The Norwegian ALICE Program

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Outline

- The ALICE Experiment and Norwegian contributions.
- Physics Analysis.
- Instrumentation.
- Norwegian grid contribution.
The ALICE Experiment

A dedicated experiment for ultra-relativistic heavy-ion physics at the LHC.

≈1500 collaborators

- A central tracking system with particle identification.
- Time Projection Chamber (TPC), Inner tracking system (ITS).
- Time-of-Flight (TOF) for particle ID, partial EMCAL coverage
- Acceptance $|\eta| \leq 0.9$, $p_T > 100$ MeV/c
- A muon arm at forward rapidities $-4.0 < \eta < -2.5$.
  Triggering, tracking and identification of muons.
- Zero-Degree Calorimeters (ZDC) – 114 m from interaction point.
ALICE - Norway

Norwegian participation in ALICE since the beginning (1993).
Groups at University of Oslo, University of Bergen, Western Norway University of Applied Sciences, University of South-Eastern Norway.
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Main focus

Physics:
- Production of charm quarks/charmonium in heavy-ion collisions
  (Ionut Arsene (Oslo) convenor of Working Group Dileptons and quarkonia)
- Ultra-peripheral collisions, two-photon and photonuclear interactions
  (Joakim Nystrand (Bergen) convenor of Working Group Ultra-peripheral collisions.)
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Instrumentation (hardware, firmware, software):
- ALICE Inner Tracking System (ITS)
- Earlier also PHOS (high res. EMCAL) and High-Level Trigger (HLT) and TPC.

Computing:
- Operation of Tier-1 within the Nordic Datagrid Facility.
ALICE - Norway

Manpower in the groups

University of Oslo: 2 Professors (+1 emeritus), 40% of Senior Engineer, 2 postdocs, 2-3 PhD students.

University of Bergen: 4 Professors, 1 Researcher (grid computing), 50% of Senior Engineer, 2 postdocs, 2-3 PhD students.

Western Norway University of Applied Sciences: 3 professors. 1-2 PhD students.

University of South Eastern Norway: 2 professors.
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Grant from Norwegian Research Council – CERN related research

8.6 MNOK per year for 2016 – 2019
Covers ALICE M&O, Travel and subsistence, Computing grid, 2-3 postdocs.


ALICE share: 16 MNOK detector upgrade + 14.5 MNOK Tier-1 upgrade.
Ultra-relativistic Heavy-Ion Physics

The goal is to produce a long-lived (on a subatomic time scale), hot and dense state of matter in the laboratory and thus explore the nuclear phase diagram.

The nuclear phase diagram
Ultra-relativistic Heavy-Ion Physics

Early days (1980’s, 1990’s):

Search for Quark Gluon Plasma “Signals” to prove that a plasma has been produced.

One early signal: $J/\psi$ suppression.
Ultra-relativistic Heavy-Ion Physics

Today:
Study the Quark Gluon Plasma properties.

[No one seems to know exactly when this transition occurred.]
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Two key observations:

- Jet-quenching
  Suppression of particles with high $p_T$.
  Most likely explanation: gluon bremsstrahlung as the partons traverse the hot and dense medium produced in the collision.

- Collective flow
  Anisotropic particle production relative to the reaction plane. The pressure of the medium converts the initial spatial anisotropy into an isotropy in momentum space.

-The $J/\psi$ remains a key observable although the interpretation is a bit more complicated than initially foreseen.
Jet-quenching

Quantify the suppression by the $R_{AA}$ measure. Scaling pp data with the number of binary collisions expected from the nuclear geometry (Glauber model)

$$R_{AA}(p_T) = \frac{\left(1/ N_{EVT}\right) d^2 N_{AA}^{\pi^0} \big/ dp_T dy}{< T_{AB}(b) > \times d^2 \sigma_{pp}^{\pi^0} \big/ dp_T dy}$$

Expectation in absence of nuclear effects.
Jet-quenching

- Clear suppression at high transverse momentum ($p_T$) in central (head on) collisions.
- No or only very small suppression in peripheral collisions.

Jet-quenching

- $R_{AA}$ measured also for the J/$\psi$.
- Reduced J/$\psi$ suppression at low $p_T$, indicating regeneration of J/$\psi$ in the quark-gluon plasma.
Jet-quenching

- $R_{AA}$ as well for the $\Upsilon(1S)$.
- Data reproduced by hydrodynamical and transport models.

QGP-like signatures in pp collisions

- $J/\psi$ yield in pp collisions found to scale with multiplicity.

- Not reproduced by Pythia 6.

- Possible explanation: Multiple Parton Interactions.
QGP-like signatures in pp collisions

- Range extended in Run 2 data to $6 \times \langle \text{mean multiplicity} \rangle$.

- Same trend persists.
QGP-like signatures in pp collisions

- Range extended in Run 2 data to $6 \times \langle \text{mean multiplicity} \rangle$.

- Same trend persists.

