Polarised Gas Targets and Polarised Ion Sources for Accelerators

Geoff Court – Physics Dept., Liverpool University

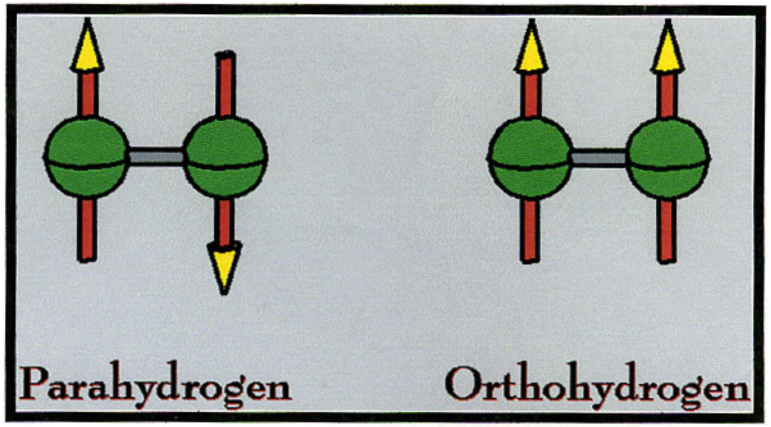
Mainly principles – time limitation

Protons only – ideas apply for other nuclei (D, ^{3}He …..)

Start point – gaseous hydrogen molecules (H_2)

I = 0

singlet state



I = 1

triplet state

End point for polarised beam sources

a) positive atomic ion beam with single spin state

b) negative atomic ion beam with single spin state

End point for gaseous polarised target

c) neutral atomic beam (gas flow) with single spin state

d) neutral molecular ortho beam (gas) - single spin state

Applied magnetic field B - quantisation axis

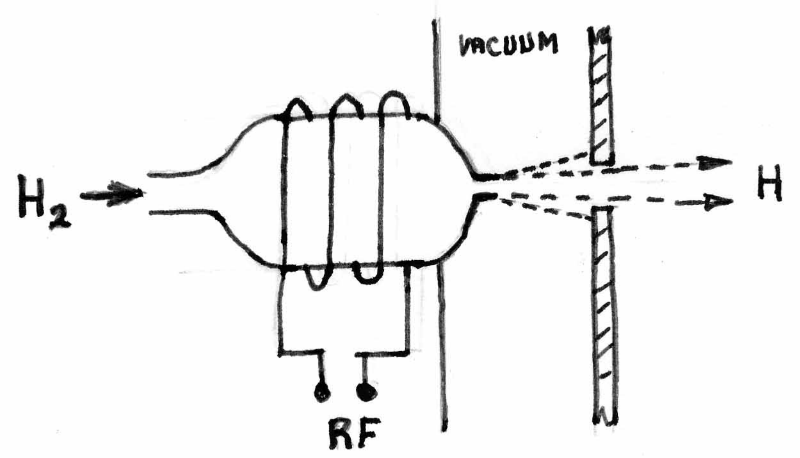
Polarisation $P = (N_{\uparrow} - N_{\downarrow}) / (N_{\uparrow} + N_{\downarrow})$ with limits ± 1

+ 1 is parallel and –1 is anti-parallel to B

Normal first stage for a), b) and c) is dissociation in a RF discharge

$H_2 + e^- \rightarrow H + H + e^-$ and other reactions.

Second stage is to form an atomic beam (AB) (or use gas flow)



Atoms effuse thru channel, beam formed if MFP >> diam.

