Beam Energy Scan on Hypertriton Production and Lifetime Measurement

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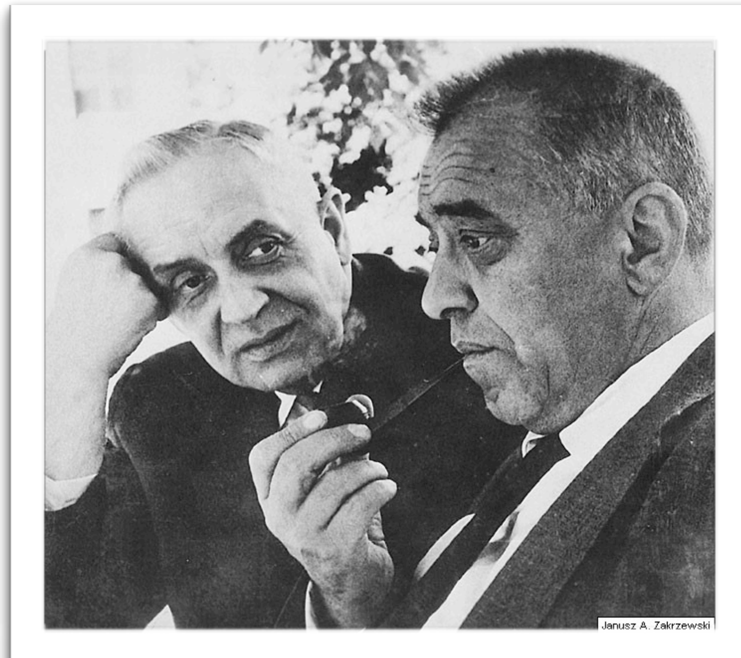
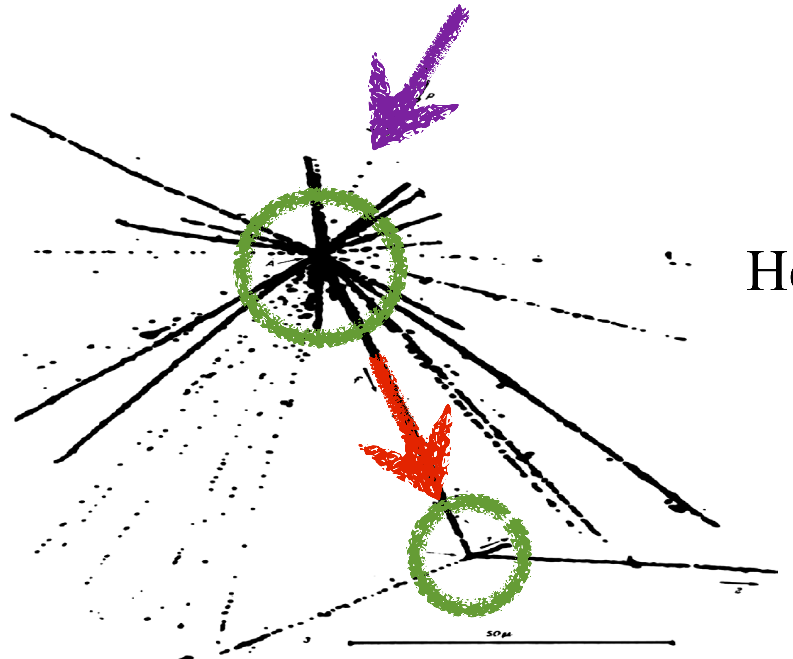
Outline

- ★ Introduction and Motivation
- ★ Analysis Details
- ★ ${}^{3}_{\Lambda}H$ Production
- ★ Beam Energy Dependence of Strangeness Population Factor
- ★ Hypertriton Lifetime Measurement
- ★ Conclusions and Outlook

Hypernucleus

Hypernucleus: Nucleus which contains at least one hyperon in addition to nucleons.



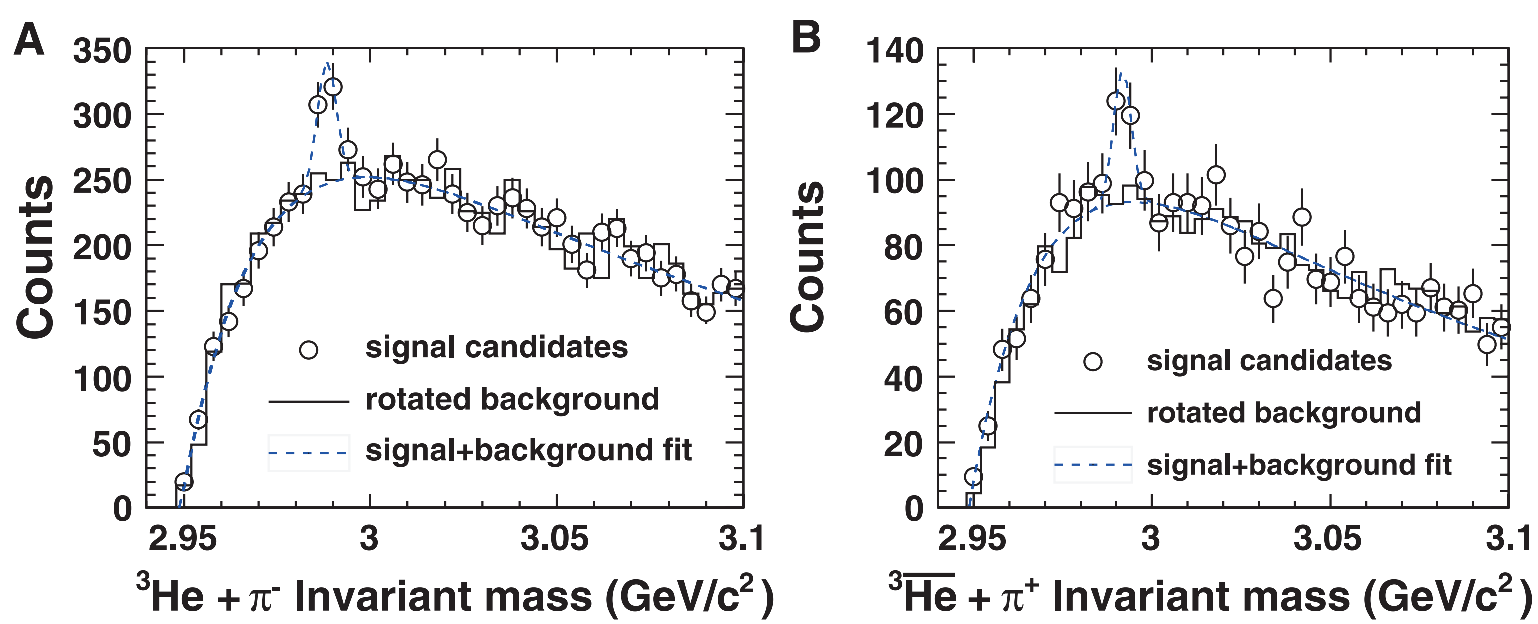


M. Danysz and J. Pniewski, Phil. Mag. 44 (1953) 348

Hyperon-Nucleon (Y-N) Interaction

Helps to understand strong interactions
Helps to study baryon octet
Helps to study neutron stars

Binding energy and lifetime are sensitive to Y-N interactions



STAR Collaboration, SCIENCE 328, 58 (2010)

Hypernucleus of Lowest A

$^3_\Lambda H(p+n+\Lambda)$(Hypertriton)

$^3_{\bar{\Lambda}}\overline{H}(\bar{p}+\bar{n}+\bar{\Lambda})$(Antihypertriton)

