The ALICE experiment

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(heavily based on a presentation by Christoph Blume)

Hades Summer School,
Riezlern, September 2007
Outline

- Heavy ion physics at LHC
- ALICE detector setup
- Physics topics and performance
- Running plans
Sources of information

1995 ALICE Technical Proposal
CERN-LHCC 95-71

Physics Performance Report, Volume I

physics topics, LHC conditions, detector summary, computing

Physics Performance Report, Volume II

combined detector performance, event reconstruction
LHC experiments
physics questions at LHC

ATLAS, CMS, LHCb:
electroweak symmetry breaking
origin of mass of quarks and gauge bosons
supersymmetric particles
CP violation

ALICE:
chiral symmetry breaking
origin of mass of hadrons
deconfinement
hadronization

ALL:
understanding high energy nuclear interactions
(input needed for cosmic ray studies)
**ALICE programme**

**mission:**
create quark-gluon matter
study its properties quantitatively
be prepared for unexpected = be versatile

**methods:**
spectra and correlations of various particles
e.g. heavy quarks (open beauty, upsilon-states)
jets in heavy ion environment
weakly interacting probes (Z\(^0\), W\(^\pm\))

**special at LHC:**
higher energy density
larger system
more heavy quarks and jets
weak probes W/Z available
access to lower x

<table>
<thead>
<tr>
<th></th>
<th>SPS</th>
<th>RHIC</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sqrt{s}_{NN}) (GeV)</td>
<td>17</td>
<td>200</td>
<td>5500</td>
</tr>
<tr>
<td>(dN_{ch}/dy)</td>
<td>~450</td>
<td>~850</td>
<td>1500-4000</td>
</tr>
<tr>
<td>(\varepsilon) (GeV/fm(^3))</td>
<td>3</td>
<td>5</td>
<td>15-60</td>
</tr>
<tr>
<td>(\tau_{QGP}) (fm/c)</td>
<td>(\leq 2)</td>
<td>2-4</td>
<td>(\geq 10)</td>
</tr>
</tbody>
</table>
Kinematic Range at LHC

Physics at smaller $x$

Bulk physics: $10^{-4} < x < 10^{-3}$
Forward regions: $x \approx 10^{-5}$

Different initial state?
Saturation of gluons
Color Glass Condensate

$Q_{sat}^2 (x, A) \sim 1/Q^2$

$x_{1,2} = (M/\sqrt{s}) e^{\pm y}$

$M = 1\text{ TeV}$
$M = 100\text{ GeV}$
$y = 0$
$y = 2$
$y = 6$

$10^0$ $10^2$ $10^4$ $10^6$ $10^8$

$10^{-6}$ $10^{-4}$ $10^{-2}$ $10^0$ $x$

$M^2 \ (\text{GeV}^2)$
Detector Requirements

Robust tracking performance
   Needs to digest highest multiplicities (O(10^5) tracks !)

Need to cover low \( p_t \) region (\( \sim 100 \) MeV/c)
   Soft physics important for event characterization

But the high \( p_t \) region as well (>100 GeV/c)
   Hard probes transmit information about early phase

Good PID capabilities over large \( p_t \)-range essential
   Many effects are flavour dependent

Sensitivity to rare probes
   Heavy flavour, quarkonia, photons, ...
The Alice Collaboration

Some numbers:
Members: ca. 1000

1000th ALICE member

Universität Frankfurt
Universität Heidelberg
FZK Karlsruhe
FH Köln
Universität Münster
FH Worms
Alice Detector

- **PHOS**
  - $\gamma, \pi^0$

- **MUON**
  - $\mu$-pairs

- **HMPID**
  - PID (RICH) @ high $p_t$

- **TOF**
  - PID

- **TRD**
  - Electron ID

- **TPC**
  - Tracking, PID

- **ITS**
  - Vertexing
  - Low $p_t$ tracking

- **PMD**
  - $\gamma$ multiplicity

- **FMD, V0, T0, ZDC**
  - (not shown)
  - Trigger, multiplicity, centrality

- **EMCAL**
  - (not shown)
  - Jet-calorimetry

- **Height**: 16 m
- **Length**: 26 m
- **Weight**: 10,000 tons
- **Price**: 10 € / kg

Acceptance for Charged Hadrons

- **central barrel** -0.9 < $\eta$ < 0.9
  - ITS, TPC, TRD, TOF 2 $\pi$ tracking, PID
  - HMPID single arm RICH
  - PHOS single arm EM cal
  - EMCAL jet calorimeter (proposed)

- **forward muon arm** 2.4 < $\eta$ < 4
  - absorber, 3 Tm dipole magnet
  - 10 tracking + 4 trigger chambers

