SHiP
Search for Hidden Particles

SHiP Project in the Comprehensive Design Study phase and beyond

“τSHiP, νSHiP, iSHiP, dSHiP”

Richard Jacobsson

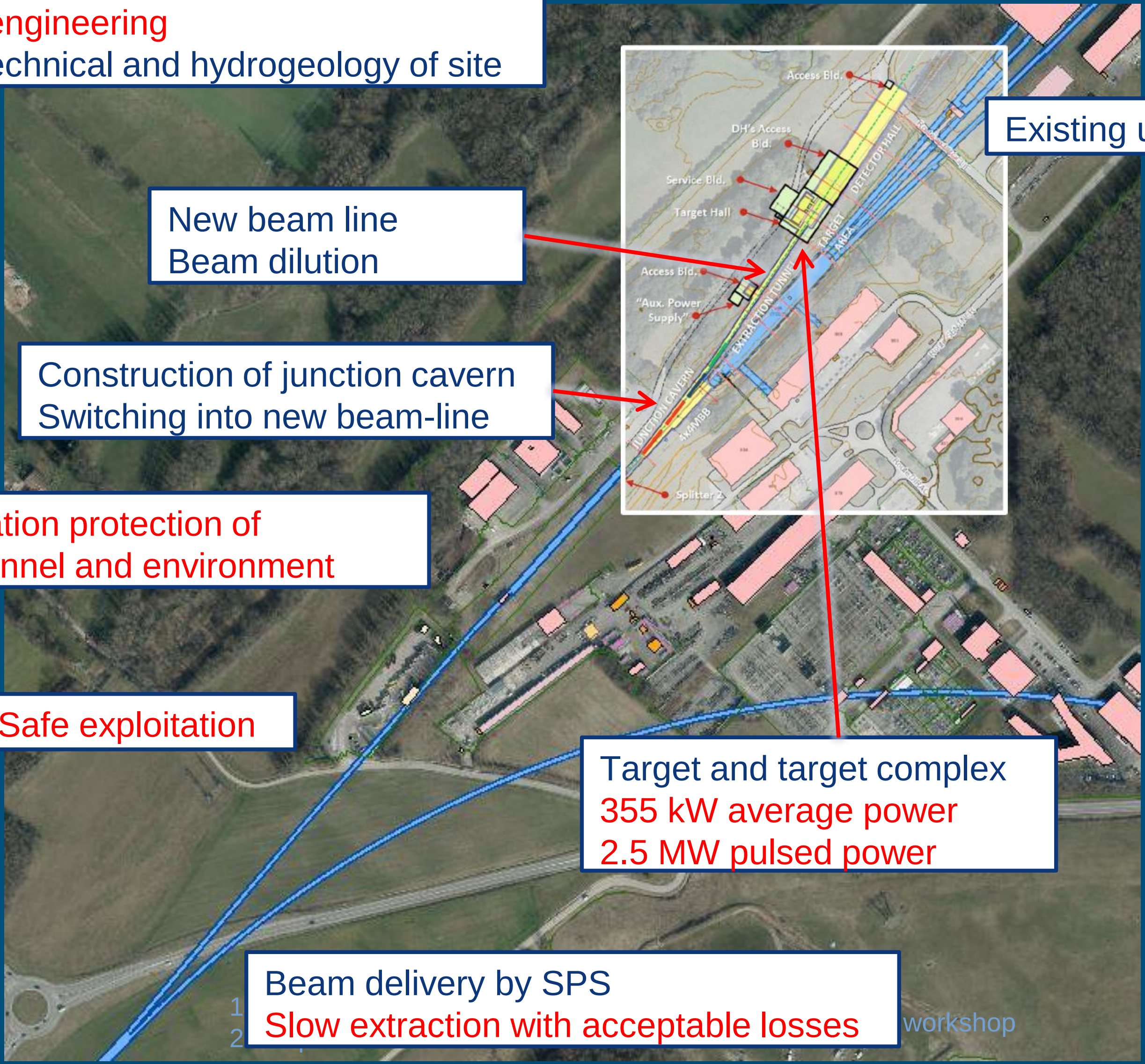
Key messages:

- An SPS Beam Dump facility opens the door to many possibilities with a GPD!
- SHiP : Zero background experiment ➔ challenging and requiring detector redundancy
- R&D and prototyping for CDS and TDR (calorimetry, see Walters talk)
- Test beams and cosmics setup

SHiP Project Structure: http://cern.ch/ship/Constitution/Project_structure.html

Beam Dump Facility WG

- Critical technical studies under PBC as specified in the SHiP Technical Proposal



Civil engineering
Geotechnical and hydrogeology of site

Existing users

New beam line
Beam dilution

Construction of junction cavern
Switching into new beam-line

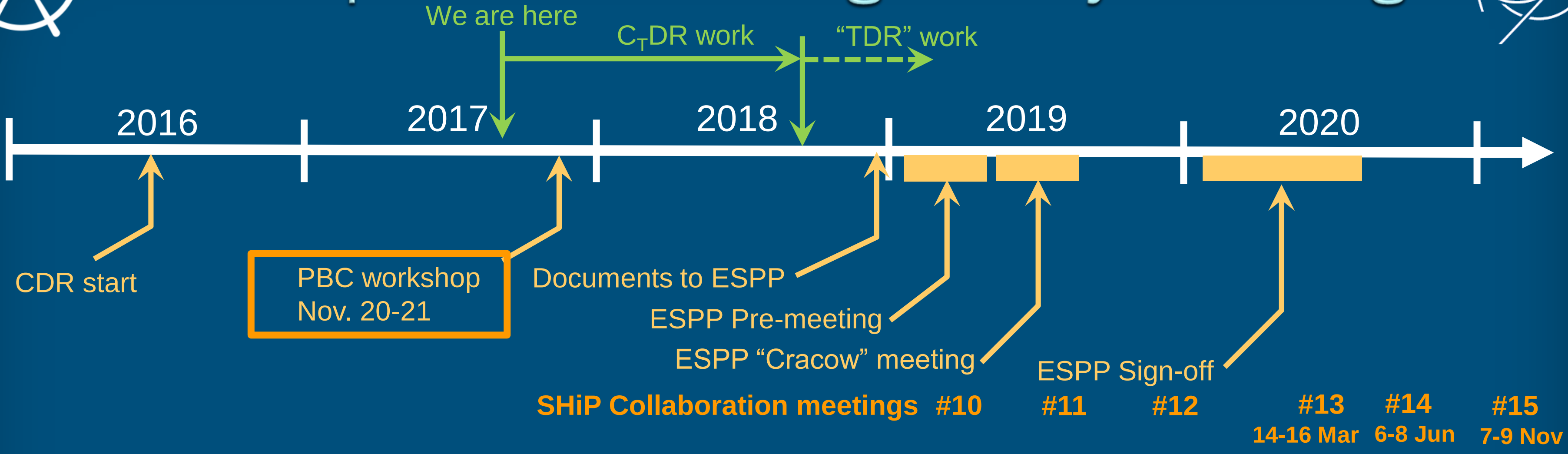
Radiation protection of
personnel and environment

