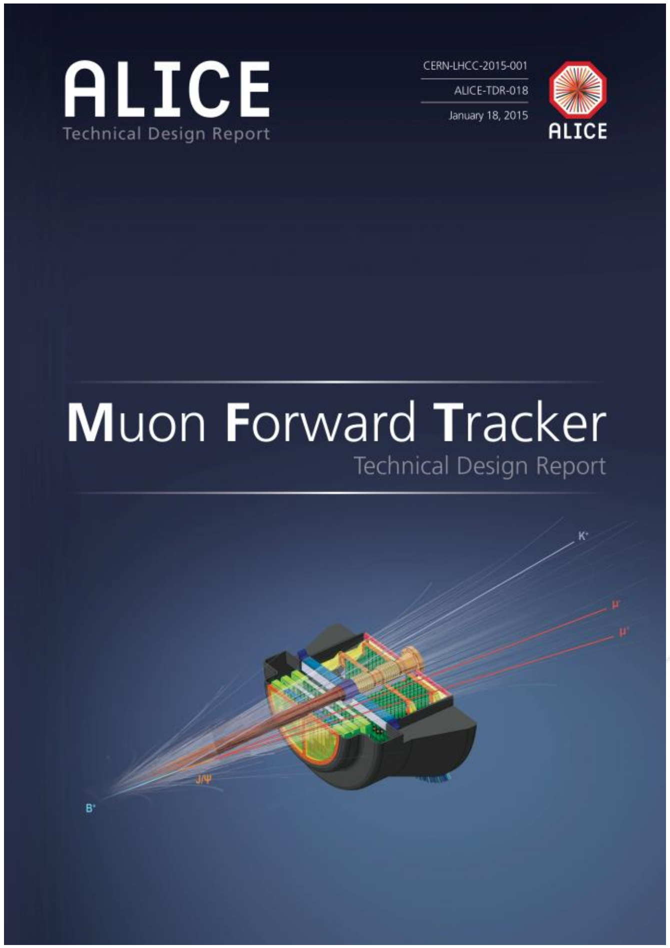
A Large Ion Collider Experiment



Muon Forward Tracker
of ALICE Experiment

Ginés MARTINEZ – Subatech CNRS/IN2P3
for the ALICE MFT project

MFT Meeting
October 5th 2015,
Hiroshima University, Japan

CDS link: http://cds.cern.ch/record/1981898. The MFT TDR has been approved by the CERN Research Board during the RB meeting on September 30th 2015.

MFT design goals

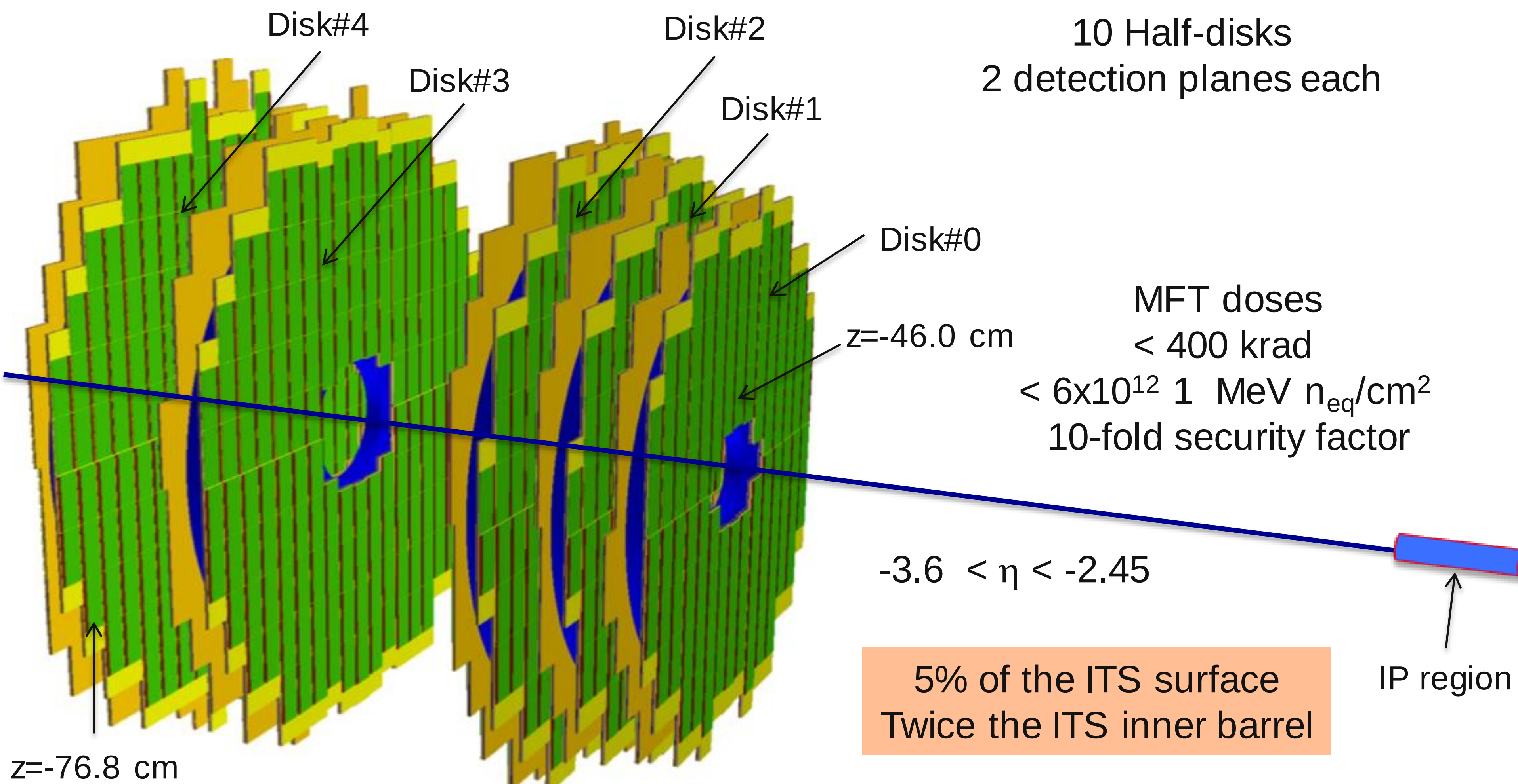
Study QGP physics at forward rapidity in ALICE

- Vertexing for the ALICE Muon Spectrometer (MS) at forward rapidity:
  - 5 detection disks of silicon pixel sensors O(25 μm x 25 μm),
  - 0.6% of X_0 per disk,
  - $-3.6 < \eta < -2.45$,
  - Disk#0 at z=-460 mm, R_{in}=25 mm (limited by the beam-pipe radius).
- Good matching efficiency between MFT and MS:
  - disk#4 at z=-768 mm (limited by FIT and the frontal absorber).
- Fast electronics read-out:
  - Pb-Pb interaction rate ~50 kHz, and pp interactions at 200 kHz.

ALICE MFT

MFT Layout

896 silicon pixel sensors (0.4 m²) in 280 ladders of 1 to 5 sensors each.



10 Half-disks
2 detection planes each

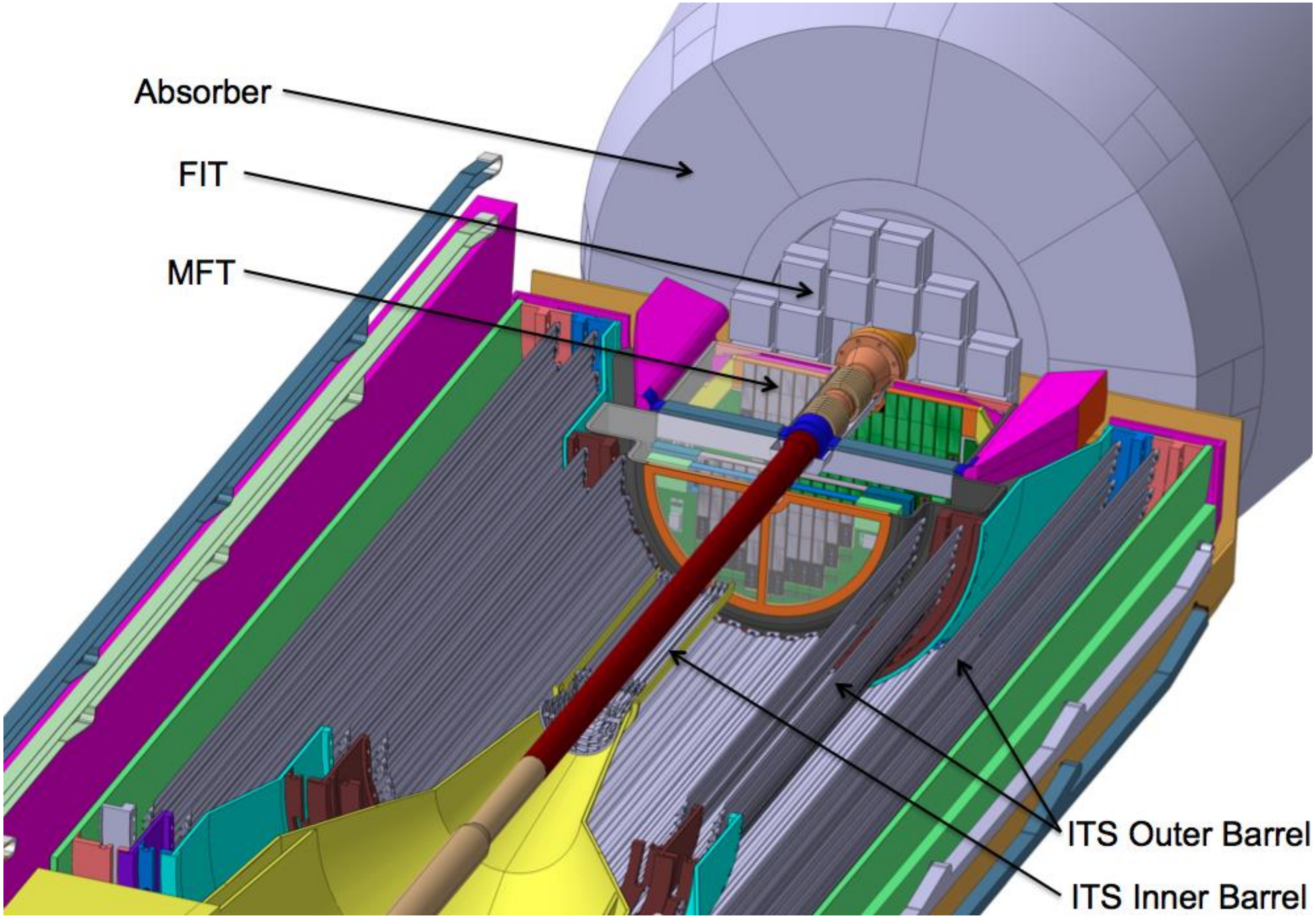
MFT doses
< 400 krad
$< 6\times10^{12}$ 1 MeV n_{eq}/cm^2
10-fold security factor

$-3.6 < \eta < -2.45$

5% of the ITS surface
Twice the ITS inner barrel

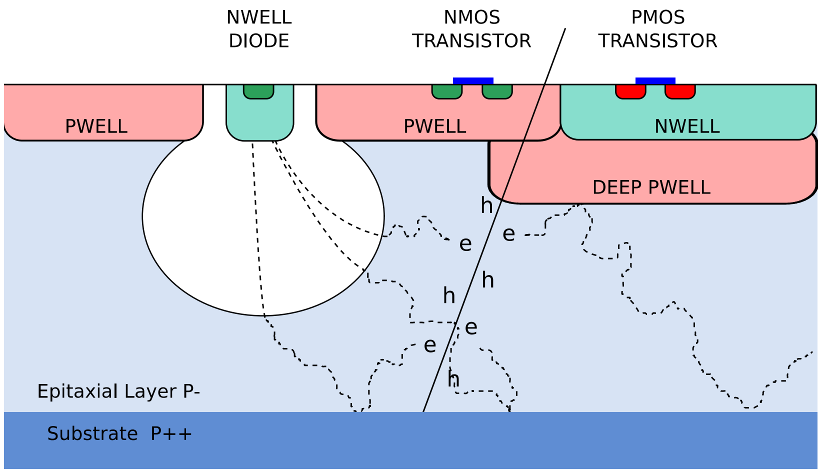
Note that final lay-out is evolving with the finalisation of the MFT disk and cone designs as it has been discussed in the MFT TB meetings.

