The HypHI Status
and
First Results

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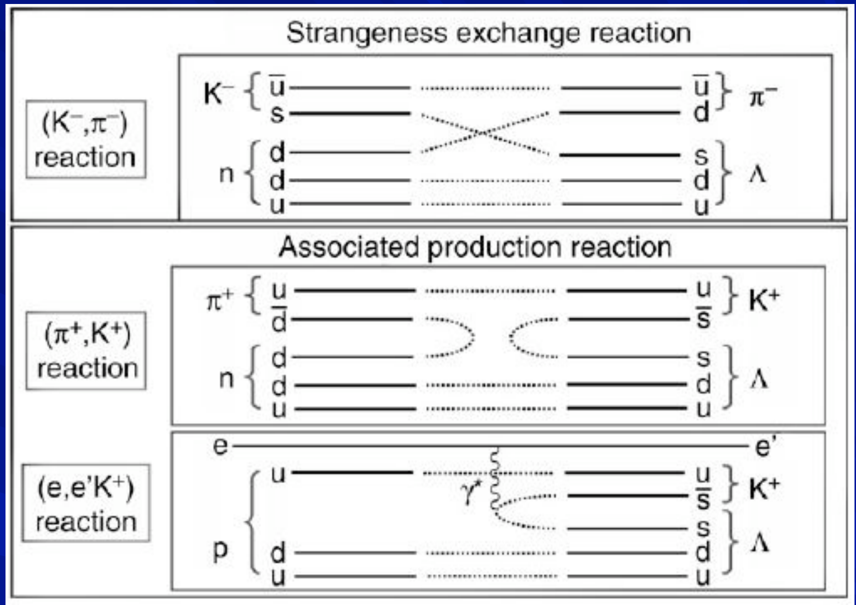
Hypernuclear spectroscopy

- (K^-, π^-) **reactions, stopped** K^-
  - Strangeness exchange
  - Small momentum transfer
  - Missing mass and γ-ray spectroscopy
  - CERN, BNL, KEK, LNF, J-PARC
- (π^+, K^+) **reactions**
  - Strangeness production
  - Large momentum transfer
  - Missing mass and γ-ray spectroscopy
  - BNL, KEK, J-PARC
- **(e, e'K$^+$) reactions**
  - Strangeness production
  - Large momentum transfer
  - Missing mass spectroscopy
  - JLAb, MAMI
- (K^-,K^+) **reaction and** Ξ^- **capture**
  - Multi-step process
  - Double strangeness
  - BNL, J-PARC, FAIR (PANDA)



Hypernuclear spectroscopy

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Advantage

- Precise spectroscopy
  - Structure in detail
- Clean experiment

Disadvantage

- Limited isospin
- Small momentum transfer to separate hypernuclei
- Difficulties on decay studies
- Only up to double-strangeness

Hypernuclear spectroscopy with heavy ion beams

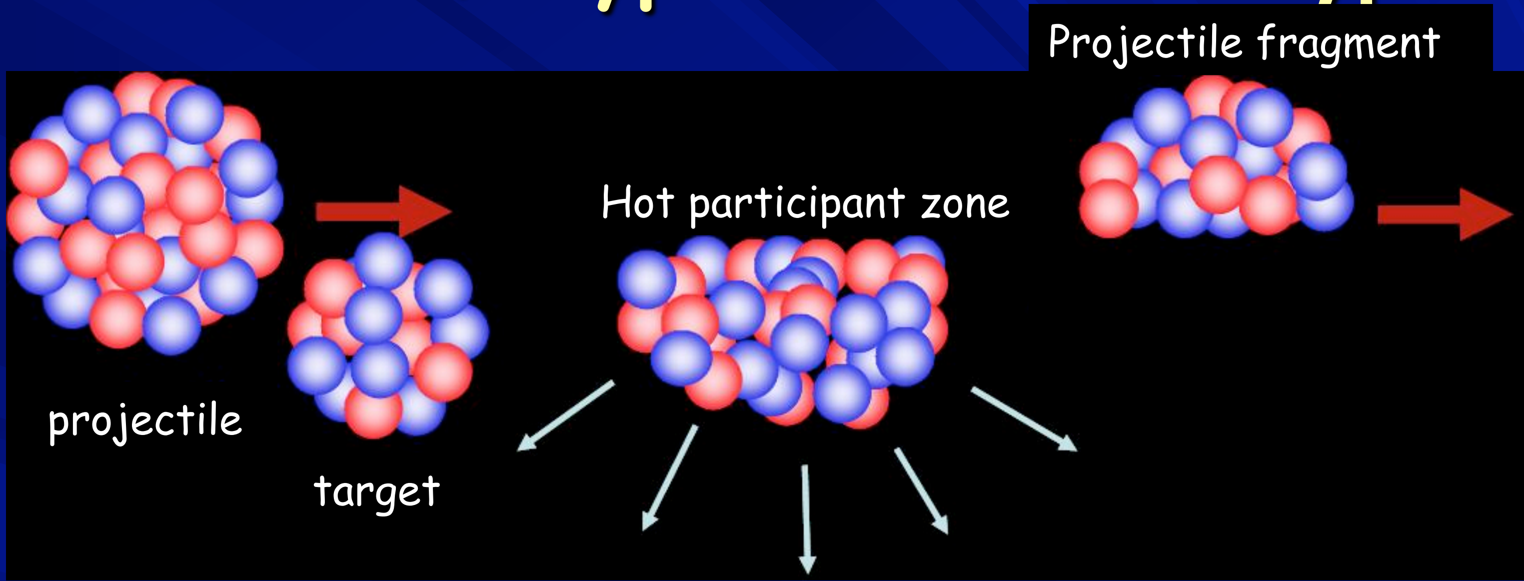
HypHI project

The HypHI project

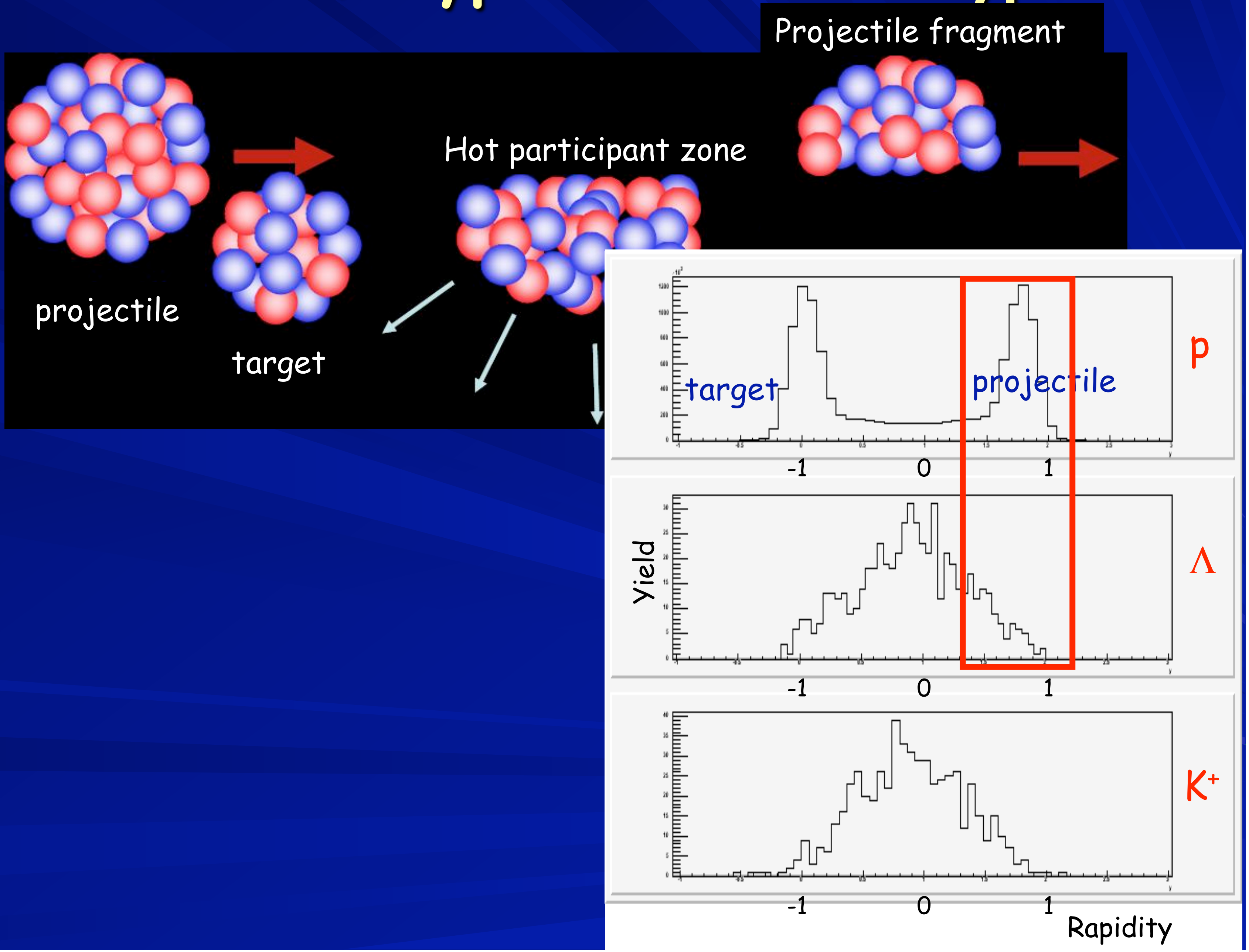
- **Precise hypernuclear spectroscopy with heavy ion induced reactions at GSI and towards FAIR**
- **Only the way to access**
  - Extreme neutron/proton rich hypernuclei
  - Hypernuclear magnetic moments
  - Hypernuclei with extremely multiple strangeness
  - Hypernuclear decay in detail
- **Difficulties:**
  - Small hypernuclear cross section
  - Huge background

- **2005:**
  - Feb. : HypHI collaboration started
  - March: LOI
- **2006**
  - April: HypHI group at GSI
  - September: Proposal for Phase 0
- **2009**
  - August/October: Phase 0 experiment
- **2010**
  - March: Phase 0.5 experiment

