A HERMES-type Gas Target, Internal to the LHC for the Study of pp Single-spin and Heavy Ion Collisions

November 9th, 2016 | Alexander Nass

Motivation

- AFTER@LHC: A Fixed-Target ExpeRiment for hadron, heavy ions and spin-physics at LHC.

- Physics goals:
  - Large-x gluon, antiquark and heavy-quark content in the nucleon and nucleus.
  - Dynamics and spin of gluons in (un)polarized nucleons
  - Heavy-ion collisions towards large rapidities

-> L. Massacrier: talk today at 10:00

Fixed target mode at LHC

Advantages of the fixed-target mode (wrt to collider):

- Access high Feynman x_F domain ($x_F = p_z/p_{zmax}$)
- High luminosities (dense targets)
- Easy change target type
- Possibility to polarize the target
    - Spin physics program

No effect on the LHC performance:

Two options possible:

- Bent crystal in the halo of the LHC beam + solid target.
- Internal gas target

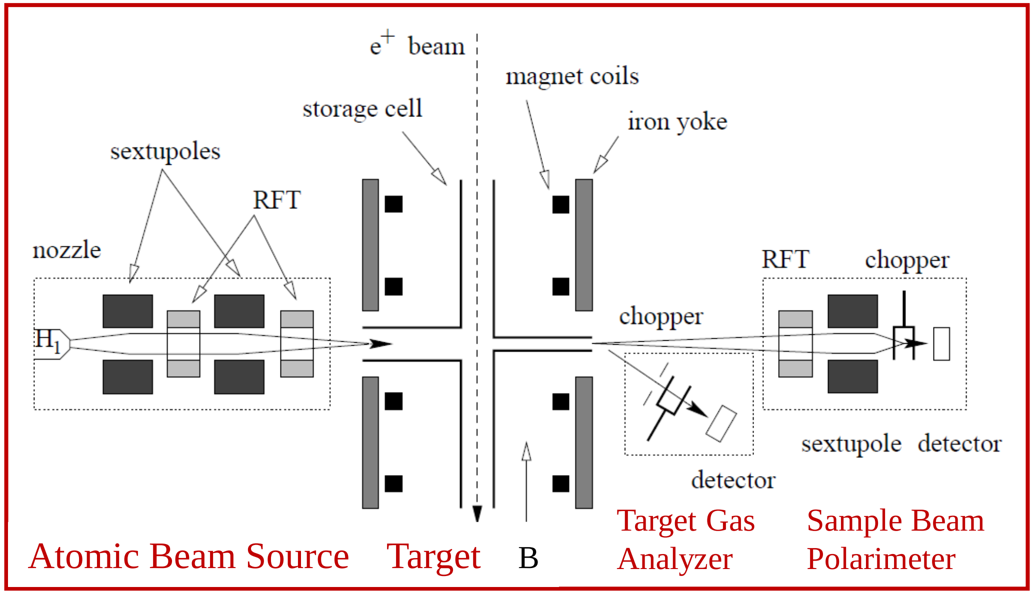
Storage cell internal gas target

History

- Teflon-coated storage cell filled with polarized H from an ABS as target for Scattering Experiments first proposed by W. Haeberly in 1965
- First experimental test of in Madison, Wisconsin (1980)
- Experimentally used with:
    - Proton beams (< 2 GeV): PINTEX@IUCF, ANKE/PAX@COSY
    - Electron/positron beam (27 GeV): HERMES@HERA (1995-2005)

The HERMES polarized internal gas target @ HERA

- Polarized atomic beam injected from atomic beam source
- Sample beam:
  - QMS (α = molecular fraction).
  - Polarimeter (P = atomic polarization).
- *Sampling corrections* to compute polarization seen by beam.



