SHiP Muon System:
Status and plans towards the Comprehensive Design Report

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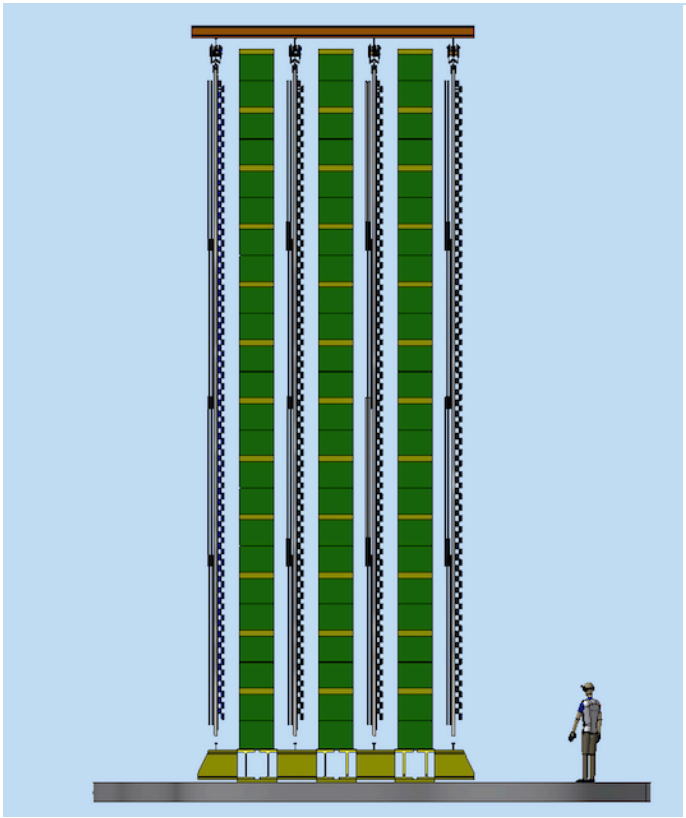
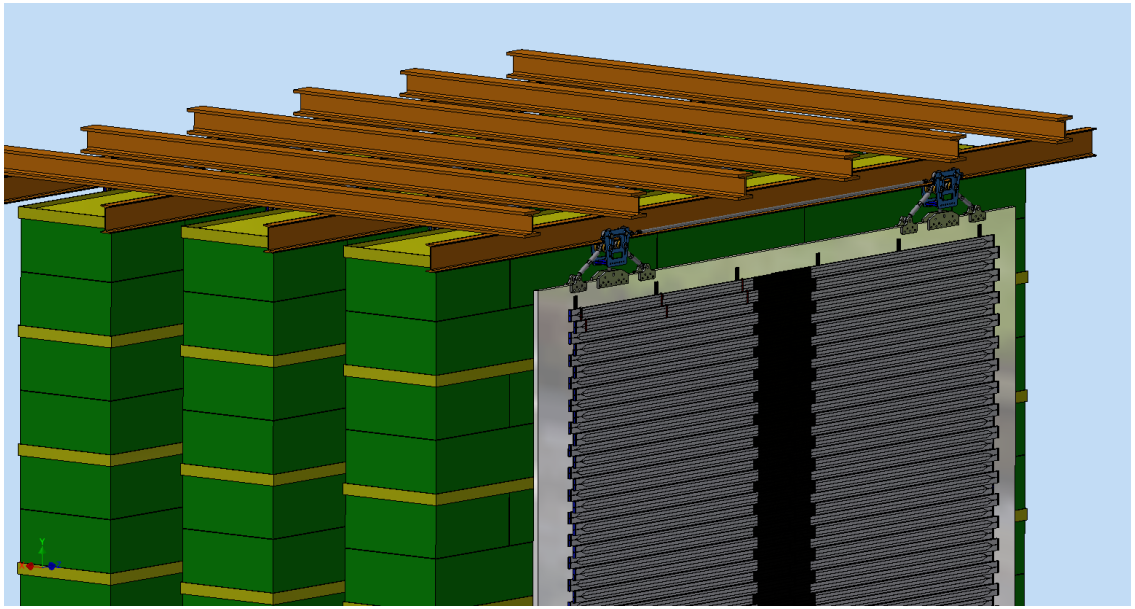
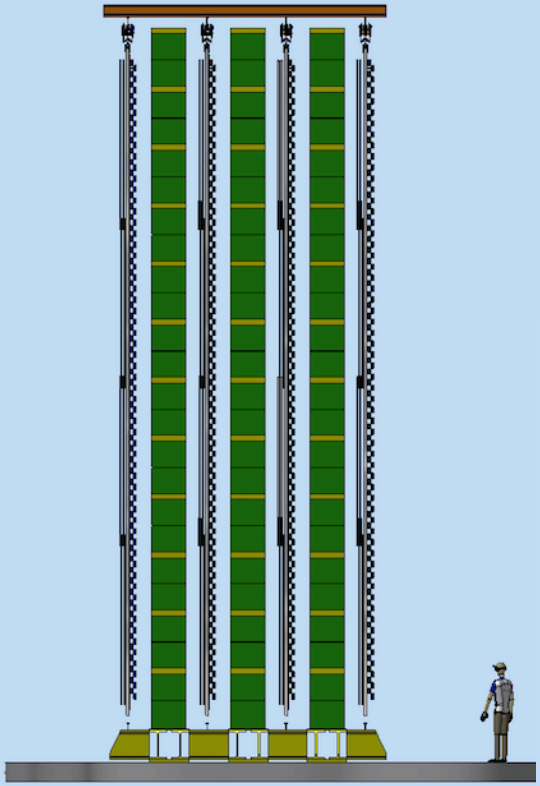




