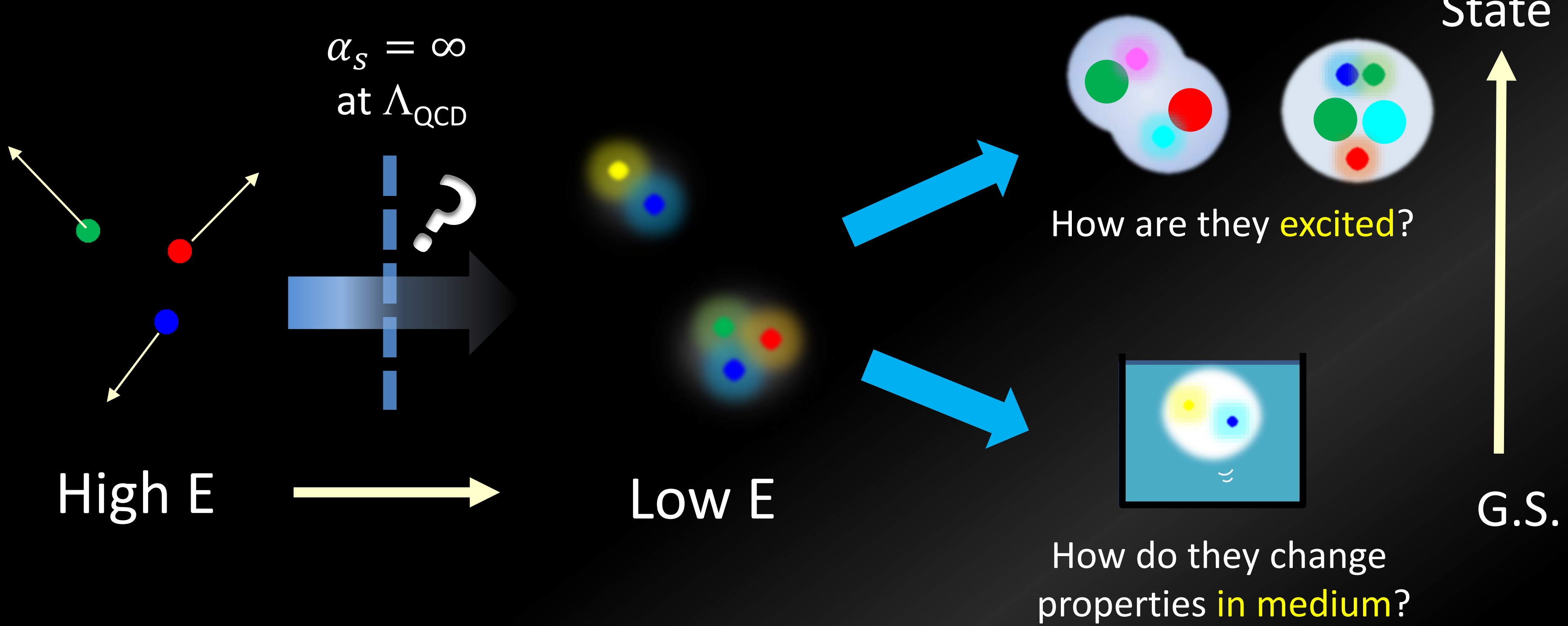
34th REIMEI Workshop on Physics of Heavy-Ion Collisions at J-PARC, August 8-9, 2016

J-PARC E50

Charmed Baryon Spectroscopy via the (π, D^{*-}) reactions

Hiroyuki Noumi
RCNP, Osaka Univ.

Hadron Physics at J-PARC



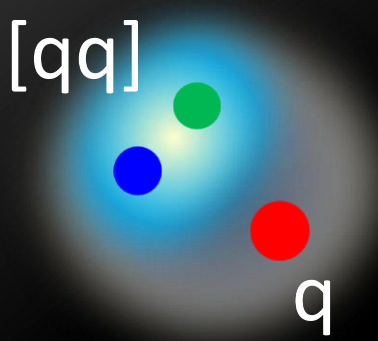
Quasi-Particles (= Effective DoF) emerging at Low E describe hadron properties effectively.

Quasi-Particles (Effective EoF) in Hadrons

Constituent Quark

hadron (colorless cluster)

Diquark?
(Colored cluster)



Diquarks

Color-Magnetic Interaction of two quarks

$V_{CMI} \sim [\alpha_s/(m_i m_j)]*(\lambda_i, \lambda_j)(\sigma_i, \sigma_j)$

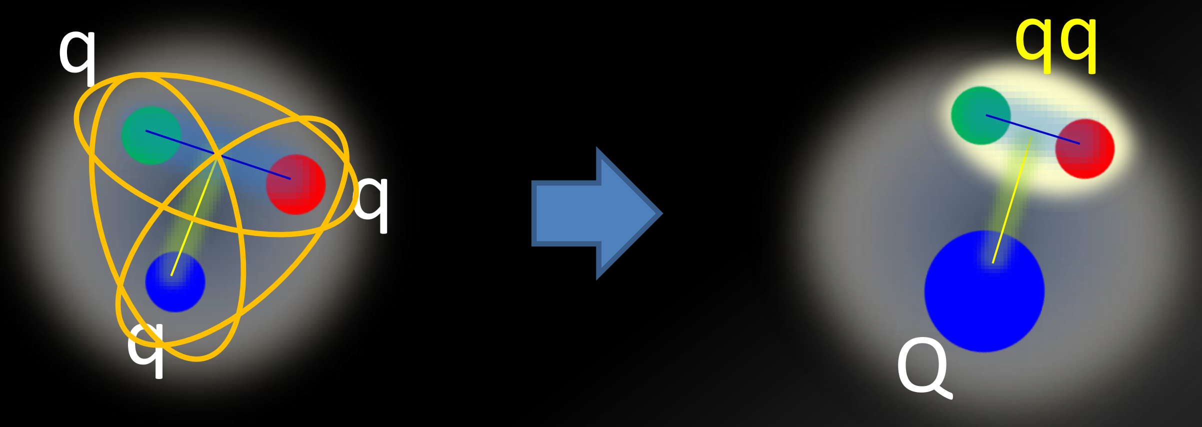
$\rightarrow 0$ if $m_{i,j} \rightarrow \infty$

"Good Diquark": Strong Attraction

$V_{CMI}(^1S_0, \bar{3}_c) = 1/2 * V_{CMI}(^1S_0, 1_c)$

[qq] $[\bar{q}q]$

What we can learn from baryons with heavy flavors

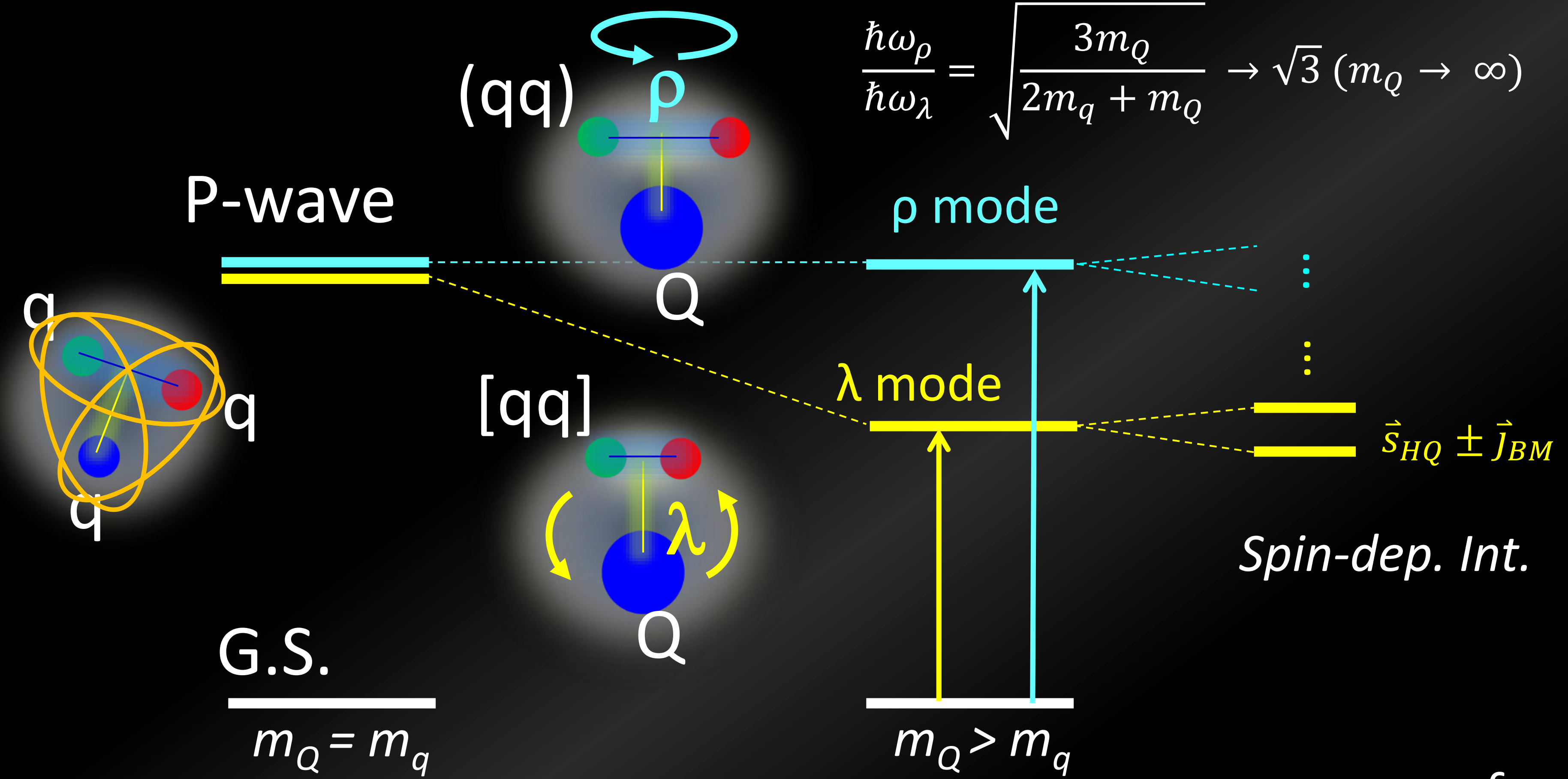


- Quark motion of “qq” is singled out by a heavy Q
  - Diquark correlation
- Level structure, Production rate, Decay properties
  - sensitive to the internal quark(diquark) WFs.
- Properties are expected to depend on a Q mass.

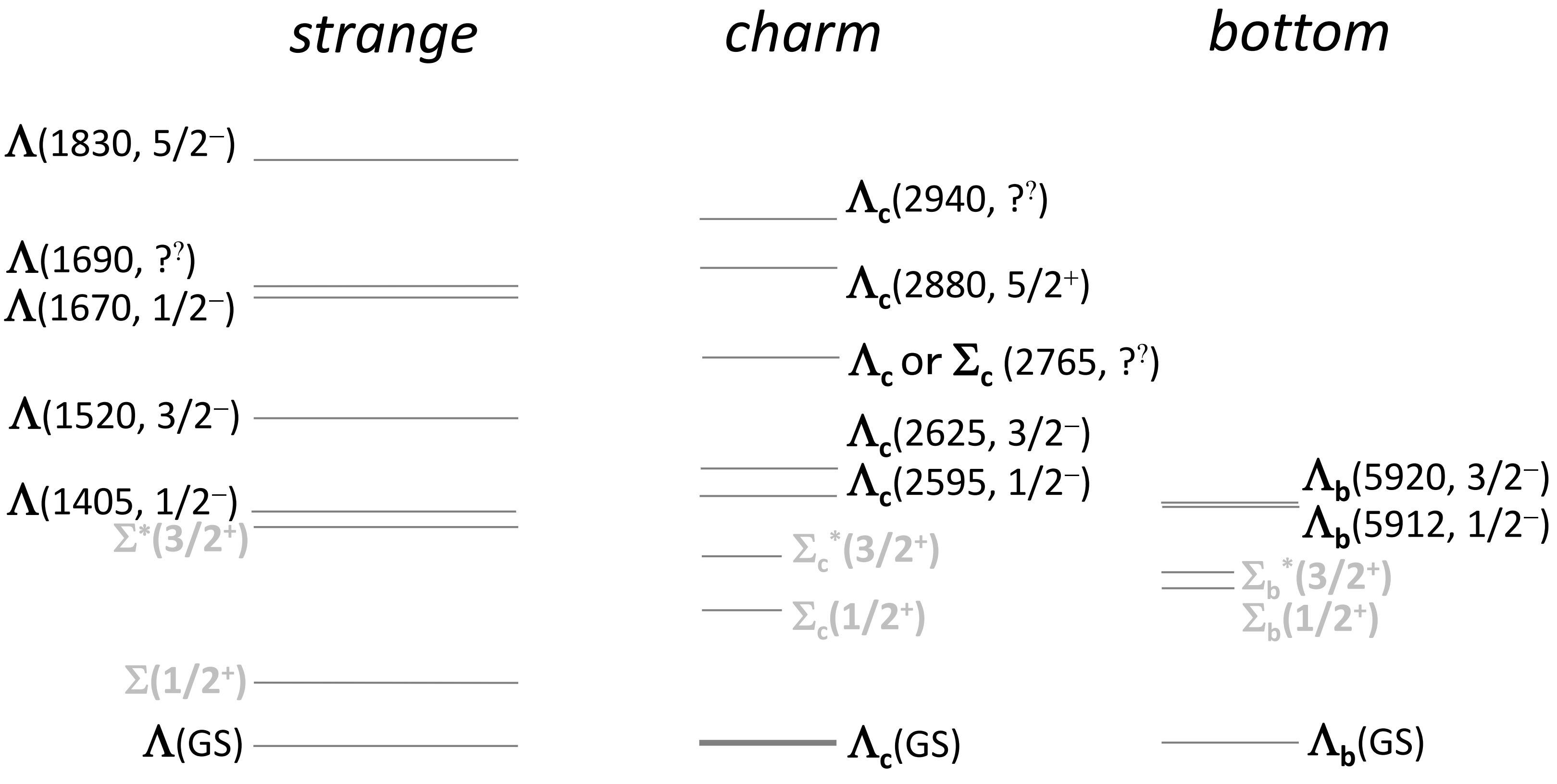
Baryon Spectroscopy w/ Heavy Quark

- Disentangle Quark Correlations in Baryon
  - λ and ρ motions split (Isotope Shift)

