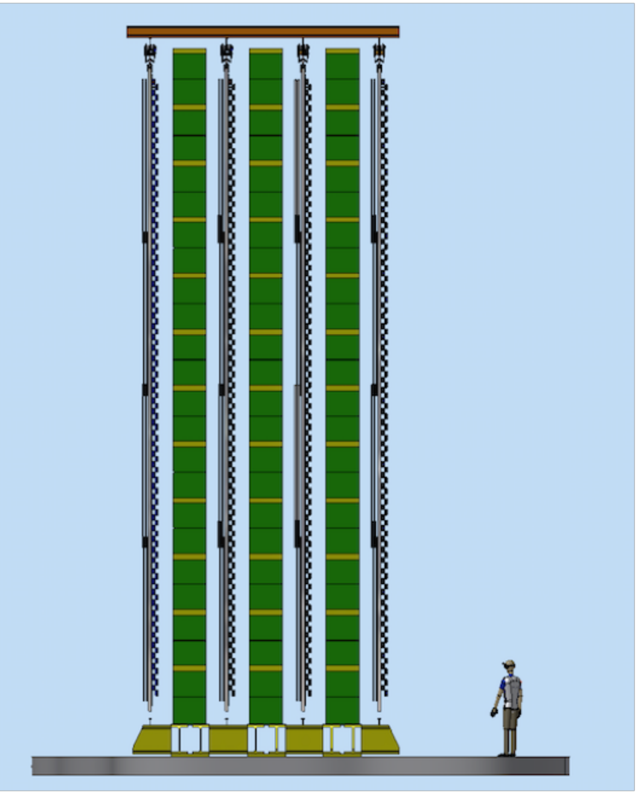
SHiP Muon Detector: towards the CDS and TDR



A. Calcaterra, P. Ciambrone, M. Dallavalle, F. Fabbri, G. Felici,
Y. Kudenko, G. Lanfranchi, A. Montanari, O. Mineev, A. Paoloni,
T. Rovelli, A. Saputi, N. Tosi
(and others)

INR, MEPhi, INFN-Bologna, INFN-Cagliari, INFN-LNF

SHiP Collaboration Meeting – June 2017

Outline

1) Test beam activities;
2) Optimization of the overall layout:
    - re-start of software activities
3) Steps towards the module 0.

Prepared for submission to JINST

Measurement of parameters of scintillating bars with wavelength-shifting fibres and silicon photomultiplier readout for the SHiP Muon Detector

W. Baldini,[a] A. Blondel,[b] A. Calcaterra,[c] R. Jacobsson,[d] A. Khotjantsev,[e] Yu. Kudenko,[e,f,g] V. Kurochka,[e] G. Lanfranchi,[c] A. Mefodiev,[e] O. Mineev,[e] A. Montanari,[h] E. Noah Messomo,[b] A. Saputi,[c] N. Tosi[h]

[a]INFN - Sezione di Ferrara, via Saragat 1, 44122 Ferrara, Italy
[b]DPNC, Section de Physique, Université de Genève, Geneva, Switzerland
[c]INFN - Laboratori Nazionali di Frascati, via E. Fermi 40, 00044 Frascati (Rome), Italy
[d]European Organization for Nuclear Research (CERN), Geneva, Switzerland
[e]Institute for Nuclear Research of the Russian Academy of Science, pr. 60-letiya Oktyabrya 7a, Moscow, Russia 117312
[f]Moscow Institute of Physics and Technology, Institutskiy per. 9, Dolgoprudny, Moscow region, Russia, 141701
[g]National Research Nuclear University MEPhI, Kashirskoe sh. 31, Moscow, Russia, 115409
[h]INFN - Sezione di Bologna, Viale Berti Pichat, 6/2, 40127 Bologna, Italy

E-mail: Caia.Lanfranchi@lnf.infn.it

Abstract: The light yield and the time resolution of different types of 3 m long scintillating bars instrumented with wavelength shifting fibres and read out by different models of silicon photomultipliers have been measured at a test beam at the T9 area at the CERN Proton Synchrotron. The results obtained with different configurations are presented. A time resolution better than 800 ps, constant along the bar length within 20%, and a light yield of ~ 140 (70) photoelectrons are obtained for bars 3 m long, ~4.5 (5) cm wide and 2 (0.7) cm thick. These results nicely match the requirements for the Muon Detector of the SHiP experiment.

