Separation of the Charm and Beauty Production in p–Pb and Pb–Pb Collisions with ALICE

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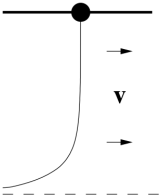
Hot Quarks 2016

Outline

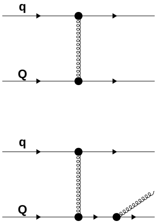
- Why measure beauty-hadron decay electrons?
- How can beauty-hadron decay electrons be measured?
- What are the results?

Heavy quarks in heavy-ion collisions

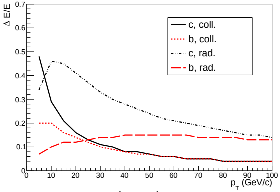
- Heavy quark production calculable with pQCD – useful probe
- Clear association with produced hadron
- Interaction with the quark-gluon plasma (QGP) - models:



- Strong-coupling, non-perturbative: AdS/CFT
- Weak-coupling, perturbative: pQCD
- many in-between



- What are the transport properties of the medium?
- What is the contribution from collisional and radiative processes?
- Do heavy quarks thermalize?



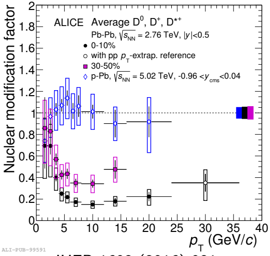
EPJ C (2016) 76:107

Measurement of heavy quarks

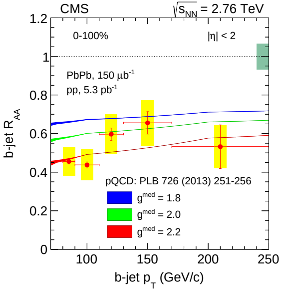
- Need to disentangle: production, interaction with medium and hadronization
- Comparison with models, but also different collision systems
- Interaction with medium leads to change in momentum distribution
- Nuclear modification factor quantifies change to pp collisions:

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{\langle N_{\mathrm{coll}}\rangle}\frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}N_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}} = \frac{1}{\langle T_{\mathrm{AA}}\rangle}\frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- To quantify non-QGP effects: Comparison to p–Pb
- Measurements exist for charm and high-p_{T} beauty → need low p_{T} information



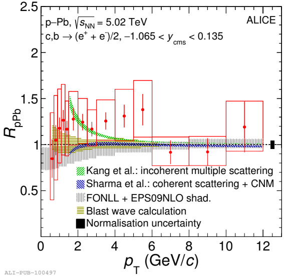
JHEP 1603 (2016) 081



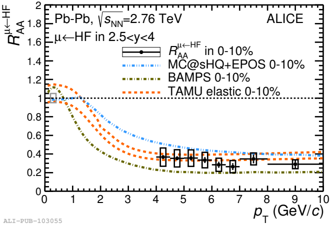
PRL 113 (2014) 132301

Heavy flavors in the electron channel

- Charm hadrons reconstructed via hadronic decay channels
- Need measurement of beauty
- Open heavy flavor (charm+beauty) measured in the semi-electronic decay channel
    - B.R. of open heavy-flavor hadrons to electrons $(\mathrm{B},\mathrm{D} \rightarrow \mathrm{e}+\mathrm{X}) \approx 10\%$
- Disentangle beauty and charm contributions to study mass dependence of interaction
- Similar measurements at forward rapidity in the muon channel