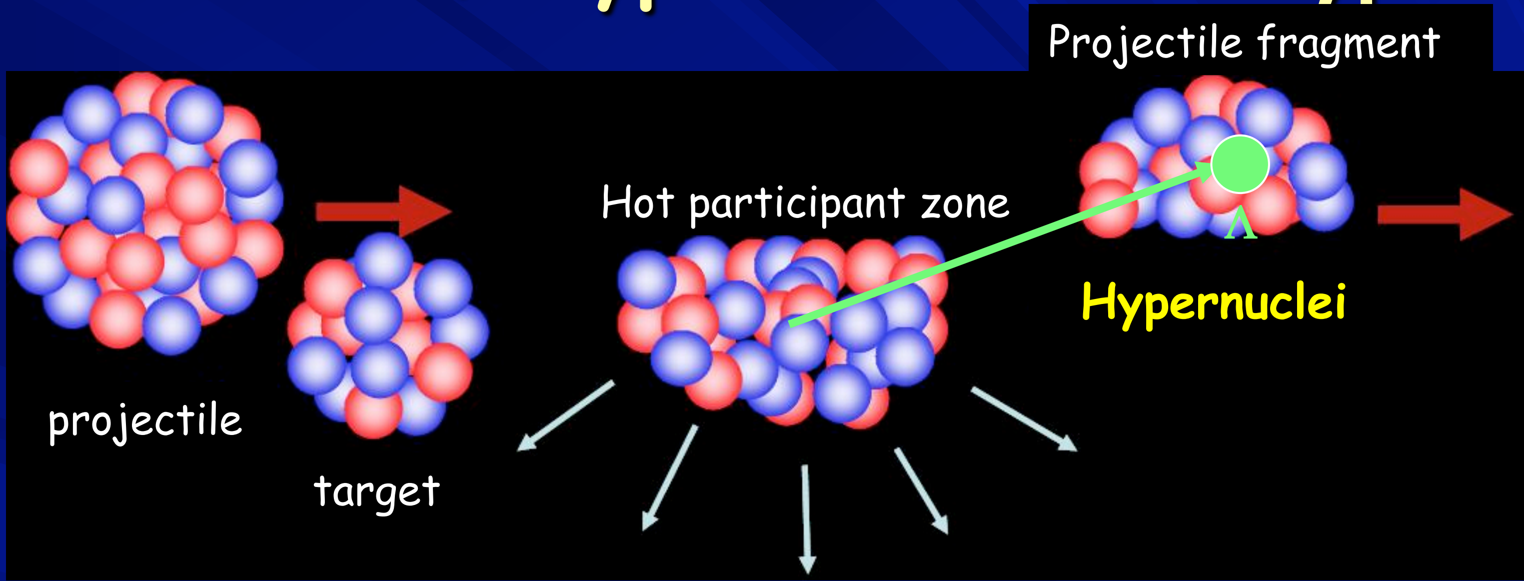
Production of Hypernuclei with HypHI



Production of Hypernuclei with HypHI

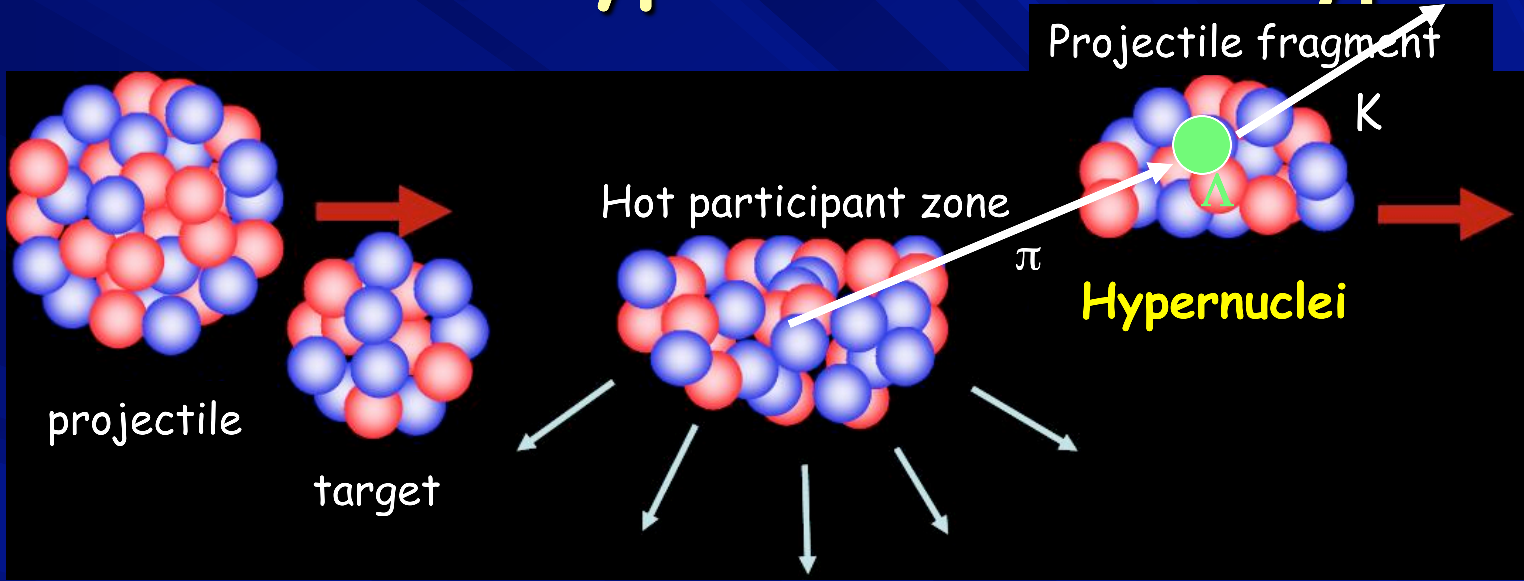


Production of Hypernuclei with HypHI



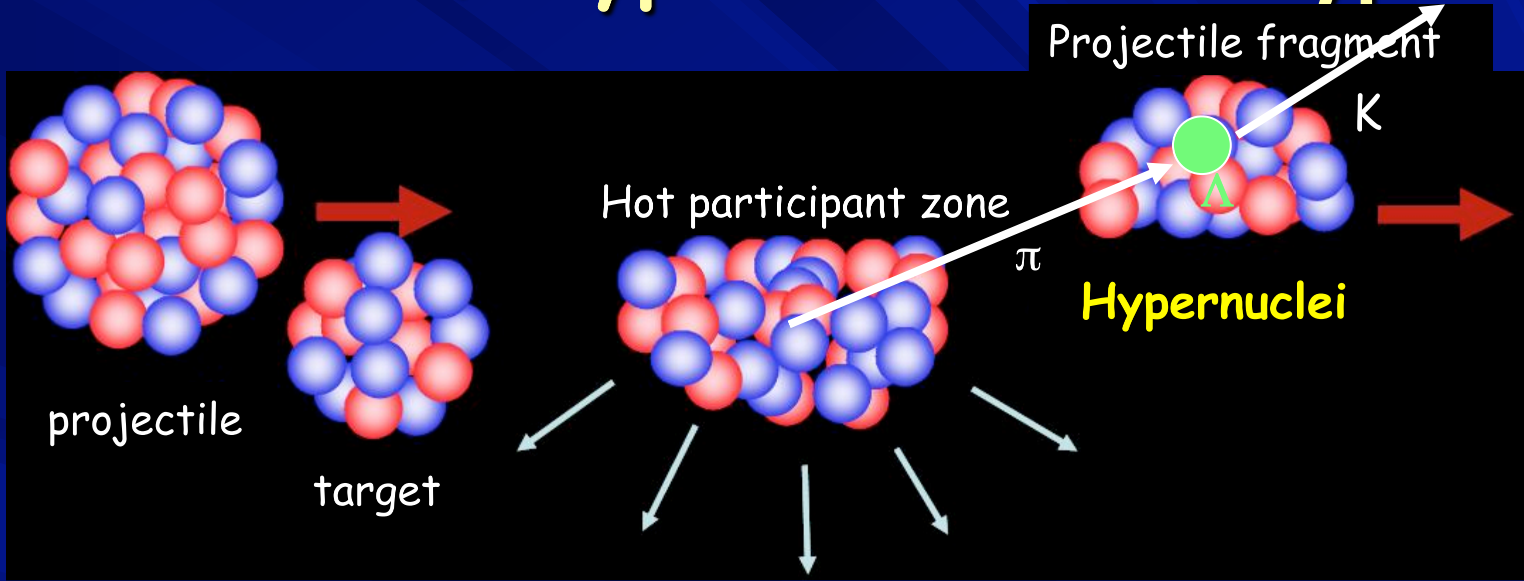
- **Coalescence of Λ in projectile fragments**

Production of Hypernuclei with HypHI



- Coalescence of Λ in projectile fragments
- (π^+,K^+) reactions in projectile fragments

Production of Hypernuclei with HypHI



- **Coalescence of Λ in projectile fragments**
- **(π^+,K^+) reactions in projectile fragments**

- **NN -> ΛKN : Energy threshold ~ 1.6 GeV**
  - Heavy ion beams with E > 1.6 A GeV needed
    - Stable heavy ion beam at GSI
    - Stable heavy ion beam at FAIR
    - **RI-beam from FRS and super-FRS**

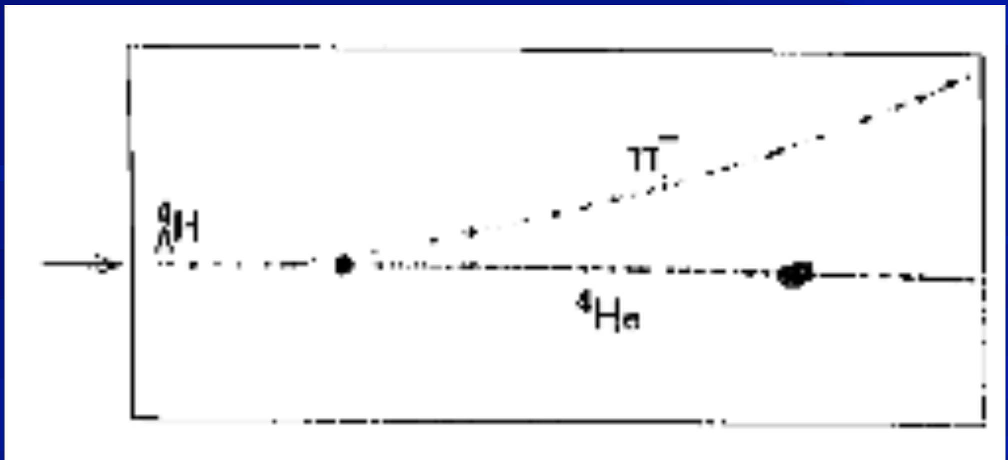
Accessible to neutron- and proton rich hypernuclei

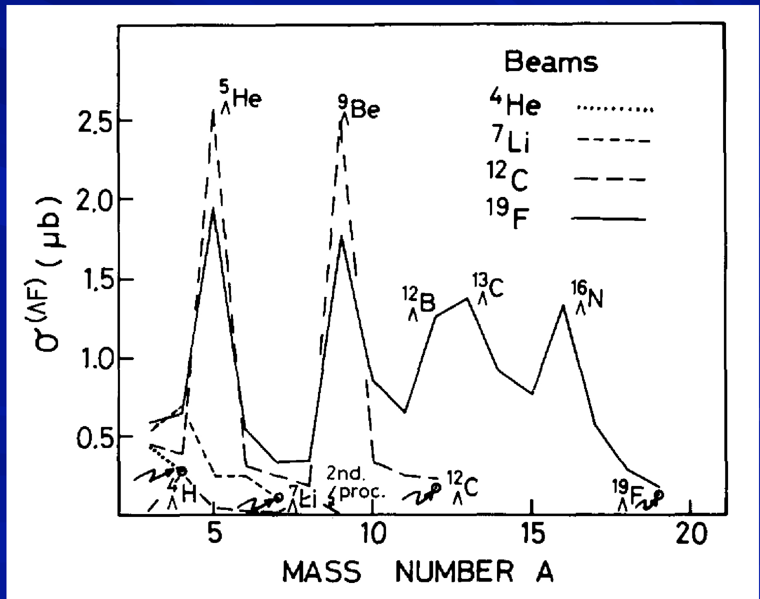
Heavy-ion induced hypernuclear production

- No RI-beam induced hypernuclear production so far

- Stable heavy-ion induced hypernuclear production at Dubna in 1989.
  - ^{4}He beam at 3.7 GeV/u on a polyethylene target
  - ^{7}Li beam at 3.0 GeV/u on a polyethylene target

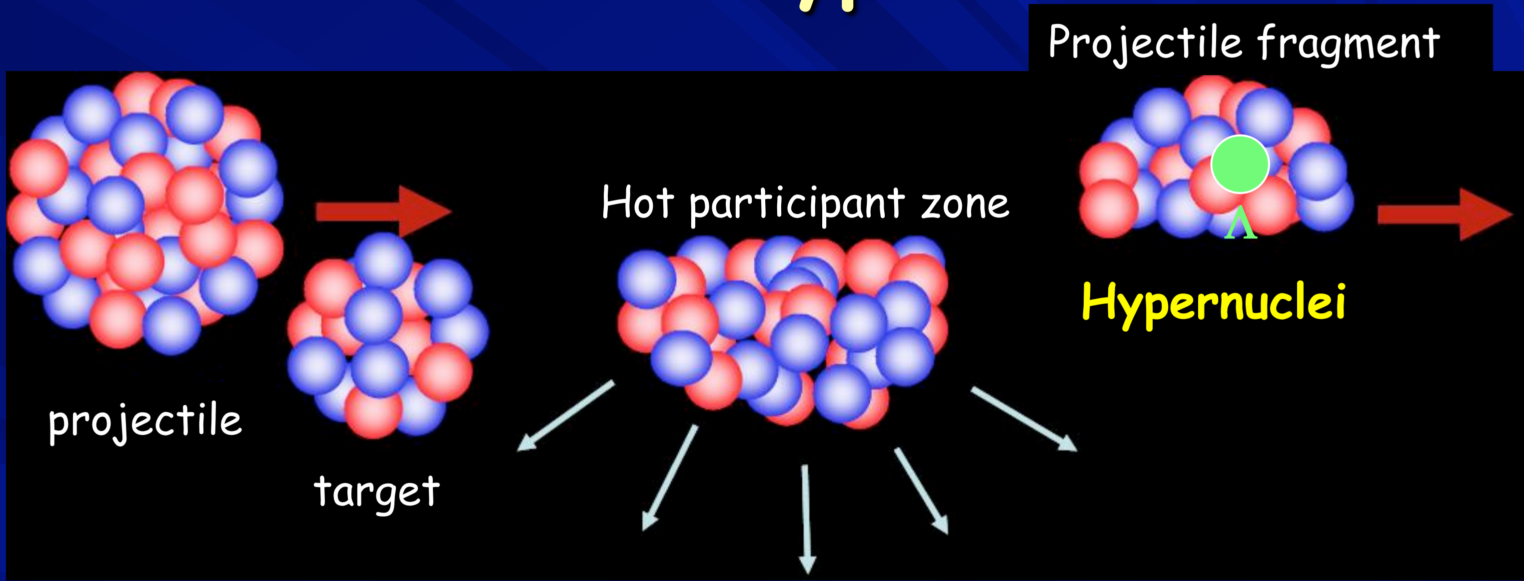
  - Streamer chamber
  - Cross section: an order of 10^{-7} barn





H. Bando et al., NPA 501 (1989) 900

Relativistic hypernuclei



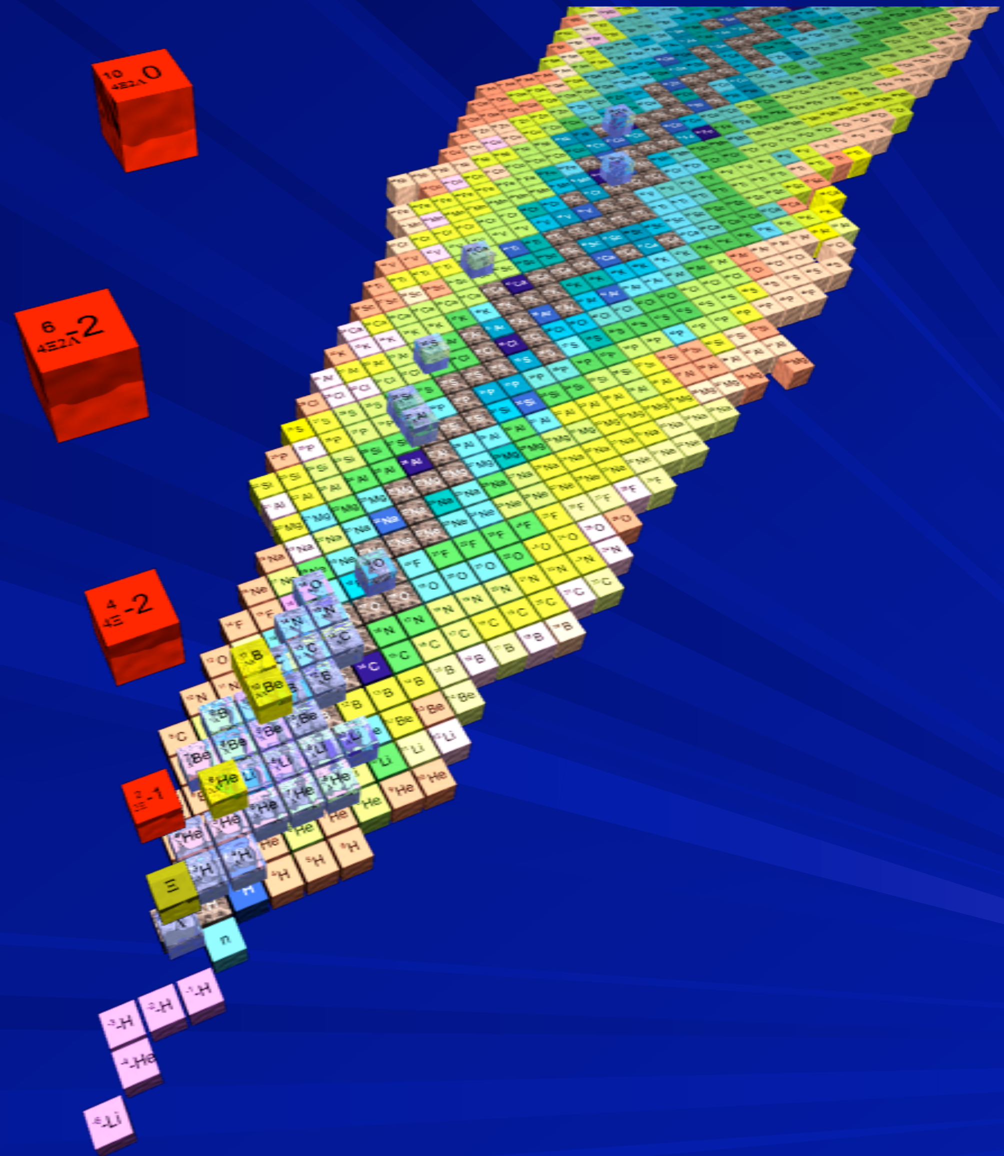
- **Large Lorentz factor** γ (>3)
  - Effective lifetime : Longer by the Lorentz factor

    200 ps -> 600 ps at GSI (ct ~ 20 cm)

    200 ps -> 4 ns at FAIR (ct ~ 120 cm)

- **Hypernuclear separation and spin precession**
  - Can be feasible with 20 Tm at 20 A GeV
  - Large spin precession in magnetic fields
    - 225 degrees with free-Λ magnetic moment

