2015 ANPhA Symposium in Korea
23-24 October 2015
Hwabaek Convention Center, Gyeongju, Korea

KPS 한국물리학회
The Korean Physical Society

Study Nucleon Partonic Structure at High-Momentum Beamline at J-PARC

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Institute of Physics, Academia Sinica, Taiwan

ANPhA
Asian Nuclear Physics Association

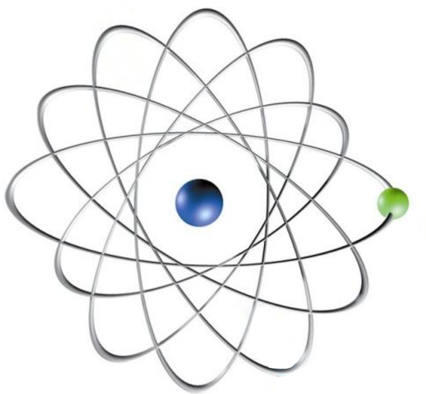
中央研究院 物理研究所
INSTITUTE OF PHYSICS ACADEMIA SINICA

Outline

- High-momentum beamline at J-PARC
- Physics processes:
  - **Charm and strangeness production**
  - **Hard exclusive process**
  - **Exclusive Drell-Yan process**
- Summary & Remarks

Mass of Composite Systems

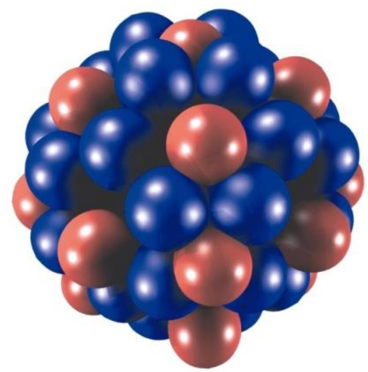
atom
10^{-10} m



$M \approx \Sigma\, m_i$

binding energy
effect $\approx 10^{-8}$

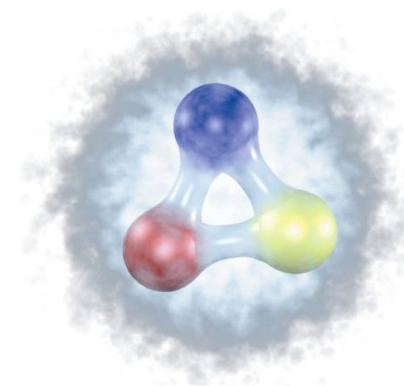
atomic nucleus 10^{-14} m



$M \approx \Sigma\, m_i$

binding energy
effect $\approx 10^{-3}$

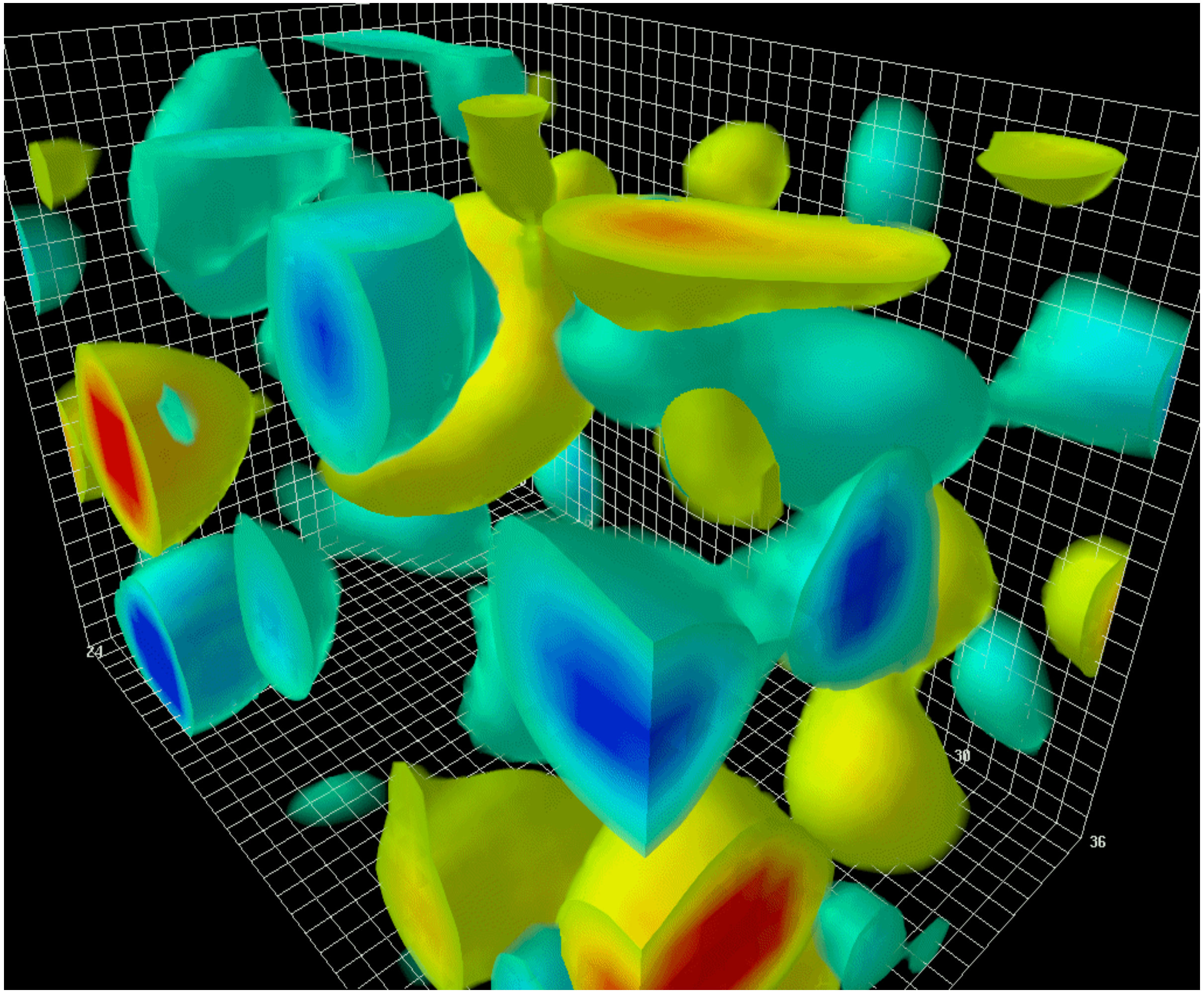
nucleon
10^{-15} m



$M \gg m_i$

<u>nucleon:</u> mass not determined by sum of constituent masses
$m = E/c^2$, “mass without mass“ (Wilczek)
mass given by energy stored in motion of quarks
and by energy in colour gluon fields

Topological Charge Density of Gluon Field

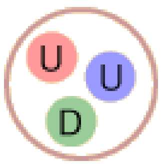


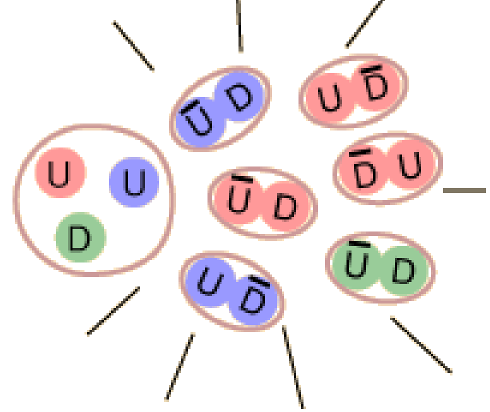
http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/ChargeAPE5LQanimXs30.gif

http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/index.html

Properties of QCD

- Quark Confinement: no isolated quarks.





- Asymptotic Freedom:

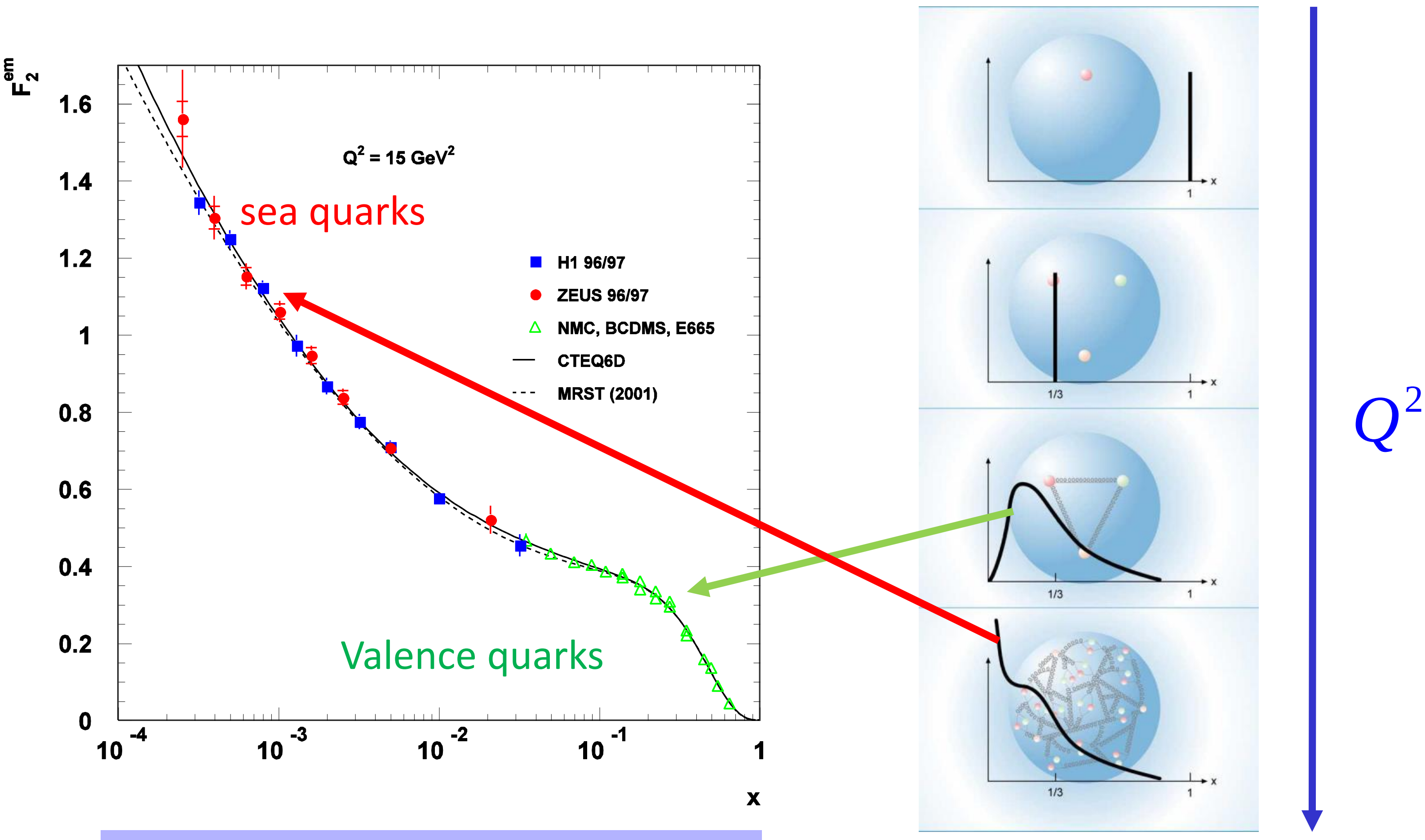
$$\alpha_s(E) = \frac{12\pi}{(33 - 2n_f)\ln\left[\frac{E^2}{\Lambda^2}\right]}$$

n_f = number of quarks active in pair production (up to 6)

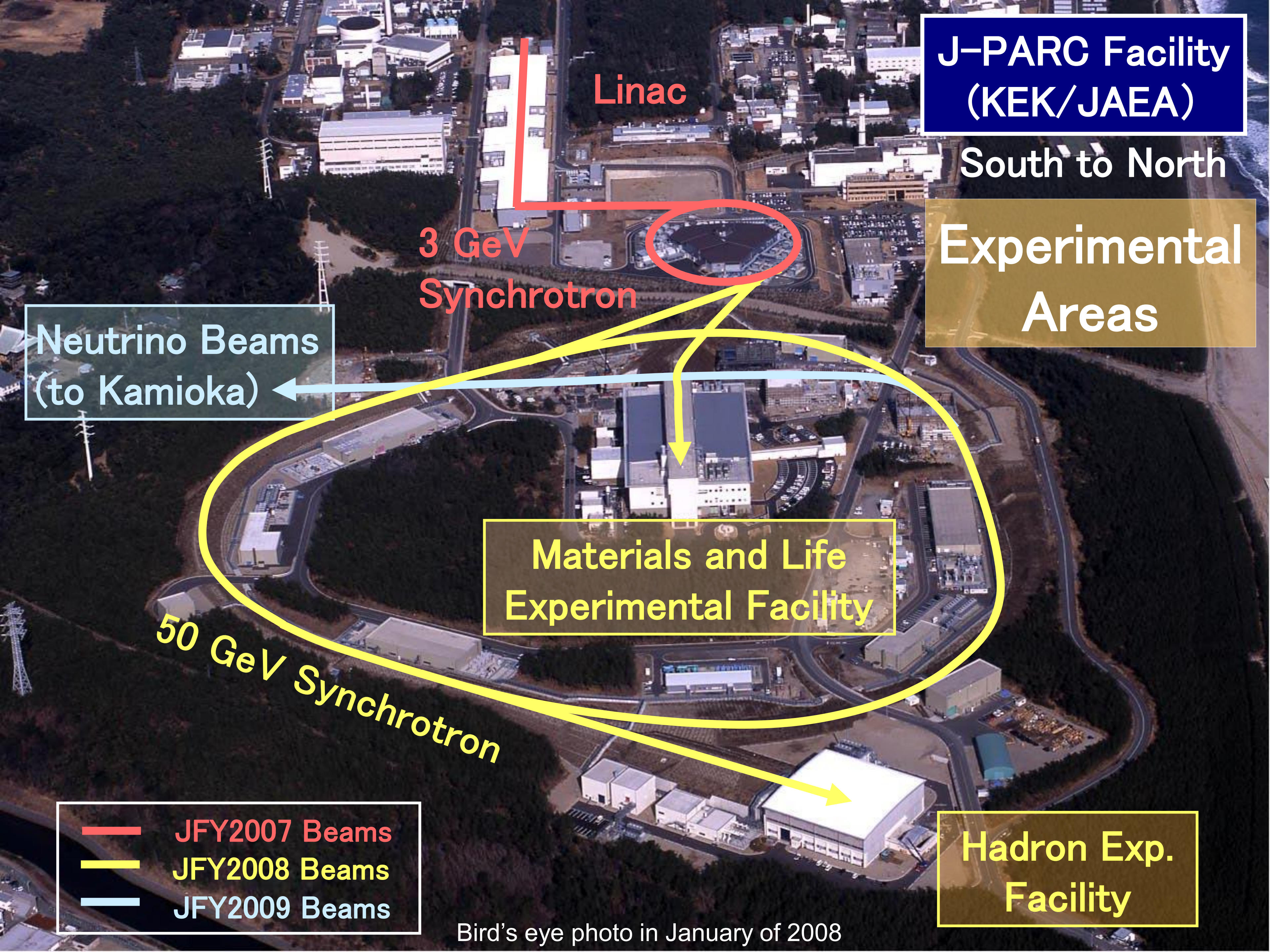
Λ = experimentally determined parameter, ≈ 0.2 GeV