Muon detector:

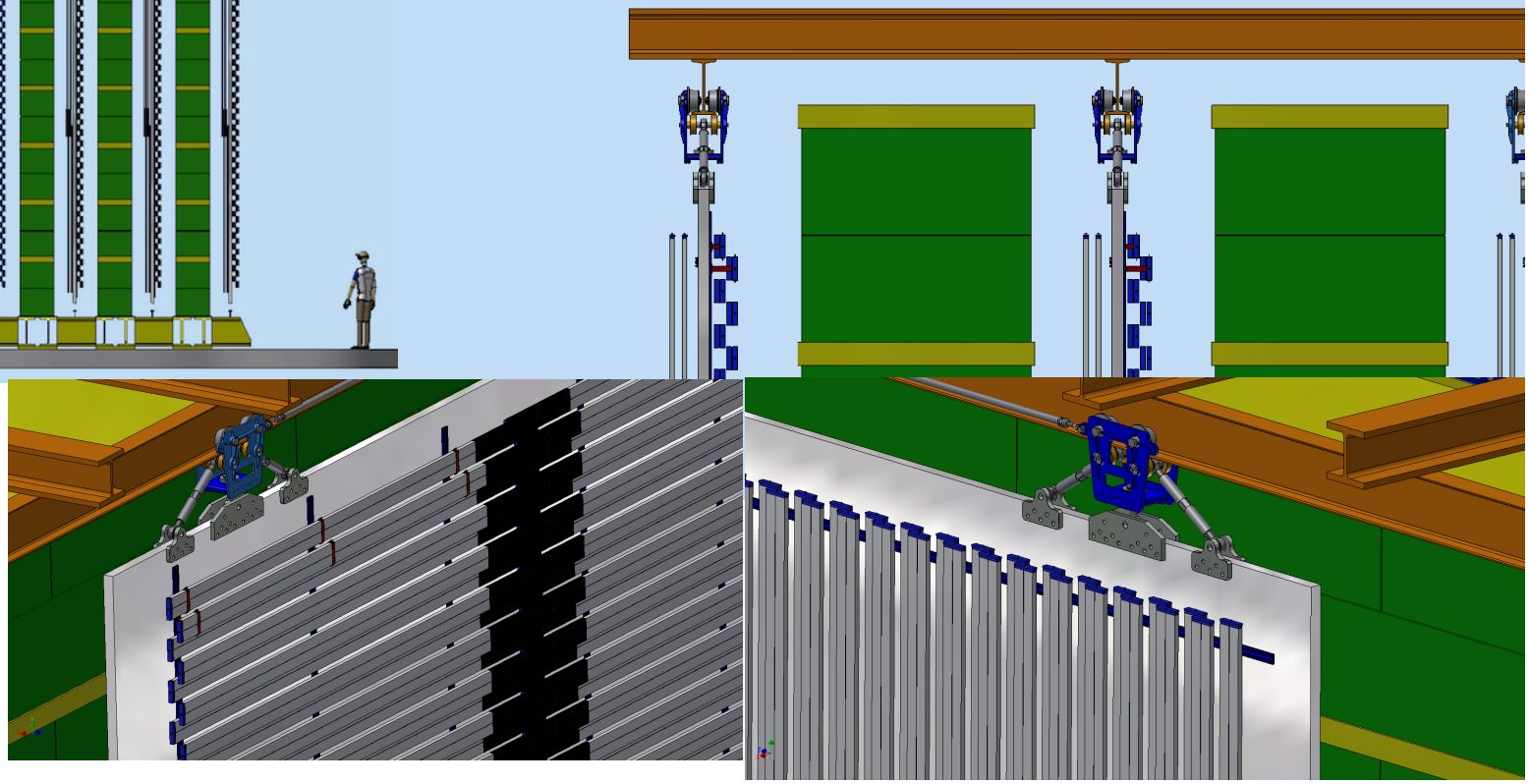
based on scintillating bars, with WLS fibers and SiPM readout

