Charmed baryon measurements with the ALICE experiment at the LHC

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Heavy flavour workshop, Inha University
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    - pp collisions
    - p-Pb collisions
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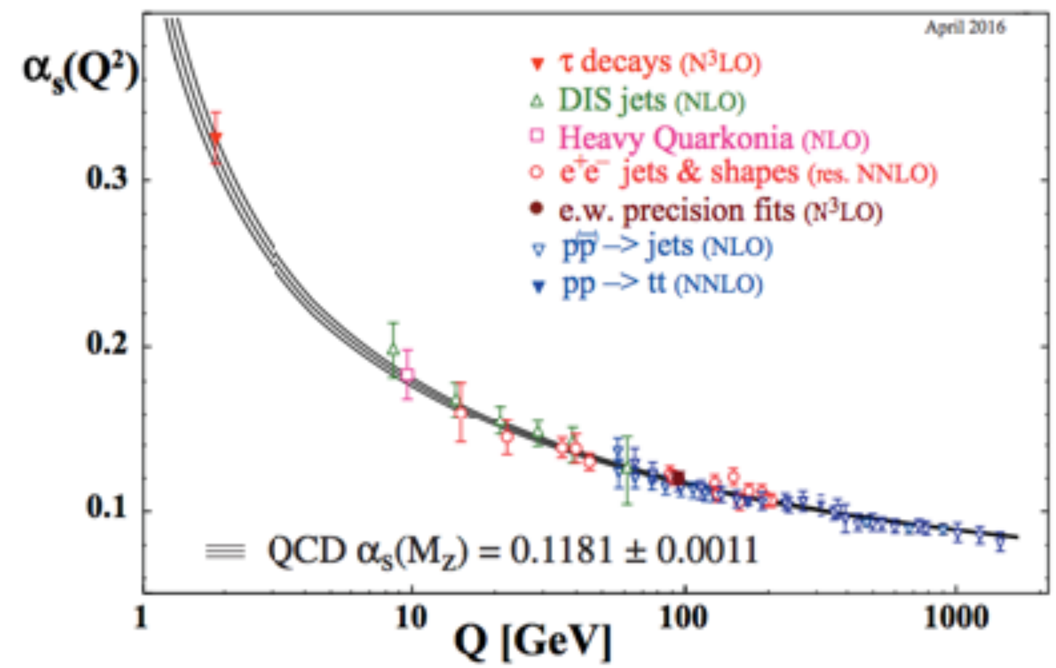
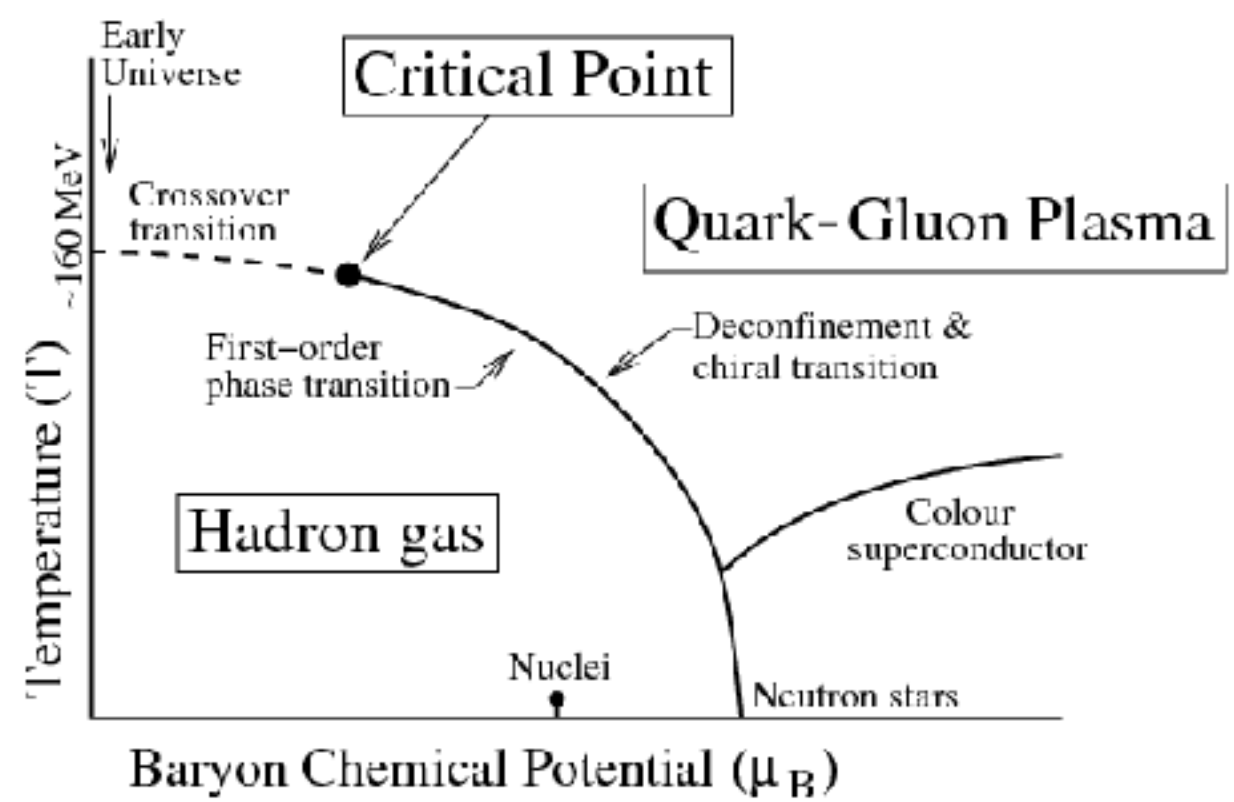
- Future measurements

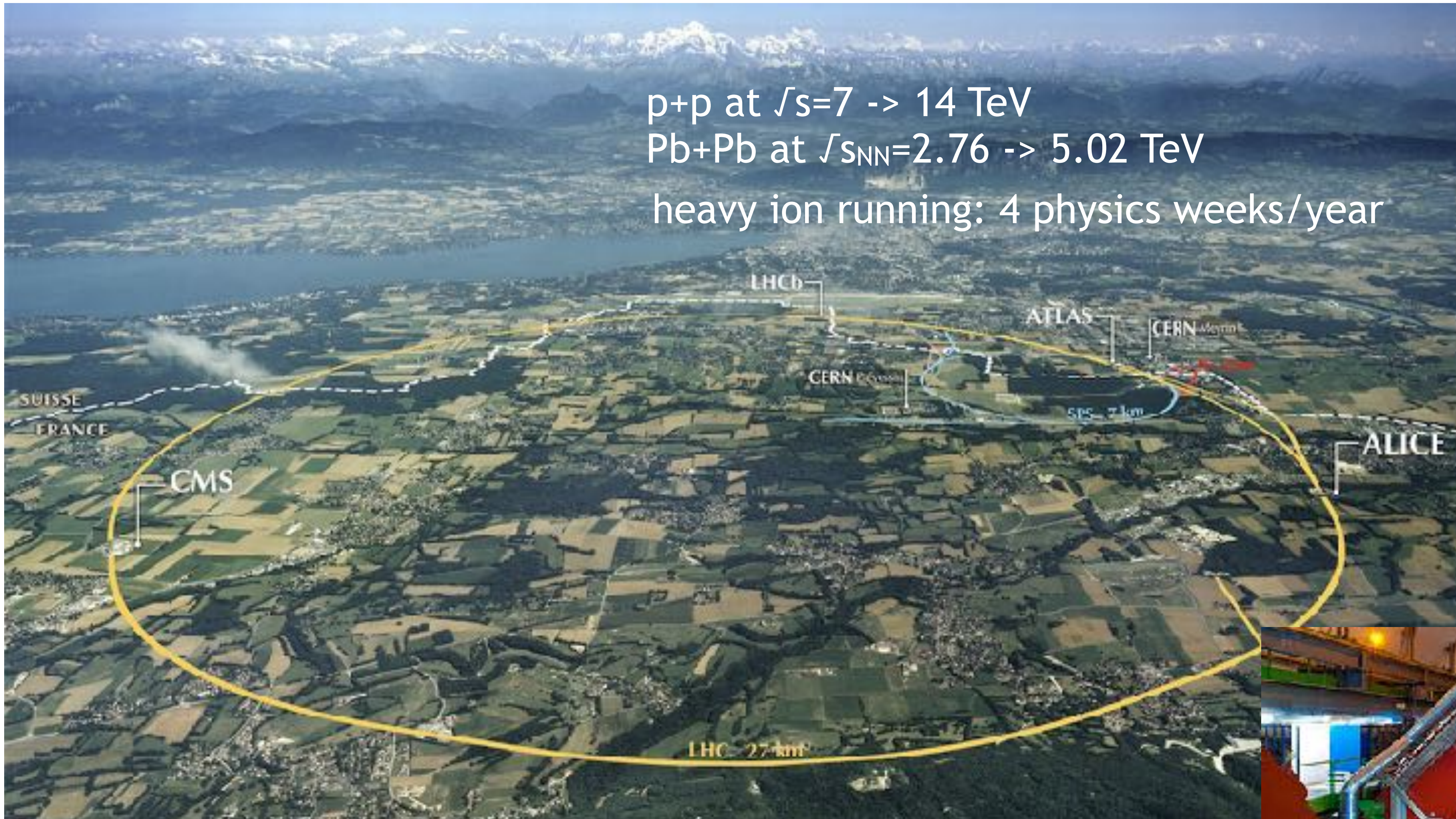
Introduction

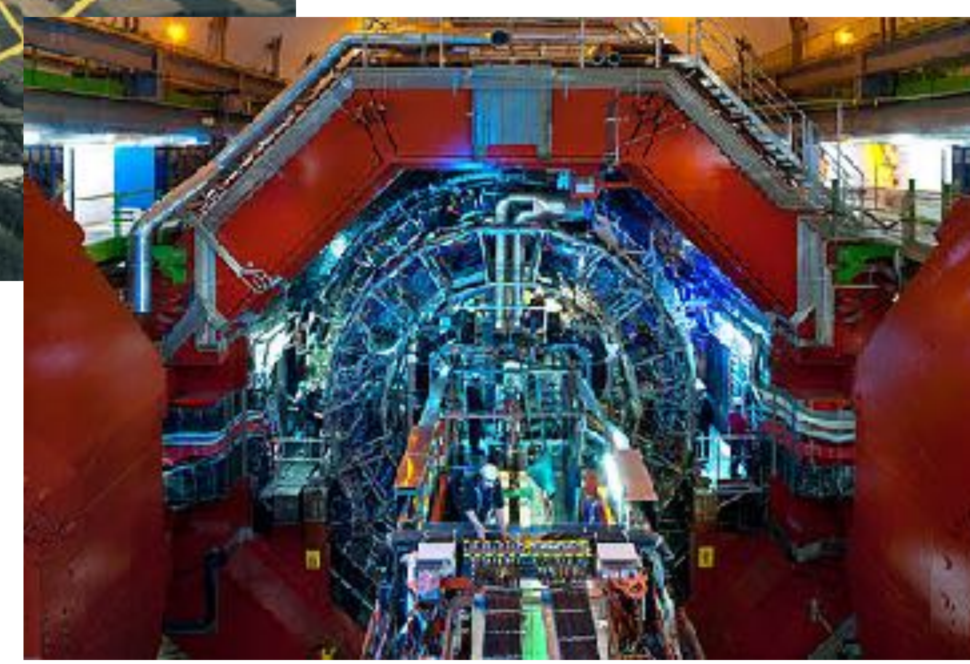
- Quantum Chromodynamics describes the dynamics of the strong interaction
  - Group structure SU(3) leads to asymptotically free coupling α_S at high energy/short distance
  - (lattice) QCD predicts phase transition where quarks are no longer confined within hadrons
- **Relativistic heavy-ion collisions** offer a way to explore the phase diagram of nuclear matter and to study the state of matter where quarks exist ‘free’, known as the **Quark Gluon Plasma** (QGP)





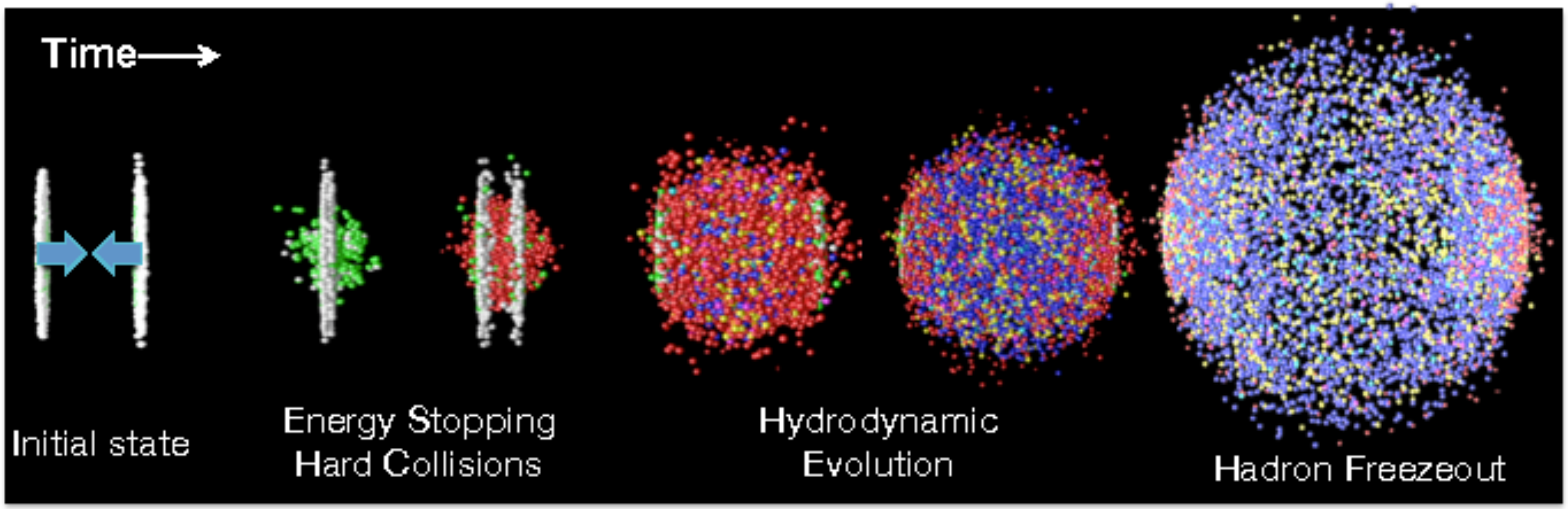
Heavy ion collisions at the LHC





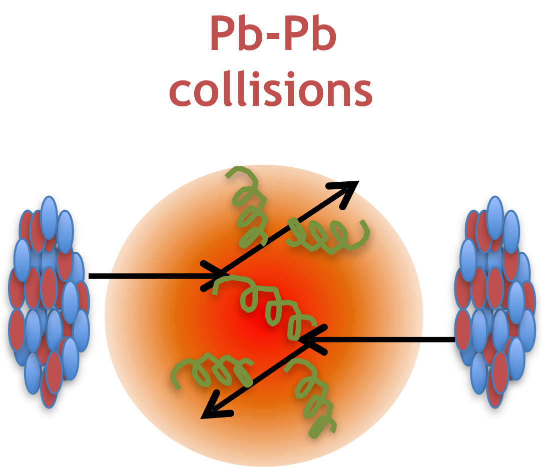
- ALICE is the experiment at the LHC designed and optimised to study heavy-ion collisions
  - Designed to **withstand huge particle multiplicities** (up to 10,000 tracks per event)
  - **High-precision tracking** over wide momentum range (down to very low track momentum
  - Excellent **particle identification** capabilities

Heavy ion collisions



We can study all stages of the system's evolution

Heavy-flavour production at ALICE

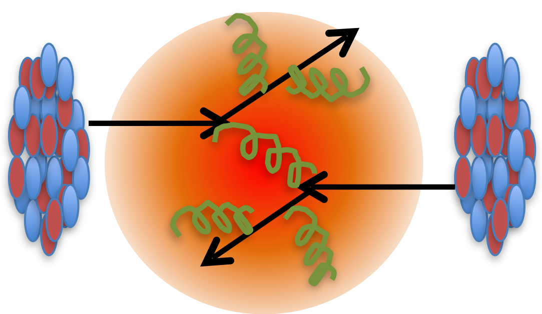


Heavy quarks (c,b)

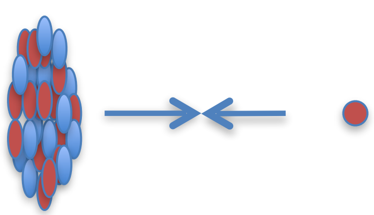
- Short formation time
- $m_{c,b} >> \Lambda_{QCD}$
  - Production described by pQCD down to pt=0 - ‘calibrated’ probe of the system
- Produced in the early stages of the collision and see full space-time evolution of collision system

Heavy-flavour production at ALICE

Pb-Pb collisions



p-Pb collisions



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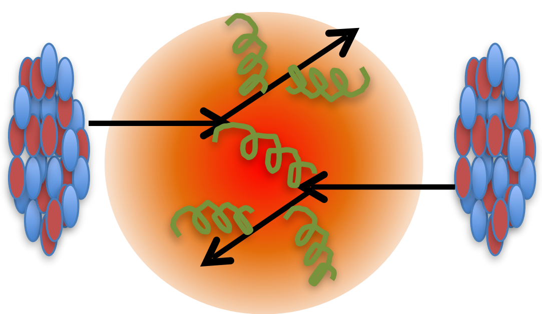
Smaller collision system helps disentangle hot/cold nuclear matter effects

- Modification of the PDFs in nuclei
- Final-state effects
  - Collectivity? Energy loss?

Heavy-flavour production at ALICE

Pb-Pb collisions



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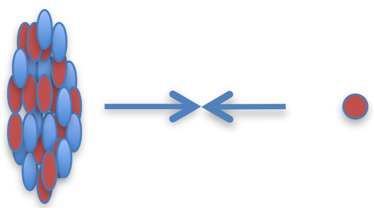

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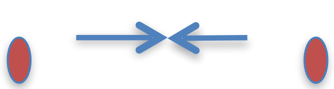
pp collisions

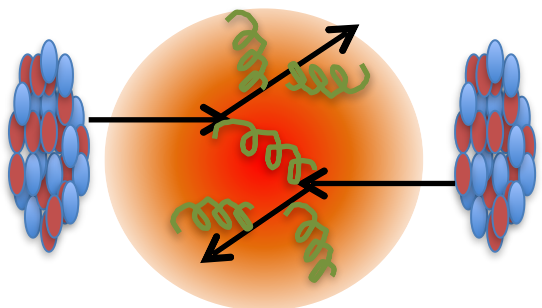


pp collisions

- Reference for p-Pb/Pb-Pb measurements
- Test of pQCD predictions/ production mechanisms
- Test of fragmentation, hadronisation
- Role of multi-parton interactions (MPIs)

Heavy-flavour production at ALICE

Pb-Pb collisions



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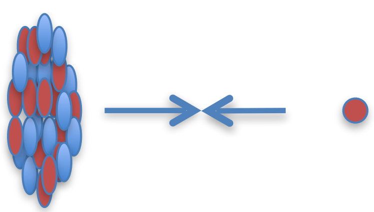

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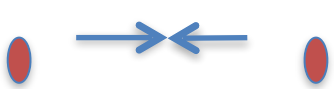
pp collisions



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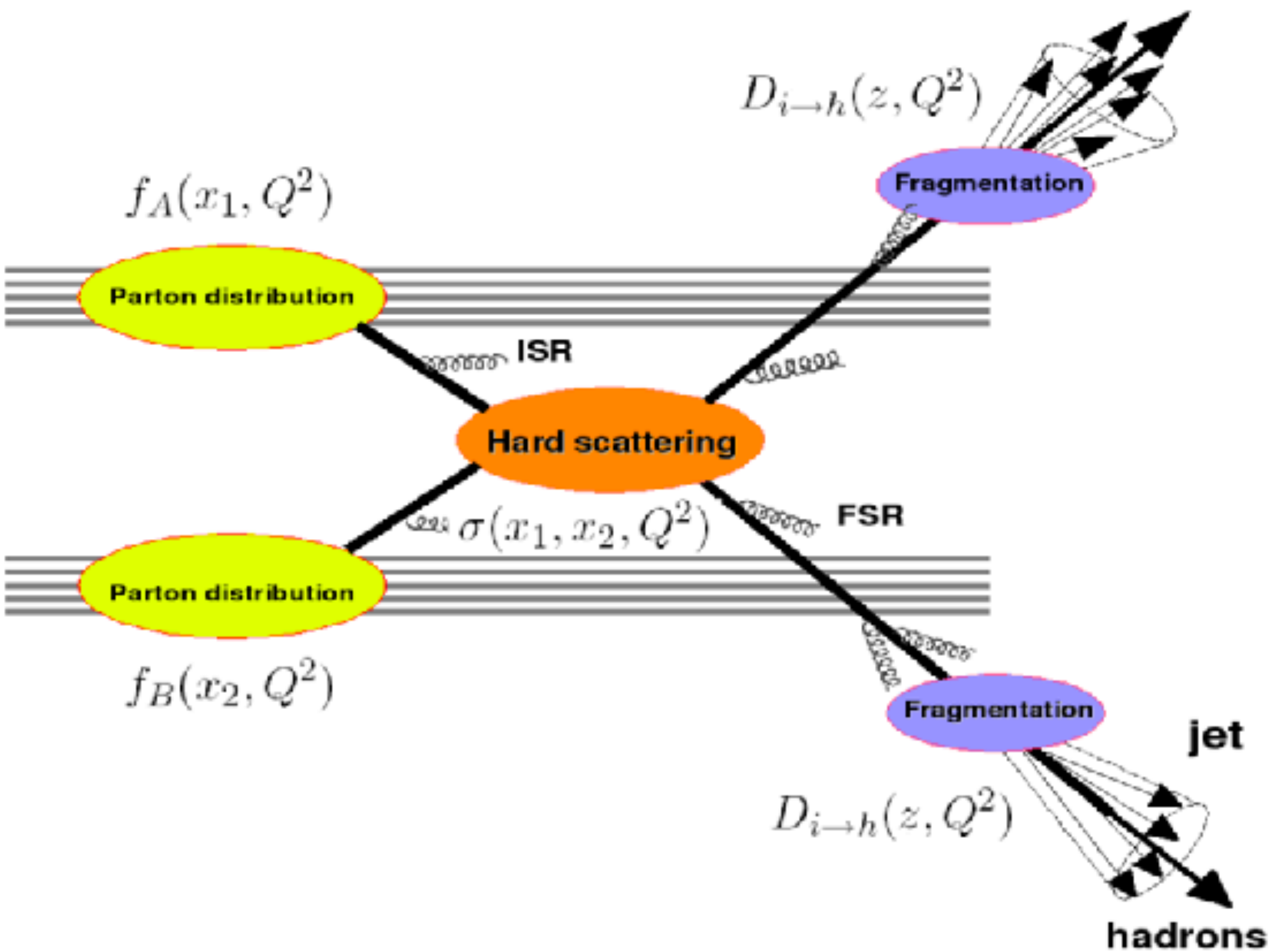
We ‘see’ heavy-flavour quarks as hadrons (bound quarks) - either mesons (Qq) or baryons (Qqq)

What can we learn from the measurement of heavy-flavour *baryons* measured at the ALICE experiment?

Heavy flavour hadron production in pp collisions

- Inclusive heavy-flavour hadron production can be calculated in QCD using the **factorisation theory**:

$$d\sigma^{hard}_{AB\to h} = f_{b/B}(x_1, Q^2) \otimes f_{a/A}(x_2, Q^2) \otimes d\sigma^{hard}_{ab\to c}(x_1, x_2, Q^2) \otimes D_{c\to h}(z, Q^2)$$



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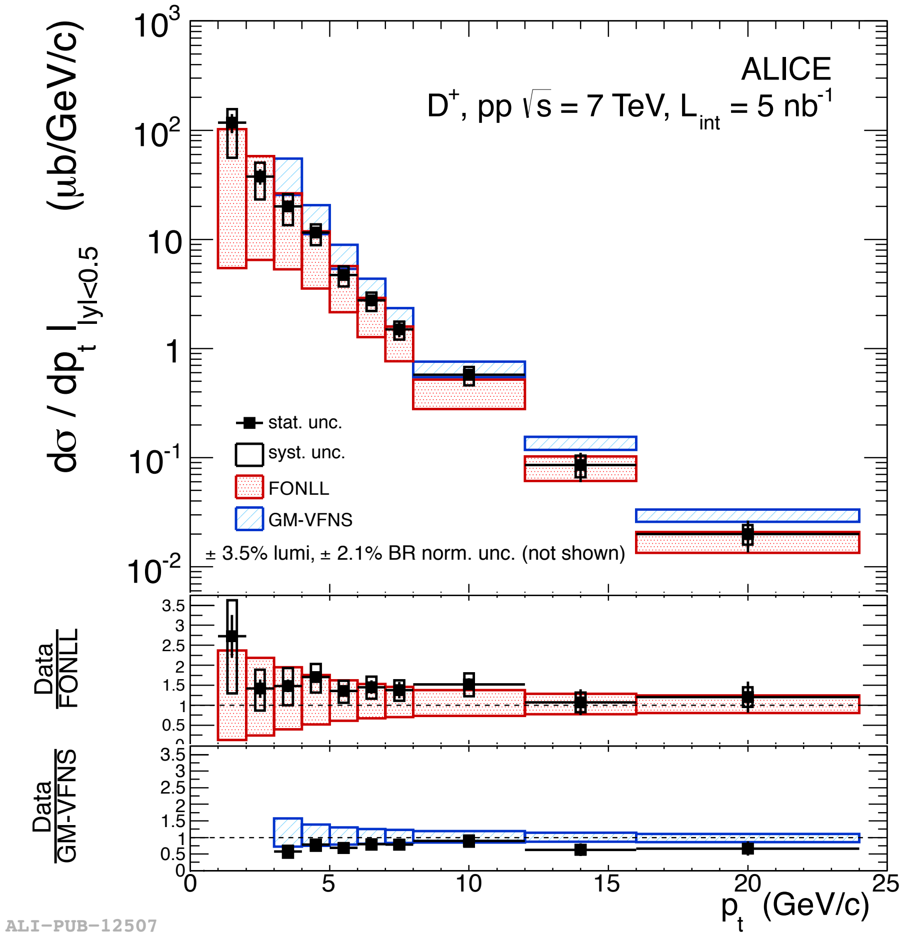
- **Production cross section** of *parton* c in *parton-parton* collision can be calculated with perturbative techniques for Q^2 >> ~200 MeV/c
- Different theoretical schemes have been developed to calculate dσ:
  - **General-Mass Variable-Flavour Number Scheme** (GM-VFNS)
    - Matches massive (high pT) and massless (low pT) perturbative QCD calculations at NLO
  - **Fixed Order Next-to-Leading Logarithm** (FONLL)
- **Schemes describes D-meson + B-meson production cross section over wide p_T range**



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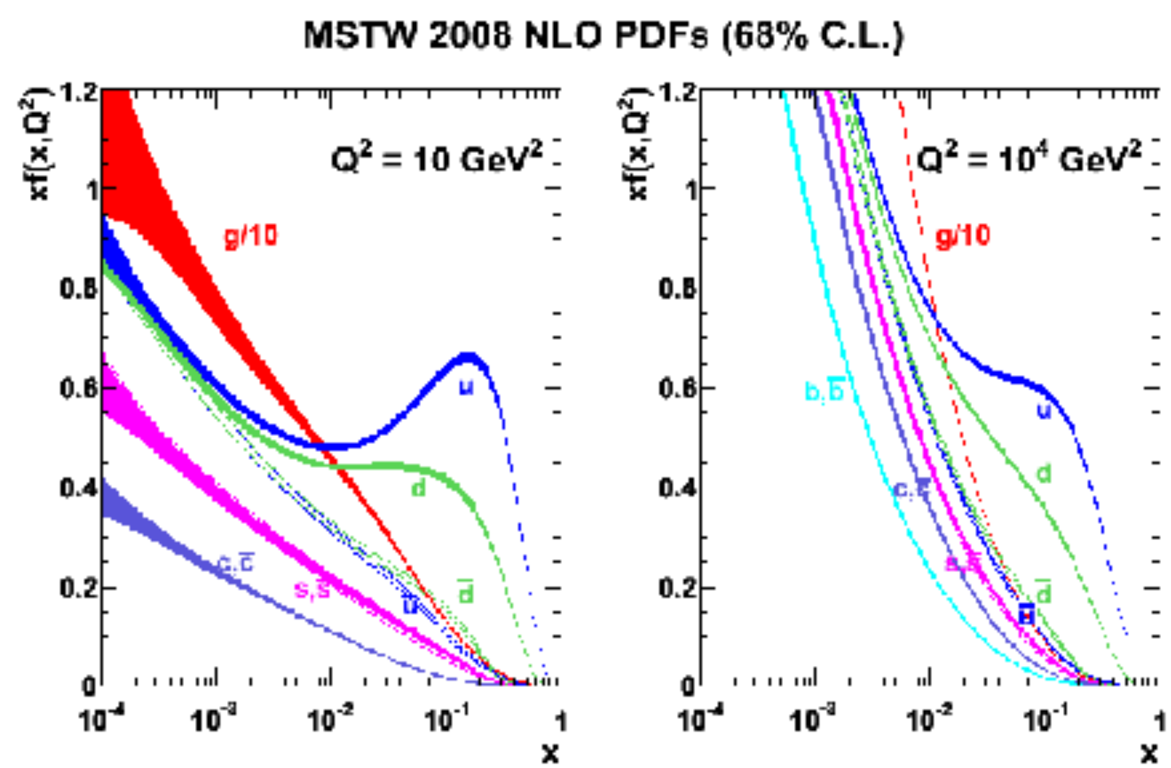
- The **parton distribution function** **(PDF)** $f_{a/A}(x, Q^2)$, parametrises the non-perturbative dynamics of the proton.
- Represents the probability of finding a parton of flavour a with a momentum fraction $x = p_{parton}/p_{proton}$ of the proton A, at a given momentum transfer Q^2
- Measured in deep inelastic scattering and evolved to different scales using pQCD (**DGLAP equations)**, well under control at LHC



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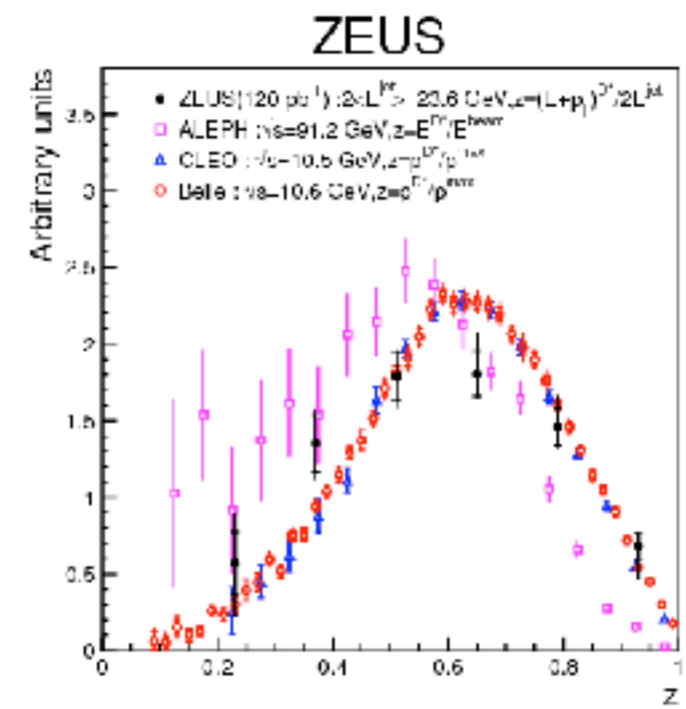
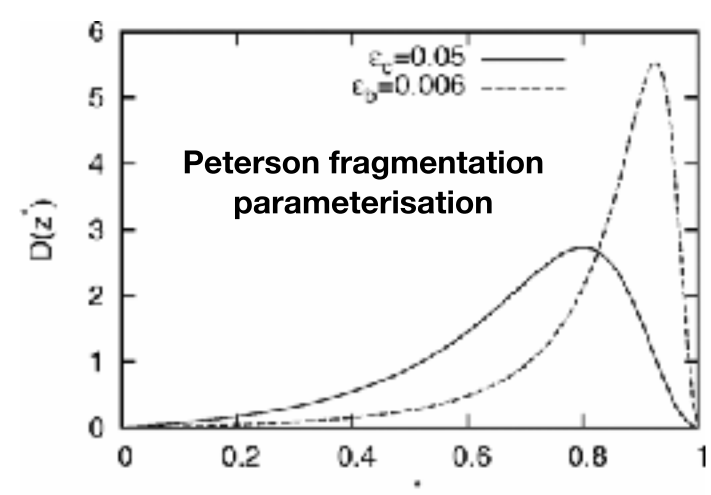
- The **fragmentation function** (FF) describes the probability that the outgoing parton fragments into a hadron h with fractional momentum z of the initial parton
- Measured at e^+e^- / ep colliders
- MC generators - Lund string fragmentation model
- Fragmentation fraction (percentage of quarks hadronising to given hadron) generally assumed to be universal (i.e. independent of collision energy/system)