MFT environment



Silicon sensor technology

ITS inner barrel and MFT will consist of the same silicon pixel sensor



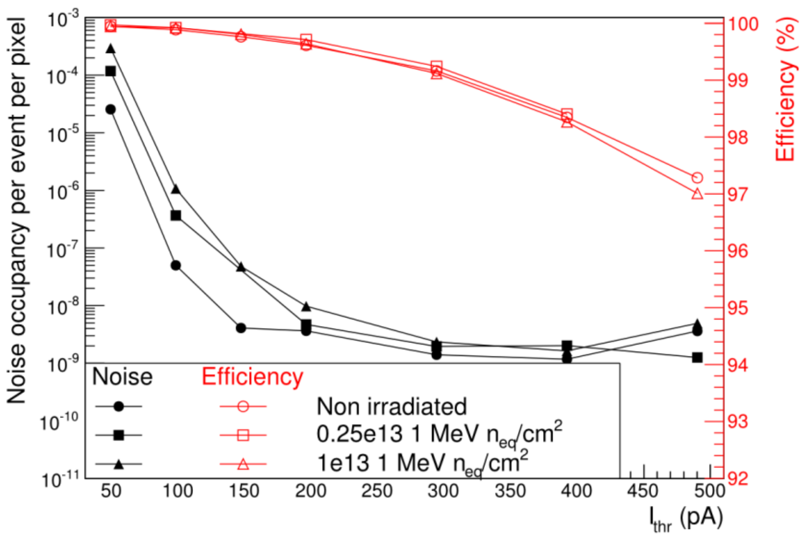
Parameter	Value
Spatial Resolution	~ 5 µm
Detection Efficiency	> 99.5%
Integration Time	< 20 µs
Sensor Thickness	50 µm
Power dissipation	≤ 150 mW/cm²
Radiation Tolerance (10-years operation)	~ O(10^{13}) n_{eq}/cm² ~ O(700) kRad

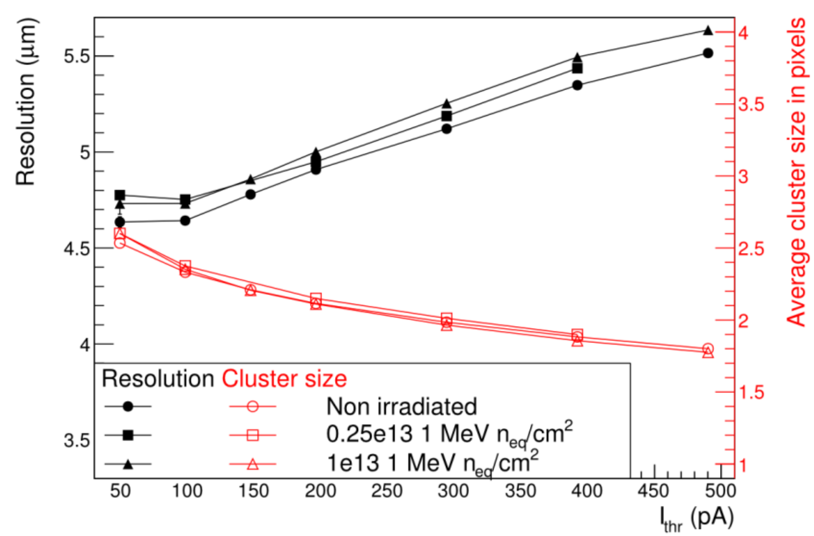
CMOS Monolithic Active Pixel Sensor (MAPS):
CMOS pixel sensor using Tower Jazz 0.18 µm CIS technology.
Sensor size 15 mm x 30 mm
The Alpide architecture exhibits good performances for the MFT:
- Event time resolution below 4 µs.
- Low power consumption <50 mW/cm².

MFT participates into Alpide ASIC design and characterization.

Pixel results

Example of measurement at PS test beam with pALIPIDEfs





Measurements at PS: 5 – 6 GeV π- , read-out rates 10-40 kHz

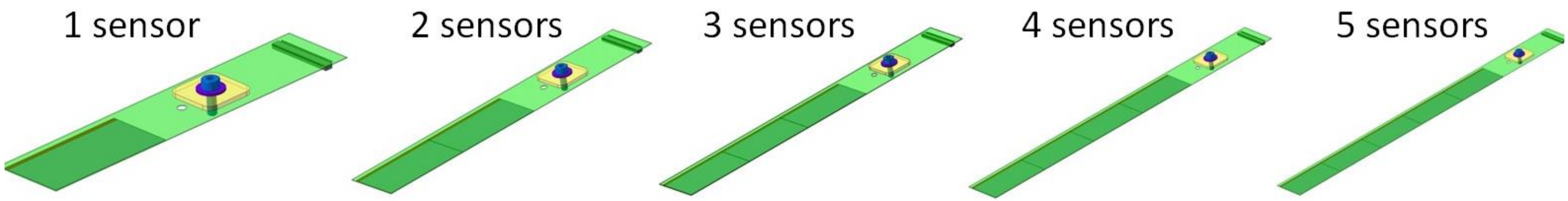
Results refer to 50 μm thick chips: non irradiated and irradiated with neutrons (0.25 x 10^{13} and 10^{13} 1MeV n_{eq} / cm2)

Note that these are the results included in the TDR. New results are available with Alpide2 and they were presented in the last ITS-MFT plenary meeting at CERN on September 9th 2015.

Joint MFT-ITS Strategy

- Requirements of ITS inner-barrel and MFT are almost identical.
- ITS-MFT common sensor.
- Main benefits are:
  - minimize sensor cost and manpower resources,
  - similar flex printed circuit,
  - same bonding technique (laser soldering),
  - same read-out architecture,
  - same cooling strategy.

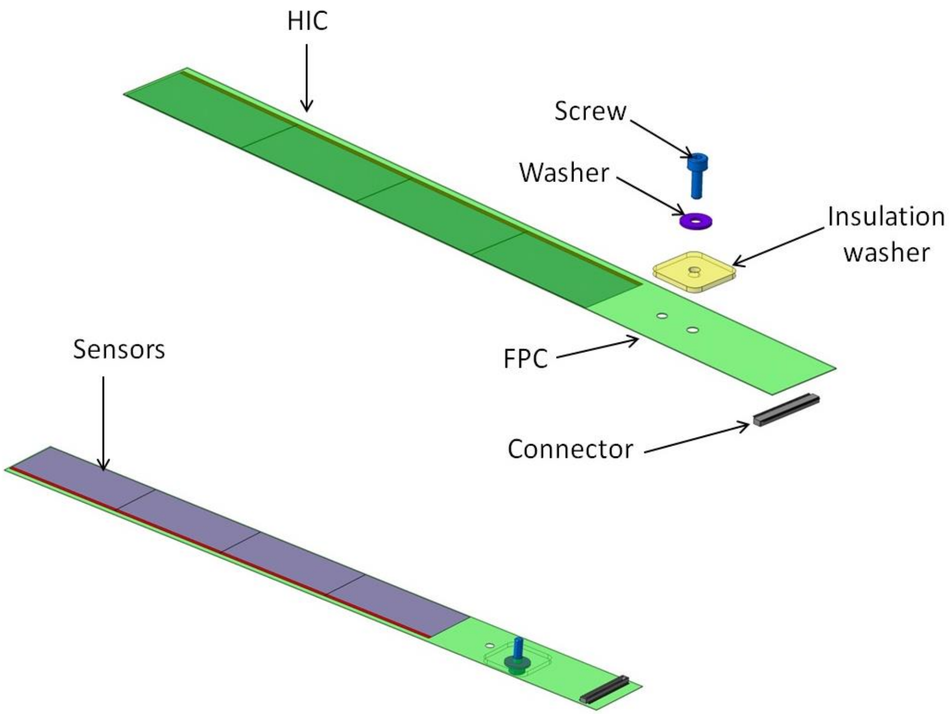
MFT ladder design



Sensor+FPC ➔ Hybrid Integrated Circuit (HIC) with 1 to 5 sensors each.

