Student Session

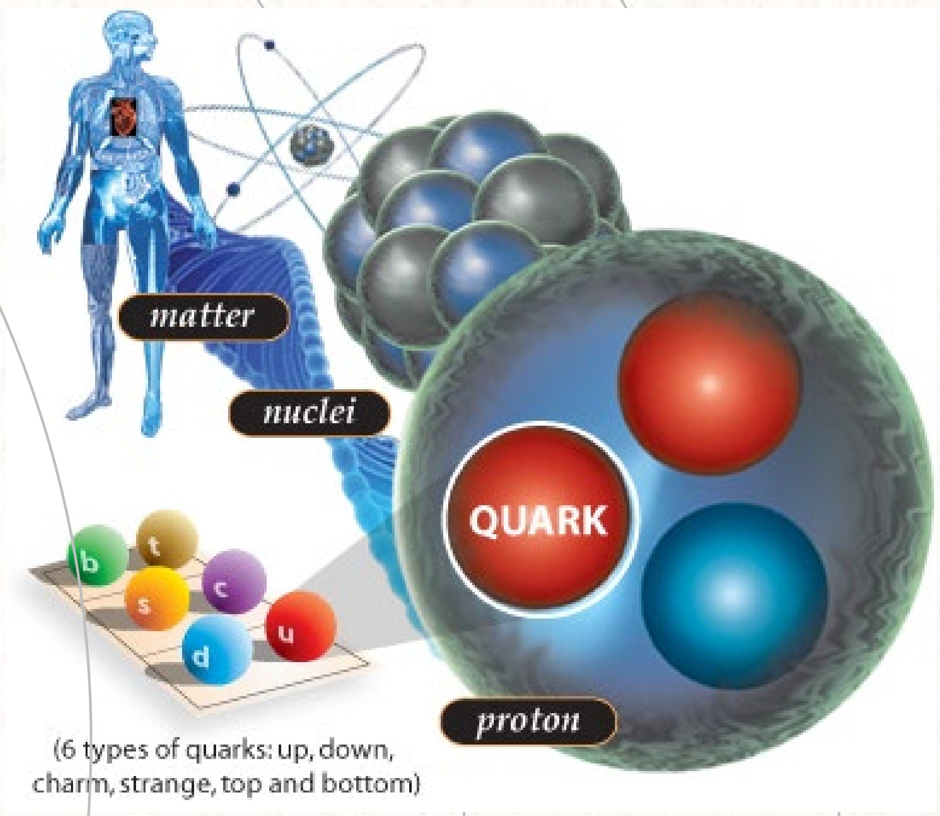
Introduction to Dilepton Measurement
- J-PARC E16 Experiment -

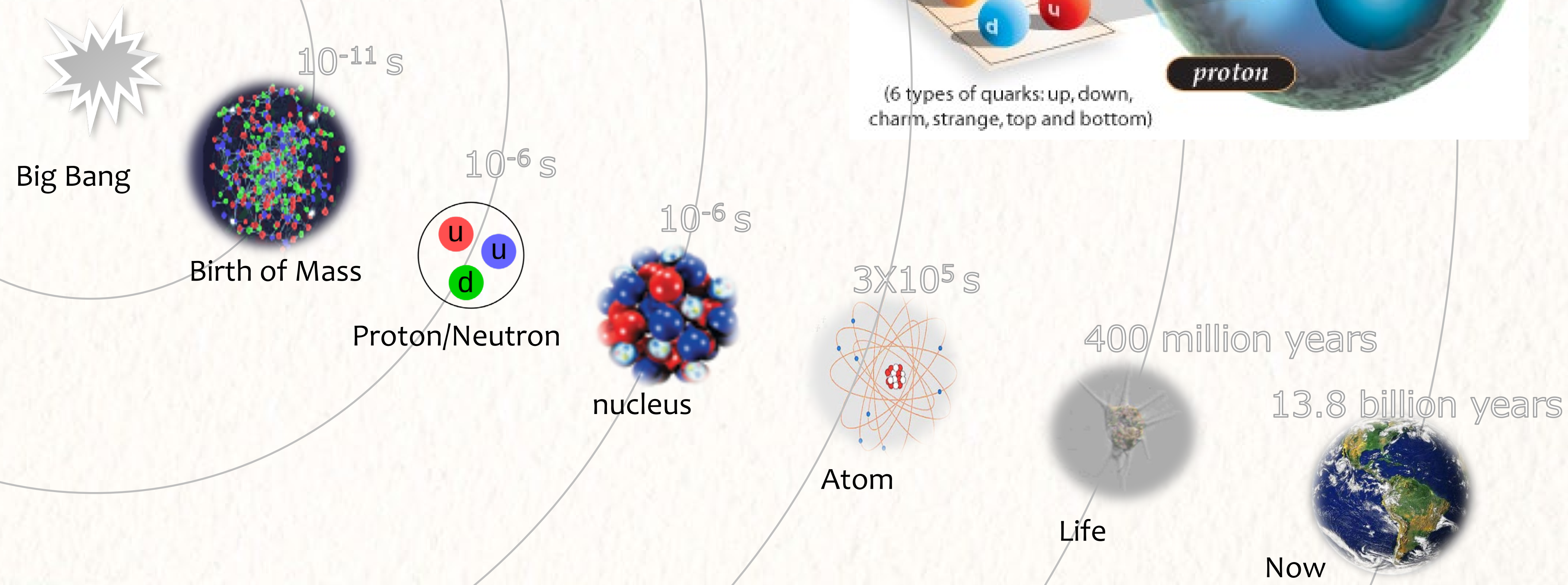
Megumi Naruki (Kyoto Univ.)

- Introduction
- overview of dilepton measurement

Origin of Matter in Universe

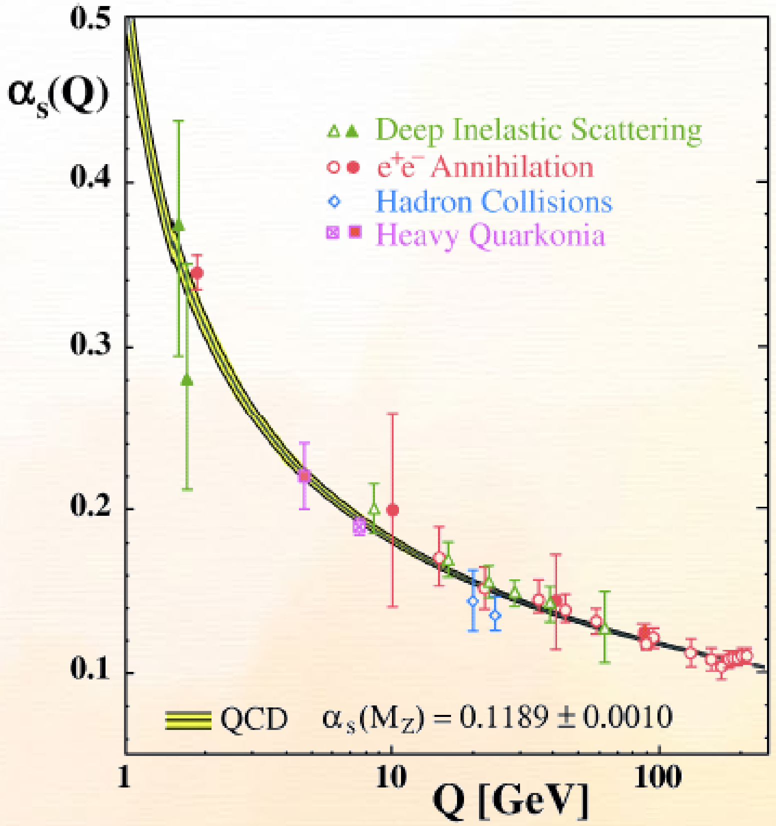
It is believed that the smallest components of matter are quarks. Particles formed by the combination of two or more quarks are called hadrons. By studying the properties of hadrons, we are conducting research to elucidate how matter has been formed since the beginning of the universe and to approach the state of unknown matter.





Quantum Chromodynamics at low-energy regime

- fundamental theory of strong interaction: QCD
  - strong > electro-magnetic > weak > gravitational
    1 > 10^{-2} > 10^{-25} > 10^{-40}
- success of perturbative QCD at high energy
  - asymptotic freedom, Gross, Politzer & Wilczek, 2004 
- at low energy
  - non-perturbative phenomena of strong coupling
  - quark confinement – Millenium prize problem
  - spontaneous breaking of symmetry: Nambu 2008 

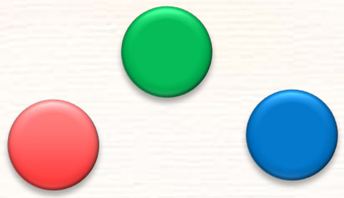


QCD Made Simple – F. Wilczek

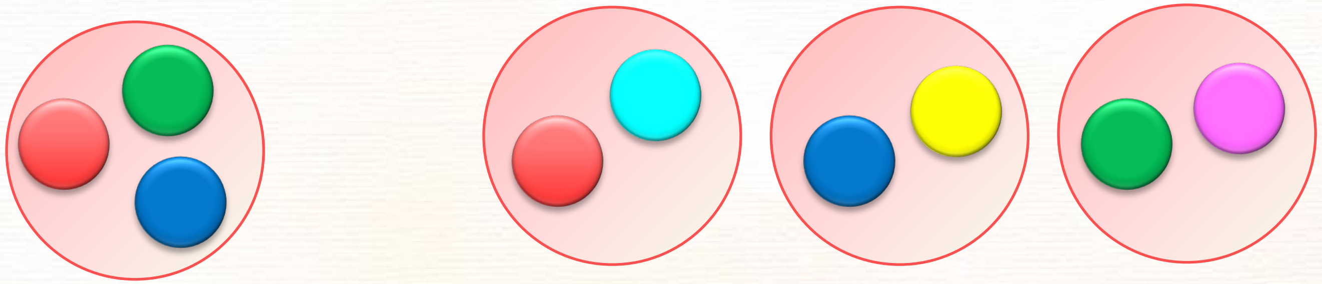
QCD is conceptually simple. Its realization in nature, however, is usually very complex. But not always.

