GSI --

Future Plans

- What
- Why
- How

W. Henning / Aug-3-00 / Chicago

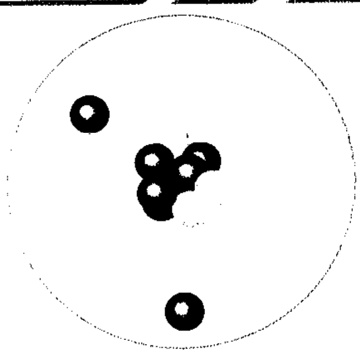
GSI Darmstadt

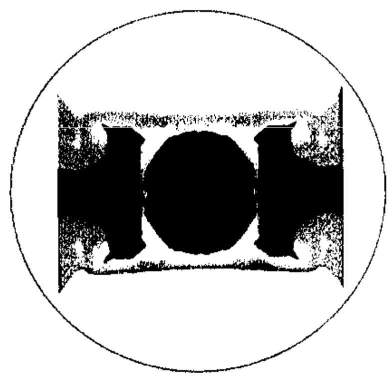
Rare Isotope Physics
- nuclei at the extremes
- nuclear astrophysics
- fundamental symmetries

Intense beams of short-lived nuclei (10^{12} 1 GeV/u ^{238}U)

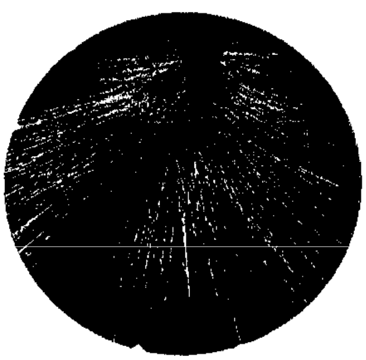
Plasma Physics
- matter at the extremes of pressure and temperature

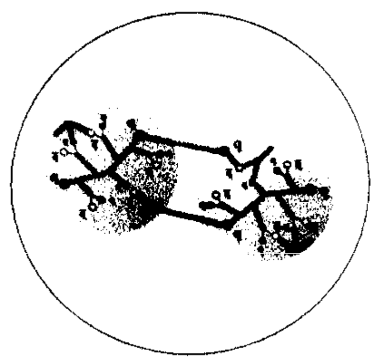
Heavy ion pulses (~0,5 GeV/u) of highest power density (20 kJ)





200 Tm





Nuclear Matter at the Highest Baryon Densities
- the nuclear matter phase diagram
- QCD phase transitions

High energy heavy ion beams (^{238}U at 22 GeV/u)

QCD Structure of Baryons and the Origin of the Nuclear Force
- Quark-Gluon dynamics of charmed particles
- CP violation in the charm sector

Intense proton (30 GeV) and cooled antiproton beams (12 GeV)

LOI

"Construction of a GLUE/CHARM Factory at GSI"

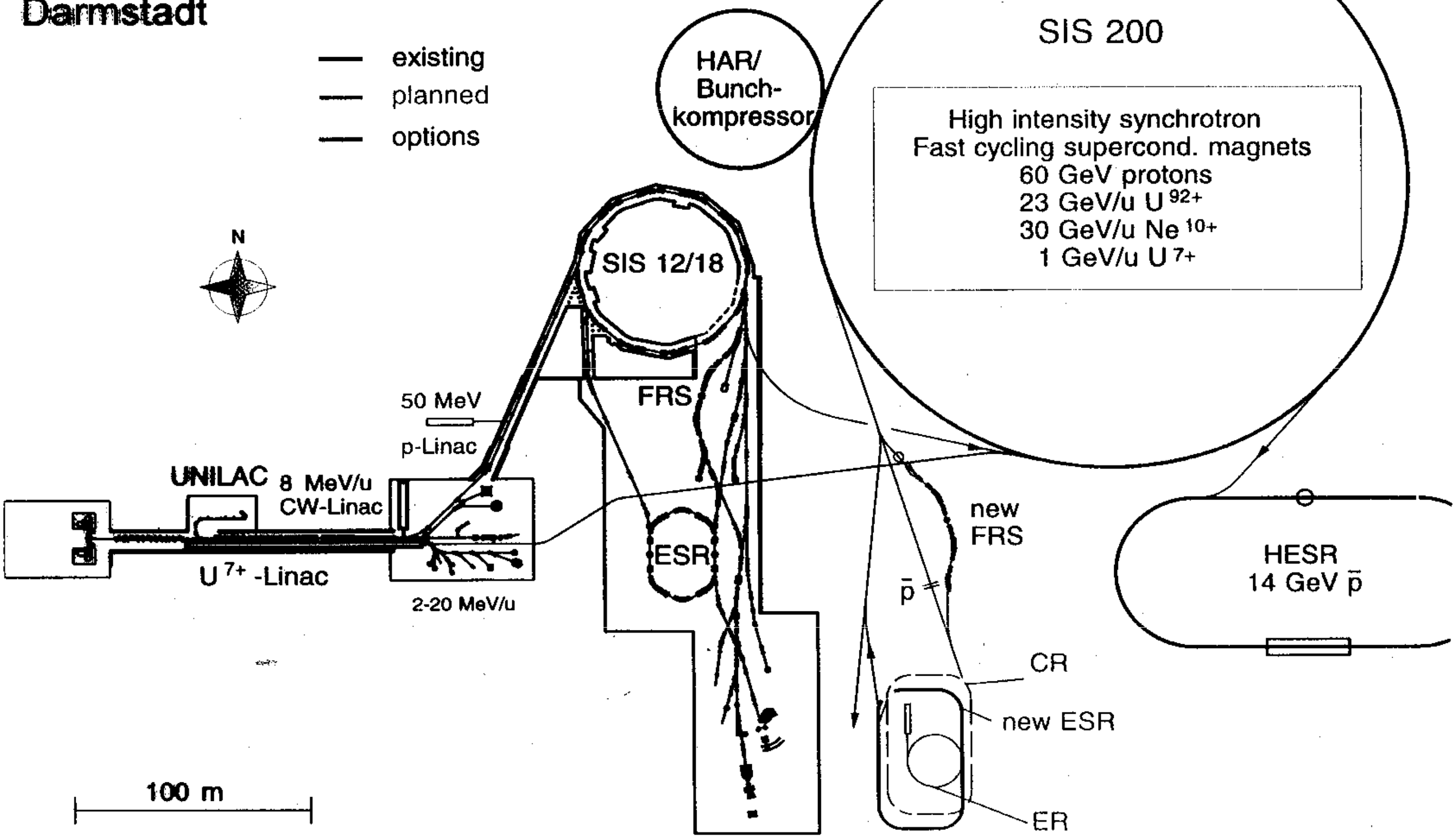
Ed. Board: B. Franzke (GSI)
P. Kienle (Munich)
H. Koch (Bochum
W. Kühn (Giessen)
V. Metag (Giessen)
U. Wiedner (Munich & CERN)

