B_c measurement in PbPb in ALICE : preliminary study with fast simulation and BDT

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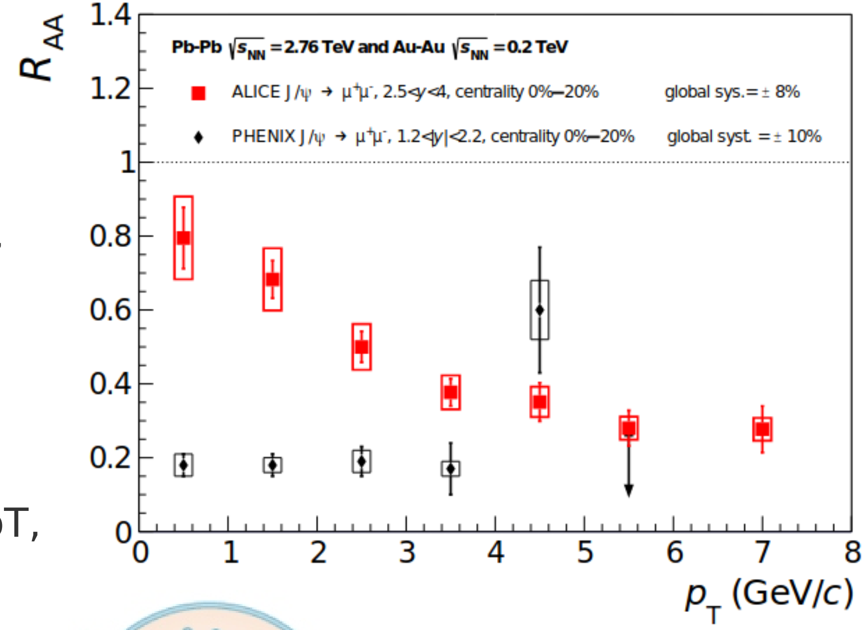
Aussois Quarkonium & QCD meeting (21/06/2021)

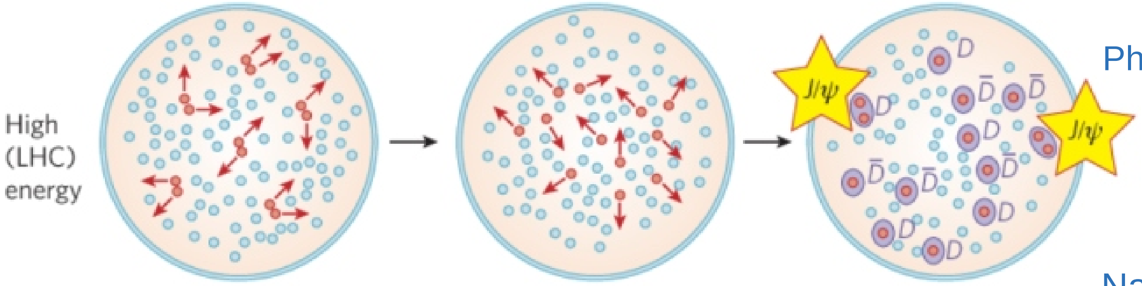
Motivation

- One signature of the production of hot deconfined medium in heavy ion collisions (Quark Gluon Plasma, QGP) : relative suppression of heavy quarkonia compared to pp
- Observed reduced J/psi suppression at LHC energies compared to RHIC energies

  → points towards a regeneration mechanism at low pT, recombination of cc pairs



Phys.Lett. B734 (2014) 314-327



Nature 448, 302–309 (2007)

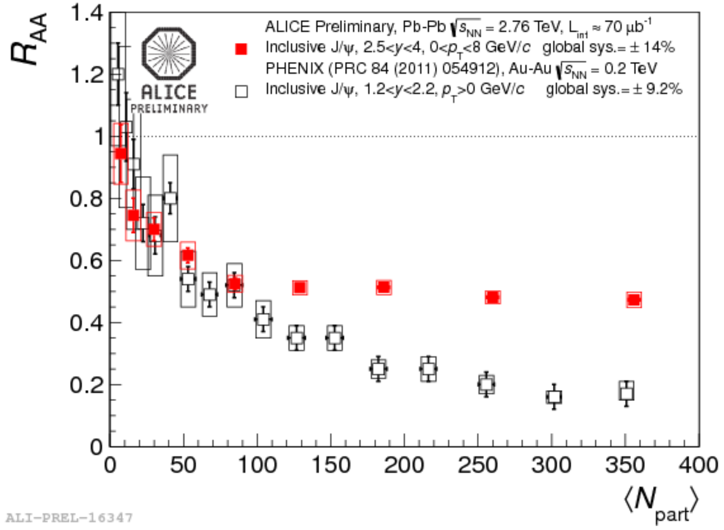
- Regeneration accounted for in transport model (continuous dissociation/recombination of bound states) as well as statistical hadronization model (statistical binding of pairs at hadronization)

Motivation

- B_c ($\bar{b}c$) as a potential probe : in pp requires production of a cc pair and a bb pair in the same collision.

  → in HIC, regeneration would contribute to a huge enhancement of B_c yields at LHC (as predicted in early 2000's in PhysRev C.62.024905)

  → Transport and thermal models predict respectively an R_{AA} of 2.3-17.5 and 3.5-13 in 2.76 TeV Pb+Pb … (PhysRev C.87.014910)



- Also possible insight into mass hierarchy of energy loss : smaller suppression for heavy quarks than for light quarks (dead cone effect ?)

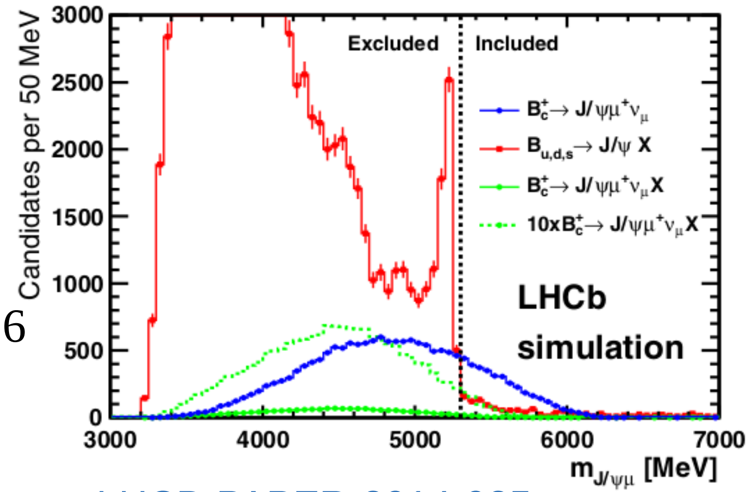
LHCb & CMS results

- Measurement of relative branching ratio for B_c in pp by LHCb (forward rapidities) : correlated background of B → J/Ψ X decays eliminated with mass selection

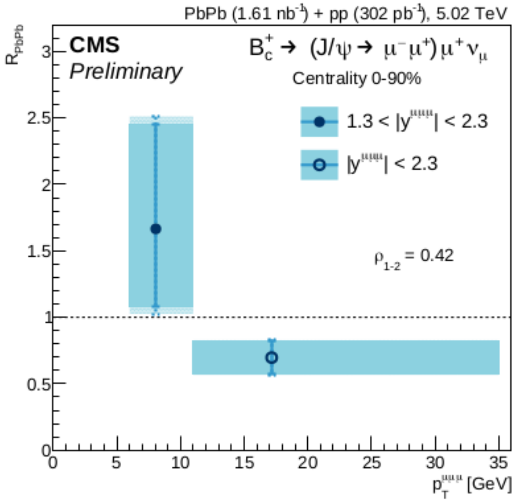
$$R=\frac{B(B_c \rightarrow J/\psi \pi)}{B(B_c \rightarrow J/\psi \mu \nu_\mu)}$$

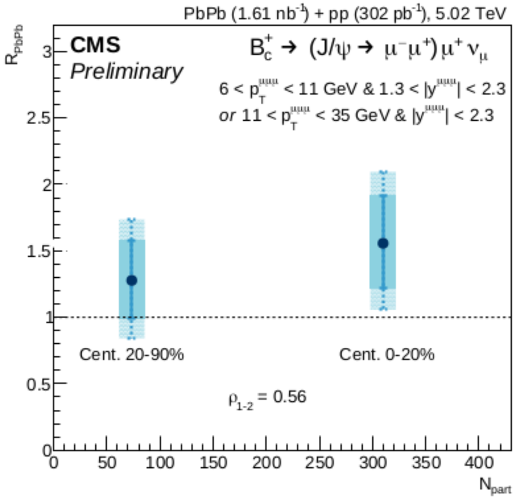
$$R(m_{J/\psi\mu}>5.3\,GeV)=0.271\pm0.016\pm0.016$$

$$R=0.0469\pm0.0028\pm0.0046$$



LHCB-PAPER-2014-025





CMS PAS HIN-20-004

- Recent analysis in pp and PbPb at 5.02 TeV by CMS in two pT bins

→ Signal extraction done with BDT and mass fit.

