Nuclear physics in Japan (hadron, high energy)

LEPS2/ELPH; Electrons and Photons,
PHENIX/ALICE; High-Energy Heavy Ions,
J-PARC (Hadron/Neutrino); High Intensity secondaries,

Kazuhiro Tanaka
IPNS, KEK & NPD, J-PARC

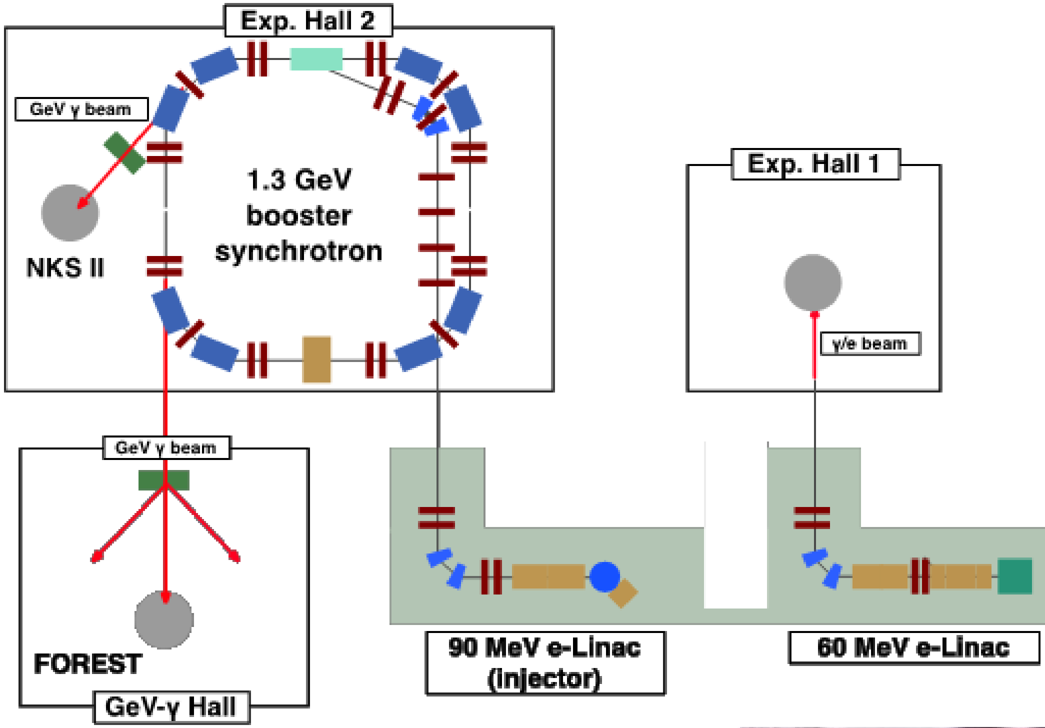
LEPS2/ELPH

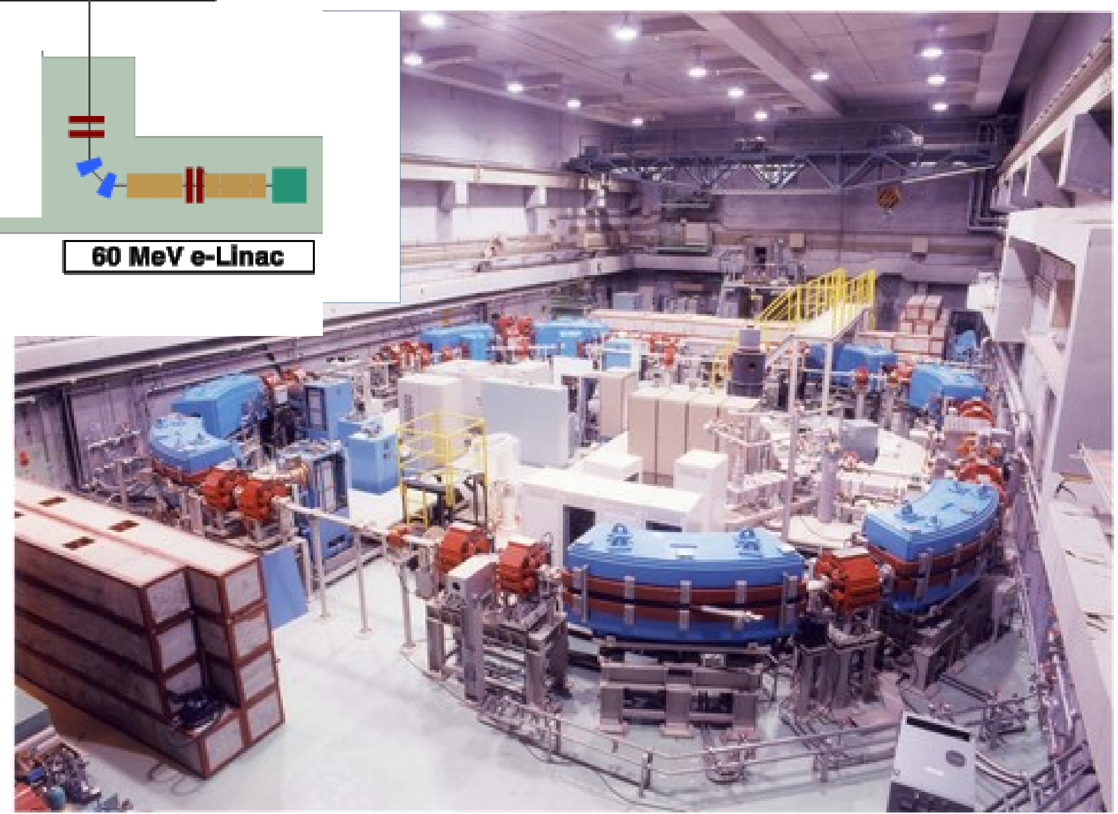
TOHOKU UNIVERSITY

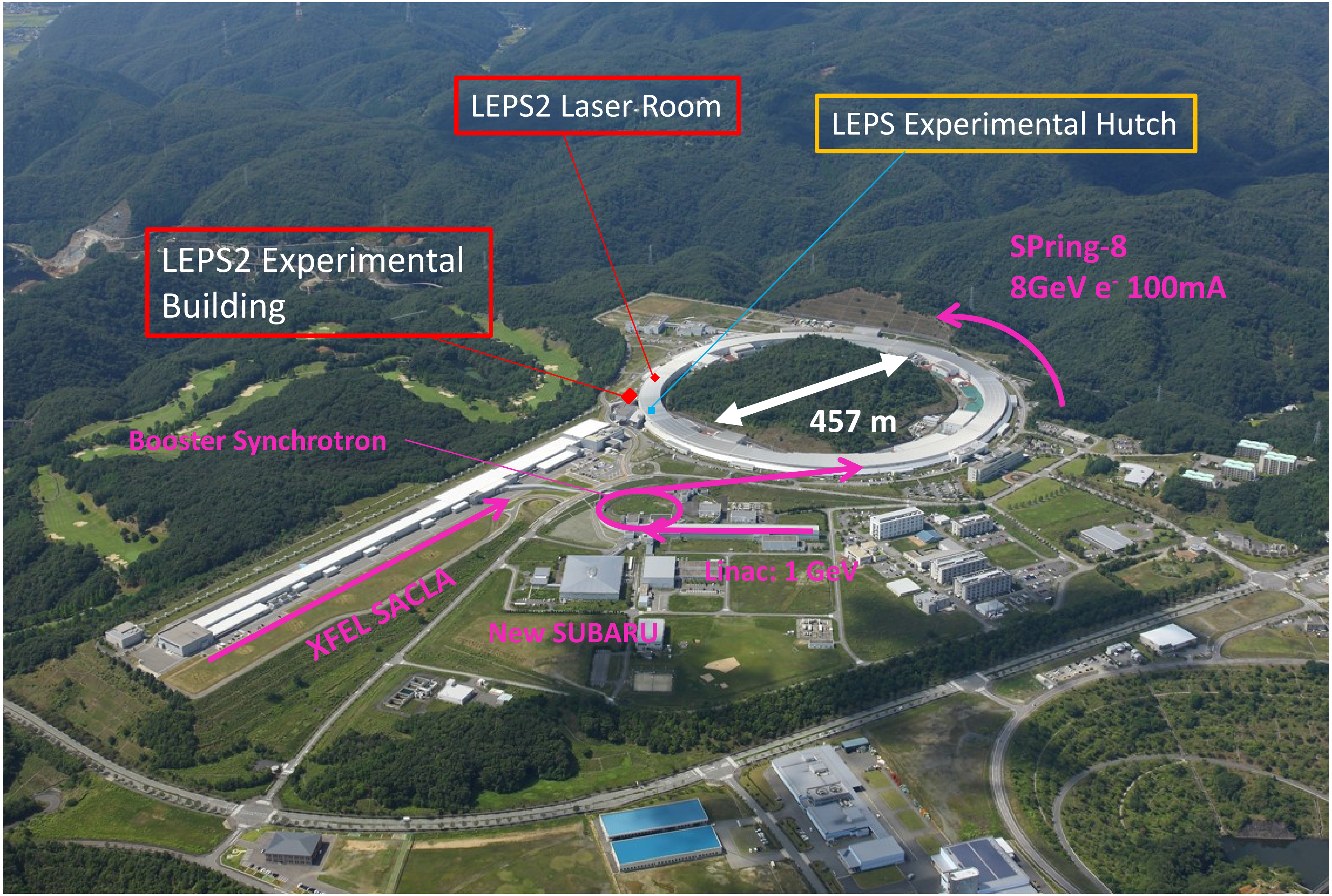
東北大学 電子光理学研究センター

RESEARCH CENTER FOR ELECTRON PHOTON SCIENCE (ELPH), TOHOKU UNIVERSITY

ELPH







Operated by RCNP, Research Center for Nuclear Physics, Osaka University

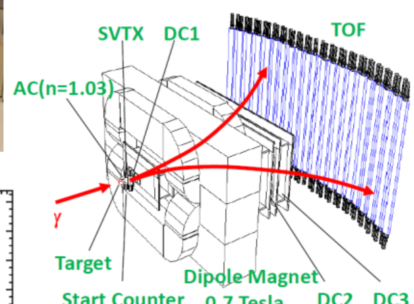
RCNP Laser-Electron Photon Beamlines @ SPring-8

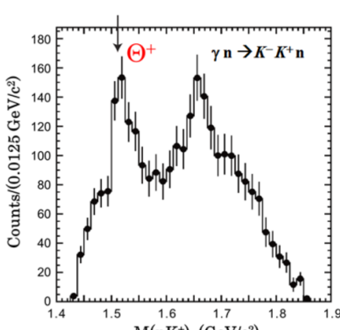
- Investigate the form of existence of hadrons with use of high energy photons.
  - Elucidate the fundamental freedom of the hadron formation.
    → **How are hadrons built with quarks?**
  - Study exotic hadrons like a pentaquark Θ^+.
    → **give a new knowledge on quark correlations (e.g., di-quark) inside the hadron.**

Laser-Electron Photon (Laser Compton scattering γ-ray)
- Small backgrounds from low energy photons
  → enable to measure forward angles include 0 degrees
- highly polarized beam → parity filter for exchanged particles
- photoproduction of hadrons with strange quark(s)

BL33LEP (LEPS)

LEPS forward spectrometer



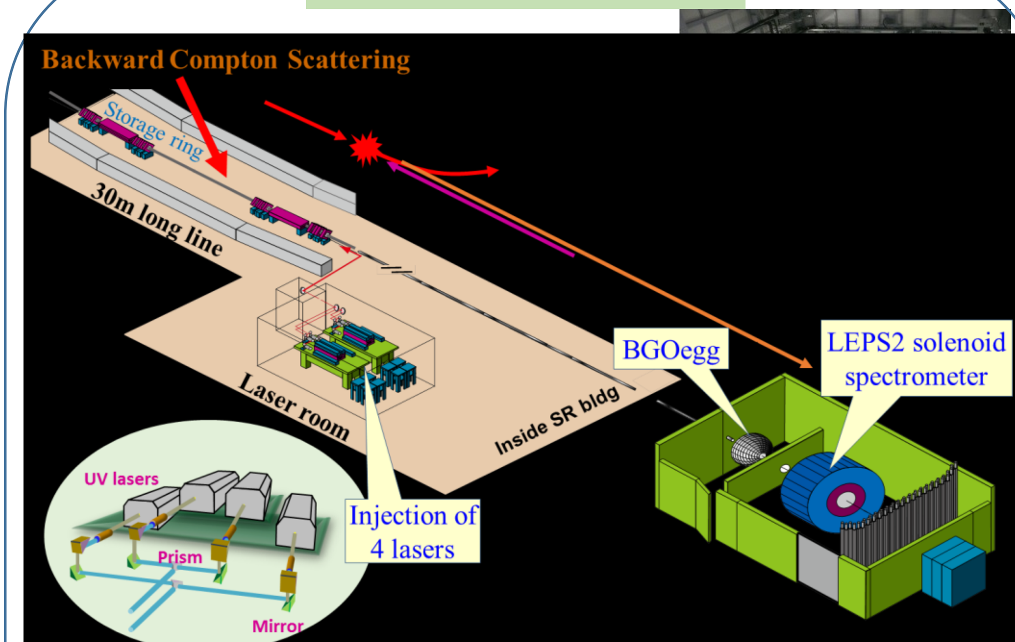


Result of Θ^+
(Few Body Syst. 54, 1245(2013))

Increase beam intensity

Extend detector acceptance

BL31LEP (LEPS2)

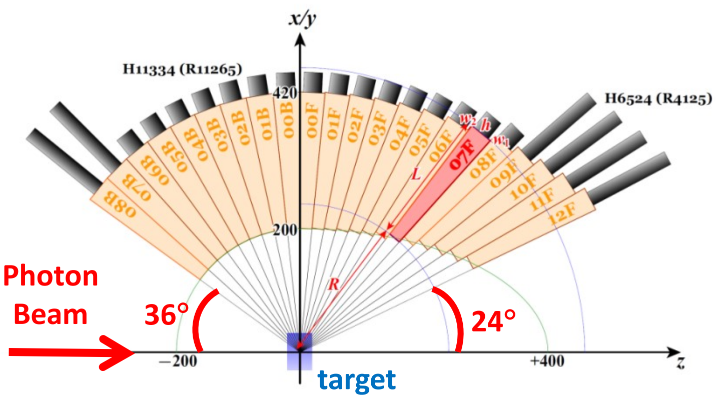


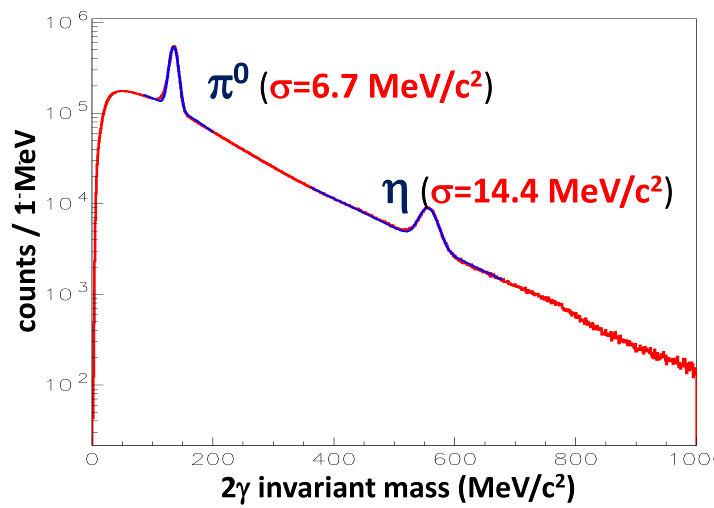
- Parallel injection of four high power UV (or DUV) lasers.
- Large 4π spectrometer using BNL-E949 solenoid magnet.
- Strong collaboration with ELPH, Tohoku University.

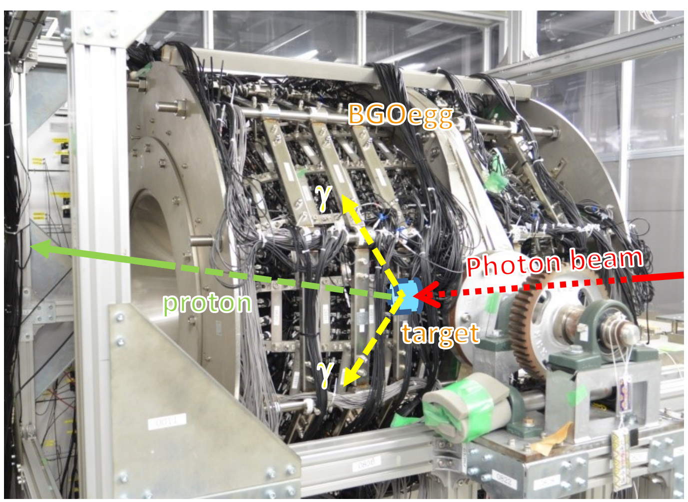
(developed by ELPH)

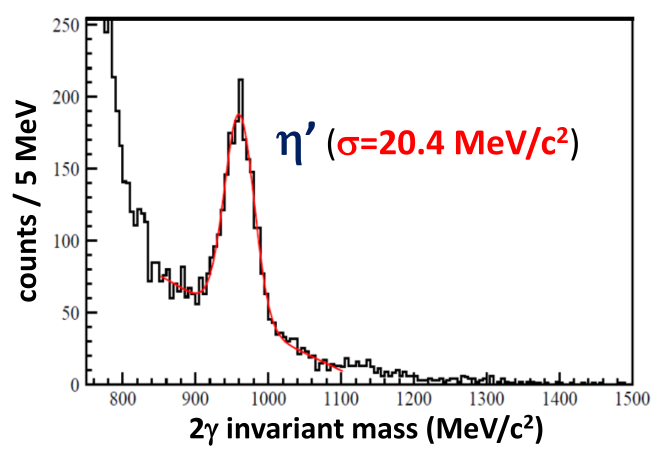
Large Acceptance EM calorimeter BGOegg

- ***'Egg'-shape assembly of 1320 $Bi_4Ge_3O_{12}$ crystals*** without supporting structures b/w crystals.
- Each BGO covers ***~6°*** in (θ,ϕ) with $L_{crystal}$ = 220 mm (***$20X_0$***). There are ***22 layers***.
- **World-highest energy resolution** in the energy region below 1 GeV. (**1.3% @ 1 GeV**)

