(Anti)helium production in pp collisions at $\sqrt{s}$ = 13.6 TeV

ALICE-ePIC meeting

27/11/2024

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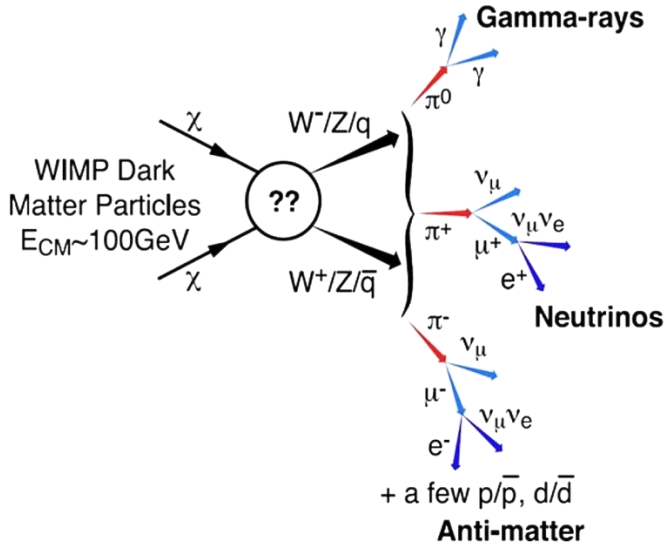
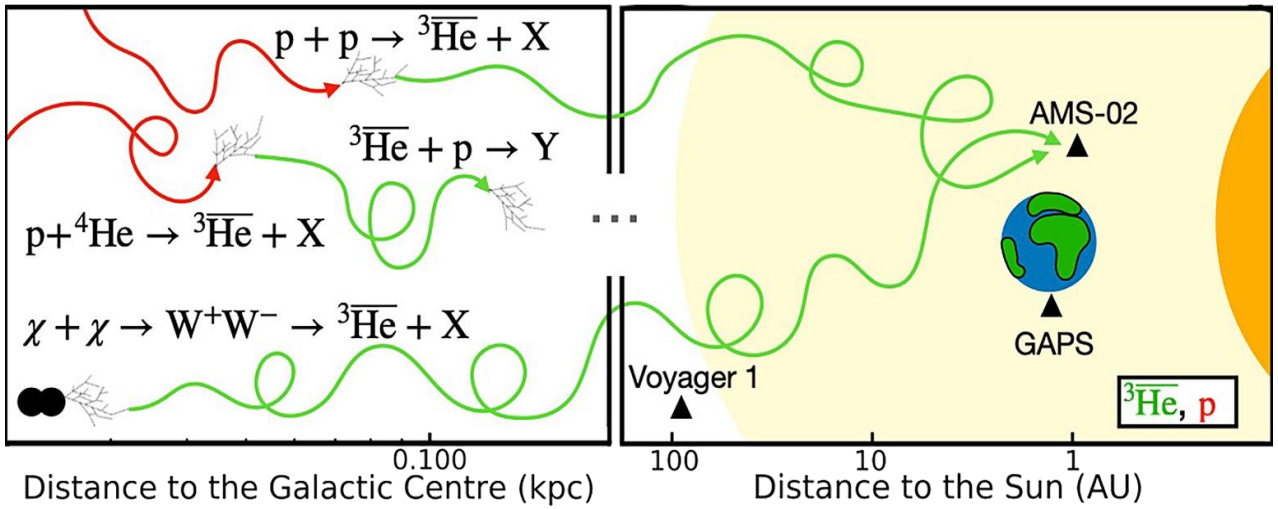
Physics motivation

Detection of antideuteron and antihelium nuclei in cosmic rays has been suggested as possible **smoking gun** for dark matter **WIMPs**, χ ($m_\chi \sim$ few GeV – few TeV)

- Antinuclei produced by $\chi\bar{\chi}$ **pair annihilation** or χ **decay** in the galactic halo
- **Low or no background from interactions of cosmic rays (CR)** with interstellar matter (ISM)
- Actively being investigated by space-based experiments as AMS-02 (ongoing) or GAPS (planned)





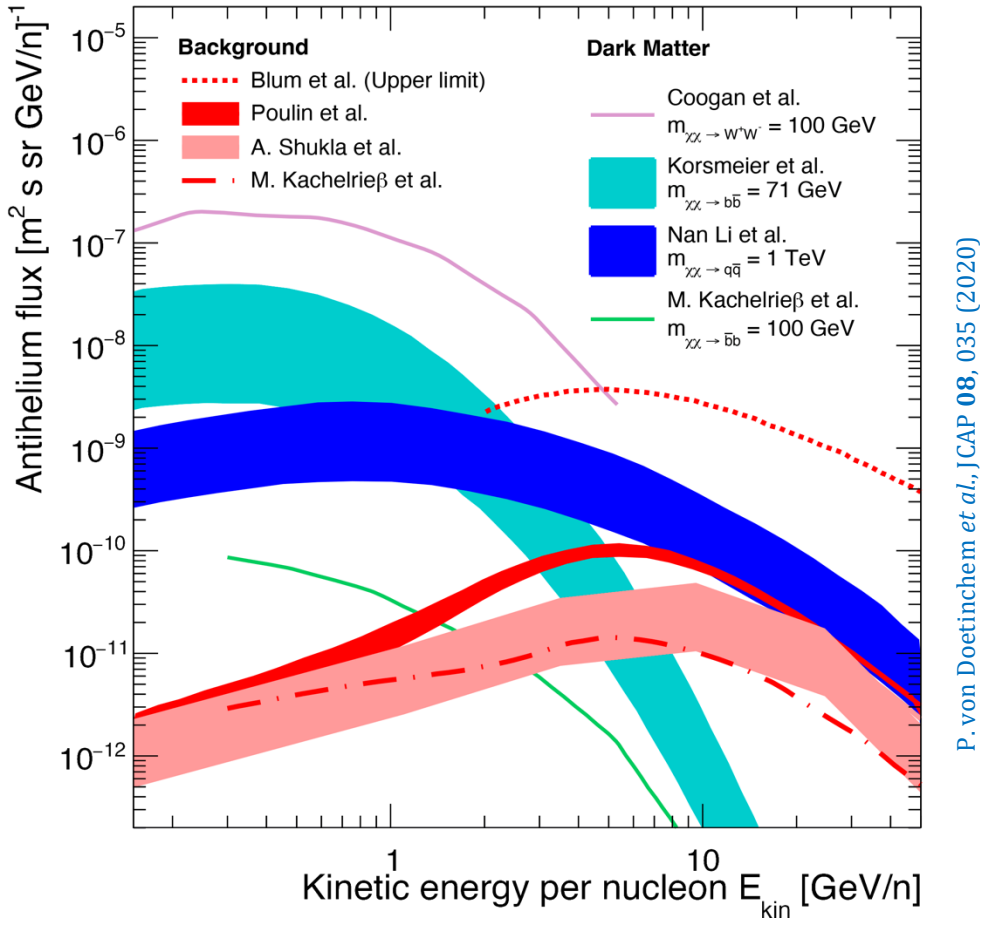
Physics motivation

What needs to be characterised?