Keywords: Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators); Photon detectors for UV, visible and IR photons (solid-state) (PIN diodes, APDs, Si-PMTs, G-APDs, CCDs, EBCCDs, EMCCDs etc);

ArXiv ePrint: 1612.01125

Results of 2015 test beam now published on JINST:
JINST 12 (2017) no.03, P03005
arXiv: 1612.01125v2

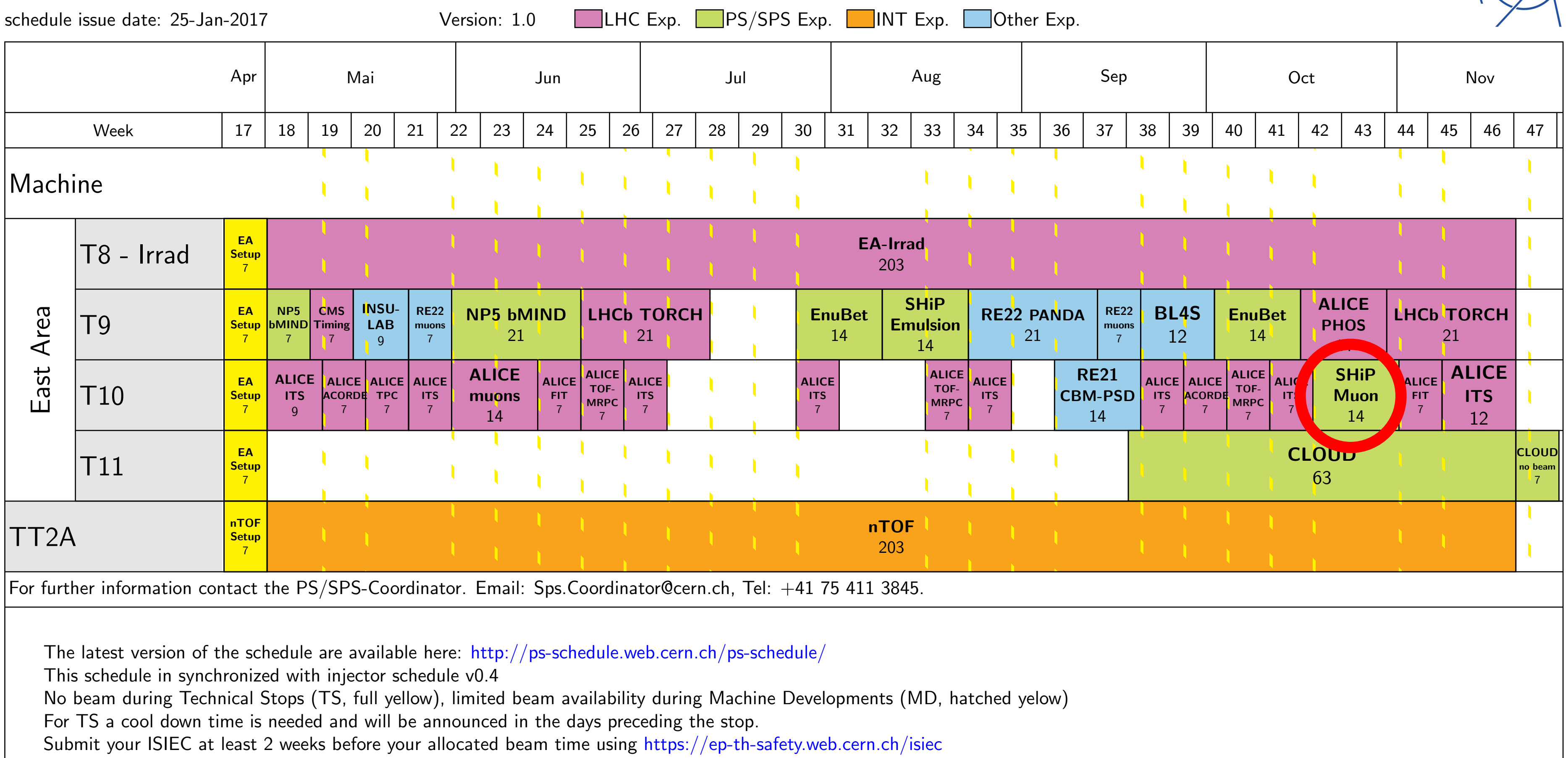
Main results:

- light yield : ~ **140 p.e.**
- detection efficiency : ~ **99.5%**
- time resolution ~ **750 ps** constant along the bar length:
  → **265 ps for 4 stations 2 layers each**

