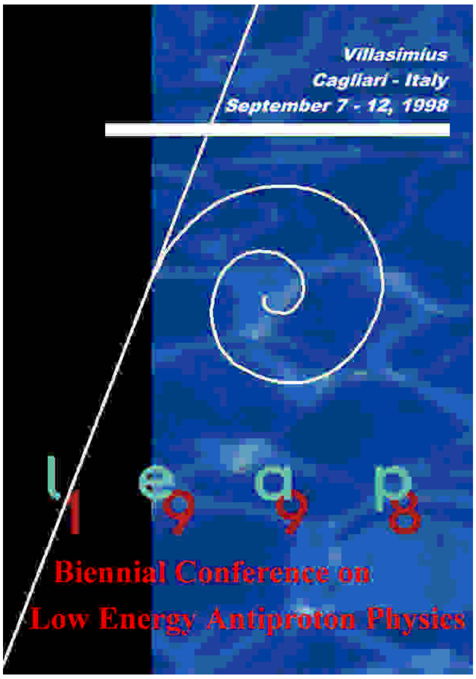
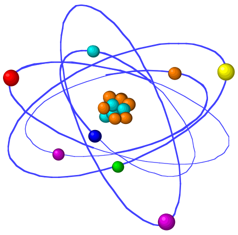
$\bar{n}p$ *total* *and* *annihilation* *cross sections* *from 50 to 400 MeV/c*



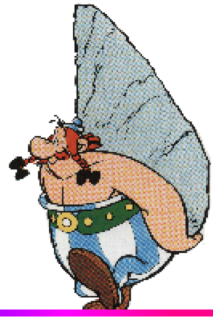
Alessandro Feliciello / I.N.F.N. - Sezione di Torino