Easiest to be produced in HIC

Sensitivity to QCD Phase Transition

Hypertriton is a local baryon-strangeness correlation system

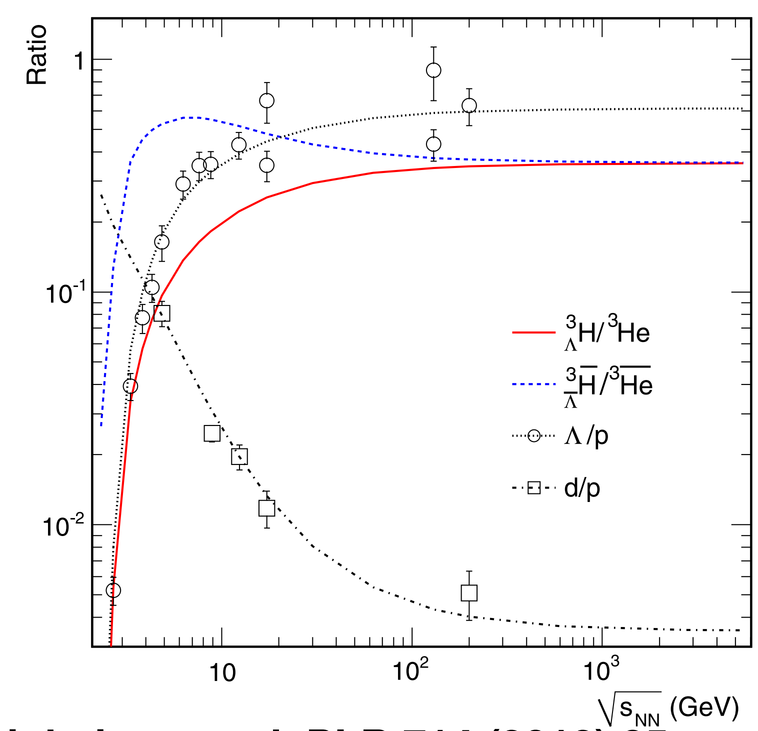
Strangeness Population Factor

$$S_3 = {}^{3}_{\Lambda}H / ({}^{3}He \times \Lambda / p)$$

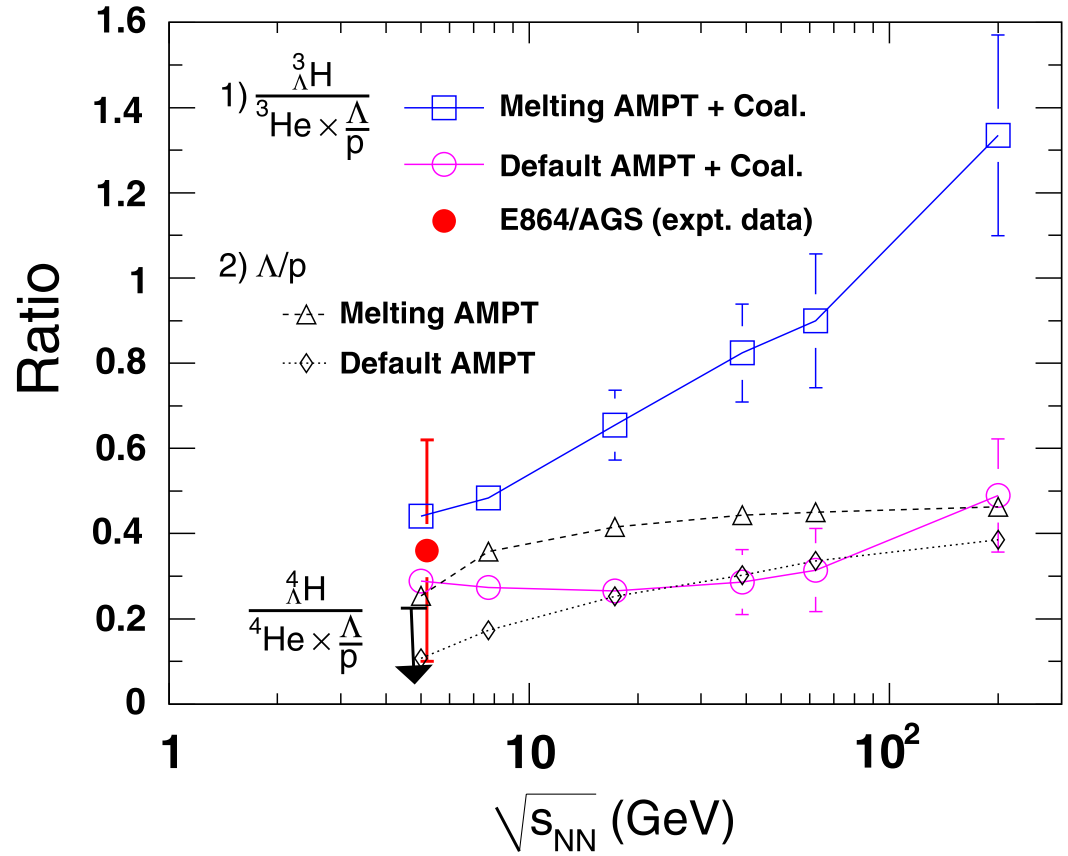
It is predicted that the beam energy dependence of S_3 would behave differently in pure hadron gas and QGP.

A.Andronic et al., PLB 697 (2011) 203

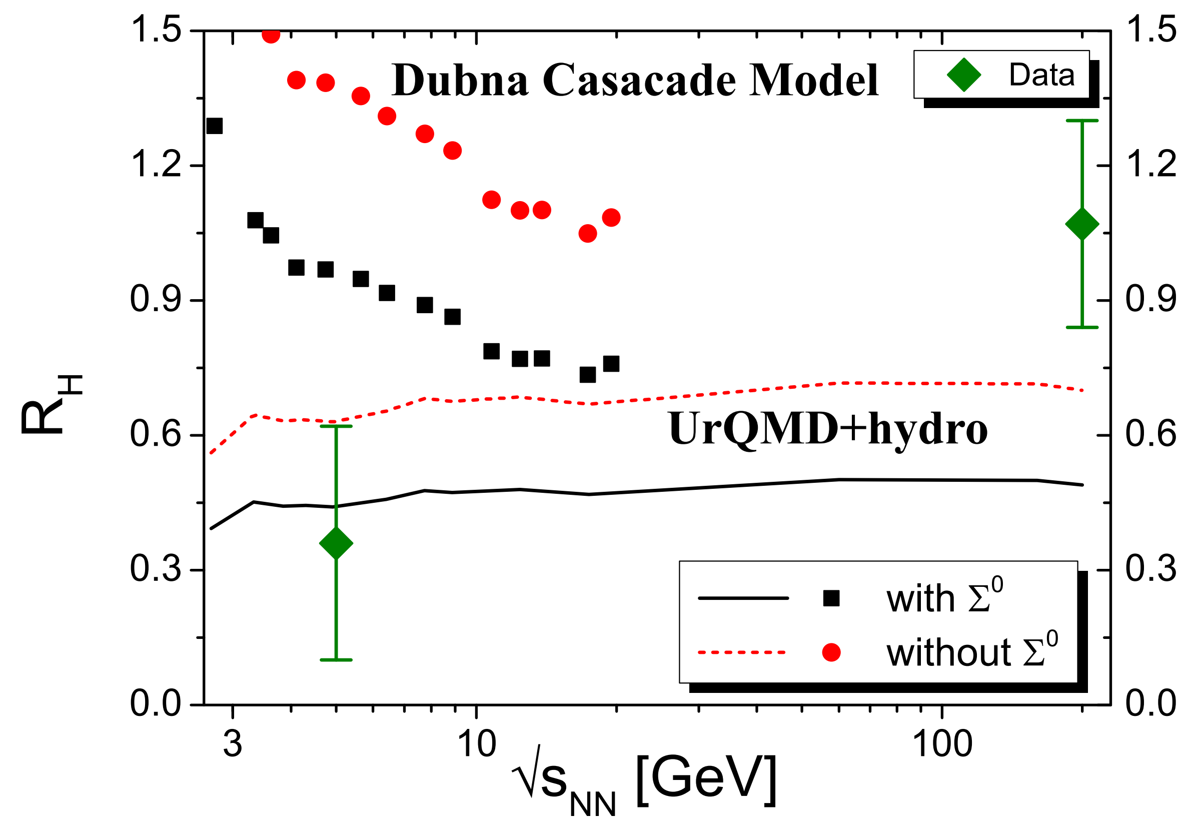
Λ / p



S.Zhang et al., PLB 684 (2010) 224



J. Steinheimer et al.,PLB 714 (2012) 85



Hypertriton Lifetime Measurement

$$\text{free } \Lambda \rightarrow \begin{cases} p\pi^- \ (\sim 63.9\%) \\ n\pi^0 \ (\sim 35.8\%) \end{cases}$$

$$\text{bound } \Lambda \rightarrow \begin{cases} \text{mesonic (suppressed)} \\ \text{nonmesonic}(\Lambda + N \rightarrow N + N) \end{cases}$$

Previous Measurements(before 1973):

Use nuclear emulsion or bubble chamber

Accepted hypertriton events: less than 80

STAR 2010 Measurement

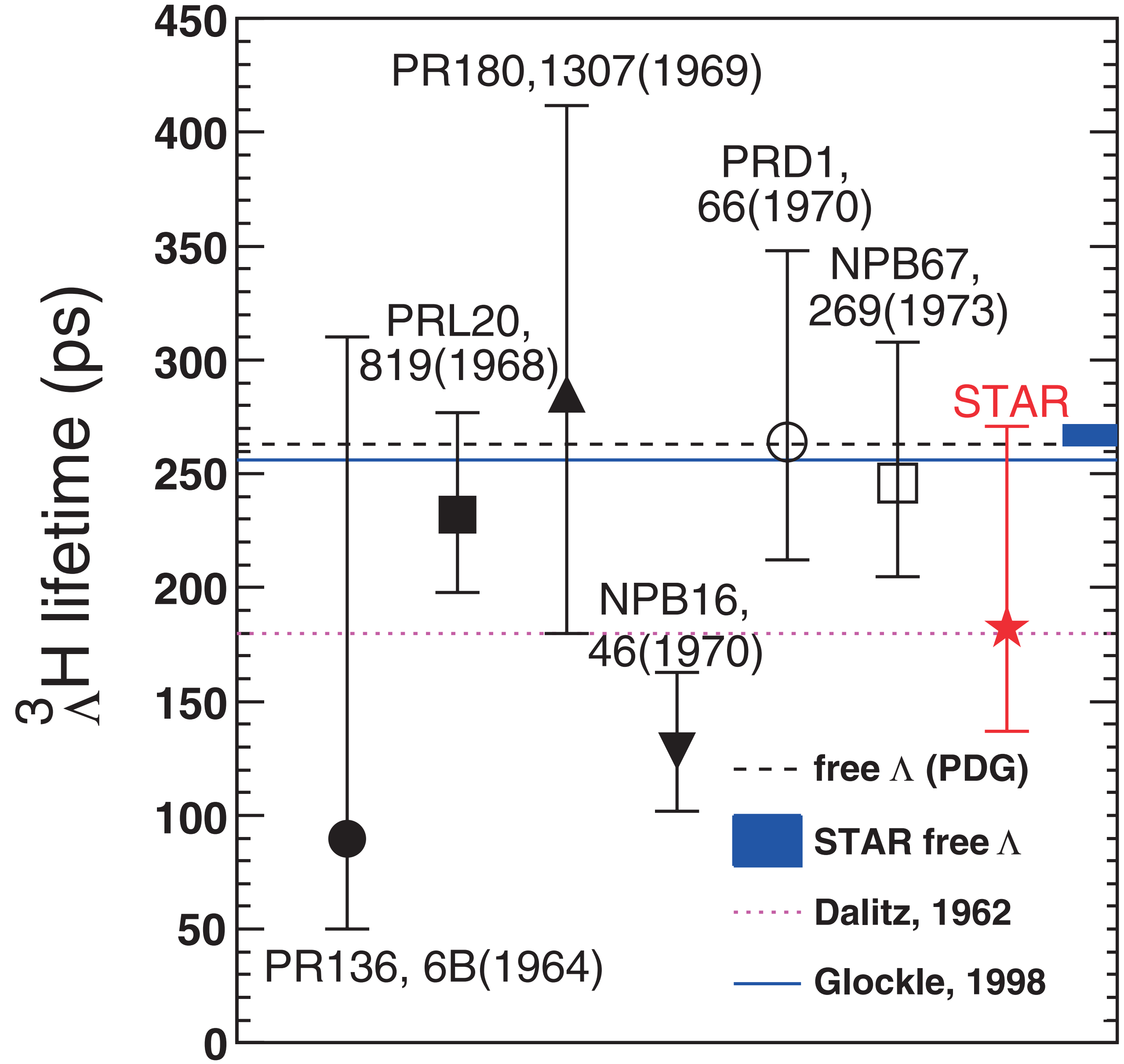
Run4 200GeV	minbias	22M
Run4 200GeV	central	23M
Run7 200GeV	minbias	68M