w. contributions from W. Cassing (Giessen),
S. Paul (Munich), J. Pochodzalla (Heidelberg)

Crit. + general support from M. Soyeur (Saclay) and
J. Wambach (Darmstadt)

GSI Darmstadt

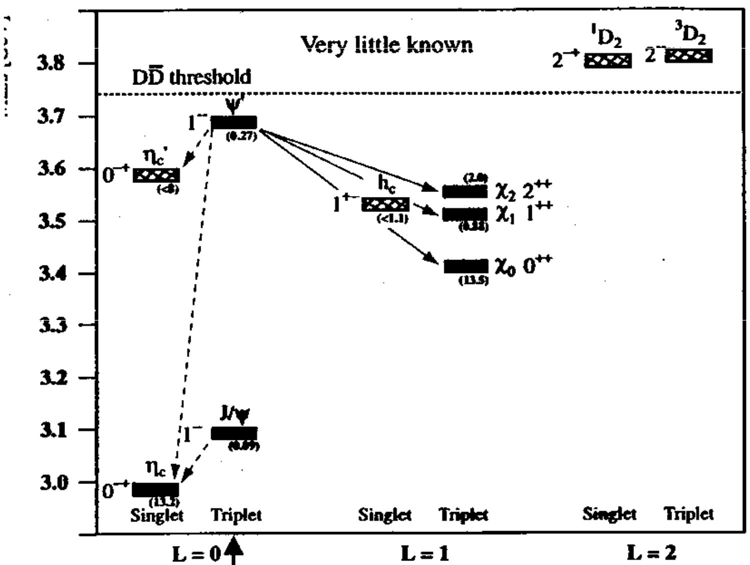
Accelerator Facilities



Physics Program at HESR

- Glueballs, hybrids (qqg)
- J/Ψ – spectroscopy ⟶ confinement
- D-meson decays
- D-mesons in the nuclear medium
- Hypernuclei
- CP-violation

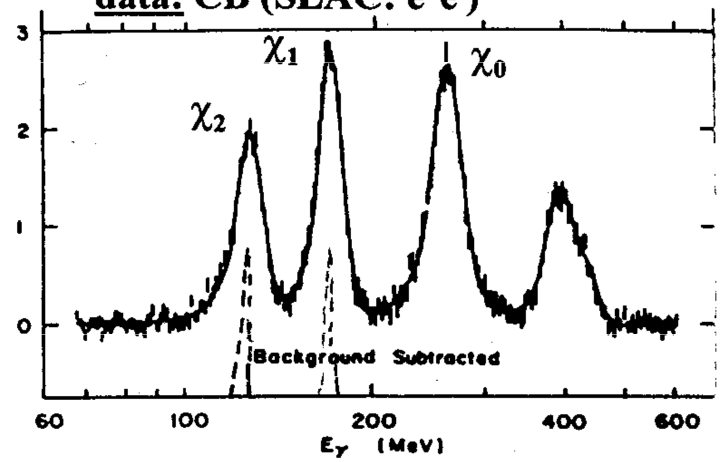
Precision-spectroscopy of J/χ ($c\bar{c}$)