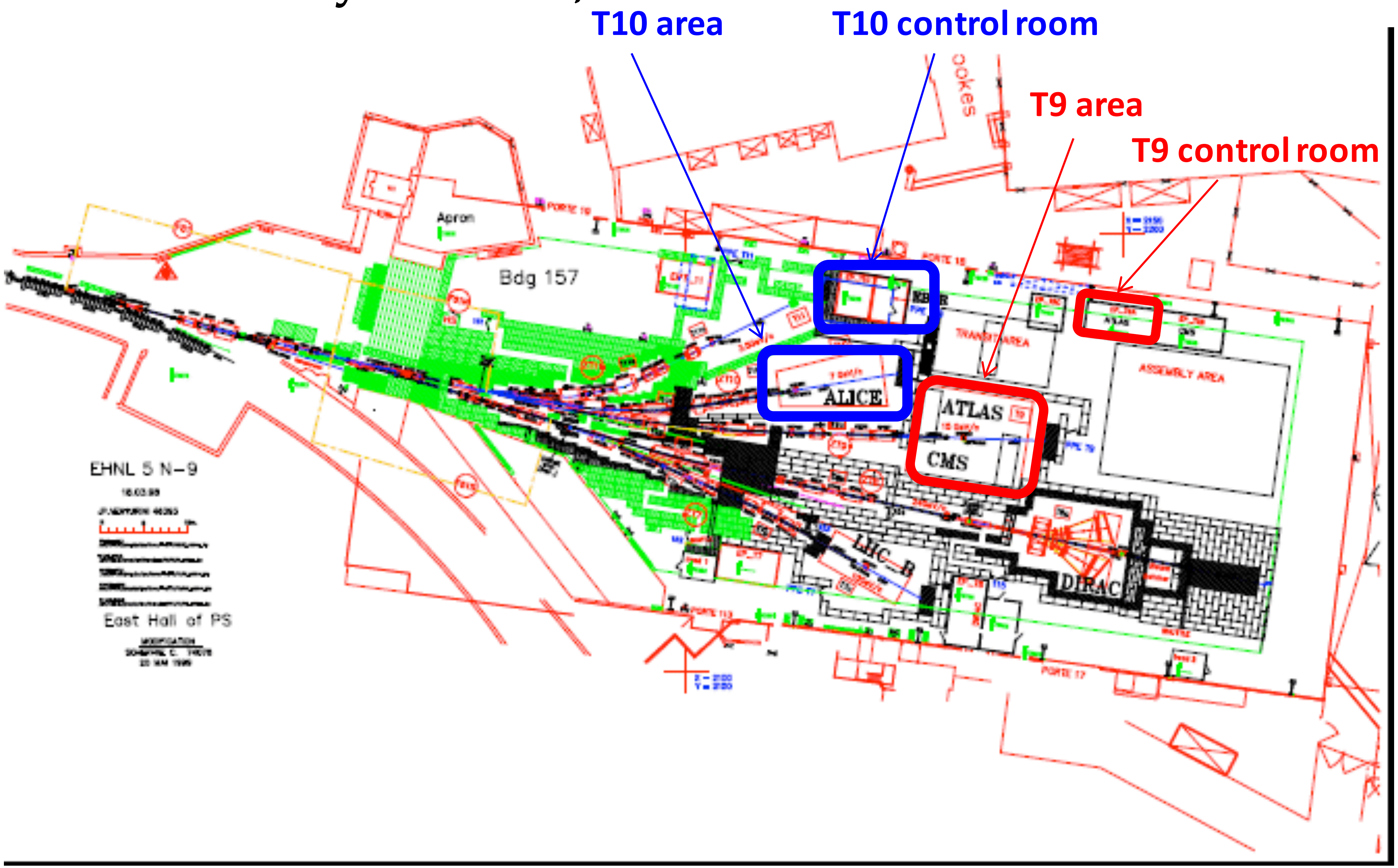
1) Test beam activities:

- Results confirmed that the technology fits well the SHiP requirements.
- Final choice of the scintillator manufacturer, fibres and SiPM types will be done by the time of the TDR (not CDS) and will be based on cost and performance
- Some missing measurements will be performed in a new 2-weeks long test beam in October 2017 at the T10 area, CERN PS.