SHiP



Technical Proposal: preliminary design
- 4 active stations;
- transverse dimensions: 1200x600 cm^2
- x,y view
- 3380 bars, 5x300x2 cm^3/each
- 7760 FEE channels
- 1000 tons of iron filters

Detector has to be reoptimized, numbers will change



Requirements for the Muon System:

1) Positive identification of signals with muons in the final state with high efficiency;

2) Mild separation between muon and hadrons/electrons:
studies performed for the TP and the Addendum showed that ν-induced and muon-inelastic backgrounds can be rejected using only kinematic cuts and veto requirements;

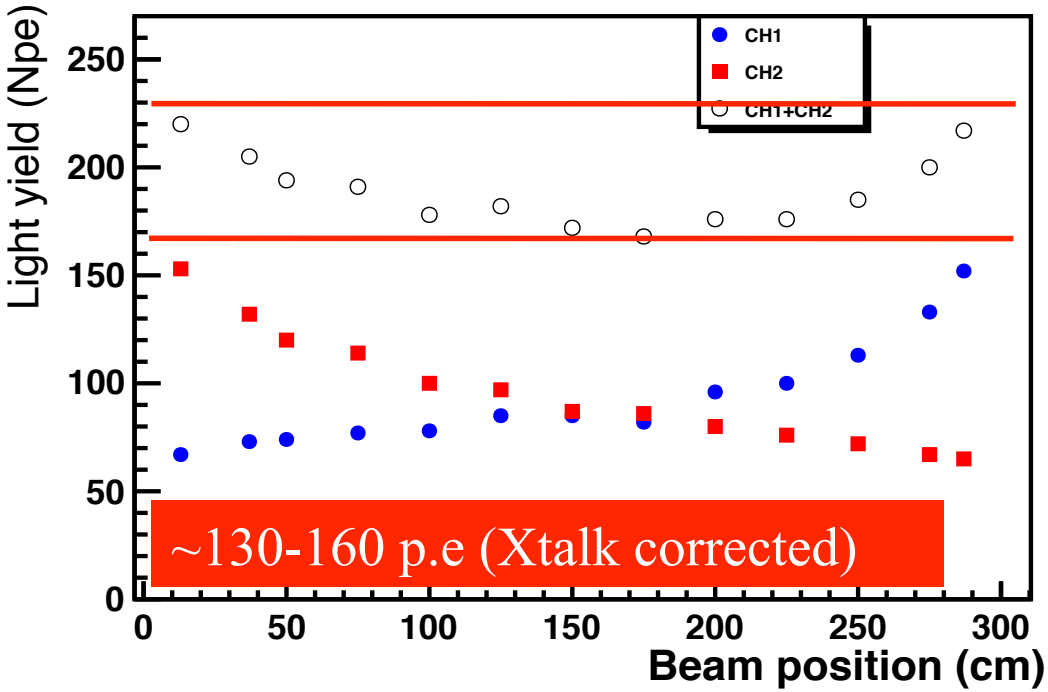
→ no need for highly performing PID system!

3) Help the timing detector in rejecting muon combinatorial background.

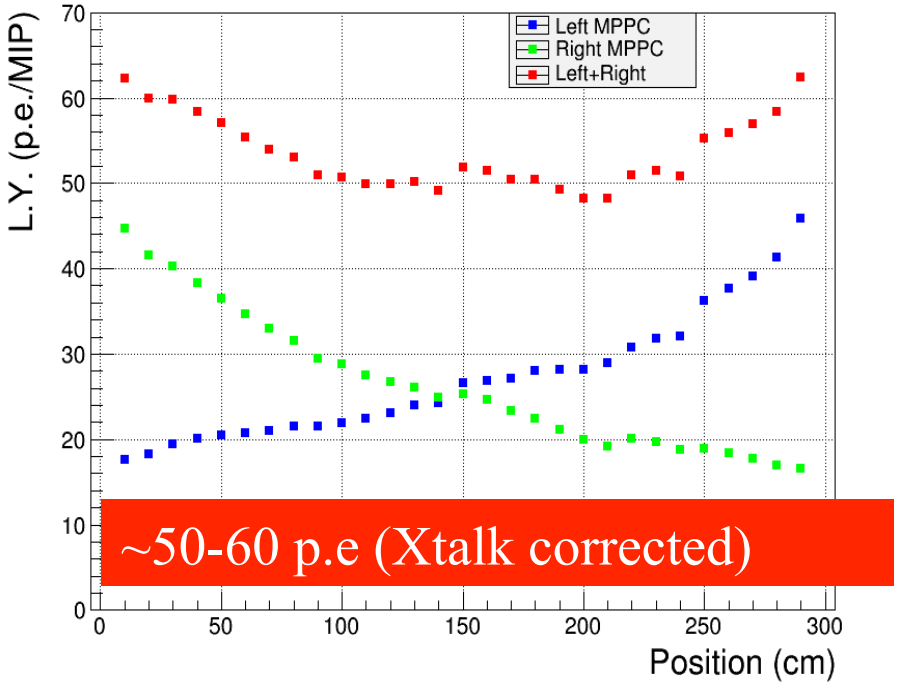
1) Positive identification of signals with muons in the final state with high efficiency:

