Hadron Physics at J-PARC

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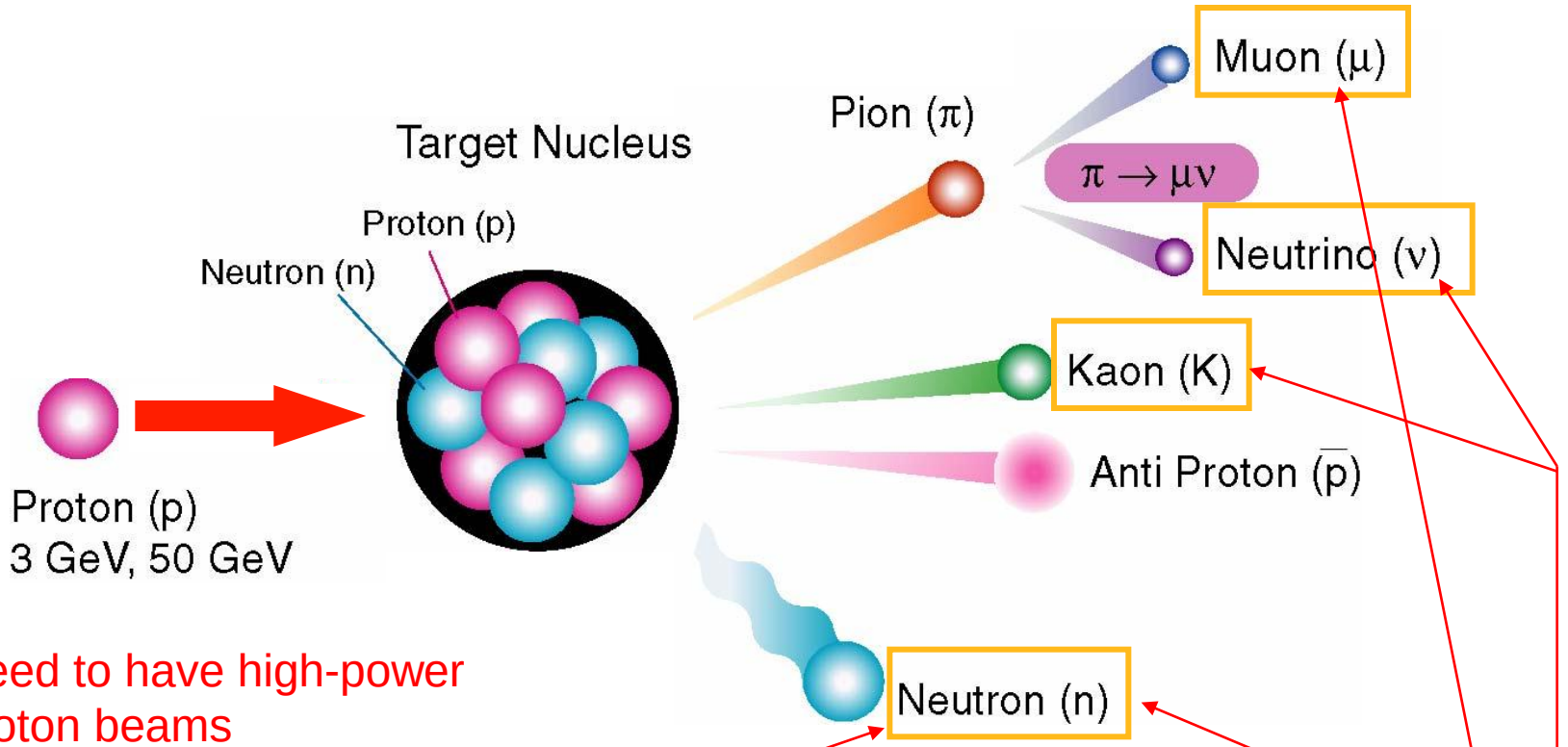
(High Energy Accelerator Research Organization, Japan)

Contents

- Overview of J-PARC and Hadron Experimental Facility (Hadron Hall)
- Physics with Low Momentum Secondary Beams
- Physics with High-Momentum Beams
- Extension
- Summary