Safe exploitation

Target and target complex
355 kW average power
2.5 MW pulsed power

Beam delivery by SPS
Slow extraction with acceptable losses

Comprehensive Design Study Planning



We are here

C_TDR work

“TDR” work

2016

2017

2018

2019

2020

CDR start

PBC workshop
Nov. 20-21

Documents to ESPP

ESPP Pre-meeting

ESPP “Cracow” meeting

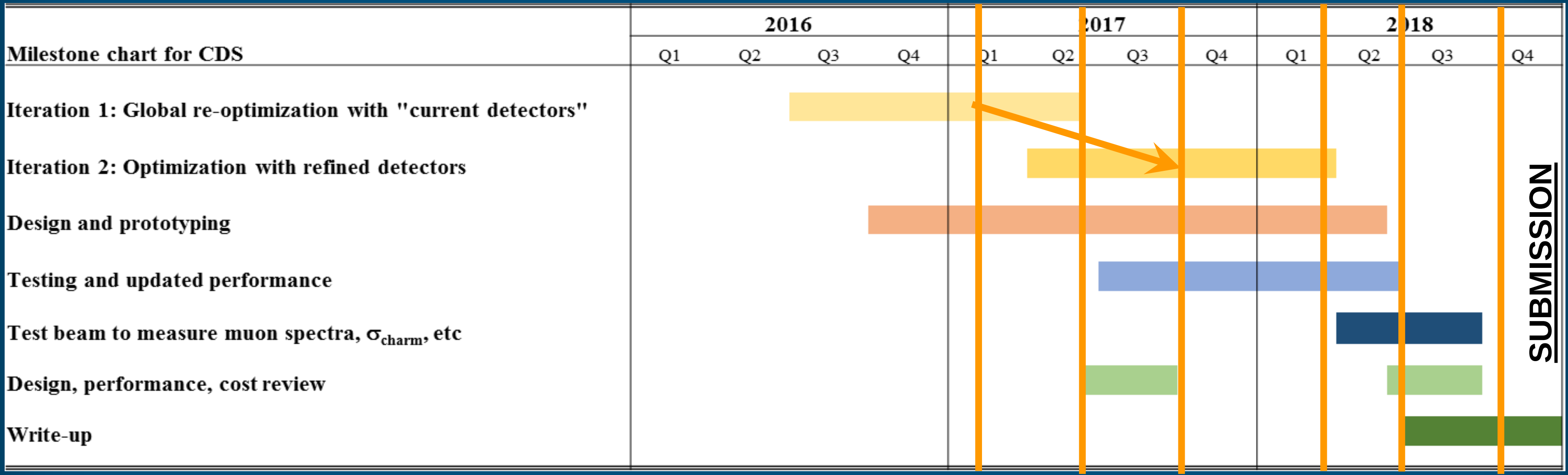
ESPP Sign-off

SHiP Collaboration meetings #10 #11 #12 #13 #14 #15

14-16 Mar

6-8 Jun

7-9 Nov



Milestone chart for CDS

2016: Q1 Q2 Q3 Q4 · 2017: Q1 Q2 Q3 Q4 · 2018: Q1 Q2 Q3 Q4

Iteration 1: Global re-optimization with "current detectors"

Iteration 2: Optimization with refined detectors

Design and prototyping

Testing and updated performance

Test beam to measure muon spectra, σ_{charm}, etc

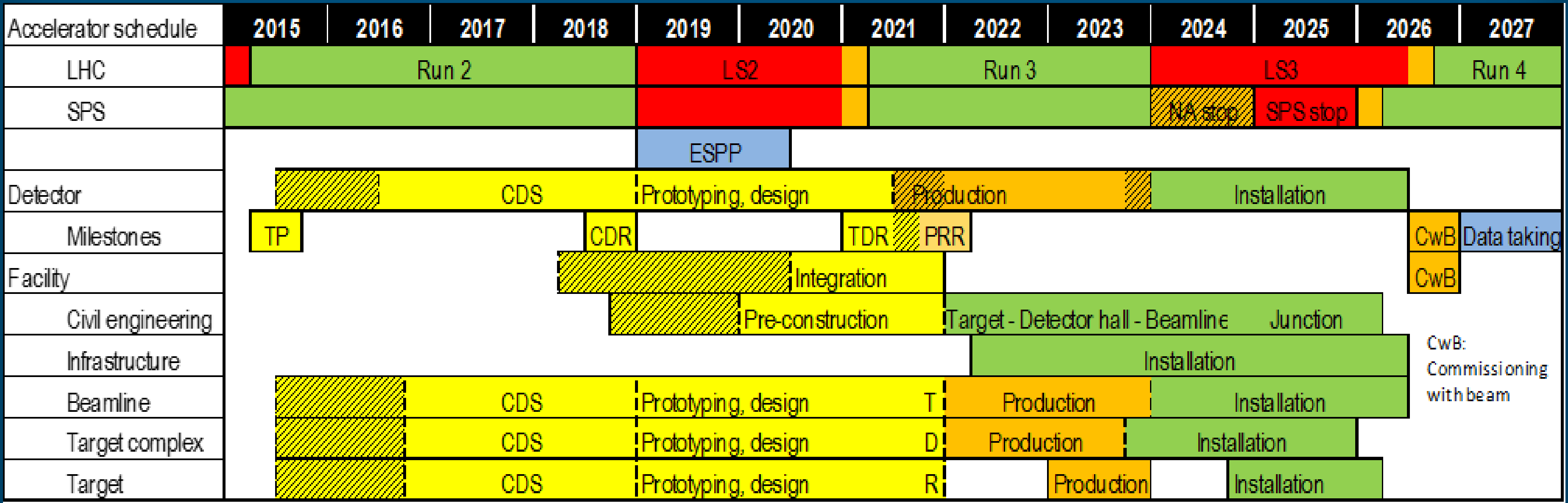
Design, performance, cost review

Write-up

SUBMISSION

- ➔ Current main topic: strategy to define baseline detector for CDS
- ➔ But CDS will not aim at selecting technologies
- ➔ Ideal time to introduce new ideas and new contributions

SHiP Master Schedule



Accelerator schedule	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LHC			Run 2			LS2		Run 3			LS3		Run 4
SPS										NA stop	SPS stop		
					ESPP								
Detector			CDS		Prototyping, design			Production			Installation		
Milestones	TP			CDR			TDR	PRR				CwB	Data taking
Facility						Integration						CwB	
Civil engineering						Pre-construction		Target - Detector hall - Beamline			Junction		
Infrastructure										Installation			
Beamline			CDS		Prototyping, design		T	Production			Installation		
Target complex			CDS		Prototyping, design		D	Production		Installation			
Target			CDS		Prototyping, design		R		Production		Installation		

