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Beam Energy Scan on Hypertriton Production and Lifetime Measurement

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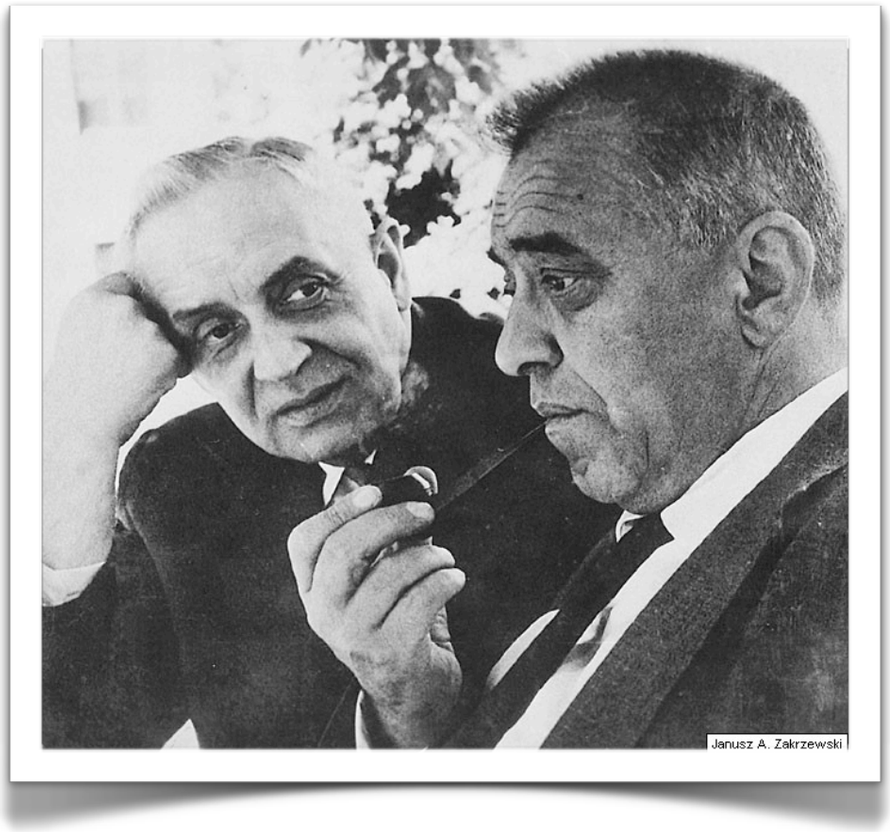
Outline

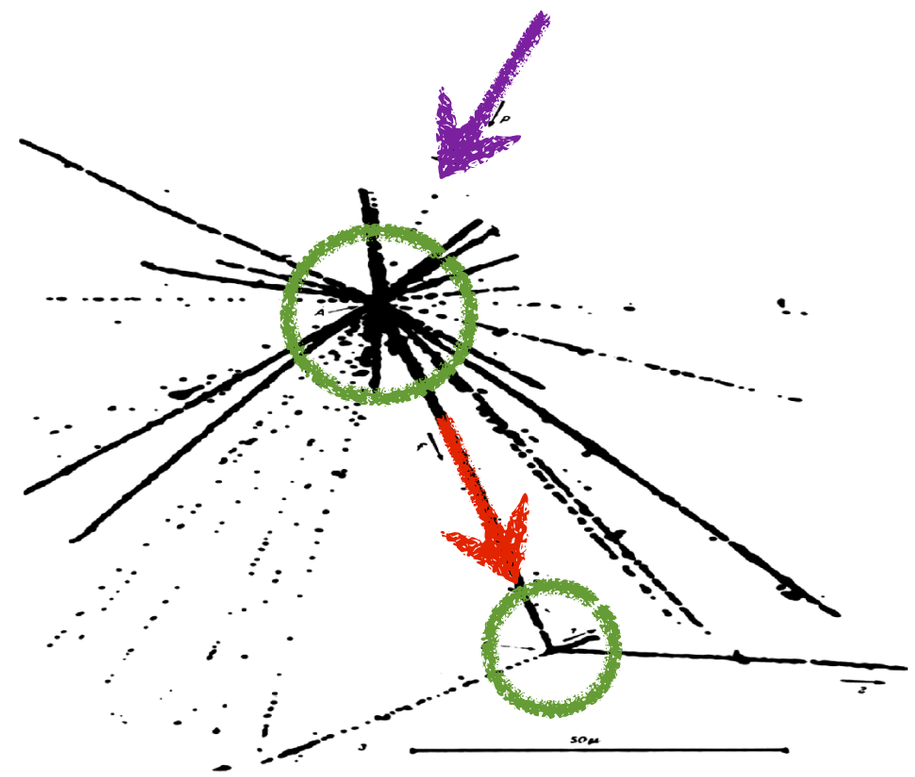
- ★ Introduction and Motivation
  - ★ Discovery of Hypernucleus
  - ★ Physics of ${}^{3}_{\Lambda}H$
- ★ ${}^{3}_{\Lambda}H$ Study at RHIC STAR
  - ★ ${}^{3}_{\Lambda}H$ Production
  - ★ Beam Energy Dependence of Strangeness Population Factor
  - ★ Lifetime Measurement
- ★ Outlook
  - ★ Lambda-neutron bound state?

Introduction and Motivation

Discovery of Hypernucleus

The first observation of hypernucleus is made by Danysz and Pniewski in 1952 in a cosmic ray experiment





Juxtaposition of two unrelated events?
Fragment carries a bound pion?
Fragment carries a bound V0?

