Heavy Ion Program@LHC
ALICE View

- Summary
- ALICE constraints
- Heavy Ions (Pb-Pb)
- pp and pA
- Light Ions
- Options

See internal note ALICE-INT-2001-10 V2.0
Summary

● **initial 4-5 years**
  - regular pp running at $\sqrt{s} = 14$ TeV
  - 2 - 3 years Pb-Pb
  - 1 year p - Pb ‘like’ (p, d or $\alpha$ beams)
  - 1 year light ions (eg Ar-Ar)

(1HI ‘year’ = $10^6$ effective s)
L $\sim 10^{29}$ and $< 3 \times 10^{30}$ cm$^{-2}$s$^{-1}$
L $\sim 10^{27}$ cm$^{-2}$s$^{-1}$
L $\sim 10^{29}$ cm$^{-2}$s$^{-1}$
L $\sim$ few $10^{27}$ to $10^{29}$ cm$^{-2}$s$^{-1}$

● **other options**, depending on physics priorities & results
  - pp collisions at $\sqrt{s} = 5.5$ TeV/n
    - short energy scan of interest also to pp expts? (connect to Tevatron?)
  - lower energy Pb-Pb

  - possibly further high energy Pb-Pb
  - possibly another light system (out of O-O, Kr-Kr, Ar-Ar, Sn-Sn)
  - possibly another pA system
ALICE constraints

- **Luminosity with Ions (light or heavy)**
  - pile-up in TPC => MinBias rate < 8 kHz
    - Pb-Pb: L < 10^{27}  
    - Ar-Ar: L < 3 \times 10^{27}  
    - p-p: L < 10^{29}  
  - muon spectrometer ‘stand-alone’: RPC limit ~ 50-100 Hz/cm²
    - considered for high statistics runs with light ions (Y suppression)
    - ‘soft’ limit, depends on RPC properties (trying to improve)
    - machine background (in particular pp) a major concern!
    - Pb-Pb: L < few 10^{28}  
    - Ar-Ar: L ~ 10^{29}  
    - p-p: L < 5 \times 10^{31}

- **Luminosity pp, p-A ‘like’**
  - no pile-up (clean events, low data volume) => MinBias rate < 8 kHz
    - untriggered MB events, large rate (kHz)
  - pile-up TPC < 20 events, no pile-up in SDD => MinBias rate < 200 kHz
    - triggered rare events, small rate (Hz)
    - pp: L < 3 \times 10^{30}  
    - d-Ar: L < 2 \times 10^{29}  
    - d-Pb: L < 8 \times 10^{28}

- **DAQ limits: BW = 1.25 Gbyte/s to storage**
  - Pb: 20 Hz MB, 20 Hz central+rare triggers, ~ 1 kHz muon arm
  - pp, d-A: ~ 1 kHz (limited by R/O time, TPC gating)

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H.I. Event samples

- **global event properties (large x-sections, soft processes)**
  - trigger on MB and central (~ 5% of total x-section)
  - data sample **limited by DAQ** capability for MB rate > 400 Hz
    - Pb-Pb: L > 5 x 10^{25} (5% of design L)
    - one reason for large DAQ bandwidth of ALICE
    - 1 ‘effective day’ (10^5 s) = 2x10^6 evts @ 20 Hz

- **semi-rare, but untriggerable events**
  - eg Ω, heavy quark mesons (D, B) hadr. & semi-leptonic decays,
  - trigger would need full, good online reconstruction to be selective
    - rate for inclusive hadrons/leptons of relevant p_t >> 1/event!
  - needs **large statistics** of MB/central events (few 10^7 evts)

- **rare triggered events**
  - lepton pairs (e, μ), high p_t particles, jets > 100 GeV
  - need **max Luminosity**, not limited by DAQ (‘high priority’ scheme)
**Base Program I**

- **start with heaviest ion, max. Energy**
  - Pb-Pb at 5.5 TeV/A

  - **Step 1:** ~ day even at very low initial Luminosity
    - few $10^3$ - $10^5$ events => global event properties

  - **Step 2:** ~ week, still below design Lum.
    - some $10^6$ events => most of hadronic signals

  - **Step 3:** ~ month (> $10^6$ effective s), max Lum.
    - Integrated luminosity => rare hard signals
Statistics needed in Ion Program

- **Minimum**: 6366 MB (382 central) events
  - few seconds at 1% design L

- **RHIC in 2000**
  - first collisions June 12, first PRL subm. July 19
  - 2nd: Aug 24, 22k MB events
  - ~3 weeks run, very low L, >10 PRL’s within <1 year
  - RHIC was commissioned with HI!

