JASMIN
Japanese-American Study of Muon Interactions and Neutron detection

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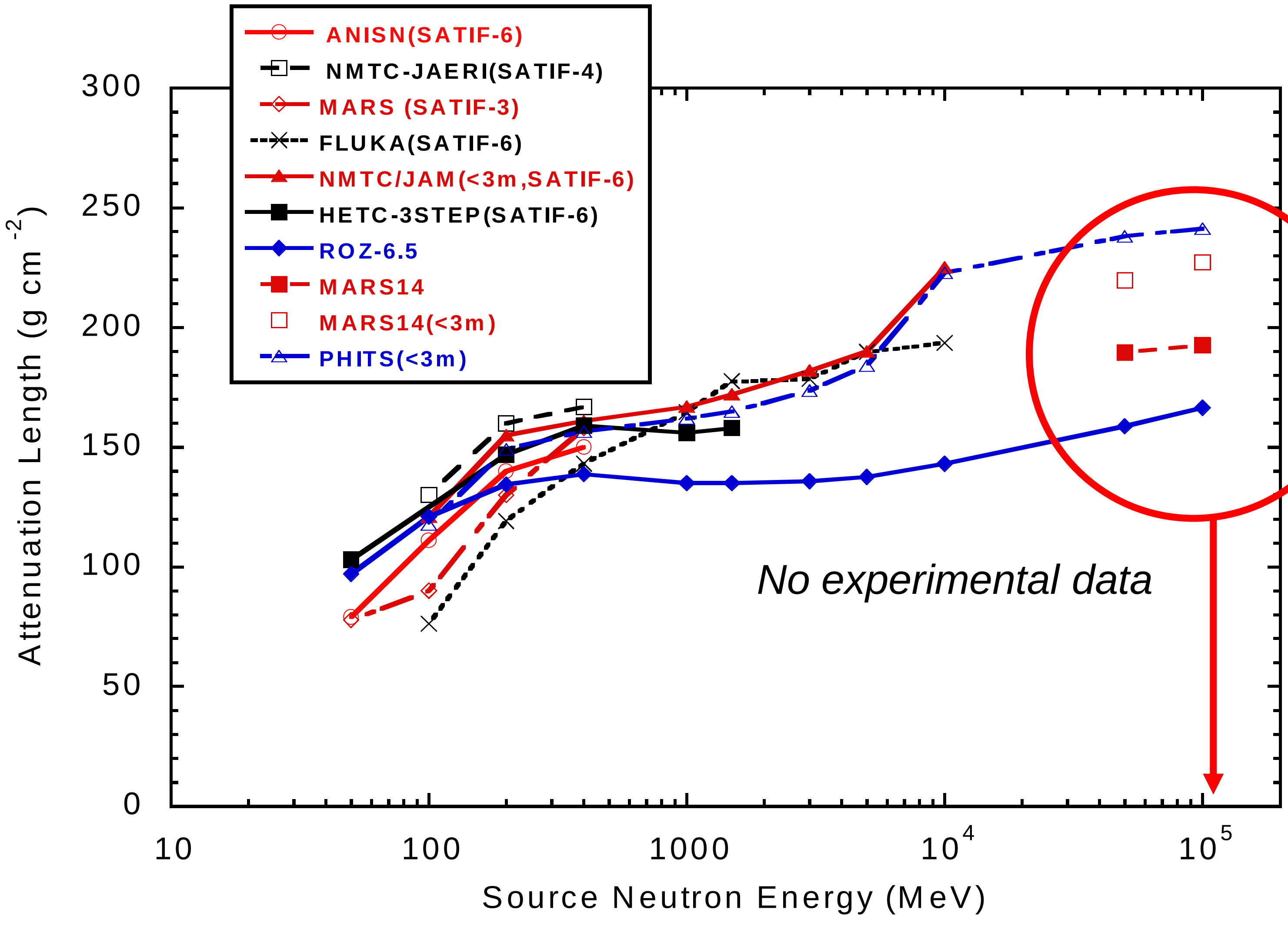
1．Background
Inter-comparison of high energy codes



Comparison of the attenuation length of iron.

Ref: INTER-COMPARISON OF MEDIUM-ENERGY NEUTRON ATTENUATION IN IRON AND CONCRETE (5), Hirayama et al., SATIF

Discussion at OECD/NEA SATIF7

- Inter-comparison of high energy particle transport codes
- Needs of experimental data for benchmarking

Proposal of FNAL at the 7th Mtg. (2005):

Shielding experiments using
high energy accelerator facilities at FNAL

- 400MeV LIANC
- 8GeV Synchrotron
- 150GeV Synchrotron (Pbar target station)
- 1TeV Synchrotron

2. Purposes of JASMIN

For high energy accelerator facilities

By taking experimental data

- Benchmarking of codes
- Modification of physical model and Parameterization

For estimation of radiation damage (in future)

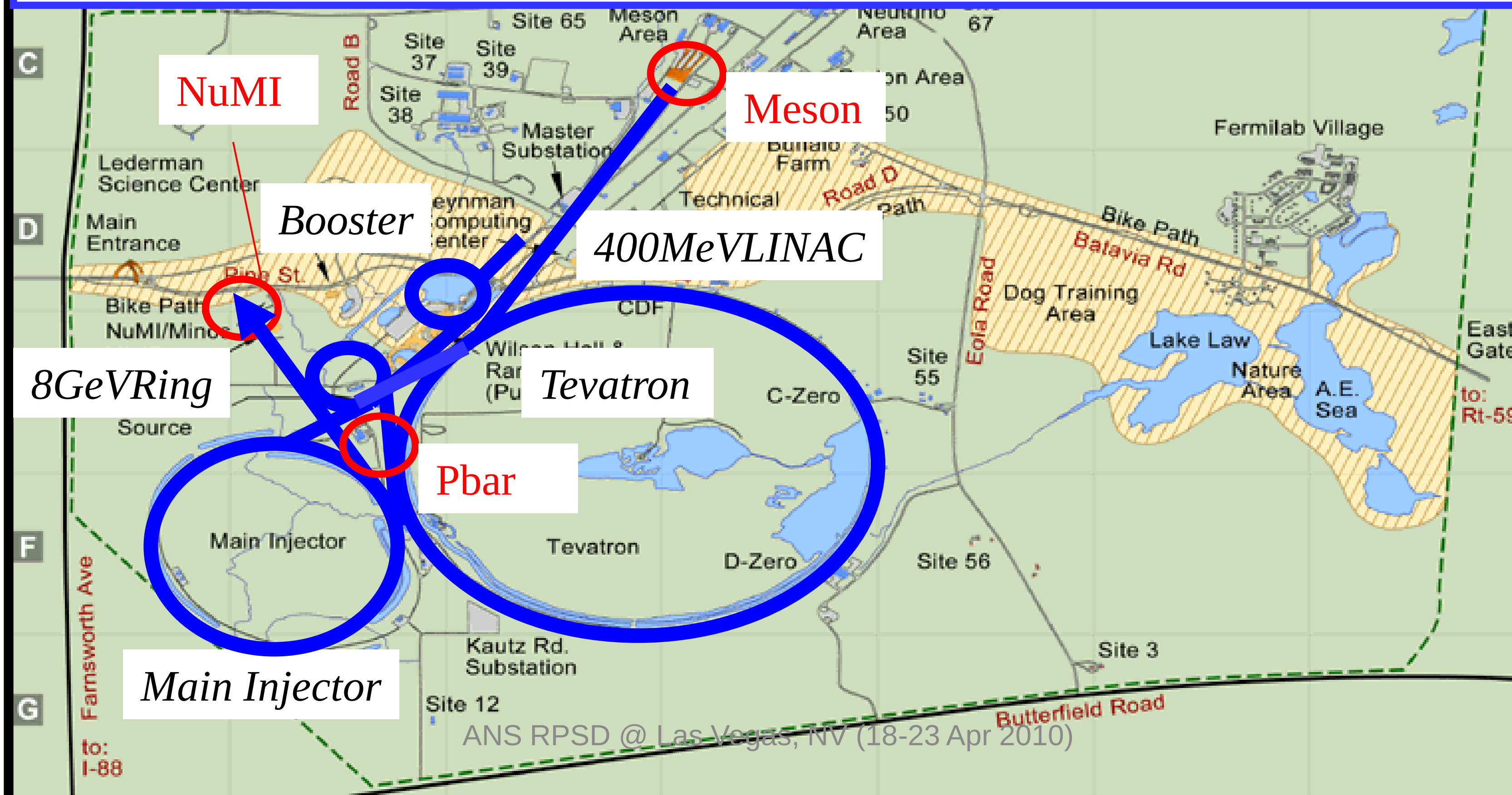
By establish of irradiation field and experimental data

- Code development for estimation of radiation damage

Application for high energy physics and space technology

3. Experiments at FNAL

1. Measurement of particle flux and residual activity around shield at Pbar station with 120GeV protons
2. Measurement of particle flux and residual activity around shield at NuMI with 120GeV protons
3. Thick target yield measurement at Meson area with 120GeV protons



Methods of Measurements

1．Measurement of the secondary particles

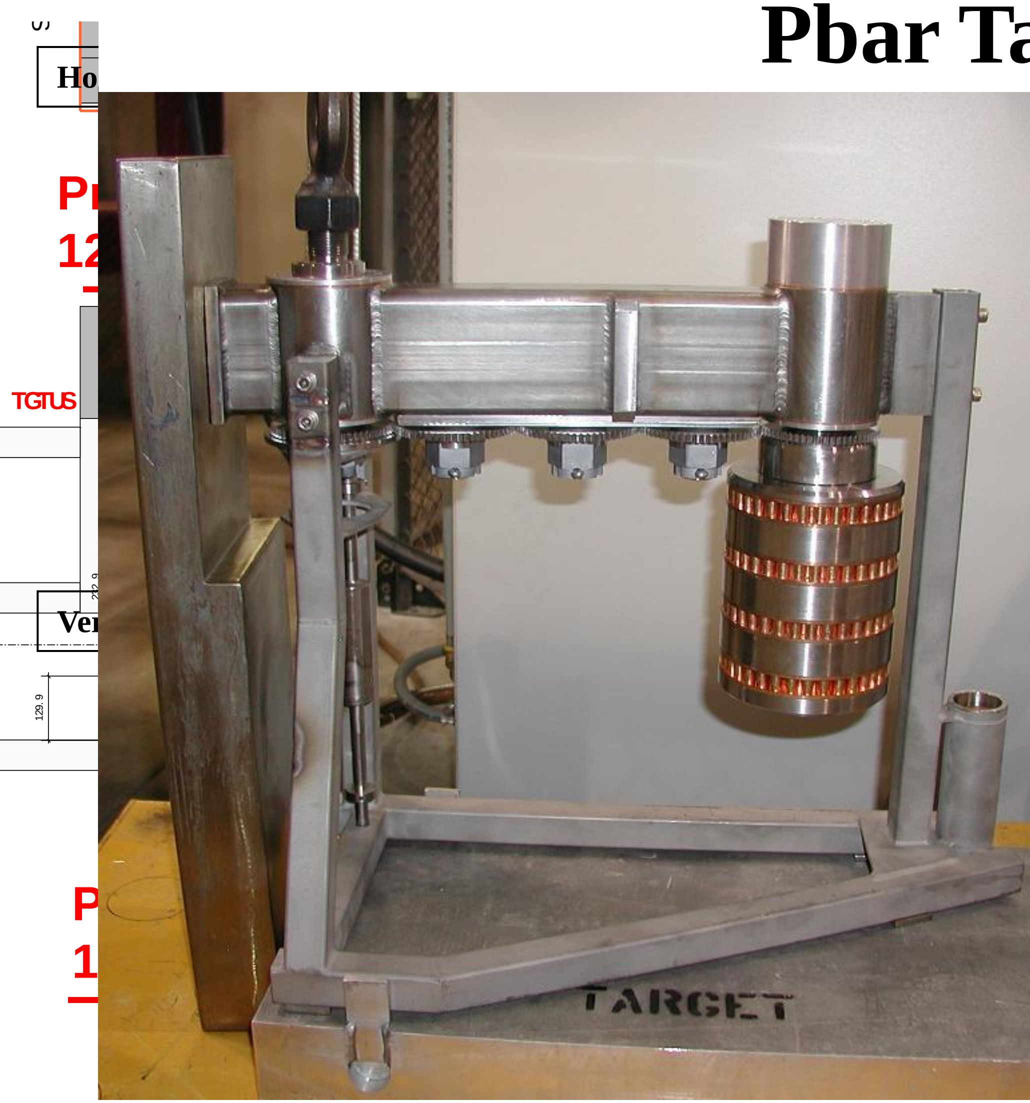
- Measurement using activation method
- Measurement using activation method with chemical separation
- Measurement using counters
  - Bonner sphere (Current mode , Pulse mode)
  - NE213 scintillation counter
  - Phoswitch detector test
  - Count rate by thin plastic scintillation counter
  - Neutron and gamma survey meters
- Measurement using TLDs and Solid State Nuclear Track Detector