Test beam held in October ‘15 at T9 area, CERN PS (see A. Montanari’s talk):

Light yield for NICADD bar



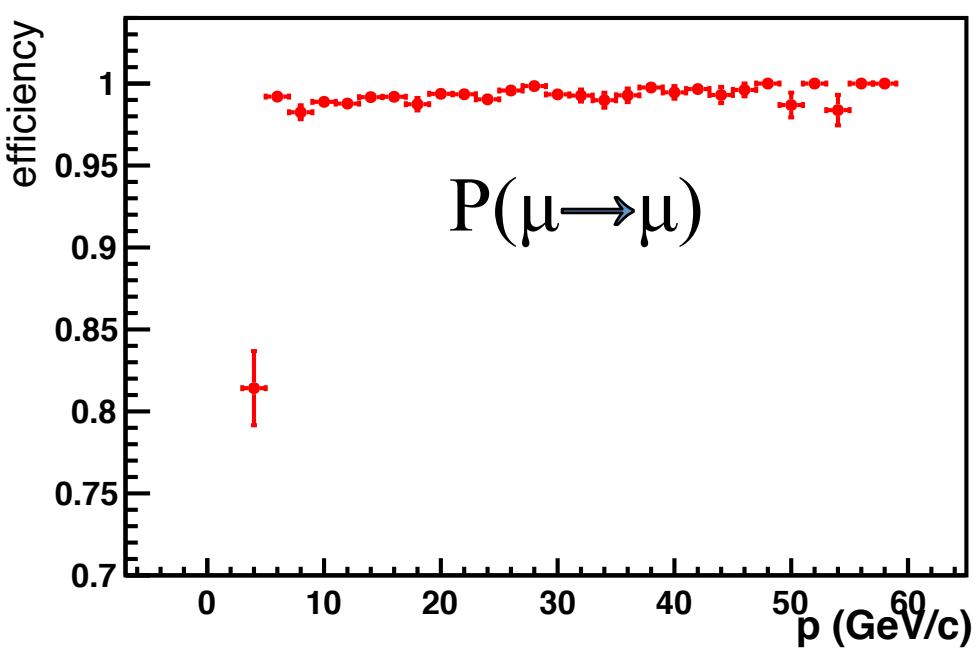
Light yield for Russian bar

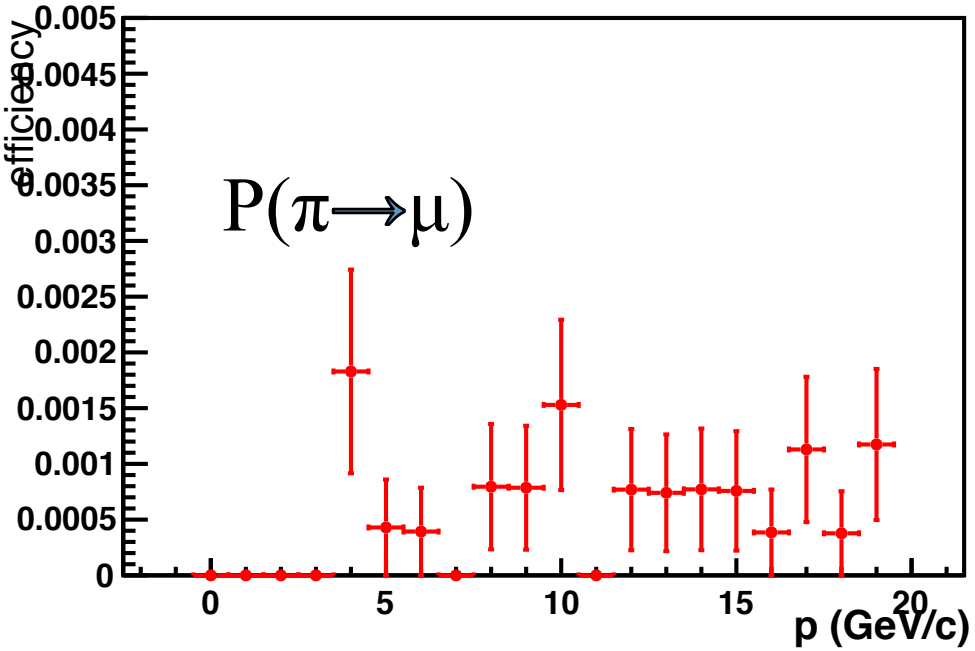


Efficiency > 98% for 3 m long bars

2) Mild separation between muons and hadrons/electrons:

Simple request of hits in Fields of Interest with width region and momentum dependent obtained for the Technical Proposal with ~0.5 M muons/pions without magnetic field.
To be redone with magnetic field (extrapolator available, thanks to T. Ruf).