Phys.Lett. B754 (2016) 81-93

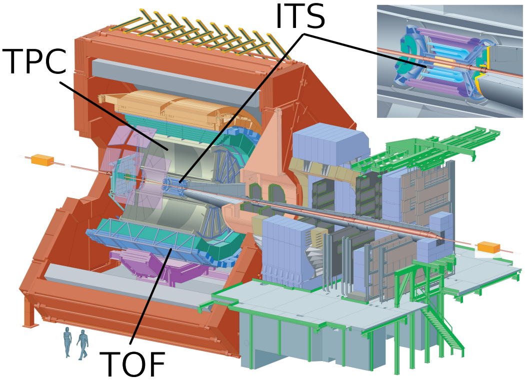


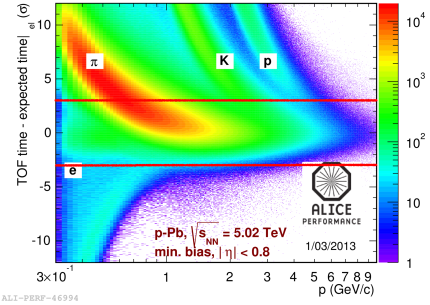
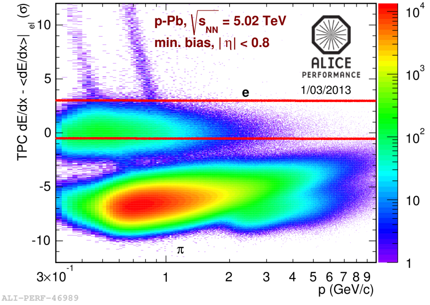
Phys.Lett. B753 (2016) 41-56

The ALICE detector

For the beauty electron measurements:

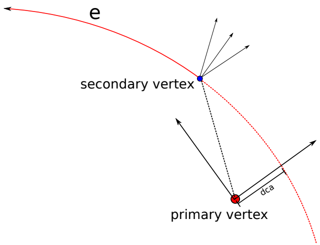
- **I**nner **T**racking **S**ystem: Tracking and reconstruction of primary vertex and track impact parameter (resolution better than 50 μm for $p_{\mathrm{T}} > 1.5$ GeV/c)
- **T**ime **P**rojection **C**hamber: Tracking and particle identification via $\mathrm{d}E/\mathrm{d}x$
- **T**ime-**O**f-**F**light Detector: Particle Identification

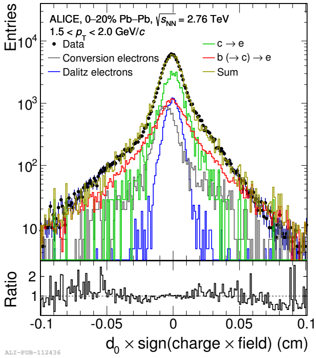


TOF	TPC
	
A $\|n_\sigma\| < 3$ on the TOF signal	A $-0.5 < n_\sigma < 3$ cut on the TPC signal

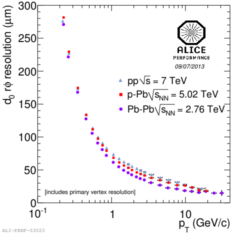
The impact parameter

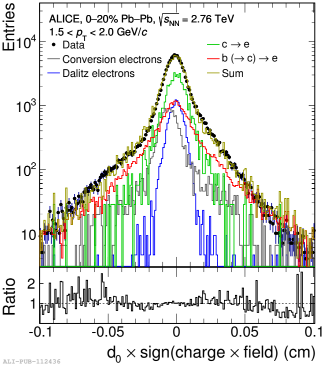
- Idea: beauty-hadron decay length larger than for most background sources
- No determination of decay vertex from single electron track – use impact parameter (IP) as proxy for decay length
- Value depends on decay vertex displacement, direction of daughter and magnetic field
- Signal: beauty-hadron conversion electrons, $c\tau(\mathrm{B}) \approx 500\ \mu\mathrm{m}$
- Background contribution: charm-hadron conversion electrons, $c\tau(\mathrm{D}^+) \approx 300\ \mu\mathrm{m}$
- IP gives additional information for separation of electrons from beauty-hadron decays
- Two alternative strategies: cut on IP or fit of distributions



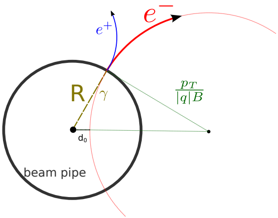


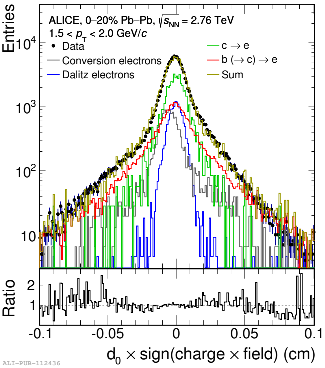
- Many electrons from decays of light mesons, e.g. $\pi^0 \to e^+ e^- \gamma$
- Most electrons produced close to the primary vertex
- Impact parameter distribution mostly determined by resolution
- Small contribution from strangeness $\to$ few electrons with wide distribution





