Physics with High Momentum Beam Line

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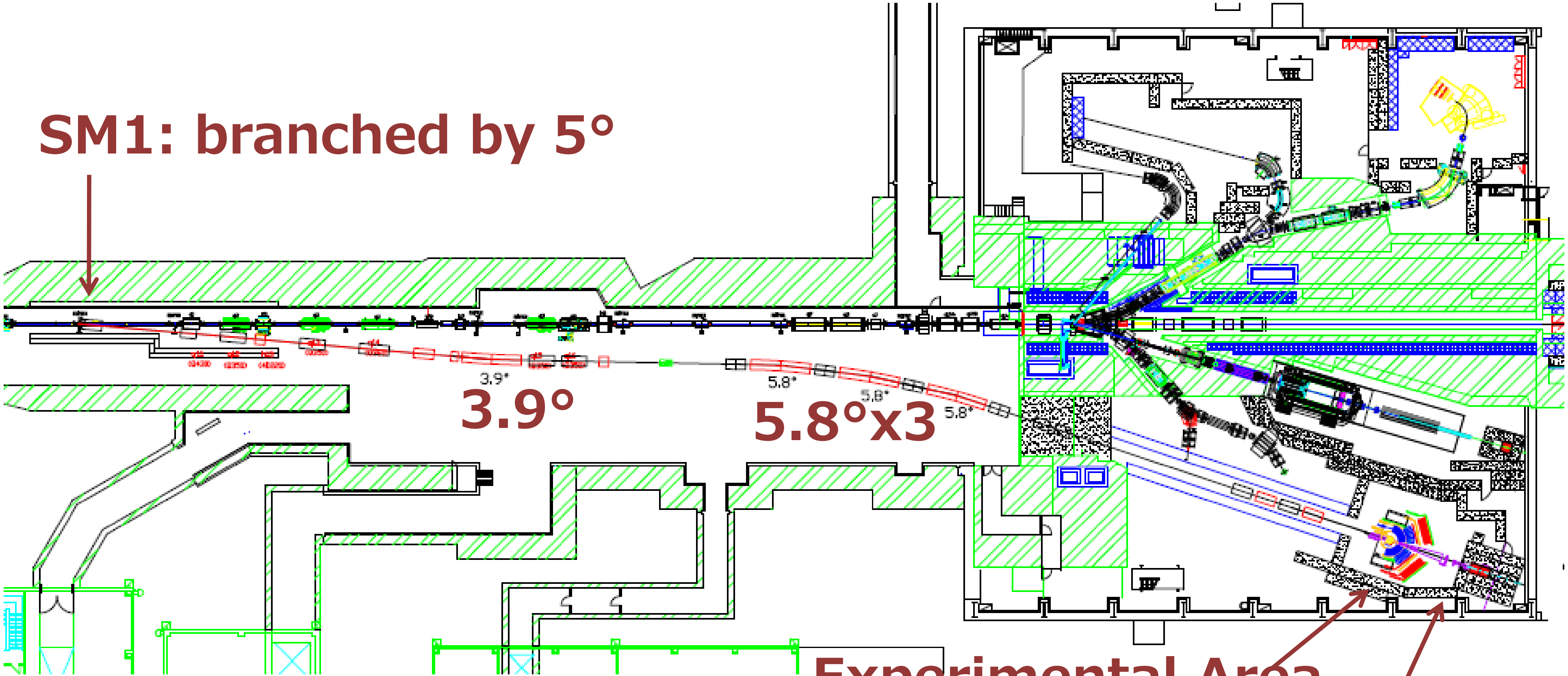
Summary of collected comments

- Two comments from existing experiment
  - **ϕ meson in nucleus (E16)**
  - ω meson in nucleus (E26)
- Following experiments are proposed or being proposed
  - **Charmed baryon mass spectroscopy**
  - Drell-yan, J/ψ using Di-muon measurements (P04)
  - Exclusive measurements of ϕ mesons in nucleus
- Several physics interests are collected
  - Additional 10 comments are received

Two Main Experiments (E16 and charm), for primary proton and secondary π beam.

High Momentum Beam Line



- 10^{10} (- 10^{12}) protons/spill
- High-p (≤ 15 GeV/c) un-separated secondary particles

What we know about hadrons?

- Colored quarks are confined.
- u, d, s quarks are no longer light.
- Pseudo-scalar mesons are light.
- Flavor $SU_f(N)$ symmetry

What we naively think?

Perturbative region

- Current quark
- $SU_L(N)$ X $SU_R(N)$

SSB

- Dynamical mass generation
- the presence of π, K, η as NG bosons

Nonperturbative region

- Constituent quark
- $SU_V(N)$

Puzzles in hadron physics

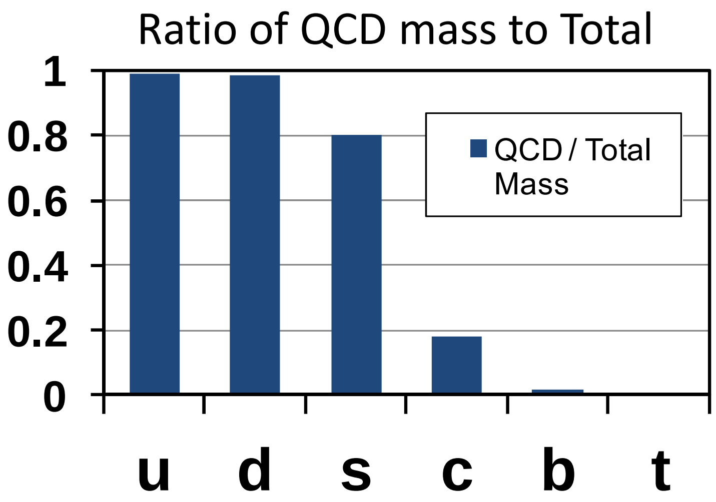
- Missing resonances.
- States cannot be easily explained by a quark model. (e.g. Roper, $\Lambda(1405)$, …)
- Unexpected states. (e.g. narrow resonances at Belle)

What we want to know?

- What are good quasi-particles inside hadron?
  - Constituent quark?
  - Di-quark?
  - Hadron as a constituent of hadron?
- How mass is dynamically generated?

These two questions are closely related and can be studied at High-p beam line.

E16: Origin of Hadron Mass



- In light quark (u, d, s) sector, hadron mass consists of Bare mass (Higgs) and Dynamical mass (QCD).

- **Establish QCD-originated effects in nucleus, experimentally.**
  - Provide experimental information for QCD mass in dense matter
- Vector meson (ϕ meson) is used as a probe.
  - Mass spectra of vector mesons are sensitive probes to QCD mass.
    - e.g. Hatsuda and Lee, PRC 46 (1992) R34
  - Use leptonic decays to avoid the final state interaction

Which is the best, ρ/ω or ϕ?

