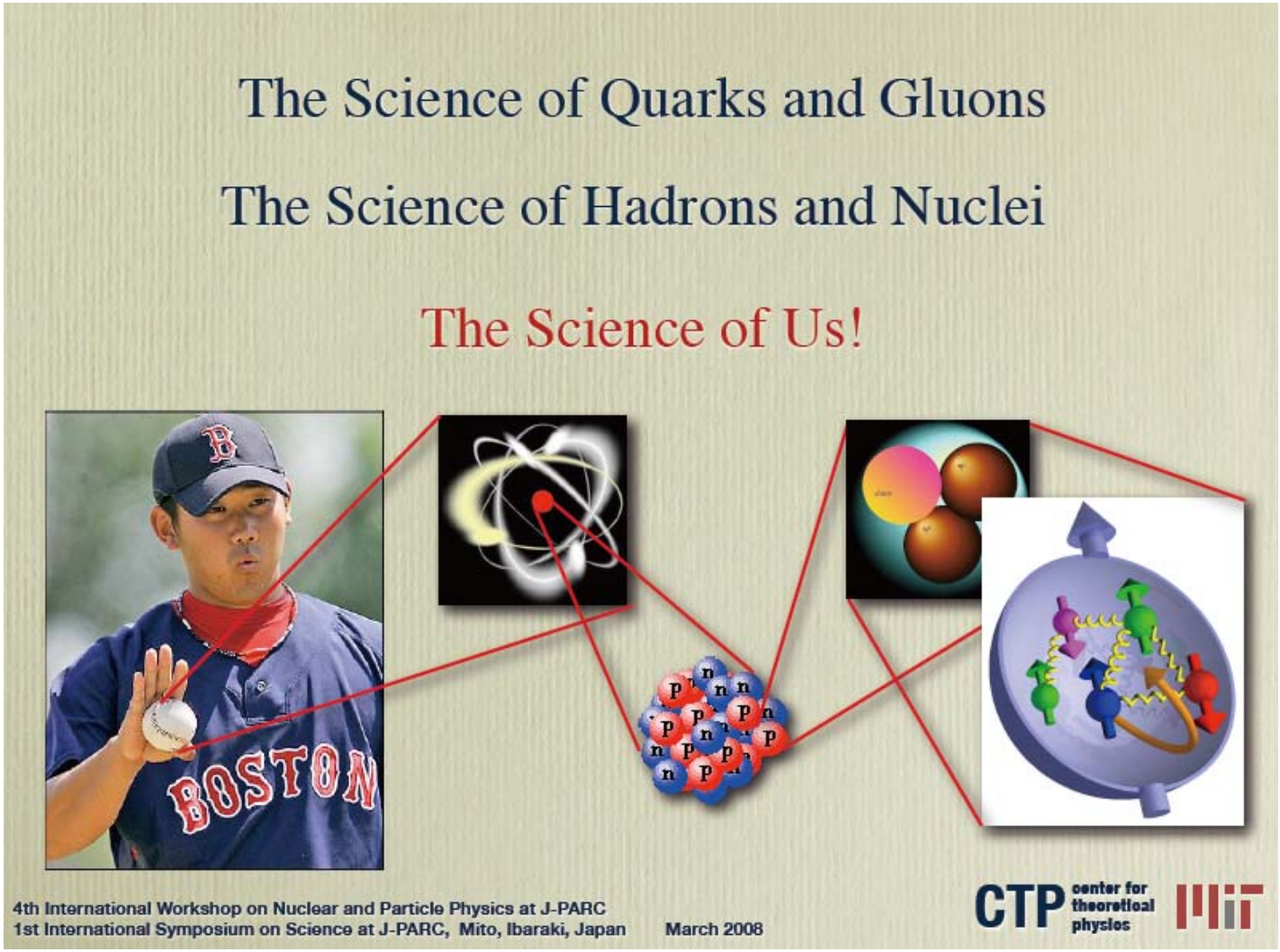
Summary of Outcome at NP08 on Nuclear/Hadron Physics Experiments at J-PARC

Shinya Sawada (KEK)
on behalf of the
Nuclear/Hadron Physics Experiments Working Group

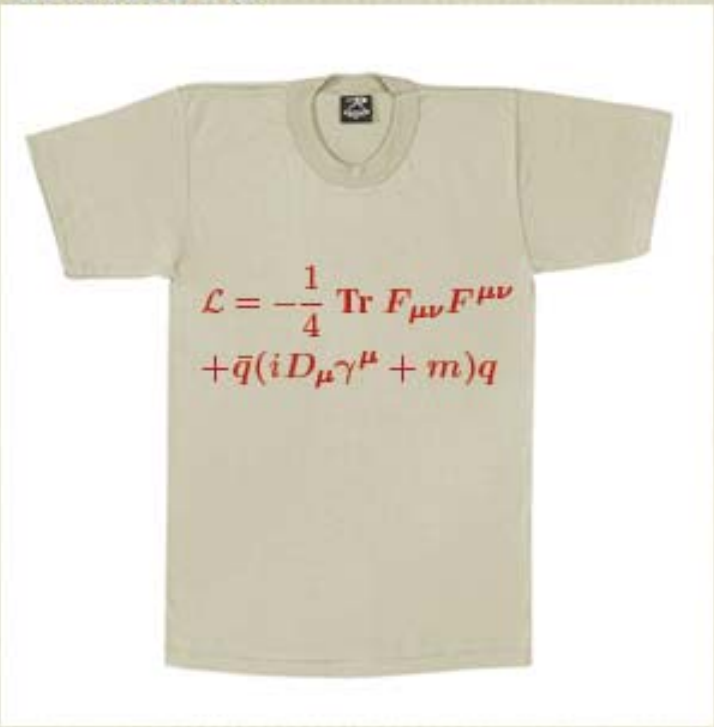
I cannot repeat Prof. Jaffe's Excellent Talk on March 5



QCD

Quantum Chromo Dynamics

- 99.97% of the visible mass of the Universe is composed of protons and neutrons.
- Protons and neutrons are made of almost massless quarks and gluons.
- Most of our mass comes from the kinetic energy of quarks and gluons fighting to escape from the small regions where QCD interactions confine them.



QCD is the only complete, correct, and internally consistent description of any aspect of Nature that we have managed to construct!

Hadron Physics in My Words

- Physics of Strong Interaction and Strongly Interacting Particles.
- Hadron physics is in a sense physics of QCD.
- To understand QCD, it is essential to

  understand hadron mass and confinement.
- And thus it's a key to understand our universe.

- Especially at J-PARC, low energy (sometimes non-perturbative), cold, static properties of hadrons are focused.

Hadron Physics has Rich Phenomena

- Proton/neutron consists of three quarks. OK?
  - Nothing else? Not too simple? Can universe be explained just with this view?
- NO!!
- In fact,
  - Protons may have pion clouds.
  - Nucleons inside nuclear matter may have different shape than free nucleons.
  - Not only uud/udd barions exist and plan an important role in the universe.
  - Low energy, non-perturbative QCD is not so straight forward to be calculated by theories.

- QCD (and hadron) is an very important and interesting object to study. Hadron physics experiments at J-PARC aim to tackle QCD problems coherently but from different directions.