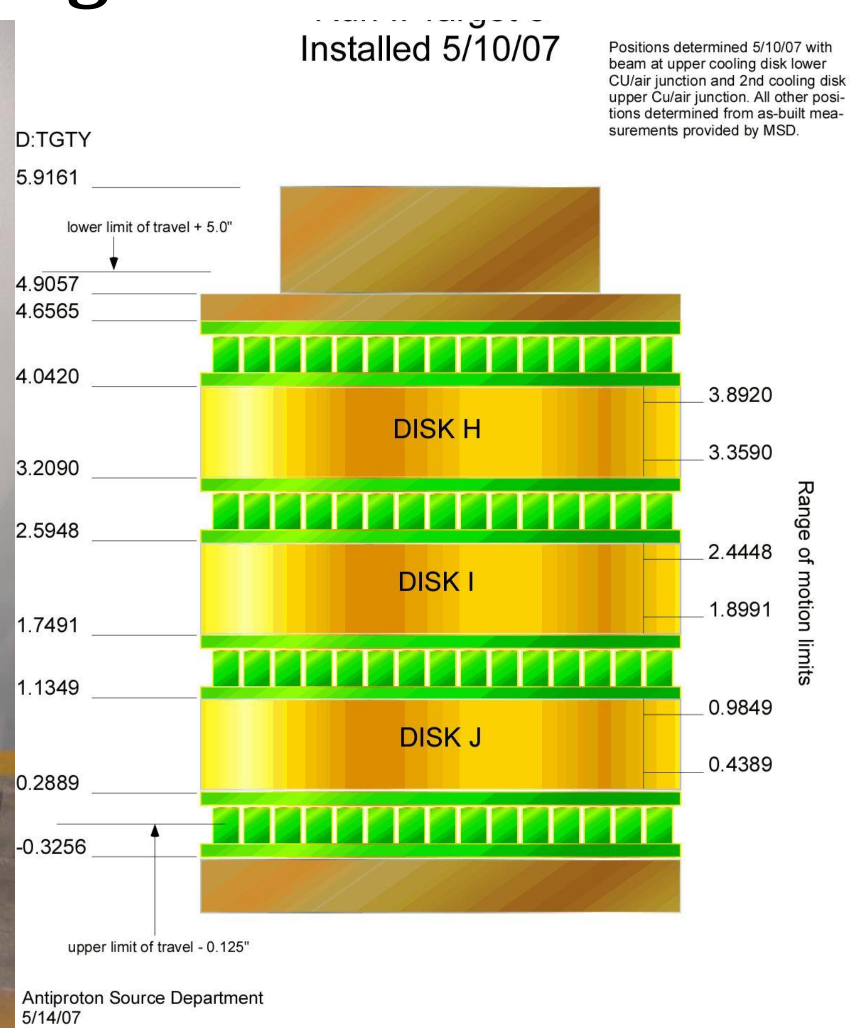
2．Measurement of residual nuclei

- Measurement using activation method
- Measurement using activation method with chemical separation
- Measurement with gas sampling

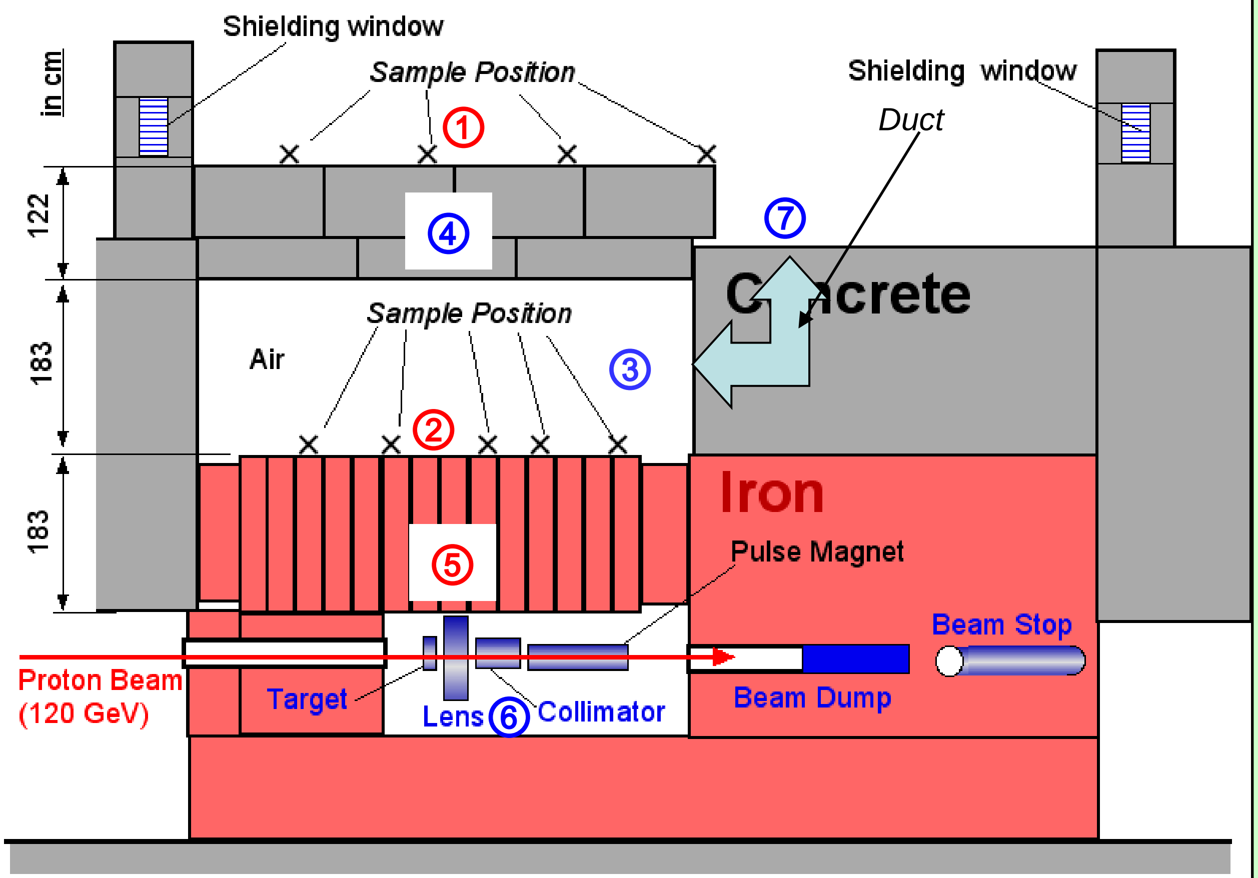
3.1 Experimental conditions around Pbar target

Pbar Target





Measurements at Pbar



① Measurement of Neutron (2nd Particles) Flux outside Concrete Shield

② Measurement of Neutron (2nd Particles) Flux outside Iron Shield

③ Measurement of Air Activation in Vault

④ Measurement of Neutron Flux inside Concrete Shield

⑤ Measurement of Neutron Flux inside Iron Shield

⑥ Measurement of Activities around Pbar

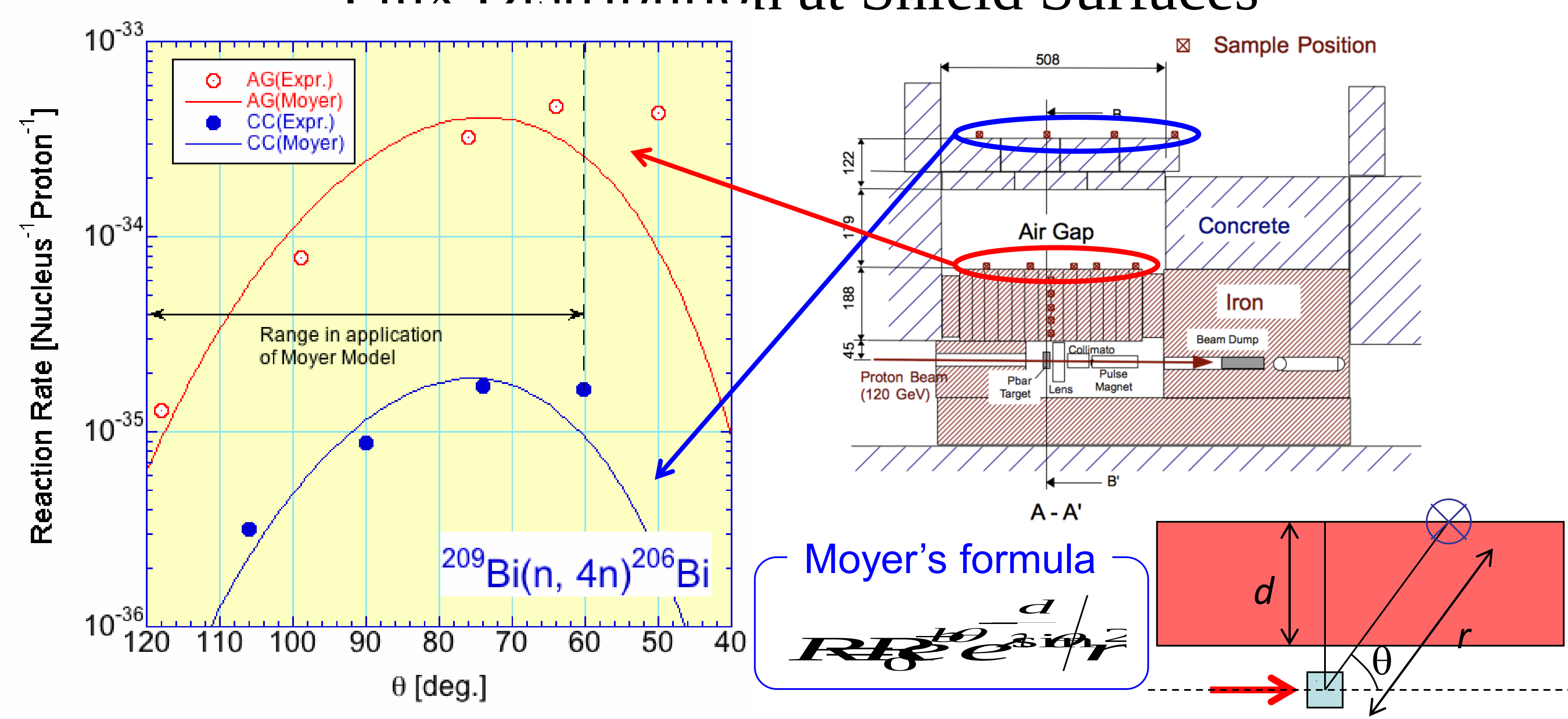
⑦ Measurement of Streaming Particle in Duct

Flux Distribution at Shield Surfaces

CC01, 03, 04

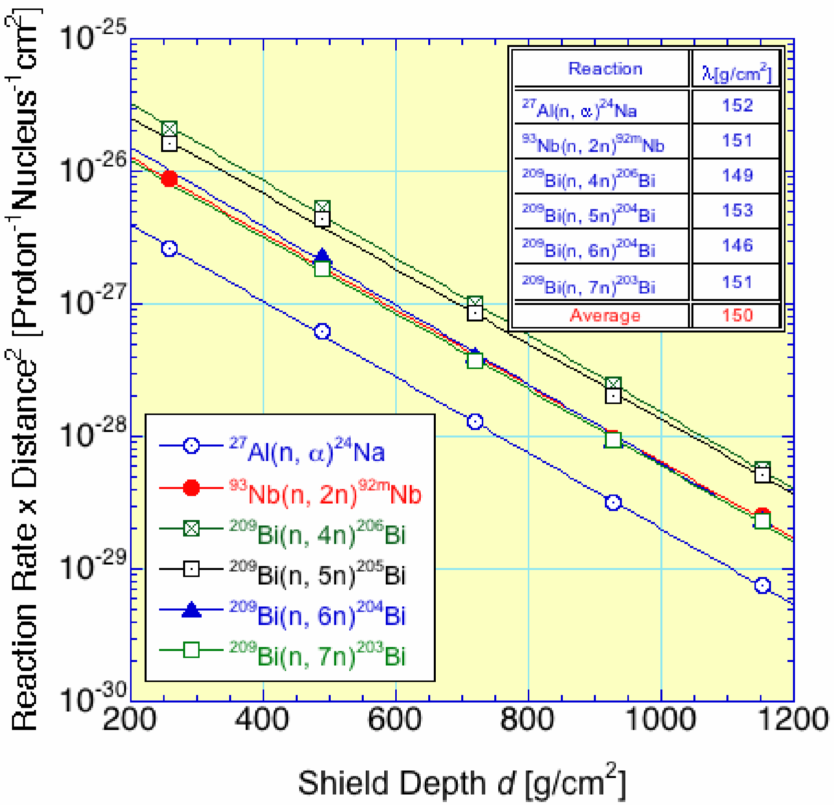
CC02+Conc.

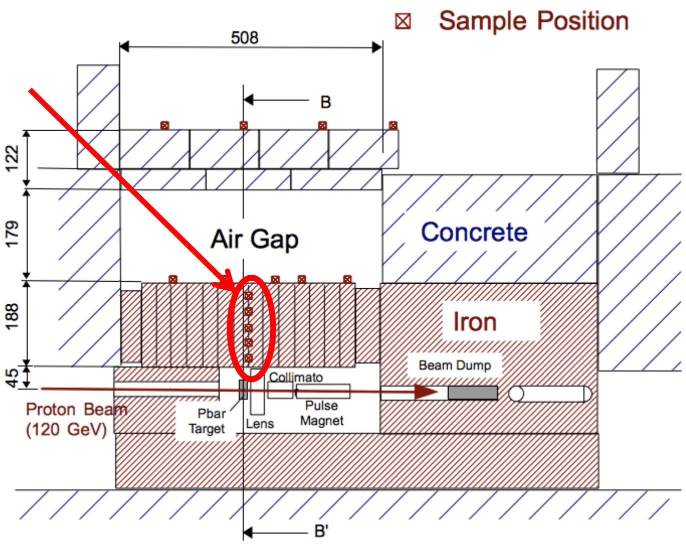
Flux Distribution at Shield Surfaces

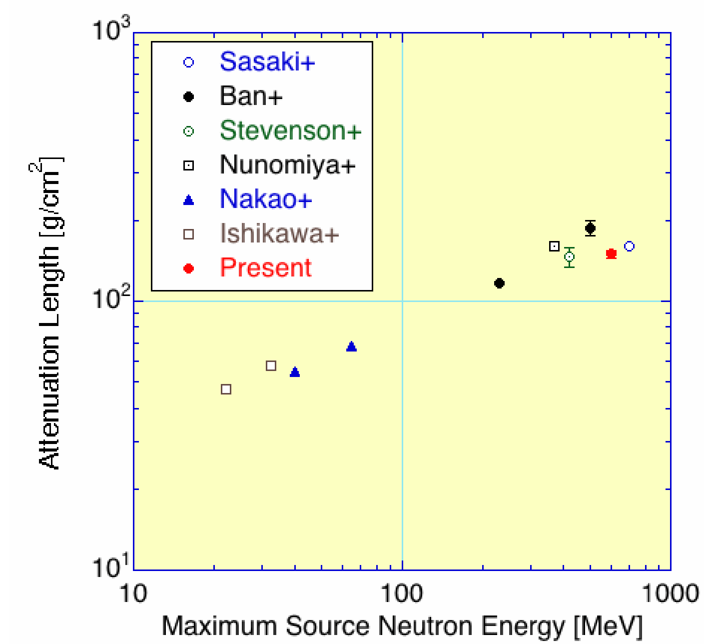


- Reaction rates at the shield surfaces could be fitted with the Moyer's formula within the application rage.
- The values of *b* needs to be set at the values around 4.0.
  - Larger than previous studies such as 2.3 by Stevenson et al.