Color Confinement

- Quarks cannot exist alone.
  - Quarks have “colors”. The three primary colors of red, blue, and green.



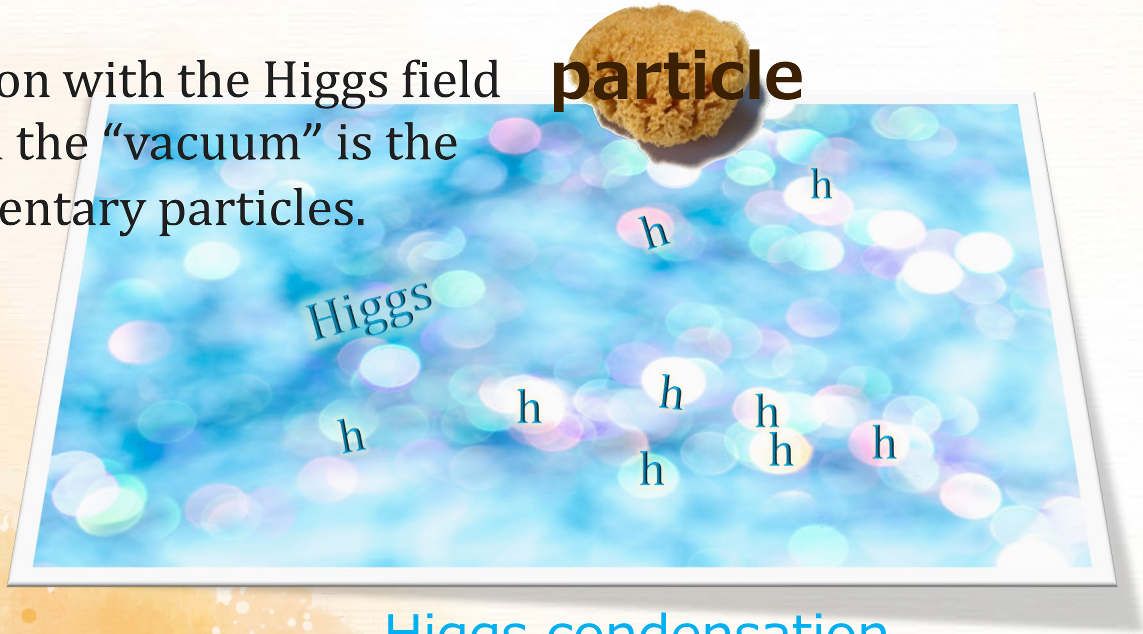
- It is trapped inside a white "bag" called a hadron.
  - It only exists in combinations that result in white as a whole.
    - ex. red + blue + green, red + cyan, blue + yellow, green + magenta



Mass of Matter

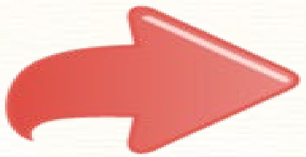
- When you step on the scale, a number appears.
- We are researching where this mass comes from.
  - There is a jump of about 100 times between the mass of elementary particles and the mass of matter.

The interaction with the Higgs field condensed in the “vacuum” is the mass of elementary particles.