- **SPS in 1986**
  - first spectrum 1 week **before** start of HI run!
Hadronic observables

*STAR, \( \sim 10^6 \) central events (Oct. 2000 conf)
  - most global properties & hadronic observables
    - (particle ratios & spectra, HBT, flow, ...): Thermodynamics & Hydrodynamics

*Some \( 10^7 \) evts needed for full hadronic physics
  - \( p_t \) spectra > 5-10 GeV
  - \( \Omega \), charm, beauty, ...

\[ D^0 \rightarrow \pi K \]

\( K^0_S \)

\( \phi \)

\( \Omega \)

\( \bar{K}^* \)

Long way from “peaks” to final spectra and ratios but the signal strength is sufficient in all cases.
Rare Hard signals

- need max Lum, max time

B -> J/Ψ -> e+e-
  (sec. vertex)
- b x-section,
- b energy loss
- J/Ψ suppression

- expected statistics
  - extrapolation to central (10%) PbPb with $A^2 / 4$
  - no suppression/enhancement
  - includes all efficiencies and analysis cuts
  - $L = 5 \cdot 10^{20}$ cm$^{-2}$s$^{-1}$, 10$^8$ s running time, 1 $\sigma$ mass cut

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- correlated bottom measurements

with $p_t^B > 3$ GeV/c, large relative yield of dimuons from bottom decay all over invariant mass

P. Crochet for the ALICE collaboration

LHCC2001, Nov. Oct.01
Need for pp & pA collisions at LHC

- **QGP analysis: study changes to signals**
  - measure same signal pp -> pA -> AA
  - same program at AGS, SPS, RHIC

- **baseline: pp reactions**
  - comparison running with pp to measure basic x-sections
  - very few results make NO reference to pp
  - pp essential part of base program. Needed to analyse AA data!

- **‘trivial’ nuclear modifications: pA**
  - initial state structure functions (shadowing)
    - large but unknown gluon shadowing at LHC
    - factor two or more uncertainty in pQCD x-sections
  - final state interaction in cold nuclear matter (quarkonia, jets, p_t distributions,..)
    - big effects, directly relevant for extracting QGP related modifications
  - pA essential part of base program. Needed to analyse AA data!
    - even more than at SPS (more shadowing, more emphasis on hard probes !)

- **number of genuine physics topics in pp, pA**
  - parton saturation, double parton scattering, diffraction, ...(not further discussed)
Example: pt Spectra

- **measure $p_t(AA)/p_t(pp)$**
  - low/med $p_t$: thermo- & hydrodynamics
  - at high $p_t$ sensitive to ‘jet-quenching’
  - needs pp data to compare

- **complication: Cronin effect**
  - final state parton scattering
  - depends on A, sqrt(s)
  - needs pA data at LHC

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**STAR**

- **Binary Collisions Scaling**
- **Wounded Nucleon Scaling**

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**CERN - SPS**

- **$E_{lab}=158$ AGeV Pb+Pb**
- $10\%$ central (WA98)
- $5\%$ central (NA49)
- $10\%$ central (WA44)
- $5\%$ central Pb+Au (CERES)

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**soft/hard transition?**

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**Example: Lepton Pairs**

- **get confidence in simulation of ‘normal’ behavior**
  - need pp and/or pA data in same detector, same analysis

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**CERES/NA45 Pb-Au 40 AGeV**

\[ \langle dN_{\text{ee}} / d\eta \rangle / \langle dN_{\text{ch}} \rangle \ (100 \text{ MeV}/c)^2 \]

\[ \alpha_0 = 30\% \]

\[ \langle dN_{\text{ch}} / d\eta \rangle = 210 \]

\[ 2.1 < \eta < 2.65 \]

\[ p_T > 200 \text{ MeV}/c \]

\[ \Theta_{\text{sep}} > 35 \text{ mrad} \]

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**No enhancement in pp and pA collisions**

**CERES p-Au 450 GeV**

\[ 2.1 < \eta < 2.65 \]

\[ p_T > 50 \text{ MeV}/c \]

\[ \Theta_{\text{sep}} > 35 \text{ mrad} \]

\[ \langle dN_{\text{ee}} / d\eta \rangle = 7.0 \]

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Example: Strangeness

- Enhancement compared to pp and pA

\[
\lambda_s = \frac{2\langle s\bar{s}\rangle}{\langle u\bar{u}\rangle + \langle d\bar{d}\rangle}
\]

Factor \(\sim 2\)

![Graph showing particle yield vs. \(<N_{\text{wound}}>\) for pBe, pPb, and PbPb collisions.](image)
Gluon Structure Functions

Hard processes ~ (#partons)²
unknown structure functions major reason for e.g. uncertainty in dN/dy

Initial ratios $R_i^A(x)$ for evolution.

EKS98 is the one with more constraints from data.
(new HIJING gluons ruled out by data in the LT, LO DGLAP).

Green: Sea quarks
Blue: gluons
Red: Valence quarks

GRV94, MRST p structure functions

Shadowing parameterizations

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Final State Interactions in Nuclei

- needs to be (re) measured at LHC for J/Psi, Y, jets, ...

