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ALICE Muon Physics Upgrade: the Muon Forward Tracker

Outline

I. ALICE: the LHC experiment dedicated to heavy ion physics

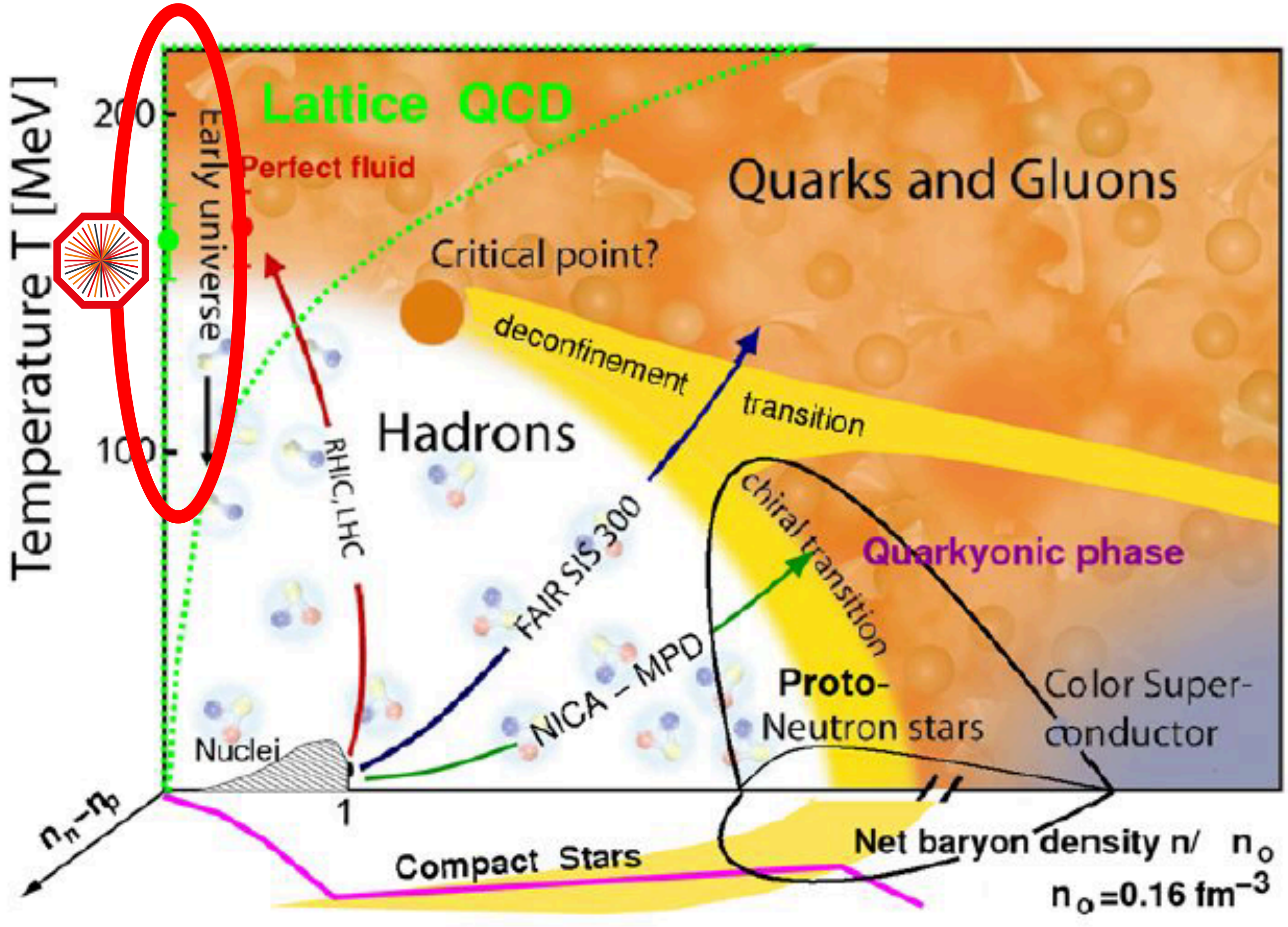
II. ALICE Muon Physics: present capabilities and limitations

III. ALICE Muon Upgrade within the ALICE Upgrade strategy: the Muon Forward Tracker project

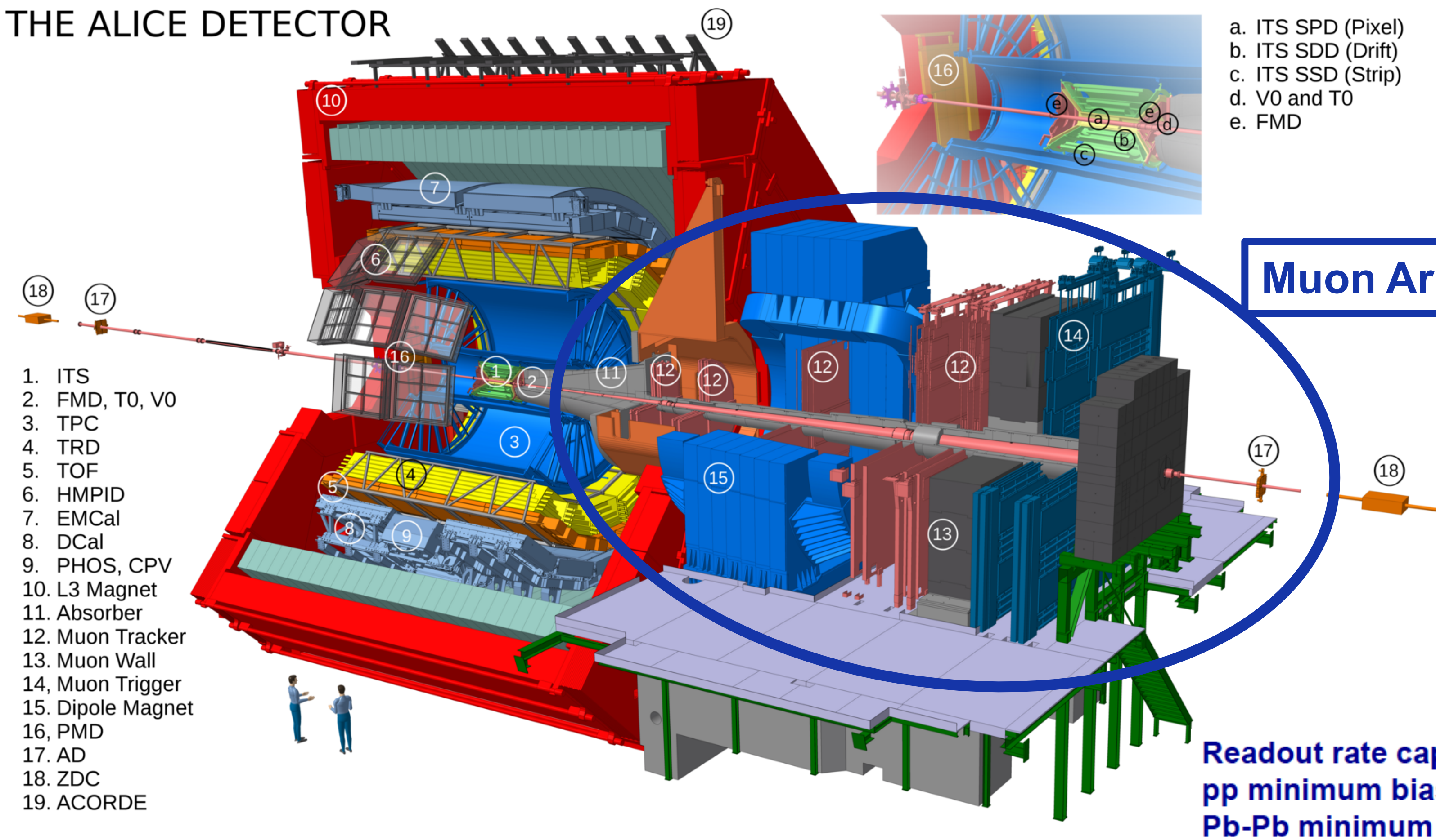
- ❑ Physics motivations
- ❑ Simulations assessing the MFT physics performances
- ❑ Chosen technologies and final design

I. ALICE: the LHC experiment dedicated to heavy ion physics

Scope of ALICE at high-energy frontier and vanishing net baryon density



- large and long-living QGP state
- large cross-sections for hard probes
- early universe conditions



Readout rate capability
pp minimum bias: ~ 1kHz
Pb-Pb minimum bias: ~500 Hz

Uniqueness of ALICE: precision tracking and particle identification down to low p_T