Nuclear matter with multiple-strangeness

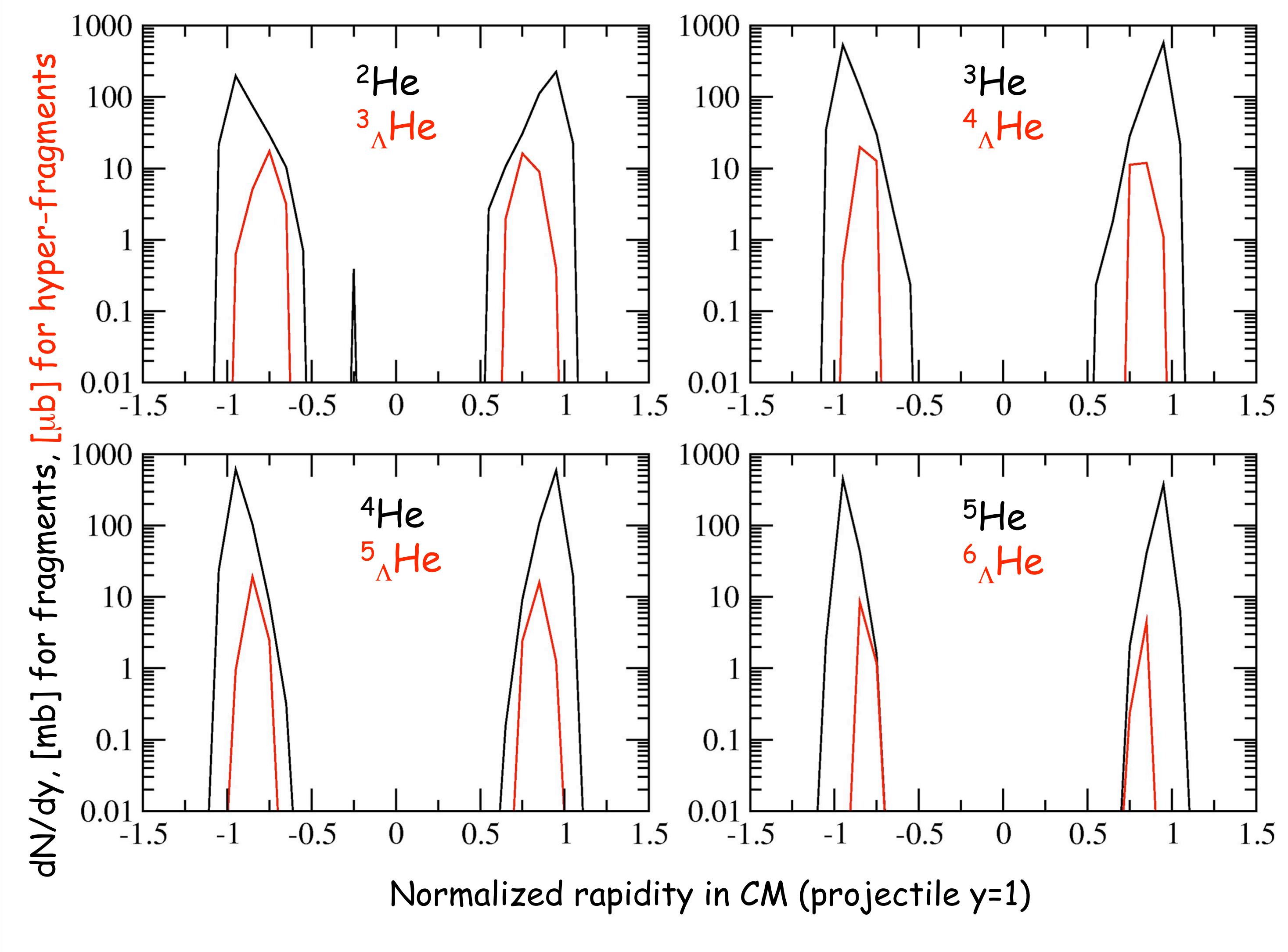


HypHI concept and requirement

- Invariant mass spectroscopy
  - A mass peak must be observed clearly on the background
  - A peak is not sufficient proof
  - Lifetime must be measured to confirm the identification

- Hypernuclei must be measured at the projectile rapidity

GI Relativistic Boltzmann-Uehling-Uhlenbeck



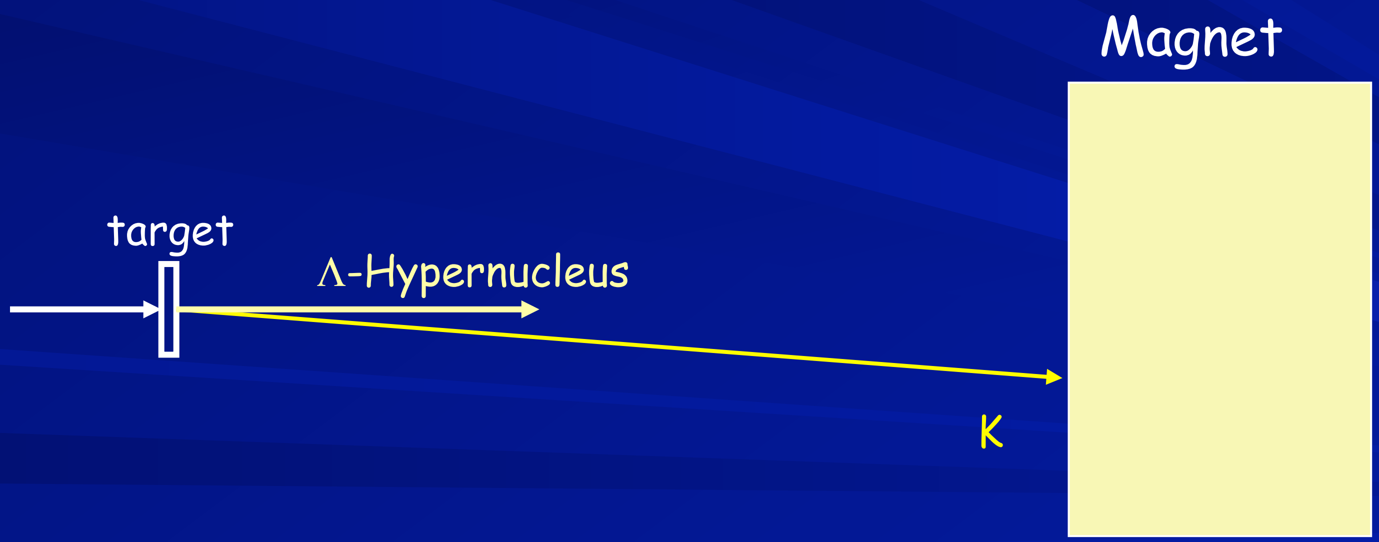
T. Gaitanos et al., Physics Letters B 675 (2009) 297

HypHI at GSI/FAIR: Concept of Experiments

Produced hypernucleus close to projectile velocity

- Large Lorents factor $\gamma > 3$
- $c\tau \sim 20$ cm at 2 A GeV

Example : $^{12}C + {}^{12}C \rightarrow {}^{A}_{\Lambda}Z + K^{+,0} + X$



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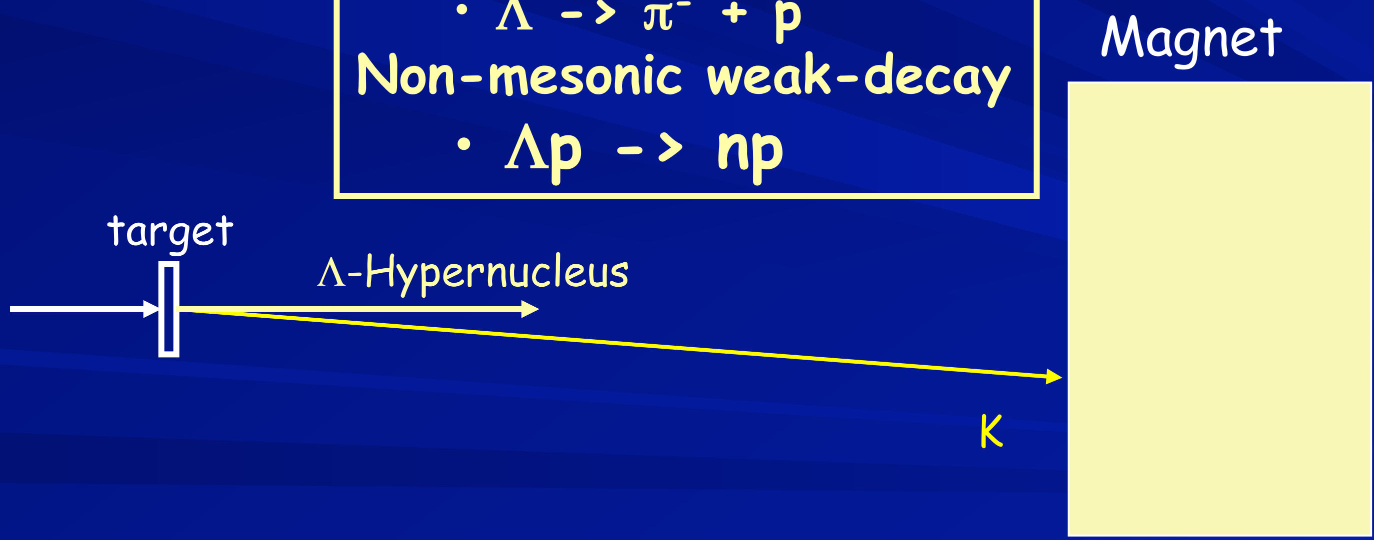
Mesonic weak decay

- $\Lambda \rightarrow \pi^- + p$

Non-mesonic weak-decay

- $\Lambda p \rightarrow np$



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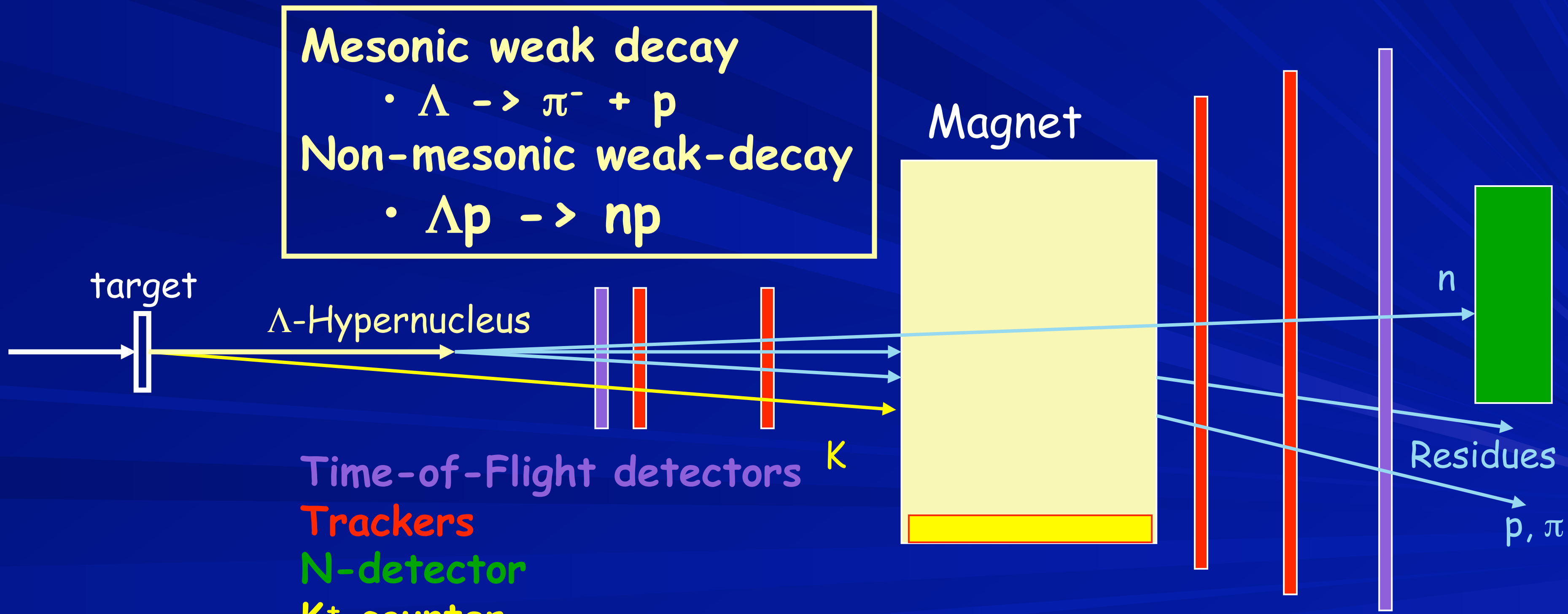
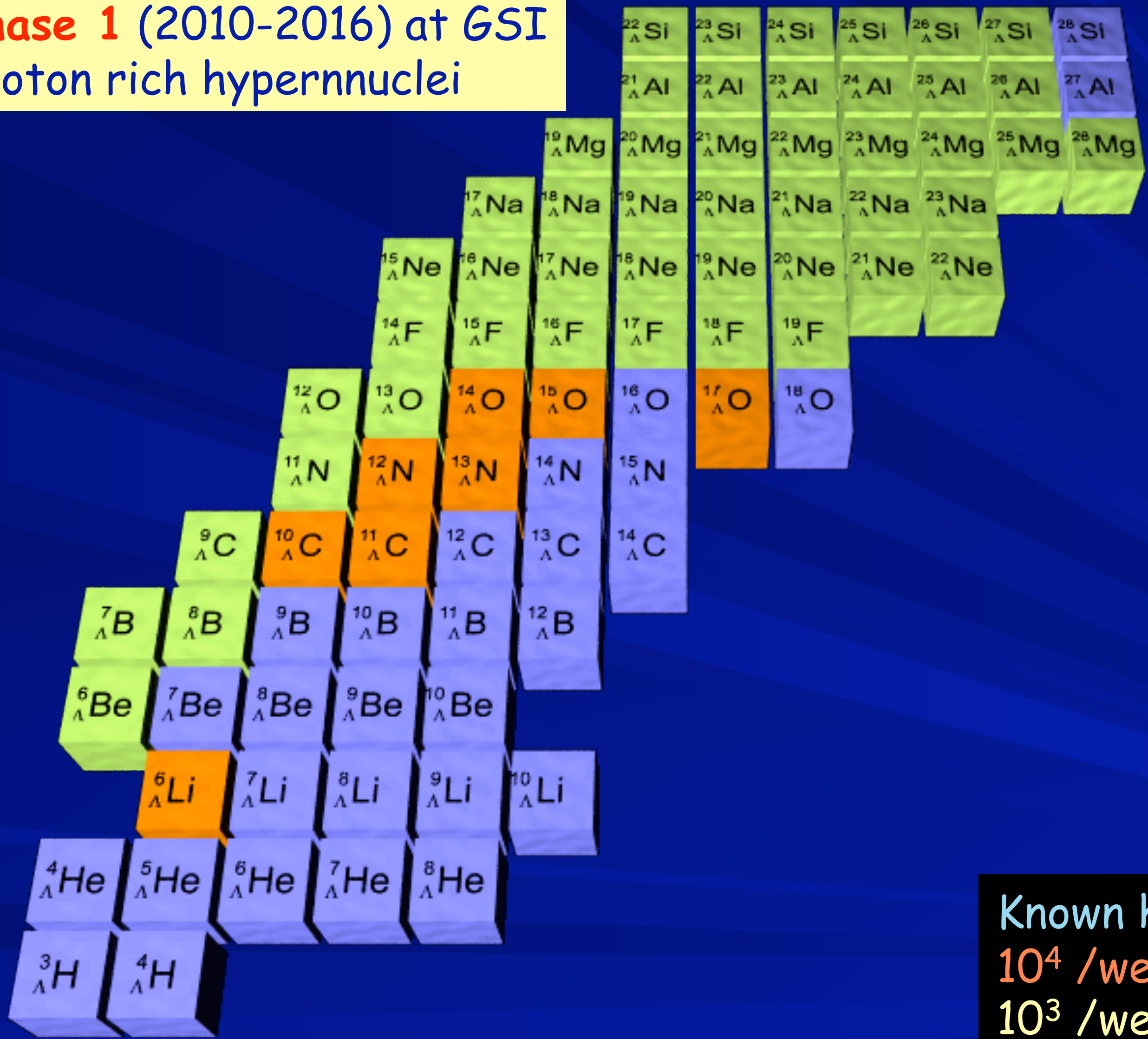


