VII International Conference on **Hypernuclear and Strange Particle Physics**

14-18 October 2003

Production of ΛΛ Hypernuclei at the AGS

Presented by

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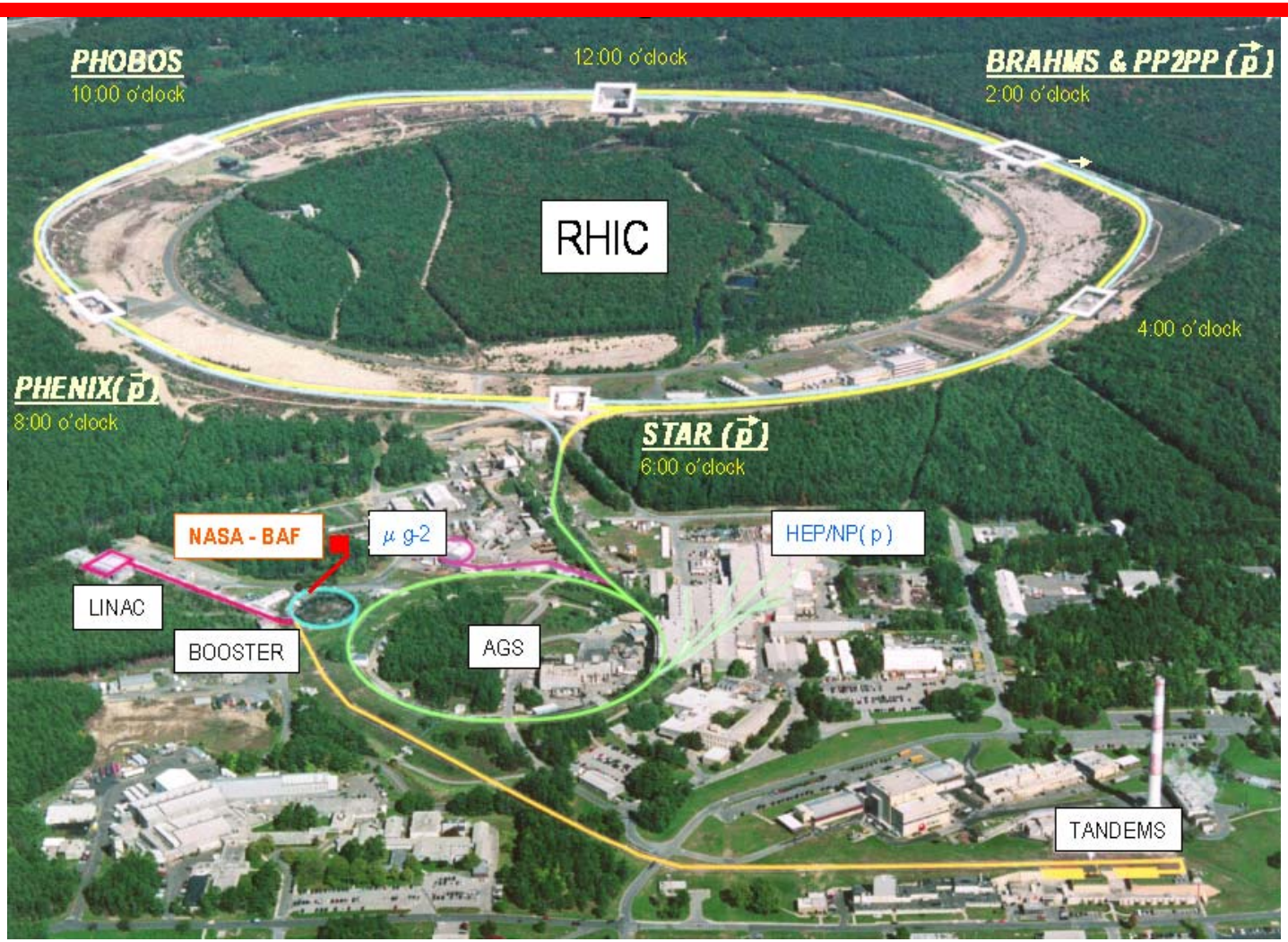
Production of ΛΛ Hypernuclei at the AGS

Outline

- BNL HE/NP Accelerator facilities
- ΛΛ Hypernuclear experiments
  - E906 – last ΛΛ experiment
  - E961 – future
  - E964 – future
- Outlook

C-AD Accelerator Facilities



AGS Fixed Target Operations in RHIC Era –

The Present Situation

- ***AGS Fixed target experiments are no longer supported concurrent with RHIC operations since HEP base support was terminated at the end of 2002.***

- AGS fixed target experiments are still supported but are scheduled to operate only outside RHIC operations and only if this can be done with minimal impact to RHIC activities. Full operations costs are recovered. Two AGS experiments ran in this mode in FY2003 – Radiobiology (NASA-E966) and Proton Radiography (NNSA-E963).

- Should AGS fixed target base support be restored (NSF RSVP for example) then cost sharing could lead to limited NP/HEP AGS experimental program concurrent with RHIC operations.

E906, A search for double Λ hypernuclei

- **E906: Collaboration**
  - BNL, CMU, Gifu, Freiburg, Hampton, INR-Russia, KEK, Kyoto, Manitoba, New Mexico, Osaka, Osaka Electro-Communication, Pusan, Temple, Tokyo, TRIUMF
  - Spokesmen: T. Fukuda (Osaka Electro-Comm.), A. Rusek (BNL), R. Chrien (BNL)

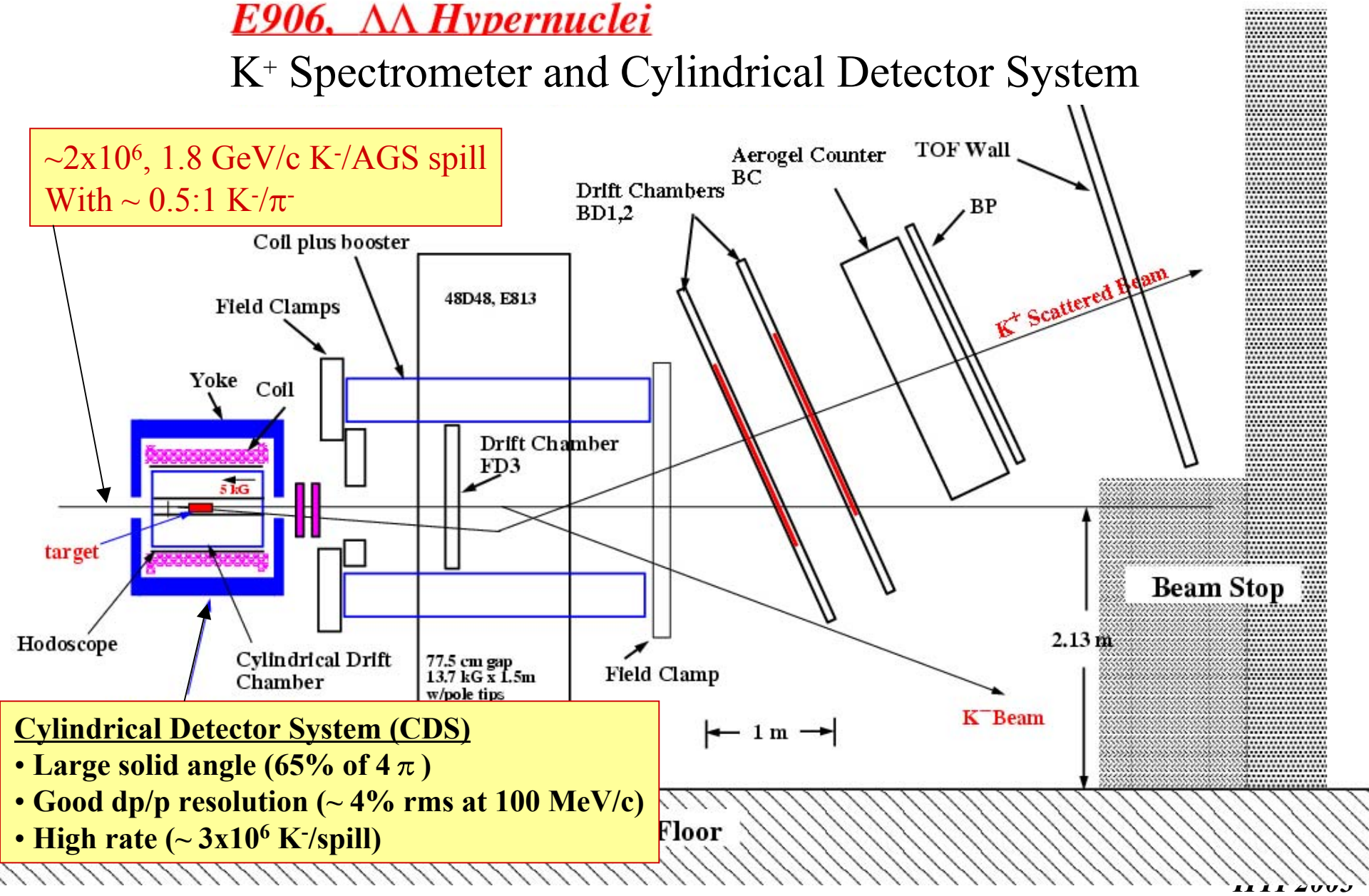
- **Thesis students:**
  - Toru Tamagawa (Tokyo)
  - Joe Nakano (Tokyo)