II. ALICE Muon Physics: present capabilities and limitations

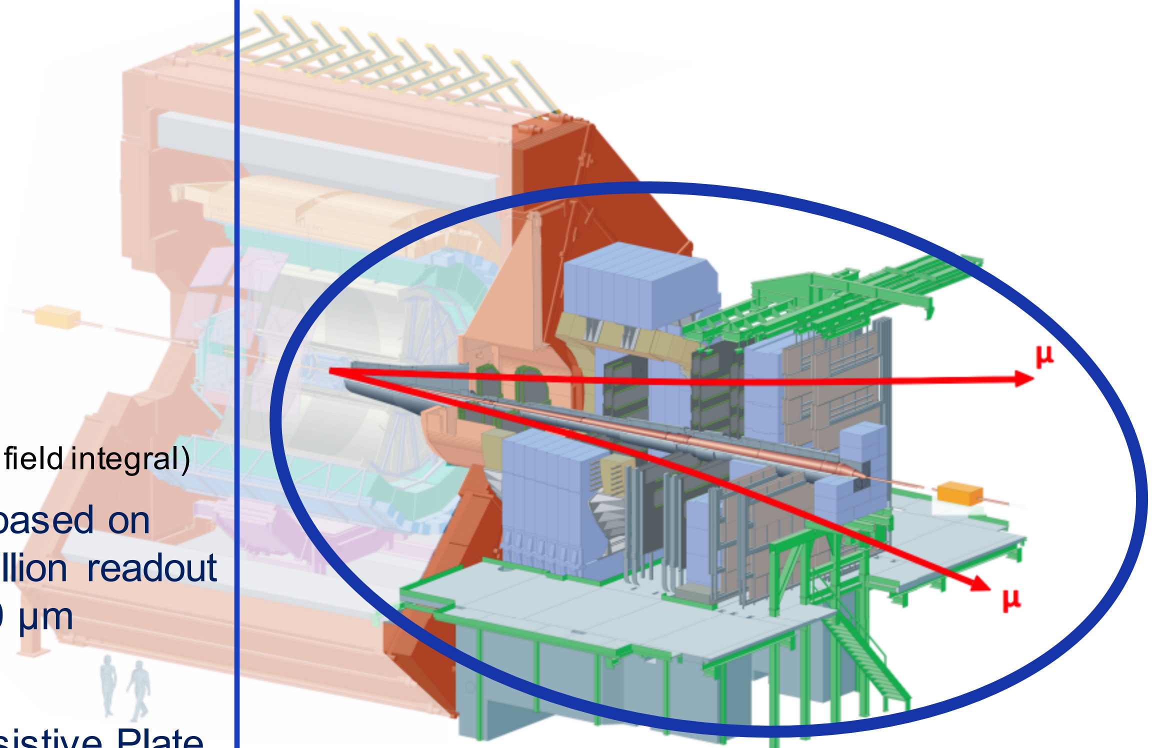
Present muon arm

detects muons in

- polar angular range 2°– 9°
  i.e. $2.5 < \eta < 4.0$
- full azimuthal range

is composed of:

- a hadron absorber
- a dipole magnet (B_{nom} = 0.7 T, 3 Tm field integral)
- 10 planes of tracking chambers based on Cathode Pad Chambers: 1.1 million readout channels, spatial resolution ~100 μm
- an iron wall
- 4 trigger chambers based on Resistive Plate Chambers: 21k readout channels providing single and dimuon triggers with configurable p_T thresholds



The present muon spectrometer led to produce 38 publications / 193 ALICE publications ~ 20 % (as of February 2018)

1. **Quarkonium states into dimuons:** J/ψ, $\psi(2S)$, and Υ family

   -> key observables: nuclear modification factors R_{AA} and elliptic flow v_2

2. **Heavy flavours into single muon**

   see Zuman's talk

3. **Low-mass neutral mesons**

… but has some limitations

High precision measurements of rare probes at low transverse momenta are out of reach for the present experimental setup

1. **Quarkonium states into dimuons**
   - ✓ Inclusive measurements of J/ψ (no discrimination of prompt J/ψ vs J/ψ from B) → large systematic uncertainties on R_{AA} and v_2 extraction
   - ✓ Large combinatorial background → ψ(2S) analysis not achievable in central Pb-Pb with S/B ~ 0.15 for J/ψ and ~ $2. 10^{-3}$ for ψ(2S)

2. **Heavy flavours into single muon**
   - ✓ Large contribution from pion and kaon decays
   - ✓ No discrimination of muons from charm and beauty

3. **Low-mass neutral mesons**
   - ✓ Limited mass resolution → σ(ϕ) ~ 60 MeV/c^2
   - ✓ High background contribution from pion and kaon decays → S/B ~ 1 in pp and S/B ~ 10^{-2} in central Pb-Pb

Muon physics goals with the upgraded muon arm

- In-medium charmonium dynamics to probe the medium temperature and the quark interaction
  → *prompt* J/ψ and ψ (2S) production and nuclear modification factors R_{AA} down to zero p_T

- Thermalization and hadronization of heavy quarks in the QGP medium
  → elliptic flow v_2 for charm down to p_T = 1 GeV/c (semi-muonic decays), beauty (semi-muonic and J/ψ decays) and *prompt* charmonium down to zero p_T

- Tomography and mass dependence of in-medium parton energy loss
  → measurement of charm (semi-muonic decays), beauty (semi-muonic and J/ψ decays) p_T-differential production yields

- QCD phase transition and its chiral nature
  → measurement of the QGP thermal radiation and the spectral shape of low mass vector mesons

III. Muon arm upgrade within ALICE upgrade strategy for Run3 and Run4 [2021 to 2023 and 2027 to 2029]

- **Be able to take data at 50 kHz in Pb-Pb** (i.e. L = 6×10^{27} cm^{-1} s^{-1}) with minimum bias (pipeline) readout (max readout with present ALICE set-up: ≈ 0.5 kHz) → gain a factor of 100 in statistics over current program: **×10** from the integrated luminosity (1 nb^{-1} → 10 nb^{-1}) and **×10** from the pipelined readout allowing inspection of all collisions.

- **Improve vertexing and tracking at low p_T** → better spatial resolution achieved on track reconstruction to improve secondary vertex reconstruction

major upgrade

- New radius beam pipe (29.8 reduced to 19.2 mm)
- New inner tracking system: upgraded ITS + **MFT** (high resolution, low material budget)
- High-rate upgrade for readout of TPC, TRD, TOF, CALs, DAQ/HLT, muon arm and trigger detectors
- Upgrade of the Online/Offline reconstruction and analysis framework

ALICE upgrade strategy for Run3 [2021 to 2023]

