Qweak collaboration mtg.
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R.T. Jones
UConn

The Mini-Torus Option

Outline

1. Fixing Q^2 : systematic $\frac{\delta A}{A}$

2. Fixing E_0 : figure of merit
   - statistical $\frac{\delta A}{A}$
   - spectrometer resolution
   - backgrounds

3. Straw-man mini-torus
   - what do we gain? $\left(\frac{\Delta\theta}{\theta}\right)\cdot\left(\frac{\Delta\phi}{2\pi}\right)$
   - design issues: optics, coil geometry
   - favorable case study

1. Fixing Q^2 : <u>Systematic errors</u>

$$A_{LR} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = a_0 \tau \left[\underline{\xi_V^p} + \underline{\Delta_n} + \underline{\Delta_s} - \underline{\quad} \right]$$

proton part : ξ_V^p (Qweak)

neutron part: $\Delta_n = \xi_V^n \dfrac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$

strange part: $\Delta_s = \xi_V^{(0)} \dfrac{\varepsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$

axial part : $\Delta_A = - \dfrac{\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}\,(1-4\sin^2\theta_W)\, G_M^p G_A}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$

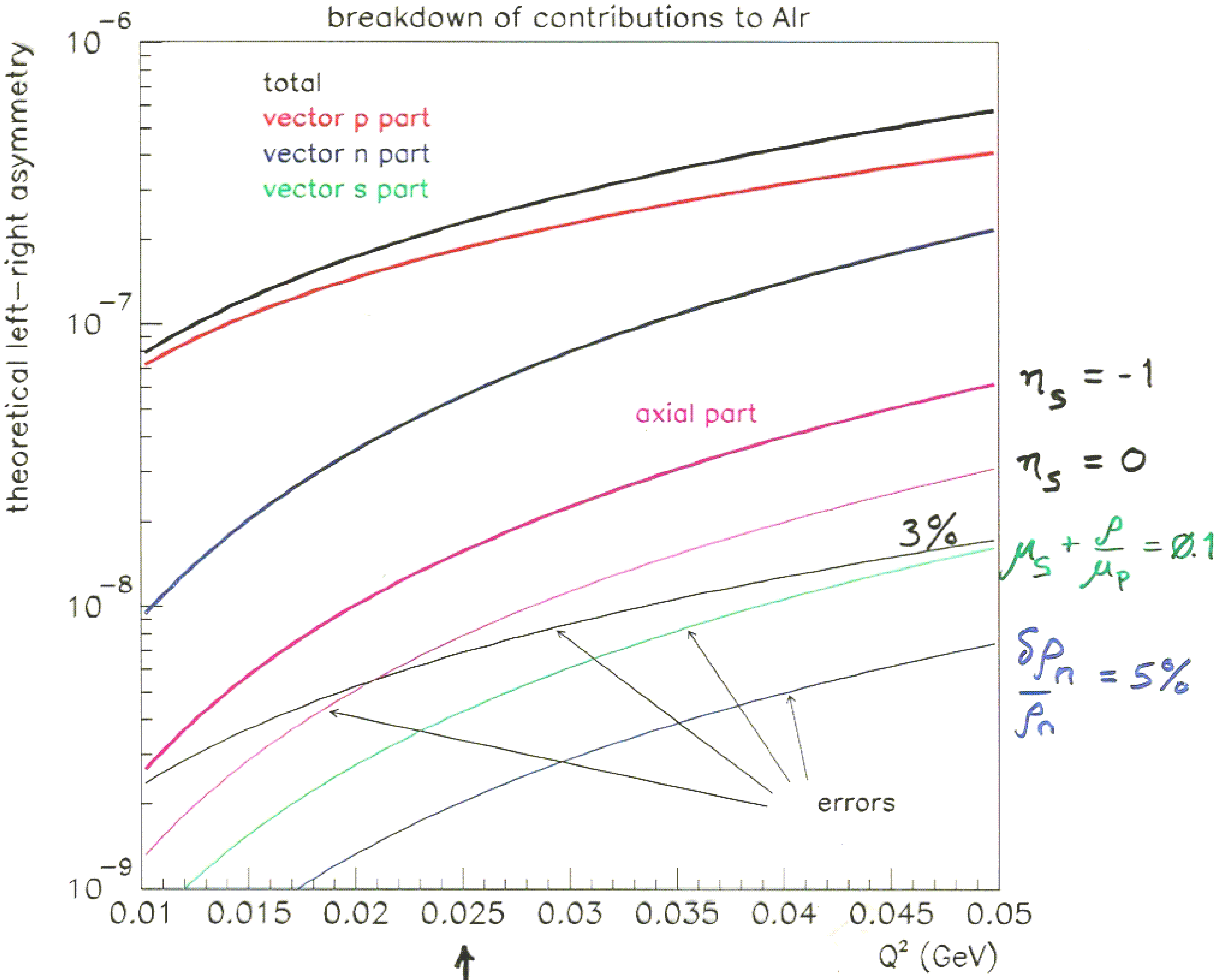
At forward angles $\sim \theta \sqrt{\tau}\, \mu_p G_A^p \times \xi_V^p$