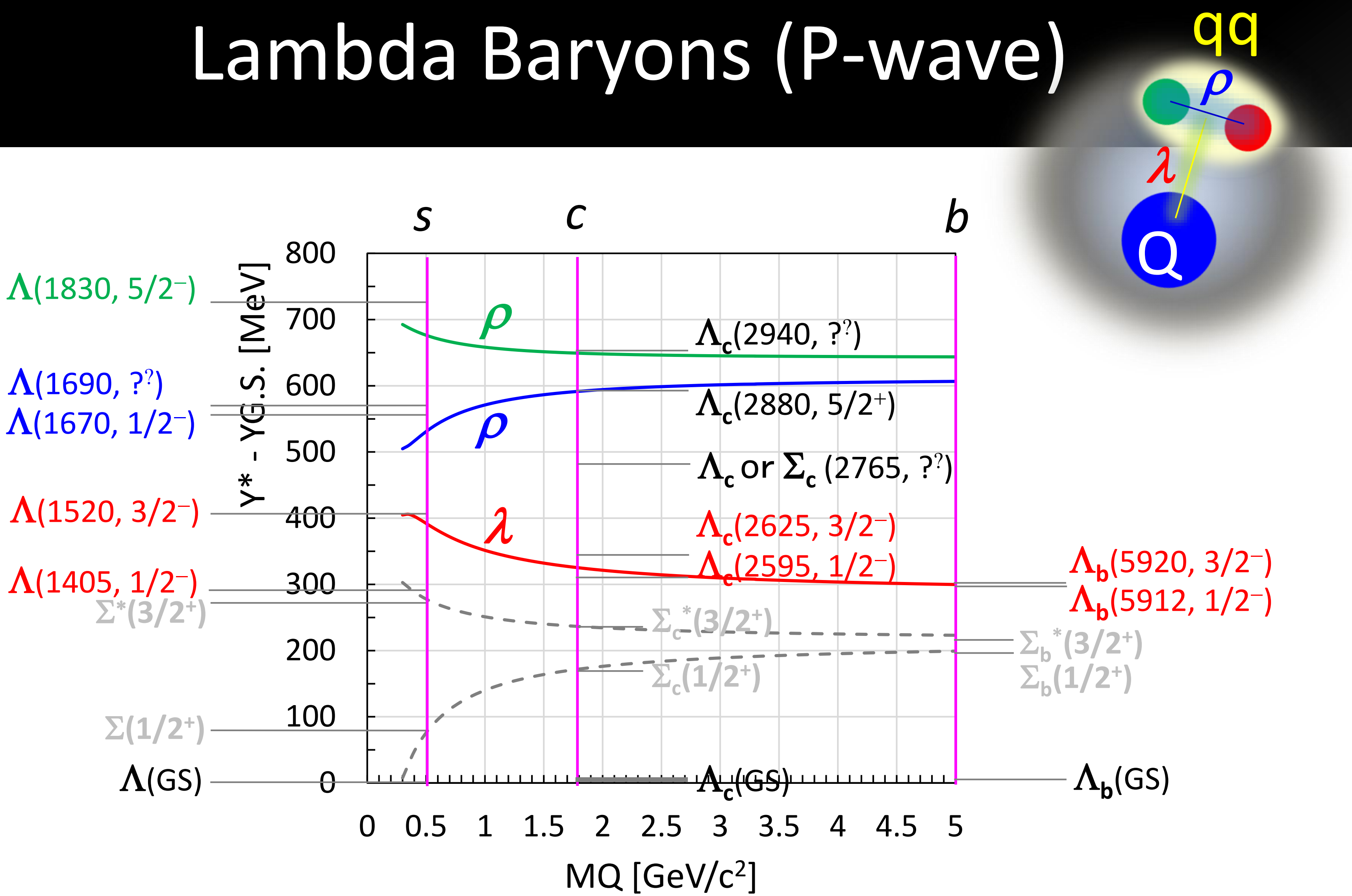
$$\frac{\hbar\omega_\rho}{\hbar\omega_\lambda} = \sqrt{\frac{3m_Q}{2m_q + m_Q}} \to \sqrt{3}\ (m_Q \to \infty)$$



Lambda Baryons (P-wave)



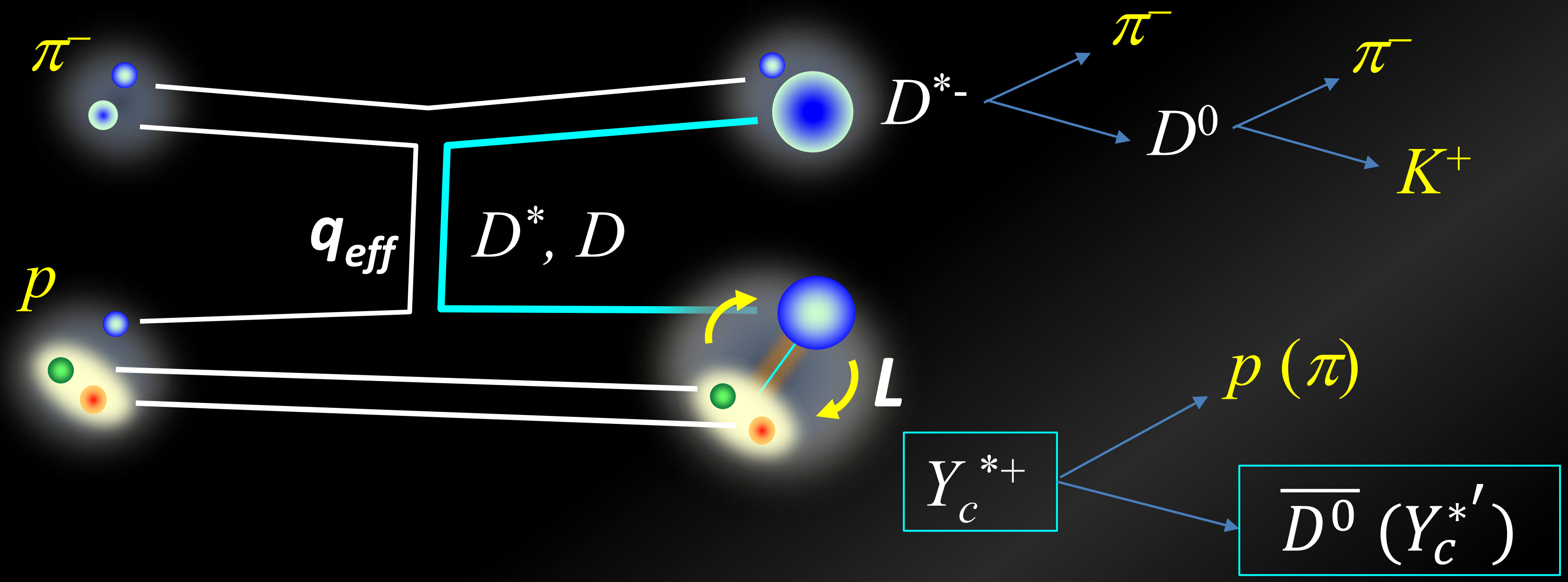
Lambda Baryons (P-wave)



non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
ρ–λ mixing (cal. By T. Yoshida)

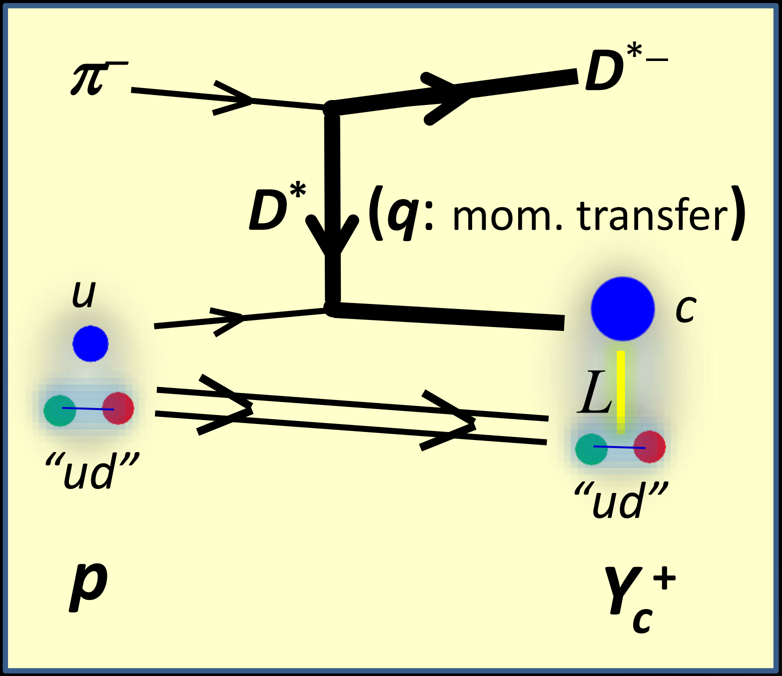
Phys.Rev. D92 (2015) 114029

Charmed Baryon Spectroscopy Using Missing Mass Techniques



- ✓ Production and Decay reflect [qq] correlation…
- ✓ C.S. DOES NOT go down at higher *L* when q_{eff}>1 GeV/c.

Production Rate



- *t*-channel *D** EX
  at a forward angle

S.H. Kim, A. Hosaka, H.C. Kim, and HN
PTEP, (2014) 103D01

Production Rates are determined by the overlap of WFs

$$R \sim \langle \varphi_f \, | \sqrt{2}\sigma_- \exp(i\vec{q}_{eff}\vec{r}) | \varphi_i \rangle$$

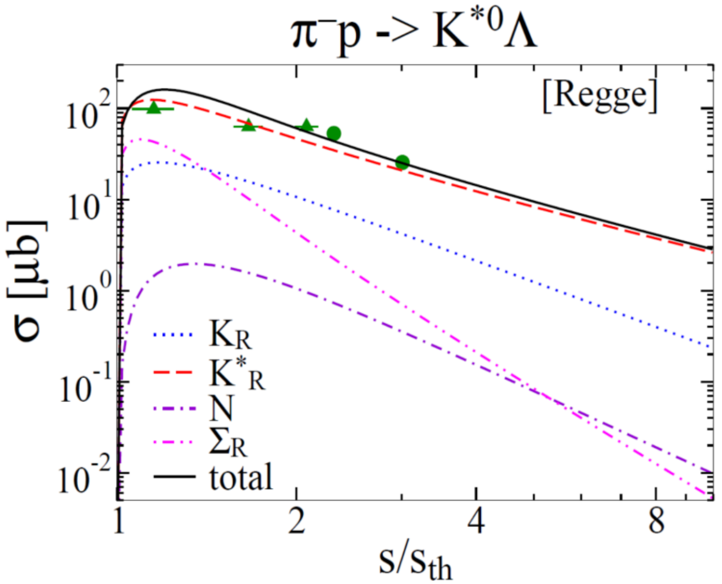
and depend on:

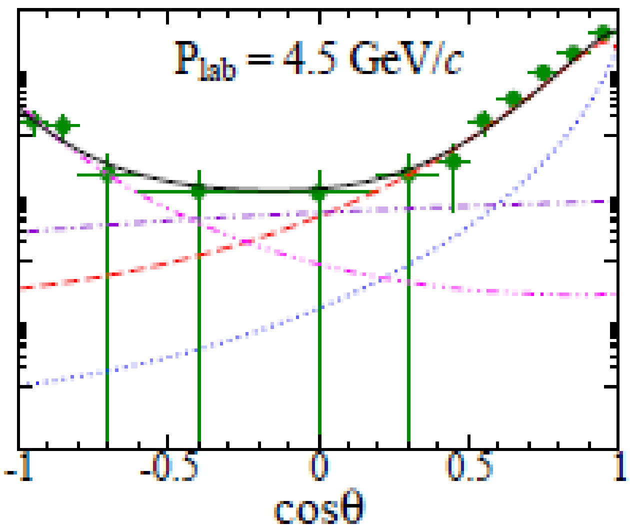
1. Spin/Isospin Config. of Y_c
   Spin/Isospin Factor
2. Momentum transfer (q_{eff})

$$I_L \sim (q_{eff}/A)^L \exp(-q_{eff}^2/2A^2)$$

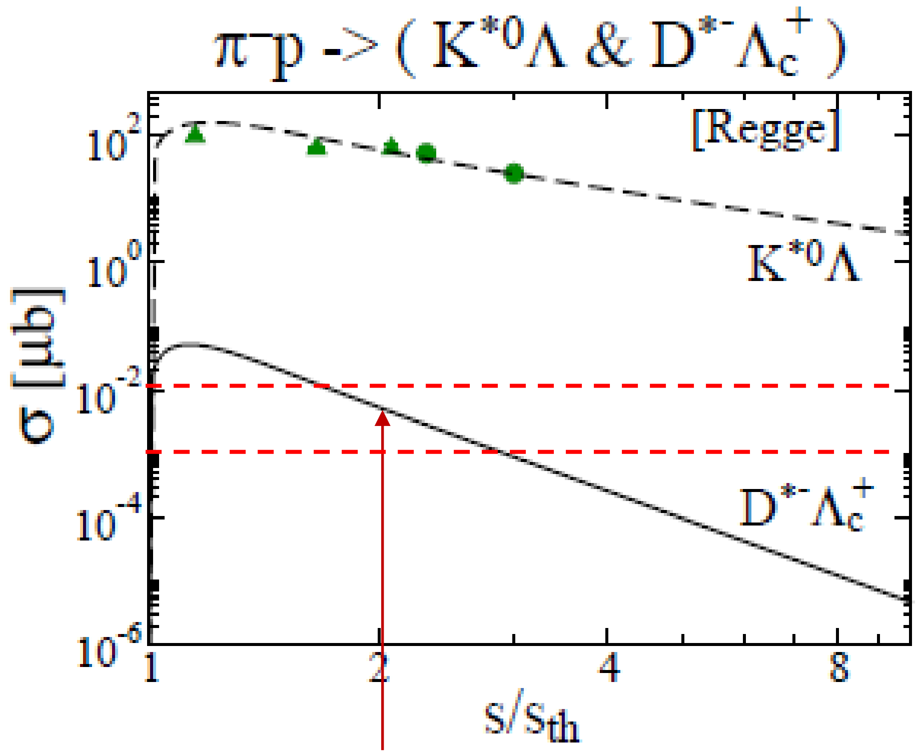
A: (baryon size parameter)$^{-1}$
~0.4 GeV/c

Production Cross Section (Regge Theor.)





