核子（原子核）のパートン構造.

1969 Bjorken scaling.

EMC effect

spin crisis (EJ sum rule).

(Gottfried S.R).

→ 核物理 community の commitment.

- spin. → グルオンの寄与. ΔG. — RHIC spin, HERMES, COMPASS

  Δq と $\Delta\bar{q}$

  ΔS.

- $s\bar{s}$ content. — JLab.
- $\bar{u}/\bar{d}$ ratio. — FNAL.
- nuclear effect. — (e-RHIC)

EMC , SMC $\quad \vec{\mu} \quad \sim 200$ GeV $\quad \vec{p}, \vec{d}$

SLAC $\quad \vec{e} \quad \sim 50$ GeV $\quad \vec{p}, \vec{d}, {}^3\vec{He}$

(HERMES) $\quad \vec{e} \quad \vec{p}, {}^3\vec{He}$

$\Downarrow$ Global fit.

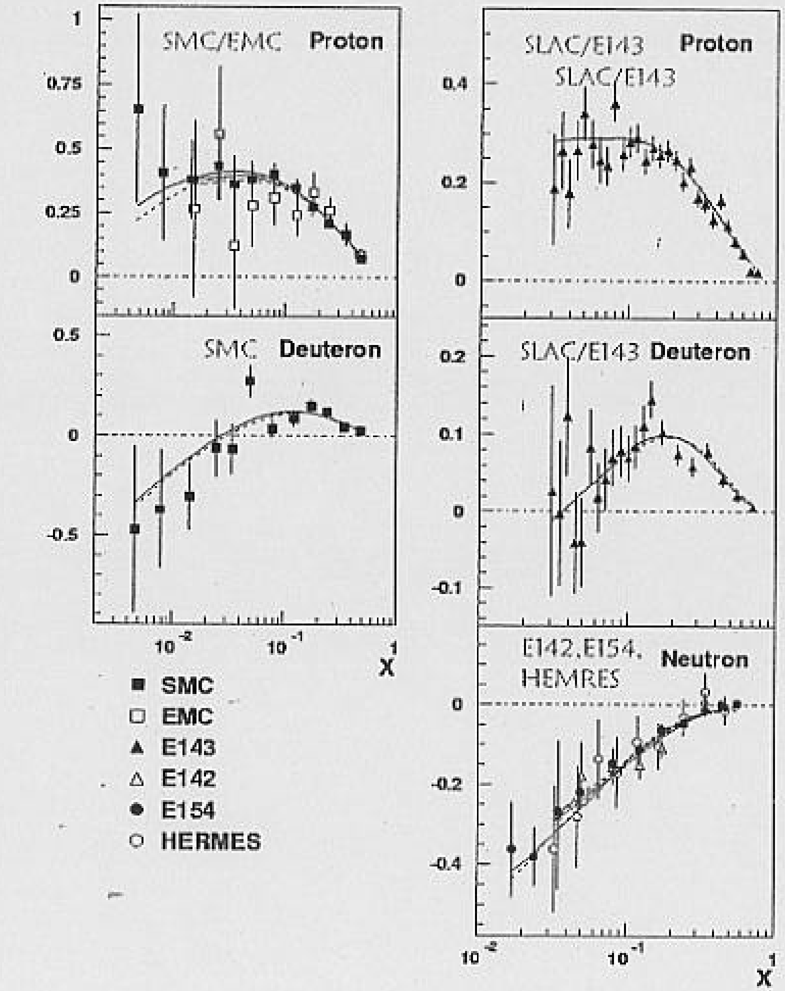
$$\Delta\Sigma = 0.28 \pm 0.07$$

$$\left\{ \begin{aligned} \Delta s &= -0.10 \pm 0.03 \\ \Delta u &= 0.77 \pm 0.03 \\ \Delta d &= -0.49 \pm 0.03. \end{aligned} \right.$$

$$\frac{1}{2}\Delta\Sigma + \Delta G + \Delta L = \frac{1}{2}.$$

Current Experimental Situation

$g_1(x)$: World Data



QCD Analysis of available Data Sets:
(SMC Phys, Rev. D58:112002, 1998)

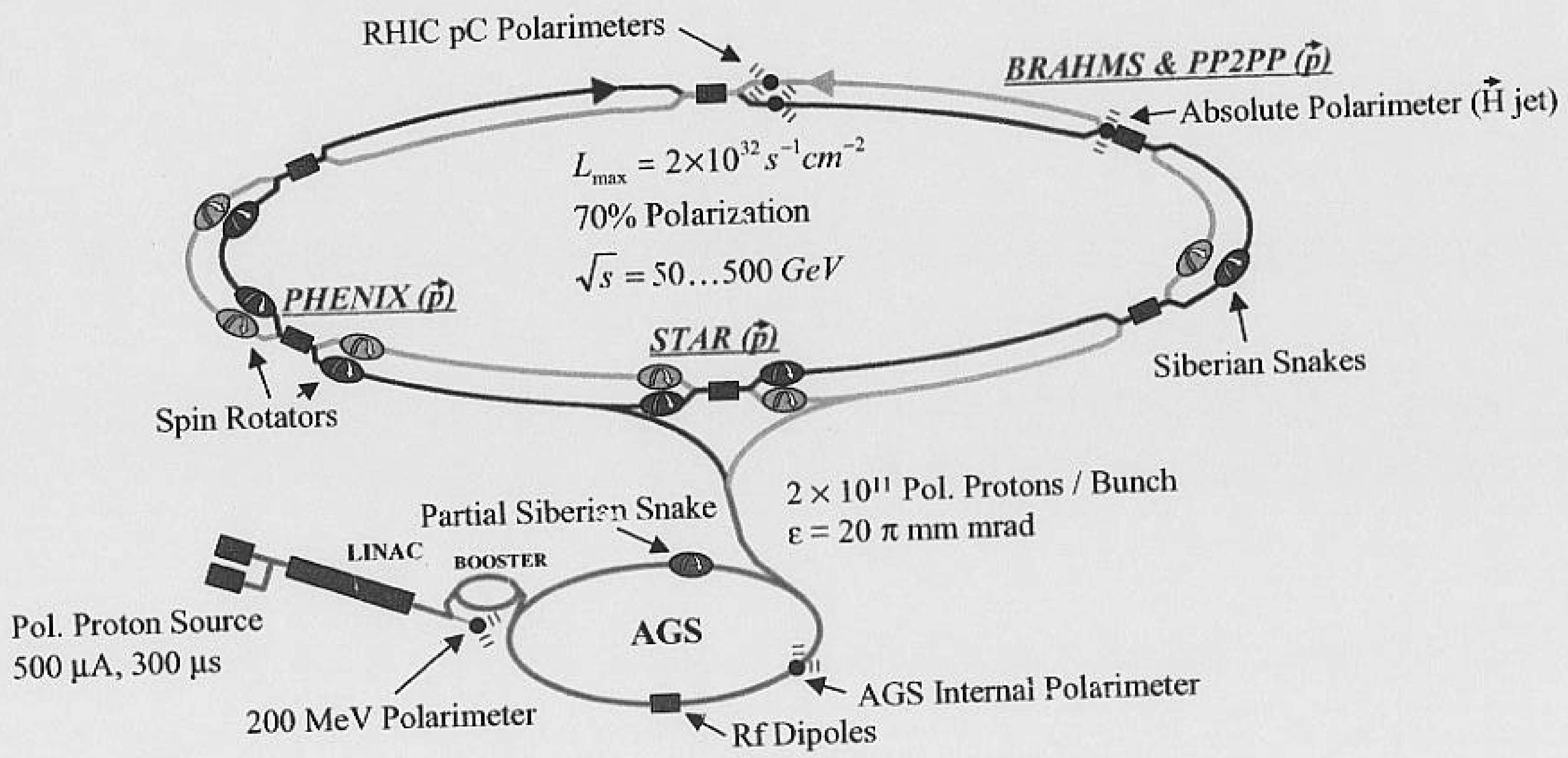
$$g_1(x,Q^2) = \frac{1}{6}\sum_{i=u,d,s} e_i^2 \int_x^1 \frac{dy}{y}\Big[C_S^q(\frac{x}{y},\alpha_s)\Delta\Sigma(x,Q^2) + 6C^g(\frac{x}{y},\alpha_s)\Delta g(x,Q^2) + C_{NS}^q(\frac{x}{y},\alpha_s)\Delta q_{NS}(x,Q^2)\Big]$$

where

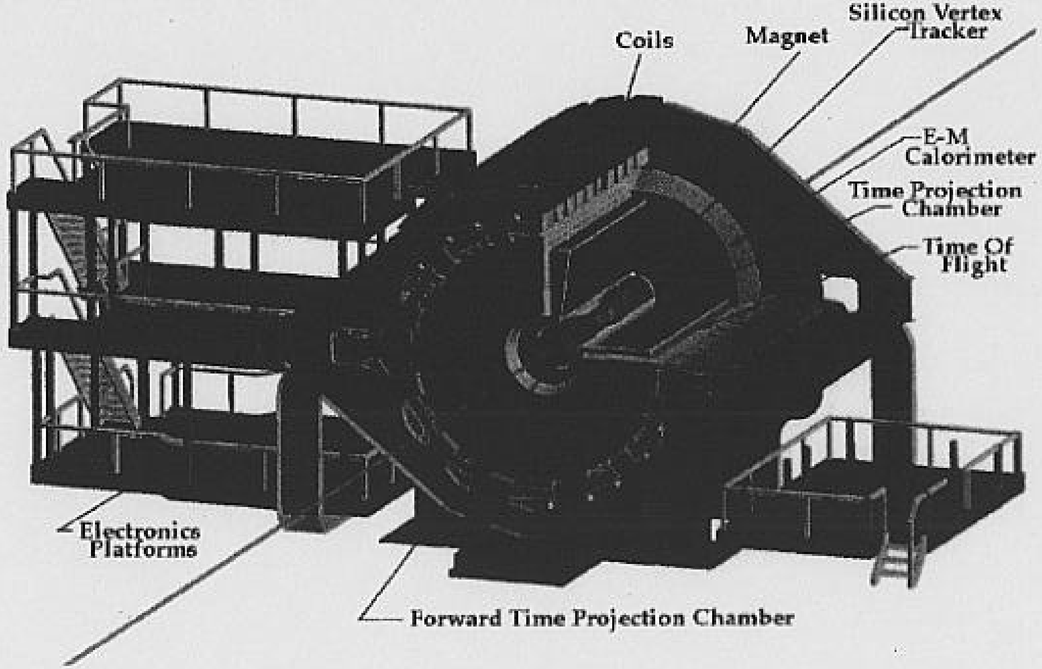
$$\Delta\Sigma(x,Q^2) = \sum_{i=u,d,s}\Delta q_i(x,Q^2)$$

$$\Delta q_{NS}(x,Q^2) = \sum_{i=u,d,s}\left(\frac{e_i^2}{\frac{1}{3}\sum_j e_j^2} - 1\right)\Delta q_i(x,Q^2)$$