STAR 2010+2011 Datasets

Run10 200GeV	minbias	~220M
Run10 200GeV	central	~180M
Low Energies	minbias	~212M

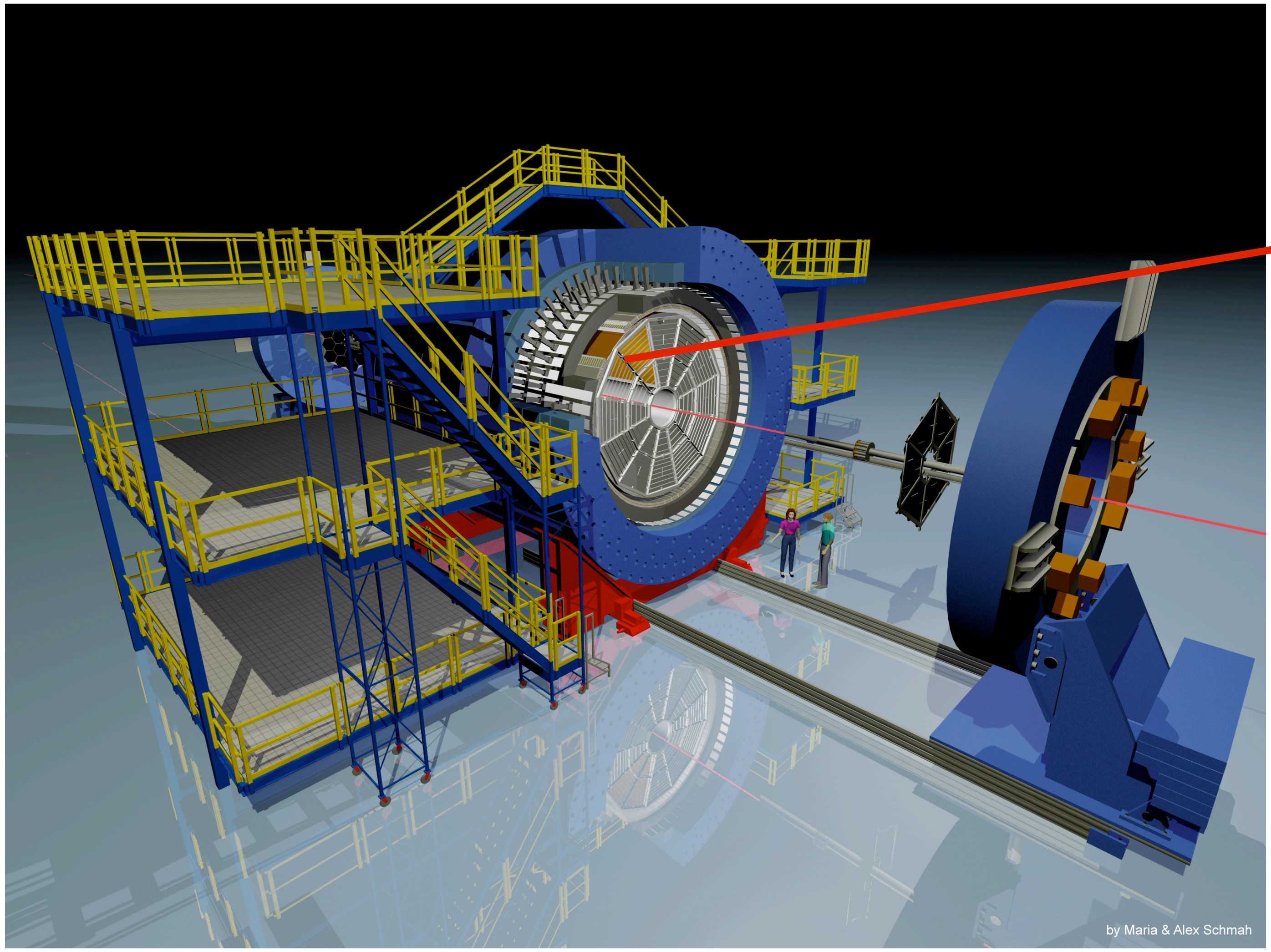
Previous Measurement

STAR Collaboration, SCIENCE 328, 58 (2010)



It is promising to obtain an improved lifetime measurement result using present datasets.

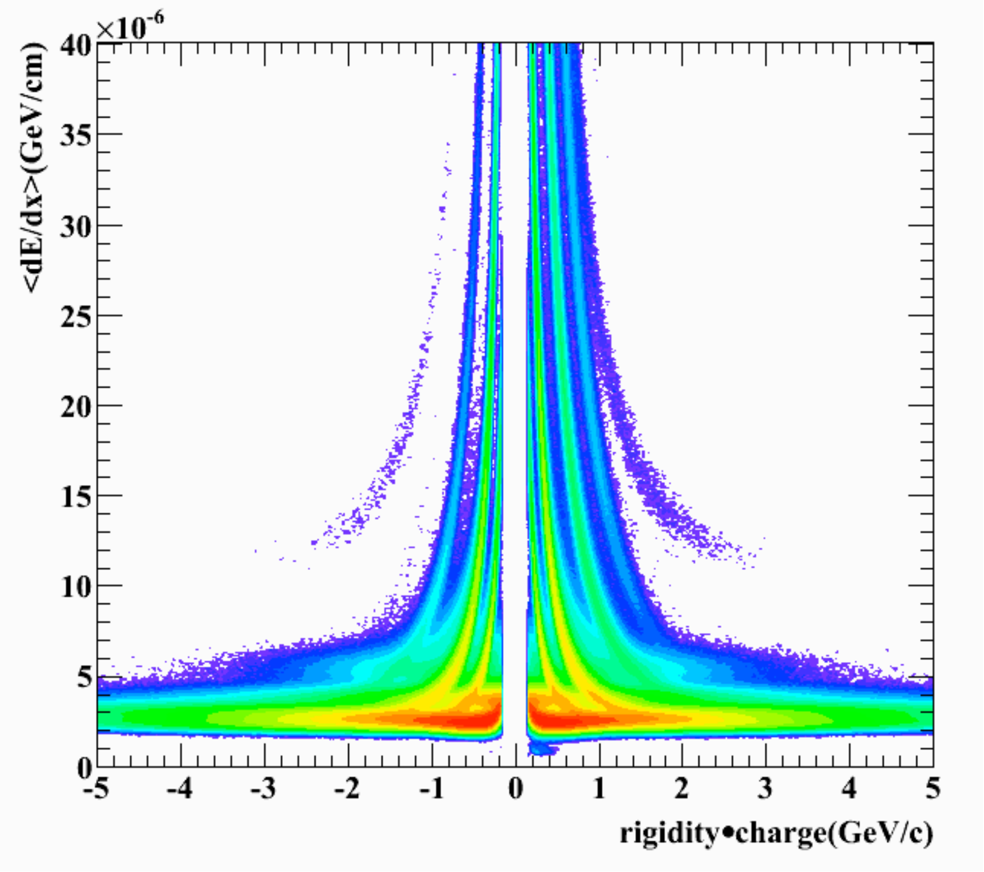
STAR Detector



Time Projection Chamber

($0<\phi<2\pi$, $|\eta|<1$)
Tracking – momentum
Ionization energy loss – dE/dx

Particle Identification



Solenoidal Tracker At RHIC

Datasets and Analysis Method

★ **Datasets**

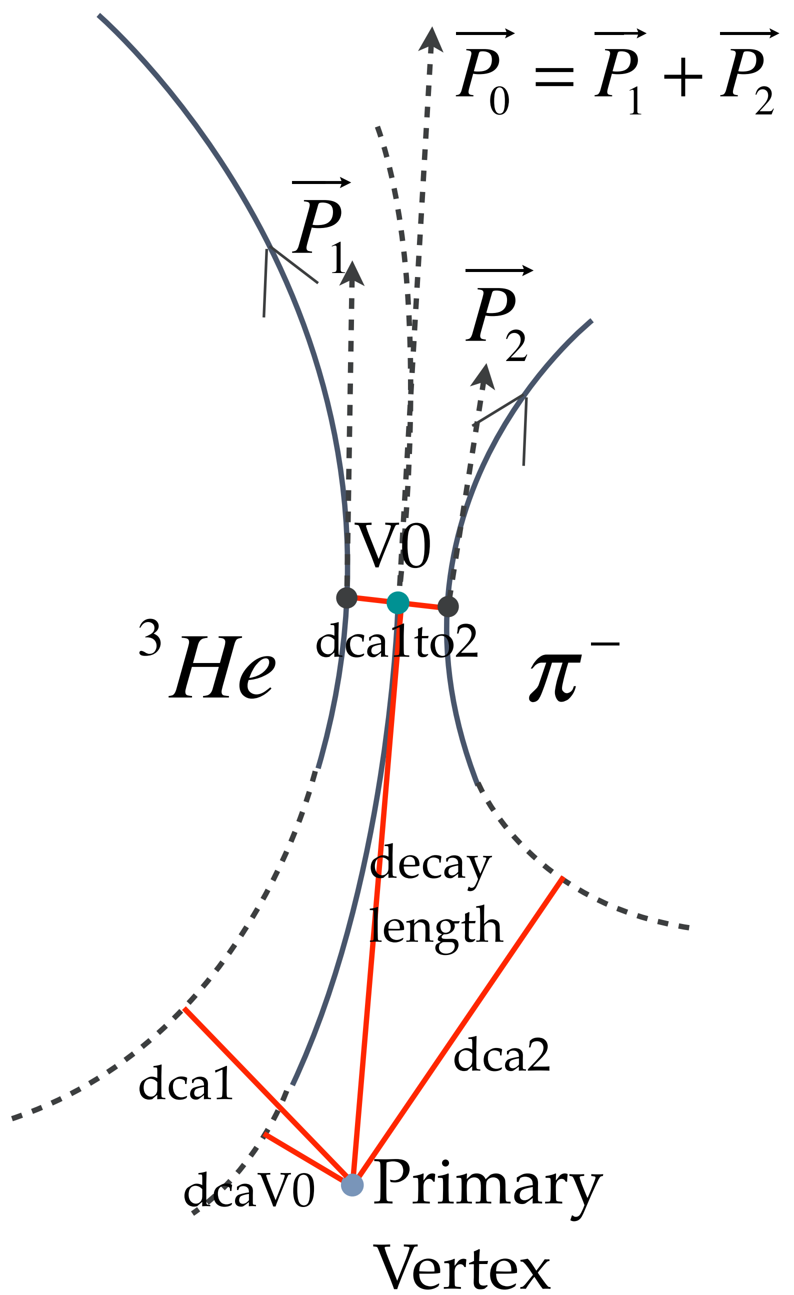
Datasets Used		
Run10 7.7GeV	minbias	~4 M
Run10 11.5GeV	minbias	~11 M
Run11 19.6GeV	minbias	~31 M
Run11 27GeV	minbias	~49 M
Run10 39GeV	minbias	~118 M
Run10 200GeV	minbias	~223 M
Run10 200GeV	central	~199 M
Run7 200GeV	minbias	~56 M

