Coalescence afterburner with PYTHIA 8 input

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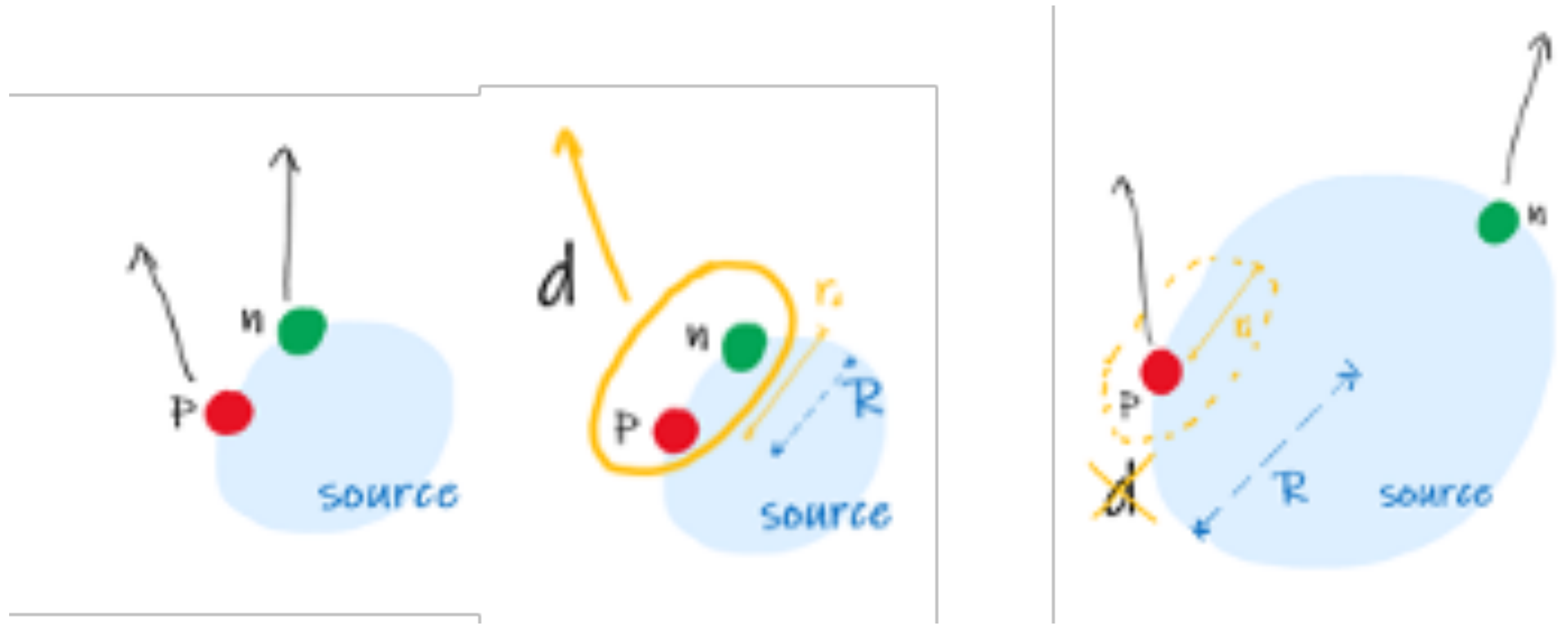
CosmicAntiNuclei

Introduction

- **Goal:** implement an afterburner based on the state-of-the-art coalescence modelling to be used to generate (anti)nuclei in commonly-employed MC event generators



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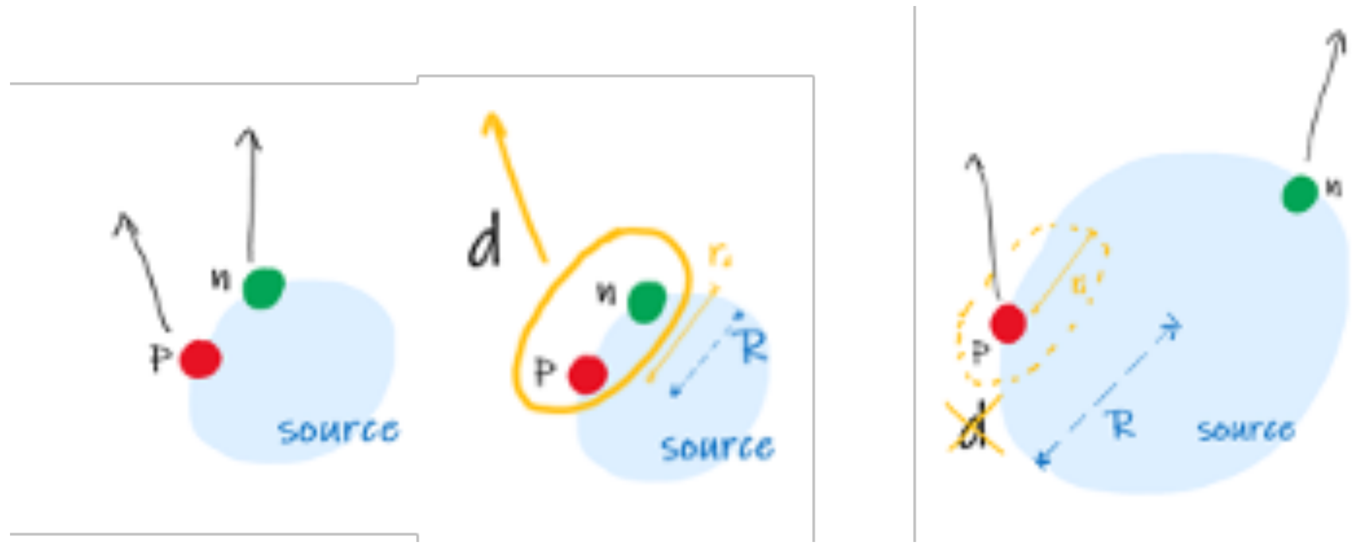

- **Why PYTHIA 8:**
  - Commonly employed in high-energy physics, tested and tuned at LHC energies
  - Newest development of PYTHIA8/Angantyr that extends PYTHIA to describe Pb-Pb phenomenology (JHEP 10 (2018) 134)
    - ➡ potential for new developments and responsiveness of the developers to questions/requests…
  - To be complementary to the effort already ongoing with EPOS3 (Maxi, Luca)

Our approach and status

1. (anti)proton spectrum input: we found a tune of PYTHIA 8 that reproduces the p and pbar measured spectra in minimum bias pp collisions
   - Check that other *basic* observables are reproduced (i.e. multiplicity)
   - Minimum bias only: representative for astrophysics, min. bias data only at low energy
   - We do not rescale the proton spectrum
   - [reminder] We do not have measurements of the source in minimum bias pp at the LHC

2. Event-by-event coalescence mechanism: implementation ongoing
   - implemented simple coalescence (no Wigner function, only the p_0 criterium)
   - Move to the Wigner approach (ongoing), with nucleons emitted from a gaussian source

Data comparison (pseudorapidity density)

- **First step:** vary settings for basic processes and check with standard LHC tunes
  - Default: MPI, CR, ISR and FSR on
  - MPI off
  - MPI on, CR off
  - MPI on, CR on, ISR, FSR off
  - MPI off, CR off, ISR, FSR off
- **Tune 5** (also referred as 4C tune): modified multi-parton interaction parameters for better agreement with some early key LHC numbers
- **Tune 14:** the Monash 2013 tune by Peter Skands at al. [1] to both e+e- and pp data. Widely compared with ALICE data

