



ALICE

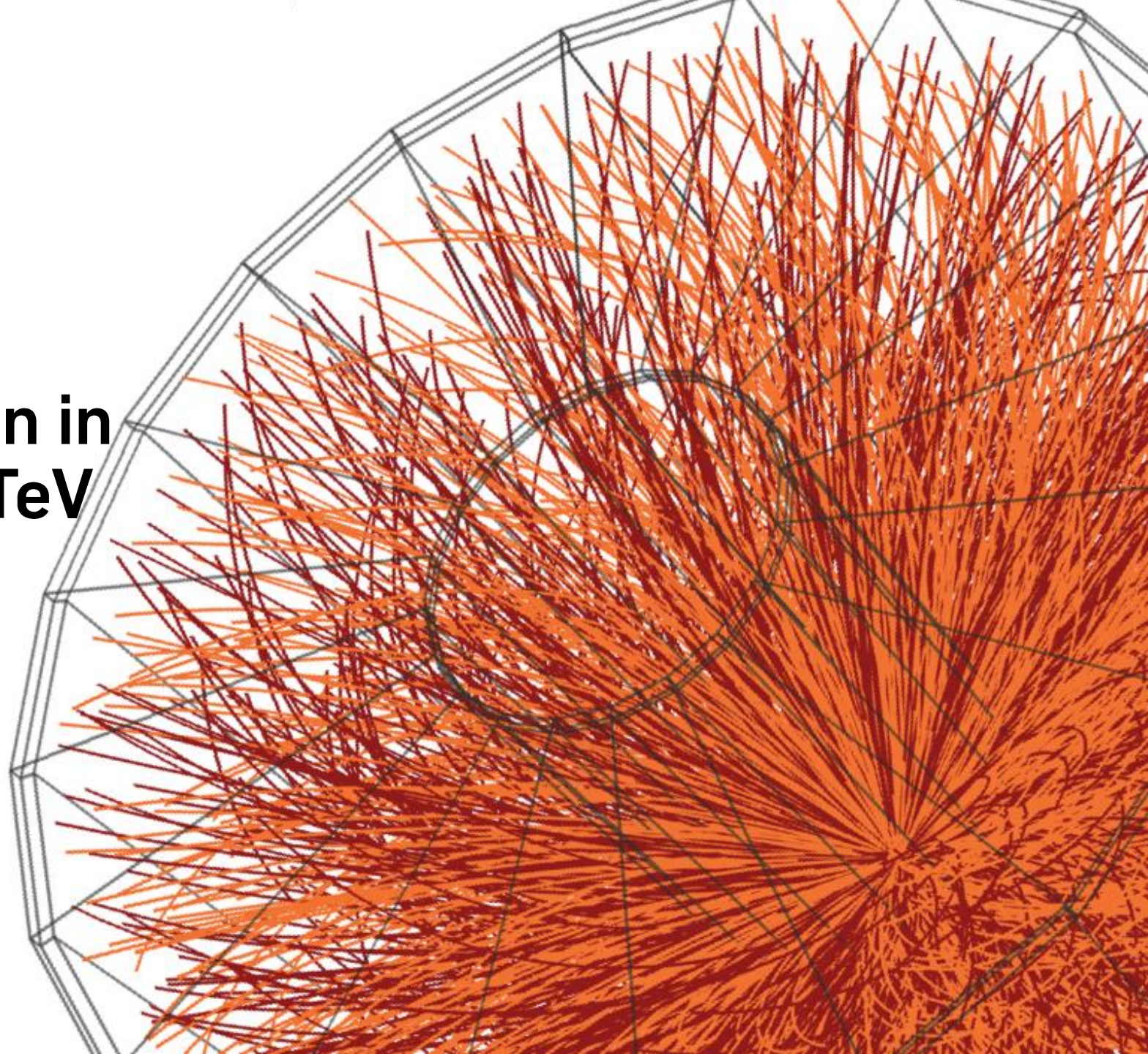
Light nuclei production in Pb-Pb collisions at 5 TeV

with Annual Report 2021

Bong-Hwi Lim (Pusan National University)

KoALICE National Workshop

05/01/2022



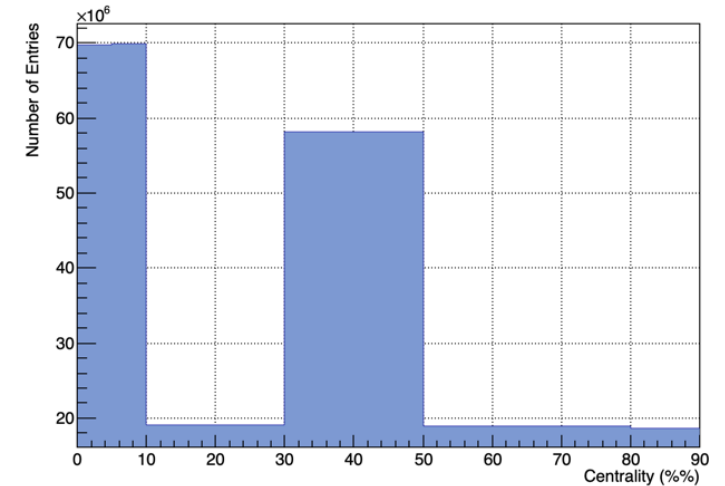
Annual Progress

- **Return from CERN at Apr.2021**
 - Stayed from Apr.2018
- **Hyperon Resonance Paper in IRC2 round**
 - Multiplicity dependent $\Sigma^{*\pm}$ and Ξ^{*0} production in pp collisions at 13 TeV
 - Target: QM2022
- **Light Nuclei Production in Pb-Pb collisions at 5.02 TeV**
 - Approved in PF for paper (21/10/2021)
 - First draft under preparation
 - Details in this talk.
- **PhD defense done in 16/12/2021**
 - **Title:** Study on Hadron Phase via Hyperon Resonance and Light Nuclei Produced in Elementary and Heavy ion collision
 - **PhD Advisory Committee:** Rene Bellwied*, Luciano Musa, Su Hounng Lee, Sanghoon Lim, In-Kwon Yoo

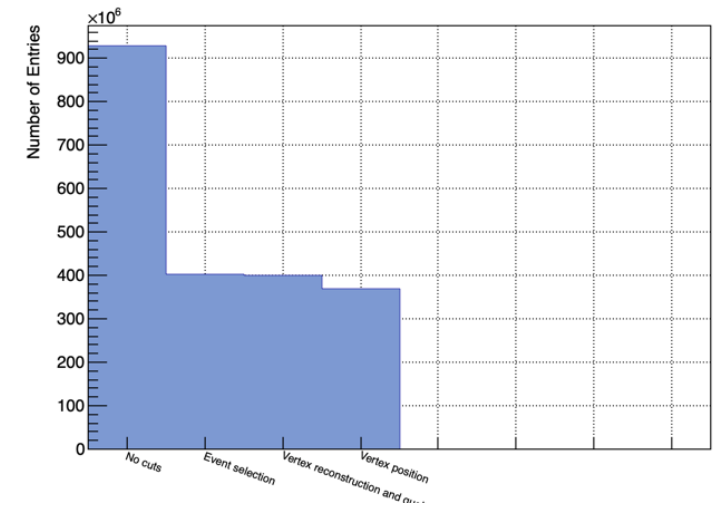
(Anti-)deuteron and (Anti-)³He production in Pb-Pb at 5 TeV

Data Sample and Event Selection

- LHC18qr Pass3 data, total ~360M events used.
- LHC20g7{a, b, c} MC used (G4, 20 nuclei injected per events)
+ **General Purpose MC** for the secondary templates
+ LHC17d5ab for Systematics (Material Budget)
- Runlist: DPG_CentralBarrel_HadronPID
- Event Cut: Used AliEventCuts Class
- Trigger: MB+Central+Semi-Central

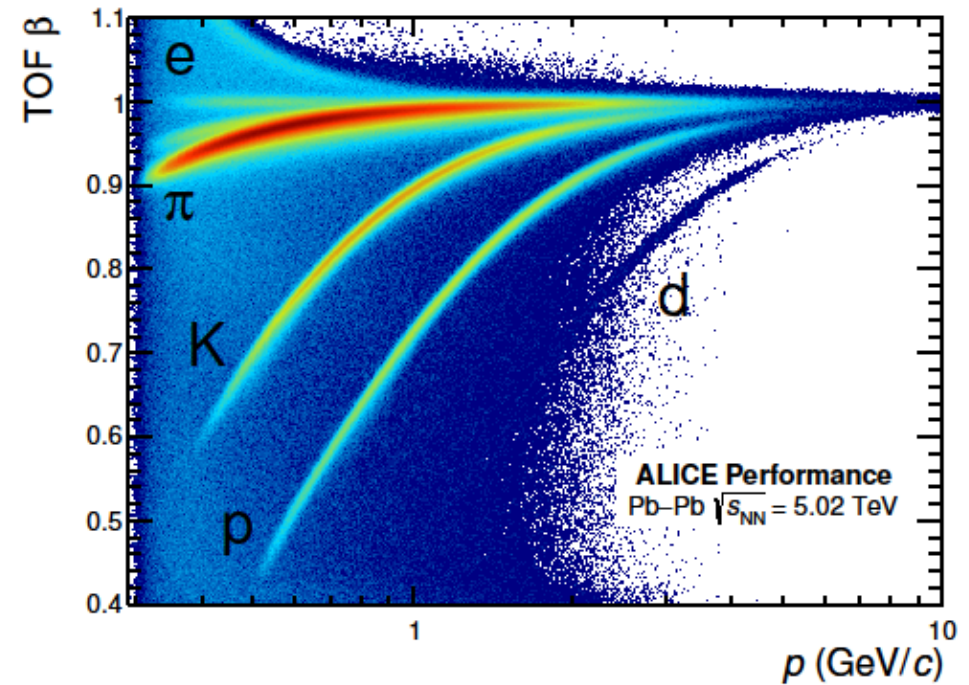
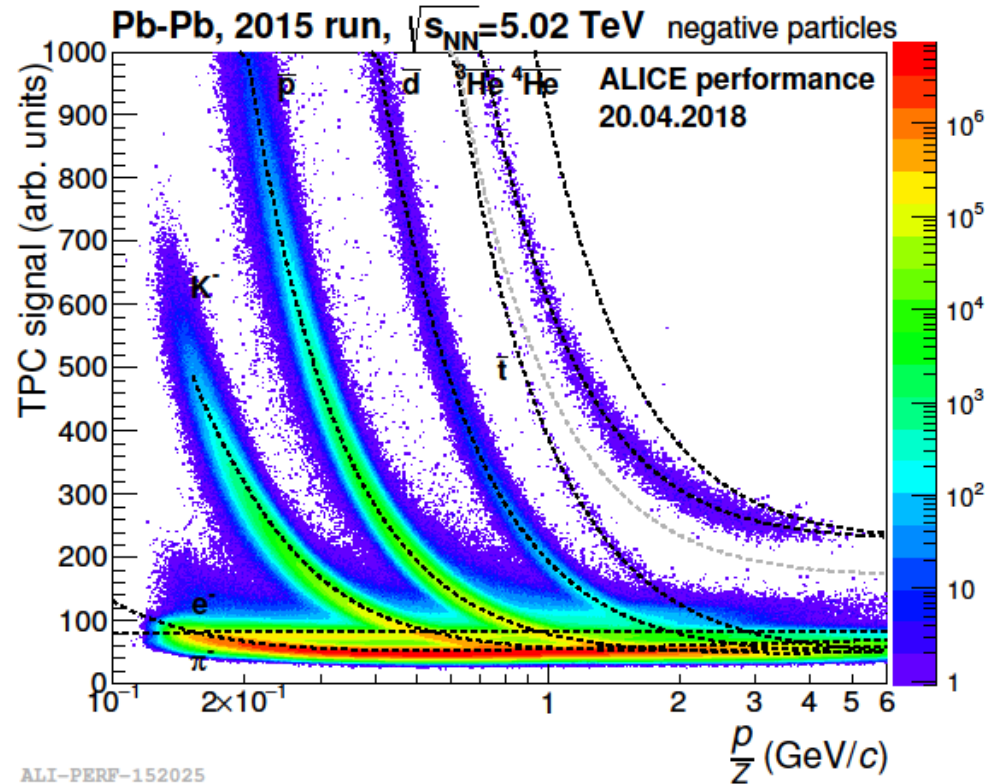