- **multiplicity** -5.4 < $\eta$ < 3
  - PMD including photon counting

- **trigger & timing**
  - FMD: silicon strip multiplicity det
  - T0: ring of quartz window PMT’s
  - V0: ring of scintillator paddles
  - 6 Zero Degree Calorimeters

![ALICE detector $\eta$ acceptance graph]
**Inner Tracking System (ITS)**

6 Layers with three different detector technologies:

- **Silicon Pixel Detector**
- **Silicon Drift Detector**
- **Silicon Strip Detector**

ITS = SPD + SDD + SSD

<table>
<thead>
<tr>
<th>Layer</th>
<th>R (cm)</th>
<th>$\sigma r_\phi$ (μm)</th>
<th>$\sigma Z$ (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SPD</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>SPD</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>SDD</td>
<td>15</td>
<td>38</td>
</tr>
<tr>
<td>4</td>
<td>SDD</td>
<td>24</td>
<td>38</td>
</tr>
<tr>
<td>5</td>
<td>SSD</td>
<td>38</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>SSD</td>
<td>43</td>
<td>17</td>
</tr>
</tbody>
</table>
## Inner Tracking System (ITS)

Longitudinal coverage:

\[ |\eta| < 1 \text{ (tracking), } |\eta| < 2 \text{ (multiplicity)} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pixels</th>
<th>Drifts</th>
<th>Strips</th>
</tr>
</thead>
<tbody>
<tr>
<td>radius (inner plane) cm</td>
<td>3.9</td>
<td>14.9</td>
<td>38.5</td>
</tr>
<tr>
<td>radius (outer plane) cm</td>
<td>7.6</td>
<td>23.8</td>
<td>43.6</td>
</tr>
<tr>
<td>cell size ((r \varphi \times z)) (\mu m^2)</td>
<td>50 \times 425</td>
<td>294 \times 150</td>
<td>95 \times 40000</td>
</tr>
<tr>
<td>resolution ((r \varphi)) (\mu m)</td>
<td>12</td>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>resolution ((z)) (\mu m)</td>
<td>100</td>
<td>23</td>
<td>730</td>
</tr>
<tr>
<td>max. occupancy (%)</td>
<td>2.1</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td>max. expected dose (10 years) (\text{krad})</td>
<td>250</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>total area (\text{m}^2)</td>
<td>0.2</td>
<td>1.3</td>
<td>4.9</td>
</tr>
<tr>
<td>total no. of channels</td>
<td>9.8 M</td>
<td>133 k</td>
<td>2.6 M</td>
</tr>
<tr>
<td>material budget (both layers) (% X_0)</td>
<td>2.06</td>
<td>1.89</td>
<td>1.78</td>
</tr>
</tbody>
</table>
Inner Tracking System (ITS)

Number of readout channels: $9.8 \times 10^6$

Material budget: $7\% X_0$

Support frame: carbon fiber

ITS as inserted in ALICE setup (15/3/07)
Silicon Pixel Detector (SPD)
Silicon Pixel Detector (SPD)

a sector

sector tests

carbon-fibre mechanics
ladder mounting
Silicon Strip Detector (SSD)
Time Projection Chamber (TPC)

Largest TPC ever built

Radius: 845 – 2466 mm
Drift length: 2 x 2500 mm
Drift time: 92 μs
Drift gas Ne–CO₂–N₂
Gas volume: 95 m³
557568 readout pads
Material: (η=0) 3% X₀
TPC assembly
Time Projection Chamber (TPC)

Lowering and insertion of ALICE TPC (15/01/07)
Time Projection Chamber (TPC)

TPC assembled and installed
- Commissioning on ground
- Performance according to design specifications
Ongoing:
- Installation of services
- Final commissioning until 11/2007

Cosmics event
May 2006
TPC laser event
**Transition Radiation Detector (TRD)**

**Purpose:**
- Electron-ID
- Quarkonia $\rightarrow e^+e^-$
- Heavy flavour

**Some numbers:**
- 540 chambers
- Total area: 736 m² (3 tennis courts)
- Gas volume: 27.2 m³
- Resolution $(r_\phi)$ 400 μm
- Number of read out channels: $1.2\times10^6$
Transition Radiation Detector (TRD)

Drift chamber
- Gas: Xe–CO₂
- Drift length: 3cm

Radiator
- Fiber/foam sandwich
  - PP, 17μm

$e/\pi$-discrimination $\sim 10^{-2}$
For 90% e-efficiency
first TRD supermodule
TRD
**TOF**

*Multi-gap resistive plate chambers (MRPC)*

- **gaps:** 10 x 250 μm
- **channels:** >8000 channels per SM
- **efficiency** 99.6%
- **resolution** $\sigma \approx 50$ ps
High Momentum Particle Id (HMPID)
High Momentum Particle Id (HMPID)

charged particle

container

$C_6F_{14}$ radiator

quartz window

collection electrode

$CH_4$

pad cathode covered with CsI film

MWPC

frontend electronics

Photon Spectrometer (PHOS)

