J-PARC HADRON EXPERIMENTAL FACILITY AND A POSSIBILITY OF HADRON STRUCTURE PHYSICS

August 3, 2016

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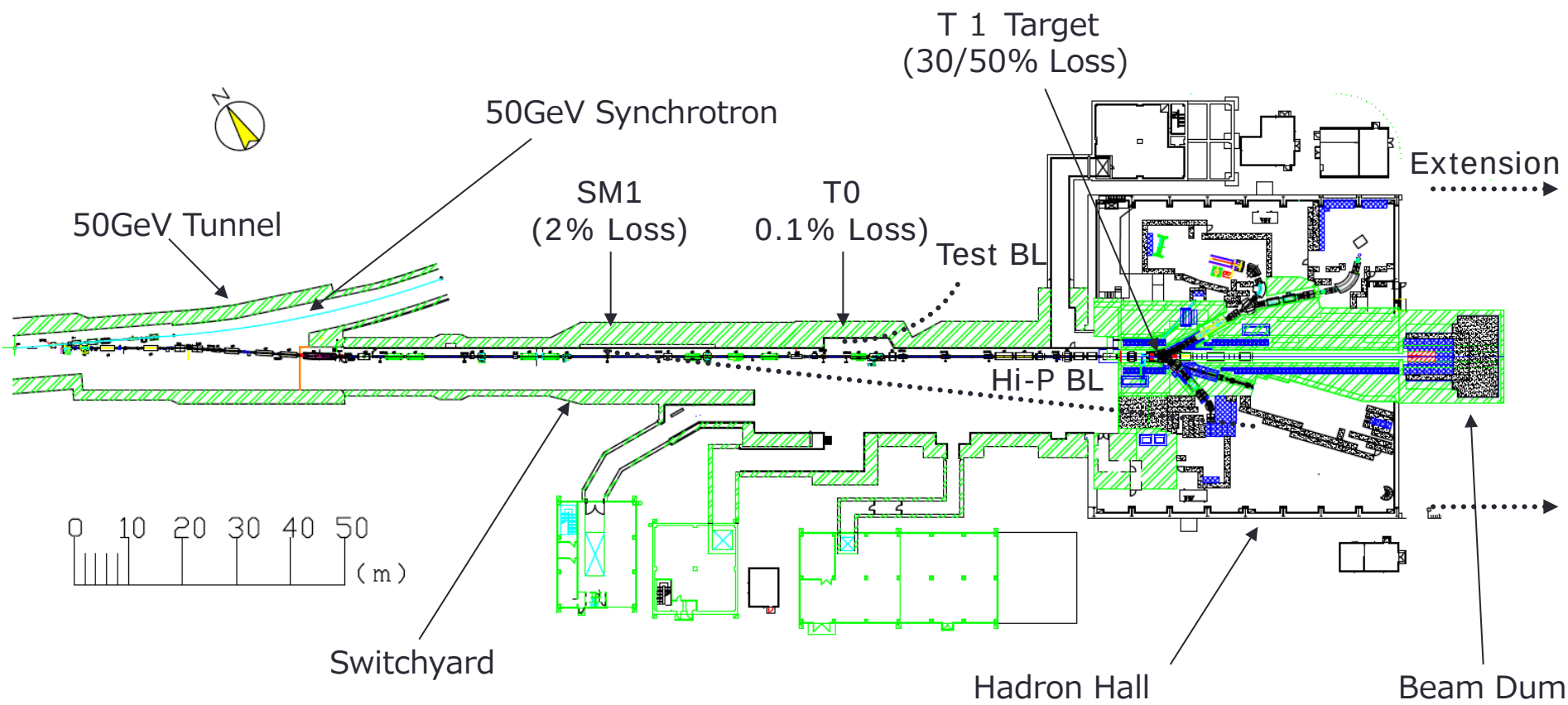
Contents

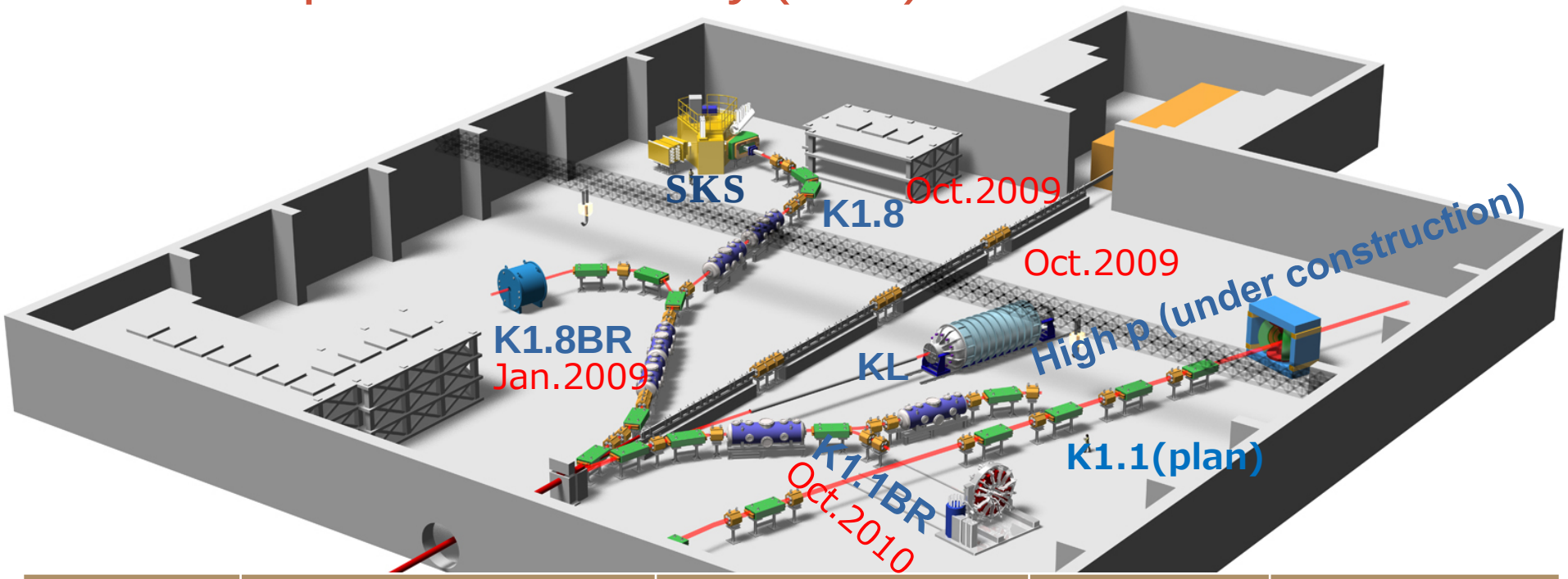
- J-PARC and Hadron Experimental Facility (Hadron Hall)
- Physics overview and fruits so far obtained
- High-momentum beam line
- Extension
- Summary


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
JFY2007 Beams
JFY2008 Beams
JFY2009 Beams
Hadron Exp.
Facility
Bird's eye photo in January of 2016

Hadron Experimental Facility (Current Layout)