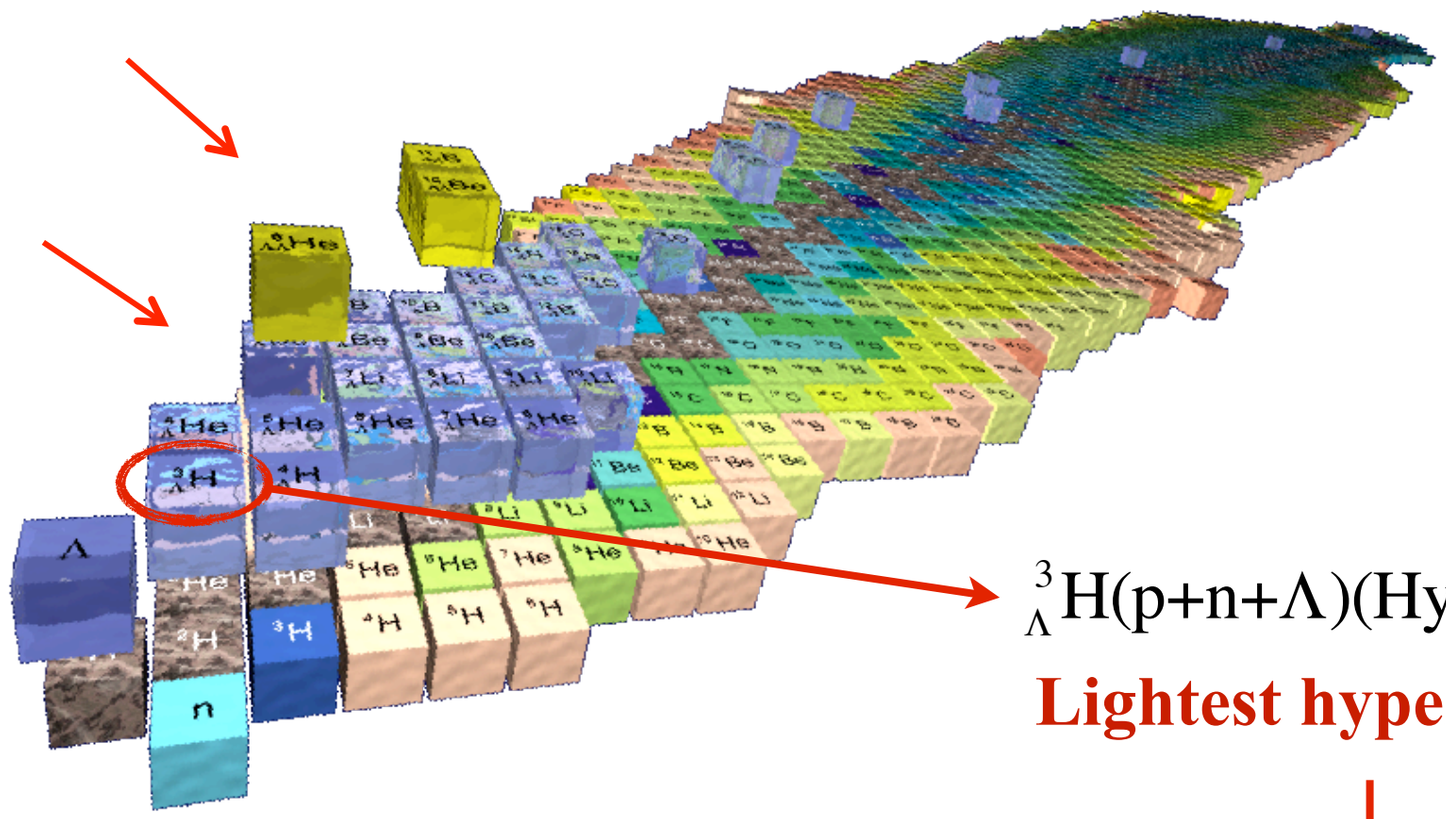
A New Dimension to the World of Nuclei

Strangeness

S=-2

S=-1

S=-0



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

Lightest hypernucleus

Easiest to be produced in HIC

Hyperon-Nucleon(Y-N) Interaction

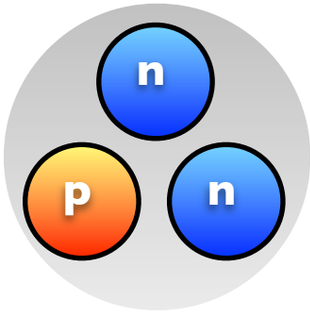
Helps to study baryon octet

Helps to understand strong interactions

Helps to study neutron stars

Physics of Hypertriton

Comparison with Triton

$^{3}_{\Lambda}H$		^{3}H
		
2.991GeV	**Mass?**	2.809GeV
0.13 ± 0.05MeV	**Binding Energy?**	8.48MeV
~2.63e-10s	**Lifetime?**	12.32 years

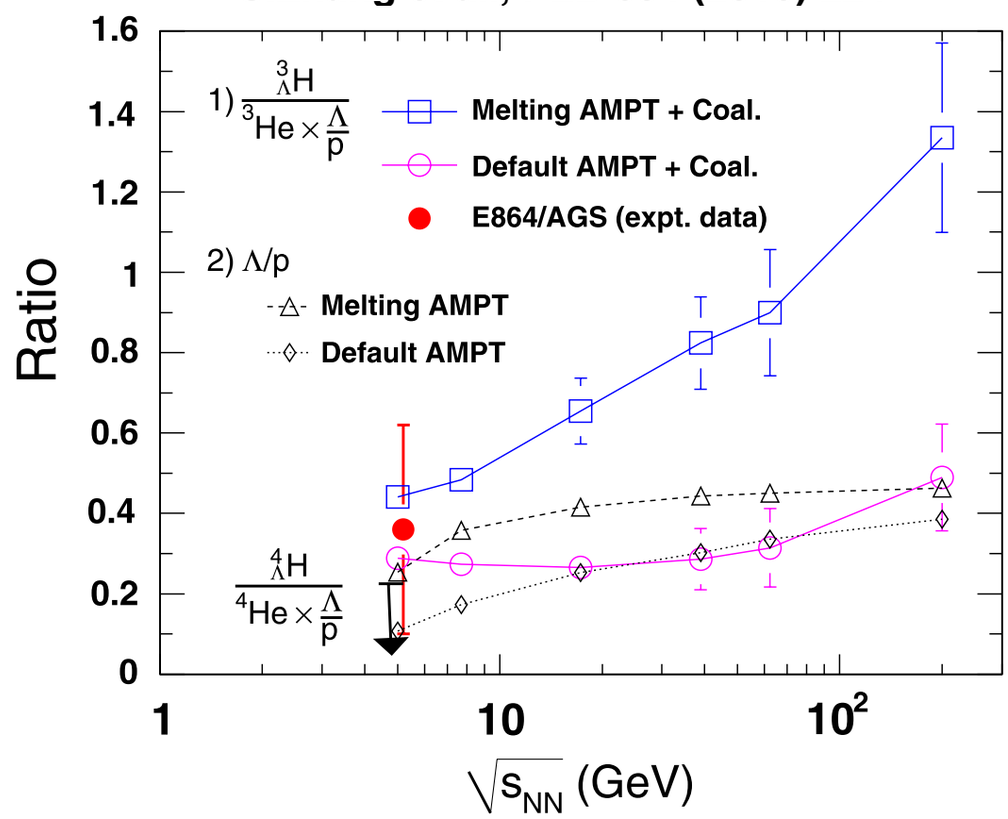
Sensitivity to QCD Phase Transition

Strangeness Population Factor

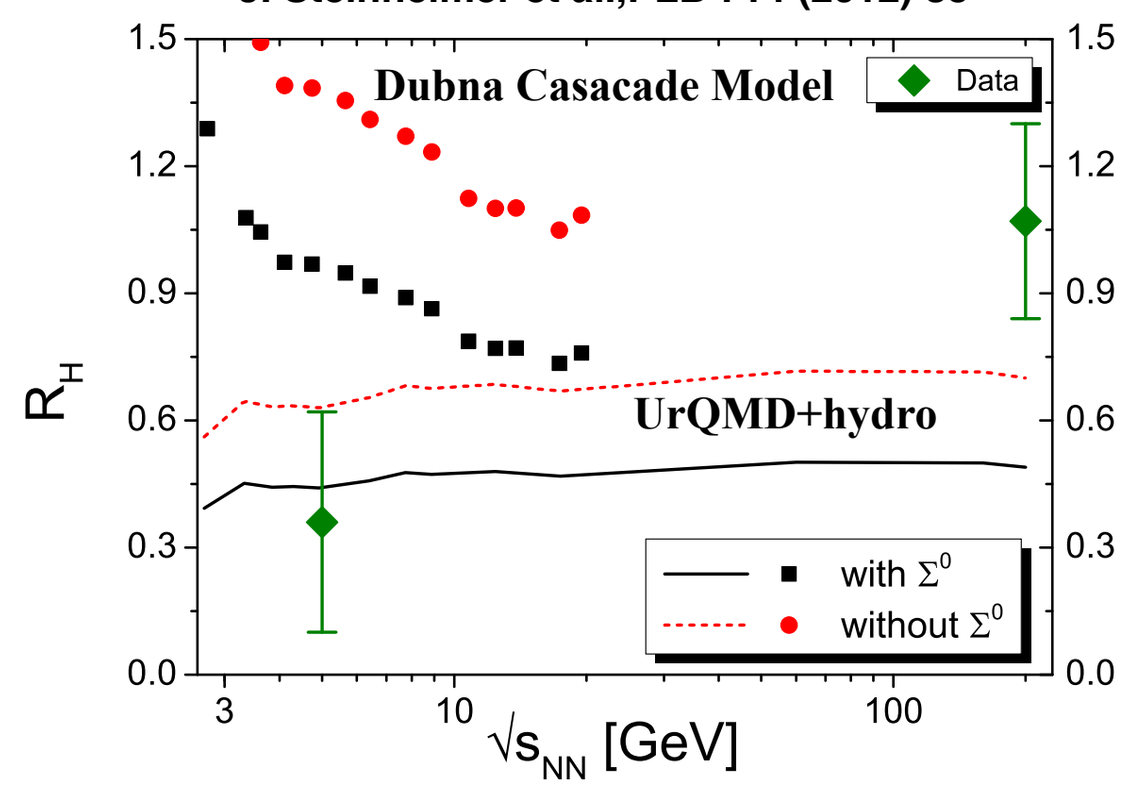
$$S_3 = {}^{3}_{\Lambda}\mathrm{H} / ({}^{3}\mathrm{He} \times \Lambda / p)$$

local baryon-strangeness correlation

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



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



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

Lifetime

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

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

Previous Measurements(before 1973):

