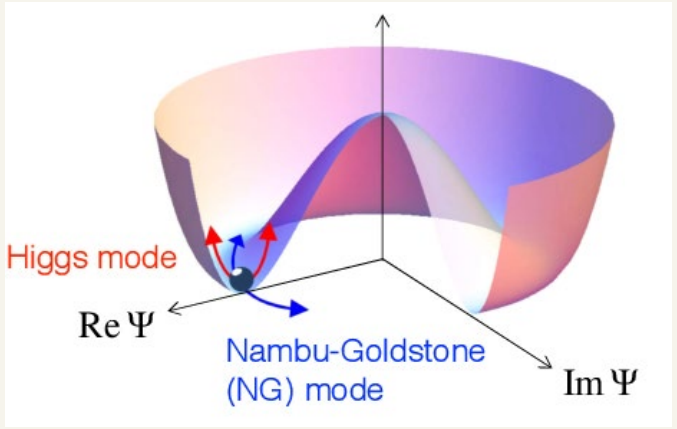
Measurement of Hadron Mass in nuclei

- M. Naruki (Kyoto Univ.) 29th May 2024, Univ. of Tokyo

Hadron Mass

- Higgs vacuum : $m_{u,d} \simeq 2$MeV



DOI:10.1146/annurev-conmatphys-031119-050813

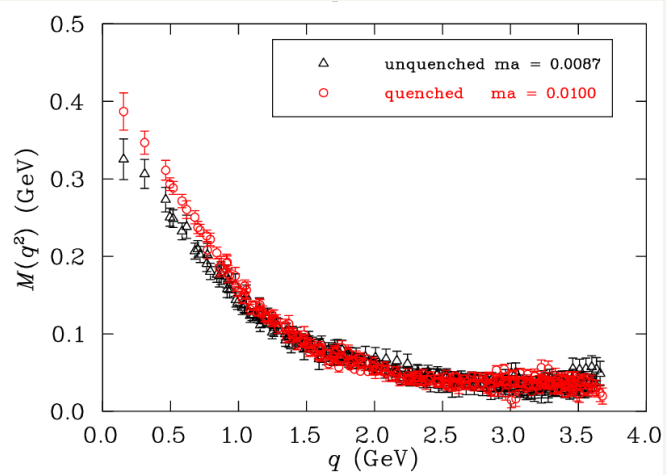
- Spontaneous breaking of chiral symmetry
  - the mechanism to generate 98% of mass in universe
    - m_p=938MeV
  - Experimental fact :spectrum of parity doublet

- QCD condensate
  - $\langle \bar{q}q \rangle$, $\left\langle \frac{\alpha_s}{\pi} G^2 \right\rangle$, ... <-> hadron mass

thanks to QCD sum rule

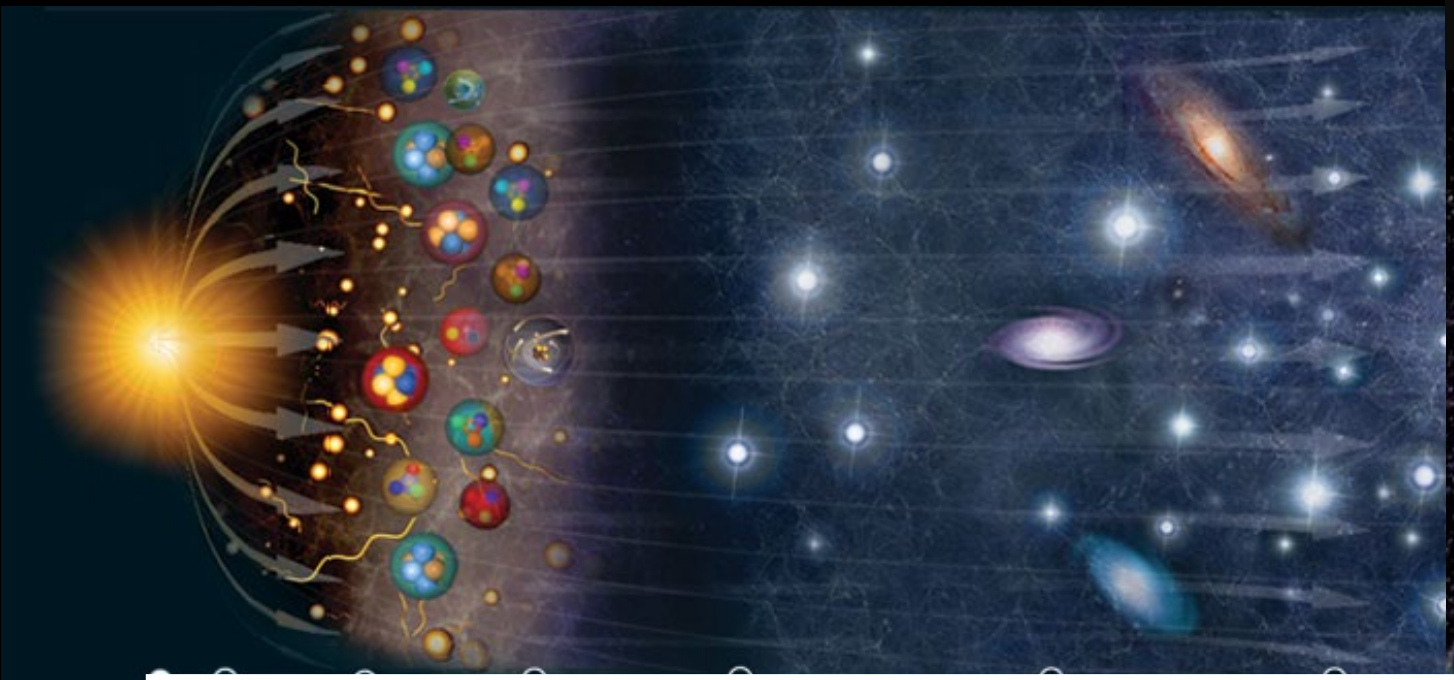
$$\int_0^{s_0} ds\, N_{\varphi \to ee}(s) s \quad = -\frac{1}{12}\left\langle \frac{\alpha_s}{\pi} G^2 \right\rangle - 2m_s \langle \bar{s}s \rangle$$

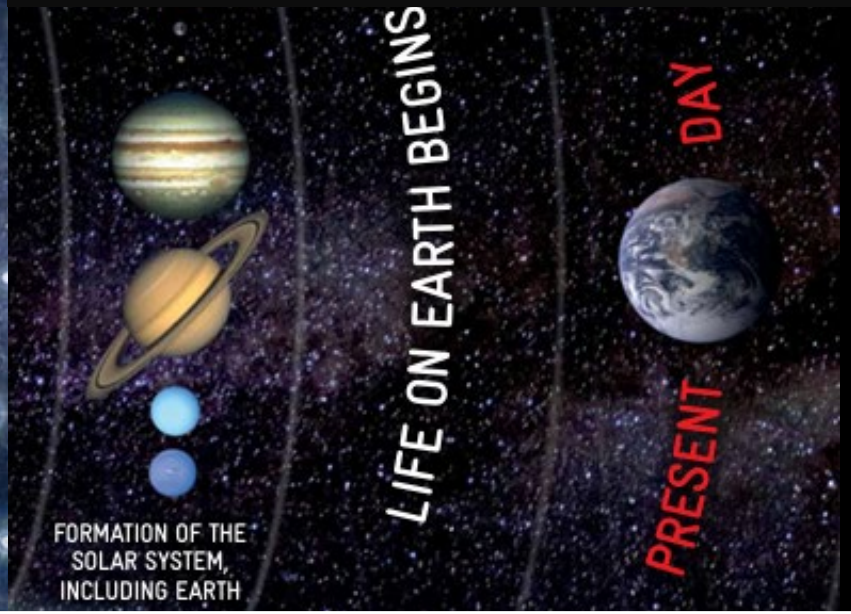
QCD Lattice calc.



