Future Perspectives of ALICE

and

Plans for ALICE upgrades

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Outline

- ALICE Performance in p+p collisions
- Possible plan for LHC operation
- Prospects of ALICE in Pb+Pb collisions
- ALICE upgrade plan, physics for upgrades and timeline
  - Completion of EMCAL/TRD
  - Trigger Plan
  - DCAL
  - VHM PID
  - ITS-vertex
  - FoCAL
- Summary and Outlook
ALICE Performance in $p+p$

ALICE demonstrated wide capabilities to measure soft & hard probes.
“Possible” Plan of LHC Operation

Studying QGP Era (MB)

2010 (official) - $\sqrt{s_{NN}} = 2.76 \text{ TeV Pb + Pb (4 weeks) } L \sim 10^{25} \text{ cm}^{-2}\text{s}^{-1}$
2011 (anticipated) - $\sqrt{s_{NN}} = 2.76 \text{ TeV Pb + Pb (4 weeks) } L \sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$
2012 (official) - Shutdown for maintenance, installation & repair
2013 - $\sqrt{s_{NN}} = 5.5 \text{ TeV Pb + Pb, } L \sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$
2014 - $\sqrt{s_{NN}} = 5.5 \text{ TeV Pb + Pb, } L \sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$

Control experiments

2015 - 6 month shutdown – LINAC 4 / Collimation / RF & detector upgrade
   - $\sqrt{s_{NN}} = 8.8 \text{ TeV } p + \text{Pb & Pb + p}, (\text{lighter A + A, p + p})$
2016 - $\sqrt{s_{NN}} = 5.5 \text{ TeV lighter A + A, p + p}$
2017 - 9 month shutdown – IR detector upgrade
   - $\sqrt{s_{NN}} = 5.5 \text{ TeV lighter A + A, p + p}$

Detail Studying Era (high L, p+A, light A+A, E-scan)

2018 - $\sqrt{s_{NN}} = 5.5 \text{ TeV high L Pb + Pb for hard probe physics}$
2019 - $\sqrt{s_{NN}} = 5.5 \text{ TeV high L Pb + Pb for hard probe physics}$
2020 - 6-12 month shutdown – …. upgrades
ALICE Prospects in Pb+Pb

- **ALICE Potential in (First) Pb + Pb collisions**
  - Collect $\sim 1.5 \times 10^7$ (2010) – $3 \times 10^8$ (2011) MB events
    - Global event properties ($10^5$ Pb + Pb events)
      - Multiplicity, charged particle spectra, elliptic flow,
    - Space-time evolution ($10^6$ Pb + Pb events)
      - Identified spectra/flow, resonances, particle ratio, correlation,
    - high-pT, Jets and heavy favors ($10^7$ Pb + Pb events)
      - Energy loss, color screening
**ALICE Upgrade plans (2013~)**

- Mid/long-term upgrade plans to enrich the physics capabilities
- **On going upgrades:**
  - Completion of TRD, PHOS, EMCal
  - Di-jet Calorimeter (DCAL)
- **Future**
  - TPC fast readout upgrade using C\textsubscript{F}4 gas/electronics
  - Very high momentum particle identification (VHMPID)
  - 2\textsuperscript{nd} generation of vertex detectors (ITS)
  - Forward Calorimeter (FoCAL)
  - Backward Tracking vertex detectors before muon arm
  - DAQ/HLT Upgrade (DDL-SIU interface, new IO bus, etc)
### Timeline for the Upgrade

- **Timeline for the upgrades**
  - (of course, the schedule could be changed…)

<table>
<thead>
<tr>
<th>Year</th>
<th>EMCAL/TRD/PHOS</th>
<th>DCAL</th>
<th>VHMPID</th>
<th>ITS upgrade</th>
<th>FOCAL</th>
<th>TPC</th>
<th>DAQ</th>
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**(Legend)**
- Full installation
- Partial installation
- Ready
Full detectors will be ready in 2013
- EMCAL 3 \(\rightarrow\) 10
- TRD 7 \(\rightarrow\) 18
- PHOS 3 \(\rightarrow\) 5

Acceptance Increase
- Jets: x 2-3
- High pT and single electron by TRD: x2.5
- Quarkonia: x 7
Possible Trigger plan for ALICE

- Minimum Bias: “V0OR” or “SPD”
- Rare Trigger:
  - Centrality trigger: SPD
  - High pT Trigger: TRD, HMPID, VHMPID
  - Jet Trigger: EMCAL, PHOS, DCAL
  - Electron/Quarkonia Trigger: TRD
  - Ultra-peripheral: TOF, TRD
- High Level Trigger:
  - High multiplicity
  - High pT particle (two particle), jets
  - Invariant mass
  - High pT J/psi
  - High pT open charm
Di-Jet Calorimeter

- 60% extension of EMCal acceptance
- Incorporate PHOS and DCAL modules to produce a single, large EM calorimeter patch back-to-back with EMCal.

\[ \Delta \eta \times \Delta \phi = 1.4 \times 0.7 \]