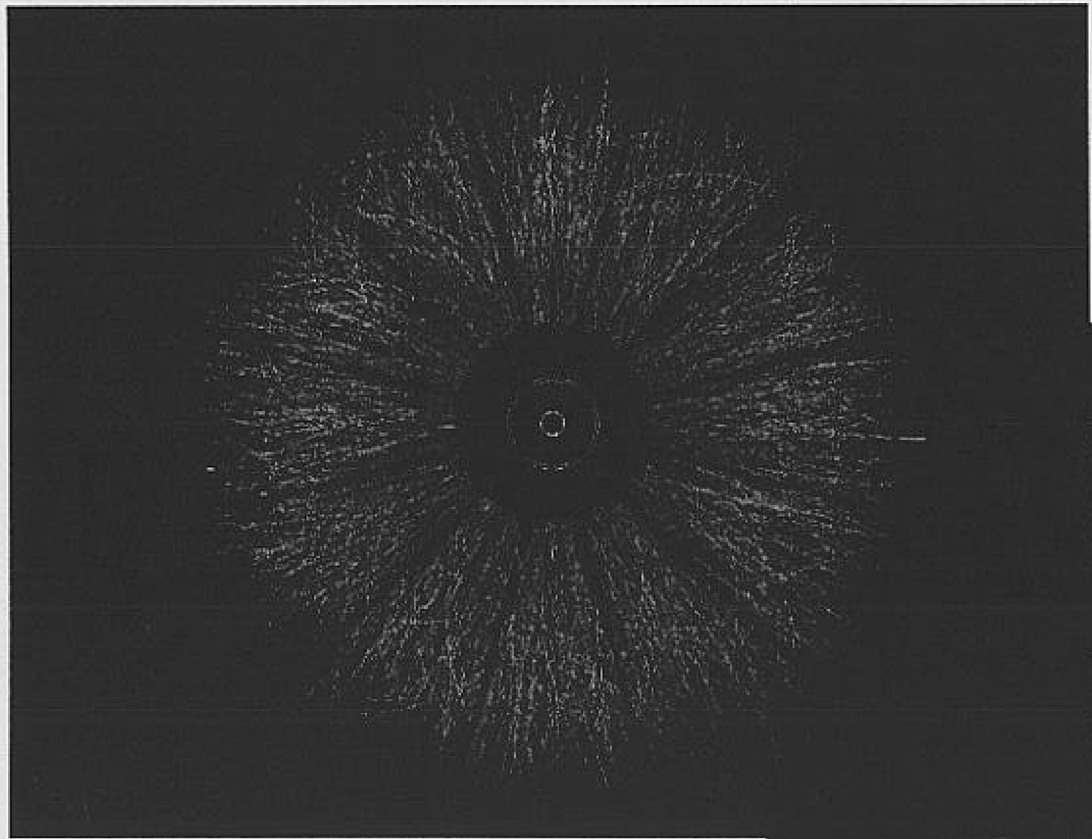
RHIC Spin Collider

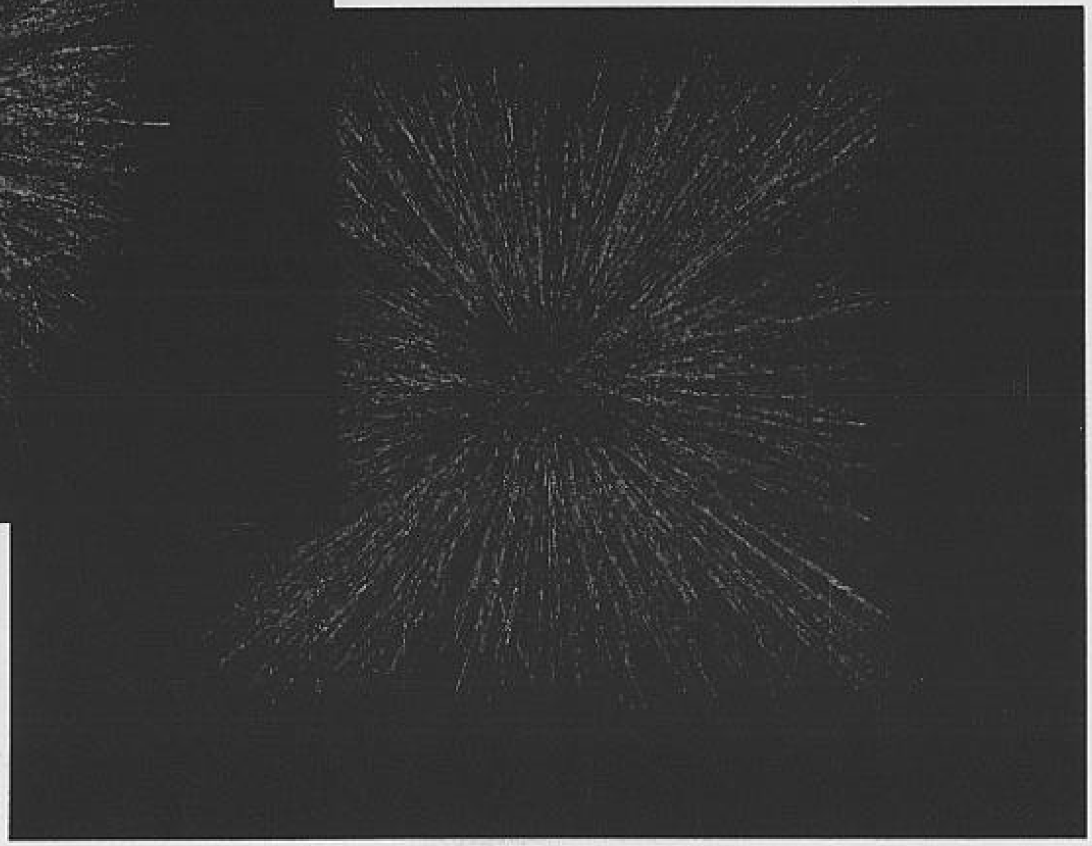


STAR Detector

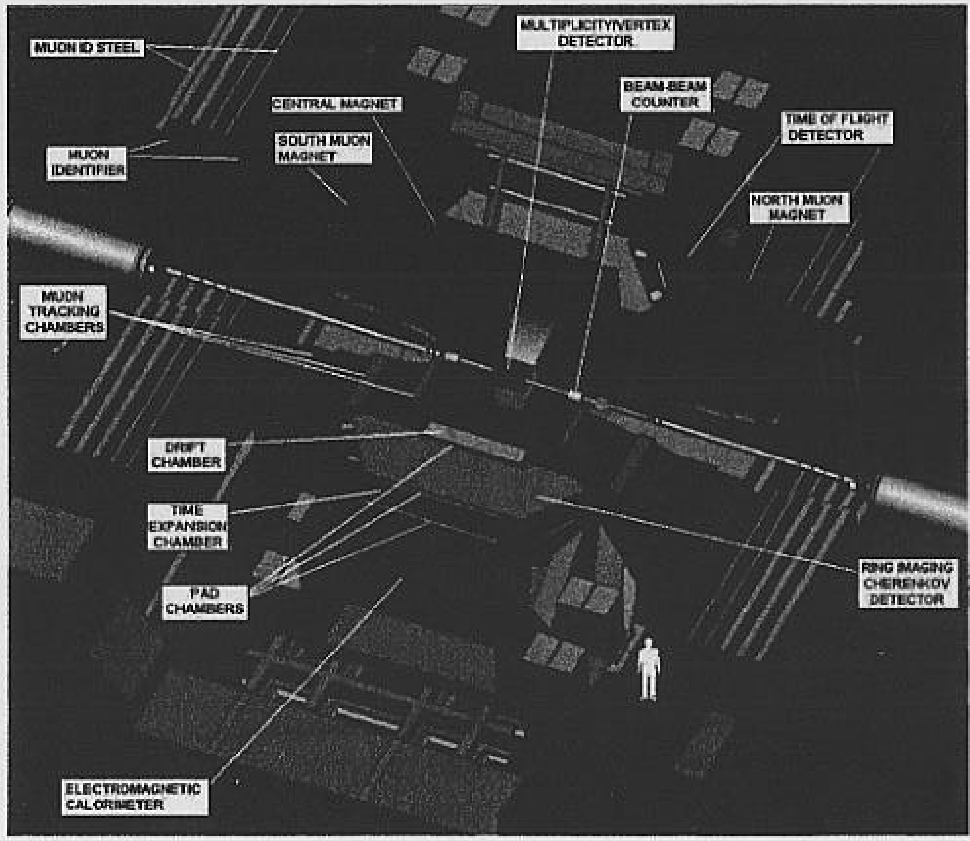


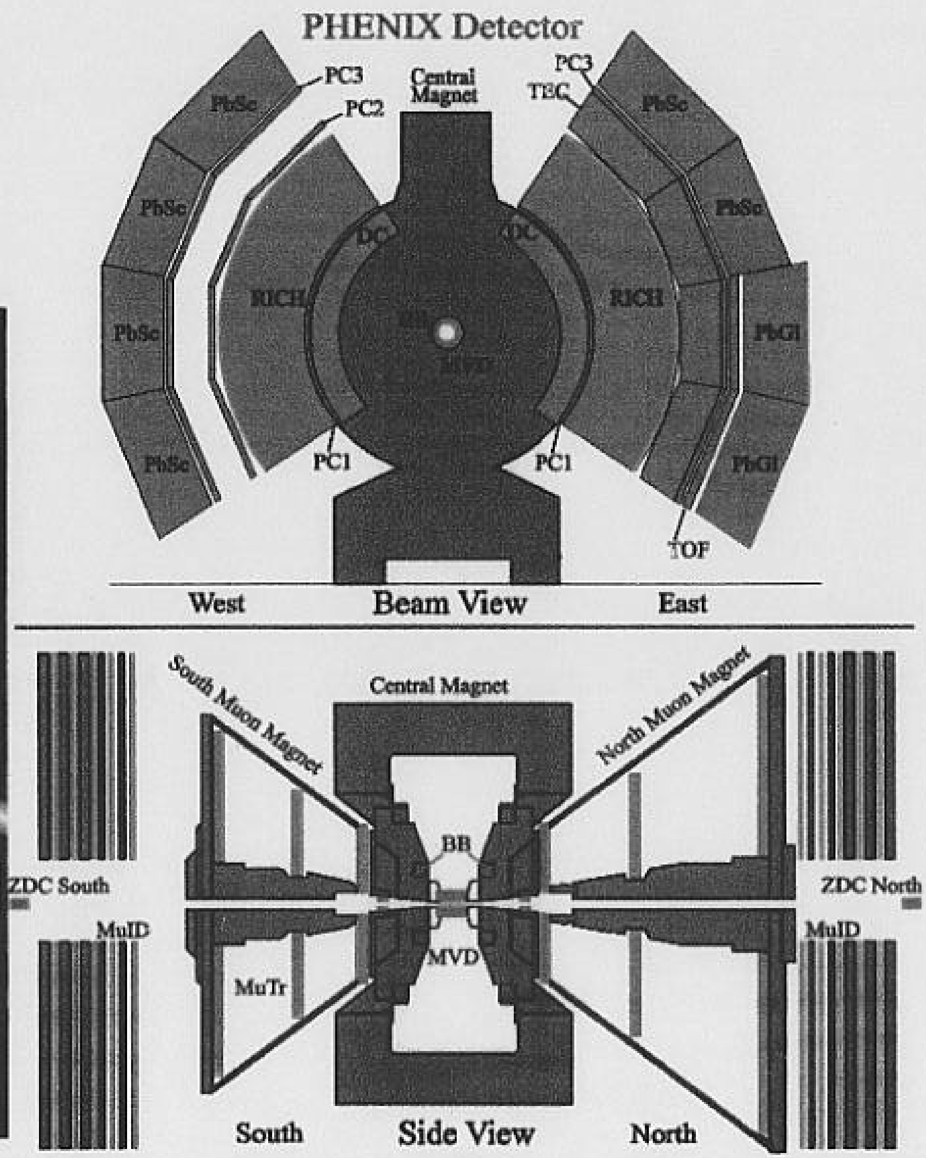
STAR



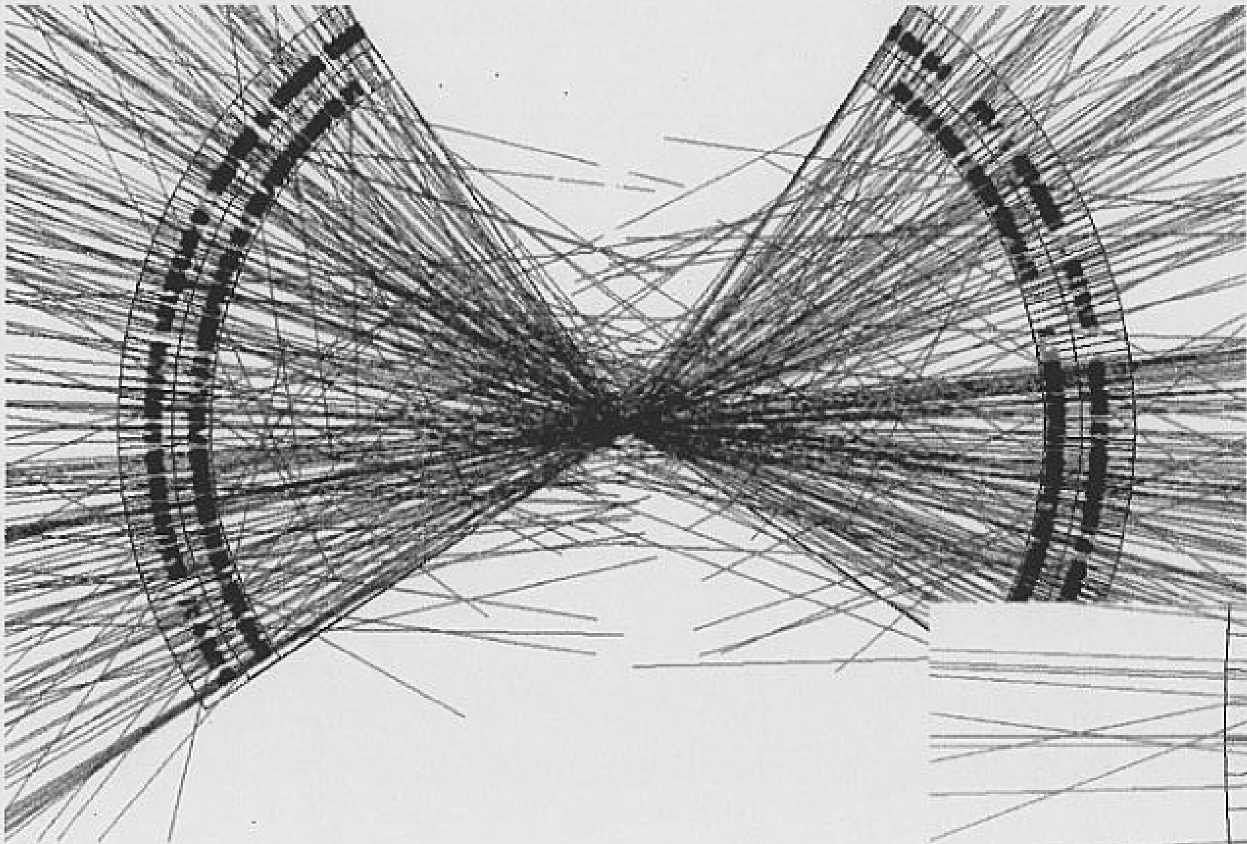


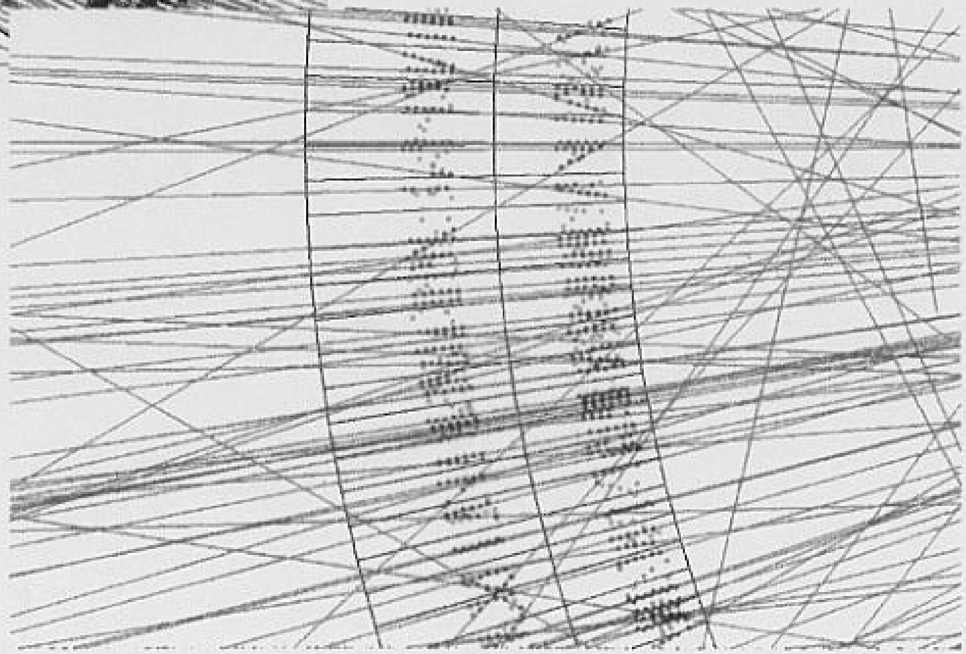
PHENIX


MUON ID STEEL
MULTIPLICITY/VERTEX DETECTOR
CENTRAL MAGNET
BEAM-BEAM COUNTER
TIME OF FLIGHT DETECTOR
MUON IDENTIFIER
SOUTH MUON MAGNET
NORTH MUON MAGNET
MUON TRACKING CHAMBERS
DRIFT CHAMBER
TIME EXPANSION CHAMBER
RING IMAGING CHERENKOV DETECTOR
PAD CHAMBERS
ELECTROMAGNETIC CALORIMETER

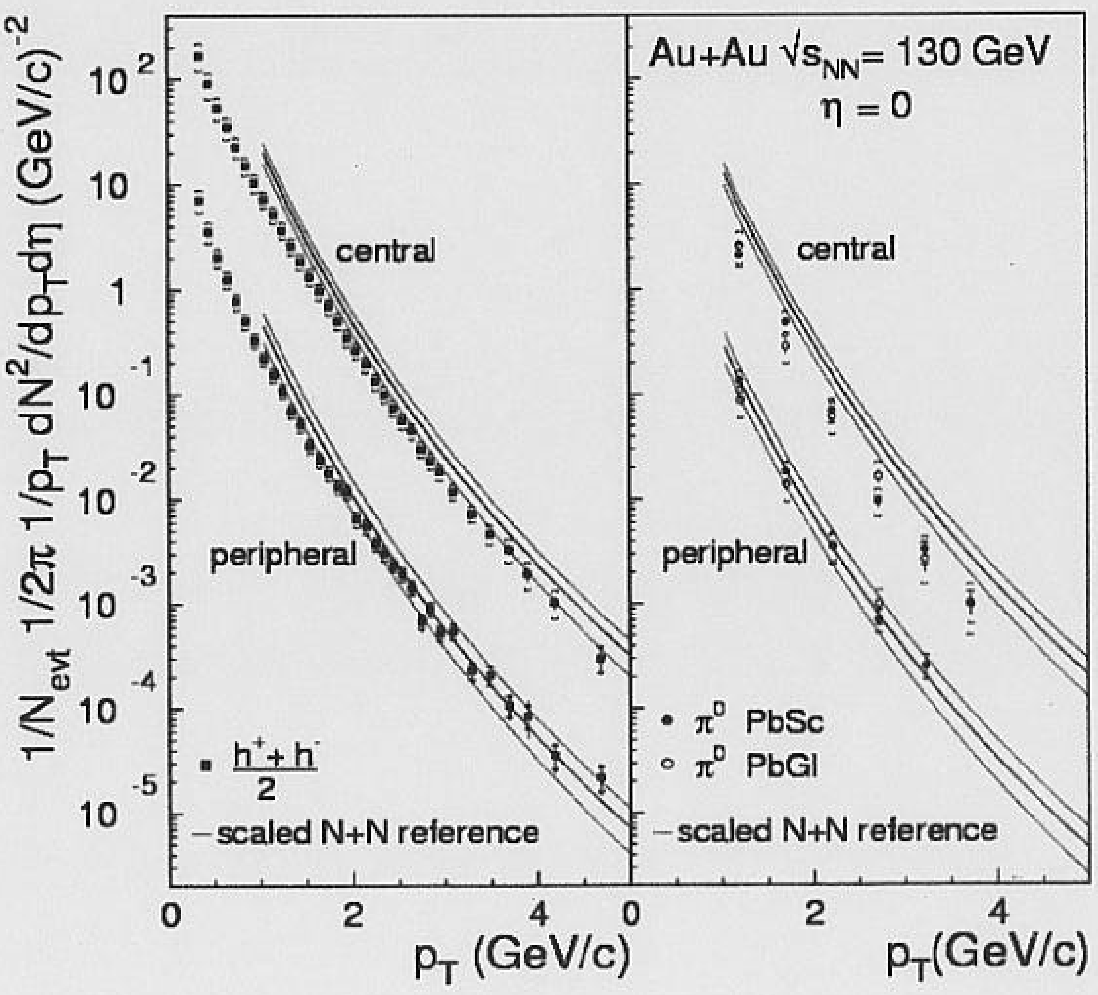

PHENIX Detector
PC3
PC2
Central Magnet
PC3
TEC
PbSc
PbSc
PbSc
PbSc
PbSc
PbSc
PbSc
DC
DC
RICH
RICH
MVD
PbGl
PbGl
PC1
PC1
TOF
West
Beam View
East
South Muon Magnet
Central Magnet
North Muon Magnet
BB
ZDC South
ZDC North
MuID
MuID
MVD
MuTr
South
Side View
North