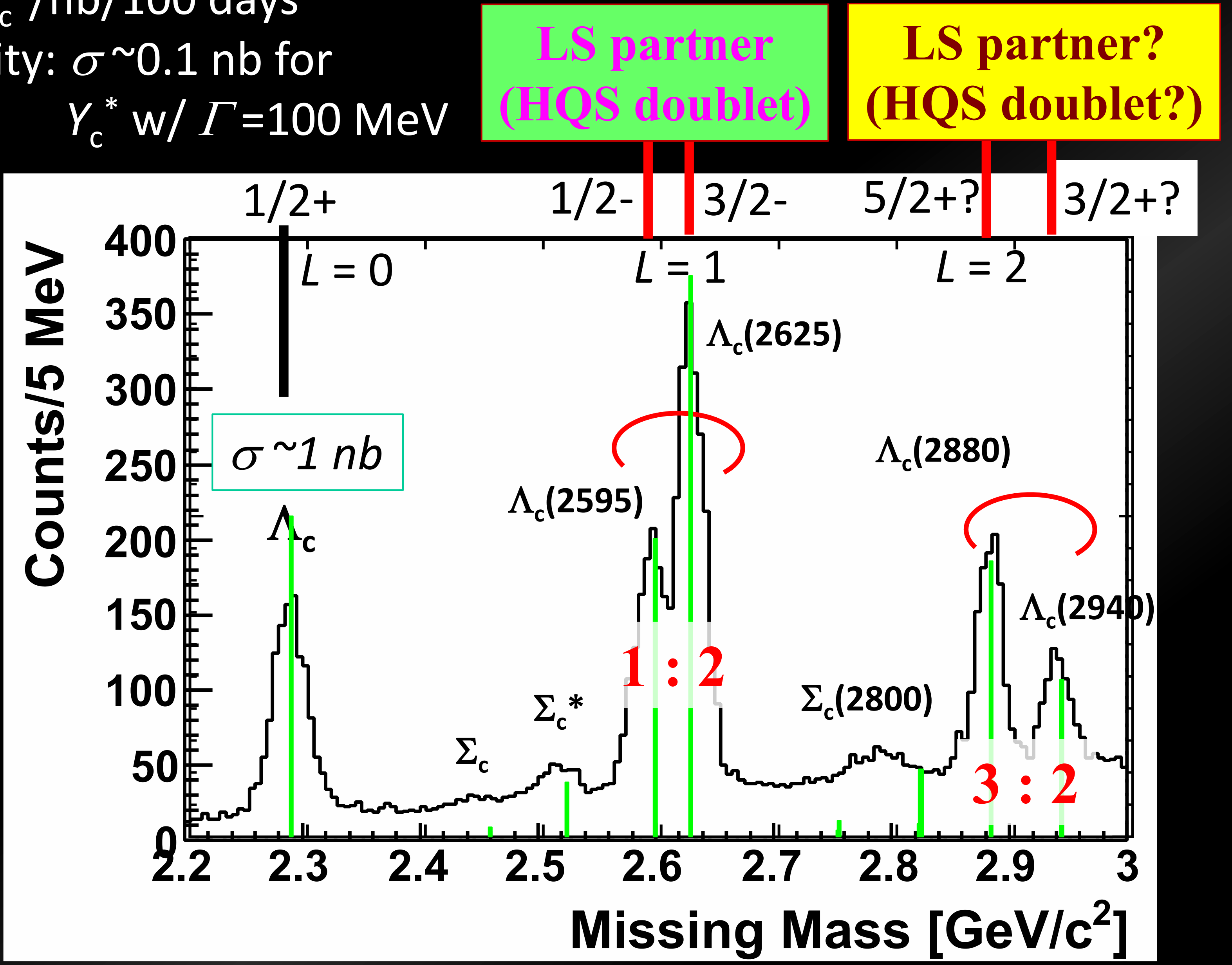
S.H. Kim, A. Hosaka, H.C. Kim, and HN
Phys.Rev. D92 (2015) 094021



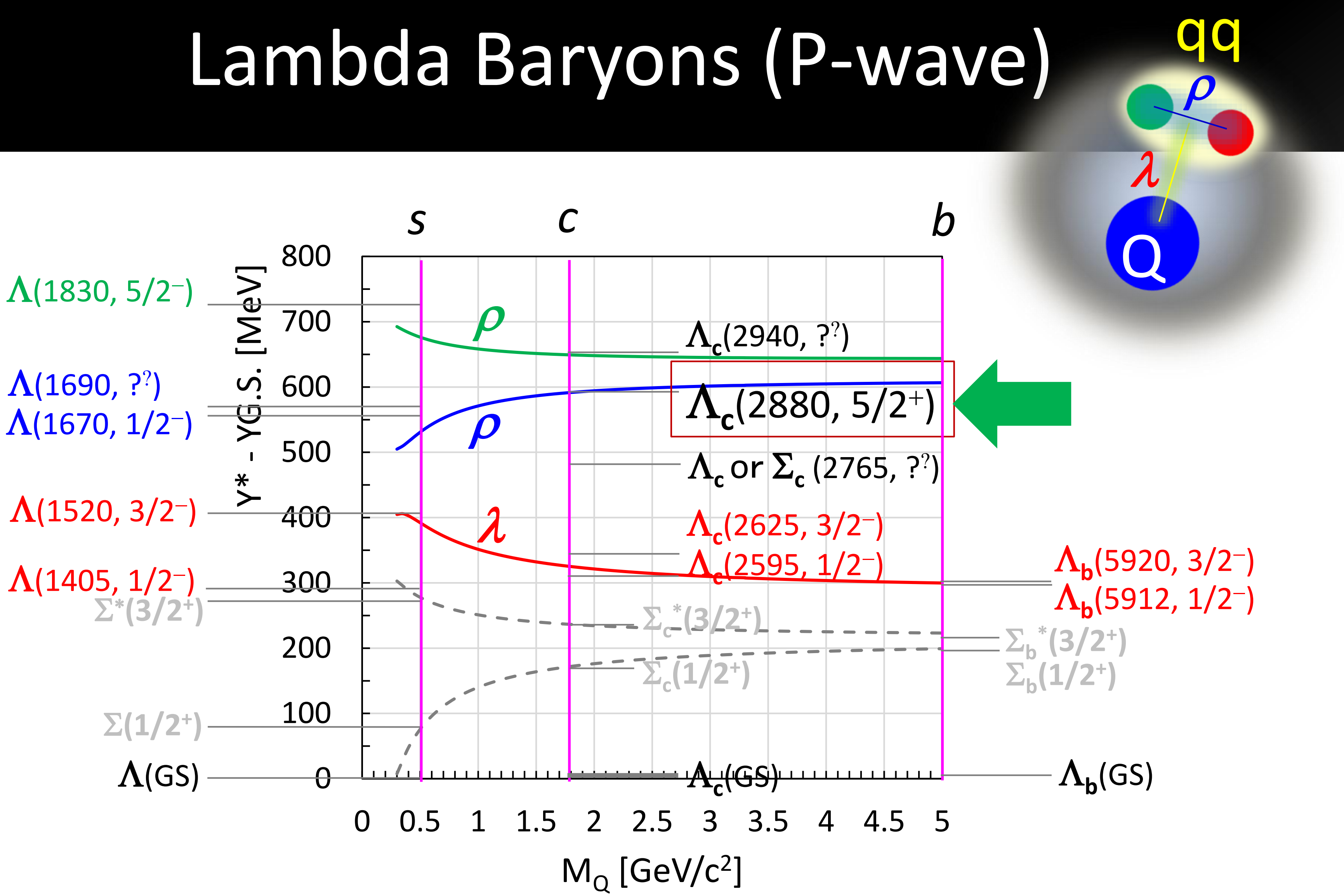
A few nb
at p_π = 20 GeV/c

Missing Mass Spectrum (Sim.)

- ~1000 Y_c^*/nb/100 days
- Sensitivity: σ~0.1 nb for Y_c^* w/ Γ=100 MeV



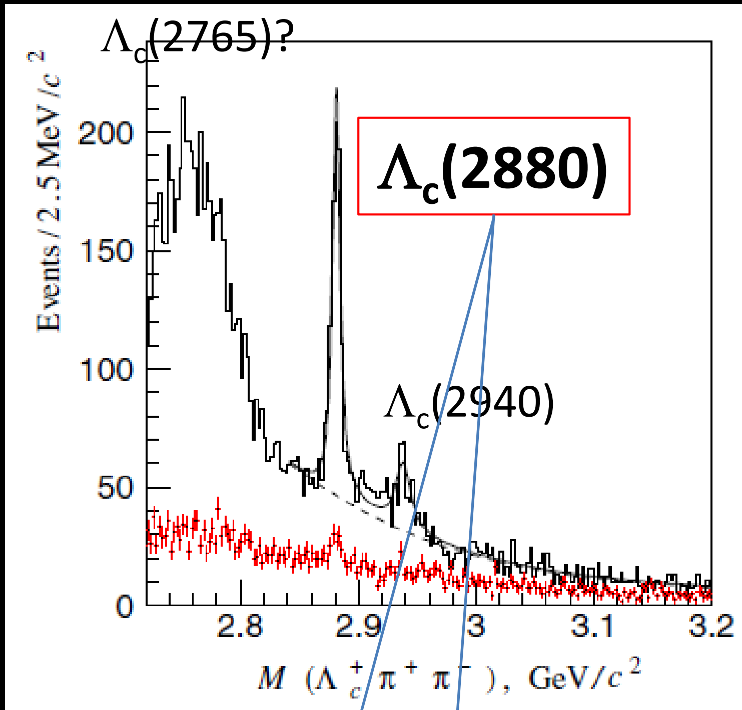
Lambda Baryons (P-wave)

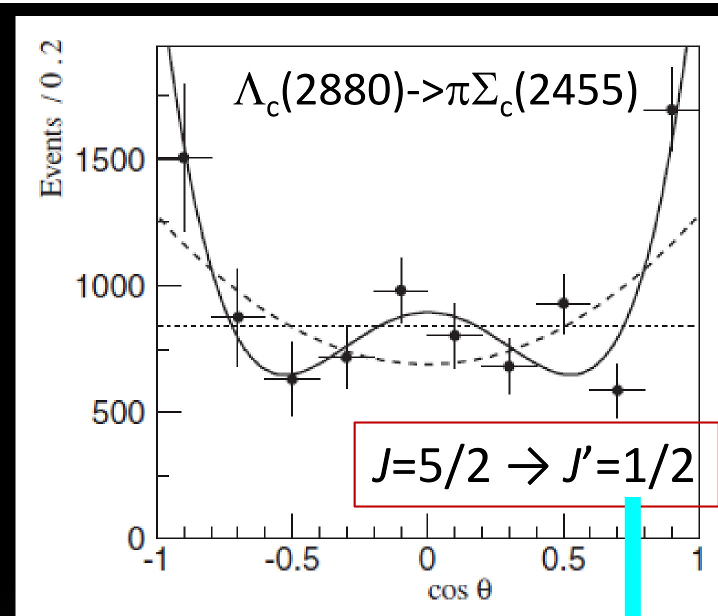


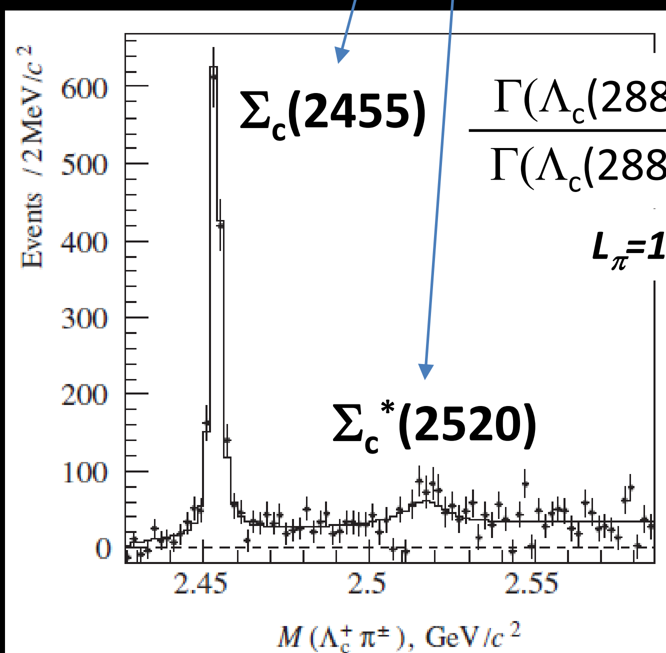
non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

$\rho-\lambda$ mixing (cal. By T. Yoshida)

Lc(2880)Belle, PRL98, 262001('07)







$$\frac{\Gamma(\Lambda_c(2880)\to\pi\Sigma_c^*(2520))}{\Gamma(\Lambda_c(2880)\to\pi\Sigma_c(2455))}=0.23$$

$L_\pi=3$ transition

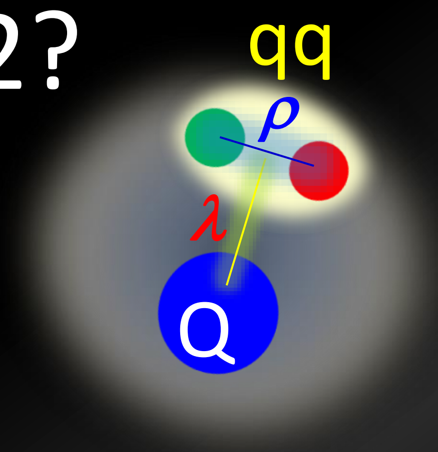
$L_\pi=1$ contribution may affect…

$J^P=5/2^+$ for $\Lambda_c(2880)$

Is it a D-wave Lambda-c Baryon?