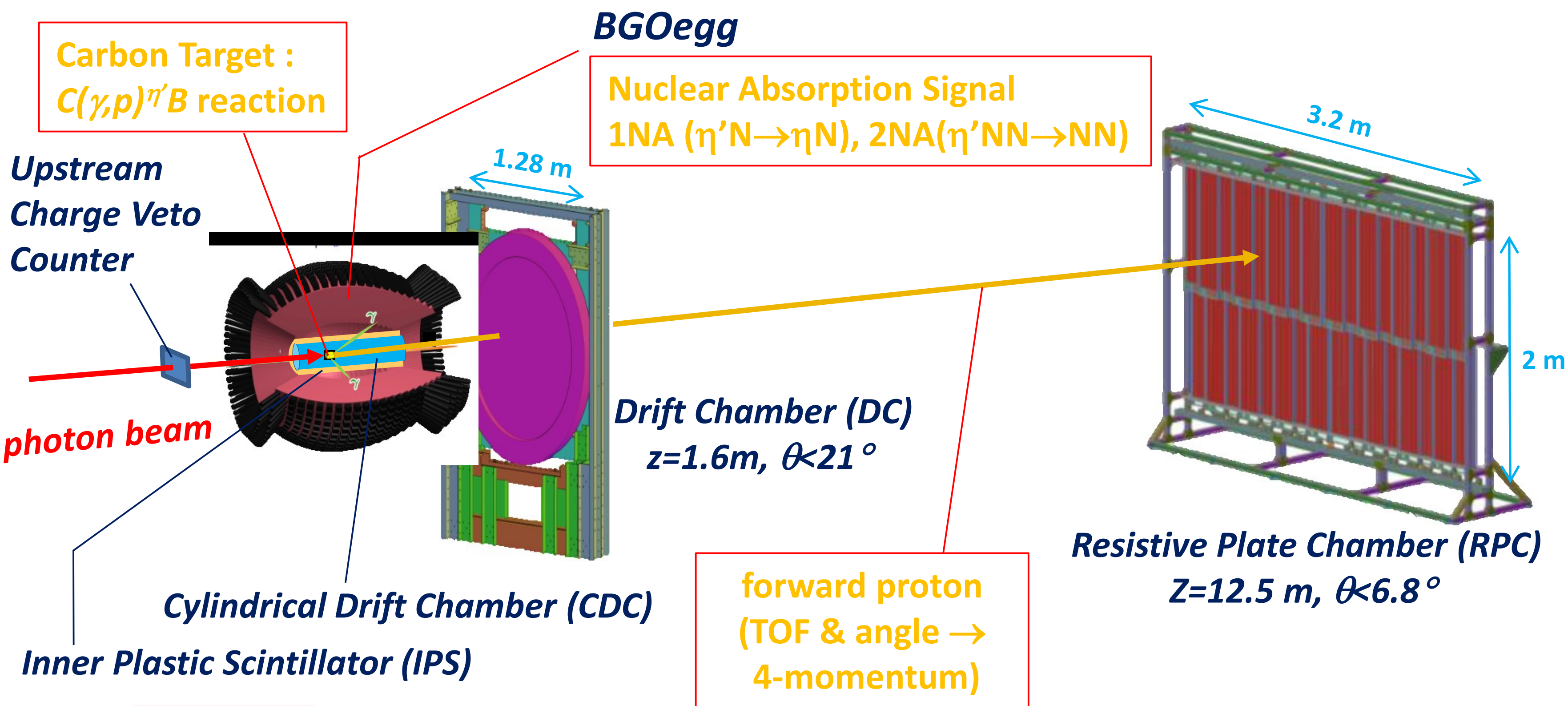


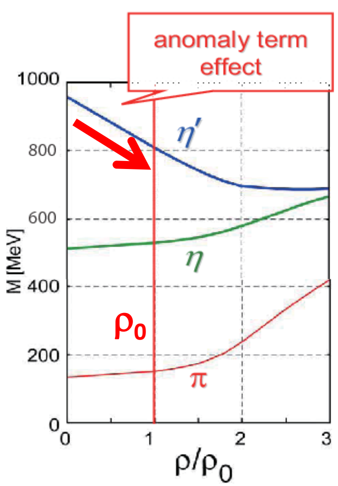


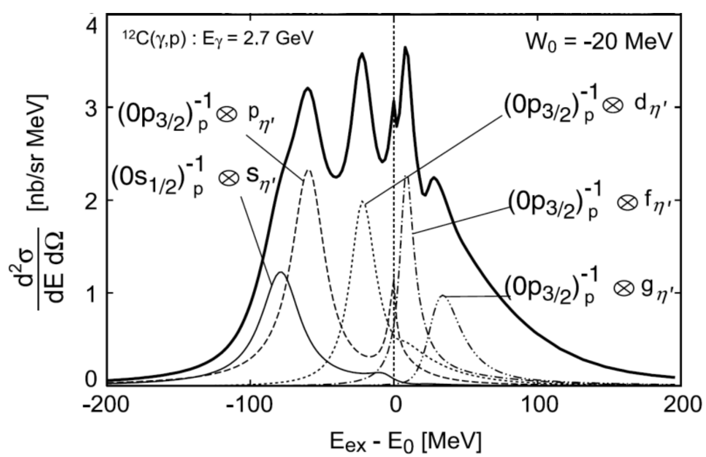




LEPS2/BGOegg Experiment for η'-mesic Nuclei Search



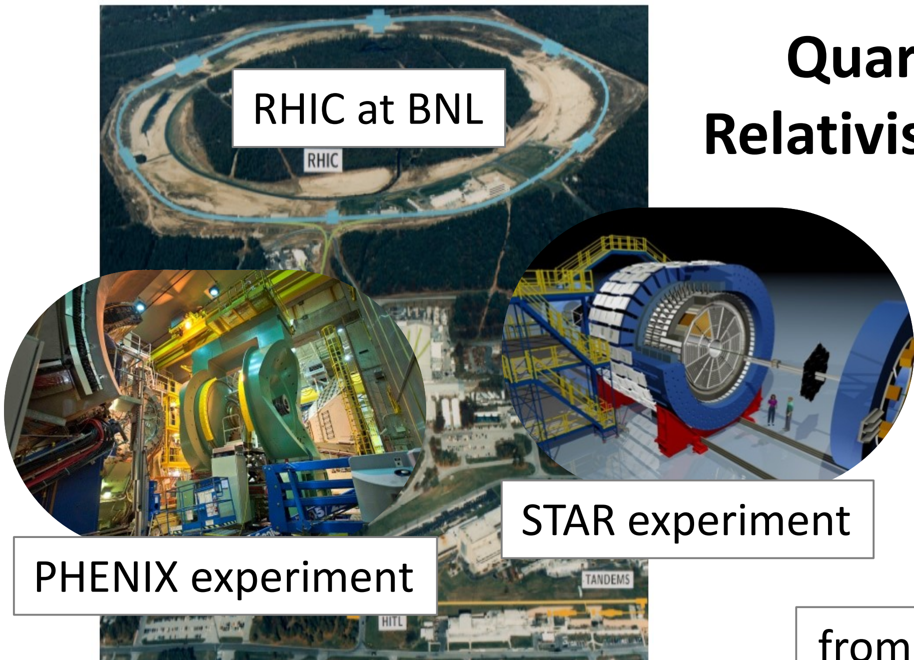


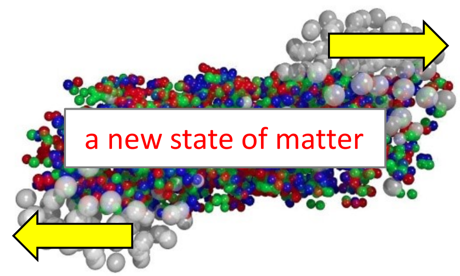


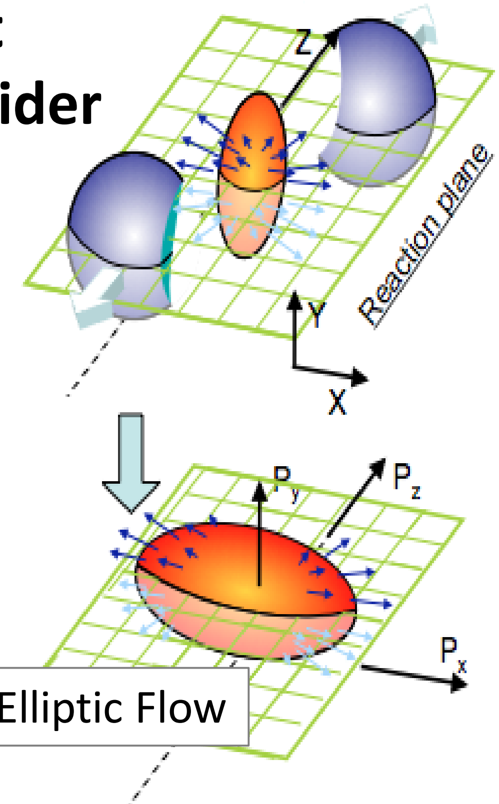
A theoretical calculation based on NJL model predicts ΔM=–150 MeV & deeply bound states. [H. Nagahiro et al., PRC74 (2006) 045203.]

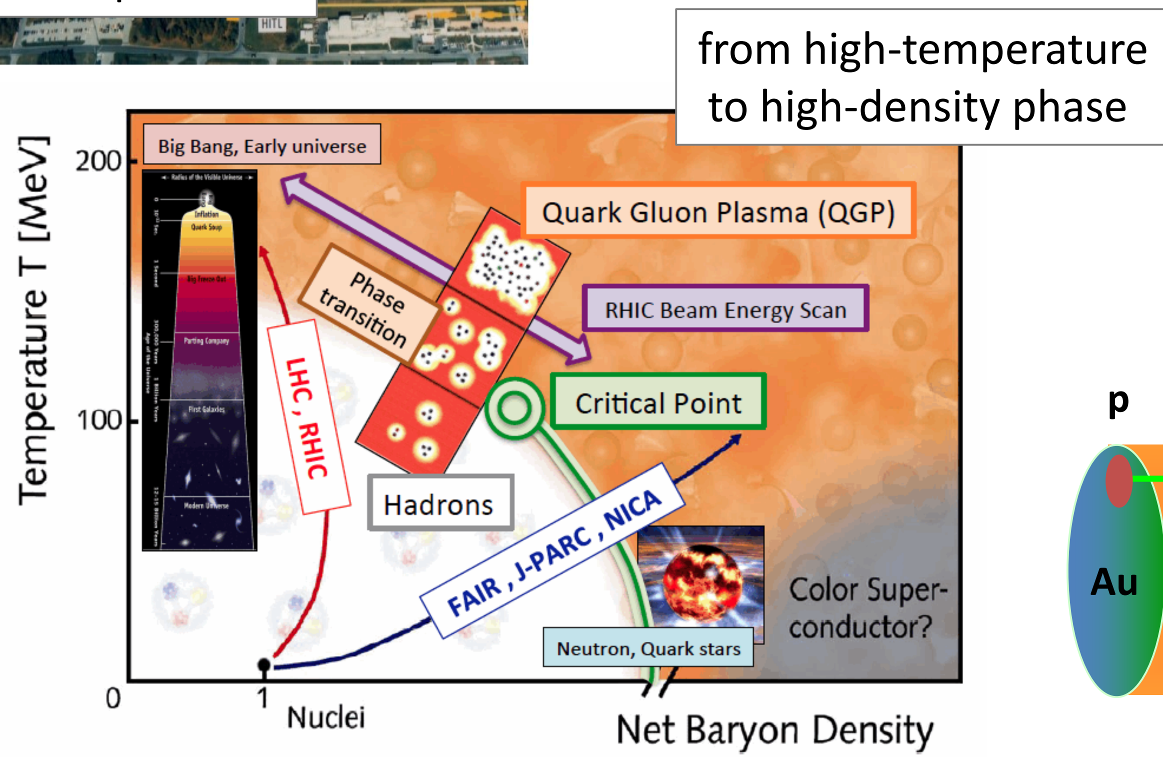
RHIC/PHENIX, ALICE

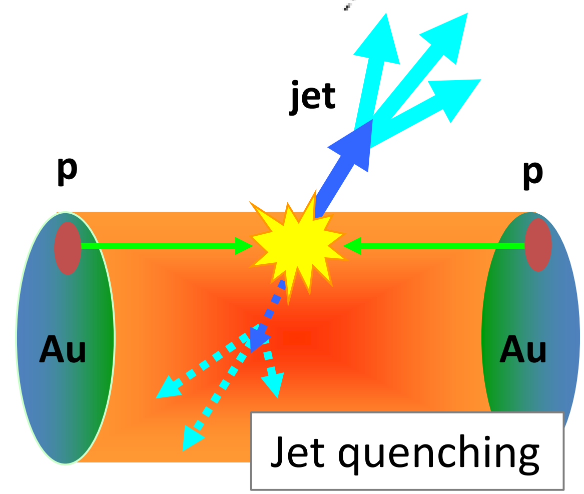
Quark Gluon Plasma at Relativistic Heavy-Ion Collider



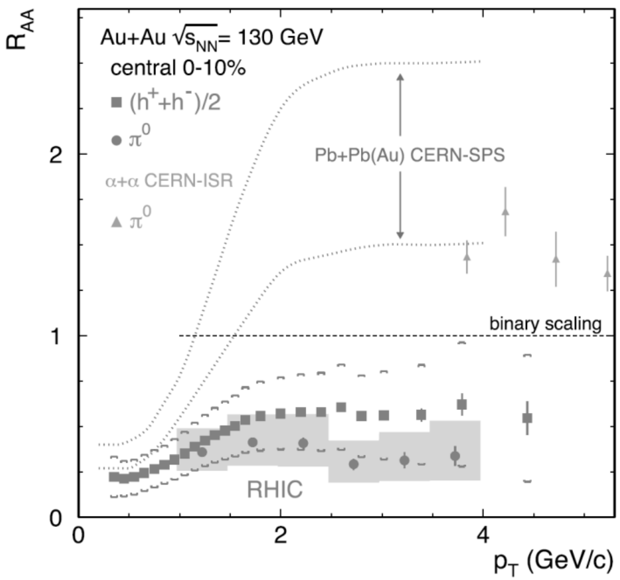


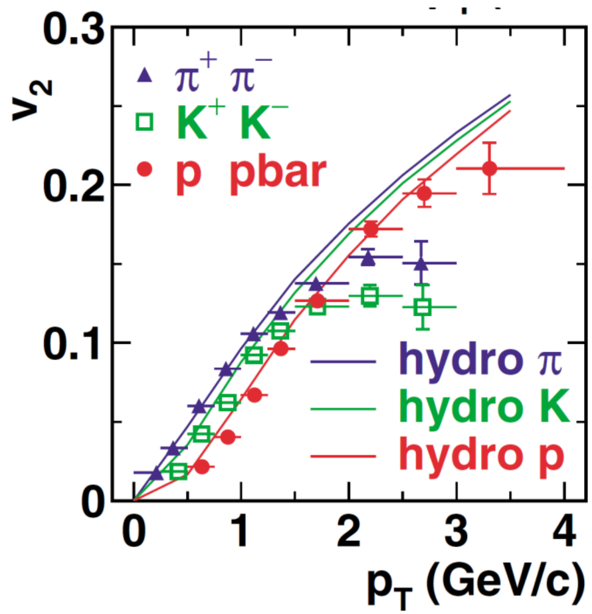


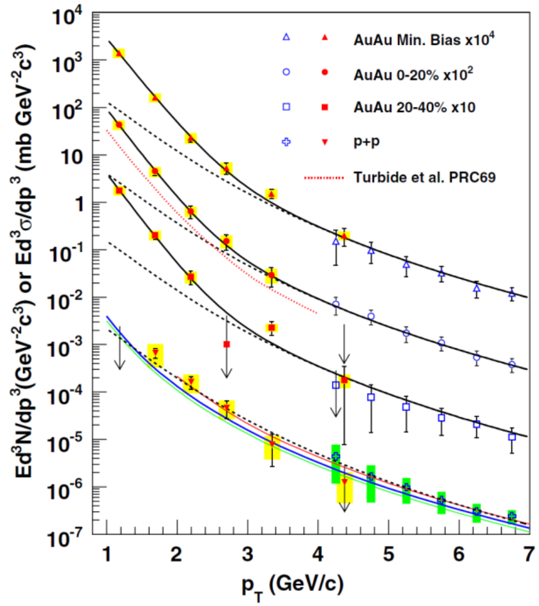




Generation of Quark Gluon Plasma







Suppression of high-pt Hadrons

→ Production of high density QGP

Strong Elliptic Flow

→ QGP as perfect fluid

Thermal direct photons

→ Very high Temp QGP

PHENIX Exp. played a central role for discovering QGP.

RHIC-Spin Today and Future

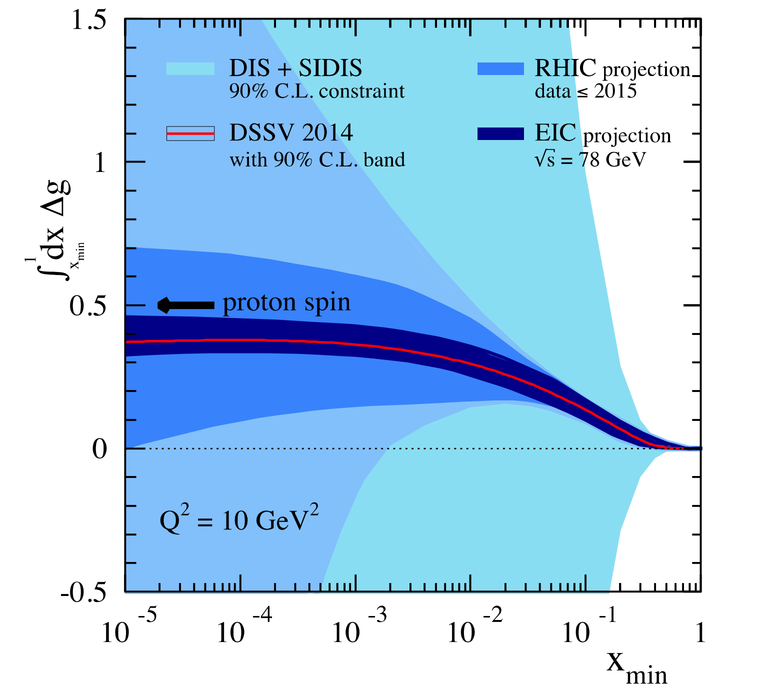
RHIC Cold QCD Plan arXiv:1602.03922

- Large fraction of proton spin carried by gluons!

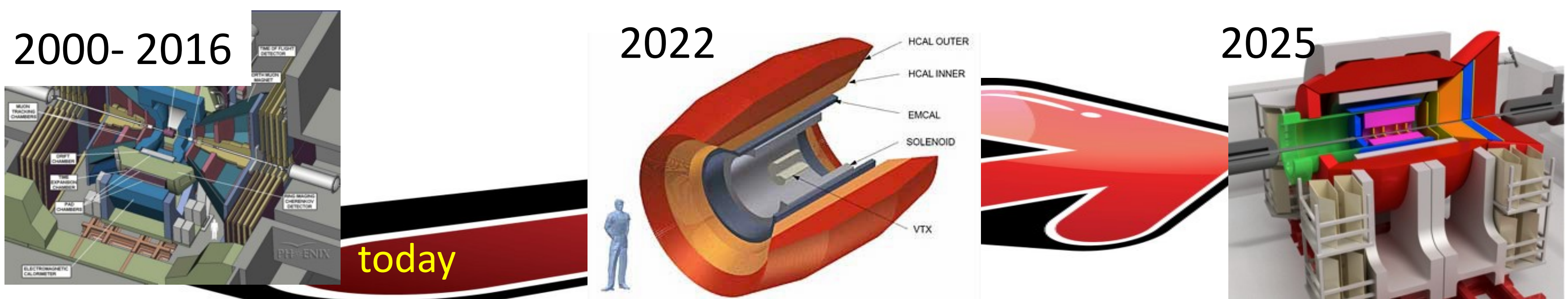
  8 Ph.D from Japanese Institutes

- New generation measurements of sea-quark polarization via W production.