Higgs condensation

100 times heavier

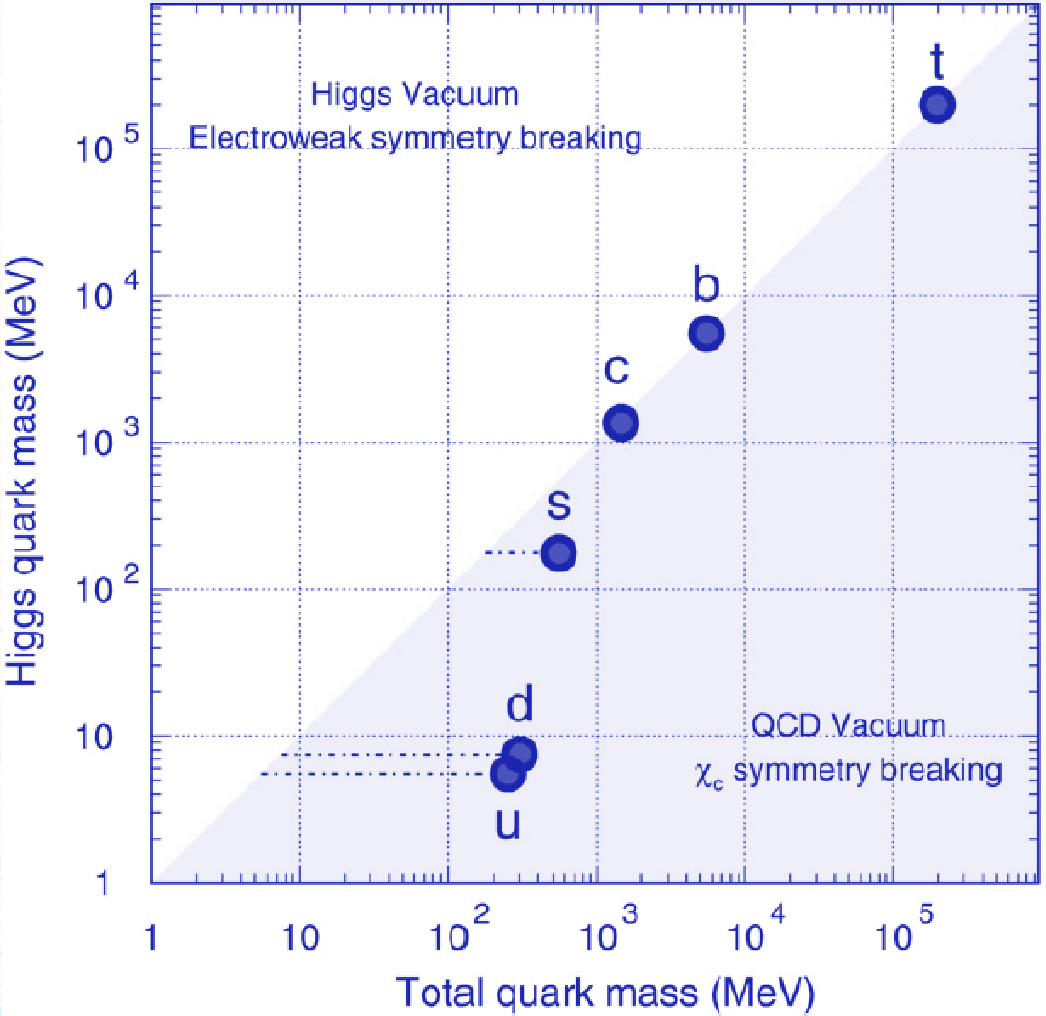


Quark Mass

charm

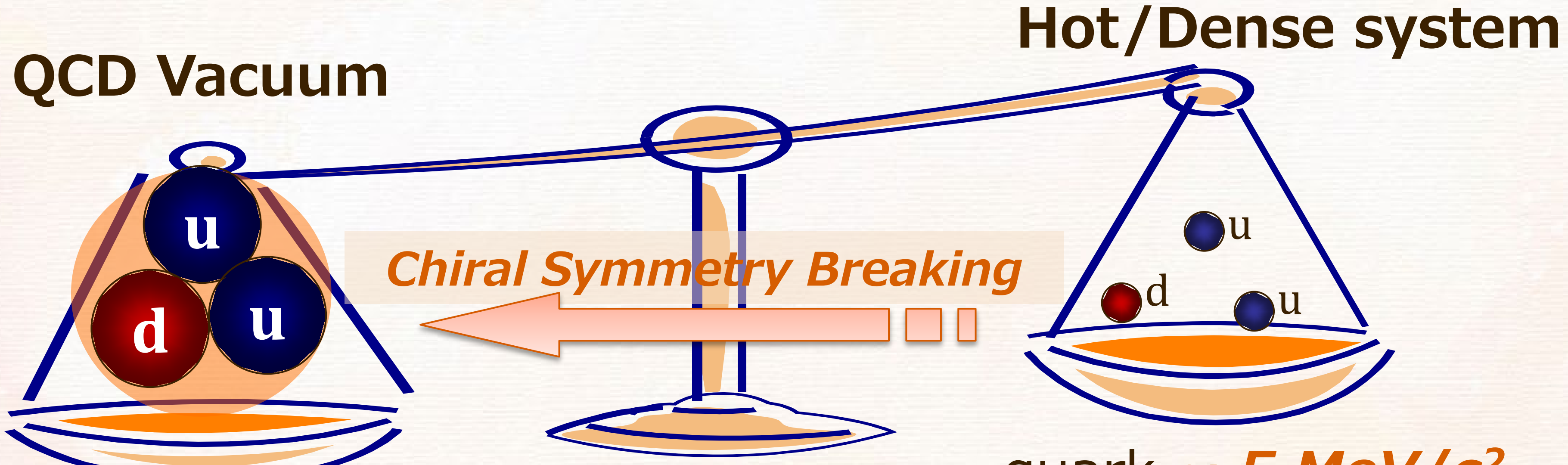
strange

our world



Λ_{QCD}

Origin of Hadron Mass

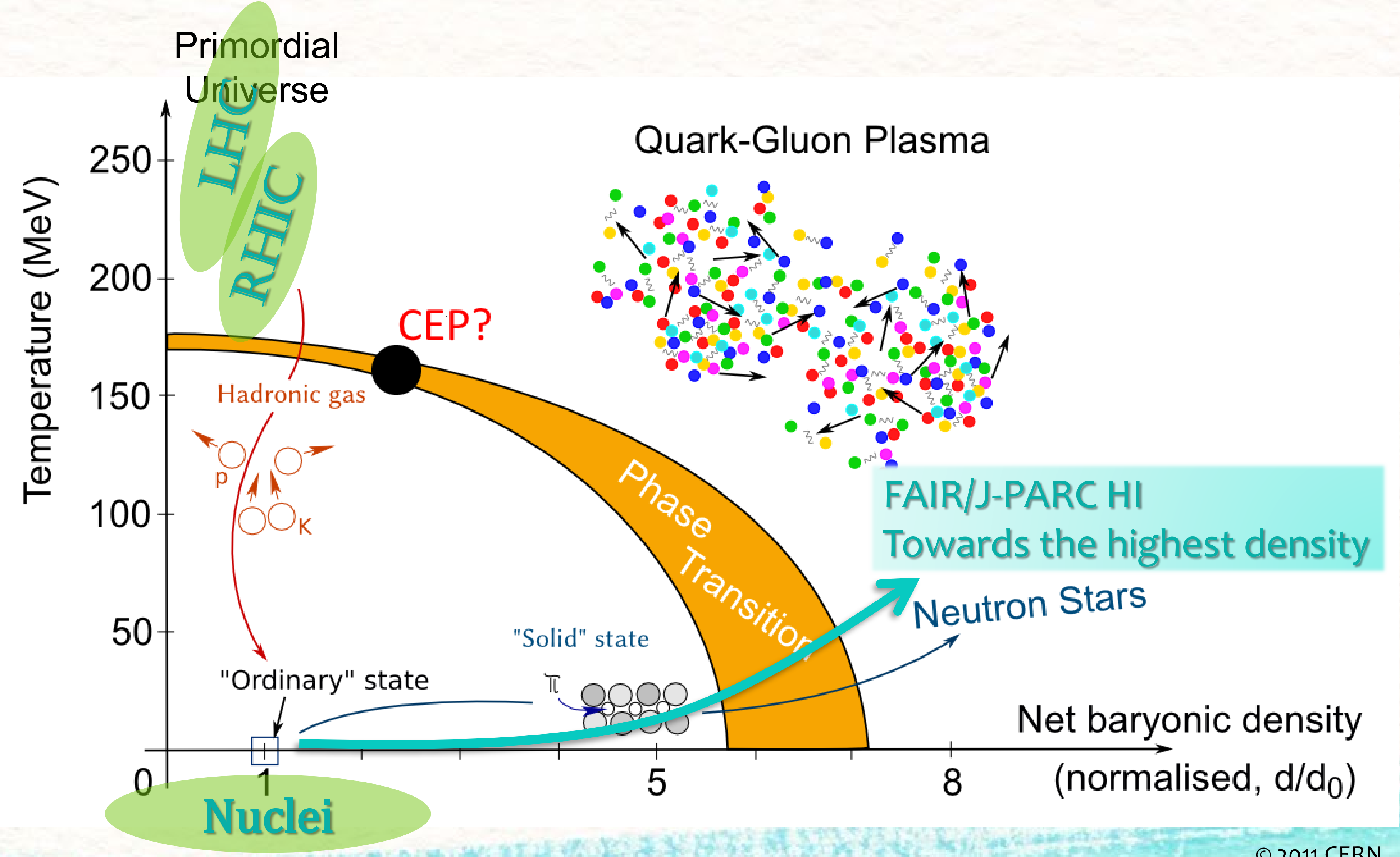


quark ~ ***5 MeV/c²***

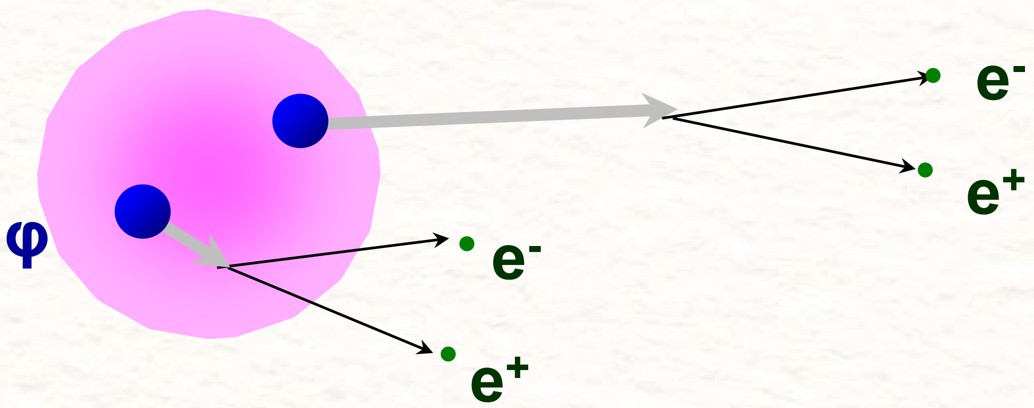
proton ~ ***1000 MeV/c²***

constituent quark ~ ***300 MeV/c²***

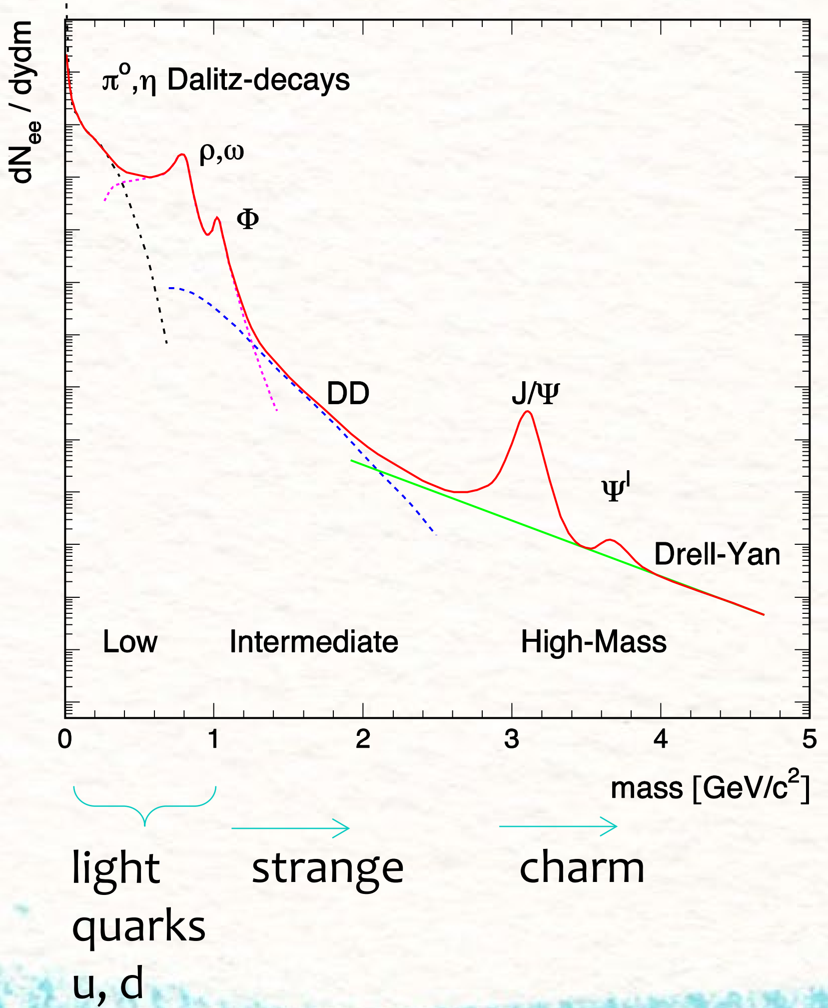
Probing Matter in Extreme Conditions



Dilepton Measurement



directly access to the properties of vector mesons



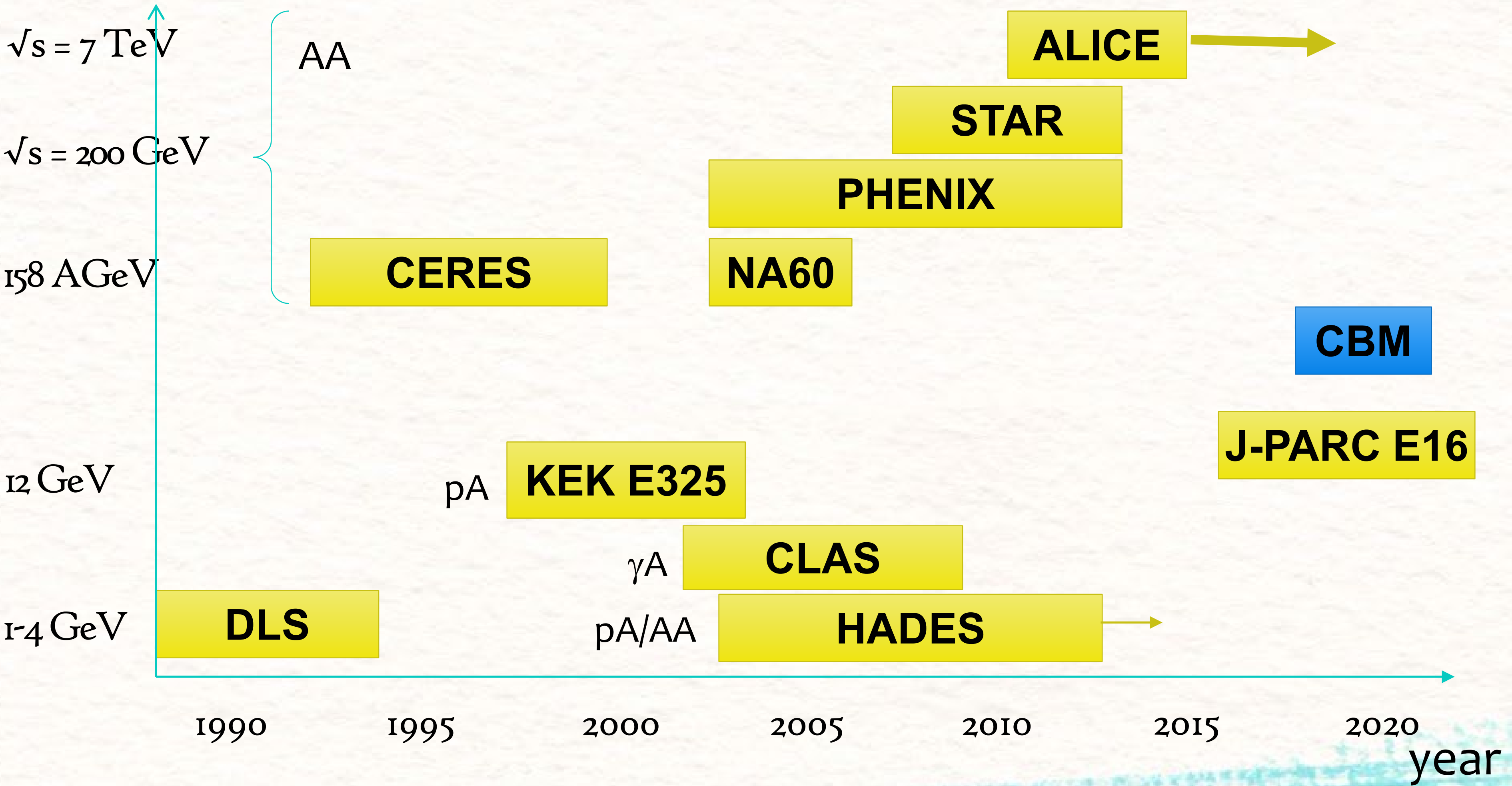
Low Mass Range (LMR) $M_{ee} < 1.1\ GeV/c^2$