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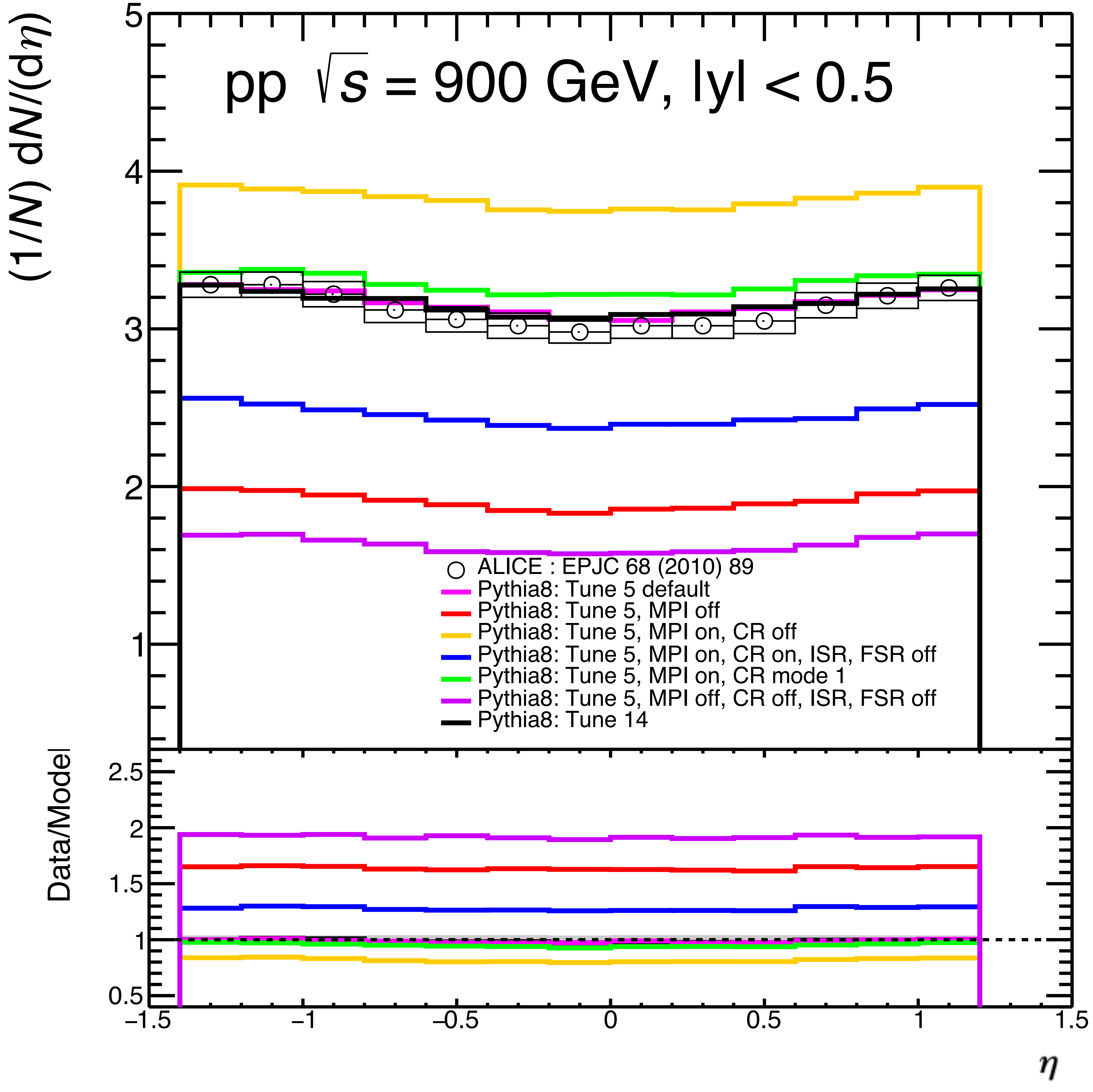
- Only default settings for both tune 5 and tune 14 successfully reproduce data



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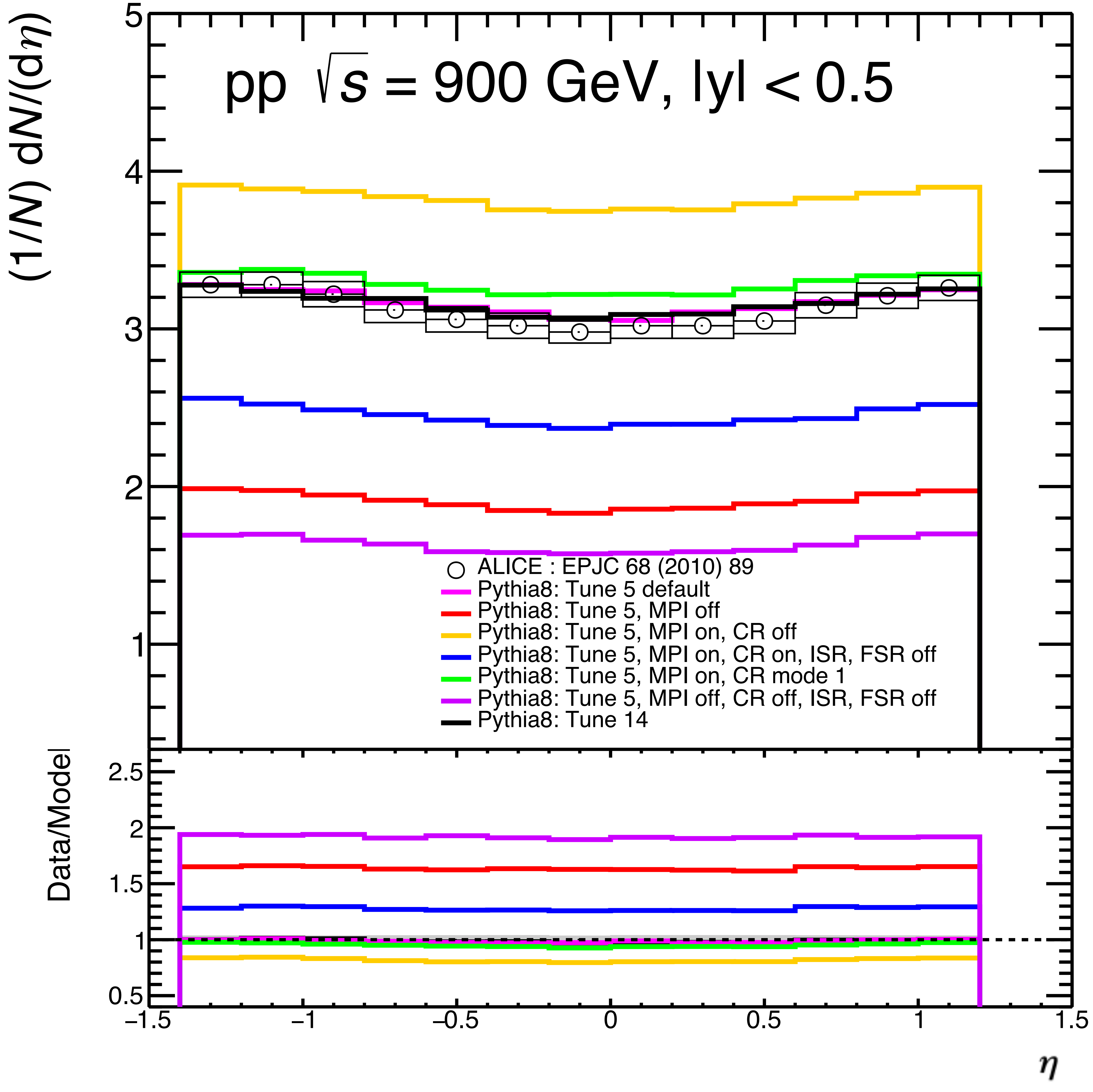
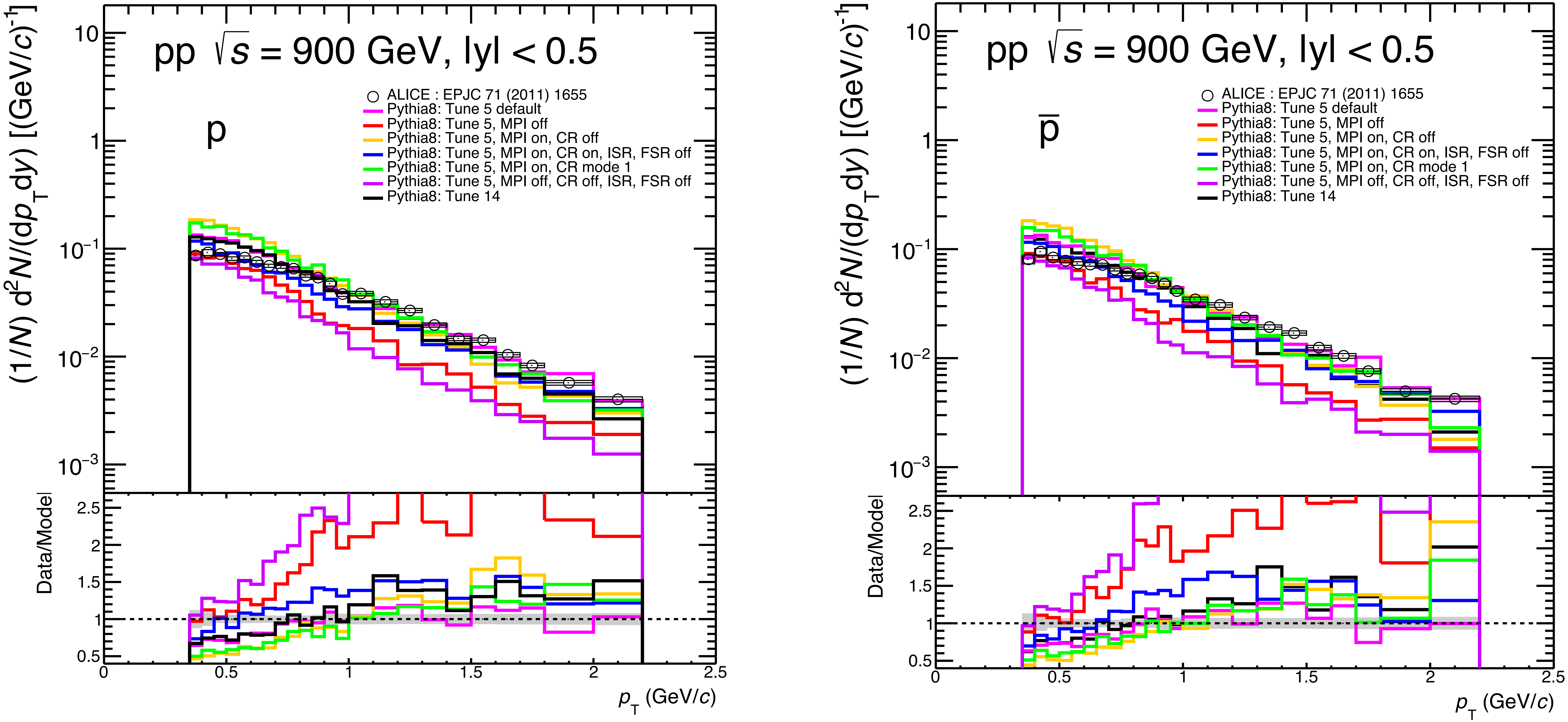
- **Next step:** proton and antiproton spectra