Goals at J-PARC

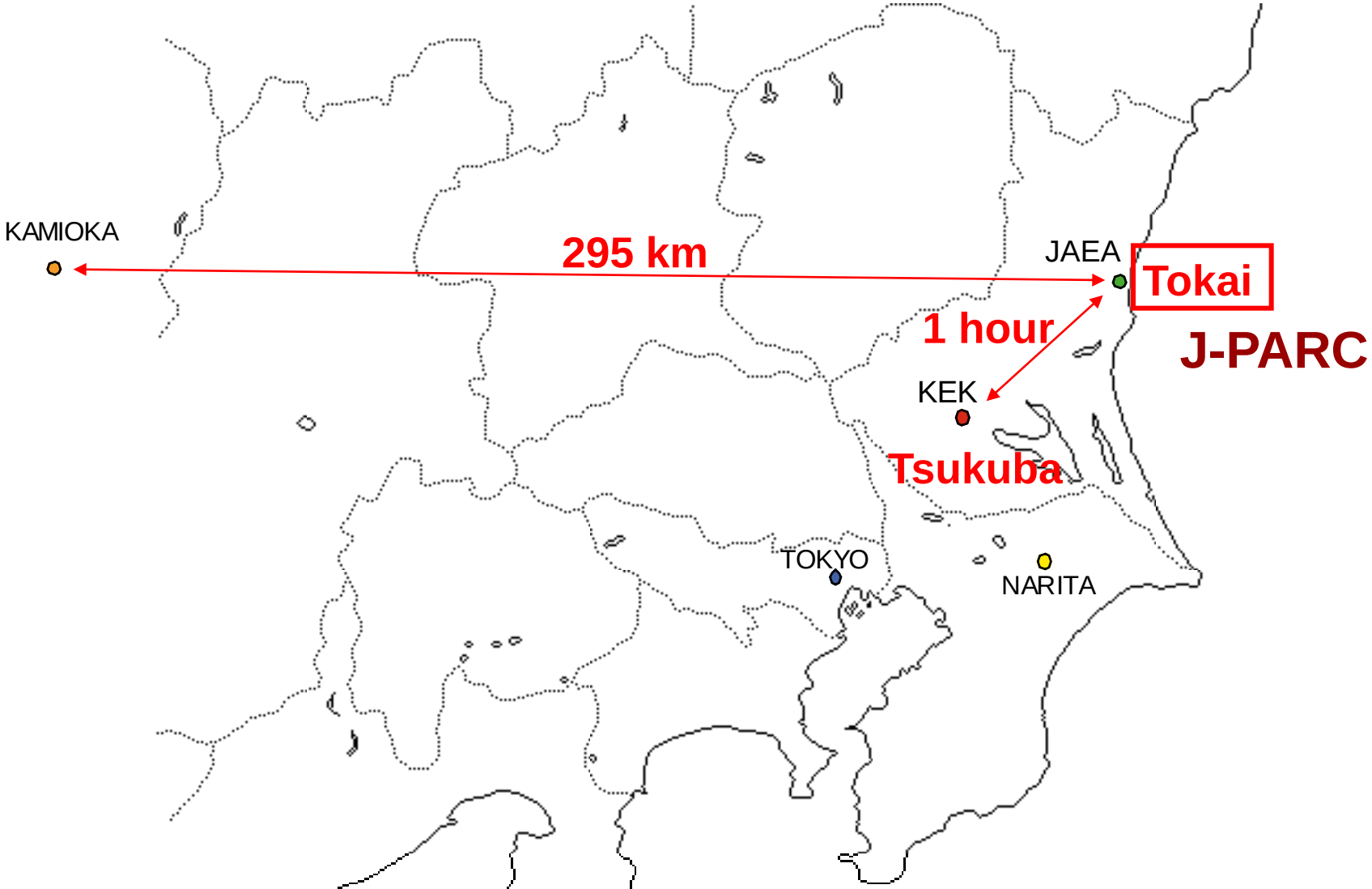


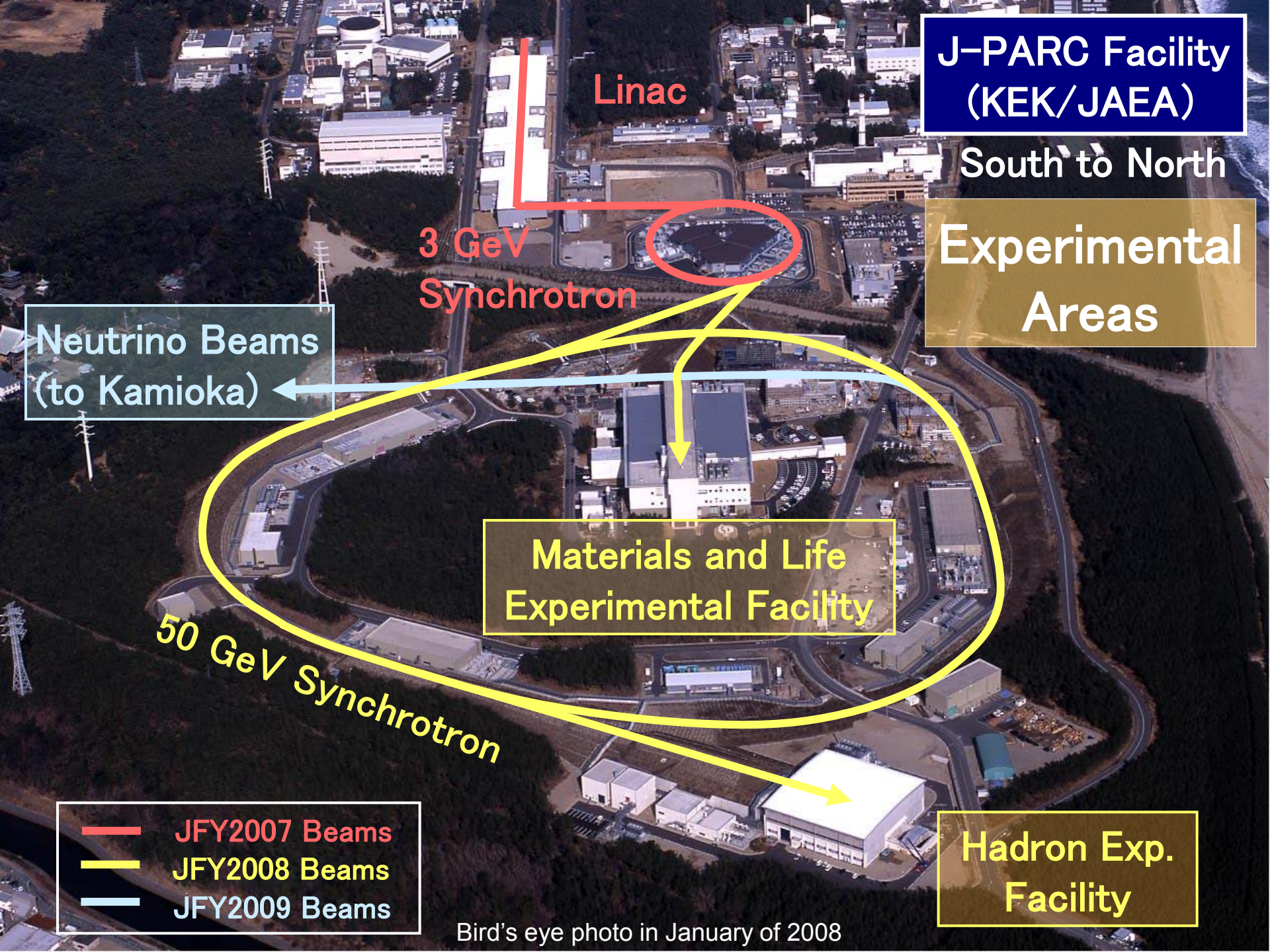
Need to have high-power proton beams

→ MW-class proton accelerator (current frontier is about 0.1 MW)

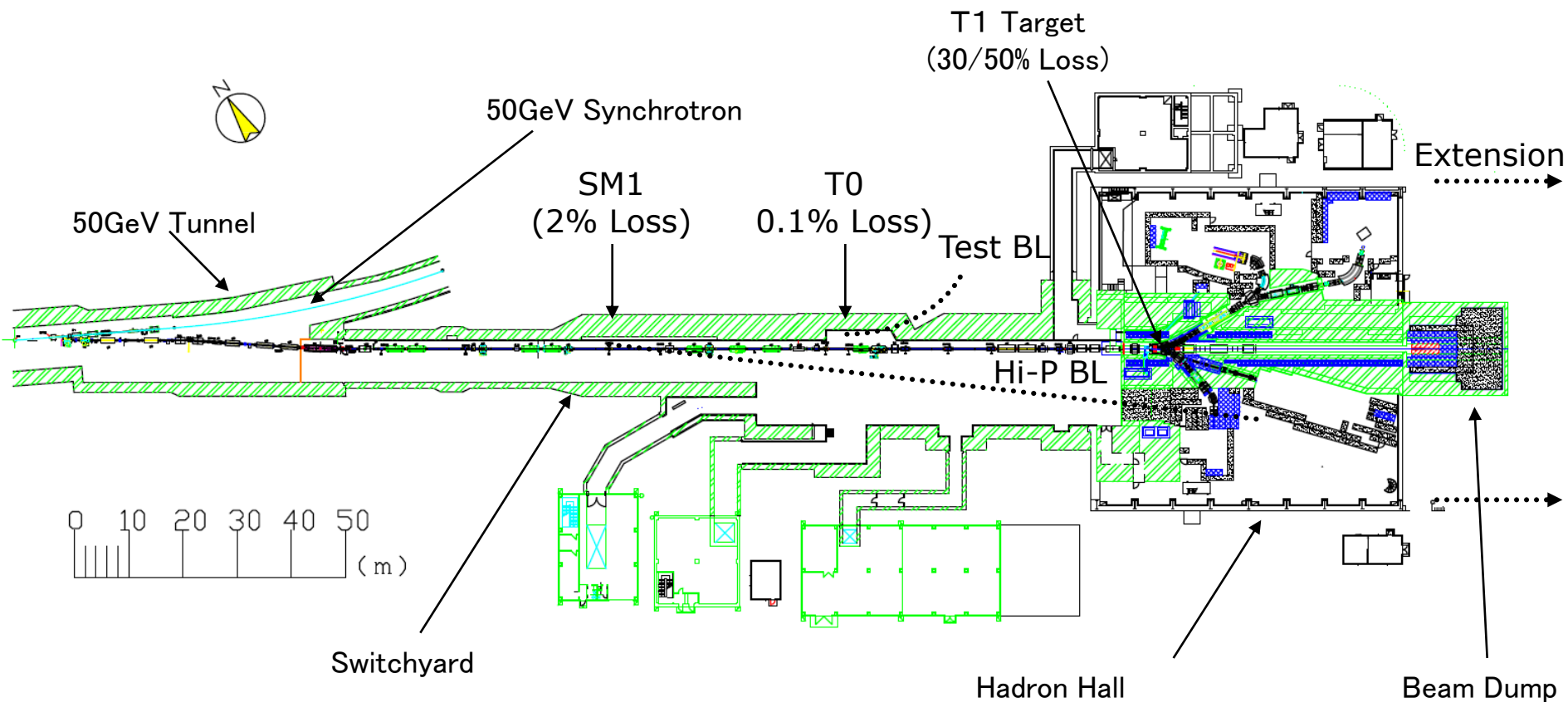
Materials & Life Sciences at 3 GeV
Nuclear & Particle Physics at 50 GeV
R&D toward Transmutation at 0.6 GeV

Location of J-PARC at Tokai



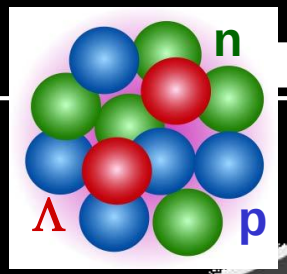

J-PARC Facility
(KEK/JAEA)
South to North
Linac
3 GeV
Synchrotron
Experimental
Areas
Neutrino Beams
(to Kamioka)
Materials and Life
Experimental Facility
50 GeV Synchrotron
Hadron Exp.
Facility
JFY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

Hadron Experimental Facility (Current Layout)



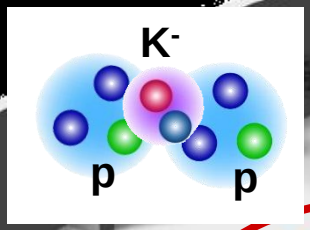
Slide By
H.Tamura

Hall



Ξ hypernuclei
ΛΛ hypernuclei
Ξ-atomic X-rays
Λ hypernuclear γ rays
Neutron-rich Λ hypern.
Pentaquark Θ+ search
K-pp bound state

Hyp. weak decay(A=4)
Hyp. weak decay(A=12)
π Double charge exch.
ω mesonic nuclei
Σp scattering

