Prospects for heavy flavour measurements with the ALICE inner tracker upgrade

C. Terrevoli
University and INFN Cagliari
for the ALICE Collaboration
Outline

- ALICE Upgrade physics program
- Inner Tracking System (ITS)
- Heavy Flavour Performance in ALICE with the current ITS
- How to Upgrade?
- Physics performances with the ITS Upgrade
- Conclusion
ALICE is the general purpose Heavy-ion detector at the CERN LHC

Investigate properties of strongly interacting matter under extreme conditions of compression and temperature in Pb-Pb collisions - Characterization of the Quark-Gluon Plasma (QGP)

The upgrade of the ALICE inner tracker detector targets physics topics in which ALICE can bring a unique contribution in QGP characterization, among others, via heavy flavour probes

- Measurements of heavy flavour transport parameters in QGP via the probe-medium interaction
  - Heavy flavour azimuthal anisotropy and $R_{AA}$
  - Heavy Flavour baryon-to-mesons ratio
  - Mass dependence of energy loss → heavy flavour $R_{AA}$ down to low $p_T$
Current Inner Tracking System

Capability to separate primary and secondary vertex of heavy flavour hadrons is provided by Inner Tracking System:
- 6 layers of silicon detectors (pixels, drift, strips)
- PID (drift and strips)
- Low material budget: 7.2% $X_0$ for whole ITS

Limit: resolution not sufficient for $\Lambda_c$ ($\tau = 60 \mu m$)
$d_0$ resolution $>60 \mu m$ for $p_t < 1 GeV/c$
Impossible in Pb-Pb
Theoretical predictions: $\Delta E_g > \Delta E_c > \Delta E_b$
- $R_{AA}$ ratio between the particle yields per binary collision in Pb-Pb and pp, vs $p_T$

Expectations: $R_{AA}^{\pi} < R_{AA}^{D} < R_{AA}^{B}$ (Y.L.Dokshitzer et al. Phys. Lett. B 519 (2001) 199.)

ALICE performance

D mesons $R_{AA}$
- High systematic uncertainties: the $R_{AA}$ comparison is not conclusive
- **Upgrade**: allow to reach $p_T$ down to 0; improved tracking resolution and efficiency, and higher statistics will improve signal extraction providing higher significance

B mesons $R_{AA}$ → no measurements
- B only via $e+X$ and non-prompt $J/\psi$ in pp;
- **Upgrade**: open the way to the study of other channels ($D^0$ and $J/\psi$ from B) allowed by improved performance and higher statistics

- Observed for p/π and Λ/K ratio at intermediate p_T

Prediction also for heavy flavour

- Λ_c, Λ_b not accessible in Pb-Pb with current detector due to limited precision and statistics

If coalescence contributes to charm hadronization

→ D_s production is expected to be enhanced w.r.t other D at low p_T

**Upgrade:** aim at measuring Λ_c/D and Λ_b/B ratios and D_s production improving tracking precision, statistics and extend the measurement to low p_T
Elliptic flow $v_2$ sensitive to the thermalization of c and b in QGP

- large D mesons $v_2$ at low momentum
- Mass dependence of $v_2(B) < v_2(D)$

ALICE performance

- $v_2$ for D mesons down to 2 GeV/c
- Limited precision for D meson and measurement not possible for beauty $v_2$

**Upgrade:** down to 0 $p_T$ for D meson $v_2$; also $B$ $v_2$ will be accessible for the first time
How To Upgrade the ITS

- Improve impact parameter resolution by a factor of ~3
  - Get closer to IP
    - Beam pipe outer radius: $r=17.2$ mm (presently 29.8 mm)
    - First layer at 22 mm (presently 39 mm)
  - Reduce pixel size
    - Pixel size ($r\phi$, $z$): 20-30, 20-50 μm (presently: 50 x 425 μm)
- High standalone tracking efficiency and $p_T$ resolution
  - Increase granularity pixels resolution 4 or 6 μm
  - Increase number of layers 7 instead of 6
- Fast readout
  - Continuous readout of Pb-Pb interactions at > 50 kHz
    in order to exploit the upgrade LHC luminosity
    (>10 nb$^{-1}$ in Pb-Pb that correspond to $\sim10^{10}$ central events)