Project Institution

Catania, CERN, Frascati, Grenoble, INFN, Jyväskylä, Nantes, Strasbourg, Tsukuba, ORNL, LBNL, Yale, Huston, LANL, Wuhan
Physics for DCAL

- Study of the parton energy loss by taking the correlation with EMCAL
  - $\gamma$-jets: quark jets
  - di-jets, $\pi^0$-jets: mostly gluon jets
  - controllable variable: “Path length”
Physics Performance of DCAL

- Improve jet energy balance
  - Balance = \((E_1 - E_2) / 0.5 \times (E_1 + E_2)\)

- Annual yield
  - Up to 100 GeV in \(\pi^0\)-jets and di-jets
  - Up to 30 GeV in \(\gamma\)-jets

\[ Q_{\text{hat}} = \begin{cases} 
0 \text{ GeV/\(\text{fm}\)} & 
Q_{\text{hat}} = 20 \text{ GeV/\(\text{fm}\)} & 
Q_{\text{hat}} = 50 \text{ GeV/\(\text{fm}\)} & 
10^3 & 
\end{cases} \]
DCAL production

- 1 SM in Tsukuba
- Infra preparation is on going.
- Beamtest of EMCAL-Tower at CERN (PS/SPS on Aug. 2011)

Assembled in Japan/Italy

Assembled in Grenoble/Nantes
VHMPID-Physics

- Study of flavor dependence of particle production in A+A
  - Energy loss for quark/gluon jets
  - Modification of hadronization
  - PID tagged jet tomography

- Extension of PID capability
  - Upgrade based on HMPID
  - Installation in ~2015

Project Institution
CERN, Chicago, Yale, Pusan, Eotvos Univ., KFKI, INFN Bari, Puebla, ICN(Mexico), Univ. Mexico MEX
Focusing RICH with spherical (or parabolic) mirrors
- $C_4F_{10}$ gas radiator $L=80$ cm, $\gamma_{th} \sim 19$
- Photon detector baseline option:
  - MWPC with CsI photocathode
  - Thick-GEM with CsI photo-converter
- High $p_T$ trigger development

*Graphs showing momentum vs number of photons for different energies and particle types.*

- $\pi$, $K$, $p$

- ~3 $\sigma$ separation

- Cut on no. of photons
**Vertex detector upgrade**

- **x2 Improve the impact parameter resolution**
  - x100 increase in charm sensitivity
  - access to charmed baryons
  - exclusive B decays and total B production cross section down to $P_T \sim 0$
  - Improve flavor tagging.

- **Thinner/smaller beam pipe**
  - $r=2.9\text{ cm} \rightarrow 1.3\text{ cm}$, $\Delta r=800\text{ um} \rightarrow 400\text{ um}$

- **New pixel technology**
  - 6->7 layers, replace SDD -> SPD
  - Thinner ($<200\text{ um} + 150\text{ um}$)
  - Higher granularity ($<150\text{ um} \times 450\text{ um}$)
  - “Hybrid active pixel detectors” or
  - “Monolithic active pixel detectors (MAPS/MIMOSA/LePIX)”
**Forward Calorimeter**

- **Forward Physics at LHC**
  - Parton PDF in proton/nuclei at small \(-x\)
    - Gluon Shadowing
    - Gluon Saturation, CGC
  - Elliptic Flow in A+A
  - Long-Range rapidity correlation:
    - Ridge phenomena

- **Important information for the initial stage of collisions/thermalization.**
  - Initial state/Glasma formation

- **Fully exploit the opportunity offered by the LHC to access the small-x region & large saturation scale by going to forward rapidity.**
Results from RHIC

- Some hints from RHIC for CGC
  - Forward hadron production in d+Au
  - De-correlation of recoil jets in d+Au
  - Suppression of away side of e-mu correlation in d+Au (mu@small-x)
  - Suppression of forward J/psi in d+Au

- Important to measure photon/π0 from hard process at forward rapidity
Motivation of FoCAL

- $(x, Q^2)$ map covered by FoCAL
- Measurement items
  - $\pi^0$, prompt $\gamma$ at $\eta=3\sim4(5)$ in $p+p/p+A$
  - $\pi^0$-jets or dijets in $p+p/p+A$
  - Inclusive photons/ $\pi^0$ (in $A+A$)
- Stage 1 ($z=3.5m, 2.5<\eta<4.5$) in 2015
- Stage 2 ($4.5<\eta<6$) in 2020.

Project Institution
CNS Tokyo, Yonsei, Kolkata, Mumbai, Jammu, Utrecht/Amsterdam, Prague Jyväskylä, Copenhagen, Bergen, Oak Ridge, Nantes, Jaipur
**Detector R&D**

- **Segmented EM (W+Si) Calorimeter**
  - 21 layers (~21X₀) of W (~3.5mm) + Si pad (~1x1cm²)
  - Si strip for $\gamma/\pi^0$ separation
  - Fine pixel readout and digital readout (MAPS, MIMOSA)
  - ~300 towers in total

- Simulation/R&D are on going.