If so, where is a spin partner ?

Does Λ(2880) have L=2?



- P-wave transition seems to be suppressed in $\Lambda_c(2880)\frac{5}{2}^+ \rightarrow \Sigma_c^*(2520)\frac{3}{2}^+ + \pi(0^-)$.
- It would be forbidden only in the case of $J_{BM}^P = 3^+$:
  - Negative party states "5/2-" have large widths.

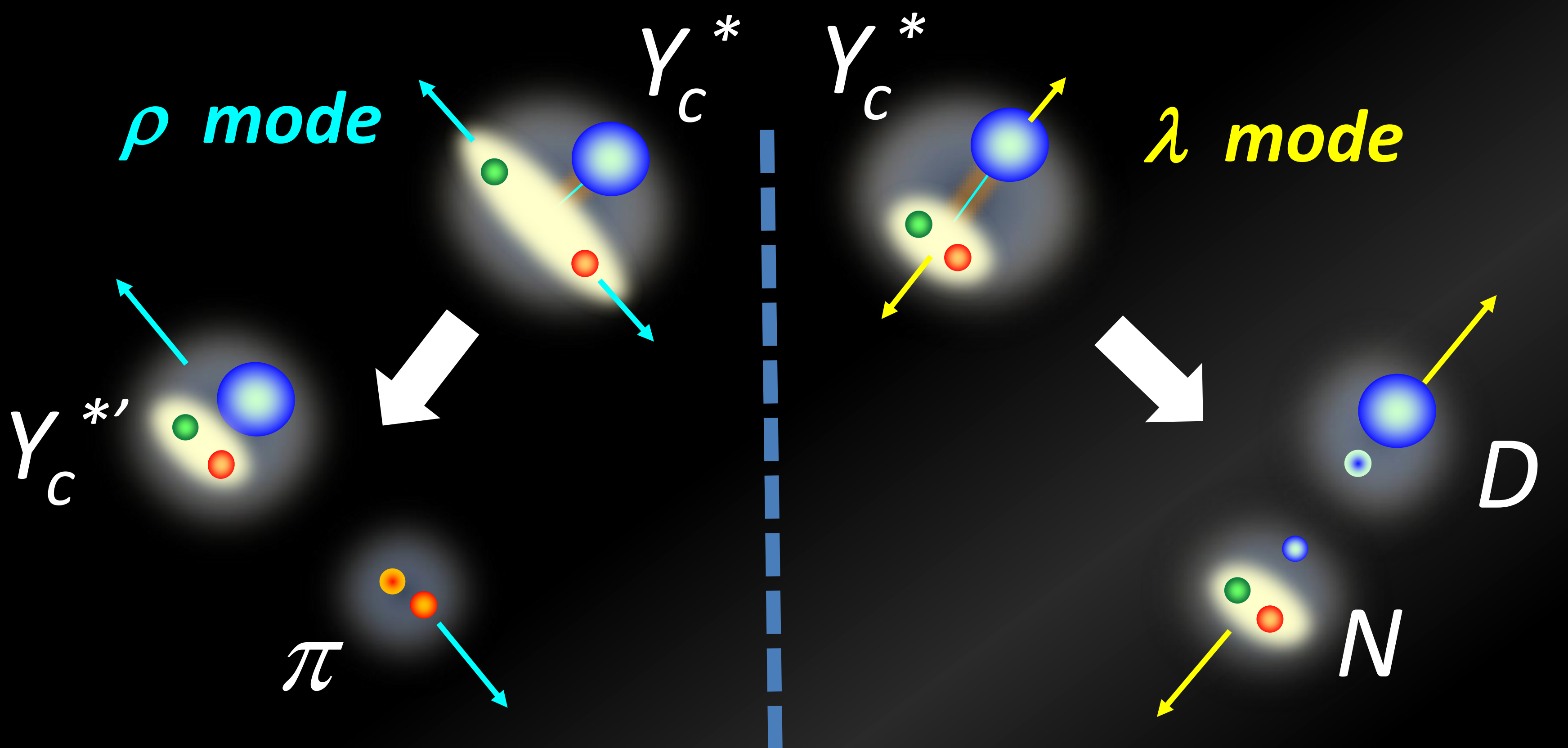
  (H. Nagahiro et al., paper in preparation)

Λ_c(2880) 5/2+	λλ	λρ	ρρ
color	Asymm.		
Isospin	Asymm. (I=0)		
Diquark spin Diquark orbit	Asymm. 0 Symm. 0	Symm. 1 Asymm. 1	Asymm. 0 Symm, 2
Lambda orbit	2	1	0
J_{BM}^P	2+	1+, 2+, **3+**	2+

Σ_c^*(2520) 3/2+
Asymm
Symm. (I=1)
Symm. 1 Symm, 0
0
1+

- $\Lambda_c(2880)\frac{5}{2}^+$ is likely to be λρ mode (λ=1, ρ=1).
- It can be tested from its production rate.

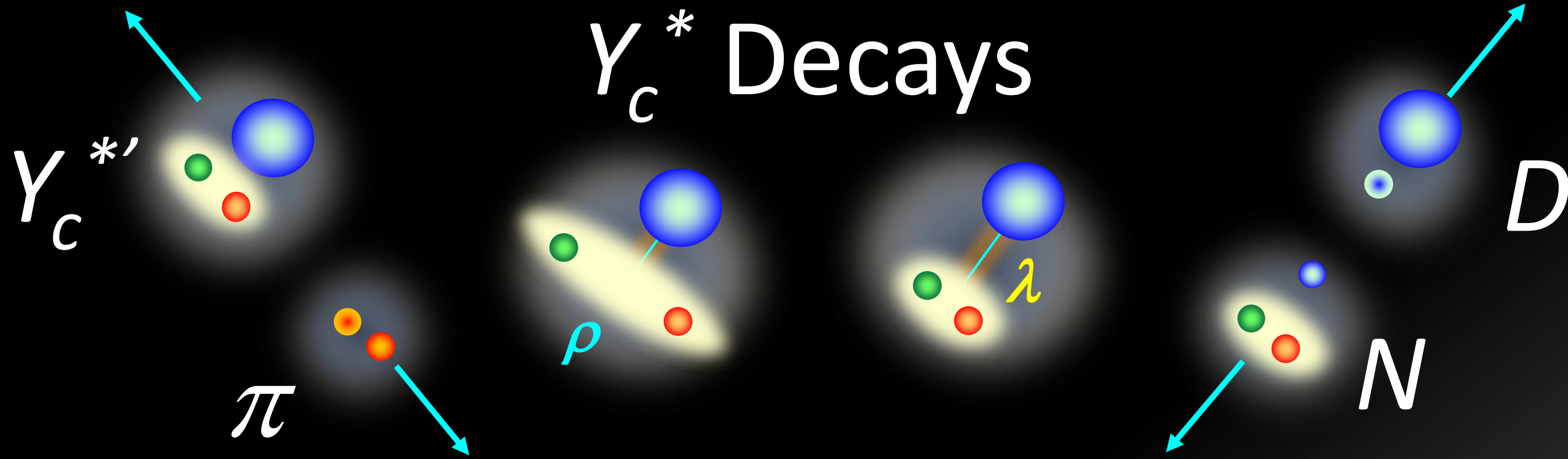
Y_c^* Decay Pattern



$\Gamma(Y\pi) > \Gamma(DN)$

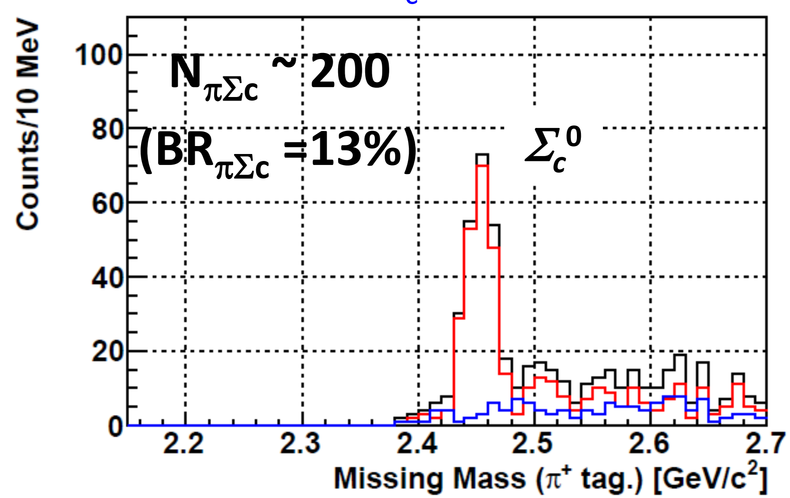
$\Gamma(DN) > \Gamma(Y\pi)$

Y_c^* Decays

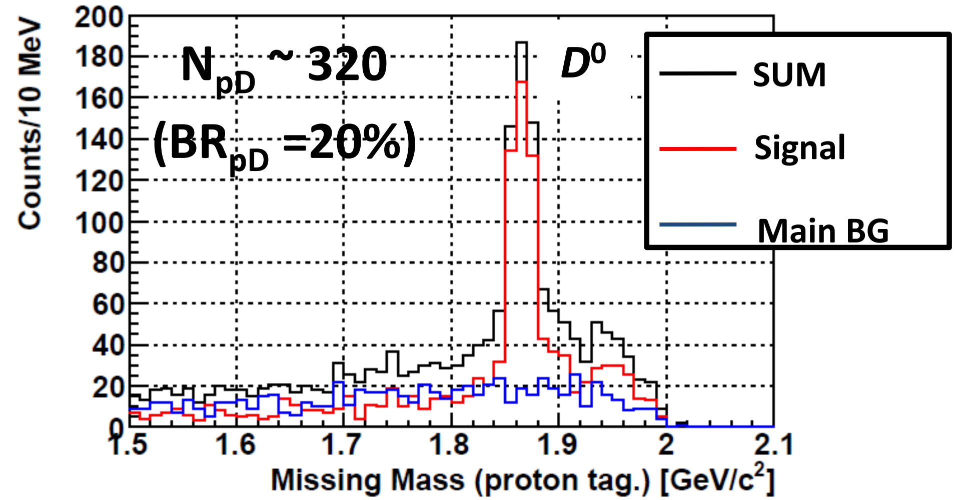


$\Lambda_c(2940) \to \Sigma_c^0\, \pi^+$

with $\Lambda_c^+\, \pi^+\, \pi^-$ selected



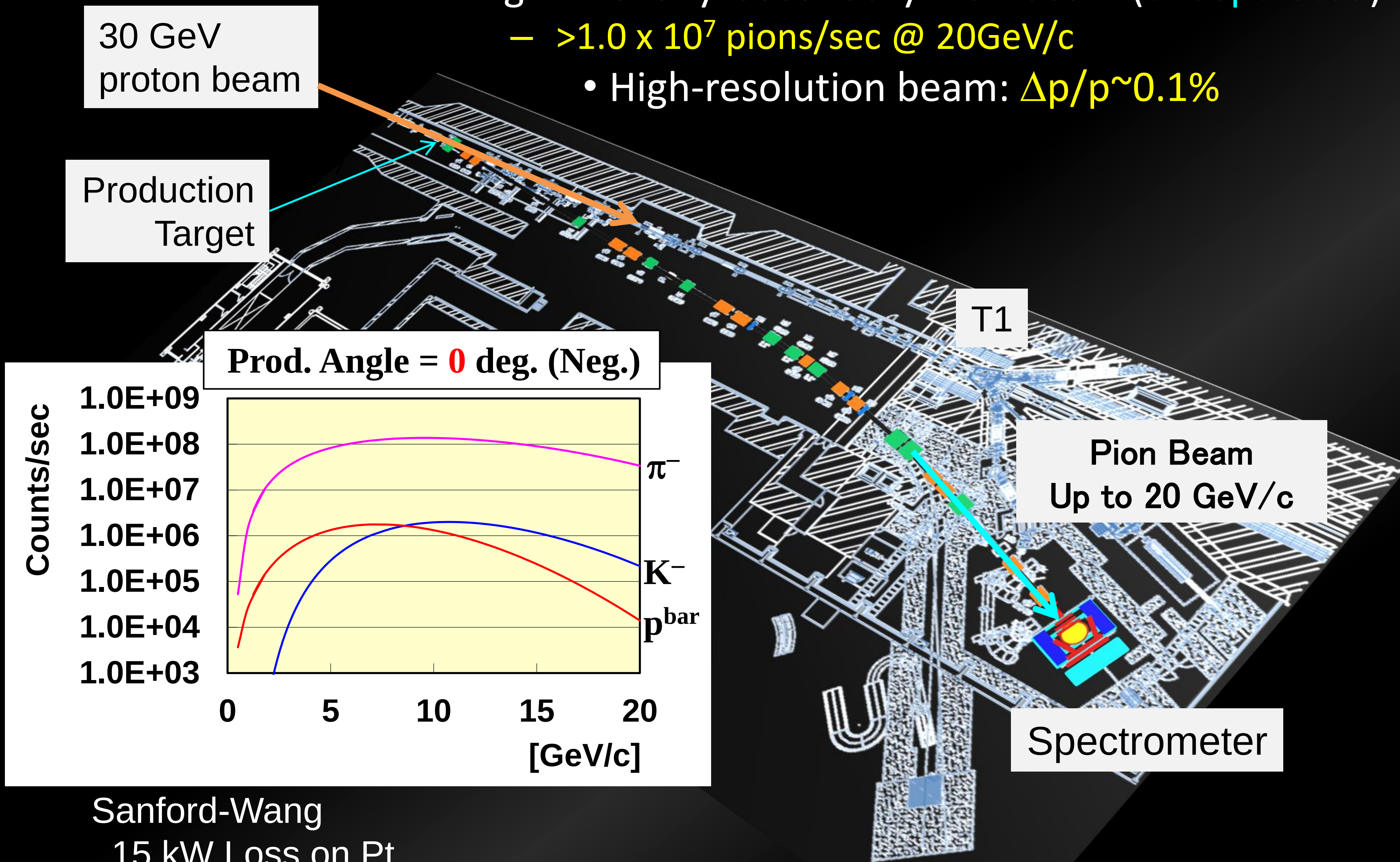
$\Lambda_c(2940) \to p\, D^0$



* Branching ratios: Diquark corr. affects $\Gamma(\Lambda_c^* \to pD)/\Gamma(\Lambda_c^* \to \Sigma_c\pi)$.

