Muon Spectrometry at Forward Rapidities in ALICE

A. Ferrero

EPS-HEP2019, Ghent, July 11th 2019
The Present ALICE Muon Spectrometer

The ALICE Muon Spectrometer:

• Muon spectrometer acceptance: $2.5 < \eta < 4$
• Tracking: Cathode Pad Chambers (CPCs)
• Trigger: Resistive Plate Chambers (RPCs)
• Warm dipole: 0.7 T (820 Tons)
• Front absorber and beam shielding
Physics with the Upgraded Muon Spectrometer

• Better statistics (one order of magnitude wrt Run 2)
  ‣ Pb-Pb collected luminosity: 1 nb\(^{-1}\) (Run 2) \(\rightarrow\) 13 nb\(^{-1}\) (Run 3 and 4)
  ‣ Benefit for rare signals: \(\Psi\) (2S), \(\Upsilon\),…

• \(J/\Psi\), \(\Psi(2S)\)
  ‣ Present Muon Arm: Inclusive \(J/\Psi\) measurement
  ‣ New: Separation prompt / non-prompt (\(B \rightarrow J/\Psi + X\))
  ‣ New: Improved \(\Psi\) (2S) due to the increase of S/B

• Heavy Flavor
  ‣ Present Muon Arm: No charm/beauty separation (large systematics, \(p_T > 3\))
  ‣ New: Open charm/beauty in semi-leptonic decays:
  ‣ New: B measurement using non-prompt \(J/\Psi\) down to \(p_T \sim 0\) GeV/c

• Low mass vector mesons (\(\rho\), \(\omega\), \(\phi\))
  ‣ Much improved mass resolution
  ‣ Important increase of S/B
**ψ(2S) Suppression Compared to J/ψ**

- Preliminary Run2 results (x3 expected with full stat.)
- Difficult analysis
- First preliminary results in Pb-Pb
- Need more statistics and better S/B

---

**Projections with upgraded Muon Spectrometer**

\[ R_{AA} \psi^* \text{ (0-10\% central Pb-Pb)} \]

- With MFT
  - Stat. only
  - Stat. ⊕ Syst.

**Projections with upgraded MUON Spectrometer**

CERN-LHCC-2015-001, ALICE-TDR-018
Heavy Flavor in Pb-Pb at 5.02 TeV

- Strong suppression of heavy-flavor decay leptons
  - No separation between charm and beauty (beauty dominates from $p_T \sim 5$ GeV/c)
  - Similar suppression at central (electrons) and forward rapidity (muons)

### Graphs

- **Run 2 Preliminary**
  - Displaced secondary vertex reconstruction with upgraded Muon Spectrometer

- **Projections with upgraded MUON Spectrometer**
  - CERN-LHCC-2015-001, ALICE-TDR-018

- **ALICE Preliminary**
  - $0-10\%$ Pb-Pb, $|y_{NN}| = 5.02$ TeV
  - $e \leftrightarrow c,b (|y|<0.6)$
  - $\mu \leftrightarrow c,b (2.5<|y|<4)$

- **Error estimation**
  - $\mu \leftrightarrow$ charm
  - $\mu \leftrightarrow$ beauty

A. Ferrero
Heavy Flavor in Pb-Pb @ 5.02 TeV

- Strong suppression of heavy-flavor decay leptons
  - No separation between charm and beauty (beauty dominates from $p_T > \sim 5$ GeV/c)
  - Similar suppression at central (electrons) and forward rapidity (muons)

Complementary to semi-muonic channels

Access to B hadrons down to $\sim 0 p_T$
The Upgraded MUON Spectrometer

• After the LS2 (2019/2020) => 13 nb⁻¹ Pb-Pb (x 10 / Run 2)
  ‣ Present LHC luminosity in Pb-Pb: L=10^{27} cm²s⁻¹ (8 kHz of interaction) => DAQ @ 1 kHz
  ‣ Upgraded Pb-Pb luminosity: L=6 \times 10^{27} cm²s⁻¹ => 50 kHz of interaction rate => DAQ @ 100 kHz

• New Muon Forward Tracker (MFT) => improved physics program

• Need to upgrade the FEE & readout of MUON Tracking and Identifier
The Upgraded MUON Spectrometer

