Storage Ring Experiments

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Talk restricted to

Please note:

Talk not about physics of Storage Ring Experiments

(allthough very important to make sure that physics is excellent!)

but about the experimental technique of such experiments!

IT

PIT

- **in single-user mode** **very important distinction!**

Design of storage ring experiments strongly related to storage ring design!

See talk by S. Martin

Advantages of Storage Ring Experiments

- Scattered beam particles remain in the beam (if $\theta_{scatt} < \theta_{acc}$) → economic use!

  important for antiprotons, rare isotopes etc!

- Pure gas targets → low background

  Open Spectrometers possible

- Targets very thin → detection of recoil particles

  e.g. recoil protons, decay of hyperons,...

- Beams can be cooled → very low beam size and momentum spread

  important for high precision measurements

- Storage rings allow for multiple passage of the target → enables Spin Filtering!

  see talk by F. Rathmann about spin filtering

Outline of Talk

Number of working Storage Ring Experiments is limited mainly to ANKE (Jülich), HERMES (Hamburg) and the RHIC-Jet (BNL). A few more experiments are working in a more irregular manner (DEUTERON-BINP, POLARIS-JINR,...).

For full coverage of the subject also past and future experiments will be discussed.

- Some Historical Remarks
- Requirements of Storage Rings for IT-Experiments
- Experiments in Electron Rings (BLAST, HERMES)
- Experiments in Ion Ring (ESR-Mass Spectrometry, WASA, ANKE, future projects)
- Conclusions

Some Historical Remarks

1984 Cluster target in the CERN ISR (single $\underline{p}$ beam) >> Charmonium spectroscopy

Later repeated in the Fermilab Accumulator ring: P. Dalpiaz et al, see talk at STORI 2005

Some Historical Remarks

SPS/CERN (≈1980), converted into **Sp$\bar{p}$S** collider → discovery of Z^o, $W^{\pm}$ (1983)

Sp$\bar{p}$S used in parallel by UA6:
- H Cluster target in the $\bar{p}$ beam
- polarized H jet target not implemented

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1988 UA6: Cluster target in the SppS antiproton beam + open spectrometer

Polarized target planned, but not installed

1985 Polarized D jet in the VEPP-2 ring at Budker Institute Novosibirsk (BINP)

1988 Polarized D jet injected into Storage Cell: first test of polarized storage cell in high energy electron beam (VEPP-3: 2.5GeV)

1985 FILTEX proposal: goal to measure double polarized pp in LEAR

Low Energy Antiproton Ring
LEAR

First dedicated ion storage ring, built as stretcher (slow extraction) and for internal target experiments:

LEAR/CERN (1983-1996) → Low energy antiproton physics ($\underline{p}$s available from AC/AA but expensive: econonomic use!!)

LEAR had electron and stochastic cooling, and ultra-slow extraction.

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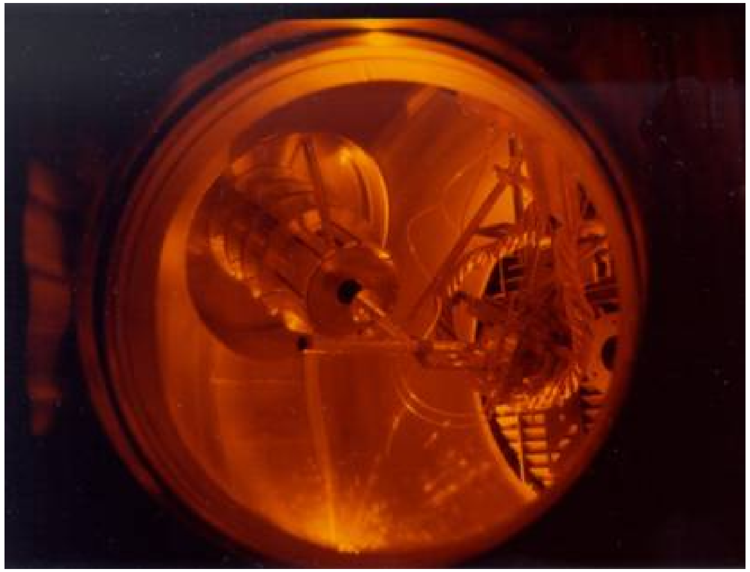
1985 FILTEX proposal: goal to measure double polarized $\underline{p}p$ in LEAR

1992 FILTEX test performed in the Heidelberg TSR >> spin filtering confirmed!

Filtex at TSR (Heidelberg)

Spin filter test experiment (1992): first polarized storage cell in an ion storage ring!



F. Rathmann. et al.,
PRL 71, 1379 (1993)

see talks by P. Lenisa and F. Rathmann

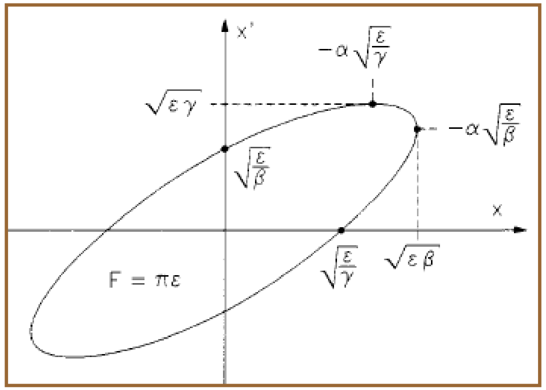
Requirements on Storage Rings for IT Experiments: some basic facts

Phase ellipse: Area F = π ε, with ε = beam emittance

(emittance grows due to scattering, shrinks due to phase space cooling -> equilibrium)

Phase ellipse upright at symmetry point, i.e. at beam waist.

The beta function b(s) is a periodic function of the coordinate s along the closed orbit.



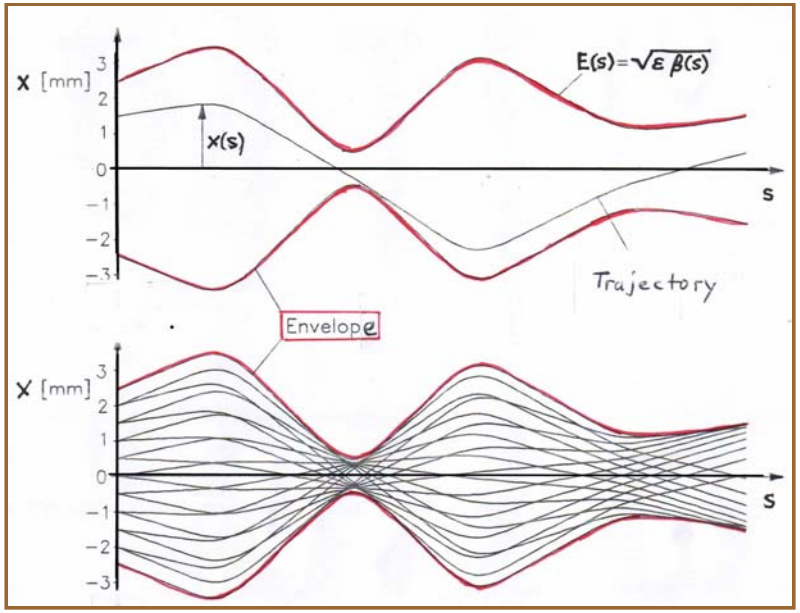
α, β, γ = Twiss parameters

Beam particle moves along trajectory x(s):

Different particles have different betatron phase:

→ trajectories are within the beam envelope E(s):

$$E(s) = [\varepsilon\, \beta(s)]^{1/2}$$



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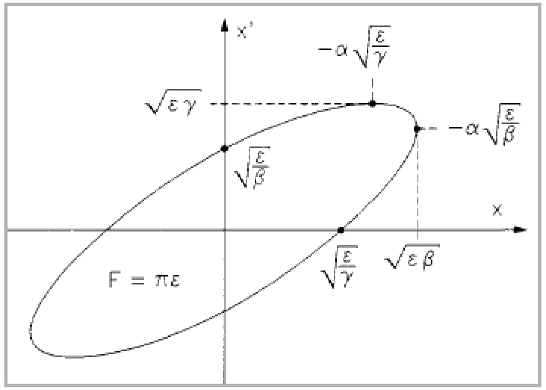
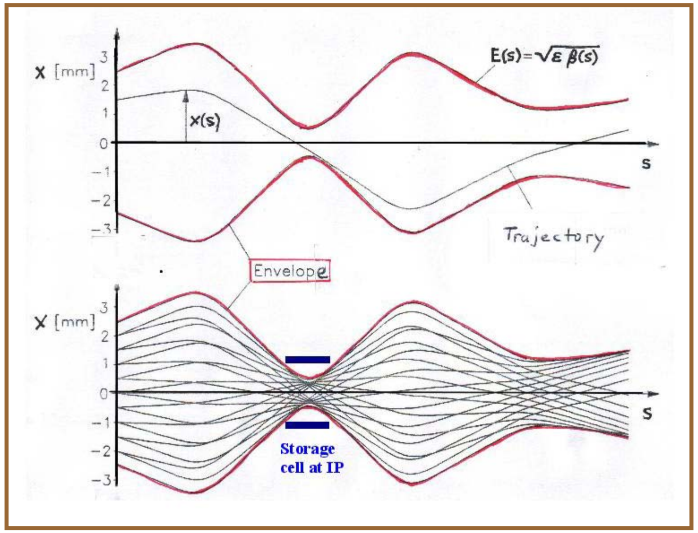


• Storage cell for PIT placed at the beam waist

• Radii x, y such that envelope is not touched

• A larger emittance of the beam during injection might require a cell with variable cross section (PAX test at CERN AD?): needs new development!



Requirements on Storage Rings for IT Experiments

- Beam cooling to compensate for heating by the target

  - Ion rings: Cooling device necessary (Electron cooling, Stochastic cooling)

  - Electron rings: usually damping of betatron oscillations due to SR sufficient!

- Sufficient acceptance at the target position (IP) A = ring acceptance

  - main losses in Ion Rings: ‚single scattering losses' prop. to Z^2/θ_{acc}^2

  - $\theta_{acc}=(A / \beta)^{1/2}$ $\longrightarrow$ low-beta values at IP required !

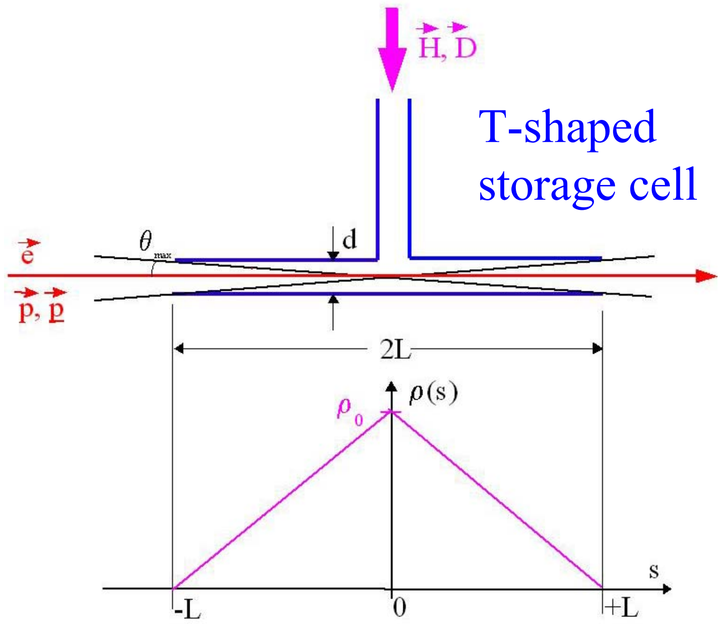
  - for A = 30mm mrad and θ_{acc} =10mrad $\rightarrow$ $\beta = 0.3$m

Requirements on Storage Rings for IT Experiments: Storage Cells

Storage Cell proposed by W. Haeberli

- Proc. Karlsruhe 1965, p. 64
- Proc. Workshop IUCF 1984, AIP Conf. Proc.#128, p.251

Polarized atoms from source



- Ballistic flow

from Atomic Beam Source H, D

- Flow driven by pressure gradient

Laser Driven Sources H, D, ^3He

Density gain compared to Jet of same intensity can be up to several hundred!

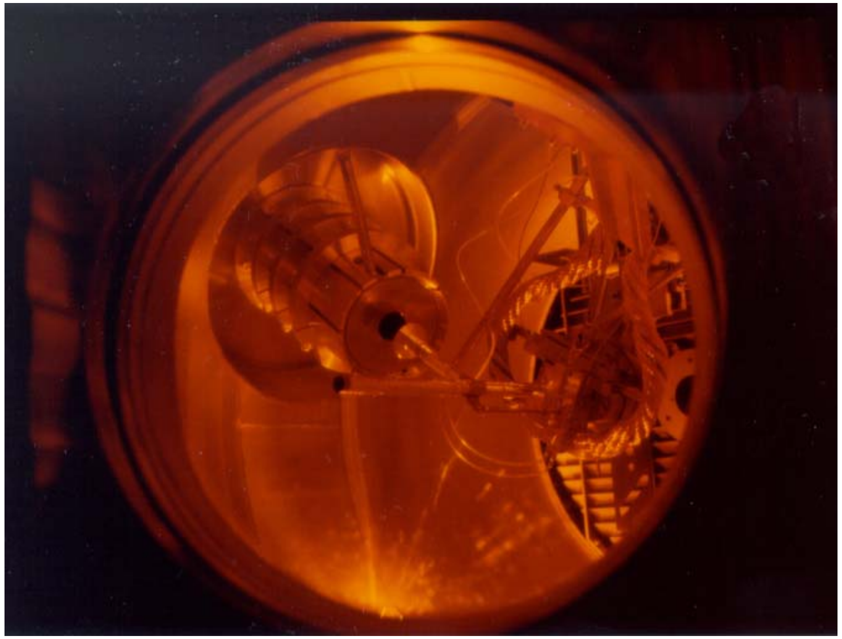
Target areal density given by

$t = L\,\rho_o$ with $\rho_o = I_t / C_{tot}$ and $C_{tot} = \Sigma C_i$

Note: Conductance of tube proportional to d^3/L

Storage Cell Design: Requirements

- Minimum aperture allowed by machine optics for high density: $t \sim 1/r^3$
  e.g. $r = x,y = 15\sigma_{x,y} + 1\text{mm}$
- Maximum length compatible with tracking detector
  e.g. 2L = 400mm (HERMES)
- Thin walls with coating for minimum recombination and depolarization
  e.g. Teflon, Drifilm
- Cooling of cell wall?
  - density enhancement
  - compensation of cell heating
  - frozen layer of water helps to prevent recombination



FILTEX target for TSR test experiment (1992)

