ALICE status report

09/03/2022

Fabio Colamaria
for the ALICE Collaboration
INFN – Sezione di Bari

149th LHCC meeting
• Recent physics highlights
  ➢ 9 new publications since last LHCC

• LS2 activities

• Detector commissioning
  ➢ Status and plan for 2022
  ➢ Detector performance from pilot beam

• Status of the upgrades
  ➢ Run4: ITS3 and FoCal
  ➢ Run5+: ALICE 3
PAPERS AND PHYSICS HIGHLIGHTS

09/03/2022

F. Colamaria – 149th LHCC meeting
<table>
<thead>
<tr>
<th>Title</th>
<th>arXiv:2112.08156</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraining hadronization mechanisms with ( \Lambda^+ / D^0 ) production ratios in Pb–Pb collisions at ( \sqrt{s_{_{NN}}} = 5.02 ) TeV</td>
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<td>Observation of a multiplicity dependence in the ( p_T )-differential charm baryon-to-meson ratios in proton-proton collisions at ( \sqrt{s} = 13 ) TeV</td>
<td>arXiv:2111.11948</td>
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<td>Measurement of beauty production via non-prompt ( D^0 ) mesons in Pb–Pb collisions at ( \sqrt{s_{_{NN}}} = 5.02 ) TeV</td>
<td>arXiv:2202.00815</td>
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<td>Forward rapidity ( J/\psi ) production as a function of charged-particle multiplicity in pp collisions at ( \sqrt{s} = 5.02 ) and 13 TeV</td>
<td>arXiv:2112.09433</td>
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<td>First study of the two-body scattering involving charm hadrons</td>
<td>arXiv:2201.05352</td>
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<td>Neutral to charged kaon yield fluctuations in Pb–Pb collisions at ( \sqrt{s_{_{NN}}} = 2.76 ) TeV</td>
<td>arXiv:2112.09482</td>
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<td>Production of light (anti)nuclei in pp collisions at ( \sqrt{s} = 5.02 ) TeV</td>
<td>arXiv:2112.00610</td>
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<td>First measurement of the absorption of ( ^3\text{He} ) nuclei in matter and impact on their propagation in the galaxy</td>
<td>arXiv:2202.01549</td>
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<td>Multiplicity dependence of charged-particle jet production in pp collisions at ( \sqrt{s} = 13 ) TeV</td>
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• Heavy quarks: excellent probes for study of microscopic QGP dynamics
  ➢ In-medium partonic energy loss due to gluon radiation (at high $p_T$) and elastic collisions (at lower $p_T$)

• $b$ quark: expected reduced energy loss compared to $c$
  ➢ Dead-cone effect vetoes gluon radiation for $\theta < \frac{m_Q}{E}$
    Also observed in pp collisions for $c$ quark (arXiv:2106.05713)

• Nuclear modification factor of $D^0$ mesons from beauty-hadron decays

$$R_{AA} = \frac{\left. \frac{dN^D}{dp_T} \right|_{\text{Pb-Pb}}}{\left. \frac{d\sigma^D}{dp_T} \right|_{\text{pp}}}$$

$R_{AA} = 1 \rightarrow$ no medium effects

$R_{AA} \neq 1 \rightarrow$ breaking of $N_{\text{coll}}$ scaling due to cold and hot nuclear matter effects

• Suppression up to factor 3 (2) in central (semicentral) collisions for $p_T > 5$ GeV/c

arXiv:2202.00815
• Ratio of non-prompt/prompt $D^0$-meson $R_{AA}$ suggests similar suppression in $2 < p_T < 3$ GeV/c, and smaller suppression for non-prompt $D^0$ at higher $p_T$

• Models with radiative+collisional energy loss and with hadronisation via fragmentation+recombination describe data within uncertainties