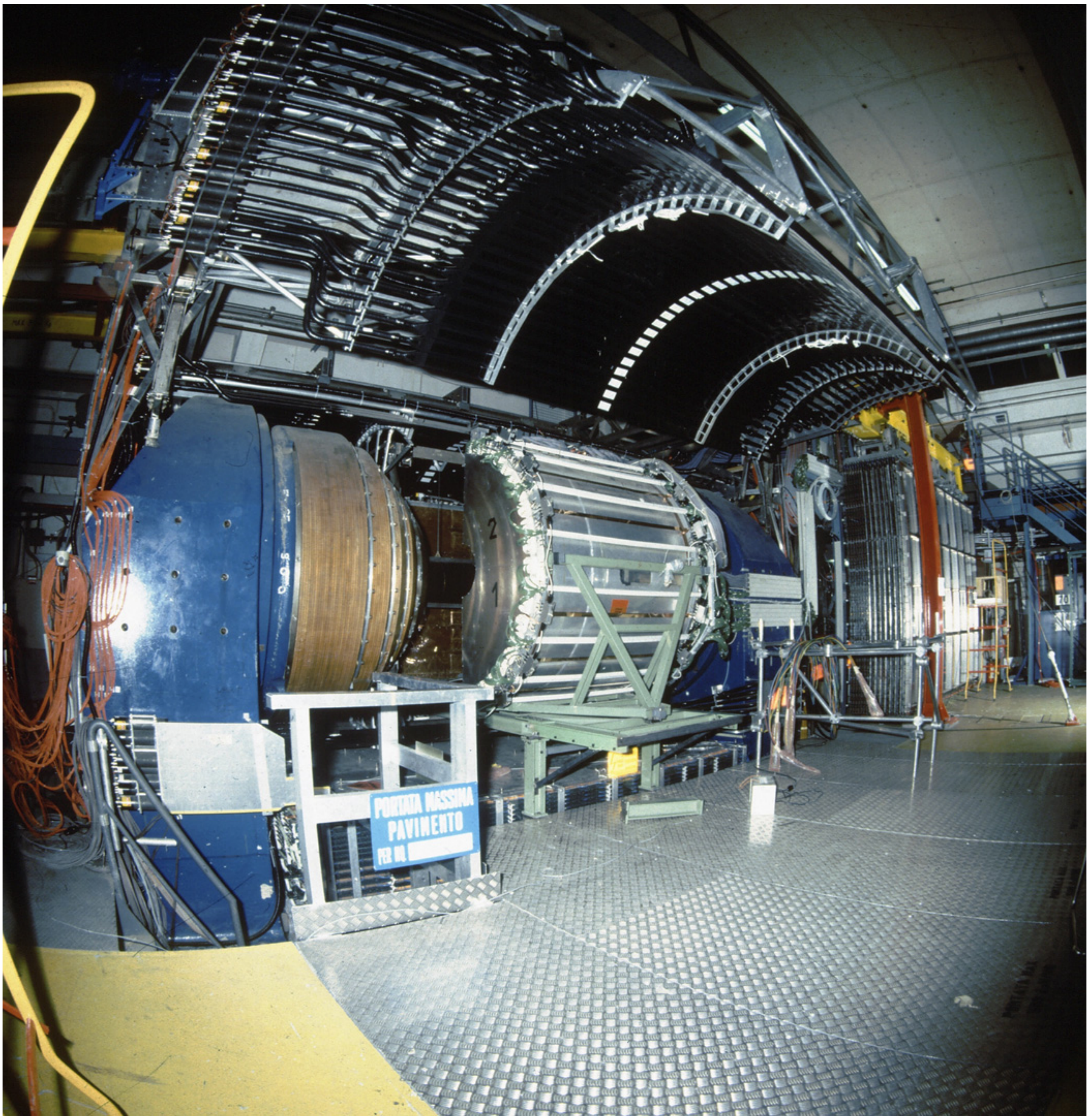


Outlook

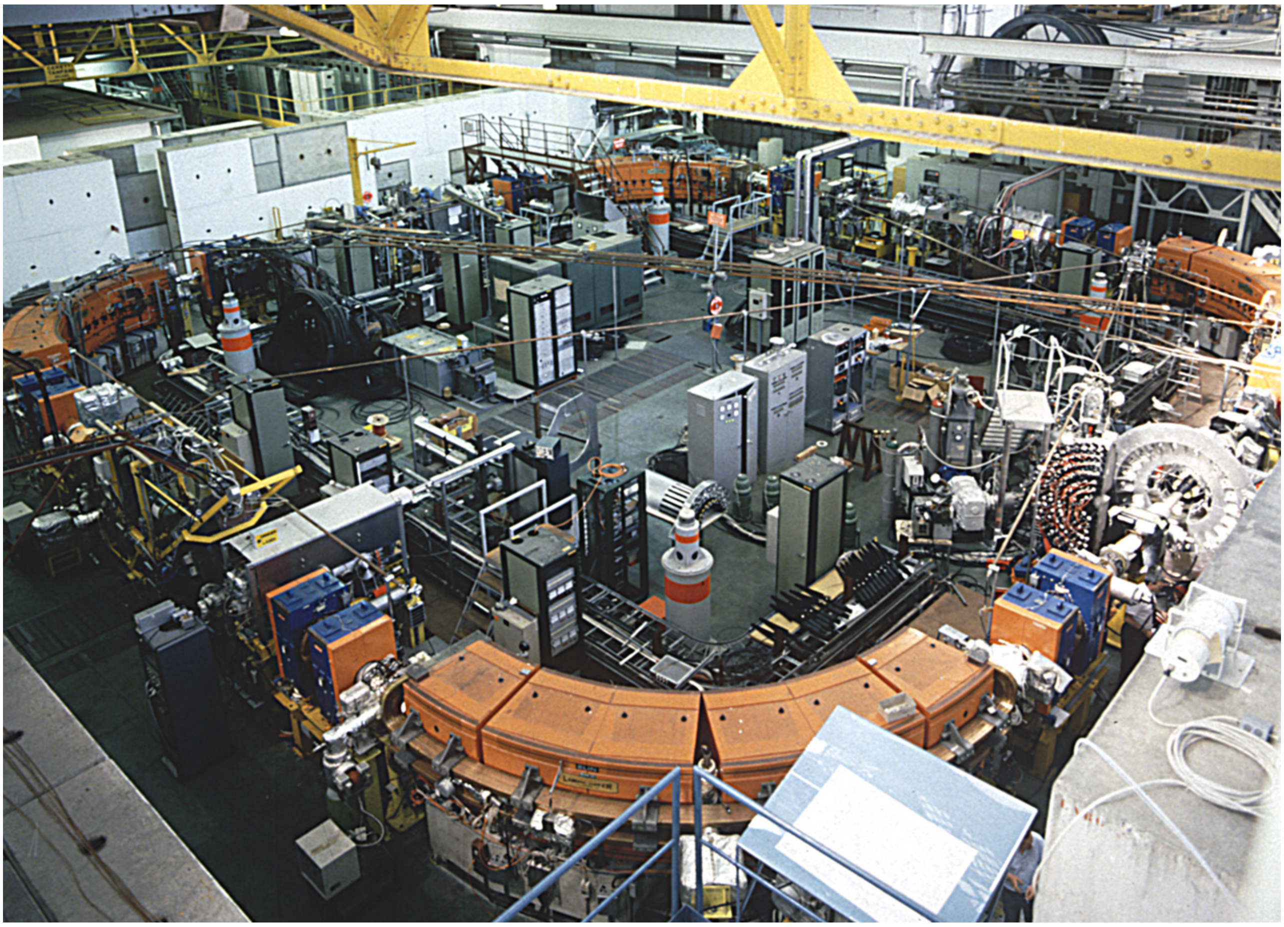
- ⋆ The OBELIX apparatus
- ⋆ The OBELIX $\bar{n}$ facility
- ⋆ $\bar{n}p$ annihilation cross sections
- ⋆ $\bar{n}p$ total cross section
- ☛ Hint for the existence of a narrow quasi-nuclear state near the threshold

The OBELIX spectrometer





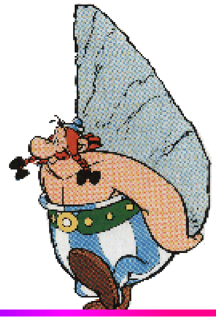
The LEAR machine



Beam intensity: $10^7\ \overline{p}/s$

$\Delta p/p$: $\sim 10^{-4}$

$\bar{n}$ interaction
Why?

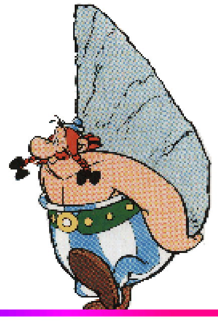


- scarce data on low-energy $\bar{n}p$ interaction
- complementary/alternative to $\bar{p}p$ interaction
- the initial $\bar{n}p$ state is a pure I = 1 state
- better energy and momentum resolution, compared to $\bar{p}d$ reaction, due to the absence of the spectator proton
- the percentage of *P*-wave in the initial state can be controlled by increasing the $\bar{n}$ momentum
- at least one prong in the final state (optimal for OBELIX)

but

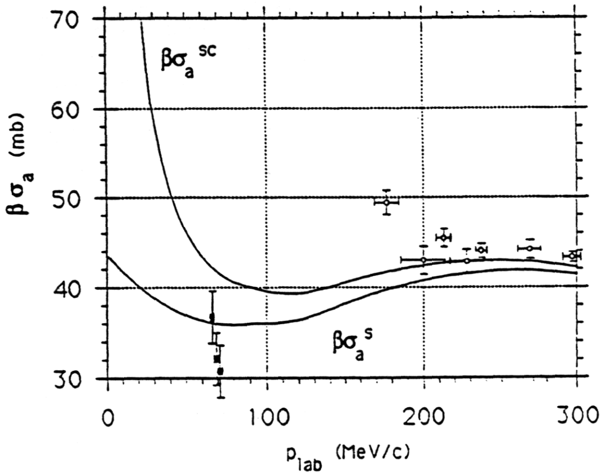
- technically difficult
- low production rate (~ 60 10^{-6} $\bar{n}/\bar{p}$)