- Reduce material budget
  - 0.3% $X_0$ per pixel layer
    (presently 1.1%)

The global Upgrade ALICE program concerns also the upgrade of the other main central barrel detectors, including the Time Projection Chamber (TPC)
The upgrade is targeted for the second long shutdown (2017-2018).

https://aliceinfo.cern.ch/system/files/alice_upgrade/LHCC-P-005.pdf
- tracking efficiency >90% down to 0.1-0.2 GeV/c
- ITS stand-alone $p_T$ resolution: improved by a factor $\sim 2$
\[ \textbf{D}^0 \rightarrow \textbf{K}^-\pi^+, \textbf{D}^0 \text{ from B}, \textbf{D}^{*+} \rightarrow \textbf{K}^-\pi^+\pi^+ \]

- **D**\(^0\) measurement down to \( p_T \rightarrow 0 \)
  - Conservative estimate of syst. errors based on current data
- Non-prompt \( \textbf{D}^0 \) to prompt \( \textbf{D}^0 \) ratio accessible

- \( \textbf{D}^* \) analysis can be carried out in a wider \( p_T \) range (1-100 GeV/c) with high significance (20-100).
  - In data: performed in \( p_T \) range [3, 36] GeV/c significance 3-7

**SQM2013**

**ALICE**

**Pb-Pb: \( \sqrt{s_{\text{NN}}} \) = 5.5 TeV**

- 8.5 \times 10^9 events
- Centrality: 0 - 10%

**Statistical error (%)**

**ALICE Upgrade**

- **D**\(^+ \rightarrow \textbf{D}^0\pi^+, |y| < 0.5**
- Pb-Pb, \( \sqrt{s_{\text{NN}}} = 5.5 \) TeV
- \( L_{\text{int}} = 10 \) nb\(^{-1}\)

Centrality 0-10%

Sensitive to mass dependence of energy loss
Beauty via displaced J/ψ → ee

Direct measurement of beauty (via D⁰ and J/ψ displaced) opens the possibility to measure with high precision the beauty energy loss (i.e. R_{AA}) and thermalization (i.e. v₂) covering a unique kinematic range (down to \( p_T \sim 1 \text{ GeV/c} \)) at LHC.

To separate prompt and secondary J/ψ (\( \leftarrow B \)) the pseudo-proper decay length \( x \) is used.

![Graph showing pseudopropor decay length vs. Entries (arb. units) for prompt J/ψ (→ e⁺e⁻) with Current ITS and Upgraded ITS]

Precise measurement of non-prompt J/ψ \( R_{AA} \) from \( p_T = 1 \text{ GeV/c} \)

- ALICE Upgrade
- Non-prompt J/ψ (→ e⁺e⁻), |y|<0.9
- Pb-Pb, \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \)
- \( L_{int} = 10 \text{ nb}^{-1} \)

![Graph showing Rel. stat. error N^{J/ψ\_non-prompt}_{\text{rel}} vs. \( p_T \) J/ψ (GeV/c) with data points for Central 0-10% and Semi-central 10-40%]

C. Terrevoli
Beauty via displaced $D^0$ and $J/\psi$: $v_2$

Upgrade:
- **precise $v_2$ measurement of prompt $D$ and $D$ from $B$**
- **positive elliptic flow for non-prompt $J/\psi$ would be observed in $3<p_T<8$ GeV/c**
Charmed baryons: $\Lambda_c$

$\Lambda_c \to pK\pi$
not accessible with the current ITS in Pb-Pb

- Upgrade
Improvement in resolution allows for cleaner vertex separation
$\Lambda_c$ production measurable down to 2 GeV/c with good precision

- $\Lambda_c/D$ ratio in Pb-Pb
- $\Lambda_c$ $R_{AA}$ down to $p_T=2$ GeV/c
**D_s**: \(R_{AA}\) and \(v_2\)

- \(R_{AA}\) of \(D_s\) larger than the \(R_{AA}\) of non-strange D mesons: seems to be larger at lower \(p_T\) but not possible to conclude within the present uncertainties!