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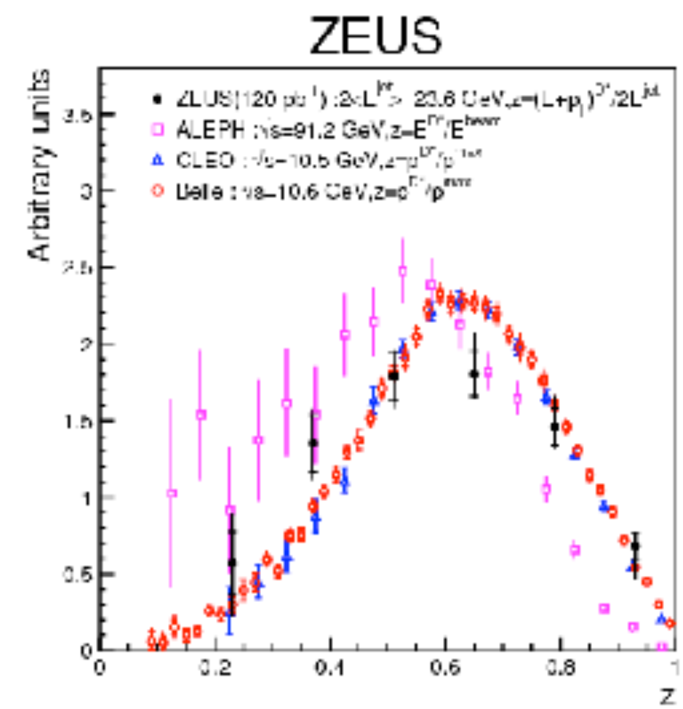
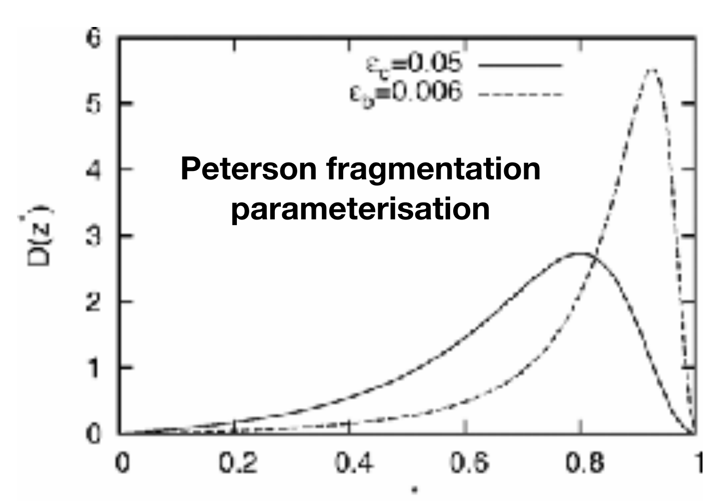
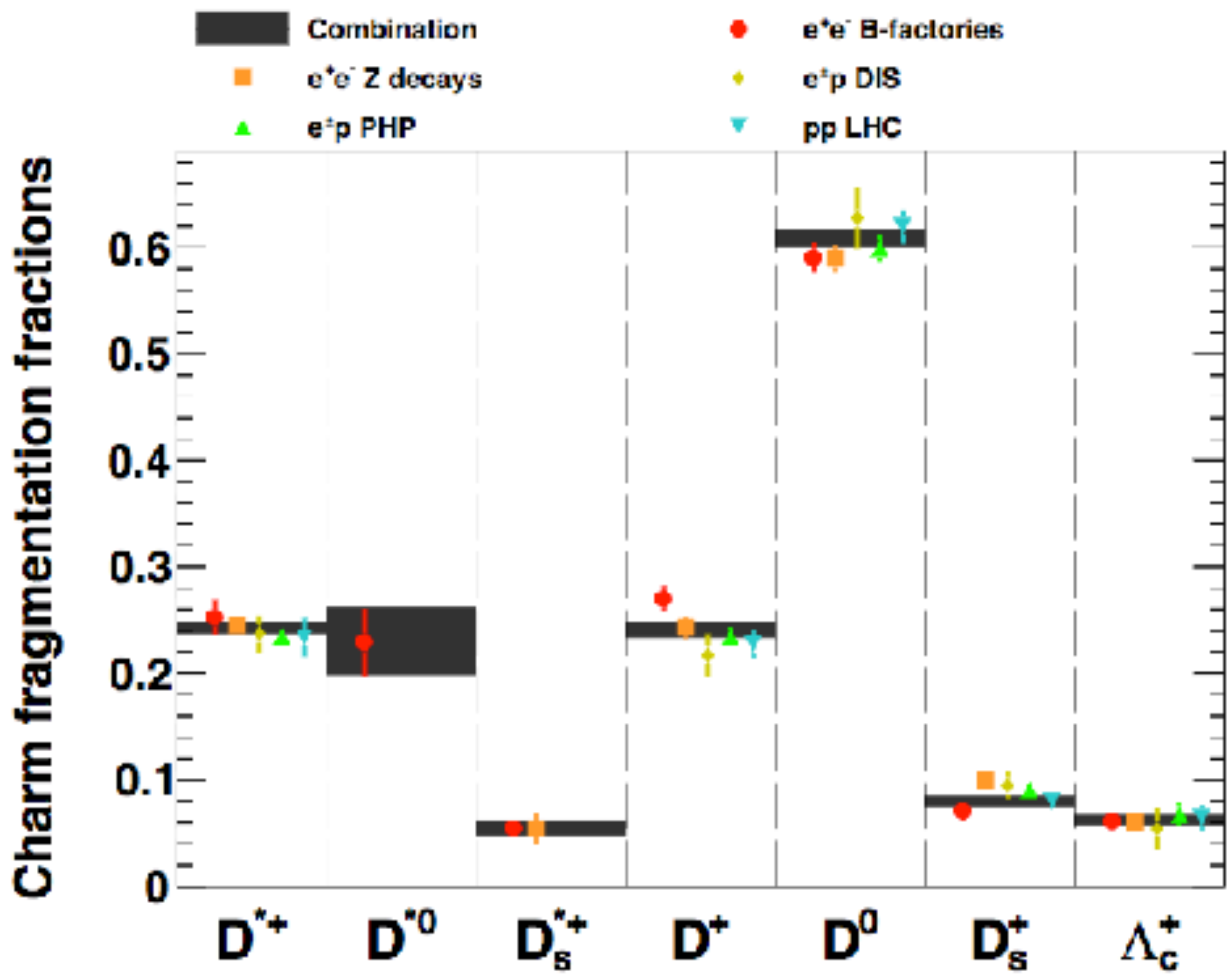
Is this assumption necessarily valid?





Charm fragmentation



EPJ C 76 (2016) no.7, 397

- Combination of charm decays (D mesons, Λ_C baryon) **supports hypothesis** that **charm fragmentation is independent of production process**
- However, note only 1 measurement in pp collisions at LHCb (will come back to this)

Beauty fragmentation

- From PDG review ‘production and decay of b-flavoured hadrons’ [1]

For rather long time, the average of fractions in $p\bar{p}$ collisions and in Z decay was used as it was assumed that the hadronization is identical in the two environments. It was clear that this assumption dost not have to hold in principle, because of the different momentum distributions of the b-quark in these processes; the sample used in the $p\bar{p}$ measurements has momenta close to the b mass, rather than $m_Z/2$.

The first indication that fraction for b-baryons depends on the momentum and thus environment came from CDF [38], but available precision did not allow for firm conclusion. The final evidence for non-universality of hadronization fractions came from LHCb, where strong dependence on the transverse momentum was observed for the Λ_b fraction [39].

Table 1: Fragmentation fractions of b quarks into weakly-decaying b-hadron species in $Z \to b\bar{b}$ decay, in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

b hadron	Fraction at Z [%]	Fraction at $\bar{p}p$[%]
B^+, B^0	40.4 ± 0.9	33.9 ± 3.9
B_s	10.3 ± 0.9	11.1 ± 1.4
b baryons	8.9 ± 1.5	21.2 ± 6.9

B-baryon fragmentation in ppbar collisions over 2x that in e^+e^- at Z resonance (though uncertainties large)

[1] http://pdg.lbl.gov/2015/reviews/rpp2015-rev-b-meson-prod-decay.pdf

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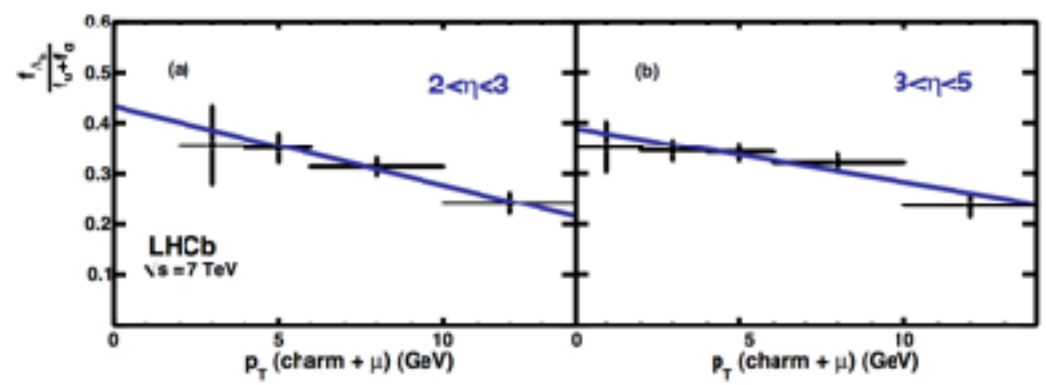


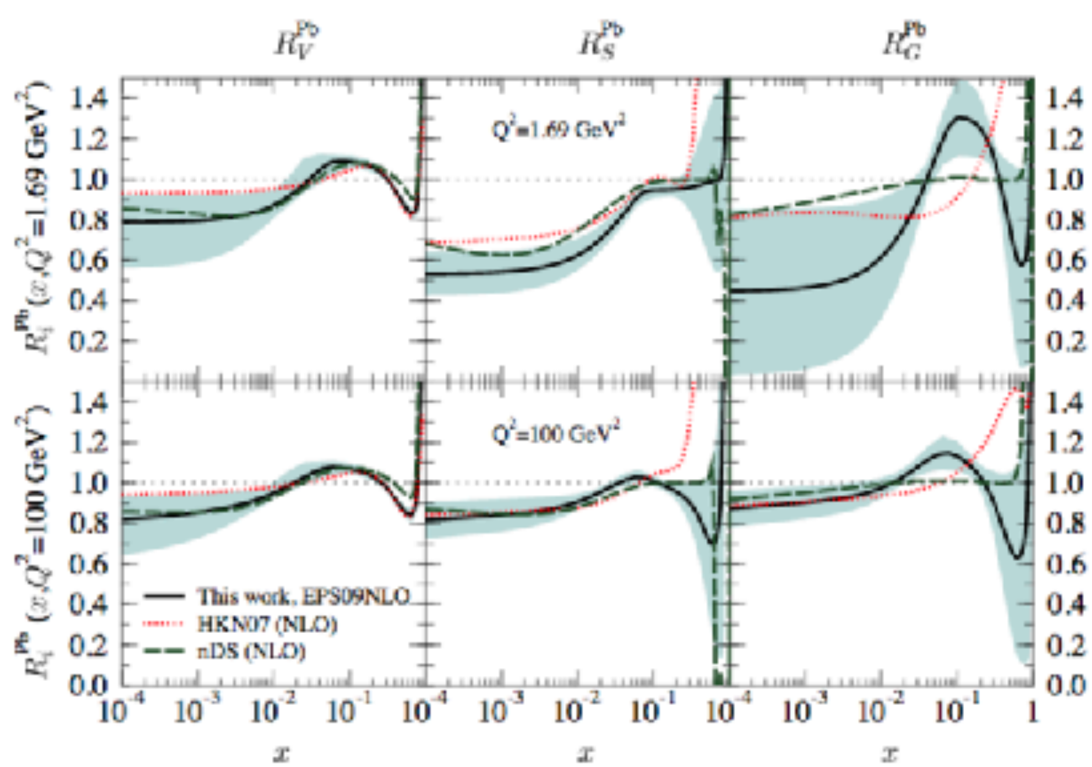
pT dependence for $f_{\Lambda b} / (f_u + f_d)$ [2]
($f_q \equiv B(b \rightarrow B_q)$)

[1] http://pdg.lbl.gov/2015/reviews/rpp2015-rev-b-meson-prod-decay.pdf
[2] Phys. Rev. D85 , 032008 (2012)

Heavy flavour hadron production in p-Pb collisions

- p-Pb collisions traditionally used to separate ‘hot’ effects in Pb-Pb collisions (effects due to deconfined QGP) from ‘cold nuclear matter effects’ (effects due to the presence of a nuclei)
- One effect of the presence of a nucleus - modification to the parton distribution function in the nucleus f_i^N :

$$f_i^N(x_i, Q^2) = R_i^N(x_i, Q^2) f_i(x_i, Q^2)$$

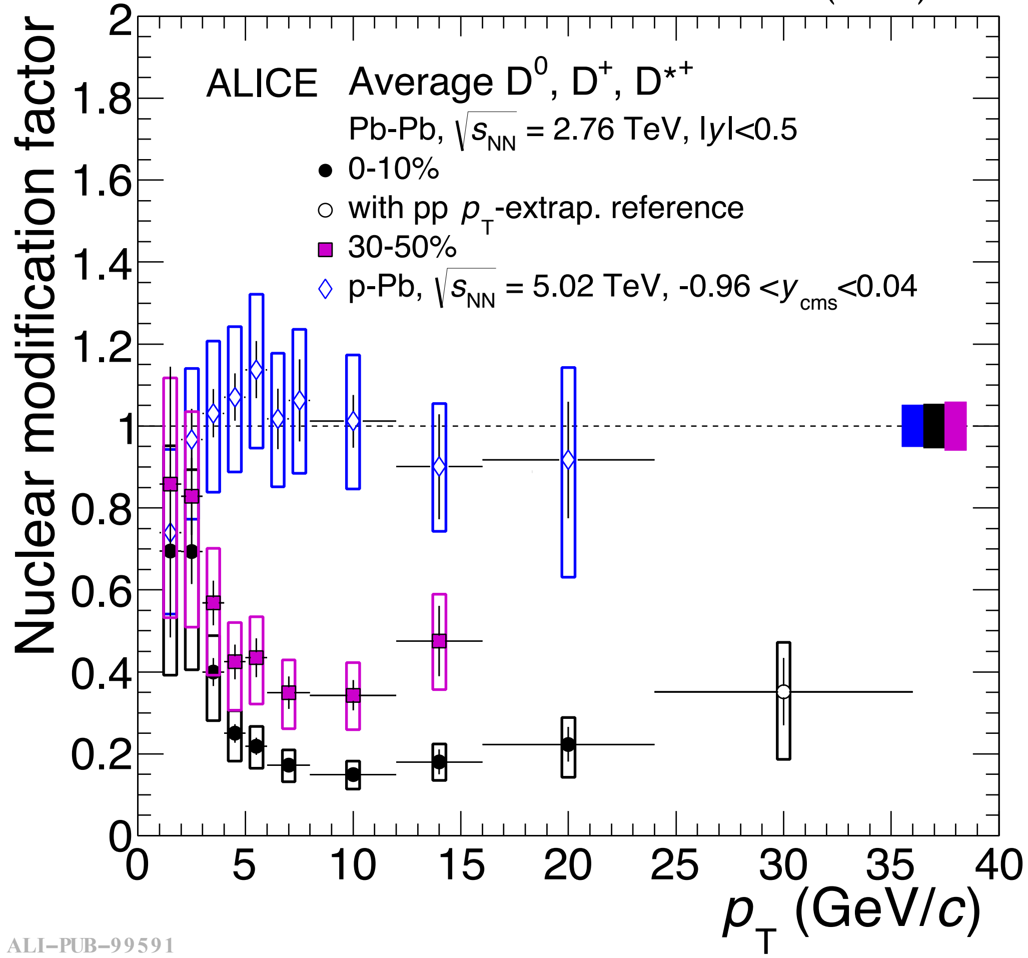


JHEP 0904:065,2009

Charm production in p-Pb collisions

$$R_{\mathrm{pPb}}(p_{\mathrm{T}}) = \frac{1}{A}\frac{\mathrm{d}\sigma_{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

JHEP 1603 (2016) 081



Seen as conclusive evidence that the suppression of high-pT charmed hadrons seen in Pb-Pb collisions was **due to a hot, deconfined medium**

central/peripheral yield

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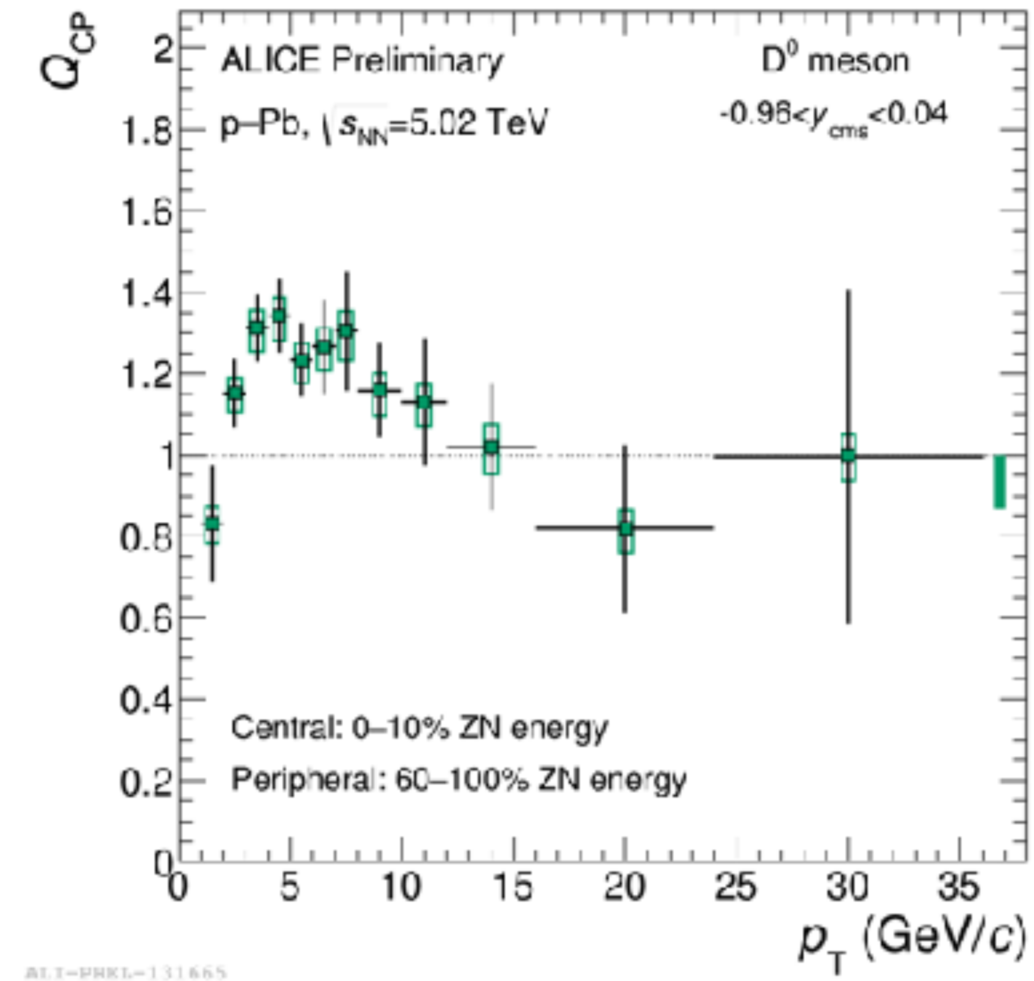
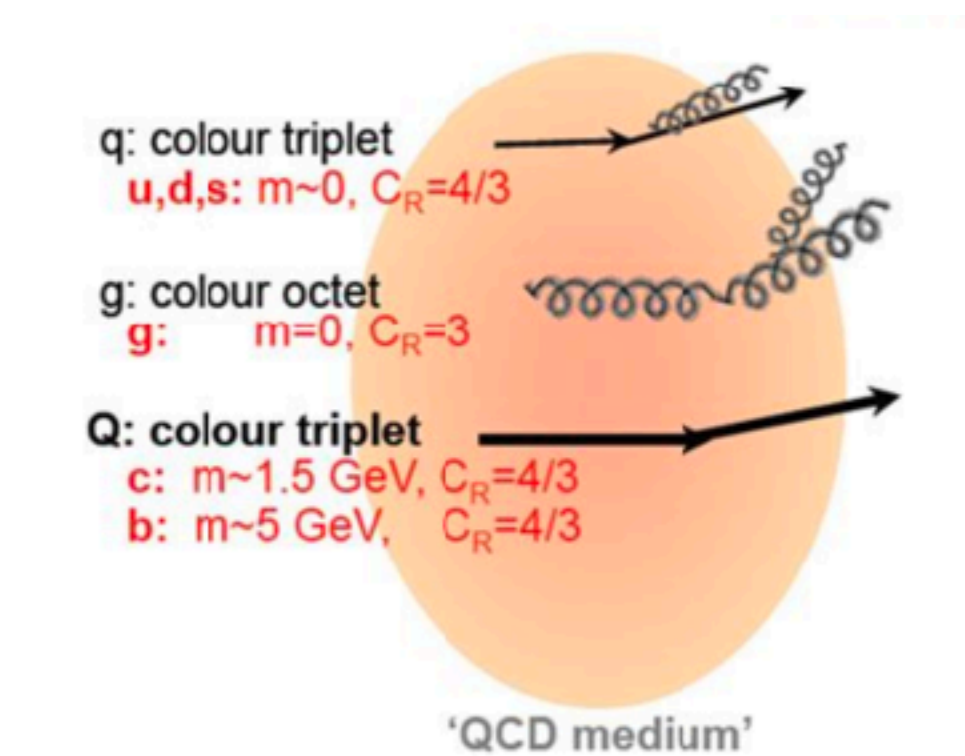


multiplicity dependence of D-meson yield? Some effects in p-Pb collisions to be understood

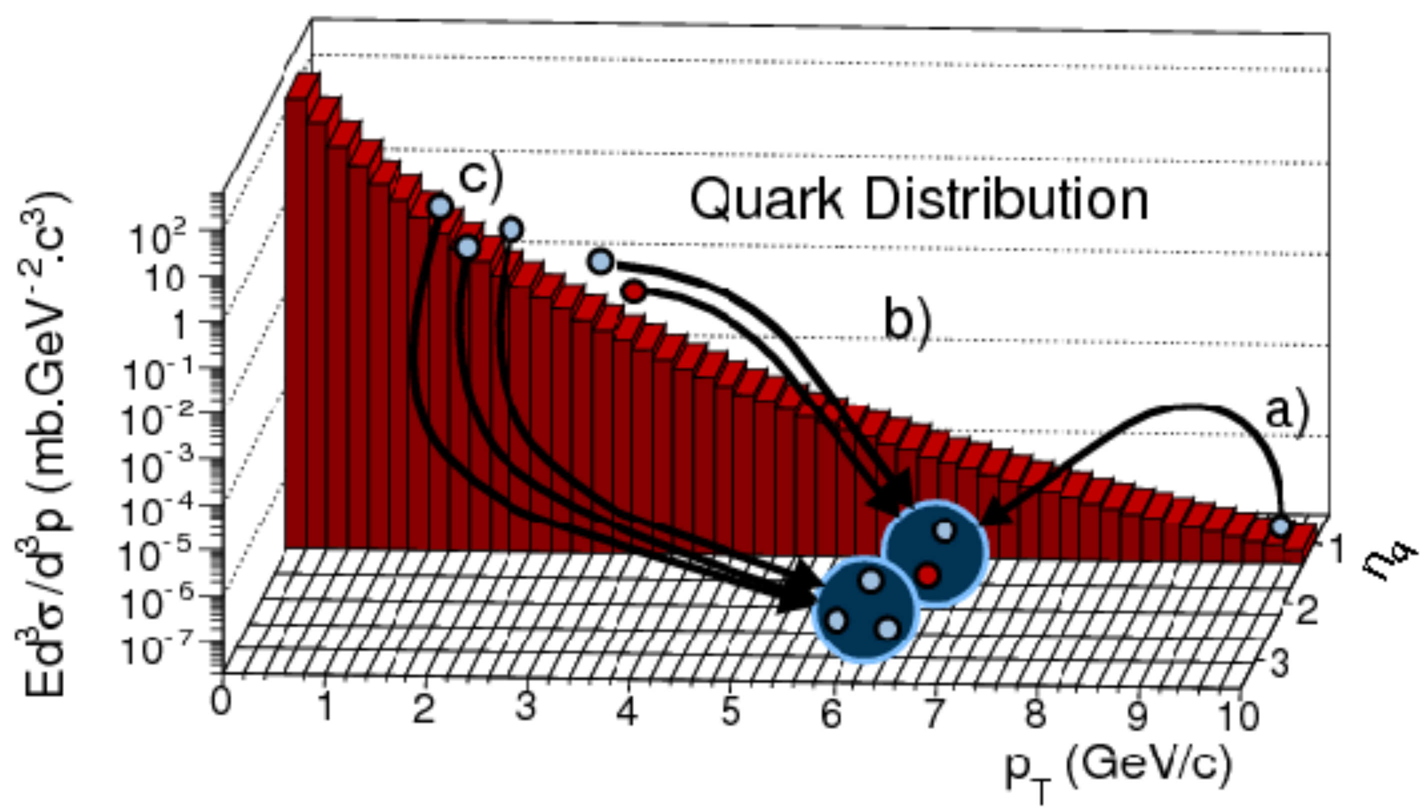
Is baryon production modified in p-Pb collisions?

Heavy flavour hadron production in AA collisions

- Heavy flavour production in AA collisions is a sensitive probe of:
  - **In-medium energy loss** of heavy quarks - transport properties of the Quark Gluon Plasma
  - Heavy quark participation in the **collective expansion** of the system
  - **Hadronisation mechanisms** - *fragmentation* vs *coalescence*



Flavour-dependent in-medium energy loss



Hadronisation via coalescence

A couple of highlights from AA collisions

$$R_{AA}(p_T) = \frac{dN_{AA}/dp_T}{\langle T_{AA}\rangle d\sigma_{pp}/dp_T}$$

$$\frac{d^2N}{d\varphi dp_T} = \frac{dN}{2\pi dp_T}\left[1 + 2\sum_{n=1}^{\infty} v_n(p_T)\cos n(\varphi - \Psi_n)\right]$$

$$\longrightarrow \quad v_2 = \langle \cos[2(\varphi - \Psi_2)] \rangle$$

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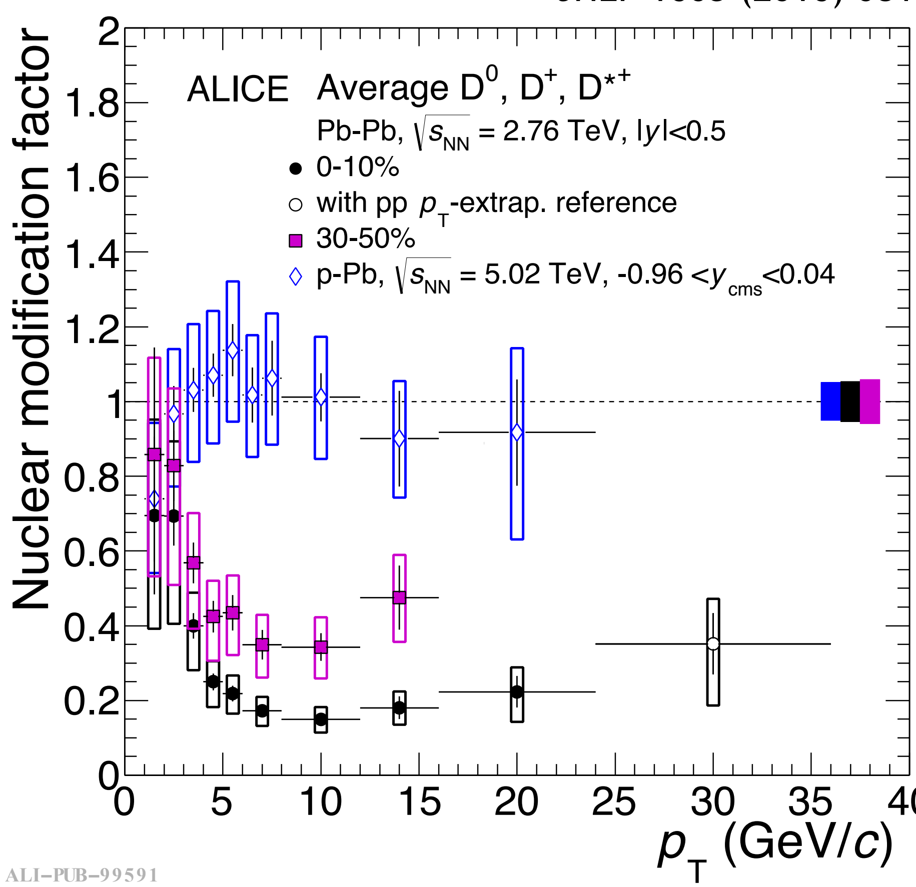
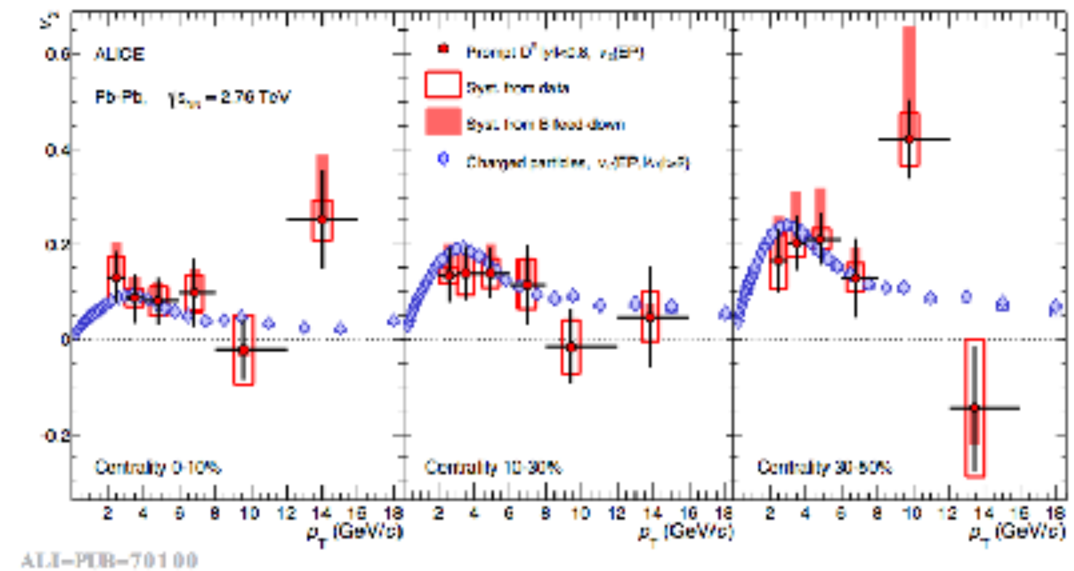


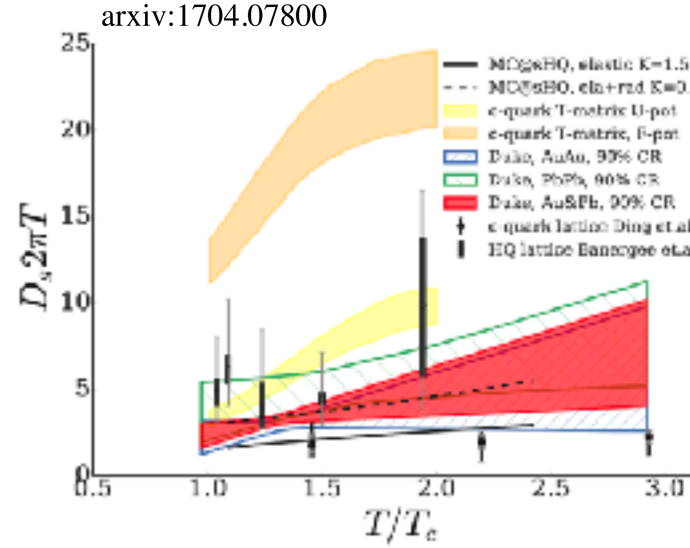
Strong suppression of high-pT light and charmed hadrons, indicating strong in-medium energy loss of high-pT partons

Phys. Rev. Lett. 111 (2013) 102301



Azimuthal anisotropy of light and charmed hadrons, indicates light and heavy quarks participate in collective expansion of the system

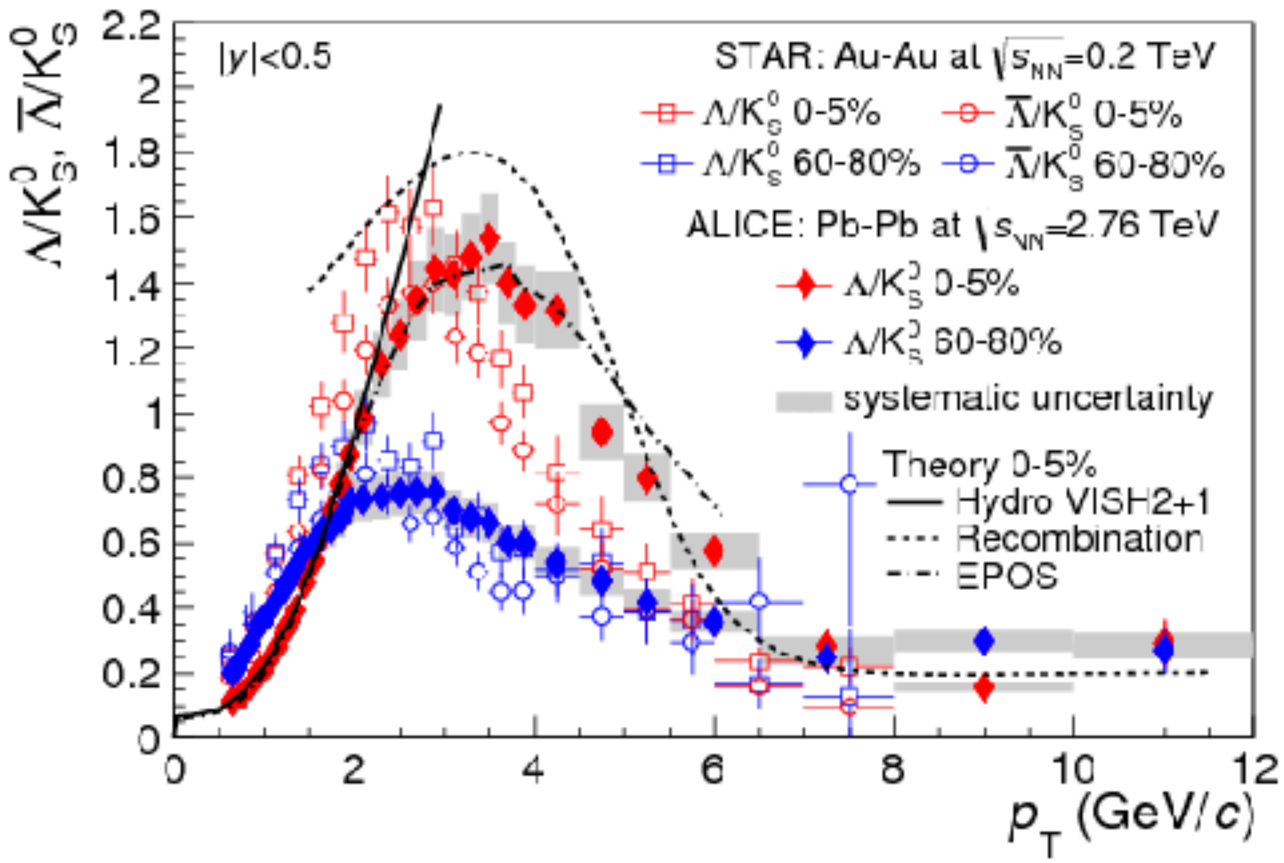
arxiv:1704.07800



Theoretical constraints to heavy-quark transport coefficients

Baryon-to-meson ratio

- Baryon-to-meson ratios gives a simple way to compare the fraction of charm quarks hadronising to baryons or mesons, and their dependence on p_T
- Measured in the light-flavour sector by ALICE, usually to compare to Pb-Pb
  - Proton/pion and Λ/K^0_s ratios enhanced in Pb-Pb collisions



Coalescence? flow? Interplay between both effects?

