Enhanced hard-probe measurements in the 2020s with the ALICE Upgrade
Physics motivations

Current ALICE measurements already provide a qualitative picture of the Quark-Gluon-Plasma properties but still **precision measurements are needed** for a complete understanding of:

- dynamical or transport properties of the medium, such as the drag and diffusion coefficient, via low-momentum heavy quarks
- hadronisation mechanisms (coalescence vs. fragmentation)
- quarkonium melting and regeneration dynamics
- temperature evolution of the QGP via thermal dileptons
- degree of thermalisation and collective-like behaviour in small systems

*ALICE will study various observables using Run 3 and Run 4 data*
Run 2: $\mathcal{L}_{\text{Pb-Pb}} = \sim 1.0 \text{ nb}^{-1}$

Run 3: $\mathcal{L}_{\text{Pb-Pb}} = 6.0 \text{ nb}^{-1}$

Run 4: $\mathcal{L}_{\text{Pb-Pb}} = 7.0 \text{ nb}^{-1}$

**ALICE strategy for Run 3 + Run 4:**

- 50 kHz Pb-Pb interaction rate (now <10 kHz)
- Collect $L_{\text{Pb-Pb}} = 13 \text{ nb}^{-1}$, $L_{\text{p-Pb}} = 500 \text{ nb}^{-1}$ untriggered data and $L_{\text{pp}} = 200 \text{ pb}^{-1}$ high multiplicity trigger
- Objectives of the experiment upgrades during Long Shutdown 2 (LS2):
  1. **Improve tracking efficiency and resolution at low $p_T$**
     - Increase tracking granularity
     - Reduce material thickness
     - Minimise the distance to IP
  2. **Preserve particle identification (PID)**
     - Consolidate and speed-up main ALICE PID detectors
  3. **Improve readout capabilities**

*Cristina Bedda (Utrecht University)*
Key ALICE Detector upgrades during LS2

New Inner Tracking System (ITS)
- CMOS pixel, MAPS technology
- Improved resolution, less material, faster readout

New TPC Readout Chambers (ROCs)
- Gas Electron Multiplier (GEM) technology
- New electronics (SAMPA), continuous readout

New Muon Forward Tracker (MFT)
- CMOS Pixels, MAPS technology
- Vertex tracker at forward rapidity

New Fast Interaction Trigger (FIT) Detector
- Centrality, event plane, luminosity, interaction time

Integrated Online-Offline system (O²)
- Record MB Pb-Pb data at 50 kHz

Readout upgrade
- TOF, TRD, MUON, ZDC, Calorimeters

Cristina Bedda (Utrecht University)
New ITS and MFT

New ITS
1. 10 m² active silicon area, 12.5×10⁹ MAPS
2. Thinner (X/X₀): ~1.14% -> ~0.3% (inner)
3. 7 layers (inner/middle/outer): 3/2/2
   from R = 22 mm (closer to IP) to R = 400 mm
4. 192 staves (IL/ML/OL): 48/54/90

New MFT
1. 0.4 m² active silicon area, 920 MAPS
2. 10 Half-disks- 2 detection planes each

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Cristina Bedda (Utrecht University)
Fulfil TPC Upgrade requirements:
- Stable operation under LHC Run 3 conditions
- Unprecedented challenges in terms of loads and performance
- Allow continuous readout -> newly developed Front-End (SAMPA chips) and readout electronics

Baseline solution: 4-GEM stack
- Combination of standard and large pitch GEM foils
- Highly optimized HV configuration
- Result of intensive R&D
- Energy resolution reachable: $\sigma_E / E < 12\%$ for $^{55}\text{Fe}$ (X-rays)

Plotted: 30 kHz Pb-Pb Collisions
- MC events overlaid on cluster level, using realistic bunch crossing structure
- Time is scaled linearly onto the z-position.
- Tracks/Clusters from different collisions are shown in different colors.
Detector performance after the Upgrade

New ITS

➤ Impact-parameter resolution of $\sim 40$ $\mu$m at $p_T = 500$ MeV/c
➤ Tracking efficiency $>95\%$ at $p_T = 500$ MeV/c
➤ Pointing resolution 3 times better in transverse plane (6 times along beam)