- **Upgrade**: Possibility to reduce strongly the uncertainties on the \(R_{AA}\) measurement and to extend the measurement in the low \(p_T\) region

**Possibility to evaluate \(v_2\)**

- **ALICE Upgrade**
  - \(D_s^+ \rightarrow K^+K^-\pi^+, |y|<0.5\)
  - \(Pb-Pb, sl_{NN} = 2.76\text{ TeV}\)
  - \(L_{int} = 10\text{ nb}^{-1}\)
  - Centrality 0-10 %

- \(R_{AA}: \) uncertainties reduced extended \(p_T\)

- \(v_2\) will become measurable for first time!

**Current analysis**

- \(Pb-Pb, sl_{NN} = 2.76\text{ TeV}\)
- \(L_{int} = 10\text{ nb}^{-1}\)
- Centrality 30-50 %
Conclusions

ALICE has a strong upgrade physics programme for precision QGP studies where Heavy flavour measurements play a central role

Main requirements:

- Enhanced rate capabilities and new Inner Tracking System
  - Strong increase of the statistical precision in the measurements of yields and spectra of charmed mesons and baryons
  - A significant extension of the present physics programme with new measurements

ALICE is looking forward to the precision phase of Quark-Gluon Plasma measurements
BACKUP
Strange D mesons: $D_s^+ \to K^- K^+ \pi^+$ with Upgrade

- Recombination: in QGP low $p_T$ partons recombined each other to form higher $p_T$ hadrons
- Enhancement of strange flavour in QGP

- The relative yield of $D_s$ w.r.t non-strange $D$ meson expected to be enhanced in Pb-Pb collisions at intermediate $p_T$ if charm quarks hadronize via recombination in the medium

- Upgrade improve existing measurements:
  - Reduce strongly the background and improve S/B
  - reduce uncertainties and extend $p_T$ range
    - current analysis in 3 $p_T$ intervals from 4 to 12 GeV/c
      - significance=3-4
    - with upgrade in 11 $p_T$ intervals from 2 to 24 GeV/c

Significance from 30 up to 200
**B → J/ψ**

Current Analysis in central barrel: only indirect measure of B via electrons.

**pseudo proper decay length resolution**

Improved resolution in prompt J/ψ due to new ITS detector

~ Factor 2
Example of $x$ and $ee$ Invariant mass extraction in $p_T$ bin 2-3 GeV/c with ITS Upgrade and high rate
Collective Flow

- Anisotropic particle momentum distributions
  - relative to the reaction plane:
  \[
  \frac{dN}{d\phi} = \frac{N_0}{2\pi} \left\{ 1 + 2\nu_1 \cos(\phi - \Psi_{RP}) + 2\nu_2 \cos(2(\phi - \Psi_{RP})) + \ldots \right\}
  \]

- Angle of particle: \( \phi \)

- Magnitude:
  \[
  \nu_n(p_t, \eta) = \langle \cos(n(\phi - \Psi_n)) \rangle
  \]

- Valuable information on particle production mechanisms
  - \( p_T < 2-3 \text{ GeV/c} \): flow pattern described by hydrodynamic models
    - Handle on equation-of-state of medium
  - \( 3 < p_T < 6 \text{ GeV/c} \): flow larger for baryons than for mesons
  - \( p_T > 8 \text{ GeV/c} \): high-energy parton fragmentation from initial hard scattering
Hybrid pixels

- Separate optimization of sensor and circuitry, complex in-pixel signal processing
- State-of-the-art detectors but are limited to inner layers due to their cost
- Charge collected by drift
- Proven radiation resistance to ALICE levels

Monolithic pixels

- Sensing layer is integrated into the CMOS chip
- Have shown significant progress in recent years and will soon be installed in STAR (HFT)
- Charge mainly collected by diffusion (though some new developments on the way)
- Radiation resistance needs to be proven