PS user schedule for 2017



Test beam activity: T10 area, CERN PS:



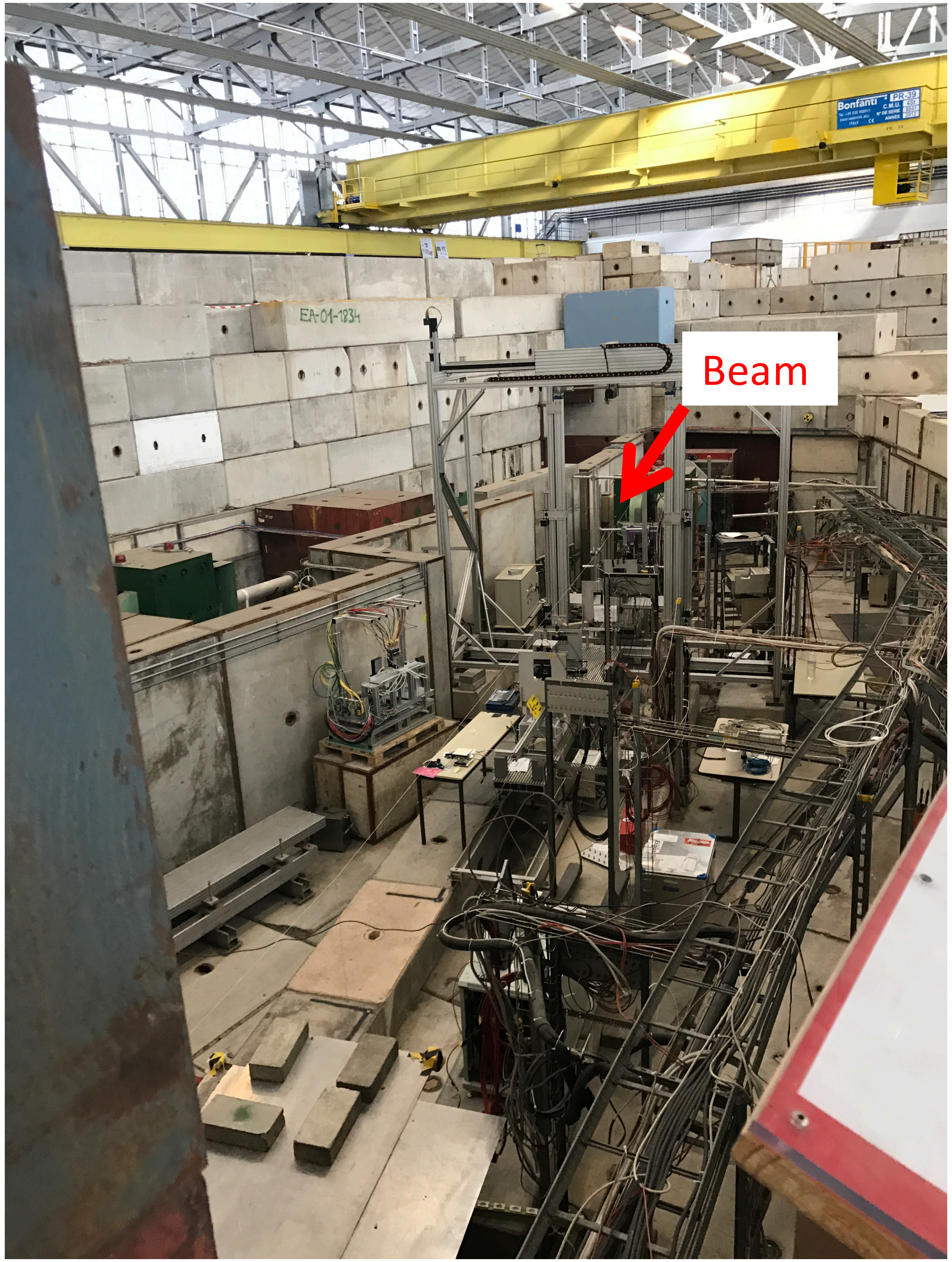
Beam available at the T10 area, CERN PS:

T10 area : at 6 GeV mainly pions; intensity comparable to T9 one, tunable with collimators
rms of the beam close to the exit window < 1 cm

East Area

Line	Momentum range	Momentum Resolution	Particles	Nominal Intensity *	Intensity range (relative)	Remarks
T9	1-15 GeV/c (±)	0.6%	mixed	$0.3\text{-}1.0*10^6$	~0.02-6	
T10	1-7 GeV/c (±)	0.5%	mixed	$0.3\text{-}1.0*10^6$	~0.02-4	
T11	1-3.6 GeV/c (±)	~1%	mixed	$0.3\text{-}1.0*10^6$	~0.02-5	

Panoramic view of the T10 area


Beam
EA-01-1834
Bonfanti

Preliminary List of measurements to be done in 2017 (1/2)

1. **Light yield, time resolution and efficiency of Russian (Vladimir, Russia) bars with 2 mm (instead of 1 mm) Kuraray fibres:**

   this configuration could be the best to use for the Muon Detector, if we keep the current layout with 3 or 4 stations interleaved with iron filters.