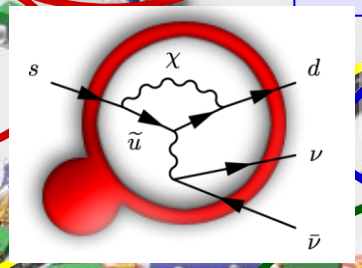


Dump

K1.8

K^0_L rare decays

Hadron mass in nuclei
Nucleon quark structure



K1.8BR

KL

K-pp bound states
K- atomic X rays
η mesonic nuclei

K1.1

High momentum line

Not constr

K1.1BR

T violation in K+ decay
Universality in K+ decay
Θ+ study by K+n scattering

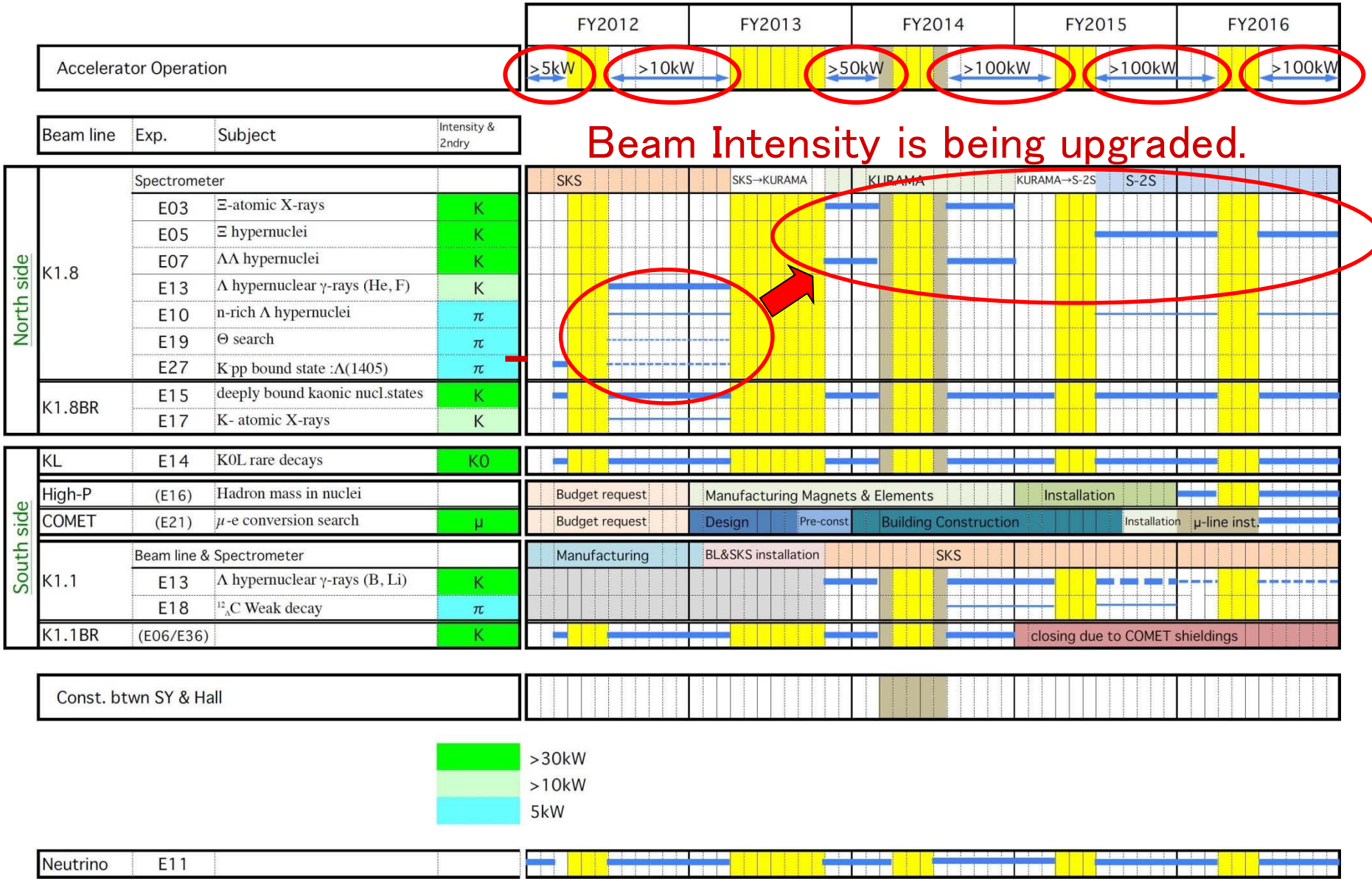
Φ mesonic nuclei
Λ hypernuclear γ rays
Σ-nuclear systems
YN scatering
Θ+ hypernuclei

30~50 GeV
primary beam

Approved (stage-2) / (stage-1) / proposed,LOI

μ-e conversion search

Season of Fruits at Hadron Hall Comes!



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Physics with Low Momentum Secondary Beams

- So far there are only low-momentum beam lines.
- Strangeness nuclear physics
  - With (pi, K), (K, pi), and (K-, K+) reactions
- Other hadron physics
  - Many strangeness related, but a few non-strange.
- Low Momentum Secondary Beams
  - Pions and Kaons <2 GeV/c at K1.8 beam line
    - Momentum was selected so that the production cross section of the Xsi baryon is at the maximum.
    - Major goal is S=-2 hypernuclei (Xsi nuclei and double-Lambda nuclei).
    - Used also for (pi, K) reaction for single hypernuclei.
  - Pions and Kaons <1.1GeV/c at K1.8BR and K1.1 beam line
    - Single Lambda hypernuclei
      - Gamma ray spectroscopy
    - Search for K-pp bound states

Three Dimensional Nuclear Chart

Nu ~ Nd ~ Ns

"Stable"

p,n,Λ,Ξ⁰,Ξ⁻

Strangeness in neutron stars ($\rho > 3 - 4\ \rho_0$)

Strange hadronic matter ($A \rightarrow \infty$)

Higher density

Strangeness

ΛΛ, Ξ Hypernuclei

Λ, Σ Hypernuclei

Z

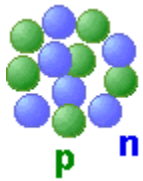
N

-2

-1

0

Λ



p n

Single strangeness experiments

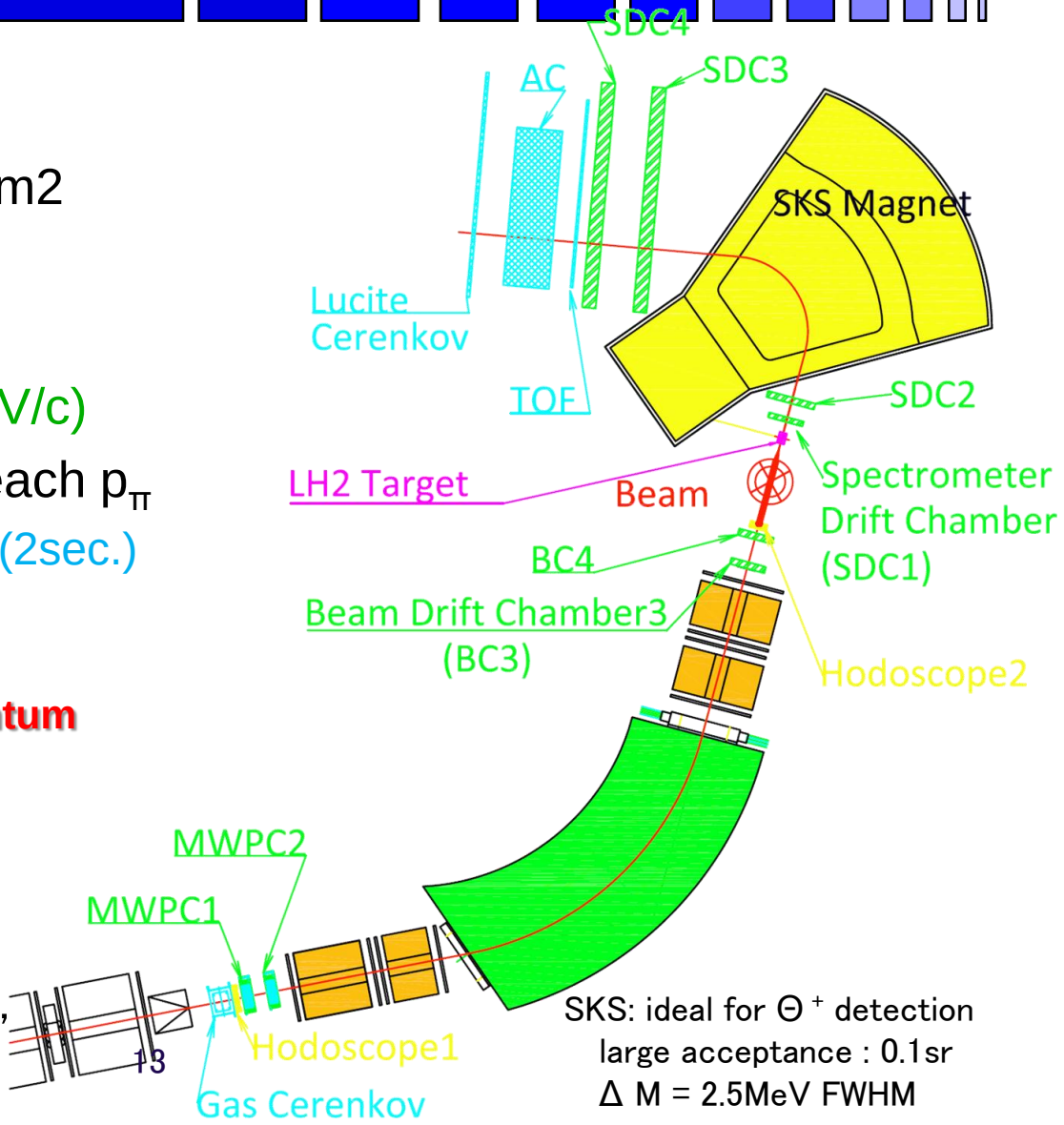
- E19 (published): Pentaquark search
- E10 (taking data): Neutron-rich hypernuclei with double-charge exchange
- E13 (coming soon): Gamma ray spectroscopy of hypernuclei
- E15 (coming soon): Search for K^-+p+p bound state
- … (many waiting)