★ **Analysis Method: Secondary Vertex Finding Technique**

- ★ Find helium-3 and pion helices
- ★ Analyze each possible helium-3 and pion pair and give appropriate V0 cuts
- ★ Plot the invariant mass spectra

Secondary vertex finding technique

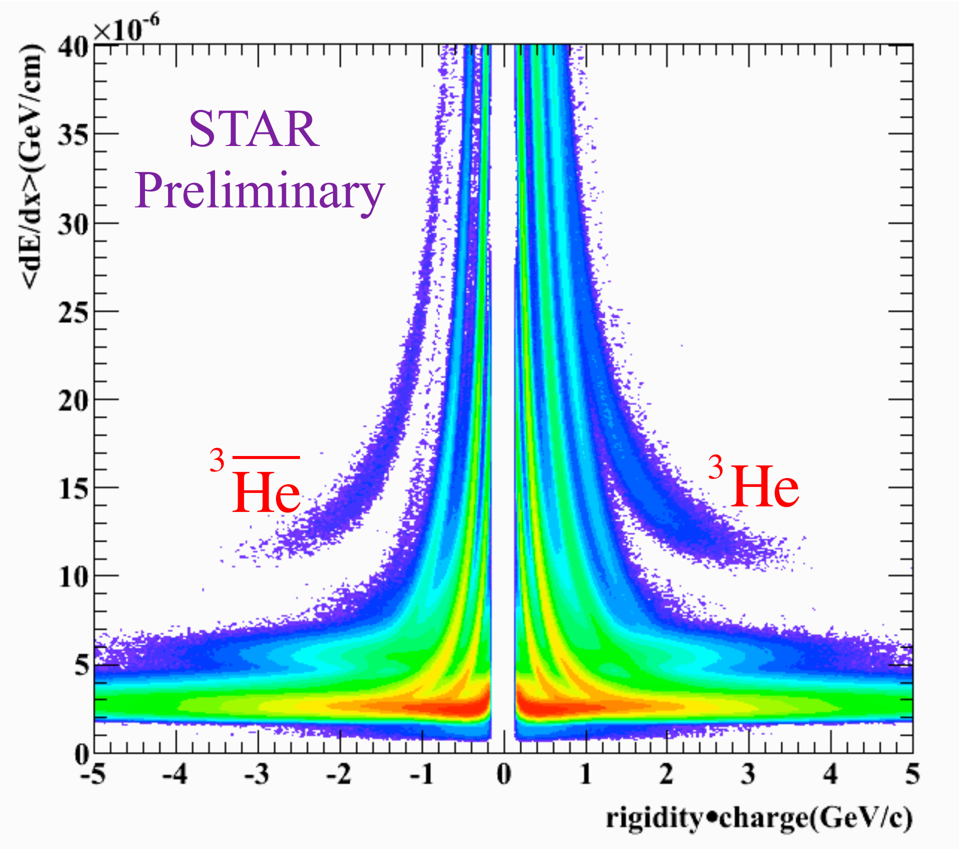
$${}^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$$

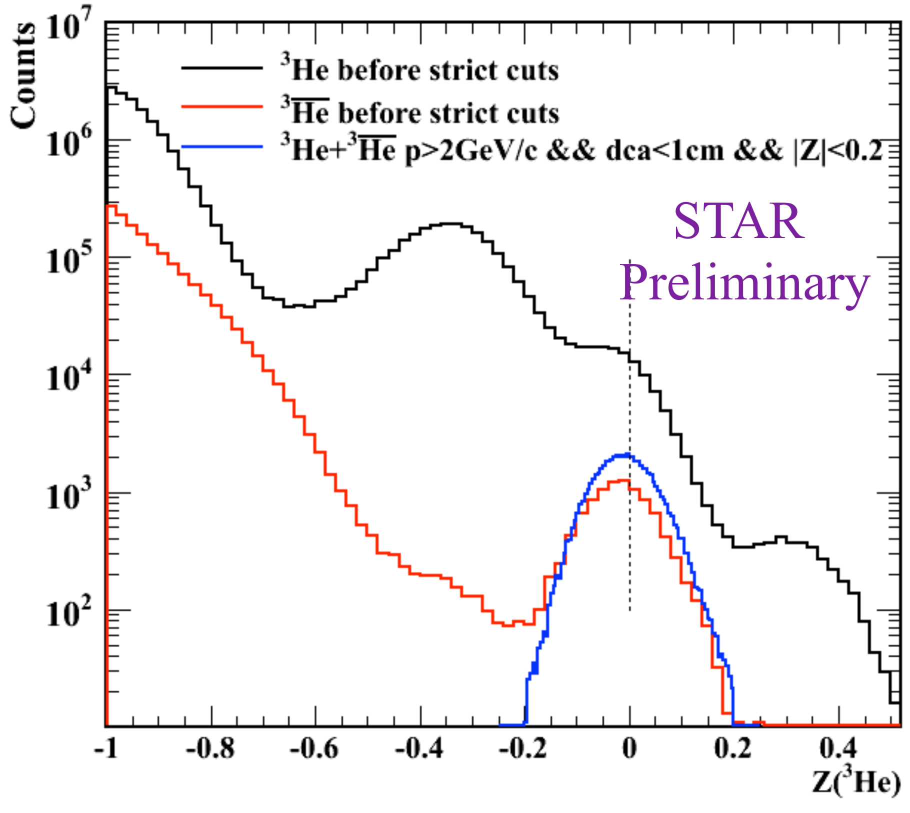


Daughter Identification

★ ^{3}He

$$Z = \ln\left(\frac{dE/dx^{data}}{dE/dx^{Bichsel}}\right)$$





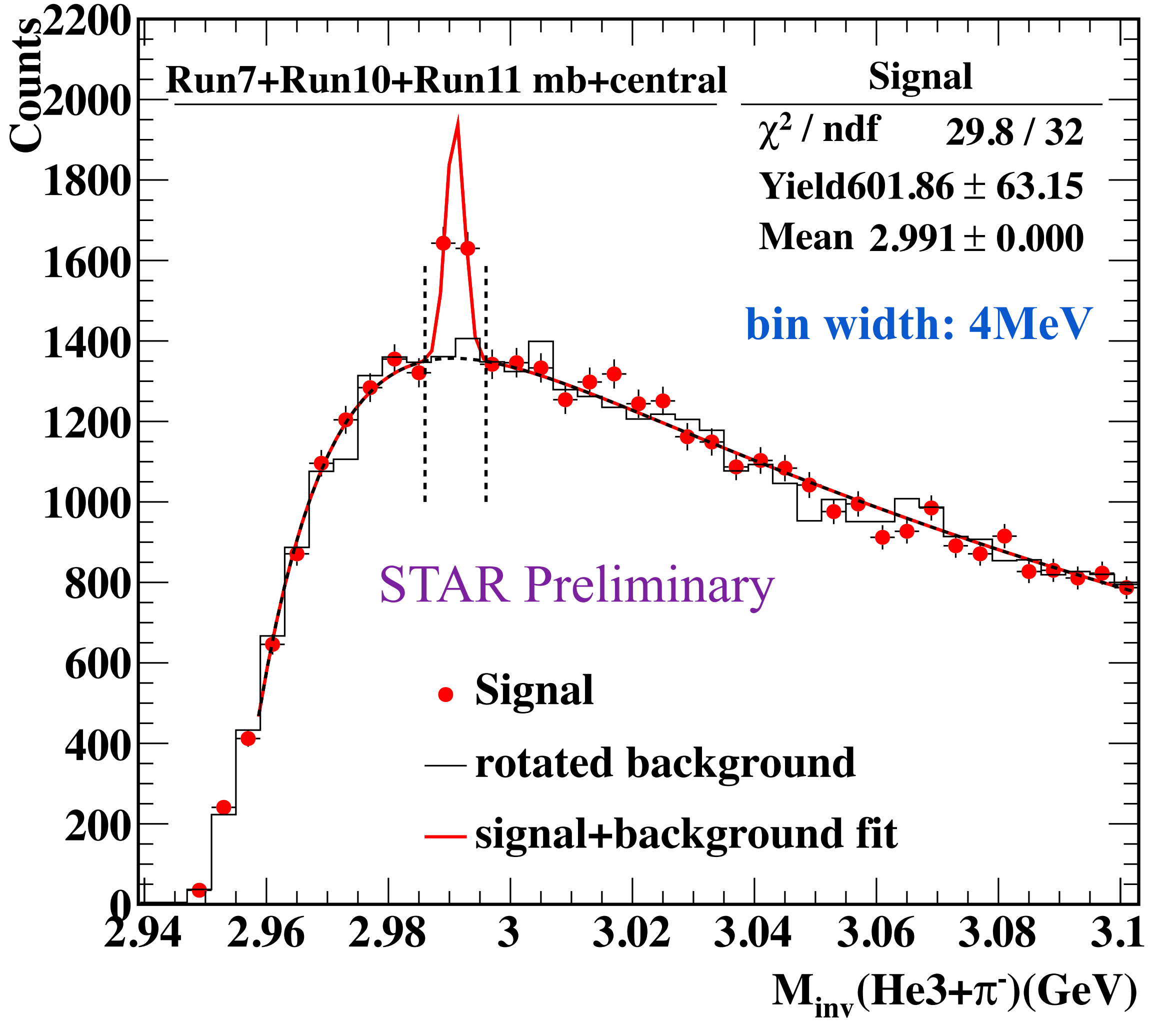
	Run10 7.7	Run10 11.5	Run11 19.6	Run11 27	Run10 39	Run10 200(minbias)	Run10 200(central)	Run7 200 minbias
^{3}He	8587	7161	6321	5312	6456	5822	11181	2264
$^{3}\overline{He}$	0	0	0	19	133	2213	4241	861