2. **Detection efficiency of FNAL bars (missing in 2015):**

   detection efficiency obtained with bars from Vladimir (Russia) is very good (99.5%): we want to repeat the measurement for FNAL bars

Preliminary List of measurements to be done in 2017 (2/2)

New: light yield and time resolution of cast scintillator pads with direct SiPM readout:

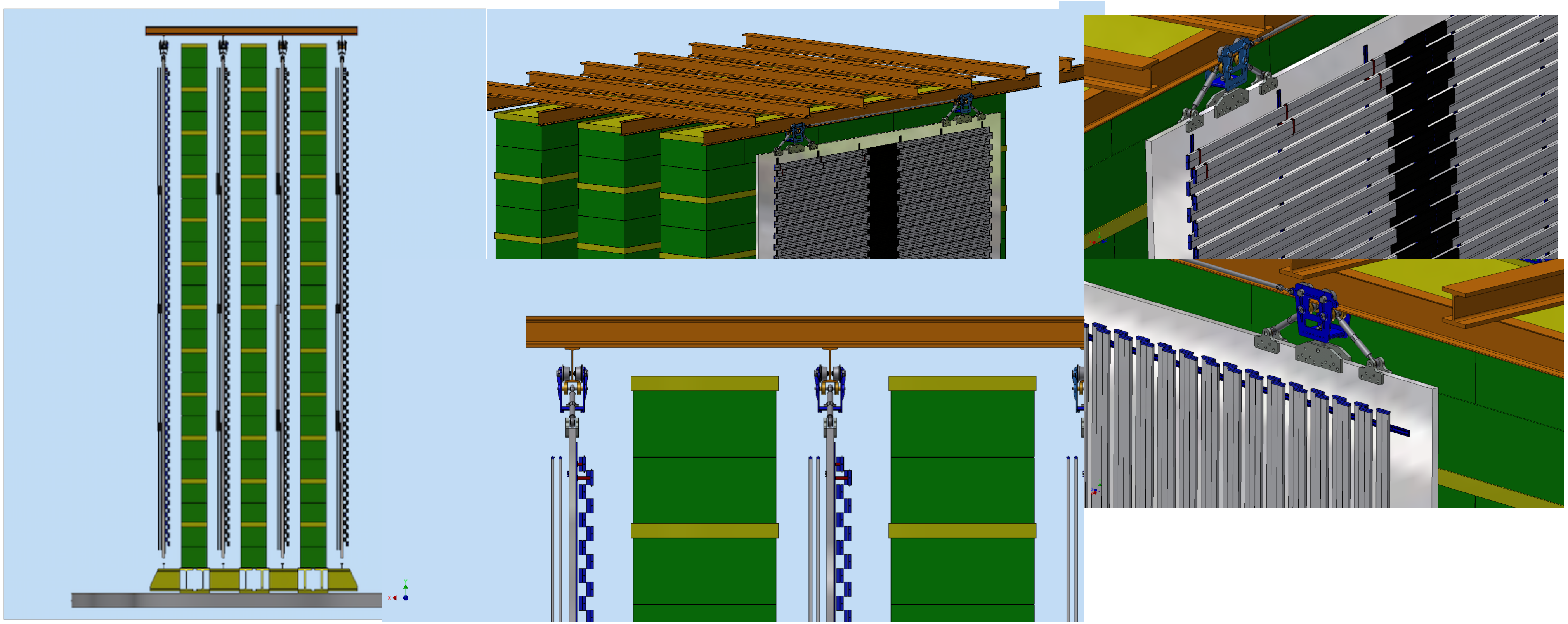
- **This is a pilot R&D;**
- **The analysis of NA62 data of $2x10^{15}$ pot taken in dump mode in December 2016** suggests that a single active layer is sufficient to detect muons if there is a suitable Hadronic Calorimeter in front (see Rainer Wanke's talk);

  - in NA62 with a timing detector (200 ps resolution) and MUV3 muon layer (~400 ps resolution) **less than 5 combinatorial muons events are left in $2x10^{15}$ pot** after requiring kinematic and timing constraints and **without any Upstream Veto**;
  no events are left if pointing is required.

