58th **International Winter Meeting on Nuclear Physics**

Production of leptons from charm and beauty quarks with ALICE at the LHC

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on behalf of ALICE Collaboration

January 24, 2020

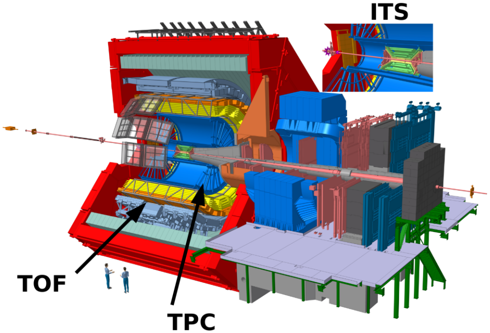
Outline

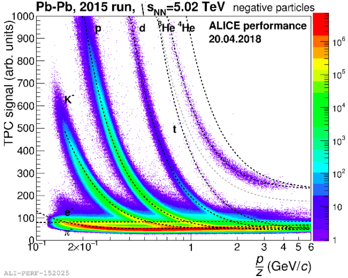
- Physics motivation
- ALICE detector
- Recent results
- Summary and outlook

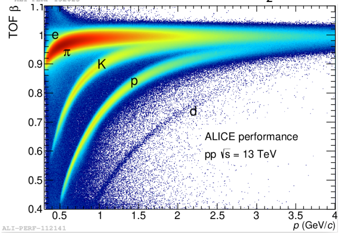
Physics motivation

- Charm and beauty quarks are produced via initial hard scattering processes at the early stages of the collision.
- $m_{c,b} \gg$ Quantum ChromoDynamics scale parameter ($\Lambda_{QCD} \approx 200$ MeV).
- $\mathrm{BR}(\mathrm{B}, \mathrm{D} \rightarrow \mathrm{l}\nu\mathrm{X}) \approx 10\%$.
- **pp collisions**
  - Provide the required reference for corresponding studies in large systems.
  - Test of perturbative Quantum ChromoDynamics.
  - Look for the signs of collectivity in muliplicity dependence study of heavy-flavour leptons.
- **Pb-Pb collisions**
  - Study the mass dependent energy loss of quarks in hot QCD medium and participation of heavy quarks to the collective expansion of the system.
- **p-Pb collisions**
  - Study the cold nuclear matter effects.

ALICE detector: Identification of electrons at low p_T

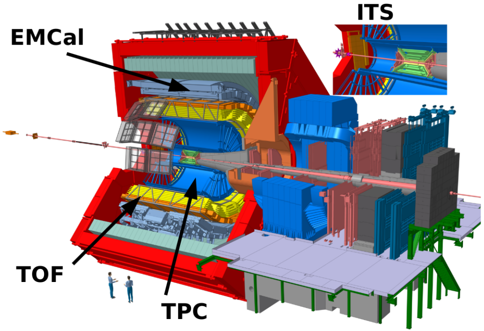


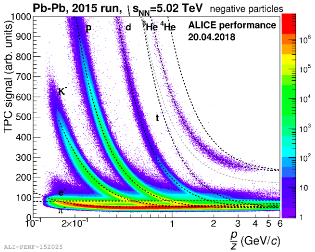


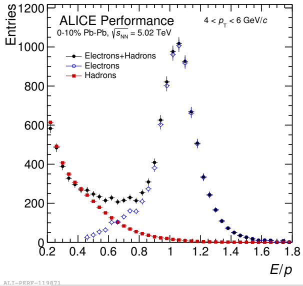


- Hits in both SPD layers to minimize the number of tracks from photon conversions.
- Selection on deviation from the expected electron dE/dx.
- $|t_{\mathrm{TOF}} - t^{e}_{\mathrm{TOF}}| < 3\,\sigma_{\mathrm{electron}}$