Cristina Bedda (Utrecht University)
Detector performance after the Upgrade

**New ITS**
- Impact-parameter resolution of ~40 μm at $p_T = 500$ MeV/c
- Tracking efficiency >95% at $p_T = 500$ MeV/c
- Pointing resolution 3 times better in transverse plane (6 times along beam)

**New Muon Forward Tracker**
- Matching muon tracks to the MFT
  - good pointing resolution in the transverse direction

**New TPC Readout Chambers (GEM)**
- Preserve momentum resolution for TPC+ITS
- Preserve particle identification via dE/dx
Hard-probes physics performance after the Upgrade

- D and B-meson production
- Heavy Flavour baryon-to-meson ratio
- Heavy Flavour direct and elliptic flow measurements
- Quarkonia
- Hadron+jet measurements
- Measurements in p-Pb collisions
- “Low mass di-leptons”
➤ Significant improvement in the non-strange D-meson production measurement down to $p_T=0$

➤ Extend $p_T$ range on $D_s$-production measurement and low statistical uncertainties
  ➤ access to hadronization mechanisms
  ➤ possibility to disentangle between theoretical models
B-meson production

- Full reconstruction of the $B^+$ meson down to 1 GeV/c
- Beauty measurements using both exclusive (non-prompt $D^0$ and $J/\psi$) and inclusive decays (B mesons to hadronic decays) at mid and forward rapidity
- Precise $R_{AA}$ allows a quantitative verification of mass dependence energy loss: $\Delta E_{\text{charm}} > \Delta E_{\text{beauty}}$ and can discriminate between models at low $p_T$
Hints of charm recombination both at RHIC and LHC, very large uncertainty from heavy-ion measurements

$\Lambda_c/D$ can discriminate between models at low $p_T$

$\Lambda_c$ measurement possible down to 2 GeV/$c$ in Pb-Pb collisions
Cristina Bedda (Utrecht University)

### Current measurement (E. Mennino talk)
- $\Lambda_{c/D}$
  - Hints of charm recombination both at RHIC and LHC, very large uncertainty from heavy-ion measurements
- $\Lambda_{c/D}$ can discriminate between models at low $p_T$
- $\Lambda_c$ measurement possible down to 2 GeV/$c$ in Pb-Pb collisions

### Upgrade simulation
- $\Lambda_{b/B}$
  - Insight into thermalisation and hadronisation of beauty quarks
  - $\Lambda_b$ measurement possible down to 4 GeV/$c$ in Pb-Pb collisions
Elliptic-flow measurement

- Elliptic flow of charm and beauty hadrons down to 0 and 1 GeV/c, respectively
- Provide the strongest constrain on the c and b quark diffusion coefficients and path-length dependence of the parton energy loss
- More differential measurement will be possible, as $v_2$ using the Event-Shape-Engineering technique
Magnetic field from moving spectators influence moving charges
- -> charge-dependent directed flow, asymmetric in rapidity

HF particles expected to have larger $v_1$ with respect to light flavours because they are produced when magnetic field is maximum, while light quarks might be produced later (Das, Greco et al., arXiv:1608.02231)

Very promising sensitivity to the effect of the early time magnetic field in heavy-ion collisions, can help constrain QGP properties
Probe Debye screening of colour charges and temperature of the QGP through quarkonium sequential dissociation pattern and regeneration

- Assess exited $\psi$ states with small uncertainties and possibility for multi-differential measurements

- Two different scenarios describing charmonium data:
  - **statistical hadronisation model**: all $\psi$ generated at hadronisation from deconfined c and c-bar
  - **transport model**: interplay between dissociation and recombination from deconfined c-quarks

*Cristina Bedda (Utrecht University)*
Cristina Bedda (Utrecht University)

Probe Debye screening of colour charges and temperature of the QGP through quarkonium sequential dissociation pattern and regeneration

➤ Assess exited ψ states with small uncertainties and possibility for multi-differential measurements

➤ Two different scenarios describing charmonium data:
   - **statistical hadronisation model**: all ψ generated at hadronisation from deconfined c and c-bar
   - **transport model**: interplay between dissociation and recombination from deconfined c-quarks
Quarkonia (Y states)

Probe Debye screening of colour charges and temperature of the QGP through quarkonium sequential dissociation pattern and regeneration

➤ More differential quarkonia measurements with high precision
➤ Assess low-$p_T$ and elliptic flow of different Y states
Investigate jet quenching, jet substructure, jet non-coplanarity

Large-angle deflection sensitive to medium structure: quasi-particle? Molière scattering?