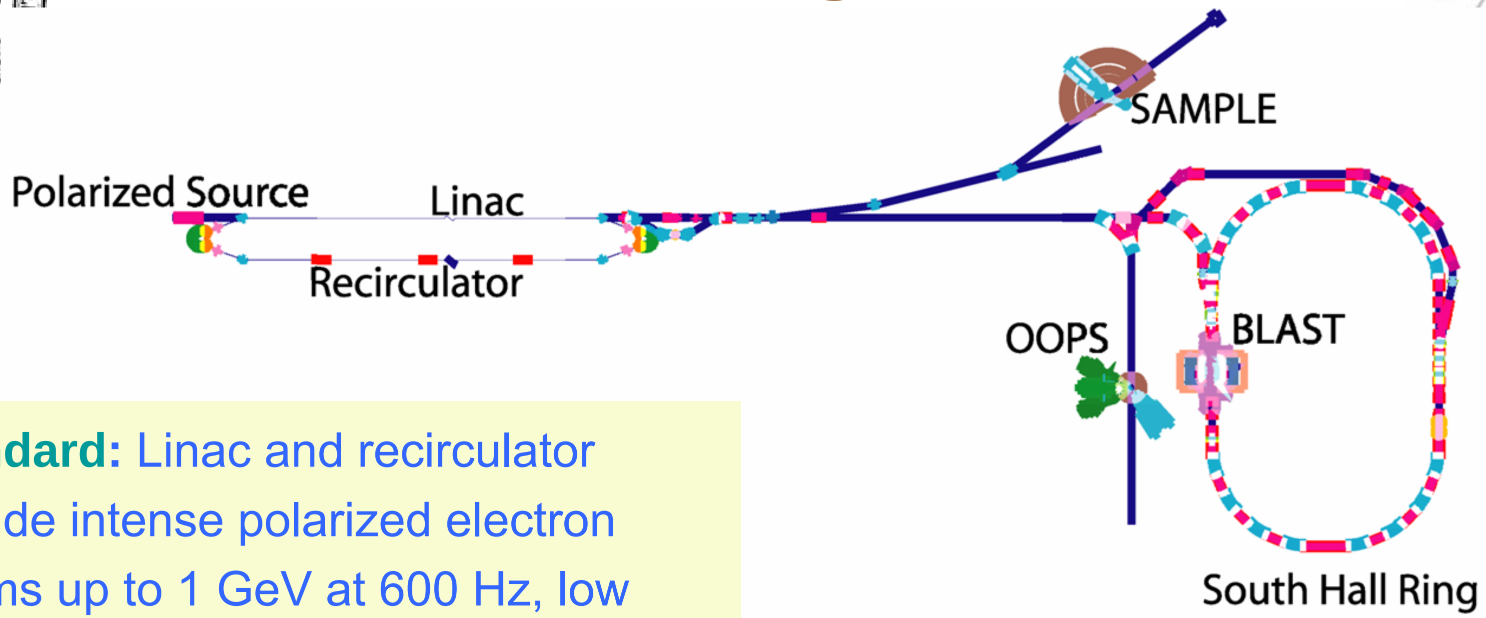
Experiments in Electron Rings

-South Hall Ring (SHR), MIT Bates

similar to AmPS, NIKHEF (dismantled)

-HERA-e, DESY

South Hall Ring @ MIT-Bates



Standard: Linac and recirculator provide intense polarized electron beams up to 1 GeV at 600 Hz, low duty cycle

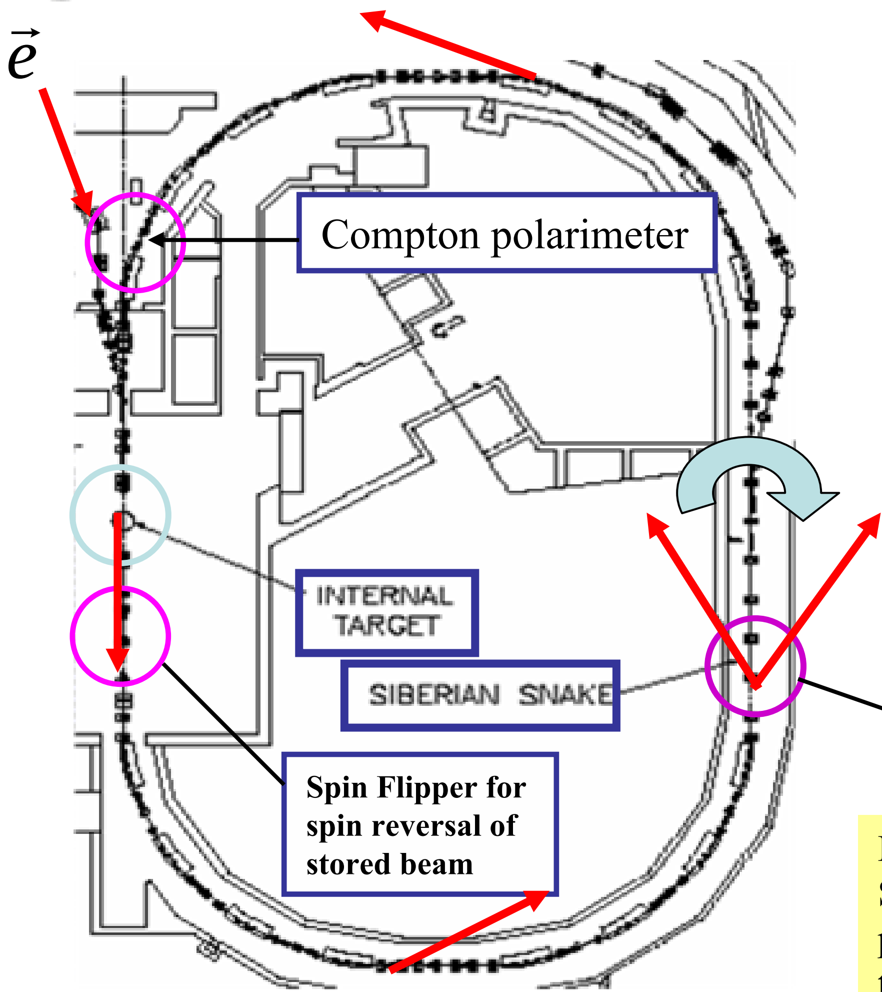
Pulse Stretcher (OOPS): Limited turns in South Hall Ring before gradual extraction to external target

Storage (BLAST): Gradual stacking of electron pulses in South Hall Ring for long-lived CW beam

South Hall Ring

- 190 m circumference
- 16 dipoles
- Single RF cavity (f=2.856 GHz)
- Racetrack design
- Full energy two-turn injection

South Hall Ring @ MIT-Bates



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- 190 m circumference
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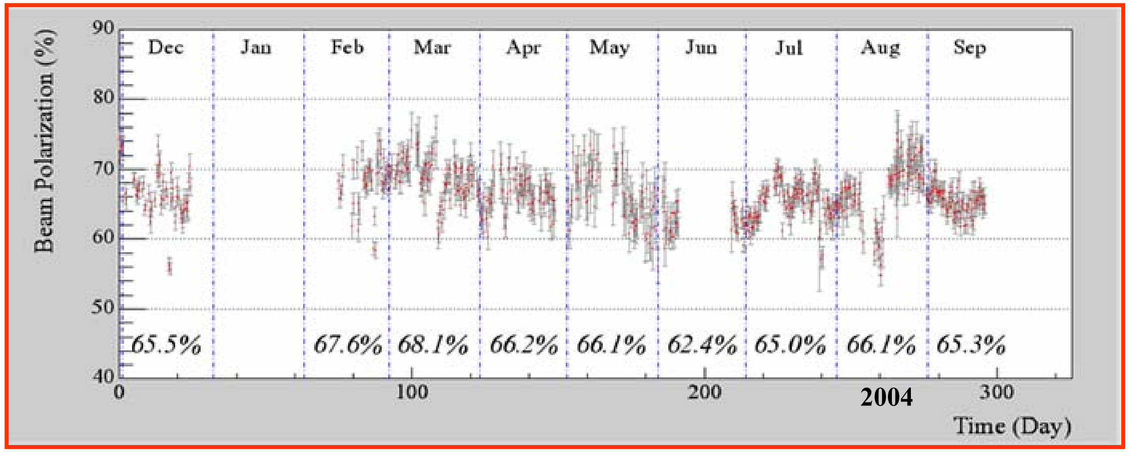
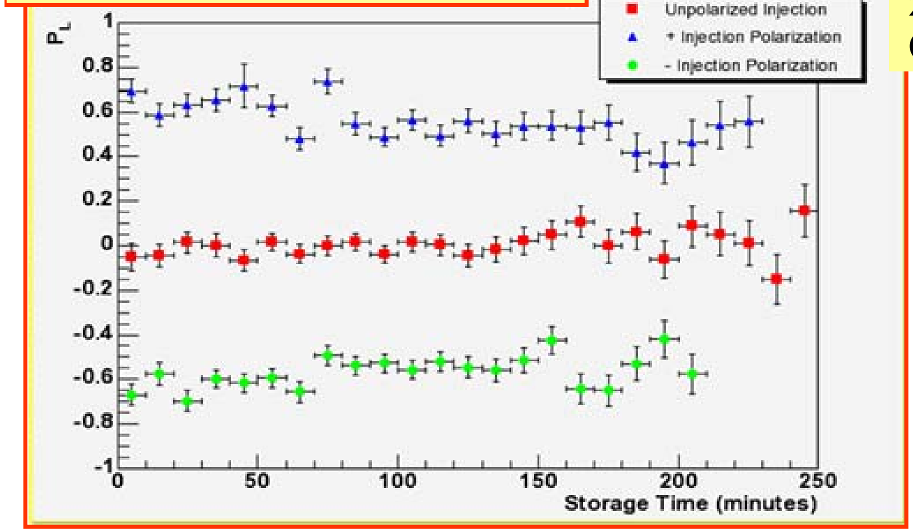
- Single RF cavity (f=2.856 GHz)
- Racetrack design
- Full energy two-turn injection
- Stored beam operation at 850 MeV from 2002-2004 for BLAST
- Over 200 mA stored electron current achieved

Full Siberian Snake for long. polarization at the target (BLAST)

South Hall Ring @ MIT-Bates



Polarization Lifetime SHR



Beam lifetime 20-30min (with target)

Full Siberian Snake for long. polarization at the target (BLAST)

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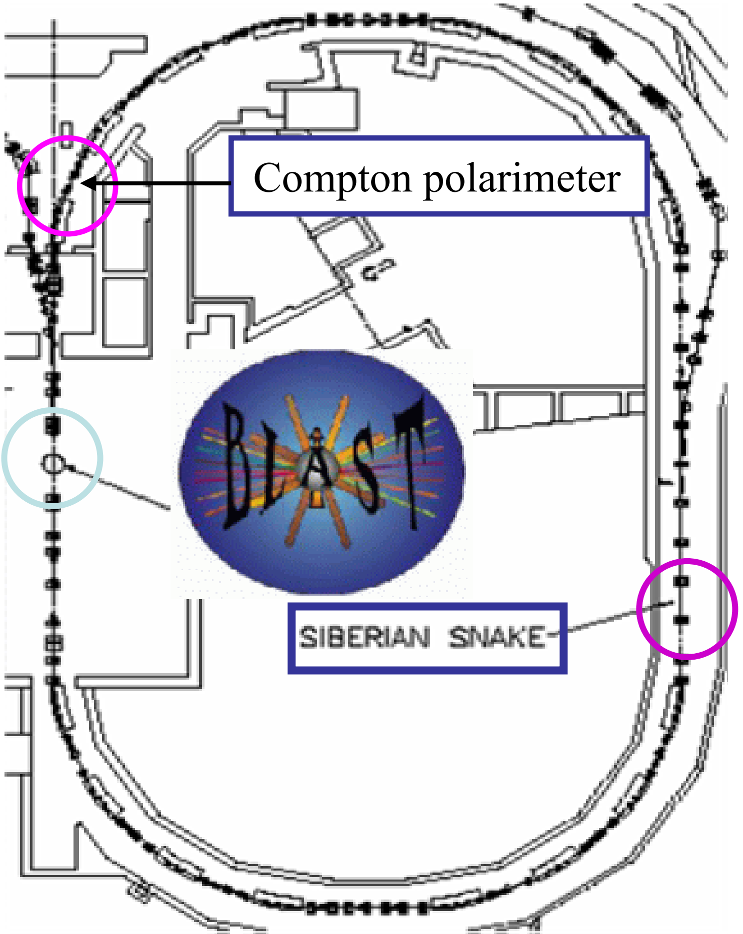
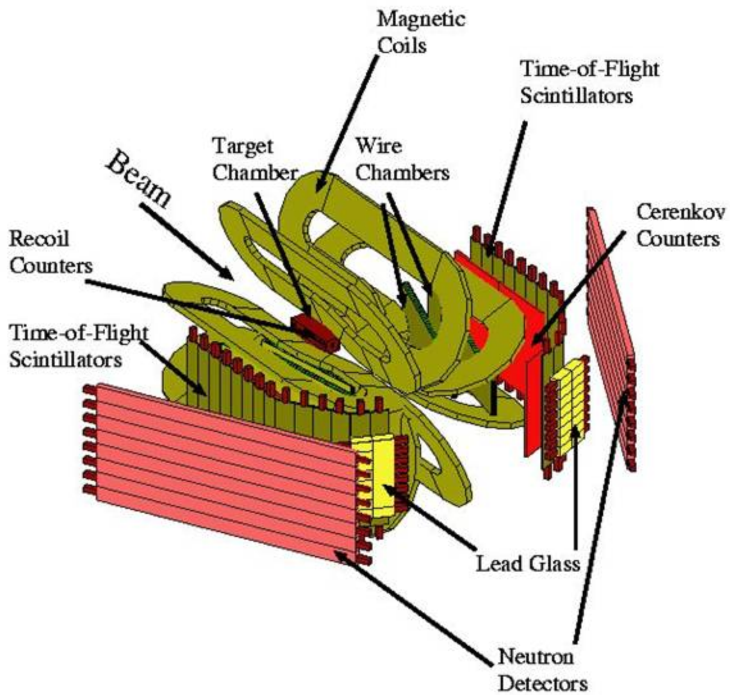


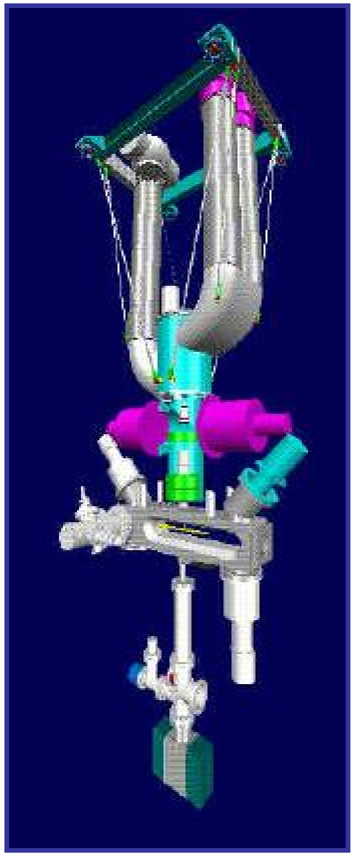
BLAST experiment:

Magnetic spectrometer with toroidal field and internal polarized storage cell target (deuterium)



South Hall Ring @ MIT-Bates

- **Target** located within the toroid spectro-meter field coils (!)
- Turbopumps placed outside the field region
- Other sensitive components are shielded or also placed outside the coil system



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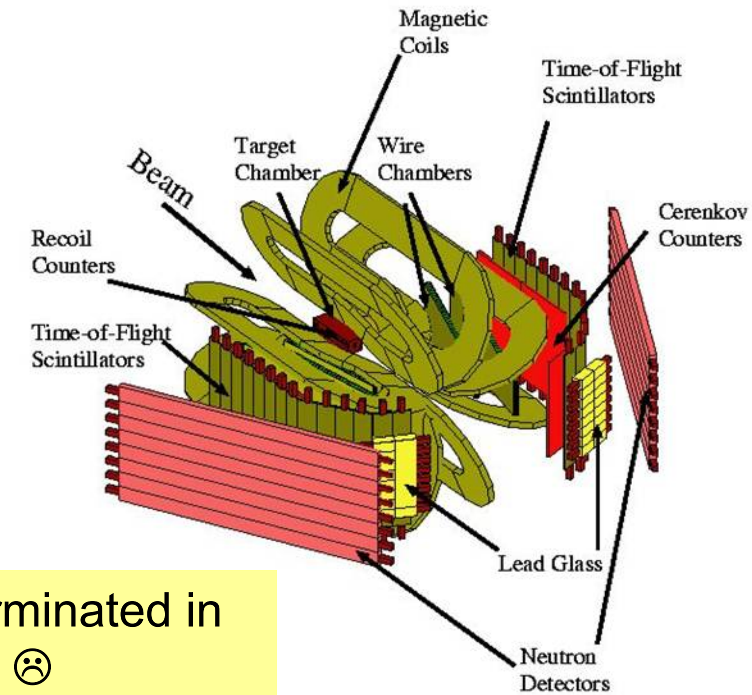
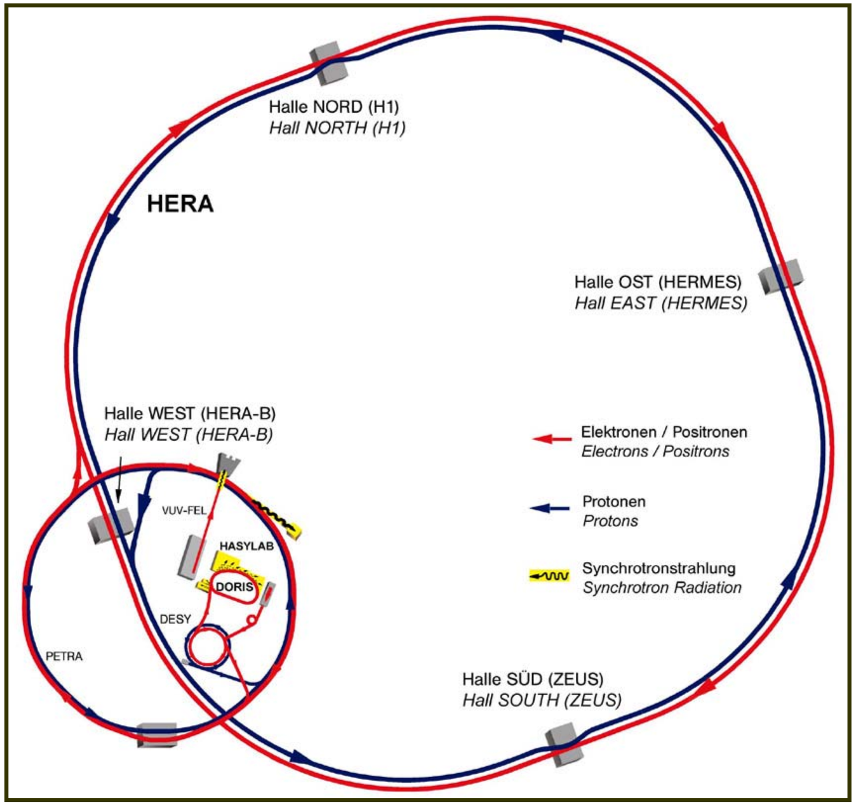


Operation terminated in June 2005 ☹

HERA Electron Proton Collider
DESY-Hamburg

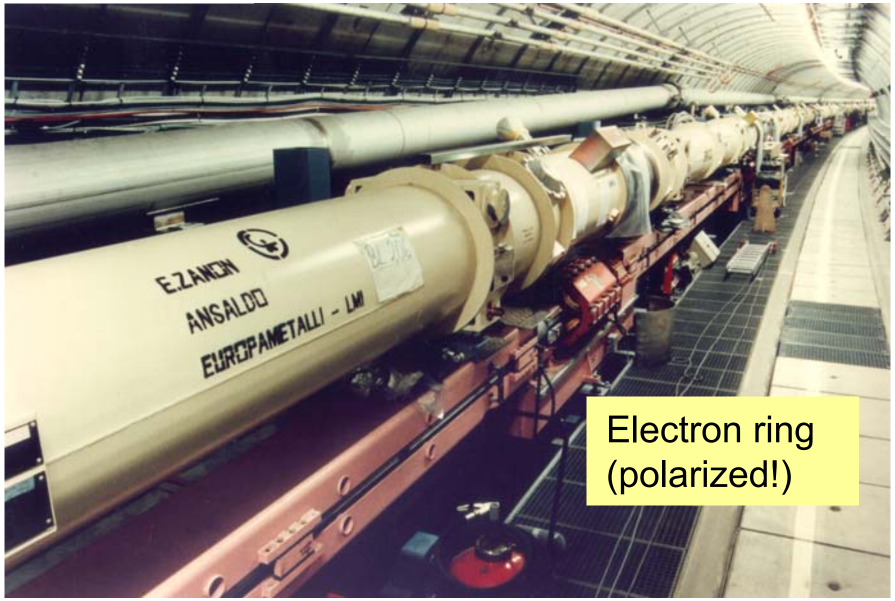


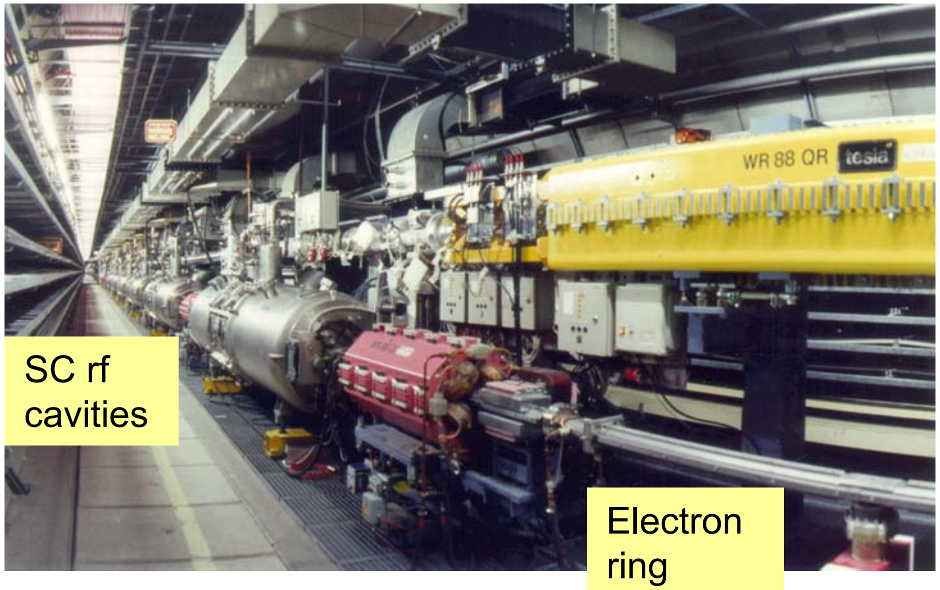
C = 6.3km, E_p = 920GeV, E_e = 30GeV (max)

First operation: 1992

HERA scheduled to shut down in July 2007

HERA Electron Ring





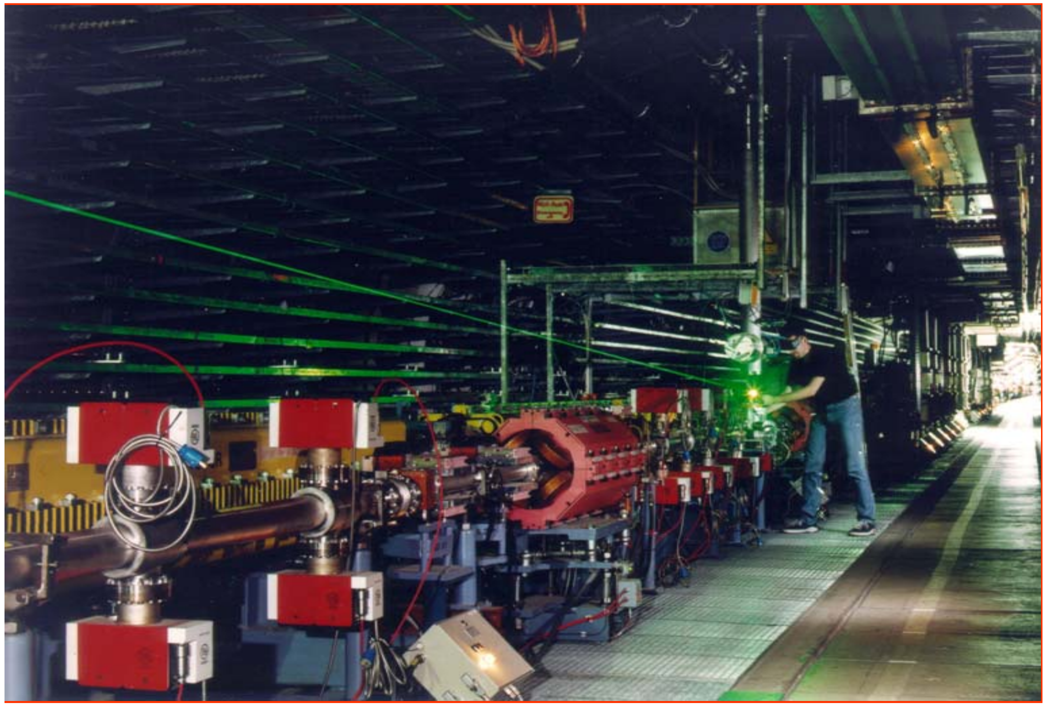
- C = 6336m, 4 straights 360m long
- Nominal energy: E_{el} = 30GeV
- $I_{max} \leq$ 50mA in 210 bunches (Δt = 96ns)
- Beam size at IP $\sigma_{x/y}$ = 0.29/0.07mm
- Acc. voltage U_{max} = 260MV (13.2MW)
- E-loss per turn 127MeV @ 30GeV
- $E_{\mathbf{operation}}$ = 27.5GeV ($\nu_{\mathbf{spin}}$ = 62.5)
- One/three Spin Rotators for longitudinal spin at IPs
- $P_{e\pm} \approx$ 60% (2000 run), rise time 30min
- Two collider experiments H1/ZEUS
- HERMES experiment with polarized H, D, 3He storage cell target

HERA Polarized Electron Ring

Beam polarization measured by Compton-Backscattering of pol. Laser photons.

Two polarimeters:

- TransPol (West Hall, op. since 1992)
- LongPol (East Hall, @ HERMES straight)



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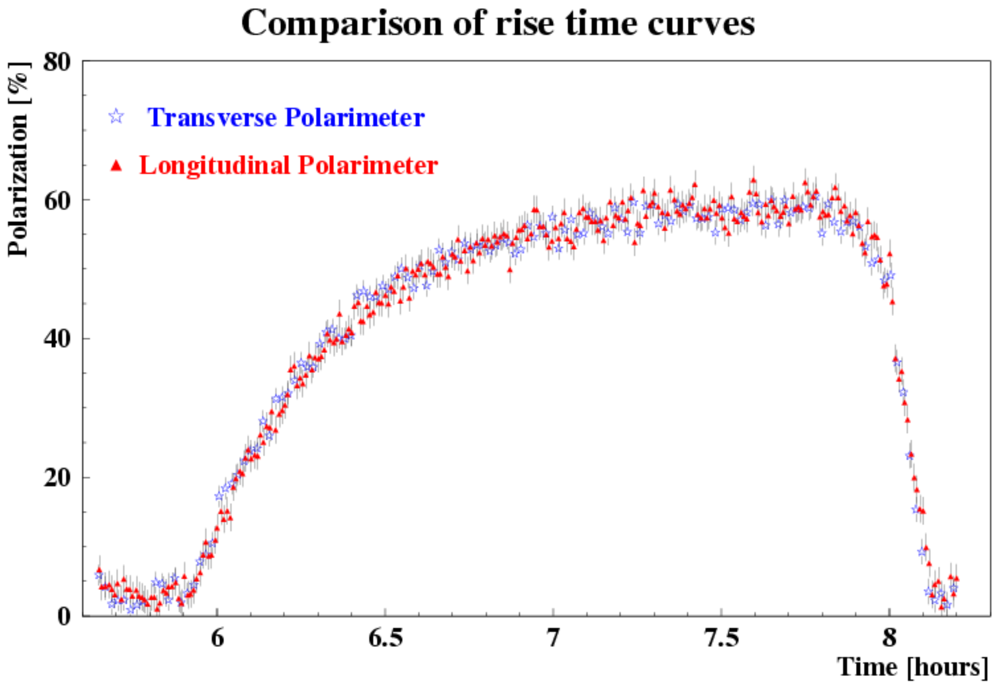