ALICE detector: Identification of electrons at high p_{T}



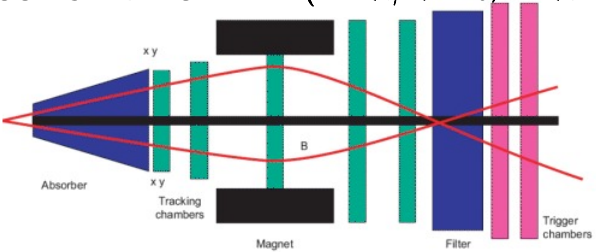


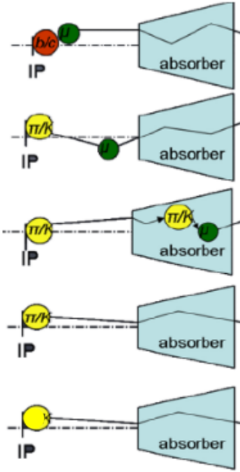


- Hits in both SPD layers to minimize the number of tracks from photon conversions
- Selection on deviation from the expected electron $\mathrm{d}E/\mathrm{d}x$.
- E/p: energy deposited in the EMCal / track momentum ($0.9 < E/p < 1.2$)

ALICE detector: Identification of muons

MUON SPECTROMETER ($-4 < \eta < -2.5$, $2^\circ < \theta < 9^\circ$)





- **Heavy-flavour decay muon signal extraction:** subtract muons from primary π, K decays via simulations with data-tuned π, K abundances.
- Background of μ from W/Z/γ^* decays subtracted with templates obtained from Monte-Carlo simulations (POWHEG).
- Background of μ from J/ψ decays is subtracted.

μ from heavy flavours

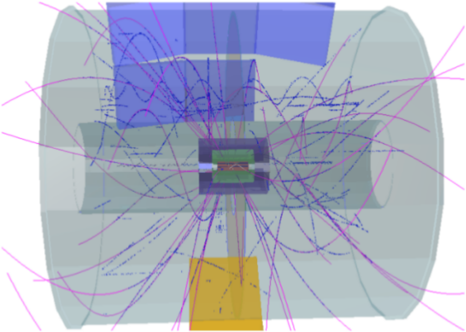
μ from primary π & K

μ from secondary π & K

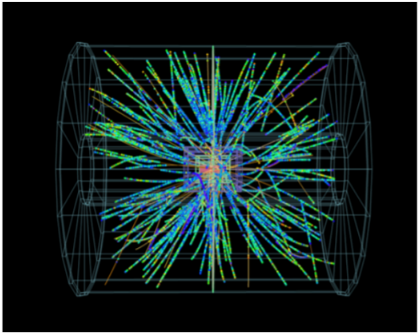
punch through hadrons

μ from W/Z and J/ψ decays

pp

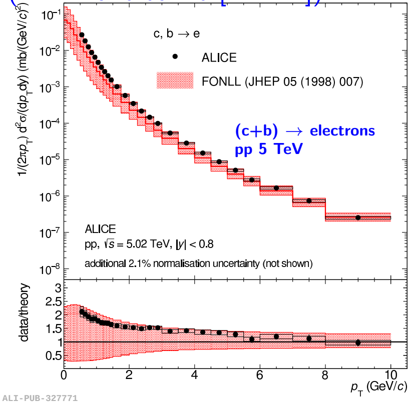


p-Pb

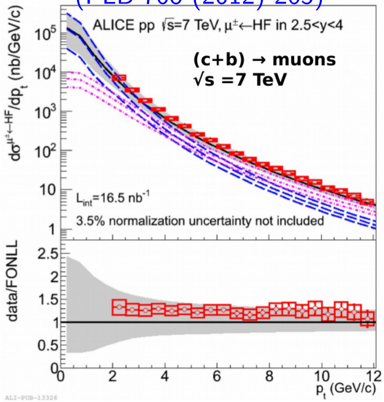


Results: p_T-differential cross sections in pp collisions

(arXiv:1910.09110 [nucl-ex])

