pA Collisions in LHCb

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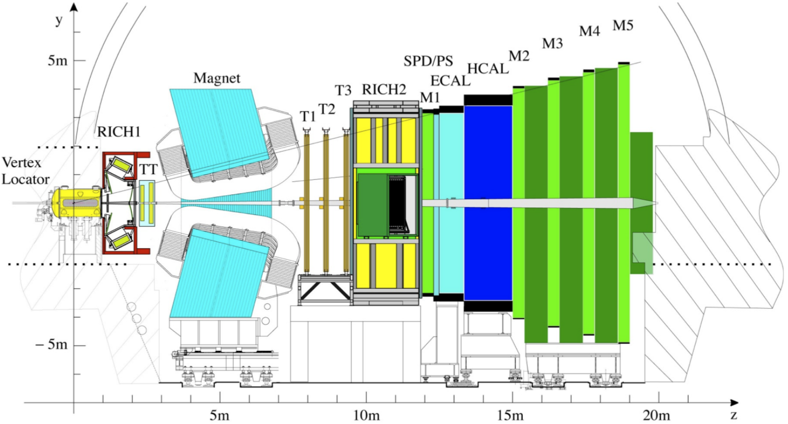
– on behalf of the LHCb Collaboration –

Outline

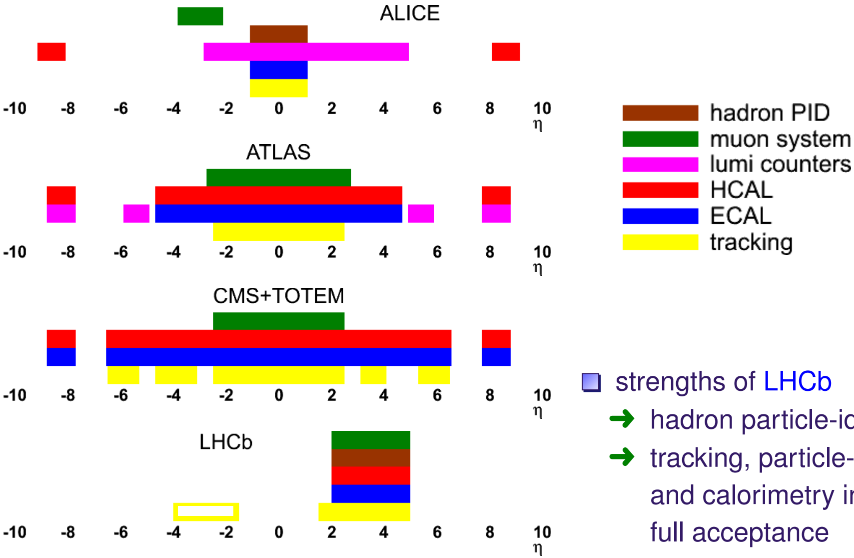
- Setting the Stage
- Experimental Constraints
- Kinematics
- Physics Topics
- Summary

→ *schematic of the LHCb detector*



- forward spectrometer $15 < \Theta < 300$ mrad
- two configurations for proton-nucleus collisions: $pA \neq Ap$

Comparison of Angular Coverage

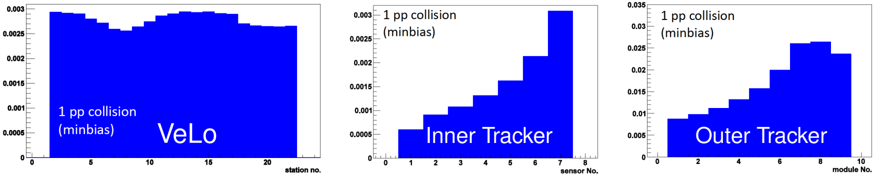


- strengths of LHCb
  - ➜ hadron particle-id
  - ➜ tracking, particle-ID and calorimetry in full acceptance

2. Experimental Constraints

➜ *can we measure anything?*

❖ consider typical occupancies in the tracking system . . .