DC





Au+Au pi0



1/N_evt 1/2π 1/p_T dN²/dp_T dη (GeV/c)^-2
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
central
peripheral
(h⁺ + h⁻)/2
scaled N+N reference
0
2
4
p_T (GeV/c)
Au+Au √s_NN = 130 GeV
η = 0
central
peripheral
π⁰ PbSc
π⁰ PbGl
scaled N+N reference
0
2
4
p_T (GeV/c)

Spin Physics at RHIC

- Spin Structure of the Nucleon
  - ΔG measurements via prompt photon, π^0, and heavy quark productions
  - Δqbar measurements via Drell-Yan production (γ^*, W, Z)
  - δq, δqbar measurements via Drell-Yan production
- Symmetry Tests
  - study of parity violation in hadron collisions; physics beyond SM, e.g. compositeness.
- QCD selection rule (R.L. Jaffe and NS)
  - switch off gluon!
  - $a_{TT}/a_{LL} << 1$
- Single Transverse Spin Asymmetry A_N
  - large asymmetry observed at lower energies
  - vanish in perturbative QCD, might be large due to higher-twist effects

Gluon Helicity Distribution

1. Inclusive Prompt Photon Production
- theoretically reasonably understood process up to NLO; both spin average and polarized
- experimentally difficulty can be overcome

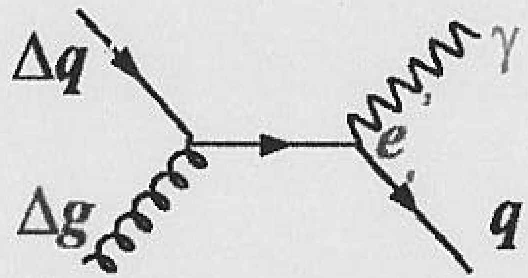
1. Inclusive π^0 Production
- experimentally rather easy; high statistics measurement
- penalty of fragmentation uncertainty

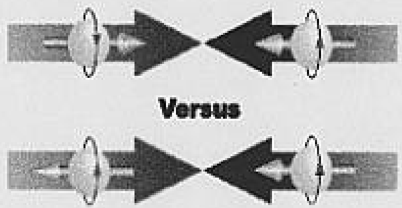
1. Open Heavy Flavor Production
- analyzing power is maximal = -1, since annihilation channel (mass correction small enough)
- possible cancellation at NLO is pointed out (not completed)
- high statistics

1. Quarkonium Production
- high stats of J/ψ; identification easy since resonance
- production mechanism not settled yet; polarization measurement would be useful to select model
- important process for both HI and SPIN program

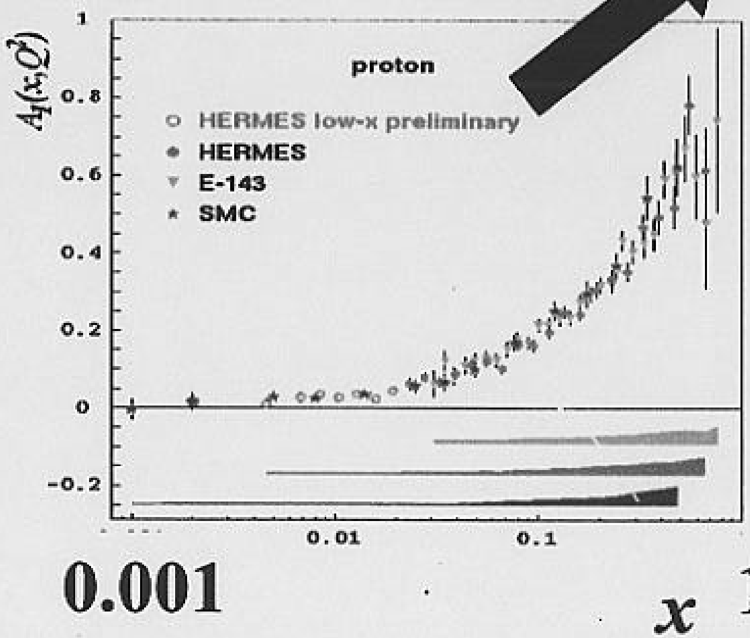
Ex-1: Prompt Photon Production

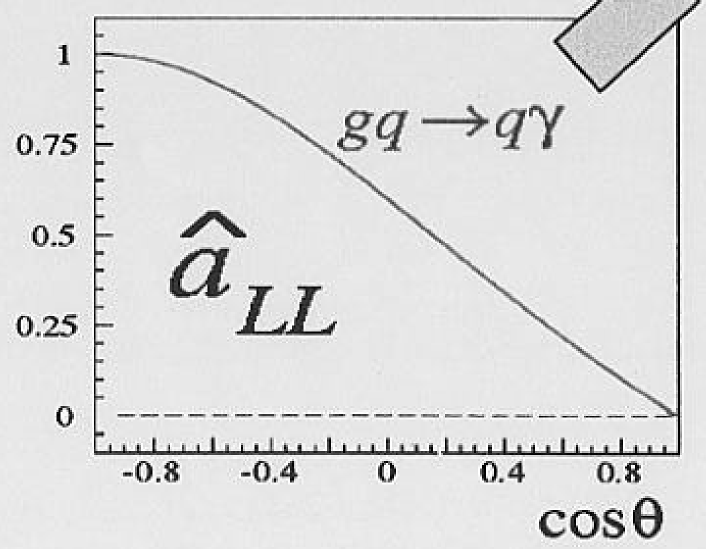
- Gluon Compton Dominates
  - Small Contamination from Annihilation
  - No fragmentation contribution in LO





$$A_{LL} = \boxed{\frac{\Delta g(x_1)}{g(x_1)}} \otimes \frac{\sum_i e_i^2 \Delta q_i(x_2)}{\sum_i e_i^2 q_i(x_2)} \otimes a_{LL}(gq \to q\gamma)$$

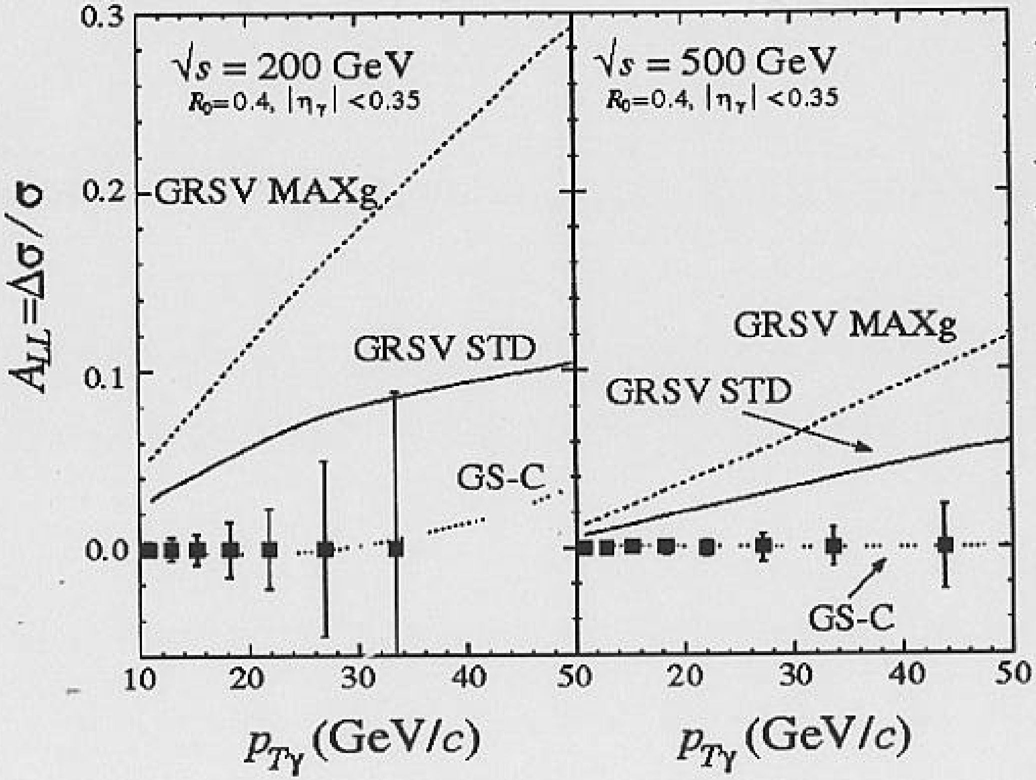




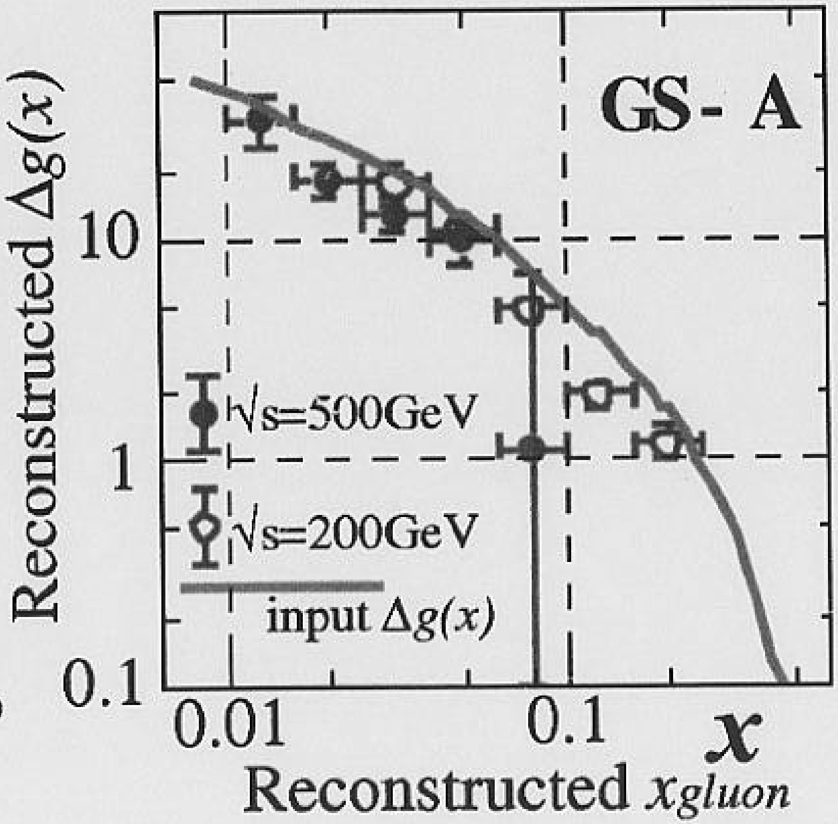
Prompt Photon Production

- **Gold Plated mode for both PHENIX & STAR**

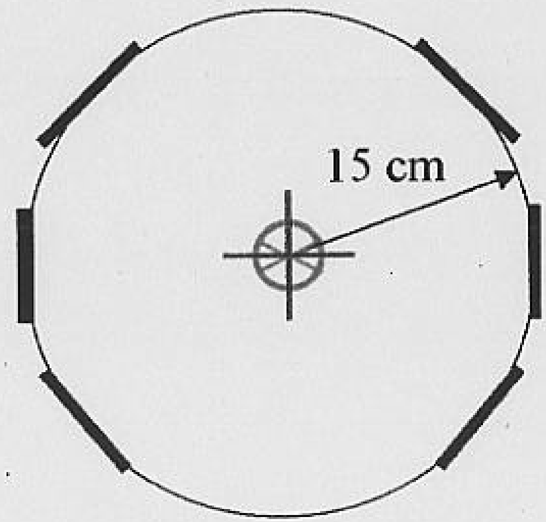
Comparison at cross section level
= direct observable