- **The Physics:** A search for ΛΛ hypernuclei by observation of sequential π^- decay using the ^{9}Be(K^-,K^+) reaction
  - 2GeV (D6) Beam Line together with Cylindrical Detector System (CDS)
  - Completed in 1999
  - Follow-up run, E961, awaiting running time

E906, ΛΛ Hypernuclei

K^+ Spectrometer and Cylindrical Detector System

~2x10^6, 1.8 GeV/c K^-/AGS spill
With ~ 0.5:1 K^-/π^-



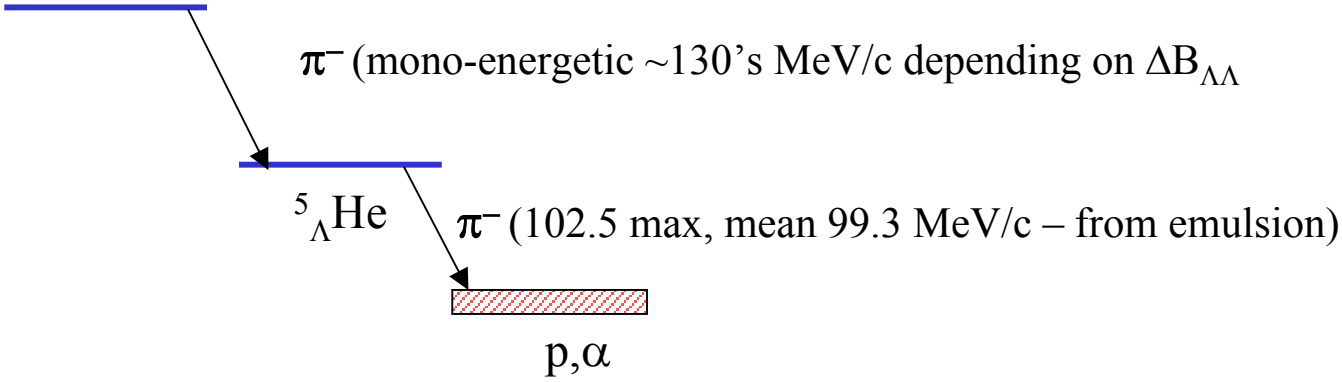
Cylindrical Detector System (CDS)

- **Large solid angle (65% of 4 π)**
- **Good dp/p resolution (~ 4% rms at 100 MeV/c)**
- **High rate (~ 3x10^6 K^-/spill)**

The E906 approach

- Use $p(K^-,K^+)\Xi^-$ reaction on nuclear target
- $\Xi^- p \rightarrow \Lambda\Lambda$ in original nucleus or after capture by another nucleus
- Identify $\Lambda\Lambda$ hypernucleus through sequential weak decay via π^- emission

Example: ${}^{5}_{\Lambda\Lambda}H$ (single Λ binds to ${}^{3}H$ by 2.0 MeV)



The E906 Experiment

- **^{9}Be Target**

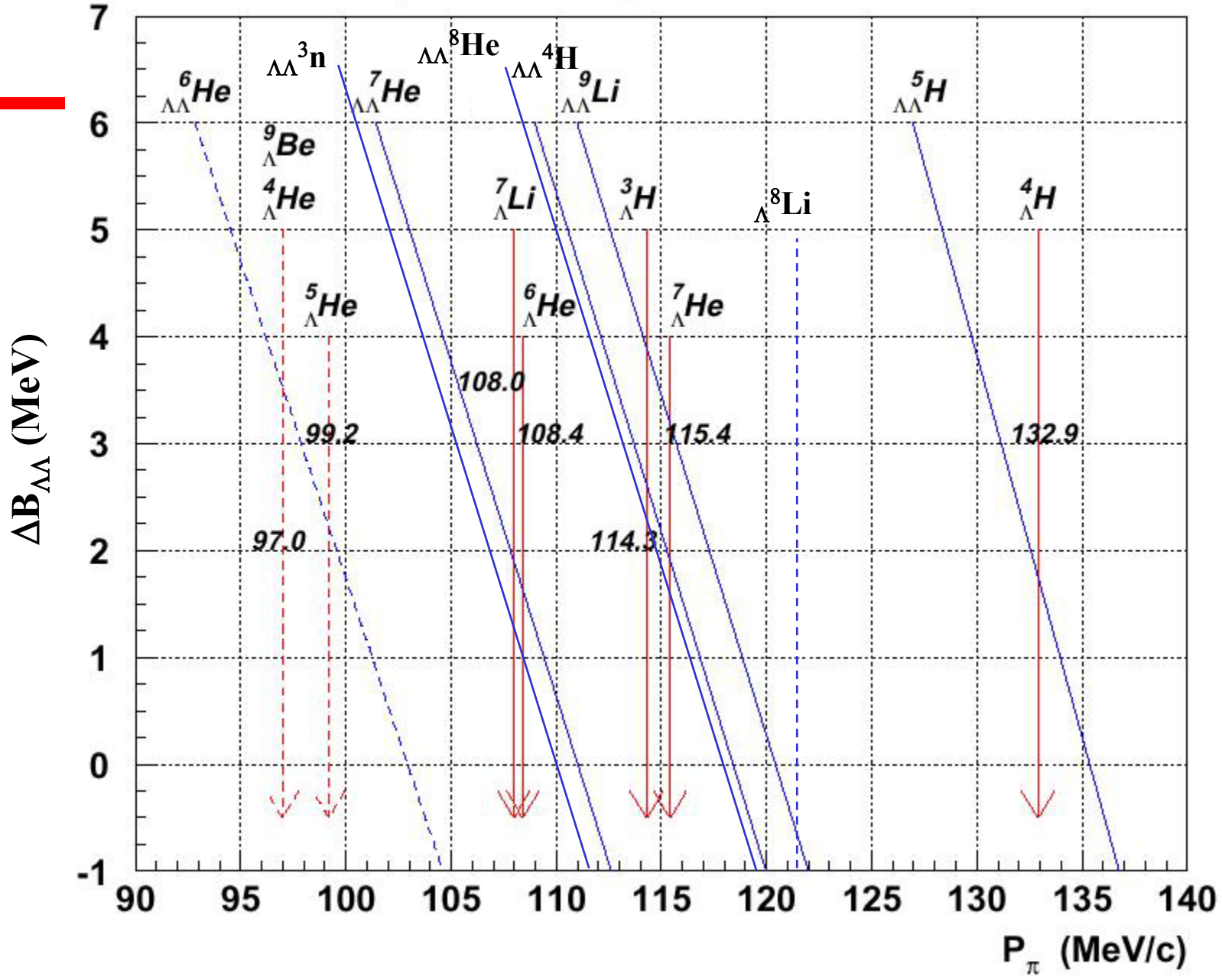
- **<u>in flight (same nucleus)</u>**

  - $K^- + {}^{9}Be \rightarrow K^+ + (\Xi^- + {}^{8}Li)$
  - $\Lambda\Lambda$ Hypernucleus Mass ≤ 8
  - $\Lambda\Lambda$ Hypernucleus $Z \leq 2$