- photons, neutral mesons, \(\gamma\)-jet tagging
- dense PbWO\(_4\) crystals \((X_0 < 0.9 \text{ cm})\) at -25°C
- \(\sim 18k\) channels, 8m\(^2\)

**good energy resolution**
- stochastic: 2.7%/\(\sqrt{E}\)
- noise: 2.5%/E
- constant: 1.3%
Forward Muon Spectrometer (MUON)

... aka Muon Arm

Absorber

Tracking chambers

Magnet

Filter

Trigger chambers
Dipole Magnet

Bending power: 3Tm
dimuon spectrometer
forward detectors

TO C

V0 A

FMD

PMD

+ ACORDE (cosmics)
forward detectors

V0

T0
**even more forward: Zero Degree Calorimeters (ZDC)**

6 calorimeters:
EM ....... 8 m from IP
ZP ..... 116 m from IP
ZN ..... 116 m from IP

trigger on spectators
measurement of v1
Hierarchical architecture
L0, L1, L2, and HLT

High Level Trigger (HLT)
Online reconstruction using ~500–600 PCs + FPGAs
Input rate 200Hz (central Pb–Pb) → up to 20 GByte/s
Generate physics trigger (e.g. jets, Upsilon, D⁰, ...)
Online data compression
Calibration tasks

Trigger

Collision
L0: Trigger detectors detect collision (V0/T0, PHOS, SPD, TOF, MUON trigger chambers)
L1: select events according to
  • centrality
  • high-\(p_t\) di-muons
  • high-\(p_t\) di-electrons (TRD)
  • high-\(p_t\) photons (PHOS/EMCAL)
  • jets (EMCAL)
L2: reject events due to
  • past/future protection

HLT: rejects events containing
  • no J/\(\psi\), \(\Upsilon\)
  • no D⁰
  • no high-\(p_t\) photon
  • no high-\(p_t\) \(\pi^0\)
  • no jet, di-jet, \(\gamma\)-jet

\(t [\mu\text{sec}]\)
<table>
<thead>
<tr>
<th>Number</th>
<th>L0 (Pb–Pb)</th>
<th>L0 (pp)</th>
<th>L1 (Pb–Pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V0 minimum bias</td>
<td>V0 minimum bias</td>
<td>TRD unlike $e$ pair high $p_T$</td>
</tr>
<tr>
<td>2</td>
<td>V0 semi-central</td>
<td>V0 high multiplicity</td>
<td>TRD like $e$ pair high $p_T$</td>
</tr>
<tr>
<td>3</td>
<td>V0 central</td>
<td>V0 beam gas</td>
<td>TRD jet low $p_T$</td>
</tr>
<tr>
<td>4</td>
<td>V0 beam gas</td>
<td>T0 right</td>
<td>TRD jet high $p_T$</td>
</tr>
<tr>
<td>5</td>
<td>T0 vertex</td>
<td>T0 left</td>
<td>TRD electron</td>
</tr>
<tr>
<td>6</td>
<td>PHOS MB</td>
<td>T0 vertex</td>
<td>TRD hadron low $p_T$</td>
</tr>
<tr>
<td>7</td>
<td>PHOS jet low $p_T$</td>
<td>PHOS MB</td>
<td>TRD hadron high $p_T$</td>
</tr>
<tr>
<td>8</td>
<td>PHOS jet high $p_T$</td>
<td>PHOS jet low $p_T$</td>
<td>ZDC 1</td>
</tr>
<tr>
<td>9</td>
<td>EMCAL MB</td>
<td>EMCAL MB</td>
<td>ZDC 2</td>
</tr>
<tr>
<td>10</td>
<td>EMCAL jet high $p_T$</td>
<td>EMCAL MB</td>
<td>ZDC 3</td>
</tr>
<tr>
<td>11</td>
<td>EMCAL jet med $p_T$</td>
<td>EMCAL jet high $p_T$</td>
<td>ZDC special</td>
</tr>
<tr>
<td>12</td>
<td>EMCAL jet low $p_T$</td>
<td>EMCAL jet med $p_T$</td>
<td>Topological 1</td>
</tr>
<tr>
<td>13</td>
<td>Cosmic Telescope</td>
<td>EMCAL jet low $p_T$</td>
<td>Topological 2</td>
</tr>
<tr>
<td>14</td>
<td>DM like high $p_T$</td>
<td>Cosmic Telescope</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>DM unlike high $p_T$</td>
<td>DM like high $p_T$</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>DM like low $p_T$</td>
<td>DM unlike high $p_T$</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>DM unlike low $p_T$</td>
<td>DM like low $p_T$</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>DM single</td>
<td>DM unlike low $p_T$</td>
<td>DM single</td>
</tr>
<tr>
<td>19</td>
<td>TRD pre-trigger</td>
<td>TRD pre-trigger</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
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<td>23</td>
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<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### DAQ