MILC Collaboration, PRD71(2005)054507

History of Universe and Matter Evolution





neutron star

$10\rho_0$

ρ_0

ρ

10^{-32} second Cosmic inflation ends

10^{-6} second Protons form

100 seconds Deuterium, helium and lithium are synthesized

100 million years First stars form

500 million years Current record holder for earliest known galaxy

4 billion years Star formation peaks

9 billion years formation of solar system, earth

10 billion years

13.8 billion years

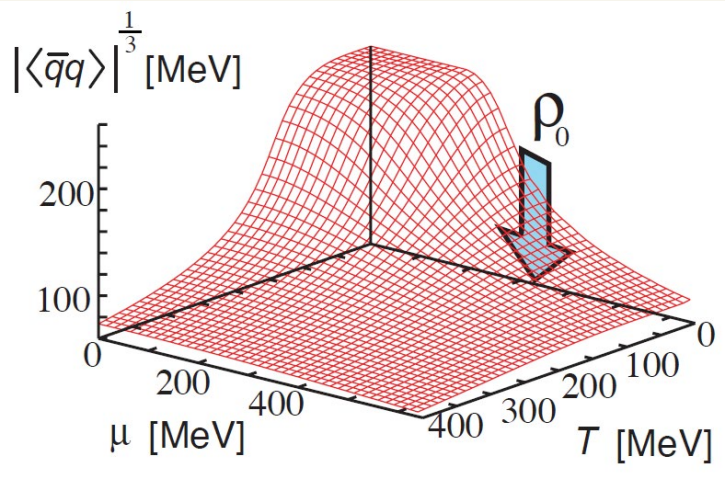
t[s]

10^{28} 10^{13} 10^{10} 3000 15 3 T[K]

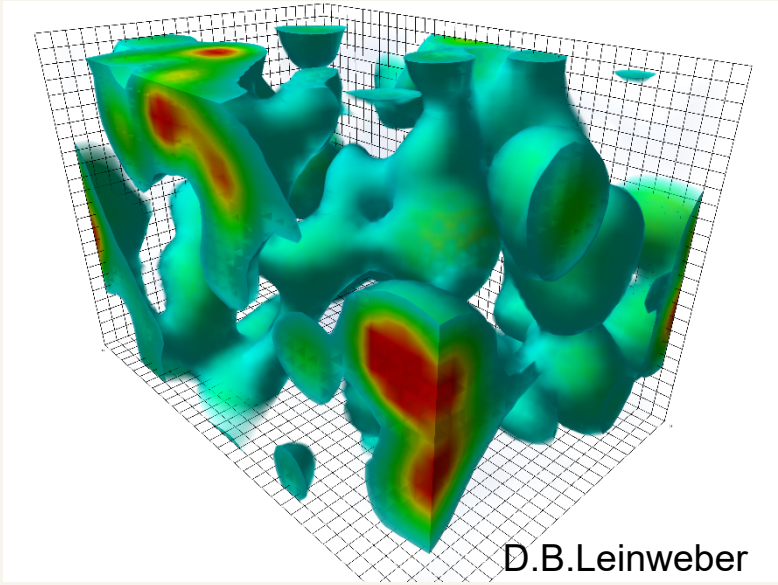
QCD Vacuum

- lowest energy state, non-perturbative vacuum
  - finite gluon, $\bar{q}q$ condensates

Lattice QCD calc.



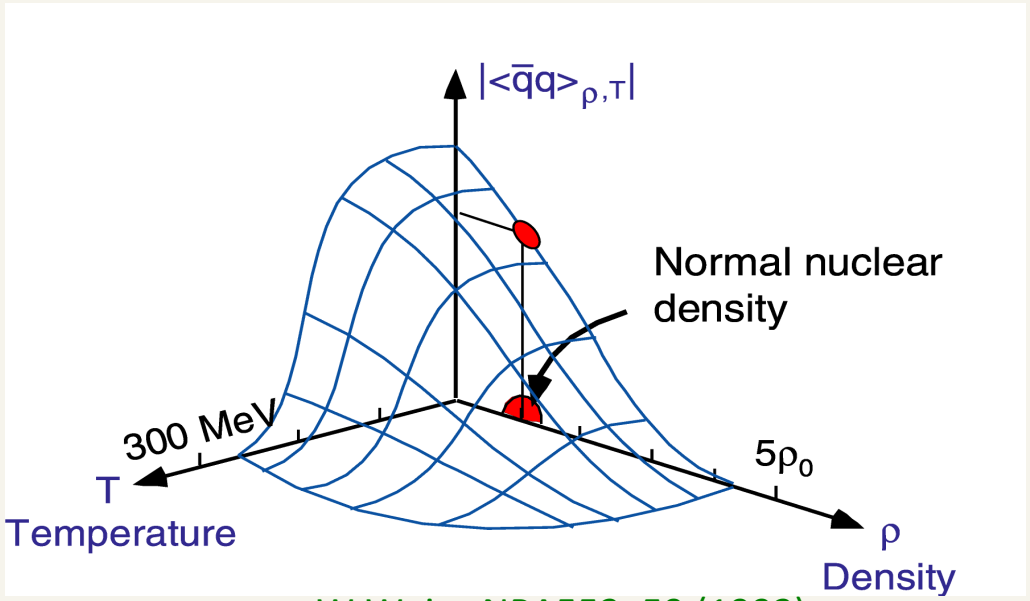
A. Nakamura, priv. comm.



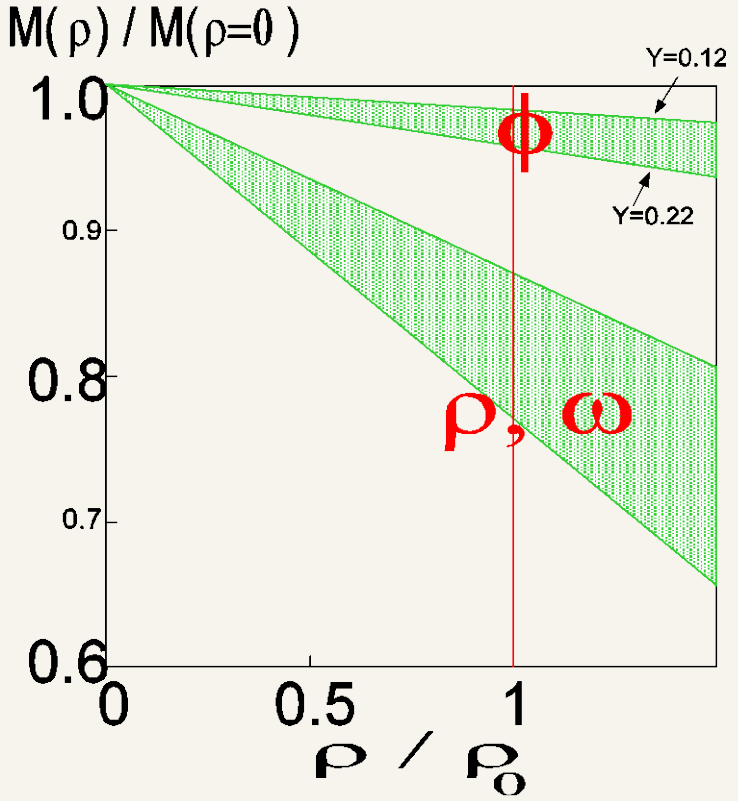
D.B.Leinweber
"Visualization of QCD"

QCD condensate and Hadron Mass

- vacuum : quark and gluon condensates
- How to examine experimentally?
  - behavior of chiral doublet
  - precise measurement of spectral function



W.Weise NPA553, 59 (1993).



