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„ Investigations of charge symmetry breaking reactions at COSY"

Investigations of charge symmetry breaking reactions

A. Magiera
for GEM collaboration

$$d + d \rightarrow {}^4He + \pi^0$$

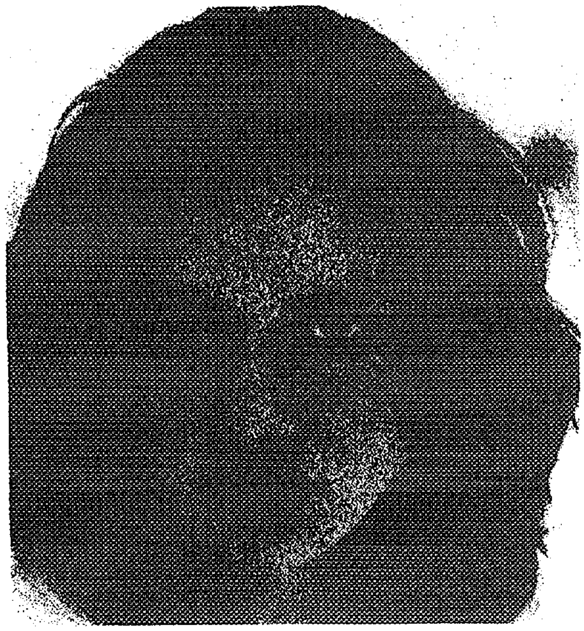
$$\sigma \neq 0$$

$$p + d \rightarrow {}^3H + \pi^+$$

$$p + d \rightarrow {}^3He + \pi^0$$

$$R = \frac{\sigma({}^3H)}{\sigma({}^3He)} \neq 2$$

SYMMETRY AND BEAUTY



84%

16%

Charge independence } first symmetries known to be broken
Charge symmetry

QCD – symmetries breaking due to:

- quark electromagnetic interaction
- quark mass difference

electromagnetic corrections $\Rightarrow m_{neutron} < m_{proton}$

experiment $\Rightarrow m_{neutron} > m_{proton}$

explanation $m_d > m_u$

Assumptions:

- $m_d = m_u \to 0$
- neglecting EM effects

$$\Downarrow$$

$$\begin{pmatrix} u \\ d \end{pmatrix} \text{ — isodoublet}$$

Isospin operators $\vec{\tau}$

$$\tau_3 |u\rangle = |u\rangle \,, \quad \tau_3 |d\rangle = -|d\rangle$$

Total isospin $\vec{T}$

$$\vec{T} = \sum_i \frac{1}{2} \vec{\tau}_i$$

Charge independence
(isospin symmetry)

$$[H, \vec{T}] = 0$$

Hamiltonian invariant under any rotation in isospin space

Charge symmetry

$$[H, P_{cs}] = 0 \quad , \quad P_{cs} = e^{i\pi T_2}$$

Hamiltonian invariant under rotation by π about 2-nd axis in isospin space

$$P_{cs}|u\rangle = -|d\rangle \; , \; P_{cs}|d\rangle = |u\rangle$$

Charge symmetry is stronger than charge independence

violation of charge symmetry
$\Longrightarrow$ violation of charge independence
violation of charge independence
$\not\Longrightarrow$ violation of charge symmetry

e.g. for two nucleons operator $T_3(1)\,T_3(2)$ preserves charge symmetry but breaks charge independence

Exceptation:
self-conjugate systems $T_3 = 0$

$$d + d \rightarrow {}^4He + \pi^0$$

$$T_3 = 0 \quad 0 \quad\quad 0 \quad 0$$

$$T = 0 \quad 0 \quad\quad 0 \quad 1$$

charge independence breaking
$\Longrightarrow$ charge symmetry breaking

Charge symmetry breaking
CSB

due to quark mass difference

$$H = m_u u\bar{u} + m_d d\bar{d} + \dots$$

$$[H, P_{cs}] |q\bar{q}\rangle \sim |m_d - m_u| |q'\bar{q}'\rangle$$

magnitude of CSB is related to quark mass difference

$$\left.\begin{array}{l} m_u = 5.1 \pm 1.5 \text{ MeV} \\ m_d = 8.9 \pm 2.6 \text{ MeV} \end{array}\right\} \text{current quark mass}$$

$\frac{m_d}{m_u} \sim 2$ strong CSB?

quark confinement $\Rightarrow$ current mass replaced by constituent mass $\sim \frac{1}{3}$ proton mass

$\Rightarrow$ CSB effects are small

Impossible to observe directly quark mass difference

It may be related to meson mixing

$$\pi^0 = \frac{1}{\sqrt{2}} |u\bar{u} - d\bar{d}\rangle$$

$$\eta = \frac{1}{\sqrt{6}} |u\bar{u} + d\bar{d} - 2s\bar{s}\rangle$$

$$\langle \pi^0 | H | \eta \rangle \sim m_d - m_u$$

CSB on hadronic level is also related to quark mass difference

Investigations of CSB

n-n and p-p scattering length difference $a^N_{pp} - a^N_{nn} = -1.5 \pm 0.5$ fm

^3H and ^3He binding energy difference 71 keV (after EM corr.)