One tower config. (9cm x 9cm x ~10cm)

- Size: 9x9 cm²
- Thickness: 535µm
- Pad size: 1.1x1.1 cm²
- Number of pads: 64
**Summary and Outlook**

- **ALICE** has a powerful potential for the study of QGP in heavy ion collisions.
  - Successfully commissioned and excellent performance in p+p collisions. Ready to explore “a new QGP world”!!
- **ALICE** started working for detector upgrades to enrich the physics capabilities.
  - Mid-term plan
    - Completion of TRD/EMCAL
    - Di-jet calorimeter
  - Long-term plan
    - Very High Momentum Particle ID
    - Inner Vertex Tracker
    - Forward Calorimeter
- Stay tuned the outcomes from LHC-ALICE!!
Back up slides
Simulation Study

Occupancy in p+Pb (z=450)

- Longitudinal shower shape
- PID and rejection
- Linearity
- Energy Resolution

- π^0 reco. vs.
- 2γ separation
- (1.5x1.5 cm^2 pad)
- → 10% acc. for
- p_T = 10 GeV & η = 3.5

1x1cm^2, 1.5x1.5cm^2

Y. Hori (Nov. 7)

Linearity

Si 0.525 mm, 1 cm × 1 cm pad, 3 × 3 cluster

- W 4.5 mm: \( \frac{20.79}{\Delta E} + 0.6149\% \)
- W 4.0 mm: \( \frac{19.55}{\Delta E} + 0.4343\% \)
- W 3.5 mm: \( \frac{17.93}{\Delta E} + 0.4014\% \)
Si tracker upstream of muon Absorber (NA60)
  - charm vs K, π decays
  - reduce combinatorial (ψ’, …)
  - J / ψ from B

Presently under study:
  - matching to muon tracks,
  - tracking performance
ALICE, in a nutshell

- ALICE is dedicated to the studies with heavy ion collisions at LHC
- Powerful tracking capability with ITS and TPC
- Various PID devices:
  - TOF
  - HMPID
  - TRD
- EM calorimeter:
  - PHOS, EMCAL
  - No intention to have hermetic energy measurement
- Muon spectrometer

"First Results from ALICE", presented in HES10 Symposium  Aug. 12, 2010
~1000 members from ~100 institutes from ~30 countries

Capital cost = ~150 MCHF (+ ‘free’ L3 magnet)

History
- 1990 - 1996: Design
- 1992 - 2002: R&D
- 2000 - 2010: Construction
- 2002 - 2007: Installation
- 2008 ~ : Commissioning

3 subsystems added:
- 1996 : muon spectrometer
- 1999 : TRD
- 2006 : EMCAL

"First Results from ALICE", presented in HESI10 Symposium  Aug. 12, 2010
Performance studies: window material vs transparency, efficiency [%]

Detector parameters

- C4F10 T (85 cm)
- CaF2 T (5 mm)
- mirror T
- CH4 T (5 mm)
- CsI QE
- total efficiency (CaF2)
- SiO2 T (5 mm)
- total efficiency (SiO2)

Simulation, 16 GeV/c pion, SiO2

Pad size (8x8) + ring radius → photons geometrical overlap

<table>
<thead>
<tr>
<th>Window</th>
<th>N_{rp}</th>
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<td>SiO2</td>
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<tr>
<td>CaF2</td>
<td>10</td>
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</tbody>
</table>

Upgrade Forum - VHMPID 28/06/10
Theoretical estimate of single contributions (errors) to single photon Cherenkov angle resolution:

### SiO₂, ΔE = 6-7.75 eV

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Error (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ_θ chromatic</td>
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<tr>
<td>σ_θ emission</td>
<td>0.5</td>
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<tr>
<td>σ_θ pixel</td>
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<tr>
<td>σ_θ total</td>
<td>2.1</td>
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<tr>
<td>N_{rp}</td>
<td>~ 7.3</td>
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</tbody>
</table>

σ_θ track = σ_θ total / √N_{rp} [mrad] ~ 0.8

### CaF₂, ΔE = 6-8.8 eV

<table>
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<th>Error (mrad)</th>
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<td>σ_θ chromatic</td>
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<td>σ_θ pixel</td>
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<tr>
<td>σ_θ total</td>
<td>2.3</td>
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<tr>
<td>N_{rp}</td>
<td>~ 10</td>
</tr>
</tbody>
</table>

σ_θ track = σ_θ total / √N_{rp} [mrad] ~ 0.8

With 8x8 mm² pads: similar σ_θ track
3σ particle separation

Theoretical estimate of needed angular resolution to achieve 3σ particle separation:

\[
\sigma_\theta \approx \frac{m_2^2 - m_1^2}{\sqrt{N_{rp} \cdot 2n_\sigma p^2 \tan \theta}}
\]

Signal (GeV/c) | Absence of signal (GeV/c)
---|---
π | 4-24
K | 11-24
p | 19-38 | 11-17

Lower limit: cut \( N_{rp} \geq 2 \)
Upper limit: 3σ separation
CaF$_2$ vs SiO$_2$

- At saturation with 8x8 mm$^2$ pads: equivalent performance
- The error from pad size is dominant, a smaller pad size would allow:
  - to go up in momentum and improve PID efficiency
  - separation of close rings
- Close to threshold CaF$_2$ is clearly an advantage; effect on contamination and efficiency to be checked with MC
- Study of pad size and window to be continued with simulations + beam tests
10x10 cm prototype layout: Triple Thick GEM with CsI coated top element, CaF₂ window Cherenkov radiator, pad readout

