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# Measurements of ${}^{3}_{\Lambda}\mathrm{H}$ $R_3$ and production in Au+Au collisions at $\sqrt{s_{NN}} = 3$ GeV at STAR

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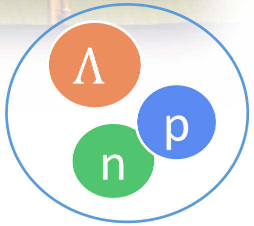
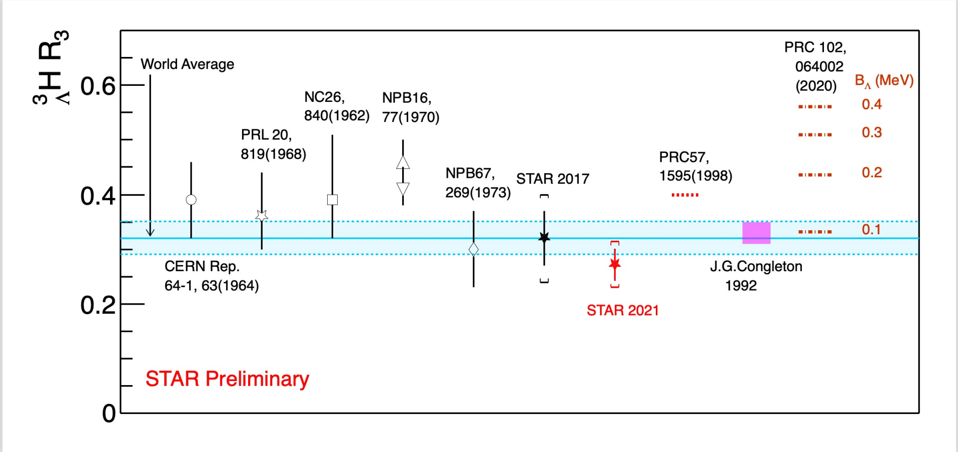
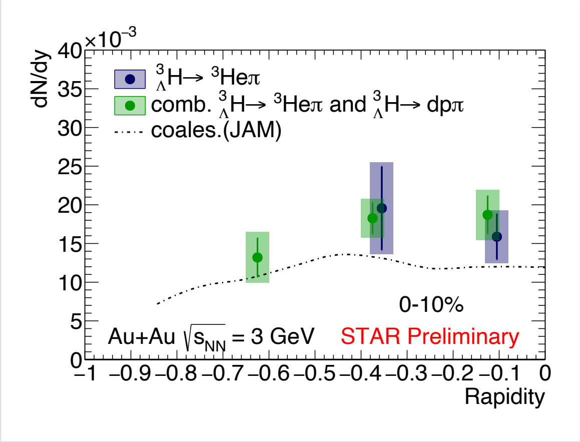


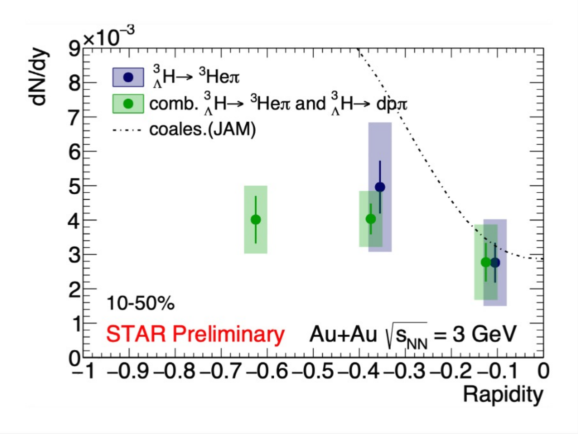

## ${}^{3}_{\Lambda}\mathrm{H}$ branching ratio $R_3$




## ${}^{3}_{\Lambda}\mathrm{H}$ dN/dy 0-10%




## ${}^{3}_{\Lambda}\mathrm{H}$ dN/dy 10-50%

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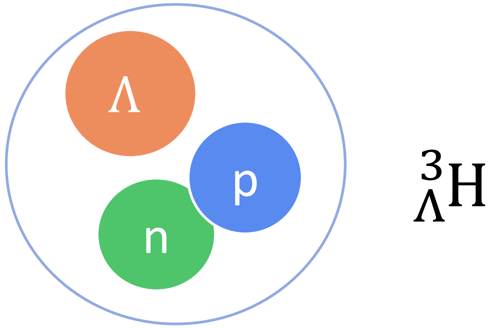
# Introduction