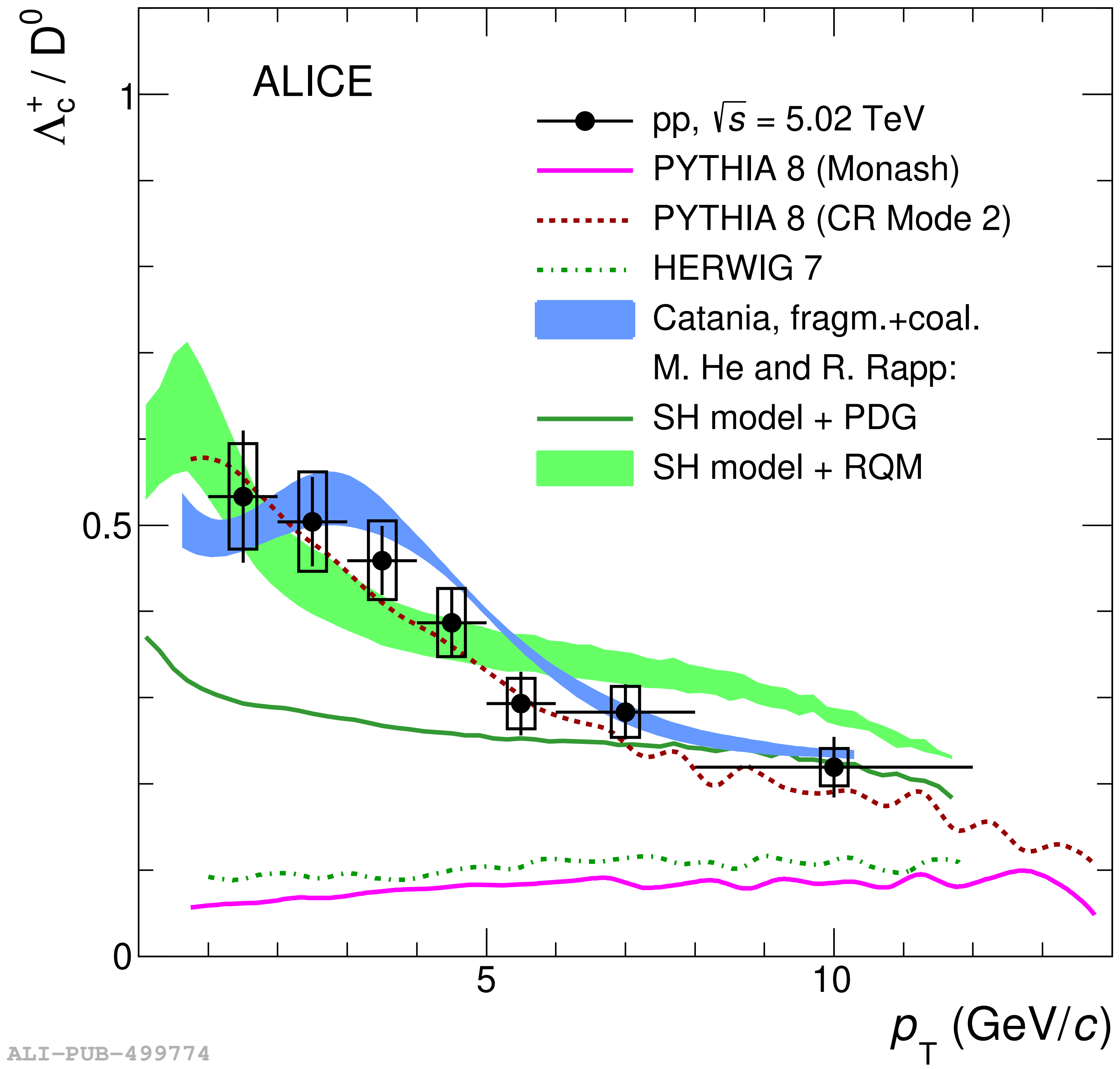
Data comparison (Proton and anti-proton p_T spectra)



None of the basic settings are able to describe the proton/antiproton spectra in complete p_T range and reproduce the final state multiplicity simultaneously

PYTHIA8 CR mode 2

- Default colour reconnection (CR) mode is the MPI-based original Pythia 8 scheme
- CR mode 2: The newer CR scheme builds on the minimization of the string length as well as the colour rules from QCD (QCD-based CR)