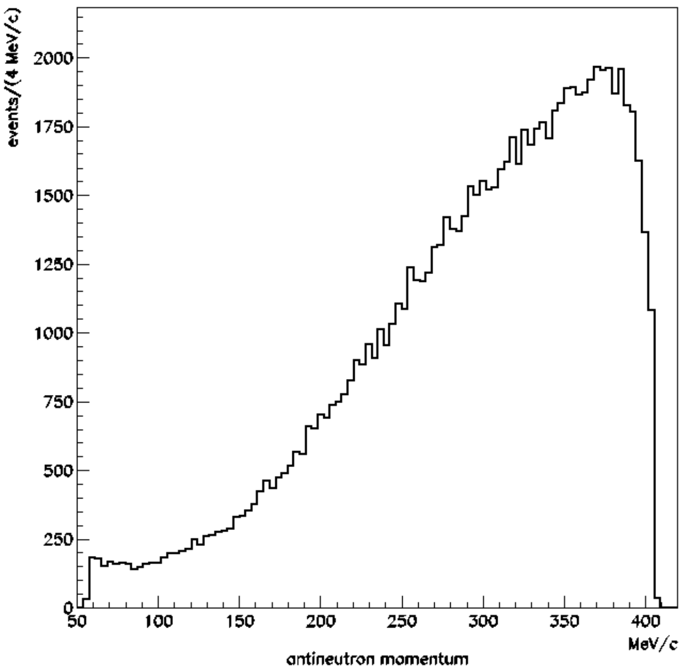
$\bar{n}p$ cross section



Absence of Coulomb interaction:
no distortion on the σ trend
in the low momentum region

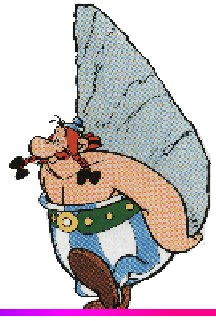
$\beta\sigma_{ann}(\bar{p}p)$



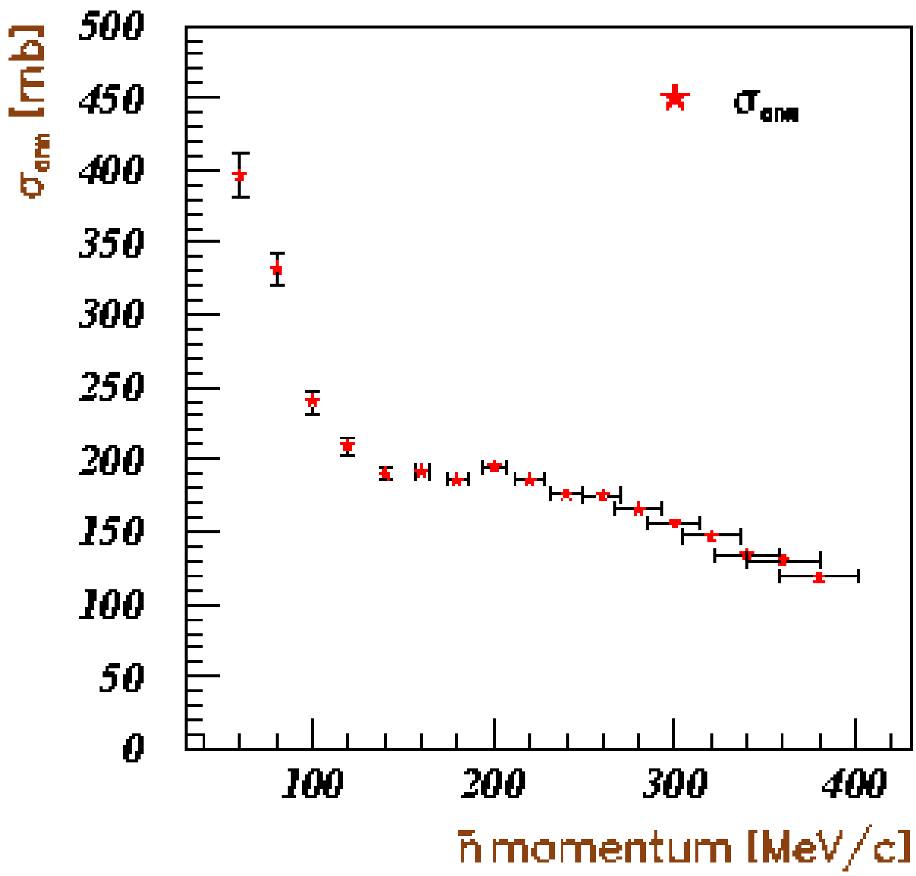


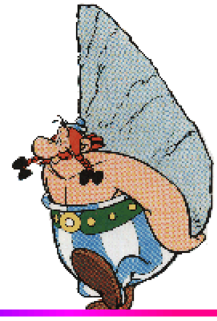
Capability of reconstructing the momentum of **each** interacting $\bar{n}$