  3 Ph.D from Japanese Institutes



Detector evolution for future hadron structure study



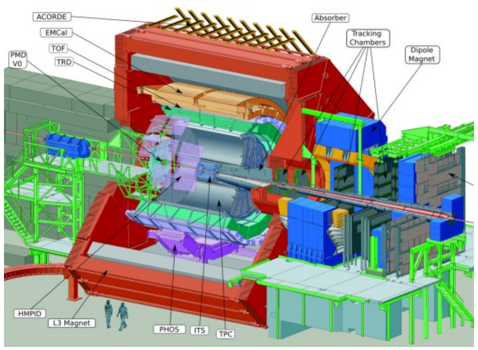
PHENIX

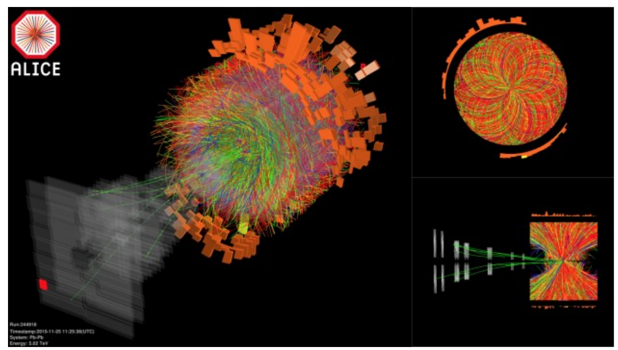
(f)sPHENIX

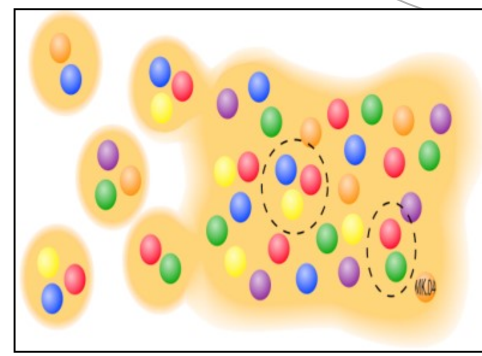
EIC detector

ALICE at CERN LHC, and ALICE Japan

- ***the*** **nucleus-nucleus collision experiment at LHC**
  - 42 countries; 174 institutes; ~1,800 members





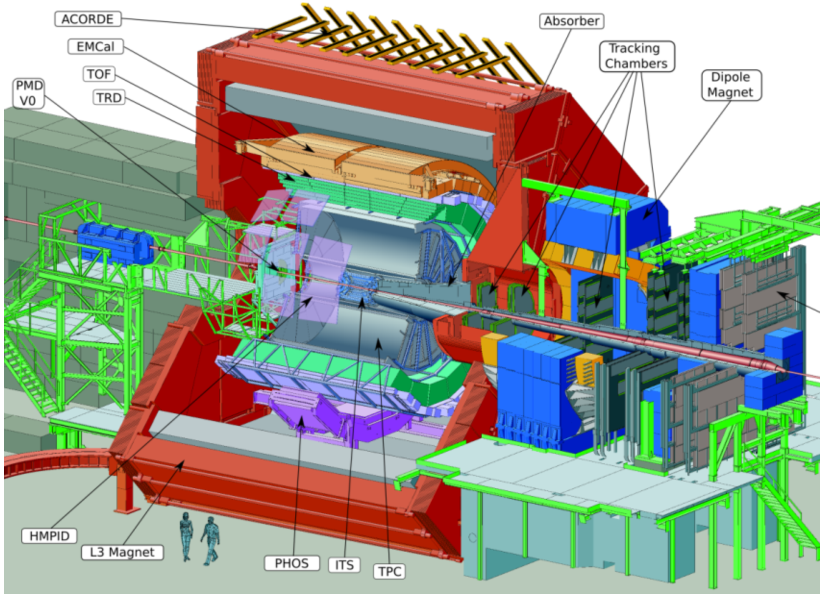


- **hottest, largest, longest-lived quark-gluon fireball**
  - nucleus-nucleus collisions at world highest energy
    - Pb+Pb at 5.02 TeV per nucleon-nucleon pair ($\sqrt{s_{NN}}$) in 2015
- **strong commitments in detector/physics/upgrade**
  - 5 full member institutes and 2 associate in Japan
    - http://www.alice-j.org/ for details

LHC-ALICE upgrade(2021-)

ALICE upgrade and ALICE-J contributions

- ITS (inner Si pixel trackers)
- GEM-TPC upgrade
- Forward Silicon pixel trackers
- O2 (DAQ-online-offline) upgrade
- Forward calorimeter (under discussion)



Precision Science of Quark-Gluon-Plasma

- 50kHz Pb-Pb Collisions from 2021-
- Inspect all Pb-Pb collisions by ALICE (unique at the LHC)
- x100 larger statistics compared to now

- Precision measurements of hadrons, multi-strangeness, heavy-flavors, jets, photons and leptons
- Detailed understanding of medium properties as a function of temperature

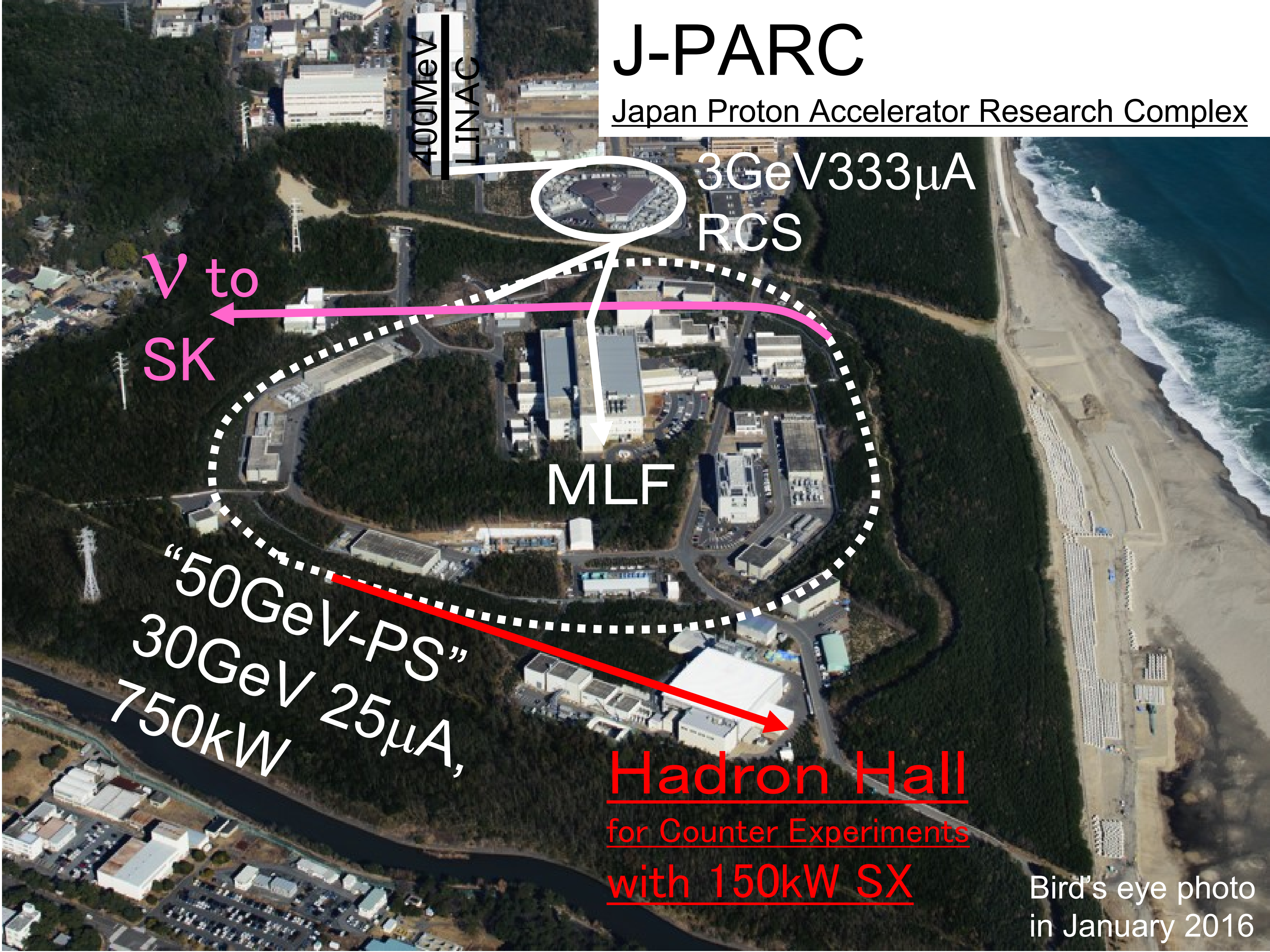
Technical design report of the ALICE upgrade
(ITS, MFT, GEM-TPC, DAQ-O2, Trigger & electronics)
→ Endorsement by the LHCC (2012)

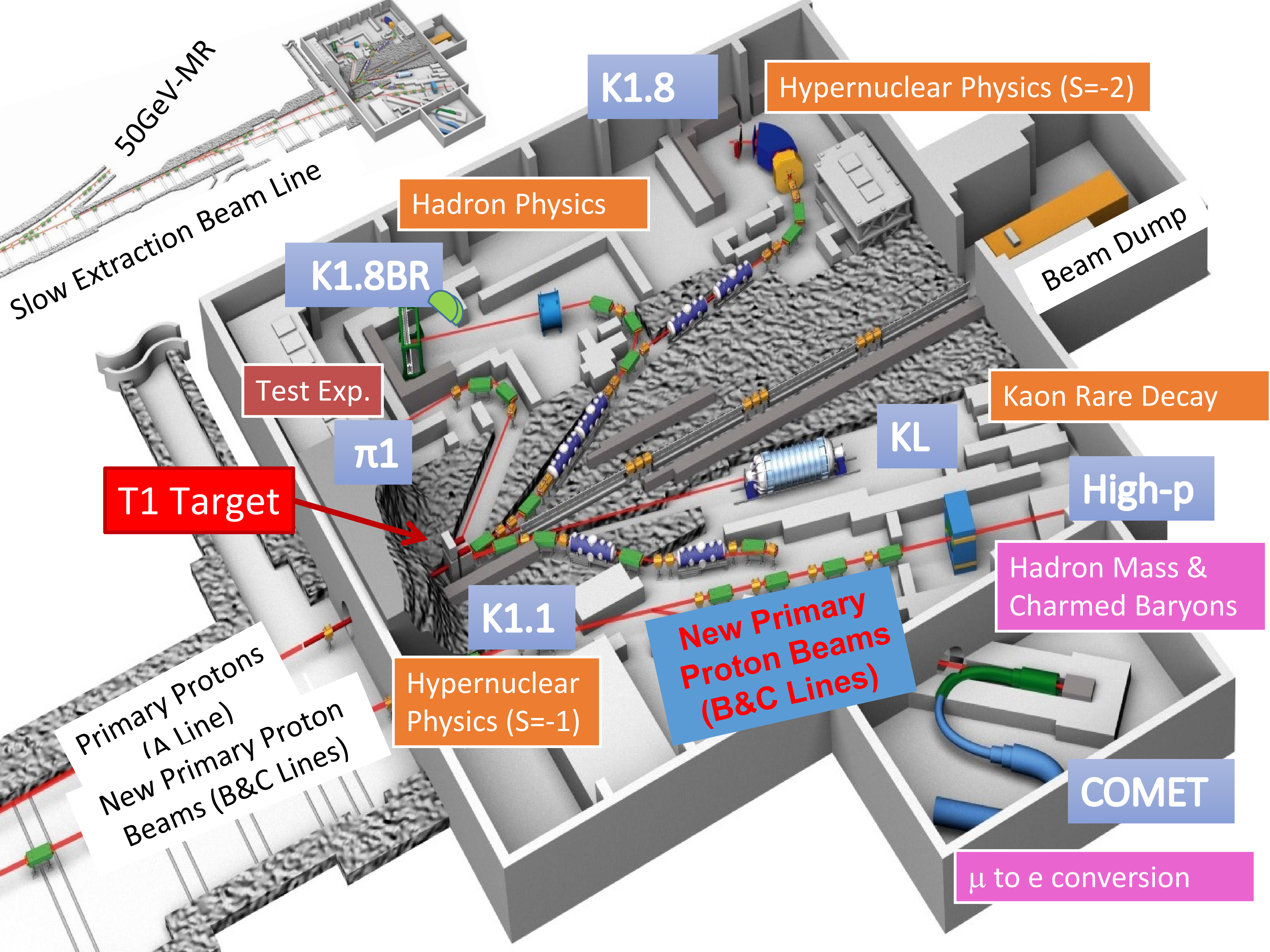
J-PARC Japan Proton Accelerator Research Complex

J-PARC at Tokai-mura, Ibaraki-ken

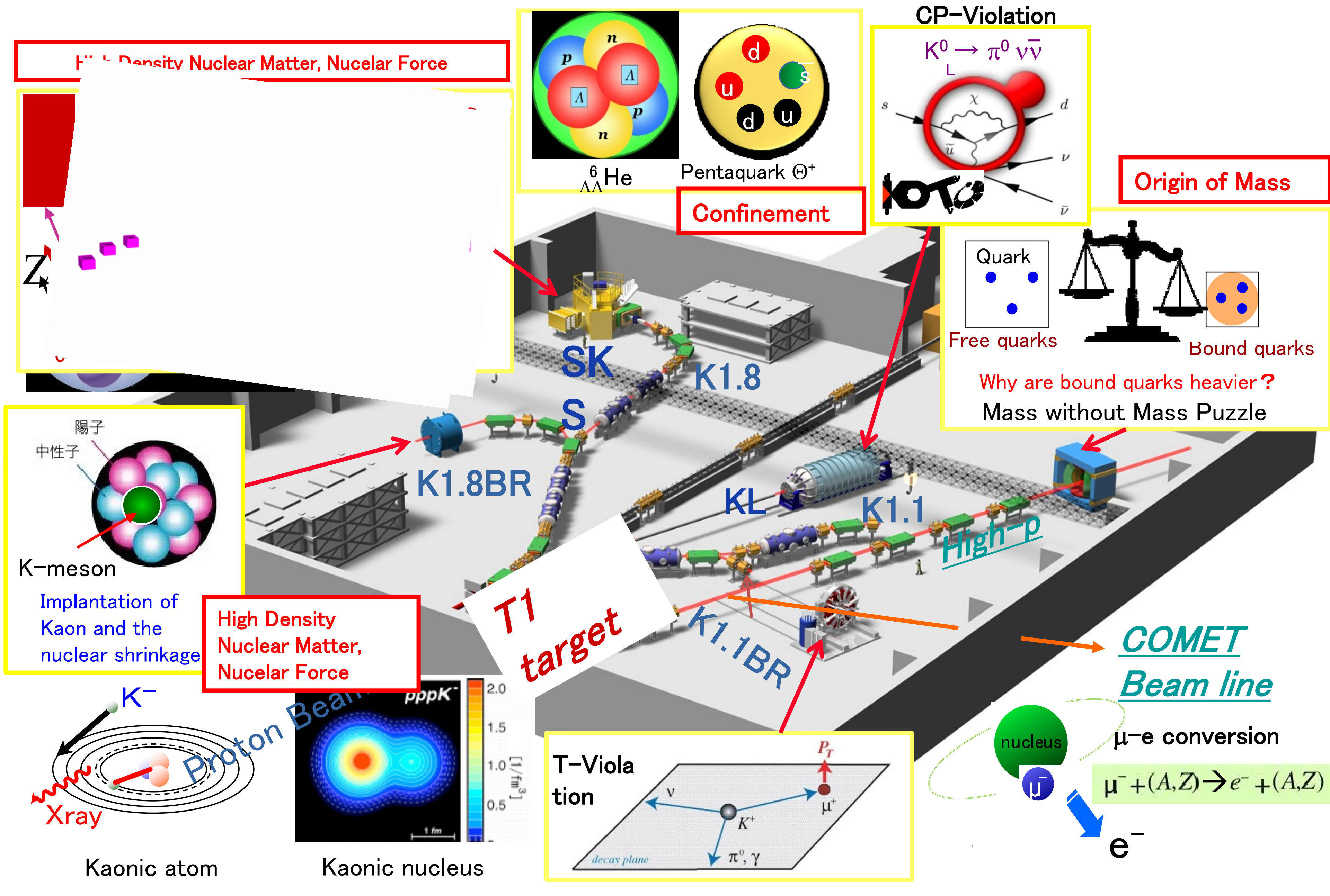
J-PARC

Japan Proton Accelerator Research Complex

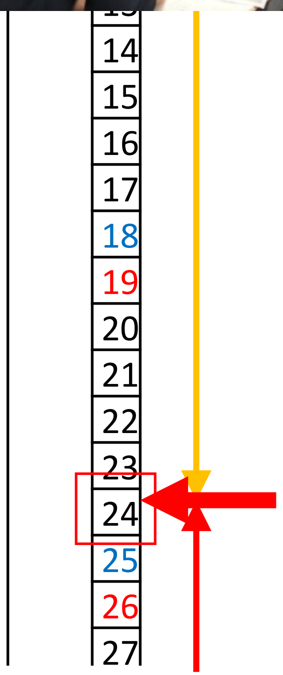



50GeV-MR
Slow Extraction Beam Line
K1.8
Hypernuclear Physics (S=-2)
Hadron Physics
K1.8BR
Beam Dump
Test Exp.
Kaon Rare Decay
π1
KL
T1 Target
High-p
Hadron Mass &
Charmed Baryons
K1.1
New Primary
Proton Beams
(B&C Lines)
Hypernuclear
Physics (S=-1)
Primary Protons
(A Line)
New Primary Proton
Beams (B&C Lines)
COMET
μ to e conversion

Nuclear, Hadron, & Particle Physics at Hadron Hall



Restart of Hadron Beam Operation



User operation restarted with the proton beam power of 24kW!