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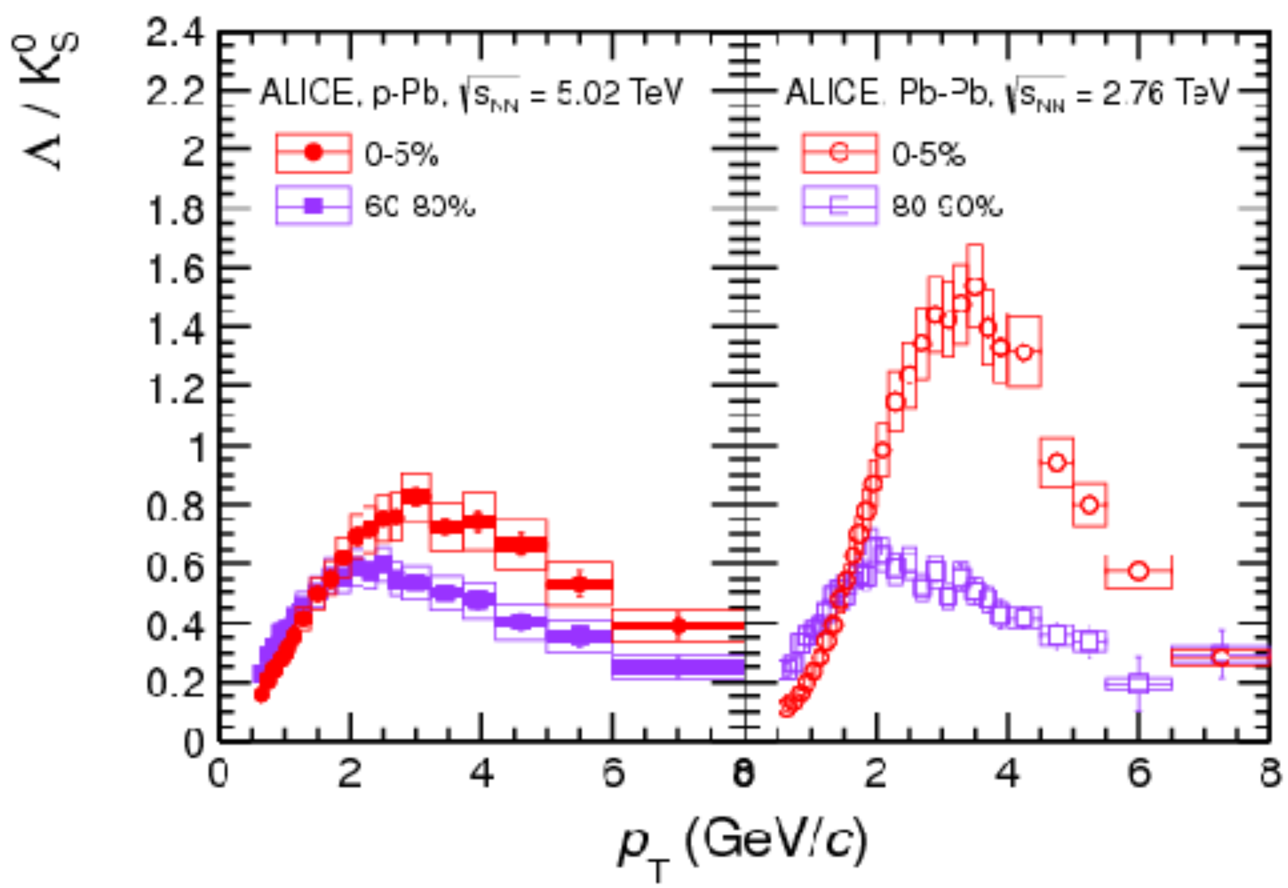
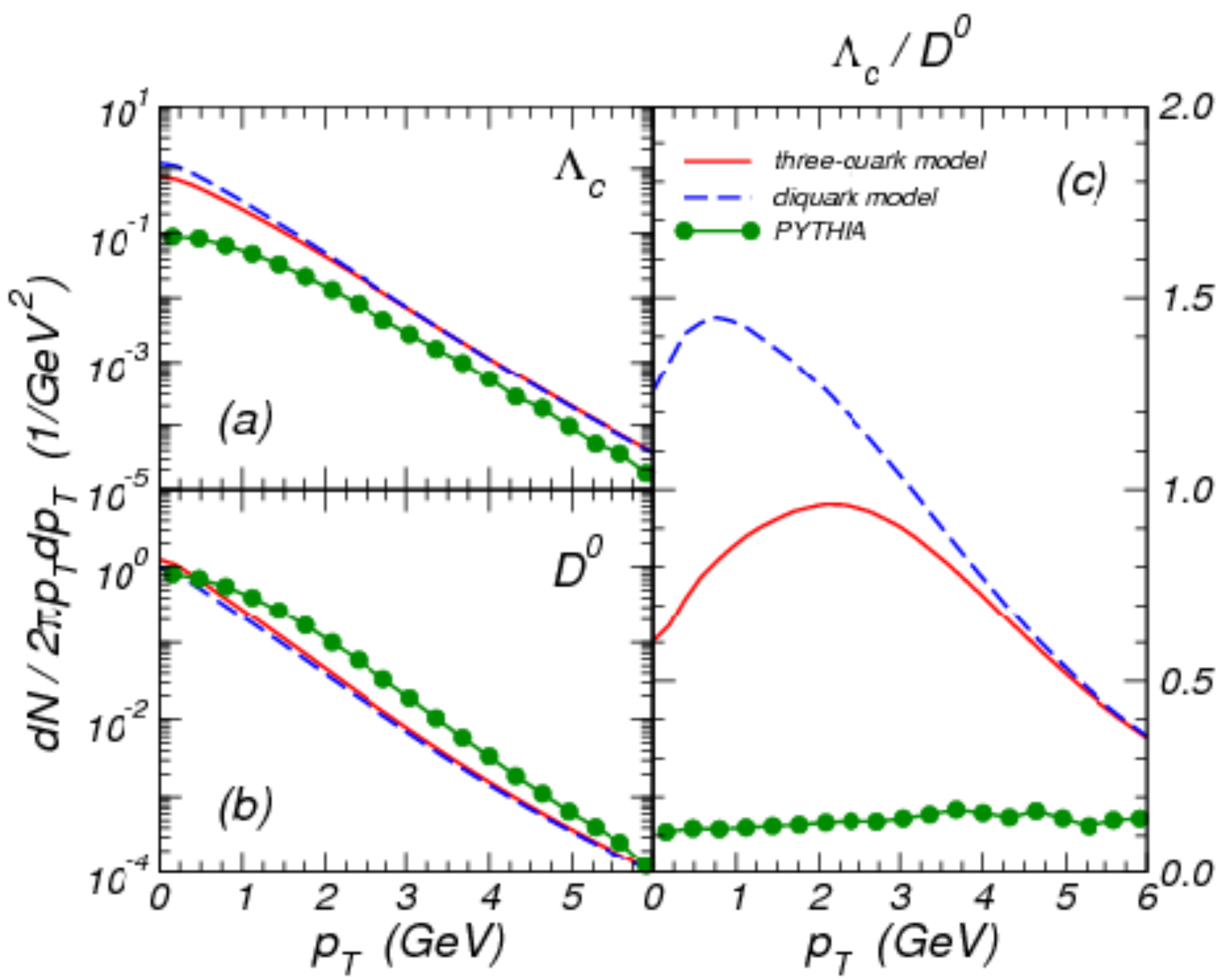


Enhancement also seen in smaller systems

Charmed baryon-to-meson ratio in Pb-Pb collisions

- The **baryon-to-meson ratio** in the charm sector in Pb-Pb collisions aims to test:
  - **Hadronisation via coalescence** [1,2]
    - **Large enhancement** expected in coalescence plays a role
  - **Diquarks in medium?** [3]
    - Binary, coloured bound states *qq*, *qg*, *gg* may exist in medium
    - Coalescence between c quark and ud light quark bound state would create **further enhancement** in the Λ_C/D^0 ratio
- Measurements in pp and p-Pb collisions also provide an **essential reference** for charmed baryon measurements in Pb-Pb collisions

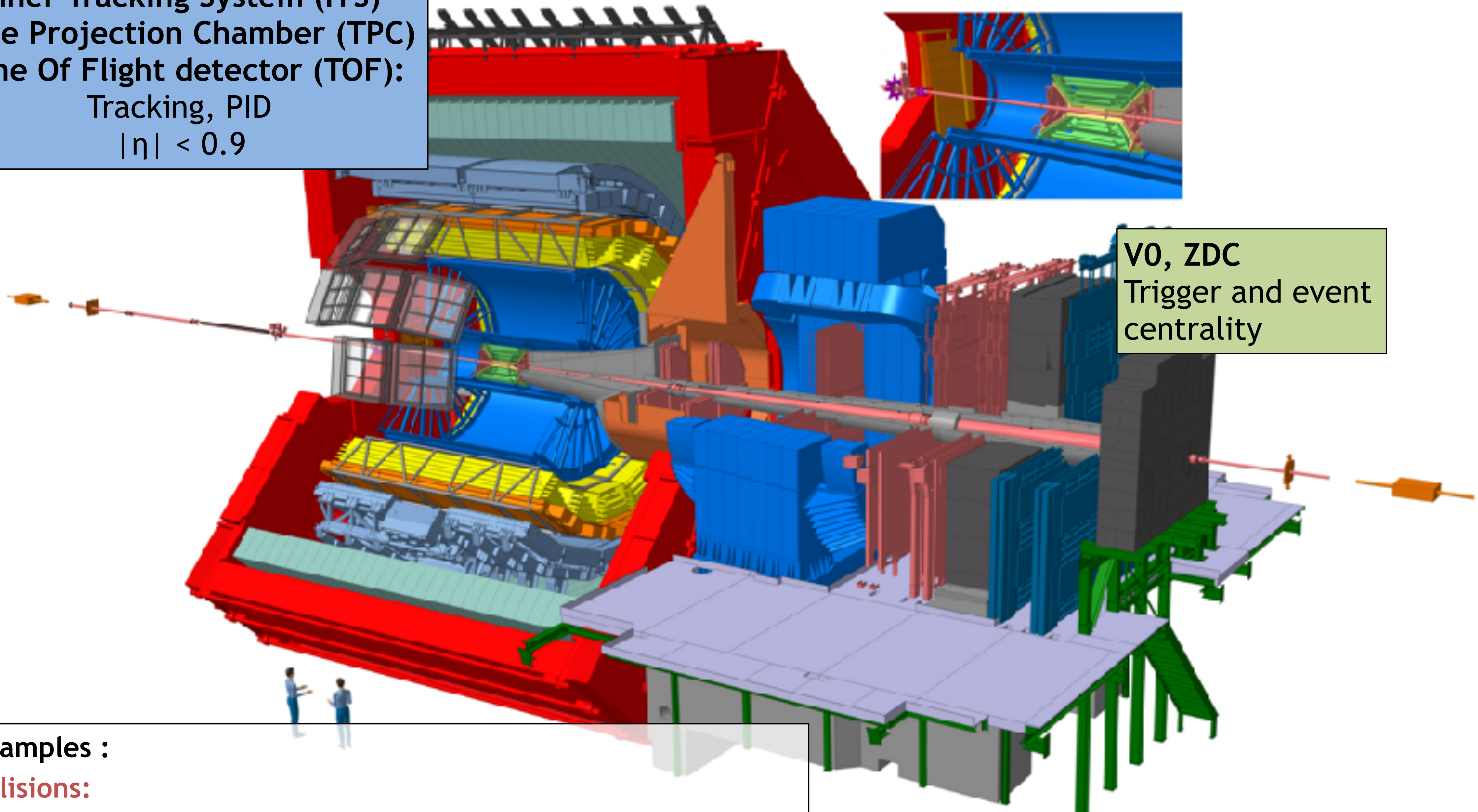


[1] S. H. Lee et al., Phys.Rev.Lett. 100 (2008) 222301
[2] Oh, Yongseok et al. Phys.Rev. C79 (2009) 044905
[3] L. Zhou, arXiv:1704.04364

Charmed baryon production measurements at ALICE

ALICE apparatus and datasets

Inner Tracking System (ITS)
Time Projection Chamber (TPC)
Time Of Flight detector (TOF):
Tracking, PID
$|\eta| < 0.9$



V0, ZDC
Trigger and event centrality

Data samples :

pp collisions:

- $\sqrt{s}$ **= 7 TeV :** ~370x10[6] min. bias events, L_{int} = 6.0 nb^{-1}

p-Pb collisions

- $\sqrt{s}$ **= 5.02 TeV :** ~100x10[6] min. bias events, L_{int} = 48.6 μb^{-1}

Charmed baryon production measurements

Λ_c^+ → M = 2.2684 GeV/c^2, cτ ~ 60μm

Ξ_c^0 → M = 2.47199 GeV/c^2, cτ ~ 34μm

$\Lambda_c^+ \rightarrow pK\pi^+$	**BR ~ 6.35%**
$\Lambda_c^+ \rightarrow pK^0_S$	**BR ~ 1.58%**
$\Lambda_c^+ \rightarrow e^+\Lambda\nu_e$	**BR ~ 3.6%**
$\Xi_c^0 \rightarrow e^+\Xi^-\nu_e$	**BR unknown**

Charmed baryon p_T-differential cross section is calculated as:

Raw yield fraction determined to be prompt

Raw yield - number of reconstructed signal

$$\frac{\mathrm{d}^2\sigma^{\Lambda_c^+}}{\mathrm{d}p_T\mathrm{d}y} = \frac{1}{2c_{\Delta y}\Delta p_T}\frac{1}{\mathrm{BR}}\frac{f_{\mathrm{prompt}}\cdot N^{\Lambda_c}_{|y|<y_{\mathrm{fid}}}}{(A\times\epsilon)_{\mathrm{prompt}}}\frac{1}{L_{\mathrm{int}}}$$

p_T, rapidity window of measurement

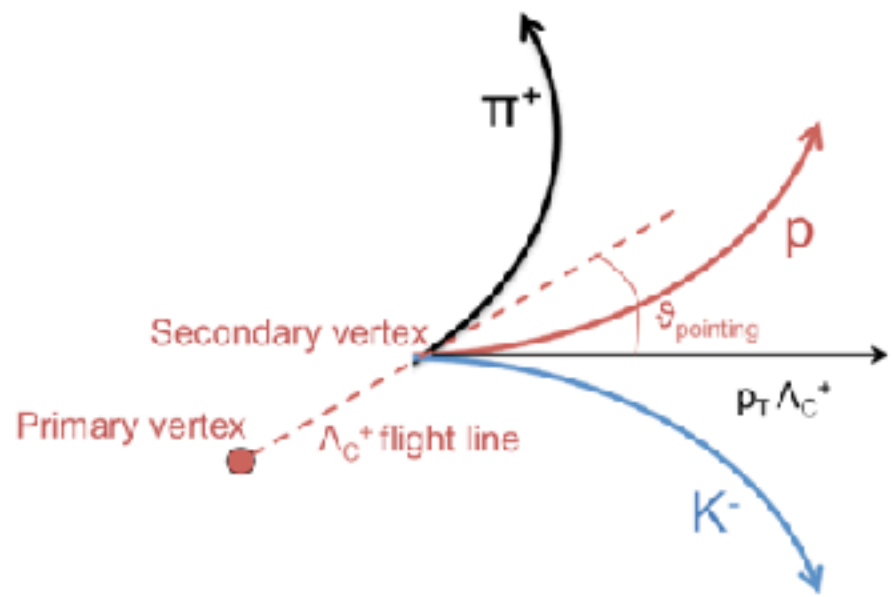
Branching fraction of Λ_c decay

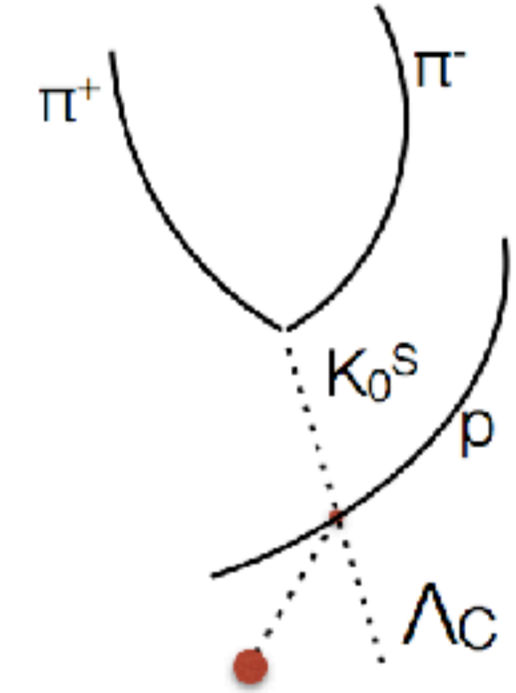
Acceptance, efficiency corrections

Integrated luminosity

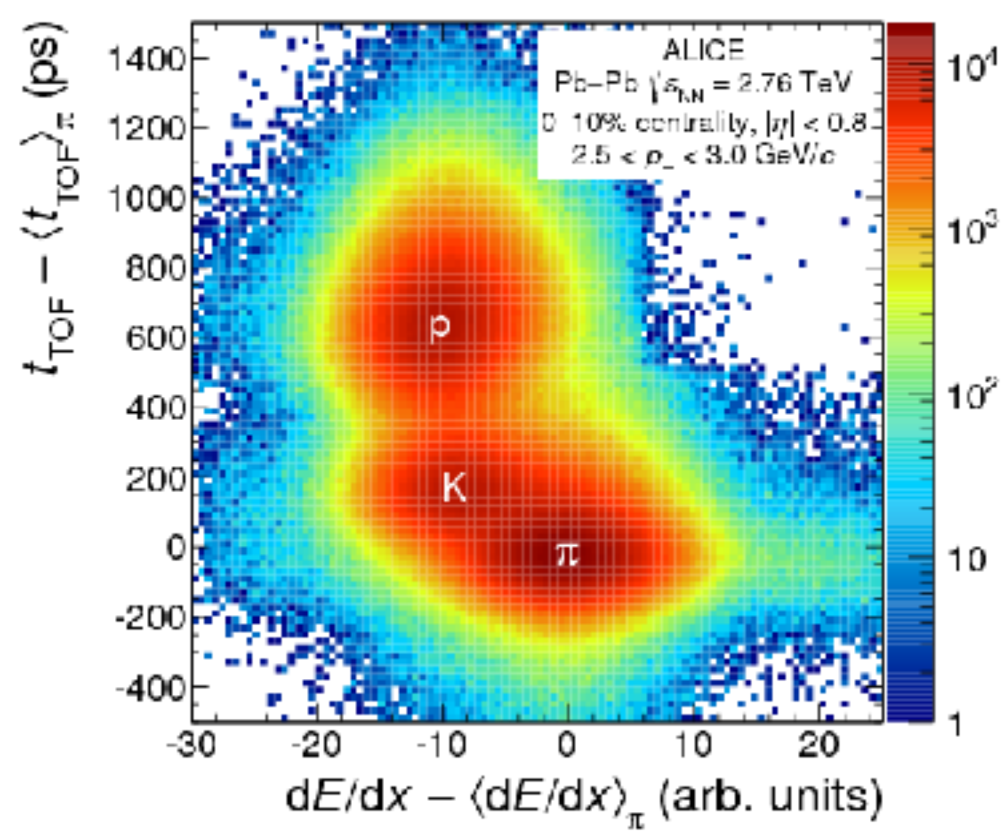
Λ_C hadronic decay reconstruction

- **PID** using TPC via d*E*/d*x* and TOF via time of flight measurement
  - nσ cuts, or Bayesian approach to identify particles



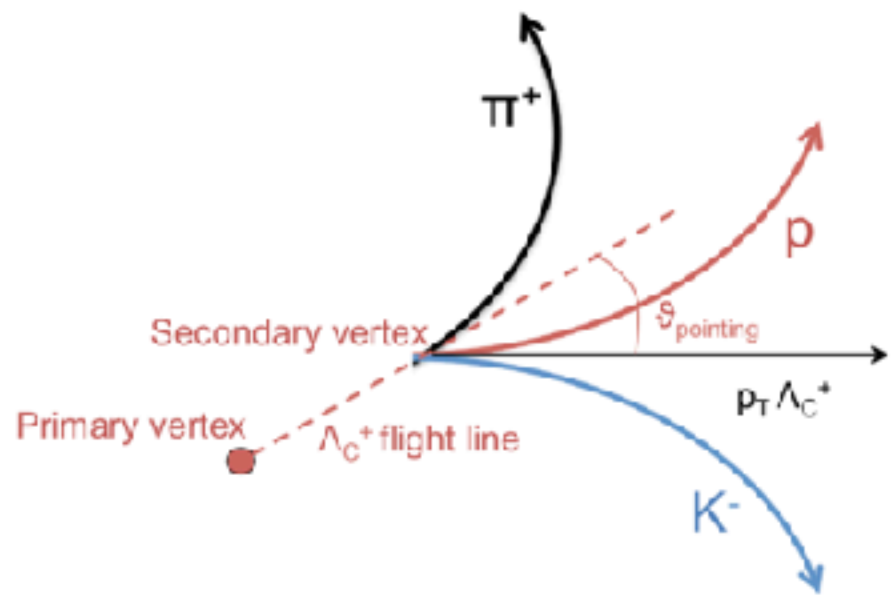


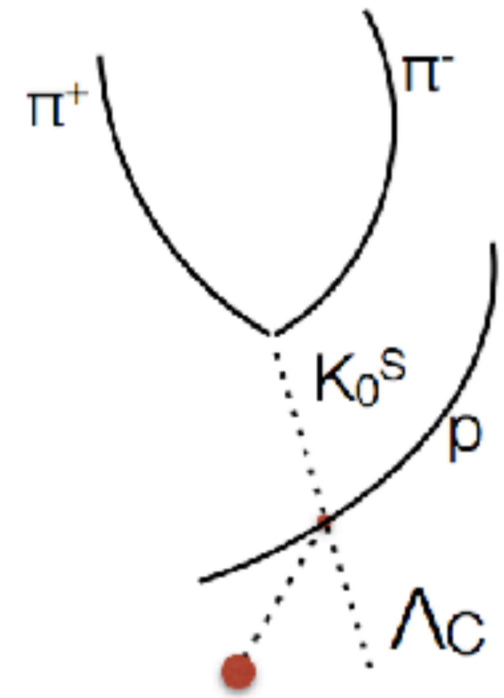
$$P(H_i|\vec{S}) = \frac{P(\vec{S}|H_i)C(H_i)}{\sum_{k=e,\mu,\pi,\ldots} P(\vec{S}|H_k)C(H_k)}$$

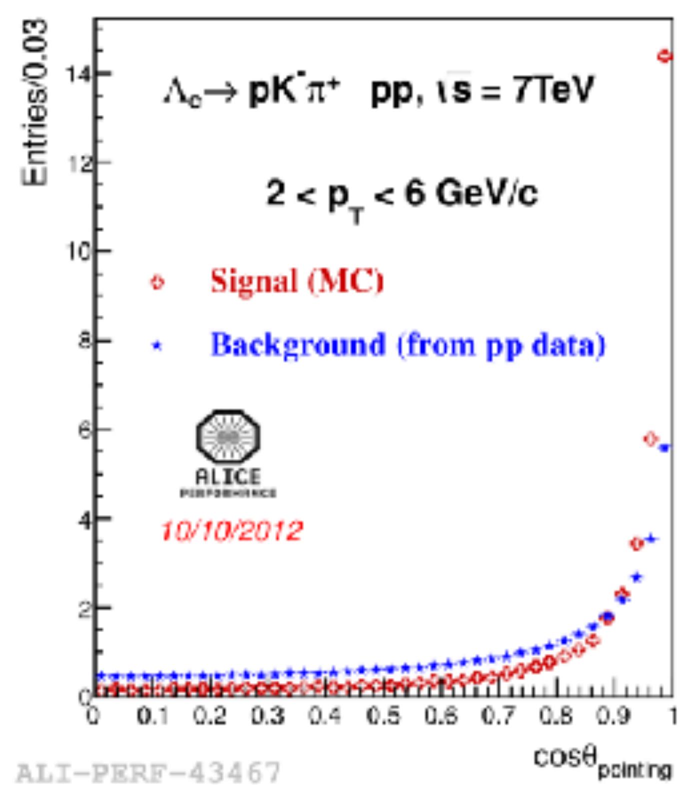


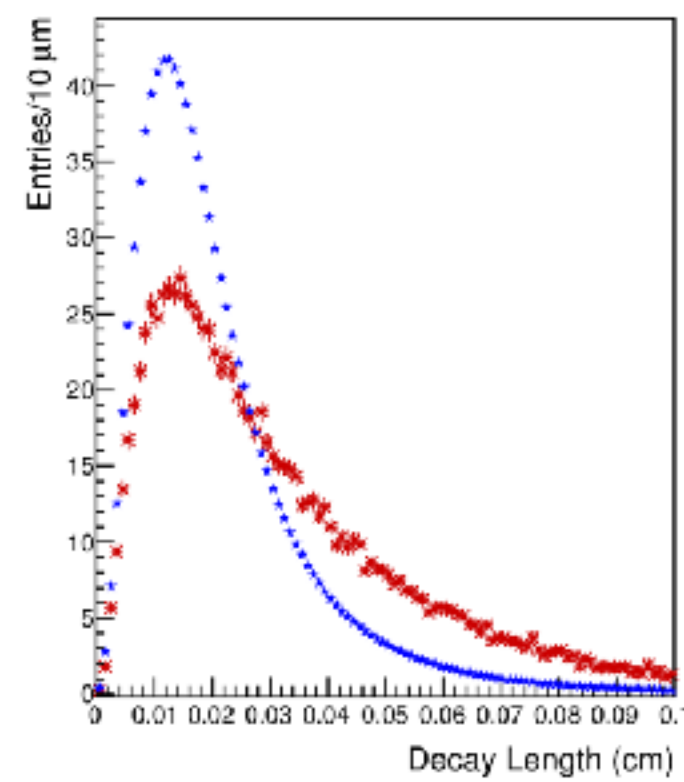
Λ_C hadronic decay reconstruction

- **PID** using TPC via d*E*/d*x* and TOF via time of flight measurement
  - nσ cuts, or Bayesian approach to identify particles
- **Cuts on decay topologies** exploiting decay vertex displacement from primary vertex