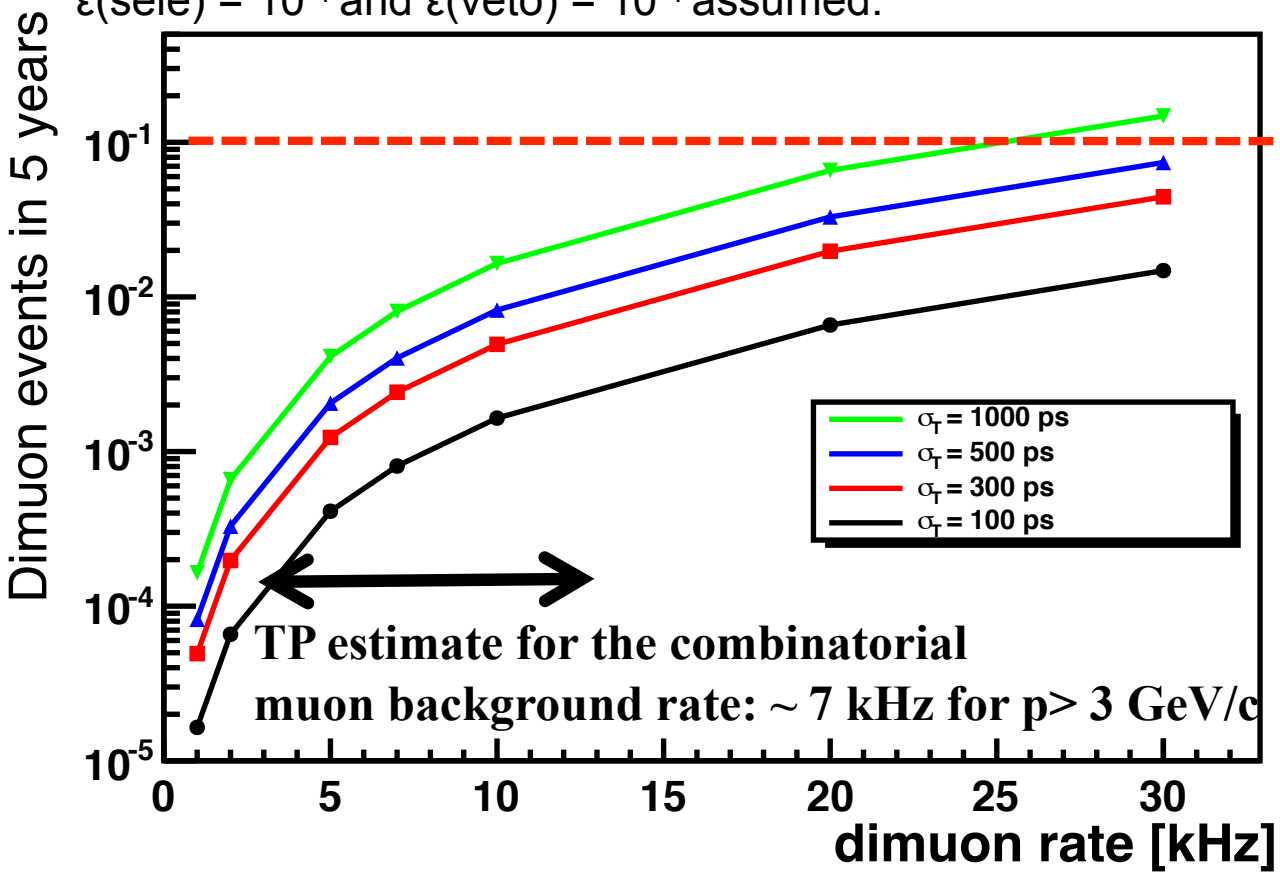
Simple request of hits in some fields of interest in muon stations gives >99% muon efficiency for < 10^{-3} pion mis-identification

⟶ more than needed, system seems overdesigned.

3) Muon combinatorial background:

Random combinations of residual muon flux from proton interactions in the target can mimic signal if they form a (fake) vertex in the fiducial volume.
For 4×10^{13} pot/spill 1 sec long, several kHz of muons after the active filter are expected in acceptance: **→ effectively rejected via a short time-coincidence.**

Reconstructed, selected and not-vetoed di-muon events in 5 years in time window $\Delta T = 3.29\ \sigma_T$ (99.9%) as a function of the muon flux after the active filter.
$\varepsilon(\text{sele}) = 10^{-4}$ and $\varepsilon(\text{veto}) = 10^{-4}$ assumed.