- **(<u>stopped Ξ^-</u>)**

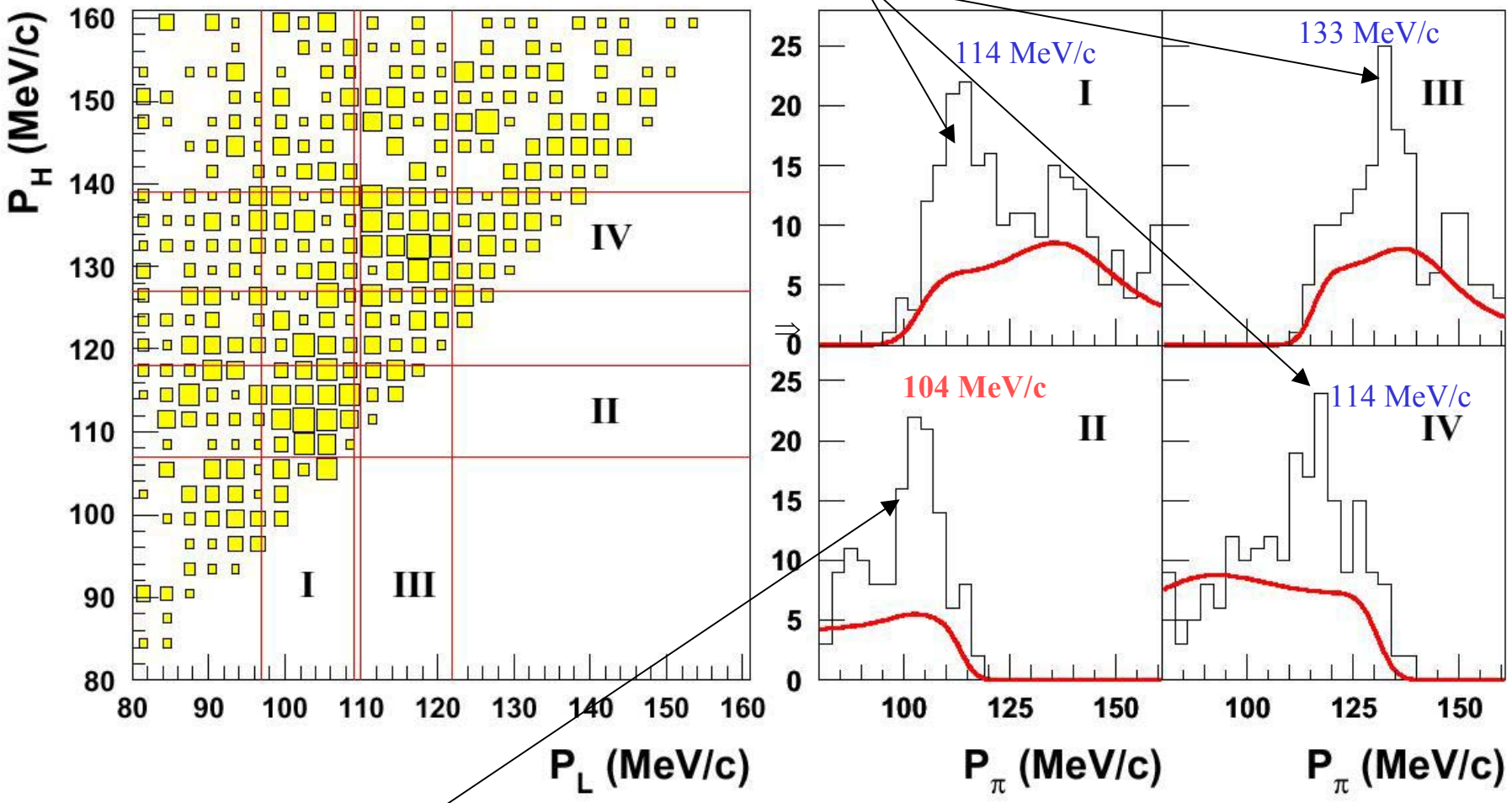
  - $\Xi^- + {}^{9}Be \rightarrow X$
  - $\Lambda\Lambda$ Hypernucleus Mass ≤ 9
  - $\Lambda\Lambda$ Hypernucleus $Z \leq 3$

Expected Signals and Lines



What we saw

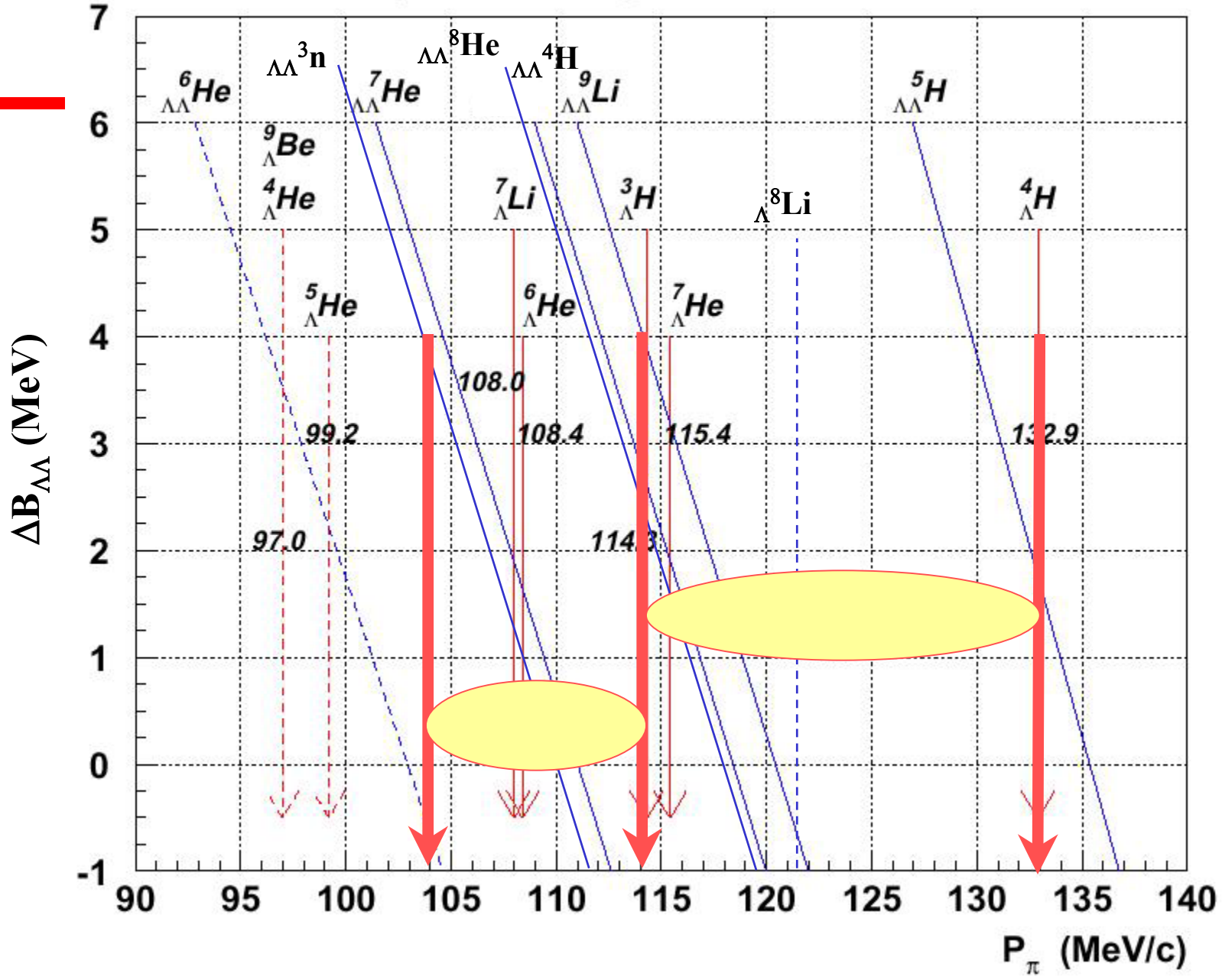
Consistent with known single Λ hypernuclei