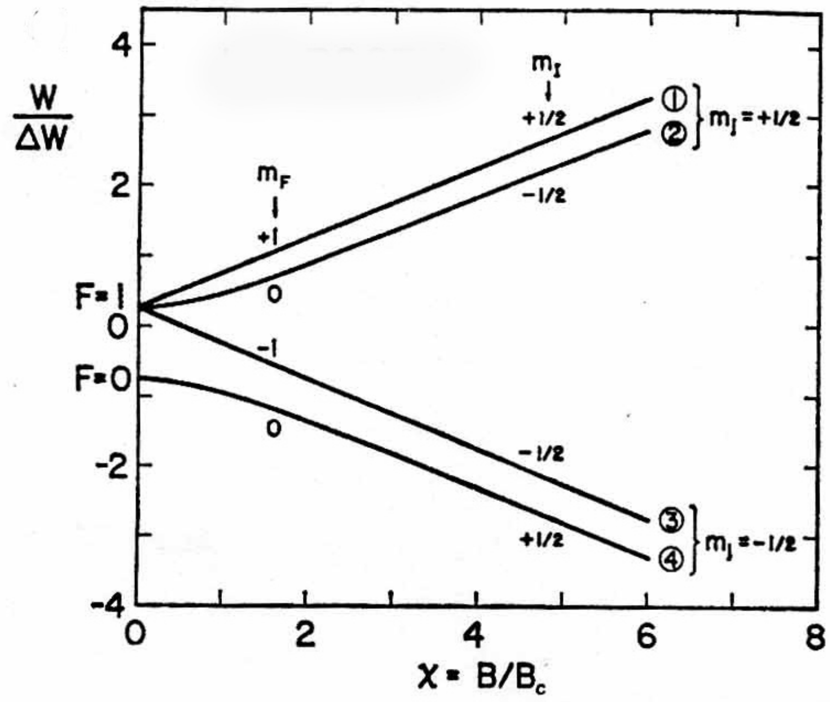
Thermal energy (E)– large ΔE

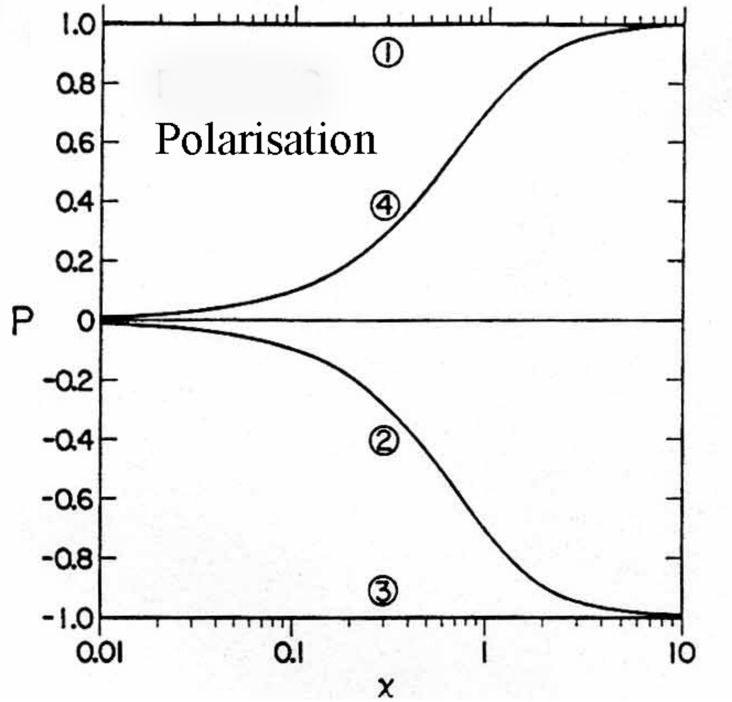
Large angular spread

Limitation - recombination (E = 3.4 eV) , but not in gas phase

Conservation of Energy and momentum – only on surfaces

Atomic hydrogen – spin energy levels in mag field





Hyperfine levels

ΔW(ν) for F = 0 to F = 1 is 1420 MHz

States 1 and 3 are QM pure spin states, 2 and 4 are mixed states

State selection type 1.