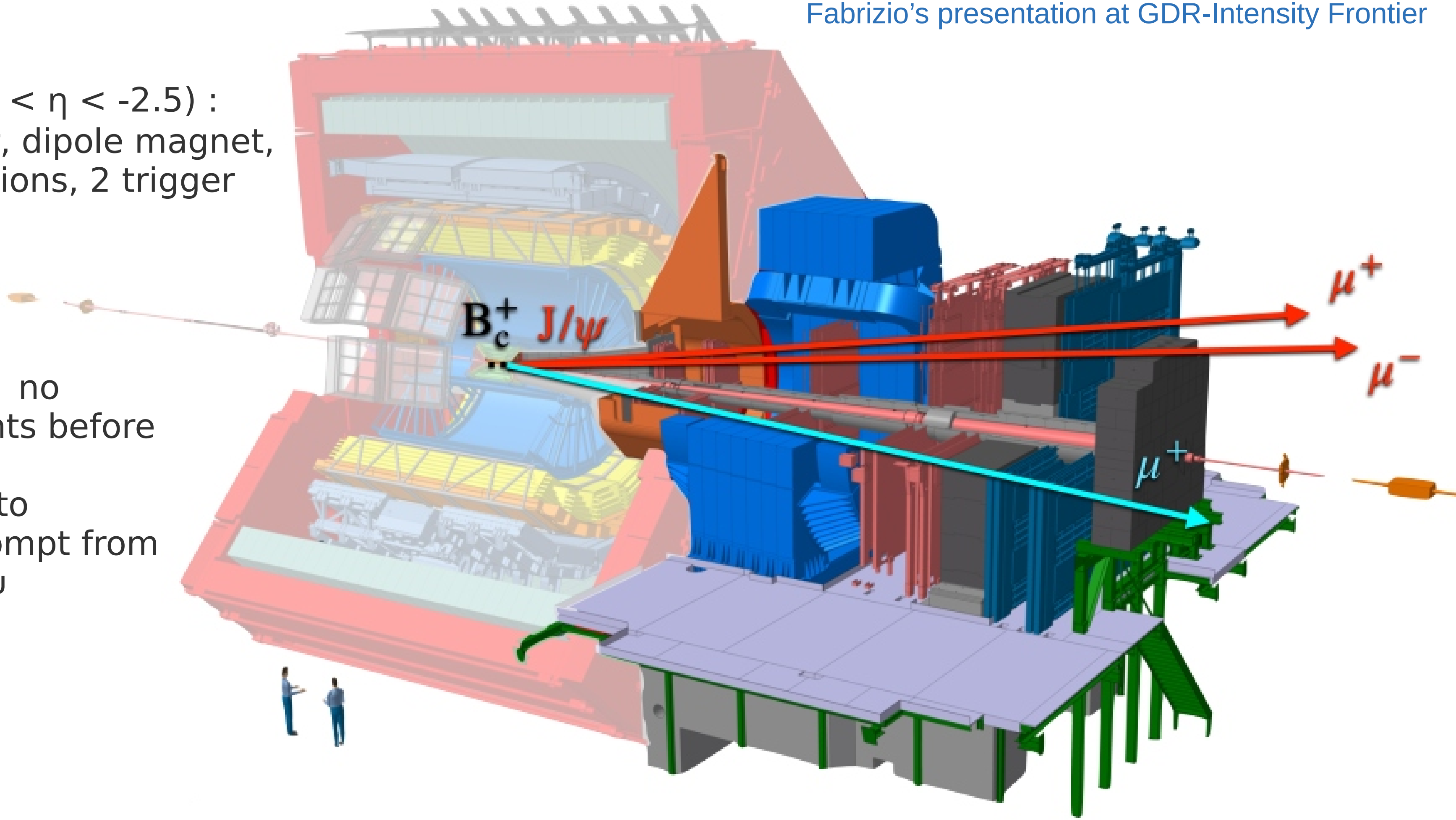
→ Large uncertainties mainly due to fit uncertainties and poorly known kinematics of B_c (p_T spectrum affects acceptance and efficiency corrections)

Bc in ALICE at forward rapidity

Fabrizio's presentation at GDR-Intensity Frontier

- MUON Arm ($-4 < \eta < -2.5$) : Front absorber, dipole magnet, 5 tracking stations, 2 trigger stations

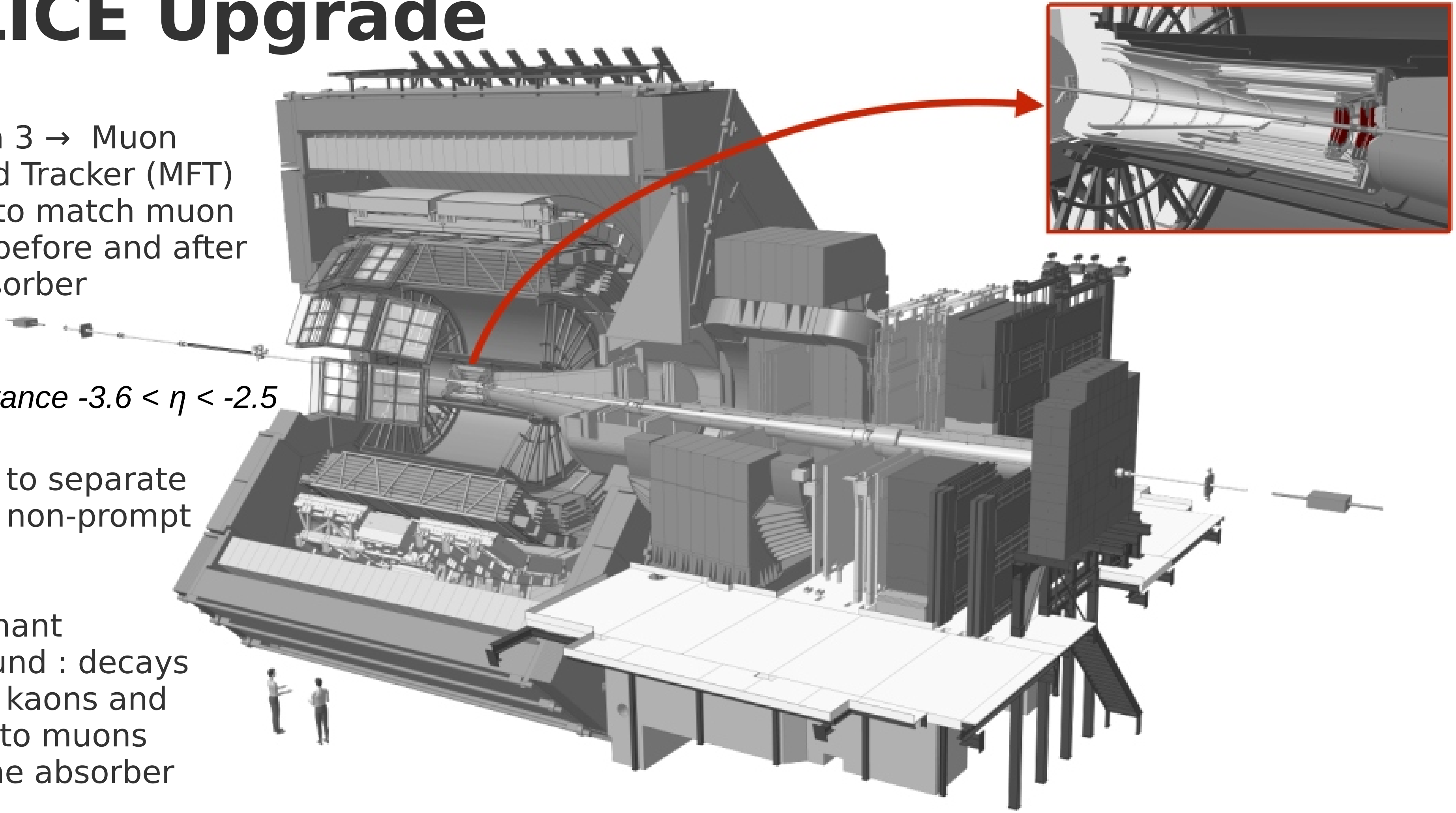
- Run 1 and 2 → no measured points before absorber
→ impossible to distinguish prompt from non-prompt J/ψ



ALICE Upgrade

- For Run 3 → Muon Forward Tracker (MFT) added to match muon tracks before and after the absorber