• Further insights by modifying LGR model configuration
  - Ratio closer to unity if using charm mass for $b$ quarks for $E$-loss calculation → Relevant role of dead-cone effect
  - Prompt-$D^0$ formation via recombination explains the minimum at 2-3 GeV/c

arXiv:2202.00815
• In QGP medium, modified hadronisation of quarks into hadrons compared to pp collisions (coalescence mechanism) + mass-dependent particle spectra $p_T$ shift from collective expansion

• Studied via baryon-to-meson ratios, also in the HF sector
  ➢ Ratio of prompt $\Lambda^+ c$ over prompt $D^0$ mesons, in Pb–Pb collisions (0-10% and 30-50% centrality)

• Significant increase of $\Lambda^+ c/D^0$ ratio from pp to Pb-Pb central collisions, in $4 < p_T < 8$ GeV/c
  ➢ 3.7$\sigma$ effect

• Qualitative agreement for models that include hadron formation via coalescence (Catania, Tamu, SHMc)
Studies vs multiplicity in pp collisions nicely connect to observed Pb-Pb enhancement at intermediate $p_T$

- Shed further light to non-universality of charm fragmentation across collision systems

- $\Lambda^+/D^0$ ratios measured vs charged particle multiplicity
  - 5.7$\sigma$ significant increase from lowest to highest multiplicity intervals in $1 < p_T < 12$ GeV/c
  - No evolution of $D_s^+/D^0$ ratios with multiplicity

- $\Lambda^+/D^0$ multiplicity hierarchy qualitatively reproduced by Pythia8 with CR modes beyond leading colour

- Good description of $\Lambda^+/D^0$ provided by CE-SH model, while $D_s^+/D^0$ overestimated at high multiplicity

Multiplicity estimator: SPD tracklets, $\propto dN_{ch}/d\eta$ at midrapidity
Alternate estimator at forward $\eta$ also checked to exclude autocorrelations

arXiv:2111.11948

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• Very similar behaviours of $\Lambda^+ c/D^0$ (HF) and $\Lambda/K^0_s$ (LF) ratios against $p_T$ and multiplicity

- **Same mechanism** at play for light- and heavy-flavour final-state particle formation?
- **Confirm modified hadronisation** mechanisms, collision-system and multiplicity dependent

• **No significant modification** of $\Lambda^+ c/D^0$ ratios integrated over $p_T > 0$ as a function of charged particle multiplicity

- Different $p_T$ trend due to modifications of baryon and meson $p_T$ spectra, not to overall baryon enhancement at high multiplicity

Extrapolation to $p_T = 0$ based on $p_T$ shape from Pythia8 CR-BLC
• Study of heavy-flavour production as a function of multiplicity in pp can also shed light on the role of MPI in heavy-quark production
  - **Self-normalised yields** of inclusive J/ψ mesons at forward rapidity in pp at \( \sqrt{s} = 5.02 \) TeV and 13 TeV

• **Approximately linear increase** with self-normalised multiplicity at midrapidity
  - Independent of collision energy
  - **Different trend** compared with midrapidity results

• Best description of data trend by 3-Pomeron CGC, Percolation and CPP models, pointing to initial-state effects

_Multiplicity estimator: SPD tracklets, \( \propto \frac{dN_{\text{ch}}}{d\eta} \) at midrapidity_
• First measurement of interaction between charm hadron and nucleon via femtoscopic studies
  ➢ Gives access to residual strong interaction in charm sector
  ➢ Also relevant to explain structure of exotic states with charm (XYZ states, $T_{cc}^+$, $P_c$ states, ...)