- **DM signal**: DM source and processes
- **Background:** secondary CR from pp, p-A collisions in space

“Ingredients”:

- **Antiproton production cross section** constrained with measurements (*e.g. LHCb, AMBER, ...*)
- **Propagation** in the Galaxy and the heliosphere → parameters constrained from CR measurements
- Antinucleus **inelastic cross section** to account for **absorption** by ISM
- **Formation mechanism of antinuclei** → typically via **coalescence**



P. von Doetinchem *et al.*, JCAP **08**, 035 (2020)

Analysis rationale

- Custom calibration of TPC response (necessary for |z| > 1)

- (Anti)helium-3 identification with both TPC and TPC+TOF detector, in p_T = (1.5, 5.0) GeV/*c* range
  - **TPC PID**: signal extracted from $N\sigma_{TPC}$ (^{3}He) via signal function integration
  - **TPC+TOF PID**: $N\sigma_{TPC}$ (^{3}He) preselection and signal extracted from $\Delta m^2 = m^2_{TOF} - m^2_{He}$ via bin counting

- Correction for p_T shift, acceptance, efficiency and primary fraction (helium only) and normalisation for the number of events

- Integration of the corrected spectra to extract p_T-integrated d*N*/d*y* and compared with theoretical values and Run 2 spectra

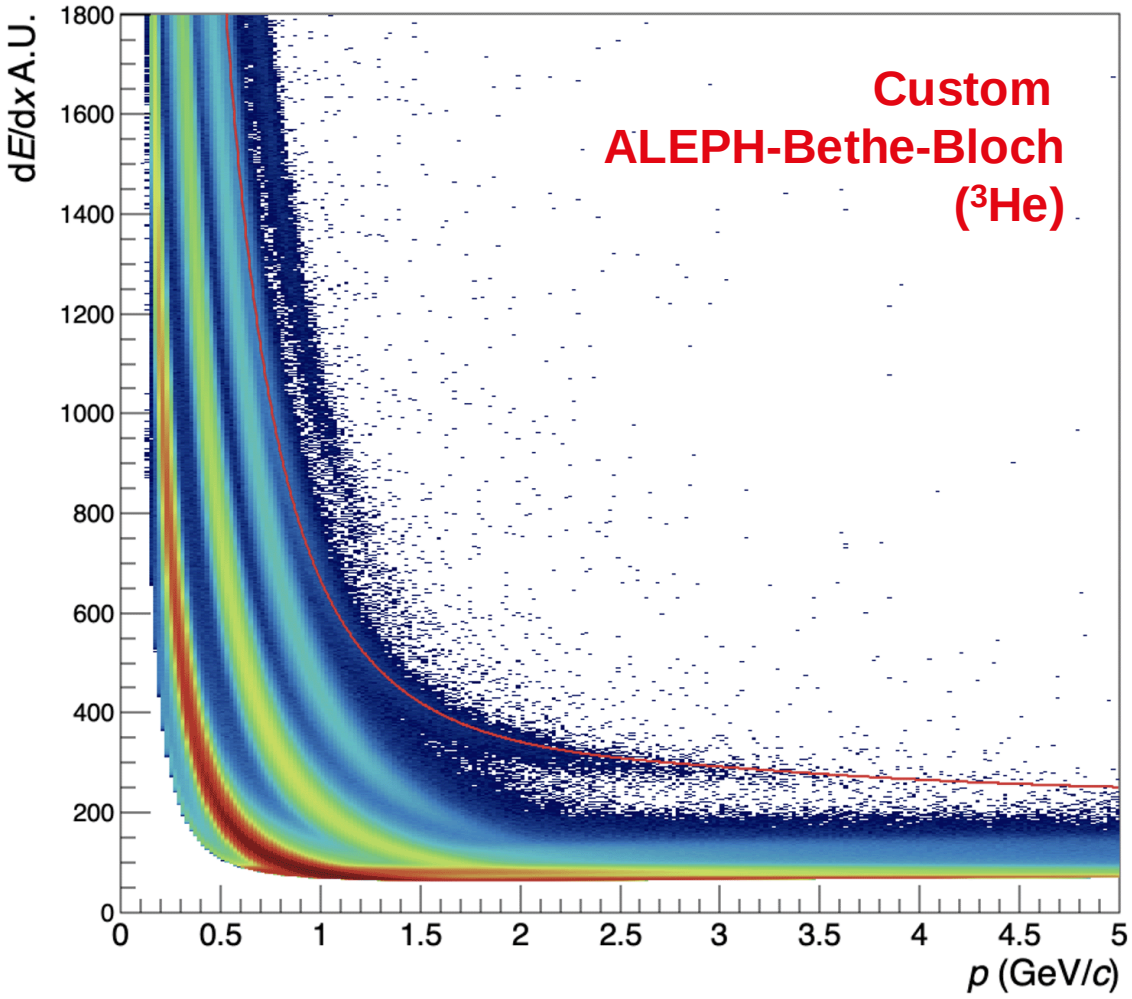
Event and track selection

- Datasets:
  DATA - LHC22_pass4_highIR
  MC - LHC23k4f – Anchored to LHC22o (pass4), **GP**
  - LHC23j6b – Anchored to LHC22_pass4, **w/(anti)(hyper)nuclei injection**

- Event selection:
  O2 Sel8 filterbit (TVX + TF + ITS ROF cuts) + $|V_z| < 10$ cm
  $N_{ev} = 4.63 \times 10^{11}$

- Track selection:
  O2 isGlobalTrackWoDCA filterbit
  + ITSibHit > 1 + $N_{ITS}^{CLS} \geqslant 6$ + $N_{TPC}^{CLS} > 120$ + $\chi^2_{TPC} < 4$ + $\chi^2_{ITS} < 36$ + $R_{TPC} \geqslant 0.8$
  + $|DCA_{xy}| < 4 \times 10^{-4} + 1.3 \times 10^{-2}/p_T$ + $|DCA_z| < 0.5$ cm +
  + $|\eta| < 0.8$ + $|y| < 0.5$

TPC response calibration



- ALEPH-Bethe-Bloch parametrization

$$f(\beta\gamma) = \frac{P_1}{\beta^{P_4}}\left[P_2 - \beta^{P_4} - \ln\left(P_3 + \frac{1}{(\beta\gamma)^{P_5}}\right)\right]$$

Needed for (anti)helium-3 response

- After calibration,
  $< \mu\ N\sigma_{TPC} > \approx 0$
  $< \sigma\ N\sigma_{TPC} > \approx 1$