Candidate for ΛΛ hypernucleus decay

Phys. Rev. Lett. **87**, 132504 (2001)

Expected Signals and Lines



in flight (same nucleus) $K^- + {}^9Be \rightarrow K^+ + (\Xi^- + {}^8Li)$
(pion momenta for decay to ground states)

Kinetic energy of Ξ ~ 100 MeV **bold → monoenergetic pion**

Mass(MeV)	**Reaction Products**		
8792.7	$(\Xi^- + {}^8Li)$		
		$p_{\pi 1}$(MeV/c)	$p_{\pi 2}$ (MeV/c)
8784.7	${}^4_\Lambda H + {}^4_\Lambda H + n$	**133.0**	**133.0**
8792.9	${}^4_\Lambda H + {}^3_\Lambda H + 2n$	**133.0**	**114.3**
8801.0	${}^3_\Lambda H + {}^3_\Lambda H + 3n$	**114.3**	**114.3**
	$\Xi^- + X$	139*(Ξ^-)	101*(Λ)

"Background"

$\Delta B_{\Lambda\Lambda}$ = 0 MeV		p_π for $\Delta B_{\Lambda\Lambda}$ = 4/ 0 MeV	p_π for $_\Lambda$X decay produc
8766.1	${}^8_{\Lambda\Lambda}He + n$	**112.0/ 118.1**	121.3
8770.0	${}^7_{\Lambda\Lambda}He + 2n$	**104.5/ 110.9**	**108.1**
8771.2	${}^6_{\Lambda\Lambda}He + 3n$	95.6/ 102.3	99.3
8793.2	${}^5_{\Lambda\Lambda}He + 4n$	94.1/ 100.7	97.3
8784.7	${}^5_{\Lambda\Lambda}H + {}^3H + n$	**129.7/ 135.3**	99.3
8794.8	${}^4_{\Lambda\Lambda}H + {}^3H + 2n$	**112.7/ 118.7**	97.3
8776.5	${}^3_{\Lambda\Lambda}n + {}^6He$	**104*/110***	**114.3**

"Signal"

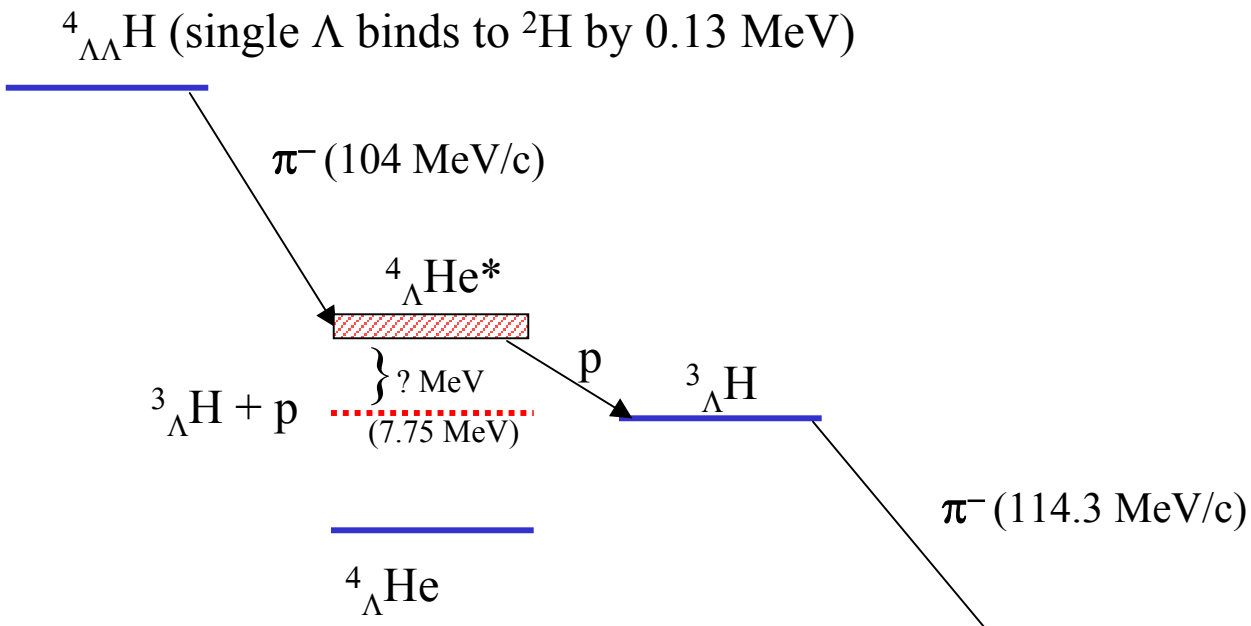
* Doppler broadened and not likely bound

(**stopped Ξ^-**) $K^- + {}^9Be \rightarrow K^+ + \Xi^- + X$; $\Xi^- + {}^9Be \rightarrow X$
(pion momenta for decay to ground states)

Mass(MeV)	**Reaction Products (Q value allowed)**	**bold → monoenergetic pion**		
9714.07	Ξ^-(stopped) + ^{9}Be			
		$p_{\pi 1}$(MeV/c)	$p_{\pi 2}$ (MeV/c)	
9701.90	$^{6}_{\Lambda}$He + $^{4}_{\Lambda}$H	**108.4**	**133.0**	
9710.07	$^{6}_{\Lambda}$He+ $^{3}_{\Lambda}$H+n	**108.4**	**114.3**	***Close!***
9702.07	$^{5}_{\Lambda}$He+ $^{4}_{\Lambda}$H+n	99.3	**133.0**	"Background"
9710.24	$^{5}_{\Lambda}$He + $^{3}_{\Lambda}$H+2n	99.3	**114.3**	
	Ξ^- + X	139*(Ξ^-)	101* (Λ)	
$\Delta B_{\Lambda\Lambda}$ = 0 MeV		p_π for $\Delta B_{\Lambda\Lambda}$ = 4/ 0 MeV	p_π for $_{\Lambda}$X decay product	
9691.2	$^{9}_{\Lambda\Lambda}$Li+n	**118.3/ 124.2**	**96.9**	
9700.9	$^{8}_{\Lambda\Lambda}$Li+2n	**103.8/ 110.3**	**97.1**	
9702.1	$^{8}_{\Lambda\Lambda}$He+^{2}H	**112.0/ 118.1**	121.3	
9699.8	$^{7}_{\Lambda\Lambda}$He+^{3}H	**104.5/ 110.9**	**108.1**	"Signal"
9701.0	$^{6}_{\Lambda\Lambda}$He+n+^{3}H	95.6/ 102.3	99.3	
9704.0	$^{5}_{\Lambda\Lambda}$H+^{5}He	**129.7/ 135.3**	99.3	
9712.3	$^{4}_{\Lambda\Lambda}$H+ ^{6}He	**112.7/ 118.7**	97.3	
9704.8	$^{3}_{\Lambda\Lambda}$n+^{7}Li	**104*/110***	**114.3**	

