Upgrade and commissioning of the ALICE muon spectrometer

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Outline

- ALICE Muon Spectrometer (MS)

  → Muon Physics program
  → MS limitations and upgrade reasons

- Upgrades:

  → Muon Identification System (MID)
  → Muon Chambers (MCH)
  → NEW Muon Forward Tracker (MFT)
  → new physics program measurements

- Conclusions

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A Large Ion Collider Experiment (ALICE)

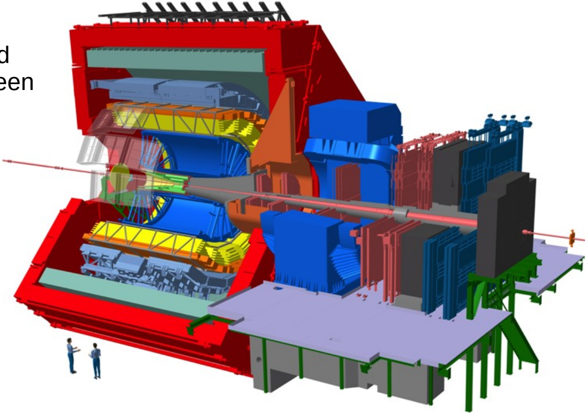
- A Large Ion Collider Experiment (ALICE) at the CERN Large Hadron Collider (LHC) is the experiment specifically designed to study the Quark Gluon Plasma (QGP) in heavy-ion (Pb-Pb) collisions

- During the Long Shutdown 2 of LHC, ALICE achieved a major upgrade of its apparatus:

  → to cope with the increased Pb-Pb collision rate foreseen for Run 3

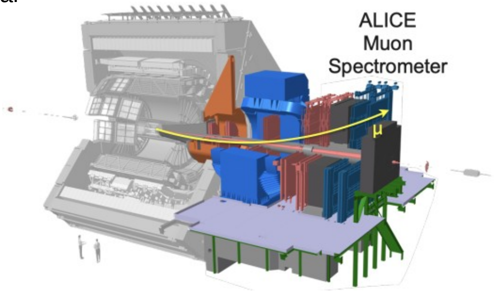
Run 2	Run 3
10 kHz	50 kHz

  → to allow a new ambitious program of high-precision measurements



The ALICE Muon Spectrometer (MS)

- It detects muons in the polar angular range 2° - 9°, i.e. it covers the pseudorapidity range $2.5 < \eta < 4$

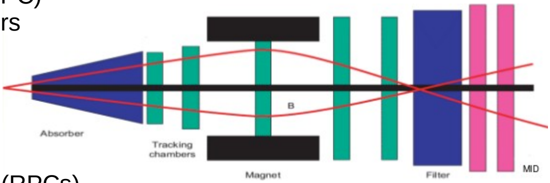


- Before the upgrade it consisted of:

1. **Absorbers**
   → front hadrons absorber
   → filter iron wall

2. **Muon Chambers (MCH)**
   → 5 stations of 2 planes of Cathode Pad Chambers (CPC) and Cathode Strip Chambers (CSC)

3. **Muon TRigger (MTR), now Muon IDentifier (MID)**
   → 2 stations of 2 planes of Resistive Plate Chambers (RPCs)



Current ALICE muon physics topics with MS

Probing the QGP at forward rapidity region by studying:

- **Quarkonia** production

  → historical probes for QGP
  → suppression in QGP
  → regeneration in the QGP or at the phase boundary

- **Open heavy-flavors particles**

  → created at the beginning of collisions (production by hard processes)
  → experience every phase of the collisions, so they are sensitive to the medium

- **Single muons and dimuons** from $W^{\pm}/Z$

- **Low-mass dimuons**

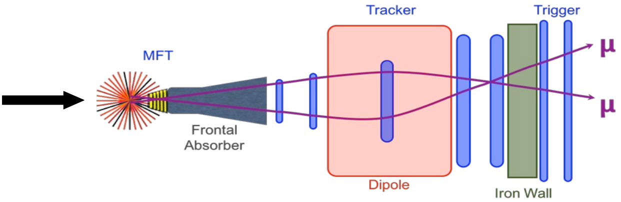
Current MS limitations and upgrades motivations

1. **Multiple scattering in the hadron absorber smears track information preventing determination of the muon production vertex:**
   → no separation of prompt/non-prompt J/ψ, which is an important source of information for beauty studies
   → no disentanglement of open charm and open beauty production