High-res., High-momentum Beam Line

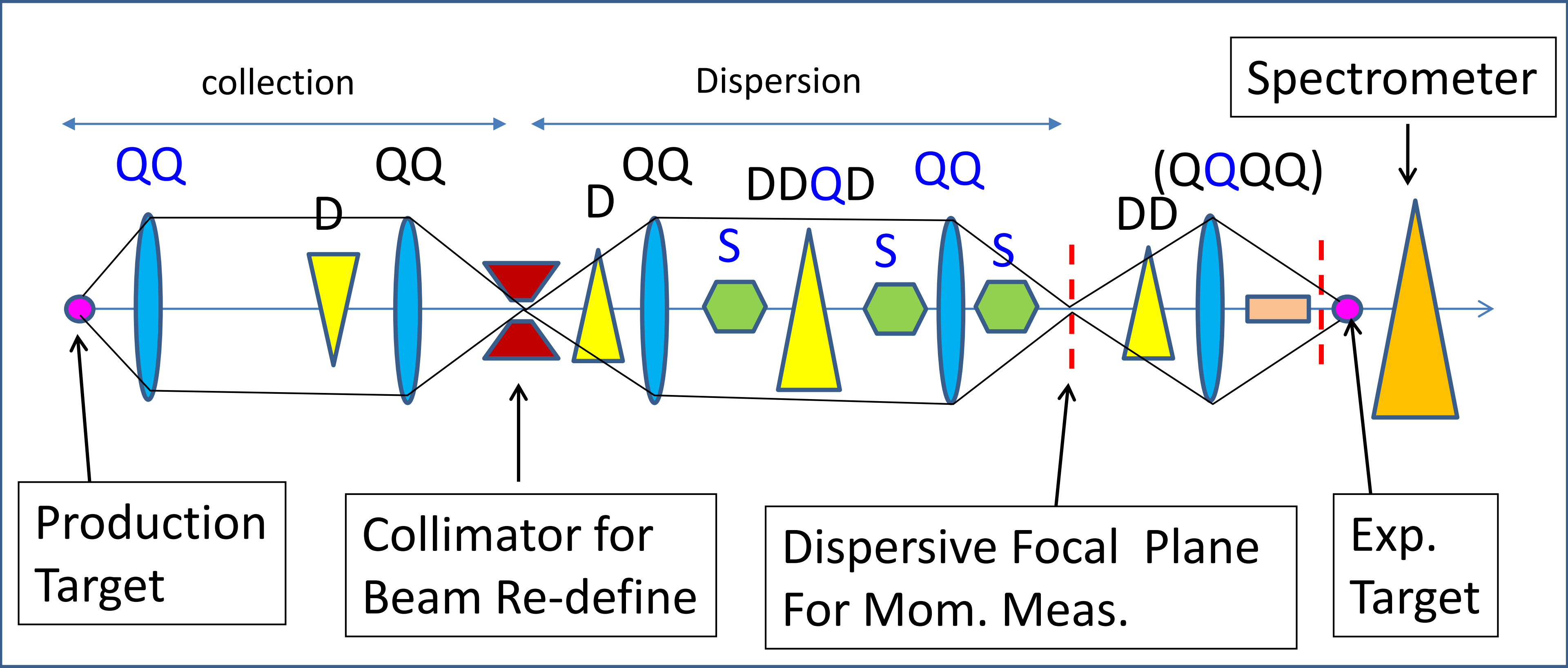
- High-intensity secondary Pion beam (unseparated)
  - $>1.0 \times 10^7$ pions/sec @ 20GeV/c
- High-resolution beam: $\Delta p/p$~0.1%



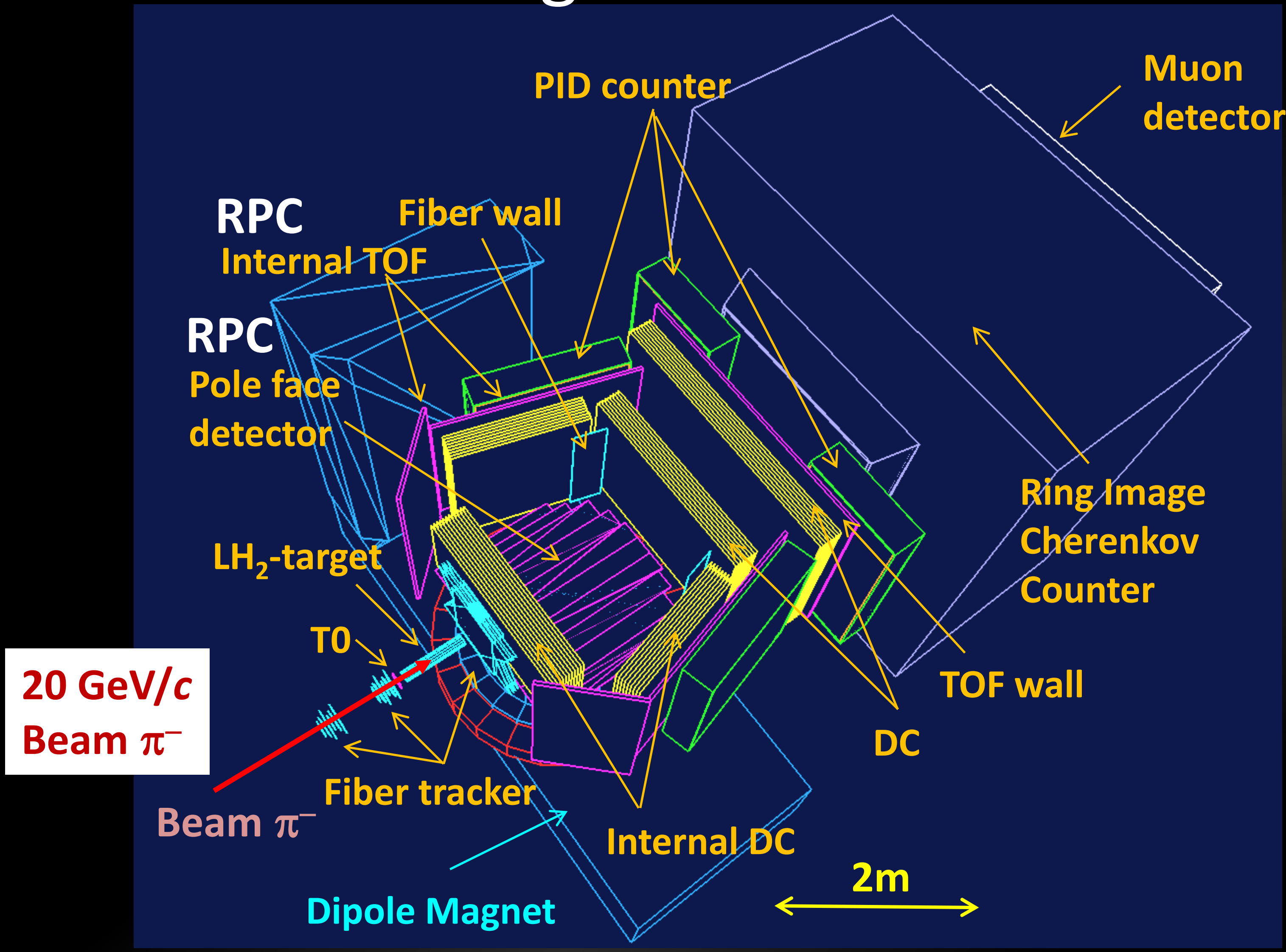
Sanford-Wang
15 kW Loss on Pt
Acceptance :1.5 msr%, 133.2 m

High-res., High-momentum Beam Line

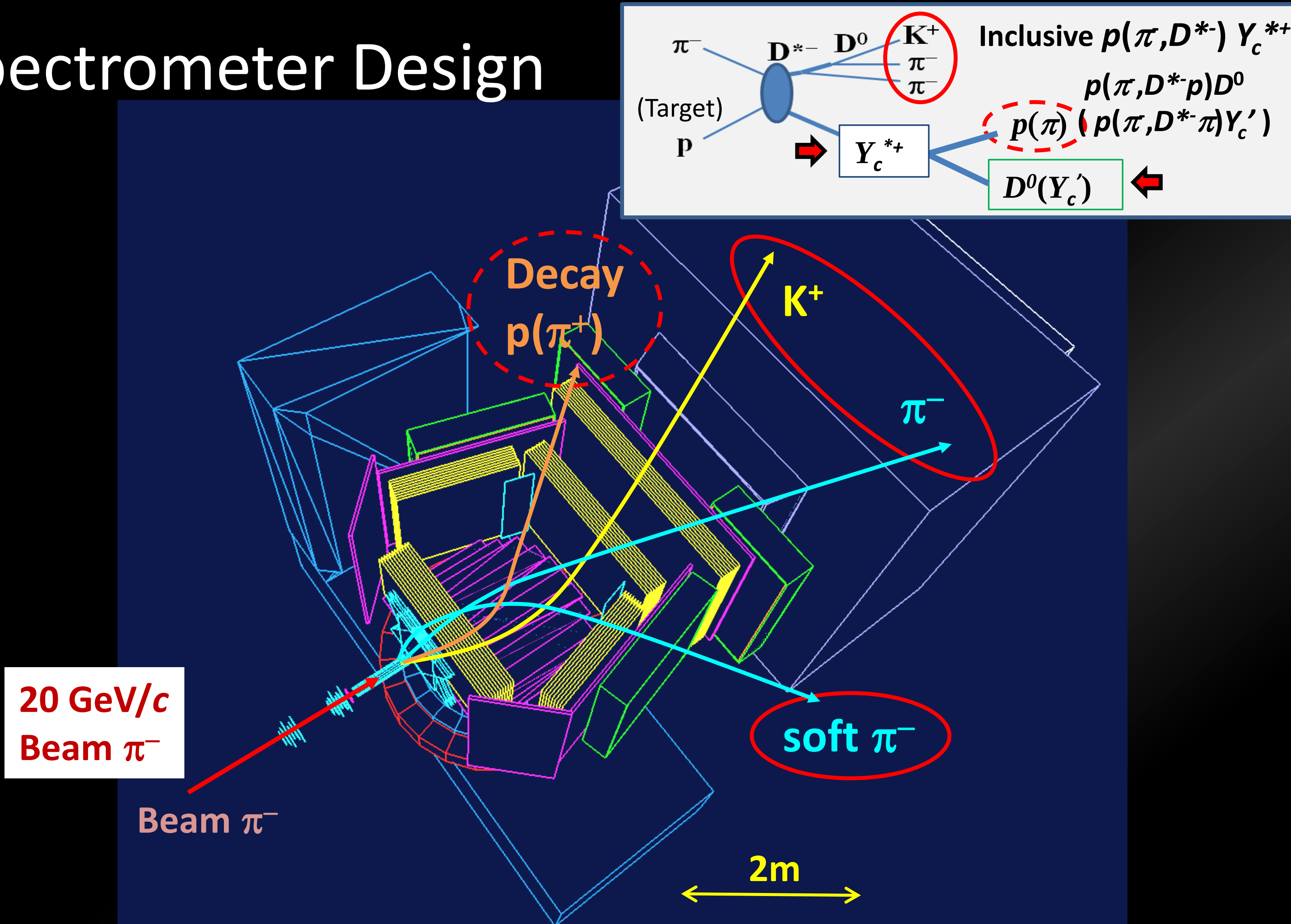
- High-intensity secondary Pion beam
  - >1.0 x 10^7 pions/sec @ 20GeV/c
- High-resolution beam: $\Delta p/p \sim 0.1\%$