- pp minimum bias interactions:
  - ➜ up to 0.3 % average occupancy in silicon detectors
  - ➜ up to 3 % average occupancy in Outer Tracker
- tracking algorithms break down at $\sim$ 30 %

❖ in the following focus at a qualitative understanding of pA collisions

➜ don’t worry (too much) about factors of 2 . . .

Expectations for pA-collisions

➜ *measurements of A-dependence at lower energies*

- total cross-sections – e.g. J. Carvalho, Nucl.Phys.A 725 (2003) 269

$$\sigma_{\text{inel}} \sim A^{0.71} \approx A^{2/3} \qquad \text{(geometric behaviour)}$$

- identified (strange) particles – e.g. HERA-B Collaboration

$$\sigma_{\text{part}} \sim A$$

- A-dependence of multiplicities and occupancies

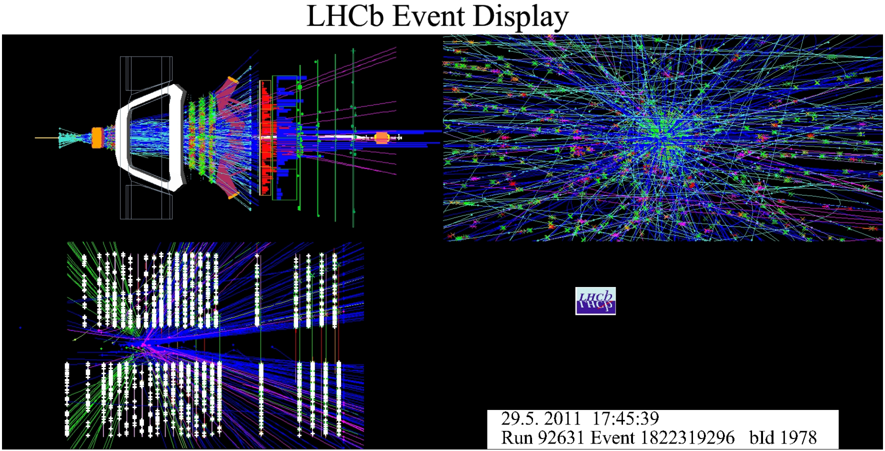
$$\text{occupancy} \propto n \sim \frac{\sigma_{\text{part}}}{\sigma_{\text{inel}}} \sim A^{1/3}$$

❖ expectation for $p - Pb$-collisions ($A = 208$)

occpancies increased by a factor $A^{1/3} \approx 6$

➜*single interactions OK for LHCb!*

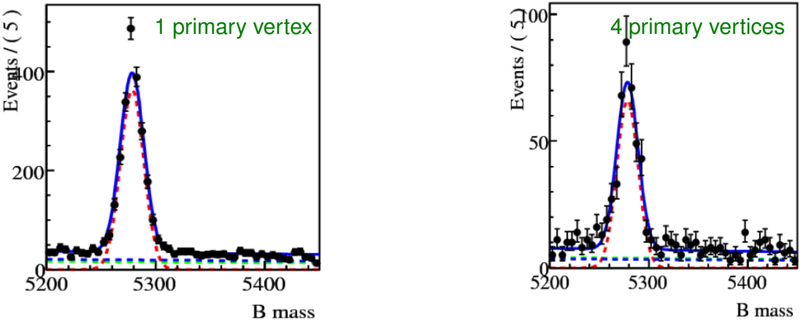
➜ *pp high-pileup event in LHCb*



➜ what about physics?

→ *e.g. reconstruction of B-meson decays . . .*

for example: $B^{\pm} \to J/\psi K^{\pm}$



- ✘ clean signal for $N_{PV} = 1$ and $N_{PV} = 4$
- ✘ S/B basically unaffected by pileup

➜ *same B-field and same radius of curvature:*

momentum per nucleon: $p_N \propto \frac{Z}{A}$

❖ in the following use Pb$(Z, A) = (82, 208)$ and assume

$p_p = 7\,\mathrm{TeV}/c$ and thus $p_N^{Pb} = p_p \cdot \frac{82}{208} \approx 2.76\,\mathrm{TeV}/c$