CwB: Commissioning with beam

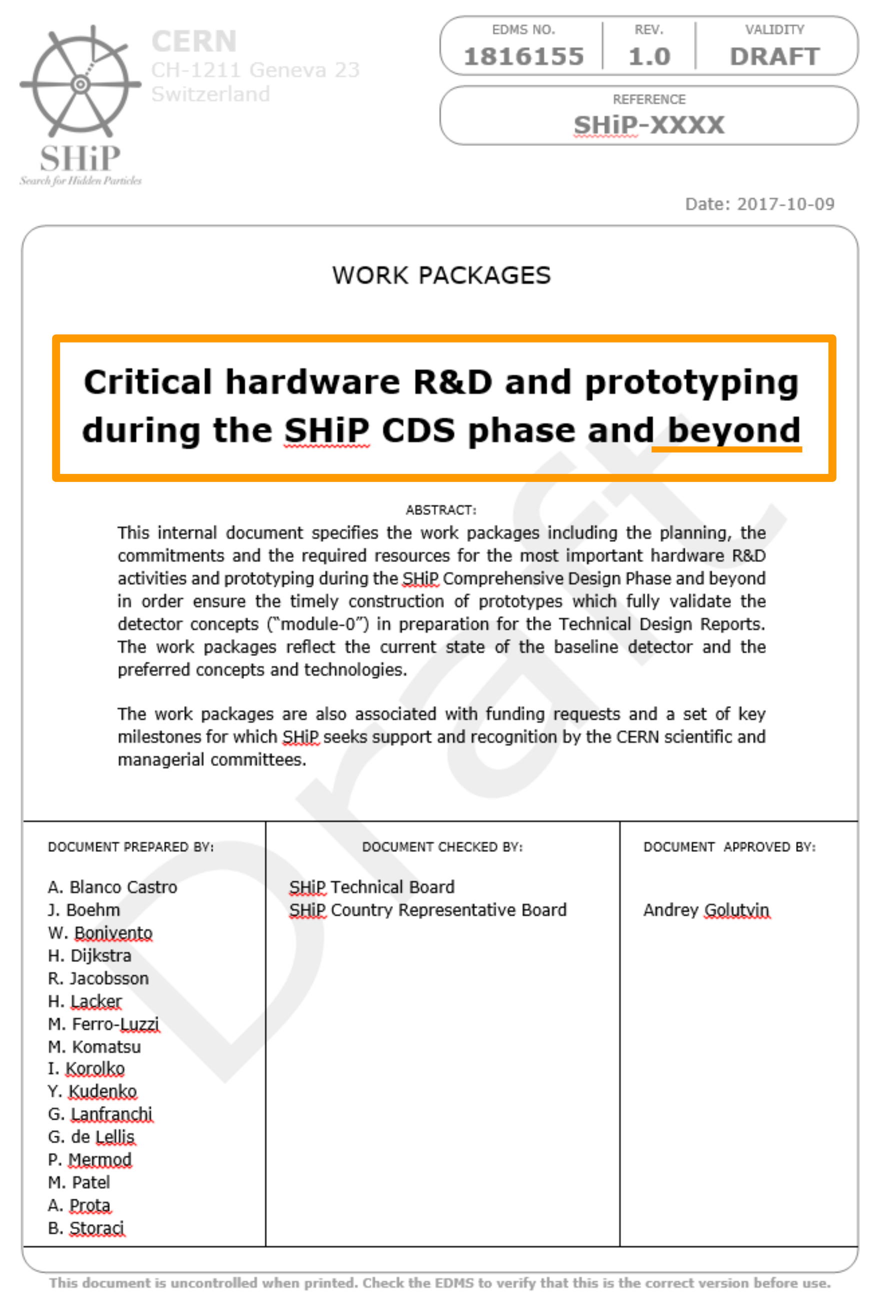
- Time line for TDRs is critical ➔ 2016 – 2018 is ON the path to TDR
- Main challenge of 2019 – 2021 is the availability of test beam facilities
  - Apply for beam time at other facilities
  - Investigating common cosmic test rig at CERN
    - Contributions very welcome, across experiments

- Description of the prototyping motivation and planning
- Small scale prototype→"module-0"
- Level of criticality and the time scale
- Groups participating
- Expected required resources and financial situation to achieve the plan

- Strategy presented to SPSC referees in June
- Complete draft to be discussed with SPSC referees next week

➔ Including estimates on funding requests up to "Module-0"

<u>Approved by January 2018</u>



CERN
CH-1211 Geneva 23
Switzerland

EDMS NO.	REV.	VALIDITY
1816155	1.0	DRAFT

REFERENCE
SHiP-XXXX

Date: 2017-10-09

WORK PACKAGES

Critical hardware R&D and prototyping during the SHiP CDS phase and beyond

ABSTRACT:

This internal document specifies the work packages including the planning, the commitments and the required resources for the most important hardware R&D activities and prototyping during the SHiP Comprehensive Design Phase and beyond in order ensure the timely construction of prototypes which fully validate the detector concepts ("module-0") in preparation for the Technical Design Reports. The work packages reflect the current state of the baseline detector and the preferred concepts and technologies.

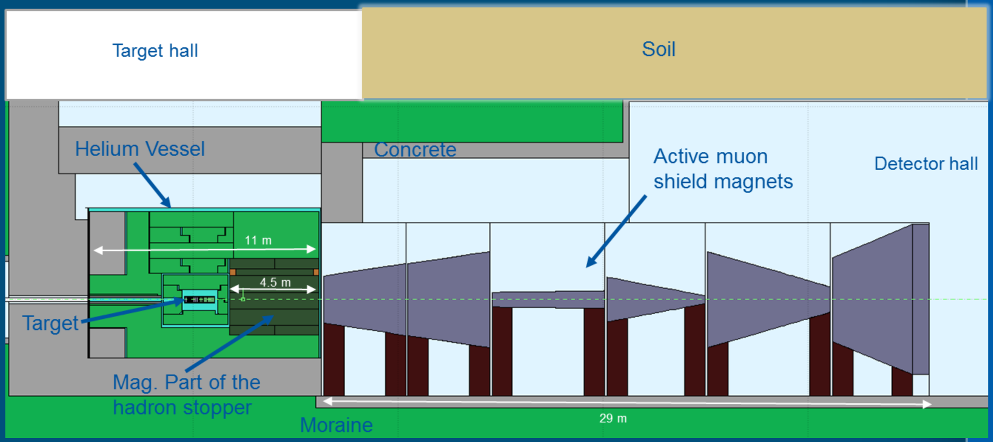
The work packages are also associated with funding requests and a set of key milestones for which SHiP seeks support and recognition by the CERN scientific and managerial committees.

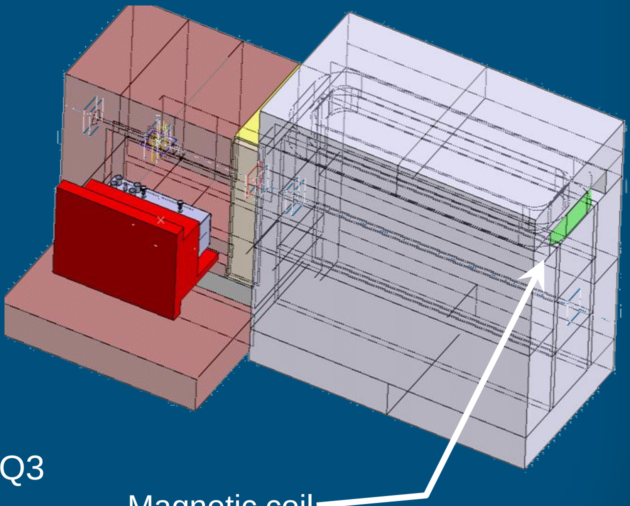
DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
A. Blanco Castro	SHiP Technical Board	
J. Boehm	SHiP Country Representative Board	Andrey Golutvin
W. Bonivento		
H. Dijkstra		
R. Jacobsson		
H. Lacker		
M. Ferro-Luzzi		
M. Komatsu		
I. Korolko		
Y. Kudenko		
G. Lanfranchi		
G. de Lellis		
P. Mermod		
M. Patel		
A. Prota		
B. Storaci		

Magnetization of hadron stopper

CERN(EP, EN/STI), RAL(UK), MISiS (RU)

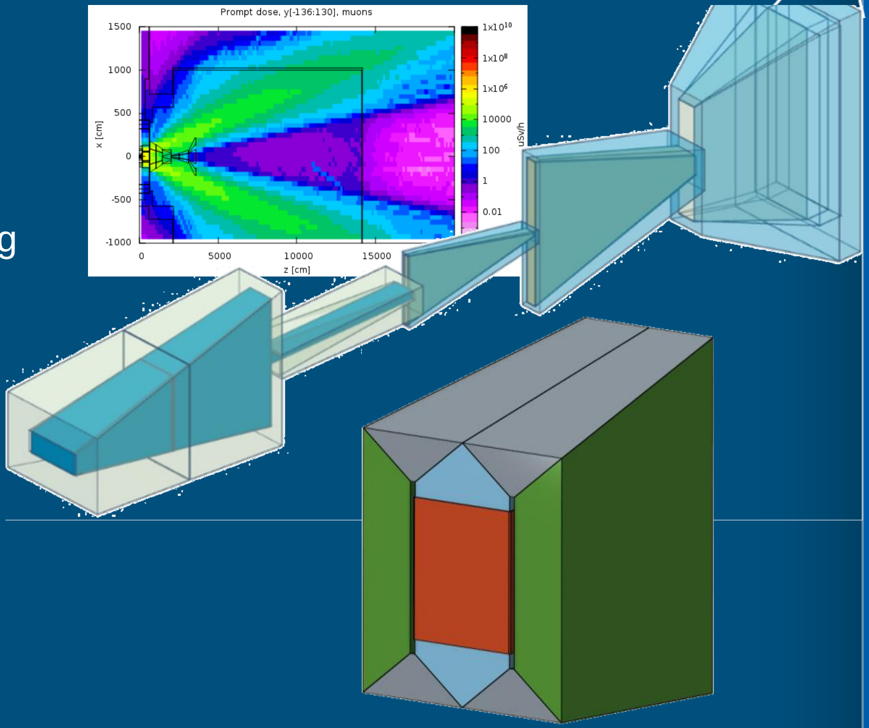
- Challenging in extreme environment
- Very strict constraints on integration, access, thermal and magnetic stresses, cooling circuit radio-activation
- Studies and challenges
  - Realistic field map from magnet modelling
  - Coil assembly
  - Insulation properties
  - Heat conductivity
  - Heat removal with external heat exchangers
  - Electrical connections
  - Handling issues
  - Durability by multiple energisation
  - Radiation resistance
- Milestones
  - Reduced scale prototype-0: 2019-Q2
  - Module-0 with cooling system and final power connections: 2020-Q3