Present hypernuclear landscape

Hypernuclear landscape with HypHI

Phase 1 (2010-2016) at GSI
Proton rich hypernnuclei



Known hypernuclei
10^4 /week
10^3 /week

Hypernuclear landscape with HypHI

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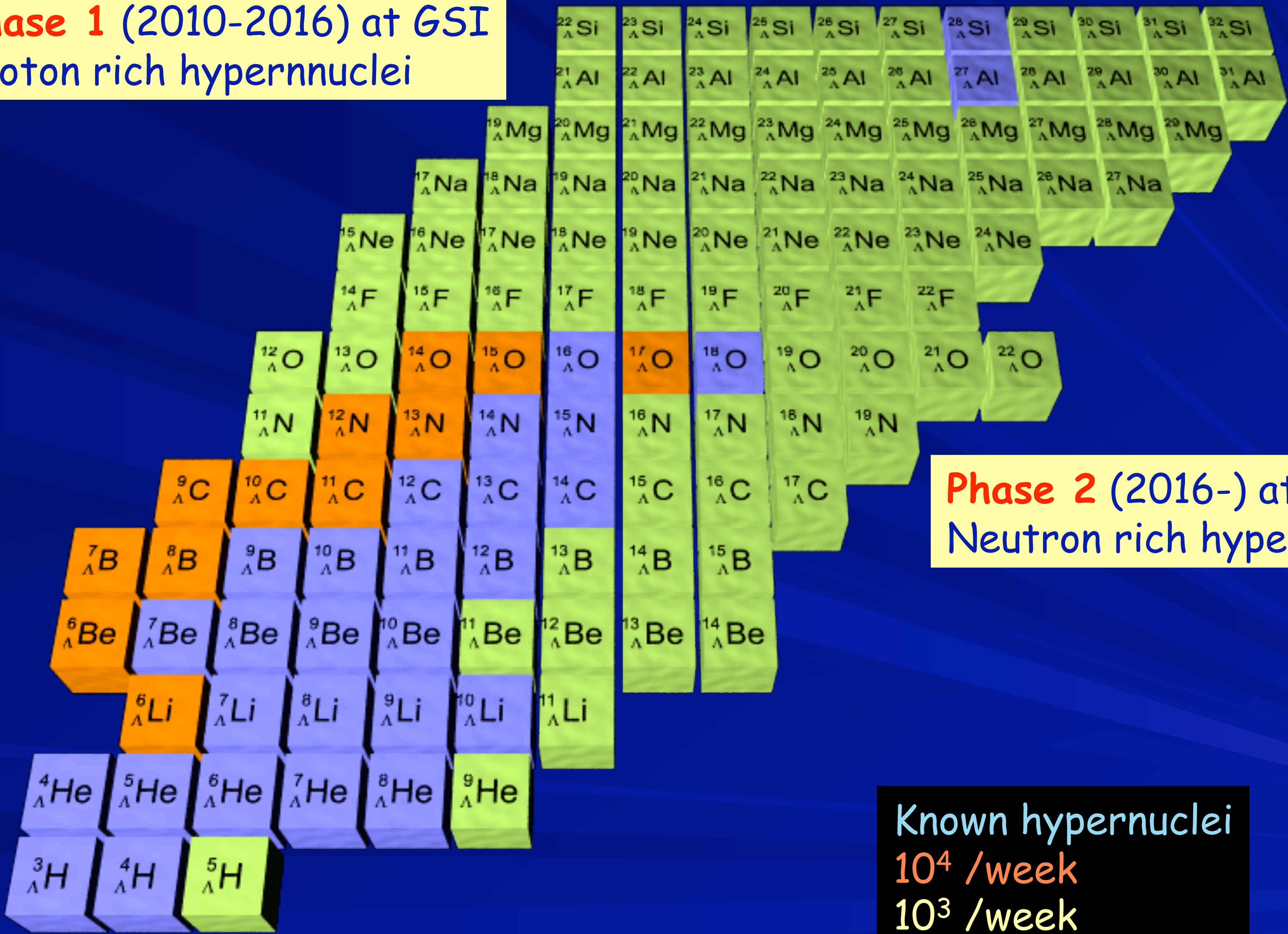
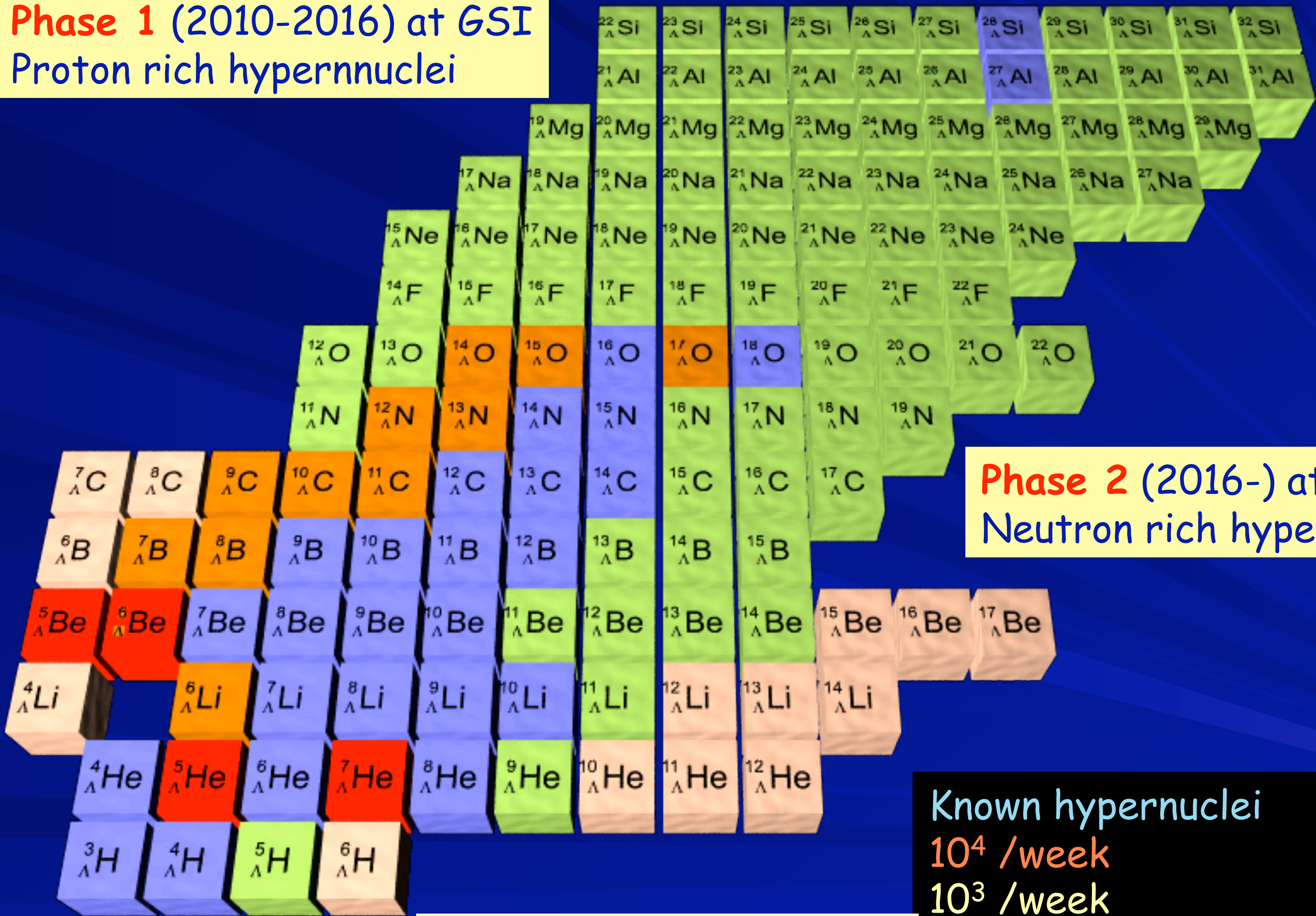


Phase 2 (2016-) at R3B/FAIR
Neutron rich hypernuclei

Known hypernuclei
10^4 /week
10^3 /week

Hypernuclear landscape with HypHI

Phase 1 (2010-2016) at GSI
Proton rich hypernnuclei



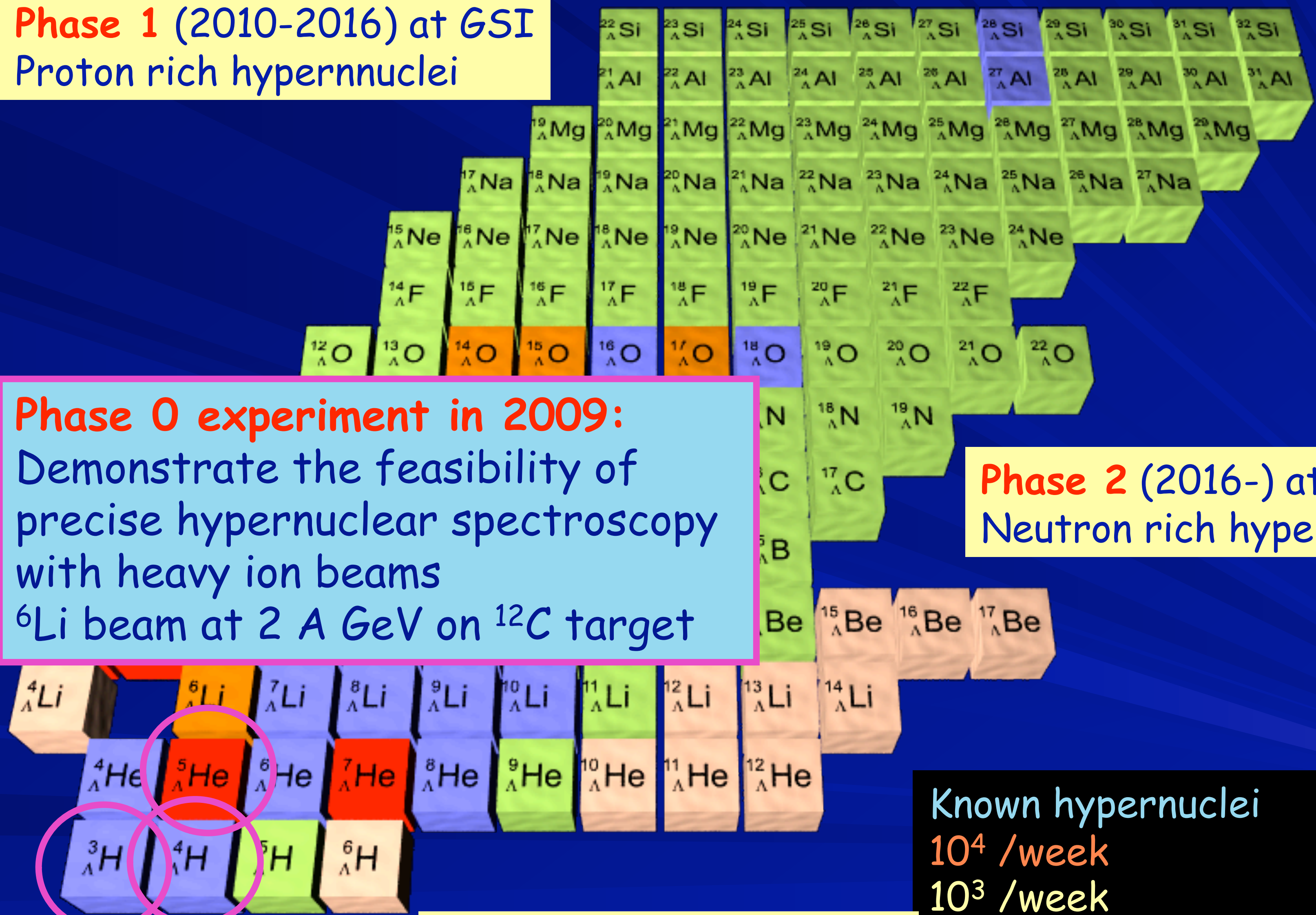
Phase 2 (2016-) at R3B/FAIR
Neutron rich hypernuclei

Phase 3 (20XX-) at FAIR
Hypernuclear separator

Known hypernuclei
10^4 /week
10^3 /week
With hypernuclear separator
Magnetic moments

Hypernuclear landscape with HypHI

Phase 1 (2010-2016) at GSI
Proton rich hypernnuclei



Phase 0 experiment in 2009:
Demonstrate the feasibility of precise hypernuclear spectroscopy with heavy ion beams
^{6}Li beam at 2 A GeV on ^{12}C target

Phase 2 (2016-) at R3B/FAIR
Neutron rich hypernuclei

Phase 3 (20XX-) at FAIR
Hypernuclear separator

Known hypernuclei
10^4 /week
10^3 /week
With hypernuclear separator
Magnetic moments