Neutron Attenuation in Steel

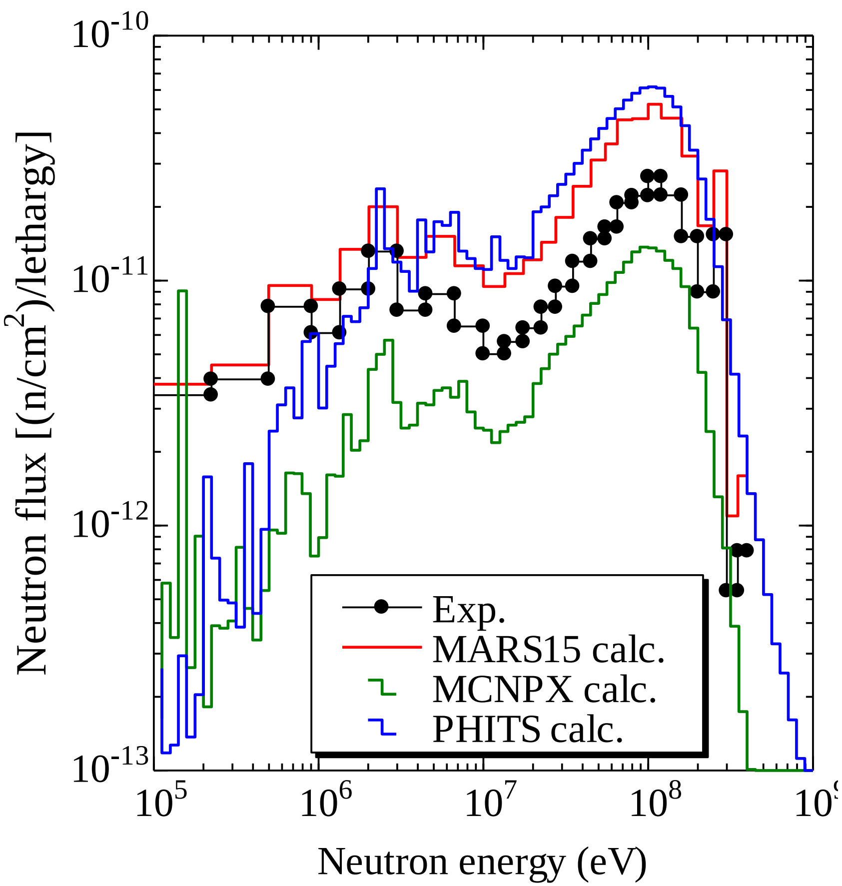


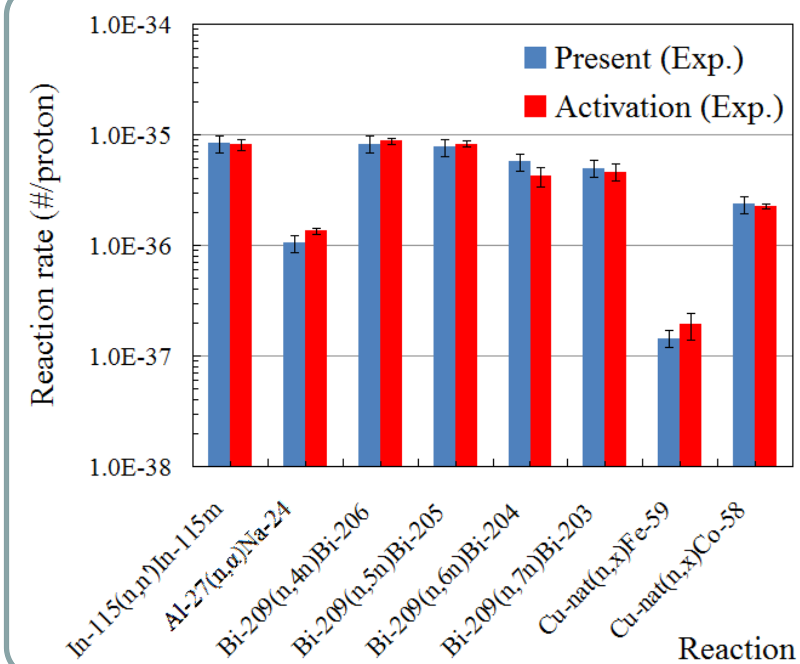




- An neutron attenuation length of the steel shield at 90° -direction was measured to be 150±5 g/cm^2.
- First measurement for a incident proton energy higher than 100 GeV
- Consistent with the previous data such as Stevenson et al.

Bonner sphere at Pbar





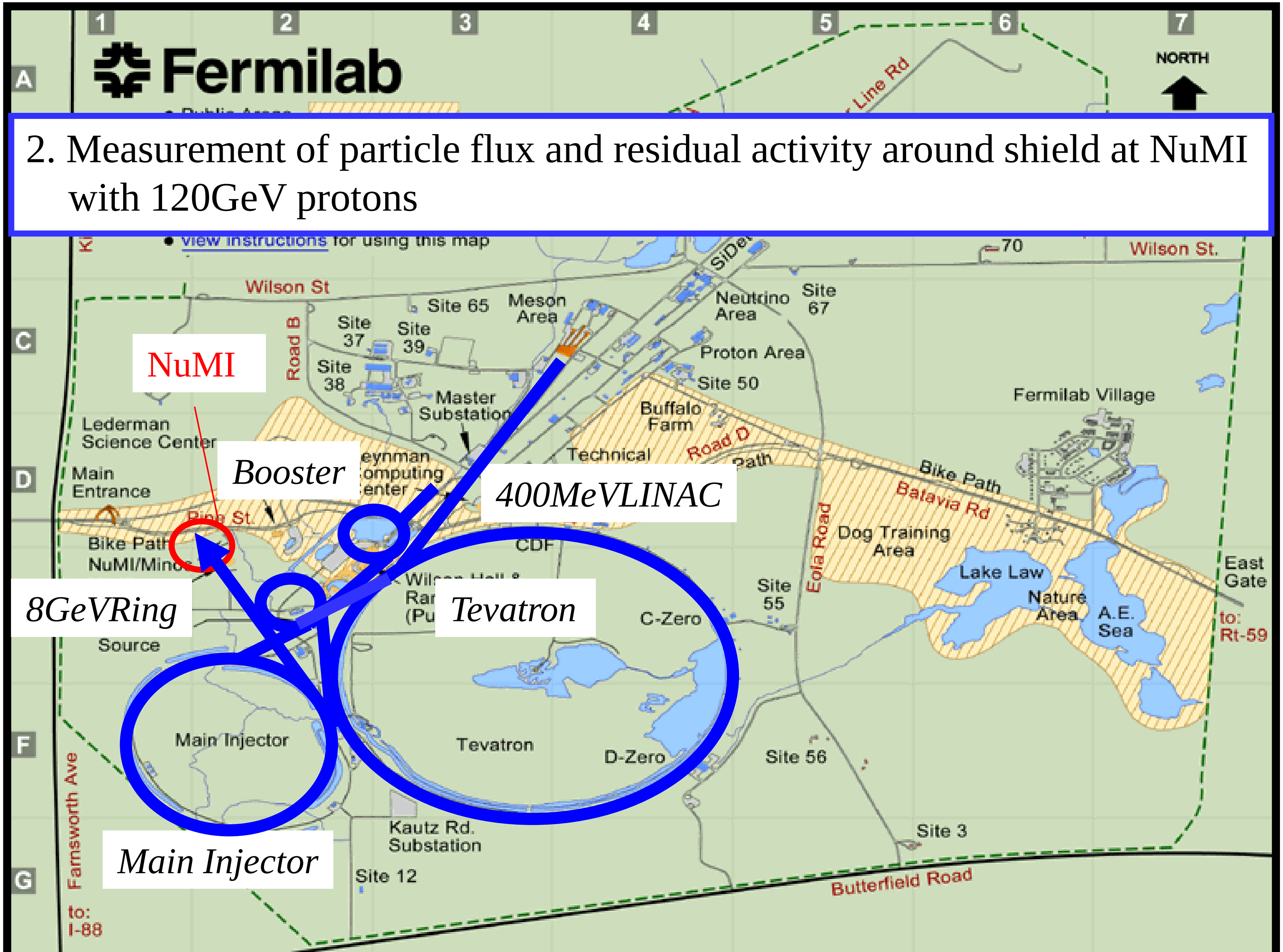
Reaction	Threshold (MeV)
^{115}In(n,n')^{115m}In	0.6
^{27}Al(n,α)^{24}Na	3.3
^{209}Bi(n,4n)^{206}Bi	22.6
^{209}Bi(n,5n)^{205}Bi	29.6
^{209}Bi(n,6n)^{204}Bi	38
^{209}Bi(n,7n)^{203}Bi	45.3

Summary:

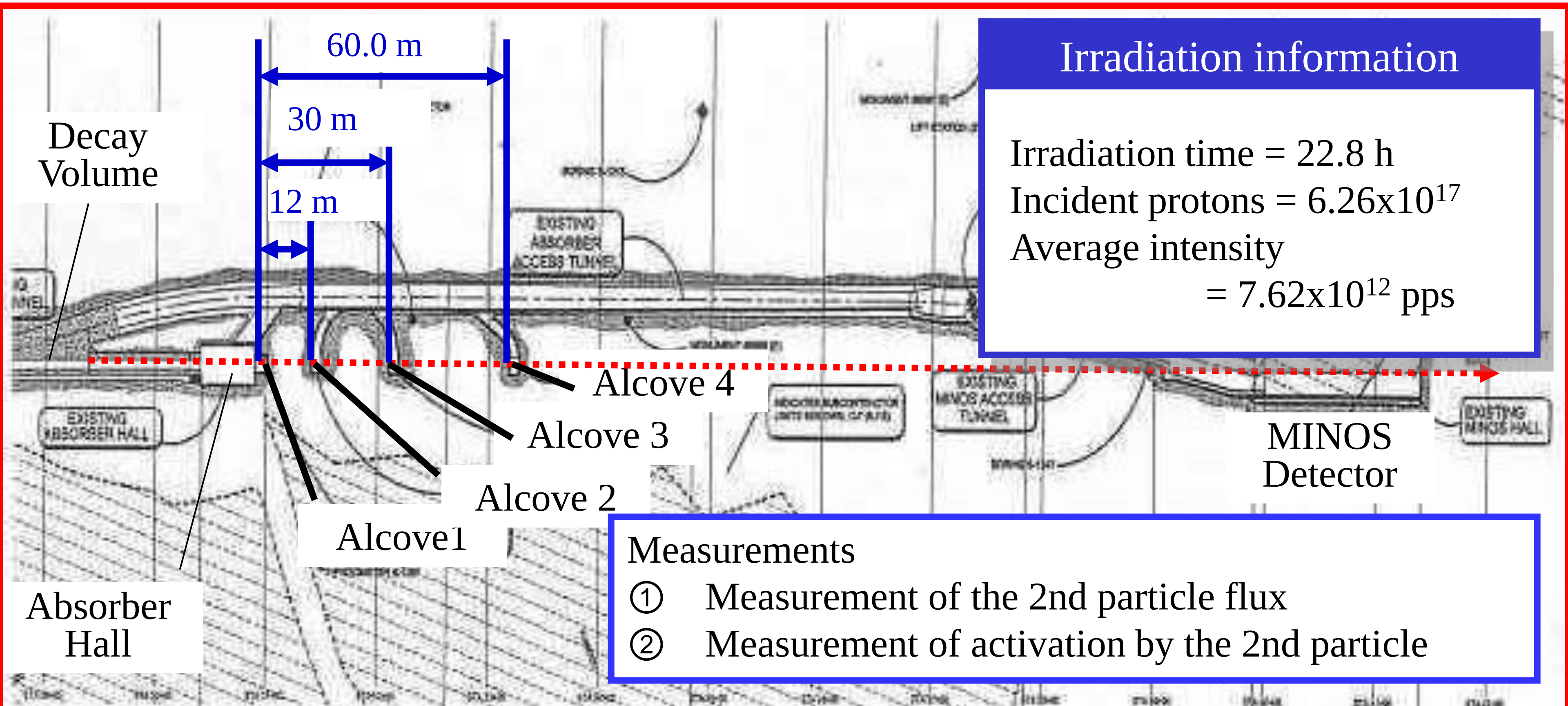
- Bonner result is consistent with activation results
- Simulation represents experiment within a factor.