Goals of the tests:
- Gas mixture % optimization (Ne/CH₄)
- HV settings/gain optimization
- FEE setting for readout of e⁻ induced signal
- Response of CsI layer evaporated on TGEM
- Prove working principle: simultaneous detection of single UV photons (Cherenkov radiation) and MIPs

Front end electronics (Gassiplex + ALICE HMPID R/O + DATE + AMORE)
Protons (mis-)ID below threshold

Reconstructed Cherenkov angle distributions for the same number of protons, kaons and pions in Pb-Pb HIJING background, “cleaning” by cut on photons content and threshold on cluster charge (photons ~ 40 ADC, MIP ~ 600 ADC)

Efficiency of identification vs momentum for $\pi$, $K$ and $p$ in progress

$~3\sigma$ separation!
Present 6 detector layers based on three silicon technologies:

- SPD (Si pixels)
- SDD (Si drifts)
- SSD (Si strips)

Unique level-zero trigger (fast OR)

Radii: 4, 7, 15, 24, 39, and 44 cm
Total material budget ~ 7%X₀ (normal incidence)
Beam pipe: radius = 3 cm, thickness = 800 µm

LHC beam interaction Sept. 12, 2008
R&D phase: 2010-2013/14

- Explore two Pixel technologies:
  - Hybrid pixel detectors: “state of the art”
    - low cost bump-bonding
    - new sensor type (3D, edgeless planar)
    - further thinning (SPD: 200 µm sensor + 150 µm FEE)
  - Monolithic pixel detectors: Mimosa and LePix
    - larger detector areas at considerably lower cost

- Layout Studies and Technical Design report

Production and pre-commissioning: 2014-2016

Installation and commissioning: 2018-2019
(aim for layer-0 installation in 2016)
Goal: a monolithic detector in standard very deep submicron CMOS technology

Advantages: cost, material budget (50 um thickness), yield, low noise, high granularity (10x10 um), radiation hard, low power consumption (20 mW/cm²)

Disadvantages: Charge collection by drift, serial readout

R&D activities: MIMOSA and LePix

- LePix: non-standard processing on high resistivity substrate
  - Advanced CMOS deep submicron technologies (130 nm and beyond) can be implemented on \( \geq 100 \ \Omega \text{cm} \) (\(~30 \mu m\) depletion at 100 V)

- MIMOSA: 'traditional' monolithic detectors, MAPS-based with serial readout
  - P-type low-resistivity Si hosting n-type "charge collectors"
    - signal created in epitaxial layer (low doping)
      \( Q \sim 80 \text{ e-h/mm} \rightarrow \text{signal} \leq 1000 \text{ e}^- \)
    - charge sensing through n-well/p-epi junction
    - excess carriers propagate (thermally) to diode
  - Prototype: MIMOSA-22, binary output, integrated zero-suppression, 18.4\( \mu \text{m} \) pitch, 1152 columns x 576 rows, \(~110 \mu \text{s}\) readout time
Monolithic Sensors

- **Active Pixel sensor**
  - Hybrid Active Pixel Sensor (HAPS)
    - Bump bonding (limitation of granularity), $C_{\text{para}}$
  - Monolithic Active Pixel Sensor (MAPS), Silicon On Insulator (SOI)
    - Integration of electronics on the same sensor substrate. No mechanical bonding
    - Many R&D projects for ILC, sLHC, RHIC

- (ex) MIMOSA looks promising
  - extremely high granularity digital chip
  - 18 µm pitch pixels with integrated readout and zero suppression algorithm
  - readout time $\approx 120$ µs
  - How to cope with our requirements?
    - High power? Radiation tolerance?
    - dynamic range?
    - More info coming.

chip size 1.73x1.73 cm²
Challenging and exciting topic
  - How to describe the transition from perturbative CGC (coherent color gauge field) to non-perturbative QGP (incoherent partons).
  - How the hard process at LHC (98%) plays in the game?

Crossing time
- RHIC: ~0.13fm/c
- LHC: ~0.01fm/c

Existence of coherent color field
- "Glasma", $\tau_f \sim 1/Q_s \sim 0.1$fm (at RHIC)
- Anisotropy in momentum space ($pt \sim Q_s$, $pz \sim 1/\tau$)

Plasma instability (decay of coherent field, de-coherent particle) or Hawking-Unruh radiation, hard particles + soft fields interaction

Equilibration time
- "Boltzmann-like kinetic process", particle-particle scattering
We will see many interesting results ($R_{AA}$, $v2$, correlation ...) and properties of the medium (ideal fluidity) at LHC.

