Perspectives for the measurement of beauty and charm hadrons in heavy-ion collisions with ALICE

Fabrizio Grosa
Politecnico and INFN Torino

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Outline

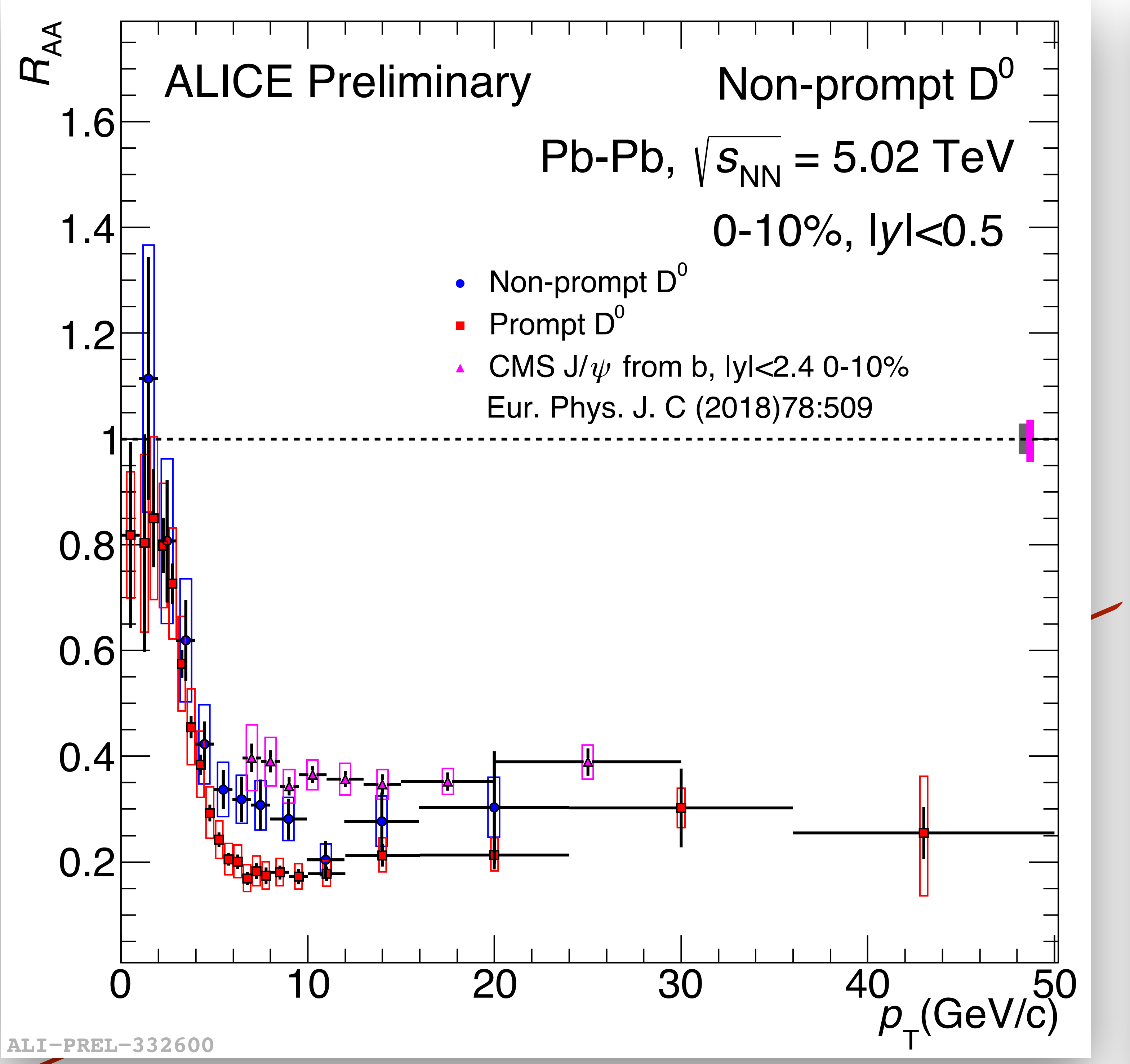
- Physics motivations
- The ALICE detector
  - ➡ possibility of B_c^+ measurement in the forward rapidity region
  - ➡ possibility of B_c^+ measurement in the mid rapidity region
- Feasibility study for the measurement of B_c^+ at forward rapidity in Run3
- Feasibility study for the measurement of B_c^+ at mid-rapidity in Run3

Disclamer:
feasibility studies very preliminary and not on behalf of the ALICE Collaboration

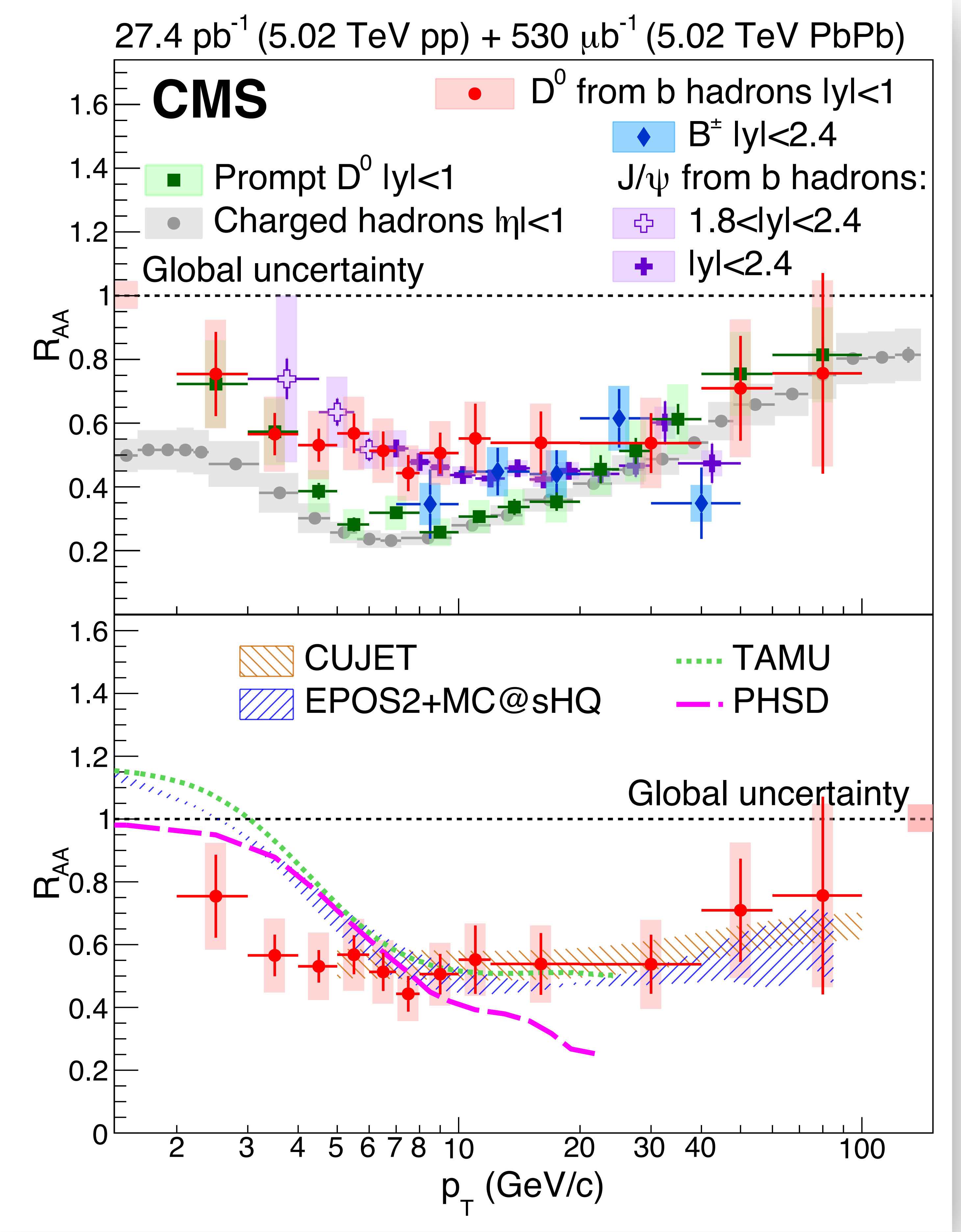
Physics motivation

- Heavy flavours (i.e. c and b quarks) in heavy-ion collisions are produced in hard-scattering processes before the QGP formation and experience the whole system evolution interacting with the medium constituents
- Smaller suppression observed for beauty mesons than for charm mesons (*dead cone effect*)

$$\Delta E_b < \Delta E_c < \Delta E_{g,u,d,s}$$

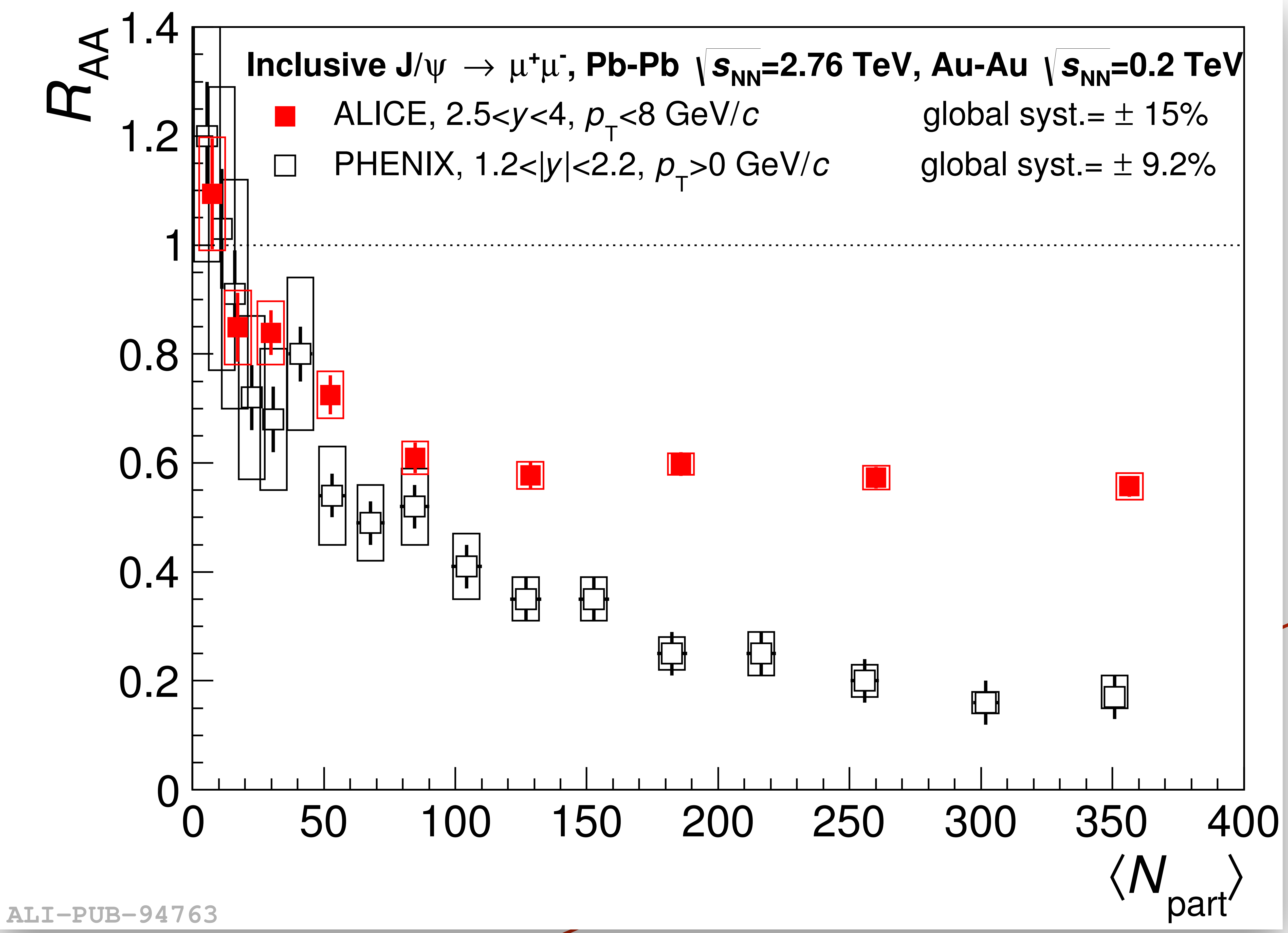


new ALICE preliminary measurement for QM19



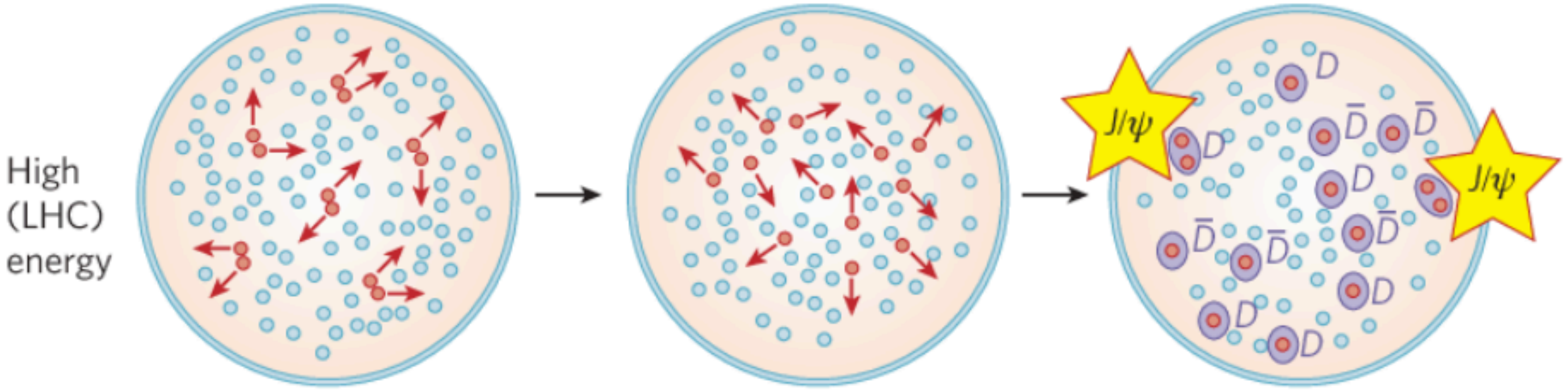
Phys. Rev. Lett. 123 (2019) 022001

Physics motivation



Phys.Lett. B734 (2014) 314-327

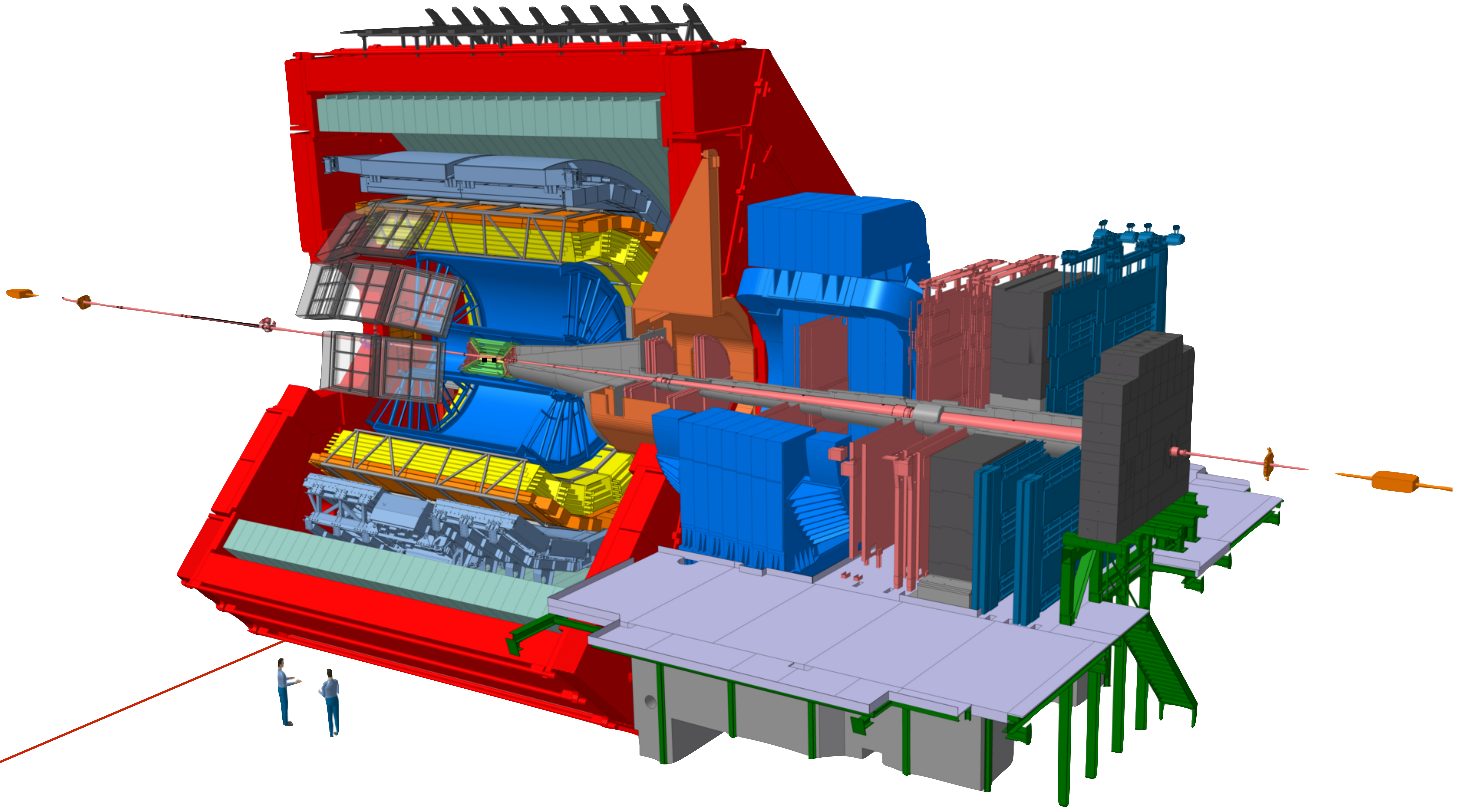
- A reduced suppression for J/psi mesons observed at LHC energies compared to that measured at RHIC energies
  ➡ regeneration of cc pairs due to statistical recombination



Nature 448, 302–309 (2007)

- B_c^+ production in heavy-ion collisions is an ideal probe to be sensitive both to dead cone effect and statistical recombination

