Nuclear/Hadron Physics

- Keyword: QCD
  - QCD at Low Energy and/or QCD Inside Nucleus
  - LQCD ←→ Hadron Spectroscopy
  - Spectral Function ←→ Mass Modification (Origin of Hadron Mass)
- Tool
  - Pi, K, p, pbar, …, HI, pol-p
  - Merit of Intensity and/or Energy

Summary of Nuclear/Hadron Physics Working Group

Shin'ya Sawada (KEK)

Nuclear/Hadron Physics Working Group (#2 group)

- Co-convenors: Spinka (ANL), Nakano (RCNP) and Sawada (KEK)
- More than 40 people for the combined session (#1&#2)
- About 20 people for the #2 dedicated session
- Talks:
  - 2 plenary talks (Spinka and Widmann)
  - 3 talks at #1-#2 combined session (Kienle, Kopeliovich, Sakaguchi)
  - 10 talks/comments at #2 dedicated session
- Discussions at the end of the #2 session

Subjects discussed

- Complementary future project at GSI (Kienle)
  - Multipurpose facility
  - Not officially approved yet. Some of the ideas can be realized at JHF.
- Research using (high momentum) p, p-bar, pi, K,...
  - Hadron physics is very well summarized by the plenary talk by Dr. Spinka.
    - Partonic content of nuclei
      - Dimuon measurement (Sawada)
    - Transition region between nucleon+meson and quark+gluon pictures
    - Baryon and meson spectroscopy
      - Possibility of pol. p-bar beam
      - Talks by Peaslee and Tsuru
        - » RF separator for K beams is now under development at IHEP (Protovino) which may be moved to JHF. JHF has much higher (orders) proton intensity.
  - Nuclear-matter-related physics
    - "Spectral function" (Asakawa)
      - Fruitful phase diagram.
    - Vector meson modification (Ozawa)

Subjects Discussed (cntd.)

    - Multifragmentation (Tanaka)
- Research using HI beams
  - Unique tool to study “relativistic hypernuclei” (Sakaguchi)
  - Important and unique tool to study nuclear matter with high baryon density (Sugitate)
    - Experimental setup for flow measurement was proposed. (Esumi)
- Research using polarized proton beams
  - Spin physics
    - Parity violation experiments (Arvieux)
  - Prof. Hatanaka suggested polarized beam might be able to be accelerated with “tune jump” method.
- Research using ultra-slow antiprotons (Widmann)
  - Not only atomic physics, but also fundamental physics.
  - They will transfer the antiproton decelerator to JHF after CERN experiments.

Hadron Physics at the Japanese 50 GeV Proton Accelerator

Hadronic beam experiments encompass a very broad range of particle physics topics. This talk will concentrate on measurements that complement experiments at RHIC, CERN, FNAL, JLAB for possible inclusion in the JHF program.

It is assumed that there will be work on hypernuclei, continuing the fine AGS experiments, and also on rare K decays, so these will not be discussed.

- Partonic content of nuclei ($\bar{q}(x)$).
- Transition region between nucleon+meson and quark+gluon pictures of the strong interaction.
- Spin physics in forward scattering and total cross sections.
- Baryon and meson spectroscopy.

H. Spinka - ANL

10 Dec. 2001

Partonic Content of Nuclei

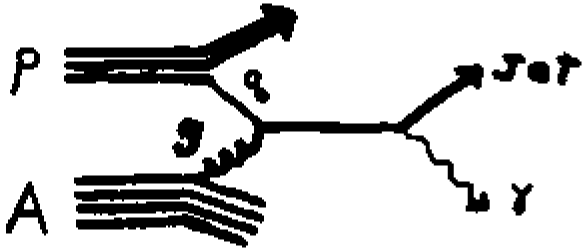
- Nuclear physics has studied the makeup of nuclei in terms of protons, neutrons, and pions in the past. More recently, measurements are focussing on the structure of nuclei in terms of quarks and gluons.

$q(x) + \bar{q}(x)$ from Deep Inelastic Scattering

$\ell A \rightarrow \ell' X$

$G(x)$ planned at RHIC

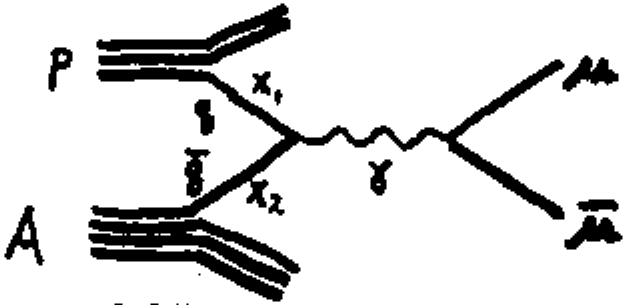
$p A \rightarrow \gamma + \text{Jet} + X$



$\bar{q}(x)$ Drell-Yan at RHIC, FNAL, JHF

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

$x_2 = M_{\mu\mu}^2 / x_1 s$



RHIC - small x_2, FNAL - medium x_2, JHF - large $x_2 \geq 0.25$

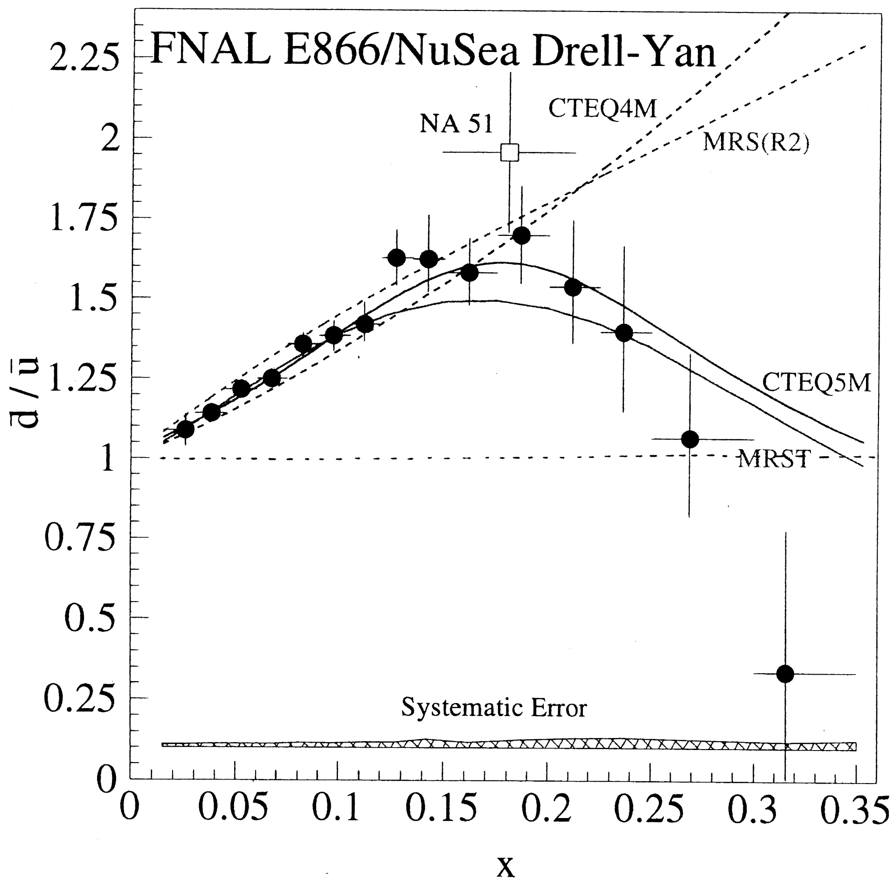
(Also $\Delta\bar{q}(x)$ in polarized pp, pd collisions - complementary to RHIC)

d-bar/u-bar at large Bjorken-x

- Compare Drell-Yan yields from nuclear targets (Liquid H_2 and D_2) and extract d-bar/u-bar.