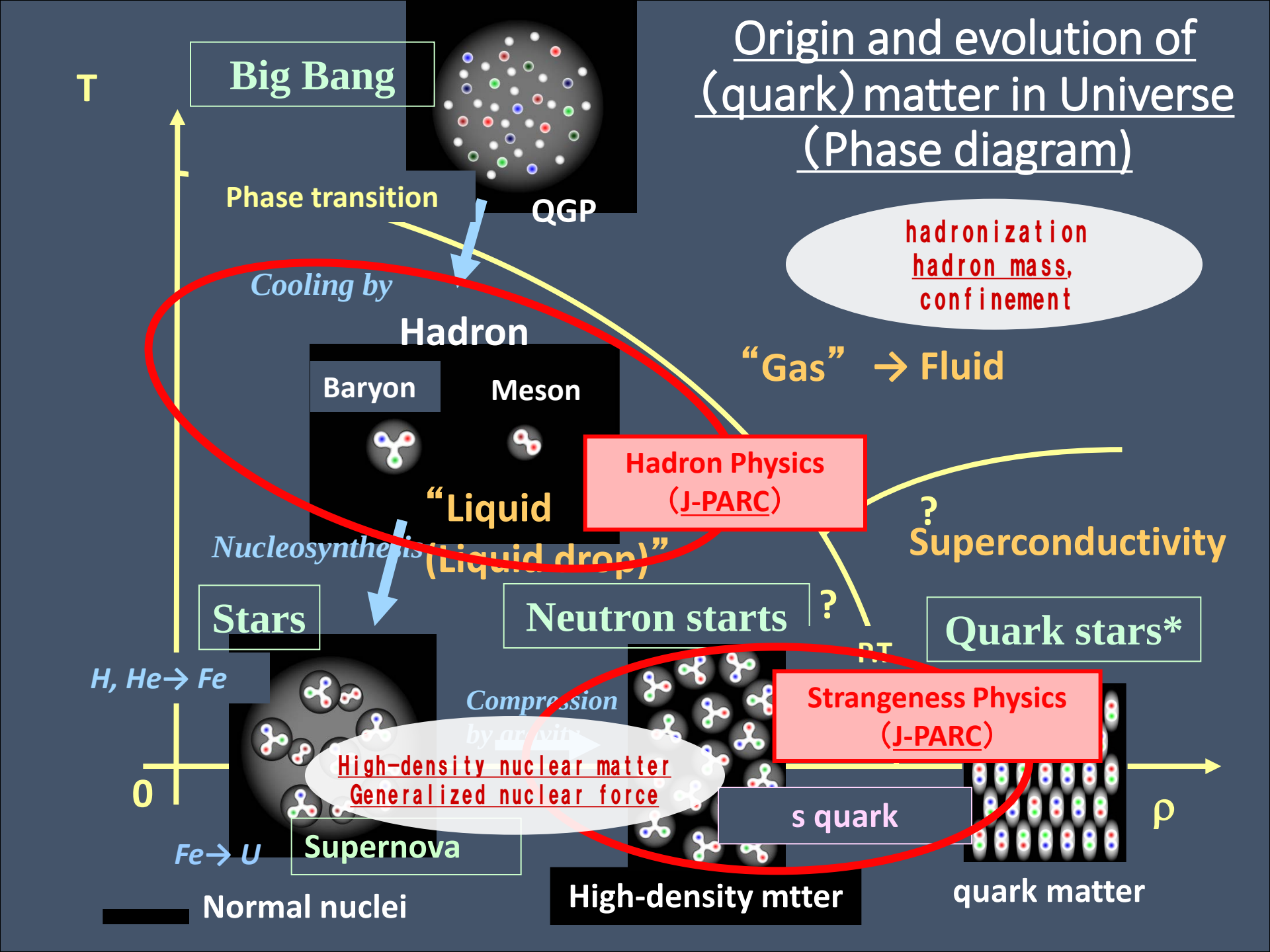
Hadron Experimental Facility (HEF)



Beam Lines	Experiment	Secondary particles	Max. Mom.	Max. Intensity
K1.8	Hypernuclei, Hadron Physics with S	π, K, p (2 separators)	< 2.0 GeV/*c*	~10^5 Hz for K^+
K1.8BR	Hadron Physics with S	π, K, p (1 separator)	< 1.0 GeV/*c*	~10^4 Hz for K^+
K1.1BR	Lepton Flavor violation	π, K, p (1 separator)	< 1.1 GeV/*c*	~10^4 Hz for K^+
KL	Neutral K rare decay	Neural Kaon	~ 2 GeV/*c*	~10^6 Hz

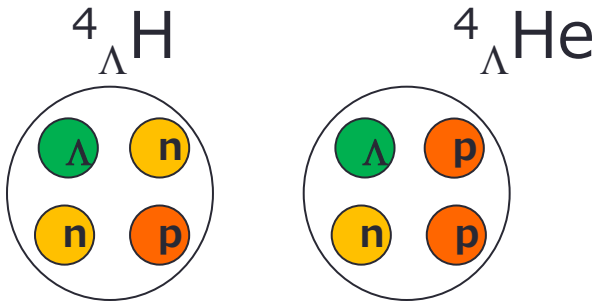
Intense Kaon Beam in the momentum range of ~ 1 GeV/c

Contents


Origin and evolution of (quark) matter in Universe (Phase diagram)
T
Big Bang
QGP
Phase transition
hadronization
hadron mass,
confinement
Cooling by
Hadron
Baryon
Meson
"Liquid
(Liquid drop)"
"Gas" → Fluid
Hadron Physics (J-PARC)
?
Superconductivity
Nucleosynthesis
Stars
Neutron starts
?
Quark stars*
H, He→ Fe
Compression by gravity
High-density nuclear matter
Generalized nuclear force
Strangeness Physics (J-PARC)
s quark
0
ρ
Fe→ U
Supernova
Normal nuclei
High-density mtter
quark matter

Nuclear/Hadron Physics at HEF

- Modern picture of nuclear force based on QCD
  - Hypernuclear spectroscopy → YN/YY int. ⇔ lattice-QCD
    - γ-ray spectroscopy(E13), double-strangeness system(E03/E05/E07/E42)
  - YN scattering (E40)
- Hadrons in vacuum and medium
  - Exotic hadrons (E19)
  - In-medium property of hadrons
    → Chiral Symmetry Breaking (CSB)
    - meson-mass spectroscopy (E16)
  - ΛNN three-body force



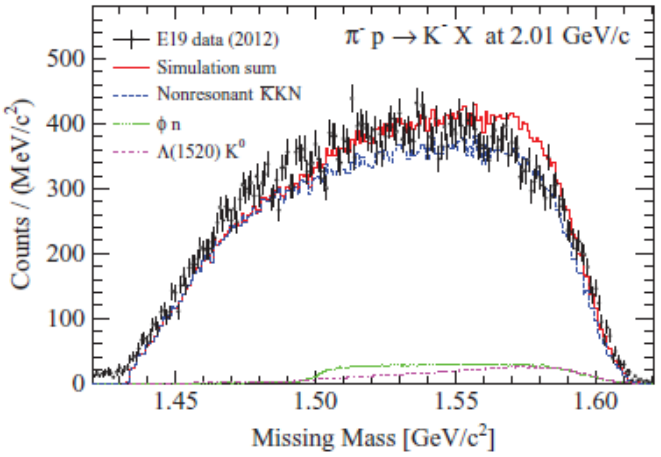
- Phase diagram and Equation Of State (EOS) of quark (hadron) matter
  - low-T high-ρ region — Strangeness physics
    - n-rich Λ-nuclei (E10), multi-strangeness, $K^{bar}N$ interaction (E15/E17/E27/E31)
  - Hadronization phase — Hadron physics
    - exotic hadrons (E19) , charmed baryon spectroscopy (E50)

Blue: performed or on-go
Red: plan

Results (1)

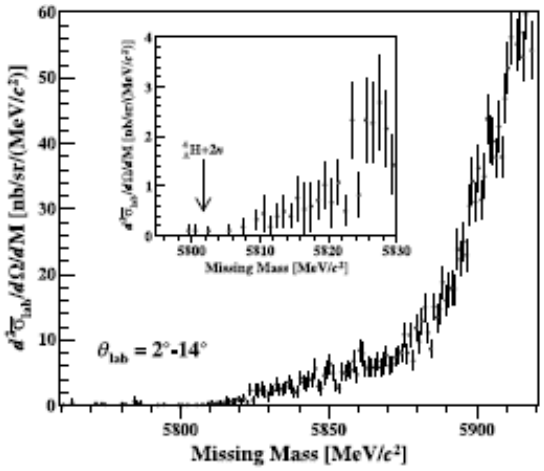
- E19:Search for Θ^+ by π^-+p→K^-X — 2010, Jan.2012
  - No peak was observed
  - U.L. of cross section : 0.28μb/sr
  - U.L. of Θ^+ width: 0.36 (1.9) MeV for ½ $^+$ (½$^-$)

PRL **109**, 132002(2012)
PRC **90**, 035205(2014)



- E10:Neutron-rich $^6_\Lambda$H via the ^{6}Li(π^-,K^+) — Dec.2012-Jan.201
  - No peak was observed
  - U.L. of cross section :1.2nb/sr
  - ⇔ Observation of 3 candidates by FINUDA (PRL **108**,04251(2012))

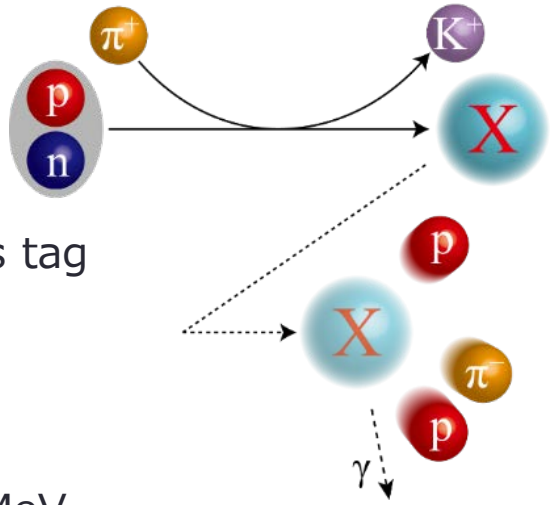
PLB **729**, 39 (2014)



Results (2)

