Hadron physics at J-PARC

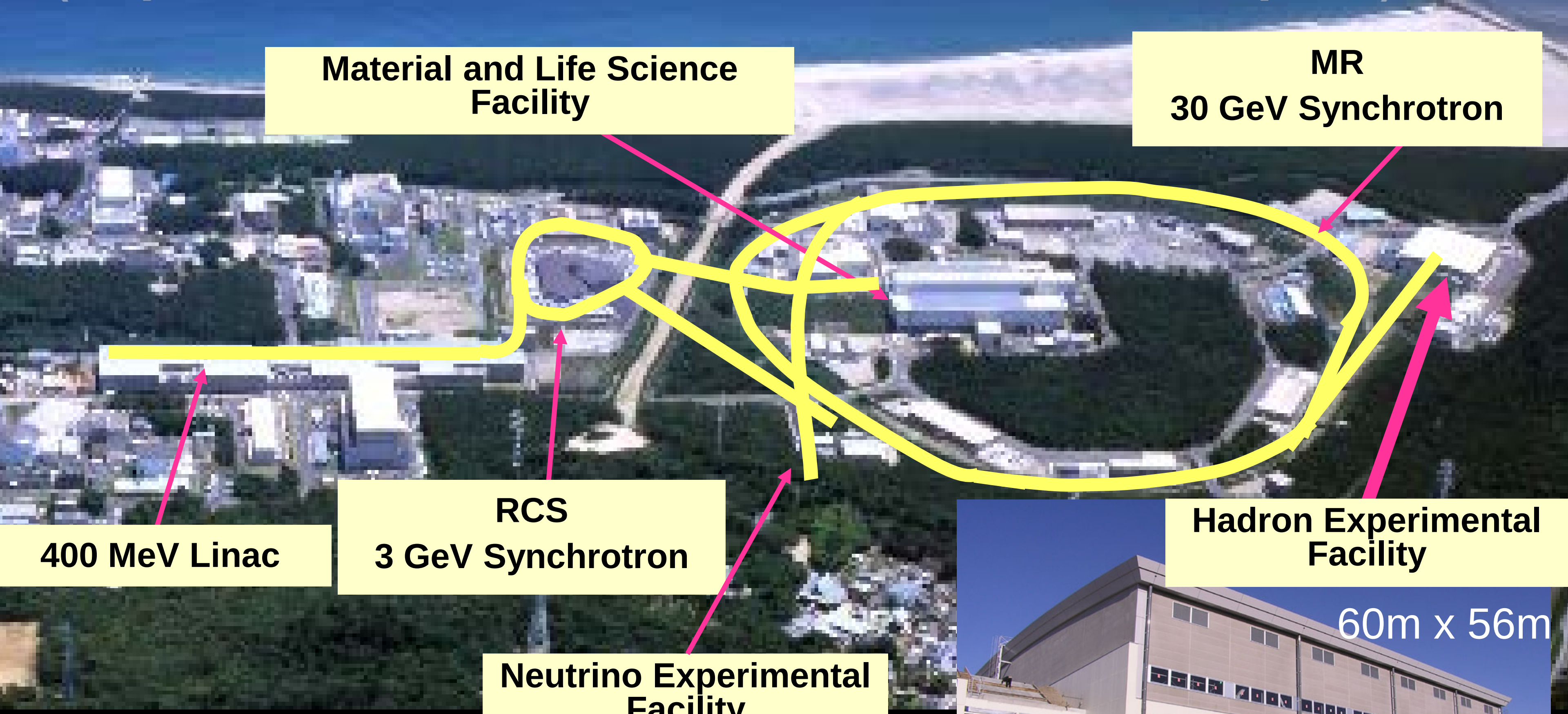
K. Ozawa (KEK)

Where is J-PARC?

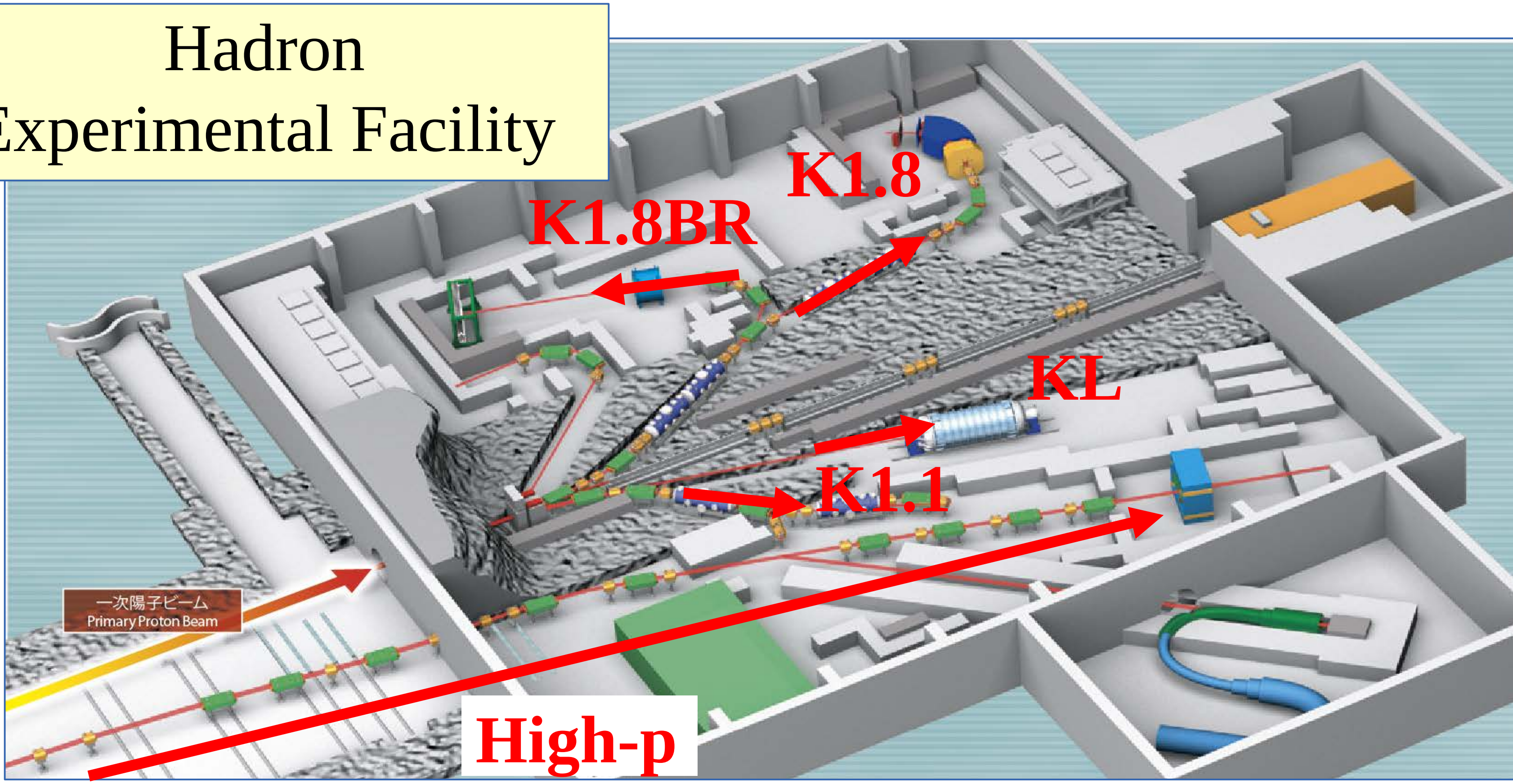
J-PARC

Tokai, Japan

(Japan Proton Accelerator Research Complex)



Hadron Experimental Facility



	Name	Species	Energy	Intensity
	K1.8	$\pi^{\pm}$, $K^{\pm}$	< 2.0 GeV/c	~10^5 Hz for K^+
	K1.8BR	$\pi^{\pm}$, $K^{\pm}$	< 1.0 GeV/c	~ 10^4 Hz for K^+
	K1.1	$\pi^{\pm}$, $K^{\pm}$	< 1.1 GeV/c	~ 10^4 Hz for K^+
New Beamline	High-p	proton	30GeV	~ 10^{10} Hz
		Unseparated	< 20GeV/c	~ 10^8 Hz

New Beam Line – Physics Program

Primary Proton Beam

pA reaction

Chiral properties of nucleus

Secondary Beam

πA reaction

Charmed baryon/meson

Multi-strangeness baryons

Nucleon structure probed by π meson

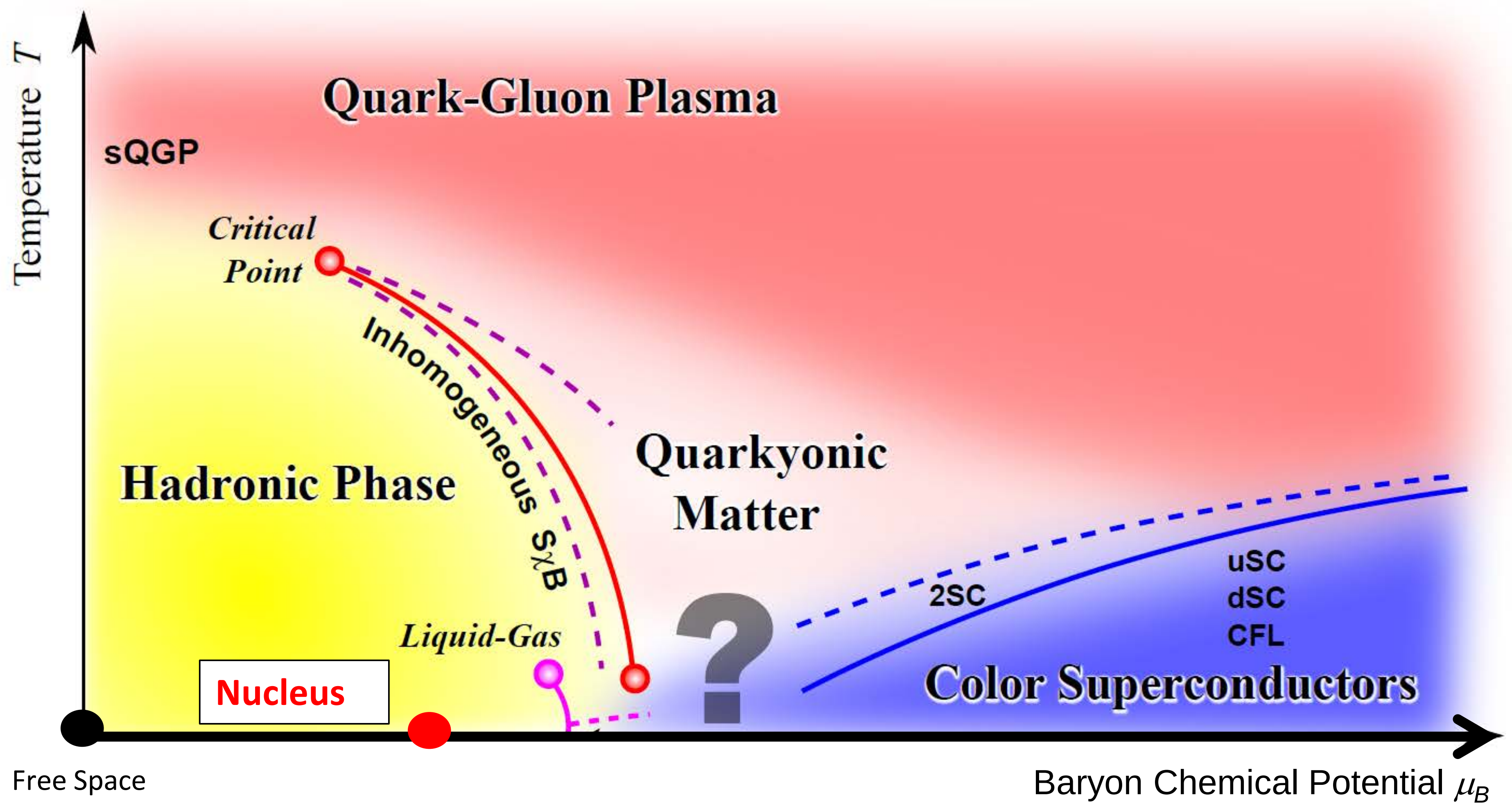
Heavy Ion Beam?

AA reaction

High density baryonic matter

Physics: Finite density QCD medium

K. Fukushima and T. Hatsuda, Rep. Prog. Phys. 74 (2011) 014001



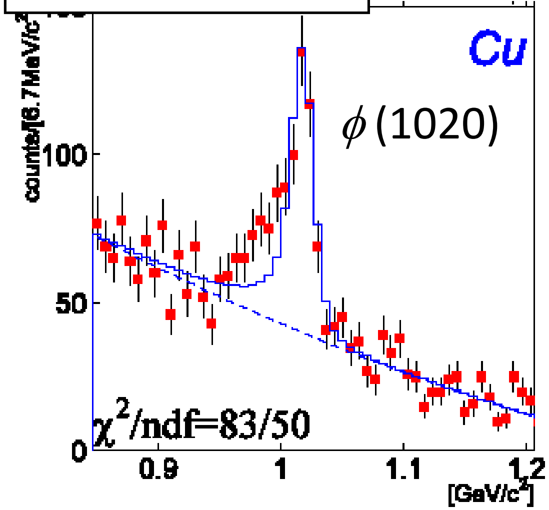
Nucleus as a finite density QCD medium

Explore high baryon density medium in Heavy Ion collisions

Vector mesons in nucleus

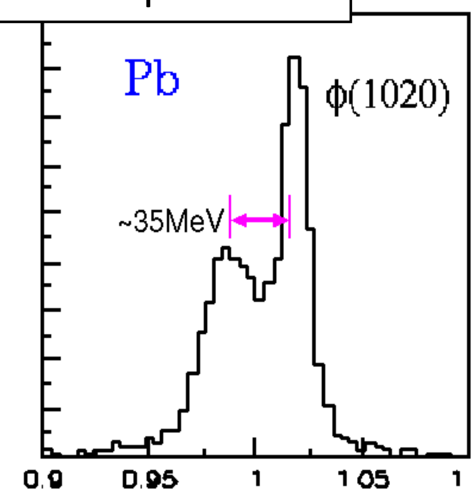
- Spontaneously broken chiral symmetry and its (partial) restoration.
  - Hadrons are excitations of QCD vacuum (ground state) and are affected by the "vacuum" property.
  - Spectral change in nuclear medium provides information on the non-trivial structure of QCD vacuum at finite density.
- Next experiment at J-APRC
  - Invariant mass spectra of e^+e^- pairs in pA collisions
    - Vector meson mass modification due to nuclear matter effects
    - High statistics/Good resolution
  - Similar as KEK-PS E325, but with x100 stat.
  - The experiment will start in early 2020

KEK E325 results



High stat.
Better res.

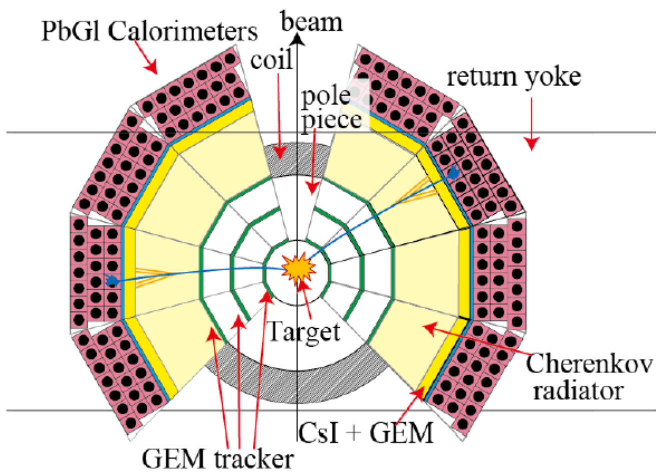
J-PARC expectation



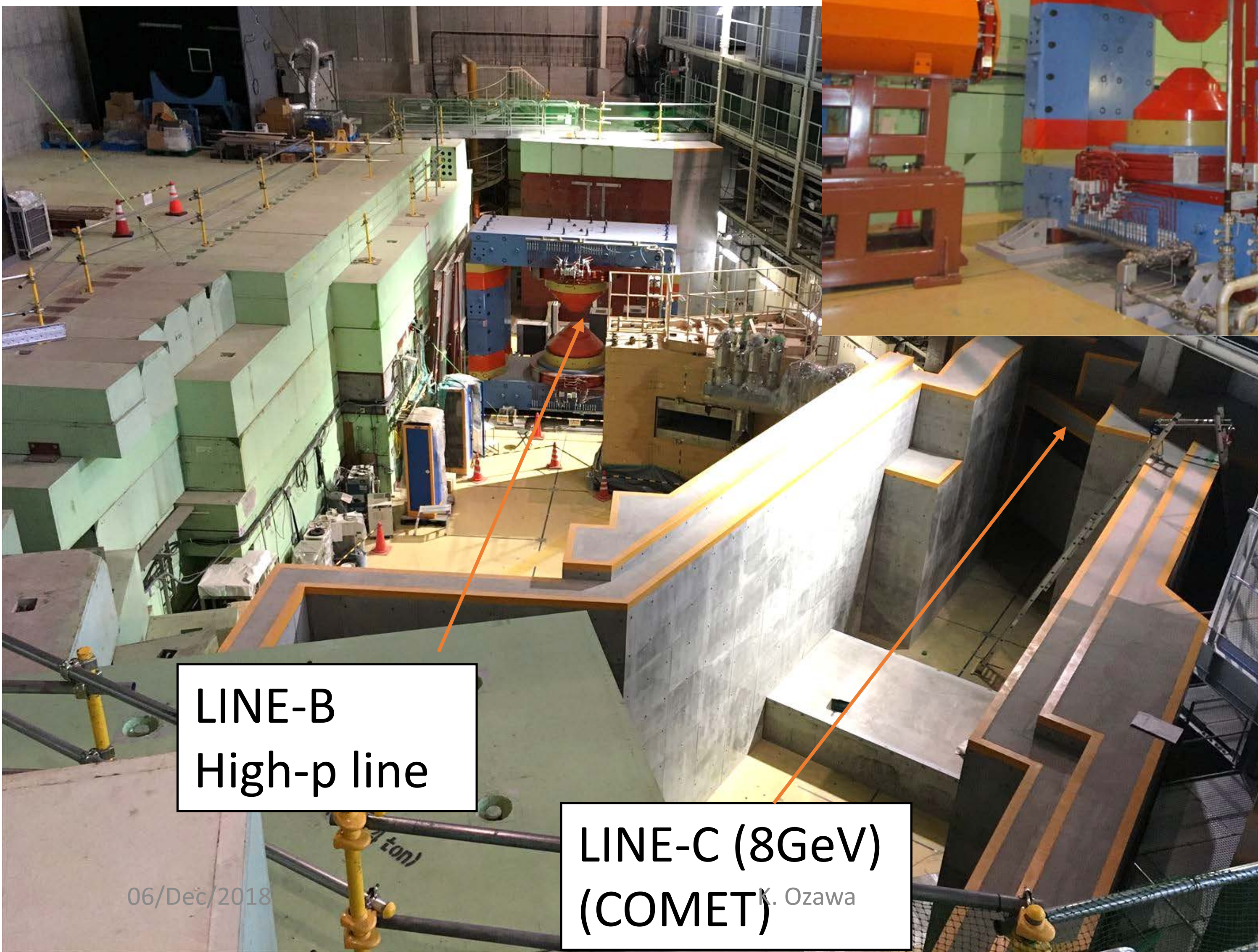
J-PARC E16 Experiment

- Measurements of e^+e^- pair invariant mass spectra in nucleus
- Coping with a high intensity beam to have a large statistics
  - 10^{10} protons per spill, spill length 6s, spill on 2s
  - Counting rate: 5 kHz/mm^2 (maximum)
  - We choose SSD and GEM trackers
- Covering a large area
  - 5 times larger pair acceptance
  - 2 times larger coverage in vertical
  - Large coverage in electron ID counters
  - Horizontal: +-15 ~ +-135, Vertical: +- 45
- Precise mass (momentum) resolution
  - ∫Bdl ~ 1Tm
  - Minimum material to avoid Multiple Scatterir
  - Position resolution of 100 μm
- Detector configuration
  - Trackers are placed near target
  - Electron ID counters are placed in outer side.
    - Total rejection factor of 1000 for two stages identification counters (HBD and LG)

