QUARK MATTER KRAKÓW 2022

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Observation of ${}^{4}_{\bar{\Lambda}}\overline{H}$

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The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations

IMP   STAR

Introduction

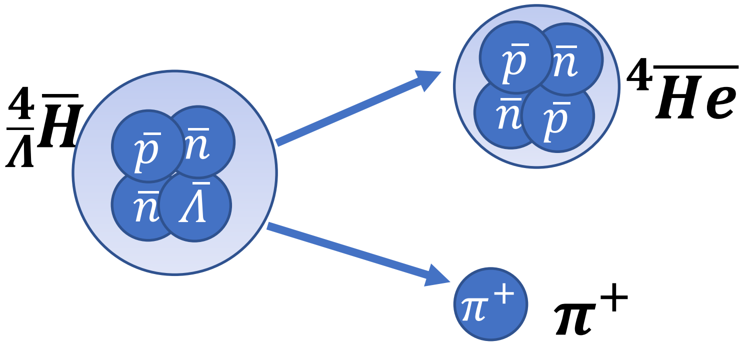
- Matter-antimatter asymmetry is a precondition necessary to explain the existence of our world made predominately of matter over antimatter
- $^{4}_{\Lambda}\overline{H}$
  - ➢ The heaviest anti-hypernucleus ever observed experimentally
  - ➢ New opportunity for the study of matter-antimatter asymmetry
- Reconstruction channels

$^{3}_{\Lambda}H \rightarrow\ ^{3}He + \pi^{-}, ^{3}_{\Lambda}\overline{H} \rightarrow\ ^{3}\overline{He} + \pi^{+}$ (Assumed branching ratio 25%)

$^{4}_{\Lambda}H \rightarrow\ ^{4}He + \pi^{-}, ^{4}_{\Lambda}\overline{H} \rightarrow\ ^{4}\overline{He} + \pi^{+}$ (Assumed branching ratio 50%)

