Hadron Production Measurement Project with Hybrid Emulsion Detector

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October 4, 2016

Workshop on Hadron production Measurements with Nuclear Emulsions

Nagoya University

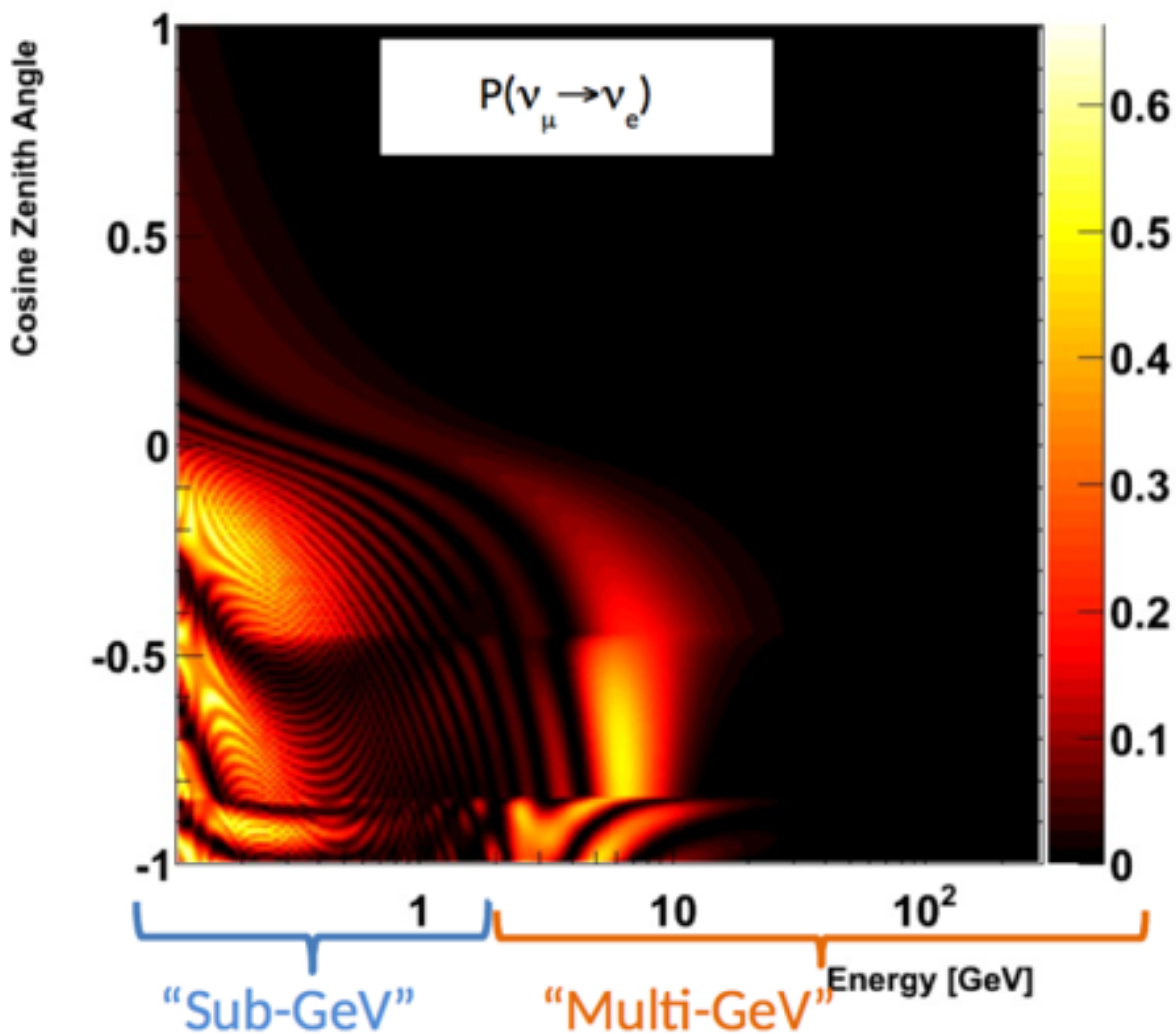
CP Violation Search

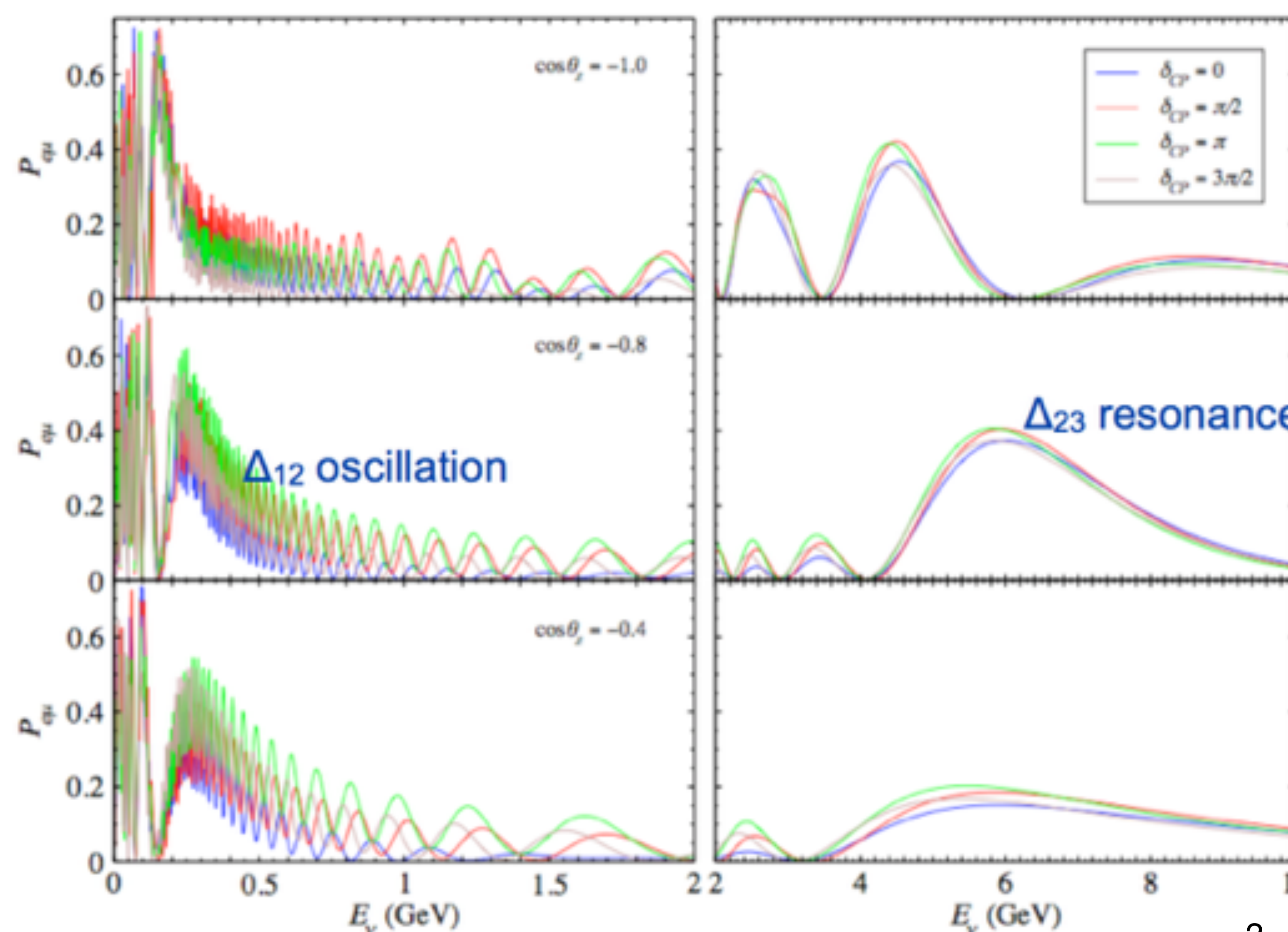
- CP violation search is one of the most important programs in neutrino physics for next few decades.
  - Ongoing experiments: T2K, SK, NOvA, IceCube, …
  - Future experiments: T2K-II (~3σ, 2020~), HK, DUNE (>5σ, 2026~)
    - Need to wait for 10years?
  - Can we improve sensitivity of the current experiments significantly?

Atmospheric $\nu_\mu \rightarrow \nu_e$ Measurement

- Several GeV region : large resonance due to Earth matter effect.
  - Sensitive to Mass Hierarchy
- Sub-GeV region : Δ12 oscillation
  - Sensitive to CP phase: ~5% effect → precise measurement is needed!

More on R. Wendell's talk



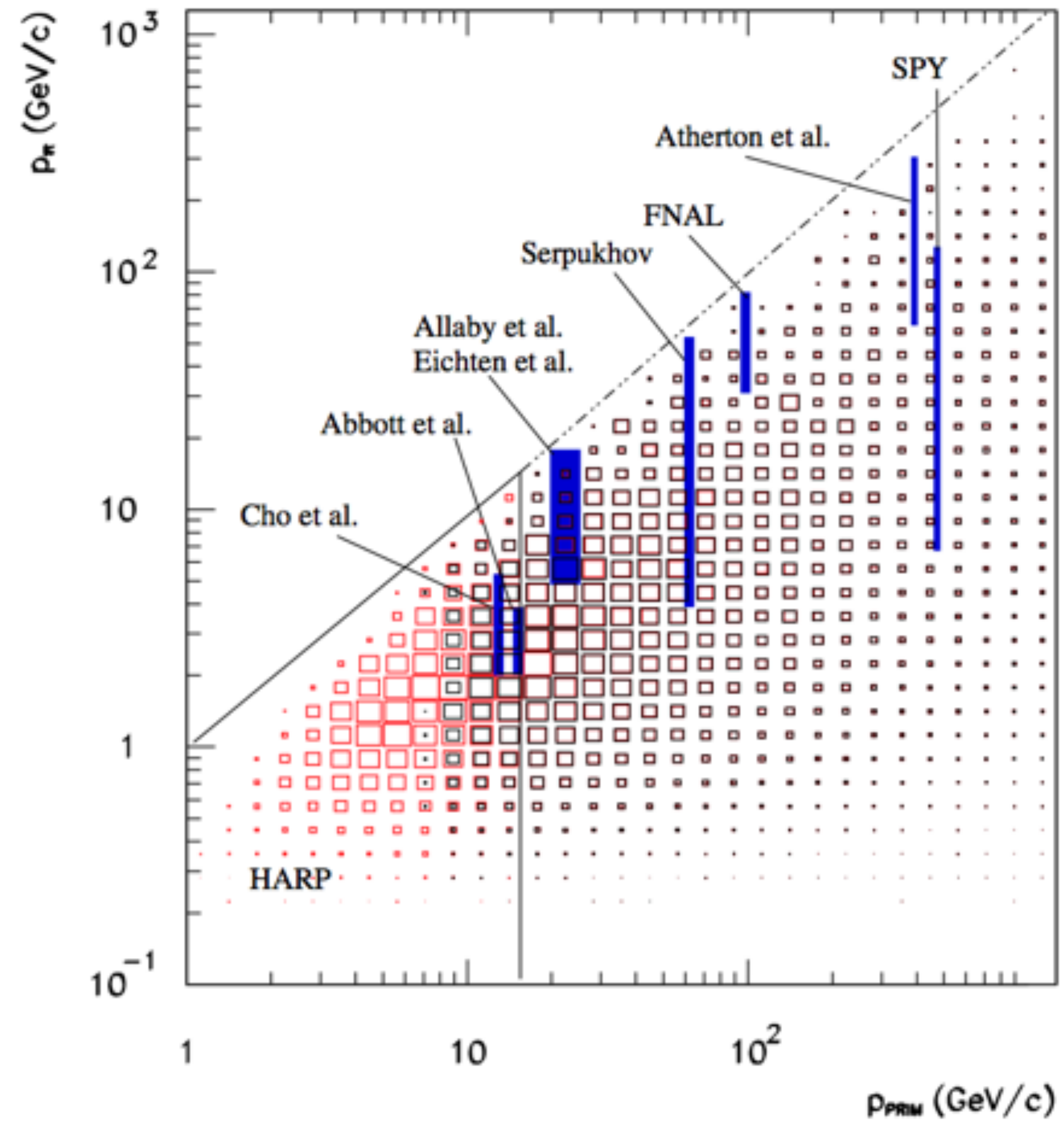


Atmospheric Neutrino Flux

- Calculation of the atmospheric flux requires modeling hadron production with incident particles as low as ~2 GeV energy
  - Neutrinos with energy < 1 GeV can contribute to the constraint on δ_{CP}
- Low energy range is currently covered by HARP data
  - More on systematic error

G.D. Barr et al.

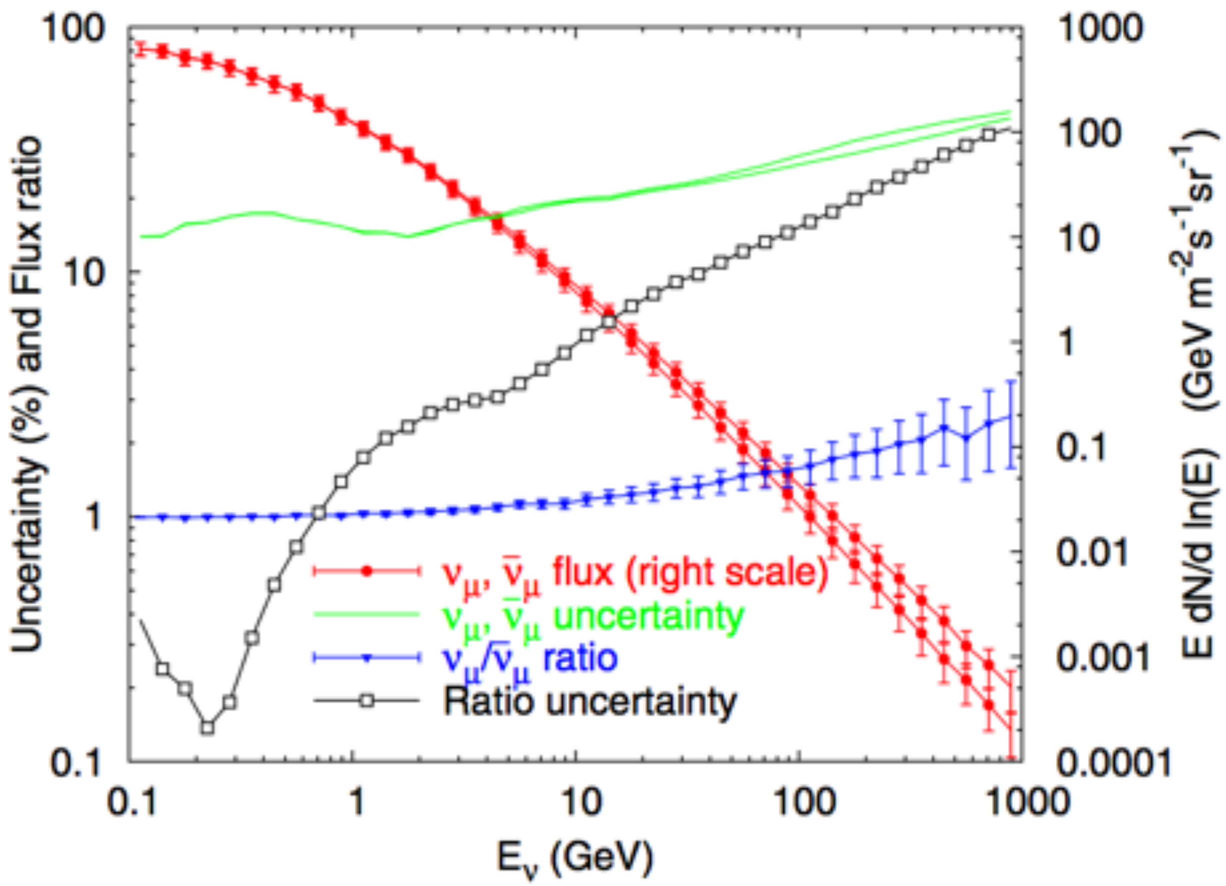
PHYSICAL REVIEW D 74, 094009 (2006)