When $E \to \infty, \alpha_s \to 0.$

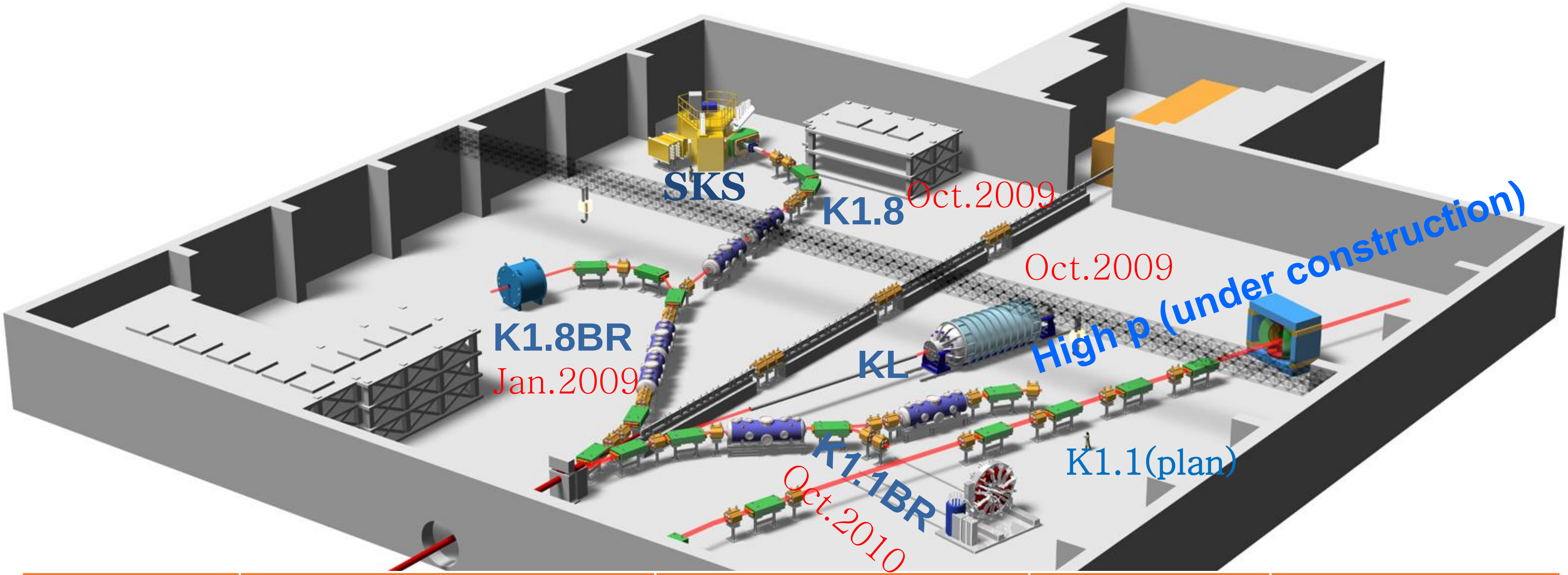
Proton Structure Function



Lots of partons at small x!


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 (HEF)

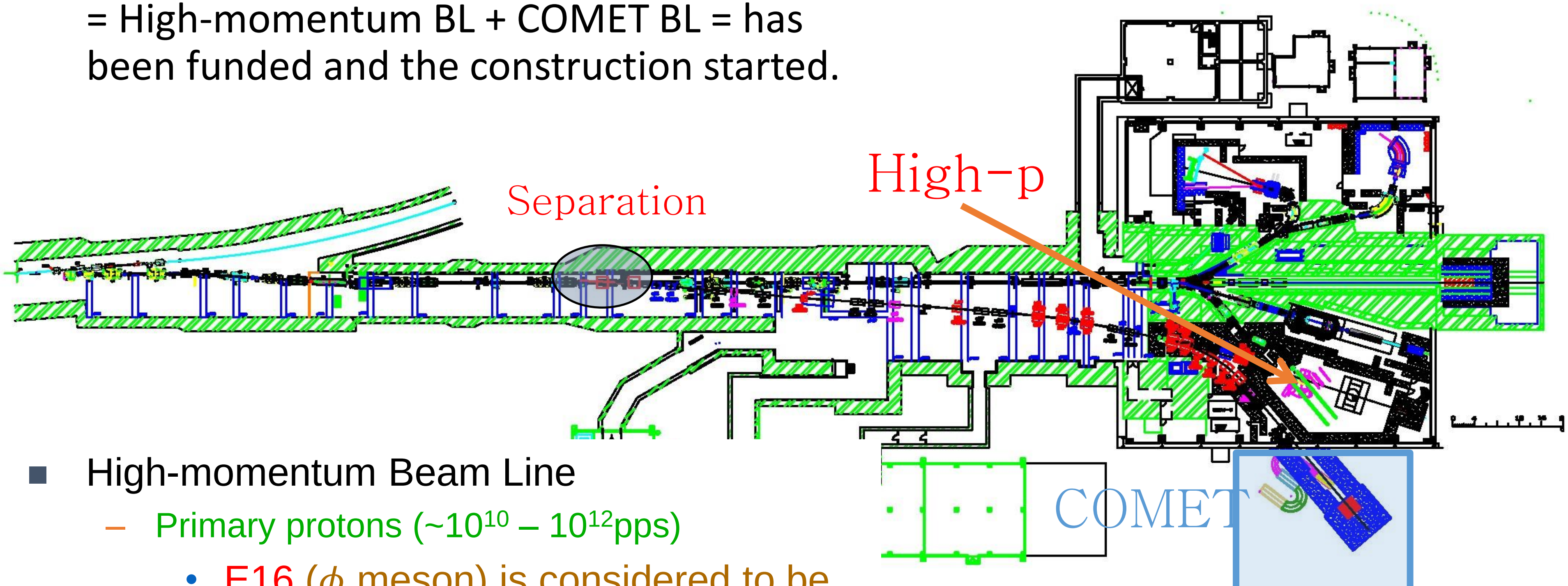


Beam Lines	Experiment	Secondary particles	Max. Mom.	Max. Intensity
K1.8	Hypernuclei, Hadron Physics with S	π, K, p (2 separators)	< 2.0 GeV/c	~10^5 Hz for K^+
K1.8BR	Hadron Physics with S	π, K, p (1 separator)	< 1.0 GeV/c	~10^4 Hz for K^+
K1.1BR	Lepton Flavor violation	π, K, p (1 separator)	< 1.1 GeV/c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

New Primary Proton Beam Line

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

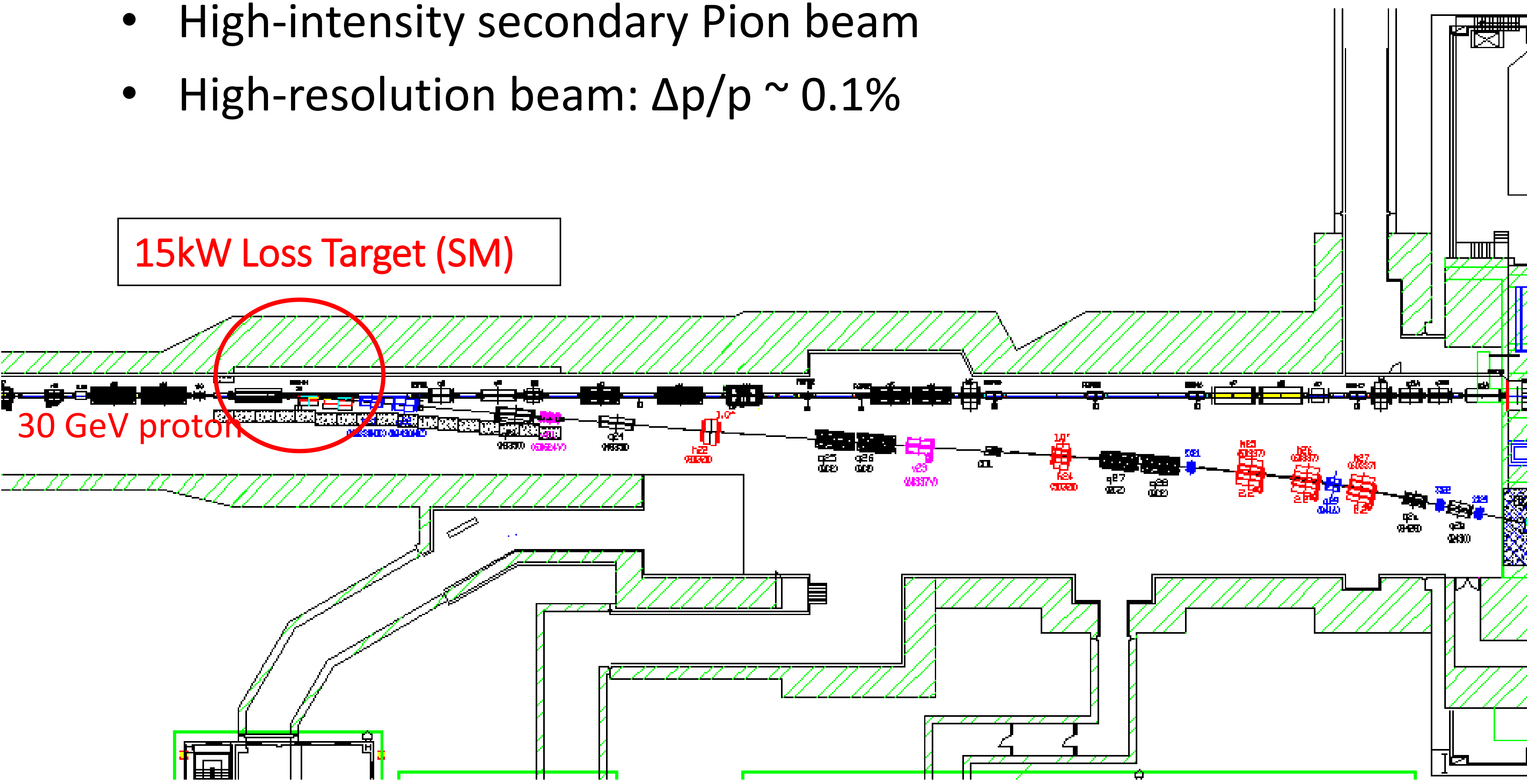


- High-momentum Beam Line
  - Primary protons (~10^{10} – 10^{12}pps)
    - E16 (ϕ meson) is considered to be the first experiment.
  - Unseparated secondary particles (π,K, $\bar{p}$,…)
    - High-resolution secondary beam by adding several quadrupole and sextupole magnets.

- 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.

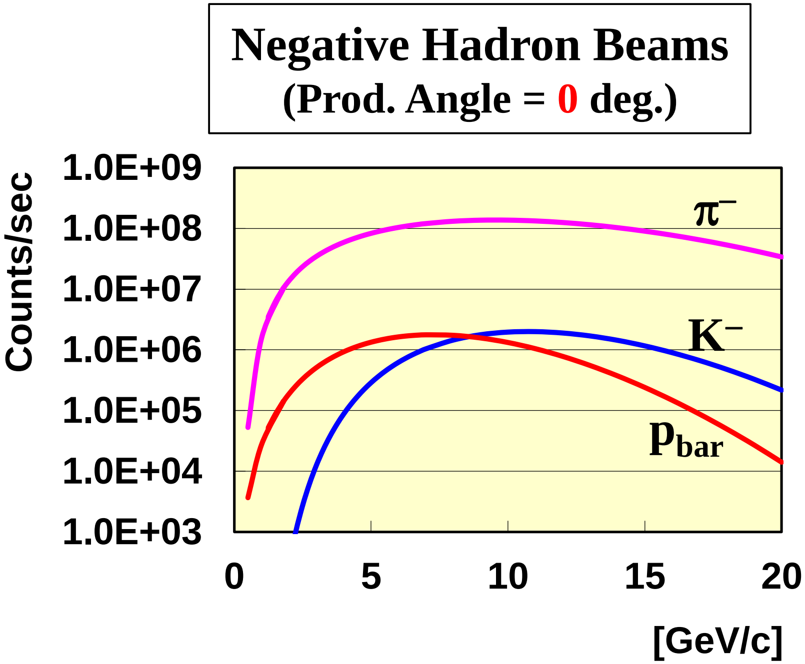
J-PARC High-momentum Beam Line (Hi-P BL)

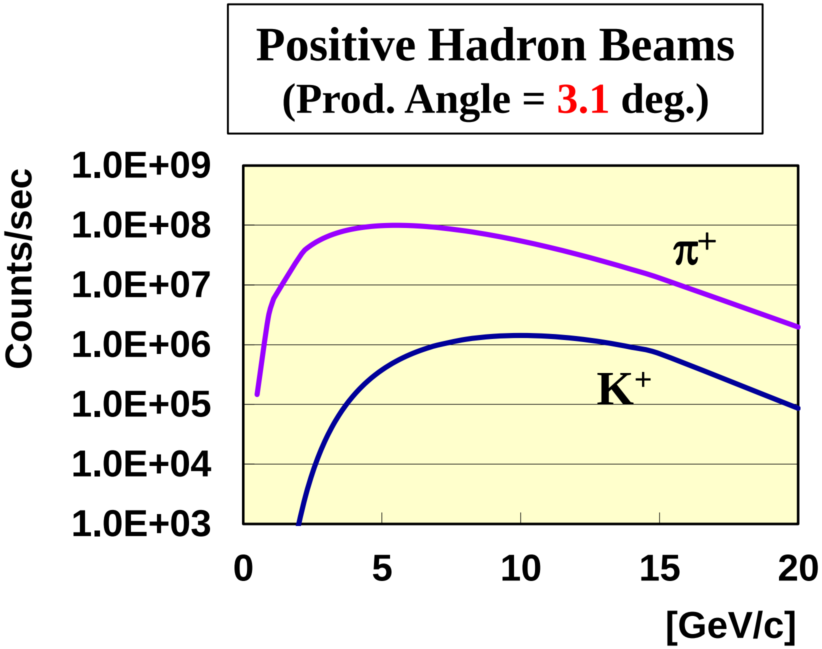
- High-intensity secondary Pion beam
- High-resolution beam: Δp/p ~ 0.1%