- **with a single active layer we can afford a better technology in terms of time resolution:**
  - The Muon detector could become also a timing detector for muons, complementing the timing detector in front of the calorimeters.

Muon system baseline solution:

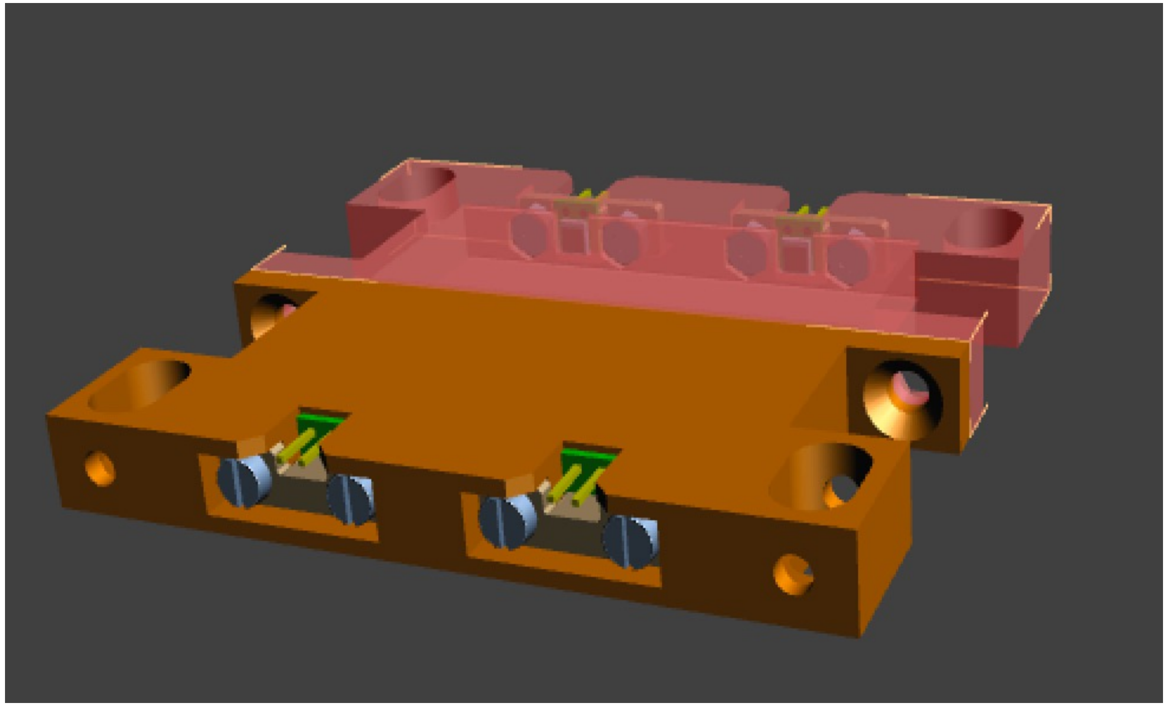
Four active stations, 1200x600 cm^2 transverse dimensions
(x,y) view, 3380 bars (5x300x2) cm^3, 7760 FEE channels, 1000 tons of iron filter.