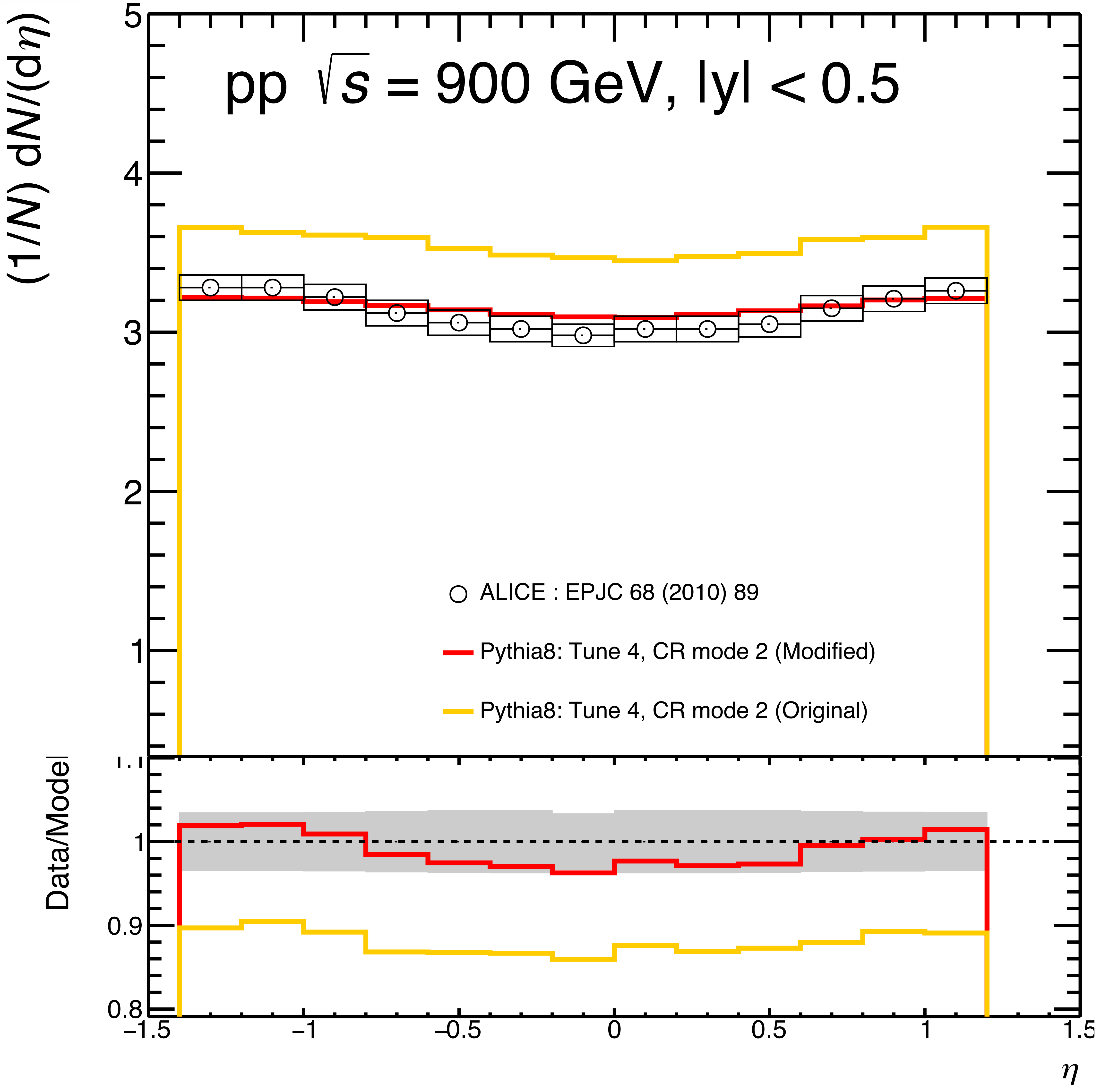


Parameter	Monash	Mode 0	Mode 2	Mode 3
StringPT:sigma	= 0.335	= 0.335	= 0.335	= 0.335
StringZ:aLund	= 0.68	= 0.36	= 0.36	= 0.36
StringZ:bLund	= 0.98	= 0.56	= 0.56	= 0.56
StringFlav:probQQtoQ	= 0.081	= 0.078	= 0.078	= 0.078
StringFlav:ProbStoUD	= 0.217	= 0.2	= 0.2	= 0.2
StringFlav:probQQ1toQQ0join	= 0.5, 0.7, 0.9, 1.0	= 0.0275, 0.0275, 0.0275, 0.0275	= 0.0275, 0.0275, 0.0275, 0.0275	= 0.0275, 0.0275, 0.0275, 0.0275
MultiPartonInteractions:pT0Ref	= 2.28	= 2.12	= 2.15	= 2.05
BeamRemnants:remnantMode	= 0	= 1	= 1	= 1
BeamRemnants:saturation	-	= 5	= 5	= 5
ColourReconnection:mode	= 0	= 1	= 1	= 1
ColourReconnection:allowDoubleJunRem	= on	= off	= off	= off
ColourReconnection:m0	-	= 2.9	= 0.3	= 0.3
ColourReconnection:allowJunctions	-	= on	= on	= on
ColourReconnection:junctionCorrection	-	= 1.43	= 1.20	= 1.15
ColourReconnection:timeDilationMode	-	= 0	= 2	= 3
ColourReconnection:timeDilationPar	-	-	= 0.18	= 0.073

Original CR mode 2

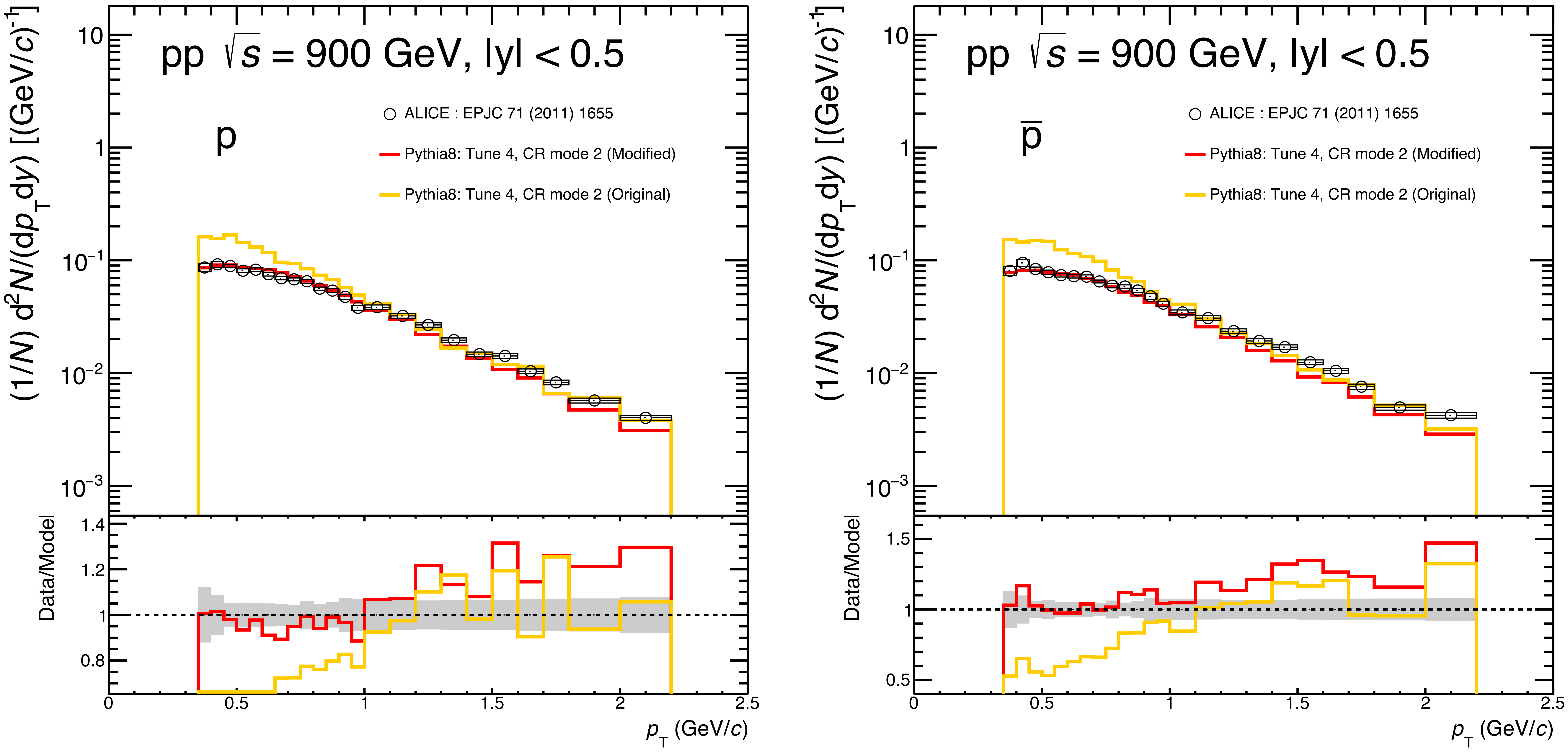
J. Christiansen and P. Skands *et. al.*, JHEP 08 (2015) 003.

Pseudorapidity density (CR mode 2)



- The original CR mode 2 differs the pseudorapidity density and multiplicity by 10%
- Thus, we have tuned the CR mode 2 settings listed in the previous slide: CR mode 2 (modified)
- Provides good agreement with LHC data

Proton and anti-proton p_T spectra (CR mode 2)



With modified CR mode 2 for Tune 4, PYTHIA 8 successfully describes the pseudorapidity density and low-p_T proton spectra simultaneously

Event-by-event coalescence mechanisms

Event-by-event coalescence

- The first tests are done for pp,13 TeV (MB) and pp, 900 GeV (MB) (10M events now, more event generation ongoing).
- Protons and neutrons are selected in loose rapidity (-1,1) —> loop over all protons and neutrons
- Final spectra obtained in rapidity range of (-0.5,0.5)
- Spin and Isospin factor: 1/2 * 3/4 = 3/8 (Phys. Rev. C 99, 014901 (2019))