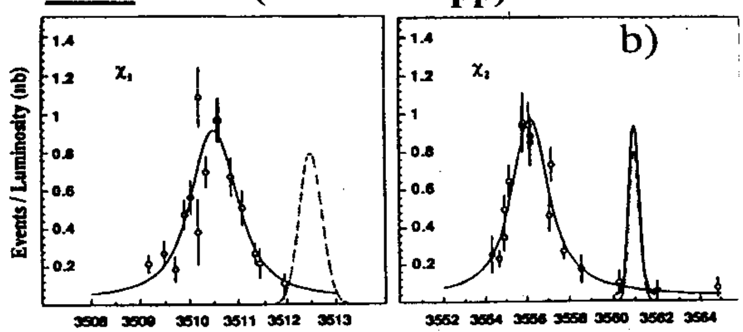
1^- states
populated in e^+e^-

⇒ confinement-potential
spin-dependence

data: CB (SLAC: e^+e^-)



data: E 760 (Fermilab: $p\bar{p}$)



beam profile

Production Rates

$c\bar{c}$	J^{PC}	M [MeV]	Γ_{tot} [MeV]	Decay mode	$\sigma(M)^*$ [pb]	Events/day**
η_c	0^{-+}	2980	13.2	$\gamma\gamma$	550	4400
η_c	0^{-+}	2980	13.2	$\Phi\Phi$	3100	24800
η'	0^{-+}	3594		$\gamma\gamma$	120	960
Ψ	1^{--}	3097	0.087	$e^+e^- + \mu^+\mu^-$	630000	5040000
Ψ'	1^{--}	3686	0.277	$e^+e^- + \mu^+\mu^-$	4480	35840
Ψ'	1^{--}	3686	0.277	$\Psi\, X$	17600	140800
χ_{c0}	0^{++}	3415	14	$\gamma\gamma$	30	240
χ_{c0}	0^{++}	3415	14	$\gamma\Psi$	52	416
χ_{c1}	1^{++}	3511	0.88	$\gamma\Psi$	3600	28800
χ_{c2}	2^{++}	3556	2.0	$\gamma\Psi$	3700	29600
χ_{c2}	2^{++}	3556	2.0	$\gamma\gamma$	220	1760
$c\bar{c}g$	**1^{--}**	**(4100)**	**(0.2)**	**$(\Psi\,\eta^{***})$**	**(120)**	**(960)**
$c\bar{c}g$	**1^{-+}**	**(4000)**	**(0.2)**	**$(\Psi\,\omega, \Phi, \gamma)$**	**(9)**	**(75)**

* For selected decay mode

** $L = 2 \times 10^{32}\ cm^{-2}s^{-1}$, 50% detection and accelerator efficency

$\rightarrow$ integrated luminosity = 8 pb^{-1}/day

*** 1% branching ratio for this decay mode

Table 1: Production of Charmonium- and Charmed Hybrid-states in $\bar{p}p$-annihilations

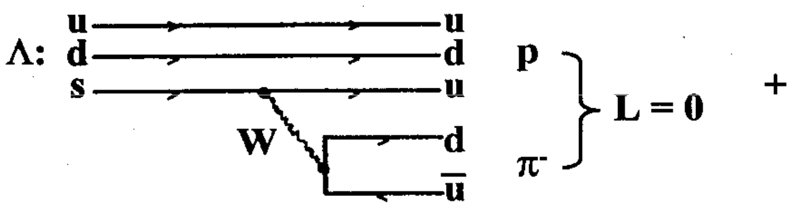
CP - Violation

$\Lambda\overline{\Lambda}$-System:

CP-violation in the weak decays of a baryonic system: $\Lambda \to p\pi^-$, $\overline{\Lambda} \to \overline{p}\pi^+$

No CP-violation by mixing in the baryonic sector: B-number conservation

Only direct CP-violation possible



$\overline{\Lambda}$: Analogously

Prediction: Difference of angular decay asymmetries $(\alpha,\overline{\alpha})$ $\quad A \approx \frac{\alpha+\overline{\alpha}}{\alpha-\overline{\alpha}} \approx 10^{-5} - 10^{-4}$

HESR: $\overline{p}(1.65\,\text{GeV}/c)p \to \Lambda\overline{\Lambda}$ **(see: PS185-Experiment at LEAR)**

$\Lambda(\overline{\Lambda}) \to p\pi^-, \overline{p}\pi^+$: $I(\Theta) = \frac{1}{4\pi}(1+\alpha(\overline{\alpha})P_\Lambda \cos\Theta)$, **Self analyzing decay**

$\frac{\delta A}{A} \leq 10^{-4}$: **40 days of measuring time**

CP - Violation

$D/\overline{D}$-System:

CP-Violation by mixing: $\left(D/\overline{D}^0\right)$

Much smaller than in $K_0/\overline{K}_0$ or $B_0/\overline{B}_0$ (no intermediate t-Quarks)

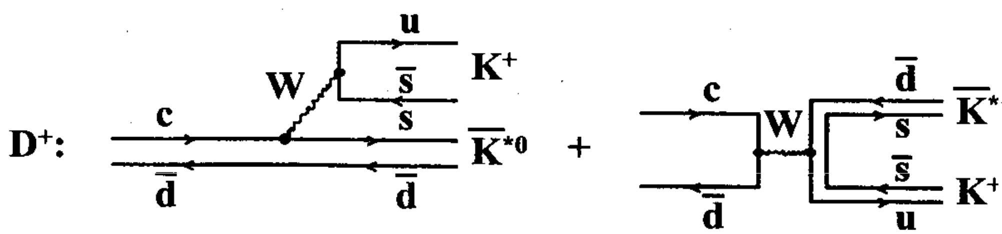
Mixing can be measured at HESR in semileptonic decays

$$r_D = \frac{\Gamma(D^0 \to l^- X)}{\Gamma(D^0 \to l^+ X)}$$

Direct CP-Violation: $\left(D^0/\overline{D}^0, D^+/D^-, D_s/\overline{D}_s\right)$