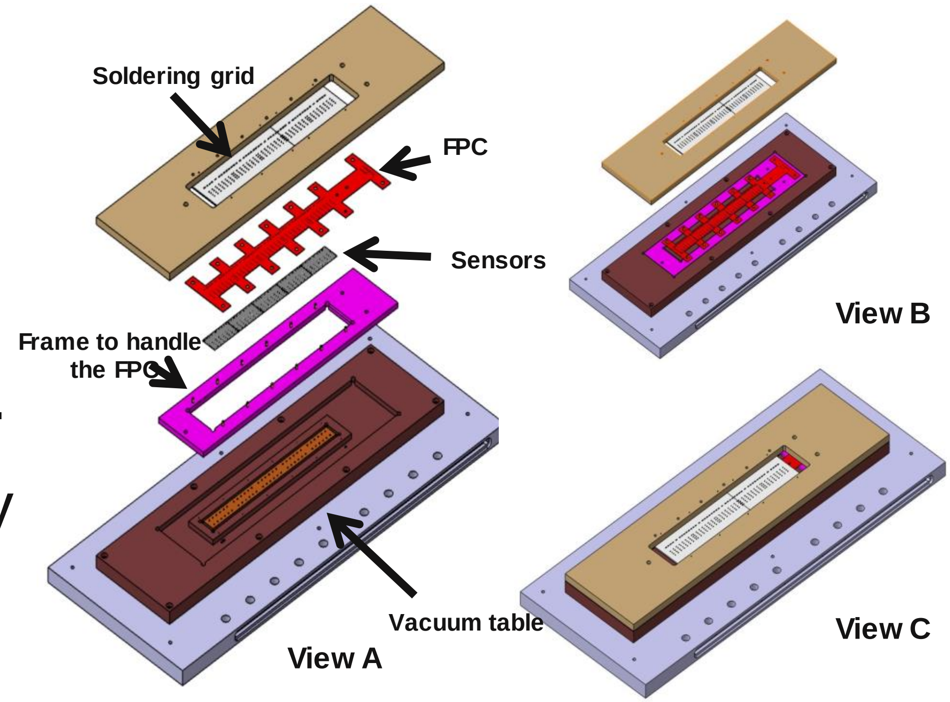
Kapton encapsulation

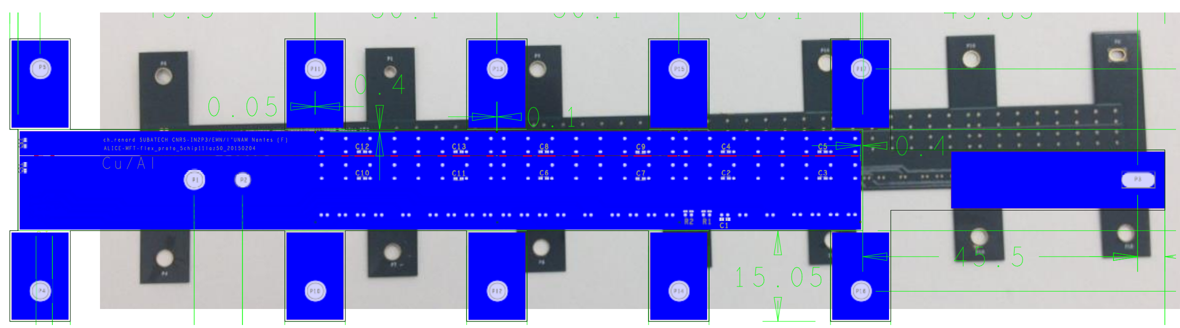
R&D ongoing



Flex printed circuit (FPC) and Hybrid Integrated Circuit (HIC)

- Similar FPC to that of ITS inner barrel, but with 1 to 5 sensors each.
- Polyimide with Al strips to minimise the material budget.
- Laser soldering developed by ITS upgrade project.
- Copper prototype realized by ATLANTEC:
  - mechanical test,
  - laser soldering test.



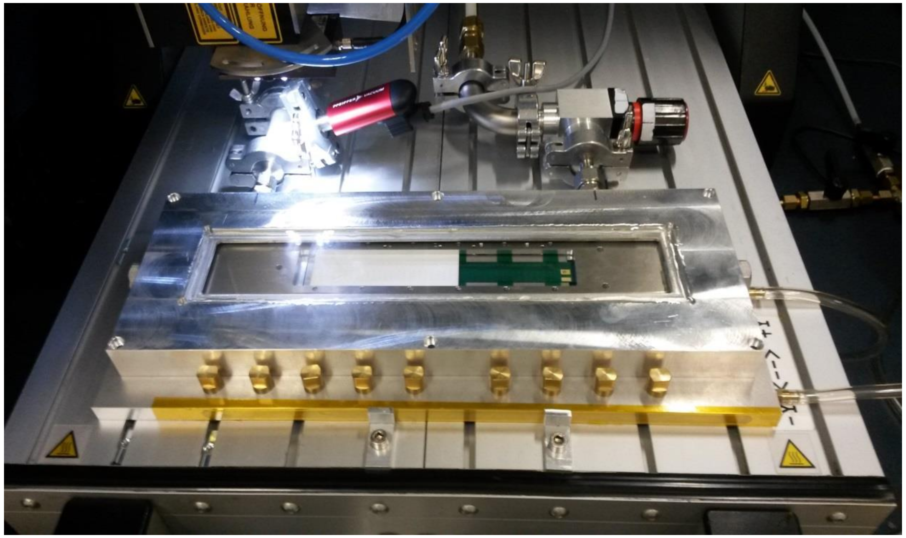


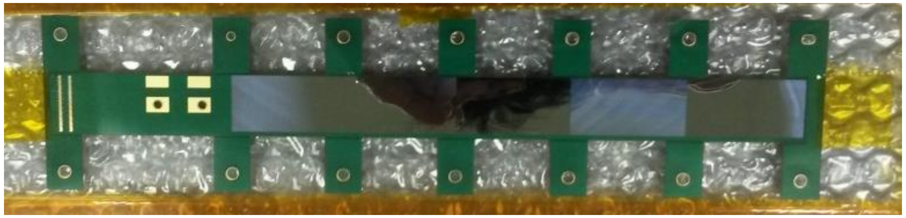
MFT 5 sensor FPC copper prototype.
Al FPC will be delivered soon for Alpide3

MFT laser soldering tests

Many tests have been performed at CERN in the last months

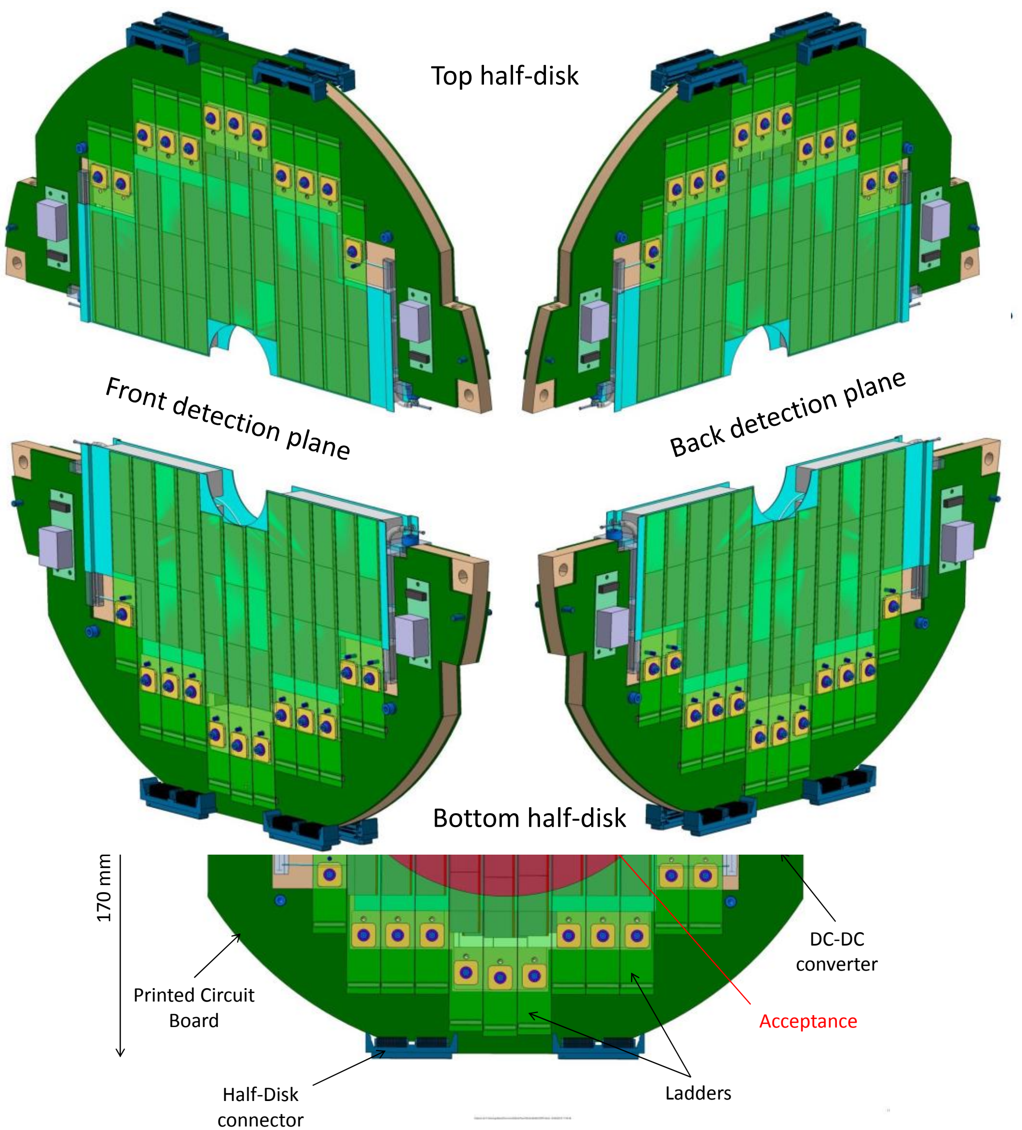
- ✓ MFT FPC prototypes. 5 (dummy) pixel sensors. 50 pad each.
- ✓ Very instructive tests.
- ✓ Optimisation of the process ongoing (w w/o ears, laser soldering on Al in the next weeks with a steel worktable ,…





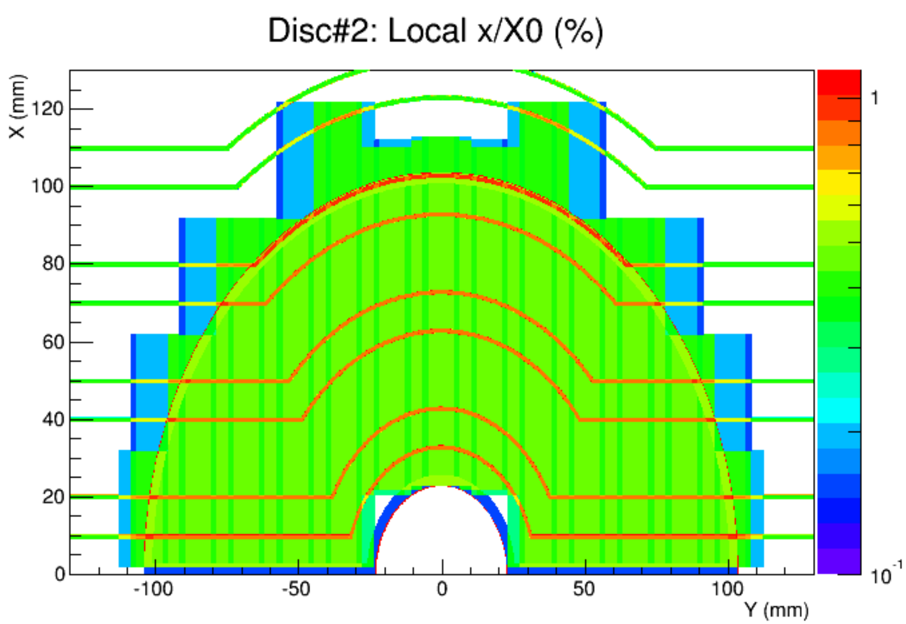
MFT half-disk design

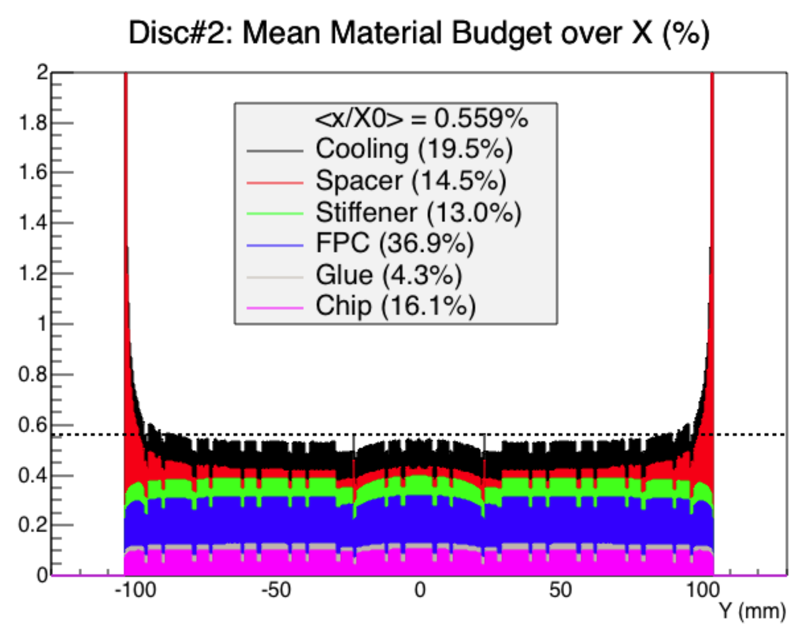
Disk#0, #1



- Two detection planes:
  - coverage around the BP,
  - Water cooled plate in between.
  - redundancy (50%),
- Two PCBs, containing the regulators, data, clock and slow control lines.
- Half-disk support.
- Half disk cool-plate.
- Survey of each sensor positioning with respect to half-disk support markers.