J-PARC High-momentum Beam Line (Hi-P BL)

- High-intensity secondary Pion beam
- High-resolution beam: Δp/p ~ 0.1%





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

http://www-conf.kek.jp/hadron1/j-parc-hm-2013/

KEK theory center workshop on
Hadron physics with high-momentum hadron beams at J-PARC in 2013

Kobayashi Hall, 1st Floor, Kenkyu-Honkan (15th, 18th)
Seminar Hall, 1st Floor, 3rd buildling (16th, 17th)

MENU

- 1st circular
- 2nd circular
- Program (slides)
- Participants
- Location: KEK
- Kenkyu-Honkan (M01)
- Kobayashi Hall
- Lounge for banquet
- Seminar Hall
- Visitor information (English)
- Visitor information (Japanese)
- How to reach KEK (General guide)
- Bus/taxi to KEK (Our original guide)
- to Urban hotel (Our original guide)
- KEK restaurant hours
- Nearby restaurants

[Update]
2012.08.09
Home page, 1st circular

2012.11.30

http://research.kek.jp/group/hadron10/j-parc-hm-2015/

KEK theory center workshop on
Hadron physics with high-momentum hadron beams at J-PARC in 2015

Kobayashi Hall, 1st Floor, Kenkyu-Honkan
March 13 - 16, 2015, KEK, Tsukuba, Japan

MENU

- Previous workshop (2013)

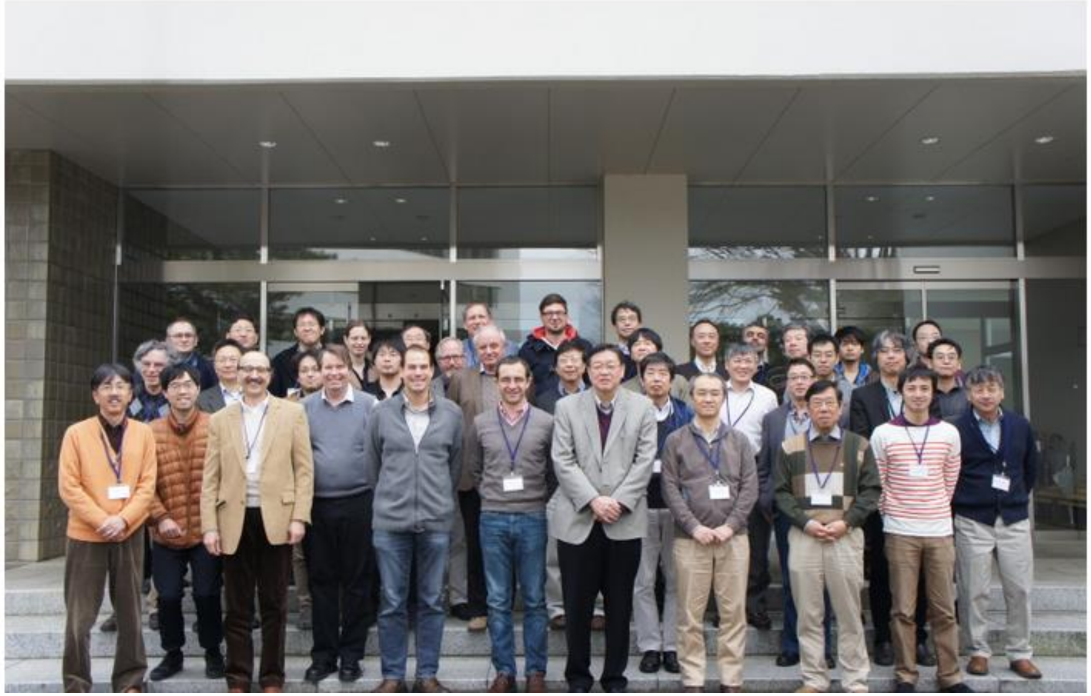
- 1st circular
- 2nd circular

- Program [slides]
- Participant list

- Location: KEK
- Kenkyu-Honkan (M01)
- Kobayashi Hall
- Coffee lounge
- Meeting room 1

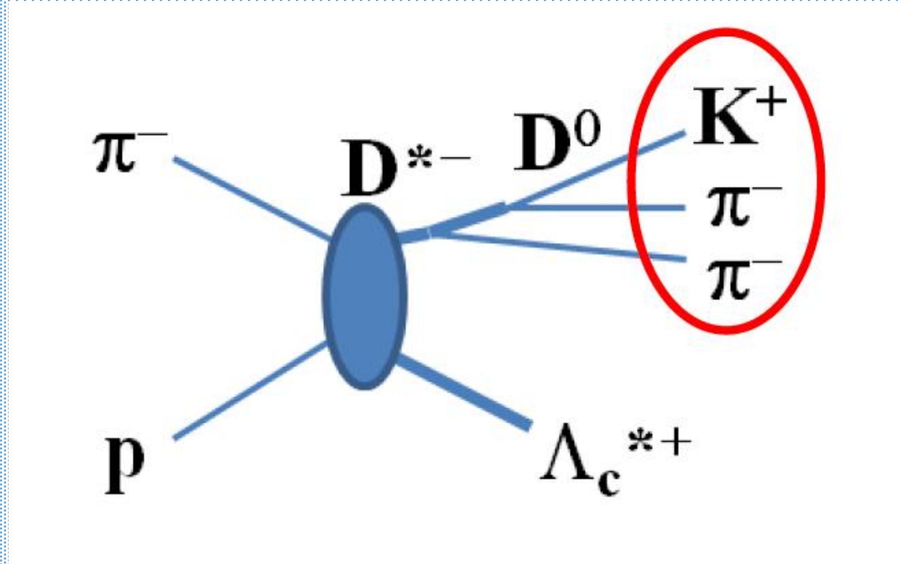
- Visitor information (English)
- Visitor information (Japanese)
- How to reach KEK
- From Narita/Haneda airports

- KEK restaurant
- KEK Cafeteria
- KEK Cafe Prime
- Nearby restaurants



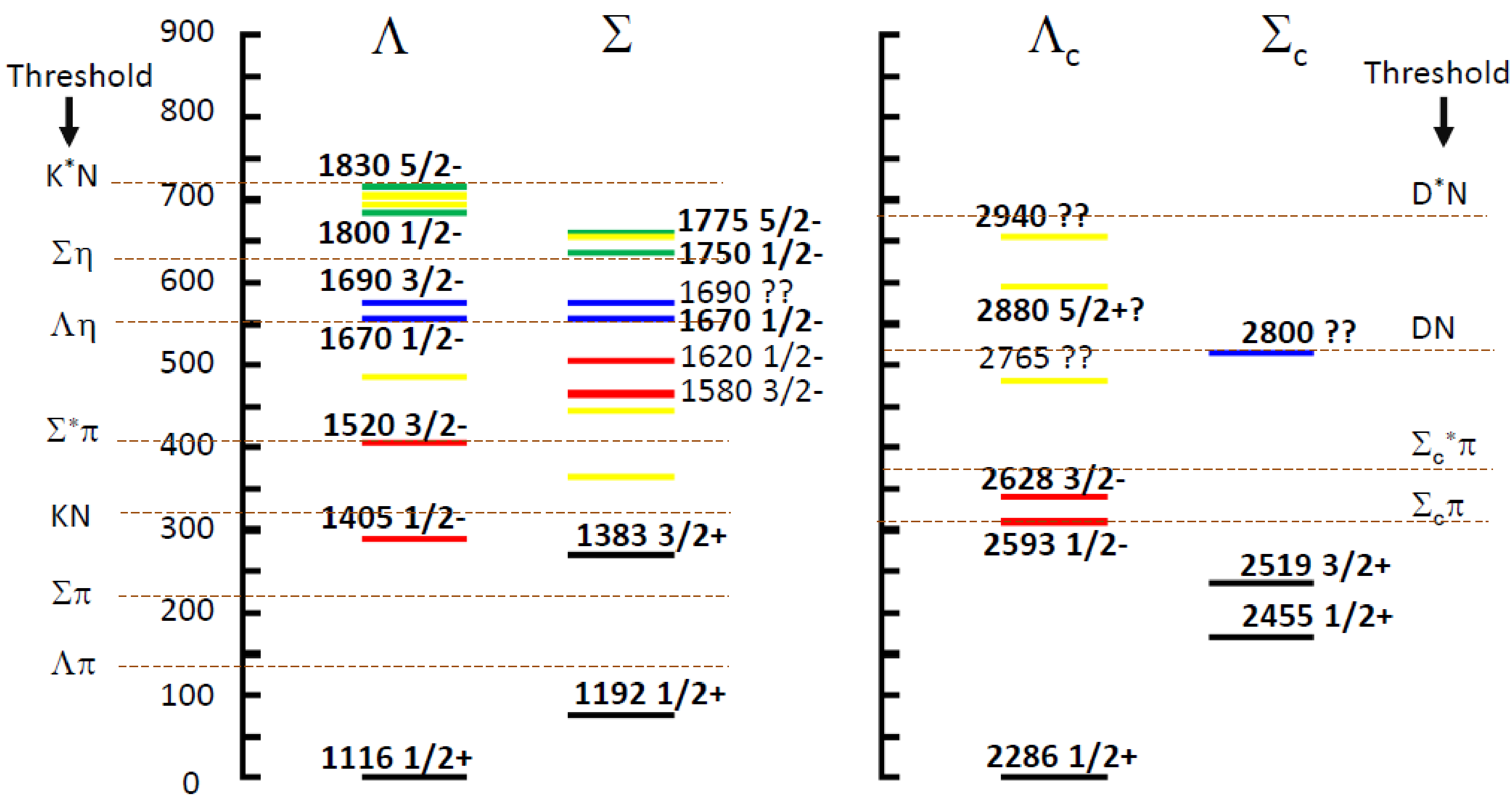
Physics Programs

- **Charm and Strange production**
- **Hard exclusive process**
  - Exclusive $\Lambda(1405)$ production at large angles
    - Valence quark structure of $\Lambda(1405)$
- **Drell-Yan process**
  - Exclusive pion-induced Drell-Yan
    - GPD of proton
    - Pion DA
  - Inclusive pion-induced Drell-Yan:
    - $d(x)/u(x)$ at large x
    - Violation of Lam-Tung relation, BM functions
    - Pion PDF



