Forschungszentrum Jülich

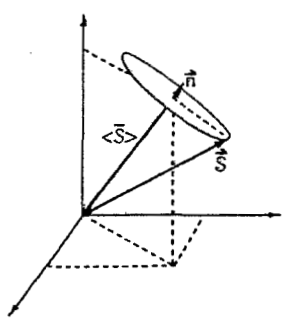
15th International Spin Physics Symposium,
September 9-14, 2002, Brookhaven National Laboratory

# Acceleration of Polarized Protons and Deuterons at COSY

- Introduction

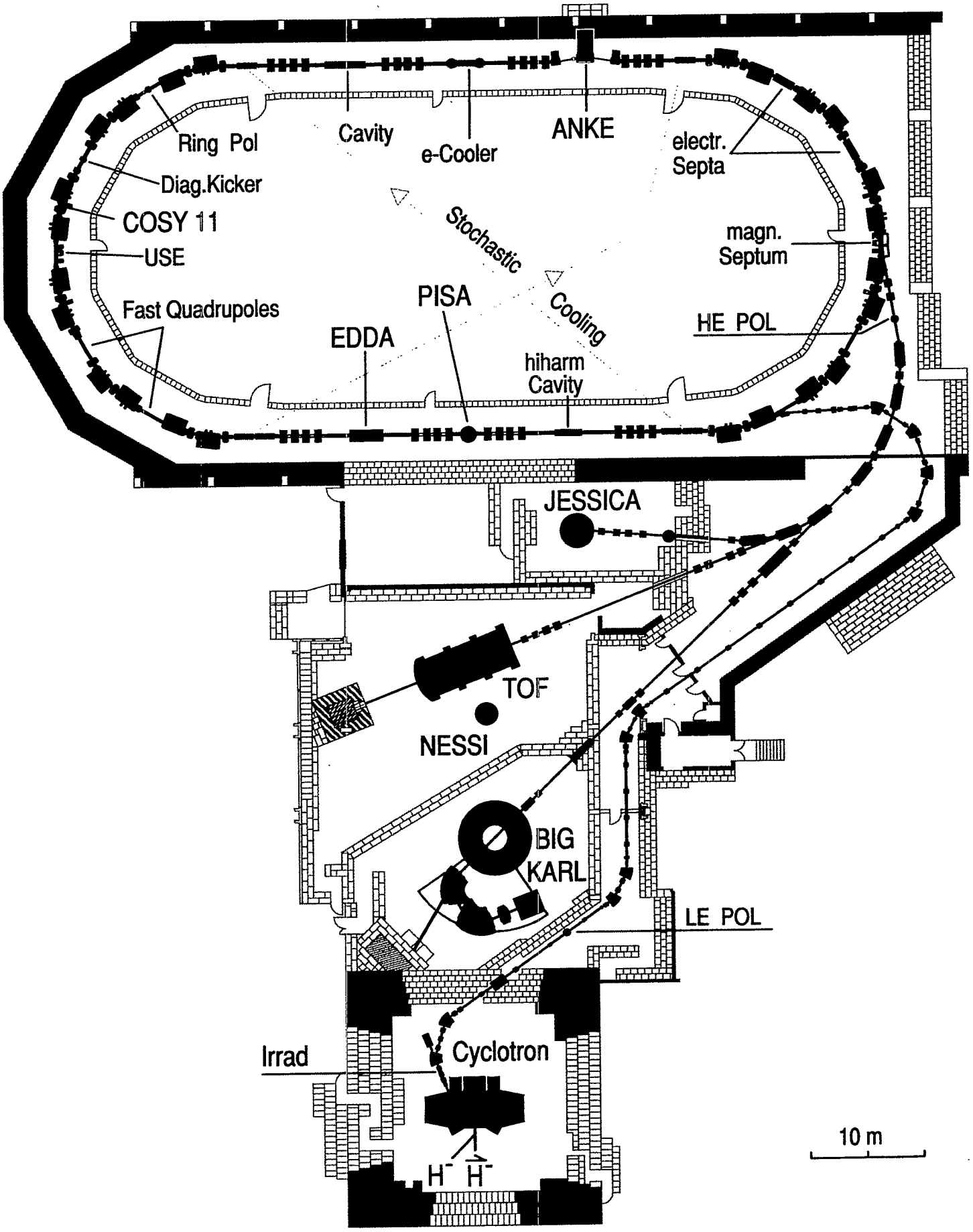
- Depolarizing resonances
- Status of the polarized proton and deuteron beam