Use nuclear emulsion or bubble chamber

Accepted hypertriton events: less than 80

STAR 2010 Measurement

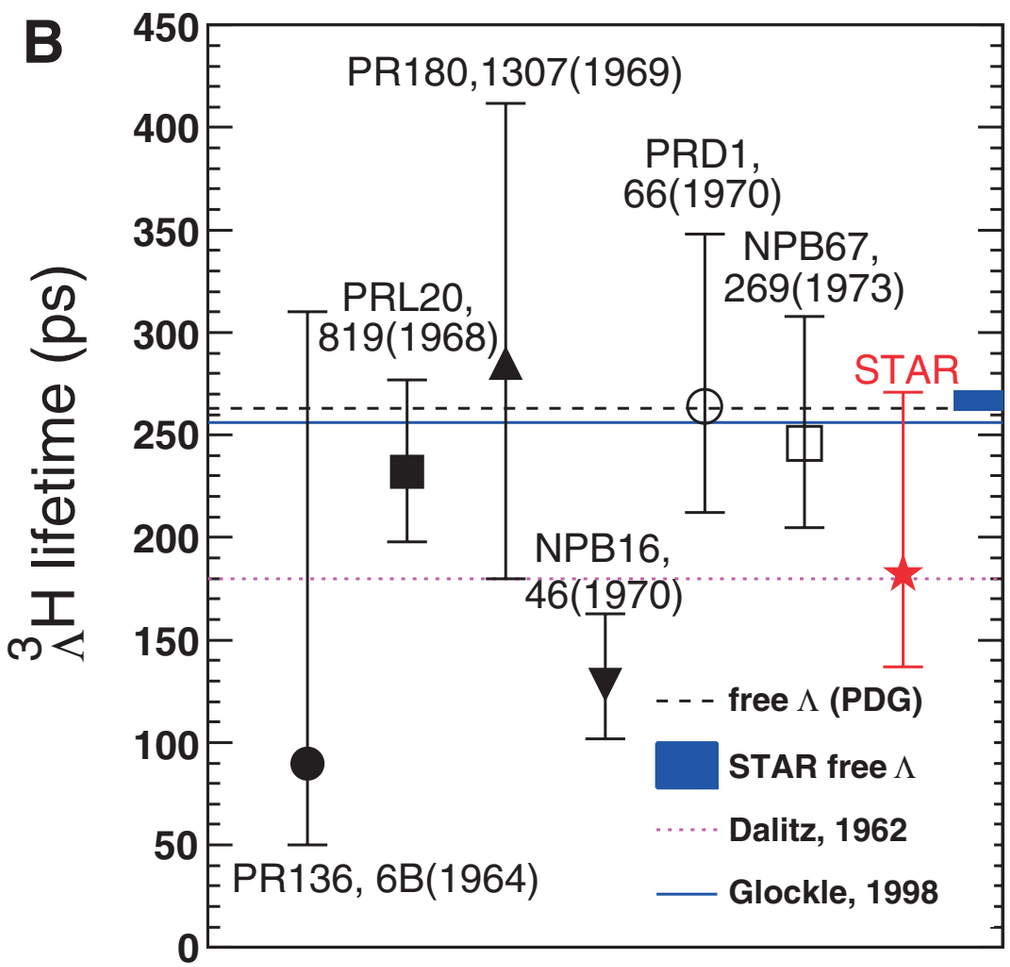
Run4 200GeV	minbias	22M
Run4 200GeV	central	23M
Run7 200GeV	minbias	68M

STAR 2010+2011 Datasets

Run10 200GeV	minbias	~223M
Run10 200GeV	central	~199M
Low Energies	minbias	~213M

Previous Measurement

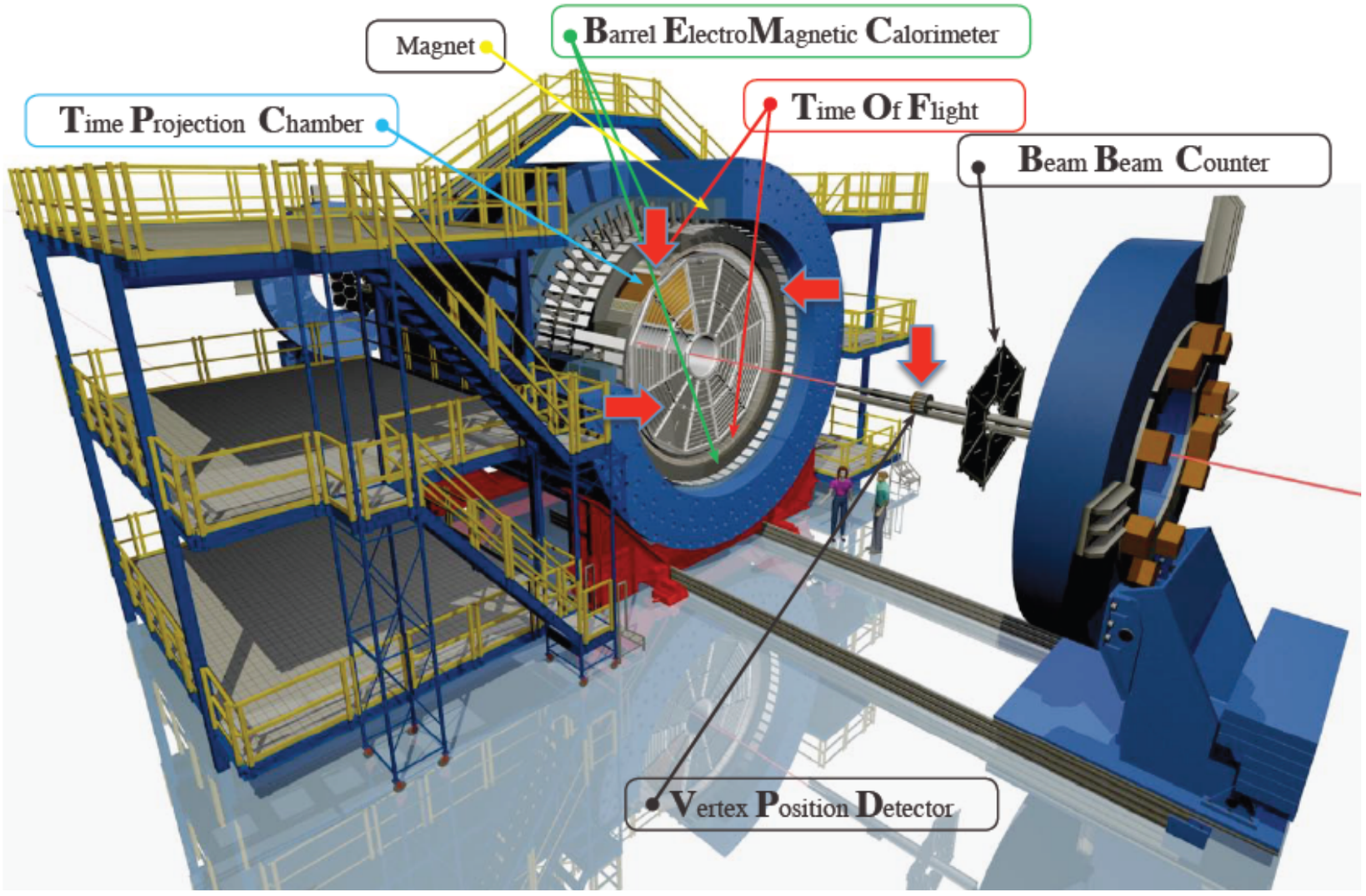
STAR Collaboration, SCIENCE 328, 58 (2010)



