Timing Wall Detector Project for HF CMS

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INSTR2020, Novosibirsk

LHC after LS2: High Luminosity

“Additional Timing Detectors are needed
for better CMS physical performance”

Physics Motivation:

Off Line Analysis Motivation:

Simplify Event Reconstruction;
Pileup Effect Reduction;
...

Forward Hadron Calorimeter

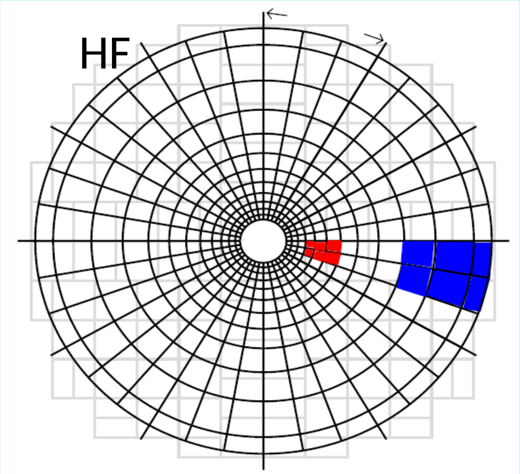
HF covers ~3 < η < 5

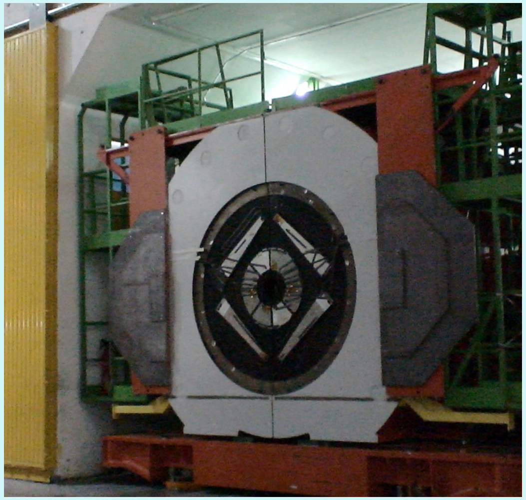
Steel absorber and rad hard quartz fibers
Cerenkov light collected via phototubes, uniform HCAL readout
36ϕ and 12η = 432 towers per side
$\Delta\phi$=10° and $\Delta\eta$=0.166
Each tower has a long and a short fiber running along z

Short is in the back ~ "ET_{HAD}"

Long is front to back ~ "ET_{EM+HAD}"

Makes 2x432=864 towers per side





S. Abdullin et al. (CMS-HCAL Collaboration)
Design, performance, and calibration of CMS forward calorimeter wedges. - Eur. Phys. J. C 53, 139–166 (2008)

Proposed Technologies for Timing Layers in CMS

The latest version – Sahin M.O., INSTR2020

Barrel Timing Layer (LYSO + SiPM); (Report Irene Dutta, CIPANP 2018.)

- Larger surface area
- Lower radiation dose
- Mature readout ASIC

Endcap Timig Layer (LGAD)

- Larger radiation dose
- Flexible installation schedule

HF Timing Layer, Variants:

- Scintillators (LYSO,...) + SiPM
- Cherenkov radiator (Quartz, Sapphire) + PM MCP
- Cherenkov radiator (Quartz, Sapphire) + SiPM
- More detailed next slide:

HF Timing Wall (aka Forward Timing Layer), Main Things:

- Time Resolution < 30 ps ;
- Radiation hardness ;
- Structure matching with HF ;

Principal Issue:

- Light Source Radiator (Scintillator/Cherenkov);
- PhotoReadout (SiPM, PM MCP, PM);
- Optical Contact (direct, air lightguide, fibers);
- Digitization;

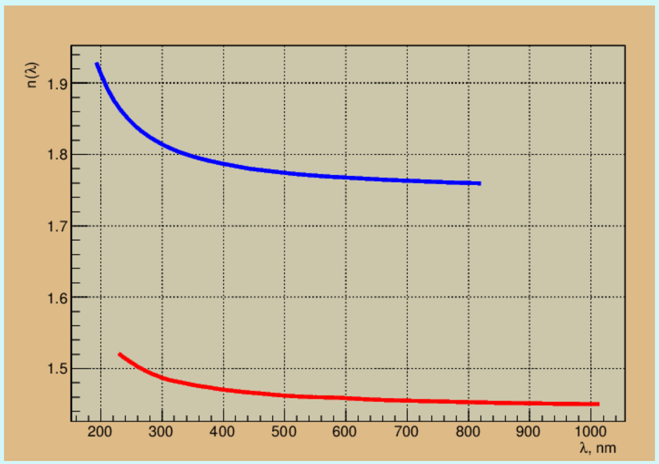
Principal Issue: Light Source Radiator (Scintillator/Cherenkov)

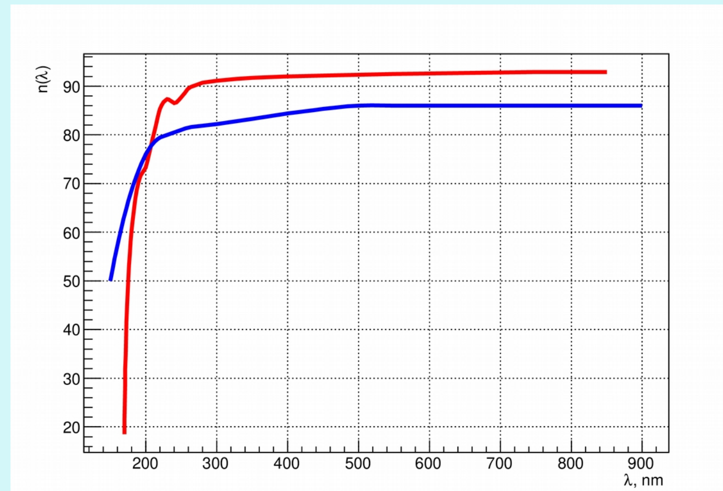
- Scintillator : LSO, BaF2, LaBr3, GAGG... :
  1. Density;
  2. Radiation hardness needed HF Region;
  3. Time Resolution ;
  4. Large square.

- Cherenkov: Quartz, Sapphire, PbF2,..:
  1. Middle and Low Density;
  2. High Radiation hardness;
  3. High Time Resolution (achieved better 50 ps).

The Choice: Cherenkov Radiator;
Additional advantages:
A lot of independent Producers;
Relatively not expensive;

Principal Issue: Light Source Radiator (~~Scintillator~~/Cherenkov)



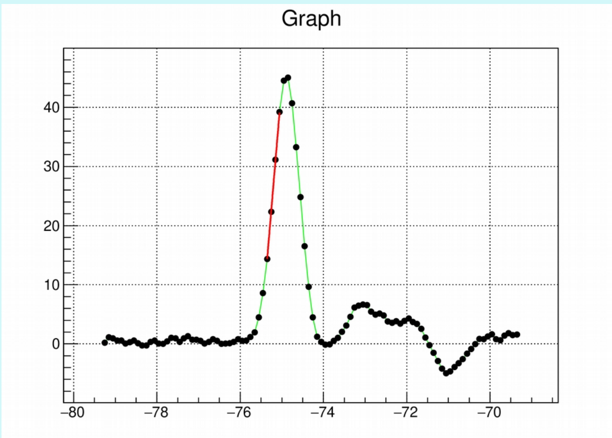


Refraction Index and Transparency (blue -Sapphire, red – Quartz) ;

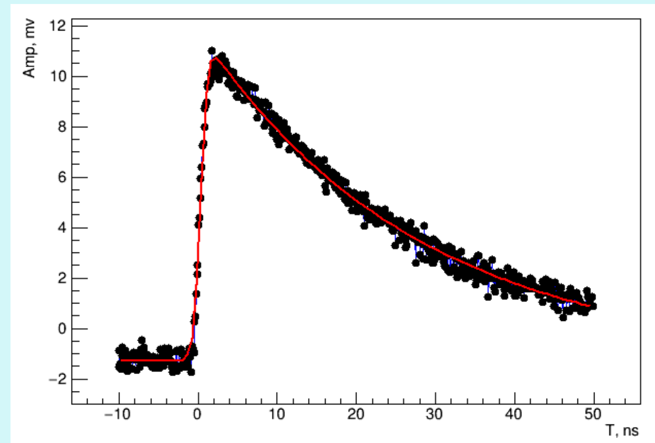
	Sapphire	Quartz
Density	3.97	2.20
Nucl.Inter.Length, g/cm^2	98.9	97.4
Rad.Length (*X0*), cm	7.04	12.3

The Choice – Quartz.

Principal Issue: PhotoReadout



PM MCP UFK-5G-2D (PPS CMS Test)



SiPM (QUARTIC Test, PPS CMS)

	PM MCP	SiPM
Power Supply, V	3000	100
Amplifier	-	+
Radiation Hardness	Next Page	look Talk of Sahin M.O.
Fronts	Fast (< 1 ns)	(Rise – fast, Decay – long)
Noise	Small	High

Principal Issue: PhotoReadout: PM MCP Life Time

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Nuclear Instruments and Methods in Physics Research A 564 (2006) 204–211
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Lifetime of MCP–PMT

N. Kishimoto, M. Nagamine, K. Inami*, Y. Enari, T. Ohshima
Department of Physics, Nagoya University, Chikusa, Nagoya 464-8602, Japan

Received 15 February 2006; received in revised form 21 April 2006; accepted 21 April 2006
Available online 6 June 2006

$2.8*10^{14}$ photons/cm^2
Qtot approx 1C/cm^2

For UFK-5G-2D(LLC KATOD, Novosibirsk):

1. Lifetime is defined under the following conditions:
Gain - 10^6 (corresponds to HV= -2700 V);
Anode current - 300nA.
2. PMT were tested on radiation resistance under the following factors:
Neutron fluence with neutron energy > 0,1 MeV – 10^{12} neutron/cm^2;
Gamma radiation exposure dose - 10^3 R;
Maximum exposure dose power - $5*10^9$ R/s.
After tests completion, PM MCP parameters remain unchanged.