HERMES H&D target

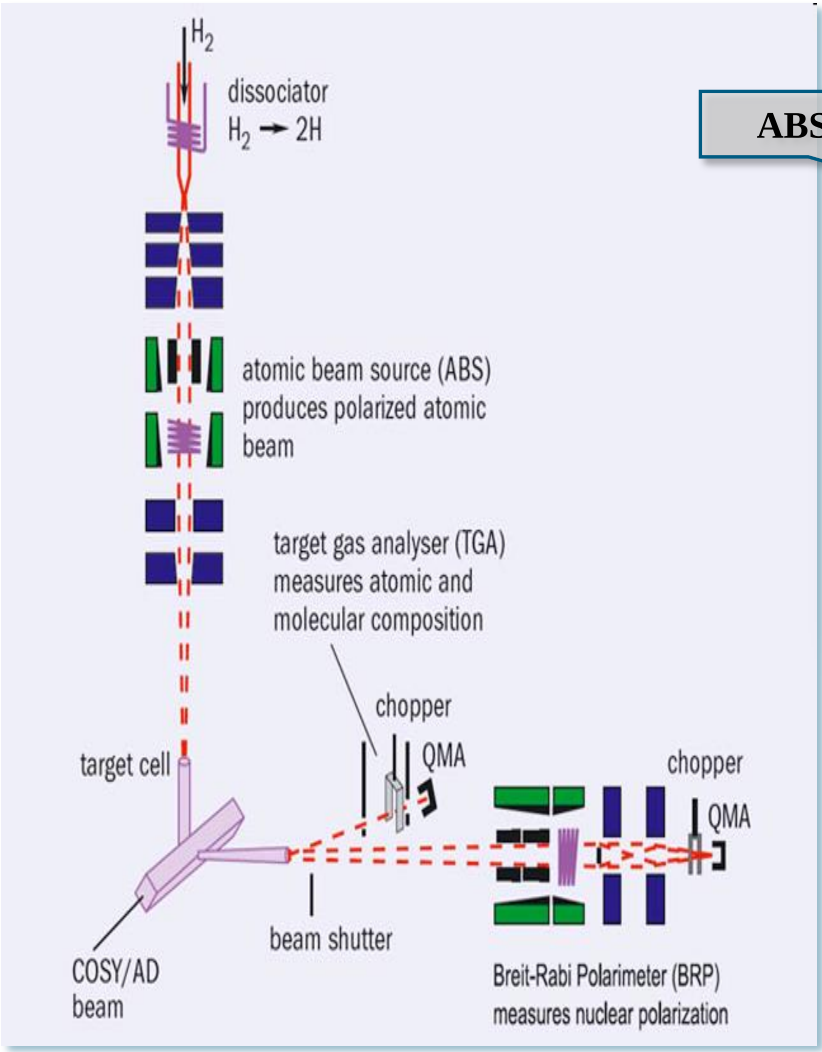
p 920 GeV

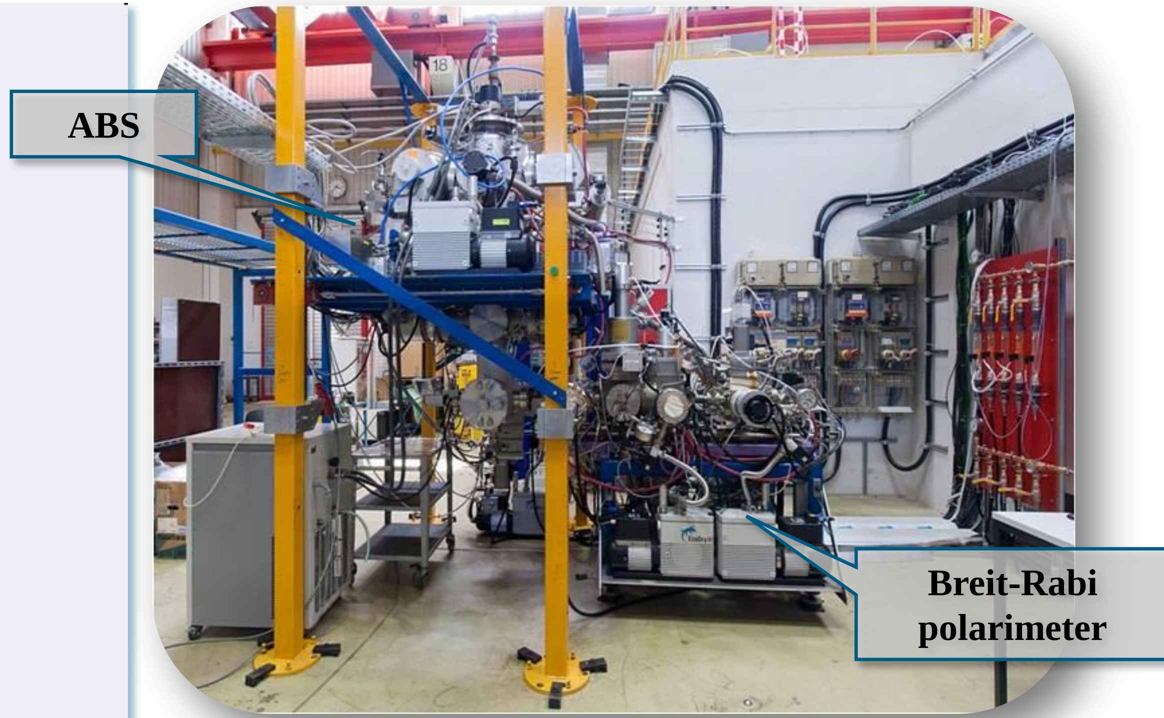
e 27.6 GeV

Mitglied der Helmholtz-Gemeinschaft

JÜLICH FORSCHUNGSZENTRUM

The HERMES target now: PAX @ COSY



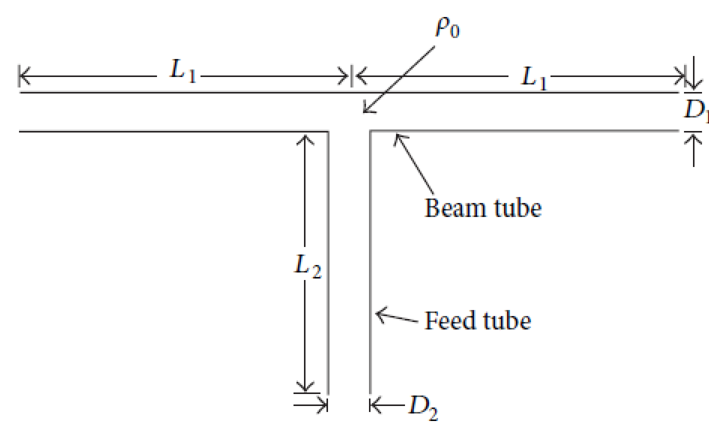


- Last achievement
    - Target compatible for H and D running (Without vacuum breaks!)