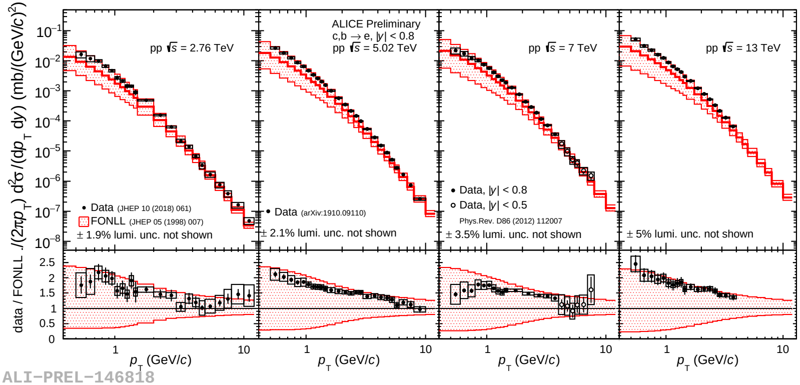


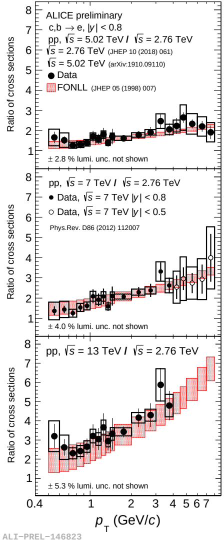
(PLB 708 (2012) 265)



- Test for pQCD calculations and reference for pA and AA collisions.
- Measured cross sections of heavy-flavour leptons are in agreement with the pQCD predictions.

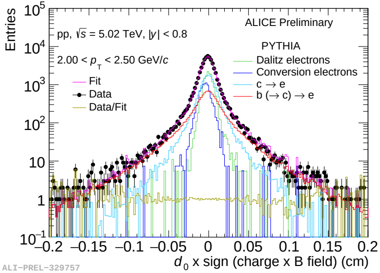
Results: p_{T}-differential cross sections in pp collisions

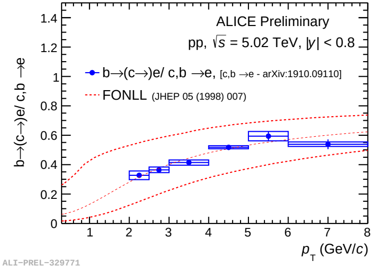


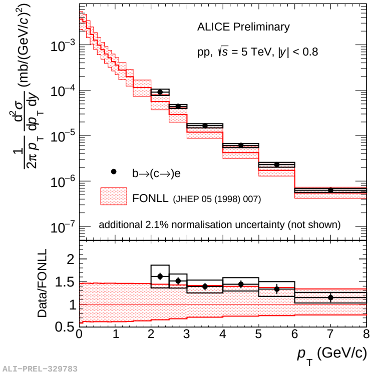


- Measured cross sections of heavy-flavour electrons are in agreement with the FONLL predictions and lie on the upper edge of the FONLL band for all energies.
- In the ratios of the cross-sections at different energies, factorization scale uncertainties dominate the FONLL band and part of the uncertainties cancels out.

Results: p_T-differential cross section of b ($\to$ c) $\to$ e in pp collisions



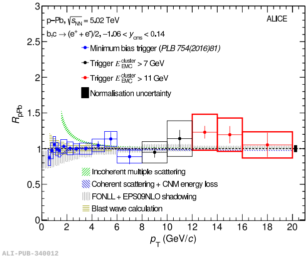


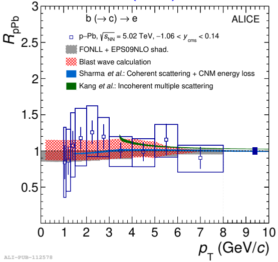


- Electrons from beauty hadron decays are measured according to DCA template method.
- Measured beauty electron cross section and fraction of b ($\to$ c) $\to$ e to c, b $\to$ e are in agreement with FONLL predictions.
- Contribution from beauty quarks starts to dominate beyond $p_T > 4$ GeV$/c$.