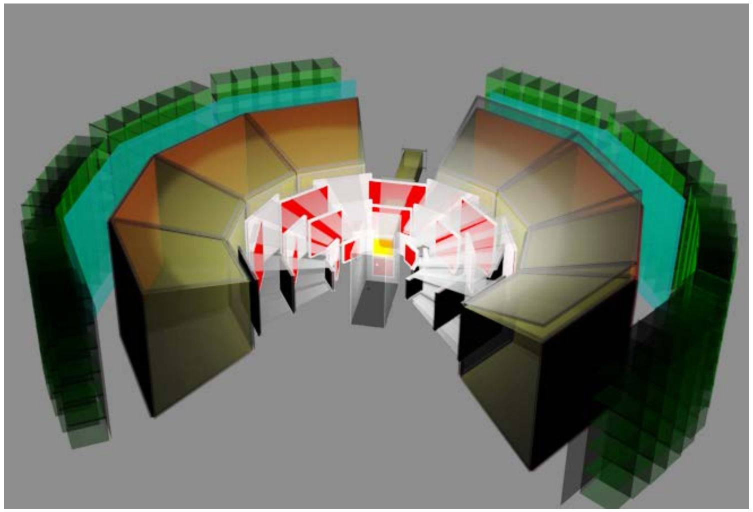
Conceptual Design



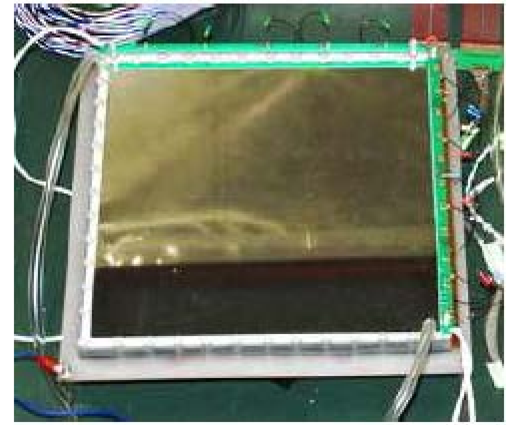
Experimental area and Magnet



Spectrometer

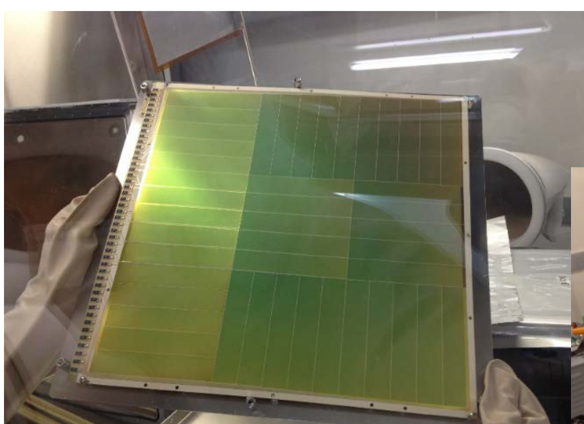


SSD



GEM Tracker

Electron ID (HBD and Lead Glass)



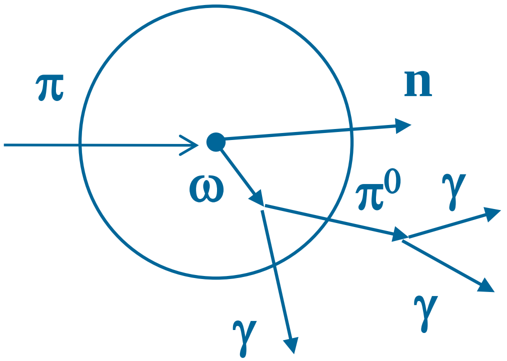
300x300mm^2 GEM with CsI

Other experiment: ω mesons at rest

- Measurements of ω mesons mass spectra in nucleus at rest
  - When we choose a momentum of the incident beam carefully, we can generate ω mesons “at rest”.
    - Forward emitted neutron carries momentum of incident beam and generated ω meson has small momentum

$$\pi^- A \rightarrow \omega + n + X$$

$$\omega \rightarrow \pi^0\gamma$$



Reaction:

$\pi^- + p$ (in A) $\rightarrow \omega + n$

We can measure

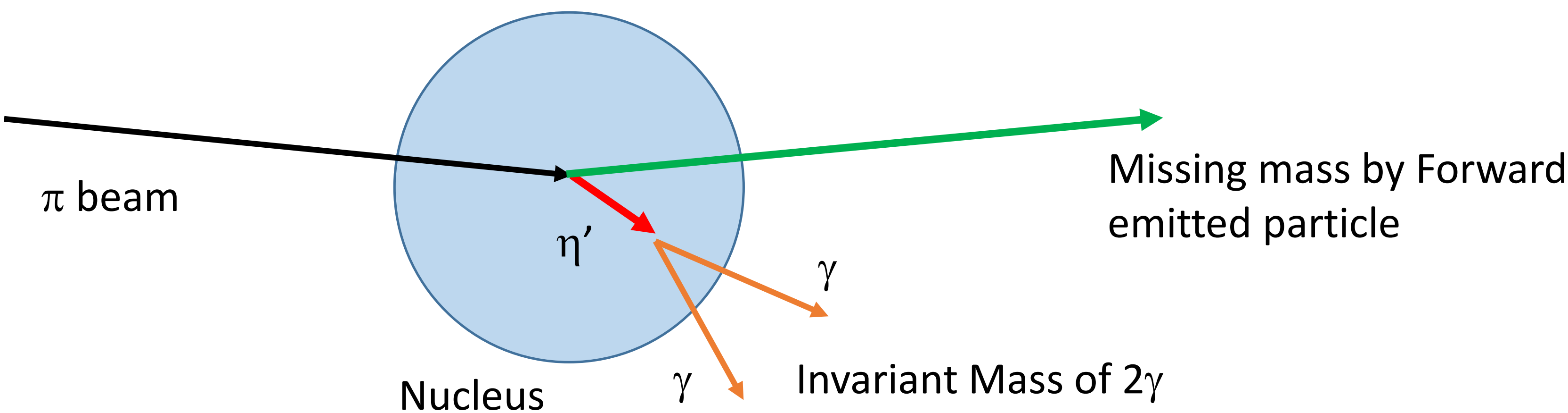
π (beam), ω (decays), emitted neutron (Forward detector)

The reaction dynamics can be identified by these measurements.

η' meson in nucleus

~ Collaboration btw Hungary and Japan

- A new experiment is being proposed by Prof. Csörgö and me to study properties of η' meson in nucleus
- Pseudo scalar mesons are Nambu-Goldstone bosons in the spontaneous breaking of the chiral symmetry. Especially, η' meson is related to UA(1) anomaly and important.
  - At RHIC-PHENIX, a large mass reduction is observed and it should be studied also in nucleus
    - T. Csörgö *et al.*, Phys. Rev. Lett. 105:182301,2010

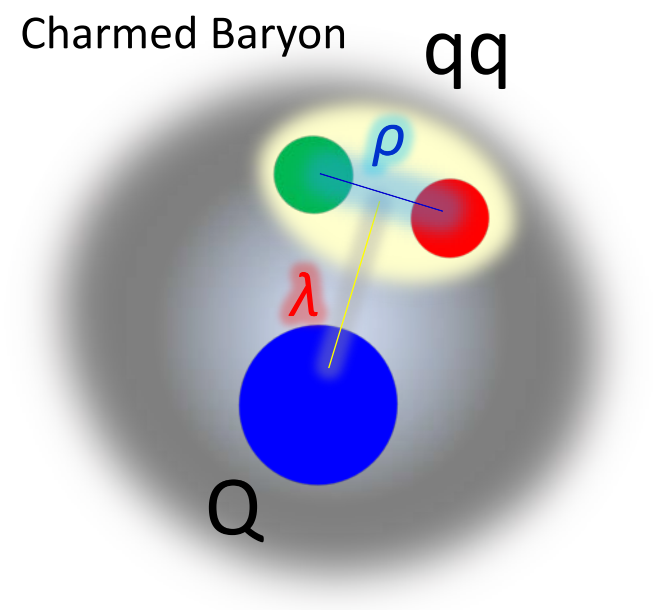


Charm sectors in nucleus

- Charmonium (ψ')
  - Effects of gluon condensates in the matter
  - Significant mass decreasing is suggested
    - Gy. Wolf, G. Balassa, P. Kovács, M. Zétényi, S.H. Lee,Phys. Lett. B780 (2018) 25, arXiv:1712.06537
  - Direct measurements using πA reactions and the same spectrometer can be used as pA reactions

- D mesons
  - Effects of chiral symmetry restoration to Heavy-Light quark system
  - Probe condensates with light constituent quark (and heavy quark)
  - 20~30 MeV mass "increasing"
    - K. Suzuki, P. Gubler, M. Oka, Phys. Rev. C 93, 045209 (2016)
    - A. Park, P. Gubler, M. Harada, S. H. Lee, C. Nonaka, and, W. Park, Phys. Rev. D 93 054035(2016)
  - Yield measurements at the threshold region are sensitive to mass modifications

Di-quark correlation



Di-quark correlation can have an important role in a finite density matter

Quark-Quark condensates for color super conducting

Study of Charmed Baryon can provide important information for Di-quark correlation

Charmed Baryon

Weak Color Magnetic Interaction with a heavy Quark

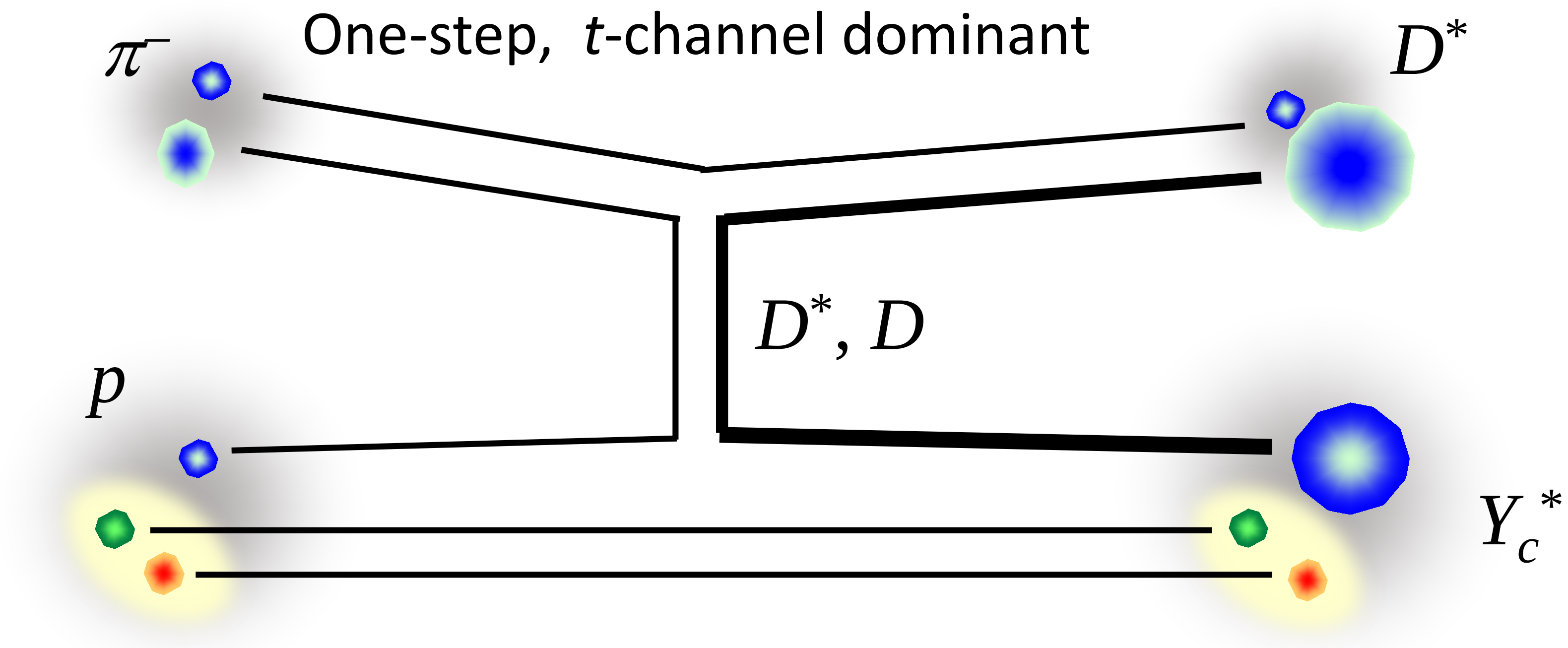
- [qq] is well Isolated and developed

- Excited mass level structure of Y_c* provides di-quark properties
  - Di-quark motion (λ mode) and single quark motion (ρ mode) can be identified

Proposed Experiment

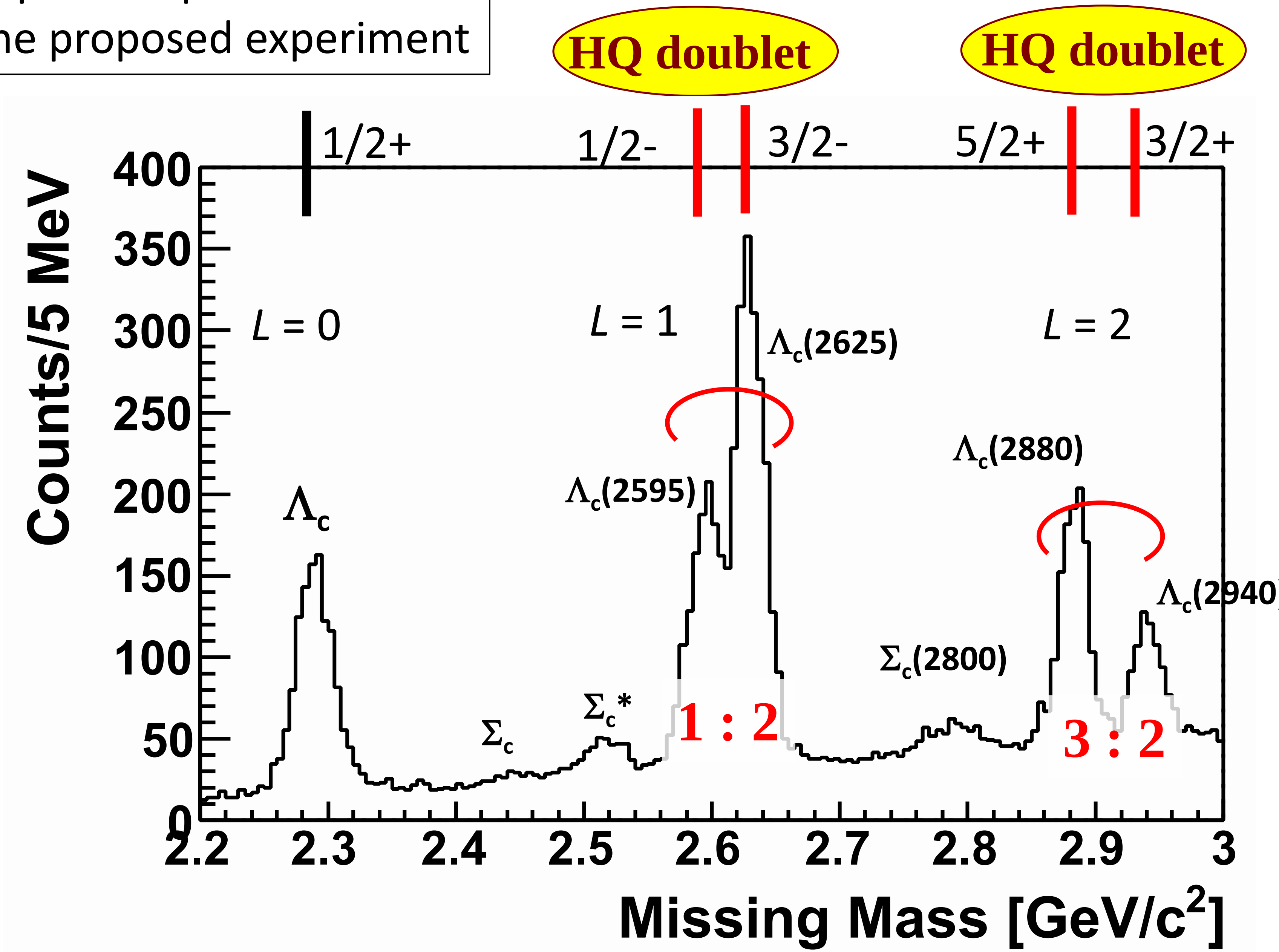
S.H. Kim, A. Hosaka, H.C. Kim, H. Noumi, K. Shirotori, PTEP 10, 103D01 (2014)

A. Hosaka *et al.*, Nuclear Physics A, in press



- ✓ Measurements of p- beam and forward emitted D*
  - ✓ Missing mass techniques to identify Charmed Baryon mass
  - ✓ Decay products are also detected to obtain further information

Expected spectrum for the proposed experiment



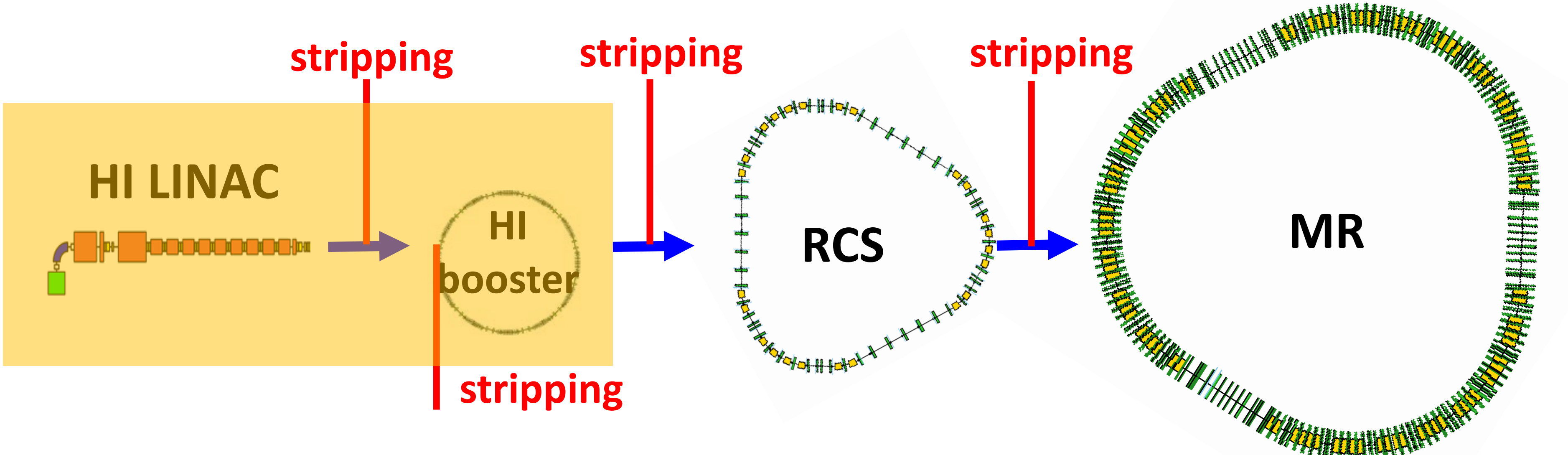
J-PARC HI Project

Acceleration Scheme for Uranium case(Proposed by H. Harada, J-PARC)

$U^{35+} \rightarrow U^{55+}$
20.0→19.86 MeV/u

$U^{66+} \rightarrow U^{86+}$
67.0→62.34 MeV/u

$U^{86+} \rightarrow U^{92+}$
735.21→727.0 MeV/u



U^{35+}
20.0MeV/u

$U^{55+} \rightarrow U^{66+}$
19.86→67.0 MeV/u

U^{86+}
62.34→735.21 MeV/u

U^{92+}
727.0Mev/u→11.15 GeV/u
(30GeV@p)

New LINAC and Booster for HI must be constructed.