Hadron/Nuclear Physics Experiements Session

			Title	Talker
6-Mar	6-Mar			
9:00	9:25	0:25:00	Some problems of strange baryons spectroscopy: chiral solitons versus quark models	V. Kopeliovich
9:25				kano
9:45				cks
10:10				uramatsu
10:30	10:50	0:20:00	High resolution spectroscopic searches on Theta + and Theta-hypernuclei	K. Tanida
10:50	11:10	0:20:00	Coffee	
11:10	11:35	0:25:00	Hyperon Spectroscopy at J-PARC	J.K. Ahn
11:35				awa
12:00				kkaichi
12:20				nishi
12:40	13:40	1:00	Lunch	
13:40	14:05	0:25:00	Parton distribution functions for the nucleon and nuclei (*)	S. Kumano
14:05				imer
14:25				wada
14:40				Peng
15:05	15:25	0:20:00	Coffee	
15:25	15:45	0:20:00	Di-muon production with meson beams at J-PARC	Seonho Choi
15:45	16:05	0:20:00	Generalized Parton Distribution at J-PARC	K. Sudoh
16:05	16:30	0:25:00	spin-orbit correlations	M. Burkardt
16:30				to
16:50				nda
17:15				isch

Theta+ and Hadron Spectroscopy

QCD Mass

Structure on Nucleon and Nucleon in Matter

Experiments with Polarized Beams

Theta+ and Spectroscopy

What are pentaquarks?

- Baryon.
- Minimum quark content is 5 quarks. $\left(qqqq\overline{Q}\right)$
- "Exotic" penta-quarks are those where the antiquark has a different flavor than the other 4 quarks
- Quantum numbers cannot be defined by 3 quarks alone.

Θ^+: $uudd\bar{s}$

Baryon number = 1/3 + 1/3 + 1/3 + 1/3 – 1/3 = 1

Strangeness = 0 + 0 + 0 + 0 + 1 = 1

e.g. $uudd\bar{c}$, $uuss\bar{d}$

T. Nakano

c.f. $\Lambda(1405)$: $uuds\bar{u}$ or uds

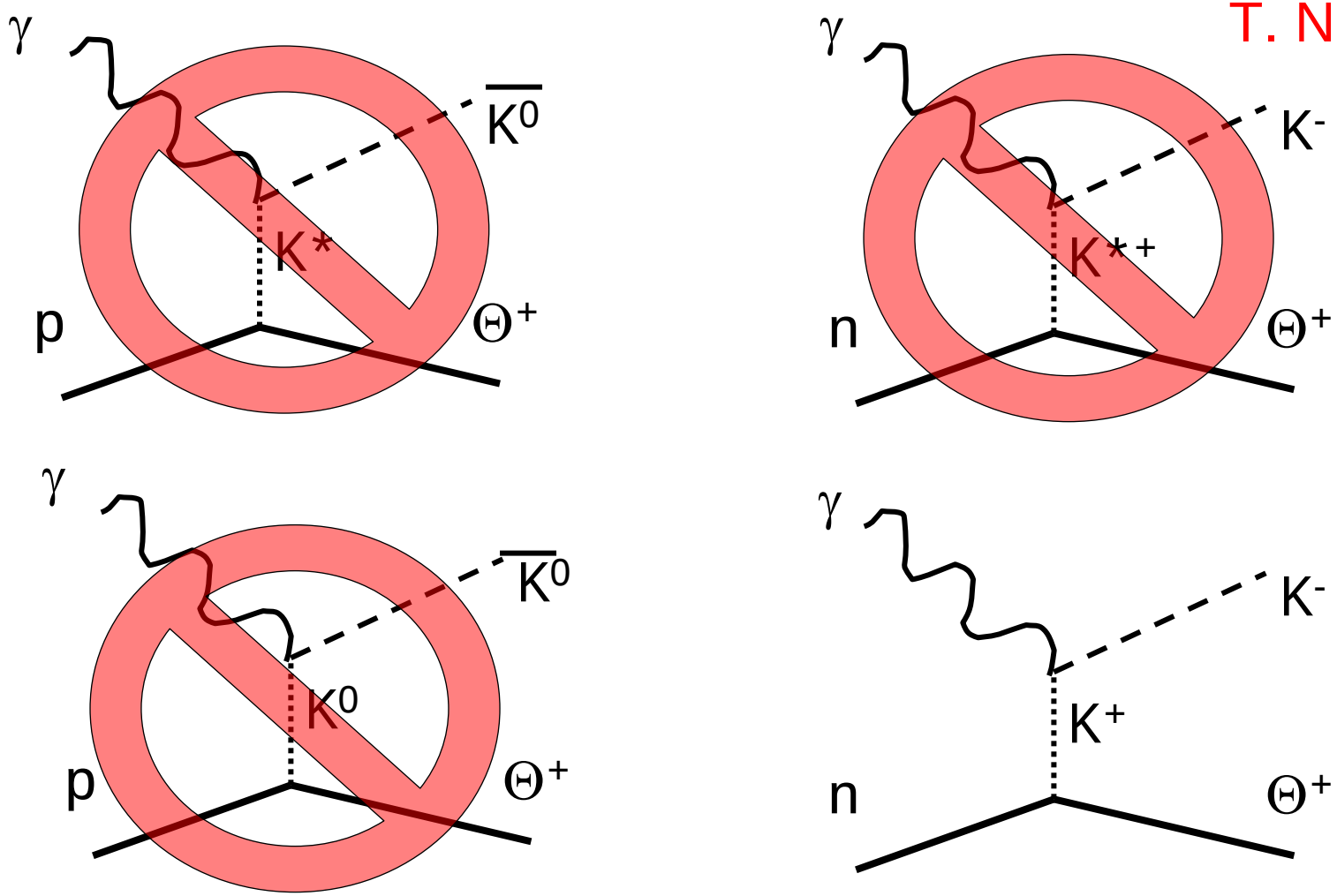
Experimental Status of Θ^+

- Not seen in the most of the high energy experiments: The production rate of $\Theta+/\Lambda(1520)$ is less than 1%.
- No published positive result from dedicated experiments CLAS γp γd, COSY-TOF pp, KEK-PS (π-,K-), (K+,π+)
- The width must be less than 1 MeV. (DIANA and KEK-B)
- LEPS observed signals in γ n$\rightarrow$K+K-n and γd$\rightarrow\Lambda$(1520)KN reactions, which could be inconsistent with CLAS γd experiment (CLAS-g10).