❖ consider kinematics of two limiting cases

- soft interactions: the proton interacts with the entire nucleus
  - ➜ 7 TeV particle with $m = 1$ on $A \cdot 2.76$ TeV particle with $M = 208$
- hard interactions: the proton interacts with a single nucleon
  - ➜ 7 TeV particle with $m = 1$ on 2.76 TeV particle with $M = 1$
    - ✘ likely to be the more relevant case

Key Quantities

→ *neglecting mass terms. . .*

- effective center-of-mass energy of the interaction

$$\sqrt{s_{\text{eff}}} = 2\sqrt{E_1 E_2}$$

- center-of-mass rapidity coverage of final state particles

$$-\ln\sqrt{s_{\text{eff}}} < y^* < \ln\sqrt{s_{\text{eff}}} \qquad (\sqrt{s_{\text{eff}}} \text{ in GeV})$$

  → soft interactions : $|y^*| < 12$

  → hard interactions: $|y^*| < 9$

- rapidity of the center-of-mass and lab-system

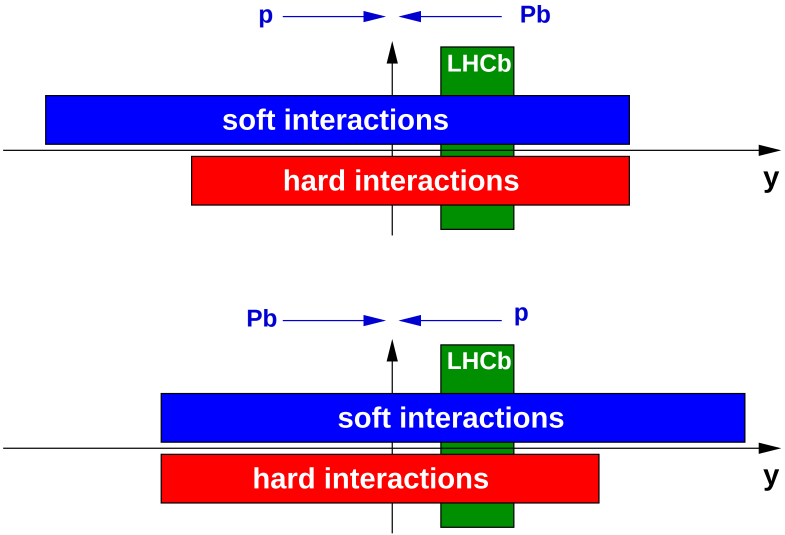
$$y_{cm} = \frac{1}{2}\ln\frac{E_1}{E_2}$$

  → soft interactions : $y_{cm} = -2.2$

  → hard interactions: $y_{cm} = 0.47$

→ visualization

Rapidity Coverage



Accessible Rapidity Range

➜ *center-of-mass rapidities y^* measured along p-direction*

- pA-collisions (proton towards LHCb)
  - ➜ soft-collisions: $y^* = [4.2, 7.2]$
  - ➜ hard-collisions: $y^* = [1.5, 4.5]$
- Ap-collisions (lead nucleus towards LHCb)
  - ➜ soft-collisions: $y^* = [-2.8, 0.2]$
  - ➜ hard-collisions: $y^* = [-5.5, -2.5]$
- discussion: qualitative arguments show. . .
  - ➜ for asymmetric detectors study pA and Ap interaction
  - ➜ even (close to) central rapidities become accessible
  - ➜ potential for a very rich physics program. . .

4. Physics Topics

→ *understanding multi-particle production at high energies*

- ✘ full picture requires studies of pp, pA, and AA collisions
- ✘ LHCb is able to contribute to pp and pA

❖ LHCb physics topics

- soft QCD measurements
  - → particle multiplicities
  - → strangeness production (V^0, ϕ, K^*, $\ldots$) and Λ-polarization
  - → energy flow and underlying event measurememts
- open charm production
- J/ψ-related measurements (likely to have largest impact w.r.t. QGP)
  - → production cross sections of charmonium states
  - → polarization studies
- . . .