Centrality distribution



Event Selection

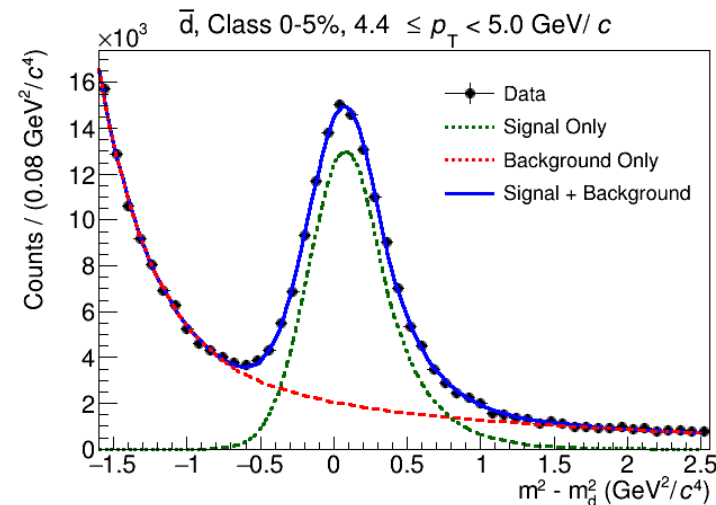
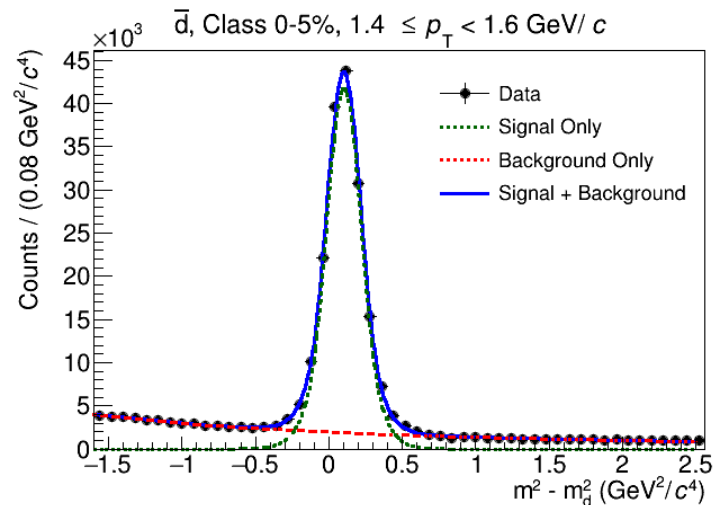
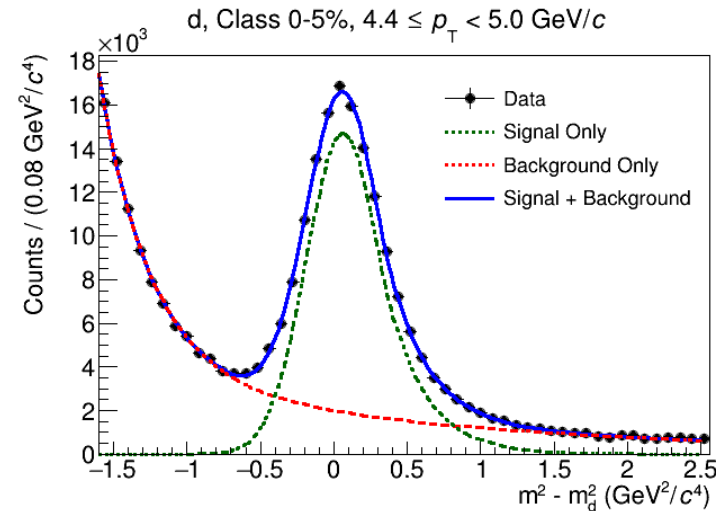
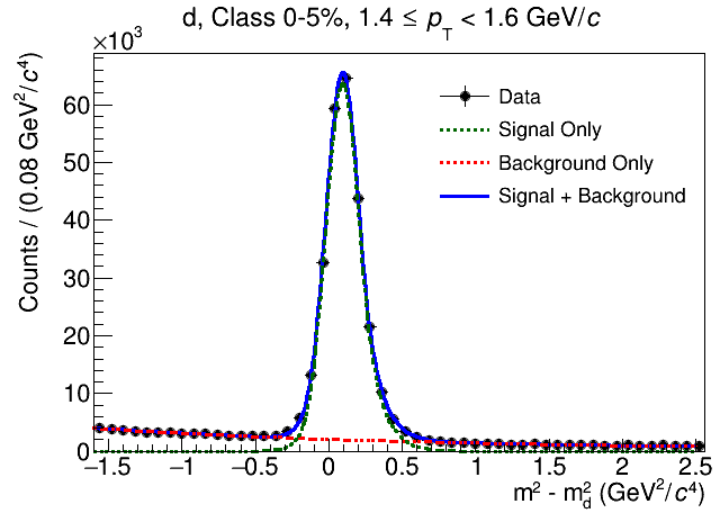
Particle Identification



ALI-PERF-106336

- Deuteron: TPC preselection + TOF PID
- ^3He : TPC PID + tracking PID

Signal extraction: (Anti-)deuteron

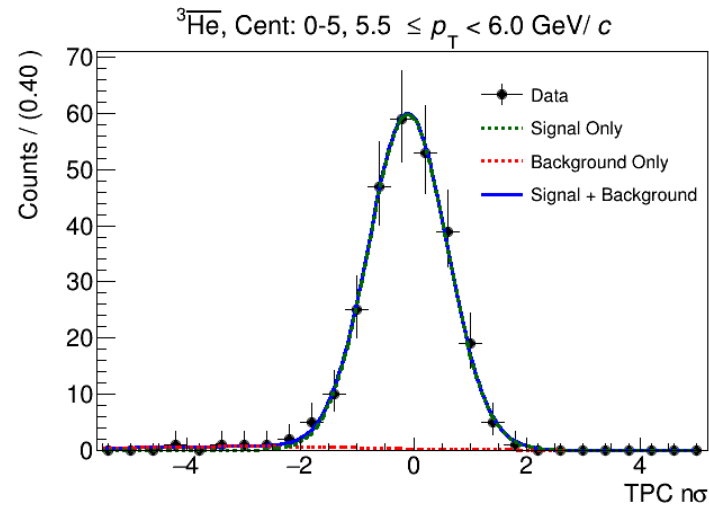
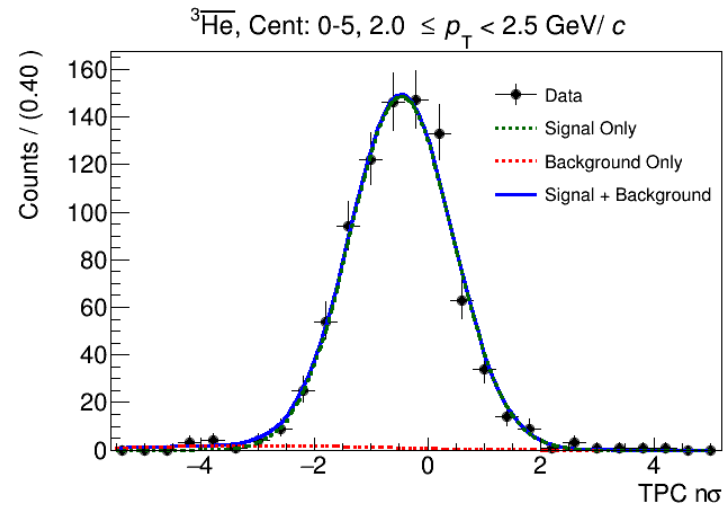
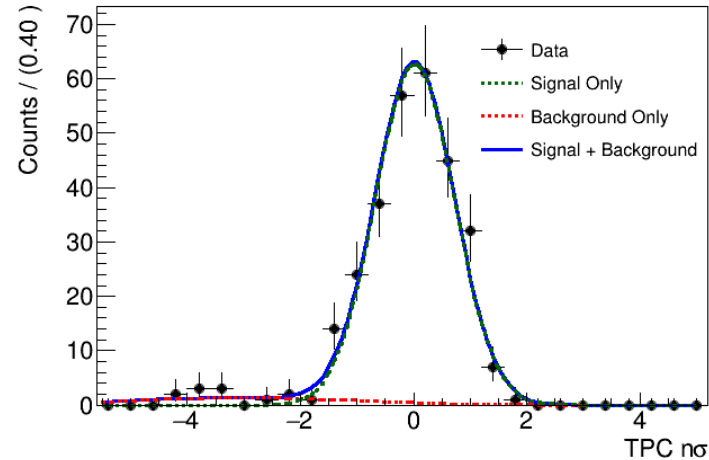
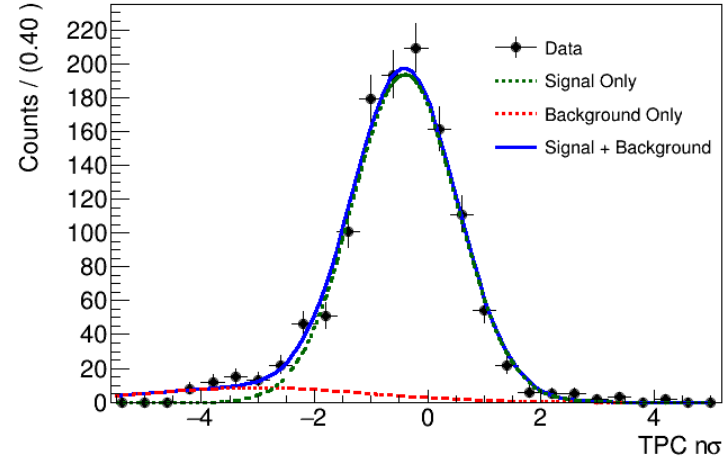


- Fit to the $m^2_{\text{TOF}} - m^2_{\text{PDG}}$ distribution
 - Gaussian + single tail for the signal
 - Double exponential for the background
 - The yield and its statistical uncertainty come directly from the fit
- Cut of 3σ PID in TPC
- Covered range: $1.0 < p_T < 6.0$ GeV/c (most central)