3.2 Measurements at NuMI　(Neutrino at Main Inject　)

2. Measurement of particle flux and residual activity around shield at NuMI with 120GeV protons



Experimental conditions at NuMI

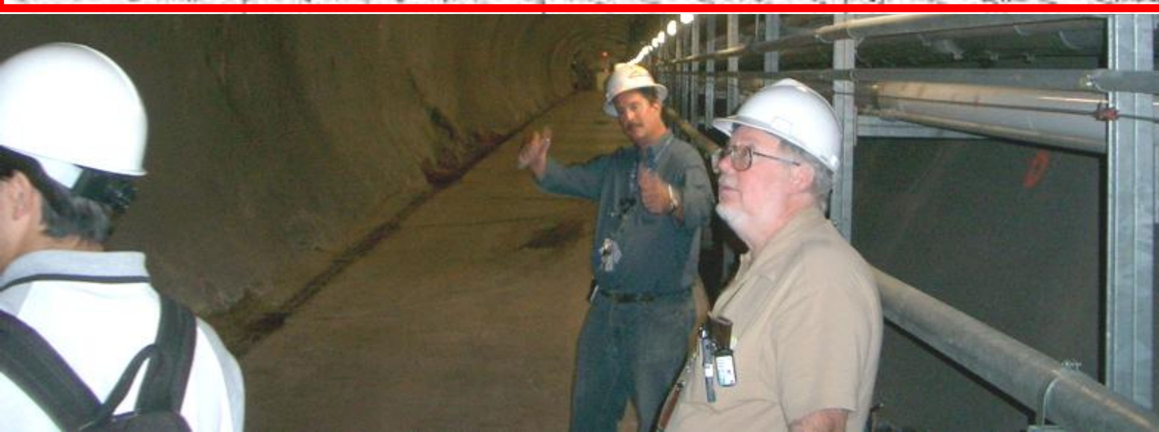


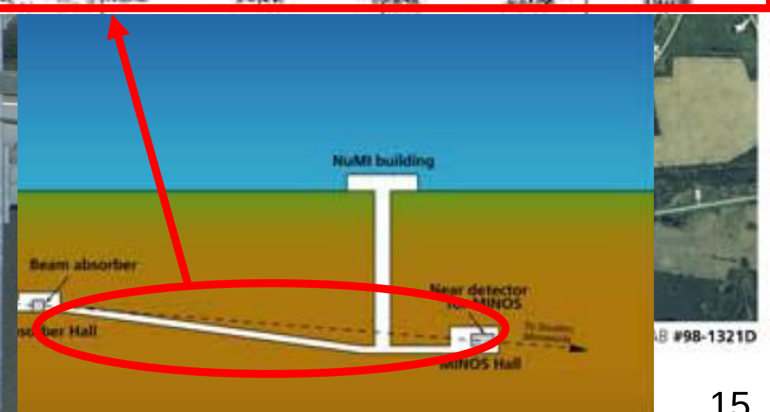
Irradiation information

Irradiation time = 22.8 h
Incident protons = 6.26×10^{17}
Average intensity
= 7.62×10^{12} pps

Measurements

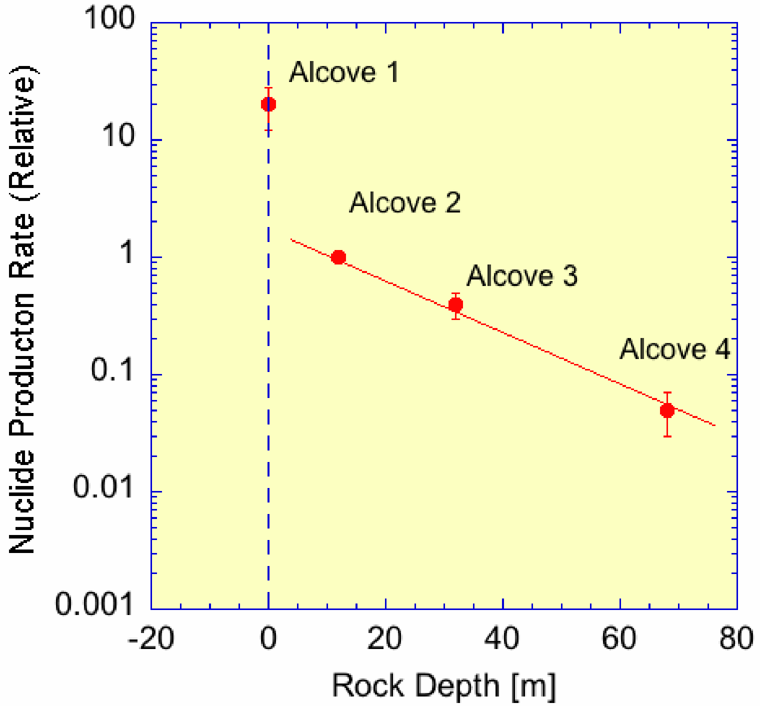
① Measurement of the 2nd particle flux
② Measurement of activation by the 2nd particle



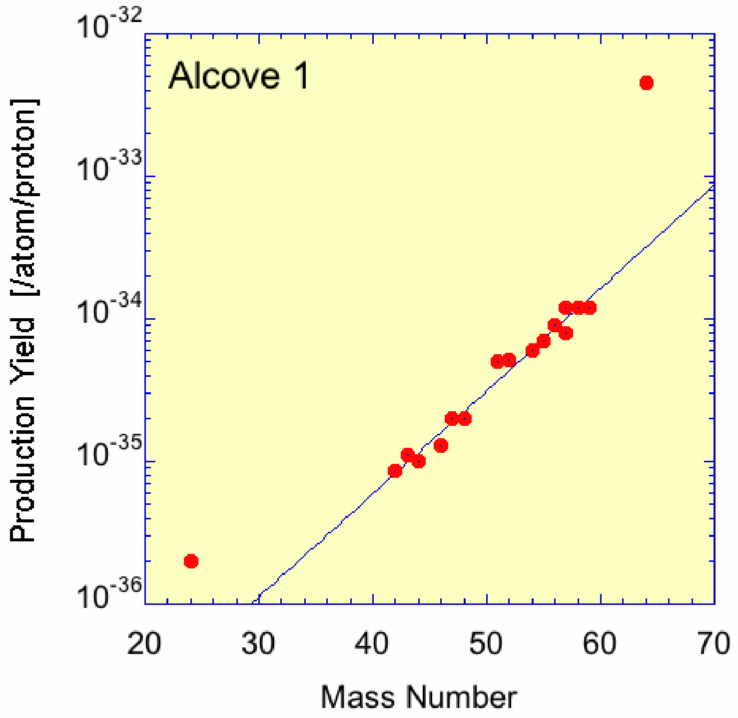


Muon Behavior in Rock

Attenuation profile measured with Cu



Mass yield of nuclide production from Cu



- Attenuation behavior at Alcove 2~4 was consistent with the estimation with MARS code.
  - Contributions of other particles needs to be considered for understanding the inconsistency at Alcove-1.
- Reaction mechanism between muons and nuclei will be understood by a detailed analysis of the slope of the mass distribution.

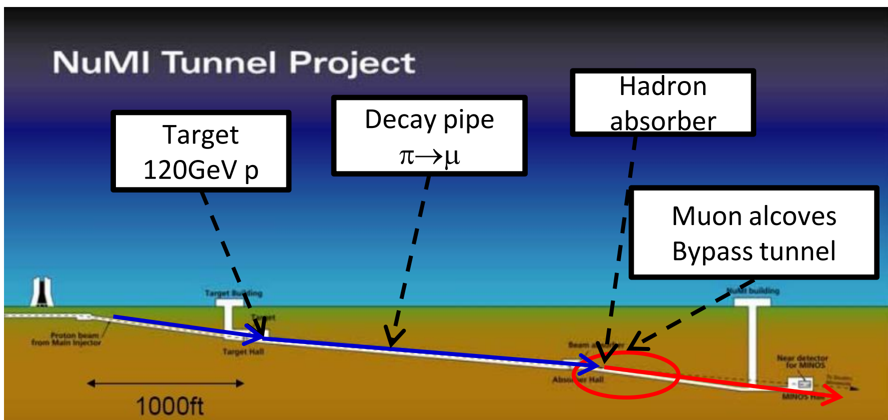
Dosimeters at NuMI

Measurement and analysis of muon and its secondary particle

Information on radiation safety design of forward angle

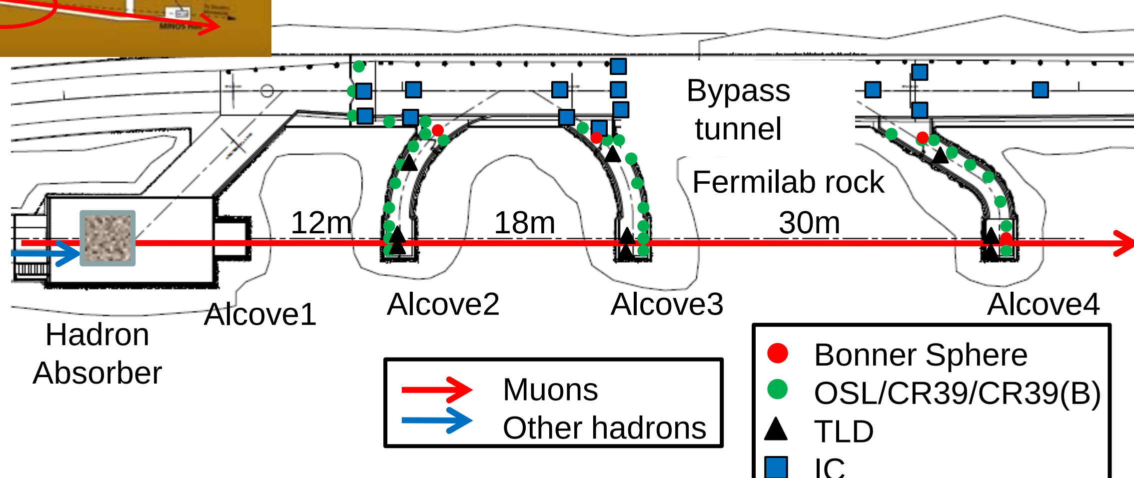
Experiment: Dosimeters, Bonner sphere and IC