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x1>>x2} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x)}{\bar{u}(x)}\right]$$

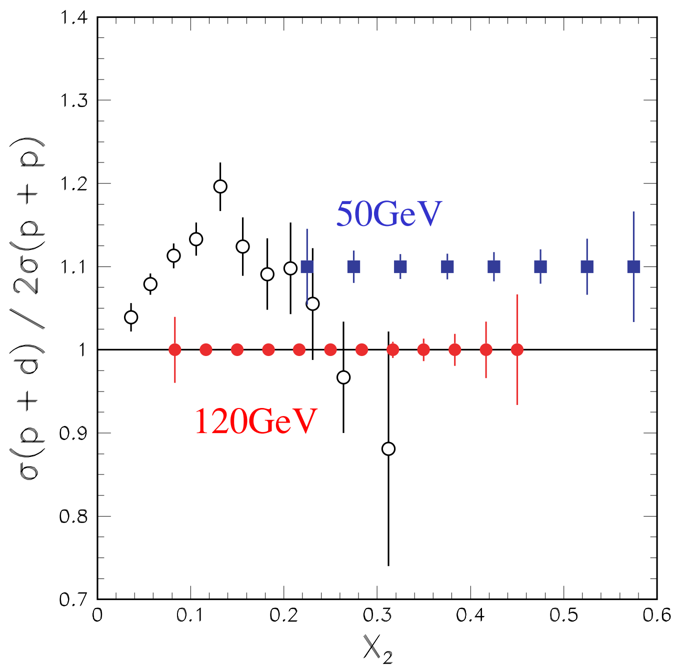
- Previous results
  - NA51 found d-bar/u-bar = 0.51+-0.04+-0.05 at x = 0.18
  - FNAL-E866 measured the ratio at x<0.33
  - Large discrepancy between various parton distribution functions especially at large x region.



➔ Need data at large x.

d-bar/u-bar at large Bjorken-x

- The Drell-Yan cross section ratios for p+p versus p+d lead to a direct measurement of the d-bar/u-bar asymmetry as a function of Bjorken-x.
- The estimated statistical error with the 50 GeV PS is shown.
  - Assumptions:
    - 60 days running period each for pp and pd measurements
    - Net efficiency of 0.5
    - 1×10^{12} protons/3sec
    - 20inch=50.8cm thickness of liquid hydrogen/deuterium target



Transition Region Physics

- The Constituent Quark Model has been very successful in explaining many features of hadronic "structure" at relatively low Q^2.
  The constituent quark effective degrees of freedom interact in this model via flux tubes or potentials or are confined in a "bag". The successes of this approach suggest the effective masses, sizes, and interactions of these objects should be derivable from QCD.

  Recent measurements at JLAB of the cross section for $\gamma\, d \rightarrow p\, n$ show agreement with constituent counting rules for the energy dependence of exclusive processes

  $$d\sigma / dt\,(ab \rightarrow cd) \sim s^{2-N} f(t/s) \qquad N = n_a + n_b + n_c + n_d$$

  n_i = # leptons, γ's or quarks in particle i.

  The same is true of pp elastic scattering. However, in that case, some spin observable data at the same kinematic conditions do not agree with the predictions of the model. S.J. Brodsky and G.R. Farrar PRL 31, 1153 (1973)

  It is suggested to investigate other exclusive reactions with a simpler amplitude structure ($\pi p \rightarrow \pi p$, $Kp \rightarrow Kp$) to test $d\sigma/dt$ and P against constituent quark model predictions. This will assist in the search for the correct effective interaction.

Hadron Spectroscopy

- Quark inspired models have been quite successful at explaining many observed hadron states and classifying them into multiplets. But there are some challenges remaining:

  * Where do the gluonic degrees of freedom appear in the spectrum?

    $\bar{q}qg$, ggg, $qqqg$

  * Where are the missing Λ^*, Σ^*, Ξ^*, Ω^* states?

    Using known N^* and Δ^* states and multiplets to which they are assigned, the number of hyperon states can be determined. The number of observed states is much less.

  * Are there additional symmetries in the data that could point to new effective degrees of freedom?

    Parity doubling and restoration of axial U(1) symmetry?

    Quark-diquark or qqq picture more appropriate?

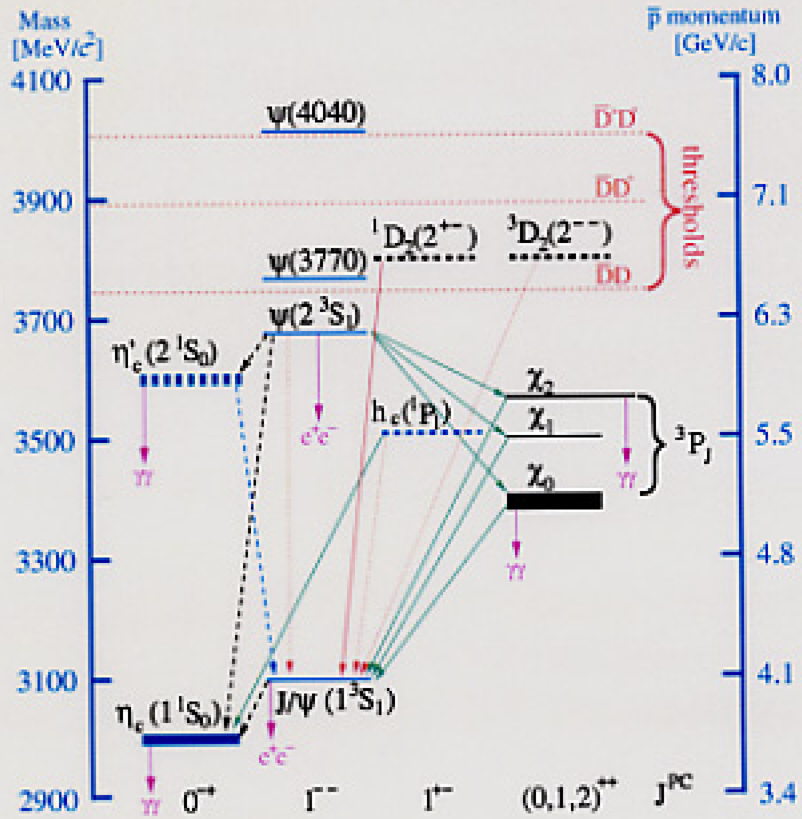


Figure 2.4. Charmonium states and their decay modes. Undiscovered and poorly known states are marked by dashes.