T. Nakano

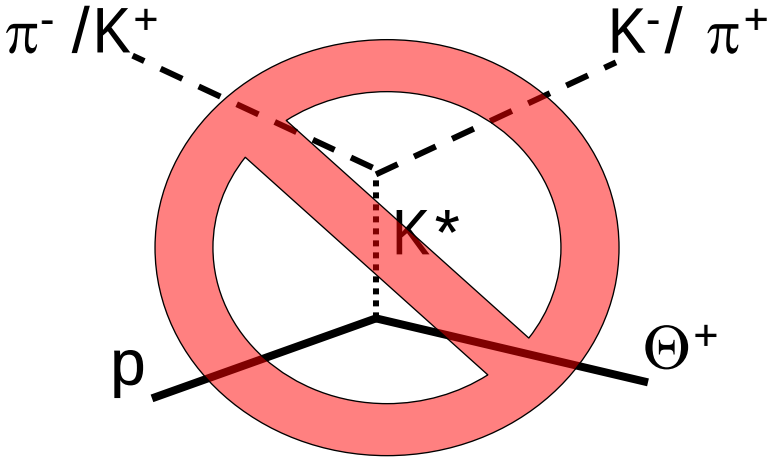
t-channel photo-production of Θ^+

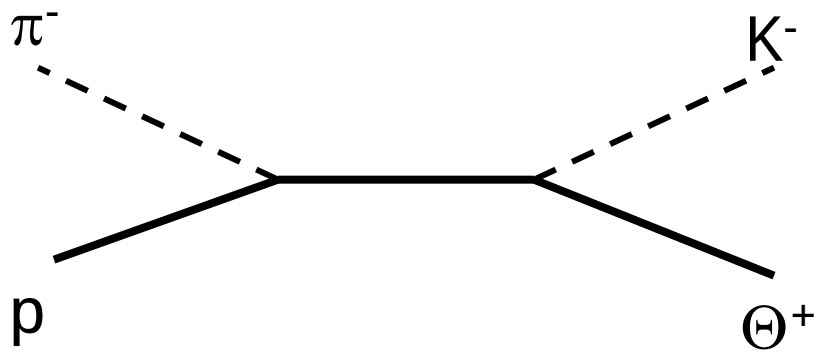
T. Nakano

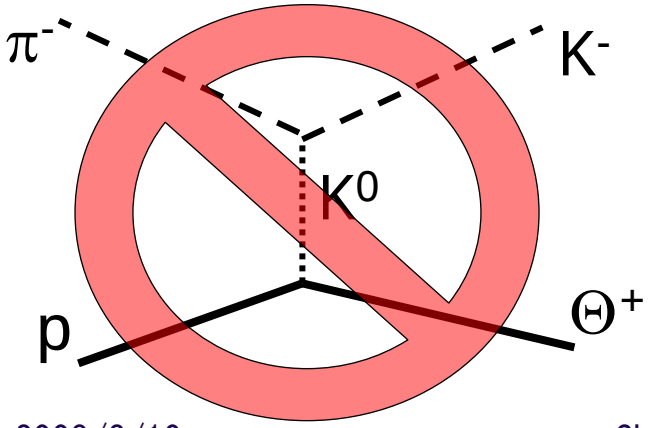


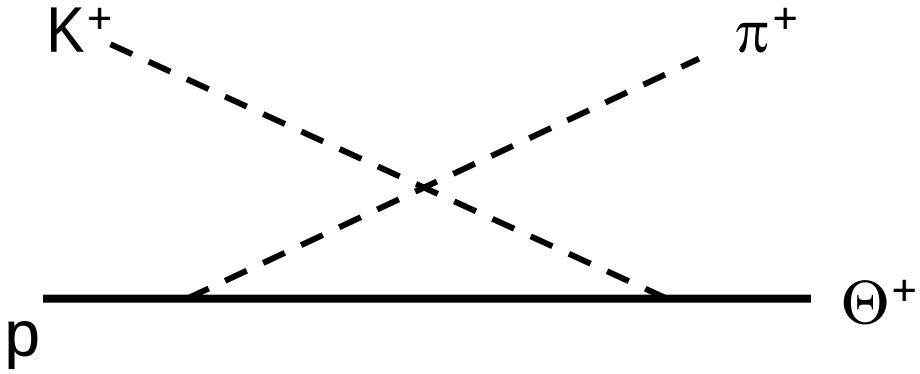
Θ^+ production in (π^-,K^-) and (K^+,π^+) reactions

T. Nakano





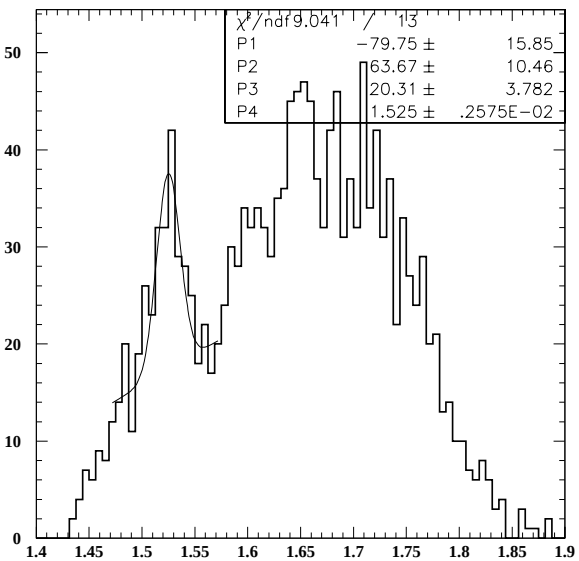




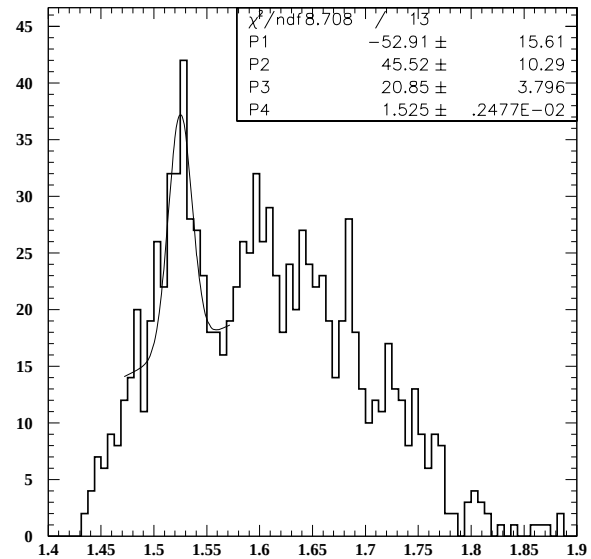
Backward peak

LEPS Results

$|p_{min}|$<70 MeV/c



MpK^- > 1.54 GeV/c²



- More than one order of magnitude larger than CLAS-g10 upper limit of stot~3 nb (95%CL).
- Can be consistent?

T. Nakano

T. Nakano

The reaction is the same: $\gamma n \rightarrow K^- \Theta^+$

LEPS		CLAS
Good forward angle coverage	⟷	Poor forward angle coverage
Poor wide angle coverage	⟷	Good wide angle coverage
Low energy	⟷	Medium energy
Symmetric acceptance for K^+ and K^-	⟷	Asymmetric acceptance
$M_{KK} \gtrsim 1.04$ GeV/c^2	⟷	$M_{KK} > 1.07$ GeV/c^2
Select quasi-free process	⟷	Require re-scattering or large Fermi momentum of a spectator

LEPS: $\theta_{LAB} < 20$ degree $|t| < 0.6$ GeV^2

CLAS: $\theta_{LAB} > 20$ degree

Θ^+ might be a soft object.

Next Steps

- Final result with optimized ϕ exclusion cut will be open soon.
- New data set with 3 times more statistics has been already taken.
- Blind analysis will be carried out to check the peak (in this year).
- A new experiment with a Time Projection Chamber was started. → wider angle coverage and Θ^+ reconstruction in pKs decay mode.
- If the peak is confirmed, we will submit a proposal to do a complete search for Θ^+ by using a low energy K^+ beam at J-PARC.

T. Nakano

Summary of Current Situation by Ken Hicks

- Theory suggests that it is still possible that a Θ^+ pentaquark exists with $J^P=3/2^+$.
  - If so, then production only at forward angles.
- Experiments suggest that only a small kinematic window is available to the Θ^+.
  - The LEPS experiment is in this window.
    - Small invariant mass & small t. Small J & small width.
  - A “formation” experiment is still needed.
- J-PARC will be able to either confirm the Θ^+ or close the door on its existence.

Θ^+ formation definitive experiment at J-PARC

N. Muramatsu

- Resonance formation reaction:
  - $K^+n \rightarrow \Theta^+ \rightarrow K_S^0 p \rightarrow \pi^+\pi^- p$
  - $P(K^+)$=417 (442) MeV/c
  - for $M(\Theta^+)$=1.53 (1.54) GeV/c2
  - K0.8 beamline is necessary.
- π^+, π^-, & proton detection by large acceptance spectrometer
  - $M(\pi^+\pi^-)$: K_S^0 reconstruction
  - $M(K_S^0 p)$: Θ^+ reconstruction
  - Independent from Fermi motion