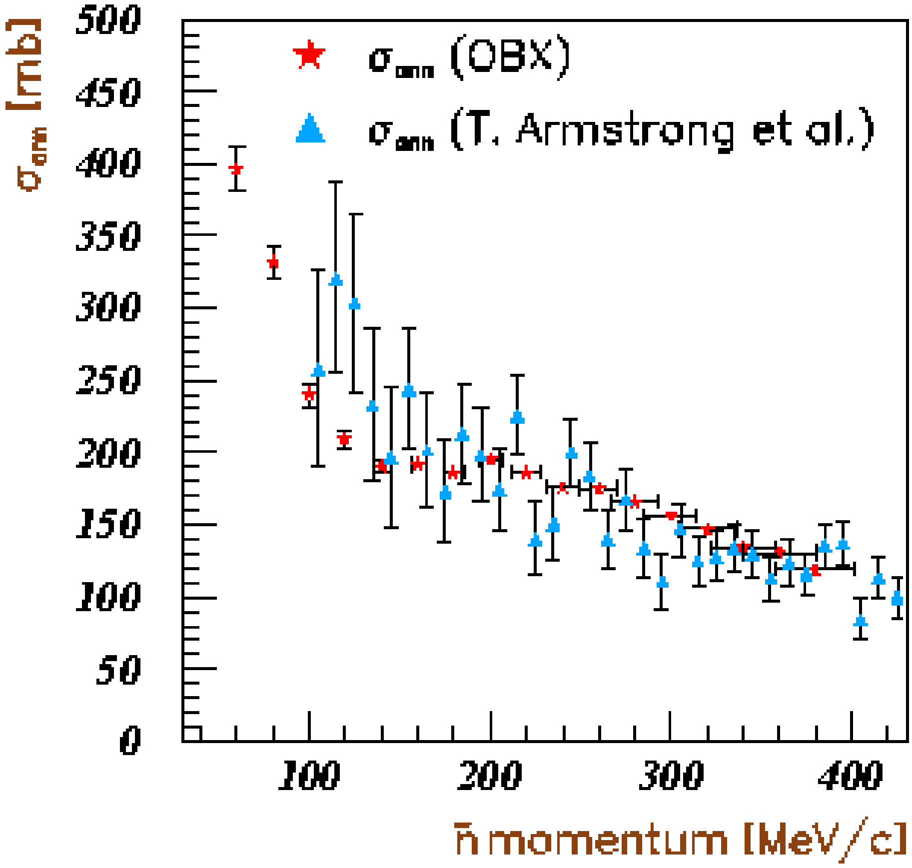
$\bar{n}p$ annihilation cross section



$$\sigma^{i}_{ann} = \frac{1}{\rho N_A \Delta z} \frac{1}{\varepsilon \varepsilon_{trig}} \frac{N^{i}_{ann}(1-\gamma^{i})}{N^{i}_{\bar{n}}}$$

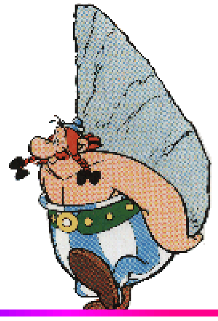






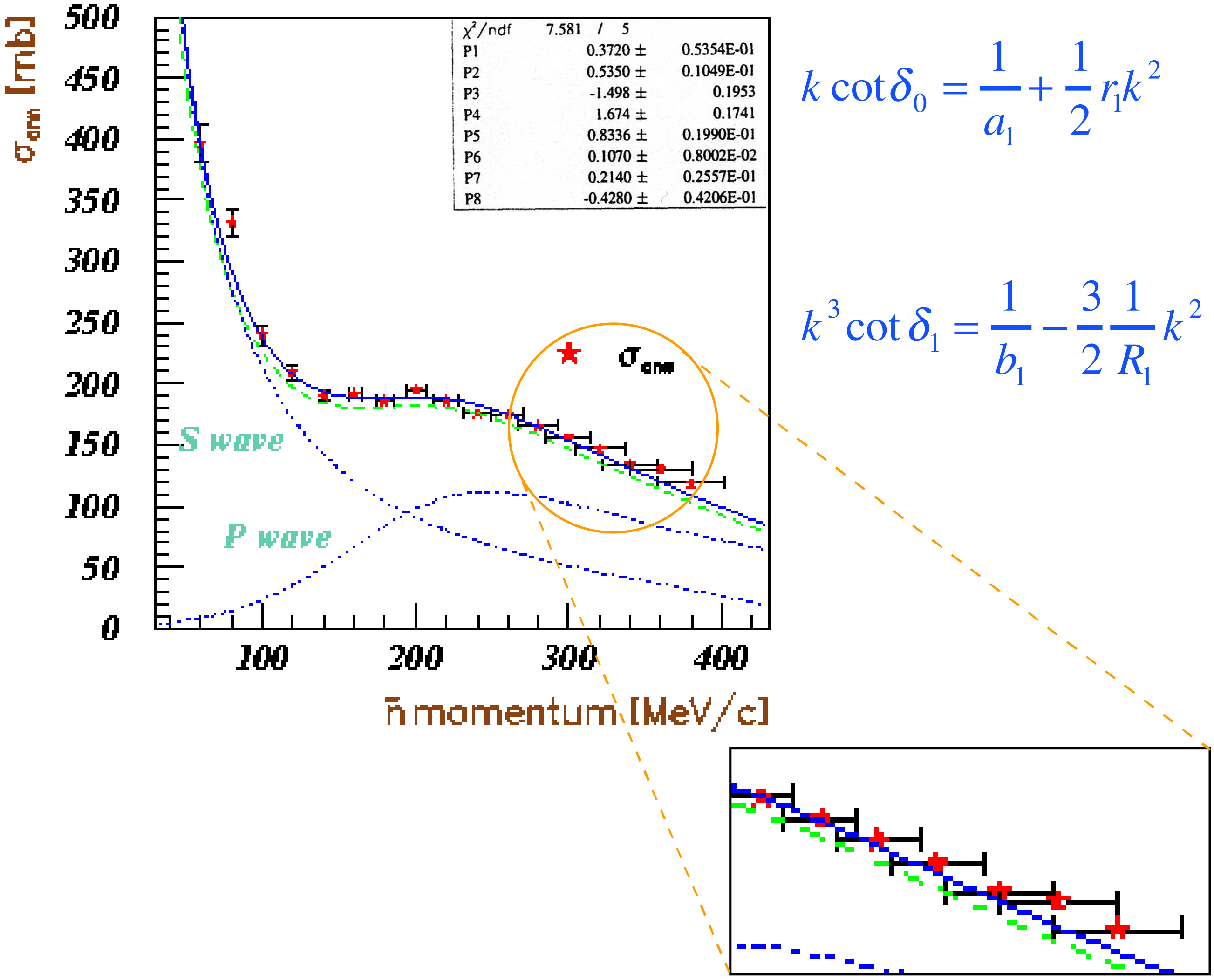
σ_ann (OBX)
σ_ann (T. Armstrong et al.)
σ_ann [mb]
500
450
400
350
300
250
200
150
100
50
0
100
200
300
400
n̄ momentum [MeV/c]