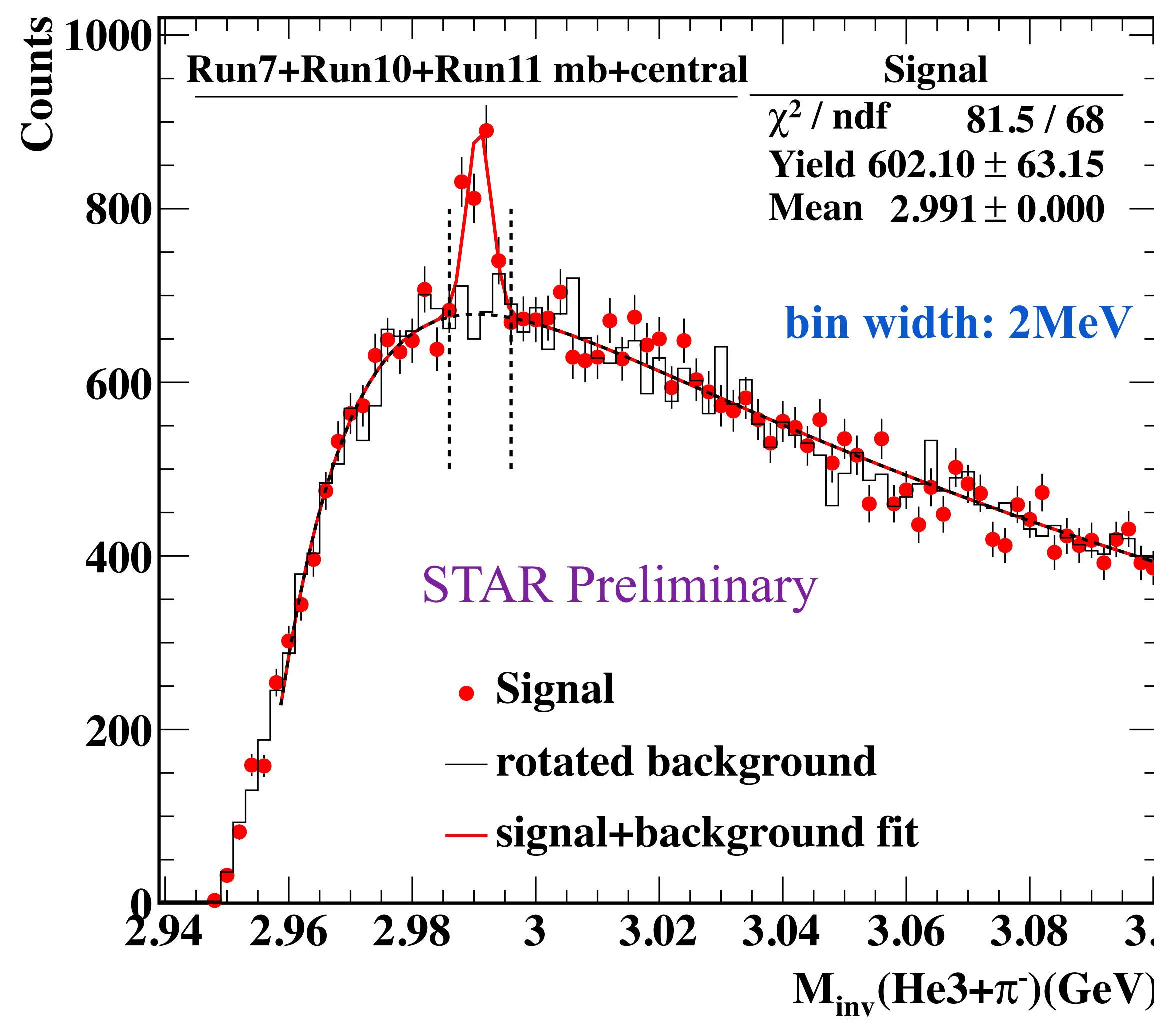
★ π^{-}

$$|n\sigma_{\pi}| < 2$$

Total $^{3}_{\Lambda}H$ Production

Statistics: Run7+Run10+Run11 minbias+central, totally 609.89M events



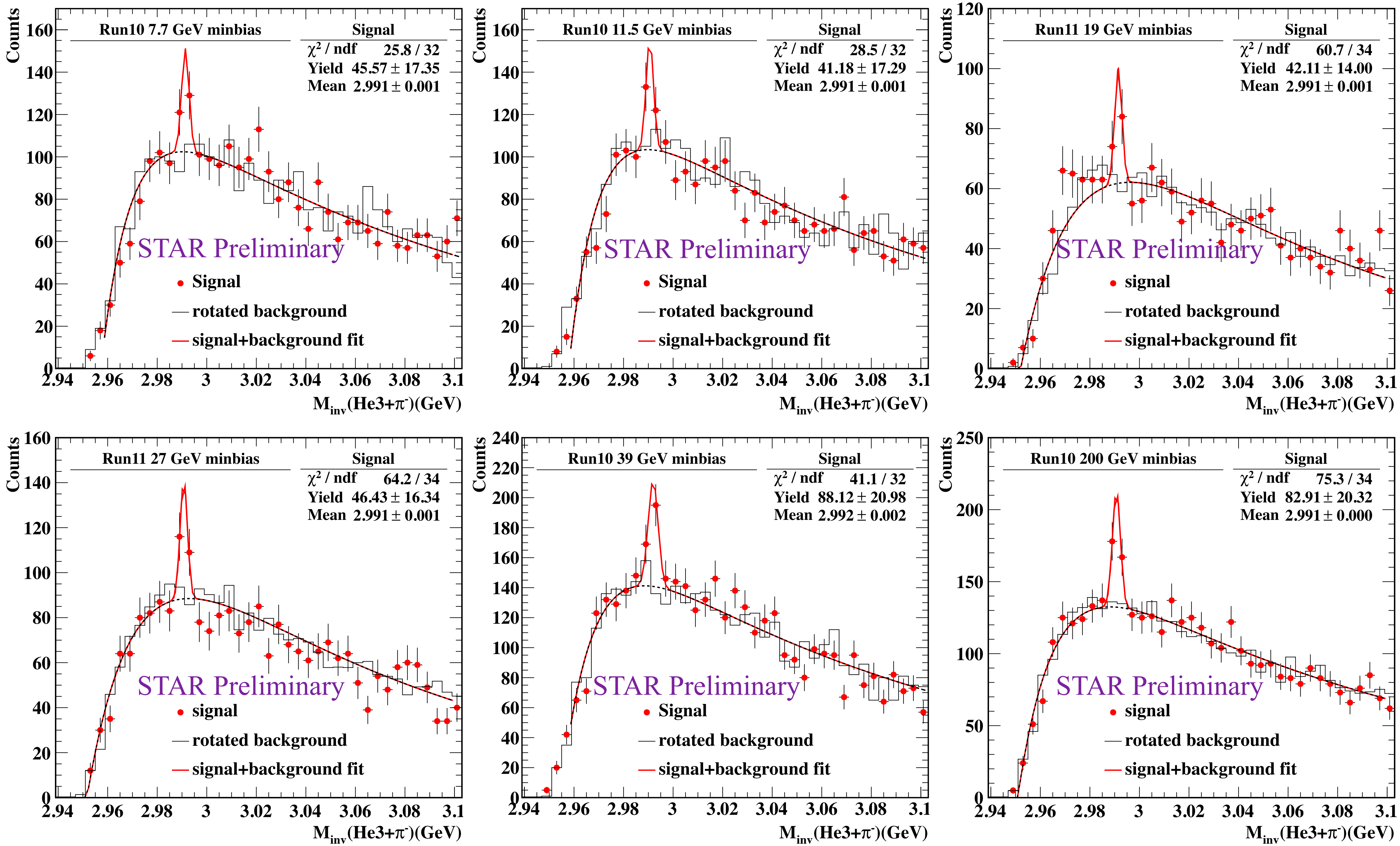


Background Estimation: Rotated background fit
Signal: Bin-bin counting in a fixed mass range : [2.986, 2.996] GeV

$^{3}_{\Lambda}H + ^{3}_{\Lambda}\overline{H}$ produced: 602 ± 63 significance: 9.6σ

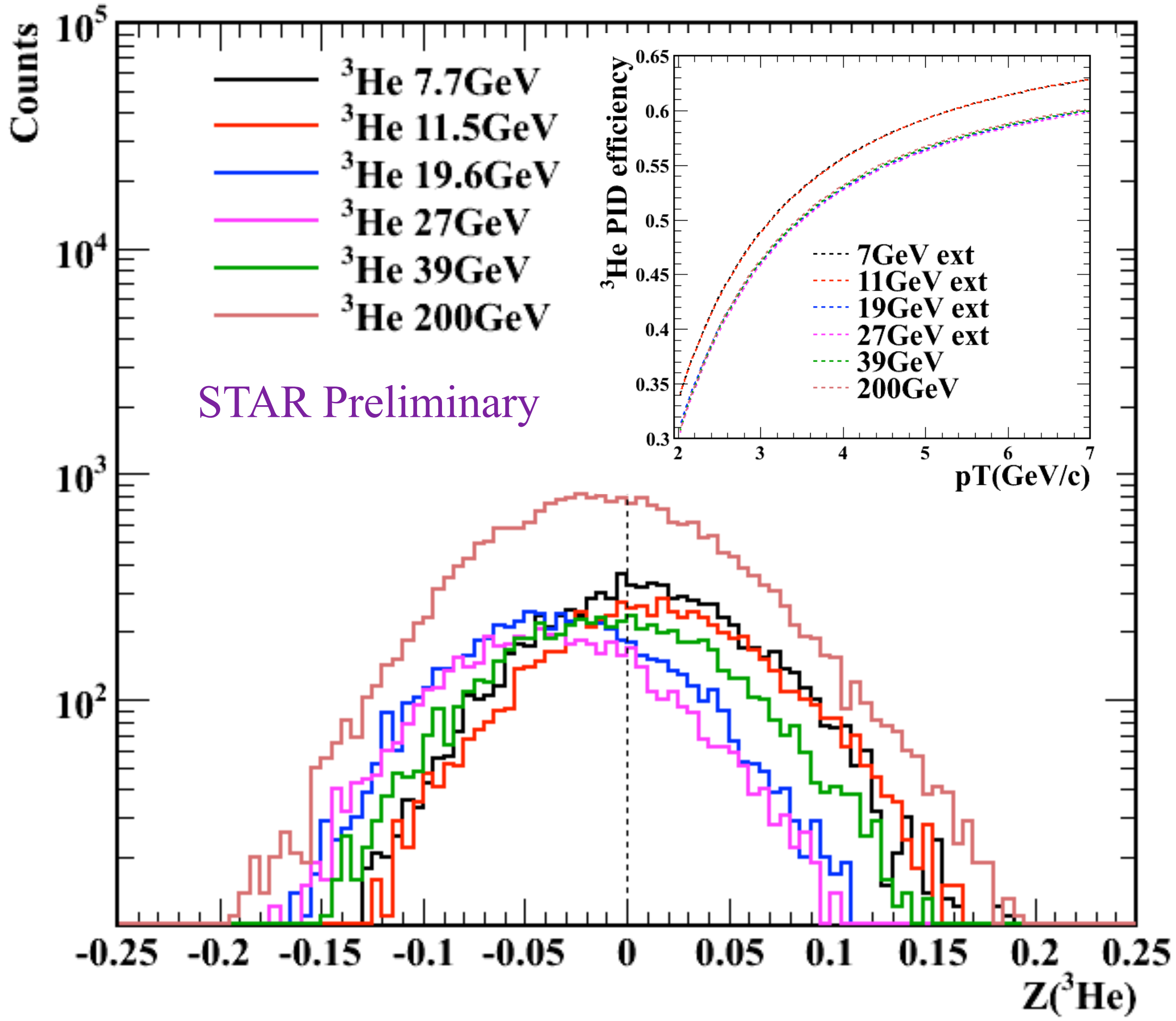
${}^{3}_{\Lambda}H$ Production in Separate Energies

$${}^{3}_{\Lambda}H + {}^{3}_{\Lambda}\overline{H} \text{ produced at } \sqrt{S_{NN}} = 7.7, 11.5, 19.6, 27, 39, 200\text{GeV(minbias)}$$