- E27: Search for K^-pp bound states by the $d(\pi^+,K^+)$ at P_π=1.7GeV/c

Experimental Method



Jun. 2012

Missing mass spectrum is obtained with two protons tag

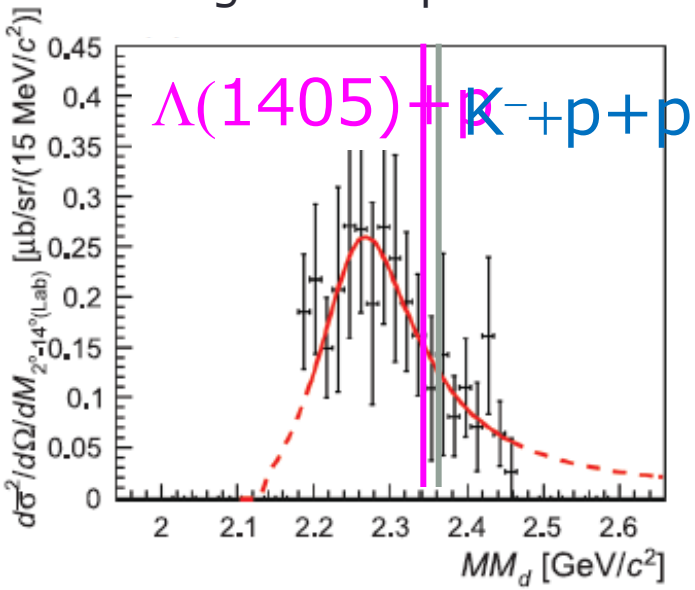
Observation of "K^-pp"-like structure

PTEP **2015**, 021D01 (2015)

Binding Energy $95^{+18}_{-17}(\text{stat.})^{+30}_{-21}(\text{syst.})$ MeV

Width $162^{+87}_{-45}(\text{stat.})^{+66}_{-78}(\text{syst.})$ MeV

Missing mass spectrum



A positive signature of K^-pp bound state was obtained. Comparison with other experiments and theoretical studies are necessary and important to establish K^-pp bound state.

Analysis of inclusive spectrum was also published.

PTEP **2014**, 101D03(2014)

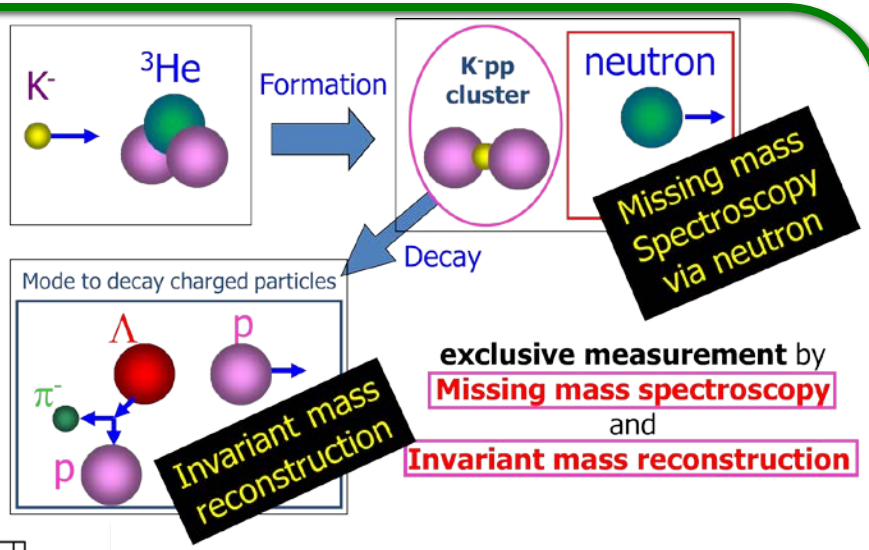
- ΣN-ΛN cusp
- Shift of Y* bump

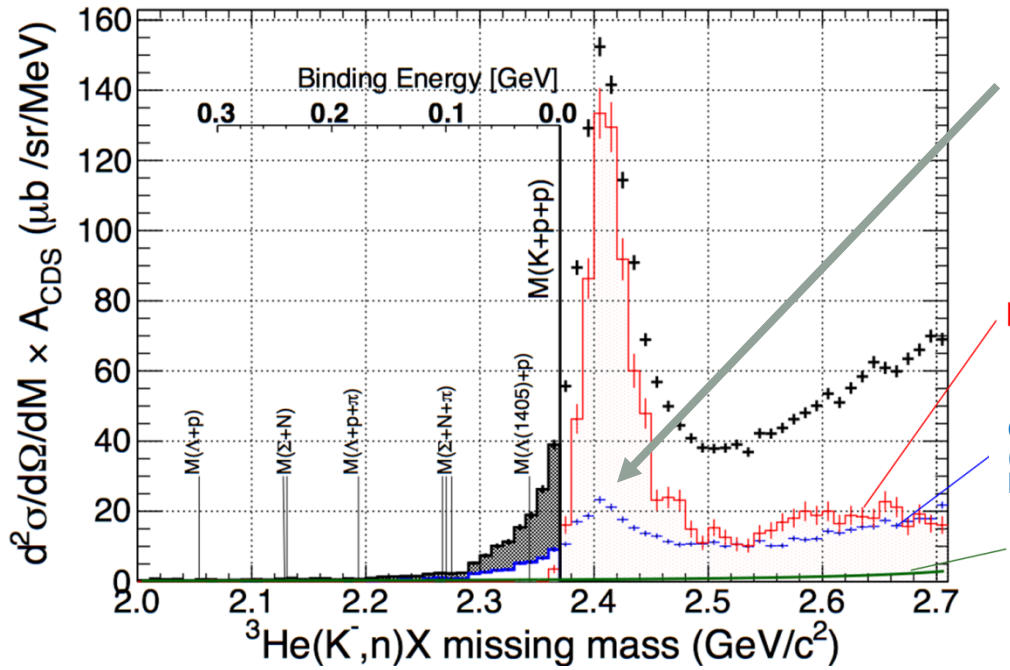
Results (3)

- E15: Search for K^-pp bound states by the $^3He(K^-,n)X \rightarrow \Lambda p$

1st- stage RUN with 1% of the proposal

arXiv:1408.5637 [nucl-ex] May 2013





Significant enhancements were observed in a bound-region

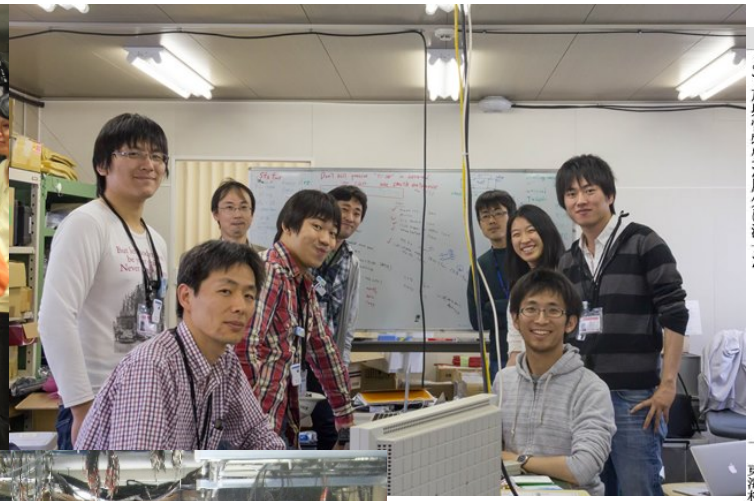
"semi"-inclusive
~10MeV/c^2 resolution

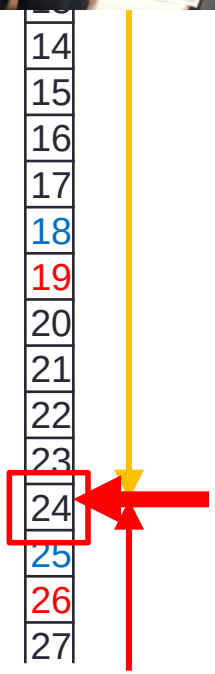
K^0_s-tagged x 8

Contribution of $\Sigma \rightarrow n\pi$
(No other contribution in a bound-region due to kinematical limitations)

Accidental

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。

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。

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（60）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）