HypHI Phase 0 in October 2009

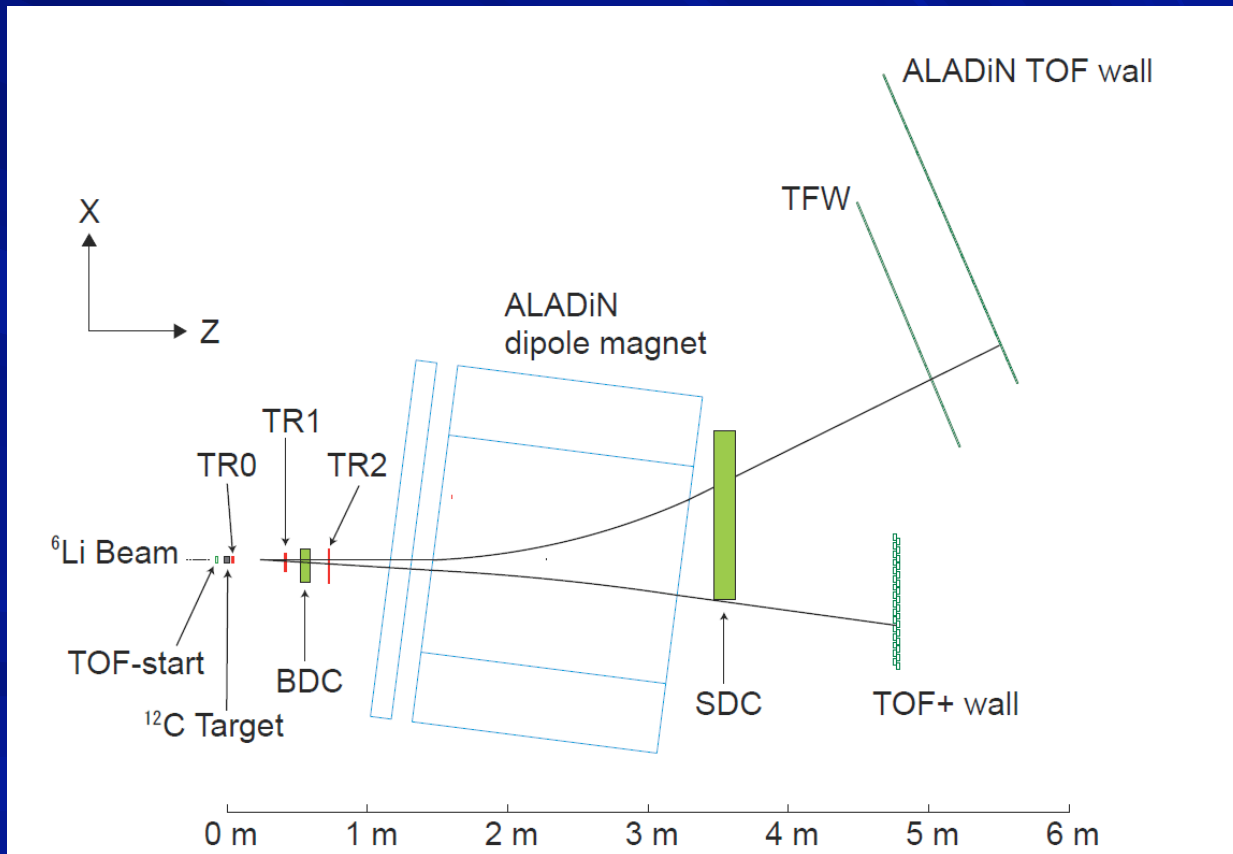
- The goal of the Phase 0 experiments
  - To demonstrate the feasibility of precise hypernuclear spectroscopy with ^{6}Li primary beams at 2 A GeV : Mesonic decay $\Lambda \to \pi^- + p$

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

$^{4}_{\Lambda}H \to \pi^- + {}^{4}He$

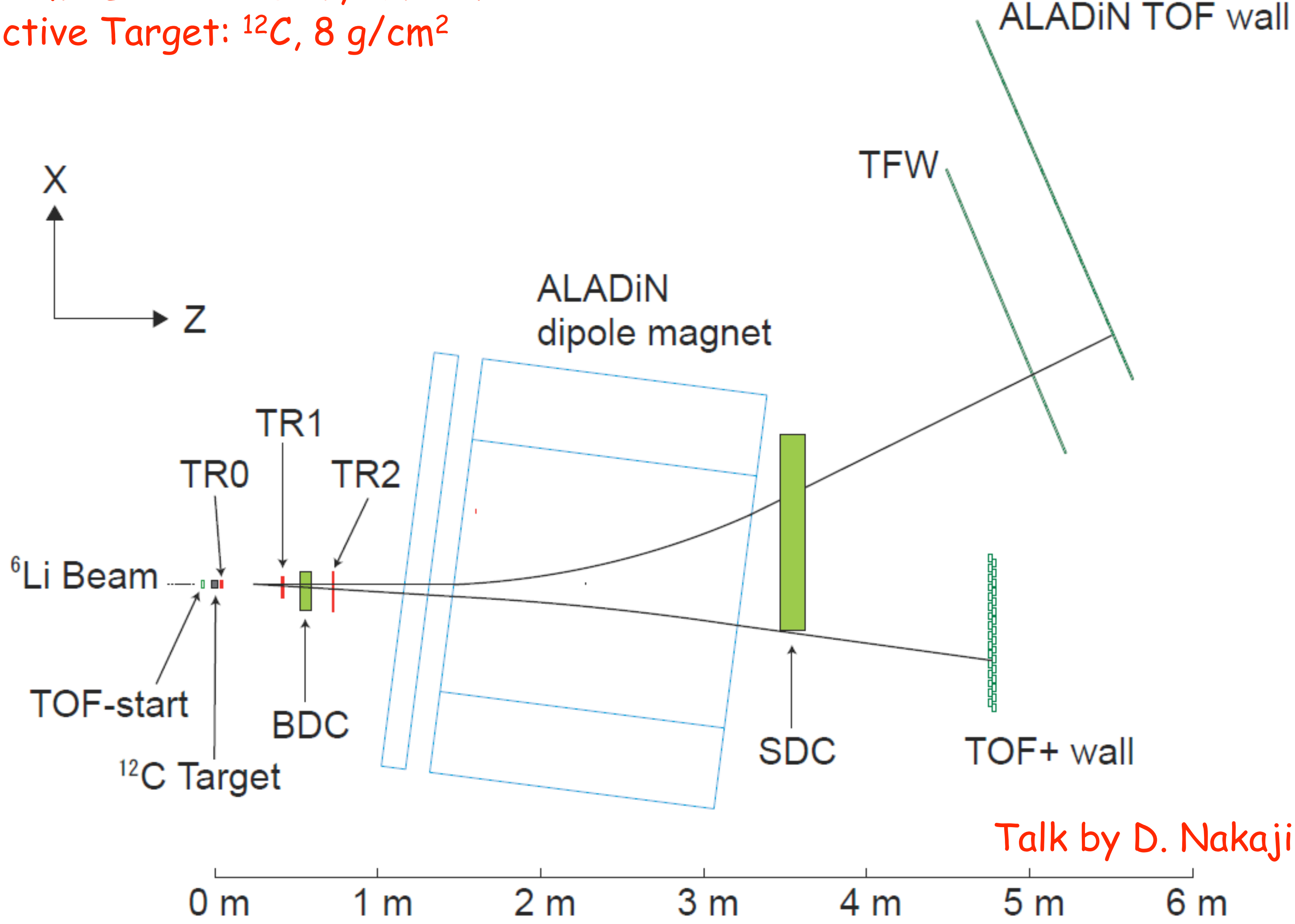
$^{5}_{\Lambda}He \to \pi^- + {}^{4}He + p$

Funding
- Helmholtz-University Young Investigators Group VH-NG-239, 2006-2012
- DFG grant SA1696/1-1 2007-2009, TOF detectors



Phase 0 setup

Beam: ^{6}Li at 2 A GeV, 7X10^{6} /s
Active Target: ^{12}C, 8 g/cm^{2}



Talk by D. Nakajima

Phase 0 setup

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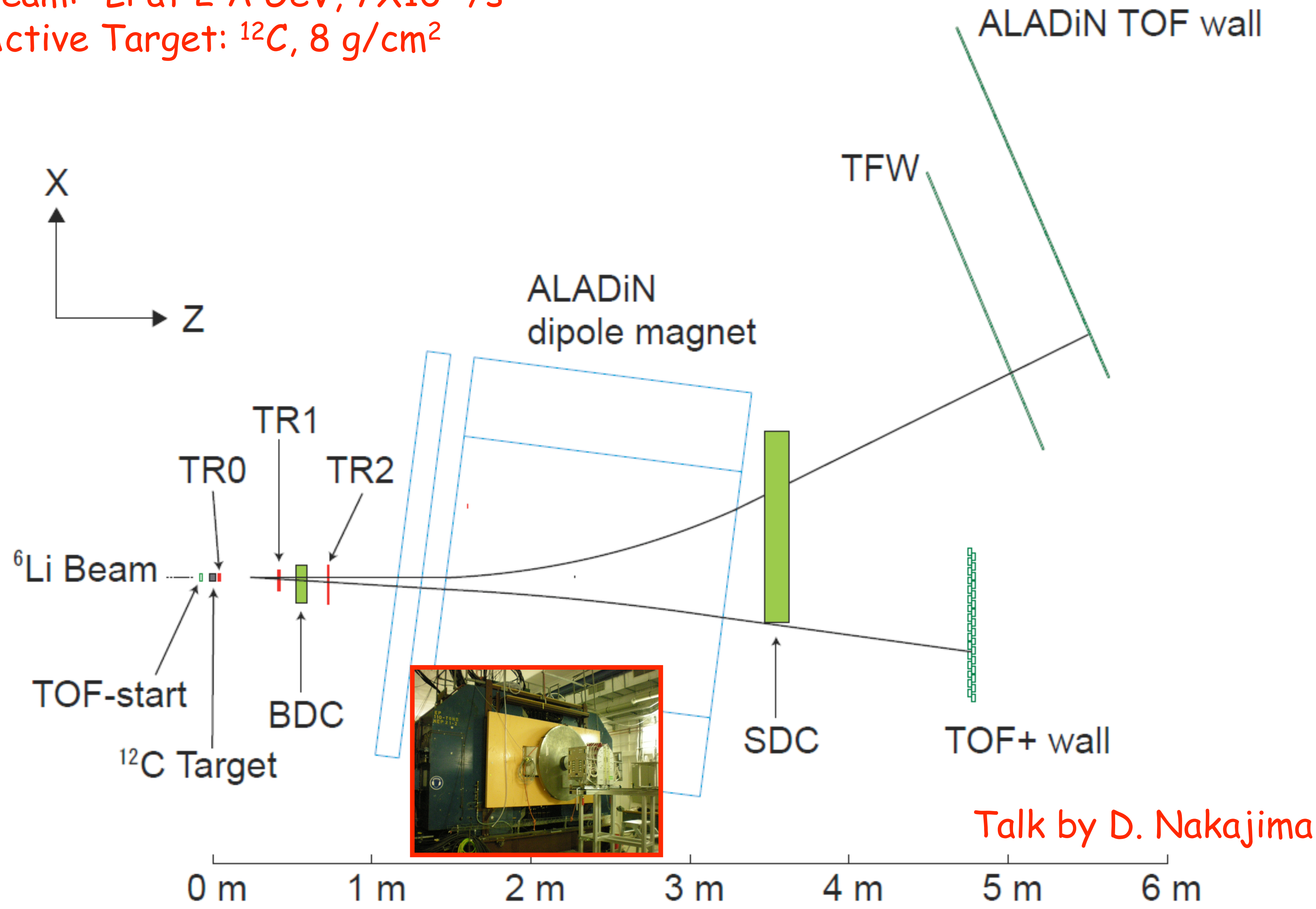

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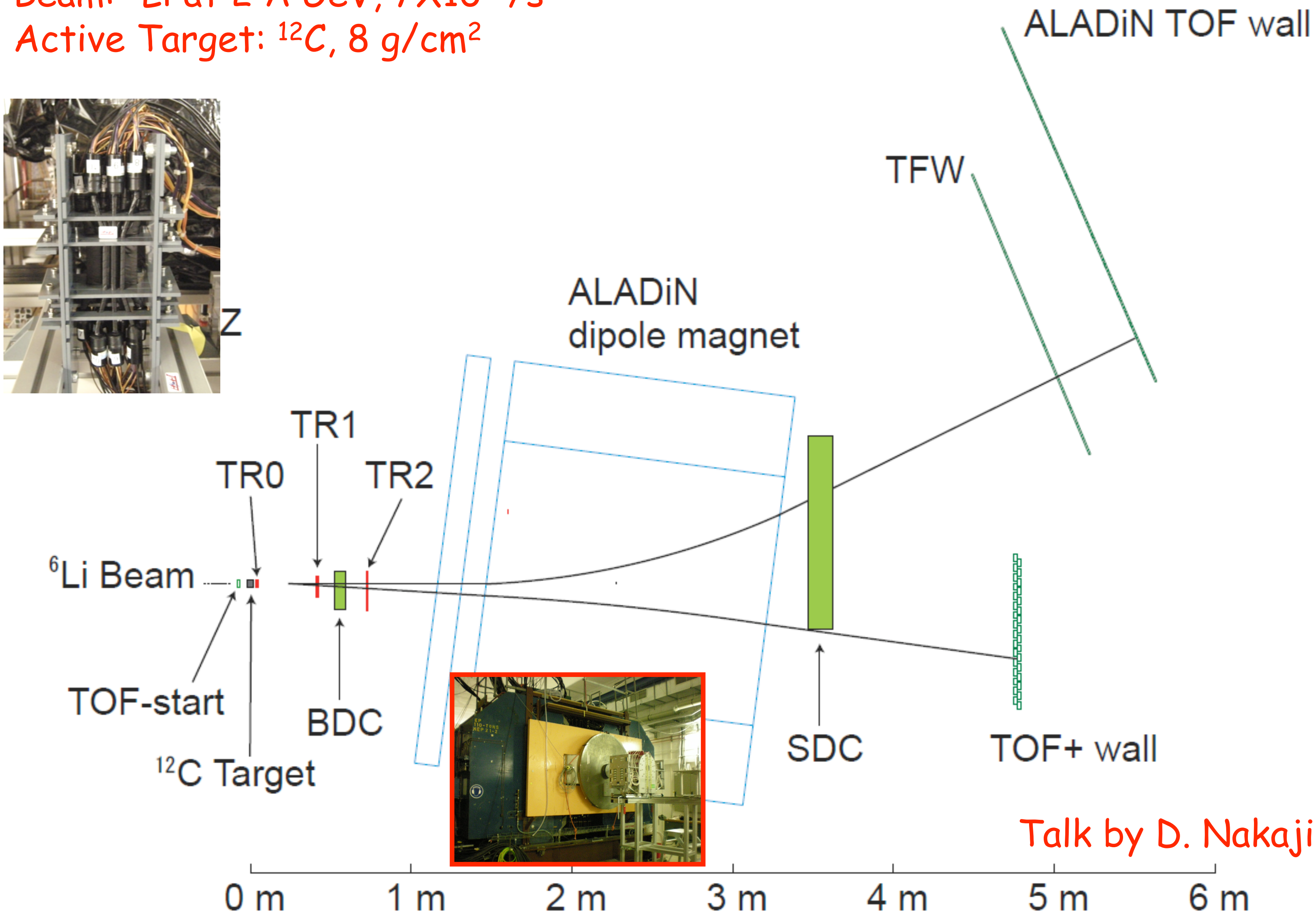