- Future plans

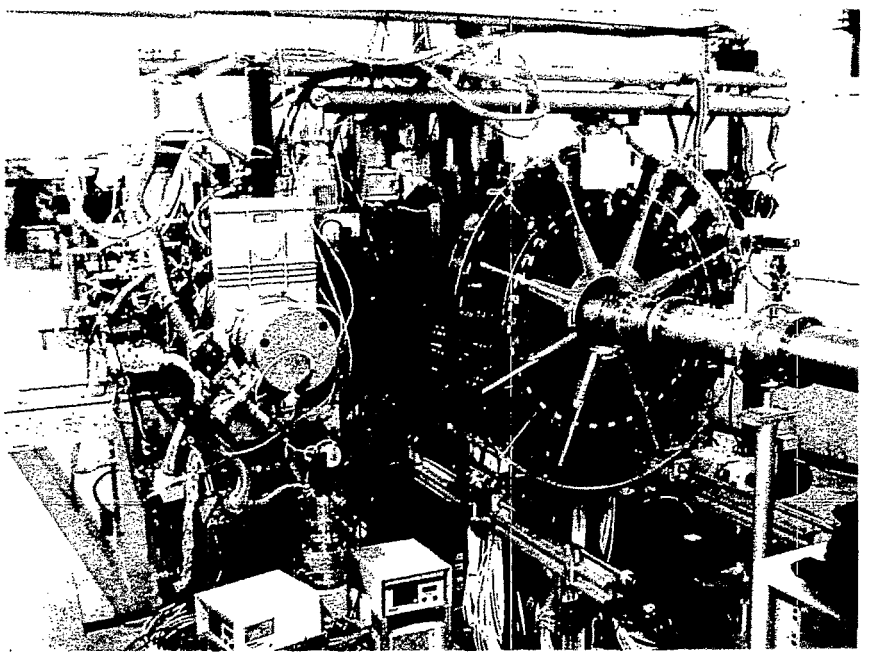



Andreas Lehrach, Fz-J

# COoler - SYnchrotron COSY

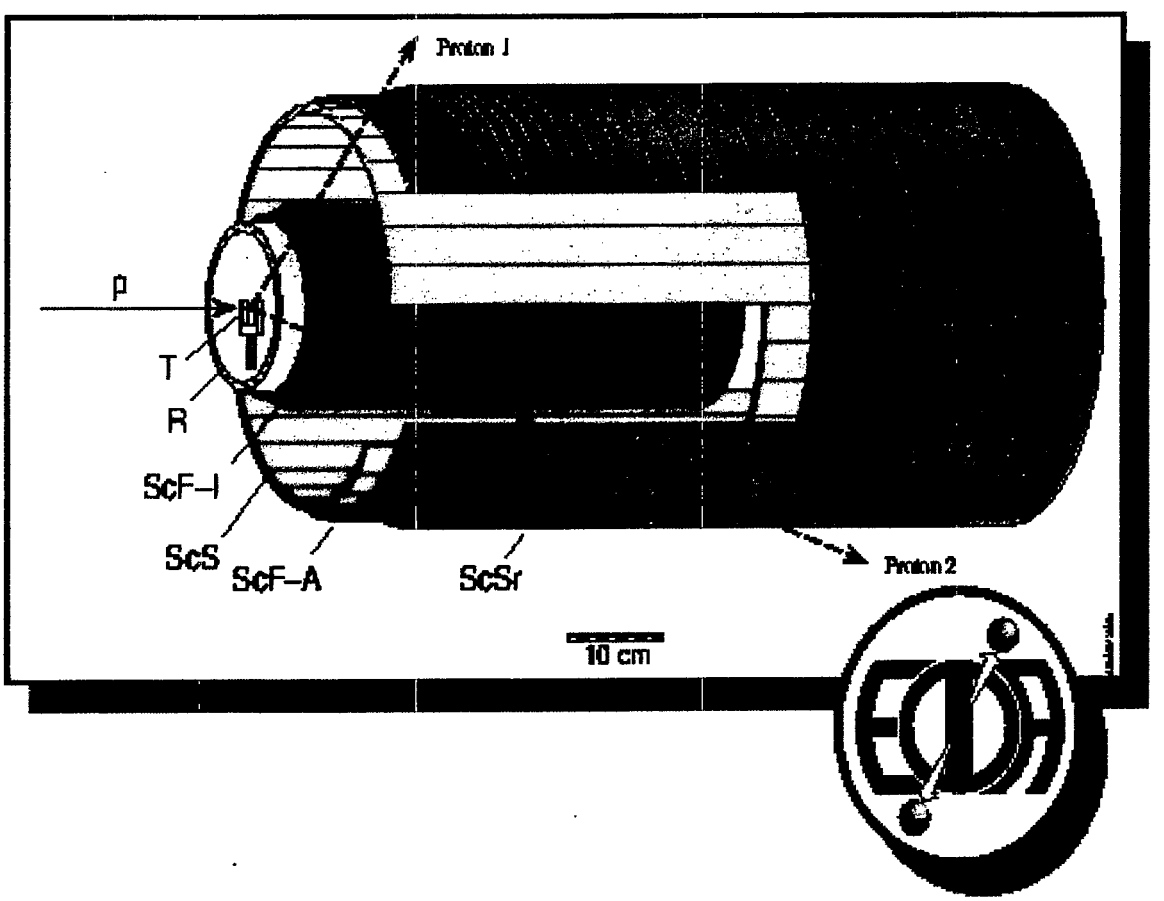


# The EDDA Experiment



**Fast polarization measurements during the acceleration cycle**

**Cut–Away View of the EDDA Detector**



# Spin motion / Depolarization

## – Thomas–BMT equation :

$$\frac{d\vec{S}}{dt} = \frac{e}{\gamma m}\vec{S} \times [(1+\gamma G)\vec{B}_{\perp} + (1+G)\vec{B}_{\parallel}]$$

Vertical bending field :

–> vertical polarization is preserved

–> number of spin rotations per turn: $\gamma G$

## – Depolarizing resonances :

**1.) imperfection:** $\gamma G = k$ **k : integer**

– correcting dipoles
– partial snake

**2.) intrinsic :** $\gamma G = kP \pm \nu_y$ **P : super periodicity**
**$\nu_y$ : working point**

– tune jump
– ac dipole

## – Siberian snakes :

**< 5 GeV :** Solenoids
**> 10 GeV :** Dipoles

# Siberian Snake

**Vertical axis (bending field):** $2\pi\gamma G$
**Horizontal axis (snake):** $\delta = 180°$

- Magnetic fields

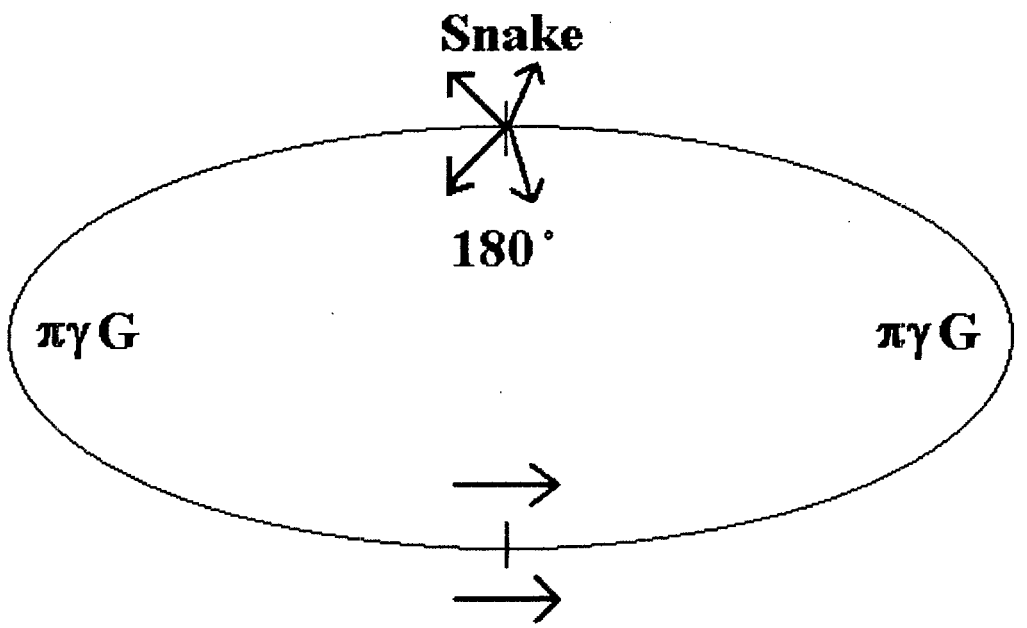
**1.) Dipole:**
**( > 10 GeV )**

$$\delta = \frac{1+\gamma G}{B\rho}\int B_{\perp}\,dl$$

**2.) Solenoid:**
**( < 5 GeV )**

$$\delta = \frac{1+G}{B\rho}\int B_{//}\,dl$$

- Spin motion:

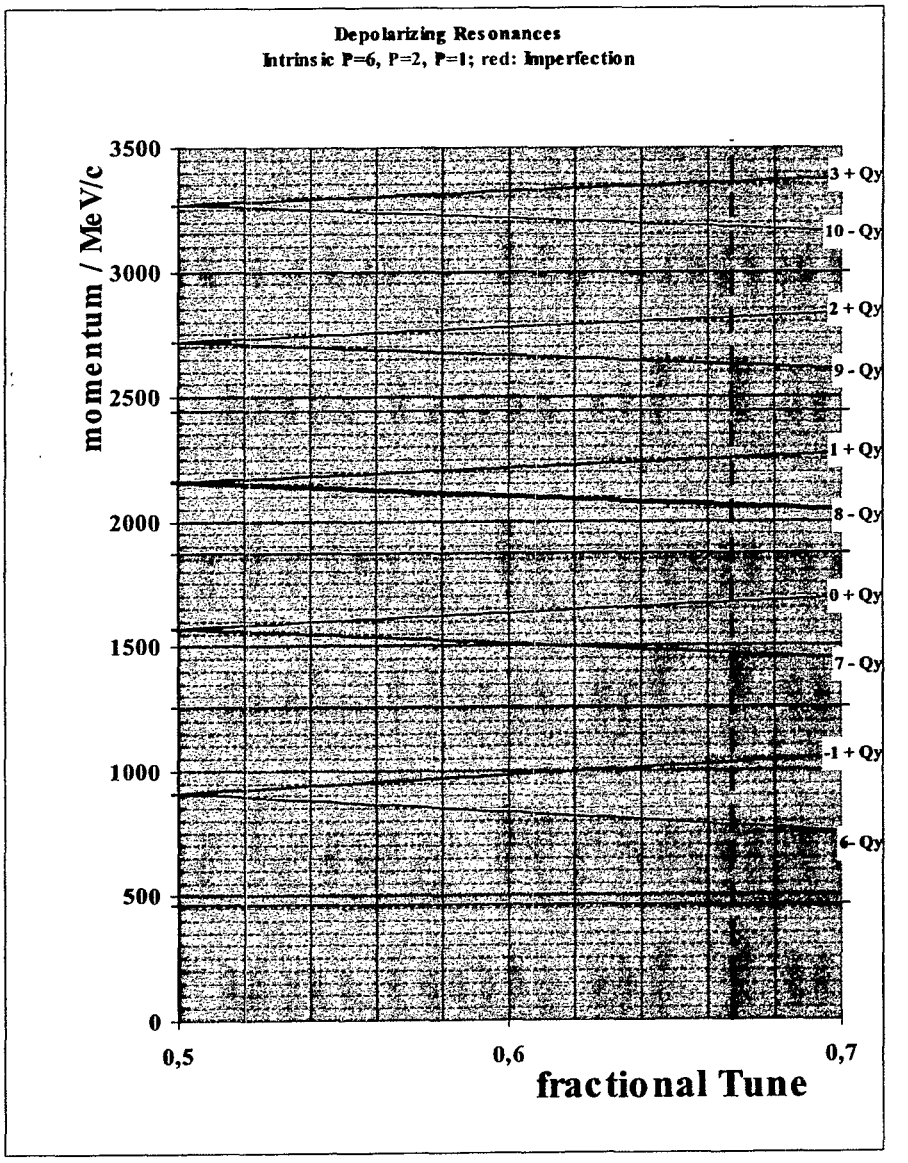


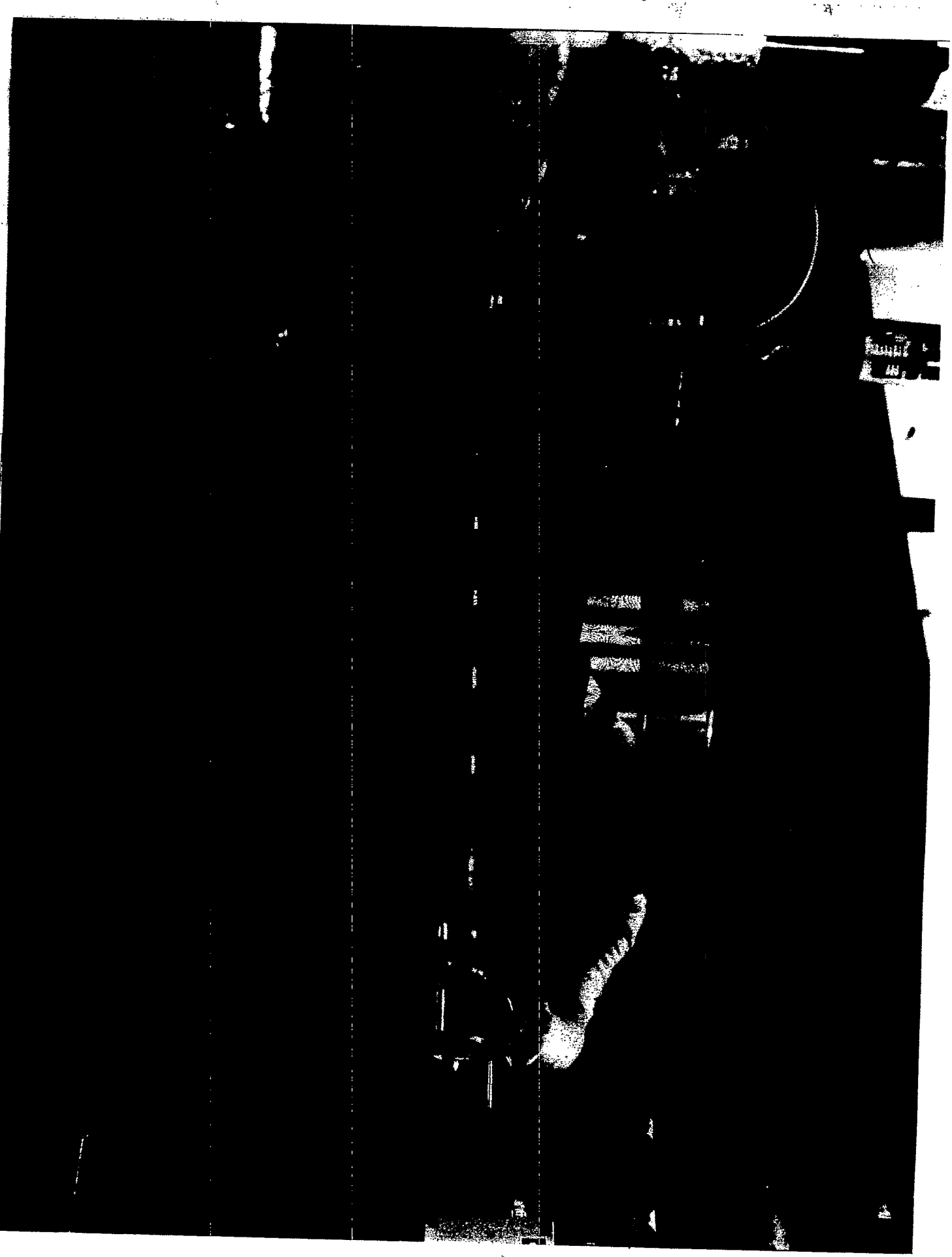

1.) Spin tune half integer
2.) Invariant spin axis horizontal

# Depolarizing resonances at COSY

| P | $\gamma G$ | T [MeV] | P [MeV/c] | $\epsilon_R$ [$10^{-3}$] |
|---|---|---|---|---|
| | 2 | 108.4 | 463.7 | 1.14 |
| 2,1 | $6-\nu_y$ | 312.4 | 826.9 | 0.61 |
| 1 | $-1+\nu_y$ | 427.5 | 992.4 | 0.24 |
| | 3 | 631.8 | 1258.9 | 0.86 |
| 1 | $7-\nu_y$ | 835.6 | 1505.3 | 0.19 |
| 2,1 | $0+\nu_y$ | 950.7 | 1639.3 | 0.30 |
| | 4 | 1155.1 | 1871.3 | 1.76 |
| 6,2,1 | $8-\nu_y$ | 1358.8 | 2096.5 | 1.62 |
| 1 | $1+\nu_y$ | 1473.9 | 2222.0 | 0.21 |
| | 5 | 1678.5 | 2442.8 | 1.06 |
| 1 | $9-\nu_y$ | 1882.0 | 2659.4 | 0.28 |
| 2,1 | $2+\nu_y$ | 1997.1 | 2781.2 | 0.32 |
| | 6 | 2201.8 | 2996.6 | 0.92 |
| 1,2 | $10-\nu_y$ | 2405.2 | 3208.9 | 0.35 |
| 1 | $3+\nu_y$ | 2520.3 | 3328.6 | 0.10 |

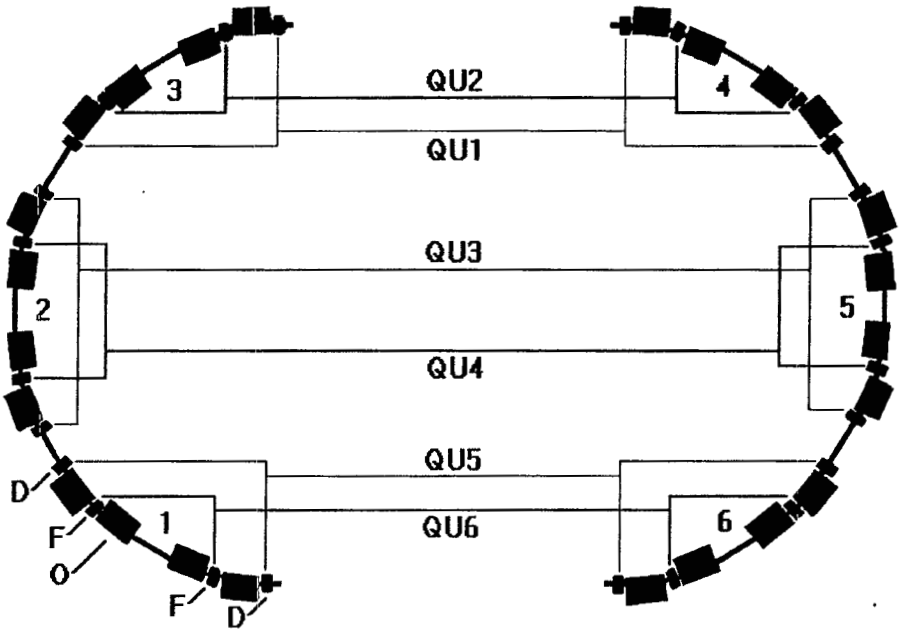
# Depolarizing Resonances as a Function of Tune