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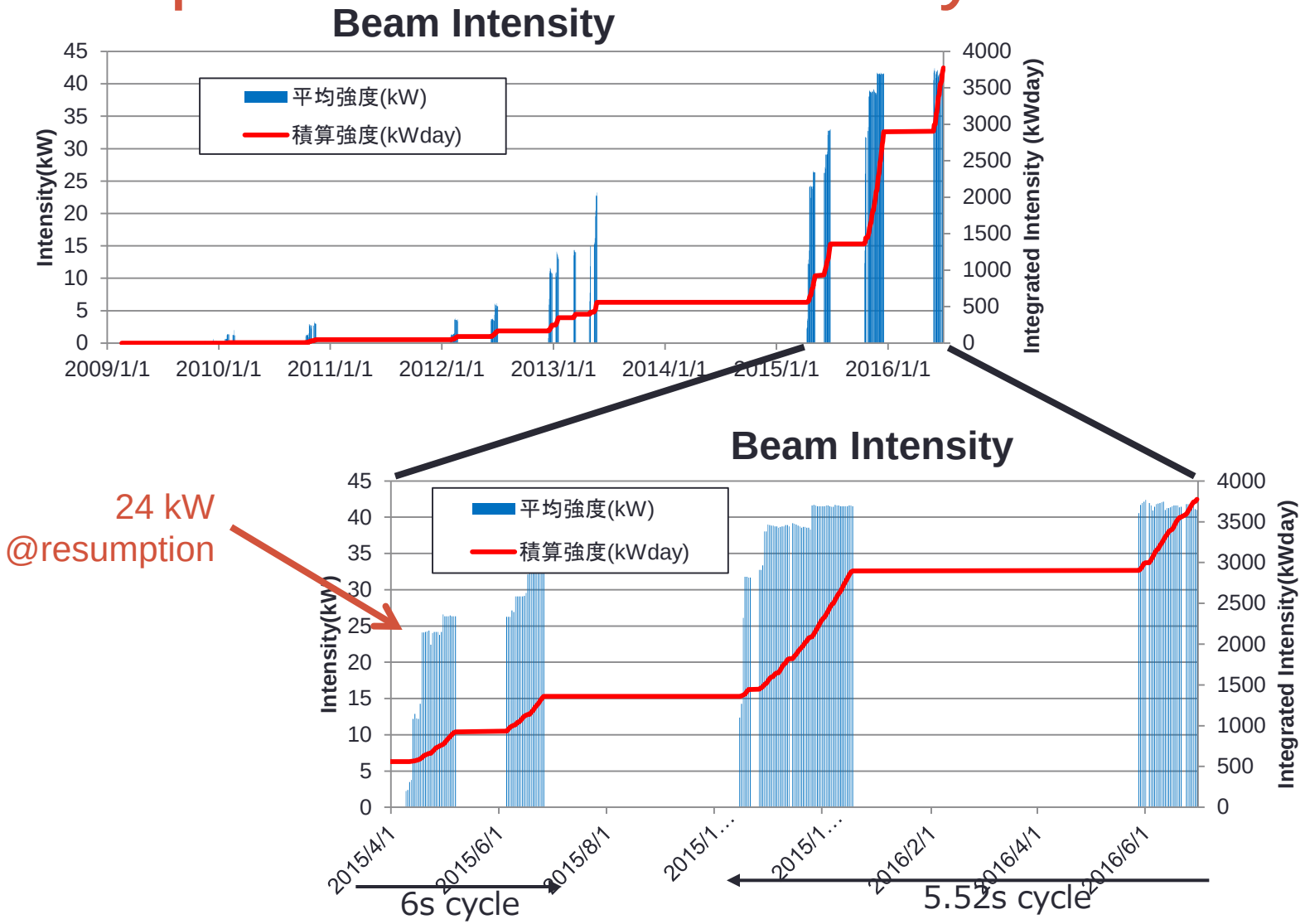
Development of Beam Intensity



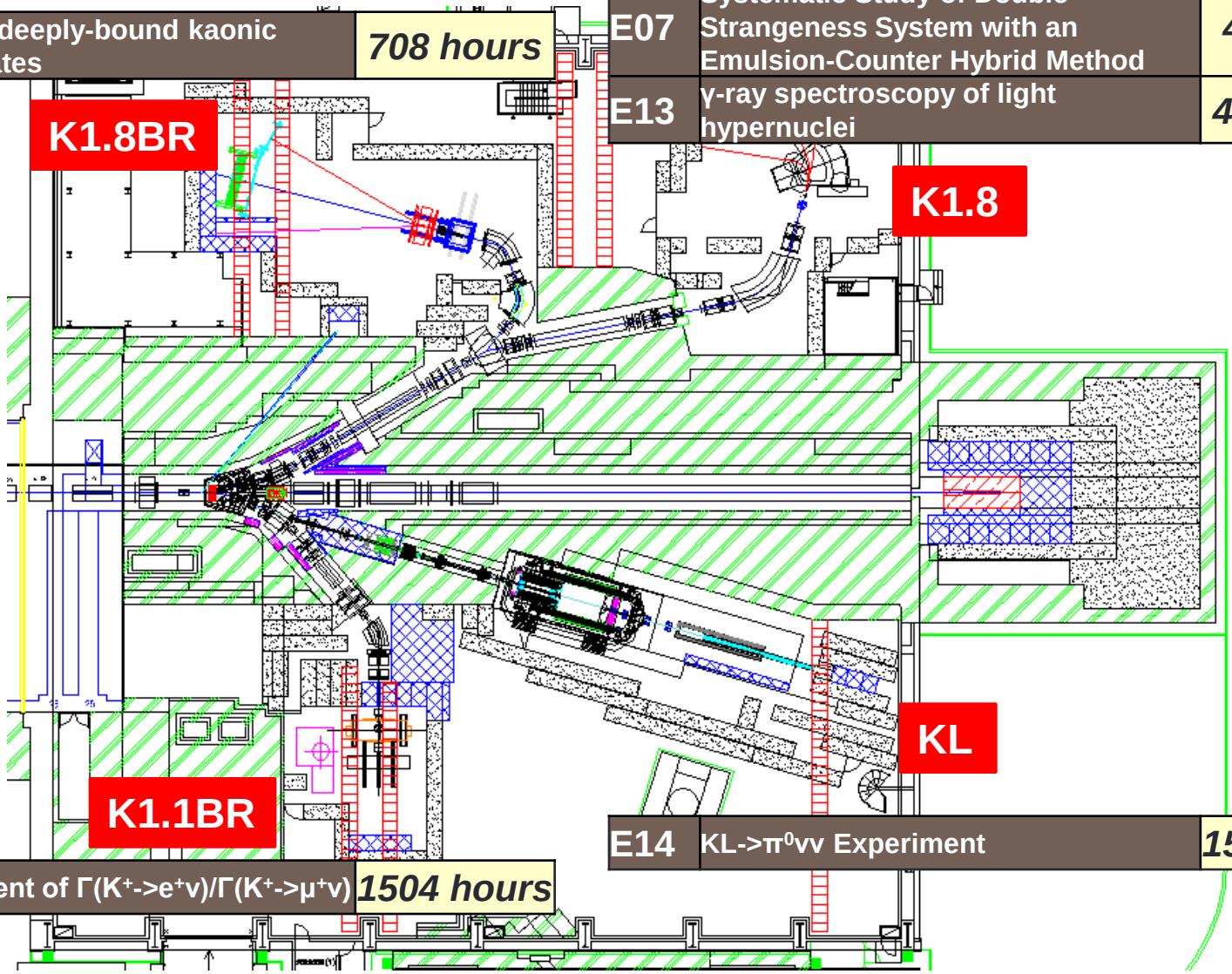
Accumulated beam time and intensity for HD

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

Beam time used by experiments in 2015

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*

E15	search for deeply-bound kaonic nuclear states	*708 hours*



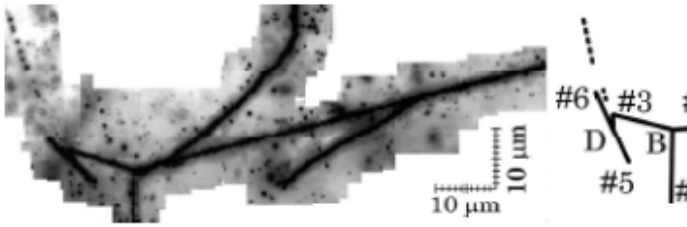
E14	KL->π⁰νν Experiment	*1509 hours*

E36	Measurement of Γ(K⁺->e⁺ν)/Γ(K⁺->μ⁺ν)	*1504 hours*

JFY2016
~50kW

E57/E62: K-atom

E31: Hyperon Resonance



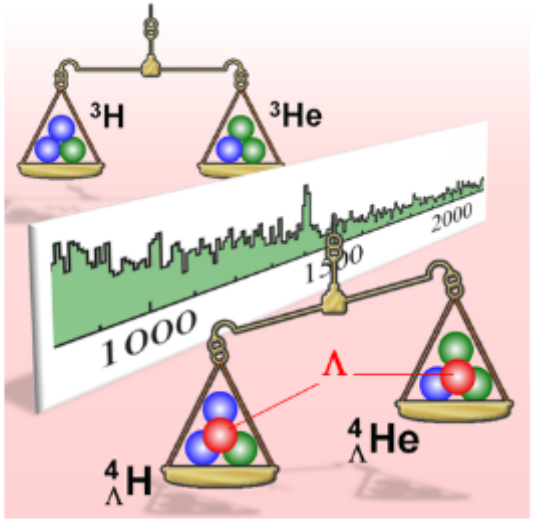
E07 Ξ-hypernuclei with Emulsion

E03

E14 KOTO

Hi-p/COMET
construction

PHYSICAL REVIEW LETTERS
moving physics forward



EDITORS' SUGGESTION

Observation of Spin-Dependent Charge Symmetry Breaking in ΛN Interaction: Gamma-Ray Spectroscopy of $^4_\Lambda$He

The energy spacing of the spin-doublet states in the $^4_\Lambda$He hypernucleus indicate a large spin dependent charge symmetry breaking in the ΛN interaction.