$\Rightarrow$ not negligible for this measurement

Key question:

How well do we think we will know

$$\eta_s \equiv \frac{G_A^s(0)}{g_A} \quad ?$$



tentative choice

$Q^2 = 0.025\ \mathrm{GeV}^2$

2. Fixing E_0 : <u>figure of merit</u>

$$\left(\frac{\delta A}{A}\right)_{meas.} = \left[A_{LR}\, P \left(\frac{d\sigma}{d\Omega}\right)^{1/2} \sqrt{\mathcal{L}\, \Delta\Omega\, T f_{el}} \right]^{-1}$$

A_{LR} = theoretical asymmetry

P = beam polarization

$\left(\frac{d\sigma}{d\Omega}\right)$ = ep elastic cross section

$\mathcal{L}$ = instantaneous luminosity

$\Delta\Omega$ = solid angle

T = duration of measurement

f_{el} = fraction of scattered electrons in elastic window

internal, external bremsstrahlung corr......

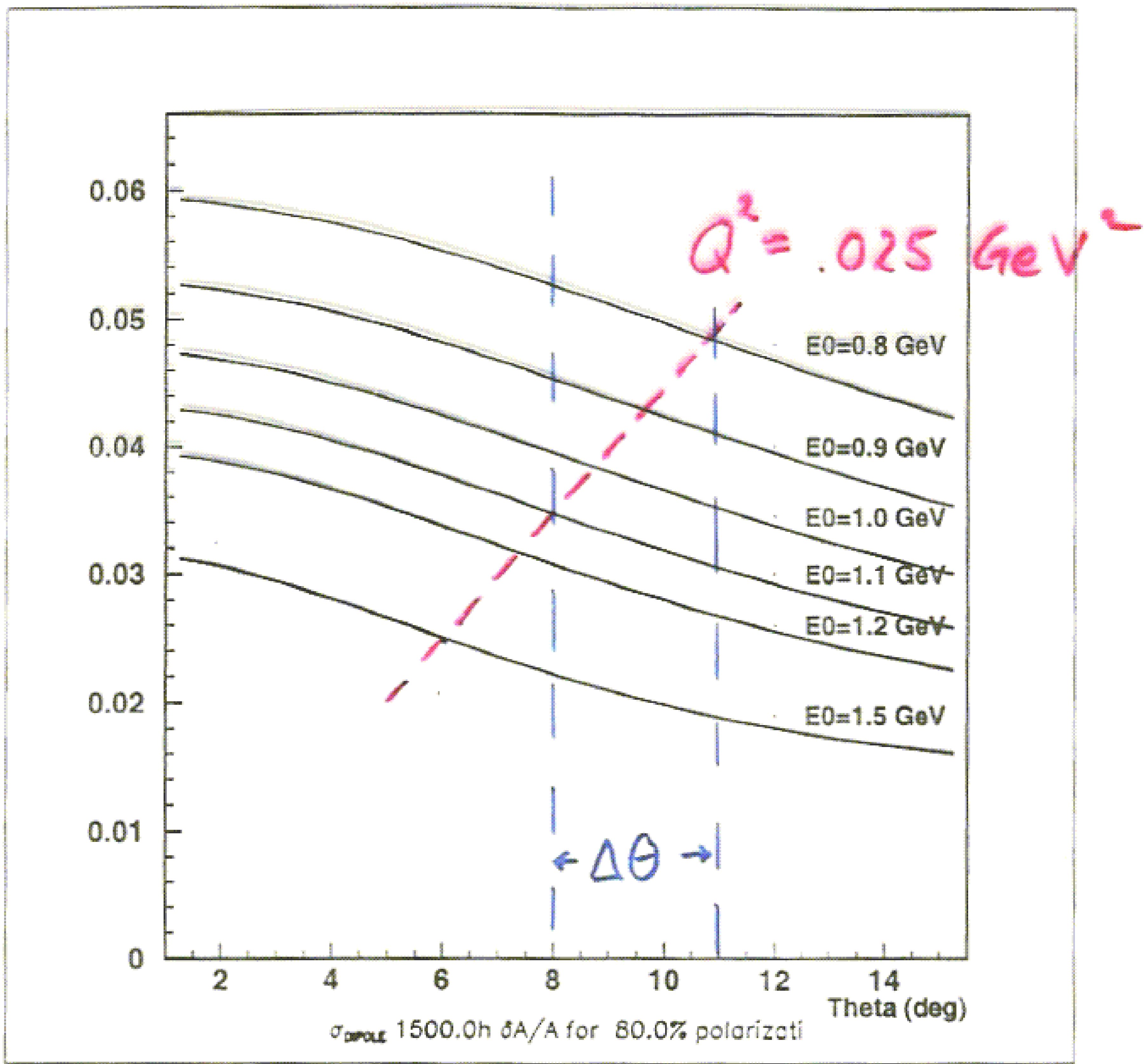


Figure 6: Relative error of the asymmetry for the elasticly scattered longitudinally polarized electrons on protons for the forward angle measurement. The beam energy ranges from 0.8 GeV up to 1.5 GeV.

From Neven 7/2000

100 μA → 150 μA
40 cm target
1500 h
80% polarization

So 3% measurement appears feasible

but going to smaller θ would help ...

F.O.M. : depends on θ, Q^2,

or E_0, Q^2 equivalently,

or D, Q^2 (given G0 geometry)

where D is target-spectrometer distance

1) Fixed Q^2: $\theta \propto \frac{1}{D} \propto \frac{1}{E_0}$

$\Rightarrow$ choice of 1 implies choice of all 3.

