E10 status

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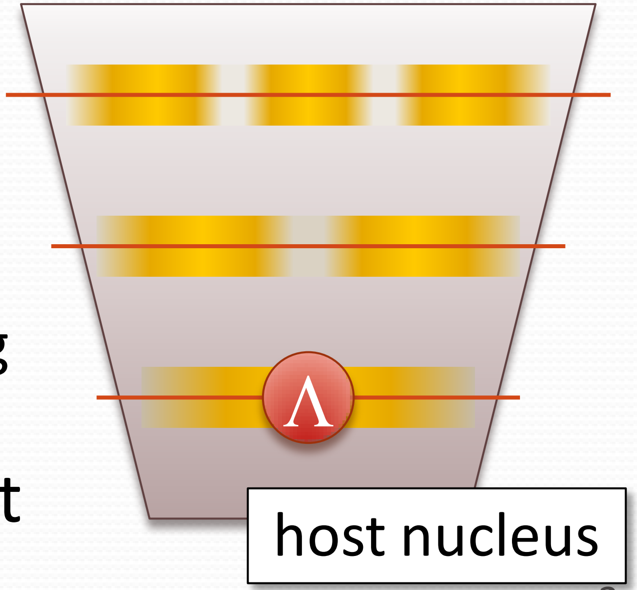
for the E10 Collaboration

Hypernuclei and issues of studies

- What is Hypernuclei?
  - A new category of "nucleus" which contains hyperon as a new ingredient
    - Hyperon should be stable against strong interaction
      - long life-time is required to form a well-defined "state"="nucleus"
      - candidate hyperons are lowest mass Λ, Σ, Ξ and Ω
  - Λ hypernuclei
    - have very clear "nuclear" structure as that of normal nuclei
    - many studies have been done already
    - interesting phenomena have been observed

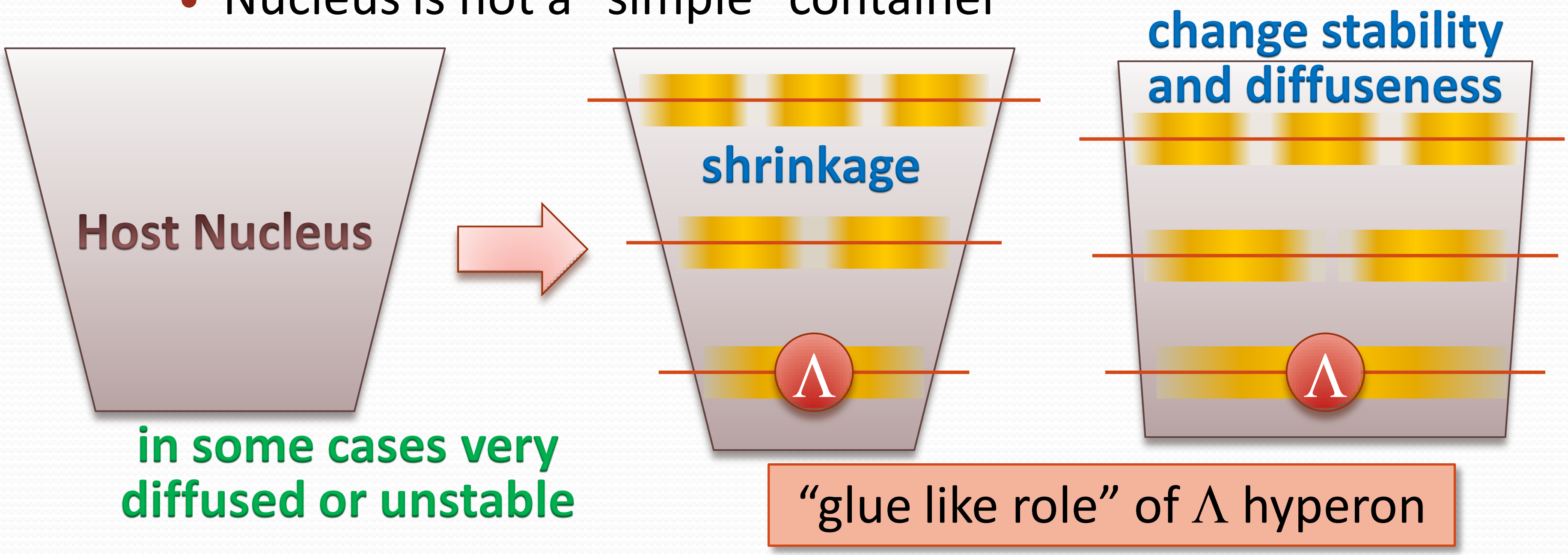
Simple picture of Λ hypernuclei

- Picture of weakly coupled Λ hyperon in a nucleus
  - Host nucleus: simple container of Λ hyperon
  - Λ hyperon: single particle moving in the container
    - Λ hypernucleus may be a good example for text books of Quantum Mechanics
- Many well-defined states observed
  - Simply came from …
    - Attractive Λ-nucleus interaction
    - Λ hyperon is free from Pauli Blocking
- Simple picture works to some extent



Further investigation of Λ hypernuclei

- In reality, Λ hypernuclei are not that simple!
  - Λ-N interaction may change "container"="host nucleus"
    - Λ-nucleus interaction is quite strong
    - Nucleus is not a "simple" container