* Doppler broadened and not likely bound

Suggested decay mode of ${}^{4}_{\Lambda\Lambda}$H and limits on $\Delta B_{\Lambda\Lambda}$

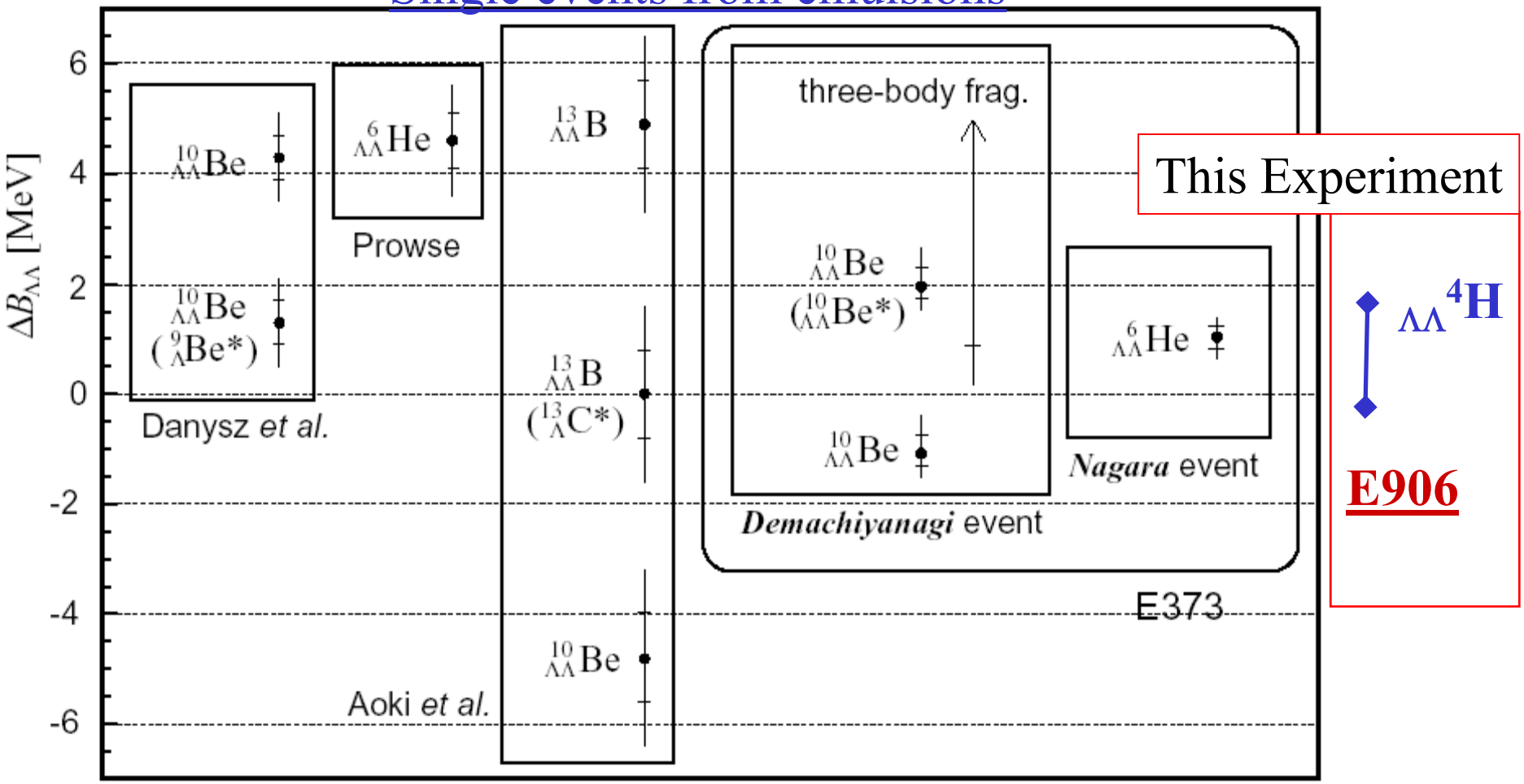


${}^{4}_{\Lambda}$He excitation(MeV)	$\Delta B_{\Lambda\Lambda}$(MeV)
7.75	1.8
8.75	0.8
9.84	-0.26

The double Λ Hypernuclei

(from Panic 02, H. Takahashi et.al,NP A721(2003)951c-954c)

Single events from emulsions



E961, An improved search for double Λ hypernuclei

- **E961: Collaboration** *(same as E906)*
  - BNL, CMU, Gifu, Freiburg, Hampton, INR-Russia, KEK, Kyoto, Manitoba, New Mexico, Osaka, Osaka Electro-Communication, Pusan, Temple, Tokyo, TRIUMF
  - Spokesmen: T. Fukuda (Osaka Electro-Comm.), A. Rusek (BNL), R. Chrien (BNL)

- **The Improvements/Changes**
  - Improved statistics (run time, protons/spill, spectrometer acceptance)
  - CDS momentum resolution
    - New target vertex chamber
    - Higher CDS magnetic field
  - Ξ^- decay background reduction
    - New target vertex chamber
    - Better target geometry
  - Replace ^{9}Be target with ^{7}Li
    - Direct reaction cannot produce two single Λ hyperfragments
    - Eliminates $Z > 1$ double Λ hypernuclei in direct reaction
    - Stopping Ξ^- reduced due to lower density of Li

E961 improvements over E906

	E906	E963	Improvement	Total
Improvement in statistics:				
• Data collection hours	450	1200	2.7	
• Protons per AGS spill	7 TP	15-30 TP*	2.1- 3.2	
• K^+ Spectrometer Acceptance	1	1.9	1.9	10 – 16
Other improvements				
• CDS momentum resolution (rms MeV/c at 100 MeV/c)	4.3	2.7	1.6	
• Ξ^- decay background reduction (S/N at 114 MeV/c)	4:1	16:1	4	

* Depends on beam allocation – assumes p's/sec constant with duty factor 46 and 67 %

in flight (same nucleus) $K^- + {}^7Li \rightarrow K^+ + (\Xi^- + {}^6He)$
(pion momenta for decay to ground states)

Kinetic energy of Ξ ~ 100 MeV **bold → monoenergetic pion**

Mass(MeV)	**Reaction Products**	$p_{\pi 1}$(MeV/c)	$p_{\pi 2}$ (MeV/c)	
6926.9	$(\Xi^- + {}^6He)$			
~~8784.7~~	~~${}^4_\Lambda H + {}^4_\Lambda H + n$~~	~~**133.0**~~	~~**133.0**~~	
~~8792.9~~	~~${}^4_\Lambda H + {}^3_\Lambda H + 2n$~~	~~**133.0**~~	~~**114.3**~~	"Background"
~~8801.0~~	~~${}^3_\Lambda H + {}^3_\Lambda H + 3n$~~	~~**114.3**~~	~~**114.3**~~	
	$\Xi^- + X$	139*(Ξ^-)	101*(Λ)	

$\Delta B_{\Lambda\Lambda}$ = 0 MeV		p_π for $\Delta B_{\Lambda\Lambda}$ = 4/ 0 MeV	p_π for $_\Lambda$X decay produc	
~~8766.1~~	~~${}^8_{\Lambda\Lambda}He + n$~~	~~**112.0/ 118.1**~~	121.3	
~~8770.0~~	~~${}^7_{\Lambda\Lambda}He + 2n$~~	~~**104.5/ 110.9**~~	~~**108.1**~~	
~~8771.2~~	~~${}^6_{\Lambda\Lambda}He + 3n$~~	~~95.6/ 102.3~~	~~99.3~~	
~~8793.2~~	~~${}^5_{\Lambda\Lambda}He + 4n$~~	~~94.1/ 100.7~~	~~97.3~~	
6911.3	${}^5_{\Lambda\Lambda}H + 2n$	**129.7/ 135.3**	99.3	"Signal"
6925.4	${}^4_{\Lambda\Lambda}H + 3n$	**112.7/ 118.7**	97.3	
6919.4	${}^3_{\Lambda\Lambda}n + {}^3H + n$	**103.8*/110.0***	**114.3**	