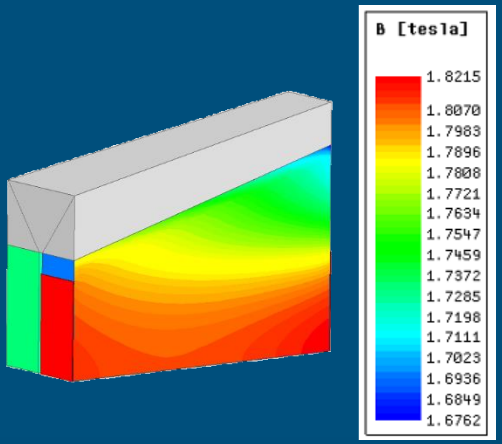


Muon shield “gun”

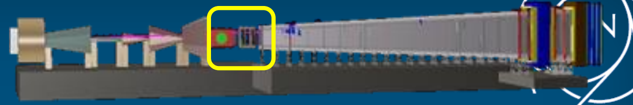
Imperial College London(UK), MISiS(RU), RAL(UK), CERN(EP)



- Global optimization still ongoing using machine learning
- Main challenge
  - Narrow separation between field directions
  - Aiming for 1.8T field density to minimise overall length with grain oriented 0.3mm steel sheets, allowing lower power and air cooling
  - Manufacturing and assembly
- Prototyping most challenging magnet
  - Reduced scale allowing test of all aspects and produce accurate costing
- Milestones
  - Prototype-1 in test beam: 2018-Q4
  - Further prototyping depends on outcome of the first prototype

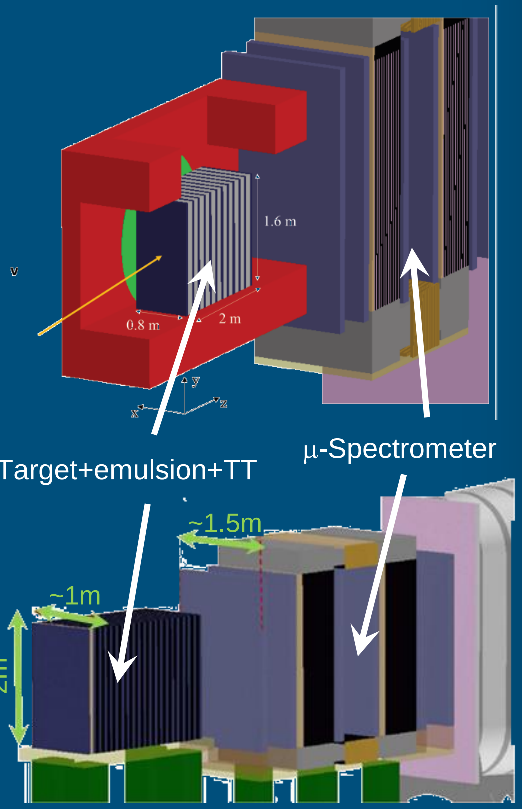


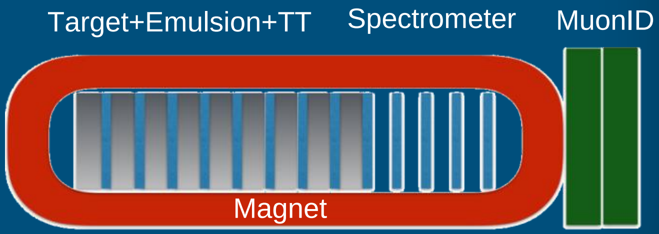
ν/iSHiP detector



Naples(IT), Bari(IT), INFN-LNF(IT), Roma (IT), INFN-Gran Sasso(IT), Nagoya(JP), Aichi(JP), Kobe(JP), Nihon(JP), Toho(JP), Kodel(KR), Gyeongsang (KR), Yandex(RU), SINP MSU(RU), LPI(RU), MISiS(RU), NRC KI (RU), METU(TR), Imperial College London(UK), EPFL(CH)

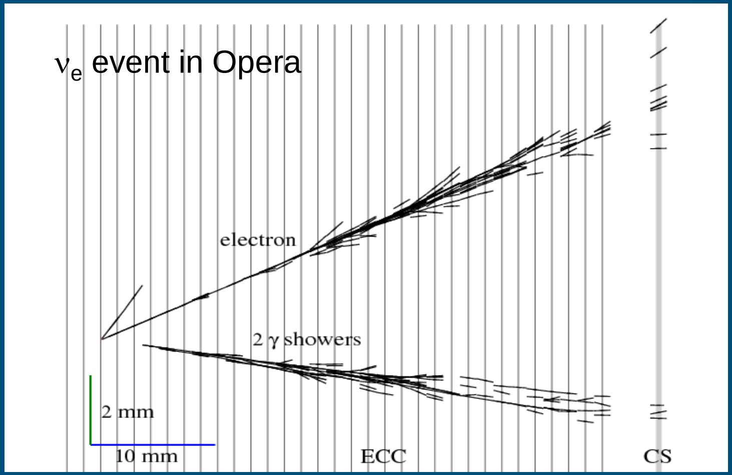
- Three global options:
  1. Magnetic field over emulsion and muon spectrometer
     - ➔ ν_τ muonic and hadronic modes but small target mass (7 tonnes)
     - ➔ Muon spectrometer with RPCs and straw tracker
  2. No magnetic field over emulsion target and muon spectrometer
     - ➔ ν_τ muonic modes only but large target mass (28 tonnes)
     - ➔ Muon spectrometer with RPC and straw tracker
  3. Extended magnetic field over emulsion and air spectrometer, and muonID
     - ➔ ν_τ muonic and hadronic modes AND large target mass
     - ➔ Compact size muonID with RPCs or plastic scintillating bars or tiles
- Basic emulsion spectrometer elements
  - Target/Emulsion Cloud Chamber
  - Target tracker (100μm, ns), options SciFi or gaseous detectors (GEM,μ-RWELL, micromega)
  - In option 3, spectrometer tracker with SciFi





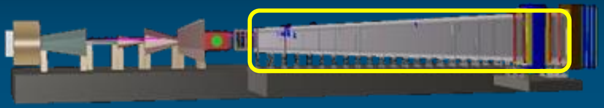
ν/iSHiP detector, cont'd

- Studies and challenges
  - Background studies
  - Geometric constraints
    - Muon shield optimization and dSHiP location
  - Emulsion Cloud Chamber
    - Acts as neutrino target, micrometric track reconstruction, fine grained electromagnetic calorimeter
    - Optimization of material thicknesses and absorber material
    - Develop pattern recognition by machine learning
  - Compact Emulsion Spectrometer (CES) for
    - Validation of the CES concept with data
  - Target Tracker (TT):
    - Connect tracks with spectrometer and muonID
    - High efficiency (>99%) for angles up to 1 rad
    - Act as electromagnetic and hadronic calorimeter
  - Design of magnet