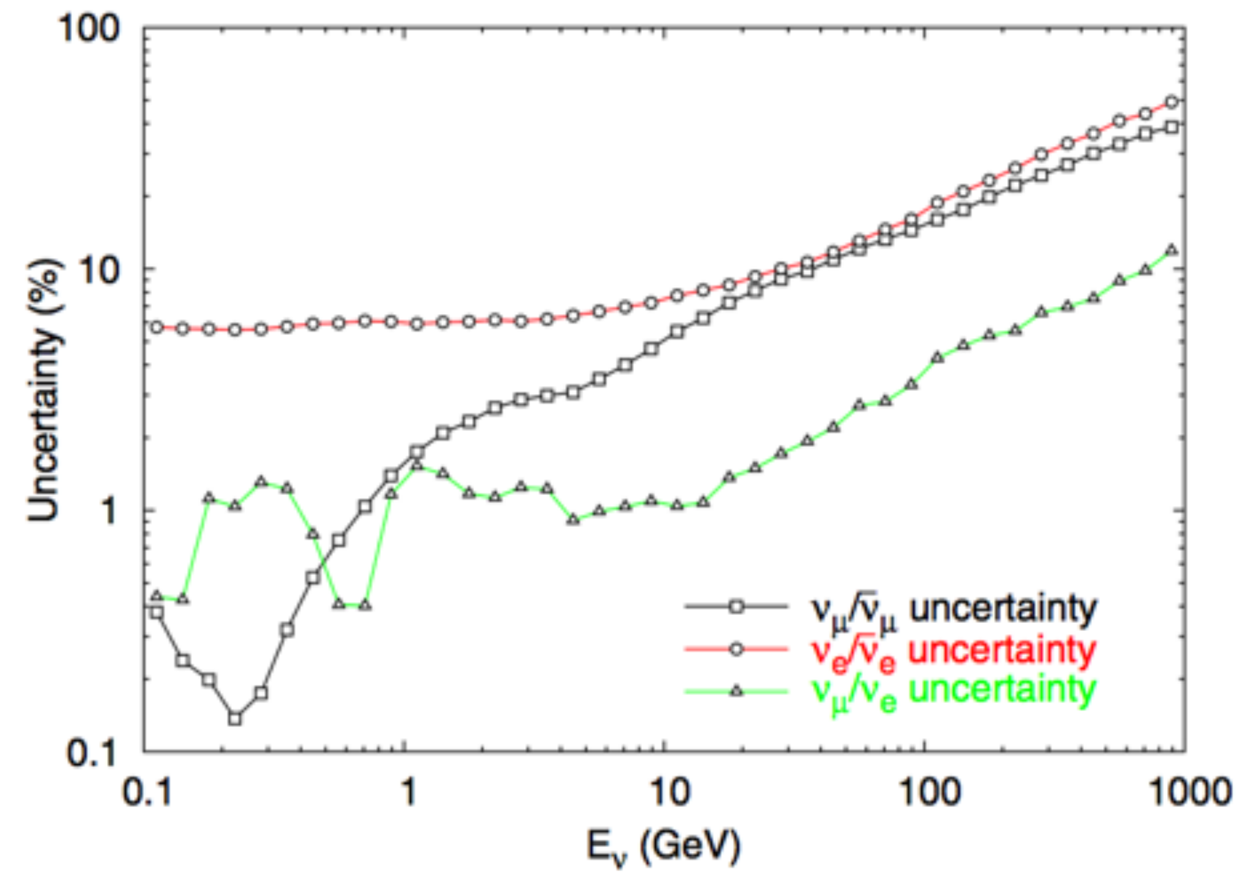


Boxes = Atmospheric neutrino contribution

Atmospheric Neutrino Flux Uncertainties

G.D. Barr et al., PRD 74, 094009 (2006)

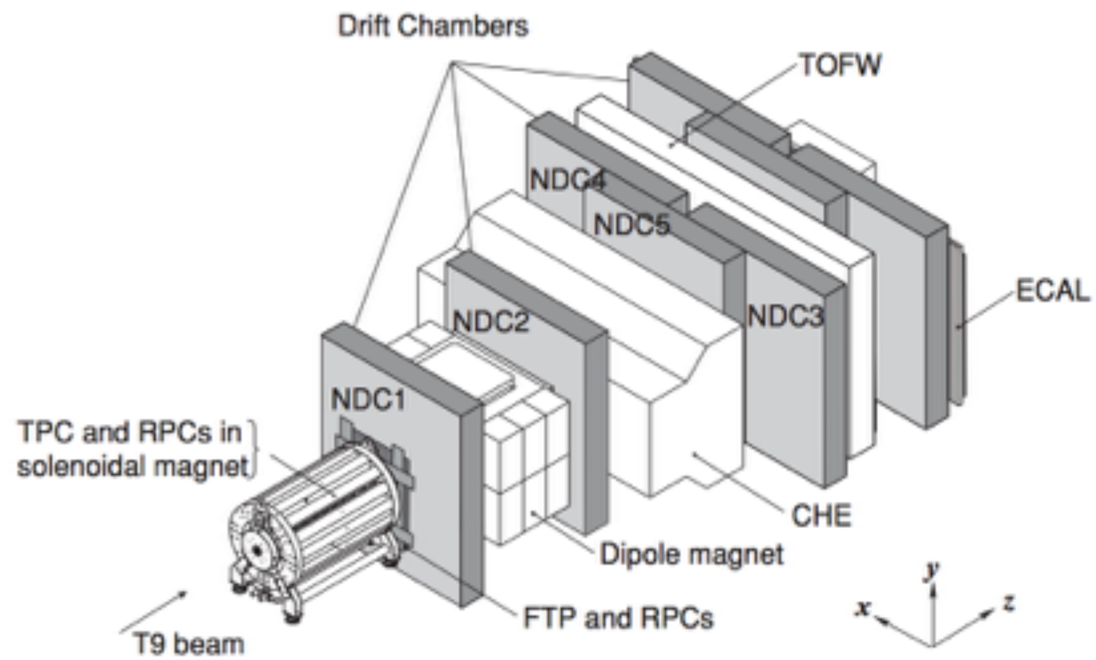




- Absolute flux uncertainties are ~15%
- Errors on ratios are reduced to <1%, however ν_e/ν_e-bar is ~6% since there is no cancellation of systematics by neutrinos from π, μ decay chain
  - Can benefit from measuring π^+/π^- ratio

More on Honda-san and Okumura-san's talks

HARP Data Limitations



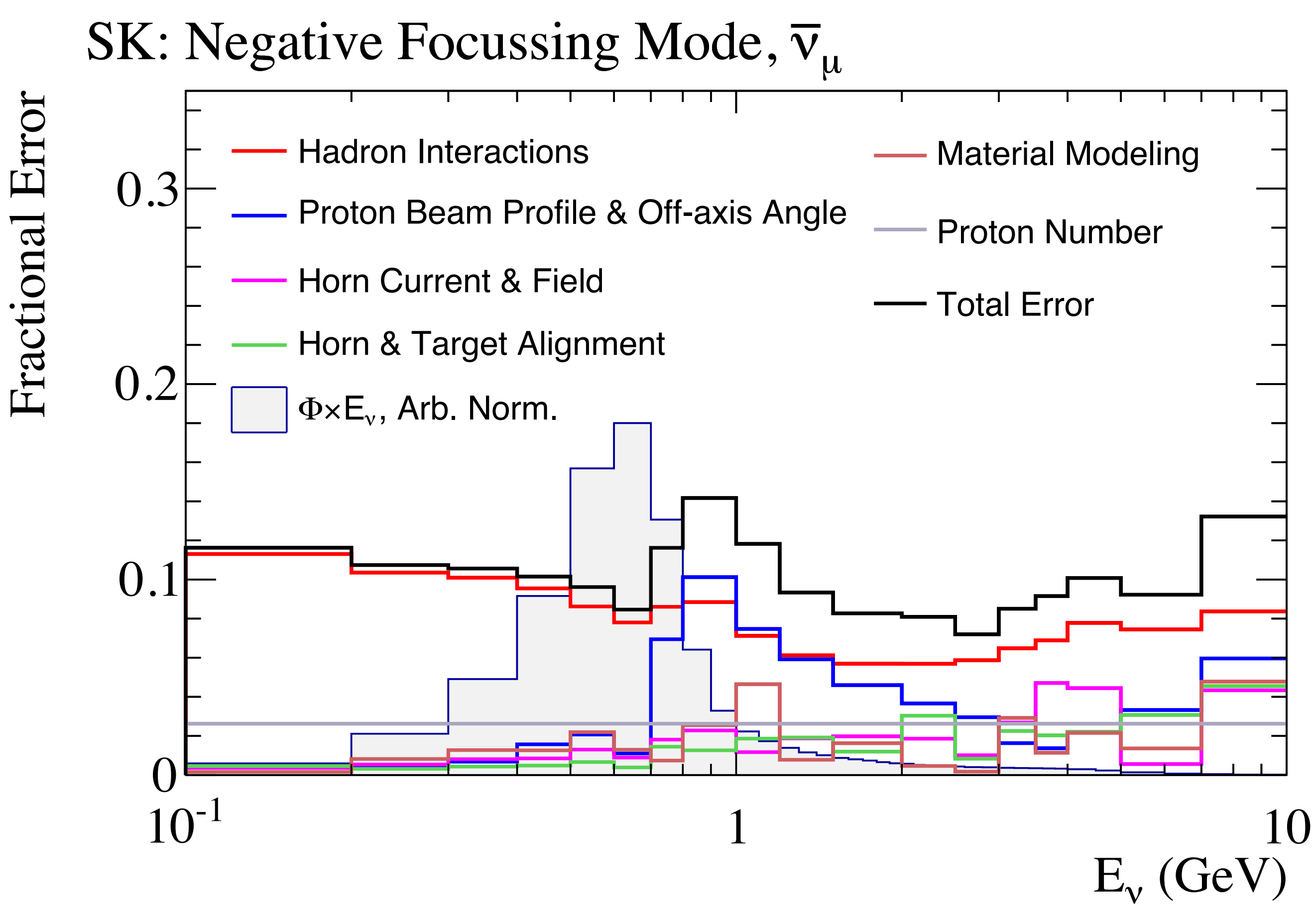
- The dominant systematic uncertainties in HARP are related to re-interactions in the TPC field cage
    - New measurements should minimize material between tracking medium and target
- Limited forward acceptance : no data for θ<0.025 rad
    - Forward acceptance can allow for measurement of quasi-elastic cross section

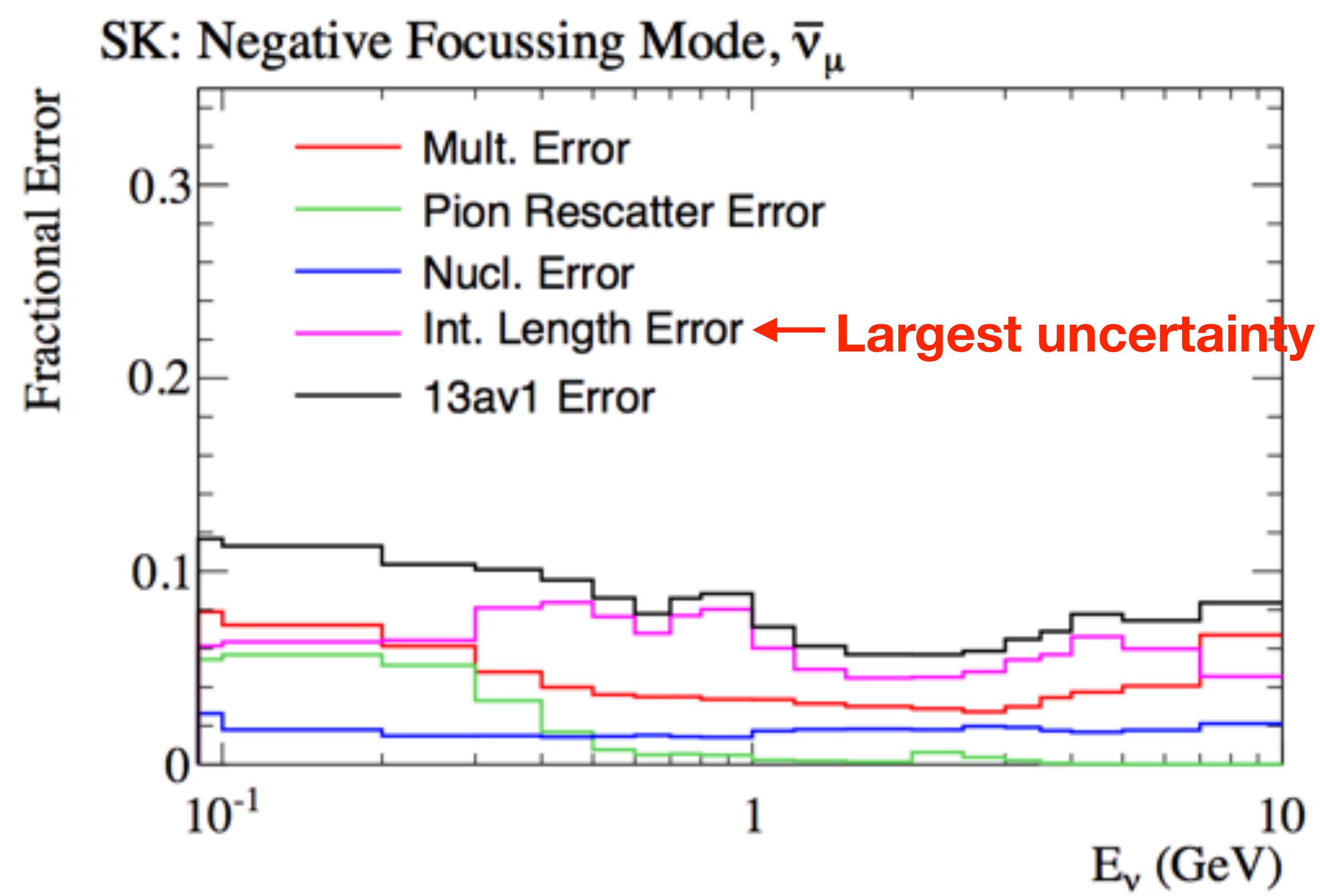
PHYSICAL REVIEW C **80**, 035208 (2009)

TABLE II. Summary of the systematic uncertainties affecting the computed π^+ double-differential cross sections and the integrated cross-section measurements for p-C interactions at 12 GeV/c. Entries are weighted bin by bin with the pion production yields.