* Doppler broadened and not likely bound

(**stopped Ξ^-**) $K^- + {}^7Li \rightarrow K^+ + \Xi^- + X$; $(\Xi^- + {}^7Li) \rightarrow X$

(stops suppressed due to low density of Li)

(pion momenta for decay to ground states)

Mass(MeV)	**Reaction Products (Q value allowed)**	**bold → monoenergetic pion**		
7855.2	Ξ^-(stopped) + ^{7}Li			
		$p_{\pi 1}$(MeV/c)	$p_{\pi 2}$ (MeV/c)	
~~9701.90~~	~~$^6_\Lambda$He + $^4_\Lambda$H~~	~~**108.4**~~	~~**133.0**~~	
~~9710.07~~	~~$^6_\Lambda$He + $^3_\Lambda$H + n~~	~~**108.4**~~	~~**114.3**~~	
~~9702.07~~	~~$^5_\Lambda$He + $^4_\Lambda$H + n~~	~~99.3~~	~~**133.0**~~	"Background"
~~9710.24~~	~~$^5_\Lambda$He + $^3_\Lambda$H + 2n~~	~~99.3~~	~~**114.3**~~	
7845.1	$^4_\Lambda$H + $^4_\Lambda$H	**133.0**	**133.0**	(not present with ^{9}Be tgt)
7853.3	$^4_\Lambda$H + $^3_\Lambda$H + n	**133.0**	**114.3**	(not present with ^{9}Be tgt)
	Ξ^- + X	139*(Ξ^-)	101* (Λ)	

$\Delta B_{\Lambda\Lambda}$ = 0 MeV		p_π for $\Delta B_{\Lambda\Lambda}$ = 4/ 0 MeV	p_π for $_\Lambda$X decay product	
~~9691.2~~	~~$^9_{\Lambda\Lambda}$Li + n~~	~~**118.3/ 124.2**~~	~~**96.9**~~	
~~9700.9~~	~~$^8_{\Lambda\Lambda}$Li + 2n~~	~~**103.8/ 110.3**~~	~~**97.1**~~	
~~9702.1~~	~~$^8_{\Lambda\Lambda}$He + ^{2}H~~	~~**112.0/ 118.1**~~	~~121.3~~	"Signal"
7830.4	$^7_{\Lambda\Lambda}$He + n	**104.5/ 110.9**	**108.1**	
7831.6	$^6_{\Lambda\Lambda}$He + 2n	95.6/ 102.3	99.3	
7853.7	$^5_{\Lambda\Lambda}$He + 3n	94.1/ 100.7	97.3	(not present with ^{9}Be tgt)
7845.1	$^5_{\Lambda\Lambda}$H + ^{3}H	**129.7/ 135.3**	99.3	
7855.2	$^4_{\Lambda\Lambda}$H + ^{3}H + n	**112.7/ 118.7**	97.3	
7859.0	$^3_{\Lambda\Lambda}$n + ^{3}H + 2n	**103.8*/110.0***	**114.3**	

* Doppler broadened and not likely bound

The expected double Λ hypernuclei (new) two body decay modes – direct reaction

1) $_{\Lambda\Lambda}{}^{5}\mathrm{H} \rightarrow {}_{\Lambda}{}^{5}\mathrm{He} + \pi^-$

- π^- momentum determines ΛΛ Binding
- For $B_{\Lambda\Lambda} = 4$ (twice Λ binding in $_{\Lambda}{}^{4}\mathrm{H}$) and $\Delta B_{\Lambda\Lambda} = 1$ MeV; $p_\pi = 133.9$ MeV/c
- $_{\Lambda}{}^{5}\mathrm{He} \rightarrow (p,\alpha) + \pi^-$ (99.3 MeV/c; π^-; momentum from emulsion)

2) $_{\Lambda\Lambda}{}^{4}\mathrm{H} \rightarrow {}_{\Lambda}{}^{4}\mathrm{He} + \pi^-$

- π^- momentum determines ΛΛ Binding
- for $B_{\Lambda\Lambda} = 0.3$ (twice Λ binding in $_{\Lambda}{}^{3}\mathrm{H}$) and $\Delta B_{\Lambda\Lambda} = 1$ MeV; $p_\pi = 117.2$ MeV/c
- $_{\Lambda}{}^{4}\mathrm{He} \rightarrow {}^{3}\mathrm{He} + p + \pi^-$ (97.3 MeV/c π^-; momentum from emulsion)

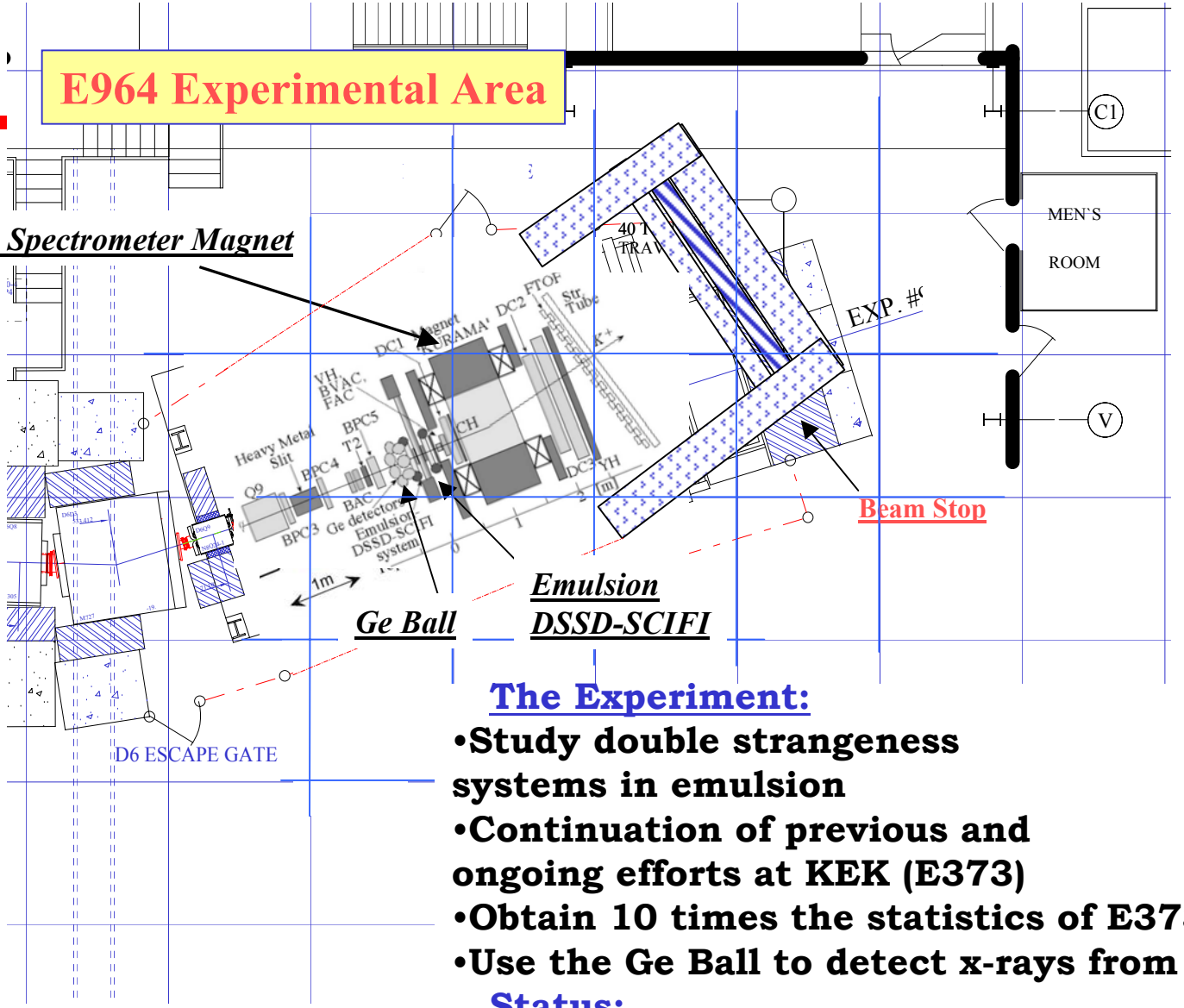
Additional two body decay mode with stopped Ξ^-