• Two-particle momentum correlation function $C(k^*)$ of $pD^-$ and $\bar{p}D^+$ pairs measured in high-multiplicity pp collisions at $\sqrt{s} = 13$ TeV

• Connection to source function and two-particle wave function:

  $$C(k^*) = \int d^3r^* S(r^*) \left| \Psi(k^*, r^*) \right|^2 \quad \text{→ Koonin-Pratt equation}$$

  ➢ Allows to extract the potential for proton and $D^-$ meson interaction
**TWO-BODY SCATTERING WITH CHARM HADRONS**

<table>
<thead>
<tr>
<th>Model</th>
<th>$f_0$ (I = 0)</th>
<th>$f_0$ (I = 1)</th>
<th>$n_{1\sigma}$</th>
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<tbody>
<tr>
<td>Coulomb</td>
<td></td>
<td></td>
<td>(1.1–1.5)</td>
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<tr>
<td>Haidenbauer et al.</td>
<td>0.14</td>
<td>−0.28</td>
<td>(1.2–1.5)</td>
</tr>
<tr>
<td>$-g_\sigma^2/4\pi = 1$</td>
<td>0.67</td>
<td>0.04</td>
<td>(0.8–1.3)</td>
</tr>
<tr>
<td>Hofmann and Lutz</td>
<td>−0.16</td>
<td>−0.26</td>
<td>(1.3–1.6)</td>
</tr>
<tr>
<td>Yamaguchi et al.</td>
<td>−4.38</td>
<td>−0.07</td>
<td>(0.6–1.1)</td>
</tr>
<tr>
<td>Fontoura et al.</td>
<td>0.16</td>
<td>−0.25</td>
<td>(1.1–1.5)</td>
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</table>

- **Data consistent with an attractive potential**
  - $1.1\sigma$–$1.5\sigma$ compatibility with Coulomb-only interaction
  - Improved agreement adding an attractive strong interaction (Yamaguchi et al., Haidenbauer et al.)

- $f_0 > 0$: Attractive potential
- $f_0 < 0$: Repulsive potential or attractive with bound state

**Inverse scattering length** $f_{0,I=0}^{-1}$ of ND system, by constraining to data the correlation function obtained varying source radius and potential $V_{I=0}$

- In $1\sigma$ from best fit: $V_{I=0} \in [-1450, -1050]$ MeV $\rightarrow f_{0,I=0}^{-1} \in [-0.4, 0.9]$ fm$^{-1}$
- Consistent with attractive interaction, with or without bound state

*arXiv:2201.05352* (estimated source size)
Measurements of antinuclei provide important input for astrophysics and dark-matter studies

- One of dominant production mechanisms is DM annihilation (e.g. $\chi + \chi \rightarrow W^+W^- \rightarrow ^3\text{He} + X$)

- Disappearance probability of antinuclei (quantified by $\sigma_{\text{inel}}$) while traversing matter is one of the main ingredients for modeling their propagation and studying the galaxy transparency

First $\sigma_{\text{inel}}$ measurement done by ALICE for $^3\text{He}$

- Antinuclei factory + interaction in detector material
- Via baryon/antibaryon ratio (pp), or TOF-to-TPC ratio (Pb-Pb)

GEANT4 modeling consistent within $2\sigma$ sigma with data

arXiv:2202.01549
ABSORPTION OF $^{3}\text{He}$ IN MATTER

- Propagation through galaxy of $^{3}\text{He}$ from **dark-matter decays** and **cosmic-ray interactions** based on transport equation
  - Inelastic interactions modeled via $p_T$- and $A$-scaling of experimentally measured $\sigma_{\text{inel}}(^{3}\text{He})$

**Distribution of DM** as a function of distance from galactic centre

**Modeled $^{3}\text{He}$ sources**

**Interactions of high-energy cosmic rays** with interstellar medium

**Dark-matter decays** (WIMPS of 100 GeV/c$^2$)

*arXiv:2202.01549*
Proposition through galaxy of $^3\text{He}$ from **dark-matter decays** and **cosmic-ray interactions** based on transport equation

- Inelastic interactions modeled via $p_T$- and $A$-scaling of experimentally measured $\sigma_{\text{inel}}(^3\text{He})$

- **Estimated flux of $^3\text{He}$** near Earth, before and after solar modulation
  - Consistent with model predictions using different $\sigma_{\text{inel}}(^3\text{He})$ parameterizations

- Transparency of galaxy about **50% for DM source**, 25% for low-$E$ $^3\text{He}$ from cosmic-ray background