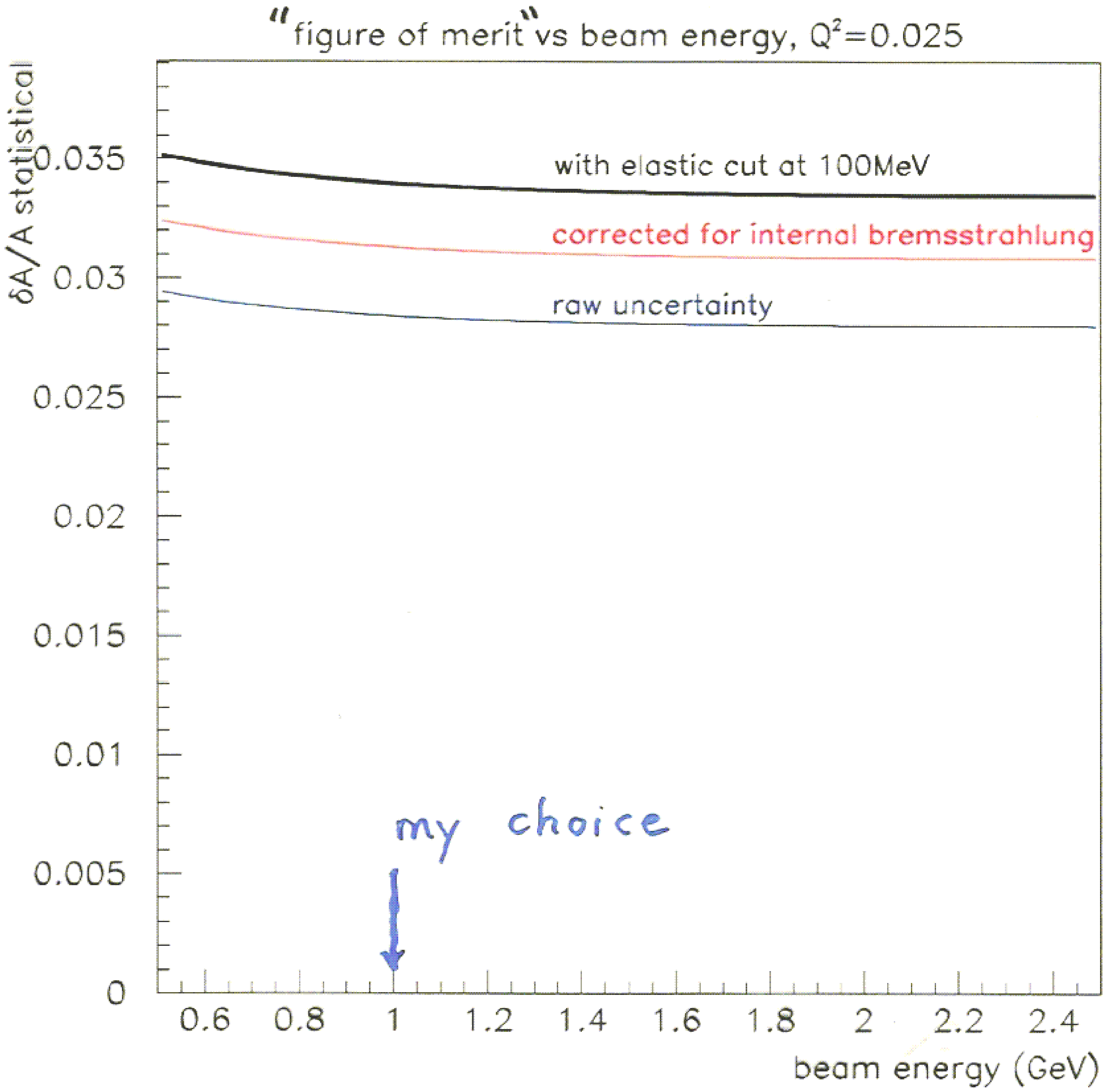
There is just one curve in Fig. 6

(once we lock θ, D, E_0 to one d.o.f.)

$\boxed{\text{To optimize } E_0 \text{, chose the minimum of FoM.}}$

... but the curve is flat

why? $\frac{d\sigma}{d\Omega} \propto E_0^2 \longleftrightarrow \Delta\Omega \propto \frac{1}{D^2}$



internal brems f_{el} ~ external brems f_{el} ~ 85%

Other considerations in choosing E_0

- spectrometer resolution
- backgrounds