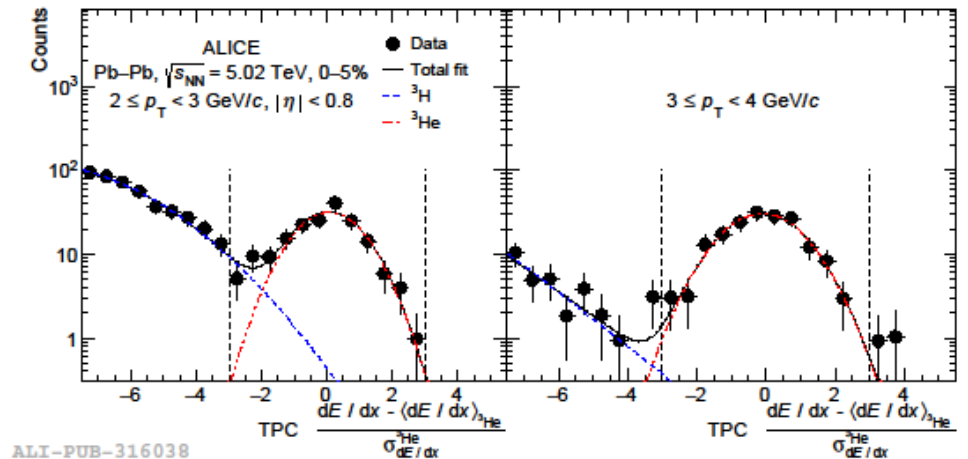
Signal extraction: (Anti-)³He

³He, Cent: 0-5, $2.0 \leq p_T < 2.5$ GeV/c

³He, Cent: 0-5, $5.5 \leq p_T < 6.0$ GeV/c

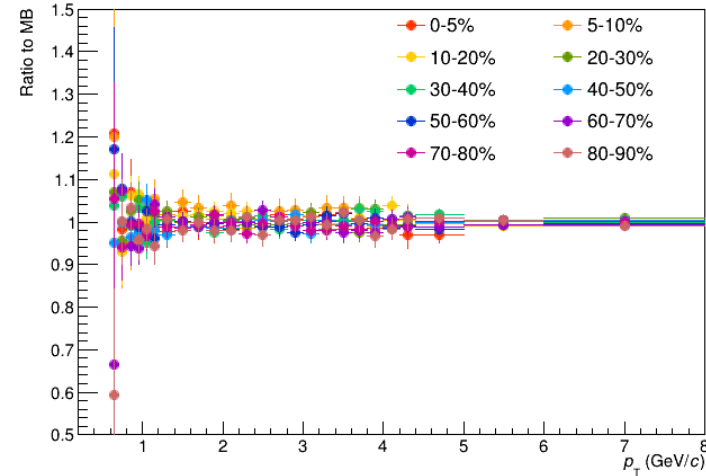
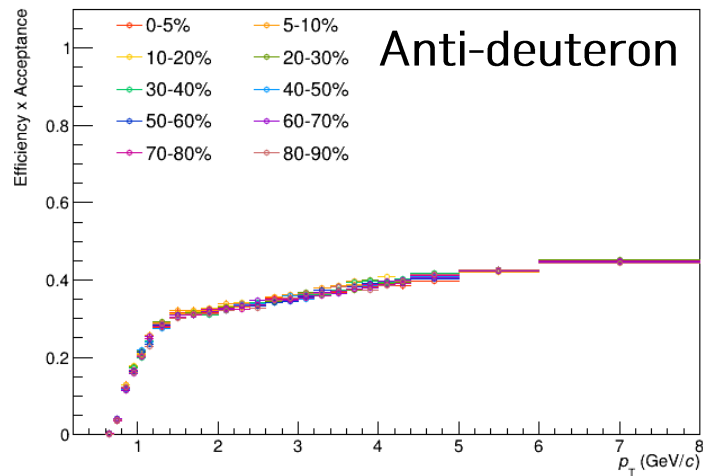
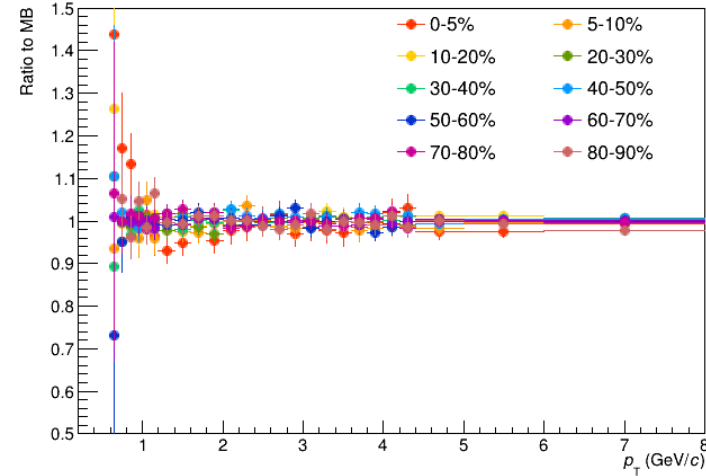
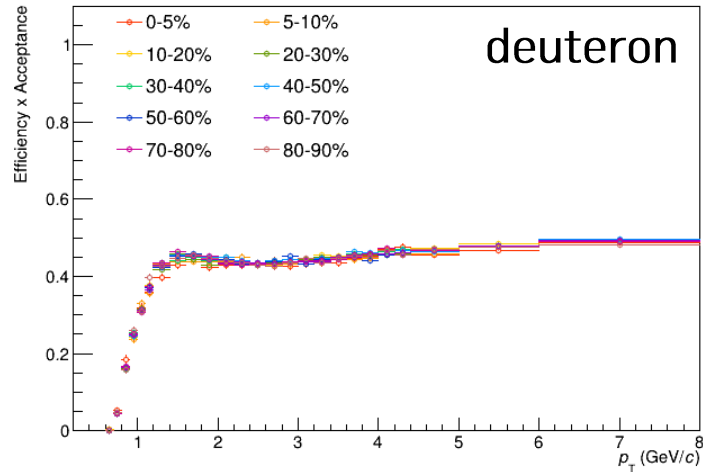


- Fit to the $m^2_{\text{TPC}} - m^2_{\text{PDG}}$ distribution
 - Tracking PID 3σ cut applied \rightarrow contamination from secondary 3H at “low p_T ” is successfully suppressed.
- Covered range: $2.0 < p_T < 7.0$ GeV/c (most central)



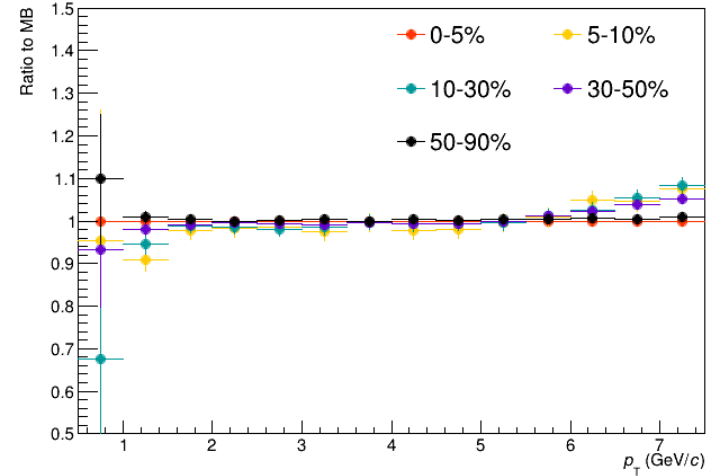
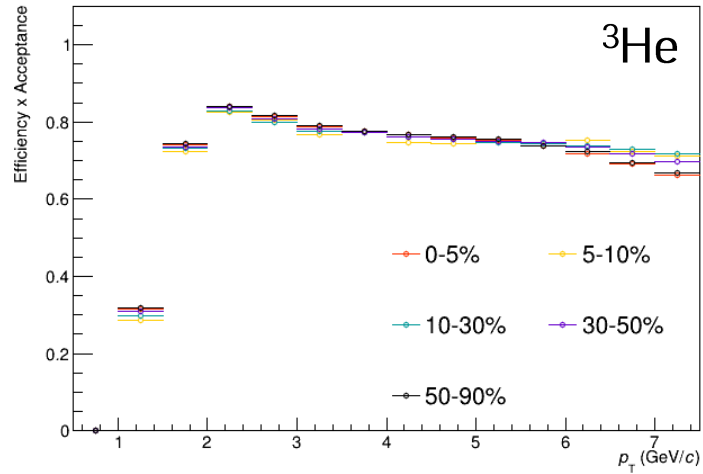
Example of the signal extraction without the tracking PID

Efficiency x Acceptance: (Anti-)deuteron

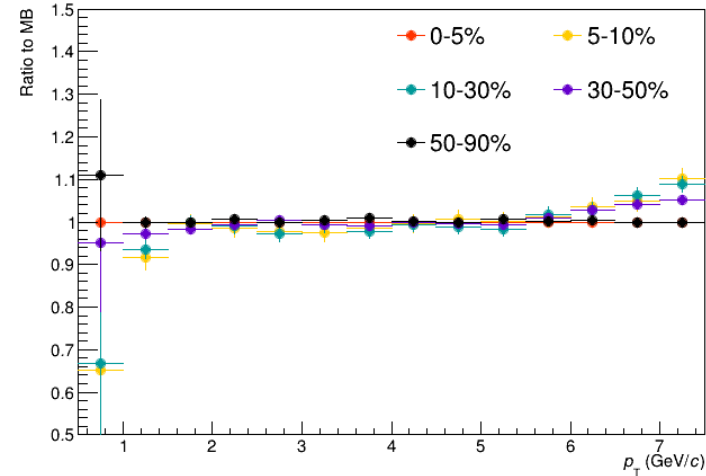
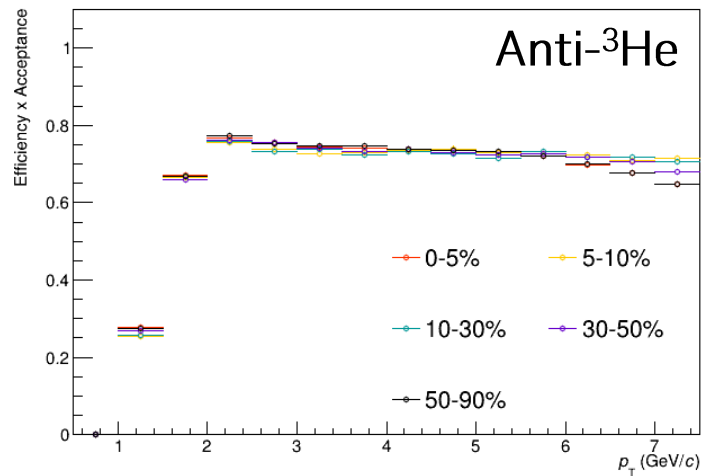


- The efficiency x acceptance is obtained with **GEANT4**
- The analysis was done p_T from 1.0 GeV/c
- The efficiency does show a mild trend with centrality
 - MB efficiency x acceptance used for correcting the raw spectra
 - Cross check ongoing: using centrality dependent efficiency