Stern – Gerlach spatial separation technique

Spins experience force in inhomogenous B-field

$F = \mu(dB_z/dz)$ with z axis is in direction of gradient

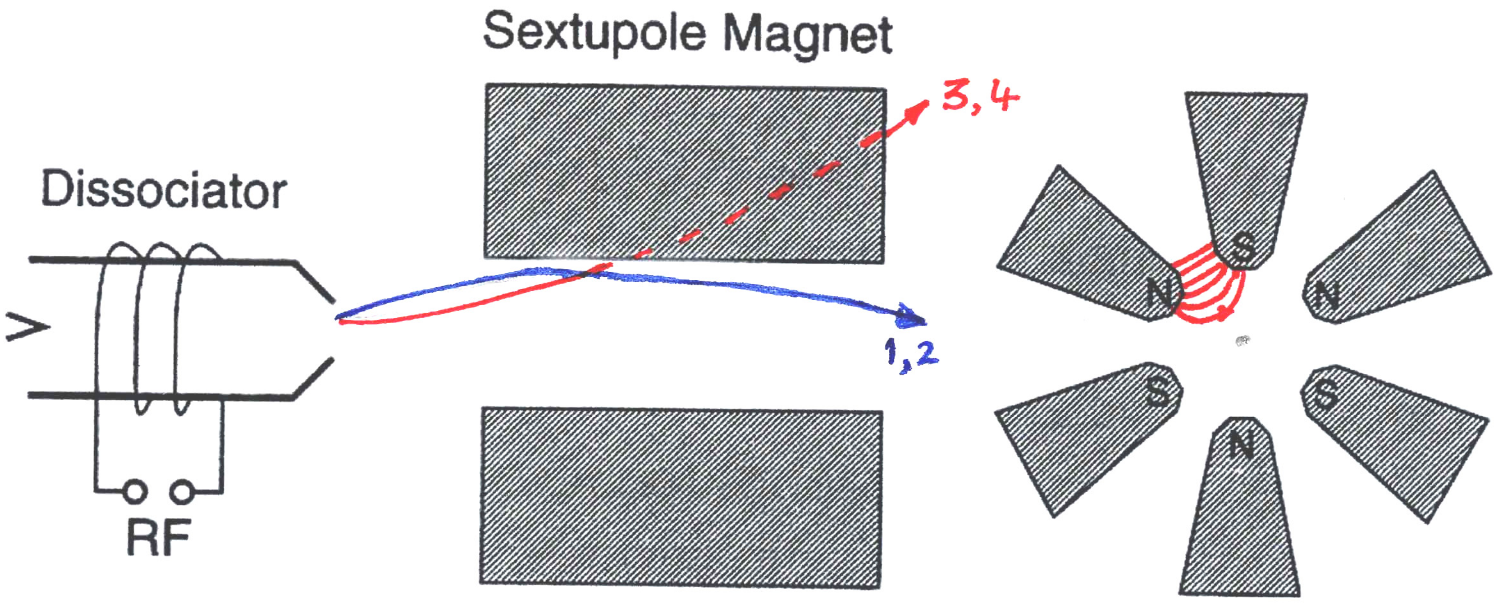
μ is effective magnetic moment

Hence in field B the force on the **electron spin** makes

States 1 and 2 ($m_j = + ½$) **low** field seekers (LFS)

States 3 and 4 ($m_j = - ½$) **high** field seekers.(HFS)