<table>
<thead>
<tr>
<th>Detector</th>
<th>pp (kB)</th>
<th>Pb–Pb (MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITS Pixel</td>
<td>0.140</td>
<td></td>
</tr>
<tr>
<td>ITS Drift</td>
<td>1.8</td>
<td>1.500</td>
</tr>
<tr>
<td>ITS Strips</td>
<td>0.160</td>
<td></td>
</tr>
<tr>
<td>TPC</td>
<td>2450.0</td>
<td>75.900</td>
</tr>
<tr>
<td>TRD</td>
<td>11.1</td>
<td>8.000</td>
</tr>
<tr>
<td>TOF</td>
<td>0.180</td>
<td></td>
</tr>
<tr>
<td>PHOS</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HMPID</td>
<td>0.120</td>
<td></td>
</tr>
<tr>
<td>MUON</td>
<td>0.150</td>
<td></td>
</tr>
<tr>
<td>PMD</td>
<td>0.120</td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td>0.120</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2500</td>
<td>86.500</td>
</tr>
</tbody>
</table>

### Event Size (byte)

![Event Size Diagram](image)

### Scenario 1

<table>
<thead>
<tr>
<th>Scenario 1 Rates (Hz)</th>
<th>Scenario 2 Rates (Hz)</th>
<th>Scenario 3 Rates (Hz)</th>
<th>Scenario 4 Rates (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>DAQ</td>
<td>Level 2</td>
<td>DAQ</td>
</tr>
<tr>
<td>Central</td>
<td>$10^3$</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Minimum-bias</td>
<td>$10^4$</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Dielectron</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Dimuon</td>
<td></td>
<td>1000</td>
<td>650</td>
</tr>
</tbody>
</table>

**Total throughput (MB s⁻¹)**

1250 1400 1400 700

*19-Sep-2007 The ALICE experiment, D. Miskowiec, Hades Summer School 2007*
Data processing aka offline

![Diagram of data processing]

- Monte Carlo
- Hits
- Dis-integrated Detector response
- Digits
- Raw data
- Comparison
- Track candidates
- Track segments
- Reconstructed space points
- Particles

19-Sep-2007  The ALICE experiment, D. Miskowiec, Hades Summer School 2007  44
Aliroot
Grid
$p_t > 1 \text{ GeV}$
Efficiency

Approaches TPC acceptance (90%)

Only very little dependence on track multiplicity

Momentum resolution

Long lever arm

ITS + TPC + TRD

(4cm < r < 3700cm)

\[ \frac{\delta p_t}{p_t} \leq 5\% \]

at \( p_t = 100 \text{ GeV/}c \)

and \( B = 0.5\text{T} \)
**PID Capabilities**

- **TPC + ITS (dEdx)**
  - $\sigma(dEdx) = 5.5(\text{pp}) - 6.5(\text{Pb-Pb})\%$

- **TOF**
  - $\sigma < 100\text{ ps}$

- **TRD**
  - $\pi$ suppression $\approx 10^{-2} @ 90\% \text{ e–efficiency}$

**ALICE Estimates (mid-rapidity)**

- **Mesons**
  - $D^0$
  - $K^0_s$, $K^\pm$

- **Baryons**
  - $\Omega$, $\Lambda$, $\Xi$, $\Lambda$ (anti-$\Lambda$)

**Particle Distribution**

- $p (\text{GeV/c})$
- $p_T (\text{GeV/c})$

**Graphical Data**

- $\pi/K$
- $K/p$
- $e/\pi$
- $\gamma/\pi^0$
- $\mu/\pi$
Soft physics

hyperons

300 Hijing evts

13 recons. $\Lambda$/event

$\Lambda$ invariant mass (GeV/c$^2$)

Counts

K*(892)$^0$ K $\pi$
15000 central Pb-Pb

resonances

Counts

Invariant mass (GeV/c$^2$)

1 event : 5000 $\pi$

event-by-event HBT

C(q inv)

$q$ inv (GeV/c)

Day 1 @ LHC: event multiplicity at y=0

- generic trends in $dN^{ch}/d\eta$
  - extended longitudinal scaling
  - self-similar trapezoidal shape

$$dN^{ch}/d\eta \bigg|_{\eta=0} \propto \ln\sqrt{s_{NN}}$$

- Saturation models predict

$$\frac{1}{N_{\text{part}}} \left. \frac{dN^{AA}}{d\eta} \right|_{\eta=0} = N_0 \sqrt{s}^\lambda \frac{N_{\text{part}}^{1-3\lambda}}{N_{\text{part}}}$$

$$dN^{\text{LHC}}/d\eta \bigg|_{\eta=0} \approx 1650$$

Extrapolations to LHC deviate from so-far generic trends in data

Impact for understanding the dynamical origin of soft physics at RHIC and LHC.
LHC tests the hydro-paradigm