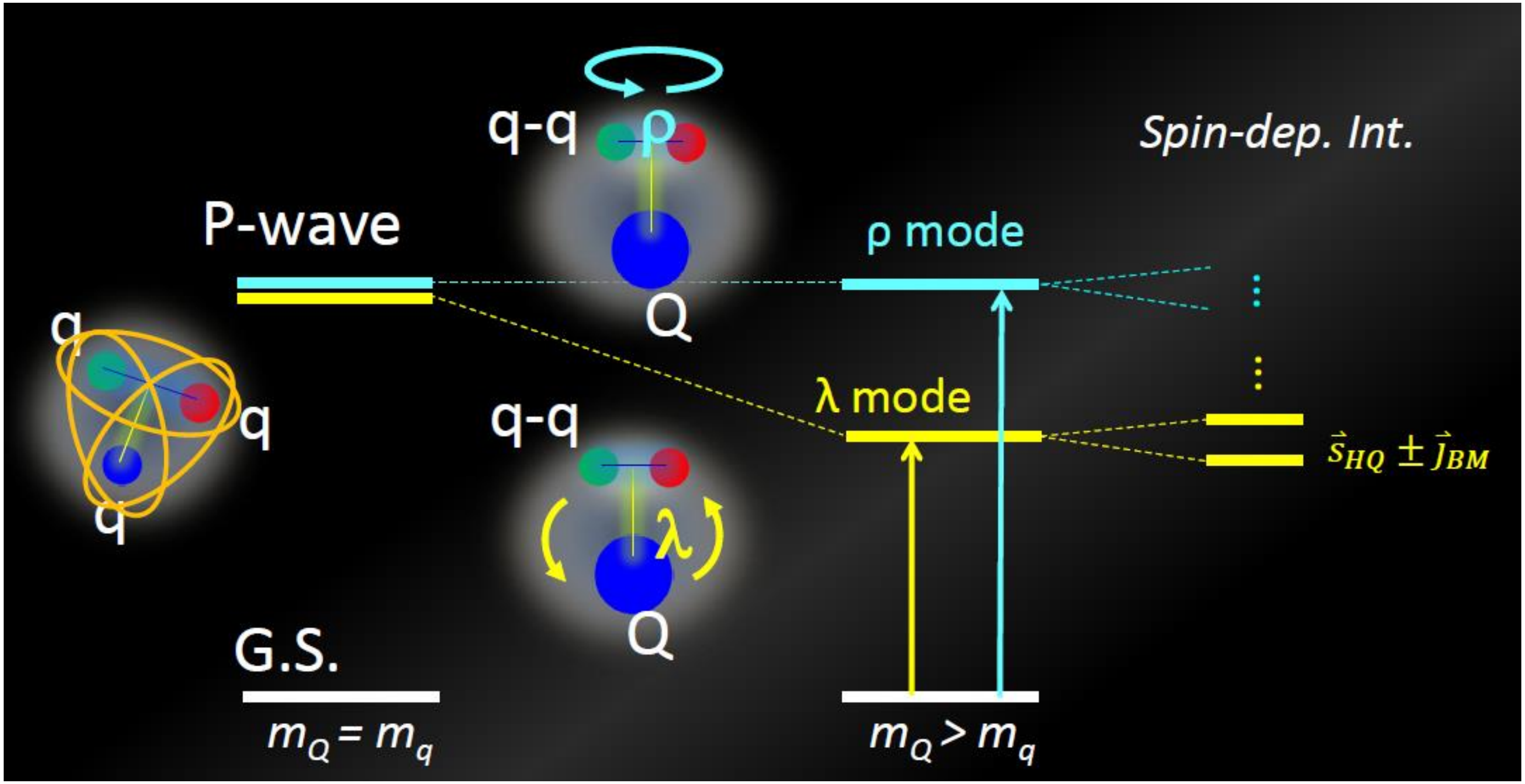
Charm and Strange production process

Charmed Baryon Spectroscopy



H. Noumi, KEK workshop 2015

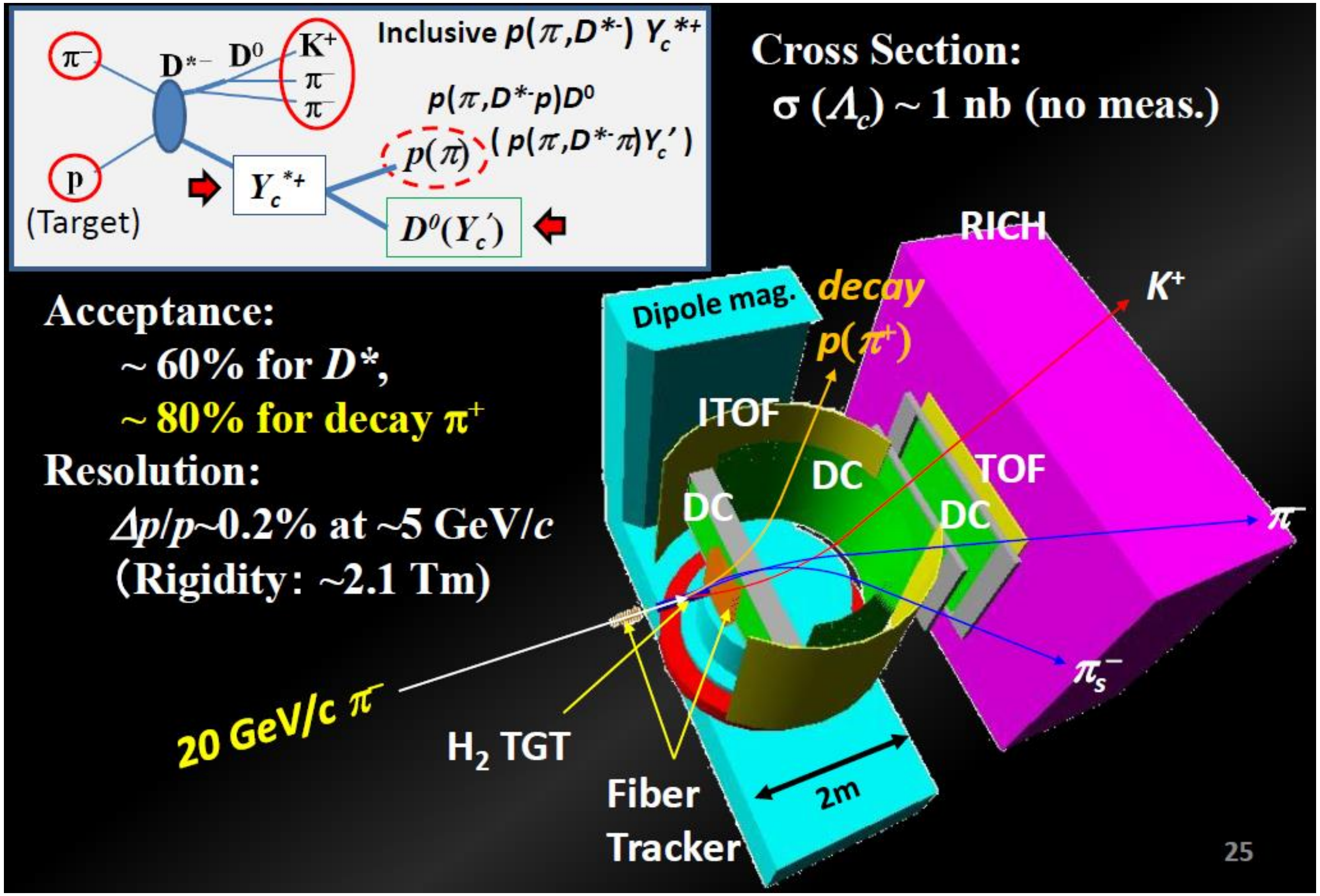
Di-quark Correlation in Heavy-quark systems



H. Noumi, KEK workshop 2015

J-PARC E50

Stage-1 approved by J-PARC PAC-18, August 12, 2014.



H. Noumi, KEK workshop 2015

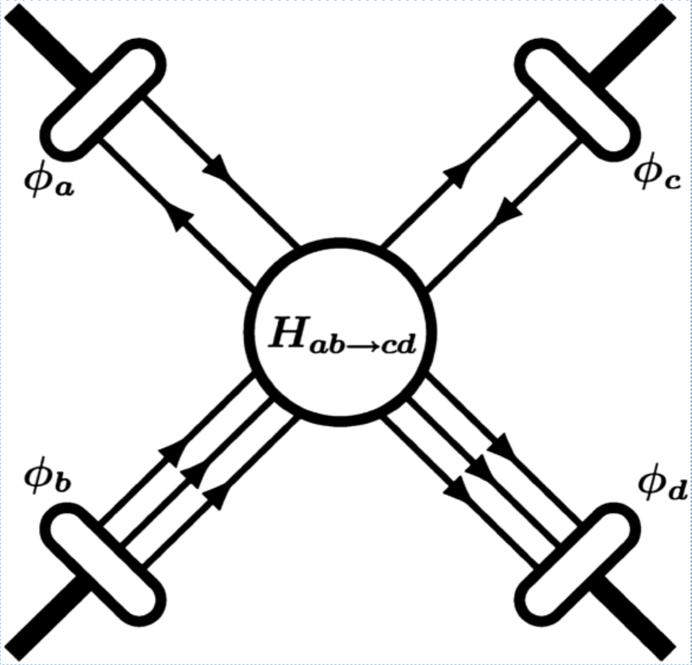
Ξ Baryon Spectroscopy (LOI)

Ξ Baryon Spectroscopy with High-momentum Secondary Beam

M. Naruki and K. Shirotori
Department of Physics, Kyoto University, Kyoto, 606-8502, Japan and
Research Center for Nuclear Physics (RCNP), 10-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan
(Dated: April 14, 2014)

We express our interest in performing the Ξ baryon spectroscopy with high-momentum secondary beams. The experimental information on the excited states of Ξ baryon is largely lacking. The physics cases and possibilities to investigate Ξ^* states using the high-momentum beam line is discussed. The enough sensitivity is expected to determine the excited state up to 2 GeV/c^2 systematically with a reasonable beam time in both kaon and π induced reactions. The high intense secondary beam provide an opportunity to investigate an unknown field of Ξ^* baryons.

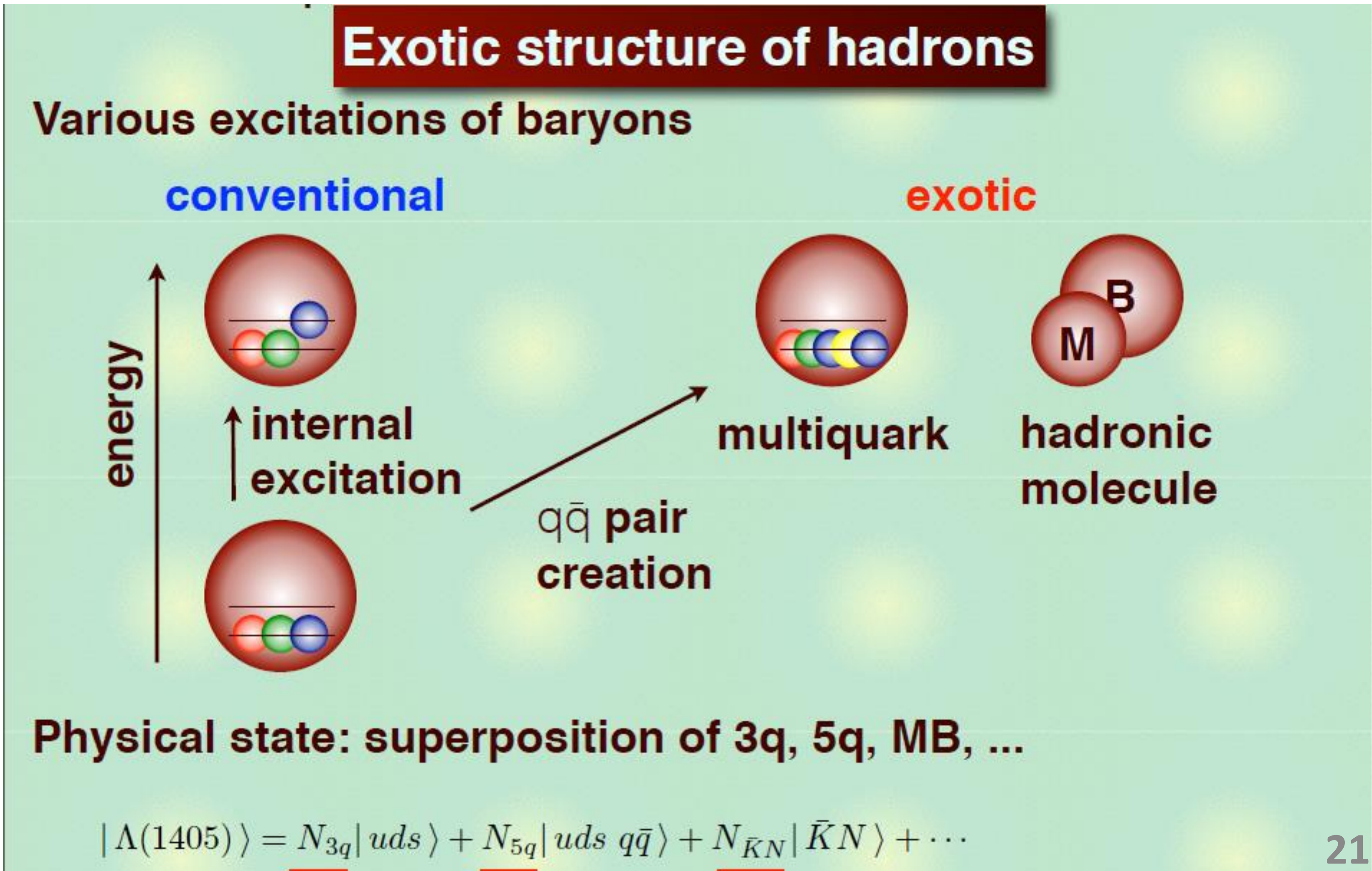
Reaction	σ [μb]	Beam [/spill]	B.R.	Acceptance [%]	Y_{Total}	$Y_{Decay/bin}$
$K^- p \to \Xi^{*-} K^+$	1.0	10^6	1.0	50	3.1×10^5	2500
$K^- p \to \Xi^{*-} K^{*+}$	1.0	10^6	0.23	50	0.7×10^5	580
$K^- p \to \Xi^{*0} K^{*0}$	1.0	10^6	0.67	50	2.1×10^5	1700
$\pi^- p \to \Xi^{*-} K^{*0} K^+$	0.1	10^7	0.67	50	3.1×10^5	2500



Hard exclusive production process

Quark Structure of Exotic Hadrons

T. Hyodo, NSTAR 2015



$\Lambda(1405)$

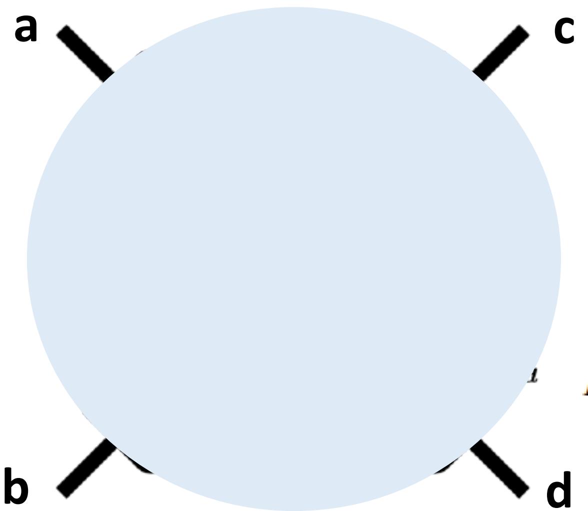
- *J. Hall et al. [PRL 114, 132002 (2015); 1411.3402]:* **Lattice QCD, $\bar{K}$Nmolecule**.
- *T. Sekihara and S. Kumano [PRC 89, 025202 (2014); 1311.4637]:* **radiative decay for determining the compositeness**.
- *L. Roca and E. Oset [PRC 87, 055201 (2013); 1301.5741]:* **Two-pole structures, $\bar{K}$N and $\pi\Sigma$**.
- *T. Hyodo [Int. J. Mod. Phys. A, 28, 1330045 (2013); 1310.1176]:* **compositeness property**.
- *T. Sekihara et al. [Phys.Rev.C83:055202(2011); 1012.3232]:* **meson-baryon coupled-channels chiral dynamics, $\bar{K}$Nmolecule**.
- …

Production from different channels, decay, size and medium effect…

Large-angle (Hard) Exclusive Process

$a + b \rightarrow c + d$

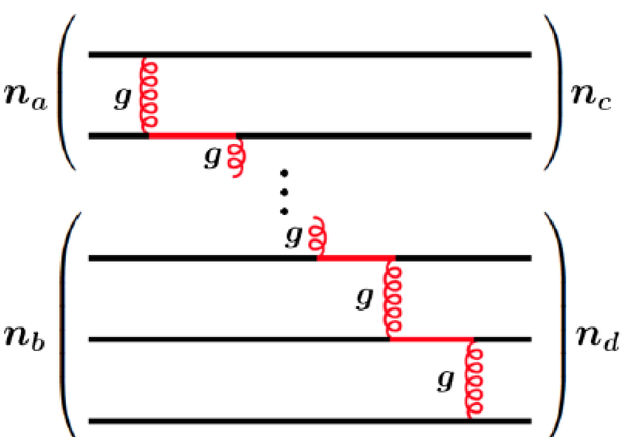
H. Kawamura et al., PRD 88, 034010 (2013)



$$\frac{d\sigma_{ab\to cd}}{dt} \simeq \frac{1}{16\pi s^2} \overline{\sum_{\text{pol}}} |M_{ab\to cd}|^2,$$

$$s,\ |t| \gg m_i^2 (i = a, b, c, d)$$

$$M_{ab\to cd} = \int [dx_a][dx_b][dx_c][dx_d] \phi_c([x_c]) \phi_d([x_d]) \times H_{ab\to cd}([x_a], [x_b], [x_c], [x_d], Q^2) \phi_a([x_a]) \phi_b([x_b]),$$



Leading and connected Feynman diagrams

Gluon propagator

External quarks

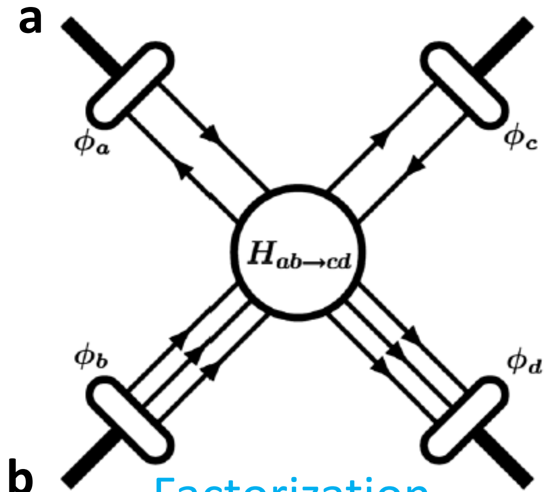
$$[\hat{M}_{ab\to cd}] = \left[\frac{1}{(P^2)^{n/2-1}} \frac{1}{P^{n/2-2}} P^{n/2} \right] = \left[\frac{1}{s^{n/2-2}} \right].$$