(however, suppressed due to low density of LiH)

1) $_{\Lambda\Lambda}{}^{7}\mathrm{He} \rightarrow {}_{\Lambda}{}^{7}\mathrm{Li} + \pi^-$

- π^- momentum determines $\Lambda\Lambda$ Binding
- For $B_{\Lambda\Lambda} = 8$ (twice Λ binding in $_{\Lambda}{}^{6}$He) and $\Delta B_{\Lambda\Lambda} = 1$ MeV; $p_\pi = 109.4$ MeV/c
- $_{\Lambda}{}^{7}\mathrm{Li} \rightarrow {}^{7}\mathrm{Be} + \pi^-$ ($p_\pi = 108$ MeV/c)

New double Λ Hypernuclear Experiment for the AGS



The Experiment:

- **Study double strangeness systems in emulsion**
- **Continuation of previous and ongoing efforts at KEK (E373)**
- **Obtain 10 times the statistics of E373**
- **Use the Ge Ball to detect x-rays from Ξ^- atoms**

Status:

- **Japan funding in place to construct experiment**
- **Awaiting go-ahead/scheduling from BNL**

Outlook for the Future

- ***AGS Fixed target experiments are no longer supported concurrent with RHIC operations since HEP base support was terminated at the end of 2002.***

- Two major HEP experiments submitted proposals to the NSF for construction and operations funds. These experiments, E926-K0PI0 and E940-MECO, collectively referred to as RSVP, were identified by the NSF for support and were included in the FY 2004 Presidents Budget request for a 2006 construction start. A third proposal, E949 (K^+ rare decay) will be submitted soon.

- Should AGS fixed target base support be restored as a result of these initiatives then cost sharing could lead to limited NP AGS experimental program concurrent with HEP and RHIC operations.