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- $\overline{P}_{e\pm}$ = 55% (2000 run), rise time 30min
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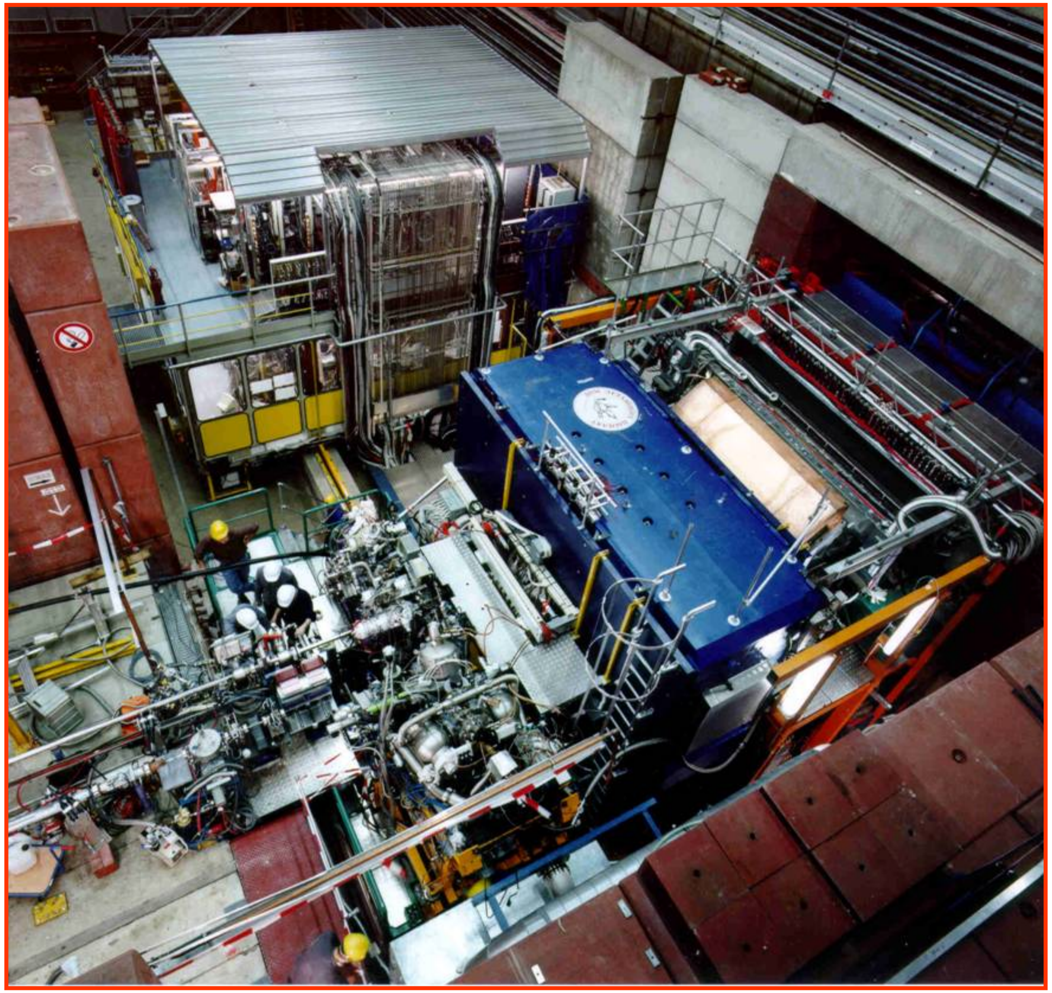
HERMES Experiment



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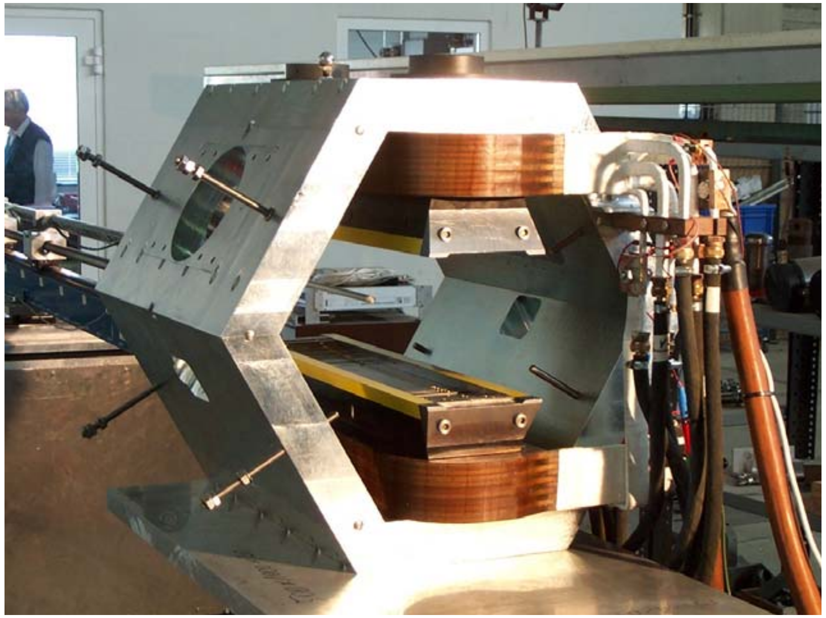
HERMES Target

- In 1995 successfully operated with ^{3}He target
- 1996-2005 ABS-SC target for H and D:
  - 1996-97 longitud. H
  - 1998-00 longitud. D
  - 2002-05 transverse H
- Operational continuously about 10 months /year
- Large data sets for DIS on polarized and unpolarized gases collected



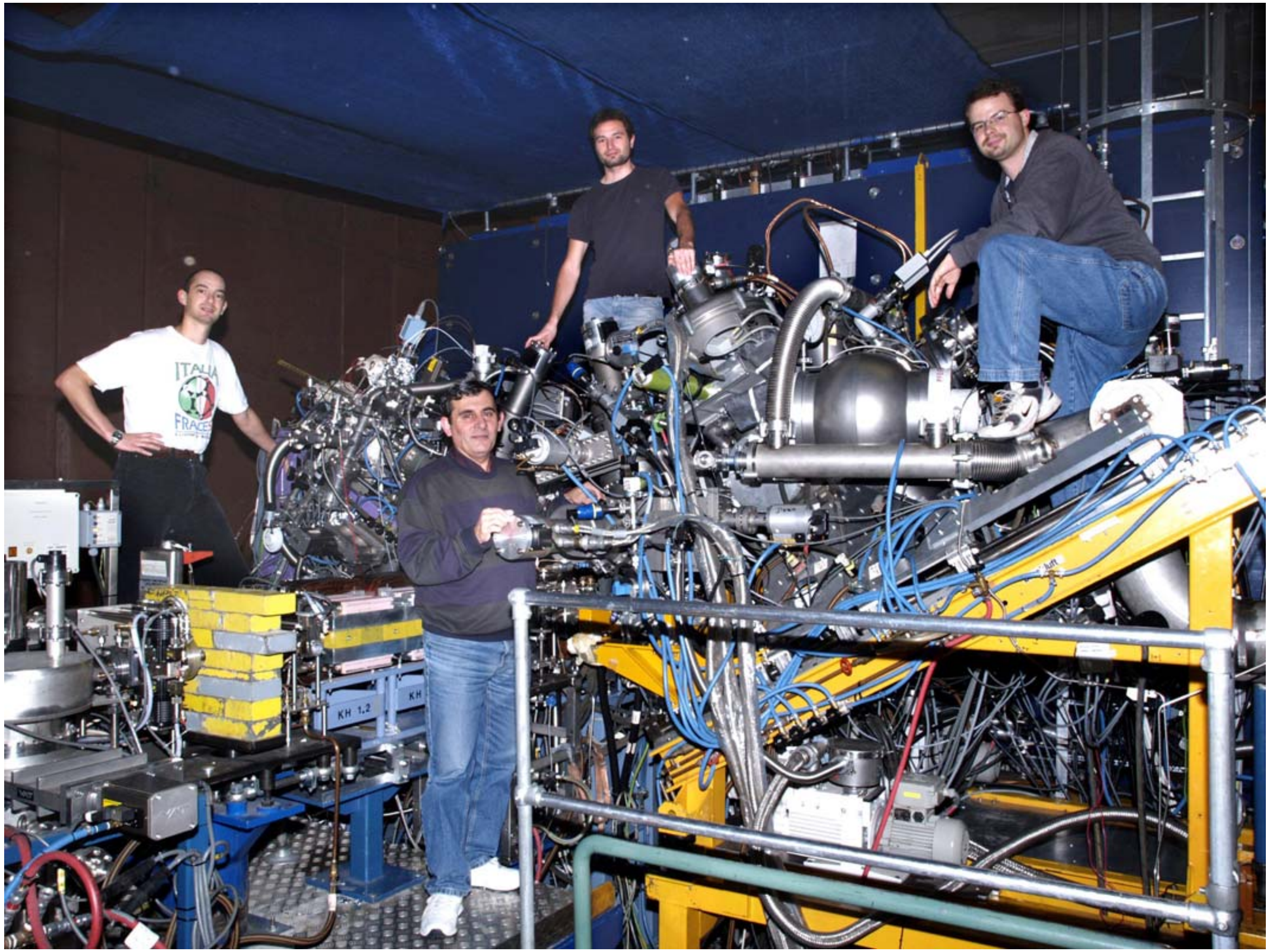
Transverse target magnet: high uniformity along cell axis required!

HERMES Target

Nov 2005:

Polarized H&D target removed!

Rest of Run-2: Recoil detector



Experiments at Ion Rings

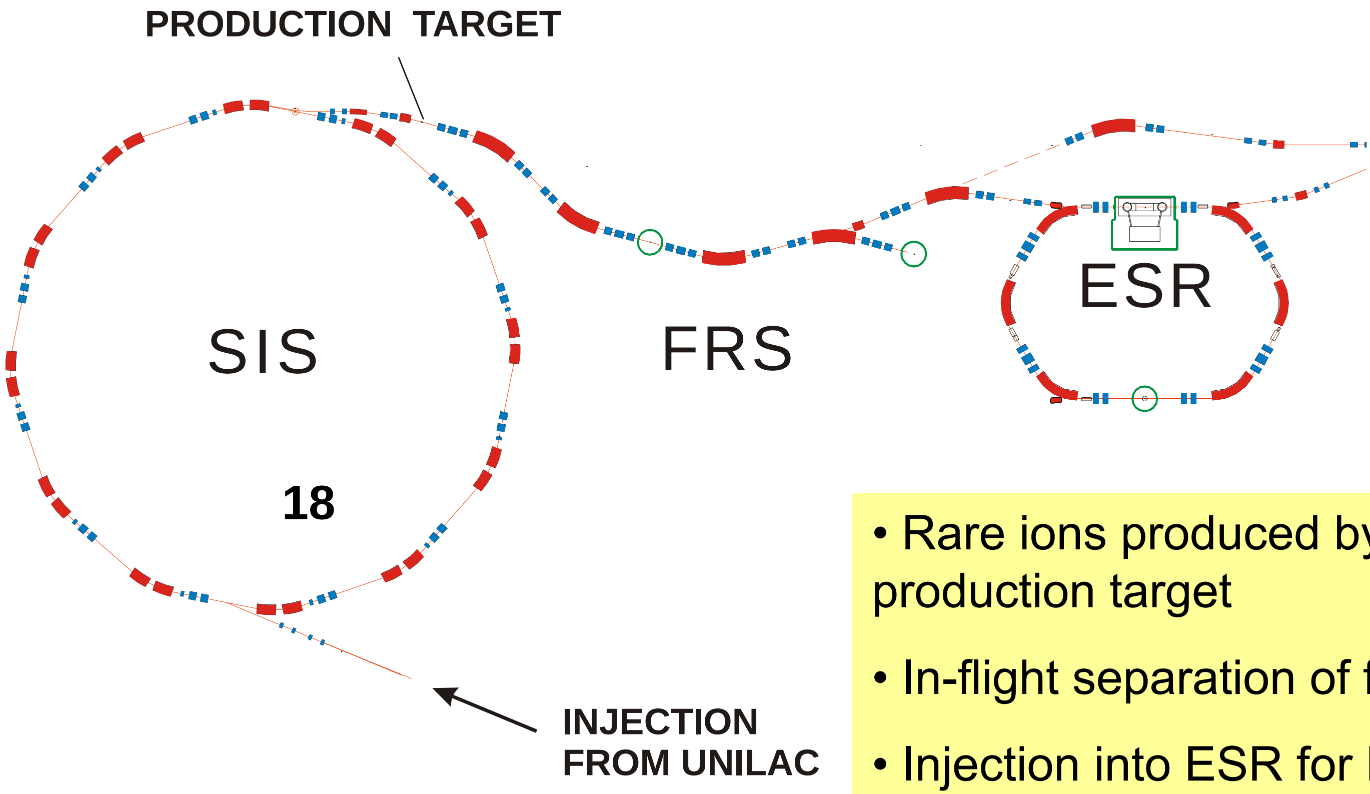
-Mass Measurements at ESR (GSI)

Use of the ESR as mass spectrometer – no target and detector!

-WASA at CELSIUS & COSY

- ANKE at COSY (Jülich)

Mass Measurement at ESR



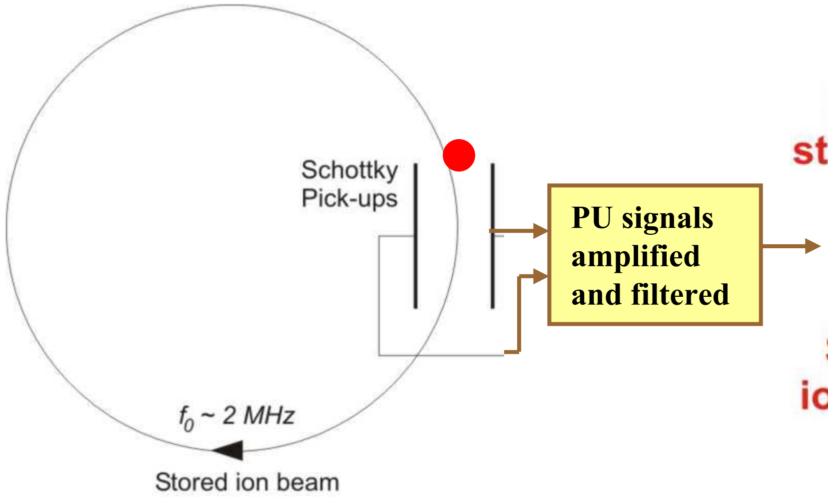
- Rare ions produced by SIS-18 beam on a production target
- In-flight separation of fragments by the FRS
- Injection into ESR for Mass Measurement via Schottky Fourier spectroscopy
- Large number of unknown isotopes far from stability measured

Measurement of Schottky Spectra

- Schottky noise is measured by means of a tuned Pick-up (quality factor Q)
- The summed signal is processed and Fourier-analyzed → High resolution!
- Two modes - cold beams: with Ecool → $\Delta v/v \approx 0$

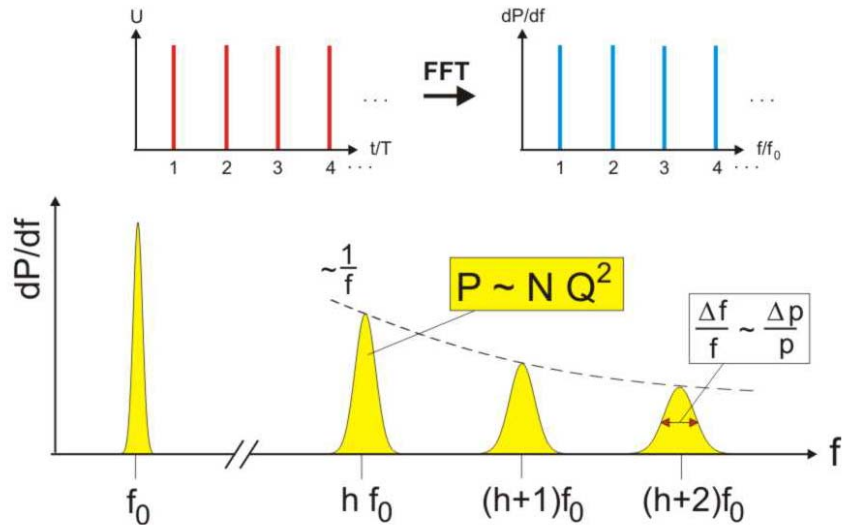
  - hot beams: with $\gamma = \gamma_t$ for $\Delta f/f \approx 0$