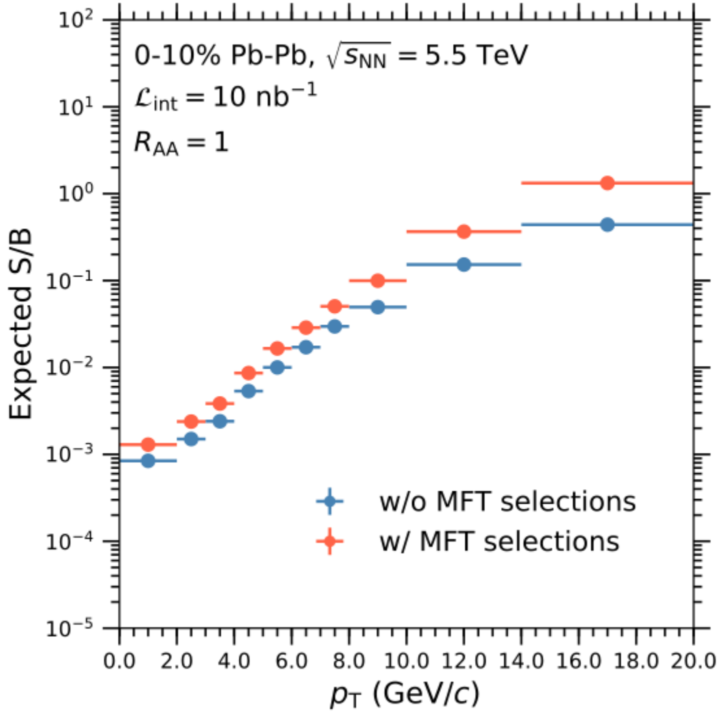
MFT acceptance -3.6 < η < -2.5



- → allows to separate prompt / non-prompt J/ψ
- → Dominant background : decays of pions, kaons and charm into muons before the absorber

Study of Bc → μ ν_μ (J/ψ → μ μ) channel

- Based on estimation of signal/background for B_c made by Fabrizio Grosa for channel B_c → μ ν_μ (J/ψ → μ μ) at forward rapidity in ALICE, see his presentation at GDR-Intensity Frontier.
- Fabrizio also looked at the B_c → D^{*+} D^0 in central barrel, seems less promising
- One of the difficulties of the 3 muon channel : only partially reconstructed → not peaked signal but broad mass spectrum
- Cross section estimated from LHCb measurements (arXiv:1411.2943, arXiv:1407.2126) and FONLL
- → estimated S/B ~ 10^-3 and significance~1 in the lowest p_T bin, *But does not exploit secondary vertexing and assuming an R_{AA}=1*



→ Can this be improved using secondary vertexing and ML ?

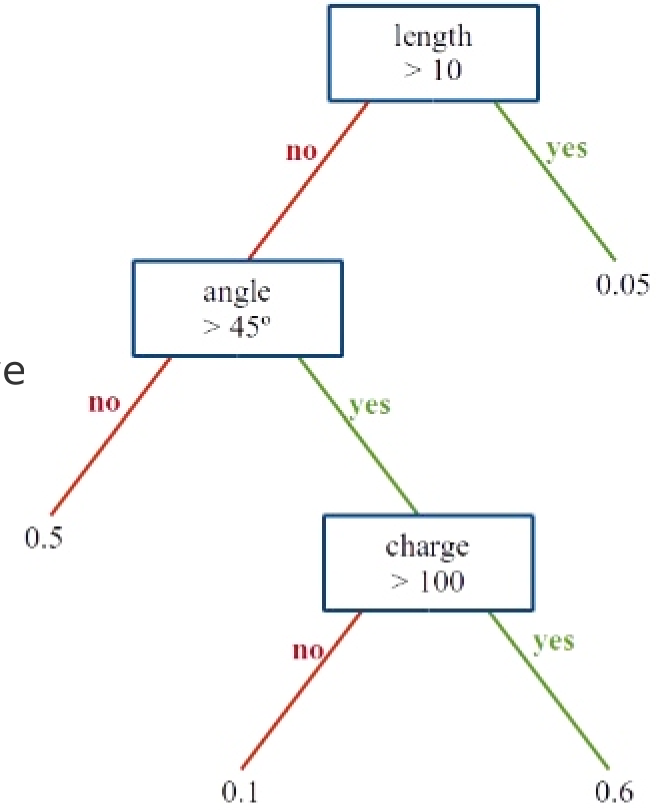
Boosted decision tree with XGBoost

- Used in e.g. Λ_c^+ in Pb+Pb
- Uses ensemble learning : many weak learners (classification/regression trees) are combined to produce a strong learner
- → Each tree's output $f_t(x)$ is given a weight w_t relative to its accuracy
- → The ensemble output is the weighted sum:

$$\hat{y}(x) = \sum_t w_t f_t(x)$$

- Boosting : each learner in the ensemble is created iteratively

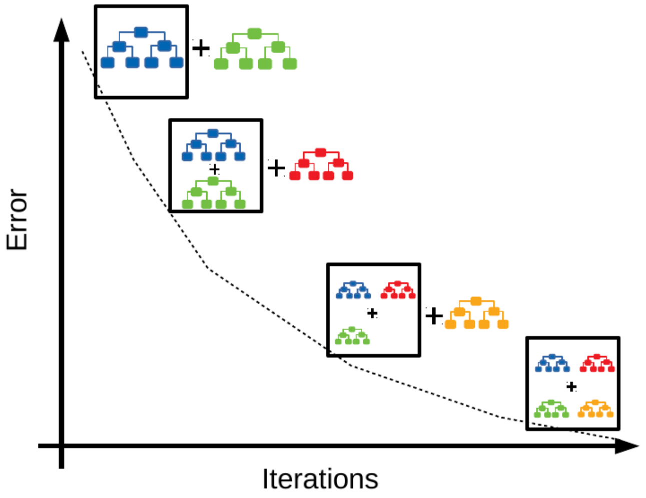
xgboost.readthedocs.io
arXiv:1603.02754



Source : K.Woodruff

- Gradient boosting : At each iteration, the new tree is constructed to minimize the function :

$$O(x) = \sum_i l(\hat{y}_i, y_i) + \sum_t \Omega(f_t)$$



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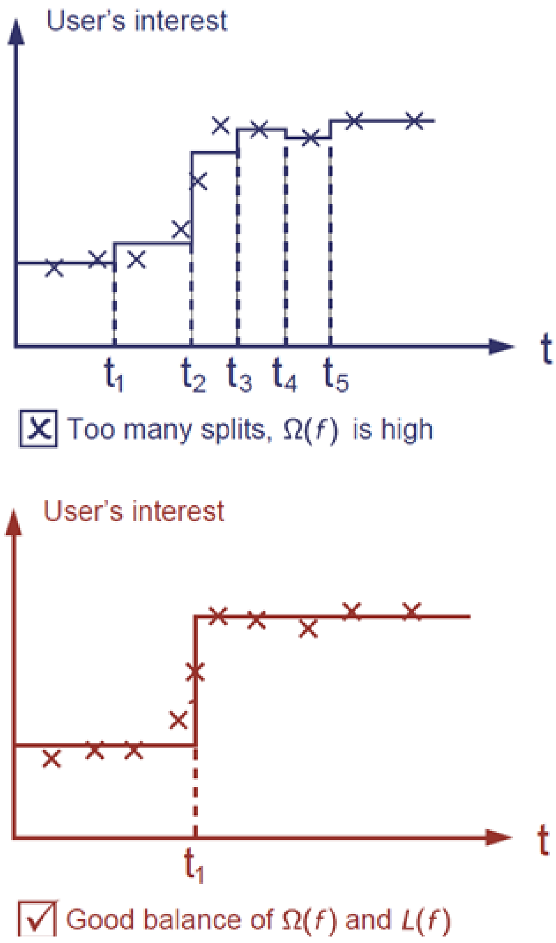


(l(ŷ,y) is a loss function, for example the logistic map for binary classification, and Ω(f) is a regularisation function to avoid over-fitting)

Features (input variables)

Three-prong variables

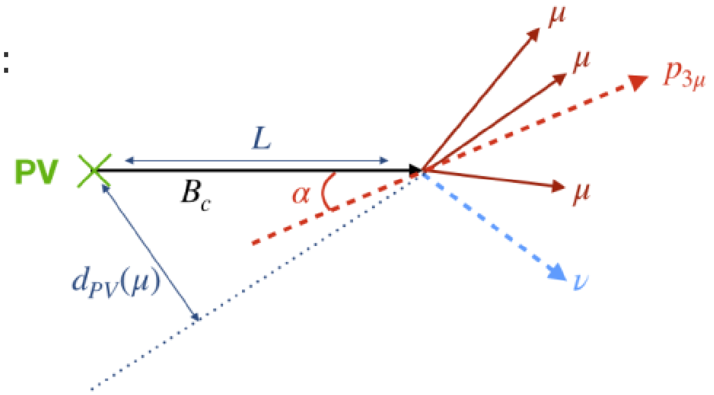
- Longitudinal B_c pseudo-proper time : $\tau_{z,\,Bc} = (L_z\, M_{Bc})/p_{z,\,Bc}$, where L_z is the longitudinal projection of the B_c decay length
- Dispersion of tracks at the secondary vertex (vertex quality) : $\sigma_{vtx}^2=\Sigma_{i=1}^3\, d_i^2$, where d_i is the DCA between the ith track and the reconstructed decay vertex
- Cosine of pointing angle cos α, where $\cos\alpha = \vec{L}\cdot\vec{p_{3\mu}}/(|L||p_{3\mu}|)$ with $\vec{L}=\vec{SV}-\vec{PV}$