2. **Need to reduce background from non-prompt sources**
   → at present significant statistical uncertainties in single and di-muon analysis due to combinatorial background from π/K muon decays

3. **Need to improve mass resolution for light neutral resonances**
   → limited resolution on the dimuon opening angle

Need for a new **high spatial resolution Muon Forward Tracker** before the absorber



4. **Faster read-out** needed for the present MS detectors, in order to cope with the expected interaction rates in Pb-Pb collisions for Run 3

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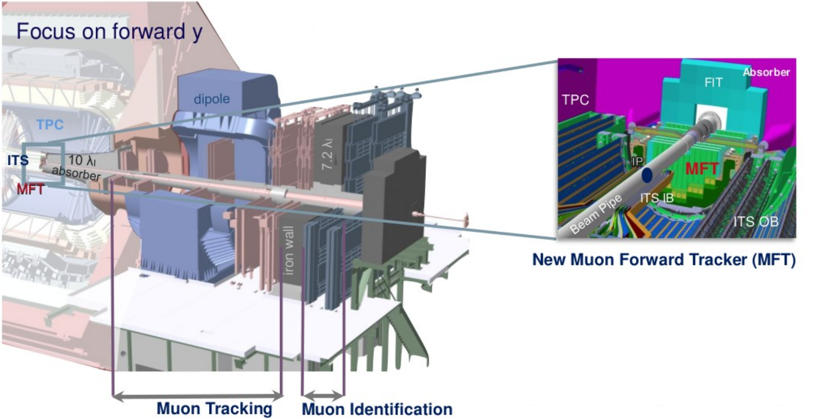
Muon Spectrometer upgrade

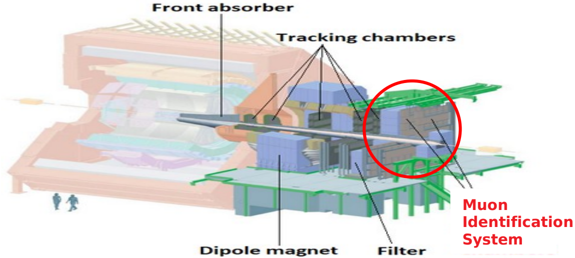


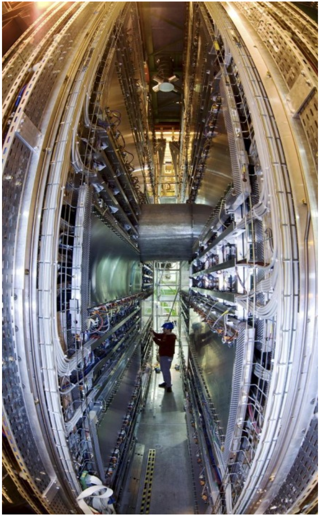
Target for Run 3:

- Collect **13 nb $^{-1}$** of Pb-Pb data
- Read out all Pb-Pb interactions up to maximum LHC collision rate of 50 kHz ($L = 6\times10^{27}cm^{-1}s^{-1}$)
- Improve vertexing and tracking capabilities at low p_T

Muon IDentification (MID) upgrade (1)

- It consists of 72 Resistive Plate Chambers arranged in 2 stations of 2 planes each, equipped with X-Y strips (21k readout channels)
- From Run 3 the detector will support **continuous readout** → this required an upgrade of the read-out electronics, which is now **completed**
- To cope with the increased counting rate and to reduce aging effects, RPC detectors will be operated at lower gain thanks to a **new front-end electronics** **(FEERIC ASIC)** which include a pre-amplification stage

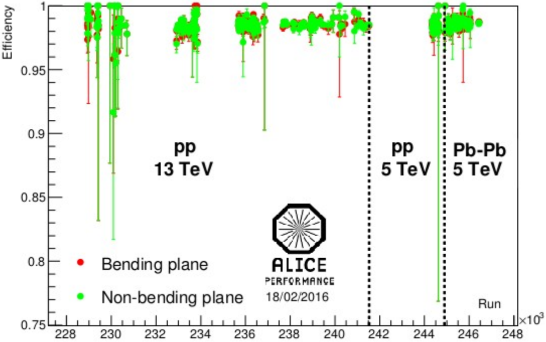




Muon IDentification (MID) upgrade (2)

- One RPC in ALICE cavern equipped with FEERIC cards during Run 2 showed similar efficiency w.r.t. the other RPCs