Next important step will be surely studying:

- How the system is thermalized?
  - What is the initial condition? CGC?
  - How the transition occurs from weakly coupled CGC to strongly coupled QGP?
    - Glasma, hard partons + soft field interaction, transport kinetics

Motivation of forward physics

- Gluon Saturation (CGC), Gluon PDF at small–$x$
- Glasma and instability, pre–thermalization
- (Medium properties at forward – boost invariance)
Interesting measurement items at forward

> Some hints from RHIC
> Studying gluon PDF and gluon saturation (CGC)
  > high pT charged hadrons
  > di–jet angular correlation
  > Heavy Quark(onium) production
  > Prompt photons
  > Multiplicity

> Studying glasma, instability, pre–thermalization
  > This is not so easy to study in experiments. But some of the observables are worthwhile to be measured.
  > Multiplicity and multiplicity correlation with rapidity gap
  > Ridge (hard/soft ridge) in A+A
  > Di–leptons/photons
Simulation Study

Inclusive $\gamma$ 8.8TeV $p$+$Pb$
4.5m away from collision point

Energy Resolution

Linearity

Si 0.525 mm, 1 cm x 1 cm pad, 3 x 3 cluster

- $W$ 4.5 mm: $\frac{20.79}{\sqrt{E}} + 0.6149\%$
- $W$ 4.0 mm: $\frac{19.55}{\sqrt{E}} + 0.4343\%$
- $W$ 3.5 mm: $\frac{17.93}{\sqrt{E}} + 0.4014\%$

$1x1\text{cm}^2$

$\pi_0$ reco. vs. $2\gamma$ separation (1.5x1.5 cm$^2$ pad) $\rightarrow$ 10% acc. for $p_T = 10$ GeV & $\eta = 3.5$

$100$ GeV/c

$\gamma$ 88.78 %

$\pi^+$ 0.32 %
By Invariant mass method using Si Pad detector

Probability that two $\gamma$ go into neighboring pad. Probability that two $\gamma$ go into same pad.

Reconstruction efficiency
Reconstruction efficiency with energy asymmetry cut (<0.8).

$\pi^0$ up to 70 GeV ($p_T=7$ at $\eta=3$) can be measured by invariant mass method. For the $\pi^0$ with more than $E>70$ GeV, we have to use alternative method.
High Energy $\pi^0 \rightarrow 2\gamma$ kinematics

- Minimum $2\gamma$ distance at FOCAL
  - 12mm for 100 GeV $\pi^0$
  - 6mm for 200 GeV $\pi^0$
- $2\gamma$ distance from 100 - 200 GeV $\pi^0$ is constant for energy asymmetry < 0.8.
- Position measurement of $2\gamma$ by Si Strip detector and merged energy measurement by Si Pad detector are useful to identify $\pi^0$. 

![Graph showing $2\gamma$ distance vs. $\pi^0$ energy at 4.5 m away from IP](image1)

![Graph showing $2\gamma$ distance vs. asymmetry for 10 GeV and 50,100,200 GeV](image2)
π^0 reconstruction using Si Strip detector

- Locate a cluster with large energy deposit in the Si Pad & define search region in the Si Strip
- Search for 2 clusters in the Si Strip & obtain distance between the clusters
- Applied cut with total energy deposit and 2 clusters distance

[Graphs and figures showing energy deposit and distance distributions for different energy values (70 GeV, 100 GeV, 150 GeV, 200 GeV).]
π⁰ reconstruction using Si Strip detector

Efficiency vs. π⁰ energy for 1mm, 0.5mm strip pitch

• Parameters used in reconstruction algorithm is optimized so that the contamination is < 1%
• 50% of the identification efficiency of high energy π⁰ (>100 GeV) is achieved using the one strip layer around 5-7X₀.
Energy balance

- γ-Jet
  - EMC - JCal

- Di-Jet
  - EMC - JCal
  - EMC - TPC
  - TPC - TPC

- Energies: 65 GeV, 105 GeV, 150 GeV, 190 GeV
Width of Di-jet energy balance

DiJet Energy-Balance Resolution

\[ \text{Pythia8} \]
\[ p+p \quad \sqrt{s} = 14.0 \text{TeV} \]
\[ \text{CellJet}(R=0.2) \]

- TPC-TPC
- EMC-TPC
- EMC-JCAL
- \( \gamma \)-Jet EMC-JCAL

\[ \sigma(E_1^2 - E_2^2/E_1) \]

\[ 1/2^*(E_{T1} + E_{T2}) [\text{GeV}] \]

✔ Energy resolution improves from 40% to 20% with J-Cal
LHC Luminosity upgrade

- LHC Machine Luminosity upgrade plan
  - LINAC4 on track, connection to PS
  - Parallel effort on LHC crab cavities

![Graph showing luminosity upgrade over years](graph.png)
- fully commissioned detector & trigger
  - alignment, calibration available from pp
- **first 10^5 events**: global event properties
  - multiplicity, rapidity density
  - elliptic flow
- **first 10^6 events**: source characteristics
  - particle spectra, resonances
  - differential flow analysis
  - interferometry
- **first 10^7 events**: high-\(p_T\), heavy flavours
  - jet quenching, heavy-flavour 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
  - \(N_{\text{PbPb collisions}} = 4 \cdot 10^8\) collisions
  - 400 Hz minimum-bias rate
  - 20 Hz central (5%)
- muon triggers:
  - ~ 100% efficiency, < 1kHz
- centrality triggers:
  - bandwidth limited
  - \(N_{\text{PbPbminb}} = 10^7\) events (10Hz)
  - \(N_{\text{PbPbcentral}} = 10^7\) events (10Hz)