E19: Pentaquark Search

- search for Θ^+ in $p(\pi^-, K^-)$
- target : liquid H2, 0.86g/cm2
- at K1.8 beamline + SKS
- beam momentum :
  - p_π=(1.87,1.92,2.00GeV/c)
- 4.8 x 10^{11} π on target for each p_π
  - beam intensity : 10^7/spill(2sec.)
  - beam time : 160 hours

Yield : 10^4 events for each momentum
Sensitivity : 75nb/sr
→ confirm the existence of Θ^+

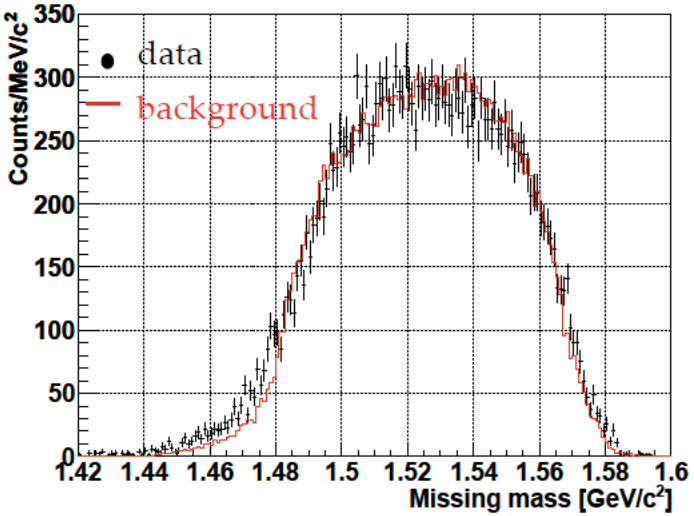
E19 took the first physics data with p=1.92 GeV/c in Oct/Nov, 2010, and p=2.0 GeV/c in Feb, 2012.

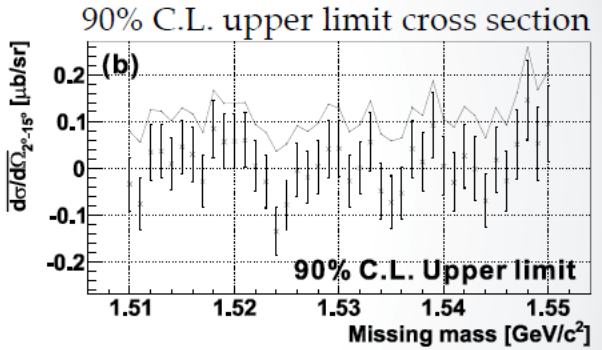


E19: Pentaquark Search

Missing Mass Spectrum

The First Data at p_π=1.92GeV/c





accepted in PRL, arXiv:1203.3604 [nucl-ex]

- no significant structure has been observed.
- upper limit is 0.26μb/sr (90%C.L.) cf. 2.9μb/sr (E522)

●17

E13: Hypernuclear γ Spectroscopy

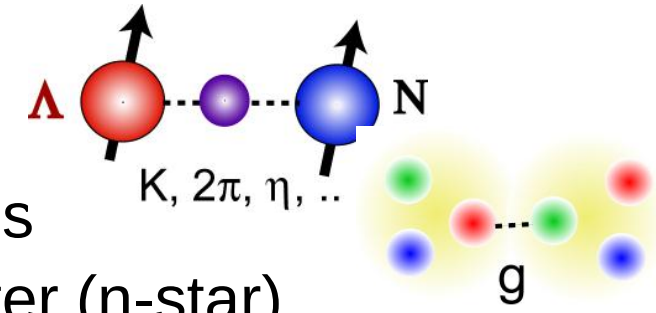
High-precision (ΔE～3 keV FWHM) spectroscopy with Ge detectors

1. YN, YY interactions

Unified picture of B-B interactions

Understand short-range nuclear forces

Understand high density nuclear matter (n-star)



Level energies ->ΛN spin-dependent forces,

Charge symmetry breaking, ΣN-ΛN force,..

E13

2. Impurity effects in nuclear structure

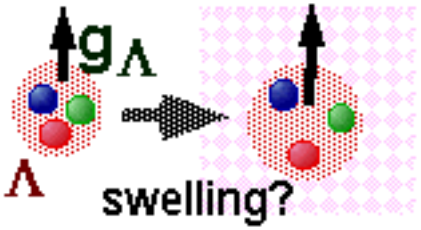
Changes of size/shape, symmetry, cluster/shell structure,..

B(E2), E(2⁺) -> shrinking effect, deformation change

3. Medium effects of baryons probed by hyperons

B(M1) -> μ_Λ in nucleus

E13

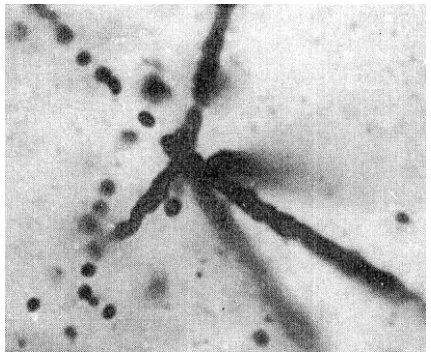


Double-strangeness hypernuclei soon

- With the improvement of the proton beam intensity, double-strangess experiments with (K-, K+) become possible soon.
- E07: Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method

PS-E176

in ~80 Ξstops



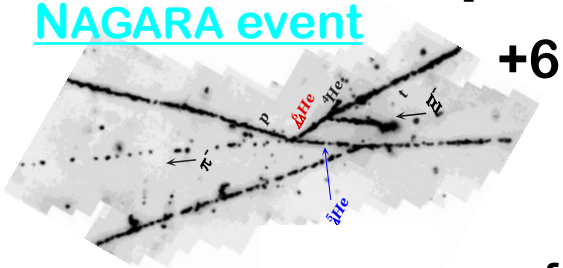
Double-Hypernucleus with sequential decay surely exists.

PS-E373

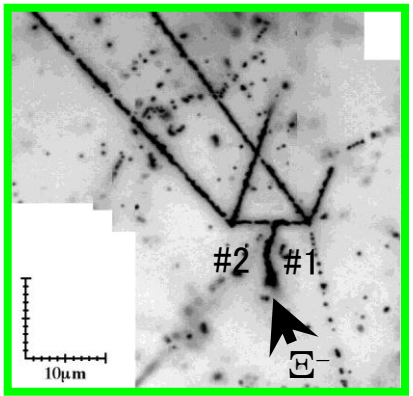
in ~700 Ξstops

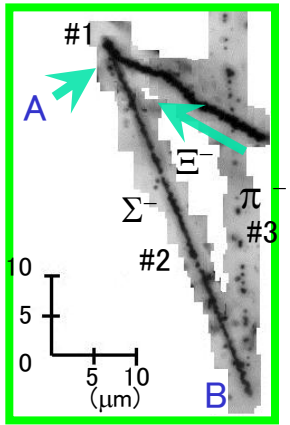
NAGARA event

+6 cand.



$\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20$ MeV for ${}^{6}_{\Lambda\Lambda}$He





Double-strangeness hypernuclei soon

- E07: Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method
  - **Physics**

    1) S=-2 nuclear chart by ~10^2 $_{\Lambda\Lambda}Z$ via 10^4 Ξ^--stopping events.

    => $\Delta B_{\Lambda\Lambda}$ of several nuclides will provide definitive informationon $\Lambda\Lambda$ interaction and structure of S=-2 nuclei.

    2) H-dibaryon state in S=-2 system ?

    => measure A-dependence of $\Delta B_{\Lambda\Lambda}$ & Σ^-decay mode of $_{\Lambda\Lambda}Z$.