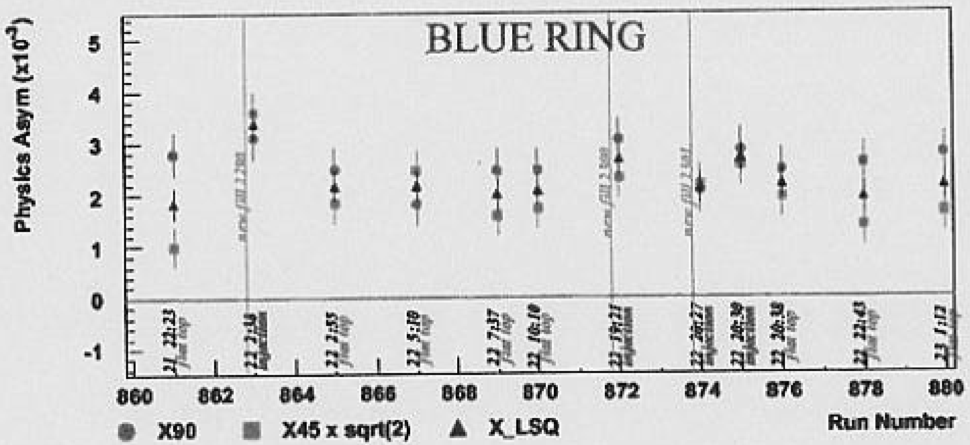


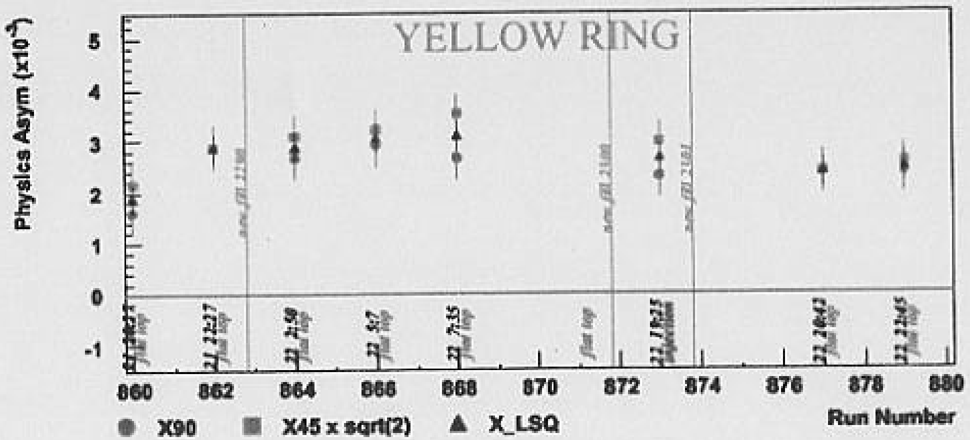
x-reconstructed using jet



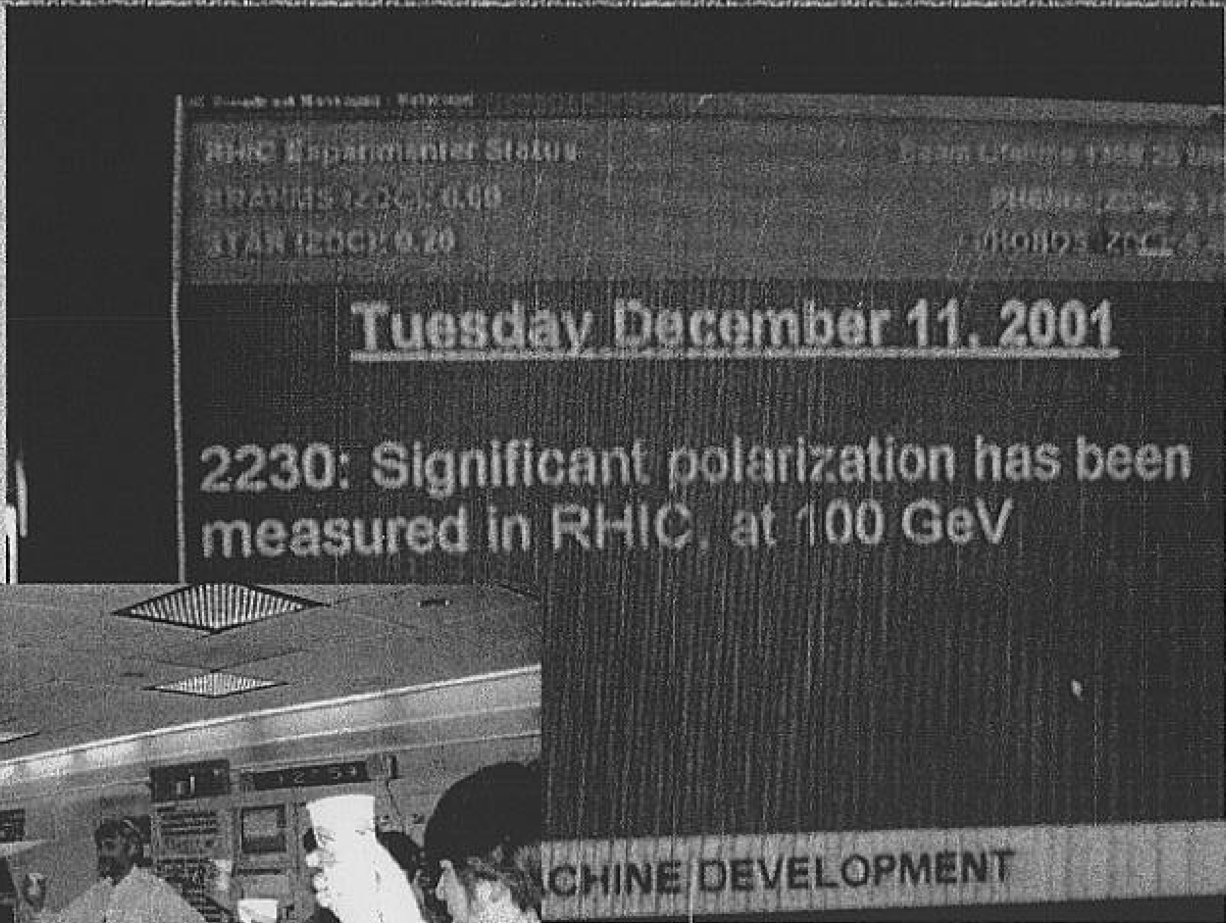
RHIC Polarimeter

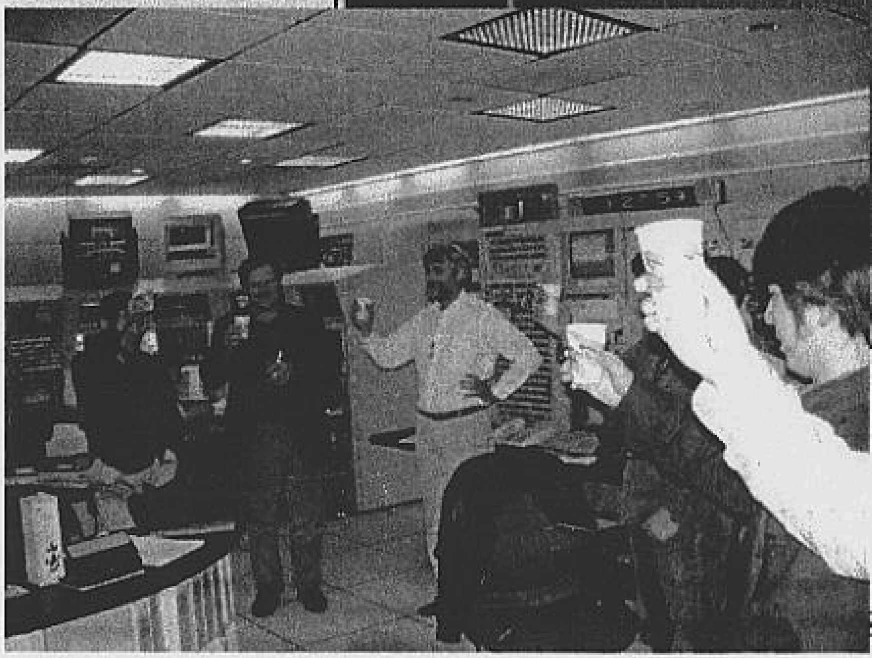






The First Polarized pp Collider





RHIC Spin Plan (PHENIX and STAR)

Year	CM Energy	Weeks	Int. Lum.	Remarks
FY2001	200 GeV	5	7 pb^{-1}	Gluon pol. with pions
FY2002	200 GeV	8	160 pb^{-1}	Gluon pol. with direct γ , jets/ TT
	500 GeV	2	90 pb^{-1}	PV W production, u-quark pol.
FY2003	200 GeV	8	160 pb^{-1}	Gluon pol. with γ + jet/ TT
	500 GeV	2	120 pb^{-1}	First ubar,dbar pol. meas..
FY2004	500 GeV	8	480 pb^{-1}	Gluon pol. with γ+jet, γ,jet+jet, heavy flavor, ubar, dbar pol.
	200 GeV	2	48 pb^{-1}	Gluon pol. with γ, γ+jet, heavy flavor/TT
FY2005	500 GeV	5	300 pb^{-1}	More statistics
	200 GeV	5	120 pb^{-1}	
FY2006	200 GeV	10	210 pb^{-1}	

Still on track if we change FY → CY or JFY

Hadron and Nuclei

- Strangeness nuclear physics

  (AGS, Jlab, Dafne, GSI)
- Nucleon and nuclear parton structure

  (RHIC Spin,,,)
- Hadron spectroscopy and nuclei

  (Spring-8)
- Hot and (dense) matter

  (RHIC heavy ion)

日本の核物理

- JHF → 統合計画

  クォーク・ハドロン多体系の物理.

  - ストレンジネス (JLab. AGS.)

  - ハドロン物理.

    spectroscopy
    structure function — RHIC spin, HERMES, COMPASS
    hadron in nuclei

  (• dense matter)

  hot matter. (RHIC).

  (• E-arena. 不安定核 → タンデム.)

- 理研 RIBF.

  - 不安定核の物理.

- RCNP

  - サイクロトロン 400MeV 精密核物理. スピンアイソスピン励起など. (GT...)
  - SPring 8 LEPS hadron physics with GeV photon.

- 各大学の中小加速器施設.

  - 特徴ある研究
  - 基地.

Strangeness

- AGS D-line （C-line)

  Double hypernuclei (E906, E946)

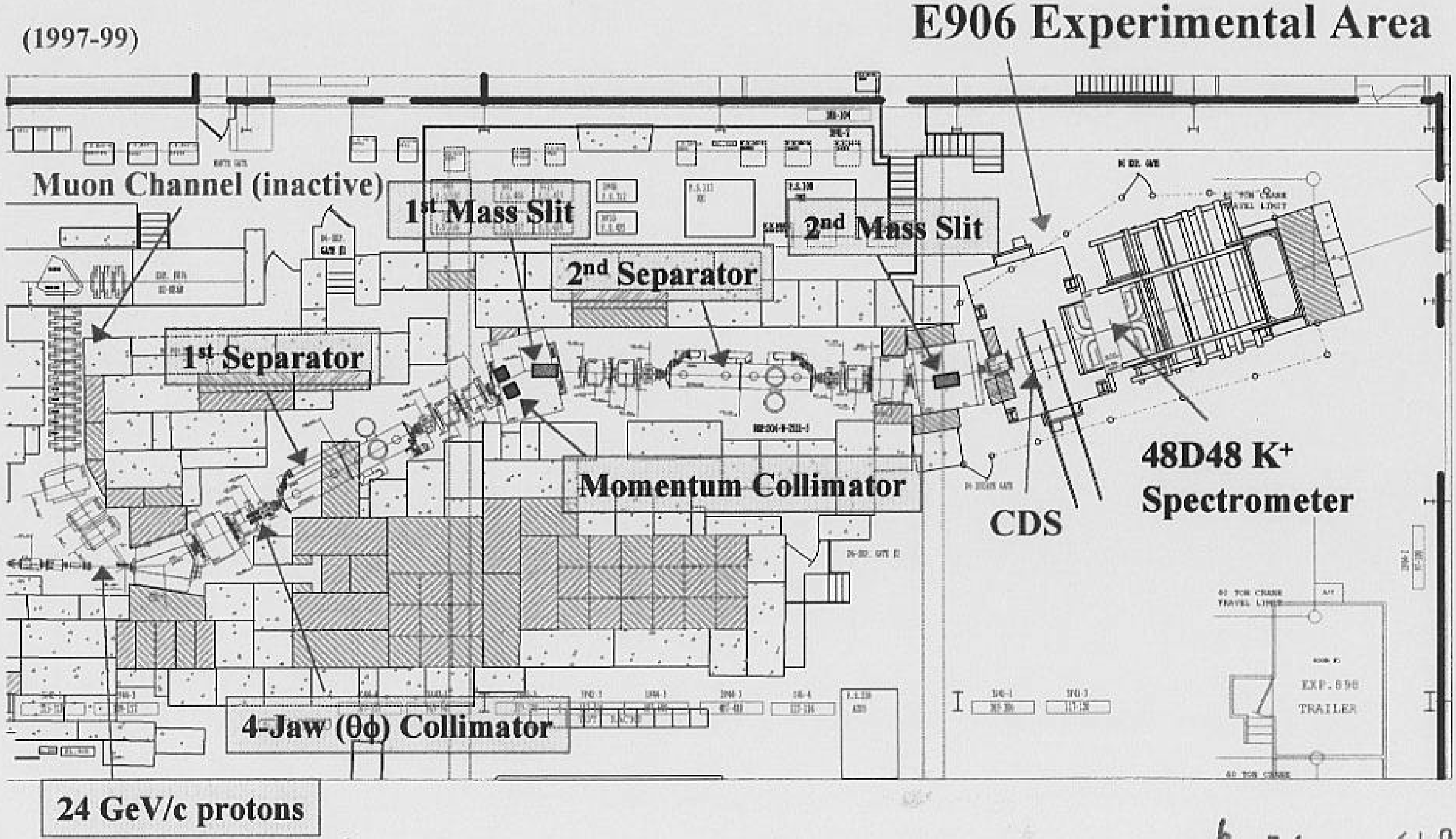
  γ-spectroscopy (E929, E930)

  日本グループ主導

  （高工研、京大、阪大、東北大、岐阜大など）

2 GeV (D6) Beam Line (BNL).

(1997-99)



0.93 GeV/c

10^5 K^-/spill $K^-/\pi^- = 10/1$!

10^6 K^-/spill (1.8 GeV/c)

$K^-/\pi^- \simeq 1/1$

ハイパー核での例

- ~~核物理~~.

核力と ~~核~~ 核構造 → magic number.

NN potential
ハイパー核 ← 和の → cluster / shell $\ell\cdot s$ / collective motion　　NN の約 $\frac{1}{100}$!

→ 核力の起源.

- hard core 安定核 (短寿命不安定核)

- NNP 核 hardcore $\xrightarrow{\text{ハイパー核}}$ saturation.

斥力

特殊性 と 普遍性 (~~証~~ $\ell\cdot s$, color-magnetic 力 / Pauli principle.)

引力

- ssuudd J=0　stabe H-dibaryon ?
物質の階層性.

クォーク → ハド~~double~~ ~~核~~...

(QCD : fundamental principle.).

$^{6}_{\Lambda\Lambda}He$ (KEK-E373)

$^{4}_{\Lambda\Lambda}H$ (BNL-E906)

application.

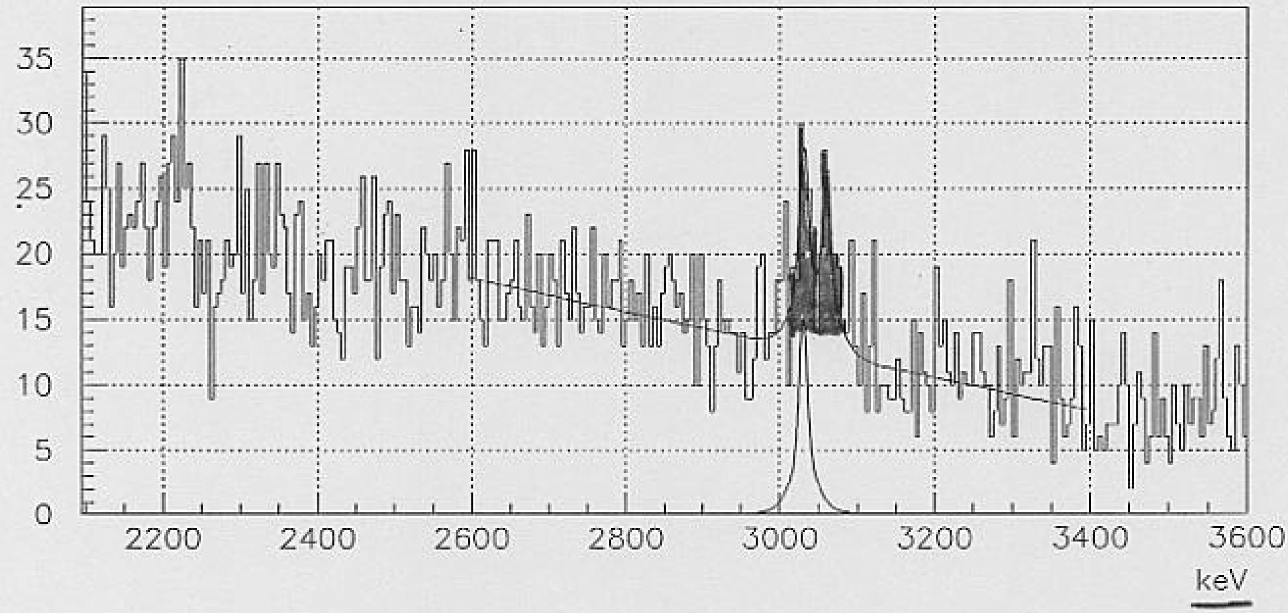
⟹ 中性子星内部のハイペロン (strangeness)

