HADRON PHYSICS AND EXCLUSIVE DRELL-YAN EXPERIMENT AT J-PARC

Aug. 29, 2019

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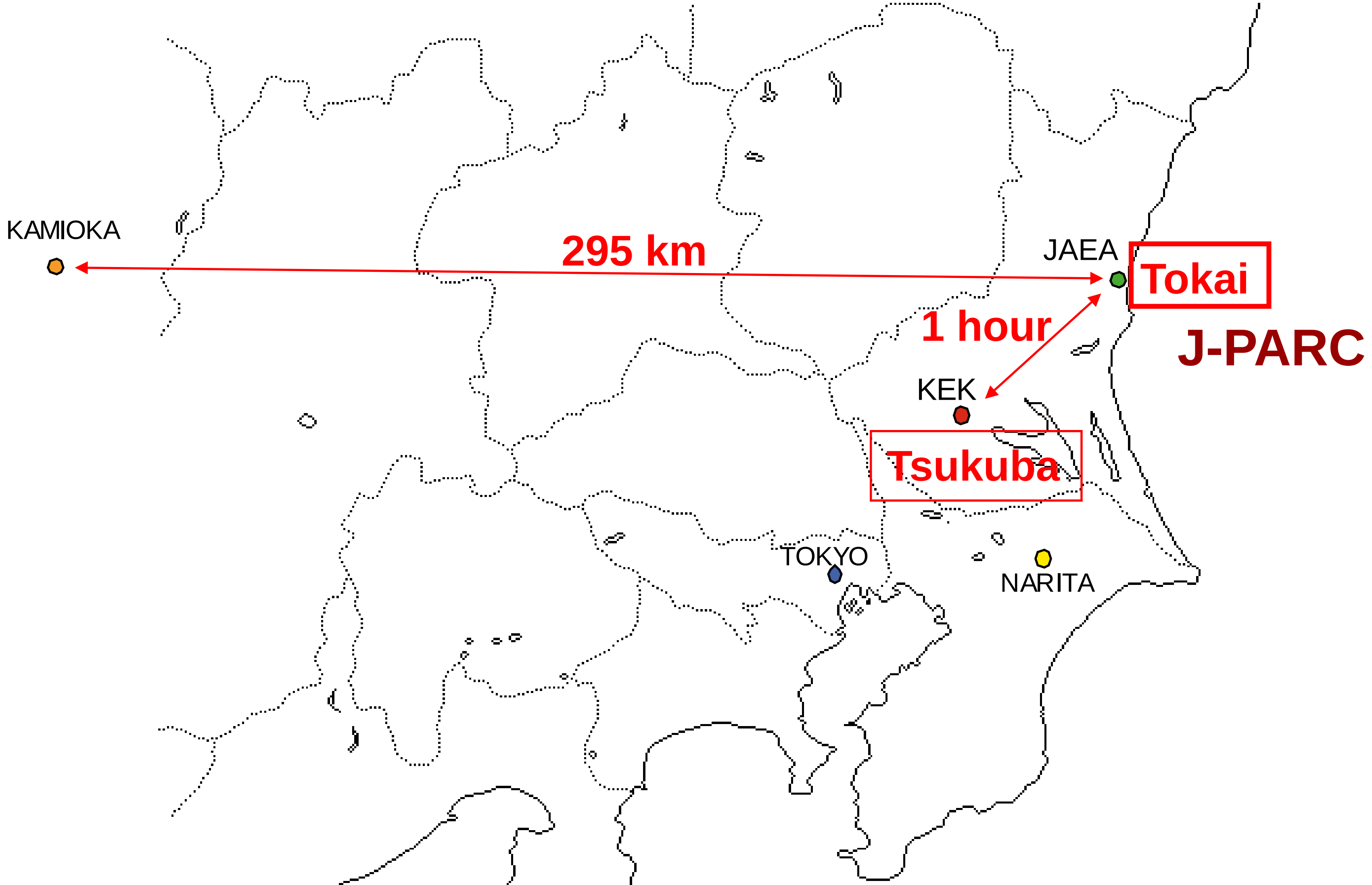
Contents

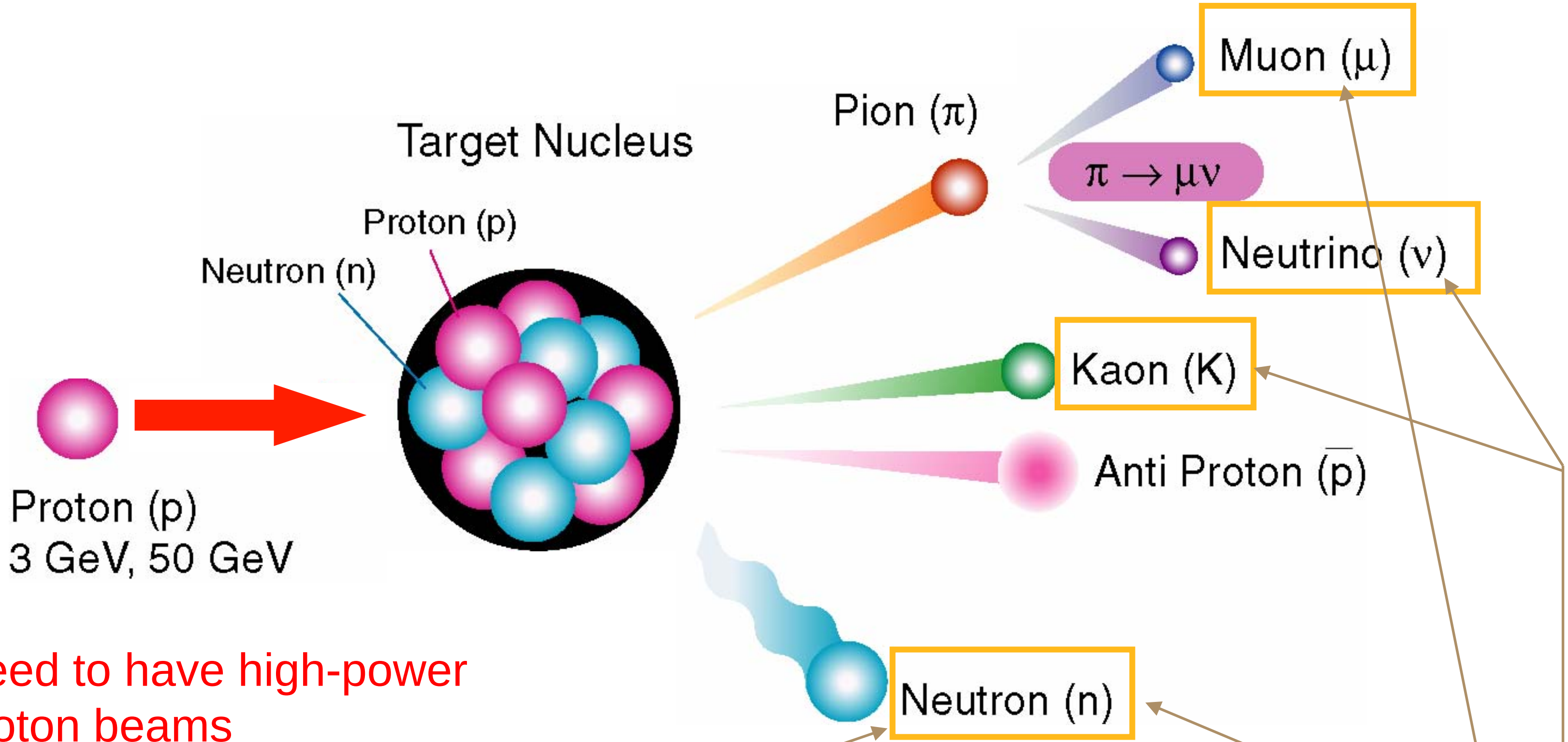
- J-PARC and Hadron Experimental Facility (Hadron Hall)
- Hadron physics overview and fruits so far obtained
- High-momentum beam line
- Summary

Bird's eye photo in January of 2016

Location of J-PARC



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

Hadron Experimental Facility

Primary Beam Line: PTEP 2012, 02B008

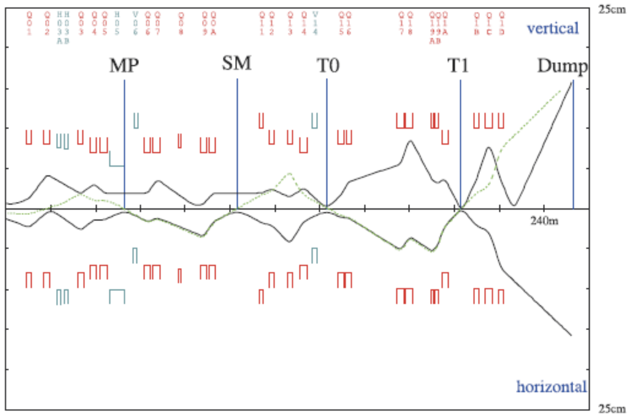
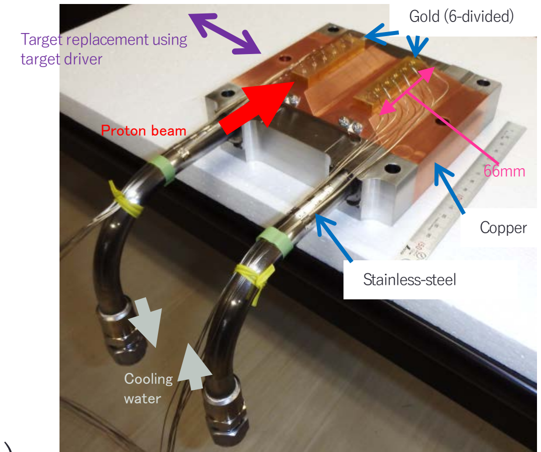
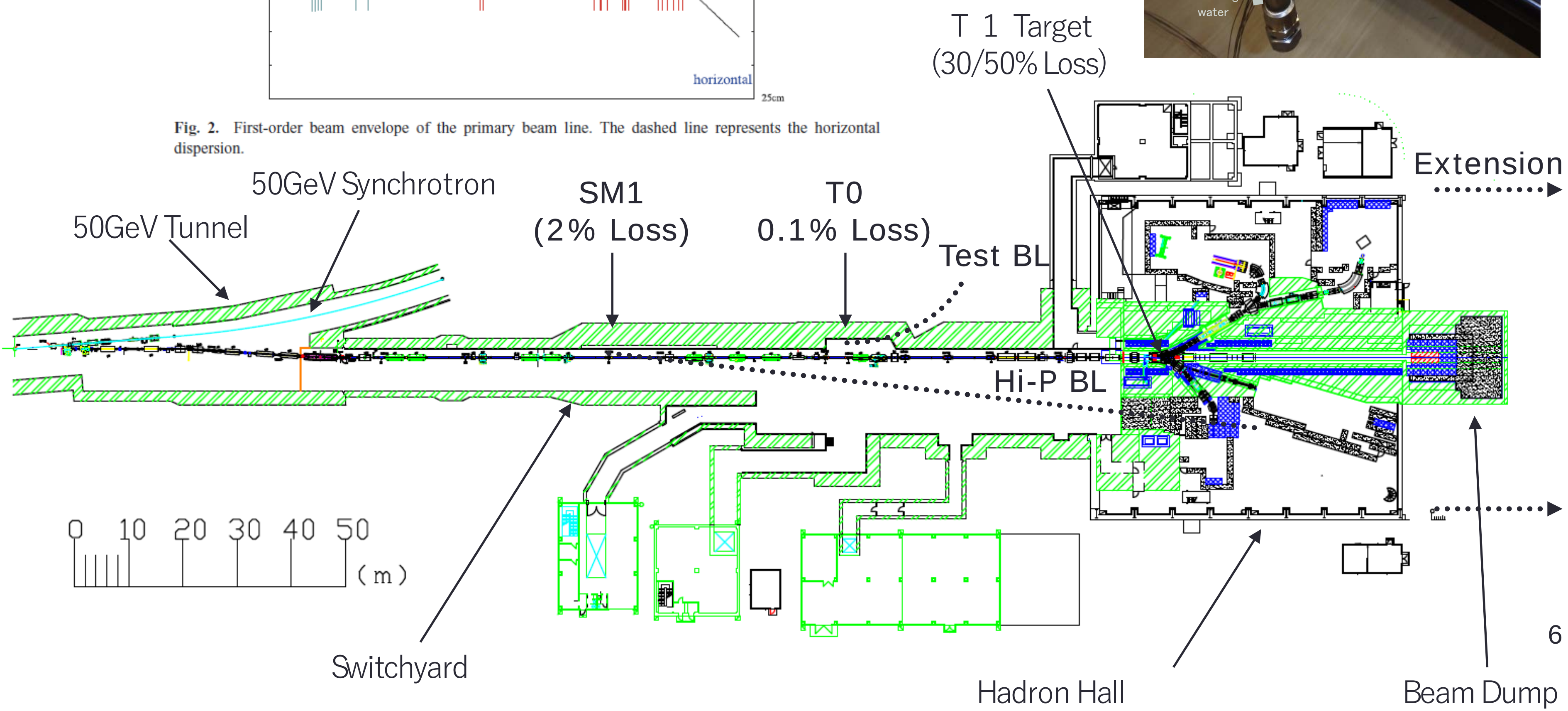
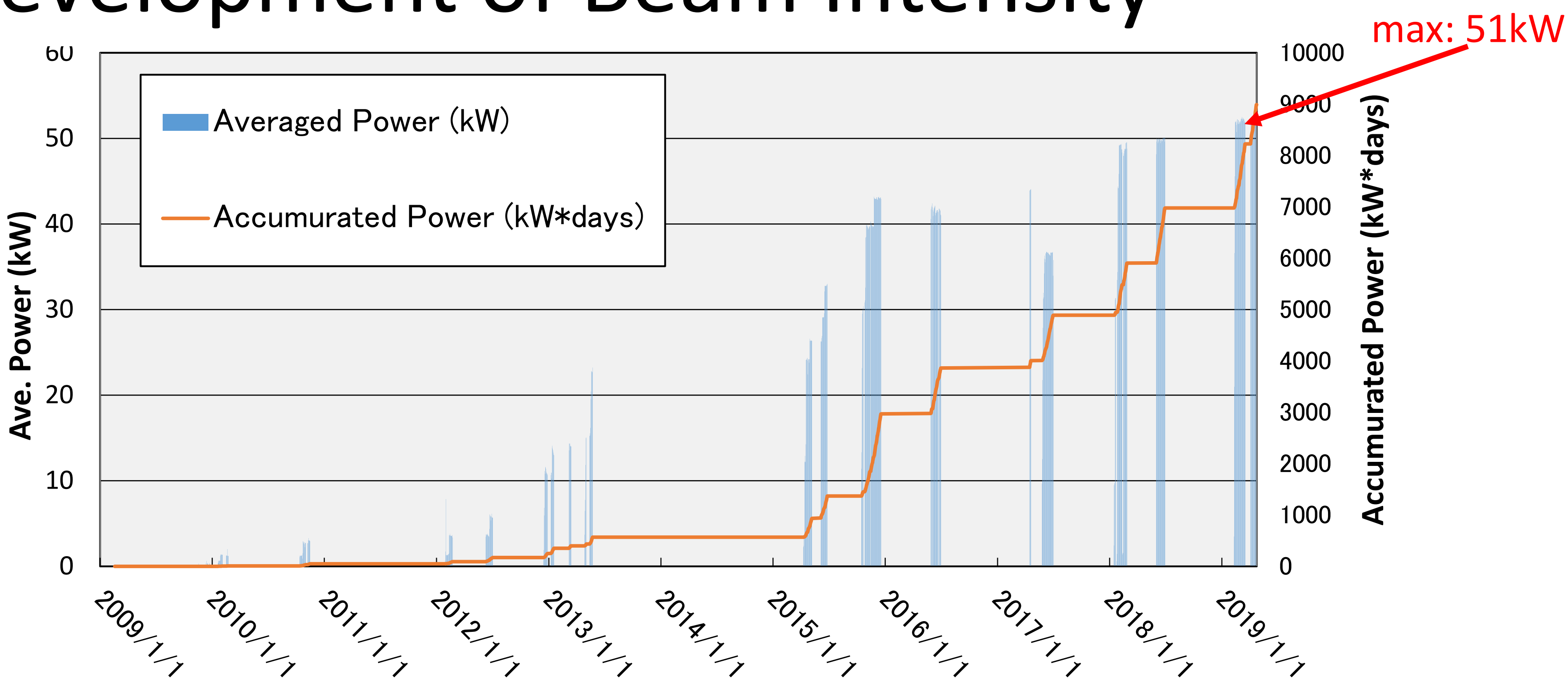