TPC signal extraction

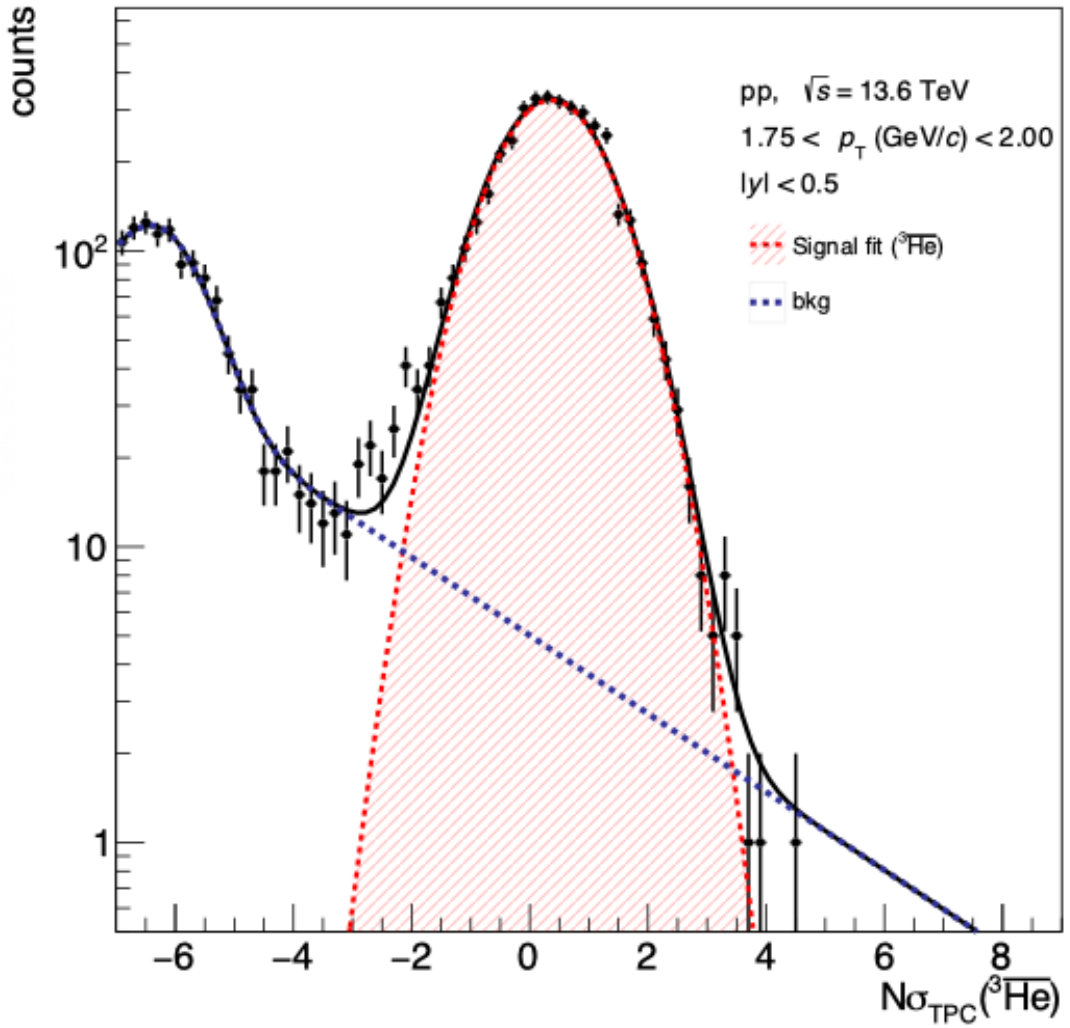
- Nσ fit w/
  f = Signal + Background

  Signal: AsymmGauss

$$S(x;N,\mu,\sigma,n) \propto N \begin{cases} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] & \text{for } x \leq \mu + n\sigma \\ \exp\left[-n\left(\frac{x-\mu}{\sigma} - \frac{n}{2}\right)\right] & \text{for } x > \mu + n\sigma \end{cases}$$

  Background:
  - **^{3}He:** AsymmGauss(d) + AsymmGauss(alpha) + Expo
  - **$^3\overline{\text{He}}$**: AsymmGauss(d) + Expo