Hatsuda & Lee, PRC46('92)R34

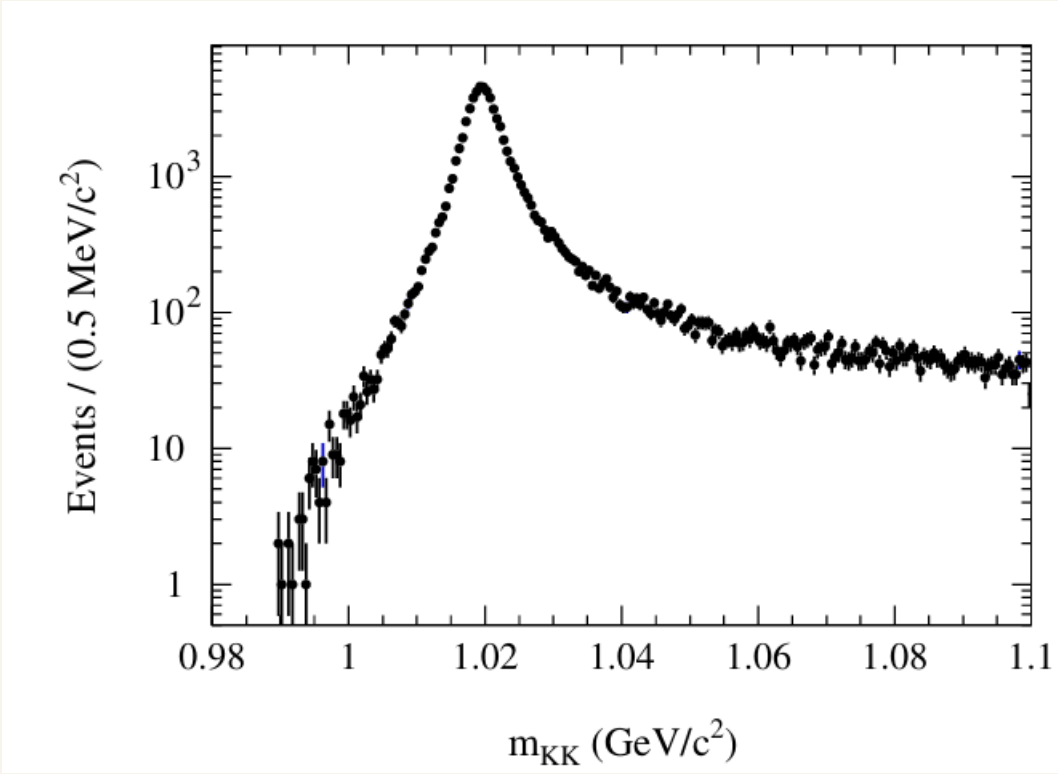
Dilepton

clean probe to address hadron properties

- hadron production in e+e−
  - spectral function in vacuum
- hadron decay into e+e−
  - messenger directly convey in-medium properties
  - cf. electron scattering