Principal Issue: The Choice:

1. Cherenkov Radiator – Quartz;

2. PhotoReadout – PM MCP;

3. Optical Contact – Direct (and test other).

4. Digitazion – now ‘as is’.

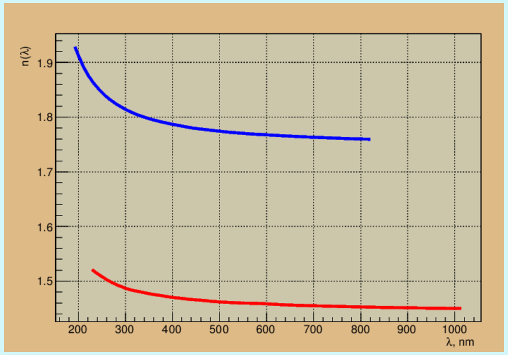
Cherenkov Light Propagation in Quartz

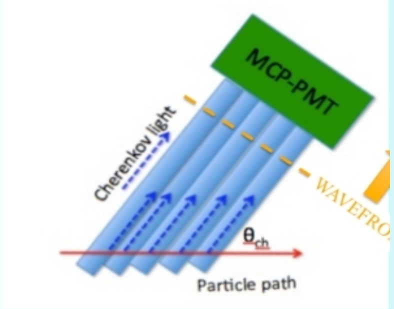
- The ‘thickness’ of Cherenkov Conus is defined by optical dispersion, n(λ). In interval of PM MCP QE it is cos(Θ) =**48-46.6**
- The Amplitude is changed by two effects :

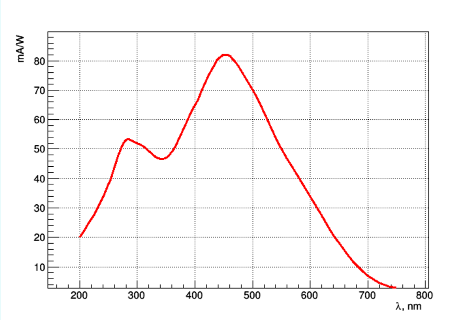
  1. Light Attenuation, $\propto$ exp(-x/λ)

  2. Multiple internal scaterring, $\propto$ $(L/\Delta)^N$,

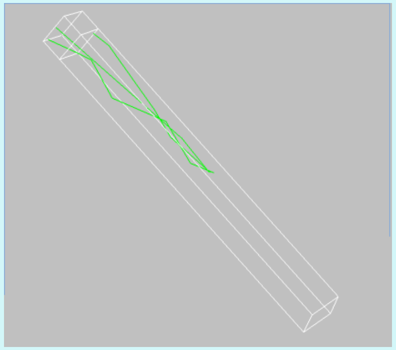
  where N is the number of reflections.

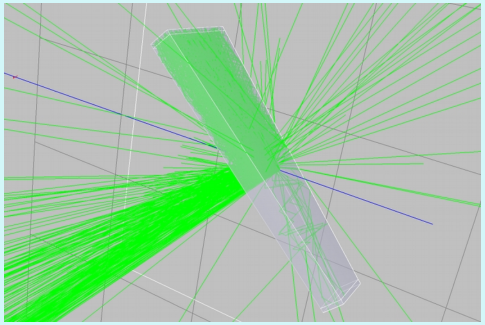




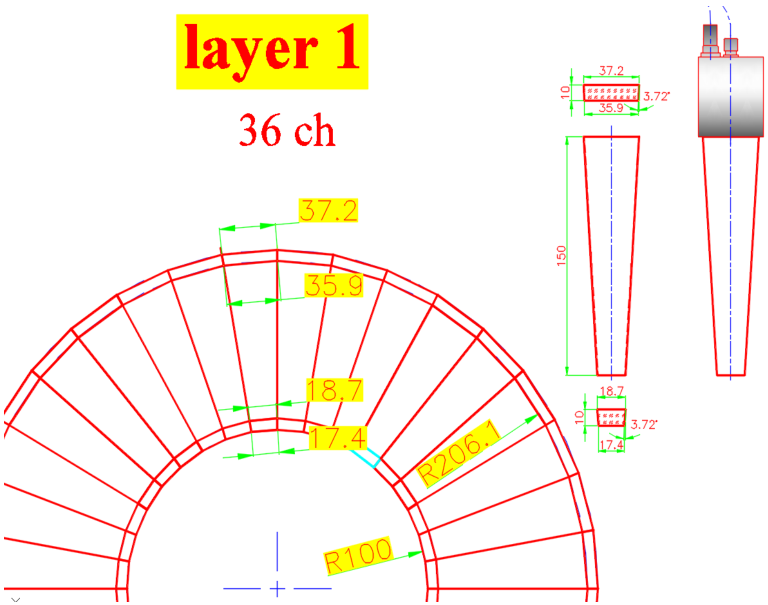


To suppress second term arrange an element under angle of Cherenkov Conus (QUARTIC experience,
M.G. Albrow et al. - Quartz Cherenkov Counters for Fast Timing: QUARTIC - JINST 7:P10027,2012).

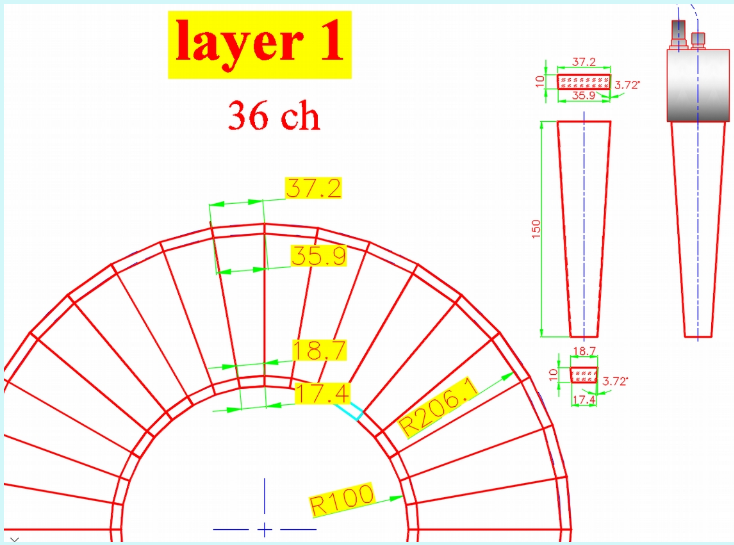


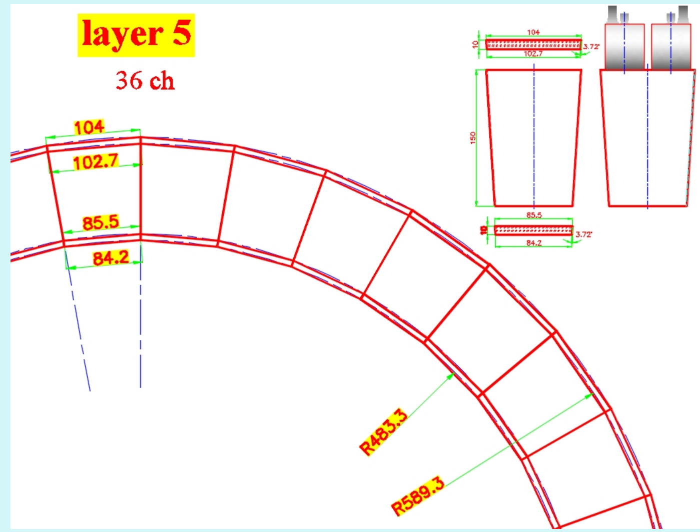


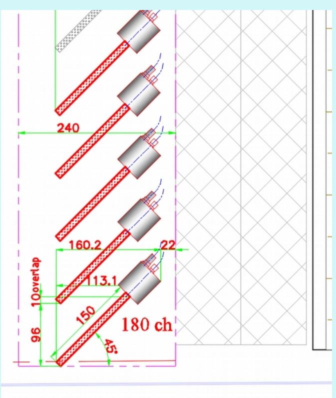
- Module Construction (June Proposal):
- Matching with HF
- One PM MCP
- Radiation Hard Quartz (fused silica) as radiator
- Development – next slide:



Geometry of sensitive Tiles and MCP



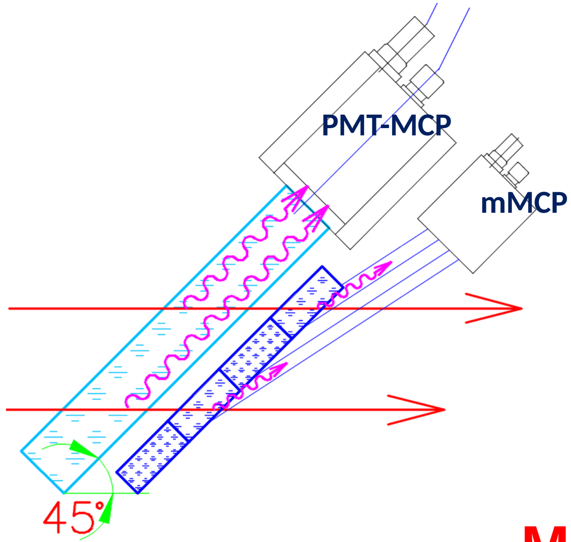




Full Structure:5 Layers, 36 Channels in each Layer, as in HF;

Timing Wall Module (TWM)

TWM– extended logical continuation of PPS approach – the measurement of weakly scattered beam protons. Long flight base allows to detect protons in high rapidity region.



TWM consists of two parts:

1. **Timing Part – Quartz Tile with PM MCP Readout (direct Cherenkov light), φ=10° (matching with HF), 4.8 < η < 6.4**
2. **R-spatial Part – for R measurement and Time correction (scintillator LSO/GAGG + quartz fiber).**

Repeats Quartz Tile geometry with equal rapidity interval η= 0.2 or with equal Time spread.

Motivation and Reasons:

Physical:

- **SM measurements with increased precision;**
- **Better chances of finding BSM phenomena;**
- **....**

Data Analysis:

- **Pileup Effect Reduction;**
- **Beam proton reconstruction.**

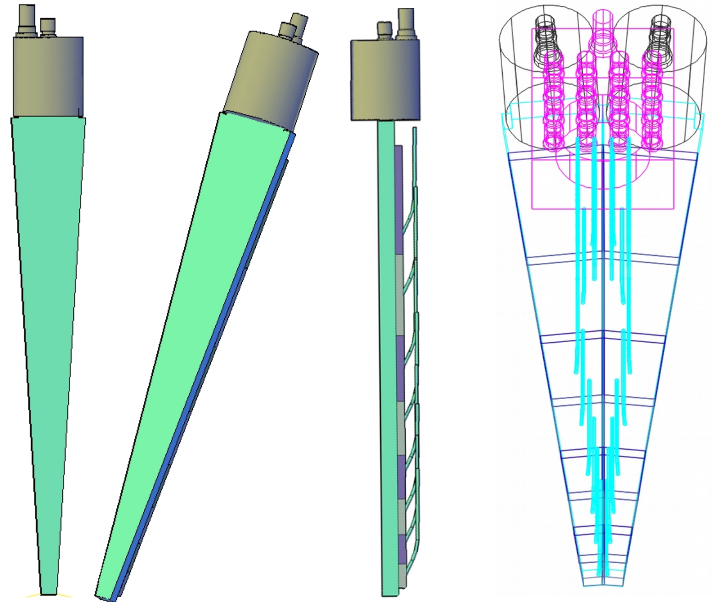
Properties:

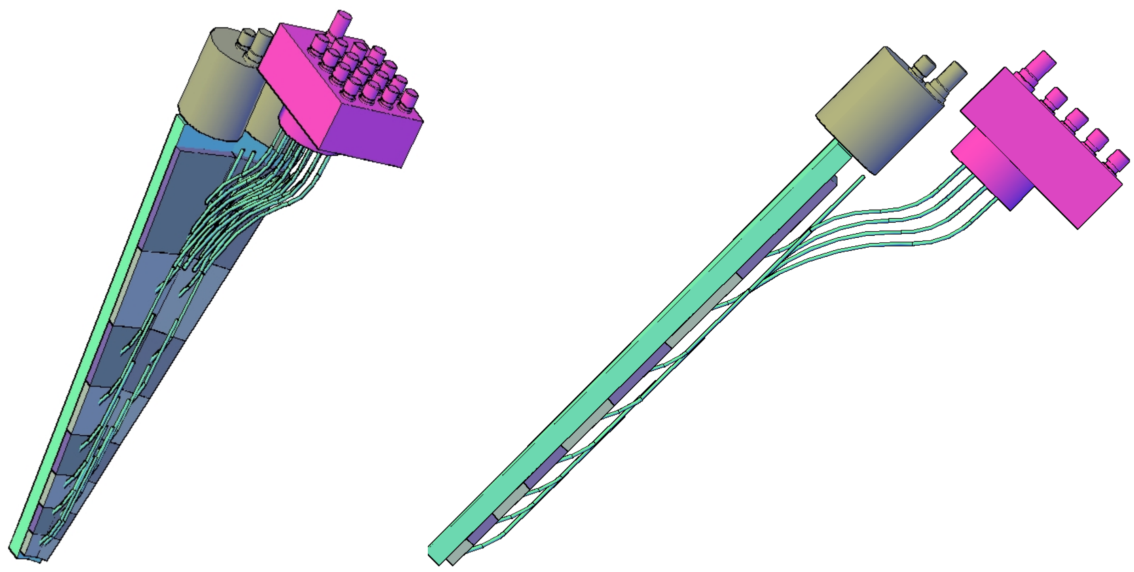
- **High Time Resolution;**
- **Structure matching with HF;**
- **R-φ Angle measurements;**
- **Radiation Hardness.**

TWM single module

3D views; Module is 2 Q-tiles + 16 strips

Single Q-tile + PMT MCP

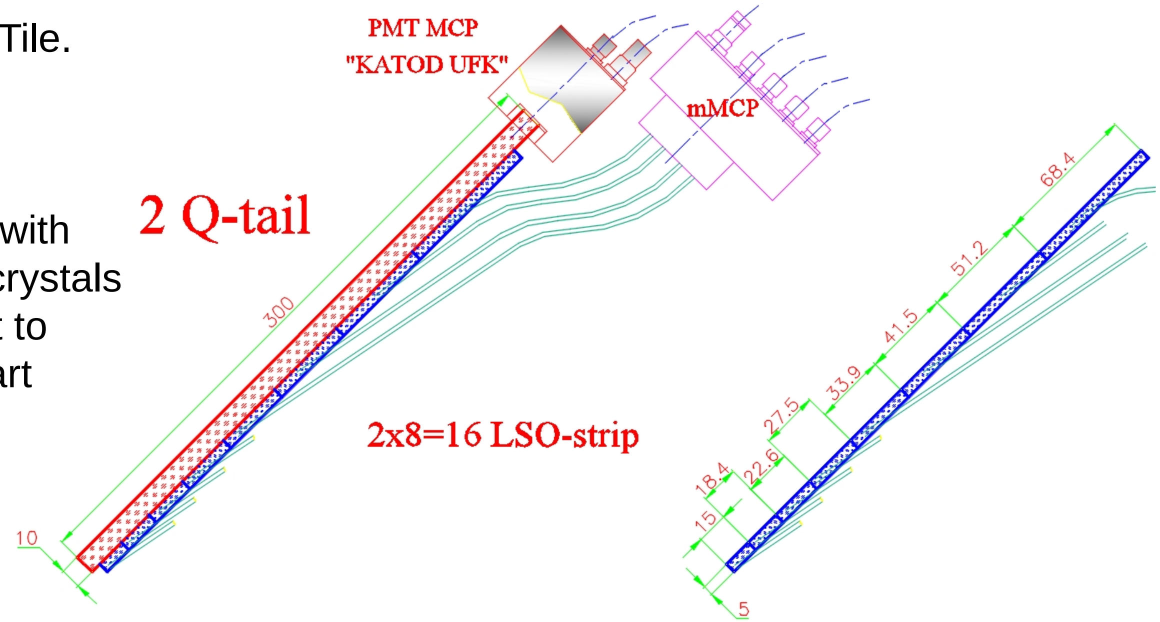




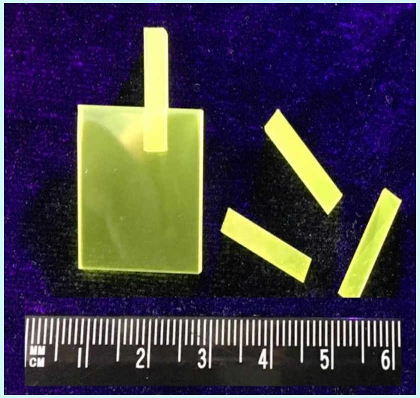
Timing Part – Cherenkov Light in Quartz Tile. Readout by MCP. Direct optical contact. Time Resolution < 25 ps.

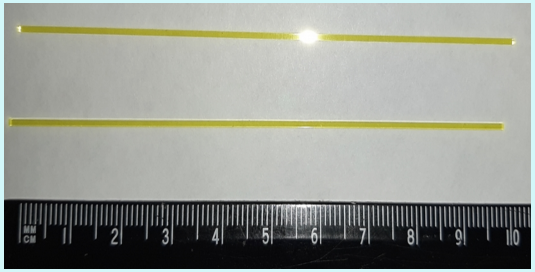
R-coordinate Part – Scint. Light. 8 strips with equal rapidity interval (0.2). GAGG/LSO crystals are used. Quartz fiber for transfer the light to multianode (16 ch.) MCP. R-coordinate Part works in logical (0/1) mode.

This approach provide high radiation hardness of the Detector.



Scintillators Part : GAGG vs LSO (under studying)



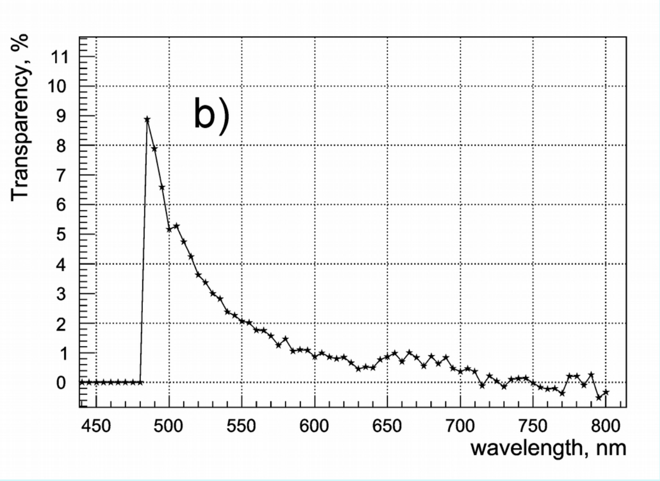


$Gd_3Al_2Ga_3O_{12}$:Ce,Mg,Ti-multidoped GAGG scintillation crydtal is under mass production by FOMOS CRYSTAL (Moscow Russia)

Development of the material is performed in cooperation with The Laboratory of Luminescent and Detecting Materials of NRC Kurchatov Institute (Russia) and INP BSU (Belarus)

Table 1
Scintillation properties of some prospective Ce-doped scintillation materials in comparison with $PbWO_4$ and plastic scintillator.

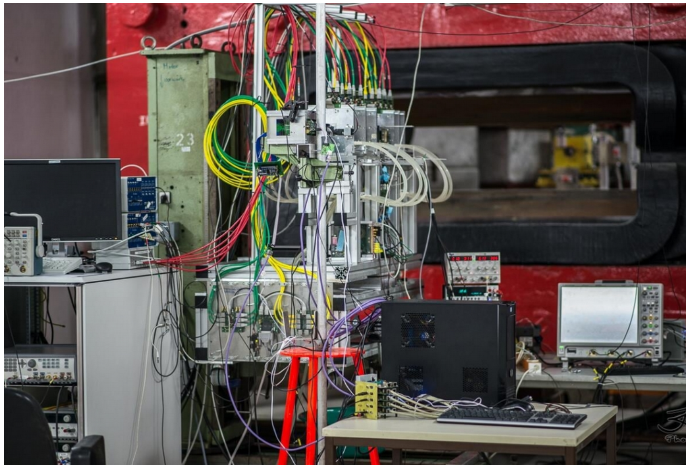
Scintillator	ρ, g/cm^2	X_0, cm	Light yield ph./MeV	τ_{sc}, ns	λ_{max} nm	Irradiation results
$Y_3Al_5O_{12}$:Ce	4.55	3.28	11 000	70	550	[13]
$(Lu\text{-}Y)_2SiO_5$:Ce	7.0	1.2	30 000	35	420	[14]
Lu_2SiO_5:Ce	7.4	1.1	27 000	40	420	[9]
$Gd_3Al_2Ga_3O_{12}$: Ce, Mg, Ti	6.67	1.61	36 000	36(73%) 122(27%)	520	This paper
$PbWO_4$	8.28	0.89	100	6	420	[2]
Polystyrene: PTP, POPOP	1.06	41.3	12 000	3	430	[15]

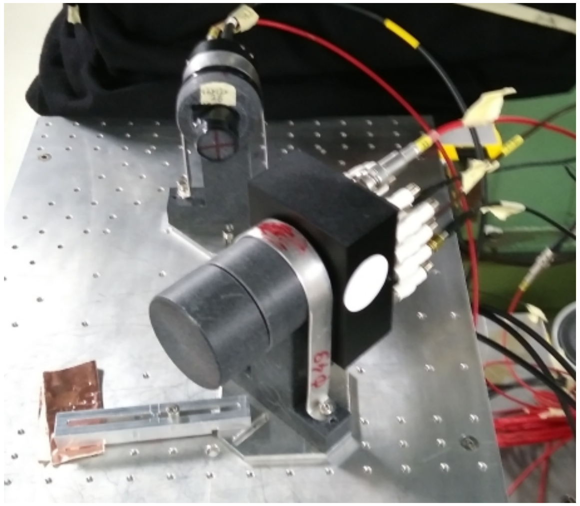


Spectrum of induced optical absorption in scintillation spectral range of GAGG after irradiation by 24 GeV protons with fluence $3.1\text{x}10^{15}$p/cm^2.

Courtesy of M.Korzhik, NRC – Kurchatov Institute;
And this Conference Talk.

Tests new multianode PM MCP, 2019 (PPS CMS)



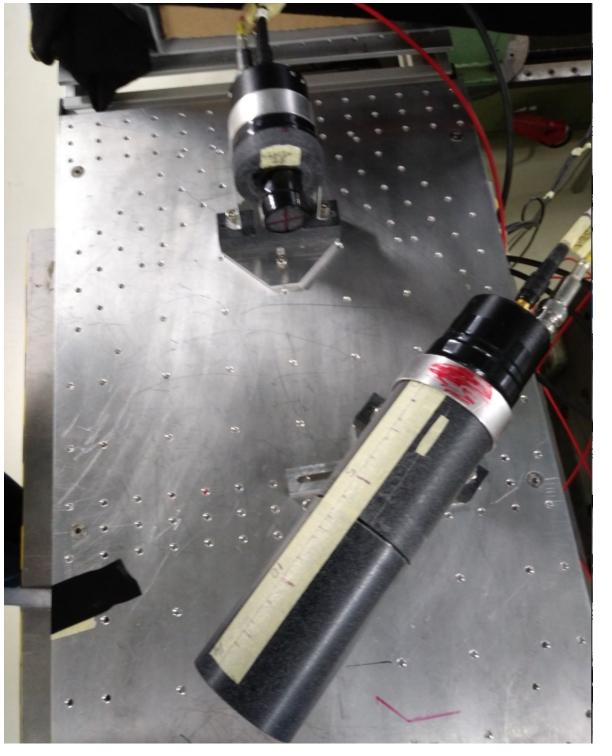


Multianode PM MCP Test Quartz Bar
(QUARTIC Variant)

MCP-PMT “KATOD” and new 4x4 (3x3 mm) multianode MCP have been tested.