Spectrometer Design



Spectrometer Design

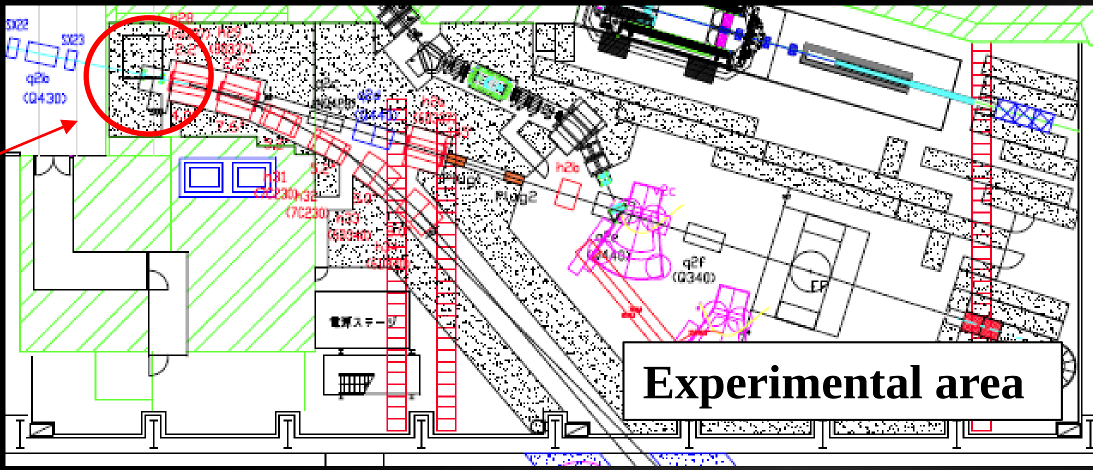


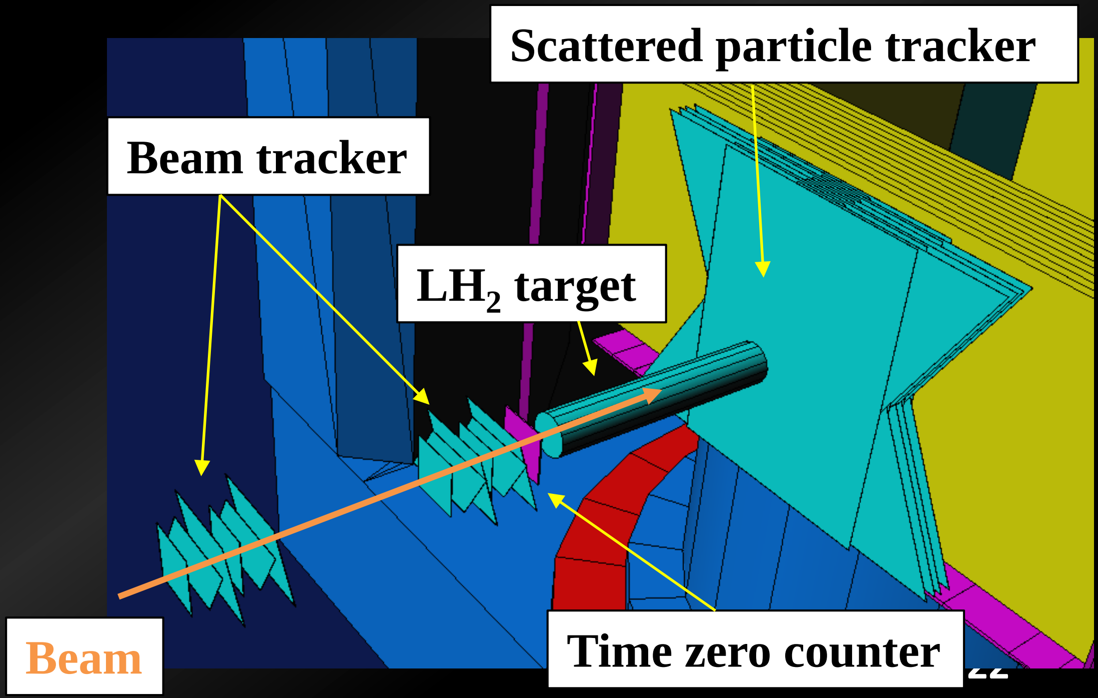
Large acceptance ~ 60% (for D^*), ~85% (for decay π^+)
Good resolution: $\Delta p/p$~0.2% at ~5 GeV/c

High-rate detectors

＊High-rate beam
– 6×10^7 /spill
(30 MHz @ 2 sec spill)

- Focal plane detector
  - Focal plane region
  - Beam momentum analysis
    - Position and angle
- Beam tracker
  - At the target upstream
  - Size: 100 mm × 100 mm
- Scattered particle tracker
  - At the target downstream
  - 600 mm × 800 mm
- Time zero counter
  - At the target upstream
  - Reference timing for TOF

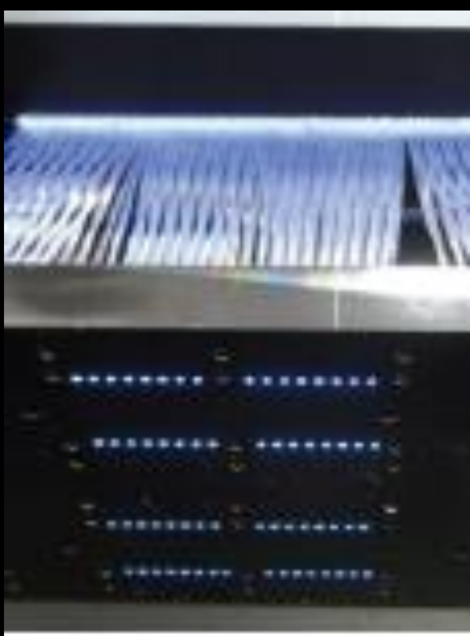


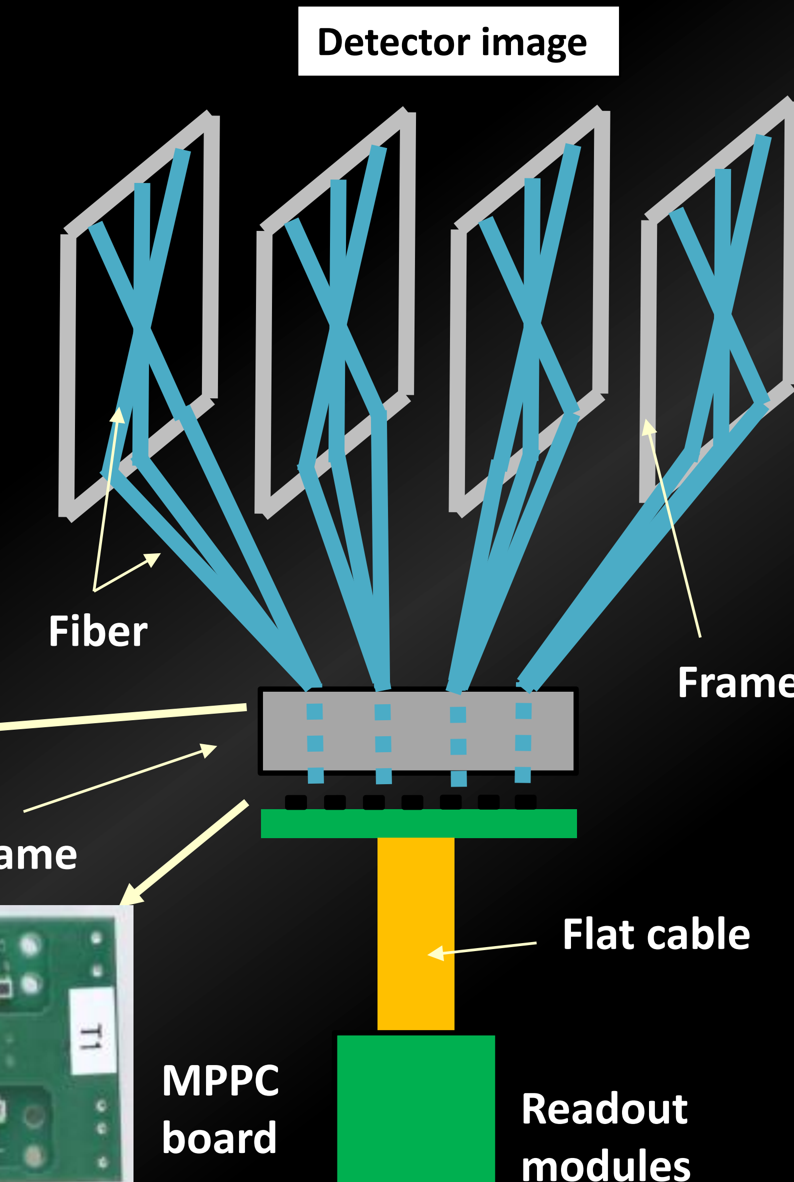


Production of prototype detector

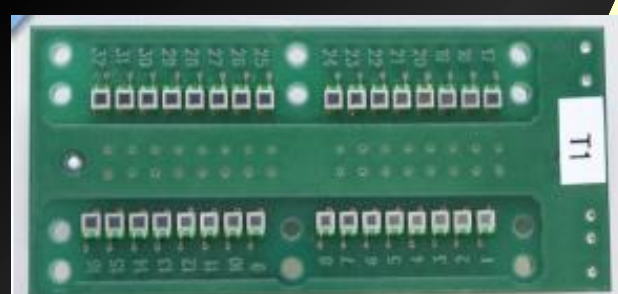
- Fibers fixed to Al frames
  - Al frames are combined by each others.

- Extracted fibers are fixed
to the MPPC attaching frames.
  - Attaching frame is fixed to Al frames.
    - Plastic frame (similar material to fibers)
  - Air contact with MPPCs



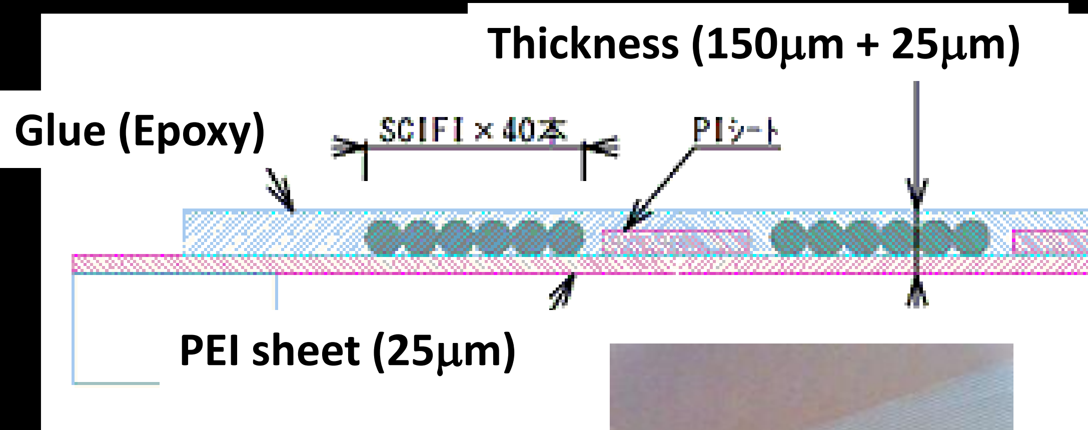


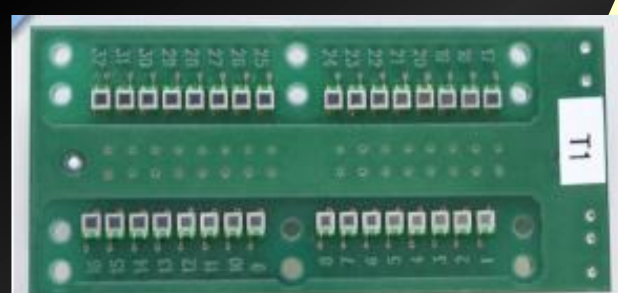
MPPC attaching frame

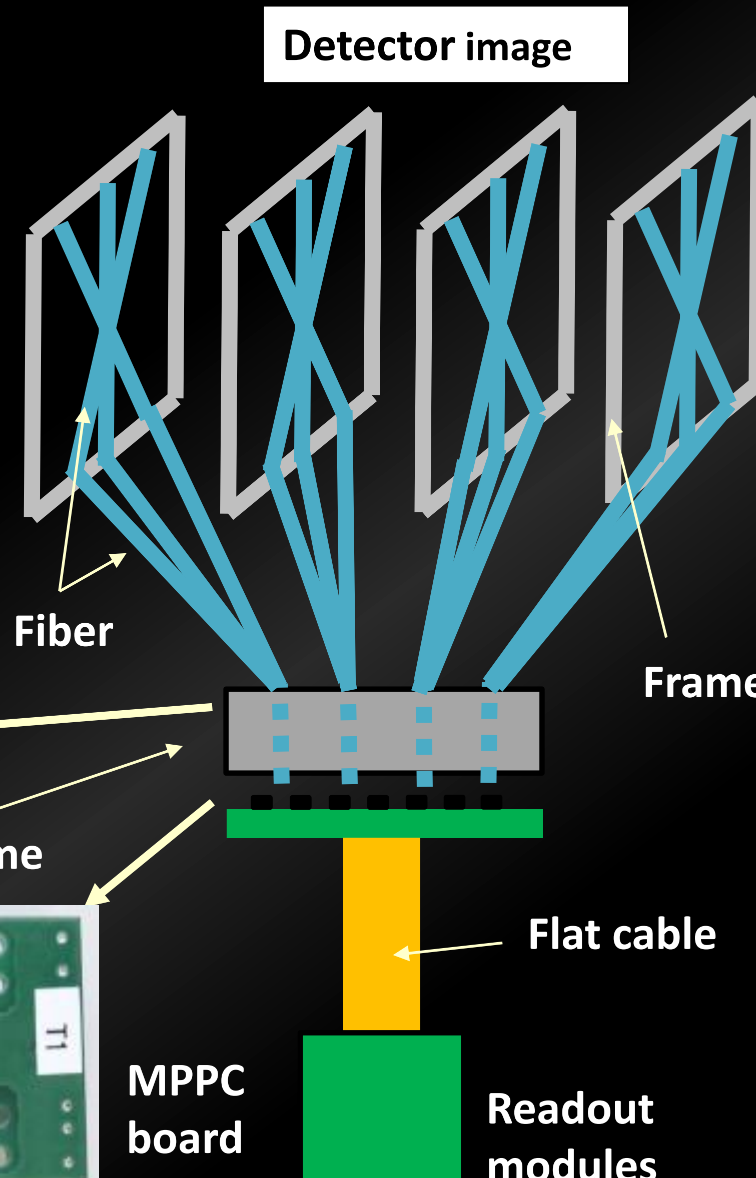


Production of prototype detector

Fiber Sheet Tech. is well established (M-Line Co.)