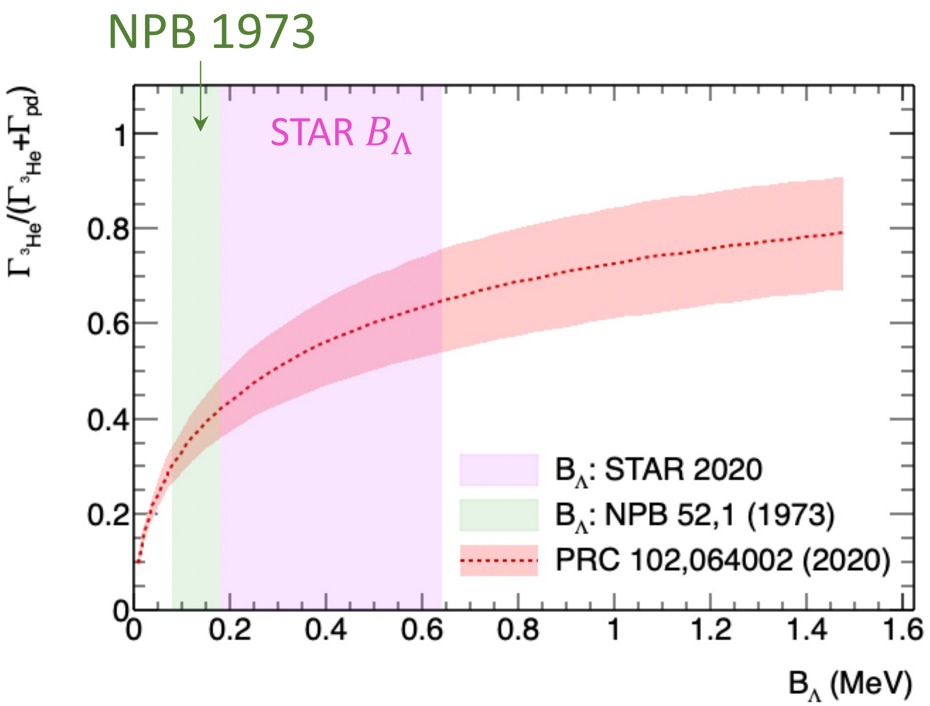
- Hyperon-nucleon (*Y-N*) interaction
  - Important ingredient for the nuclear equation of state.
- ${}^{3}_{\Lambda}\mathrm{H}$ binding energy ~0.2 MeV, weakly bound system.




## Outline

- ${}^{3}_{\Lambda}\mathrm{H}$ branching ratio $R_3$
  - Complementary to $B_\Lambda$ measurements.
  - Constrains on *Y-N* interaction strength.

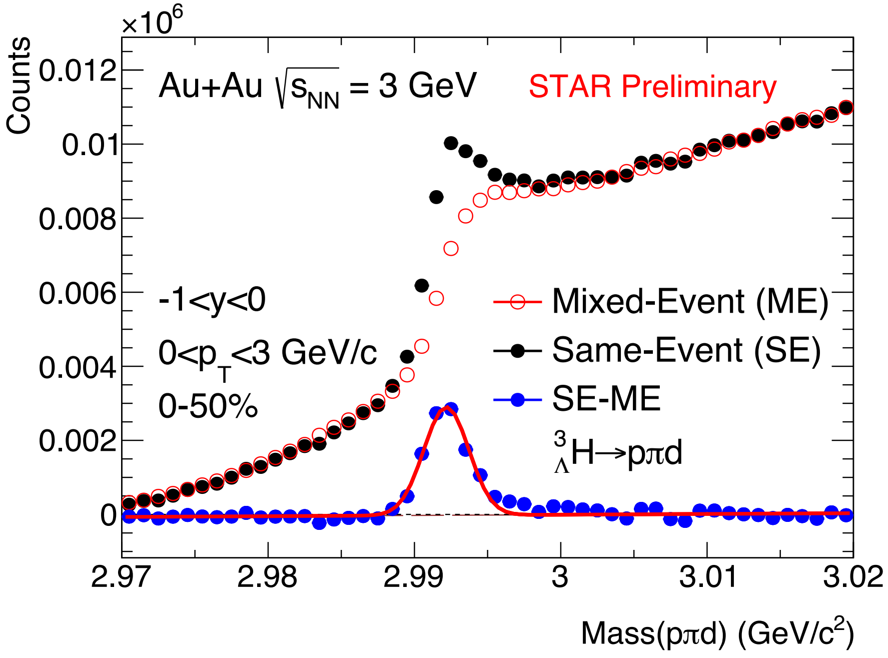
- ${}^{3}_{\Lambda}\mathrm{H}$ production yields in Au+Au $\sqrt{s_{NN}} = 3$ GeV
  - Hypernuclei production mechanism in heavy-ion collisions.