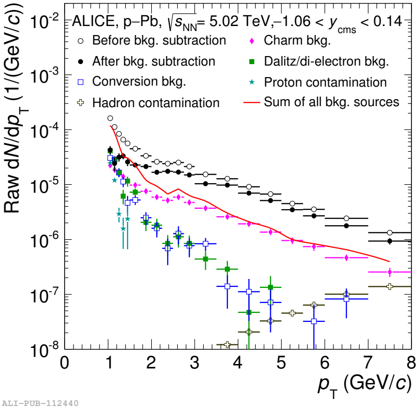
- Electrons from photon conversion in the detector material
  $\pi^0 \to \gamma\gamma,\ \gamma \to e^+e^-$
- Production vertex far from primary vertex
- Impact parameter distribution mostly determined by magnetic field and resolution
- Multiplied by charge and field configuration to make asymmetric for additional separation





The impact parameter cut method (p–Pb collisions)

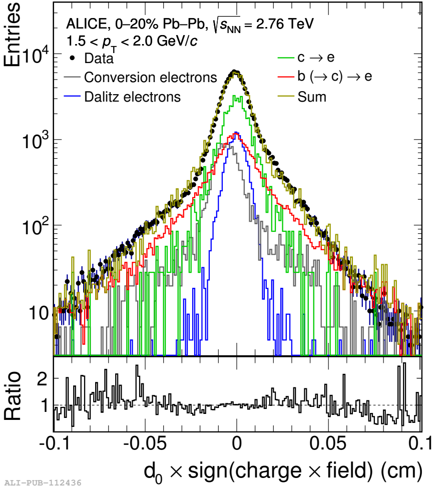
- Approach:
  - Require minimum impact parameter to suppress background
  - Subtract estimate of remaining background based on other measurements (e. g. D-meson measurement)
- Correct using Monte Carlo simulations, tuned to the measured background sources
- This affects both particle abundances and impact parameter cut efficiency



ArXiv: 1609.03898
Raw yields after impact parameter cut

The impact parameter fit method (Pb–Pb collisions)

- Approach:
  - Make templates of the impact parameter distributions of the sources
  - Fit the templates to the distribution in data
- Important to make sure the templates are representative of the data
- Take into account finite statistics in templates as well as in data
- Perform fits within different p_{T} intervals
- Method cross-checked in p–Pb and pp collisions



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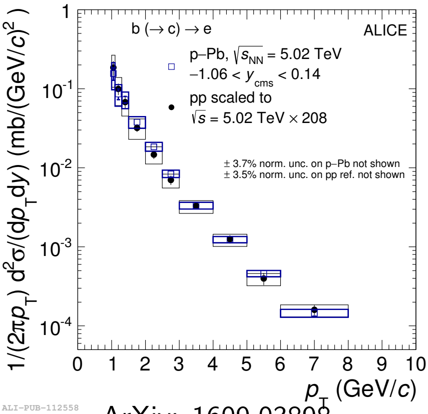
Example of impact parameter fit



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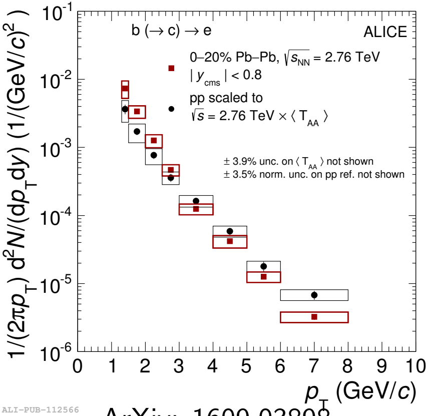
Invariant cross section in p–Pb with scaled reference