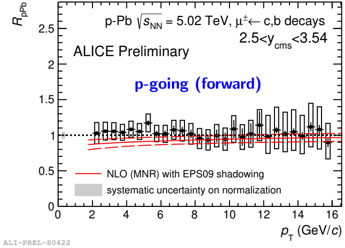
R_{pPb} Results: Leptons from heavy-flavour decays in p-Pb collisions

Phys. Lett. B 754(2016) 81-93 **(c+b) → e** JHEP 1707, (2017) 052

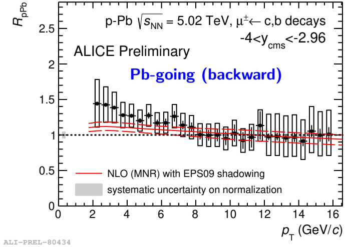




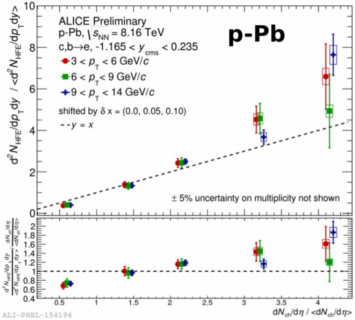
(c+b) → muons

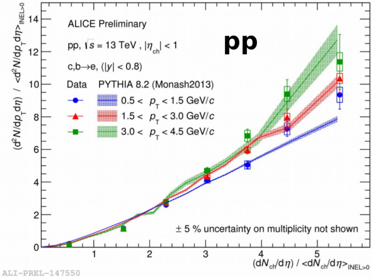


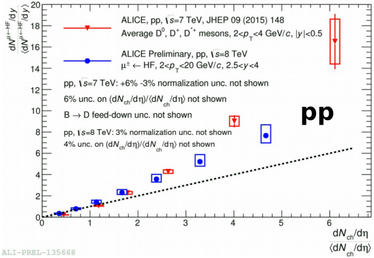
- R_{pPb} of electrons from heavy-flavour and beauty hadron decays is consistent with unity in the measured p_{T} range.
- It is also in the agreement with various theoretical predictions which include initial state effects.
- heavy-flavour decay muons described by calculations including cold nuclear matter effects: Different x regimes explored in different rapidity ranges with heavy-flavour probes.



Results: Heavy-flavour lepton yield vs. multiplicity

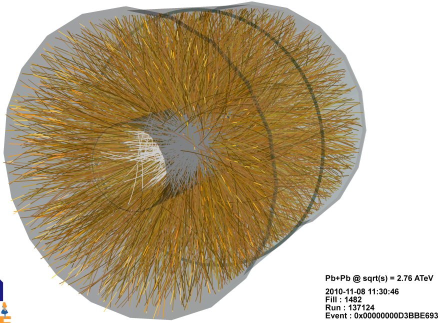






- D mesons and heavy-flavour leptons show faster than linear increase w.r.t charged-particle multiplicity in both systems.
- Insight into processes in the collisions at the partonic level, such as Muti-Parton Interactions (MPI).
- Results are fairly well described by PYTHIA in pp collisions with MPI and Color Reconnection (CR) on.

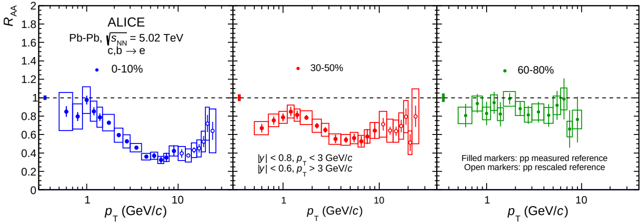
Pb–Pb


Pb+Pb @ sqrt(s) = 2.76 ATeV
2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

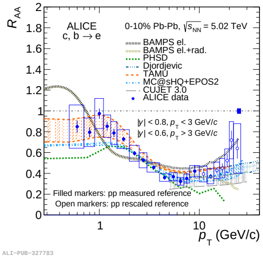
R_{PbPb} Results: Leptons from heavy-flavour decays in Pb-Pb collisions