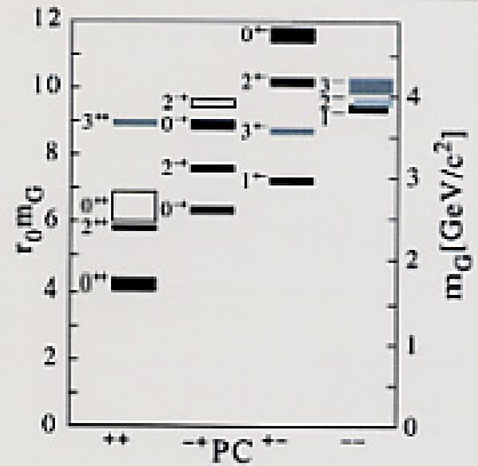


Figure 2.10. The glueball spectrum as derived from recent LQCD calculations [33], with 15 states in the mass region between 1.5 and 5.0 GeV/c^2. The relative mass uncertainties are indicated by the vertical extent of the boxes. For the $J^{PC} = 0^{++}$ ground state, a good experimental candidate has been found in $\bar{p}p$-annihilations, namely the $f_0(1500)$. All other glueballs are awaiting experimental discovery. The 2^{+-} state at 4.3 GeV/c^2 is of special interest, because it has exotic quantum numbers and can thus be easily distinguished from $q\bar{q}$ states.

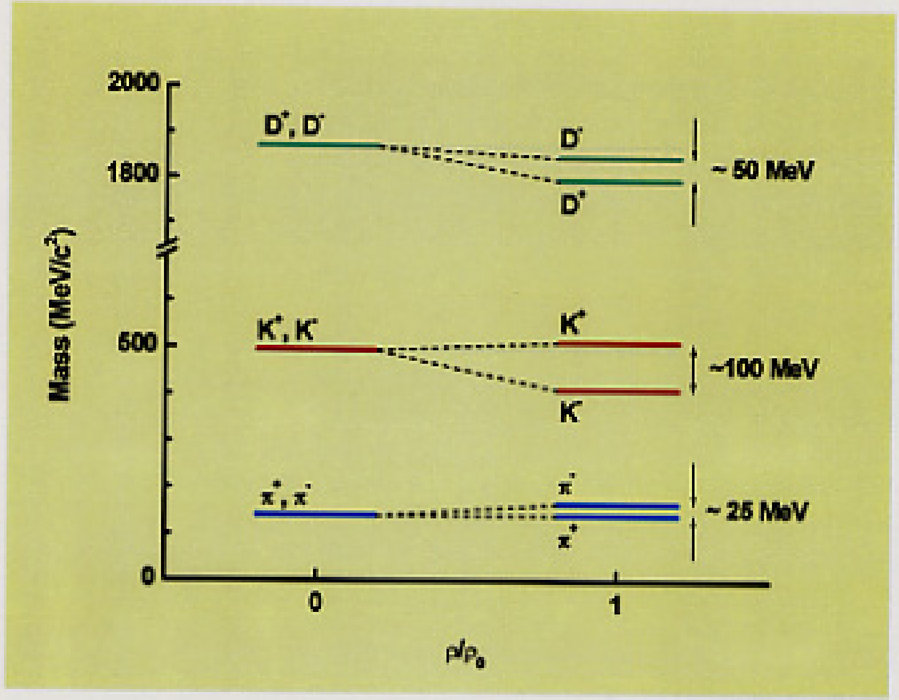


Figure 2.13. Schematic picture of hadron masses in vacuum and mass splitting in the nuclear medium at normal nuclear matter density as derived from [36,38,39].

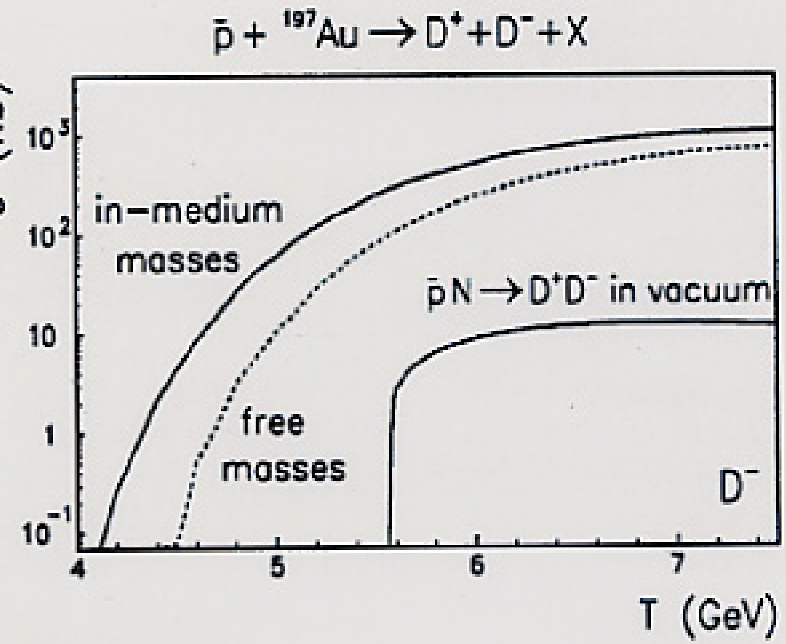
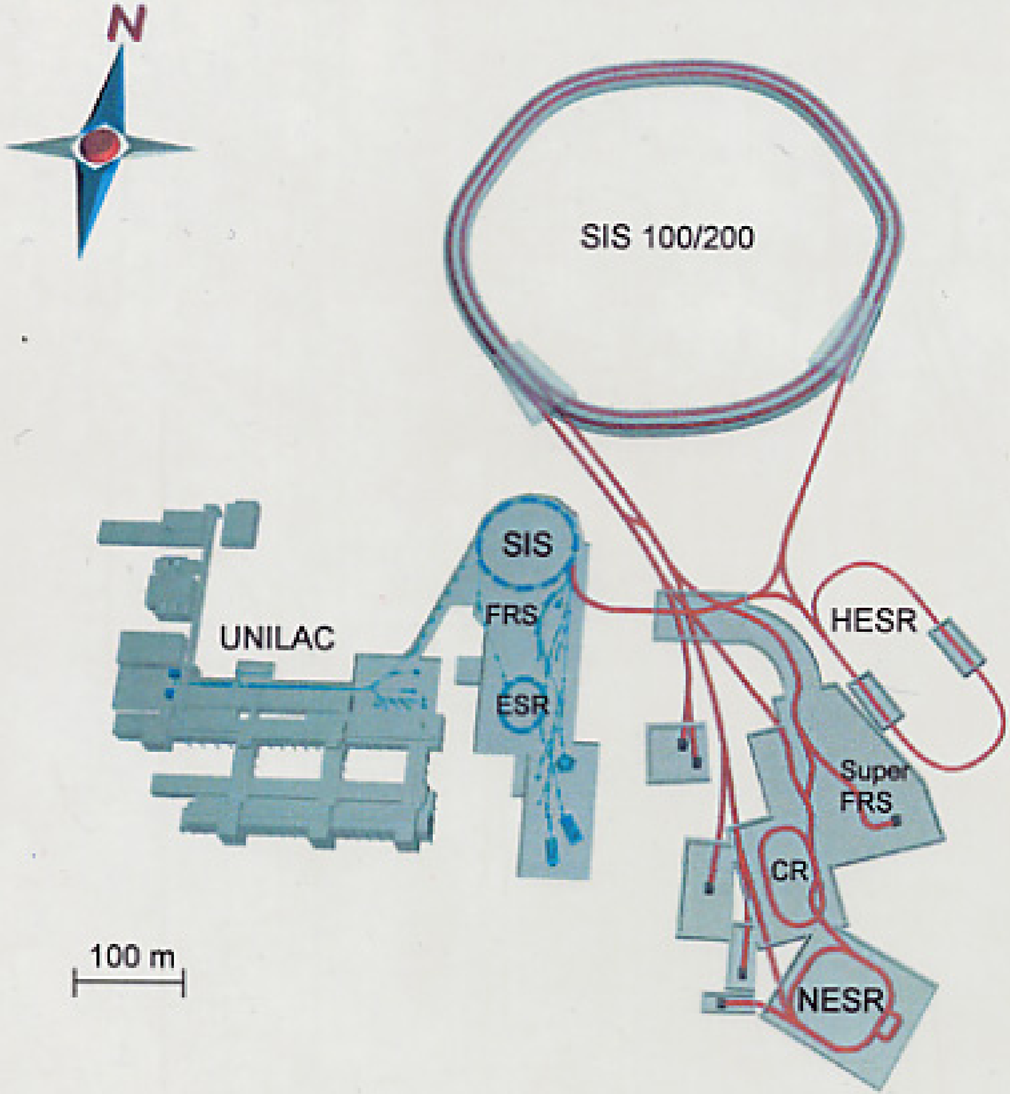