$\pi^+ + {}^3H, {}^3He$ and $\pi^- + {}^3H, {}^3He$ scattering

$^4He(\gamma, p)^3H$ and $^4He(\gamma, n)^3H$ reactions

deviations of ratios of the cross section from values expected from the isospin conservation

Main problems:

- EM effects corrections
- calculations of nuclear structure effects

CSB in strong interaction hidden by other effects

CSB reactions without EM effects

$n + p \rightarrow d + \pi^0 \qquad A(\theta, \pi-\theta) = \frac{\sigma(\theta) - \sigma(\pi-\theta)}{\frac{1}{2}[\sigma(\theta) + \sigma(\pi-\theta)]}$

$T_n = 795$ MeV	$A = -0.15 \pm 0.50\,\%$	no CSB evidence
308–643 MeV	$1.5 \pm 2\,\%$	
325–675 MeV	$-0.36 \pm 0.66\,\%$	

$\vec{n} + p \rightarrow n + p$

$\vec{p} + n \rightarrow p + n$

$\Big\} \; A_n(\theta_n) \neq A_p(\theta_p)$

$T_n = 477$ MeV	$A_n - A_p = (47 \pm 22 \pm 8)\cdot 10^{-4}$
347 MeV	$(65 \pm 11 \pm 11)\cdot 10^{-4}$
183 MeV	$(33 \pm 6 \pm 4)\cdot 10^{-4}$

$d + d \rightarrow {}^4He + \pi^0 \qquad \sigma \neq 0$

$T_d = 1.1$ GeV (SATURNE)

? $\frac{d\sigma}{d\Omega}(\theta_{c.m.} = 107^\circ) = 0.97 \pm 0.20 \pm 0.15 \, \frac{pb}{sr}$

CSB due to meson mixing

$\vec{n} + p \to n + p$
$\vec{p} + n \to p + n$ $\Big\}$ $A_n(\theta_n) \neq A_p(\theta_p)$

$\Rightarrow$ possible explanation ρ^0-ω mixing

$|\pi^0\rangle = \cos\theta\, |\tilde{\pi}\rangle - \sin\theta\, |\tilde{\eta}\rangle$

$|\eta\rangle = \sin\theta\, |\tilde{\pi}\rangle + \cos\theta\, |\tilde{\eta}\rangle$

$d + d \to {}^4He + \tilde{\eta}$ → ${}^4He + \eta$ / → ${}^4He + \pi^0$

close to η production threshold

$|\tilde{\eta}\rangle = \cos\theta \left(|\eta\rangle - \mathrm{tg}\,\theta\, |\pi^0\rangle \right)$

$f(dd \to {}^4He\,\pi^0) \approx -\mathrm{tg}\,\theta\, f(dd \to {}^4He\,\eta)$

not sufficient to explain observed cross sections

? strong ${}^4He\,\eta$ FSI enhance ${}^4He\,\pi^0$ cross section [Wilkin PLB331 (1993)276]

$p + d \to {}^3He + \pi^0$ and $p + d \to {}^3H + \pi^+$

$$R = \frac{d\sigma/d\Omega(pd \to {}^3H\pi^+)}{d\sigma/d\Omega(pd \to {}^3He\pi^0)} \neq 2$$

