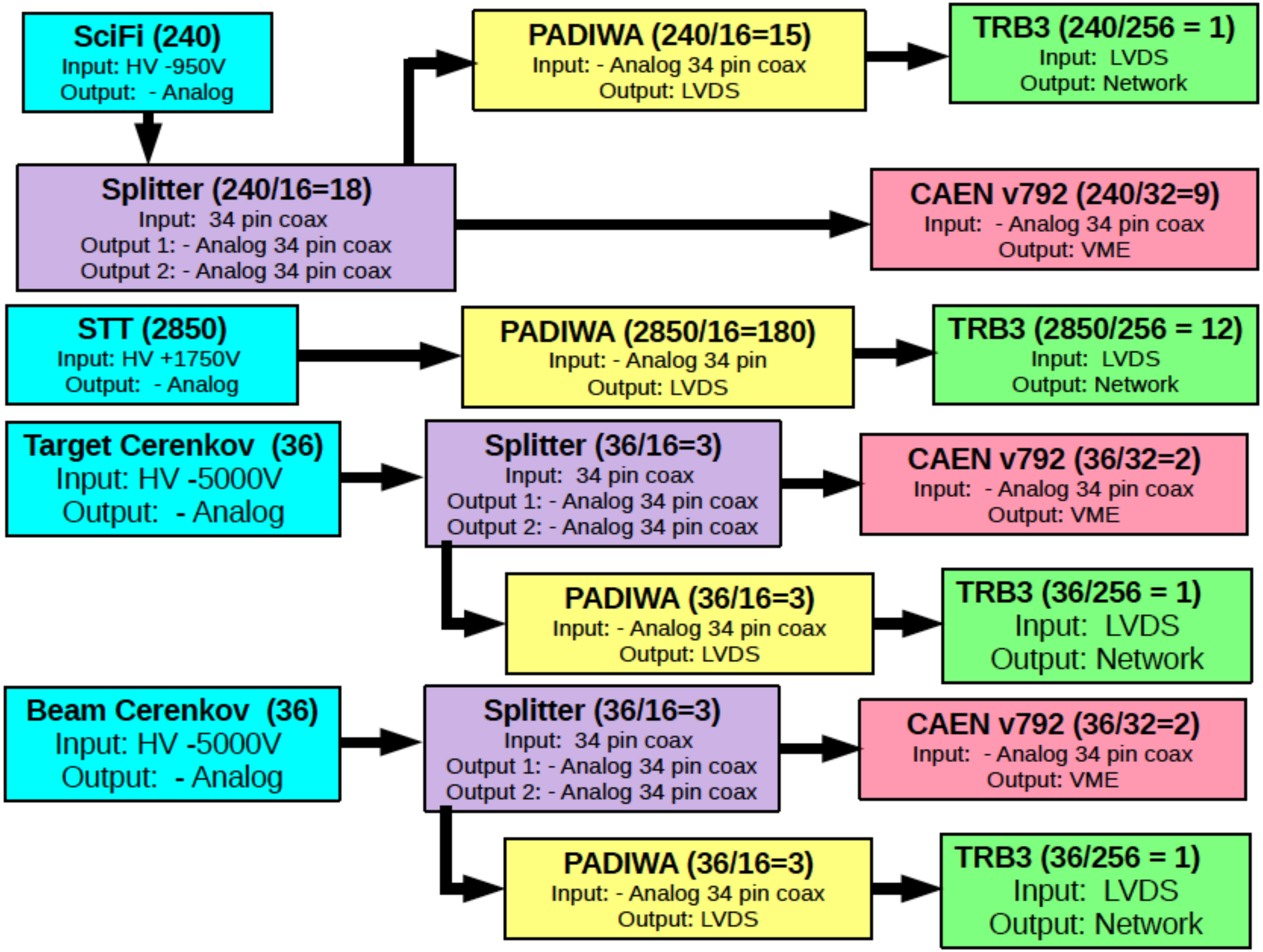
Triggering and Data Acquisition

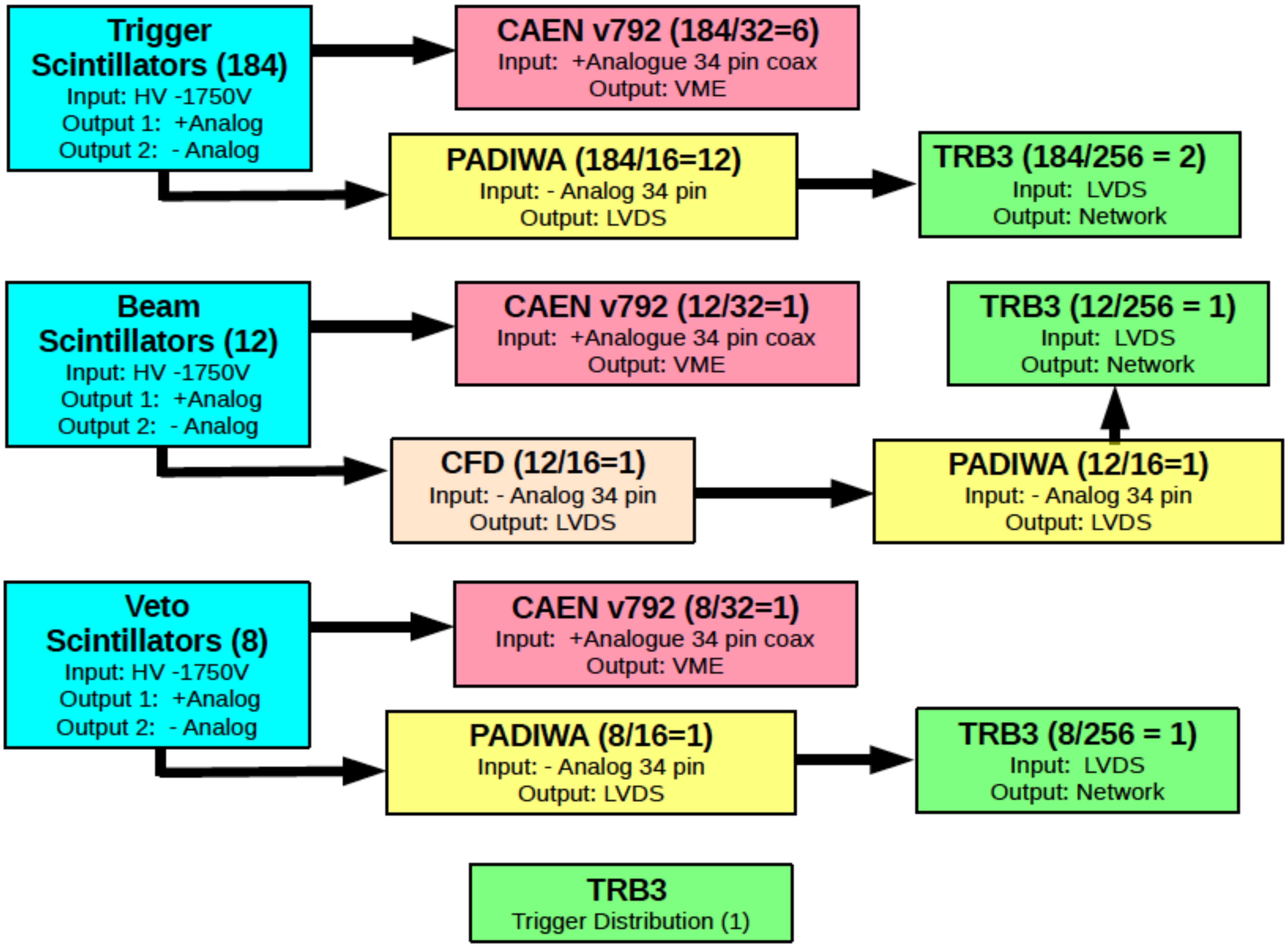


- GSI designed Time-to-Digital converters (25ps resolution).
- FPGAs as front end discriminator/amplifier.
- High channel density (256ch/board).
- ADC signals into standard CAEN architecture (v792).
- Custom designed signal splitters where needed.
- Triggering implemented on same architecture.