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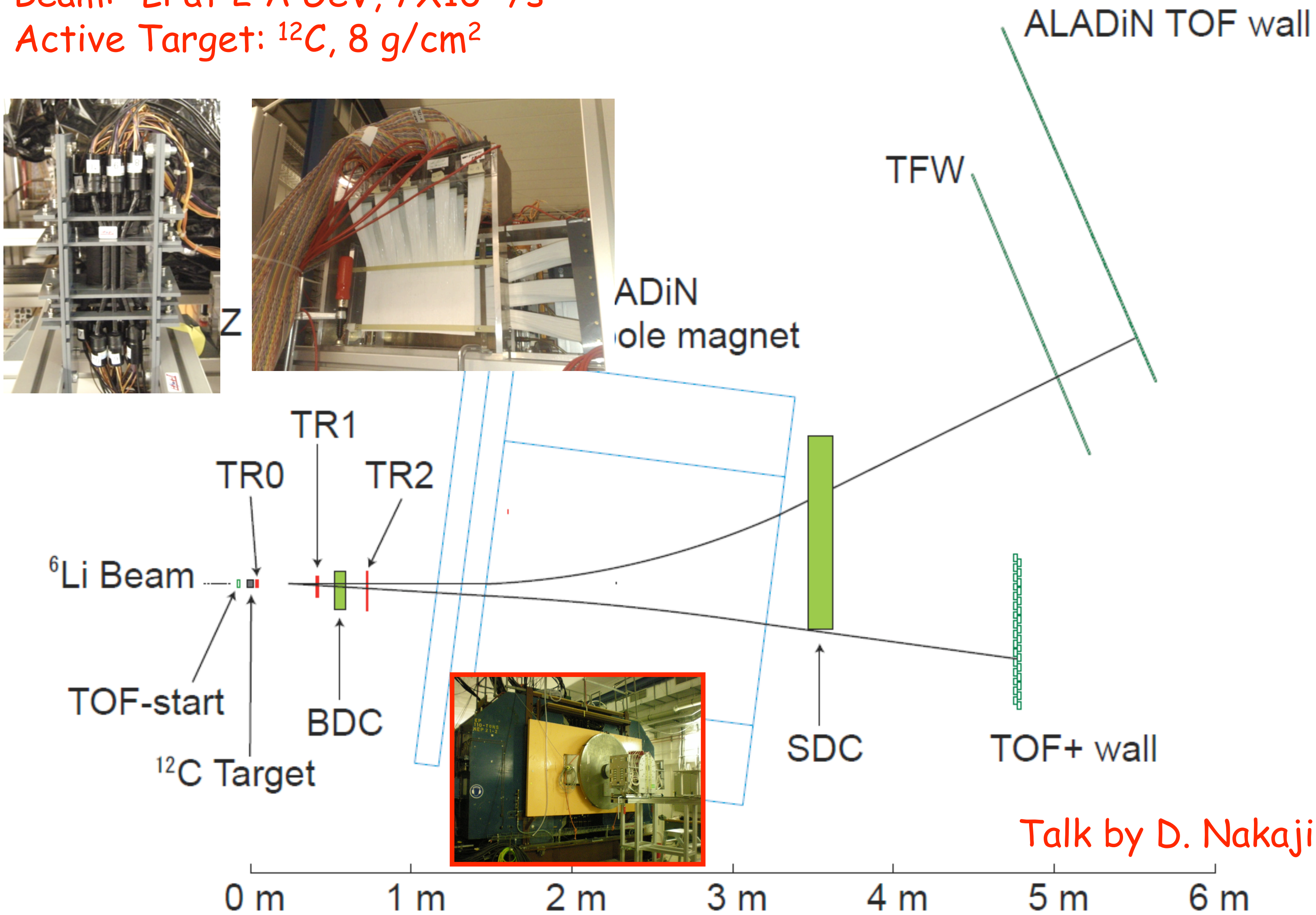

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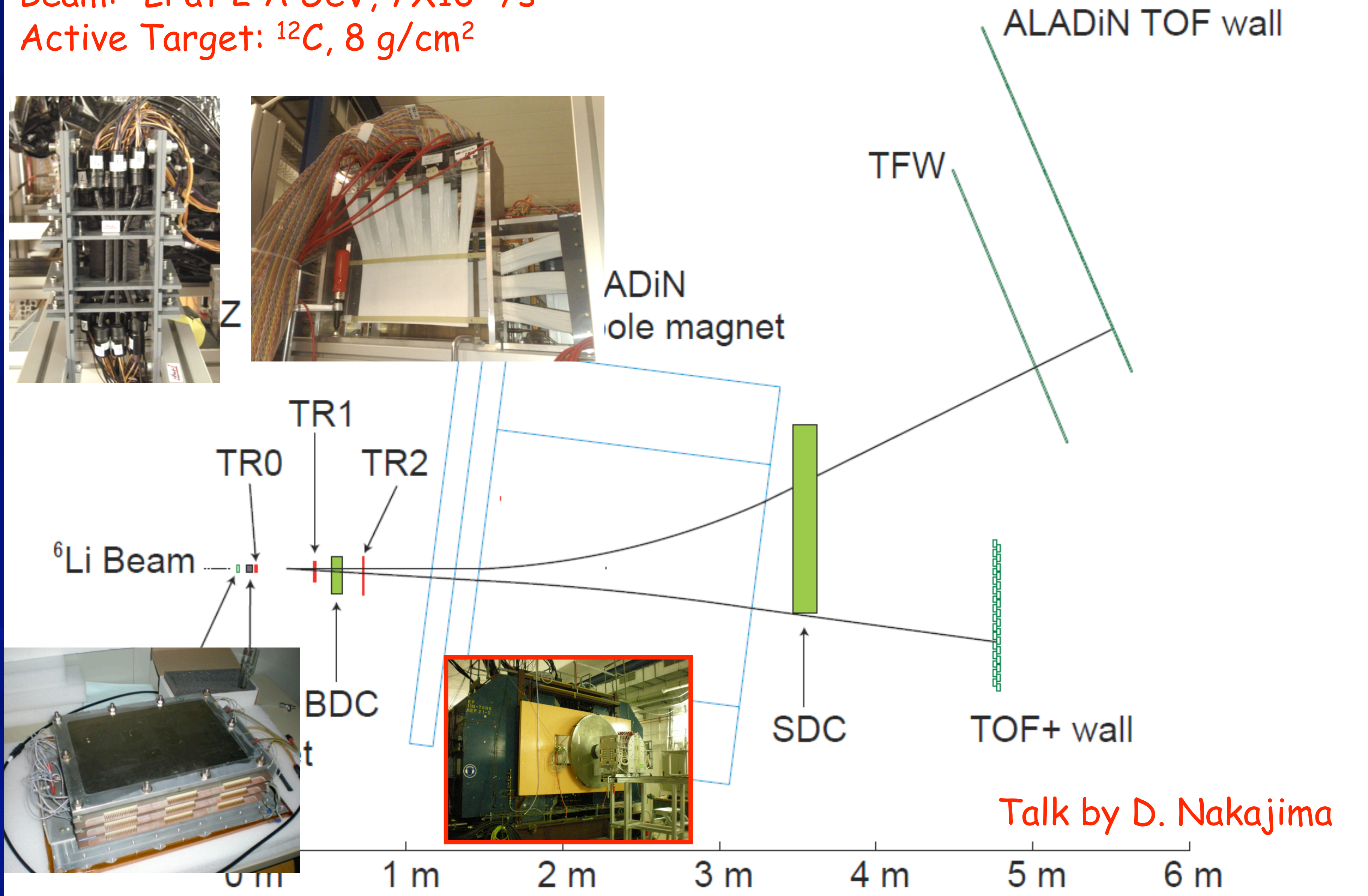

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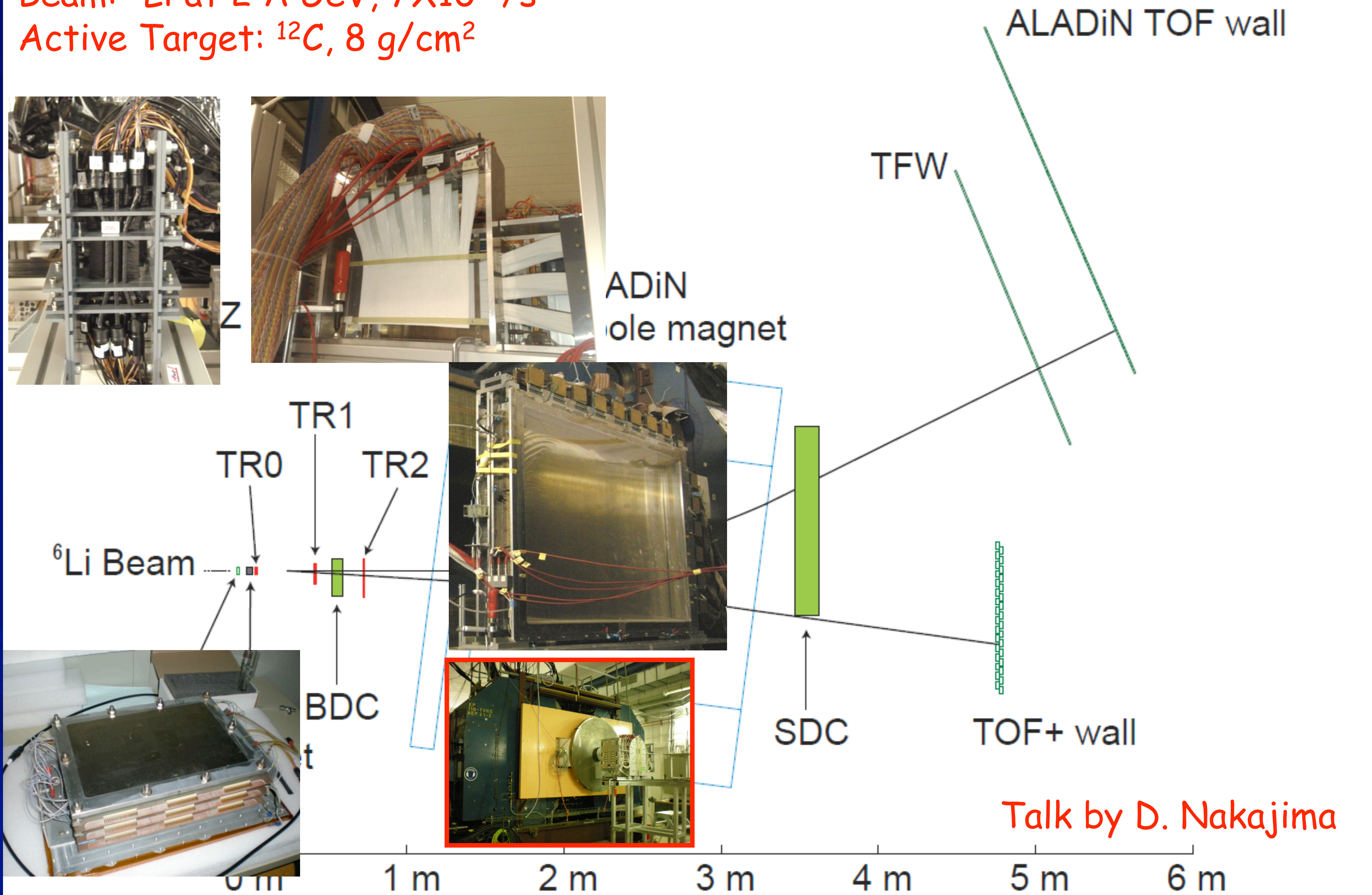

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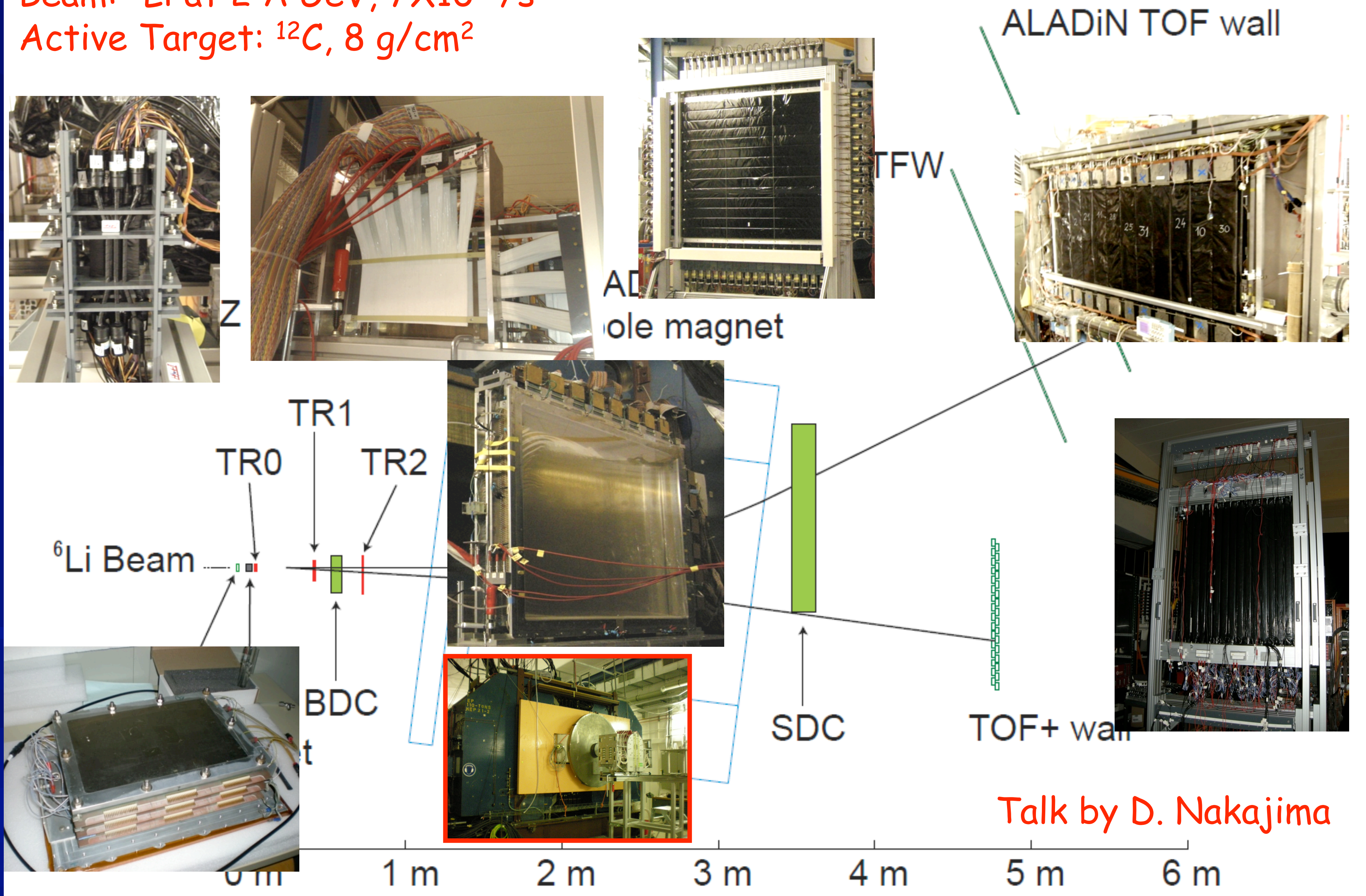