- Experimentally-driven uncertainties reduced to **10%-15%**, subleading w.r.t. other ingredients used for DM modelling

*Propagation performed using GALPROP code*
LS2 ACTIVITIES AND COMMISSIONING
Main objectives for ALICE detector for Run 3+4:

• Collect $L_{\text{int}} \approx 13 \text{ nb}^{-1}$ of Pb-Pb collisions $\rightarrow x50$-$x100$ statistics increase for most of the observables

• Sustain rate of 50 kHz for Pb-Pb collisions, with continuous readout and online data reconstruction

• Substantial improvements in vertexing capabilities and tracking efficiency

New/improved systems:

• New tracking systems based on MAPS:
  - Inner Tracking System (ITS)
  - Muon Forward Tracker (MFT)

• New Fast Interaction Trigger (FIT) detector

• TPC readout chambers employing GEM

• New Online/Offline system (O2) for data processing and reconstruction

• Upgraded readout systems for the other detectors, to cope with continuous readout
Latest activities at P2 and roadmap

- **Finished installation** of ALICE subsystems, **maintenance/replacement activities** for several detectors (TOF, ITS, MFT, TPC, MCH, EMCal, Dcal, PHOS)
- L3 doors closed February 14, ventilation reinstalled February 15, miniframe shielding installed the following week
- ALICE closed by week 9 (March 2nd) and restart magnets in week 10 (March 7th)
- **Underground access** ends on **March 24th**
- **Machine commissioning with beam** expected to start on **April 13th** (Easter week)
ALICE COMMISSIONING – PLANS UP TO STABLE BEAMS

Roadmap to 13.6 TeV Collisions

• **Week 8-14** (February-April): Global and standalone commissioning with Weekly Run Plans
• **Week 15-23** (April-June): Global commissioning with synthetic runs exploiting MC fake data

- **Weeks 19,23**: new rounds of 900 GeV collisions (min 2 fills)
- Then **ready for Stable Beams** at 13.6 TeV
  - **Start-up plans** for p-p running after first SB are ready, to be discussed with machine experts
- Decided to preserve possibility of **Virtual Shift Blocks** for some systems, until the beginning of data taking
**HIGHLIGHTS FROM PILOT BEAM**

- Good **detector performance** from pilot beam
- Data are being exploited for alignment studies
- New analysis framework commissioned with data

**ITS pre-alignment using cosmics and pilot-beam data**

**TOF PID performance**

**TPC PID performance**

DeltaX between prongs of cosmic muon tracks
HIGHLIGHTS FROM PILOT BEAM

FT0 vs track-based $z_{vtx}$ position

$\eta$ of standalone MFT tracks vs $z_{vtx}$ position

Invariant mass peak of $\pi^0$ from EMCal+DCal

calibration ongoing

Two-cluster invariant mass distribution

ALICE pilot beam data
$pp \, \sqrt{s} = 900 \text{ GeV}$
clus. rec with EMCal + DCal

$3.00 < p_{\pi} \leq 4.00 \text{ GeV/c}$
Replacement of ITS2 inner barrel with the novel ITS3 during LS3
- Three layers of wafer-scale sensors of ultra-thin MAPS, bent around the beam pipe
  - ~6x less material budget: ~0.02-0.04% $X_0$ per layer
  - First layer at 18 mm from IP $\rightarrow$ 2x pointing resolution and low-$p_T$ efficiency

Mechanics updates

Wind tunnel studies with model + heaters
- Verified possibility of cooling via airflow
- Larger heating at periphery, can be dissipated via a carbon foam radiator, no water cooling required

Super-ALPIDE chips
- Assembled and bent, to be bonded on exoskeleton and tested

LoI: CERN-LHCC-2019-018
Sensor developments
Test structures from MLR1 submission received (TowerJazz 65 nm)