$$|\tilde{\eta}\rangle = \cos\theta(|\eta\rangle - tg\theta|\pi^0\rangle)$$

$$|\tilde{\pi}\rangle = \cos\theta(|\pi^0\rangle + tg\theta|\eta\rangle)$$

$$pd \to {}^3He\,\tilde{\pi} \to {}^3He\,\pi^0$$

$$pd \to {}^3He\,\tilde{\eta} \to {}^3He\,\pi^0$$

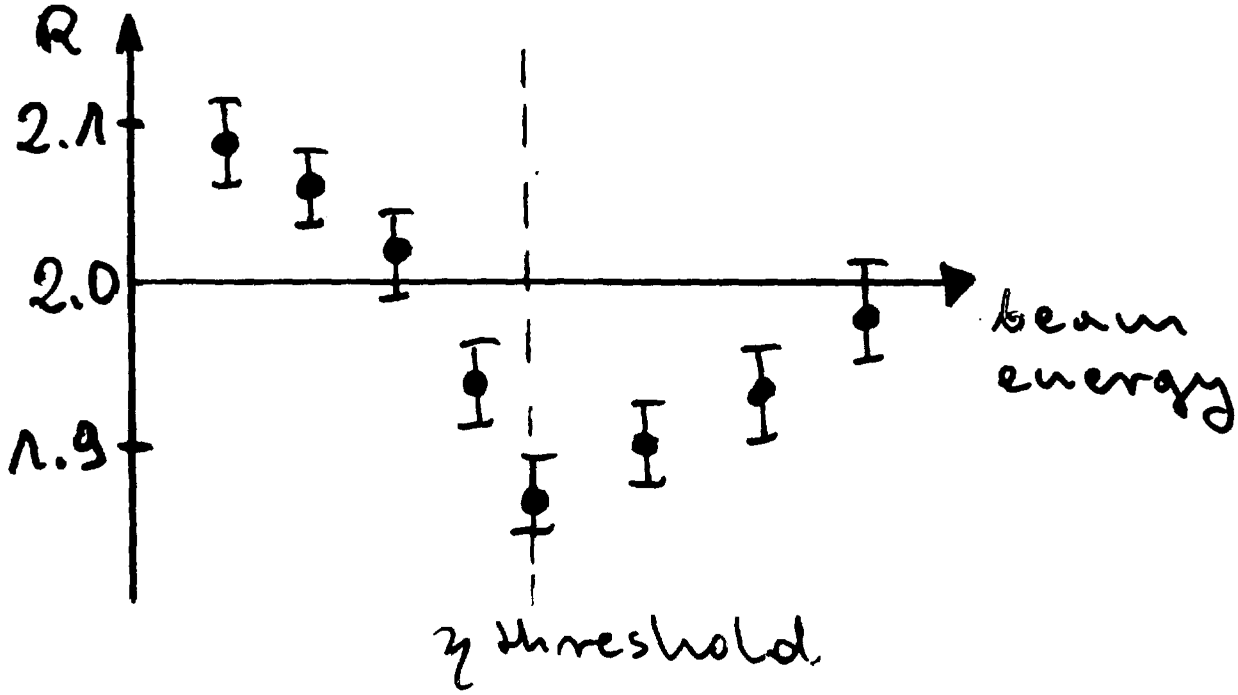
$$f_{\tilde{\pi}}(pd \to {}^3He\pi^0) \sim 1$$

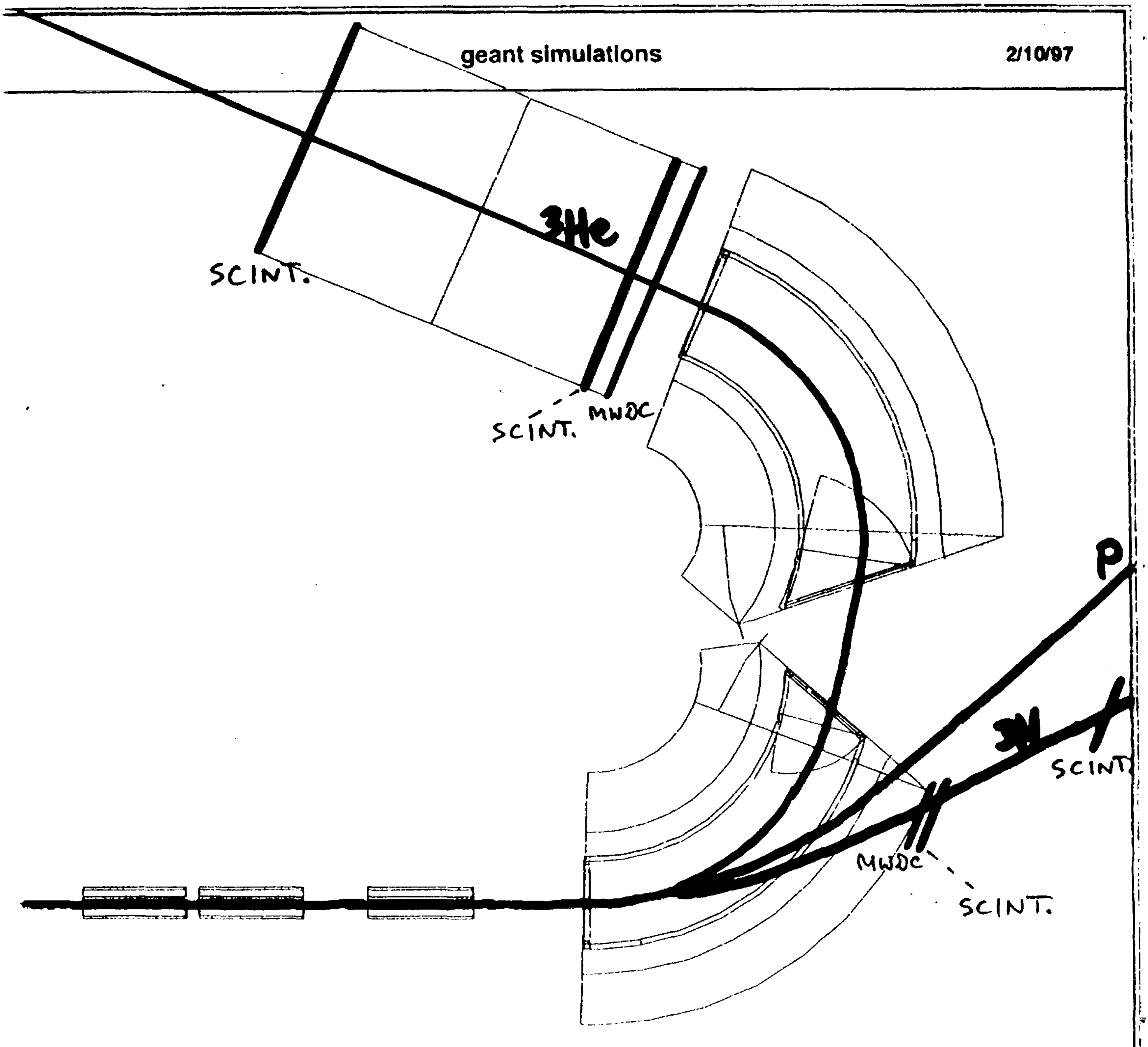
$$f_{\tilde{\eta}}(pd \to {}^3He\pi^0) \sim -tg\theta$$

$$f(pd \to {}^3He\pi^0) \sim 1 - tg\theta$$

interference with isospin respecting amplitude

At energies close to η production threshold the interference term can be very large leading to oscillations of R value as function of beam energy, oscillations magnitude ~ 10%