Talk by D. Nakajima

Trigger

1: Secondary vertex with fiber

- Vertex out of the target
  - Hypernuclear decay
  - Free-Λ decay
- **FPGA/DSP based trigger module**
- Efficiency to ${}^{4}_{\Lambda}H$ $\pi^{-}\alpha$ decay channel : ~ 14 %

2: π^{-} with ALADiN TOF

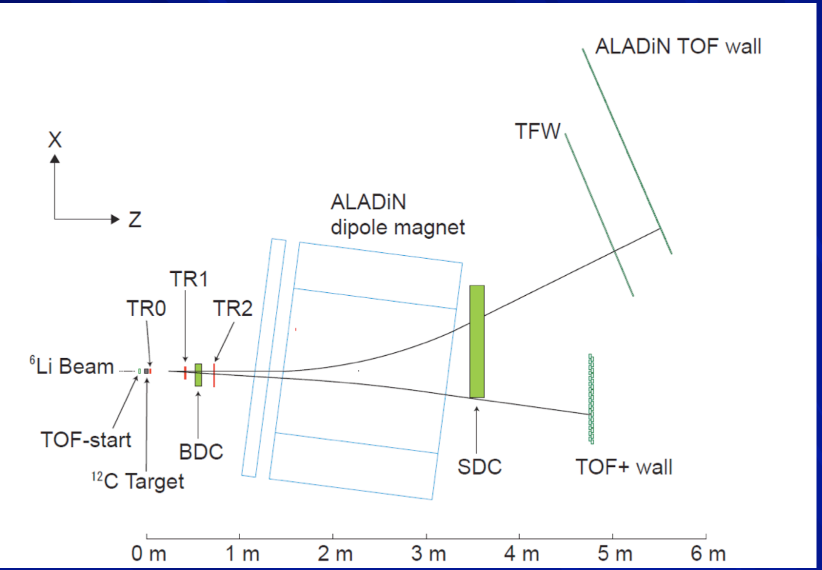
- π^{-} from hypernuclear decay
- 28 % for ${}^{4}_{\Lambda}H$ $\pi^{-}\alpha$ decay channel

3: Fragments with TOF+

- ${}^{3}_{\Lambda}H \rightarrow$ **${}^{3}He$** $+ \pi^{-}$, ${}^{4}_{\Lambda}H \rightarrow$ **${}^{4}He$** $+ \pi^{-}$, ${}^{5}_{\Lambda}He \rightarrow$ **${}^{4}He$** + **p** $+ \pi^{-}$, ${}^{4}_{\Lambda}He \rightarrow$ **d** + **d**
- Efficiency to ${}^{4}_{\Lambda}H$ $\pi^{-}\alpha$ decay channel : ~ 94 %

1 & 2 & 3: Efficiency 7%

- Background reduction down to 0.017 %

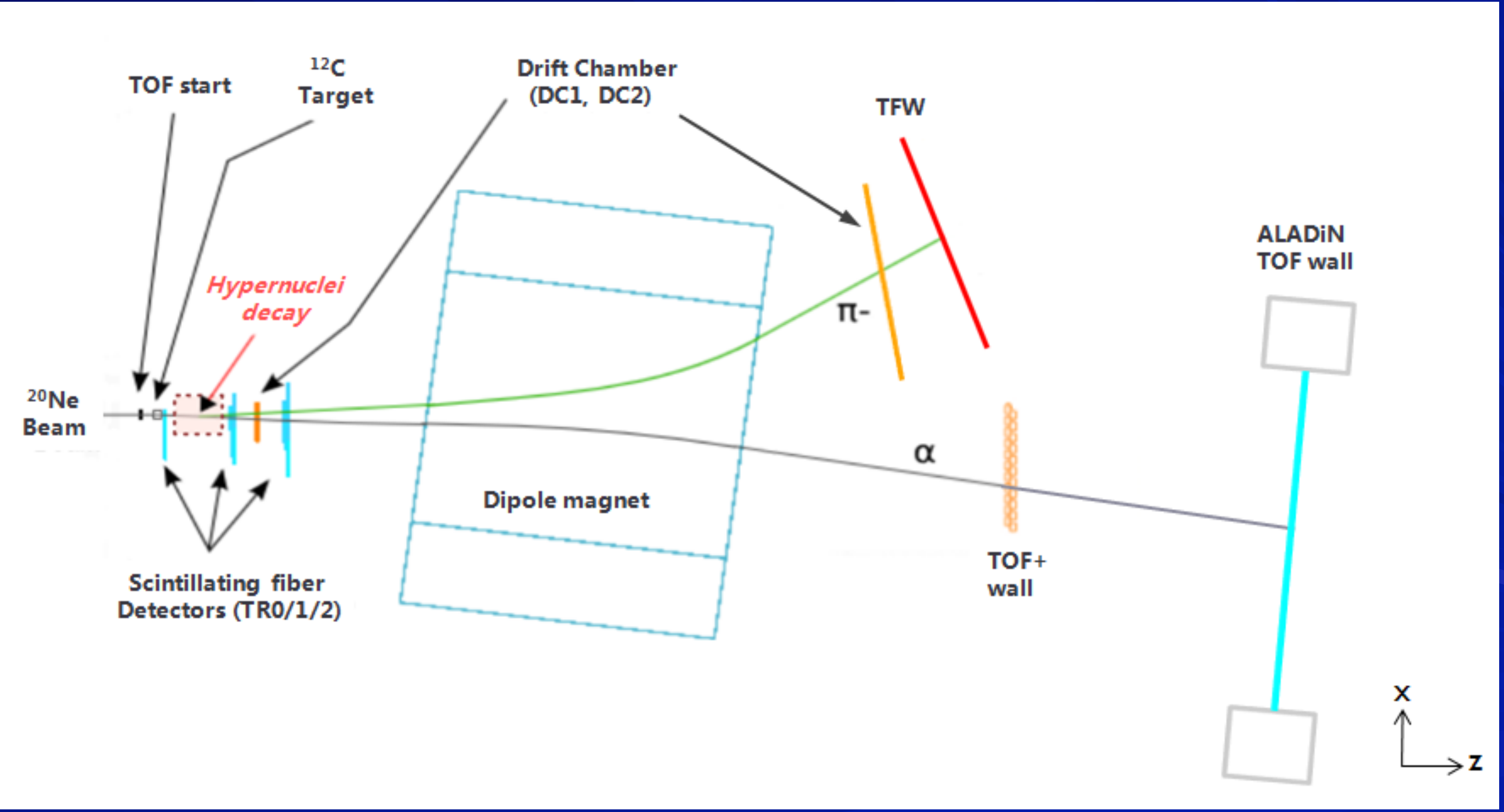


C. Rappold, PhD thesis

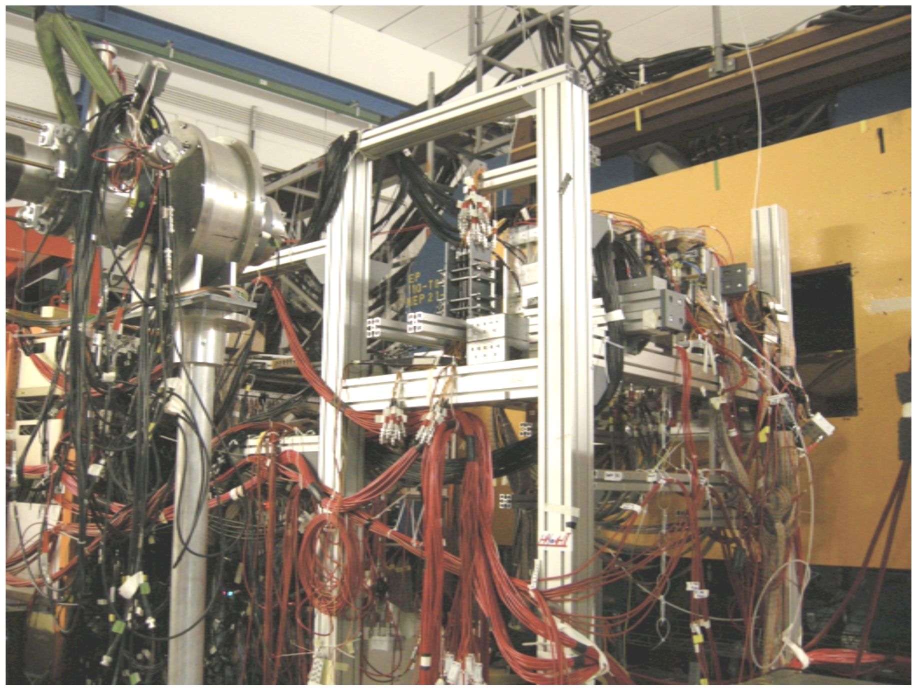
Talk by C. Rappold

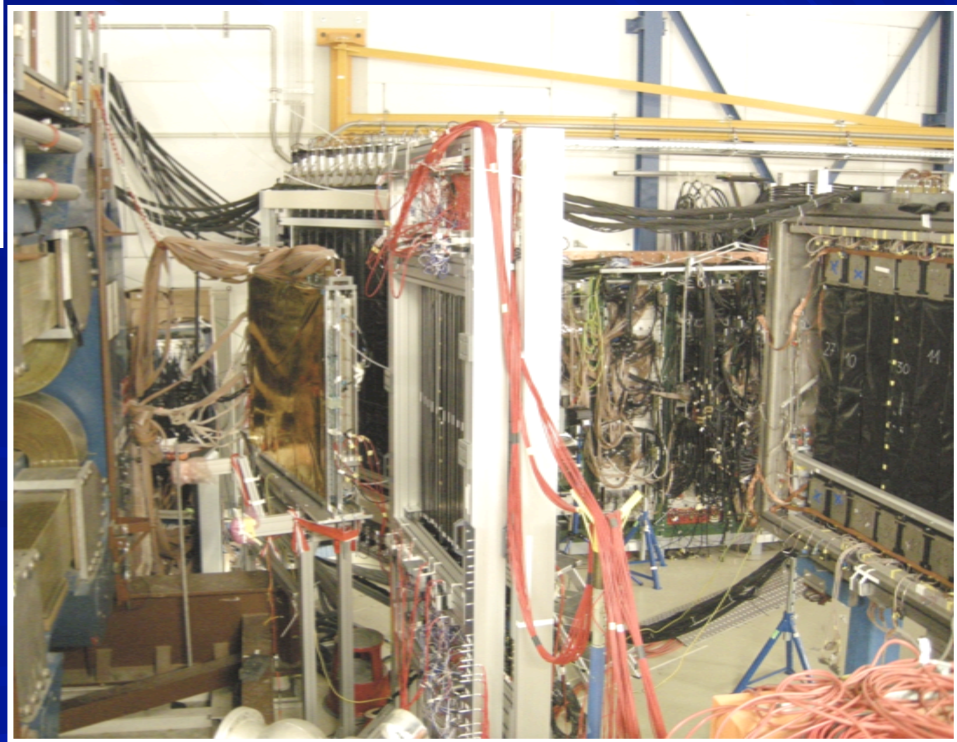
Phase 0.5 experiment in March 2010

- Hypernuclear spectroscopy with heavier projectiles: ^{20}Ne
- H and He hypernuclei
- Li, Be, B and C hypernuclei