- ρ/ω
  - Dynamical mass contribution is dominant
    $M_\pi \sim 130$ MeV/c^2 $M_\rho \sim 770$ MeV/c^2
  - Large hadronic effects and background issues are large
- ϕ
  - Still, dynamical mass contribution is dominant
    $M_\eta \sim 550$ MeV/c^2 $M_\phi \sim 1020$ MeV/c^2
  - Narrow width (4.3 MeV/c^2)
    - Small background issue
  - **Small effects of hadron-hadron interactions**
    - e.g. Binding energy of ϕN is 1.8 MeV (Phys. Rev. C 63(2001) 022201R)

To see QCD-originated effects, ϕ meson is the most promising probe.

Current status of experiments

Most measurements are done for ρ/ω mesons

- High energy heavy ion collisions
  - SPS-NA60 (PRL 96 (2006) 162302)
    - Modification of ρ meson due to hadronic effects
  - RHIC-PHENIX (PRC81(2010) 034911)
    - Origin of the enhancement is under discussion
- Nuclear targets
  - CBELSA/TAPS (Phys.Rev. C82 (2010) 035209)
    - Modification of ω is not observed
  - J-LAB CLAS G7 (PRL 99 (2007) 262302)
    - Mass broadening of ρ due to hadronic effects
  - KEK-PS E325 (PRL 96 (2006) 092301)
    - Peak shift and width broadening of ρ/ω

Large uncertainty in background subtraction method

Several hadronic and experimental effects cause difficulties in ρ/ω measurements.

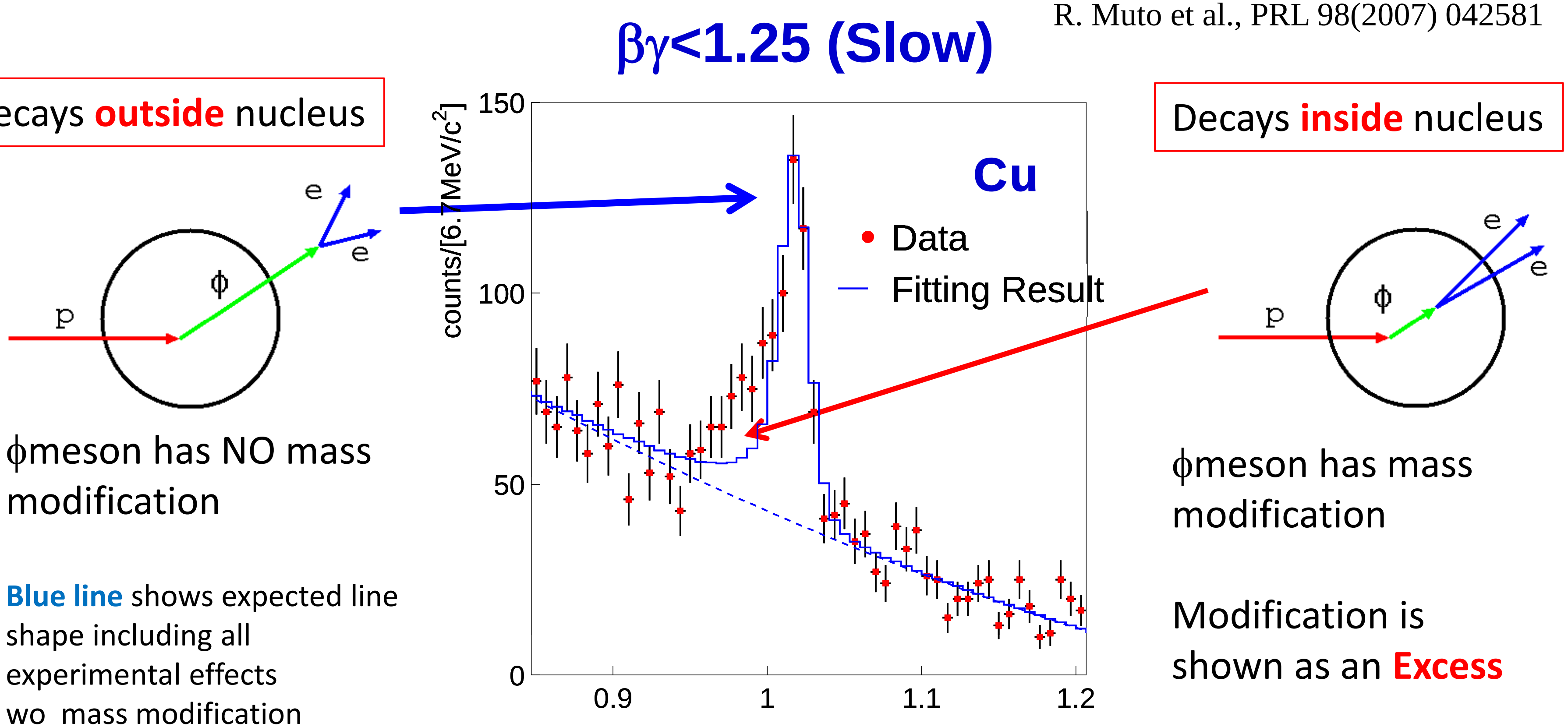
Clear measurements of ϕ meson at KEK-PS.

The only one measurement on medium modification of ϕ meson.

R. Muto et al., PRL 98(2007) 042581

Decays **outside** nucleus

Decays **inside** nucleus



e^+e^- invariant mass [GeV/c^2]

ϕmeson has NO mass modification

Blue line shows expected line shape including all experimental effects wo mass modification