(Almost 2 years after the accident)

朝日新聞　２０１５年４月２５日　朝刊　２８ページ　茨城全県

J−PARC 実験施設が再開
放射能漏れから2年

東海村にある加速器実験施設「J−PARC」で24日、放射性物質の漏出事故＝＝を起こしたハドロン実験施設の運転が約2年ぶりに再開された。

「標的温度、異常なし」

午前11時すぎ、陽子ビームを標的に当てる作業を開始。運転管理室では職員が標的の温度や放射能濃度のモニター画面を確認した。

この日から、国内外の大学や研究機関の三つの実験が始まった。他に約10の実験が控えているという。

J−PARCは、日本原子力研究開発機構と高エネルギー加速器研究機構が共同で運営。ハドロン実験施設は2009年に完成した。陽子ビームの出力が高く、世界最高性能の施設とされる。標的となる金などの原子核と衝突させて粒子を作り出し、物質の起源や宇宙の成り立ちを探究している。事故前の12年度は利用期間中、常時約100人が利用した。

事故で八つの実験が中断や延期を余儀なくされた。事故当時、チームの責任者として実験に取り組んでいた大阪大の山中卓教授（高エネルギー物理学）は「2年は長かったが、安全対策や住民への説明を丁寧にした結果。ようやく研究を進められるのでホッとしている」と話す。

J−PARC側は、約19億円をかけて安全対策を講じた。異常な量のビームが出る原因となった電源基板に劣化対策を施し、放射性物質が外に漏れないよう排気ファンを撤去。異常時の行動基準もマニュアルに盛り込んだ。こうした再発防止策を踏まえ、県や村は先月、運転再開を了承した。

事故以降、一市民の立場でJ−PARCの動向をブログで発信してきた常総市の行政書士古性隆さん(50)は、ウェブサイトでの会議資料の掲載など情報公開が進んだことに一定の評価をしつつ、釘を刺す。「研究者と住民との安全認識の差はだいぶ縮まった。ただ、施設全体の災害対策でまだ不安な点がある。今後も住民目線で監視したい」

J−PARCの斉藤直人センター長は「安全確保を最優先に施設を運営する。最先端の研究成果を生み出し、社会に貢献していきたい」と話している。

（酒本友紀子）

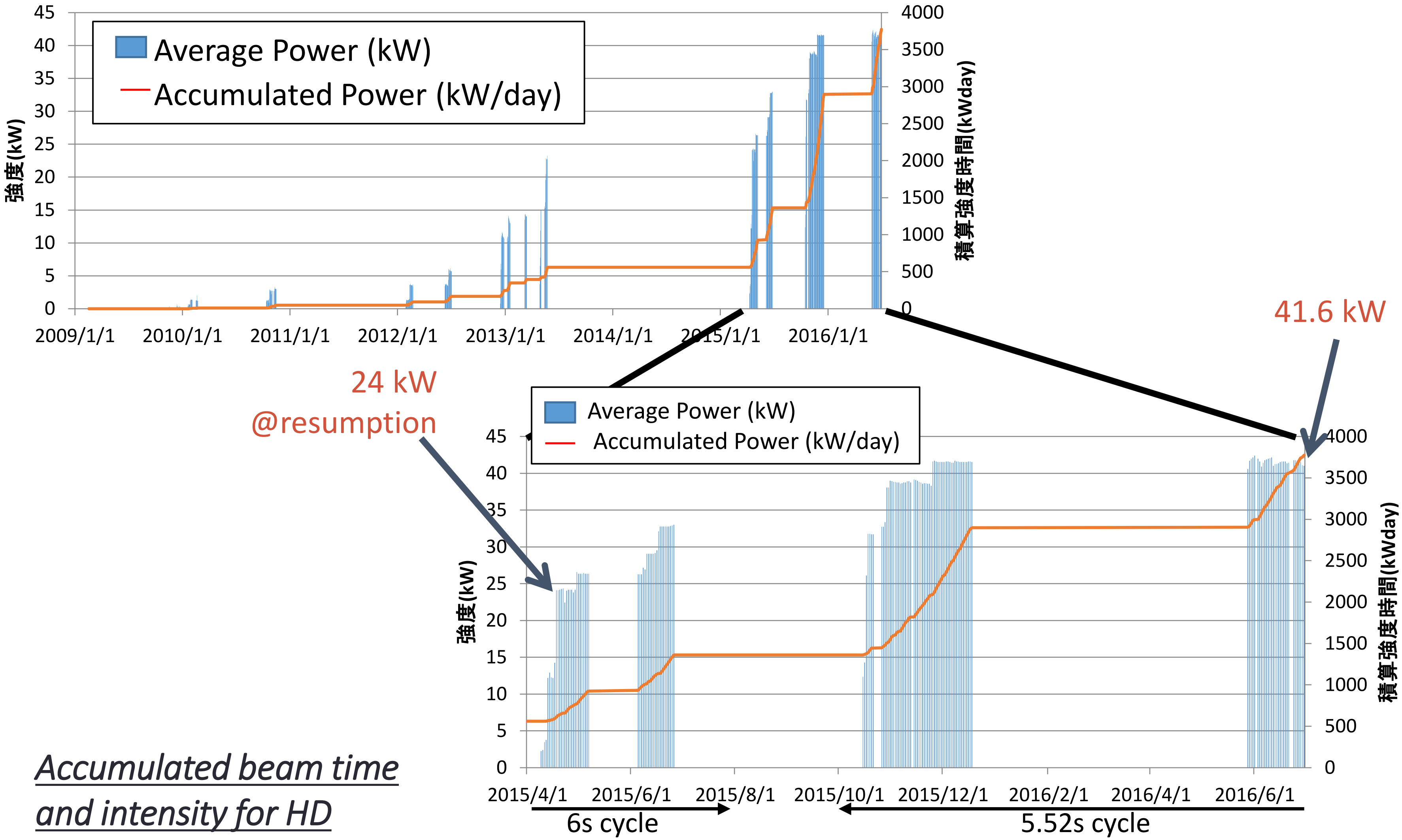
運転管理室で標的の温度などを確認する職員ら＝東海村のJ−PARC

放射性物質の漏出事故

2013年5月、陽子ビームを標的の金に当てて粒子を発生させる実験中に起きた。機器劣化による誤作動で設定値を大きく超えるビームが当たり、金の中の放射性物質が蒸発。研究者ら34人が被曝（ひばく）し、排気ファンを回したことで放射性物質が屋外に漏れた。警報が出た後も4時間以上実験を続け、自治体への報告が1日半遅れたことが批判を浴びた。

事故は国際原子力事象評価尺度で、1995年の高速増殖炉もんじゅ（福井県）のナトリウム漏れ事故と同じ「レベル1」とされた。

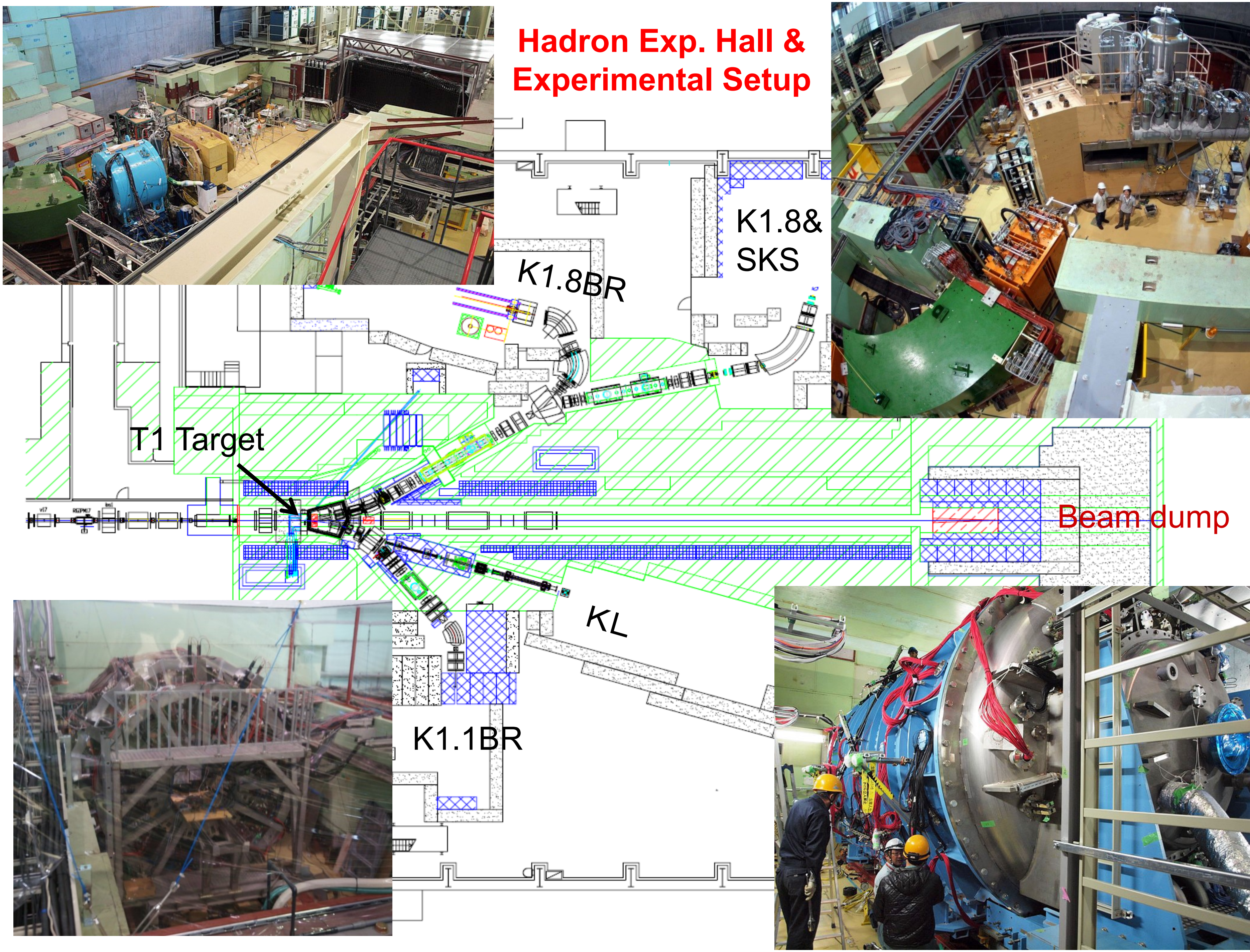
Development of Beam Intensity



Accumulated beam time and intensity for HD

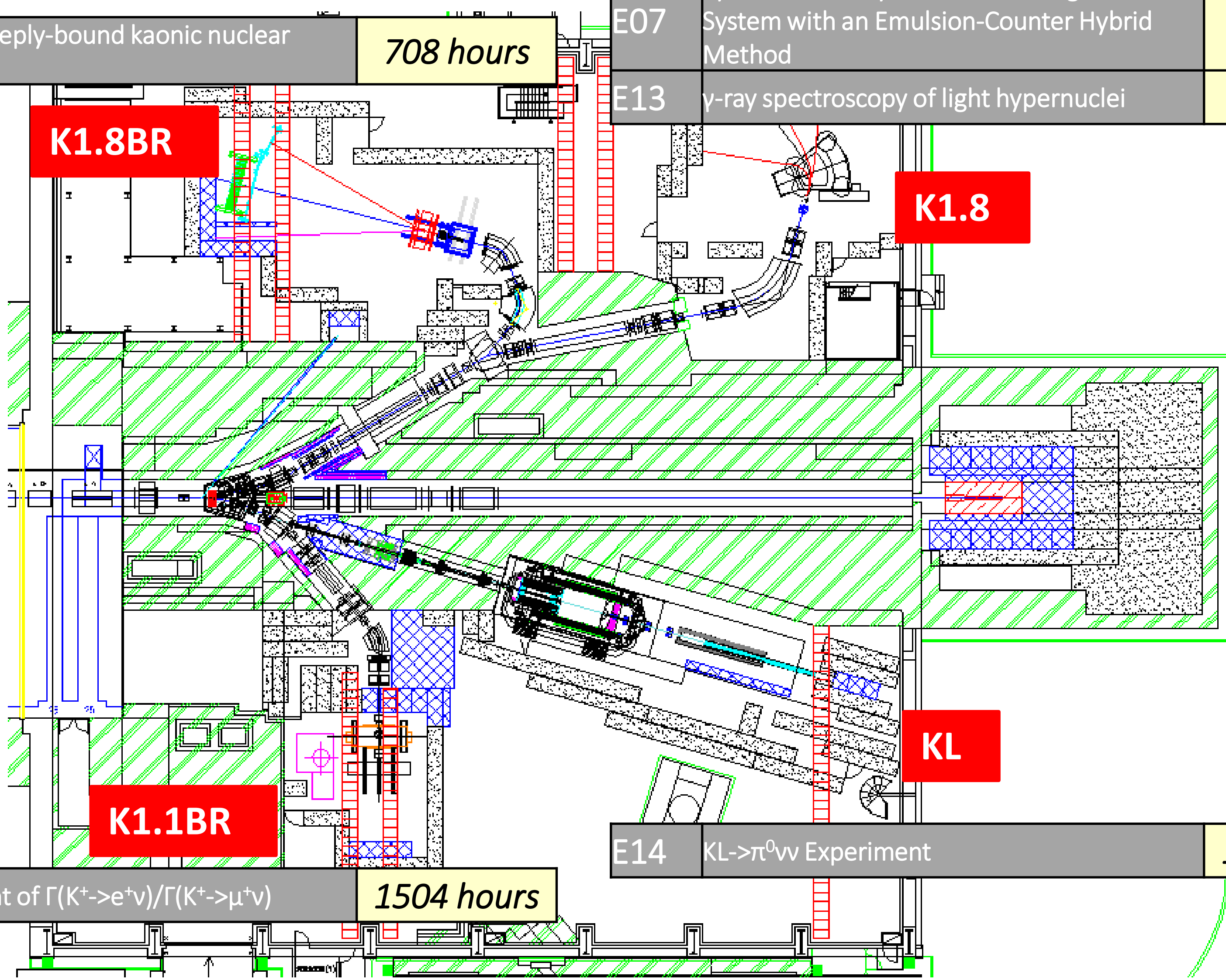
Feb, 2009 - May, 2013: 1.26x10^6 spills, **560 kW*days** ←Before Hadron Incident
Apr, 2015 - Dec, 2015: 1.05x10^6 spills, **2338 kW*days** ←in JFY2015
May, 2016 - Jun, 2016: 0.33x10^6 spills, **875 kW*days** ←in June 2016 Run

Hadron Exp. Hall & Experimental Setup



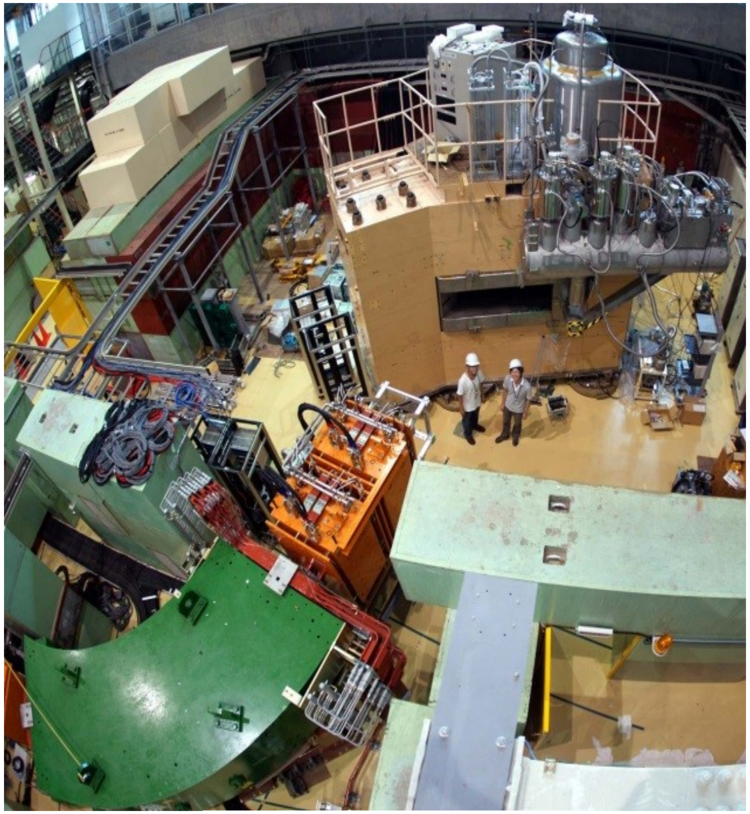
Beam time used for experiments in 2015 run

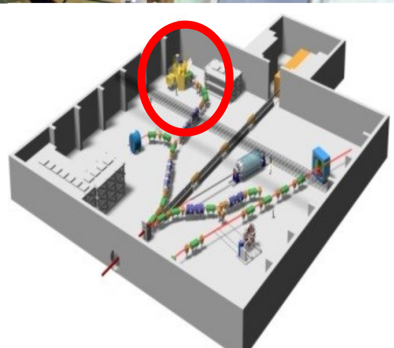
E15	search for deeply-bound kaonic nuclear states	*708 hours*
E05	Spectroscopic Study of Ξ-Hypernucleus	*319 hours*
E07	Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method	*42 hours*
E13	γ-ray spectroscopy of light hypernuclei	*435 hours*
E14	KL->$\pi^0\nu\nu$ Experiment	*1509 hours*
E36	Measurement of $\Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$	*1504 hours*