Fig. 2. First-order beam envelope of the primary beam line. The dashed line represents the horizontal dispersion.





Development of Beam Intensity

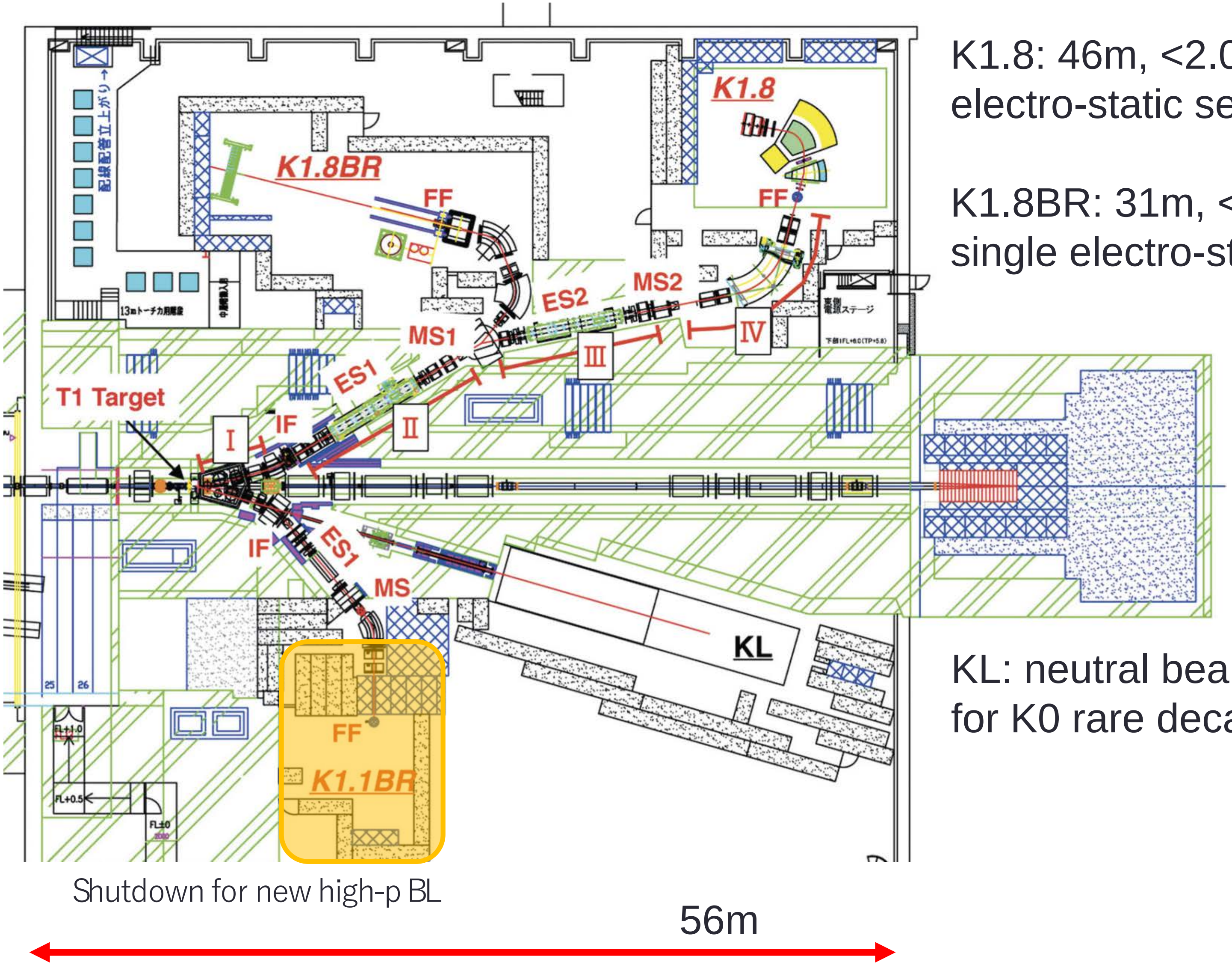


Accumulated beam time and intensity for HD

※spill: # of beam shots to HD

Before accident (Feb, 2009 – May, 2013)	1.28×10^6 spills	568 kW*days
JFY2015 run (Apr, 2015 – Dec, 2015)	1.07×10^6 spills	2365 kW*days
JFY2016 run (May, 2016 – Jun, 2016)	0.34×10^6 spills	893 kW*days
JFY2017 run (Apr, 2017 – Feb, 2018)	0.81×10^6 spills	2039 kW*days
JFY2018 run (Jun, 2018 – Mar, 2019)	0.76×10^6 spills	2321 kW*days
JFY2019 run (Apr, 2019)	0.25×10^6 spills	765 kW*days

Secondary Beam Lines



Shutdown for new high-p BL

K1.8: 46m, <2.0 GeV/c, double electro-static separators

K1.8BR: 31m, <1.1 GeV/c, single electro-static separator

KL: neutral beam line dedicated for K0 rare decay experiment

K beam intensity

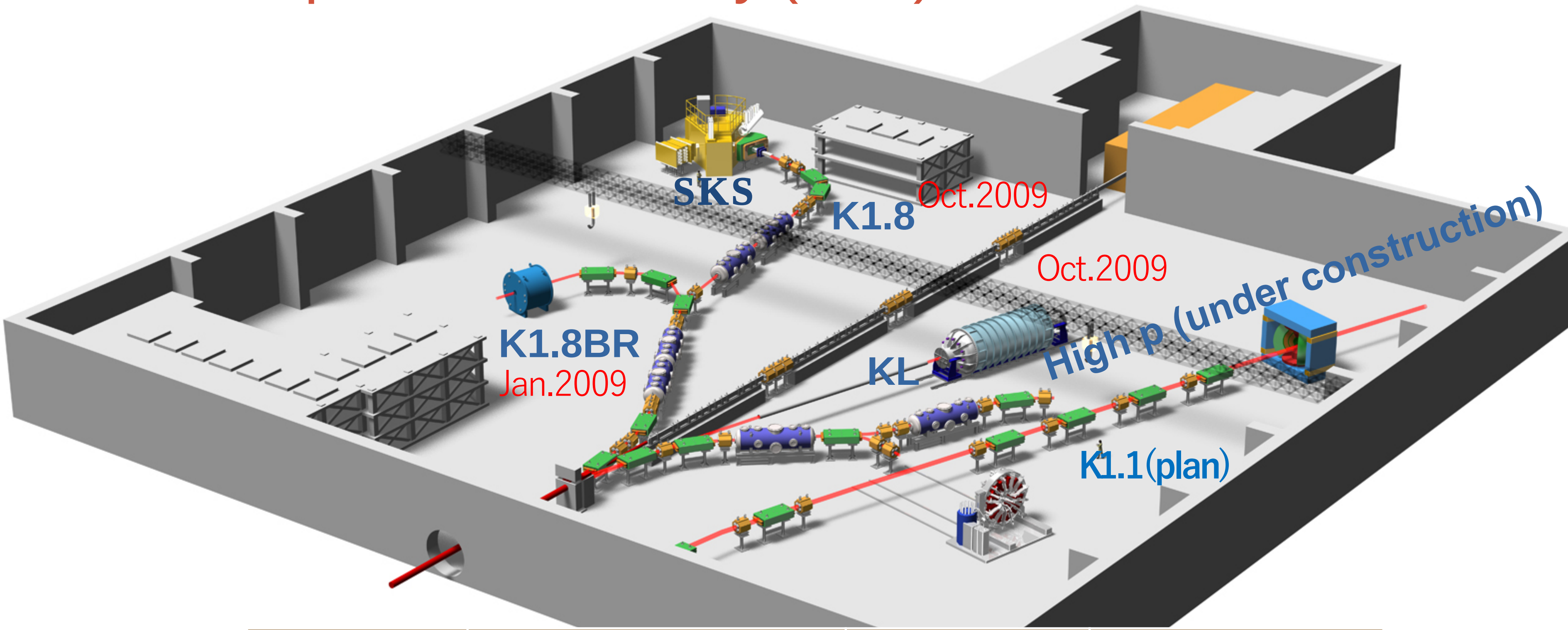
KEK-PS: K purity was for example ~25%.