Material budget per half-disk

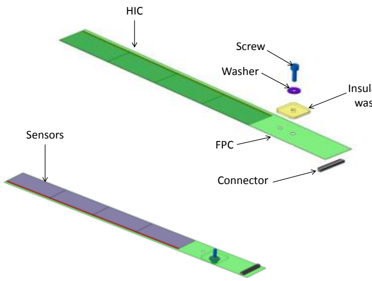


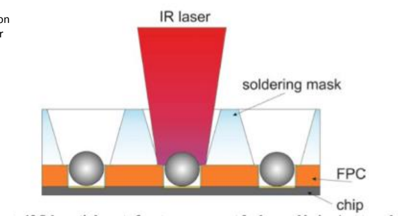


- Perpendicular water cooling option.
- FPC is the main contributor to the material budget (38%), followed by the cooling (19.5%) and silicon pixel sensor (16%).
- Material budget per disk below 0.6% of X_0.
- Axial cooling geometry was also studied as similar results were obtained.

MFT ladder assembly

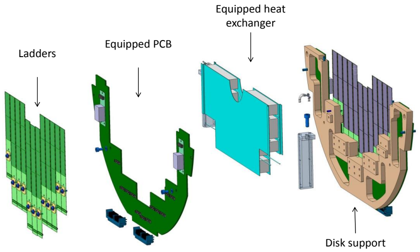
- Preparation of the ladder elements:
  - ITS-MFT sensors, FPC, kapton encapsulation,
  - soldering of SMD components and connector on the FPC.
- HIC Soldering (FPC and sensors):
  - common semi-automatic assembly system for ITS inner barrel and MFT at CERN,
  - visual inspection and electrical tests.



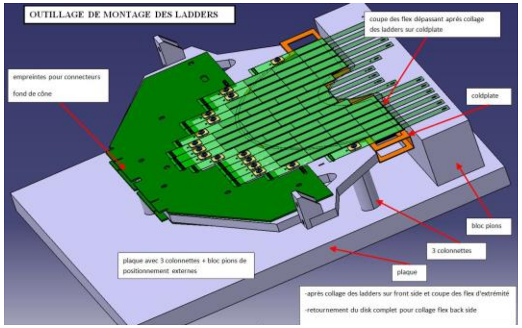


- HIC and kapton gluing.
- Qualification test.
- Production of ladders (TDR version):
  - an MFT represents 280 ladders: 16, 36,120, 92, 16 ladders of 1 to 5 sensors respectively,
  - 5 half-disk spares and 20% of ladder spares: total of 506 ladders,
  - duration of ladders production is estimated to 12 months.

MFT half-disk assembly



- Preparation of the half-disk elements:
  - ladders, half-disk support, half-disk plate, 2 PCBs.
- Positioning of the ladders on the half-disk:
  - positioning (~0.3 mm precision) of ladders on the front and back planes,
  - gluing on the half-disk spacer,
  - Electrical test.



- Qualification tests.
- Survey of the sensor positions wrt the half-disk support.
- Production of half-disks:
  - MFT represents 10 half-disks + 5 spare half-disks,
  - duration of half-disk production is estimated to 5 months

MFT mechanical structures

Half-cone

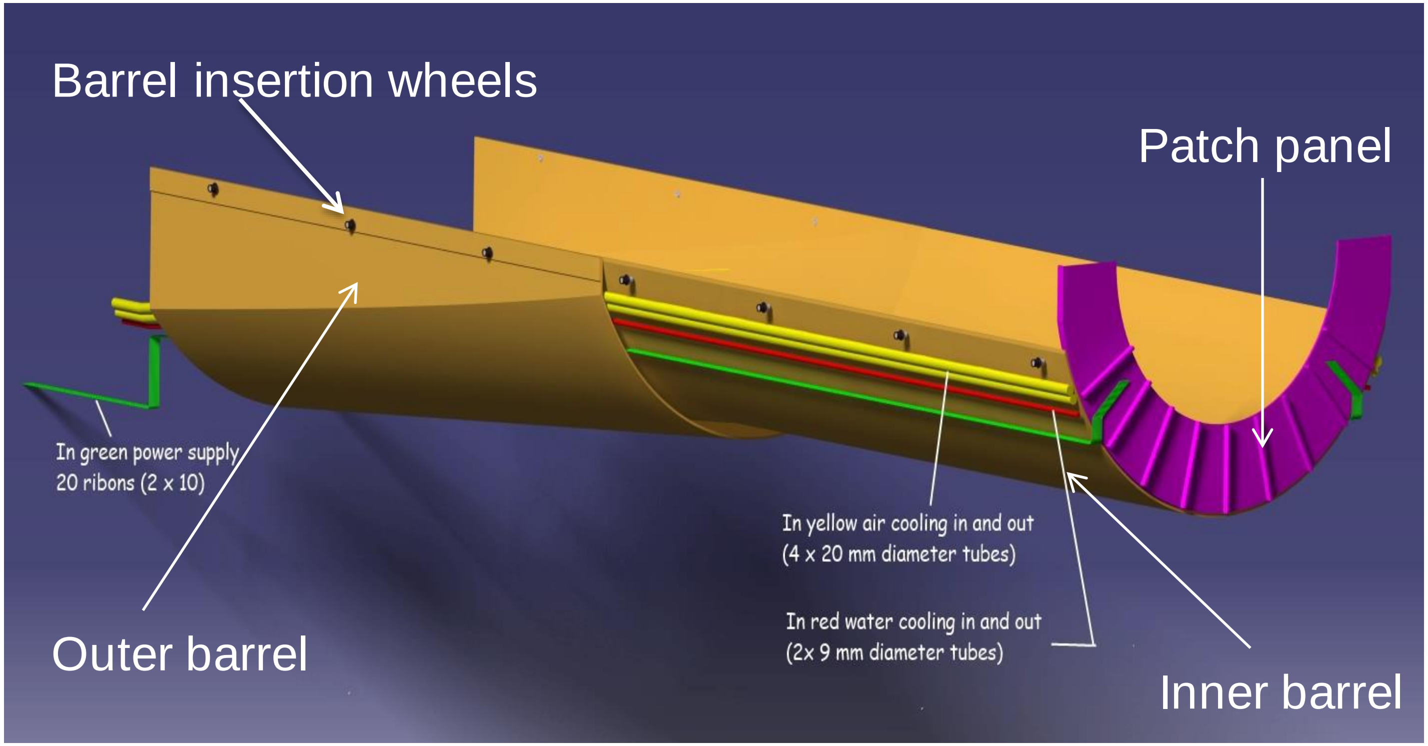
Two half-cones:
top and bottom

Structure in carbon fibre. Support half- disks, service distribution (water/air tubes, power supply), DCS, RO, SC cables.

A Large Ion Collider Experiment

MFT mechanical structures

Half-barrel



Two half-barrels:
top and bottom

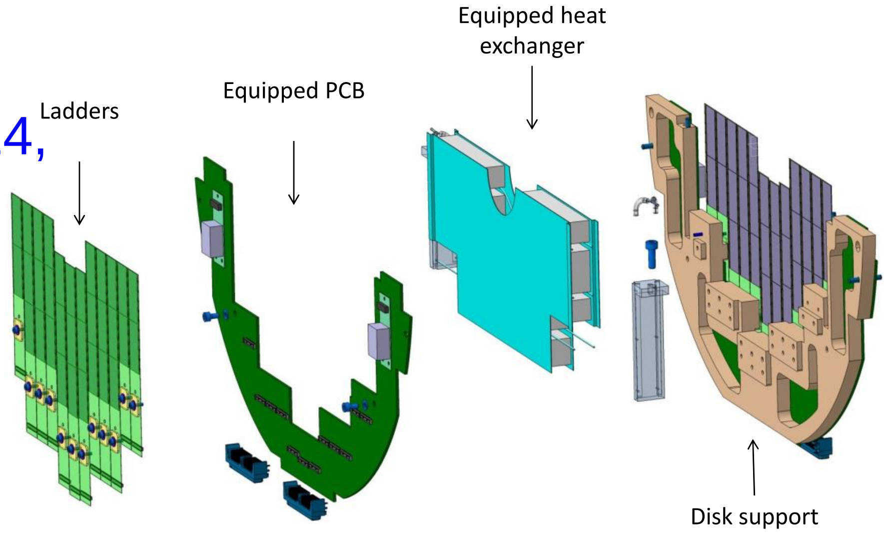
Insertion tool of the MFT, supporting half-cone, routing services from A-side, and DCS, read-out cables from C-side.

Cooling

Considering water cooling as ITS

Water-cooling technic is robust (ITS TDR).

- decision taking in December 2014,
- assumed 50 mW/cm^2 for the sensor,
- polyimide pipes are foreseen for half-disk plane: half-disk cold-plate,
- perpendicular and axial water cooling option are being considered.
- preliminary thermal studies confirm the robustness of the water cooling option.



- Water-cooling in the PCBs:
  - Cooling of the DC-DC converters.