The Time Tesolution for Q-Bars with MCP was obtained approx. 30 ps (prelimin).

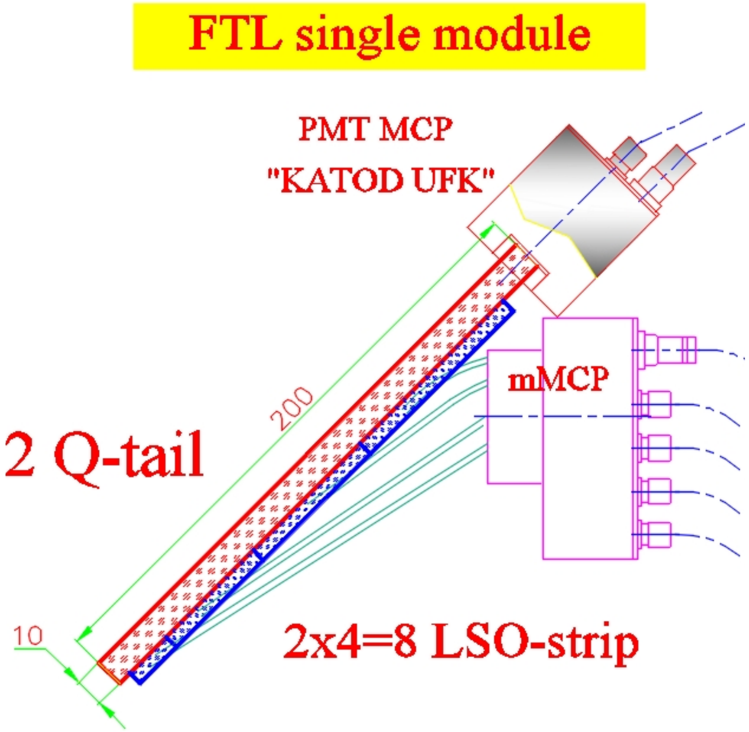
Preliminary Results of DESY Test with Plex Module Prototype: Time Resolution: Distance Scan, Angle Scan (PPS CMS).

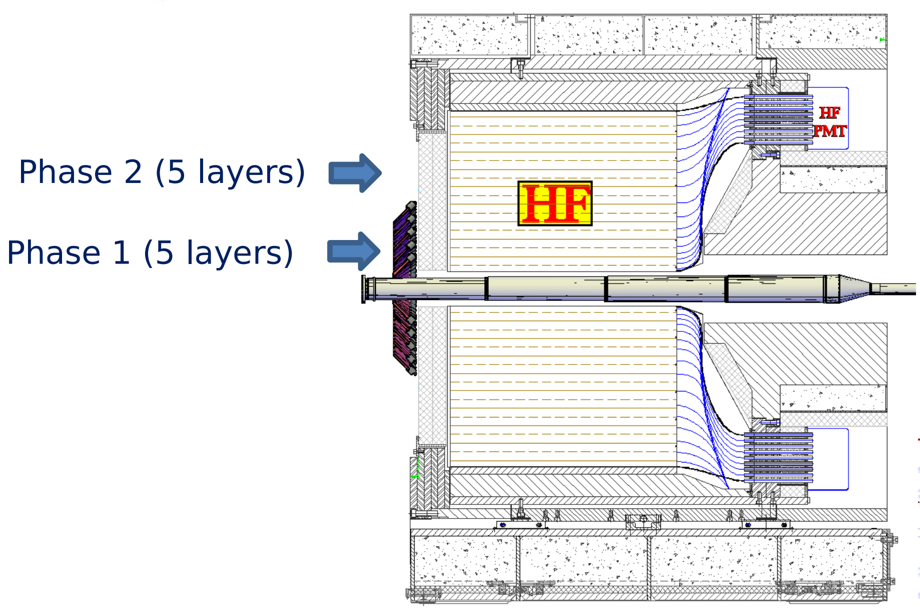


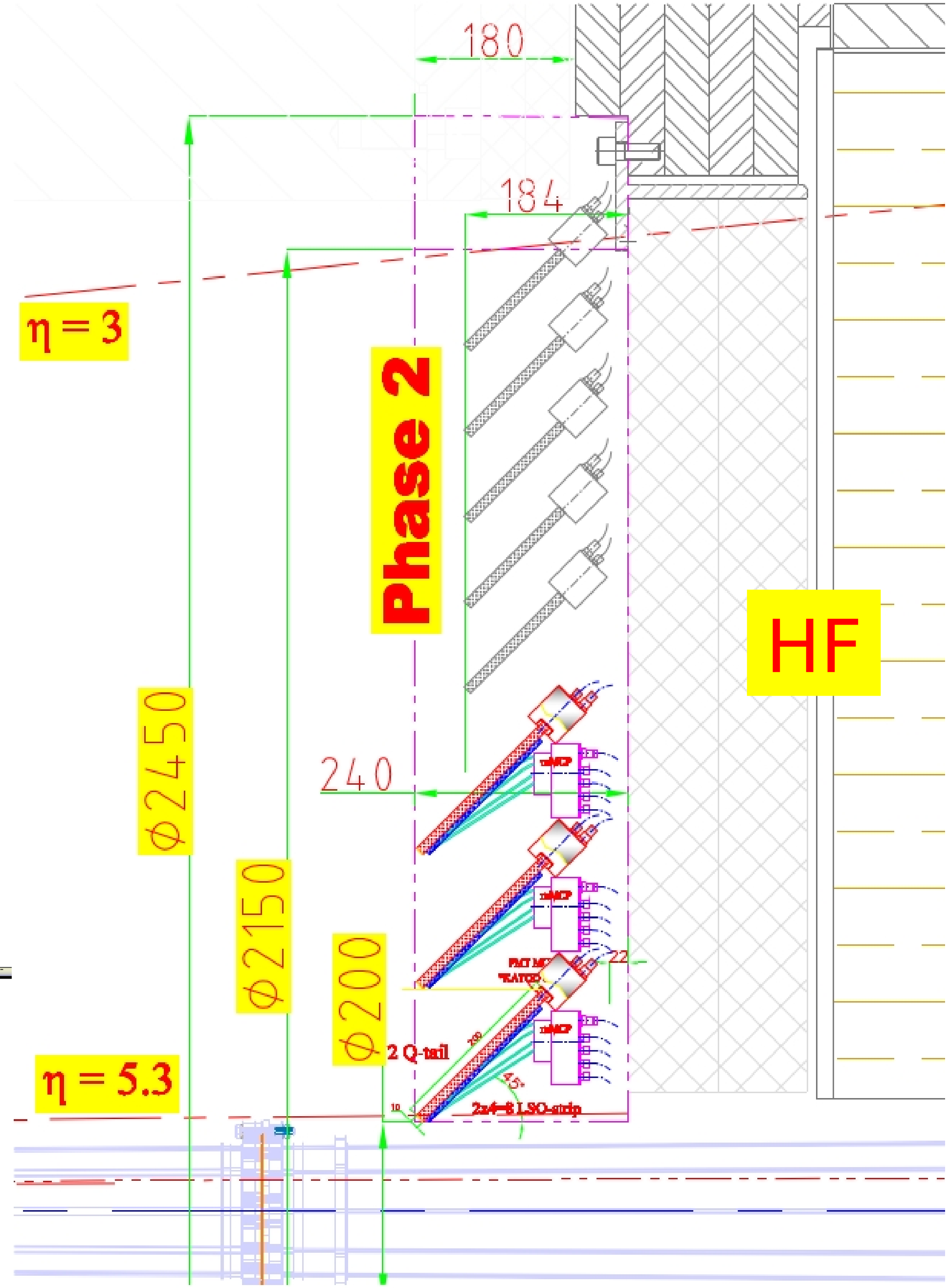
Time Resolution: Z = 145 mm Sigma = 38 ps
Z = 70 mm Sigma = 35 ps
Z= 20 mm Sigma = 31 ps

Correction for TRC dimensions + angle projection did not apply.

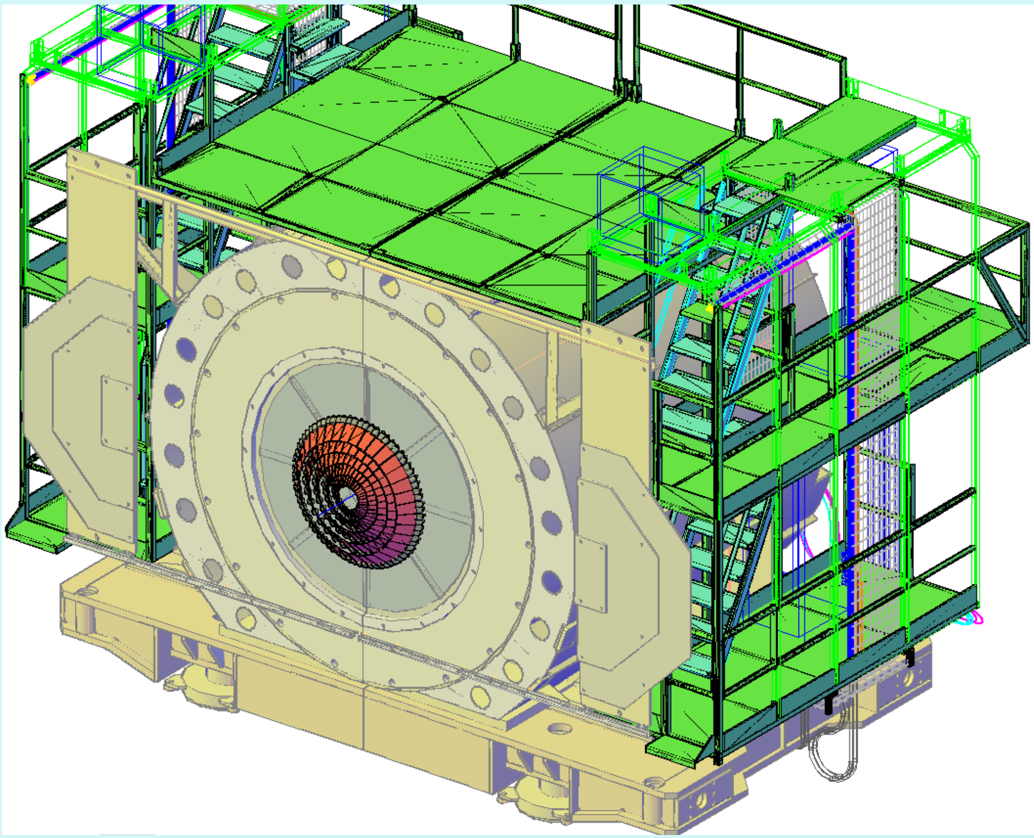
FTL Phase 1 (3 layers)