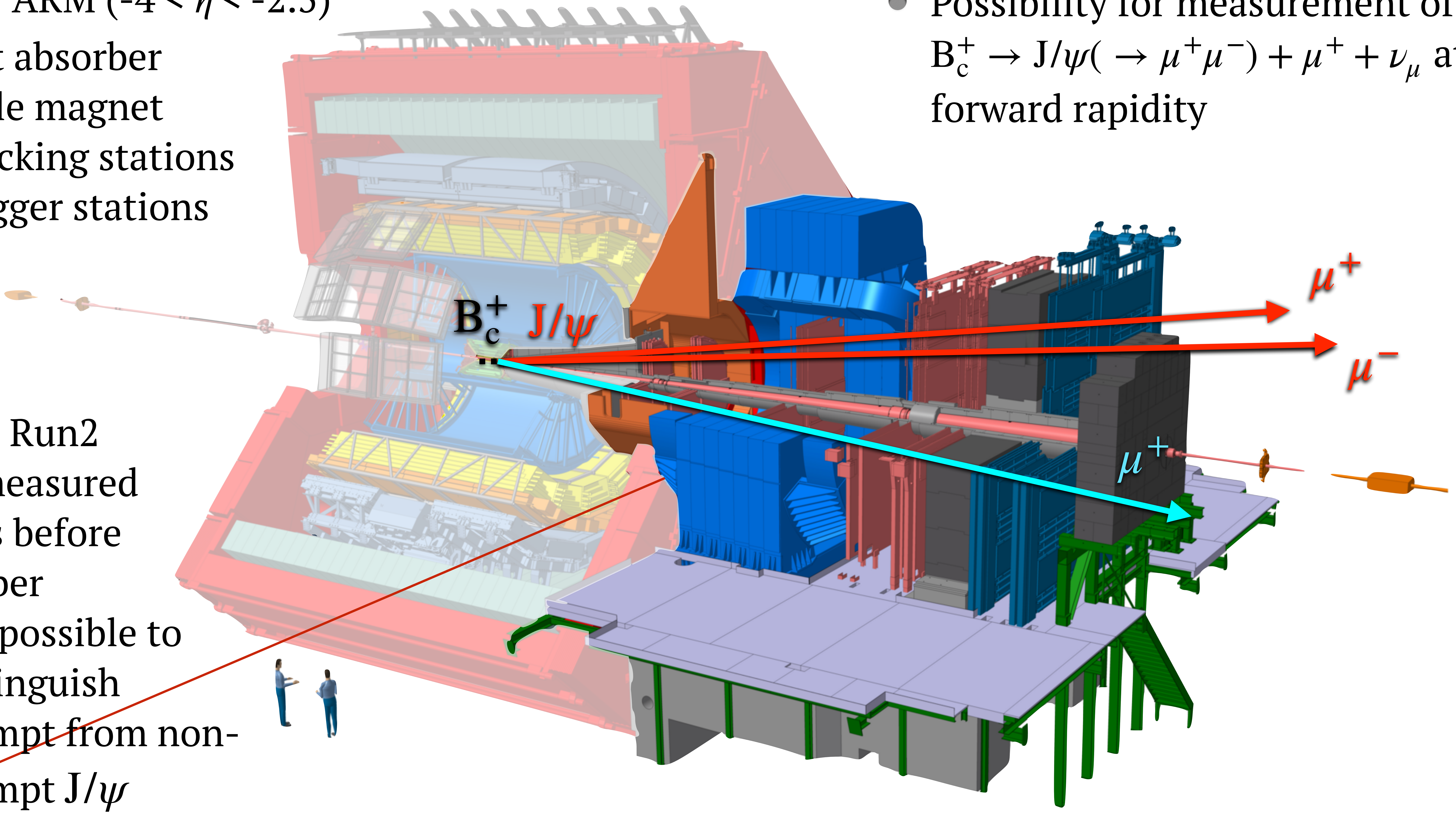
A Large Ion Collider Experiment



A Large Ion Collider Experiment

- MUON ARM ($-4 < \eta < -2.5$)
  - ➡ front absorber
  - ➡ dipole magnet
  - ➡ 5 tracking stations
  - ➡ 2 trigger stations

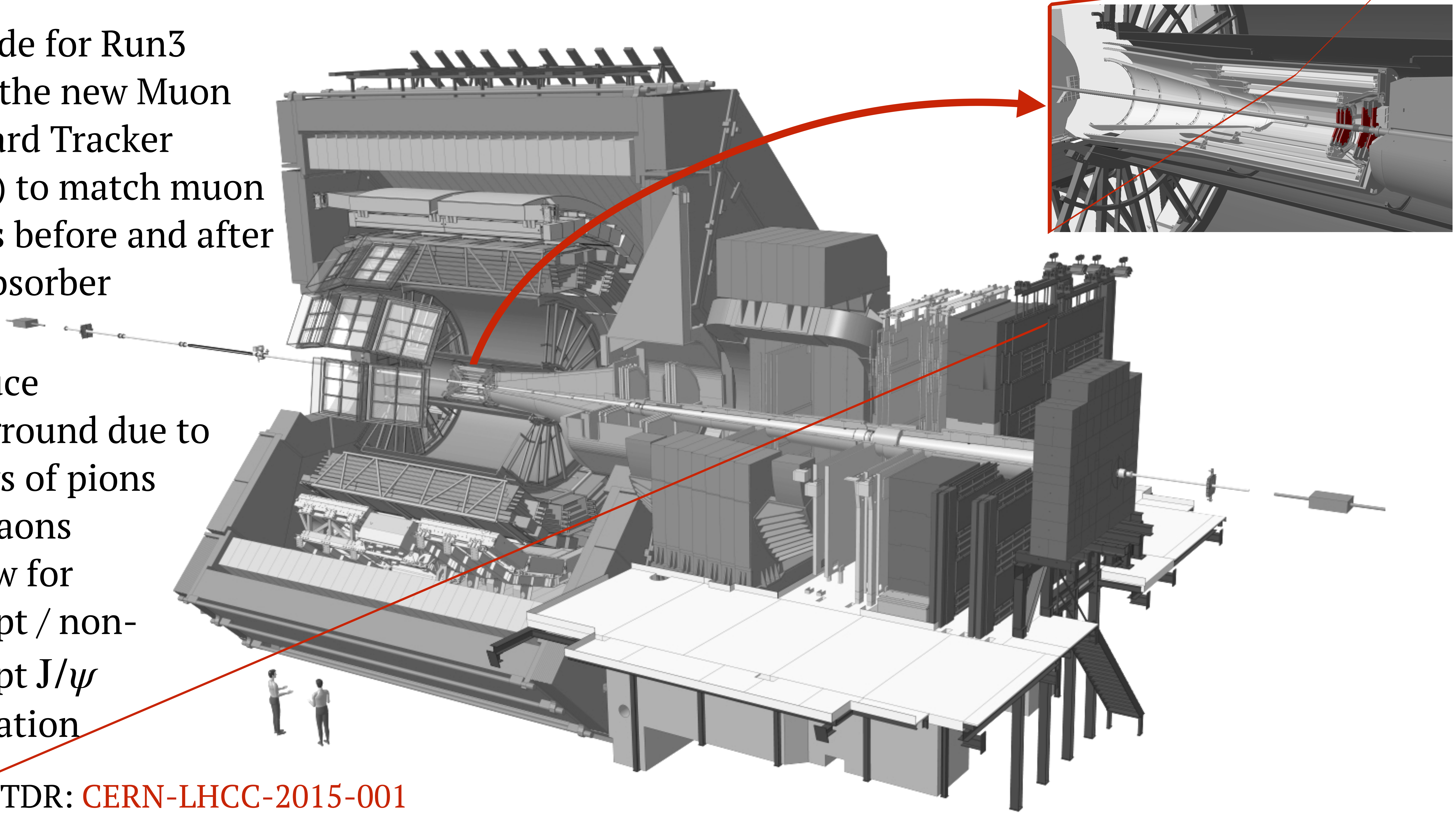
- Possibility for measurement of $B_c^+ \rightarrow J/\psi(\rightarrow \mu^+\mu^-) + \mu^+ + \nu_\mu$ at forward rapidity



- Run1 - Run2
  - ➡ no measured points before absorber
    - ➡ impossible to distinguish prompt from non-prompt J/ψ

A Large Ion Collider Experiment

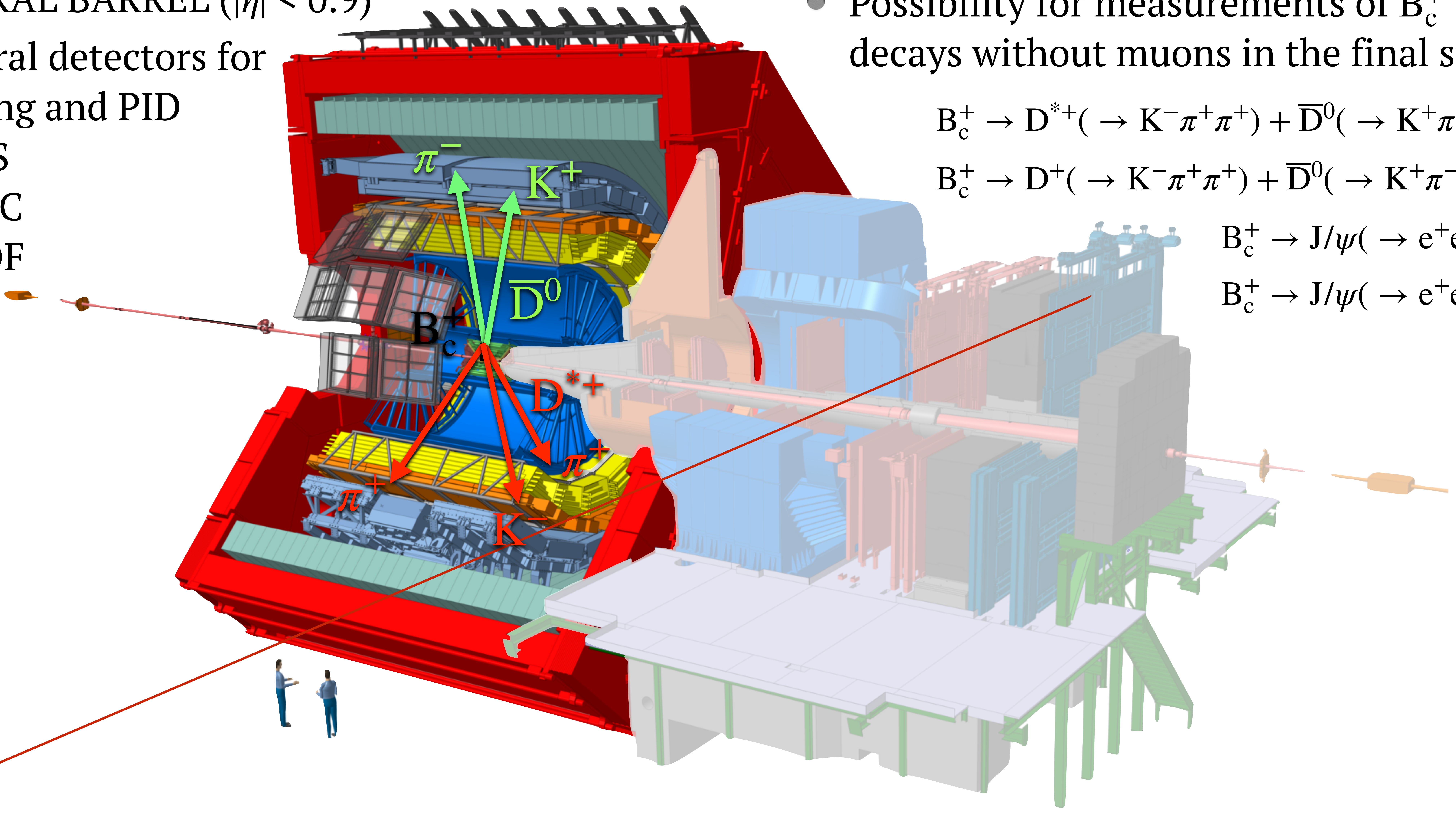
- Upgrade for Run3
  - ➡ add the new Muon Forward Tracker (MFT) to match muon tracks before and after the absorber
  - ➡ reduce background due to decays of pions and kaons
  - ➡ allow for prompt / non-prompt J/ψ separation



MFT TDR: CERN-LHCC-2015-001

A Large Ion Collider Experiment

- CENTRAL BARREL ($|\eta| < 0.9$)
  - ➡ several detectors for tracking and PID
    - ➡ ITS
    - ➡ TPC
    - ➡ TOF



- Possibility for measurements of B_c^+ via decays without muons in the final state

$$B_c^+ \to D^{*+}(\to K^-\pi^+\pi^+) + \overline{D}^0(\to K^+\pi^-)$$

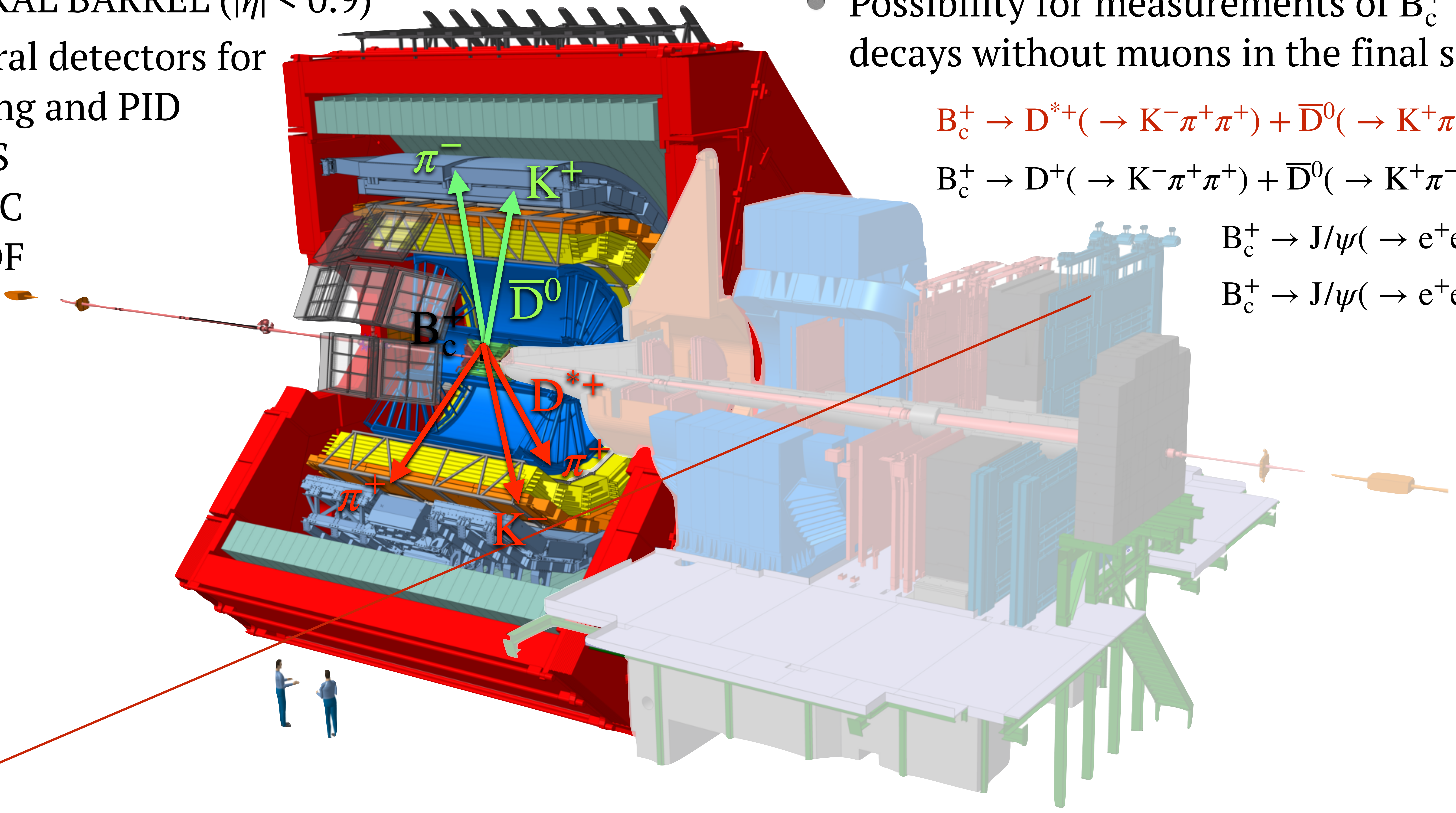
$$B_c^+ \to D^{+}(\to K^-\pi^+\pi^+) + \overline{D}^0(\to K^+\pi^-)$$

$$B_c^+ \to J/\psi(\to e^+e^-) + e^+ + \nu_e$$

$$B_c^+ \to J/\psi(\to e^+e^-) + \pi^+$$

A Large Ion Collider Experiment

- CENTRAL BARREL ($|\eta| < 0.9$)
  - ➡ several detectors for tracking and PID
    - ➡ ITS
    - ➡ TPC
    - ➡ TOF



- Possibility for measurements of B_c^+ via decays without muons in the final state