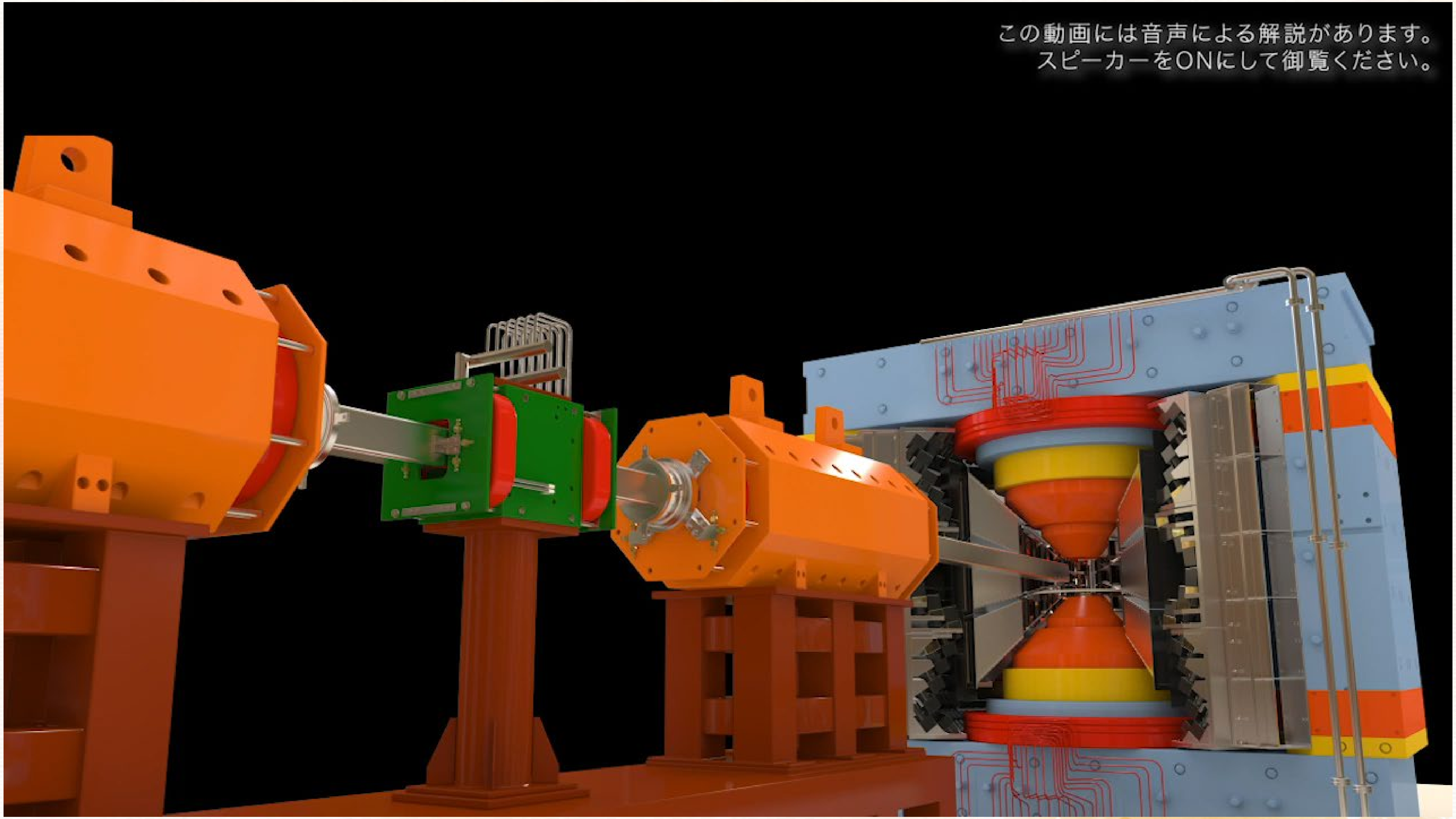
in-medium modification of vector mesons
possible connection to CSB

	Width	cτ	ρ,ω vs φ
ρ	149.2 MeV	1.3 fm	large effect overlap
ω	8.44 MeV	24 fm	
φ	4.26 MeV	47 fm	single peak

Dilepton Measurements

History vs. Energy scale





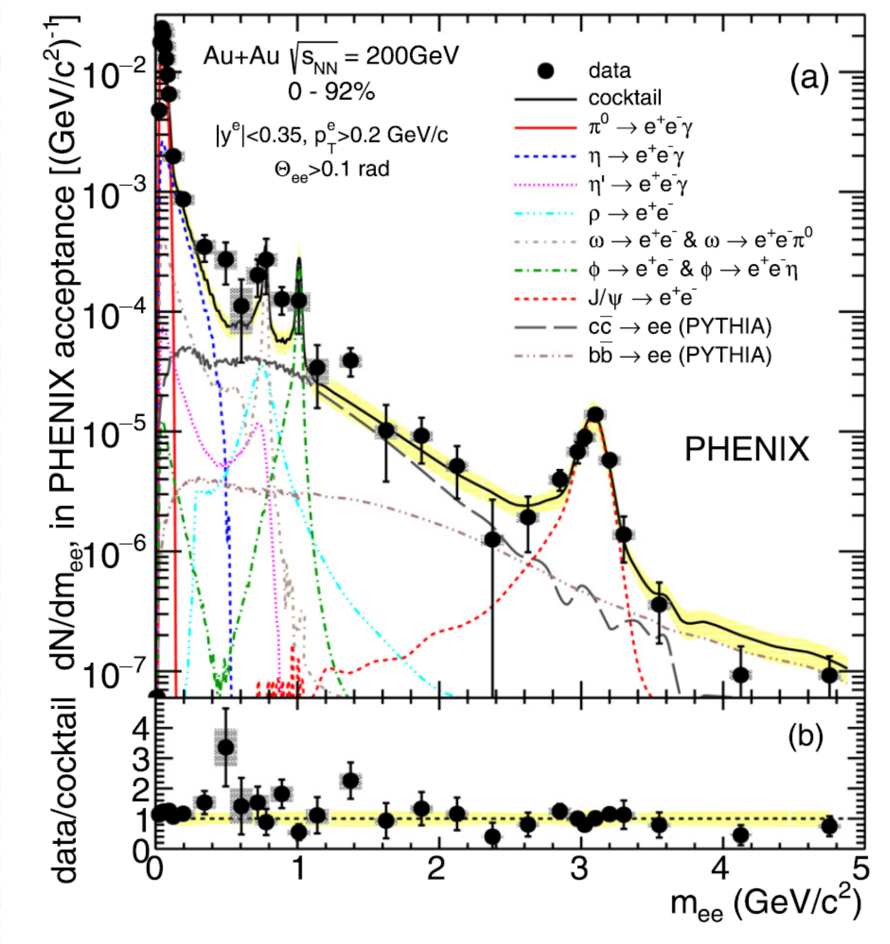
J-PARC 季刊誌 No.12 2019

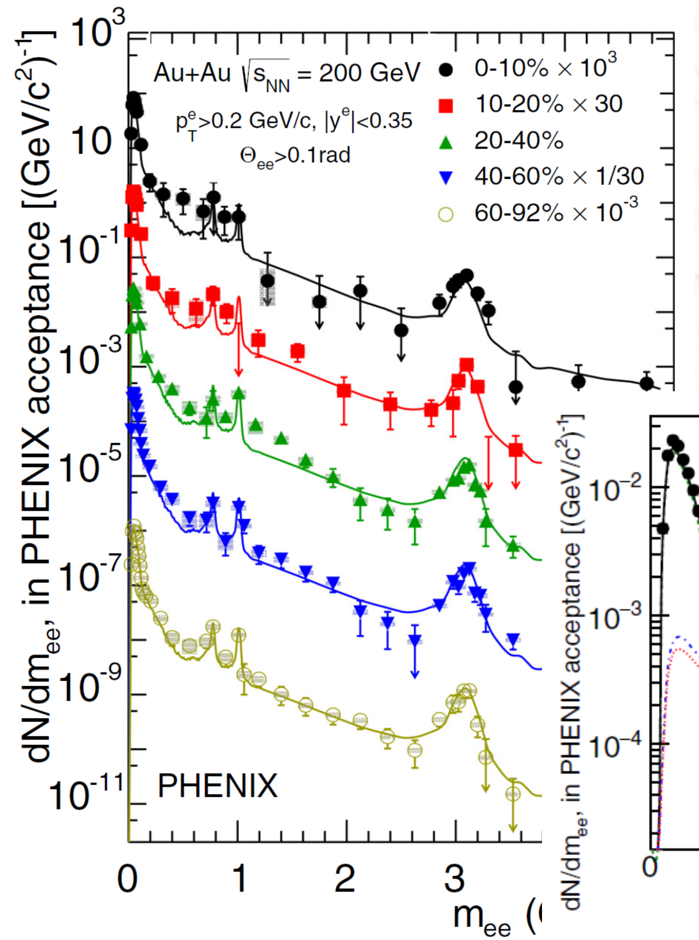
http://j-parc.jp/picture/2019/06/J-PARCmagazine2019_12.mp4