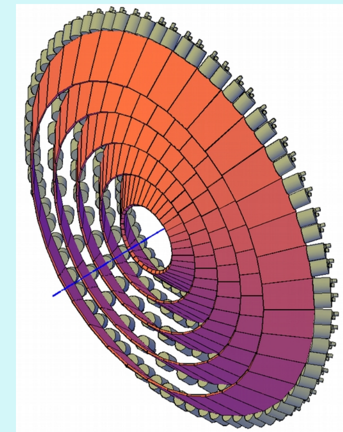


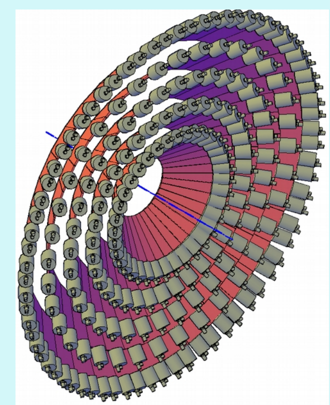




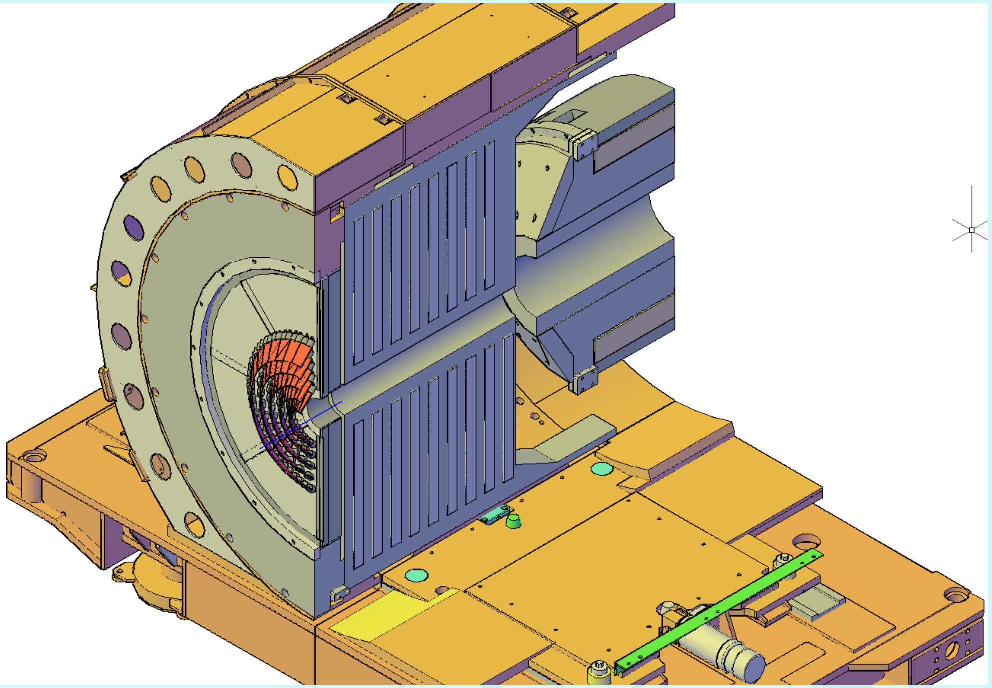
3D, Phase 1

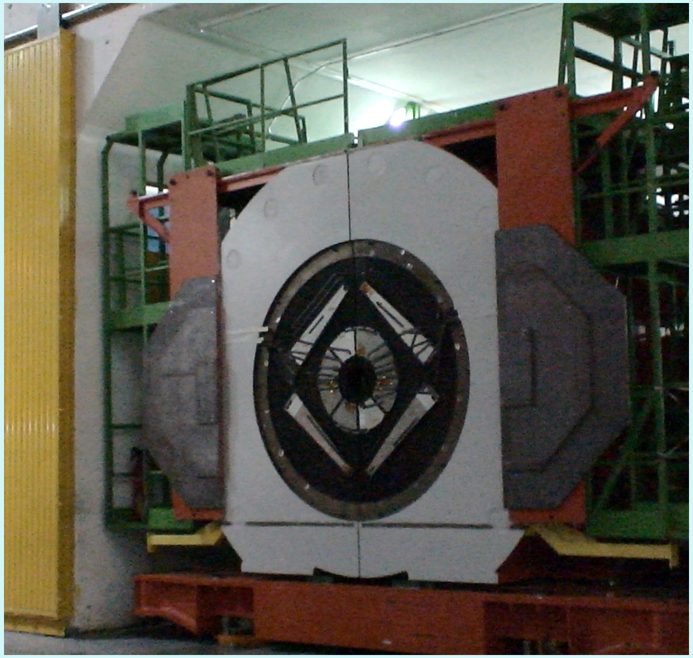




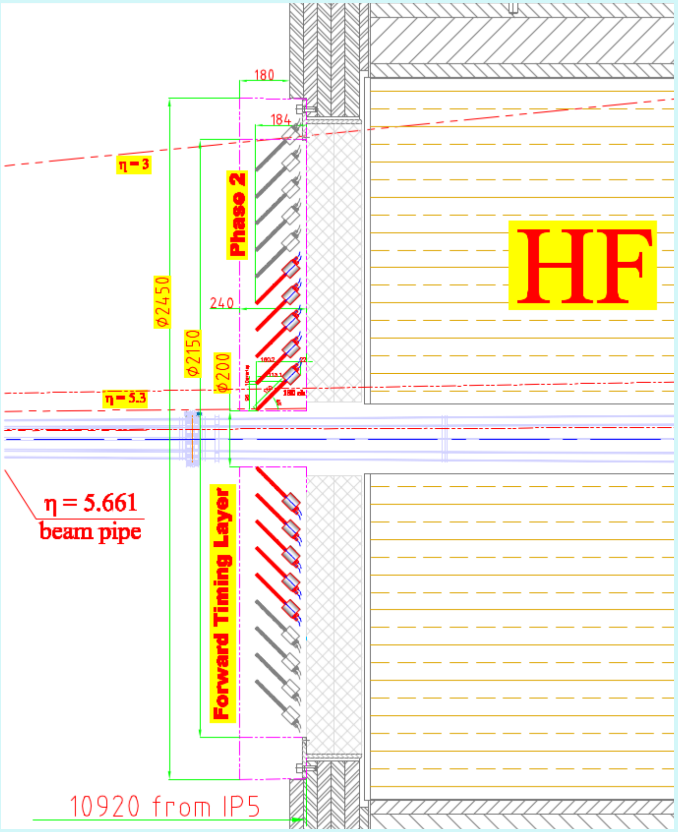


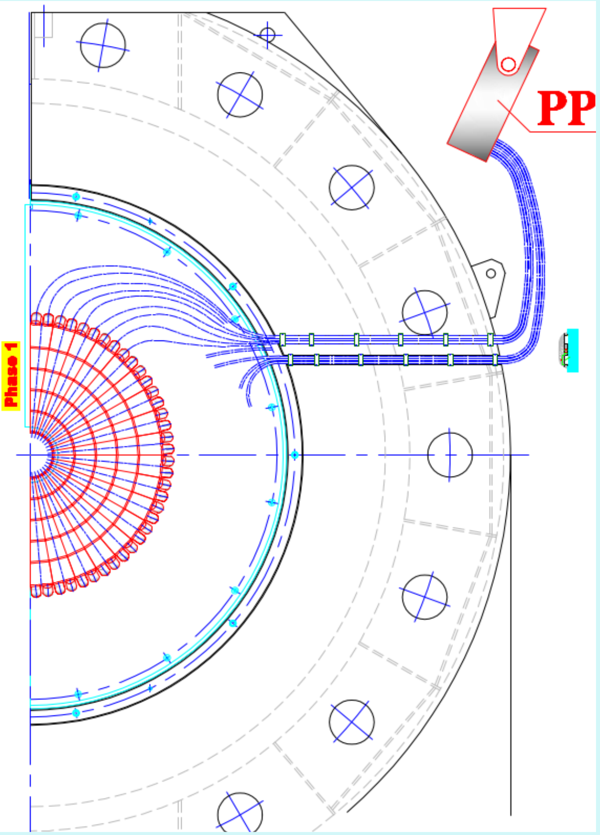
3D, Phase 1

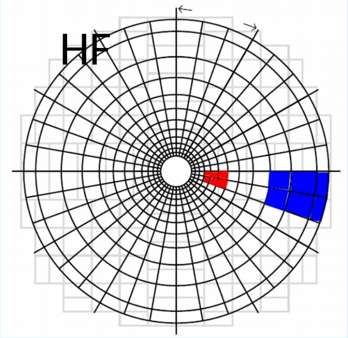


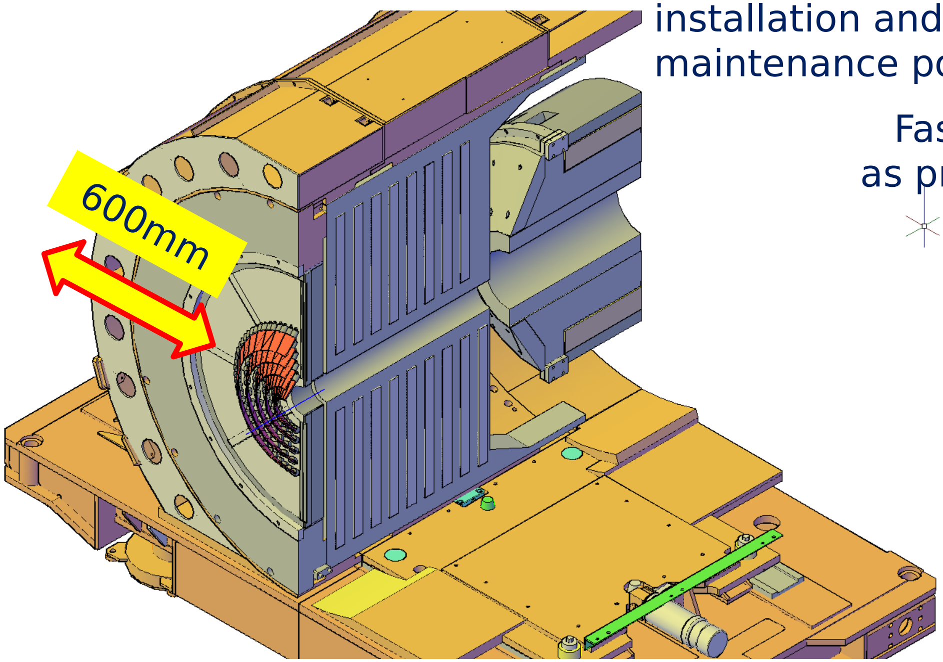


HF Timing Wall Variant



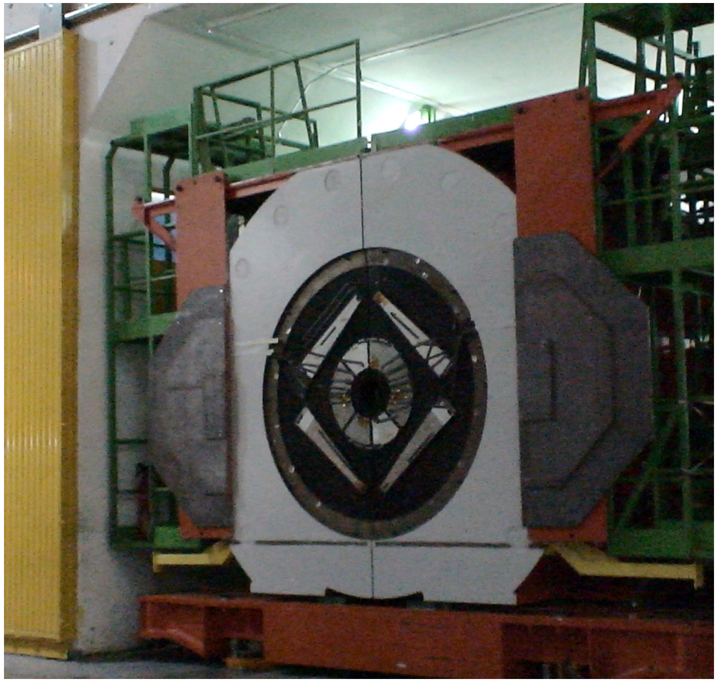


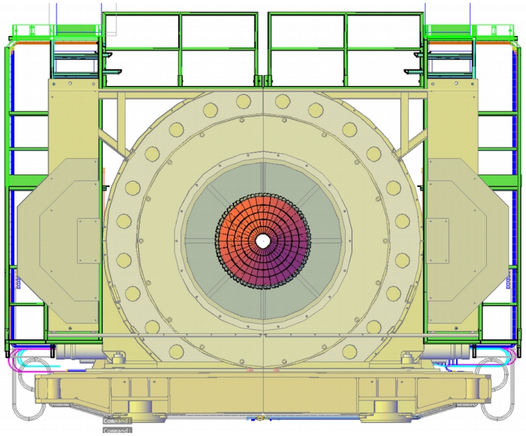


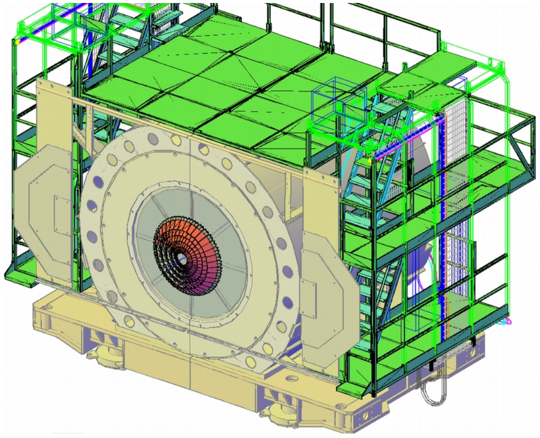


HF in the garage - installation and maintenance position