Quark propagator

Large-angle (Hard) Exclusive Process

$a + b \to c + d$

H. Kawamura et al., PRD 88, 034010 (2013)

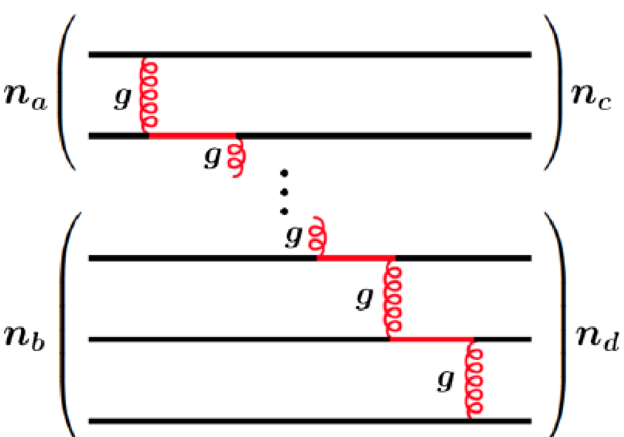


Factorization

$$\frac{d\sigma_{ab\to cd}}{dt} \simeq \frac{1}{16\pi s^2} \overline{\sum_{\text{pol}}} |M_{ab\to cd}|^2,$$

$$s,\ |t| \gg m_i^2 (i = a, b, c, d)$$

$$M_{ab\to cd} = \int [dx_a][dx_b][dx_c][dx_d] \phi_c([x_c]) \phi_d([x_d]) \times H_{ab\to cd}([x_a],[x_b],[x_c],[x_d],Q^2) \phi_a([x_a]) \phi_b([x_b]),$$



Leading and connected Feynman diagrams

Gluon propagator   External quarks

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Quark propagator

Constituent-Counting Rule in Hard Exclusive Process

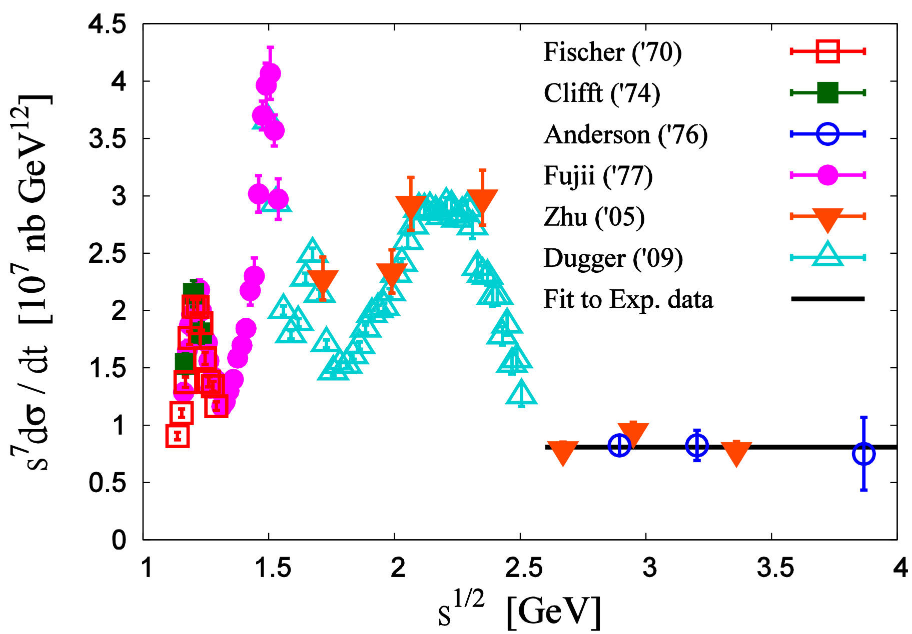
H. Kawamura et al., PRD 88, 034010 (2013)

$$\frac{d\sigma}{dt}(a+b \to c+d) = \frac{1}{s^{n-2}} f(\theta_{CM}) \quad n = n_a + n_b + n_c + n_d$$

G. P. Lepage and S. J. Brodsky, PRD 22, 2157 (1980).

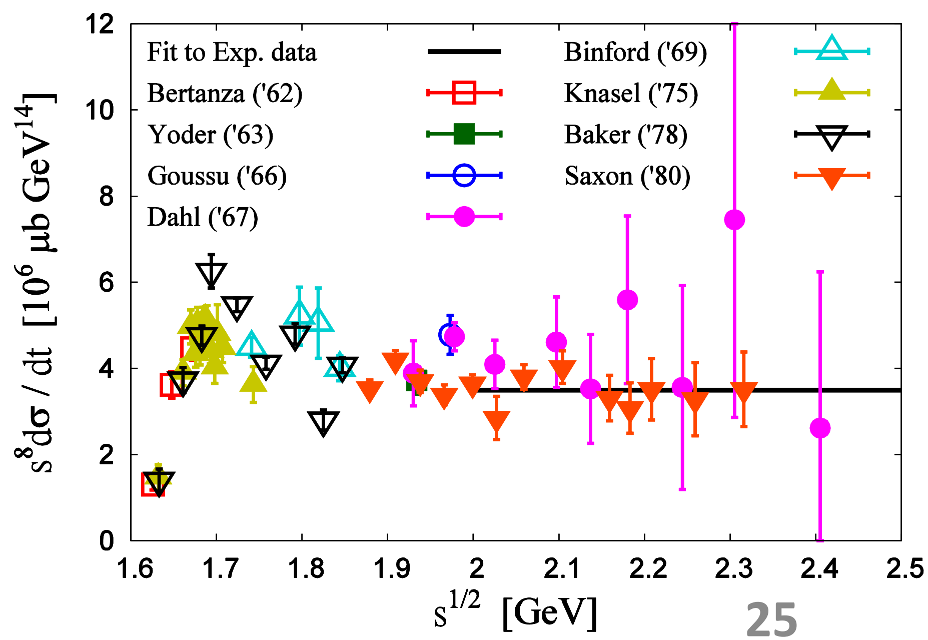
$n = 1+3+2+3 = 7$

$\gamma + p \to \pi^{+} + n$



$n = 2+3+2+3 = 8$

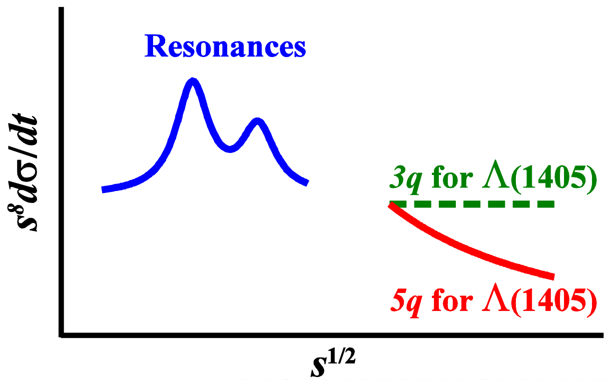
$\pi^{-} + p \to K^{0} + \Lambda$

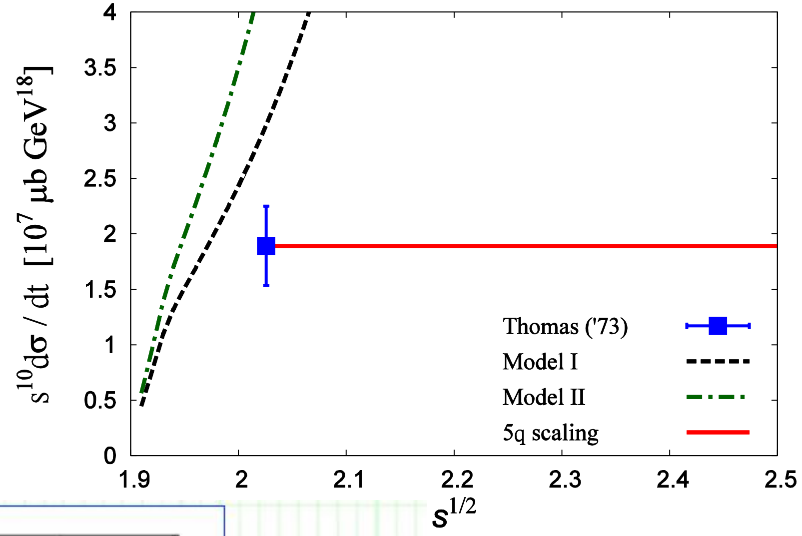


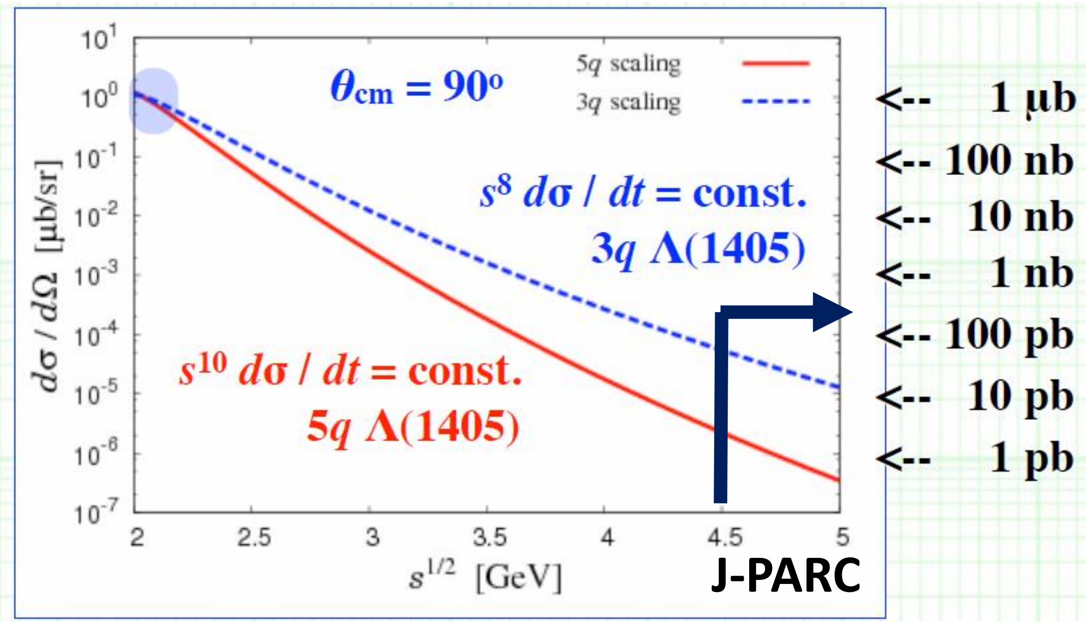
Valence-Quark Degrees of Λ(1405)

H. Kawamura et al., PRD 88, 034010 (2013)

$$\pi^- + p \rightarrow K^0 + \Lambda(1405)$$



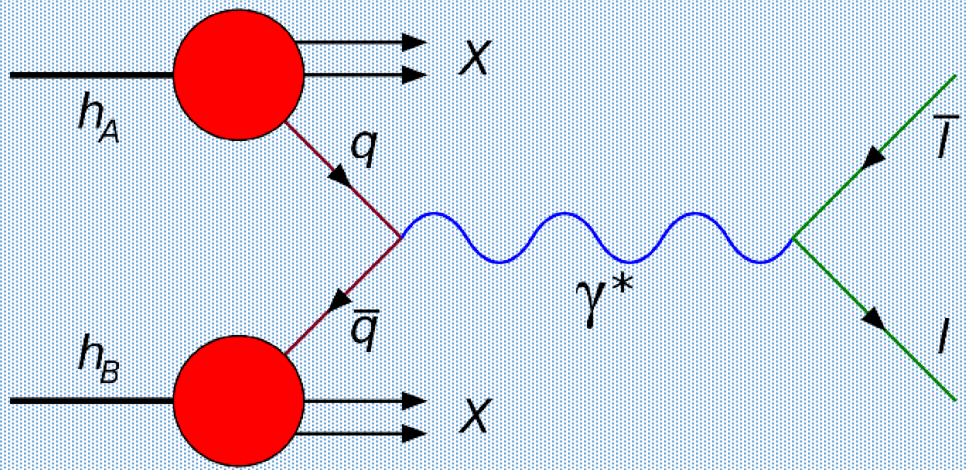




T. Sekihara
KEK workshop 2015

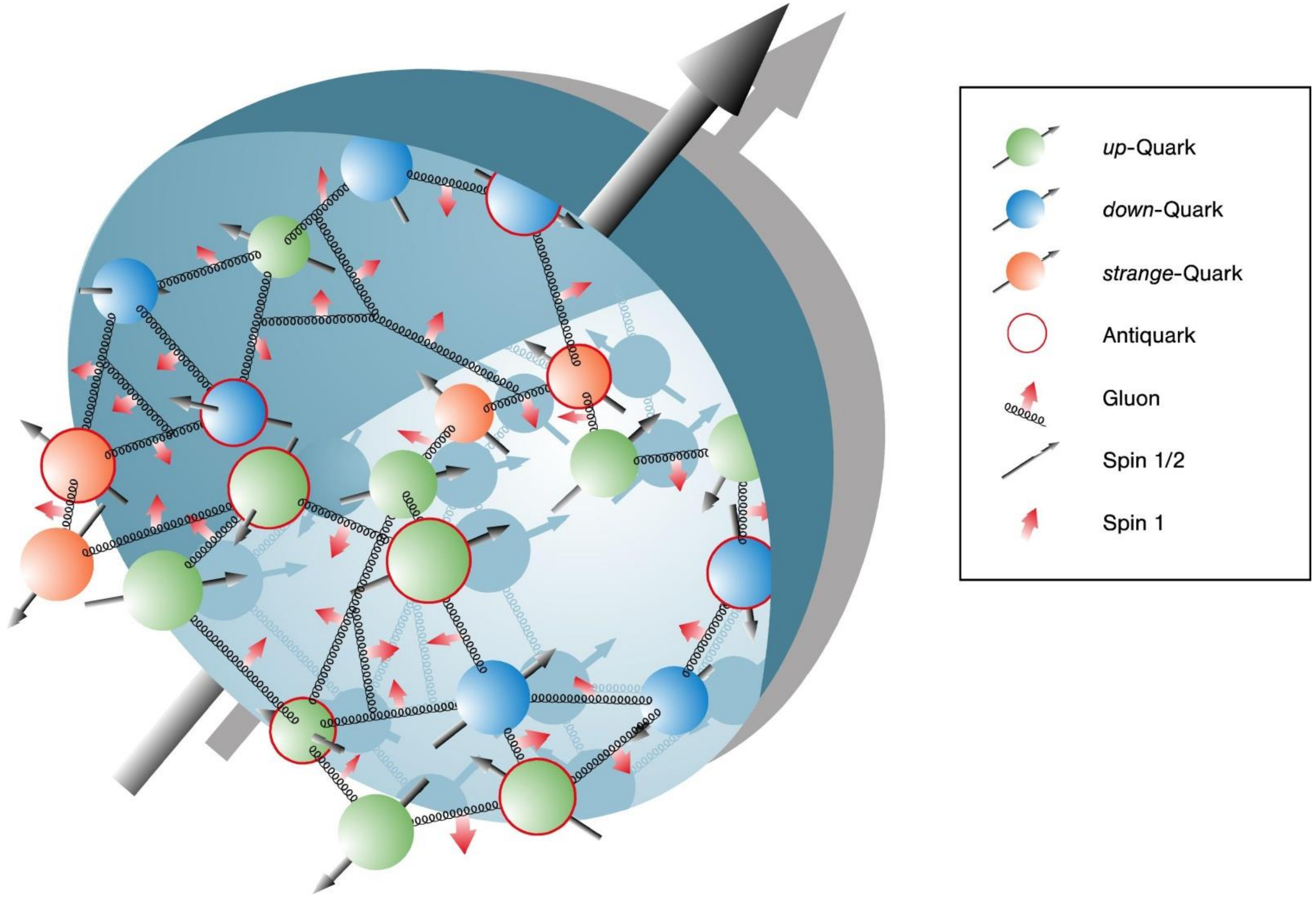
Uniqueness of hadron physics studied at Hi-P BL of J-PARC

- The beam energy of hadrons at J-PARC at **5-15** GeV ($\sqrt{s} = \mathbf{3 - 5.5}$ GeV) is most ideal for studying the **hard exclusive processes** and discerning the quark-hadron transition in the strong interaction.
  - Valance-like partonic degrees of freedom of hadrons could be discerned, compared to the collisions at low-energy regime.
  - Reasonably large cross sections, compared to those at higher energies.