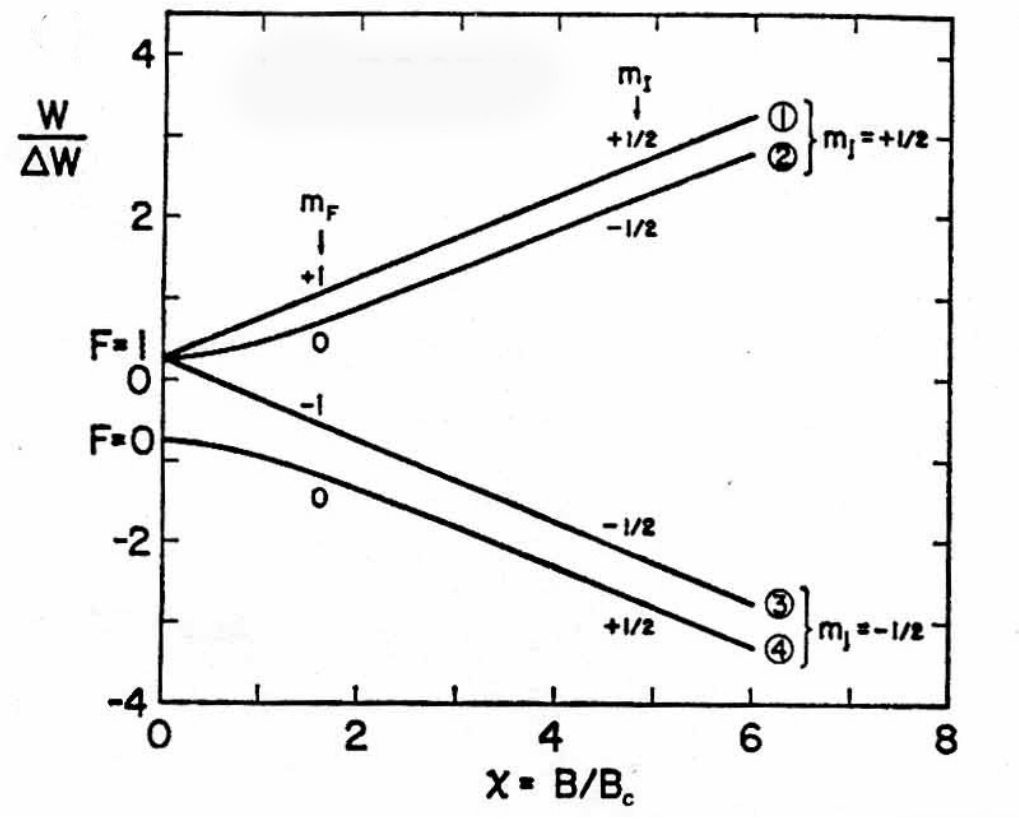
Remember $\mu_P << \mu_e$

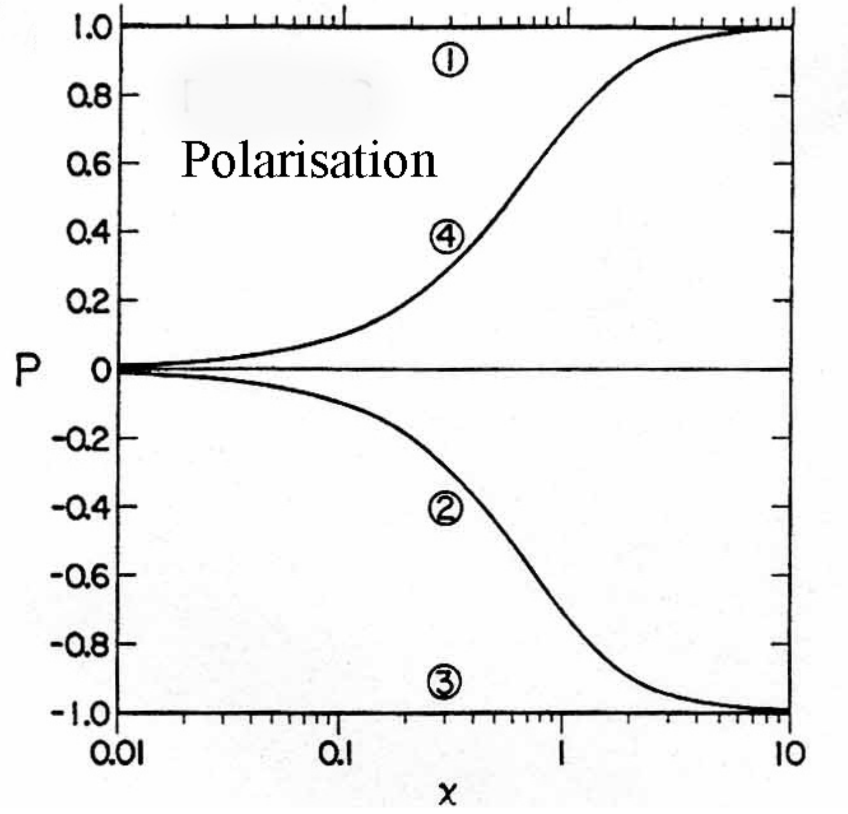


LFS focussed and HFS defocussed,

$P_e = 1$ and $P_n = 0.5$ in low B and $P_n = 0$ in high B

Modify state populations with adiabatic RF transitions e.g. exchange population from 1 to 3 then $P_e = 0$, $P_n = -1$



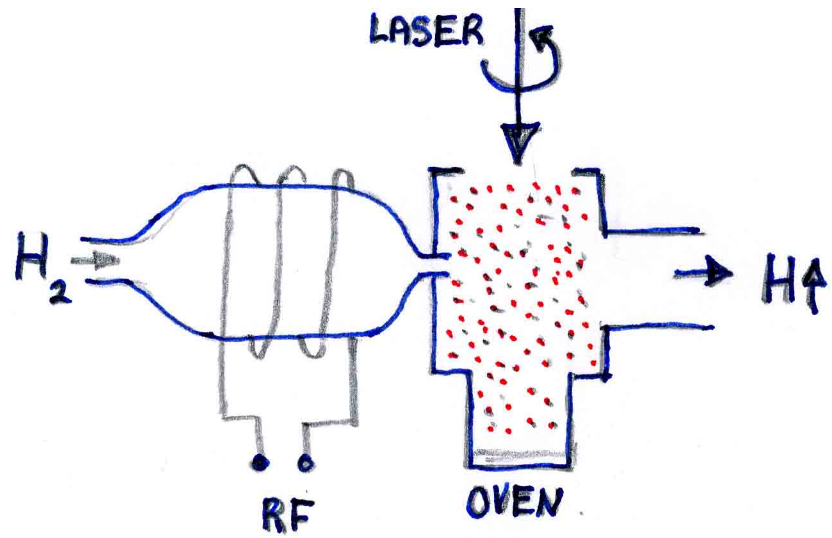


State selection 2.

Optical pumping technique – select spin state using **polarised** laser source at transition frequency (LDS)

Problem with H – atomic transition levels are in far UV

Practical solution - pass beam through optically electron polarised alkali metal vapour (visible or IR)



Spin exchange interaction gives initially – high P_e with high P_n after large number of collisions

Uses Na, K, Rb or Cs

Result from 1 or 2 is a neutral atomic beam or gas flow

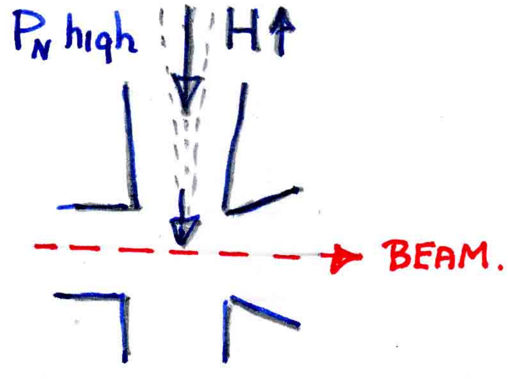
In principle with P_e **or** $P_n = \pm 1$ (actually 0.8 to 0.9)