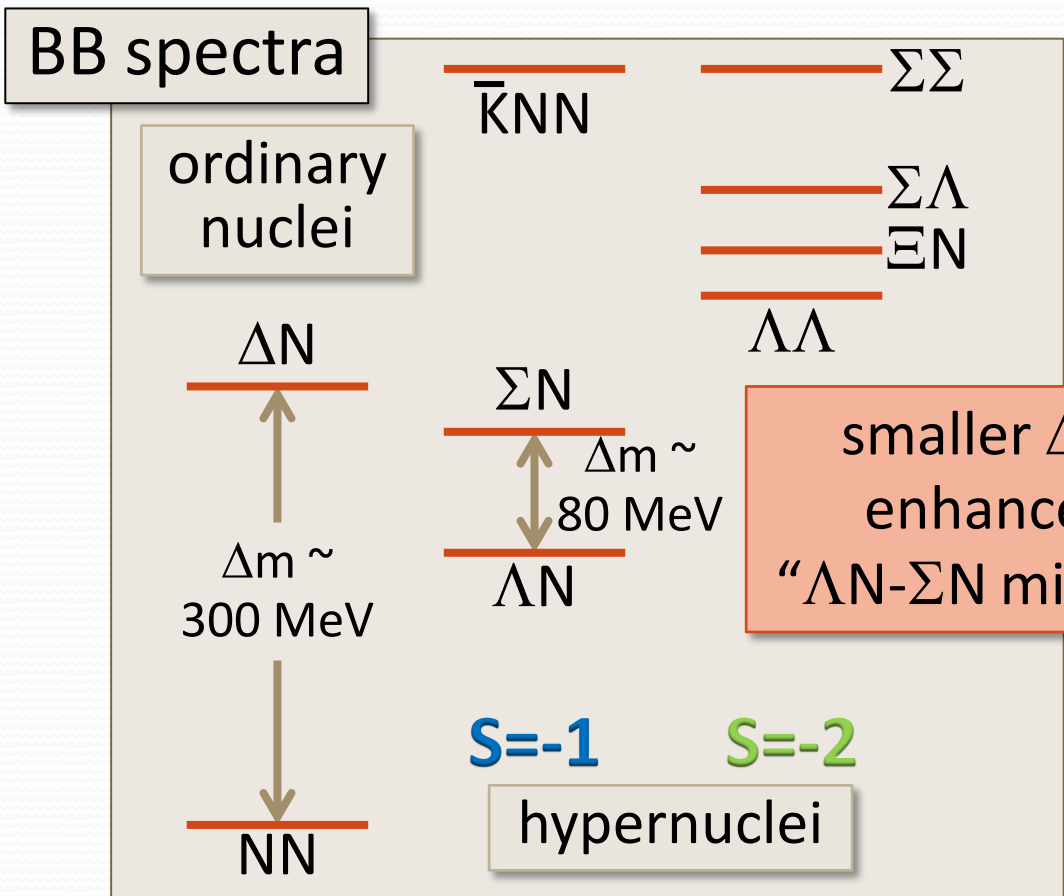


  - The effect is significant for loosely bound host nuclei

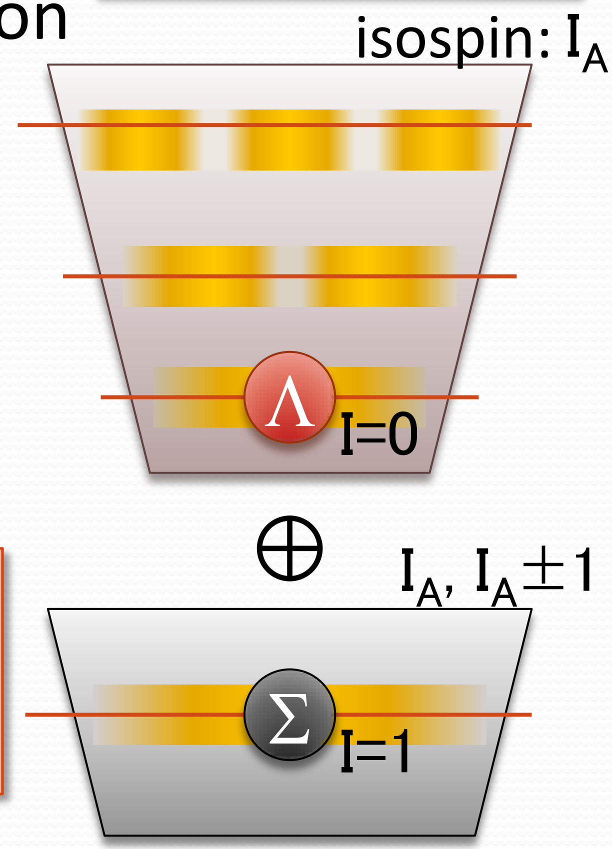
ΛN-ΣN mixing

- Λ hyperon in nucleus ≠ free Λ hyperon
  - Strong mixing of ΛN and ΣN states

$I_A \neq 0$ is essential



smaller Δm enhances "ΛN-ΣN mixing"



larger mixing expected in nuclei with larger I_A

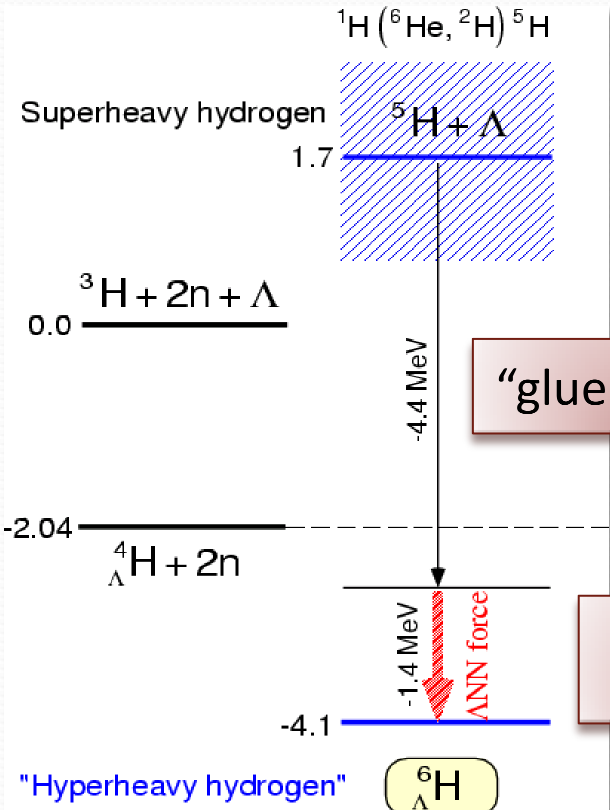
Aims of E10 experiment

- **Aim 1**: production of Λ hypernuclei close to the neutron drip-line, $^{6}_{\Lambda}H$ and $^{9}_{\Lambda}He$
  - E10 may produce highly neutron-rich Λ hypernuclei
    - $^{6}_{\Lambda}H$ (1p, 4n and 1Λ), $^{9}_{\Lambda}He$ (2p, 6n and 1Λ)
    - These are exotic hypernuclei we have never seen clearly
  - "glue like role" of Λ hyperon is critical in such loosely bound hypernuclei
    - Ground state of ^{5}H is an unbound resonant state. We may extend the boundary of stability by adding a Λ hyperon.
    - ^{8}He is a typical "halo nucleus". We may see a drastic change of structure of the host nucleus by adding a Λ hyperon.