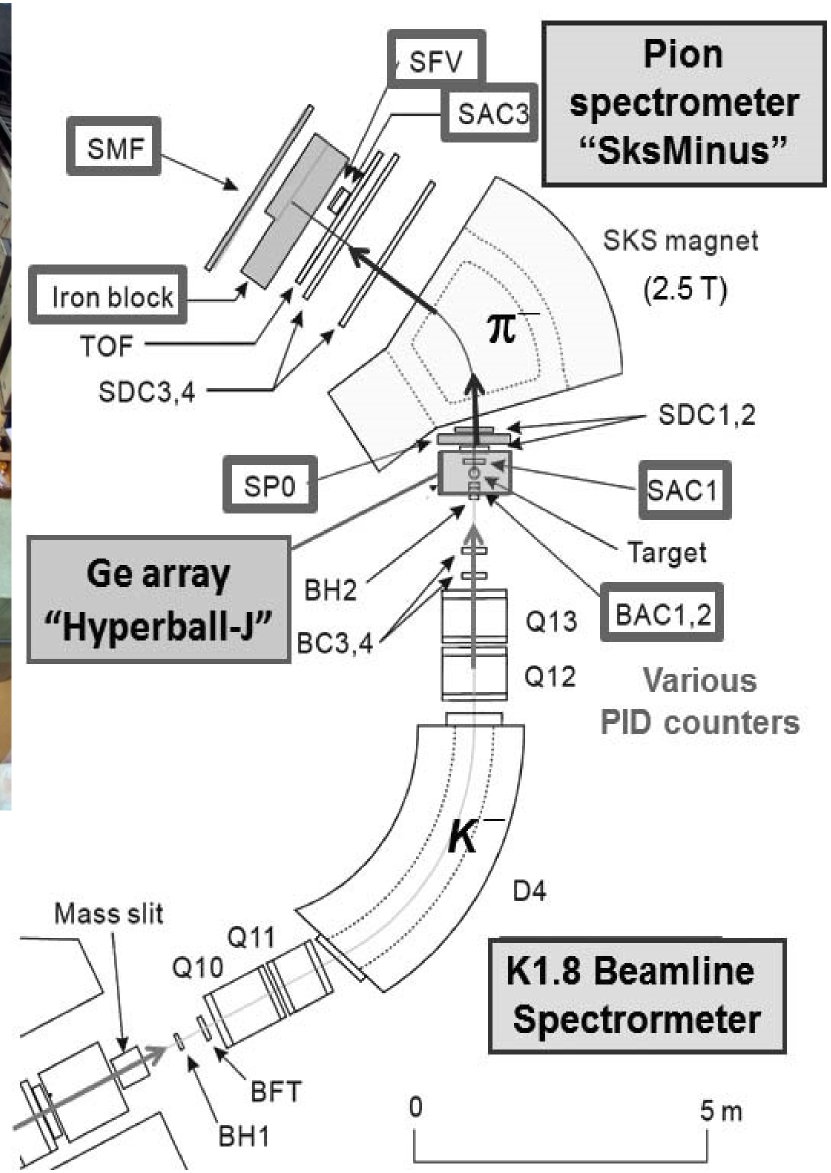


Setup at K1.8 for E13-1

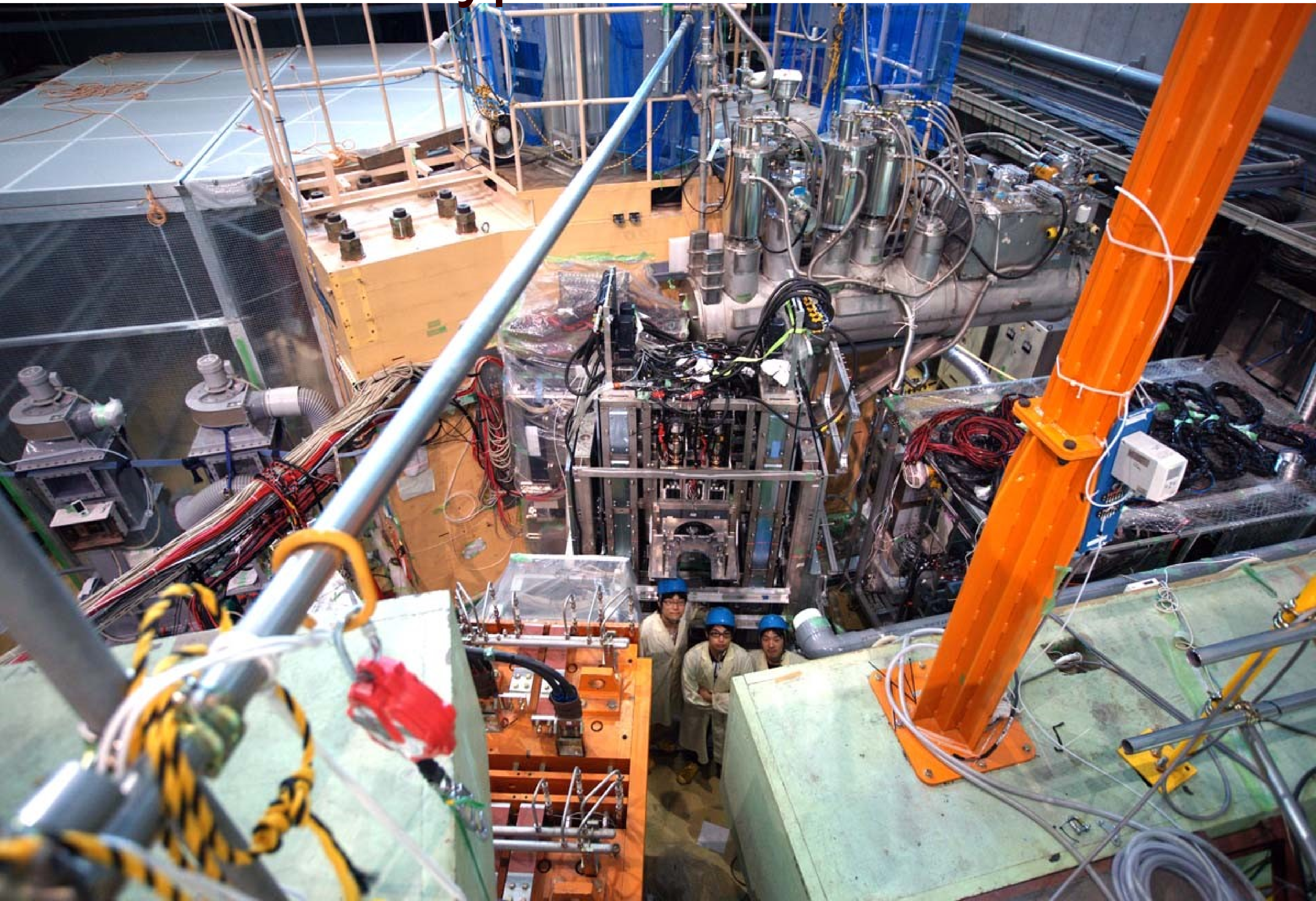
- Detect gamma-rays from hypernuclei



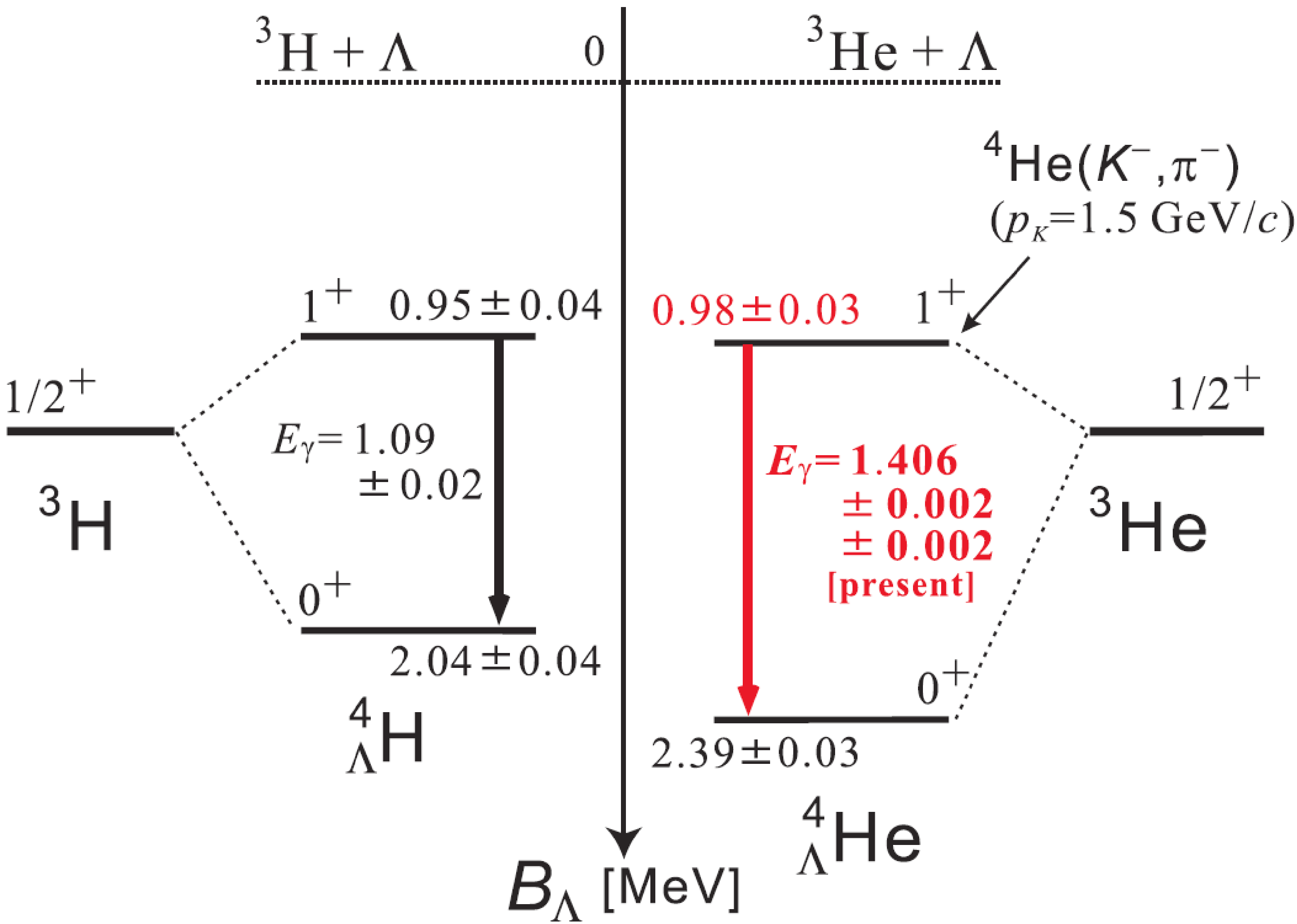




Hyperball-JとSKS



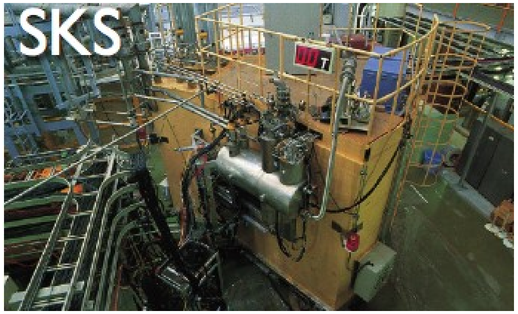
Charge Symmetry Breaking in ΛN interaction from hypernuclear γ-ray spectroscopy (E13)



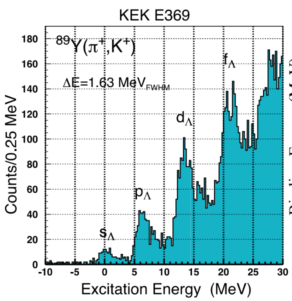
Development of Strangeness Nuclear Physics

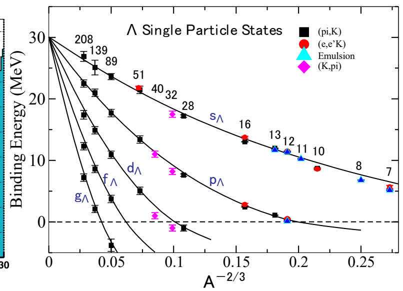
For the understanding of Nuclear Force between Baryons and high density nuclear Matter

Spectroscopy of heavy hyper nuclei via (π,K) reactions

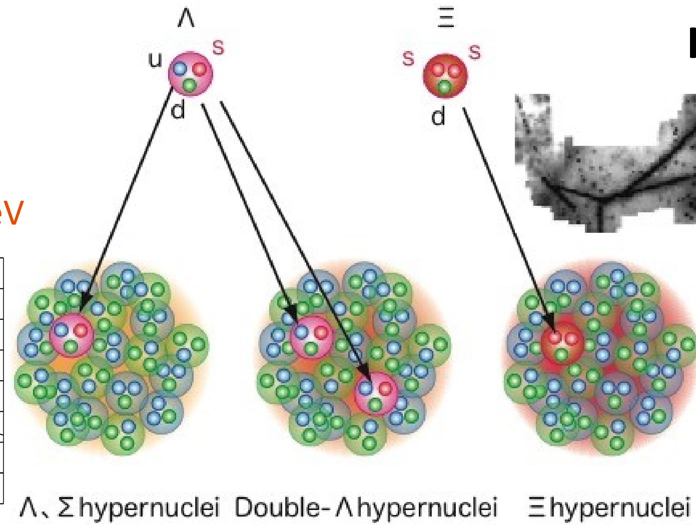


V_Λ= -30 MeV

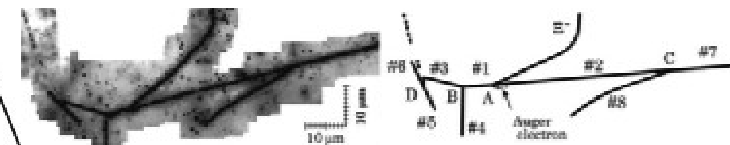




Hybrid Emulsion Experiments



KISO event (Ξnuclesu)

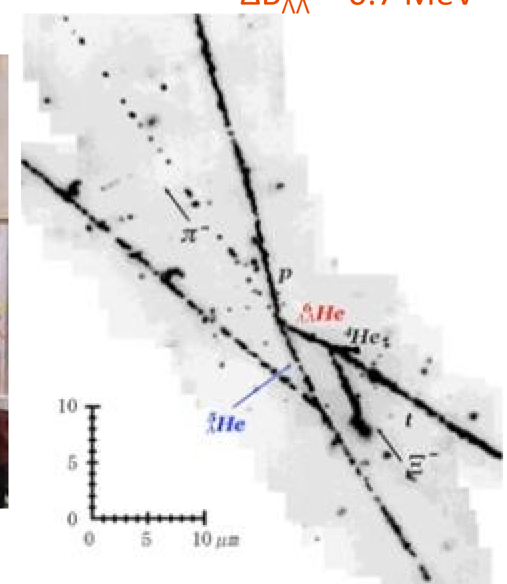


B_Ξ= 1~4 MeV

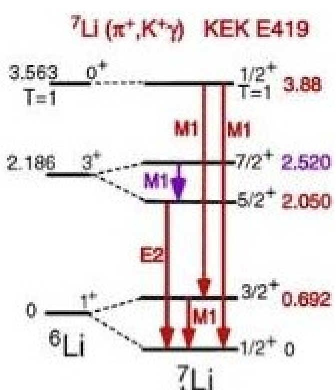
NAGARA event

(ΛΛ nucleus)

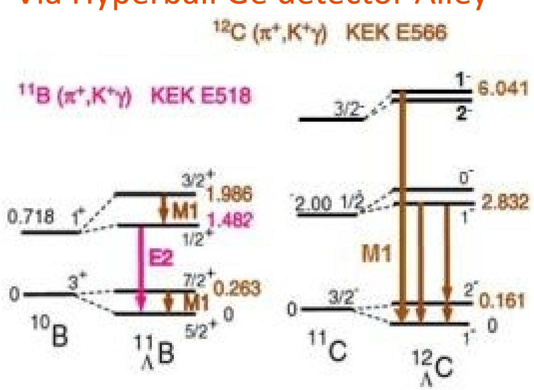
$\Delta B_{\Lambda\Lambda}$= -0.7 MeV

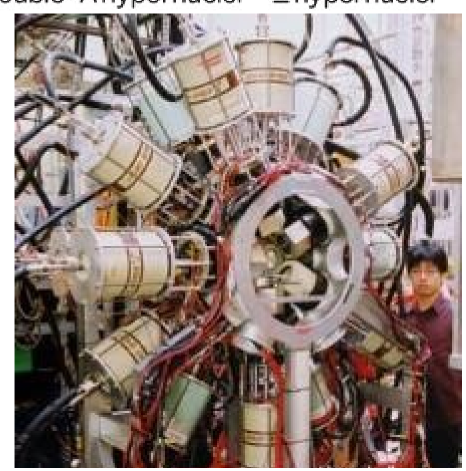


Hypernuclear Gamma ray Spectroscopy



Via Hyperball Ge detector Alley





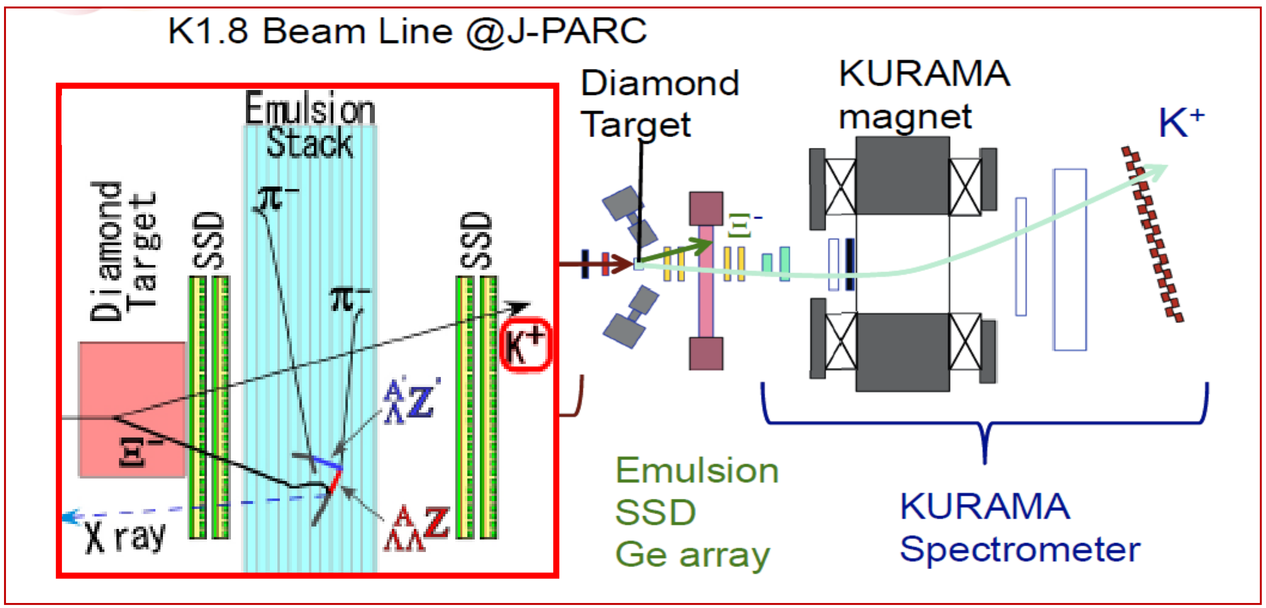
Hyper Ball

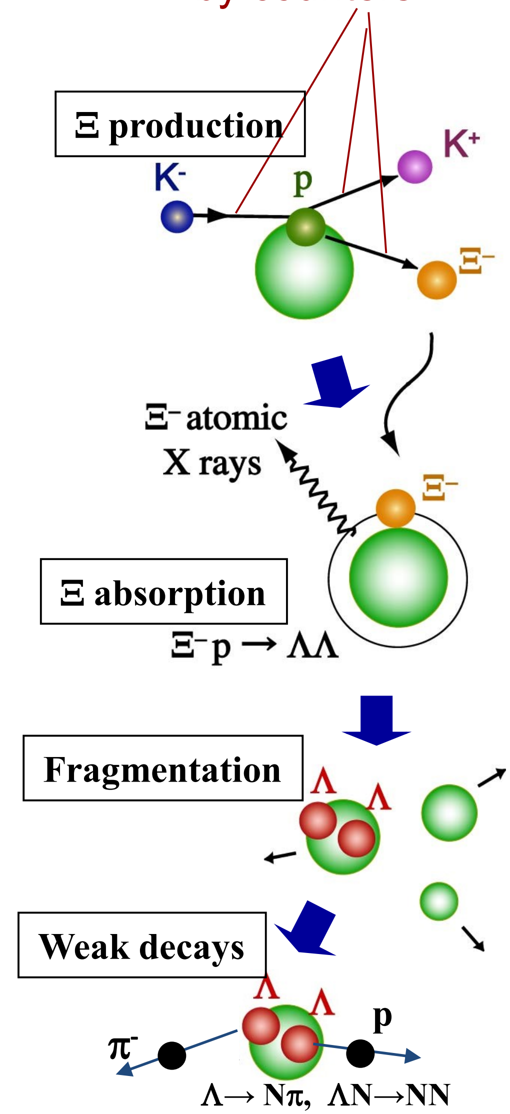
Toward **double strangeness** systems

J-PARC E07: S=-2 Systems by emulsion

- Collect ~10^2 $\Lambda\Lambda$ hypernuclear events from ~10^4 Ξ^-_{stop}
  - $\Lambda\Lambda$ interaction strength without nuclear effects
- Measure Ξ^- -atomic X-rays with Ge detectors
  - Shift and width of X-rays -> Ξ-nuclear potential
  - Stopped Ξ^- events identified from emulsion image