Tests in laboratory and with beam
- Digital Pixel Test Structures (DPTS) operational with 100% efficiency
  - DPTS remains fully efficient after combined NIEL + TID irradiation
- Further tests performed with DPTS and other types of structures
  - Position resolution, cluster size, time resolution, ...
- 65 nm process is a viable solution for ITS3 and beyond

DPTS test beam setup

Test beam results with two displaced DPTS

Reconstructed telescope tracks, on plane between 2 DPTS sensors

DPTS D
- wafer: 22
- chip: 1
- version: 1
- split: 4 (opt.)
- $V_{peak} = -1.2$ V
- $I_{peak} = 100$ mA
- $I_{bias} = 10$ mA
- $V_{bias} = 300$ mV
- $V_{res} = 250$ mV

DPTS E
- wafer: 22
- chip: 1
- version: 1
- split: 4 (opt.)
- $V_{peak} = -1.2$ V
- $I_{peak} = 10$ mA
- $I_{bias} = 100$ mA
- $V_{bias} = 300$ mV
- $V_{res} = 280$ mV
FoCal: forward electromagnetic+hadronic calorimeter → Run4 upgrade

- **FoCal-E**: high-granularity Si-W sampling calorimeter for direct $\gamma$ and $\pi_0$
- **FoCal-H**: metal-scintillator sampling calorimeter for photon isolation and jets

**Test beam in September 2021**

- **FoCal-E**: 2 pixel (ALPIDE) layers, 1 pad layer
- **FoCal-H**: complete prototype, commercial readout system
- Full-pixel prototype: **EPICAL-2**

**Next steps:**

- Further laboratory tests of pad readout
- Construct full FoCal-E tower prototype
- 2 test beams planned in 2022 (June for pad electronics, Sep/Oct for full demonstrator)

LoI ALICE-PUBLIC-2019-005
Several questions in key areas still expected to remain unaddressed after Run 3+4!

→ New dedicated heavy-ion detector currently under planning for Run 5 and beyond: ALICE 3

Selection of key points of ALICE 3 physics programme

• Precision measurements of dileptons
  ➢ Characterisation and evolution of the QGP
  ➢ Chiral symmetry restoration

• Systematic measurements of (multi-)heavy-flavoured hadrons
  ➢ Transport properties and diffusion in the QGP
  ➢ Mechanisms of hadronisation

• Hadron correlation measurements
  ➢ Interaction potentials
  ➢ Fluctuations of conserved charges
• Goal: understand **heavy quark diffusion** and how they reach thermalisation

• **Charm and beauty transport** in the diffusion regime:
  - $R_{AA}$ and $v_2$ of mesons and baryons down to low $p_T$
  - Access to **angular decorrelation** and further sensitivity to **energy loss** mechanisms via $D\bar{D}$ correlations
Multi-charm and exotic states

- **Multi-charm baryons**: unique probe of hadron formation
  - Requires production of multiple c quarks via (>1) hard scatterings
- **SHM predicts very large enhancement** in AA
  - Characteristic relation between $n$-charm yields ($g_c^N$)

- **Characterisation of charm exotic states**: $X(3872)$, $T_{cc}^+$, ...
  - Yield measurements to understand dissociation and regeneration in QGP
  - Femtoscopic studies to investigate their structure
**Electromagnetic probes**

- Precise measurement of *QGP temperature* in its early stages from invariant mass dilepton measurements
  - $1 < m_{ee} < 3 \text{ GeV}/c^2$ range dominated by thermal emission
  - Differential measurement to probe *time dependence* of $T$

- **Improved precision** compared to Run 3+4 measurements

- Complementary measurement of temperature via spectrum of *direct photons*
  - Different set of systematic uncertainties

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**Dilepton invariant mass spectrum**

- Dominated by black-body radiation from QGP
Letter of Intent submitted and reviewed by LHCC

- Lol draft endorsed by ALICE Collaboration Board with very strong support
- Submitted to the LHCC for review
  - The review process has led to a report from the LHCC review panel for discussion this week
- Final version in preparation, public release of final version shortly
SUMMARY