The HERMES target (1995-2005) @ DESY

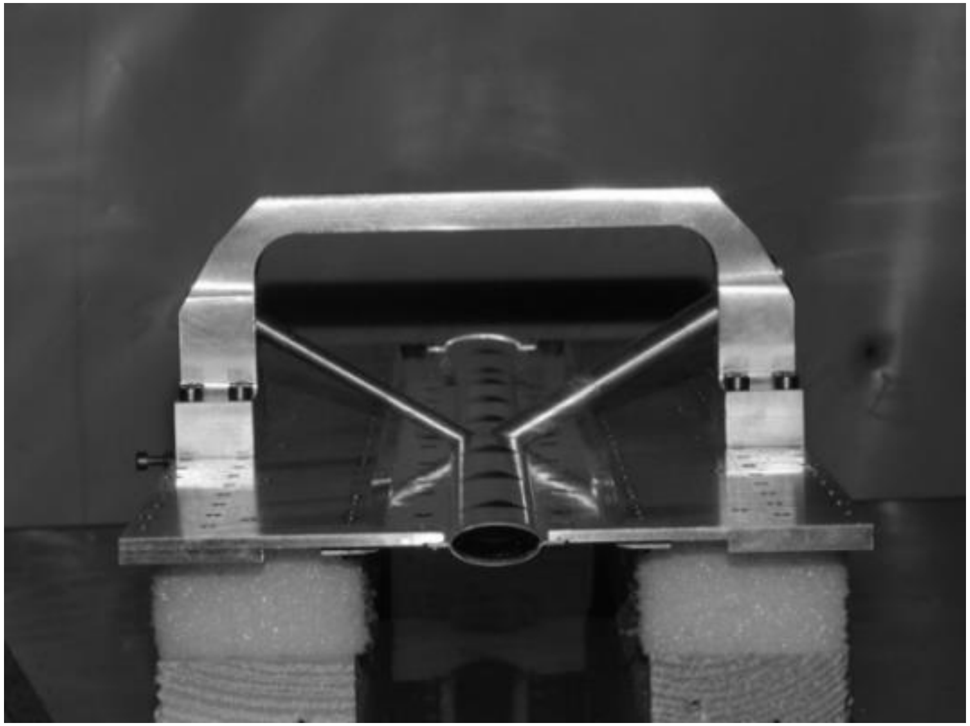
- Low-β section @ 30 GeV HERA e^+/e^-
- Polarized ^3He, ^1H, ^2D and unpolarized gas H_2 to Xe *[NIM **A540** (2005) 68]*.
- T-shaped Al-storage cell
    - 400 mm long, Elliptical cross section $r_{x,y} \approx 15\ \sigma_{x,y} + 1$ mm
    - Feed tube: 100 mm long, 10 mm (plus capillary for gas feed system).

- Density ρ_0 at cell center: $\rho_0 = I / C_{tot}$
- Narrow tube gives high density, but space for the beam needed!
- Additional requirements:
    - wall coating for low recombination and depolarization;
    - strong guide field.



JÜLICH FORSCHUNGSZENTRUM

The HERMES storage cell



Material: 75 μm Al with Drifilm coating

Size: length 400mm, elliptical cross section (21 mm x 8.9 mm)

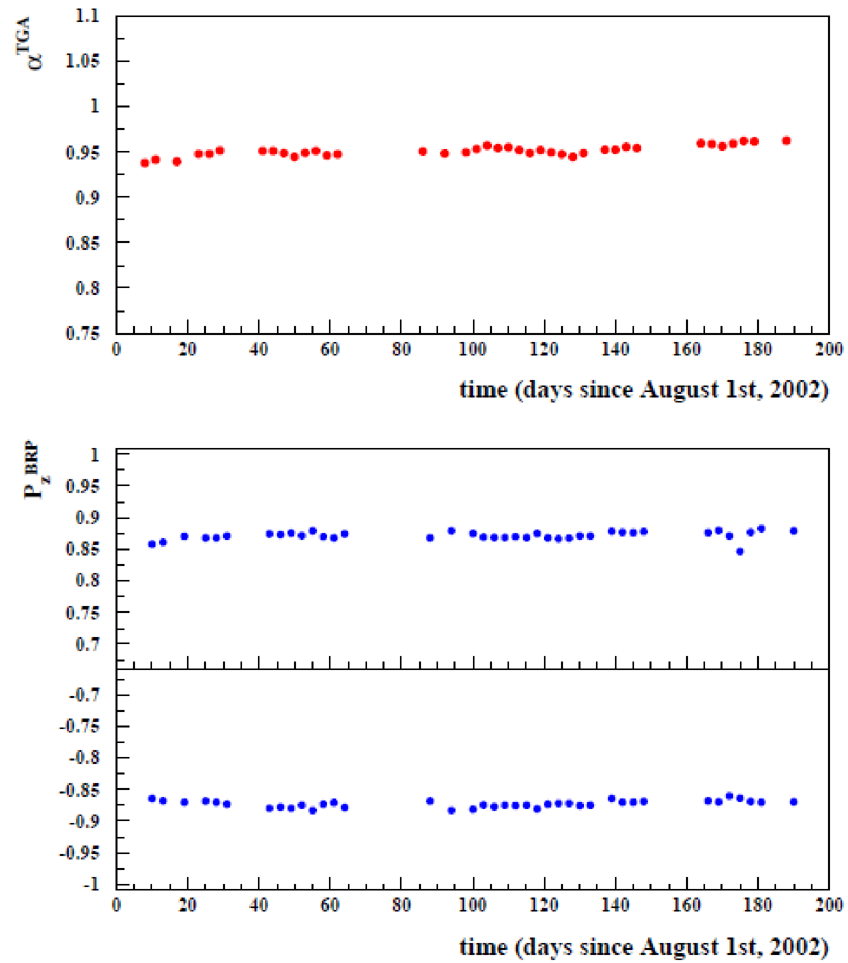
Temperature: 100 K (variable 35 K – 300 K)