- After the LS2 (2019/2020) => **13 nb\(^{-1}\) Pb-Pb (x 10 / Run 2)**
  - Present LHC luminosity in Pb-Pb: L=10\(^{27}\) cm\(^{-2}\)s\(^{-1}\) (8 kHz of interaction) => **DAQ @ 1 kHz**
  - Upgraded Pb-Pb luminosity: L=6 \(10^{27}\) cm\(^{-2}\)s\(^{-1}\) => 50 kHz of interaction rate => **DAQ @ 100 kHz**

- New **Muon Forward Tracker** (MFT) => improved physics program

- Need to upgrade the FEE & readout of **MUON Tracking and Identifier**

### Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FAM</td>
<td>JAN</td>
<td>FAM</td>
<td>JAN</td>
<td>FAM</td>
<td>JAN</td>
<td>FAM</td>
<td>JAN</td>
<td>FAM</td>
<td>JAN</td>
<td>FAM</td>
</tr>
<tr>
<td></td>
<td>MJ</td>
<td>JAS</td>
<td>MJ</td>
<td>JAS</td>
<td>MJ</td>
<td>JAS</td>
<td>MJ</td>
<td>JAS</td>
<td>MJ</td>
<td>JAS</td>
<td>MJ</td>
</tr>
<tr>
<td></td>
<td>MJD</td>
<td>ASO</td>
<td>MJD</td>
<td>ASO</td>
<td>MJD</td>
<td>ASO</td>
<td>MJD</td>
<td>ASO</td>
<td>MJD</td>
<td>ASO</td>
<td>MJD</td>
</tr>
<tr>
<td></td>
<td>SJ</td>
<td>ON</td>
<td>SJ</td>
<td>ON</td>
<td>SJ</td>
<td>ON</td>
<td>SJ</td>
<td>ON</td>
<td>SJ</td>
<td>ON</td>
<td>SJ</td>
</tr>
</tbody>
</table>

- **Long shutdown 2**
- **Run 3**
- **Long shutdown 3**
- **Run 4**

We are here
The Muon Forward Tracker (MFT)
ALICE MFT

- Tracker located in front of the Muon Arm
  - High spatial resolution (~5 μm)
  - Secondary vertex capabilities

- 5 planes of CMOS sensors (ALPIDE)
  - Technology: Tower Jazz 0.18 microns
  - Pixel size: 29x27 μm²
  - Thickness: ~0.7% X/X₀ per plane
  - ~1000 sensors, ~0.4 m²
  - 460 mm from nominal interaction point

See Y. Morales’ talk earlier this morning
MFT Assembly

- Heat Exchanger
- Sensors
- Ladders
- PCB
- Support
- Half-Disk
- 5 Half-Disks
- Power Supply Unit
- Mother Boards
- Half-MFT cone
- Full MFT
ALICE MFT Ladders

- Ladders
  - It ensures data, slow control, reverse back bias and power supply from/to the chips
  - AI FPC chosen. Produced @ CERN

Module Assembly Machine @ CERN

Chip alignment precision (5 µm)

- sensor probe card
- sensor vacuum chuck
- sensor tray

Chip bonding performed at CERN bonding lab
MFT Integration

• MFT Barrel
  ‣ Insertion & positioning
  ‣ Cooling/LV/Readout connections
The Muon Tracking Upgrade
The Muon Tracking

• 10 planes of Cathode Pad Chambers (CPC) arranged in 5 stations
  ‣ Stations 1&2 quadrant type (3 pad segm.)
  ‣ Stations 3, 4, 5 slats type (3 pad segm.)

• CPC
  ‣ Gas mixture Ar/CO$_2$ 80:20, gap 5 mm (4.2 mm St. 1)
  ‣ Gain of $\sim 10^4$, HV $\sim 1650$ V
  ‣ Spatial resolution of $\sim 100$ μm and $\varepsilon \sim 100\%$

• 156 detection elements, 1.1 M channels

Only the CPC readout electronics will be upgraded during LS2
MUON Tracking Upgrade

- Replacement of the current electronics (FEE, Data bus, Readout)

- New: frontend SAMPA chip, new data buses, SOLAR concentrator card, CRU

FEC: Orsay
FLEX: Cagliari
SOLAR: Saclay
CRU: India
(Kolkata, Aligarh)
LV: South Africa