Compare e.g.: $\Gamma\left(D^+ \to K^+\overline{K}^{*0} \to K^+K^-\pi^+\right)$

to $\Gamma\left(D^- \to K^-K^{*0} \to K^-K^+\pi^-\right)$



D^-: Analogously

Prediction: $\alpha_{CP} \leq 1.0\text{x}10^{-3}$

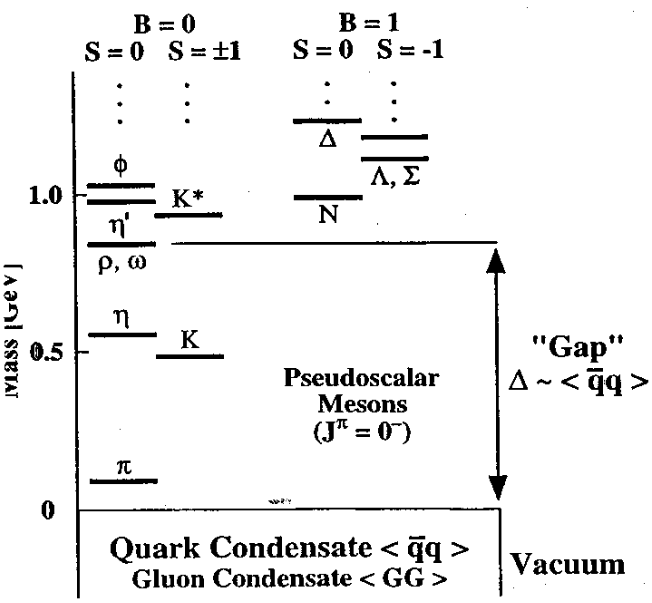
HESR:

10^8 reconstructed $D\overline{D}$-pairs

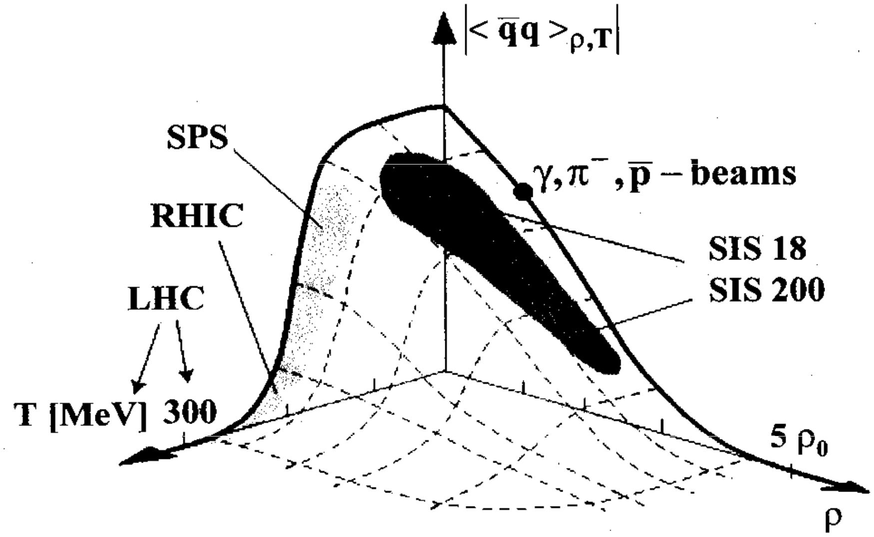
↘ Observation of 3σ-effect

hadron masses

free hadrons

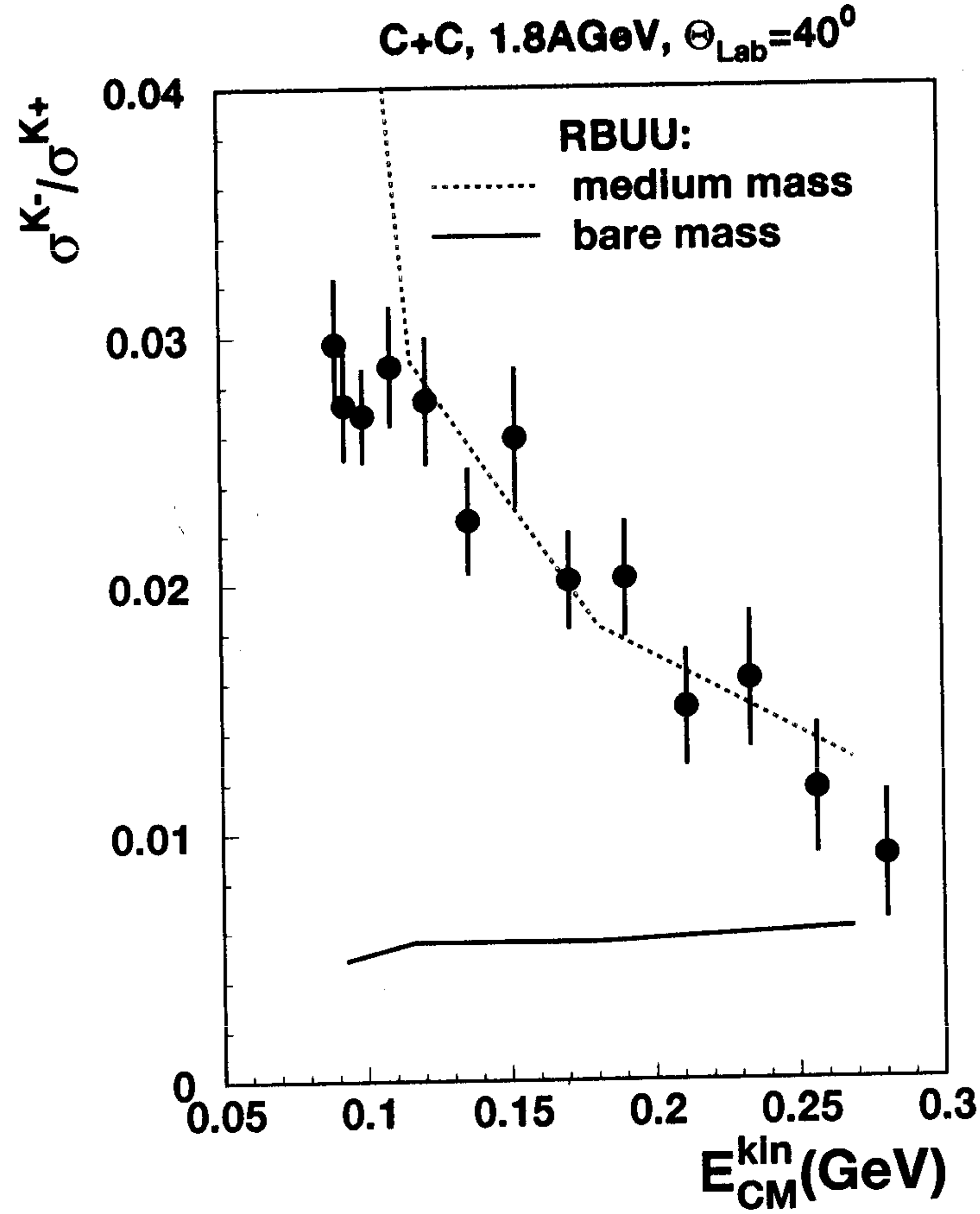


hadrons in the nuclear medium



hadron masses can be modified by the nuclear medium

K^-/K^+ ratio from C+C collisions

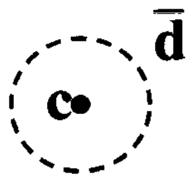


KaoS data:
F.Laue, C.Sturm et al., Phys. Rev. Lett. 82 (1999) 1640

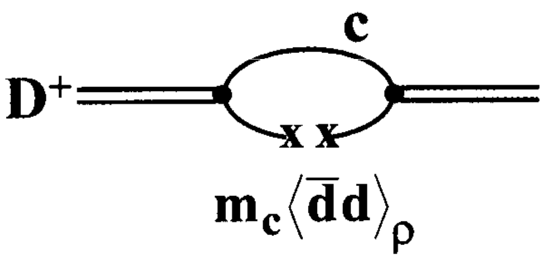
RBUU calculations:
W.Cassing and E.Bratkovskaya, Phys. Rep. 308 (1999) 65

D-mesons in matter

D^+:



D-meson = "H-atom" of QCD



sensitivity to in-medium change of chiral condensate

QCD-sum rule analysis:

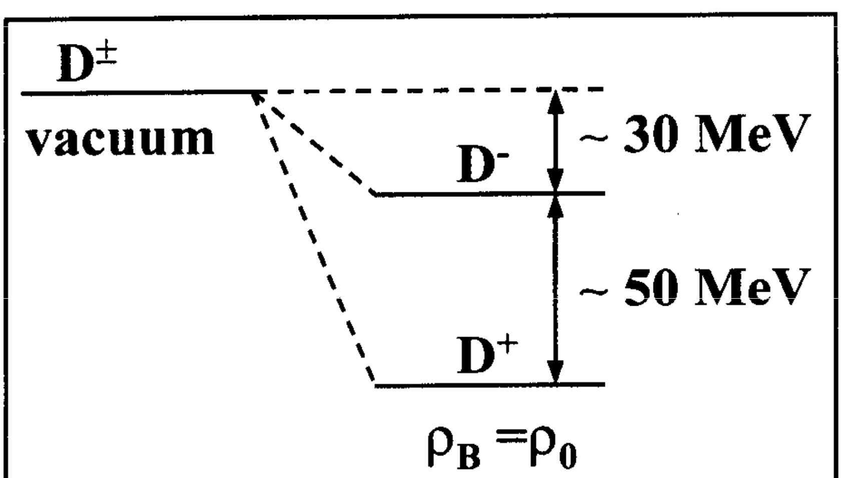
$$m_{D^\pm}(\rho) - m_D = -\frac{m_c}{4f_D^2 m_D}\left[\langle\bar{q}q\rangle_\rho^* - \langle\bar{q}q\rangle_0\right] \mp \frac{1}{4f_D^2}\langle d^+ d\rangle$$

$\uparrow$ $3/2\ \rho_B$

D-meson decay constant: $\sqrt{2}\, f_D = (190 \pm 20)$ MeV

$D^\pm$ in nuclear matter (preliminary):

(Ph. Morath, S.-H. Lee, W. Weise)