J-PARC Heavy Ion specification

“Low energy” program (Linac)
for unstable nuclei research

- Ion species
  – Ne, Ar, Fe, Ni, Kr, Xe,…,U
- Beam energy
  – 1 - 10 AMeV (U)
- Beam current
  – 10-30 pμA
  – 10ms, 25Hz

“High Enegy” Program (30 GeV MR)

- Ion species
  - p, Si, Ar, Cu, Xe, Au(Pb), U
  - Also light ions for hypernuclei
  - Maximum baryon density in U+U
- Beam energy
  - 1 - 11 AGeV(U, $\sqrt{s_{NN}} = 2{-}4.9\text{GeV}$)
  - 19 AGeV(U, $\sqrt{s_{NN}} = 6.2\text{GeV}$) for 50GeV
- Rate
  - 10^{10}-10^{11} ions per cycle (~a few sec)

Physics

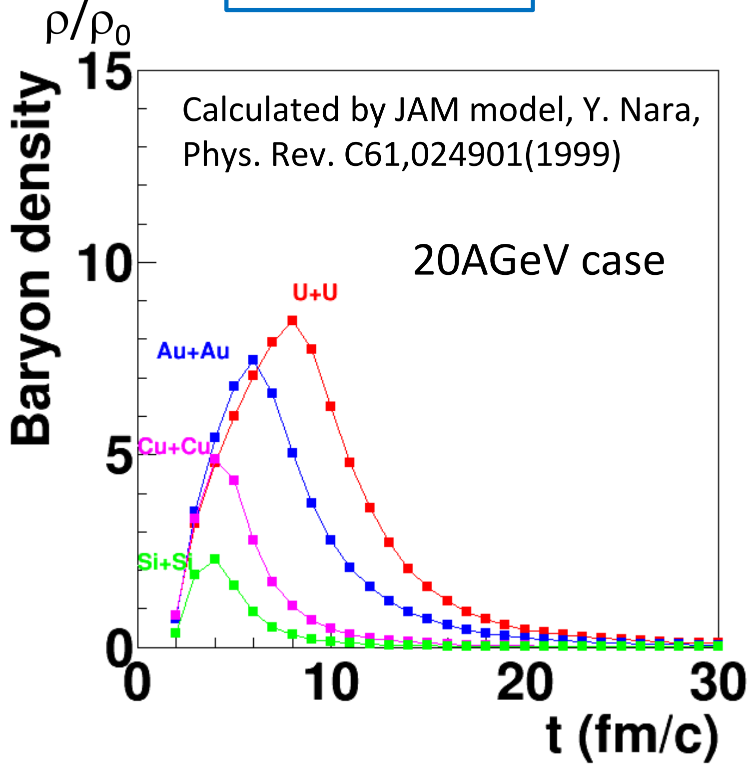
- Study of High Density Matter
  - Strange meson and baryons
  - Event-by-event fluctuations
  - Two particle correlations
    (YN, YY correlations in high baryon density)
  - flow (related to EOS?)
  - Di-leptons (di-electron and di-muon)
    - Vector meson mass spectra

- Hadron Physics
  - Hypernuclei
  - Exotic hadrons
    - $\Lambda(1405)$
    - Dibaryon (H-dibaryon, ΩN, $\Delta\Delta$,…)
    - Kaonic nucleus (K^-pp,…)
  - Charm
    - J/ψ, D, charmed baryons

Onset of QGP

Search for critical point

Properties of Dense matter



Summary

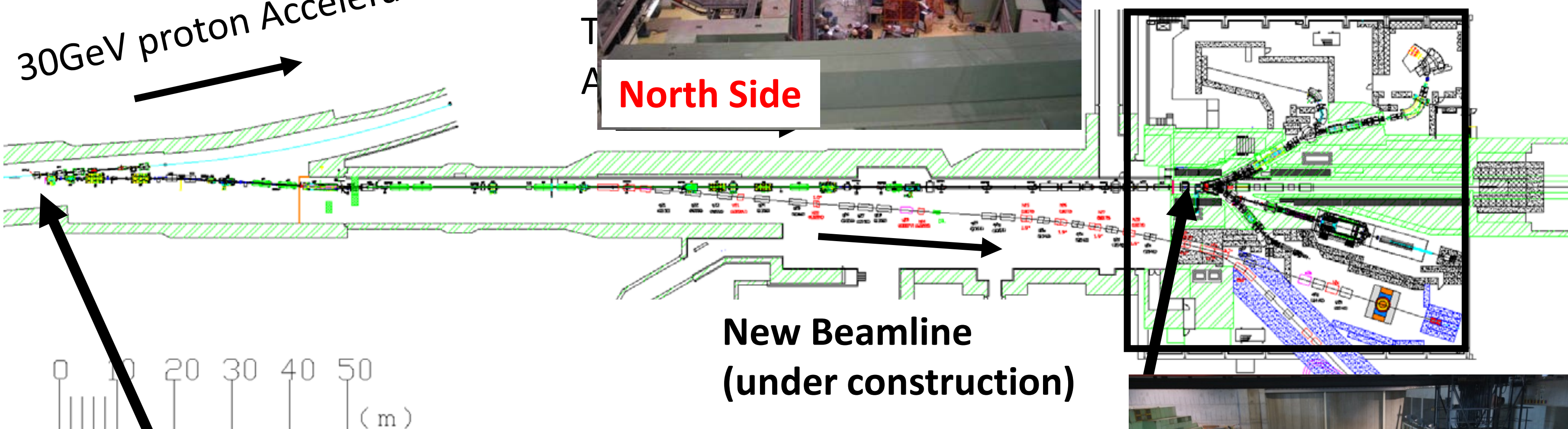
- New beam line is under construction. The beam line will provide following beams
  - Primary Proton for pA experiment
  - Secondary produced beam for πA experiment
  - Heavy Ion Beam for AA experiment
- An experiment to measure vector mesons in nucleus is in preparation and several related experiments are proposed.
- Future Heavy ion program at J-PARC is under discussion.

Back up

30 GeV Accelerator & Hadron Experimental Facility

Hadron Experimental Facility

30GeV proton Accelerator



New Beamline (under construction)

Branch Point from Acc. to Hadron

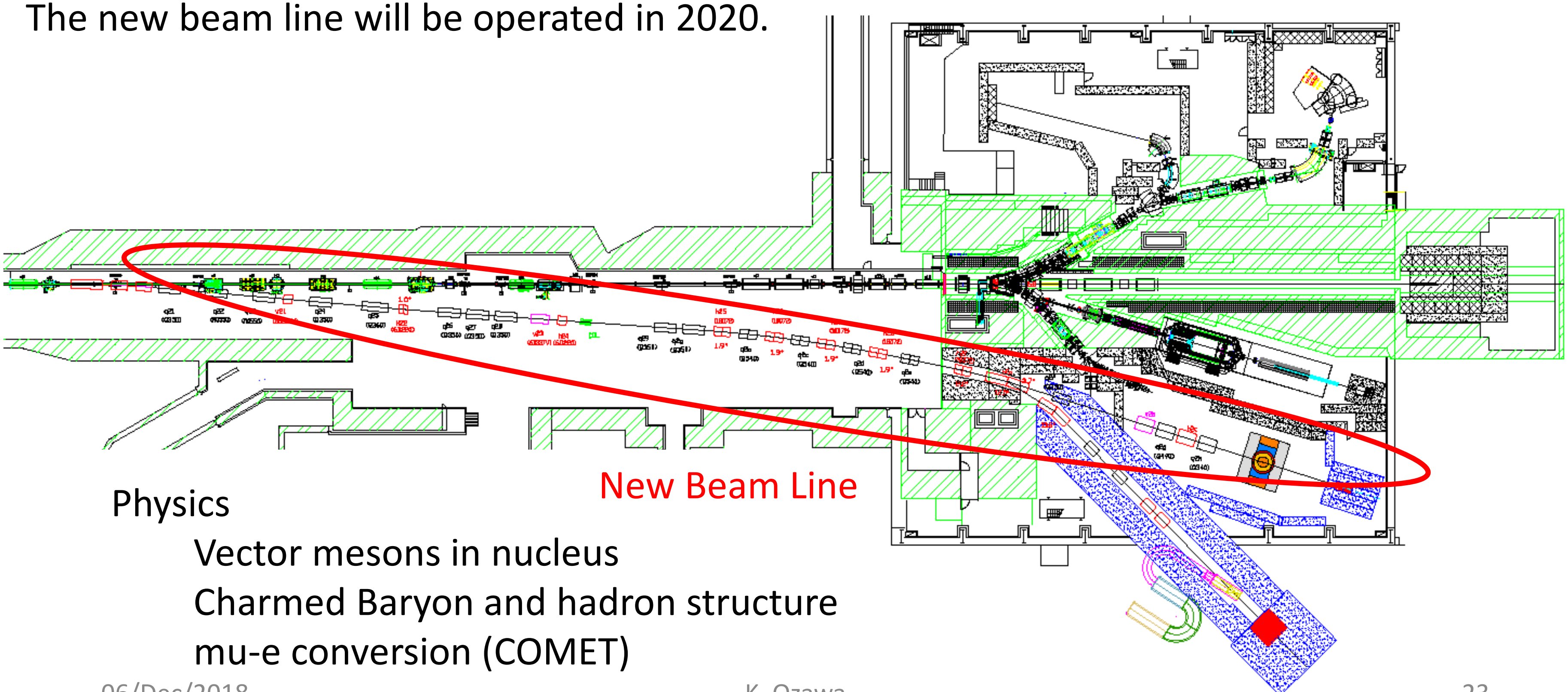
Current Pr target for beams

New Beam Line

Construction of New Beam Line is proposed as a high priority plan of the lab.
Characteristics of the beam line is following.

- Primary Proton Beam (30GeV), 10^{10} per spill
- High Momentum un-separated secondary beam (< 20GeV/*c*), 10^{8} per spill
- Primary Proton Beam (8GeV) for COMET

The new beam line will be operated in 2020.



Physics

- Vector mesons in nucleus
- Charmed Baryon and hadron structure
- mu-e conversion (COMET)

Medium properties and χ-sym.

Spontaneous breaking of a symmetry is marked by a non-zero order parameter, a quark condensate $\langle \bar{q}q \rangle$ for this case

Observables for $\bar{q}q$ condensates

- Decay constant of π meson
    - Gell-Mann-Oakes-Renner relation
        - M. Gell-Mann *et al.*, PRL 175(1968) 2195.
    - Experimentally, πN scattering lengths in nucleus is measured using a deeply bound pionic atom
        - K. Suzuki et al., Phys. Rev. Let. 92(2004) 072302 (Experiment)
        - D. Jido, T. Hatsuda, T. Kunihiro, Phys. Lett. B670:109-113, 2008 (Theory)

- Mass spectra of vector and axial vector
    - Weinberg type sum rule

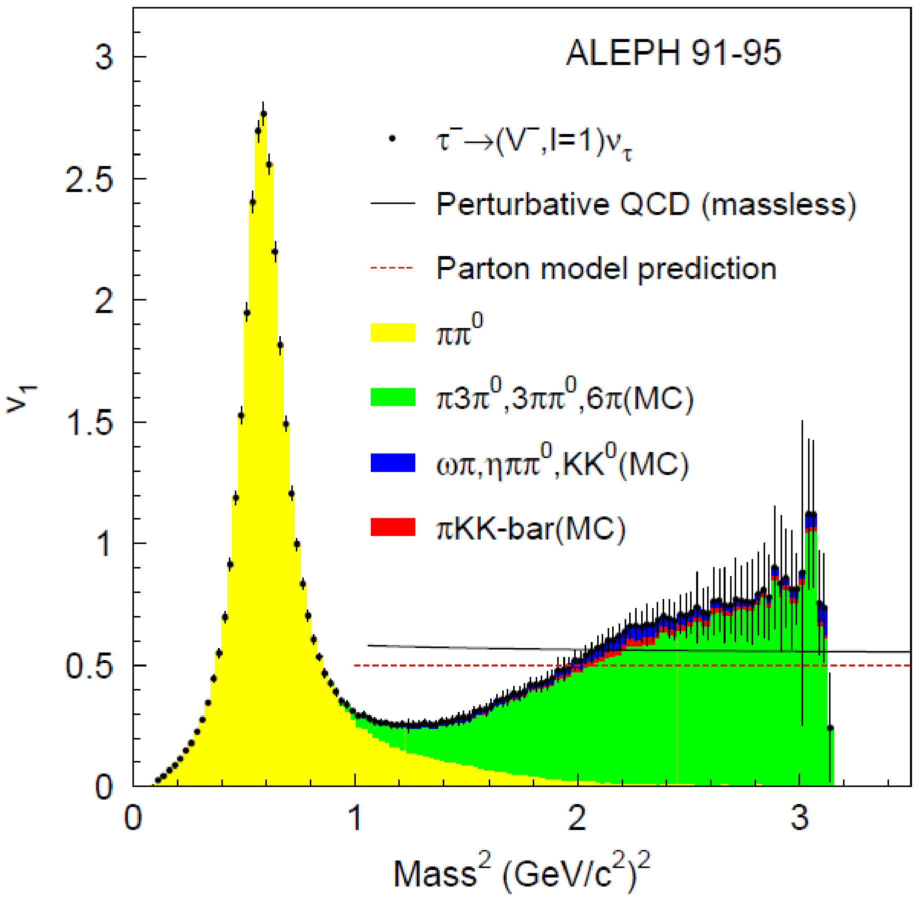
V-A Mass spectra

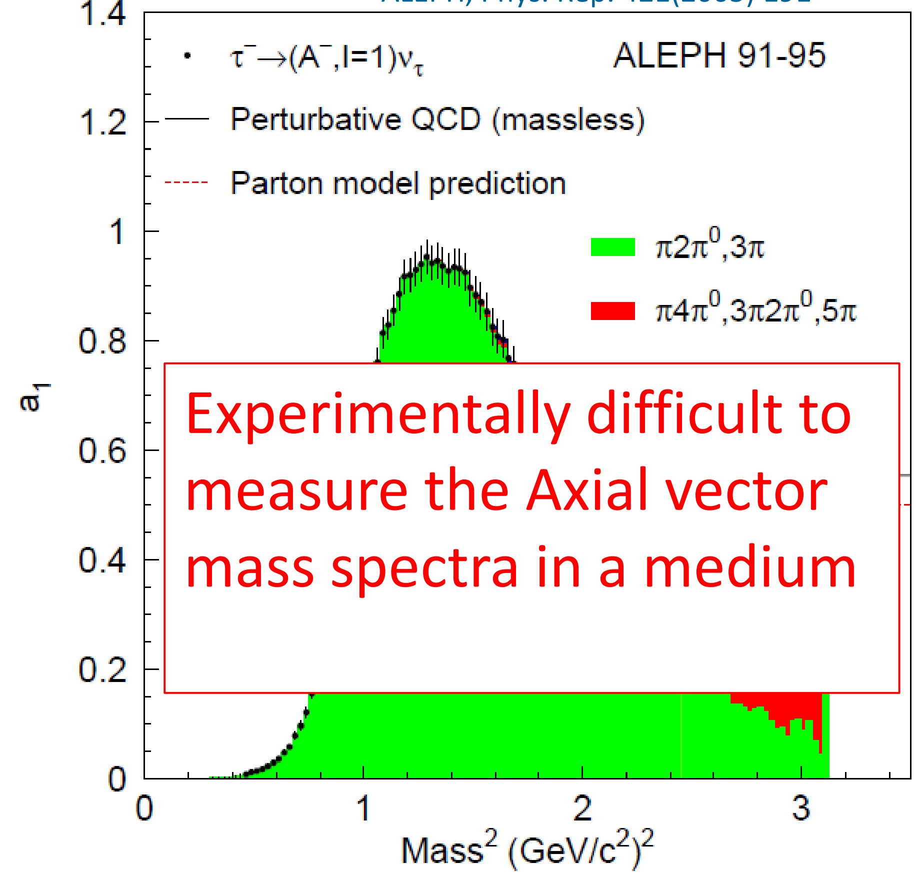
Hatsuda, Koike and Lee, Nucl. Phys. B394 (1993) 221
Kapusta and Shuryak, Phys. Rev. D49 (1994) 4694

Weinberg type sum rule

$$\int_0^\infty d\omega^2 \omega^2 (\rho_V(\omega) - \rho_A(\omega)) = -\frac{4\pi}{3}\alpha_s \langle O_{4q} \rangle$$

ALEPH, Phys. Rep. 421(2005) 191





What can we do in a medium?

- Using a QCD sum rule, a relation between a mass spectrum of a vector meson and a quark condensate is suggested.
  - Hatsuda and Lee, Phys. Rev. C46 (1992) R34

- Experimentally,
  - Mass spectra of vector mesons can be measured through di-leptons spectra
  - It can be measure in nucleus and hot and dense matters
    - It can probe an amount of quark condensates in several “QCD medium”.