Error category	$\delta^{\pi}_{\mathrm{diff}}$ (%)	$\delta^{\pi}_{\mathrm{int}}$ (%)
Track yield corrections:		
Reconstruction efficiency	1.1	0.5
Pion, proton absorption	3.7	3.2
Tertiary subtraction	8.6	3.7
Empty-target subtraction	1.2	1.2
Subtotal	9.5	5.1
Particle Identification:		
Electron veto	<0.1	<0.1
Pion, proton ID correction	0.1	0.1
Kaon subtraction	<0.1	<0.1
Subtotal	0.1	0.1
Momentum reconstruction:		
Momentum scale	2.8	0.3
Momentum resolution	0.8	0.3
Subtotal	2.9	0.4
Angle reconstruction:		
Angular scale	1.3	0.5
Total syst.:	10.0	5.1
Overall normalization:	2.0	2.0

Accelerator Neutrino Fluxes



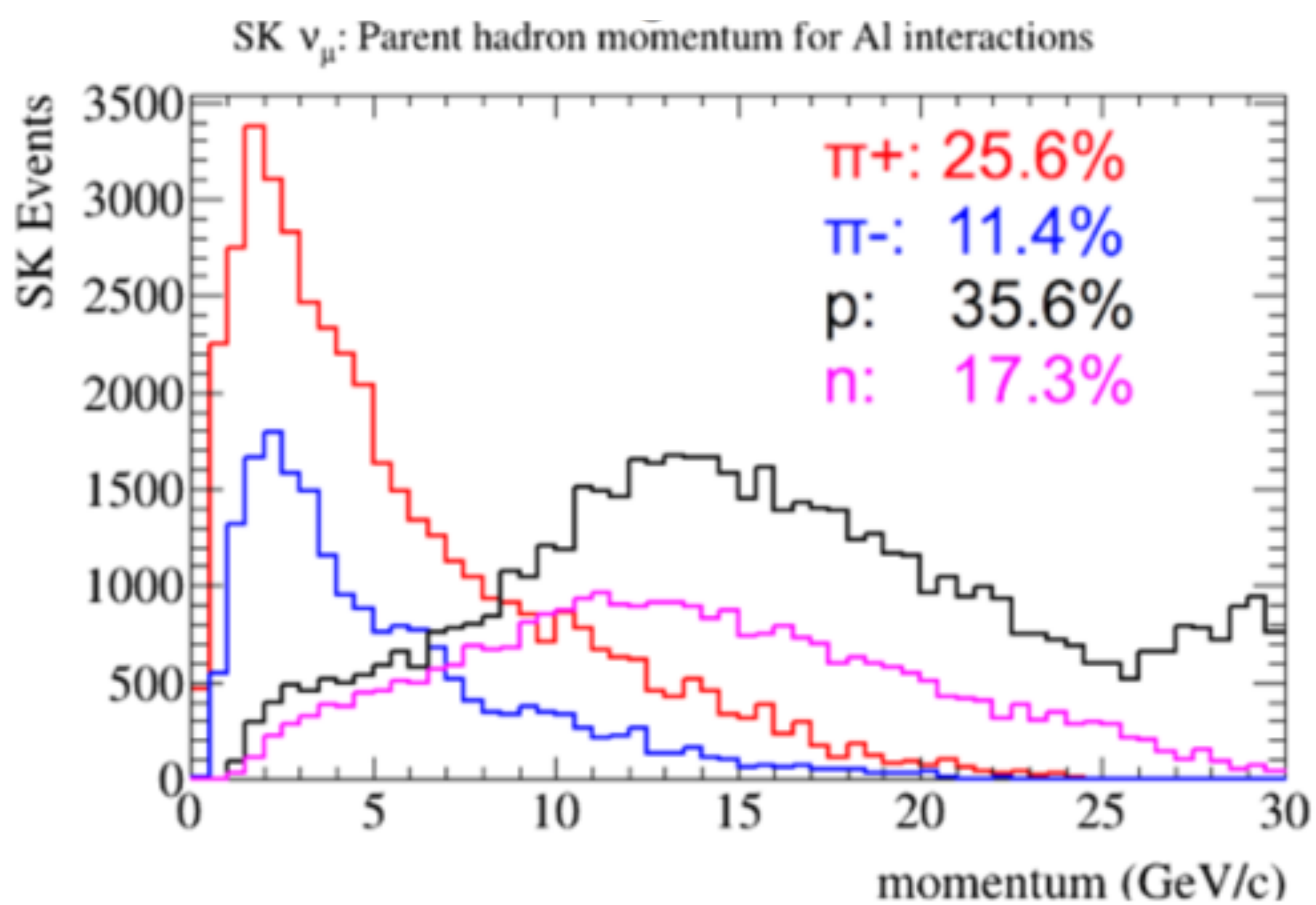


- Absolute flux uncertainty : ~9% around flux peak
- Hadron interaction uncertain is dominant : ~8%
- Hadron interaction length uncertainties largely come from lack of measurements separating the inelastic and quasi-elastic cross sections

→ hadron production measurements in forward region is important

Effect on Accelerator Neutrino Studies

- Precise hadron production measurements can improve ν flux uncertainties.
  - Neutrino flux uncertainty is major component for near detector measurements (for cross-section, etc.)
    - Need to improve uncertainty of cross-section ratio $\sigma(\nu_e)/\sigma(\bar{\nu}_e)$
  - Dominant background for ν_e appearance due to contamination of wrong-sign neutrinos → Need to estimate more precisely.

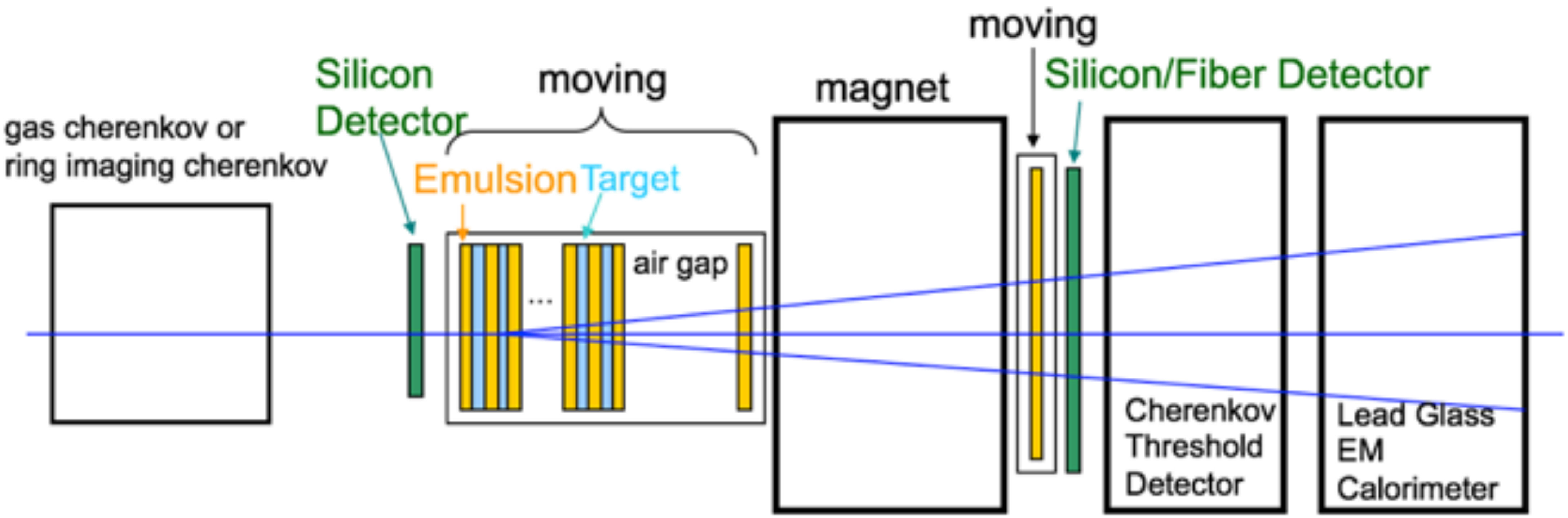


Hadrons interacting in Al to produce wrong-sign flux

New Hadron Production Experiment

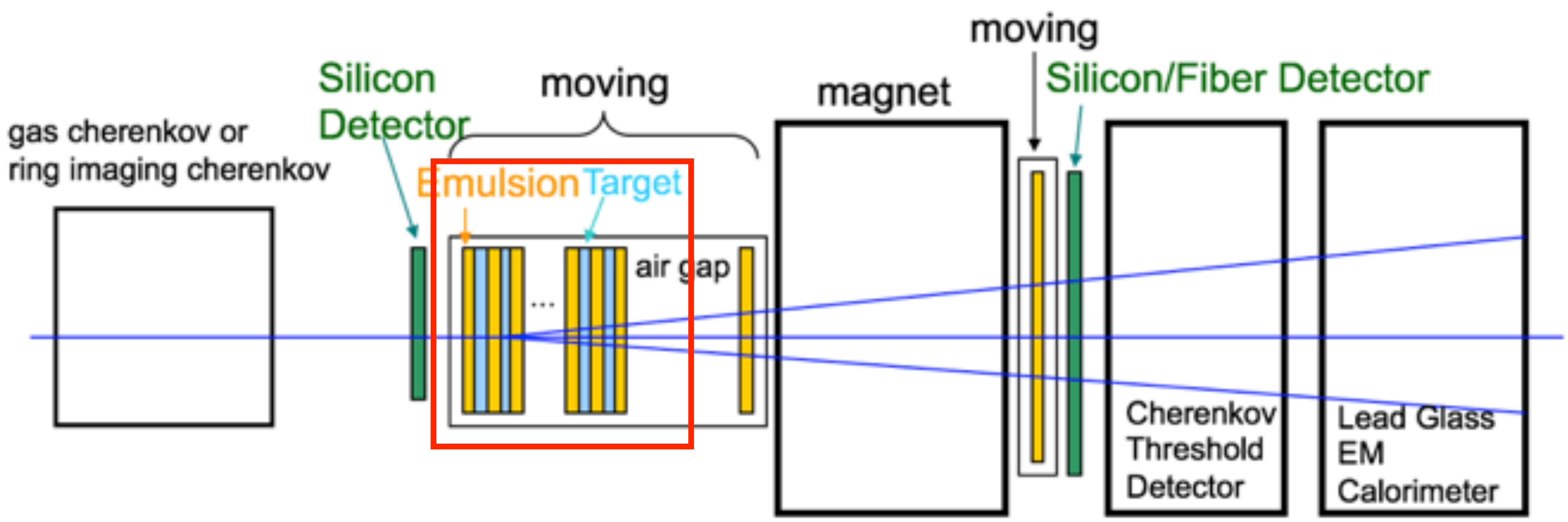
- Goals
  - Make measurements of forward scattering to measure the elastic/quasi-elastic cross sections
  - Minimize material between target and tracking region to avoid largest systematic error in HARP
  - A portable detector that can be easily moved to different beam lines operating at different energies
- Solution
  - A hybrid nuclear emulsion/electronic detector

Schematic Design



- Emulsion/target layers to give very precise interaction vertex/track information
  - Full coverage of the vertex, minimum inactive region
- Emulsion measurements on both sides of a magnetic field region to measure charge and momentum
- Silicon strip detectors give timing information by matching tracks between emulsion and SSD
- Upstream and downstream electron fine-grained detectors to match emulsion tracks to particle ID detectors

Schematic Design



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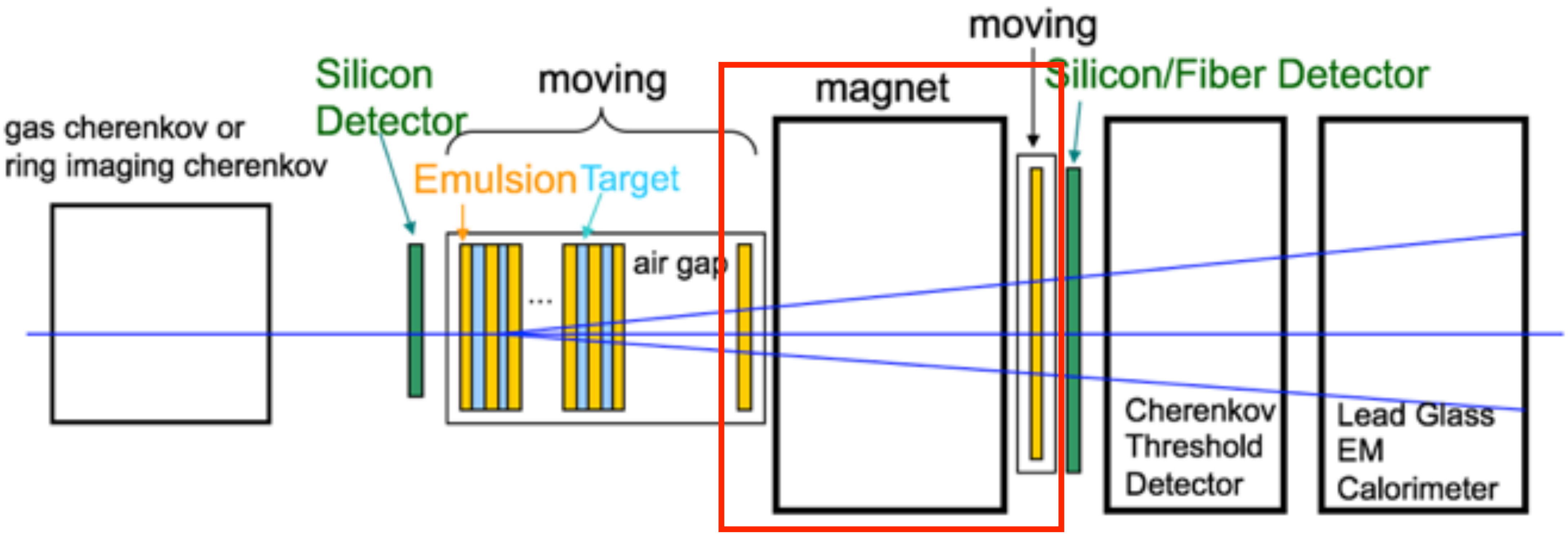