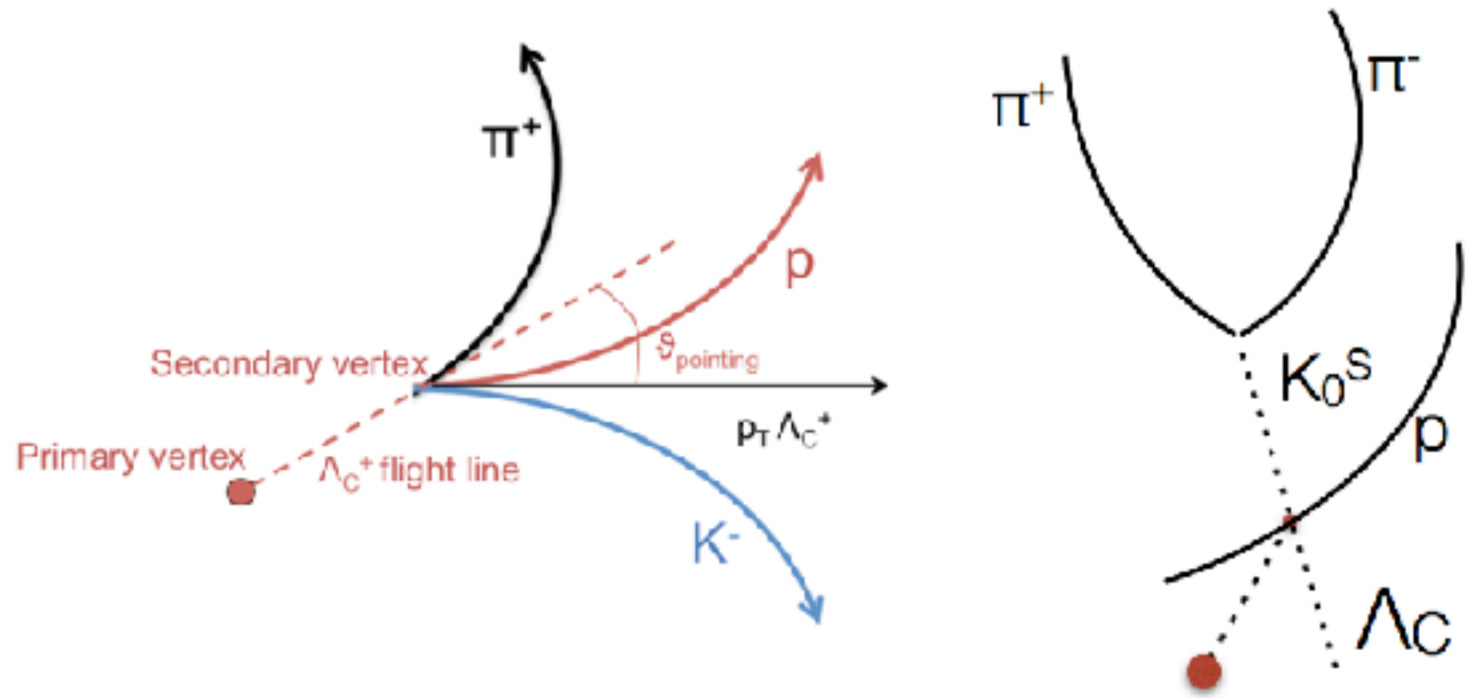


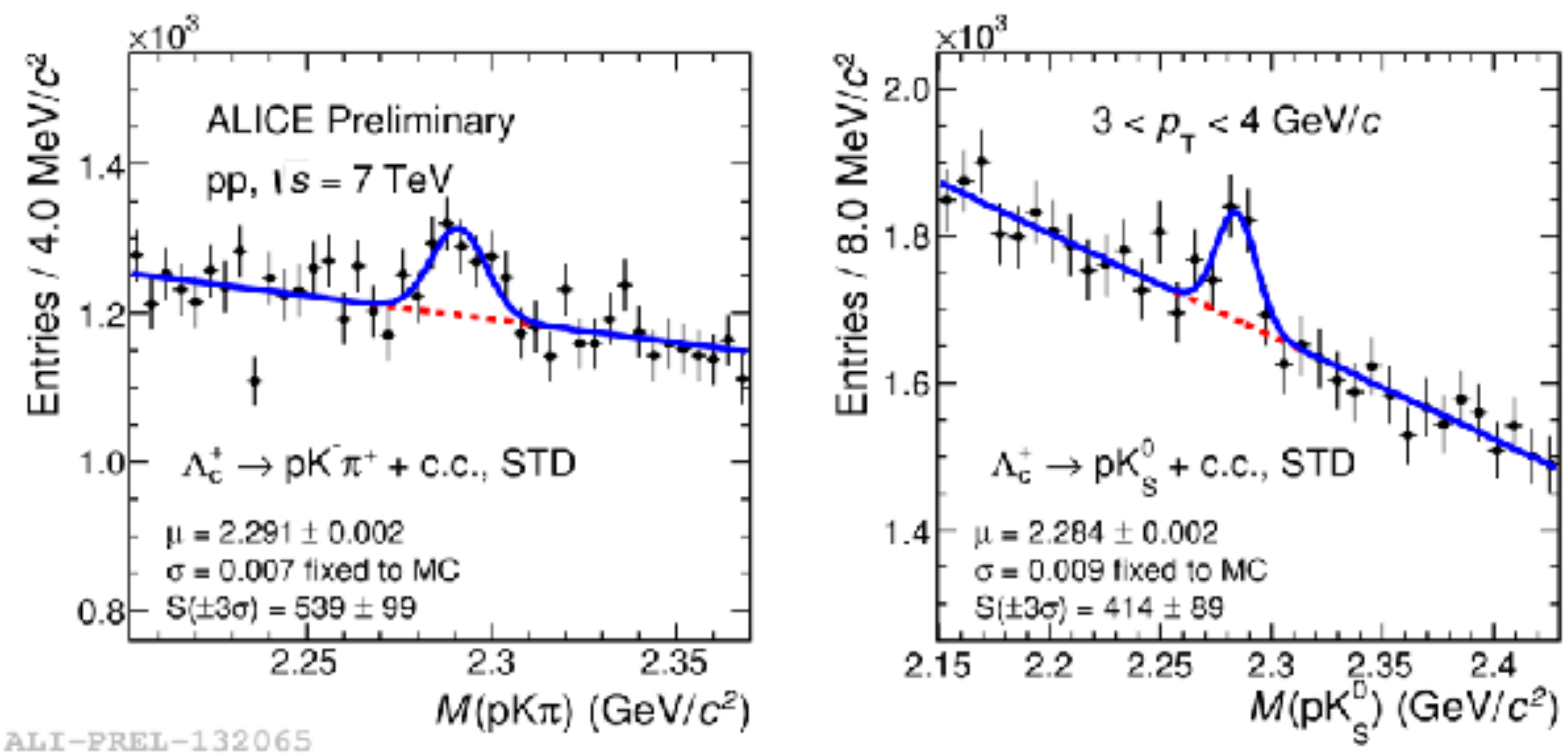




Λ_C hadronic decay reconstruction

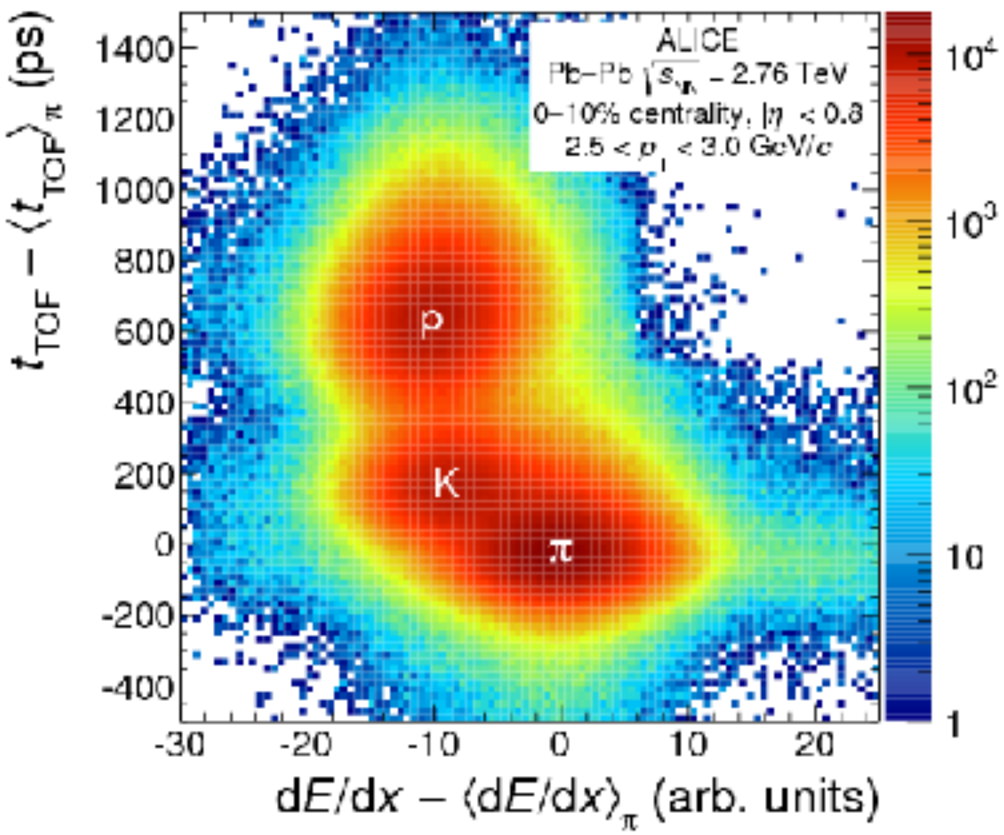
- **PID** using TPC via d*E*/d*x* and TOF via time of flight measurement
  - nσ cuts, or Bayesian approach to identify particles
- **Cuts on decay topologies** exploiting decay vertex displacement from primary vertex
- **Signal extraction** via invariant mass distribution
- **Feed-down (b) subtracted** using pQCD-based estimation of charmed baryon production
- **Correct for efficiency + normalisation**





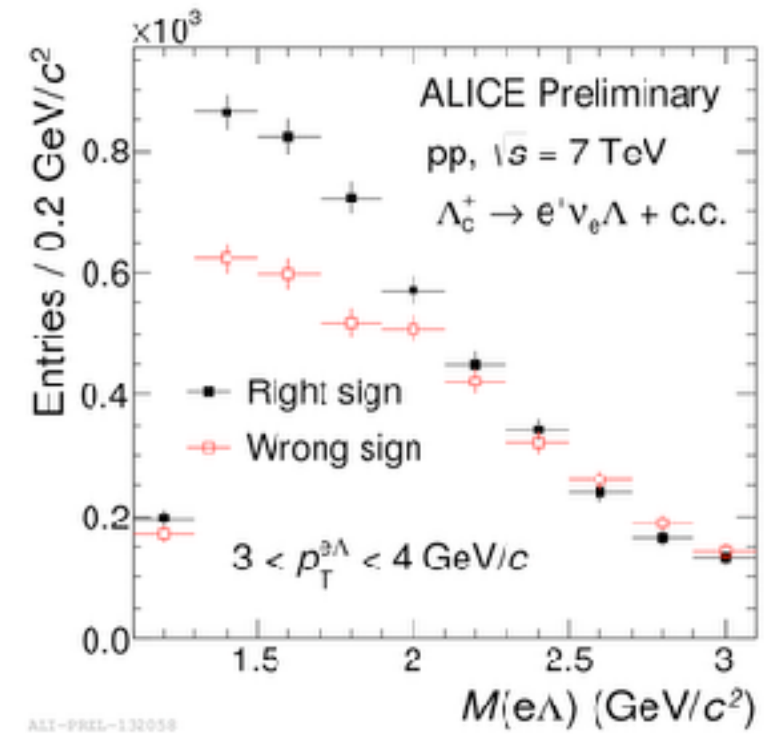
Λ_c ,Ξ_c^0 semileptonic decay reconstruction

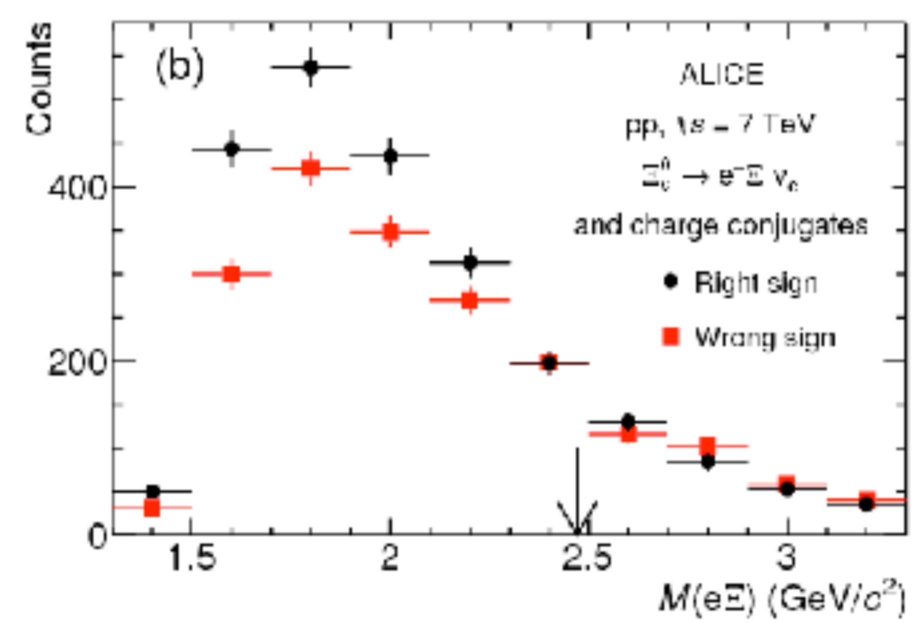
- **PID** using TPC via d*E*/d*x* and TOF via time of flight measurement



Λ_c ,Ξ_c^0 semileptonic decay reconstruction

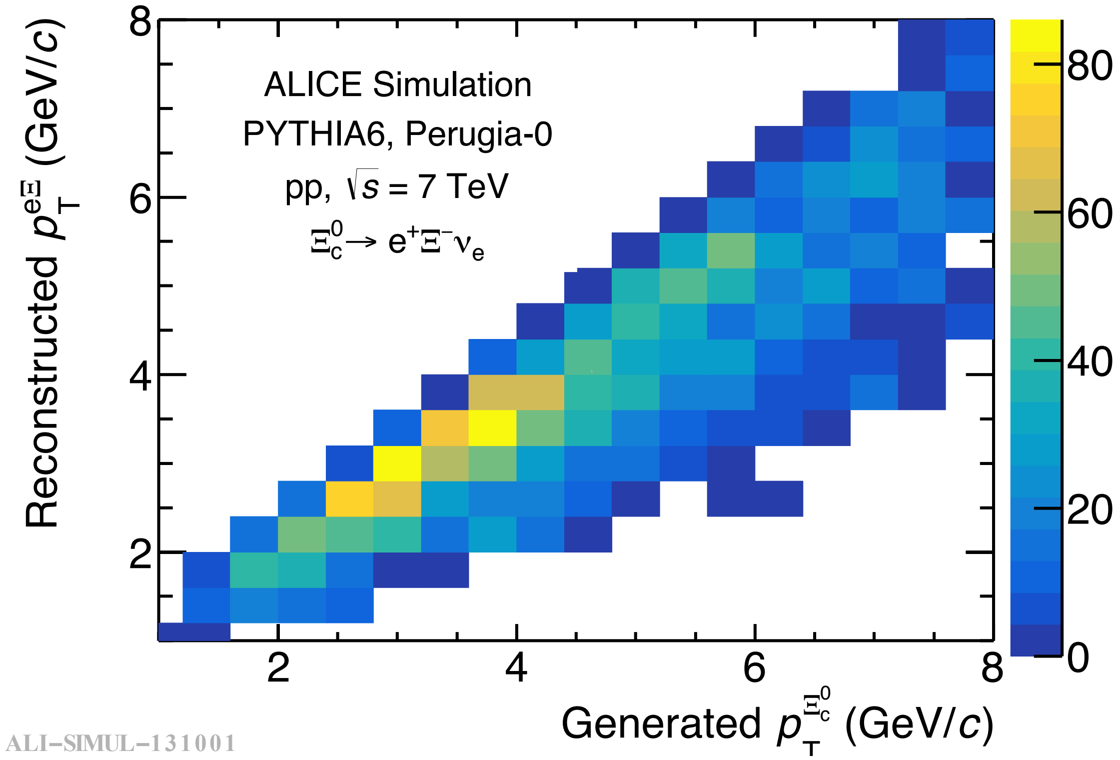
- **PID** using TPC via dE/dx and TOF via time of flight measurement
- **Wrong-sign** $e^-\Lambda$ ($e^-\Xi^-$) pairs subtracted from **right-sign** spectra $e^+\Lambda$ ($e^+\Xi^-$)





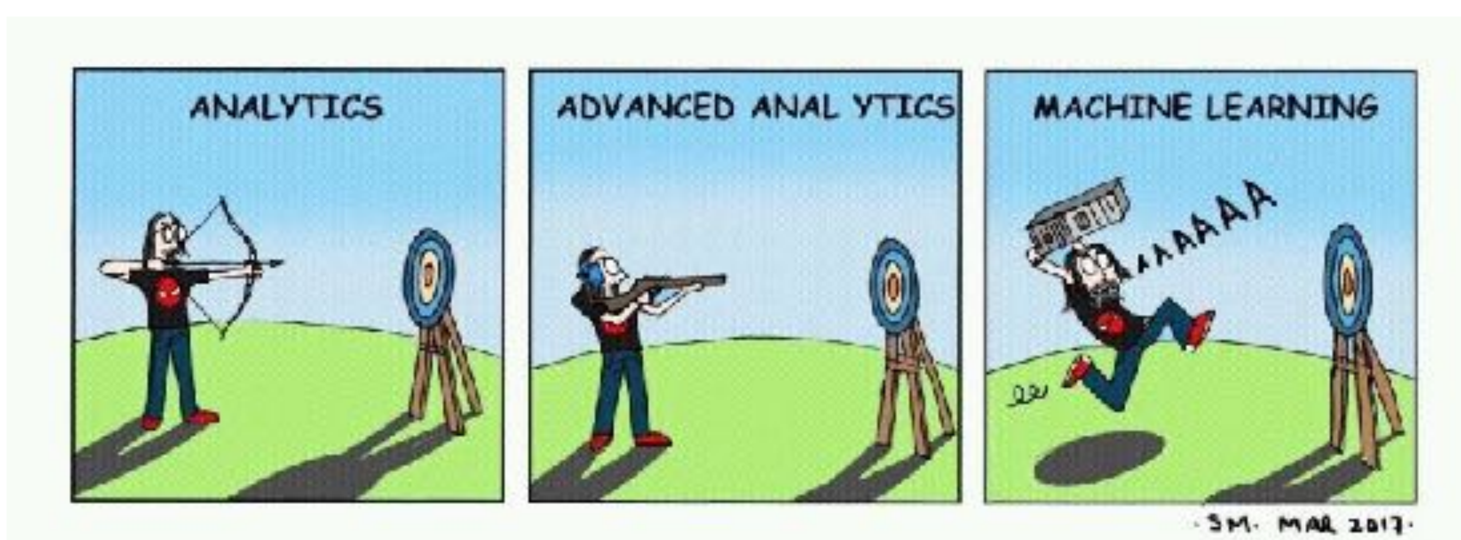
Λ_C ,Ξ_C^0 semileptonic decay reconstruction

- **PID** using TPC via d*E*/d*x* and TOF via time of flight measurement
- **Wrong-sign** $e^-\Lambda$ ($e^-\Xi^-$) pairs subtracted from **right-sign** spectra $e^+\Lambda$ ($e^+\Xi^-$)
- Correct for:
  - **Λ_b^0 (Ξ_b^0) contribution** in wrong-sign spectra
  - $\Xi_c^{0,+}$ **contribution** in right-sign spectra for ΛC measurement
- **Unfold** $e^+\Lambda$ p_T spectra to obtain Λ_C^+ spectra
- **Correct for efficiency + normalisation**



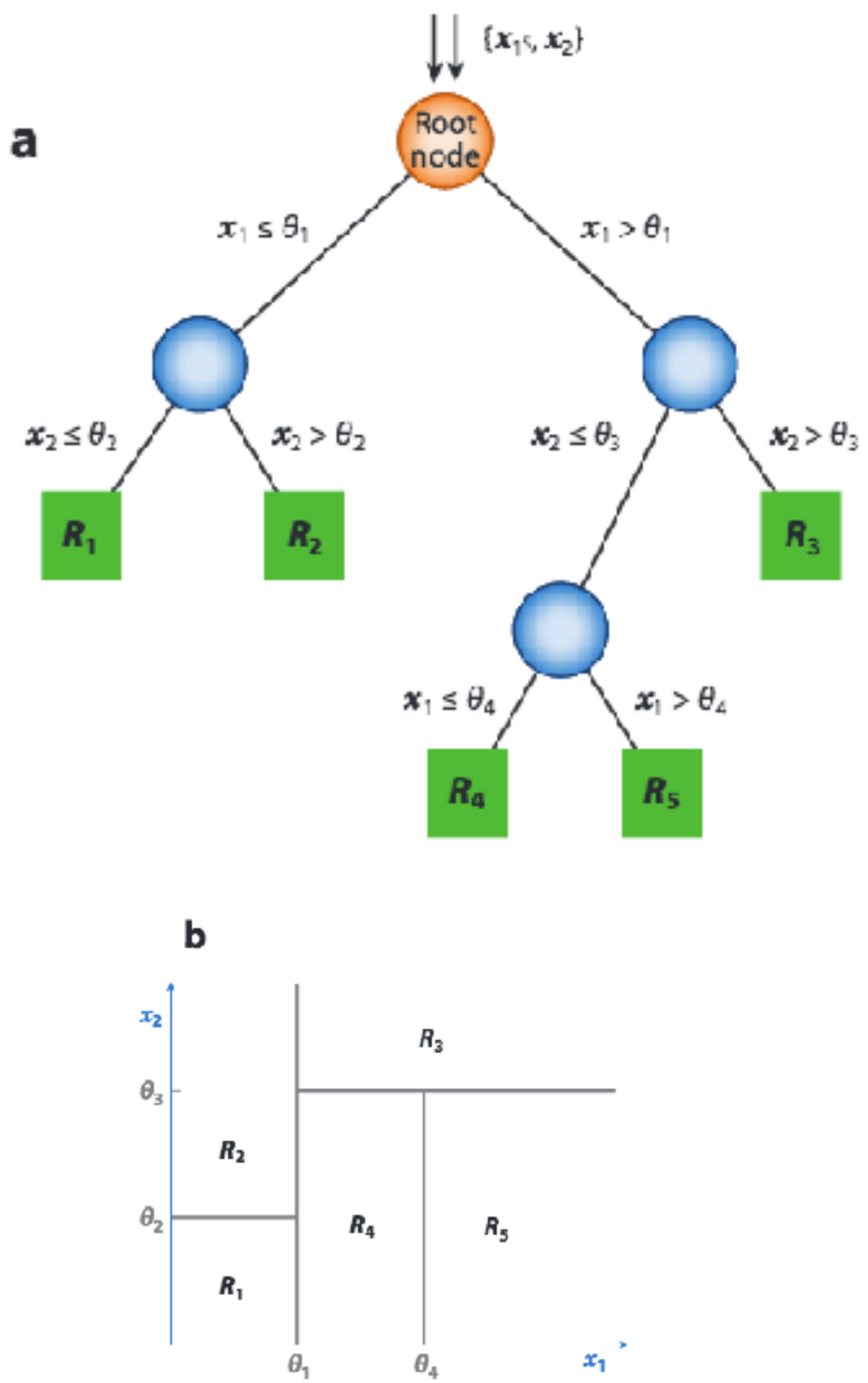
Applying machine learning

- Λ_C signal extraction difficult at present
    - **Large combinatorial background**
    - **Short Λ_C lifetime** ($c\tau$ = 60 μm) means secondary vertex reconstruction is at the limit of the current ITS detector resolution
- Rectangular selection on properties of the Lc decay may not be optimal
- Can we do better? **Answer - yes!**
- **Multivariate algorithms** offer a way to combine properties of a physics signal to optimise the rejection of background
- I will briefly show work I have done exploring this in the $\Lambda_C^+ \rightarrow pK\pi^+$ decay channel



Boosted Decision Trees (BDTs)

https://doi.org/10.1146/annurev.nucl.012809.104427



- Decision trees employ sequential cuts to perform **classification**, *trained* on sample of known 'signal' and 'background' makeup
- 'Variable' space split into partitions, and mapped onto one-dimensional classifier
  - Selection on classifier corresponds to decision boundary in feature space
- *Boosted* decision trees: create many small trees, and combine - reduce misbehaviour due to fluctuations

✓ Can often perform more optimally than 'standard' rectangular cuts

✓ Deals with lots of input data very well – automatic selection of strongly discriminating features

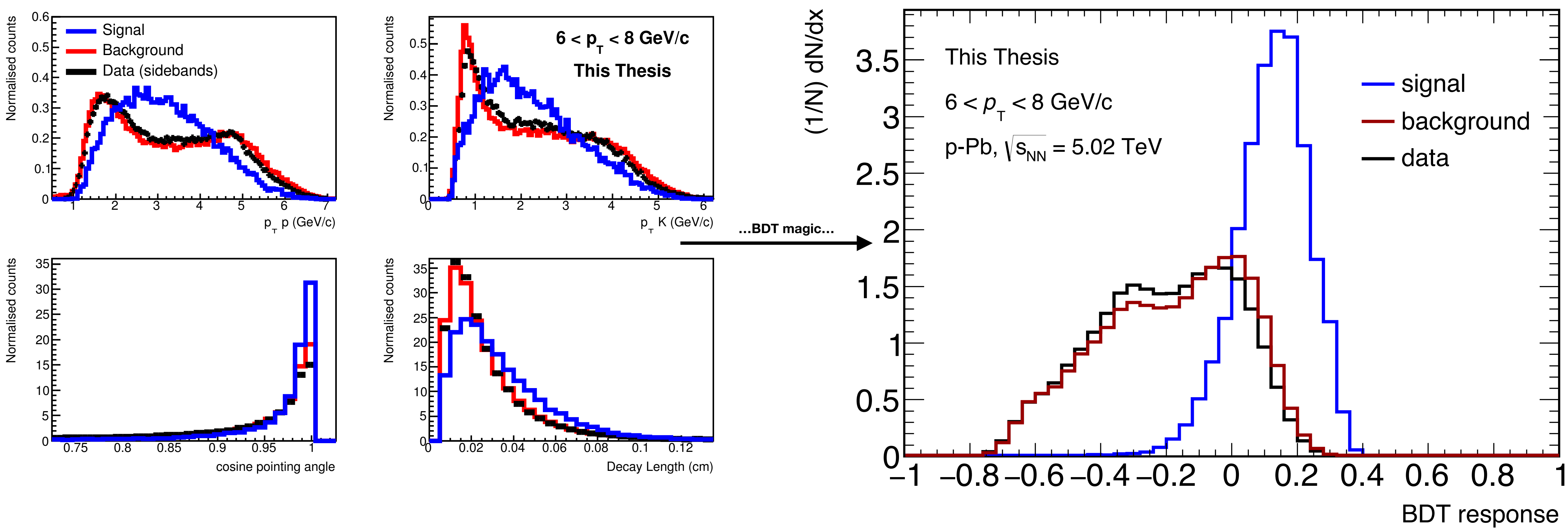
✓ 'Algorithm-of-choice' for many other collaborations

- Top quark mass[1], Higgs discovery[2], $B_s^0 \rightarrow \mu\mu$[3] …

[1] Phys. Rev. D.58,052001 (1998)
[2] Phys. Lett. B 716 (2012) 30
[3] Nature 522, 68-72 (04 June 2015)

BDT analysis

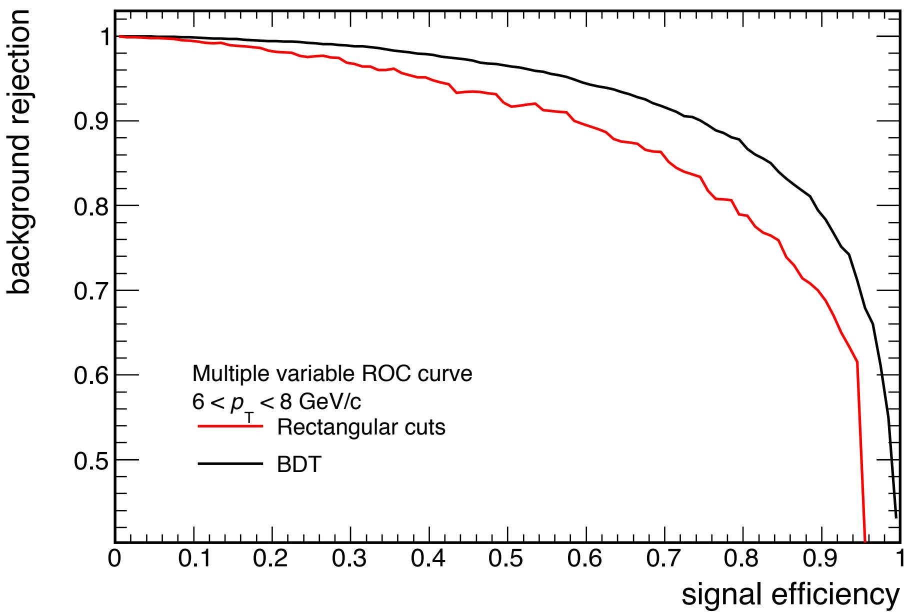
My thesis

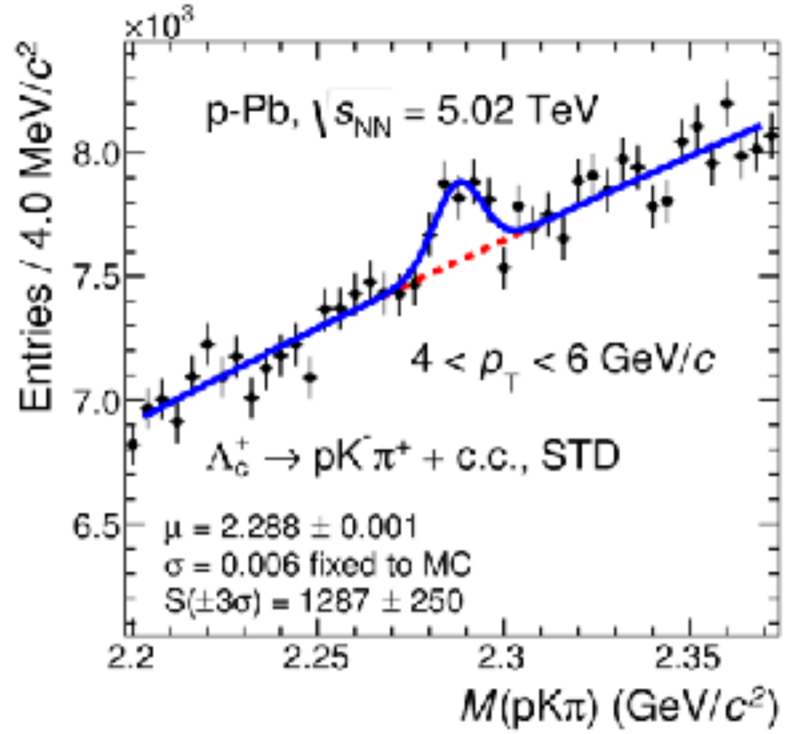


- BDT trained on simulated signal sample, data background sample, then applied on data
- Input variables include kinematic (pT decay products) topological (decay length, quality of reconstructed vertex, cosine pointing angle…) and PID (Bayesian PID track probabilities) variables associated with the ΛC decay - **verified to describe the data well**
- BDT response shows clear separation between signal and background