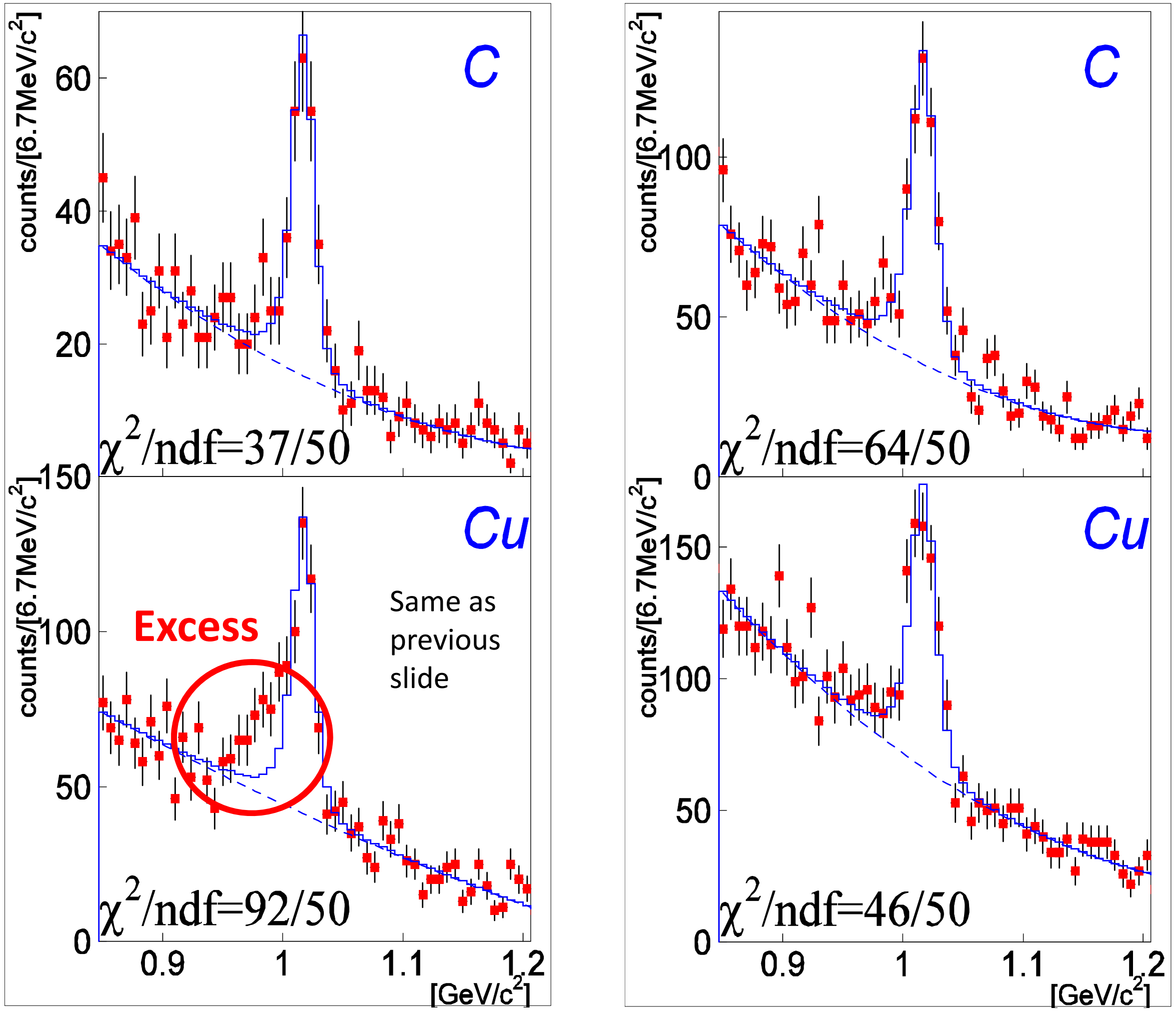
ϕmeson has mass modification

Modification is shown as an **Excess**

Indication of QCD-originated mass modification!

Target/Momentum dep.

βγ<1.25 (Slow) **1.25<βγ<1.75**



e^+e^- invariant mass

Two nuclear targets:

Carbon & Copper

Inside-decay increases in **large nucleus**

Momentum bin

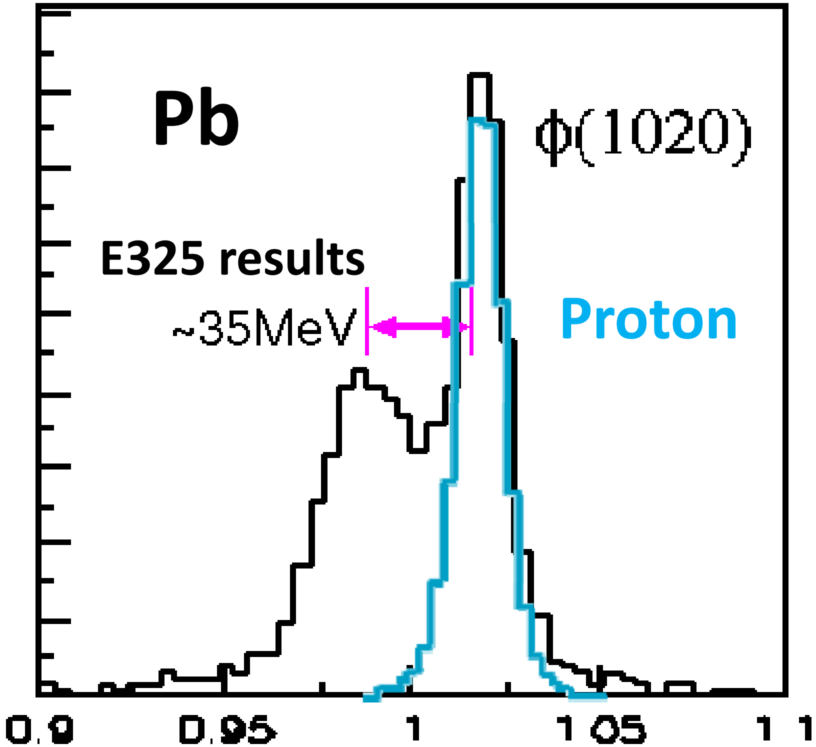
Slowly moving ϕ mesons have larger chance to decay inside nucleus

Only one momentum bin shows a mass modification under the current statistics.

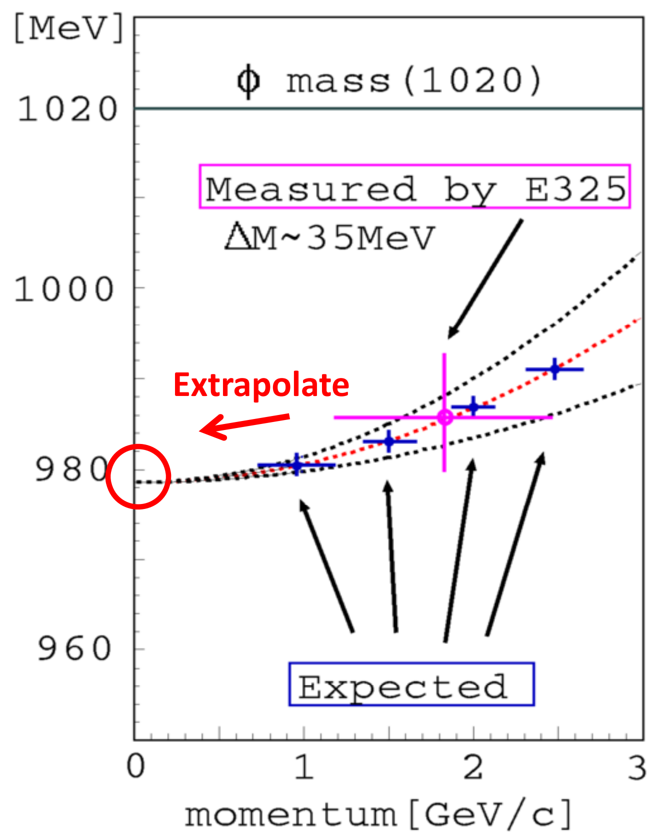
To see clear mass modification and establish QCD-originated effects, significantly larger statistics are required.