    3) Ξ^--nucleus potential

    => detection of twin hypernuclei

    => First measurement of X-ray of Ξ^-atom

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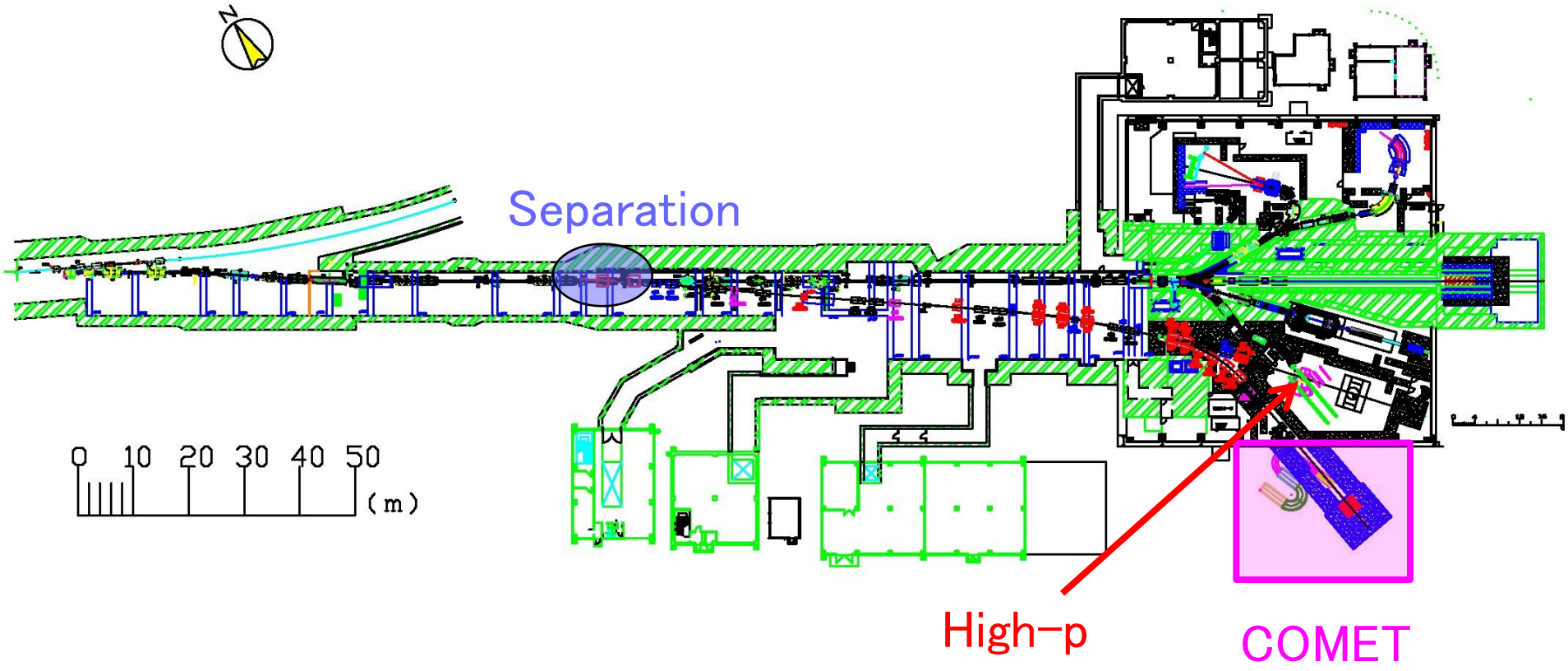
Physics with High-Momentum Beams

- “High-momentum beam line” has just been funded!
- High-momentum primary proton beam (30GeV)
  - Meson mass modification inside nuclei
  - Dilepton measurement for nucleon and baryon structure
- High-momentum meson (pion) beam (~<15 GeV/c)
  - Pion-induced Drell-Yan?
  - Baryon spectroscopy with pion beams.

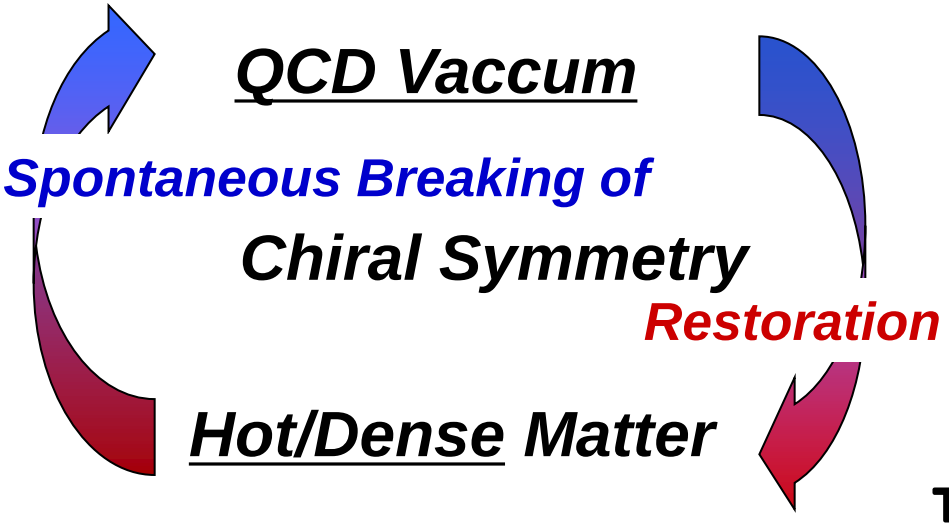
High-p and COMET

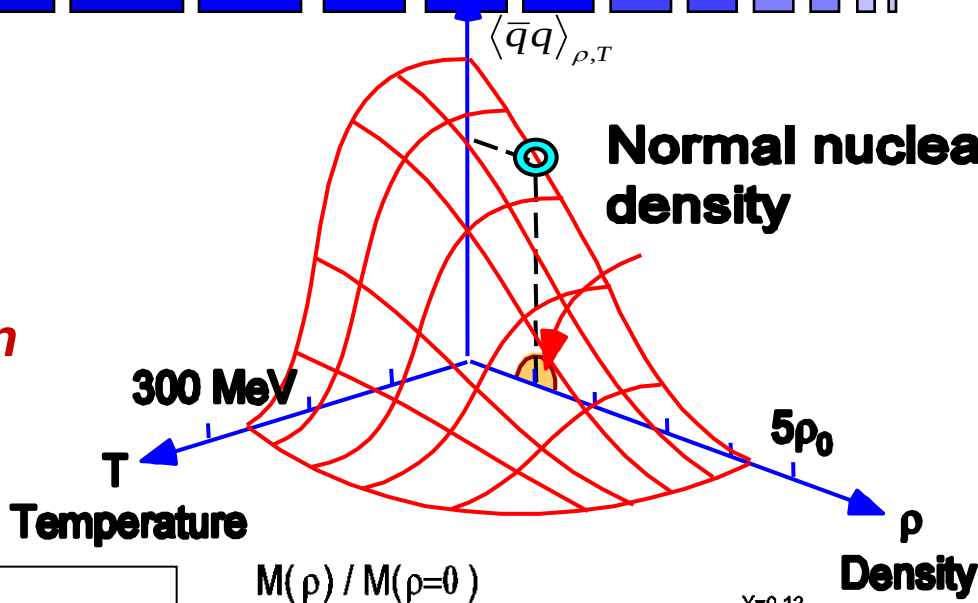
- New primary Proton Beam Line
  = High-momentum BL + COMET BL
- High-momentum Beam Line
  - Primary protons (~10^{10} – 10^{12}pps)
    - E16 (phi meson) is considered to be the first experiment.
  - Unseparated secondary particles (pi, …)
    - High-resolution secondary beam by adding several quadrupole and sextupole magnets.
- COMET
  - Search for μ to e conversion
  - 8 GeV, 50 kW protons
  - Branch from the high-momentum BL
  - Annex building will be built at the south side.

