Performance Study for a Muon Forward Tracker in the ALICE Experiment

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Outline

- **Physics Motivations:**
  - Main topics of the current ALICE Muon Arm Physics
  - Current limitations of muon measurements in ALICE

- **The Muon Forward Tracker Proposal:**
  - Concept and Design
  - What could be achieved with a Muon Forward Tracker

- **Preliminary studies on MFT performances:**
  - Realistic plane geometry
  - Global tracking strategy
  - Offset resolution for single muons
  - Improvement of the mass resolution for resonances
  - Offset resolution for prompt and displaced muon pairs
Physics Motivations
Current ALICE Muon Physics: Quarkonia

Quarkonia in p-p collisions to investigate perturbative and non-perturbative aspects of QCD:
- Rapidity distributions
- Transverse momentum distributions
- Angular distributions (polarization)

\[ \text{arXiv:1105.0380v1} \]

Quarkonia in A-A collisions to probe the QGP:
- Test of suppression/regeneration mechanisms
- \( R_{AA} \) vs centrality, rapidity and \( p_T \)
- Yields ratios for the excited states vs centrality

\( R_{AA} \) in Pb-Pb \( \sqrt{s_{NN}} = 2.76 \) TeV, \( 2.5<y<4, p_T>0 \)

Main limitation: only inclusive J/ψ production can be studied.
No way to disentangle J/ψ from b (\(~20\%\) of the prompt J/ψ cross section)
Open Heavy Flavors in p-p:
- baseline for p-A and A-A collisions
- test NLO perturbative QCD in a new energy regime

Open Heavy Flavors in A-A:
- short formation time, giving information on the initial stage of the collisions
- probing the deconfined medium by studying the observed quenching
- nuclear modification factors as a function of the centrality and the kinematics
Current ALICE Muon Physics: Low-Mass Dimuons

Low mass dimuons in p-p and A-A:

- understanding the dynamics of soft hadron interactions
- study of strangeness enhancement via $\phi/\omega$ cross section ratio
- light vector mesons properties in cold and deconfined nuclear matter
The presence of the Hadron Absorber prevents the Muon Spectrometer to "see" the details of the vertex region

Only inclusive J/ψ production can be studied. No way to disentangle and study J/ψ from b (~20% of the prompt J/ψ cross section)

Open charm and open beauty disentanglement relies on models (not a direct measurement). Large contamination from muon decays of pions and kaons which cannot be rejected by direct observations

Low mass dimuons suffer from large combinatorial background (semi-muonic decays of pions and kaons). Degradation of the mass resolution for the resonances

The Muon Forward Tracker should correct this "myopia"...
Designed to detect muons in the **polar angular range** 2 – 9°, i.e. \(-4.0 < \eta < -2.5\) and in the full azimuthal range

**Main limitation:** it cannot see the **details of the vertex region**, because of the hadron absorber
Extrapolating back to the vertex region degrades the information on the kinematics.
Muon tracks are extrapolated and matched to the MFT clusters before the absorber.

High pointing accuracy gained by the muon tracks after matching with the MFT clusters.
The MFT in the Current ALICE Setup

The MFT
**OFFSET**: transverse distance between the primary vertex and the muon track(s)

Muons coming from D ($c\tau \approx 150 \, \mu m$) or B ($c\tau \approx 500 \, \mu m$) mesons will have an offset large enough to be measured with the MFT.

**Offset measurement for the muons will allow to:**

- disentangle **displaced dimuons** (open charm/beauty) from **prompt dimuons** (quarkonia, thermal photons)
- **distinguish open charm and open beauty dimuons** on the basis of the analysis of the pair's offset (model-independent)
- **disentangle single muons** coming from D and B mesons, without any model dependence
Main sources of background:
- $\mu$ from primary $\pi/K$ decaying inside the absorber
- $\mu$ from primary $\pi/K$ decaying before the absorber
- $\mu$ from secondary $\pi/K$ decaying inside the absorber
- punch-through hadrons

Current limitations imposed by background:
- contamination of open charm/beauty measurement in the single muon measurements
- huge dimuon contamination at low mass and low $p_T$

Background rejection with the MFT:
A fraction of background muons will be discarded applying a quality cut on the match with the MFT clusters
Preliminary Studies on MFT Performances
Each plane is an assembly of **active**, **readout** and **support** elements.

The segmentation of the active elements is such that the front and back parts are complementary.

CMOS technology is being investigated for the active elements, ensuring high granularity (20×20 μm²) and low material budget.
1) The MUON track is **extrapolated** back to the origin.

2) The extrapolation is **evaluated** at the last plane of the telescope (the one closest to the absorber).