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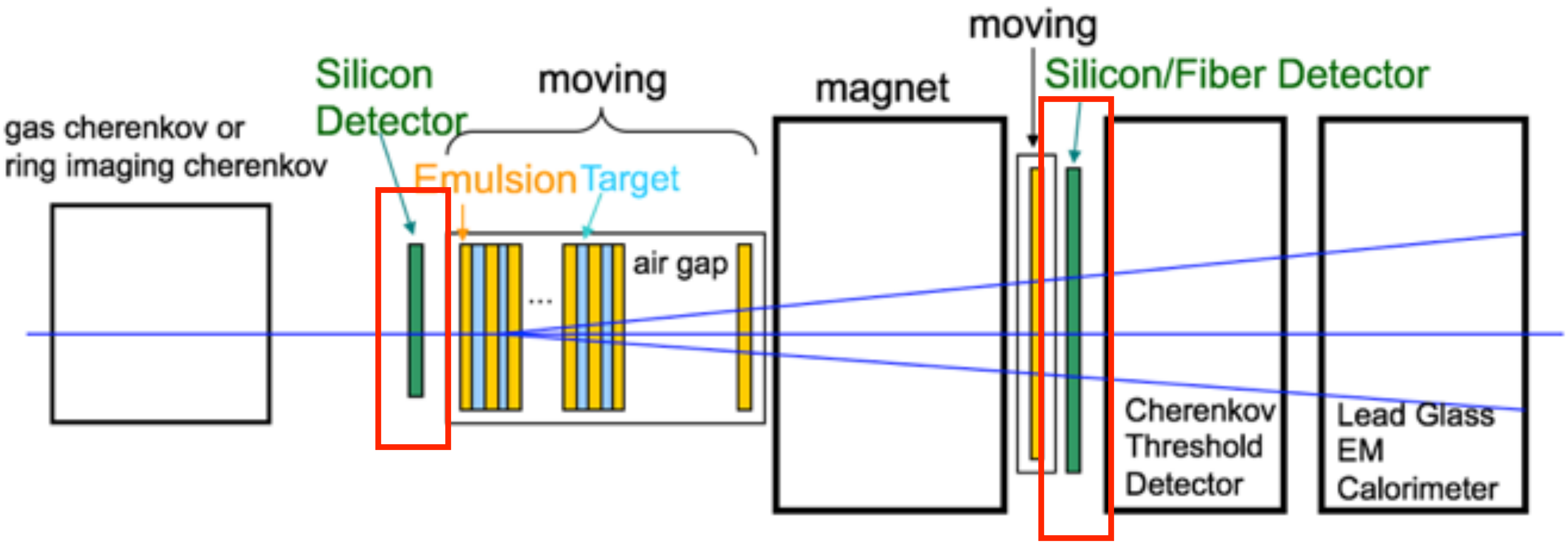

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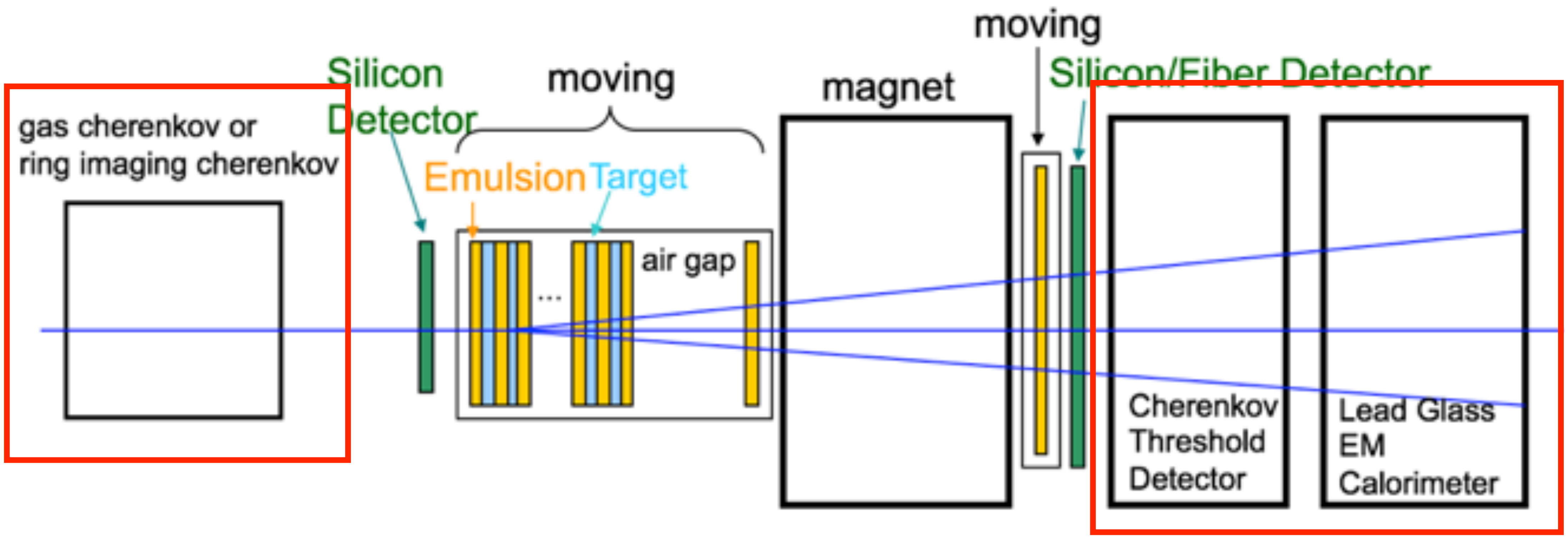

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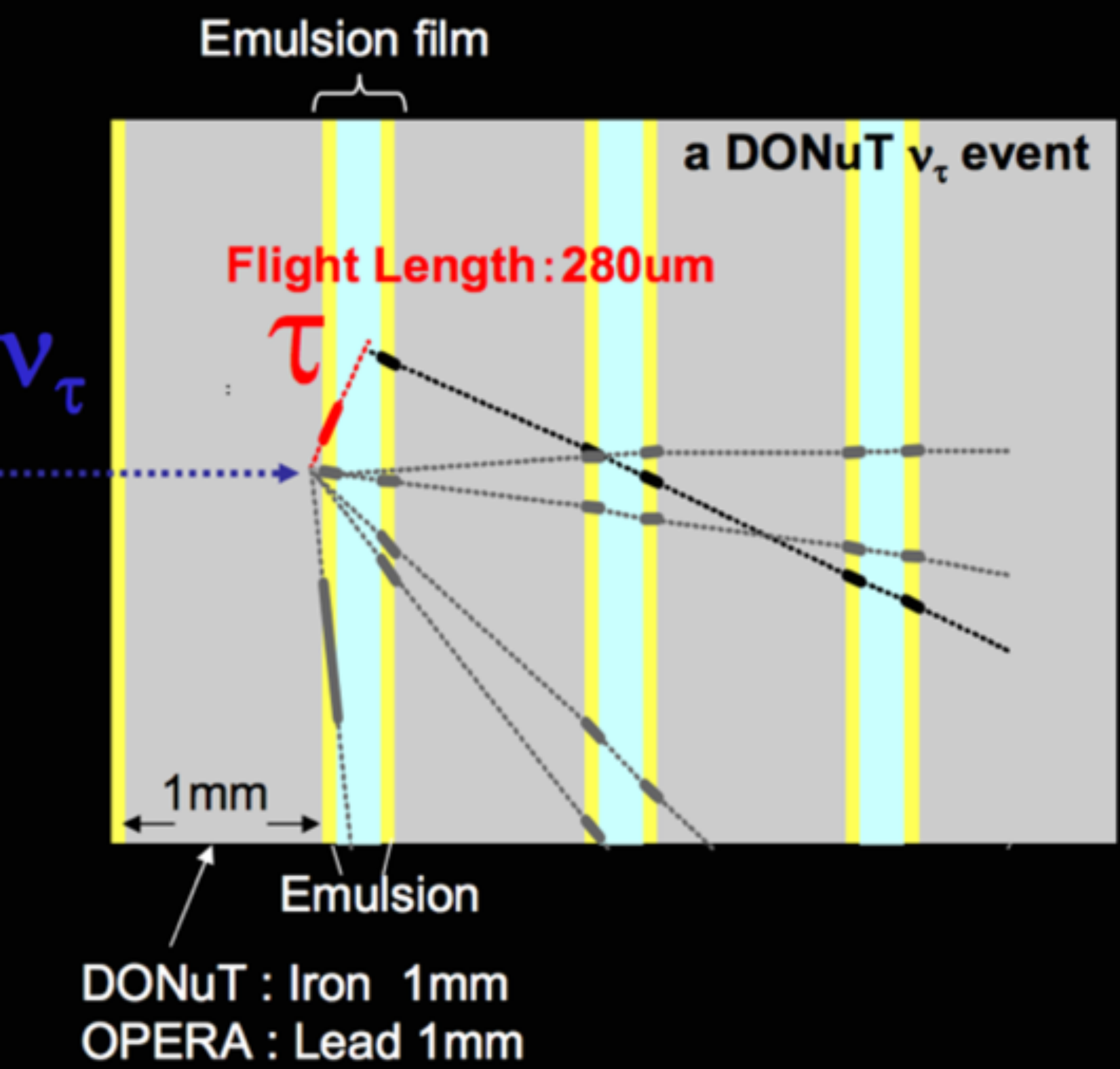
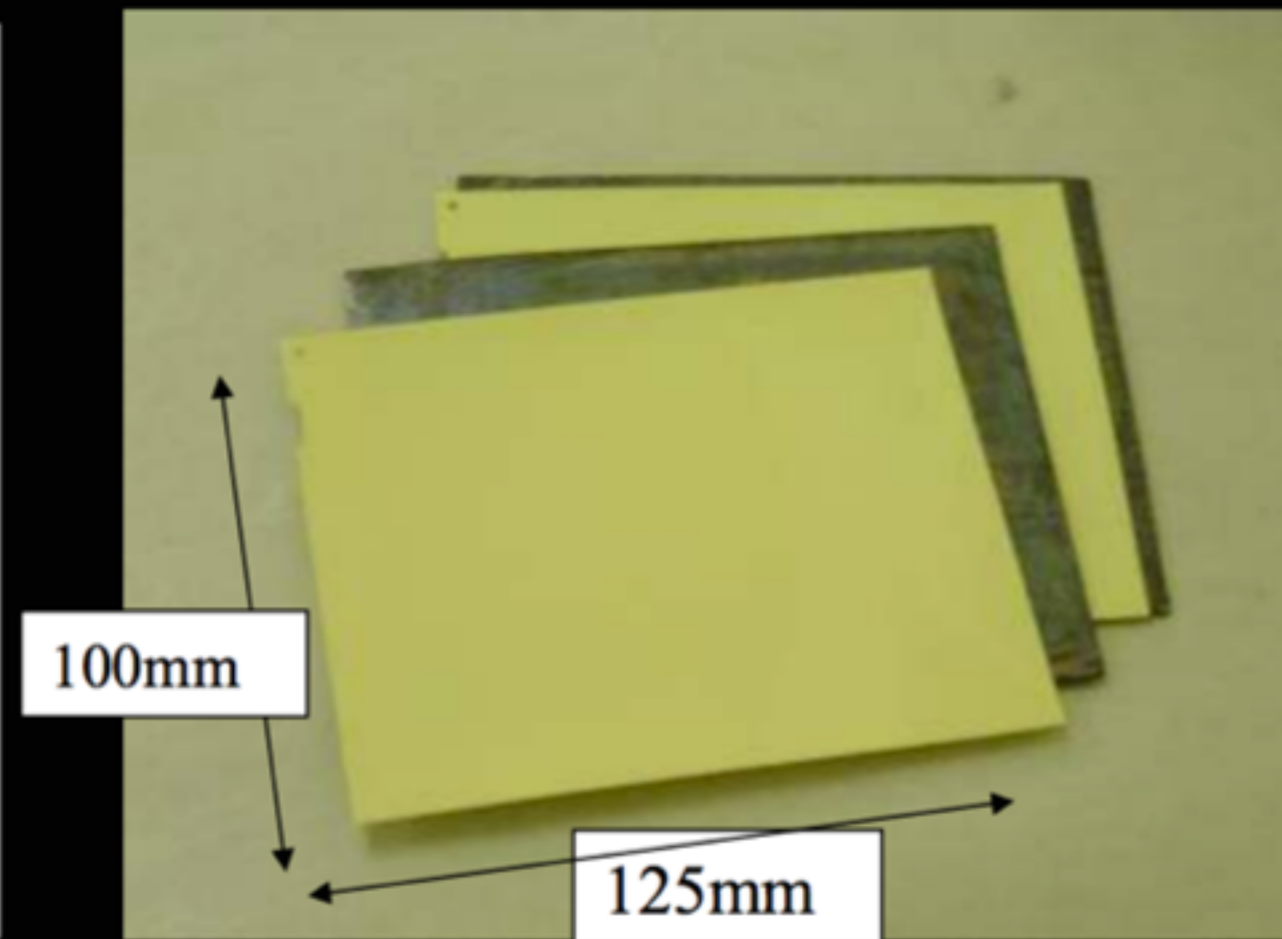
ECC for Target



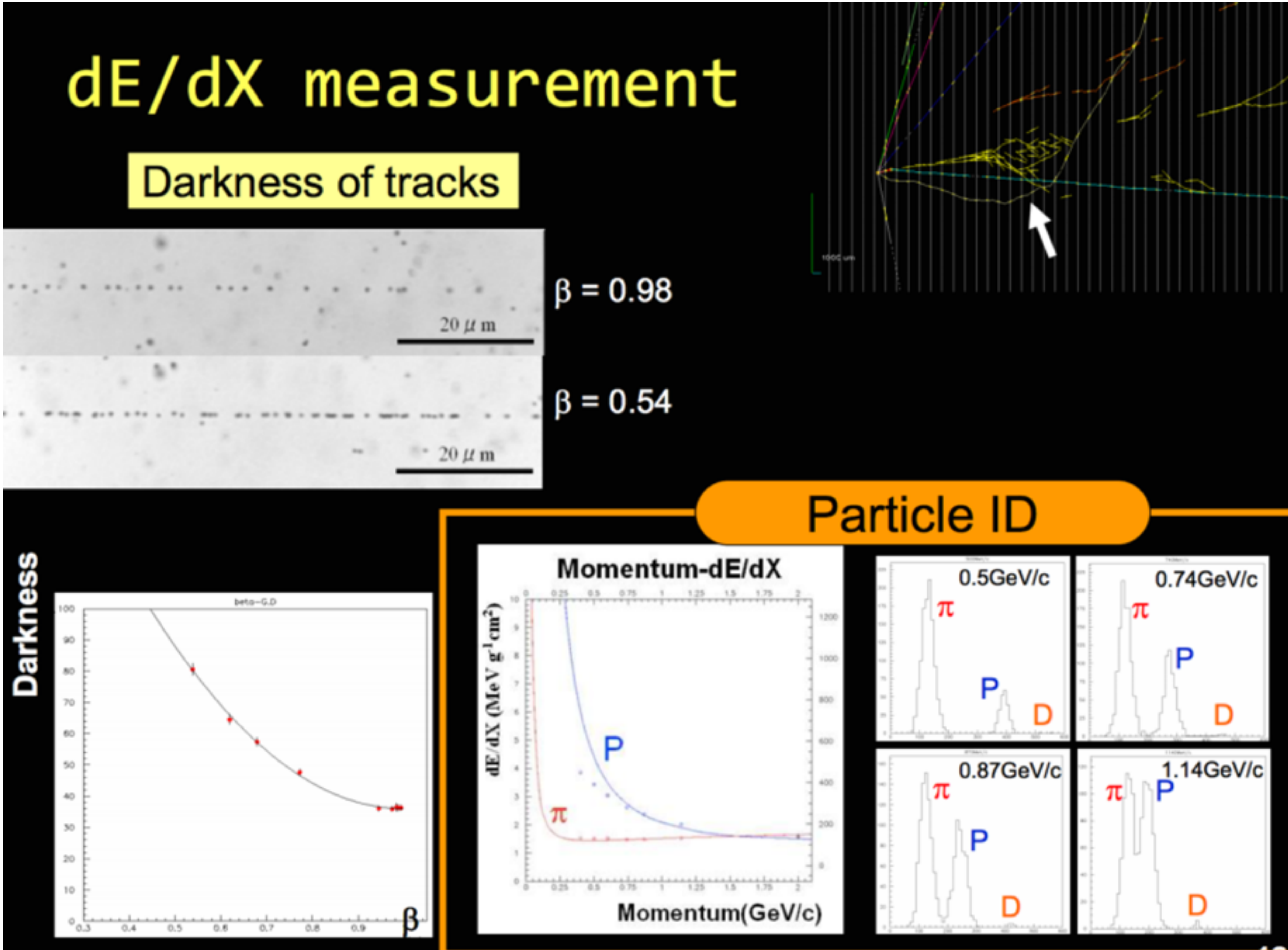


Sandwich structure of emulsion films and metal plates.