Figure 2.14. Total D meson pair production cross section in $\overline{p}$ annihilation on Au (upper curves) and on nucleons (lower curve) as a function of the antiproton energy. The cross sections for annihlation on Au were calculated for free (dashed curve) and in-medium (upper solid curve) masses of the D mesons. The figure is taken from [42].

GSI Future Project



Gain Factors

- Primary beam intensity: Factor 100 – 1000
- Secondary beam intensities for radioactive nuclei: up to factor 10,000
- Beam energy: Factor 15

Special Properties

- Intense, fast cooled energetic beams of exotic nuclei
- Cooled antiproton beams up to15 GeV
- Internal targets for high-luminosity in-ring experiments

New Technologies

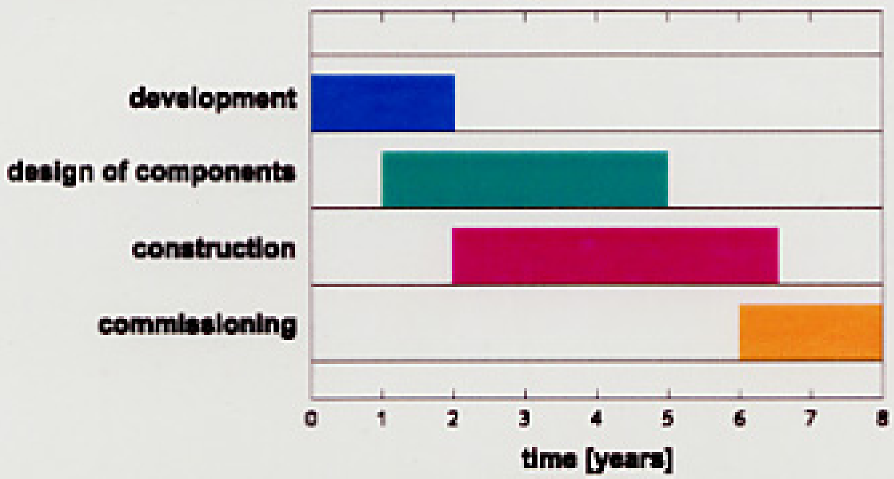
- Fast cycling superconducting magnets
- Electron cooling at high ion intensities and energies
- Fast stochastic cooling

GSI Future Project

COSTS

Building and infrastructure:	225 Mio.
Accelerator:	265 Mio.
Experimental stations / detectors:	185 Mio.
Total:	675 Mio.