KEK-PS Beamline	K / spill (4s)	Protons / spill (4s)	Note
K2	2×10^4 K^-	2×10^{12}	1.67GeV/c, E522
	1×10^4 K^-	3×10^{12}	1.0GeV/c, E549
K5	1.9×10^5 K^+	2.2×10^{12}	0.66GeV/c, E470
	6×10^3 K^-	1.5×10^{12}	stopped, E549
K6	1.3×10^4 K^+	0.87×10^{12}	1.2GeV/c, E559

J-PARC K1.8 Beamline (with 51kW primary proton beam):

Beamline	K / spill (5.2s)	Protons / spill (5.2s)	Note
K1.8	3.3×10^5 K^-	5.4×10^{13}	1.8GeV/c, E07 purity=82.5%
	7.0×10^5 K^-	5.4×10^{13}	1.8GeV/c, purity=44%

Hadron Experimental Facility (HEF)

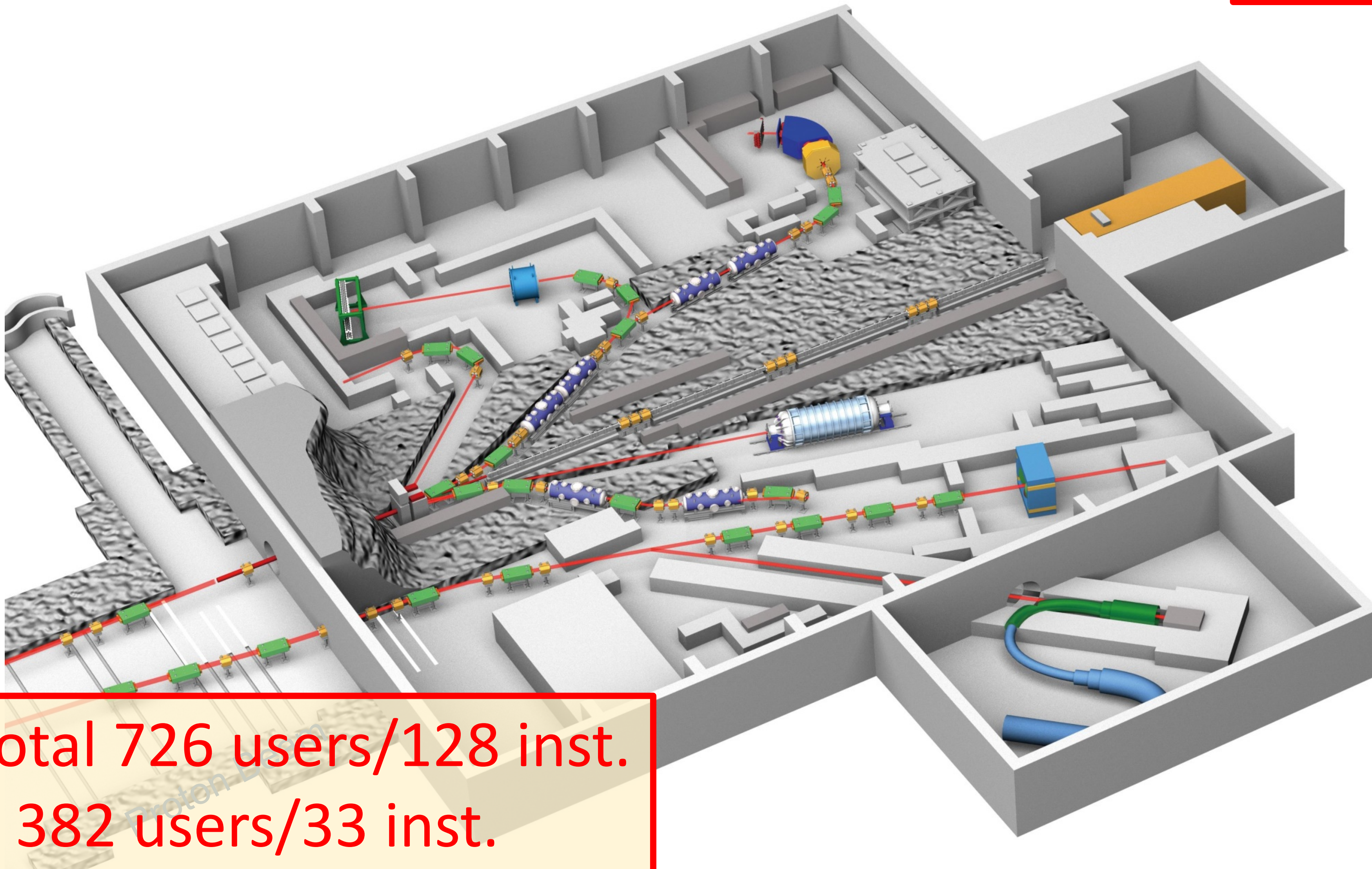


Beam Lines	Secondary particles	Max. Mom.	Max. Intensity
K1.8	π, K, p (2 separators)	< 2.0 GeV/*c*	~10^6 /spill for K^-
K1.8BR	π, K, p (1 separator)	< 1.1 GeV/*c*	~10^5 /spill for K^-
KL	Neutral Kaon	~ 2.1 GeV/*c*	~10^7 /spill

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

Number of Users/Institutions (as of 2017)

domestic
abroad



Total 726 users/128 inst.
= 382 users/33 inst.
+ 344 users/95 inst.

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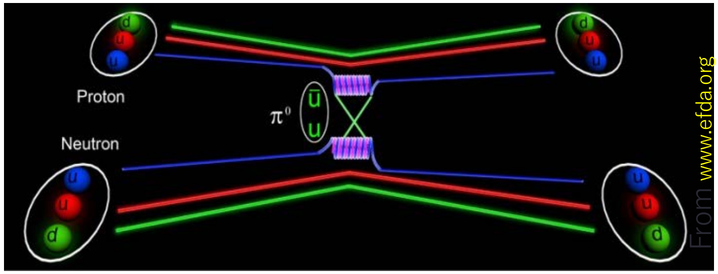
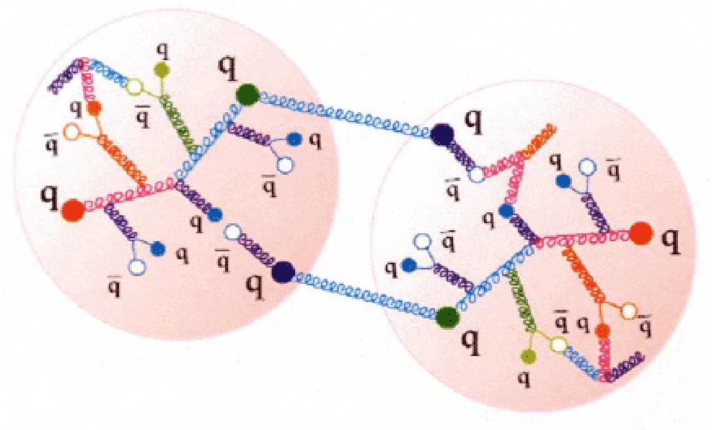
Nuclear/Hadron Physics at J-PARC

- Interaction and structure of hadrons!
  - Nucleon-nucleon interaction, especially at medium and long ranges, has been rather well studied, since Yukawa's prediction of the pi meson.

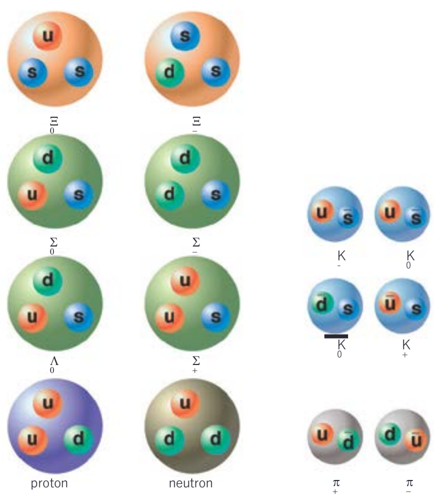


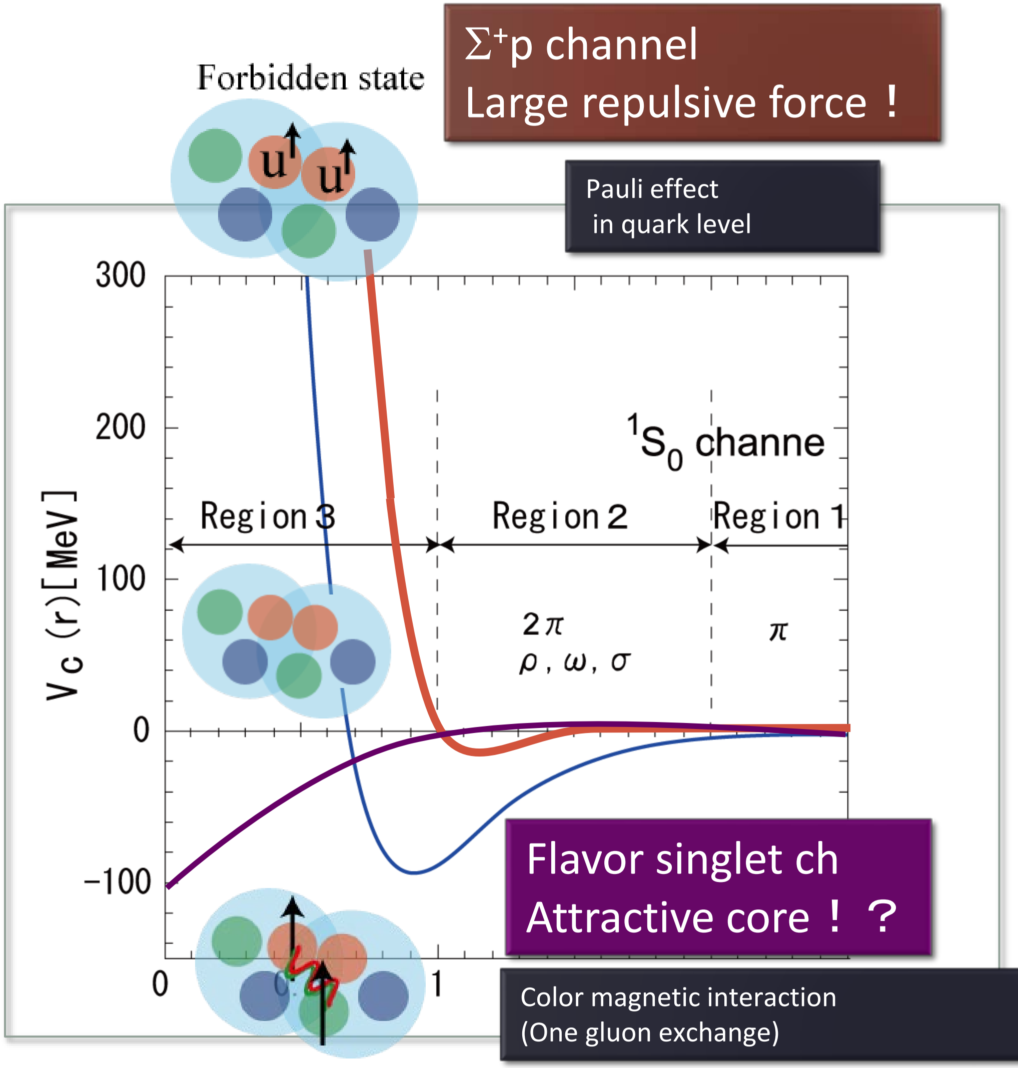
  - But at the short range, substructures of the nucleon should affect the interaction.



Nuclear/Hadron Physics at J-PARC

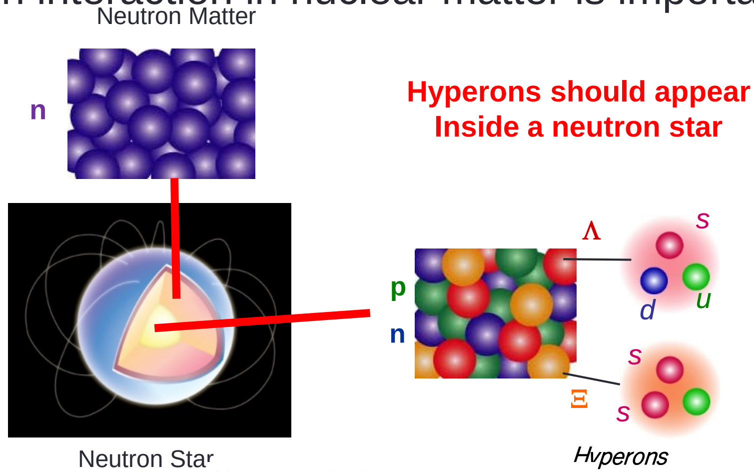
- Especially, the origin of the repulsive core and the spin-orbit force has not been understood.
- We explore the hadron interaction not only with up and down quarks but also with strange quarks.

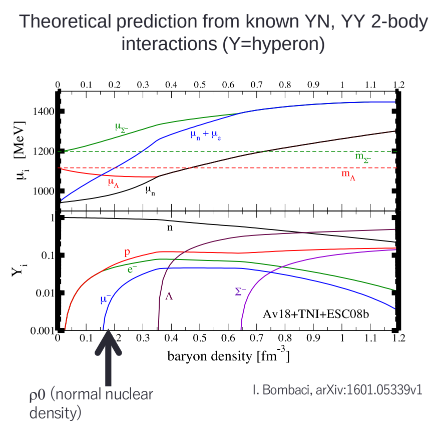


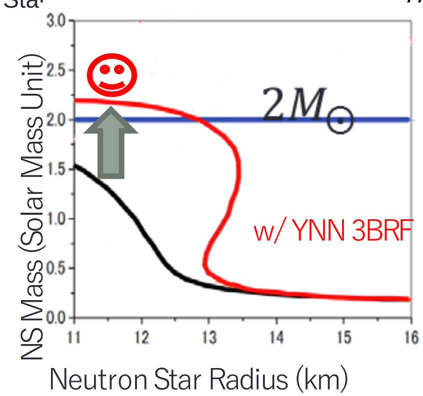


Importance of understanding hadron interaction

- Recent observation of 2-solar-mass neutron stars
  - Our understanding of hadron interaction and the equation of state (EoS) based on it cannot well describe the neutron star EoS.
  - Baryon interaction in nuclear matter is important.