T. O. Yamamoto *et al.* (J-PARC E13 Collaboration)

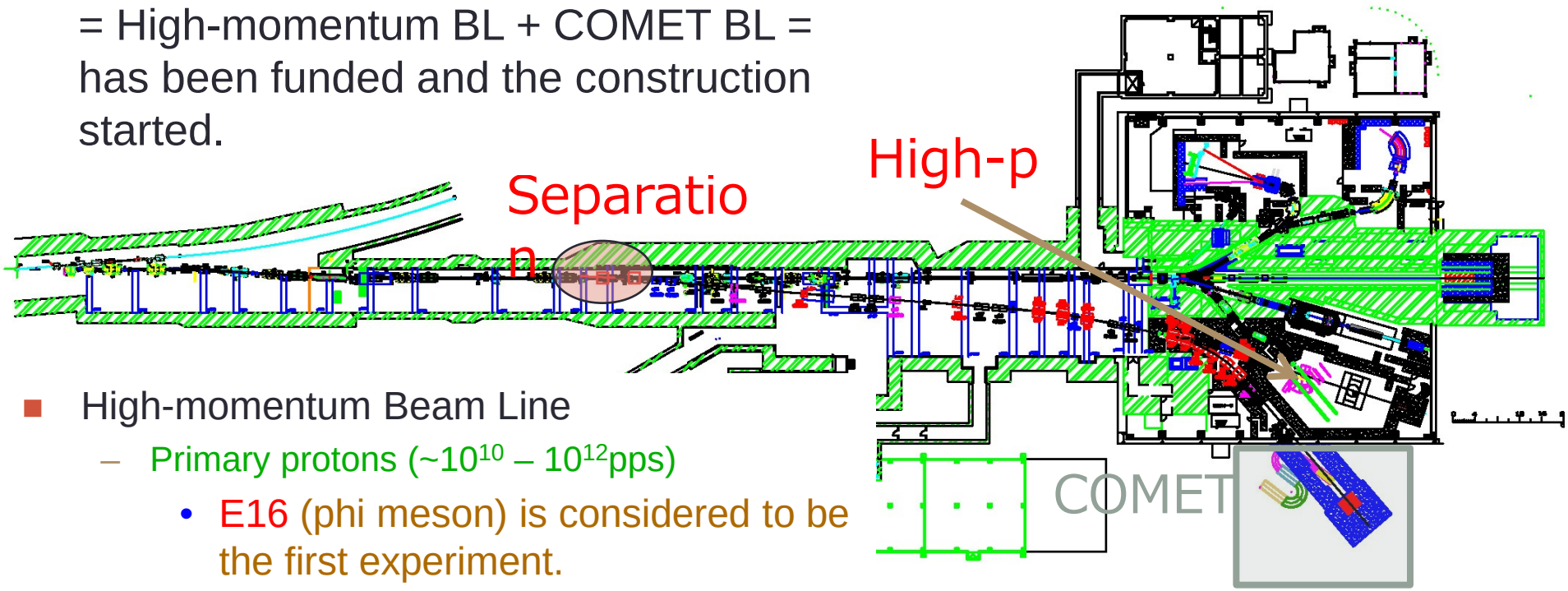
Phys. Rev. Lett. **115**, 222501 (2015)

Press-released from Tohoku U., KEK, JAEA, J-PARC

Contents

New Primary Proton Beam Line

- New primary Proton Beam Line
  = High-momentum BL + COMET BL =
  has been funded and the construction started.

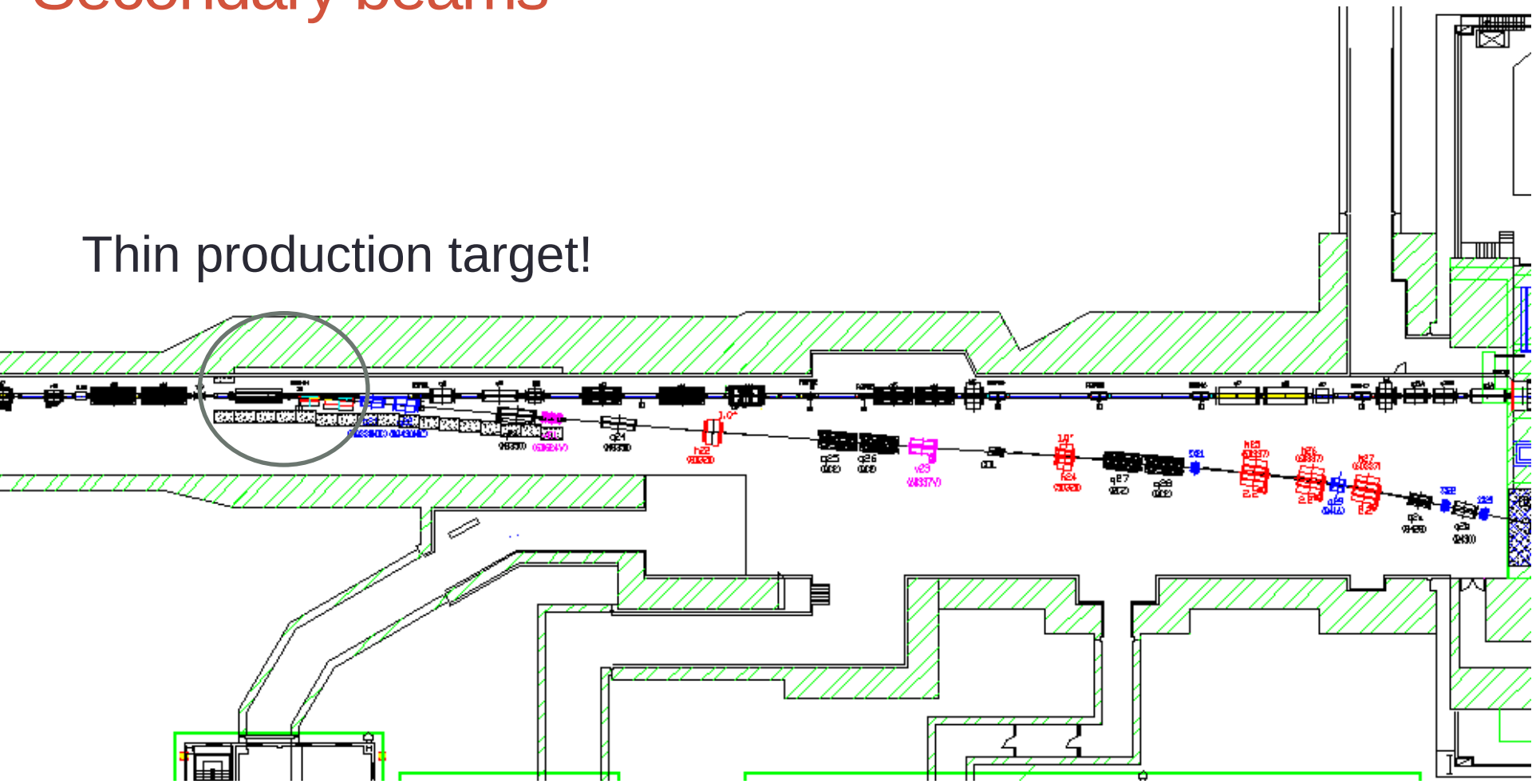


- High-momentum Beam Line
  - Primary protons (~10^{10} – 10^{12}pps)
    - E16 (phi meson) is considered to be the first experiment.
  - Unseparated secondary particles (pi, …)
    - High-resolution secondary beam by adding several quadrupole and sextupole magnets.

- COMET
  - Search for μ to e conversion
  - 8 GeV, 50 kW protons
  - Branch from the high-momentum BL
  - Annex building is being built at the south side.