MFT services

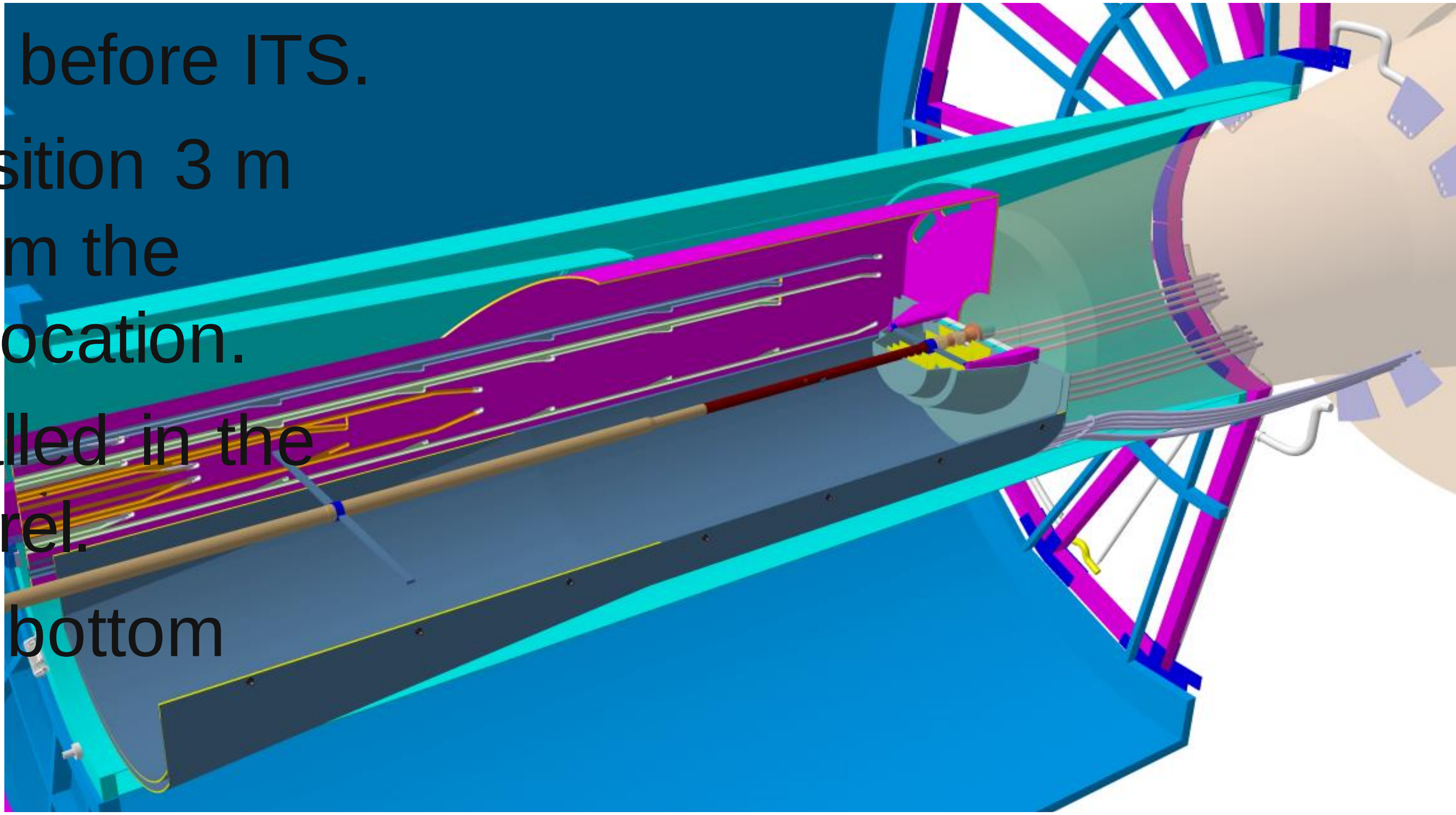
Half-barrel services

- Power supply (A-side):
  - 300 W for 896 sensors and 160 DC-DC converters,
  - 20 Aluminium bus-bars, total section of 80 mm^2 (0.1 V drop).
- Readout and DCS cables (C-side):
  - 1 per sensor, Samtec AWG30 Twinax cable, 4 m “firefly”: 896 cables,
  - 1 slow control and 1 clock cable per ladder: 560 cables
  - 116 cables for detector control system (voltage, current and temperature sensors).
- Cooling (A-side)
  - 8 water-pipes with a diameter of 5 mm,
  - air flow from A-side along the half-barrel.

Note that the final values are evolving with the finalisation of the MFT design as it has been discussed in the MFT TB meetings.

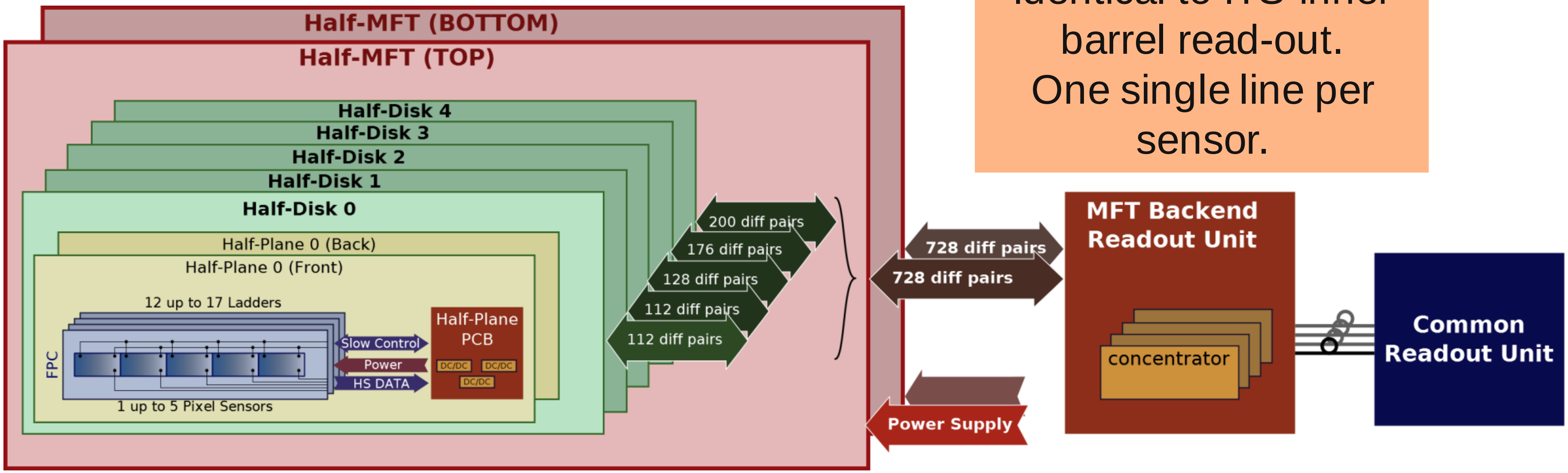
Installation and removal

- Installed before ITS.
- Final position 3 m away from the parking location.
- FIT installed in the MFT barrel.
- Top and bottom



Removal possible during a winter shutdown.

Read-out architecture



Identical to ITS inner barrel read-out. One single line per sensor.

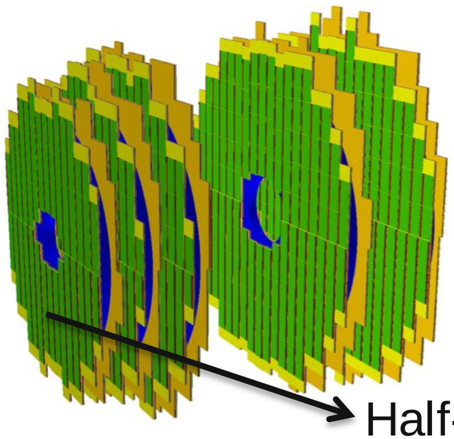
- Between 128-264 high speed data signals (1.2 Gb/s) per disk.
- Between 96-136 clock and slow control signals per disk.
- Total of 1456 twinax cables for read-out.
- Concentrator board ~ 4 m away, where TID about 10 krad.

Note that a big progress on readout activities has been achieved by WG6 (Cyrille GUERIN) during the last months. Recently the Chinese colleagues have delivered the first disk PCB prototype for readouot and mechanical tests.

MFT data throughput

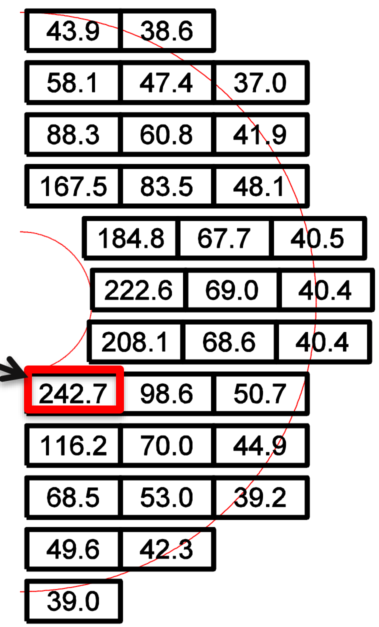
Average data throughput estimation

includes Pb-Pb collisions, QED, noise.



Collision Rate	100 kHz
Integration Time	4 μs
Fake Hit Rate	10^{-5}
Average Hit Encoding	35.1 bits

Maximum average data throughput of 243 Mb/s for the sensor closest to the beam-pipe in disk#0

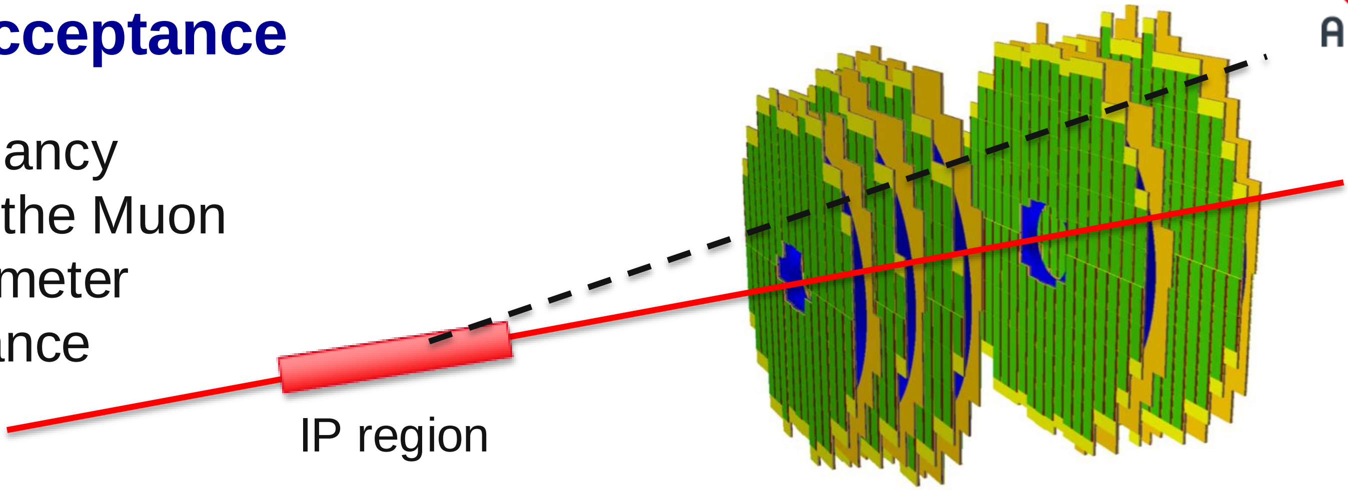


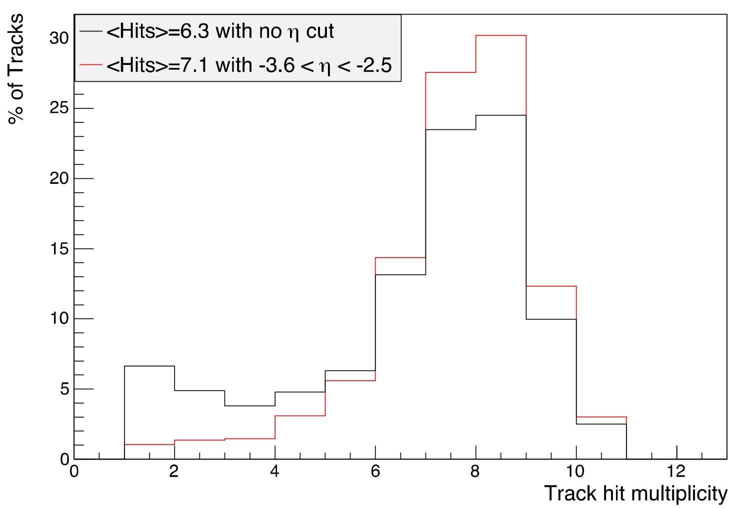
High speed 1.2 Gb/s lines comply with MFT requirements.