Direct confirmation of Θ^+ existence

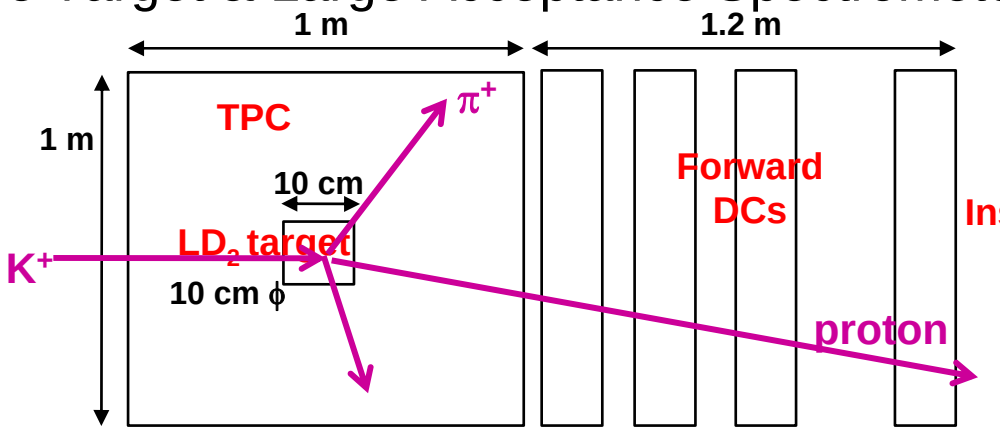
Independent from reaction mechanism

Width can be measured from cross section

Spin measurement by decay angular distribution

Possible Experimental Setup

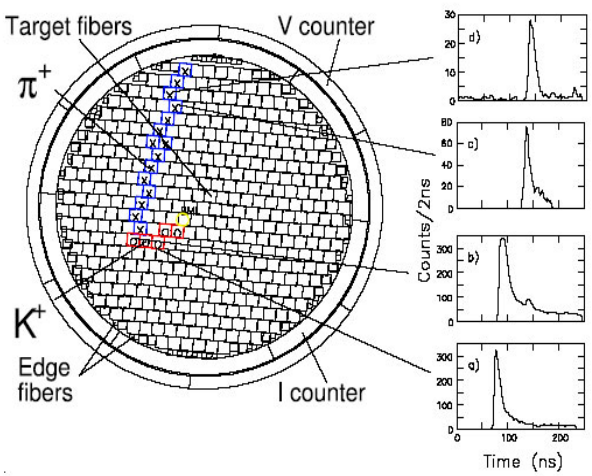
- Inactive Target & Large Acceptance Spectrometer

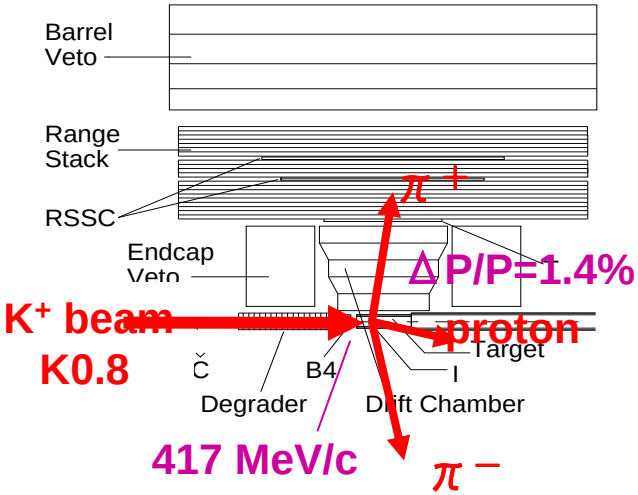


N. Muramatsu

Inside 1 Tesla solenoid

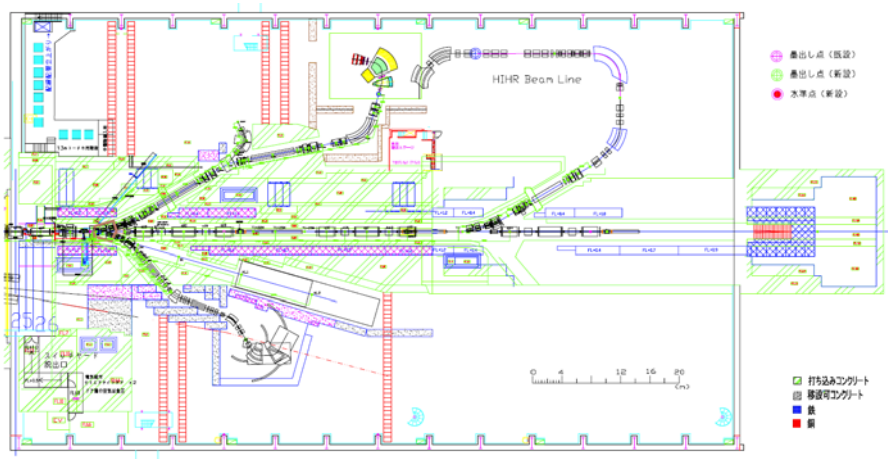
- Active Target & Side Spectrometer [like E949]





Other Θ+ Experiments

- High resolution mass width measurement via (pi-, K-)



- Θ+ nucleus?
  - d(K+, p)Θ+
  - K1.8 or K1.1 with SKS+

K. Tanida

Baryon Spectroscopy with Strangeness

- V. Kopeliovich: rich physics on strange baryon spectroscopy.

- $\Lambda(1405)$ J. K. Ahn
  - uds or KN or $\pi\Sigma$ quasi-bound state or?
  - K^-N reaction
- $\Sigma(1480)$ search with K beams
- Ξ Resonances and Exotics
  - 2 – 10 GeV/c π and K
  - 50 GeV p

Hyperon Resonances

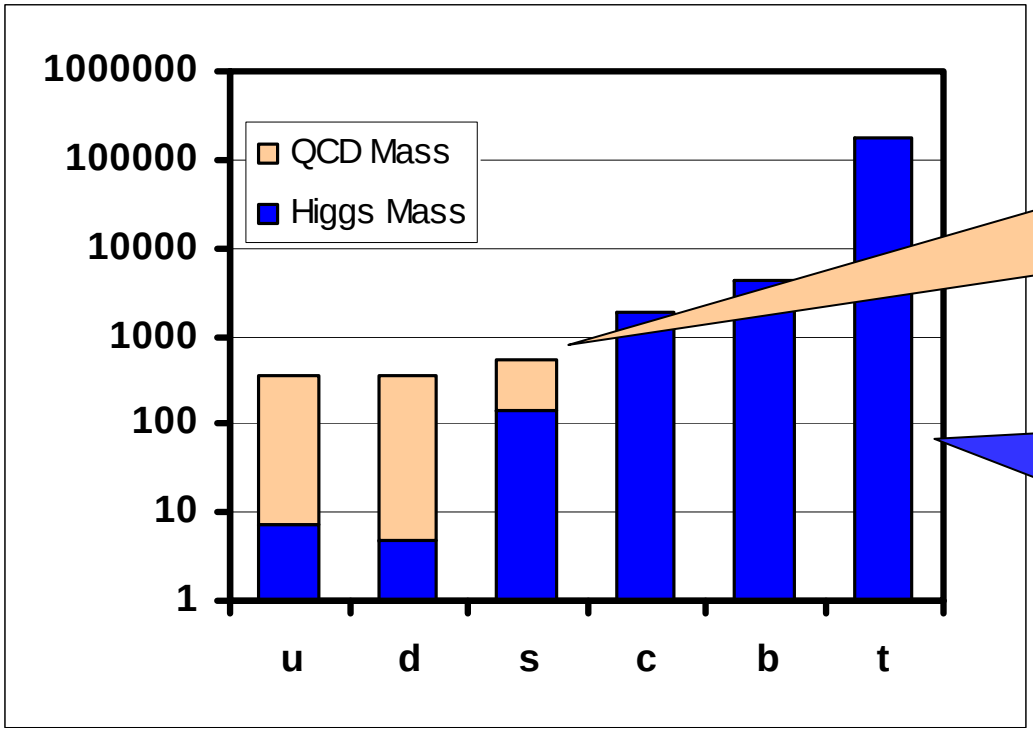
➔ **6 GeV/*c* K beam for 2.5 GeV/c² Y* Production**

QCD Mass

K. Ozawa

Origin of Mass

95% of the (visible) mass is due to the **spontaneous breaking of the chiral symmetry**. Only 5% of the mass is due to the Higgs field.