> Spectrometer resolution:

✓ solution demonstrated at $E \sim 1\,\text{GeV}$

✓ probably scales to $E_0 > 1\,\text{GeV}$ but elastic separation may decrease

> Backgrounds

✓ lower E_0 is better

Chose
$$\boxed{\begin{aligned} E_0 &= 1\ \text{GeV} \\ \theta_0 &= 10.5^\circ \\ D &= 500\ \text{cm} \end{aligned}}$$

3. Straw-man mini-torus

★ $\frac{\delta A}{A}$ is flat in θ, D, E_0 @ fixed Q^2

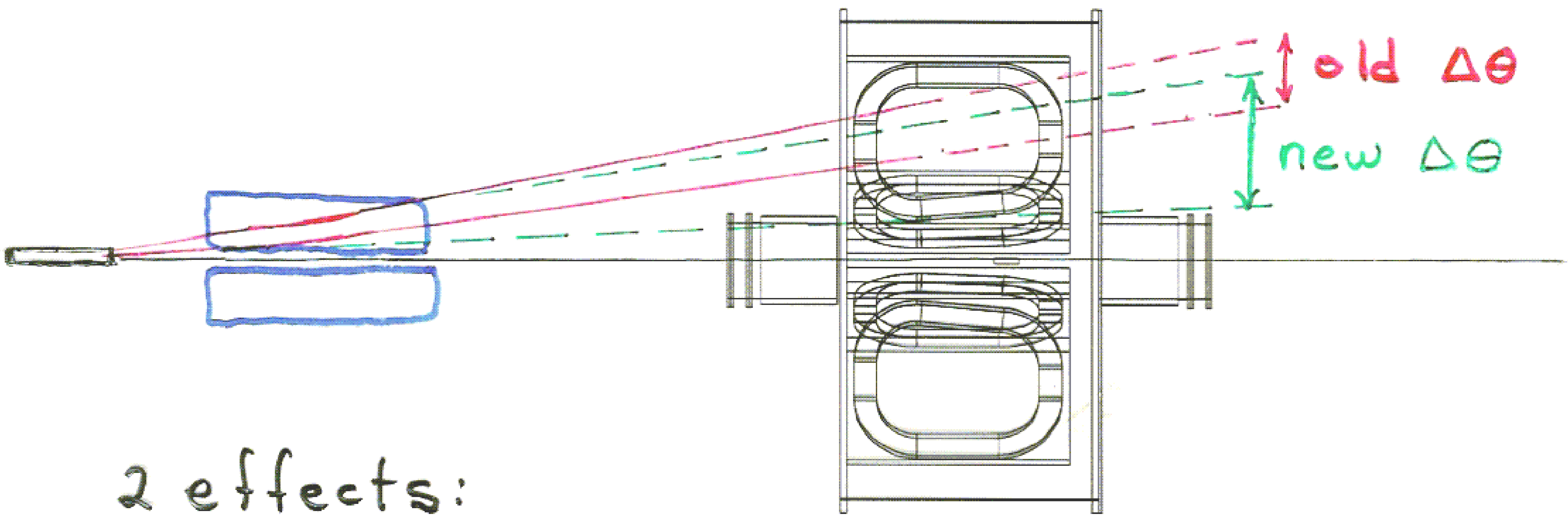
Where can we gain ?