- **Aim 2**: Λ-N interaction at the extreme condition
  - The ΛN-ΣN mixing effect may be observed in the hypernuclear structure.
    - R.H. Dalitz and R. Levi Setti discussed binding energies of ${}^{6}_{\Lambda}H$ and ${}^{9}_{\Lambda}He$ in 1963, "Some Possibility for Unusual Light Hypernuclei".
    - B.F. Gibson et al. pointed out the importance of ΛN-ΣN mixing in hypernuclear structure in 1972.
    - Y. Akaishi et al. suggested coherent ΛN-ΣN mixing to understand structure of s-shell hypernuclei, recently.
  - Neutron-rich Λ hypernuclei are good laboratories to study the ΛN-ΣN mixing effect

Predicted ΛN-ΣN mixing effects

- Structure and cross section of neutron-rich hypernuclei may give us information of the ΛN-ΣN mixing

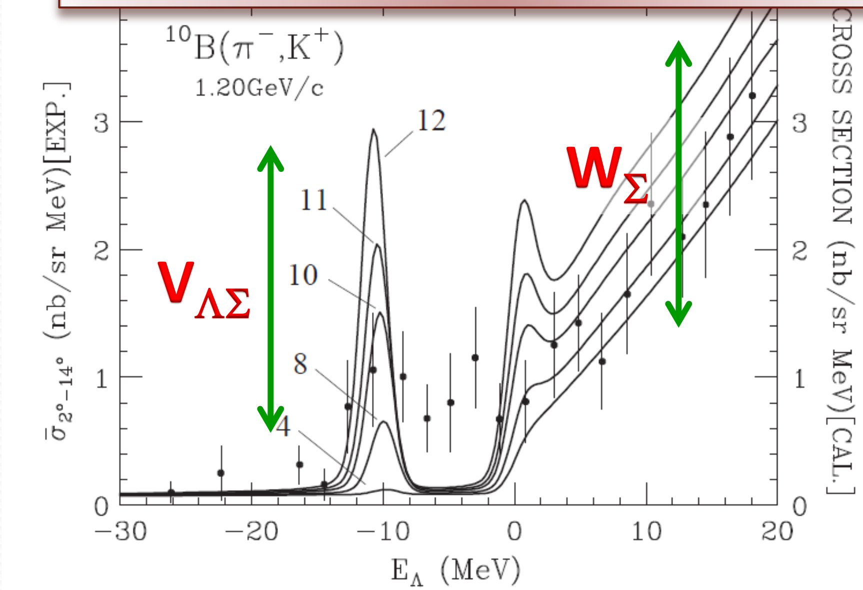


"glue like role"

coherent ΛN-ΣN

K. Swe Myint and Y. Akaishi, PTP Supplement 146 (2002) 599

mixing effects to reaction mechanism

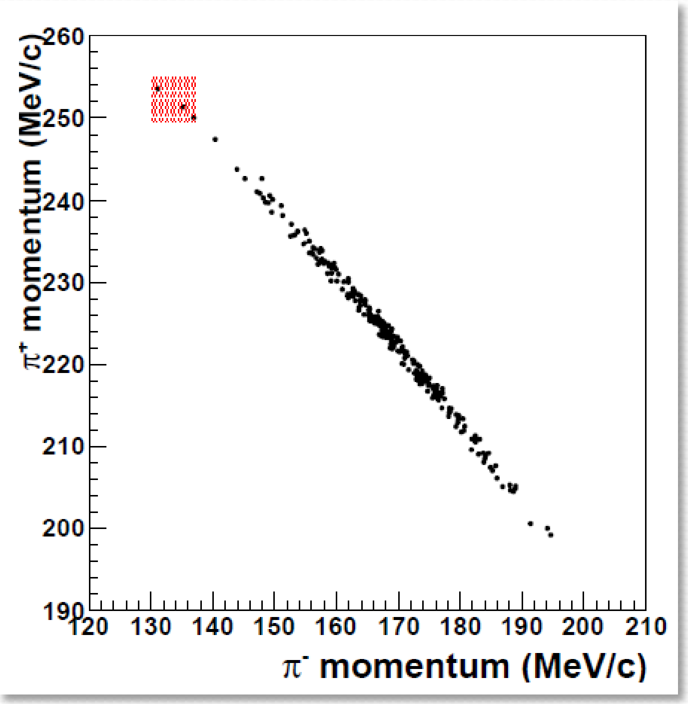


T. Harada et al., Phys Rev C79 (2009) 014603

E10 experiment can provide these information

Past studies of neutron-rich Λ hypernuclei

- Experiments with stopped-K^- beams
  - KEK-PS in 1996 and FINUDA/DAΦNE in 2006
    - Only upper-limits of branching ratio were obtained
  - New result from FINUDA/DAΦNE
    - ^{6}Li(stopped-K^-,π^+) reaction
      - saw also weak decay kinematics
    - 3 events of candidate of $^{6}_{\Lambda}$H
  - Interesting , need more events
- Experiment with (π^-,K^+) reaction
  - KEK-521 produced $^{10}_{\Lambda}$Li
  - E10 is based on this method