New Primary Proton Beam Line



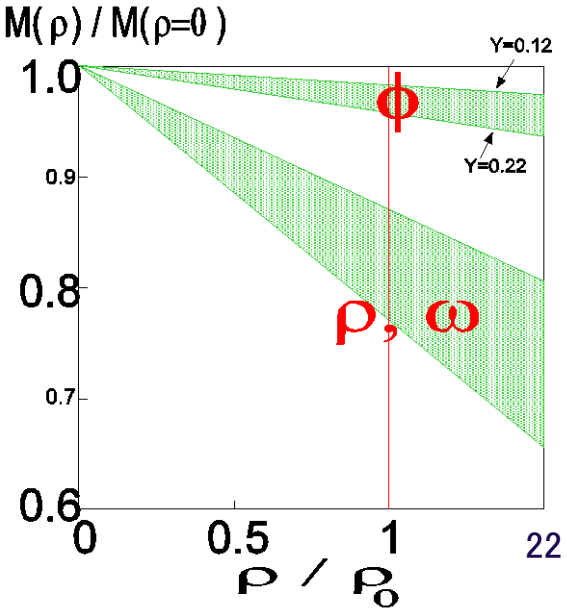
Mass modification of vector meson



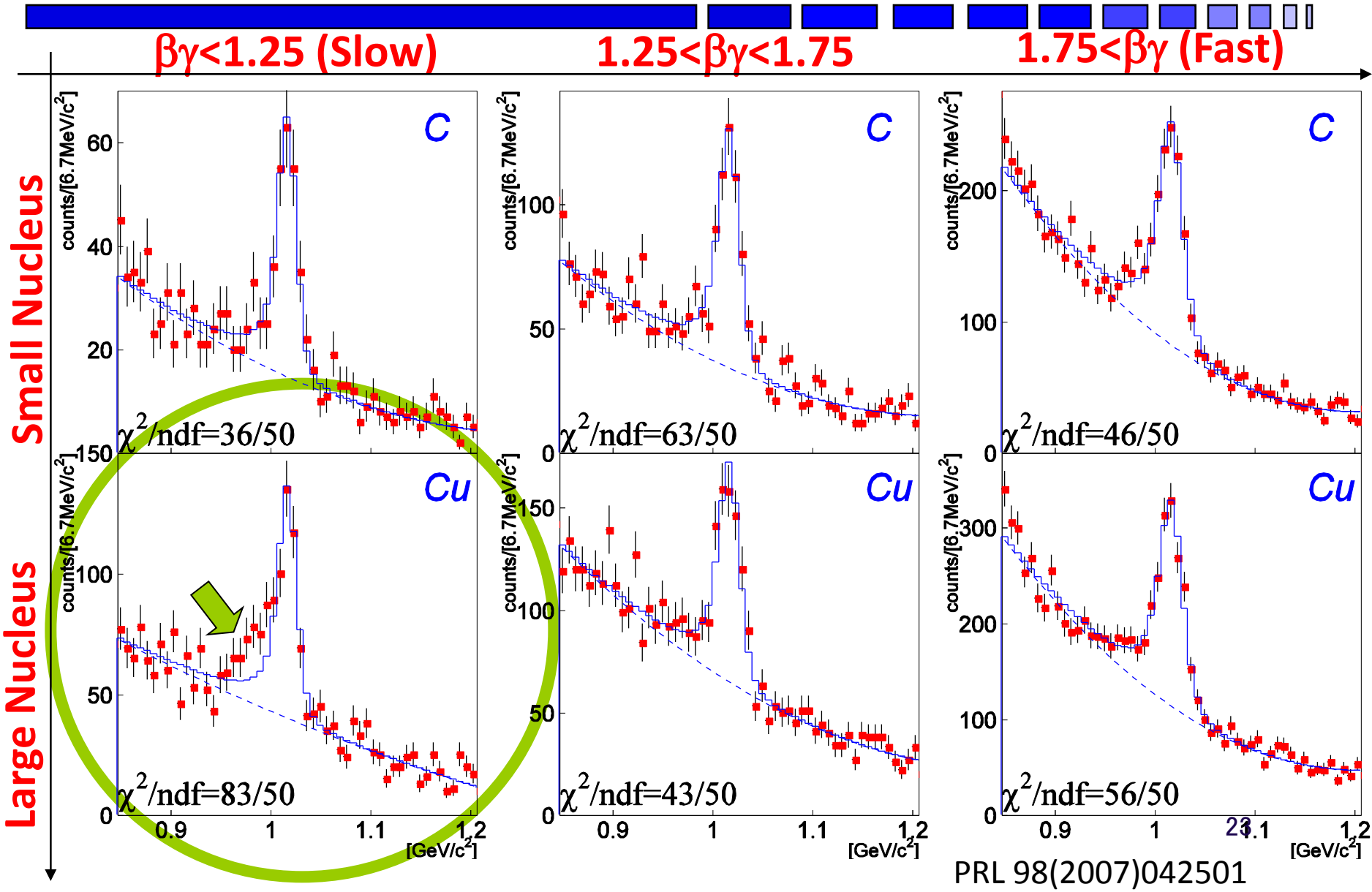


Vector meson mass
at normal nuclear density

$m^*/m=1-k\rho/\rho_0$
(Hatsuda&Lee PRC46(92)R34)
ρ/ω : Δm = 130 MeV at ρ_0
ϕ : Δm = 20~40 MeV at ρ_0

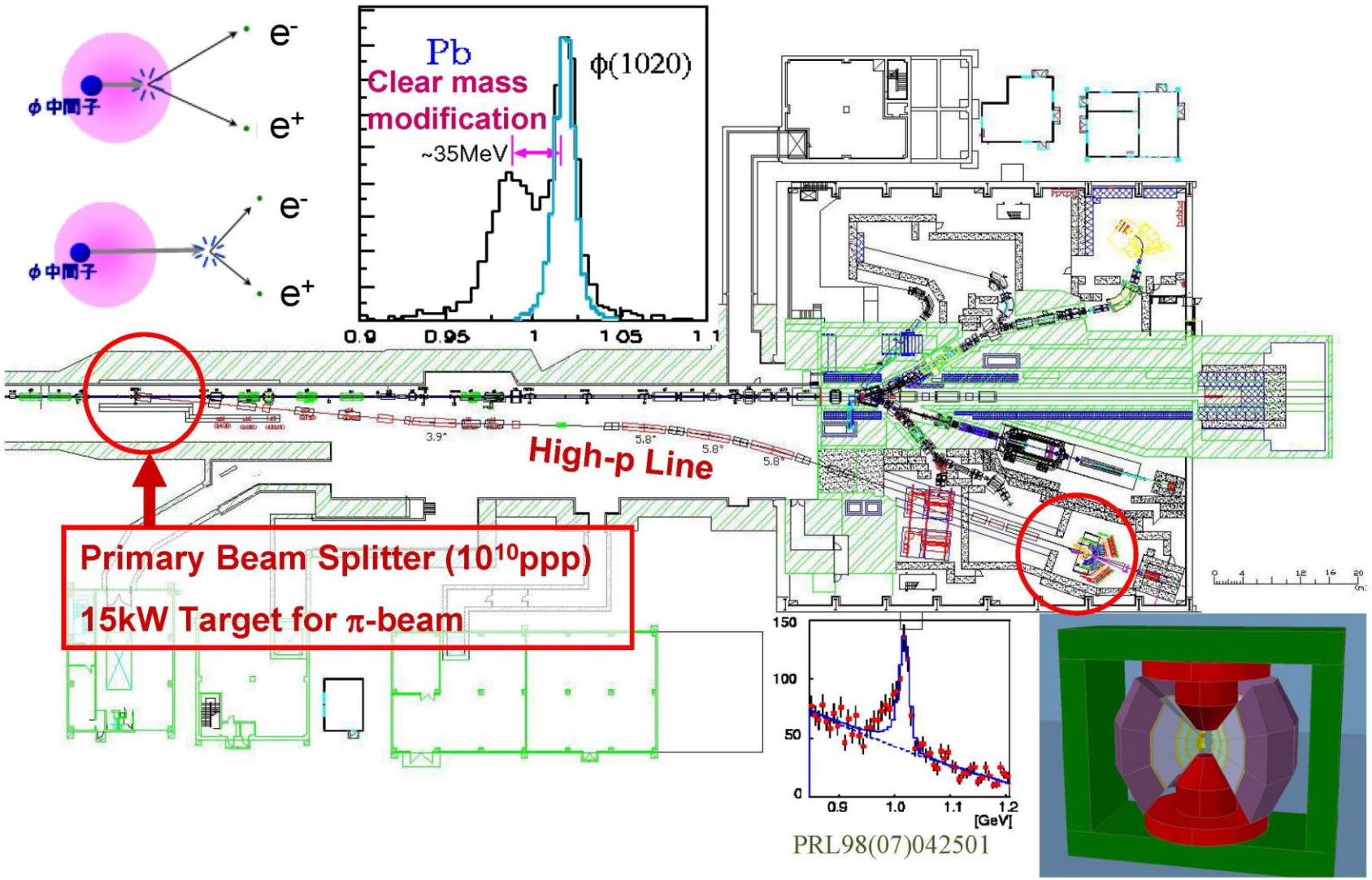


Results of a previous experiment (KEK-PS E325): Invariant mass spectra of $\phi \rightarrow e^+e^-$



PRL 98(2007)042501

High-p Line and E16 Spectrometer

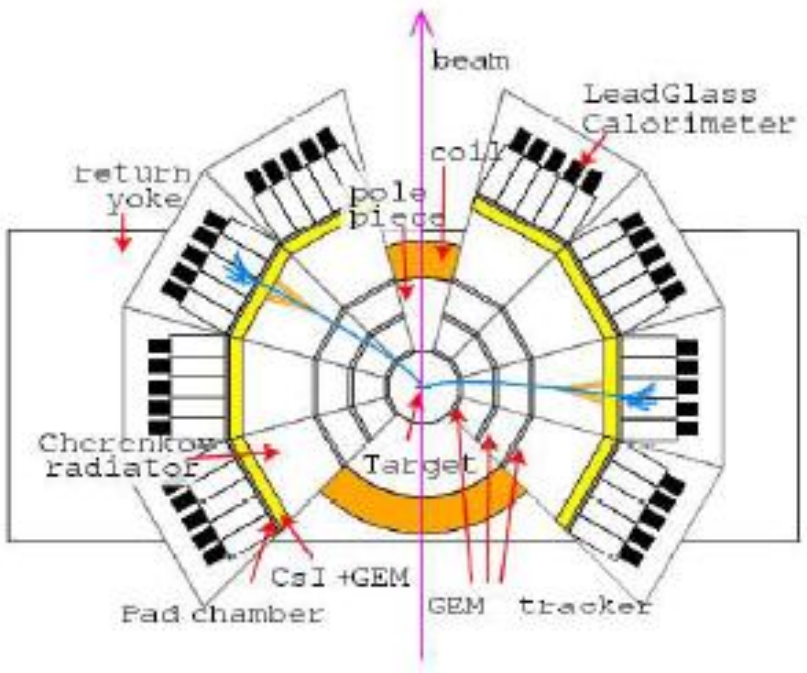


PRL98(07)042501

J-PARC E16: Electron pair spectrometer to explore the chiral symmetry in QCD

primary proton beam at high momentum beam line
+ large acceptance electron spectrometer