Drell-Yan process

Origin of Proton Spin



High energy spin experiments

C.A. Aidala, S.D. Bass, D. Hasch, G.K. Mallot, Rev. Mod. Phys. 85, 655–691 (2013)

Experiment	Year	Beam	Target	Energy (GeV)	Q^2 (GeV^2)	x
Completed experiments						
SLAC – E80, E130	1976–1983	e^-	H-butanol	$\lesssim 23$	1–10	0.1–0.6
SLAC – E142/3	1992–1993	e^-	NH_3, ND_3	$\lesssim 30$	1–10	0.03–0.8
SLAC – E154/5	1995–1999	e^-	NH_3, ^6LiD, ^3He	$\lesssim 50$	1–35	0.01–0.8
CERN – EMC	1985	μ^+	NH_3	100, 190	1–30	0.01–0.5
CERN – SMC	1992–1996	μ^+	H/D-butanol, NH_3	100, 190	1–60	0.004–0.5
FNAL E581/E704	1988–1997	p	p	200	~ 1	$0.1 < x_F < 0.8$
Analyzing and/or Running						
DESY – HERMES	1995–2007	e^+, e^-	H, D, ^3He	~ 30	1–15	0.02–0.7
CERN – COMPASS	2002–2012	μ^+	NH_3, ^6LiD	160, 200	1–70	0.003–0.6
JLab6 – Hall A	1999–2012	e^-	^3He	$\lesssim 6$	1–2.5	0.1–0.6
JLab6 – Hall B	1999–2012	e^-	NH_3, ND_3	$\lesssim 6$	1.-5	0.05–0.6
RHIC – BRAHMS	2002–2006	p	p (beam)	2× (31–100)	~ 1–6	$-0.6 < x_F < 0.6$
RHIC – PHENIX, STAR	2002+	p	p (beam)	2× (31–250)	~ 1–400	~ 0.02–0.4
Approved future experiments (in preparation)						
CERN – COMPASS–II	2014+	μ^+, μ^-	unpolarized H_2	160	~ 1–15	~ 0.005–0.2
		π^-	NH_3	190		$-0.2 < x_F < 0.8$
JLab12 – HallA/B/C	2014+	e^-	HD, NH_3, ND_3, ^3He	$\lesssim 12$	~ 1–10	~ 0.05–0.8


October 5th-8th, 2015
Institute of Physics, Academia Sinica
Taipei, Taiwan
The 10th Circum-Pan-Pacific Symposium on High Energy Spin Physics
Pacific Spin 2015
Transverse and longitudinal spin structure of nucleons
Nucleon structure (form factors, generalized parton distributions)
Spin structure of hadrons
Spin in hard QCD processes
Fundamental symmetries and physics beyond the SM
Polarized ion and lepton sources and targets
Organizers:
Wen-Chen Chang (Academia Sinica, Co-Chair)
Jiunn-Wei Chen (National Taiwan Univ.)
Chung-Wen Kao (Chung Yuan Christian Univ.)
Cheng-Pang Liu (National Dong Hwa Univ.)
Augustine Ei-Fong Chen (National Central Univ.)
Hai-Yang Cheng (Academia Sinica, Co-Chair)
Hsiang-Nan Li (Academia Sinica)
International Advisory Committee:
Mauro Anselmino (Torino)
Hai-Yang Cheng (Academia Sinica)
Haiyan Gao (Duke Kunshan/Duke Univ.)
Takahiro Iwata (Univ. Yamagata)
Shunzo Kumano (KEK)
Zuo-Tang Liang (Shandong Univ.)
Jian-Wei Qiu (BNL/Stony Brook)
Ernst Sichtermann (LBL)
Jian-Ping Chen (JLAB)
Seonho Choi (Seoul National Univ.)
Yuji Goto (RIKEN)
Xiang-Dong Ji (SJTU/Maryland)
Fabienne Kunne (CEA/IRFU Saclay)
Bo-Qiang Ma (Peking Univ.)
Toshi-Aki Shibata (Tokyo Tech)
Anthony W. Thomas (Univ. Adelaide)
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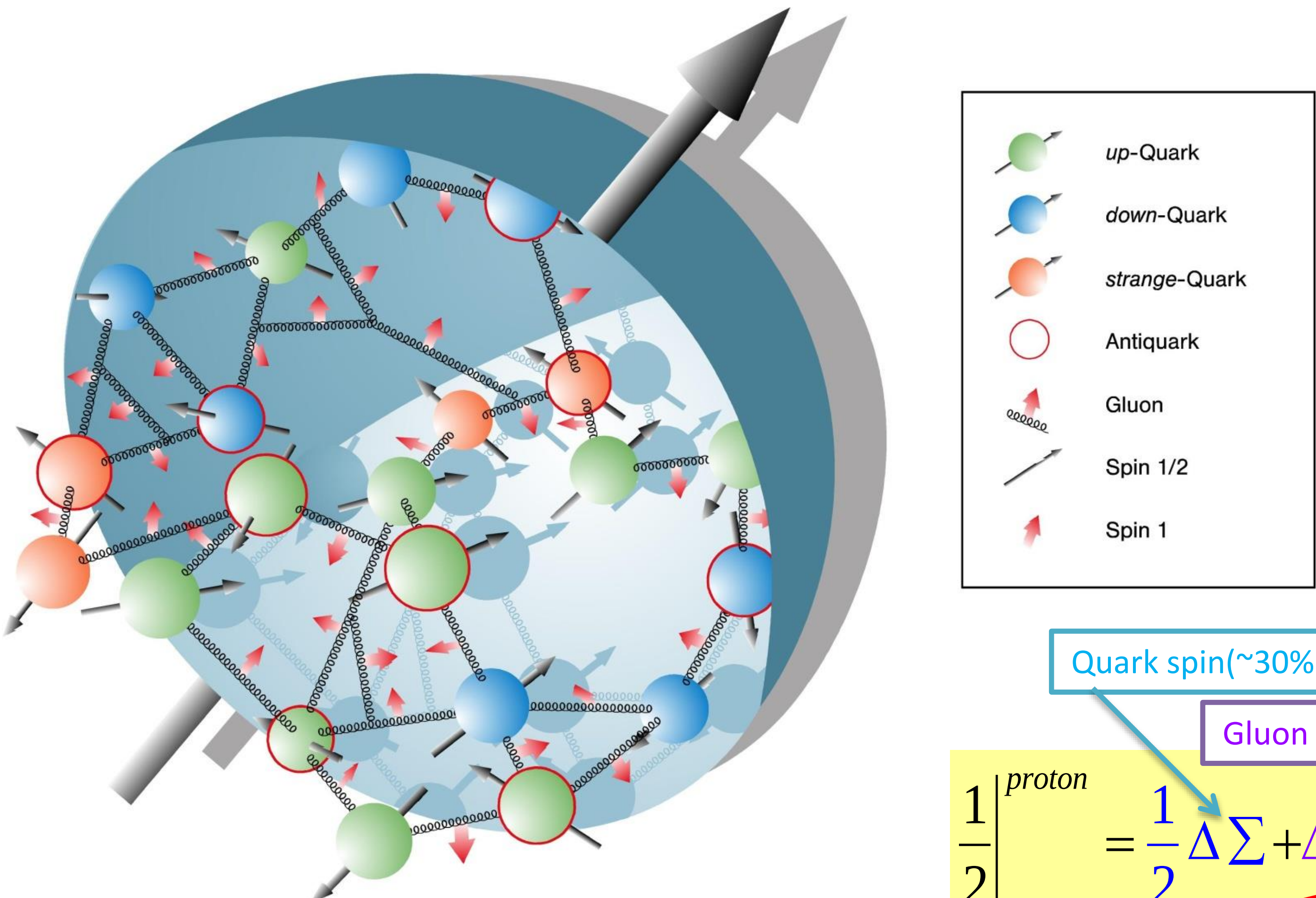
Ministry of Science and Technology
ANPhA
http://www.phys.sinica.edu.tw/PacSPIN2015/

Pacific Spin 2015

http://www.phys.sinica.edu.tw/PacSPIN2015

Origin of Proton Spin



Quark spin(~30%)

Gluon spin(~0)

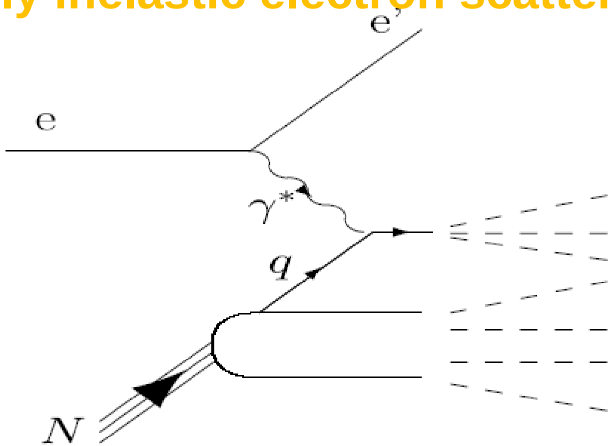
$$\frac{1}{2}\bigg|^{proton} = \frac{1}{2}\Delta\Sigma + \Delta g + L_q$$

Quark orbital angular momentum(?)

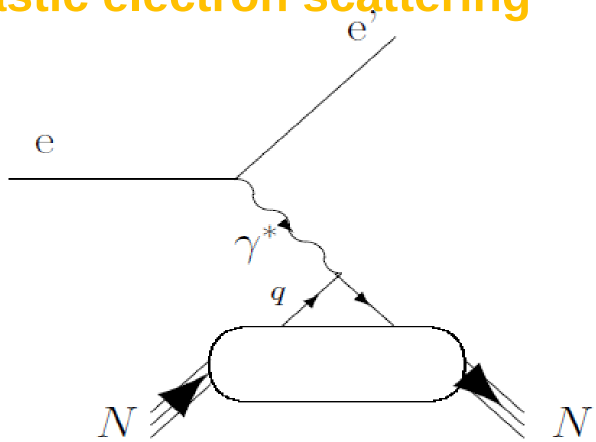
$$\overrightarrow{L_Z} = \overrightarrow{r_T} \times \overrightarrow{P_T}$$

Parton Distribution Functions and Form Factors

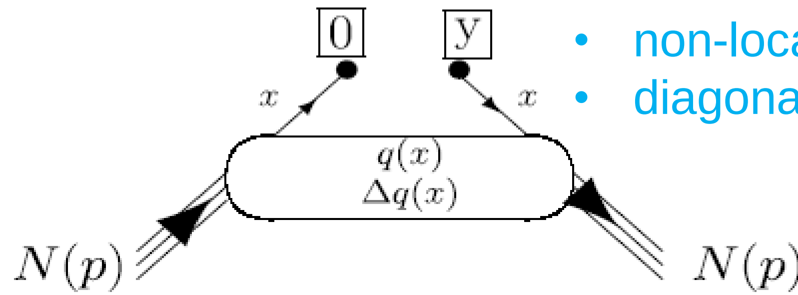
Deeply inelastic electron scattering (DIS)