➔ By changing the aperture

$$\left(\frac{\Delta\theta}{\theta}\right) \quad \left(\frac{\Delta\phi}{2\pi}\right)$$

33% 67%

Consider :



2 effects:

1) angular shift (bend) denominator ↓
2) angular compression (focus) numerator ↑

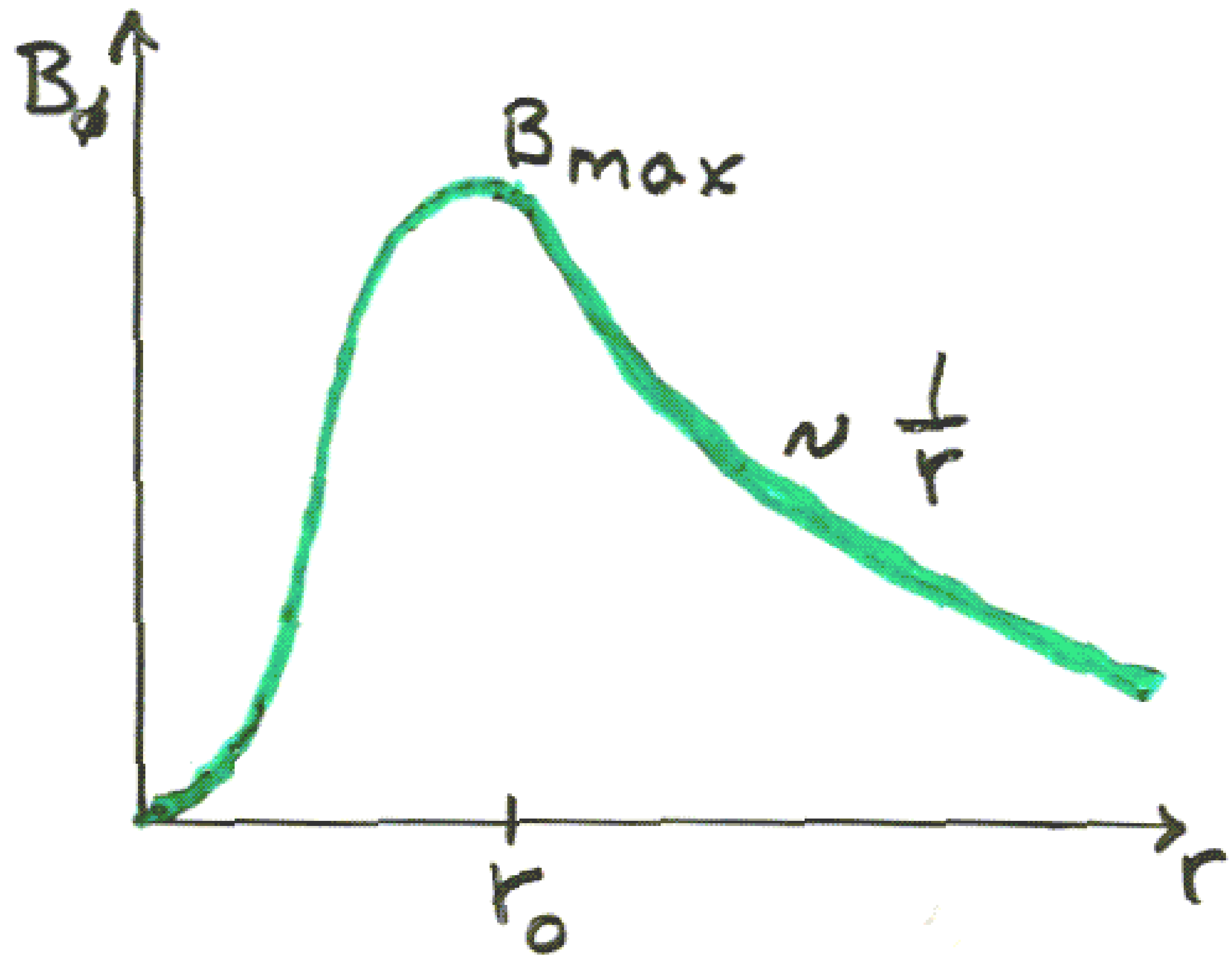
- Optics

... more quantitatively,

Consider an idealized toroid:

$B(r) = B_{max}\left(\frac{r_0}{r}\right)$

(within acceptance)



Recall bend:

$$\delta\theta = \frac{0.3\, B\ell}{P\,(\text{GeV})}$$ where $B\ell$ is in T·m

$$\therefore \quad \theta' = \theta + \frac{\theta_0^2}{\theta} \quad \text{(within acceptance)}$$

$$\therefore \quad \Delta\theta' = \left(1 - \frac{\theta_0^2}{\theta^2}\right)\Delta\theta$$: θ_0 measures $r_0 B_{max}$