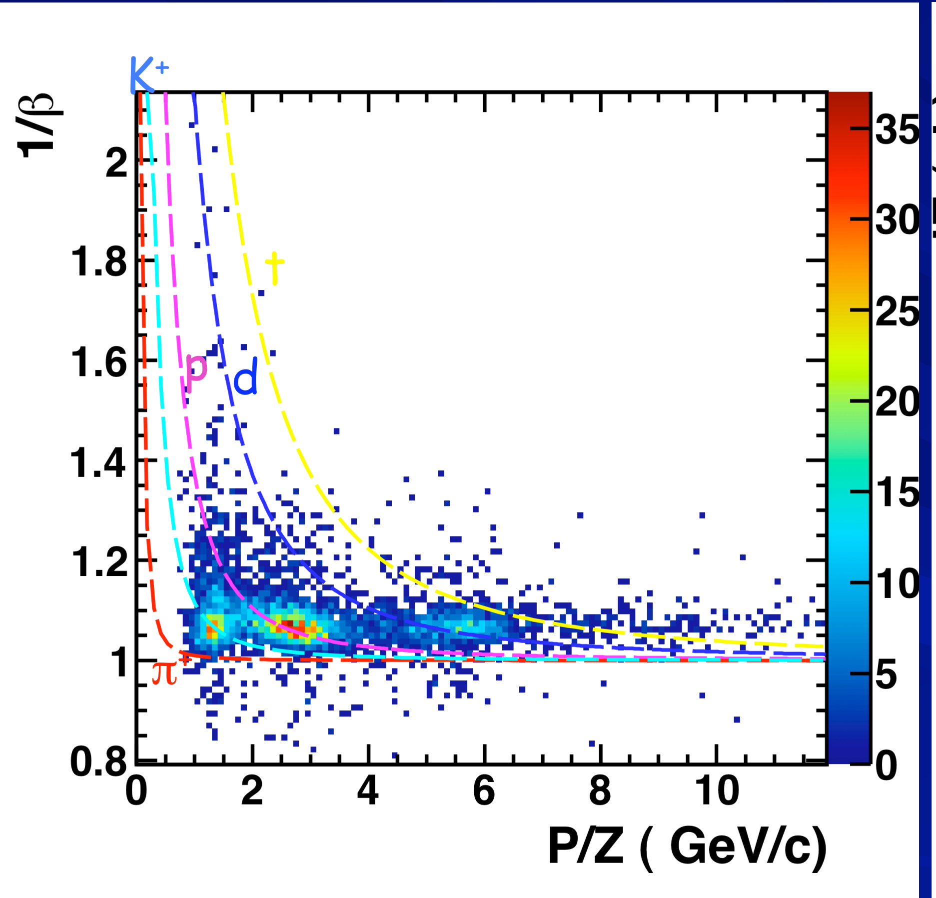


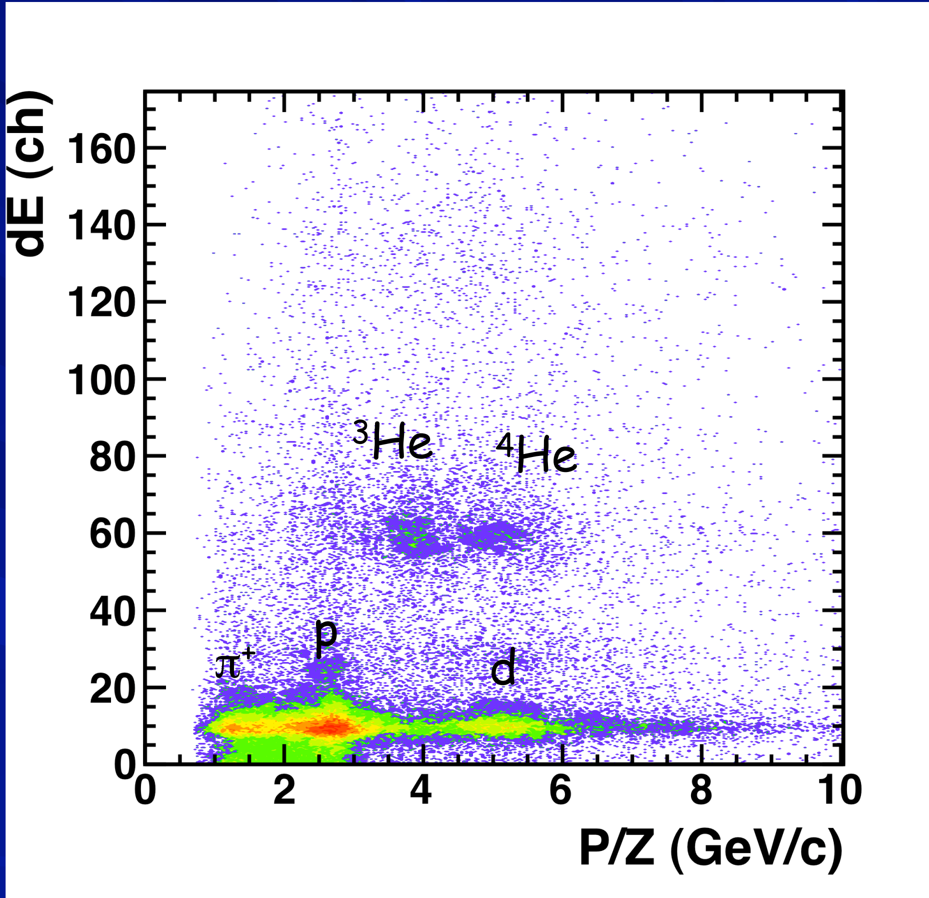
Setup in March 2009





Particle identification

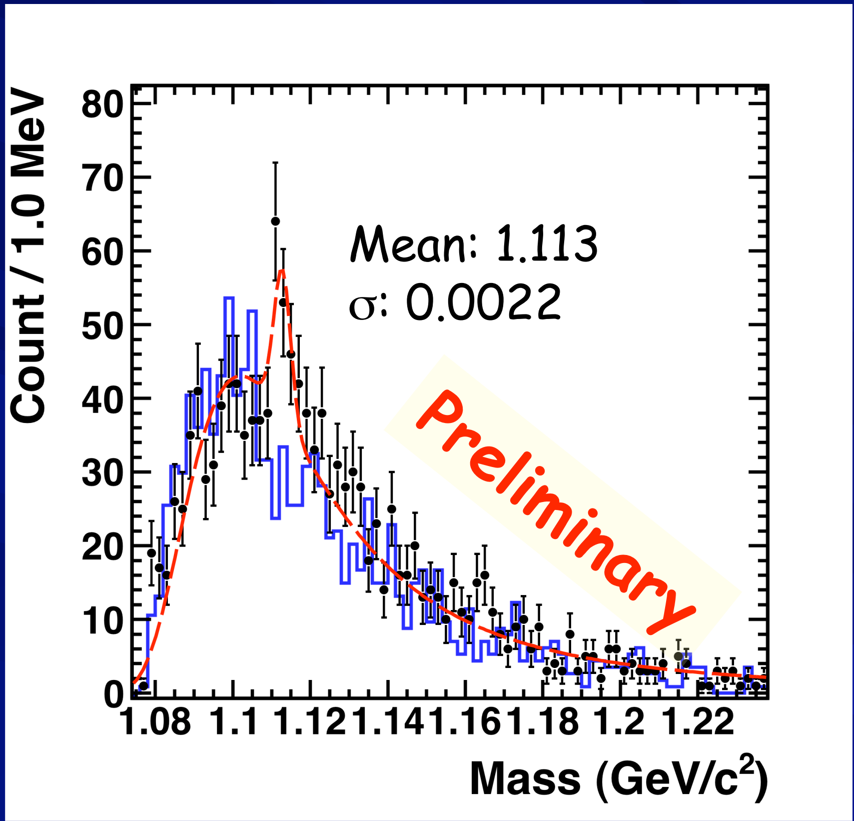


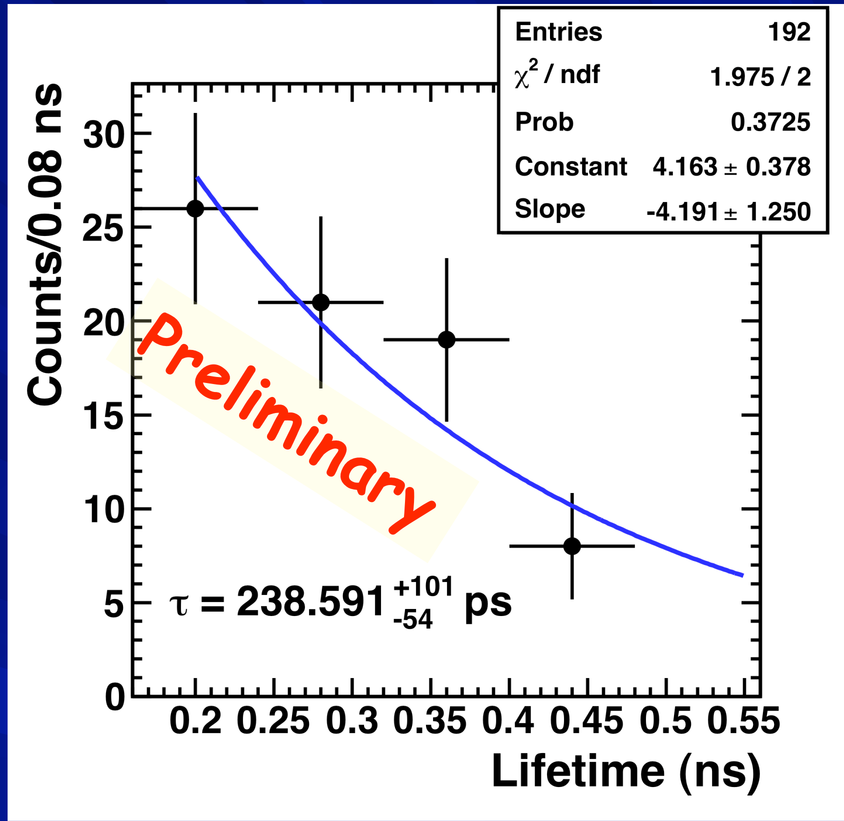


D. Nakajima, PhD thesis
C. Rappold, PhD thesis

Talk by D. Nakajima

Lambda hyperon trial





Known mass: 1.115 GeV

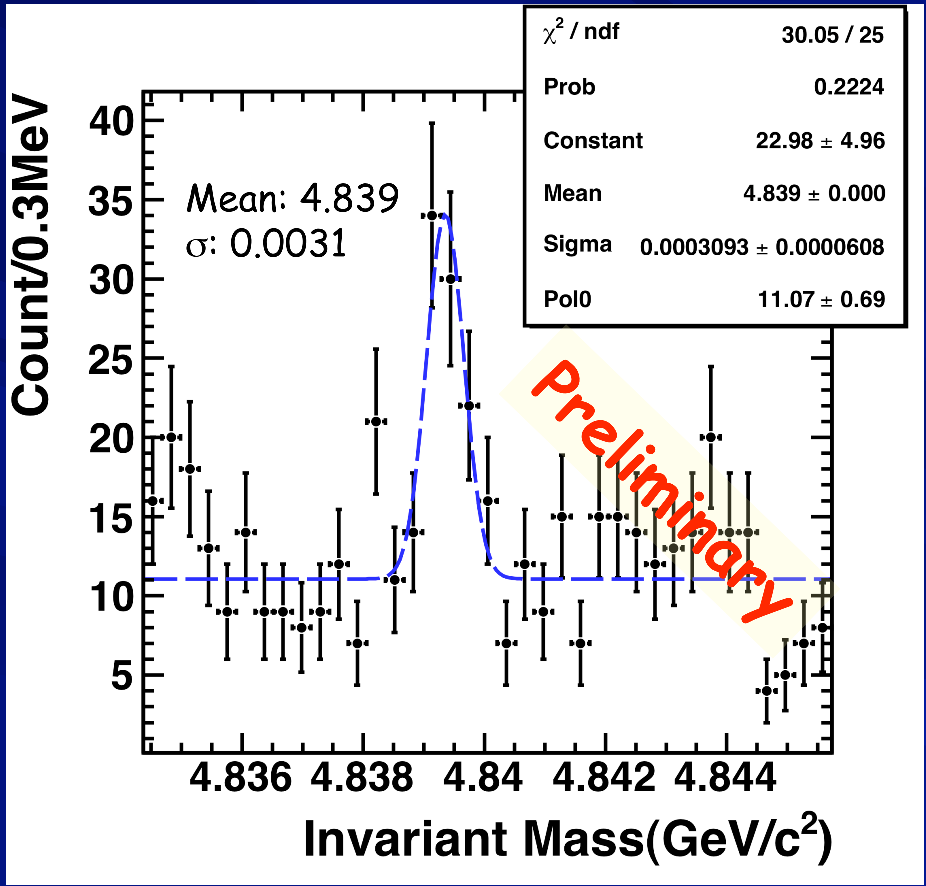
Known lifetime: 263 (20) ps

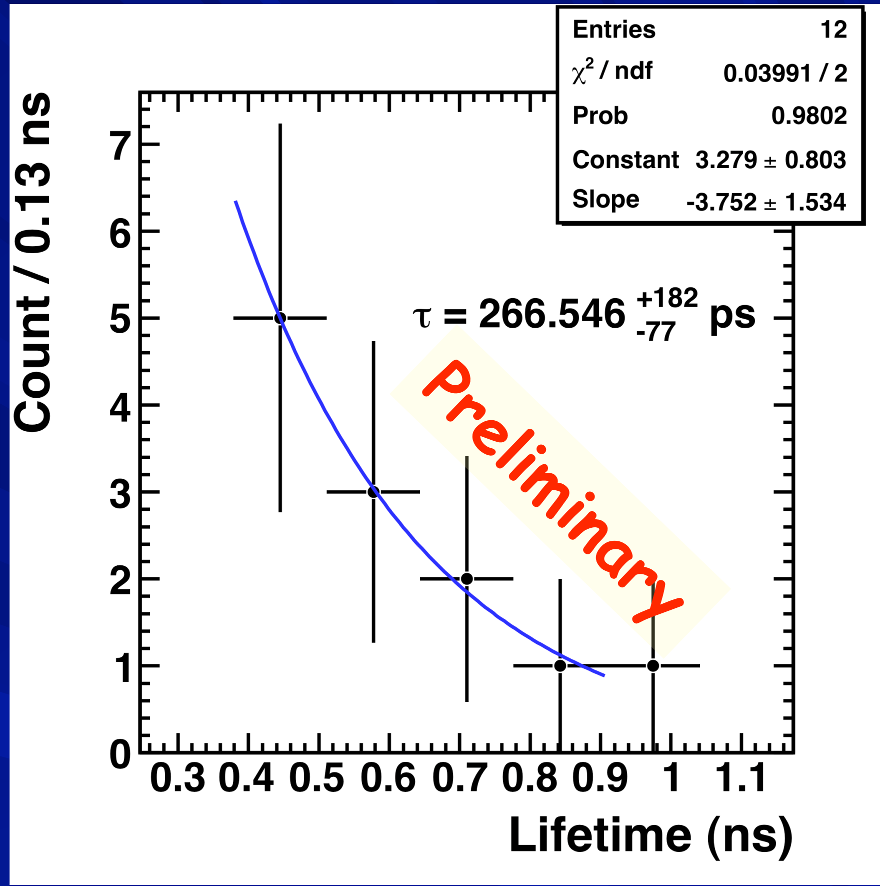
Less than 5 % of full statistics, with low efficiency analyses

D. Nakajima, PhD thesis
C. Rappold, PhD thesis

Talk by D. Nakajima

$^{5}{}_{\Lambda}$He trial





Known mass: 4.840 GeV

Known lifetime: 256 (20) ps

Less than 1 % of full statistics, with full reconstruction method

D. Nakajima, PhD thesis

C. Rappold, PhD thesis

Talk by C. Rappold

Summary and Outlook

- **Hypernuclear spectroscopy with heavy ion beams**
  - Hypernuclei at extreme isospin
  - Hypernuclei with multiple strangeness
  - Hypernuclear magnetic moments
- **Invariant mass hypernuclear spectroscopy**
  - At projectile rapidity region
  - Clear mass peak on the background
  - Lifetime measurements
- **Phase 0 and Phase 0.5 experiments**
  - ^{6}Li and ^{20}Ne beams at 2 A GeV on ^{12}C
  - Successfully performed
  - Full data analysis in progress

- **Perspective**
  - 2011: New development for the tracking detector and trigger system
  - 2012: Phase 1 experiment at GSI
  - Experiments at JINR and Lanzhou

People working for HypHI Phase 0-0.5

- GSI Helmholtz-University Young Investigators Group VH-NG-239
  - S. Bianchin (GSI)
  - O. Borodina (Mainz Univ., GSI)
  - V. Bozkurt (Nigde Univ., GSI)
  - B. Göküzüm (Nigde Univ.)
  - E. Kim (Seoul Univ., GSI)
  - D. Nakajima (Tokyo Univ., GSI)
  - B. Özel-Tashnov (GS)
  - C. Rappold (Strasbourg Univ., GSI)
  - T.R. Saito (Spokes person)
- Mainz University
  - P. Achenbach, J. Pochodzalla
- GSI HP2 and Mainz University
  - D. Khaneft, Y. Ma, F. Maas
- GSI HP1
  - W. Trautmann
- GSI EE department
  - J. Hoffmann, K. Koch, N. Kurz, S. Minami, W. Ott, S. Voltz
- GSI Nuclear reaction
  - T. Aumann, C. Caeser, H. Simin
- GSI Detector Lab.
  - M. Träger, C. Schmidt
- KEK
  - T. Takahashi, Y. Sekimoto
- KVI
  - E. Guliev, M. Kavatsyuk, G.J. Tambave
- Kyoto University
  - Y. Hayashi, T. Hiraiwa, M. Moritsu, A. Okamura, T. Nagae, M. Sako, T. Sugimura
- Nigde University
  - Z.S. Ketenci, S. Erturk
- Osaka University
  - S. Ajimura, A. Sakaguchi, K. Yoshida
- Osaka Electro-Communication University
  - T. Fukuda, Y. Mizoi
- Seoul National University
  - H. Bhang, M. Kim, S. Kim, K. Tanida, C.J. Yoon
- Tohoku University
  - T. Koike, H. Tamura

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