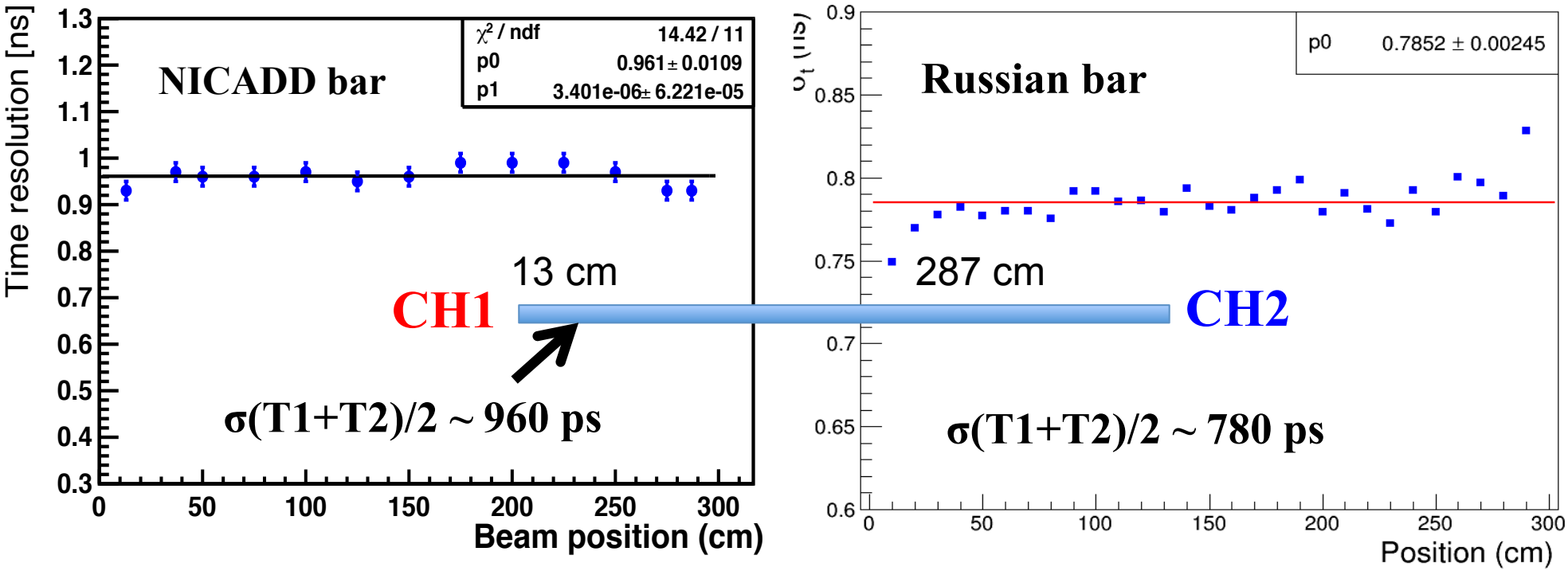


< 0.1 event/5 years

~1 ns time resolution seems to be adequate up to 4 times the rate assumed in the TP

Test beam, October 2015, T9 area, CERN PS (see A. Montanari's talk):