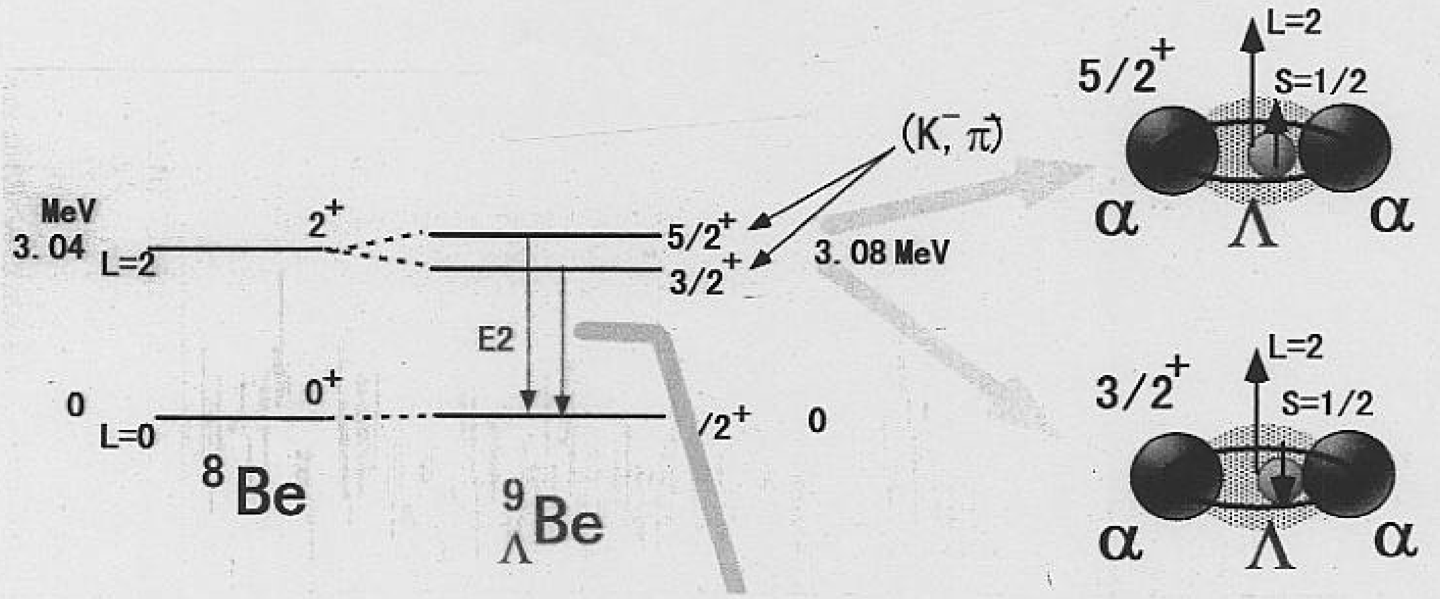
(strange quark matter.).

BNL-E930

$K^- + {}^9Be \rightarrow \pi^- + {}^9_\Lambda Be^* \rightsquigarrow \gamma$

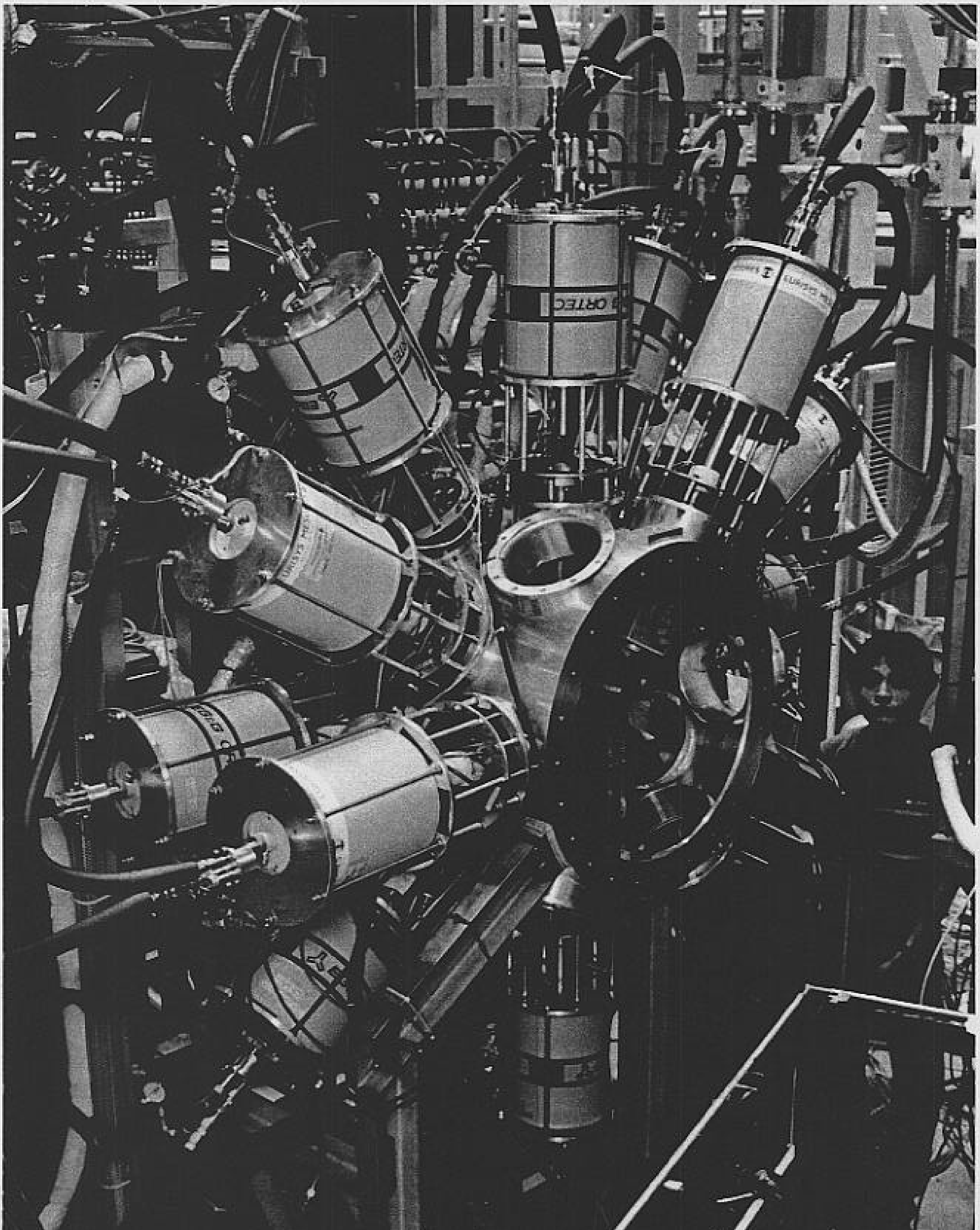
↔ 30 keV !





Sensitive to LS interaction

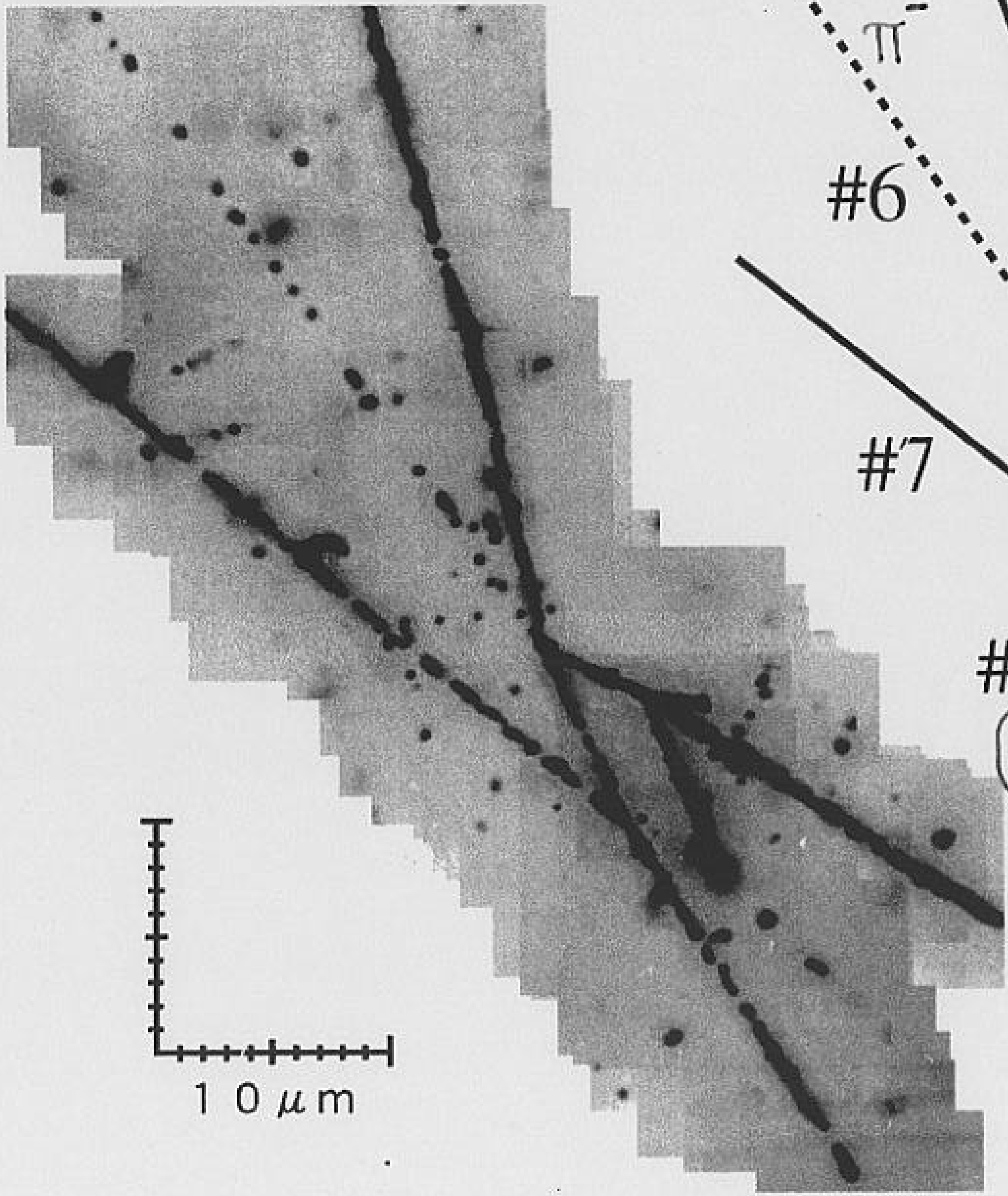
H. Akikawa et al., PRL.

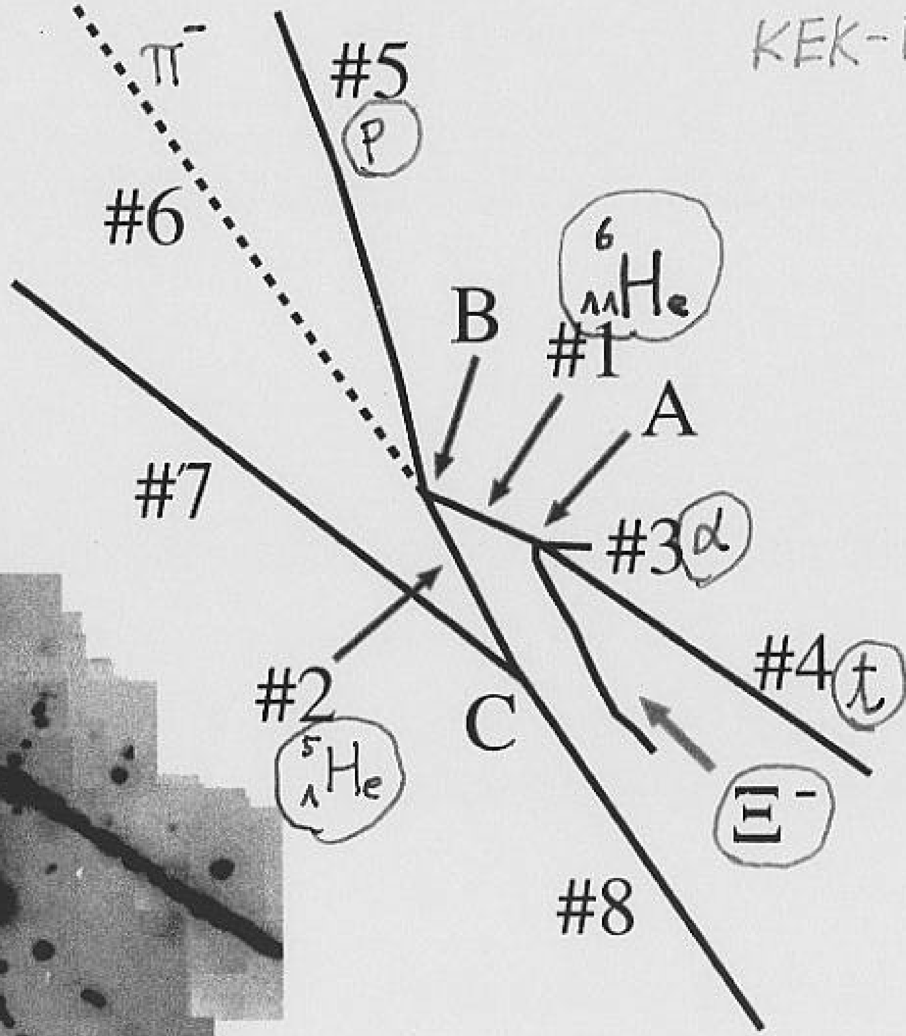

ORTEC

"NAGARA" Event

found by
Y.S.Iwata (Gifu Univ.)

KEK-E373





(Top View)

The nuclide and the decay mode have been identified **uniquely**:

$$\boxed{\begin{array}{c} {}^{12}\mathrm{C} + \Xi^- \longrightarrow {}^{6}_{\Lambda\Lambda}\mathrm{He} + {}^{4}\mathrm{He} + \mathrm{t} \\ {}^{6}_{\Lambda\Lambda}\mathrm{He} \longrightarrow {}^{5}_{\Lambda}\mathrm{He} + \mathrm{p} + \pi^- \end{array}}$$

The Λ–Λ interaction energy has been **uniquely** determined **for the first time**:

$$\underline{\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20\,^{+0.18}_{-0.11}\ \mathrm{MeV}}$$

The lower limit of the mass of the H dibaryon:

$$M_H > 2223.7\ \mathrm{MeV}\ \ (90\%\ \mathrm{C.L.})$$

Strangeness

Jlab (e,e'K)

High resolution spectroscopy（東北大）

Dafne (stopped K^-,π^-)

weak decay, spectroscopy

GSI (π^+,$K^+\gamma$)

γ-spectroscopy

E964の目的

★ S=−2核のミニチャート ⟶ 質量の系統性.

★ 崩壊分岐比の測定 ⟶ H核の可能性.