Integral of azimuthal distribution at large angles used to explore jet deflection

\[ \Sigma(\Delta\phi_{\text{thresh}}) = \int_{\pi/2}^{\pi - \Delta\phi_{\text{thresh}}} d\Delta\phi [\Phi \Delta\phi] \]

Project with Run 2 L_{\text{int}}

Project with Run 3+4 L_{\text{int}}

Projection with JEWEL (recoils off) for expected integrated luminosity of run 3 and 4

Statistical uncertainty \(\sim 5\%\) at \(\Delta\phi_{\text{threshold}} \sim 1\)

-dominated by the pp reference

More details in J. Norman talk
Measurement of low-mass di-leptons $\rightarrow$ electromagnetic radiation from QGP, sensitive to:

- medium temperature $\frac{dN}{dM_{ee}} \propto \exp\left(-\frac{M_{ee}}{T_{fit}}\right)$

- chiral-symmetry restoration by modification of $\rho$ spectral function

Current ITS and statistics simulation

Upgrade simulation

- Up to now difficult to disentangle all the electron-background sources

- After the ALICE upgrade:
  - Charm rejection and reduced combinatorial background thanks to the new ITS and the MFT
  - Dedicated run at $B=0.2$ T to extend electron $p_T$ range and acceptance

Measurements in p-Pb collisions

- Precise D-meson $R_{pPb}$ measurement to $p_T=0$, also for $D_s$ with $L_{int} = 50 \text{ nb}^{-1}$
- Quantitative constraints to models including CNM effects and/or small QGP
More differential heavy-flavour and quarkonia measurements with high precision

Investigate initial/final-state effects in high-multiplicity p-Pb collisions also at low $p_T$

Investigate collective-like effects in p-Pb collisions
Conclusions

➤ The ALICE Upgrade project has successfully completed the R&D phase and it is now in the production/assembly phase -> upgraded detectors

➤ Enhanced readout capabilities and higher LHC luminosity -> very large statistics

High precision measurements of QGP properties will be possible

➤ dynamical or transport properties of the medium via low-momentum heavy quarks

➤ hadronisation mechanisms (coalescence vs. fragmentation)

➤ quarkonium melting and regeneration dynamics

➤ temperature evolution of the QGP via thermal dileptons

➤ high-statistics jet modification studies

➤ degree of thermalisation and collective-like behaviour in small systems
Backup
Physics after the upgrade

From the ITS Technical Design Report

Decay characteristics

<table>
<thead>
<tr>
<th>Observable</th>
<th>Current, 0.1 nb⁻¹</th>
<th>Upgrade, 10 nb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_{T}^{\text{min}}$ (GeV/c)</td>
<td>statistical uncertainty</td>
</tr>
<tr>
<td>D meson $R_{AA}$</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>$D_{s}$ meson $R_{AA}$</td>
<td>4</td>
<td>15%</td>
</tr>
<tr>
<td>D meson from B $R_{AA}$</td>
<td>3</td>
<td>30%</td>
</tr>
<tr>
<td>$J/\psi$ from B $R_{AA}$</td>
<td>1.5</td>
<td>15% ($p_{T}$-int.)</td>
</tr>
<tr>
<td>B⁺ yield</td>
<td>not accessible</td>
<td>2</td>
</tr>
<tr>
<td>$\Lambda_{c}$ $R_{AA}$</td>
<td>not accessible</td>
<td>2</td>
</tr>
<tr>
<td>$\Lambda_{c}/D^{0}$ ratio</td>
<td>not accessible</td>
<td>2</td>
</tr>
<tr>
<td>$\Lambda_{b}$ yield</td>
<td>not accessible</td>
<td>7</td>
</tr>
<tr>
<td>D meson $v_{2}$ ($v_{2} = 0.2$)</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>$D_{s}$ meson $v_{2}$ ($v_{2} = 0.2$)</td>
<td>not accessible</td>
<td>&lt;2</td>
</tr>
<tr>
<td>D from B $v_{2}$ ($v_{2} = 0.05$)</td>
<td>not accessible</td>
<td>2</td>
</tr>
<tr>
<td>$J/\psi$ from B $v_{2}$ ($v_{2} = 0.05$)</td>
<td>not accessible</td>
<td>1</td>
</tr>
<tr>
<td>$\Lambda_{c}$ $v_{2}$ ($v_{2} = 0.15$)</td>
<td>not accessible</td>
<td>3</td>
</tr>
</tbody>
</table>