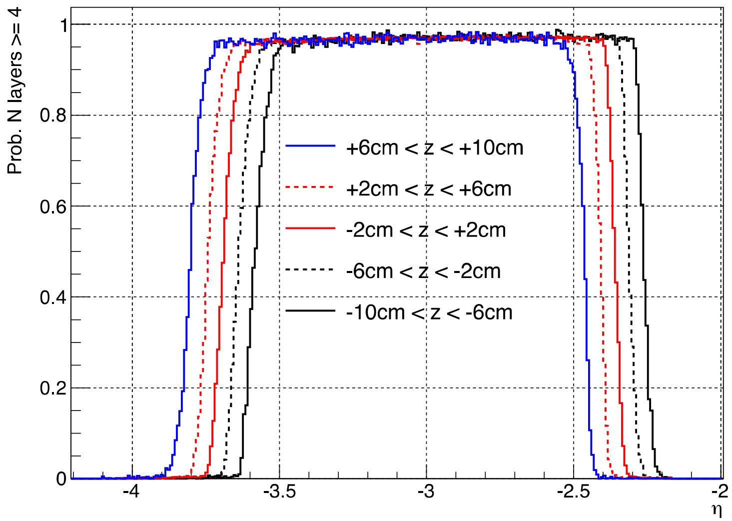
Full MFT data throughput 57 Gb/s.

MFT Acceptance

Redundancy
Most of the Muon spectrometer acceptance

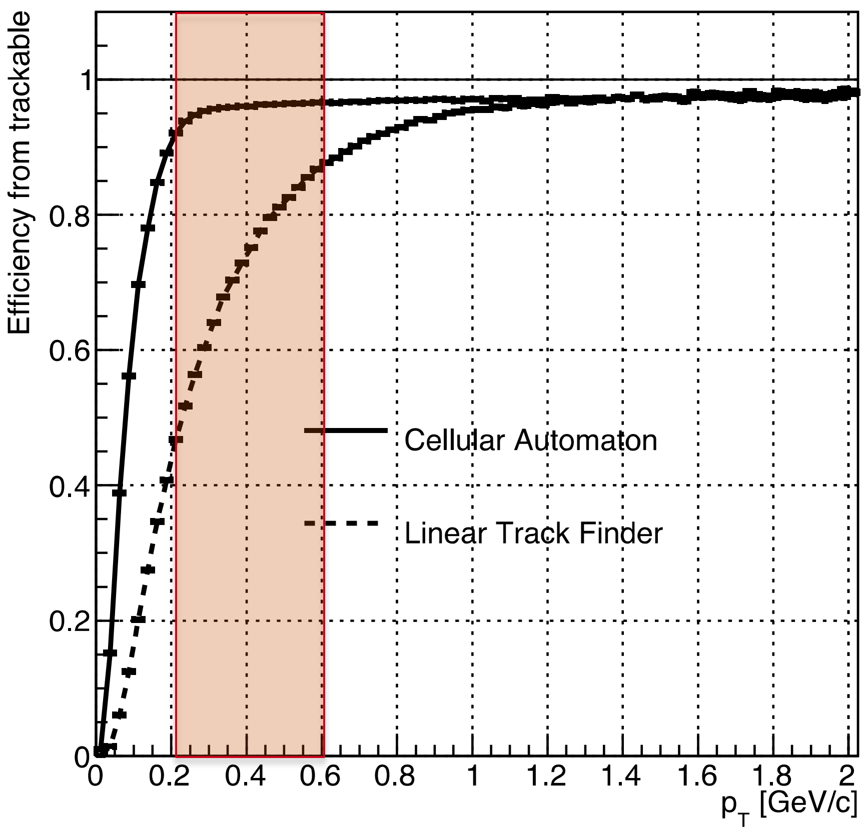






MFT standalone tracking

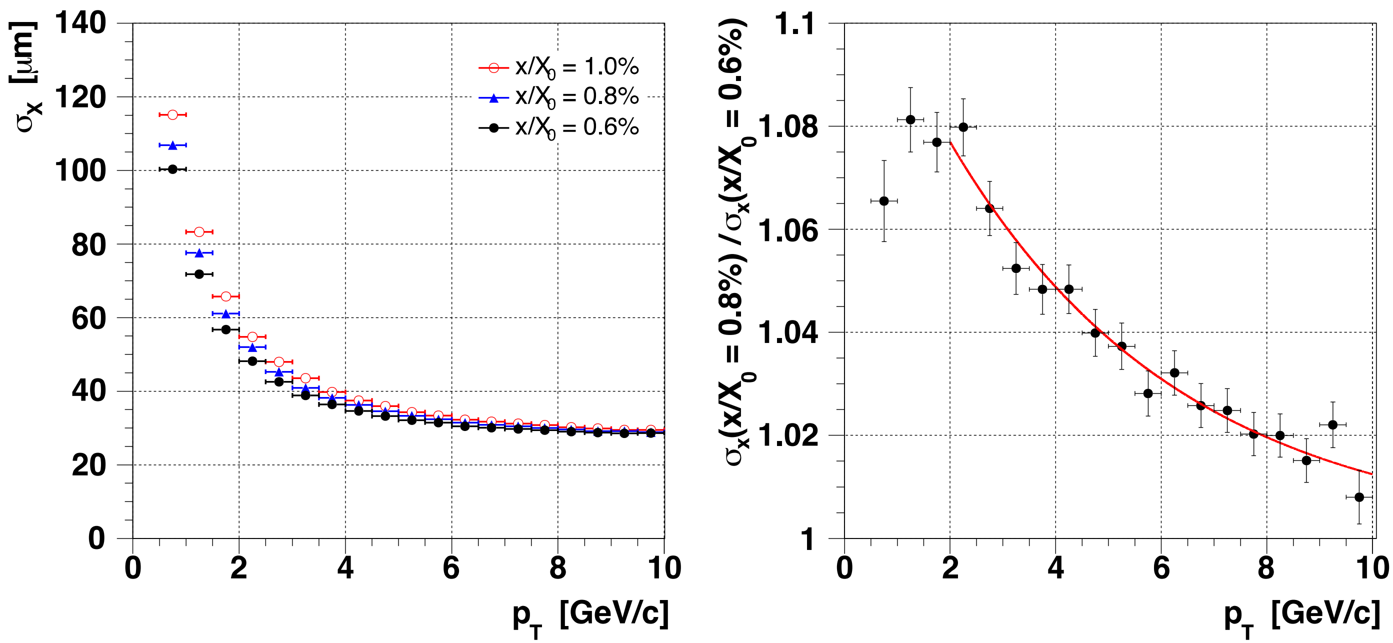
- Two standalone tracking algorithms have been implemented in AliRoot framework.
- Cellular automaton algorithm:
  - Needed for charge particle multiplicity, reaction plane measurements, correlation studies.
- Linear track finding algorithm:
  - Optimizing the MS-MFT matching efficiency
- Studying track charge sign.



Frontal absorber cut
p>4 GeV/c

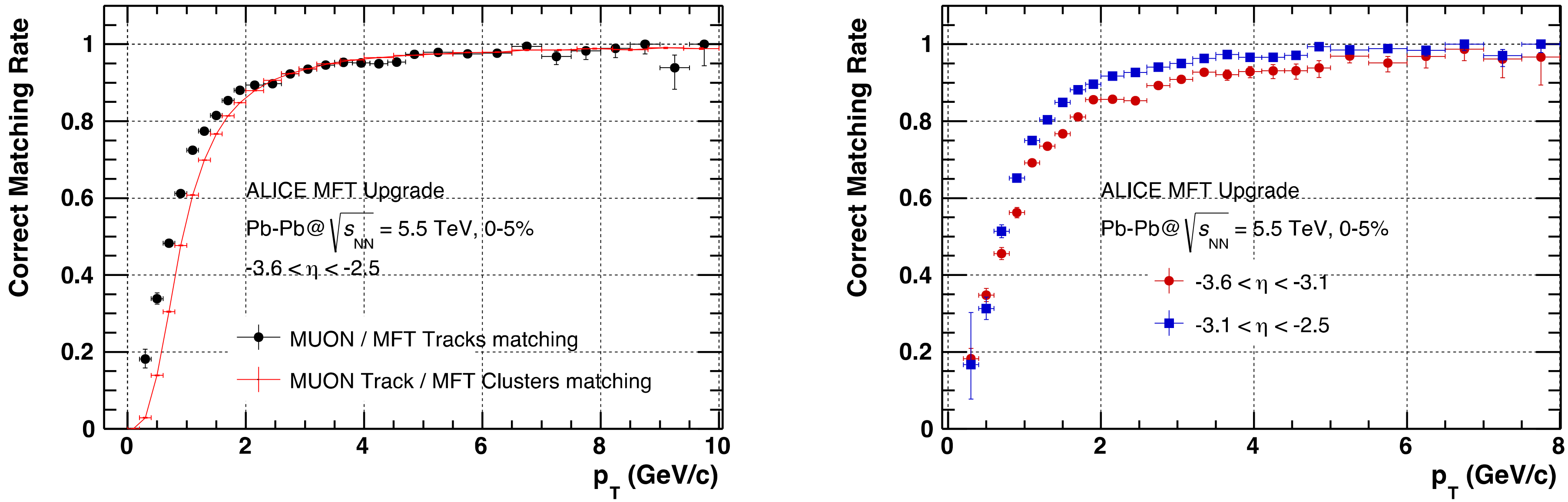
Impact parameter resolution

- ✓ Resolution below 100 μm for p_T>1 GeV/c.
- ✓ J/ψ from B hadron decay (cτ ~ 500 μm), muon from charmed hadrons (cτ ~ 150 μm), muons from B hadrons (cτ ~ 500 μm). Lorentz factor ~10 at η=3.



MS-MFT single matching efficiency

- Two methods have been studied:
  - MFT-cluster with MS-track matching (LoI),
  - MFT-track with MS-track matching (new).
- Central Pb-Pb collisions.