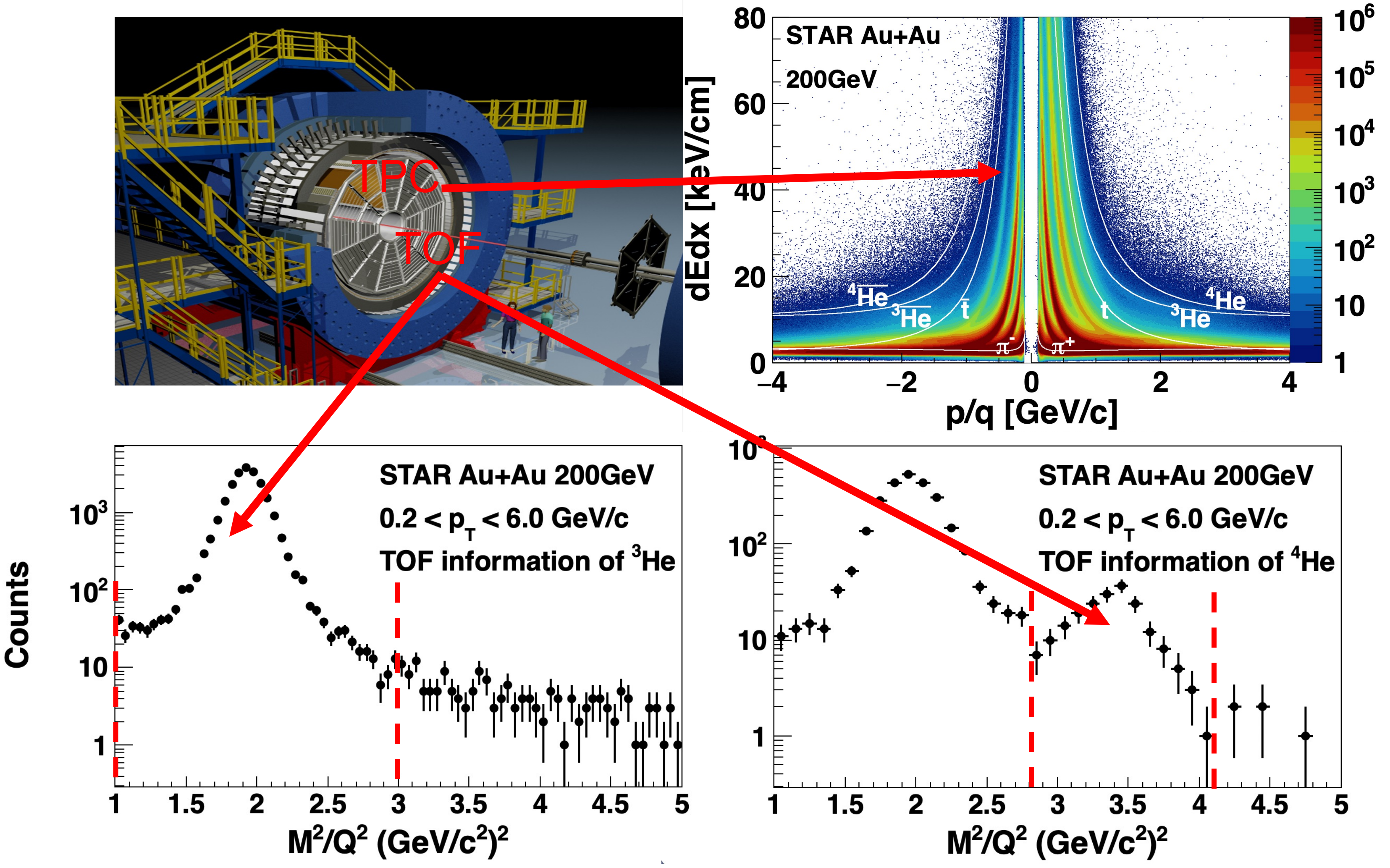
- Datasets from STAR at RHIC facility

Year	$\sqrt{s_{NN}}$ GeV	System	Events
2010	200	Au+Au	0.67B
2011	200	Au+Au	0.68B
2012	193	U+U	0.67B
2018	200	Ru+Ru, Zr+Zr	4.61B



➢ Due to low production yield, data from various collision systems and triggers are used in the search, to maximize the statistics.

Particle identification



- **Event selection:**
  $-40<V_Z<40$ cm,
  $\sqrt{V_X^2+V_Y^2}<2$ cm
- **Track selection:**
  $n_{Hits}>20$,
  $n_{Hits}/n_{HitsMax}>0.52$
- **Particle identification:**
  π: $|n\sigma_{\pi}|<3$
  ^3He: $|n\sigma_{^3He}|<3$,
  if TOF matched,
  $1.0 < m^2/Q^2 < 3.0$ GeV^2/c^4
  ^4He: $|n\sigma_{^4He}|<3$ && ($|n\sigma_{^3He}|>3.5$
  || ($2.8 < m^2/Q^2 < 4.1$GeV^2/c^4
  && |TOF local y|<2))