Calculation: MASR with modeling NuMI over 1 km geometry

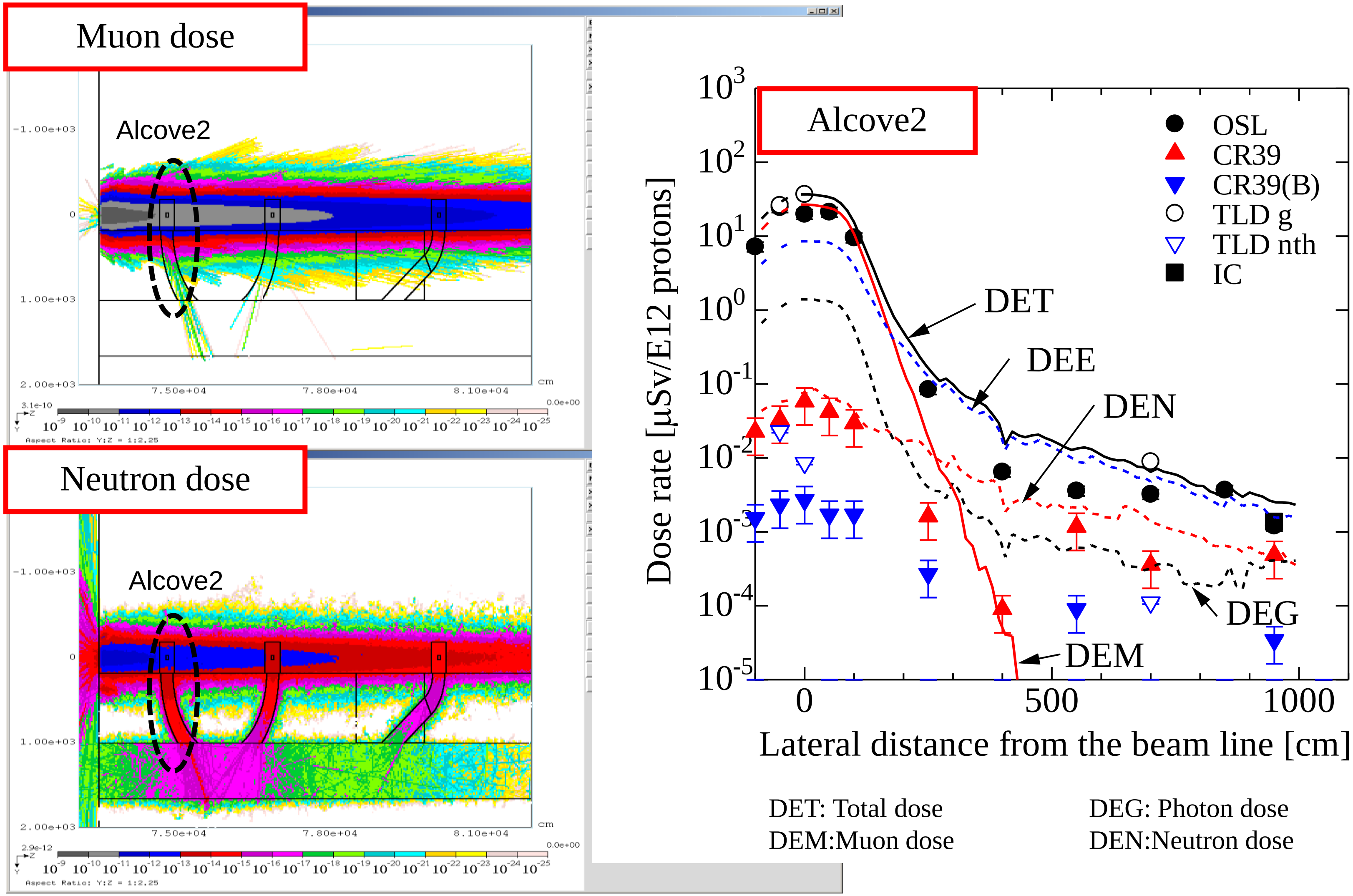


Dosimeters were placed in

muon alcoves

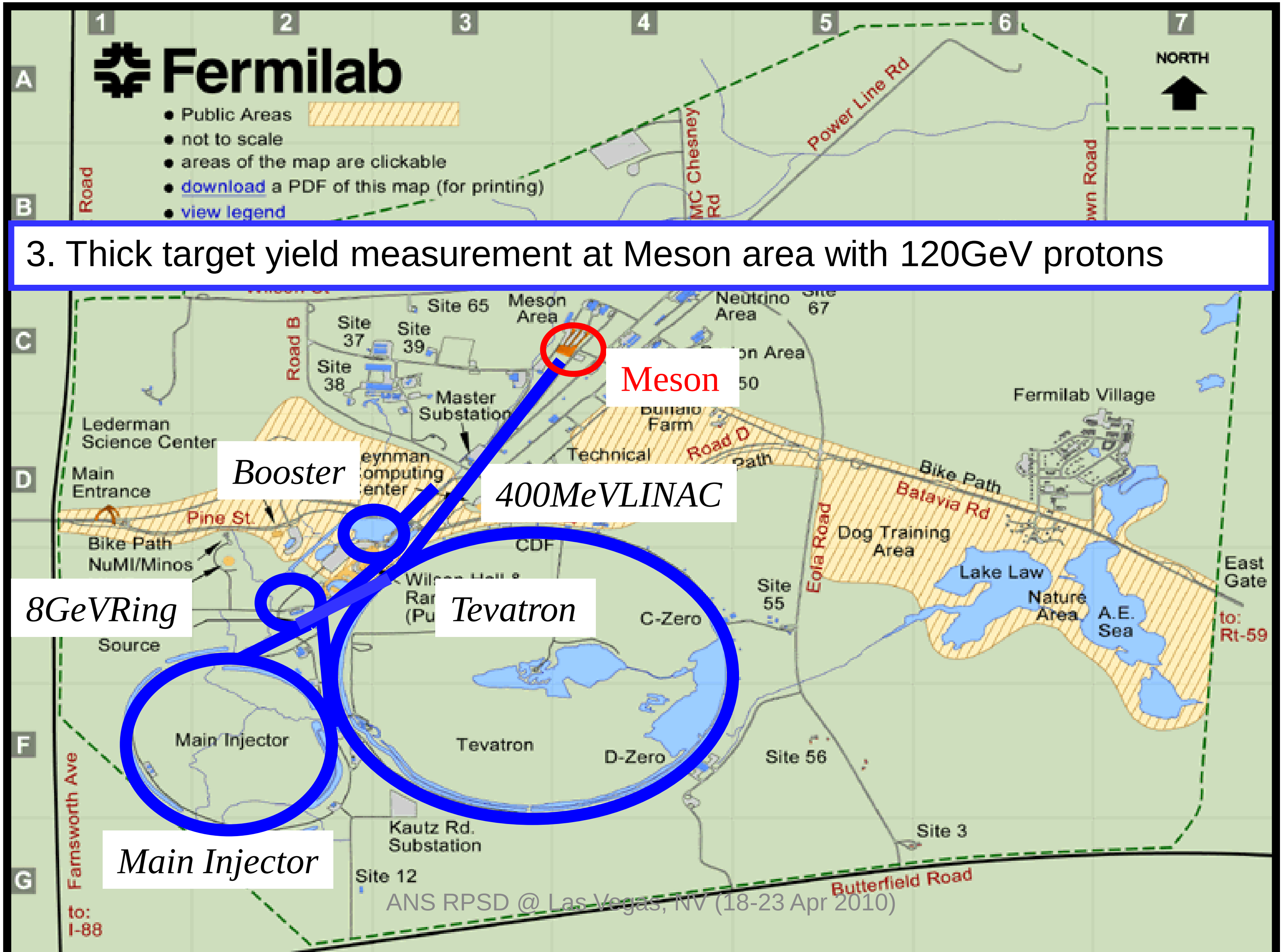


Dose distribution around NuMI



<u>Good agreement for both muon, gamma and neutron on dose base comparison</u>

2.3 Thick target yield measurement at MTBF



4. Summary

- Experimental results on particle flux and mass distributions were obtained and analyzed by some calculation methods.
- Shielding parameters such as neutron attenuation length were measured and compared with the previous values.
- The results were analyzed by PHITS and MARS, and the accuracy behind thick shield was confirmed within a factor.
- MARS results are in good agreement with experiments on dose distribution due to the secondary particles from high energy muon.

- Future plan:

Thick target yield and cross section measurements at MTBF

Establishment of irradiation field for study on radiation damage

Experiment with other accelerators at FNAL

Spare slides

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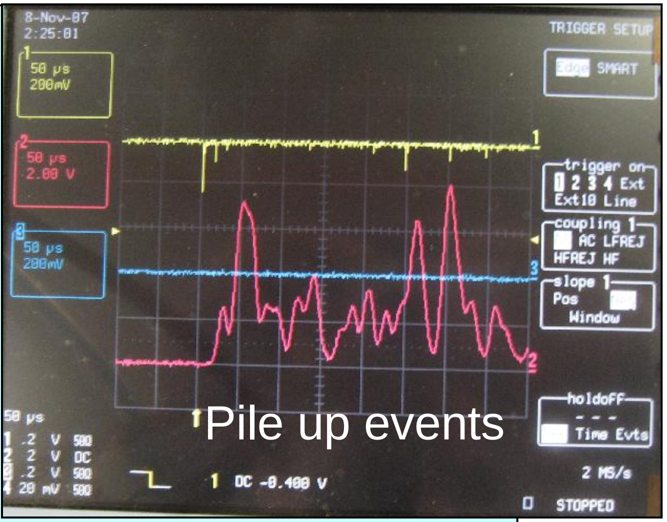
2. Experimental method

- **Multi-moderator spectrometer (Bonner sphere)**
  Widely used in neutron spectrum measurements
  To apply it to burst radiation field → severe count loss problem

A current readout Bonner sphere



1. Measure induced charge as current (integrated charge)

→ no signal pile-up problem

2. online measurement

→ synchronize with beam status

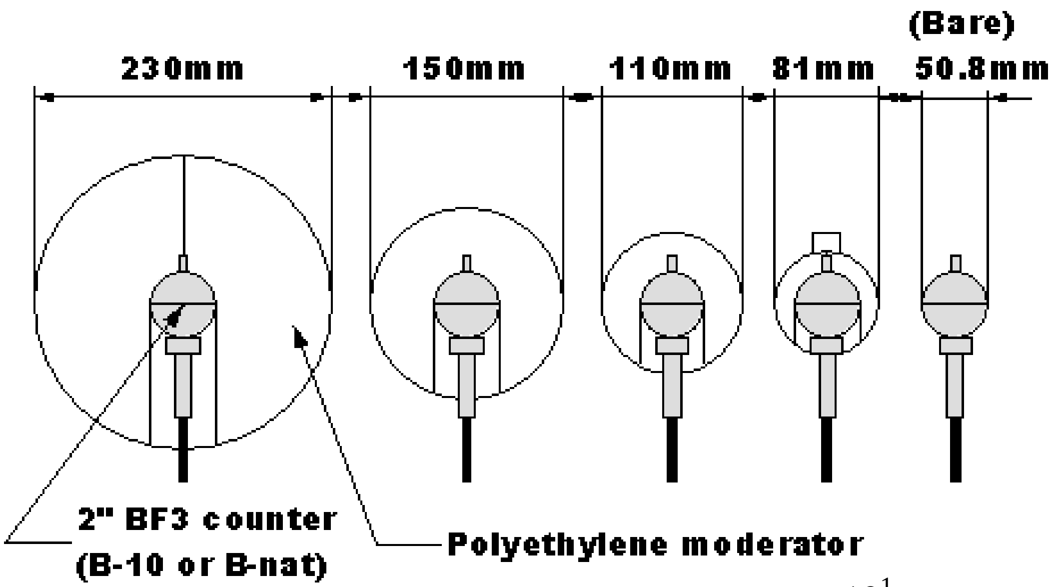
3. use of a pair of different ^{10}B-enriched BF_3 subtraction method [$^{10}BF_3$ (^{10}B 96%), $^{nat}BF_3$ (^{10}B 18%)]

→ elimination of contribution of γ-rays and muons

sensitivity (thermal neutron) : $^{10}B > {}^{nat}B$
sensitivity (γ-rays and muons): $^{10}B \approx {}^{nat}B$

Neutron Spectrum Measurements in Intense Pulsed Neutron Fields of The 120-GeV Proton Facility Using A Current Bonner Sphere Technique (M. Hagiwara)

2. 2. Multi-moderator spectrometer

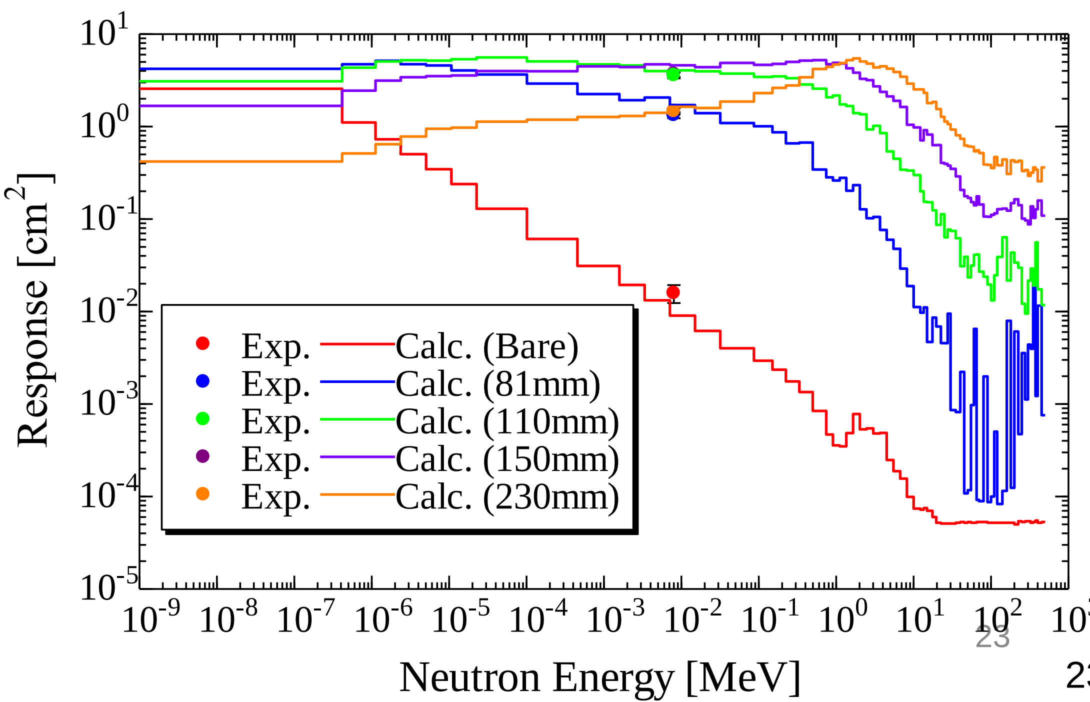


Five moderators type (polyethylene shell; 0 mm, 81mm, 110mm, 150mm, 230mm in diameter)

2"BF_3 counter（LND 2708）
$^{10}BF_3$ (^{10}B 96%) 1 atm,
$^{nat}BF_3$ (^{10}B 18%) 1 atm

Response functions of $^{10}BF_3$ (^{10}B 96%) 1 atm, calculated by MCNPX

Exp. at FRS in JAEA using 8 keV monoenergetic neutrons to confirm their validations



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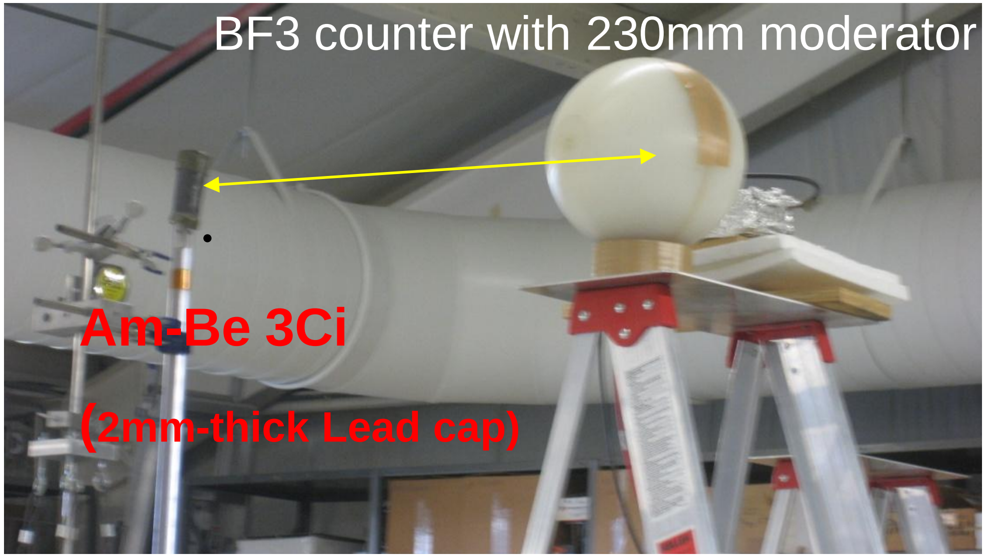
3. Calibration of current readout

with ^{241}Am-Be 3Ci

measure **Conversion factors** by comparison of counts/neutron in each mode and each counter

irradiation distance in Pulse mode: 74 cm and Current mode 17 cm



Conversion factors

Current → number of pulse

$$f_{^{nat}B}(p/c) = \frac{pulse\ (^{nat}B)}{current\ (^{nat}B)} = 61.8$$

$$f_{^{10}B}(p/c) = \frac{pulse\ (^{10}B)}{current\ (^{10}B)} = 56.6$$

^{10}B – ^{nat}B → ^{10}B

$$f(^{nat}B/^{10}B) = \frac{pulse\ (^{nat}B)}{pulse\ (^{10}B)} = 0.29$$

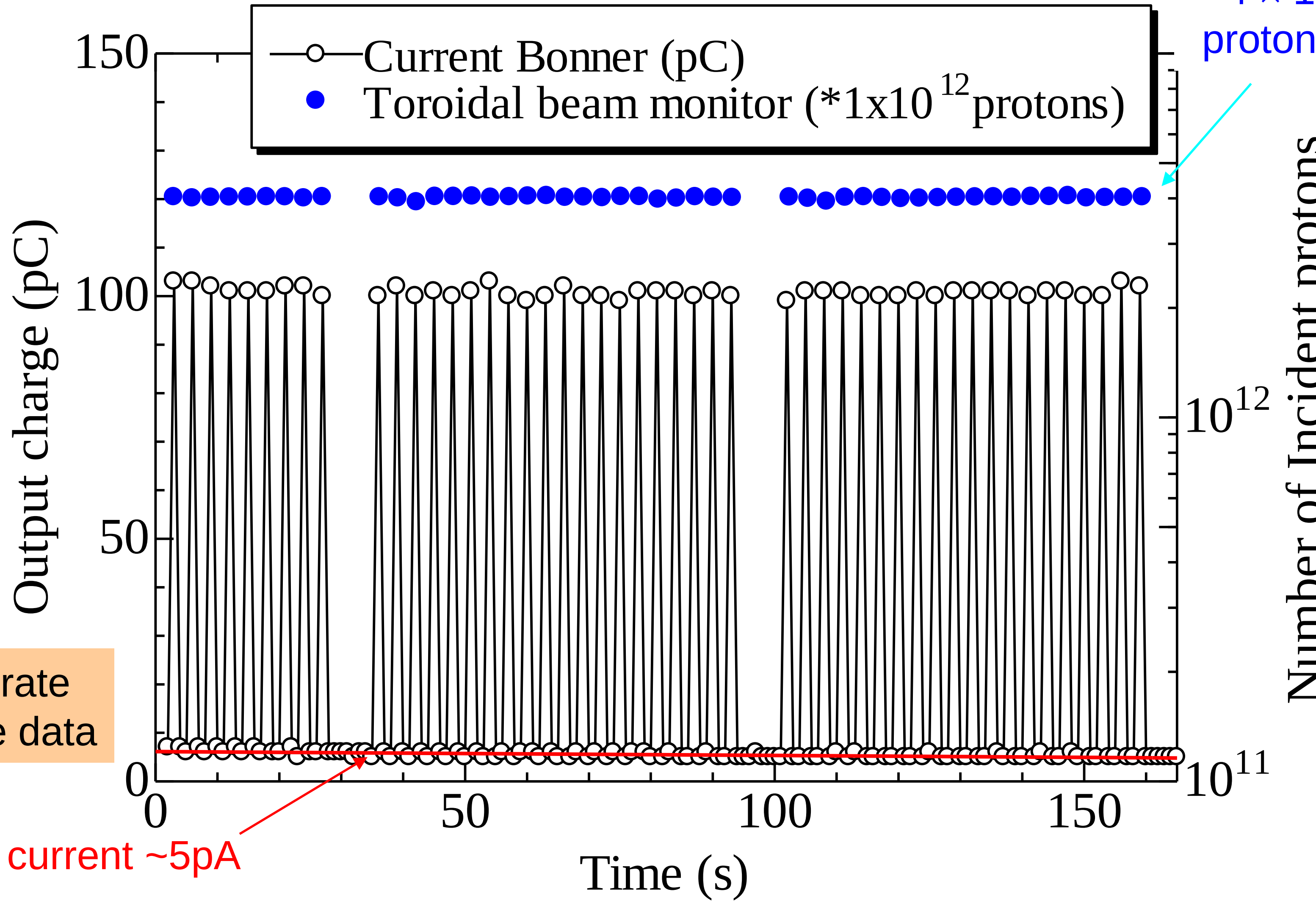
$C_{meas}(^{10}B)$, $C_{meas}(^{nat}B)$: measured current in $^{10}BF_3$ and $^{nat}BF_3$ counter