$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

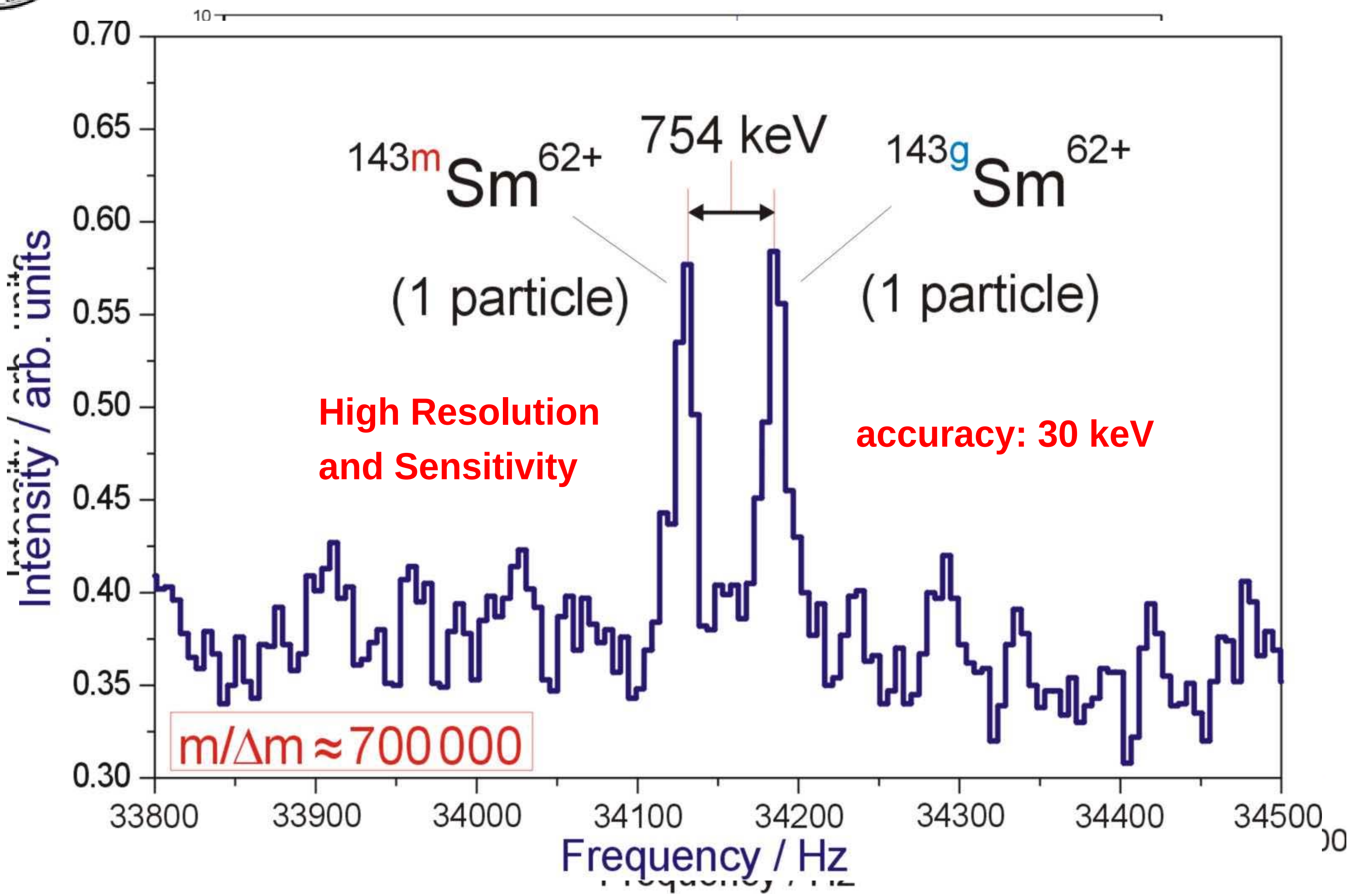


Single stored ion

Stored ion beam



Results on Mass Measurements

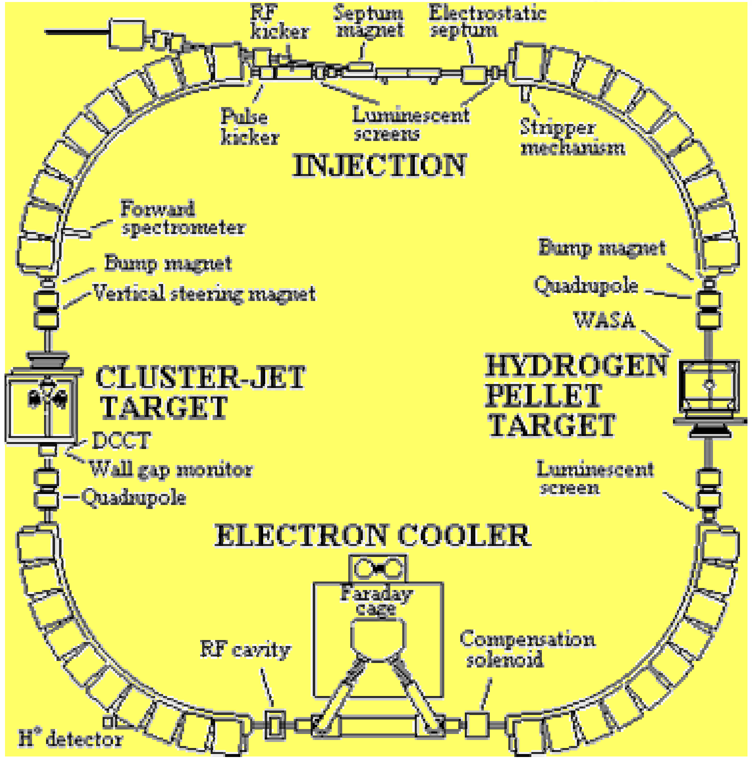


CELSIUS Ring

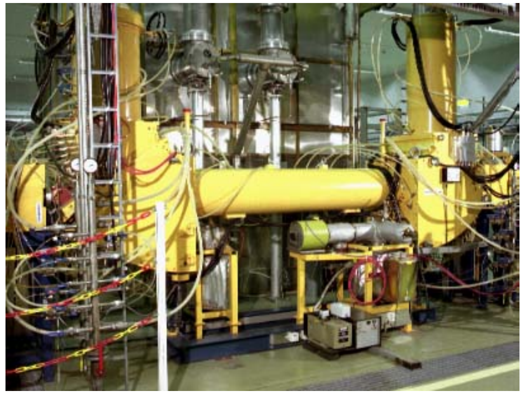
Previous incarnations:

•CERN (g-2) experiment

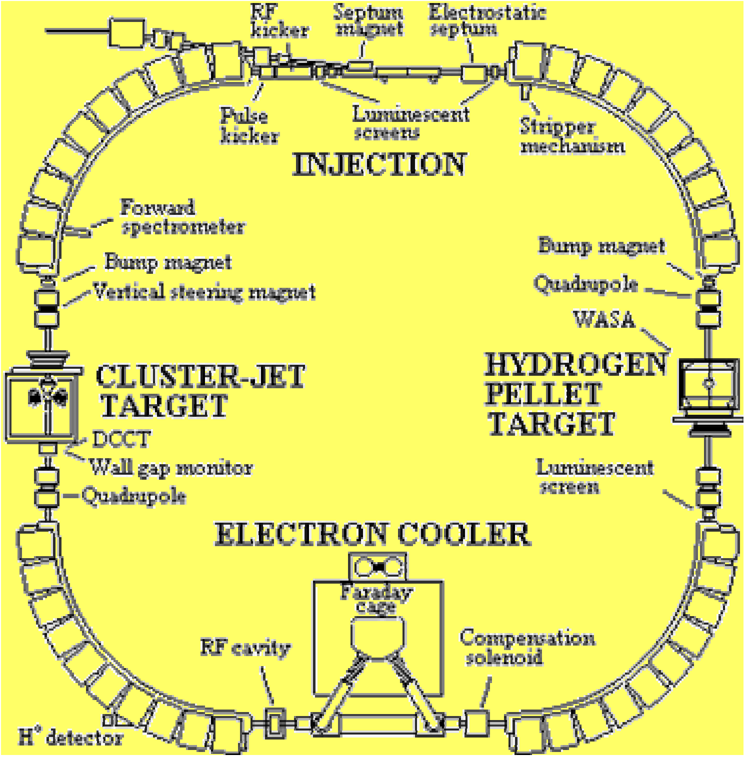
• ICE (initial cooling experiment)



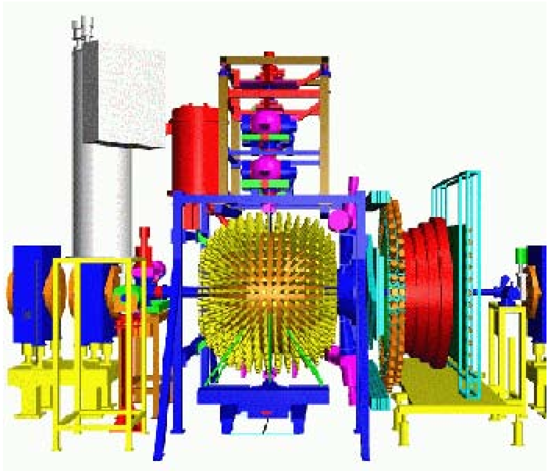
Circumference	81.8 m
Length of cooling and injection straight sections	9.6 m
Length of target straight sections	9.3 m
Bending radius	7.0 m
Maximum rigidity (at present)	7.4 Tm
Maximum kinetic energy (protons)	1.43 GeV
Maximum kinetic energy per nucleon for ions with $q/A = 1/2$	500 MeV



WASA Experiment



CELSIUS ring (1988 – 2005)



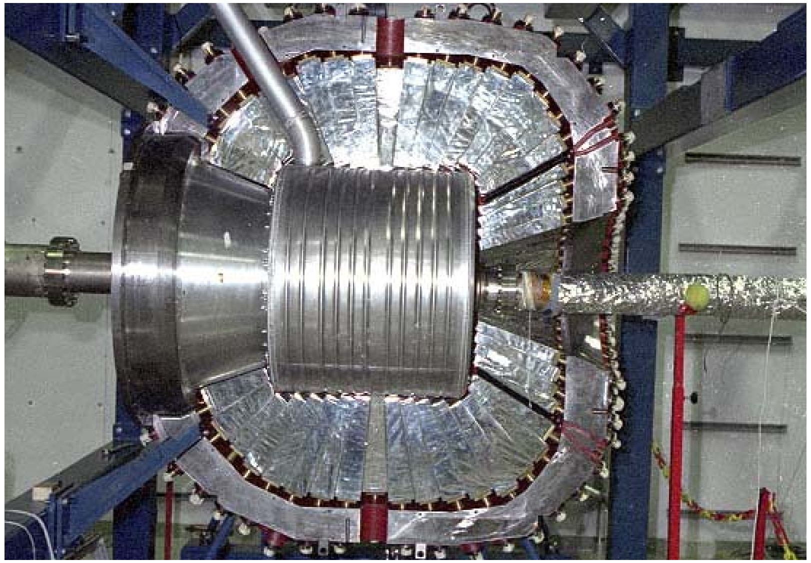
WASA experiment (1999-2005)

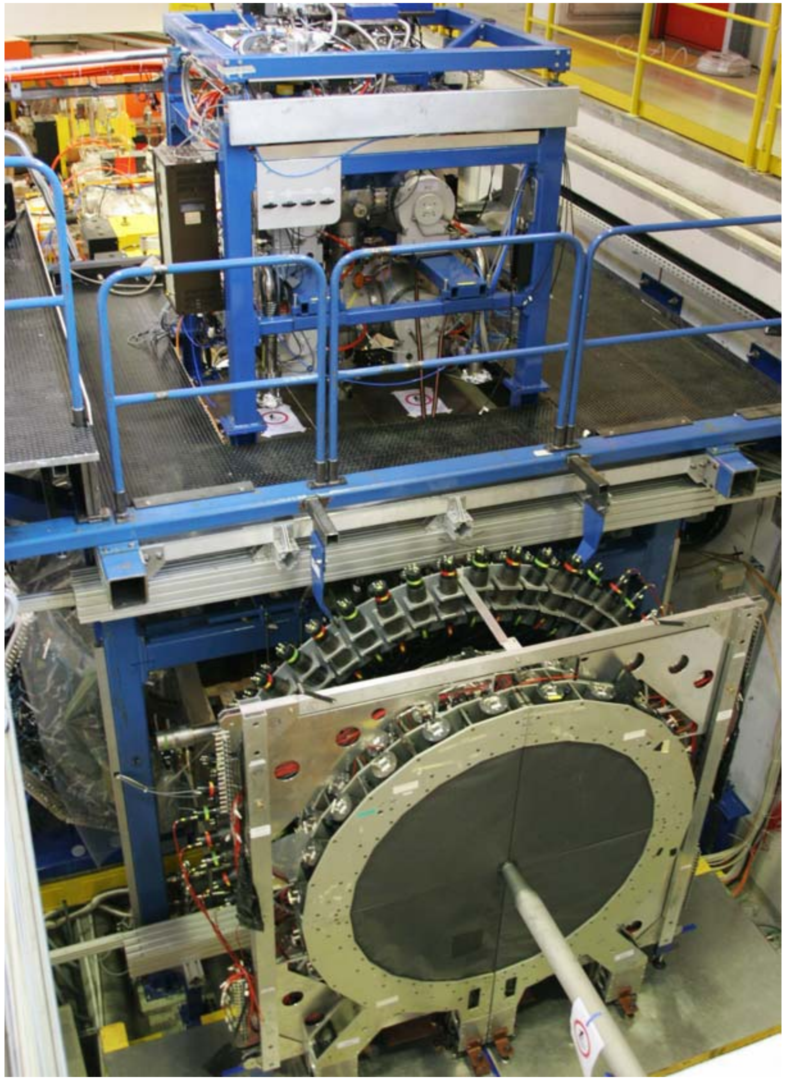
After the shutdown of CELSIUS in June 2005 WASA has been re-installed at COSY: new program in an extended energy range!