Constituent quark masses generated by spontaneous chiral symmetry breaking

Current quark masses generated by spontaneous symmetry breaking (Higgs field)

I'd like to experimentally establish the relation between chiral symmetry and hadron mass.

K. Ozawa

Hadron Mass Experiments

- Spontaneous breaking of a symmetry is marked by a non-zero order parameter, the quark condensate <qq> in the case of QCD

$$<\bar{q}q> \approx 250 MeV^3$$

$$<\bar{q}q> \approx 0$$

High T
High ρ

- Two approaches
  - Models link meson bound states to the quark condensate. G.E.Brown and M. Rho, PRL 66 (1991) 2720
  - Models link hadron masses to the quark condensate. T.Hatsuda and S. Lee, PRC 46 (1992) R34

$$\frac{m^*}{m} \approx \frac{\langle \bar{q}q \rangle^*}{\langle \bar{q}q \rangle} \approx 0.8 \left(\rho \approx \rho_0\right)$$

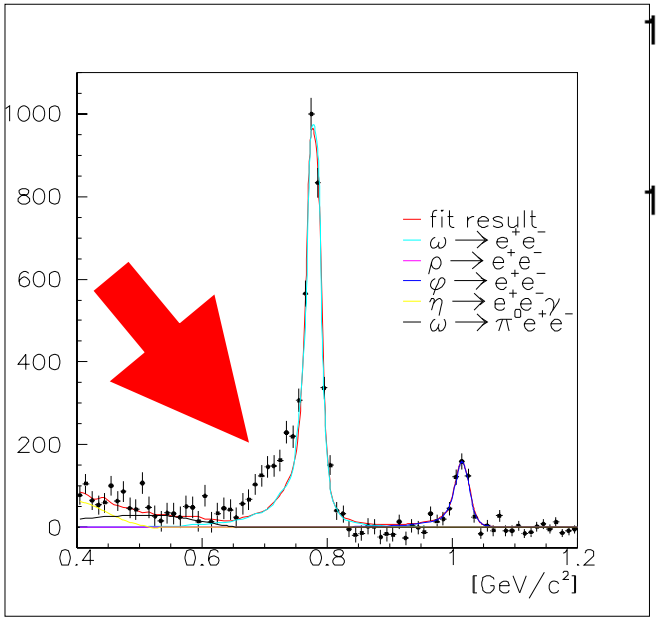
$$\frac{m_V^*}{m_V} = \left(1 - \alpha \frac{\rho_B}{\rho_0}\right); \ \alpha \approx 0.18$$

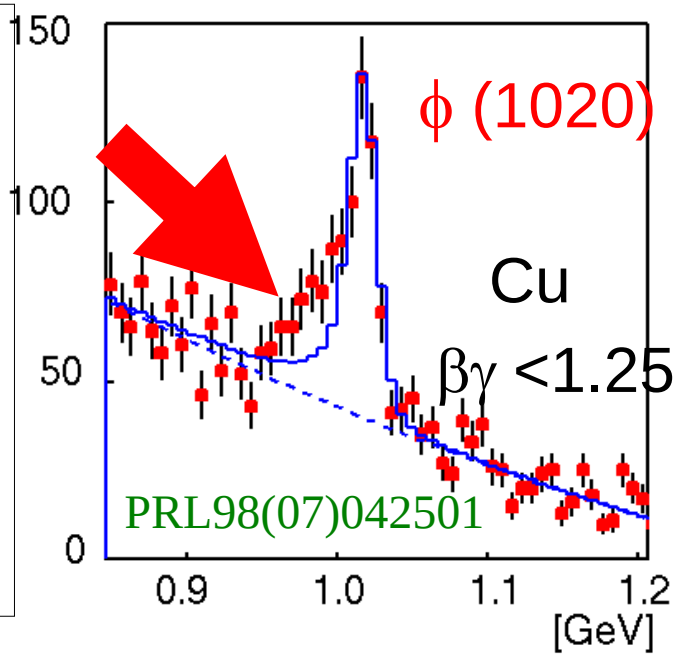
- Two experimental methods
  - Meson bound state spectroscopy
    - Discussed in detail at the strangeness physics WG.
  - Direct measurements of mass spectra

S. Yokkaichi

Low Mass Dielectrons

KEK-PS E325



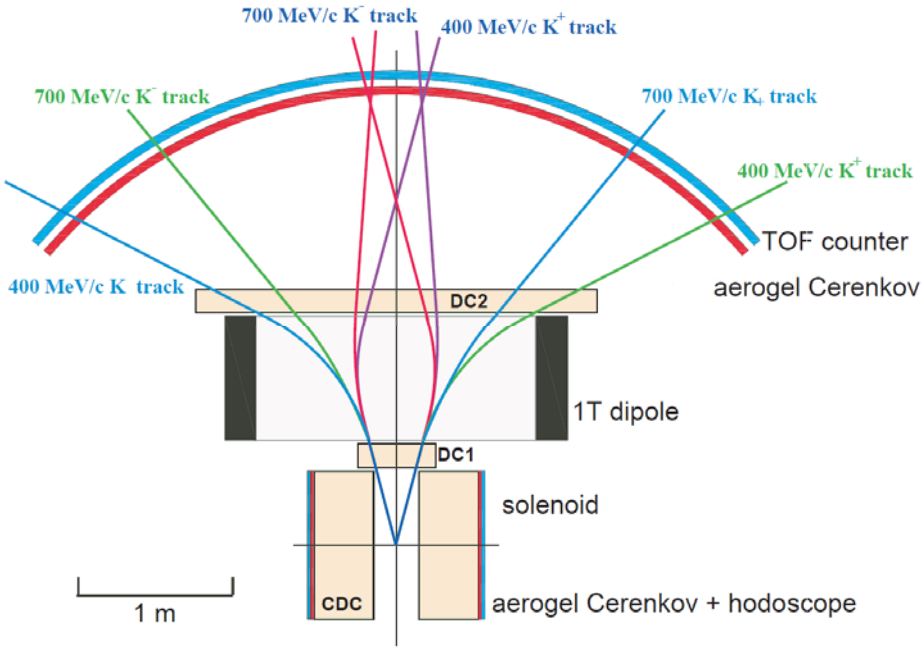


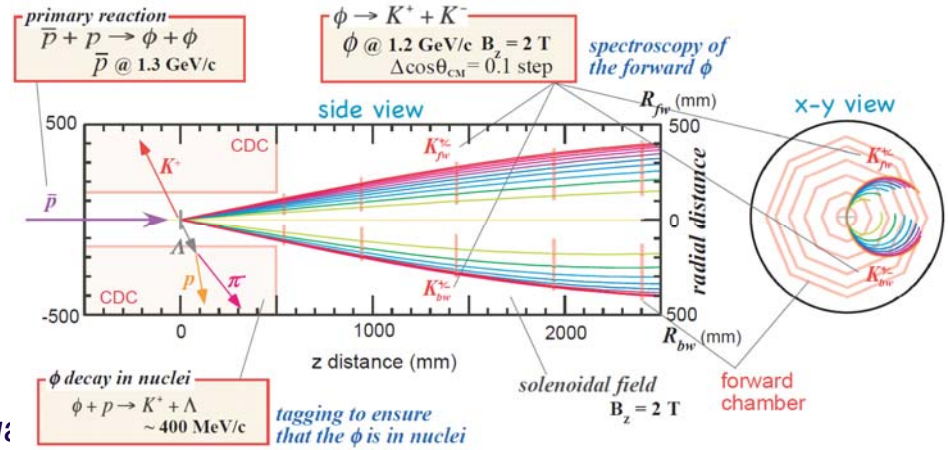
- 30 (or 50) GeV primary proton beam (~1x10^{10} /sec) and new electron pair spectrometer
- Take 100 times more statistics
  - get dispersion relation (mass vs momentum) → clearer understanding