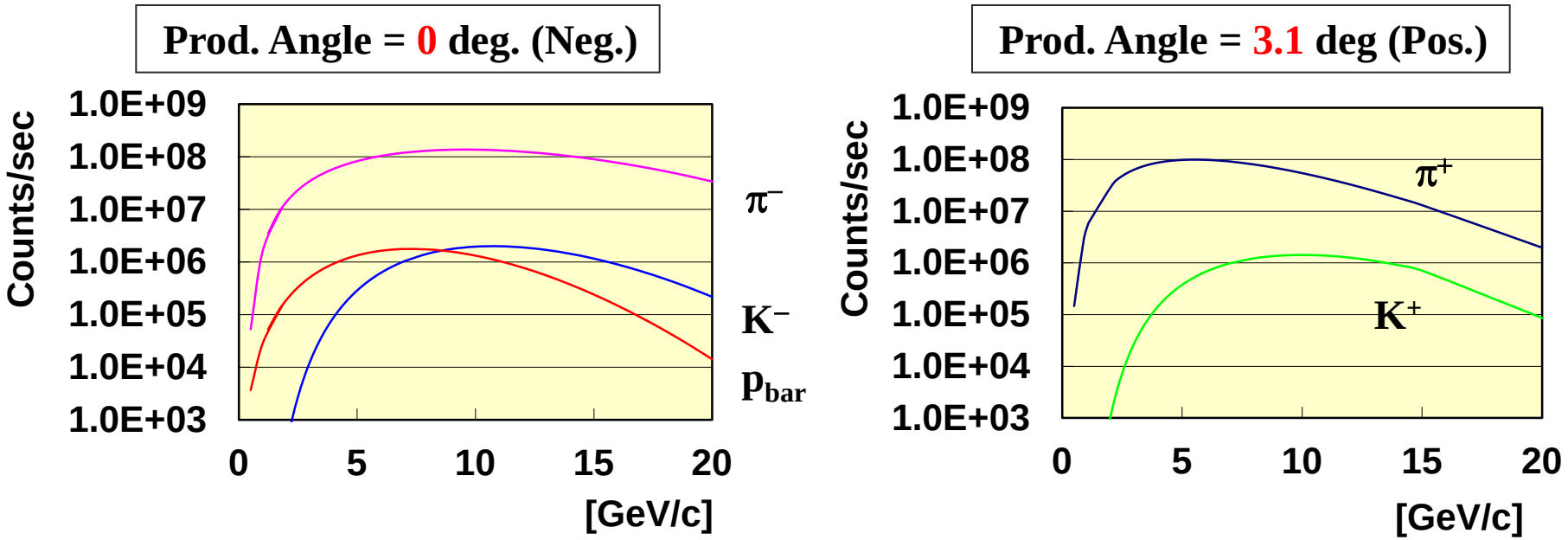
Secondary beams

Thin production target!



Unseparated Secondary Beam

Noumi

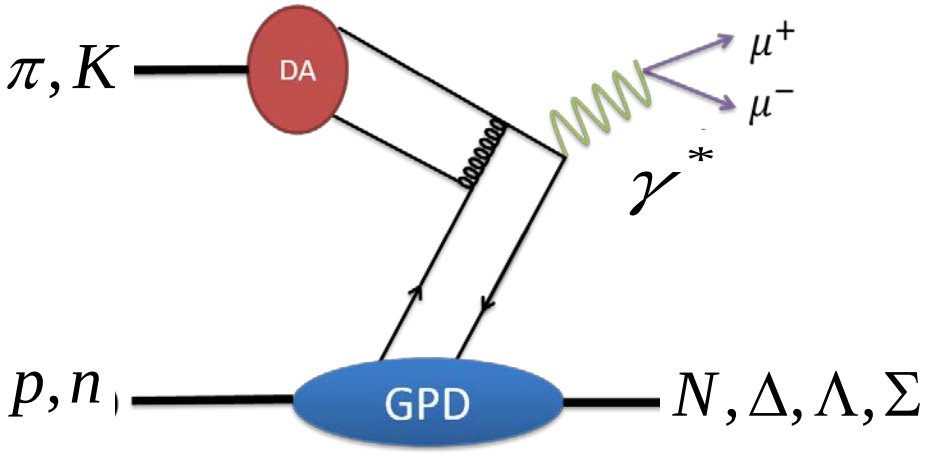


* Sanford-Wang:15 kW Loss on Pt, Acceptance :1.5 msr%, 133.2 m

“GPD” and “Transition GPD”

- $\pi^- \mathrm{p} \rightarrow \gamma^* n$
- $\pi^- \mathrm{p} \rightarrow \gamma^* \Delta^0$
- $\pi^- \mathrm{n} \rightarrow \gamma^* \Delta^-$
- $\pi^+ \mathrm{n} \rightarrow \gamma^* \mathrm{p}$
- $\pi^+ \mathrm{p} \rightarrow \gamma^* \Delta^{++}$
- $\pi^+ \mathrm{n} \rightarrow \gamma^* \Delta^+$

- $K^- \mathrm{p} \rightarrow \gamma^* \Lambda$
- $K^- \mathrm{p} \rightarrow \gamma^* \Lambda(1405)$
- $K^- \mathrm{p} \rightarrow \gamma^* \Lambda(1520)$
- $K^- \mathrm{n} \rightarrow \gamma^* \Sigma^-$



GPD with pion beams at J-PARC

PHYSICAL REVIEW D 93, 114034 (2016)

Accessing proton generalized parton distributions and pion distribution amplitudes with the exclusive pion-induced Drell-Yan process at J-PARC

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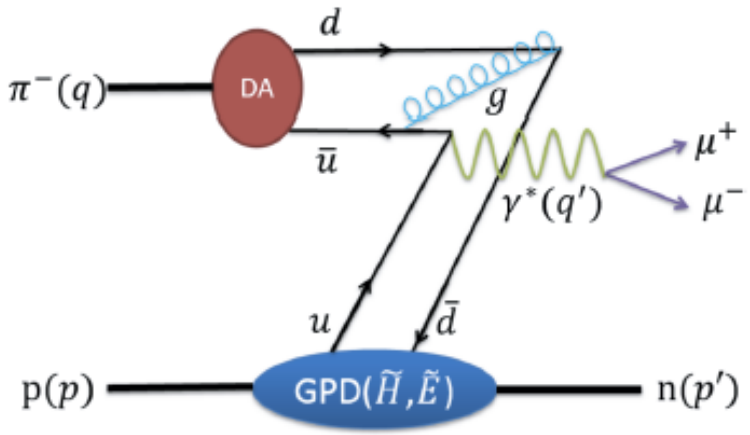
(Received 15 May 2016; published 29 June 2016)