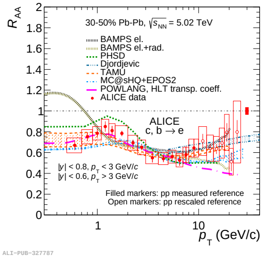
(arXiv:1910.09110 [nucl-ex])

(c+b) $\rightarrow$ electrons



ALI−PUB−327779

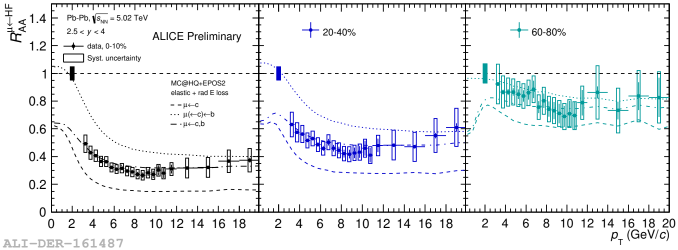


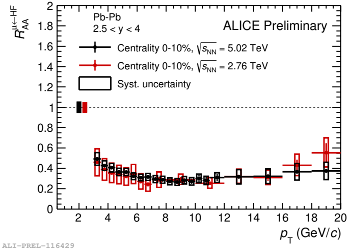


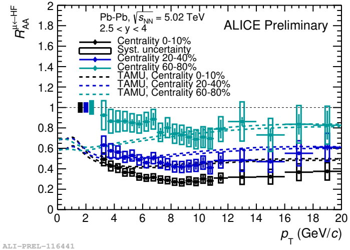
- R_{AA} of electrons from heavy-flavour decays in Run 2 is measured in different centrality classes and suppression decreases.
- For different centralities, it is consistent with various theoretical models which include radiative and collisional energy loss.

R_{PbPb} Results: Leptons from heavy-flavour decays in Pb-Pb collisions

(c+b) $\rightarrow$ muons

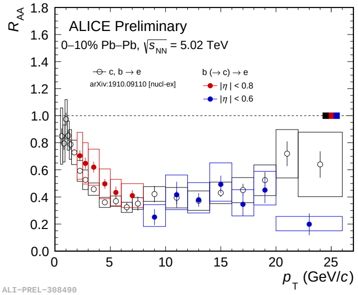


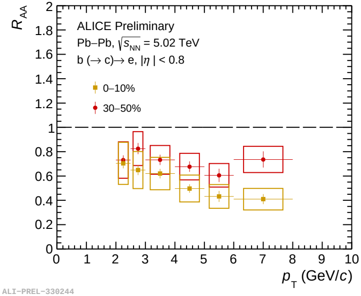


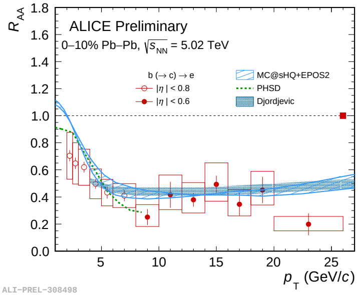


- R_{AA} of heavy-flavour decay muons measured in Run 2 shows good agreement with Run 1 measurement.
- R_{AA} is compared with the theoretical predictions of muons from charm and beauty contributions.
- It shows consistency which those models that consider radiative and collisional energy loss.

Results: Electrons from beauty decays in Pb-Pb collisions





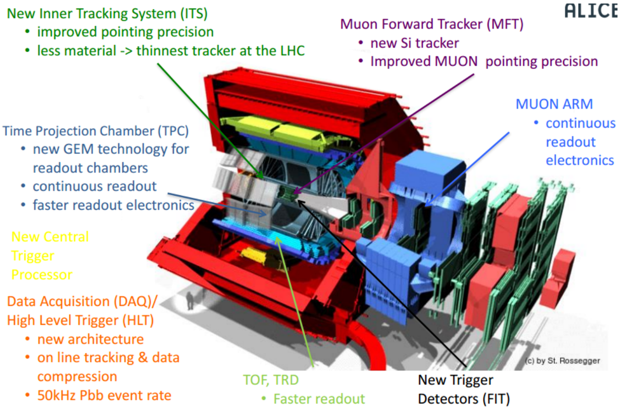


- Hint of smaller supression of b (→ c)→ e with respect to b, c → e.
- Indication of a centrality dependence of the energy loss in the medium in the beauty sector. New pp reference at 5 TeV is used which has improved the precision on the statistical and systematic uncertainties.
- R_{AA} consistent with models that consider mass-dependent radiative and collisional energy loss.