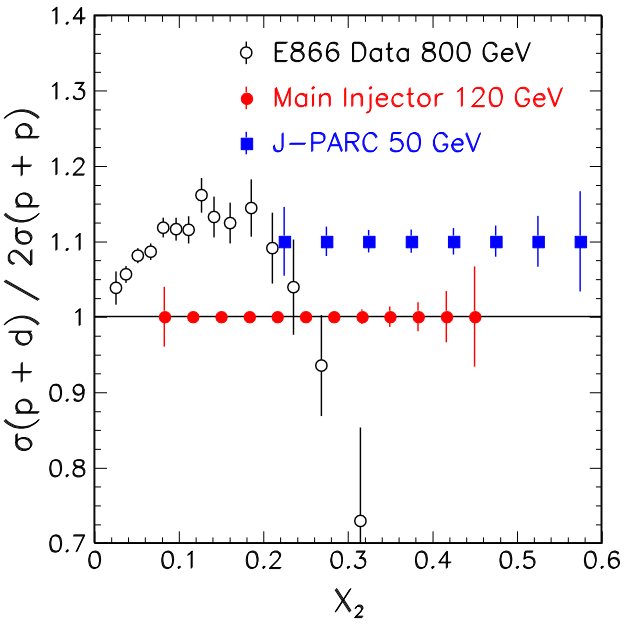
10^7 interaction (10 X E325)
10^{10} protons/spill
with 0.1% interaction length target
→ **GEM Tracker**
eID : **Gas Cherenkov**
+ Lead Glass
Large Acceptance (5 X E325)



velocity dependence
nuclear number dependence (p → Pb)
centrality dependence
→systematic study of mass modification

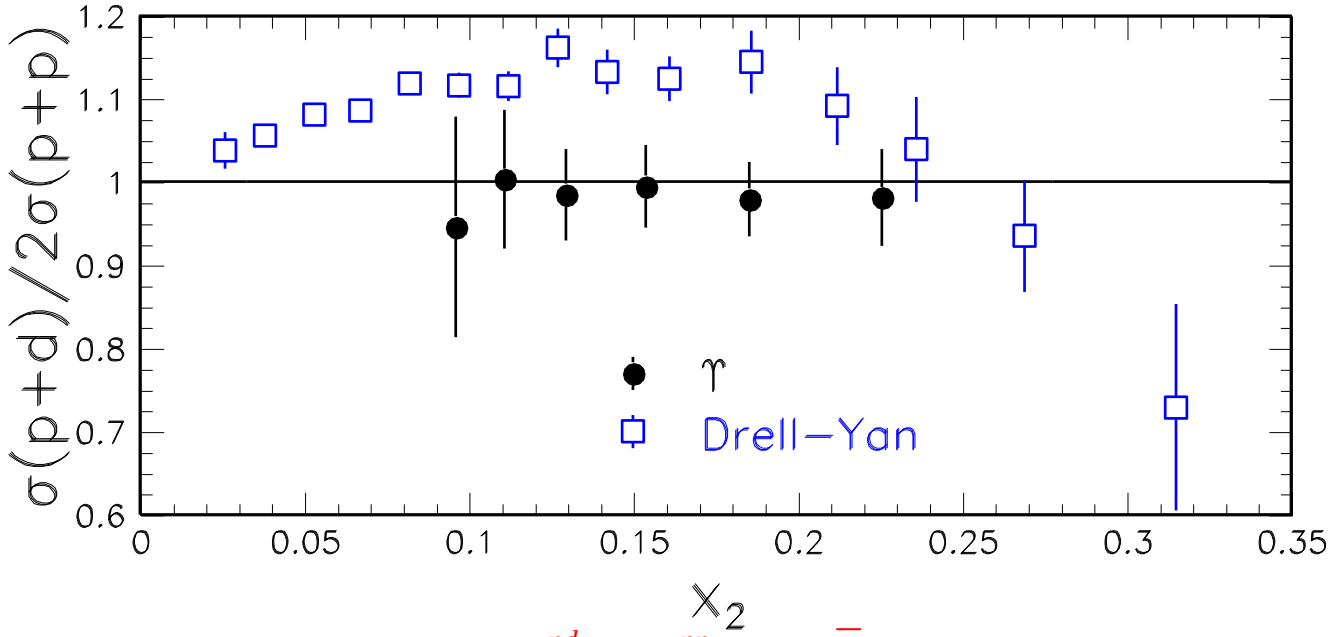
Possible hadron exps at high-momentum BL

- Sea quark structure through Drell-Yan measurement
  - Currently the E906/SeaQuest is running at Fermilab with 120-GeV protons to see d-bar/u-bar asymmetry.
  - Larger x possible with 50-GeV protons at J-PARC.
    - J-PARC is currently operated with 30-GeV and there are no demands of 50-GeV operation from other experiments, which needs modification of a part of the accelerator components.
  - There could be other possibilities of physics with dimuon measurement such as,
    - J/Psi measurements to see the nucleon sea,
    - dimuons from pion/kaon induced reactions to see meson-like substructure of a nucleon.
- Spin related quantities
  - Polarized beam relatively far future.
  - Polarized target would be available in the near future.
  - Measurement such as Bohr-Mulders can be carried out even with unpol. Drell-Yan measurements.



J/Psi: gg or q-qbar?

E866 data: $\sigma(p+d\rightarrow \Upsilon X)/2\sigma(p+p\rightarrow \Upsilon X)$



Lingyan Zhu et al., PRL, 100 (2008) 062301

Drell-Yan: $\sigma^{pd}/2\sigma^{pp}\approx[1+\bar{d}(x)/\bar{u}(x)]/2$

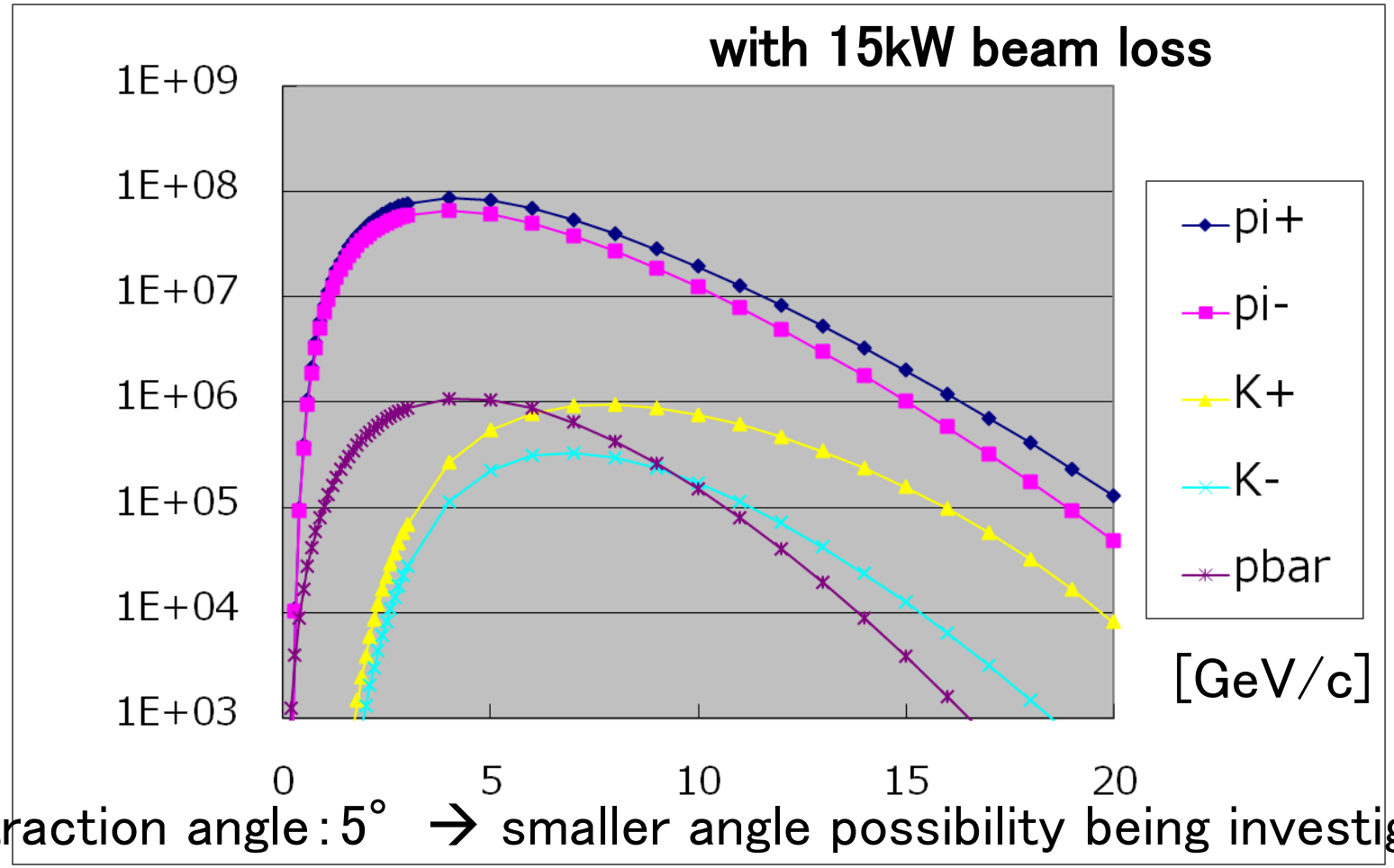
$J/\Psi,\Upsilon$: $\sigma^{pd}/2\sigma^{pp}\approx[1+g_n(x)/g_p(x)]/2$