- Thus, measurements of vector meson mass spectra in “QCD media” are important as basic experimental information

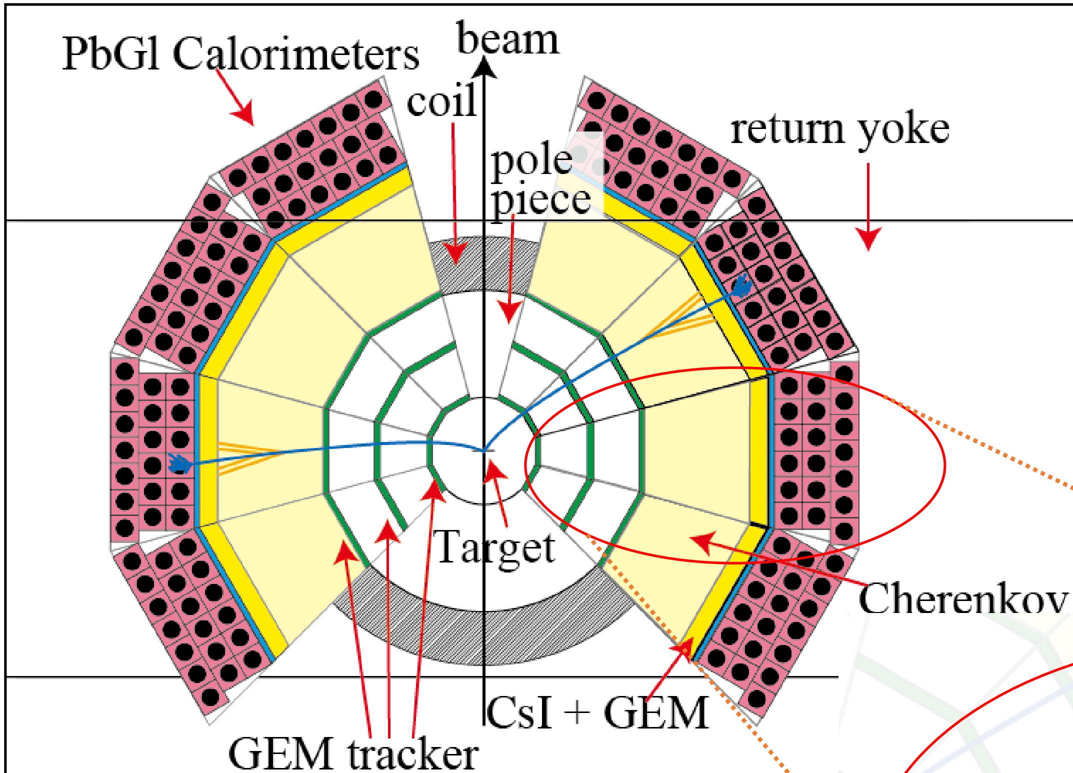
Many measurements are done

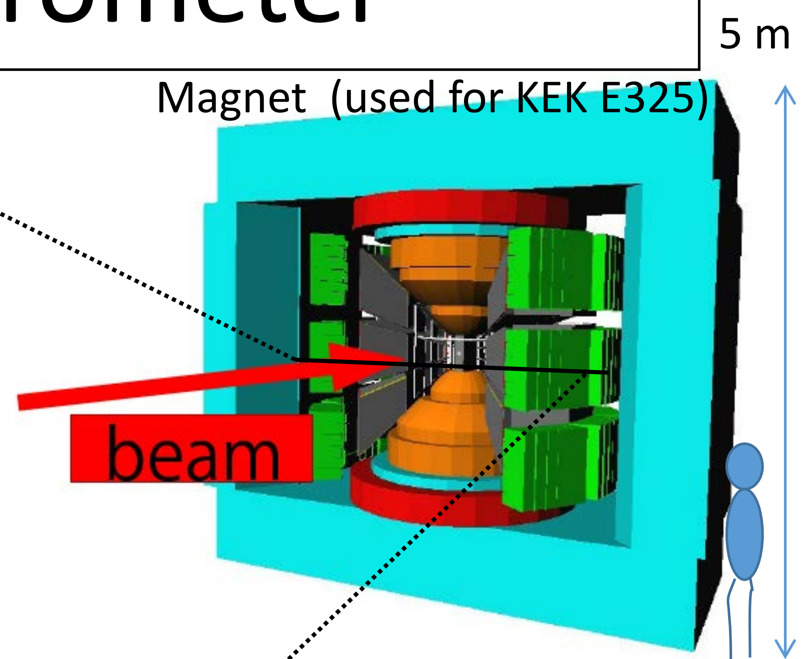
Modifications of spectra are observed, however, condensates are not yet evaluated.

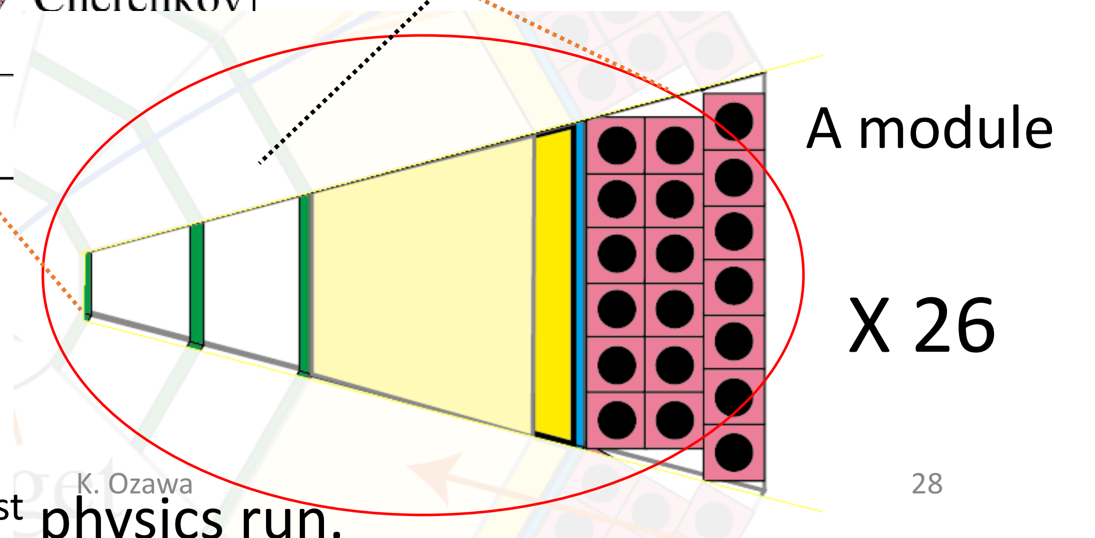
- High energy heavy ion collisions
  - SPS-NA60 (PRL 96 (2006) 162302)
    - Modification of ρ meson due to hadronic effects
  - RHIC-STAR (PRL113(2014) 022301)
  - RHIC-PHENIX (PRC81(2010) 034911, arXiv:1509.04667(PRC))
    - Enhancement in low mass region

- Nuclear targets
  - HADES (G. Agakishiev et al. Eur. Phys. J. A 48 64 (2012).)
    - Enhancement in low mass region
  - 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
    - Large Width of ϕ (Phys. Rev. Lett. 105 (2010) 112301)
  - LEPS (Phys. Lett. B608 (2005) 215)
    - Large Width of ϕ
  - KEK-PS E325 (PRL 96 (2006) 092301, PRL 98(2007) 042581)
    - Peak shift and width broadening of ρ/ω, ϕ

The J-PARC E16 spectrometer







SSD : Tracking

GTR : Tracking

HBD : eID (Cherenkov)

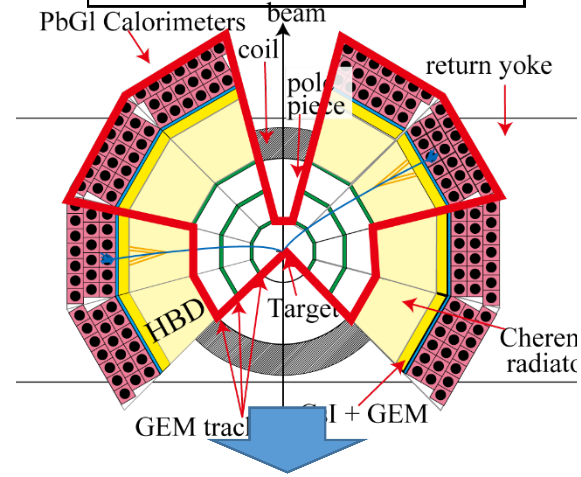
LG : eID (Calorimeter)

26 modules in total. 8 for the 1st physics run.

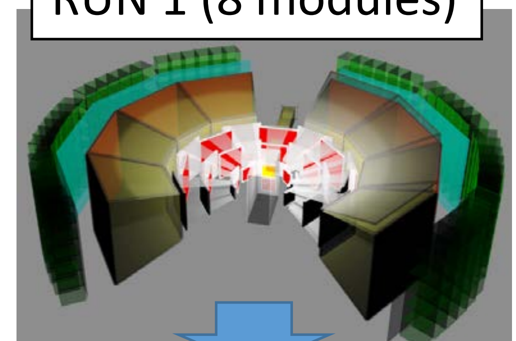
Strategy

- **<u>RUN 0 - 2020</u>** -- 40 shifts (8hrs/shift)
  - **6 (SSD) + 8 (GTR) + 4 (HBD) + 4 (LG)**
    - The current budget allows us to build (budget profile is taken into account)
    - We already have 6 SSDs. But not satisfactory.
  - BL / Detector commissioning + yield
    - Prove that the E16 spectrometer works as a whole.
- **<u>RUN 1</u>** – 160 shifts
  - **8 (SSD) + 8 (GTR) + 8 (HBD) + 8(LG)**
  - Physics data taking. ϕ: 15k
- **<u>RUN 2</u>** -- 320 shifts
  - **26 (SSD) + 26 (GTR) + 26 (HBD) + 26 (LG)**
  - Produce physics results which we've advertised for years!

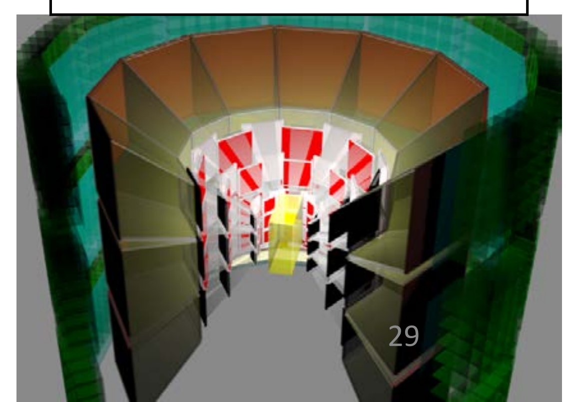
RUN 0 configuration



RUN 1 (8 modules)



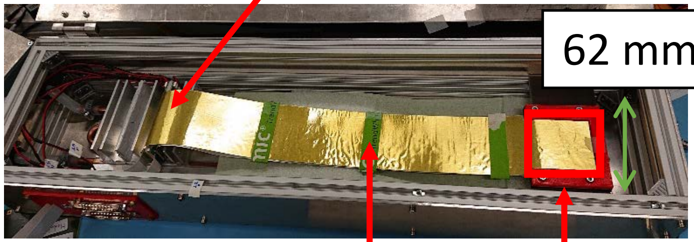
RUN 2 (26 modules)



Silicon Strip Detector

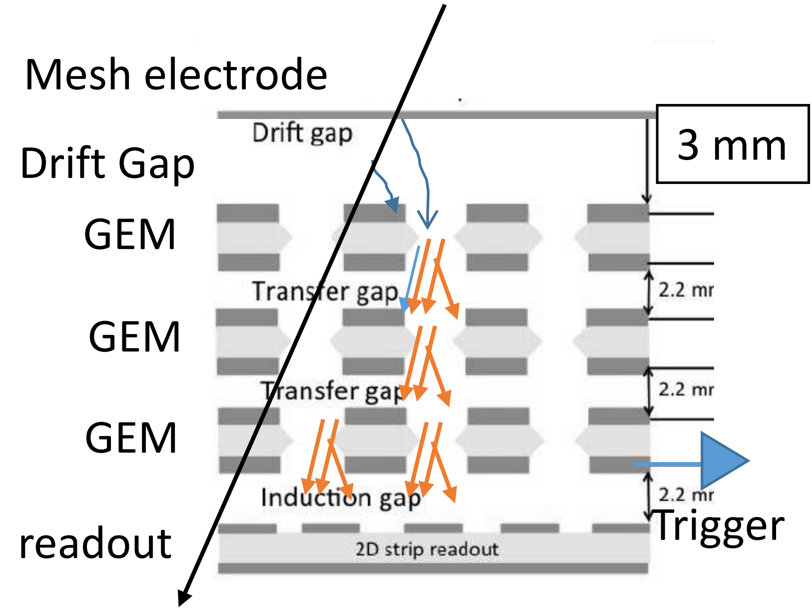
- Run0
  - Existing 6 SSDs used for another J-PARC experiment.
    - ATLAS sensor
    - Sensitive area: 61 mm x 62mm
    - Strip pitch 80 um. (1D)
    - Timing Resolution 4ns
    - It has large unwanted frame.
    - The readout ASIC is APV-25

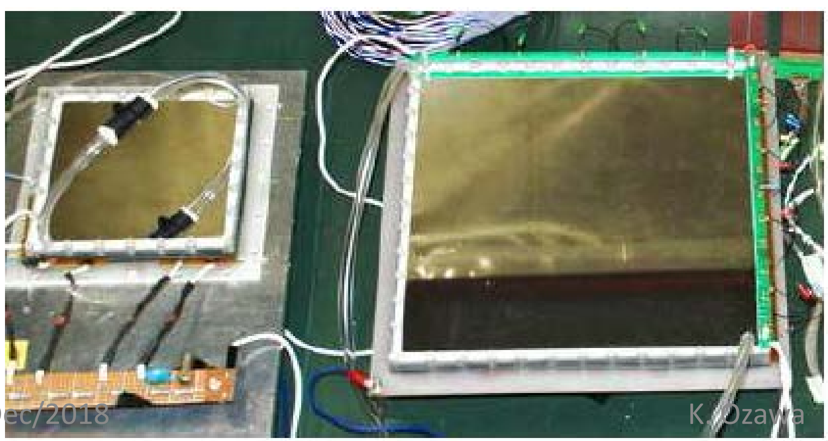
- Run1
  - Starting collaboration with FAIR-CBM
    - CBM developed sensor
    - Sensitive area: 60 mm x 60 mm
    - Strip pitch 50um (Double sides)
    - Almost no frame
    - The readout ASIC is a CBM special chip
      - Developed for the streaming DAQ, however it can be used for a triggered DAQ

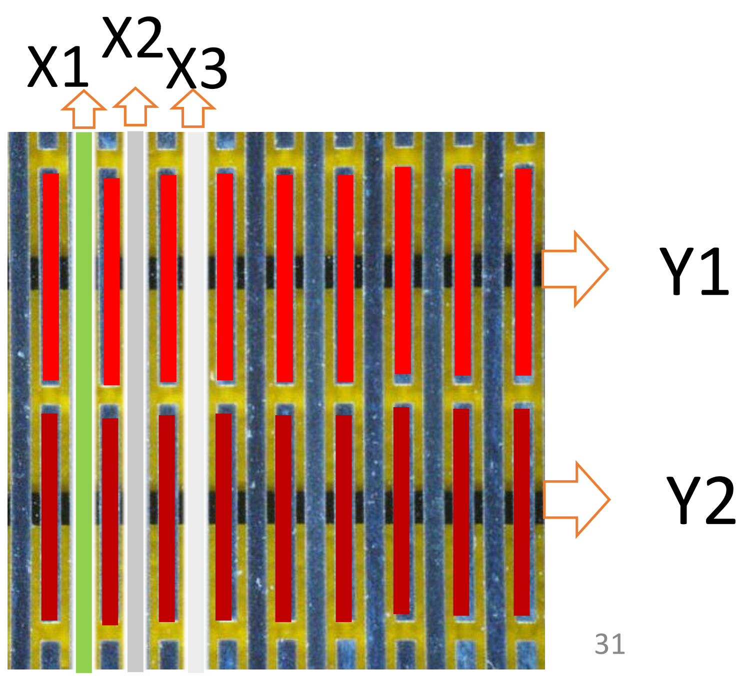


GTR (GEM Tracker)

- Ionization electrons in the drift gap are collected and amplified by GEMs.
- Charge collected on to 2D strip readout.
  - X: 350um pitch
    - Sensitive to bending direction.
    - 100 um resolution required.
  - Y: 1400um pitch
- Assembly works are on-going.

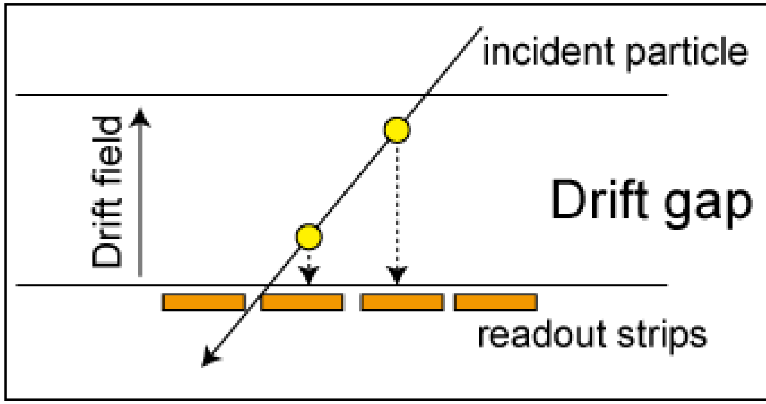






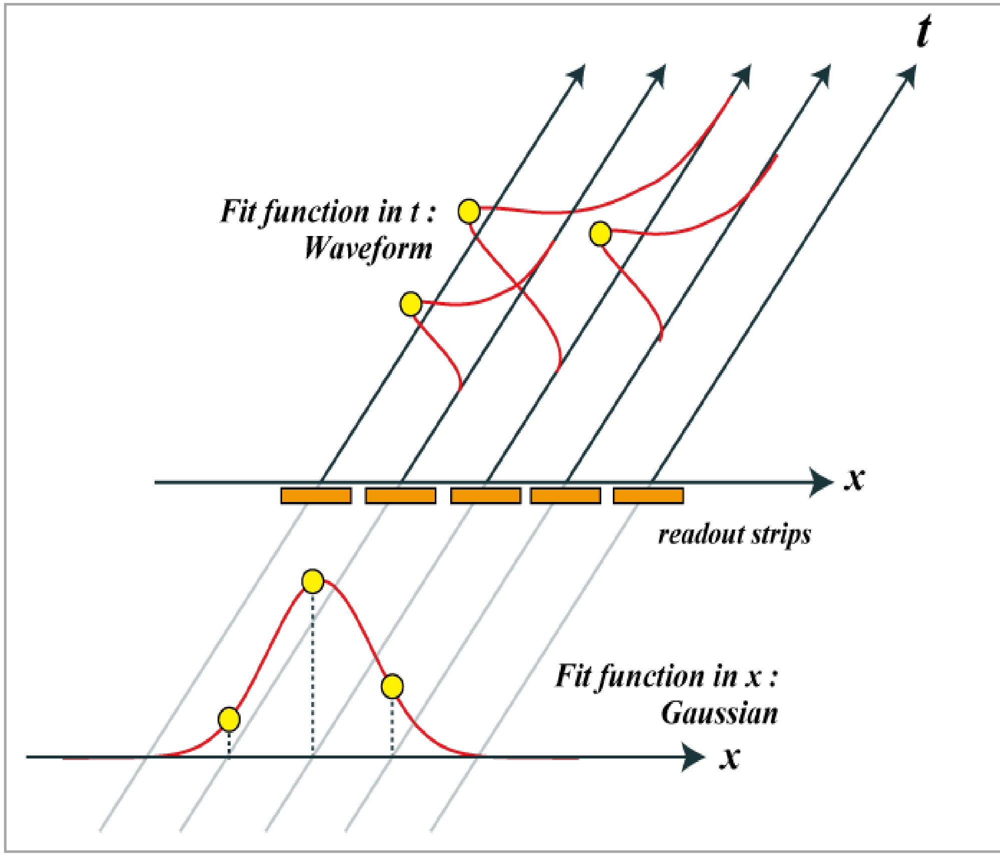
GTR Performance

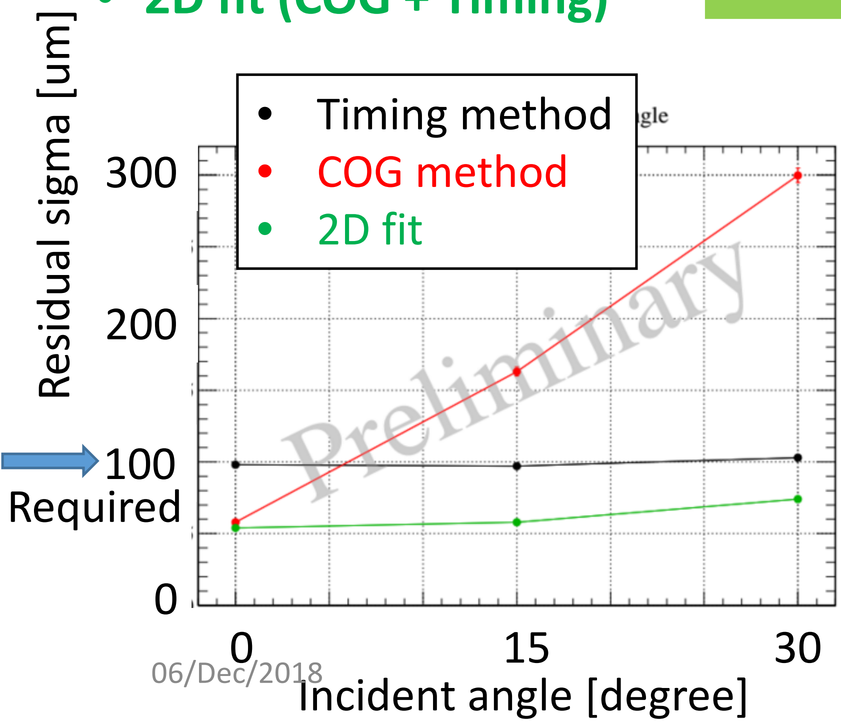
- Center Of Gravity (COG) Method
  - Ordinal analysis method
  - ~ 60 μm @ 0 degree of incident angle
  - Worse results for inclined tracks