Effective range expansion



$$\sigma_{ann} = \frac{4\pi}{k^2}\sum_l (2l+1)(Imf_l - |f_l|^2)$$

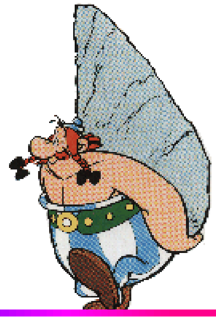
$$f_l = \frac{1}{\cot\delta_l - i}$$



$$k\cot\delta_0 = \frac{1}{a_1} + \frac{1}{2}r_1k^2$$

$$k^3\cot\delta_1 = \frac{1}{b_1} - \frac{3}{2}\frac{1}{R_1}k^2$$

Effective range expansion



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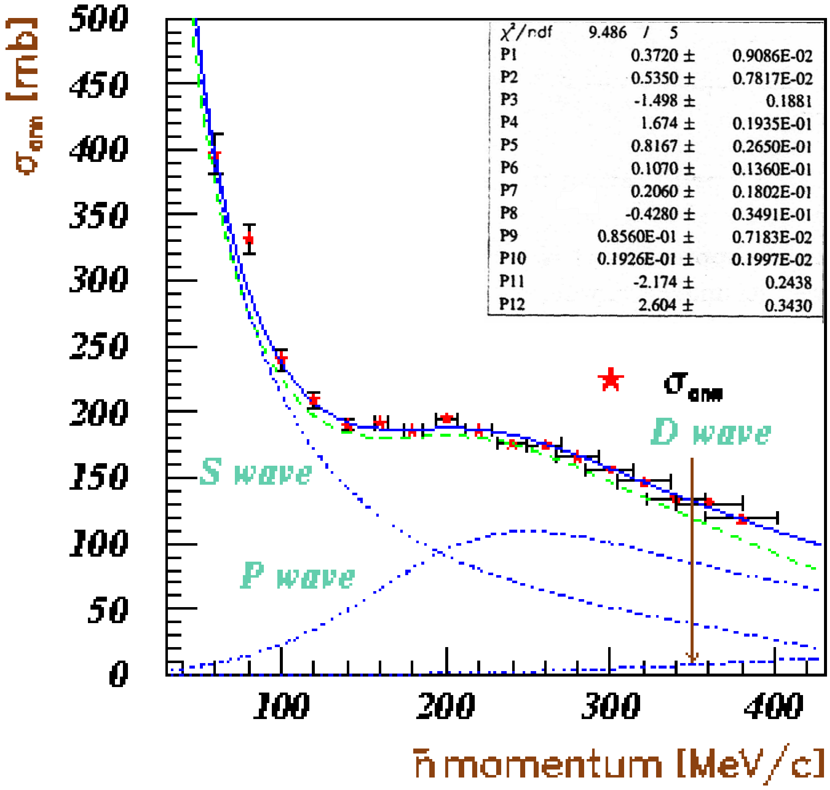

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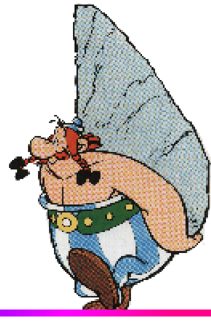
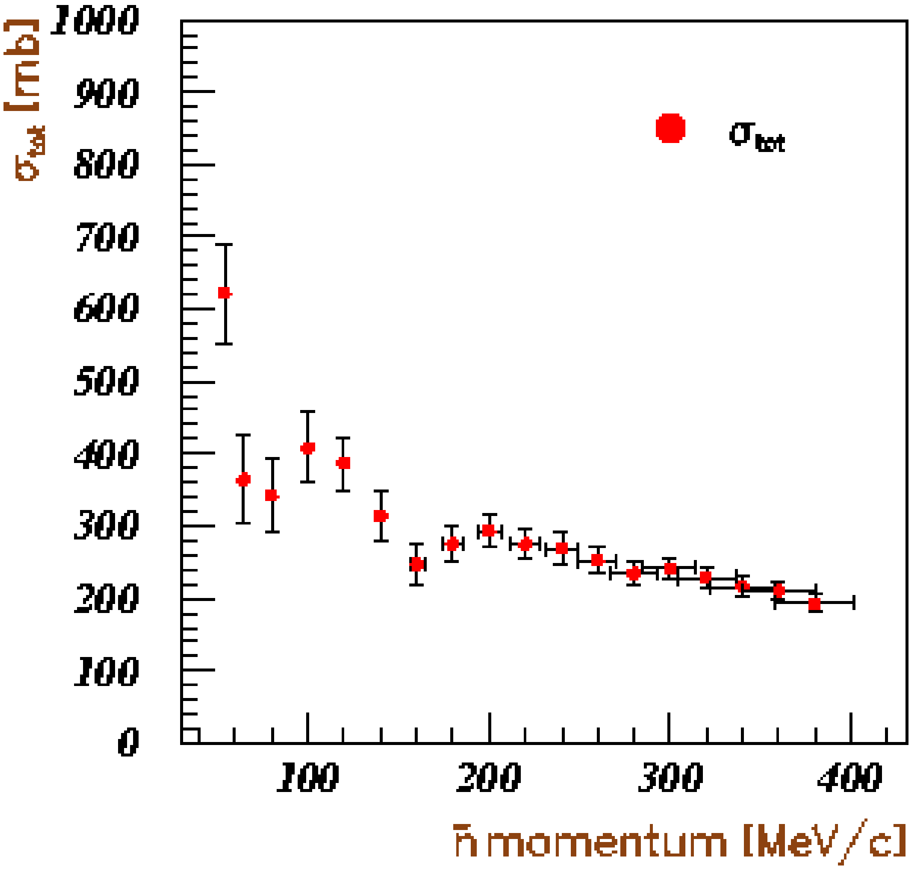
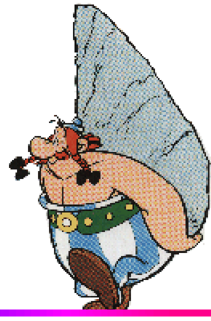
$$k^5\cot\delta_2 = \frac{1}{c_1} + \frac{5}{2}\frac{1}{\rho_1^3}k^2$$