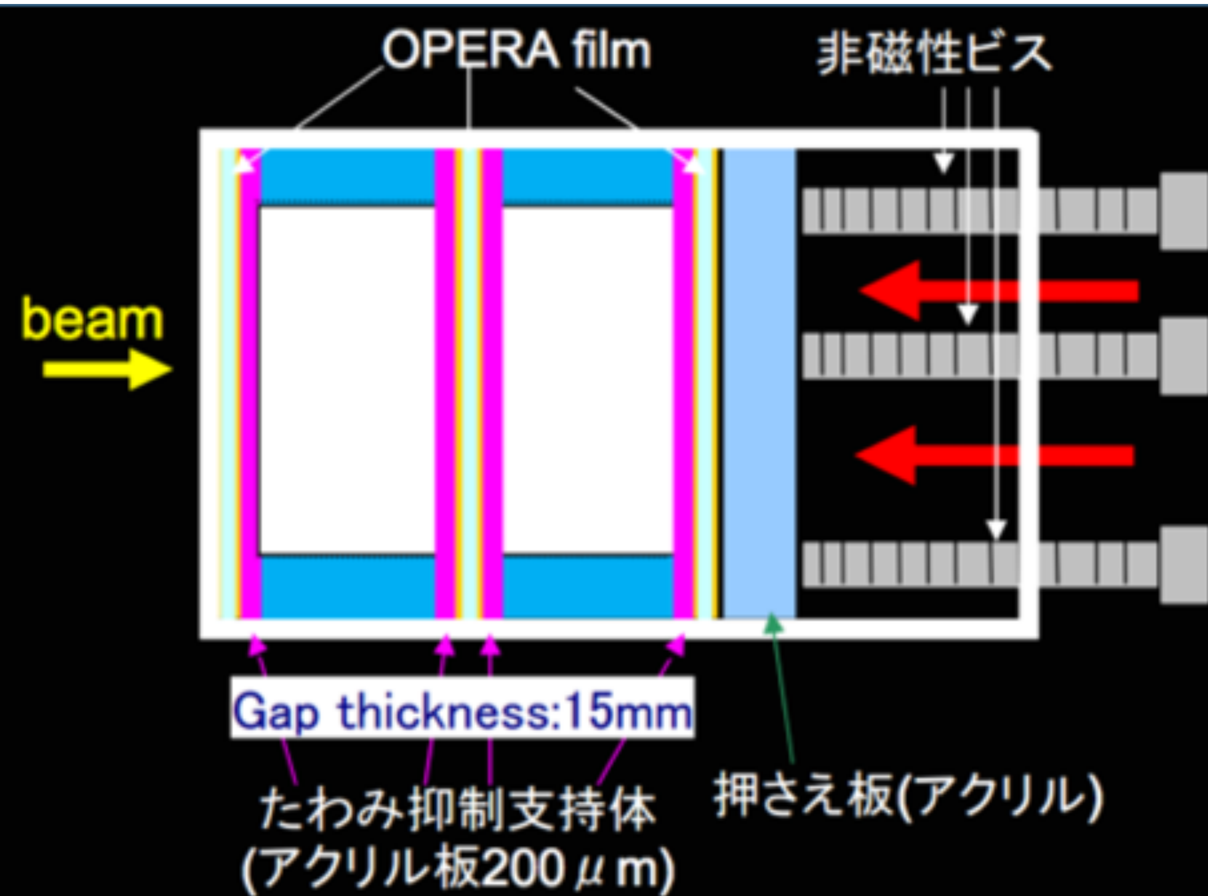
Suitable for Hadron Production Measurements

- Track densities up to 10^5 particles/cm^2 can be reconstructed
  - Interested in sample sizes of ~10^7 for hadron production measurements
  - ~100-1000cm^2
- Many different solid targets can be placed between emulsion layers (Be, C, Al, Fe)
- Track darkness provides particle ID measurements
- Can measure track position and angle very precisely