- Working point at lower HV value w.r.t. to Run 2, thanks to FEERIC



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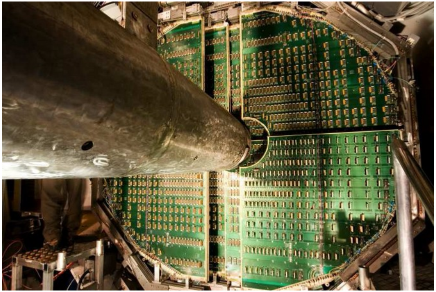
- Efficiency higher than 97% in both the bending and non-bending plane, for different collision systems

- All FEERIC cards have already been produced and installed

Muon CHambers (MCH) upgrade (1)

- Tracking chambers based on Cathode Pad – Chatode Strip Chambers arranged in 10 planes with 1.1 million readout channels and a spatial resolution of ∼100 µm

- To cope with the higher rate, for Run 3 CPC - CSC detectors will have a **new front-end electronics** (FEE) and a **new readout chain**

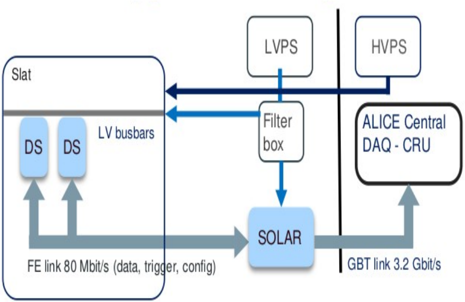


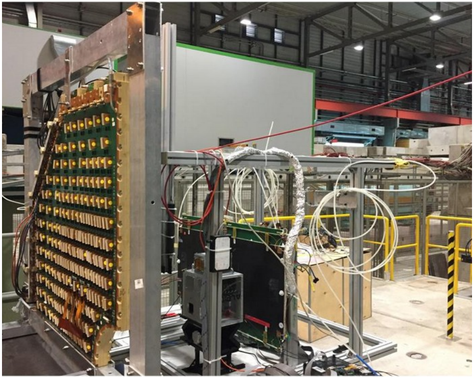
- New FEE chip called **SAMPA** developed jointly with the ALICE Time Projection Chamber upgrade project

- New FE boards: amplification, digitization, filtering and compression of the signal

Muon CHambers (MCH) upgrade (2)

- Data from Dual Sampa (DS) boards sent through **FE links** implemented on printed circuit board
- New concentrator board **SOLAR** with GBT links protocol taking data from several DS through FE links
- **Common Readout Unit** (CRU)





- Full chain successfully tested in test beam in 2017 at CERN SPS
- All components produced and installed

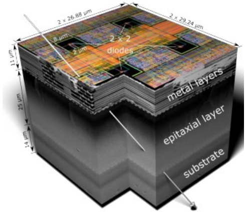
Muon Forward Tracker (MFT): from design...

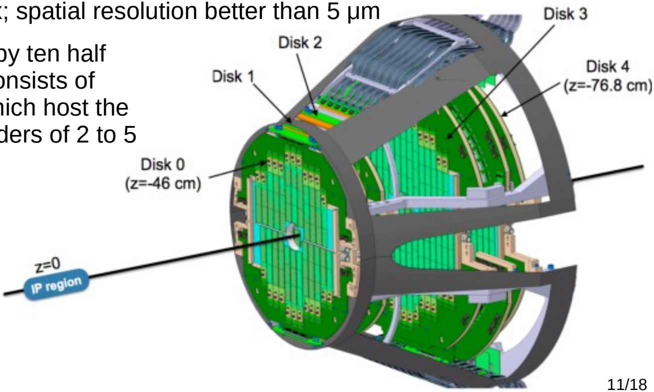
New Pixel Tracker at forward rapidity:

- improve vertexing and tracking capabilities in the pseudorapidity range $2.5 < \eta < 3.6$
  → matching between extrapolated muon tracks reconstructed in MCH after the absorber with MFT tracks before the absorber

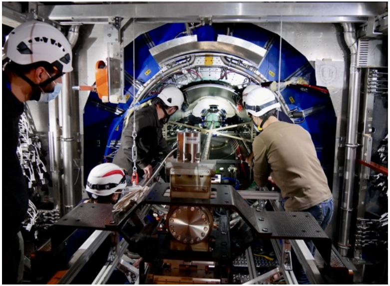
- 936 **ALPIDE Silicon pixel sensors** (0.4 m^2), based on Monolithic Active Pixel Sensors (MAPS). Sensor size 15 × 30 mm^2; pixel size 27 μm × 29 μm; 512 × 1024 pixel matrix; spatial resolution better than 5 μm