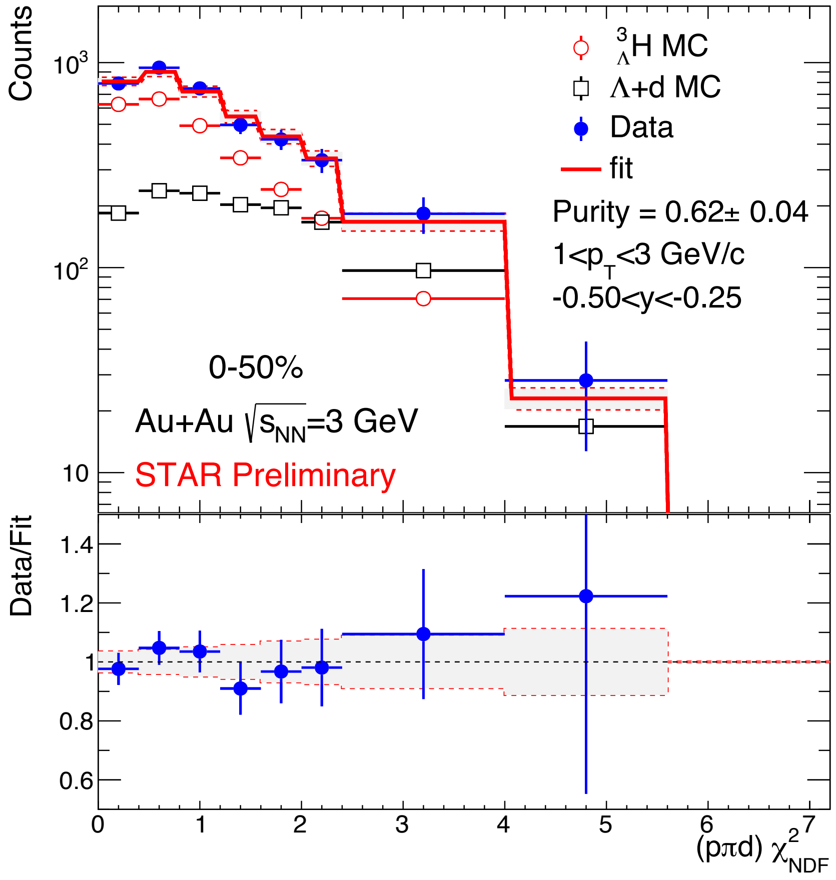


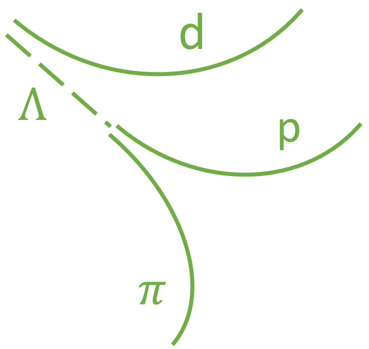
# Methodology

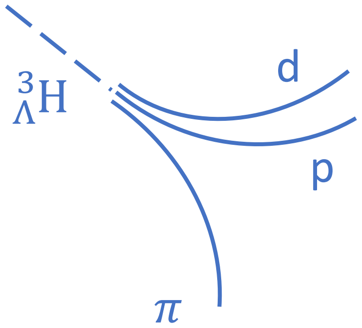
## Signal reconstruction

- Decay channel: ${}^{3}_{\Lambda}\mathrm{H} \rightarrow p\pi d$.
- KF Particle package is used to improve significance.
- Combinatorial background is estimated by mixed-event method.
- Candidates (SE-ME) contain real ${}^{3}_{\Lambda}\mathrm{H}$ signal and kinematically correlated $\Lambda + d$ ($\Lambda \rightarrow p\pi^{-}$).




