First Physics
with ALICE

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International School of Nuclear Physics, 30th Course, Erice, 20 Sep 2008
overheated supermagnet

the most expensive experiment of the world is broken
Prospects for First Physics with ALICE

- commissioning without beam
- first pp running
- early heavy ion physics

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Start-up Configuration 2008

- **complete** - fully installed & commissioned
  - ITS, TPC, TOF, HMPID, MUONS, PMD, V0, T0, FMD, ZDC, ACORDE, DAQ

- **partially completed**
  - TRD (25%) to be completed by 2009
  - PHOS (60%) to be completed by 2010
  - HLT (30%) to be completed by 2009
  - EMCAL (0%) to be completed by 2010/11

- at start-up full hadron and muon capabilities
- partial electron and photon capabilities
Overall Plan

- **commissioning phase (ongoing since February)**
  - fully commission trigger, DAQ, ECS
  - align and calibrate the entire system
  - use of beam gas interactions (10 Sep 08)

- **first pp run (on the verge of being started)**
  - important pp reference data for heavy ions
  - minimum bias running
  - unique pp physics to ALICE

- **early heavy ion run (10^6 s @ 1/20 luminosity - 10d 2009)**
  - establish global event characteristics
  - bulk properties (thermodynamics, hydrodynamics…)
  - start of hard probe measurements
Alignment of Inner Tracking System (ITS)

Silicon Pixel Detector (SPD):
- ~10M channels
- 240 sensitive vol. (60 ladders)

Silicon Drift Detector (SDD):
- ~133k channels
- 260 sensitive vol. (36 ladders)

Silicon Strip Detector (SSD):
- ~2.6M channels
- 1698 sensitive vol. (72 ladders)

ITS total: 2198 alignable sensitive volumes → 13188 d.o.f.
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ITS Russian Dolls - Sliding the SSD/SDD over the SPD

TPC

SPD

SSD/SDD
ITS tracking of cosmics: at IP2: $p > 10$ GeV/c, $<p> \sim 20$ GeV/c (Hebbeker, Timmermans, 2001)
- expect $10^4 \mu$/wk in ITS
- uses L0 SPD FastOR trigger ($\varepsilon=81\%$ w. 97\% purity)
- robustness tested with “extreme” misalignment scenarios
- provides partial alignment (5 weeks -> SPD - order 10 $\mu$m)
- $d_0$ resolution measurement via two-track matching of cosmics

\[ \sigma_{d_0} = 12 \mu m \]

\[ \sigma_{d_0} = 21 \mu m \]
resolution of $d_0$ is the key parameter for the reconstruction of weak decays of D- and B-mesons

decay length: $c\tau = 300$-$500\ \mu m \ (D^\pm)$, $c\tau = 124\ \mu m \ (D^0)$
laser system for drift velocity determination and ExB-measurement
100 samples, each with ~2300 tracks (fitted and extrapolated)
60-70 $\mu$m precision in x and y, 30 $\mu$m – in z
initial requirement: better than 100 $\mu$m
< 0.05 mrad precision on rotation angles
initial requirement: better than 0.1 mrad
TPC - The Largest Ever

- radius: 85 cm – 247 cm
- length: 2x2.5 m
- gas: Ne/CO₂ (90/10) 88 m³
- drift time: 88 μs (500 bins)
- #channels: 560,000
- 560 million pixels
- max. trigger rate: 200 Hz
- 180 space points/track
  (σₓ,ᵧ,ᵣ<500μm)
- can handle up 15000 tracks
tracking efficiency at small $p$

- robust and redundant tracking from ~100 MeV to 100 GeV
- $\delta p/p < 5\%$ at 100 GeV
- in conjunction with excellent particle ID

$\text{dN}_{\text{ch}}/\text{dy} = 6000$

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Actual TPC Performance (I)

tracking cosmics in magnetic field

Krypton gain calibration

C. Garabatos, M. Ivanov, A. Kalweit
Actual TPC Performance (II)

particle ID
5\times10^6 cosmics
Kr calibration

cosmics

momentum resolution
ALICE detector performs very well in pp
- very low momentum cutoff (<100 MeV/c)
- new $x_T$-regime ($10^{-5}$)
- $p_T$-reach up to 100 GeV/c
- comparison to other experiments
- excellent particle identification
- efficient min. bias trigger