- Hydro prediction for low LHC multiplicity
  \[ \nu_2 \approx 0.055 \]

- Extrapolation of generic RHIC trend
  \[ \nu_2 \approx 0.075 \]

Also consistent with Teaney et al., nucl-th/0110037

(In)consistency with generic trend

Characterization of microscopic dynamics underlying collectivity
Open charm and beauty

goal: measure parton energy loss in QGP

effectuation: energy loss color dependent (different for quarks and gluons)

dependent energy loss flavour dependent (smaller for heavy quarks)

advantage at LHC: high abundance of c and b (direct reconstruction possible)

RHIC: Non-photonic electrons used to estimate charm

<table>
<thead>
<tr>
<th>System</th>
<th>p+p</th>
<th>Pb+Pb (5% cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{s_{NN}}$ (TeV)</td>
<td>14</td>
<td>5.5</td>
</tr>
<tr>
<td>NN cross section (mb)</td>
<td>11.2/0.5</td>
<td>6.6/0.2</td>
</tr>
<tr>
<td>Shadowing</td>
<td>---</td>
<td>0.65/0.85</td>
</tr>
<tr>
<td>Total multiplicity</td>
<td>0.16/0.007</td>
<td>115/4.6</td>
</tr>
</tbody>
</table>
Open charm and beauty – detection channels

Open charm:
\[ D^0 \to K^- + \pi^+ \quad (c \tau = 123 \, \mu\text{m}, \text{BR} = 3.8 \%) \]
See next slides
\[ D^+ \to K^- + \pi^+ + \pi^+ \quad (c \tau = 312 \, \mu\text{m}, \text{BR} = 9.5 \%) \]
Pb+Pb (central): \( S/B \approx 0.1, S \approx 10^4 \, D^+ \) in 10^7 central events
\[ D \to e^\pm (\mu^\pm) + X \]
\[ D_{s}, ... \]

Open beauty:
\[ B \to e^\pm (\mu^\pm) + X \quad (c \tau \approx 500 \, \mu\text{m}, \text{BR} = 10.9 \%) \]
\[ ( + B \to D (\to e^\pm (\mu^\pm) + X) + X', \text{BR} \approx 10\%) \]
See next slides
\[ B \to J/\psi \, (+ X) \to e^+e^- \quad (c \tau \approx 500 \, \mu\text{m}, \text{BR} = 0.07 \%) \]
...

Impact parameter reconstruction

e.g.: $D^0 \rightarrow K^-\pi^+$

Impact parameters $\sim 100 \mu m$

Central Pb+Pb
**D mesons**

Example: $D^0 \rightarrow K^- \pi^+$

- Full reconstruction of $D$-decays
- Separation of charm and beauty
- $S/B \approx 10\%$
- Significance $\approx 40$
  (1 month Pb+Pb running)
- Similar in $p+p$

![Diagram of D meson decay with $D^0 \rightarrow K^- \pi^+$ and distribution plots for Pb+Pb and p-Pb at different energies.]
**B mesons**

Example: $B \rightarrow e^{\pm} + X$

- e–Identification: TRD
- Impact parameter: ITS

Impact parameter cut:
- $d_0 > 200 \ \mu m$, $p_t > 2 GeV/c$
- $\rightarrow 80\%$ purity
- $\rightarrow 8 \times 10^4$ $e^{\pm}$ from B’s
in central Pb+Pb
(1 month Pb+Pb running)
Quarkonia in dielectron channel

Central barrel

ITS+TPC+TRD

$-0.9 < \eta < 0.9$

e-ID with TRD

Resolution:

$\sigma_m(J/\psi) \approx 30\text{MeV}$

$\sigma_m(\Upsilon) \approx 90\text{MeV}$

Di-electron in central barrel

<table>
<thead>
<tr>
<th>State</th>
<th>$S \times 10^3$</th>
<th>$B \times 10^3$</th>
<th>S/B</th>
<th>S/$\sqrt{S+B}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi$</td>
<td>110.7</td>
<td>92.1</td>
<td>1.2</td>
<td>245</td>
</tr>
<tr>
<td>$\Upsilon$</td>
<td>0.9</td>
<td>0.8</td>
<td>1.1</td>
<td>21</td>
</tr>
<tr>
<td>$\Upsilon'$</td>
<td>0.25</td>
<td>0.7</td>
<td>0.35</td>
<td>8</td>
</tr>
</tbody>
</table>
MUON–arm

Forward region 2.4 < \eta < 4.0

Resolution:
\sigma_{m}(J/\psi) \approx 70\text{MeV}
\sigma_{m}(\Upsilon) \approx 100\text{MeV}