A few examples
Heavy Ions: ‘The First 3 Minutes’

- **Minimum Statistics needed:**
  - Few seconds at 1% design L
  - SPS in 1986
    - First spectrum 1 week before official start of HI run!
  - RHIC in 2000: first collisions June 12
    - 1st paper July 19, dNch/dη, excluding 90% of predictions
    - 2nd: Aug 24, 22k events, flow surprise ($v_2$)
    - ~3 weeks run, very low L,
      > 10 PRL’s within <1 year
      - RHIC was commissioned with HI!
Physics of ‘The First 3 Minutes’: Multiplicity

First estimate of energy density
Saturation, CGC?

integrated multiplicity distributions from Au-Au/Pb-Pb collisions and scaled pp collisions

Before RHIC, predictions for the LHC were considerably higher, ranging up to \( dN_{ch}/dy = 8000 \)

\[ dN_{ch}/dy = 2600 \]

saturation model
Eskola hep-ph/050649

\[ dN_{ch}/dy = 1200 \]

\( \ln(\sqrt{s}) \) extrapolation

Before RHIC, predictions for
the LHC were considerably higher, ranging up to
\( dN_{ch}/dy = 8000 \)
One of the first answers from LHC

- Experimental trend & scaling predicts large increase of flow
- Hydrodynamics: modest rise
Particle composition can be described in terms of a statistical model (grand canonical ensemble) with 2 free parameters (thermalization temperature and bariochemical potential). Consistent with a thermalization of the system with $T \sim 170 \text{ MeV}$, $\mu_B \sim 30 \text{ MeV}$

**Limiting temperature reached for large $\sqrt{s}$.

**First data at LHC** will check if the hypothesis survives at *20 the RHIC cm energy
Pilot run Physics: $\rho, \phi, K^*, K^0_S, \Lambda, \Xi, \Omega...$

Measure:
- strangeness production
- medium modification of mass and widths

10$^7$ events:
- $p_t$ reach $\phi, K, \Lambda$
  $\sim$ 13-15 GeV
- $p_t$ reach $\Xi, \Omega$
  $\sim$ 9-12 GeV

Reconstruction rates:
- $\Lambda$: 13/event
- $\Xi$: 0.1/event
- $\Omega$: 0.01/event

$p_T$: 1 to 3-6 GeV

Mass resolution $\sim$ 2-3 MeV

$\rho^0(770) \rightarrow \pi^+\pi^-$

10$^6$ central Pb-Pb

$\rho^0(770) \rightarrow \pi^+\pi^-$

Mass resolution $\sim$ 2-3 MeV

(b)
Jet production is copious.

**Table:**

<table>
<thead>
<tr>
<th>$E_T$ Threshold</th>
<th>$N_{jets}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 GeV</td>
<td>$5 \times 10^4$</td>
</tr>
<tr>
<td>100 GeV</td>
<td>$1.5 \times 10^3$</td>
</tr>
<tr>
<td>150 GeV</td>
<td>300</td>
</tr>
<tr>
<td>200 GeV</td>
<td>50</td>
</tr>
</tbody>
</table>
First full run Physics: $D^0 \rightarrow K^-\pi^+$

A major ALICE asset: measure $Y$, $B$, $J/\psi$ and $D$ in the same experiment: natural normalization, Bkgd subtraction, in central region identify $J/\psi$ from $B$ decays

- Golden channel for open charm
- $S/B \approx 10\%$
- Significance for 1 month Pb-Pb run ($10^7$ events): $S/\sqrt{S+B} \approx 40$

![Graph](image.png)

Pb-Pb, $\sqrt{s_{NN}} = 5.5$ TeV

$D^0 \rightarrow K\pi$

- statistical.
- systematic.
ALICE is dedicated to the studies with heavy ion collisions at LHC.

- Pb+Pb @ $\sqrt{s_{NN}} = 5.5$ TeV (1 month/year)
- Powerful tracking capability with ITS & TPC
- Various PID devices
  - TOF
  - HMPID
  - TRD
- EM calorimeter
  - PHOS, EMCal
  - No intention to have hermetic energy measurement
- Muon spectrometer

ALICE experiment
LHC “Short-term” H.1 Plan

ALICE Prospects for “First Physics”

- First physics in ALICE is NOW – pp important reference data for heavy-ions
  Examples:
  - multiplicity distribution, baryon transport
  - identified particle spectra
  - measurement of charm cross section major input to pp QCD physics

- First $10^5$ PbPb events: global event properties
  - multiplicity, rapidity density, charged particle spectra
  - elliptic flow

- First $10^6$ PbPb events: source characteristics and spacetime evolution
  - identified particle spectra, resonances
  - differential flow analysis
  - particle correlations, interferometry

- First $10^7$ PbPb events: high-$p_T$ and heavy flavors
  - suppression, “jet” quenching, heavy flavor energy loss
  - charmonium production