Two-prong variables

- Longitudinal J/ψ pseudo-proper time : $\tau_{z,\,J/\psi} = (L_z\, M_{J/\psi})/p_{z,\,J/\psi}$, where L_z is the longitudinal projection of the J/ψ decay length

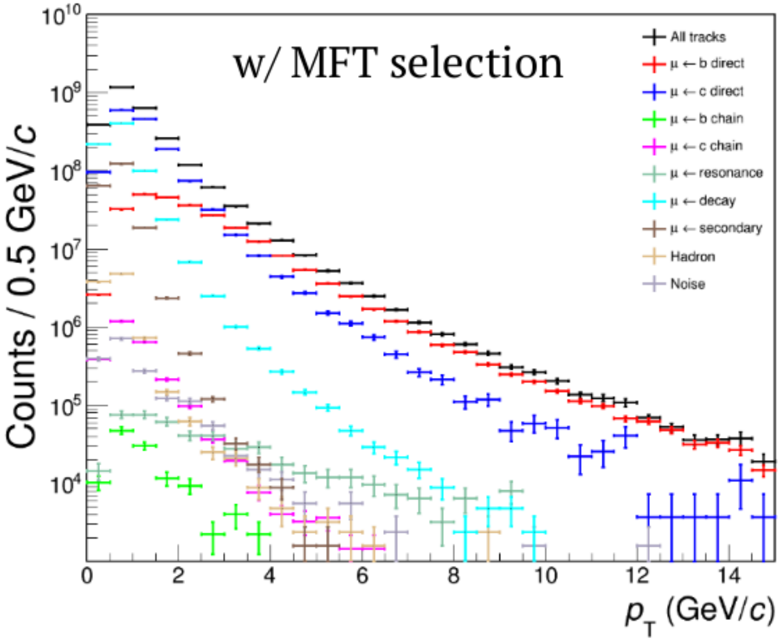
Single track variables

- Impact parameter (distance of closest approach) in the transverse plane of the three muons to the primary vertex



G.Falmagne, GDR-Intensity Frontier

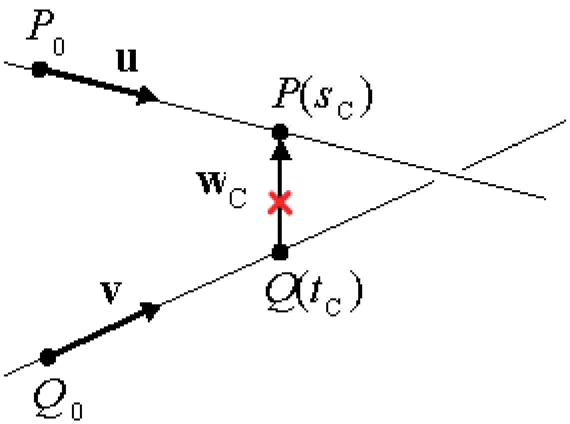
Fast simulation



→ Considered only the uncorrelated background from decay of K, π and charm before the absorber (at 46 cm)

→ Checked that we could reproduce J/psi background

- *Done with fast simulation software RapidSim, using FONLL cross sections and designed for LHCb*
  → Modified geometry (distance to primary vertex, magnet)
  → Modified resolutions (momentum, DCA, vertex)



→ Simplified secondary vertexing : finding the vector of minimal length between two tracks, taking its midpoint & smearing this point with fixed resolution (no p_T dependence)

Background composition

Three contributions to the uncorrelated background considered :

- ***‘Fake’ J/ψ + muon*** : Three background muons from the decay of π, K or charm in the same event (two of them represent a ‘Fake’ J/ψ, i.e. background under the J/ψ peak)
- ***Prompt J/ψ + muon*** : Mixing a prompt J/ψ with a background muon in the same event
- ***Non-prompt J/ψ + muon*** : Mixing a non-prompt J/ψ with a background muon in the same event

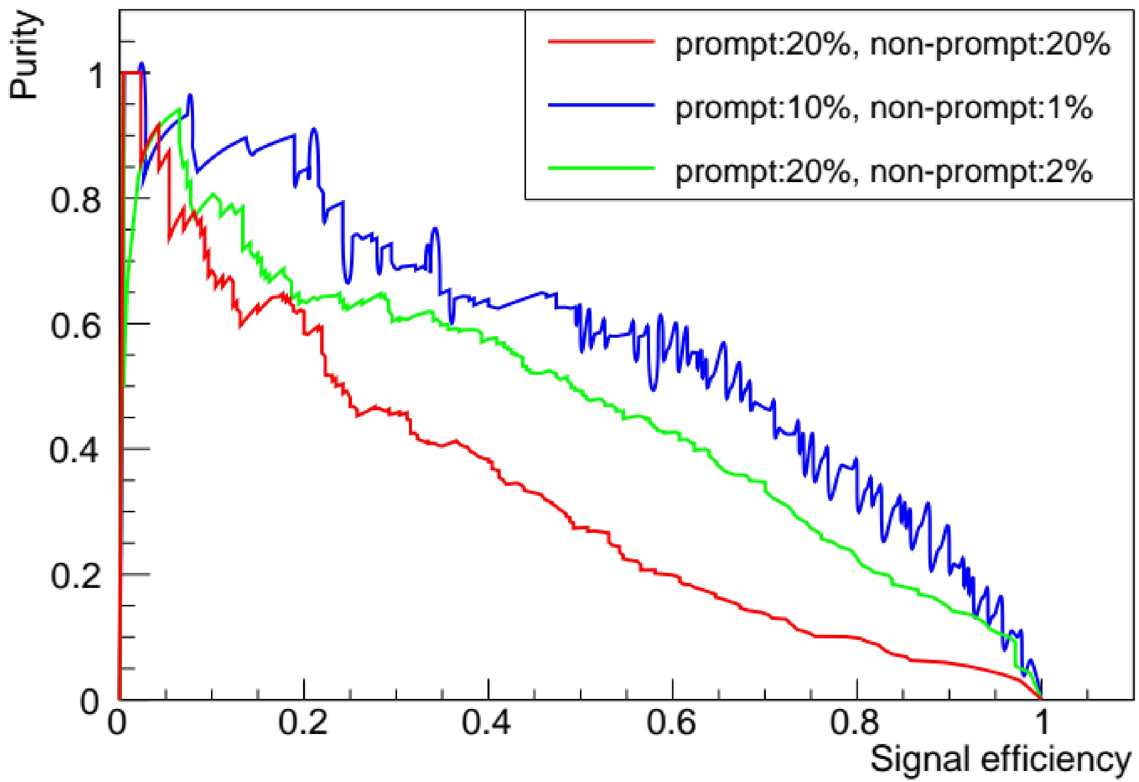
→ Varying the composition of the background by varying the percentage of these three types in the total background, while keeping a Signal/Background ~ 10^{-3} (Reproducing Fabrizio’s estimate) with a total sample of ~1M candidates

→ Monitor the impact on signal efficiency and purity at the output of the BDT

→ All p_T and mass integrated

BDT training and testing

- Varying background composition in sample
- 80% of sample for training, 20% for testing
- Learning rate = 0.1
- Maximum depth = 3
- ratio of features used = 0.3
- ratio of the training instances used = 0.3
- Iterate over 400 trees



→ Before selection : total signal

→ After selection : true signal (true positive) & false signal (false positive)

Purity = true signal / (true signal + false signal)

Efficiency = true signal / total signal

Conclusion

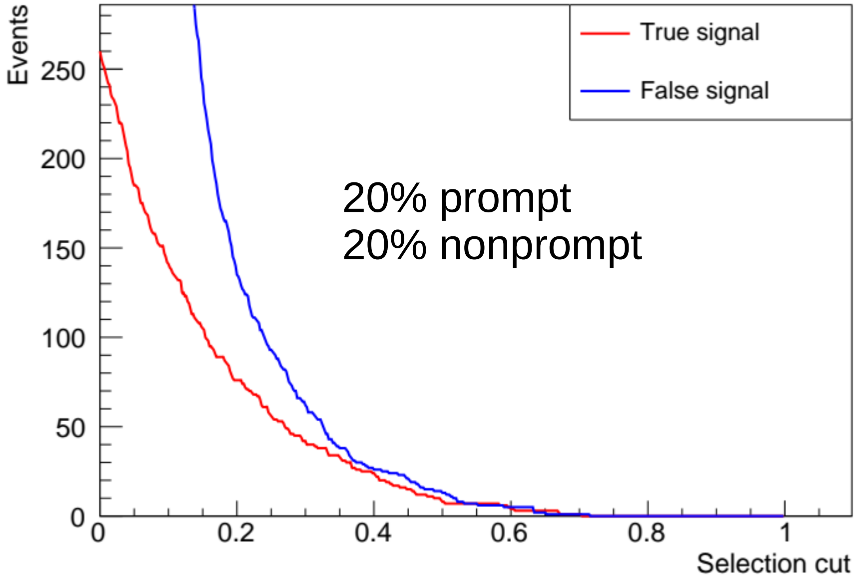
- Simplified modelling of background and secondary vertexing with fast simulation, not taking into account correlated background, feed-down pT dependence of resolution
- Significant improvement of S/B with gradient boosting :