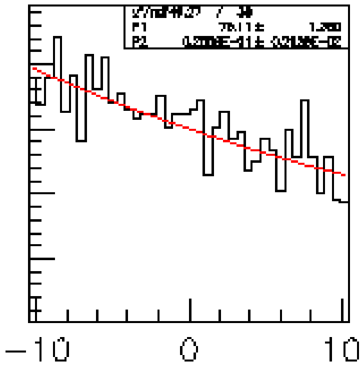
$\bar{n}p$ total cross section



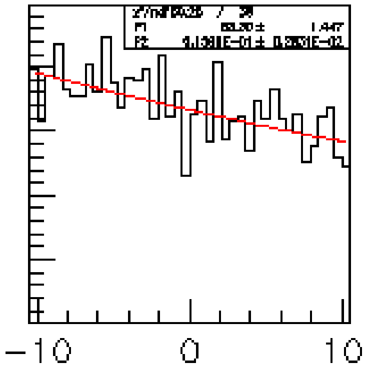


Transmission method

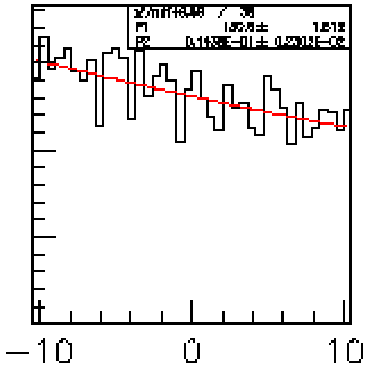




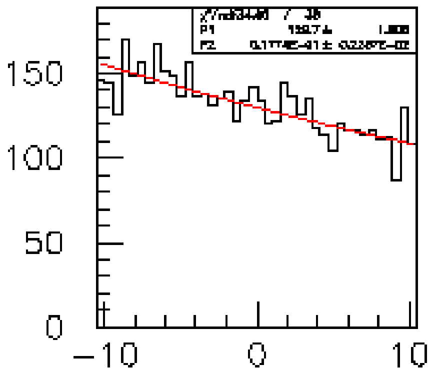
50 < p < 60



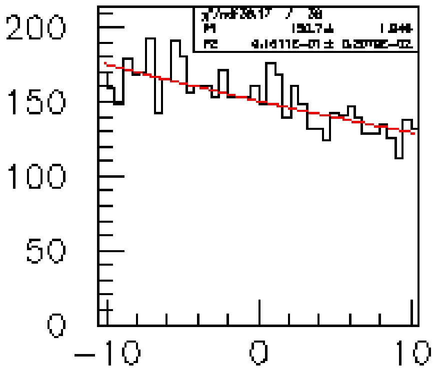
60 < p < 70



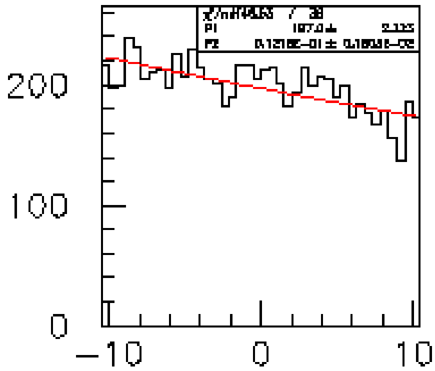
70 < p < 90



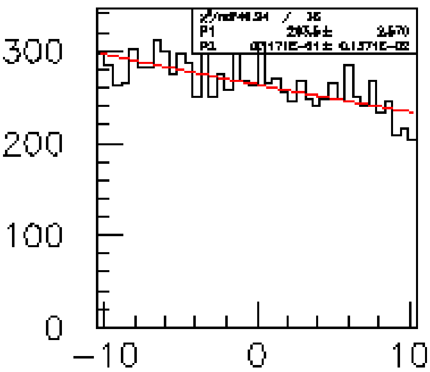
90 < p < 110



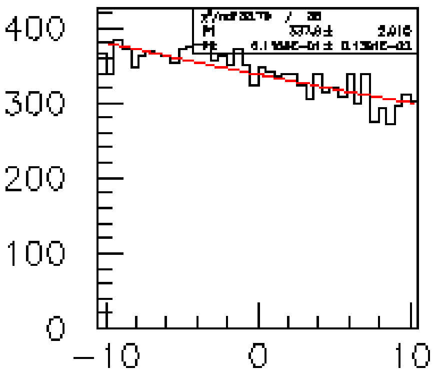