- cone structure formed by ten half disks. Each half-disk consists of structures (ladders), which host the ALPIDE chips (280 ladders of 2 to 5 sensors)

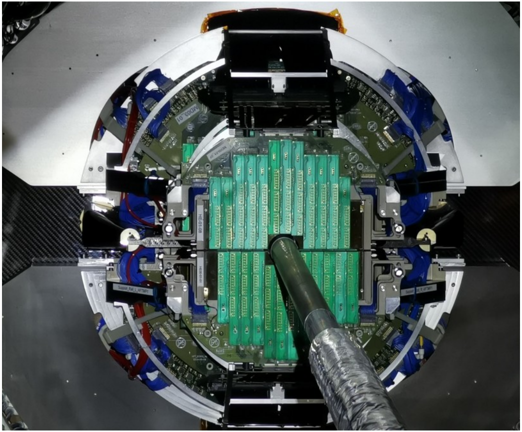


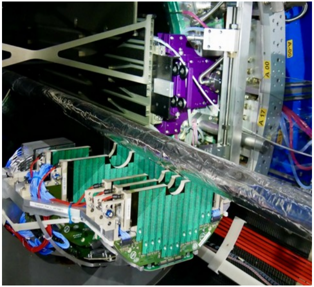


Muon Forward Tracker (MFT): ...to real object



MFT installed in ALICE since Jan ‘21
→ now under commissioning



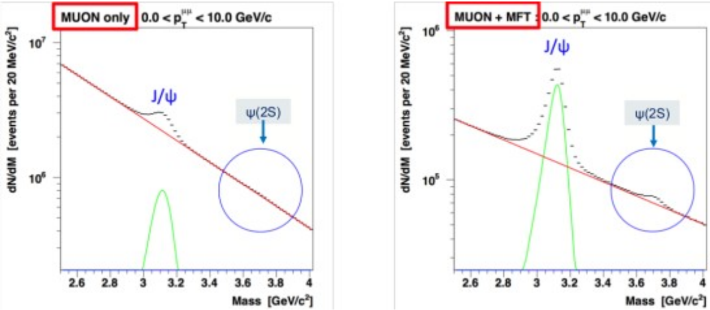


Physics measurements with the MFT: charmonia

- By improving the signal-to-background ratio by a factor of 5-6 w.r.t. the previous value, the MFT allows for:
  → precise measurements for J/ψ at forward rapidity
  → ψ(2S) measurements in Pb-Pb collisions

- dissociation/recombination models for charmonia can be tested by comparing the R_{AA} of J/ψ and ψ(2S) down to zero p_T

- precision measurement for the J/ψ elliptic flow (v_2)



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Physics measurements with the MFT: beauty

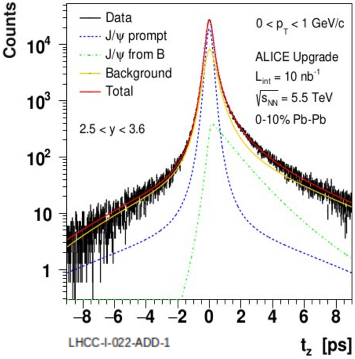
- **Separation between prompt and non-prompt J/ψ** , by measuring the pseudo-proper decay time t_Z associated to the secondary vertex

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

- Prompt and non-prompt J/ψ separation is possible down to zero p_T within 5% statistical and systematic uncertainties

→ this gives us access to beauty measurements

→ beauty R_{AA} measurement possible down to zero p_T of the J/ψ within 7% statistical and systematic uncertainties in central Pb-Pb

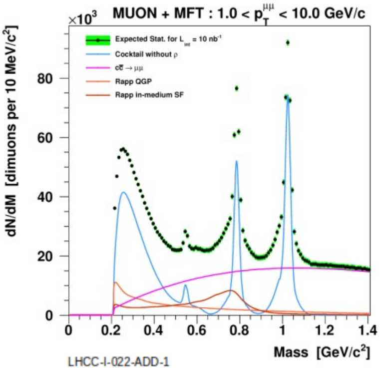


Physics measurements with the MFT: low-mass dimuons

- Improving low-mass dimuon measurement with the MFT:

  → by reducing the combinatorial background from the semi-muonic decays from kaons and pions

  → by improving the mass resolution, thanks to the precise measurement of the opening angle of muon pairs