$P_{mean}(^{10}B)$: mean number of $^{10}B(n,\alpha)$ reaction in $^{10}BF_3$ counter

$$P_{mean}(^{10}B) = \frac{C_{meas}(^{10}B) \times f_{^{10}B}(p/c) - C_{meas}(^{nat}B) \times f_{^{nat}B}(p/c)}{1 - f(^{nat}B/^{10}B)}$$

4. Result of Current readout

MCS output of the $^{10}BF_3$ counter with the 110-mm-diameter moderator



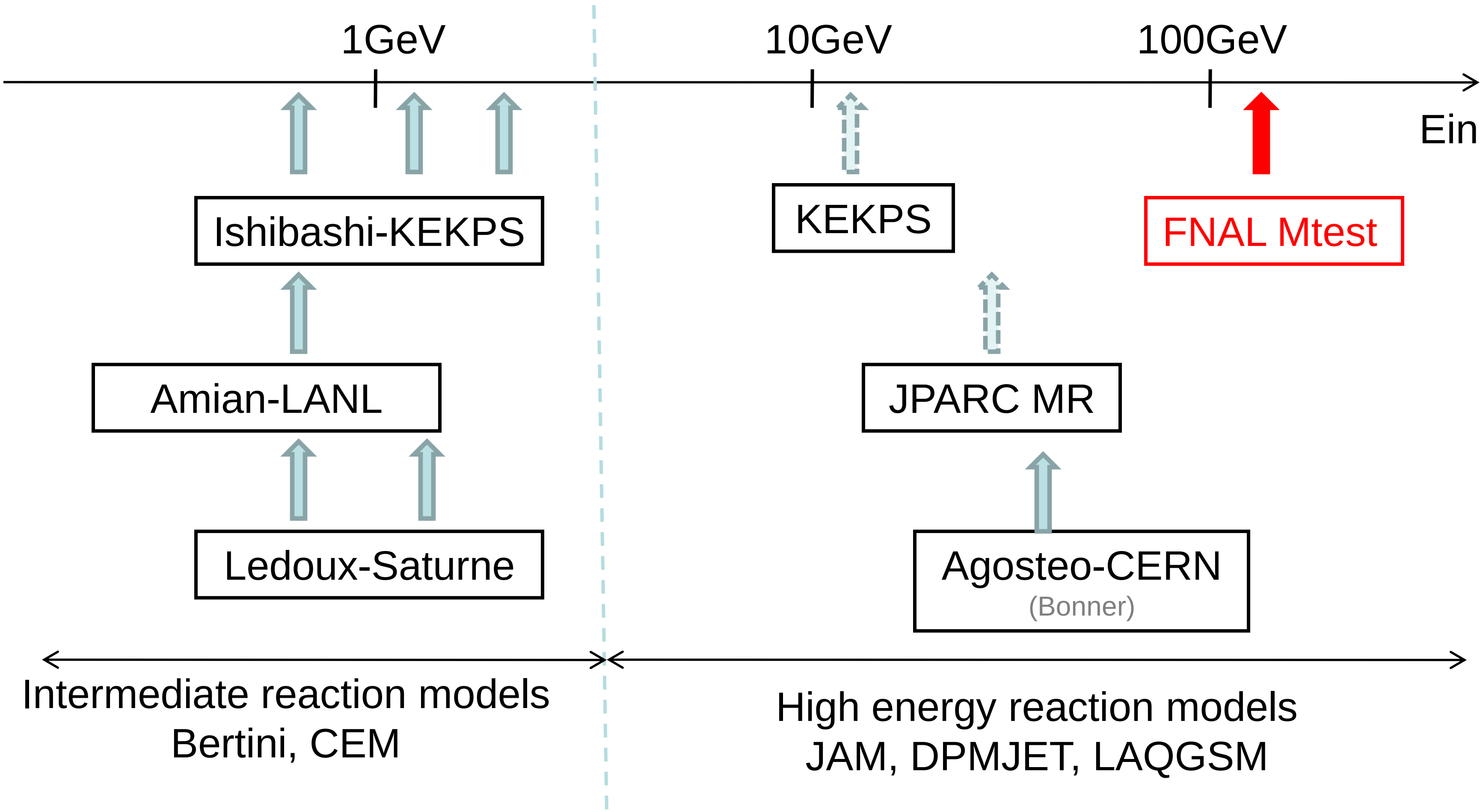
Toroidal beam monitor ~4 × 10^{12} proton/pulse

Integrate pulse data

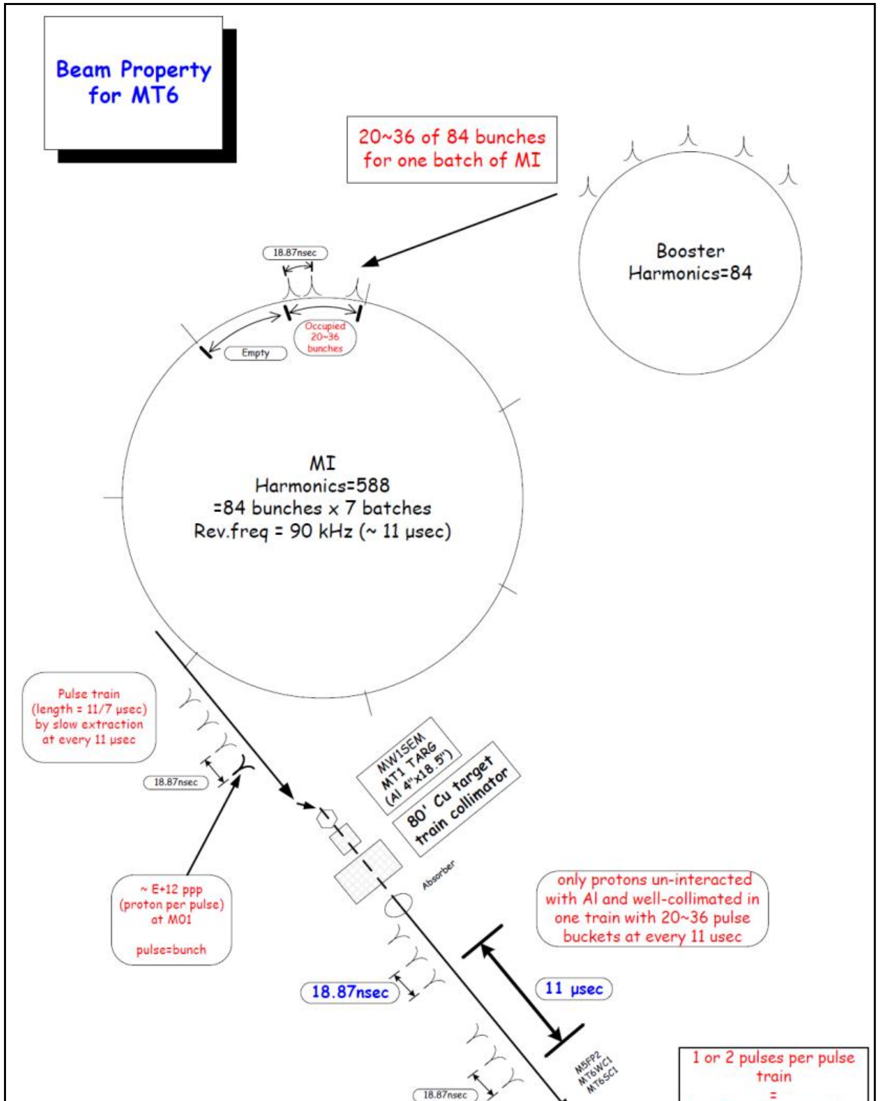
Dark current ~5pA

High energy DDX

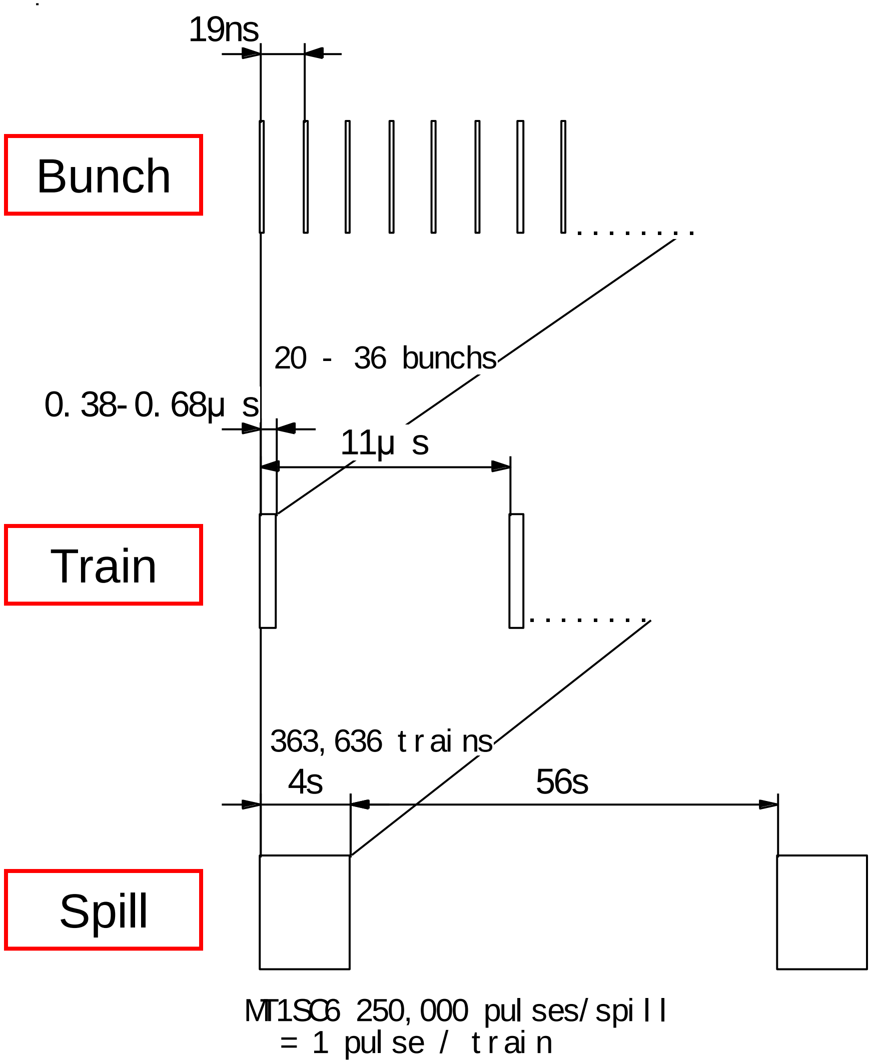
Status of double differential cross section (DDX) data for high energy nucleon