First physics in ALICE will be pp
- provides important "reference" data for heavy ion program

Unique pp physics in ALICE e.g.
- multiplicity distribution
- baryon transport
- measurement of charm cross section
- major input to pp QCD physics

Start-up
- some collisions at 900 GeV
  $\rightarrow$ connect to existing systematics

PP nominal run
- $\int \mathcal{L} dt = 3 \cdot 10^{30} \text{cm}^{-2} \text{s}^{-1} \times 10^7 \text{s}$
  30 pb$^{-1}$ for pp run at 14 TeV
  $N_{pp\text{ collisions}} = 2 \cdot 10^{12}$ collisions
- muon triggers:
  $\sim 100\%$ efficiency, $< 1$ kHz
- electron trigger:
  $\sim 25\%$ efficiency of TRD L1
- min. bias triggers:
  20 events pile-up (TPC)
  $N_{pp\text{ minb}} = 10^9$ collisions
Day 1 - Charged Particle Acceptance

ALICE detector $\eta$ acceptance

- operating with fast multiplicity trigger L0 from Silicon Pixels
- efficiency studied for
  - single diffractive
  - double diffractive
  - non-diffractive events
previous experiments triggered on and published non-single-diffractive events (NSD)

- ALICE will measure full inelastic cross section

\[
\sigma_{\text{total}} = \sigma_{\text{elastic}} + \sigma_{\text{non-diffractive}} + \sigma_{\text{single-diffractive}} + \sigma_{\text{double-diffractive}}
\]

\[
\text{insensitive}
\]

**ALICE trigger**

- ND-INEL: 98.2%
- SD: 55.4%
- DD: 58.4%
Charged Particle Multiplicity

- extend existing energy dependence
- unique SPD trigger (L0) for min. bias precision measurement
- new look at fluctuations in pp (neg. binomials, KNO…)

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Only a few ten thousand events are necessary for these analyses
First Strange Particle Studies

- based on Pythia for LHC
- significant samples of strange particles in 70 million minimum bias events:
  - $K^0: 7 \times 10^6$
  - $\Lambda: 7 \times 10^5$
  - $\Xi: 2 \times 10^4$
  - $\Omega: 270$
- detailed study of flavor composition

<table>
<thead>
<tr>
<th></th>
<th>$K^0_s$</th>
<th>$\Lambda$</th>
<th>$\Xi$</th>
<th>$\Omega$</th>
<th>$p$</th>
<th>$\bar{p}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>yield per event</td>
<td>0.1</td>
<td>0.01</td>
<td>$2 \times 10^{-4}$</td>
<td>$10^{-5}$</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

$\Lambda^*(1520) \rightarrow pK$
Baryon - Antibaryon Asymmetry

- experimental challenge: distinguish between the two pictures
  - baryon number transport via quark exchange
  - baryon number transport via string junction exchange
    

- large rapidity gap at LHC (> 9 units)

- predicted absolute value of the second case ~ 3-7%

- additional prediction: asymmetry multiplicity dependent

\[ A = 2 \cdot \frac{N_B - N_{\overline{B}}}{N_B + N_{\overline{B}}} \]

- systematic error of asymmetry below 1% for $p > 0.5$ GeV/c: contributions from uncertainties in the cross sections, material budget, beam gas events
- statistical error < 1% for $10^6$ pp events (< 1 day)
- can be extended to $\Lambda, \overline{\Lambda}$ (asymmetry larger)
Heavy Flavor Precision Measurements

- $D^0 \rightarrow K + \pi$ in $pp$ from reconstructed secondary vertices
- $B \rightarrow e + X$ in $pp$ (depends on initial TRD overage)

- Expected sensitivity in comparison to different pQCD parameterizations (from $10^9$ events)
Heavy Flavor in Muon Channel

- muon channel: $J/\psi$, $Y \rightarrow \mu^+\mu^-$
  - $(2.5 < y < 4)$
  - 60000 $J/\psi$ and 2000 $Y$
- initial sample sufficient to study production rates of $J/\psi$ and $Y$ states in muon channel