Summary

- p_{T}-differential cross sections of heavy-flavour leptons in pp collisions are consistent with the theoretical predictions.
- Nuclear modification factors (R_{pA}) of heavy-flavour leptons in p–Pb collisions are consistent with unity and agrees with the theoretical prediction which includes initial state effects.
- Heavy-flavour lepton yields show faster than linear behavior with respect to charge particle multiplicity in pp and pPb collisions.
- R_{AA} of heavy-flavour leptons agree with the theoretical predictions which include radiative and collisional energy losses.

Outlook



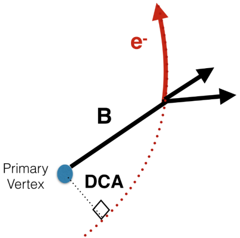
- With the ongoing detector upgrades, the precision on the measurement will considerably increase.
- The improved impact-parameter resolution, together with the improved luminosity of the LHC accelerator complex, will improve the significance of the upcoming measurements.

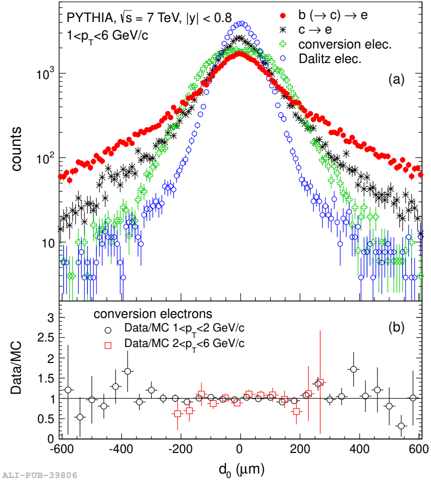
Thank You...

BACK-UP

Analysis Strategy: Electrons from beauty quarks via DCA cut method

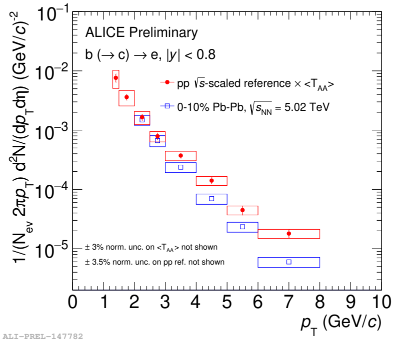
(pp 7 TeV and p-Pb 5.02 TeV)

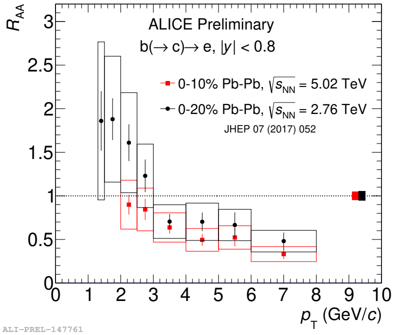




- The b $\rightarrow$ e have larger DCA compared to the electron background $\Rightarrow$ cut on the minimum DCA to increase the S/B ratio.
- In pp and p-Pb collisions, $|\mathrm{DCA}| > [64+780 \times \exp(0.56 p_{\mathrm{T}})]$ (DCA in μm, p_{T} in GeV/c).