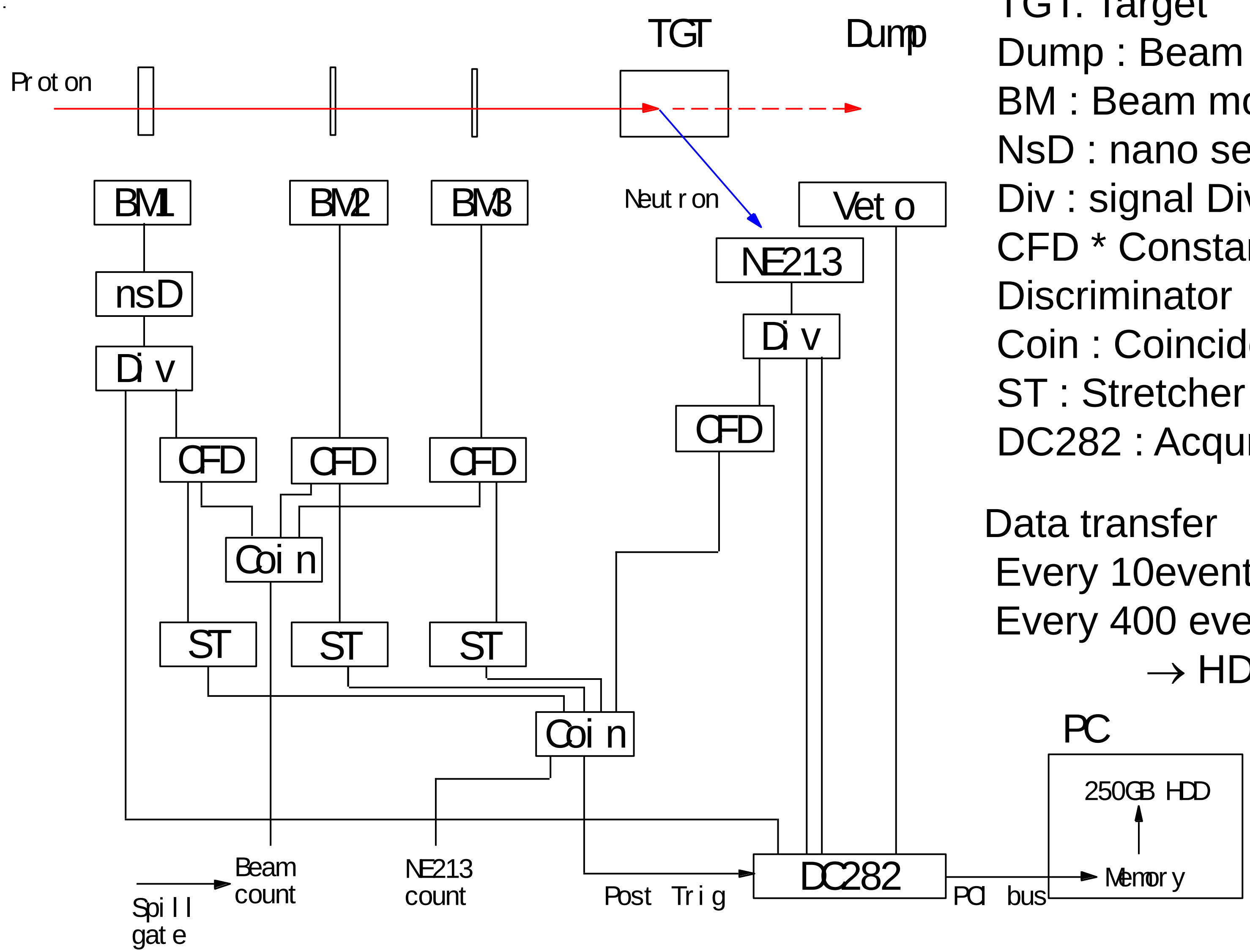
Time structure of proton beam at MT2



By H.S.Lee



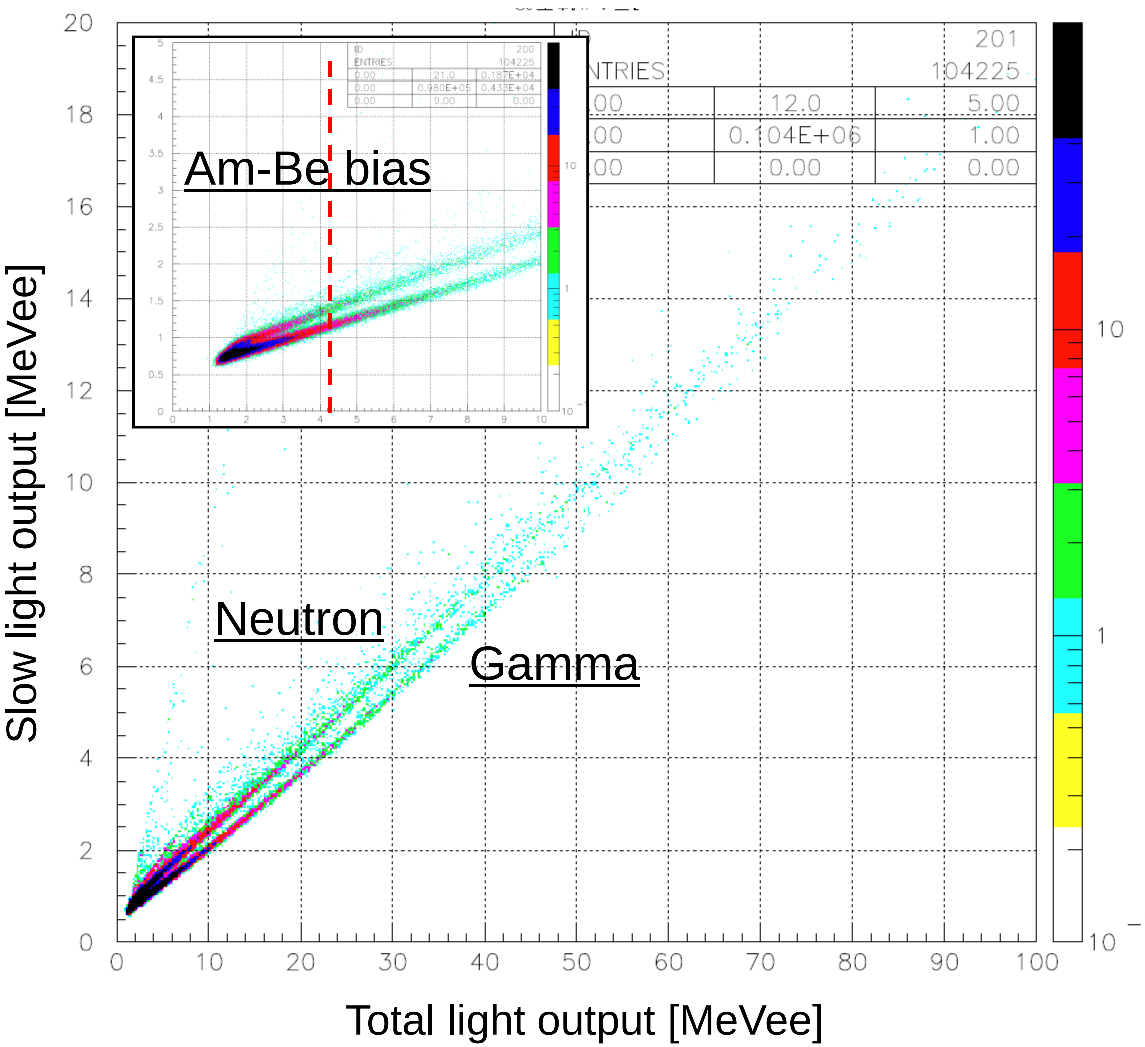
Electronics for waveform data taking



TGT: Target
Dump : Beam dump
BM : Beam monitor
NsD : nano second Delay
Div : signal Divider
CFD * Constant Fraction Discriminator
Coin : Coincidence
ST : Stretcher
DC282 : Acquris Digitizer

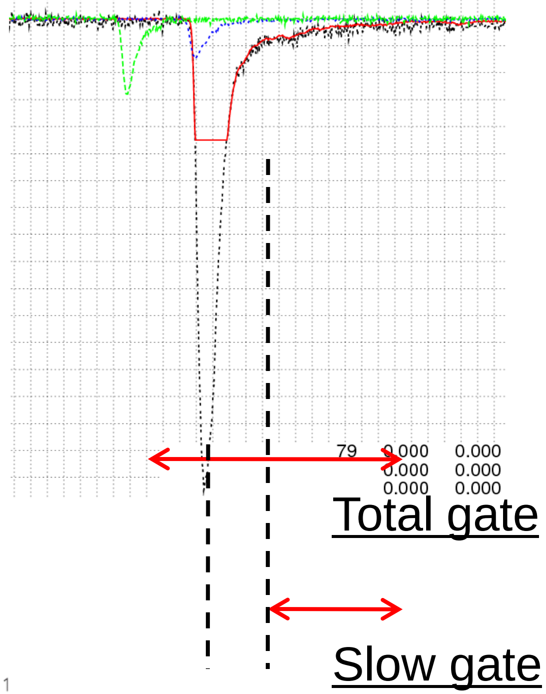
Data transfer
Every 10event → Memory
Every 400 event (=1 spill) → HDD

Neutron gamma separation

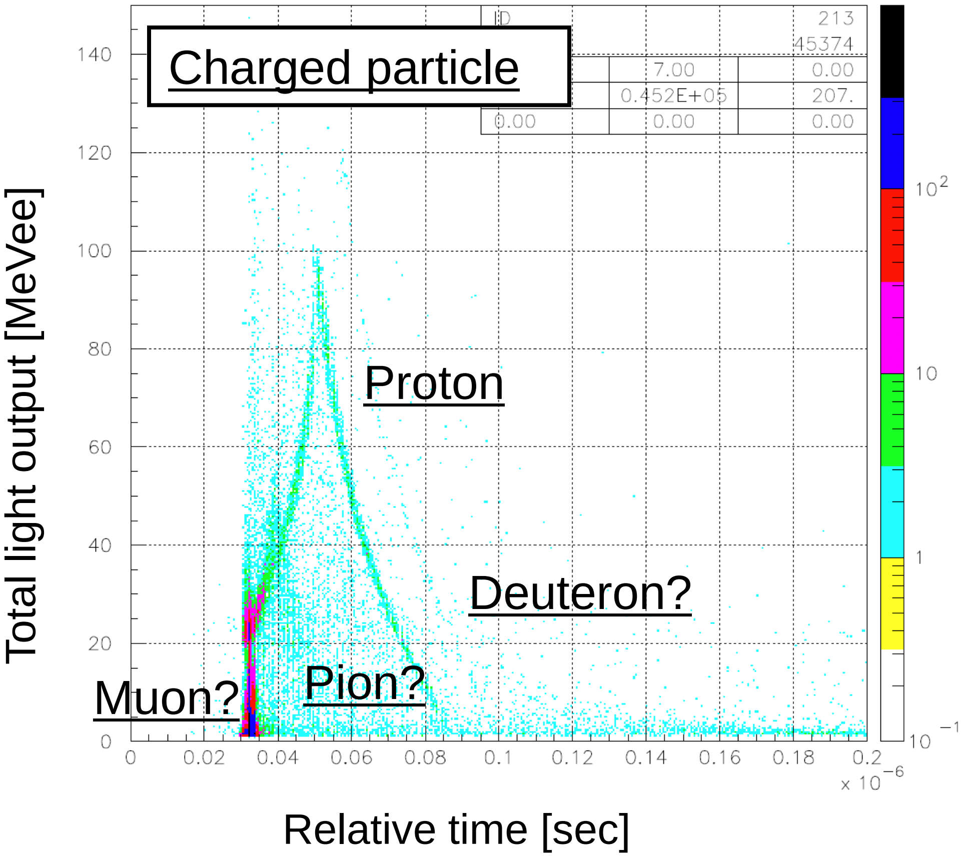


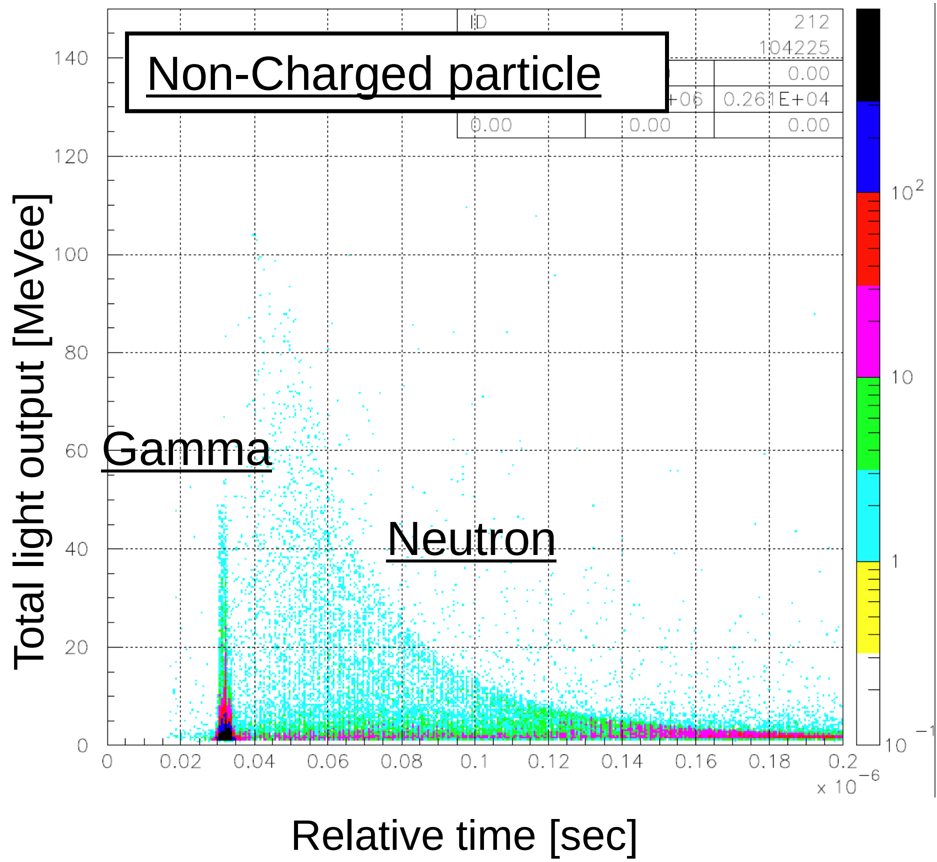
Conventional two gate method

Separate down to 2MeVee



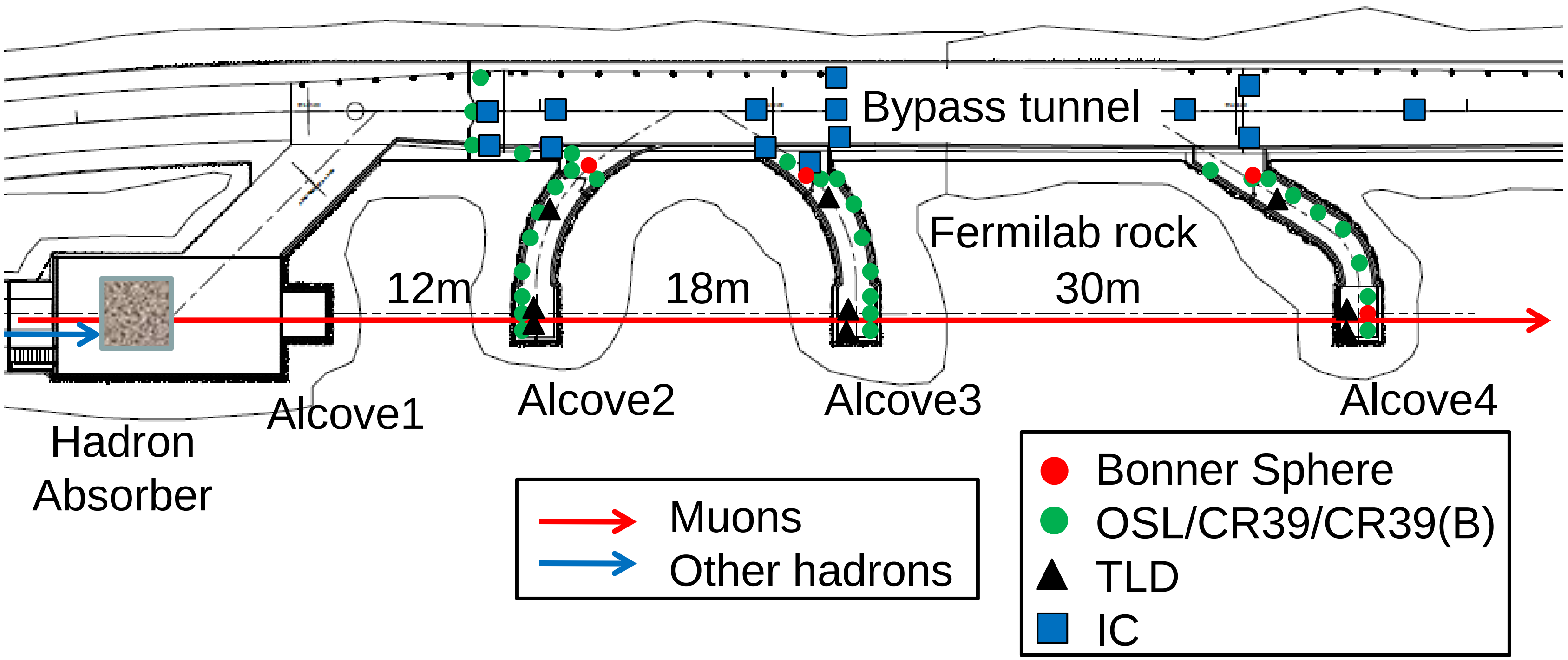
TOF vs PH for charged and non-charged





Dosimeters in NuMI Alcoves and Bypass tunnel

- Muons from 120 GeV, 260 kW proton beam
  - 800 m long decay volume, Thick hadron absorber
  - Up to 60 m thick rock