WASA Installation at COSY

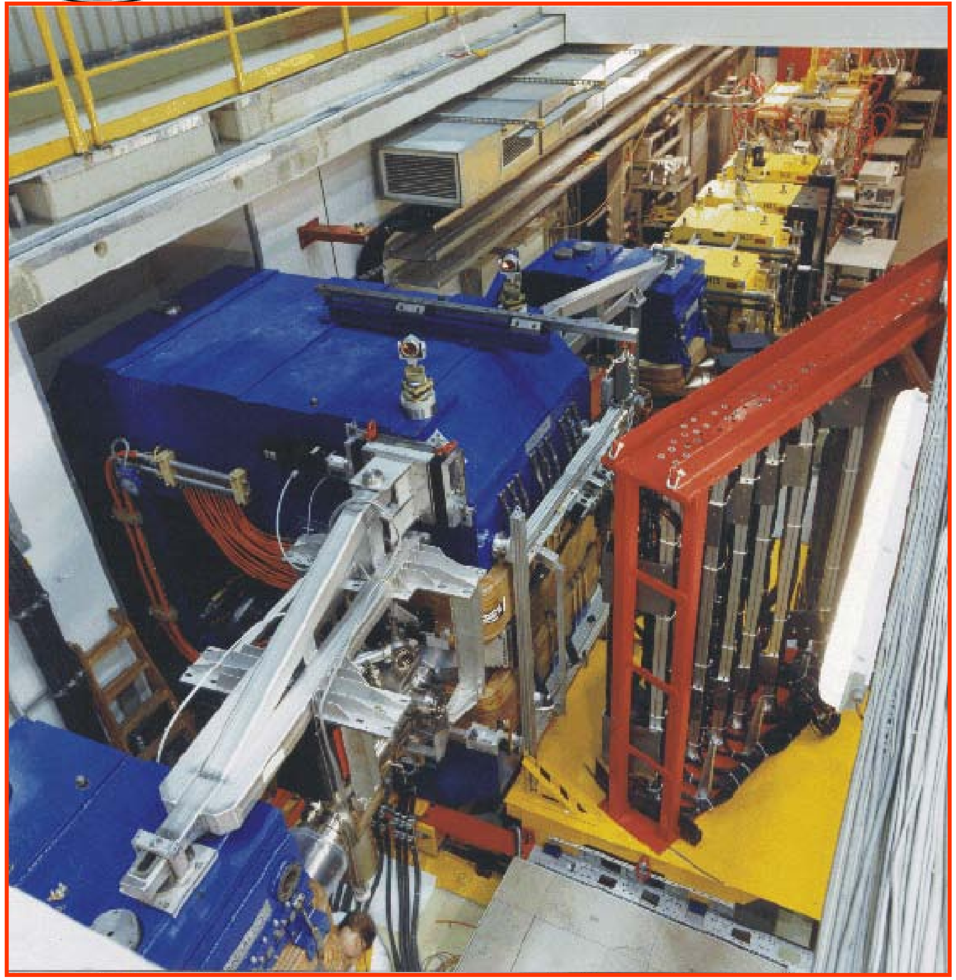
Task: to exploit photons in the final state as a probe!

Pellet target allows for close-to-4π geometry of the detector





ANKE Experiment at COSY



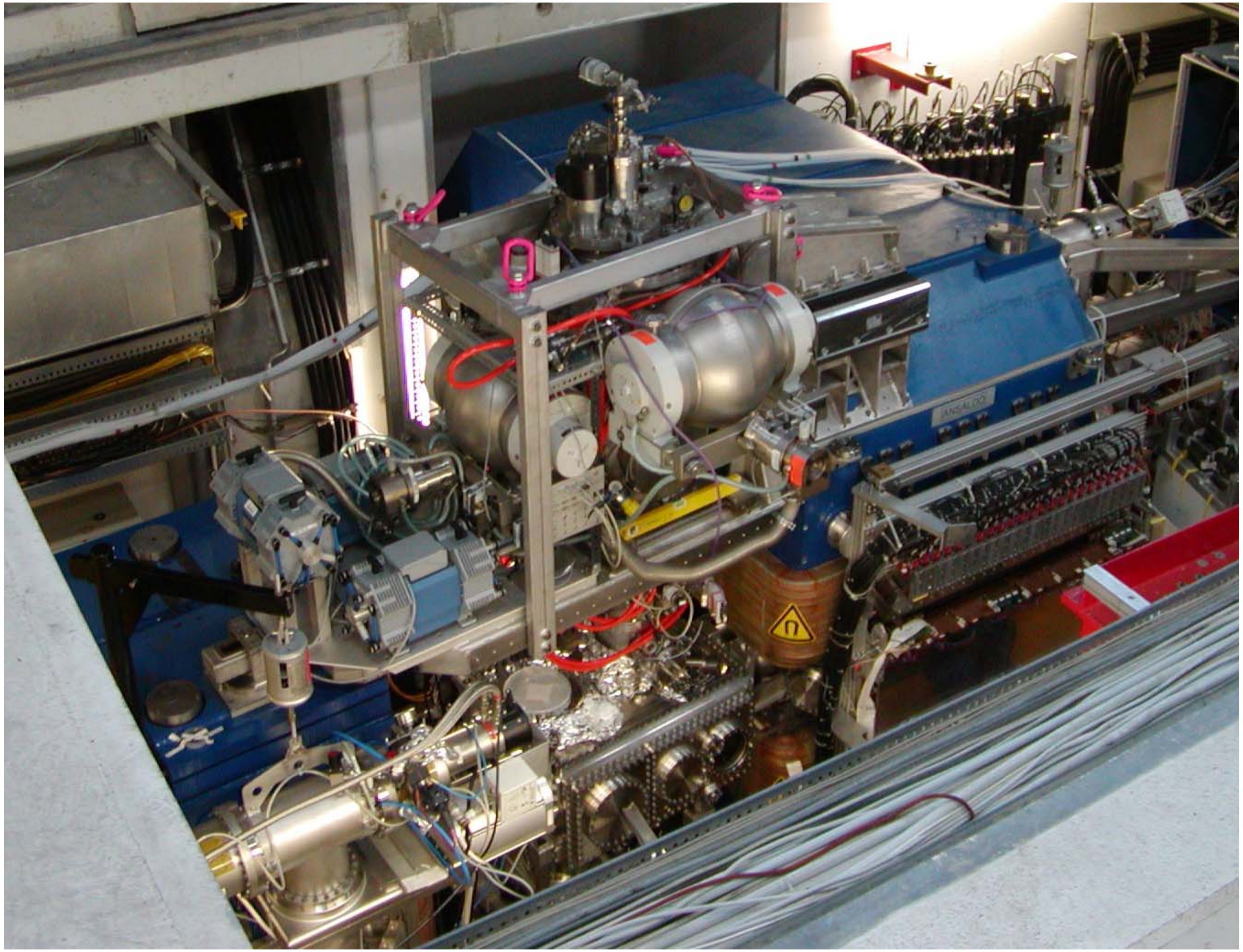
see talks by A. Kacharava (exp.) and R. Engels (target)

- COSY: Storage Ring with synchrotron acceleration and cooling
- Momentum range 0.3 - 3.7GeV/c
- Storage of polarized p and d beams
- Electron cooling at ≈ injection
- Stochastic cooling at high momenta
- Several internal target experiments:
  - EDDA (H jet / cell)
  - COSY-11 (H cluster target)
  - ANKE ($\vec{H}$, $\vec{D}$ cell)

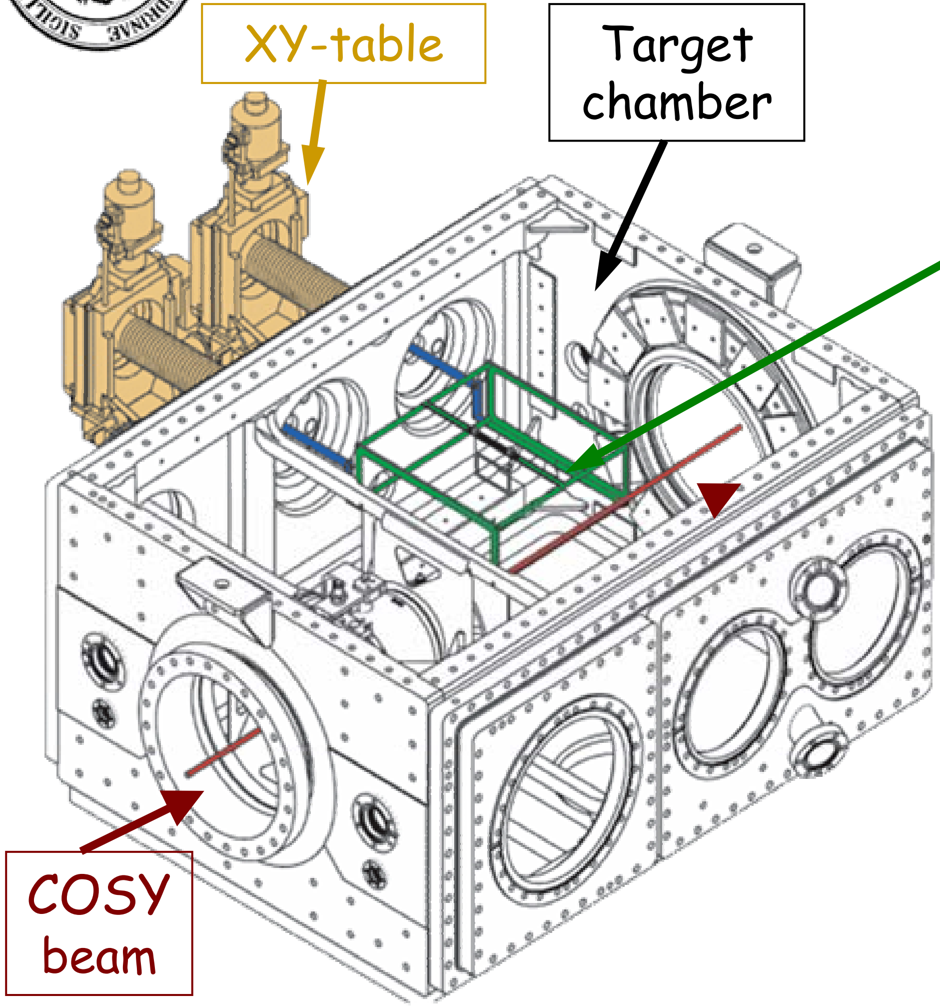
Commissioning: - WASA (H pellet target)

PIT at ANKE

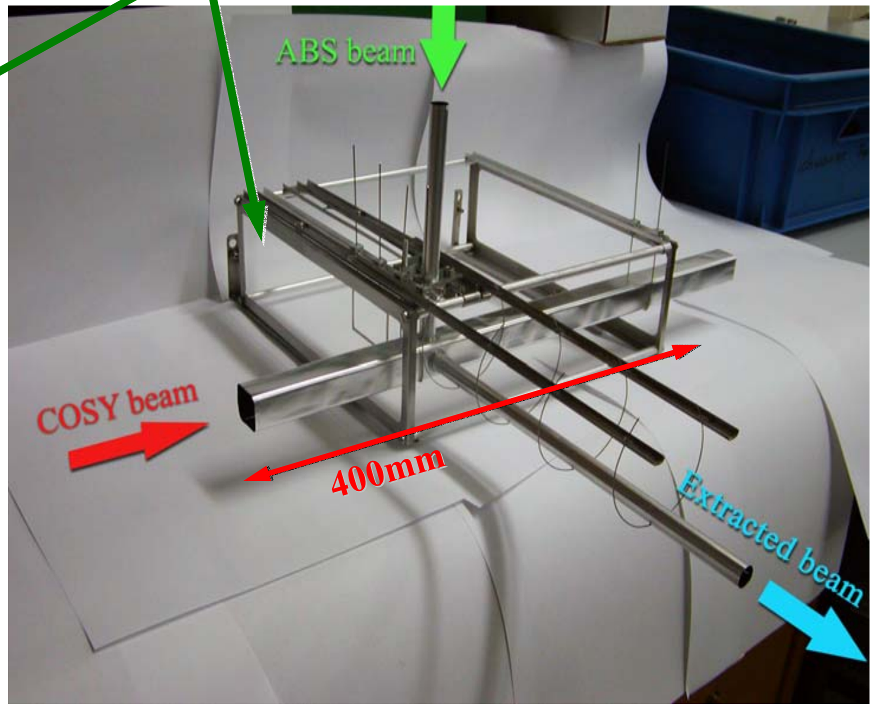
see talk by R. Engels/F. Rathmann



Storage Cell Setup



Frame with storage cell and aperture



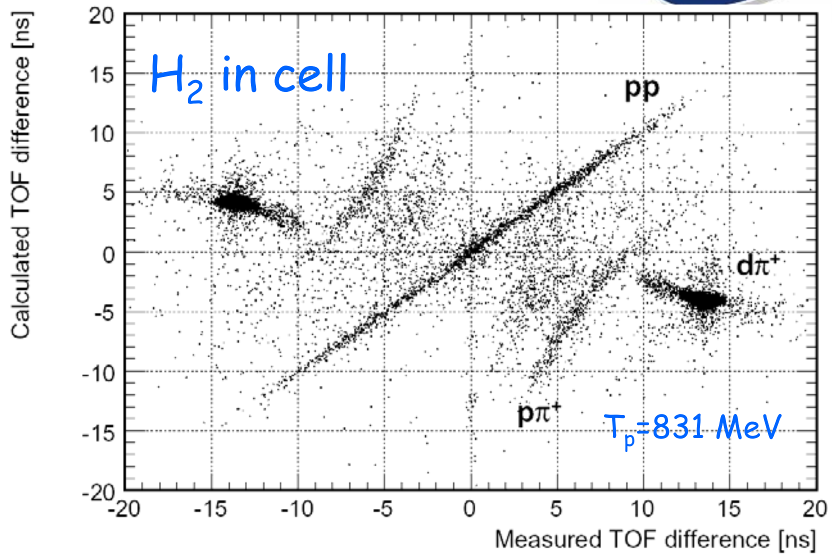
Feeding tube:	**l = 120 mm, Ø = 10 mm**
Extraction tube:	**l = 230 mm, Ø = 10 mm**
Beam tube :	**l = 400 mm, 20x20 mm^2**

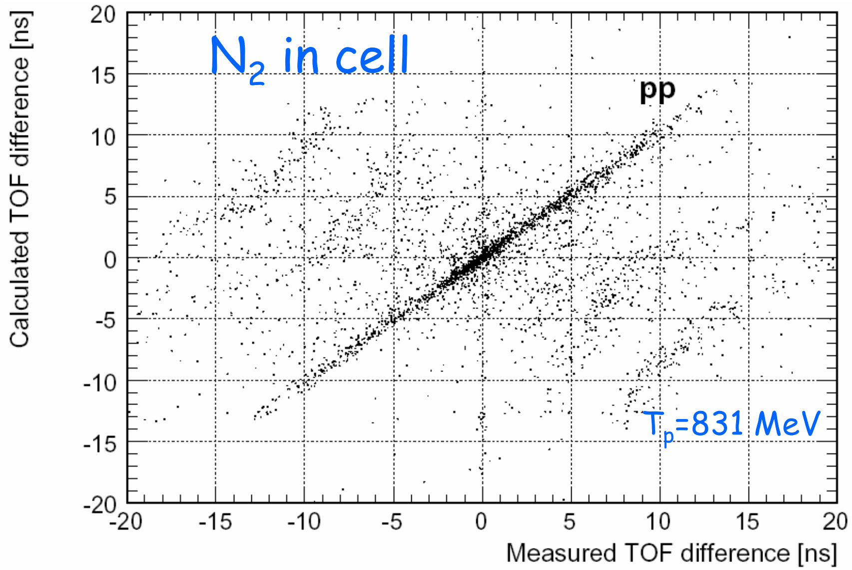
Background from Cell Wall

Use of Nitrogen gas in the cell to simulate background from interactions with the cell wall