Elastic electron scattering

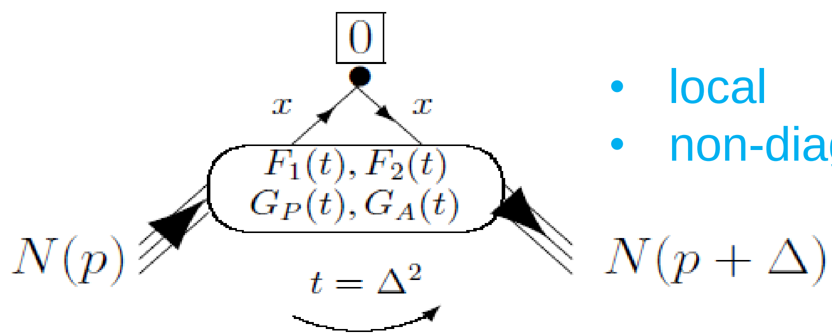


Parton Distribution Functions



- non-local
- diagonal

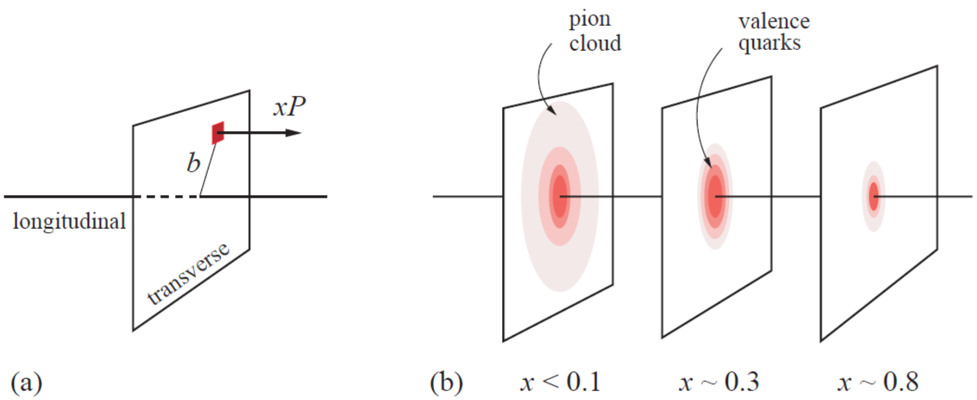
Form Factors



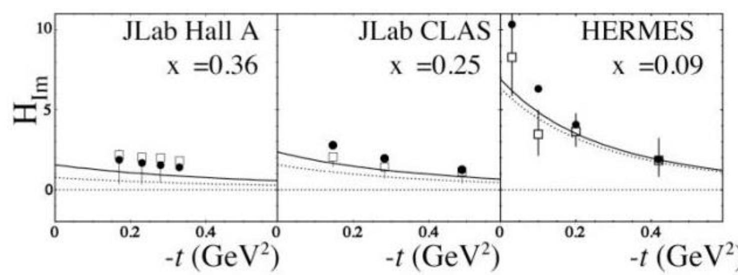
- local
- non-diagonal

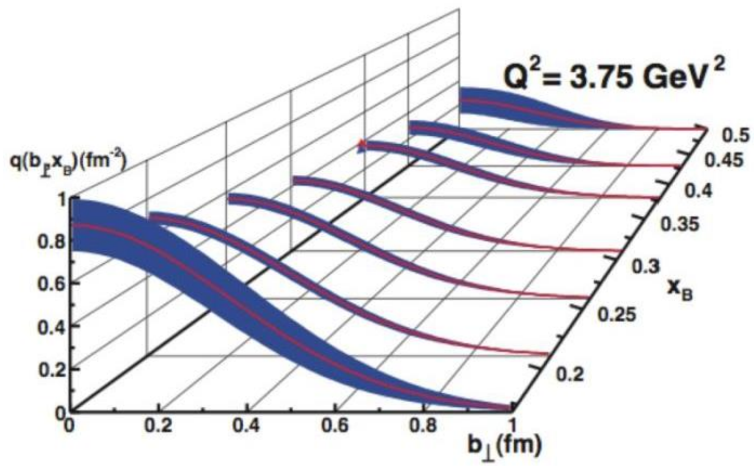
M. Guidal, H. Moutarde and M. Vanderhaeghen, Rep. Prog. Phys. 76 (2013) 066202.

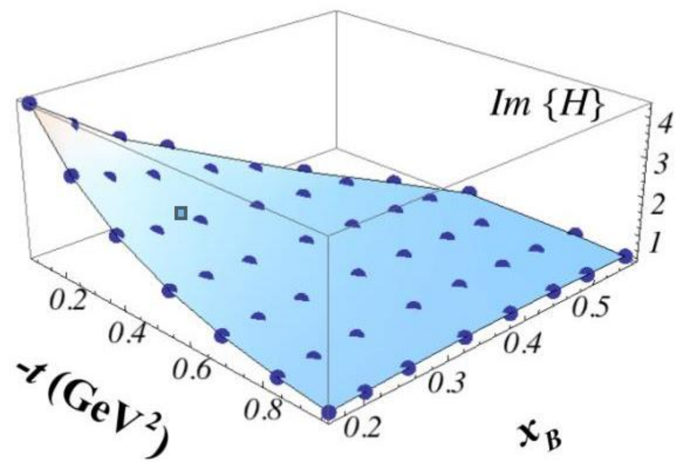
Generalized Parton Distribution



JLAB12 CDR, arXiv:1208.1244

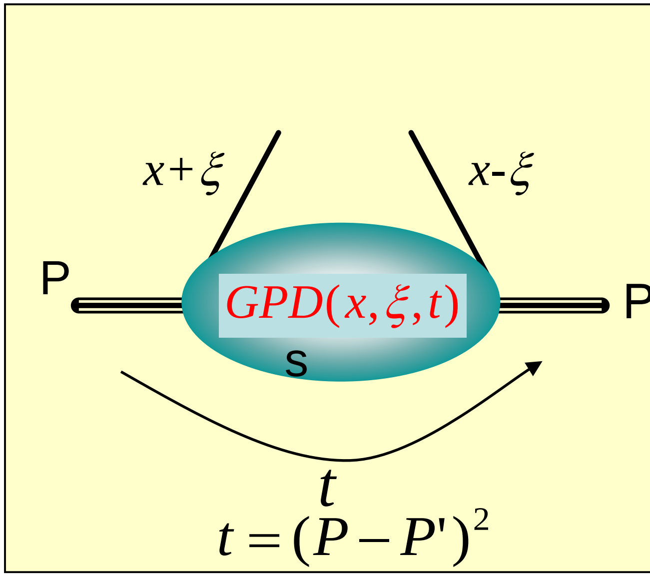






- 1+2D description of the nucleon structure
- Correlations among longitudinal momenta and transverse positions
- Connection to quark orbital angular momentum

Generalized Parton Distribution (GPD)



$t=\xi=0$

$$H_f(x,0,0)=q_f(x)=-\bar{q}_f(-x)$$
$$\tilde{H}_f(x,0,0)=\Delta q_f(x)=-\Delta\bar{q}_f(-x)$$

The first moments

$$\int_{-1}^{1}dx\sum_f H_f(x,\xi,t)=F_1(-t)$$
$$\int_{-1}^{1}dx\sum_f E_f(x,\xi,t)=F_2(-t)$$
$$\int_{-1}^{1}dx\sum_f \tilde{H}_f(x,\xi,t)=G_A(-t)$$
$$\int_{-1}^{1}dx\sum_f \tilde{E}_f(x,\xi,t)=G_p(-t)$$

The second moments

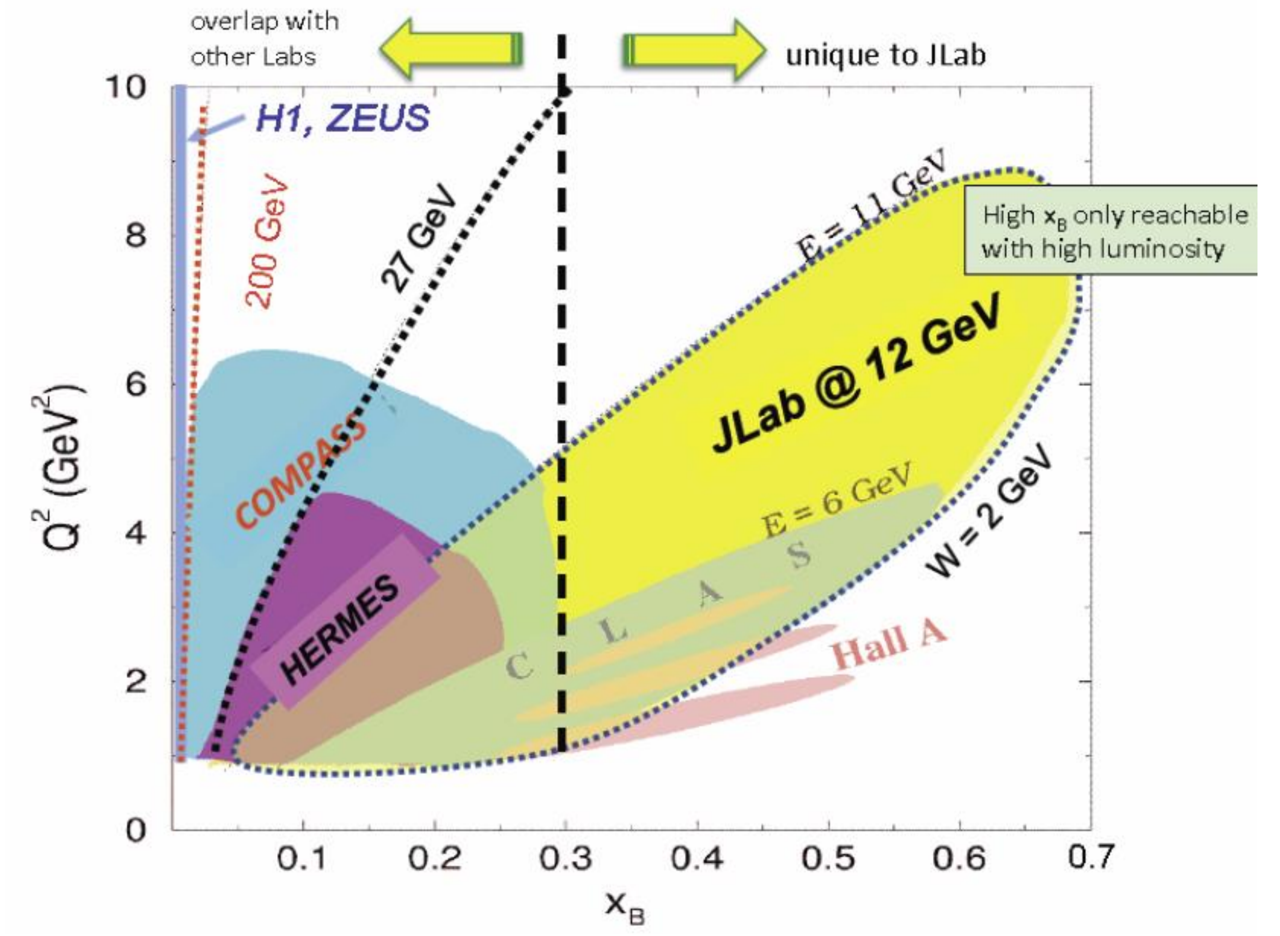
	γ^μ	$\gamma^\mu\gamma^5$
no spin flip	$H_f(x,\xi,t)$	$\tilde{H}_f(x,\xi,t)$
spin flip	$E_f(x,\xi,t)$	$\tilde{E}_f(x,\xi,t)$

Ji's sum rule

$$J_f=\frac{1}{2}\Delta\Sigma^f+L^f=\frac{1}{2}\int_{-1}^{1}xdx\,[H_f(x,\xi,0)+E_f(x,\xi,0)]$$

The orbital angular momentum of quarks can be known.