3) For each **cluster** in the plane, its **compatibility** with the parameters of the extrapolated track is checked, in terms of the quantity:

\[
\chi^2_{\text{clust}} = \frac{\Delta x^2 \cdot \sigma_y^2 + \Delta y^2 \cdot \sigma_x^2 - 2 \cdot \Delta x \Delta y \cdot \text{cov}(x, y)}{\sigma_x^2 \cdot \sigma_y^2 - \text{cov}^2(x, y)}
\]

- **Distance between the cluster and the track at the plane along X and Y**
- **Covariance matrix elements of the track parameters after extrapolation (+ cluster size along X and Y)**
As the extrapolation proceeds towards the vertex region:

- Research radius **shrinks**
- Number of compatible cluster **decreases**
- Number of candidate tracks **converges**
• 20×20 μm² pixels have been considered in these preliminary simulations

• Charge dispersion has been taken into account: all pixels falling within 20 μm from the hit are fired (rather pessimistic, it will depend on the threshold)
Offset: transverse distance between the primary vertex and the muon track

- Strong dependence as a function of momentum (expected)
- Improvement is expected by optimizing the global fit strategy

Small differences between X and Y directions arise at low momentum

Residual effects deriving from X-Y asymmetry in the magnetic field in the spectrometer? Investigations are needed
MFT capabilities:

- no information on the magnitude of muons' momenta (⊥ magnetic field $\sim 0$)
- significant improvement for the uncertainty on the opening angle

**ω meson**

- Spectrometer only
- Spectrometer + MFT

**φ meson**

- Spectrometer only
- Spectrometer + MFT
Tentative Gaussian fit on the peaks: low and high mass tails are excluded

\[ \sigma_\omega \approx 16 \text{ MeV}/c^2 \]

\[ \sigma_\phi \approx 20 \text{ MeV}/c^2 \]
Prompt, open charm and open beauty dimuons have different offset distributions.

Offset distributions can be used to disentangle signal components on a statistical basis (model independent).

Efficiency may increase by improving the global fit strategy (e.g. refit with a common vertex).
The MFT may improve and expand the Muon Arm physics:

- **Quarkonia measurement**, with improved mass resolution and capabilities to disentangle prompt and displaced production
- **Open Heavy Flavor** with the possibility of a model-independent disentanglement of charm and beauty production
- **Low mass dimuons**, with improved mass resolutions and much favorable signal/background especially in A-A collisions

**Preliminary studies on MFT realistic performances are encouraging:**

- Single muons' offset resolution below 170 μm for P > 10 GeV/c
- Improvement of mass resolution for ω and φ mesons by a factor 3
- Possibility to disentangle prompt, open charm and open beauty dimuons by means of their offset distribution
Summary and Outlook

Next steps for the analysis at LOW multiplicities:
- Optimization of the fit strategy
- Focus on the available physics channels (low masses, quarkonia, open HF)

Next steps for the analysis at HIGH multiplicities:
- Performance studies for the fitting strategy (matching efficiency)
- Impact of the beam pipe geometry (pollution from secondary particle production) and mechanical integration with the central ITS upgrade
- Investigation of expected pile-up levels and ways to limit its impact on the fitting strategy (mix of hybrid and CMOS technologies?)
Clear signal from $J/\psi$ both in p-p and Pb-Pb collisions over the background

Limited statistics for the $\Upsilon$ region and the $\psi(2S)$
Low mass dimuon physics is an exciting field: results from SPS and RHIC

- dynamics of soft hadron interactions
- in-medium modifications of light vector mesons (ρ meson)
- thermal dimuons emission from the QGP

![Graph](image)

**Perfect control of the background** (NA60: 1% precision over 4 order of magnitudes)

**Offset must be measured** to identify prompt continuum (thermal emission)

The MFT should significantly reduce the background, and allow identification of prompt dimuons
Having a high-granularity forward tracker would allow to improve the ALICE capabilities independently on the activity of the Muon Spectrometer:

- Direct **multiplicity measurements** at high rapidity: at the moment, forward multiplicity can be studied by means of the VZERO detector, which needs anyway to be calibrated by direct comparison with the ITS

- Measurement of the **reaction plane** and any other **azimuthal anisotropy** complementing the central barrel detectors

- **Trigger capabilities** (possibly implementing topological schemes)

- Study of **long range correlations** exploiting the complementary ITS coverage at central rapidities
The segmentation of the MFT planes is such that the front and back parts are complementary:
Crucial Points under Investigation

Two main challenges must be faced by the MFT

1) Material budget & pixel technology
   - Main focus on reducing the material budget between the I.P. and the MFT planes: thinner beam pipe is foreseen, implementation of a conical geometry may be mandatory (under investigation)
   - Choice of pixel technology: we need high granularity, low material budget, fast readout capabilities. CMOS technology is currently the best candidate

2) Matching & Tracking
   - Offline reconstruction algorithms must avoid fake matching between muon tracks and MFT clusters
   - Efficient and robust standalone tracking must be implemented
Offset: transverse distance between the primary vertex and the muon track

- Strong dependence as a function of **momentum**
- Choice of beam pipe geometry **not crucial here** (additional multiple scattering seems to be not relevant)