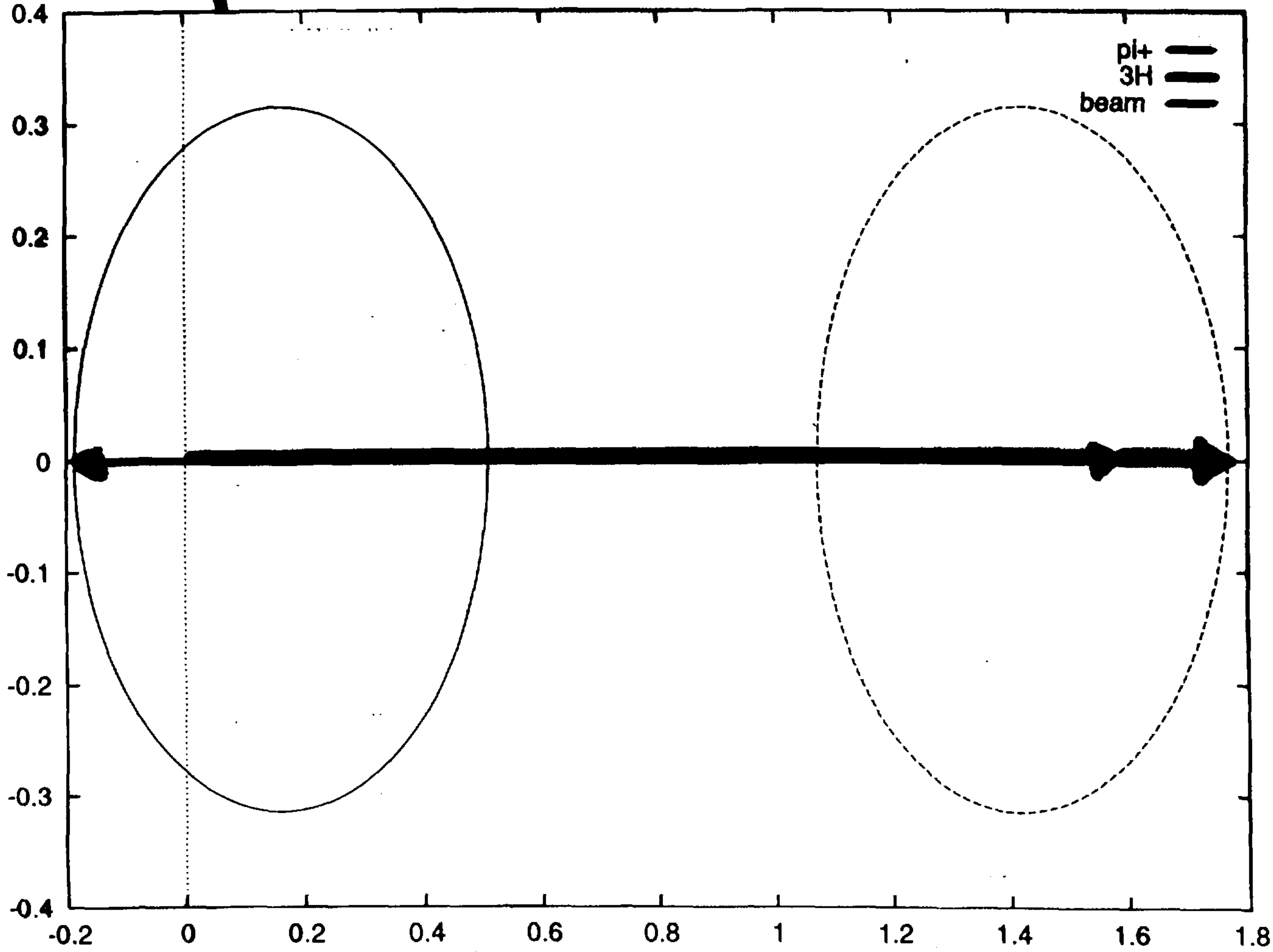


Identification: momentum, ΔE_1, (ΔE_2), TOF

Fig. . Experimental set-up for the measurements of pd→^{3}Heπ^0 and pd→^{3}Hπ^+ reactions. The tracks of direct beam protons and ^{3}He, ^{3}H outgoing particles are also shown.