M. Agnello et al., FINUDA Collaboration, Phys. Rev. Lett. 108 (2012) 042501

Proposed plan of E10 experiment

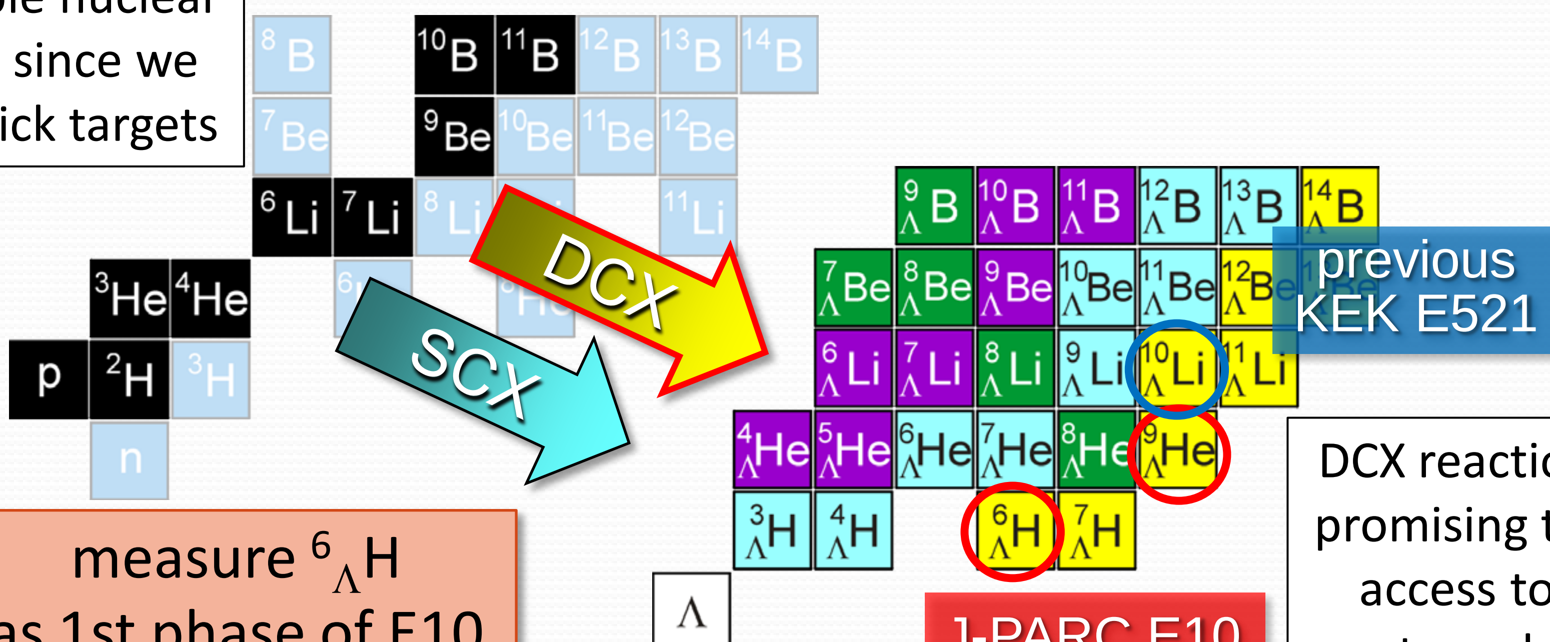
- How to produce neutron-rich Λ hypernuclei?
  - Use Double Charge-eXchange (DCX) reaction

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

$$^{6}Li\left(\pi^-, K^+\right) {}^{6}_{\Lambda}H$$

Z=3 Z=1

use stable nuclear targets since we need thick targets



measure $^{6}_{\Lambda}H$ as 1st phase of E10

DCX reaction is a promising tool to access to the neutron-drip line

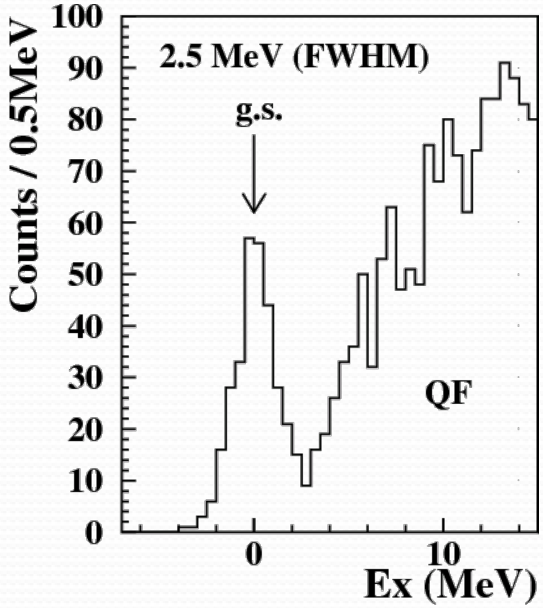
Proposed E10 run conditions

- High intensity pion beam is necessary
  - Practical difficulty of DCX reaction is tiny cross section
    - KEK E521 obtained only 47 events of $^{10}_{\Lambda}$Li ↔ 10nb/sr
  - Proposed to use 10M/spill high intensity pion beams
- Thick target and large acceptance spectrometer
  - Target (^{6}Li and ^{9}Be) thickness (3.5 g/cm^2) was optimized for yields and resolution.
  - SKS spectrometer has large acceptance (100 msr) and good momentum resolution (about 0.1%)
- Pion beam momentum
  - 1.2 GeV/c selected due to larger DCX cross section

Yield estimation in E10 proposal

- $^{6}_{\Lambda}$H yields estimated under the run conditions
  - 3 weeks with 10M/spill (6 s acc. cycle) → 3 T pions

Parameters	Values
Pion beam momentum	1.2 GeV/c
Pion beam intensity	10M/spill
Total number of pions (6 s acc. cycle)	3T pions
Target thickness (^{6}Li)	3.5 g/cm^2
DCX cross section (assumed)	10 nb/sr
SKS acceptance	100 msr
Spectrometer efficiency (due to K decay)	0.5
Analysis efficiency	0.5
Estimated $^{6}_{\Lambda}$H yield	265



- Yields is roughly 6 times larger than previous KEK E521

Current plan and prospects

- Ripples of 50GeV PS magnet affect duty factor of SX
  - SX duty factor was 25-30% during beamtime in June
    - Duty factor may depends on time-scale
    - 25-30% was estimated by accidental coincidence rate
  - Even in the poor duty factor, we may run at least up to beam intensity of 5M/spill
    - Instantaneous beam rate 15M/spill equivalent or more, but current detector system accepts the beam intensity
    - We are planning improvements of tracking detectors to go higher beam intensity; e.g., 7M/spill or higher

→ see performance study and update plan

Updated yield estimation

- Yield estimated under the practical run conditions
  - 3 weeks with 5M/spill (6 s acc. cycle) → 1.5 T pions