## Estimation of ${}^{3}_{\Lambda}\mathrm{H}$ purity

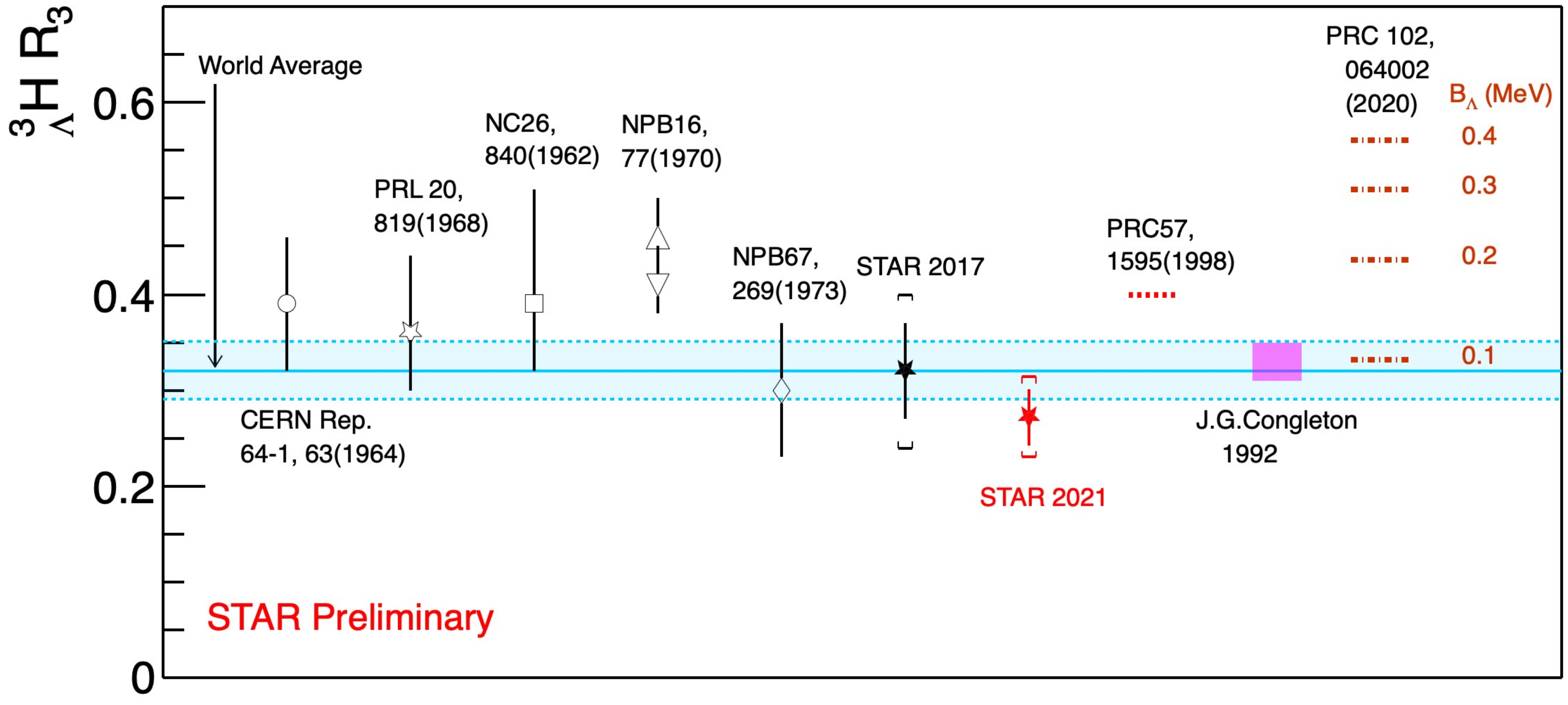
- Normalized $\chi^{2}_{NDF}$ distribution of Λ+d and ${}^{3}_{\Lambda}\mathrm{H}$ templates from MC ($f_{\Lambda d}$ and $f_{{}^{3}_{\Lambda}\mathrm{H}}$), and SE-ME candidates $f_{Data}$.
- ${}^{3}_{\Lambda}\mathrm{H}$ purity: the fraction of ${}^{3}_{\Lambda}\mathrm{H}$ $f_{{}^{3}_{\Lambda}\mathrm{H}}$ in $f_{Data}$ from fitting $f_{Data} = p_0 \cdot (f_{\Lambda d} + p_1 \cdot f_{{}^{3}_{\Lambda}\mathrm{H}})$.