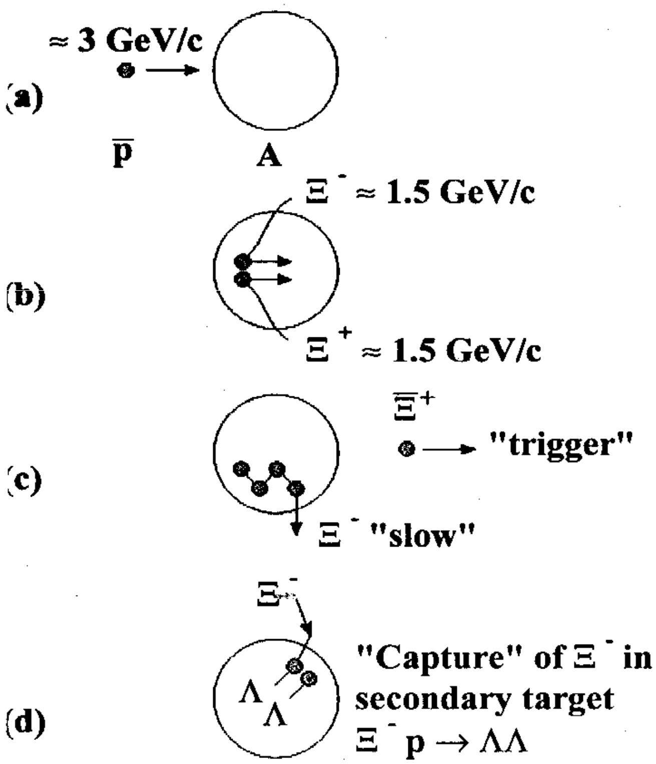
mass splitting by $\mp \frac{3}{8 f_D^2}\rho_B$ – term

overall shift (governed by $m_c\langle\bar{q}q\rangle_\rho$-term) : ≈ 55 MeV

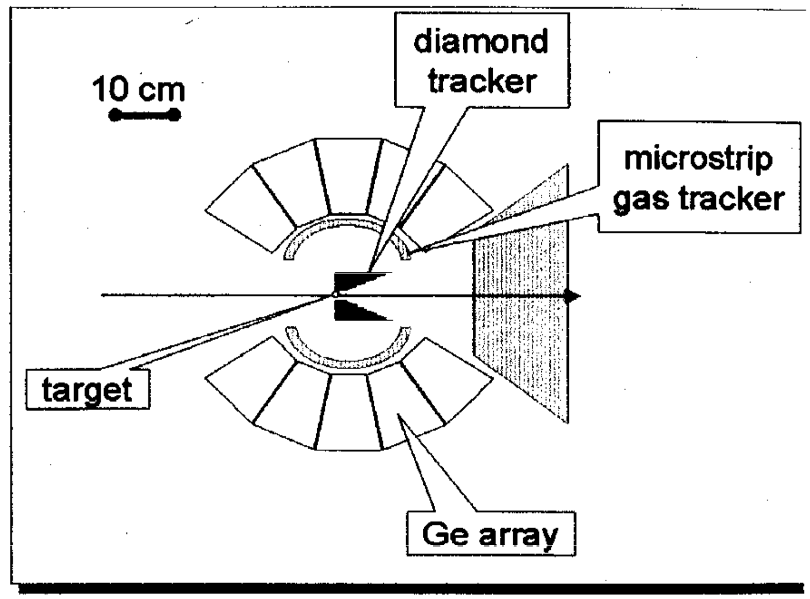
Double Hypernuclens Spectroscopy

(J. Pochodzalla et al.)

double hypernuclens production



detector scheme



<u>rates:</u>	Λ Λ hypernuclei:	8000 per month
	detected γ-transitions:	80 per month

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HESR – Specifications

ENERGY: $B\rho$=50Tm ≅ 15GeV/c ($\bar{p}$); 7.5GeV/c(Z/A=0.5)

- Charmonium + ($c\bar{c}g$): p~9GeV/c
- Associated charmed hyperon production: $\Omega_c\bar{\Omega}_c \approx 15GeV/c$
- Subthreshold charm production: $D\bar{D} \approx 9GeV/c$

Conclusion: For cooled heavy ions a higher $B\rho$ may be wanted

Luminosity: 2×10^{32} cm^{-2}s^{-1} is desireable

- Consumption Limitation: $L_c = (1/\sigma_t)(dN/dt)$
  σ_t = 60mb a $\bar{p}$-source with dN/dt = $1.2\times10^7\bar{p}$/s is needed.
  CERN in 1990: $1.7\times10^7\bar{p}$/s
- Target Luminosity: $L_t = N\cdot f\cdot N_t$
  N=$2\times10^{12}\bar{p}$ f=0.5MHz N_t= 2×10^{14} cm^{-2}s^{-1}
  Thickness of target determines $\Delta p/p$: ~7.10^{-6}!

Momentum spread and Beam diameter

Request: $\delta p/p$~7×10^{-6} desireable for $c\bar{c}$ spectroscopy
D ~ 20μm needed for D-tracking!

Electron Cooling needed: E_e=8MeV(15GeV/c); 3.5MeV(6.5GeV/c)
L=20m; j_e=0.1A/cm^2; B~0.3T
τ_ε<60s ($E_{\bar{p}}$=5GeV) τ_p<1s R_D=18MeV/s ≅ 30eV/turn

Energy variation and calibration.

- $E_{\bar{p}}$ variation continous by change of E_e! Sweep mode
- $E_{\bar{p}}$-calibration: From e^-- voltage!