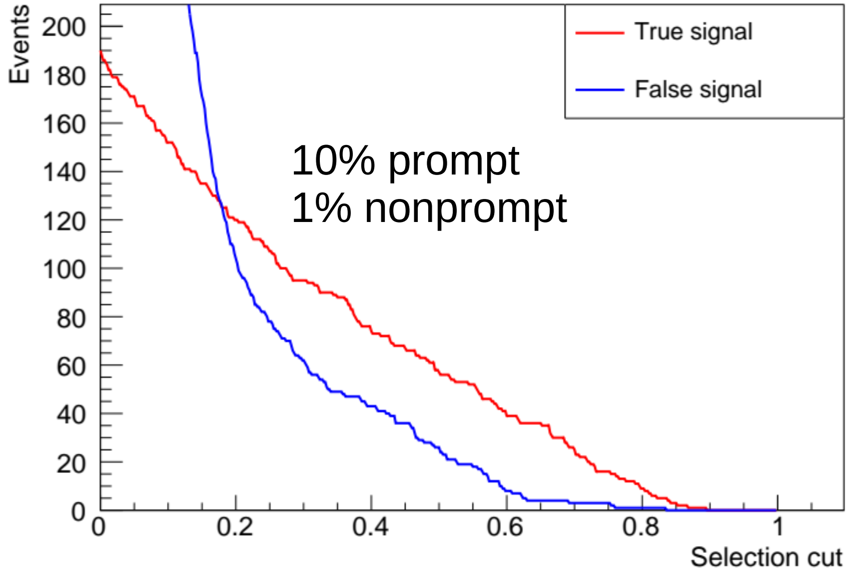
  e.g. for signal efficiency of 0.4 (starting with S/B~1e-3, sig~1)

  S/B~0.5, sig~11 (20% prompt, 20% non-prompt),
  S/B~1.7, sig~16 (10% prompt, 1% non-prompt),
  S/B~1.4, sig~15 (20% prompt, 2% non-prompt)
  without any mass fitting (compared to sig~4 in CMS analysis)
- Seems too good to be true … Need full simulation !

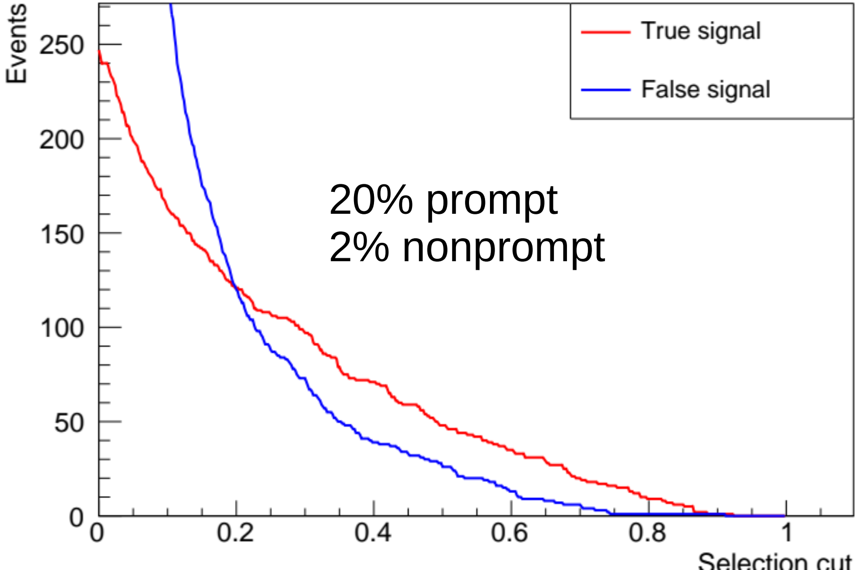
Thank you !

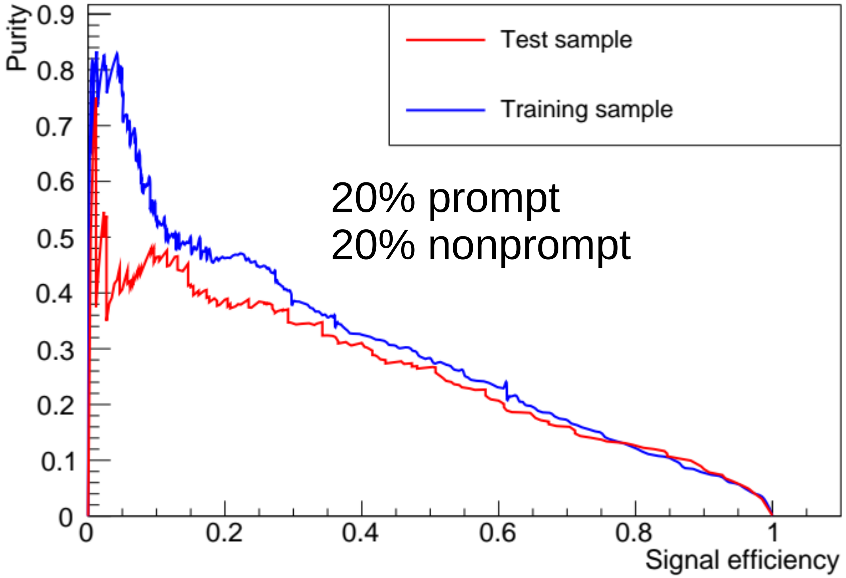
Backup

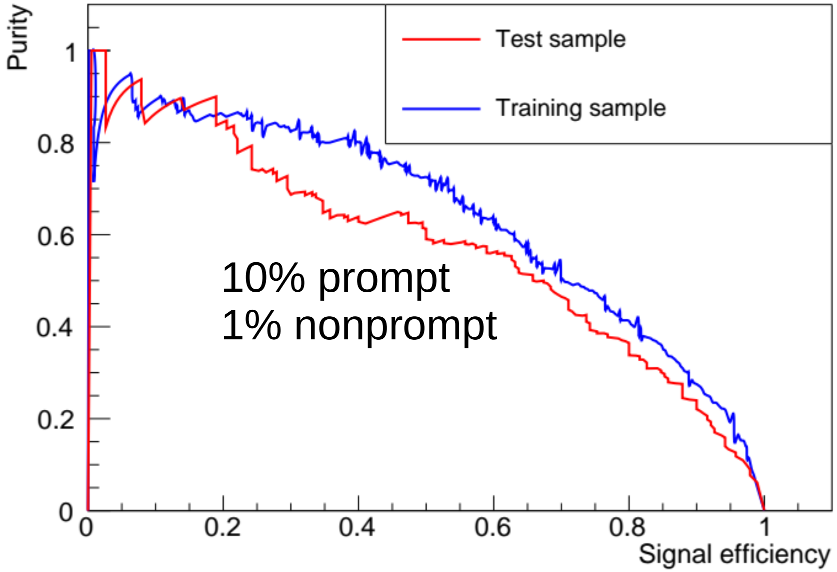




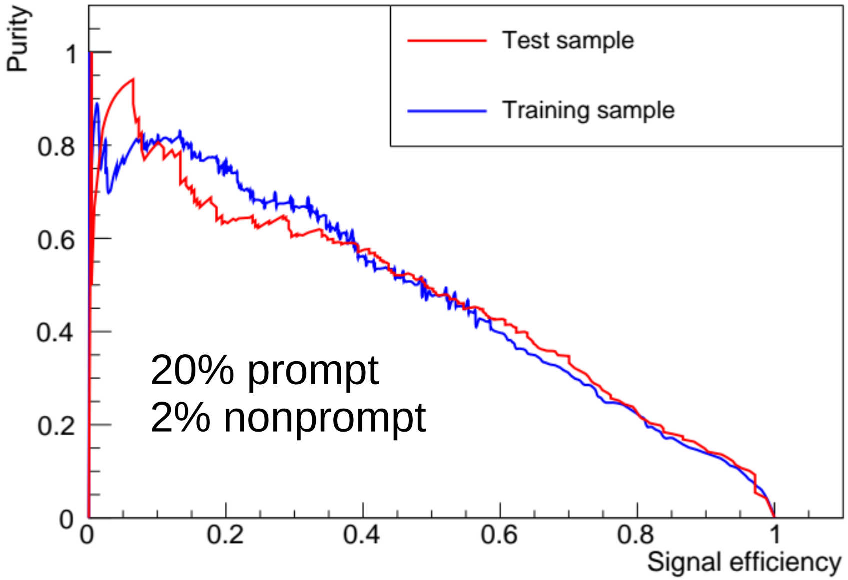
- Compare True signal and False signal in the selected sample as a function of the selection cut parameter (i.e. the output classifying parameter of the BDT)