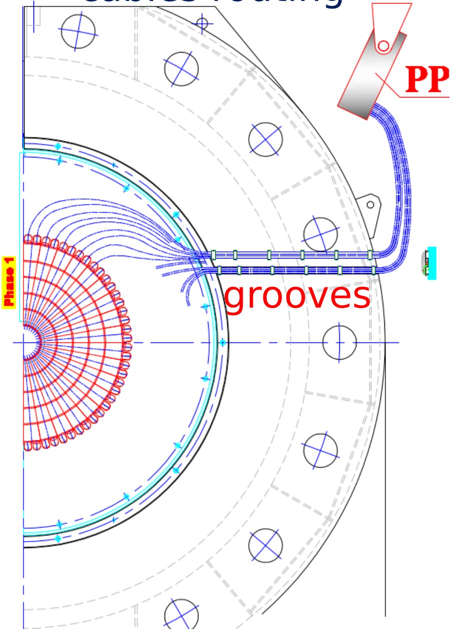
Fastening is as previous BSC





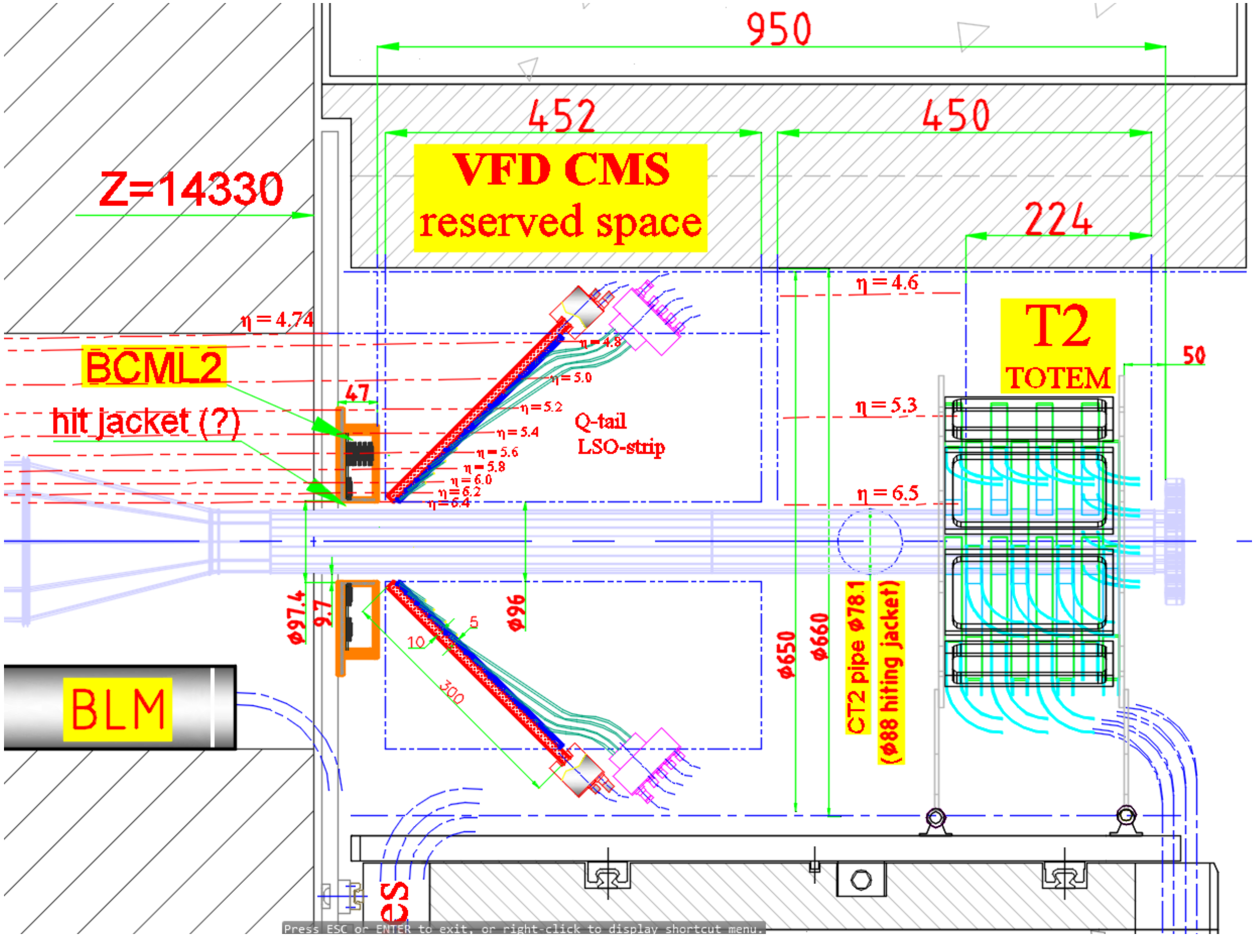


Front (IP side) of HF cables routing



General layout on CMS

To study radiation hardness and performance of TWM, up to end, make one ring and allocate it at CASTOR Table, with extremely hard rad. Env.

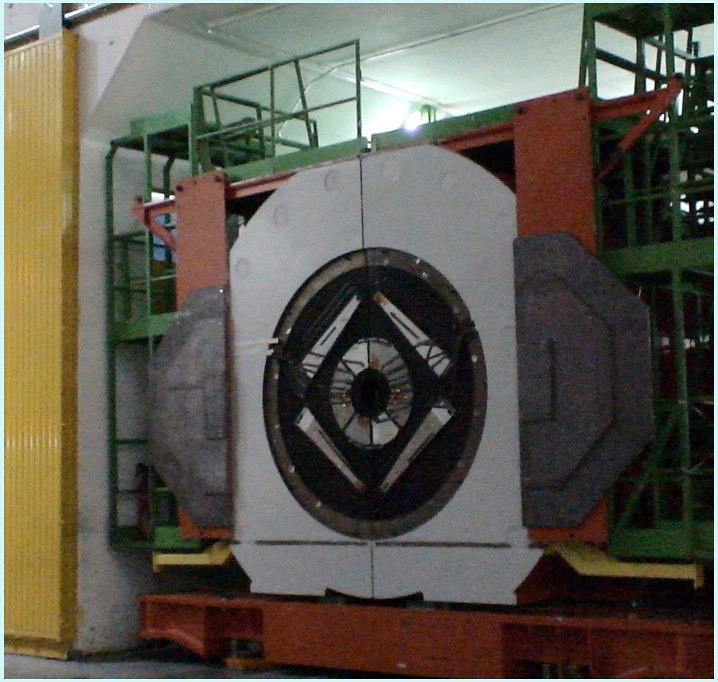


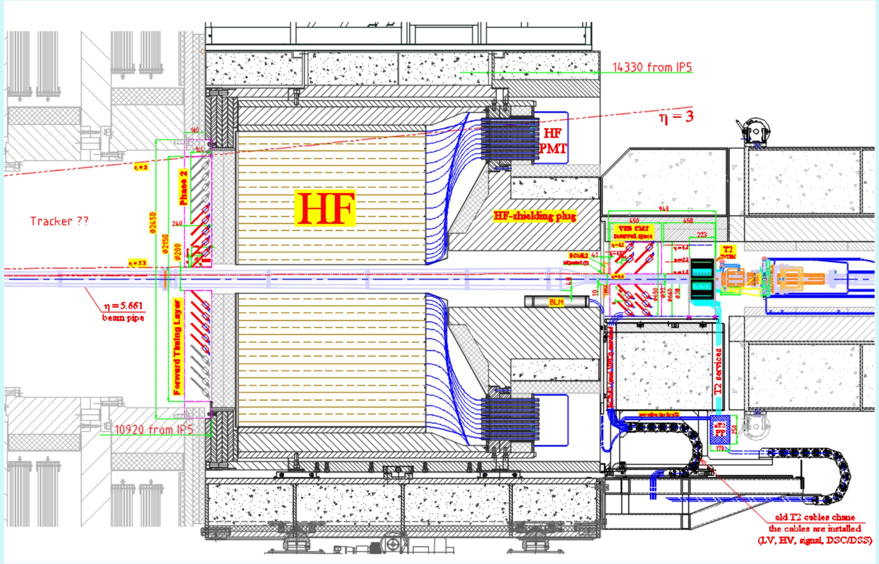
Conclusion

- The Variant HF Timing Wall is proposed ;
- Principial Issues for the Timing Wall Performance were considered ;
- The Wall Element can be produced and tested in 2020.