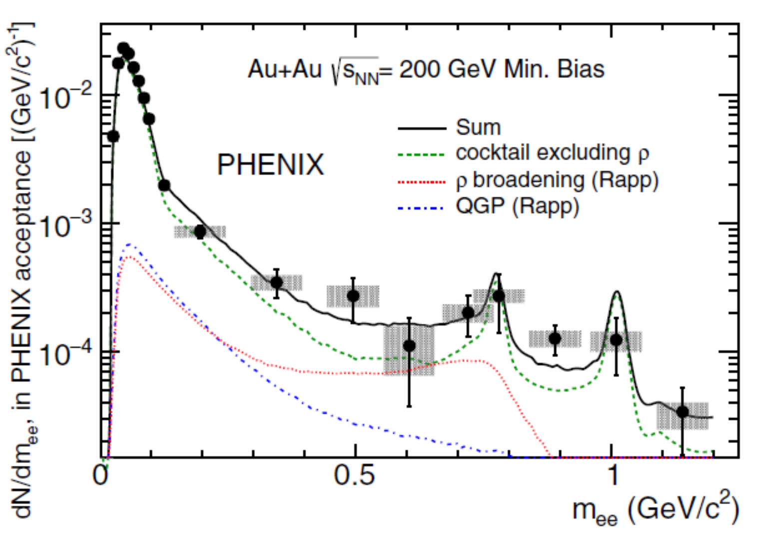
Experimental results at high temperature

PHENIX w/ HBD

PRC93(2016)014904



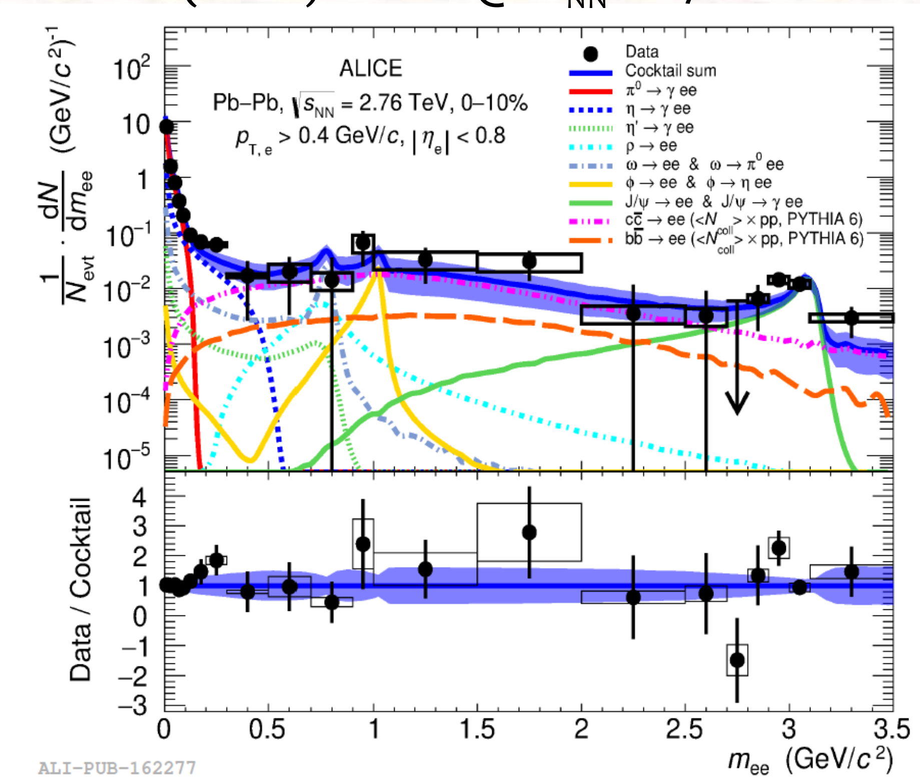




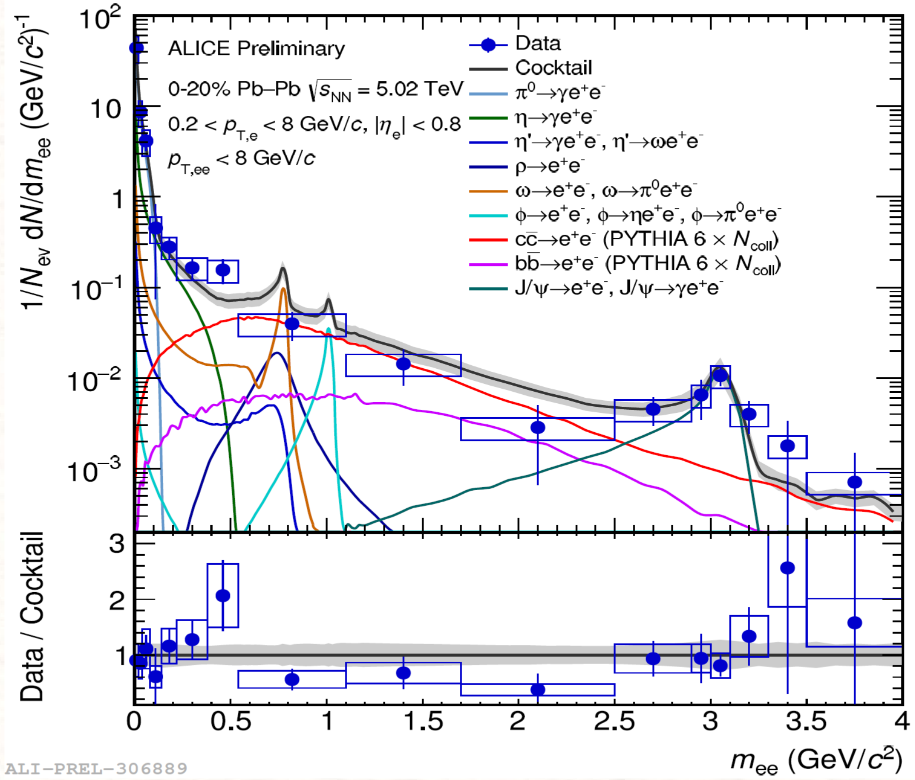
consistent with STAR

Pb-Pb w/ ALICE @ LHC

(0-10%) Pb–Pb @$\sqrt{s_{NN}}$ = 2.76 TeV



(0-20%) Pb–Pb @$\sqrt{s_{NN}}$ = 5.02 TeV



R=1.4±0.28 (stat.)±0.08(syst.)±0:27(cocktail)