- Compare signal efficiency vs purity results from test sample and training sample
  → Estimates the overfitting



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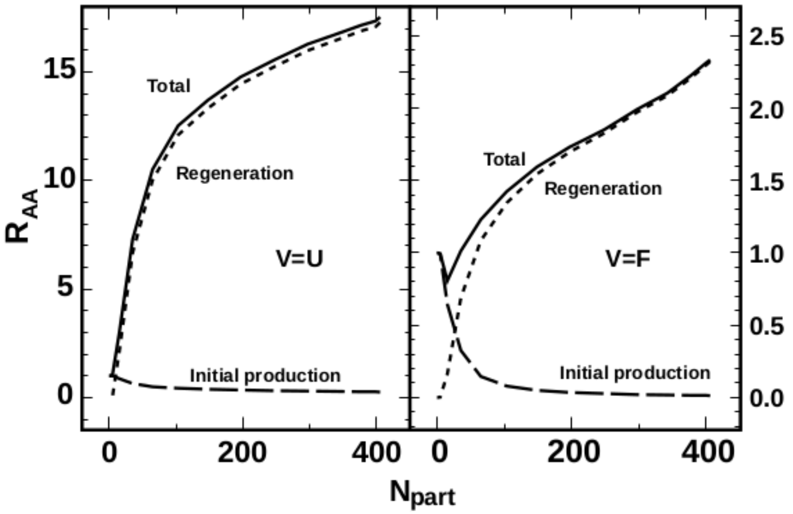
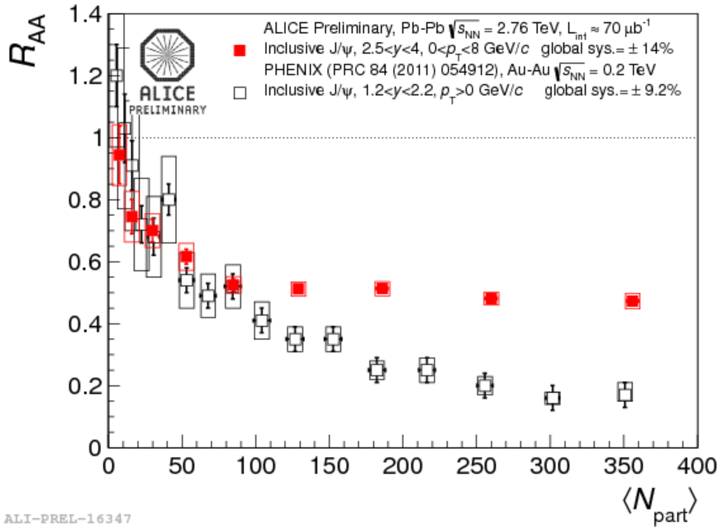
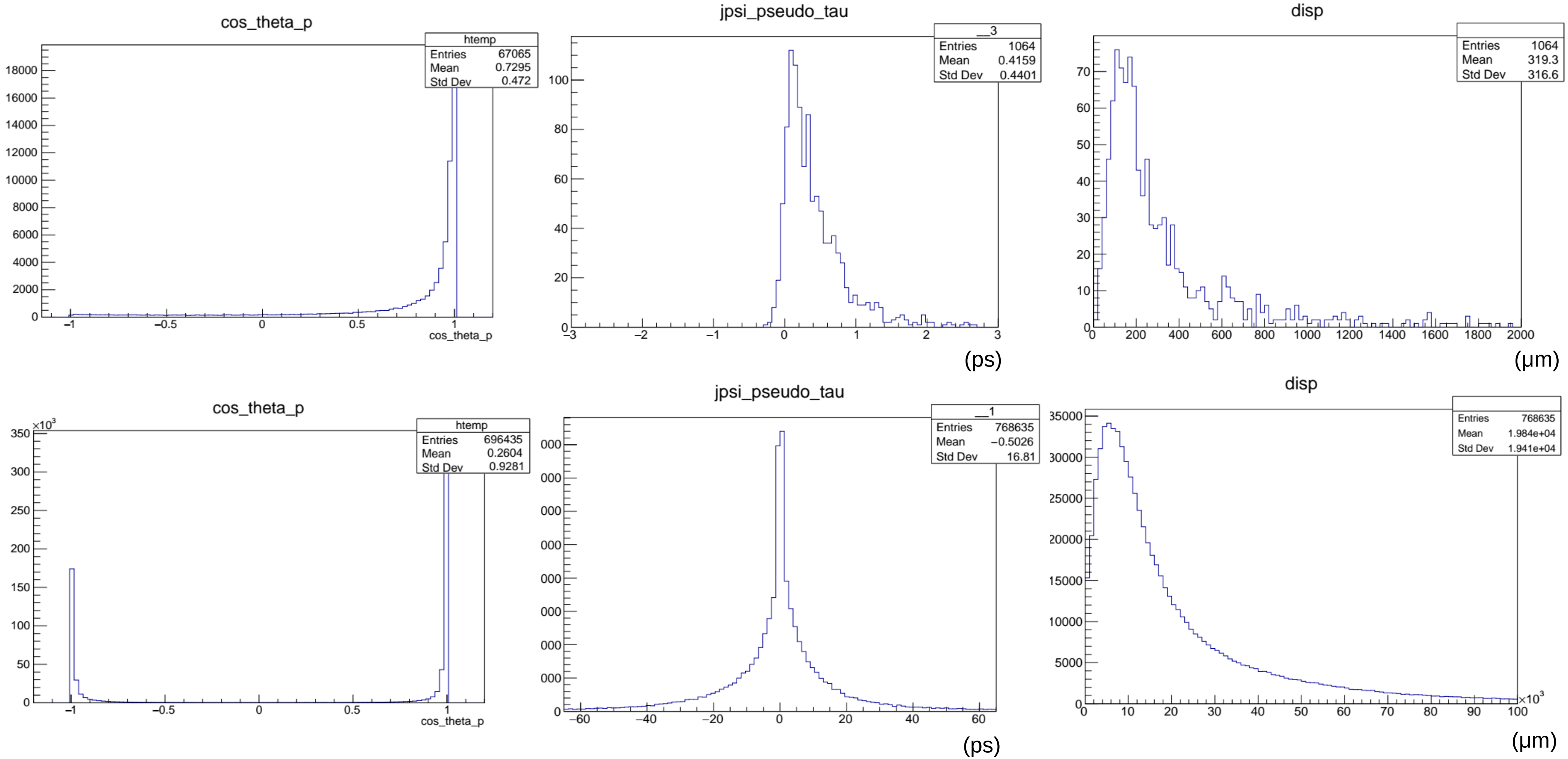
- Also possible insight into mass hierarchy of energy loss : smaller suppression for heavy quarks than for light quarks (dead cone effect ?)

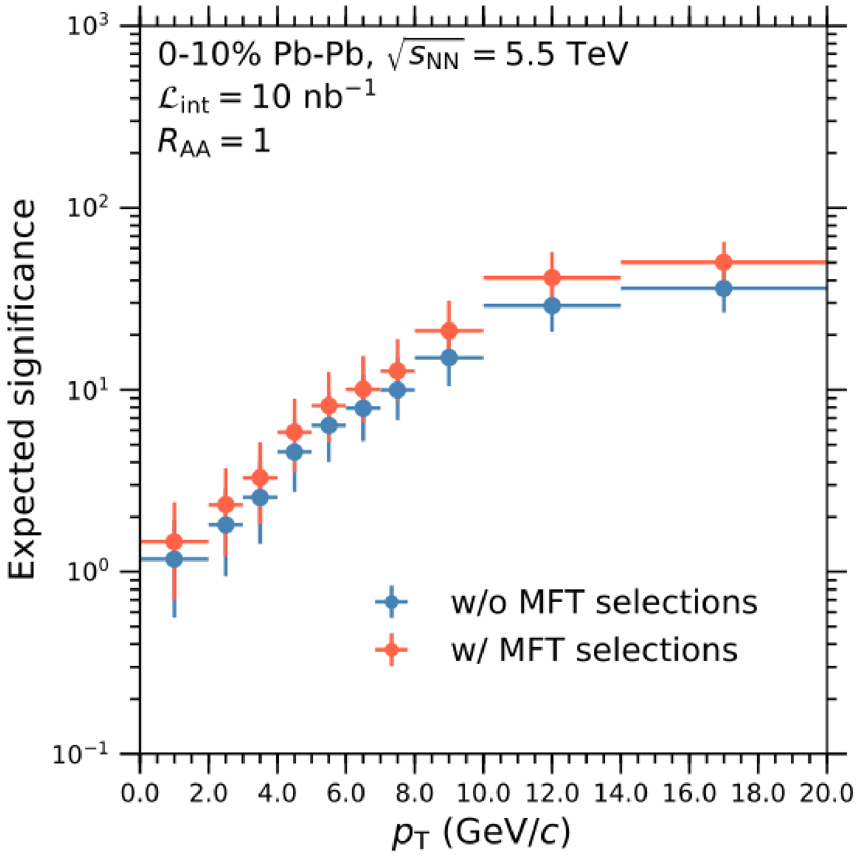
$$(R_{AA}(b) > R_{AA}(c) > R_{AA}(u,d,s))$$