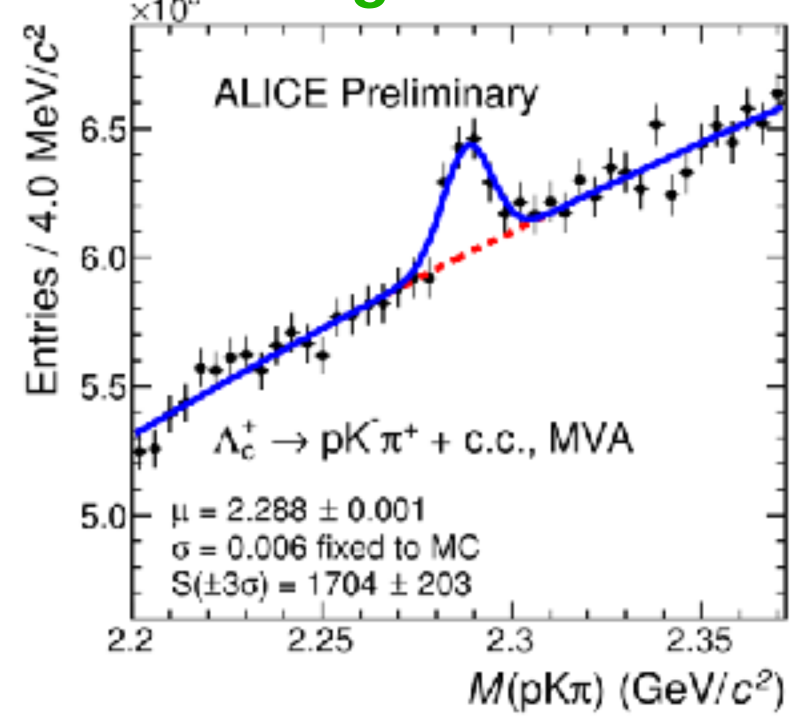
BDT analysis

My thesis





Background reduced, signal increased



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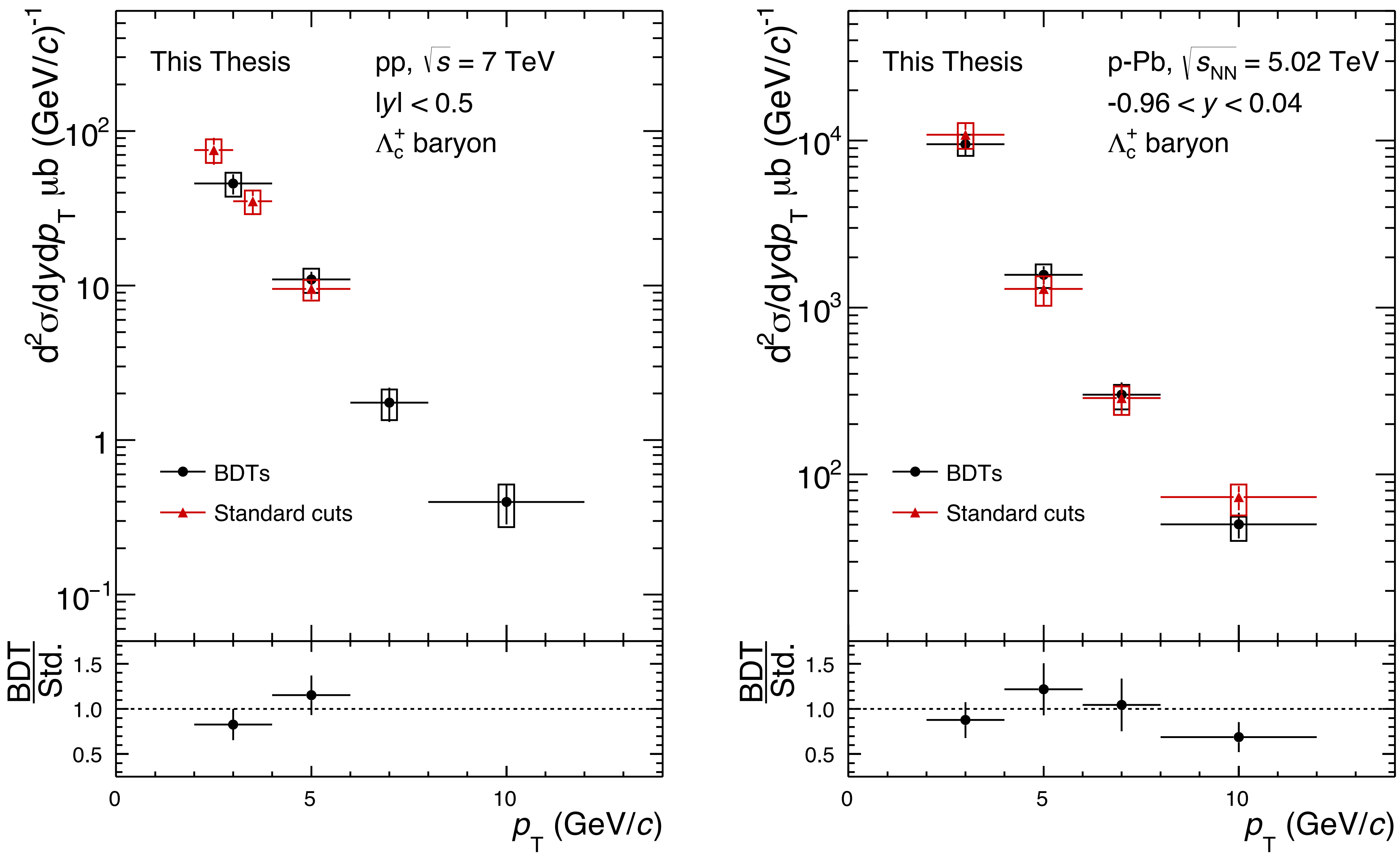
- BDT response shows clear separation between signal and background
- **Clear improvement** in background rejection/signal efficiency with respect to rectangular cut method

BDT analysis

My thesis

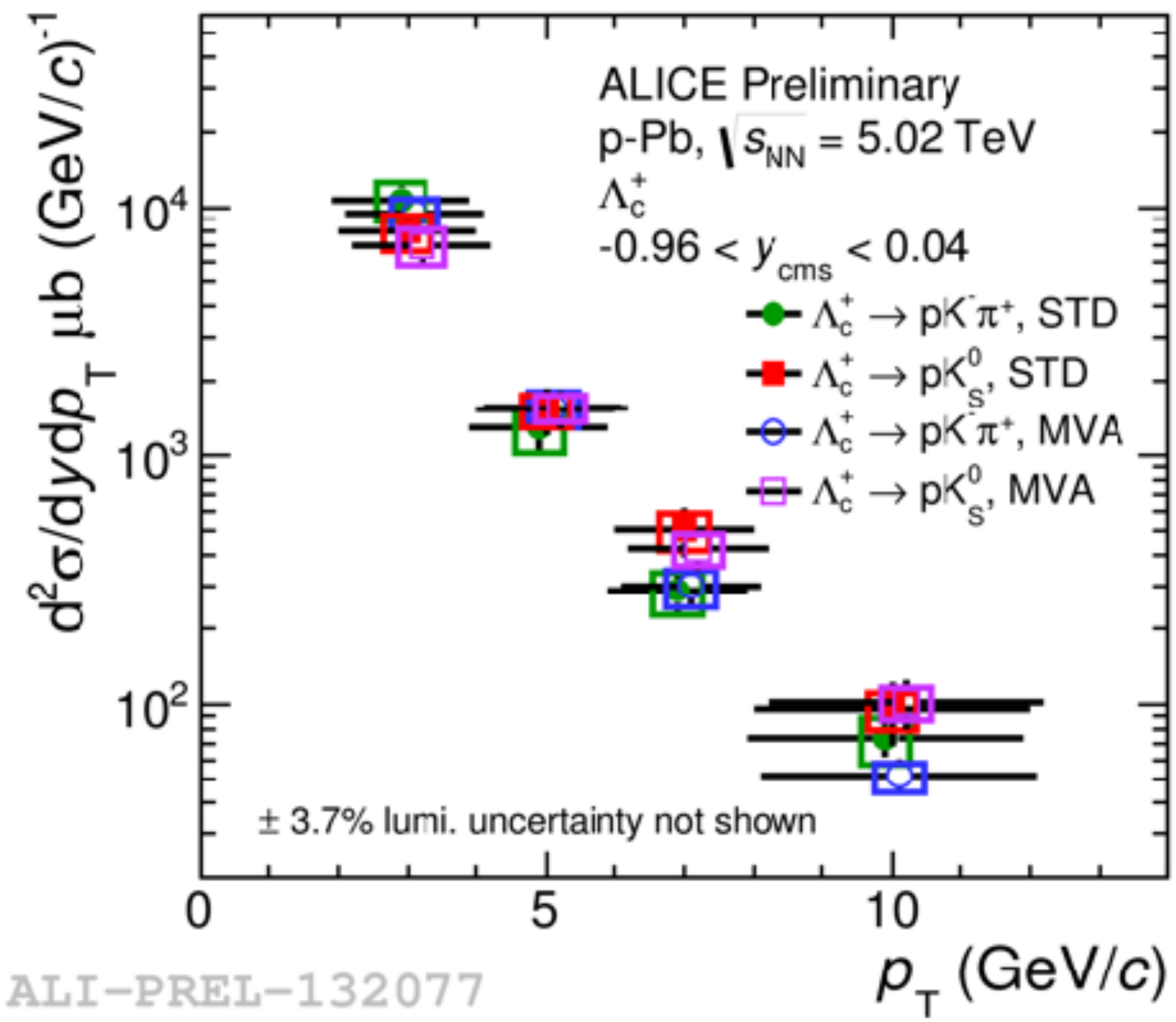


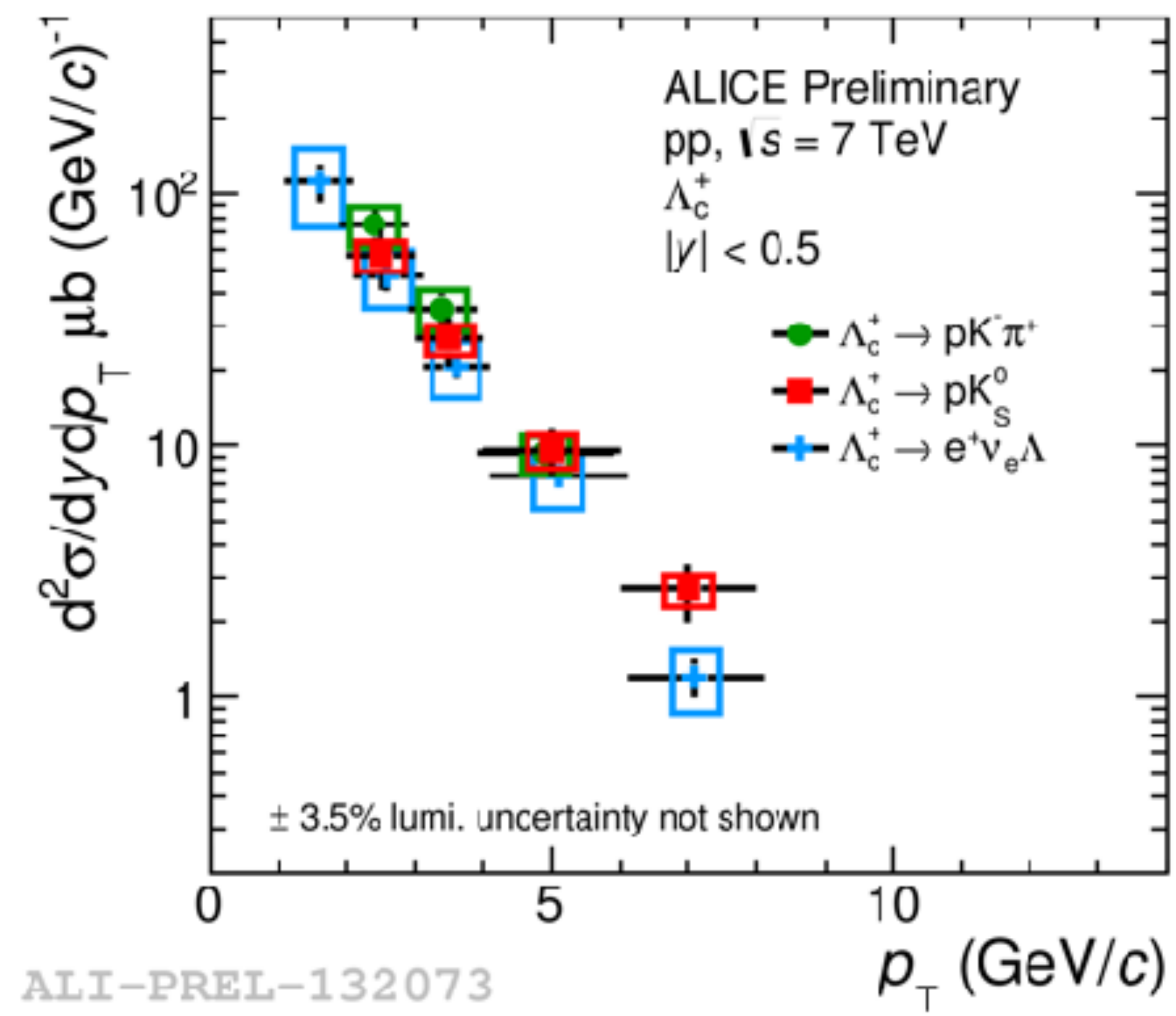
- BDT analysis shows good agreement with standard analysis
  - Smaller uncertainties
  - p_T reach extended in pp collisions
- p-Pb analysis merged with other analyses for paper in preparation - pp analysis serves as a useful cross-check

Results

Λ_C^+ p_T-differential cross section

arxiv:1711.02393

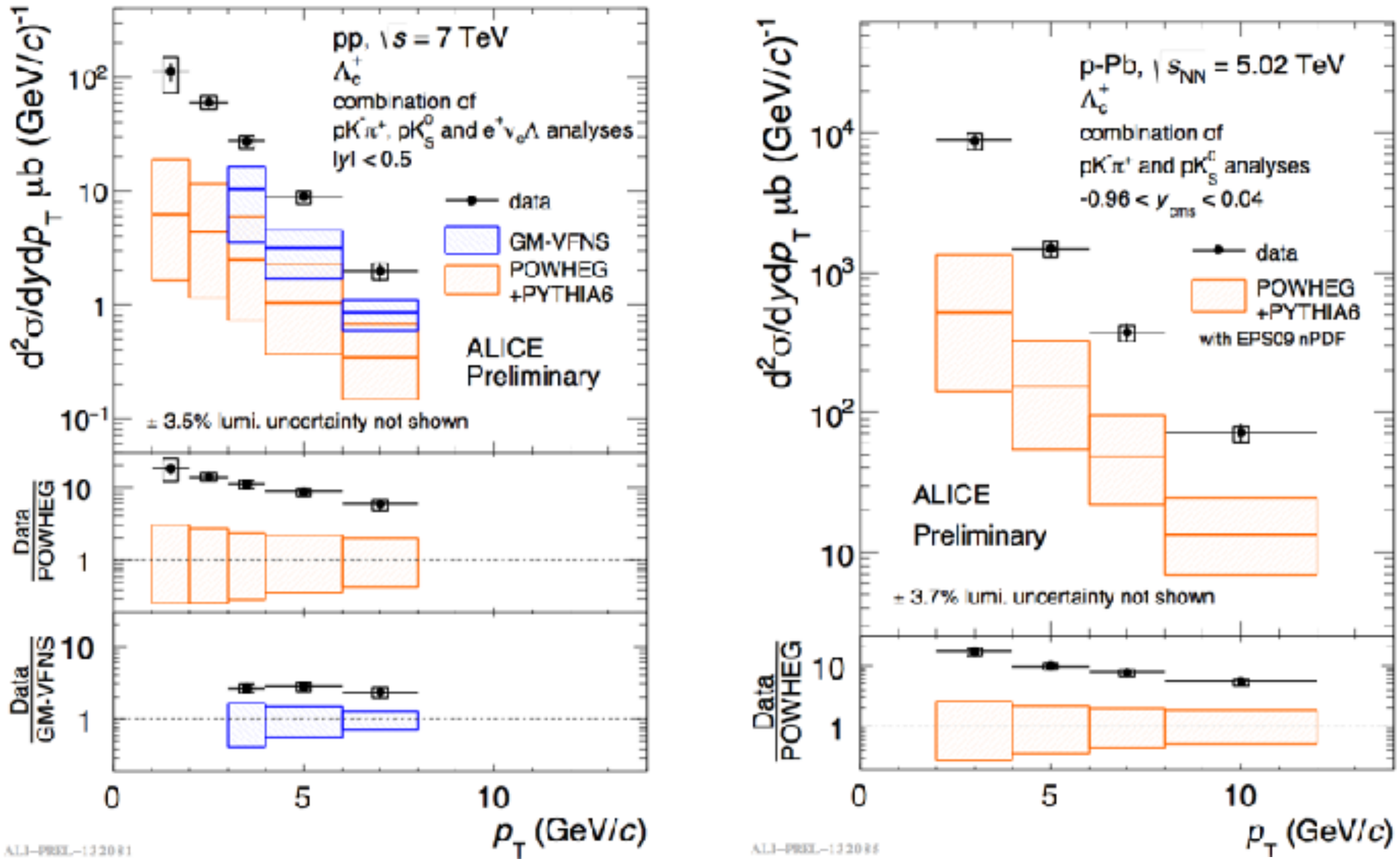




- Good agreement between different decay channels + different analysis methods
- Largest discrepancy = 1.7σ (stat.+syst. uncertainties)

Λ_C^+ p_T-differential cross section

arxiv:1711.02393



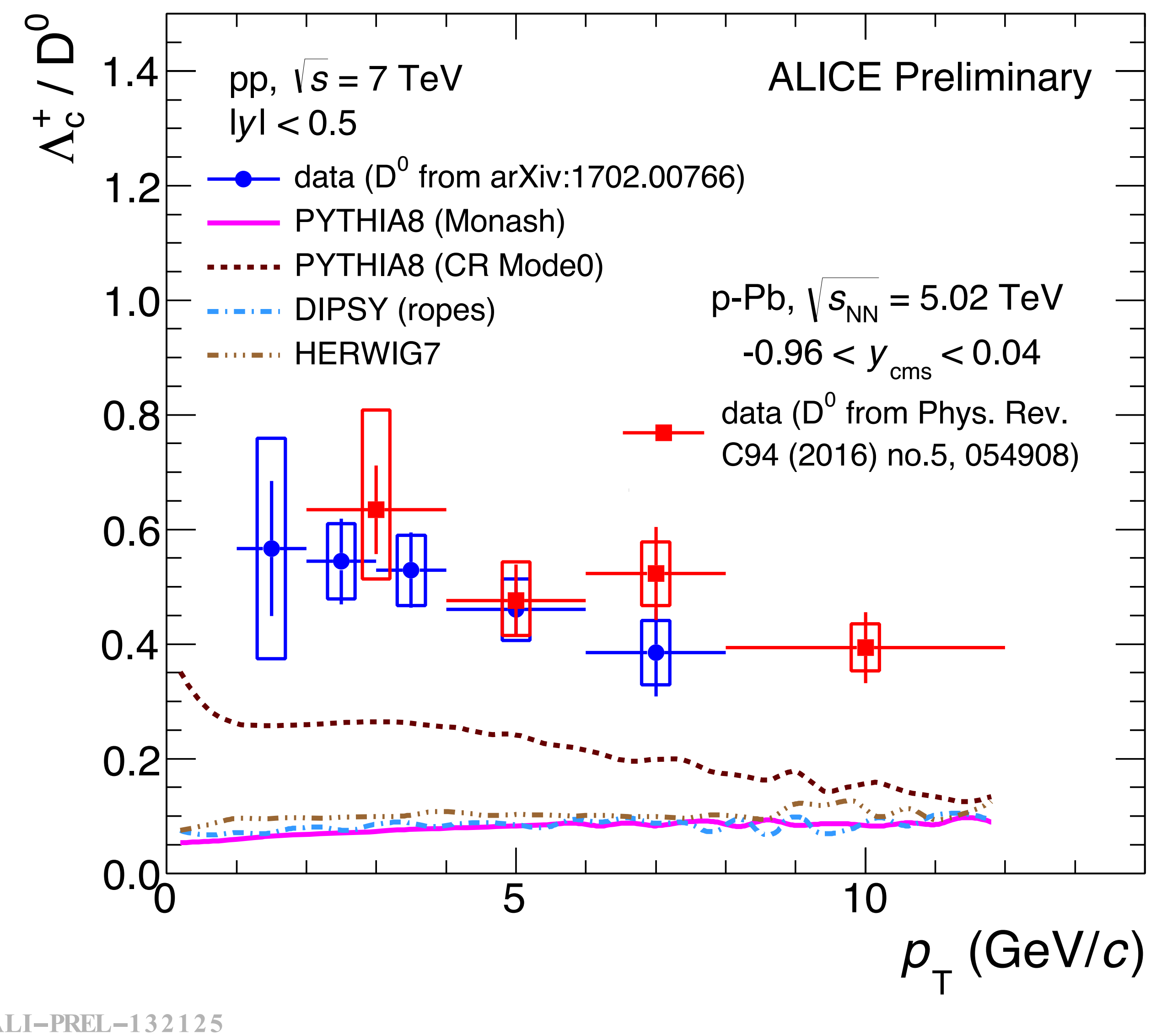
Different decay channels merged taking into account correlation of statistical and systematic uncertainties

- Λ_C^+ p_T-differential cross section **significantly underestimated** by theory in pp and p-Pb collisions
  - x2-3 higher than GM-VFNS in pp collisions
  - Up to x20 higher than POWHEG+PYTHIA6 in pp and p-Pb collisions
- **NOTE: fragmentation parameters calculated from e+e- collision data**

GM-VFNS: Eur. Phys. J. C41 (2005) 199-212, Eur. Phys. J. C72 (2012) 2082
POWHEG: JHEP 06 (2010) 043

Λ_C^+/D^0 baryon-to-meson ratio

arxiv:1711.02393



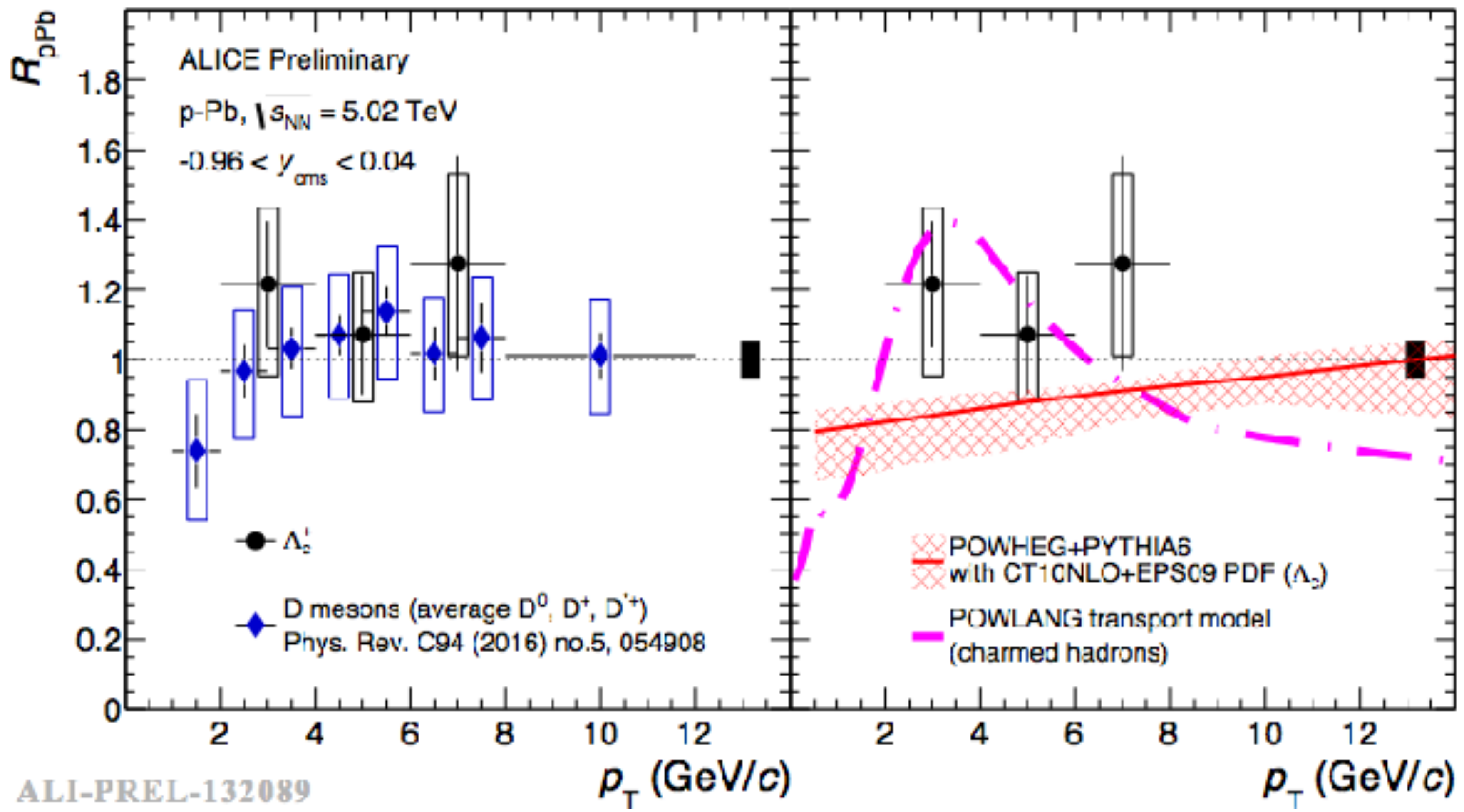
- Λ_C^+/D^0 in pp and p-Pb collisions **compatible within uncertainties**
- Λ_C^+/D^0 ratio **higher than expectation** from MC
- **Colour reconnection** mode in PYTHIA 8 closer to data

PYTHIA8: Comput. Phys. Commun. 178 (2008) 852-867, CR, ropes: Phys. Rev. D92 no. 9, (2015) 094010, DIPSY:*JHEP* 08 (2011) 103 , HERWIG: Eur. Phys. J. C58 (2008) 639-707

$\Lambda_C^+ R_{pPb}$

arxiv:1711.02393

$$R_{pPb}(p_T) = \frac{1}{A}\frac{d\sigma_{pPb}/dp_T}{d\sigma_{pp}/dp_T}$$

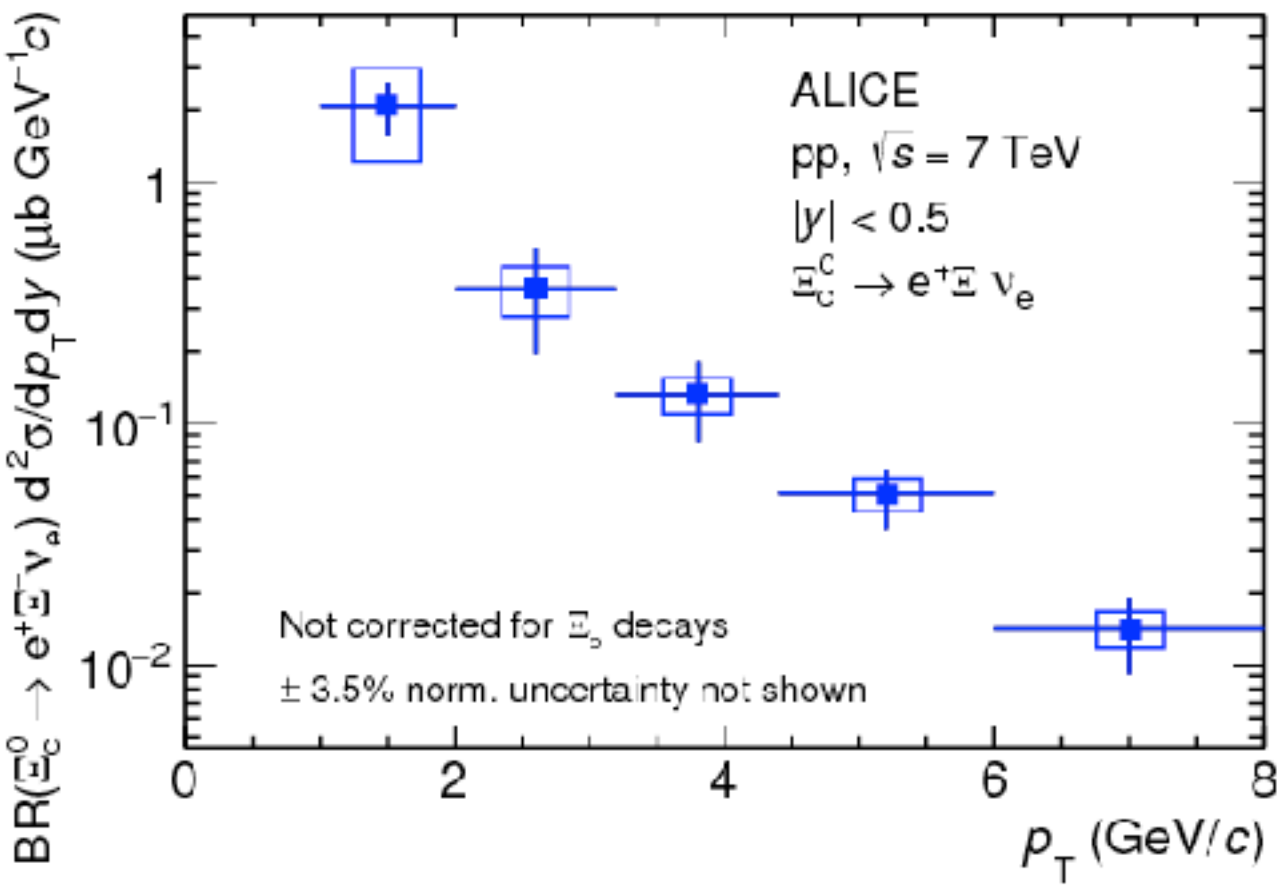


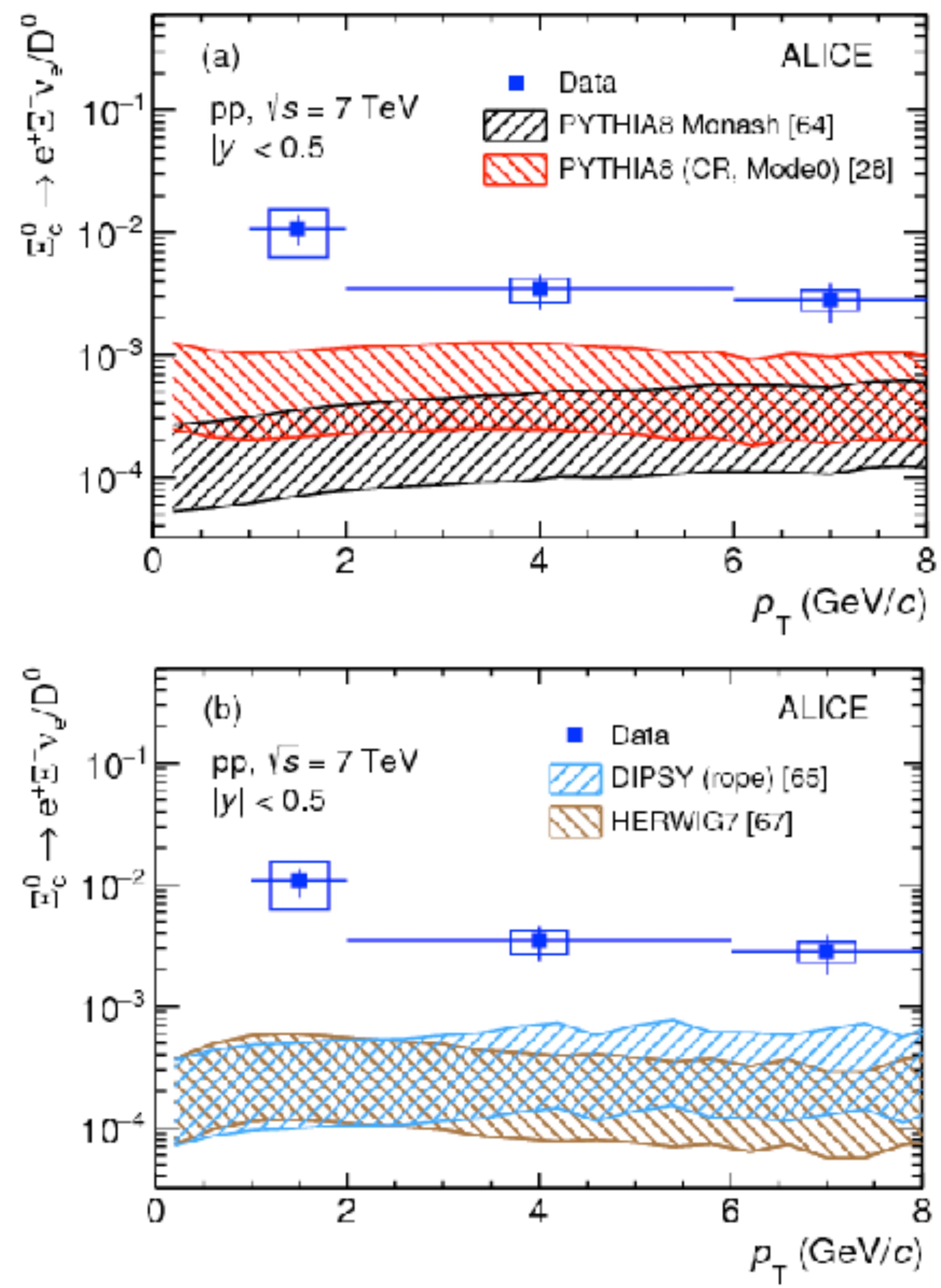
- $\Lambda_C^+ R_{pPb}$ **consistent with unity**, **with D R_{pPb}** and **with models** assuming **cold nuclear matter** effects, or **'hot' medium** effects
  - **POWHEG + PYTHIA with CT10NLO+EPS09 PDF** - parameterisation of nuclear PDF
  - **POWLANG** – 'small-size' QGP formation, collisional energy loss only

Ξ_C^0 production

arxiv:1712.04242

First measurement of Ξ_C^0 production at the LHC





- **Baryon-to-meson ratio $\Xi_C^0 \to e^+\Xi^-\nu_e$ / D^0 also significantly larger than predictions**
- BR not measured – range (0.3% - 3.2%) estimated from theory [1]

[1] Phys. Rev. D40 (1989) 2955, Phys. Rev. D43 (1991) 2939, Phys. Rev. D53 (1996) 1457