# ${}^{3}_{\Lambda}\mathrm{H}$ branching ratio $R_3$

STAR 2021 (preliminary):

$R_3 = 0.272 \pm 0.030 \pm 0.042$

$$R_3 = \frac{\mathrm{B.R.}({}^{3}_{\Lambda}\mathrm{H} \to 3\mathrm{He}\pi^-)}{\mathrm{B.R.}({}^{3}_{\Lambda}\mathrm{H} \to \mathrm{pd}\pi^-) + \mathrm{B.R.}({}^{3}_{\Lambda}\mathrm{H} \to {}^{3}\mathrm{He}\pi^-)}$$



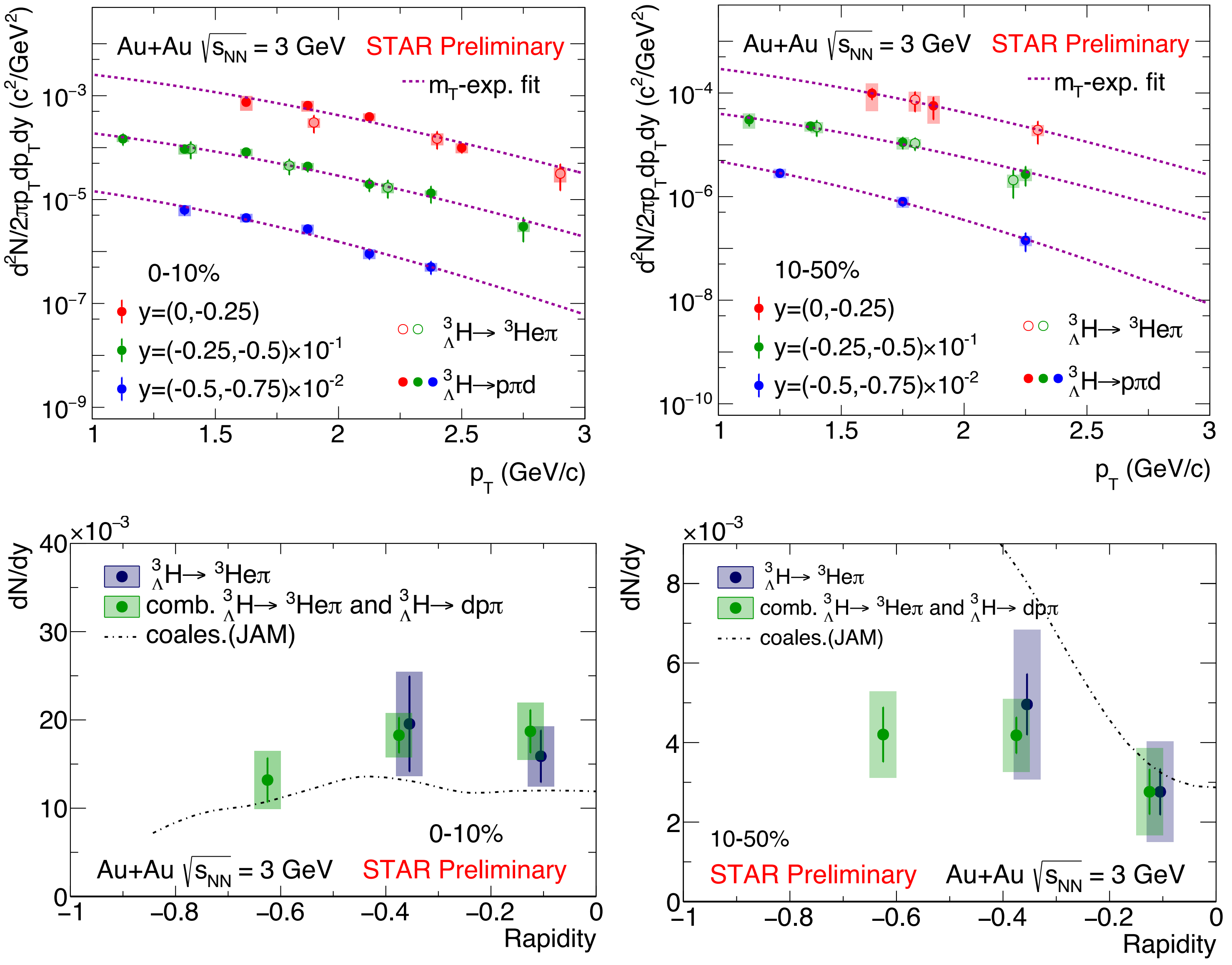

- Improved precision compared to previous measurements.
- Updated world average $R_3$ consistent with theory calculation assuming $B_\Lambda \sim 0.1$ MeV.

# ${}^{3}_{\Lambda}\mathrm{H}$ production in 3 GeV Au+Au collisions

- ${}^{3}_{\Lambda}\mathrm{H}$ reconstruction via ${}^{3}_{\Lambda}\mathrm{H} \rightarrow p\pi d$ extends kinematic coverage to larger rapidity.
- Coalescence calculations of ${}^{3}_{\Lambda}\mathrm{H}$ dN/dy show similar tendency as data in 0-10% centrality.
    - Transport model (JAM) with coalescence of all hadrons as afterburner.

Coales. (JAM): PLB 805, 135452 (2020)