Performance for $\vec{H}$ (2002/03)

HERMES 2002/03 data taking with transverse proton polarization

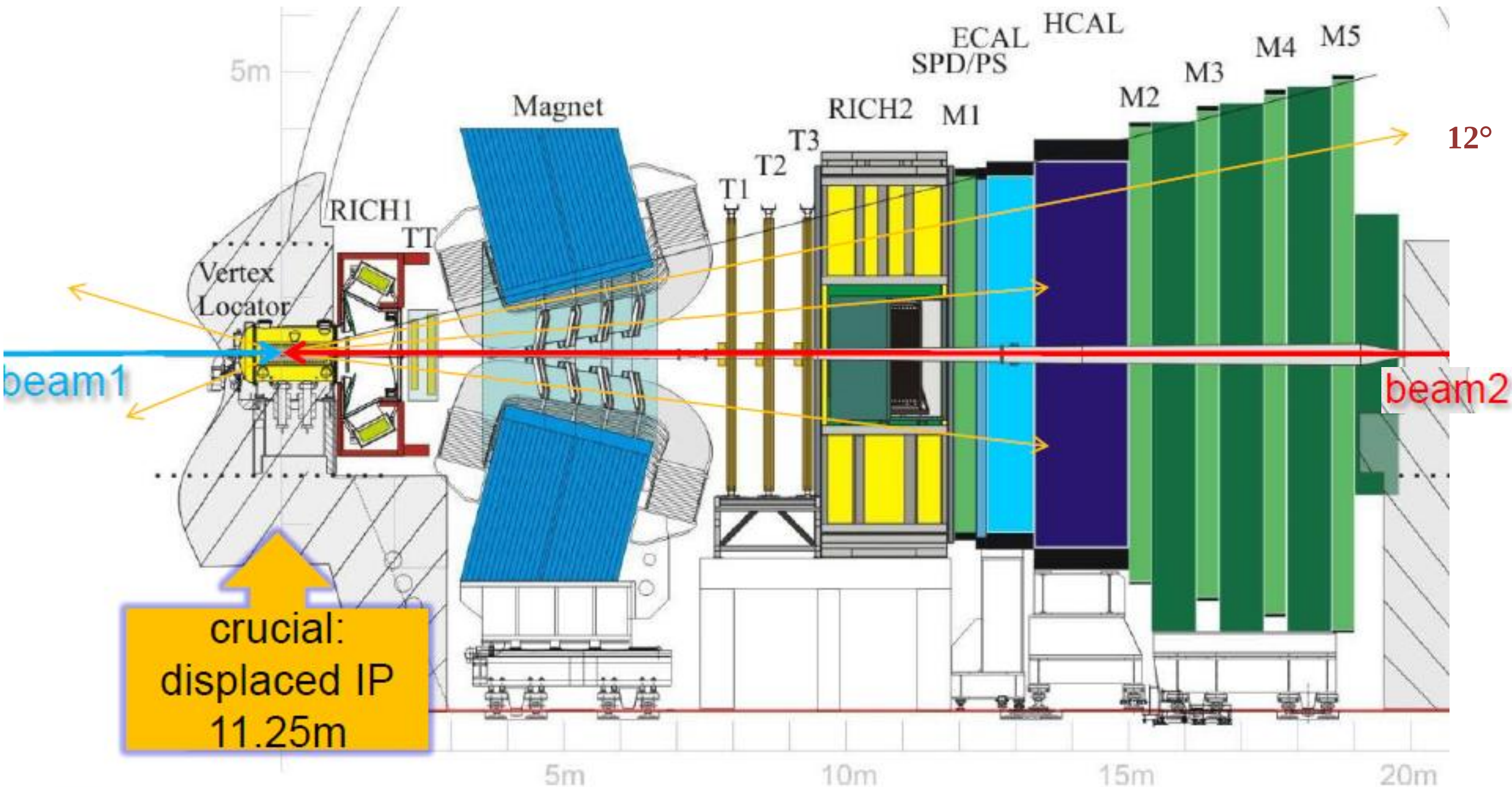
Top: Degree of dissociation measured by the TGA (α = 1: no molecules);