- Models which include Multiple Parton Interaction give a reasonable description of the data.
Photoproduction in ultra-peripheral collisions

The EM fields correspond to an equivalent flux of photons.

These can lead to two-photon or photonuclear interactions in collisions where no hadronic interactions occur ($b>2R$).

Exclusive vector meson production ($\gamma+A \rightarrow V+A$) of particular interest as a probe of the gluon distribution $g(x,Q^2)$.
Two-photon production of lepton pairs at the LHC

Results on two-photon production of dilepton pairs measured by ALICE and ATLAS in complementary invariant mass ranges (0.5 < M_{inv} < 10 GeV/c^2 and 10 < M_{inv} < 100 GeV/c^2, respectively).

Find good agreement with leading order QED (STARLIGHT model) over nearly 9 orders of magnitude in cross section and more than two orders of magnitude in M_{inv}!
Two-photon production of lepton pairs at the LHC

Exclusive vector meson production

Exclusive production: \( \text{Pb+Pb} \rightarrow \text{Pb+Pb+J/\psi} \).
Underlying reaction: \( \gamma+\text{Pb} \rightarrow \text{Pb+J/\psi} \).

Nuclei remain intact.
Signal for coherent production when \( p_T(J/\psi) < 1/R \approx 50 \text{ MeV/c} \)

Provides a clear experimental signature:
- 2 tracks in an otherwise empty detector
- Very low \( p_T \).
Exclusive production: \[ \text{Pb}+\text{Pb} \rightarrow \text{Pb}+\text{Pb}+\text{J}/\psi. \]
Underlying reaction: \[ \gamma+\text{Pb} \rightarrow \text{Pb}+\text{J}/\psi. \]

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Provides a clear experimental signature:
- 2 tracks in an otherwise empty detector
- Very low \( p_T \).

- Nearly background free event sample
- Some irreducible, physical background from \( \gamma\gamma \rightarrow \mu^+\mu^- \).
Exclusive vector meson production

Cross section for coherent J/ψ production dependent on nuclear gluon distribution.

\[
\frac{d\sigma}{dt}\bigg|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xg(x, \frac{M_V^2}{4})\right]^2
\]

Uncertainty in nuclear gluon distribution translates into different cross section for photoproduction of J/ψ at mid-rapidity \((d\sigma/dy \propto [g(x,Q^2)]^2)\).

\[S_{Pb} = g_A(x,Q^2) /[A \cdot g_p(x,Q^2)]\]
Photoproduction in Semi-central collisions

- In a semi-central collision, photons can be emitted by (at least) the spectator parts.

- Not clear if only spectators contribute or all nucleons (fields are “frozen in”?).

- spectator and participant matter can act as target.

- In certain regions of phase space $\sigma$(electromagnetic) $\gg \sigma$(hadronic).
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- $p_T$ distribution of $e^+e^-$ pairs from $J/\psi \rightarrow e^+e^-$ in collisions with 70-90% centrality.

- A peak corresponding to coherent photoproduction is seen.
Photoproduction in Semi-central collisions

- Strong enhancement over hadronic production in the $0.0 < p_T < 0.3$ GeV/c range seen in $R_{AA}$.
- The cross section for photoproduction has been measured.
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Several open issues:

- What are the sources of the fields: spectator parts or spectator+participant parts?
- How can the slow moving photoproduced $J/\psi$ survive? It should be “eaten” by the expanding fireball.
- Can photoproduced $J/\psi$s be used to probe the Quark Gluon Plasma?
Norwegian instrumentation activities in ALICE

- The Norwegian contribution to ALICE instrumentation is in 2018 related to the ALICE Inner Tracking System (ITS) upgrade project.

- ITS has defined several Work Packages for its upgrade project. The most important ones for Norway is:
  - WP5 – ALPIDE testing and stave testing and characterisation
  - WP10 – Readout Electronics developments

- Norway has 5 PhD projects connected to ALICE ITS:
  - 2017 (3 yrs) -> Rune Langøy, University of South-Eastern Norway
  - 2017 (4 yrs) -> Qasim Waheed Malik, University of Oslo
  - 2016 (4 yrs) -> Simon Voigt Nesbø, Western Norway University of Applied Sciences
  - 2017 (4 yrs) -> Magnus Rentsch Ersdal, University of Bergen
  - 2018 (4 yrs) -> Shiming Yuan, University of Bergen

- In addition, several MSc projects have been defined as part of this instrumentation activity
ALICE Upgrades – Layout and key systems

New Inner Tracking System (ITS)
- CMOS Pixels
  → improved resolution, less material, faster readout

New Muon Forward Tracker (MFT)
- CMOS Pixels
  → vertex tracker at forward rapidity

New TPC Readout Planes
- 4-GEM detectors, new electronics
  → continuous readout

New trigger detectors (FIT, AD)
- Centrality, event plane

Upgrades readout for TOF, TRD, MUON, ZDC, Calor.