Dielectrons

<table>
<thead>
<tr>
<th>Observable</th>
<th>Yield m.b., 0-10%</th>
<th>dN/dy$<em>{p</em>{T}}$ m.b., 0-10%</th>
<th>ct (µm)</th>
<th>decay channel</th>
<th>B.R.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^{0}$</td>
<td>23, 110</td>
<td>23, 111</td>
<td>$\approx 120$</td>
<td>$K^{-}\pi^{+}$</td>
<td>3.8%</td>
</tr>
<tr>
<td>$D^{*+}$</td>
<td>9, 44</td>
<td>0.9</td>
<td>4.4</td>
<td>$\approx 0$</td>
<td>$D^{0}\pi^{+}$</td>
</tr>
<tr>
<td>$D^{+}$</td>
<td>4.3, 20</td>
<td>0.4, 20</td>
<td>$\approx 150$</td>
<td>$\phi(\rightarrow K^{+}K^{-})\pi^{+}$</td>
<td>4.4% (×49%)</td>
</tr>
<tr>
<td>$\Lambda_{c}^{0}$</td>
<td>2.9, 14</td>
<td>0.29, 14</td>
<td>$\approx 60$</td>
<td>$pK^{-}\pi^{+}$</td>
<td>5.0%</td>
</tr>
<tr>
<td>B</td>
<td>1.3, 6.2</td>
<td>0.2, 0.9</td>
<td>$\approx 500$</td>
<td>$J/\psi(\rightarrow e^{+}e^{-}) + X$</td>
<td>1.4% (×69.9%)</td>
</tr>
<tr>
<td>$D^{0}(\rightarrow K^{-}\pi^{+})\pi^{+}$</td>
<td>0.5% (×38%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Lambda_{c}^{+}$</td>
<td>2.9, 14</td>
<td>0.29, 14</td>
<td>$\approx 60$</td>
<td>$pK^{-}\pi^{+}$</td>
<td>5.0%</td>
</tr>
<tr>
<td>$\Lambda_{c}^{+}$</td>
<td>2.9, 14</td>
<td>0.29, 14</td>
<td>$\approx 60$</td>
<td>$pK^{-}\pi^{+}$</td>
<td>5.0%</td>
</tr>
<tr>
<td>$\Lambda_{b}^{0}$</td>
<td>0.1, 0.5</td>
<td>0.015, 0.07</td>
<td>$\approx 400$</td>
<td>$\Lambda_{c}^{+}(\rightarrow pK^{-}\pi^{+}) + e^{+} + X$</td>
<td>9.9% (×5%)</td>
</tr>
<tr>
<td>$\Lambda_{b}^{0}$</td>
<td>0.1, 0.5</td>
<td>0.015, 0.07</td>
<td>$\approx 400$</td>
<td>$\Lambda_{c}^{+}(\rightarrow pK^{-}\pi^{+}) + e^{+} + X$</td>
<td>9.9% (×5%)</td>
</tr>
</tbody>
</table>

Production rate

<table>
<thead>
<tr>
<th>System</th>
<th>Pb-Pb</th>
<th>Pb-Pb</th>
<th>pp (measured)</th>
<th>pp</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{s_{NN}}$</td>
<td>2.76 TeV</td>
<td>5.5 TeV</td>
<td>7 TeV</td>
<td>14 TeV</td>
</tr>
<tr>
<td>$\sigma_{NN}^{\text{NN}}$ [mb]</td>
<td>2.1</td>
<td>3.4</td>
<td>6.9 (8.5 ± 2.5)</td>
<td>11.2</td>
</tr>
<tr>
<td>$N_{\text{c.c.}}^{\text{min.-bias}}$, 0–10% central</td>
<td>12, 50</td>
<td>19, 80</td>
<td>0.10</td>
<td>0.16</td>
</tr>
<tr>
<td>$\sigma_{NN}^{\text{NN}}$ [mb]</td>
<td>0.08</td>
<td>0.14</td>
<td>0.23 (0.28 ± 0.06)</td>
<td>0.50</td>
</tr>
<tr>
<td>$N_{\text{c.c.}}^{\text{min.-bias}}$, 0–10% central</td>
<td>0.5, 1.9</td>
<td>0.8, 3.3</td>
<td>0.003</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Cristina Bedda (Utrecht University)
ITS Upgrade design objective