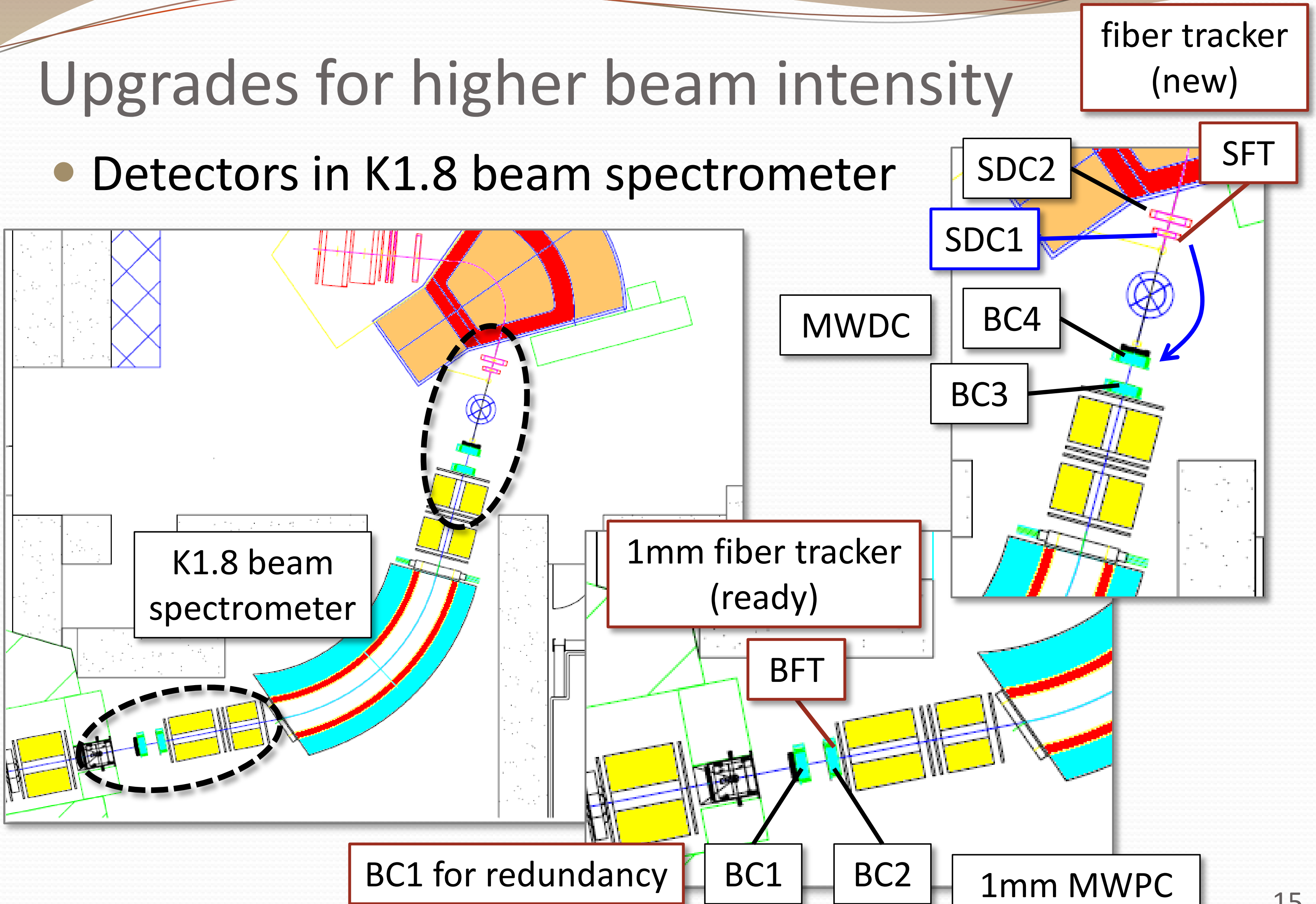
Parameters	Values
Pion beam intensity	5M/spill
Total number of pions (6 s acc. cycle)	1.5T pions
Other conditions	same as before
Estimated ${}^{6}_{\Lambda}H$ yield	132

Baseline of yields in E10

- We are making efforts to go higher beam intensity (5M/spill → 7M/spill → 10M/spill)
  - Studied detector and trigger performances
  - Prepare BFT (beam fiber tracker), SFT (spectrometer fiber tracker) and vertex SSD