No-focus constraint $\Rightarrow$ $\theta_0 \lesssim \theta_{min}$

(lets G0 produce the target image)

Sets scale for torus size, B_{max}

Example: $\theta_0 = 4°$

$[8°, 11°] \longrightarrow [4°, 10.5°]$

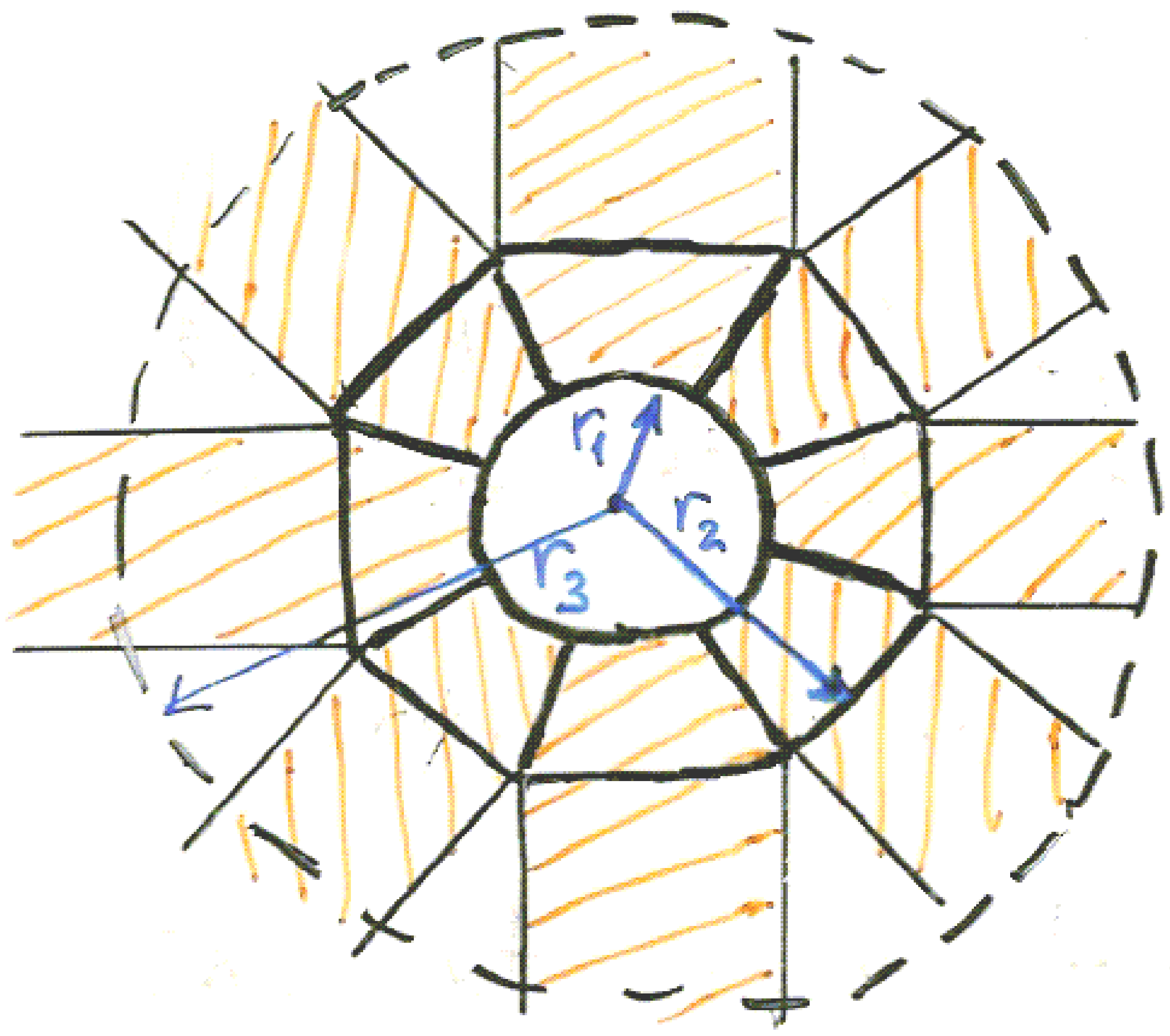
$\frac{\Delta\theta}{\theta}$: 32% 95% $\boxed{\times 3 !}$

This is an over-estimate because

1) there will be some cost in $\Delta\phi$

2) the coils may block access to very low angles like 4°.

- Coil geometry



r_1 = beam keep-out zone

r_2 = radius of inner coi[l] boundary

r_3 = start of acce[ptance] of collimat[or]

Assume acceptance starts when

$$\frac{\Delta\phi}{2\pi} = 0.5$$

$\Rightarrow$ $\boxed{r_3 = 2r_2}$ (after some tri- .