Next Goal

A clear shifted peak needs to be identified to establish QCD-originated effects



Momentum Dependence



100 times larger statistics are required.

Requirements for beam and spectrometer

- To obtain 100 times larger statistics
  - High beam energy of 30 GeV (x2 statistics)
  - Beam intensity: 10^{10} per spill (x10)
  - Extended acceptance of the spectrometer (x5)

- Mass Resolution needs to be improved to ~ 5MeV/c^2
  - ΔM ~ 35 MeV/c^2, Γ ~ 15 MeV/c^2: E325 (~ 11 MeV/c^2)

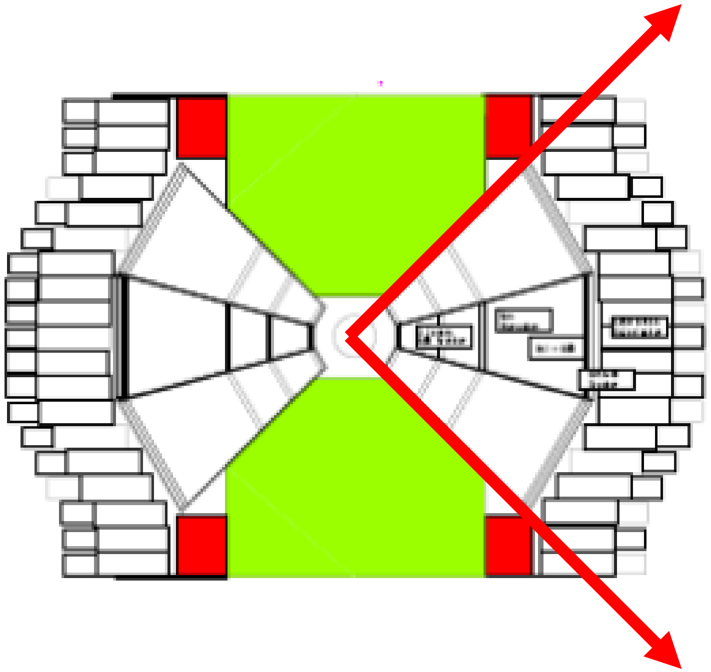
- Wider target mass range to have a clear modification
  - Proton and Lead targets

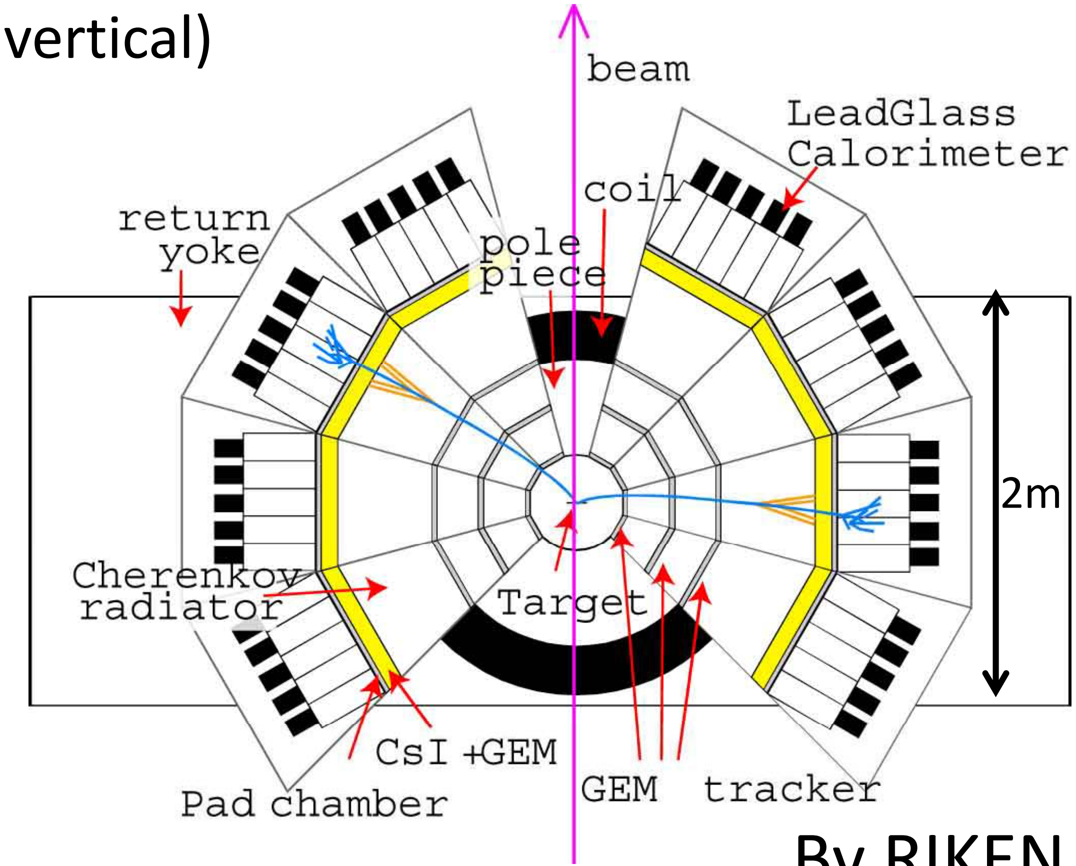
To satisfy above requirements, we need to construct a new beam line and totally new detectors.

Spectrometer

Cope with 10^{10} per spill beam intensity

Extended acceptance (90° in vertical)



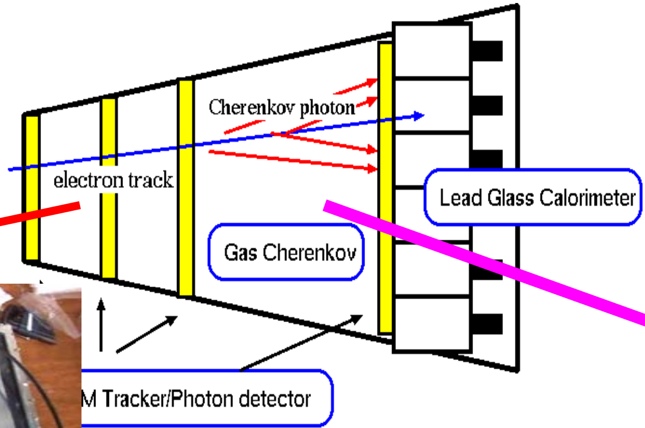


By RIKEN

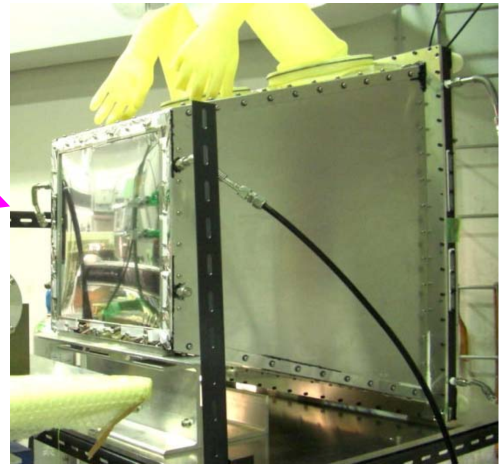
Gas Electron Multiplier (GEM) technology is fully adopted.