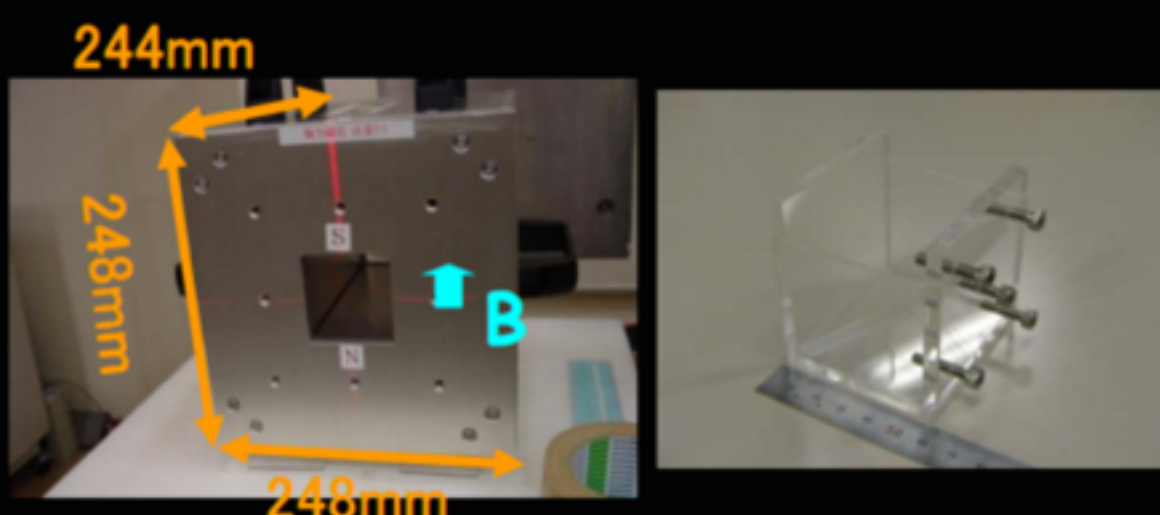
dE/dx Measurement

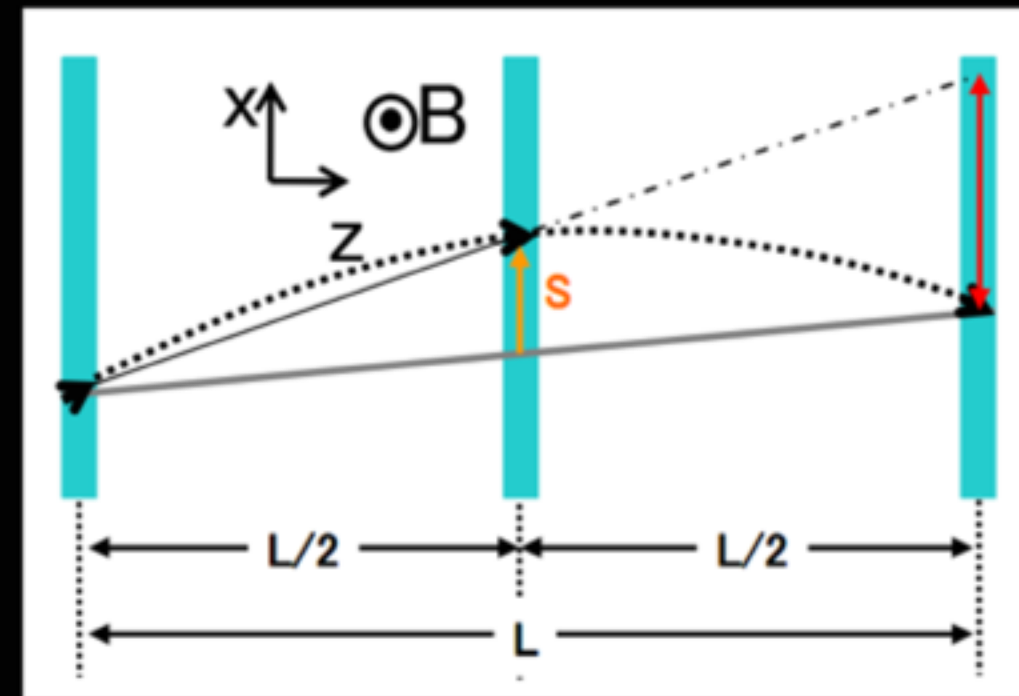


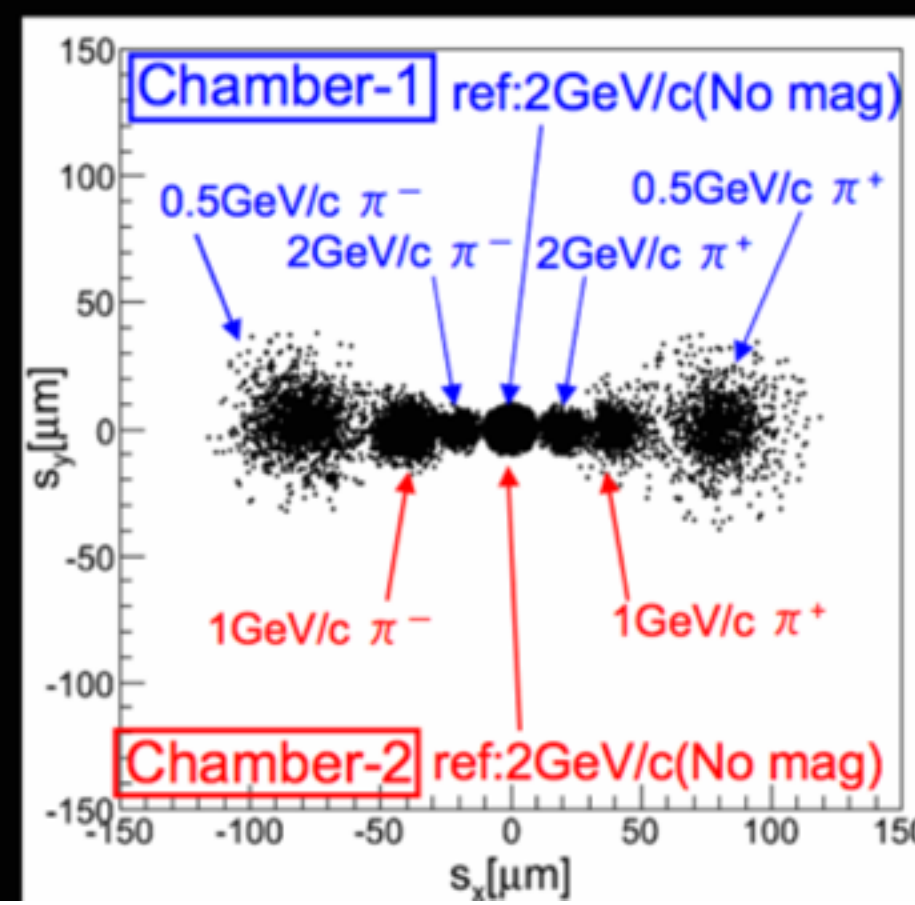
Momentum Measurement in B Field



Test beam : 15mm gap, B = 1T



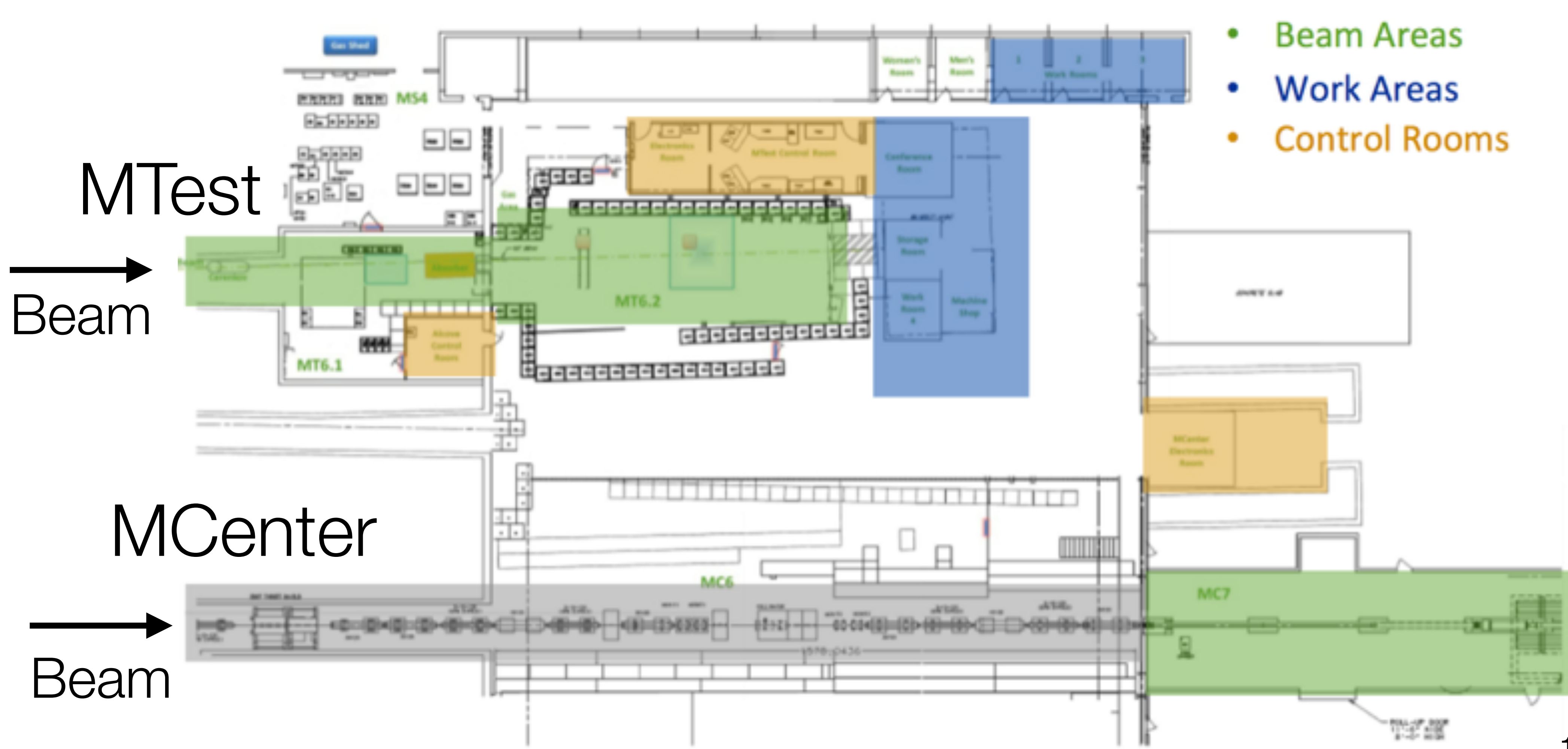




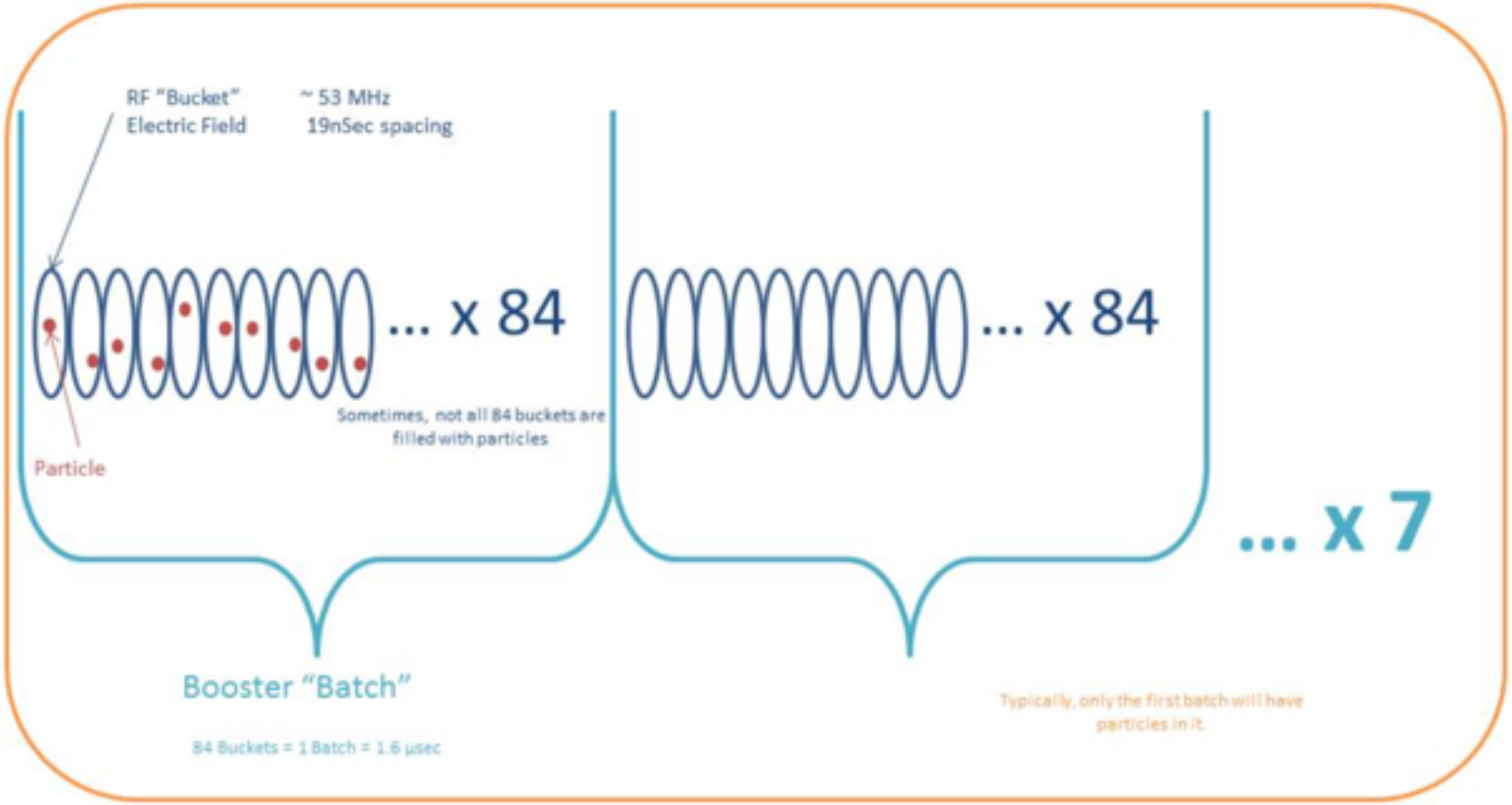
C. Fukushima et al., Nucl. Instr. and Meth. A 592 (2008) 56

Possible Site: Fermilab Test Beam Facility (FTBF)

- Two beamlines: 120 GeV primary protons from Main Injector
  - MCenter: Seconday beam (GeV), tertiary beam down to 200 MeV
  - MTest: Secondary beam (1-66 GeV), 1-300kHz intensity
  - 4 second per 1 minute

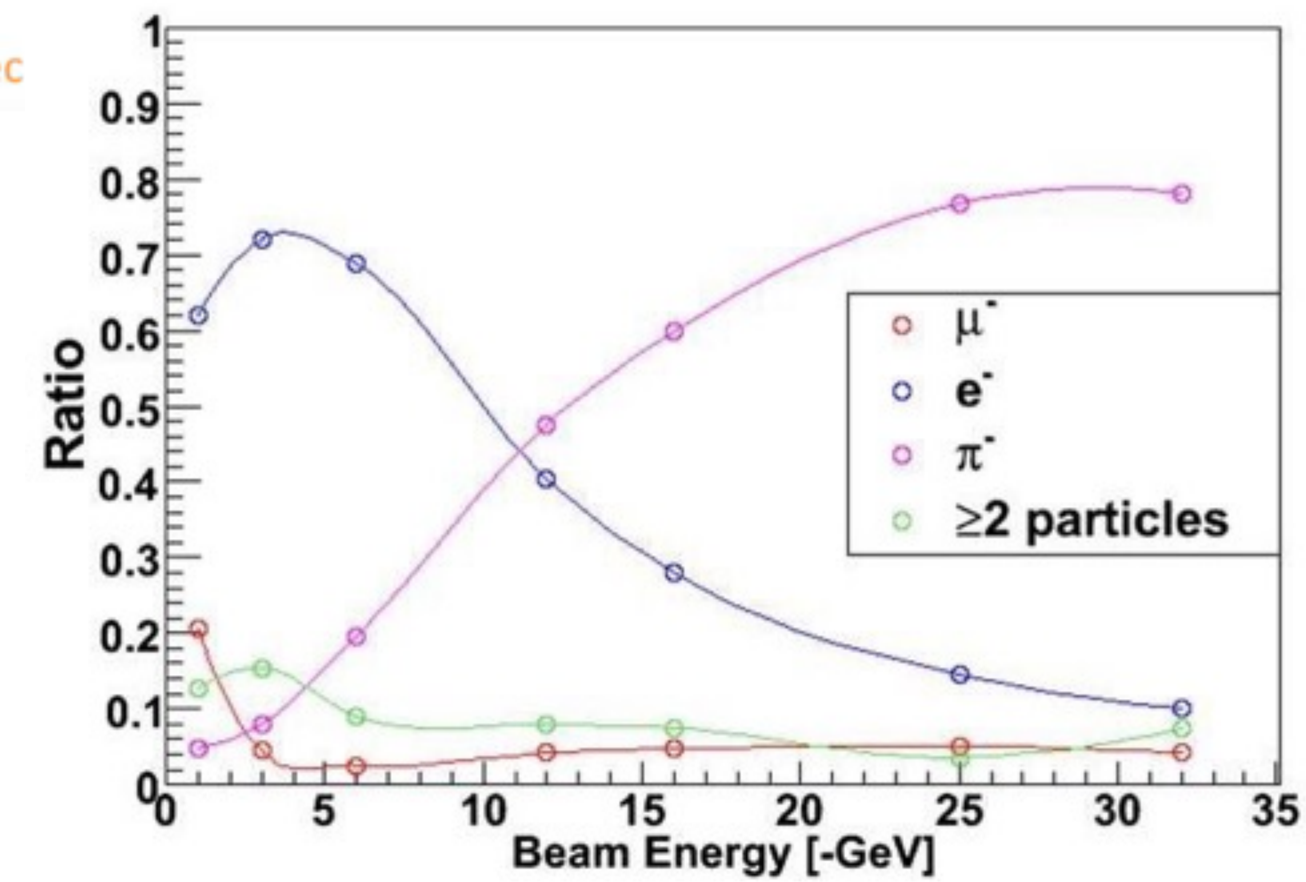


Beam Structure and Particle Content

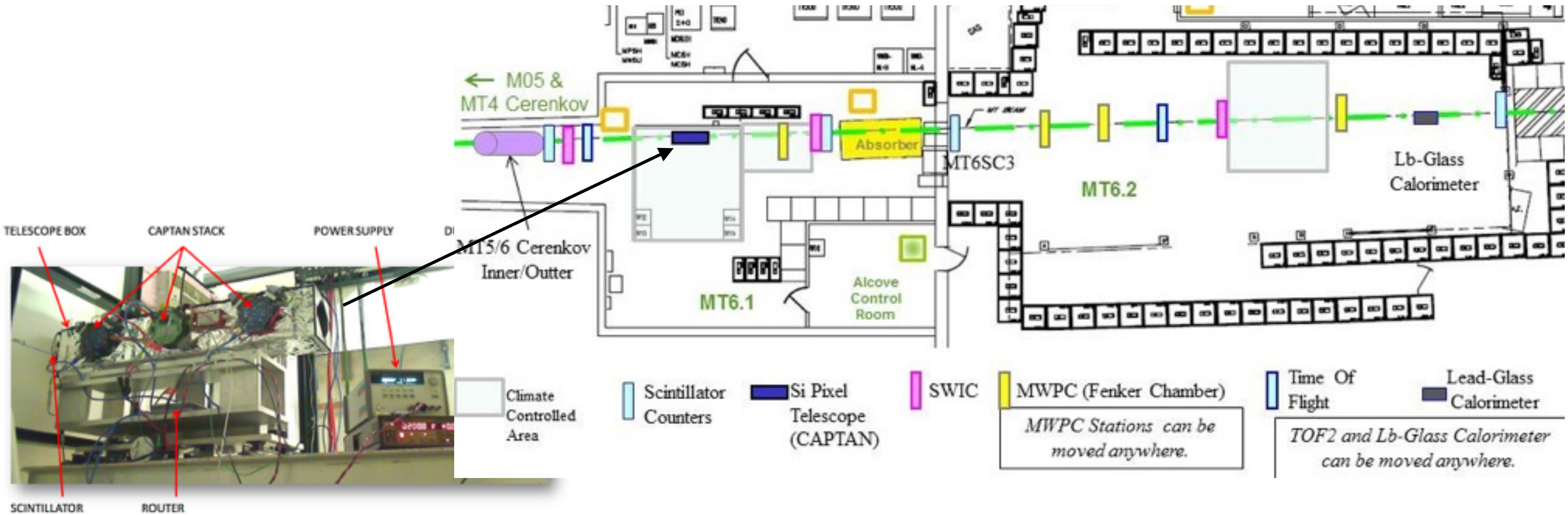


7 Batches = 1 MI Cycle = 11.2 microSec

- RF bucket : 19 ns spacing
- large electron contamination at low energy



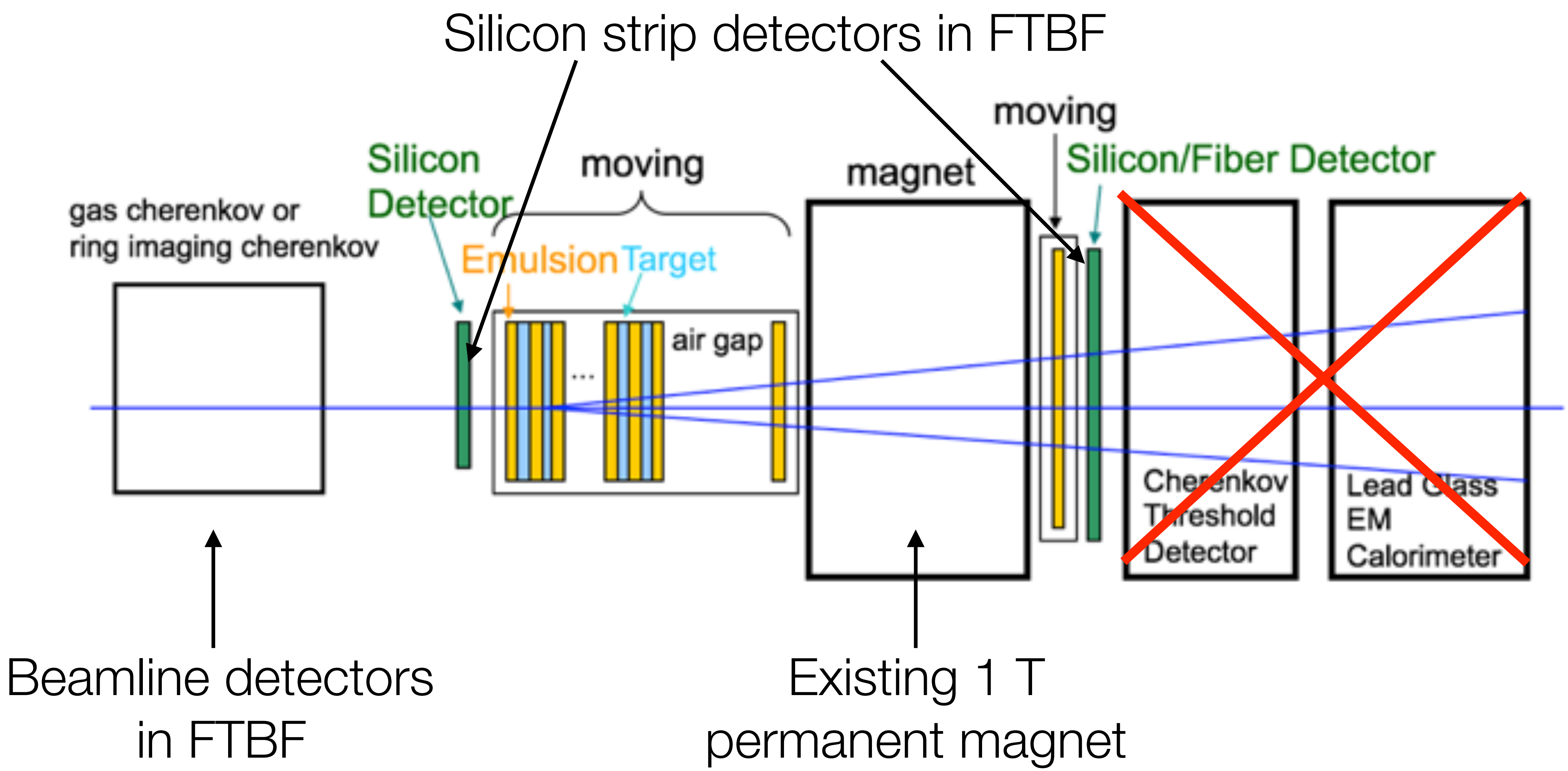
Beamline Detectors at FTBF



- Many beamline detectors are available for users
  - Trigger : Scintillation Counters
  - Particle ID : Cherenkov detectors, TOF counters
  - Beam profile : Segmented Wire Ionization Chambers
  - Beam position : MWPCs, Si Pixel or Strip Telescope