The cell was fed with H_2 or N_2:

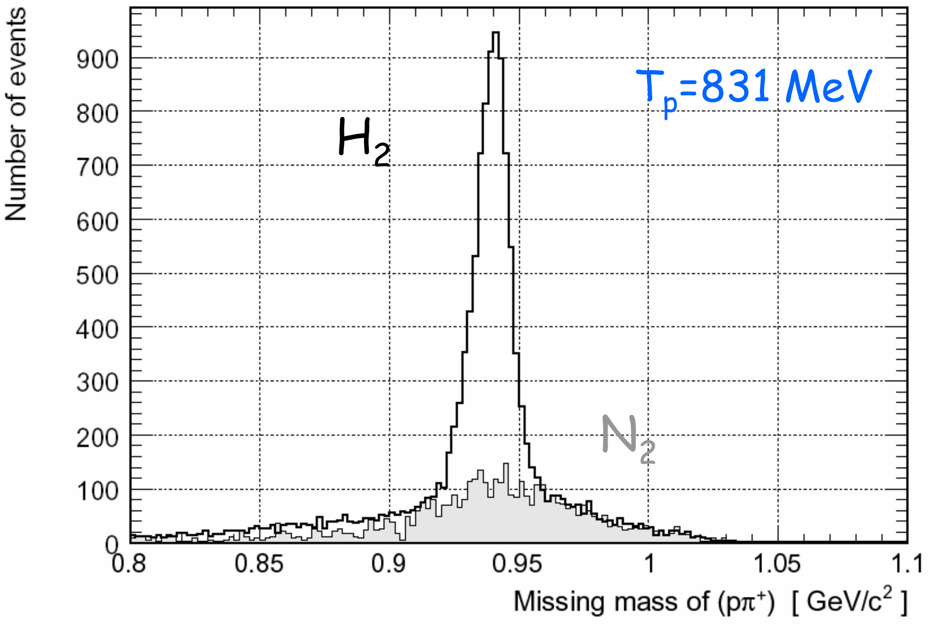
- H_2 flux adjusted to match target chamber pressure at equivalent flux of single HFS.
- N_2 flux adjusted to yield the same energy loss per unit of time in COSY compared to H_2, i.e. similar beam heating.

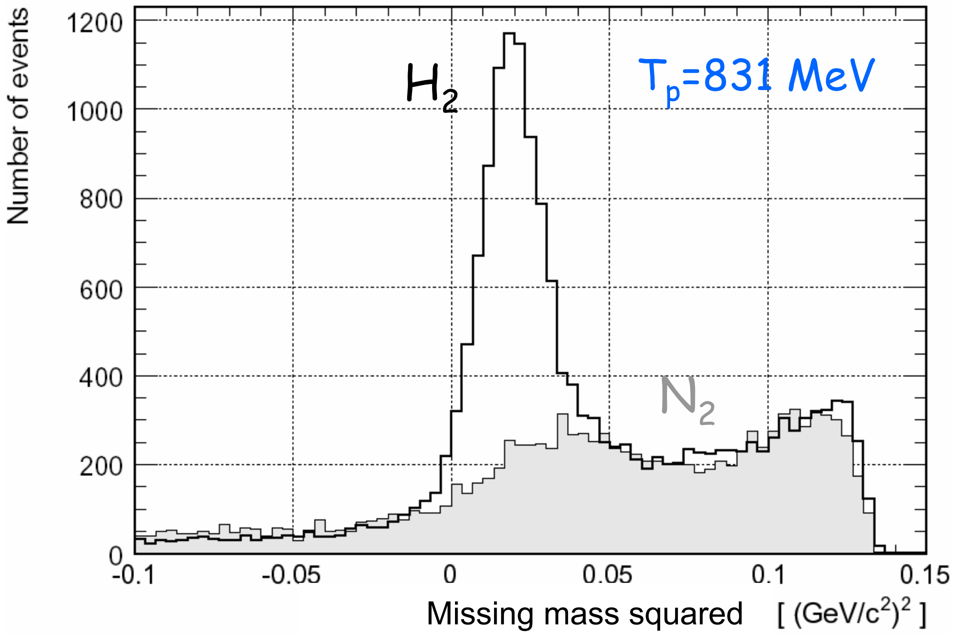




Missing Mass Distributions

$pp \rightarrow pn\pi^+$ $\qquad$ $pp \rightarrow pp\pi^0$



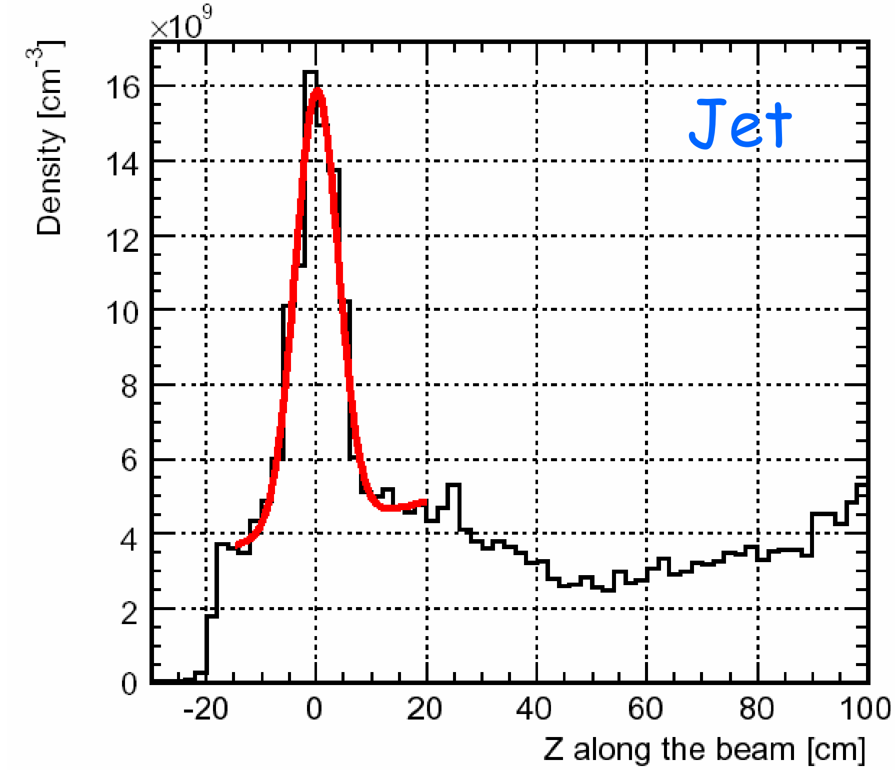


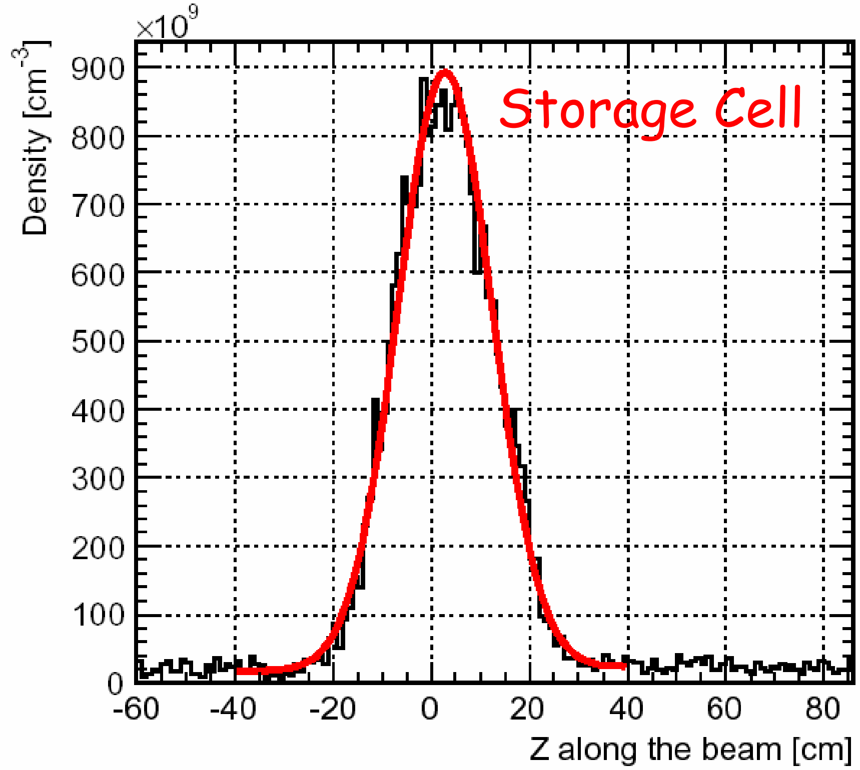
Stochastic Cooling

- compensates the beam heating
- keeps the background from beam-wall interactions at a tolerable level
- Identification of three-body final states with PIT at ANKE is possible

Target Thickness (from pp→dπ+)

See talk by S. Dymov





Method	Jet [atoms/cm²]	Storage Cell [atoms/cm²]
ABS flux (+ cell geometry)	$(1.6\pm0.1)\cdot10^{11}$	$(1.9\pm0.1)\cdot10^{13}$
Rates (pp→dπ+)	$(1.5\pm0.1)\cdot10^{11}$	$(2.1\pm0.1)\cdot10^{13}$

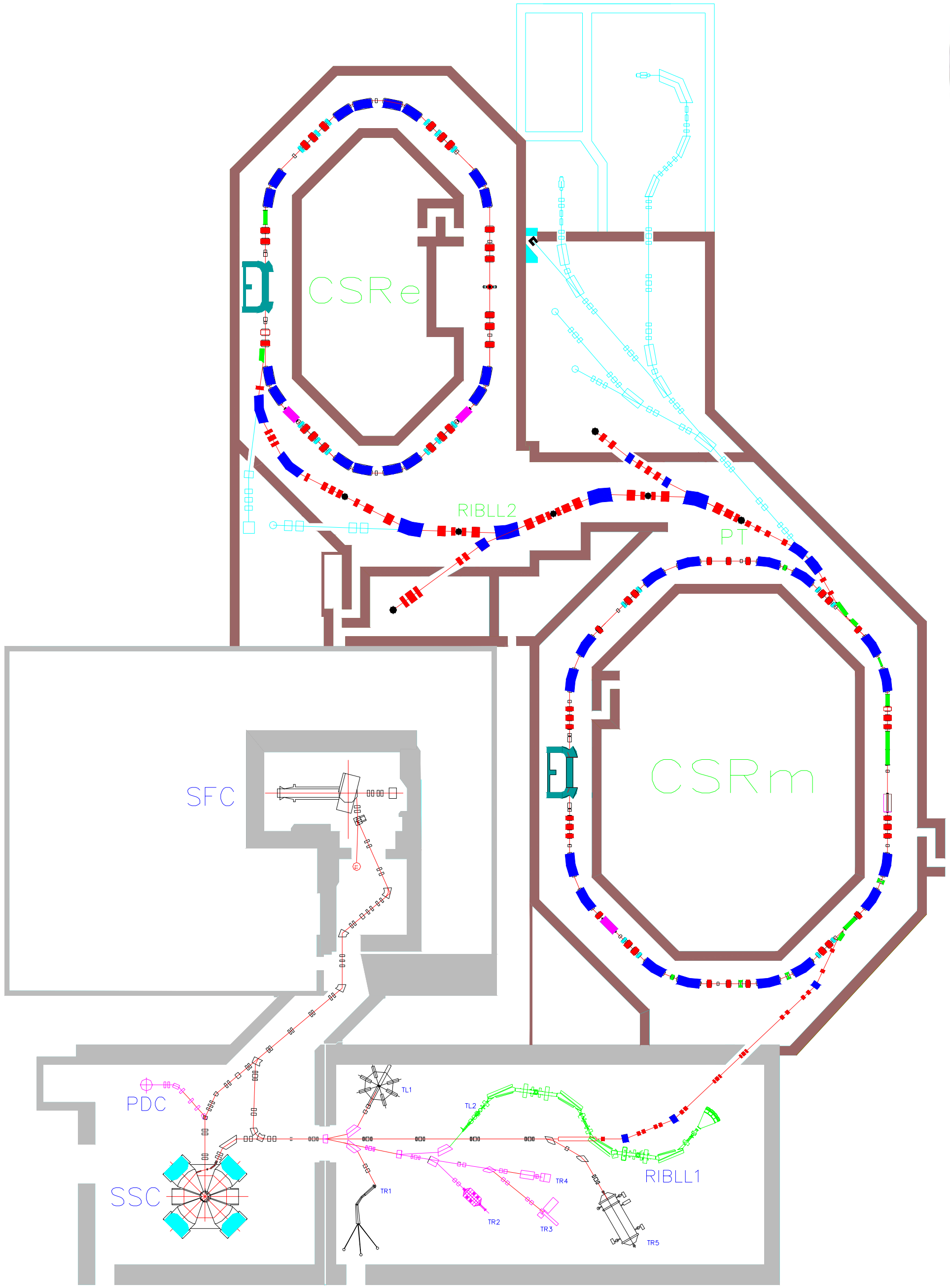
Future Challenges

Future experiments

- at CSR-e/m (Lanzhou)
- and at FAIR (Darmstadt)

HIRFL-CSR (Lanzhou)

- Rare Ions produced by the SSC (K=450)
- accepted by **CSRm** and accelerated
    - Q/A = ½: 900MeV/A
    - U^{70+}: 400MeV/A
- transfered to **CSRe** for internal target experiments with RIs
    - Q/A = ½: 600MeV/A
    - U^{90+}: 400MeV/A
- both rings equipped with electron cooling (35keV / 300keV)