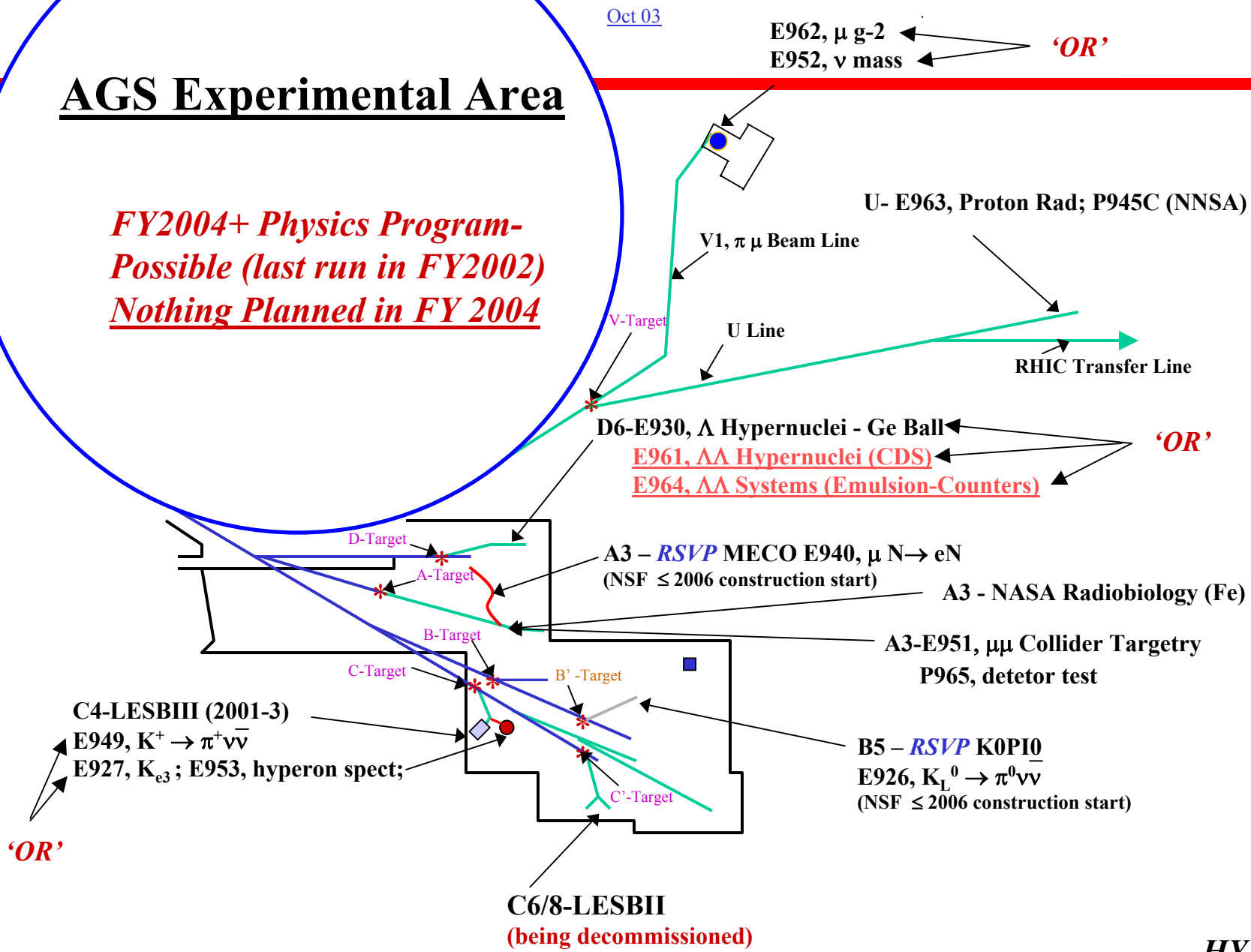
SUPPLEMENTAL INFORMATION

E906 Collaboration

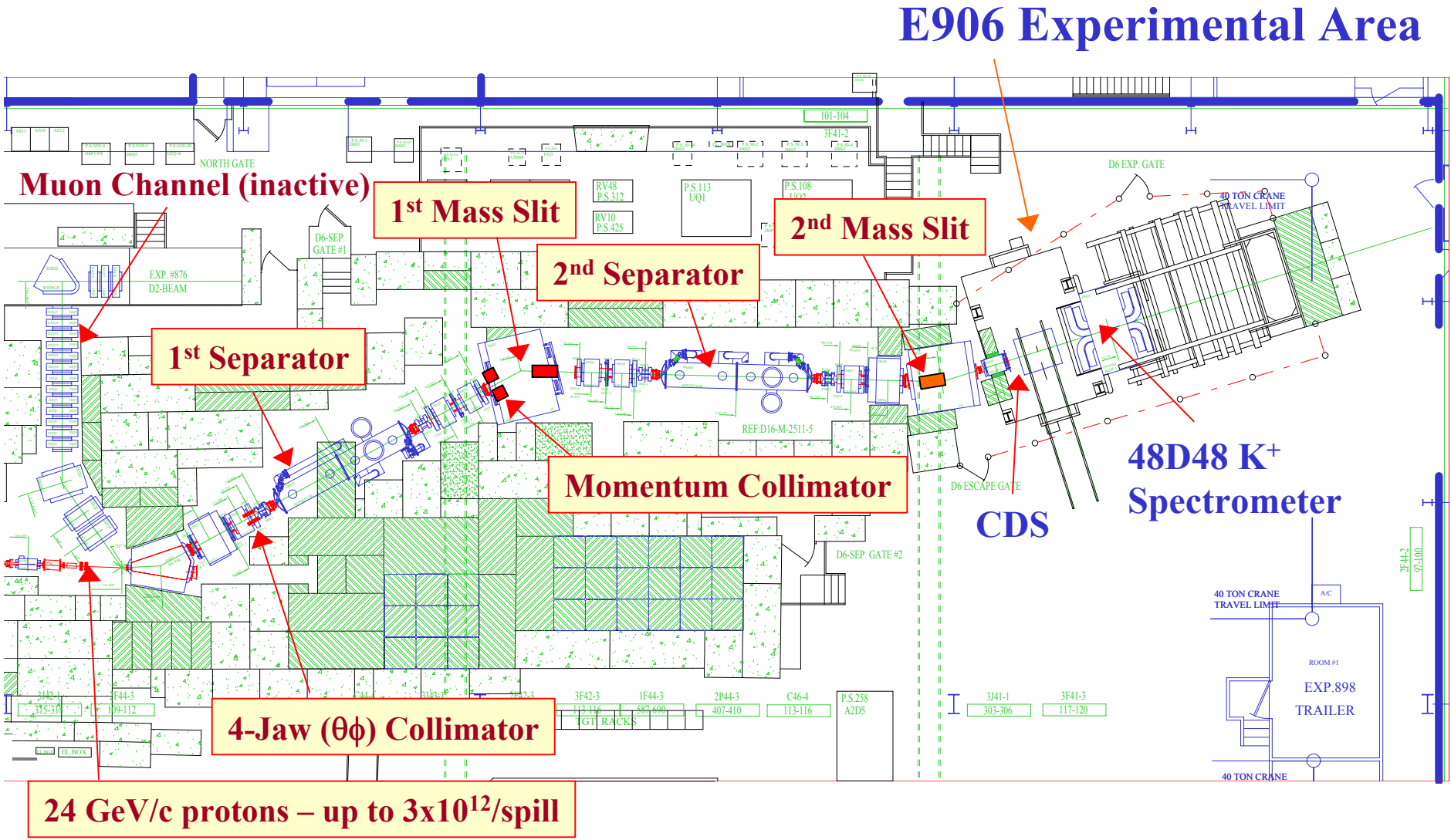
KEK	T.Fukuda, T.Nagae, H.Outa, M.Sekimoto
U-Tokyo	H.Hotchi, T.Miyachi, J.Nakano, T.Tamagawa, K.Tanida
BNL	R.E.Chrien, M.May, E.Meyer, P.Pile, A.Rusek, R.Sutter
CMU	A.Berdoz, D.Carman, P.Eugeno, G.B.Franklin, P.Khaustov, P.Koran, C.Meyer, K.Paschke, B.P.Quinn, R.A.Schumacher
Hampton-U	L.Gan, L.Tang, L.Yuan
INR(Moscow)	A.Kourepin, V.Rasin, M.Prokhabatilov, K.Shileev
Kyoto-U	J.K.Ahn, H.Akikawa, K.Imai, A.Ichikawa, K.Yamamoto M.Yosoi
Osaka-U	S.Ajimura, T.Kishimoto, H.Kori, S.Minami, Y.Shimizu
Temple-U	Z.Meziani
U-Freiburg	H.Fischer, J.Franz, H.Schmitt
U-Manitoba	C.A.Davis, M.Landry
U-New Mexico	B.Bassalleck

AGS Experimental Area

FY2004+ Physics Program-
Possible (last run in FY2002)
Nothing Planned in FY 2004

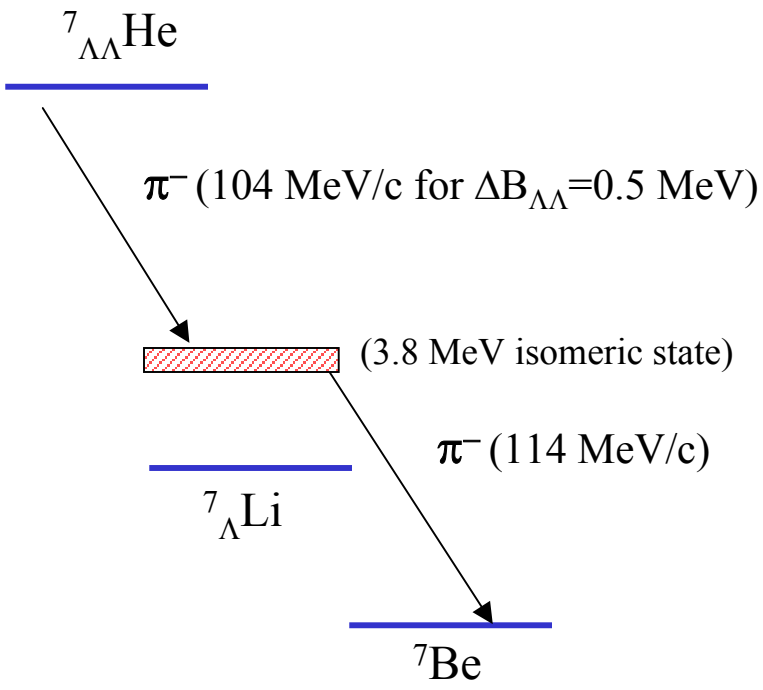


D6 Beam Line and Experimental Area



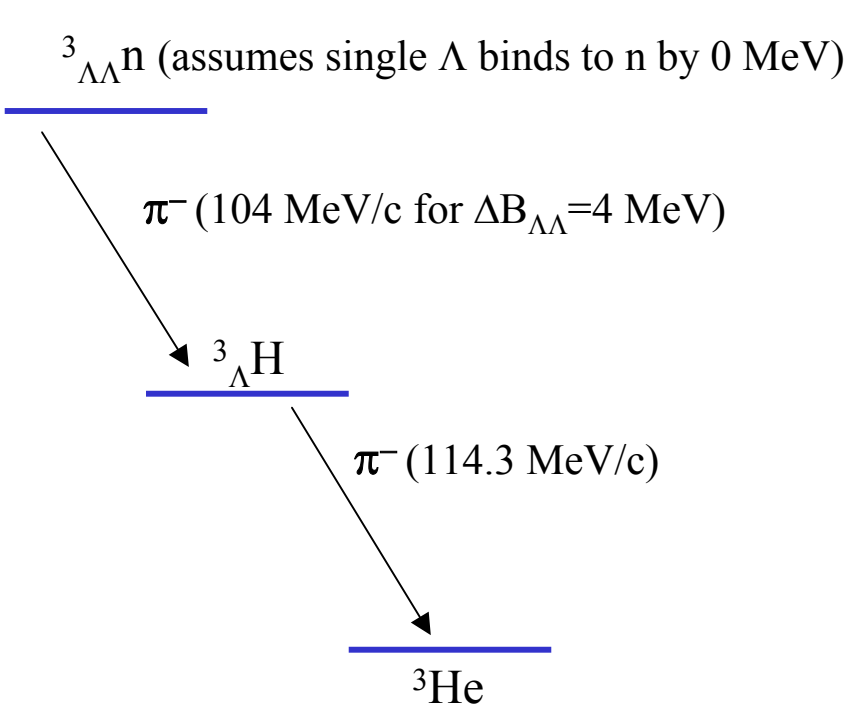
Another Possibility $^{7}_{\Lambda\Lambda}$He (Hungerford)

104 X 114 MeV Lines



Another Possibility ${}^{4}_{\Lambda\Lambda}n$ (Gal)

104 X 114 MeV Lines



114 X 133 MeV Lines