- Timing method
  - Distance in drift field dir. Can be obtained using flight time like mini-TPC
  - ~ 100 μm for all tracks

- **2D fit (COG + Timing)**

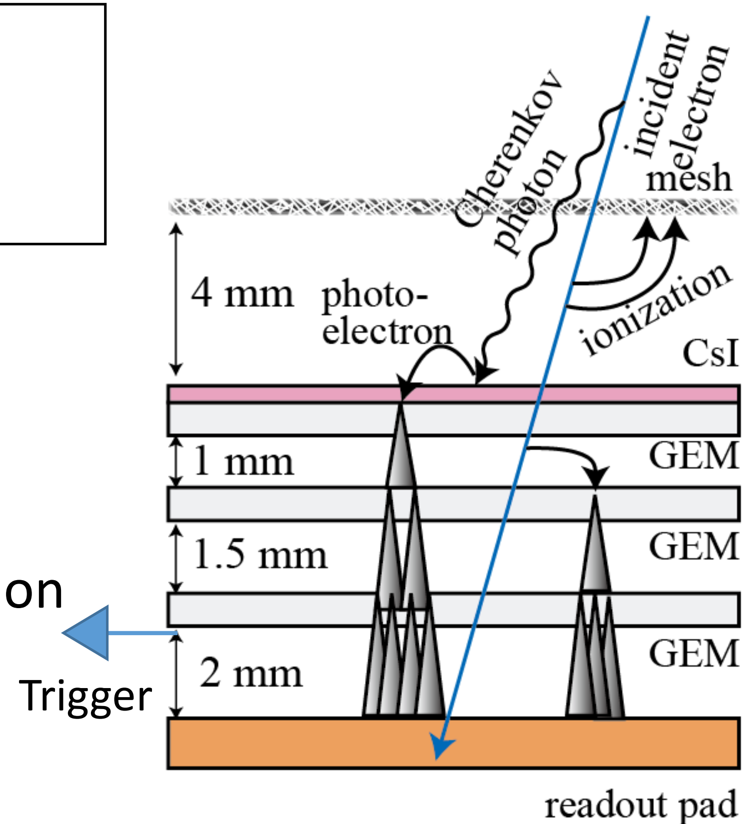


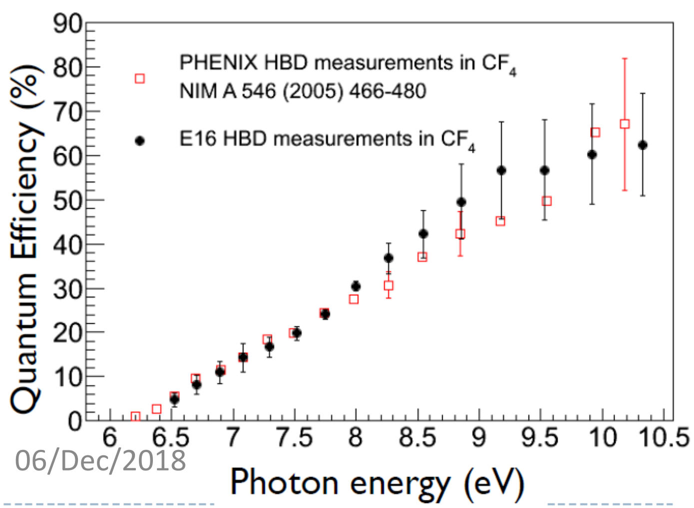


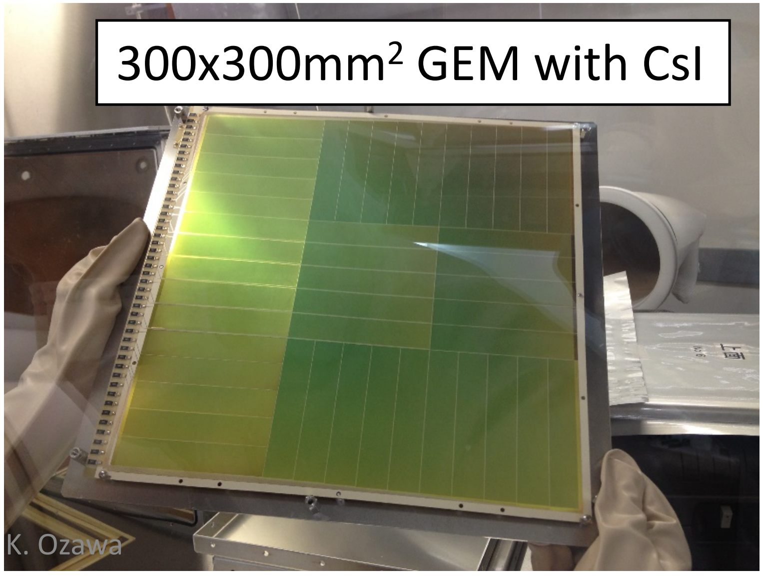
HBD
(Hadron Blind Detector)

- Based on PHENIX HBD.
- CF4 serves as radiator and amplification gas
  - Radiator 50 cm. / p.e. ~ 11

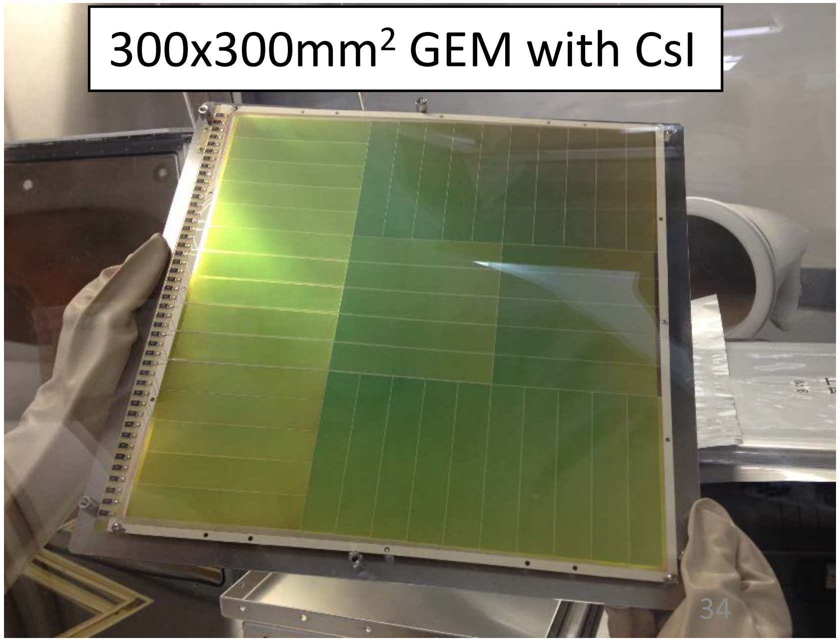
- Gas Electron Multiplier (**GEM**) for amplification
- **CsI** is evaporated on top GEM
  – Photocathode (> ~6eV)

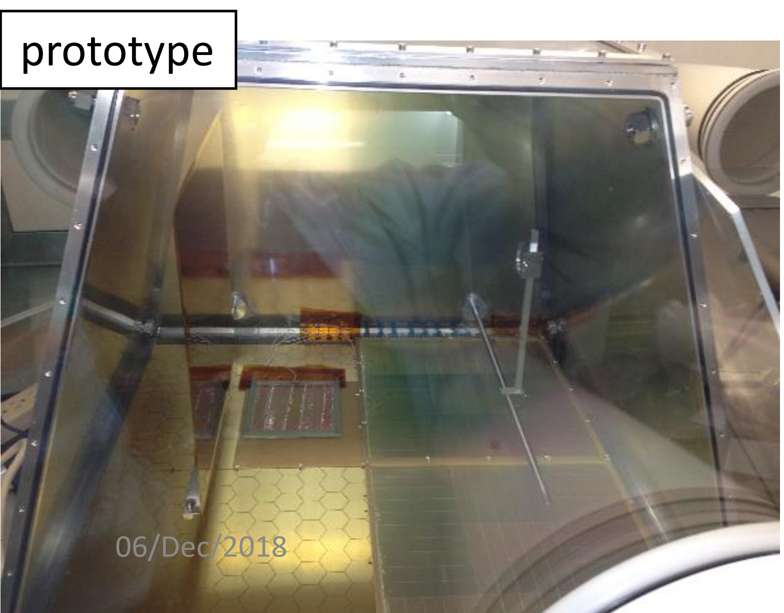


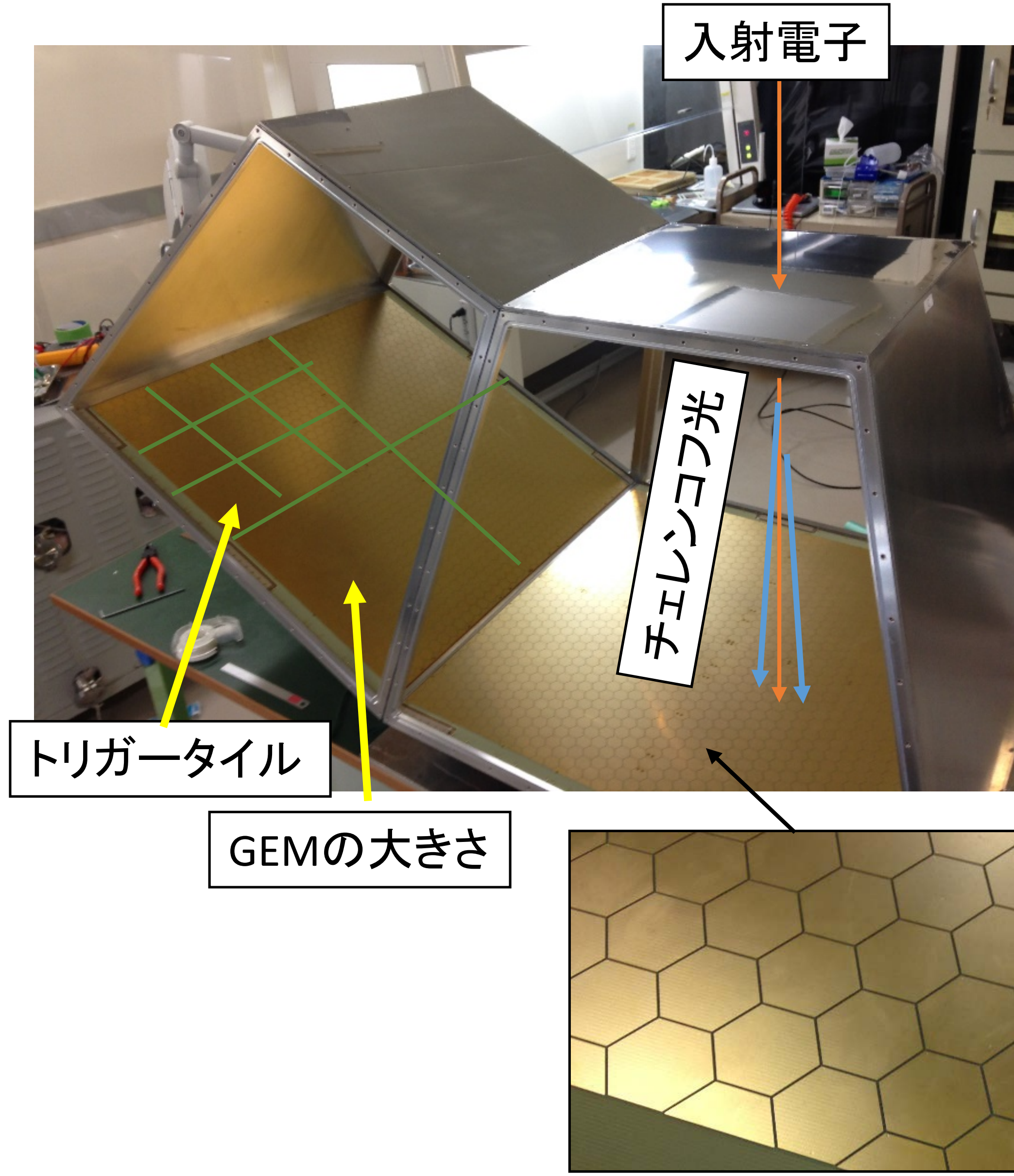




Pictures of HBD



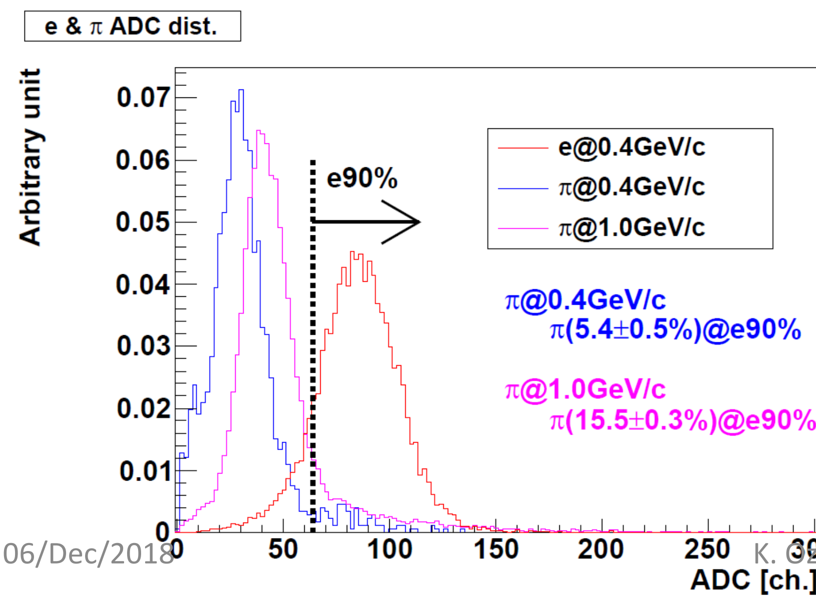




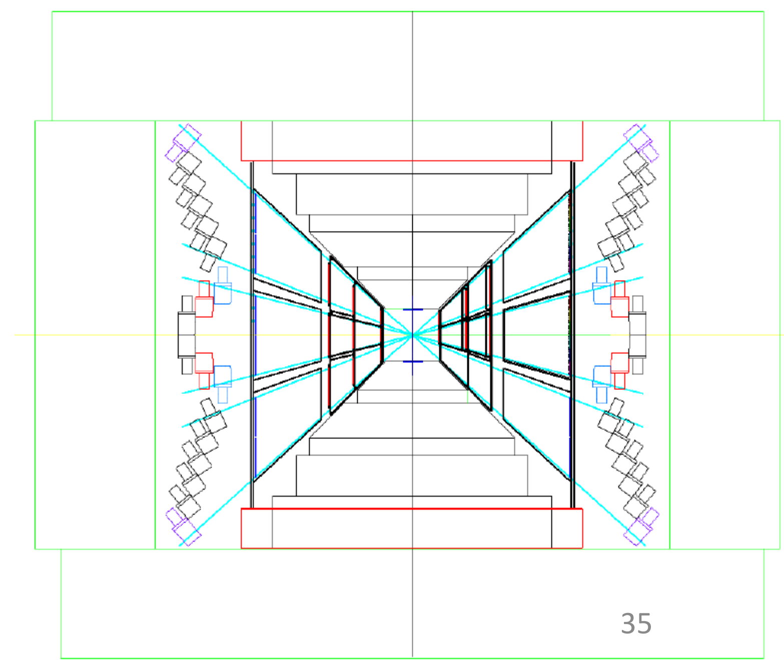
六角パッド (一辺 10 mm)

LG (Lead Glass Calorimeter)

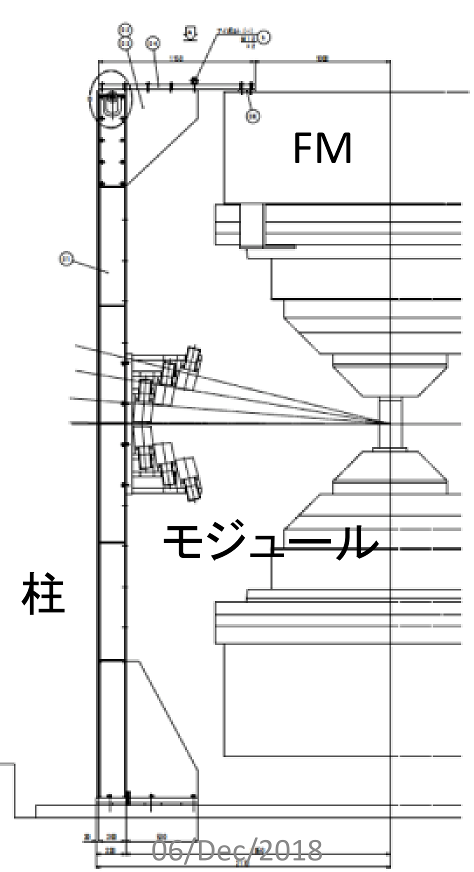
- Reuse from TOPAZ
  - ~300 at the 1st stage.
  - ~1000 in total
  - We have all we need.
- Expected Rejection Power
  - ~25 offline (energy dep. th.)
  - ~10 online (fixed th.)

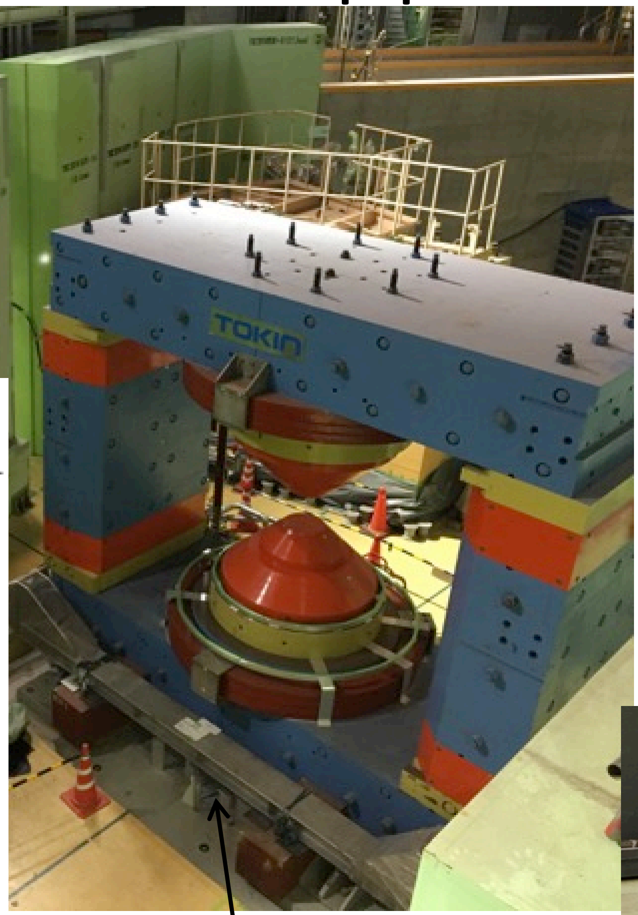


We've got all we need.