Reminder of physics cases

Reminder of the MFT LoI

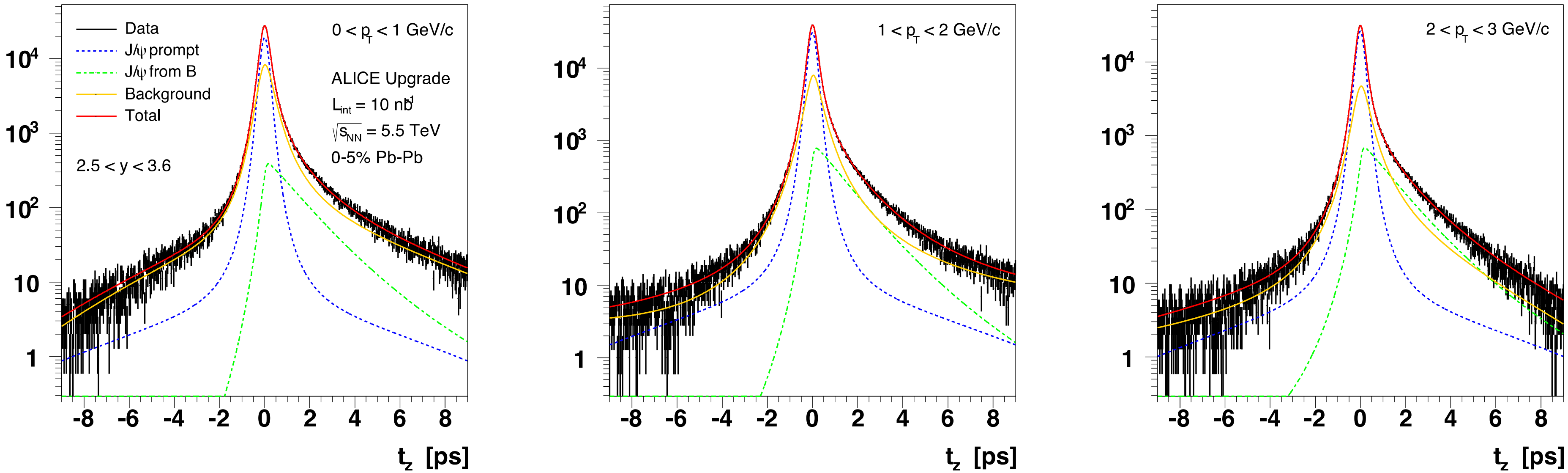
- Open Heavy Flavour:
  - charm in the single muon channel down to p_T=1 GeV/c,
  - beauty in the J/ψ channel, down to p_T=0.
- Charmonium
  - separation between prompt and decay J/ψ,
  - measurement of the ψ(2S).
- Low mass dimuon:
  - improvement of the invariant mass resolution,
  - higher sensitivity to the continuum.

Improved performances (J/ψ from B decays)

Good discrimination between prompt and B-decay J/ψ down to p_T=0 thanks to the Lorentz boost along the z-axis.

t_z is weakly dependent on p_T for $p_T<M_{J/\psi}$.

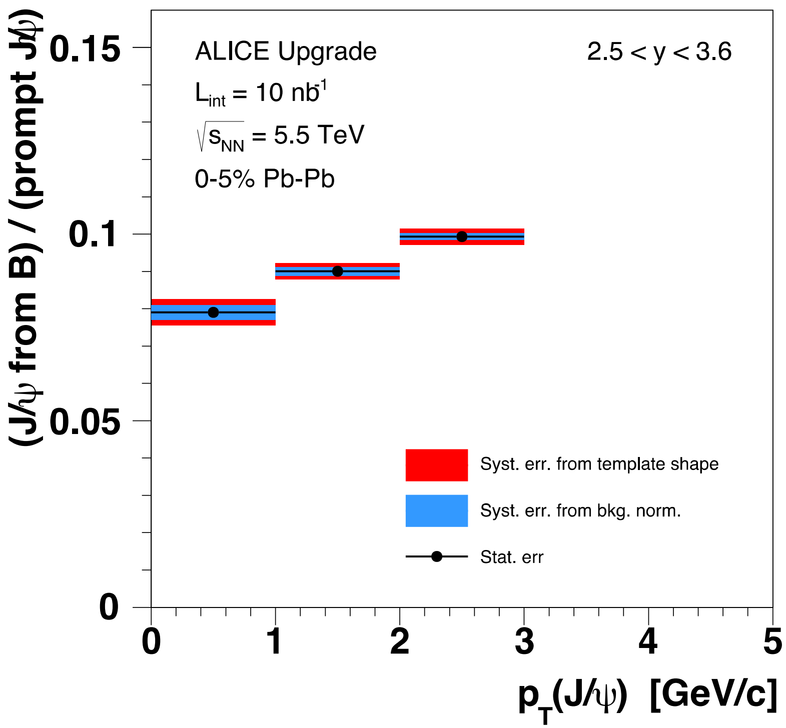
$$t_z = \frac{(z_{J/\psi} - z_{vtx}) \cdot M_{J/\psi}}{p_z}$$

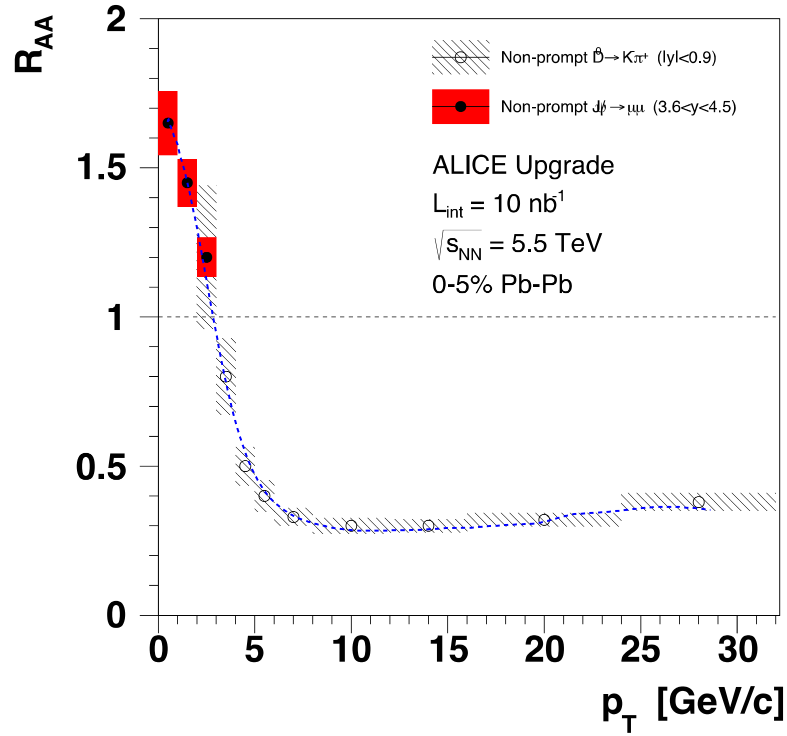


Reconstructed by the MFT+MS

Beauty production down to p_T=0

R_{AA} of J/ψ from B hadron decay down to p_T=0





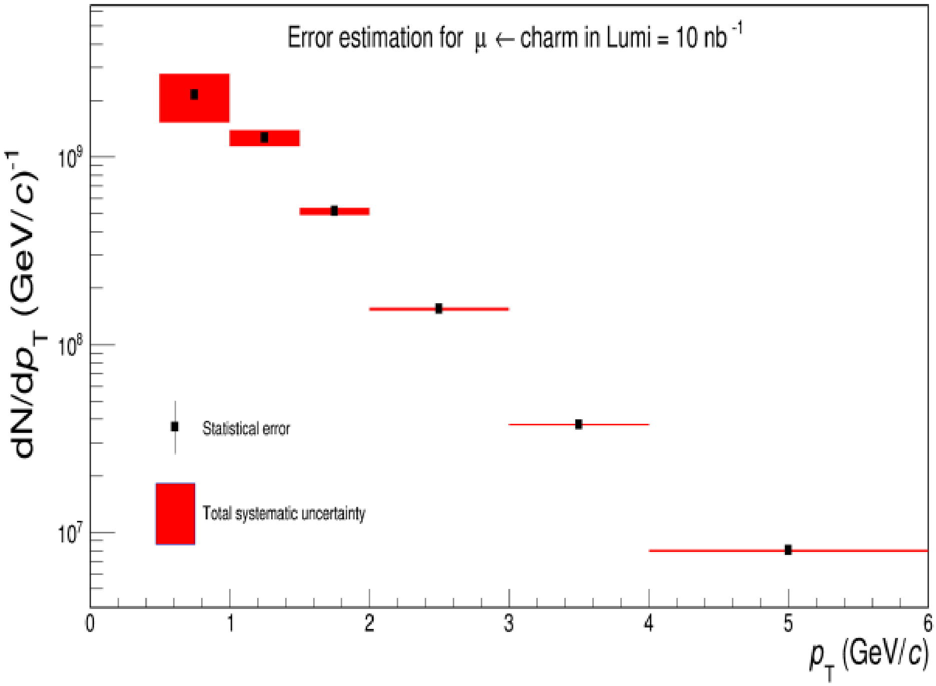
✓ Excellent performances at low p_T.

✓ Unique beauty measurement at the LHC in HI.

Charm production

Muons from charm hadron decays down to p_T=0.5 GeV/c

- ✓ MFT-ITS residual mis-aligment, p_T MC and MFT pointing resolution were considered for the evaluation of the systematic uncertainty
- ✓ 29% systematics at 0.5-1 GeV/c
- ✓ 10% at 1-1.5 GeV/c.



Organisation

MFT Coordination Board

The Project Leader (PL) heads the Muon Forward Tracker Project. He is assisted by the MFT Deputy Project Leader (DPL) and the MFT Technical Coordinator (TC). PL, DPL and TC are the members of the MFT coordination board. The MFT PL, DPL and TC are all members of the ALICE Technical Board and thus ensuring the coherence of the project within the ALICE experiment. A MFT coordination board meeting takes place every week.

Organisation

MFT Institute Board

Representative of the laboratories participating to the MFT project. Issues of financial, managerial and organisational nature are discussed and decided by the MFT Institute Board. This board also endorses technical matters recommended by the MFT Technical Board and proposed by the MFT Project Leader. The Project Leader, Deputy Project Leader and Technical Coordinator are ex-officio members of the Institute Board. The MFT-IB meets at least once per year.

A Large Ion Collider Experiment

Organisation

MFT Institute Board

Table 2.1: Institutes participating in the MFT Project (April 2015).