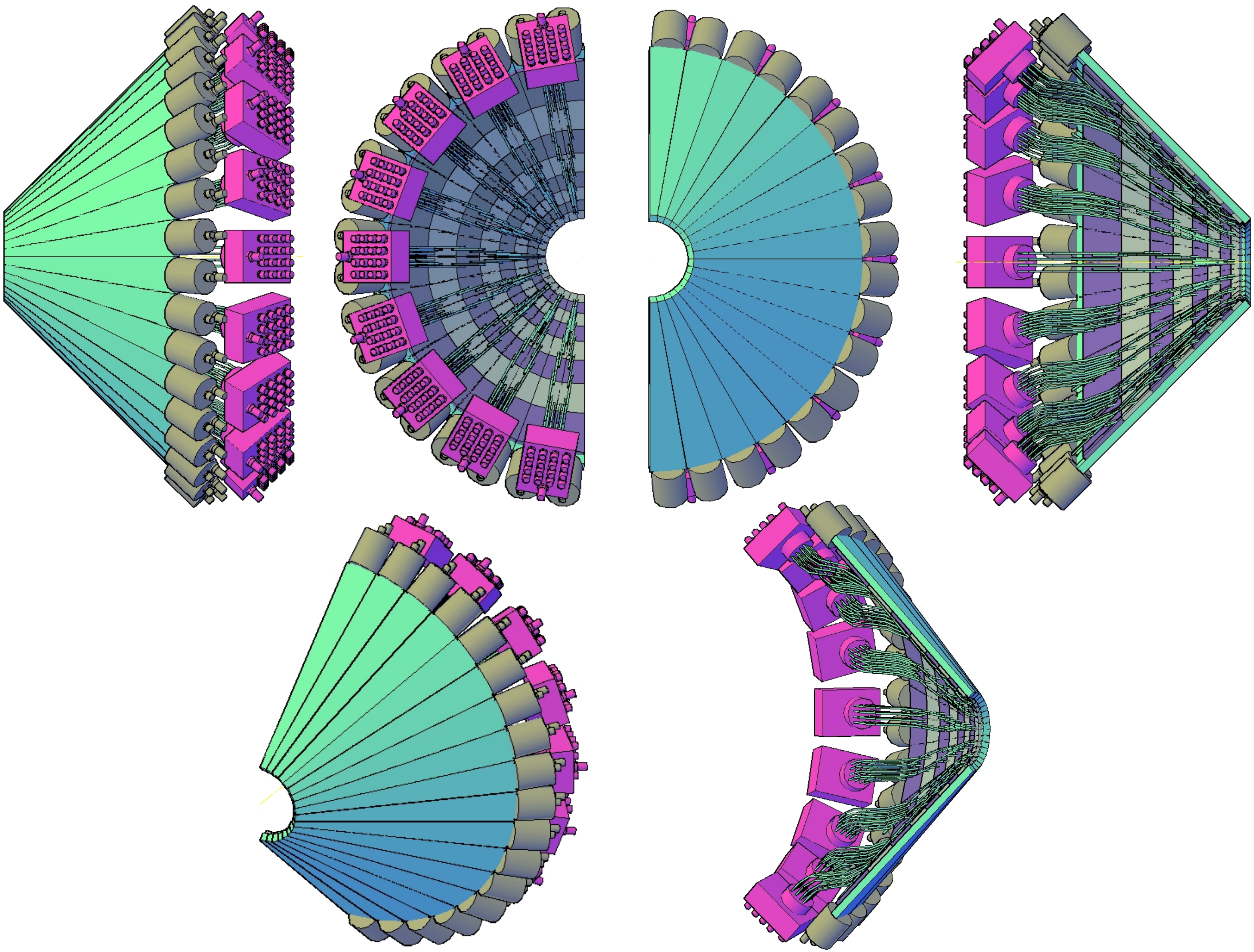
Backup Slides

General Layot HF on CMS





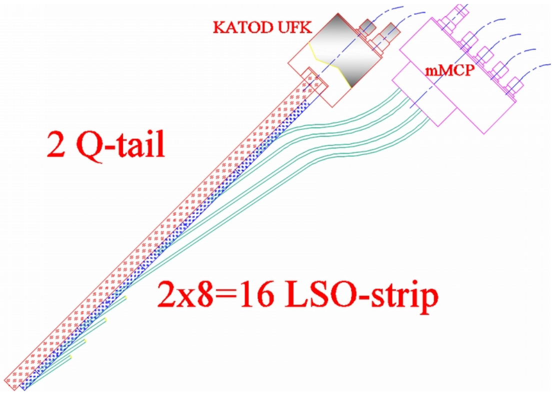
DFP assembly



Signal digitization

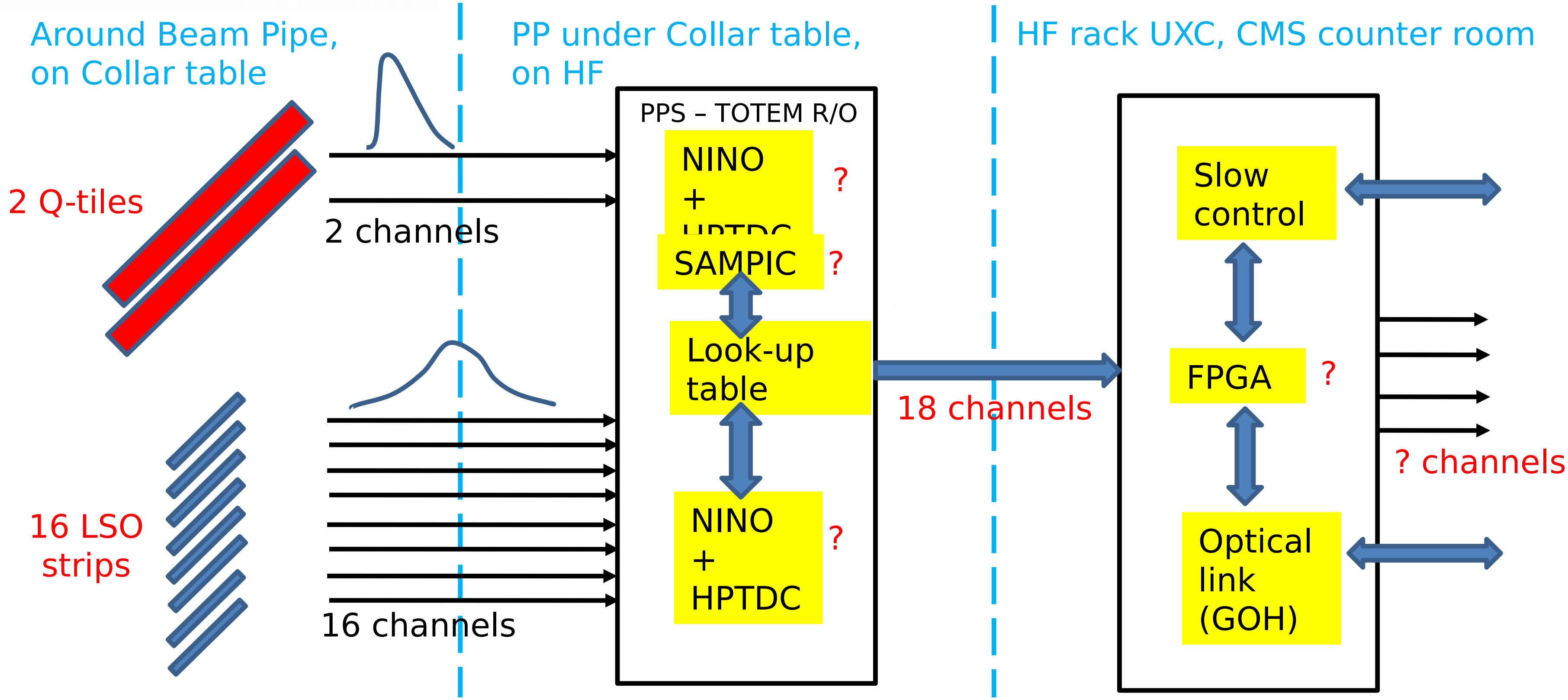
Single module

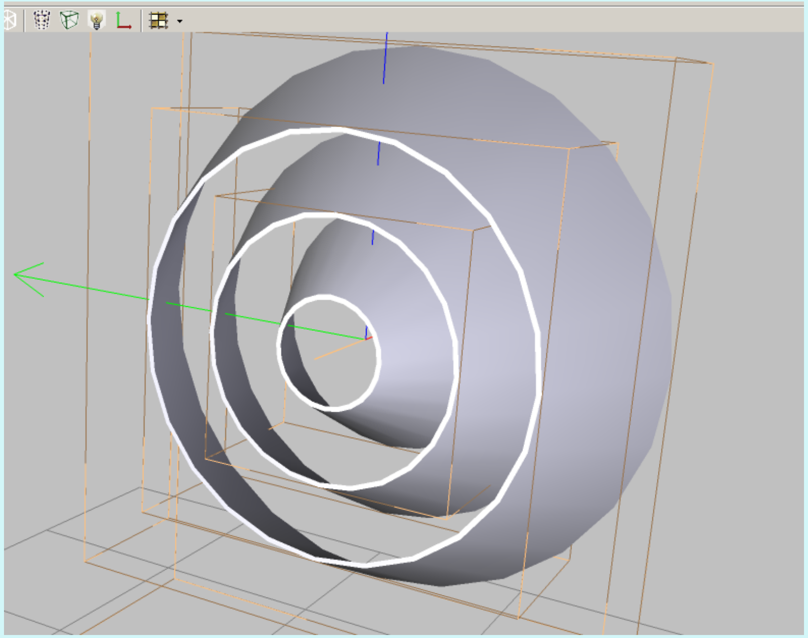
(18 modules per CMS End)

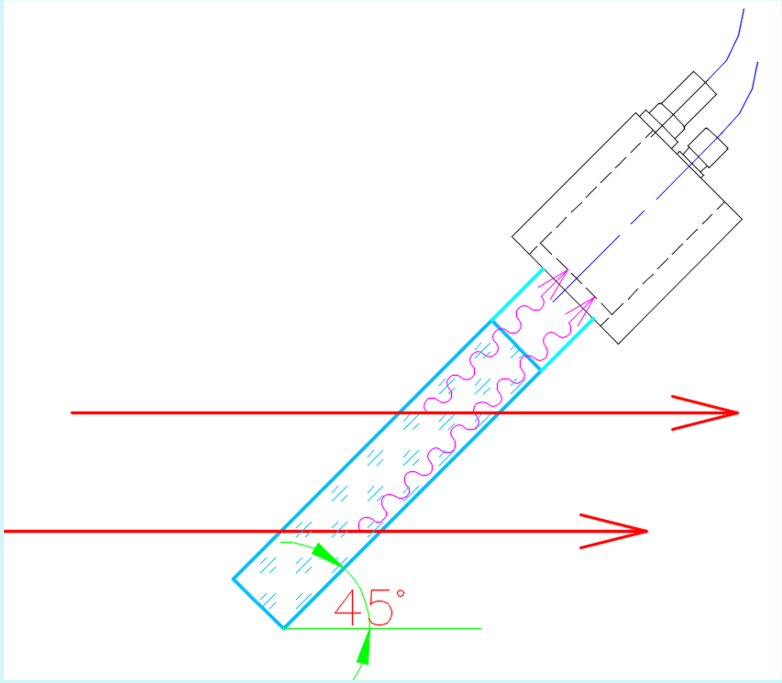


Timing Part – Fast Waveform is preferable (SAMPIC) or NINO HPTDC (considered).