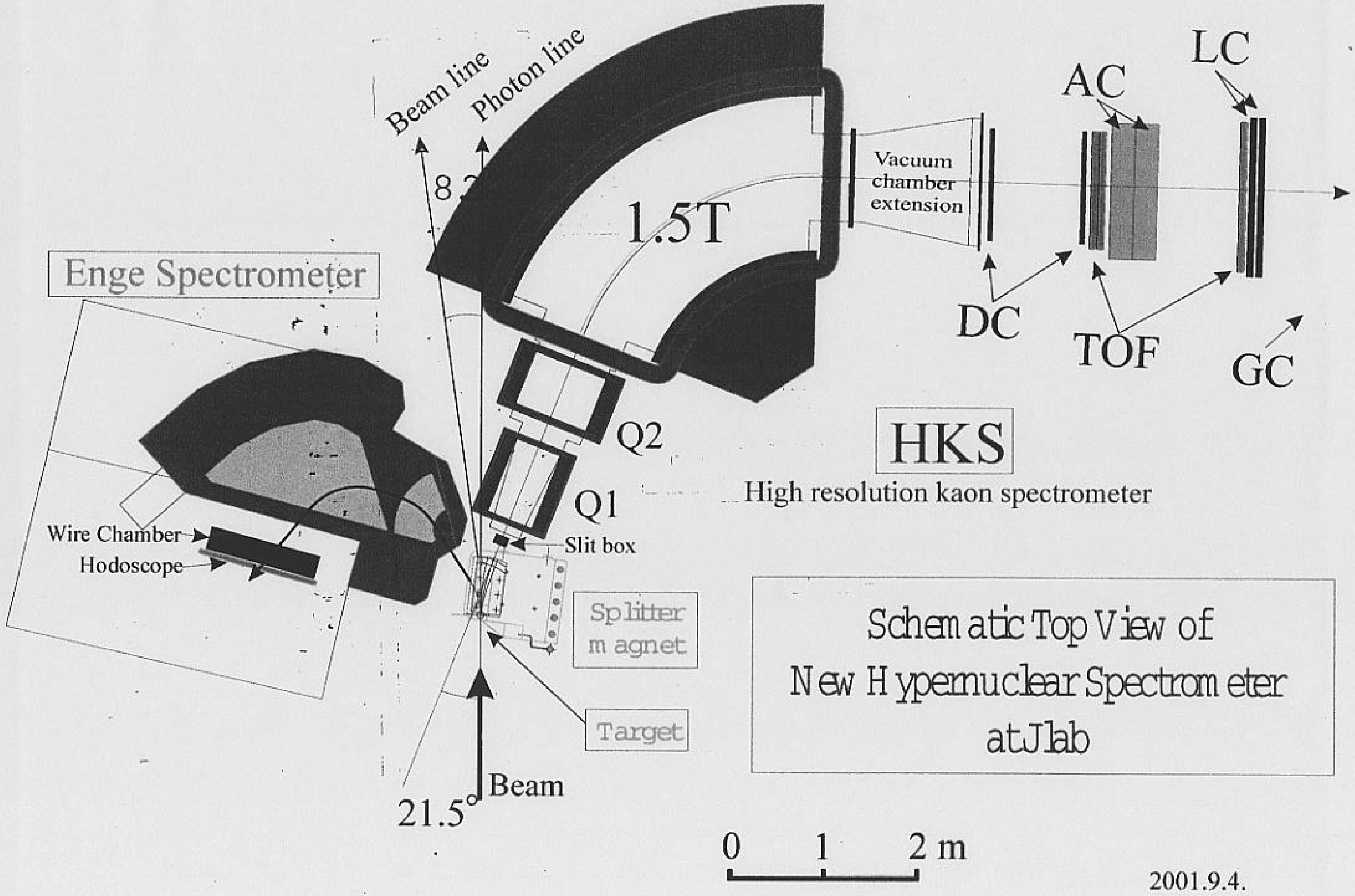
★ 共鳴状態としてのHダイバリオンの探索.

★ Ξ⁻原子のX線測定 ⟶ Ξ⁻核ポテンシャル.

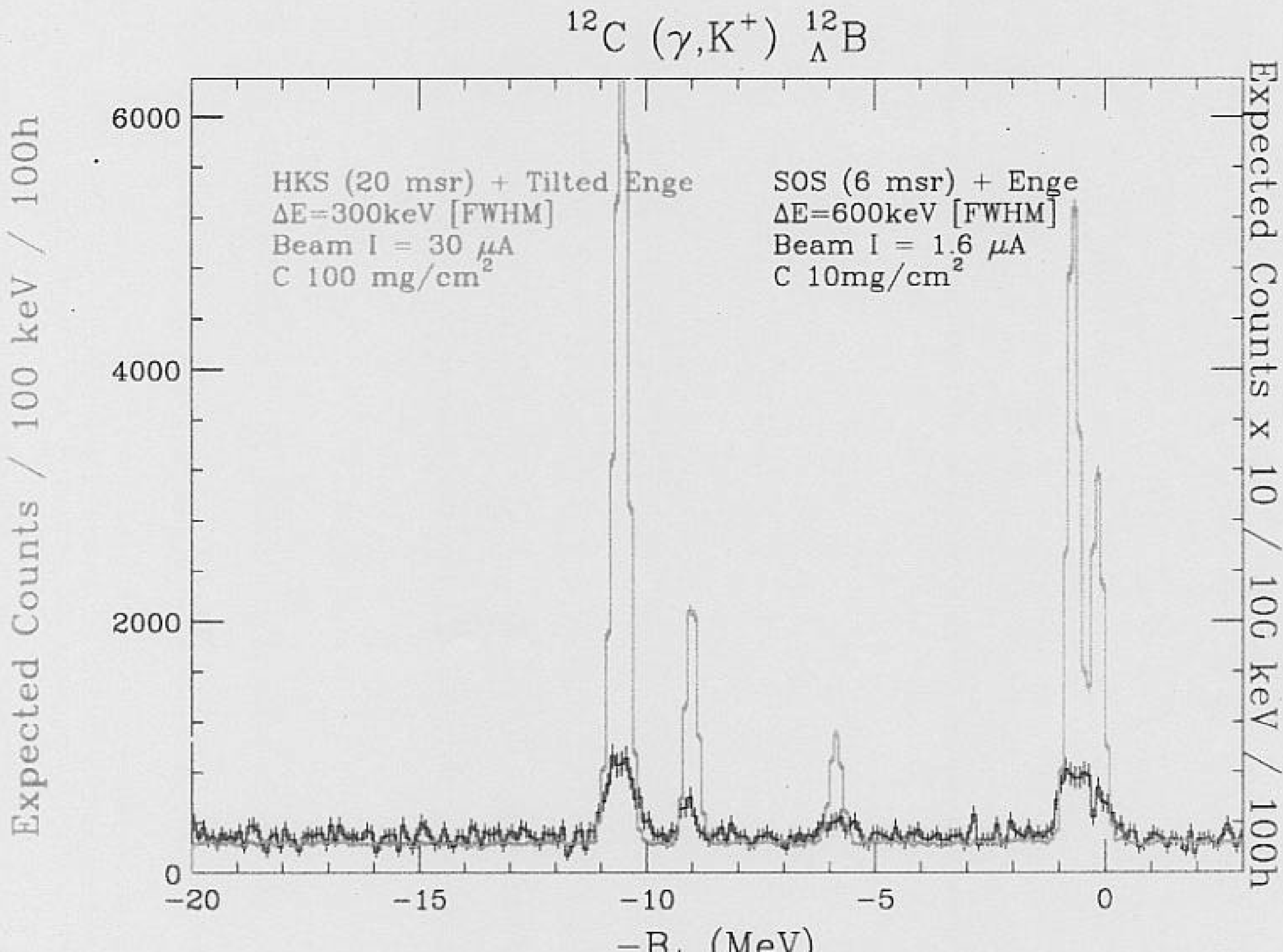
⟶ { KEK-E373の10倍以上の統計. (10^4 stop Ξ^-)
　　とGe (ハイパーボール) との組み合せ.

(γ, K^+) spectroscopy

- large momentum transfer (like (π^+, K^+))
  ΔL.
- unnatural parity state
- low cross section. JLab.
- mirror hypernuclei ((π^+, K^+), (K^-, π^-)).
- high resolution



Engge Spectrometer
Wire Chamber
Hodoscope
Beam line
Photon line
8.2
1.5T
Vacuum chamber extension
DC
AC
TOF
LC
GC
Q2
Q1
Slit box
Splitter magnet
Target
Beam
21.5°
HKS
High resolution kaon spectrometer
Schematic Top View of
New Hypernuclear Spectrometer
at Jlab
0 1 2 m
2001.9.4.



$^{12}C\ (\gamma,K^+)\ ^{12}_{\Lambda}B$
HKS (20 msr) + Tilted Enge
ΔE=300keV [FWHM]
Beam I = 30 μA
C 100 mg/cm²
SOS (6 msr) + Enge
ΔE=600keV [FWHM]
Beam I = 1.6 μA
C 10mg/cm²
Expected Counts / 100 keV / 100h
Expected Counts x 10 / 100 keV / 100h
$-B_{\Lambda}$ (MeV)
6000
4000
2000
0
−20
−15
−10
−5
0

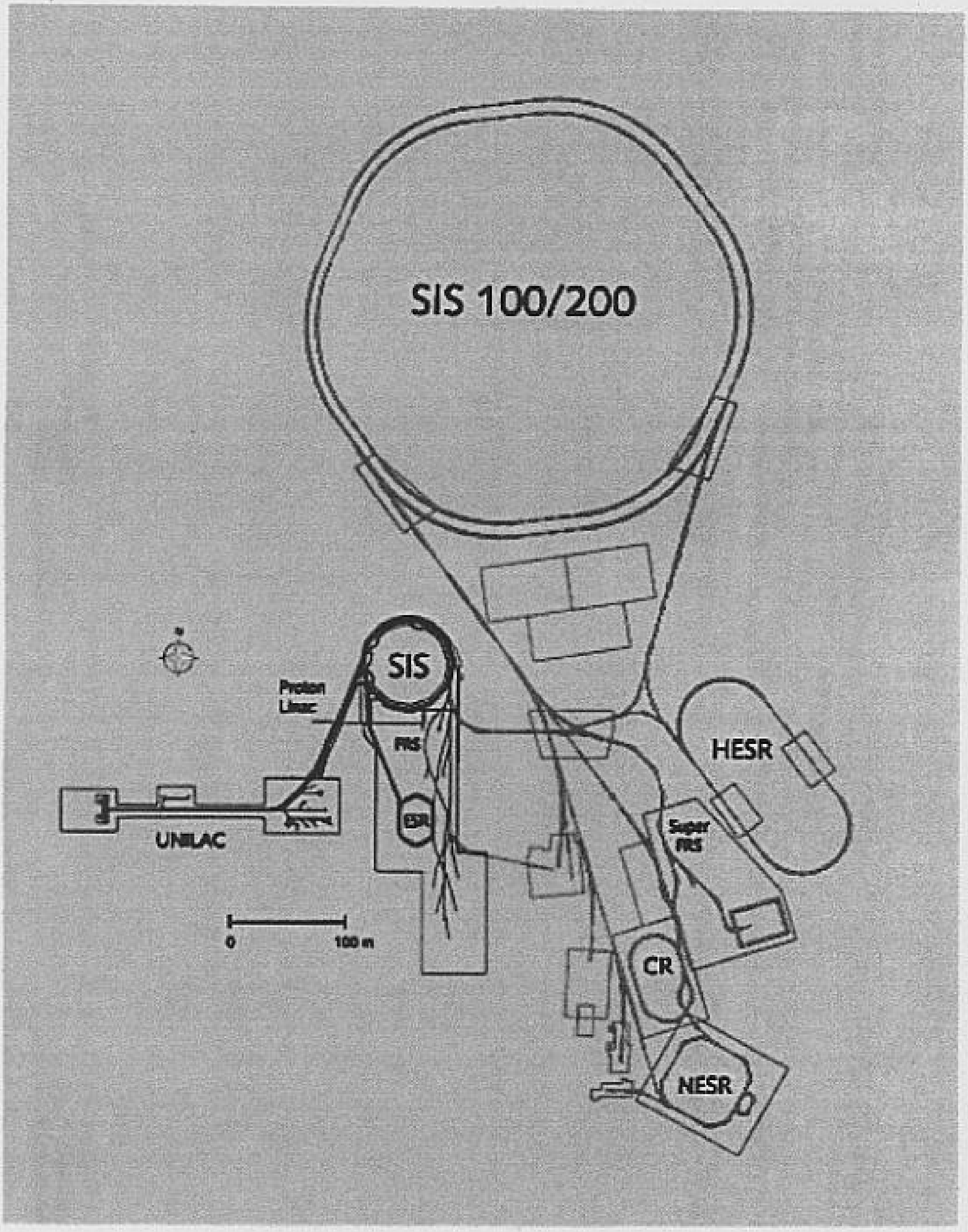


Figure 1: The existing GSI facility (blue) with the linear accelerator UNILAC, the heavy-ion synchrotron SIS18, the fragment separator FRS and the experiment storage ring ESR; and the new project (red) with the double-ring synchrotron SIS100/200, the high-energy storage ring HESR, the collector ring CR, the new experiment storage ring NESR, the super-conducting fragment separator Super-FRS and several experimental stations. The present UNILAC/SIS18 complex serves as injector for the new double-ring synchrotron.

Table 2.2: Primary beam parameters from the SIS100/200 facility for the different research fields

Research Field	Energy	Peak Intensity	Average Intensity	Pulse Structure
Radioactive Ion Beams	1.0 - 1.5 GeV/u for all elements up to uranium	10^{12} per cycle for storage ring experiments	10^{12} per second high duty cycle for fixed target experiments	≤ 50 ns for transfer into the storage ring
Antiprotons	29 GeV p	2.5x10^{13} per cycle	--	≤ 50 ns
Dense Nuclear Matter	up to 22.3 GeV/u U, up to 30 GeV/u Ne	--	10^{9} per second high duty cycle	--
Plasma Physics	.4 to 1 GeV/u ions	2x10^{12} per cycle	--	100 – 30 ns (fixed target)
Atomic Physics	1 to 22.3 GeV/u ions	--	10^{9} per second high duty cycle	

Parallel Operation and Synergy

An important consideration in the design of the facility was a high degree of truly parallel operation of the different research programs. Simple beam splitting and switching to different target locations is of course generally possible at an accelerator with relatively little effort. But this would in general not change the integrated luminosity. Truly parallel operation, with the constraints of accelerator cycles, is considerably more difficult. It would, however, provide maximum integrated beamtime, or integrated luminosity for each of the different programs operated in parallel. This implies that the facility operates for the different programs more or less like a dedicated facility.

The proposed facility concept is therefore very cost-effective. A modest addition in facility structure, say an additional storage ring, can provide an essentially full scale new program without the need of a central facility, since that already exists for the other programs, or vice versa. The proposed scheme of accelerator and storage rings has the characteristics to optimize such a parallel and highly synergetic scheme. We are confident that the proposed scheme will work very well due to the considerable development and experience at the present facility: At the existing system, parallel operation of different beams from the three UNILAC injectors, acceleration of these beams to different energies and with different intensities, and serving different experiments at the UNILAC, at SIS (including tumor beam therapy), and at the ESR has been routinely demonstrated. Figure 2.2 illustrates how parallel operation would be performed with a cooled and post-accelerated antiproton beam, in parallel to

active beam intensities by a factor of up to 10,000. It will provide high-intensity antiproton beams, high-energy proton and ion beams (about 15 times higher than presently available at GSI), and short ion pulses with energies up to 100 kJ.

The key parameters and specifications of the proposed synchrotrons and accelerator/storage rings are shown in Table 2.1. The beams that can be provided for the different research fields are displayed in Table 2.2.