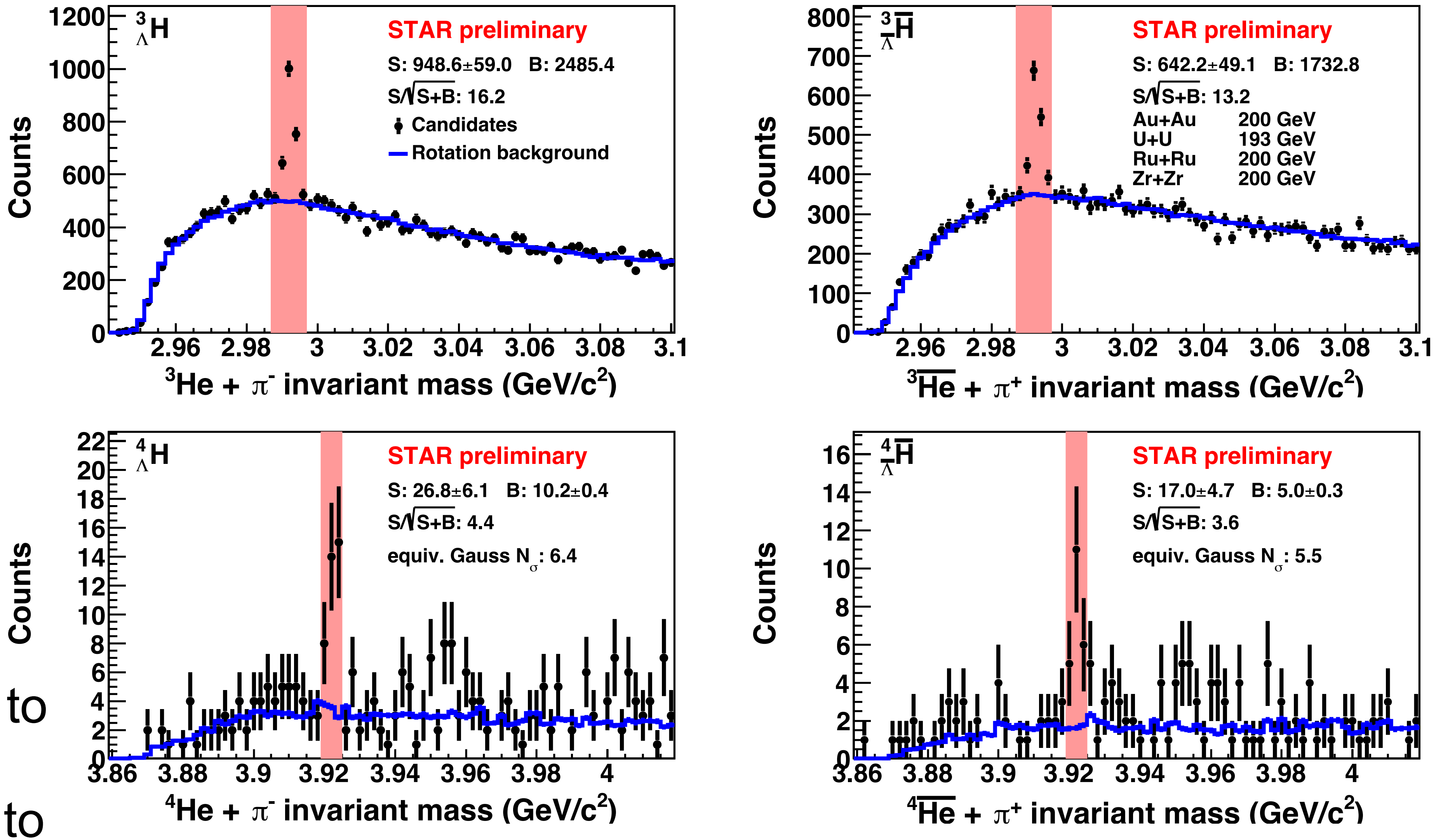
^4He need much tighter cuts because of ^3He contamination

${}^{3}_{\Lambda}H$, ${}^{3}_{\bar{\Lambda}}\bar{H}$, ${}^{4}_{\Lambda}H$ and ${}^{4}_{\bar{\Lambda}}\bar{H}$ signals