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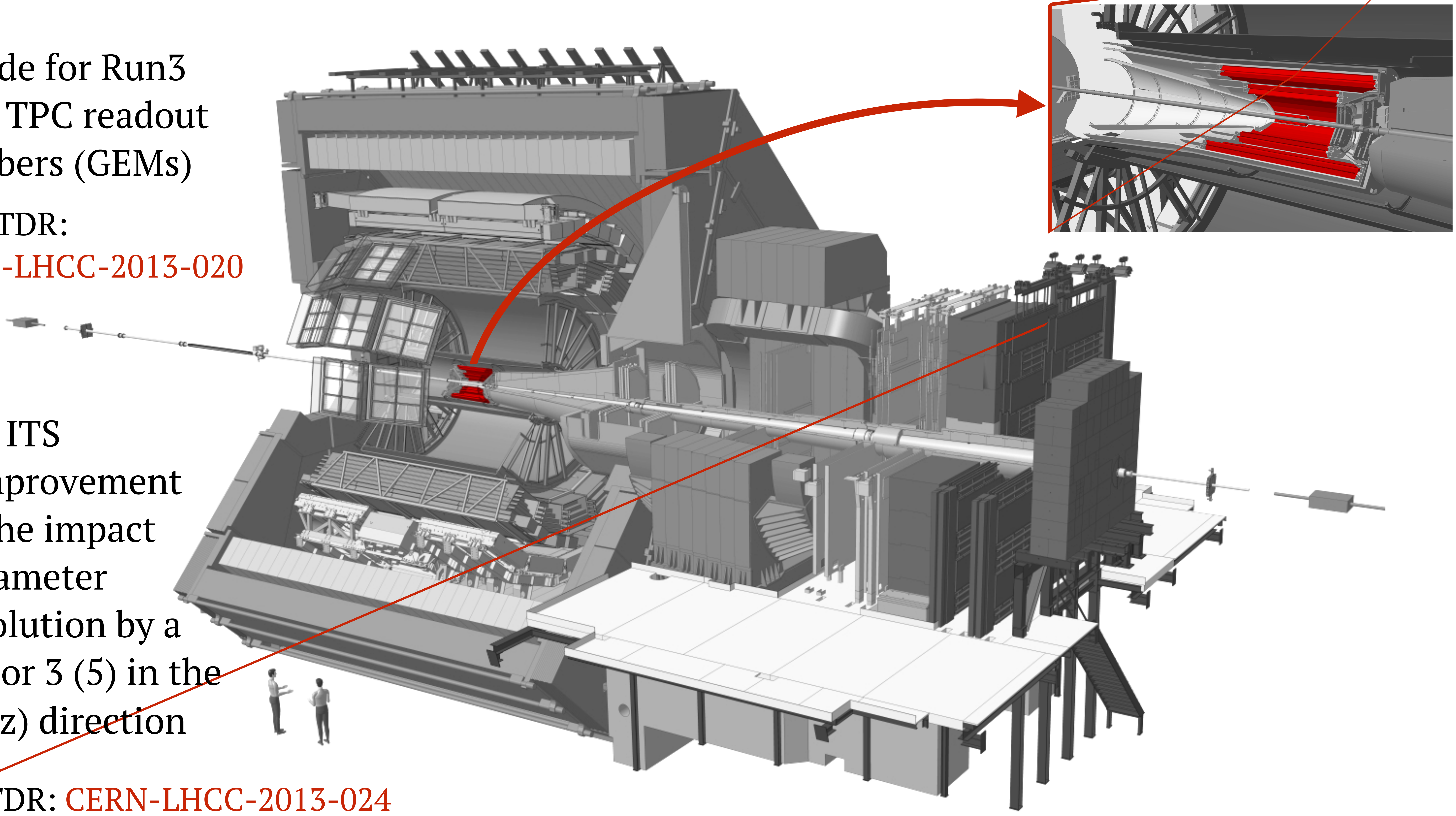
$B_c^+ \to J/\psi(\to e^+e^-) + e^+ + \nu_e$

$B_c^+ \to J/\psi(\to e^+e^-) + \pi^+$

A Large Ion Collider Experiment

- Upgrade for Run3
  - ➡ new TPC readout chambers (GEMs)

  📚 TPC TDR: CERN-LHCC-2013-020



  - ➡ new ITS
    - ➡ improvement in the impact parameter resolution by a factor 3 (5) in the rφ (z) direction

  📚 ITS TDR: CERN-LHCC-2013-024

~~$\mathrm{B_c^+} \to \mathrm{J}/\psi + \mu^+ + \nu_\mu$ - signal estimation~~

- Expected raw signal estimated as:

$$N_{\mathrm{raw}}(\mathrm{B_c^\pm}) = 2 \cdot \Delta p_{\mathrm{T}} \cdot \Delta y \cdot \left[\frac{\mathrm{d}\sigma_{\mathrm{pp}}(\mathrm{B_c^+})}{\mathrm{d}p_{\mathrm{T}}}\right] \cdot \mathrm{BR}(\mathrm{B_c^+} \to \mathrm{J}/\psi \mu^+ \nu_\mu) \cdot \mathrm{BR}(\mathrm{J}/\psi \to \mu^+\mu^-) \cdot (\mathrm{Acc} \times \epsilon) \cdot R_{\mathrm{AA}} \cdot \langle T_{\mathrm{AA}} \rangle \cdot N_{\mathrm{events}}$$

$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - signal estimation

- Expected raw signal estimated as:

$$N_{\rm raw}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to J/\psi \mu^+ \nu_\mu) \cdot BR(J/\psi \to \mu^+\mu^-) \cdot (\mathrm{Acc} \times \epsilon) \cdot R_{AA} \cdot \langle T_{AA} \rangle \cdot N_{\rm events}$$

$$= \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to J/\psi \pi^+) \cdot \frac{BR(B_c^+ \to J/\psi \mu^+ \nu_\mu)}{BR(B_c^+ \to J/\psi \pi^+)}$$

→ 1/0.0469 from LHCb measurement

Phys. Rev. D 90, 032009 (2014)

$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - signal estimation

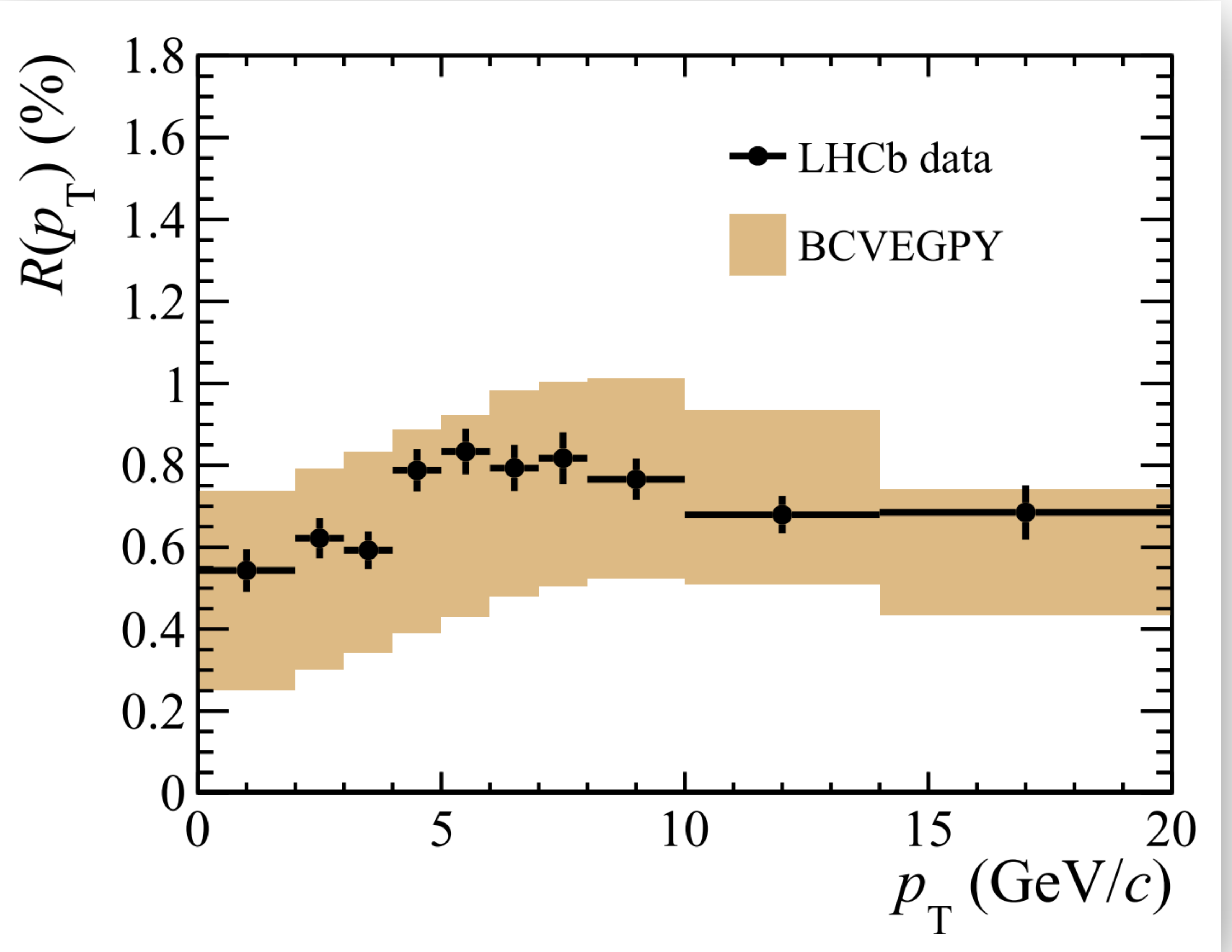
- Expected raw signal estimated as:

$$N_{\mathrm{raw}}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot \mathrm{BR}(B_c^+ \to J/\psi\mu^+\nu_\mu) \cdot \mathrm{BR}(J/\psi \to \mu^+\mu^-) \cdot (\mathrm{Acc}\times\epsilon) \cdot R_{AA} \cdot \langle T_{AA}\rangle \cdot N_{\mathrm{events}}$$

$$= \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot \mathrm{BR}(B_c^+ \to J/\psi\pi^+) \cdot \frac{\mathrm{BR}(B_c^+ \to J/\psi\mu^+\nu_\mu)}{\mathrm{BR}(B_c^+ \to J/\psi\pi^+)}$$

$$= \left[\frac{d\sigma_{pp}(B^+)}{dp_T}\right] \cdot \mathrm{BR}(B^+ \to J/\psi K^+) \cdot R$$

Phys. Rev. Lett. 114, 132001 (2015)



$$R = \frac{d\sigma(B_c^+) \cdot \mathrm{BR}(B_c^+ \to J/\psi\pi^+)}{d\sigma(B^+) \cdot \mathrm{BR}(B^+ \to J/\psi K^+)}$$

$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - signal estimation

- Expected raw signal estimated as:

$$N_{raw}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to J/\psi\mu^+\nu_\mu) \cdot BR(J/\psi \to \mu^+\mu^-) \cdot (Acc \times \epsilon) \cdot R_{AA} \cdot \langle T_{AA} \rangle \cdot N_{events}$$

$$= \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to J/\psi\pi^+) \cdot \frac{BR(B_c^+ \to J/\psi\mu^+\nu_\mu)}{BR(B_c^+ \to J/\psi\pi^+)}$$

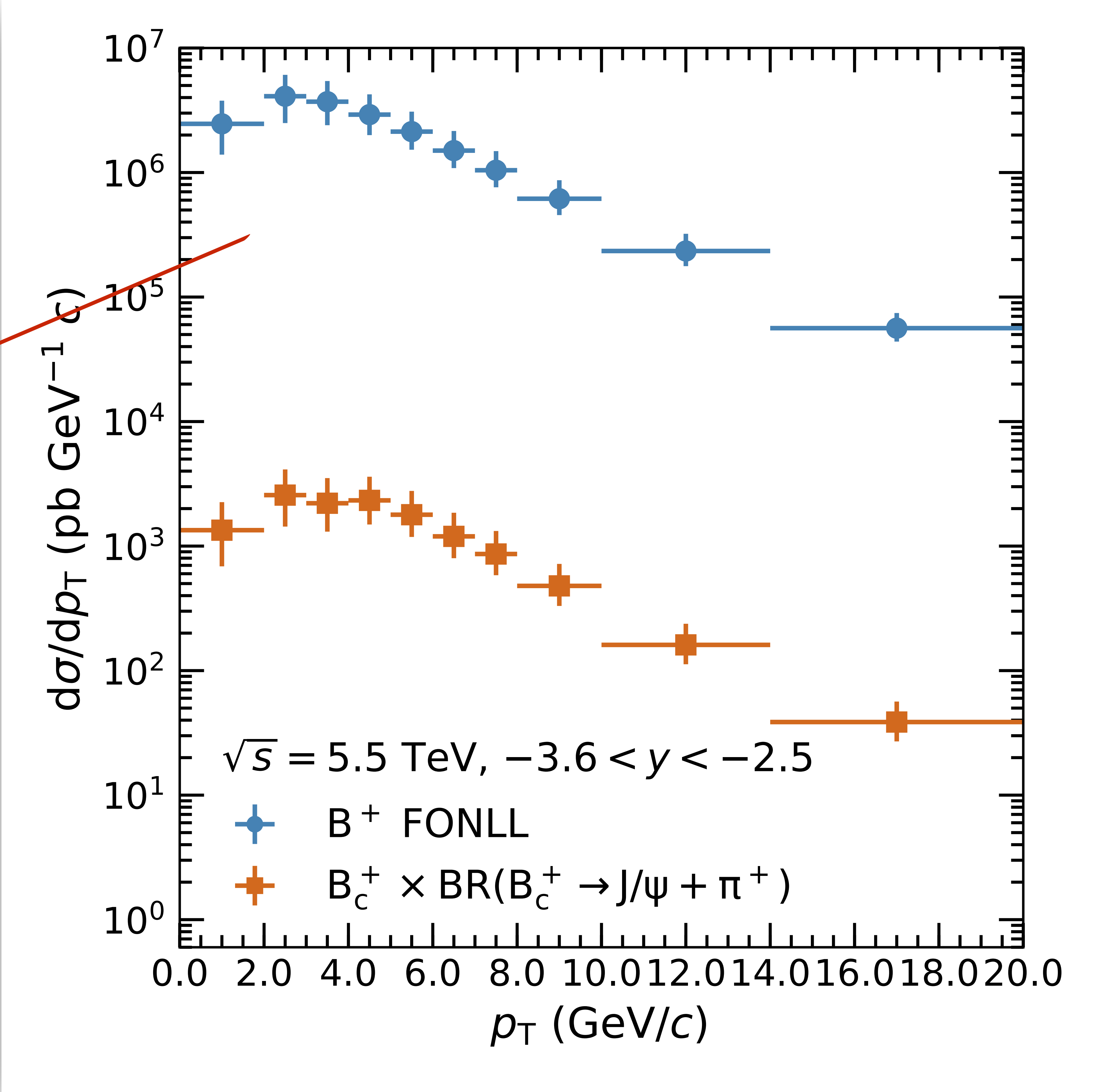
$$= \left[\frac{d\sigma_{pp}(B^+)}{dp_T}\right] \cdot BR(B^+ \to J/\psi K^+) \cdot R$$

FONLL calculations
at $\sqrt{s}$ = 5.5 TeV in -3.6 < y < -2.5

JHEP 9805, 007 (1998)

0.00101 from PDG

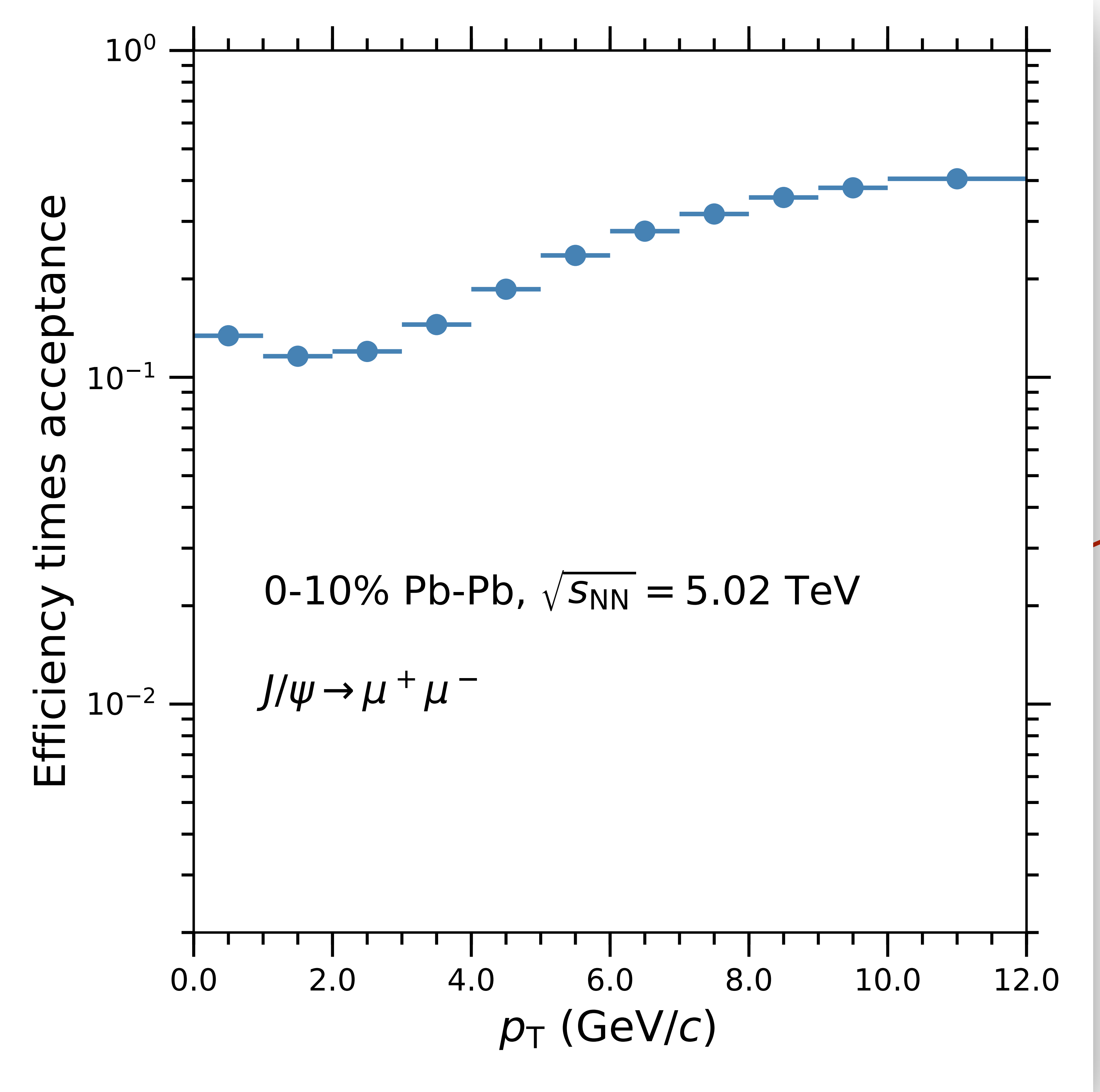
Phys. Rev. D 98, 030001 (2018)



$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - signal estimation

- Expected raw signal estimated as:

$$N_{\mathrm{raw}}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to J/\psi \mu^+ \nu_\mu) \cdot BR(J/\psi \to \mu^+\mu^-) \cdot (Acc \times \epsilon) \cdot R_{AA} \cdot \langle T_{AA} \rangle \cdot N_{\mathrm{events}}$$