Bottom: Vector polarization P_z measured by Breit-Rabi-Polarimeter for 2 different injection modes.



The SMOG gas target @ LHCb for diagnostic purposes (vertex locator)

from talk by M. Ferro-Luzzi (CERN) workshop **AFTER@LHC** on 17-Nov-2014



The SMOG internal gas target @ LHC

- **AFTER@LHC** M. Ferro-Luzzi (CERN):
- Originally: pure residual gas (10^{-9} mbar).
  - Switching off the pumps, pressure up to $5 \cdot 10^{-9}$ mbar used as target.
- Since 2012: Ne injected up to $p \approx 1.5 \cdot 10^{-7}$ mbar
  - At T=293K corresponds to $\rho = 4 \cdot 10^{12}$ /cm^3.
  - Pressure bump 10 m long areal density θ is $4 \cdot 10^{15}$/cm^2.
  - Beam losses negligible ($\tau >> 10^8$ s).
- Si-strip detector (VELO): two halves positioned near beam axis.
  - Closed position: detectors-distance to beam: 8 mm, Al housing: 5 mm.
  - Opened position: free space of ≈ 50 mm.

Conclusions:

- "LHCb has pioneered the use of gaseous "fixed target" in the LHC …"
- "Extensions involving target polarization require bigger investments and long studies (!) …."

LHC operation

p and Pb beams intensities @ LHC

- Protons: $I_p = 3.63 \cdot 10^{18}$ p/s @ 7 TeV.
- Lead: $I_{Pb} = 4.64 \cdot 10^{14}$ Pb/s @ 2.76 TeV/u.

Beam half-life: ≈ 10 h

- Parasitic operation requires small reduction of half-life (< 10%)

1σ-radius at IP (full energy): < 0.02 mm

- Negligible compared with the cell radius (> 5 mm)

Safety radius at injection (450 GeV for p): > 25 mm

- “Openable” cell required.