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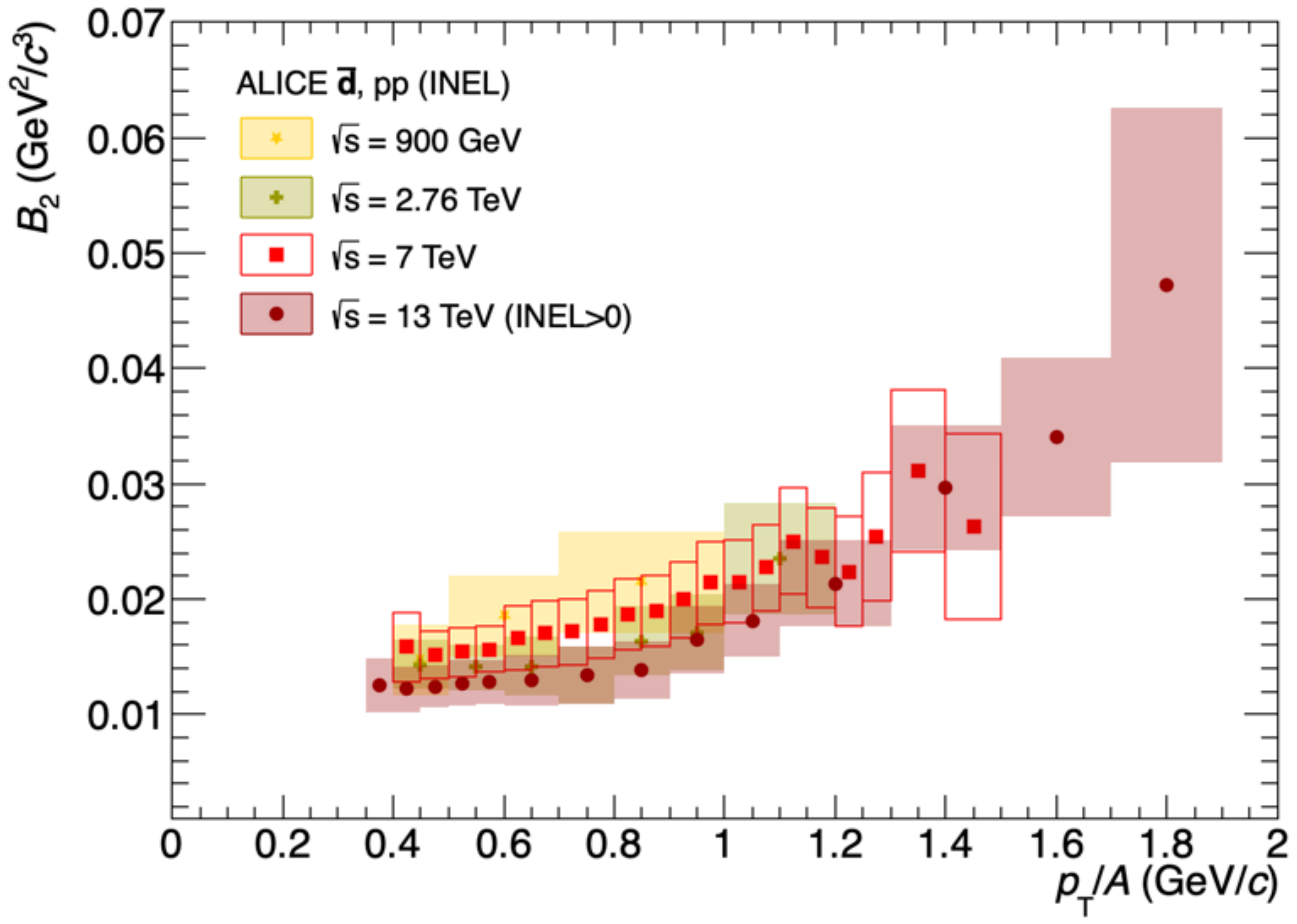
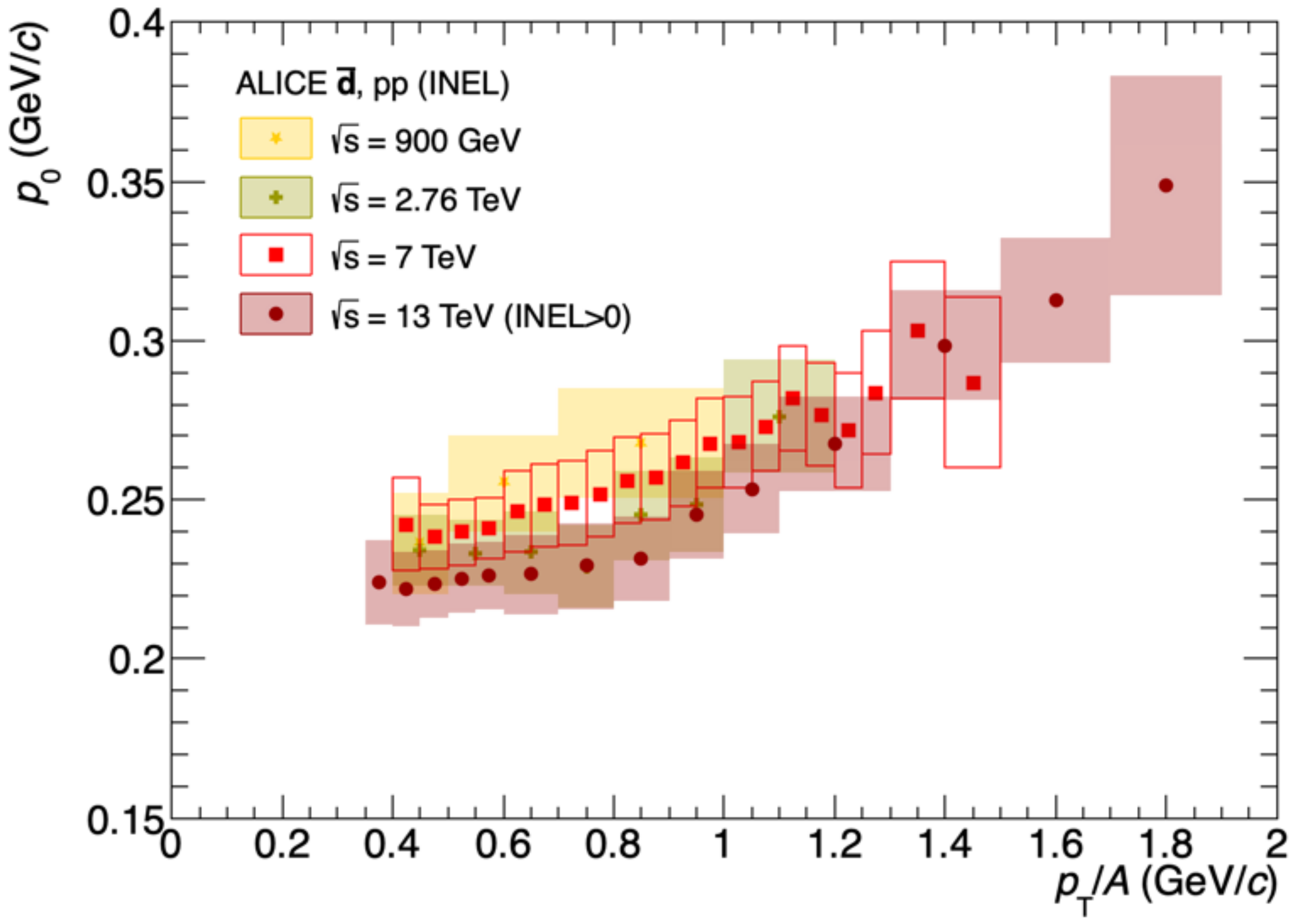
Simple Coalescence:

- No spatial correlations
- $|\overrightarrow{p_p} - \overrightarrow{p_n}| < p_0$

$$B_2 = \frac{m_D}{m_p m_n} \frac{\pi p_0^3}{6}$$

- We implement p_T and collision energy dependence of p_0 (uncertainties are also propagated)





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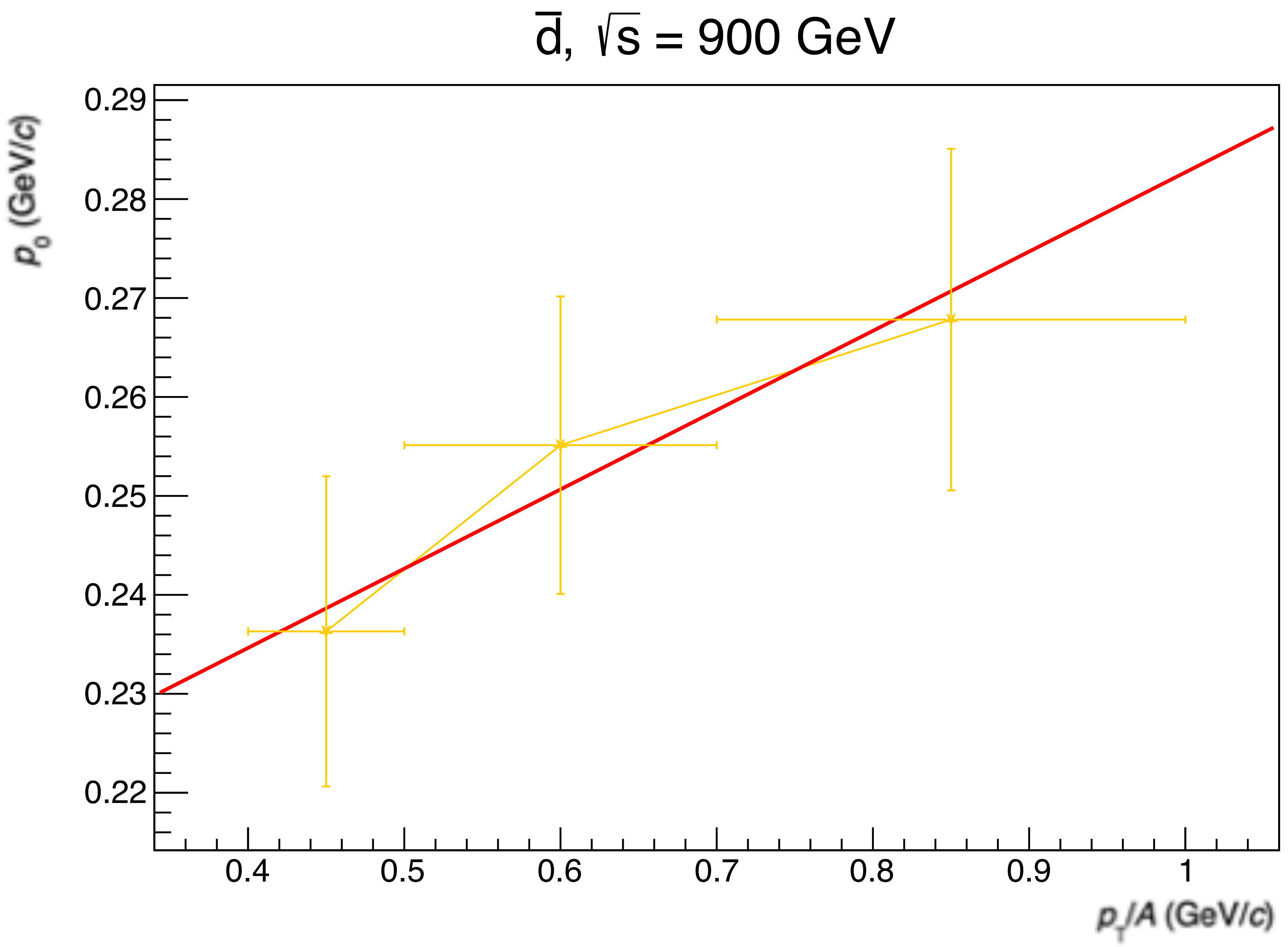