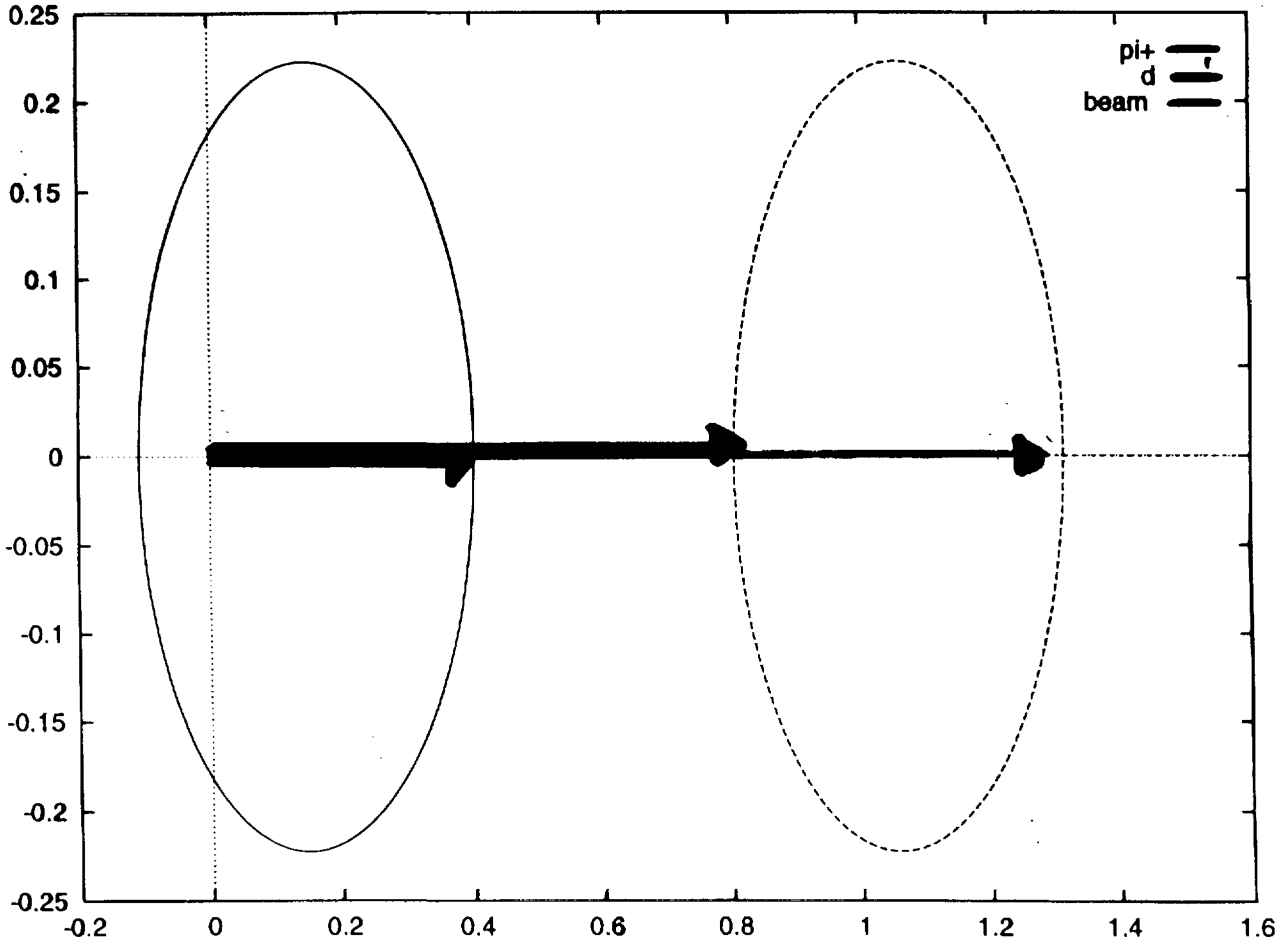
$p\,d \to {}^3H\,\pi^+$

$p\,d \to {}^3He\,\pi^0$



$P_{beam} \sim 1.58$ GeV/c

$pp \to d\pi^+$



$\frac{p_d}{p_\pi} \sim 2 \qquad p_{beam} = 1.2\ \frac{GeV}{c}$

Counting rate

$\frac{d\sigma_{c.m.}}{d\Omega}(\theta = 0^\circ) = 40$ nb/sr $\quad pd \to {}^3H\,\pi^+$

$\frac{d\sigma_{c.m.}}{d\Omega}(\theta = 0^\circ) = 20$ nb/sr $\quad pd \to {}^3He\,\pi^0$