ee→KK

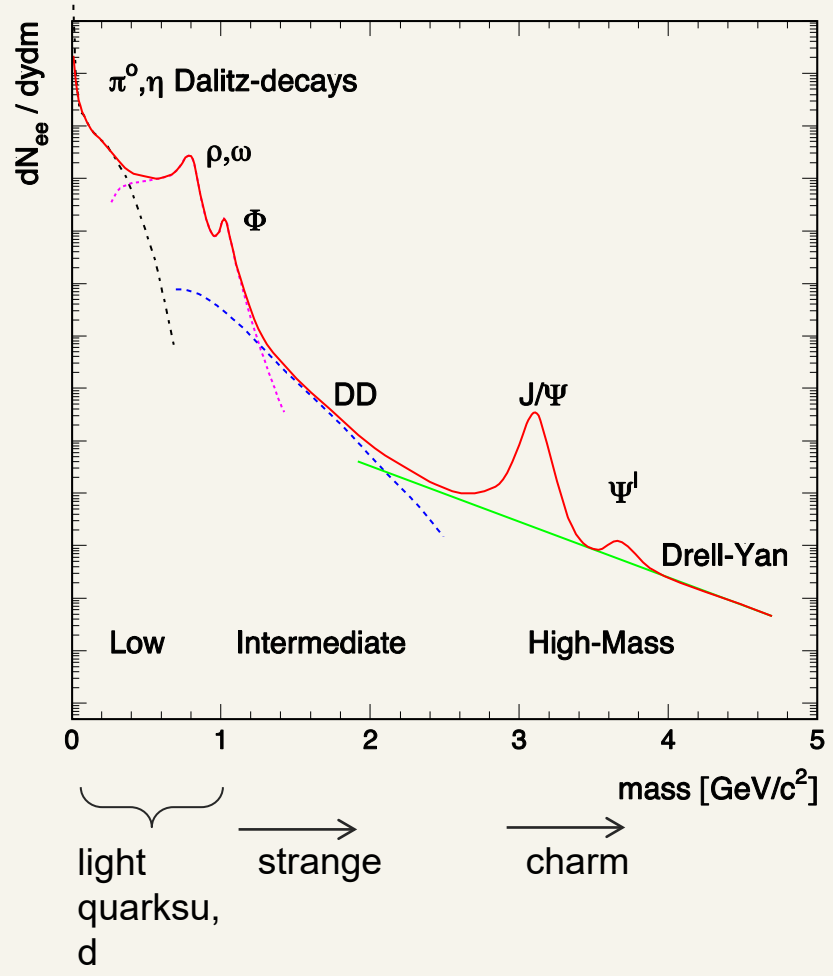
PEP-II at SLAC



BaBar, PRD88(2013)032013

Dilepton Measurement

vector mesons（$J^P=1^-$）: clean probe to measure mass directly

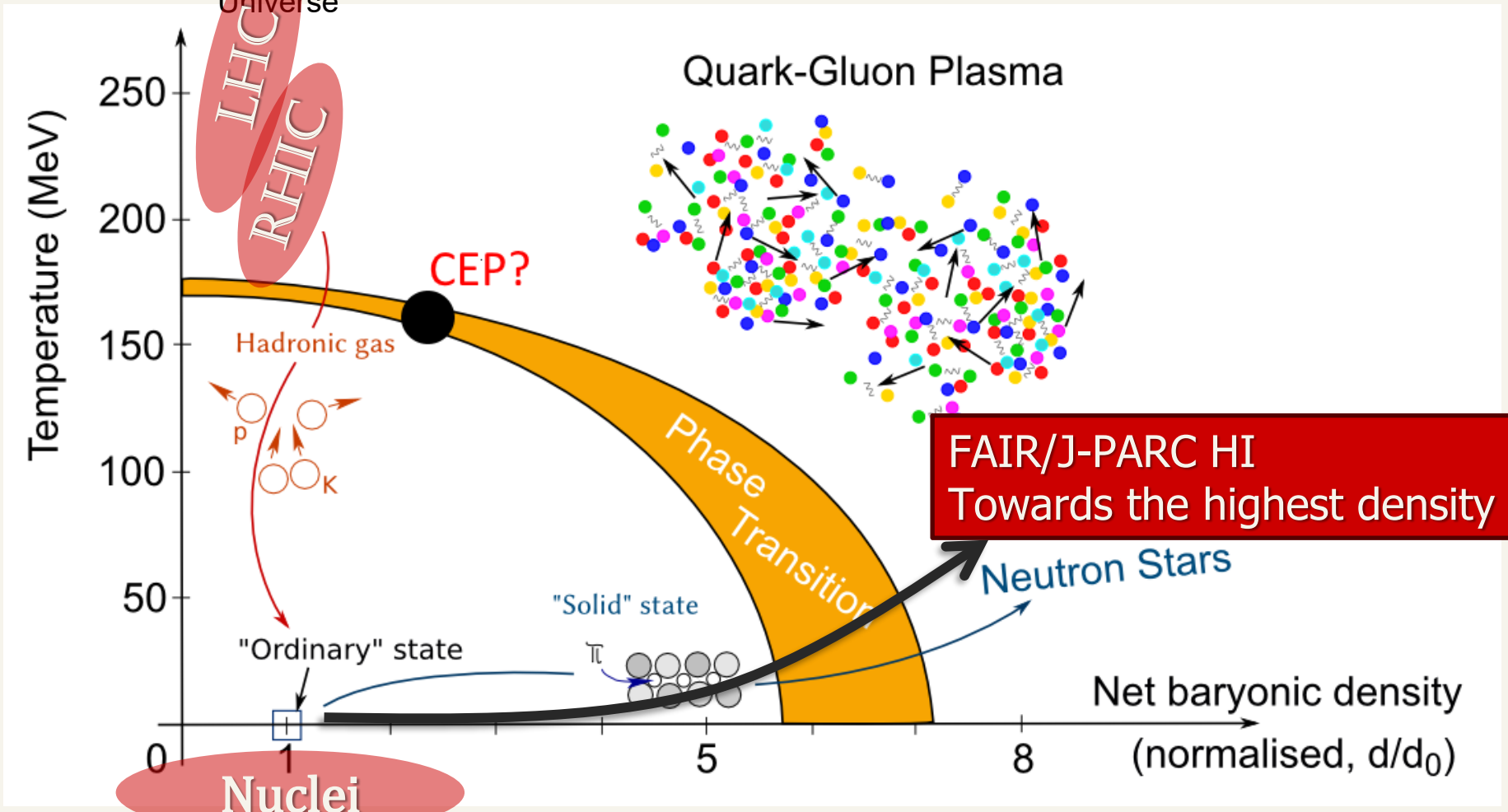


Low Mass Range (LMR) M_{ee}< 1.1 GeV/c^2

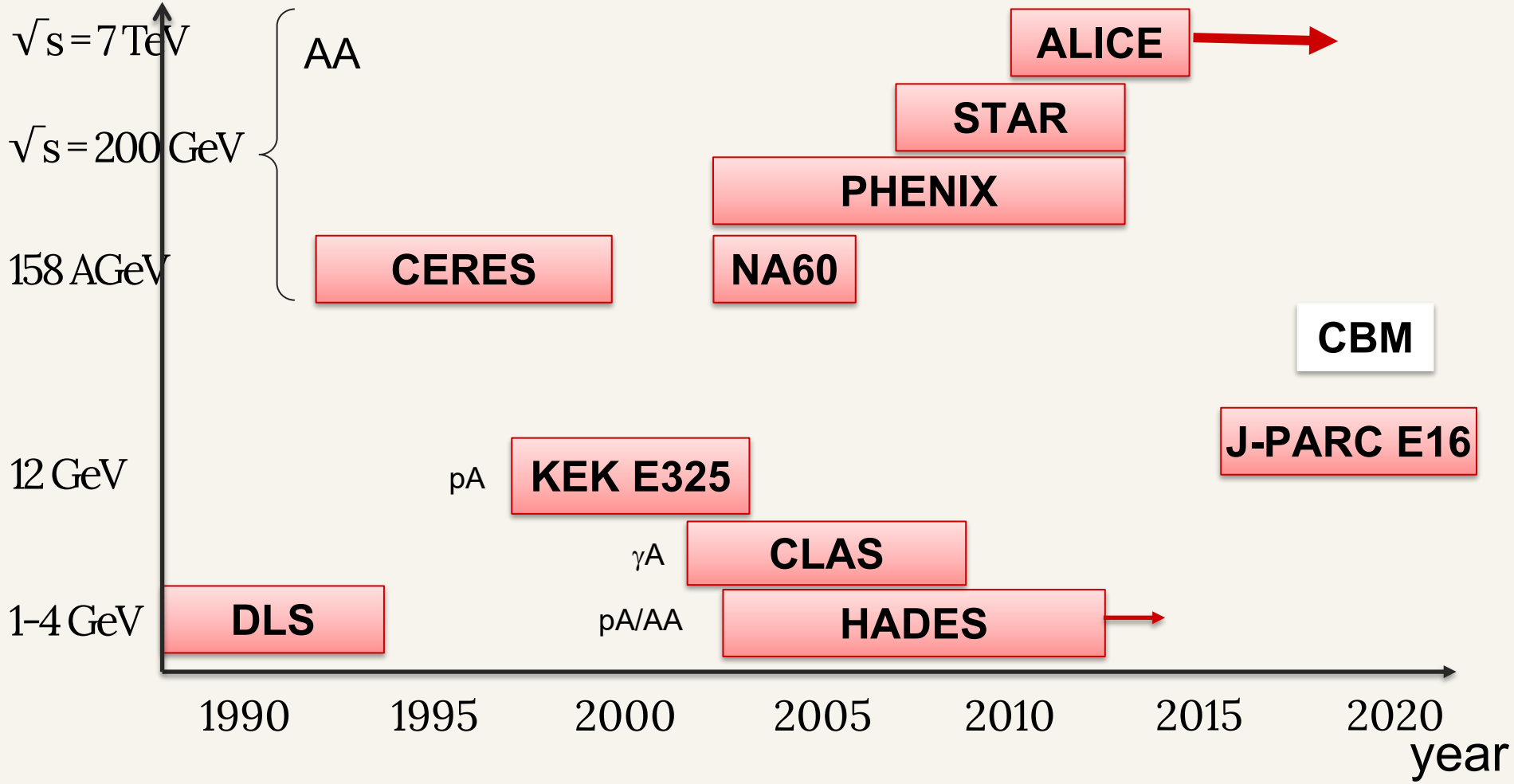
Sensitive to $\langle \bar{q}q \rangle$ in medium

		width	cτ	
ρ	$q\bar{q}$	149.2 MeV	1.3 fm	large effect overlap
ω	$q\bar{q}$	8.44 MeV	24 fm	
ϕ	$s\bar{s}$	4.26 MeV	47 fm	single peak