Time resolution vs beam position

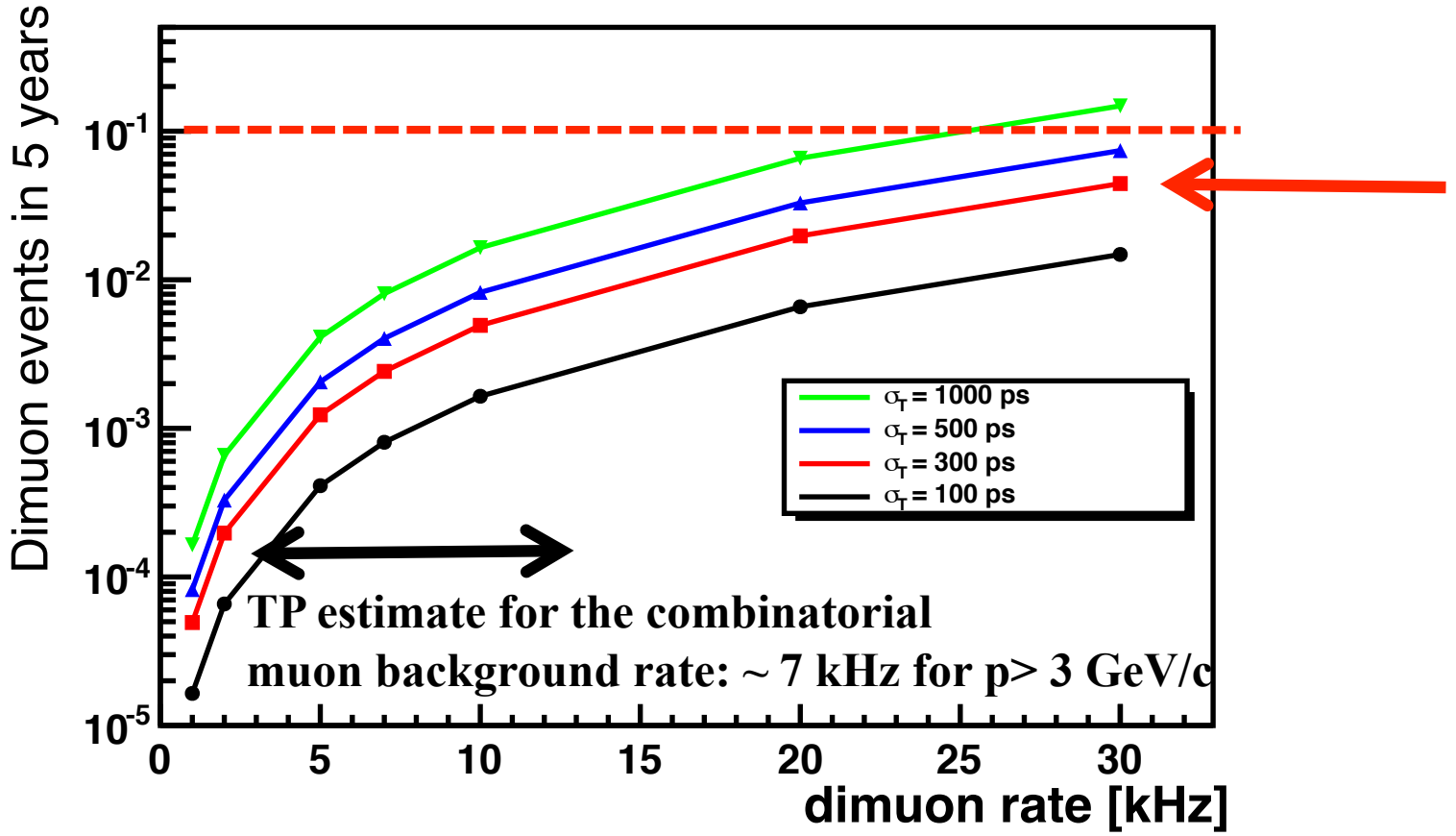


Time resolution for double-end readout is ~ **constant at 0.8-1.0 ns** over 3 m long bar.

A muon system with 4 stations, 2 views/station can provide time information with an accuracy of σ_t ~280 ps

Test beam, October 2015, T9 area, CERN PS (see A. Montanari's talk):

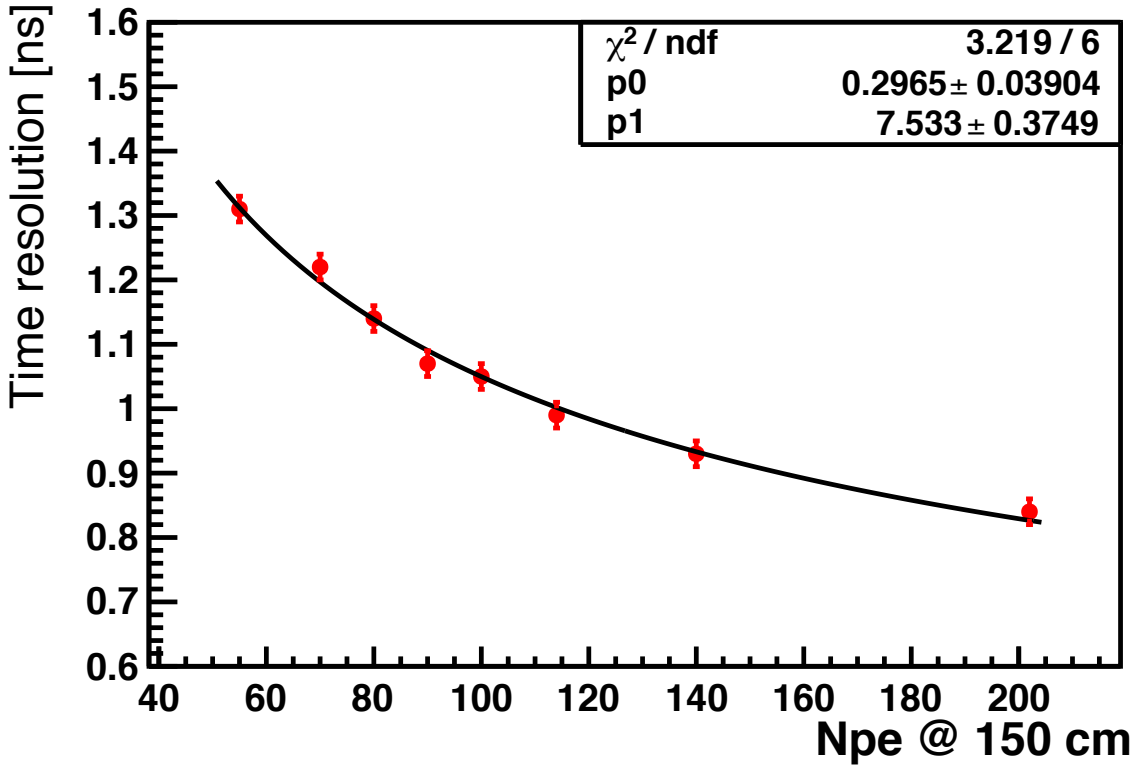
Time resolution vs beam position



A muon system with 4 stations, 2 views/station can provide time information with an accuracy of σ_t ~280 ps

Test beam, October 2015, T9 area, CERN PS (see A. Montanari's talk):

Dependence of the time resolution with the integrated charge:



Points fit with the function: $\sigma(t) = p0 + p1/\sqrt{Npe}$

Asymptotic limit for time resolution is ~0.3 ns.