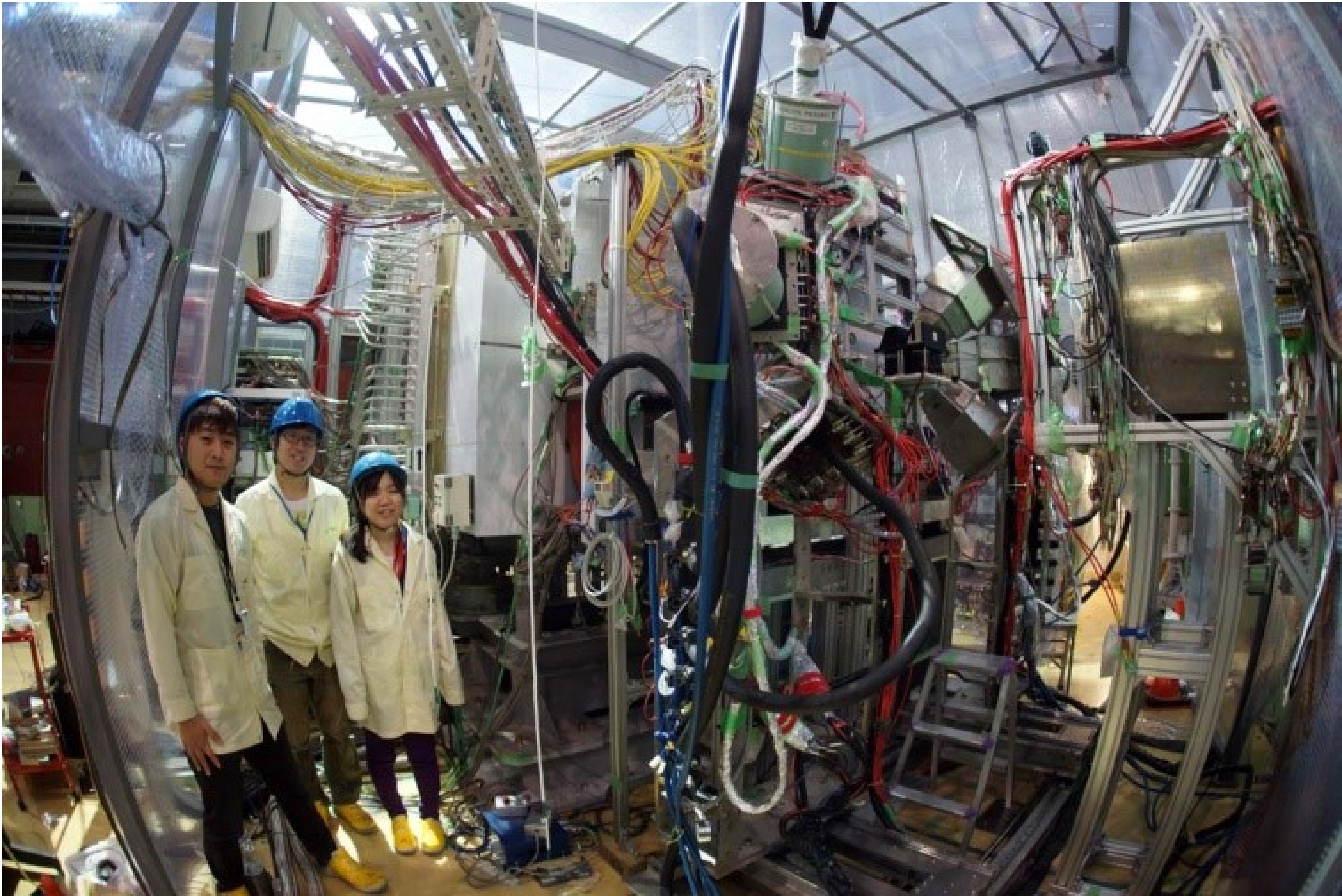
  –> no background





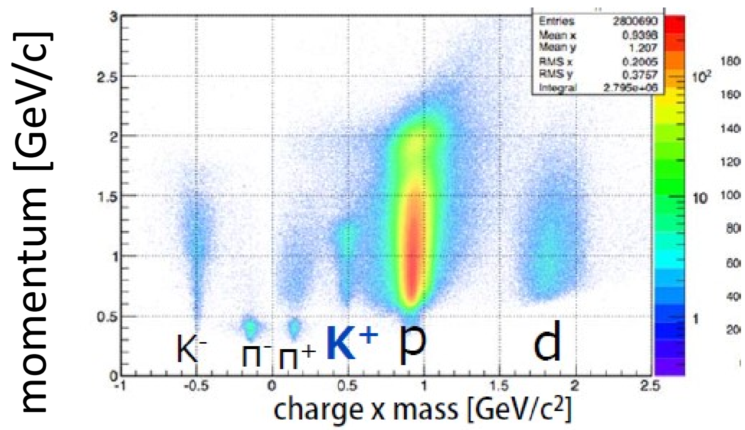
Emulsion and all the counters are beam-tested and ready.
Under switchover from SKS to KURAMA now

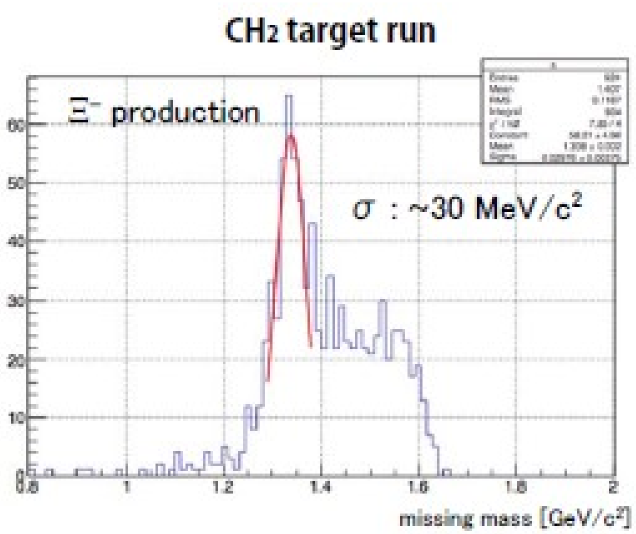
Kurama for hybrid emulsion exp.1

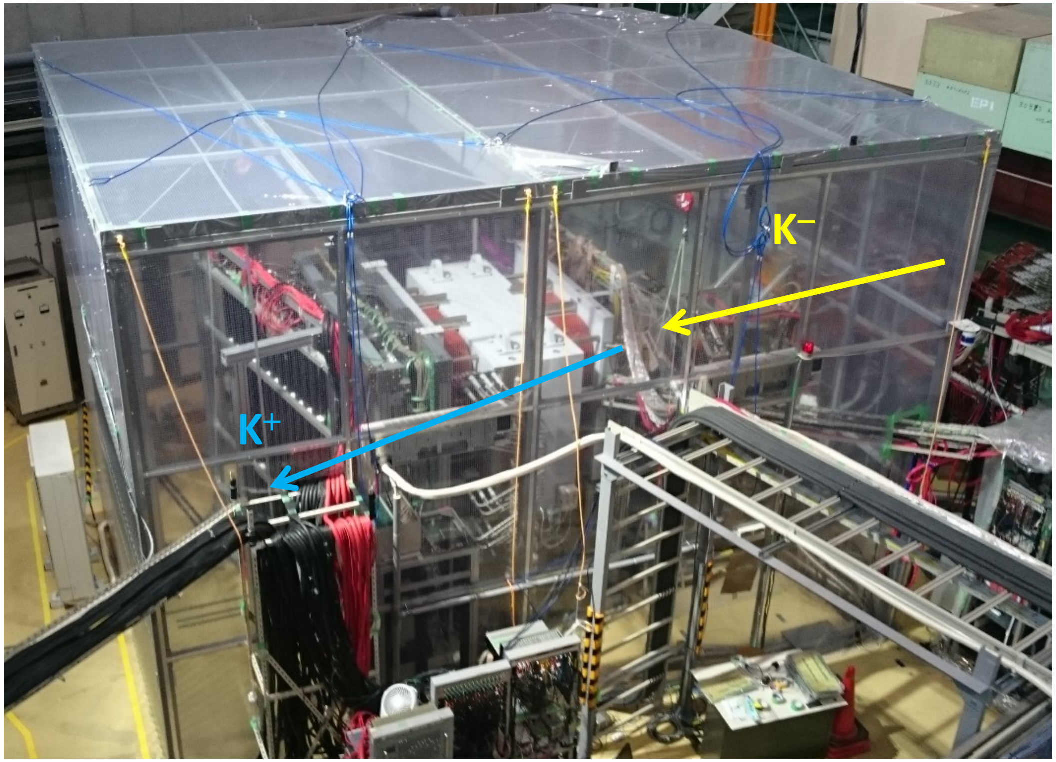


Start of E07 (Emulsion exp.) at K1.8

KURAMA (~260msr) installed at K1.8

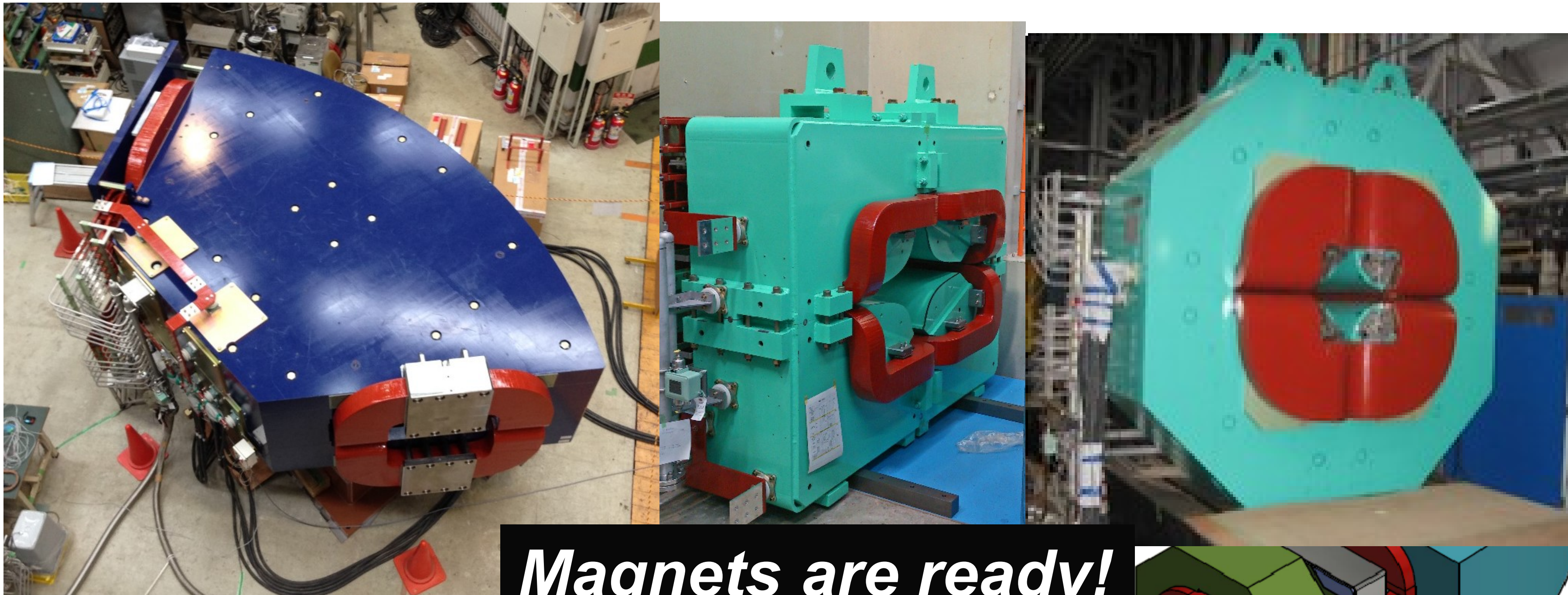






Beam was exposed to the 18/118 emulsion stacks in June 2016.

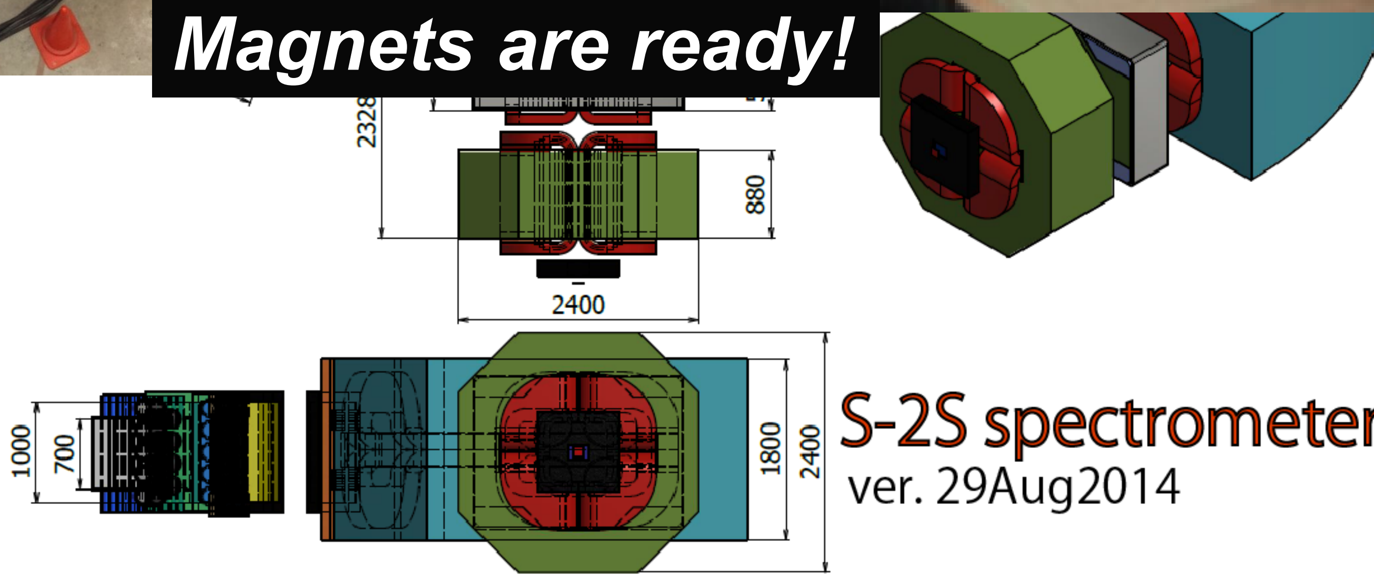
S-2S spectrometer for E05



Magnets are ready!

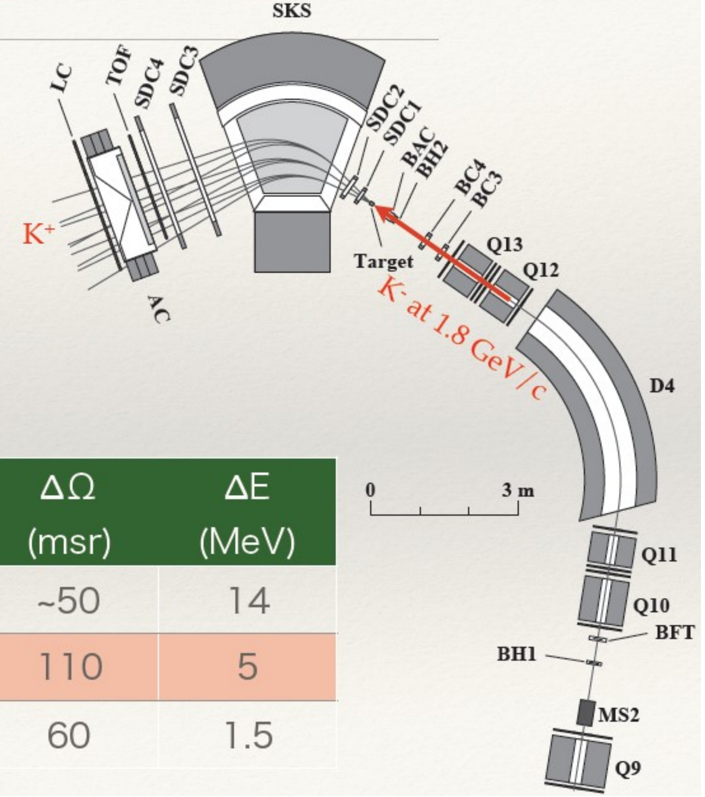
2S(QQD): ~3 years

- ★ Installation in 2016
- ★ Data taking in 2017 with > 50 kW !!

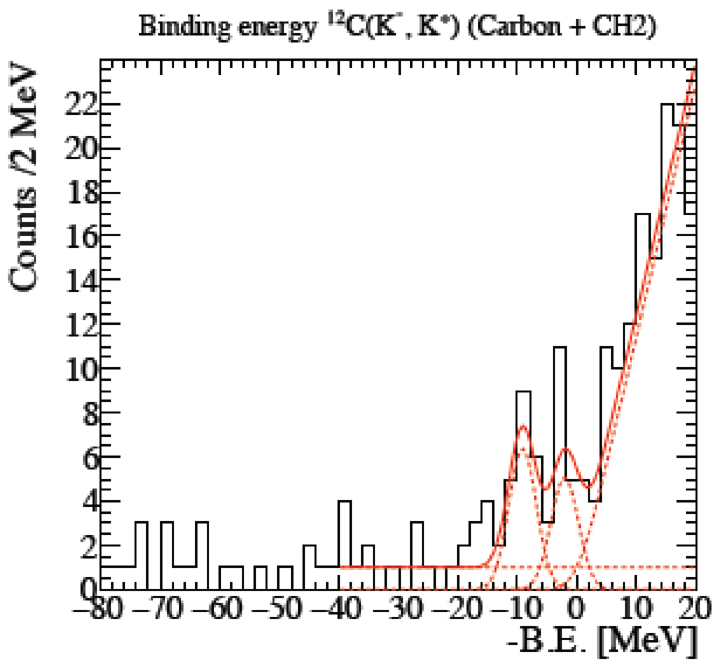


E05 Pilot Run

- K1.8 beam line with SKS' (110 msr)
  - AC + LC for π^+, p veto in trigger
  - $CH_2(K^-,K^+)$ 9.54g/cm^2 → ΔE=5 MeV_{FWHM}
- Two weeks of beam time ; Oct.26 - Nov.19, 2015
  - Detector tuning 1 day
  - $p(K^-,K^+)\Xi^-$@1.5-1.9 GeV/c 2 days
  - $^{12}C(K^-,K^+)$ 9.36g/cm^2 10 days



	ΔΩ (msr)	ΔE (MeV)
BNL	~50	14
SKS'	110	5
S-2S	60	1.5



Two Gaussians
(fixed width=5.4 MeV)

- B_Ξ=9.1 MeV and 2.1 MeV

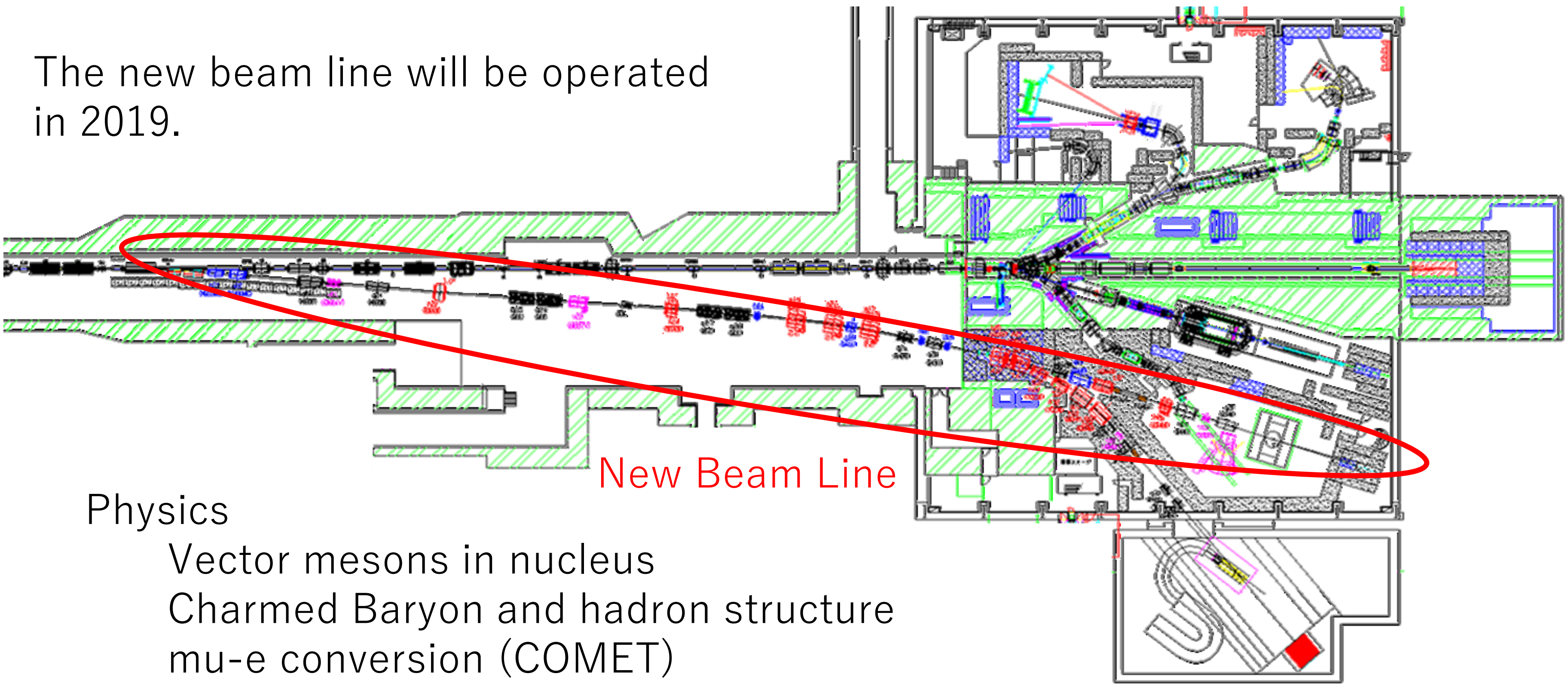
- $Re(U_\Xi)$ > 14 MeV (B_Ξ~4.5 MeV).