Probing Matter in Extreme Conditions

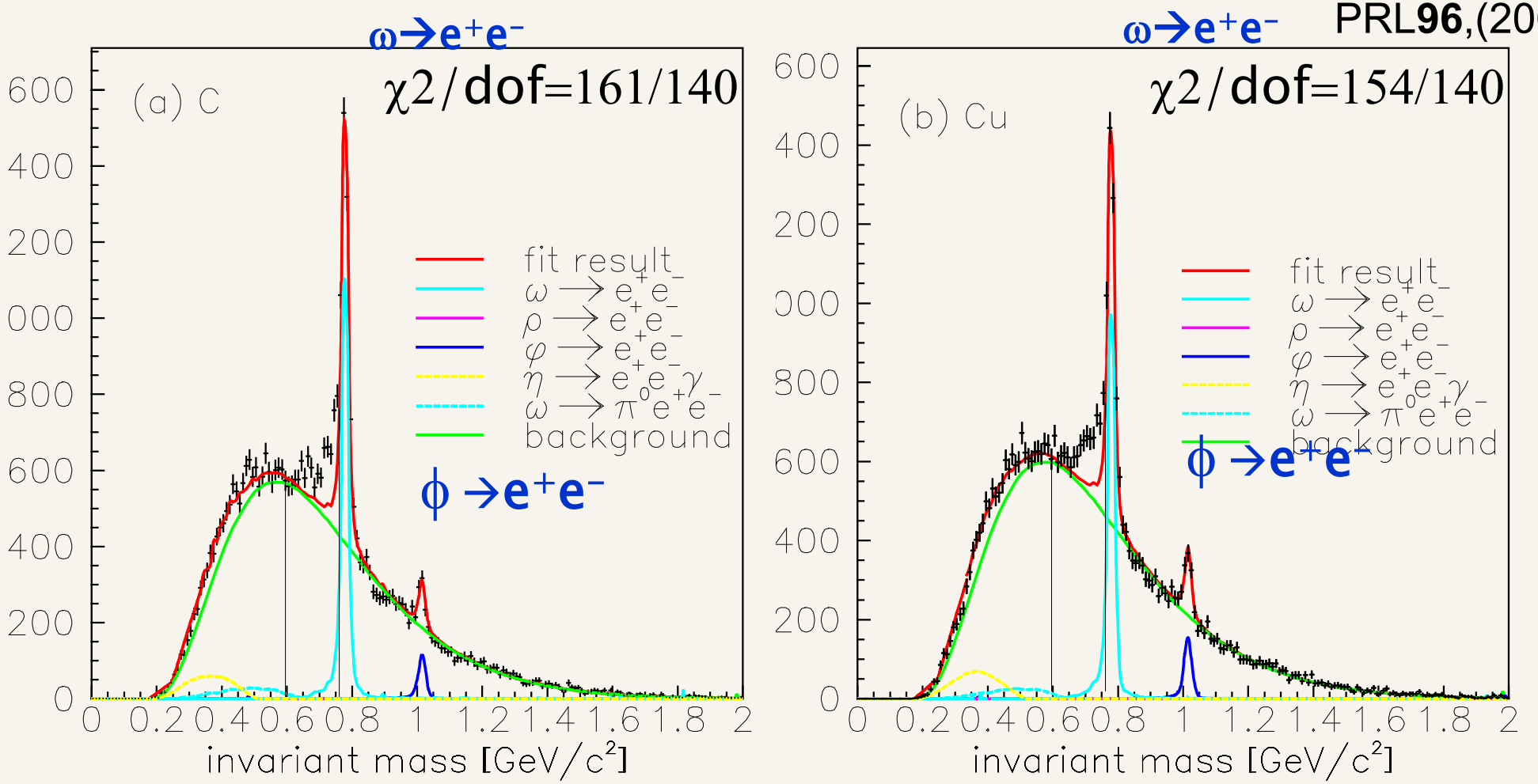


History of Dilepton Measurements



KEK-PS E325 : e+e− invariant mass spectrum

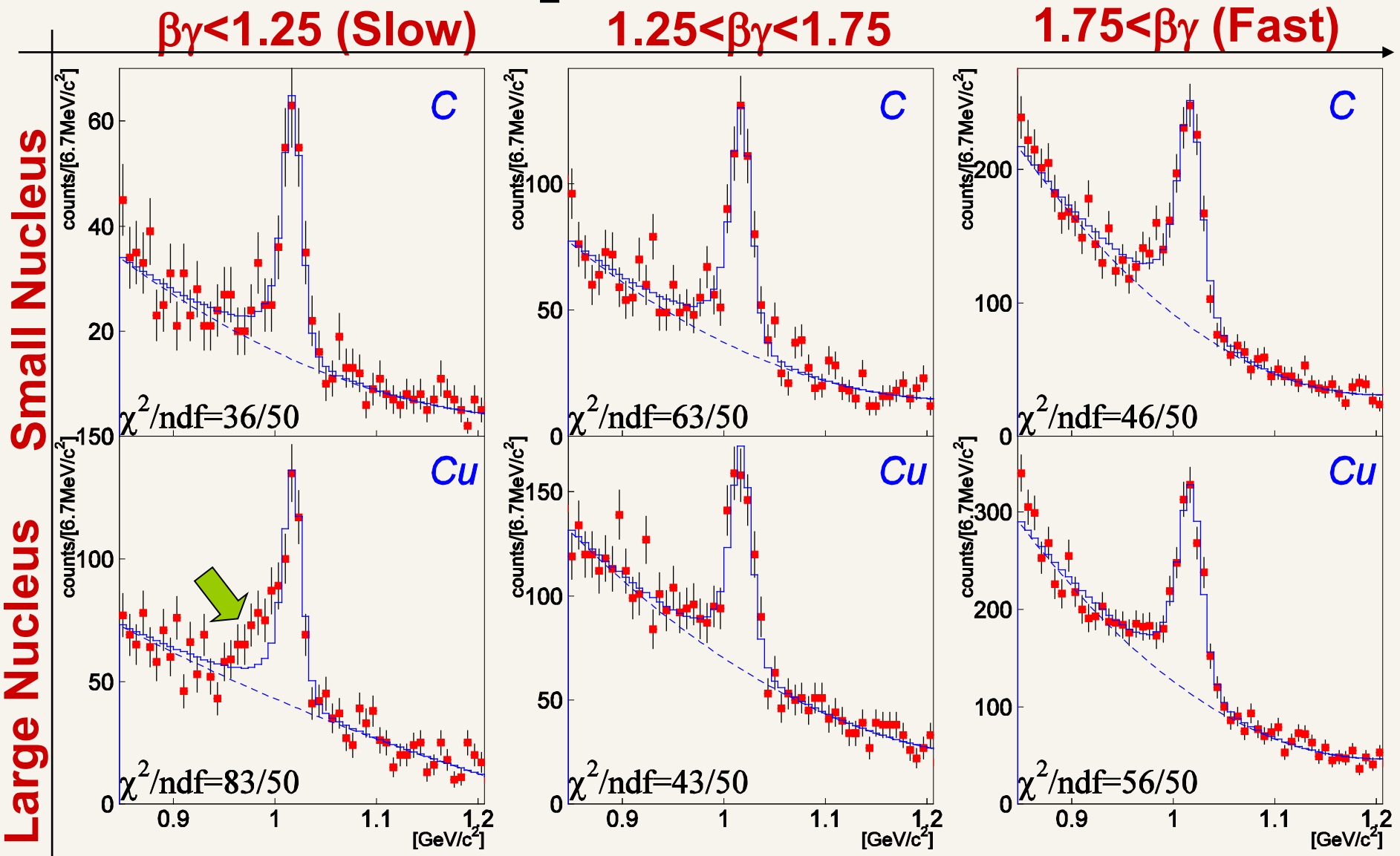
PRL**96**,(2006) 092301



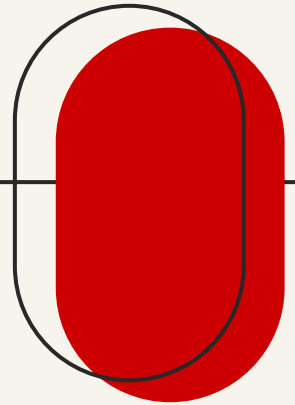
the excess over the known hadronic sources on the low mass side of ω peak has been observed.