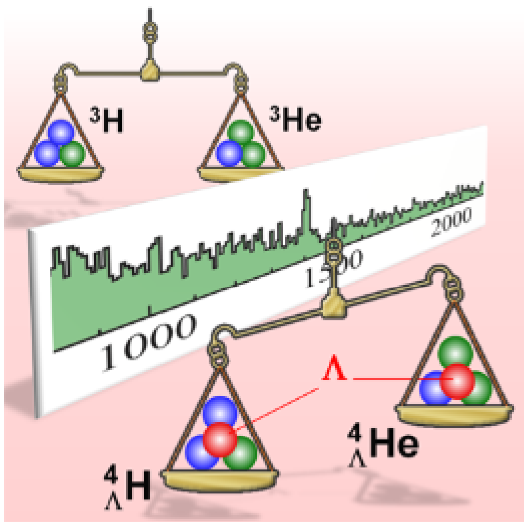






Neutron star merger detected by gravitational waves also attracts interests on the EoS.

PHYSICAL REVIEW LETTERS
moving physics forward



EDITORS' SUGGESTION

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

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.

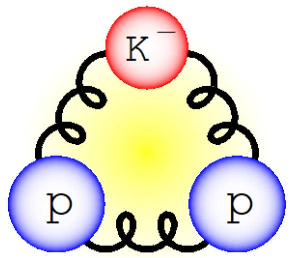
T. O. Yamamoto *et al.* (J-PARC E13 Collaboration)

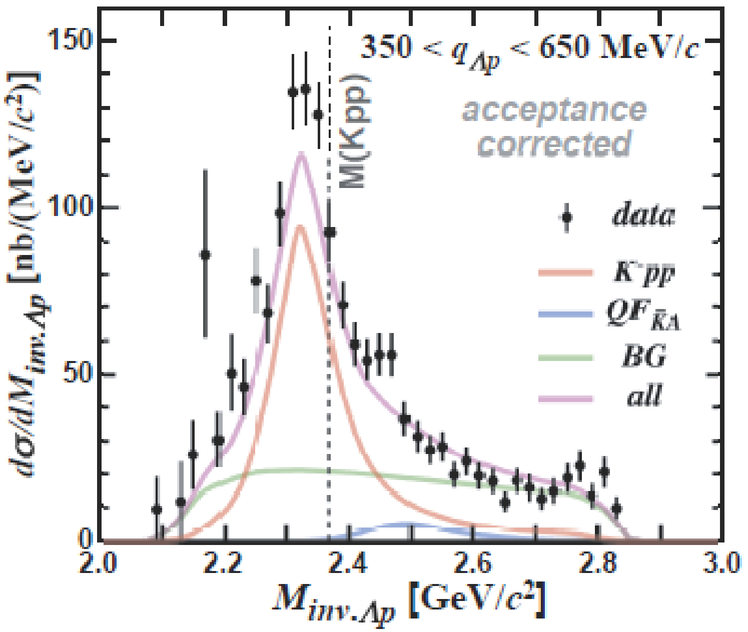
Phys. Rev. Lett. **115**, 222501 (2015)

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

K-pp states

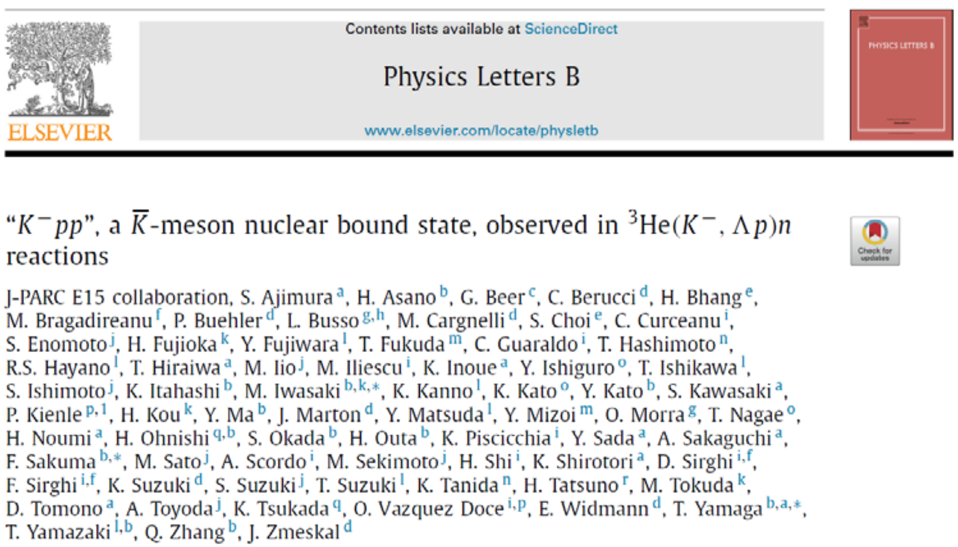
- The E15 collaboration has announced findings of a bound state of $K^- + p + p$.
- This should be a door to investigation of high density matter.





$B_{K\text{-}pp}$ = 47+-3(stat.)+3-6(sys.) MeV

$\Gamma_{K\text{-}pp}$ = 115+-7(stat.)+10-9sys.) MeV


Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

"K^-pp", a $\bar{K}$-meson nuclear bound state, observed in $^3\mathrm{He}(K^-, \Lambda p)n$ reactions

J-PARC E15 collaboration, S. Ajimura[a], H. Asano[b], G. Beer[c], C. Berucci[d], H. Bhang[e], M. Bragadireanu[f], P. Buehler[d], L. Busso[g,h], M. Cargnelli[d], S. Choi[e], C. Curceanu[i], S. Enomoto[j], H. Fujioka[k], Y. Fujiwara[l], T. Fukuda[m], C. Guaraldo[i], T. Hashimoto[n], R.S. Hayano[l], T. Hiraiwa[a], M. Iio[j], M. Iliescu[i], K. Inoue[a], Y. Ishiguro[o], T. Ishikawa[l], S. Ishimoto[j], K. Itahashi[b], M. Iwasaki[b,k,*], K. Kanno[l], K. Kato[o], Y. Kato[b], S. Kawasaki[a], P. Kienle[p,1], H. Kou[k], Y. Ma[b], J. Marton[d], Y. Matsuda[l], Y. Mizoi[m], O. Morra[g], T. Nagae[o], H. Noumi[a], H. Ohnishi[q,b], S. Okada[b], H. Outa[b], K. Piscicchia[i], Y. Sada[a], A. Sakaguchi[a], F. Sakuma[b,*], M. Sato[j], A. Scordo[i], M. Sekimoto[j], H. Shi[i], K. Shirotori[a], D. Sirghi[i,f], F. Sirghi[i,f], K. Suzuki[d], S. Suzuki[j], T. Suzuki[l], K. Tanida[n], H. Tatsuno[r], M. Tokuda[k], D. Tomono[a], A. Toyoda[j], K. Tsukada[q], O. Vazquez Doce[i,p], E. Widmann[d], T. Yamaga[b,a,*], T. Yamazaki[l,b], Q. Zhang[b], J. Zmeskal[d]

E07: S=-2 Spectroscopy with emulsion

20190113T18

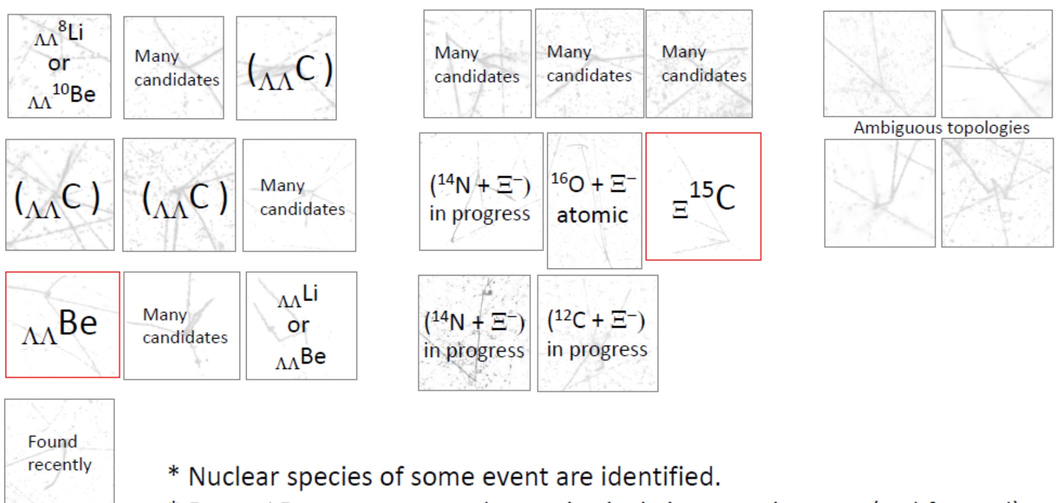
So far, 53% of emulsion sheets has been scanned at least once.

	KEK-PS E373	E07 (current)
Ξ^- stop with nuclear fragment	430	1145 (1145/430 = 2.7)
Double strangeness system	9	22

10 double Lambda events

8 twin events

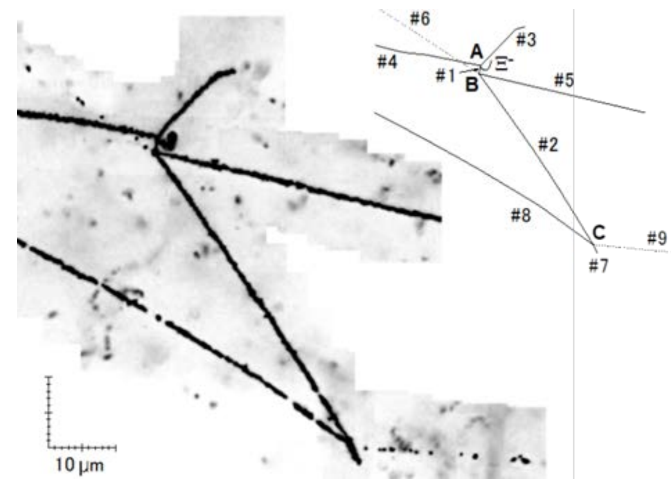
4 double or twin



* Nuclear species of some event are identified.

* B_{Ξ^-} or $\Delta B_{\Lambda\Lambda}$ are measured quantitatively in several events (red framed).

7



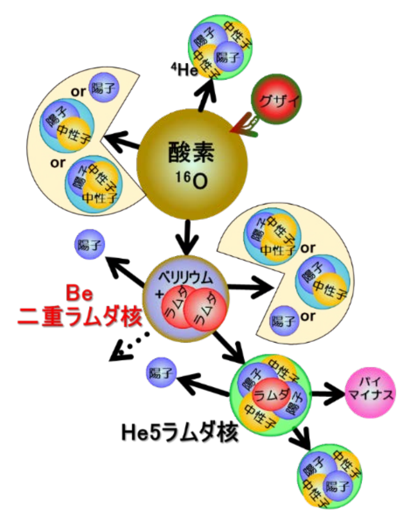
PTEP

Prog. Theor. Exp. Phys. 2019, 021D02 (11 pages)
DOI: 10.1093/ptep/pty149

Letter

Observation of a Be double-Lambda hypernucleus in the J-PARC E07 experiment

H. Ekawa[1,2,*], K. Agari[3], J. K. Ahn[4], T. Akaishi[5], Y. Akazawa[3], S. Ashikaga[1,2],



“Mino” event

Taking Data

Σ+p scattering (unique) Miwa, Tamura

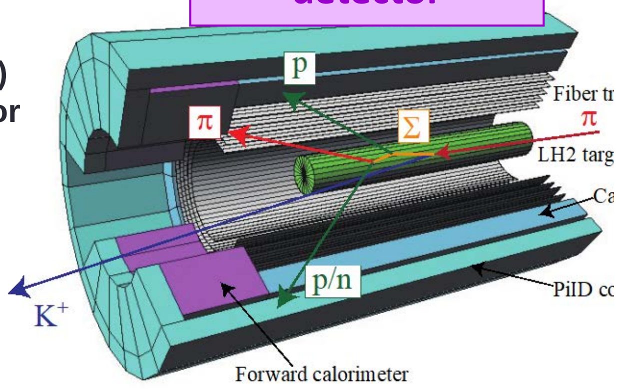
-> Σ−n (= Σ+p) int.

=> Σ− exists in n-star or not

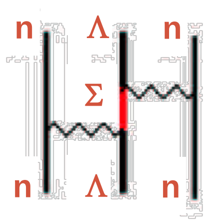
E40

Sattered proton detector

Ultra-fast (x100) Tracking detector Using MPPC

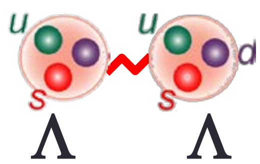


Λ–Σ coherent coupling

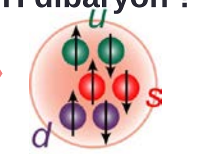


Near Future →

ΛΛ int.



H dibaryon ?