Gluon distributions in proton and neutron are very similar at 800 GeV. At much lower energies, J/Psi might be produced by q-qbar annihilation. → Azimuthal angle dependence. If J/Psi production is q-qbar annihilation, J/Psi becomes a tool to investigate quark structure of nucleon at lower energies.

Unseparated Secondary Beam Intensity

beam loss limit @ SM1:15kW

(limited by the thickness of the tunnel wall)

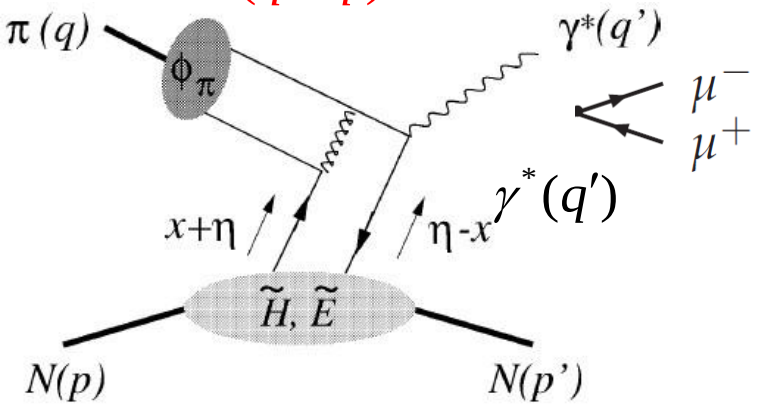


extraction angle : 5° → smaller angle possibility being investigated

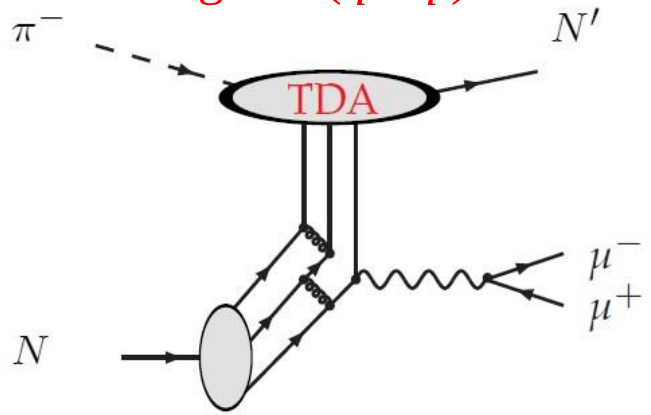
Exclusive Pion-Induced Drell-Yan Process

Bernard Pire , IWHS2011

small $t=(q-q')^2$



large $t=(q-q')^2$



ϕ_π : pion distritribution amplitude (DA)

- DA characterizes the minimal valence Fock state of hadrons.
- DA of pion are also explored by pion–photon transition form factor in Belle and Barbar Exps.

TDA : π-N transistion distritribution amplitude

- TDA characterizes the next–to–minimal valence Fock state of hadrons.
- TDA of pion–nucleon is related to the pion cloud of nucleons.

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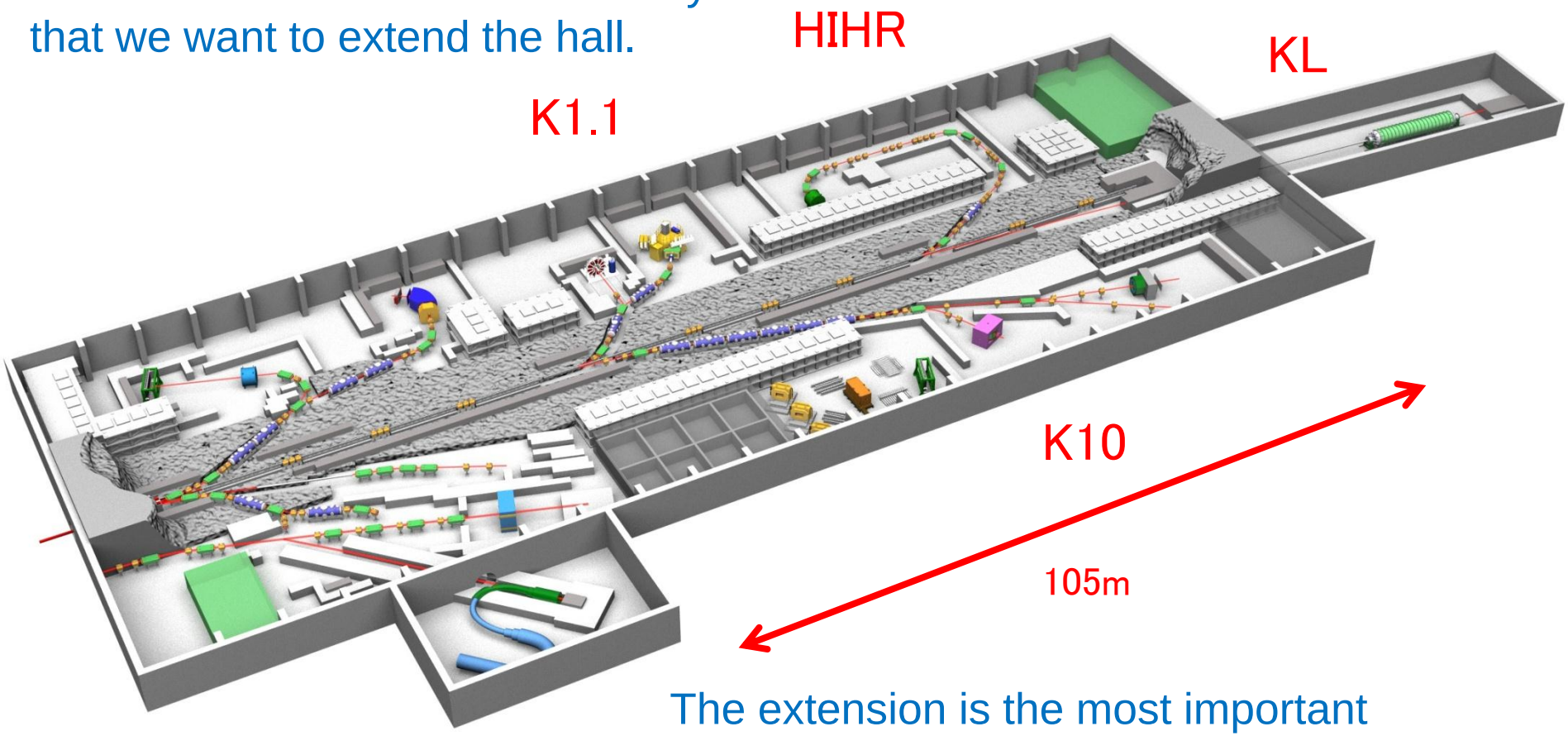
Extended Hadron Hall

The current Hadron Hall is so busy that we want to extend the hall.



The extension is the most important goal next to the completion of the high-momentum beam line.

Summary

- Physics experiments have started at the Hadron Hall of J-PARC, and the first physics paper is being published from the E19 experiment. So far experiments with lower momentum pions/kaons are being carried out.
- The funding for the high-momentum beam line with COMET has just been approved by the government. The construction starts soon. Mass shift of phi meson would be the first experiment, and other experiments are being discussed.
- The extension of the Hadron Hall is the next step. A working group discusses physics cases and beam lines.