Table 2.1: Key parameters and features of the proposed synchrotrons and cooler/storage rings

Ring	Circumference [m]	Bending Power [Tm]	Beam Energy	Specific Features
Synchrotron SIS100	1080	100	2.7 GeV/u U^{28+} 29 GeV protons	fast pulsed superferric magnets up to 2 T, 4 T/s, bunch compression to 50 ns, fast and slow extraction, 5x10^{-12} mbar operating vacuum
Synchrotron SIS200	1080	200	22.3 GeV/u U^{92+}	pulsed super-conducting cosθ-magnets up to 4 T, 1 T/s, slow extraction with high duty cycle, 5x10^{-12} mbar operating vacuum
Collector Ring CR	187	13	740 MeV/u, A/q=2.7 3 GeV antiprotons	acceptance for fragments and antiprotons 200/240 mm mrad, Δp/p [illegible], fast stochastic cooling of radioactive ions and antiprotons, mass spectrometer for short lived nuclei
New Experimental Storage Ring NESR	208	13	740 MeV/u, A/q=2.7 3 GeV antiprotons	electron cooling of radioactive ions with up to 450 keV electron-beam, precision mass spectrometer, accumulation and stochastic cooling of antiprotons, internal target experiments with atoms and electrons, electron-nucleus scattering facility
High-Energy Storage Ring HESR	430	50	14 GeV antiprotons	stochastic cooling of antiprotons up to 14 GeV, electron cooling of antiprotons up to 9 GeV

Criteria (NSAC)

- Big question?
- International leadership
- Opportunity for discovery
- Community
- Application
- Attractiveness to young people

Experimental Setup

Dipole Spectrometer

Study of forward cross-sections and lineshape analysis with respect to different charged decay modes is underway!

Solenoid

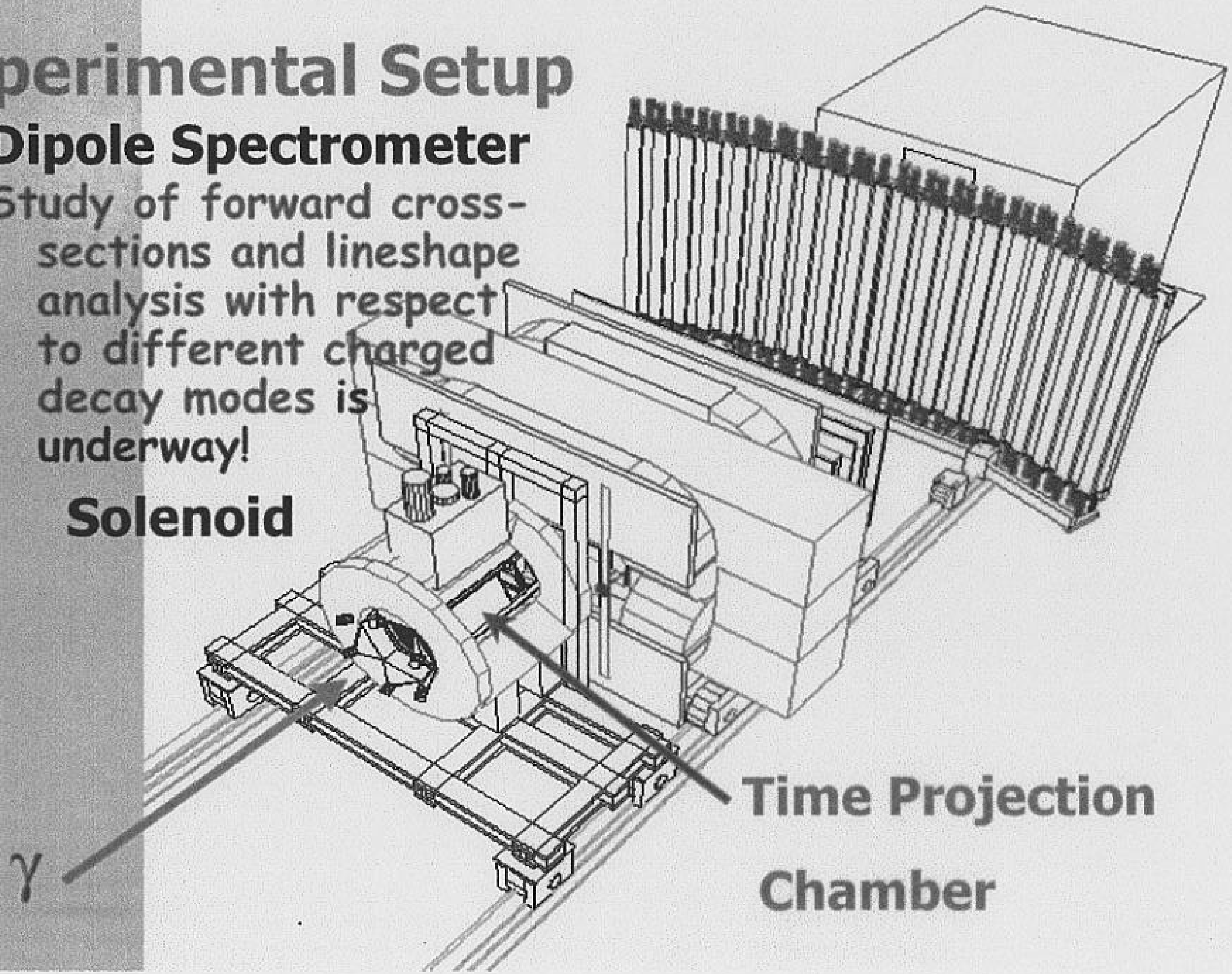


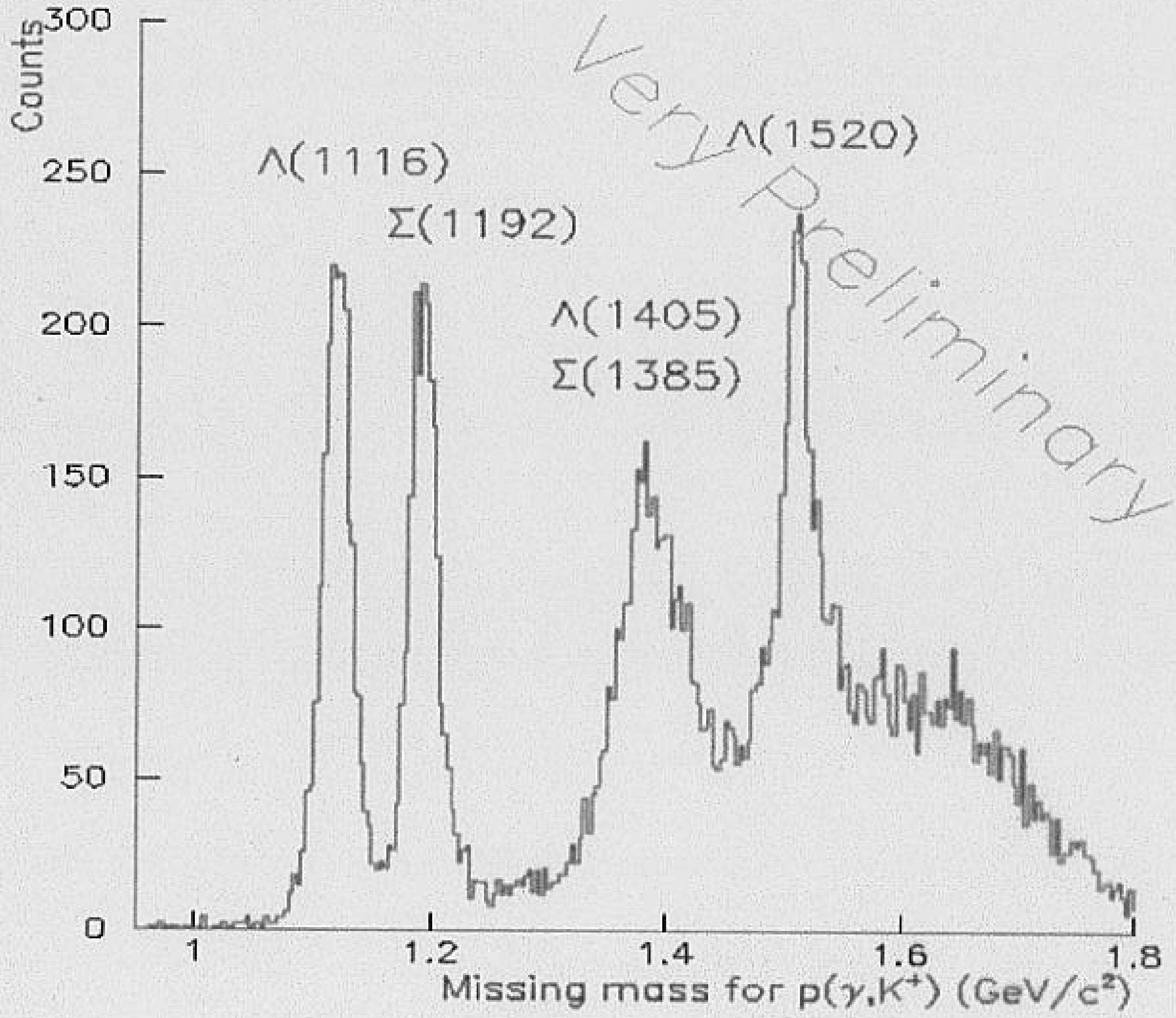
Photo-production of $\Lambda(1405)$ in nuclei

- qqq state vs. meson-baryon resonance.
- Big change of the decay width in nuclear medium for the meson-baryon case .
  - → Chiral unitary model .
- Need to identify the decay products ($\Sigma\pi$)
- Time Projection Chamber is constructed.

K^+ Photo-production with linearly polarized photons.

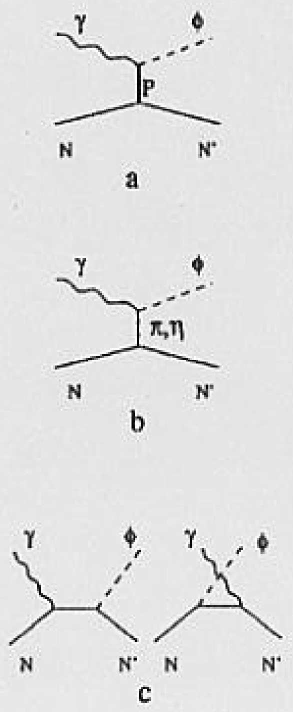
- Search for missing baryon resonances.
- SAPHIR and Jlab data indicate a structure in the $p(\gamma, K^+)\Lambda$ cross-section around W=1.9 GeV.
- Photon-beam asymmetry is sensitive to the existence of the baryon resonace.
- Complementary to the experiment at GRAAL.

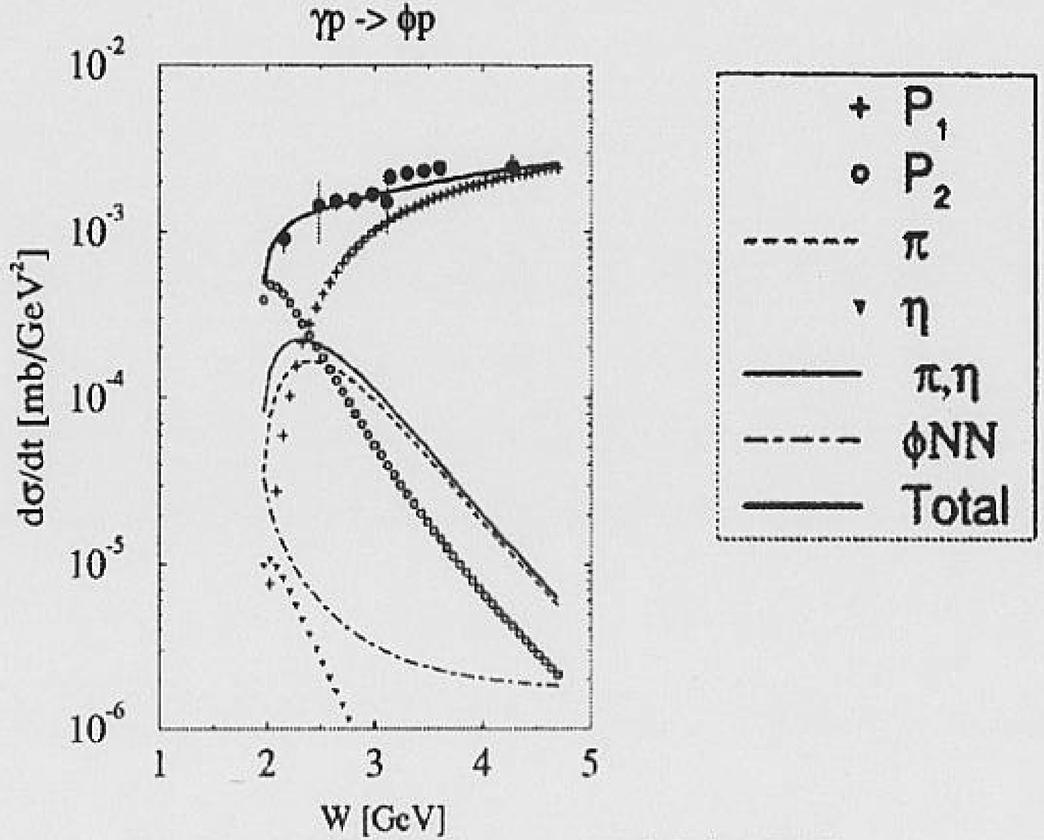
K^+ Photo-production



φ photoproduction near production threshold

Titov, Lee, Toki Phys.Rev C59(1999) 2993



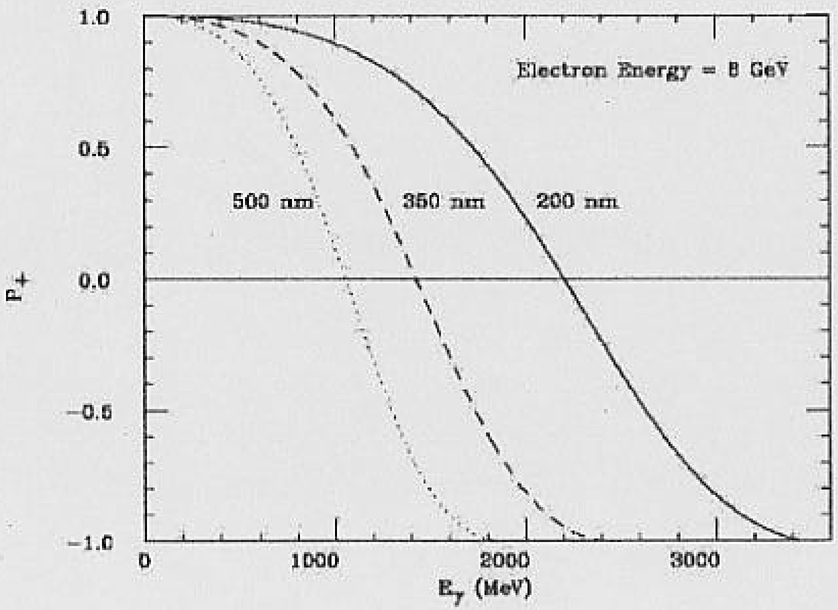


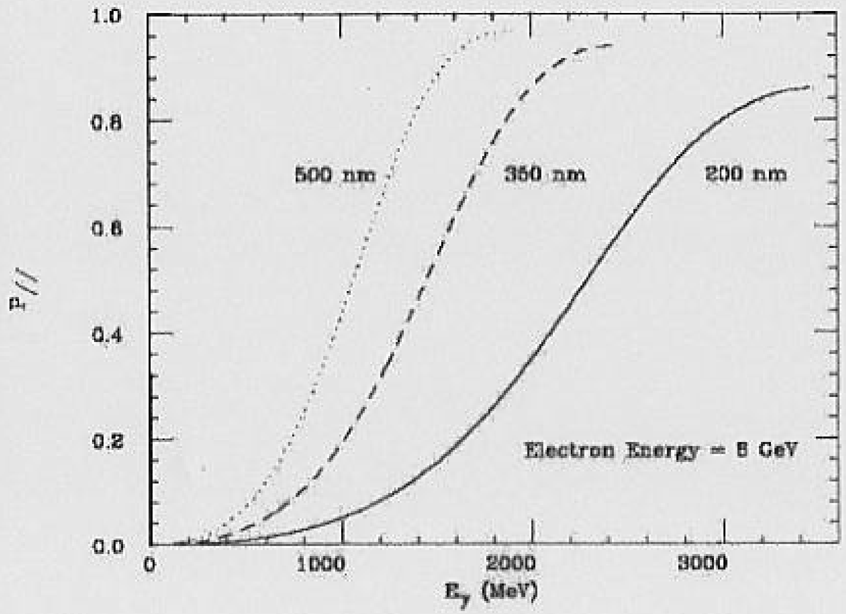
P2 : 2^{nd} pomeron ~ 0^+ glueball (Nakano, Toki (1998))