Sensitivity
\( (e^+e^-/\mu^+\mu^-) \)

J/\psi, \Upsilon, \Upsilon' : High with normal stat.
\Upsilon'' : Needs 2–3 years high lum.
\psi' : Difficult

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>J/\psi</td>
<td>130</td>
<td>680</td>
<td>0.20</td>
<td>150</td>
</tr>
<tr>
<td>\Psi'</td>
<td>3.7</td>
<td>300</td>
<td>0.01</td>
<td>6.7</td>
</tr>
<tr>
<td>\Upsilon(1S)</td>
<td>1.3</td>
<td>0.8</td>
<td>1.7</td>
<td>29</td>
</tr>
<tr>
<td>\Upsilon(2S)</td>
<td>0.35</td>
<td>0.54</td>
<td>0.65</td>
<td>12</td>
</tr>
<tr>
<td>\Upsilon(3S)</td>
<td>0.20</td>
<td>0.42</td>
<td>0.48</td>
<td>8.1</td>
</tr>
</tbody>
</table>

1 month Pb–Pb

0 < b < 3 fm

\begin{align*}
\text{Resolution:} \\
\sigma_{m}(J/\psi) & \approx 70\text{MeV} \\
\sigma_{m}(\Upsilon) & \approx 100\text{MeV}
\end{align*}

Sensitivity
\( (e^+e^-/\mu^+\mu^-) \)

J/\psi, \Upsilon, \Upsilon' : High with normal stat.
\Upsilon'' : Needs 2–3 years high lum.
\psi' : Difficult
Jets

- jet suppression
- fragmentation function
- jets in high multiplicity environment
- calorimetry or charged tracks

<table>
<thead>
<tr>
<th>1 month of running</th>
<th>E_T &gt;</th>
<th>N_jets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 GeV</td>
<td>2.0 x 10^7</td>
</tr>
<tr>
<td></td>
<td>100 GeV</td>
<td>1.1 x 10^6</td>
</tr>
<tr>
<td></td>
<td>150 GeV</td>
<td>1.6 x 10^5</td>
</tr>
<tr>
<td></td>
<td>200 GeV</td>
<td>4.0 x 10^4</td>
</tr>
</tbody>
</table>
jets in p+pbar at 1.8 TeV
CDF, PRD 64 (2001) 032001

jets in Pb+Pb at 5.5 TeV (ALICE sim)

\[ R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} \]
jets with an EM calorimeter (CDF)

jets with charged particles (ALICE ITS+TPC+TRD)

fraction of jet energy in form of charged particles
Jets with ITS, TPC, TRD – TRD trigger

trigger condition:
3 charged particles with $p_T > p_T\text{min}$ in one TRD module
Jets with EMCAL

- **EM Sampling Calorimeter** - latest addition to ALICE by US, France, Italy

- **Pb-scintillator linear response**
  - $-0.7 < \eta < 0.7$
  - $60^\circ < \phi < 180^\circ$

- **Energy resolution** $\sim 15\%/\sqrt{E}$
Jets with both

Response to jet with $E_T = 100\text{GeV}$

\begin{itemize}
\item $\Delta E/E \sim 50\%$
\item $\Delta E/E \sim 30\%$
\end{itemize}
Jet fragmentation function

Sensitive to energy loss mechanisms
- Quenching of leading hadron
- Additional hadrons by gluon radiation
- Transverse heating

Observable:
- Ratio of fragmentation functions: \[ \frac{FF(Pb+Pb)}{FF(p+p)} \]

Annual ALICE run statistics
\( E_{\text{input}} \approx 175 \text{ GeV} \)
\( \langle \hat{q} \rangle = 50 \)

\[ \xi = \ln \left( \frac{1}{z} \right) = \ln \left( \frac{E_{\text{jet}}}{p_{\text{hadron}}} \right) \]
Photons

**PHOS - thermal photons** ($p_t < 5\text{GeV/c}$)

**EMCAL - high energy photons**

**Central Barrel - $\gamma \rightarrow e^+e^-$**

<table>
<thead>
<tr>
<th>Detector</th>
<th>$p_t^{\text{max}}$ (1 year) (GeV/c)</th>
<th>$\gamma$</th>
<th>$\pi^0$</th>
<th>High-$p_t$ trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHOS</strong></td>
<td>~100 (shower shape)</td>
<td>~150</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td><strong>EMCAL</strong></td>
<td>~150 (shower shape)</td>
<td>~200</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td><strong>Central Barrel</strong></td>
<td>~20 ($\gamma \rightarrow e^+e^-$)</td>
<td>-</td>
<td>✔️</td>
<td></td>
</tr>
</tbody>
</table>
Interactions at energies typical to cosmic rays
### LHC machine parameters