Integrated Online-Offline system (O²)
- Record minimum-bias Pb-Pb data at > 50kHz
  (currently ~ 1 kHz)
Readout Electronics

Detector Readout → 192 READOUT UNIT

Inner layer (0.1.2)
0.6 (1.2) Gb/s high speed data,
80 Mb/s clock and control

Outer layers (3.4.5.6)
400 Mb/s high speed data,
80 Mb/s clock and control

Each Readout Unit is connected to one stave
both for Inner and Outer Barrels

Central Trigger Processor

One way, passive optical splitting, no busy back

Identical Readout Units (RU) cover the full ITS

Data (320 Mb/s max)

Data (960 Mb/s max)

Data (3.6 Gb/s max)

Common Readout Unit & OZ

GBT optical

Control

GBT optical

Control

Data (9.6 Gb/s max)

2015-16 Readout Components radiation test and selection
Readout Prototype Board RUv0

2017 Readout Prototype Board RUv1: system integration (DAQ, trigger and DCS), integration with services

Readout Unit Production prototype
Jan-Apr 2018

Production Readiness Review
⇒ Apr 2018

Production & test
May-Dec 2018

Characterization ongoing

Engineering Design Review (Jan 2017)

L. Musa (CERN) – LHCC Referees Meeting, Feb 2018
WP5 – Stave Assembly and Testing

Norwegian participants:

• Shiming Yuan (June – September 2018)
• Magnus Rentsch Ersdal (September – November 2018)

• Tasks:
  • Test assembled staves (9 ALPIDEs stitched together on one PCB)
  • Assemble staves to build the full ITS inner barrel
• Highly challenging work as there are many fault signatures
WP10 – Design of full Readout Chain

• The Norwegian contribution to WP10 is:
  • Simulation of ALPIDE Busy situations
    • ALPIDE = The Active Pixel Sensor for the ALICE ITS upgrade
  • Radiation mitigation of Readout Unit
  • Specification and design of the Detector Control System for the ITS Frontend electronics
  • Integration and design of Common ReadOut Unit.
    • The Common ReadOut Unit is a generic HW platform that does all communication towards the Frontend electronics.
PbPb simulations (triggered mode) – Results

Average BUSY link fraction per trigger per layer

- Does not imply data loss

Average ABORT link fraction per trigger per layer

- 1% loss

Average BUSY Violation fraction per trigger per layer

- Worst case: Loss of data

(1.0 – BUSYV fraction) is essentially the efficiency per layer (assuming that ALPIDE frames lost due to BUSYV is a relatively accurate representation of data loss)

Note:
The statistics simulated has a large error, because only 20,000 events were simulated. At 50 kHz there is 0 BUSYV in layer 0, and 1 BUSYV each in layer 1 and 2.
Radiation Mitigation design

- The Radiation mitigation design is in the Microsemi Flash FPGA (PA3) on the ITS Readout Unit.
- It reads configuration files for the Xilinx Ultrascale from the local Flash device to do:
  - Initial configuration – Needed since the Ultrascale is volatile and must be configured on each power on.
  - Scrubbing – To correct single event upsets in the configuration memory of the Ultrascale.
- The additional challenge is that both the PA3 and the Flash device can experience single event effects.
  - This means that the design must be mitigated also here.
- The design has been proven to work according to specifications of the experiment, and has been qualified in irradiation campaigns.
Irradiation campaigns

- The norwegian team has participated in 4 irradiation campaigns to qualify the Readout Unit
  - CHARM (CERN) – Mixed field
  - CHIPIR (Rutherford Appleton Laboratory, Oxford) – Neutrons
  - THE NUCLEAR PHYSICS INSTITUTE (Prague) – Protons

- Result: Readout Unit behaves according to specs – some minor adjustments are needed.
ALICE Grid activities in Norway

- Part of Nordic Tier-1 centre operated by NeIC/NDGF
- 1 researcher + 1 system manager devoted to Tier-1 operations
- ALICE resources installed in Bergen (UiB)
- Norway represents around 50% of Nordic ALICE activities
- Currently installed in Bergen:
  - 6 kHEPSPEC06, 1 PB disk, 0.2 PB tape
  - Upgrade strongly needed – targets for 2019:
    - 13 kHEPSPEC06, 2.2 PB disk, 1.2 PB tape
- Computer upgrade financed through infrastructure grant
Grid research activities

- Centered at Western Norway University of Applied Sciences (3 staff, 1 PhD student)
- Use of cloud and virtualisation techniques in AliEn Grid
- Participate in development of jAliEn
  - (rewrite of AliEn in Java, next version of the ALICE grid environment)
Summary

- ALICE has taken and analyzed a huge amount of data during the last 8 years.

- Norway has participated in the construction, physics and data analysis.

- Current physics focus: Charmonium and ultra-peripheral collisions.

- Current hardware focus: Readout electronics for new Inner Tracking System.

- Reasonable funding of ALICE upgrade through 30 MNOK grant for “National Infrastructure”.