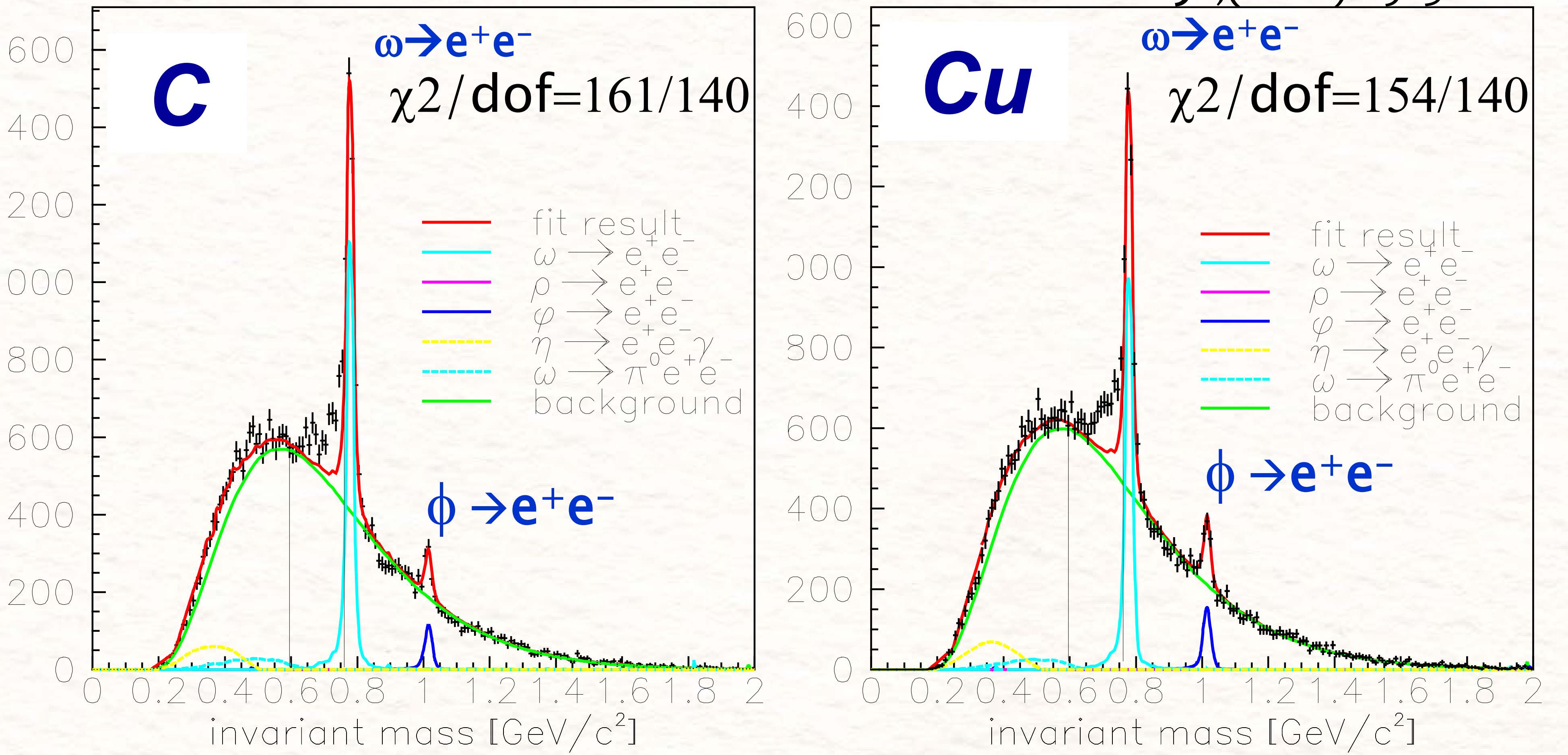
MDPI Proc. 10 (2019) no.1, 24

Experimental Results in cold nuclear matter

E325 @ KEK-PS

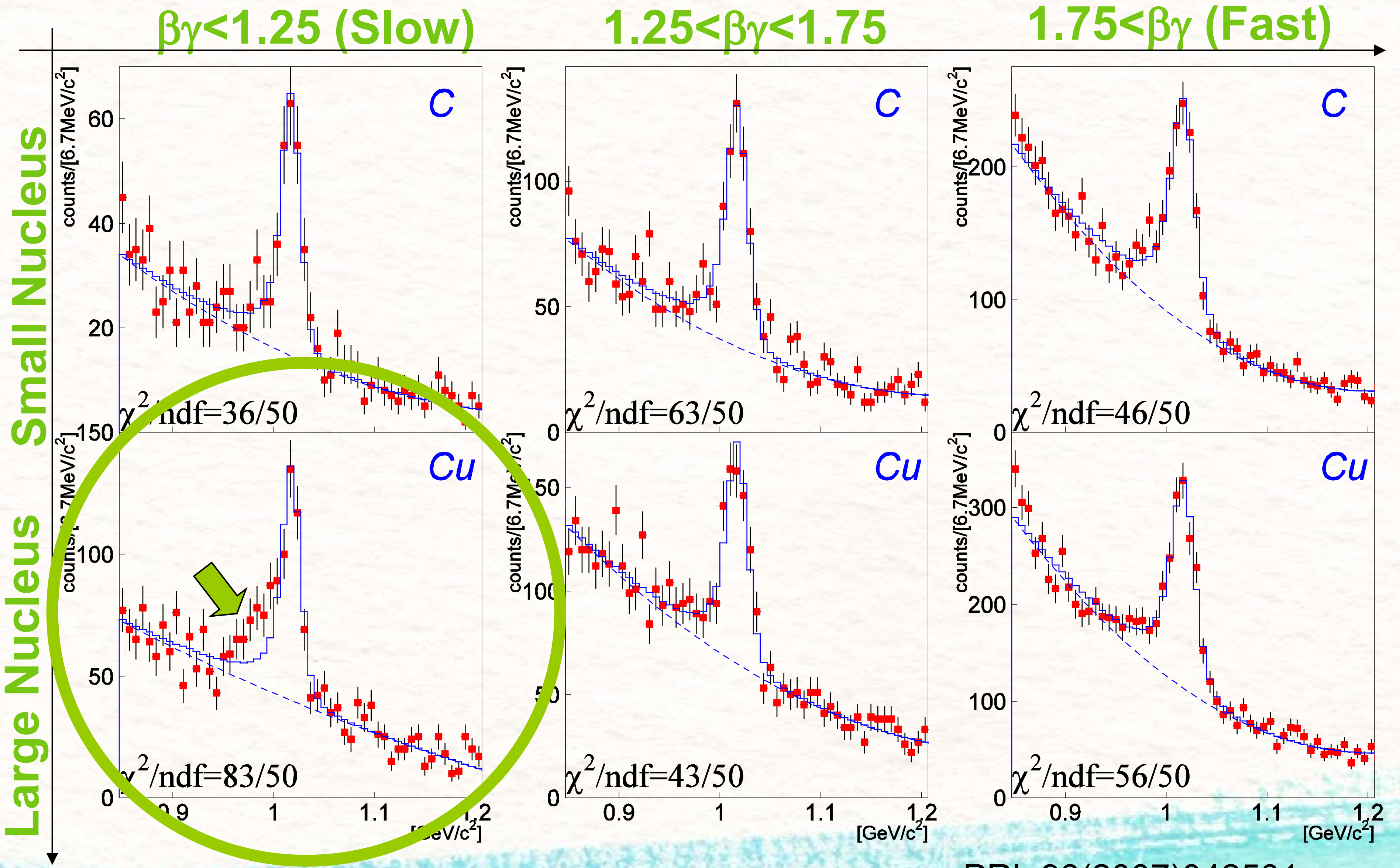
Invariant Mass Spectrum of e+e− in 12GeV/c p+A

PRL**96**,(2006) 092301



the excess over the known hadronic sources on the low mass side of ω peak has been observed.