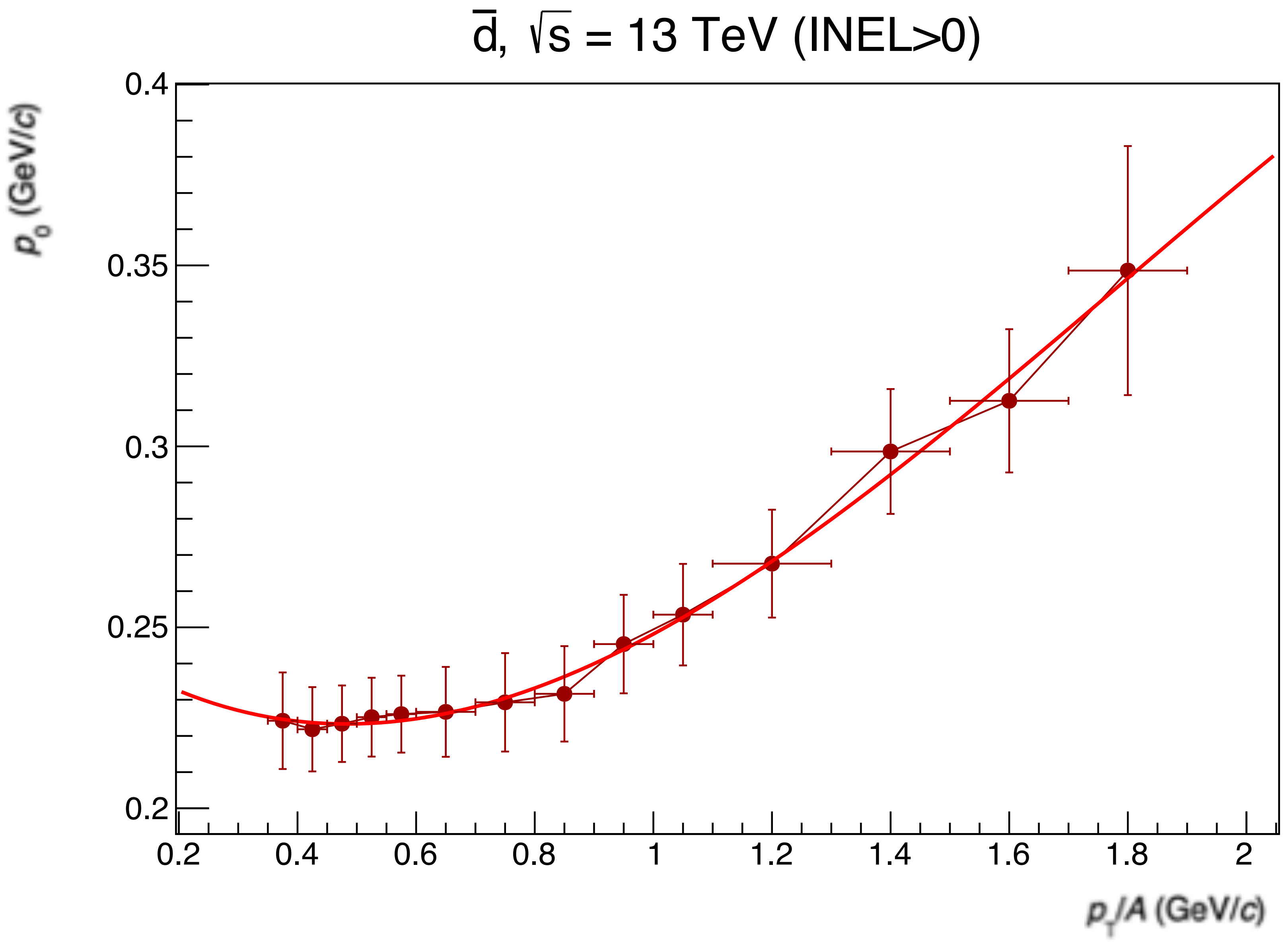

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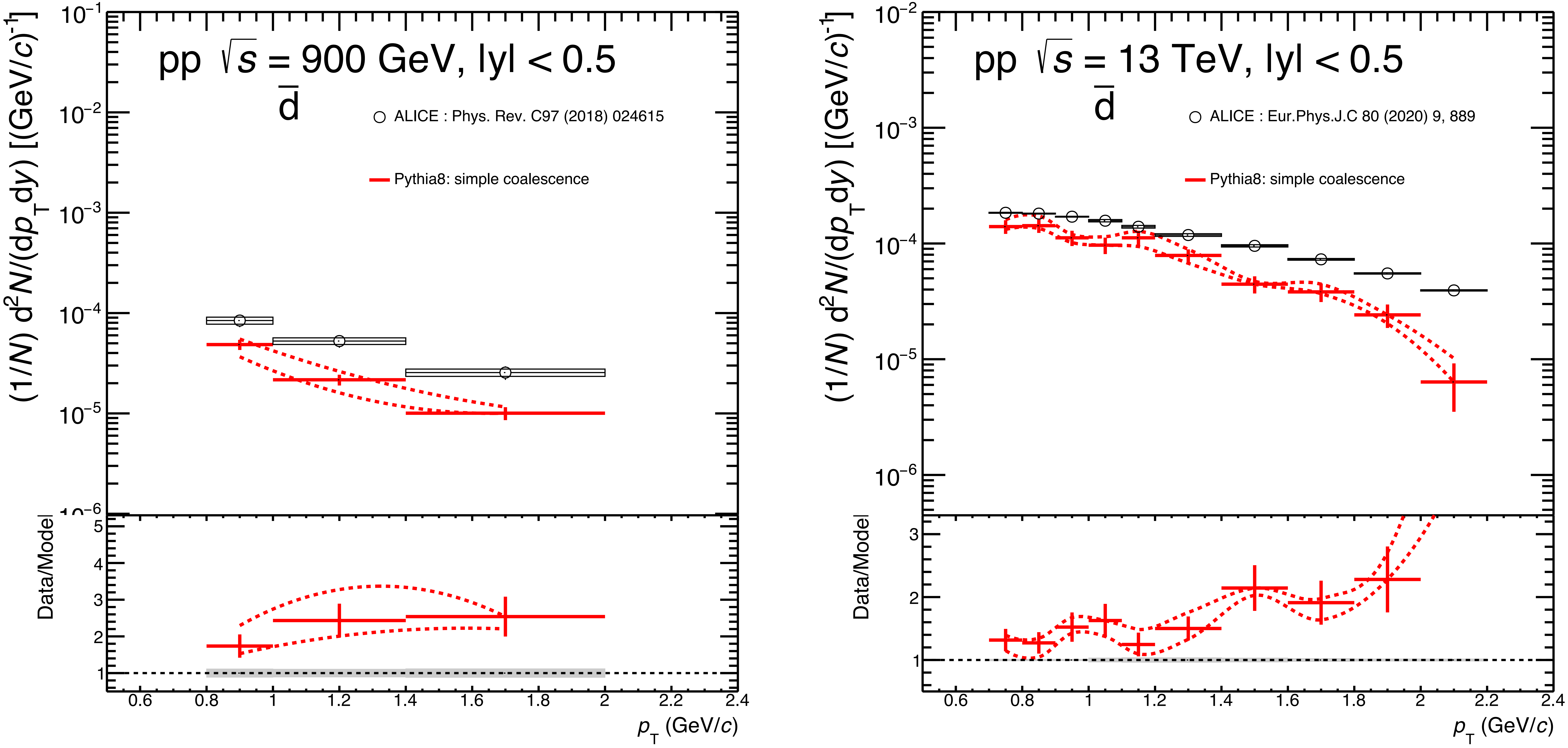