H. Ohnishi

in-medium ϕ(1020)-meson mass through bound state search

- mass reduction of ϕ
  → ϕ mesic nucleus may be formed
- p-bar+p→Φ Φreaction
  → ϕ captured by A
- p-bar beam ~ 1.3 GeV/c
- Detector
  - Conventional: LEPS type
  - Challenging: Large solenoid
  - 4 strangeness tag





Structure of Nucleon

S. Kumano

J-PARC hadron physics

Understanding of strongly interacting matter & Search for new state of matter

Quantum Chromodynamics (QCD)

- **Asymptotic freedom, …**

  Perturbative QCD, Parton distribution functions, Nucleon spin, …

- **Color confinement**

  Hadron spectroscopy, Quark-hadron matter

- **Chiral symmetry**

  Hadrons in nuclear medium

Jaffe@J-PARC-NP08

S. Kumano

Hadron physics with 30 – 50 GeV proton beam

30 GeV
- **J/ψ production**
  - **Transition: Hadron → Quark degrees of freedom**
  - **Hadron interactions in nuclear medium**
  - **Short-range NN interactions**
  - **GPDs**
  - **…**

P. Reimer, S. Sawada, J.-C. Peng, S. Choi

50 GeV
- **Drell-Yan (unpolarized PDFs)**
  - **Single spin asymmetries**
  - **Tensor structure at 50 GeV (Spin-1 hadrons)**
  - **Fragmentation functions (Hadron productions)**
  - **…**

K. Sudoh, M. Burkardt

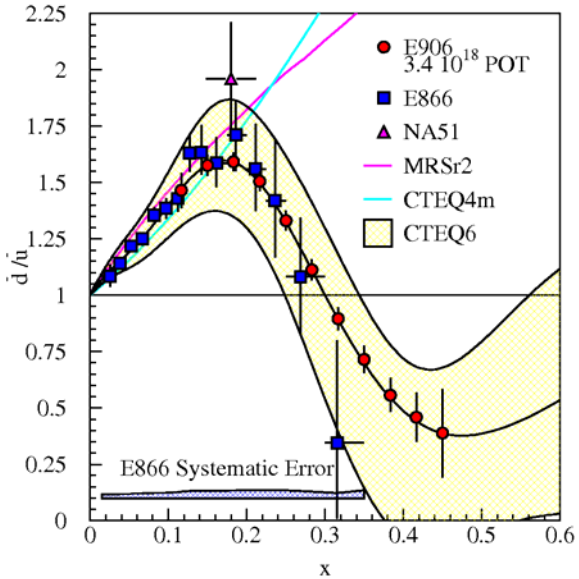
Proton-beam polarization
- **Drell-Yan: Double asymmetries (Polarized PDFs)**
- **Complimentary to RHIC-Spin (large *x* physics)**
- **…**

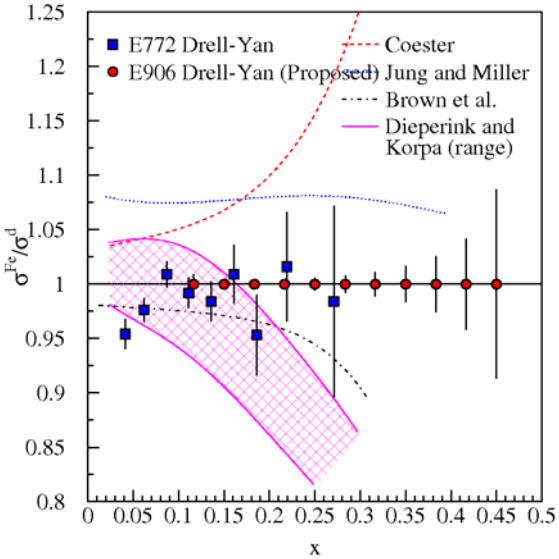
Y. Goto, A. Krisch

P. Reimer, S. Sawada

E906 and Dimuon Spectrometer

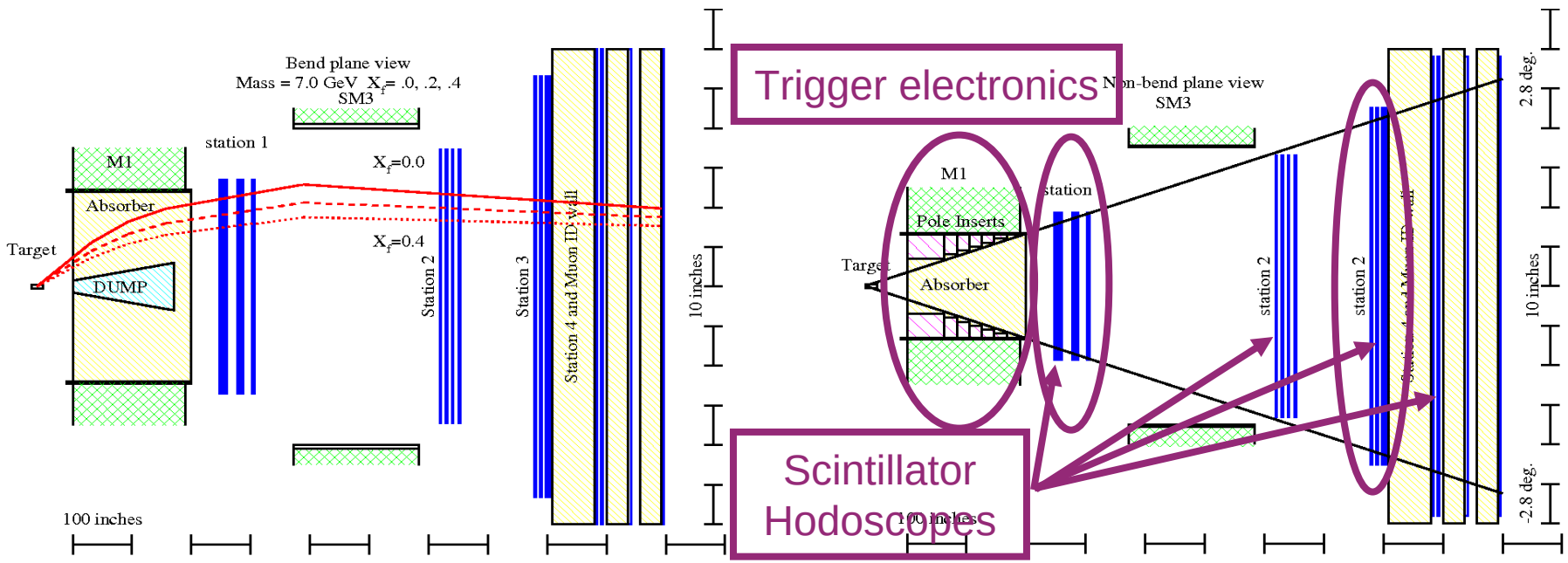
- E906 at Fermilab
  - d-bar/u-bar
  - sea quark distributions in nucleus.
    - nuclear binding
  - beam (120GeV protons): 2010-2012
  - Japanese group is negotiating to participate and applied for US-Japan.