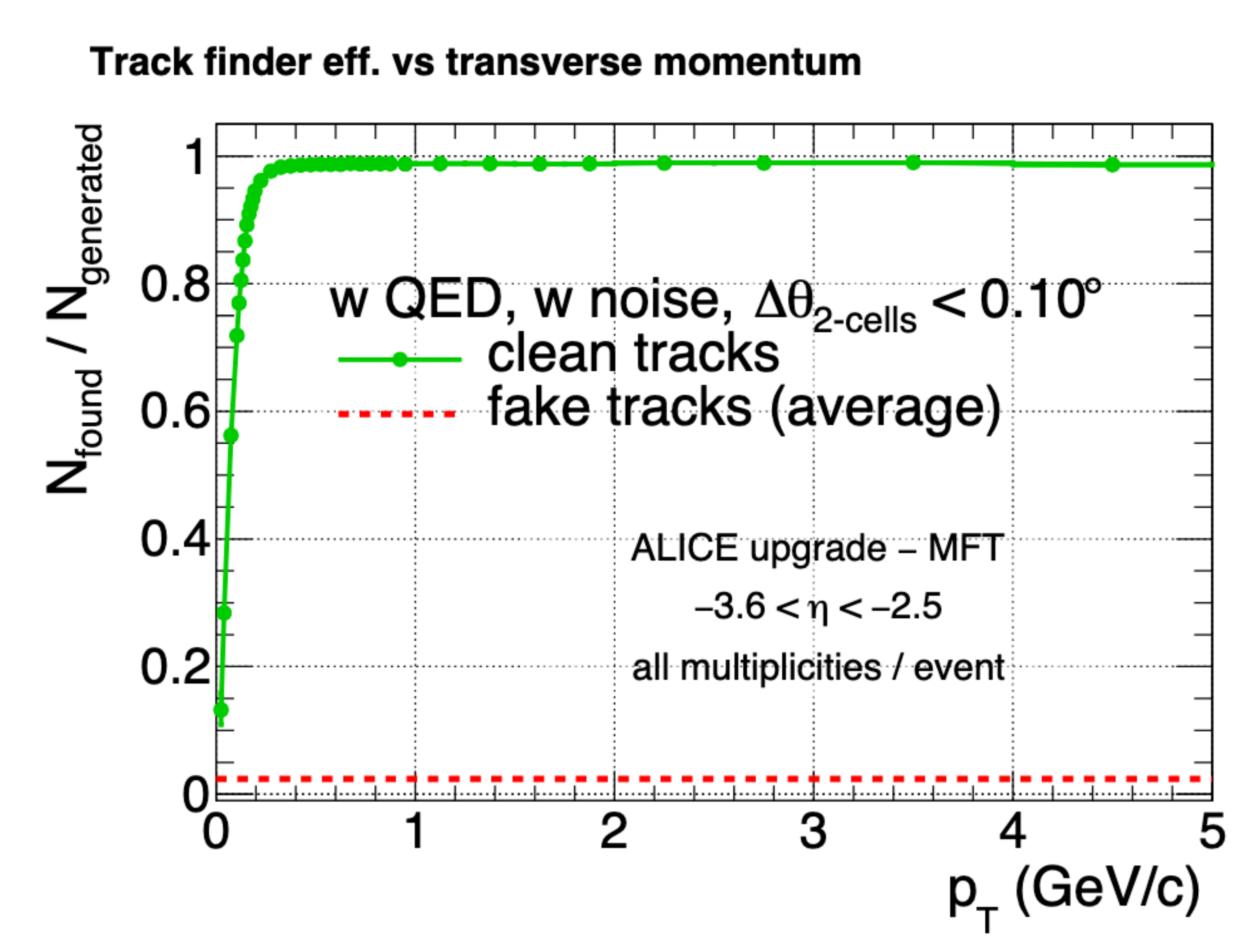
- Efficiency times acceptance for J/ψ assumed to be equal to the current one in Pb-Pb collisions at 5.02 TeV

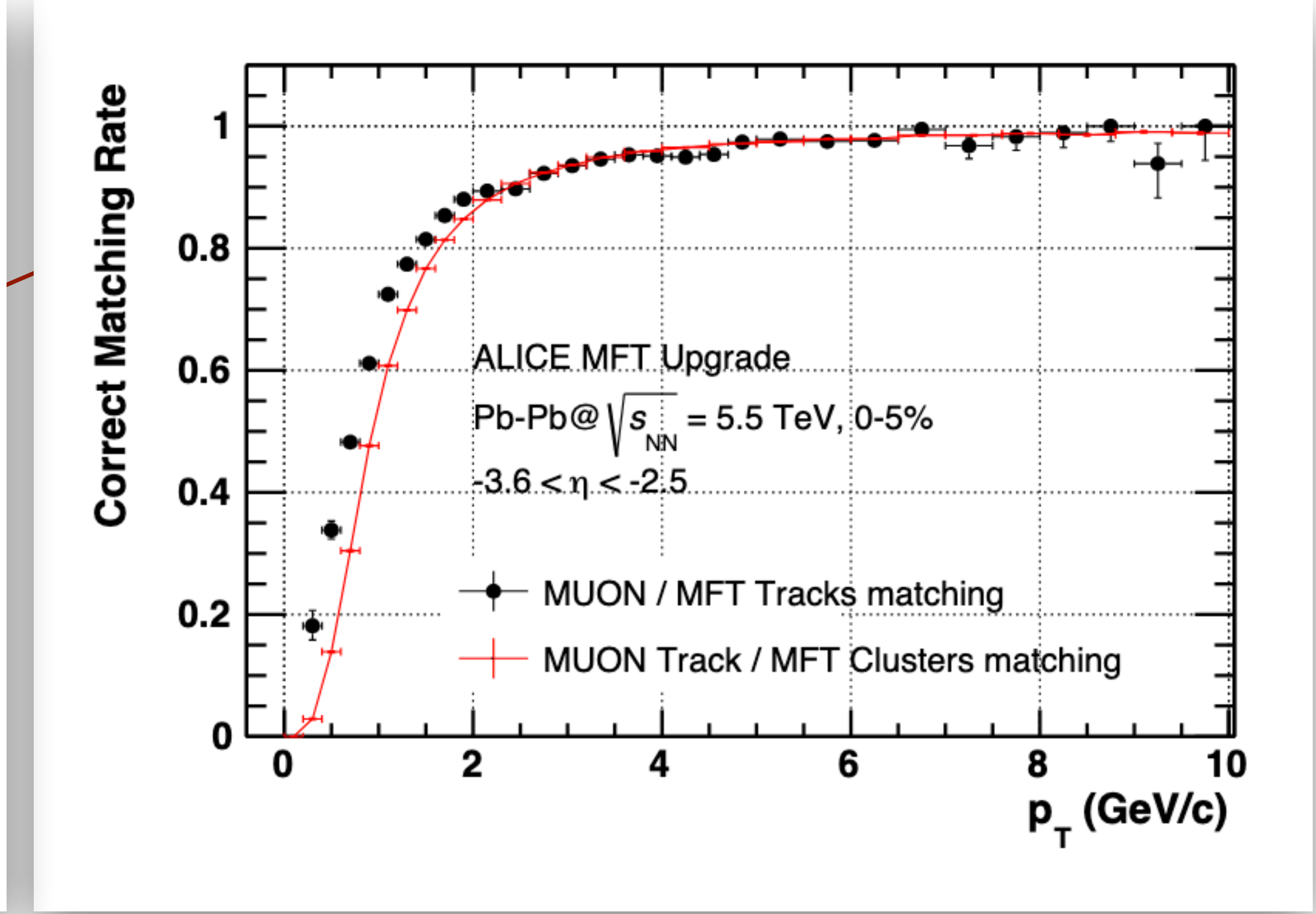
$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - signal estimation

- Expected raw signal estimated as:

$$N_{raw}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to J/\psi\mu^+\nu_\mu) \cdot BR(J/\psi \to \mu^+\mu^-) \cdot (Acc \times \epsilon) \cdot R_{AA} \cdot \langle T_{AA} \rangle \cdot N_{events}$$

- Reconstruction efficiency for muon obtained as product of tracking efficiency and matching efficiency between MFT and MUON ARM tracks



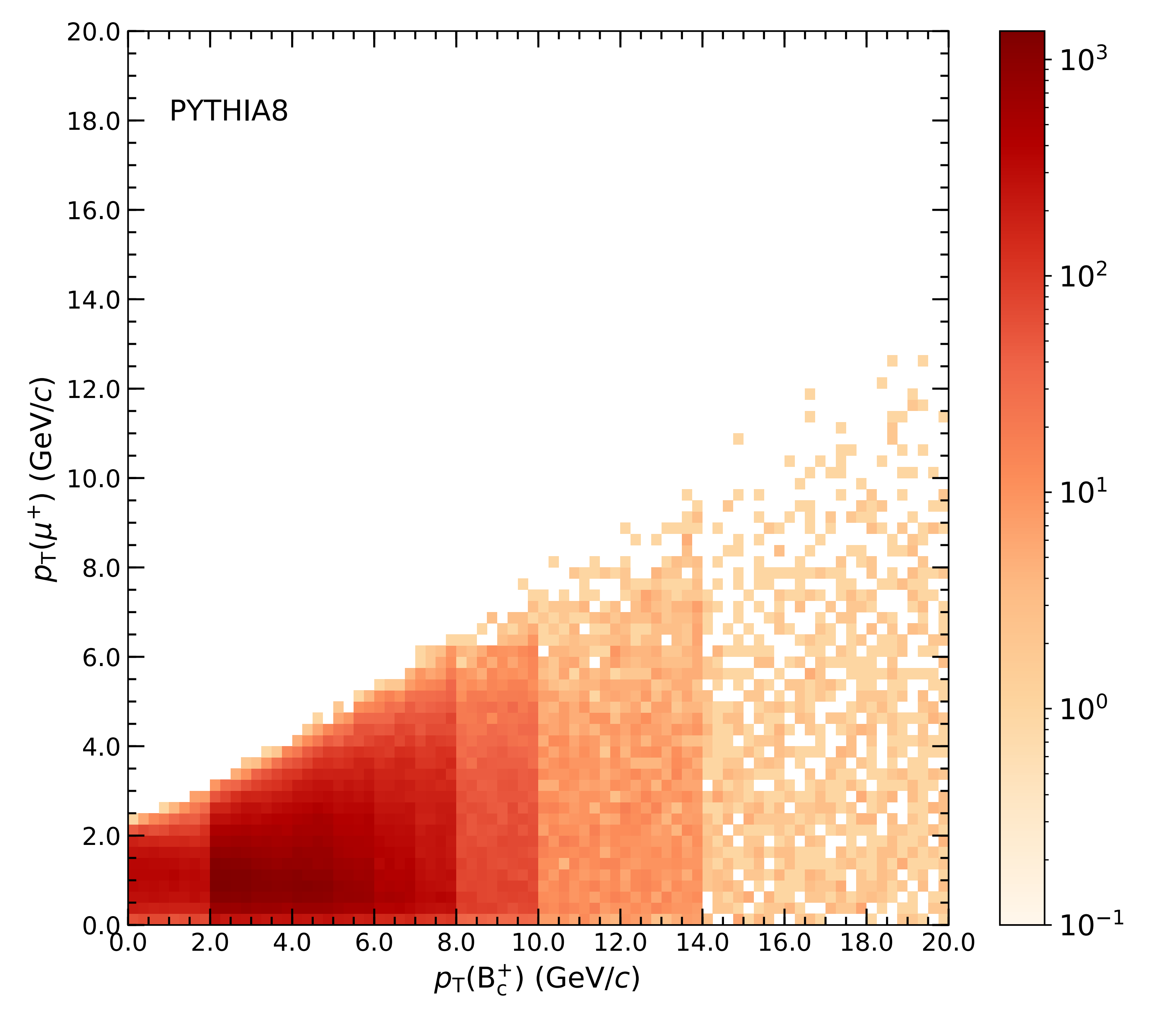


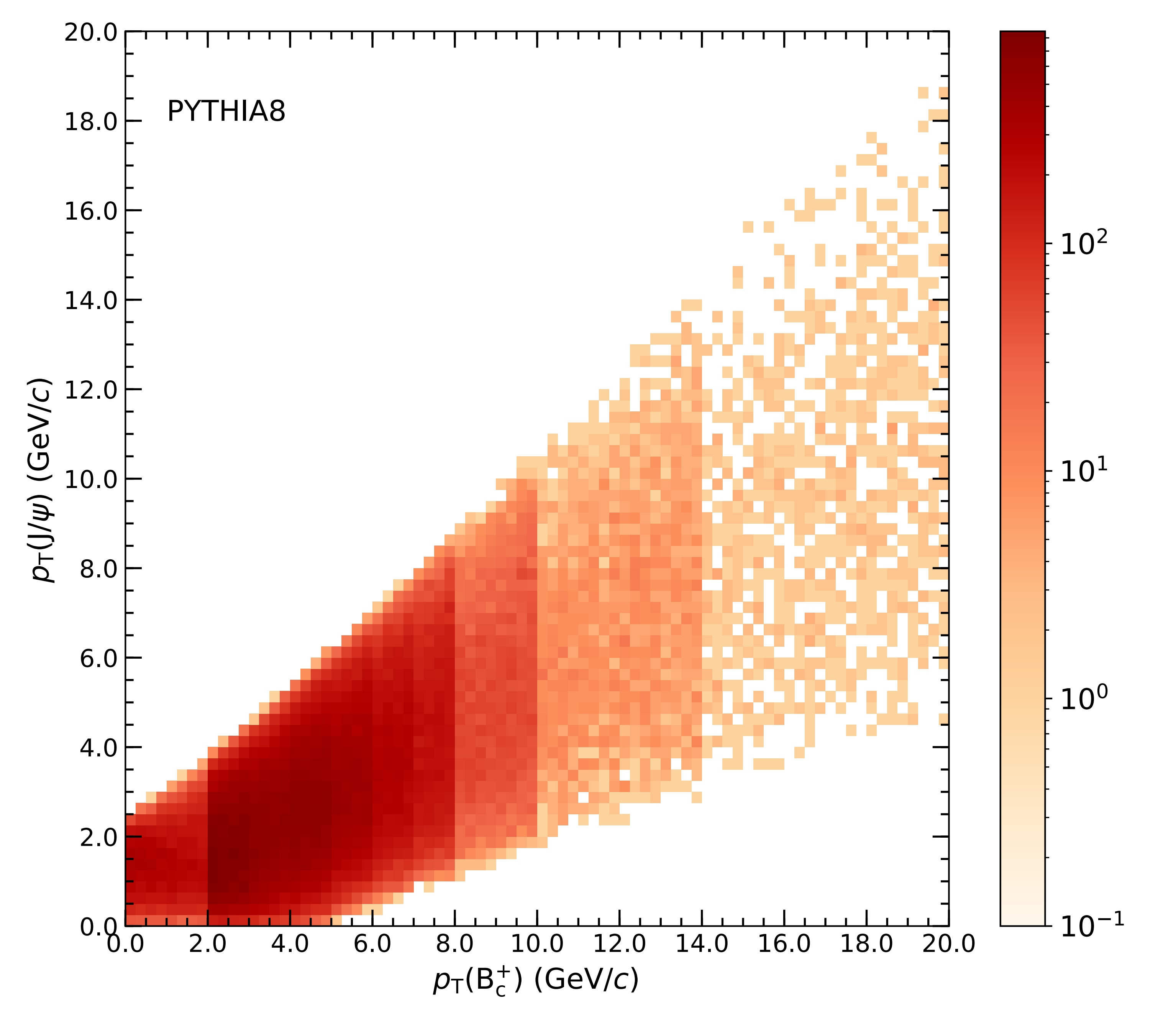
CERN-LHCC-2015-001

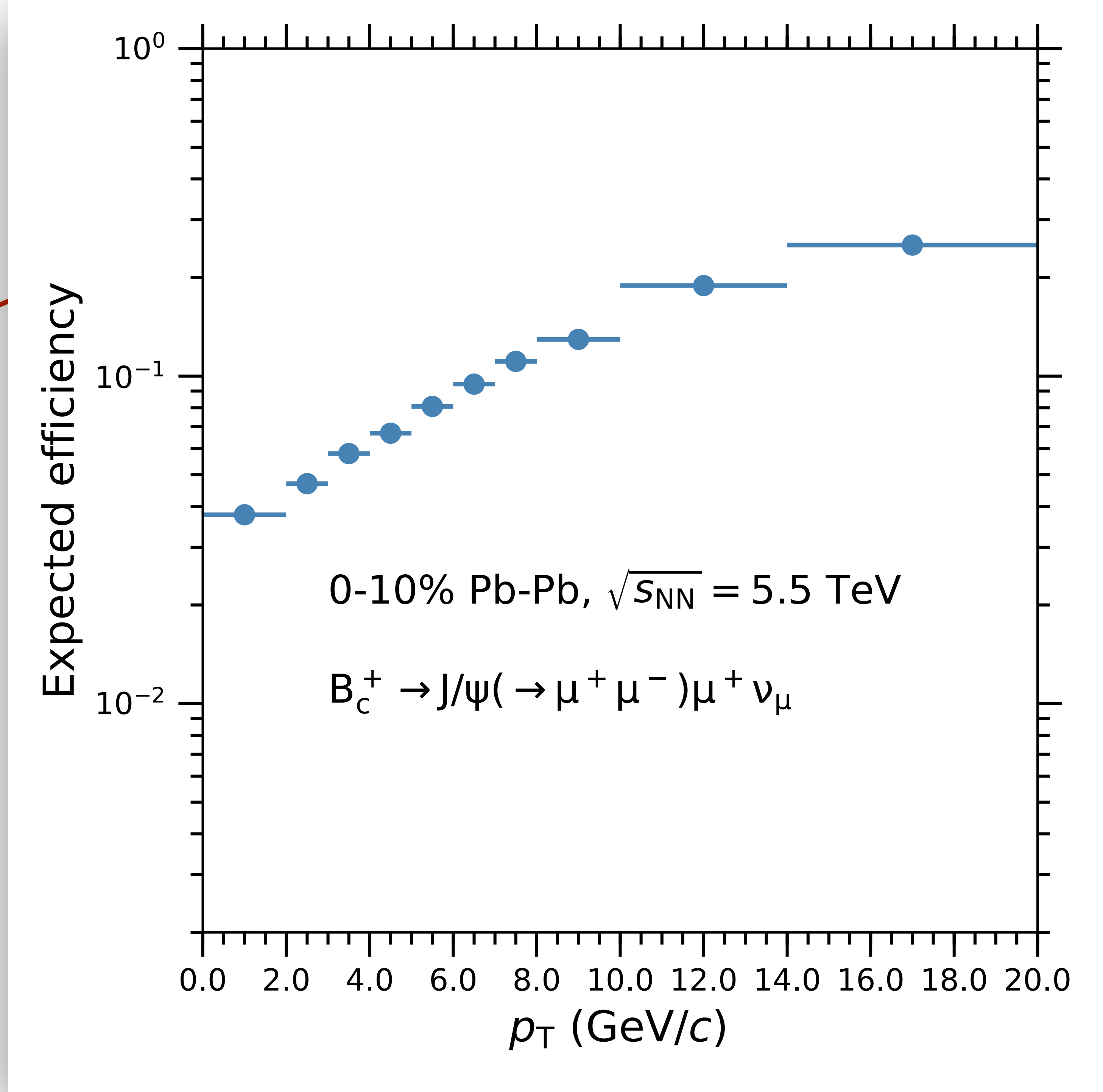
$B_c^+ \rightarrow J/\psi + \mu^+ + \nu_\mu$ - signal estimation