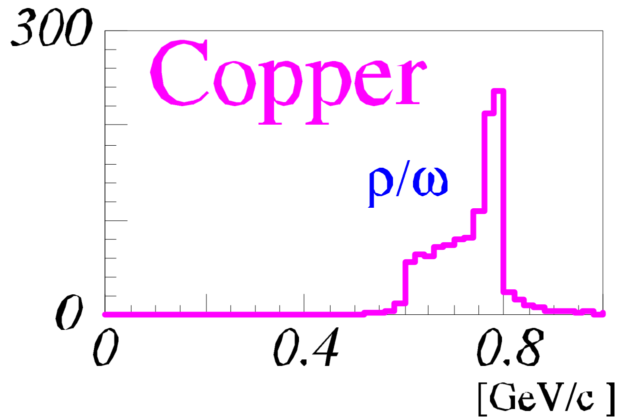
SCHEDULE



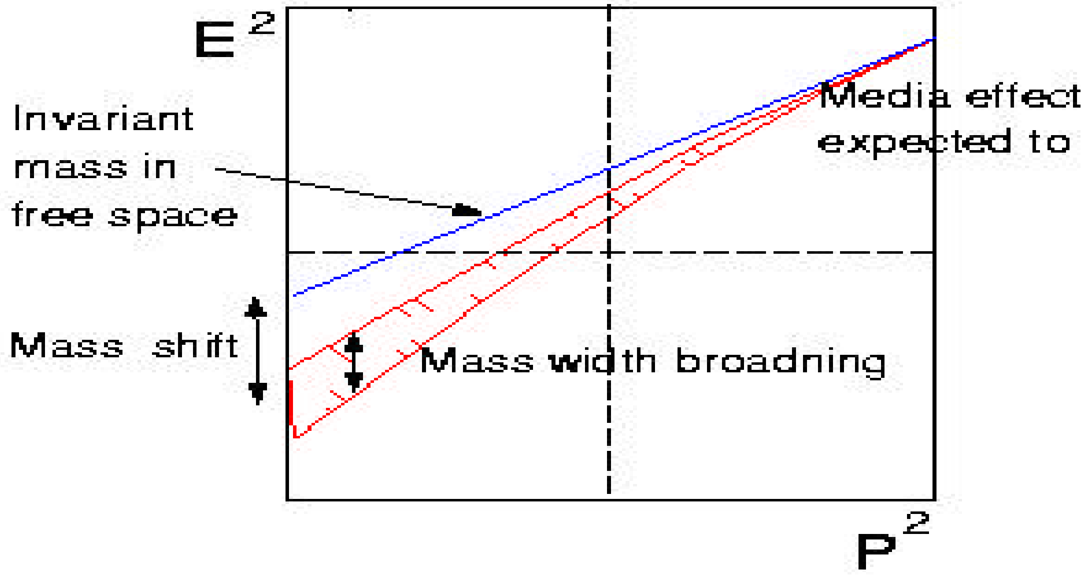
GSI

Expected experimental signals

- **Direct measurements of mass modification**
  - ➔**Lepton decays of vector mesons**
    - ➔ρ, ω, ϕ, J/ψ
  - ➔**K* -> Kγ**

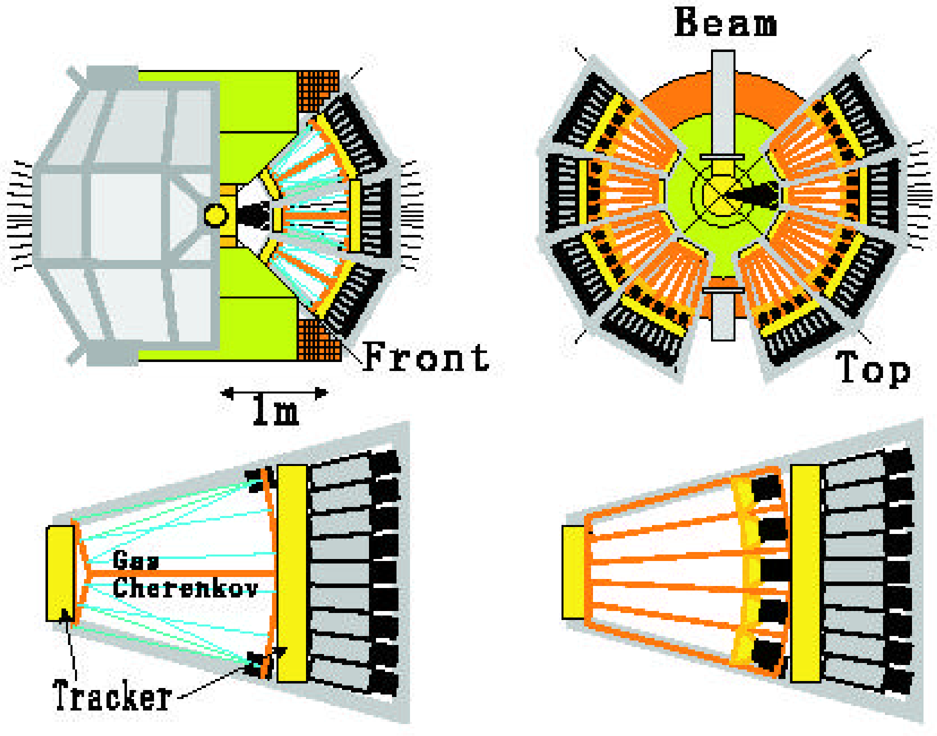


- **In-media mass modification**
  - ➔shift of resonance position
  - ➔resonance broadening/narrowing
    - ➔**We have to measure dispersion relation**
    - ➔**Need high statistics**



Proposed spectrometer for JHF experiment

- A mosaic of 23 identical units, each of which has an aperture of 30 degrees by 30 degrees.
- Major electron identification is given by gas Cherenkov counters.
- EM calorimeter is used to measure not only electrons, but also photons. The measurements of K*->K+γ is available.
- 100 times larger statistics is expected.



Schematic view of spectrometer

Physics at High Baryon Density Region

Where we are
Physics at JHF
Plan and R&D issue

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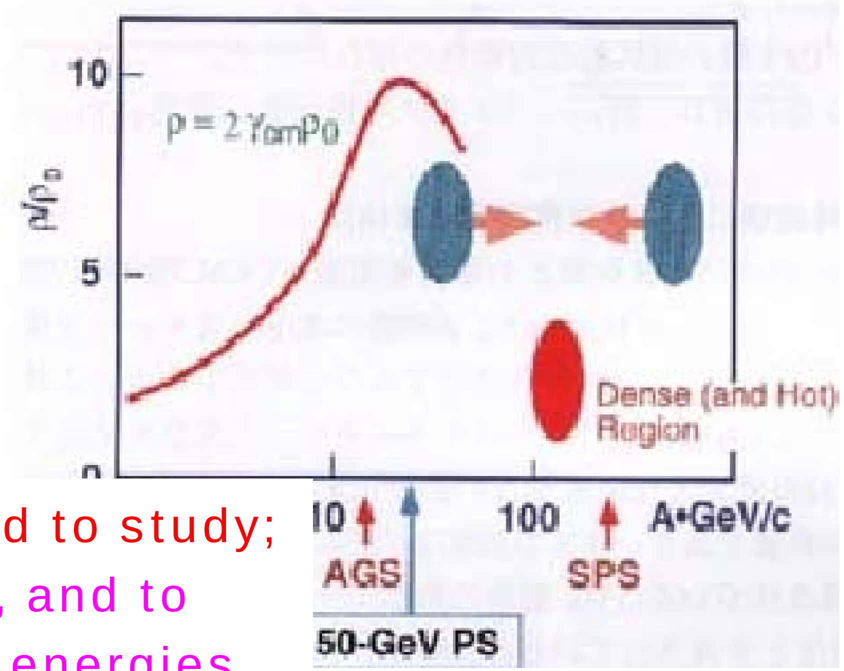
Where we are?

“Flow dynamics at energies between 10 and 160 GeV/c” presented by *Yasuo Miake* (Tsukuba U.) at the last workshop in 2000. (KEK Report 2000 - 11)



Heavy-Ion beam in JHF is demanded to study;
properties of dense nuclear matter, and to link physics between AGS and SPS energies

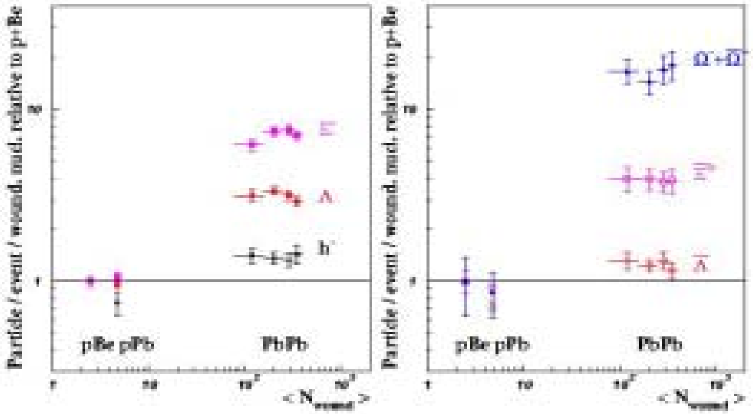
Update the activities by Shin’Ichi Esumi (Tsukuba)

However, the energy gap getting narrower in these days; since the SPS went down to 80 A and 40 A GeV/c, and plans down to 30 A and even 20 A GeV/c.