- Milestones
  - Validation of technological solutions, design optimization and detector configuration: 2018-Q2
  - Construction and test of different configurations of the ECC modules at DESY: 2019-Q4
  - Full longitudinal slice of final configuration with module-0's of emulsion target with EM shower detection and spectrometer in test beam with magnet at CERN: 2021-Q2

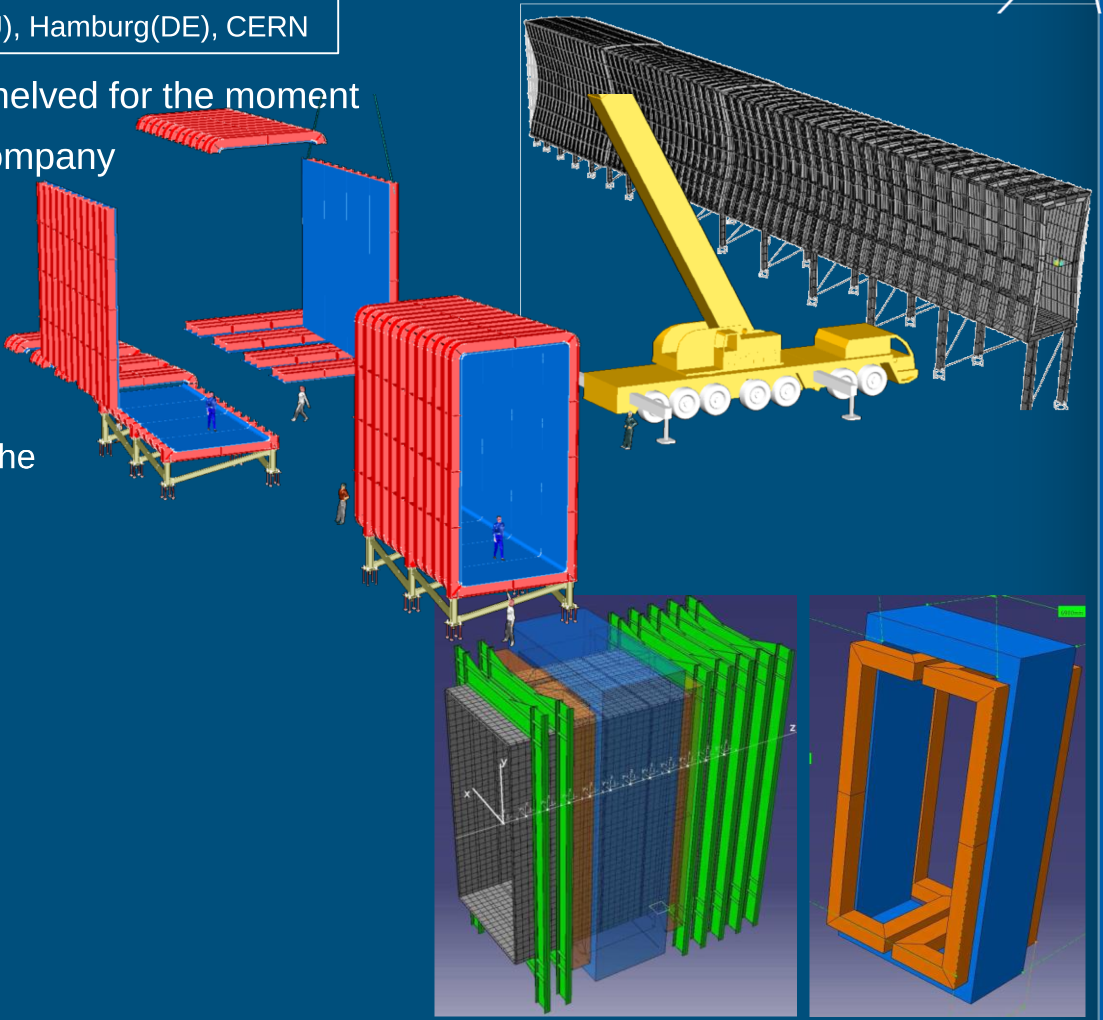
Vacuum vessel



Naples University (IT), MISIS(RU), NRC KI (RU), Hamburg(DE), CERN

- Vacuum option baseline, helium balloon shelved for the moment

➔ Very good progress in collaboration with company



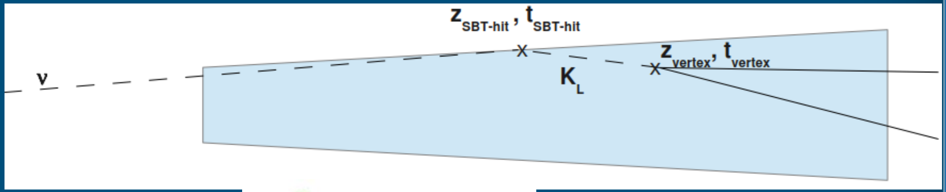
- Vacuum vessel consists of five sections
  - Front-cap
  - Decay volume
  - Straw tracker sections (x2)
  - Spectrometer magnet section including the spectrometer magnet
  - End-cap
- Challenges
  - Light-weight and “thin”
  - Cost
  - Manufacturing, transport and assembly
  - Mechanical interfaces
- Prototyping
  - Review with experts at CERN for CDS
  - Small scale prototype (manufacturing technique, system integration): 2019-Q4
  - Module-0 including front/end-cap technology constructed and tested: 2020-Q4

  - Straw tracker sections to be prototyped with straw tracker

Surrounding and Upstream Background Tagger

Berlin (GE), Geneva (CH), ITEP(RU), Kyiv (UA), Mainz (GE), Napoli (IT), Orsay(FR)

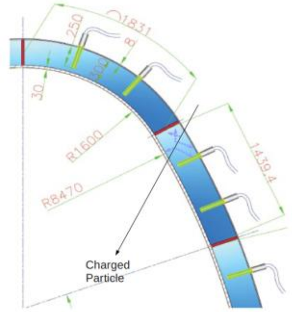
- Includes upstream veto system, two options
  - Liquid scintillator modules, linear alkylbenzene (LAB) with PMT or SiPM
  - Plastic scintillator with SiPM



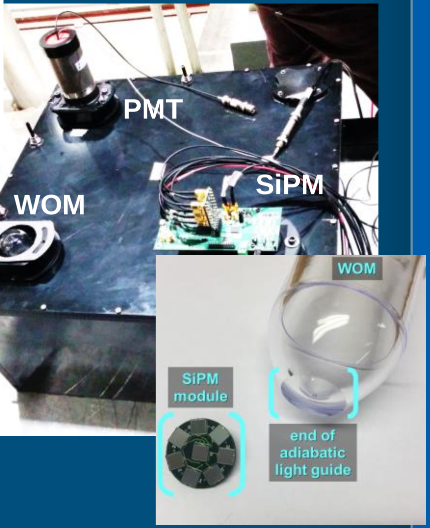
- Studies and challenges
  - Physics requirements (large hit rates)
  - Mechanical integration

LiqSci
  - Optimization of light-yield (LS composition, module, dimension, wall reflectivity, circulation, WLS)
  - Proof-of-principle detector for the LS-WOM detector technology

PlSci
  - Granularity
  - Light-yield and detection efficiency (particle incident at small angles)
  - Layering
  - ➔ Plastic scintillator well-known technology, synergy with other SHiP detectors