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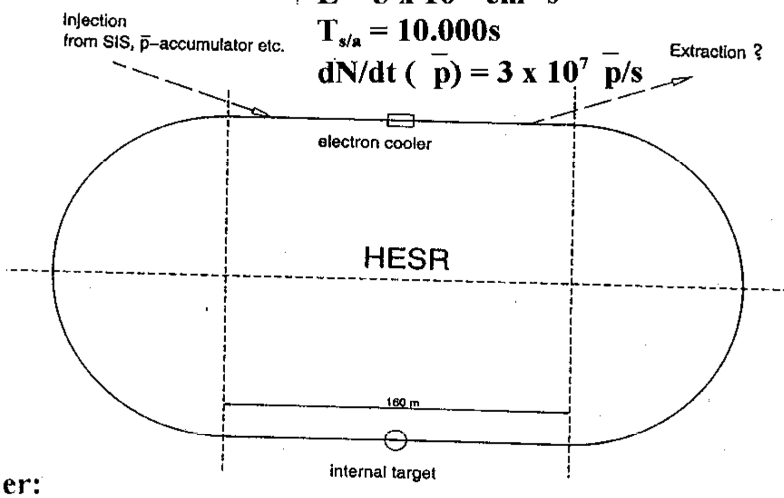
C 2

HESR 50 : $B\rho = 50$ Tm 15GeV/c $\bar{p}$
C = 600m: 2 x 150 m straight; 2 x 150 m 180° arcs;sc magnets
fr = 0.5 MHz; stored beam: $\bar{p}$ up to 10^{11} = 24mA
target: supersonic jet 3 x 10^{15} atoms/cm^2

$L = 5 \times 10^{32}$ cm^{-2} s^{-1}
$T_{s/a} = 10.000$s
$dN/dt(\bar{p}) = 3 \times 10^7 \; \bar{p}$/s



Electron cooler:
Energy: $E_e = 7.5$ MeV; eff. length = 20m; $j_e = 0.1$ A/cm^2;B 0.3 T in solenoid
Design aim:
$\varepsilon_x \leq 1\pi\mu$m mrad $\sqrt{\beta.\varepsilon} = 10\mu$m (!) for $\beta = 0.1$m **$R_D = 10$eV/turn = 5 MeV/s**
$\Delta p/p \leq 10^{-5}$ **dE ~ 0.015eV/turn (3x 10^{15}at/cm^2)**

Notizen:

High energy electron cooling of 15 GeV p̄

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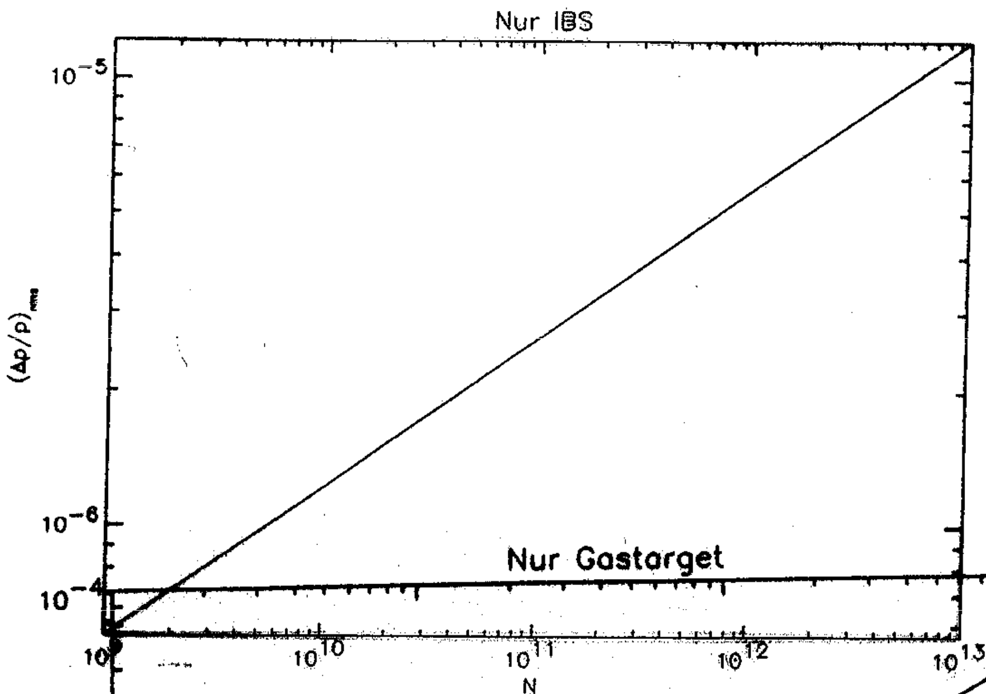


Figure 2: Longitudinal momentum spread of an electron cooled proton beam stored in the HESR in equilibrium with intra-beam scattering vs. number of stored protons [ref. 3]. Cooling parameters are taken from table 7.