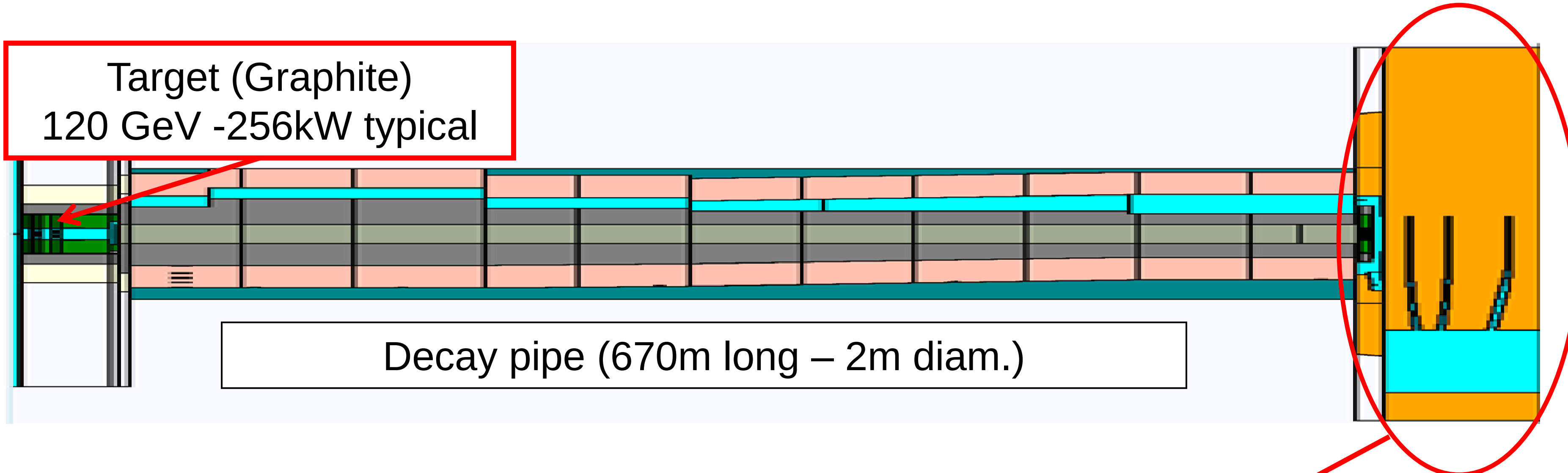


Detectors

- Various detectors, various responses

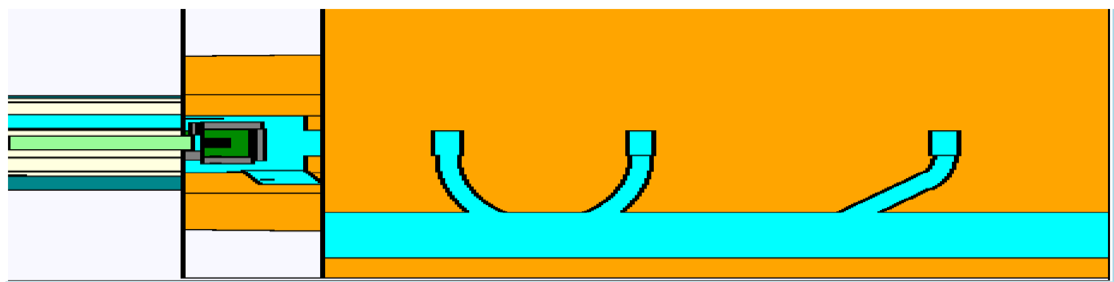
	OSL	CR39	CR39(B)	TLD	TLD(n)	IC
Muon	☺	☻	☻	☺	☻	☺
Photon	☺	☻	☻	☺	☻	☺
Thermal neutron	☻	☻	☺	☻	☺	☻
Fast Neutron	☻	☺	☻	☻	☻	☻
HighE neutron	☻	☻	☻	☻	☻	☻

Monte Carlo simulation



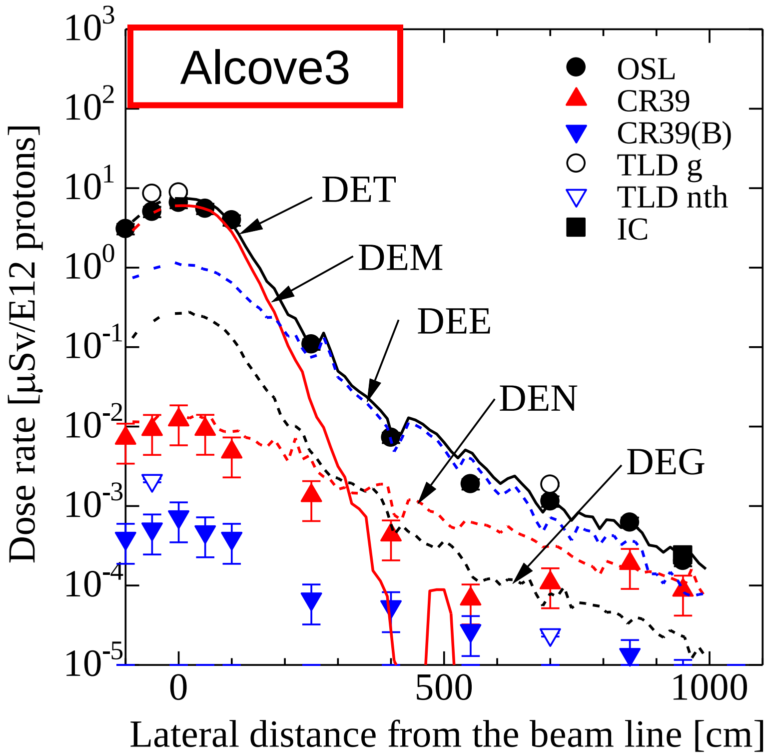
Written by FNAL stuff
MARS15 reg1 geometry

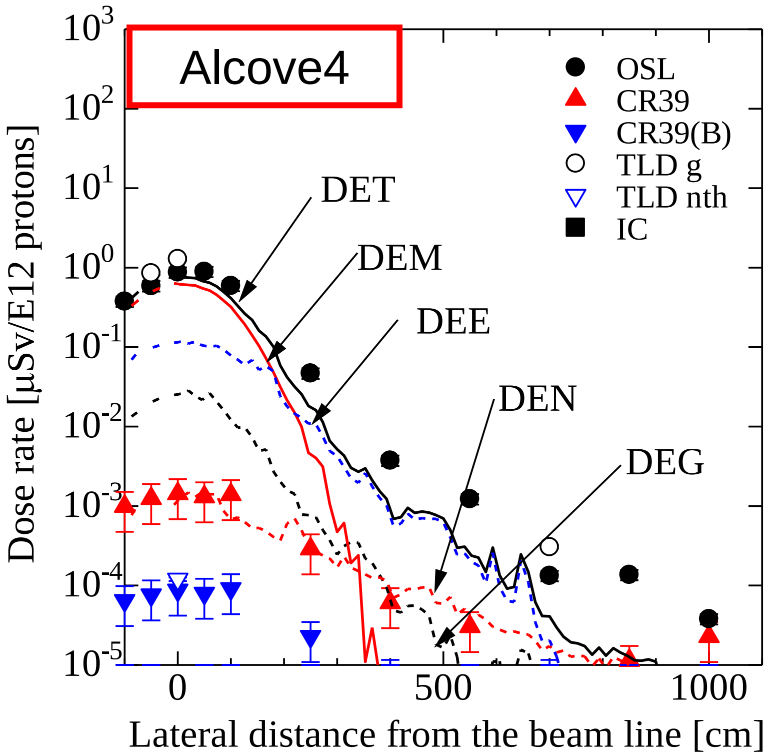
Points modified
Adjust m1507 format
Add bypass tunnel
Add Alcove 2,3,4 tunnels



Absorber hall and muon alcoves

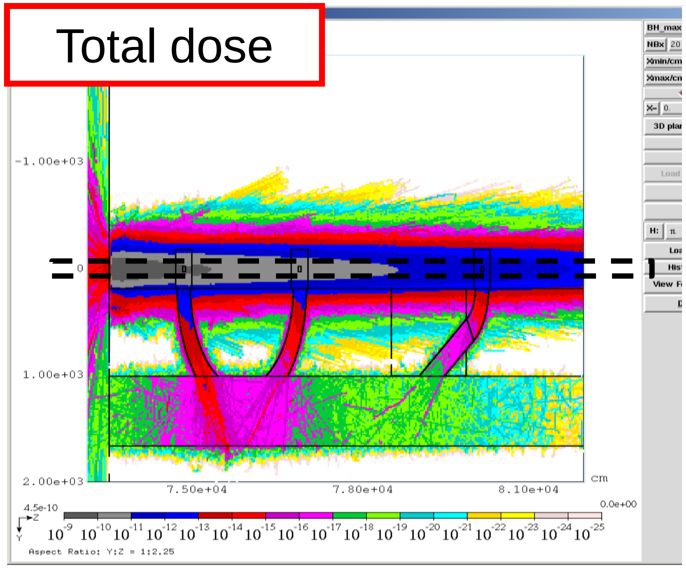
Dose distribution perpendicular to beam axis





- Dose from muon is dominant around the beam line
- Dose from electron, photon and neutron are 28%, 3% and 0.1% of total
- Dose at more than 5 m from the center is from electron, neutron and photon
- The calculation well describes experimental data

Attenuation along the beam axis

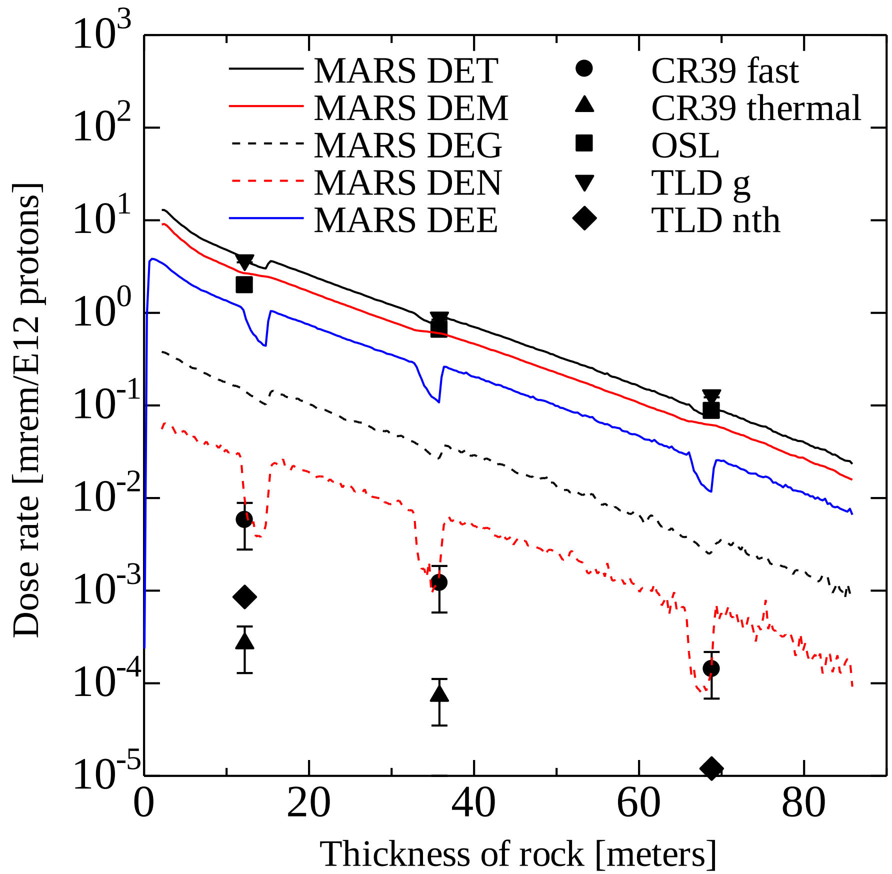


Secondary particles (e, γ,n) are generated in the rock

$\rightarrow$ Muon beam initiate electro-magnetic cascade

Ratio to total dose are

μ:e:γ:n = 0.68:0.28:0.03:0.01



MARS15 simulates muon attenuation very well