<table>
<thead>
<tr>
<th></th>
<th>pp</th>
<th>Pb–Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy per nucleon (TeV)</td>
<td>7</td>
<td>2.76</td>
</tr>
<tr>
<td>$\beta$ at the IP: $\beta^*$ (m)</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>R.m.s. beam radius at IP: $\sigma_t$ ($\mu$m)</td>
<td>71&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.9</td>
</tr>
<tr>
<td>R.m.s. bunch length: $\sigma_l$ (cm)</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>Vertical crossing half-angle ($\mu$rad) for</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pos. (neg.) $\mu$-spectr. dipole polarization</td>
<td>150 (150)</td>
<td>150 (100)</td>
</tr>
<tr>
<td>No. of bunches</td>
<td>2808</td>
<td>592</td>
</tr>
<tr>
<td>Bunch spacing (ns)</td>
<td>24.95</td>
<td>99.8</td>
</tr>
<tr>
<td>Initial number of particles per bunch</td>
<td>$1.1 \times 10^{11}$</td>
<td>$7.0 \times 10^7$</td>
</tr>
<tr>
<td>Initial luminosity (cm$^{-2}$ s$^{-1}$)</td>
<td>$&lt;5 \times 10^{30}$</td>
<td>$10^{27}$ &lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> For low-intensity runs $\beta^*$ could be 0.5 m and $\sigma_t = 15.9 \mu$m as in Pb–Pb.

<sup>b</sup> Early operation will be with 62 bunches and $\beta^* = 1$ m, which yields an initial luminosity of $5.4 \times 10^{25}$ cm$^{-2}$ s$^{-1}$. 
### ALICE running conditions

<table>
<thead>
<tr>
<th>System</th>
<th>$\sqrt{s_{NN}}_{\text{max}}$ (TeV)</th>
<th>$\Delta y$</th>
<th>$\sigma_{\text{geom}}$ (b)</th>
<th>$\mathcal{L}_{\text{low}}$ (cm$^{-2}$ s$^{-1}$)</th>
<th>$\mathcal{L}_{\text{high}}$ (cm$^{-2}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb–Pb</td>
<td>5.5</td>
<td>0</td>
<td>7.7</td>
<td>$1.0 \times 10^{27}$</td>
<td></td>
</tr>
<tr>
<td>Ar–Ar</td>
<td>6.3</td>
<td>0</td>
<td>2.7</td>
<td>$2.8 \times 10^{27}$</td>
<td>$1.0 \times 10^{29}$</td>
</tr>
<tr>
<td>O–O</td>
<td>7.0</td>
<td>0</td>
<td>1.4</td>
<td>$5.5 \times 10^{27}$</td>
<td>$2.0 \times 10^{29}$</td>
</tr>
<tr>
<td>N–N</td>
<td>7.0</td>
<td>0</td>
<td>1.3</td>
<td>$5.9 \times 10^{27}$</td>
<td>$2.2 \times 10^{29}$</td>
</tr>
<tr>
<td>$\alpha\alpha$</td>
<td>7.0</td>
<td>0</td>
<td>0.34</td>
<td>$6.2 \times 10^{29}$</td>
<td></td>
</tr>
<tr>
<td>dd</td>
<td>7.0</td>
<td>0</td>
<td>0.19</td>
<td>$1.1 \times 10^{30}$</td>
<td></td>
</tr>
<tr>
<td>pp</td>
<td>14.0</td>
<td>0</td>
<td>0.07</td>
<td>$1.0 \times 10^{29}$</td>
<td>$5.0 \times 10^{30}$</td>
</tr>
<tr>
<td>pPb</td>
<td>8.8</td>
<td>0.47</td>
<td>1.9</td>
<td>$1.1 \times 10^{29}$</td>
<td></td>
</tr>
<tr>
<td>pAr</td>
<td>9.4</td>
<td>0.40</td>
<td>0.72</td>
<td>$3.0 \times 10^{29}$</td>
<td></td>
</tr>
<tr>
<td>pO</td>
<td>9.9</td>
<td>0.35</td>
<td>0.39</td>
<td>$5.4 \times 10^{29}$</td>
<td></td>
</tr>
<tr>
<td>dPb</td>
<td>6.2</td>
<td>0.12</td>
<td>2.6</td>
<td>$8.1 \times 10^{28}$</td>
<td></td>
</tr>
<tr>
<td>dAr</td>
<td>6.6</td>
<td>0.05</td>
<td>1.1</td>
<td>$1.9 \times 10^{29}$</td>
<td></td>
</tr>
<tr>
<td>dO</td>
<td>7.0</td>
<td>0.00</td>
<td>0.66</td>
<td>$3.2 \times 10^{29}$</td>
<td></td>
</tr>
<tr>
<td>$\alpha\text{Pb}$</td>
<td>6.2</td>
<td>0.12</td>
<td>2.75</td>
<td>$7.7 \times 10^{28}$</td>
<td></td>
</tr>
<tr>
<td>$\alpha\text{Ar}$</td>
<td>6.6</td>
<td>0.05</td>
<td>1.22</td>
<td>$1.7 \times 10^{29}$</td>
<td></td>
</tr>
<tr>
<td>$\alpha\text{O}$</td>
<td>7.0</td>
<td>0.00</td>
<td>0.76</td>
<td>$2.8 \times 10^{29}$</td>
<td></td>
</tr>
</tbody>
</table>
ALICE general running plans