Detector components

GEM Tracker



HBD (Hadron-Blind Cherenkov detector)



100x100   200x200   300x300

Position resolution of 100μm is achieved

Key Technology:

CsI evaporated GEM as a photo cathode

Q.E. of 40% is achieved

Concern about long term stability of CsI (Reply to PAC13 comments)

- We assume 1-2 month running per year and several years
  - PHENIX-HBD already prove the 6 month operation in Run-10 : accumulated life is same order
  - Re-evaporation of CsI is possible between our Runs for damaged one

International Competition

GSI/FAIR SIS 100

protons up to **29 GeV, 2.5×10^{13}ppp**

Heavy Ion $^{238}U^{28+}$ 2.7GeV/u 2.5×10^{11}ppp

Civil construction of FAIR first version is finished by **2016**.
Then, accelerator and detectors will be installed.
HADES detectors are already working and CBM is in preparation.

Their main physics is study of high density matter.
However, combination of SIS100 and CBM has a capability for ϕ mesons in nucleus and becomes a strong competitor.

→ Construction of the high momentum beam line needs to be started in one year.

New Exp.: Structure of hadron

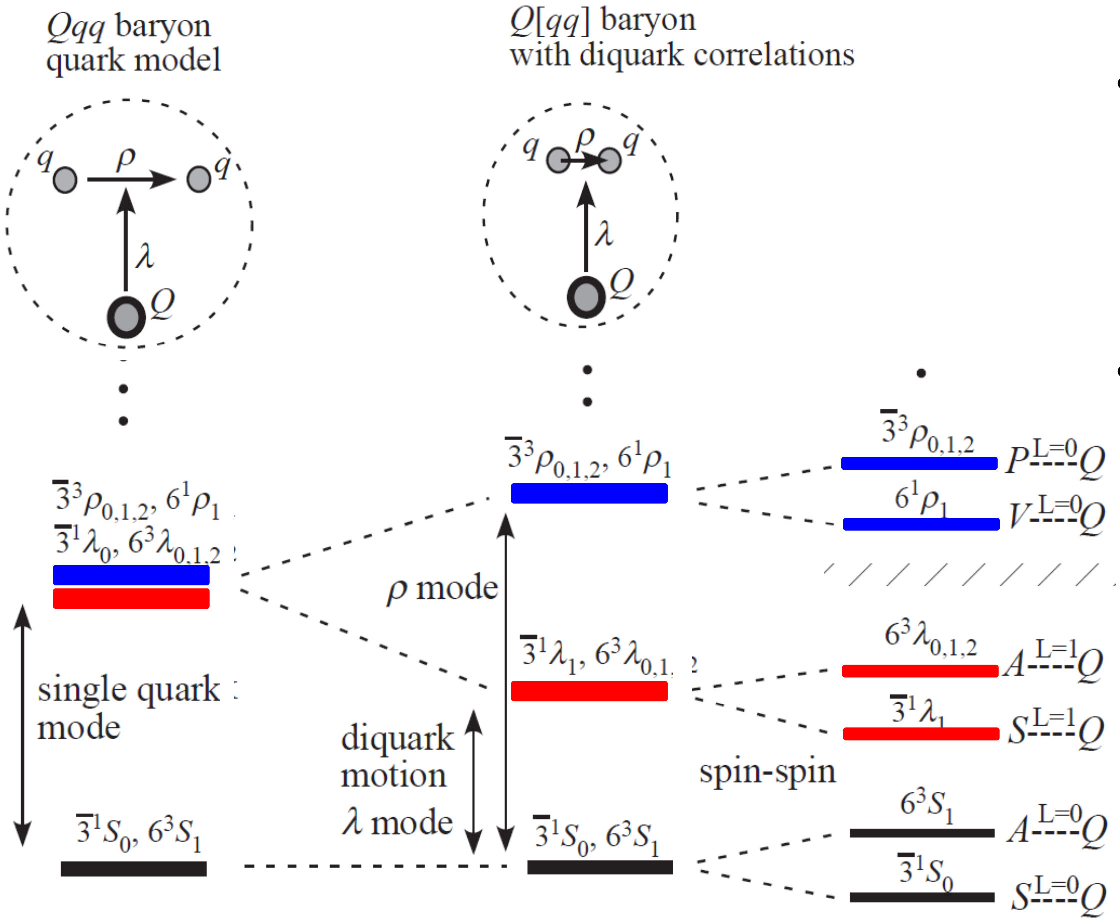
- Light hadron is interesting
  - Interesting phenomena which are not easily explained by a quark model
    - Missing resonances
      - may indicate importance of other degree of freedom such as di-quark.
    - Roper, $\Lambda(1405)$
- Measurements are difficult due to complicated issues
  - (Spin dependent) strong quark correlation.
  - Strong coupling to π meson (NG bosons).

- To understand light quark hadrons, use charmed baryons (Λ^+_c, Σ_c) information
  - Charm quark inside hadron is heavy and easy to handle.
    - Non-relativistic treatment can be adopted.
  - Interactions are simplified.
    - Spin dependent interaction is suppressed

Heavy quark baryon

λ: orbital motion

ρ: di-quark correlation



- When single quark picture is still a good picture, excited states are degenerated.
- If Cqq (q=u,d) system is considered as C and di-quark correlations, orbital motion of λ is lowered due to the collectivity of the di-quark motion.
- Spin correlations between light quarks give additional level separations.