P. Reimer, S. Sawada

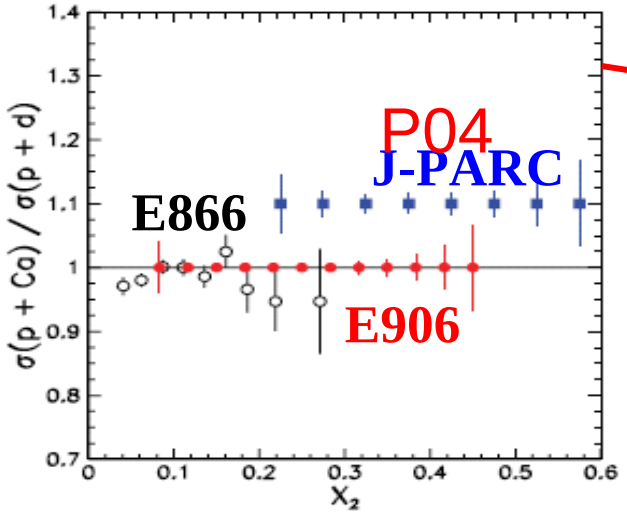
E906 and Dimuon Spectrometer

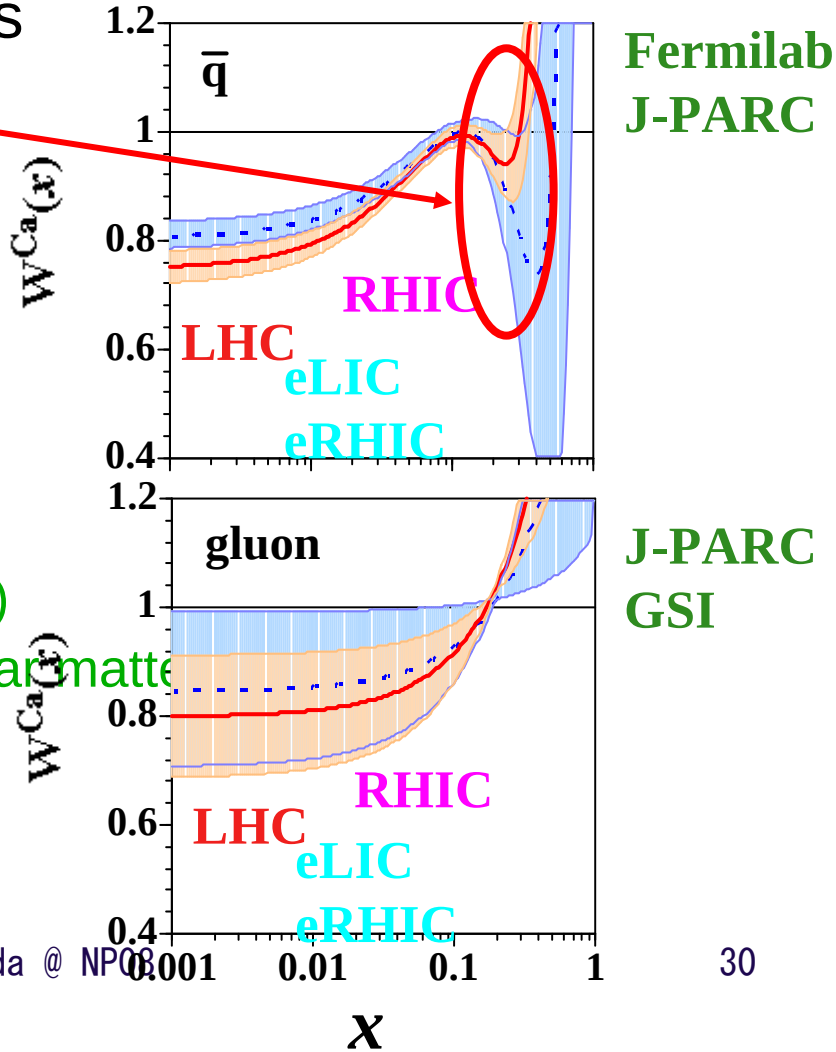


- Apparatus will be shipped to J-PARC in 2013.

Dimuon Measurement at J-PARC

- sea quark asymmetry at even larger x for nucleon and nucleon inside nucleus



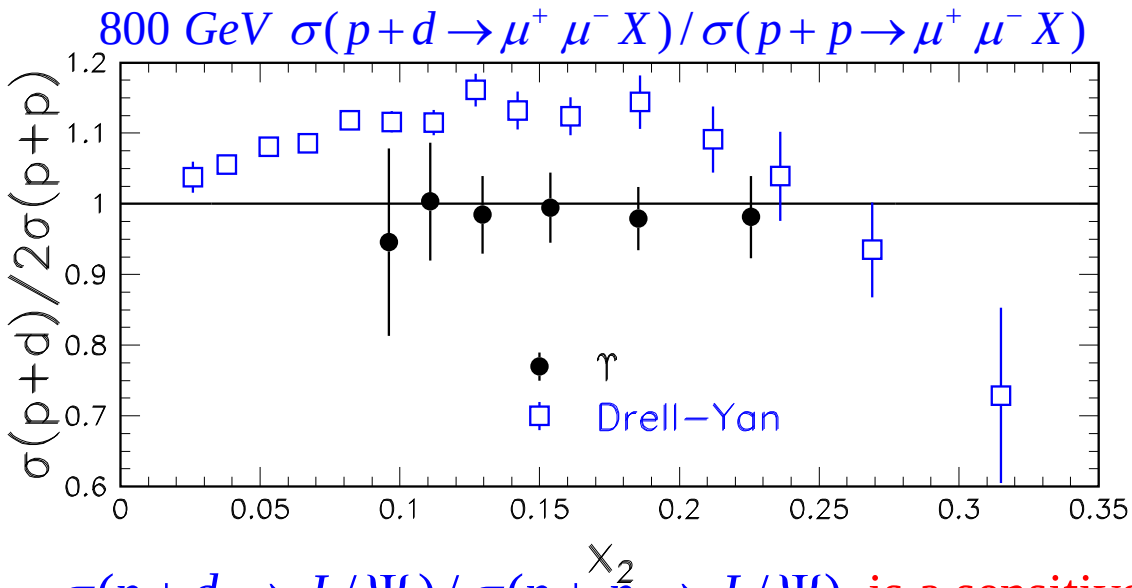


  - sea asymmetry (d-bar/u-bar)
  - sea asymmetry inside nuclear matter
  - parton energy loss

S. Kumano

J.C. Peng

Even at 30 GeV: Quarkonium Production



E866 collaboration: PRL 100 (2008) 062301

$\sigma(p+d\to J/\Psi)/\sigma(p+p\to J/\Psi)$ is a sensitive test for the production mechanism

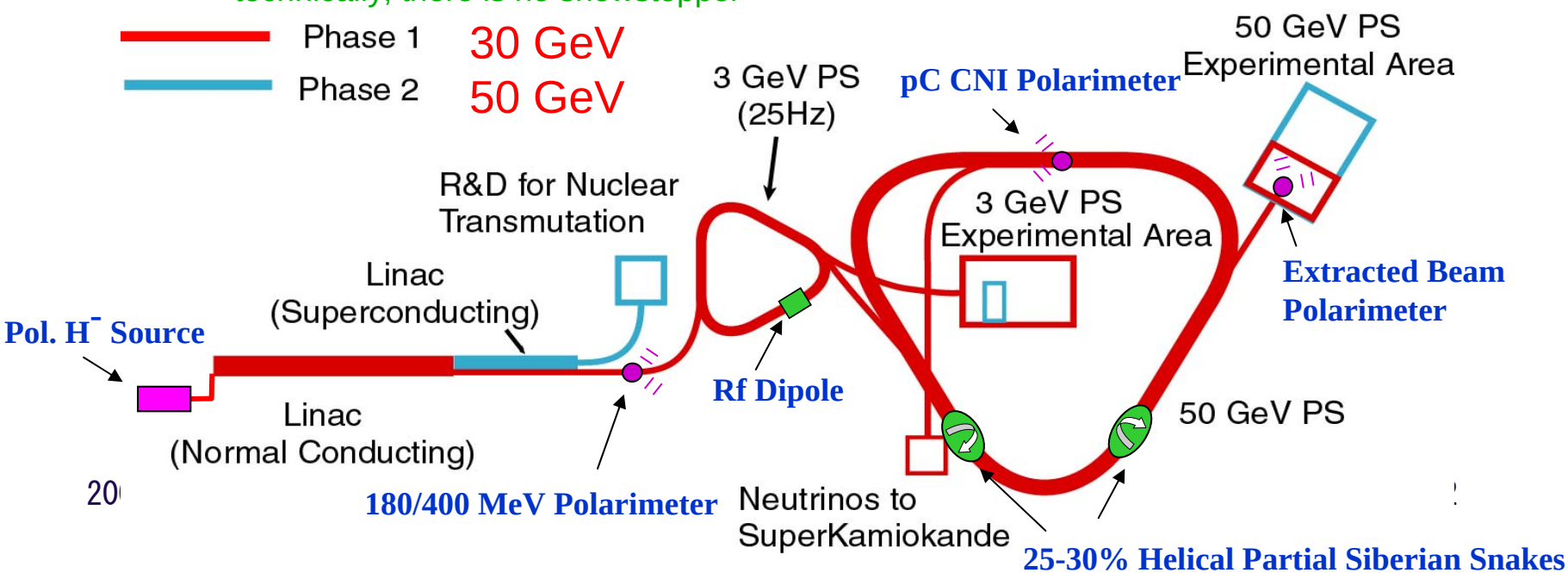
- If the J/Psi production is dominated by quark-antiquark annihilations at 30 GeV, J/Psi production can be used as a tool to study sea quark distributions.
- Also, pion/kaon Drell-Yan may be possible even at 30 GeV.