LD_2 target 4 mm thickness

beam intensity $5 \cdot 10^8$/s

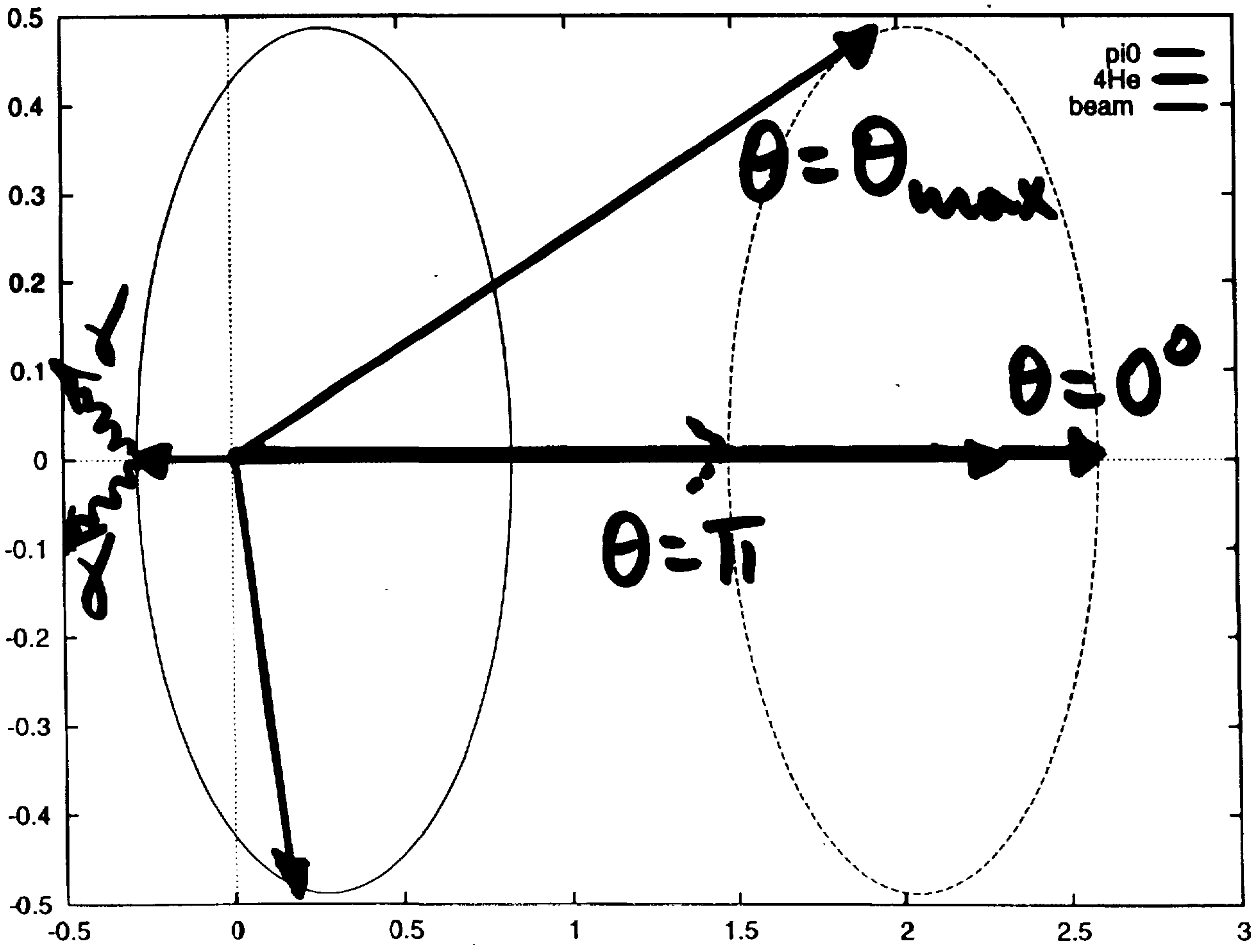
Big Karl solid angle ~7 msr

$\Rightarrow$ 2200/day ^3H, 1100/day ^3He

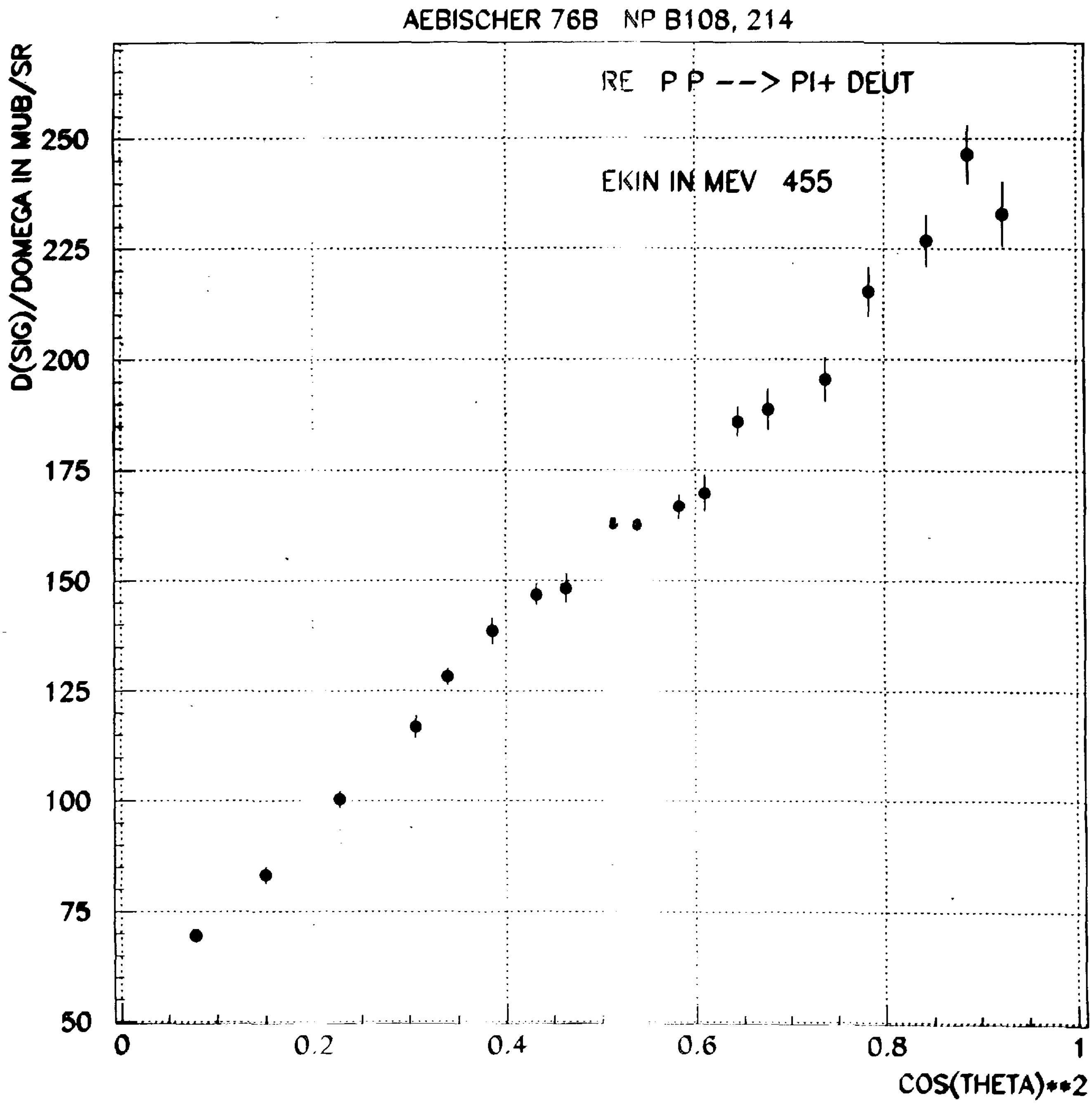
Ratio R measurements for beam momentum range 1.56 – 1.60 GeV/c

2.5% accuracy $\Rightarrow$ 4 days per beam momentum

$dd \rightarrow {}^4He\,\pi^0$



$P_{beam} = 2.3$ GeV/c


AEBISCHER 76B NP B108, 214
RE P P --> PI+ DEUT
EKIN IN MEV 455
D(SIG)/DOMEGA IN MUB/SR
250
225
200
175
150
125
100
75
50
0
0.2
0.4
0.6
0.8
1
COS(THETA)**2