- Expected raw signal estimated as:

$$N_{\rm raw}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \rightarrow J/\psi\mu^+\nu_\mu) \cdot BR(J/\psi \rightarrow \mu^+\mu^-) \cdot (Acc \times \epsilon) \cdot R_{AA} \cdot \langle T_{AA} \rangle \cdot N_{\rm events}$$







➡ Efficiencies of daughter particles propagated to the mother B_c^+ with decay kinematics from PYTHIA8

➡ Acceptance factor for J/ψ and third muon computed with the same PYTHIA8 simulation

$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - signal estimation

- Expected raw signal estimated as:

$$N_{\rm raw}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to J/\psi\mu^+\nu_\mu) \cdot BR(J/\psi \to \mu^+\mu^-) \cdot (\mathrm{Acc} \times \epsilon) \cdot R_{AA} \cdot \langle T_{AA} \rangle \cdot N_{\rm events}$$

0.05961 from PDG

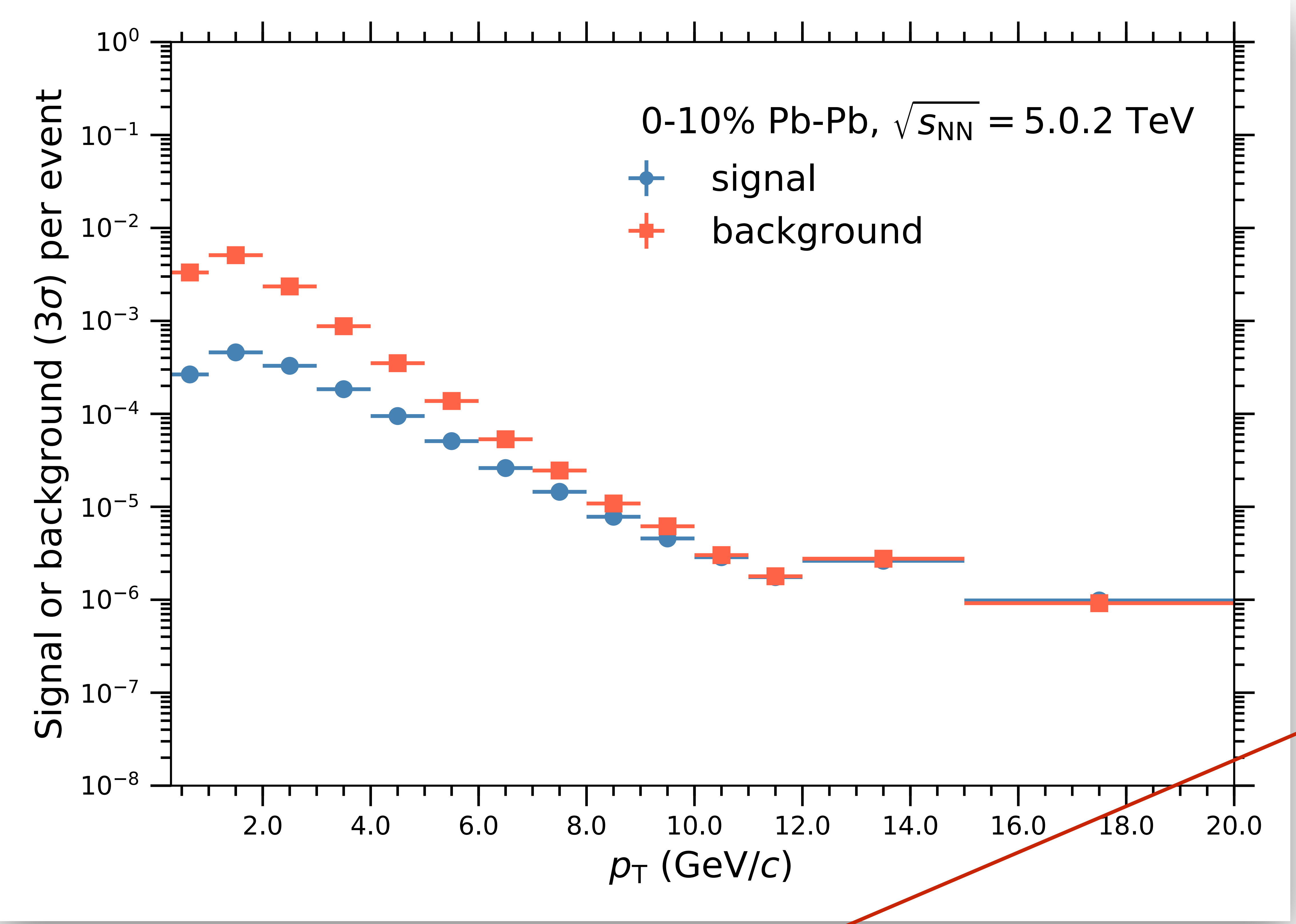
Phys. Rev. D 98, 030001 (2018)

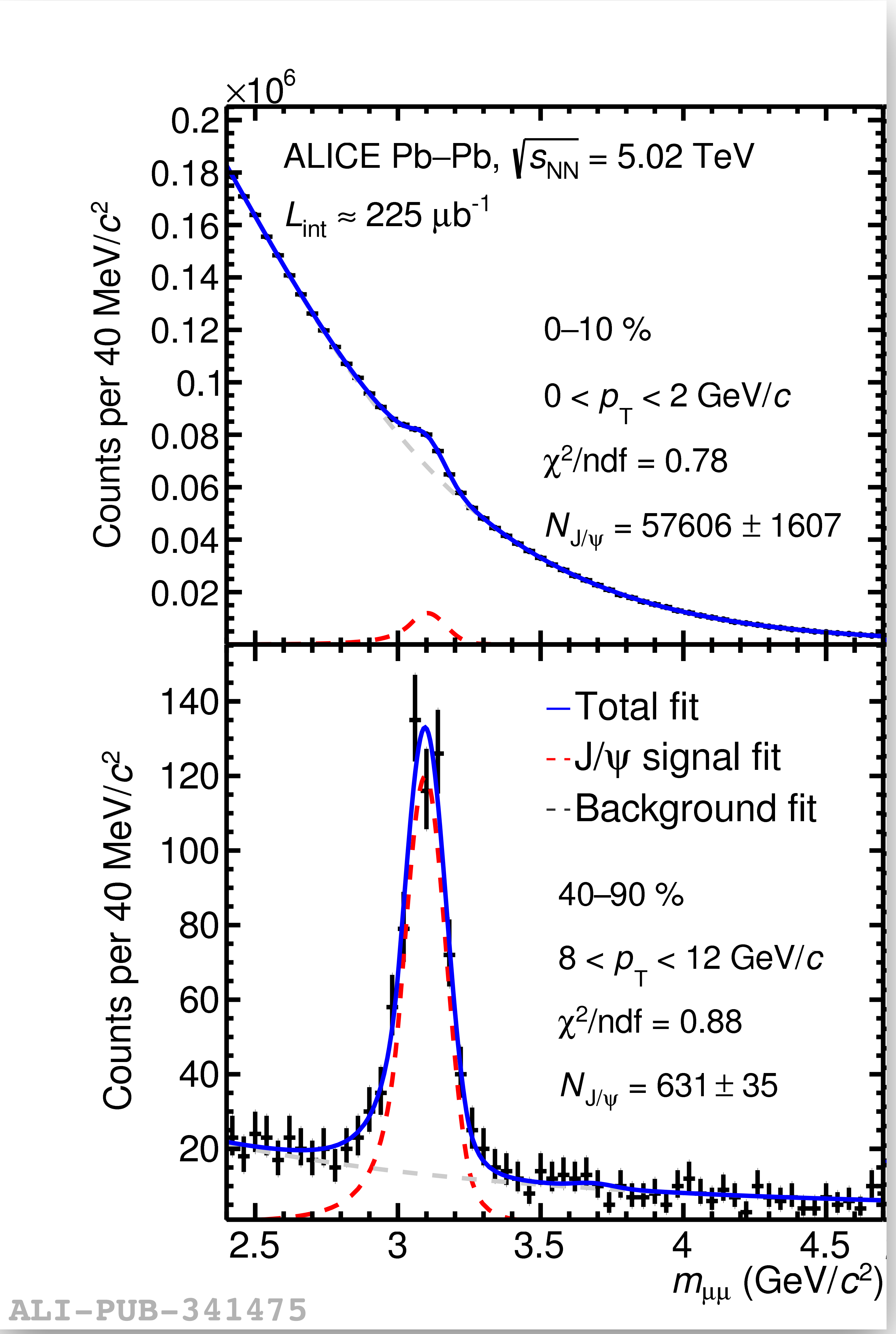
initially assumed to be equal to unity

nuclear overlap function for the 0-10% centrality class 23.07 μb^{-1}

8×10^9 number of events corresponding to the expected luminosity of $\mathscr{L}_{\rm int} = 10\ nb^{-1}$

$B_c^+ \rightarrow J/\psi + \mu^+ + \nu_\mu$ - background estimation

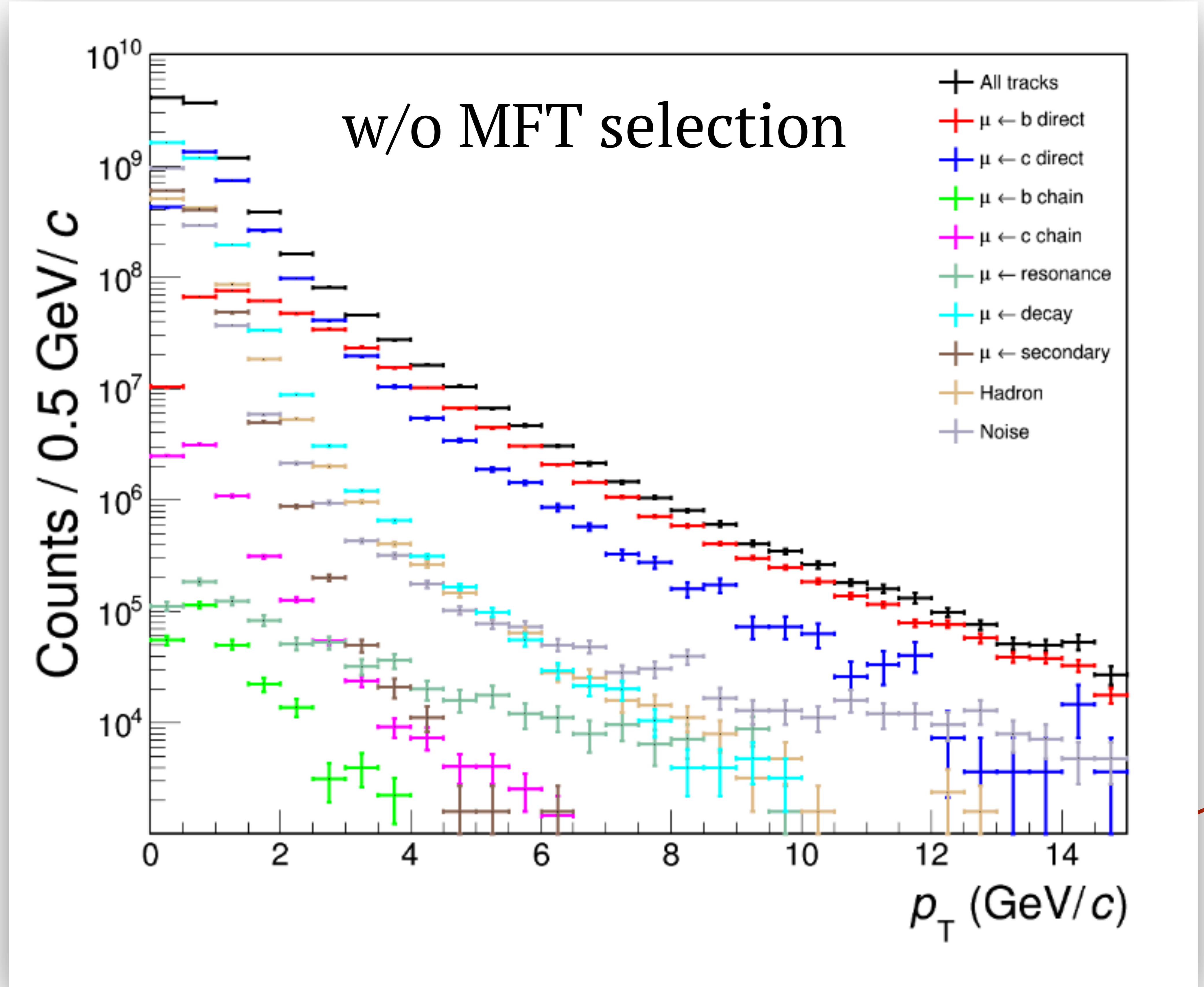


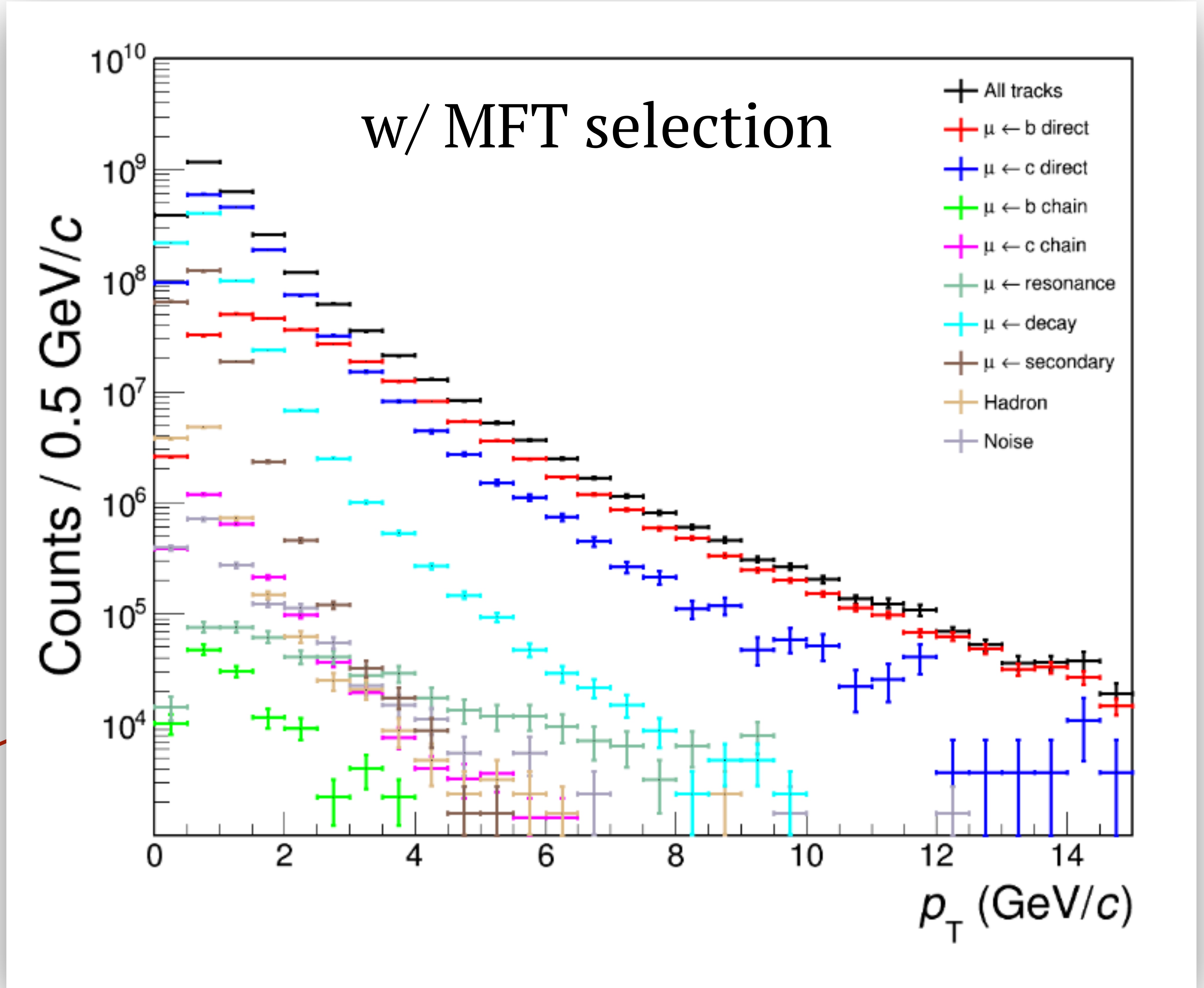


- J/ψ candidates (S + B) per event contribute to the combinatorial background
  - ➡ assumed to be equal to those measured in the Run2 analyses in Pb-Pb collisions at 5.02 TeV