Physics programs

- **Photo-production of ϕ meson near threshold in the forward angles.**
  - **Pomeron (multi-gluon) exchange > meson exchange.**
  - **Search for additional multi-gluon (0^+ glueball) exchange.**
  - **Linearly polarized photons help to decompose natural and un-natural parity exchange contributions.**
  - **Complementary to the CLAS (Jlab) experiments.**

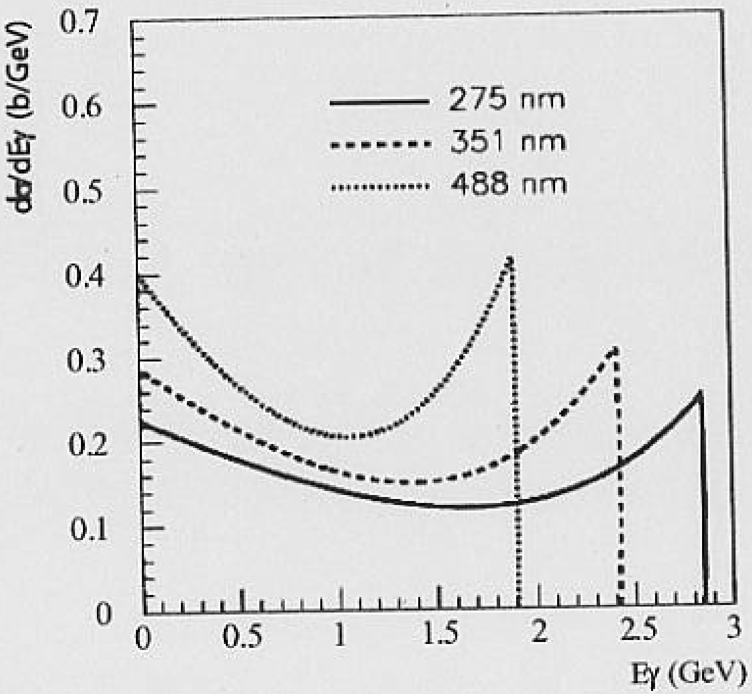
Polarization of LEP Beam

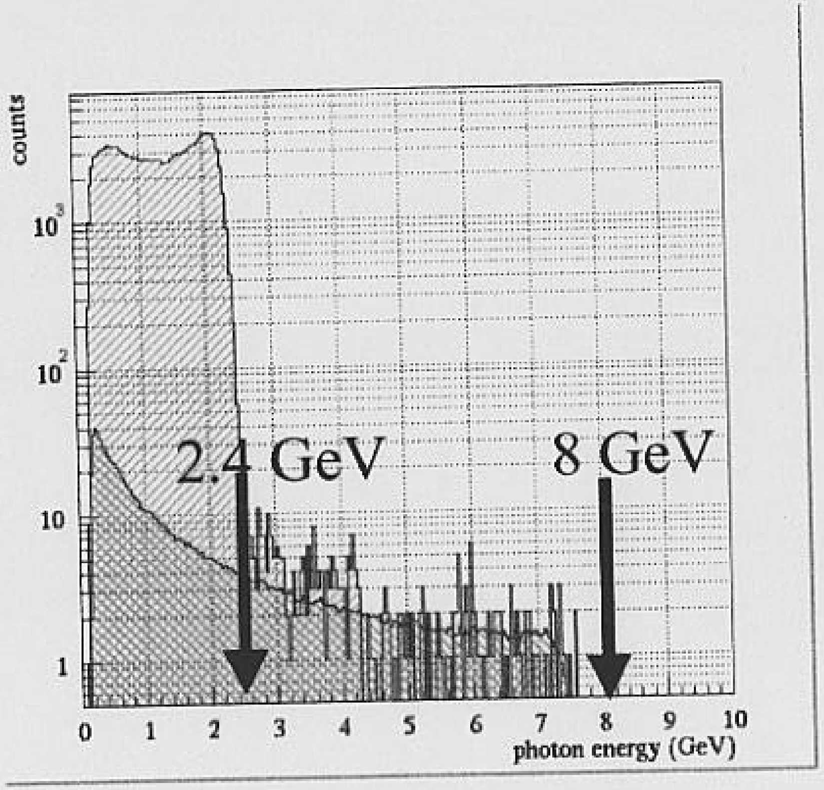




Linear Polarization : 95 % at 2.4 GeV

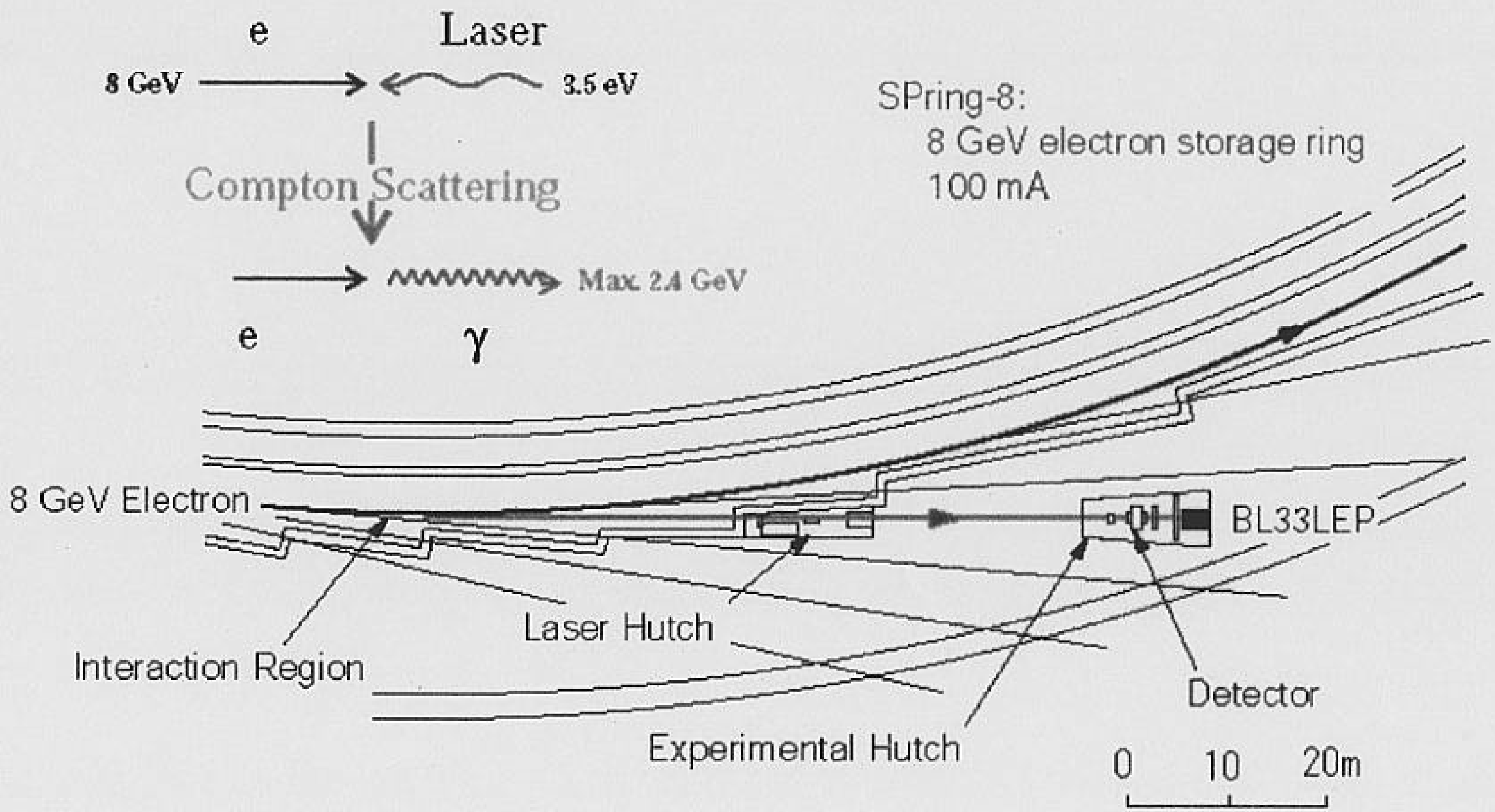
Energy Spectrum





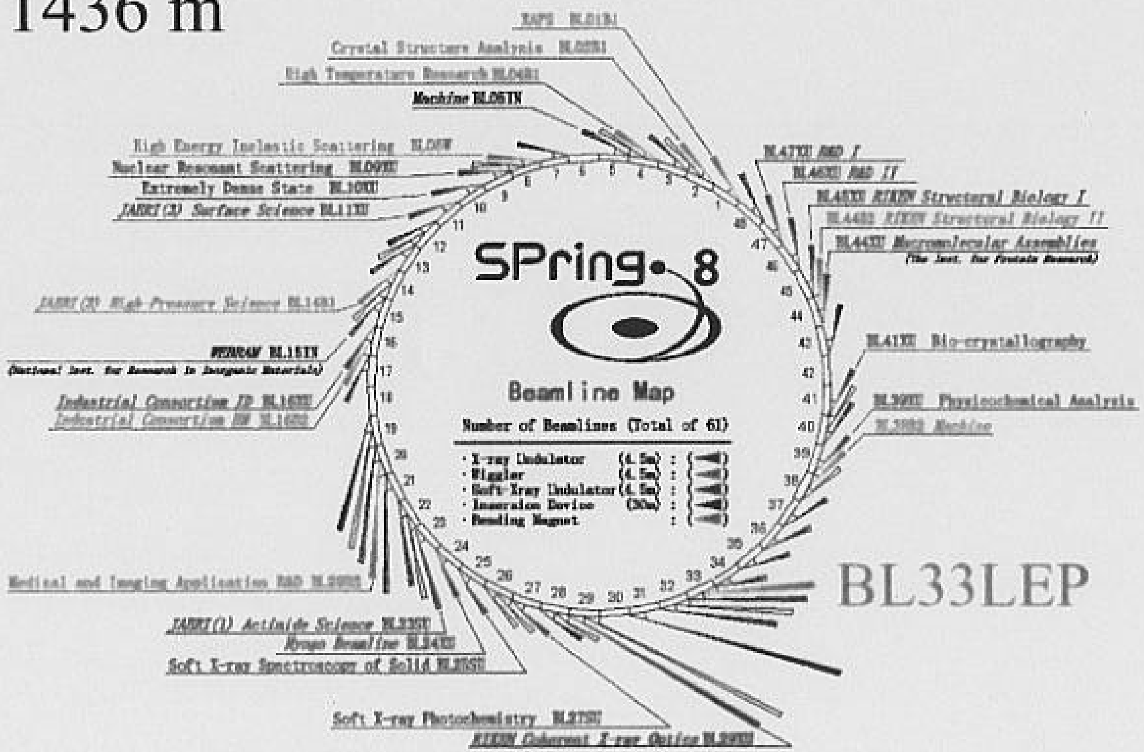
·Intensity (Typ.) : $2.5 * 10^6$ cps

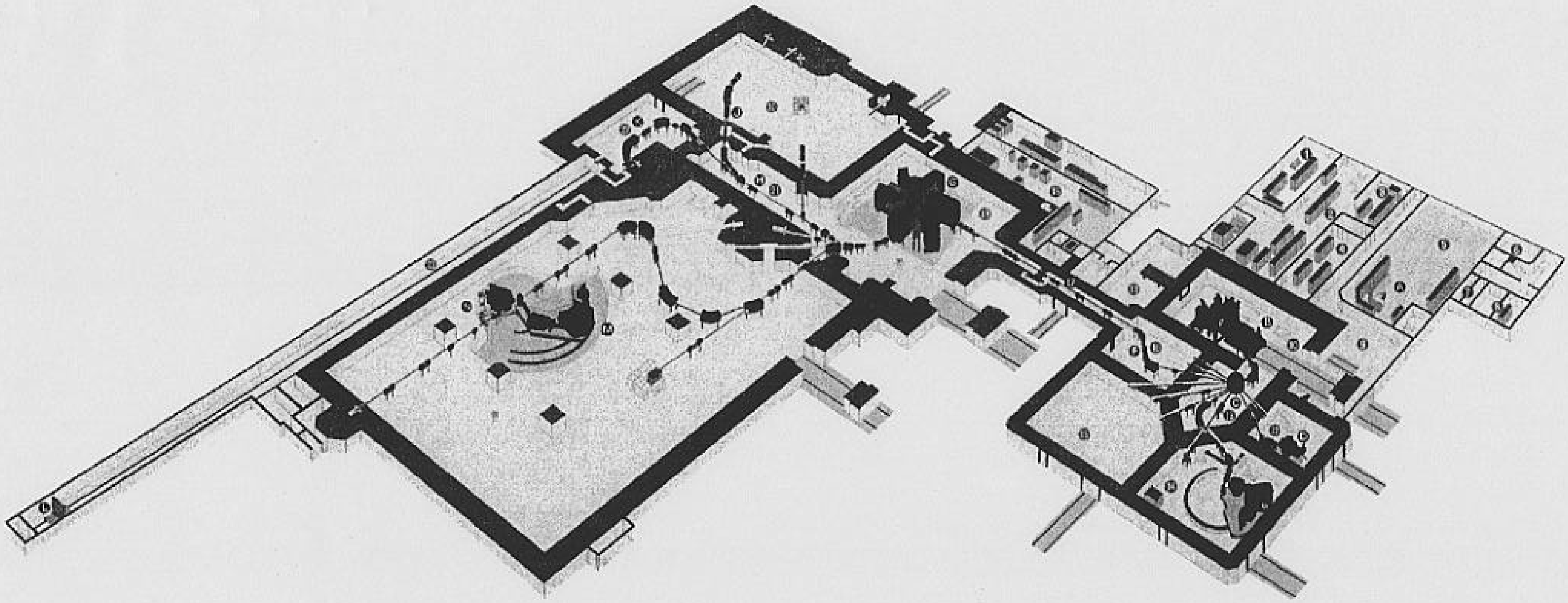
Laser electron Photon at Spring-8



SPring-8
(Super Photon ring-8 GeV)

- Third-generation synchrotron radiation facility
- Circumference: 1436 m
- 8 GeV
- 100 mA





①受電室
②電源室
③制御電源室
④制御機器室
⑤制御計数室
⑥打ち合わせ室
⑦手洗い室
⑧放射線管理室
⑨サイクロトロン調整室
⑩AVFサイクロトロン室
⑪サイクロトロン準備室
⑫Ｓ実験室
⑬ビーム分配室
⑭W実験室
⑮M実験室
⑯N実験室
⑰入射ビーム輸送室
⑱新制御計数室
⑲リングサイクロトロン室
⑳東実験室
㉑ビーム輸送室
㉒中性子実験室
㉓中性子TOFトンネル
㉔西実験室
Ⓐサイクロトロン制御卓
ⒷAVFサイクロトロン
Ⓒビーム分配電磁石
Ⓓ反跳核質量分析器CARP
Ⓕ入射ビームライン
Ⓖリングサイクロトロン
Ⓗビームライン
Ⓘバイオスペクトロメータ
Ⓙ重イオンコース
Ⓚ中性子実験装置
Ⓛ中性子検出器
Ⓜ高分解能磁気スペクトルグラフ
GRAND-RAIDEN
Ⓝ大口径スペクトルグラフ