1 FEC = 2 SAMPA = DualSAMPA
16500 + 2500 (spares)

Detection Element

FEC

1.2V analog
1.2V digital
GND

2.5V
GND

Filter box

LVPS
WIENER
PL512

HVPS
No change

DCS

30

FLP
(O2)

CRU

LTU

CTP

GBT link
3.2 Gbit/s

FE link 80 Mbit/s (Data, Trigger, Config)

FE link:
FLEX (slats)/PCB (quadrants)
+ flat cable
~3000

Cavern

Control room
DualSAMPA Frontend Electronics

- DualSAMPA FEE based on new SAMPA ASICs
  - On-chip **zero suppression** and **continuous readout** (up to 1.28 Gbps)
  - 10 bits, up to 20 Msamples/s ADCs with Charge Sensitive Amplifiers, 32 channels/chip
SOLAR Data Concentrator Board

- Data from 80 SAMPA chips collected and transferred via optical uplink
- Based on GBTx chip from CERN

FE link 80 Mbit/s (Data, Trigger, Config)
FLEX (slats) /PCB(quadrants) + flat cable ~3000
Cavern

LVPS WIENER PL512
Filter box
SOLAR

FEC

1.2V analog
1.2V digital
GND

LV 3 busbars

FE link 80 Mbit/s (Data, Trigger, Config)
FLEX (slats) /PCB(quadrants) + flat cable ~3000
Cavern

1 FECA = 2 SAMPA

1 FECA = 2 SAMPA

FFSD-20 ribbon cable
Testbeam Results

Validation of the full readout chain
@ SPS in Sept. 2017 / Oct. 2018
20 GeV/c muon beam

Spatial Resolution

σ ~ 70 µm
ε ~ 95% (± 1mm) within specifications

σ ~ 75 µm
ε ~ 94% (± 1mm) within specifications
The Muon Identifier (MID)
The Muon Identifier Upgrade

- No hardwired trigger anymore => continuous readout mode
  - Replacement of the current readout electronics (Regional, Local, J2-bus)

- Slow down the aging of the RPCs after LS2
  - Solution: Front-end electronics with amplification
MID FEE Upgrade: The FEERIC project

- **Goal: slow down RPC aging after LS2**
  - FE with amplification (FEERIC) for RPCs
  - 2384 FEERIC cards
    20992 ch.

- **Factor 4 less charge released in the RPC gas**
  => reduced aging

- **New wireless threshold distribution**
  - Threshold setting per FEERIC card
  - ZIGBEE protocol from master to node

- **Project status**
  - Production and installation completed
  - Commissioning from 2nd half of 2019
MID Readout Upgrade

- Replacement of the 234 Local cards and of the 16 Regional cards presently in operation

- Readout electronics for continuous mode
  - Regional card interfaced with CRU via 2 GBTs

- Production ongoing
Summary and Schedule

• Muon Forward Tracker (MFT)
  ‣ New detector for displaced vertex reconstruction and improved S/B for di-muon resonances
  ‣ Production and assembly: first half MFT -> June 2019, second half MFT -> December 2019
  ‣ Commissioning and installation: Surface -> December 2019, Cavern -> April 2020

• Muon Tracking
  ‣ Electronics production: DualSAMPA -> 03/2020, SOLAR -> 10/2019
  ‣ Stations 1 & 2 readout replacement: November 2019 to July 2020
  ‣ Stations 3, 4, 5 readout replacement: August 2019 to June 2020
  ‣ Readout commissioning in parallel with installation

• Muon Identifier
  ‣ FEERIC readout and threshold boards already installed, commissioning ongoing
  ‣ Local and regional boards: January 2019 to October 2019
Backup Slides
Common Readout Unit (CRU)

- Up to 24 bi-directional front-end links based on the Versatile Link and the GigaBit Transceiver (GBTx) chip
- Common development with LHCb
- First-level processing: **data compression and formatting**
DualSampa to SOLAR

• Quadrants St.1,2
  ‣ 6 (St1) or 8 (St2) PCBs per cathode
  ‣ Prototypes already tested
  ‣ St 1: end of prod by Nov.
  ‣ St 2: end of prod by Sept.

• Slats St. 3,4,5
  ‣ 5 DualSampa per flex (hybrid circuit)
  ‣ Tendering done. Company about to be chosen
  ‣ Pre-series by mid May
  ‣ Prod by end of June