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

Hypertriton Study at RHIC STAR

STAR Detector at RHIC



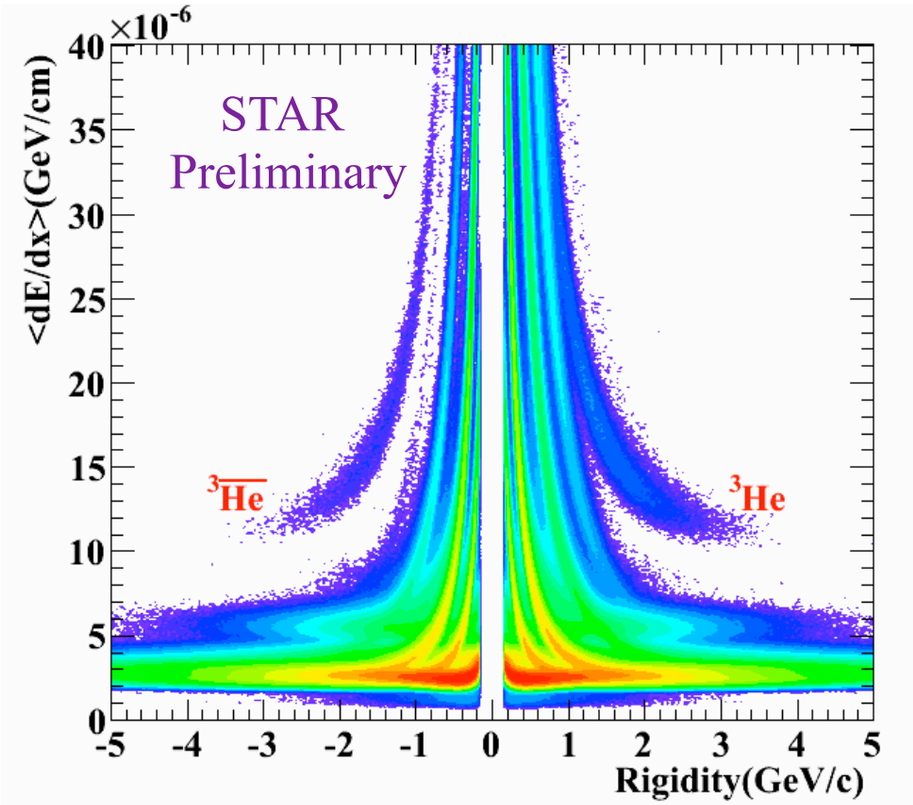
★ STAR: a complex set of various detectors, a wide range of measurements and a broad coverage of different physics topics.

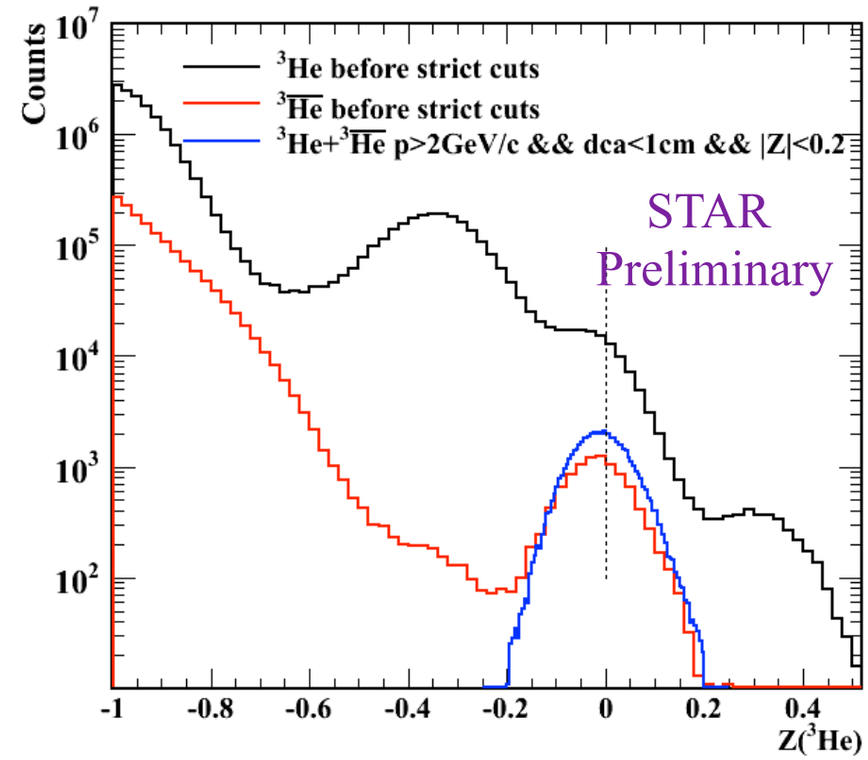
★ TPC: effectively 3-D ionization camera with over 50 million pixels.

Daughter Identification

★ ^{3}He

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





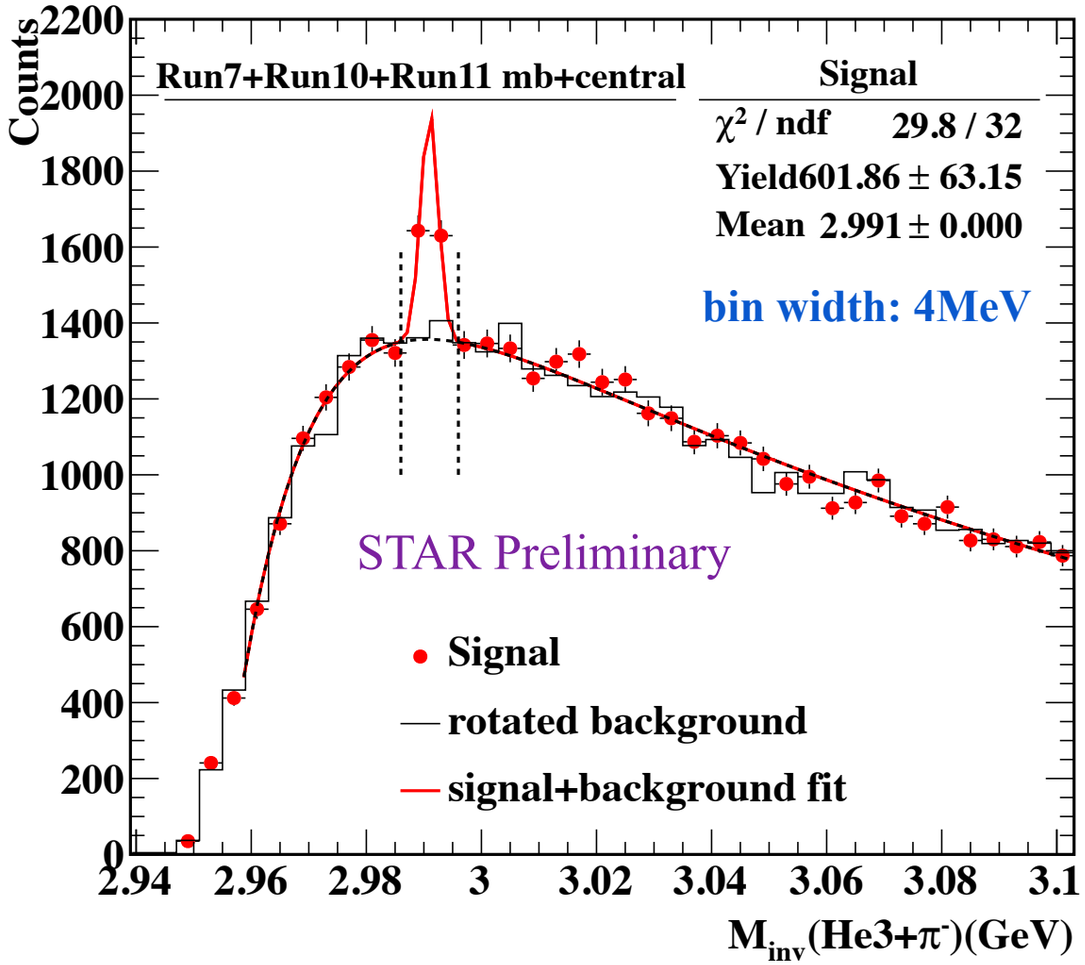
	Run10 7.7	Run10 11.5	Run11 19.6	Run11 27	Run10 39	Run10 200(minbias)	Run10 200(central)	Run7 200 minbias
^{3}He	8587	7161	6321	5312	6456	5822	11181	2264
$^{3}\overline{He}$	0	0	0	19	133	2213	4241	861