- Kalman-Filter package is used

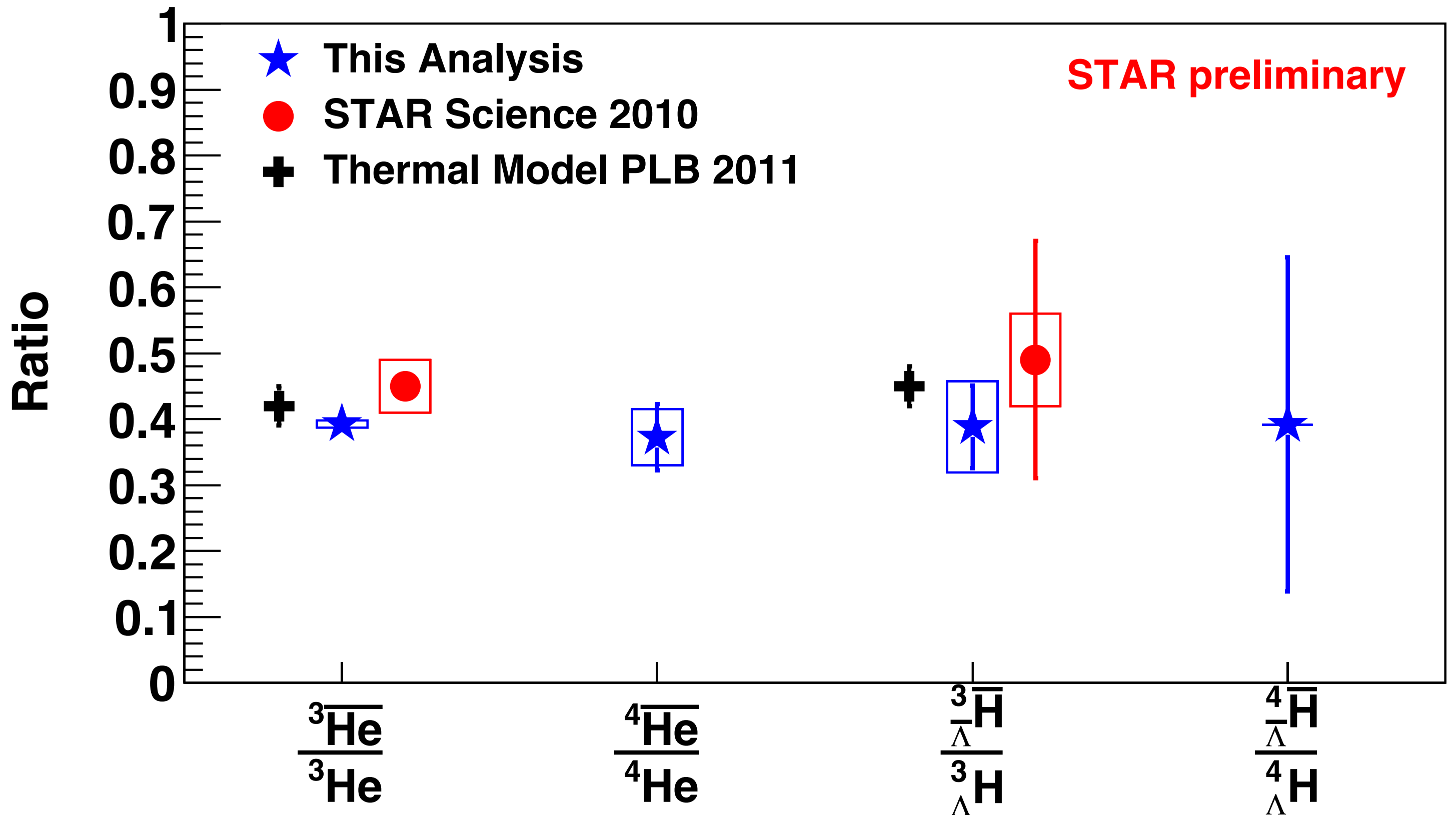
Cuts	${}^{3}_{\Lambda}H, {}^{4}_{\Lambda}H$	${}^{3}_{\bar{\Lambda}}\bar{H}, {}^{4}_{\bar{\Lambda}}\bar{H}$
$\chi^{2\ \pi}_{prim}$	>10	>10
$\chi^{2\ He}_{prim}$	<2000	<2000
χ^{2}_{ndf}	<5	<5
χ^{2}_{topo}	<2	<3
L/dL	>3.4	>3.4
L	>3.5	>3.5
He DCA	<1	-

- Cuts obtained by optimizing ${}^{3}_{\bar{\Lambda}}\bar{H}$ signals to avoid biasing towards larger ${}^{4}_{\bar{\Lambda}}\bar{H}$ signals due to fluctuations



- First observation of heaviest anti-hypernucleus in experiment!