Openable storage cell development in Ferrara

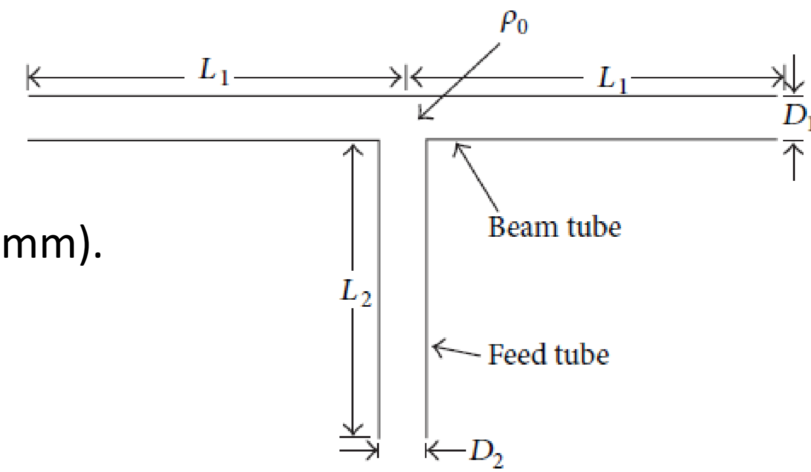
(Storage cell for 2 GeV p/d beam at COSY (FZ-Juelich)

JÜLICH FORSCHUNGSZENTRUM

Proposed geometry for a LHC storage cell

LHC Requirements:

- Beam tube
  - Length: 1000 mm (L_1 = 500 mm)
  - Closed: D_1 = 14 mm (> D_{VELO} = 10 mm).
  - Opened: D_1 = 50 mm
- Feed tube:
  - D_2 = 10 mm and L_2 = 100 mm
- Cell temperature: T = 300 K.



Conductance: $C_i\,[l/s] = 3.81\,\sqrt{T/M}\cdot D_i^3 / (L_i + 1.33\,D_i)$ *(M = molecular weight)*

Density: $\rho_0 = I / C_{tot}$ *with* $C_{tot} = C_1 + C_2 + \ldots$ *(I [part/s] gas flow-rate)*

Example: H, $C_{tot} = 2\,C_1 + C_2 = 12.81$ *l/s,* $I = 6.5\cdot 10^{16}$*/s (HERMES):*

$\rho_0 = 5.07\cdot 10^{12}/cm^3$

areal density $\theta = L_1\cdot \rho_0 = \mathbf{2.54\cdot 10^{14}/cm^2}$

Polarized ^{1}H gas target performance

Polarized H injected into storage cell

- Areal density: $\theta = 2.54 \cdot 10^{14}$ H/ cm^2
- Proton current $I_p = 3.63 \cdot 10^{18}$/s *(similar @ TeV)*

Total luminosity: $p\vec{p}$ **L_{pp} = 0.92·10^{33}/ cm^2 s**

- (About 10% of the collider luminosity)
- (x20 RHIC p↑-p↑ luminosity)
- Possibility to cool down the cell to 100 K (θ increase by $\sqrt{300/100}$ = 1.73)

σ_{pp} @ $\sqrt{s} \approx 100$ GeV = 50 mb = $5 \cdot 10^{-26}$ cm^2

- Loss rate dN/dt: $4.5 \cdot 10^7$/ s
- Stored protons: $N = 3.2 \cdot 10^{14}$

Max. *relative* loss rate: (dN/dt)/N = $1.4 \cdot 10^{-7}$/ s.

The H target does not affect the life time of the 7 TeV proton beam.

Polarized ^{2}D and ^{3}He gas targets

- Polarized ^{2}D target produced with densities comparable to ^{1}H.
- HERMES: ^{3}He target operated at HERA in 1995.
  - ^{3}He gas polarized by Metastability Exchange Optical Pumping (1083 nm laser).
  - Modern lasers make a ^{3}He source (much) more intense than an ABS

Choice of the best target has to be made in an early phase of the project!

Unpolarized gas targets (H_2, ^{20}Ne, ^{84}Kr, ^{131}Xe,...)

- LHC enables collisions of beams of same rigidity
  - i.e. p-p collisions @ E_{max}= 2x7 TeV

    and Pb-Pb @ E_{max} = 2x2.76 TeV/nucleon.
  - (Other ions than p or Pb not used for experiments so far).