Efficiency x Acceptance: (Anti-)³He

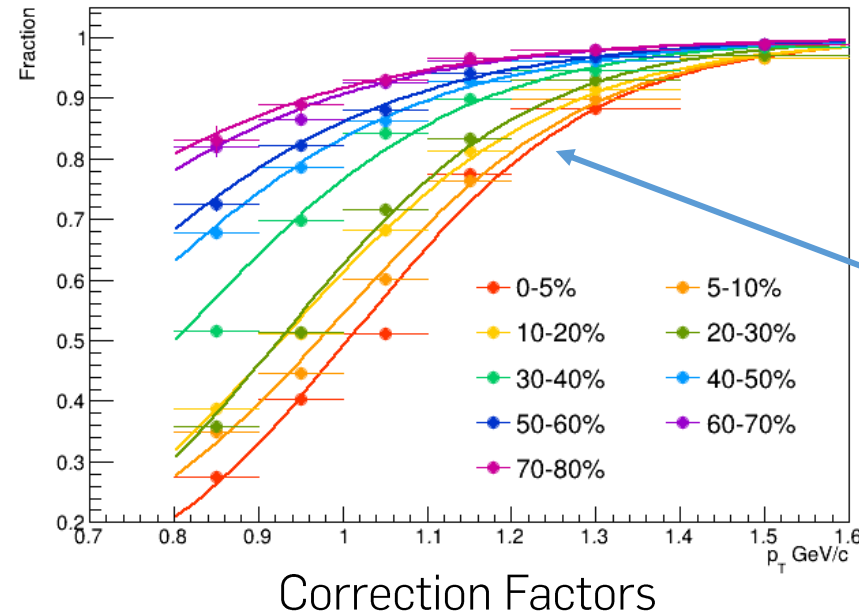
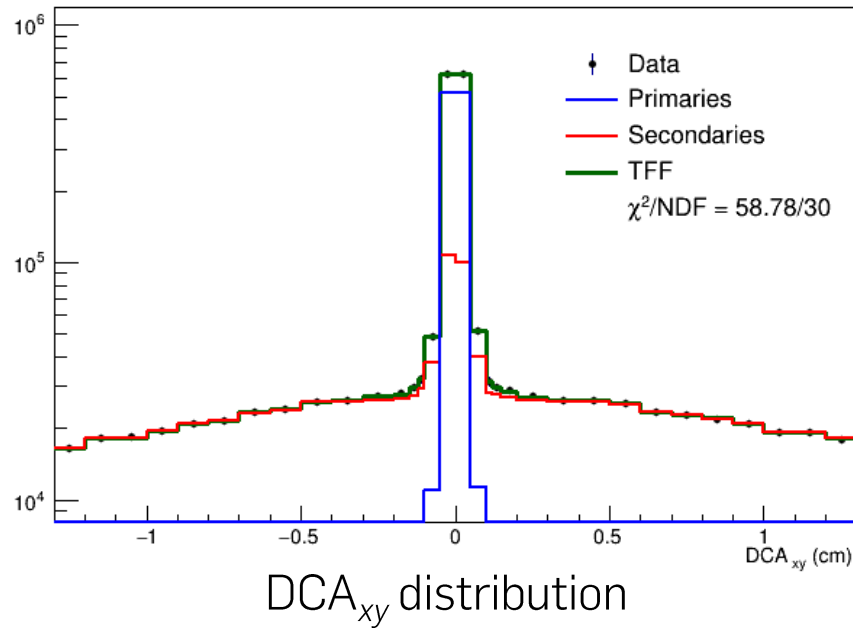


- The efficiency x acceptance is obtained with **GEANT4**
- The analysis was done p_T from 2.0 GeV/c
- The efficiency shows a trend with centrality
 - Centrality dependent efficiency x acceptance used for correcting the raw spectra



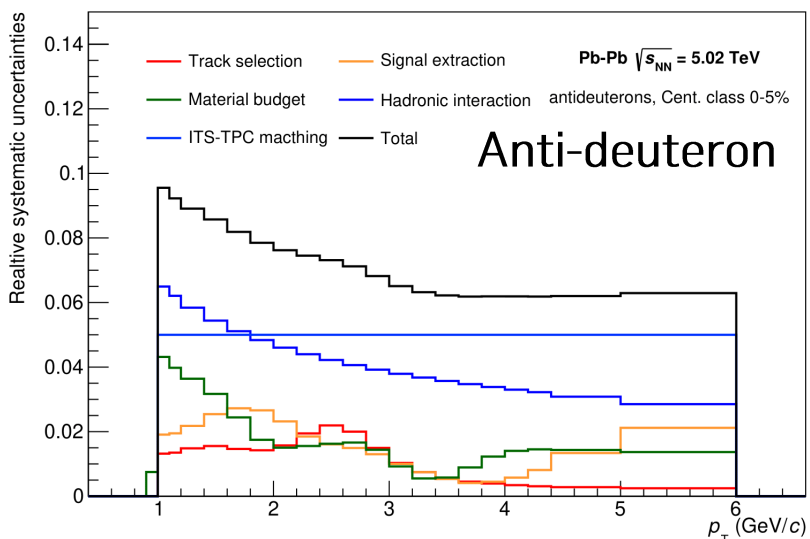
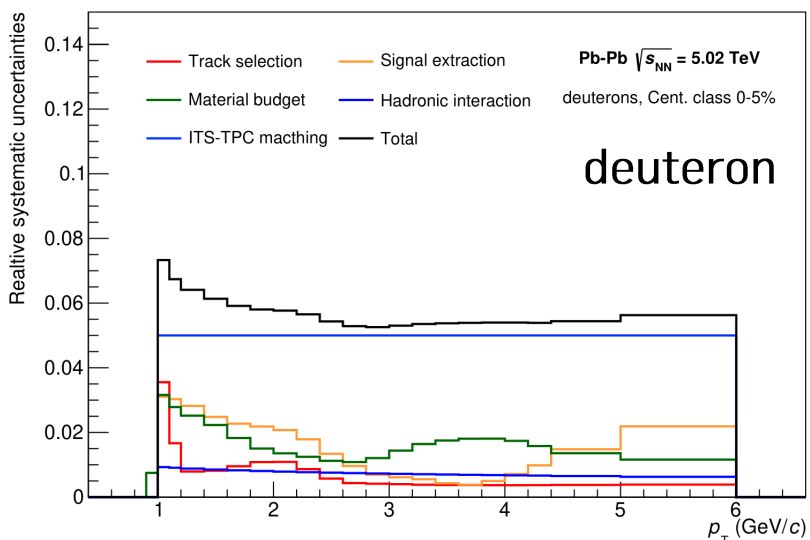
Correction for Secondary Particles

Mult: 0 - 5% , $1.1 < p_T \leq 1.2$ (GeV/c)



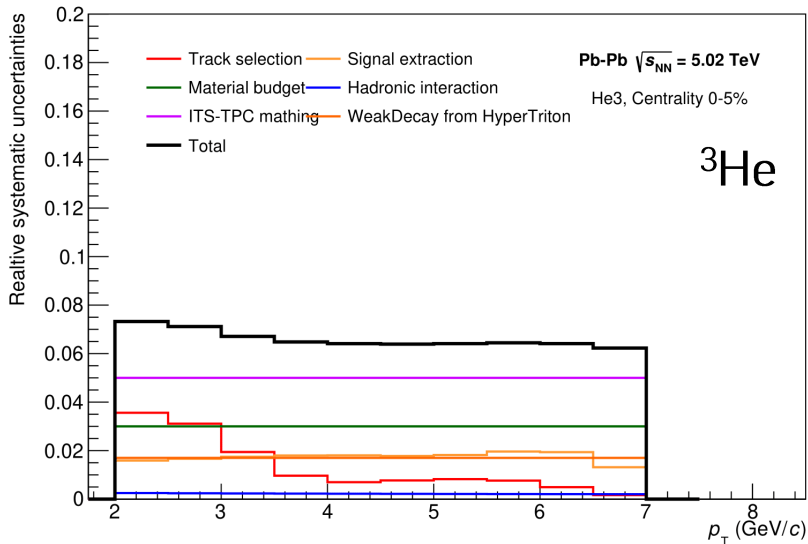
- Fit on a range of DCA_{xy} distribution wider than the cut used to extract the signal.
 - **Blue:** Primary template obtained from nuclei injected MC (LHC20g7)
 - **Red:** Secondary template obtained from general purpose MC
 - **Green:** Fit result by TFractionFitter
- A wider binning in central region used for better fit result.