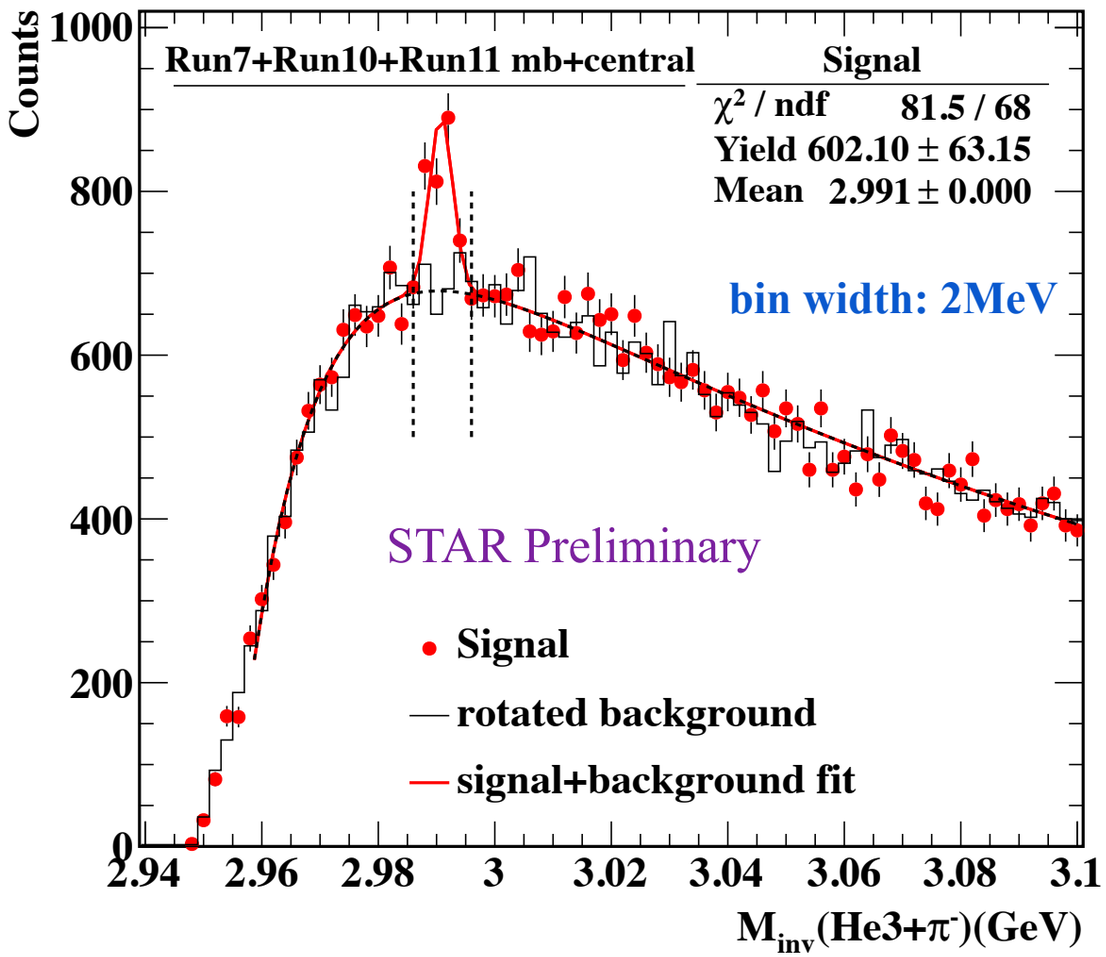
★ π^{-}

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

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

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



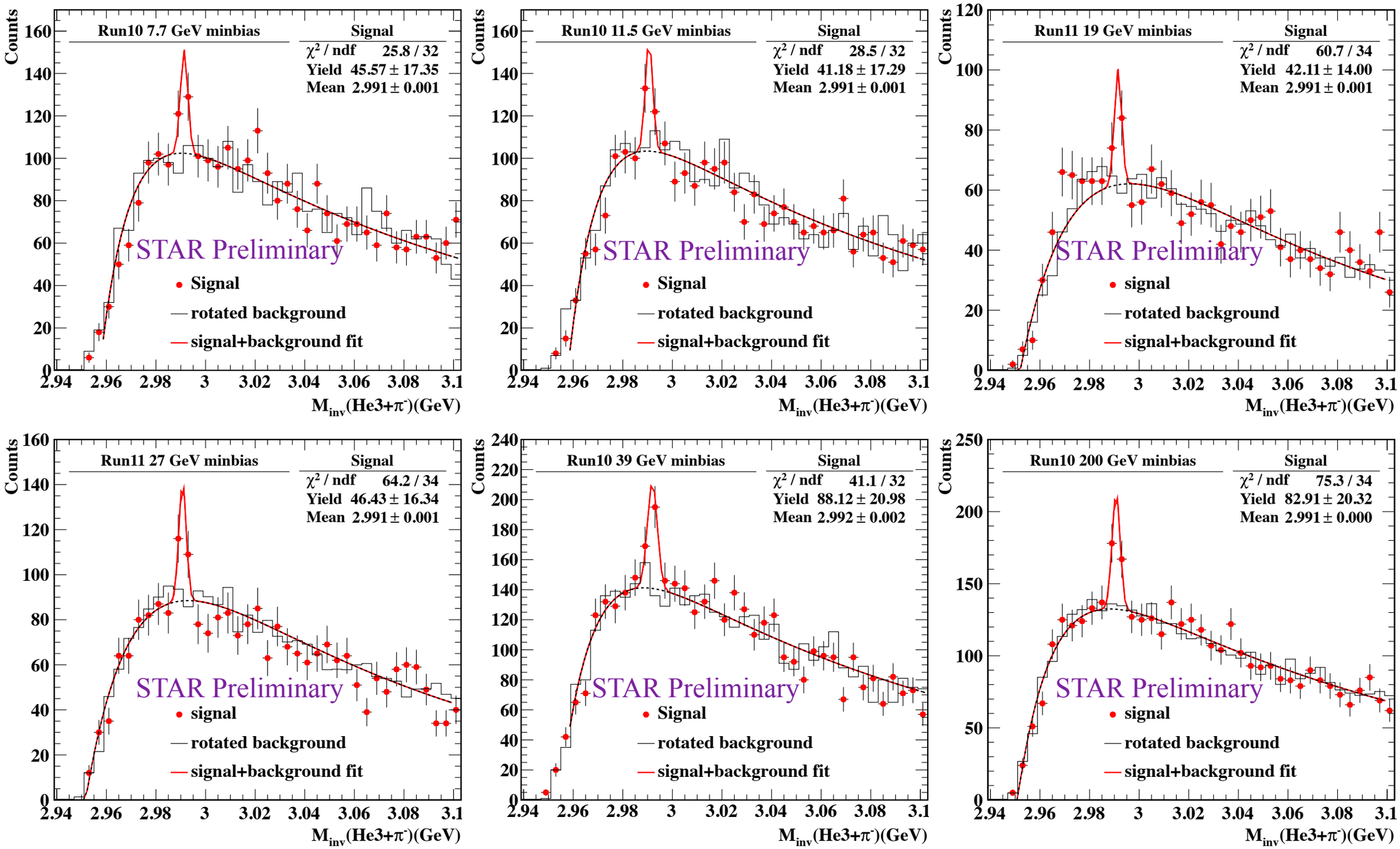


Background Estimation: Rotated background fit
Signal: Bin-bin counting in a fixed mass range : [2.986, 2.996] GeV