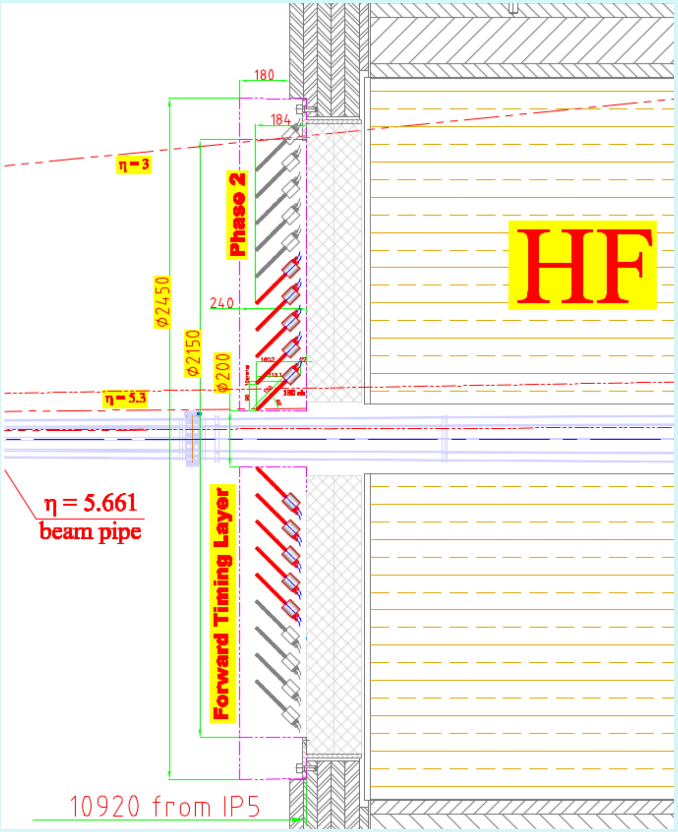
R-Part – Thr. Discr. + simple Timing (for Timing Window);
NINO – tag the strip ON
Time correction – look-up table.

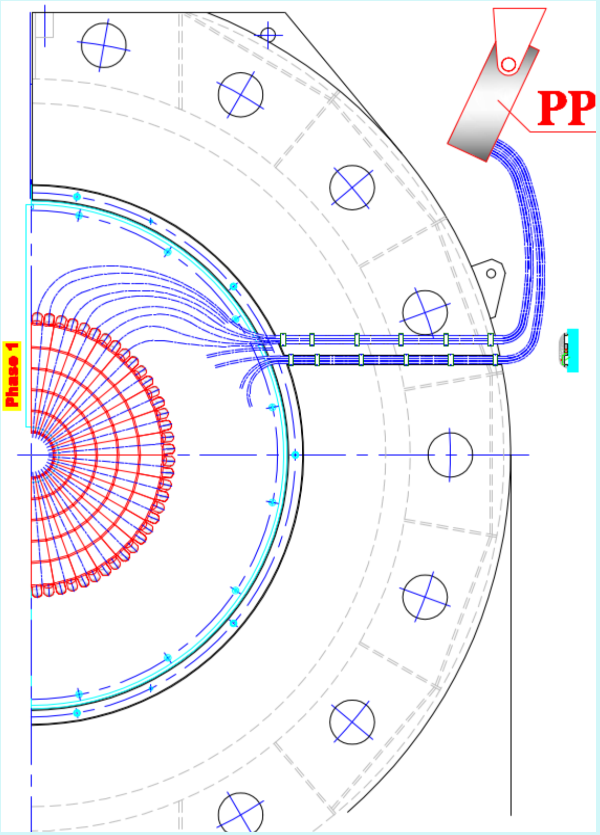


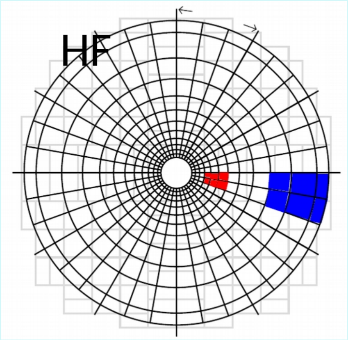



45°

HF Timing Wall Variant





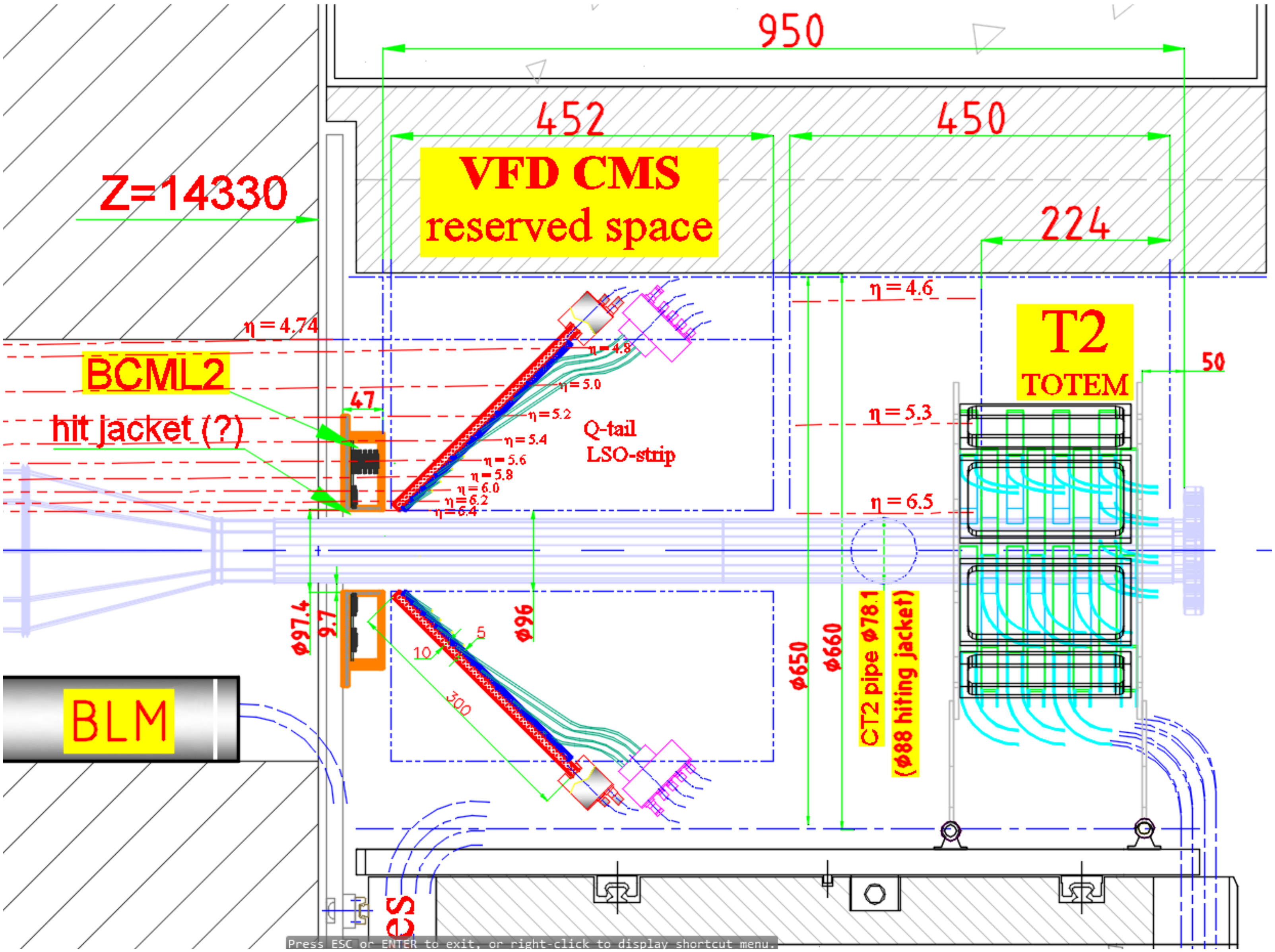


Design description

The DFP is structurally divided into two complementary halves, called DFP-quarters. Each DFP-quarter consists of nine identical modules (covering 180 degree in the azimuthal angle ϕ), to make possible a fast installation around the beam pipe on two sliding rails. The detector can be installed in a very short time by hand. The new DFP detector, as the original T2-GEM and CASTOR (on Minus End only), will be installed in the CMS Forward zone symmetrically on both Ends of the interaction point IP5 at a distance of 14.5 m. It will measure in the pseudorapidity range $\eta = 4.8 \div 6.4$. Two identical detectors will be placed on each side of the CMS detector using the existing CASTOR-tables as main support. The installation / removal of the detector will require access to the CASTOR-table, which implies to switch off the CMS magnet, removal of Collar shielding and the opening of the thin section of the CMS Rotation Shielding The sliding supports, a solution that has already been used in the past, allow for a reliable, precise and quick installation / removal of the Forward detectors. The support and holding structure is designed with standard aluminum mechanical components.

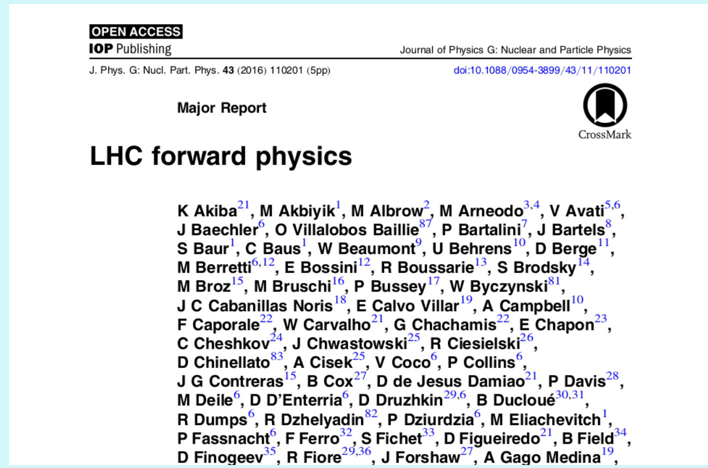
The DFP-quarters can be installed and adjusted separately. Dimension of the detectors fits the CMS geometry in the z = 15 m zone. At this location the beam pipe diameter is 78 mm and the sensitive part of the detectors will begin at R=48 mm from the LHC circulating beam. The envelope of VFD detector has an inner diameter of 96 mm to leave sufficient clearance for the beam pipe: the nominal clearance is 9 mm, and a “no-go zone” of 5 mm is added to take into account tolerances and possible movements, as it was done for the old T2-GEM and CASTOR detectors. The outer diameter of the detector is 600 mm, determined by the internal dimension of the existing CMS Collar shielding. The total length of the DFP along z is around 400 mm.

General layout on CMS



Detector for Forward Physics (DFP) – similar design

Physical Motivation:



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Major Report

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LHC forward physics

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Detector for Forward Physics (DFP) – extended logical continuation of PPS approach – the measurement of weakly scattered beam protons. Long flight base allows to detect protons in high rapidity region.

DFP on CMS

Nine DFP modules are assembled in one design, forming two symmetrical detector halves mounted around the Beam Pipe (CT2 part) on the distance at 14.5m from IP5 on both CMS Ends.