Production yield ratios



- Particle yields are efficiency corrected, with only minimum-bias trigger and $\frac{p_T}{M} \epsilon [0.7,1.5], y \epsilon [-0.7,0.7]$
- $\frac{^3\overline{He}}{^3He} \sim \frac{^3_{\overline{\Lambda}}\overline{H}}{^3_{\Lambda}H}, \quad \frac{^4\overline{He}}{^4He} \sim \frac{^4_{\overline{\Lambda}}\overline{H}}{^4_{\Lambda}H}$
- The newly measured yield ratios are consistent with previous results and model

Conclusion and outlook

- $^4_{\overline{\Lambda}}\overline{H}$ signal observed for the first time with over 5σ significance
- Various antimatter / matter ratios consistent with expectations
- Lifetime measurement on-going

Back up

Equivalent Gaussian significance

- Gaussian distribution precondition is that the number of events is large enough to show the independence. For ${}^{3}_{\Lambda}\boldsymbol{H}$ and ${}^{3}_{\Lambda}\overline{\boldsymbol{H}}$, there are several hundreds counts per bin, so Gaussian distribution can be used to describe the significance. But for ${}^{4}_{\Lambda}\boldsymbol{H}$ and ${}^{4}_{\Lambda}\overline{\boldsymbol{H}}$, the candidates in one bin is rare(~10/bin), Gaussian distribution cannot be used in this situation.
- Poisson distribution is suitable for this situation. Significance is equal to the signal peak confidence level, according the side band region, we can get an expectation background counts(λ) if there is no signal in the peak range. But the fact is that counts in this region is k, so the possibility of the peak fluctuated by the background can be calculated by:

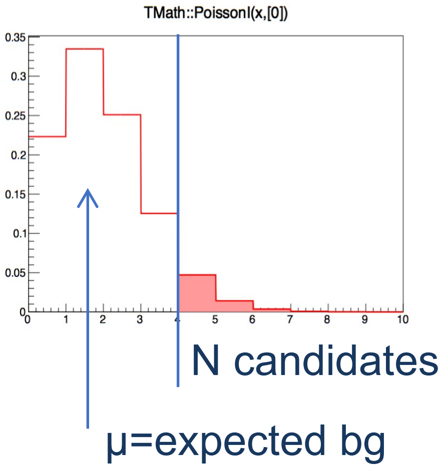
$$p(X = k) = \frac{e^{-\lambda}\lambda^{k}}{k!}$$

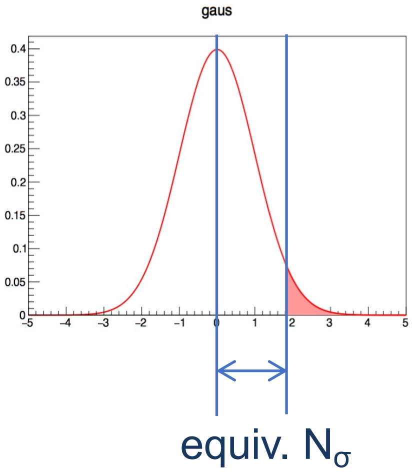
For example in ${}^{4}_{\Lambda}\overline{\boldsymbol{H}}$, the signal window is 3 bins, the expected background counts are 5.0, and the total bin counts are 22.0. If we believe this is caused by fluctuation, we can get the possibility:

$$p(X = 22) = \frac{e^{-5}5^{22}}{22!} = 1.4292267e - 08$$

This possibility shows that background fluctuated peak can be accepted within $1.4292267e - 08$, which we can believe the peak structure is from a bound state -- ${}^{4}_{\Lambda}\overline{\boldsymbol{H}}$.