arXiv:1909.03158

$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - background estimation

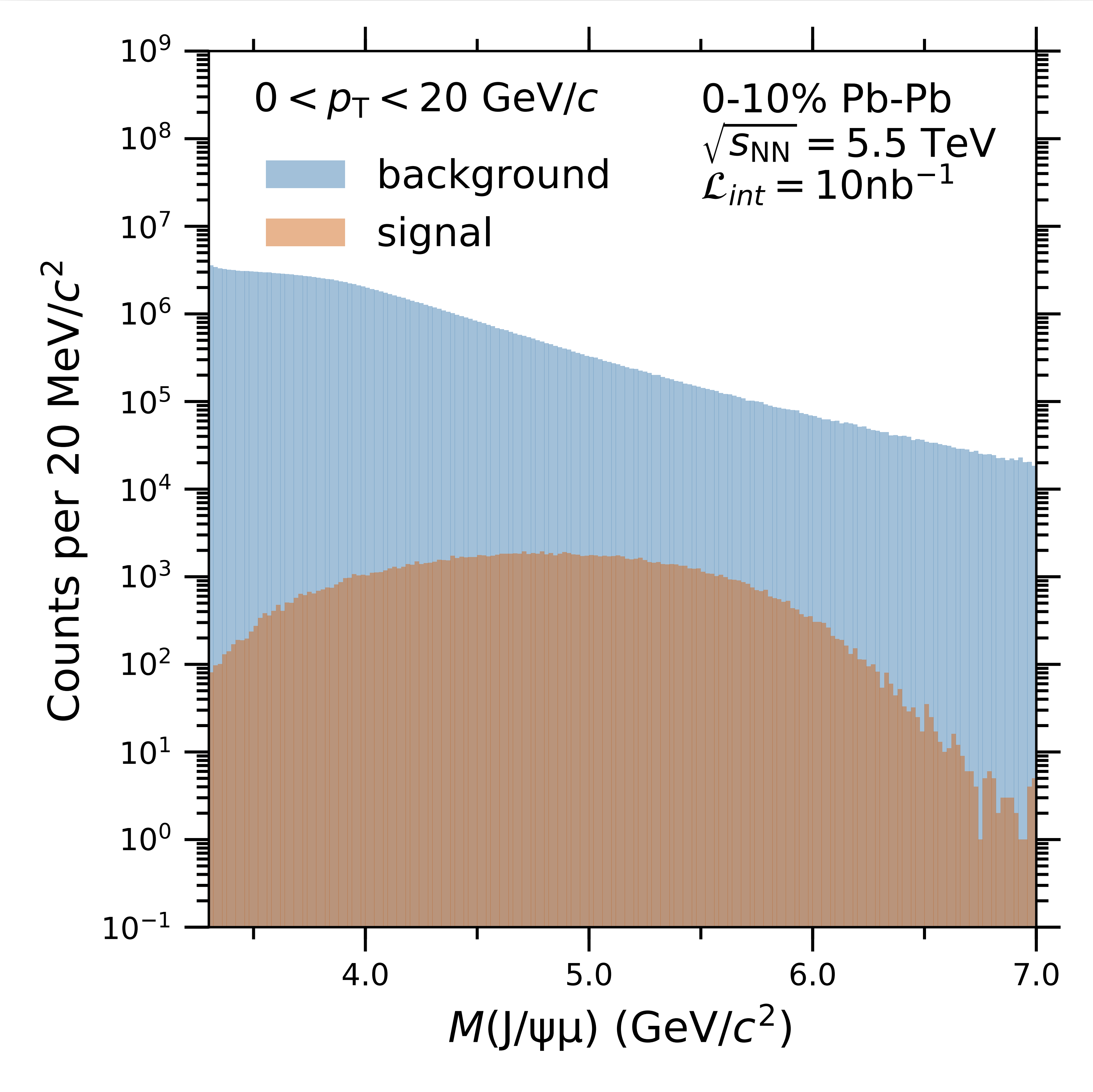


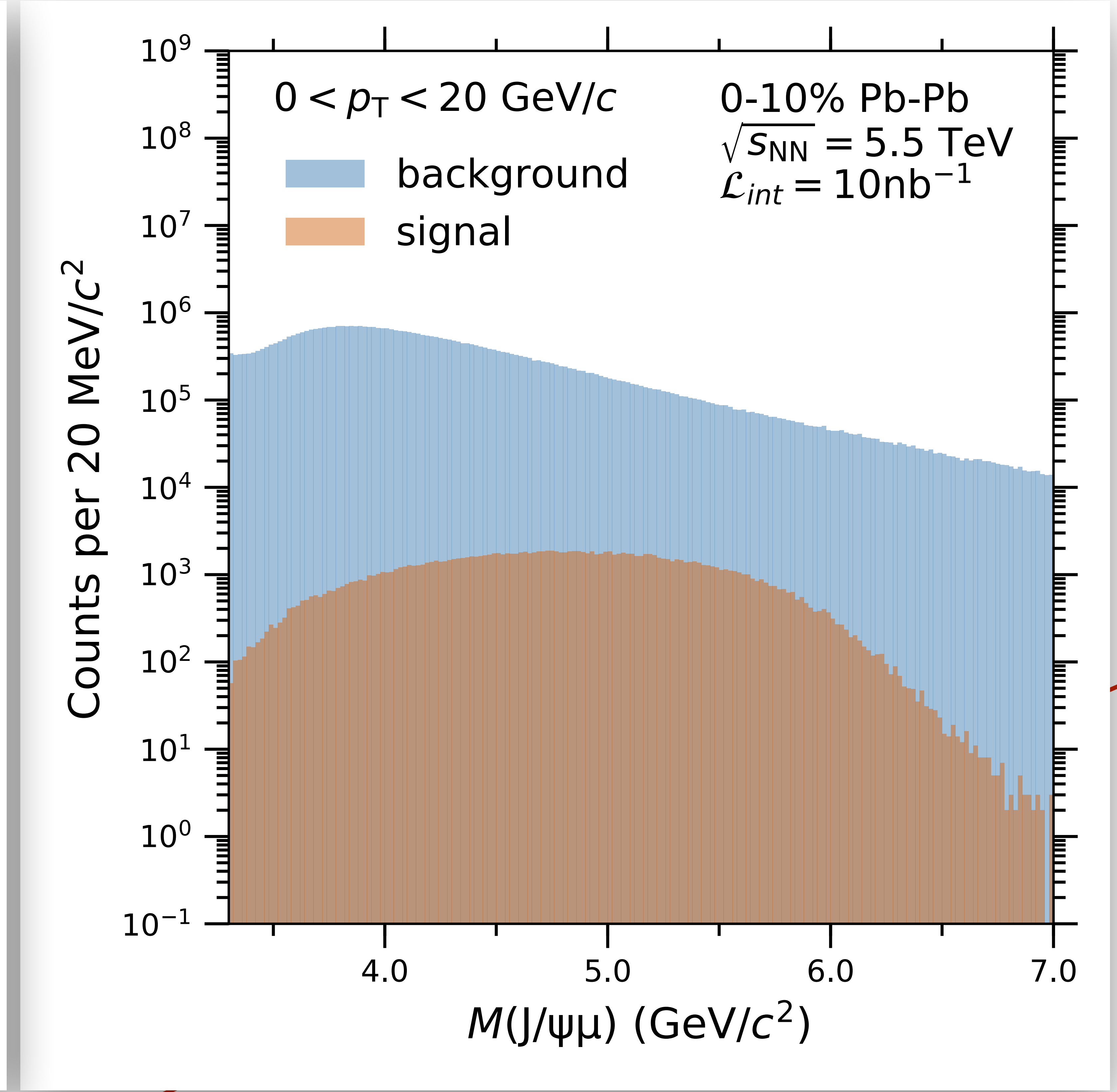


CERN-LHCC-2015-001

- For single muon yield two configurations considered:
  - ➡ all muon tracks without any MFT requirement
  - ➡ muon tracks that fall in the MFT acceptance and are matched to a MFT track

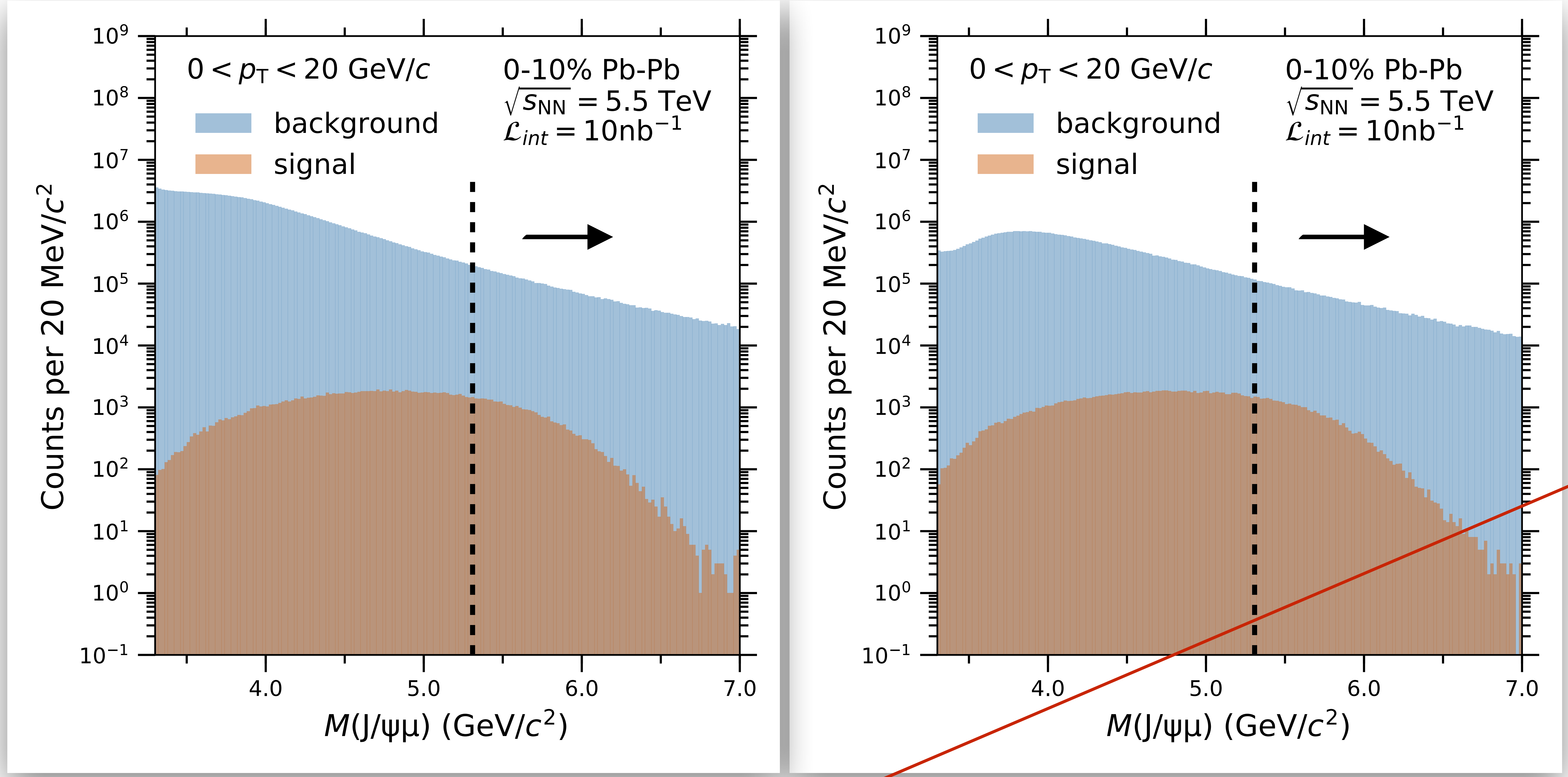
$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - invariant-mass distribution

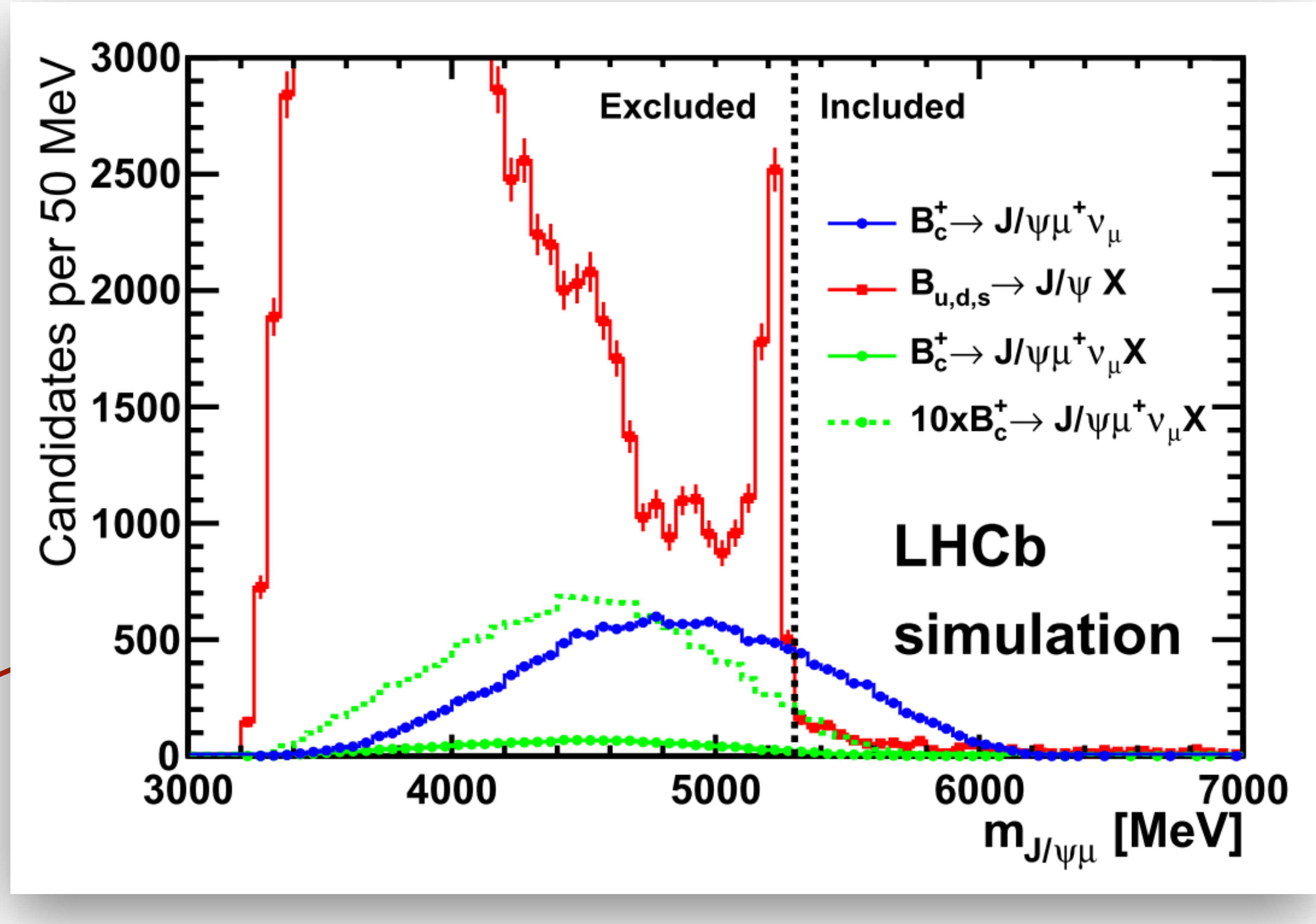




- Invariant-mass distribution for combinatorial background computed with a fast MC simulation performed using p_T distribution of expected number of J/ψ (S+B) and muons per event
- Invariant-mass distribution for signal computed using decay kinematics from PYTHIA8, applying a smearing to the daughters momenta to mimic experimental resolution