Simple Configuration

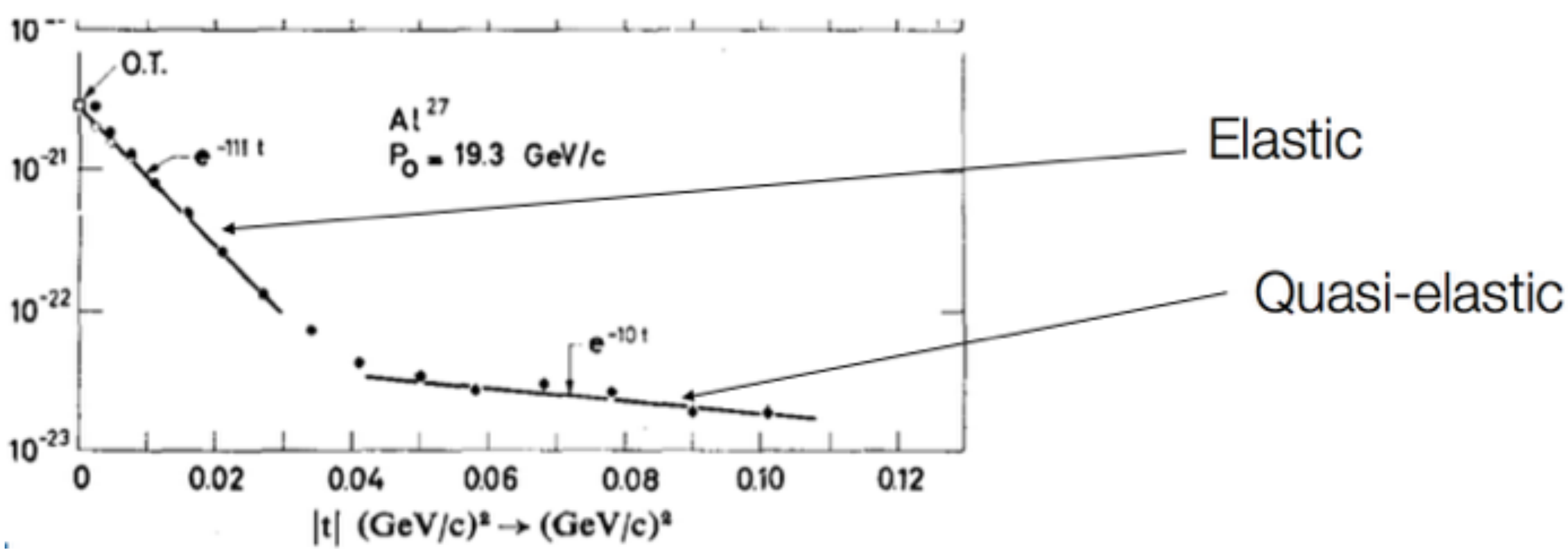
- Use easily-available or existing equipments for measurements in 1st stage.
  - Many beamline detectors can be available in FTBF
  - Silicon strip detectors are also available in FTBF



Measurements with Simple Configuration

- Place in tertiary beamline to measure dE/dx performance
  - Pions and protons at 0.2-1 GeV/c
- Place in secondary beamline to measure quasi-elastic and elastic cross sections
  - Measurements at 30 GeV useful for T2K
  - ~1mrad angular resolution, can reproduce the Bellettini et al. measurements at different beam energies and targets

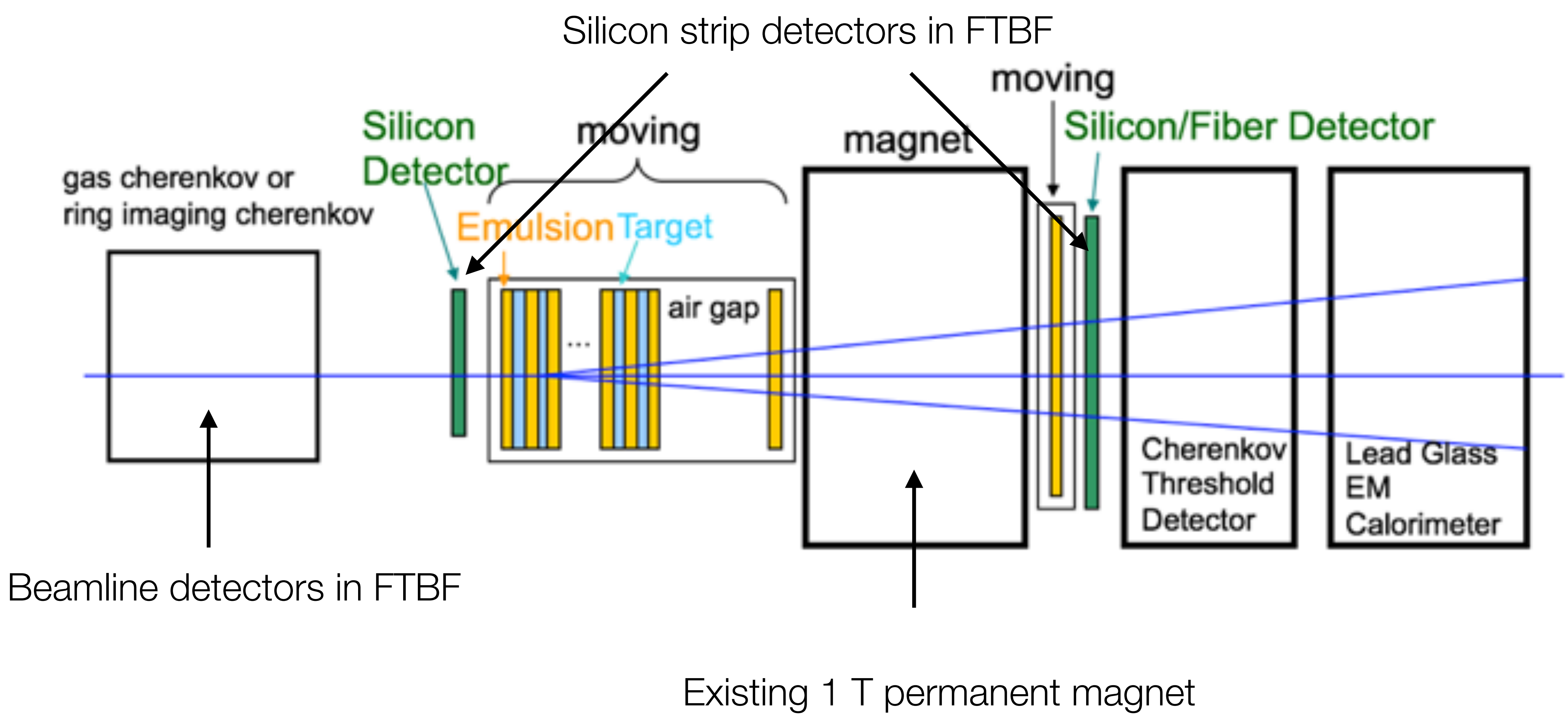
G. Bellettini et al., Nucl. Phys. 79, 609 (1966)



Full Configuration

- PID is crucial to measure production cross-section measurements
  - dE/dx in emulsion → only up to 1 GeV available.
  - Cherenkov threshold detector
  - Lead glass calorimeter

Tolerance for high intensity is key



PID by Cherenkov Threshold Detector

Study by M. Hartz

Cherenkov Thresholds

- Assume 5 layers with different indices of refraction of 1.01, 1.03, 1.05, 1.1, 1.3 (need to be optimized)
- Particles above Cherenkov threshold:

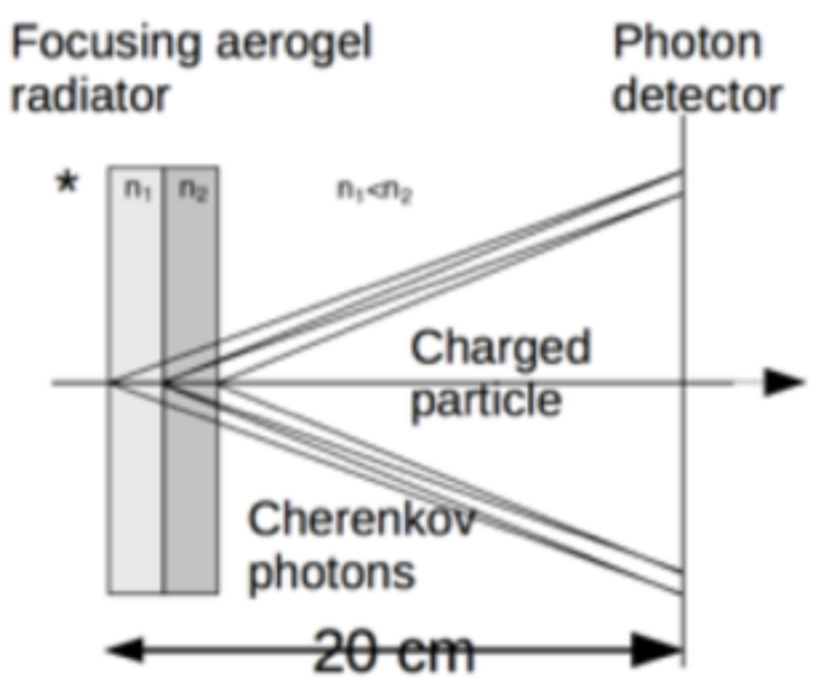
	n=1.01	n=1.03	n=1.05	n=1.1	n=1.3
0.5 GeV/c	e	e,μ	e,μ,π	e,μ,π	e,μ,π
1.0 GeV/c	e,μ,π	e,μ,π	e,μ,π	e,μ,π	e,μ,π,K
1.5 GeV/c	e,μ,π	e,μ,π	e,μ,π	e,μ,π,K	e,μ,π,K,p
2.0 GeV/c	e,μ,π	e,μ,π	e,μ,π,K	e,μ,π,K	e,μ,π,K,p
2.5 GeV/c	e,μ,π	e,μ,π,K	e,μ,π,K	e,μ,π,K,p	e,μ,π,K,p
3.0 GeV/c	e,μ,π	e,μ,π,K	e,μ,π,K,p	e,μ,π,K,p	e,μ,π,K,p
3.5 GeV/c	e,μ,π,K	e,μ,π,K	e,μ,π,K,p	e,μ,π,K,p	e,μ,π,K,p
4.0 GeV/c	e,μ,π,K	e,μ,π,K,p	e,μ,π,K,p	e,μ,π,K,p	e,μ,π,K,p

- Above 1 GeV/c, no separation of e,μ,π
- Separation of e,μ,π and K up to 3.0 GeV/c
- Separation of e,μ,π and p up to 6.5 GeV/c

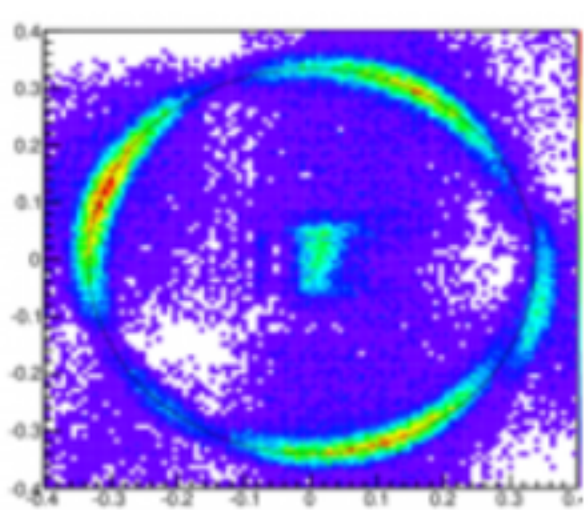
Alternatives?

A. Konaka

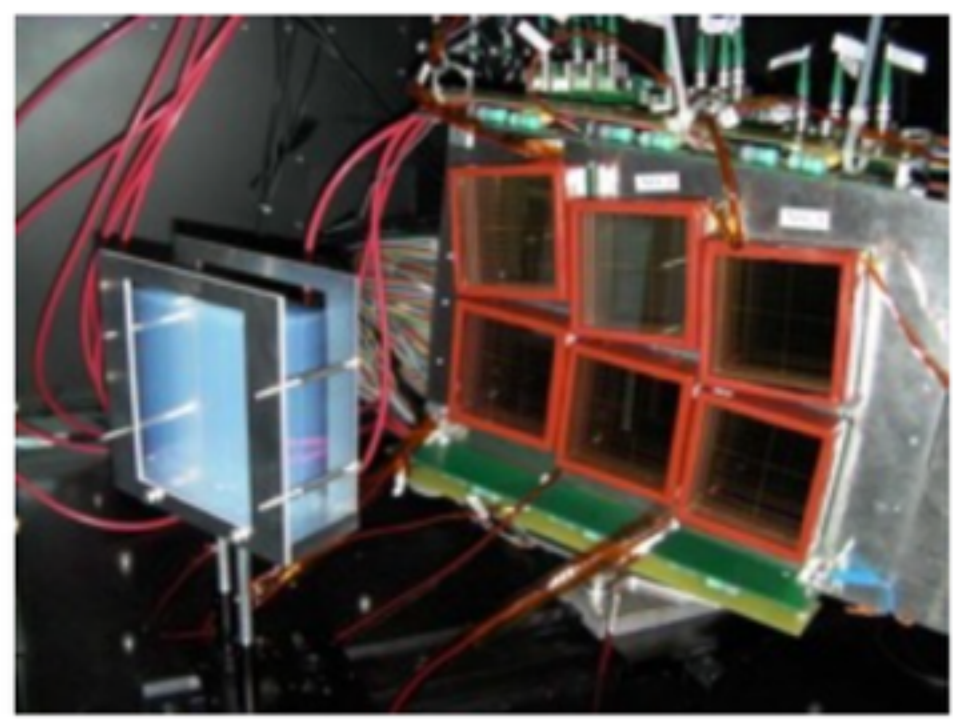
Particle Identification by A-RICH (Belle2)?



Iijima et. al. NIMA548(2005)383



- Aerogel ring imaging Cherenkov
  - π / K / p separation in 1-5 GeV/c
    - more flexible than threshold Cherenkov
    - Lower index aerogel extends momentum range
  - Multi-track capability!