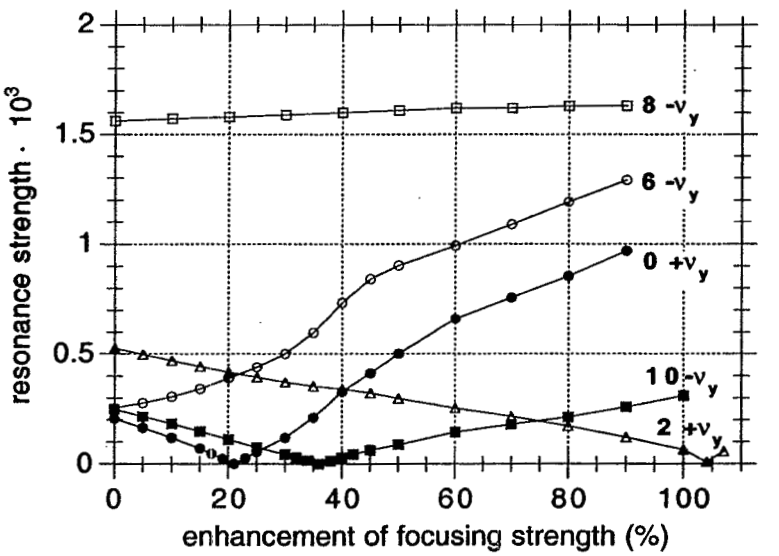


# Matching Intrinsic Spin Harmonics

## Lattice

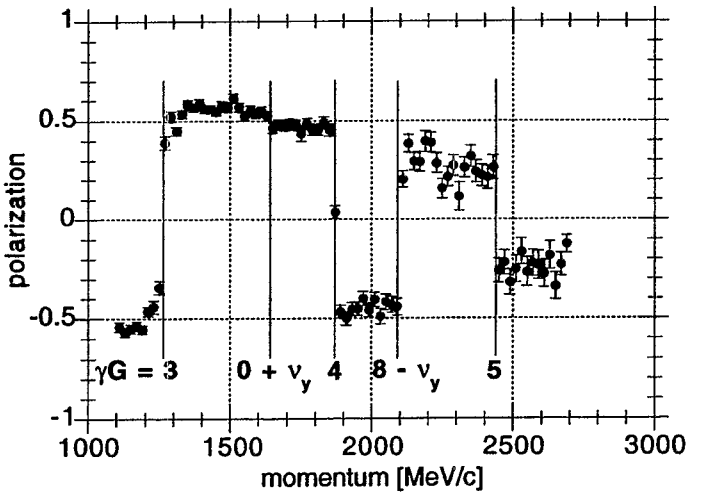



## Simulations



# Matching Intrinsic Spin Harmonics

## Results for $\gamma G = 0 + \nu_y$




## $P_f / P_i$ : 0.13 → 0.88

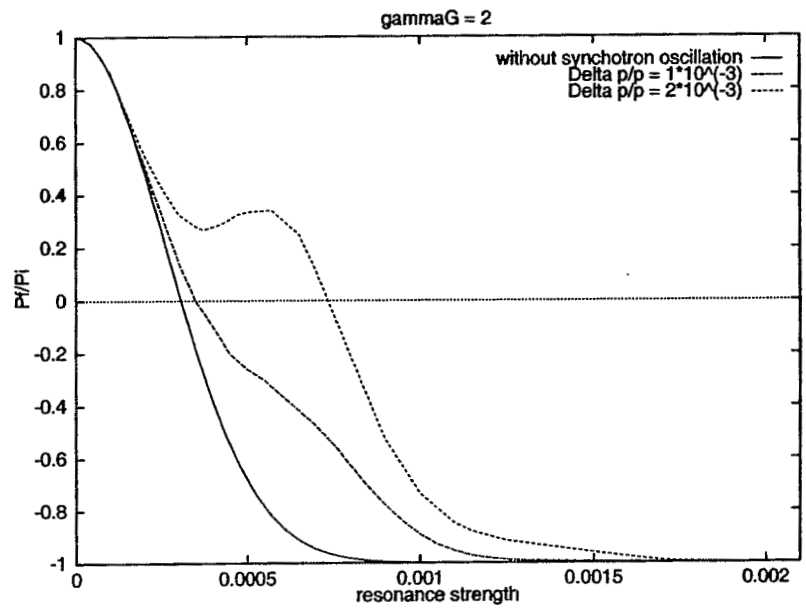
A. Lehrach et al., Matching Intrinsic Spin Harmonics at COSY, NIMA 439, 26-30(2000)