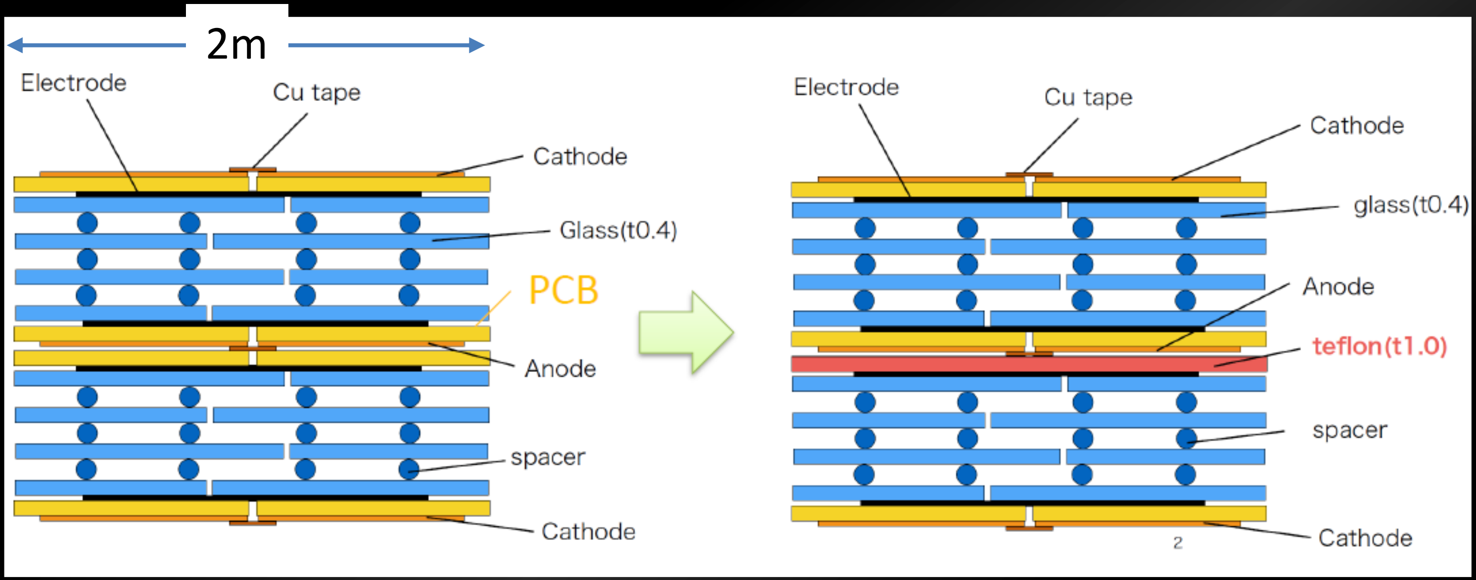


Large Strip RPC

By N. Tomida (RCNP)

- 2m Long RPC for LEPS2
  - Signal reflection caused by Impedance Mis-Matching
  - Dispersion during Signal Propagation
  - Transmission Line Theory (D. Gonzalez-Diaz)

Change Materials to minimize dispersion during Signal Propagation, changing coupling C to control Signal Propagation Speed



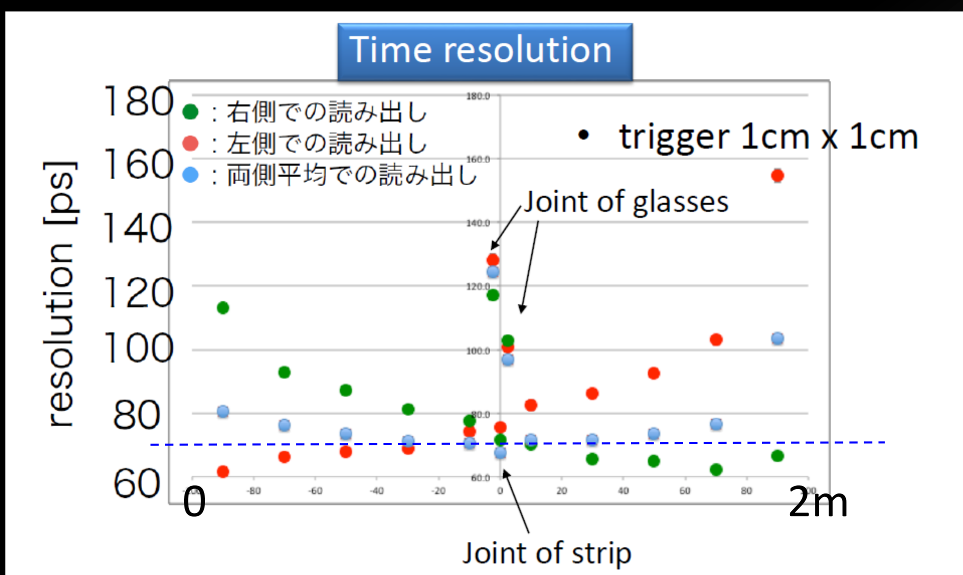
Large Strip RPC

By N. Tomida (RCNP)

- 2m Long RPC for LEPS2
  - Signal reflaction caused by Impedance Matching
  - Dispersion during Signal Propagation
  - Transmission Line Theory (D. Gonzalez-Diaz)

Before (res. ~ 70 ps)

After (res. to be improved)



Now Testing at SPring-8

LEPS/J-PARC joint R&D
FPGA-based HR-TDC Test Board

OPamp

comparator

DRS4

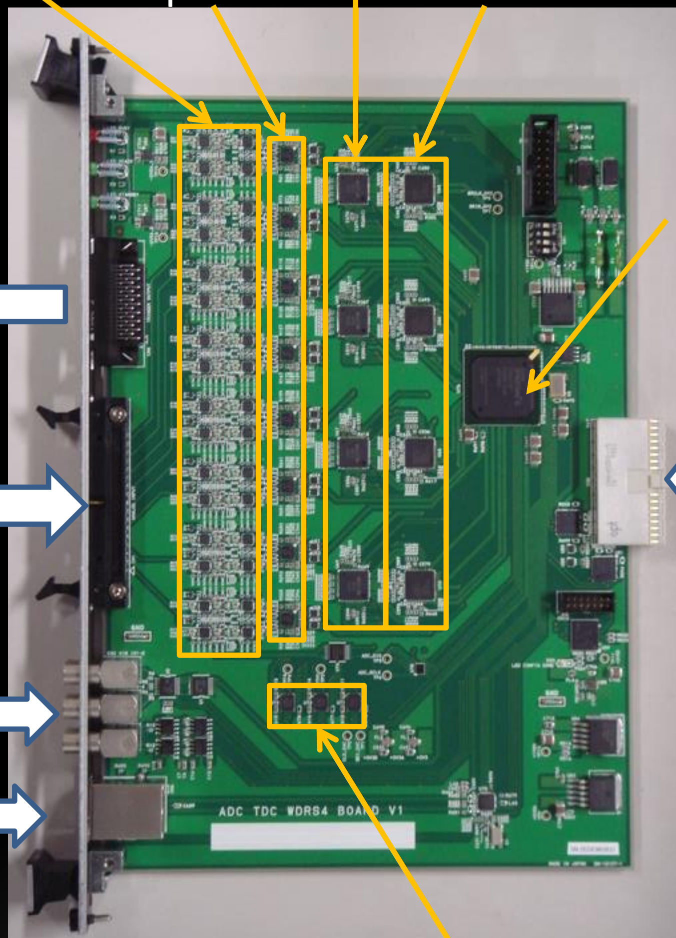
AD9637
(ADC 12bit, 40MSPS)

comparator out
(LVDS)
16 ch

analog input
(single-end)
16 ch

User I/O (NIM)

100BASE-T

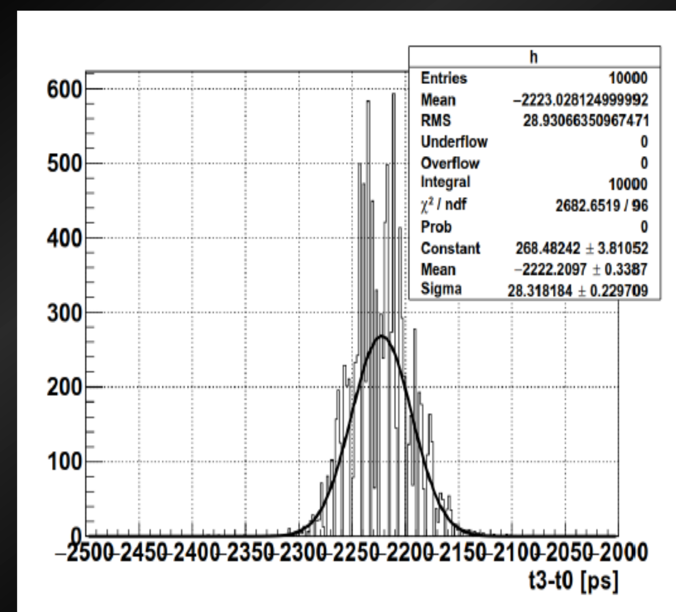


FPGA
Spartan-6
LX150

KEK-VME
+3.3V
-3.3V

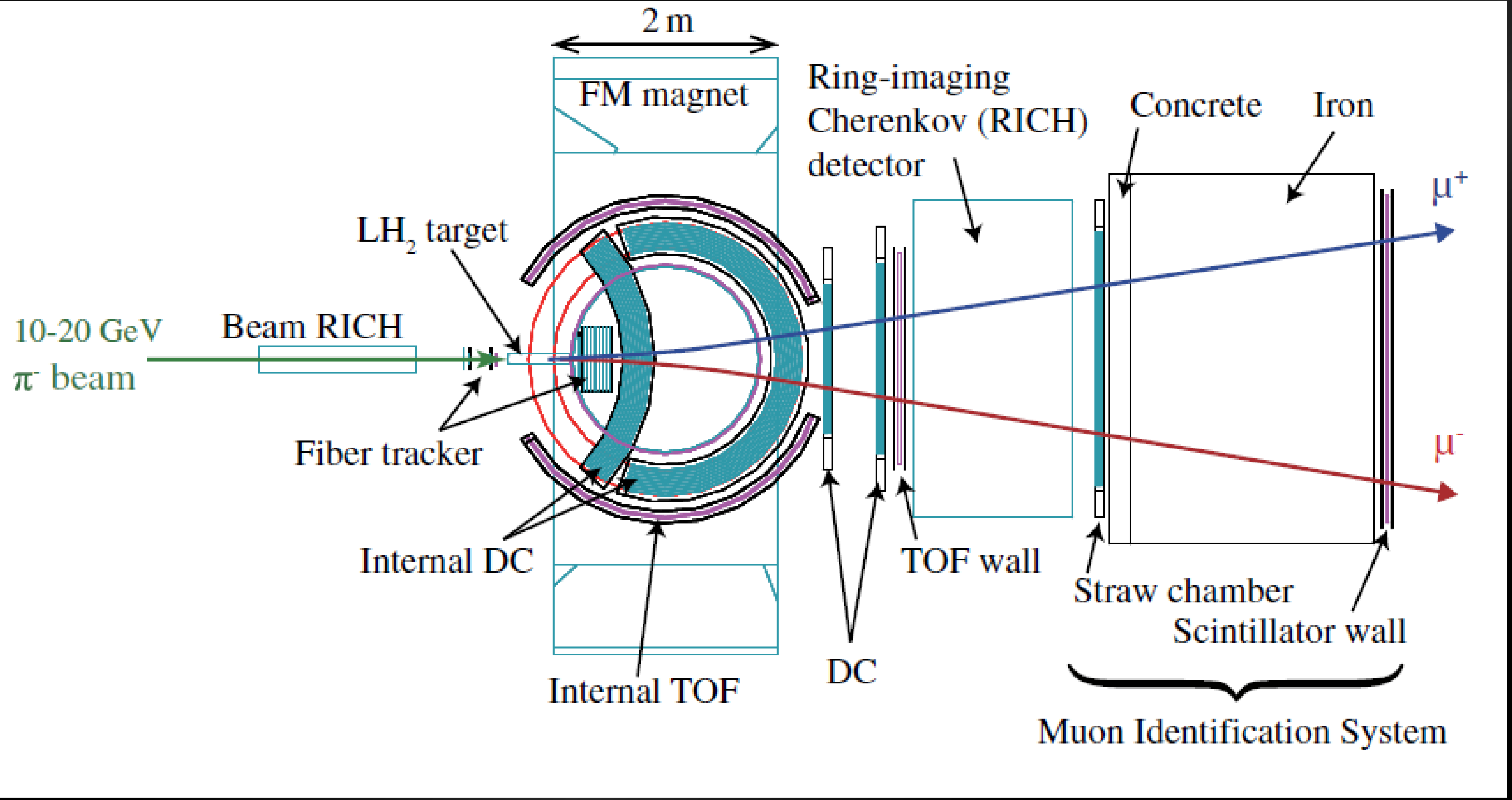
DAC (for bias, threshold)

σ_t~20ps (=28/$\sqrt{2}$ps)
w/ Clock Pulse
→Test at LEPS



By T.N. Takahashi(RCNP)