• New physics results from Run 2 being continuously released in key areas
• ALICE 2 ready for end of LS2, detector commissioning is on track
• Successful pilot beam data taking, data being exploited for alignment and first measurements
• Run 4 upgrades advancing at a good pace
• LoI of ALICE 3 submitted and reviewed by LHCC
• From charm baryon-to-meson ratio measurements, **charm fragmentation is not universal** across collision systems
  
  ➢ pp ratios enhanced compared to $e^+e^-$, $e^-p$, in particular at low $p_T$

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**Λ⁺/D⁰ production ratios versus multiplicity in pp collisions**

ALICE

**ALICE**

**pp, √s = 5 TeV**

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**ARXIV:2011.06078**

**ARXIV:2105.05187**

**ALICE Preliminary**

**pp, √s = 5 TeV, |y| < 0.5**

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**Δ: Λ⁺/D⁰ production ratios versus multiplicity in pp collisions**

**ALICE**

**pp, √s = 13 TeV**

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**PYTHIA 8.243, Monash 2013**

**PYTHIA 8.243, CR-BLC:**

Mode 0  Mode 2  Mode 3

SHM+RQM  Catania  QCM

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**PYTHIA 8**

Monash × BR  CR-BLC  Mode 2 × BR  Data  QCM × BR

**QCM**

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**BR(Ω⁺ → Ω π⁺) = (0.51 ± 0.07)% [EPJC 80, 1066 (2020)]**

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**09/03/2022**
**Nuclear modification factor of prompt $\Lambda^+ c$ consistent with unity up to 6 GeV/c, $\Lambda^+ c$ suppression for higher $p_T$**

- Similar $R_{AA}$ values between the two centrality classes

**Hint of larger $R_{AA}$ compared to D-meson average for central collisions in $6 < p_T < 12$ GeV/c range**

- **Hint of hierarchy of** $R_{AA}(\Lambda^+ c) > R_{AA}(D^+_s) > R_{AA}(D^0, D^+, D^{*+})$ points toward relevant impact of coalescence on charm hadron formation

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[Graph and plot showing $R_{AA}$ values for different centrality classes and $p_T$ ranges.]

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**ALICE**

Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV

Prompt $\Lambda^+_c$, $|y| < 0.5$

F. Colamaria – 149th LHCC meeting

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arXiv:2112.08156
• Production of (anti)nuclei as a function of multiplicity in pp collisions

• d/p and $^3$He/p results qualitatively described by coalescence model and SHM for canonic ensemble

• Discrepancies possibly related to system size determination
Isospin fluctuations in kaon sector, and their multiplicity dependence, sensitive to chiral phase transition

\[ v_{\text{dyn}} = R_{cc} + R_{00} - 2R_{c0} \]

Breaking of centrality scaling observed for \( v_{\text{dyn}}/\alpha \) not reproduced by models

No significant low-\( p_T \) enhancement observed, not supporting the production of disoriented chiral condensates (DCC)
• Measurement of inclusive charged jets production vs charged particle multiplicity in pp
  ➢ Better agreement with NLO models, compared to LO, though yields overestimated below 20 GeV/c

• From ratios of production cross sections at different $R$, stronger collimation for high-$p_T$ jets observed

• Self-normalised yields: faster-than-linear increase observed for all values of jet radius $R$
Recommissioning without beam is progressing well

- **MW2 (week 7):** first large testing focused on **detector calibrations**, with strong development and progresses
- MW approach extended with **Weekly Run Plans**
  - Plan activities by balancing detector standalone testing and exercise Central Systems to achieve long term stability
- **Global runs** done with cosmic data taking and synthetic running (unstable beam)

- Now possible to perform **CRU+CRORC** global runs
- Possibility to run with **intermittent error conditions** using incomplete TF building

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**Example:** 8.5h run with EMC (CRORC) + MFT + MID + TOF + TPC + TRD (CRU)