- Signal integrated in $(-5\sigma + \mu,\ 5\sigma + \mu)$



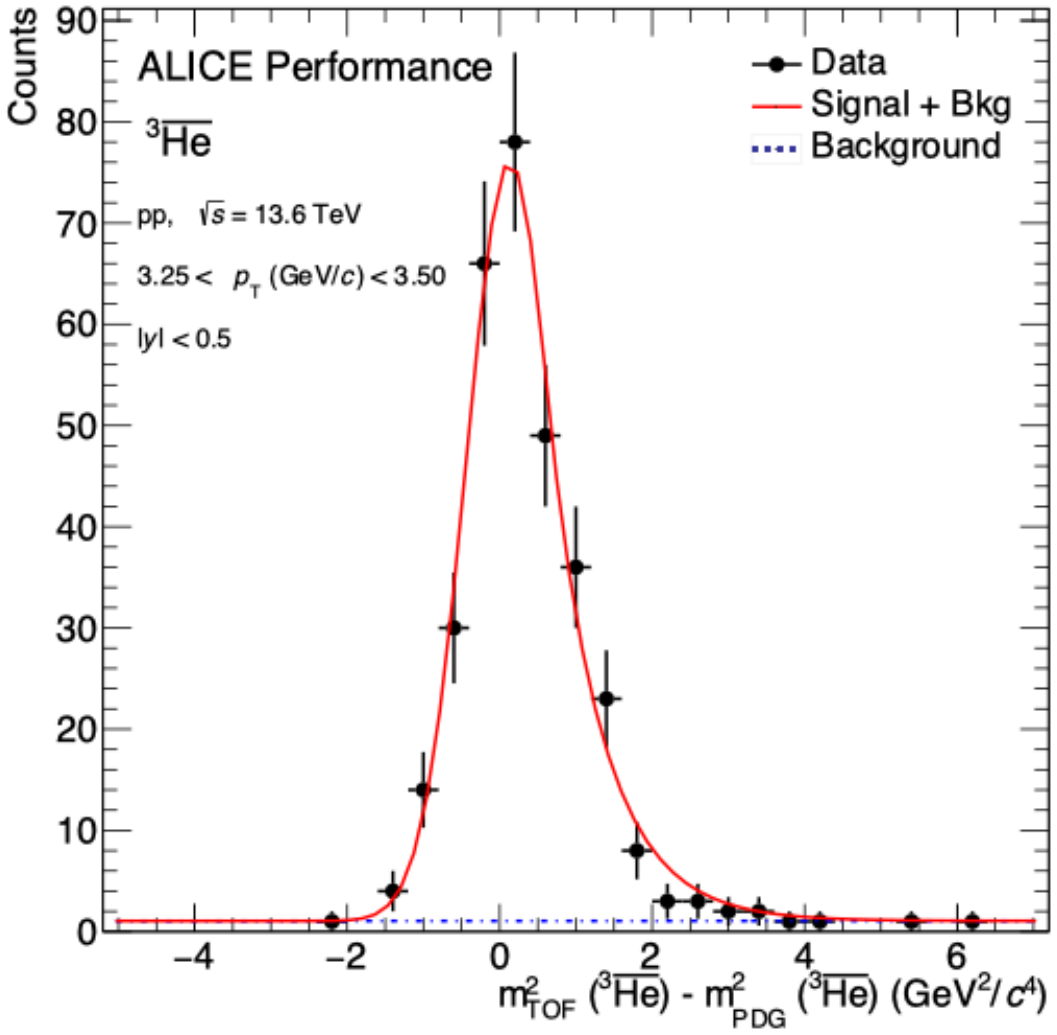
TPC+TOF signal extraction

- Preselection in $N\sigma_{TPC}(^3He) = (-5, 5)$

- Nsigma fit w/
  f = Signal + Background

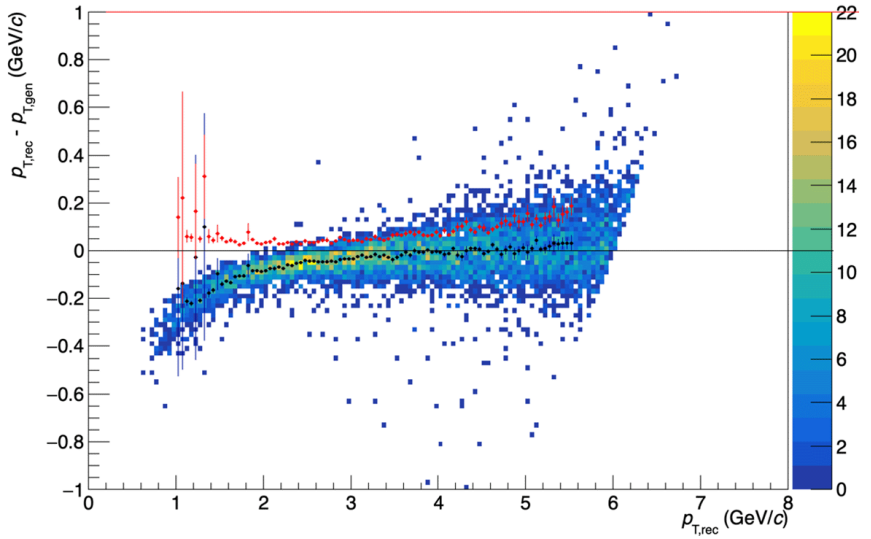
  Signal: AsymmGauss
  Background: Pol1

- Signal extracted in
  $(-5\sigma + \mu,\ 5\sigma + \mu)$
  via bin counting

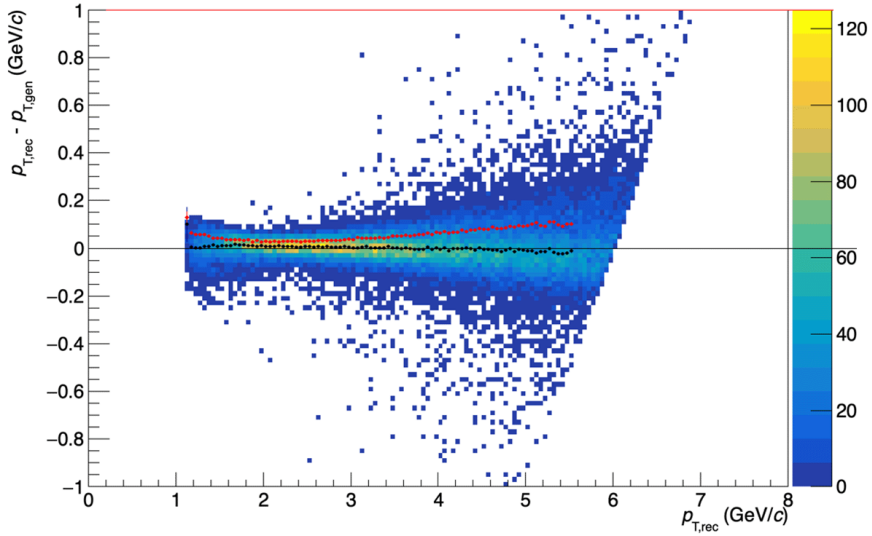


p_T–shift correction

Before



After

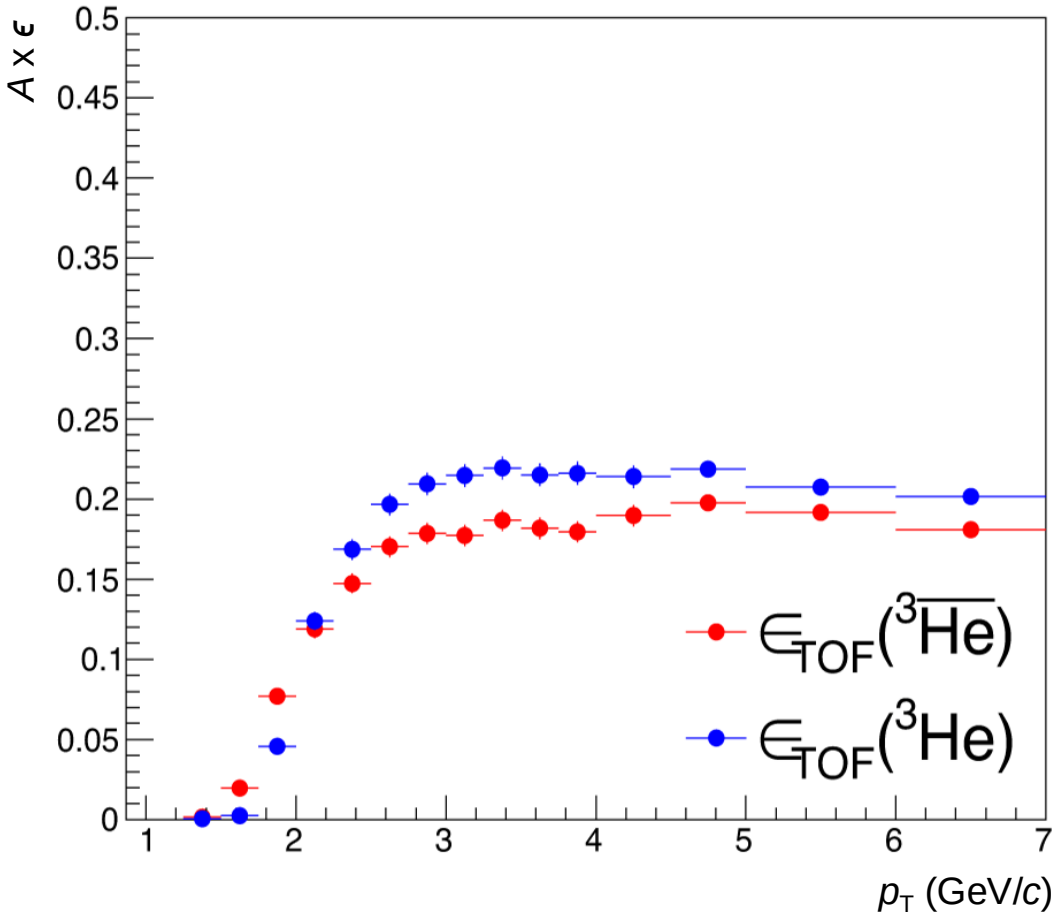


- $p_{T,rec}$ - $p_{T,gen}$ vs $p_{T,rec}$ distribution is fitted with

$$f = Ae^{B+Cx} + D + Ex$$

- The parameters extracted from fit are used to recalibrate the p_T values for the (anti)helium candidates
  - The p_T–shift mean values after the calibration are centred around 0