<u>Use as a gaseous target</u>

<u>Polarised jet target</u>

Needs cool H↑ beam

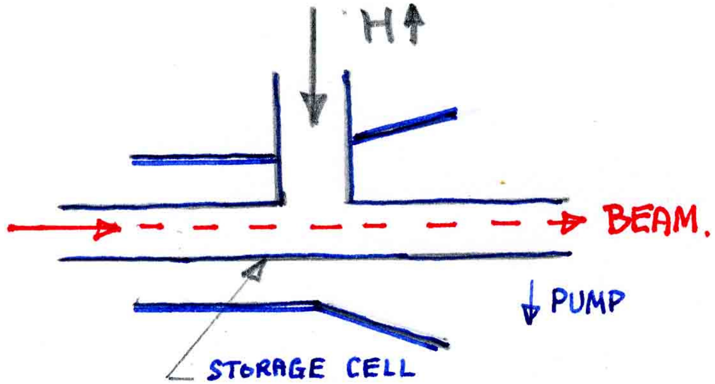
Very low luminosity



<u>Storage cell target</u>

Needs cooled cell

Higher lumi (≈ x100)



Polarised ion sources

1. Using an ABS or LDS - thermal atomic beam(gas flow)

a) Convert H^0 beam to H^+ beam with an ioniser

RF discharge - electron cyclotron resonance (ECR)

High static field, electrons circulate in resonance with RF

High efficiency in small volume, field inhibits P_P loss

Ion extraction, beam formation via DC potential (~ 3KV)

b) Convert H^0 to H^-

Pass H^0 beam through Na vapour cell, picks up e^-

Works best with higher energy H^0 beam

2. Using a high energy H^0 beam (OPPIS)

a) Generate ~ 3.5 KeV H^+ beam with ECR

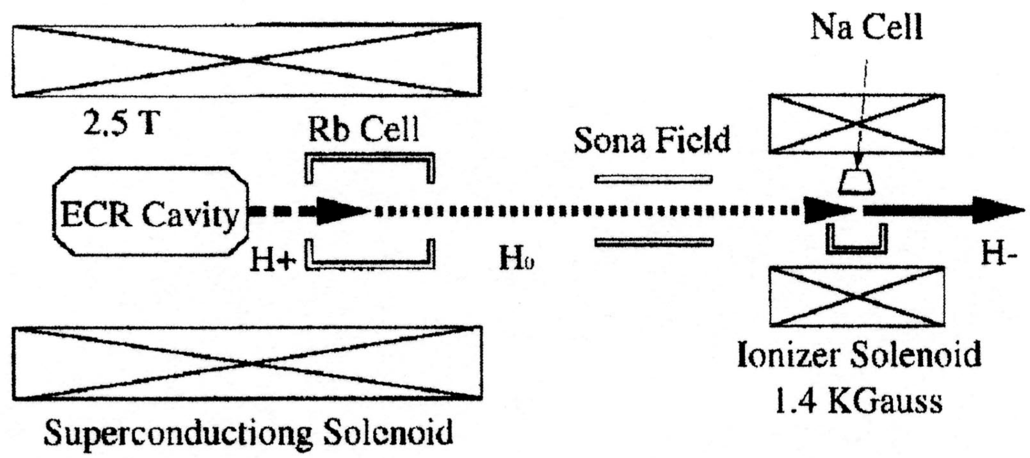
b) Capture polarised electron from optically pumped Rb atoms giving H^0 (e↑).

c) Transfer electron spin to proton via Sona * transition giving H^0 (p↑).

d) Ionise to H^- with Na cell

* Sona transition is spin state population redistribution when beam crosses a field zero