Test beam Sep 2017



- Milestones

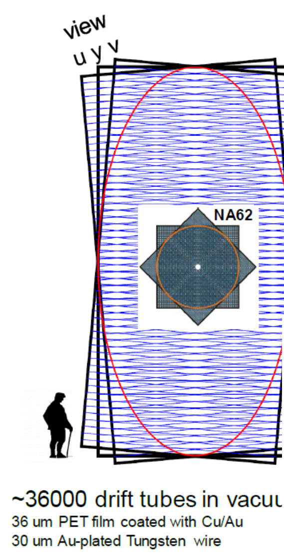
LiqSci
  - Prototype-0 (small scale box with several WOMs) constructed and tested: 2017Q4
  - Prototype-1 (small scale box with several WOMs) constructed and tested: 2018Q4
  - Module-0 constructed and tested with cosmics: 2019Q4
  - Module-0 tested with test beam including photo-sensor and readout scheme: 2020Q2

PlSci
  - Prototype-1: Construction of prototype plastic counters and tests with different SiPMs: 2019-Q2
  - Module-0 test in cosmics: 2020-Q4
  - Final tests of plastic counters at CERN: 2021-Q2

Spectrometer straw tracker

Hamburg(DE), JINR Dubna (RU), Kyiv(UA), PNPI/Polytec(RU), CERN

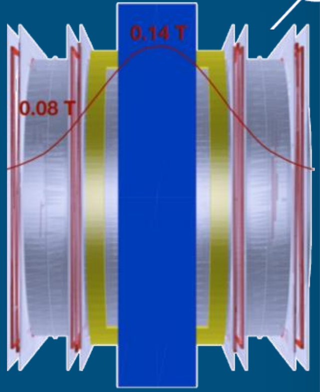
- Straw tracker made up of 5m thin polyethylene terephthalate (PET) tubes
  - 4 views (Y, U, V, Y) for each station
  - Expected 10^7 hits/station in 1 s ==> 2kHz/straw (NA62 500 kHz/straw)
- Studies and challenges
  - Straw optimization (diameter, wire, coating, gas, HV)
  - Wire/tube sagging under gravity, strain, gas pressure, fields
  - Mechanical mounting of straw stations (assembly procedure)
  - Integration of services
  - Insertion in vacuum vessel
- Milestones
  - Prototype straw array constructed and tested: 2018-Q4
  - First station: 2019-Q3
  - Module-0 testing in vacuum:2020-Q1



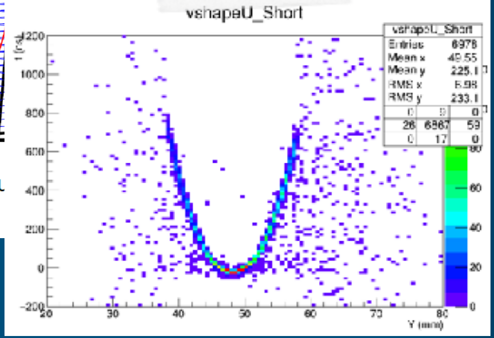
~36000 drift tubes in vacuu

36 um PET film coated with Cu/Au

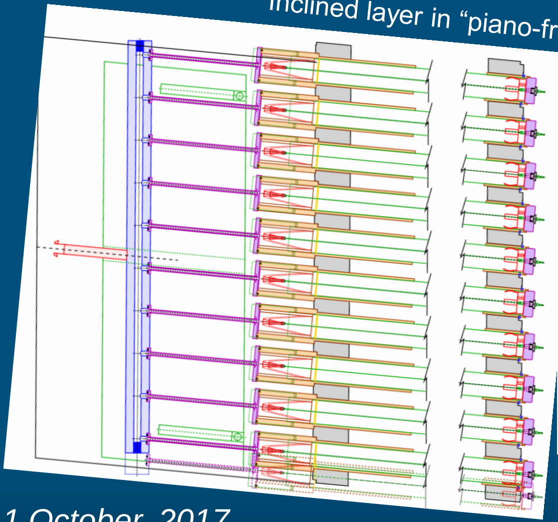
30 um Au-plated Tungsten wire



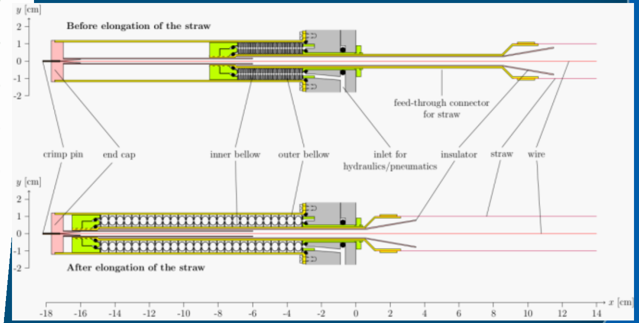
Test beam Sep 2017



Inclined layer in "piano-frame"



Wire/tube tensioning



Spectrometer timing detector

Geneva(CH), Zurich(CH), LIP(PT), Barcelona(ES), Orsay(FR)

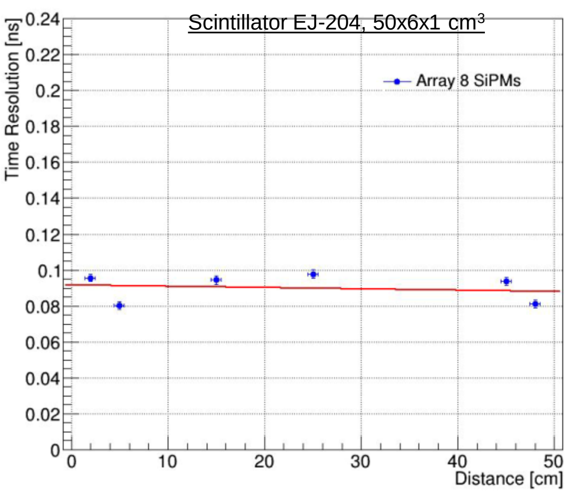
- Suppression of combinatorial di-muon background by coincidence with a timing resolution of ≤100 ps
- Two options
  - Plastic scintillators read-out by PMT or large area SiPMs (6x6mm^2)
  - Multigap resistive plate chambers (MRPCs) with 6 x 0.3mm gaps
- Studies and challenges

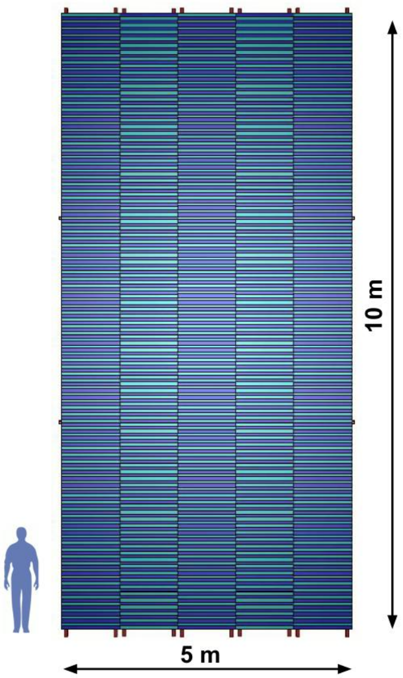
  PlSci
  - Scintillating bar dimensions
  - SiPM configuration
  - Electronics
  - Timing alignment of 50 m^2
  - Mechanics
  - MRPC developed for HADES
- Milestones:

  PlSci
  - Mechanical design and final optimization of single element: 2018-Q1
  - Prototype-1, 32 bars array (~1.7m of length): 2018-Q4
  - Module-0, 3x3 bars array (>5m of length): 2019-Q2

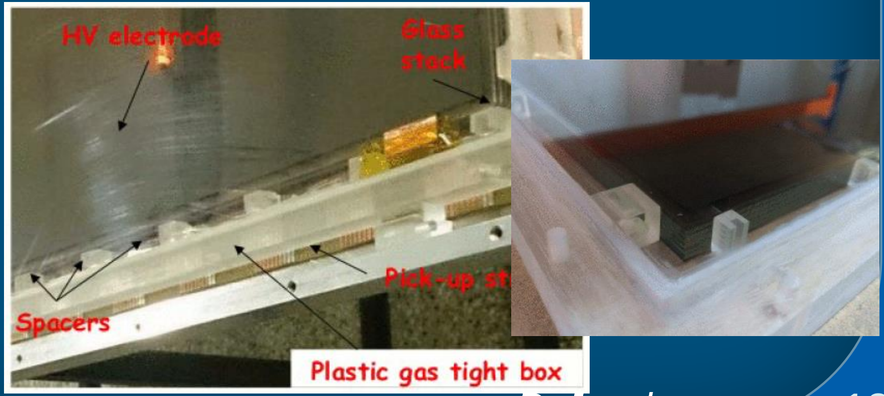
  MRPC
  - Full chain prototype-1: 2017-Q4