Acceptance x efficiency correction



- Needed to account for the undetected and untracked particles

$$(A \times \epsilon)(^3\mathrm{He}) = \frac{\#\ \mathrm{rec.}\ ^3\mathrm{He}, |y| < 0.5}{\#\ \mathrm{gen.}\ ^3\mathrm{He}, |y| < 0.5}$$

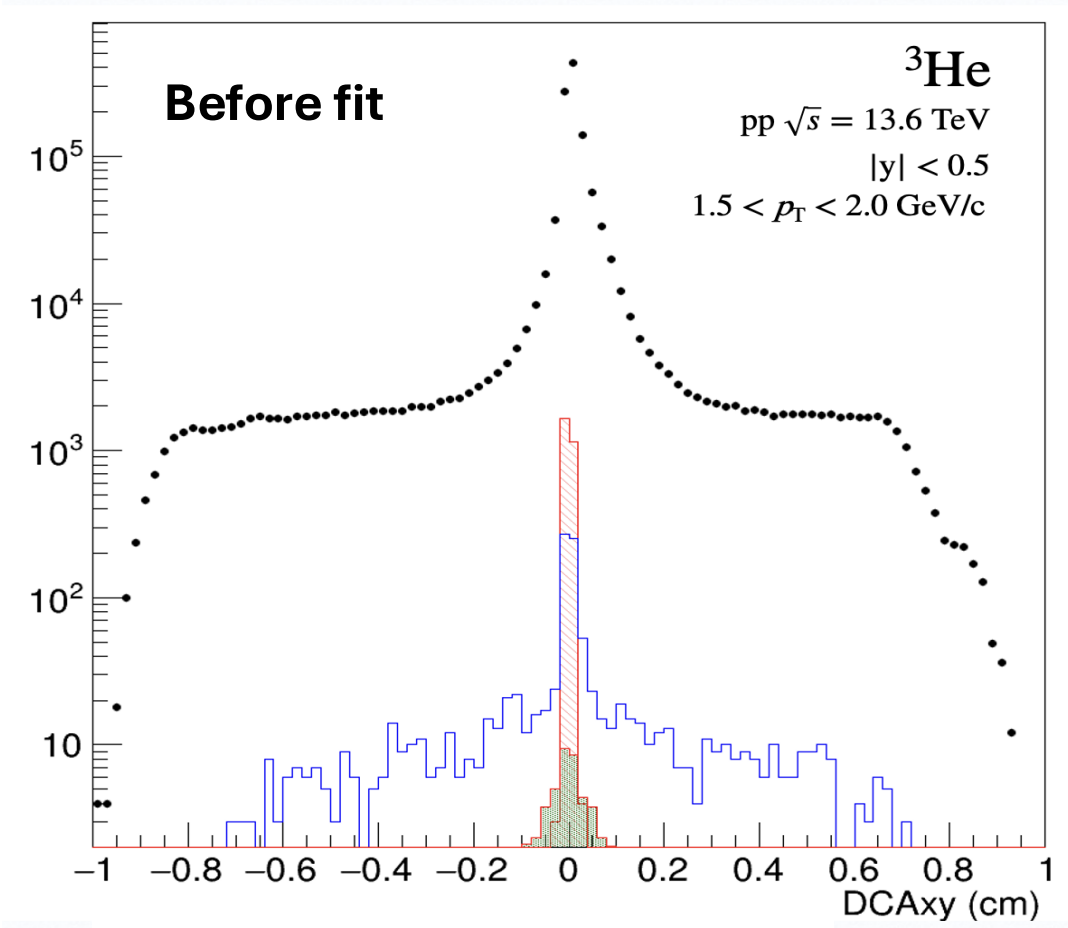
- Estimated using the MC w/ injection
  Same cuts used for the data
- Used to correct TPC and TPC+TOF raw spectra

Primary fraction correction (for helium)

- Needed to account for **secondary helium** contamination
- Estimation based on DCA_{xy} distribution fit

- Primary template from MC w/inj.
- Secondary template from GP MC
- Weak decay template from MC w/inj., scaled by w_{weak} (≈ 8.5 x 10^{-3})

$$w_{\text{weak}} = \frac{\mathrm{d}N/\mathrm{d}y(^3_\Lambda H)}{\mathrm{d}N/\mathrm{d}y(^3\mathrm{He})} \times \mathrm{B.R.}(^3_\Lambda\mathrm{H} \rightarrow {}^3\,\mathrm{He}\,\pi)$$