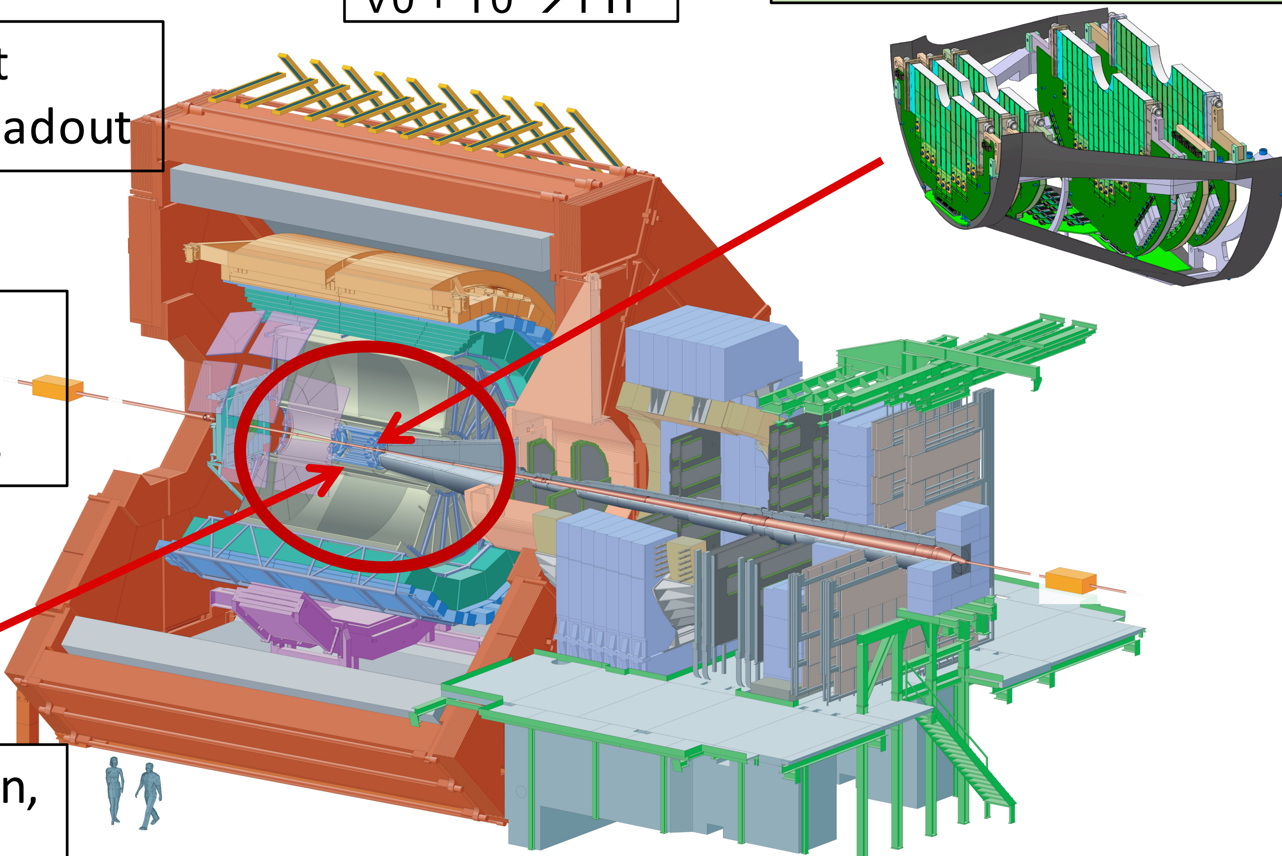
Muon Forward Tracker

V0 + T0 → FIT

TPC: new GEM readout chambers, pipelined readout

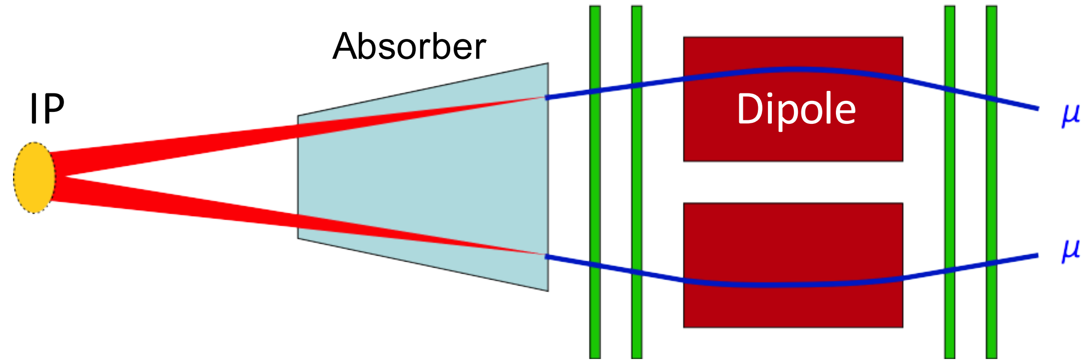
TRD, TOF, PHOS, EMCAL, muon spectrometer: New readout electronics

New ITS: high resolution, low material budget



The Muon Forward Tracker project

Poor determination of production vertex
→ no charm/beauty discrimination in single μ
→ no measurement of J/ψ from B



Muon spectrometer upgrade by the MFT

Poor determination of production vertex
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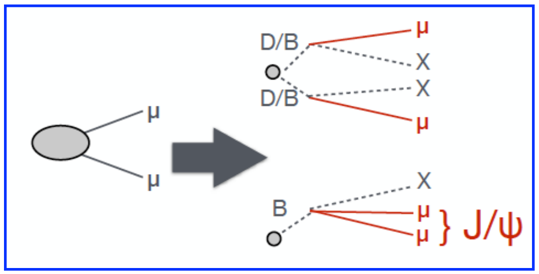

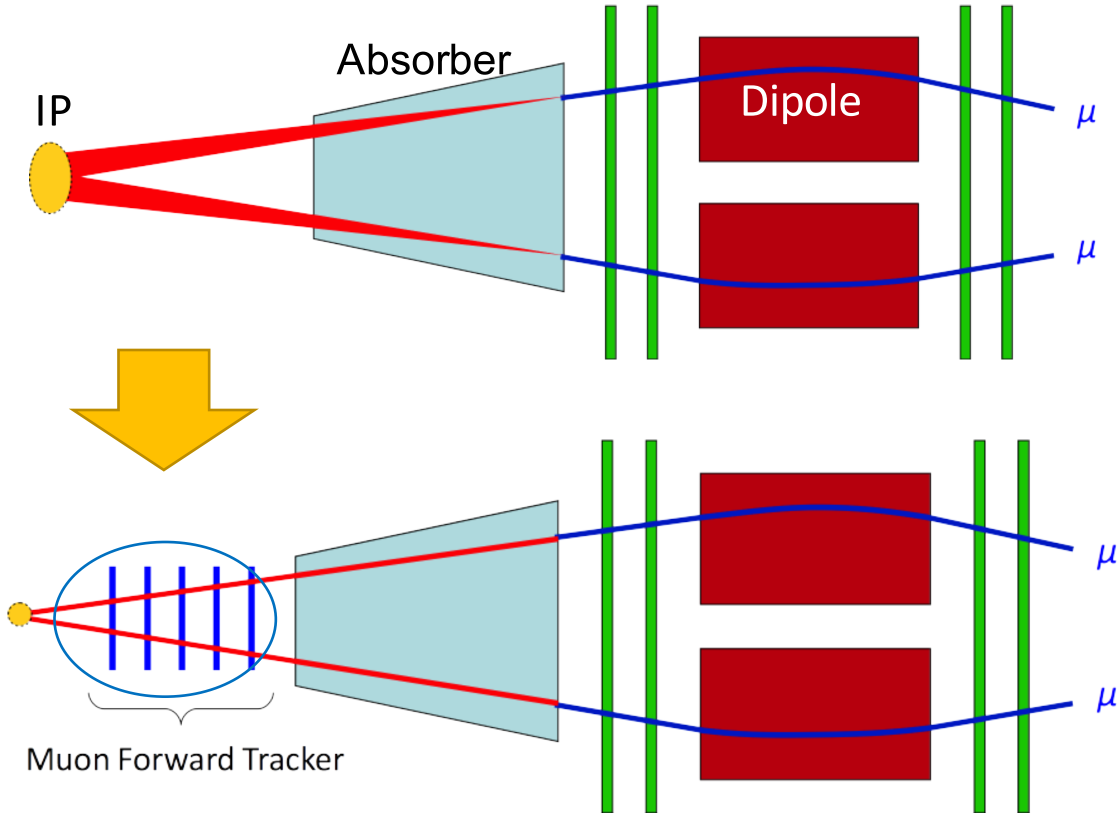

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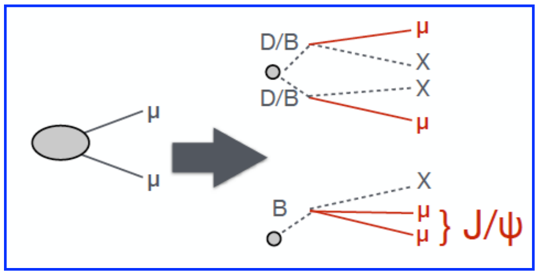
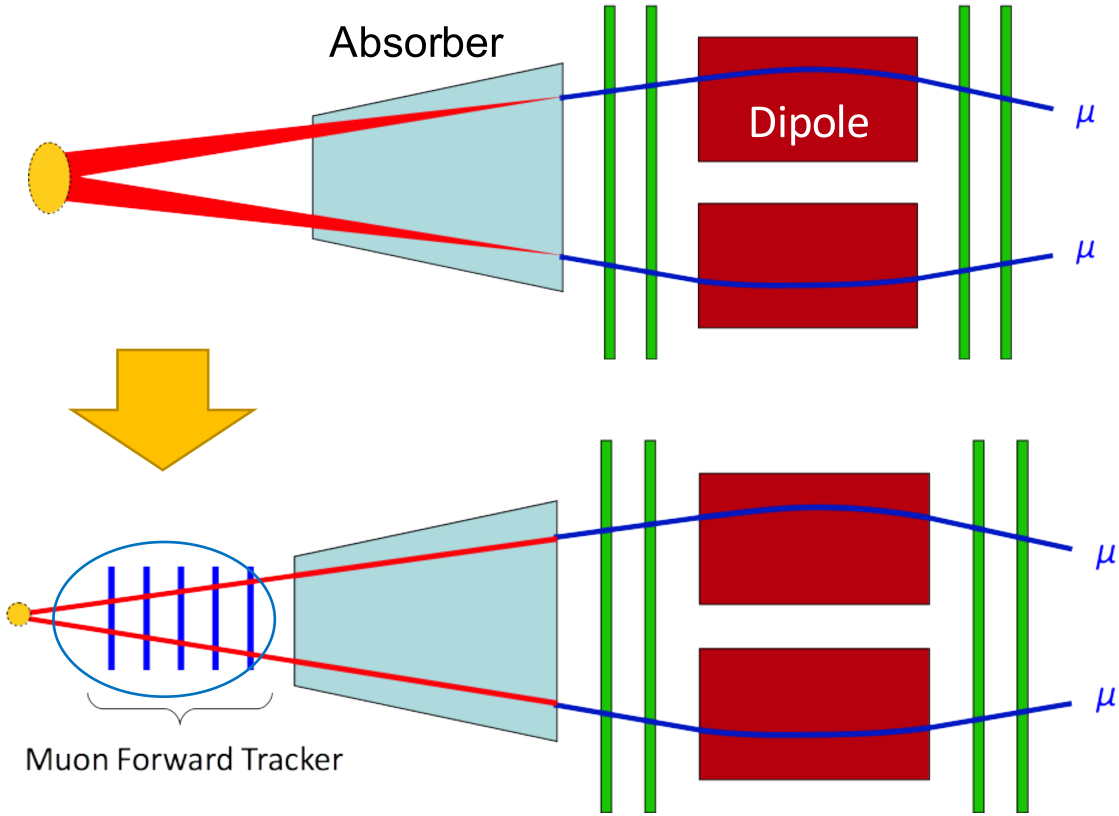
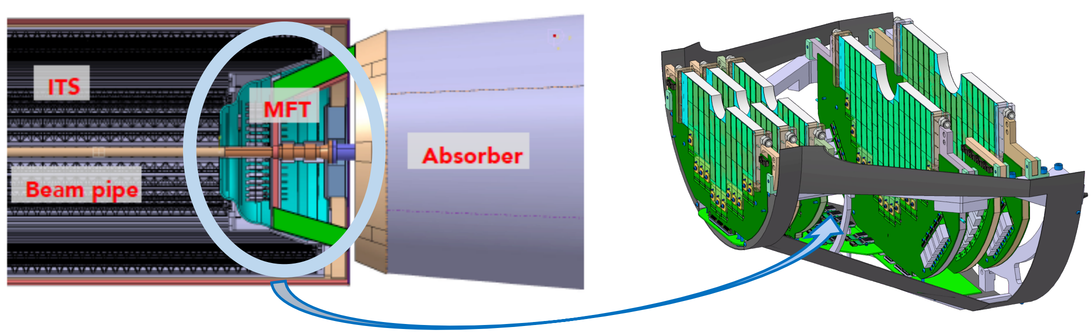