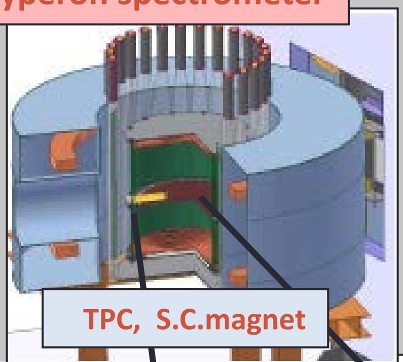


ΛΛ correlation

(Unique in the world)

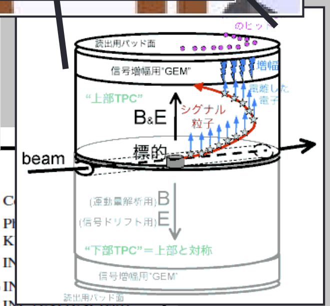
Hyperon spectrometer

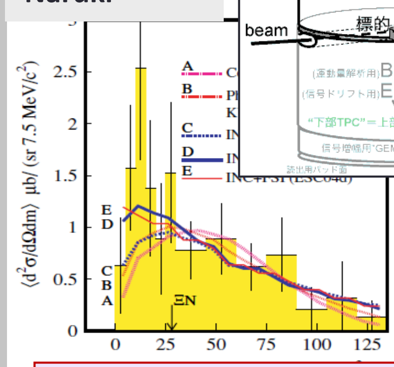
E42



TPC, S.C.magnet

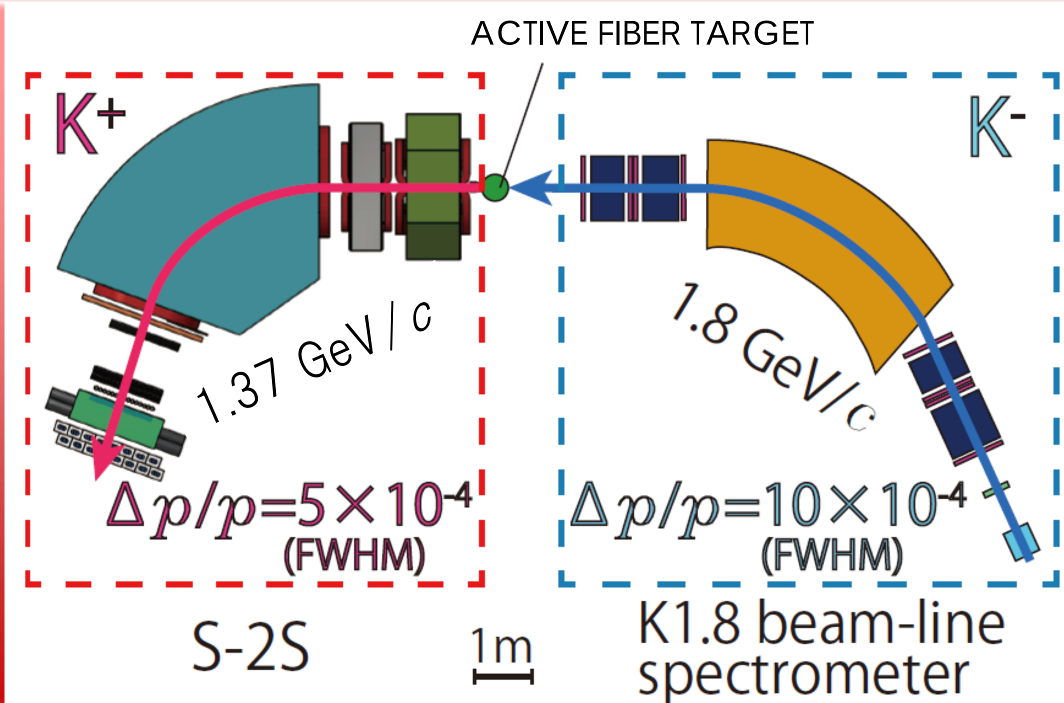
Sato, Imai, Takahashi, Naruki





Peak in ΛΛ invariant mass

Multi-Strangeness world revealed with S-2S



J-PARC K1.8

(K^-,K^+) spectroscopy

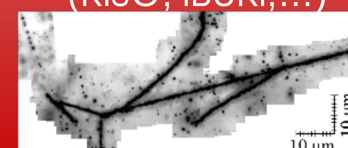
$\Delta E<2$ MeV

$\Delta\Omega=55$msr

Establish the Ξ bound states

Hints in Emulsion

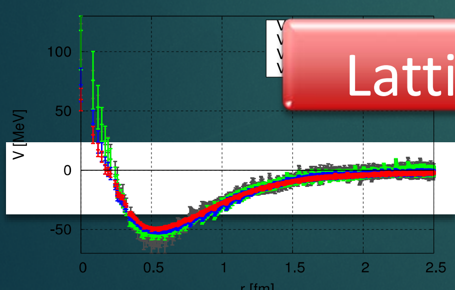
(KISO, IBUKI,…)



B-B Interactions

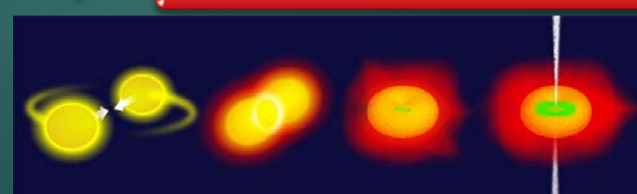
EOS@ High-density

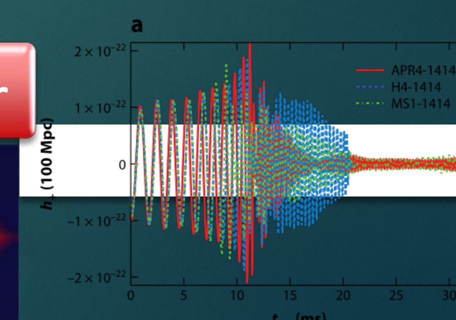
Lattice QCD



(b) $V_{N\Xi-N\Xi}$

Binary NS Merger





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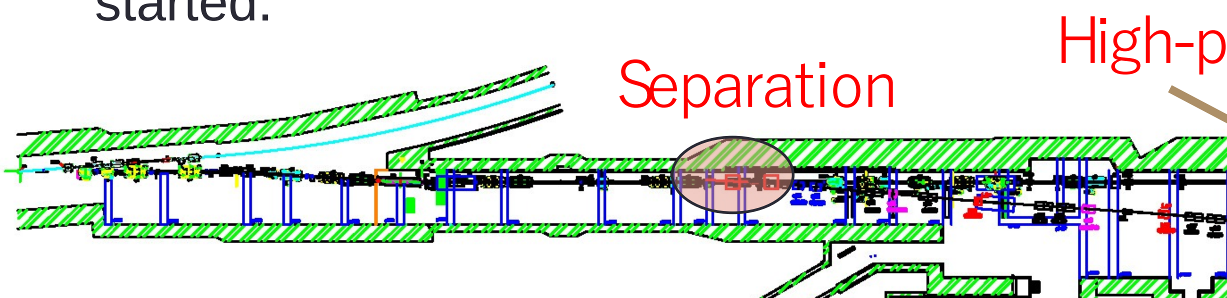
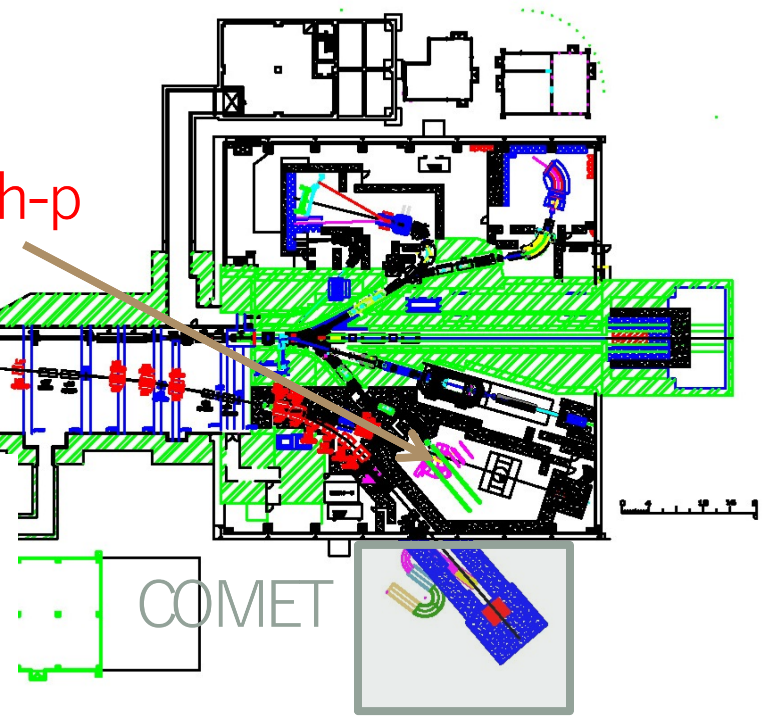
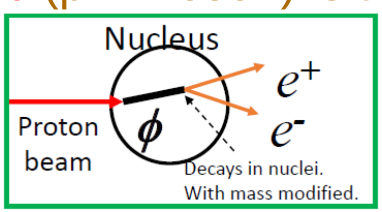
New Primary Proton Beam Line

- 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 the first experiment.

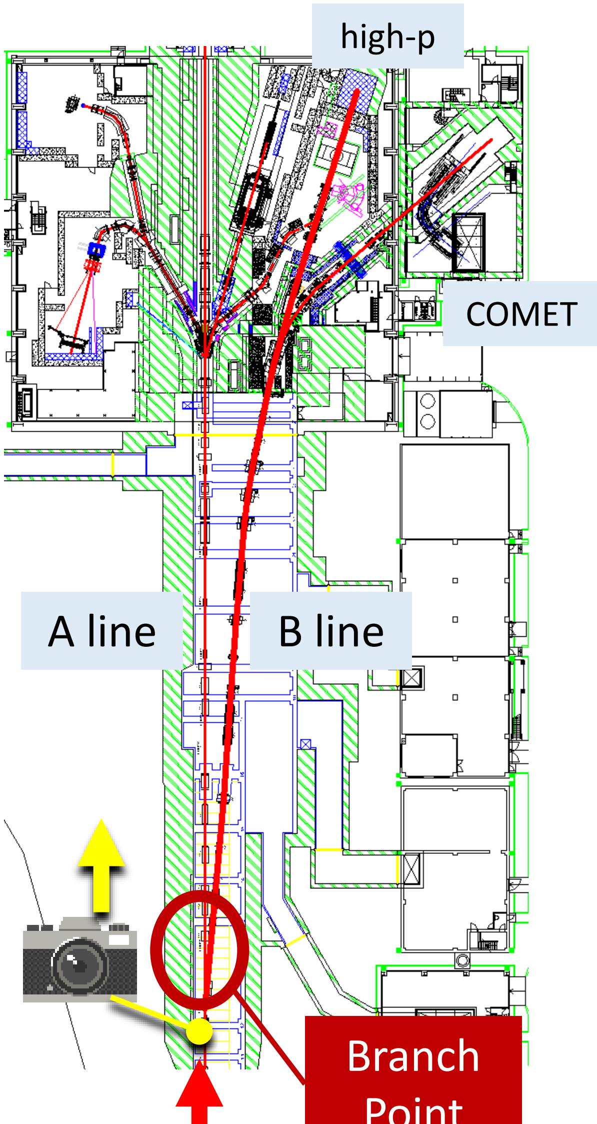


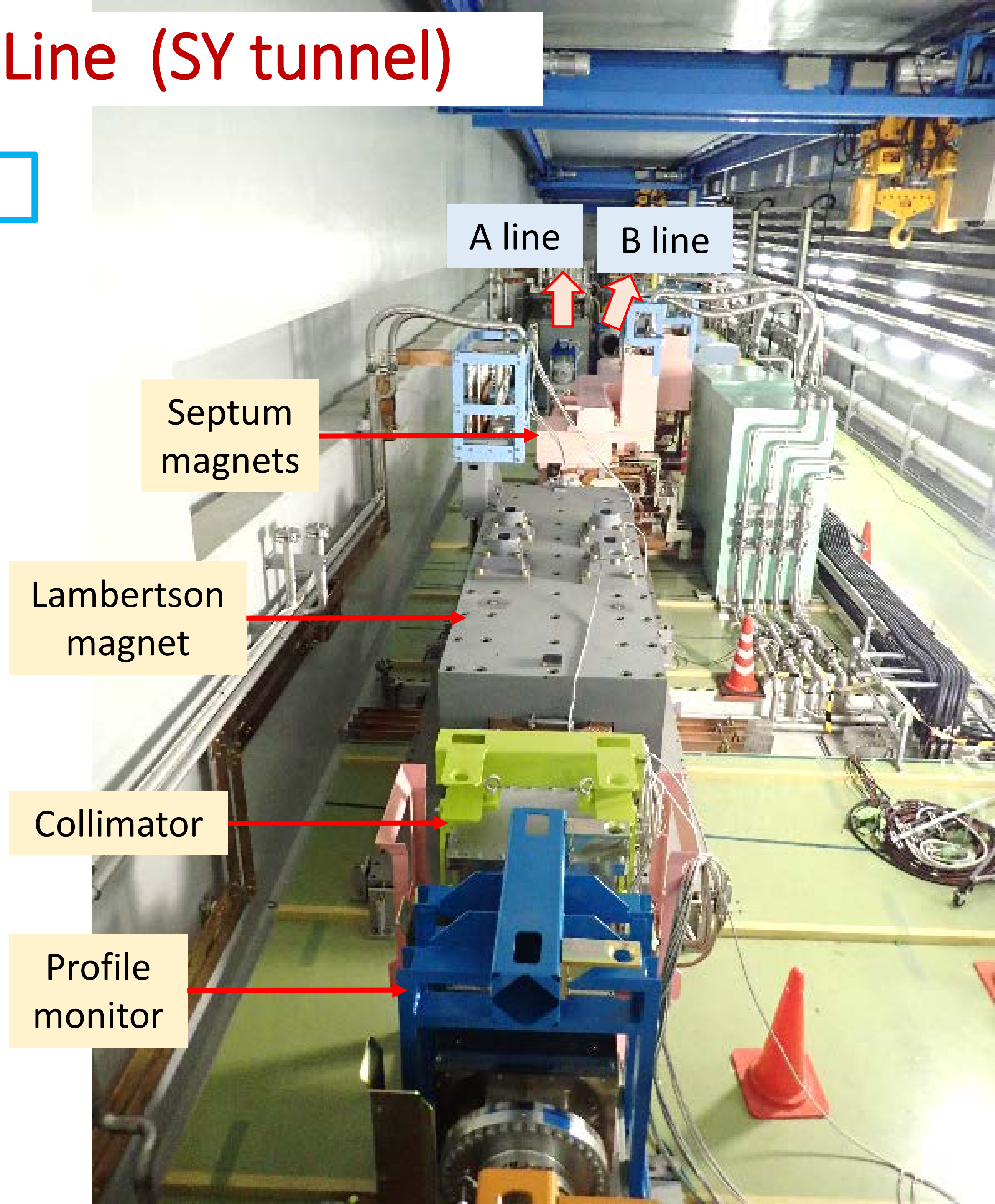
  - Unseparated secondary particles (pi, …)
    - High-resolution secondary beam by adding several quadrupole and sextupole magnets.