Invariant mass spectra of φ→ e+e−

PRL 98(2007)042501

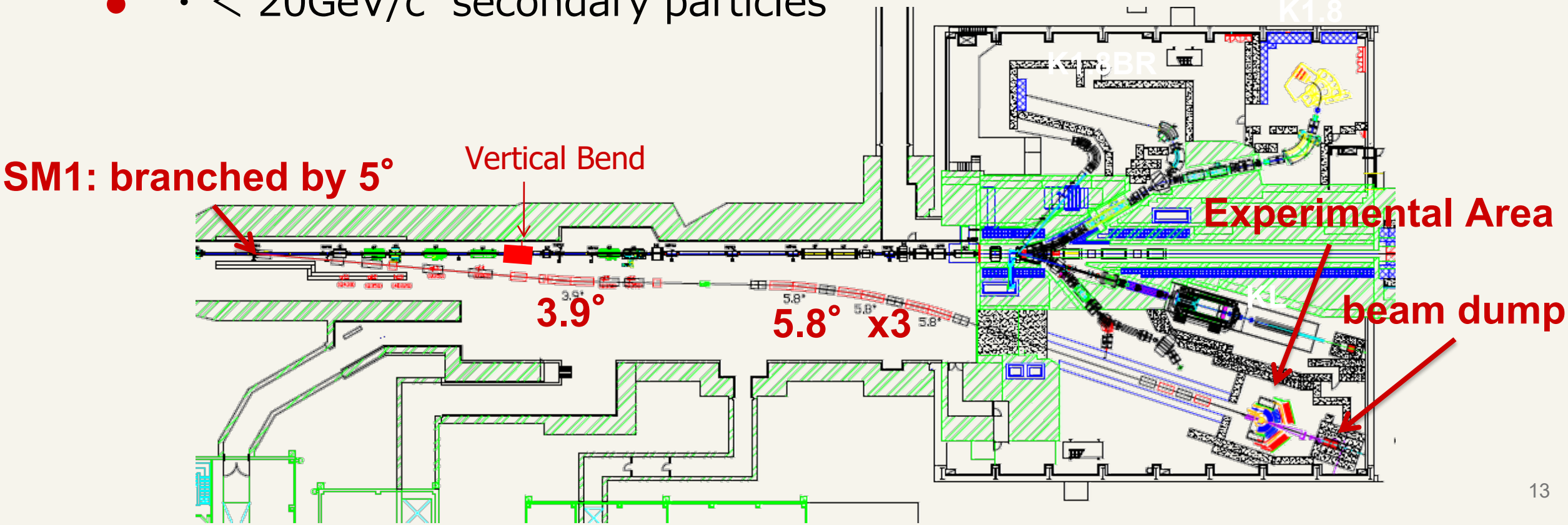


Dilepton Measurement at J-PARC



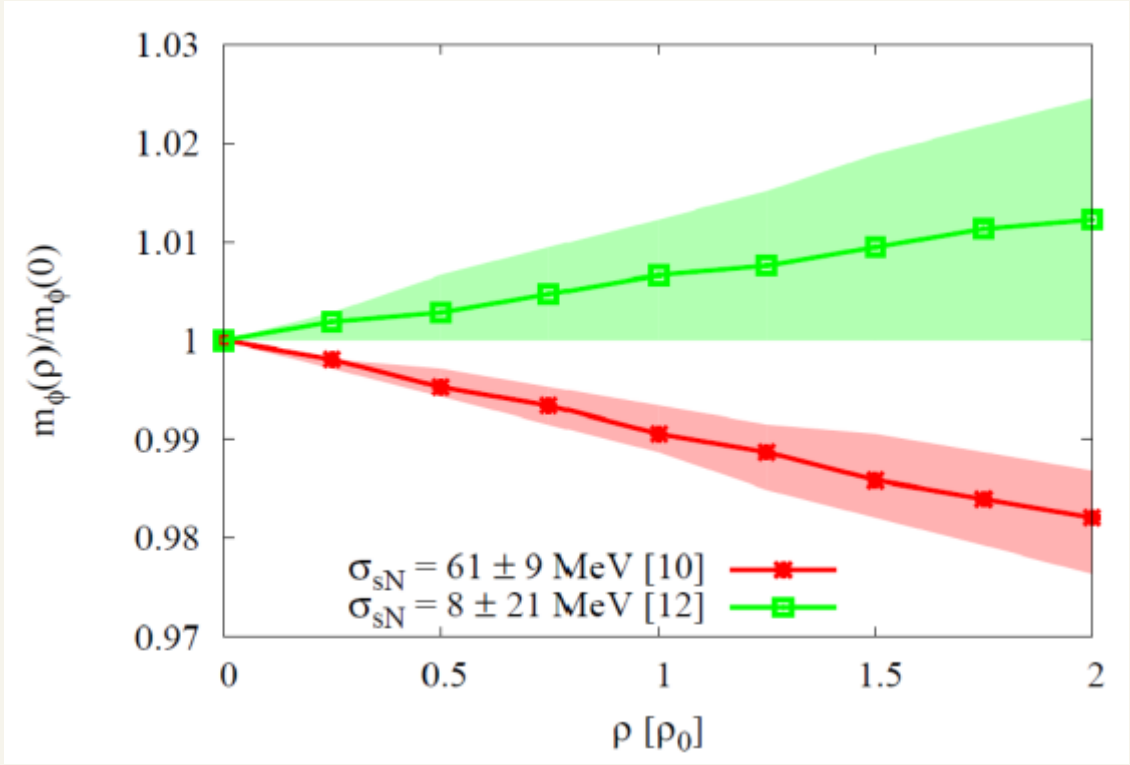
High momentum beamline

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



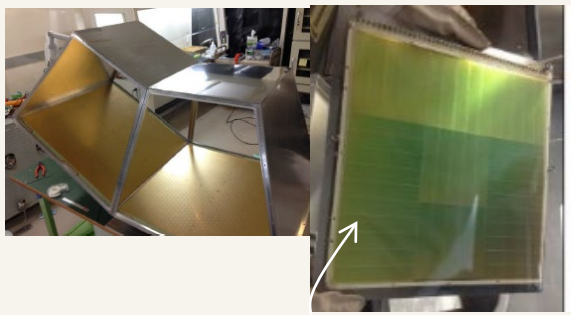
In-medium Spectral function of Vector Mesons - J-PARC E16 -

- Mass in medium
  - determine QCD condensates in medium
- Clean probe of dilepton e+e−
  - almost free from final state interactions
- New spectrometer
  - detect ρ,ω,φ produced in pA reaction
  - intense primary proton beam 10^{10} ppp
  - large acceptance
  - high mass resolution of 5.5 MeV



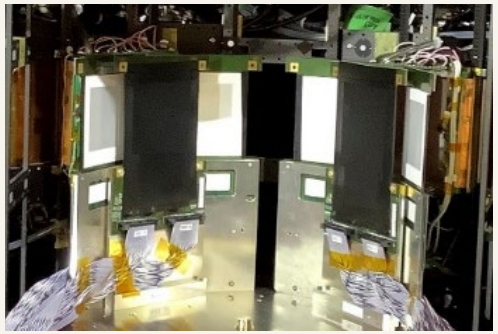
P. Gubler and K. Ohtani, PRD 90, 094002 (2014)