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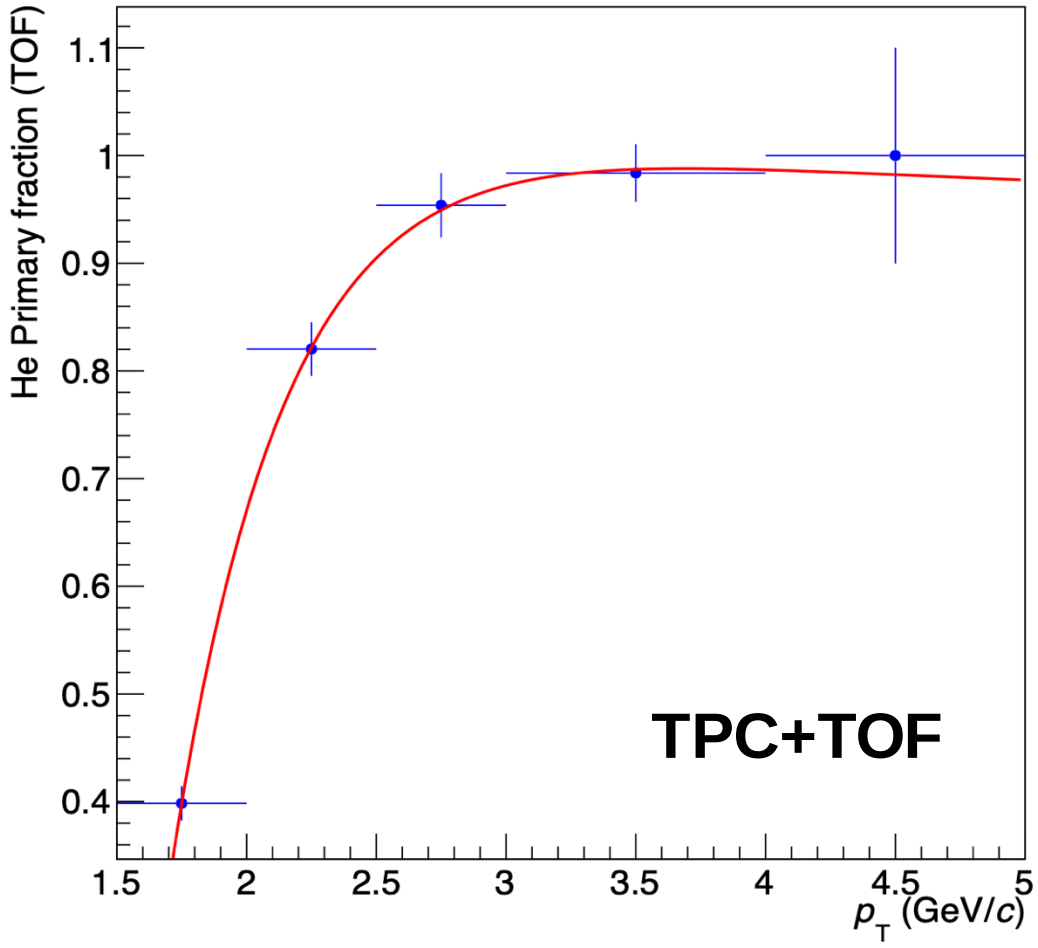
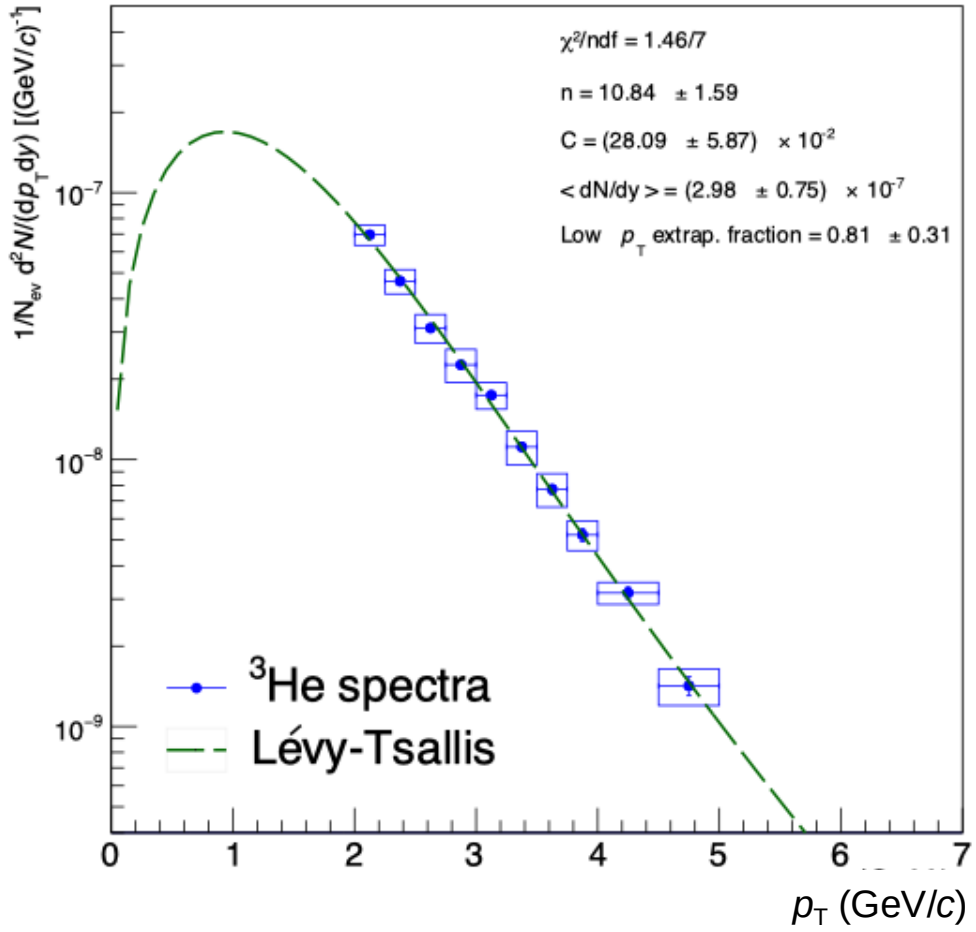
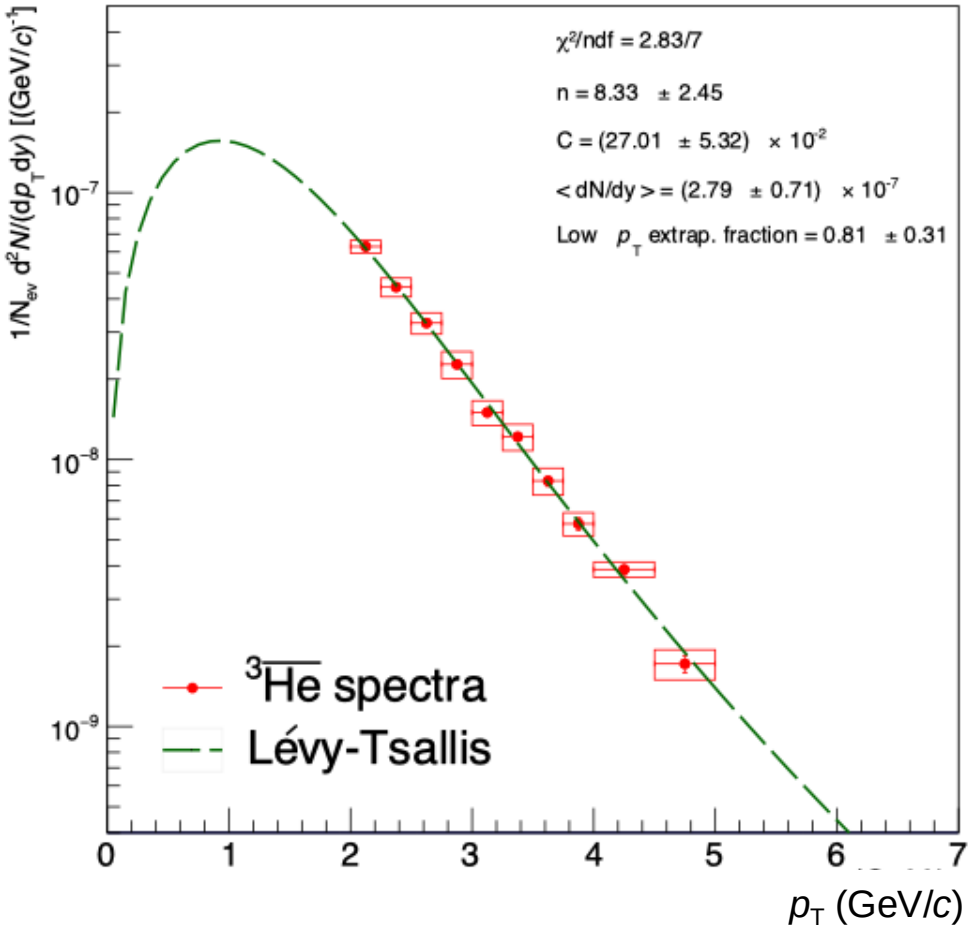