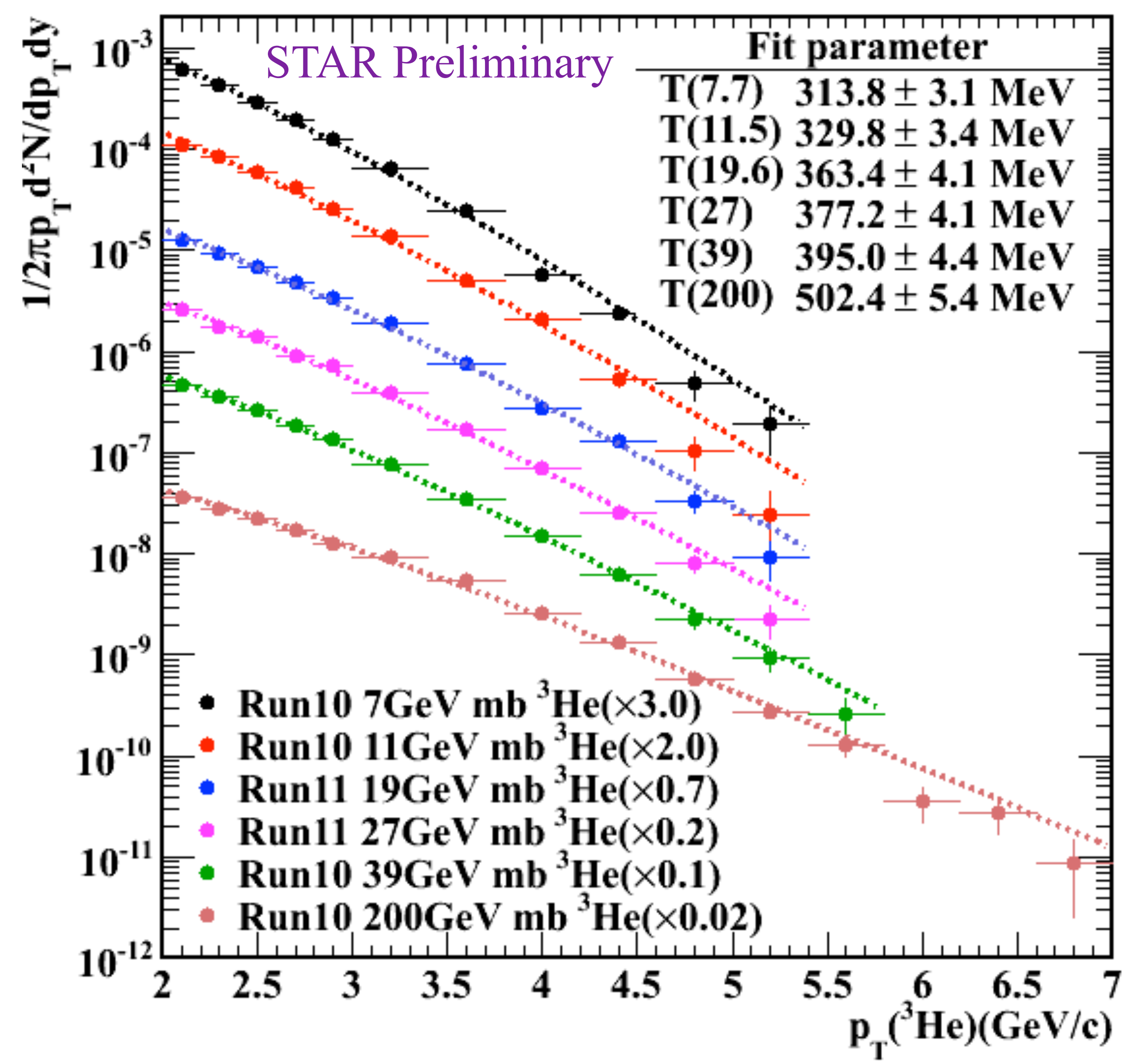


^{3}He p_T Spectra

^{3}He PID and Efficiency

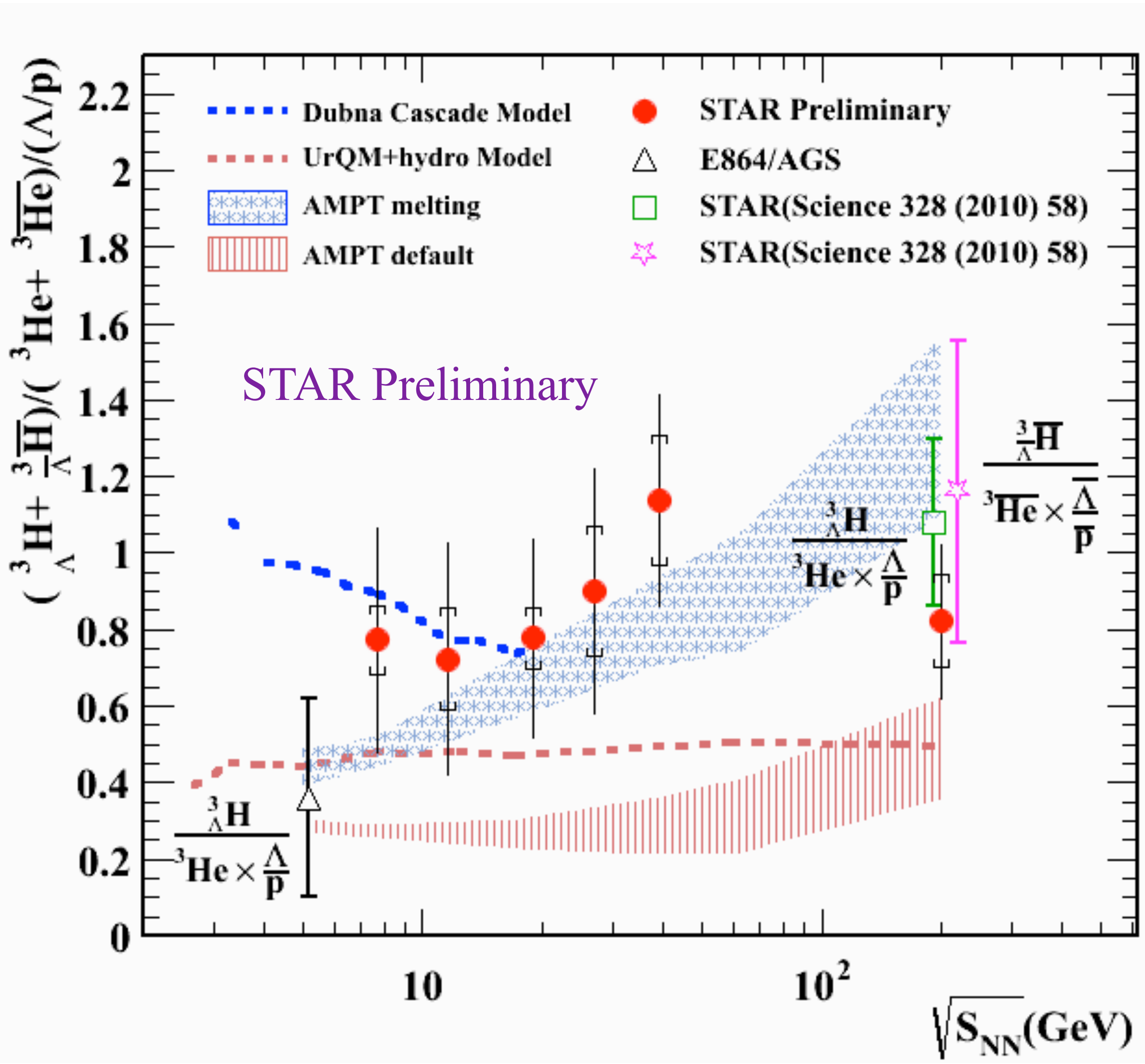


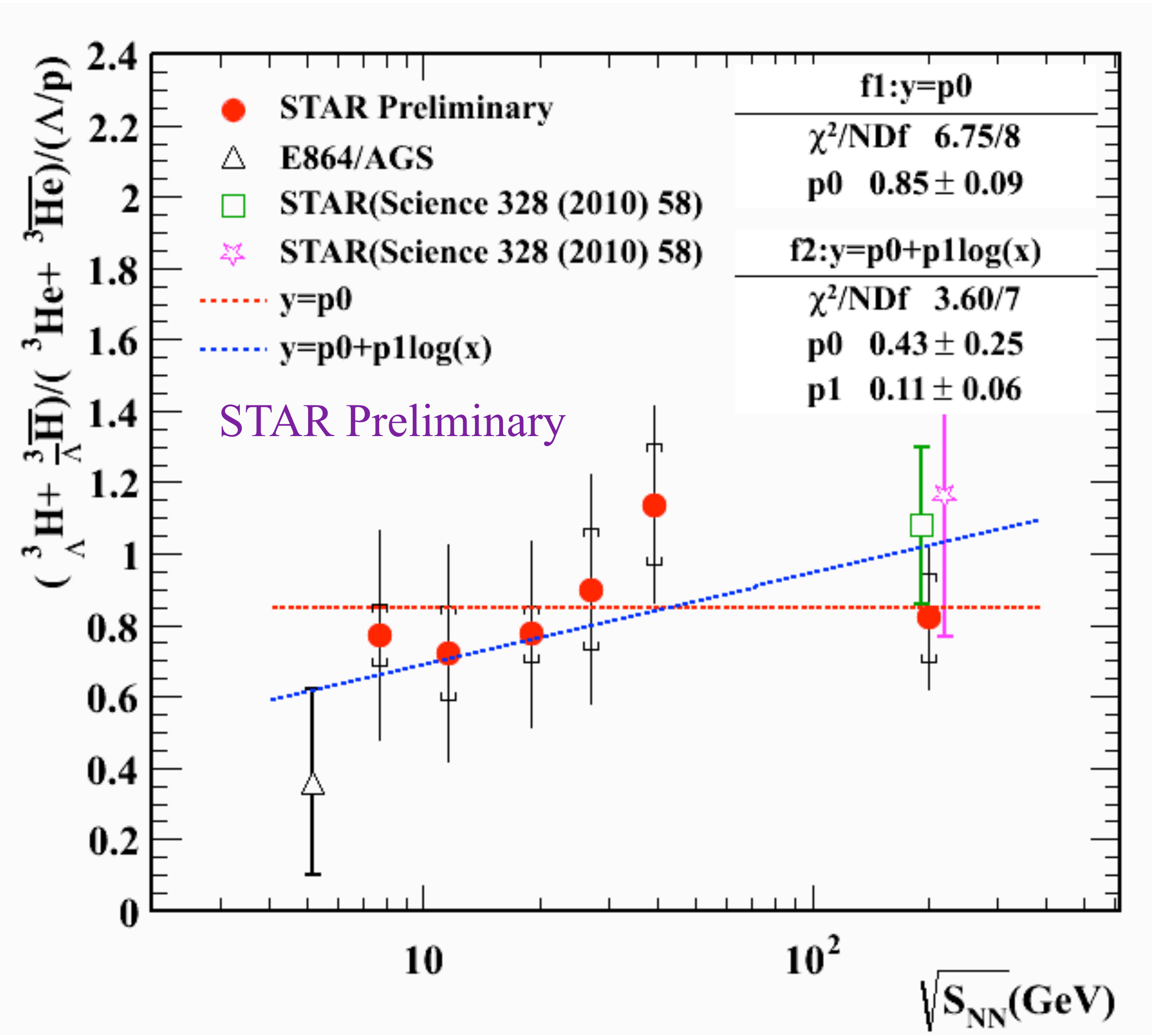
^{3}He p_T Spectra



^{3}He p_T Spectra becomes harder with the increase of beam energy. From this spectra, $^{3}_{\Lambda}H$ / ^{3}He ratio can be obtained by dividing their yields in p_T range [2,5]GeV/c

Beam Energy Dependence of S_3



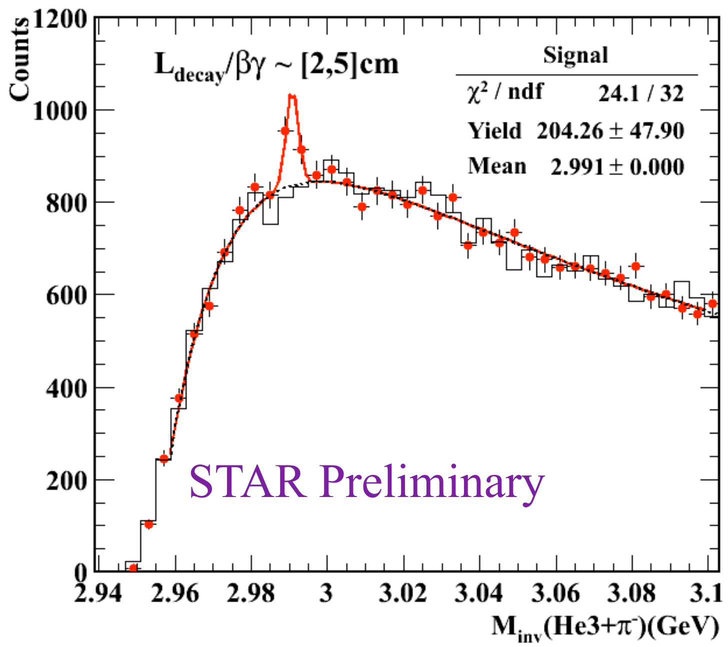


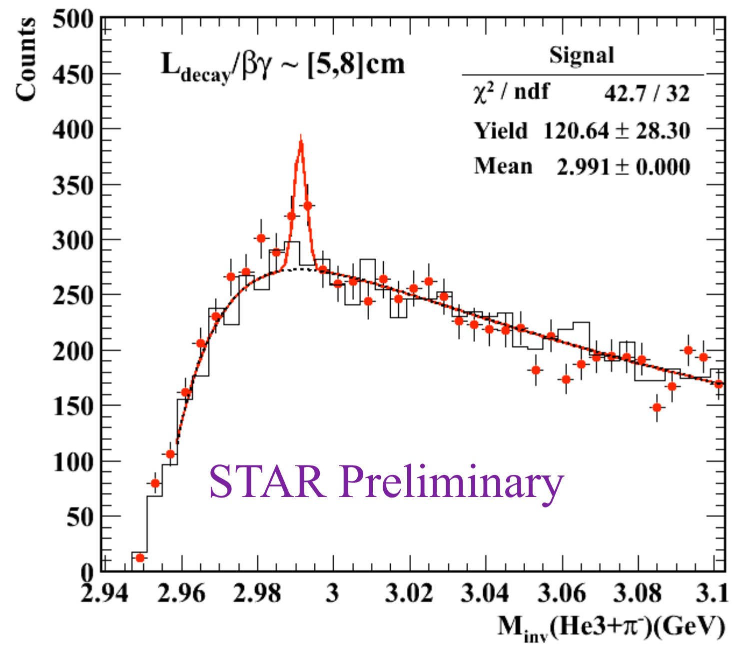
With present statistics, the strangeness population factor indicates (with 1.7σ) an increasing trend with the increase of energy(from 5.2GeV to 200GeV)

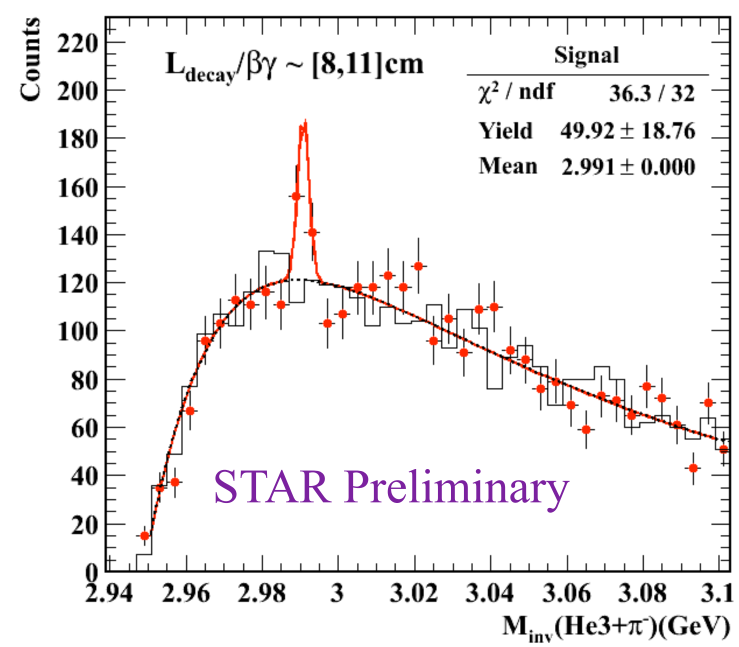
Lifetime Measurement