Physics at the highest baryon density

Hadronic probe physics (presented b

- Origin of collective force - Flow
- Properties of high dense nuclear matter

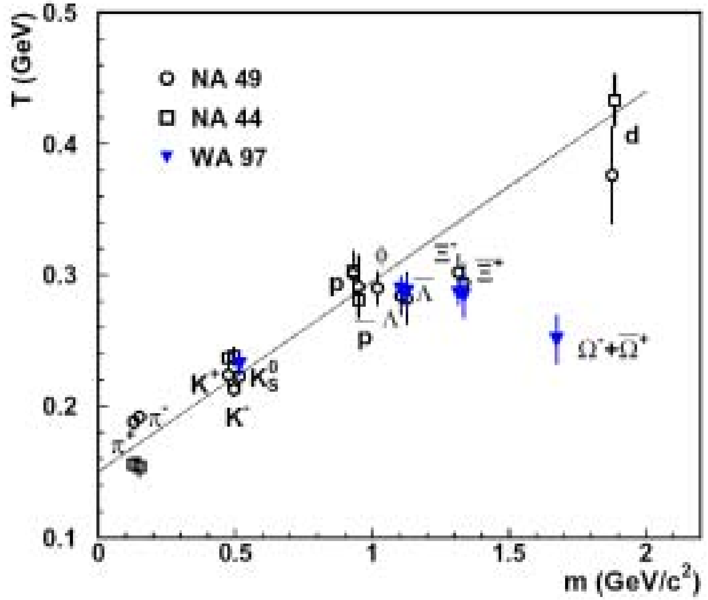


Leptonic probe physics

- Low mass spectroscopy – Onset of mass m
- Vector meson mass – Chiral symmetry

Production of multi-strangeness baryons

- Onset of strange quark enhancement
- Short-lived strange matter search



Anti-nucleus production

- Anti-helium production
- Long-lived strange matter search

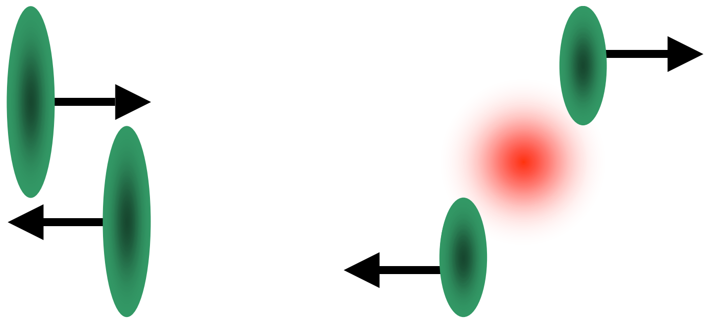
Some Exotics (presented in ‘95)

- HBT of direct γ’s
- Mass of unflavored meson η’(958)

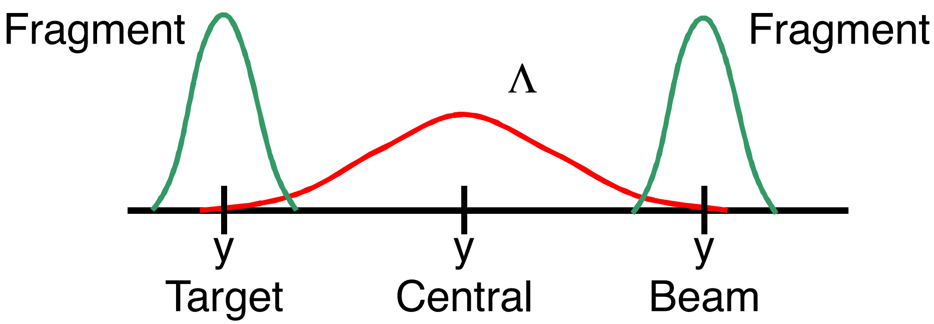
Value of Relativistic Hypernuclei

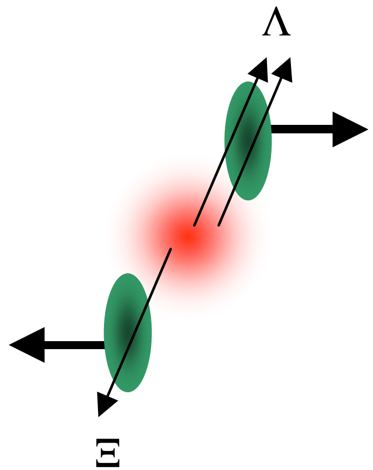
Production of Hypernuclei in Relativistic Heavy-Ion Collisions

- Originally proposed to produce multi-Λ hypernuclei
  - Relativistic heavy-ion collisions
    - See projectile fragment region



  - Coalescence of fragment and Λ particles
    - No limit on number of Λ to coalesce





Energy dependence of cross section

- Primary coalescence process stay constant
- Secondary process increase with beam energy
- Change over around 10 GeV/u