# Effect of Synchrotron Motion

$\gamma G = 2$

$\Delta p/p = 1\text{-}2*10^{-3}$

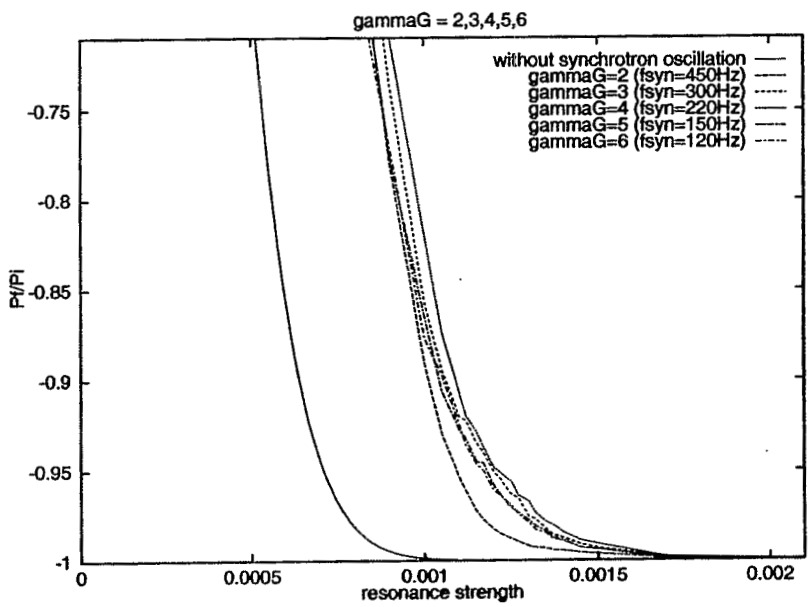
$f_{syn} = 450Hz$




$\gamma G = 2,3,4,5,6$

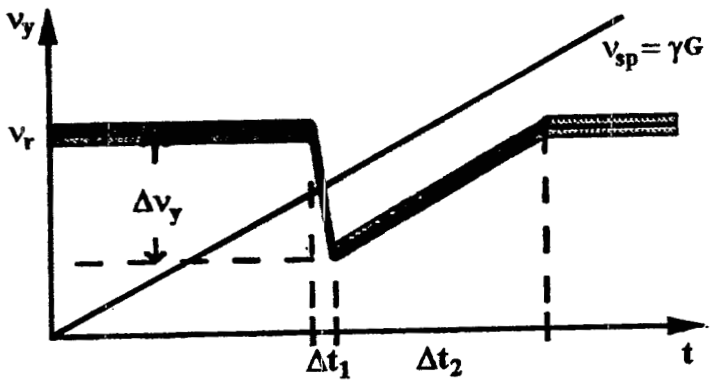
$\Delta p/p = 1*10^{-3}$

$f_{syn} = 450\text{-}120Hz$

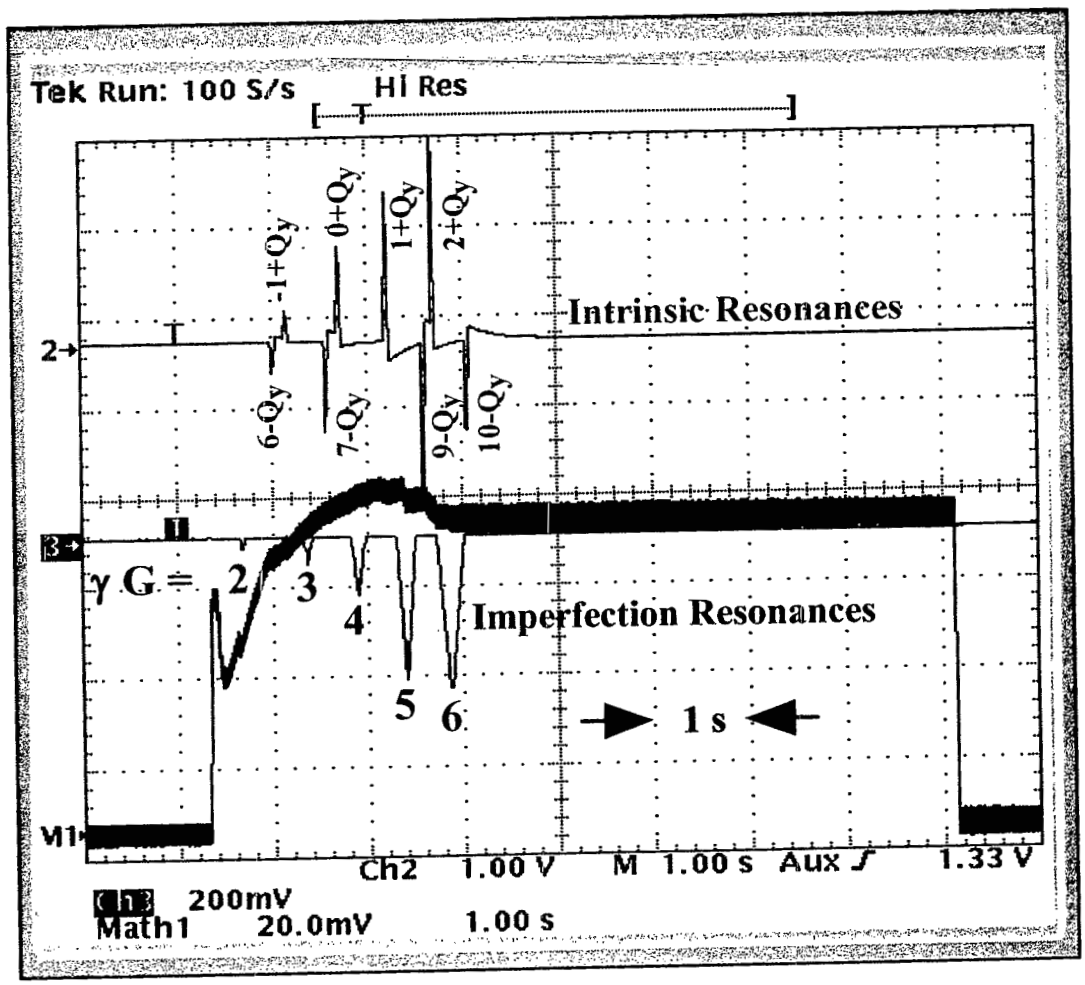


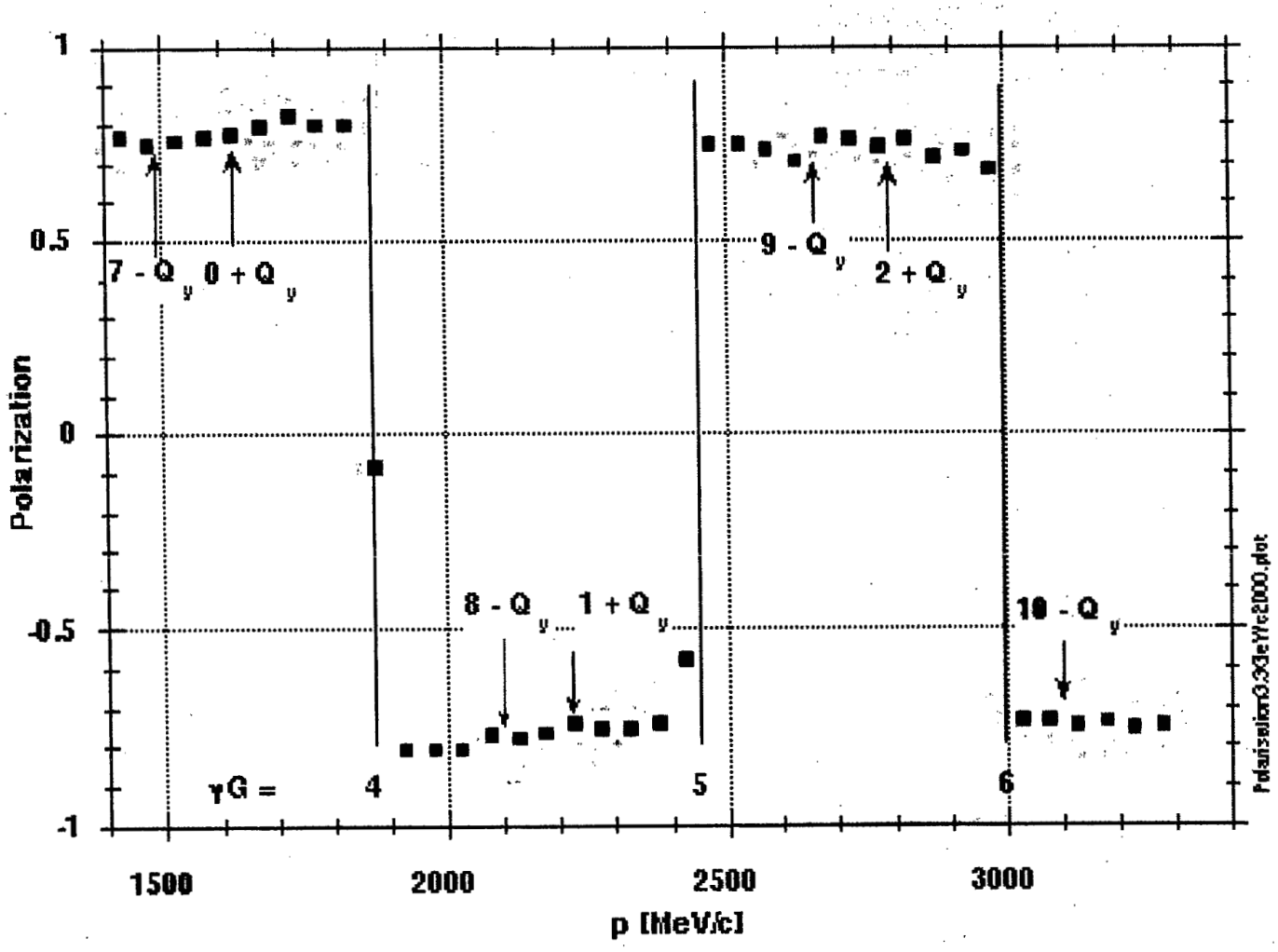

**Enhancement of resonance strength for adiabatic spin flip !**

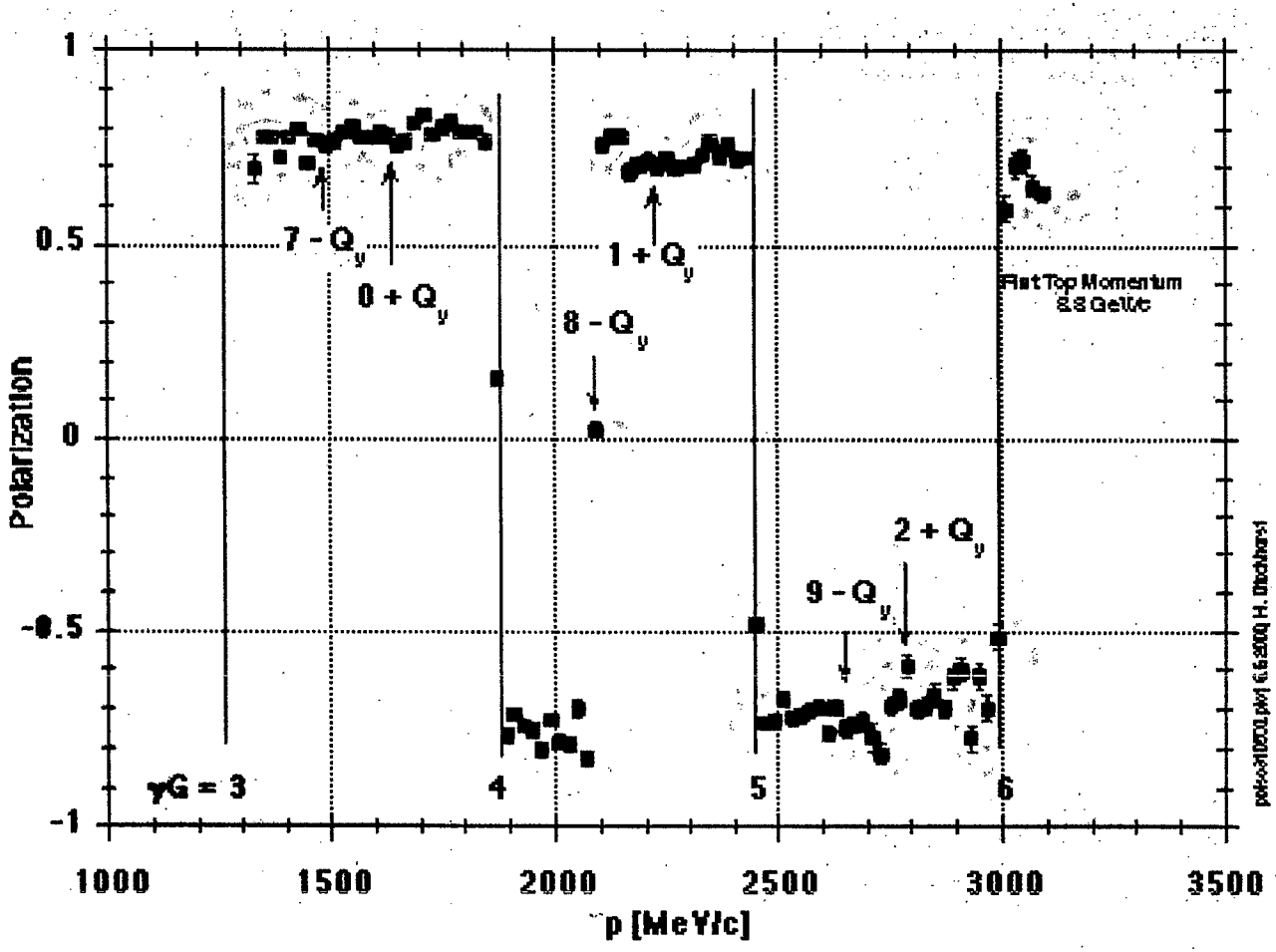
# Resonance crossing



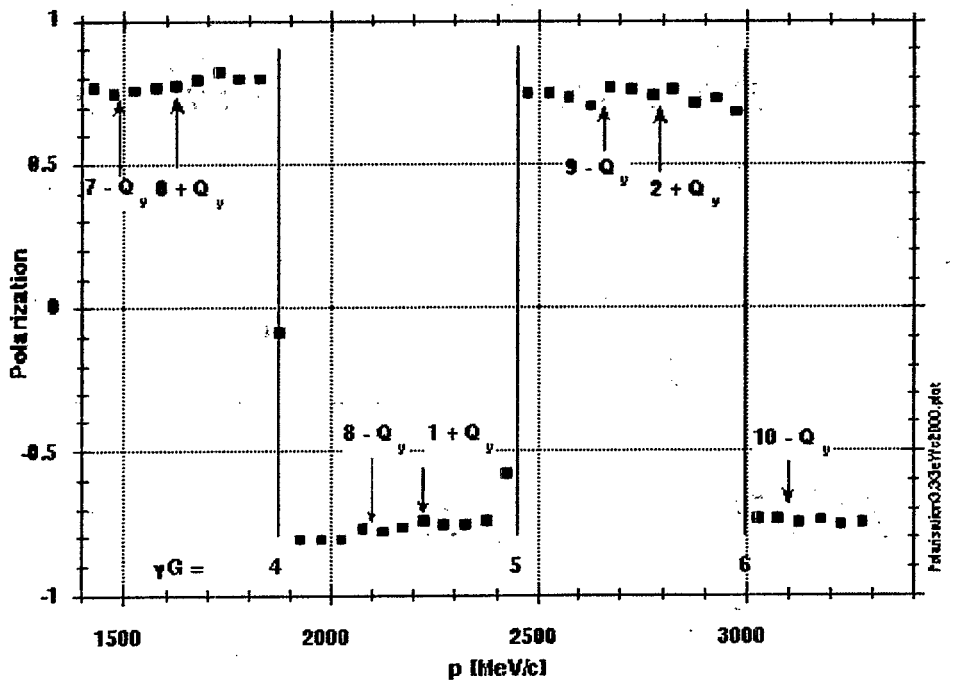

Fast tune jump



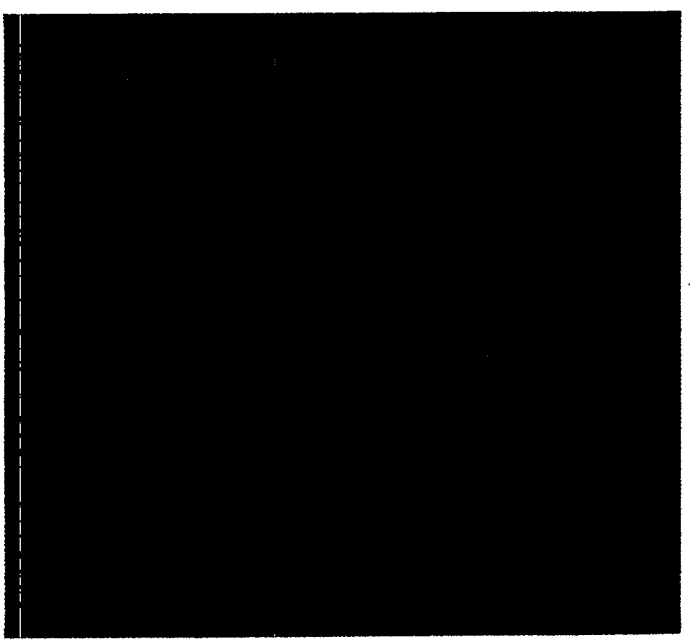

1
0.5
0
-0.5
-1
Polarization
7 - Q y
0 + Q y
8 - Q y
1 + Q y
9 - Q y
2 + Q y
10 - Q y
γG =
4
5
6
1500
2000
2500
3000
p [MeV/c]
Polarisation3.30GeVc2000.plot


Polarization
1
0.5
0
-0.5
-1
1000
1500
2000
2500
3000
3500
p [MeV/c]
γG = 3
4
5
6
7 - Q_y
0 + Q_y
8 - Q_y
1 + Q_y
9 - Q_y
2 + Q_y
Flat Top Momentum
8.8 GeV/c

# Status of the polarized proton beam

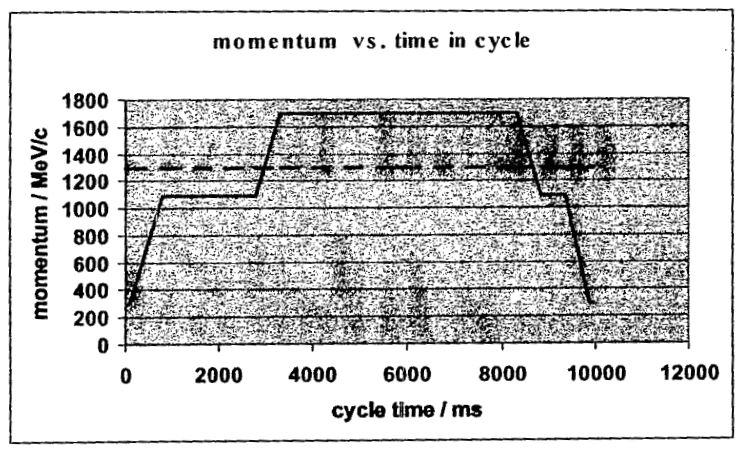



- $1*10^{10}$ Protons at 3.3 GeV/c
- Degree of Polarisation
- > 75% at 3.3 GeV/c



# Beam Gymnastics (for the polarized beam time at ANKE)

- Required momentum:
  1.0 und 1.7 GeV/c




- EDDA was needed to measure the absolut polarization