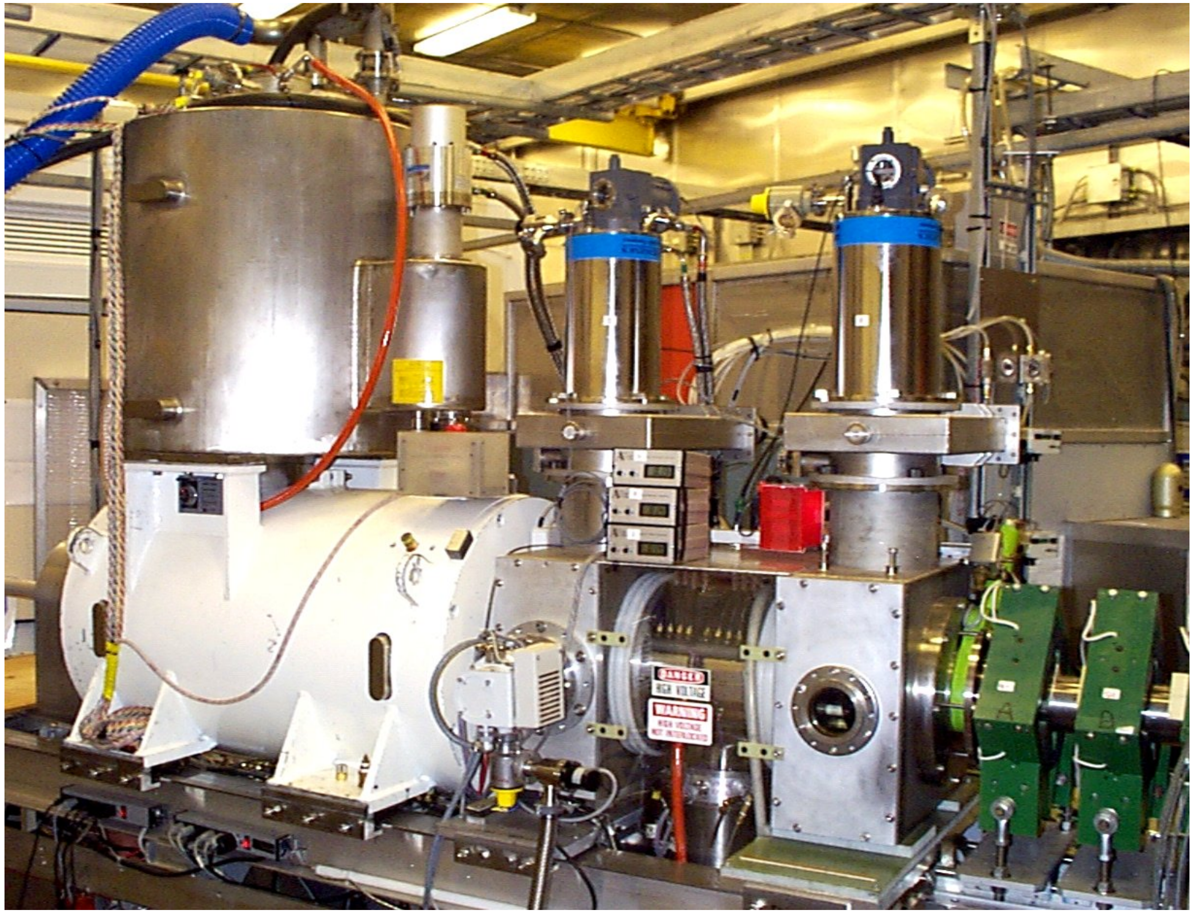
Typical OPPIS schematic layout



Polarisation reversal - optical technique

Change sense of circular polarisation of laser light

A High Intensity Polarised Ion Source



KEK OPPIS
upgraded at TRIUMF

75 - 80 % Polarization

15×10^{11} protons/pulse
at source

6×10^{11} protons/pulse
at end of LINAC

For use in RHIC at Brookhaven

General issues

1. Polarisation reversal

   Needs to be fast and systematic effect free

- With ABS change RF transition frequency
- With LDS or OPPIS change laser polarisation

2. Which technique?

ABS (LDS?) for polarised targets

OPPIS for polarised ion source

3. Other Nuclei

a) Deuteron - spin 1
Techniques mainly as for proton

b) ^{3}He - spin ½,
Optical pumping only as it is a two electron atom
(no electron polarisation possible)

Information and references

Polarised Gas Targets - Steffens and Haberli
Rep. Prog. Phys. **66**(2003) 1187-1935

Polarised Ion Sources for High Energy Accelerators – Levy and Zelenski
Rev. Sci. Inst. **69** - 2 (1998) 732-736

International Symposium on High Energy Spin Physics - Biennial Conference series with 17th in Japan (SPIN06) this year.