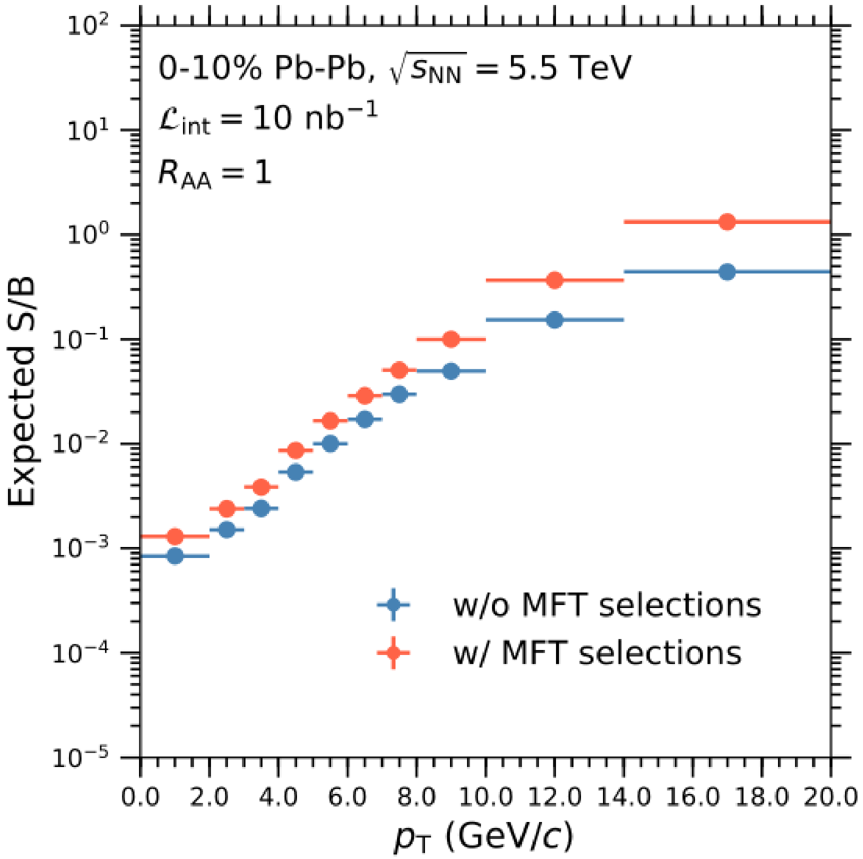




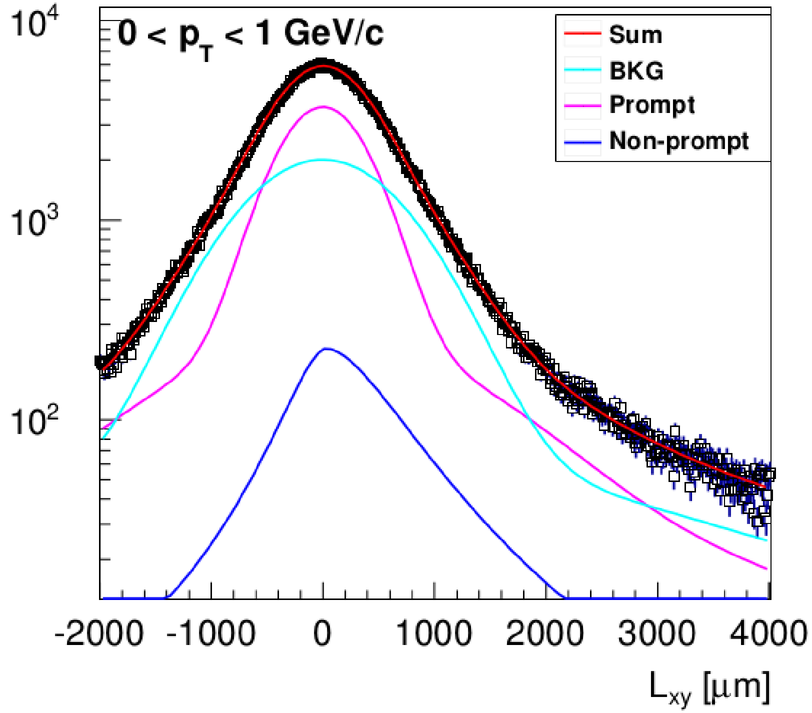


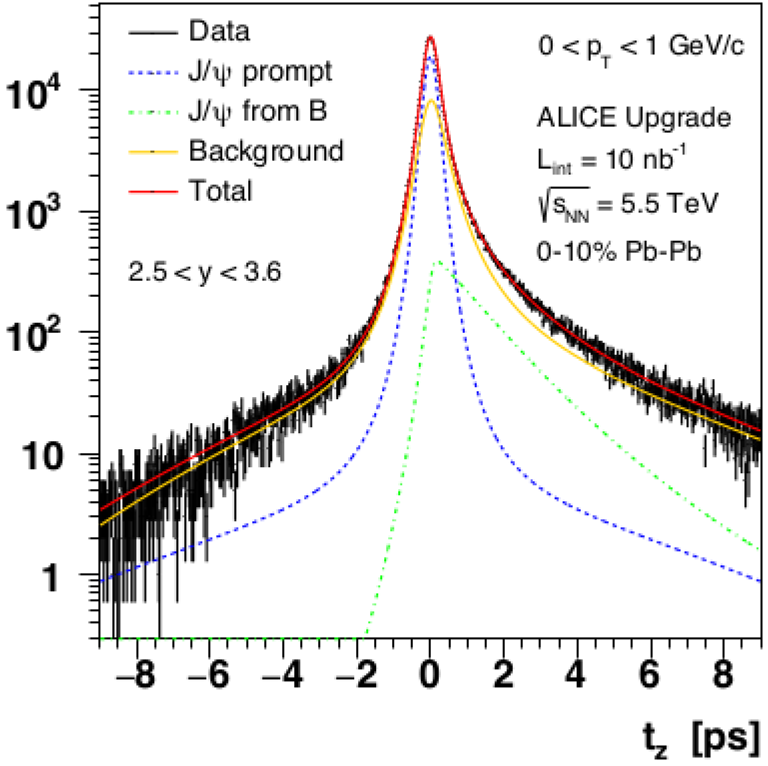
(Top : signal distributions for cosθ_p J/psi candidates pseudo-proper times and track dispersion at secondary vertex,
Bottom : same distributions for background candidates (10% prompt, 1% non-prompt))