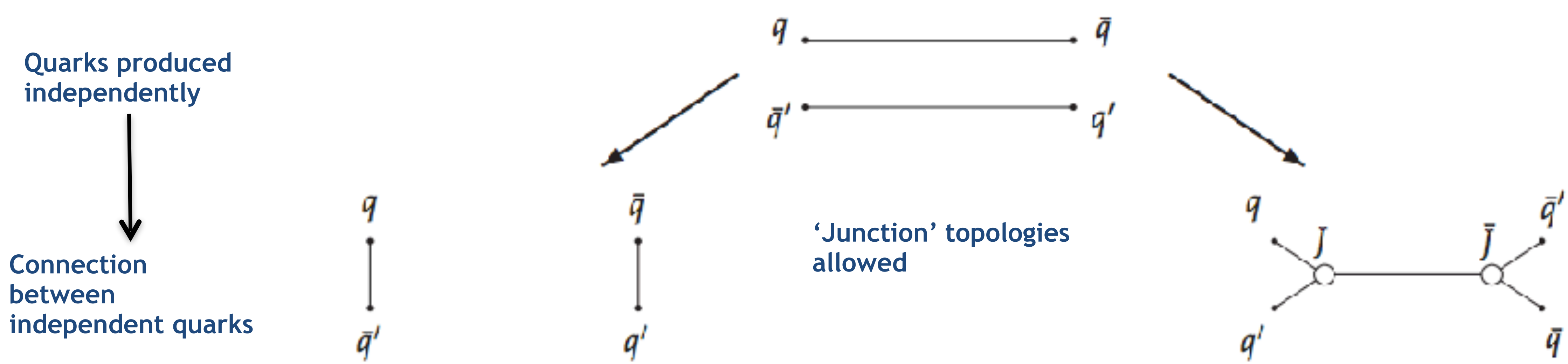
PYTHIA 8 Monash: P. Skands, S. Carrazza, and J. Rojo, Eur. Phys. J. C74 (2014) 3024
Colour reconnection: J. R. Christiansen and P. Z. Skands JHEP 08 (2015) 003

Colour reconnection

- Some models predict higher yield of baryons - **what are they doing?**

- **pp collisions** - hadronisation models (based on Lund string model [1]) modify baryon production:
  - Colour reconnection [2]
  - Rope hadronisation [3]

  —> baryon junctions
- Models qualitatively reproduce baryon-to-meson ratios in light sector

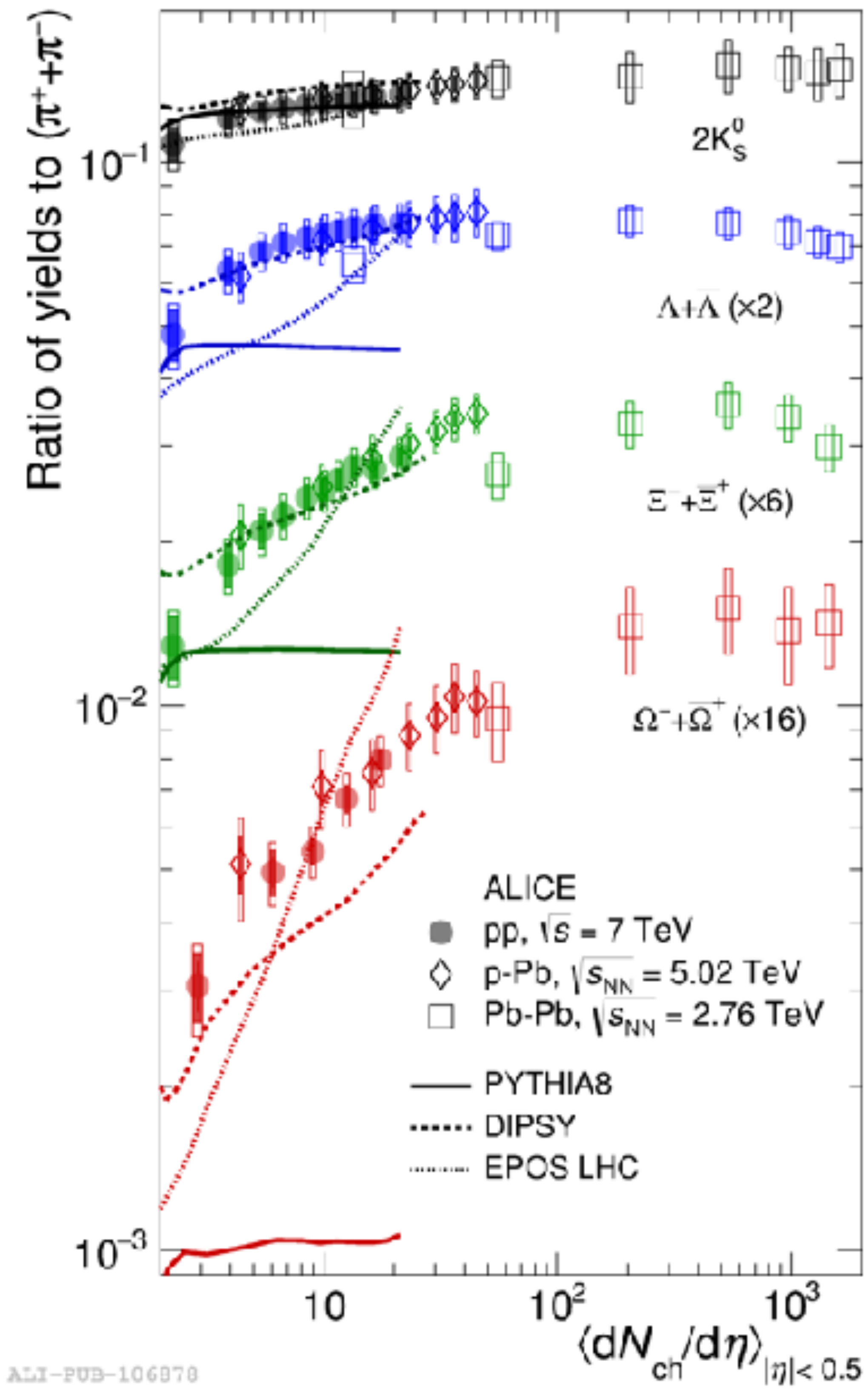


[C. Bierlich, J. Christiansen Phys. Rev. D 92, 094010 (2015)]

[1] Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. 7 (1997) 1-471
[2] J. Christiansen, P. Skands, JHEP 08 (2015) 003
[3] T. Biro et. al, Nucl. Phys. B 245 (1984) 449-468

Strings in the light sector

Nature Physics 13, 535–539 (2017)

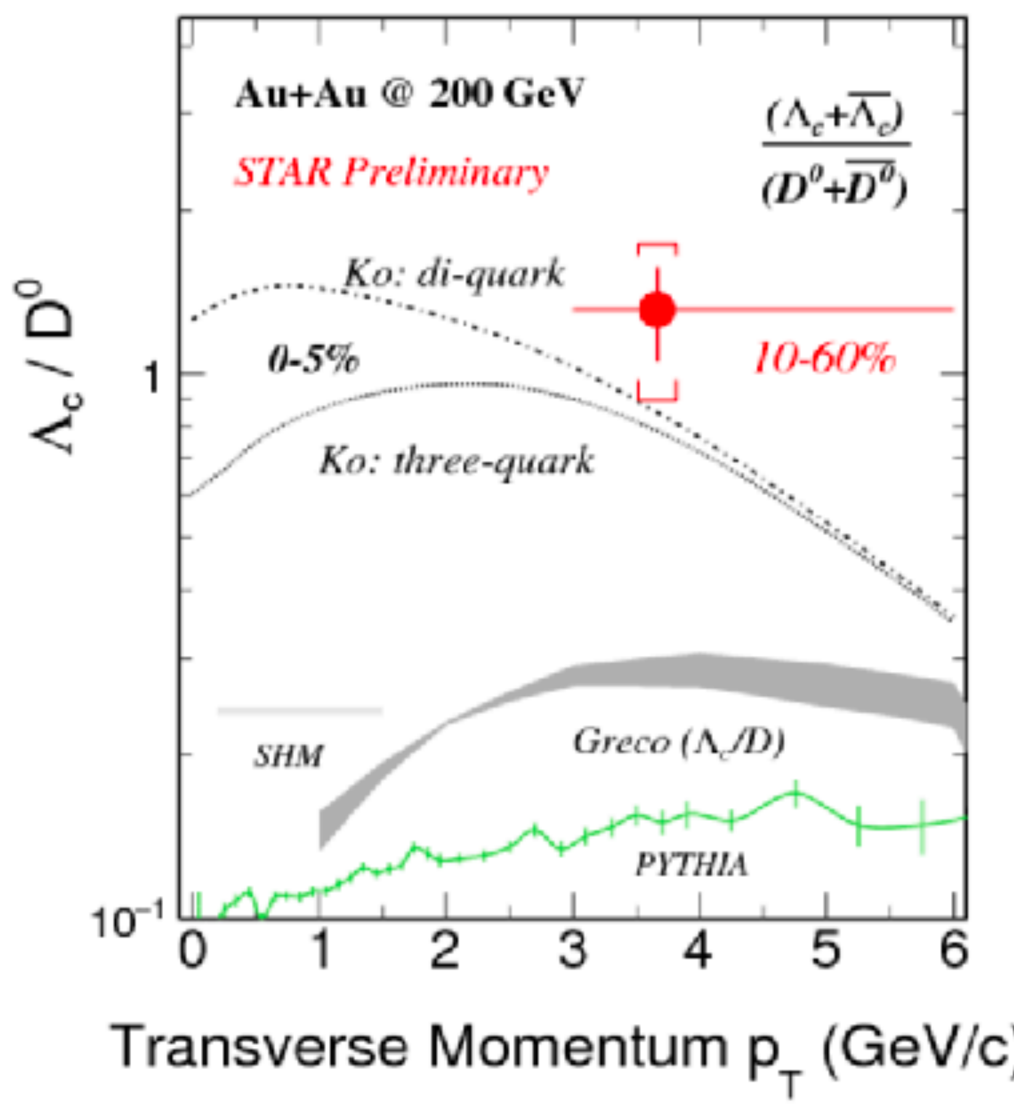


- ‘String’ dynamics included in models which qualitatively reproduce multi-strange yield as function of multiplicity (rope hadronisation in DIPSY)
- **One of the most surprising/ interesting results from ALICE so far** - Collectivity/strangeness enhancement in lighter systems?

Some more recent charmed baryon measurements

- First measurement of the **Λ_C baryon in AA collisions** at $\sqrt{s_{NN}}$ = 200 MeV presented by STAR at Quark Matter 2015
  - **Clear indication of a large Λ_C/D^0**
  - In agreement with models including hadronisation via coalescence
- **However…**
  - reference measurement *crucial* for interpretation of the data
  - Models use theoretical pp baseline - known to underpredict Λ_C/D^0 in pp collisions
  - STAR plan to measure Λ_C/D^0 in peripheral collisions (R_{CP})

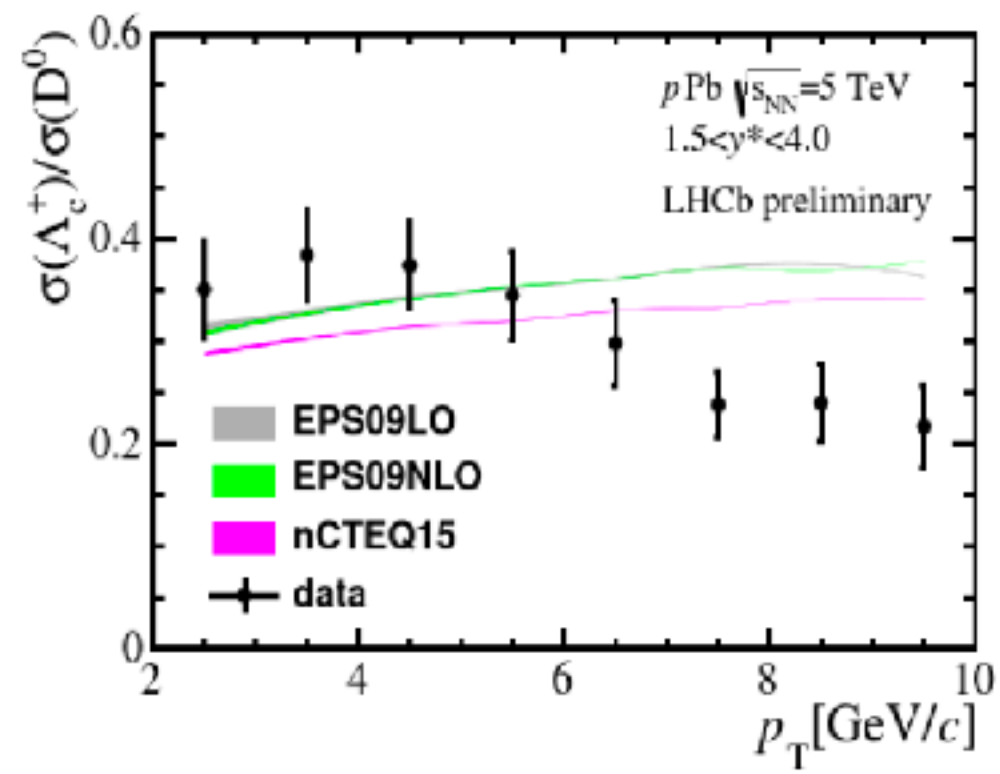
arXiv:1704.04364



Some more recent charmed baryon measurements

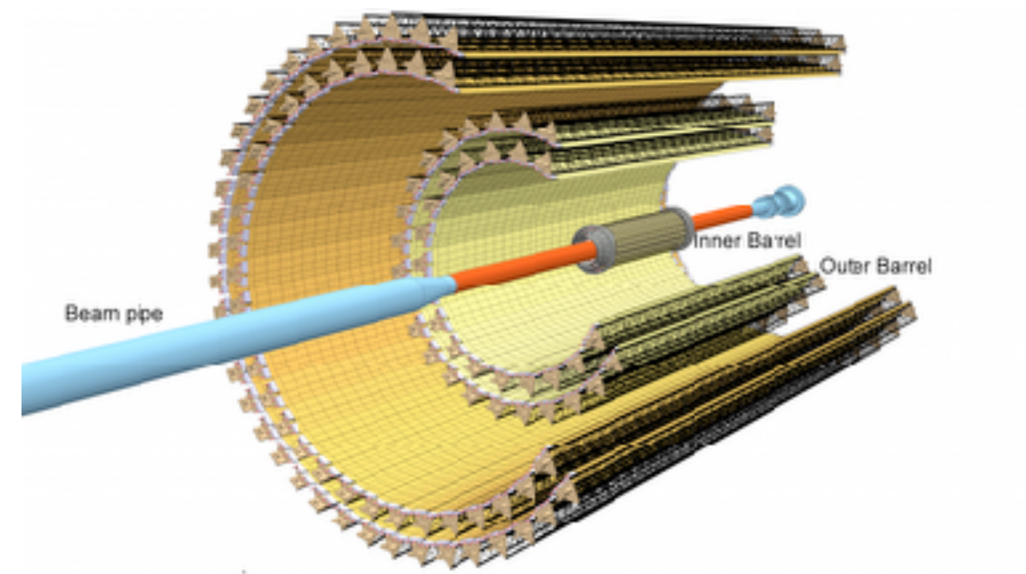
LHCb-CONF-2017-005

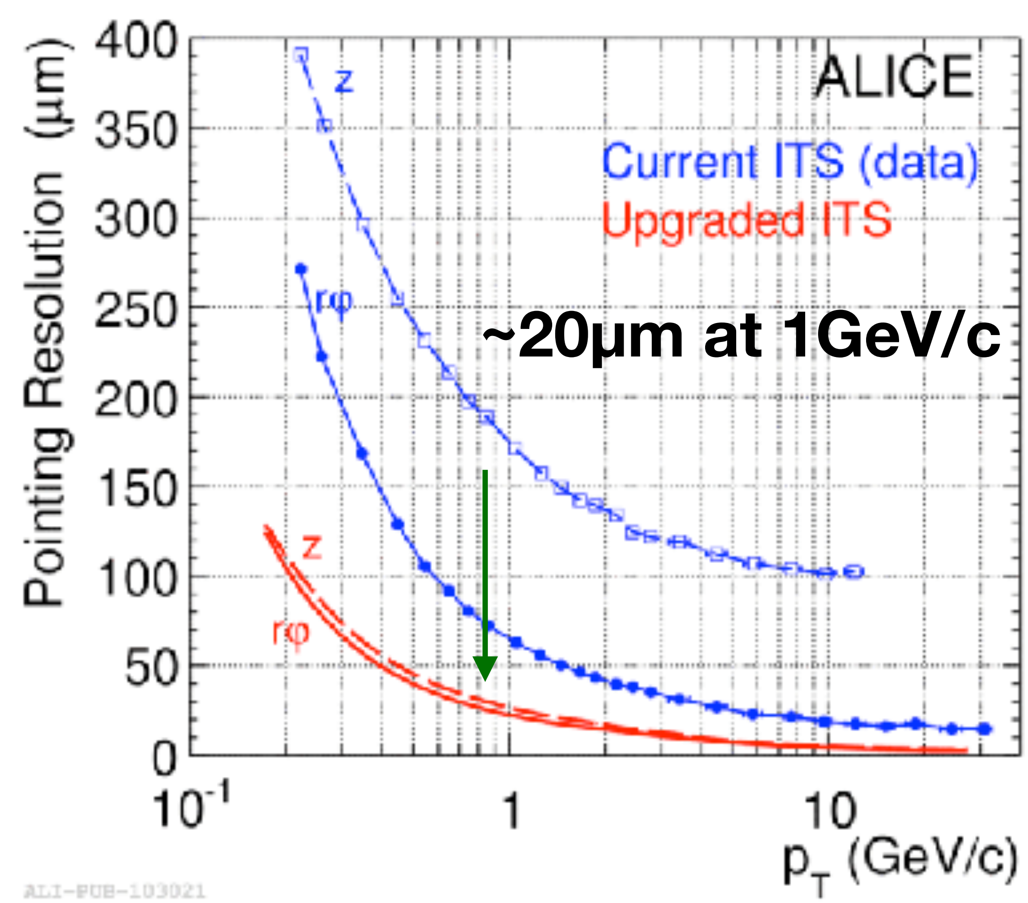
- LHCb presented measurement of Λ_C/D^0 in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
- Within 1-2σ of ALICE points (different rapidity regions)



Run 3-4 at the LHC (2021 onwards)

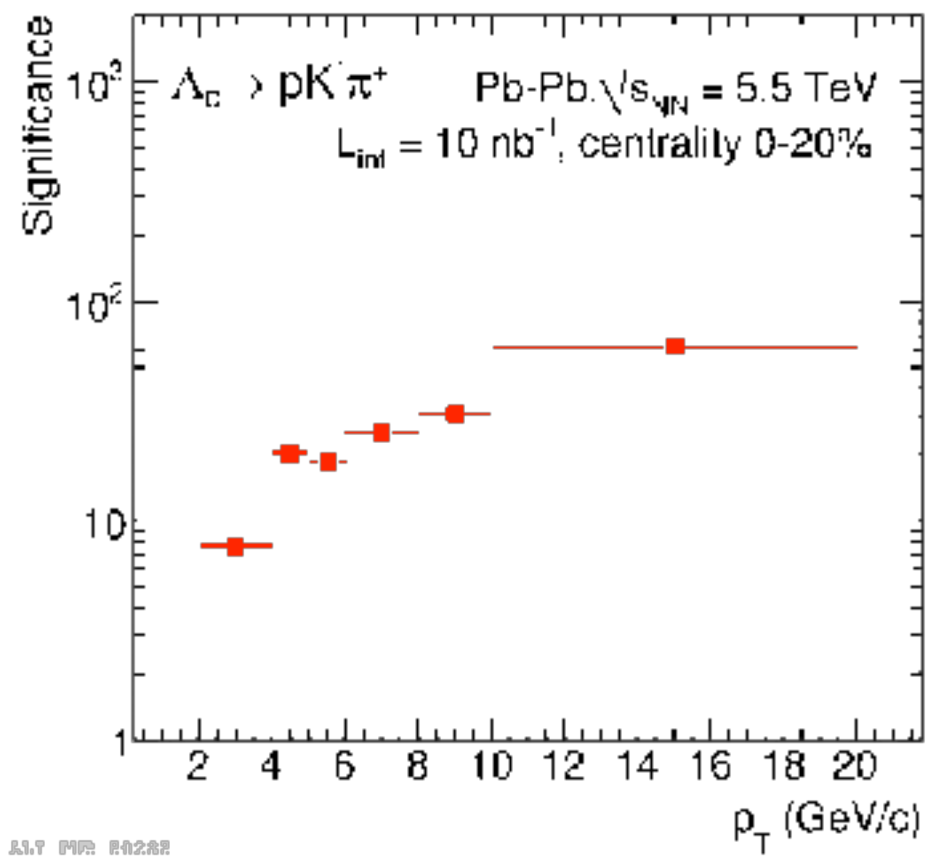
- Completely new Inner Tracking System
  - 7 layer silicon pixel detector
  - Closer to interaction point 39mm —> 22mm
  - Reduced material budget —>X/X^0 ~1.14% —> 0.3%
  - Reduced pixel size 50μm x 425μm —> 30μm x 30μm
- Continuous TPC readout - max rate 50kHz, **100x faster readout**
  - Factor 100x target integrated luminosity over full program
- Will allow to study
  - D-mesons down to pT=0
  - B-mesons down to low p_T
  - **Λ_C down to low pT ~2 GeV/c**
  - **Λ_b down to low pT ~2 GeV/c**

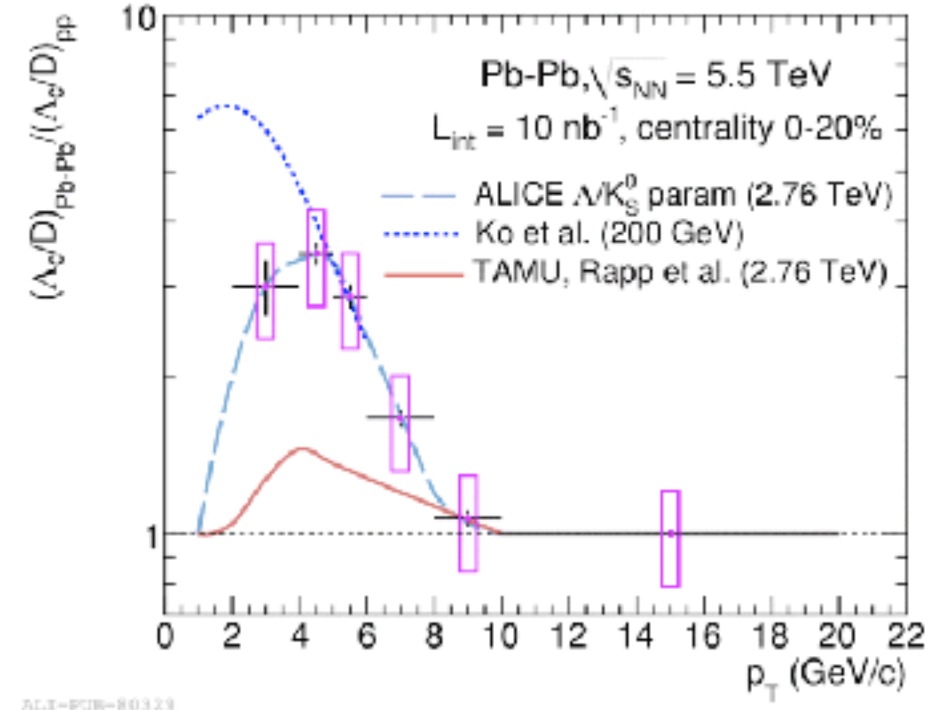


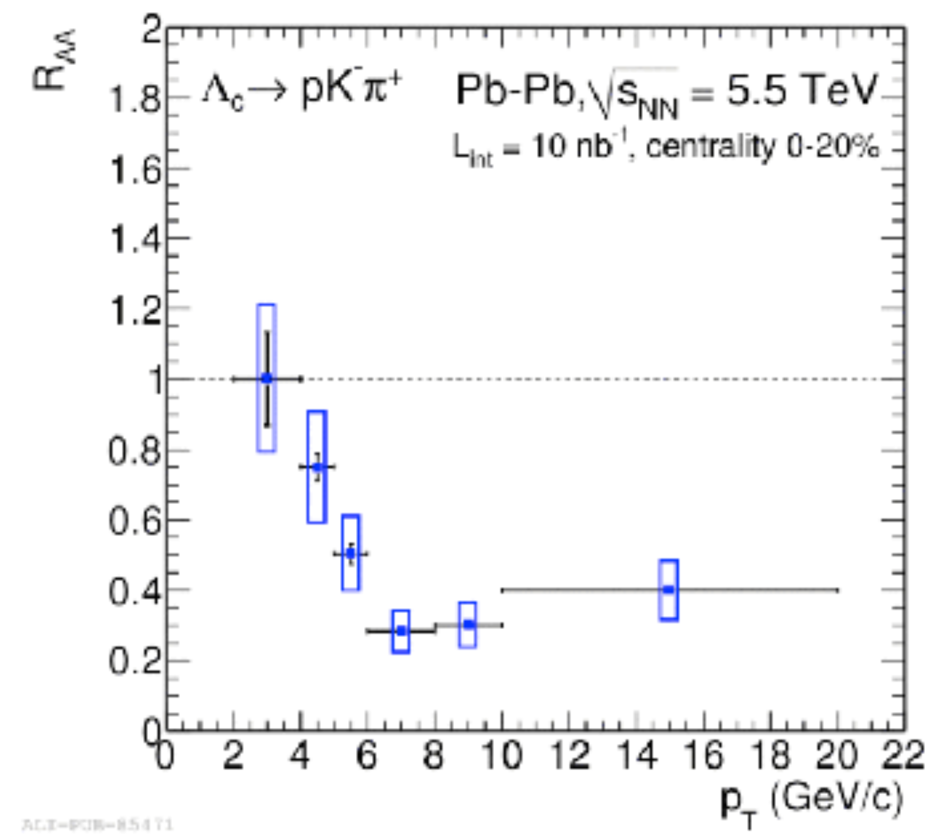


Λ_C measurement in Pb-Pb collisions

ITS upgrade TDR - J. Phys. G 41 (2014) 087002



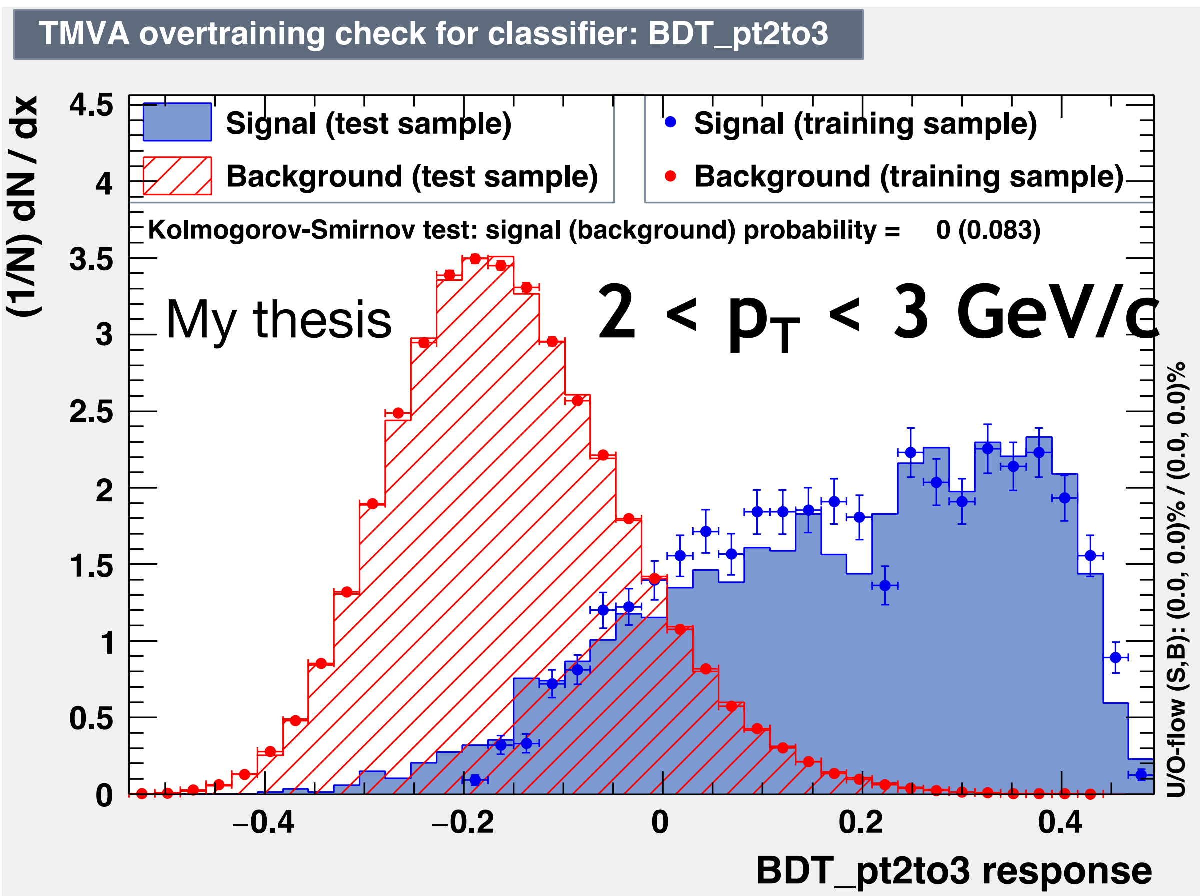


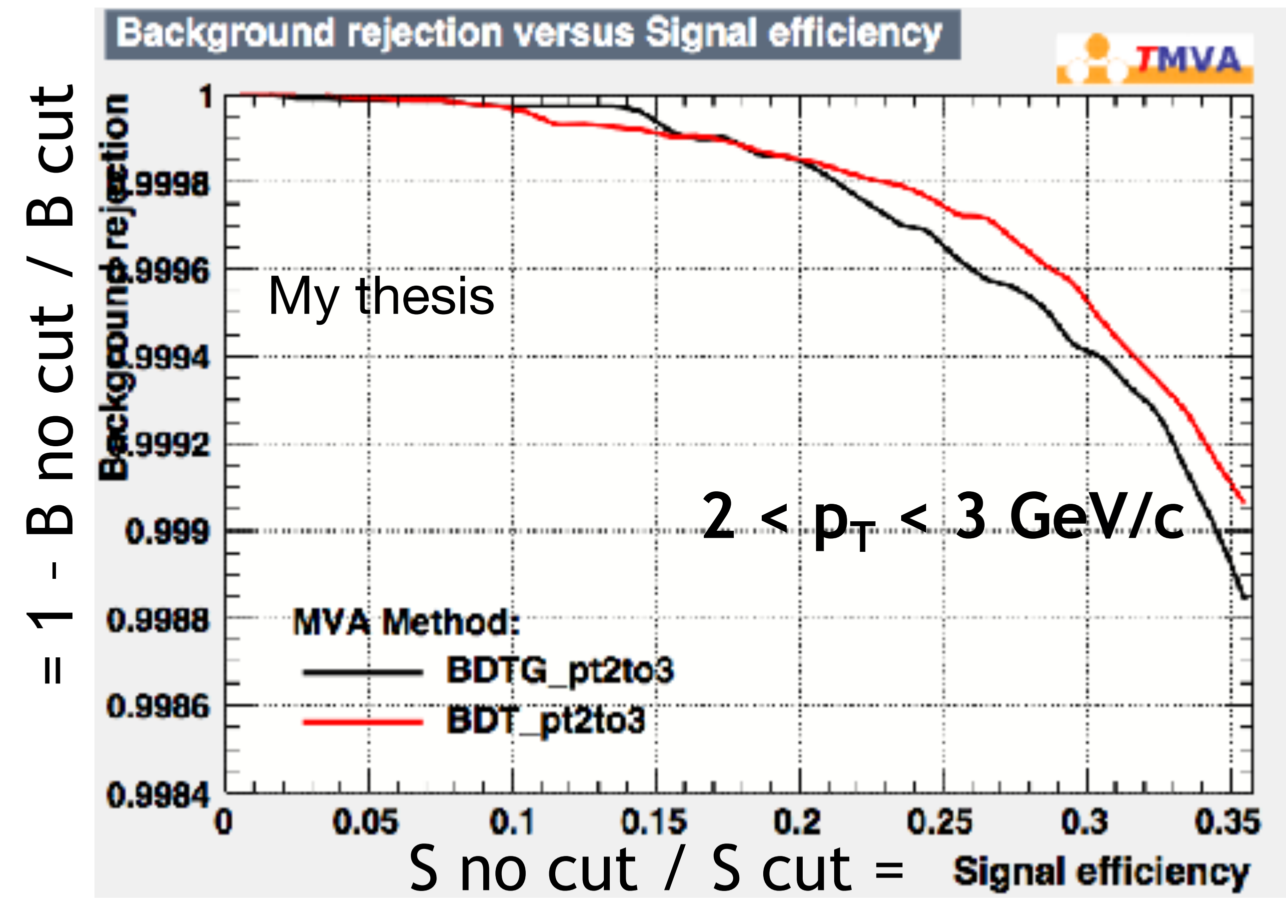


- Simulation studies - HIJING events at $\sqrt{s_{NN}}$ = 5.02 TeV with detector simulation including full geometry of ITS upgrade
    - Topological cuts, PID tuned on simulation
    - Expected statistical significance of Λ_C signal extraction (S/ sqrt(S+B)) > 8 corresponds to statistical uncertainty > 12%
- **Can we do better?**

Method - BDT

- BDTs **trained on simulation** (*similar to pp/p-Pb analysis*), and 1 dimensional classifier constructed attempting to maximise signal/background separation.