110 < p < 130



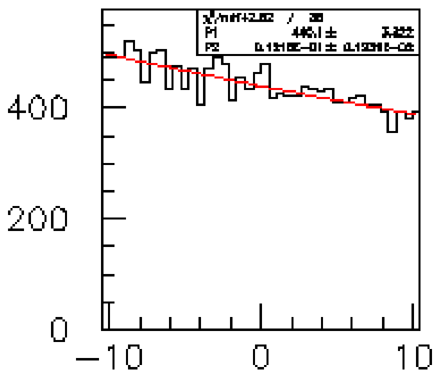
130 < p < 150



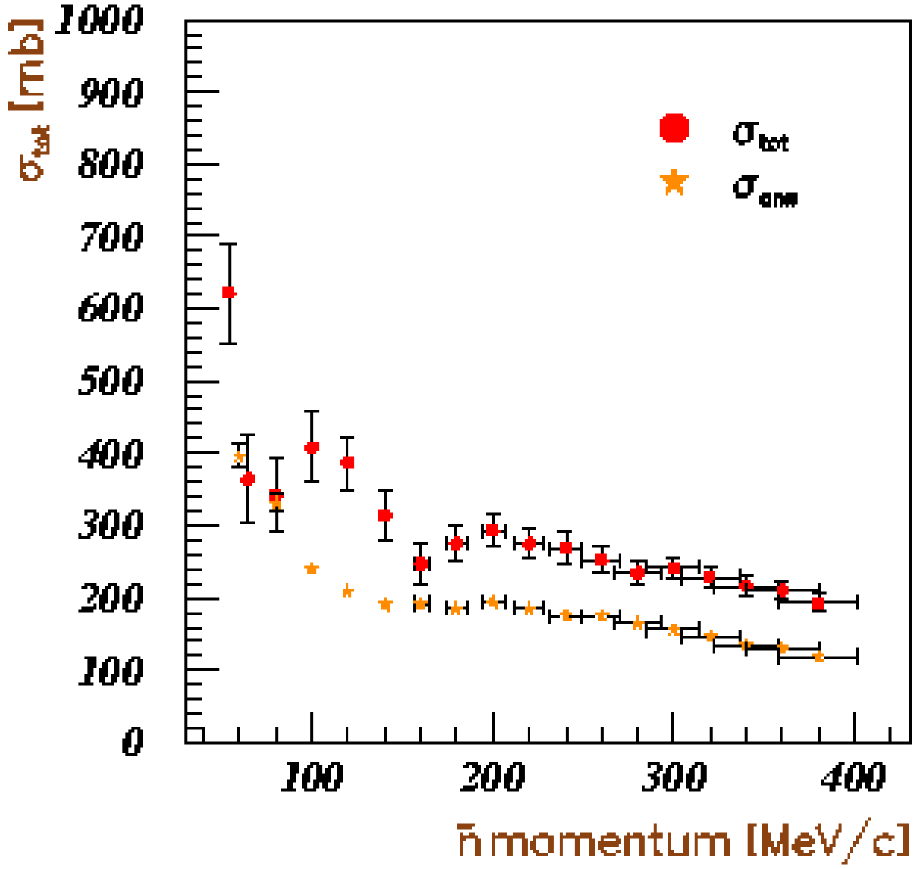
150 < p < 170

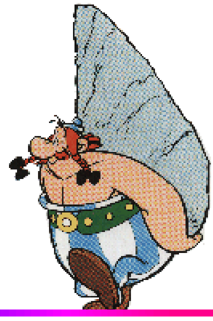


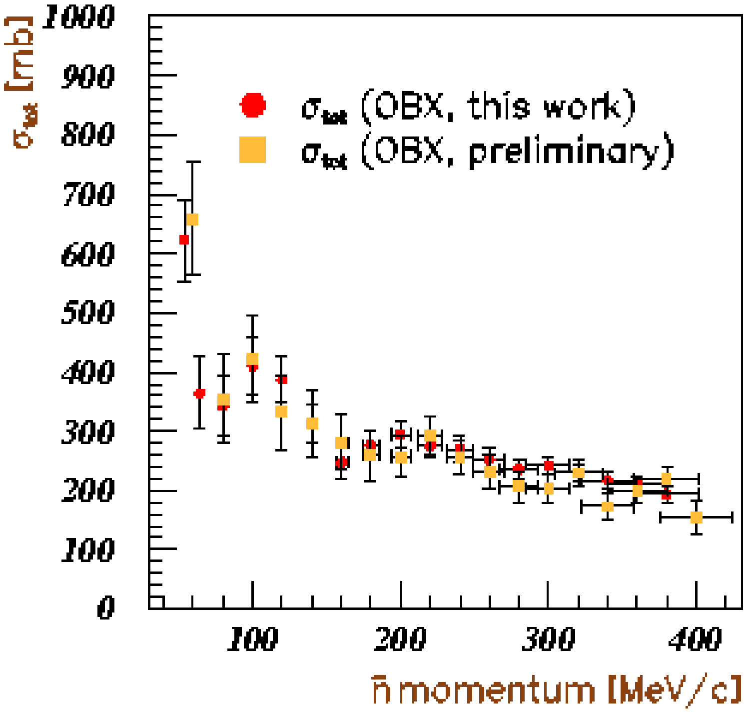
170 < p < 190



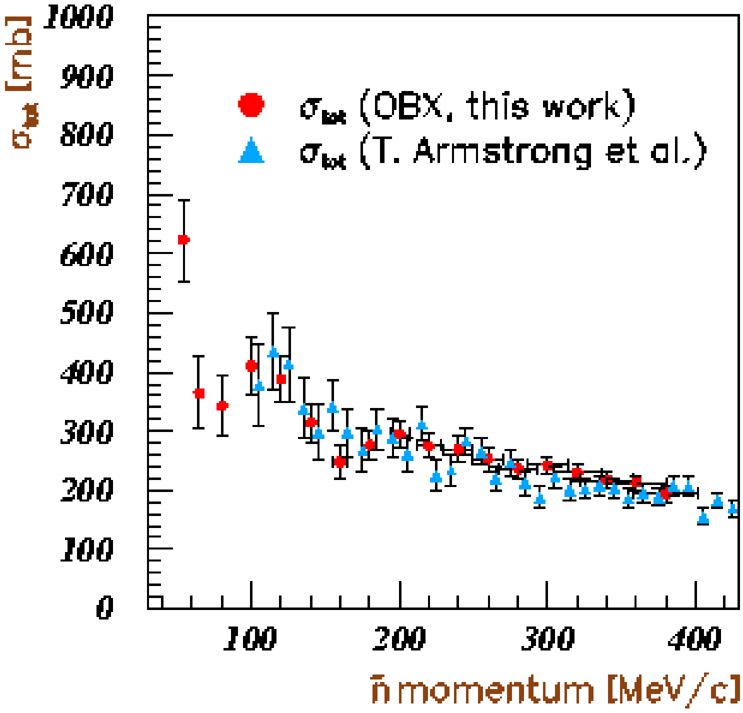
190 < p < 210

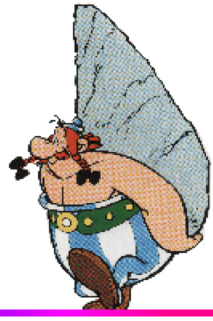

σ_tot [mb]
1000
900
800
700
600
500
400
300
200
100
0
σ_tot
σ_ann
100
200
300
400
n̄ momentum [MeV/c]