Precise determination of production vertex and tracking
→ measurement of single μ offset at primary vertex
→ measurement of secondary vertices (discrimination of prompt J/ψ and J/ψ from B)



❑ Physics motivations: new observables accessible with MFT

ALICE

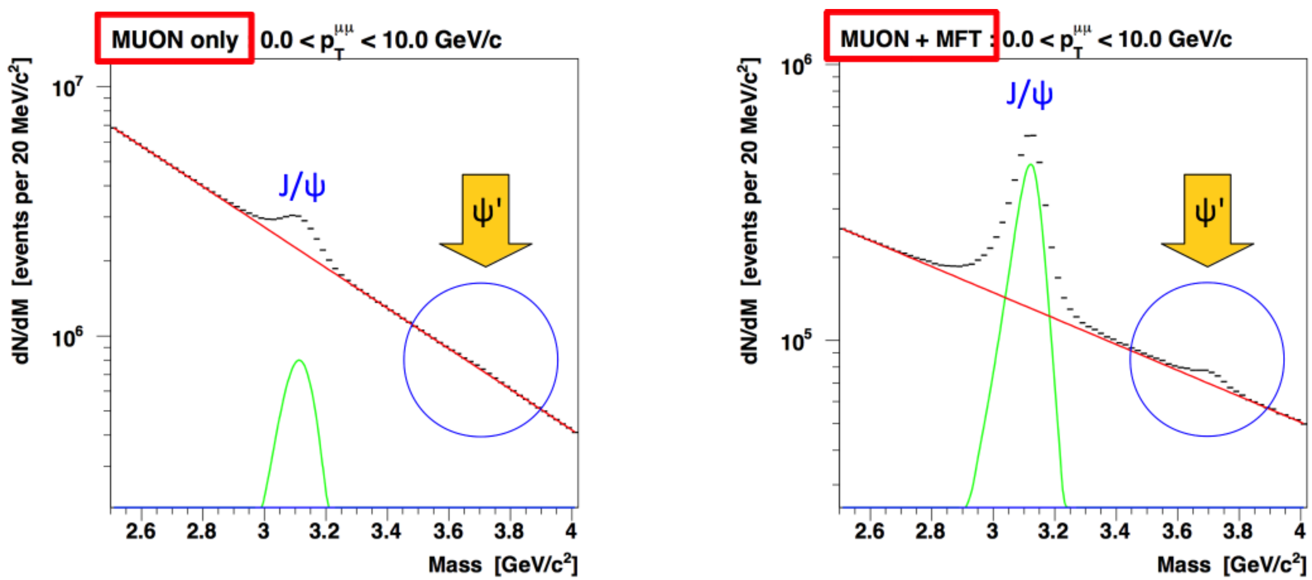
Topics	Observables	Muon Upgrade	Muon+MFT Upgrade
Charmonia	R_{AA} (prompt J/ψ)	Not accessible	$p_T > 0$ 10%
	v_2 (prompt J/ψ)	Not accessible	Estimation ongoing
	Ψ(2S)	$p_T > 0$ 30%	$p_T > 0$ 10%
Heavy flavors	R_{AA} (J/ψ from B)	Not accessible	$p_T > 0$ 10%
	v_2 (J/ψ from B)	Not accessible	Estimation ongoing
	μ decays from c-hadrons	Not accessible	$p_T > 1$ 7%
	μ decays from b-hadrons	Not accessible	$p_T > 2$ 10%
Low masses	Low Mass spectral function and QGP radiation	Not accessible	$p_T > 1$ 20%

❑ Simulations assessing the MFT physics performances

For all physics topics, reduction of background from pions/kaons by matching MFT and Muon Spectrometer tracks

1. Charmonium states into dimuons

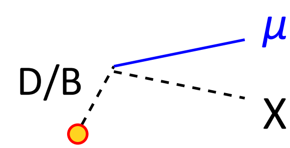
Access to **ψ(2S)** measurement by enhancement of S/B ratio by a factor 5 to 6

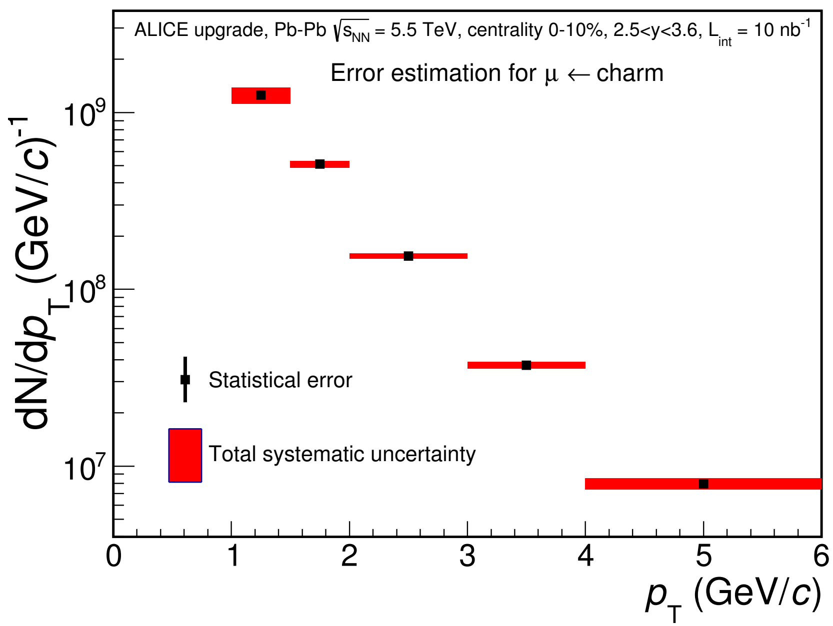


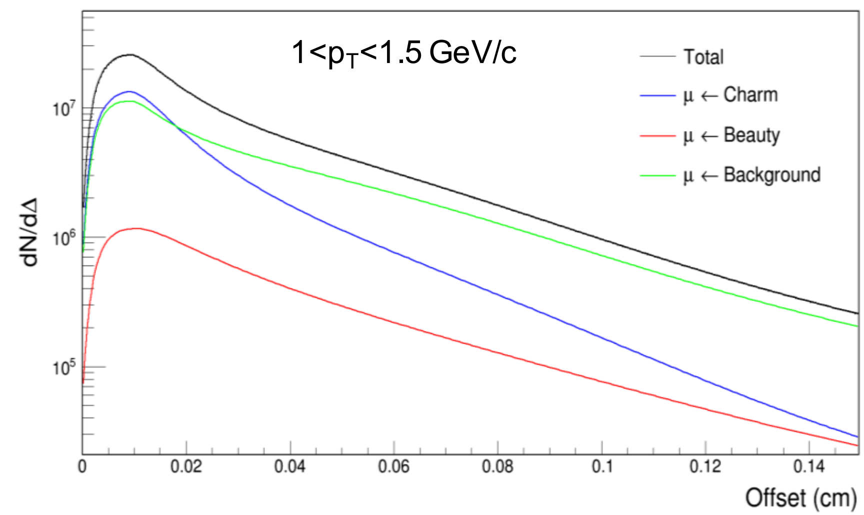
→ **dissociation/recombination models** for charmonia will be possibly tested by comparing the nuclear modification factors R_{AA} of J/ψ and ψ(2S) down to zero p_T

2. Charm measurement from single muons

- Discrimination of charm using the offset to primary vertex measurement
- Reduction of background from π/K decays