**initial phase**

- pilot Pb+Pb
- 1-2 years Pb+Pb
- 1 year p+Pb (or like)
- 1-2 years Ar+Ar

**subsequent options**

- pp at sqrt(s) = 5.5 TeV
- N+N or O+O or Kr+Kr...
- another pA
- lower energy Pb+Pb
- high stat full energy Pb+Pb
Subject: Fermilab Statement on LHC Magnet Test Failure
From: Robert Aymar <Robert.Aymar@cern.ch>
Date: 03/29/07 17:53
To: cern-staff (List of all staff members at CERN) <cern-staff@cern.ch>,
users (CERN Users) <users@cern.ch>,
cern-fellows (list of fellows presently at CERN) <cern-fellows@cern.ch>

Dear Colleagues,

On Tuesday evening 27 March 2007, there was an incident during a pressure test involving one of the LHC's inner triplet magnet assemblies provided by Fermilab and KEK. No people were involved. The consequences of the incident on the LHC start-up schedule are not yet known. Details are available in a statement from Fermilab, with which CERN is in agreement, at


Regards,

Robert Aymar
July 20, 2007 — Inner Triplet Successfully Completes Pressure Test

An inner triplet assembly of quadrupole magnets at Point 8-Right of the LHC at CERN successfully completed a pressure test in the accelerator tunnel on Friday, July 13. The triplet, which included three quadrupole magnets and the associated cryogenic and power distribution box, or DFBX, met all test specifications at the requisite pressure of 25 atmospheres for one hour. The triplets will focus particle beams prior to particle collisions at each of four interaction regions in the Large Hadron Collider, now under construction at CERN.

The pressure test is designed to test the accelerator components in conditions that will occur during LHC operations. To withstand the asymmetrical forces generated by the pressure, the Q1 and Q3 magnets, at either end of the triplet assembly had each been fitted with a set of four metal cartridges. The cartridges reinforce internal support structures that broke in two such magnets during an earlier pressure test on March 27. The cartridges limit movement of the magnets inside their metal jackets, or cryostats.

Metal brackets attach the cartridges to one end of each of the affected magnets. The cartridges have a compound design consisting of an aluminum alloy tube and an Invar rod to allow them to function over a broad range of temperatures. Invar is a form of steel whose dimensions change very little in response to temperature differences.
LHS schedule as of Aug-2007
ALICE status Sep-2007

ACORDE: installed. DAQ, DCS, ECS connection ongoing

EMCAL: support ready to be installed.

FMD: 2/3 installed

HMPID: installed, going to measure cosmics

MUON: nearly completely installed

PHOS: first module under test with cosmics on the surface, installed in Nov

SDD: installed, tests ¾ done.

SPD: installed, electronics tests

SSD: installed, electronics tests and debugging
ALICE status Sep-2007

TOF: sm0 and sm8 installed, cosmics

TPC: parking position because of ITS, long term electronics tests

TRD: sm8 installed, sm0 soon ready to be installed

T0: C-side installed (electronics not yet). A-side installed in Jan

V0: C-side installed (electronics not yet). A-side integrated with FMD3 in Oct, installed in Jan

ZDC: first ZDC installed, second one being installed now

Startup configuration for 2007:

complete ITS, TPC, HMPID, MUON arm, PMD, V0, T0, ZDC, Accorde

partial PHOS(1/5), TOF(9/18), TRD (2-3/18), DAQ (20%)
Summary

Heavy ion physics will do a big step ahead with LHC startup
  Era of precision measurements of the QGP matter

ALICE will be ready for data taking with the first pp run
  Experimental setup is multi-purpose and flexible

Summary of *foreseen* ALICE physics:
  ALICE Physics Performance Report, Vol. II,
The End
$\mu^+\mu^- e^+e^-$
Expected performance on $D, B R_{AA}$

**colour charge dependence**

$$R_{D/h}(p_t) = R_{AA}^D(p_t)/R_{AA}^h(p_t)$$

**mass dependence**

$$R_{B/D}(p_t) = R_{AA}^{e \text{ from } B}(p_t)/R_{AA}^{e \text{ from } D}(p_t)$$

1 year at nominal luminosity
(10$^7$ central Pb-Pb events, 10$^9$ pp events)