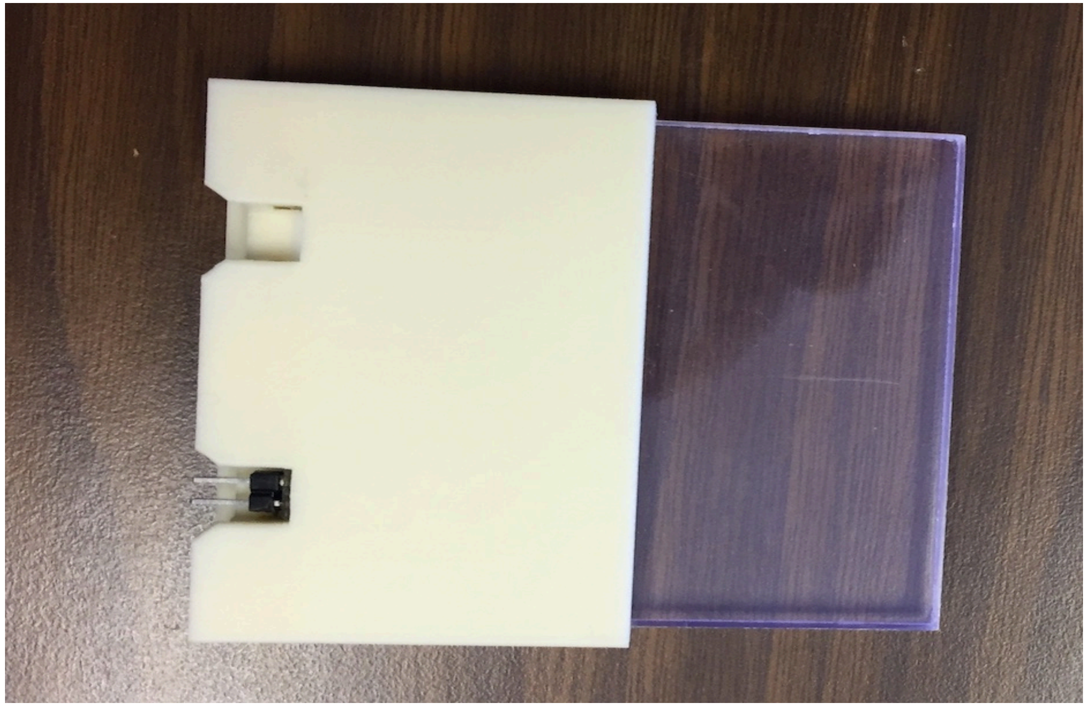


Alternative solution: a single layer of tiles, no iron.

Scintillating tiles with direct SiPM readout:

Mechanical drawing (left) and simplified prototype (right) of a (10x10x0.6) cm^3 tile of EJ200 each side is read-out by two 3x3 mm^2 SiPMs from AdvanSid company:





A time resolution of o(300-400) ps seems to be adequate for connecting in time the hit to the timing detector
A possible layout could be tiles of 10x20x1 cm^3; for 5x10 m^2, 2500 tiles, 5000 readout channels.
(baseline layout: 3840 bars, 7680 readout channels). To be studied…..

- Another test beam needed in 2018 to test this option for SHiP.

Slide shown already in Berlin

2) Optimization of the general layout:

number of stations, bar dimensions, thickness of passive filters;
then start mechanical drawings, engineering.

This optimization requires to know:

a) which is the level of muon/non-muon separation required (10%,1%,10^{-3},etc):
   - this defines the number of stations and thickness of the muon filters;
   - work to be only in collaboration with software/analysis groups;

b) how much material we have in front of the system:
   - this defines the multiple scattering and thus the bars dimensions;
   - depends on the presence (absence) of HCAL.

Overall optimization of the muon system requires external inputs from the software/analysis groups and from the calorimeter group.

While waiting for input from the physics and calorimeter groups……

Tiziano Rovelli (INFN-Bologna), who was very active in the Proposal phase, is restarting the work on simulation of the muon detector:

1) First step: study the performance as a function of the number of stations;
2) second step: implement some granularity of the detector and consequent digitization of the hits.

Four steps towards the module "0":