- Eventual goals - bulk properties of medium & parton energy loss mechanisms
  - energy density, temperature, pressure
  - heat capacity/entropy, viscosity, sound velocity, opacity
  - susceptibilities, order of phase transition
New conditions & new probes at LHC

$\sqrt{s_{nn}} = 5.5\text{TeV}$
(x 30 wrt. RHIC)

Much higher energy density (x 3-10)

Better overall conditions to study the QGP

Initial temperature $T (x 2) > 3T_c$

Larger QGP volume,
Longer QGP life time $\tau$ (x3-5)

Hard processes

Bulk properties strongly influenced by hard processes

Very hard probes copiously produced

Multiplicity

$\frac{dN_{ch}}{d\eta} = 2600$

Event by event physics
In the low density limit $v_2$ is driven by $\epsilon$ and $dN/dy$.

In ideal hydrodynamics $v_2$ driven by the (space time averaged) velocity of sound, $v_2/\epsilon = \text{constant}$.

Hydro limit (full local thermalization) at RHIC? More likely at LHC?

Anisotropic Flow

Continuous increase with $K_n^{-1}$ ($K_n = \text{mean free path}/\text{system size}$, $K_n^{-1} \sim \sigma (1/S)$)

$\text{dN/dy} \rightarrow \text{no saturation seen in data}$

Hydro limit: $K_n \ll 1$

$v_4 = 0.5 (v_2)^2$ at large $p_T$

Data: $v_4/v_2^2 \sim 1.2$ suggest $K_n \sim 1$:

No thermalisation at RHIC!

Qualitative predictions for LHC

• Closer to ideal hydro.
• Significant increase of $v_2$
• $v_4/(v_2)^2$ smaller than at RHIC

Initial conditions CGC + hydro (until $T \sim 170$ MeV) i.e., contribution of the QGP + hadronic cascade

At LHC, contribution from QGP much larger than at RHIC

T. Hirano

N. Borghini, J.Y. Ollitrault

In the low density limit $v_2$ is driven by $\epsilon$ and $dN/dy$.
Why short-lived resonances?

Resonances are strongly decaying particles which have lifetimes of about a few fm/c (i.e. $\tau_{\text{resonance}} \sim \tau_{\text{fireball}}$)

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$c\tau$ (fm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho(770) \rightarrow \pi^+\pi^-$</td>
<td>1.3</td>
</tr>
<tr>
<td>$f_0(980) \rightarrow \pi^+\pi^-$</td>
<td>2.6</td>
</tr>
<tr>
<td>$K^*(892)^0 \rightarrow K\pi$</td>
<td>3.9</td>
</tr>
<tr>
<td>$\Lambda(1520) \rightarrow Kp$</td>
<td>13</td>
</tr>
<tr>
<td>$\Phi(1020) \rightarrow K^+K^-$</td>
<td>44</td>
</tr>
</tbody>
</table>

Partial chiral symmetry restoration

Interaction of the resonances and/or their daughters with fireball medium

Modifications of properties of resonances (peak, width)

Resonances may give information on the dynamics and on the chiral property of the hot and dense matter which is produced in the collision

A. Badalà- SQM07- Levoča - 24/06/-29/06/07
Jet statistics in pilot Pb run

Jets are copiously produced...

\[ p_T (\text{GeV}) \begin{array}{cccc} \text{2} & \text{20} & \text{100} & \text{200} \\ \text{100/event} & \text{1/event} & 10^3 \text{ in first } 10^6 \text{ Pb-Pb events} \end{array} \]

- Underlying event fluctuations
- Single particle spectra
- Correlation studies

ALICE Acceptance

\[ E_T \text{ threshold} \quad N_{\text{jets}} \]

\begin{array}{|c|c|}
\hline
E_T \text{ threshold} & N_{\text{jets}} \\
\hline
50 \text{ GeV} & 5 \times 10^4 \\
100 \text{ GeV} & 1.5 \times 10^3 \\
150 \text{ GeV} & 300 \\
200 \text{ GeV} & 50 \\
\hline
\end{array}

10^6 \text{ central Pb-Pb events
critically dependent on integrated luminosity…

taking, as an example:

> 2 \( \mu b^{-1} \)
> no suppression, no enhancement

\textcolor{red}{\rightarrow} a few 1000s J/\( \psi \)
> say 5 centrality bins \( \rightarrow \) significance \( \sim 15-20 \)
> out to 6-7 GeV pT?