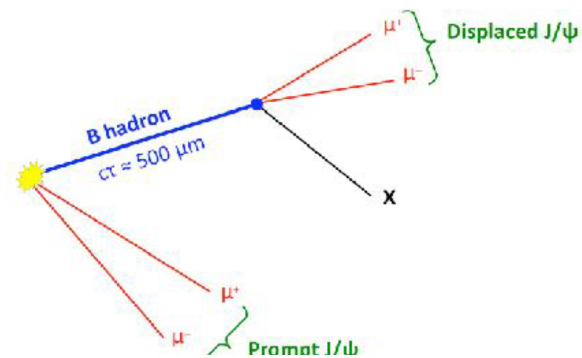




→ **Charm yield accessible down to $p_T(\mu)$ ~1 GeV/c**

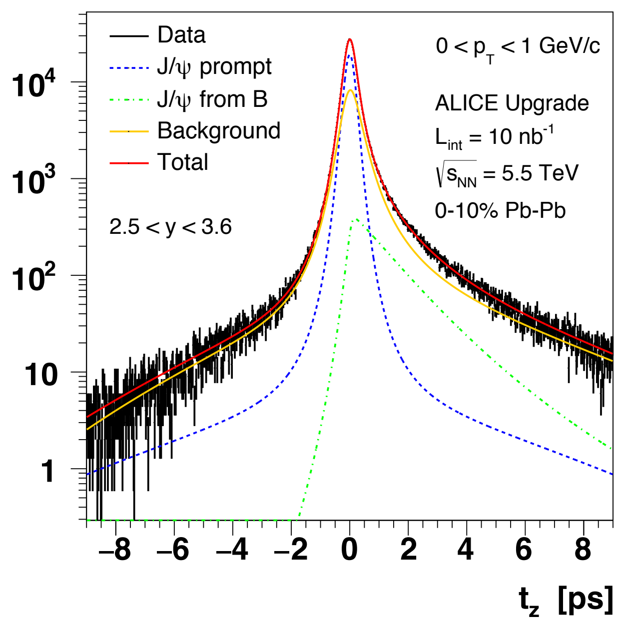
Beauty measurement from non-prompt J/ψ

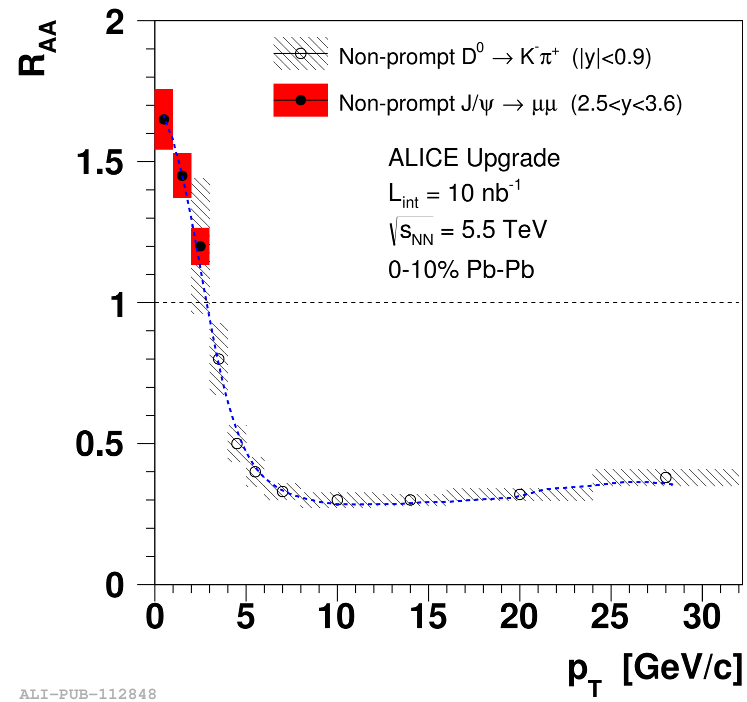
Prompt/displaced J/ψ discrimination down to zero p_T is achieved using the pseudo-proper decay time:



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

and a **simultaneous fit** of dimuon invariant mass and t_z distributions



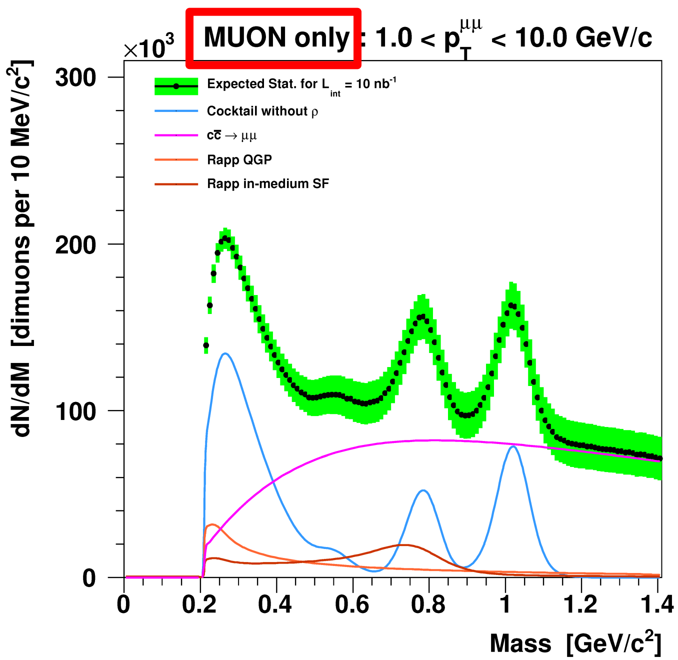


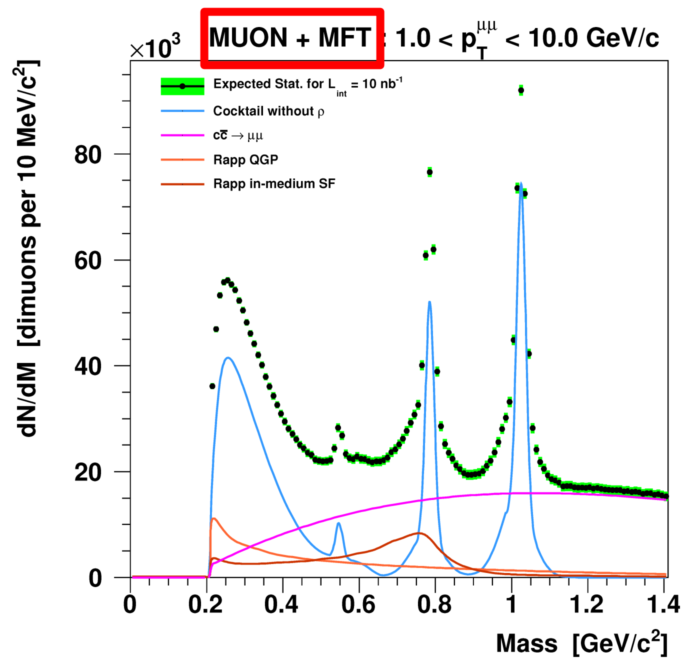
→ **beauty R_{AA} measurement down to zero p_T(J/ψ) within 7% stat + syst uncertainties in central Pb-Pb**

3. Low-mass neutral mesons

Possible study of light resonances into dimuons due to

- better dimuon opening angle resolution
- reduction of combinatorial background



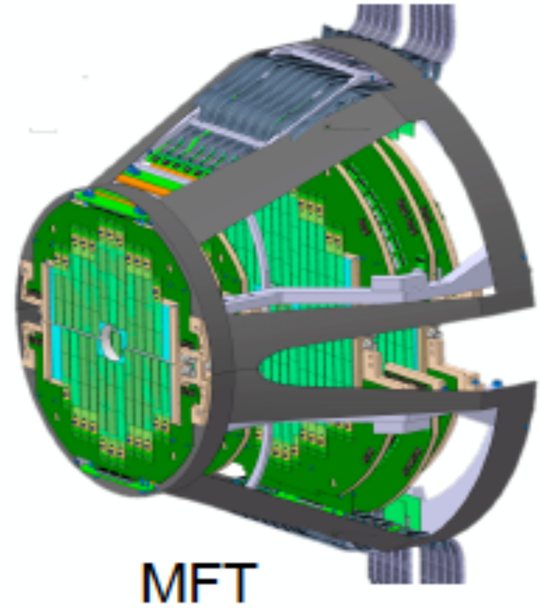


❑ Chosen technologies and final design

ALICE

Design requirements:

- ✓ **Vertexing** for the muon spectrometer at forward rapidity
- ✓ **Good matching efficiency** between MFT and muon spectrometer
- ✓ **Fast electronics readout** (interaction rates ~ 200 kHz in pp collisions and ~ 50 kHz in Pb-Pb)



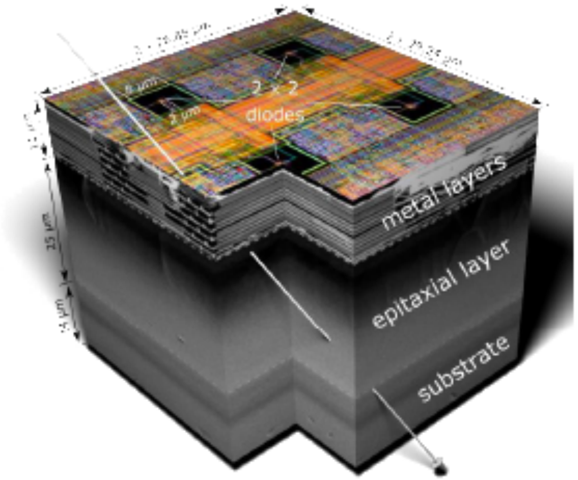
- **Sensor technology** shared with Inner Tracker System → CMOS pixel sensor ALPIDE