$B_c^+ \to J/\psi + \mu^+ + \nu_\mu$ - invariant-mass distribution

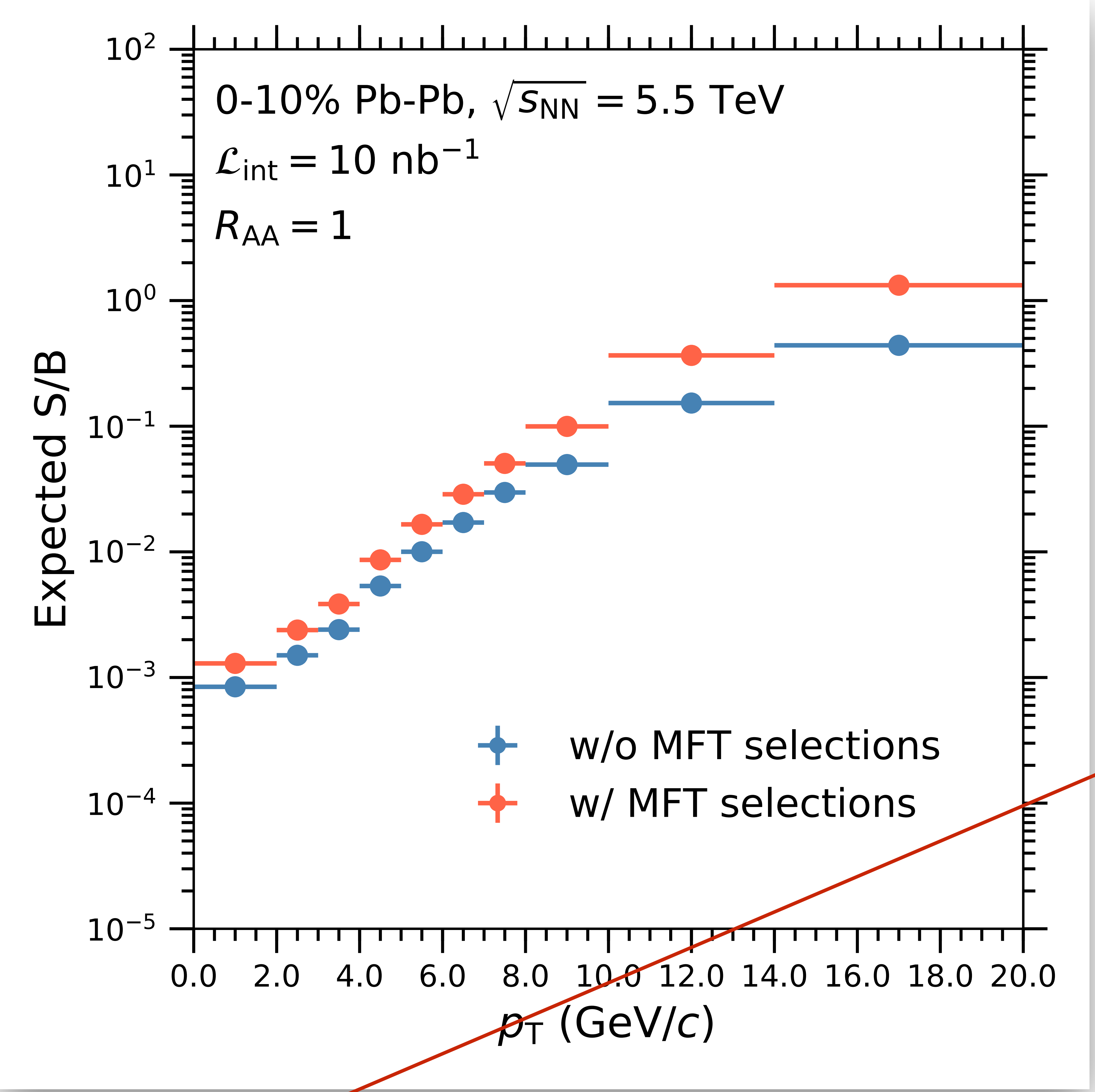


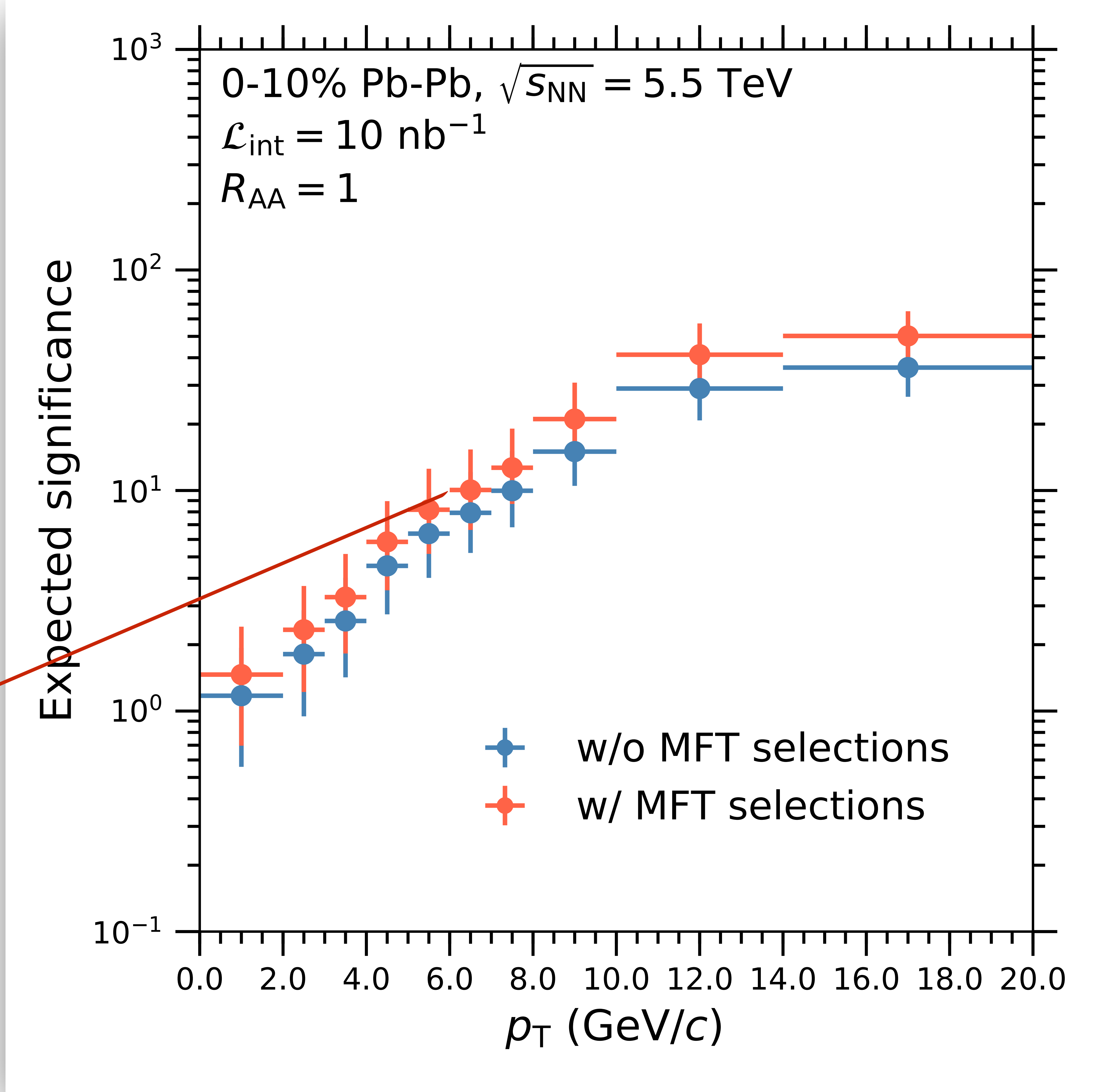


Phys. Rev. D 90, 032009 (2014)

- Correlated backgrounds not taken into account with this simple fast MC simulation
  - ➡ selection on invariant-mass applied to select region where the contribution of correlated backgrounds is small (from LHCb paper)
    - ➡ NB: most of the correlated backgrounds are from $B_{u,d,s} \to J/\psi(\to \mu^+\mu^-) + \pi^+/K^+$ which would not contribute in ALICE because of the hadron absorber

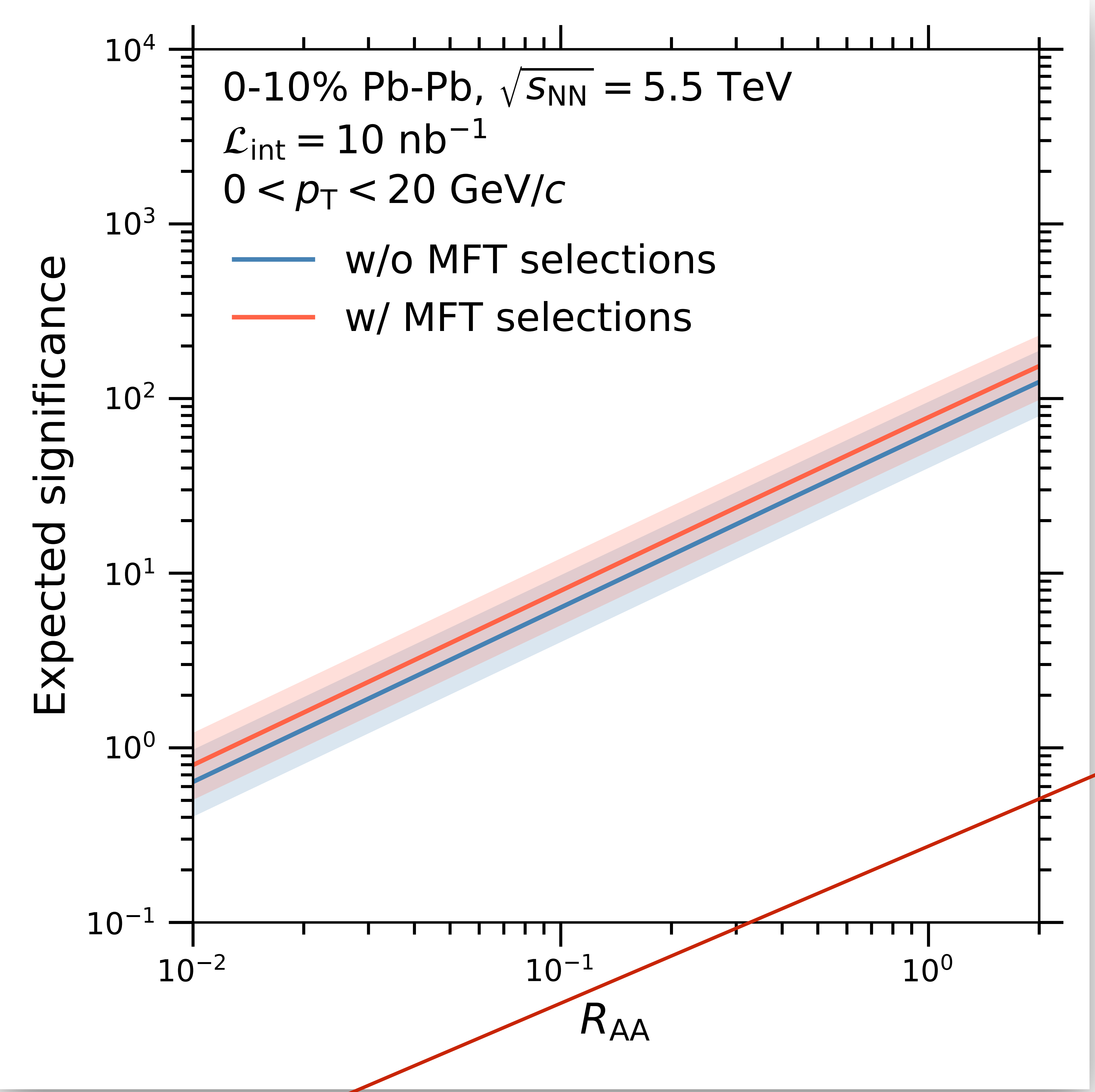
$B_c^+ \rightarrow J/\psi + \mu^+ + \nu_\mu$ - significance estimation

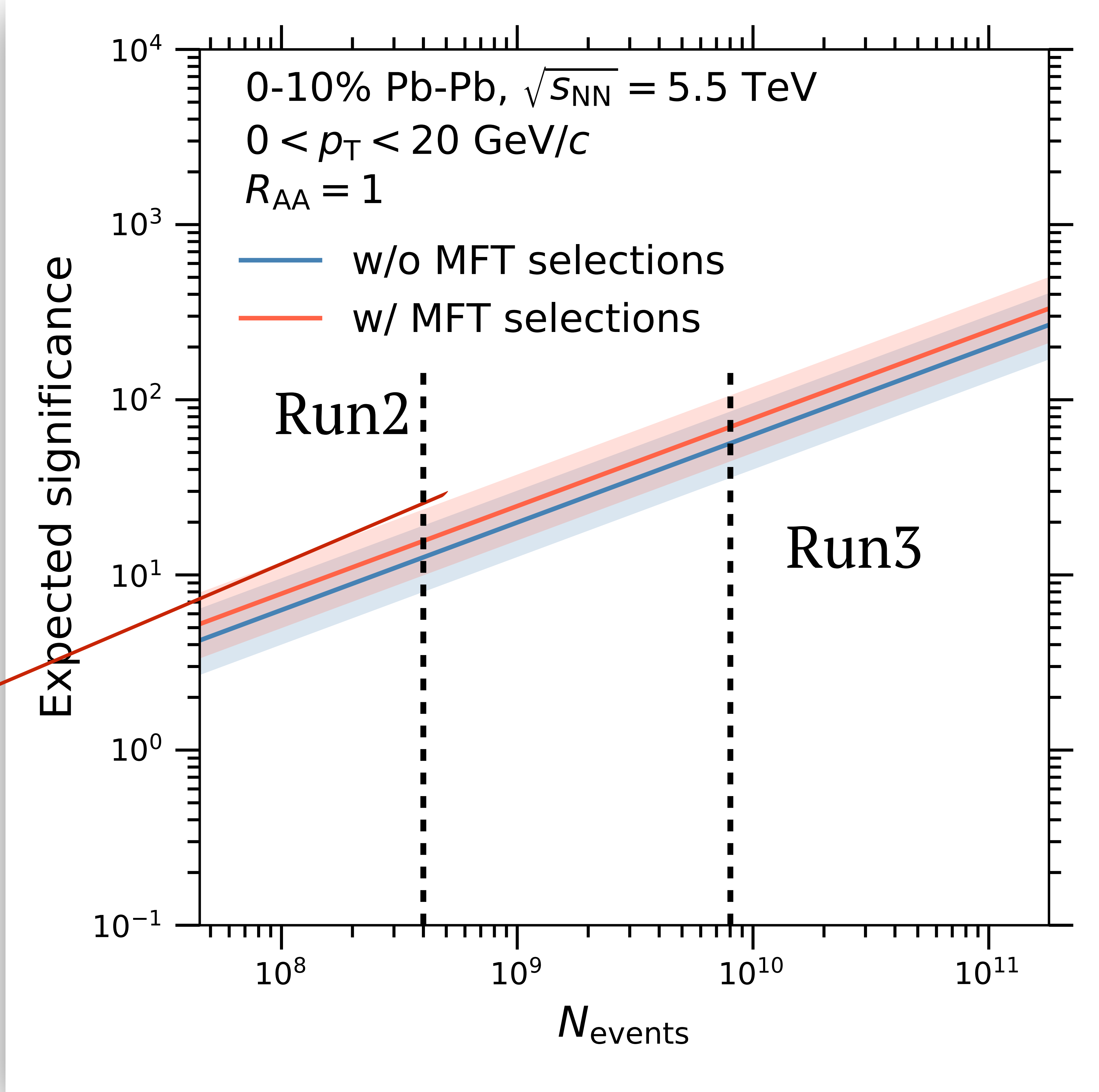




- With these assumptions significance expected to be larger than ~5 for p_T > 4 GeV/c
- Improvement with MFT (additional improvement could come from selection of displaced vertices)

$B_c^+ \rightarrow J/\psi + \mu^+ + \nu_\mu$ - significance estimation





- Good expected significance also for small R_{AA} values (~0.1)

$B_c^+ \to D^{*+} + \overline{D}^0$ - signal estimation

- Expected raw signal estimated as:

$$N_{\mathrm{raw}}(B_c^\pm) = 2 \cdot \Delta p_T \cdot \Delta y \cdot \left[\frac{d\sigma_{pp}(B_c^+)}{dp_T}\right] \cdot BR(B_c^+ \to D^{*+}\overline{D}^0) \cdot BR(D^{*+} \to K^-\pi^+\pi^+) \cdot BR(D^0 \to K^-\pi^+) \cdot (\mathrm{Acc} \times \epsilon) \cdot R_{AA} \cdot \langle T_{AA} \rangle \cdot N_{\mathrm{events}}$$

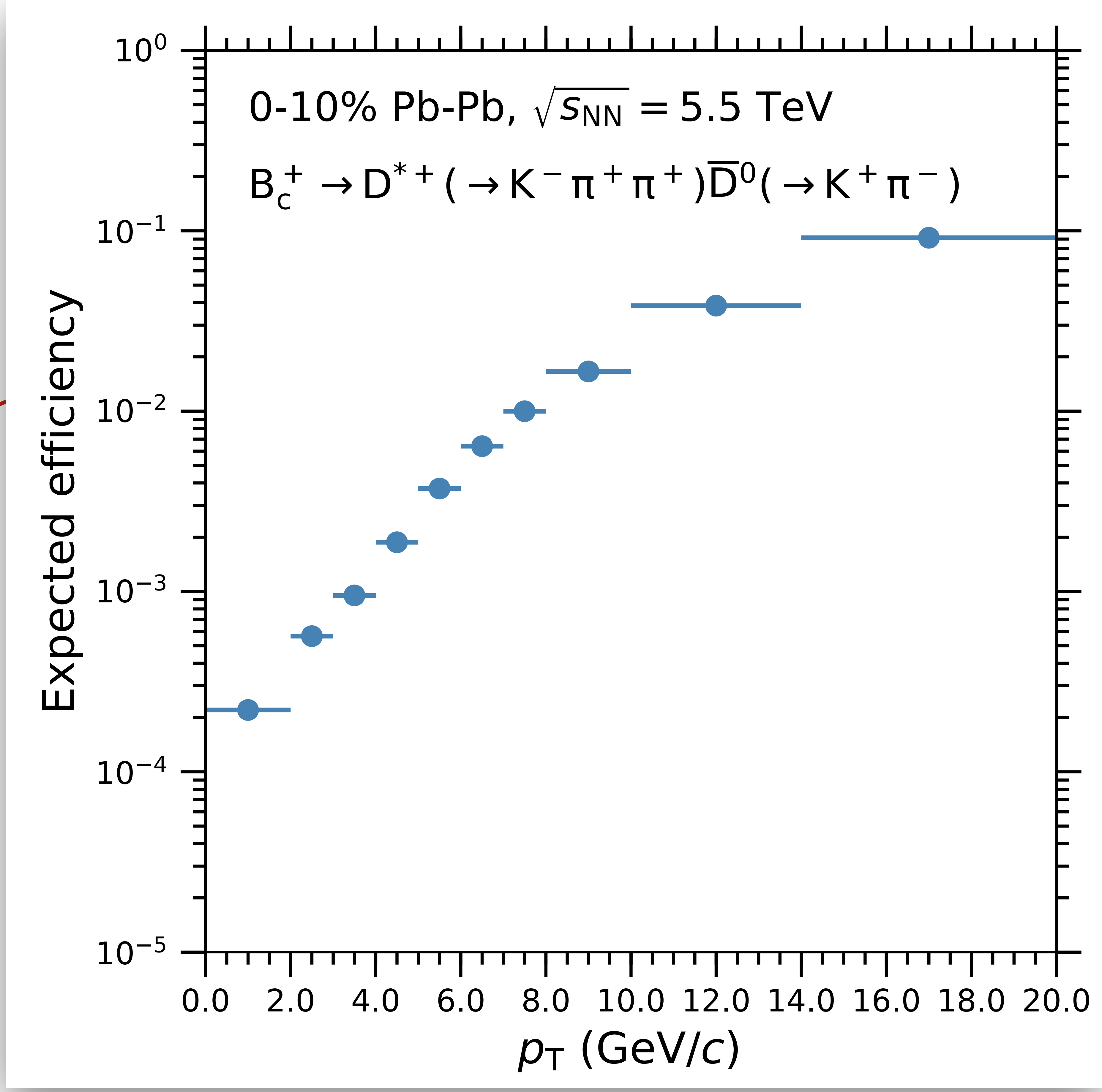
- same strategy adopted for the estimate of $B_c^+ \to J/\psi(\to \mu^+\mu^-) + \mu^+ + \nu_\mu$
  - ➡ different rapidity interval (|y|<0.5)
  - ➡ ratio between BR of $B_c^+ \to D^{*+}\overline{D}^0$ and $B_c^+ \to J/\psi\pi^+$ not measured

from theory

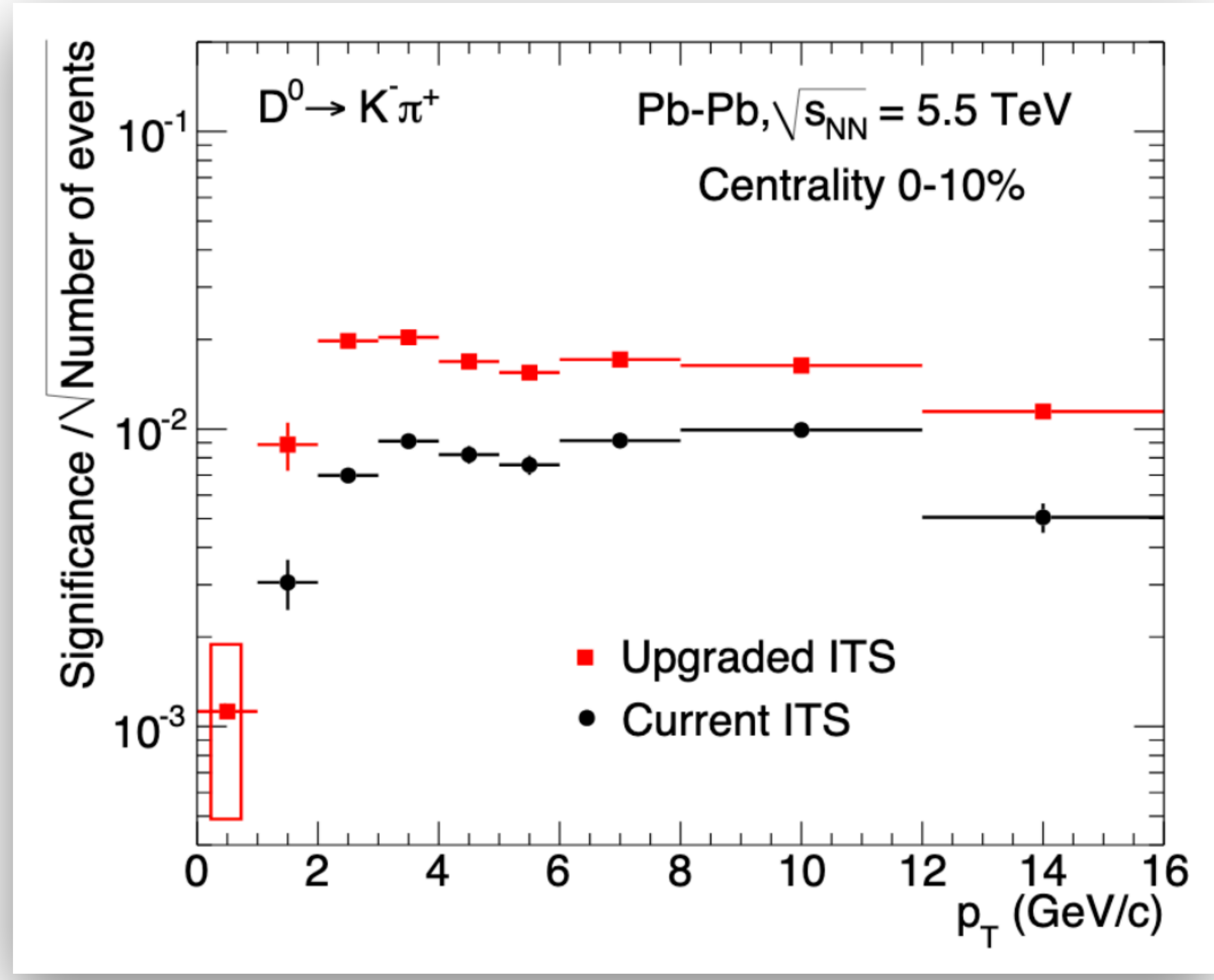
$$\frac{BR(B_c^+ \to D^{*+}\overline{D}^0)}{BR(B_c^+ \to J/\psi\pi^+)} = 0.038$$