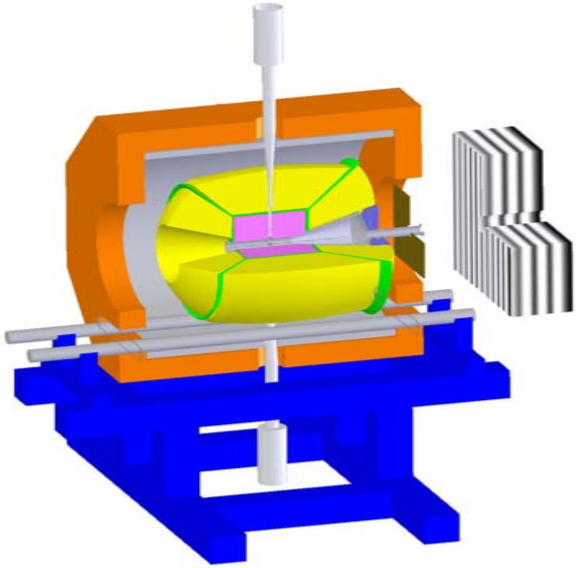
Status of CSR complex

- Both rings assembled
- CSRm in the commissioning phase

CSRm

CSRe

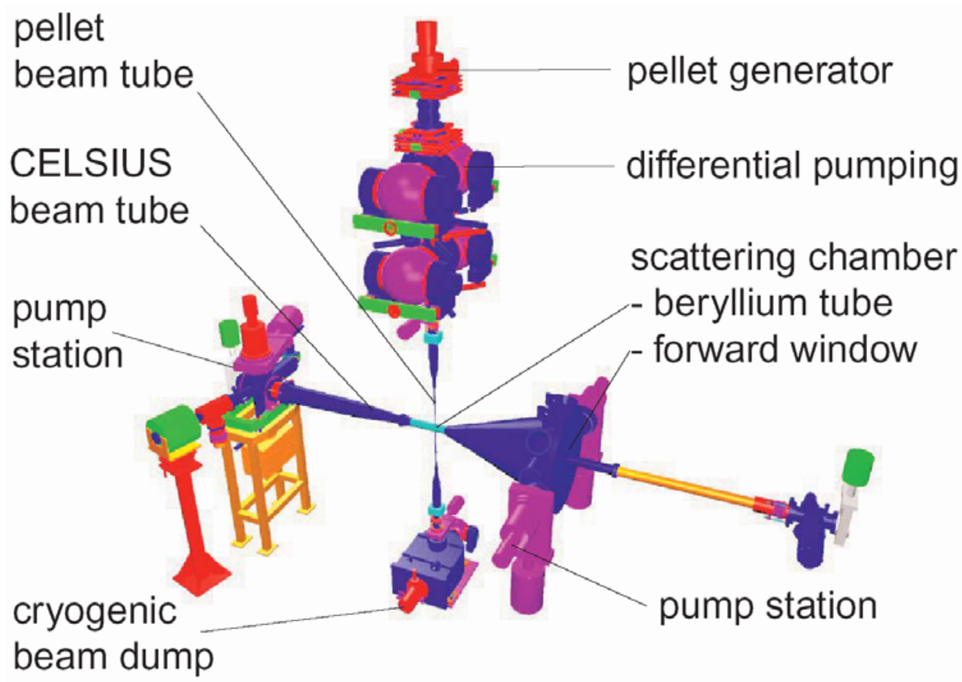
4π Detector for CSRm



Pellet Target

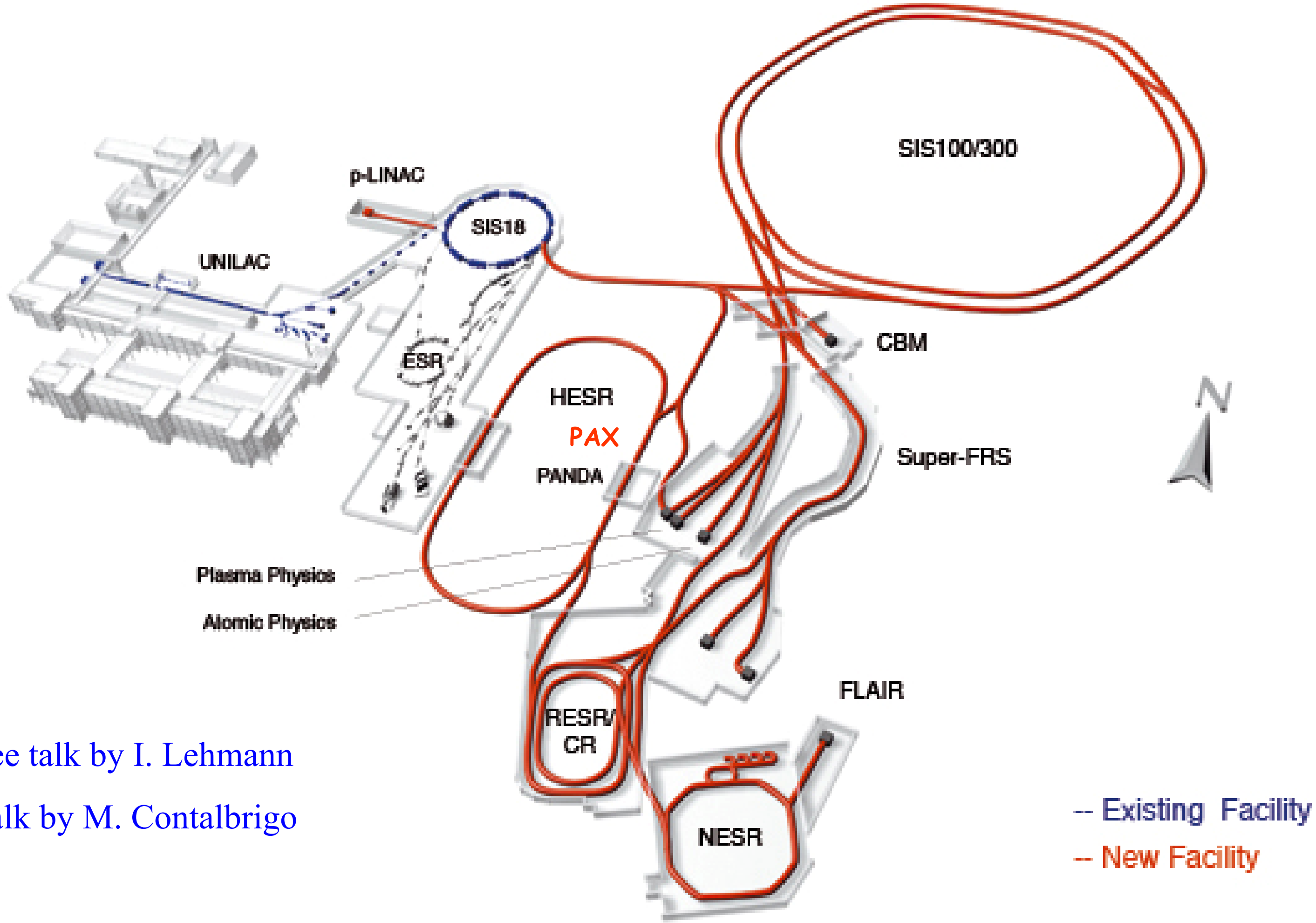
Forward detector (4°~18°)

Central detector (20°~160°)



In collaboration with TLS, Uppsala, Sweden

Future of Hadron Physics in Europe: FAIR (GSI-Darmstadt)



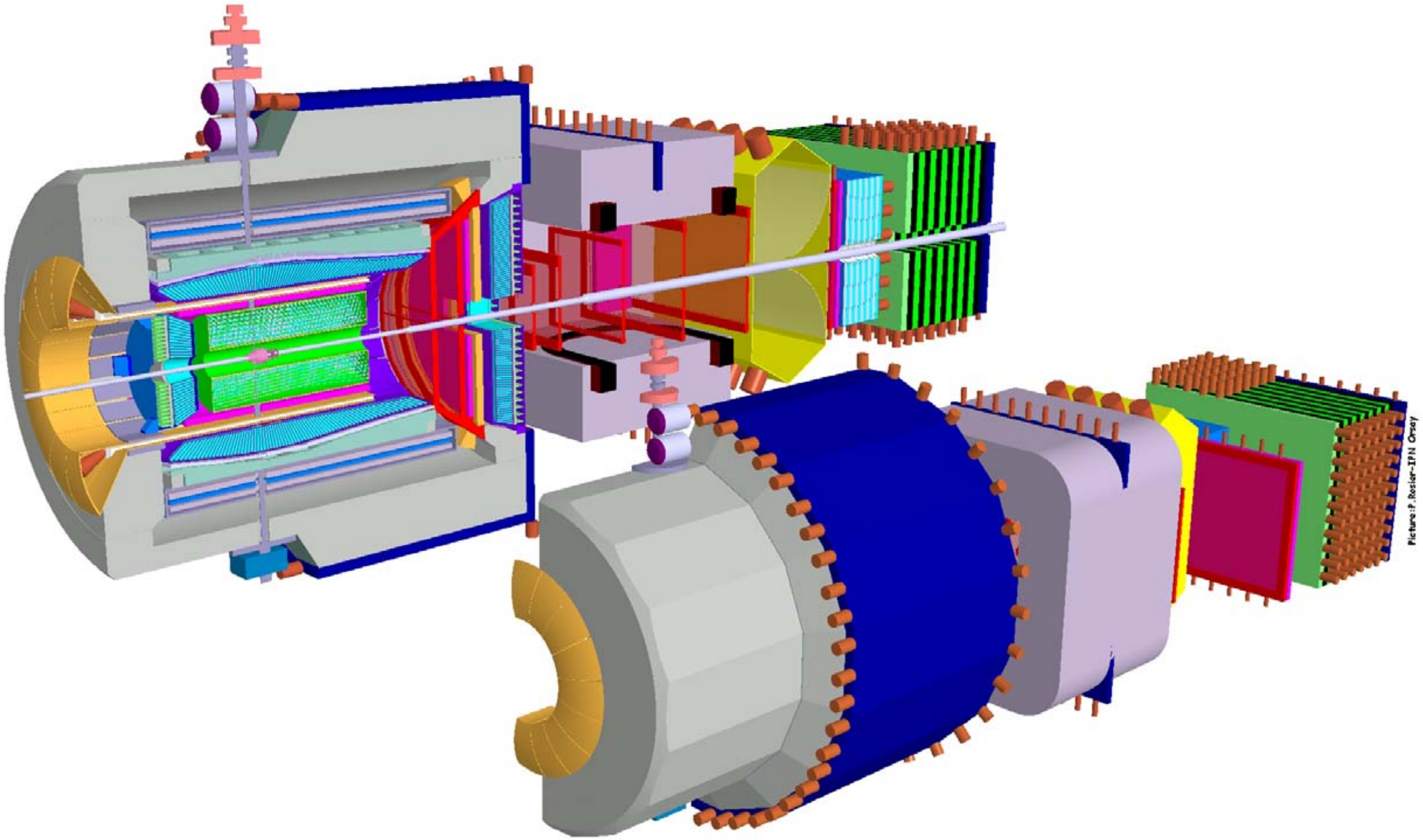
PANDA: see talk by I. Lehmann

PAX: see talk by M. Contalbrigo

PANDA Experiment

see talk by I. Lehmann

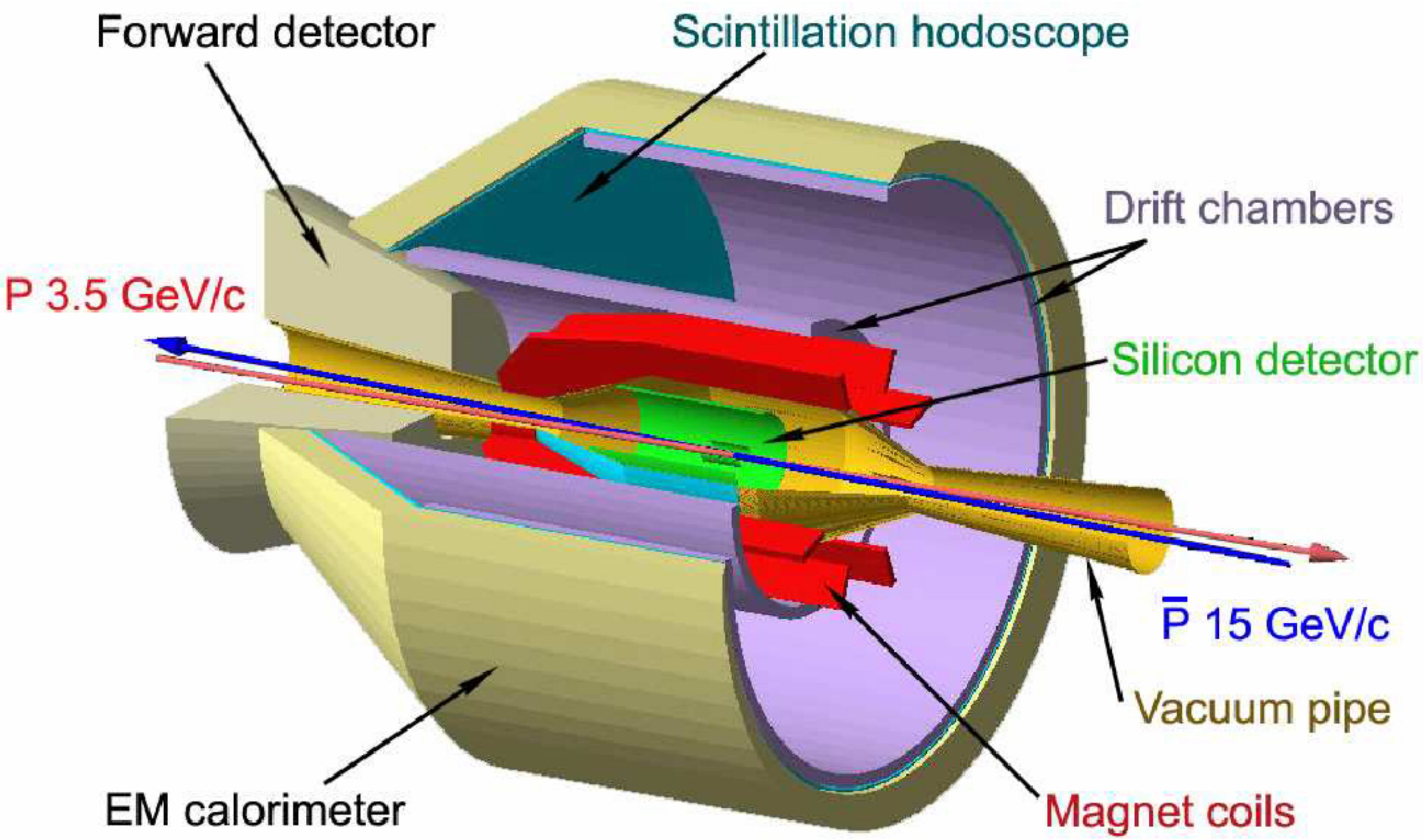
- 4π detector surrounding the IP
- Pellet target for high luminosity
- Dipole magnet for forward region



PAX Detector

see talk by M. Contalbrigo

- Barrel-type detector with toroidal field coils for low stray field
- Inner Si-tracker
- Intermediate drift tracking chambers
- Outer segmented em calorimeter
- Dual use of the detector for fixed target and collider operation



Conclusions

• Storage ring experiments represent a very advanced, powerful tool for Nuclear and Hadron Physics and other fields

• We are discussing an impressive variety of operating and future facilities

• New large-scale facilities in Europe, China and Japan in the design or commissioning phase will enable experiments of excellent potential

• Hadron physics using ion and antiproton beams has great promise for the future!

Thank you for your attention!

ABC