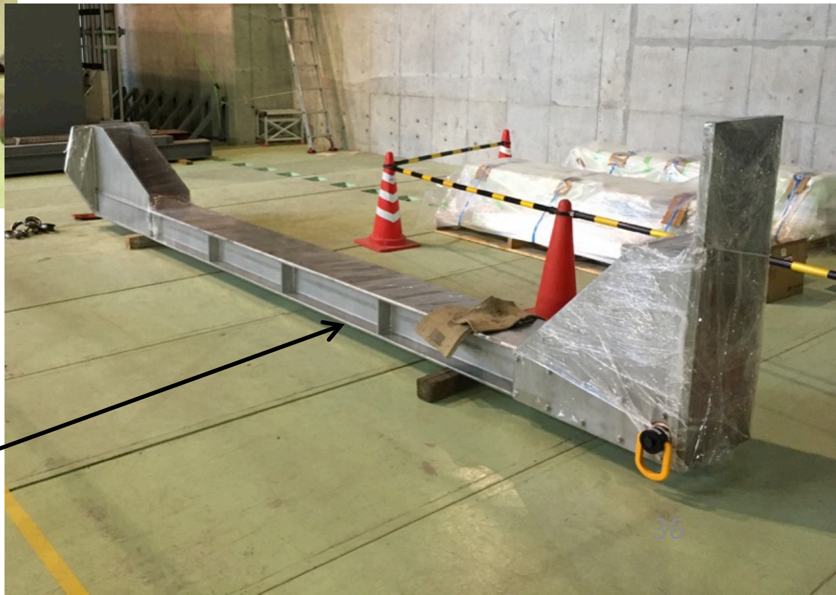


Pictures of LG support





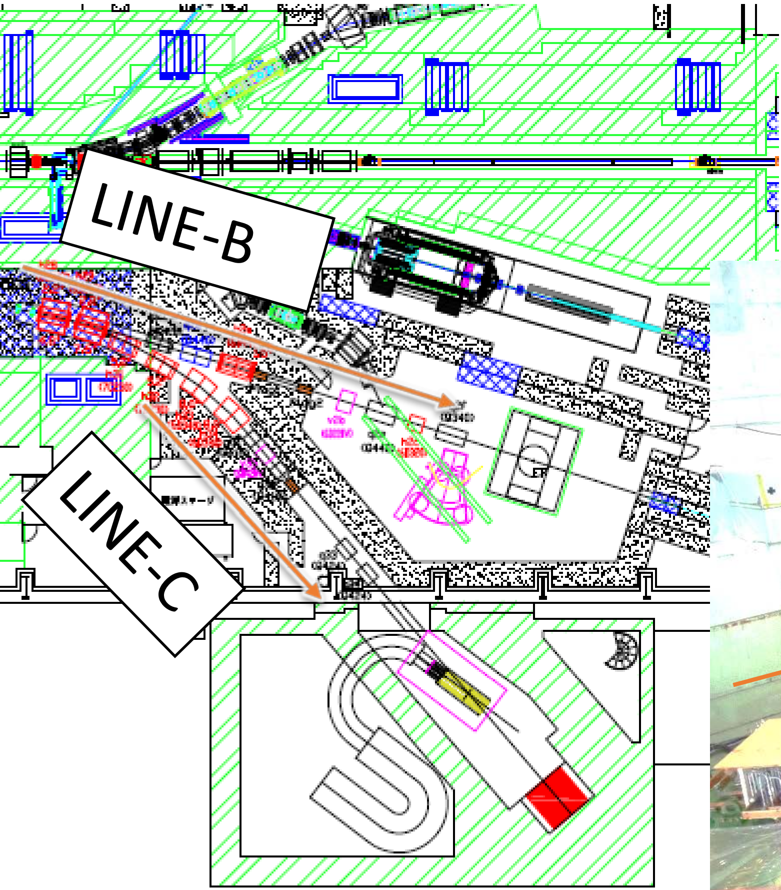
Frame for a module

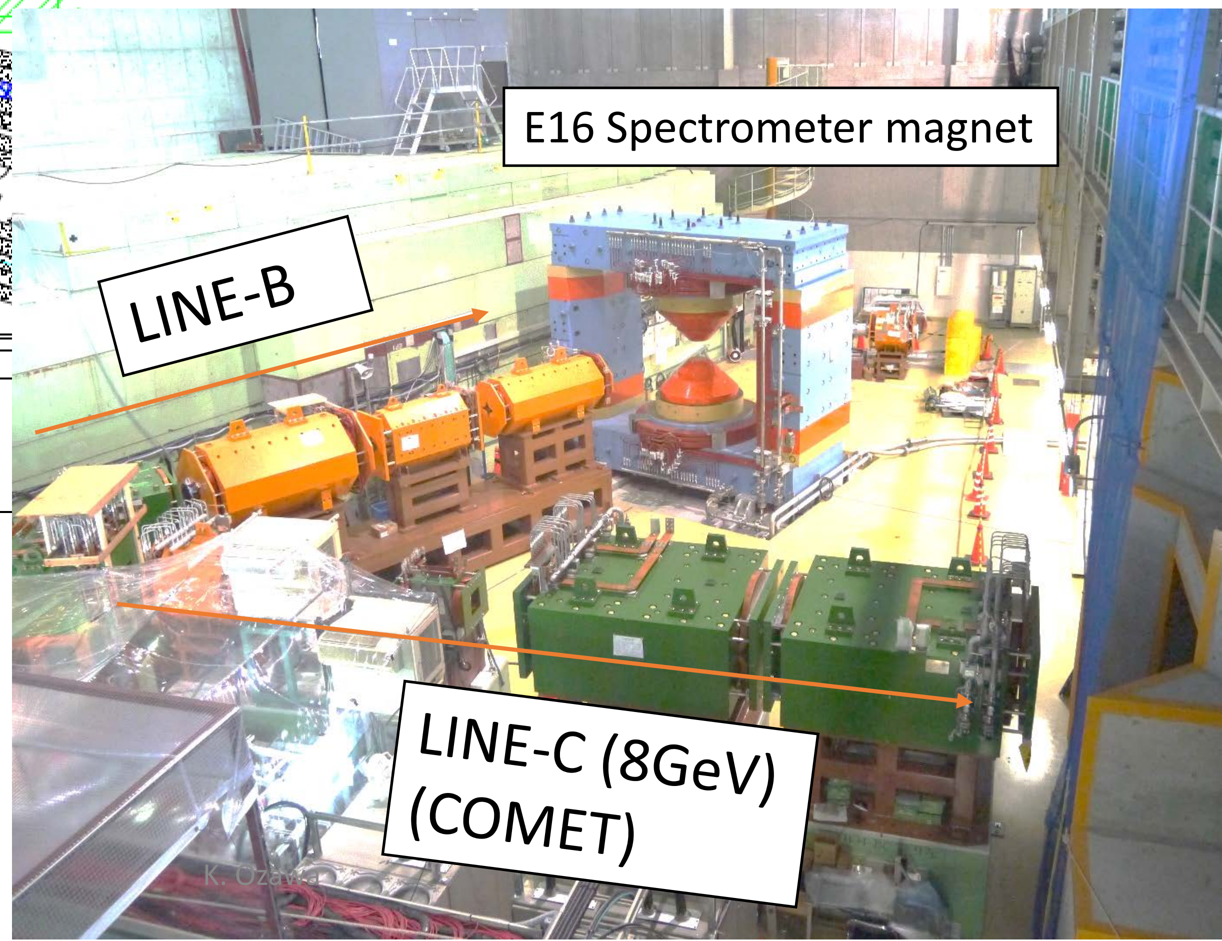


Main Frame, weight 1t.

Beamline magnets in Hadron Hall.

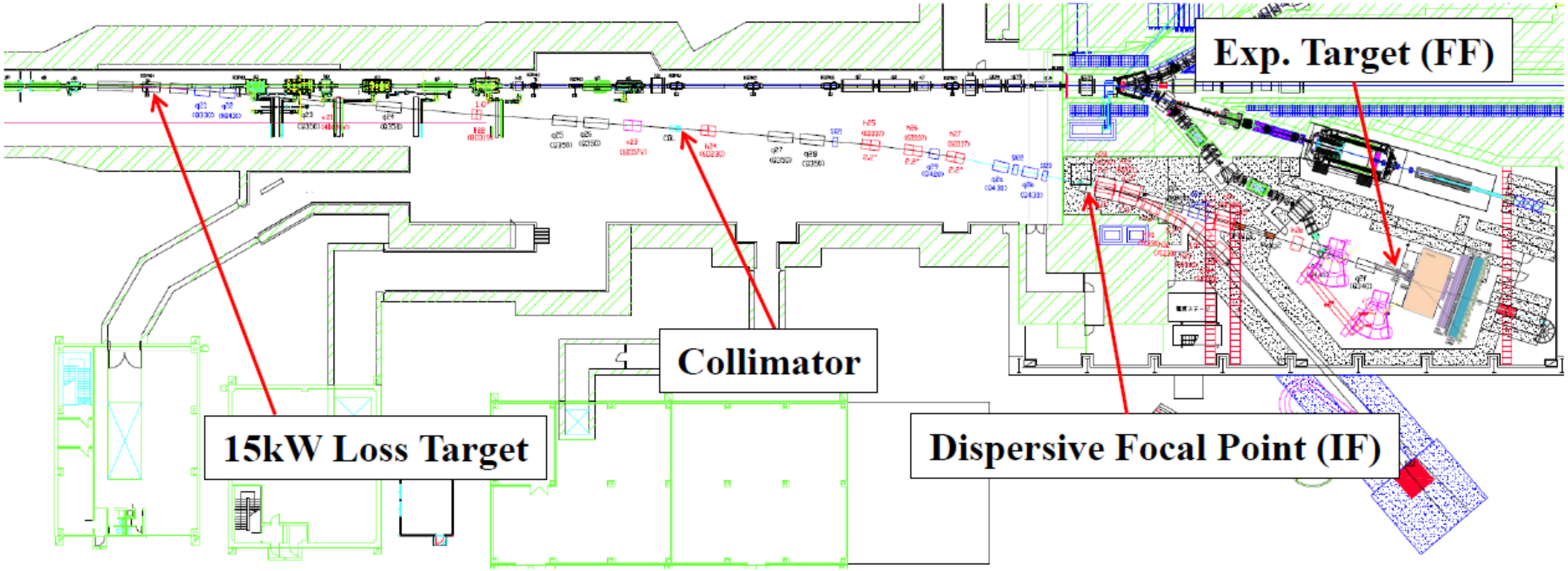
- Mag. construction completed
- Alignment needs to be done.





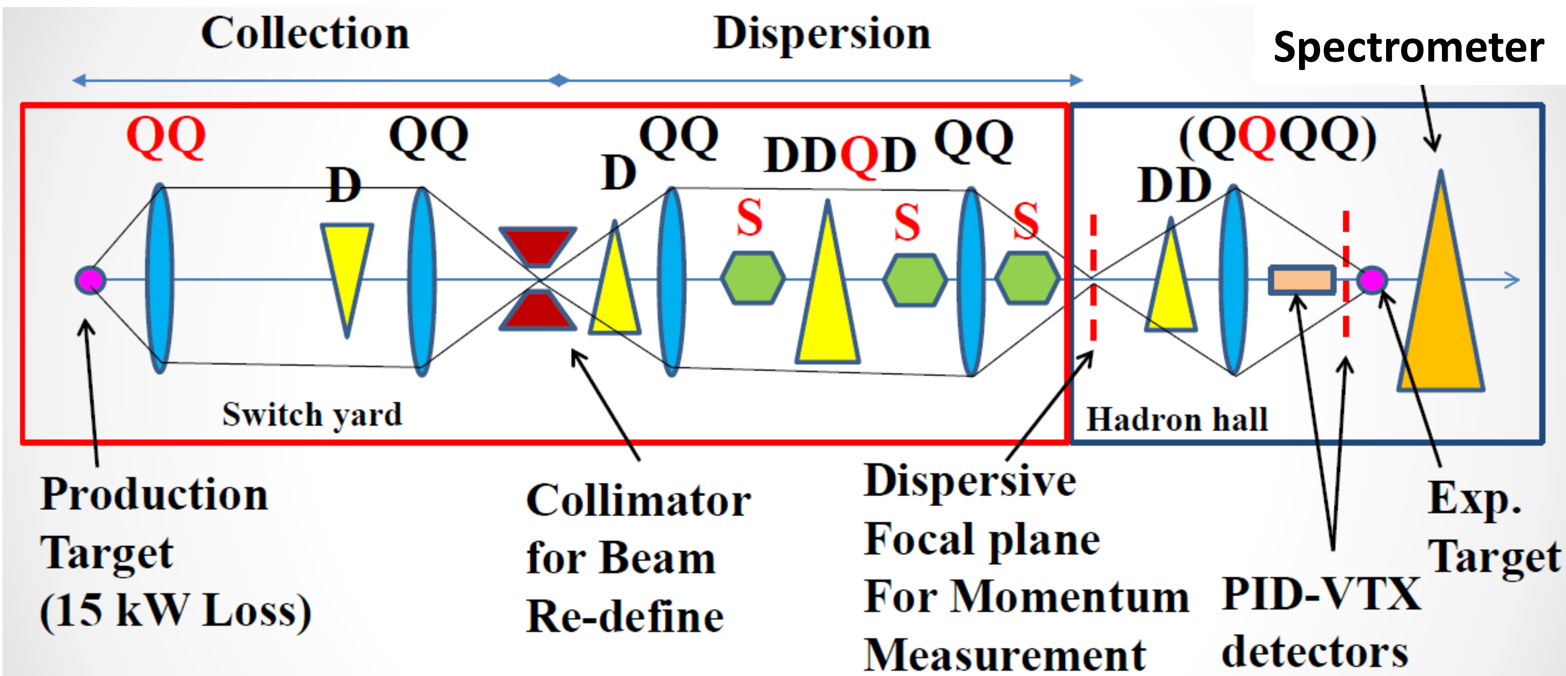
High momentum secondary beam

- New beam line will be used as a high momentum secondary beam line which delivers un-separated secondary beam.
  - Main component is π mesons
  - K mesons and protons are also contained
- Physics
  - Di-lepton measurements
  - Charmed baryon spectroscopy



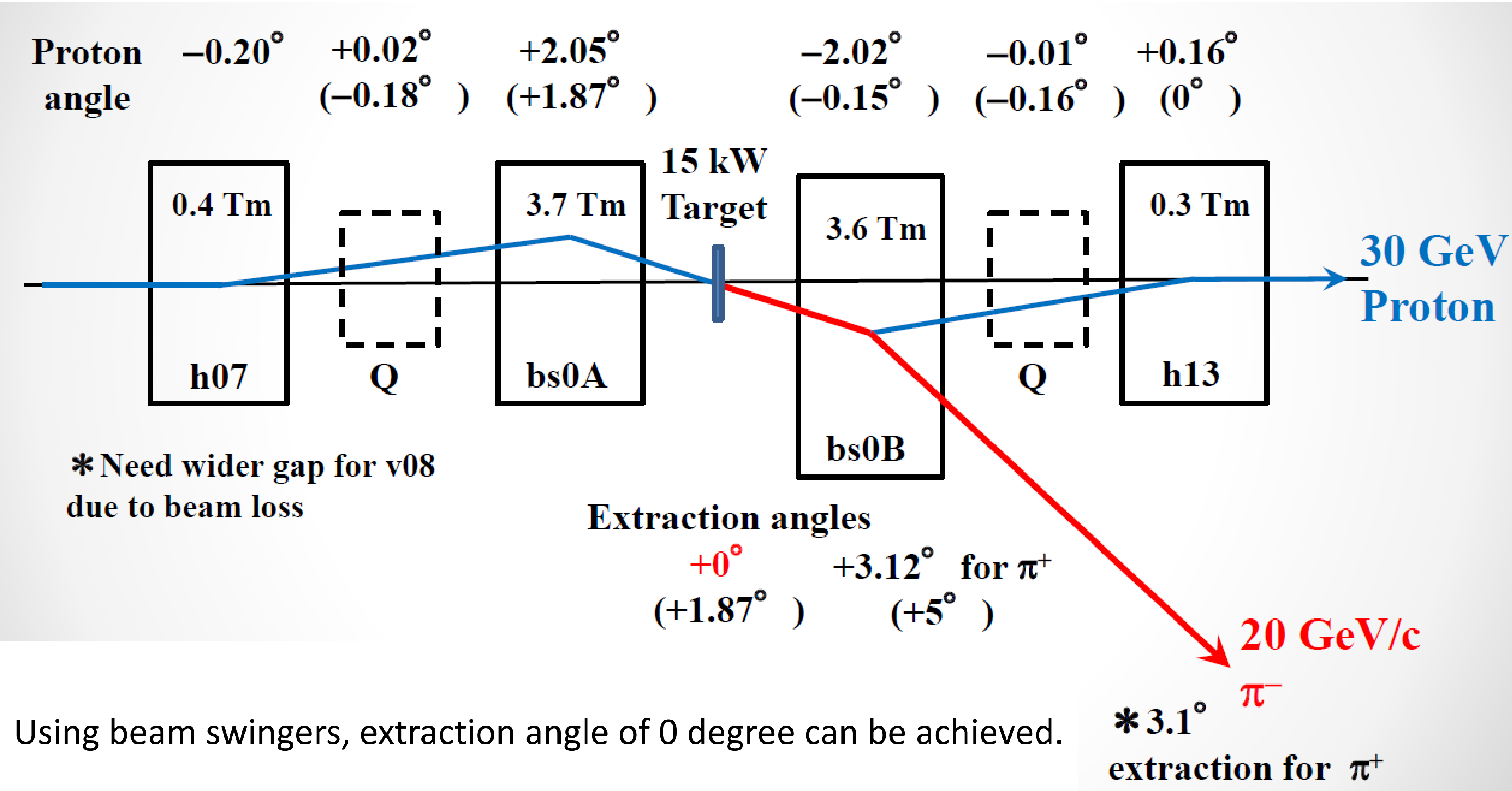
Key components

- High resolution of the beam momentum measurements using a dispersive focal plane method.
  - Δp/p ~ 0.12%



- Small extraction angle to maximize a beam intensity.

Production target & extraction



Using beam swingers, extraction angle of 0 degree can be achieved.