Note: The *B.R.* measured from this analysis is used. Uncertainties (19%) in *B.R.* are not shown in the plots.






${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He}\pi$ data: arXiv:2110.09513

- Back ups

# Calculate ${}^{3}_{\Lambda}\mathrm{H}$ *B.R.* from $R_3$

- *B.R.*$({}^{3}_{\Lambda}\mathrm{H} \rightarrow 3\mathrm{He}\pi^{-})$ = $0.178 \pm 0.034$
- *B.R.*$({}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{pd}\pi^{-})$ = $0.475 \pm 0.090$

Assumption:

- Isospin rule:

$$\frac{\Gamma({}^{3}_{\Lambda}\mathrm{H} \rightarrow 3\mathrm{He}\pi^{-})}{\Gamma({}^{3}_{\Lambda}\mathrm{H} \rightarrow 3\mathrm{H}\pi^{0})} = \frac{\Gamma({}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{pd}\pi^{-})}{\Gamma({}^{3}_{\Lambda}\mathrm{H} \rightarrow nd\pi^{0})} = 2$$

PRC 57, 1595-1603 (1998)

- 2% contribution from non-pion decay channels and other pion decay channel.

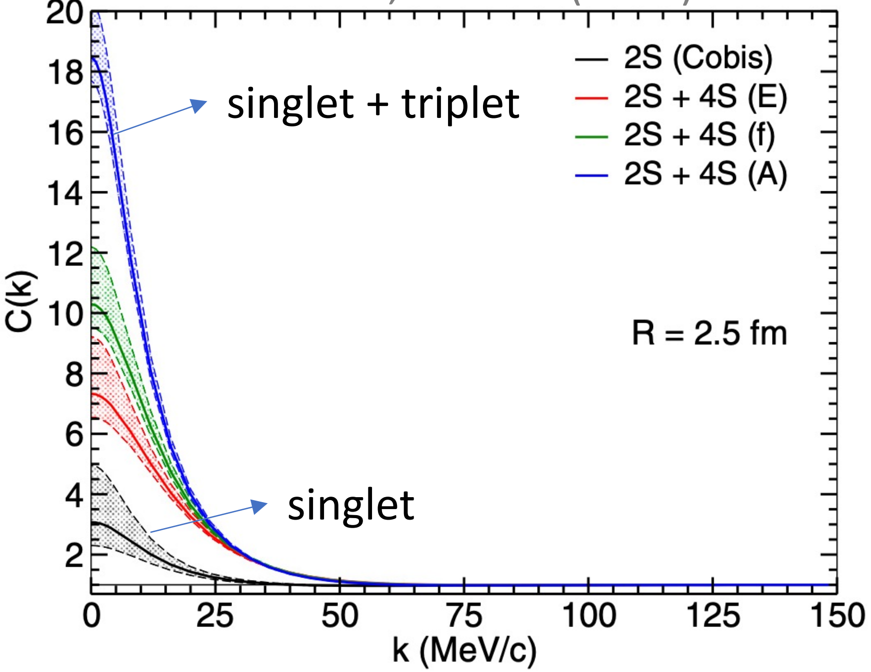
-> *B.R.*$({}^{3}_{\Lambda}\mathrm{H} \rightarrow 3\mathrm{He}\pi^{-})$ = $R_3 \times 0.98 \times \frac{2}{3}$