Invariant mass spectra of φ→ e^+e^-



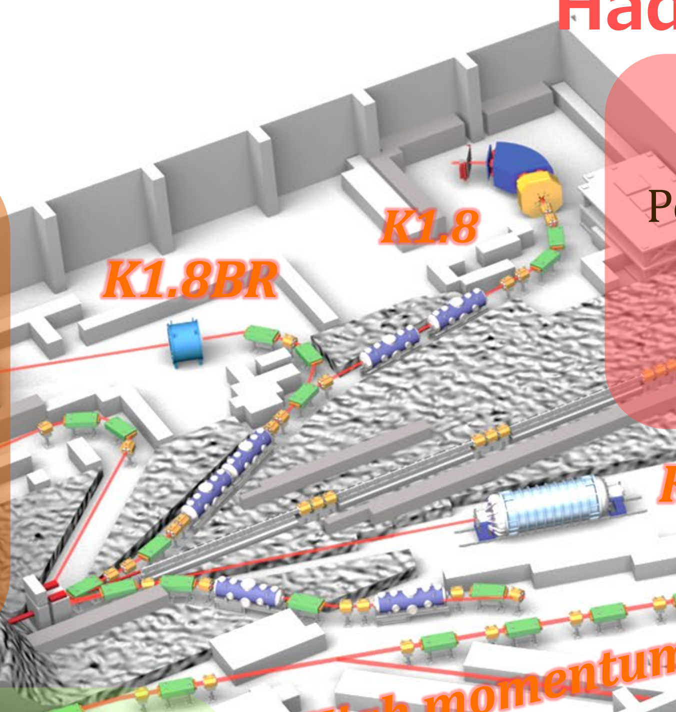
PRL 98(2007)042501

J-PARC bird's-eye view

Tokai village, Ibaraki

Physics at J-PARC Hadron Facility

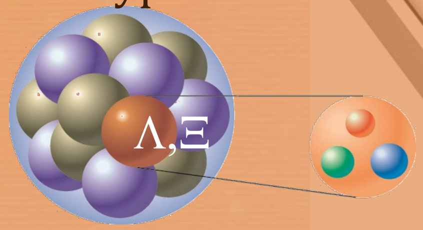
intense kaon beam



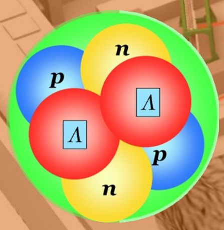
Strangeness nuclear physics

Hypernuclei

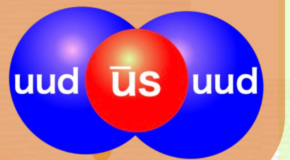
multi-strangeness hypernuclei



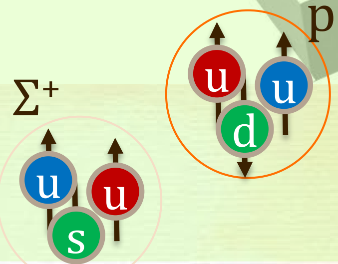
double-L



Few-body systems



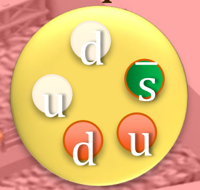
Hadron-Hadron Interaction



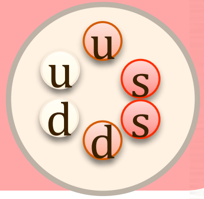
Hadron Spectroscopy

Exotic Hadrons

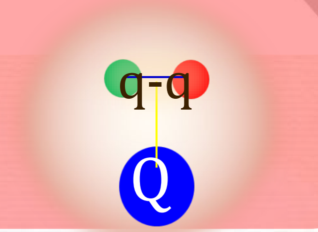
Pentaquark Θ+



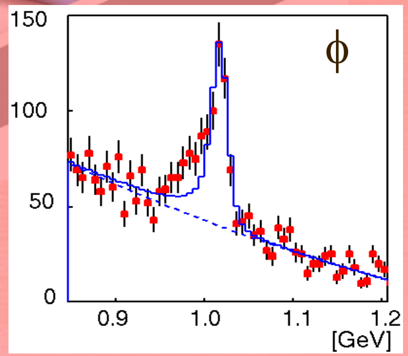
H dibaryon



Baryon spectroscopy

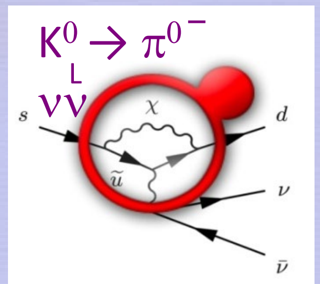


Hadron Mass

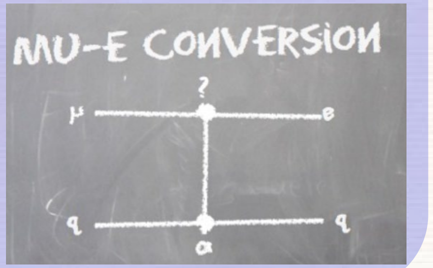


Flavor physics

CP violation



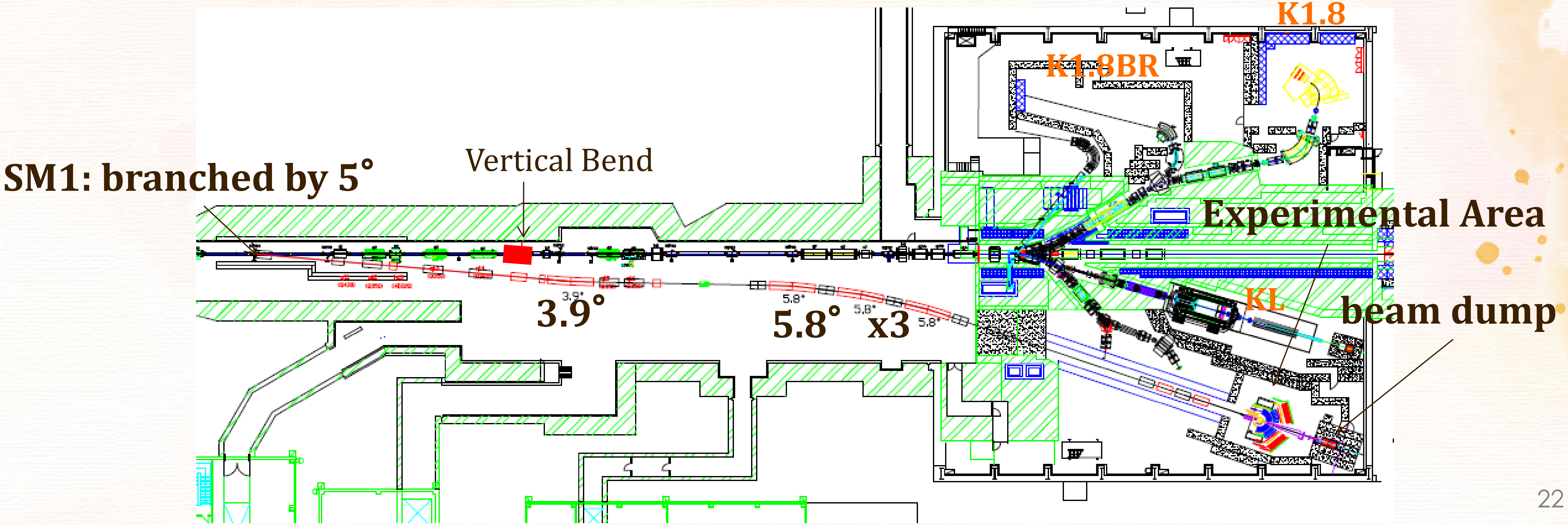
Lepton Flavor Violation



High-momentum beamline

- at SM1 protons branches off from the primary line
- 30 GeV primary proton (10^{10}/s)
- 8 GeV primary proton for COMET
- 2 - 20GeV/c secondary particles

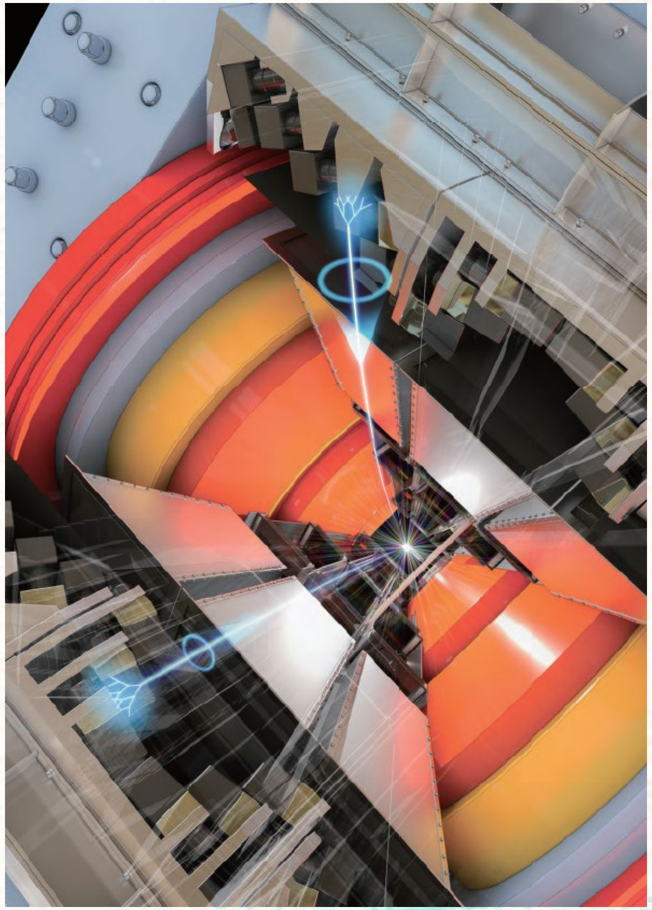
Name	Particles	P_{max} (GeV/c)	Intensity (/spill)
K1.8	π, K	2.0	10^6 K^-
K1.8BR	π, K	1.1	10^6 K^-
KL	K^0		
High-p	**proton**	**31**	10^{10} p
High-p2	**π/K**	**20**	10^6 K^-



Dilepton Measurement
How meson mass modified at finite density?

- **clean intense proton beam & thin targets**
  - –10^{10} p/spill & 0.1% target
- **high-rate capability**
  - –10^{7} interaction w/ STS&GEM Tracker
  - –high granularity （100k channels)
- **large acceptance**
- **high mass resolution**
  - –magnetic field ：special spectrometer magnet
  - –high position resolution ：SSD & GEM

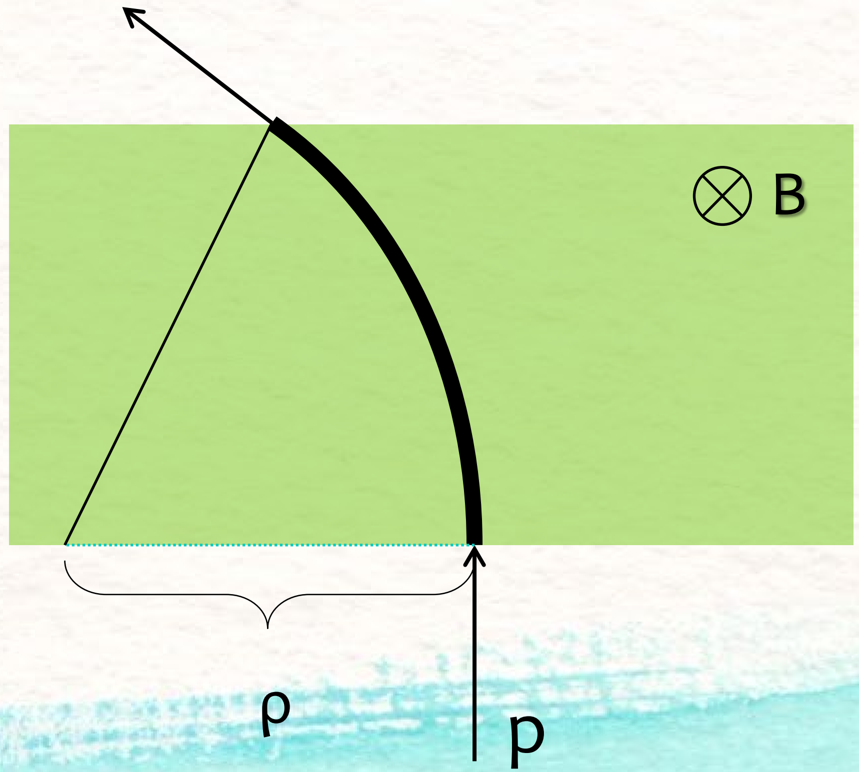
E16 Spectrometer



Experimental Technique

- Mass Determination
  - $M^2 = E^2 - p^2 = (E_1 + E_2)^2 - (p_1 + p_2)^2$

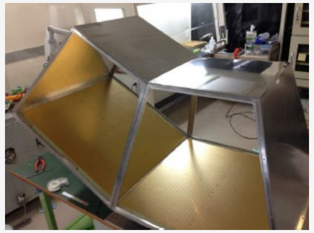
    mother particle   decay particles
- Momentum measurement
  - $p = 0.3B\rho$
    - B: magnetic field
    - ρ : radius of circle ← position measurement
- Particle Identification
  - $M_e^2 = E_e^2 - p_e^2$
- Data Acquisition

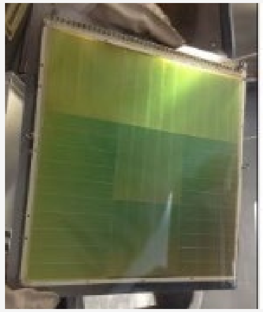


PID detectors
rejection power : 3x10-4

Tracking Devices
position resolution : 10/100um

Hadron Blind Detector (HBD)

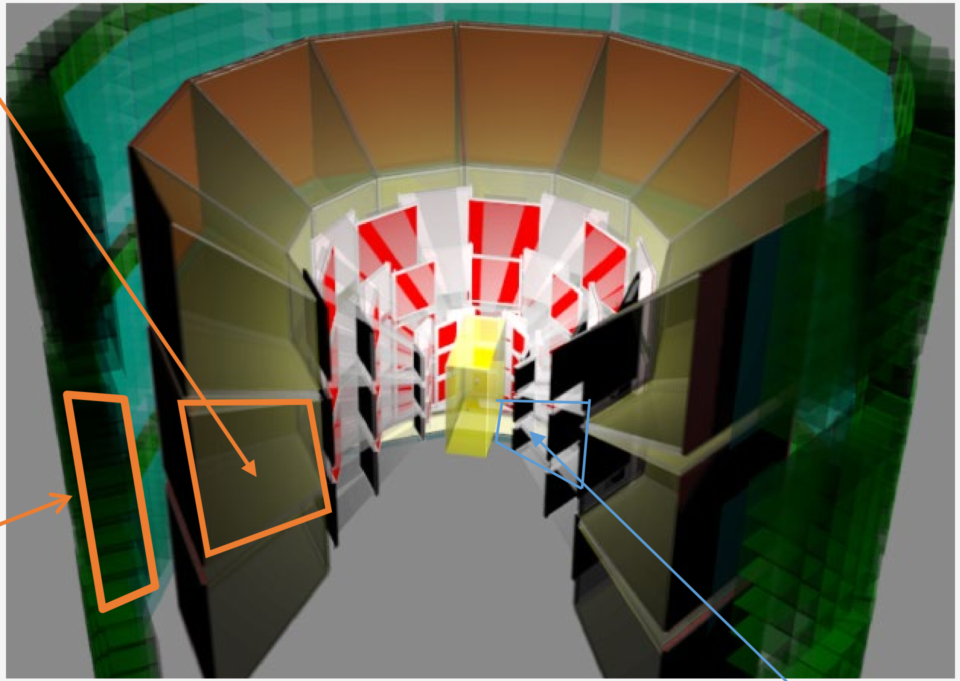




CsI evaporated GEM
(inside the gas chamber)