- pA was essential to establish:
  - ‘normal’ suppression up to S-U
  - ‘abnormal’ suppression in Pb-Pb
Base Program II

- **detector commissioning and start-up with pp**
  - few months at LHC start-up, to get detector in shape & understood
  - few weeks before each ion run, even if no pp data is needed (after few years)
    - SPS praxis, to not waste the short HI run after longer shut-down

- **comparison running pp, ‘p’A**
  - $\sigma(AA) \sim A \sigma(pp) - A^{4/3} \sigma(pp)$ (1 central AA event $\sim 200 - 1000$ pp events)
  - statistics untriggered: few $10^9$ events (error comparable to few $10^6$ AA events)
    - needs few $10^6$ s @ up to 1 kHz to tape
    - preferably ‘clean’ events ($L < 10^{29}$), only 0.3 Pbyte (versus 1.2 Pbyte with pile-up)
      at few $10^{30}$ > 90% of hits are from pile-up!
  - statistics triggered events (eg Y, jets..)
    - few months as well, see below

- **‘default’ scenario: ~ 5 years pp, 1 month ‘p’A**
  - pp running probably more defined by practical considerations
    - change of detector over time, **new physics questions** to be answered, ..
    - **in practice:** full running in early years, shorter runs later
Luminosity Requirements

Rate Limited (200 kHz)

Life Time Limited (1h)

Source Limited
Nucleon Luminosity
pp comparison data: ~ 1 year needed for statistics

- split between high and low Luminosity
- pp error < Pb-Pb, ~ comparable to high Lumi Ar-Ar

\[
\frac{R_{ij}}{R_{ij}^{\text{PbPb}}} \times 10 \text{ (running time)}
\]
pA versus dA

- **advantage of deuteron beams**
  - center of mass energy closer to AA cms
    - d-Pb: 6.4 TeV, p-Pb: 8.8 TeV
    - d-Ar: 7 TeV, p-Ar: 9.9 TeV
  - shift of midrapidity smaller
    - d-Pb: 0.12, p-Pb: 0.46
    - d-Ar: 0, p-Ar: 0.35
  - factor 2 larger cross section for hard processes!
  - isospin similar to nuclei (less important at LHC, only for large $x_F$)

- **pA versus dA still being discussed**
  - larger $x_F$-range for PDF’s (pA, Ap)?
  - problems with multiple parton scatterings?

- **Luminosity for 200 kHz interaction rate**
  - d-Pb: $7 \times 10^{28}$ cm$^{-2}$ s$^{-1}$
  - d-Ar: $2 \times 10^{29}$ cm$^{-2}$ s$^{-1}$
energy density dependence

- scale parameter(s) of QGP physics
  - $\varepsilon$, $T_c$, parton density, volume, impact parameter, # of participants..
  - all related via nuclear geometry (‘Glauber’ calculation)
- investigate quantitative (smooth) and qualitative (thresholds) variations

mostly done via impact parameter variation

special cases need light ions instead

- very peripheral:
  - difficult experimentally (background)
  - low statistics for hard processes
  - ‘diffuse’ geometry (colliding nuclear tails)
- scale parameter for specific structures (if present)
  - eg NA60 experiment (J/Psi threshold behaviour)

Luminosity (light) versus energy density (heavy) ???

- good statistics $Y'$, $Y''$ only possible with light ions !!

choice of light ions:

- ‘light’ (eg Ar) for lowest energy density, but choice might change after first runs!
- $^{20}$Ar split into low (8 kHz, TPC) and high (200 kHz, muons) Lumi run
Energy Density
**Examples**

- **Strangeness**
  - low statistics at large $b$

- **J/Psi suppression**
  - low statistics, large systematics at large $b$
  - crucial region to establish ‘threshold’

- **Lepton pair continuum**
  - connect to pp via S-U
Origin of Charmonium Suppression

- A measurement of charmonia melting in a lighter collision system will confirm or rule out specific deconfinement models.

- A specific prediction: the J/ψ suppression pattern in In-In collisions exhibits a break at an impact parameter ~ 3.5 fm (M. Nardi & H. Satz)
Light ions are the best (only ?) way to scan low energy densities (around the phase transition)
Options: Energy scan

● **pp at 5.5 TeV**
  ➞ *interpolation* Tevatron - top LHC should be **rather reliable**
  ➞ done at RHIC, adds some (but not major) systematic error
  ➞ currently looks not very urgent, but I might be wrong...
  ➞ eventually, **some energy scan will be done** in any case at LHC
    ➞ was done at SppS, Tevatron

● **Ions at lower energy**
  ➞ connect to RHIC results ?
  ➞ strong case only if some drastic changes between RHIC and peripheral LHC
Beam Conditions

- **pp**
  - really low Lumi for MB events (few months), because of:
    - **data quality** (no pile-up)
    - **data volume**, offline CPU, already ‘promised’ to LCG project!
  - ~ stable conditions at both $10^{29}$ and few $10^{30}$
    - displaced beams, highest possible $\beta^*$
  - acceptable **background** (beam gas)
    - data quality, data volume, RPC limit!
    - currently under investigation...

- **Pb-Pb**
  - max integrated **luminosity**
  - stable rate during spill as far as possible
    - space charge effects in TPC
  - both is very much helped by $\beta^*$ **tuning**
    - better also for >1 experiment
      (quench limit in machine)