Wigner approach

Kachelriess et. al., Eur. Phys. J. A (2020) 56:4

Deuteron Wave function:

- Single Gaussian:

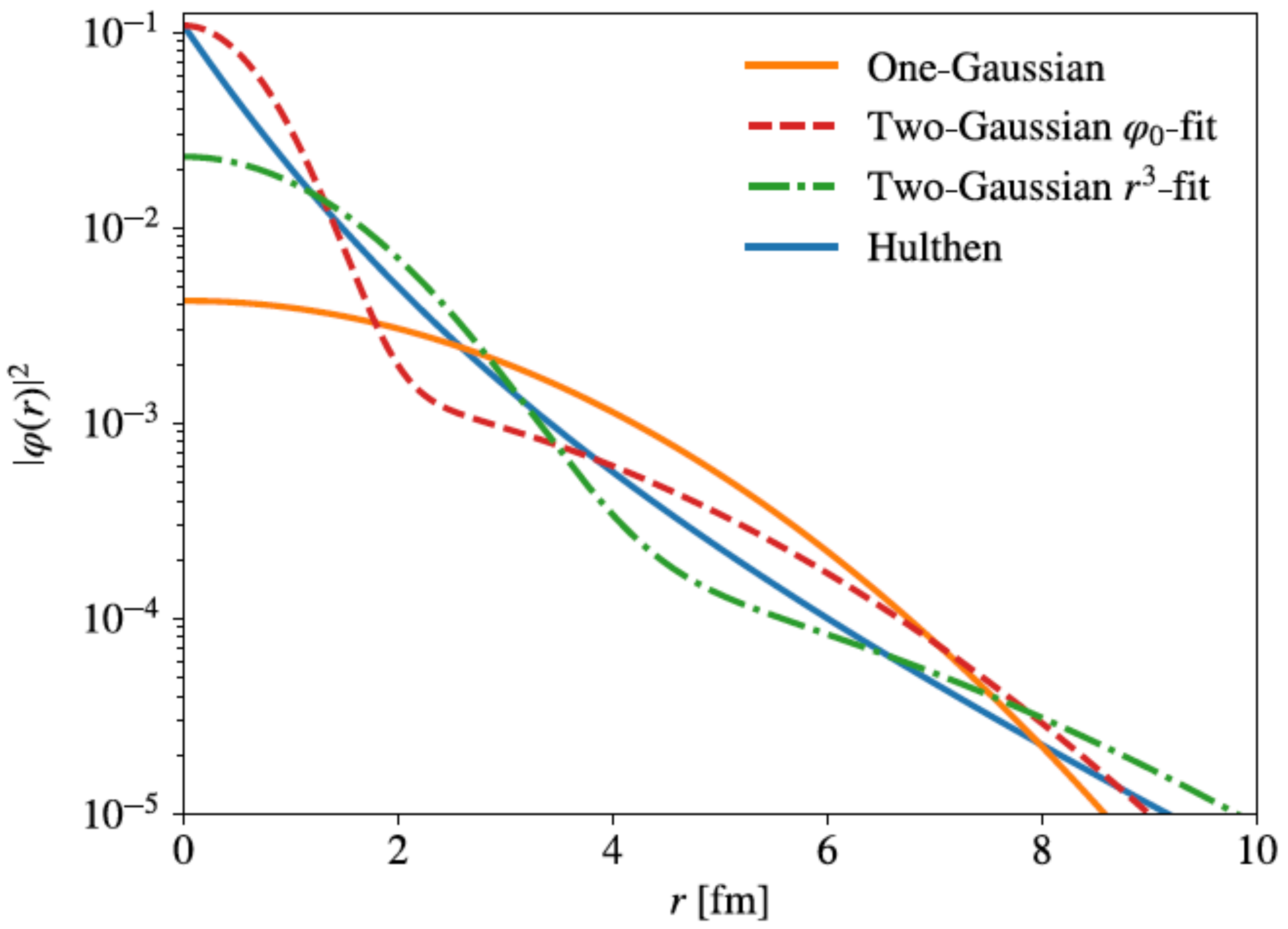
$$\varphi_{\rm d}(\boldsymbol{r}) = \left(\pi d^2\right)^{-3/4} \exp\{-\frac{r^2}{2d^2}\}$$

d = 3.2 fm

- Double Gaussian, $|\varphi_d(r)|^2$ fitted to Hulthen wave function:

$$\varphi_{\rm d}(\boldsymbol{r}) = \pi^{-3/4}\left[\frac{\Delta^{1/2}}{d_1^{3/2}}{\rm e}^{-r^2/(2d_1^2)} + {\rm e}^{{\rm i}\alpha}\frac{(1-\Delta)^{1/2}}{d_2^{3/2}}{\rm e}^{-r^2/(2d_2^2)}\right]$$

  - Fit to $|\varphi_d(0)|^2$, <r>, and <r²> (φ_0-fit):
    $\Delta = 0.581,\ d_1 = 3.979$ fm and $d_2 = 0.890$ fm
  - Fit to < r >, <r²> and <r³> (r³-fit):
    $\Delta = 0.247,\ d_1 = 5.343$ fm and $d_2 = 1.810$ fm



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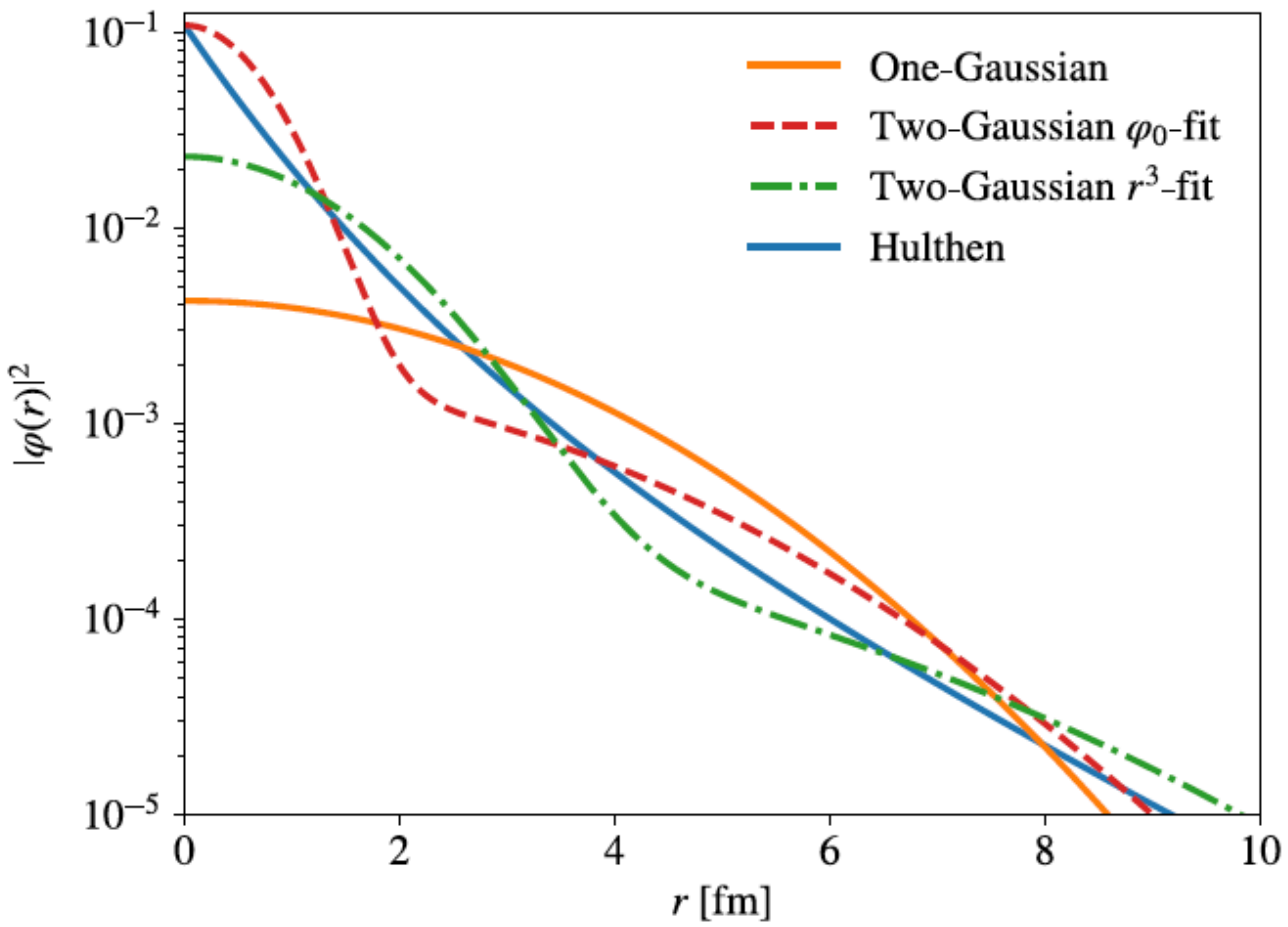