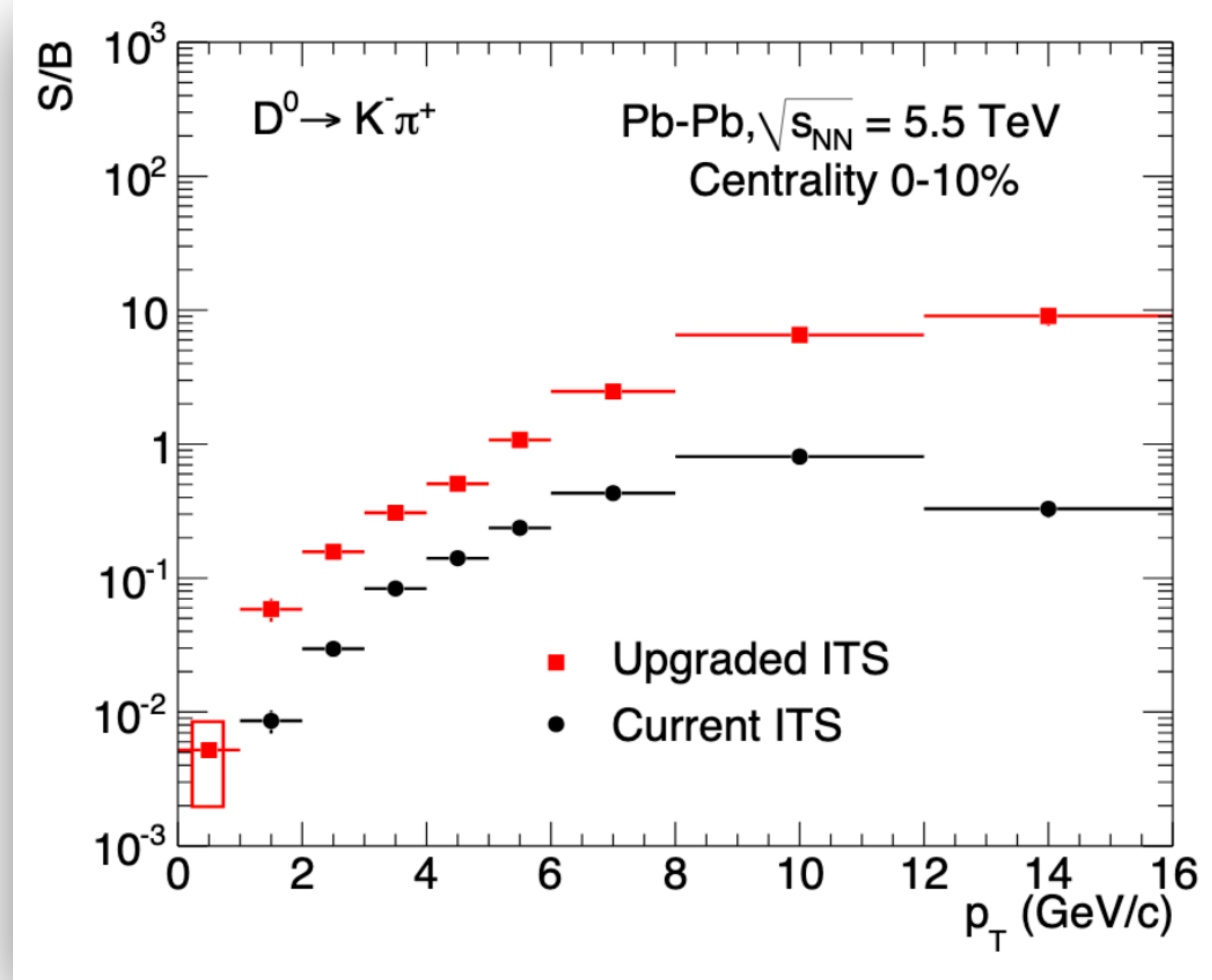
📚 Phys.Atom.Nucl. 67:1559-1570, 2004

  - ➡ lower reconstruction efficiency due to low reconstruction efficiencies of D^0 and D^{*+} mesons
    - ➡ taken from ITS TDR (CAVEAT: selections optimised for the measurement of prompt D)



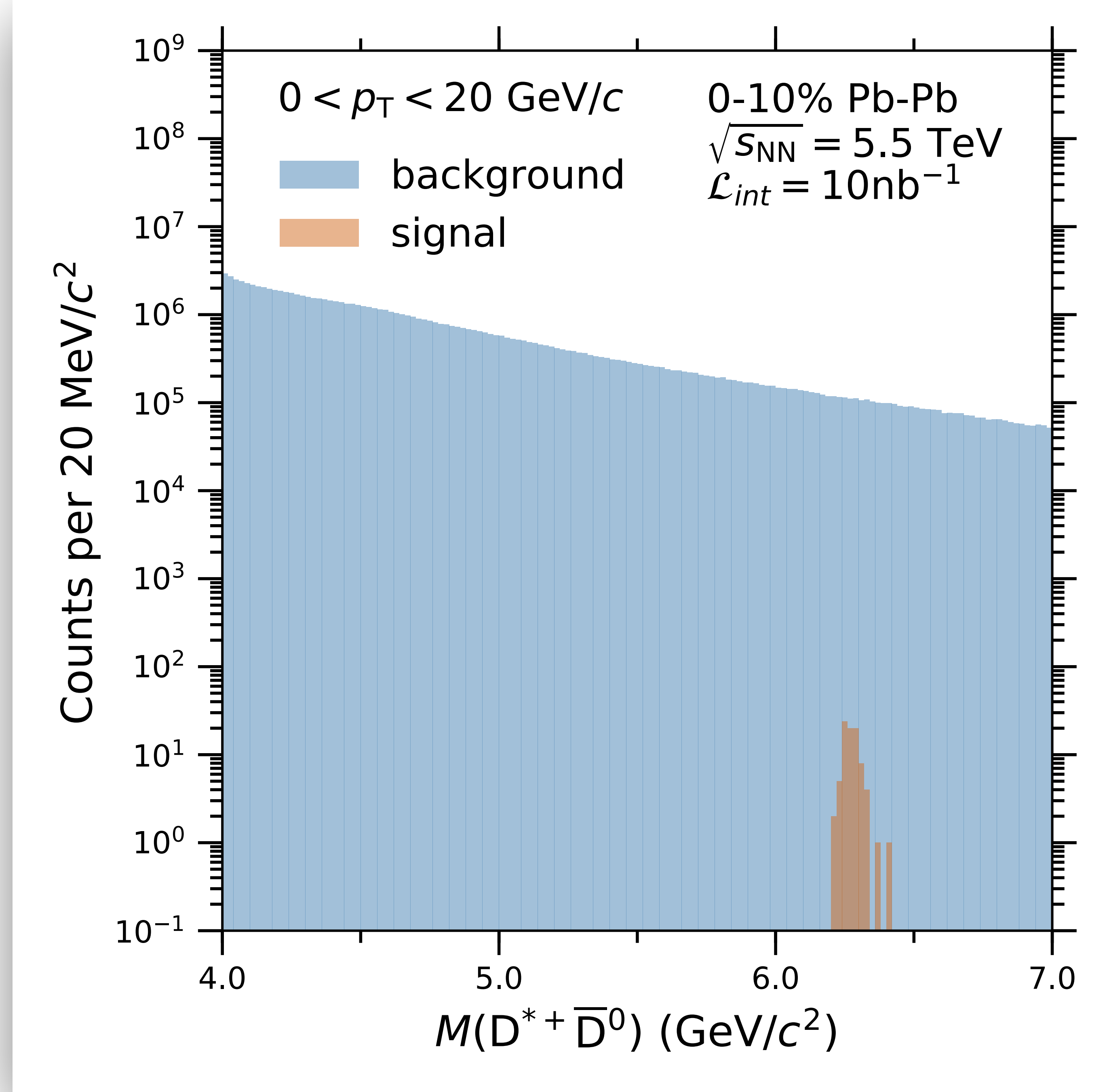
$B_c^+ \rightarrow D^{*+} + \overline{D}^0$ - background estimation





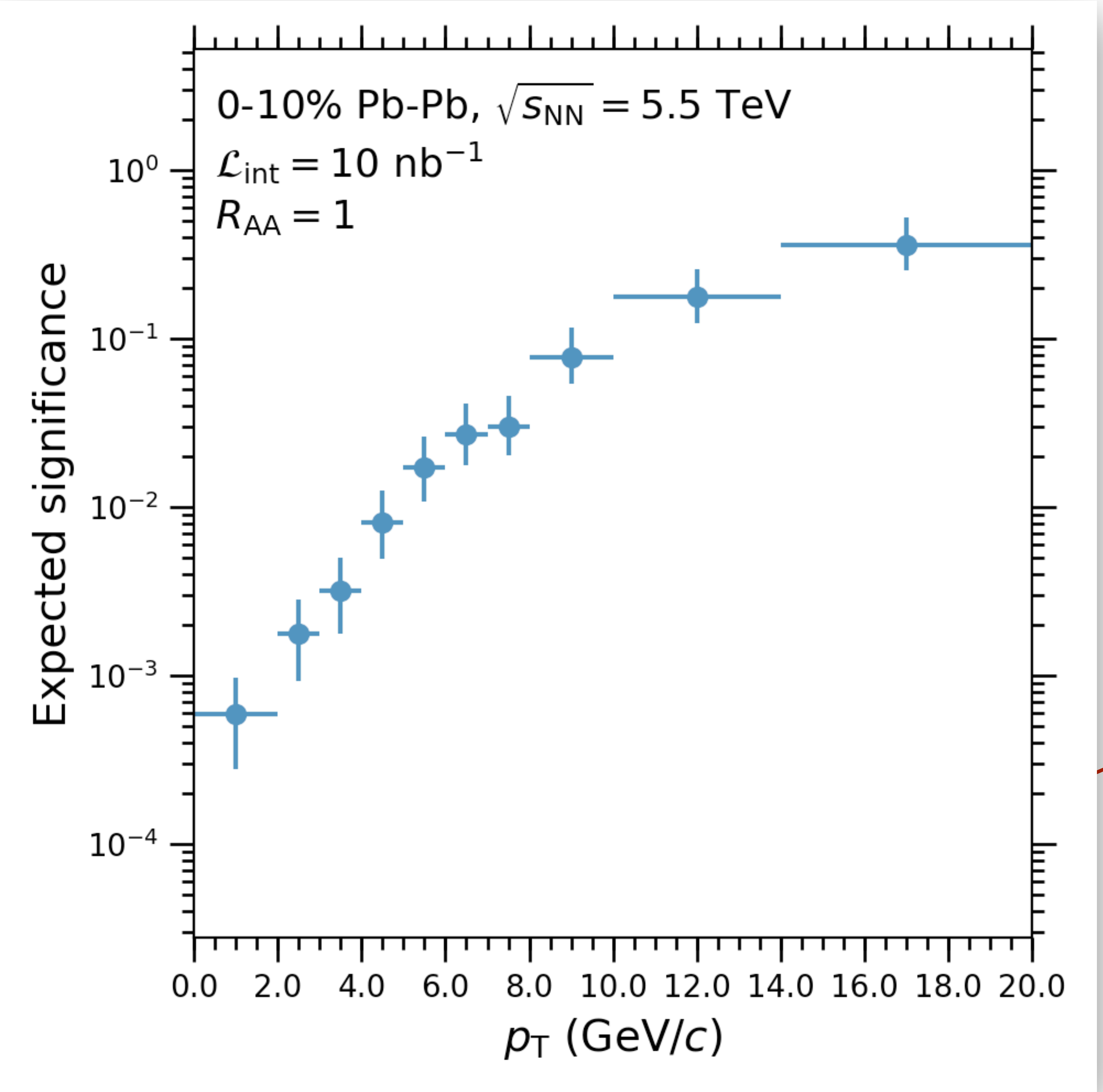
CERN-LHCC-2013-024

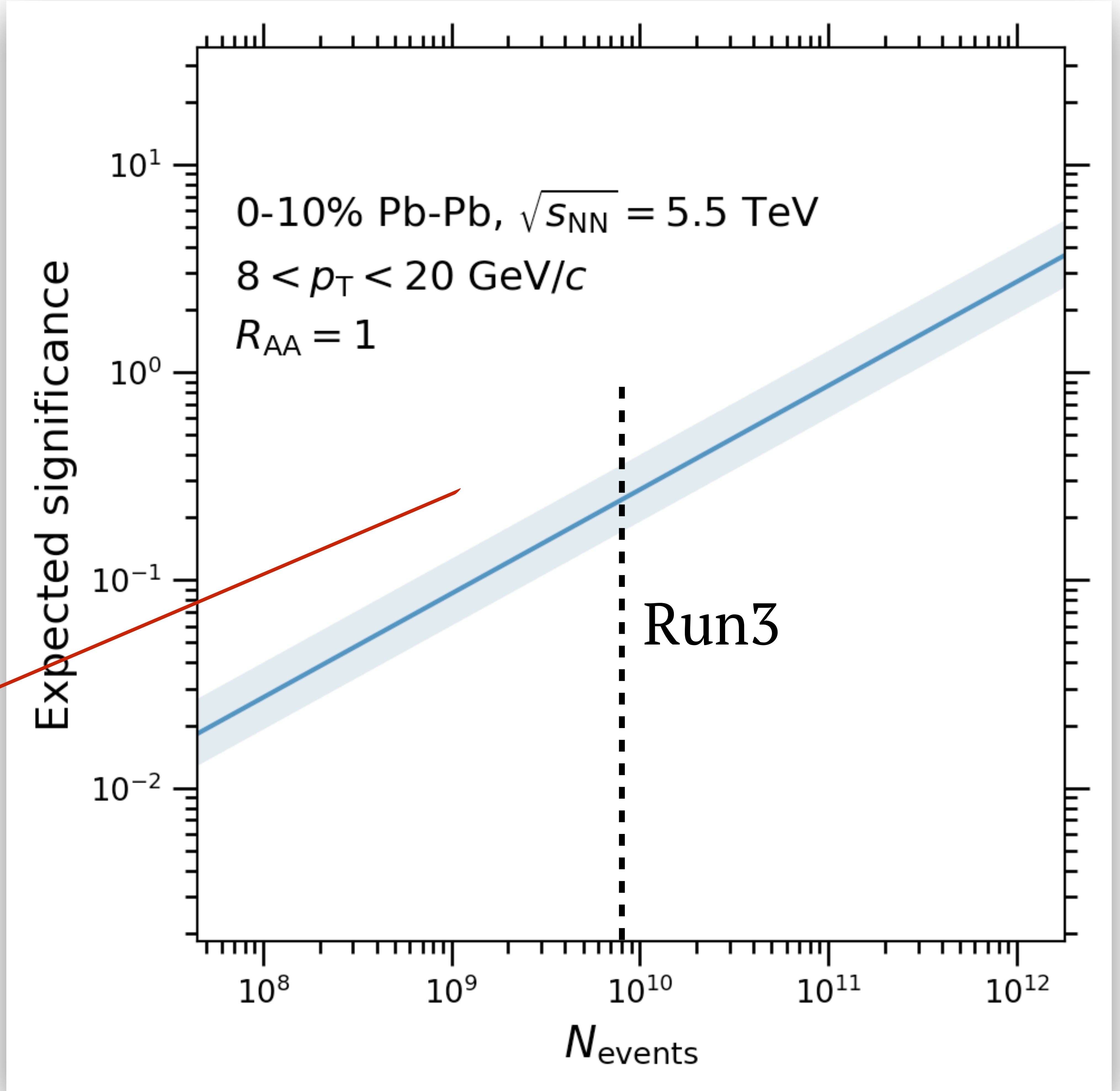
- expected signal and background per event both for D0 and D*+ candidates taken from ITS TDR
  - ➡ CAVEAT: selections optimised for the measurement of prompt D (which only contribute to the combinatorial background)



- Invariant-mass distributions for combinatorial background and signal obtained with the same strategy adopted for the $B_c^+ \rightarrow J/\psi + \mu^+ + \nu_\mu$ channel
- Correlated backgrounds not taken into account

$B_c^+ \to D^{*+} + \overline{D}^0$ - significance estimation





- Significance expected to be of the order of ~0.1 for p_T > 8 GeV/c and lower below
- x100 luminosity than the one expected for Run3 needed to reach ~3-5 significance

Conclusions

- ALICE for Run3 has the potential to study the B_c^+ meson production in heavy-ion collisions via different decay channels at mid and forward rapidity
  - ➡ $B_c^+ \rightarrow J/\psi(\rightarrow \mu^+\mu^-) + \mu^+ + \nu_\mu$ seems to be the most promising channel (measurement at forward rapidity)
    - ➡ improvement expected for the introduction of the MFT in Run3 (only partially took into account in this study)
  - ➡ Measurement via decays with D mesons at mid rapidity disfavoured by BR and reconstruction efficiencies

- More detailed studies with full MC productions are needed to have a more quantitative estimation of the expected performance

ADDITIONAL SLIDES

$B_c^+ \rightarrow D^{*+} + \overline{D}^0$ - decay kinematics