- *Parallel operation of heavy-Ion Fixed-Target program possible:*
  - Storage cell target fed with unpolarized gas:
    - Different combinations of masses could be studied (e.g. Pb on Xe or Ne).

Example: Pb on Xe target

- Pb lifetime in Pb-Pb collider: τ_c = 10 h/ 0.693 = 14.4 h
  - Max Induced target life time: τ_t = 10·14.4 h = 144 h
  - Loss rate dN/dt = $\dot{N}$ (N = number Pb ions = $4 \cdot 10^{10}$):

    $\dot{N}/N$ = 1/144 h -> $\dot{N}$ = N/$5.18 \cdot 10^5$ s = $7.72 \cdot 10^4$/s = $\mathbf{L}_{Pb\text{-}Xe} \cdot \sigma_{tot}$ (Pb-Xe)

  - $\sigma_{hadronic}$: 7.65 barn -> scaling with nuclear radii: σ_{tot} (Pb-Xe) = 6.6 barn

Max. Pb-Xe lumi: $\mathbf{L}_{Pb\text{-}Xe} = 1.17 \cdot 10^{28}/\ cm^2 s$

- *(10 x Pb-Pb collider design luminosity ($10^{27}/\ cm^2\ s$)*
- Xe density θ: $2.52 \cdot 10^{13}/cm^2$
- Xe flow rate at 300 K: $2.1 \cdot 10^{-5}$ mbar l/s

Conclusions

- **Interesting physics perspectives for a fixed target at LHC.**
- **Storage cell target** provides highest areal density at minimum gas input.
  - **Solid technology** tested at the HERA - 27.6 GeV e^+/e^- at I = 40 mA
- **Polarized H gas target:**
  - Cell with L=1 m and ϕ = 14 mm assumed (as SMOG/VELO @ LHCb)
  - $10^{33}/cm^2$ s accessible (16% of collider lumi)
- **Unpolarized target:**
  - p-A and Pb-A collisions with H_2, He, Ne, Ar, Kr and Xe
  - Max. Pb-Xe lumi: $\mathbf{L}_{Pb\text{-}Xe} = 1.17 \cdot 10^{28}/\ cm^2 s$ (10 x higher than collider lumi)

- **Locations at LHC to be identified for realistic planning and design!**

Further reading …..

Advances in High Energy Physics

Physics at a Fixed-Target Experiment Using the LHC Beams

http://www.hindawi.com/journals/ahep/si/354953/

Thank you !

Backup slide

Extracted beam by bent-crystal

AFTER@LHC (Phys. Part. and Nucl.(2014) p. 336):

- LHC beam halo (p)extraction by bent-crystal onto polarized proton target.
  - Exp beam intensity: $i_p = 5 \cdot 10^8$/s.
- COMPASS type frozen spin target too large for LHC tunnel.
- UVa-type NH_3 DNP target with smaller target set-up considered:
  - $n_t = 1.5\ 10^{23}/cm^2$, $P_p = 0.85$, dilution $f = 0.17$, FoM $= n_t\ P^{\,2}\ f^{\,2} = 3.1 \cdot 10^{21}/cm^2$.
  - Beam intensity i_p also enters the measurement quality:
    - $FoM^* = i_p \cdot FoM = P^2 \cdot f^{\,2} \cdot i_p \cdot n_t = P^2 \cdot f^{\,2} \cdot \mathbf{L}$

Comparison:

UVa-target and bent-crystal extr. beam:	$FoM^* = 1.57 \cdot 10^{30}/cm^2\ s$
'COMPASS-target " " "	$FoM^* = 1.87 \cdot 10^{32}/cm^2\ s$
'HERMES' target and full LHC beam: (T = 300/100 K, P = 0.85, $\alpha = 0.95$)	$FoM^* = 0.60/1.04 \cdot 10^{33}/cm^2\ s$