Worldwide Activities for Measuring GPD

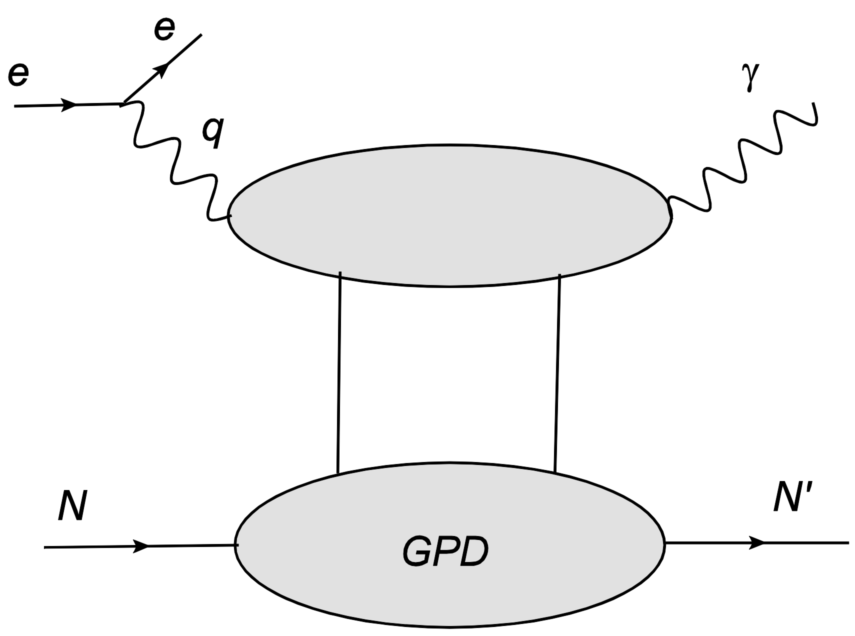


arXiv:1208.1244

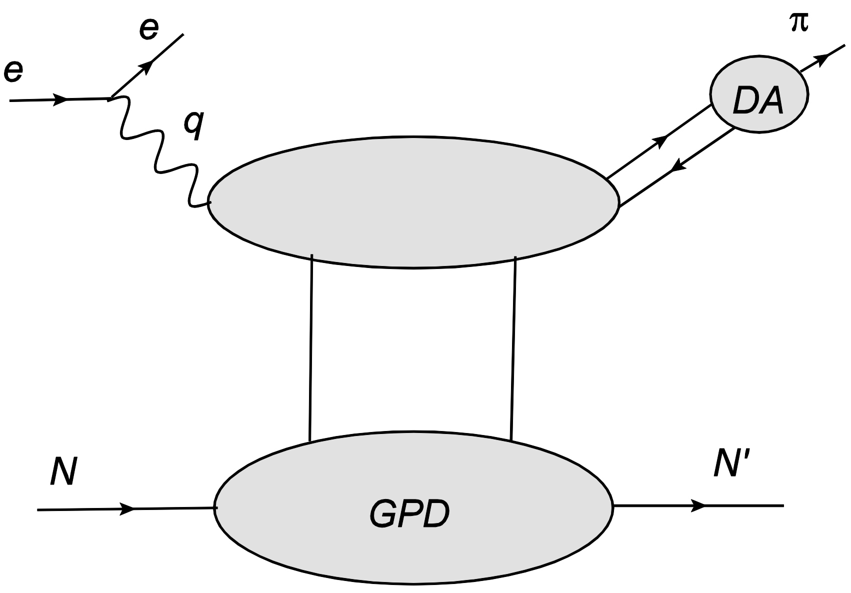
Explore GPD by Electron Beams

Deeply Virtual Compton Scattering

Deeply Virtual Meson Production



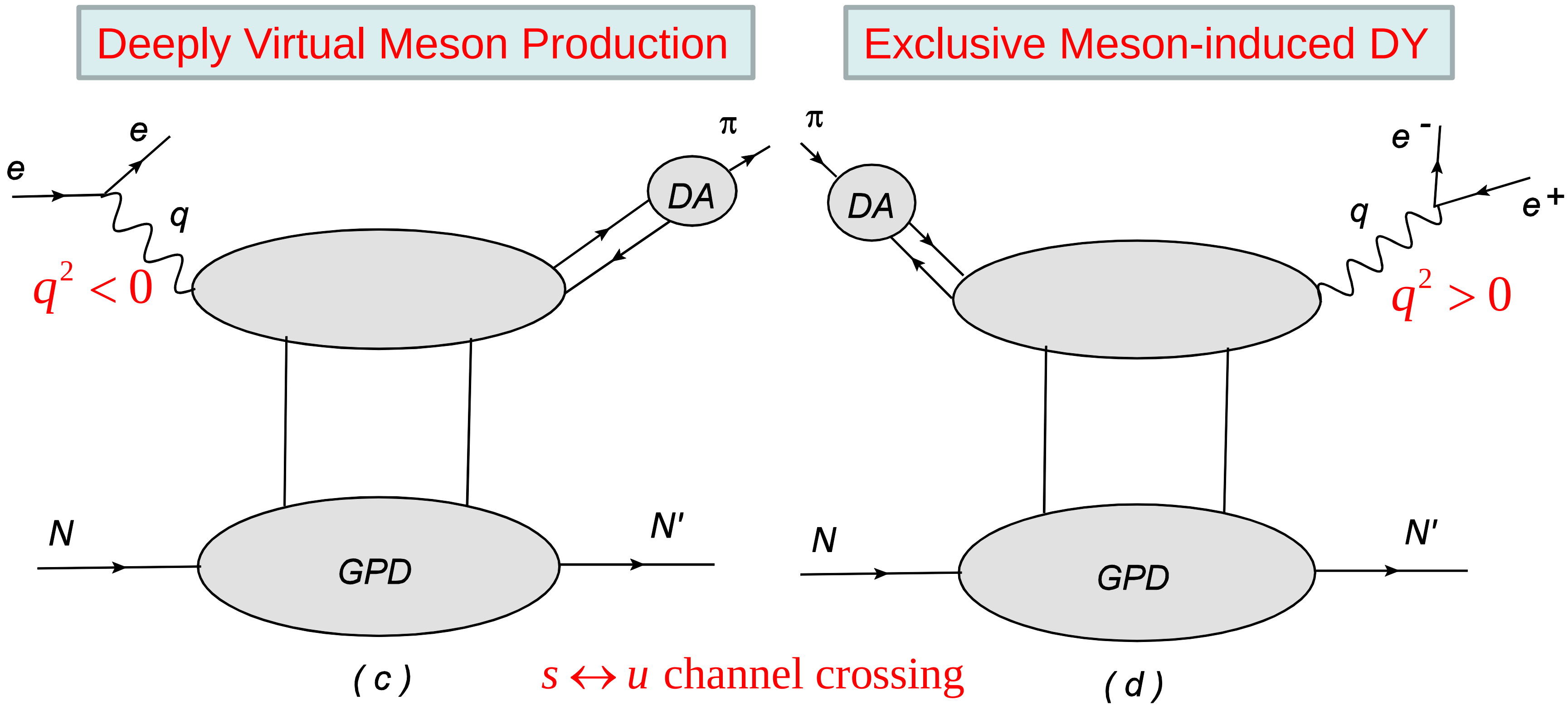
(a)



(c)

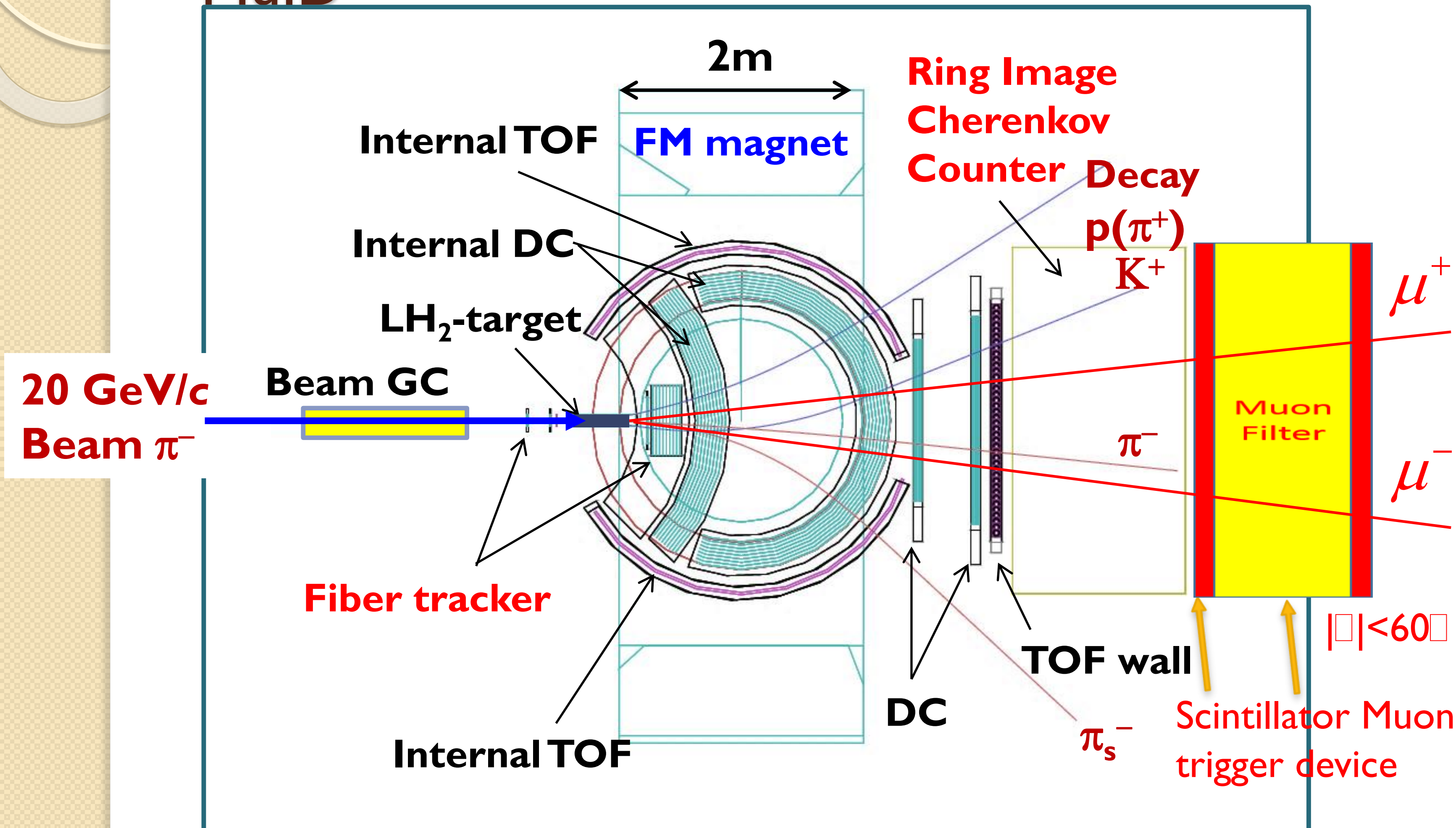
HERMES, JLAB, COMPASS

Spacelike vs. Timelike Processes



$$\pi^- p \rightarrow \mu^+ \mu^- n$$

Missing Mass Technique in E-50 Spectrometer + MuID



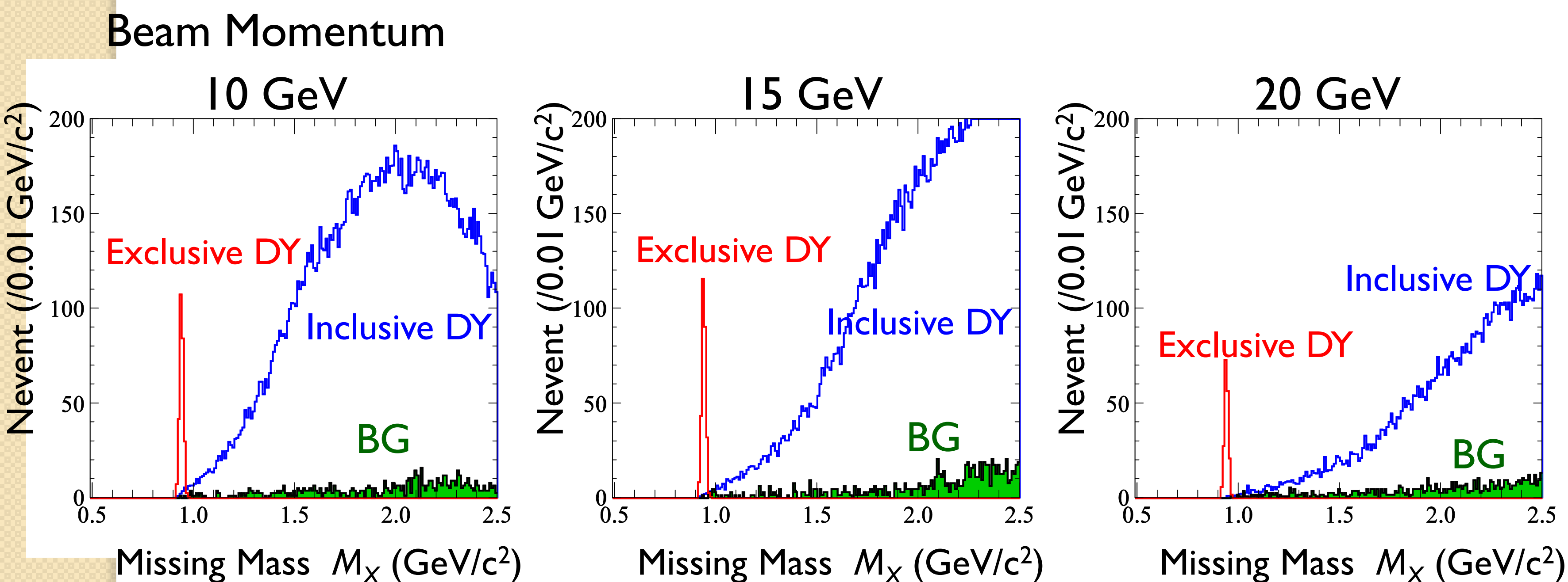
Acceptance: ~ 60% for *D, ~80% for decay π^+**
Resolution: $\Delta p/p$~0.2% at ~5 GeV/c （Rigidity： ~2.1 Tm)

$\pi^- p \rightarrow \mu^+\mu^- X$

M_X In E-50 Spectrometer + MuID

π⁻ beam 50 days

$1.5 < M_{\mu^+\mu^-} < 2.9$ GeV/c²



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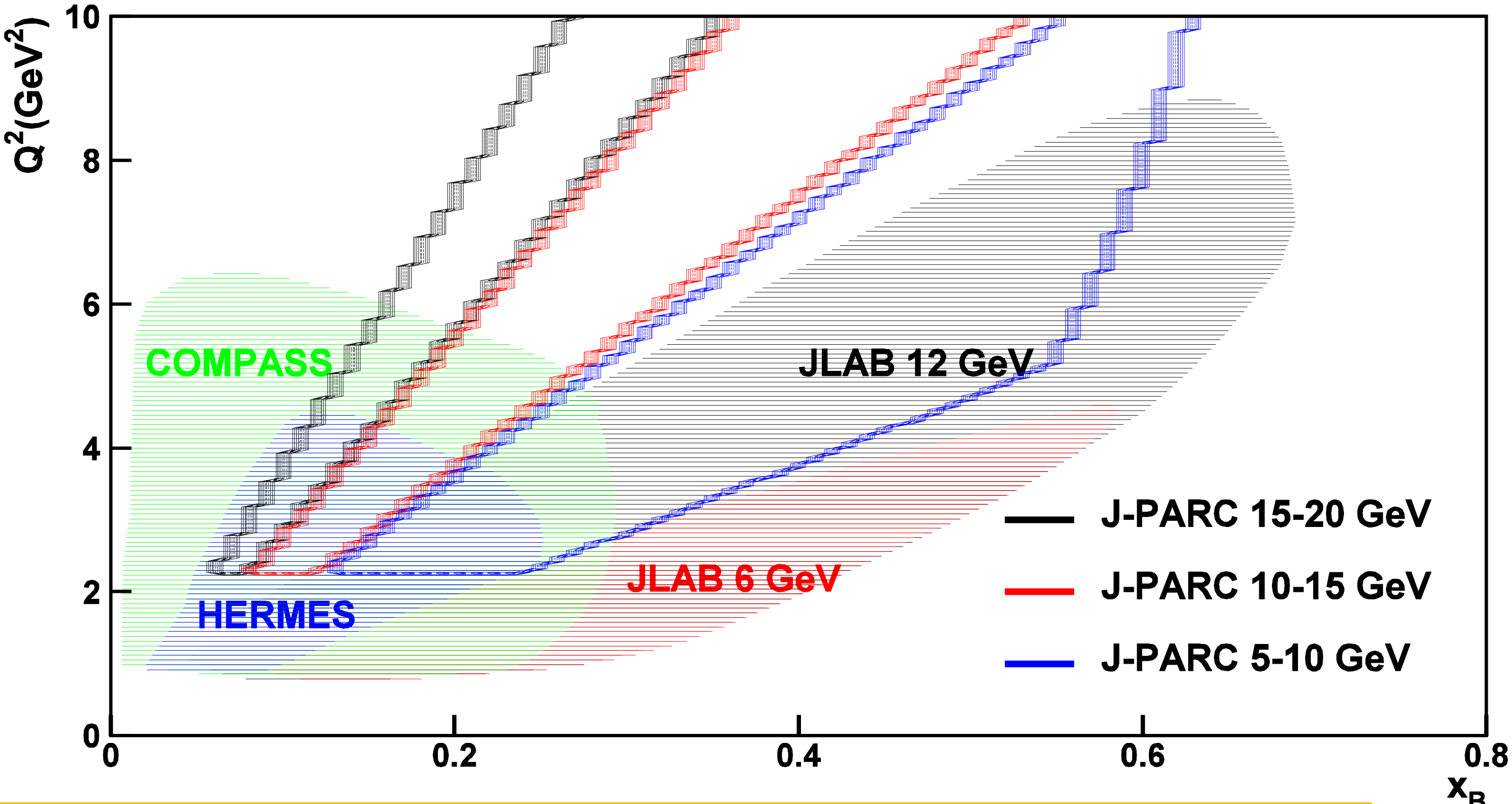
J.C. Peng (UIUC)
T. Sawada (AS)
W.C. Chang (AS)

- The signal of exclusive Drell-Yan processes can be clearly identified in the missing mass spectrum of dimuon pairs.
- Because of the low event rate, this program could be accommodated into the E50 experiment.

GPD(x_B,t; Q^2) from space-like and time-like processes

Large-Q^2 region



- J-PARC: **time-like** approach and **large-Q^2** region.

Summary & Remarks

- The partonic structure of nucleons remains the most important testing ground for understanding QCD, especially on the non-perturbative aspect.
- High-energy hadron beams at J-PARC is unique for studying “hard exclusive processes” in hadronic interactions.
- “E50 collaboration” is formed to look for the internal structures of heavy-quark system and exotic hadrons and also the 3-d partonic structure of nucleons.
- We very much welcome the collaboration (from Asia Pacific region) in carrying out the proposal/experiment.