- 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.

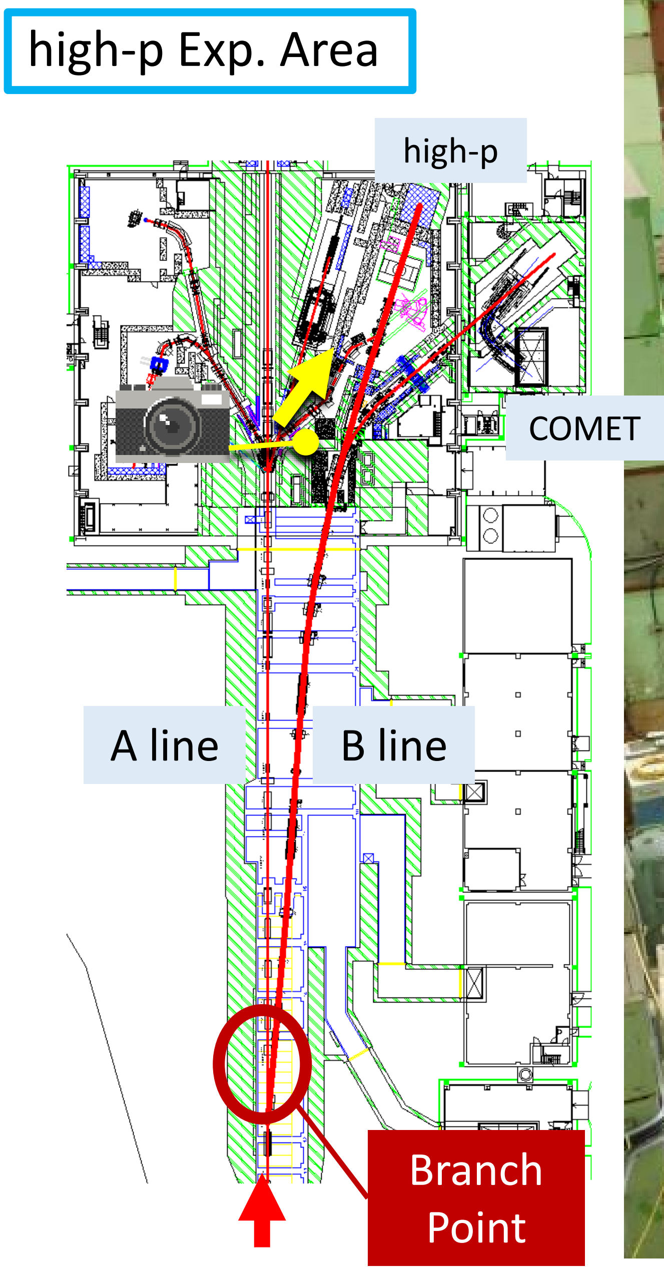
New Primary Beam Line (SY tunnel)

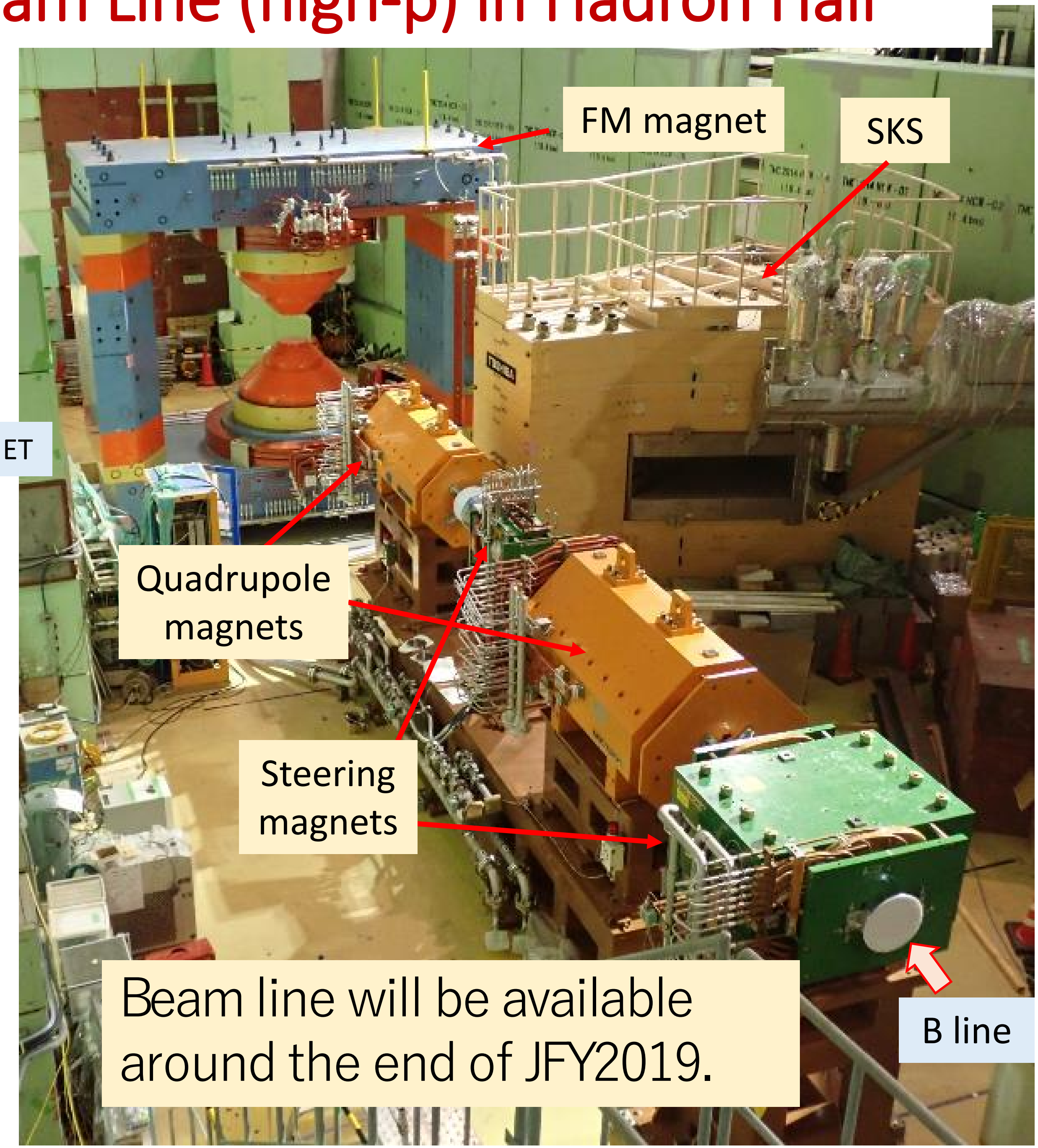
Lambertson Magnet to B-Line





New Primary Beam Line (high-p) in Hadron Hall



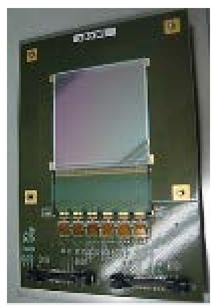


J-PARC E16

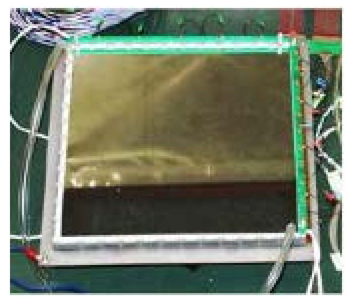
- New experiment at J-PARC
  - Invariant mass spectra of e^+e^- pairs in pA collisions
    - Vector meson mass modification due to nuclear matter effects
    - High statistics/Good resolution
  - Similar as KEK-PS E325, but with x100 stat.
  - The experiment will start in early 2020

Construction of a beam line and a spectrometer are on-going

Spectrometer magnet (FM)

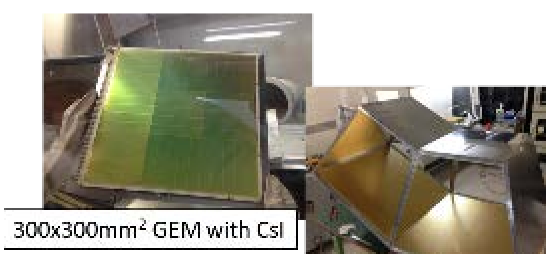


SSD

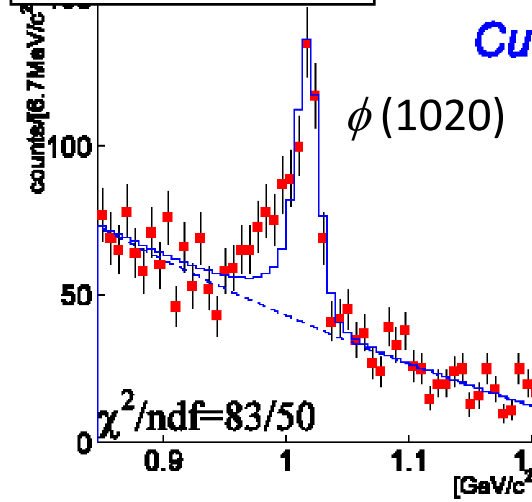


GEM Tracker

Electron ID (HBD and Lead Glass)