\textcolor{red}{\rightarrow} \( \psi' \) marginal…

\textcolor{red}{\rightarrow} a few 10s of \( Y \) at significance \( \sim 5 \)?
Full detectors:
ITS, TOF, TPC, HMPID, MUON, T0, V0, FMD, PMD, ZDC:

Partial detectors:
PHOS 3/5
EMCAL(*) : 4/12
TRD(*) : 7/18
60% of High Level Trigger (HLT)
**Heavy Ion Physics at LHC**

- ALICE is dedicated to the studies with heavy ion collisions@LHC
- ALICE will study the similar observables as what RHIC experiments see. “Similar” or “Different” trend from RHIC to LHC?:
  - Initial conditions, thermalization, time scale
    - Shadowing, Saturation, CGC
    - Gluon seed + (energetic) mini-jet production
      - How the system is thermalized? Still quickly thermalized?
  - Space-time evolution, time scale, properties
    - $v_2$ will be saturated? More or less $v_2$? Viscosity?
    - QGP is still strongly coupled? Or More like a gas?
    - Thermal model works?
  - Energy loss and response of the medium
    - Microscopic process
    - Flavor and mass dependence?
    - Sway side response? How large dissipative effects in the medium (hydro) by intruding jets (high energy partons)?
  - Color screening of the medium
    - Deconfinement? Melting temperature? Other competing effects? Important feedback to the RHIC results.
First Pb+Pb collisions in 2010/2011 at ALICE

- 4 weeks in November
- $L \sim 5 \times 10^{25} \text{ cm}^{-2}\text{s}^{-1}$, $\sim 100\text{Hz}$ Min. Bias (2010)
- $L \sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$, $\sim 2\text{kHz}$ in Min. Bias (2011)
- Collect few $5 \times 10^6$ (2010) – $10^8$ (2011) min. bias events.

Prospects for the “First” Physics

- **Global event properties** ($10^5$ Pb+Pb events)
  - Multiplicity, rapidity density (correlation),
  - charged particle spectra, elliptic flow,
- **Space-time evolution** ($10^6$ Pb+Pb events)
  - identified spectra, resonances, particle ratio,
  - particle correlation, differential elliptic flow, HBT
- **high-pT, Jets and heavy favors** ($10^7$ Pb+Pb events)
  - energy loss (mass/path length dependence)
First three minutes/Day-1

- **RHIC in 2000:** first collisions June 12
  - 1st paper July 19, $dN_{ch}/d\eta$ from PHOBOS
  - 2nd: Aug 24, 22k events, *flow surprise* ($v_2$) by STAR

- Multiplicity and flow (integrated $v2$)
  - Estimation of $E_{bj}$, Saturation, CGC
  - $v_2$$\sim$hydro limit? More or less?

![Graph showing $v_2$ vs. multiplicity]
Strangeness/resonances

- Strangeness hadrons ($\Lambda, \Xi, \Omega$)
  - Chemical composition, statistic model, space-time evolution
- Short lived resonances ($\rho, K^*, \phi, \omega$)
  - Chiral property of the medium, chemical/kinetic freeze out

Statistical limit for 1 year: $\sim 10^7$ central Pb-Pb, $(10^9$ min. bias pp)

- $p_T \sim 13$ - $15$ GeV for $K^+, K, K^0_s, \Lambda$
- $p_T \sim 9$ - $12$ GeV for $\Xi, \Omega$
- Mass resolutions $\sim 1.5$ - $3$ MeV
- $p_T$ stat. limits from $8 (\rho)$ to $15$ GeV ($\phi, K^*$)
**Heavy quarks**

- Significant increase at LHC
  - x10 for charm, x 100 for bottom
- 2010/2011 runs (10^8 events)

### Simulation for $\sqrt{s_{NN}} = 5.5$ TeV
(10^7 central Pb-Pb events, 10^9 pp events)

also for $\sqrt{s_{NN}} = 2.75$ TeV in 2010 & 2011
Charm p_T spectrum to 15 GeV/c

### Heavy Quarkonia

- ~10k J/ψ per experiment
- in several p_T bins up to 10 GeV/c
- in ALICE down to p_T = 0
- Several 100 ψ' per experiment, but low S/B & significance
- ~100 Y in ALICE, low background
Dominance of hard process at LHC

Hard probe statistics with 0.5\,nb^{-1} in ALICE (L\sim0.5\times10^{27}\,\text{cm}^{-2}\text{s}^{-1})

Hard Probe statistics in ALICE:
10^4/\text{year in nominal MB Pb+Pb run}

Inclusive jets : \(E_T \sim 200\,\text{GeV}\)
Di-jets (EMCAL-TPC) : \(E_T \sim 170\,\text{GeV}\)
\(\pi^0\) (EMCAL) : \(p_T \sim 75\,\text{GeV}\)
\(\pi^0\) (PHOS) : \(p_T \sim 50\,\text{GeV}\)
Inclusive \(\gamma : p_T \sim 45\,\text{GeV}\)
Inclusive e : \(p_T \sim 30\,\text{GeV}\) (heavy quark jets)
\( \pi^0 \) & Jets

Measurement by PHOS/EMCal

\[ \int L \, dt (Pb+Pb) = 0.01 \text{nb}^{-1}, 0.1 \text{nb}^{-1}, 0.3 \text{nb}^{-1} (N_{\text{col}} \text{ scaling}) \]

\( \pi^0 \) spectra to \( p_T \sim 30,40,50 \text{ GeV/c} \)

\[ \int L \, dt (p+p) = 10, 100, 300 \text{ nb}^{-1} \]

Jets in EMCAL
An ALICE Approach to High $p_T$: HMPID

- ring imaging Cherenkov with CsI photocathode

\[ \gamma_{th} = 1.57, \quad |\eta| < 0.6, \quad \Delta\phi = 58^\circ \]