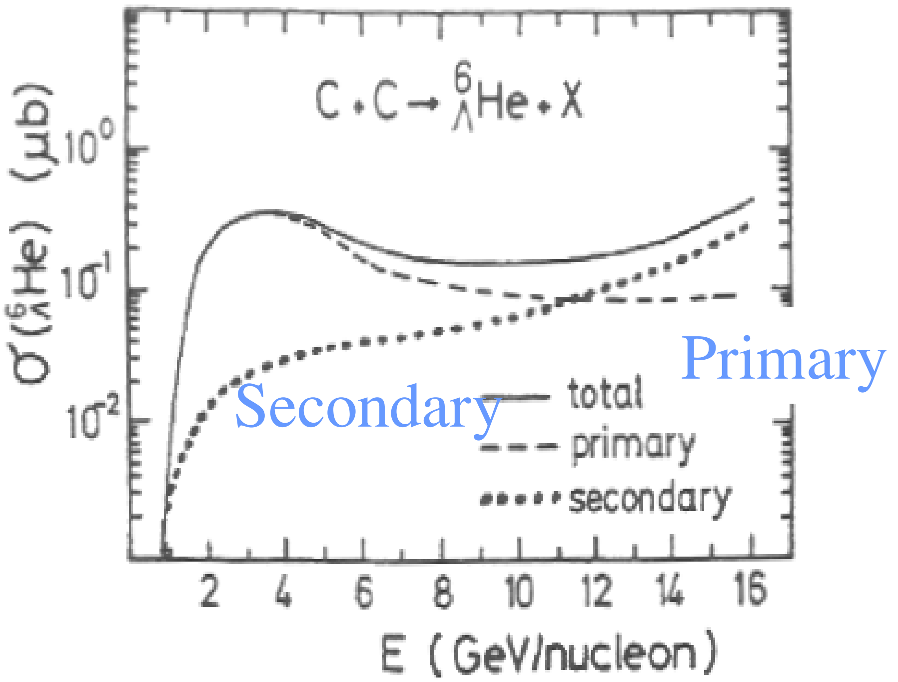
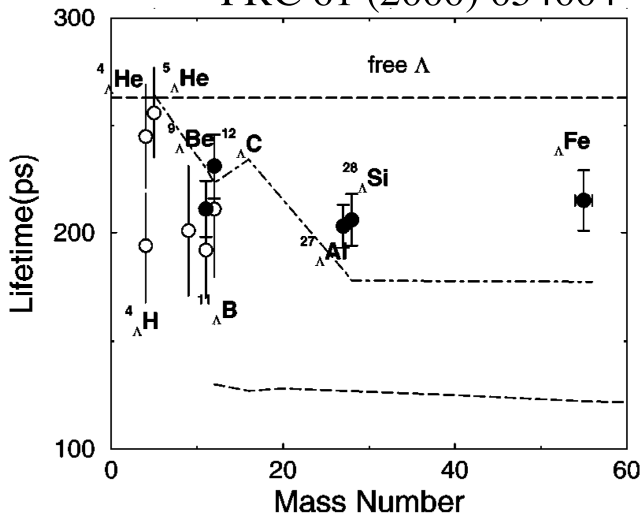
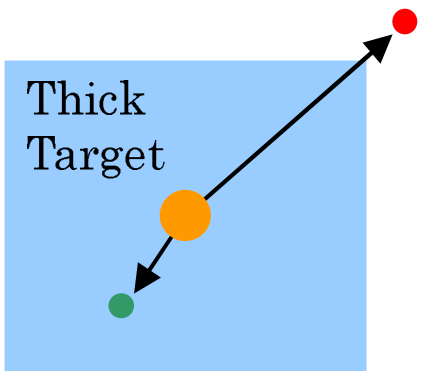


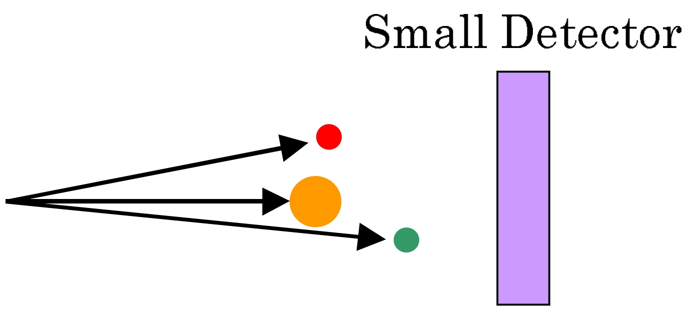
Fig. 6. Beam energy dependence of $^{6}_{\Lambda}$He production cross section in $^{12}C+^{12}C$ collisions.

PRC 61 (2000) 054004



- Really new experiment possible ?
  - Precise lifetime measurement
    - $\Delta Z_{VTX} \sim 1$ cm $\Rightarrow$ $\Delta\tau < 1$ %
      $\beta\gamma c\tau \sim 200$ cm
  - Complete decay branch
    - Mesonic and non-mesonic modes at the same time
    - Detect decay particles efficiently





  - Inverse kinematics
    - Size of hypernuclei
  - n- or p-rich hypernuclei
    - Fragment (target) may be unstable

Considerations on Experiment at 50-GeV PS

Beam

- Light heavy-ion (say ^{12}C, ^{16}O, ^{28}Si, etc.)
  to be available in near future, I hope
- Energy: 25 GeV/u
  $\beta\gamma c\tau$ (Λ) ~ 2.1m
- Intensity: 10^9~10^{10} ion/burst (<200W)
- Good emittance
  assume 6π mm·mrad ⇒ a few mm and a few mrad

Production Target

- 5% reaction length for heavy-ion beam
  ^{12}C: about 1 g/cm^2
  Multiple scattering of fragment negligible (~0.05mrad)
- 50 ~ 500 hypernuclei/burst at production target

A Low-Energy High-Intensity Antiproton Facility at JHF

Physics Motivation and Layout

E. Widmann

ASACUSA collaboration, University of Tokyo

Workshop on Antiproton Physics at JHF

Tsukuba, February 16, 2002

Low-energy Antiproton Facility (100 MeV/c)

- Currently only existing facility: AD @ CERN
  - Only pulsed extraction
  - No accumulation -> low production rate and repetition rate
- Future of AD (CERN?) uncertain after 2005
  - No other plans for low-energy pbar facility exist (GSI: 14 GeV)
- Possibility at JHF
  - High intensity 50 GeV PS (pbar production threshold ~ 6 GeV)
  - Japanese groups have strong involvement in AD
    - _Ultra-low energy pbar (10 eV – keV) beam for atomic physics being developed at AD
  - AD construction was partly financed by Monbusho
  - Antiproton accumulator (AA) was shipped to KEK after dismantling during construction of AD
  - Agreement exists that AD can also be sent to KEK if CERN stops its operation

Physics With Low-energy Antiprotons

- Precision spectroscopy, CPT, 3-body QED calculations

  Antihydrogen, Antiprotonic helium

- Atomic collision physics

  Unique ultra-low energy pbar beam (MUSASHI)

  _atom formation, atomic collisions, ionization, energy loss

  Antiprotonic helium: state dependent quenching cross sections with He

- Chemical physics

  Antiprotonic helium: state dependent quenching cross sections with H2

- Nuclear Physics (mostly requiring continuous beam)