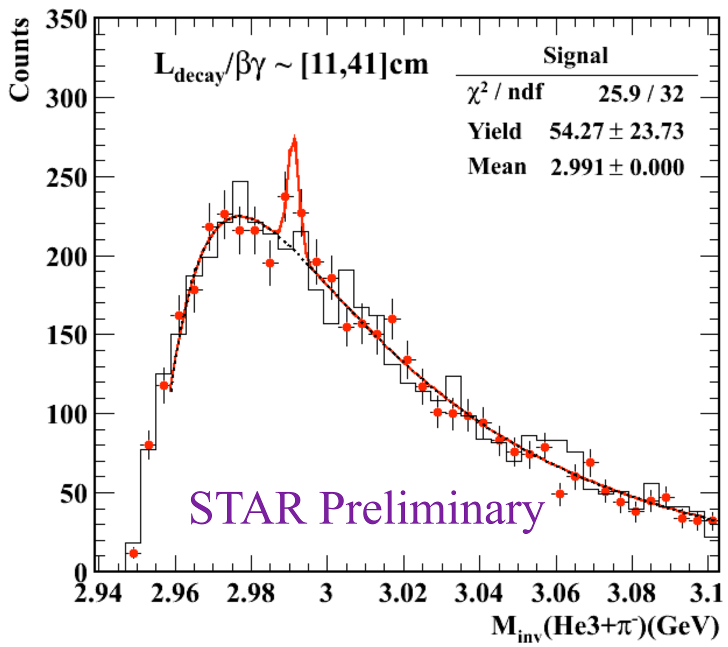
Radioactive Decay Law

$$N(t) = N(0)\times e^{-t/\tau} = N(0)\times e^{-\frac{l}{\beta\gamma}\Big/c\tau}$$, l is the decay length









4 Bins:
[2,5]cm, [5,8]cm, [8,11]cm, [11,41]cm

Datasets:
Run10 7.7,11.5,39,200 minbias,
Run10 200 central,
Run11 19.6, 27 minbias

Systematic Study on Lifetime

Absorption

Hypertriton interacts with air and detector structure materal

$$e^{-\frac{\sigma_{{}^{3}_{\Lambda}H+material}}{\sigma_{p+material}}\cdot\frac{l}{\lambda_T/\rho}} \sim e^{-\frac{\sigma_{{}^{3}_{\Lambda}H+p}}{\sigma_{p+p}}\cdot\frac{l}{\lambda_T/\rho}} < e^{-\frac{\sigma_{pd}+\sigma_{p\Lambda}}{\sigma_{pp}}\cdot\frac{l}{\lambda_T/\rho}}$$