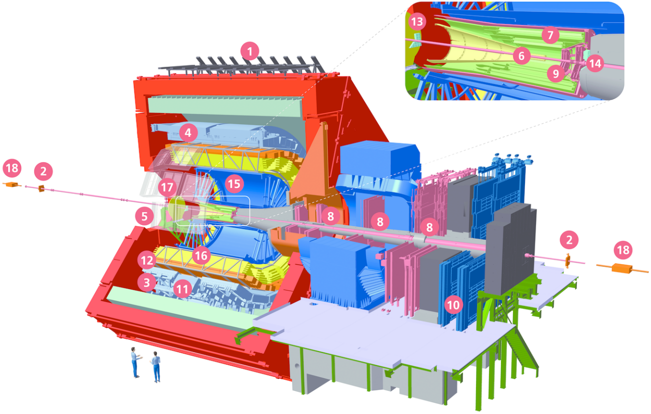
Results: Electrons from beauty quarks in Pb-Pb at 5.02 TeV





- R_{AA} shows good agreement with Run 1 measurement.
- Indication of smaller supression of b $(\rightarrow$ c$)\rightarrow$ e with respect to b, c $\rightarrow$ e at low/intermediate p_{T}.
- The scaled pp reference is used which is obtained from scaling it from 7 TeV using FONLL.
- Analysis of new pp reference is ongoing which would reduce the systematic uncertainties in the R_{AA} measurement and can give more precise results.

ALICE: RUN3



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

Models

Kang et al., incoherent multiple scattering: Phys. Lett. B 740, 23 (2015)
Bith inial-state and final-state interaction

Sharma et al., coherent multiple scattering: Phys. Rev. C 80, 054902 (2009)
Energy loss in cold nuclear matter and shadowing

FNOLL + EPOS09NLO: JHEP 9805, 007 (1998) + JHEP 0904, 065 (2009)
Initial state-effects (nuclear shadowing)

Blast-wave calculation: Phys. Lett. B 731, 51 (2014)
Hydrodynamic expansion

MC@sHQ+EPOS2: PR C89 (2014) 014905
Coll+Rad Eloss, recombination, EPOS-expansion

PHSD: PR C92 (2015) 1, 014910, PR C93 (2016) 3, 034906
Parton-Hadron-String Dynamics transport, coalescence

Xu, Cao, Bass: PR C88 (2013) 044907
Langevin with Coll+Rad Eloss, recombination+hydro

SCETM,G NLO: arXiv: 1610.02043
Soft Collinear Effective Theory, Bjorken expansion

Djorkevic: PR C92 (2015) 024918
Coll+Rad Eloss, recombination, finite-size hydro

POWLANG HTL: EPJ C71 (2011) 1666; JP G38 (2011) 124144
Langevin transport, Coll Eloss, recombination, hydrodynamics

AdS/CFT: JHEP 1411 (2014) 017; PR D91 (2015) 8, 085019;
Ads/CFT correspondence, Langevin Eloss + fluctuations, hydro

BAMPS: JP G 38 (2011) 124152; PL B 717 (2012) 430
Boltzmann transport, Coll. Eloss, expansion

TAMU: PL B735 (2014) 445-450
Transport, Coll. Eloss, resonant scatt. and coalescence+hydro

Models

TRANSPORT MODELS	Collisional Energy loss	Radiative Energy loss	Coalescence	Hydro	nPDF
BAMPS + rad. J. Phys. G42 (2015) 115106	✓	✓	✗	✓	✗
LBT arXiv:1703.00822	✓	✓	✓	✓	✓
PHSD PRC 93 (2016) 034906	✓	✓	✓	✓	✓
POWLANG EPJC 75 (2015) 121	✓	✗	✓	✓	✓
TAMU Phys. Lett. B735 (2014) 445	✓	✗	✓	✓	✓
MC@sHQ+EPOS PRC 89 (2014) 014905	✓	✓	✓	✓	✓

pQCD Eloss MODELS	Collisional Energy loss	Radiative Energy loss	Coalescence	Hydro	nPDF
CUJET3.0 JHEP 02 (2016) 169	✓	✓	✗	✗	✗
Djordevic PRC 92 (2015) 024918	✓	✓	✗	✗	✓
SCET JHEP 03 (2017) 146	✓	✓	✗	✗	✓

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