Level pattern tell us:

✓Mass of di-quark

✓Strength of di-quark correlation

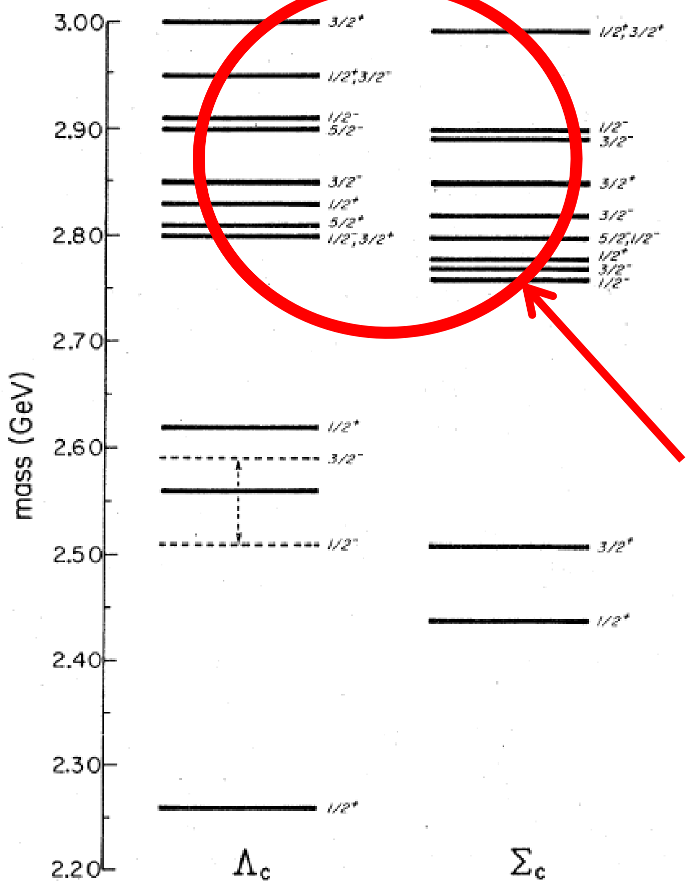
✓Spin dependent correlation between light quarks

Measurements of all levels are important

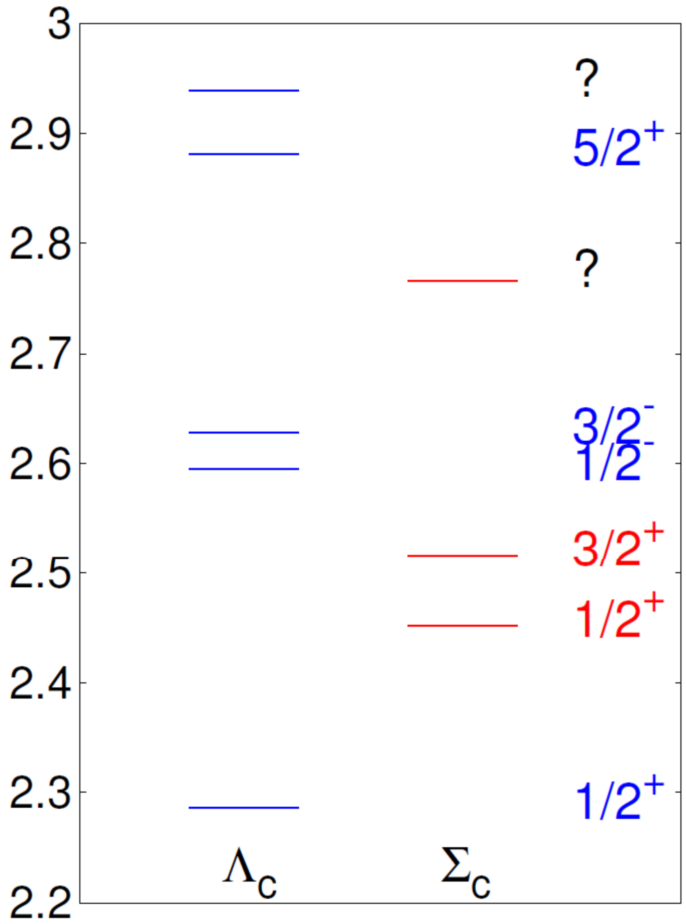
Charmed Baryon Spectroscopy

Example of predicted states

(L.A. Copley et. al, Phys. Rev. D 20 (1979) 768)



Observed charmed baryons



Many states are unknown

Measure level pattern in this region

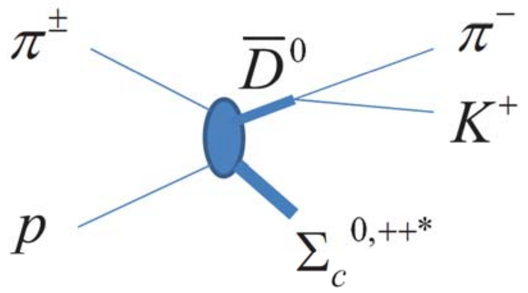
Study level structure of charmed baryon below 3 GeV.