Systematic Uncertainties: (Anti-)Deuteron



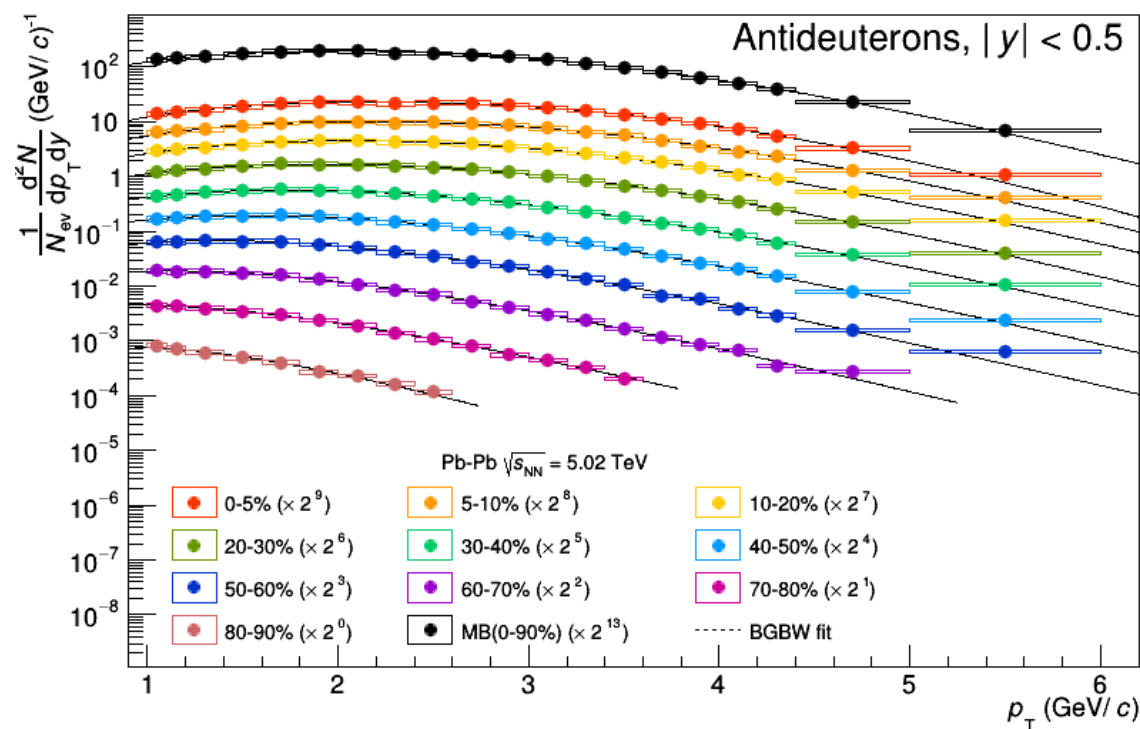
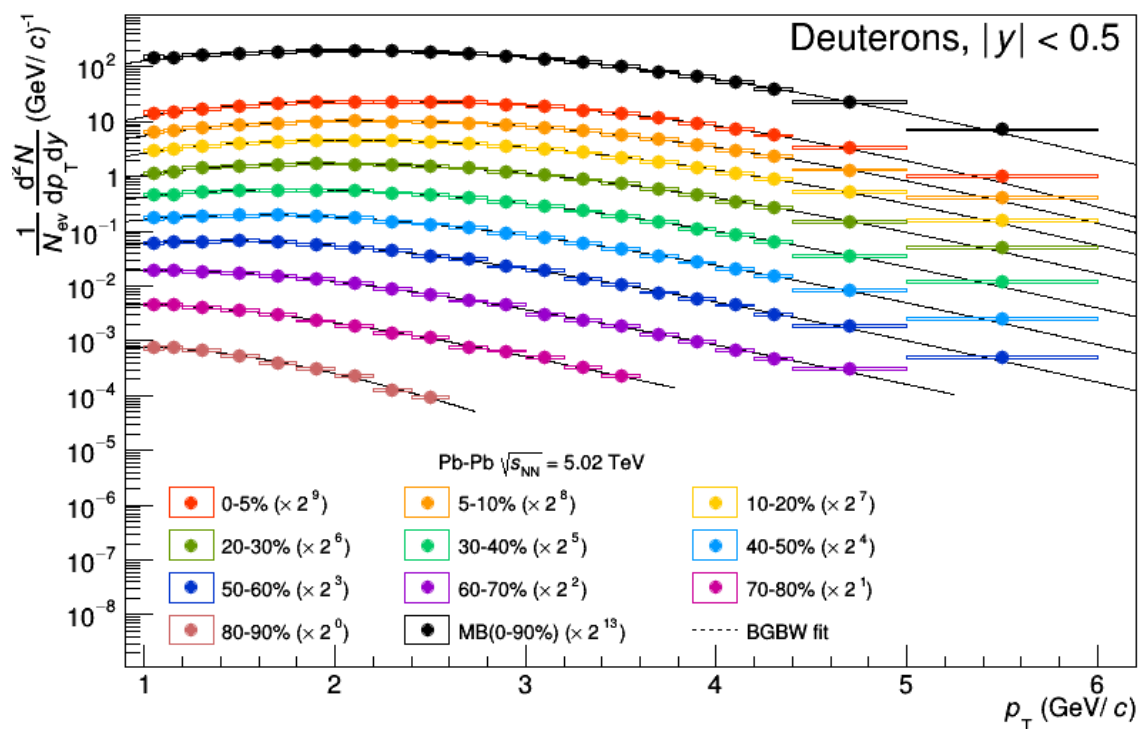
- Track Selection & Signal Extraction
 - TPC Clusters, DCAz, TPC PID
 - Range-Broadening, Shifting
- Material Budget
 - Used MC: LHC17d5a (material 1.045), LHC17d5b (material: 0.955)
 - Ratio of Efficiencies to Normal -> Half of average used (p_T differential)
- Hadronic Interaction
 - Deuteron (TOF): $0.00939 * T_{\text{Math}}::\text{Power}(p_T, -0.23572)$
 - Anti-deuteron (TOF): $0.06654 * T_{\text{Math}}::\text{Power}(p_T, -0.49699)$
- ITS-TPC Matching efficiencies
 - 5% (constant) used
 - (3~7% for the given p_T bins, 0-10% cent bin, proton case)

Systematic Uncertainties: (Anti-)³He



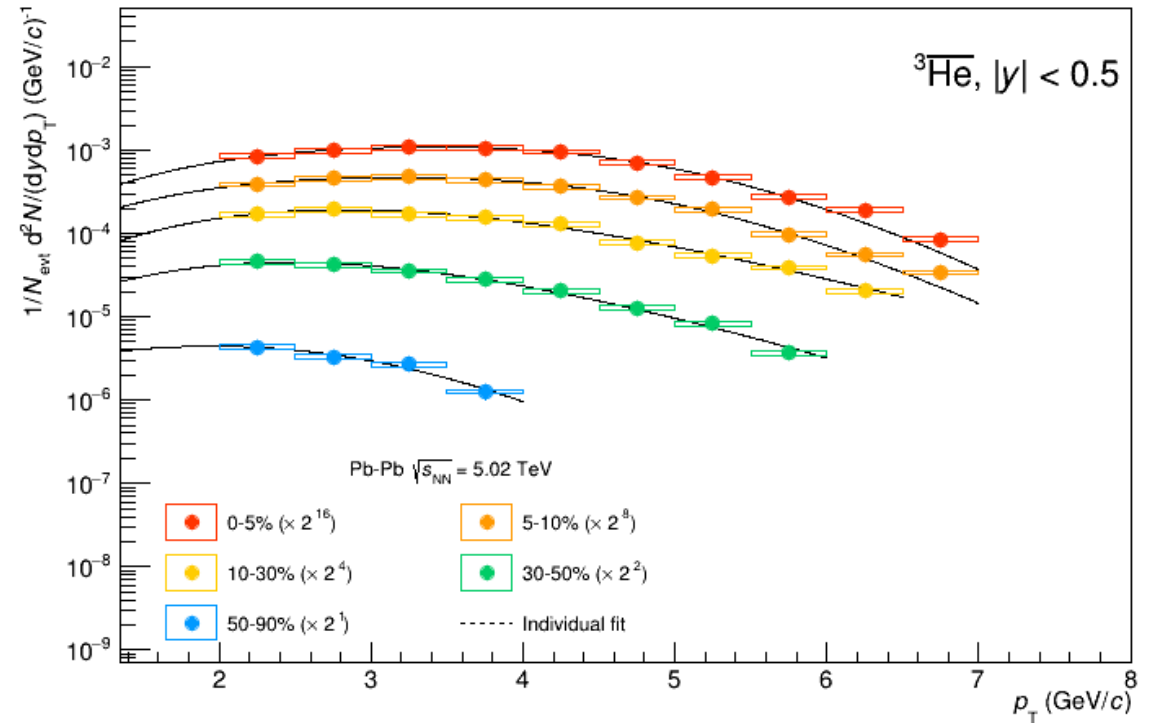
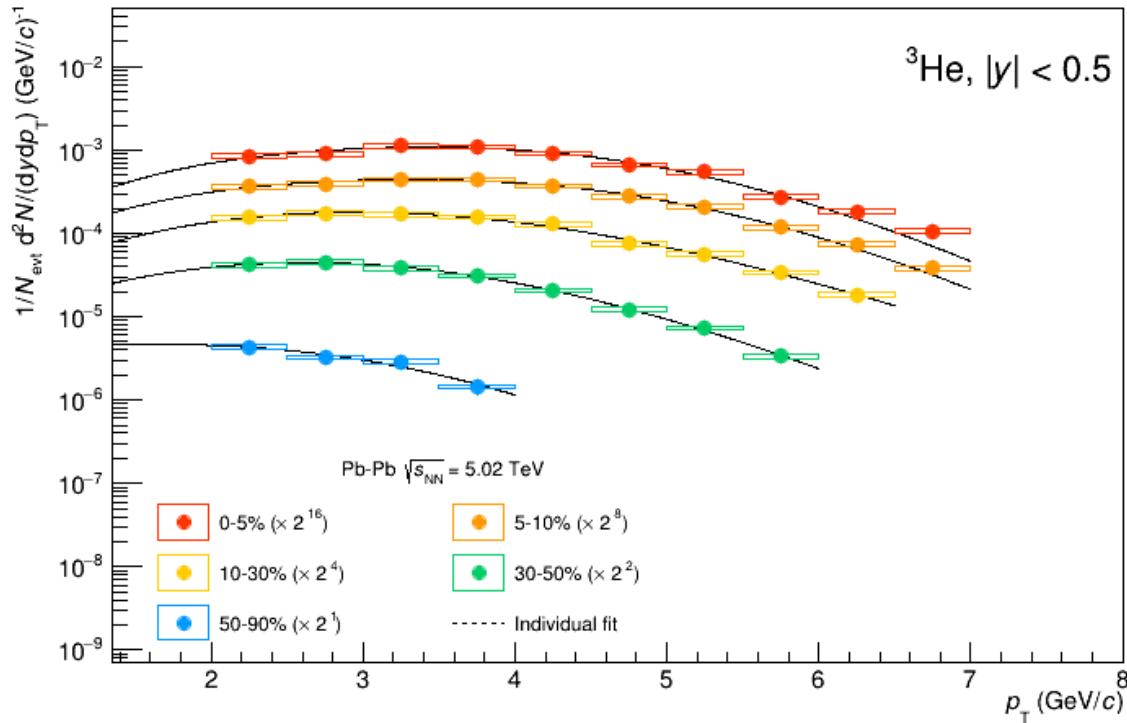
- Track Selection & Signal Extraction
 - TPC Clusters, DCAz, TPC PID
 - Range-Broadening, Shifting
- Material Budget
 - (Temporally) 3% (constant) used.
 - Will be updated with the same method applied in (Anti-)deuteron
- Hadronic Interaction
 - ³He (TPC): $0.00294 * T_{Math}::Power(pt, -0.19483)$
 - Anti-³He (TPC): $0.02088 * T_{Math}::Power(pt, -0.48766)$
- ITS-TPC Matching efficiencies
 - 5% (constant) used
 - (3~7% for the given pT bins, 0-10% cent bin, proton case)
- WeakDecay from Hyper Triton
 - 1.7% (constant) used

Spectra: (Anti-)Deuteron



- Thanks to the bigger data sample we could extend the centrality reach of the analysis.
- Fit to the spectra with the Blast Wave function.