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

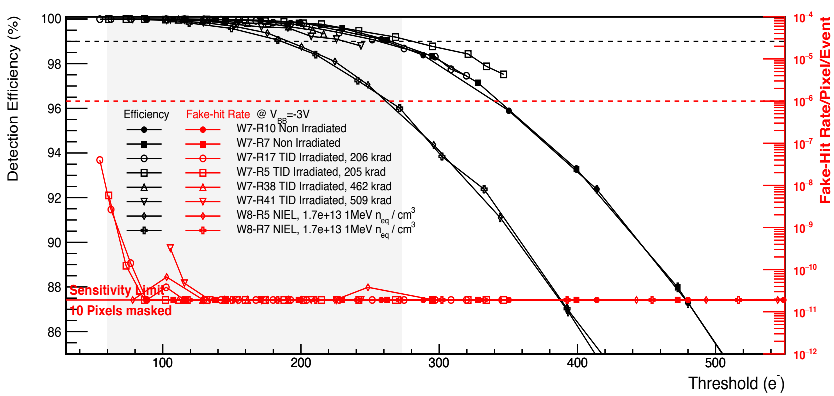
- **928 silicon pixel sensors (0.4 m²)** in 280 ladders of 2 to 5 sensors each
- **10 double-sided half-disks, 0.7% of X_0 per disk**
- **5% of the ITS surface, twice the ITS inner barrel**
- **Nominal acceptance:** 2.5 < η < 3.6 and full azimuth

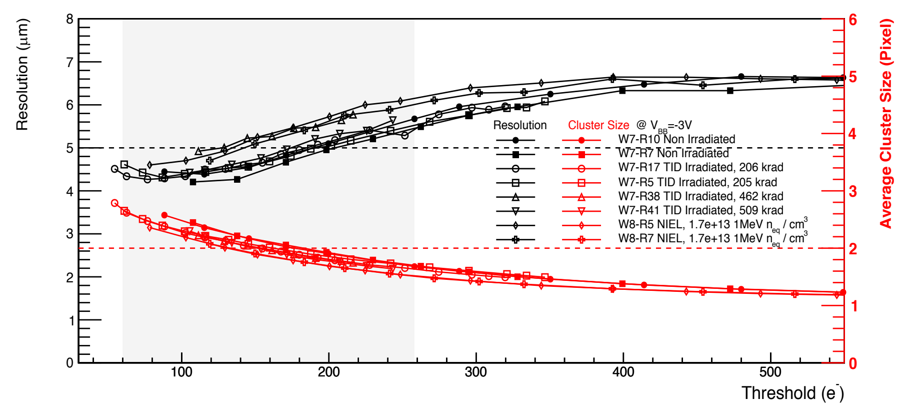
ALPIDE pixel sensor features

Monolithic Active Pixel Sensors (MAPS), TowerJazz 0.18 μm technology



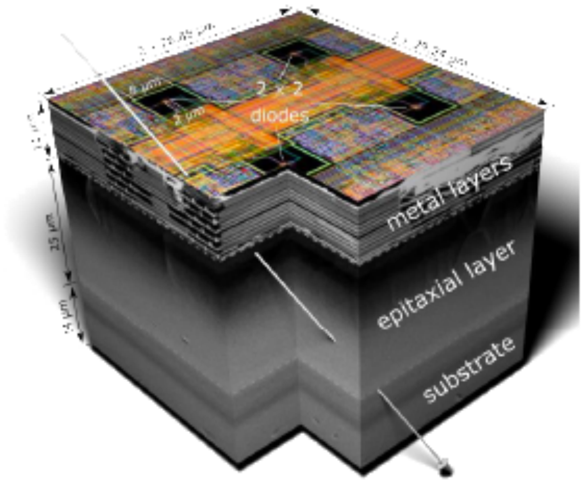
- Sensor size: 15 mm x 30 mm
- Pixel size: 29 μm x 27 μm
- **Detection efficiency > 99%**
- **Space resolution: 5 μm**
- Event time resolution < 4 μs
- Power consumption: ~ 40 mW/cm²
- In-pixel amplification and discrimination





ALPIDE pixel sensor features

Monolithic Active Pixel Sensors (MAPS), TowerJazz 0.18 μm technology



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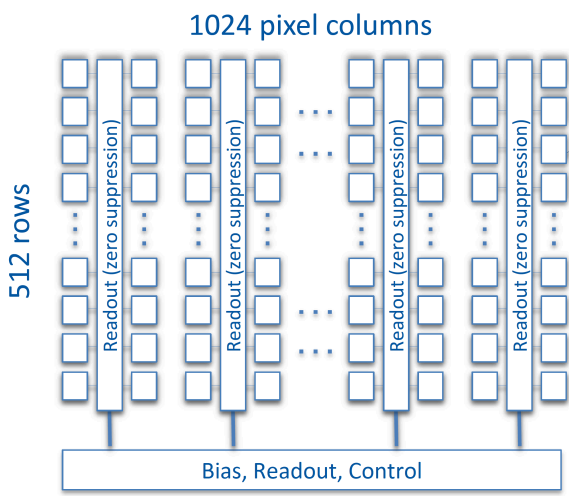
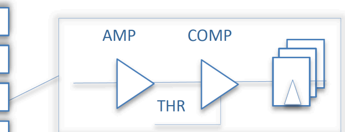
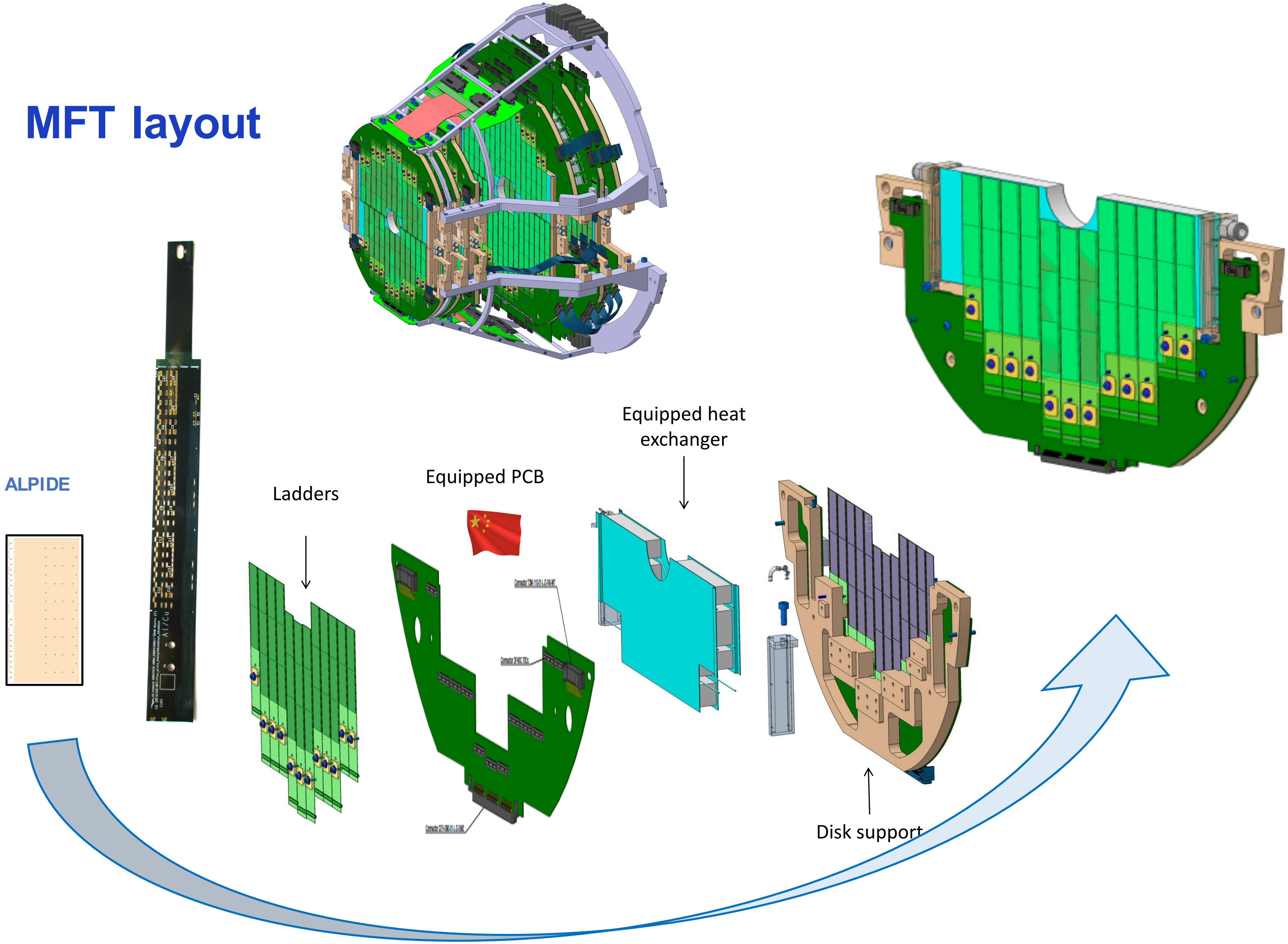