dd → ^{4}Heπ^0

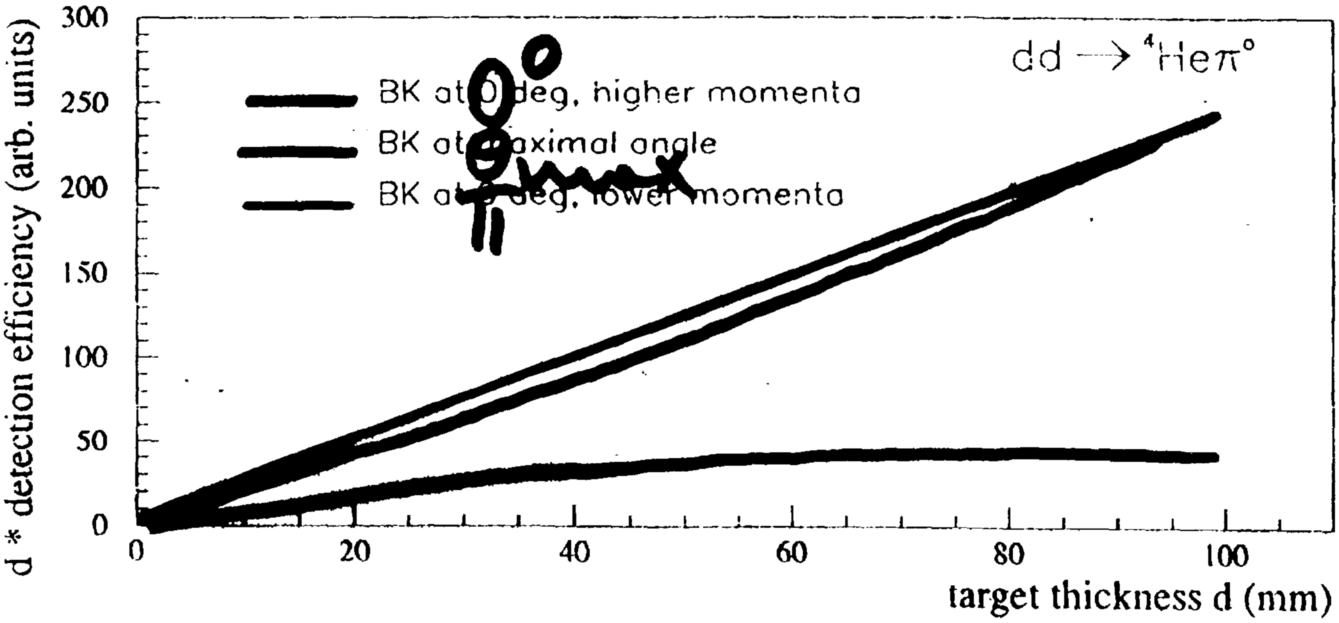
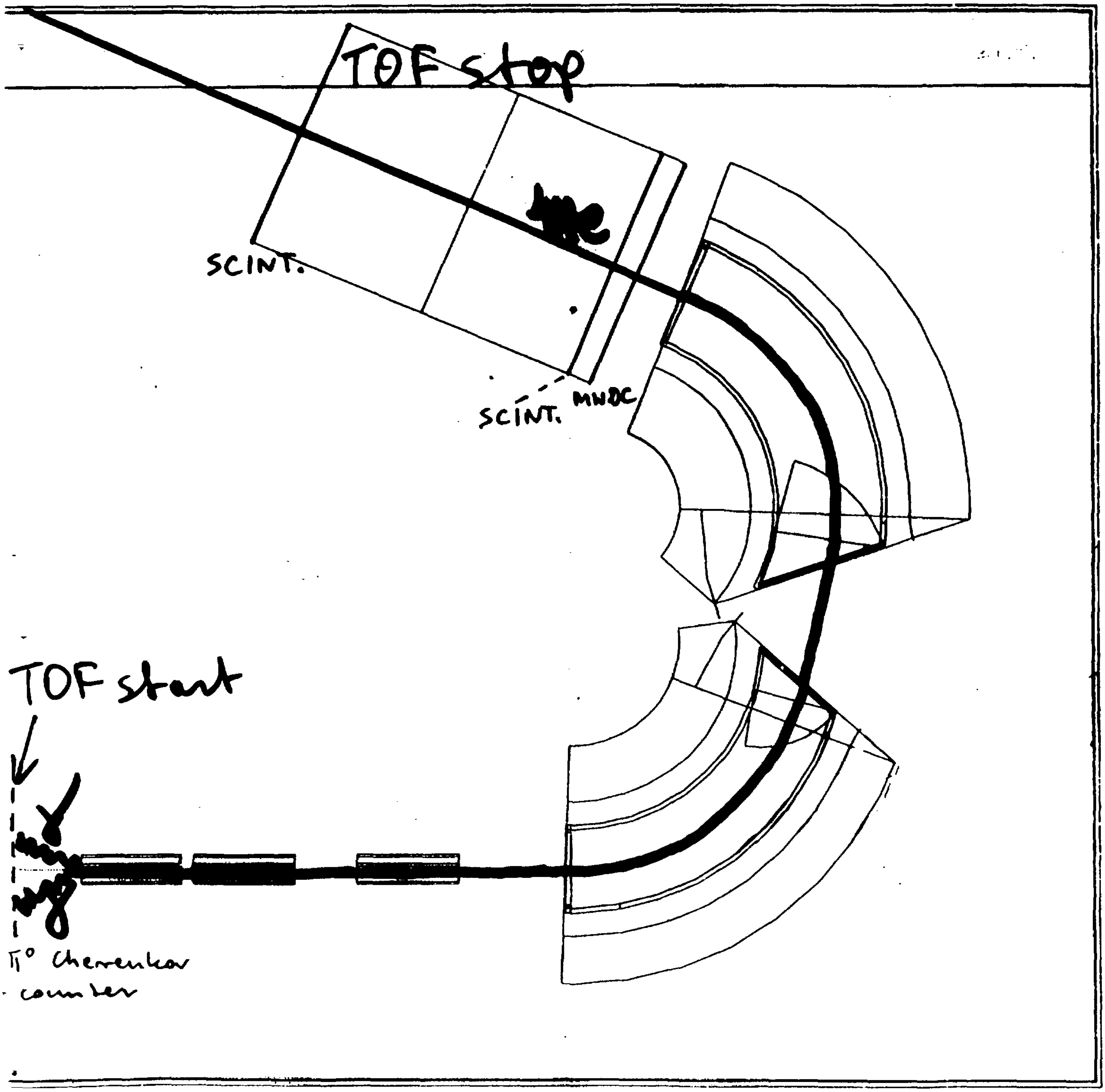


Fig. 2. The counting rate (arbitrary units) for the measurement of dd→^{4}Heπ^0 reaction as a function of target thickness. The dependence is shown for ^{4}He detected at zero degree with minimum and maximum momentum and ^{4}He detected at maxium kinematically allowed angle.

⁴He γγ coincidence



⁴He identification:

ΔE_1 scint., ΔE_2 scint., TOF

momentum

What have to be done:

- thick LD_2 target ~ 40 mm
- π^0 detector
- upgrade of dipoles power supply

Expected counting rate

$$\frac{d\sigma_{c.m.}}{d\Omega} = 1\ pb/sr$$

$$d + d \rightarrow {}^4He + \pi^0$$

1 event / day

Beam request

- check operation of the detection system at first dipole exit
- optimization of this detection system
- measurements of background
- relative efficiency measurement using $pp \to d\pi^+$ reaction

⇓

7 days of the beam time (first half 1998)