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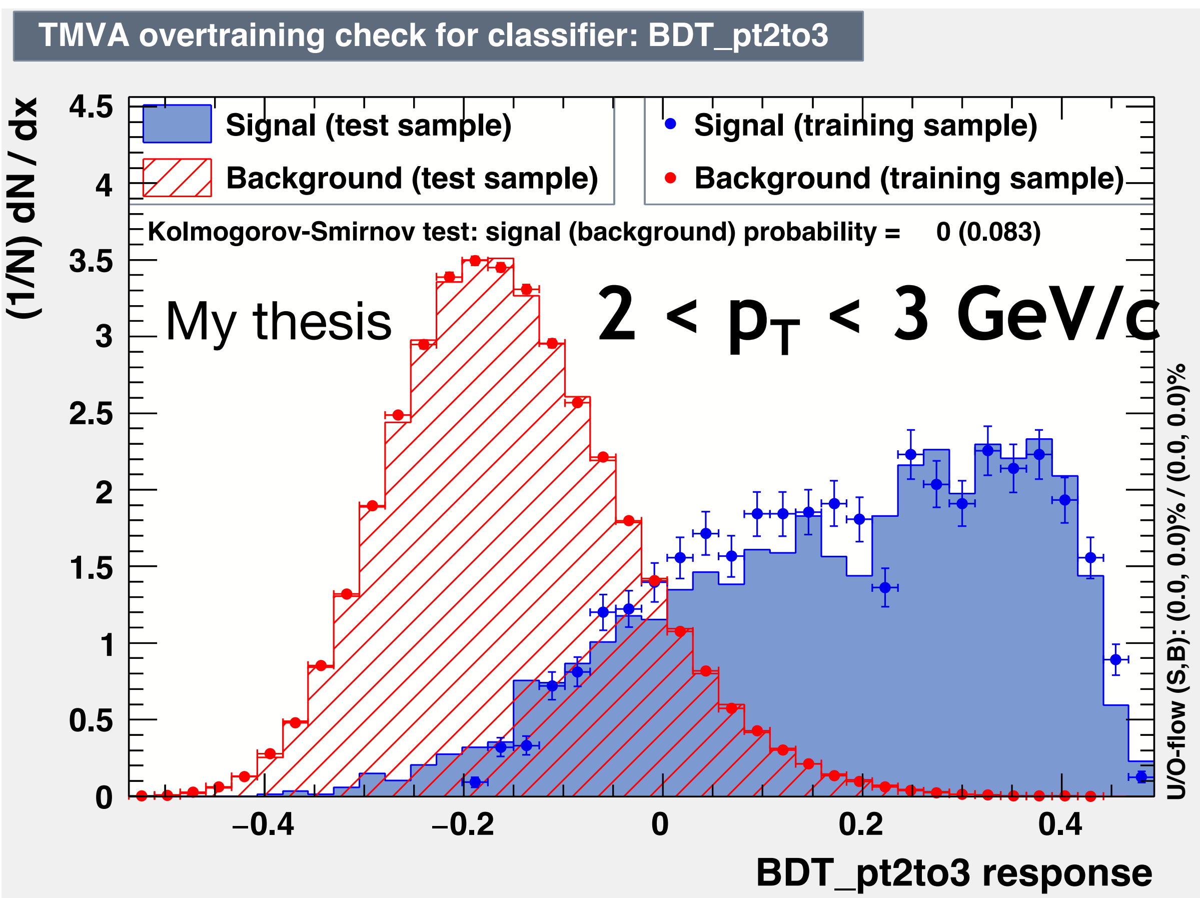

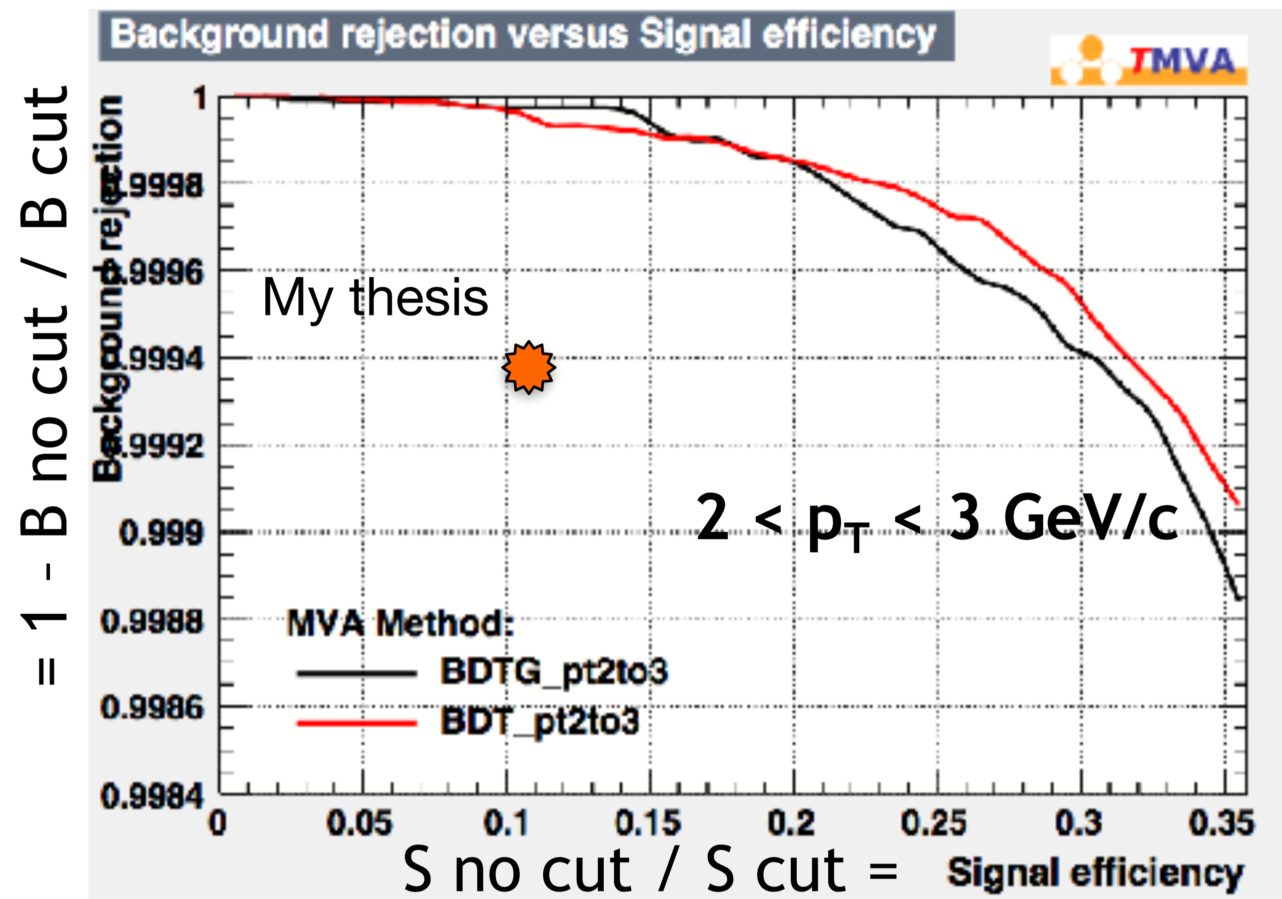

- Cuts chosen on BDT response improving standard cut-based method such that:
  1. Improve background rejection for same signal efficiency
  2. Improve signal efficiency for same background rejection

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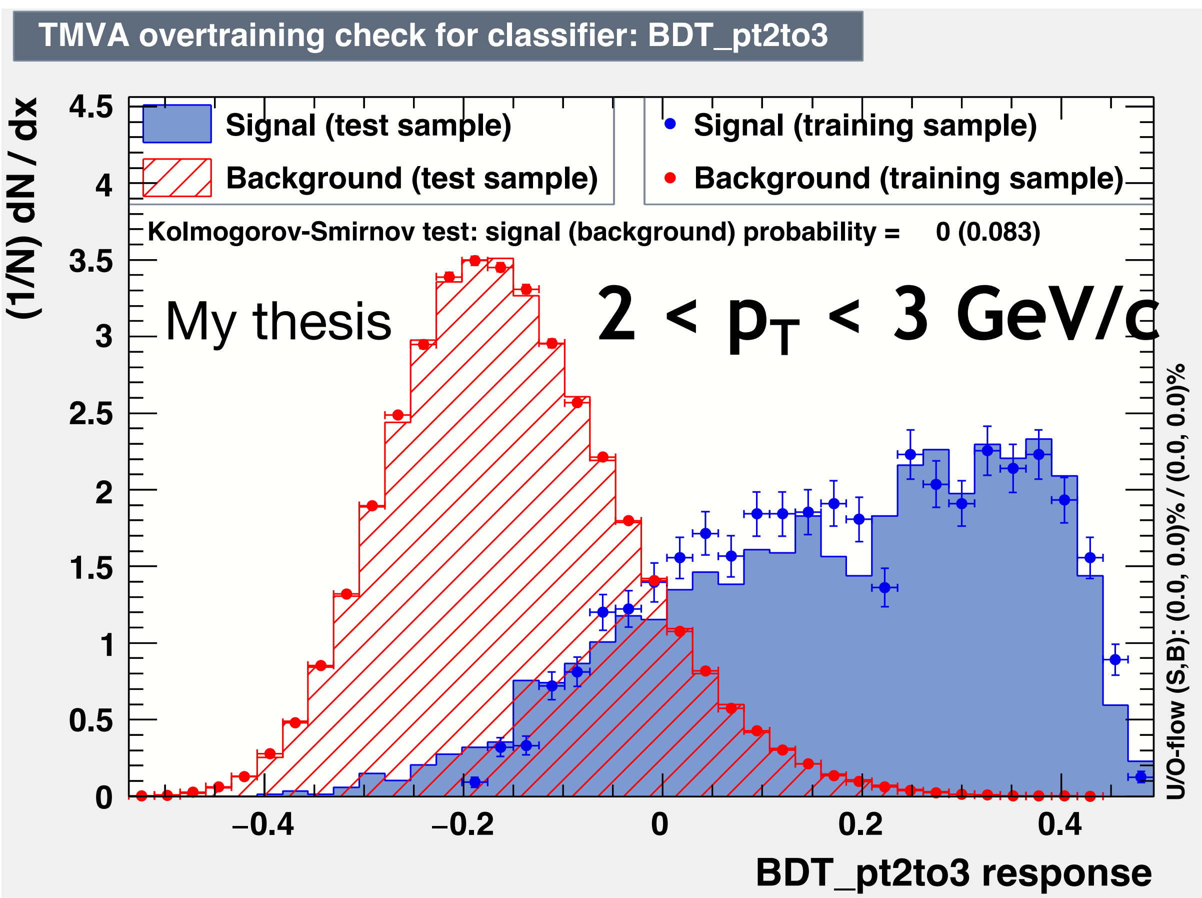

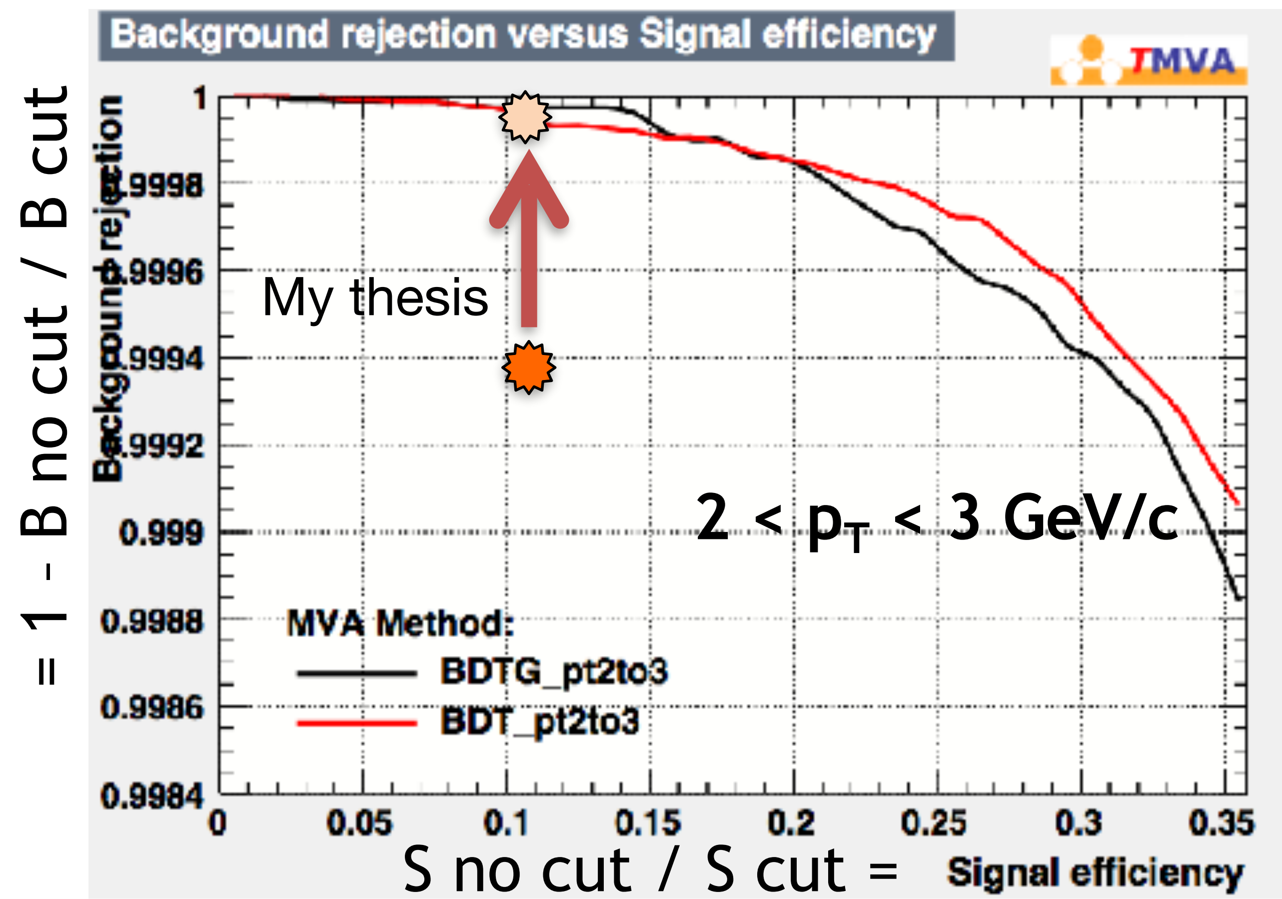

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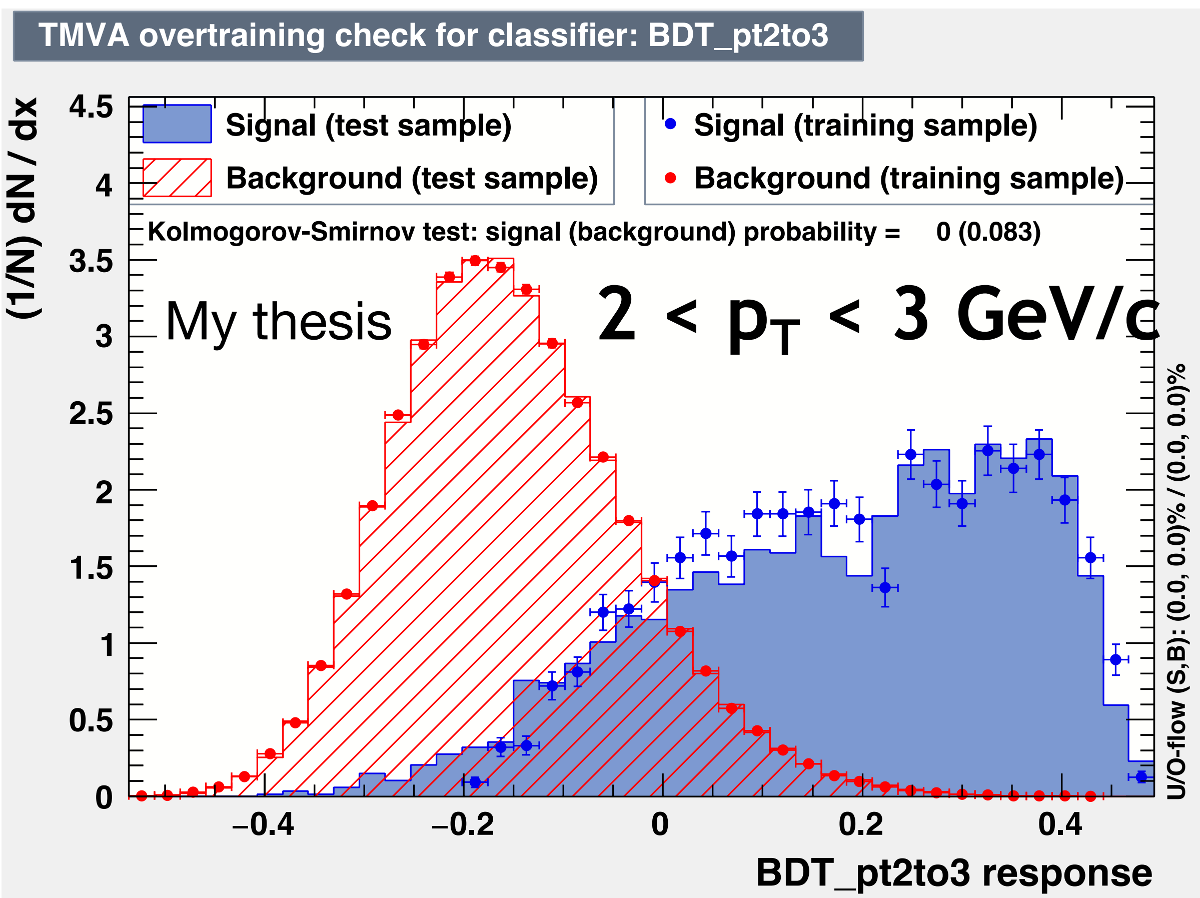

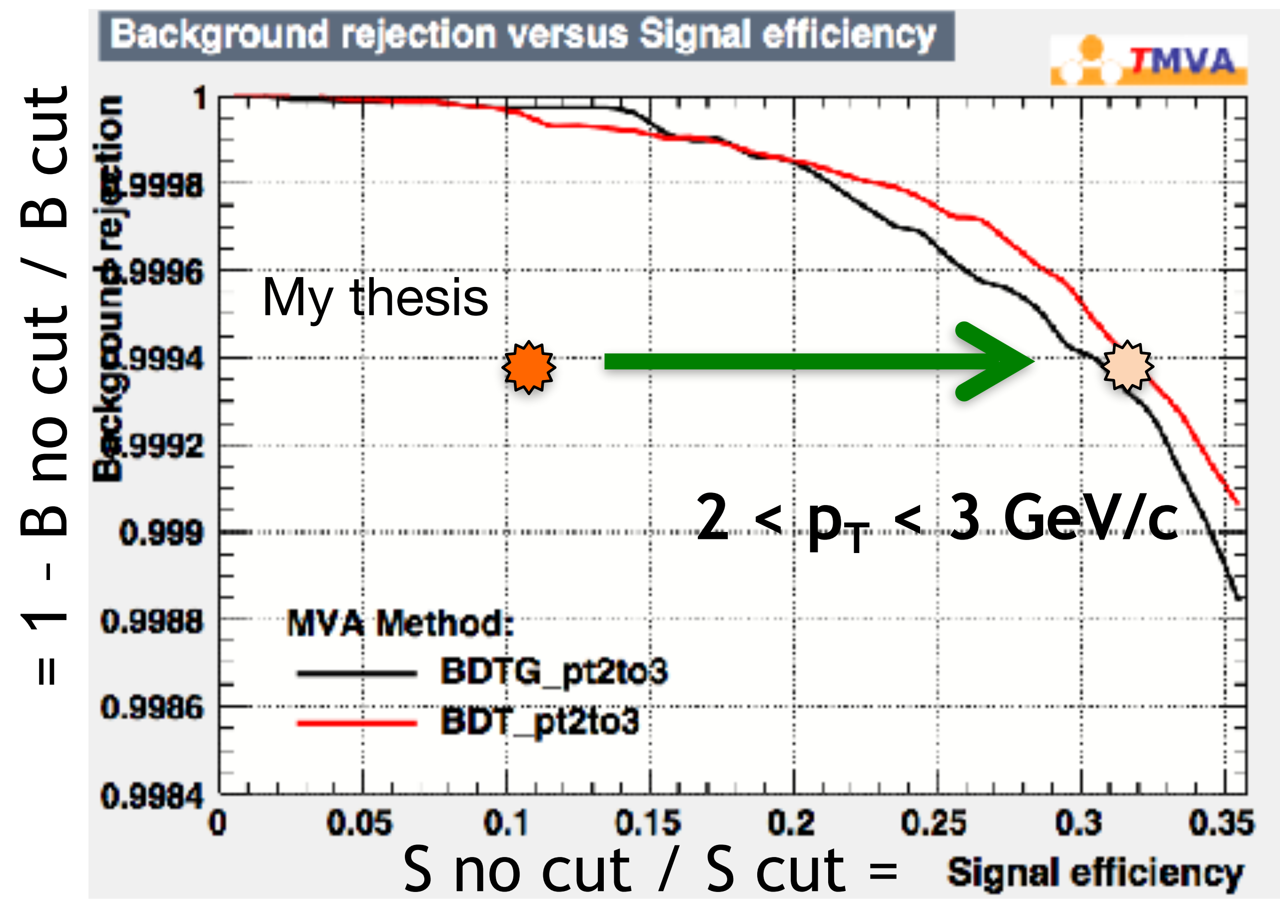

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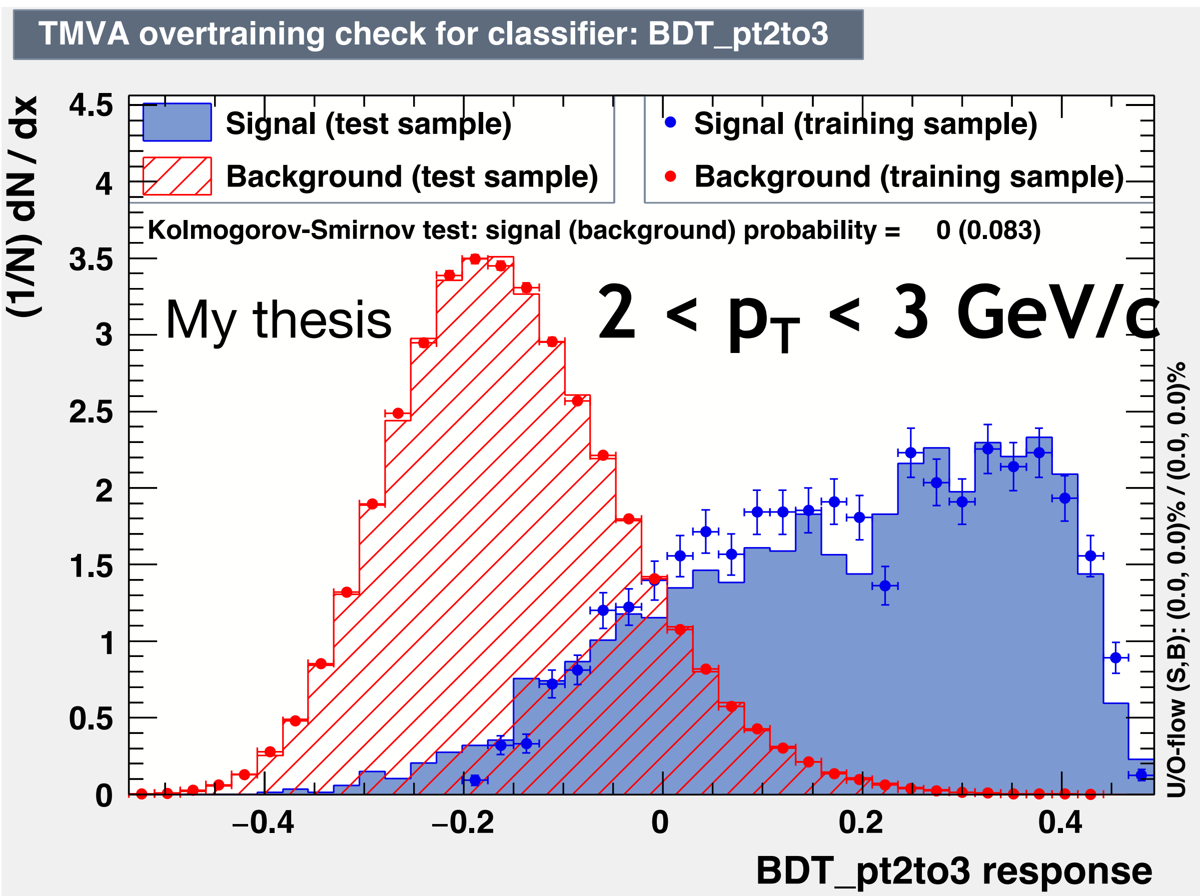

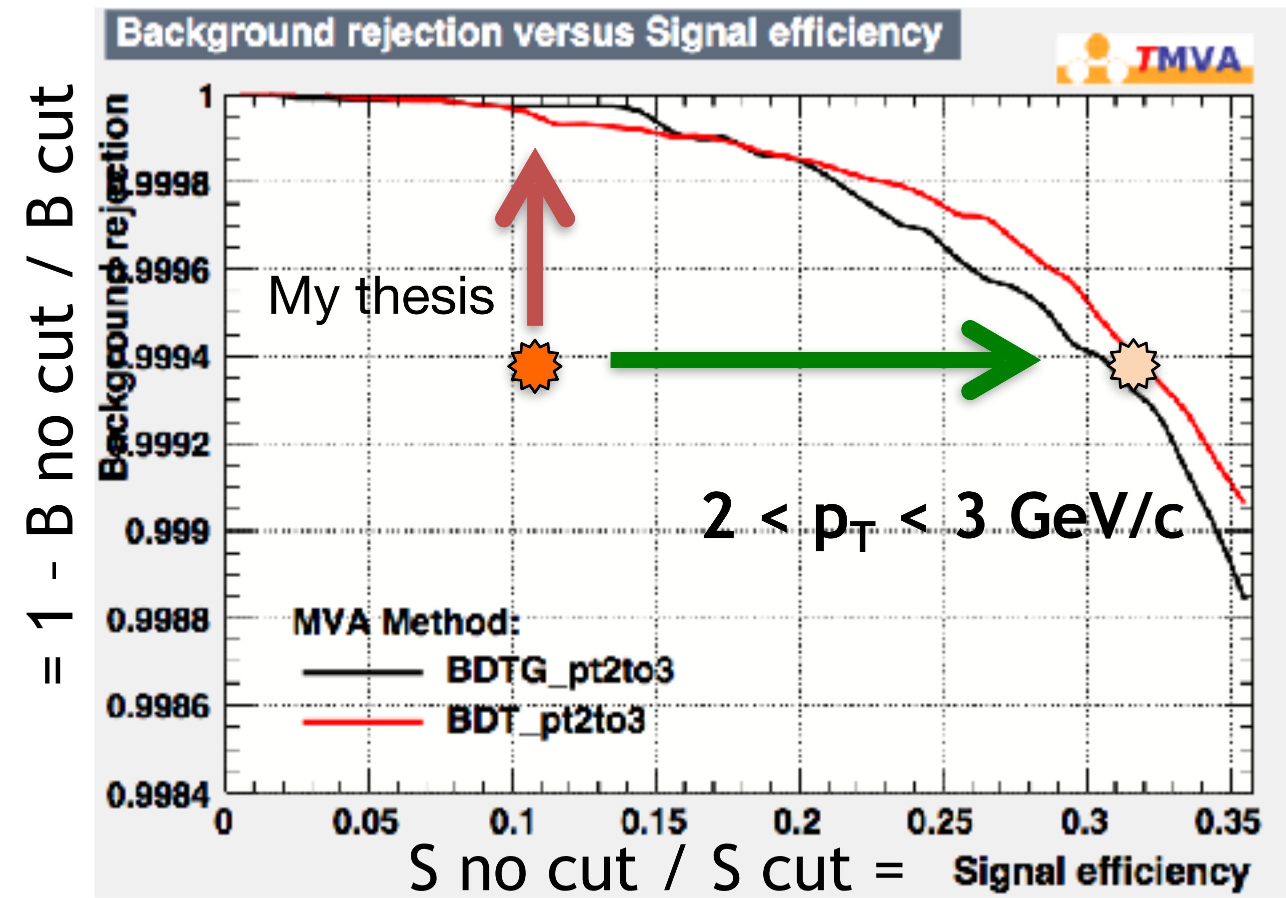

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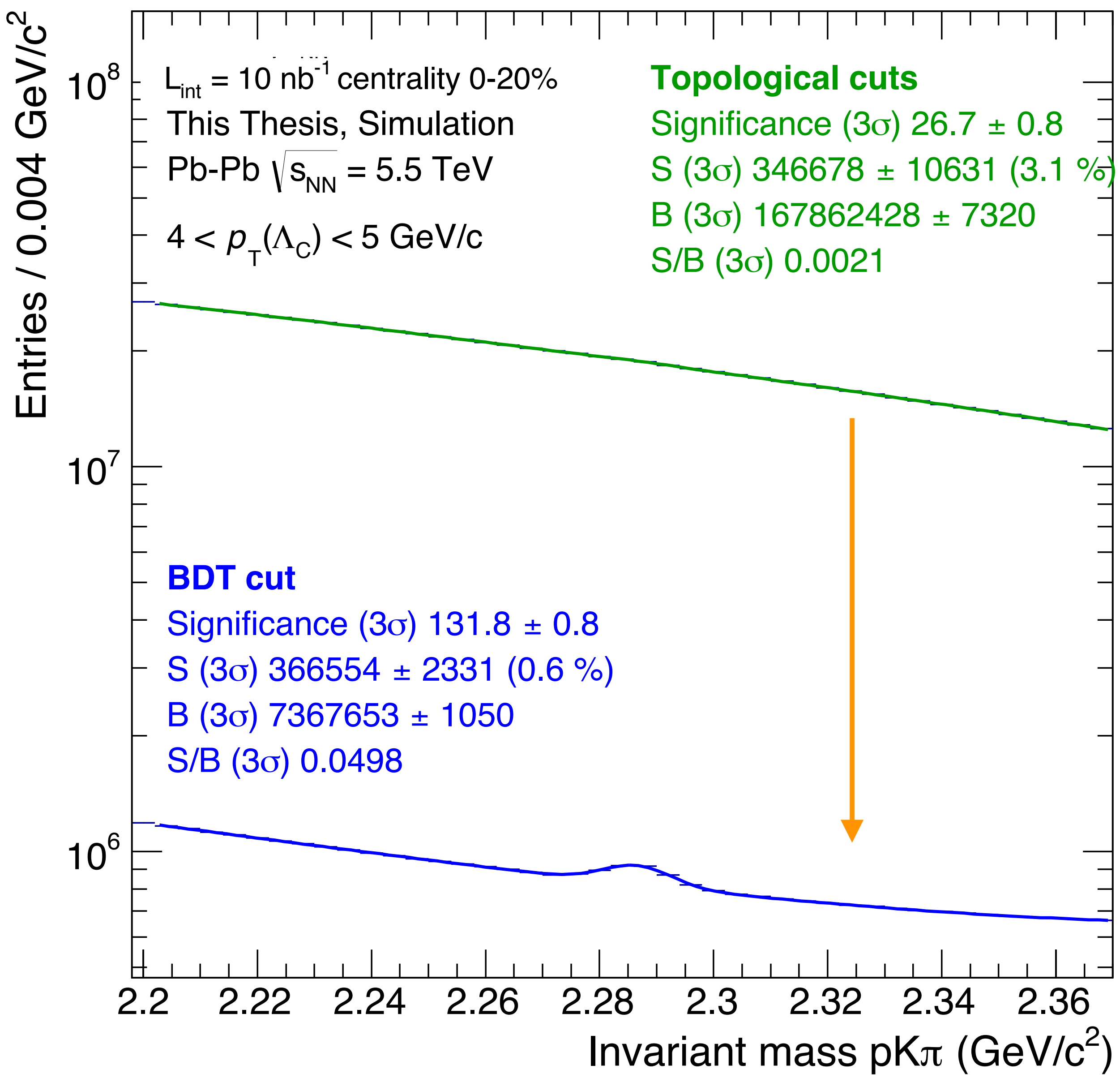
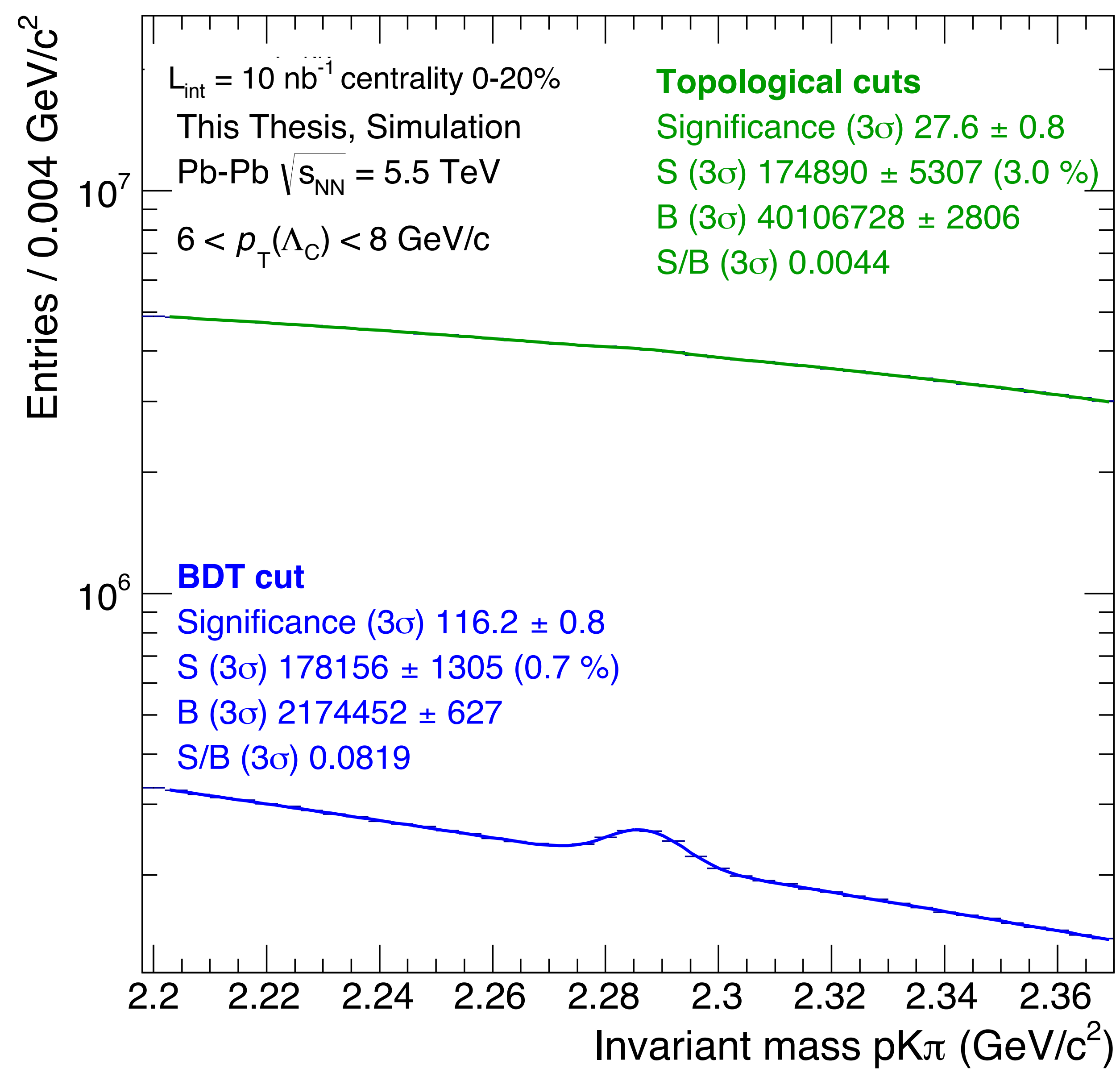
    1. Improve background rejection for same signal efficiency
    2. Improve signal efficiency for same background rejection