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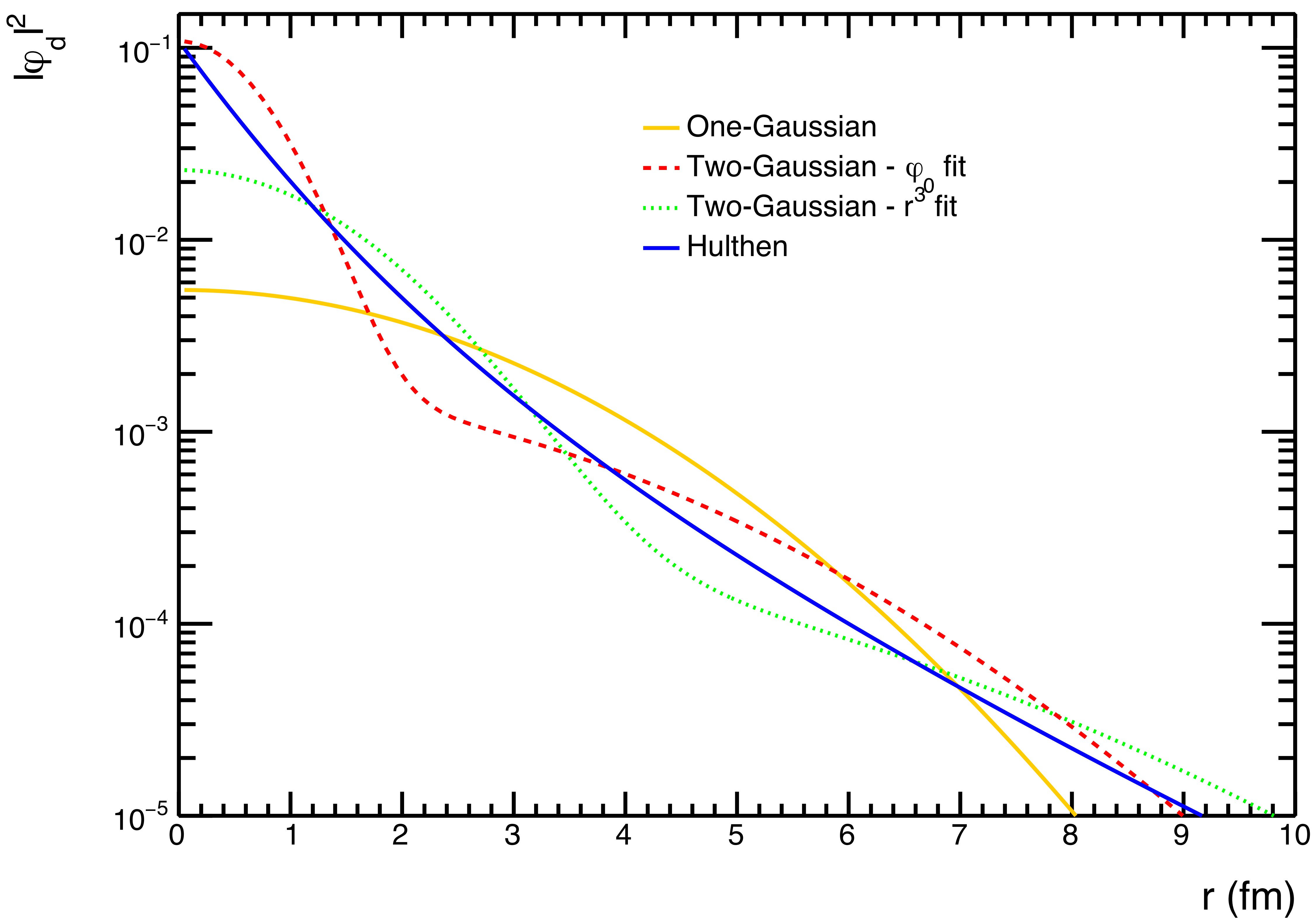

This work

Wigner approach

Kachelriess et. al., Eur. Phys. J. A (2020) 56:4

Coalescence probability

- Single Gaussian:

$$w = 3\zeta e^{-q^2 d^2} \quad \zeta \equiv \left(\frac{d^2}{d^2 + 4\sigma^2}\right)^{3/2}$$

$q = (\vec{p_n} - \vec{p_p})/2,$

d = rms of deuteron radius (3.2 fm),

- Double Gaussian, $|\varphi_d(r)|^2$ fitted to Hulthen wave function:

$$w = 3\left(\zeta_1 \Delta e^{-q^2 d_1^2} + \zeta_2 [1 - \Delta] e^{-q^2 d_2^2}\right)$$

- Fit to $|\varphi_d(0)|^2$, <r>, and <r^2> (φ_0-fit):
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- Fit to < r >, <r^2> and <r^3> (r^3-fit):
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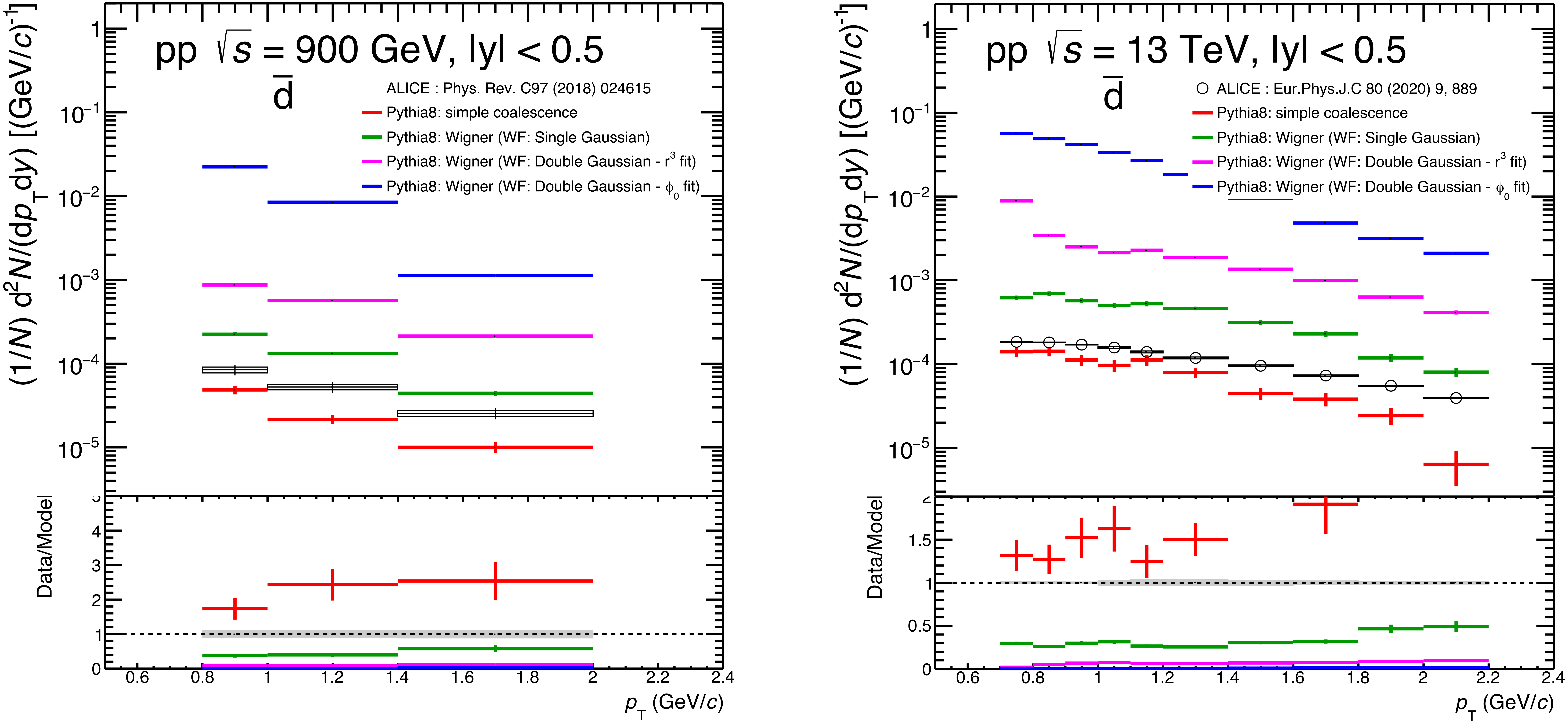
Source size:

- 1 fm fixed (for 900 GeV)
- r_0 vs. m_T from ALICE, PLB 811 (2020) 135849 (for 13 TeV)

Wigner approach



Backup