Spectra: (Anti-)³He

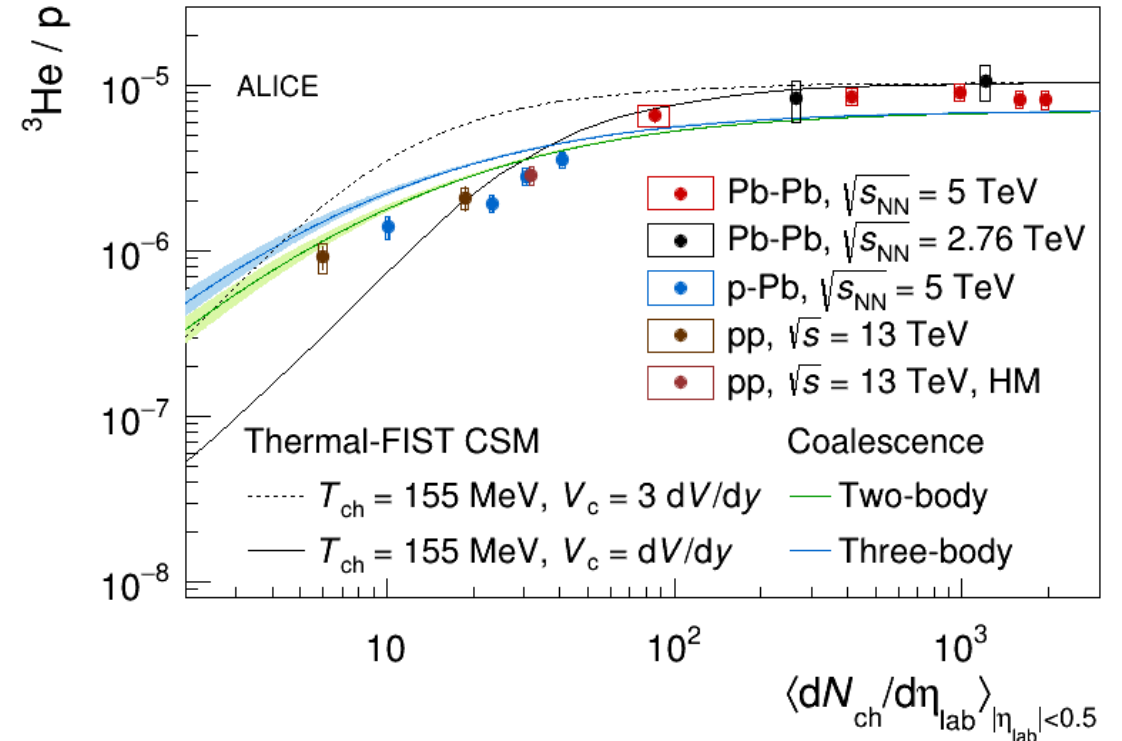
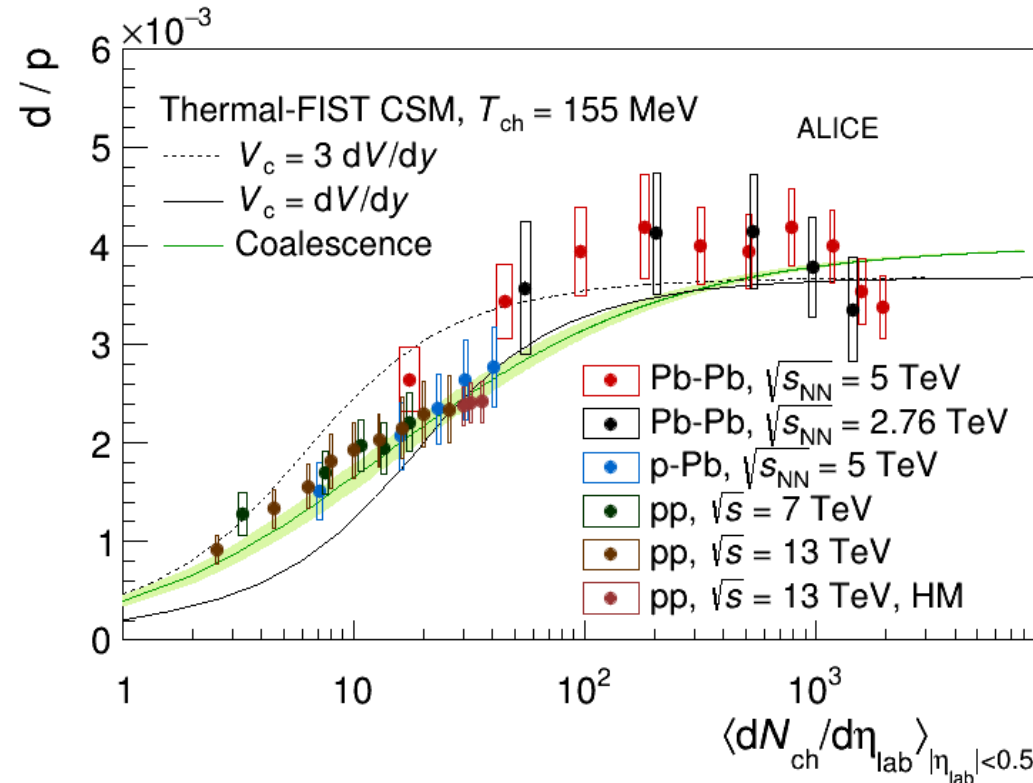


- Thanks to the bigger data sample we could extend the centrality reach of the analysis.
 - 0-5, 5-10, 10-30, 30-50, 50-90% bin
- Fit to the spectra with the Blast Wave function.

Yields: (Anti-)Deuteron and (Anti-)³He

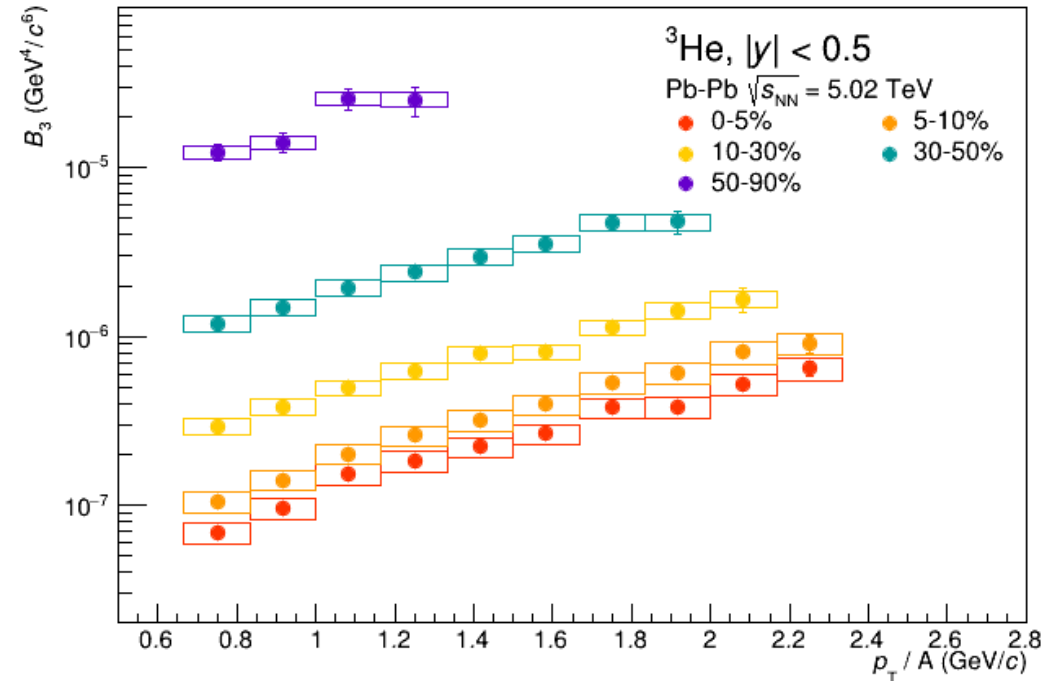
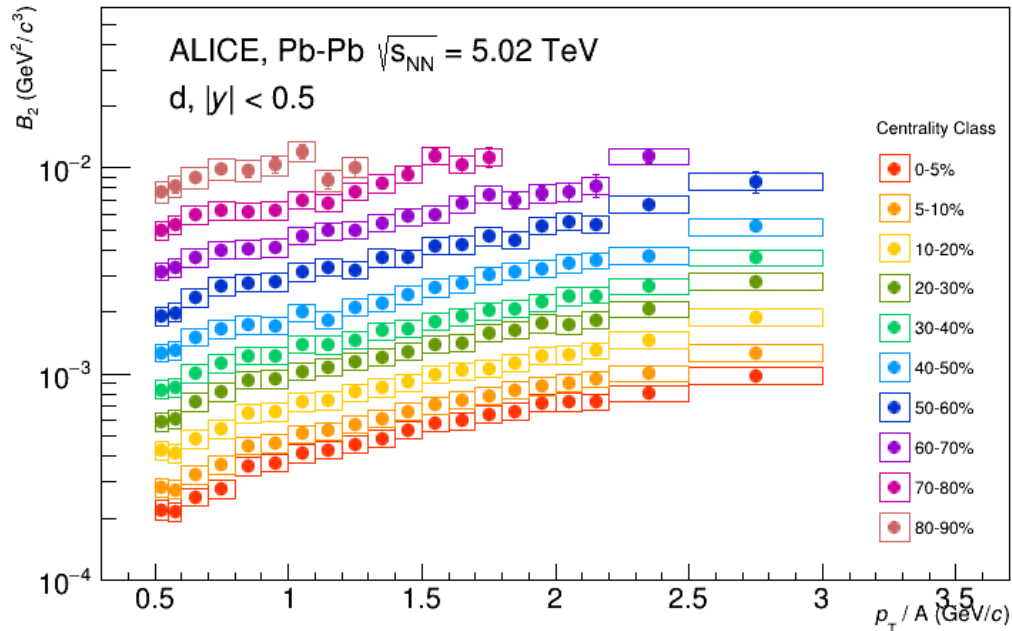
Centrality	dN/dy	$\langle p_T \rangle$ (GeV/c)	χ^2/ndf
d (0-5%)	$(1.31 \pm 0.00 \pm 0.05 \pm 0.04) \times 10^{-1}$	$2.47 \pm 0.00 \pm 0.04 \pm 0.02$	1.19
d (5-10%)	$(1.13 \pm 0.00 \pm 0.04 \pm 0.03) \times 10^{-1}$	$2.43 \pm 0.00 \pm 0.03 \pm 0.02$	1.47
d (10-20%)	$(9.68 \pm 0.01 \pm 0.29 \pm 0.30) \times 10^{-2}$	$2.35 \pm 0.00 \pm 0.03 \pm 0.02$	0.68
d (20-30%)	$(7.09 \pm 0.01 \pm 0.17 \pm 0.22) \times 10^{-2}$	$2.25 \pm 0.00 \pm 0.02 \pm 0.02$	0.68
d (30-40%)	$(4.55 \pm 0.00 \pm 0.08 \pm 0.18) \times 10^{-2}$	$2.09 \pm 0.00 \pm 0.02 \pm 0.02$	0.93
d (40-50%)	$(2.94 \pm 0.00 \pm 0.04 \pm 0.11) \times 10^{-2}$	$1.91 \pm 0.00 \pm 0.01 \pm 0.02$	0.41
d (50-60%)	$(1.83 \pm 0.00 \pm 0.03 \pm 0.08) \times 10^{-2}$	$1.75 \pm 0.00 \pm 0.02 \pm 0.02$	1.18
d (60-70%)	$(9.80 \pm 0.02 \pm 0.09 \pm 0.38) \times 10^{-3}$	$1.51 \pm 0.00 \pm 0.01 \pm 0.02$	1.23
d (70-80%)	$(4.02 \pm 0.02 \pm 0.03 \pm 0.15) \times 10^{-3}$	$1.35 \pm 0.00 \pm 0.02 \pm 0.02$	1.64
d (80-90%)	$(1.16 \pm 0.08 \pm 0.02 \pm 0.07) \times 10^{-3}$	$1.17 \pm 0.05 \pm 0.03 \pm 0.05$	1.71
³ He (0-5%)	$(3.12 \pm 0.08 \pm 0.34 \pm 0.22) \times 10^{-4}$	$3.91 \pm 0.06 \pm 0.32 \pm 0.09$	1.07
³ He (5-10%)	$(2.51 \pm 0.06 \pm 0.22 \pm 0.17) \times 10^{-4}$	$3.75 \pm 0.06 \pm 0.25 \pm 0.08$	0.17
³ He (10-30%)	$(1.72 \pm 0.04 \pm 0.09 \pm 0.12) \times 10^{-4}$	$3.15 \pm 0.05 \pm 0.04 \pm 0.06$	0.23
³ He (30-50%)	$(7.74 \pm 0.17 \pm 0.05 \pm 0.05) \times 10^{-5}$	$2.6 \pm 0.03 \pm 0.10 \pm 0.04$	0.81
³ He (50-90%)	$(1.34 \pm 0.12 \pm 0.01 \pm 0.10) \times 10^{-5}$	$1.93 \pm 0.07 \pm 0.01 \pm 0.04$	0.76