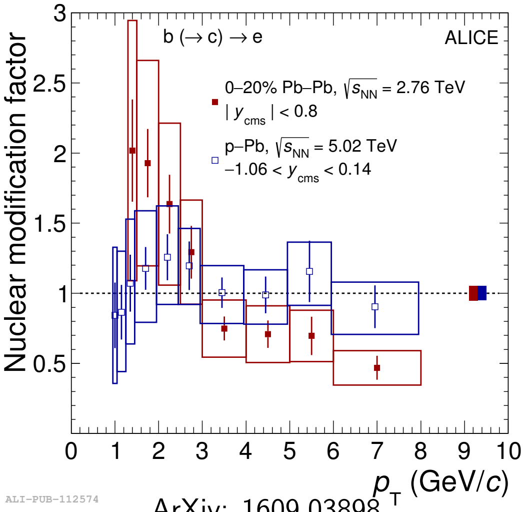


ArXiv: 1609.03898

Invariant yield in Pb–Pb with scaled reference

The nuclear modification factor

- Clear difference in shape between p–Pb and Pb–Pb cases
- Lower value for R_{AA} than R_{pA} at high p_{T} points to medium effects
- p–Pb consistent with unity
- Drop in R_{AA} below unity towards high p_{T} points toward energy loss of fast beauty quarks



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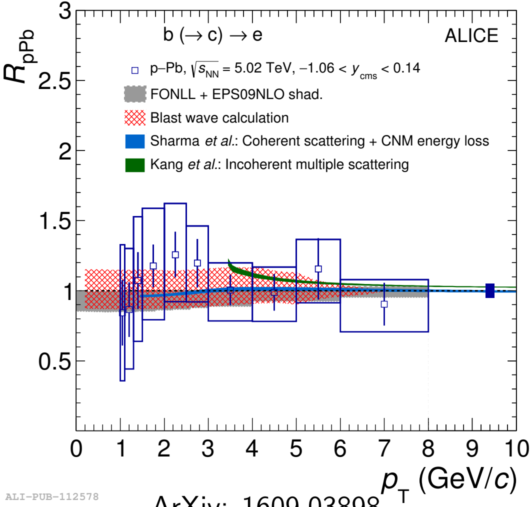
R_{pA} compared with models

- Most models suggest scaling with nucleon-nucleon collisions
- Blast wave (assuming full thermalization) can also lead to almost flat R_{pA}



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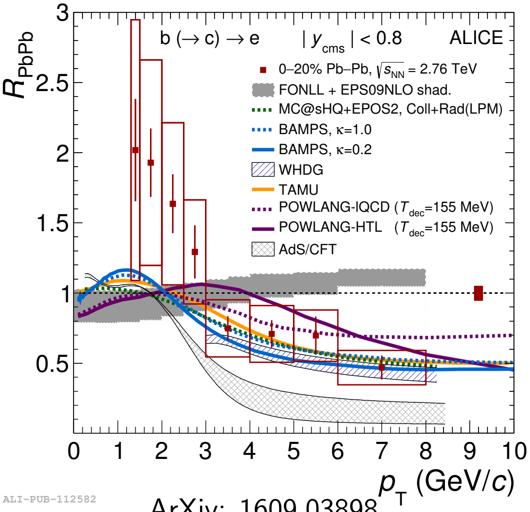
R_{AA} compared with models

- Qualitative agreement in suppression at high p_T
- Low p_T rise weaker in models but consistent within uncertainties
- AdS/CFT-inspired model underpredicts R_{AA}



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Summary

- First measurements of beauty-hadron decay electrons in p–Pb and Pb–Pb collisions at LHC energies
- Combination of impact parameter information and PID
- Both statistical separation based on fits and subtraction of background after cut feasible
- Comparison of R_{AA} and R_{pA} points to in-medium modification of momentum distribution in Pb–Pb collisions due to final-state effects

Steps:

- By sampling create new MC templates from the old MC templates
- Add the templates according to the assumed truth
- Sample this sum, to create toy data (statistics as in actual measurement)
- Apply the fit to the toy MC and data distributions
- Compare known "true" value and measurement for this model
- Repeat many times and look at distribution of the difference
- The width of this distribution for a given parameter (or function thereof) is the statistical error of the measurement of this parameter
- The shift in mean of the distribution relative to the "true" value is the bias of the fit in this bin and will go into the systematic error in the end
- Important point: Estimation assumes truth is similar to measured value, so it is a "first order approximation" of the error