New Beam Line @ J-PARC

Construction of New Beam Line is under way.
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
- Heavy Ion Beam (Future Plan)

The new beam line will be operated in 2019.

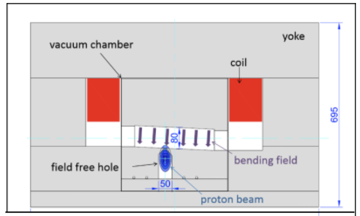


Physics

- Vector mesons in nucleus
- Charmed Baryon and hadron structure
- mu-e conversion (COMET)
- High density baryonic matter (Future)

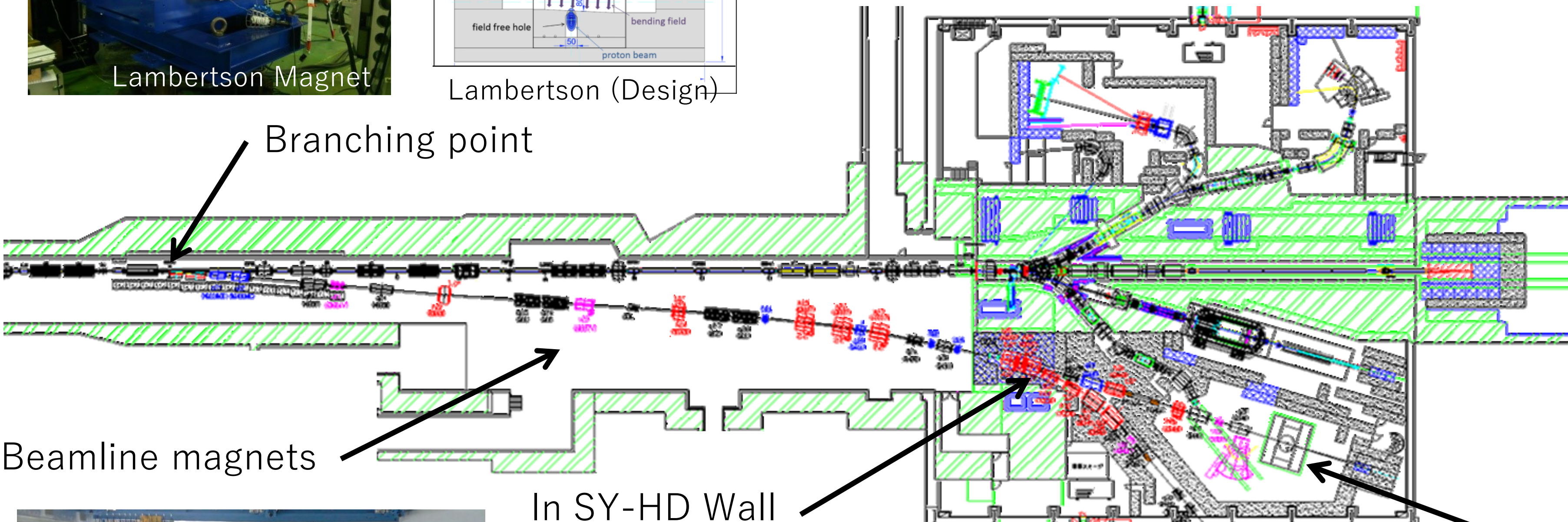
Construction Status of the beam line

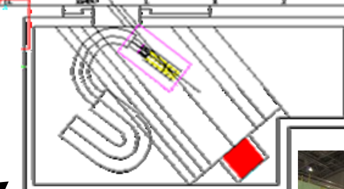
Lambertson Magnet



Lambertson (Design)

Branching point





Beamline magnets

In SY-HD Wall

Spectrometer Magnet

New Line

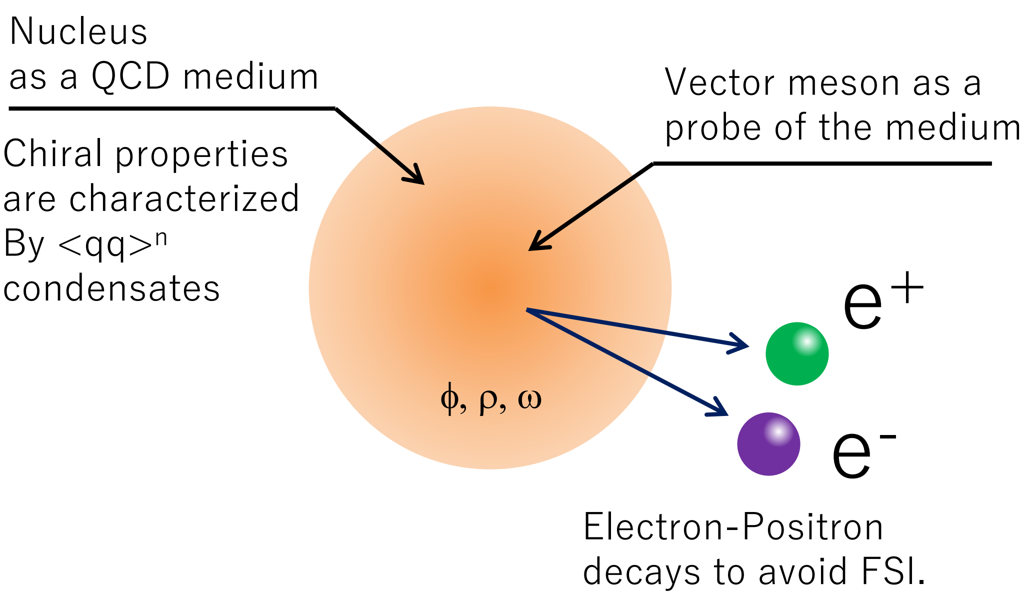
Existing A-Line

COMET & Control room

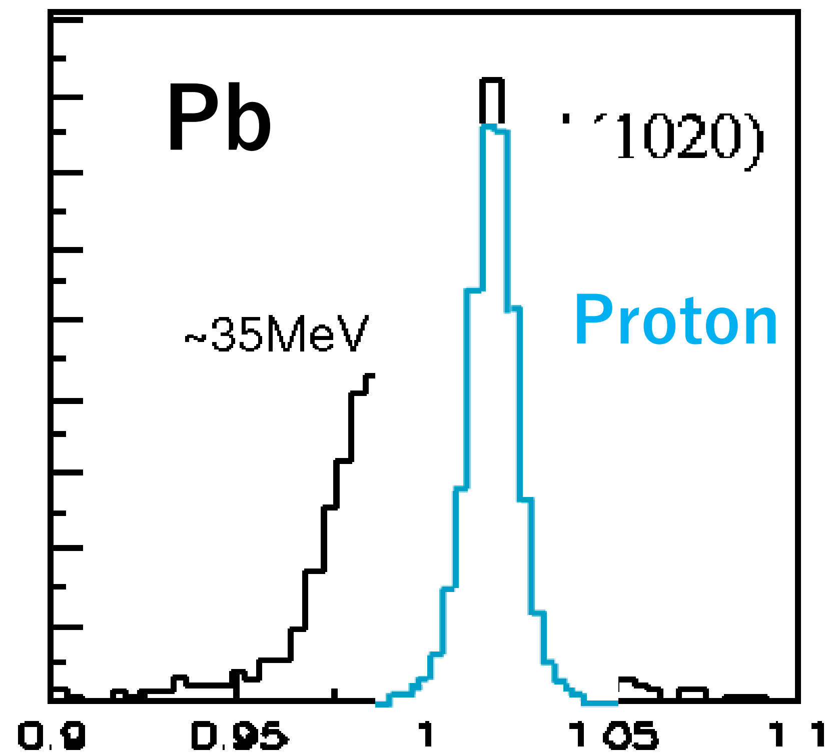
First Experiment (J-PARC E16)

Measurements of invariant mass spectra of electron-positron pairs in ϕ meson mass region to investigate chiral properties of nucleus

Mass spectrum of vector mesons strongly relates with quark condensates in a QCD medium. (Hatsuda and Lee, Phys. Rev. C46 (1992) R34)



Expected Spectrum



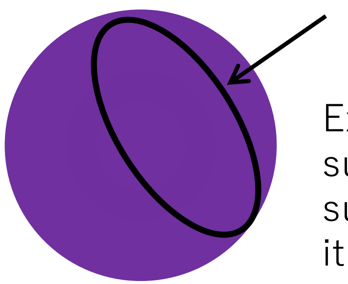
Invariant Mass of e^+e^-

Clear Mass modifications of vector mesons in nucleus will be measured soon

Experiments in (near) future

Di-quark Correlation

Light quark baryon



Di-quark correlation in a baryon are suggested.

Experimental information, such as Regge trajectory, supports di-quark. However, it is difficult to study di-quark in light quark baryons due to other effects.

High Density Matter

Future Heavy Ion beam is under discussions to explore a high density matter

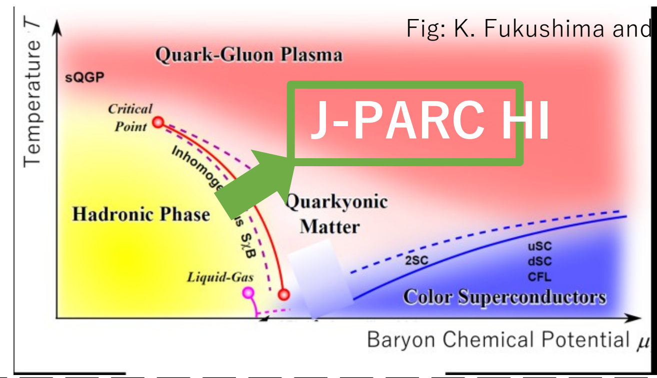
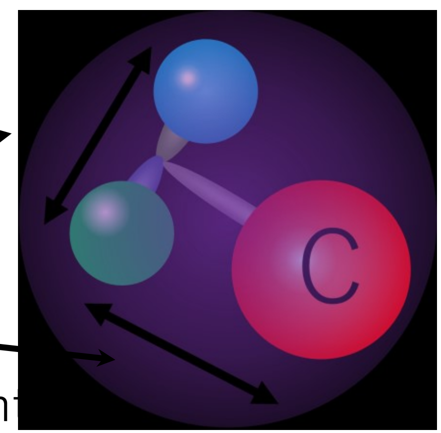


Fig: K. Fukushima and T. Hatsuda

Charmed baryon excited states

Following two excitation will be distinguished.

<u>Di-quark excitation</u>
<u>Charm – qq excitation</u>



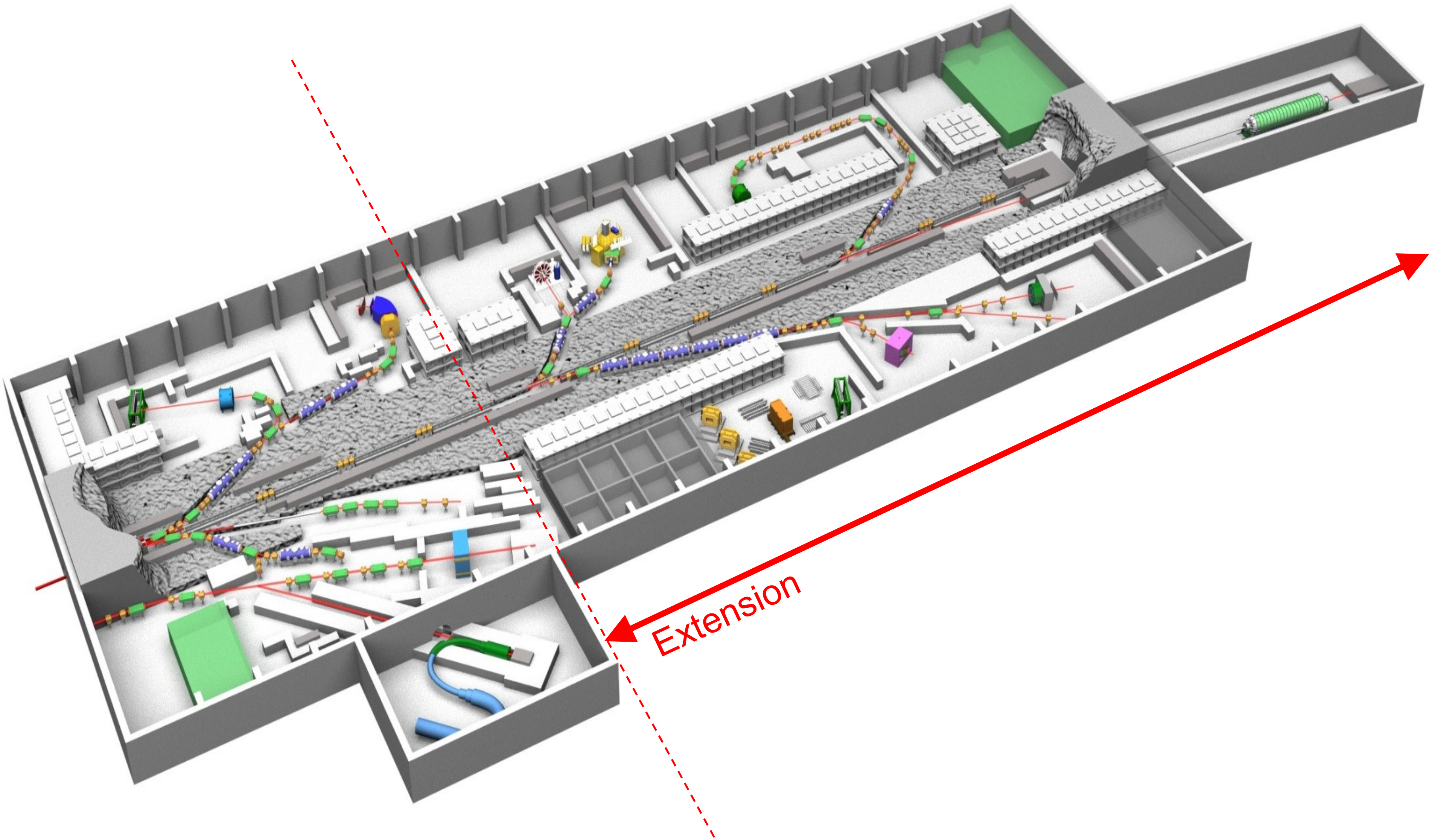
Detailed study of level structure is a key measurement

High momentum and high intensity secondary beam and missing mass spectroscopies are one of the most promising methods

Summary 1

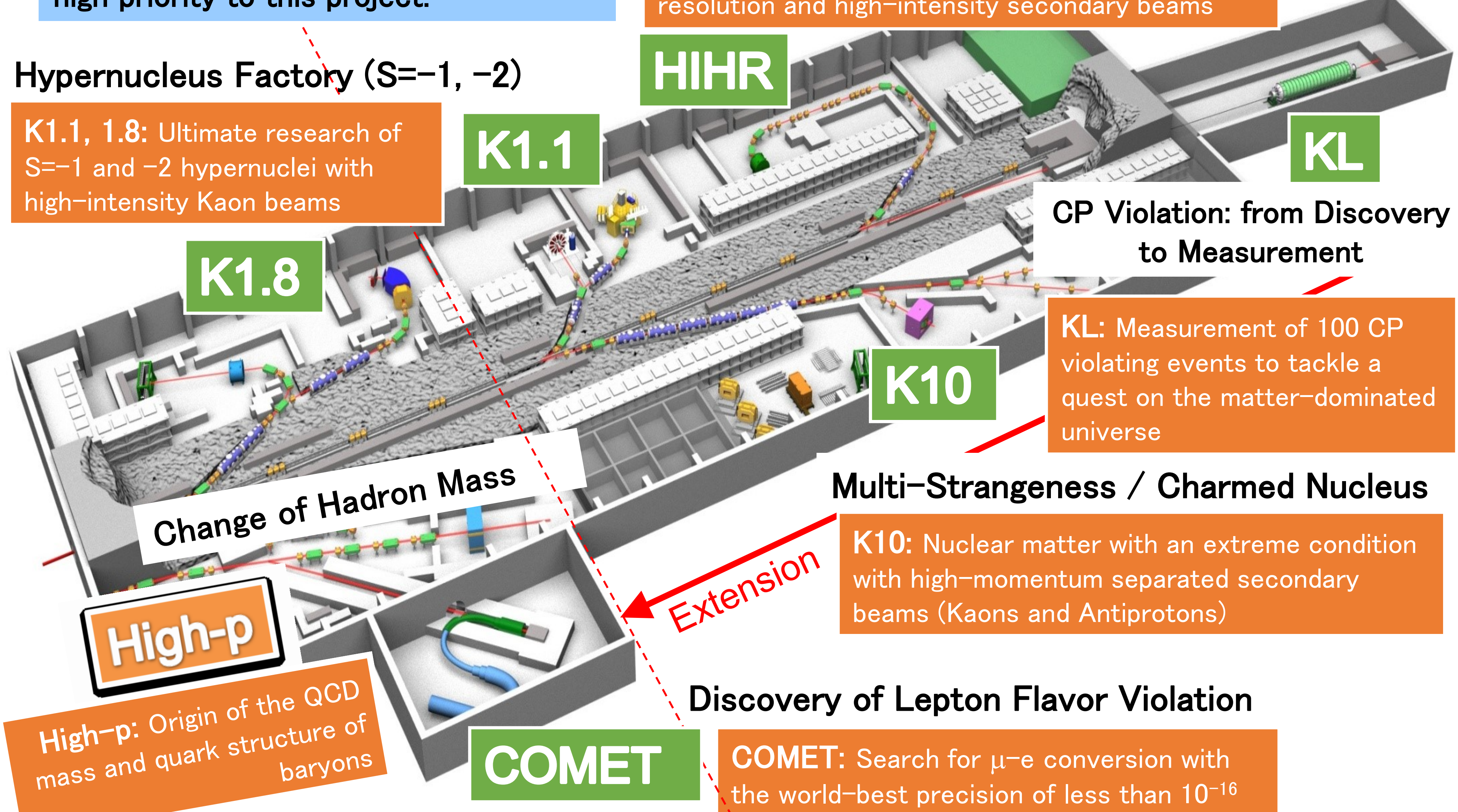
- Physics experiments re-started at the Hadron Experimental Facility (HEF) of J-PARC.
- Beam Intensity is now ~50kW. We are ready to increase beam power up to 80kW.
- Main nuclear physics experiments at HEF are now going to S=-2 hypernuclei!