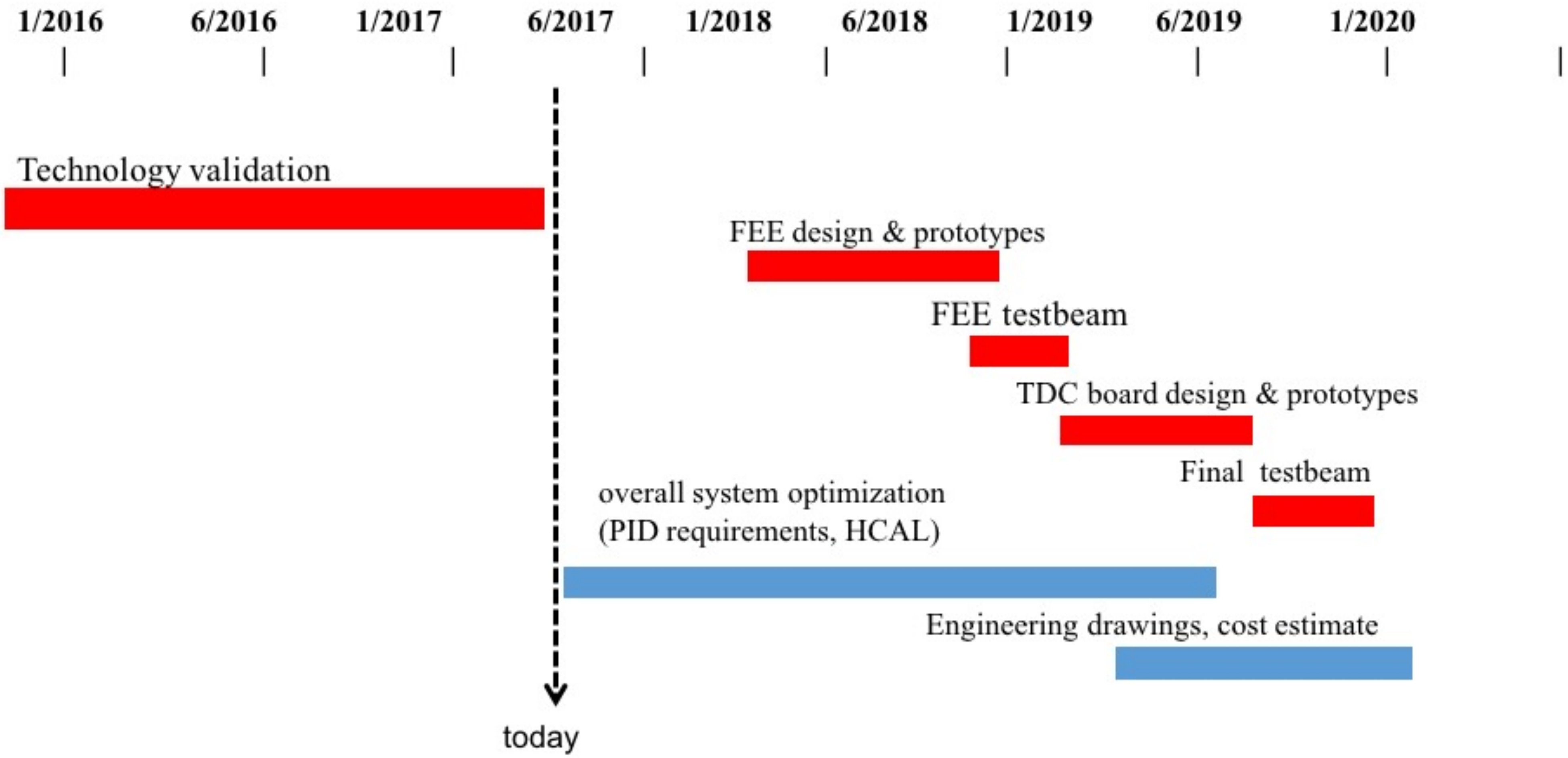
First prototypes have been already tested and the results nicely confirmed that the technology matches well the SHiP requirements. Further R&D is necessary in order to finalize a full size prototype (module 0) equipped with a customized front-end electronics.

Steps towards the module "0" include:

1. develop and test precise optical connectors for WLS/MPPC readout.
2. perform an R&D on optimization of the thickness of extruded scintillator to obtain maximal light yield per MIP (and save money)
3. R&D of the FEE
- design a motherboard with:
  - a stage for fine control of the SiPM bias voltages to equalize the gains and to compensate temperature variations, with a channel by channel programmable voltage regulation with remote setting/monitoring;
  - a stage for signal amplication/shaping:
  - a stage for signal discrimination.
- design a TDC board with o(100 ps) time resolution and relative interface with the TDAQ system.

4. Perform a final test beam with a module 0 equipped with the **final electronics.**

Time schedule (if the "module 0" has to be ready for the CDS):



This time schedule would allow us to be ready to start production in 2020++
This implies to get the necessary funds by January 2018.
Otherwise everything will be properly rescheduled.

Cost estimate:

Table 1: Preliminary cost estimate of the R&D phase of a module 0.

Development and test of precise optical connectors for WLS/MPPC readout	$\sim$ 10 kEuro
R&D on optimization of the thickness of extruded scintillators	$\sim$ 18 kEuro
Design of a prototype of a motherboard with power supply/amplification/discrimination stages	$\sim$ 15 kEuro
Design of a 16/32 channels TDC board with $\sim$ 100 ps resolution	$\sim$ 15 kEuro
Test beam with a full size prototype instrumented with the full electronic chain	$\sim$ 12 kEuro

The FEE can be used for both configurations, with and without fibres.

Person power

- 6 months of an electronic engineer;
- 6 months of a mechanical engineer;
- 6 months of an electronic technician;
- 1-2 months of a detector technician;
- 1 year of 2-3 FTE (full time equivalent) physicists.

Conclusions:

Muon system well on track :

One successful test beam in 2015, another planned in October 2017;

Steps towards a module 0 identified, with detailed cost estimate and person power needed;

An alternative layout with a single layer of scintillating tiles with SiPM readout being investigated aside the “baseline” solution.

Waiting for input from Collaboration (as far as the optimization is concerned) and money from the funding agencies to do the necessary steps.