Nucleus/proton ratios



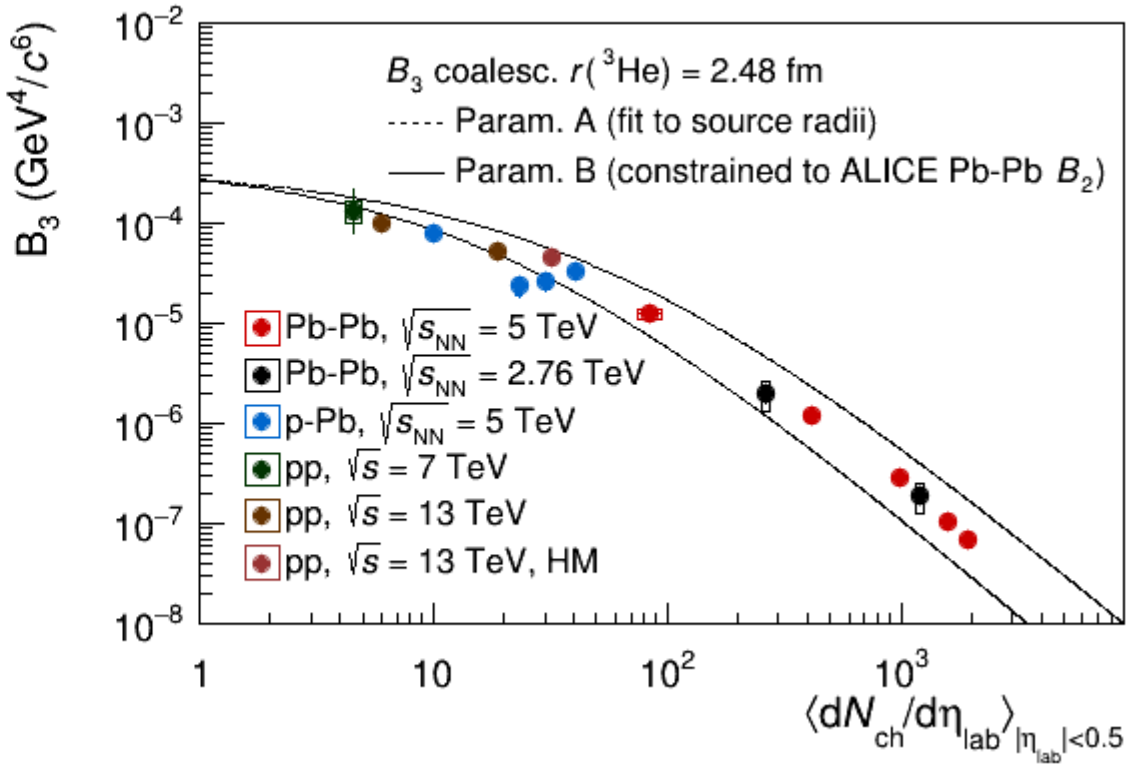
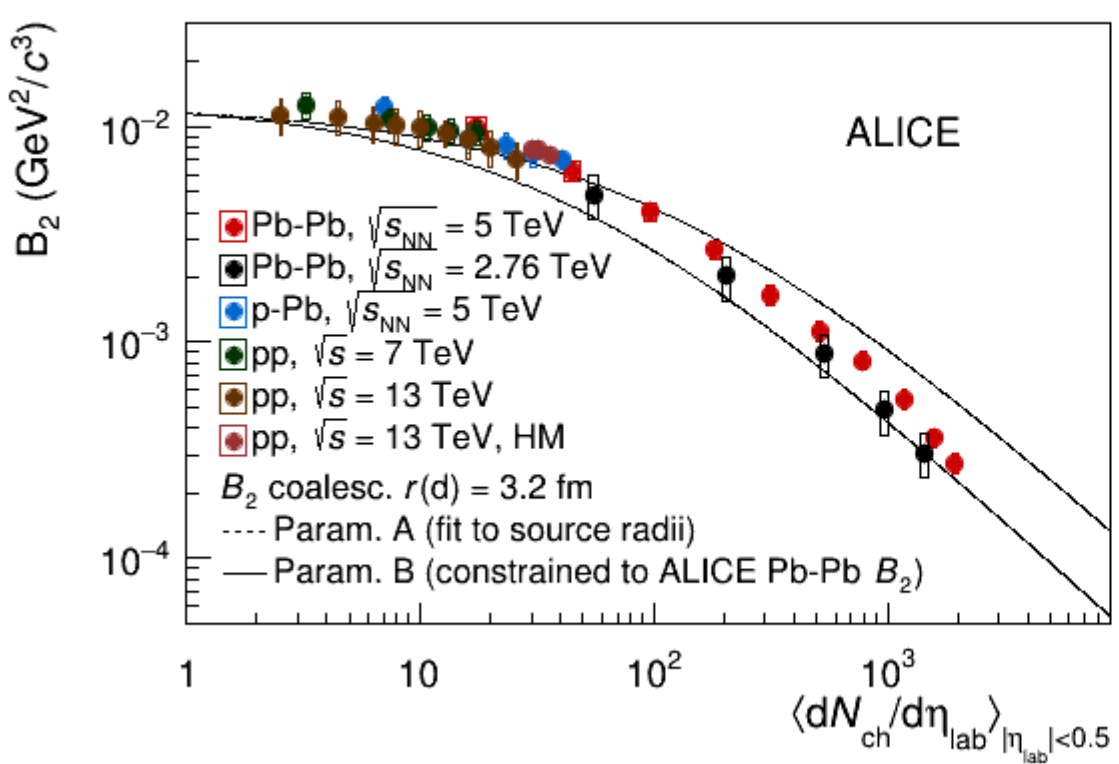
- Large extension of the multiplicity reach for the d/p
- Decrease of the d/p in central collisions confirmed.
- Correlated uncertainty computed for deuteron, yet not available for protons.

Coalescence Parameter with p_T



- Peripheral Pb-Pb B_2 / B_3 are similar to the p-Pb
- Clear separation with centrality, increasing trend in central collisions can be related with the correlation of

Coalescence Parameter with multiplicity



- This study (RED) follows results from various collisions/energy.
- Rapid drop at higher multiplicity

Conclusions

- **Annual Report**
 - Return from CERN at Apr.2021
 - PhD defense done in 16/12/2021
 - Title: Study on Hadron Phase via Hyperon Resonance and Light Nuclei Produced in Elementary and Heavy ion collision
 - PhD Advisory Committee: Rene Bellwied*, Luciano Musa, Su Houng Lee, Sanghoon Lim, In-Kwon Yoo
- **Light Nuclei Production in Pb-Pb Collisions at 5.02 TeV**
 - Analysis approved to paper in Physics Forum
 - Aim: short paper (6-8 pages) to be submitted to PRC
 - **Physics message:** nuclei production in Pb-Pb collisions follows SHM expectations with few twists
 - B_A evolution with momentum
 - Nucleus/p decrease in very central collisions is confirmed by the measurement at a different energy

Back up

ITS-TPC Matching efficiencies and Systematic uncertainties (%) for Pb-Pb 2018 PASS 3:

- The final systematic uncertainty is evaluated looking at the weighted average between (eff_MC/eff_data)_ITSTPC and (eff_MC/eff_data)_TPCOnly.
- See details here: <https://indico.cern.ch/event/970509/>.

pT bins (GeV /c)	0-10% centrality class				30-50% centrality class			
	18q piK	18q proton	18r piK	18r proton	18q piK	18q proton	18r piK	18r proton
0.5 - 1.0	3%	7%	3%	10%	3%	10%	3%	10%
1.0 - 2.0	5%	4%	5%	4%	4%	4%	4%	4%
2.0 - 3.0	6%	6%	6%	6%	4%	6%	4%	6%
3.0 - 4.0	5%	7%	5%	7%	4%	5%	4%	5%
4.0 - 5.0	4%	5%	4%	6%	3%	4%	3%	5%
5.0 - 6.0	2%	3%	2%	3%	2%	2%	1%	2%
6.0 - 7.0	3%	4%	3%	4%	1%	2%	2%	3%
7.0 - 8.0	3%	2%	2%	2%	1%	1%	1%	1%
8.0 - 9.0	3%	2%	3%	3%	1%	1%	2%	1%
9.0 - 10.0	3%	2%	2%	2%	1%	1%	1%	1%
10.0 - 11.0	2%	1%	2%	1%	1%	1%	1%	1%
11.0 - 12.0	2%	1%	2%	2%	1%	1%	1%	1%
12.0 - 13.0	1%	1%	1%	1%	1%	1%	1%	1%
13.0 - 14.0	2%	1%	1%	1%	1%	1%	1%	1%

Systematic uncertainties: Weak Decay from Hyper Triton

(Anti)³He: primary fraction

Secondaries from hypertriton weak decays

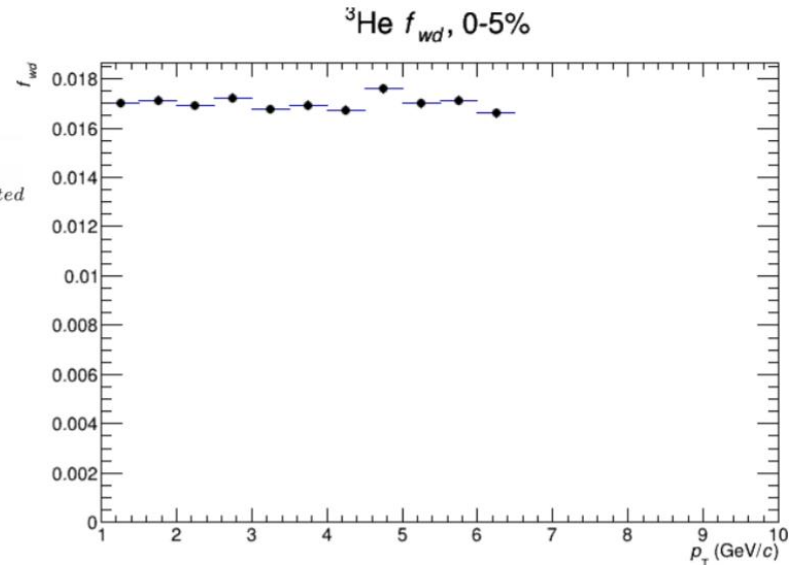
- Additional contribution in (anti)³He

$$f_{WD} = \frac{(\epsilon \times \text{Acc.})_{WD}}{(\epsilon \times \text{Acc.})_{prim}} \cdot BR(\Lambda^3\text{H} \rightarrow {}^3\text{He} + \pi^-) \cdot \left(\frac{{}^3\Lambda\text{H}}{{}^3\text{He}}\right)_{corrected}$$

$$- BR(\Lambda^3\text{H} \rightarrow {}^3\text{He} + \pi^-) = 0.25$$

$$- ({}^3\Lambda\text{H}/{}^3\text{He})_{corrected} \simeq 0.34$$

- For $p_T \geq 6.5$ GeV/c, this correction deviates from its plateau
 - to be checked
 - Now, the correction is extended at higher p_T with a fit to the points