Test beam May 2017





Baseline: 3 x 168 cm



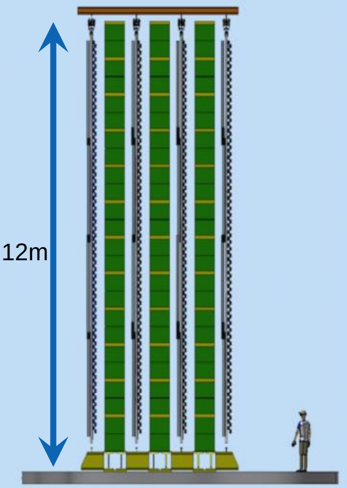
Calorimetry

INFN Cagliari (IT), University of Mainz (DE), LPNHE (FR)

- See Walter’s talk
- Vessel end-cap material is light
- Leaves open the possibility of staging

Downstream muon system

INRAS(RU), MEPhI(RU), INFN-Bologna(IT), INFN-Cagliari(IT), INFN-LNF(IT)



- Two options:
  - Four stations of active layers of extruded plastic scintillator strips with WLS fibers and SiPMs separated by three muon filters
  - Single layer of scintillating tiles of 10x20x1 cm^3 with SiPMs
- Studies and challenges
  - Future optimization of muon system depends on strategy for PID with calorimetry and physics requirements
  - Granularity depends on the overall multiple scattering
  - Optimization of thickness and dimensions of bars/tiles (light yield and timing studied with 3m bars in test beam)

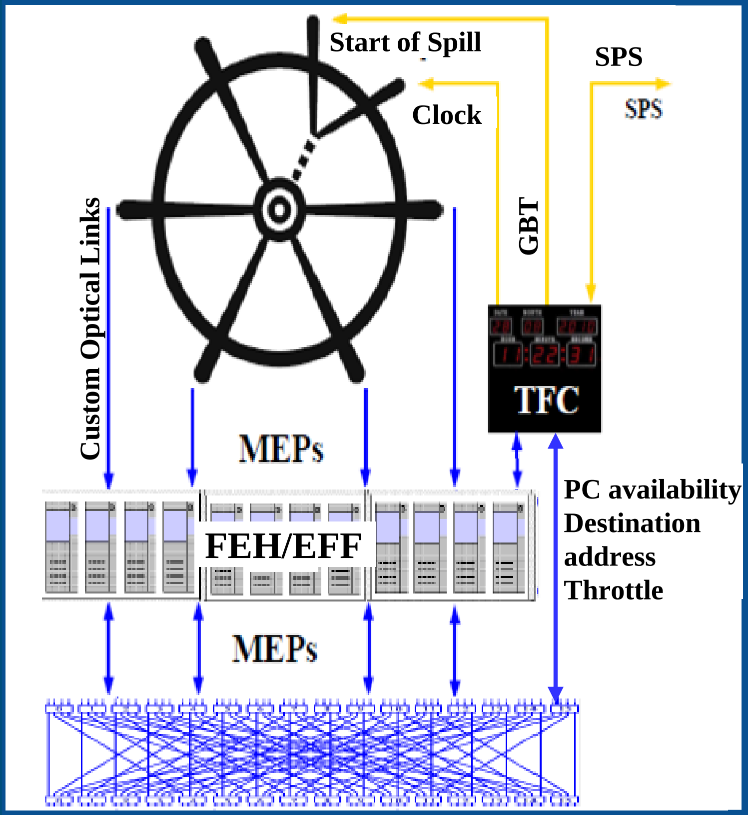
Scintillating tile 10x10x0..6 cm^3 ,
each side equipped with 3x3mm^2 SiPMs

- Milestones:
  - Prototype-0 (3 m long bars with WLS fibres and SiPMs readout) constructed and tested: 2017Q4
  - Prototype-1 (scintillating tiles with direct SiPM readout) constructed and tested: 2018Q4
  - Module-0 constructed and tested with cosmics: 2019Q4
  - Module-0 tested at a test beam including final version of the FEE: 2021-Q2

Online system

CERN, Niels Bohr(DK), Uppsala(SE), UCL(UK), Stockholm(SE), Orsay(FR)

- Main components
  - Front End (FE) electronics producing data
  - Timing controller (TFC)
  - Front End Host processes (FEH)
  - Event Filter processes (EFF)
  - Switched network, PCs, storage
- Studies and challenges
  - Data transport and format
  - System simulations
  - Online event reconstruction
  - Real-time event filter



- Milestones
  - DAQ demonstrator: 2018-Q1
  - Complete slice of online system (ECS, TFC, DAQ): 2020-Q1

Common electronics and services

Orsay(FR)

- SHiP electronics coordinators Jihane Maalmi and Dominique Breton
  - Electronics contacts appointed per subsystem
  - First electronics workshop October 25
- A very good time to define system architecture, investigate commonality, and evaluate existing solutions
  - How far upstream can commonality be defined considering today's programmability?
- No problem with huge data rates, synchronization, radiation, cooling, space constraints, access… just the opposite of what we are mostly faced with… only very scattered
  - Commercial, integrated, programmable, cheap, luxury…!
- Experimental infrastructure specs by end of the year for BDF integration and service studies

Computing

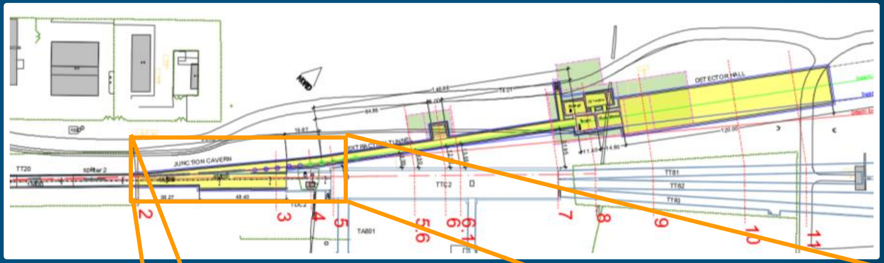
- Computing framework based on FairRoot ➔ FairSHiP

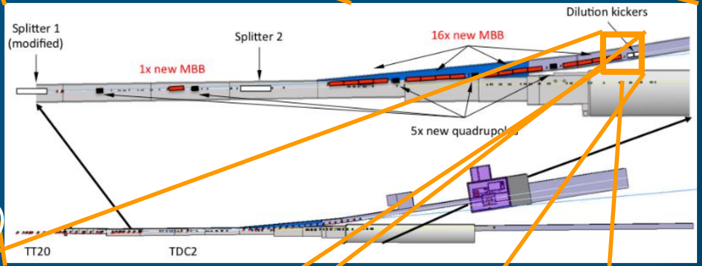
- Task list
    - Data base, the usage of time / version dependent conditions in the simulation / reconstruction
    - Job submission at Yandex or on the Grid, DIRAC-like
    - Methods of speeding up simulation of muon background
    - Detector digitization
    - Proper simulation of event time in the context of DAQ
    - Reconstruction (muon flux and charm measurement)
    - Online event filtering