Results - Corrected spectra

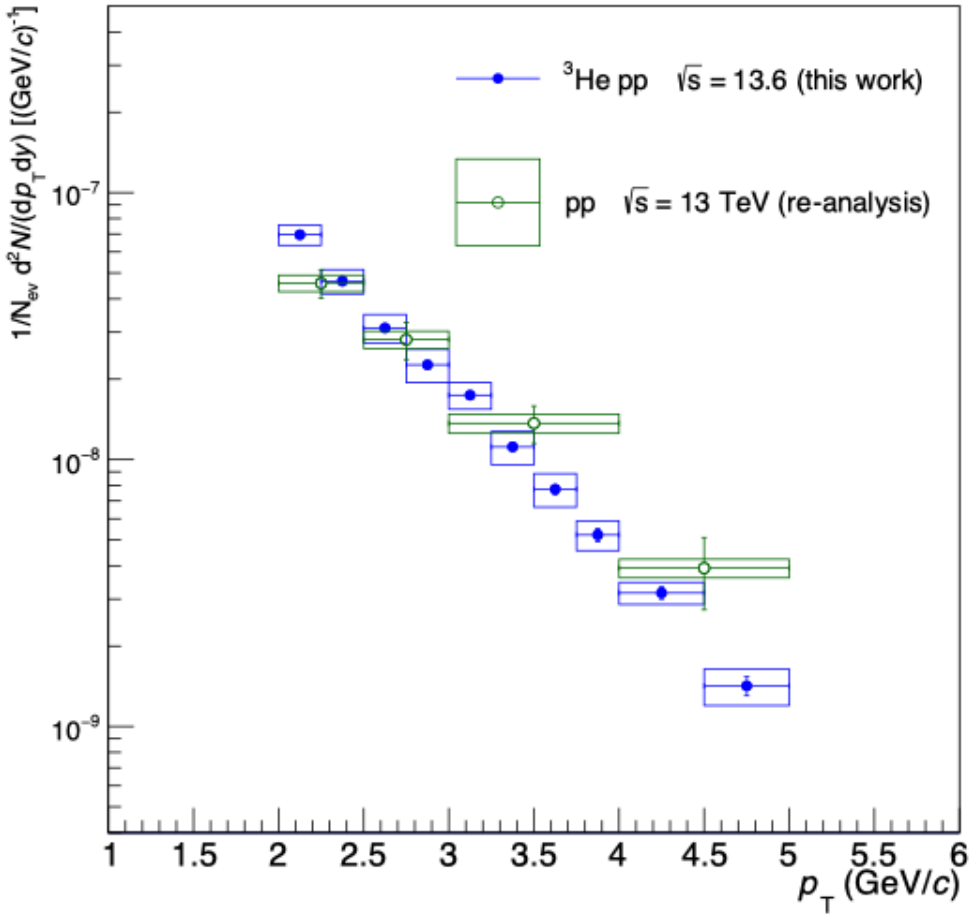
Average of TPC/TPC+TOF, fit w/ Lévy-Tsallis function

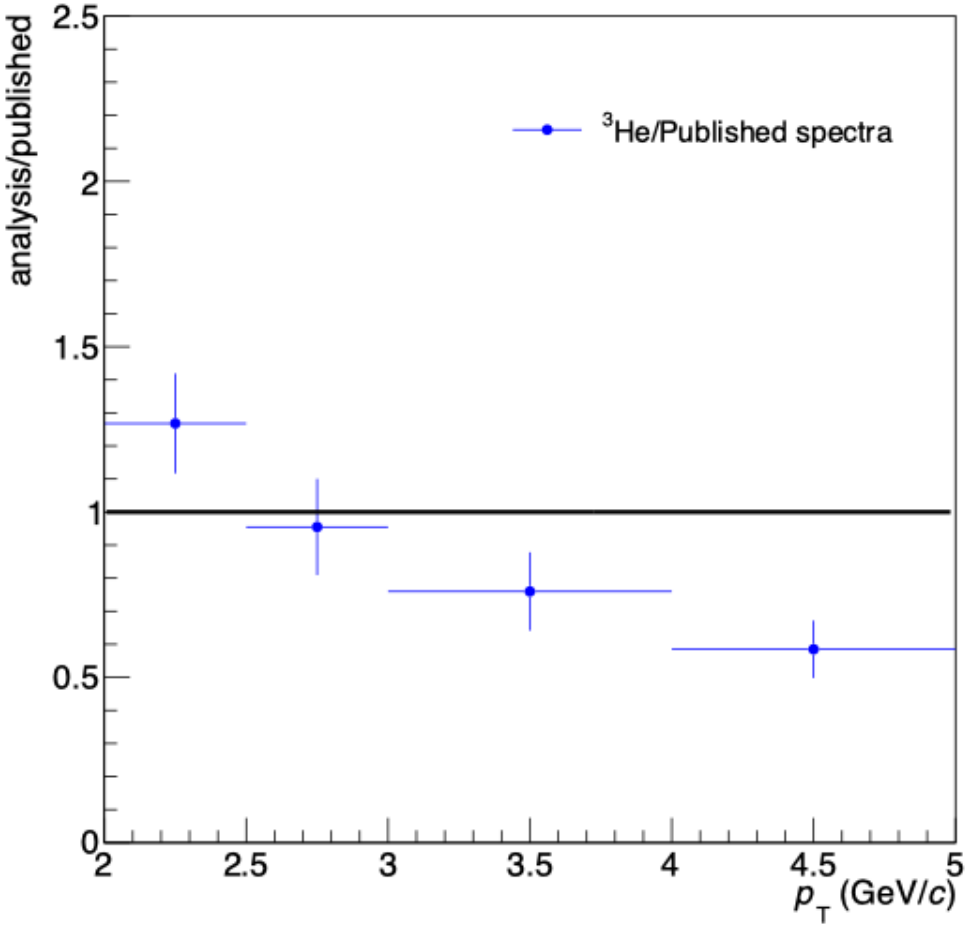




Results - Corrected spectra (helium)