SciFi (240)
Input: HV -950V
Output: - Analog
Splitter (240/16=18)
Input: 34 pin coax
Output 1: - Analog 34 pin coax
Output 2: - Analog 34 pin coax
PADIWA (240/16=15)
Input: - Analog 34 pin coax
Output: LVDS
TRB3 (240/256 = 1)
Input: LVDS
Output: Network
CAEN v792 (240/32=9)
Input: - Analog 34 pin coax
Output: VME
STT (2850)
Input: HV +1750V
Output: - Analog
PADIWA (2850/16=180)
Input: - Analog 34 pin
Output: LVDS
TRB3 (2850/256 = 12)
Input: LVDS
Output: Network
Target Cerenkov (36)
Input: HV -5000V
Output: - Analog
Splitter (36/16=3)
Input: 34 pin coax
Output 1: - Analog 34 pin coax
Output 2: - Analog 34 pin coax
CAEN v792 (36/32=2)
Input: - Analog 34 pin coax
Output: VME
PADIWA (36/16=3)
Input: - Analog 34 pin coax
Output: LVDS
TRB3 (36/256 = 1)
Input: LVDS
Output: Network
Beam Cerenkov (36)
Input: HV -5000V
Output: - Analog
Splitter (36/16=3)
Input: 34 pin coax
Output 1: - Analog 34 pin coax
Output 2: - Analog 34 pin coax
CAEN v792 (36/32=2)
Input: - Analog 34 pin coax
Output: VME
PADIWA (36/16=3)
Input: - Analog 34 pin coax
Output: LVDS
TRB3 (36/256 = 1)
Input: LVDS
Output: Network



Trigger Scintillators (184)
Input: HV -1750V
Output 1: +Analog
Output 2: - Analog
CAEN v792 (184/32=6)
Input: +Analogue 34 pin coax
Output: VME
PADIWA (184/16=12)
Input: - Analog 34 pin
Output: LVDS
TRB3 (184/256 = 2)
Input: LVDS
Output: Network
Beam Scintillators (12)
Input: HV -1750V
Output 1: +Analog
Output 2: - Analog
CAEN v792 (12/32=1)
Input: +Analogue 34 pin coax
Output: VME
TRB3 (12/256 = 1)
Input: LVDS
Output: Network
CFD (12/16=1)
Input: - Analog 34 pin
Output: LVDS
PADIWA (12/16=1)
Input: - Analog 34 pin
Output: LVDS
Veto Scintillators (8)
Input: HV -1750V
Output 1: +Analog
Output 2: - Analog
CAEN v792 (8/32=1)
Input: +Analogue 34 pin coax
Output: VME
PADIWA (8/16=1)
Input: - Analog 34 pin
Output: LVDS
TRB3 (8/256 = 1)
Input: LVDS
Output: Network
TRB3
Trigger Distribution (1)

Data Acquisition

- Data Acquisition based on standard PSI DAQ software (MIDAS).
- Trivial integration with PSI slow controls.
- Distributed frontend allow for high event rate (not limited by software/DAQ).
- Test runs carried out with individual modules of each type of component needed for the DAQ.

New Equipment Summary

Detector	Who	Technology
Beam SciFi	Tel Aviv	conventional
GEMs	Hampton	detector exists
Sapphire Cerenkov	Rutgers	prototyped (Albrow et al)
Trigger	Rutgers	TRB3 based
Target	George Washington	conventional - very low power
Straw Tube Tracker	Hebrew U	copy existing system (PANDA)
Scintillators (including beam and veto)	South Carolina	copy existing system
DAQ	George Washington	conventional, except TRB3