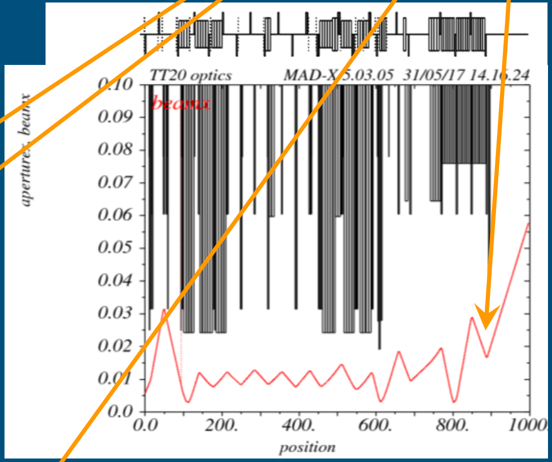
τSHiP

Opportunity for τ → 3μ

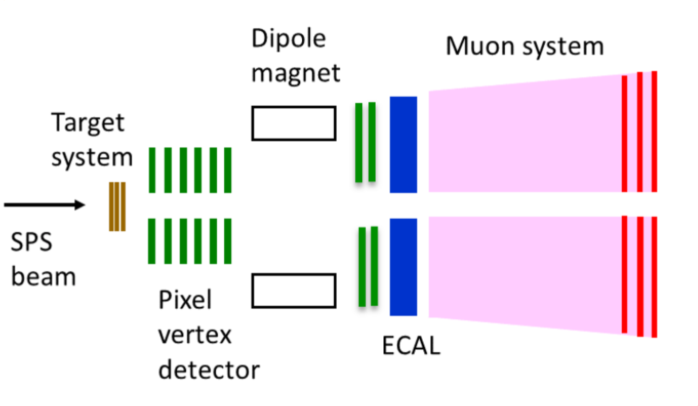
- Studies and challenges
  - Parallel operation with iSHiP and dSHiP most efficient!
  - Radiological aspects
  - Additional experimental cavern
  - Slightly longer transfer line to target complex (15-20m drift space)
  - Experiment-machine interfaces
  - → Simulations needed!
  - → Very interesting and challenging technologically







6σ beam envelope incl. 5 mm orbit deviation and 10% beta beating → RMS 3mm



Conclusions

Deck is open for discussion!

- A very intense and vivid program of work ahead in CDS and beyond
- Contributions welcome in a very large number of areas

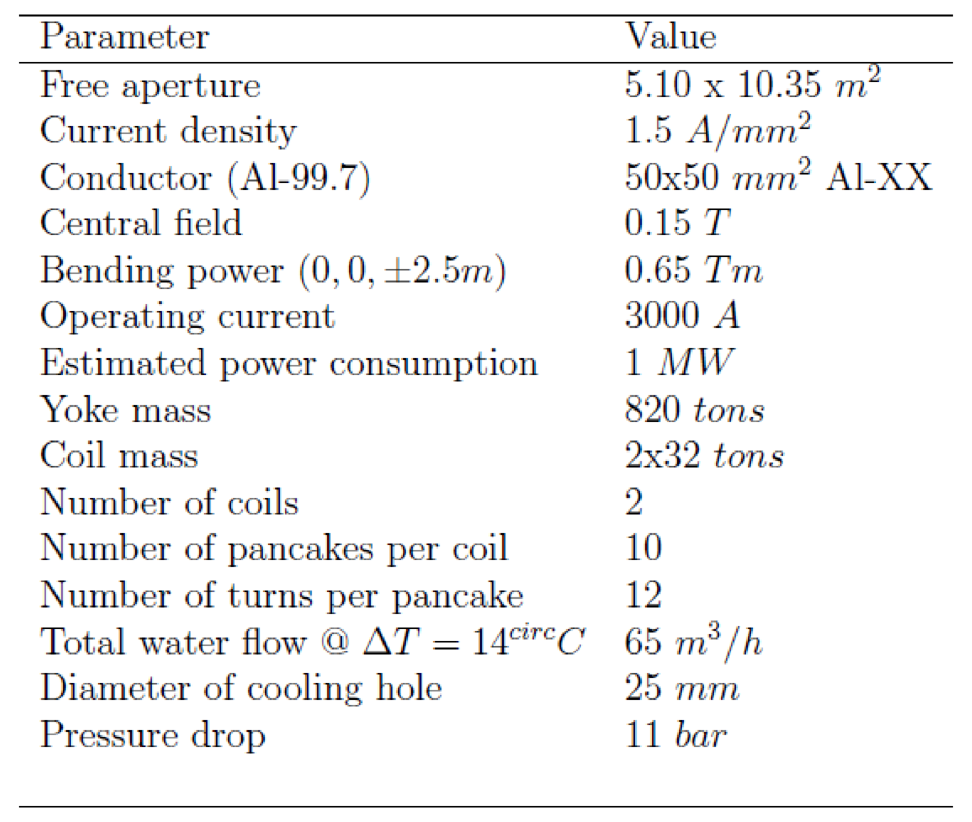
Magnet design

Magnet design for TP (April 2015) was done by Davide Tommasini and his team (“LHCb-like”)

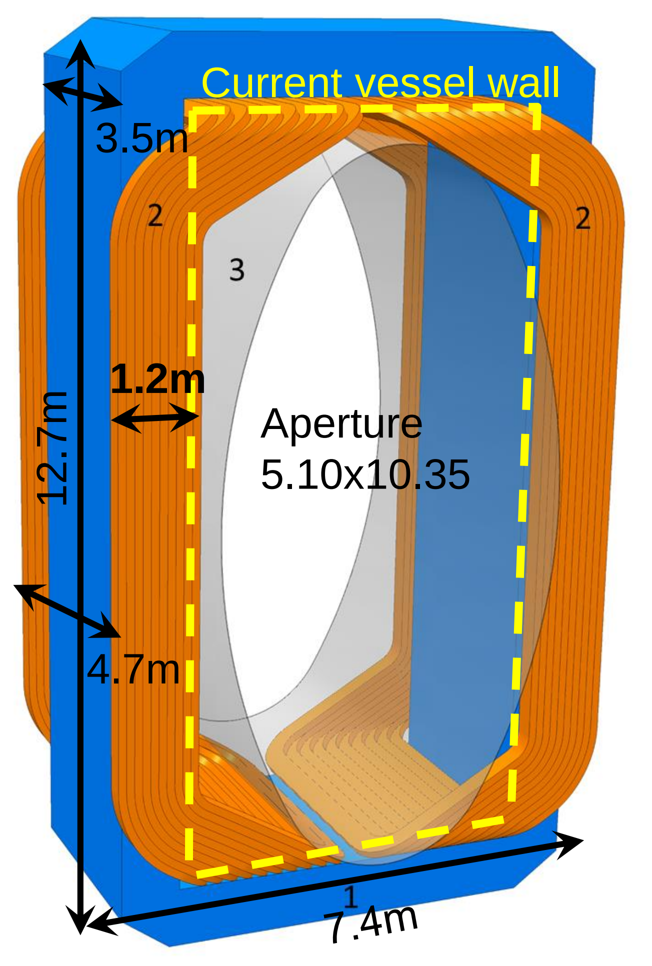
➔ Stand alone design, no integration with vacuum vessel

- Magnet designed with emphasis on low power
  - Design for 0.65 Tm with upgrade up to 1 Tm

D. Tommasini,
E. Solodko,
A. Sanz Ull



Parameter	Value
Free aperture	5.10 x 10.35 m^2
Current density	1.5 A/mm^2
Conductor (Al-99.7)	50x50 mm^2 Al-XX
Central field	0.15 T
Bending power $(0, 0, \pm 2.5m)$	0.65 Tm
Operating current	3000 A
Estimated power consumption	1 MW
Yoke mass	820 $tons$
Coil mass	2x32 $tons$
Number of coils	2
Number of pancakes per coil	10
Number of turns per pancake	12
Total water flow @ $\Delta T = 14^{circ}C$	65 m^3/h
Diameter of cooling hole	25 mm
Pressure drop	11 bar



CDS Global optimization