Improvement in signal extraction is then assessed

Invariant mass distributions

My thesis





- Invariant mass distributions corresponding to improved background rejection case
- Signal, background distributions scaled to expected integrated luminosity, expected signal yield and suppression (R_{AA}) hypothesis
- **Significant improvement** seen when using **BDTs** with respect to **standard, topological cuts**

S/B, improved background rejection

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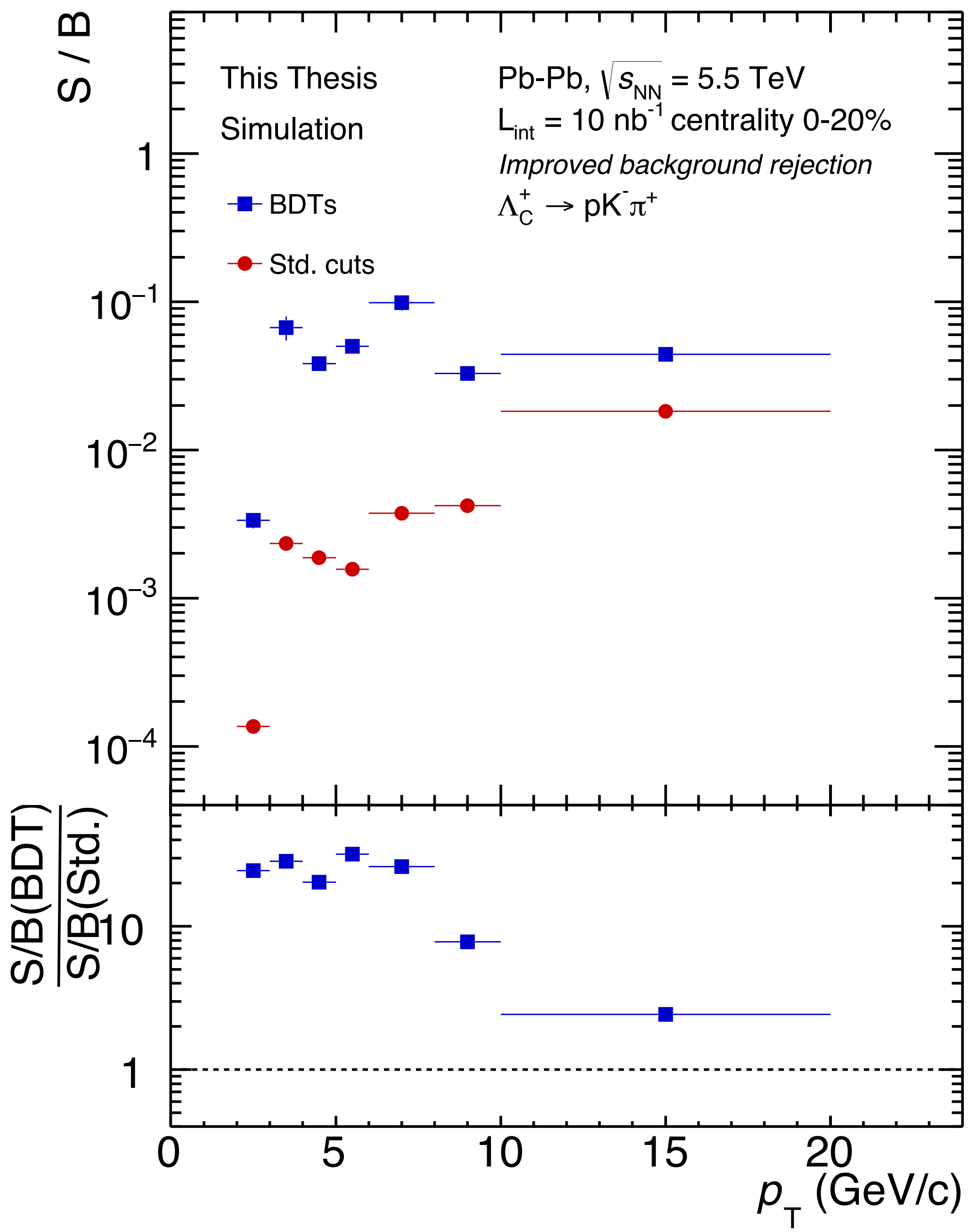

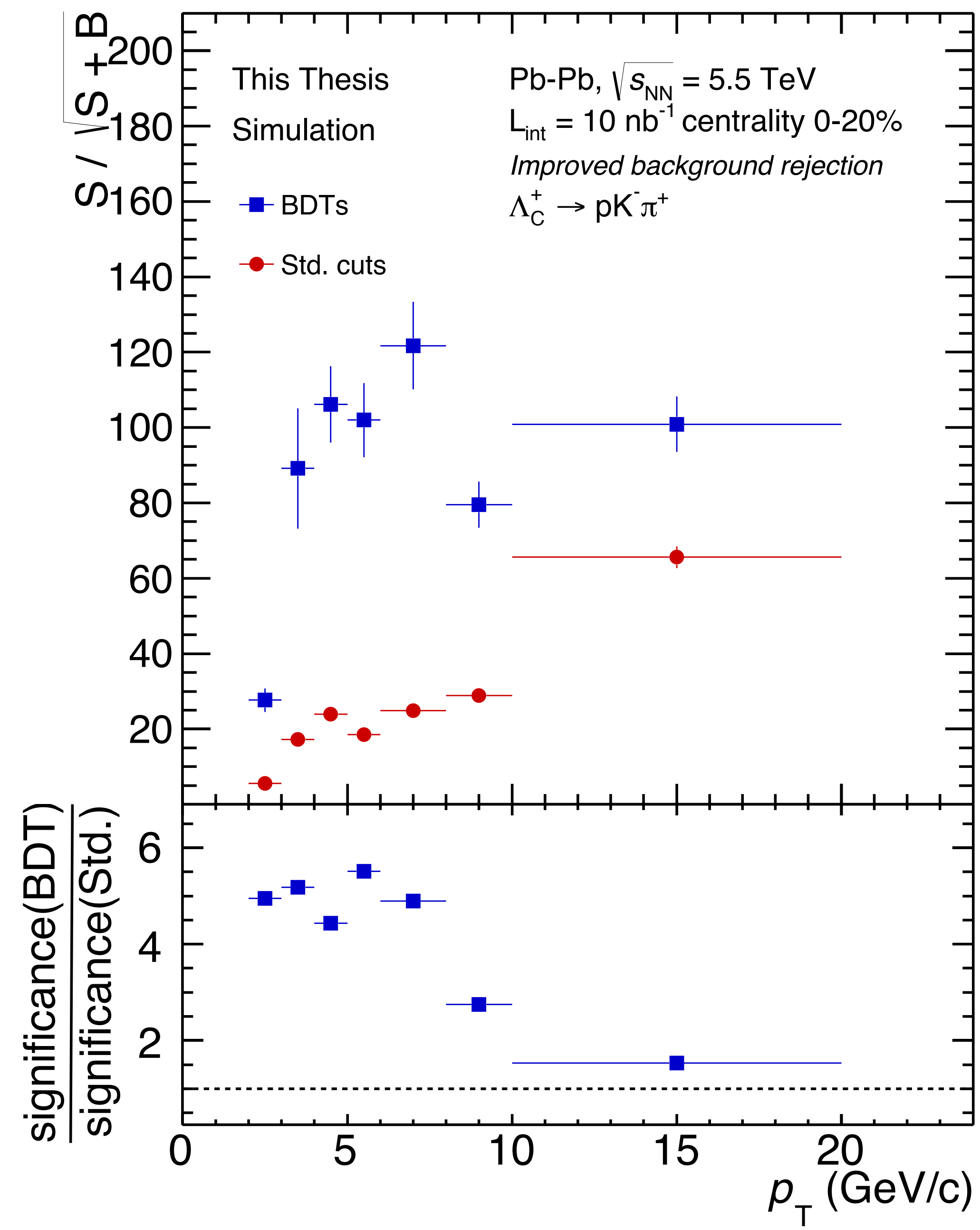

- Significant improvement **up to 30x** in the S/B
- Corresponds to **up to 6x** improvement in the statistical significance (statistical uncertainty)

S/B, improved signal efficiency

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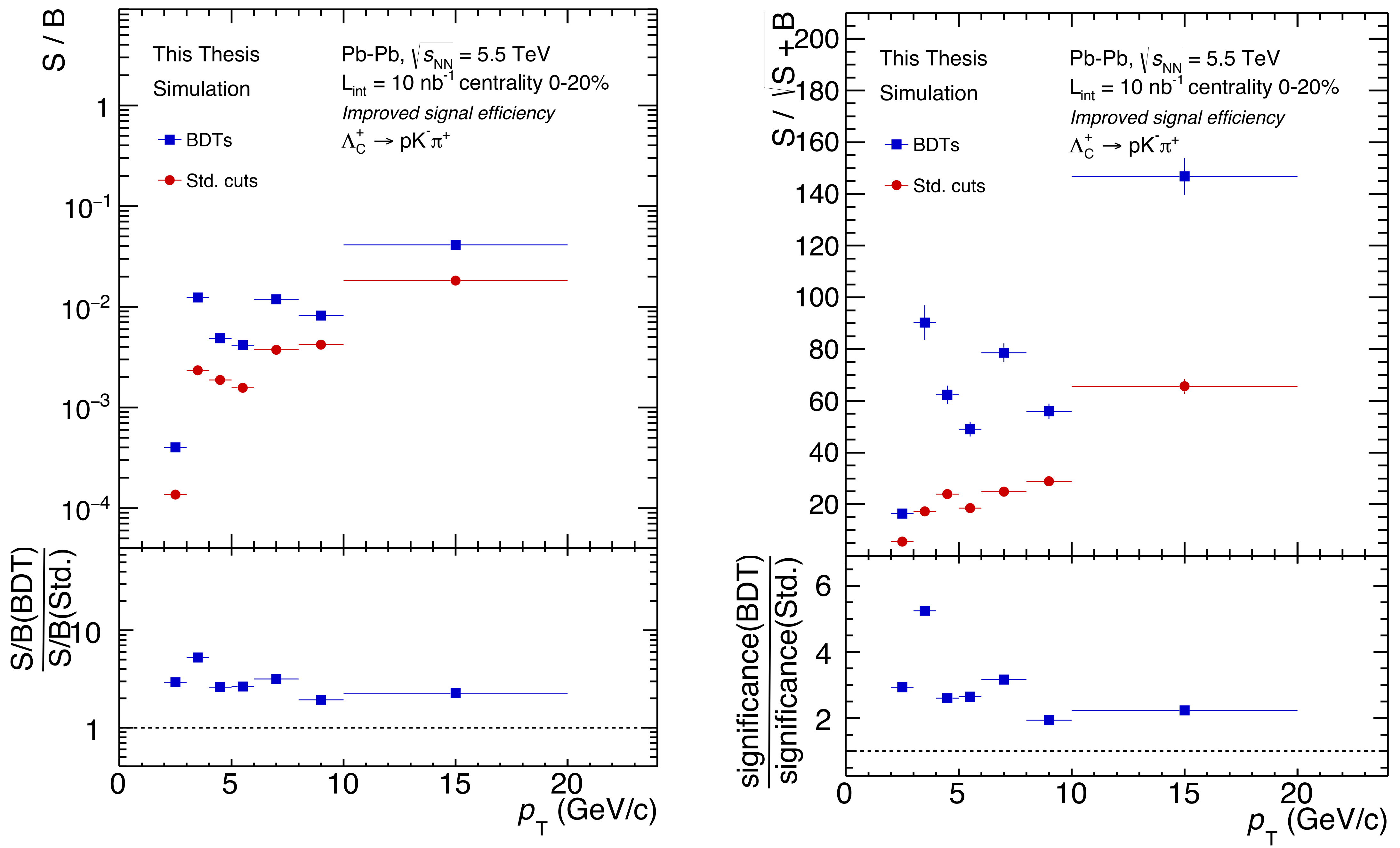

- Significant improvement **up to 5x** in the S/B
- Corresponds to **up to 5x** improvement in the statistical significance (statistical uncertainty)

A beautiful baryon

- Measurement of Λ_b will further help constrain coalescence/ diquark models
- Λ_b study with ITS upgrade has shown that the measurement is at the limit of the expected performance (full Run3/4 dataset)
- A multivariate approach is also being studied here - could hugely benefit measurement

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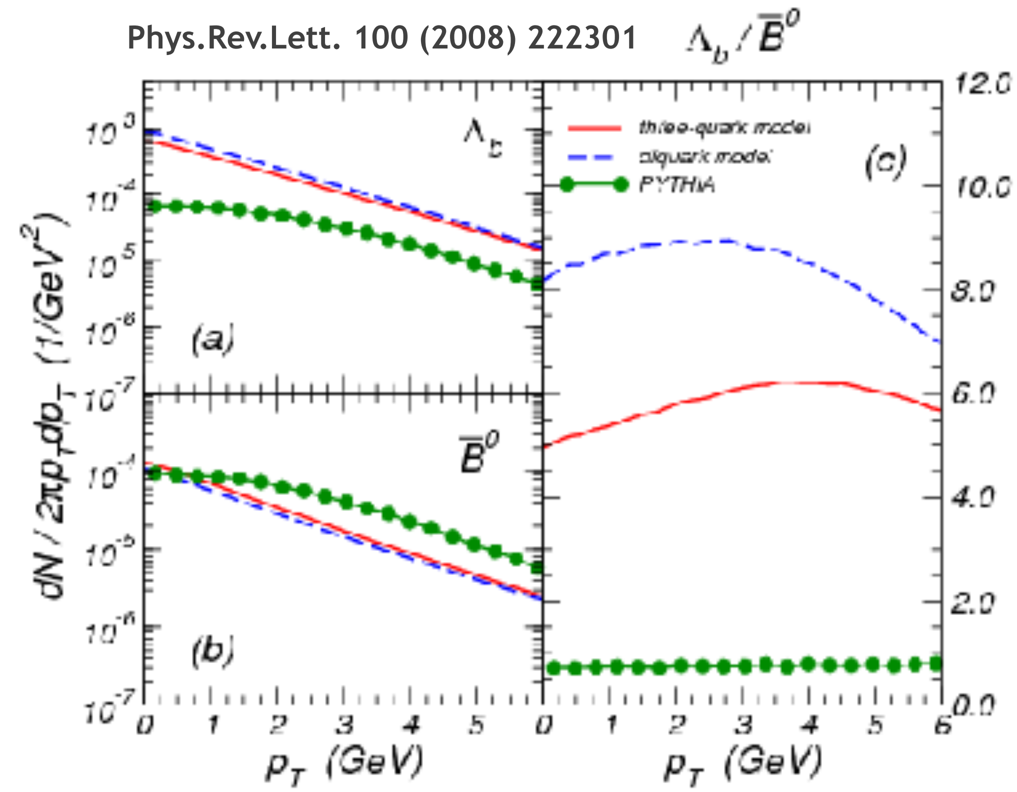

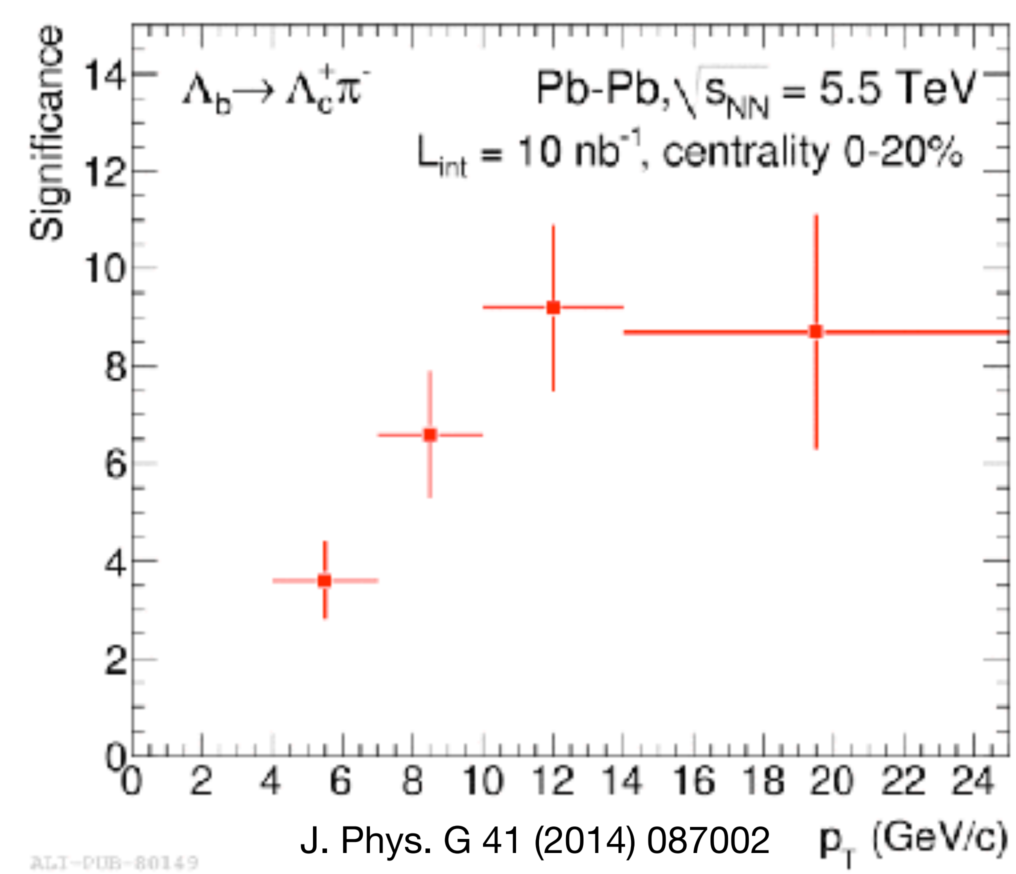

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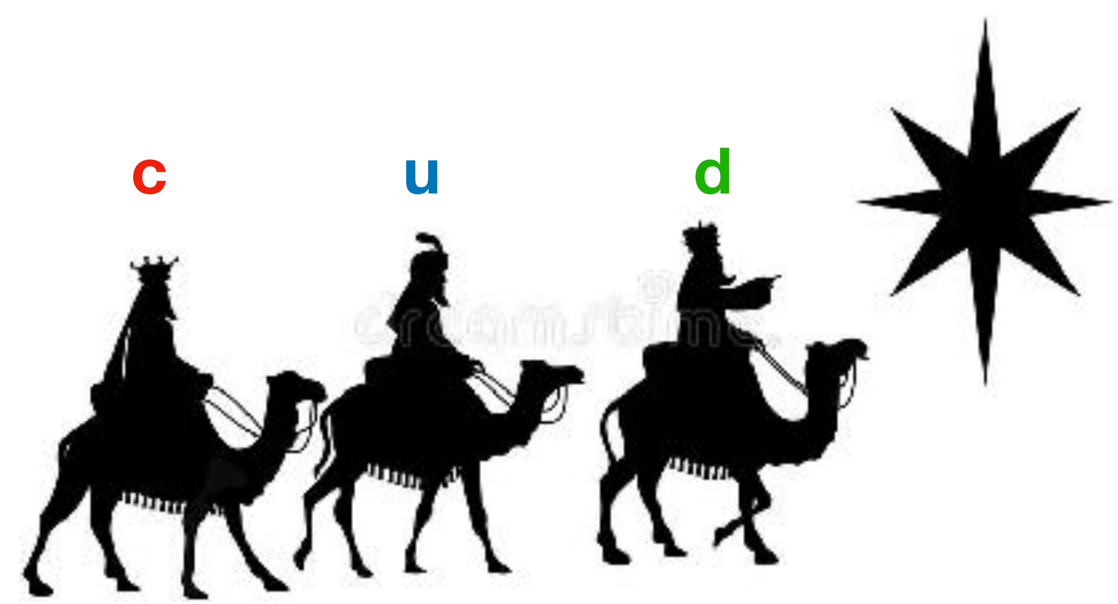
Summary

- Heavy-flavour baryon measurements can tell us a lot about heavy-flavour production and hadronisation processes
    - Measurement in pp, p-Pb collisions larger than expectations
    - Hints of enhanced charmed baryon production in AA collisions
    - Modified hadronisation in hadron collisions?
- The use of multivariate analysis methods can help us when extracting a small signal from a large background
- Run 3/4 at the LHC will allow for a precision measurement of charmed baryons in Pb-Pb collisions
- Many more exciting measurements ahead!



Backup

BDT analysis

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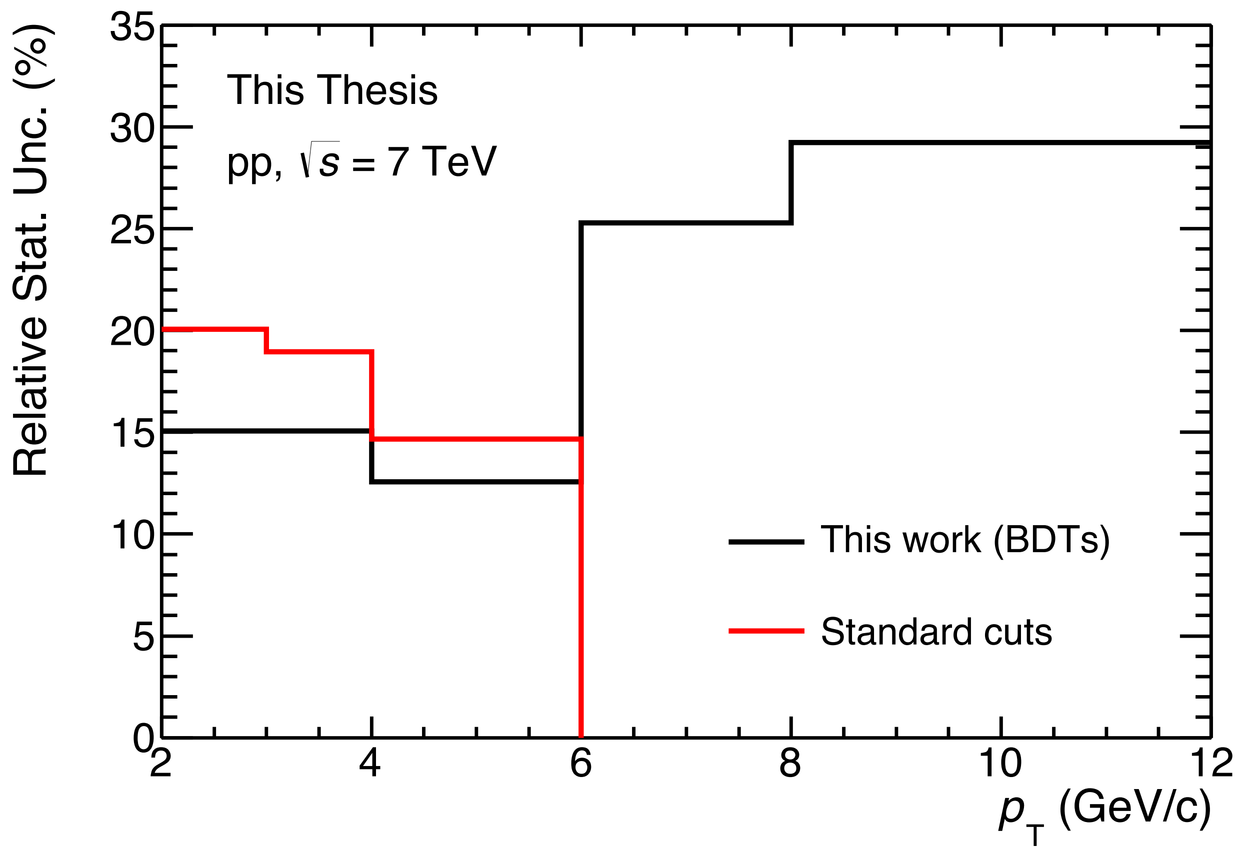

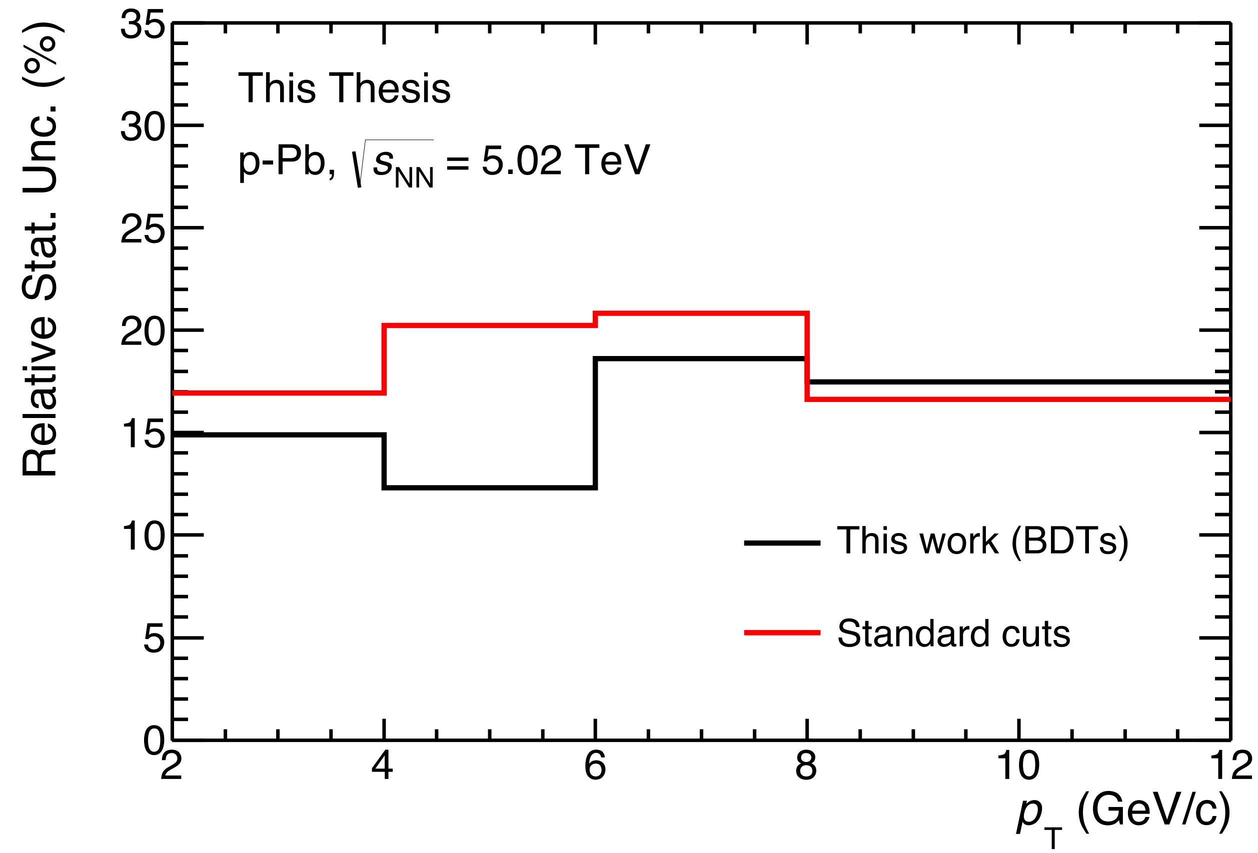

- Statistical uncertainty reduced from BDT analysis

Merging decay channels

- Statistically uncorrelated analyses - different decay channels.
  - Uncorrelated uncertainties - raw yield extraction, Λ_C selection, PID efficiency. Additional semileptonic uncertainties considered uncorrelated
  - Correlated systematic uncertainties - tracking efficiency, generated Λ_C p_T shape, b feed-down, luminosity
- Statistically correlated analyses - same decay channels, different analysis techniques.
  - Statistical uncertainty treated as fully correlated (checked, good approximation)
  - Uncorrelated uncertainties - raw yield extraction
  - Correlated systematic uncertainties - Λ_C selection, PID efficiency, tracking efficiency, generated Λ_C pT shape, b feed-down, luminosity