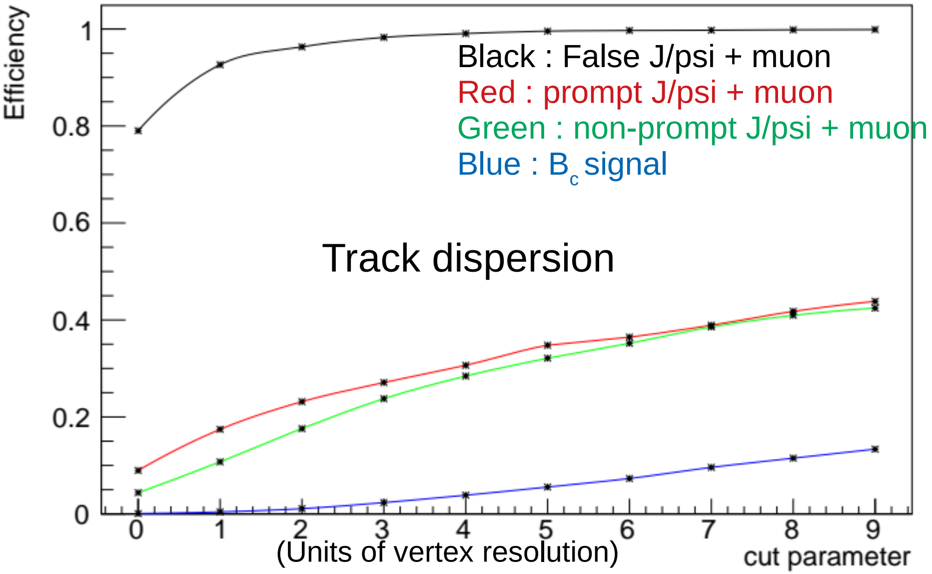


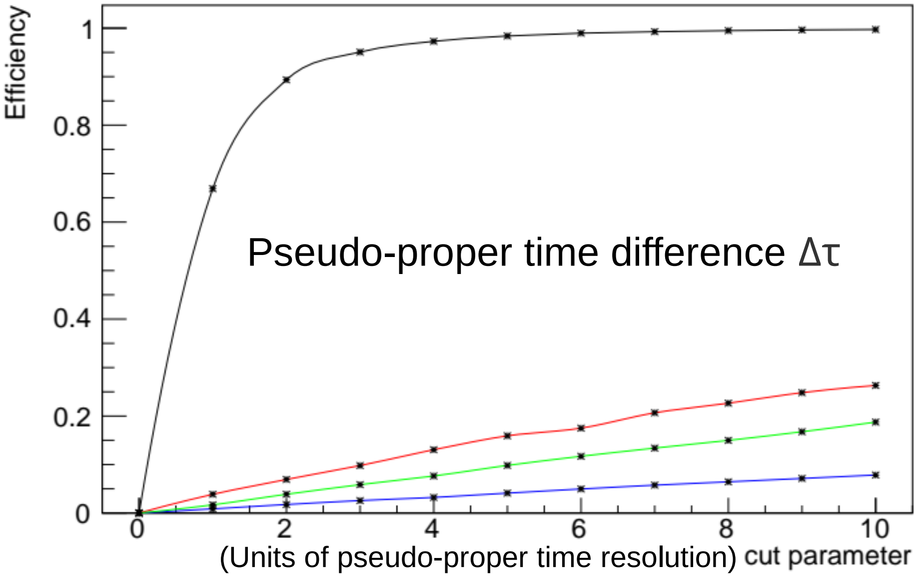


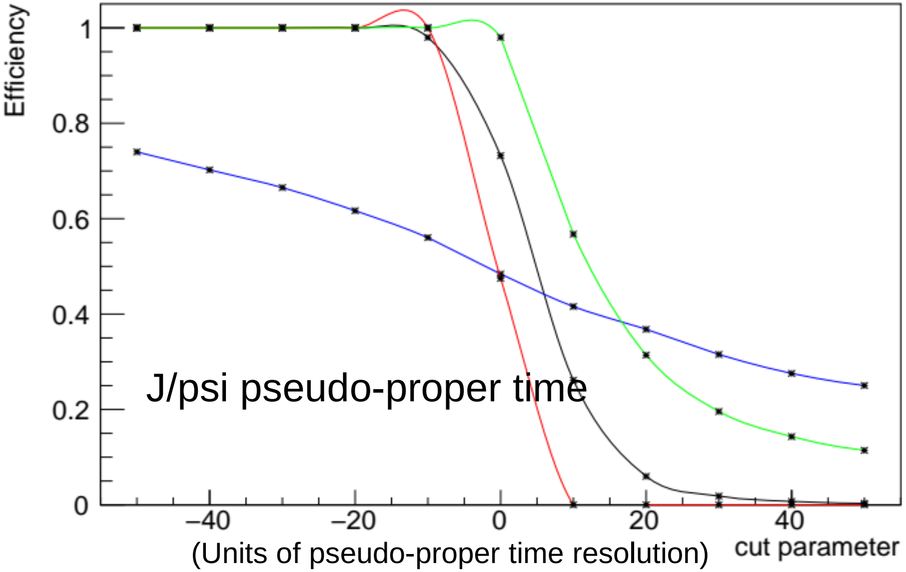
From Fabrizio’s presentation

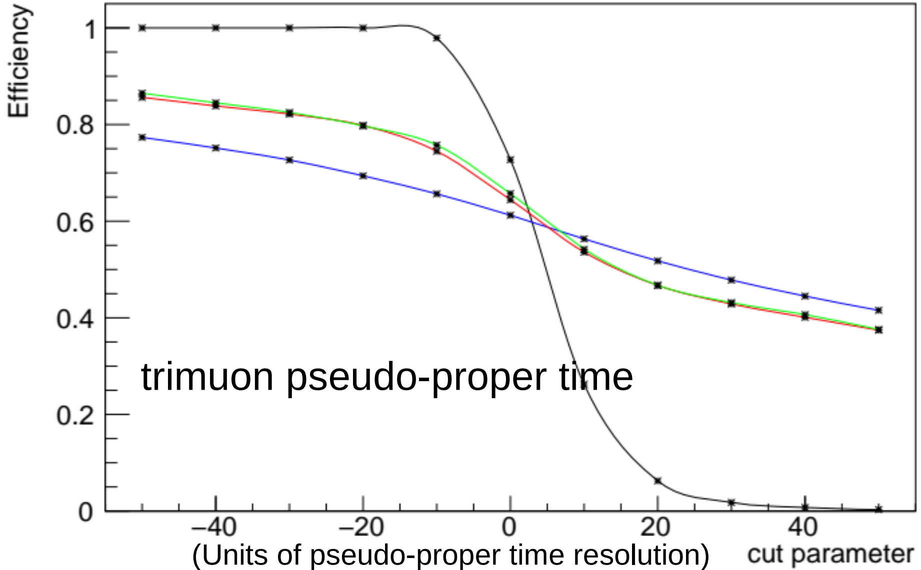

0 < p_T < 1 GeV/c
Sum
BKG
Prompt
Non-prompt
10^4
10^3
10^2
-2000 -1000 0 1000 2000 3000 4000
L_{xy} [μm]

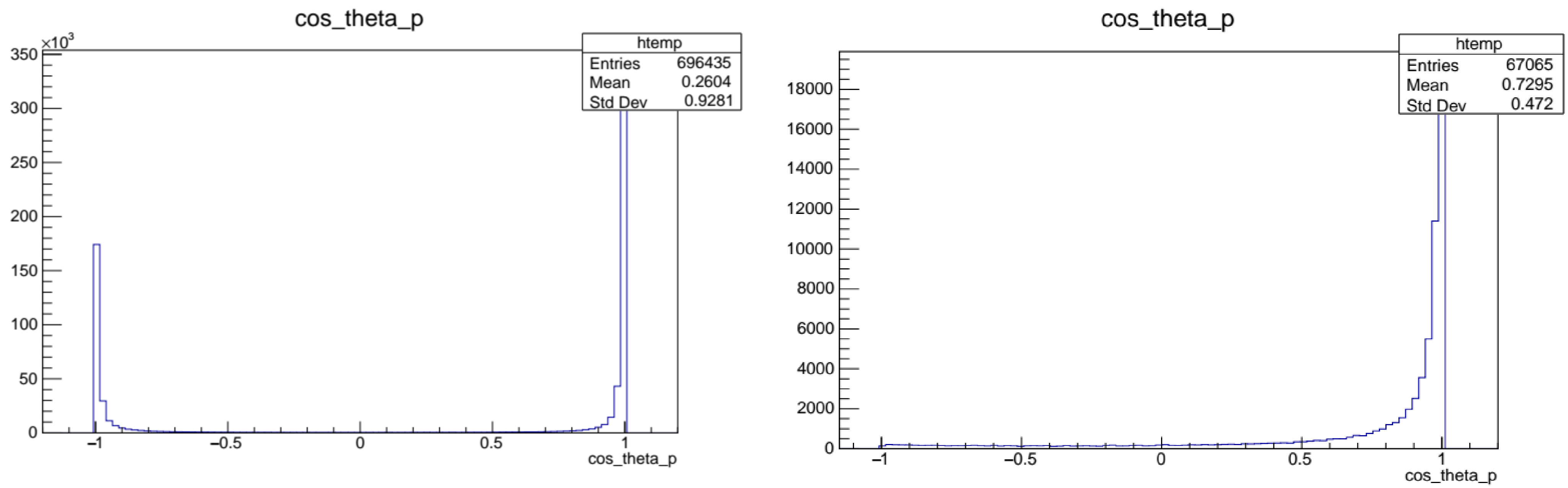

Data
J/ψ prompt
J/ψ from B
Background
Total
0 < p_T < 1 GeV/c
ALICE Upgrade
L_{int} = 10 nb^{-1}
$\sqrt{s_{NN}}$ = 5.5 TeV
0-10% Pb-Pb
2.5 < y < 3.6
10^4
10^3
10^2
10
1
−8 −6 −4 −2 0 2 4 6 8
t_z [ps]


Efficiency
Black : False J/psi + muon
Red : prompt J/psi + muon
Green : non-prompt J/psi + muon
Blue : B$_c$ signal
Track dispersion
(Units of vertex resolution)
cut parameter


Efficiency
Pseudo-proper time difference Δτ
(Units of pseudo-proper time resolution)
cut parameter


Efficiency
J/psi pseudo-proper time
(Units of pseudo-proper time resolution)
cut parameter


Efficiency
trimuon pseudo-proper time
(Units of pseudo-proper time resolution)
cut parameter



Background (left) and signal (right) distributions for the $\cos\theta_p$ input variable