- High tracking efficiency and \( p_T \) resolution at low \( p_T \)
  - increase granularity: 6 layers \( \rightarrow 7 \) pixel layers
  - reduce material budget: \(~1.14\% \ X_0 \rightarrow ~0.3\% \ X_0\) (inner layers)

- Excellent secondary vertex resolution (\( \Lambda_c \ c\tau \sim 60 \mu m \))
  - get closer to interaction point: 39mm \( \rightarrow 23 \)mm (innermost layer)
  - reduce pixel size: 50x425\( \mu m^2 \rightarrow O(30x30 \ \mu m^2)\)
  - Spatial resolution: currently 12 \( \mu m \times 100 \mu m \) (SPD) \( \rightarrow 5 \ \mu m \times 5 \ \mu m \)

- High-statistics, un-triggered data sample (\( >10 \) nb\(^{-1} \) Pb-Pb)
  - readout of Pb-Pb up to 50 kHz (presently 1kHz) and 200 kHz for pp to exploit LHC luminosity increase

- Withstand radiation load (10 years operation) up to TID: \(~ 270 \) krad,
  NIEL: \(~1.7x10^{12} 1\)MeV \( n_{eq} \)/ \( cm^2 \)

- Fast insertion and removal to replace non-functioning detector staves during yearly shutdown
CMOS Pixel Sensor - TowerJazz 0.18µm CMOS Imaging Process

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25µm) on p-type substrate
- Small n-well diode (2 µm diameter), ~100 times smaller than pixel => low capacitance (~fF)
- Reverse bias voltage (-6V < V_{BB} < 0V) to substrate (contact from the top) to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors (full CMOS circuitry within pixel active area)
CMOS Pixel Sensor - TowerJazz 0.18μm

Key features:
- In-pixel:
  - amplification
  - discrimination
  - multi event buffer
- In-matrix zero suppression (priority encoding)
- Ultra-low power (entire chip): < 40mW/cm² (140mW full chip)
- triggered acquisition (200 kHz Pb-Pb, 1 MHz pp) or

**Table:**

<table>
<thead>
<tr>
<th>Resolution (μm)</th>
<th>Detection Efficiency</th>
<th>Fake Hit Rate/Pixel/Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95</td>
<td>0.95</td>
<td>0.015% pixels masked</td>
</tr>
<tr>
<td>0.96</td>
<td>0.96</td>
<td>0.015% pixels masked</td>
</tr>
<tr>
<td>0.97</td>
<td>0.97</td>
<td>0.015% pixels masked</td>
</tr>
<tr>
<td>0.98</td>
<td>0.98</td>
<td>0.015% pixels masked</td>
</tr>
</tbody>
</table>

**Graphs:**
- Detection efficiency > 99%
- Spatial resolution < 5 μm

Cristina Bedda (Utrecht University)
ITS Upgrade design objective

- High tracking efficiency and $p_T$ resolution at low $p_T$
  - increase granularity: 6 layers $\rightarrow$ 7 pixel layers
  - reduce material budget: $\sim$1.14% $X_0$ $\rightarrow$ $\sim$0.3% $X_0$
    (inner layers)

- Excellent secondary vertex resolution ($\Lambda_c\tau\sim60$ µm)
  - get closer to interaction point: 39mm $\rightarrow$ 23mm (innermost layer)
  - reduce pixel size: 50x425µm² $\rightarrow$ $O(30x30$ µm²)
  - Spatial resolution: currently 12 µm x 100 µm (SPD) $\rightarrow$ 5 µm x 5 µm