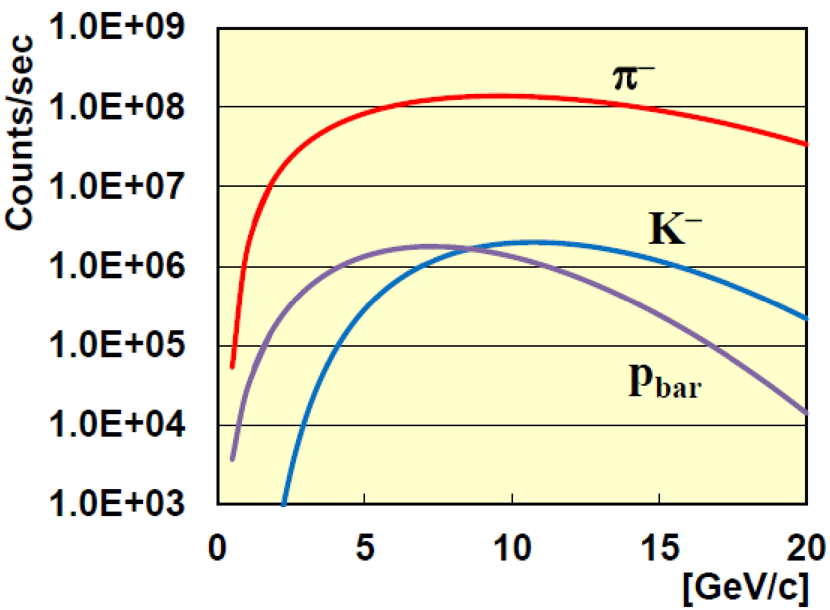
Secondary beam intensity

- **Calculated by Sanford-Wang**
  - **15 kW loss on Pt (30 kW on 6 cm length)**
  - **Acceptance :1.5 msr%, 133.2 m**

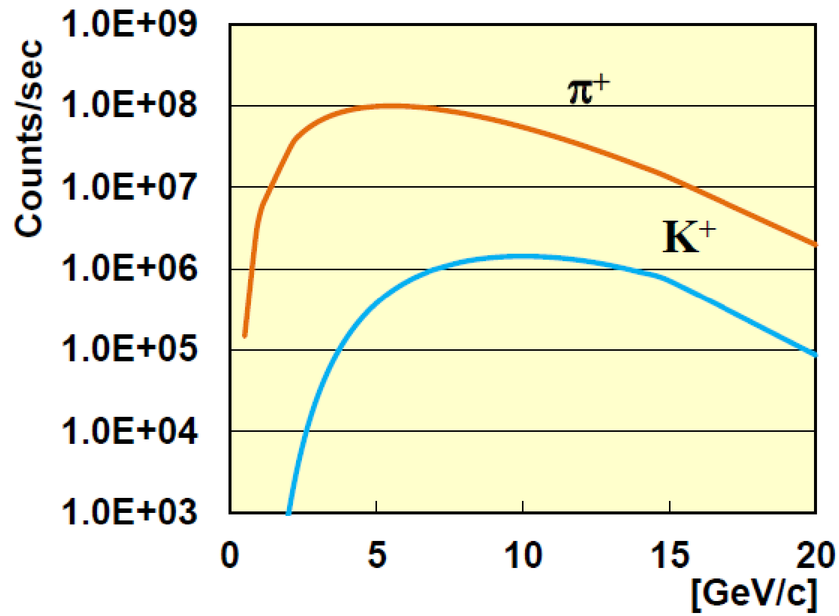
⇒ High-rate π beam available: > 10^7 /spill

- **K^- and p_{bar} beam: > 10^5 /spill**

***Minus*: Prod. Angle = 0 degrees**



***Plus*: Prod. Angle = 3.1 degrees**



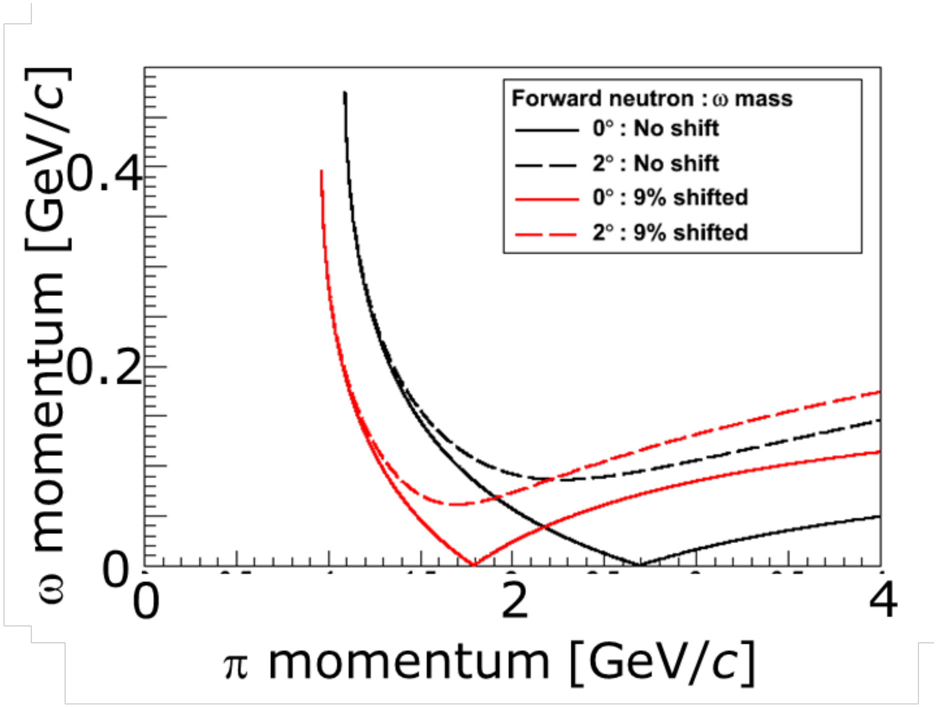
ω at rest

- In addition, when we choose a momentum of the incident beam carefully, we can generate ω mesons "at rest".
  - Note: Due to a Fermi motion and experimental effects, ω mesons still have small momentum.

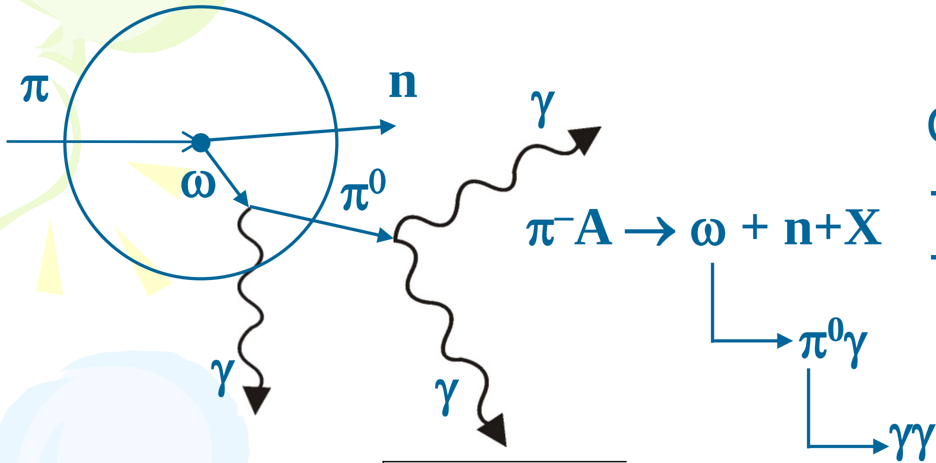
- Elementary reaction
  - π^+ + n (in A) → ρ/ω + p

- Forward emitted proton carries momentum of incident beam and generated w meson has small momentum

- We can measure mass spectra in nucleus at "p~0".



Reaction and Beam momentum



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

Stopped ω meson

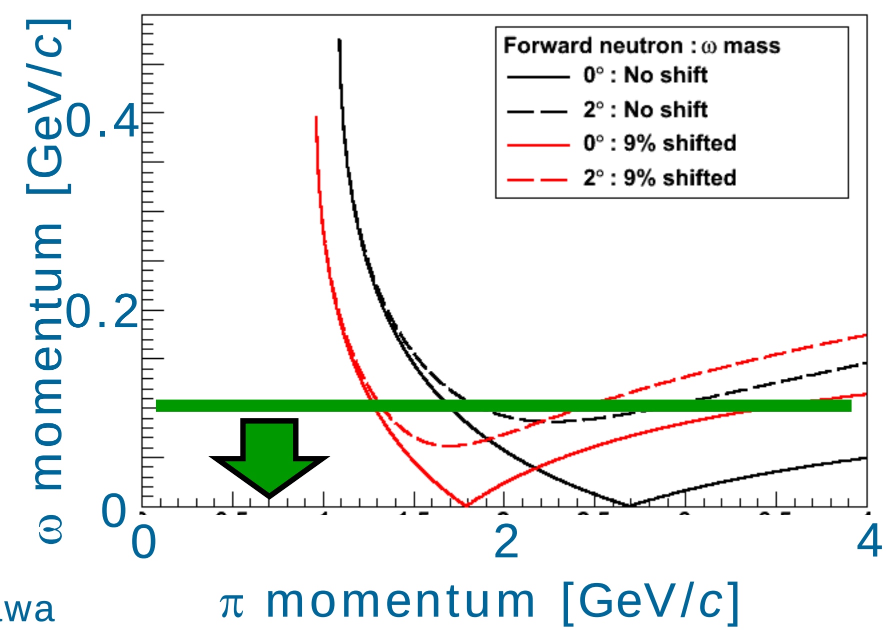
Generate ω meson using π^- + p.
- Decay of ω meson is detected.
- Emitted neutron is detected at 0°.

If π momentum is chosen carefully, momentum transfer will be ~ 0.

As a result of KEK-E325, 9% mass decreasing (70 MeV/c^2) can be expected.

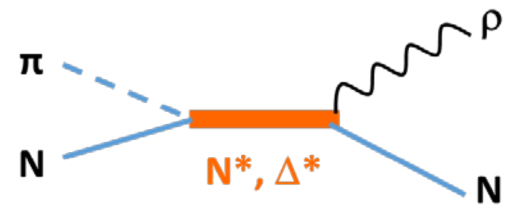
To generate stopped modified ω meson, beam momentum is ~ 1.8 GeV/*c*. (K1.8 will be used.)

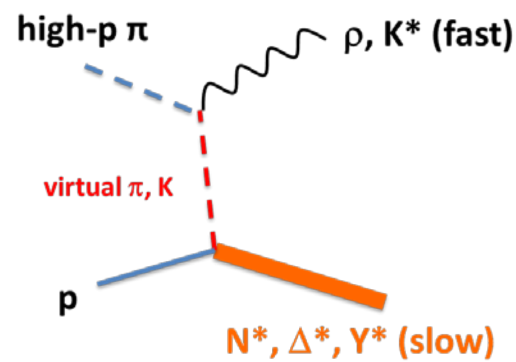
Focus on p_ω < 100 MeV/*c*



Other physics opotunities

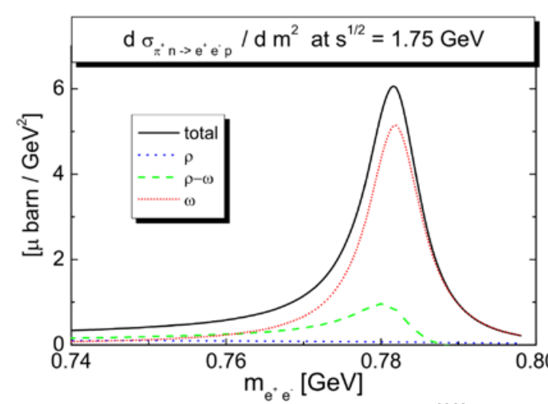
- Precise measurements of resonance effects
  - HADES pointed out that Nucleon resonance states have a significant role in e^+e^- mass spectrum in ρ mass region
  - In addition, relatively high momentum π beam can probe a structure of N*





- ρ/ω interference and mass modification
  - M.F.M. Lutz, B. Friman, M. Soyeur calculated effects of ρ/ω interference on di-lepton mass spectra

Nucl. Phys, A713(2003), 97



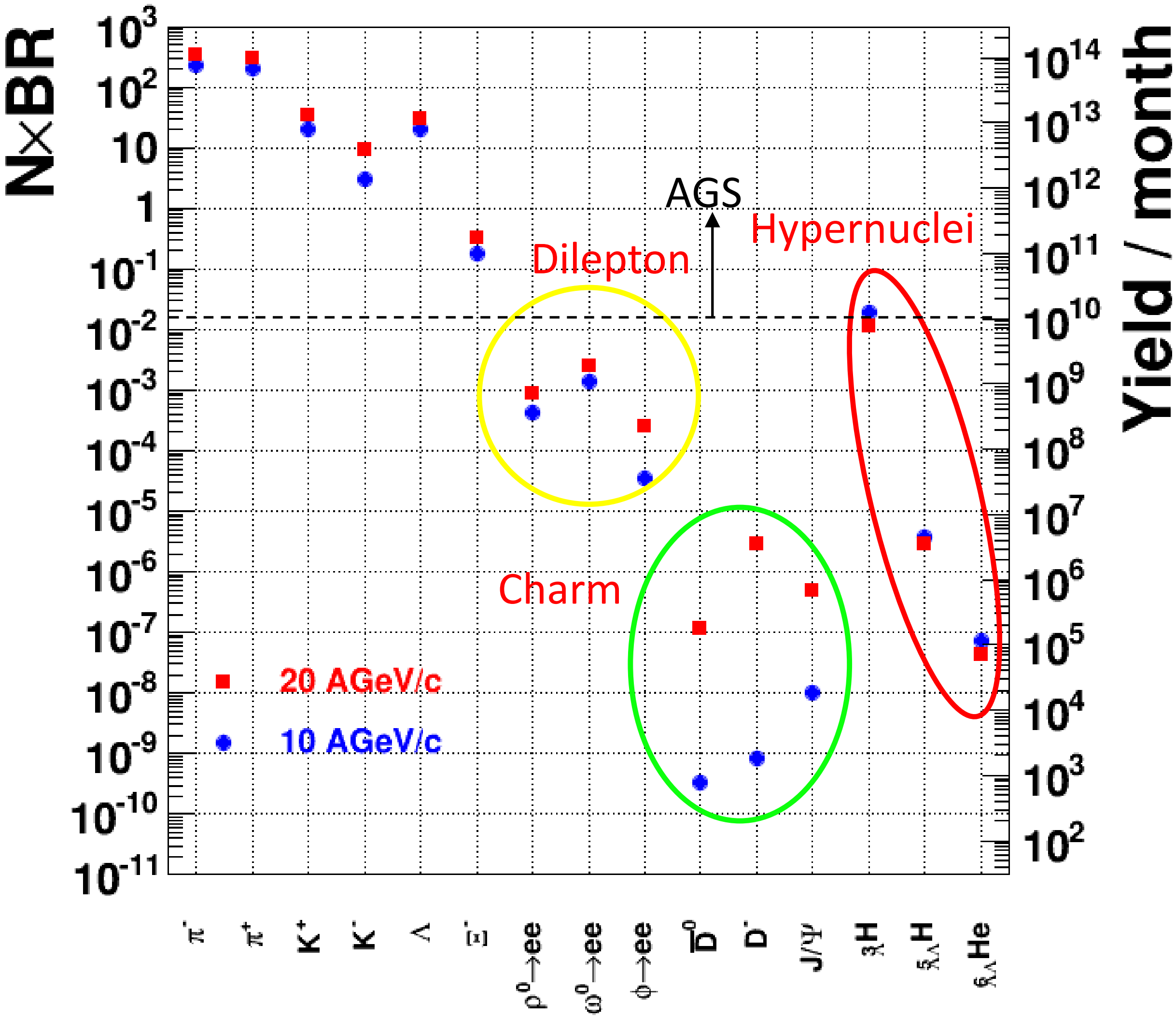
Beam Energy Consideration

- Currently, main ring of J-PARC has a beam energy of 30GeV for a proton acceleration.
  - It is the same as SIS100/FAIR.
    - For HI, 11AGeV, $\sqrt{s_{NN}} = 4.9\mathrm{GeV}$
  - Original designed energy of the ring is 50GeV for proton
    - For HI, 19AGeV, $\sqrt{s_{NN}} = 6.2\mathrm{GeV}$

- Original designed energy should be recovered
  - Highest density expected at $\sqrt{s_{NN}} = 8\mathrm{GeV}$
    - Randrup, PRC74(2006)047901
  - Significant increasing of charm production cross section
  - Seamless connection to SPS/RHIC BES
- New power supply is required

High Intensity Beam for rare probes

Ref: HSD calculations in FAIR Baseline Technical Report (Mar 2006)
A. Andronic, PLB697 (2011) 203



To collect a significant statistics for rare probes, High intensity beam is required.

Beam : 10^{10} Hz
0.1% target
→ Interaction rate 10^{7} Hz
Centrality trigger 1%
→ DAQ rate = 100kHz

In 1 month experiment:
$\rho,\omega,\phi \rightarrow ee$ 10^{7}-10^{9}
D,J/Ψ 10^{5}-10^{6} (20AGeV)
(10^{3} -10^{4}(10AGeV))
Hypernuclei 10^{5} -10^{10}

Experimental challenges

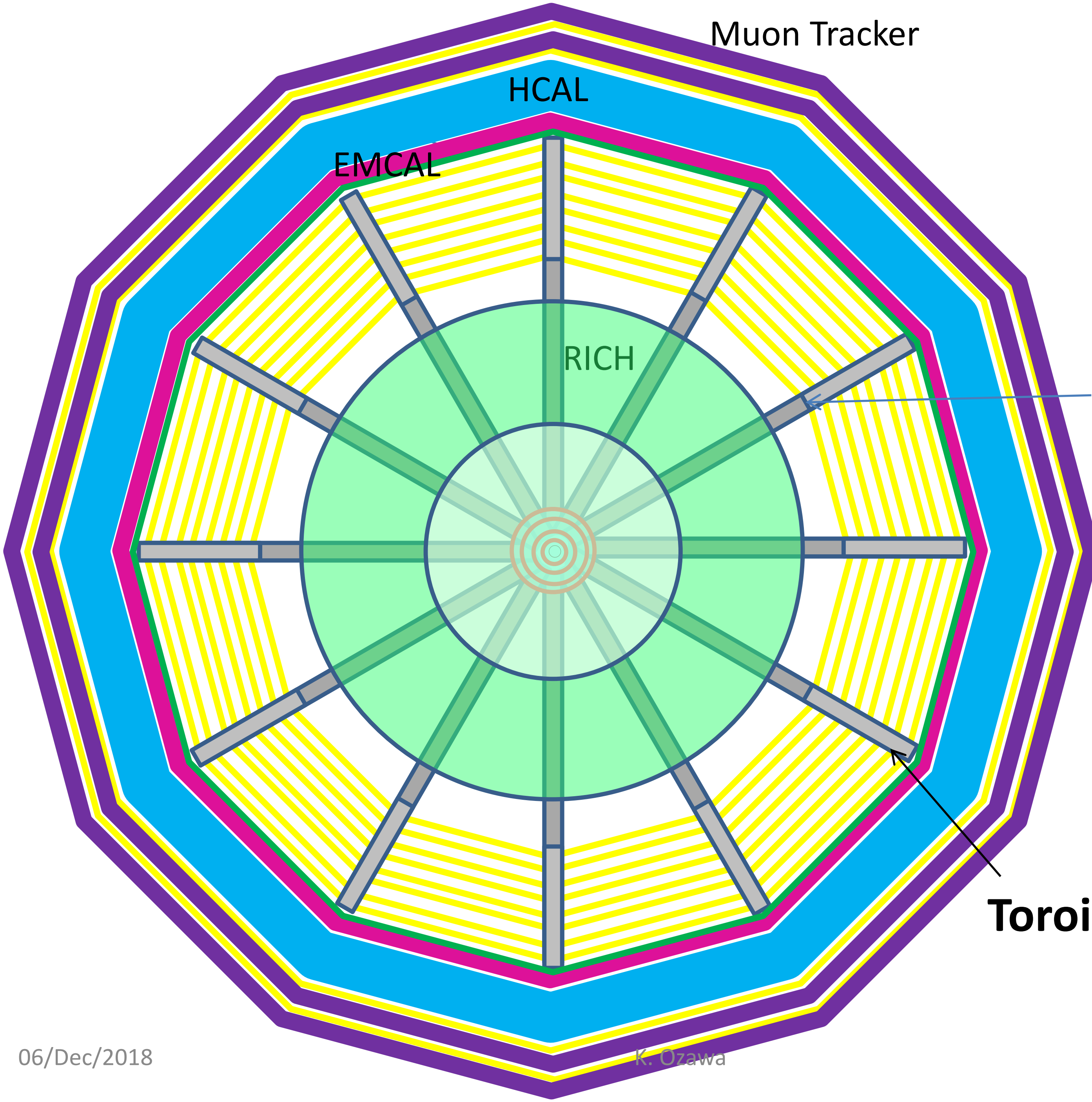
- High rate capability
  - Fast detectors
    - Silicon trackers, GEM trackers, …
  - Extremely fast DAQ → trigger-less DAQ
    - >= 100kHz
- High granularity
  - Pixel size < $3x3mm^2$