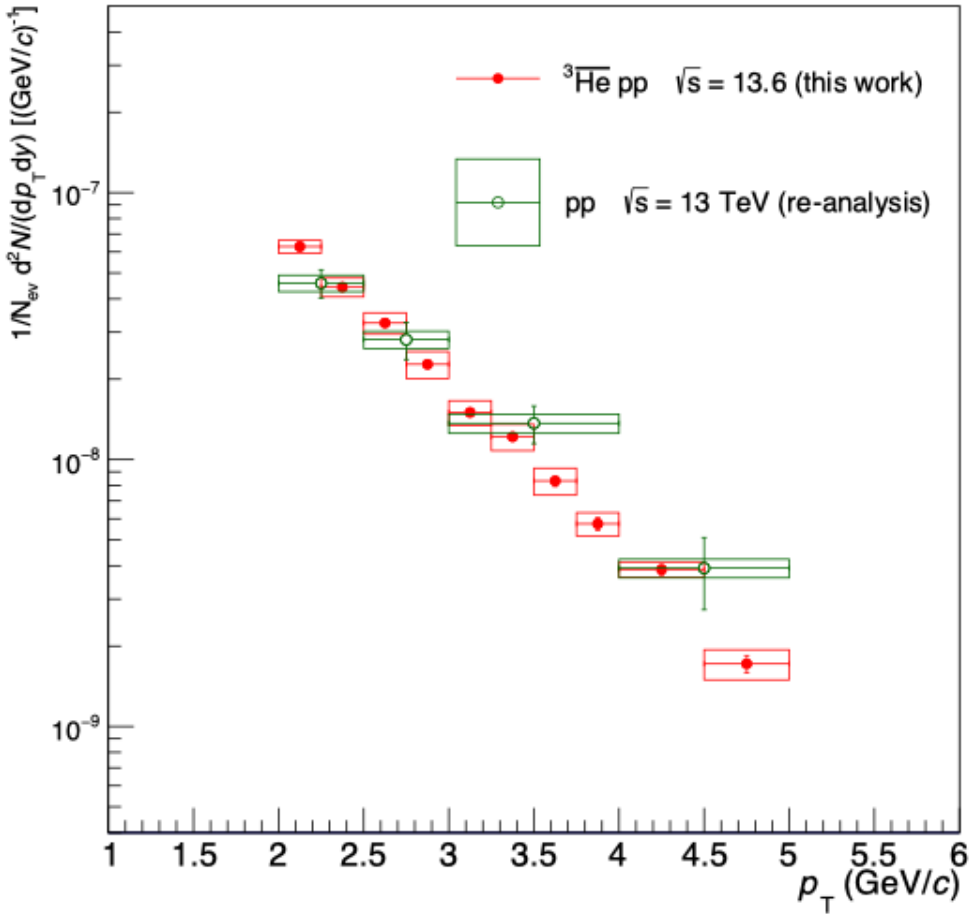
Comparison w/ Run 2 pp $\sqrt{s}$ = 13 TeV

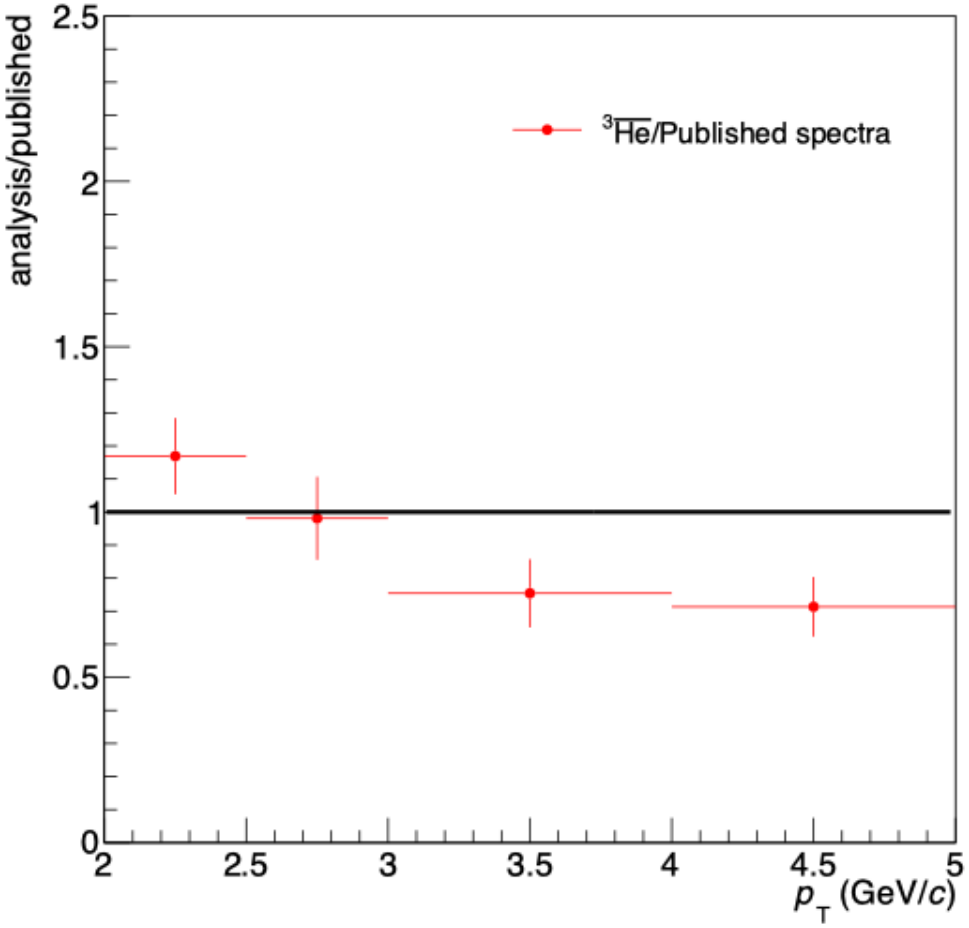




Results - Corrected spectra (anti-helium)

Comparison w/ Run 2 pp $\sqrt{s}$ = 13 TeV





Results – Integrated yield

TYPE	SPECIES	ENERGY	<d*N*/d*y*>	# σ wrt this work
This work Measured (Run3)	$^{3}\mathrm{He}$	13.6 TeV	(2.98 ± 0.28 ± 0.75) x 10^{-7}	/
This work Measured (Run 3)	$^{3}\overline{\mathrm{He}}$	13.6 TeV	(2.79 ± 0.25 ± 0.54) x 10^{-7}	/
Measured (Run 2)	$\frac{^{3}\mathrm{He} + ^{3}\overline{\mathrm{He}}}{2}$	13 TeV	(2.4 ± 0.3 ± 0.4) x 10^{-7}	<1
Thermal-FIST, V = V_c	$\frac{^{3}\mathrm{He} + ^{3}\overline{\mathrm{He}}}{2}$	13.6 TeV	2.76 x 10^{-7}	< 1
Thermal-FIST, V = 1.6 V_c	$\frac{^{3}\mathrm{He} + ^{3}\overline{\mathrm{He}}}{2}$	13.6 TeV	9.16 x 10^{-7}	> 5

Conclusion… and next steps

- **Exciting preliminary results**, compatible with both Run 2 data and theoretical prediction
- The analysis is being extended to **2023 and 2024 pp data** (largest dataset ever)
- Systematics partially **inherited from Run 2** studies and estimated using the **anti-helium spectra only**
  - To be improved differentiating **charge dependent** contributes
- **Primary fraction** estimation must be improved (fit not always consistent, empty bins, weak decay approx to 0)
- Event and track selection will be reconsidered (e.g. DCA cuts)

Thanks for your attention