# Correlated $\Lambda d$ contamination in ${}^{3}_{\Lambda}\mathrm{H}$ signal

- $\Lambda d$ may have kinematic correlations according to theory calculation.

C(k*)=$\frac{P(\Lambda d)}{P(\Lambda)P(d)}$ , p is the possibility of finding particle
No correlation -> C(k*)=1
k* -> relative momentum between $\Lambda$ and $d$

PRC 102, 034001 (2020)




When k*=0, in $\Lambda$ and $d$ pair CMS framework:

$$p_{\Lambda} = -p_{d} = 0$$

$$\Lambda : ( p_{\Lambda}, E_{\Lambda} ) = (0, m_{\Lambda})$$

$$\mathrm{d} : ( p_{d}, E_{d} ) = (0, m_{d})$$

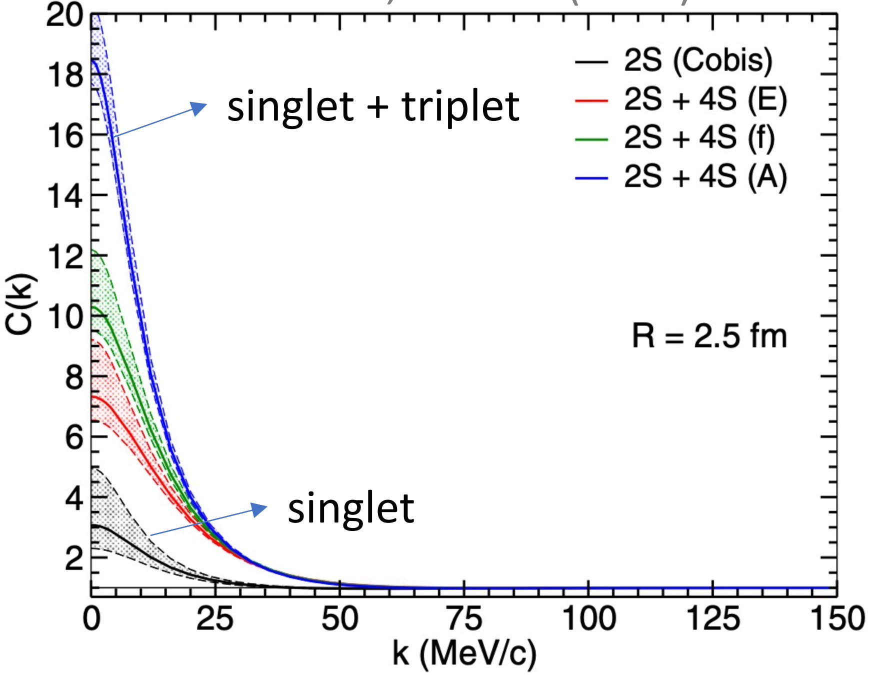
$$\text{->} (\Lambda d) : ( p_{\Lambda} + p_{d}, E_{\Lambda} + E_{d}) = (0, m_{\Lambda} + m_{d})$$

# Correlated $\Lambda d$ contamination in ${}^{3}_{\Lambda}\mathrm{H}$ signal

- $\Lambda d$ may have kinematic correlations according to theory calculation.
- When $\Lambda d$ C(k*) >1 at k*-> 0, peak structure is formed near $M(\Lambda) + M(d)$ threshold.
  - $M(\Lambda) + M(d)$ ~2.9913 GeV/c$^2$, M(${}^{3}_{\Lambda}\mathrm{H}$)~2.991 GeV/c$^2$ .

-> Correlated $\Lambda d$ could residual in real signal even after subtracting combinatorial background.

PRC 102, 034001 (2020)




Set C(k*) weight on uncorrected Λ and d

From Λ(MC)+d(data) embedding