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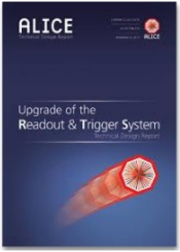
Physics measurements with the MFT

Sum up of the physics measurements made possible by the MFT addition

Observable	p_T-coverage (GeV/c)
Charm	
Prompt J/ψ – R_{AA} & v_2	$p_T(J/\psi) > 0$
$\psi(2S)$ – R_{AA}	$p_T(\psi') > 0$
μ from c-hadron decays – R_{AA} & v_2	$p_T(\mu) > 1$
Beauty	
Non-prompt J/ψ – R_{AA} & v_2	$p_T(J/\psi) > 0$
μ from b-hadron decays – R_{AA} & v_2	$p_T(\mu) > 3$
Chiral symmetry and QGP temperature	
Light vector mesons spectral functions and QGP thermal radiation	$p_T(\mu\mu) > 1$

Conclusions

- MCH and MID have been upgraded with new front-end and readout electronics to cope with the higher interaction rates in Run 3
- MFT will significantly improve the muon physics program for Run 3
- ALPIDE chips used by the MFT (and ITS) are a result of an intense R&D program and all of them have already been installed
- all the components for the MS data readout chain have successfully been tested and installed



References

1. ALICE Collaboration, The ALICE experiment at the CERN LHC, JINST 3, S08002 (2008).

2. ALICE Collaboration, Letter of Intent for the Upgrade of the ALICE Experiment, CERN-LHCC-2012-012, LHCC-I-022, 2012.

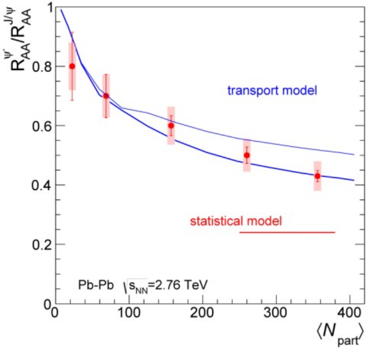
3. ALICE Collaboration, Addendum of the Letter Of Intent for the Upgrade of the ALICE Experiment: The Muon Forward Tracker, CERN-LHCC-2013-014, LHCC-I-022-ADD-1, 2013.

4. The ALICE Collaboration, Upgrade of the ALICE Read-out & Trigger System, CERN-LHCC-2013-019, July 2014.

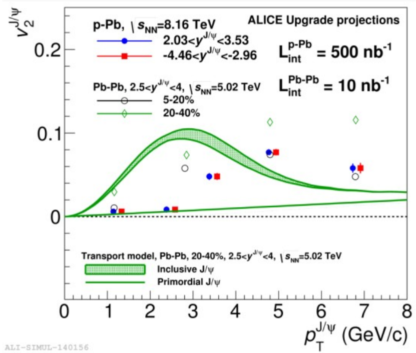
Thank you for your kind attention!

Back up slides

Physics measurements with the MFT: charmonia

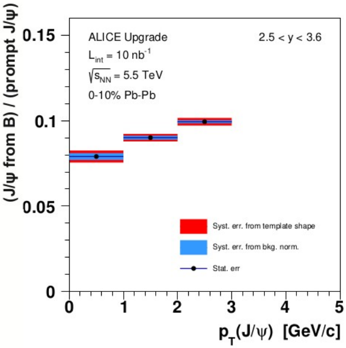


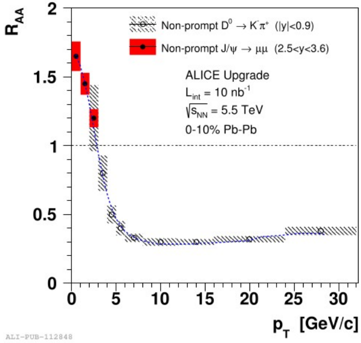
MUON+MFT performance for the ψ(2S)/(J/ψ) measurement



J/ψ v_2 measurement with ALICE upgrade

Physics measurements with the MFT: beauty





Expected uncertainties on the measurement of the prompt and non-prompt J/ψ ratio

Performance for the measurement of the beauty R_{AA} at central and forward rapidity

Physics measurements with the MFT: beauty

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

- simultaneous fit of the dimuon invariant mass spectrum and the t_Z distribution of the dimuons falling within the chosen J/ψ mass window

- the fit of the invariant mass spectrum fixes the normalization of the background and the inclusive J/ψ signal. The fit of the t_Z-distribution then separates the two J/ψ contributions