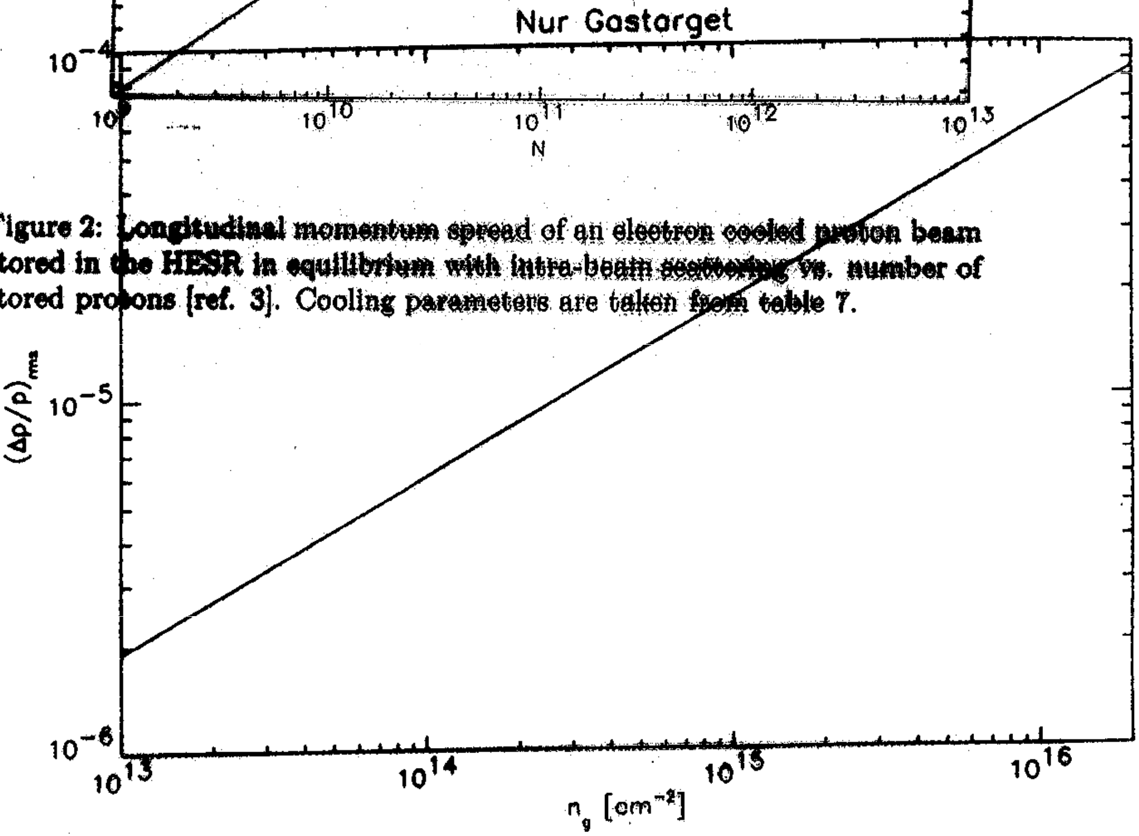
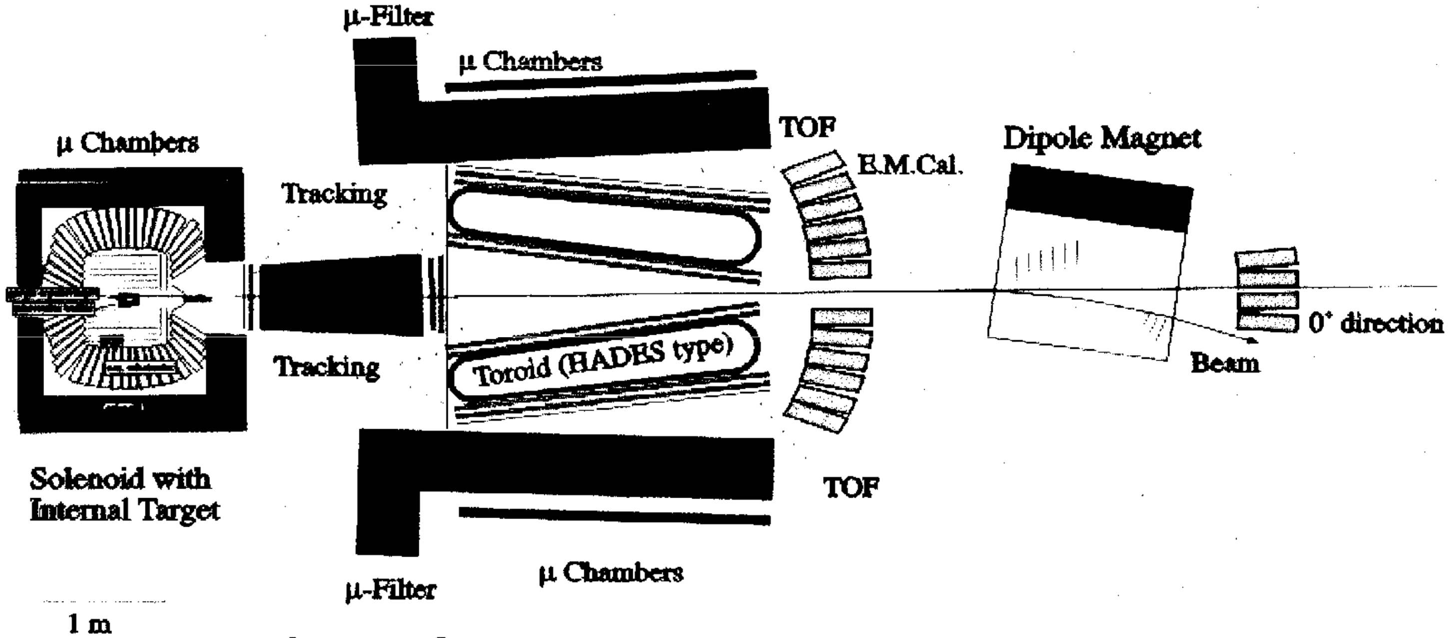


Figure 3: Longitudinal momentum spread of an electron cooled proton beam

detector scenario for HESR



<u>detector features:</u>
high rate capability
sophisticated and fast trigger scheme
tracking of charged particles
measurement and identification of γ, $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$