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

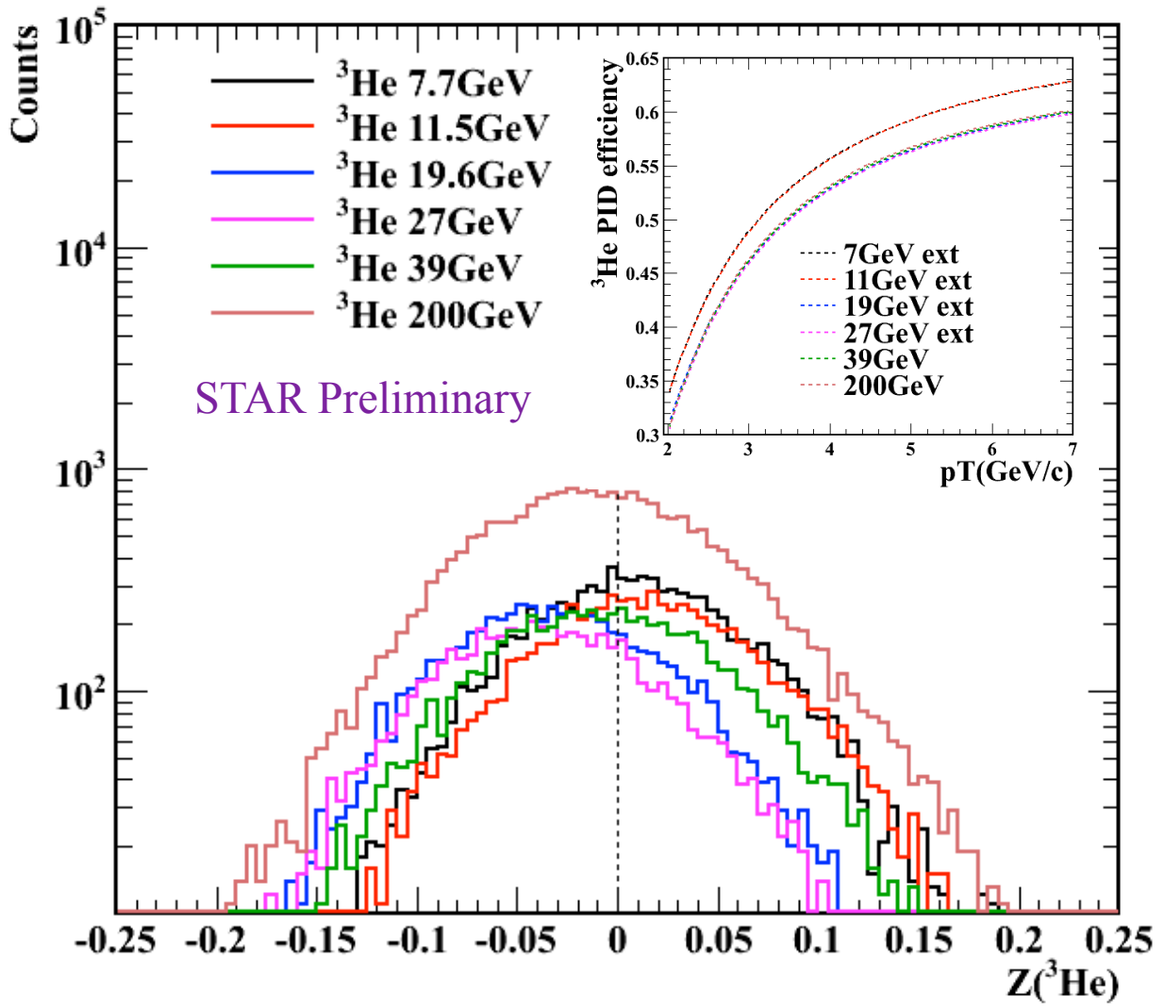
${}^{3}_{\Lambda}$H Production in Separate Energies