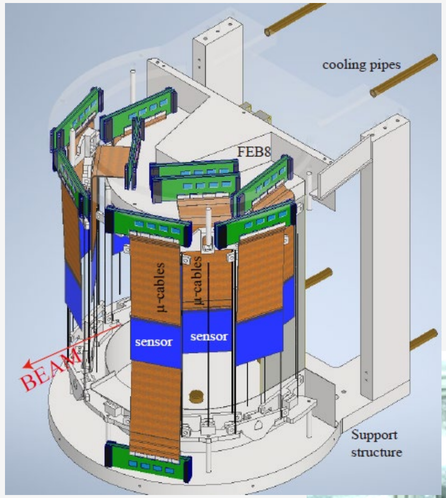
Lead-glass calorimeter

SF6W crystals

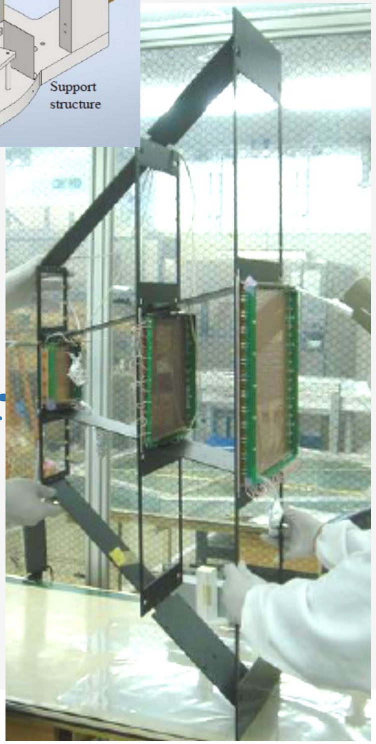


Magnet

Silicon Tracking System



GEM Tracker

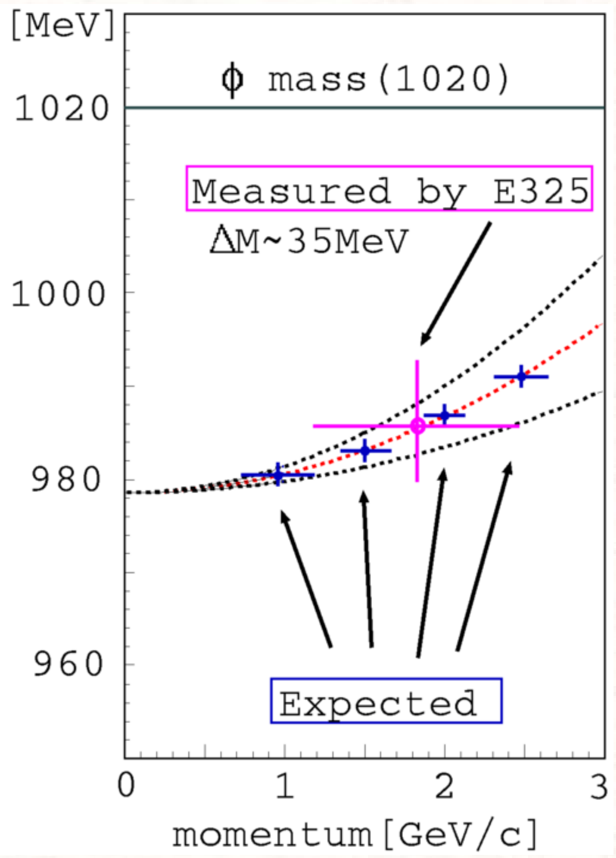


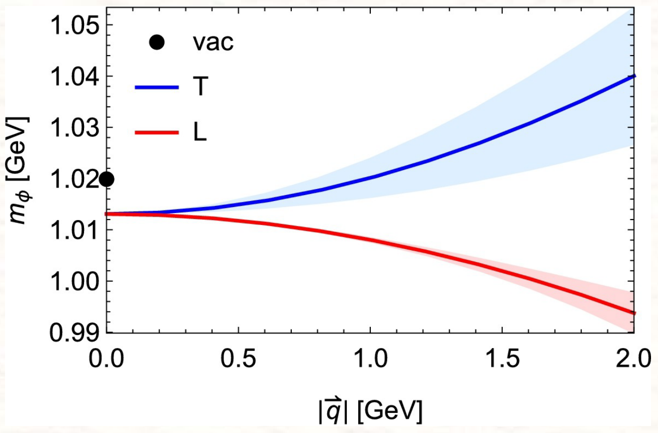
GEMs w/ 3 sizes
(10, 20 and 30 cm on one side)

Expected Signals

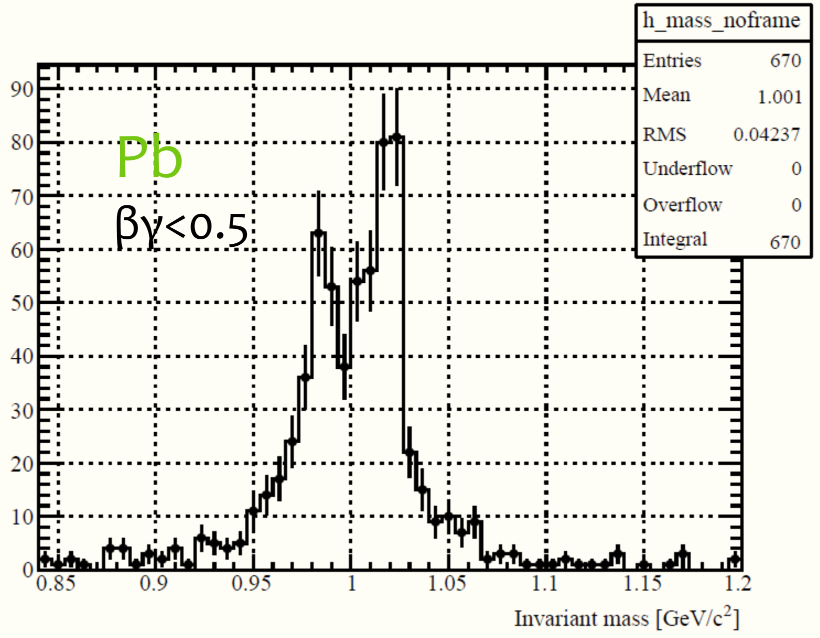
momentum dependence of mass

- High mass resolution
- High statistics





φ



In-medium mass spectral function

Kim & Gubler, PLB 805 (2020) 135412

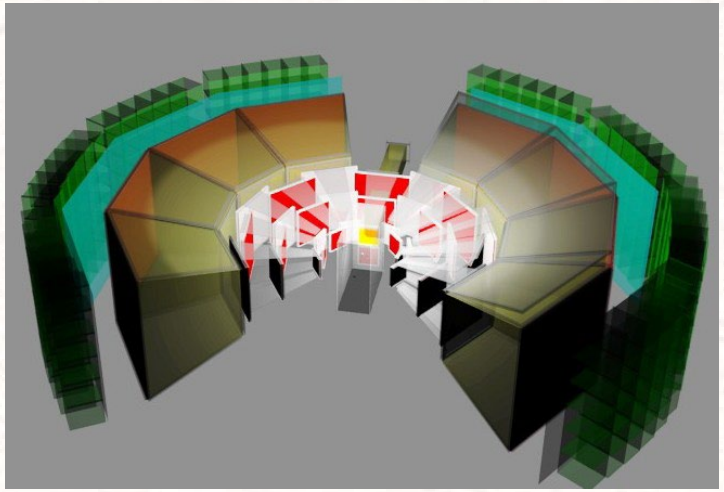
S.H.Lee, PRC57 (1998) 927

Schedule

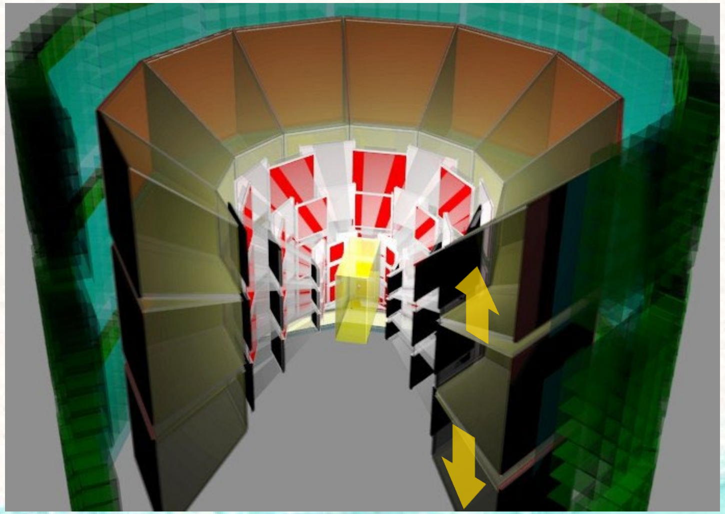
- 2020-2021 RUN0 -- 403 hours, C/Cu targets
  - Beamline / Detector commissioning
- 2023 April Run0d -- 21 hours (terminated due to fire accident)
  - Beamline / Detector commissioning
- 2024 April Run0e -- 205 hours
  - BL & trigger commissioning

- 2025 RUN1 -- 1280 hours, C/Cu targets
  - Physics run 15k of φ mesons
- 2026- RUN2 -- 2560 hours, C/Cu/Pb targets
  - nuclear size & velocity dependences
  - dispersion relation

RUN 1 (8 modules)



RUN 2 (26 modules)



Summary

- Dilepton is a clean probe to investigate mass modification at finite density
- Already we observed spectral modifications on vector meson mass in the sector of light quarks.
  - hot matter：width broadening of ρ meson ←many body effect caused by surrounding hadrons
  - finite density：mass decreases of ρ,ω,φ mesons ← QCD condensations
- J-PARC E16 aims at determining QCD condensations from the measurements of spectral functions at finite density