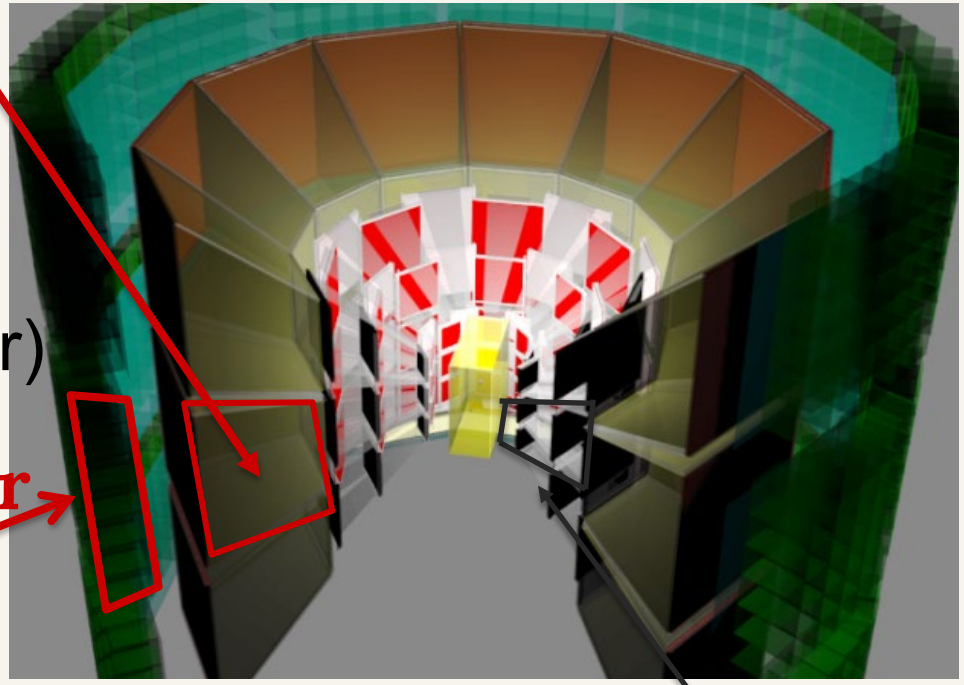
Hadron Blind Detector (HBD)



CsI evaporated GEM
(inside the gas chamber)

STS(SSD)





Lead-glass calorimeter

rejection power :
3x10-4

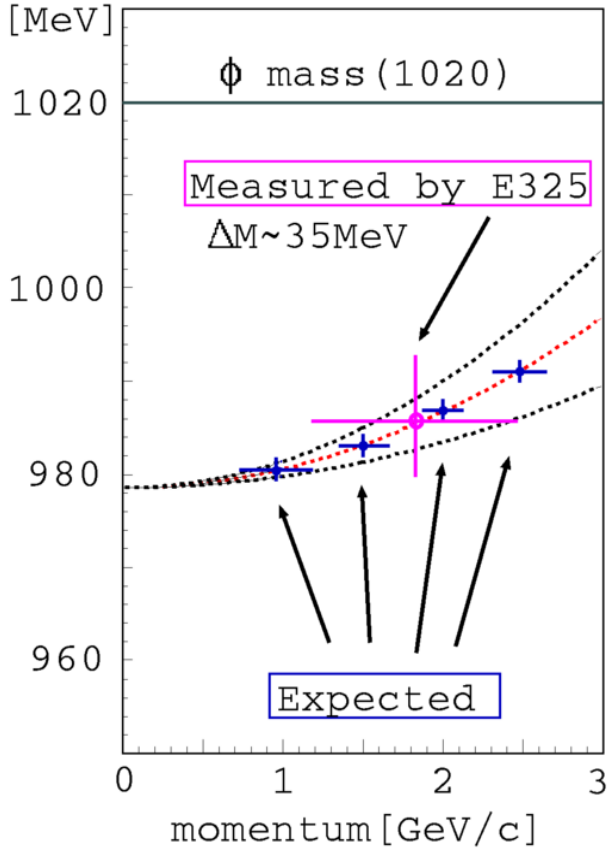
SF6W lead-glass

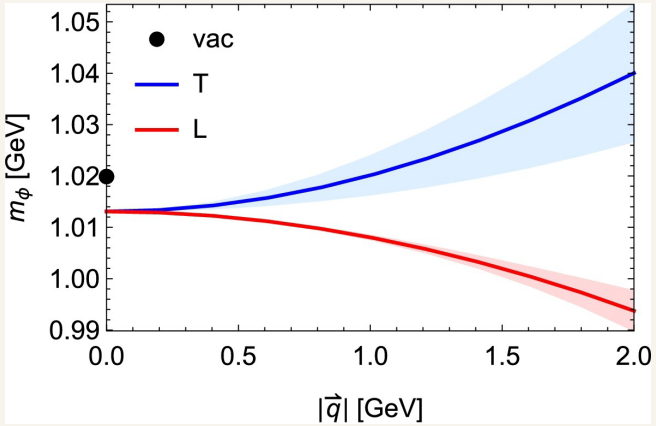
GEM Tracker

3 size of GEM
(10, 20 and 30 cm)