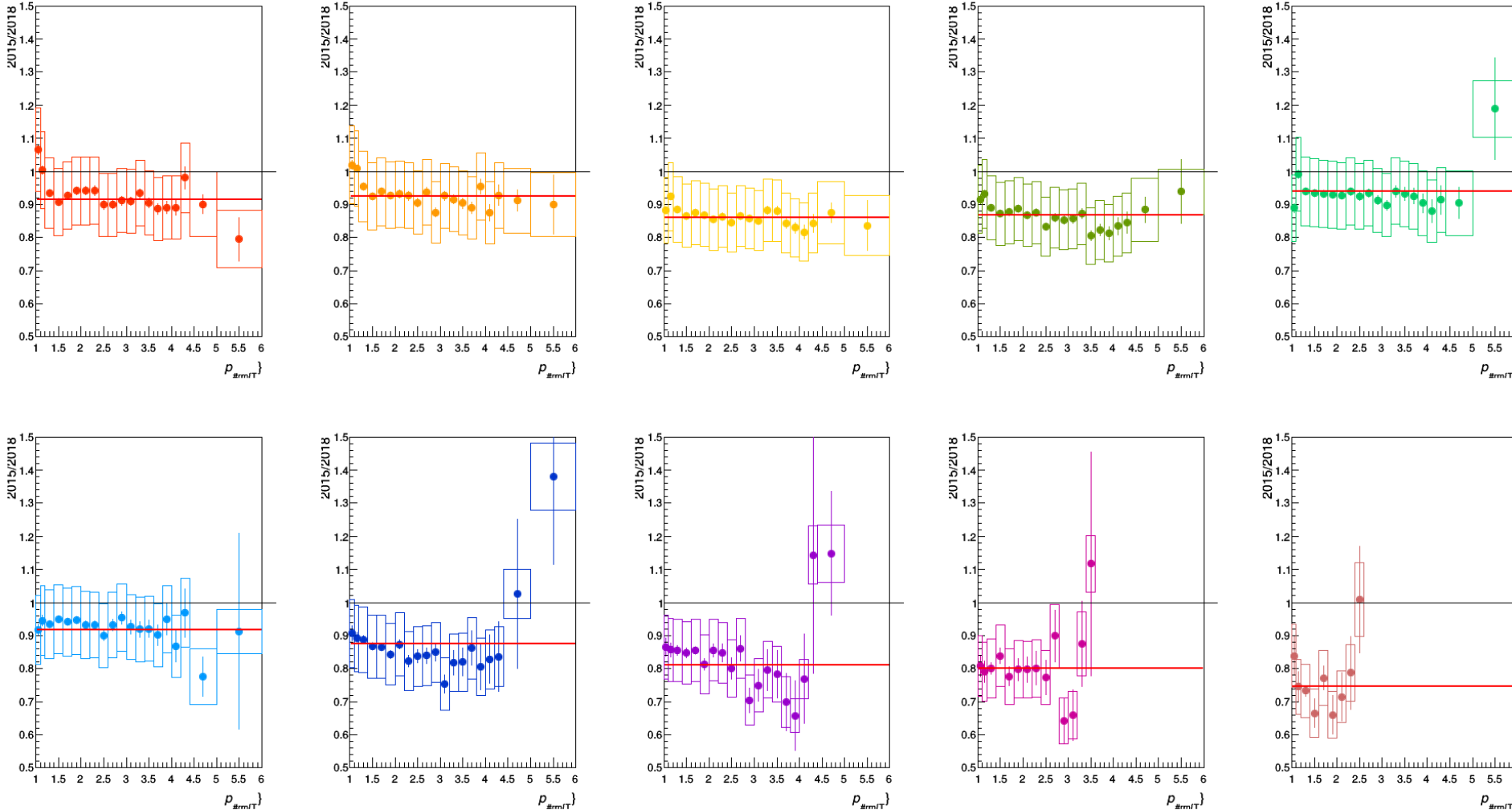
3rd June 2021

NUCLEX-PAG Meeting – Mario Ciacco

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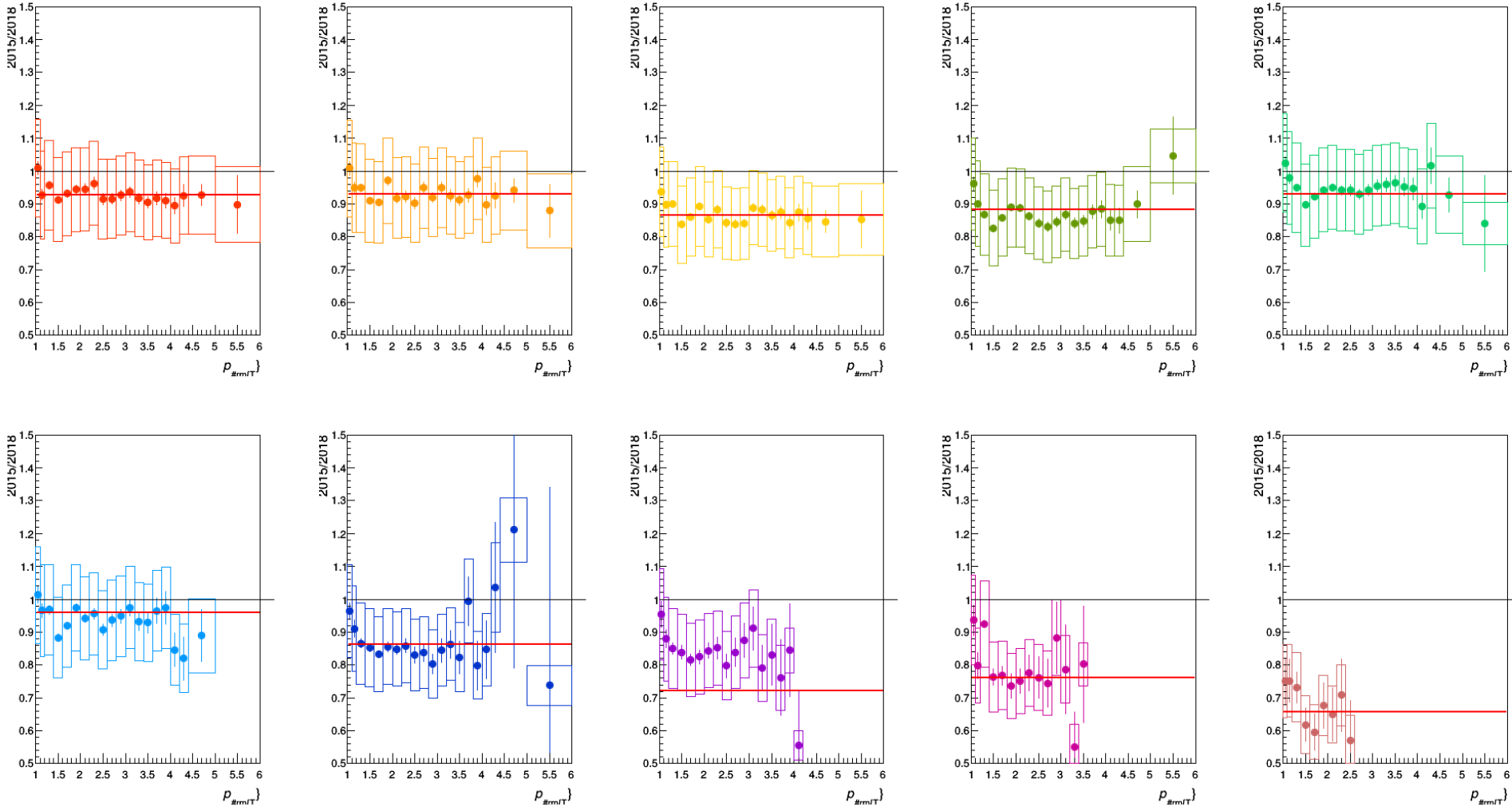
<https://indico.cern.ch/event/982602/#1-study-of-antimattermatter-ra>

Comparison with the preliminary: Deuteron



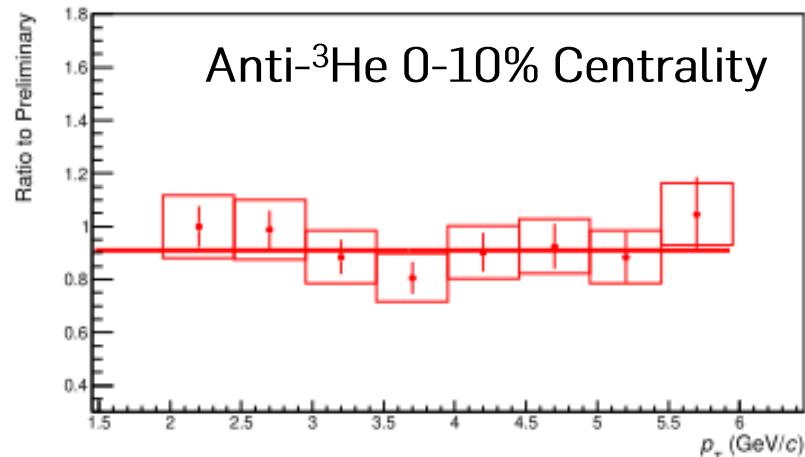
- Proper G4 correction + additional correction for hadronic interaction
- Fix bug in the task that was removing some tracks (randomly) from the analysis (thus the trend vs centrality in the ratio for deuterons)

Comparison with the preliminary: Anti-Deuteron

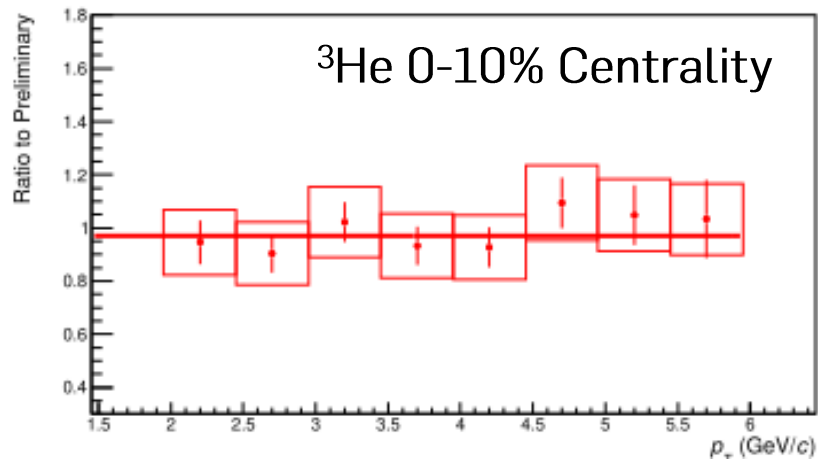


- Proper G4 correction + additional correction for hadronic interaction
- Fix bug in the task that was removing some tracks (randomly) from the analysis (thus the trend vs centrality in the ratio for deuterons)

Comparison with the preliminary: (Anti-)³He



- Since ³He centrality bin has been updated, the comparison was done only in 0-10% bin in analysis level.
 - Preliminary: 0-10, 10-40, 40-90
 - This analysis: 0-5, 5-10, 10-30, 30-50, 50-90



Comparison with 0-10% cent bin