- But usually, we used Gaussian distribution significance to estimate the possibility, thus Equivalent Gaussian N_{σ} significance is obtained by having equal integrals of the tail for Poisson above N candidates and for Gaussian above N_{σ}

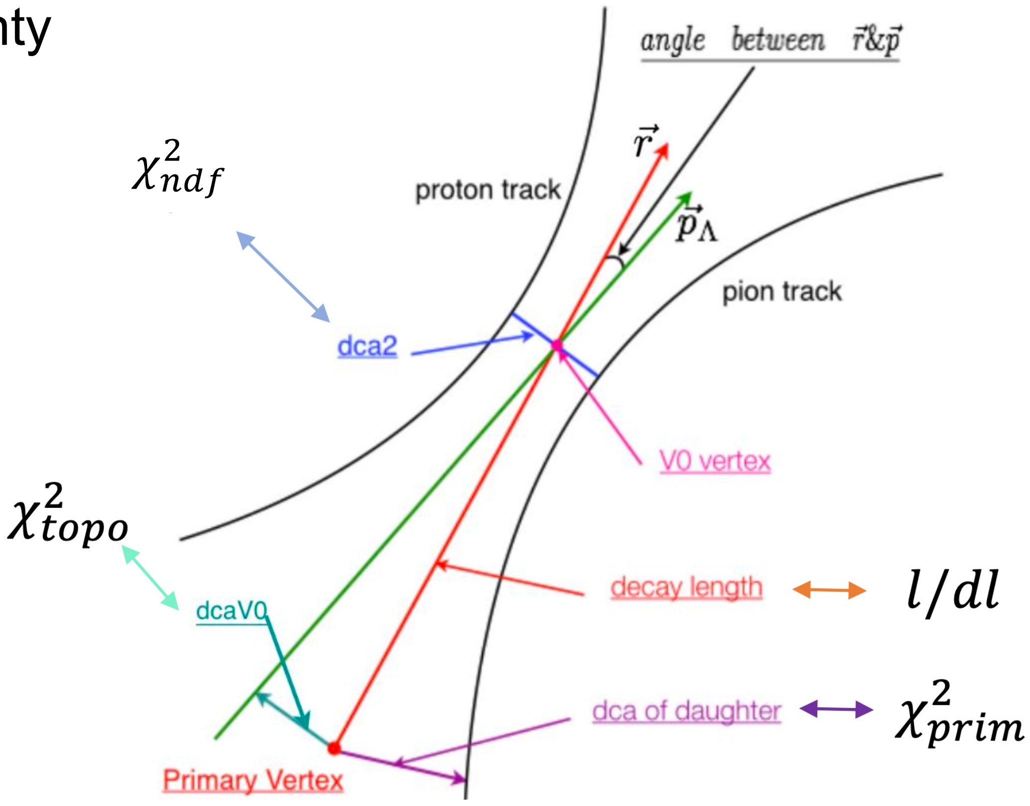




Back up

KF particle package topology cuts

- χ^2_{ndf}: DCA (distance of closest approach) between helium and pion tracks, in terms of uncertainty
- $\chi^{2\ He}_{prim}$: helium deviation from PV, in terms of uncertainty
- $\chi^{2\ \pi}_{prim}$: pion deviation from PV, in terms of uncertainty
- χ^2_{topo} : V0 deviation from PV, in terms of uncertainty
- $\mathbf{L/dL}$: decay length / decay length error
- $\mathbf{L}$: decay length
- $\mathbf{He\ DCA}$: helium DCA from PV



Plot from Jakub Kubát, 2019, Faculty of Nuclear Science and Physical Engineering