  Antiprotonic X-rays: strong interaction shift and width

  Investigation of the nuclear periphery via antiprotonic X-rays

- Industrial and medical applications

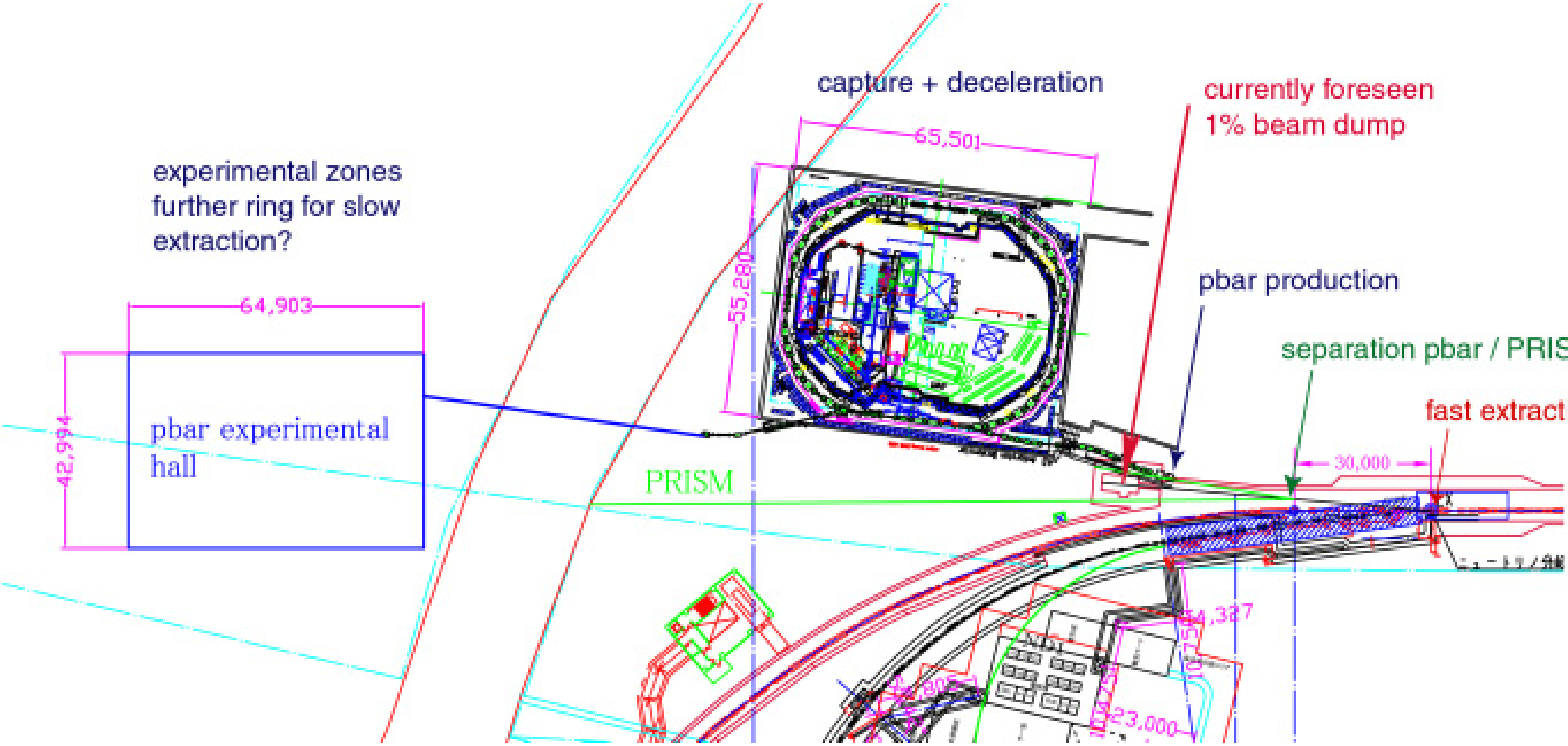
  Rocket propulsion (NASA)

  Creation of short-lived radioisotopes for e.g. PET scans

- Gravitation

Preferred solution **A**

- At fast extraction beam dump outside 50 GeV ring
- No conflict with PRISM (slides shown at NP01)

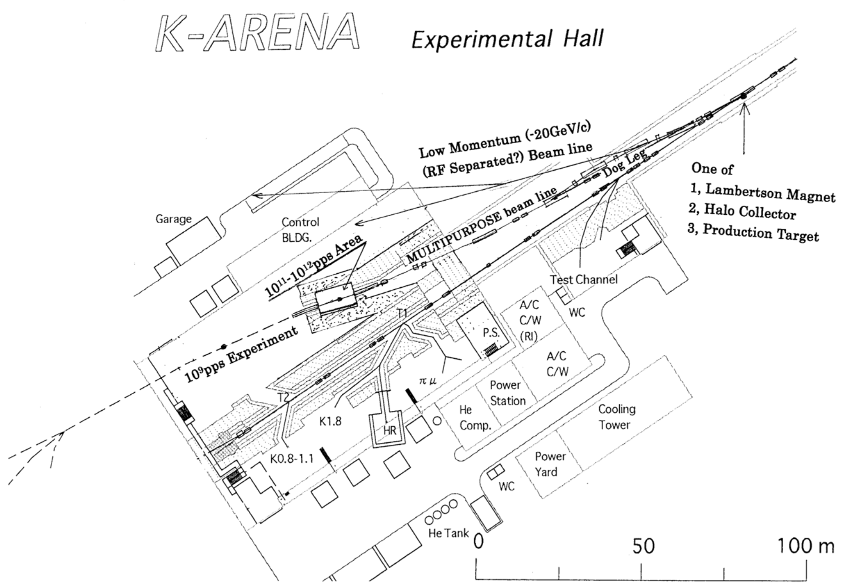


Strategy

- First of all, we should brush up the physics cases.
  - Uniqueness, relationship with experiments at other facilities, ...
  - Will make documentations in the coming year.
- For experiments using high momentum p, p-bar, pi, K, ...
  - Will start design work and R&D for the "multipurpose beam line". The key is the quality of the beam. Beam channel expert (Tanaka) think we will be able to have a design of a good quality beam line in half a year.
  - Consider possibility of the RF separators.
  - Detector R&D will be started, including hadron blind detectors etc. by the subgroups. This is related with the ongoing research programs (RHIC, LHC, etc.).
- For HI experiments:
  - We should not only brush up the physics cases, but also consider various realistic possibilities of HI acceleration.
  - Will ask project headquarters to consider construction of the HI injectors with these studies.

Multipurpose Beam Line

- To accommodate various needs for beams from hadron physics experiments;
  - 50-GeV protons with ~10^{12} pps <= Str. Fn.
  - 50-GeV protons with ~10^{9} pps <= Vec. Meson
    - Very small beam size (~1mm2), stable, very small beam halo
  - 5~50-GeV variable energy protons with ~10^{9} pps <= Multifragmentation
  - 5~30-GeV variable energy secondary particles with ~10^{9} pps <= Multifragmentation & others
  - HI beams with 10^{10} ions per second



Strategy (cntd.)

- For polarized proton experiments:
  - Question on the needs of pol. proton beams at JHF is open, when we have pol. p beams at AGS/RHIC-Spin.
  - We should ask wide range of the physics communities.

My Personal Concluding Comments

- At the end of my summary, I would like to say:
  - We know many people who could not attend this workshop with regrets but have strong interests in this field at JHF.
  - This field has much relationship with ongoing projects in the world (RHIC, CERN, GSI, ...). Therefore our nuclear/hadron physics has many potential researchers who will come out as our real collaborators in near future.
  - A series of workshops, which may be held abroad, will be very valuable.