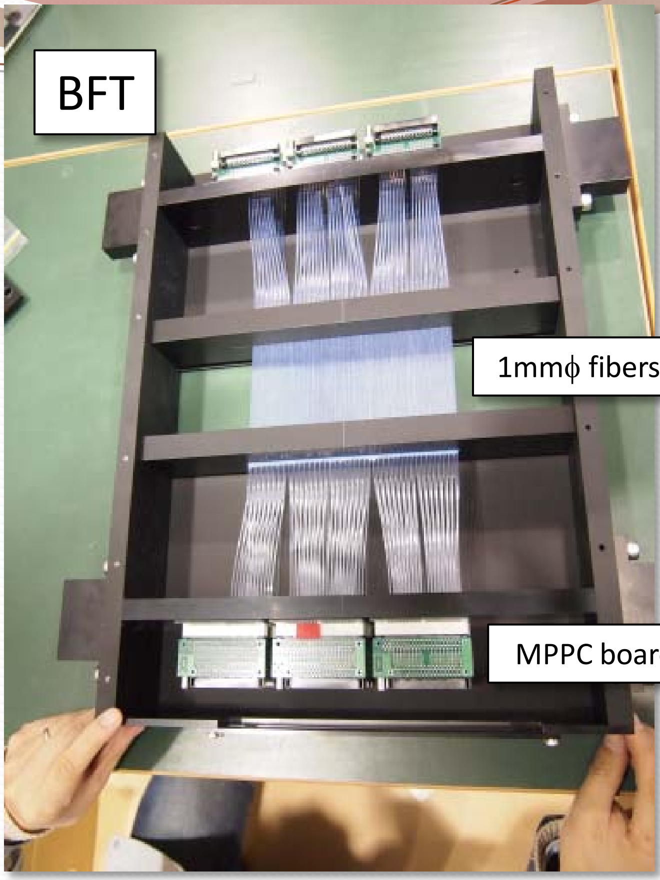
Upgrades for higher beam intensity

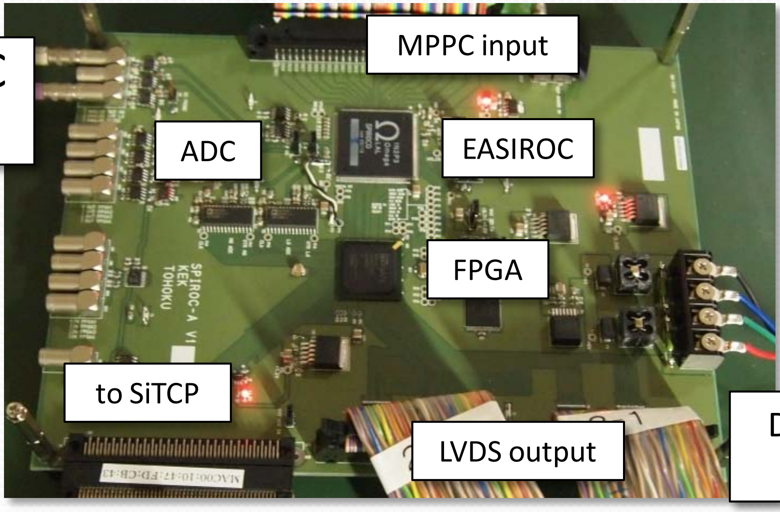
- Detectors in K1.8 beam spectrometer

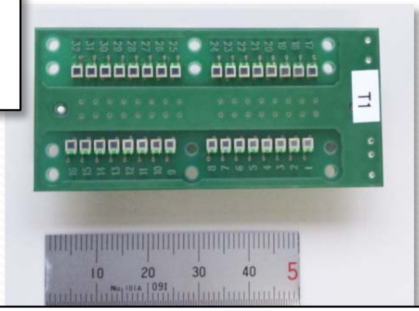


BFT high-rate beam study

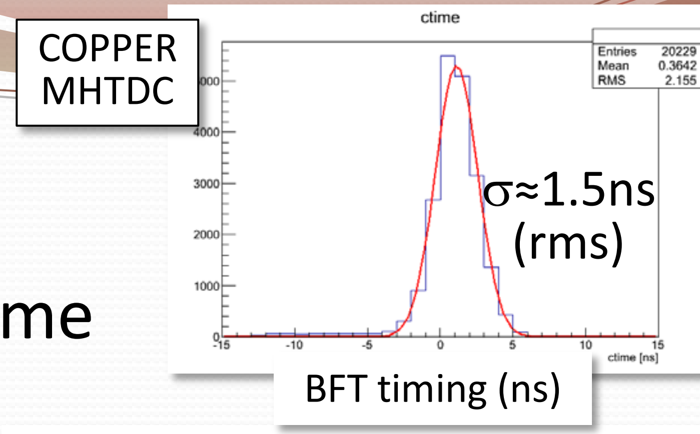
- BFT (beam fiber tracker) design
  - 1mm ϕ scintillating fibers
    - 2 layers staggered by 0.5mm
    - $160 \times 2 = 320$ fibers
  - Read out by MPPC+EASIROC
    - Flexible and easy to handle



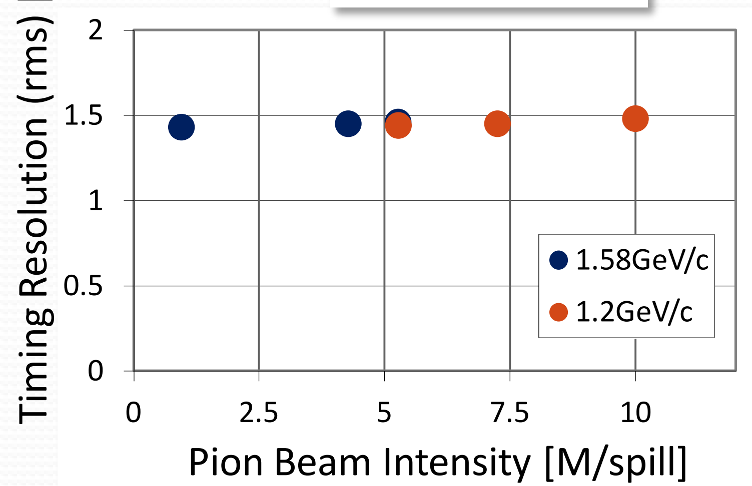


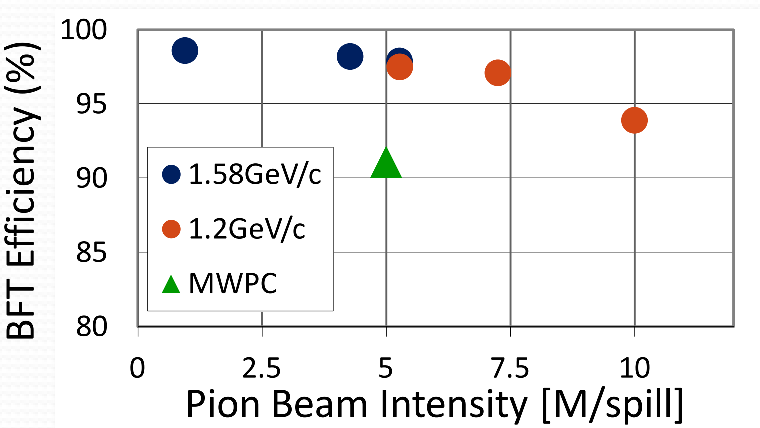


Developed by K. Miwa, S. Hasegawa and R. Honda
(Tohoku Univ. and JAEA)



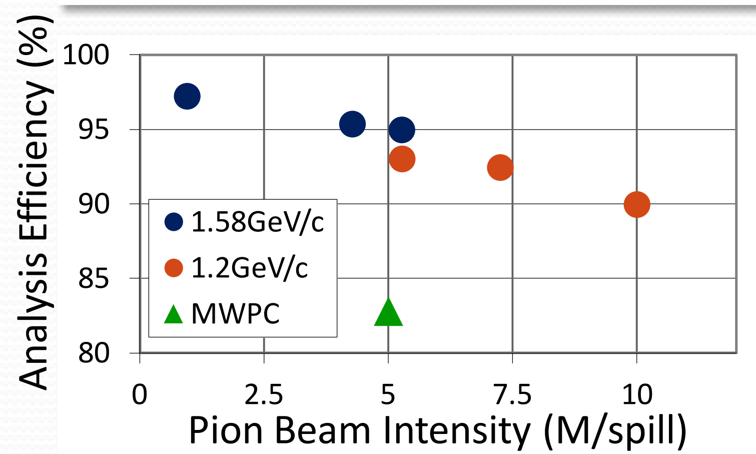
- BFT performance in June beamtime
  - Timing resolution
    - 1.5ns (rms) w/o corrections
    - Better than current MWPCs
      - MWPC encoder: 10 ns
      - Drift time spread: 30 ns
  - Analysis efficiency