Cristina Bedda (Utrecht University)
ALICE Time Projection Chamber

- Diameter: 5 m, length: 5 m
- Gas: Ne-CO$_2$-N$_2$, Ar-CO$_2$
- Max. drift time: $\sim$100 µs
- 18 sectors on each side
- Inner and outer readout chambers: IROC, OROC

- Current detector (Run 1, Run 2):
  - 72 MWPCs
  - $\sim$550 000 readout pads
  - Wire gating grid (GG) to minimize Ion Back-Flow (IBF)
  - Rate limitation: few kHz

Operate TPC at 50 kHz → no gating grid
Continuous Readout with GEMs

TPC Upgrade requirements:

➤ Nominal gain = 2000 in Ne-CO$_2$-N$_2$ (90-10-5)
➤ IBF < 1% ($\varepsilon = 20$)
➤ Energy resolution: $\sigma_E/E < 12\%$ for $^{55}$Fe
➤ Stable operation under LHC Run 3 conditions
➤ Unprecedented challenges in terms of loads and performance

Baseline solution: 4-GEM stack

➤ Combination of standard (S) and large pitch (LP) GEM foils
➤ Highly optimized HV configuration
➤ Result of intensive R&D
**Heavy flavour Jets**

**Probe the nature of interactions between coloured particle in the QGP:**

through the study of attenuation of high-$p_T$ quarks and gluons: Differential studies of jets, b-jets, di-jets, photon/Z-jet correlation at very high $p_T$

Flavour-dependent in-medium fragmentation functions, studying particle-identified fragmentation functions

**D meson in jets**

**select quark jet and study flavour-dependence of FF modification**
Figure 8.13: $B^+ \rightarrow \bar{D}^0\pi^+$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV: the significance (left) is scaled to $8 \times 10^9$ events for 0–10% centrality, corresponding to $L_{\text{int}} = 10$ nb$^{-1}$. The signal-to-background ratio is shown on the right.

Figure 8.14: $\Lambda_c \rightarrow pK\pi$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV: significance (left) and $S/B$ ratio (right) as a function of $p_T$. The significance is scaled to $1.6 \times 10^{10}$ events, which correspond to the statistics in the centrality class 0–20% for $L_{\text{int}} = 10$ nb$^{-1}$. 
D mesons $R_{pPb}$: models

$$R_{pPb} = \frac{\left( \frac{d\sigma}{dp_T} \right)_{pPb}}{A \times \left( \frac{d\sigma}{dp_T} \right)_{pp}}$$

Models including CNM effects:

Models including the QGP formation:
$D^0$ ESE $v_2$

ALICE Upgrade projection
30–50% Pb–Pb, $\sqrt{s_{NN}} = 5.5$ TeV, $L_{int} = 10$ nb$^{-1}$

$D^0$ $|y|<0.5$

- 0–10% $q_2$
- 90–100% $q_2$

ALICE Upgrade projection
30–50% Pb–Pb, $\sqrt{s_{NN}} = 5.5$ TeV, $L_{int} = 10$ nb$^{-1}$

- $D^0$ $|y|<0.5$, 90–100% $q_2$
Di-muon measurement with the MFT

\[ \text{dN/dM} \] [dimuons per 10 MeV/c]

\[ \times 10^3 \quad \text{MUON + MFT} : 1.0 < p_T^{\mu\mu} < 10.0 \text{ GeV/c} \]

\[ \text{Mass [GeV/c}^2] \]

Cristina Bedda (Utrecht University)
Small systems (pp vs multiplicity)

ALICE, pp \( \sqrt{s} = 7 \text{ TeV} \)
Average D\(^0\), D\(^+\), D\(^{**}\) meson, |\(y\)|<0.5

\[
\frac{d^2N}{dydp_T} / \langle dN/d\eta \rangle
\]

Relative statistical uncertainty

ALICE Upgrade projection
pp, \( \sqrt{s} = 7 \text{ TeV} \)
D\(^0\) meson, |\(y\)|<0.5, 2 < \(p_T\) < 4 GeV/c
- \(\mathcal{L}_{\text{int}} = 5 \text{ nb}^{-1}\), JHEP09 (2015) 148
- \(\mathcal{L}_{\text{int}} = 6 \text{ pb}^{-1}\)
- \(\mathcal{L}_{\text{int}} = 200 \text{ pb}^{-1}\)