Luminosity Issues

➜ *wanted: large event sample of single pPb-collisions ...*

- small average number of inelastic interactions per bunch crossing

$$\mu = \frac{L \cdot \sigma_{inel}}{f_{\text{rev}} \cdot N} \ll 1$$

- satisfied with $\mu = 0.02$, assuming...
  - ➜ instantaneous luminosity $L = 10^{29}\,\text{cm}^{-2}\text{s}^{-1}$
  - ➜ total inelastic cross section $\sigma_{\text{inel}} = 2\,\text{b}$
  - ➜ revolution frequency $f_{\text{rev}} = 10\,\text{kHz}$
  - ➜ number of colliding bunches $N = 1000$
- assuming 10^6 s running time and $L = 10^{29}\,\text{cm}^{-2}\text{s}^{-1}$:
  - ➜ integrated luminosity $L_{\text{int}} = 100\,\text{nb}^{-1}$
  - ➜ $2 \cdot 10^9$ events written to disk – 1% of all inelastic interactions

Physics Reach

→ *lower limit, based on extrapolation from current analyses*

❖ minbias running with veto on empty events, 2 kHz logging rate

- available integrated luminosity $L_{\rm int} = 1\,{\rm nb}^{-1}$
- assume that cross sections scale with A
- assume same detector performance as for 7 TeV pp physics
- expected yields of reconstructed particles in LHCb acceptance

→ 70 000 000 $K_S^0 \rightarrow \pi^+\pi^-$

→ 12 000 000 $\phi \rightarrow K^+K^-$

→ 600 000 $D^0 \rightarrow K^-\pi^+ + CC$

→ 20 000 $J/\psi \rightarrow \mu^+\mu^-$ (up to 100 times more with trigger)

flavour physics remains the primary goal, but
LHCb is keen to explore its potential in pA collisions!

5. SUMMARY

➜ *pA studies interpolate between pp and AA*

- LHCb detector expected to be able to handle pPb collisions
  - ➜ extended physics program will require extra computing resources!
- large rapidity coverage when combining pA and Ap running
  - ➜ swap p and A to make optimal use of asymmetric detectors!
- rich physics program, covering e.g.
  - ➜ soft QCD
  - ➜ open charm
  - ➜ J/ψ measurements

➜ *to explore and understand the physics potential:*

If collisions are possible in the pA-test this year
LHCb is ready to collect data!

Backup Slides

Relativistic Kinematics (i)

➜ *center-of-mass energy:*

calculate the Mandelstam-variable $s = E^2_{cm}$:

$$s = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 \approx (E_1 + E_2)^2 - (E_1 - E_2)^2 = 4\,E_1\,E_2$$

➜ *rapidity coverage of final state particles:*

consider relativistic particles travelling along the rapidity axis

$$y = \frac{1}{2}\ln\frac{E+p}{E-p} = \frac{1}{2}\ln\frac{(E+p)^2}{E^2-p^2} \approx \frac{1}{2}\ln\frac{4E^2}{m^2} = \ln\frac{2E}{m}$$

and thus, assuming a mass $m = 1$ and all units in GeV:

$$y_{max} = \ln 2E_{\mathrm{max}} = \ln\sqrt{s}$$

➜ *rapidity of the center-of-mass system:*

Use the first intermediate result of the above calculation:

$$y_{cm} = \frac{1}{2}\ln\frac{(E+p)^2}{E^2-p^2} \approx \frac{1}{2}\ln\frac{((E_1+E_2)+(E_1-E_2))^2}{s} = \frac{1}{2}\ln\frac{E_1}{E_2}$$

Relativistic Kinematics (ii)

Setting for $p - Pb$-collisions the proton energy to $E_1 = E$ one has:

- hard collisions:
  - ➜ $E_2 = E \cdot Z/A$
  - ➜ $\sqrt{s} = 2\,E\sqrt{Z/A}$
  - ➜ $y_{\mathrm{max}} = \ln(2\,E\sqrt{Z/A})$
  - ➜ $y_{cm} = 0.5\,\ln(A/Z)$
- soft collisions :
  - ➜ $E_2 = E \cdot Z$
  - ➜ $\sqrt{s} = 2\,E\sqrt{Z}$
  - ➜ $y_{\mathrm{max}} = \ln(2\,E\sqrt{Z})$
  - ➜ $y_{cm} = 0.5\,\ln(1/Z)$