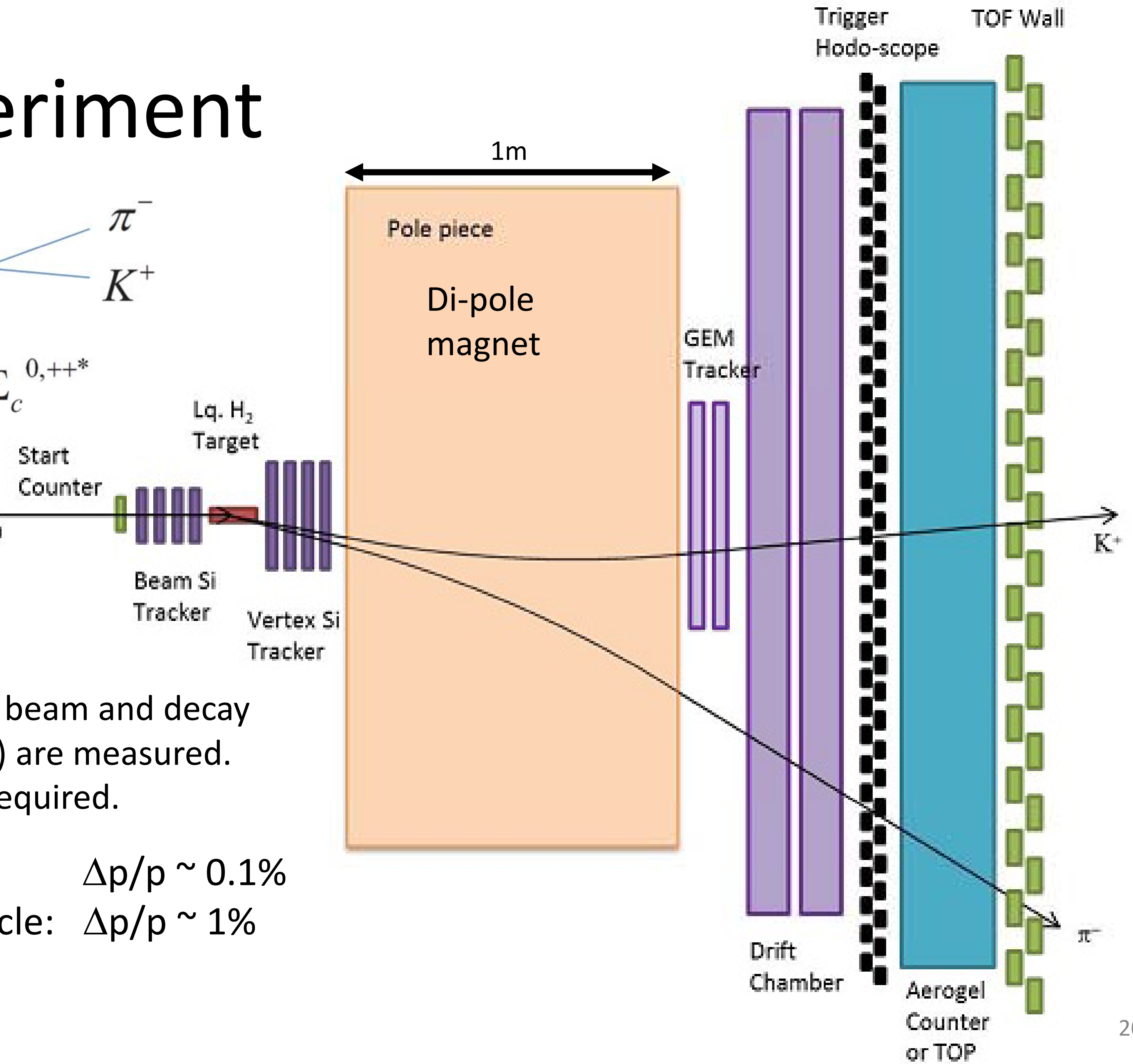
Experimental Method

- Decay and Invariant mass method
  - Large statistics
    - e.g. Belle and LHC-heavy ion
  - Several excited states can't be recognized
    - States with large intrinsic width
    - Low resolution for neutral particles
- Missing mass method
  - All levels are searched
    - Independent to decay mode
    - Large intrinsic width states are recognized
  - Relatively small detector

Missing mass method is suitable to study level structure of charmed baryon

Experiment





Momenta of beam and decay particles (Kπ) are measured.

K ID is required.

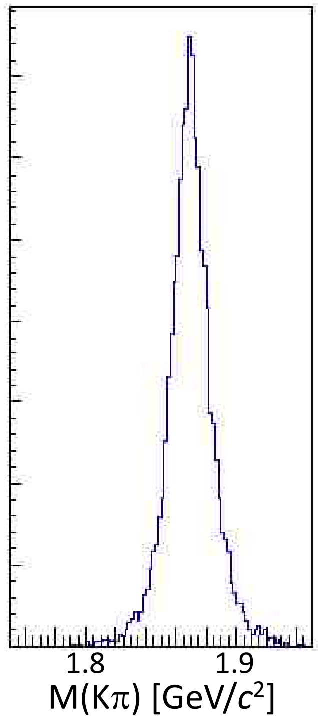
Beam: $\Delta p/p \sim 0.1\%$

Decay Particle: $\Delta p/p \sim 1\%$

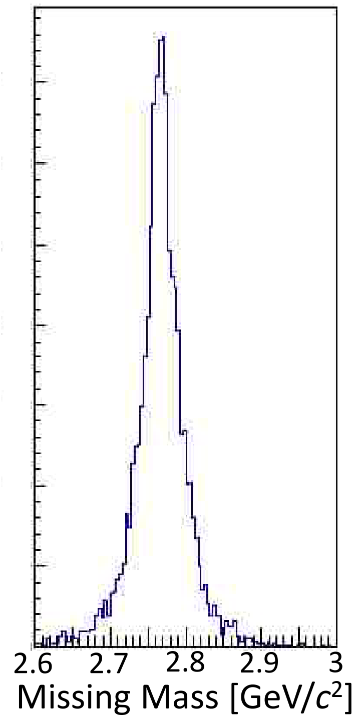
Final Spectra

D meson is reconstructed and identified using measured momenta of π and K.
Then, calculate missing mass using momenta of D meson and π beam.

Reconstructed
D meson

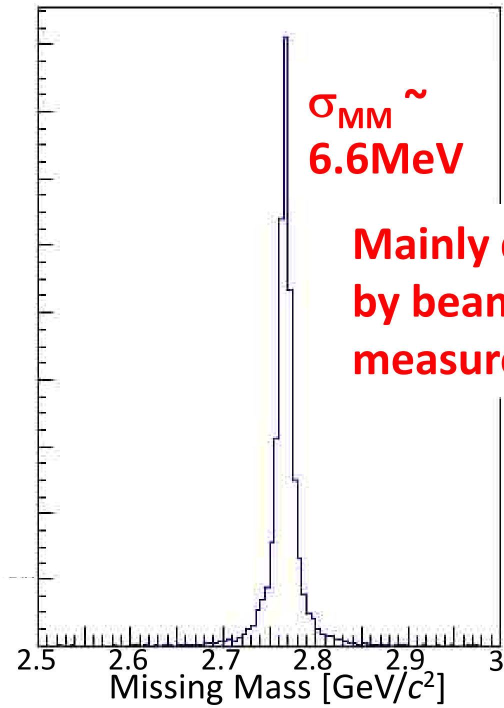


Missing mass
spectrum



Resolution is determined by decay measurements.

Correction:
$M_{D\ meson}$ is known.
Measured Kπ momenta are corrected to reproduce nominal D meson mass.



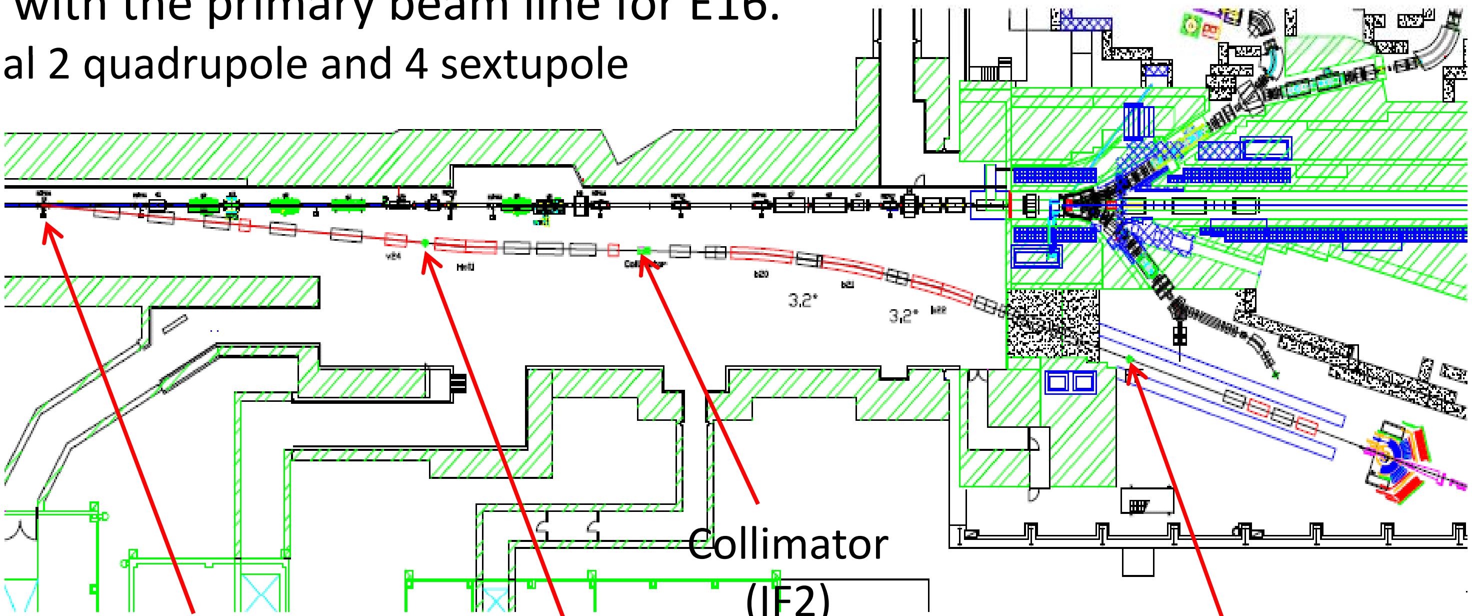
σ_{MM} ~ 6.6MeV

Mainly determined by beam measurements.