Still margin to improve.

R&D towards the Comprehensive Design Report

1) Optimization of the general layout: **12/2016**

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

2) Final choice of the scintillator types, fibers, SiPM and bar dimensions: **6/2017.**

3) FEE (design, prototypes and test): **6/2018**

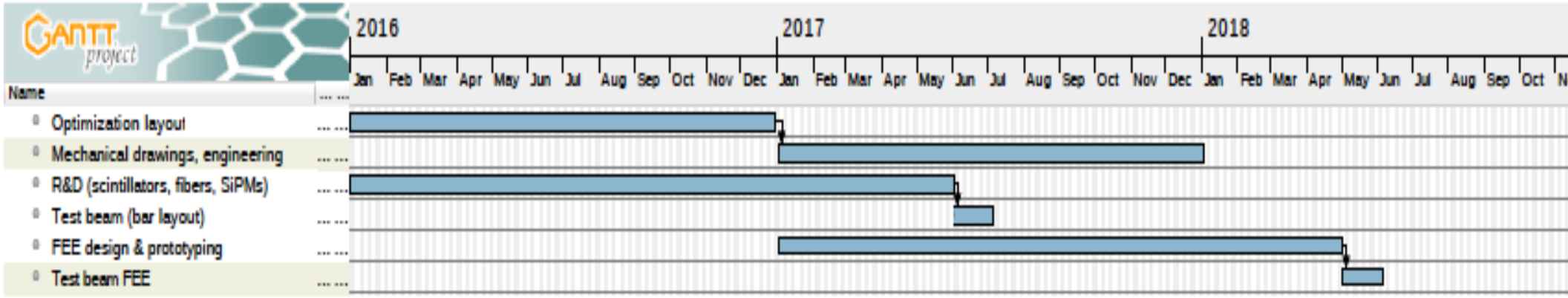
3.1) design of a motherboard with:

- 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**:

3.2) design of a **TDC board with 100 ps time resolution** with data processed, zero suppressed, formatted, stored in local buffer and sent to the FARM;

3.3) **beam test** of a final module instrumented with final electronic chain;

R&D towards the Comprehensive Design Report: interconnections between projects



Optimization of the general layout: cost

	Cost/unit ($)	Quantity	Cost (k$)
scintillating bars	25/ kg	11,5 t	288
WLS fibres	4 /m	23,000 m	92
SiPMs	30/ each	7 680	230
FEE	100 /channel	7 680	768
cables SiPM-FEE (including connectors and tooling)	25/channel	7 680	192
cables FEE-Ethernet concentrators (including connectors and tooling)	–	–	25
plugs and optical connectors WLS fibre-SiPM	10/pc	7 680	77
bar instrumentation	30/bar	3 840	115
support structure	–	–	280
support panels for the bars	56,000/pc	4	230
trailer tracks for support panels	28,000/each	4	113
installation (including toolings, mechanics, etc.)	–	–	100
Total (w/o iron filters)	–	–	2 510
iron filters	2.5 /kg	930 t	2 330
Total (w iron filters)			4 840

Current cost estimate: 2.5 M (active part) + 2.33 (passive filters, in kind?) = 4.84 M$

Drop one station → **save 25% of the total cost**

Increase bar width from 5 cm → 10 cm (halve cost of FEE, cables, SiPMs, connectors):

→save 20% of the total cost (~0.8 M$)

Resources needed for the Comprehensive Design Report

Item	Cost (kEuro)
2 test beams	2x10
R&D on scintillators, fibers, SiPMs	10
FEE mother board (design, prototypes)	15
FEE TDC board (design, prototypes)	15
TOTAL	**60**

Item	Person power 2016-2018
Optimization general layout, PID performance	1.0 FTE (physicist)
R&D scintillators, fibers, SiPMs (including test beams)	2 FTE (physicists) + 0.5 FTE (technicians)
Mechanical drawings, engineering	1 FTE (mechanical engineer)
FEE design, prototypes	1.5 FTE (electronic engineers)

Conclusions

- R&D for the muon system well on track.
- Milestones clearly identified.
-Resources required for the Comprehensive Design Report seems to be within the reach of our Institutes but collaboration with new groups is welcome.