- Mimimimum momentum for pol. Measurements at EDDA:
- 1.3 GeV/c

Solution: two identical cycles with a ***global momentum jump*** with different flat top times

# Polarized Deuterons

| | |
|---|---|
| **Polarization states:** | **(2S+1) → 3 states for Spin 1** |
| **Vector polarization:** | $P_z = (n_+ - n_-) / (n_+ + n_- + n_0)$ |
| | $P_z^{max} = \pm 1$ |
| **Tensor polarization:** | $P_{zz} = (1 - 3n_0) / (n_+ + n_- + n_0)$ |
| | $P_{zz}^{max} = 1, -2$ |
| **Gyro magnetic anomaly:** | $G_p / G_d = -12.6$ |
| **Spin tune:** | $\gamma_p G_p / \gamma_d G_d = -25.2$ |
| **Depolarizing resonances:** | 13 (low energies) to 25 (high energies) times weaker |
| | 25 times further apart |
| **Isolated resonance crossing:** | different for vector and tensor polarization |


Theoretically:

H. Huang, S.Y. Lee, L. Ratner, The Evolution of Tensor Polarization

H. Huang, S.Y. Lee, L. Ratner, Transfer matrices of spin tensor polarization with and without snake, Proc. of Part. Acc. Conf. p.432, (1993)

Experimentally:

V. S. Morozov , Spin Flipping and Polarization Lifetimes of a 270 MeV Deuteron Beam, Talk at this conference

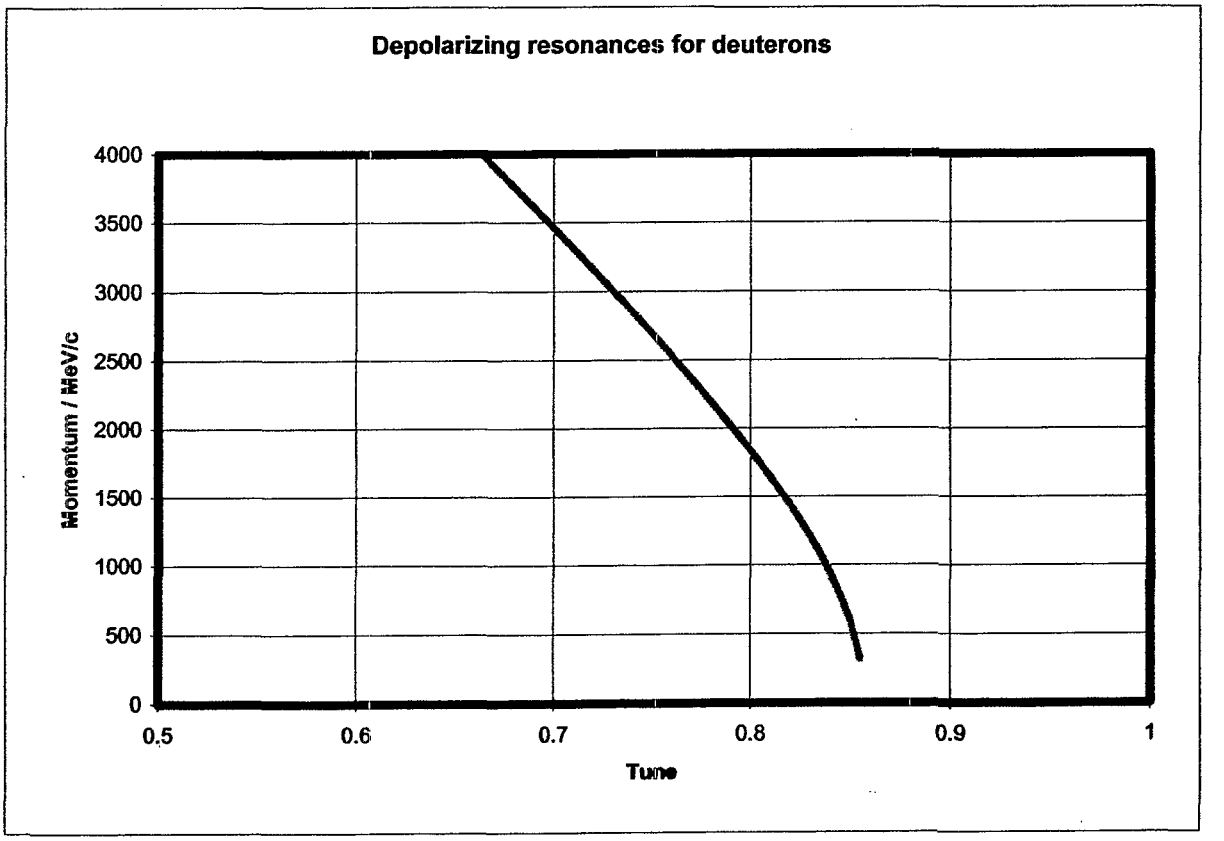
# Status of the polarized deuterons beam