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

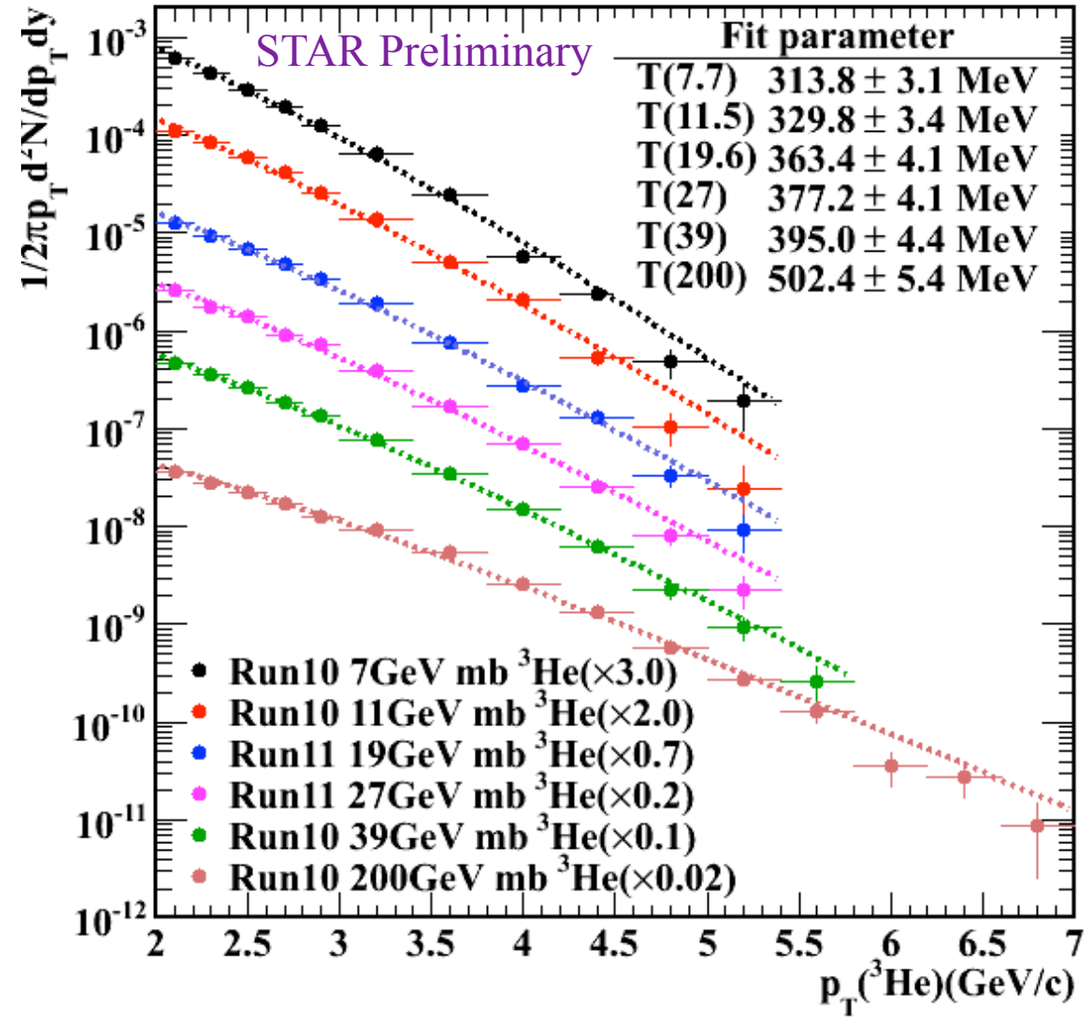


^{3}He p_T Spectra

^{3}He PID and Efficiency

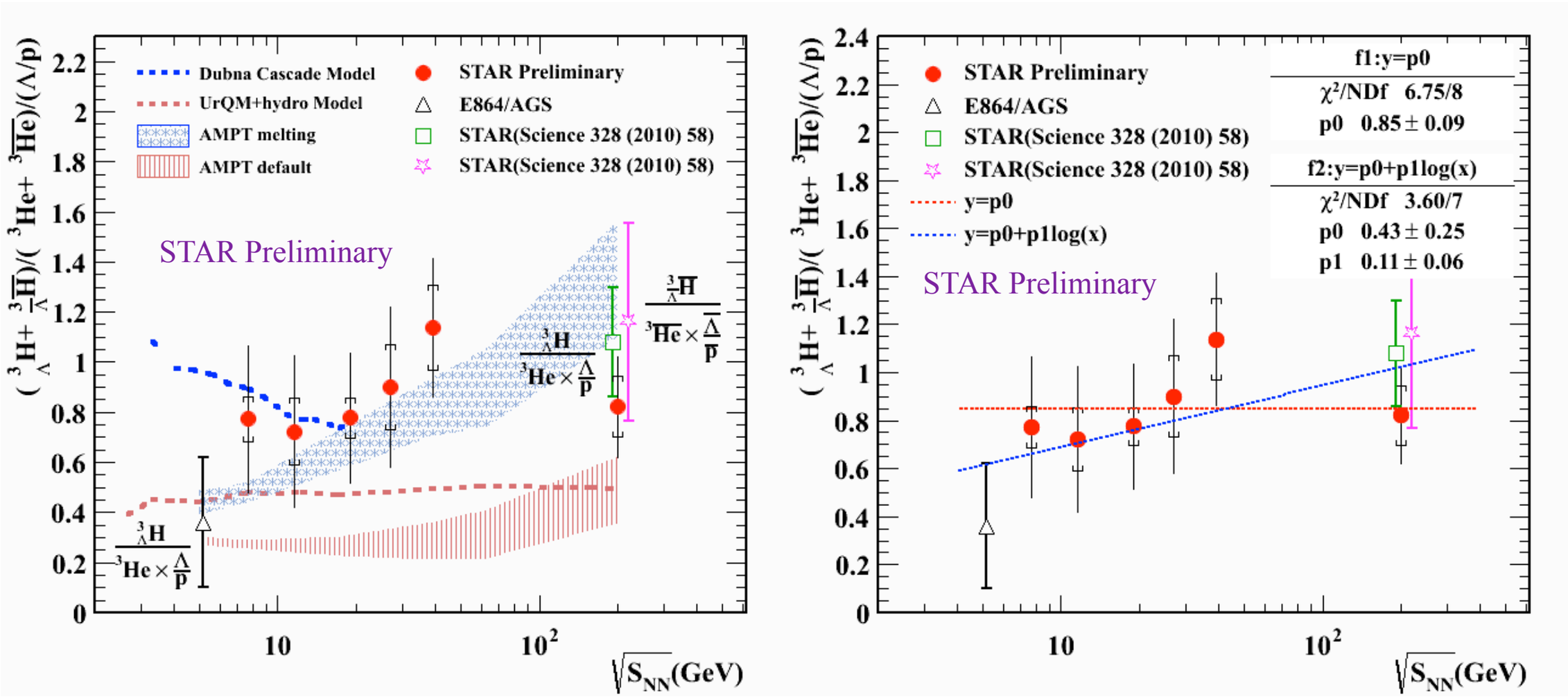


^{3}He p_T Spectra



^{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

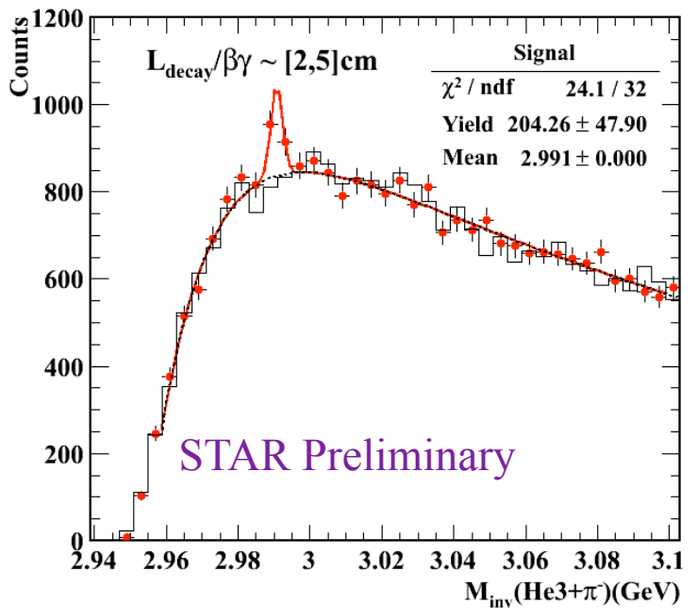


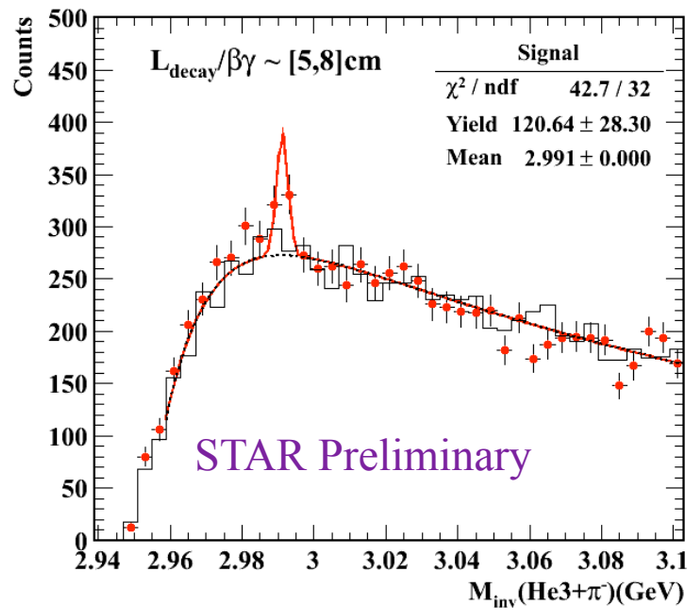
With present statistics, the strangeness population factor indicates (with 1.7σ) an increasing trend with the increase of energy(from 5.2GeV to 200GeV)