- $b \rightarrow \mu$

**pp @ 14 TeV**

- $dN_{b}/dp_T$ (GeV$^{-1}$c$^{-1}$) vs $p_T$ (GeV/c)
  - All $\mu^\pm$
  - Beauty $\mu^\pm$
  - Charm $\mu^\pm$
  - $W\mu^\pm$
  - $Z\mu^\pm$

**$J/\psi$**

- $N_{\mu}$ (counts) vs $M_{\mu\mu}$ (GeV/c$^2$)

**$Y$**

- $N_{\mu}$ (counts) vs $M_{\mu\mu}$ (GeV/c$^2$)
Heavy Ion Physics with ALICE

- fully commissioned detector and trigger
  - alignment and calibration available from pp
- first 10⁵ events: global event properties
  - multiplicity, rapidity density
  - collective flow
- first 10⁶ events: source characteristics
  - particle spectra, resonances
  - differential flow analysis
  - interferometry
- first 10⁷ events: high p_t, heavy flavors
  - jet quenching, heavy flavor energy loss
  - charmonium production
- yield bulk properties of created medium
  - energy density, temperature, pressure
  - heat capacity/entropy, viscosity, sound velocity, opacity
  - susceptibilities, order of phase transition

early ion scheme

- 1/20 of nominal luminosity
- \( \int L dt = 5 \cdot 10^{25} \text{ cm}^{-2} \text{ s}^{-1} \times 10^6 \text{ s} \)
  - 0.05 nb\(^{-1}\) for PbPb at 5.5 TeV
  - \( N_{\text{PbPb collisions}} = 2 \cdot 10^8 \text{ collisions} \)
  - (400 Hz)
- muon triggers:
  - \( \sim 100\% \) efficiency, < 1kHz
- centrality triggers:
  - bandwidth limited
  - \( N_{\text{PbPb minb}} = 10^7 \text{ events (10Hz)} \)
  - \( N_{\text{PbPb central}} = 10^7 \text{ events (10Hz)} \)
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Estimated Charged Particle Multiplicity Density

Integrated multiplicity distributions from Au+Au/Pb+Pb collisions and scaled p+p collisions

- ALICE designed (before RHIC) for $dN_{ch}/dy = 3500$
- Design checked up to $dN_{ch}/dy = 7000$

$dN_{ch}/dy = 2600$
- Saturation model
Eskola hep-ph/050649

$dN_{ch}/dy = 1200$
- $\ln(\sqrt{s})$ extrapolation


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Elliptical Flow - Day 1 Physics

- Data increase linearly
- Hydrodynamical limit reached at RHIC → ‘ideal fluid’
- Clear predictions from hydrodynamics
- Sensitive to equation-of-state

- Very robust signal - no PID necessary
- Event plane resolution < 10°
with part of the event removed displaced vertices can be seen

$\Xi^- \rightarrow \Lambda \pi^-$
Reconstruction of Resonances
\( (\rho, \phi, K^*, K_0^0, \Lambda, \Xi, \Omega \ldots) \)

10^7 events:
- \( p_t \) reach \( \phi, K, \Lambda \)
  - \( \sim 13\text{-}15 \text{ GeV} \)
- \( p_t \) reach \( \rho, \Xi, \Omega \)
  - \( \sim 9\text{-}12 \text{ GeV} \)

300 central events
\( \Lambda \)
13 \( \Lambda/\text{evt} \)

\( \rho^0(770) \rightarrow \pi^+\pi^- \)
10^6 central Pb-Pb
Mass resolution
- \( \sim 2\text{-}3 \text{ MeV} \)

\( \phi(1020) \rightarrow K^+K^- \)
Mass resolution
- \( \sim 1.2 \text{ MeV} \)

- hadrochemical analysis
- chemical / kinetic freeze-out

- medium modifications of mass, widths
Multiplicities at LHC allow for measurement of event-by-event fluctuations

\(<p_T>, T, \text{ multiplicity, particle ratio, strangeness, azimuthal anisotropy, long range correlations, balance function, …}\)