Absorption effect is less than 1.5% and can be neglected

Bin Width

Present is 4MeV bin, τ fit result is 123 ± 24ps

For 2MeV bin, τ fit result is 116 ± 23ps

Systematic error due to binning is 5.7%

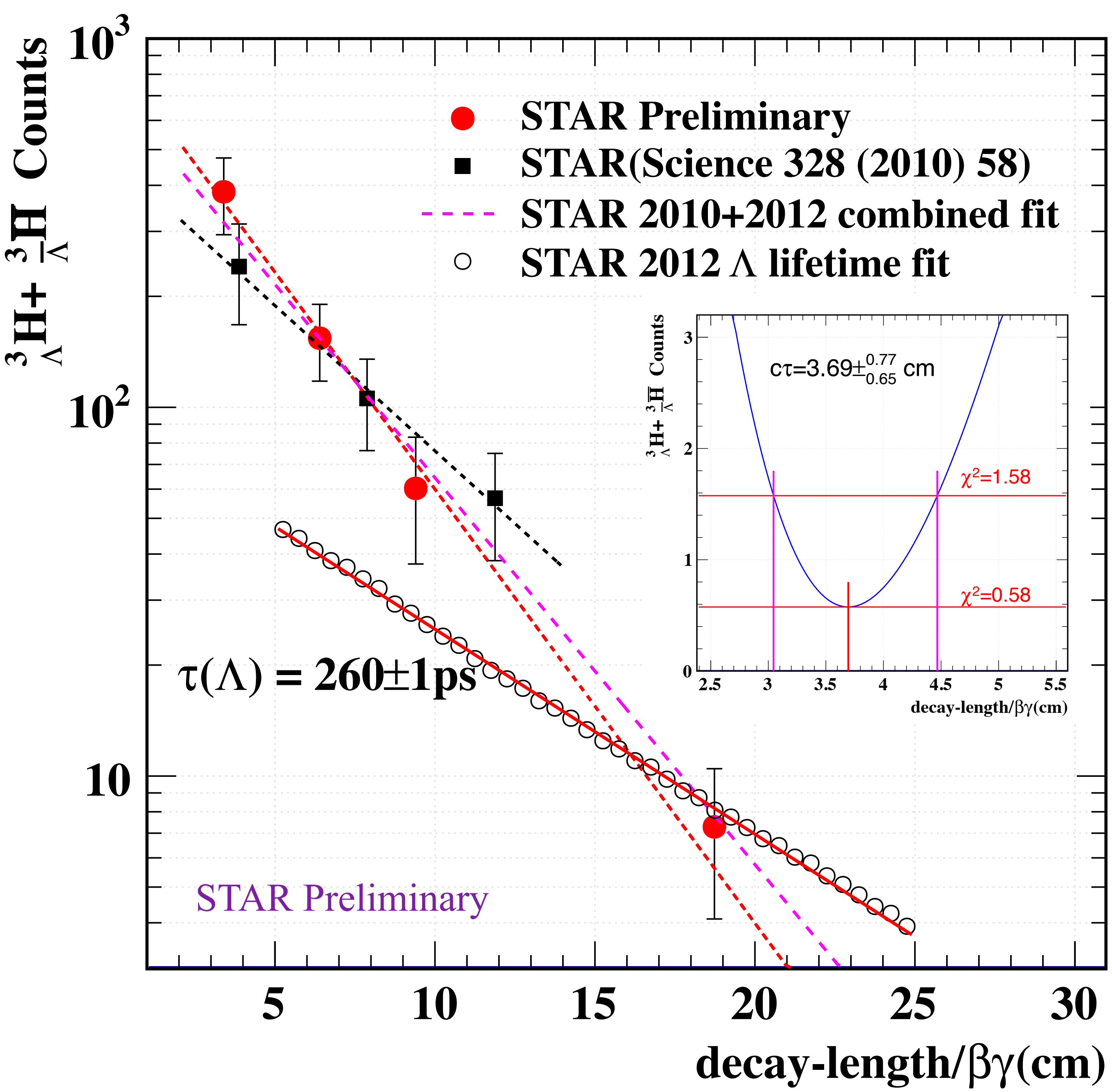
Different Cuts

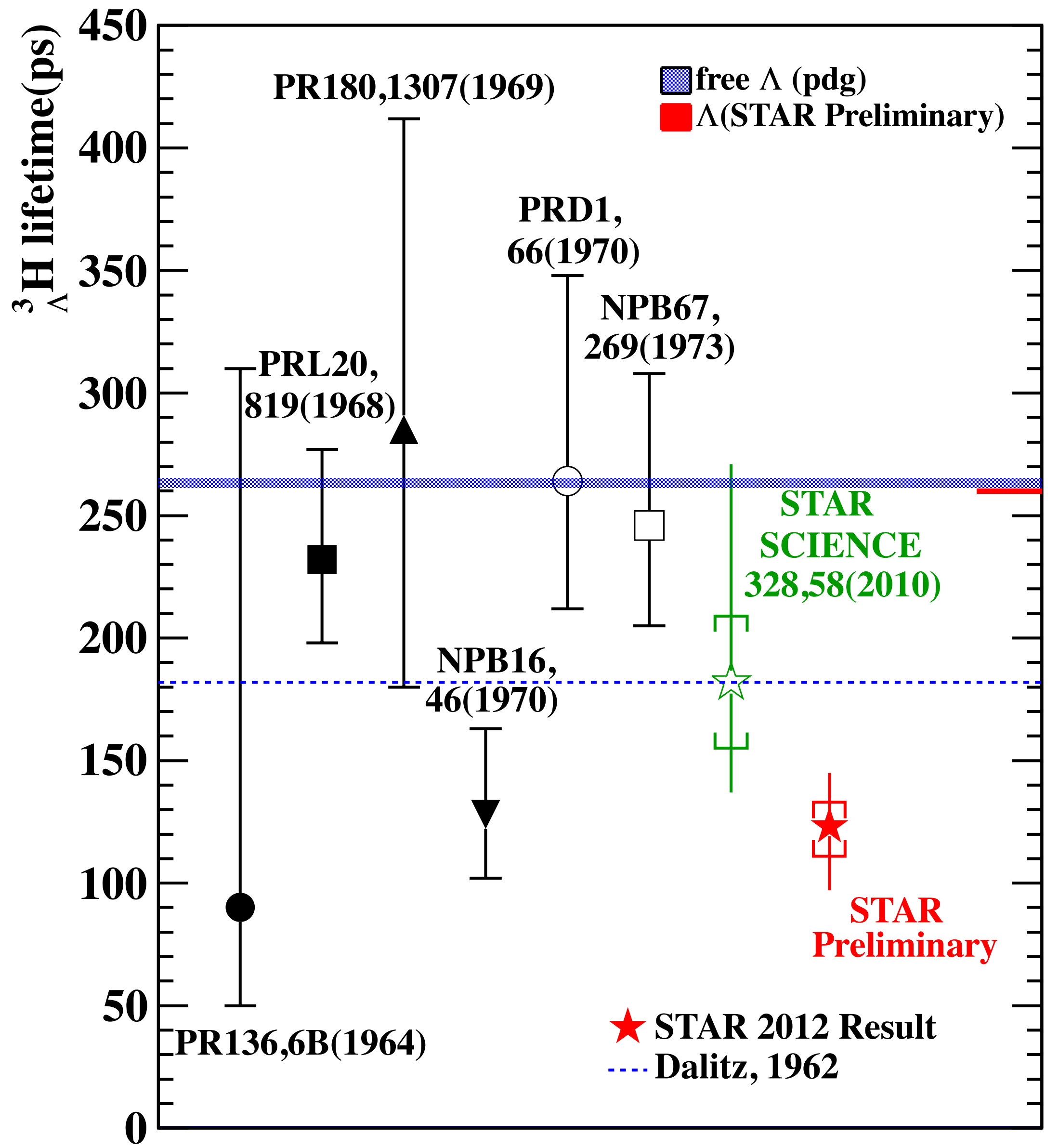
Change cuts 1): $\tau : 120 \pm 30$ps Change cuts 2): $\tau : 130 \pm 28$ps

Systematic error due to cuts is 6.2%

Total Systematic Error: ~8.4%

Lifetime Measurement





STAR 2012 result: $\tau = 123 \pm^{26}_{22} \pm 10\, ps$

STAR 2010+2012 combined fit: $\tau = 138 \pm^{23}_{20}\ ps$

Conclusions and Outlook

★ Over 600 ${}^{3}_{\Lambda}\mathrm{H} + {}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ are reconstructed with 9.6σ significance

★ ${}^{3}_{\Lambda}\mathrm{H} + {}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ signal at separate energies is reconstructed

★ Strangeness population factor tends to increase with energy with 1.7σ

★ A statistically improved lifetime $\tau = 123 \pm^{26}_{22} \pm 10\, ps$ is obtained.

★ Subsequent study on the lifetime related physics

★ RHIC BES-II Project to improve the low energy statistics

Thanks!

Backup

V0 cuts at separate energies

	Run10 7.7	Run10 11.5	Run11 19.6	Run11 27	Run10 39	Run10 200(minbias)	Run10 200(central)	Run7 200 minbias
dca1to2	<1.0cm	<0.8cm	<0.9cm	<1.0cm	<1.0cm	<0.8cm	<1.0cm	<1.0cm
v0dca	<1.0cm	<0.8cm	<1.0cm	<1.0cm	<0.9cm	<1.0cm	<1.1cm	<1.0cm
dca(helium-3)	<1.0cm	<1.0cm	<1.0cm	<1.0cm	<1.0cm	<1.0cm	<1.0cm	<1.0cm
dca(pion)	>0.9cm	>0.8cm	>1.0cm	>1.2cm	>0.7cm	>1.0cm	>0.9cm	>0.8cm
V0 decaylength	>2.4cm	>2.1cm	>3.3cm	>3.5cm	>2.0cm	>3.3cm	>2.6cm	>2.4cm

V0 cuts for lifetime measurement

V0 cuts	v0dca	dca1to2	dca(heium-3)	dca(pion)	v0 decaylength
	<1.0cm	<1.0cm	<1.0cm	>0.8cm	>2.4cm

Difference cuts for systematic study on lifetime

Present cuts: $l > 2.4cm$,dca(π)>0.8cm,dca1to2<1.0cm,v0dca<1.0cm

Change cuts 1): $l > 4.0cm$ and dca(π)>1.2cm, $\tau : 120 \pm 30$ps

Change cuts 2): dca1to2<0.7cm and v0dca<0.7cm, $\tau : 130 \pm 28$ps

Validity to combine different datasets to calculate lifetime

${}^{3}_{\Lambda}H$ efficiency vs $l / \beta\gamma$