Request Single Hit

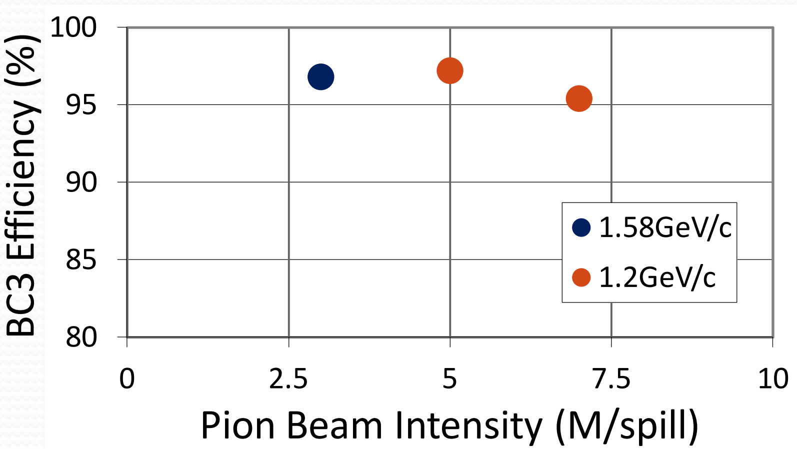
Efficiency ≥ 90%



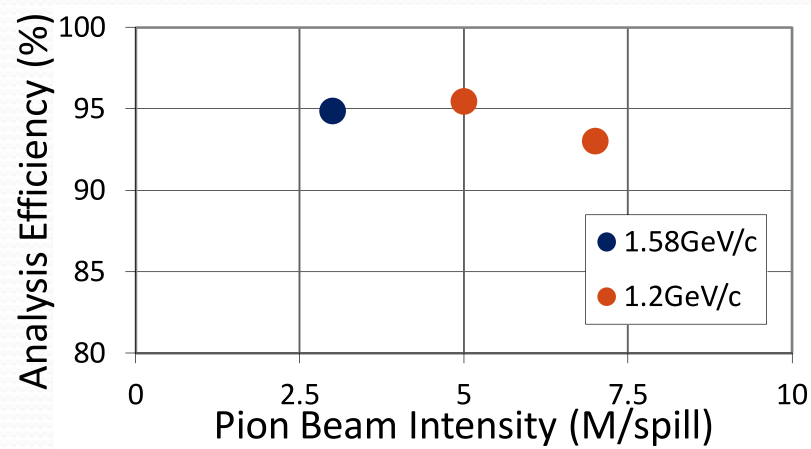
MWDC high-rate beam study

- MWDC (BC3) at beam spectrometer exit
  - BC3: 3mm MWDC (SDC1 is similar with DC3)

Efficiency ≥ 93%



Request Single Hit



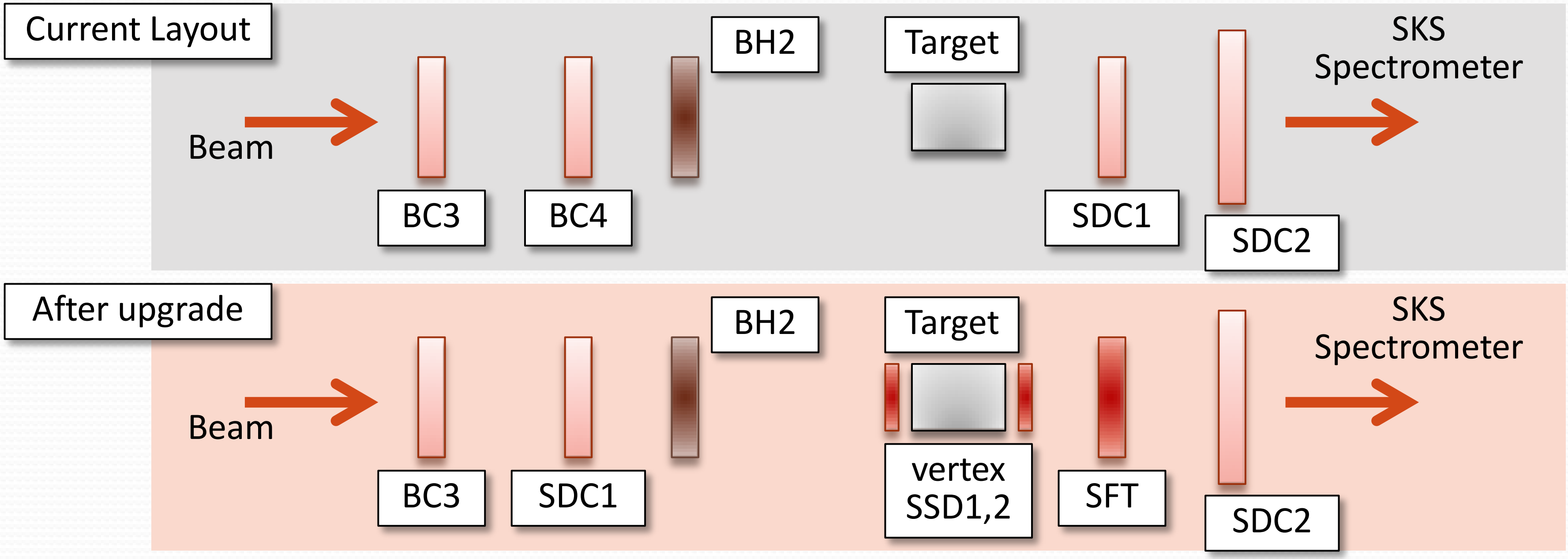
  - BC3 and BC4 plane efficiencies

Pion Beam Intensity	BC3	BC4
3 M/spill	> 99%	> 99%
5 M/spill	> 99%	99%
7 M/spill	> 99%	97%