**Source has delivered** vector **and** tensor polarized beams

**Acceleration to maximum energy:** $2*10^{11}$ **particles**

**Next beam time:** February 2003

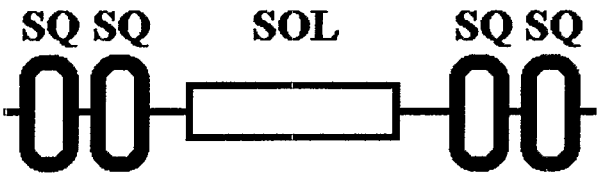
## Depolarizing resonances at COSY



# Siberian Snake

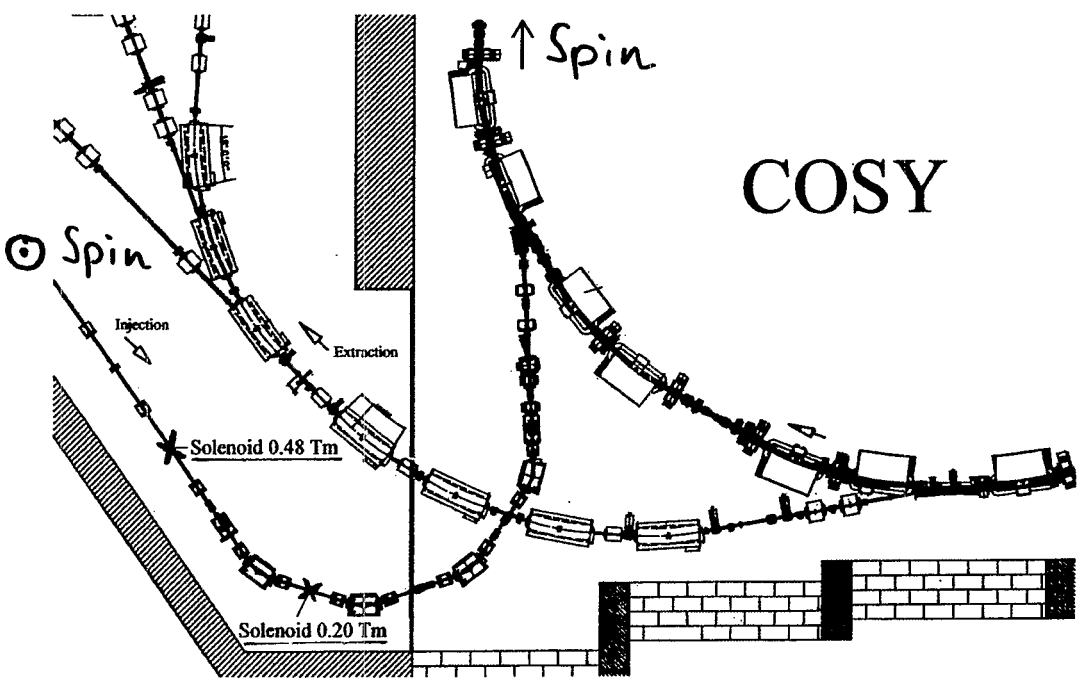
**Solenoid magnet:** $\int B_{sol}\, dl_{sol} = 12.8$ Tm

## - Without coupling




| | | | | | | |
|---|---|---|---|---|---|---|
| **length (cm)** | **45** | **45** | **260** | | **45** | **45** |
| | **25** | **35** | | | **35** | **25** |
| **field (T/m)** | **34.2** | **-32.2** | | | **-32.2** | **34.2** |
| **field (T)** | | | **4.9** | | | |
| **angle (°)** | **21.5** | **15.2** | | | **21.5** | **15.2** |