Possible Schedule

- We are applying to JSPS grant (Kaken-hi) and US-Japan grant
- FY2017
  - Production and purchase : ~November, 2017
  - Shipment to FNAL : ~December, 2017
  - Preparation for beam test : ~January, 2017
    - setup dark room, electronics, and DAQ
  - Beam test : ~February, 2018
    - emulsion setup (1 week), detector setup (a few days), beam exposure (1 week)
    - Analysis : ~March, 2018
- FY2018 : preparation/setup full detector, measurements with low/high intensity beams
- FY2019 : measurements with high intensity beam

Summary

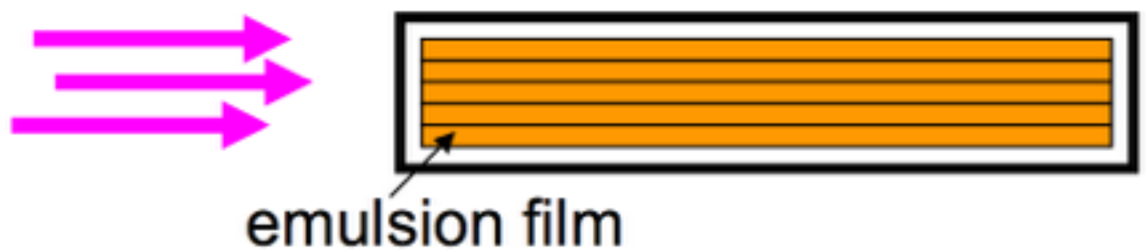
- Precise measurements of hadron production and scattering
  - Hybrid emulsion/electronic detector is proposed.
    - Low inactive region
    - Better vertex/track information expected
  - Plan to use beamlines at FTBF for sub-10 GeV proton/pion beams
  - Simple configuration is used to check dE/dx performance and measure quasi-elastic/elastic cross sections
    - Emulsion detector and related equipments are prepared in Japan and shipped to FNAL.
  - Beam test planed in February, 2017.

Supplemental Slides

Beam Exposure

- Test sample #1: only emulsion films
  - Check tracking efficiency, angle accuracy, and dE/dx reaction

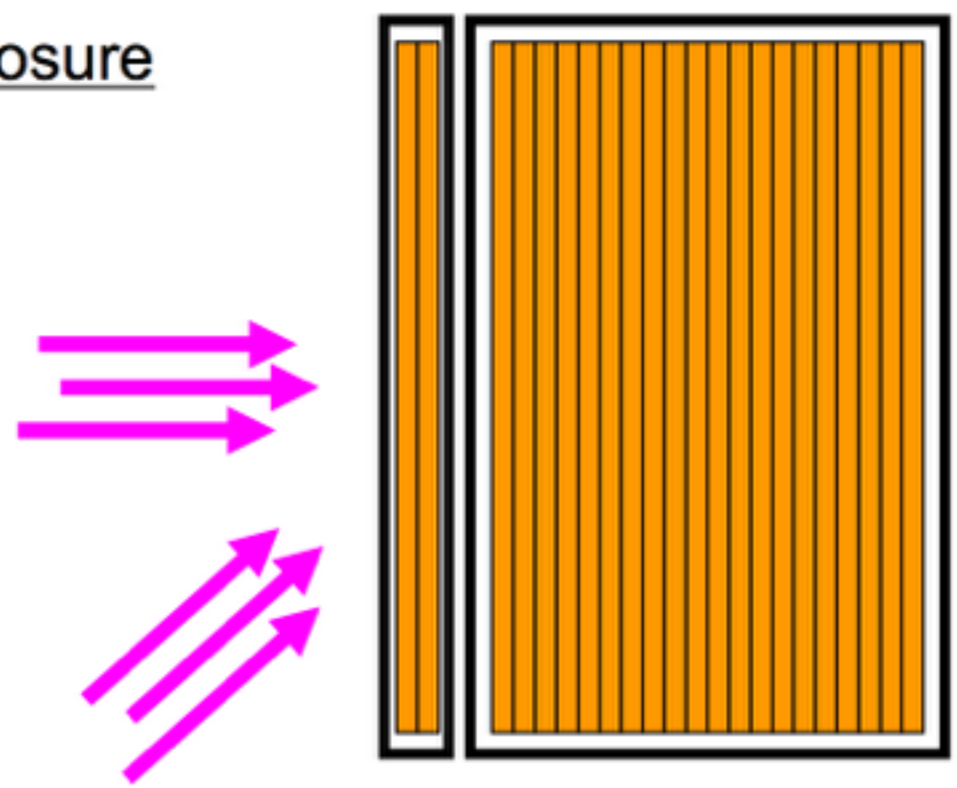
Horizontal exposure (grain based analysis)



Beam particle and momentum:
0.2 -1.5 GeV/c proton and pion

Beam density:
~2*10^4 particles/cm^2 for 1 spot

Vertical exposure

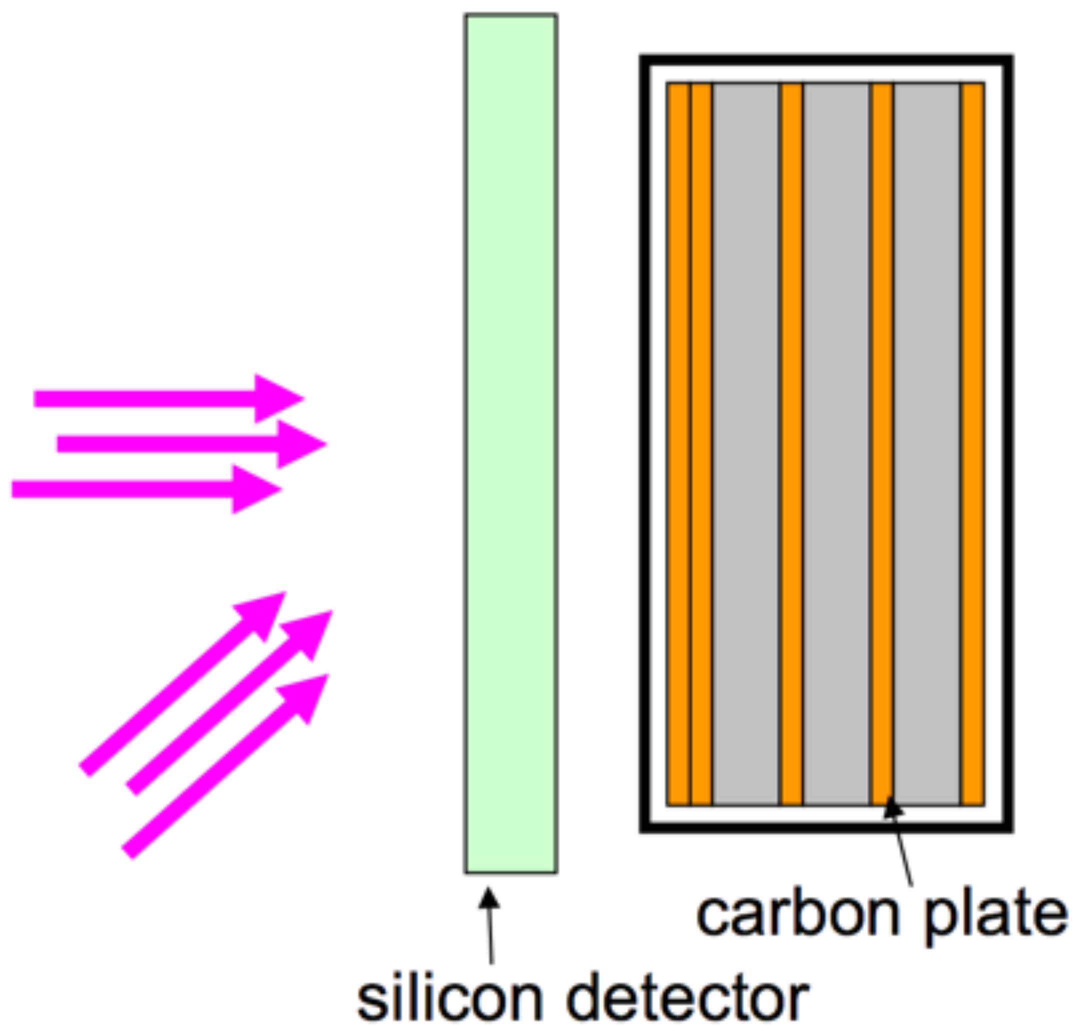


Beam particle and momentum:
0.2-1.5 GeV/c proton and pion

Beam density:
~10^4 particles/cm^2 for 1 spot

Beam Exposure

- Test sample #2: emulsion films and carbon plates
  - Check the connection to the electronic detectors

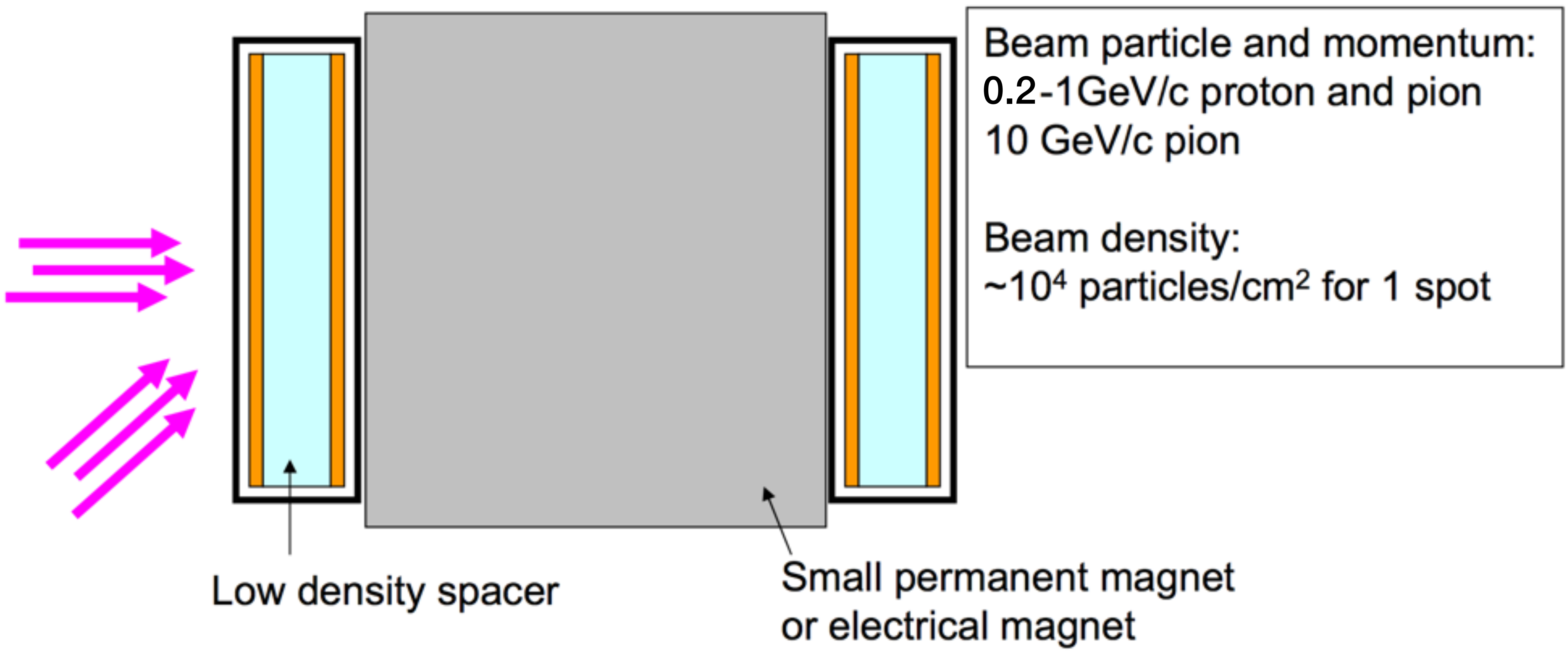


Beam particle and momentum:
10GeV/c proton and pion

Beam density:
~10^4 particles/cm^2 for 1 spot

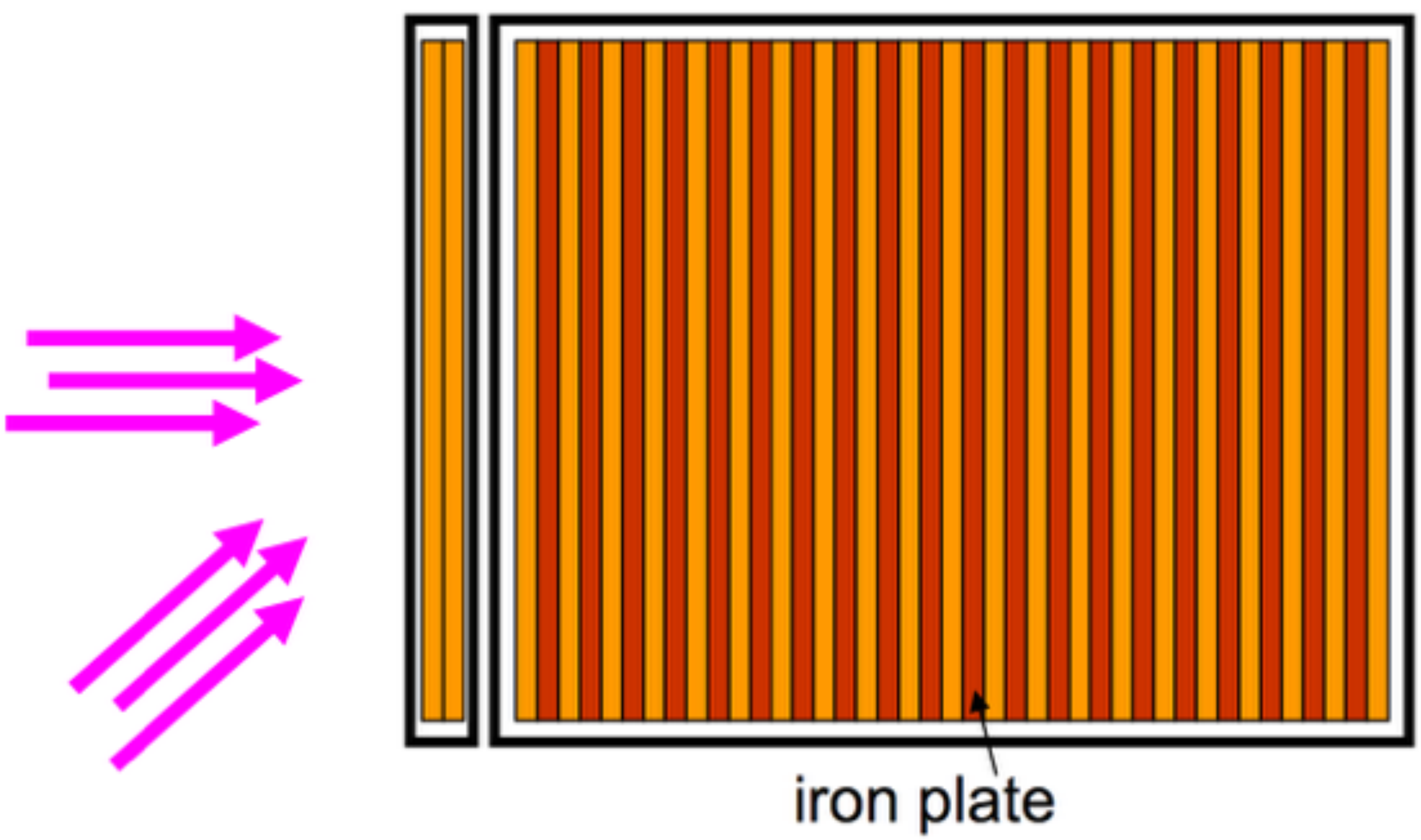
Beam Exposure

- Test sample #3: emulsion films and magnetic field
  - Check momentum measurement and charge sign judgement



Beam Exposure

- Test sample #4: emulsion films and iron plates
    - Check momentum measurement by multiple scattering



Beam particle and momentum:
0.2-1GeV/c proton and pion

Beam density:
~10^4 particles/cm^2 for 1 spot