No deterioration up to 7 M/spill for BC3

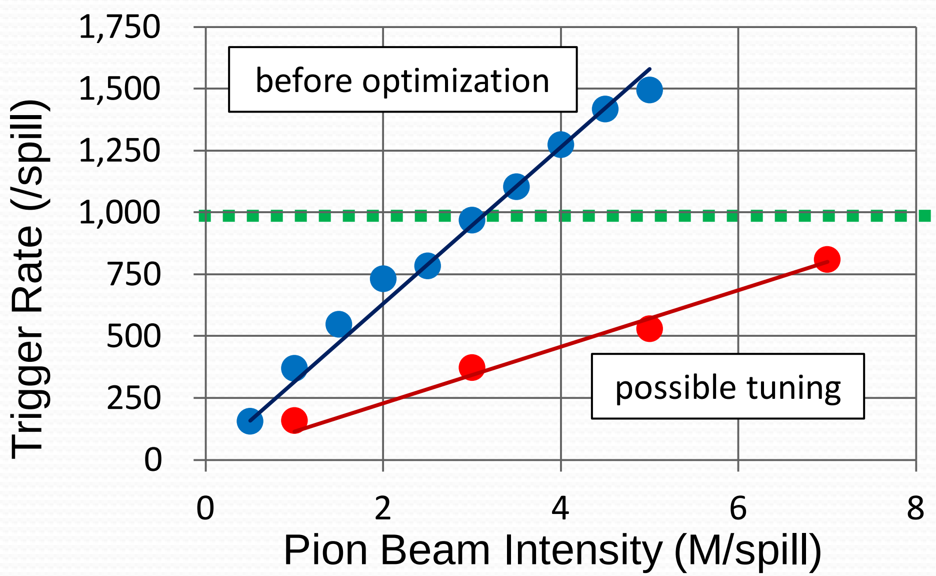
SFT (Spectrometer Fiber Tracker) design

- Replace SDC1 (Spectrometer DC) with fiber tracker
  - 0.5mmϕ scintillation fiber, xx’-uu’-vv’ 6 planes
    - 2 fibers are ganged and read out by a MPPC
    - xx’: 192mm wide, uu’ and vv’: 160mm wide (45º titled)
- Upgrade plan of tracking detectors around target



Trigger issues and studies

- Requirement for DAQ trigger rate
  - Reasonable trigger rate is about 1000 trigger/spill to keep DAQ efficiency better than 80%
- Trigger studies were done during beamtime in June
  - Optimization of Čerenkov detectors (proton rejection)

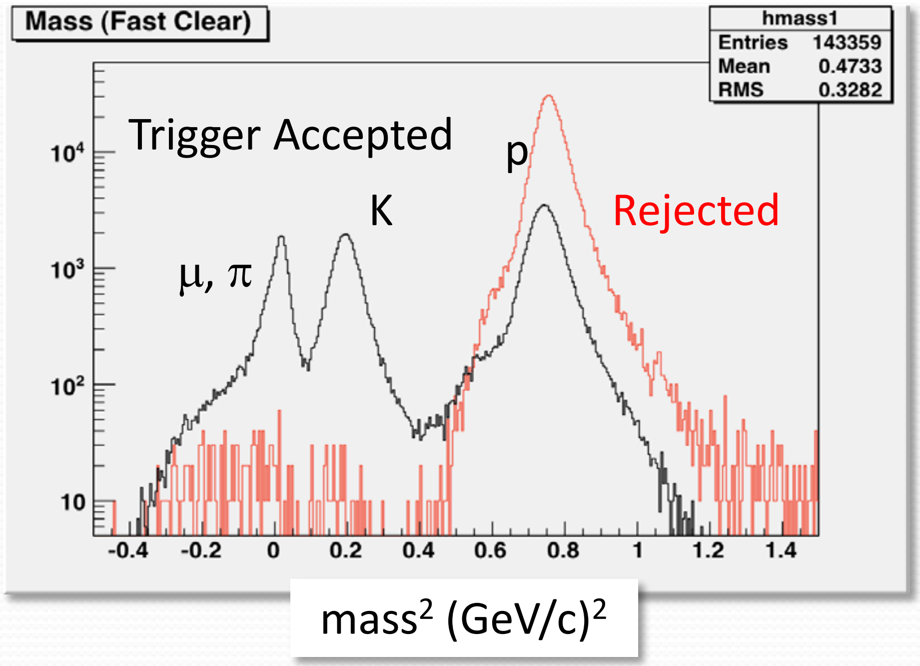


study made by $3.5 g/cm^2$ C
estimation for $3.5 g/cm^2$ ^{6}Li

possible operation modes of Čerenkov detectors at least up to 8M/spill pion beams to keep trigger rate low

detailed off-line analysis (kaon eff. etc.) is in progress

- New 2nd level mass trigger to select kaons
  - Cut time-of-flight (beam hodoscope ↔ TOF hodoscope)
    - **Red**: events rejected
      - mainly protons
    - **Black**: events accepted
      - K, π and μ
  - Trigger rate was improved
    - reduced to about 30%
  - Kaon miss-rejection 0.7%



- Overall trigger performance
  - We can achieve a reasonable trigger rate by these improvements of trigger up to very high beam intensity

E10 run plan

- List of runs and time estimate

Purpose	Time required	Beam conditions
Beam line, detector and trigger tuning	1 day	0.8-1.2 GeV/c π^+ and π^- 1-5M/spill
Calibrations before production runs Σ^+ and Σ^- productions for energy calib. ${}^{12}{}_{\Lambda}C$ production for energy calib.	 1 day 1 day	 1.2 GeV/c π^+ and π^- 5M/spill 1.2 GeV/c π^+ 5M/spill
Production runs DCX with ${}^{6}Li$ target (${}^{6}{}_{\Lambda}H$ production)	 21 days	 1.2 GeV/c π^- 5M/spill
Calibration after production runs ${}^{12}{}_{\Lambda}C$ production for energy calib.	 1 day	 1.2 GeV/c π^+ 5M/spill

- E10 beamtime request: 25 days in total
- Run with at least 5M/spill pion beams on target
- Improvement of SX duty factor is really helpful for E10

Summary

- Aims of E10
  - E10 aims to produce neutron-rich Λ hypernuclei, $^{6}_{\Lambda}H$ and $^{9}_{\Lambda}He$, close to the neutron drip-line.
  - We may obtain information of Λ-N interaction in the extreme condition, especially ΛN-ΣN mixing effects, from the hypernuclear structures and reaction mechanisms.
- Current beam status and our plan
  - Although the 50 GeV PS beam condition is not so suitable for SX (duty factor 25-30%), we may run at least at beam intensity of 5M/spill (proposed intensity was 10M/spill).

- Studies and preparations for E10
  - Good timing resolution of BFT (Beam Fiber Tracker) may improve performance of tracking in beam line.
  - The performance of tracking MWDC (BC3 and SDC1) is good enough at least up to 7M/spill.
  - We are planning to fabricate a new tracing detector SFT (Spectrometer Fiber Tracker).
  - Vertex SSDs are almost ready.
  - Trigger rate may be kept in a reasonable rate with the tuning of trigger detectors and the new mass trigger.
  - ^{6}Li and ^{9}Be targets are ready. ^{6}Li is used in the 1st runs.