Seonho Choi

M. Burkardt, Y. Goto, J.C. Peng

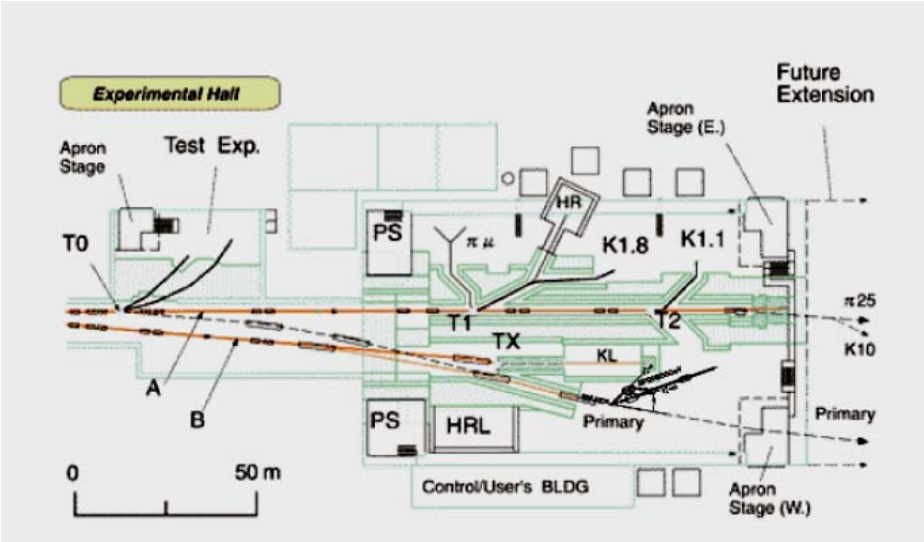
Dimuon with Polarized Target/Beam

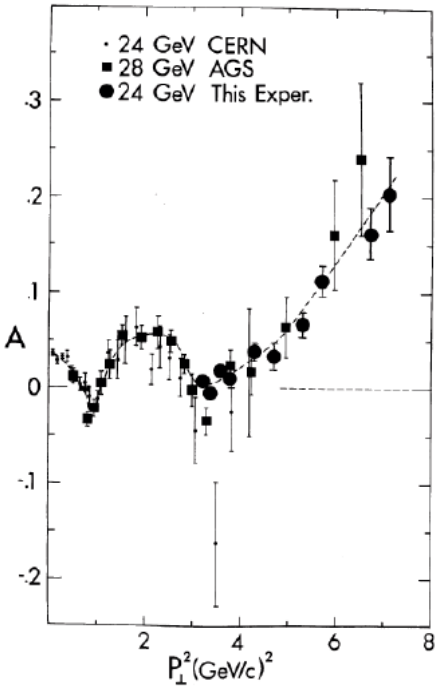
- Polarized Drell-Yan experiment with dimuon measurment using polarized proton beam at J-PARC has a rich physics programs
  - flavor asymmetry of sea-quark polarization → higher precision for $\Delta\Sigma$ and ΔG
  - SSA measurements for Sivers and higher-twist effects and transversity → link to orbital-angular momentum
- Importance of GPD was emphasized.
  - K. Sudoh proposed GPD research via unpolarized p p → p pi Delta reaction.
- We propose to make the J-PARC facility allow acceleration of polarized proton beams to 30-50 GeV
  - feasible in discussion with J-PARC and BNL accelerator physicists
  - technically, there is no showstopper



Experiments with Polarized Proton Beams

- H. Kanda: Study of double pion production on the deuteron.
  - polarized proton/neutron beam with 1-3 GeV/c.
- A. Krisch: SPIN@J-PARC
  - pol.p + p scattering at large pT





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QCD Mass

Structure on Nucleon and Nucleon in Matter

Experiments with Polarized Beams

Summary

- A lot of hadron physics experiments are waiting to be done at J-PARC.

Physics (Experiments)	Schedule	Beam line	Approval	Detector / Comments
Theta+ production		K0.8	To be proposed	Large acceptance
Theta+ with pi beam	2009	K1.8	Stage 2	SKS, high res required for high res mass width
Theta+ nucleus		K1.8/1.1	To be proposed	SKS+
Hyperon spectroscopy		K1.8, high p	To be proposed	
Electron pair from phi	2011-2013?	High p	Stage 1	Di-electron spectrometer
Phi bound states		P-bar 1.3GeV/c	To be proposed	Large acceptance
Dimuon (DY, J/Psi)	2013-?	High p	deferred	Mainly from Fermilab
Pol Dimuon (DY, J/Psi)	2013-?	High p	proposed	Same, Pol beam/target
Meson DY		High p	To be proposed	Same
pp → p pi Delta GPD		High p	To be proposed	Large acceptance
Double pion on deutron		Pol. p	To be proposed	1-3 GeV/c
SPIN@J-PARC		High p	proposed	Large PT spectrometer

Summary

- A lot of hadron physics experiments are waiting to be done at J-PARC.
- Experiments tackle to core QCD problems (mass and confinement) from different directions, but the efforts are coherent so that we are discussing with each other.
- As a result of our discussion during NP08, it turns out that some of the detectors may be shared by different experiments.
- We need various beam lines (K0.8, K1.8, high mom, high resolution, …).
- Timely construction of beam lines / extension of experimental areas are strongly expected.
- Also upgrades of accelerators such as polarized proton acceleration will make the facility much more powerful to understand QCD.

A possible Schedule of Beam Delivery

	2007	2008	2009	2010	2011
K1.1					
K1.1BR					
K1.8					
K1.8BR	Primary Beam				
K0					
High P					

Oct.

Dec.

Neutrino

Expectation from NP08 by Shoji Nagamiya

- Neutrinos + Approved Hadrons :
  - Reconfirm the construction schedule.
  - Desired scenario for the beam time schedule.
  - Needed upgrades for 2009 – 2014.
- Non Approved Experiments:
  - Find scientific opportunities.
  - Desired location of the experiment.
  - Cost (if known) and other requests to the J-PARC.
  - Potential participants.
  - International contributions, if any.
  - Any other issues.
- Preparation for the Users Steering Committee:
  - Timeline of all proposed projects.
  - Priority setting among individual proposals, if at all possible.
  - Demand to the accelerator.
  - International competition and/or coordination.