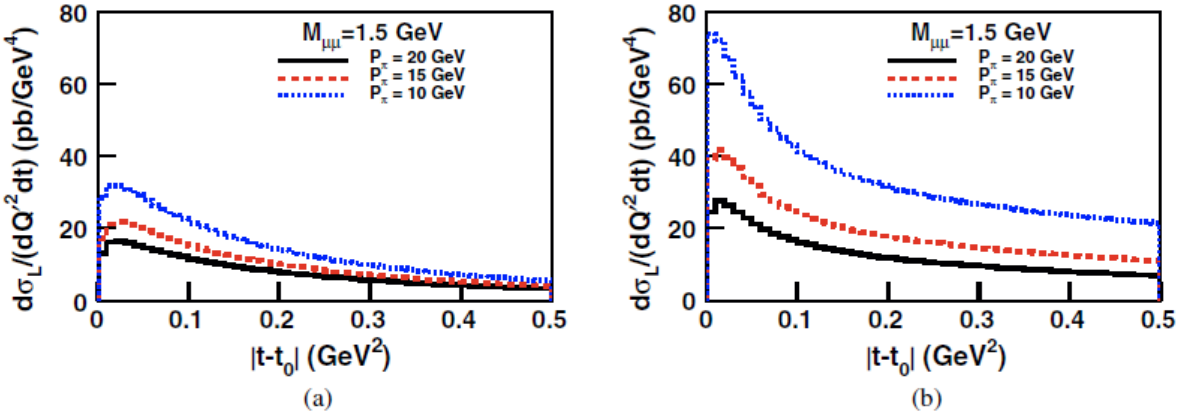
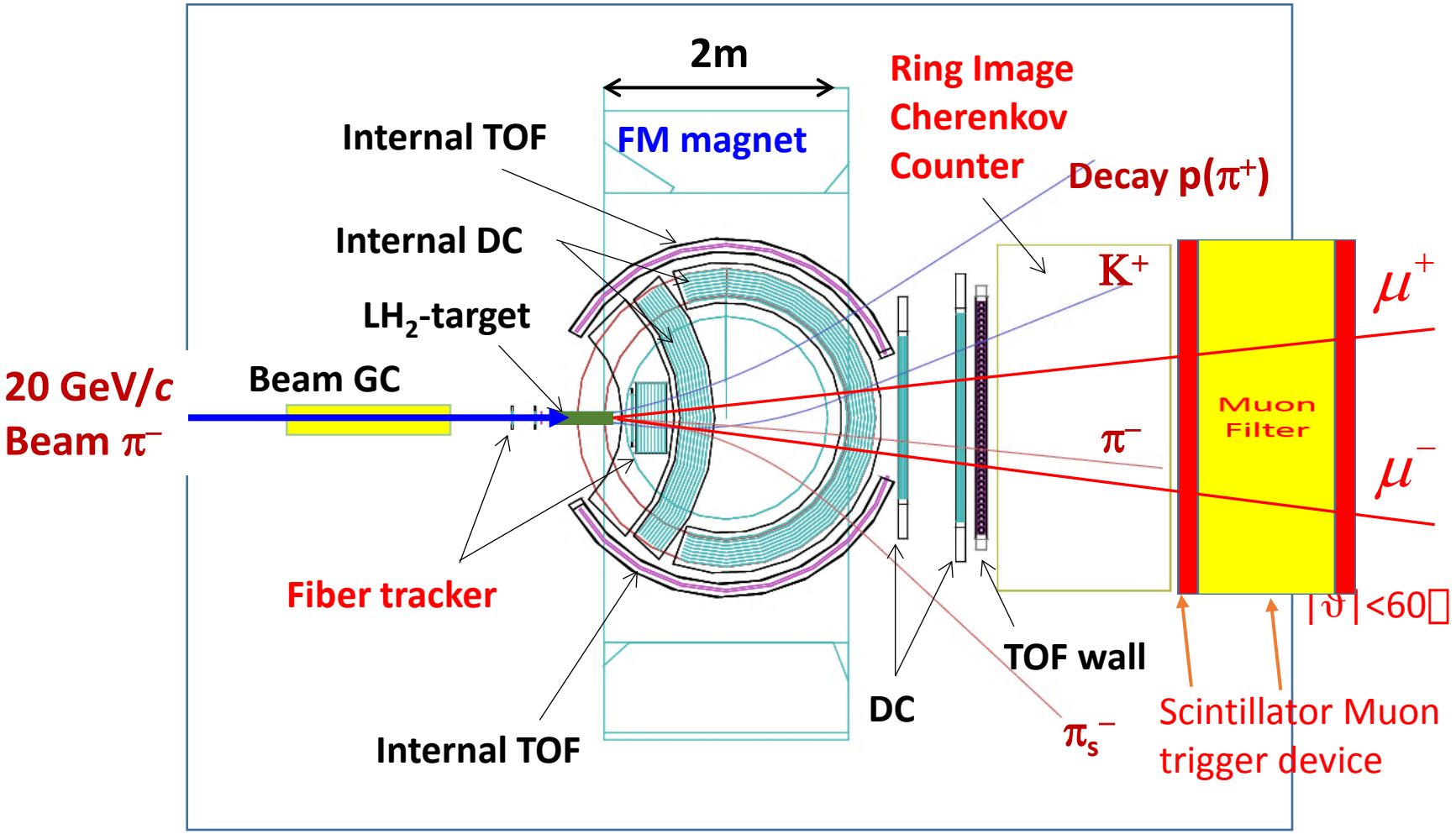


FIG. 10. Differential cross sections of exclusive Drell-Yan events, Eq. (20), as a function of $|t - t_0|$ at $M_{\mu^+\mu^-} = 1.5$ GeV for $P_\pi = 10$, 15, and 20 GeV with the input GPDs: (a) BMP2001 and (b) GK2013.

J-PARC E50 Spectrometer + MuID



Acceptance: ~ 60% for *D, ~80% for decay π^+**

Resolution: $\Delta p/p$~0.2% at ~5 GeV/*c* (Rigidity: ~2.1 Tm)

GPD with pion beams at J-PARC

Experimental conditions:
4g/cm2 H2 target, 1.83/1.58/1.00E7 p-/spill (for 10/15/20 GeV beam), 50-day beam time.

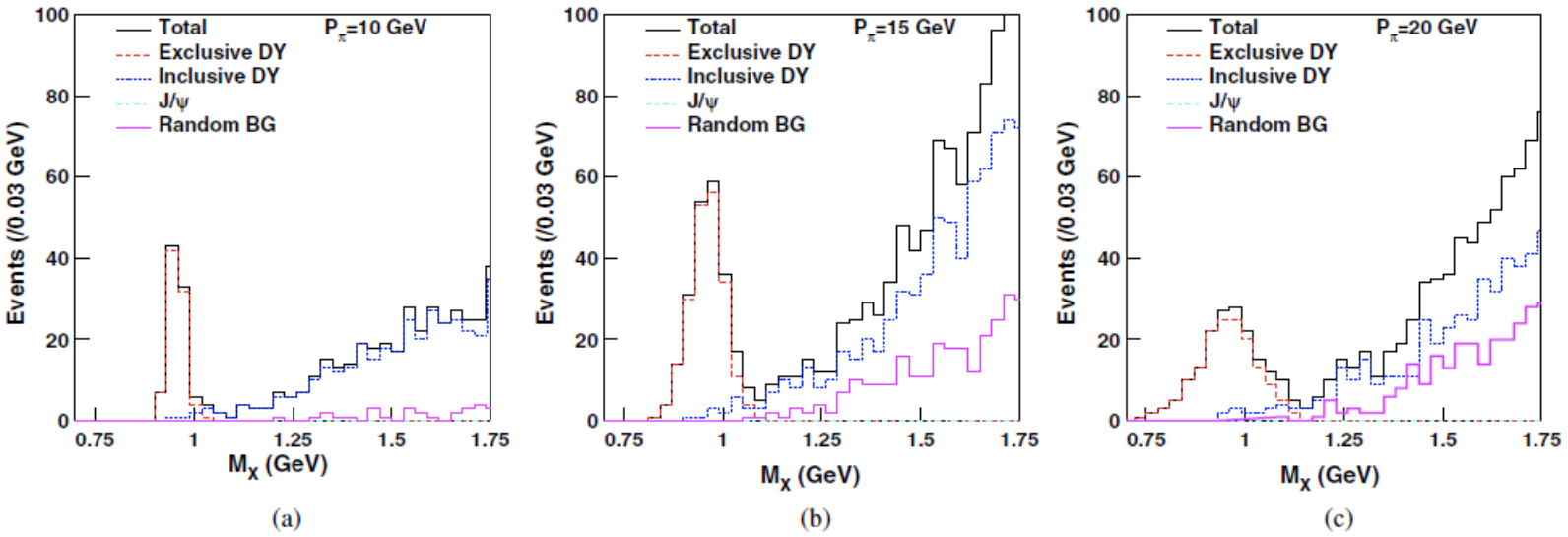


FIG. 14. The Monte Carlo simulated missing-mass M_X spectra of the $\mu^+\mu^-$ events with $M_{\mu^+\mu^-} > 1.5$ GeV and $|t - t_0| < 0.5$ GeV^2 for $P_\pi = 10$ (a), 15 (b), and 20 (c) GeV. Lines with different colors denote the contributions from various sources. The GK2013 GPDs is used for the evaluation of exclusive Drell-Yan process.