... and r_2 depends on r_1 and the amount of Copper needed

Recall for an ideal solenoid:

$$B_{max} = \frac{\mu_0 I}{2\pi r_0} = \frac{\mu_0}{2\pi r_0} j\,(r_2^2 - r_1^2)\pi$$

where j is the current density of copper coils:

500 A/cm² (P. Brindza)

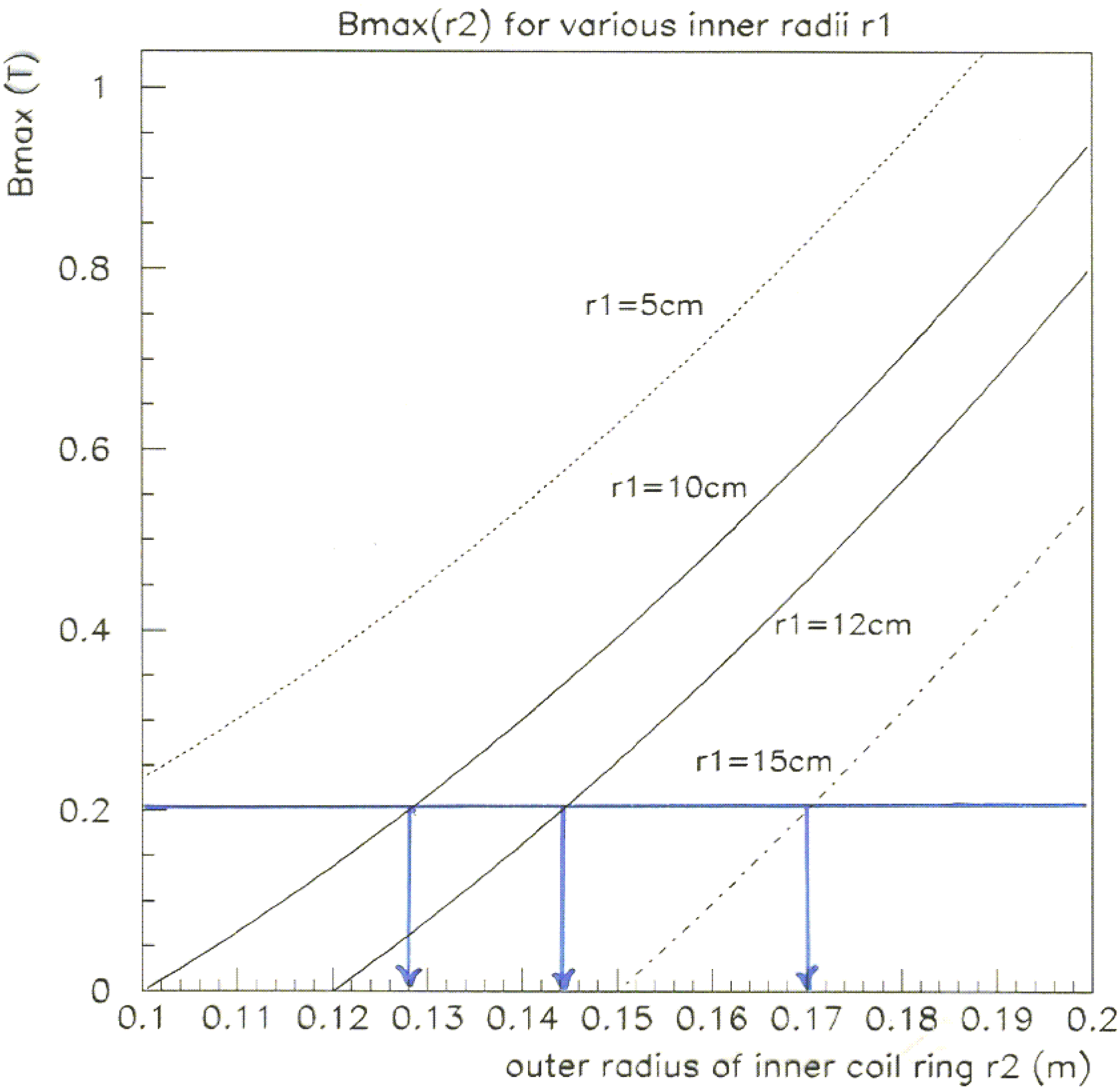
$\theta_0 = 4°$ would require $\ell \cdot B_{max} = 3$ kG to capture 4° electrons.