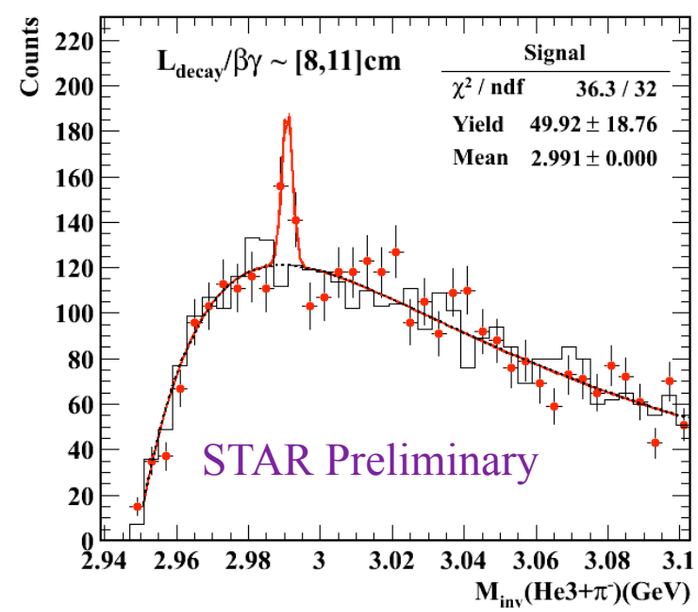
Lifetime Measurement

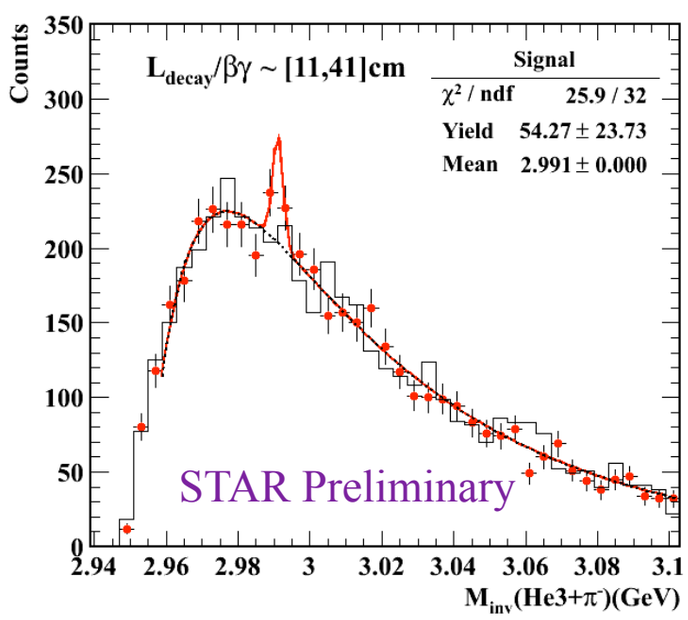
Radioactive Decay Law

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

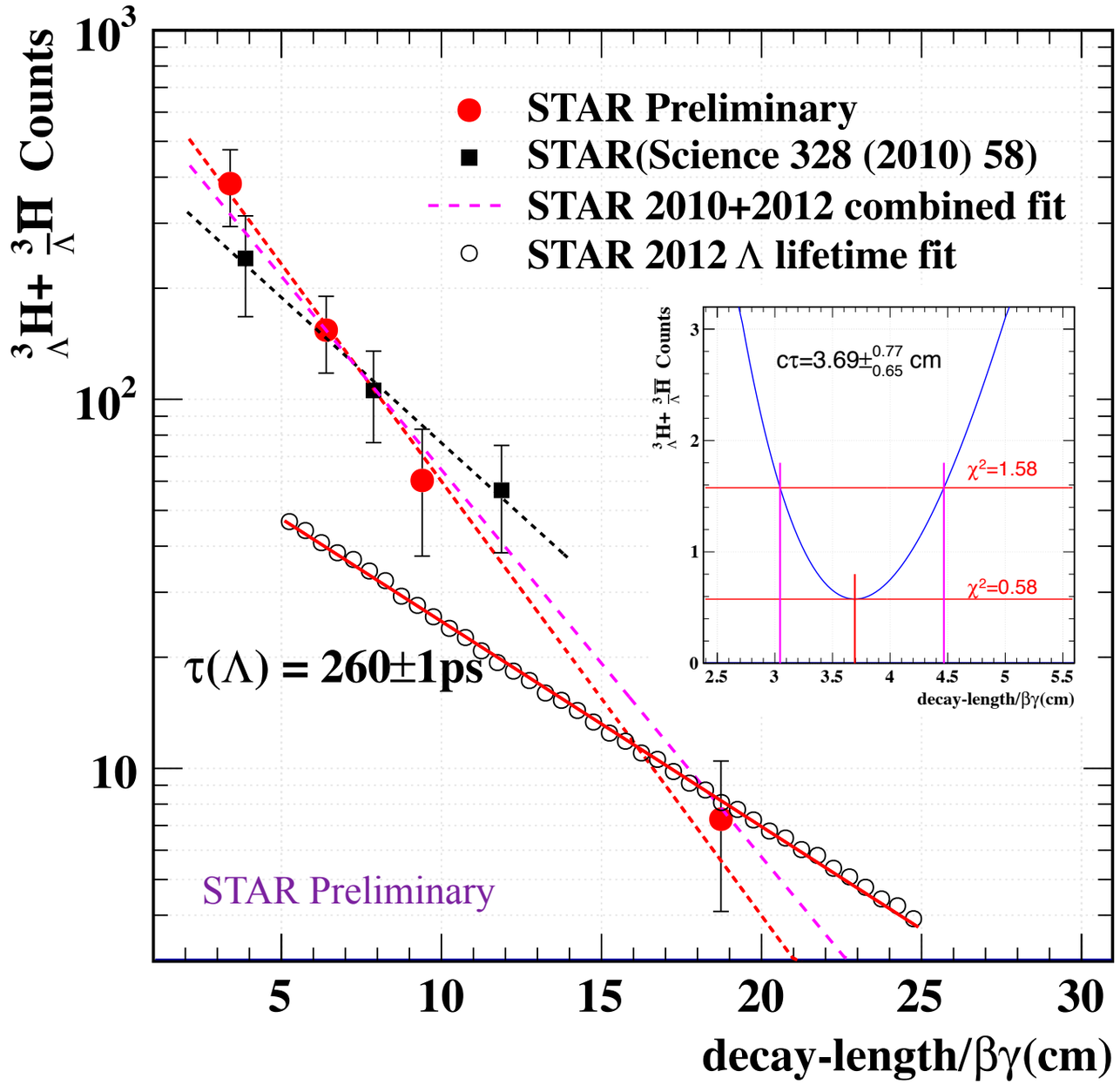
Different Cuts

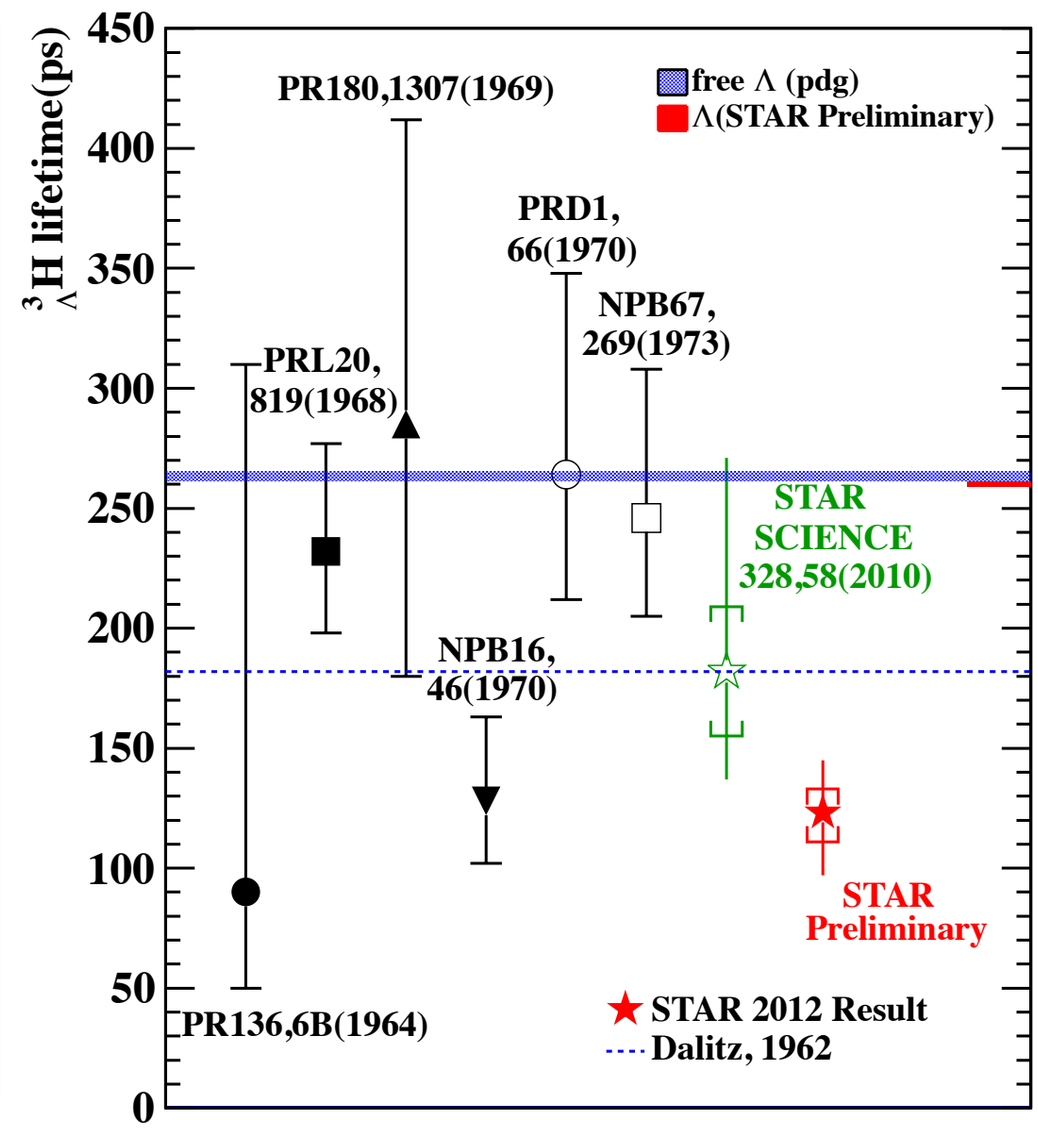
Change cuts 1): τ :120 ± 30ps Change cuts 2): τ :130 ± 28ps

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: $\tau = 138 \pm^{23}_{20}\, ps$

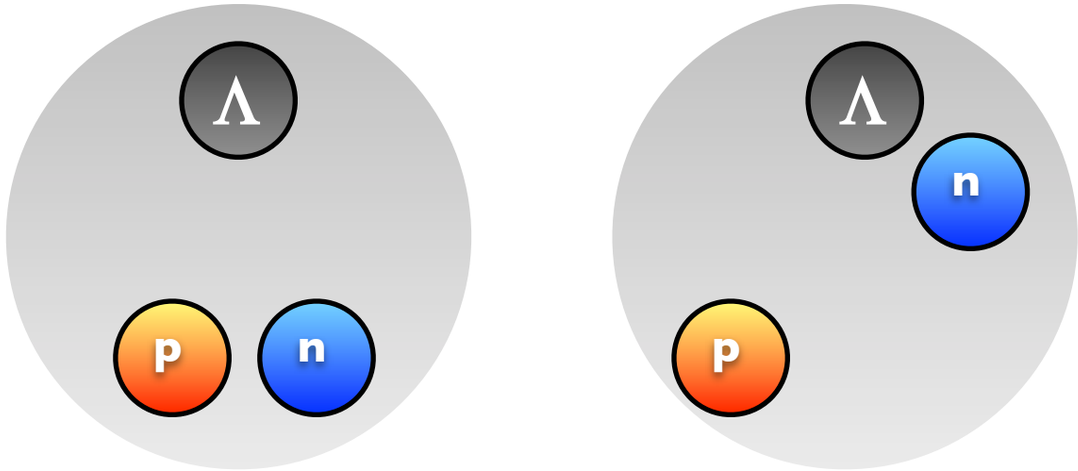
Outlook

Smaller Lifetime?

Modifications to the previous theoretical assumptions

1. Decay rates?
2. Binding energy?

Different Construction?



Thanks!