Appendix: Maximum Likelihood Fits

- Generic Problem:
  - Histogram with distribution of some quantity in data d_{bin}
  - Functional description of distribution $f_{bin}(\vec{\alpha})$
  - Within individual bins: Poissonian fluctuations (counts)
- Likelihood (L): Probability of data for given set of parameters interpreted as function of parameters
  - For one bin: $L_{bin} = \frac{f_{bin}(\vec{\alpha})^{d_{bin}} \cdot \exp(-f_{bin}(\vec{\alpha}))}{d_{bin}!}$

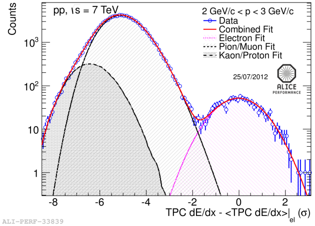


Figure : Fit of the TPC signal in pp collisions for illustration purposes

- Maximum Likelihood method:
  - Total likelihood is product of contributions in bins
  - Find maximum w.r.t. unknown parameters
- Useful: Log of likelihood for simpler calculation

$$L(\vec{\alpha}) = \prod_{bin} \frac{f_{bin}(\vec{\alpha})^{d_{bin}} \cdot \exp(-f_{bin}(\vec{\alpha}))}{d_{bin}!} \Rightarrow \log L = \sum_{bin} d_{bin} \log f_{bin}(\vec{\alpha}) - f_{bin}(\vec{\alpha})$$

Appendix: Fit Likelihood – Two Contributions

$$\log L = \sum_{bin} data(bin) \cdot \log fit(bin) - fit(bin)$$
$$+ \sum_{bin} \sum_{source} N_{source}(bin) \cdot \log A_{source}(bin) - A_{source}(bin)$$

$$fit(bin) = \sum_{source} p_{source} \cdot A_{source}(bin)$$

Likelihood for weighted sum of expectation values to correspond to data

Likelihood for Expectation values to correspond to MC templates

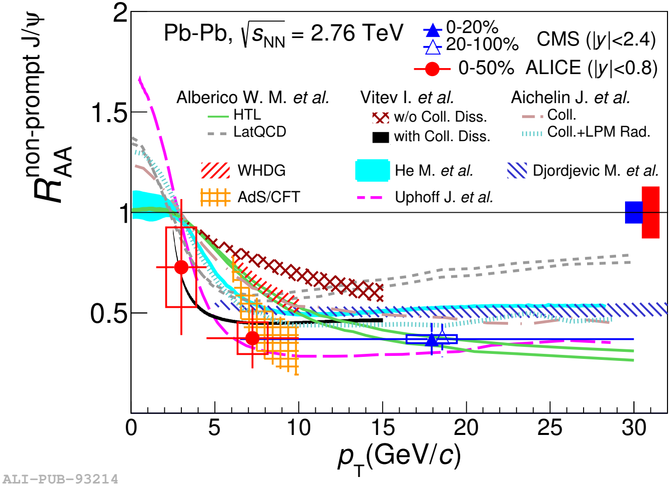
- For 200 bins per source – 804 free parameters
- Barlow, Beeston: Maximization w.r.t. $A_{source}(bin)$ can be done in iterative process
- Only 4 free parameters remain for TMinuit (p_{source})

Appendix: Template Fit Likelihood

- In each impact parameter bin, data entries and template entries fluctuate
- The underlying probability distribution is Poissonian
- Idea of template fits:
  - Expectation value of data entries unknown
  - Expectation value of template entries also unknown
  - Expectation values of template entries are free parameters of the fit
  - Expectation value of data entries is weighted sum of template expectation values
- Several hundred free parameters
- Barlow, Beeston (Comp. Phys. Comm. 77(2):219-228, 1993) showed method for maximizing likelihood efficiently – leaves only amplitudes as free parameters
- Fit uncertainties estimated via toy model

$$\log L = \sum_{bin} data(bin) \cdot \log fit(bin) - fit(bin) + \sum_{bin} \sum_{source} N_{source}(bin) \cdot \log A_{source}(bin) - A_{source}(bin)$$

$$fit(bin) = \sum_{source} p_{source} \cdot A_{source}(bin)$$



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