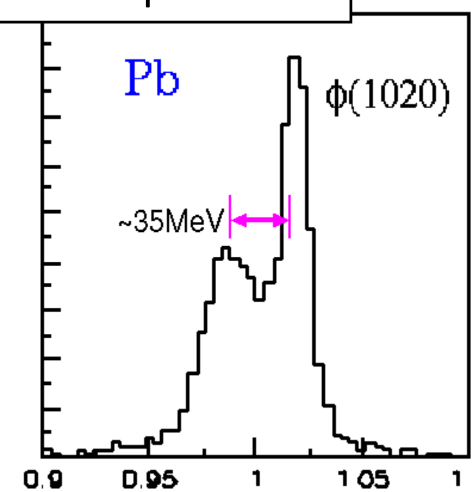


KEK E325 results



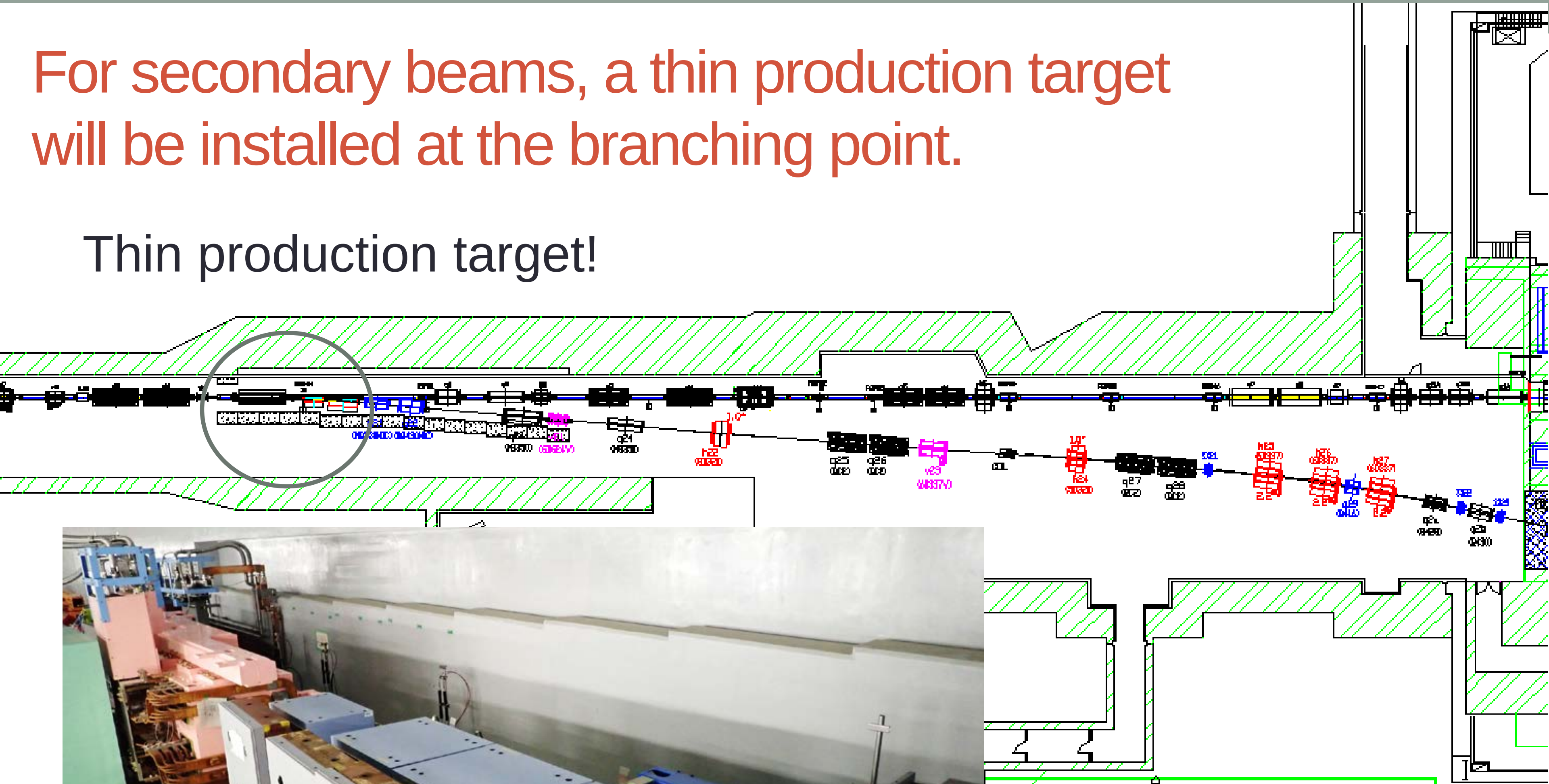
High stat.
Better res.

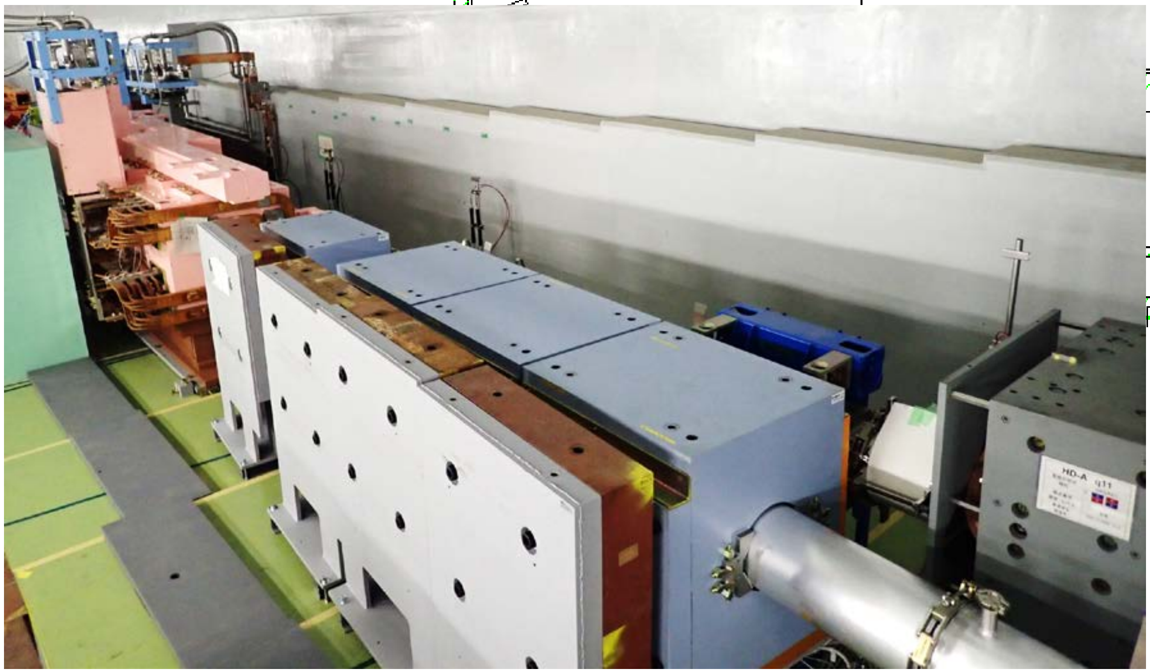
J-PARC expectation



For secondary beams, a thin production target will be installed at the branching point.

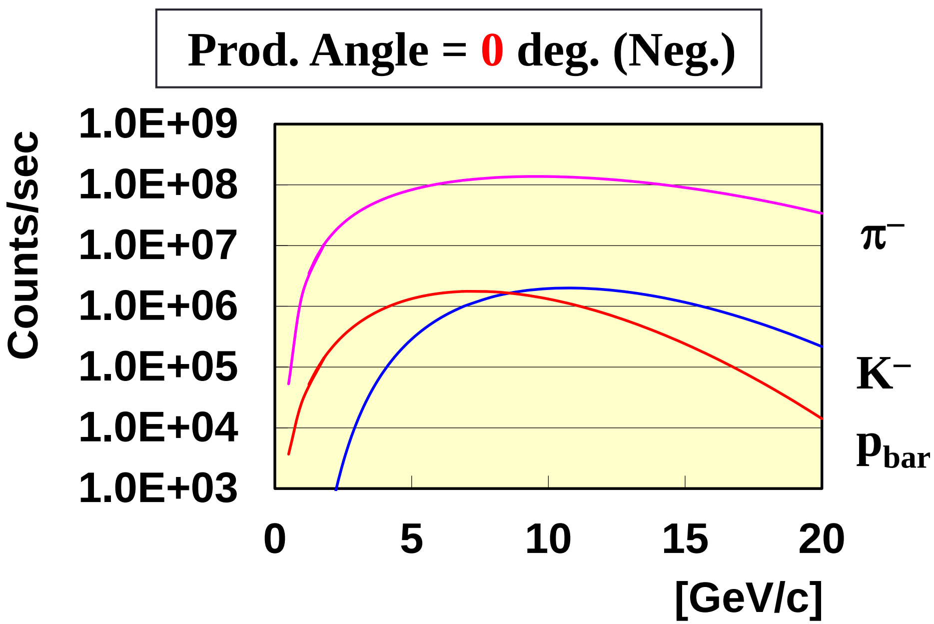
Thin production target!

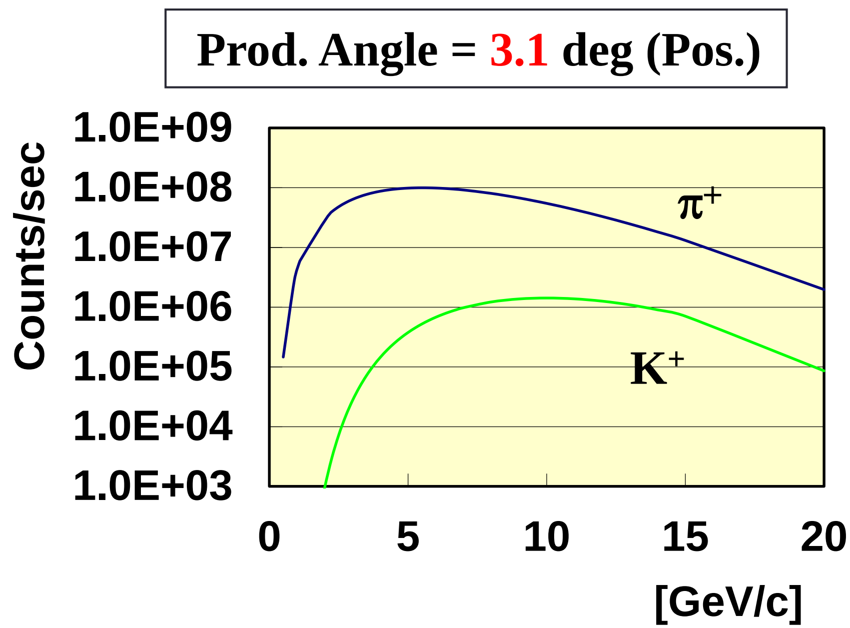




Unseparated Secondary Beam in the future

Noumi





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

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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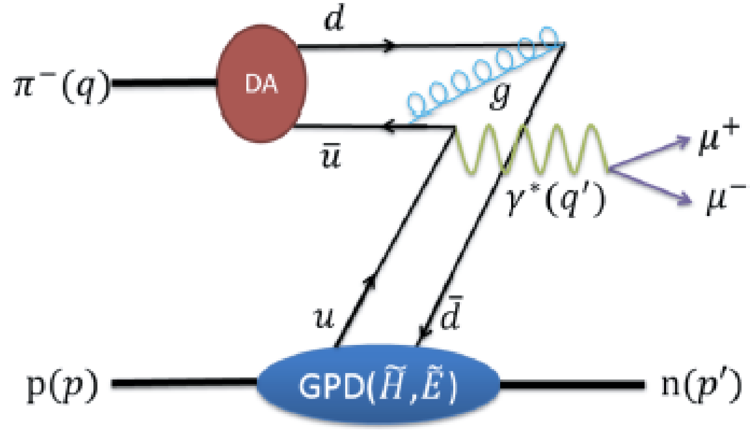
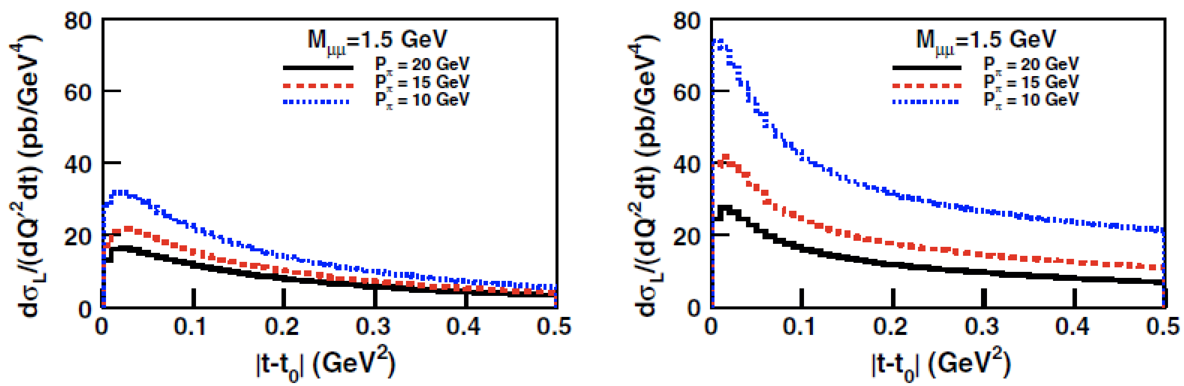
(Received 15 May 2016; published 29 June 2016)





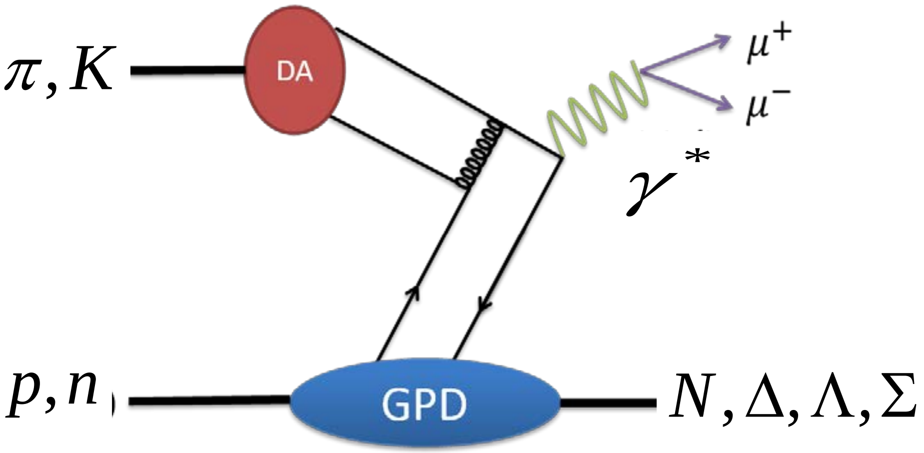
(a) (b)

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.