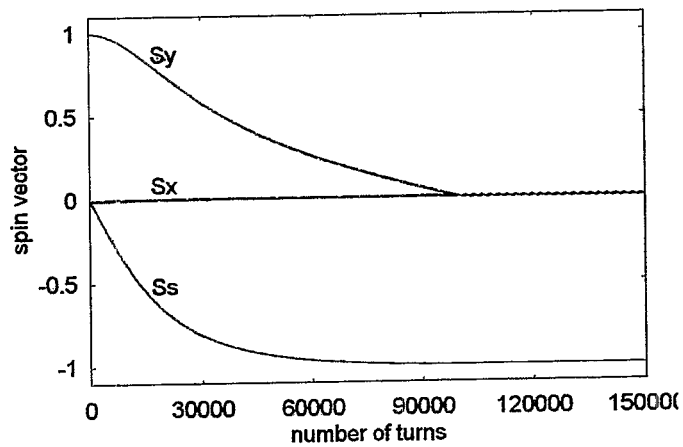
## - Spin preparation at injection




**Solenoid magnets:** $\int B_{sol}\, dl_{sol} = 0.48$ Tm, 0.20 Tm

# Siberian Snake

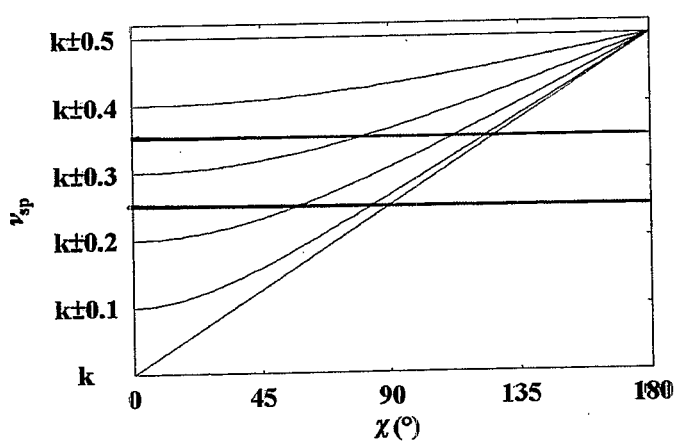
## - Spin preparation at injection




## - Depolarizing resonances

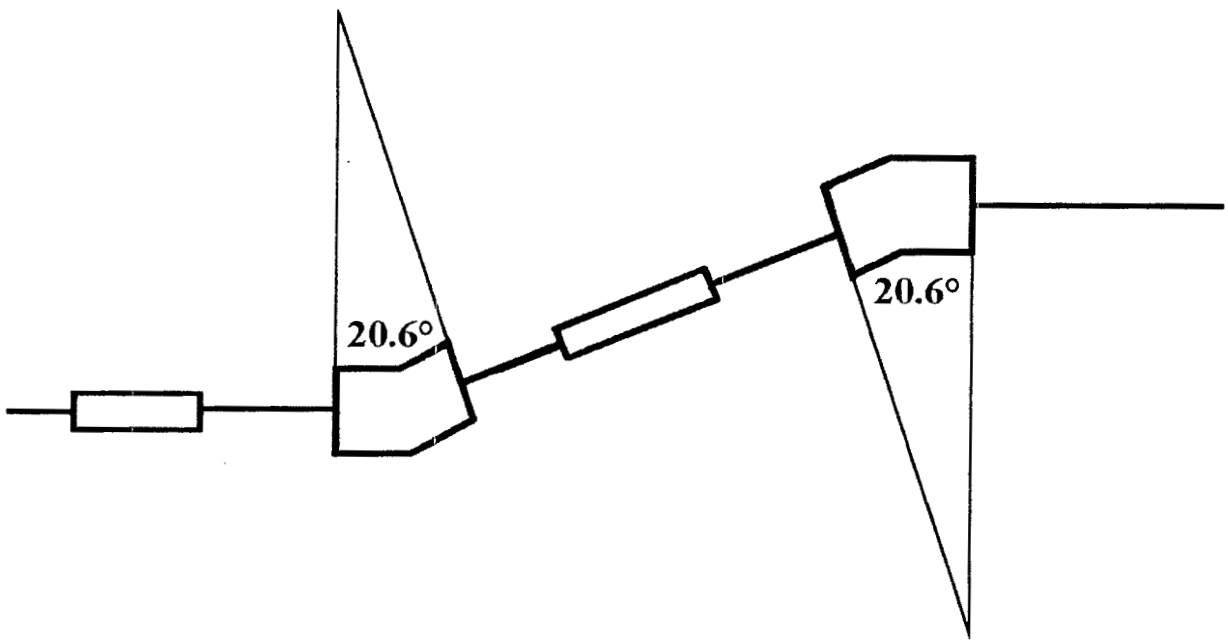
$E_{kin}$ = 370 MeV + k 523 MeV

**Spin tune at injection:** $\gamma G_{inj} = 1.88$



# Spin Rotator (external)

Solenoid Dipole Solenoid Dipole




- spin (cms): $\theta_1, \theta_2, \theta_3, \theta_4$

**- conditions for $\theta_2 = -\theta_4$:**

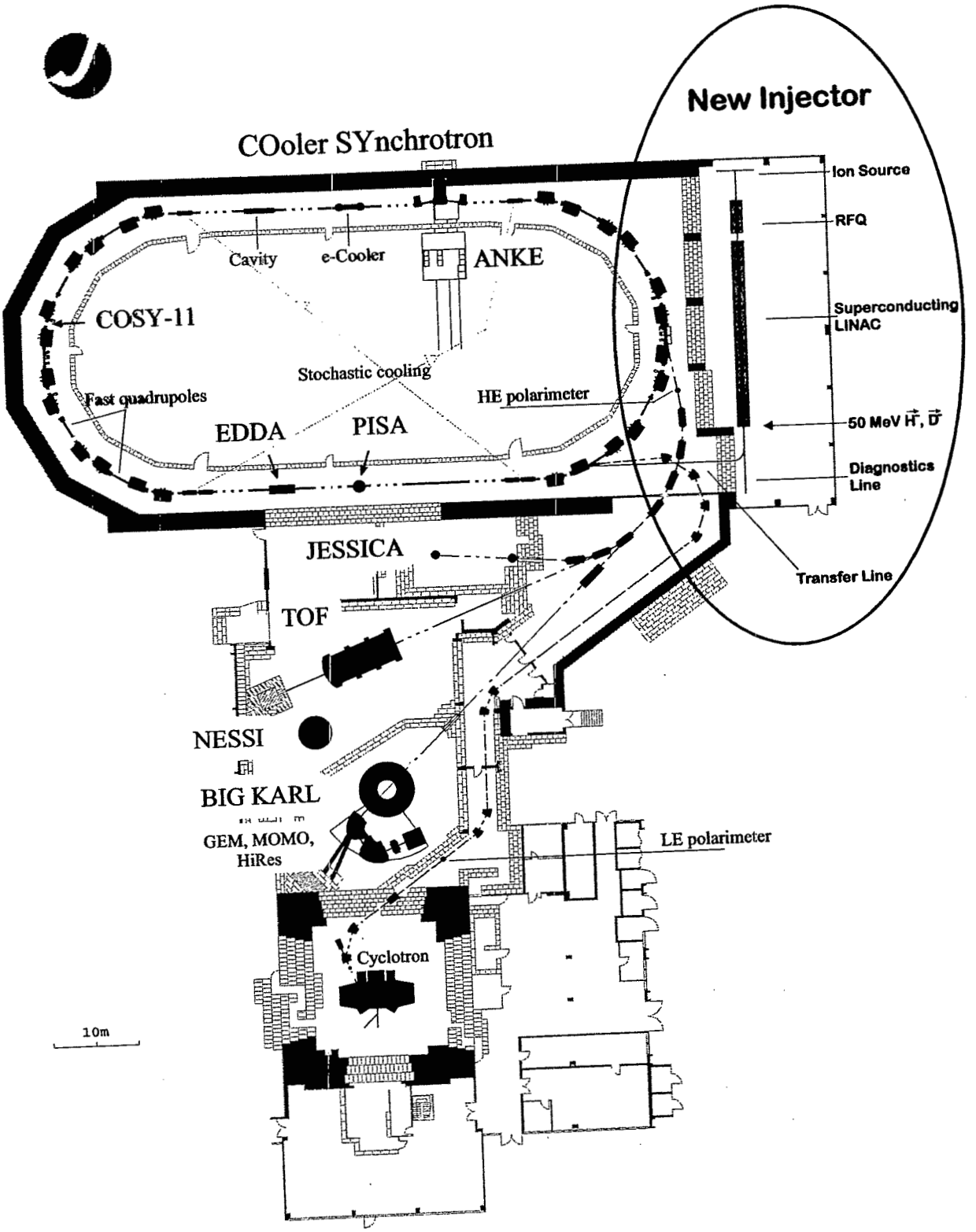
**(1) $\cos\theta_3 = -(\cot\theta_2)^2$**

**(2) $\tan\theta_1 = \cot\theta_3 / \cos\theta_2$**

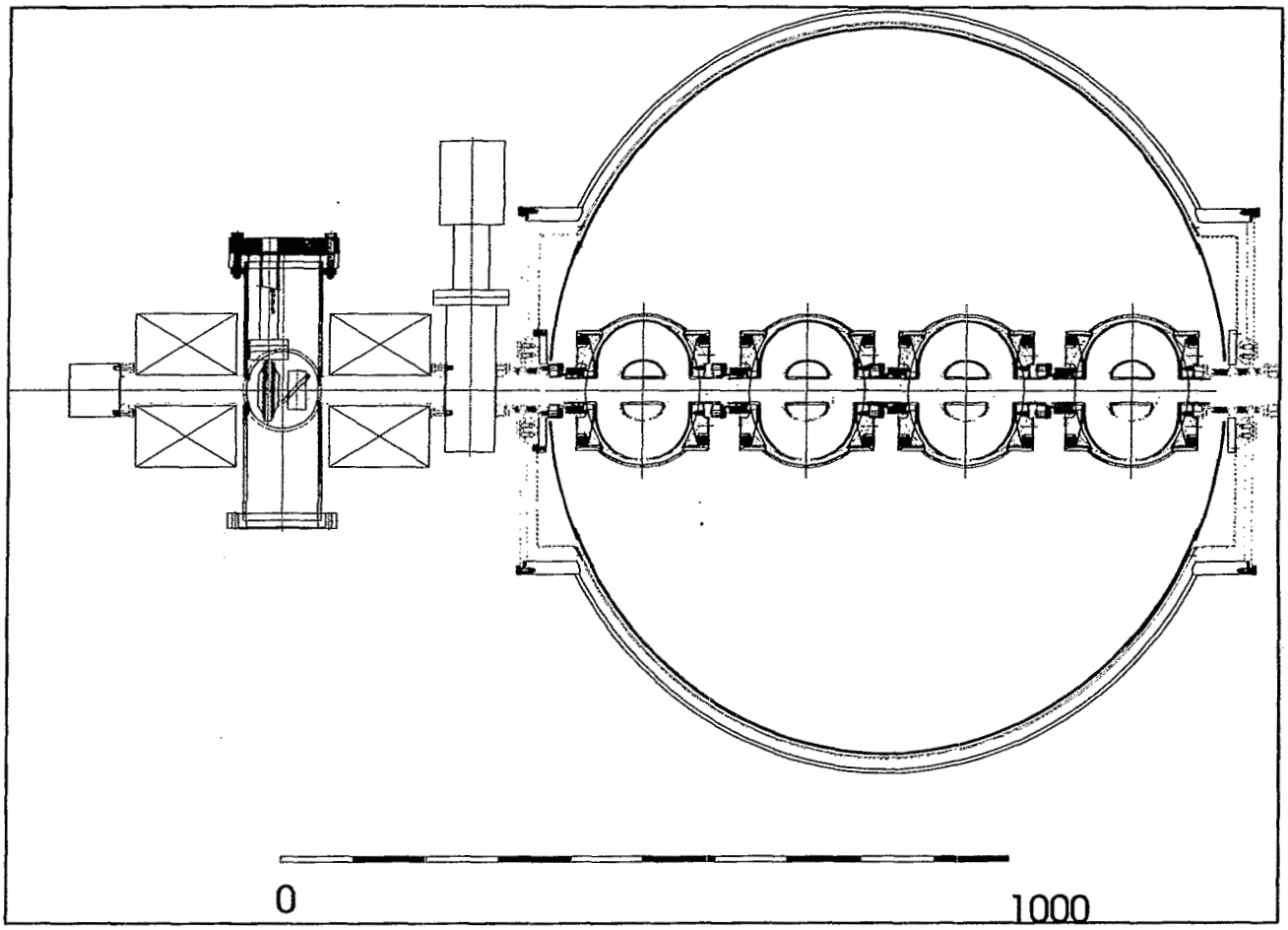
$$\gamma_{max} / \gamma_{min} = 3$$

**dipole bending angle $\theta_2, \theta_4 = 20.6°$:**

| P (GeV/c) | $\theta_1$ (°) | $\theta_2$ (°) | $\theta_3$ (°) | $\theta_4$ (°) |
|---|---|---|---|---|
| 0.65 | -90 | 45 | 180 | -45 |
| 2.1 | 0 | 90 | 90 | -90 |
| 3.3 | 90 | 135 | 180 | -135 |


New Injector
COoler SYnchrotron
Ion Source
RFQ
Superconducting LINAC
50 MeV H⃗, D⃗
Diagnostics Line
Transfer Line
Cavity
e-Cooler
ANKE
COSY-11
Stochastic cooling
Fast quadrupoles
HE polarimeter
EDDA
PISA
JESSICA
TOF
NESSI
BIG KARL
GEM, MOMO, HiRes
LE polarimeter
Cyclotron
10m

# Linac unit cell




## Quadrupole magnets:

**Aperture 38 mm, length 125 mm → $g_{max} \leq 45$ T/m**
**Drift between quads 130 mm**

# Conclusion

- **Polarized proton beam**

  Routinely operation

  High polarization, low intensity

  → New sc Injector Linac

- **Polarized deuteron beam**

  Vector and Tensor polarisation

  Beam time next February

# Future plans

- **Siberian Snake, Spin Flipper**

  Not Funded yet

- **New Injector Linac**

  Funded, first beam planned in 2005