Expected Signals

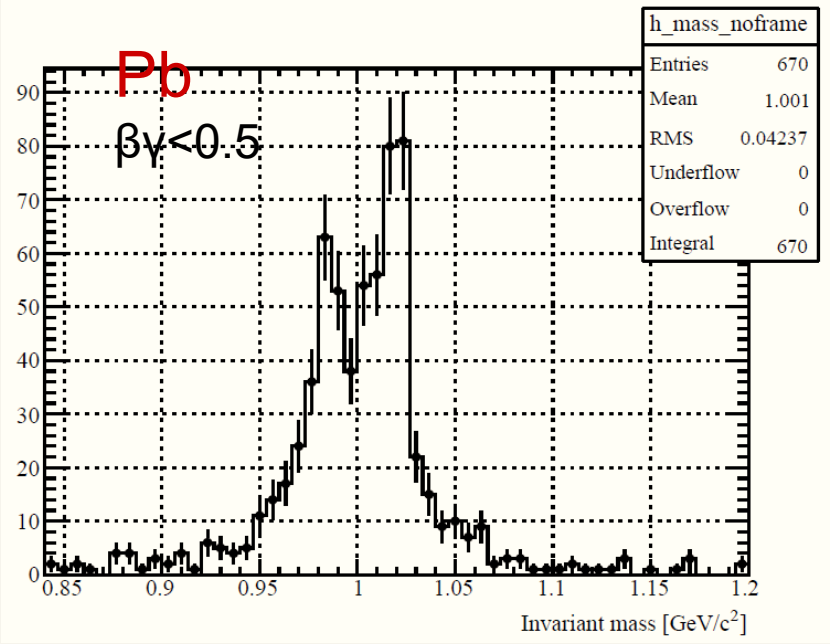
momentum dependence of mass





- High mass resolution
- High statistics

φ



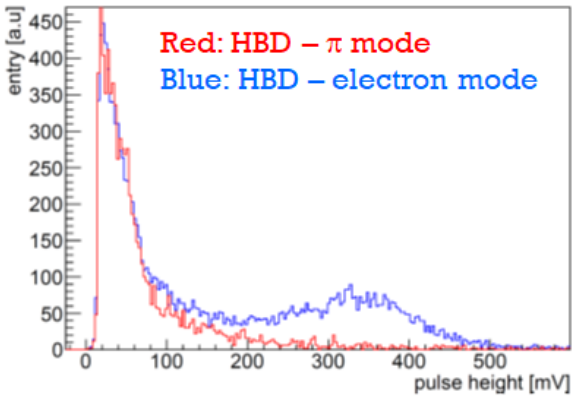
In-medium mass spectral function

Kim & Gubler, PLB 805 (2020) 135412
S.H.Lee, PRC57 (1998) 927

Current Status

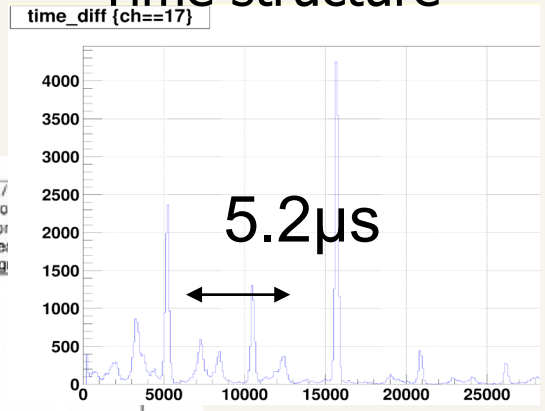
- beam commissioning has been completed
  - ✓ profiles : OK
  - time structure → addressed by DAQ upgrade
- detector commissioning
  - ✓ high rate capability (10MHz interaction)
  - ✓ vertex reconstruction
  - ✓ PID

PID performance

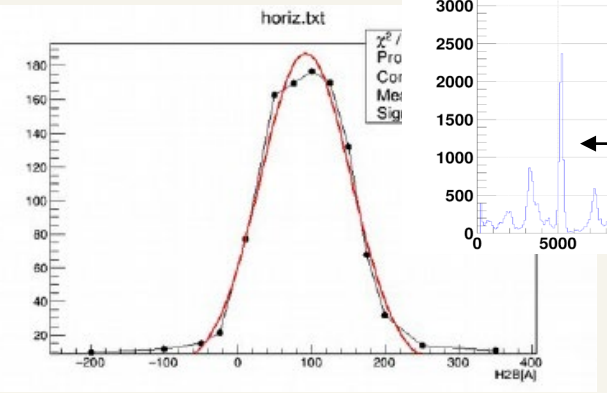


Pulse Hight Distribution of Lead Glass

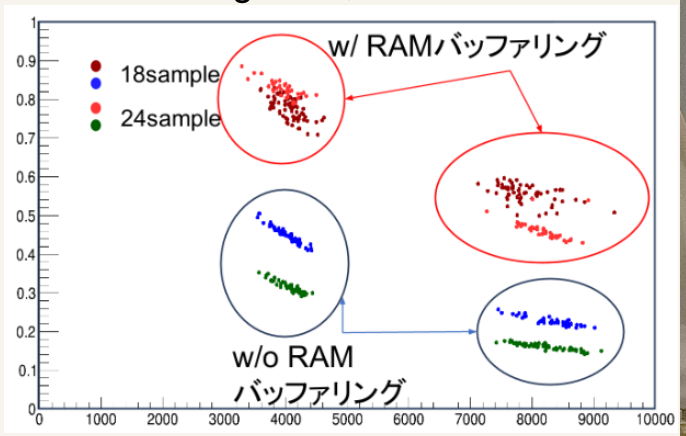
Time structure



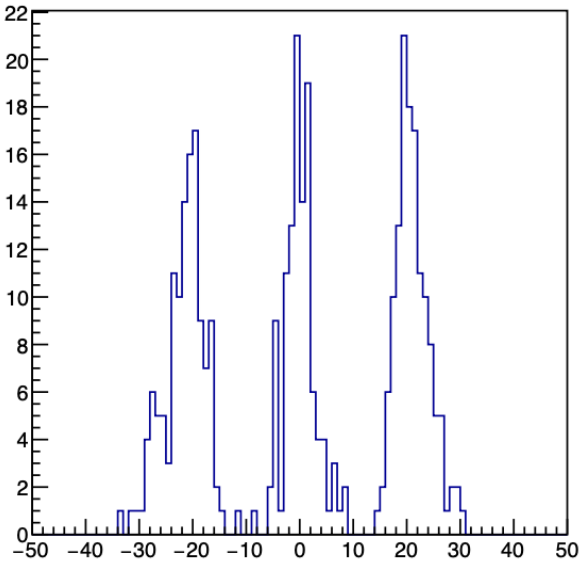
beam profile



S.Nagafusa, Master thesis



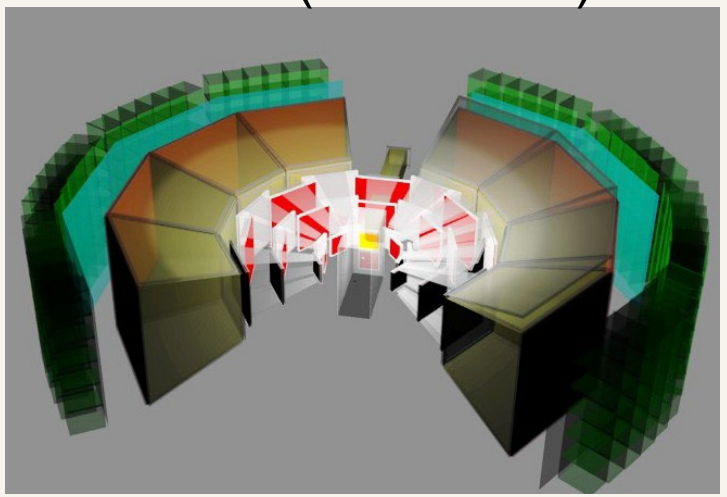
Vertex distribution



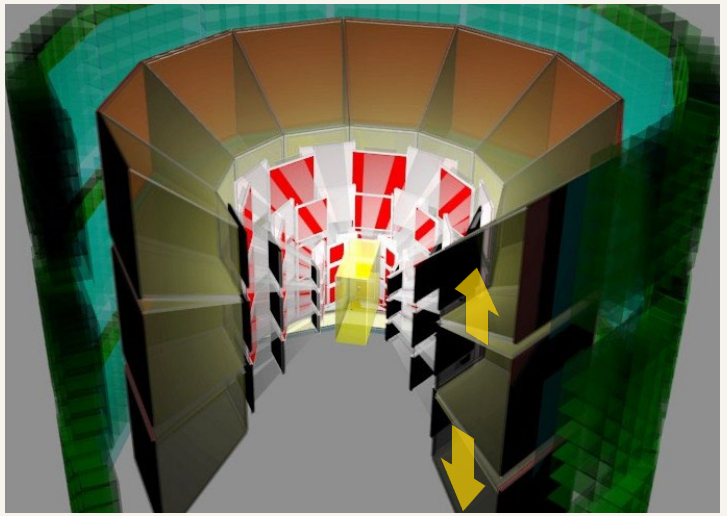
Schedule

- 2020-2021 RUN0 -- 320 hours, C/Cu targets
  - Beamline / Detector commissioning
- 2023 April Run0d -- 201 hours
  - BL commissioning
- 2024 April Run0e -- 117 hours
  - BL & trigger commissioning
- 2024-5 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 spectrometer is completed at J-PARC.
- The first physics run will be performed FY2024/2025.
- Stay tuned!

- Future possibilities
  - hadron decay of phi meson (KK)
  - sigma meson – we will have plenty pipi data
  - chiral doublet – kaons as NG bosons