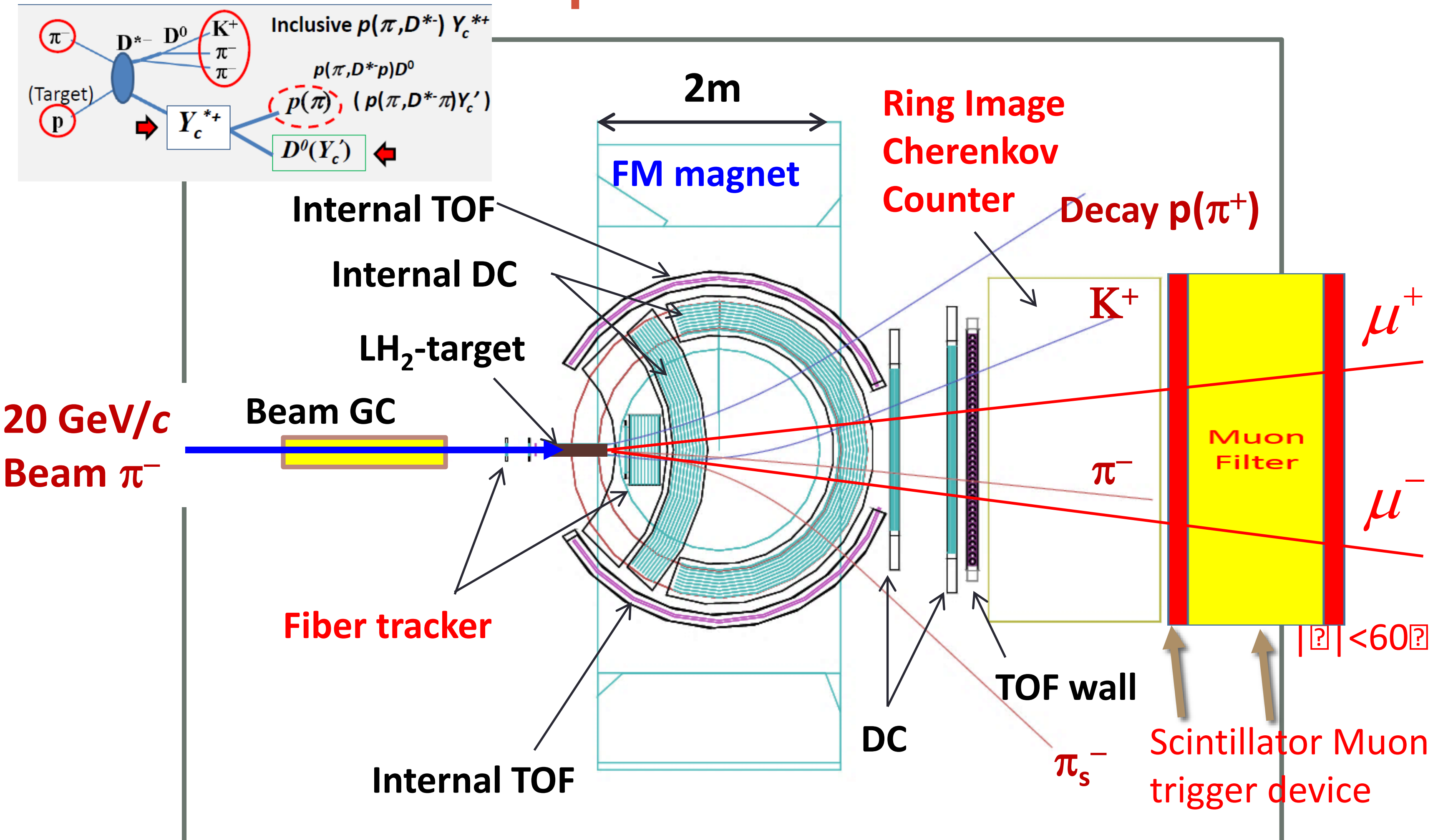
"GPD" and "Transition GPD"

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

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



J-PARC E50 Spectrometer + MuID



DY trigger rate is expected to be very low, so that the DY measurement can be a “by-product” of the main E50 experiment.

GPD with pion beams at J-PARC

Experimental conditions:
4g/cm^2 H_2 target, 1.83/1.58/1.00E7 π^-/spill (for 10/15/20 GeV beam), 50-day beam time.

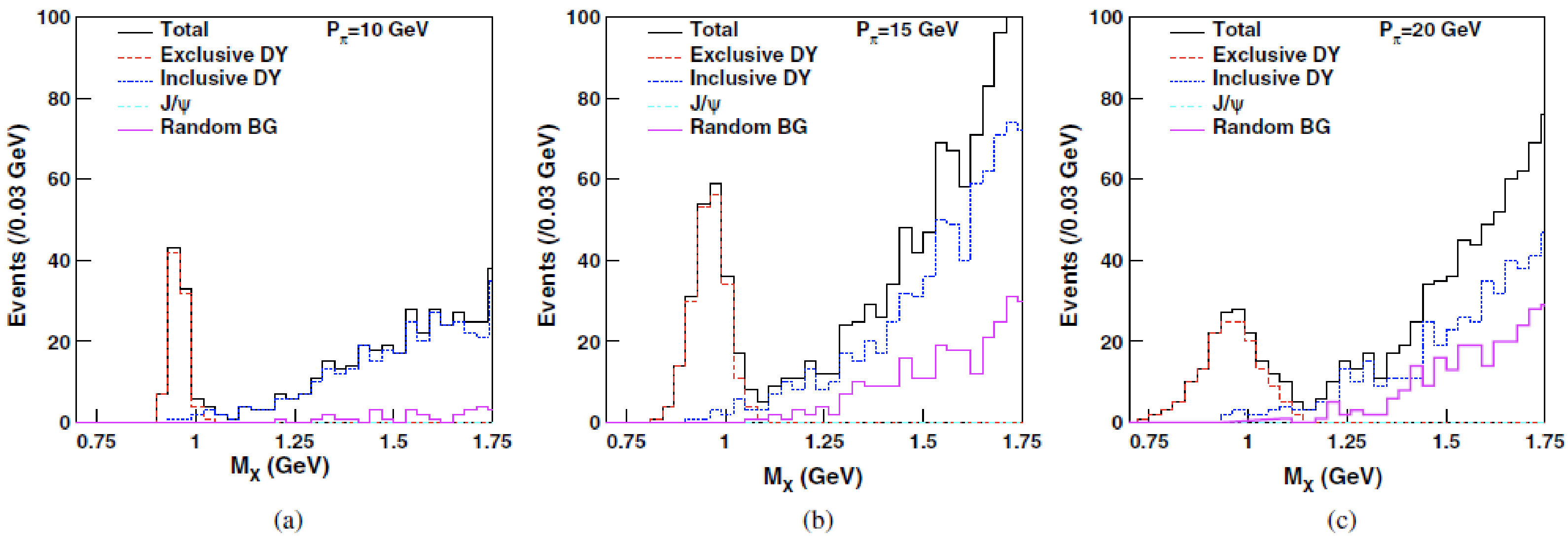


FIG. 14. The Monte Carlo simulated missing-mass M_X spectra of the $\mu^+\mu^-$ events with $M_{\mu^+\mu^-} > 1.5$ GeV and $|t - t_0| < 0.5$ GeV^2 for $P_\pi = 10$ (a), 15 (b), and 20 (c) GeV. Lines with different colors denote the contributions from various sources. The GK2013 GPDs is used for the evaluation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

Expected statistical errors of the exclusive Drell-Yan measurement for two GPD inputs

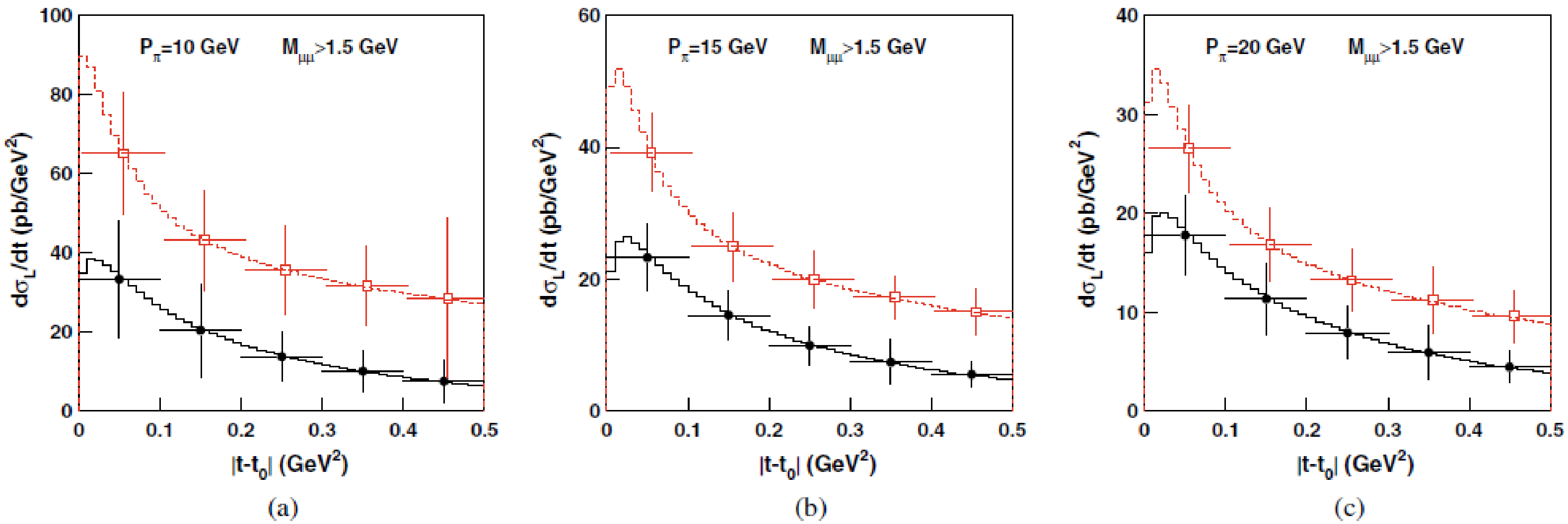


FIG. 15. The expected statistical errors of the exclusive Drell-Yan measurement for two GPDs inputs, BMP2001 (black) and GK2013 (red), as a function of $|t - t_0|$ in the dimuon mass region of $M_{\mu^+\mu^-} > 1.5$ GeV for 10 (a), 15 (b), and 20 (c) GeV beam momentum.

- 50 days data taking
- 1.5 < M(mu+mu-) < 2.9 GeV

The statistical accuracy is adequate for discrimination between the two current GPD modelings.

GPD with pion beams at J-PARC

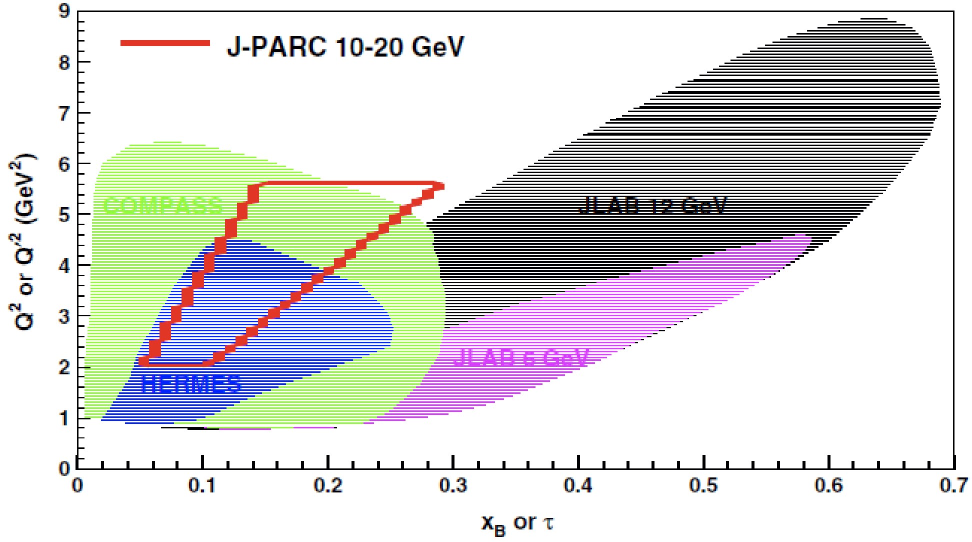


FIG. 16. The kinematic regions of GPDs explored by the experiments at JLab, HERMES and COMPASS and J-PARC (exclusive Drell-Yan). The region is either $[Q^2, x_B]$ for spacelike processes or $[Q'^2, \tau]$ for timelike ones.

Impacts of GPD measurement at J-PARC:

- Test of universality GPD in space-like and time-like processes
- Test of factorization of exclusive Drell-Yan process

Further possibilitis:

- Information of GPD at larger Q^2 region
- Test of QCD evolution properties of GPD

Letter of Intent to J-PARC being prepared.

Summary

- The beam power has been improved gradually to 51kW. The Hadron Experimental Facility is now in the era of K-induced experiments.
- A major goal is to investigate hadron interactions and structures.
- The high-momentum beam line for primary protons is almost completed, and an experiment to measure phi meson mass inside nuclei will be performed.
- High-momentum pion beams will be available if equipment for secondary beams is installed to the high-momentum beam line. An exclusive Drell-Yan experiment is being discussed.