High resolution beam line

- Good momentum resolution: $\Delta p/p$~0.1%
  - Dispersive beam at FF
  - Eliminate O(2) aberrations
- High Intensity Secondary Beam :
  - 1.6 msr･%
  - 1.0 x 10^6 Hz (6 x 10^6 per spill, 6 sec spill length) @ 15GeV π
- Compatible with the primary beam line for E16.
  - Additional 2 quadrupole and 4 sextupole

By RCNP



Schedule

Fiscal Year	2012	2013	2014	2015	2016	2017	2018
Beam Line		Manufacturing		Install			
E16							
Magnet	Construction						
Detector		1/3 ready		Full install			
Beam Time					Experiment		
Charmed Baryon							
High Res. Beam	Design	Manufacturing		Install			
Detector	Design	R&D		Production		Install	
Beam Time							Exp.

GSI/FAIR	**Construction**					**Install**	**Start**

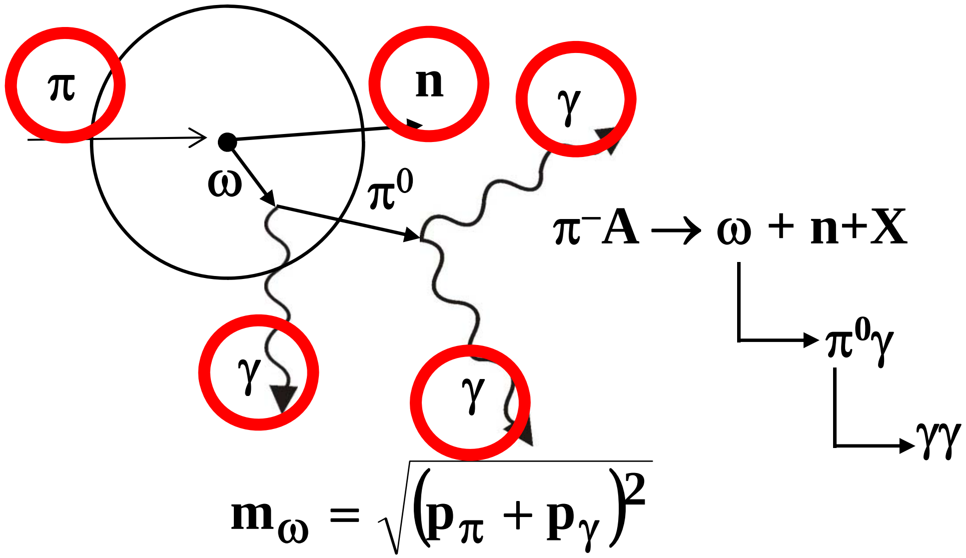
Organization

- KEK build basic beam line components.
- To achieve high resolution of beam line, RCNP and KEK have a collaborative work.

- E16 experiment:
  - Host institutes: KEK and RIKEN
- Charm baryon spectroscopy:
  - Host institutes: KEK and RCNP

RELATED PHYSICS & EXPERIMENTS @ HIGH MOMENTUM BEAM LINE

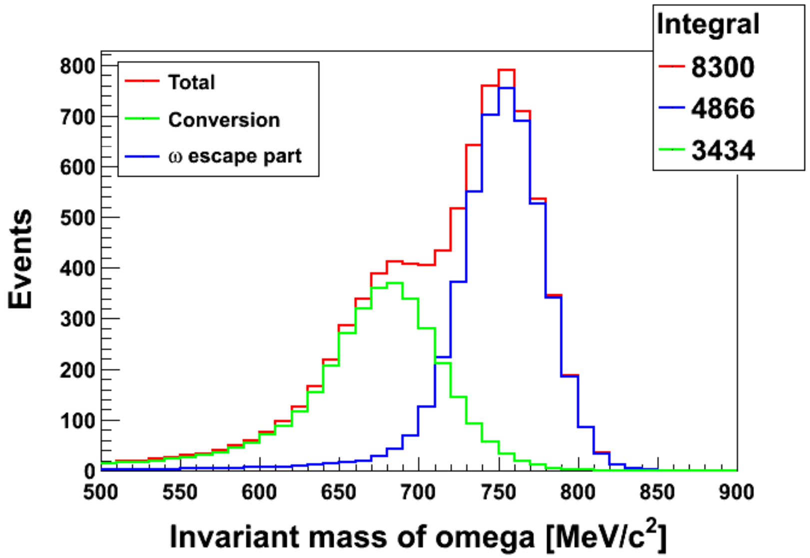
E26: Omega in nucleus



$$m_\omega = \sqrt{(p_\pi + p_\gamma)^2}$$

Measurements of ω meson mass spectrum

- Physics is similar with E16
- Production of ω is also measured
- Focus on low momentum ω meson
- Clarify effects of hadron interactions and mass modification



Construct

- Neutron counter
- Gamma Detector

Beam Momentum is 2.0 GeV/c

It can be done at the high momentum beam line

Missing mass resolution is improved.

H. Fujioka, S. Hirenzaki, K. Itahashi, D. Jido, H. Nagahiro, K. Ozawa

Measurement of $\pi^- p \to \eta' n$ cross section

- η'N interaction
  - ***weakly interacting?***
    ←COSY-11 (pp→ppη′), $|a_{\eta' N}|$~0.1fm *PLB482, 356 (2000)*
  - ***strongly attractive?***
    ←near-threshold cross section of $\pi^- p \to \eta' n$ reaction
    (against s-wave behavior: σ/p*=const.) *Nuovo Cimento A75, 163 (1983)*
    - indicating N* resonance near η′N threshold?
  - $U_A(1)$ anomaly and chiral symmetry restoration *arXiv: 1109.0394* *PLB709, 87 (2012)*
- Precise measurement at high momentum beam line
  - with γ detector and neutron counterfor E26 exp. (ω mesic nuclei)

P04: Antiquarks in nucleons