Country	City	Representative	Institute
China	Wuhan	Daicui ZHOU	Central China Normal University (CCNU)
France	Clermont-Ferrand	Philippe CROCHET	Laboratoire de Physique Corpusculaire (LPC), Clermont Université, Université Blaise Pascal, CNRS/IN2P3
France	Nantes	Guillaume BATIGNE	SUBATECH, Ecole des Mines de Nantes, Université de Nantes, CNRS/IN2P3
France	Saclay	Alberto BALDISSERI	Commissariat à l'Energie Atomique, IRFU
France	Villeurbanne	Brigitte CHEYNIS	Université de Lyon, Université Lyon 1, CNRS/IN2P3, IPN-Lyon
India	Kolkata, Aligarh	Sukalyan CHATTOPADHYAY	Saha Institute of Nuclear Physics and Aligarh Muslim University
Japan	Hiroshima	Kenta SHIGAKI	Hiroshima University
Korea Republic	Pusan, Incheon, Yonsei	In-Kwon YOO	Pusan National, Inha University and Yonsei Universities
Peru	Lima	Alberto GAGO MEDINA	Pontificia Universidad Católica del Perú
Russia	Gatchina	Volodia NIKULIN	Petersburg Nuclear Physics Institute
Thailand	Nakhon Ratchasima, Chachoengsao	Wutthinan JEAMSAKSIRI	Suranaree University of Technology and Thai Microelectronics Center

Organisation

MFT Working Groups

The MFT project is organised into eight Working Groups. Conveners organise the discussion, keep track of the decisions and report to the MFT coordination and, if it is needed, to the ALICE Technical Board. The Working Group conveners are nominated by the Project Leader and endorsed by the MFT Institute Board.

Coordination Board

G. Martinez (Project Leader)
G. Batigne (Deputy Project Leader)
F. Orsini (Technical Coordinator)

MFT Working Groups

Physics Simulations
A. Uras

Simulation and Reconstruction
L. Molnar
in synergy with ITS WPs

Standalone and Global Tracking
F. Manso
R. Tieulent

CMOS Pixel and Sensors production
F. Guilloux
in synergy with ITS WPs

Ladder, Disk and Global Assembly
S. Bouvier (Disk Assem.)
S. Herlant (Ladder Assem.)

Readout and FPCs
C. Guerin
in synergy with ITS WPs

Mechanics and Thermal Studies
J.M. Buhour
E. Schibler

Services and DCS
in synergy with ITS WPs

Organisation

MFT Technical Board and Plenary meetings

Technical Board

The MFT Technical Board is formed by the WG conveners, MFT coordination members and MFT-IB members. The MFT-TB meets every week.

Plenary meetings

The MFT collaboration meets during the ALICE mini weeks (on average one per month except during the months with an ALICE week) and presents the status of the project to the ALICE collaboration during the ALICE weeks (3 per year). When it is needed, common meeting with ITS are organised, on average once per year.

MFT cost and sharing responsibilities

Pixel Sensors	**483.4**	
CMOS wafers	310.8	**IRFU, Thai Microelectronics Center**, *in synergy with ITS*
Thinning & dicing	44.3	**IRFU**, Thai Microelectronics Center, *in synergy with ITS*
Series tests	128.3	**Pusan National University, Inha University and Yonsei University**, IRFU, *in synergy with ITS*
Ladders	**837.3**	
FPCs manufacturing & tests	82.4	**SUBATECH**
FPCs electronic components & tests	12.3	**SUBATECH**
Automatic assembly system for HICs	258.3	**SUBATECH, IRFU**, *in synergy with ITS*
Stiffeners manufacturing	93.0	**SUBATECH**
HICs and ladders assembly & tests	163.9	**IRFU, SUBATECH**, AMU, IPNL, LPC CL, PNPI, SAHA *in synergy with ITS*
Ladders qualification tests	227.4	**IRFU, IPNL**, LPC CL, SAHA, HIROSHIMA, LIMA

MFT cost and sharing responsibilities

Disks	**371.5**	
Disk Spacers, support manufacturing	172.2	**SUBATECH**
Disks Assembly	84.3	**SUBATECH, IPNL, IRFU**, AMU, LPC CL, PNPI, SAHA
Disks Tests	84.3	**IRFU, IPNL**, LPC CL, SAHA, HIROSHIMA, LIMA
Shipments	30.7	**SUBATECH**
Global assembly	**296.0**	
Cone manufacturing	61.5	**SUBATECH**
Half MFT Assembly & test	93.5	**SUBATECH, IRFU, SAHA**, IPNL, PNPI, HIROSHIMA, LIMA
Services barrel, connections	141.0	**IPNL**
Integration in ALICE	**324.6**	
Insertion Tools	36.9	**IPNL**, SUBATECH
Barrel manufacturing	61.5	**IPNL**
Check-out in surface	113.1	**IPNL, IRFU, SUBATECH**, PNPI
Installation in cavern	113.1	**IPNL, IRFU, SAHA, SUBATECH**, PNPI

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MFT cost and sharing responsibilities

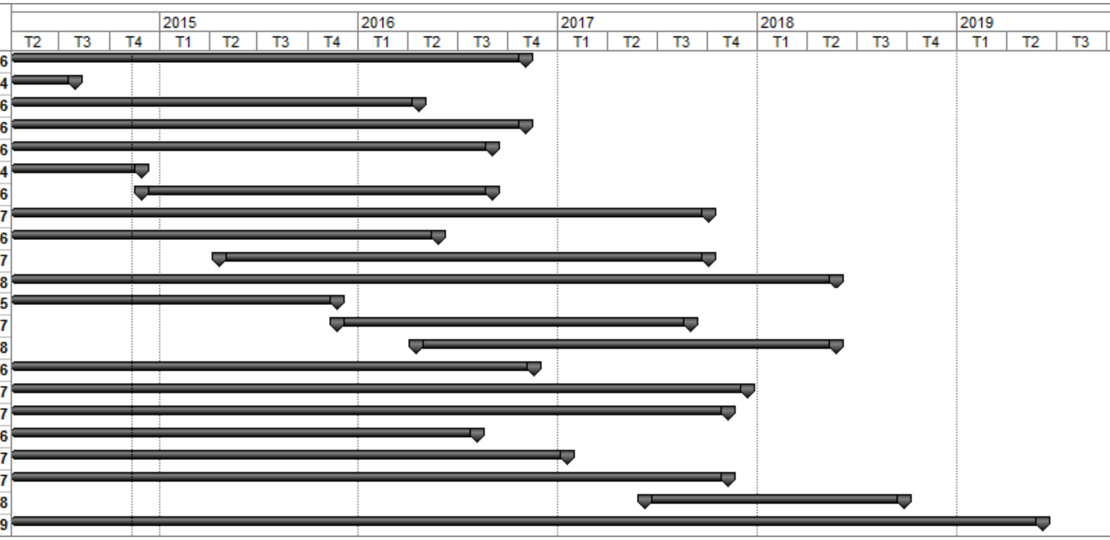
Readout electronics	**490.8**	
Printed Circuit Boards	49.2	**IPNL** , CCNU, IFIC
Data e-links	34.8	**IRFU, IPNL**, *in synergy with ITS*
Patch Panels equipped	47.4	**IPNL**
Optical fibers	64.8	**SAHA**, IPNL
Readout Units	121.5	**AMU, SAHA, IRFU, IPNL**, *in synergy with ITS*
Common Readout Units	173.0	**AMU,SAHA** *in synergy with ITS and ALICE Electronics coordination*
Services	**541.6**	
Power Distribution	123.7	**SUBATECH**, *in synergy with ITS*
Power Supplies	173.8	**SUBATECH**, *in synergy with ITS*
Power Regulations	36.9	**SUBATECH**, *in synergy with ITS*
Cooling & Ventilation Plants	89.1	**PNPI**, *in synergy with ITS*
DCS	118.1	**PNPI**, *in synergy with ITS*

Total Cost of MFT detector 3.3 MCHF

Note that a new evaluation of the MFT cost is being performed that will be presented in the Memorandum of Understanding that has to be signed in the next months.

MFT project schedule

N°	Nom de la tâche	Durée	Début	Fin
8	**CMOS sensors**	**54,18 mois**	**Lun 31/10/11**	**Mar 01/11/16**
9	**MFT CMOS sensors development (MFT oriented)**	**31,07 mois**	**Lun 31/10/11**	**Mer 30/07/14**
22	**ITS CMOS sensors development (IL/OL oriented --> 1 cl**	**24 mois**	**Lun 06/01/14**	**Jeu 21/04/16**
28	**CMOS sensors Production Phase**	**33,18 mois**	**Lun 02/09/13**	**Mar 01/11/16**
41	**Flexible Printed circuits**	**37,03 mois**	**Lun 04/03/13**	**Ven 02/09/16**
42	**FPC Prototyping Phase**	**19,03 mois**	**Lun 04/03/13**	**Jeu 27/11/14**
56	**FPC Production Phase**	**18 mois**	**Ven 28/11/14**	**Ven 02/09/16**
66	**Ladders**	**42,03 mois**	**Lun 16/09/13**	**Lun 02/10/17**
67	**Prototyping Phase**	**28,29 mois**	**Lun 16/09/13**	**Jeu 26/05/16**
101	**Production Phase**	**25,03 mois**	**Jeu 23/04/15**	**Lun 02/10/17**
115	**Disks**	**66,21 mois**	**Lun 05/03/12**	**Mer 23/05/18**
116	**Design Phase**	**40,5 mois**	**Lun 05/03/12**	**Mar 24/11/15**
130	**Production Phase**	**18 mois**	**Mar 24/11/15**	**Mer 30/08/17**
137	**Disks assembly**	**21,71 mois**	**Ven 15/04/16**	**Mer 23/05/18**
144	**Readout Electronics (from sensors to CRU)**	**37 mois**	**Lun 20/05/13**	**Jeu 17/11/16**
155	**Services**	**66,24 mois**	**Jeu 13/10/11**	**Mer 13/12/17**
176	**MFT support structures (outside acceptance)**	**60,69 mois**	**Lun 05/03/12**	**Mer 08/11/17**
177	**MFT cone**	**48 mois**	**Lun 05/03/12**	**Ven 05/08/16**
185	**MFT barrel**	**52 mois**	**Lun 05/03/12**	**Mer 18/01/17**
193	**Installation tools**	**48 mois**	**Lun 15/04/13**	**Mer 08/11/17**
201	**Half-MFT Assembly**	**13,22 mois**	**Jeu 08/06/17**	**Mar 25/09/18**
211	**MFT Integration in cavern and commisioning**	**73,28 mois**	**Lun 02/07/12**	**Jeu 06/06/19**



- Schedule very tight.
- R&D Phase should end by the end of 2015 (all designs have to be completed and assembly processes defined in details).
- Production phase for all items should be launched in 2016.
- Critical path is given by pixel sensors activities.
- Cost, sharing and planning being reviewed.

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Summary

MFT TDR: Vertexing for the Muon Spectrometer

- ✓ High precision tracker at forward rapidity.
- ✓ Common ITS-MFT silicon pixel sensor.
- ✓ Unique physics cases in heavy ions at forward rapidity at the LHC:
  - ✓ open charm and beauty at low p_T,
  - ✓ prompt charmonia (J/ψ and $\psi(2S)$),
  - ✓ low mass dimuon.
- ✓ MFT Technical Design Report has been approbed by the CERN research board on September 30th 2015 meeting.
- ✓ CDS link: http://cds.cern.ch/record/1981898