In pixel:
Amplification
Discrimination
3 hit storage registers (MEB)

- Continuously active front-end
- Zero-suppressed matrix readout
- **Triggered or continuous readout modes**

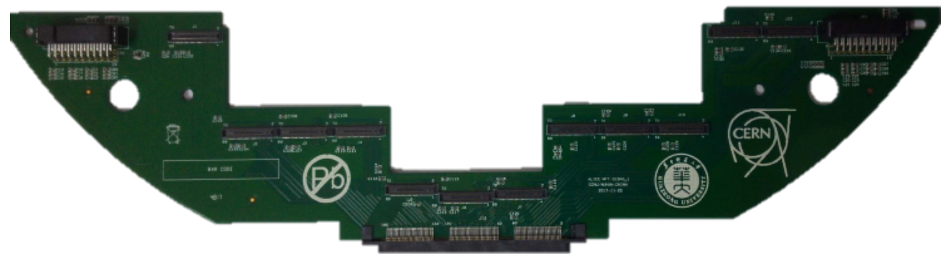
MFT layout

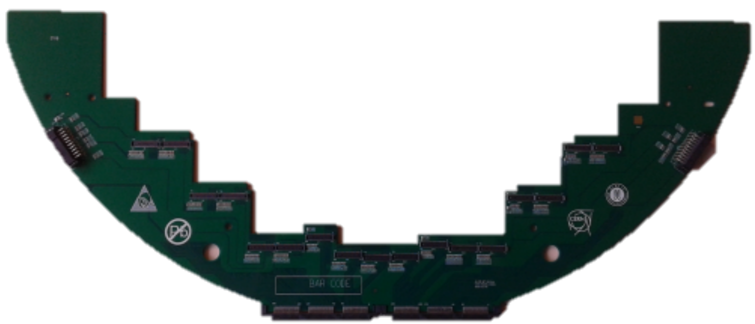

ALPIDE
Ladders
Equipped PCB
Equipped heat exchanger
Disk support

Disk PCBs in charge of CCNU-Wuhan

Designed to

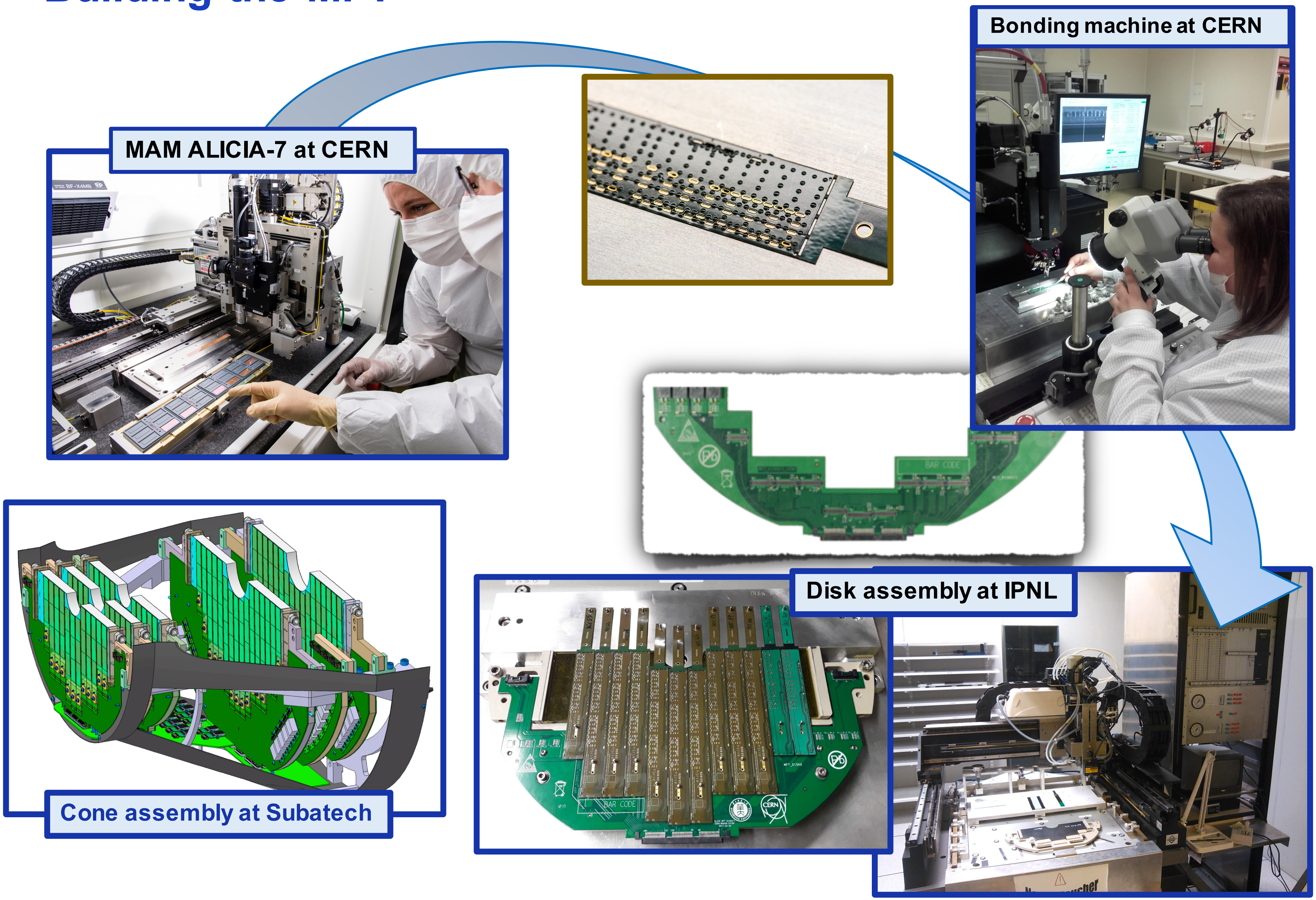
- ✓ transfer signals and slow controls from ladders to Readout Units
- ✓ host temperature sensors
- ✓ power the chips



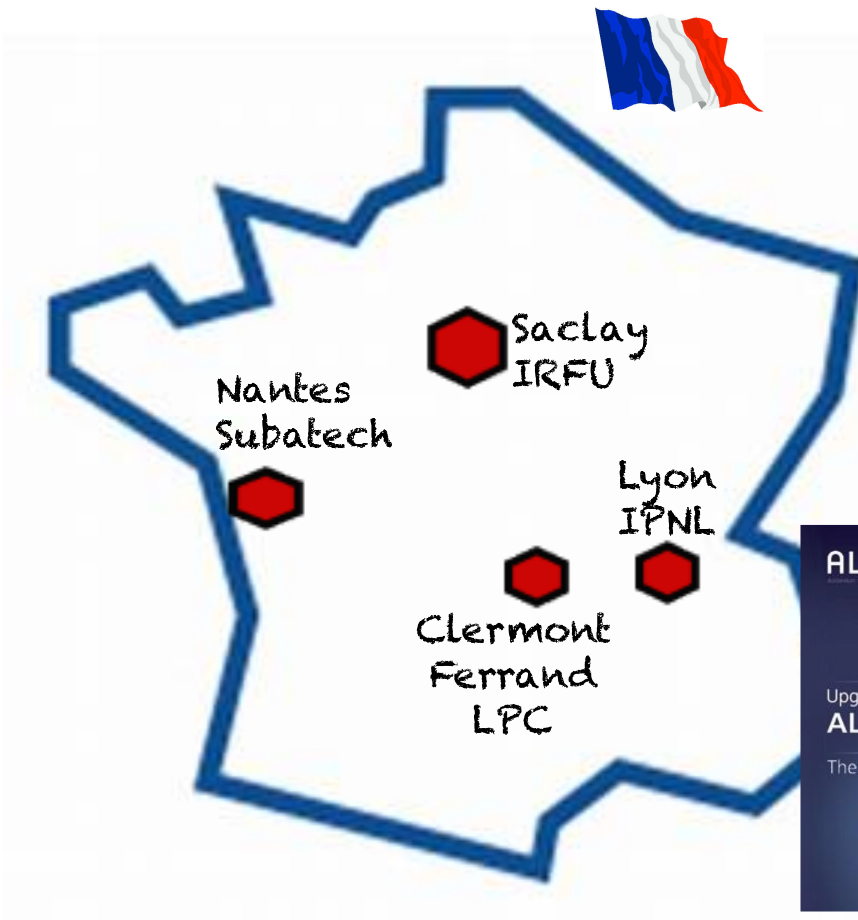


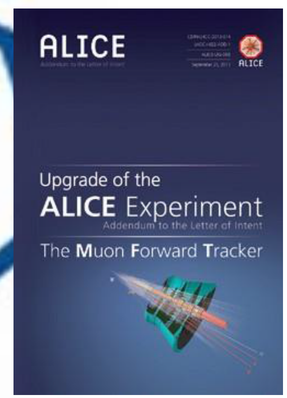
Prototypes have been produced for four disks out of five by Dong Wang, Jun Liu and Junling Chen and are now tested