GPD with pion beams at J-PARC

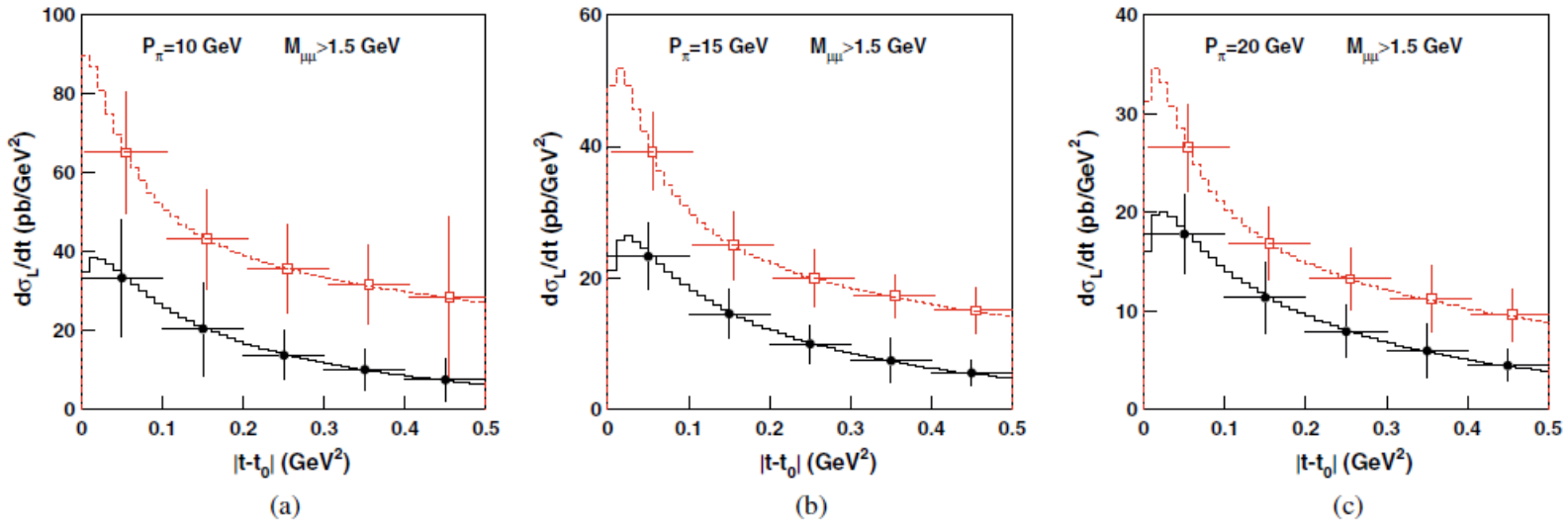


FIG. 15. The expected statistical errors of the exclusive Drell-Yan measurement for two GPDs inputs, BMP2001 (black) and GK2013 (red), as a function of $|t - t_0|$ in the dimuon mass region of $M_{\mu^+\mu^-} > 1.5$ GeV for 10 (a), 15 (b), and 20 (c) GeV beam momentum.

GPD with pion beams at J-PARC

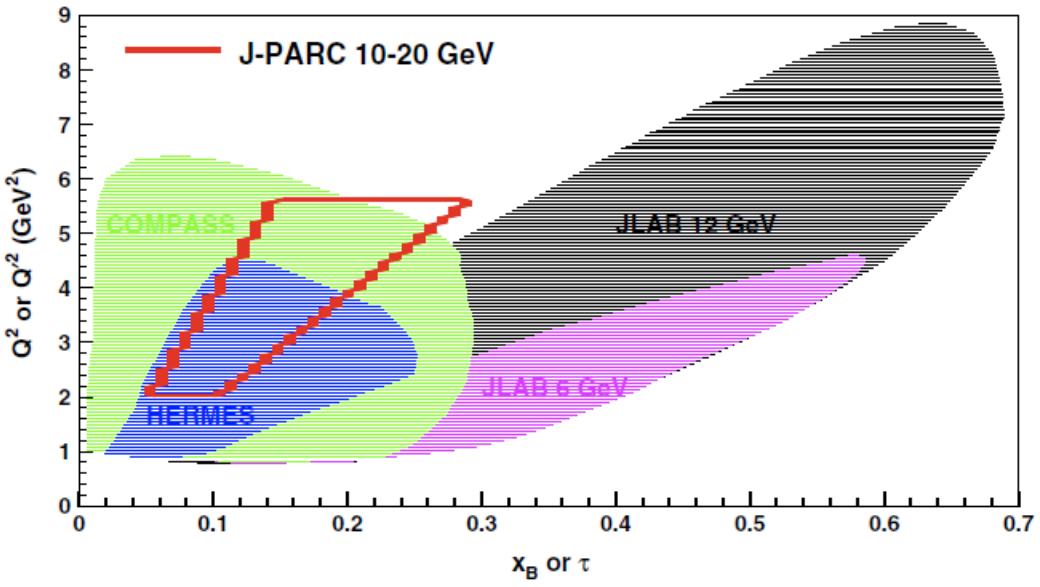


FIG. 16. The kinematic regions of GPDs explored by the experiments at JLab, HERMES and COMPASS and J-PARC (exclusive Drell-Yan). The region is either $[Q^2, x_B]$ for spacelike processes or $[Q'^2, \tau]$ for timelike ones.

Letter of Intent to J-PARC being prepared.

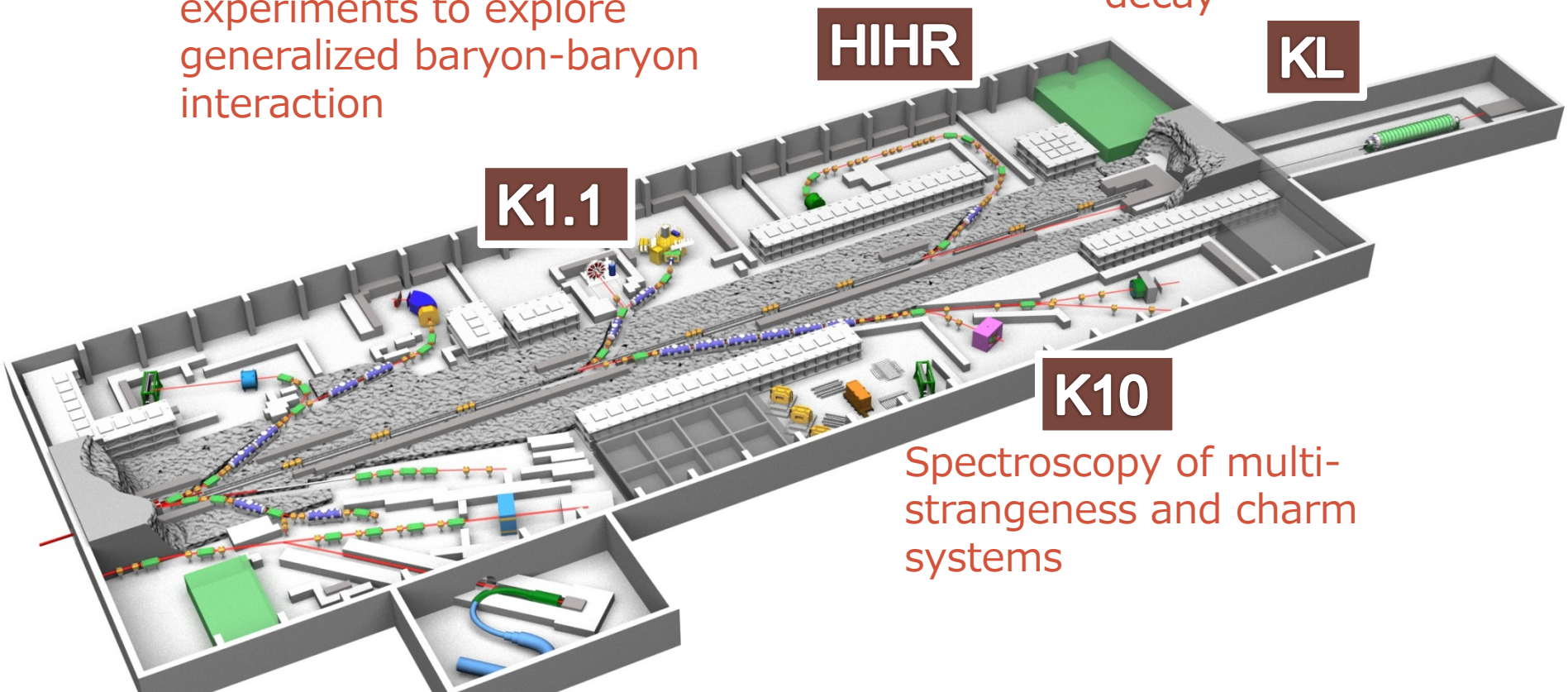
Contents

Hadron Hall Extension

- Extend the Hadron Hall for ~105m.
- Construct 2 production targets with beam lines.

Single strangeness experiments to explore generalized baryon-baryon interaction

From discovery to measurement of K0 rare decay



Spectroscopy of multi-strangeness and charm systems

Hadron Hall Extension

- Hadron Hall extension has been proposed to the Science Council of Japan for their recommendation as a next big project, and selected as one of the 27 important big projects.
- A review committee at MEXT selected the J-PARC future project including the Hadron Hall extension as one of the 11 major projects on its roadmap.
- The Institute of Particle and Nuclear Studies, KEK has made the discussion for future projects (ILC, neutrino, and Hadron extension) at the research program committee, and they have concluded that the Hadron extension should be promoted, as well as other projects.
- At the discussion of the KEK Project Implementation Plan, the Hadron Hall Extension was assigned a priority to realize.

Summary

- The beam operation at the Hadron Facility restarted from April, 2015.
- The beam power at the restart was 24kW, and then improved gradually to 42kW in December.
- The high-momentum beam line is under construction, and will be available in a few years.
- An experiment to measure nucleon GPDs with pion beams is being planned.
- The extension of the Hadron Hall has been proposed, and got a good message from initial reviews.