Fluctuations are associated with phase transition

4\textsuperscript{th} moment of the net charge

Lattice computations at small chemical potential (S. Ejiri, F. Karsch, K. Redlich)

Resolution \(\sigma_T/T\): 0.5 % for \(\pi\)
Jet Production at LHC

10^7 events

- first measurement up to 100 GeV (untriggered charged jets only)
- detailed study of fragmentation possible
- sensitive to energy loss mechanism
- accuracy on transport coefficient <^q> ~20%

<table>
<thead>
<tr>
<th>p_t jet &gt; (GeV/c)</th>
<th>jets/event Pb+Pb</th>
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<tbody>
<tr>
<td>5</td>
<td>3.5 10^2</td>
</tr>
<tr>
<td>50</td>
<td>7.7 10^-2</td>
</tr>
<tr>
<td>100</td>
<td>3.5 10^-3</td>
</tr>
<tr>
<td>150</td>
<td>4.8 10^-4</td>
</tr>
<tr>
<td>200</td>
<td>1.1 10^-4</td>
</tr>
</tbody>
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Annual ALICE run statistics

- <E_{input}>~125 GeV
- Pb+Pb 0-10%: <p_t>~50
- p+p norm

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- compare these cross sections to pp cross sections $\rightarrow R_{AA}$
- energy loss of c,b quarks in medium

\[ \text{error decomposition} \]

\[ \frac{d^2 \sigma_{NN}}{dp_T dy} \text{ [mb/(GeV/c)]} \]

Pb-Pb, $\sqrt{s_{NN}} = 5.5$ TeV
B $\rightarrow$ e+X

- stat $\pm$ syst error
- stat error

10$^7$ events (full TRD)
11% from overall normalization not included

Relative error on beauty [%]

- statistical
- cross-section norm.
- tot. $p_T$-dep. syst.
- syst. from MC corr.
- syst. from charm subtr.
Transition Radiation Detector (TRD)

- 540 modules \(\rightarrow \sim 760\text{m}^2\)
- length: 7m
- \(X/X_0 \sim 21\%\)
- 28 m\(^3\) Xe/CO\(_2\) (85:15)
- 65 kW LV power
- 1.2 million channels
- 30 million pixels

- electron ID in central barrel \(p>1\text{ GeV/c}\)
- fast trigger for high momentum particles

processing of track segments
local tracking on each chamber:

- 275000 CPUs process 65 MB of data from track segments within 6.5 \(\mu\text{s}\)
- search electron pairs
Charmonia via Di-Electron Measurement

- electron ID with TPC and TRD
- expect 2500 $\Upsilon$ per PbPb year with good mass resolution and S/B

Simulation: $2 \cdot 10^8$ central PbPb collisions
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ALICE (Di)-Muon Spectrometer

- Dipole magnet
- Muon chambers
- Muon absorber
- Muon filter
Quarkonia Suppression ($\mu$-Channel)

Suppression depends on $T_D/T_C$

- Suppression 1
  - Quenched QCD $T_C=270$ MeV

- Suppression 2
  - Unquenched QCD $T_C=190$ MeV

$J/\Psi$:
- Excellent sensitivity to different suppression scenarios stat. err~5%

- If production enhanced compared to pp direct signal for deconfinement
- $J/\Psi$ produced via stat. hadronization

Andronic et al., PLB in print
Summary & Outlook

- **commissioning phase**
  - fully commission trigger, DAQ, ECS
  - align and calibrate the entire system
  - further use of beam gas interactions

- **first pp run**
  - important pp reference data for heavy ions
  - unique physics to ALICE
    - minimum bias running
    - fragmentation studies
    - baryon number transport
    - heavy flavor cross sections

- **first few heavy ion collisions**
  - establish global event characteristics
  - important bulk properties

- **first long heavy ion run**
  - quarkonia measurements
  - jet suppression studies
  - flavor dependences

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**Outlook**

- **high luminosity heavy ion running (1nb⁻¹)**
  - dedicated high $p_t$ electron triggers
  - jets > 100 GeV (EMCAL)
  - $Y$ - states
  - $\gamma$ - jet correlations
  - ...

- **pA & light ion running**