Next Step: Hadron Hall Extension

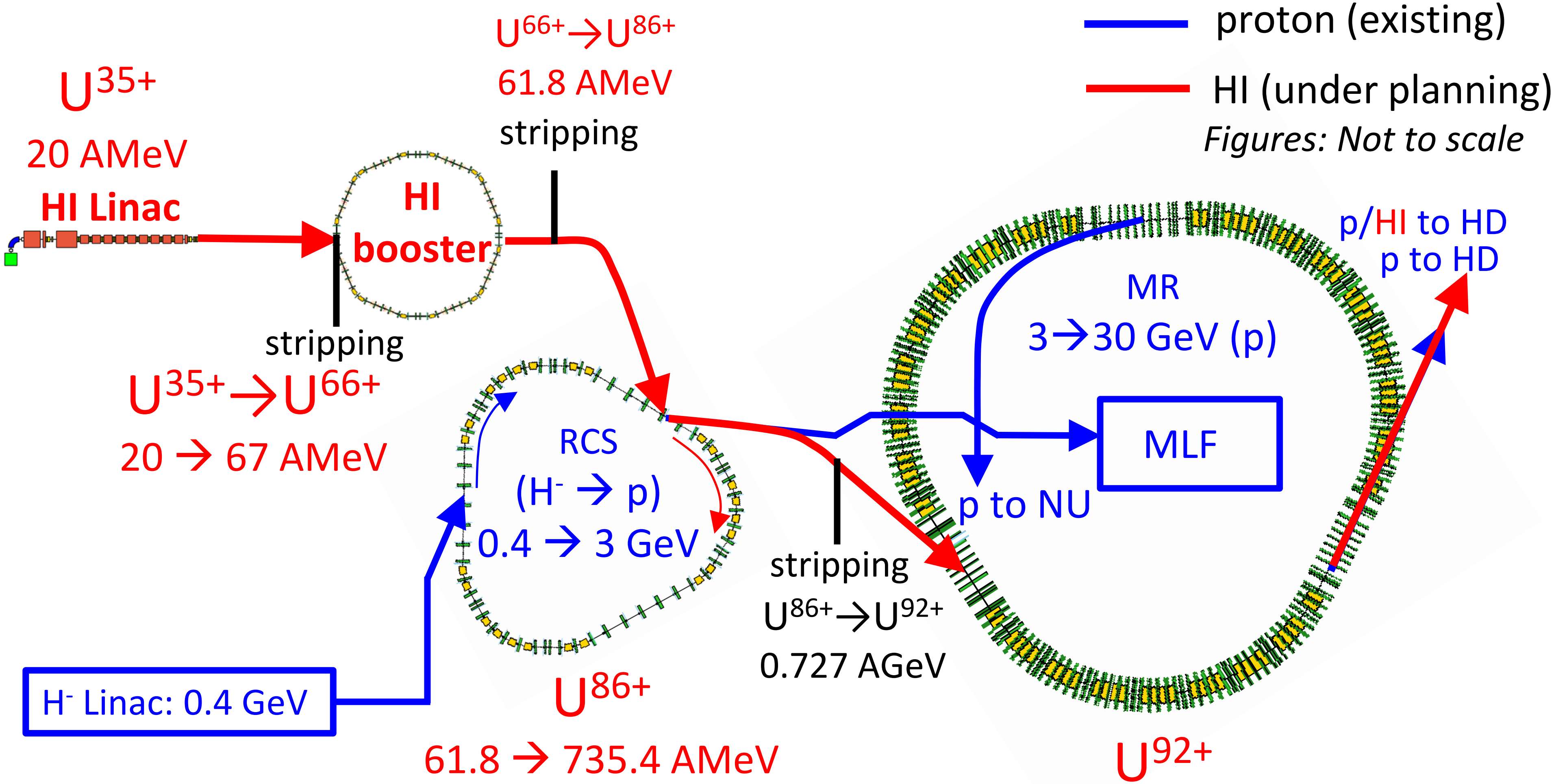


Next Step: Hadron Hall Extension

Both Nuclear Physics community and High Energy Physics community gave high priority to this project.



HI Accelerator scheme in J-PARC (preliminary)



In the RCS, more than 10^{11} U^{86+} ions can be achieved without any significant beam losses.


J-PARC
(JAEA & KEK)
400 MeV H- Linac
HI linac
&
Booster
3 GeV RCS
NU
50 GeV MR
MLF
HD

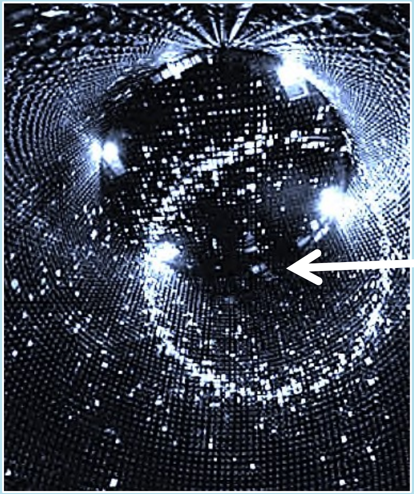
Backup (Neutrino)

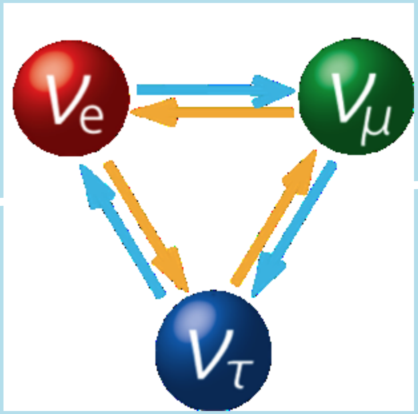
T2K (Tokai-to-Kamioka) Experiment

Purpose of the T2K experiment ;
Generate intense neutrino beam at J-PARC and shoot Super-Kamiokande detector, measure neutrino properties at SK to explore neutrino oscillation parameters, and eventually detect CP violation in the neutrino sector.

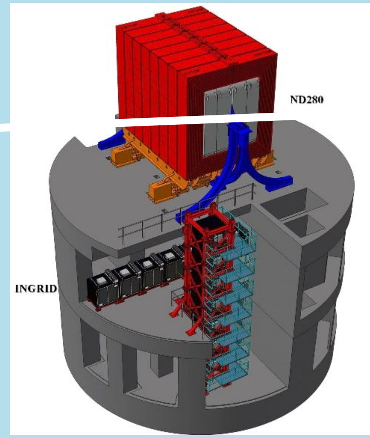
Neutrino changes its species while travelling 295km from J-PARC to SK.

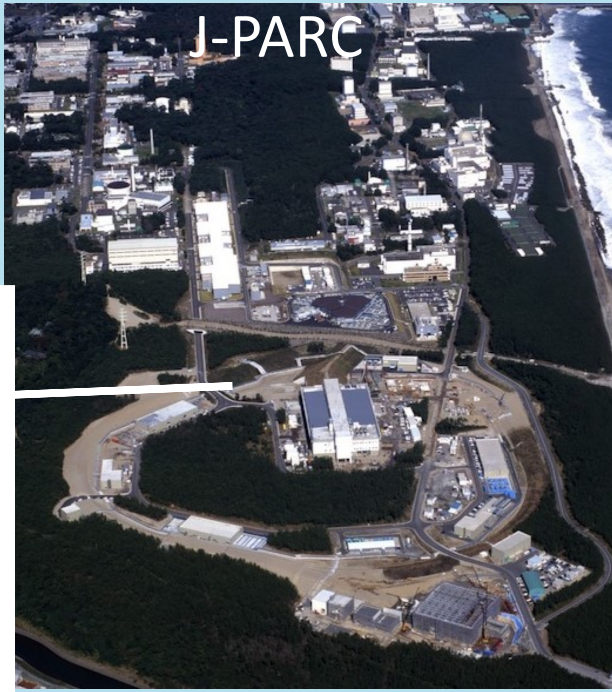
Super-Kamiokande to measure property after 295km-flight

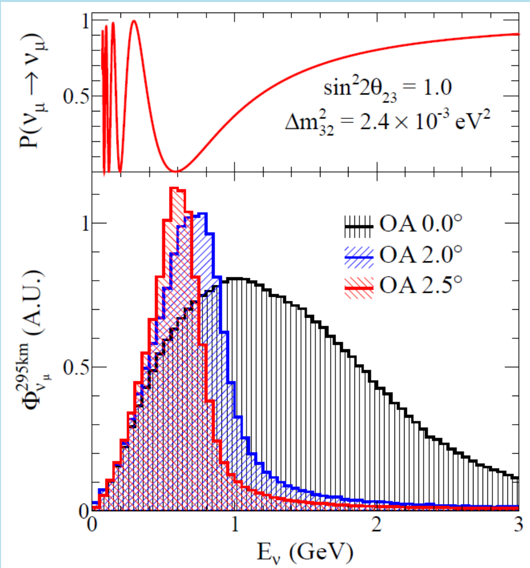


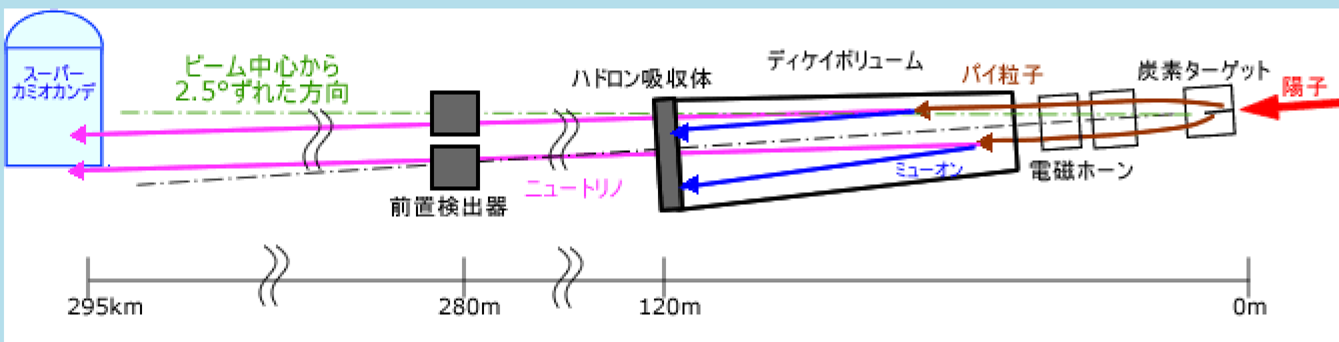


Near Detector to measure property just after production



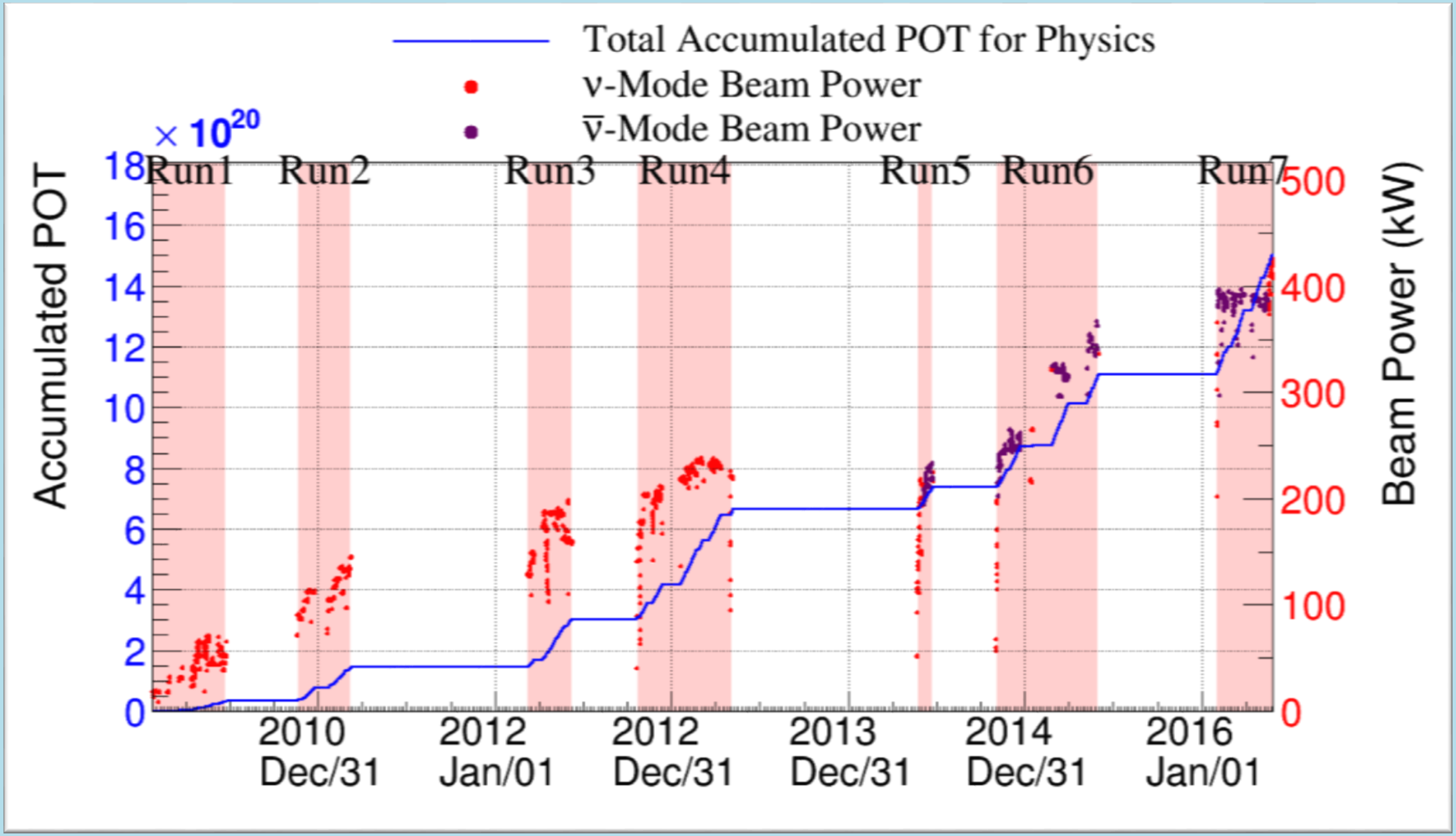






Off-axis configuration generates neutrino beam of quasi-monochromatic energy which peaks at the oscillation-maximum energy of ~0.6GeV.

Beam Power and POT Accumulation

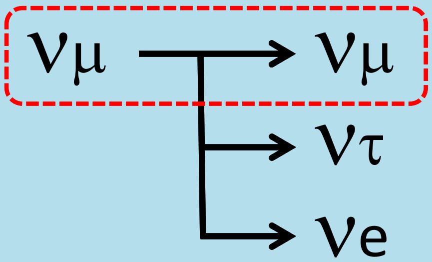


As of 27 May 2016 (before summer shut-down)

- Accumulated POT total = 1.51×10^{21}
- Achieved Beam Power = 425kW

After summer maintenance, beam operartion resumed on 10/26.

ν_μ Disappearance Result

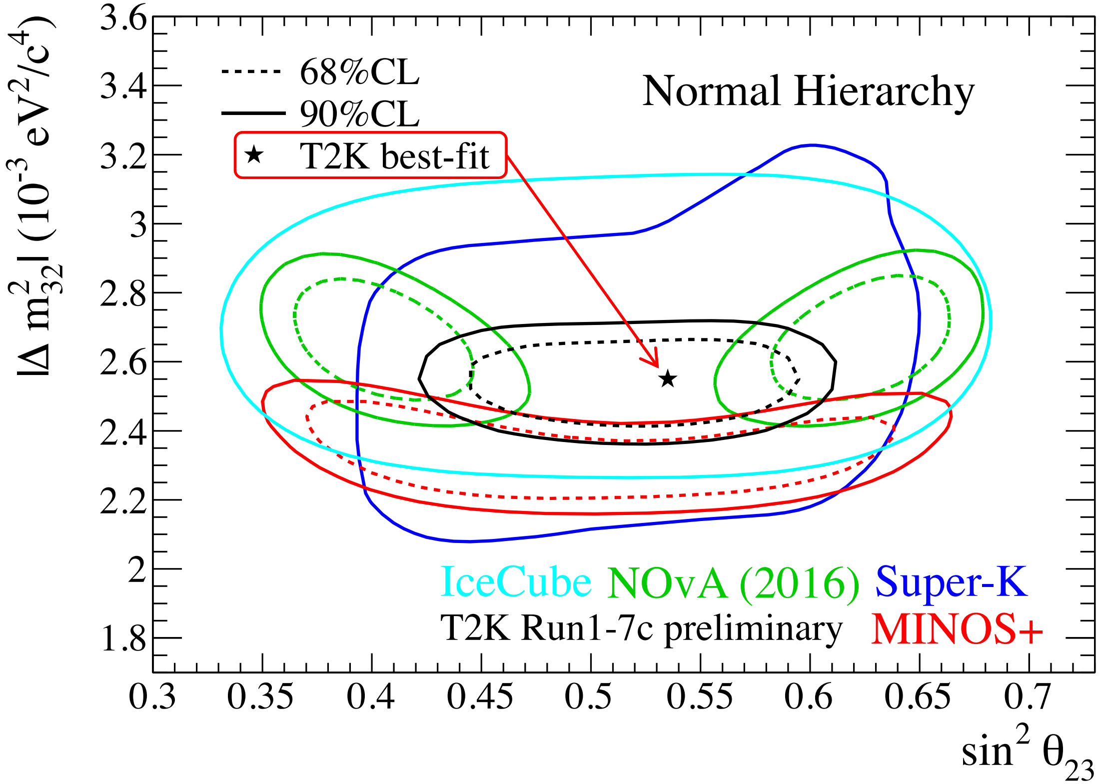


measures decrease of ν_μ flux and gives θ_{23} of the mixing matrix.

$$U_{PMNS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & +c_{23} & +s_{23} \\ 0 & -s_{23} & +c_{23} \end{pmatrix} \begin{pmatrix} +c_{13} & 0 & +s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & +c_{13} \end{pmatrix} \begin{pmatrix} +c_{12} & +s_{12} & 0 \\ -s_{12} & +c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$(c_{ij} = \cos\theta_{ij}, s_{ij} = \sin\theta_{ij})$

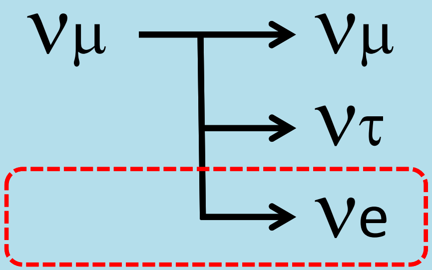
T2K best fit result is consistent to the maximal mixing, while NOvA prefers non-maximal mixing.



Daya Bay:
$|\Delta m^2_{ee}| = (2.45 \pm 0.08) \times 10^{-3} eV^2$
90% CL (NH)

K.Iwamoto @ ICHEP2016

νe Appearance Result and CP constraint



$$U_{PMNS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & +c_{23} & +s_{23} \\ 0 & -s_{23} & +c_{23} \end{pmatrix} \begin{pmatrix} +c_{13} & 0 & +s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & +c_{13} \end{pmatrix} \begin{pmatrix} +c_{12} & +s_{12} & 0 \\ -s_{12} & +c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$(c_{ij} = \cos\theta_{ij}, s_{ij} = \sin\theta_{ij})$$

measures appearance of νe flux and gives θ13 of the mixing matrix.

By θ13 measurement of T2K and constraint with reactor measurements, CP parameter δ is obtained. Non-0 δ is preferred as below.