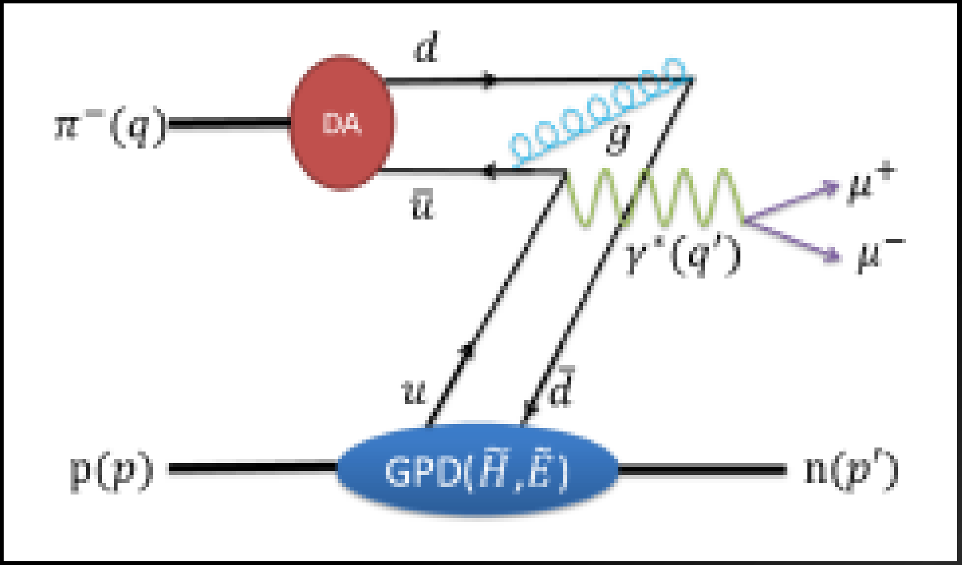
Muon ID

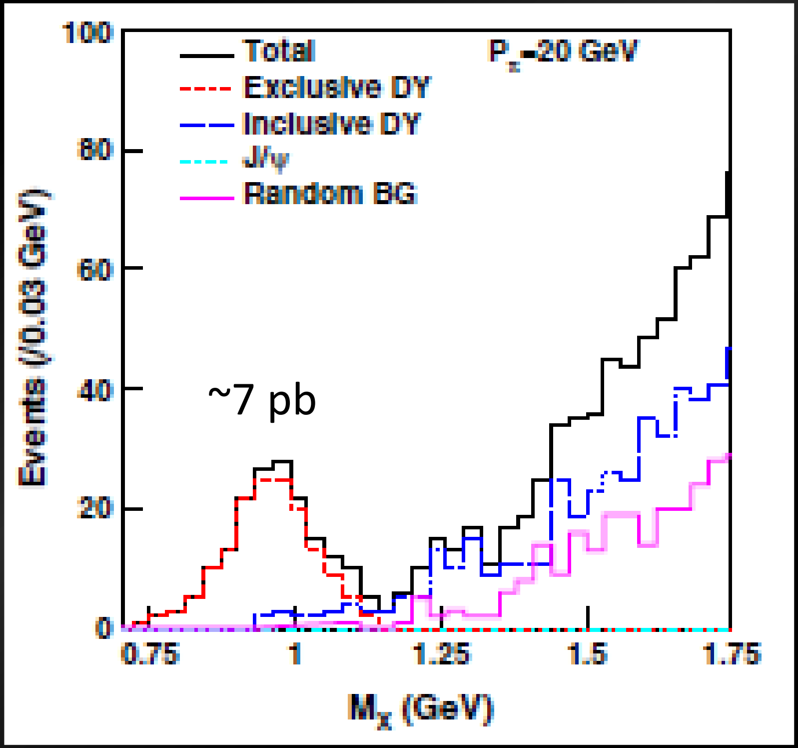

2 m
FM magnet
Ring-imaging
Cherenkov (RICH)
detector
Concrete
Iron
μ+
LH2 target
10-20 GeV
π- beam
Beam RICH
Fiber tracker
μ-
Internal DC
TOF wall
Straw chamber
Scintillator wall
DC
Internal TOF
Muon Identification System

Nucleon Structure via Exclusive DY

- $\pi^- p \to \mu^+ \mu^- "n"$

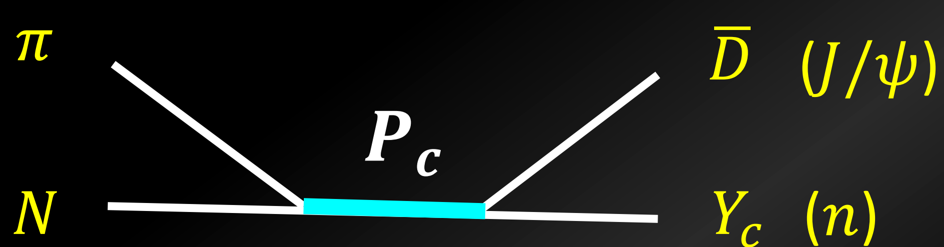
T. Sawada, W.C. Chang , S. Kumano, J.C. Peng, S. Sawada, K. Tanaka, Phys.Rev. D93 (2016) 114034

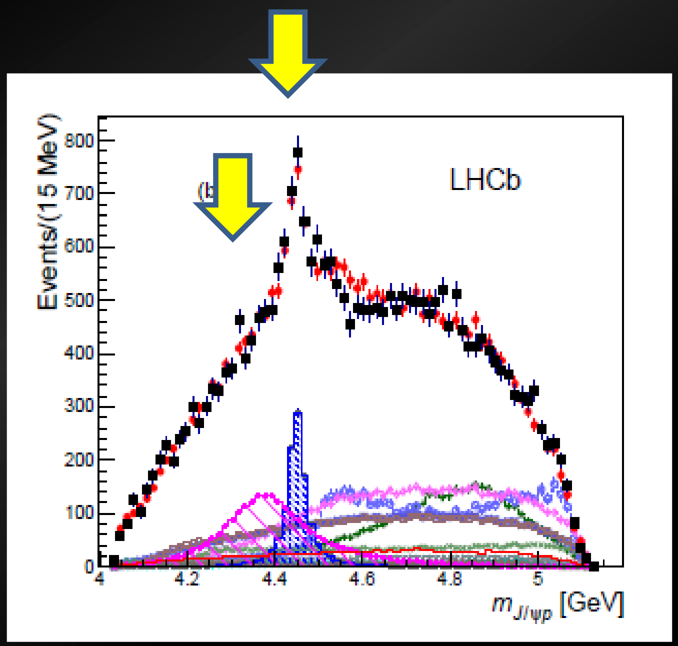




$P_c(4380), P_c(4450)$

- Is P_c^+ the N* with a hidden c-cbar?
- P_c^0 can be excited on its mass with 10 GeV/c pion beam at J-PARC.
- Its decay modes to $Y_c + \bar{D}$.
- Its family?





High-speed DAQ system for E50

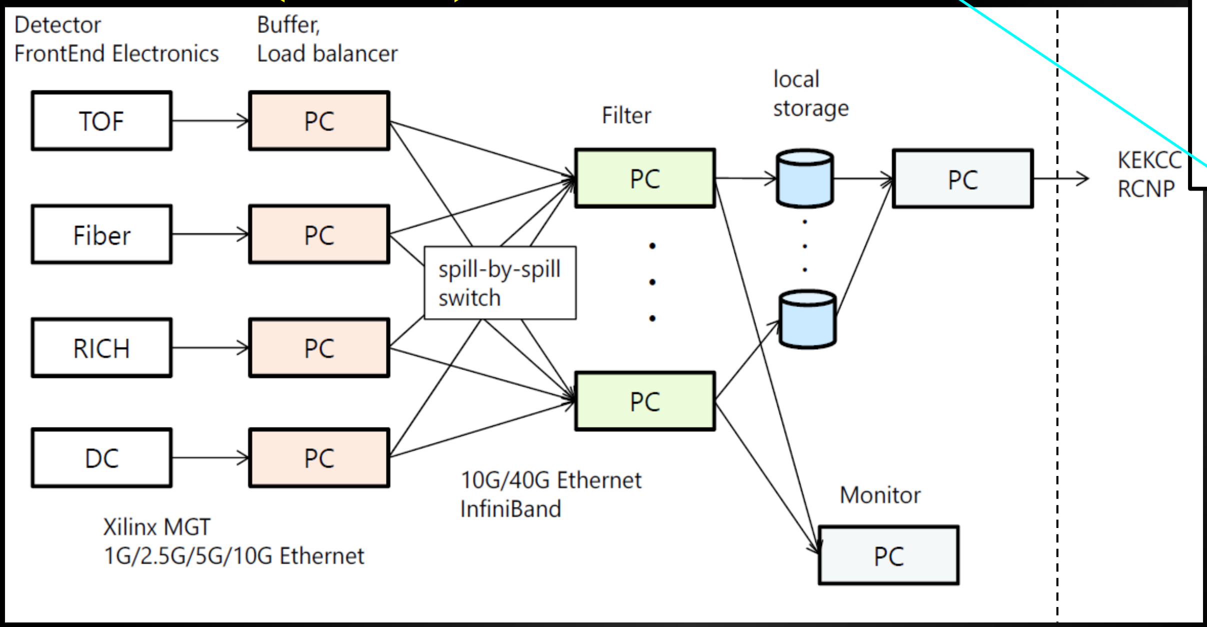
Streaming DAQ(~50 GB/spill)

Frontend modules
- ✱ **Signal digitalization**
  - **Pipelined system**

Buffer PCs
- ✱ **Data accumulation**
  - **Several 10 GB memories**

~50 GB/spill

✱ High-speed data link (Local)



Filter PCs
- ✱ **Event reconstruction**
  - **100–200 CPUs**

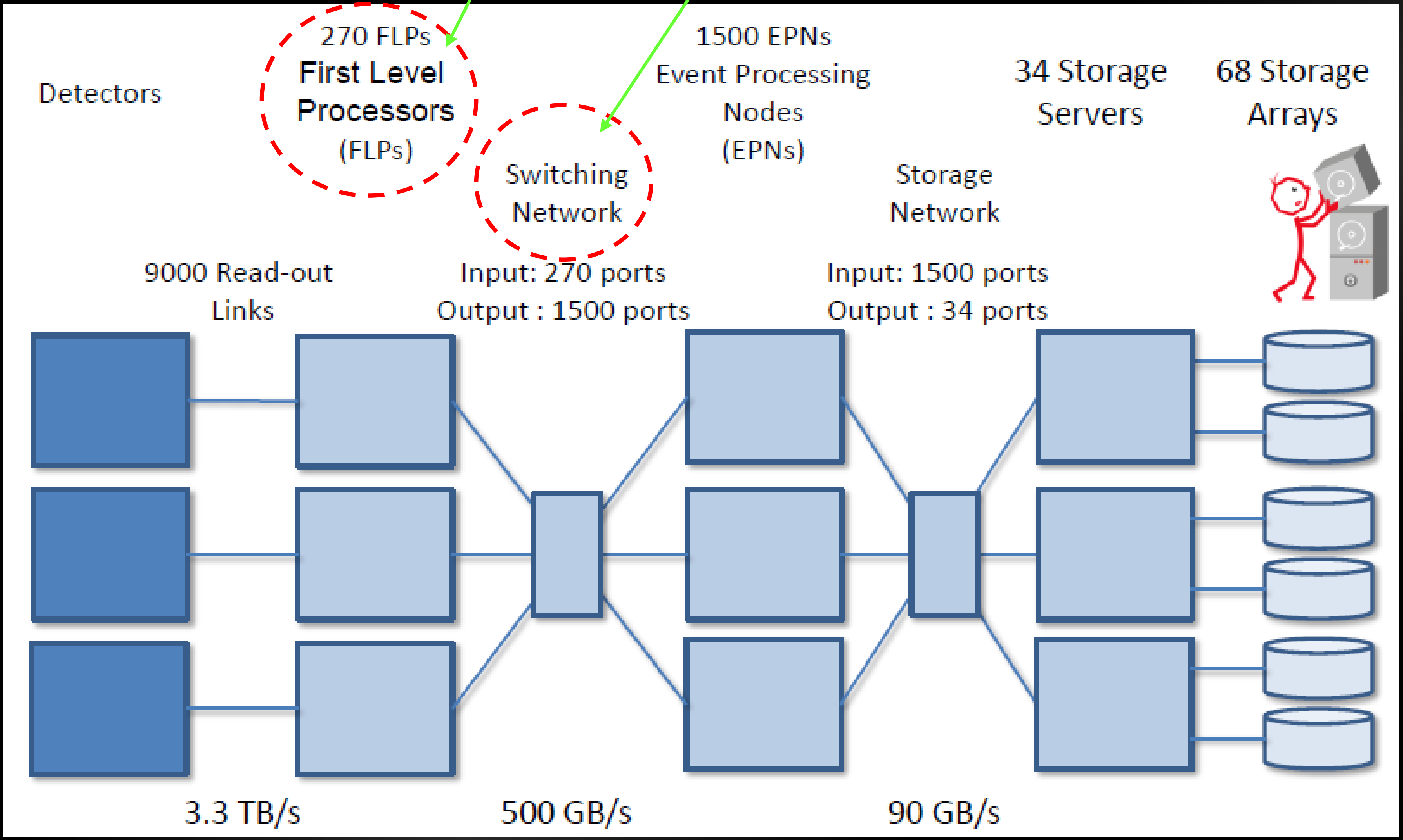
<0.5 GB/spill

Storage
- **Local storage**
- **Transferred to KEKCC/RCNP**

Flexible triggers can be accommodated.

ALICE O2 Hardware Facility

Sofware R&D (Sako) Load Balancing/Data Flow Regulation R&D (Ma)



Summary

- A heavy quark disentangles quark correlation in baryons.
- A diquark correlation will be singled out in level structure, production rate, and decay branching ratio of excited charmed baryons.
  - Missing mass spectroscopy via $p(\pi^-, D^{*-})Y_c^*$ is suitable and unique.
- The high-momentum beam line and a general purpose spectrometer will provide a unique platform for hadron physics.