  (at 1m from the target, θ<2deg, 10% occupancy)
- Large acceptance (~4π)
  - Coverage for low beam energies
    - Up to $\sqrt{s_{NN}} = 6.2\text{GeV}$, even for 19AGeV beam
  - Maximum multiplicity for e-b-e fluctuations
  - Backward physics (target fragment region)
- Electron measurement
  - Field free region for RICH close to the target

→ Troidal Magnet Spectrometer

Beam View

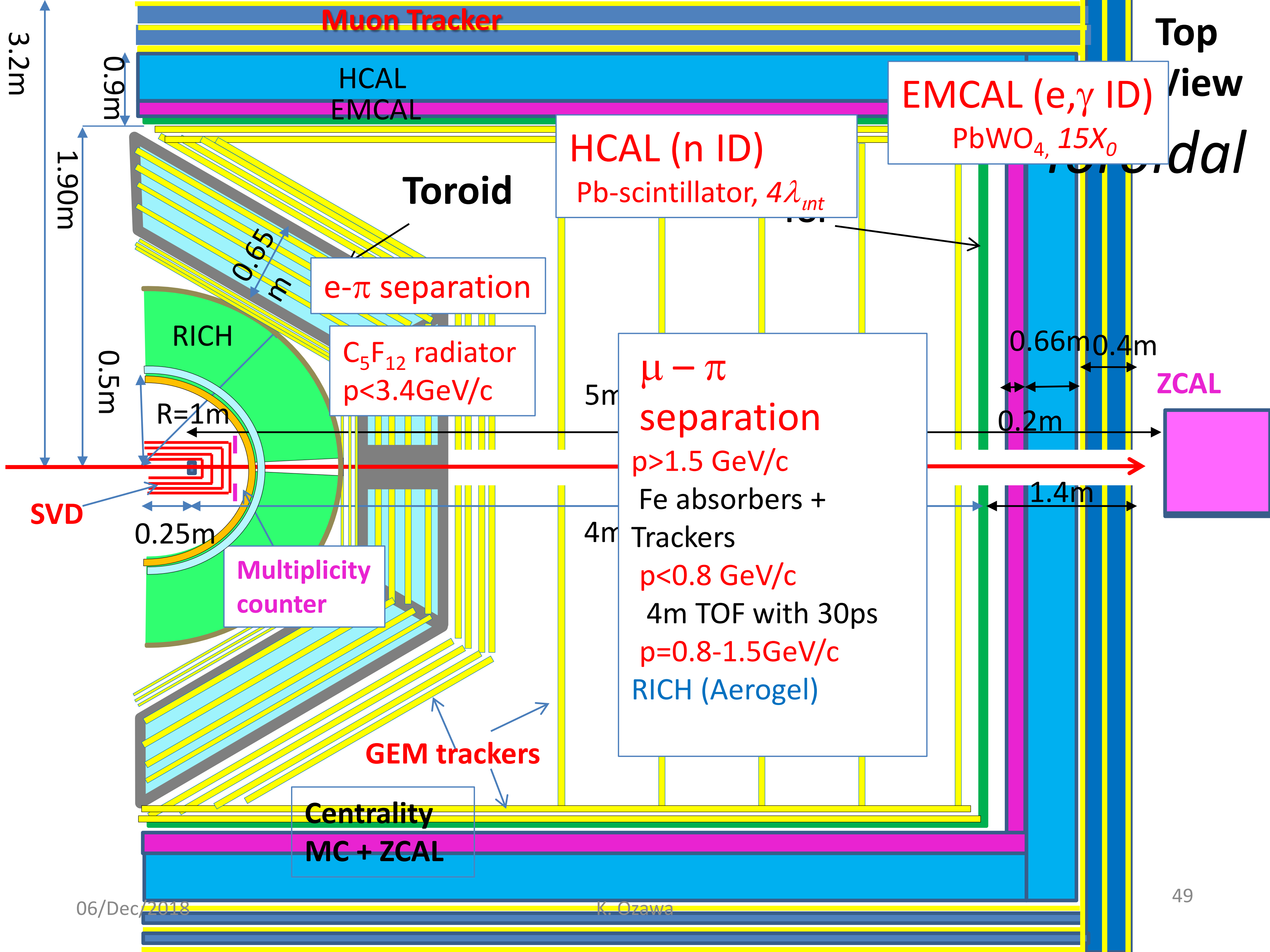
Toroidal



Coils = insensitive area

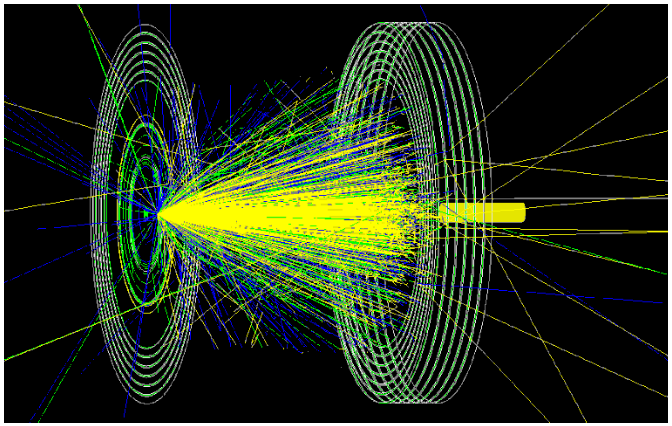
Better Bϕ uniformity
With larger number
Of coils
With 12 coils
Variations ~+-20%

Toroid coils



Muon Tracker
HCAL
EMCAL
Top View
Toroidal
EMCAL (e,γ ID)
PbWO4, 15X0
HCAL (n ID)
Pb-scintillator, 4λint
TOF
Toroid
0.65 m
e-π separation
C5F12 radiator
p<3.4GeV/c
RICH
R=1m
5m
4m
μ – π separation
p>1.5 GeV/c
Fe absorbers + Trackers
p<0.8 GeV/c
4m TOF with 30ps
p=0.8-1.5GeV/c
RICH (Aerogel)
0.66m
0.4m
0.2m
1.4m
ZCAL
SVD
0.25m
Multiplicity counter
GEM trackers
Centrality
MC + ZCAL
3.2m
0.9m
1.90m
0.5m

Spectrometer performance



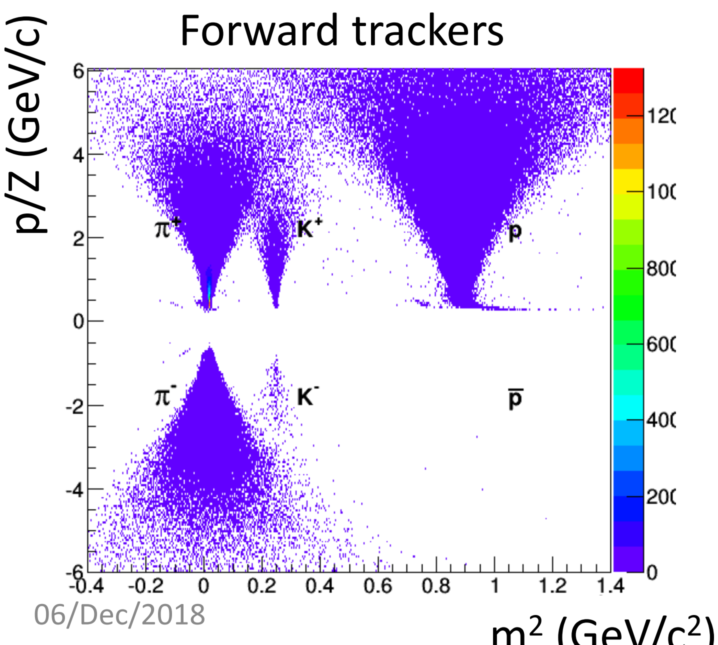
H. Sako, B.C. Kim

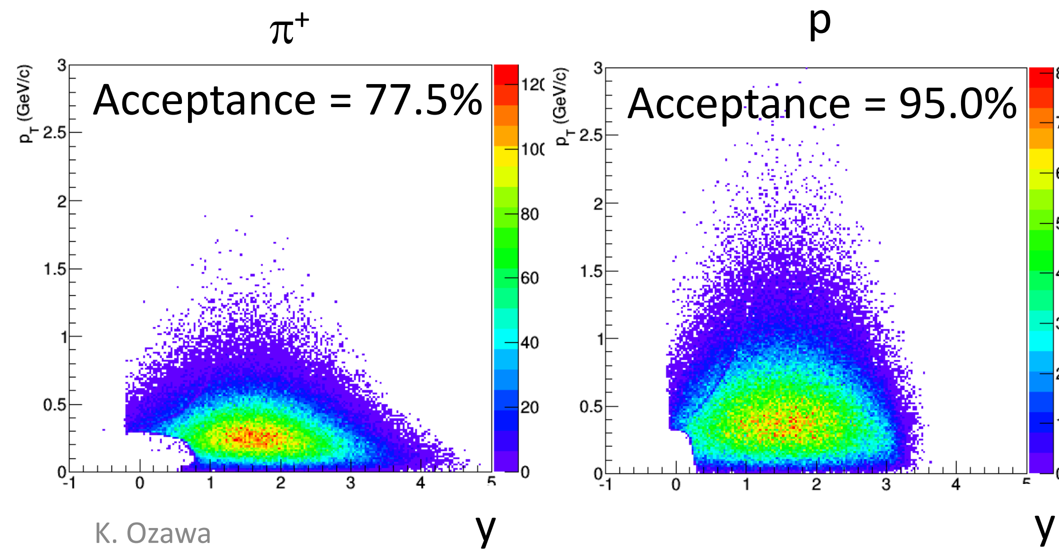
U+U at 10AGeV/c with JAM + GEANT4

- Assumption for simplicity
  - Half-spherical toroidal shape
  - Uniform B_ϕ field
  - Dead area due to coils is not implemented
- **Acceptance >= 78 %**
- **π/K separation 2.5GeV/c (2.5σ)**

Assuming TOF resolution of 50 ps

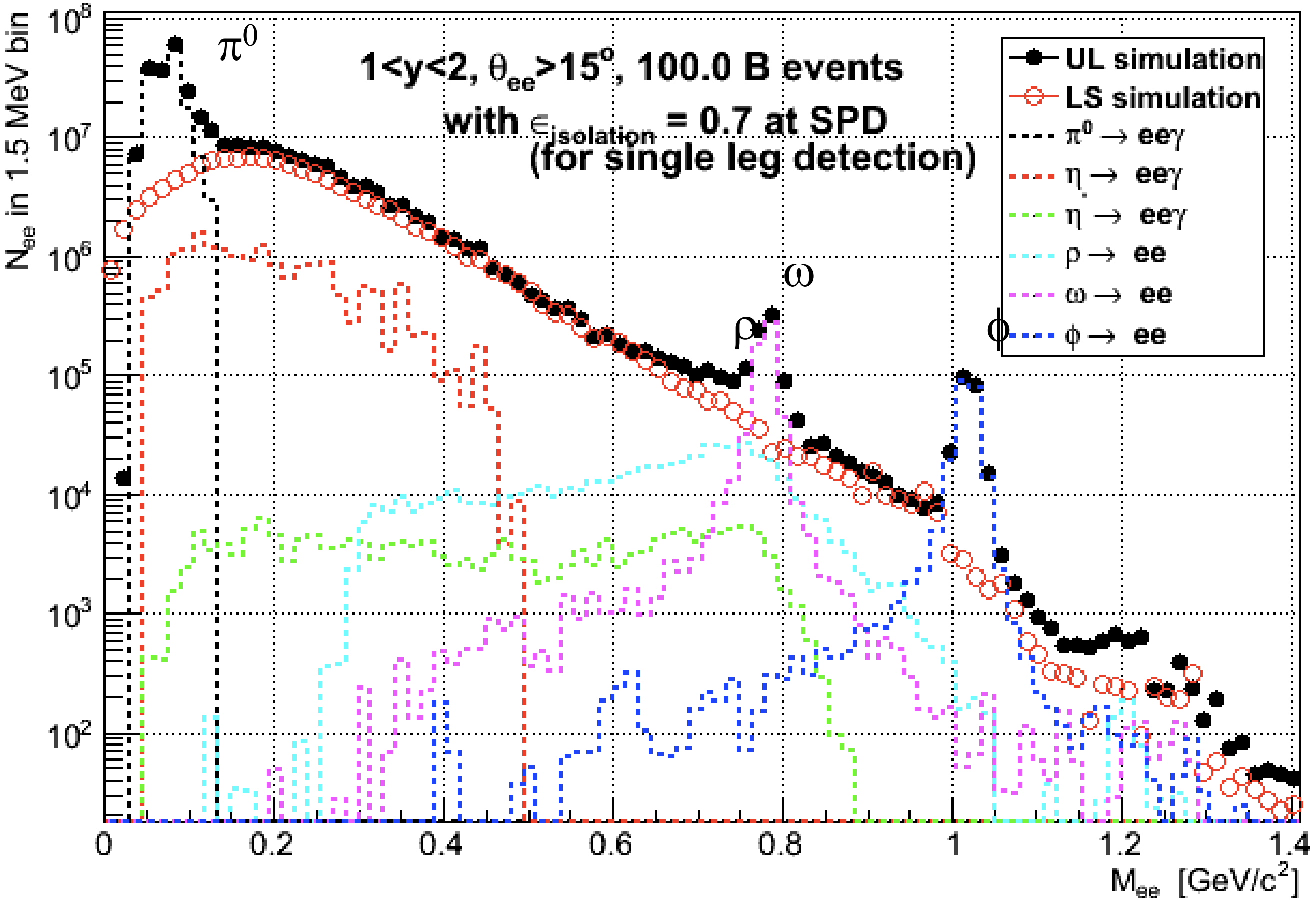
Forward trackers





K. Ozawa

Simulated di-electron spectrum (preliminary)



Calculations by T. Gunji and T. Sakaguchi

Based on π^0 spectra of JAM

Other hadrons m_T-scaled

b<1fm (0.25% centrality)

Momentum resolution 2%

Electron efficiency 50%

(No detector response)

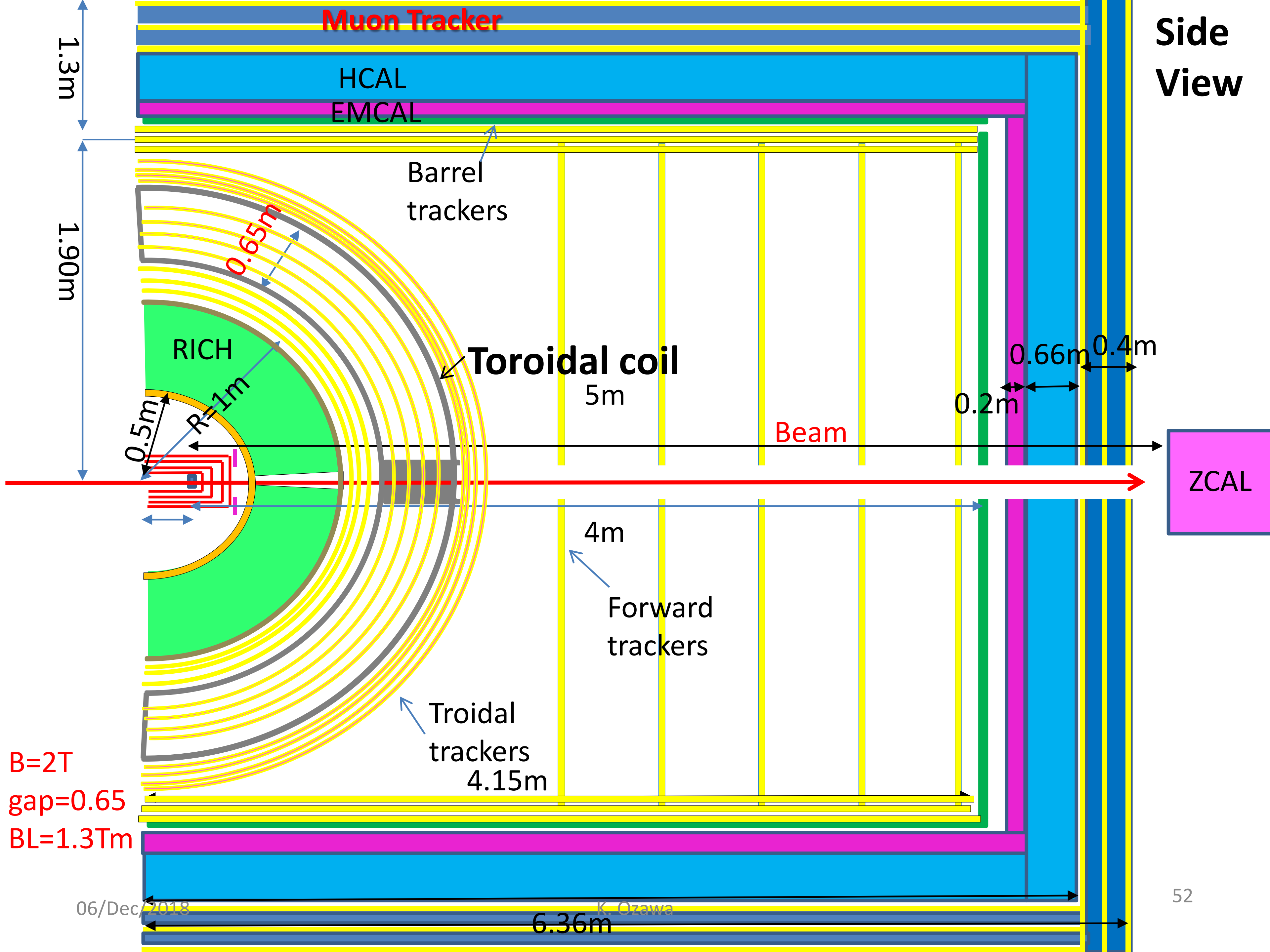
10^{11} events

⇔100k events/s

x 1 month running

$\varepsilon_{isolation}$ = rejection efficiency of close opening angle Dalitz pair

Solenoid+Dipole setup



Muon Tracker
HCAL
EMCAL
Side View
1.3m
1.90m
Barrel trackers
0.65m
RICH
R=1m
0.5m
Toroidal coil
5m
0.66m
0.4m
0.2m
Beam
ZCAL
4m
Forward trackers
Troidal trackers
4.15m
B=2T
gap=0.65
BL=1.3Tm
6.36m

Heavy-ion programs in the world

Accelerator	Type	Beam energy (AGeV)	C.M. energy √s(AGeV)	Beam rate / Luminosity	Interaction rate (sec^{-1})	Years of experiments
RHIC Beam Energy Scan (BNL)	Collider		7.7-62	10^{26}-$10^{27}cm^{-2}s^{-1}$ (√s=20AGeV)	600~6000 (√s=20AGeV)	2004-2010 2018-2019 (e-cooling)
NICA (JINR)	Collider Fixed target	0.6-4.5	4-11 1.9-2.4	10^{27} $cm^{-2}s^{-1}$ (√s=9AGeV Au+Au)	~6000	2019- 2017-
FAIR SIS100 (CBM)	Fixed target	**2-11(Au)**	**2-4.7**	**1.5×10^{10} $cycle^{-1}$** (10s cycle, U^{92+})	**10^5-10^7** (detector)	**2021-**
J-PARC	Fixed target	**1-19(U)**	**1.9-6.2**	**10^{10}-10^{11} $cycle^{-1}$** (~6s cycle)	**10^7-10^8 ?** (0.1% target)	?

References

RHIC: A. Fedotov, LEReC Review, 2013

FAIR: FAIR Baseline Technical Review, C. Strum, INPC2013, Firenze, Italy; S. Seddik, FAIRNESS-2013, C. Hoehne, CPOD2014

NICA : A. Kovalenko, Joint US-CERN-Japan-Russia Accelerator School, Shizuoka, Japan, 2013, A. Sorin, CPOD2014