Try: $\ell = 1.5$ m, $B_{max} = 2$ kG

This sets scale for $r_0 \sim \ell\theta_0 = 10$ cm

Solve for r_2 given r_1

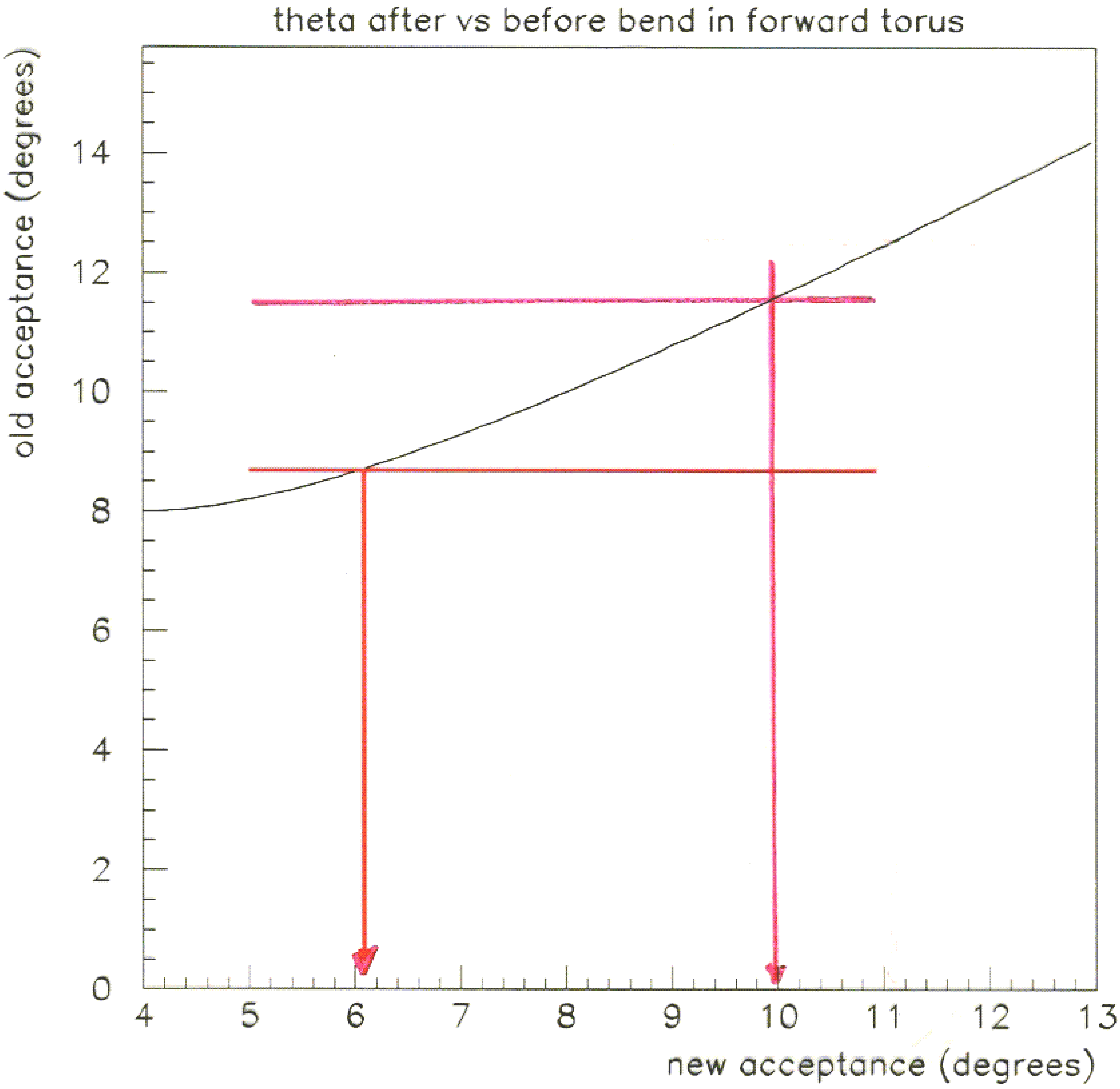
r_1	r_2	r_3
10cm	13 cm	26cm
12cm	14.5cm	29 cm
15cm	17 cm	34cm



Take a favorable case for study:

$r_1 = 10\,cm \qquad r_2 = 13\,cm \qquad r_3 = 26\,cm$

$B_m = 2\,kG \cdot \frac{r_0}{r}, \quad r_0 = 10\,cm, \quad \ell = 15$



$\frac{\Delta\Theta}{\Theta} = 50\%$

$\frac{\Delta\phi}{2\pi} = 50\%$

$\boxed{\text{combined factor } \underline{1.14} \text{ improvement}}$