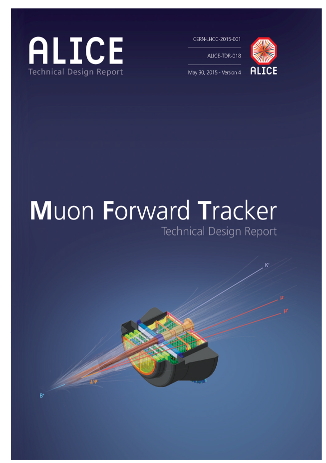
Building the MFT



France and China in the MFT project







CERN-LHCC-2013-014; LHCC-I-022-ADD-1
http://cds.cern.ch/record/1592659

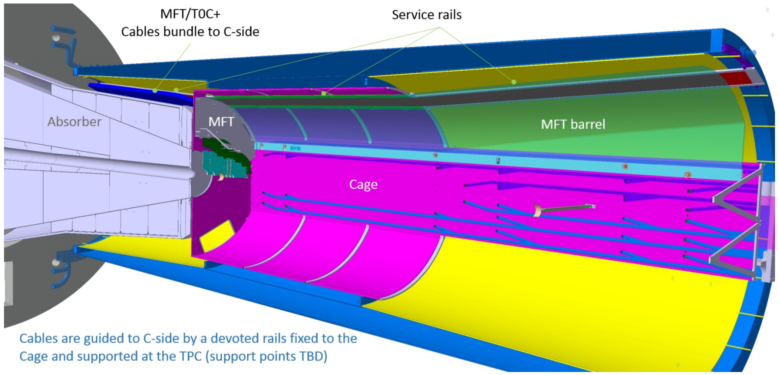
CERN-LHCC-2015-001 ; ALICE-TDR-018
http://cds.cern.ch/record/1981898

Summary

- ALICE will undergo a major upgrade during Long Shutdown 2 enabling the **transition from exploratory to precision measurement of the Quark-Gluon Plasma.**

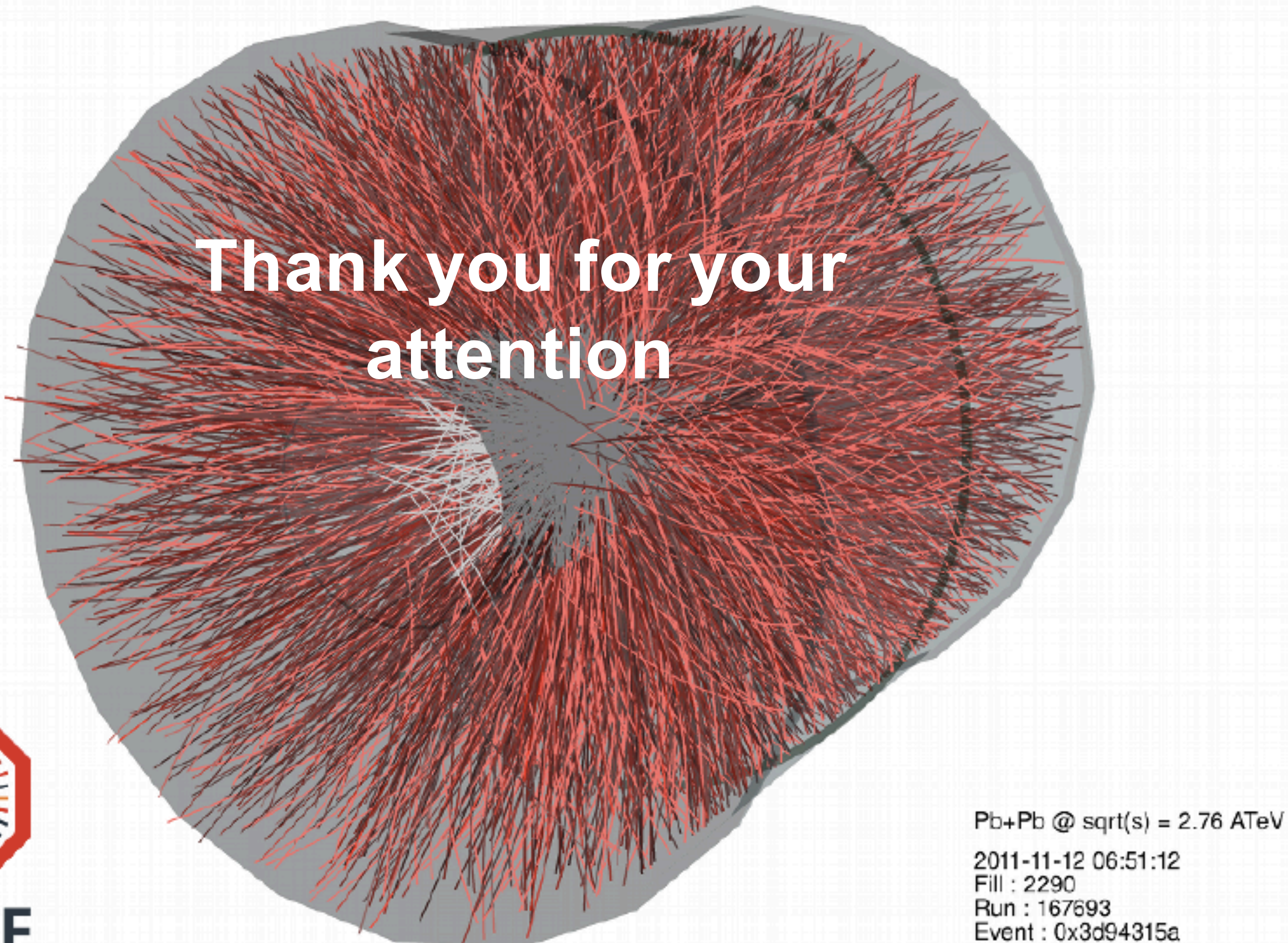
- **The Muon Forward Tracker** will provide precision dimuon measurement at forward rapidity and enhance the muon physics program in a broad range of physics observables such as heavy flavors, quarkonium states, dimuon low masses, and continuum.

- Engineering Design Reviews and Production Readiness Reviews have been successfully passed and work on production is ongoing. Commissioning and installation in situ are foreseen in 2019-2020.



50 kHz of these on the horizon …

Thank you for your attention



" Pour ce qui est de l'avenir, il ne s'agit pas de le prévoir, mais de le rendre possible. “ Antoine de Saint-Exupéry

Backup slides

Rare probes in ALICE

ALICE

CERN-LHCC-2013-024 Observable in PbPb	Current, $0.1\,\text{nb}^{-1}$		Upgrade, $10\,\text{nb}^{-1}$	
	p_T^{min} (GeV/c)	statistical uncertainty	p_T^{min} (GeV/c)	statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
D_s meson R_{AA}	4	15 %	< 2	3 %
D meson from B R_{AA}	3	30 %	2	1 %
J/ψ from B R_{AA}	1.5	15 % (p_T-int.)	1	5 %
B^+ yield	not accessible		3	10 %
Λ_c R_{AA}	not accessible		2	15 %
Λ_c/D^0 ratio	not accessible		2	15 %
Λ_b yield	not accessible		7	20 %
D meson v_2 ($v_2 = 0.2$)	1	10 %	0	0.2 %
D_s meson v_2 ($v_2 = 0.2$)	not accessible		< 2	8 %
D from B v_2 ($v_2 = 0.05$)	not accessible		2	8 %
J/ψ from B v_2 ($v_2 = 0.05$)	not accessible		1	60 %
Λ_c v_2 ($v_2 = 0.15$)	not accessible		3	20 %
Dielectrons				
Temperature (intermediate mass)	not accessible			10 %
Elliptic flow ($v_2 = 0.1$) [4]	not accessible			10 %
Low-mass spectral function [4]	not accessible		0.3	20 %
Hypernuclei				
${}^3_\Lambda$H yield	2	18 %	2	1.7 %

Central barrel:

$D^0 \rightarrow K^-\pi^+$

$D^+ \rightarrow K^-\pi^+\pi^+$

$D_S^+ \rightarrow K^-K^+\pi^+$

$D^{*+} \rightarrow D^0\pi^+$

$\Lambda_c^+ \rightarrow pK^-\pi^+$

$\Lambda_c^+ \rightarrow pK_S^0$

$B \rightarrow J/\psi+X$

$D/B \rightarrow e+X$

$B \rightarrow e+X$

Muon arm:

J/ψ, ψ(2S), ϒ

Low-mass resonances