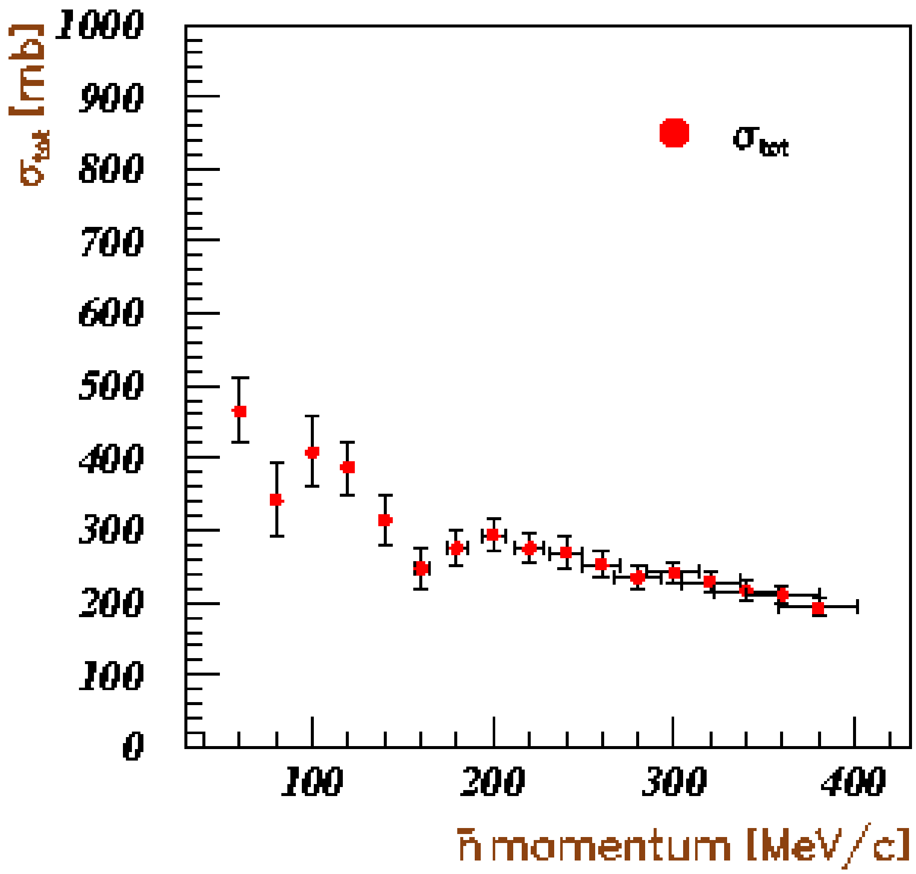




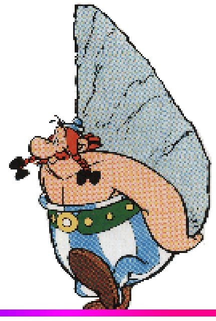
$$\sigma^{i}_{tot} = \sigma_0 \log \frac{N^{i}_{ann}(R_1)}{N^{i}_{ann}(R_2)\varepsilon}$$





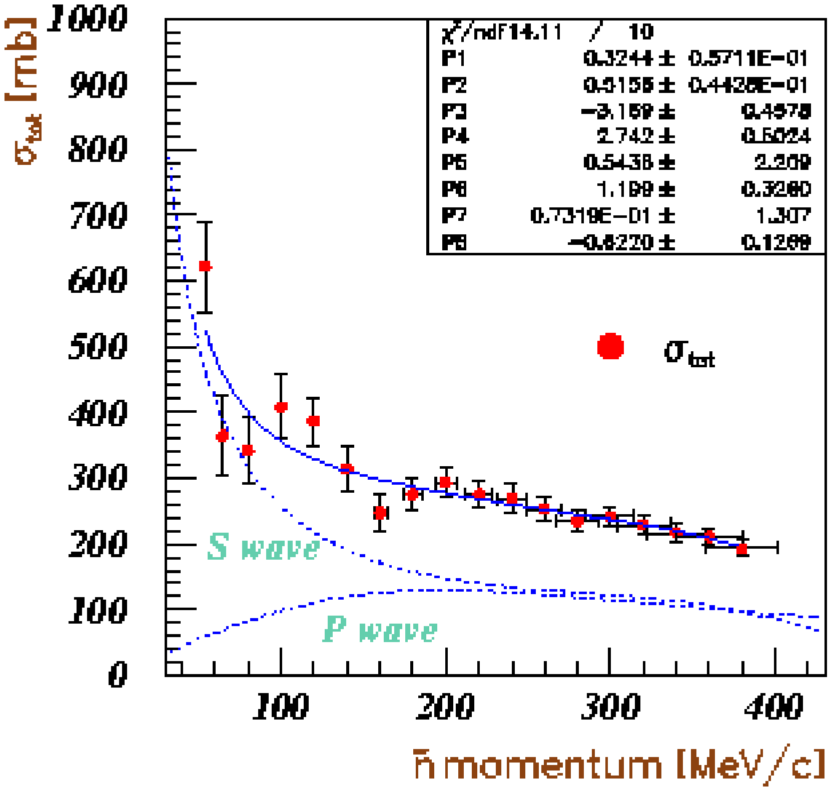

σ_tot [mb]
1000
900
800
700
600
500
400
300
200
100
0
σ_tot
100
200
300
400
n̄ momentum [MeV/c]

Effective range expansion



$$\sigma_{tot} = \frac{4\pi}{k^2} \sum_l (2l+1) Im f_l$$

$$f_l = \frac{1}{\cot \delta_l - i}$$



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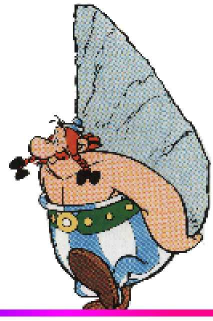
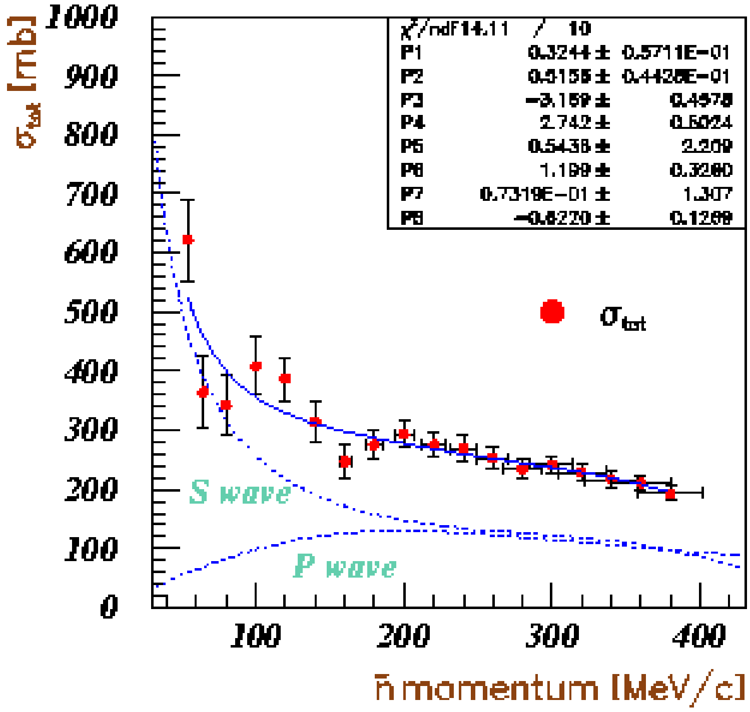
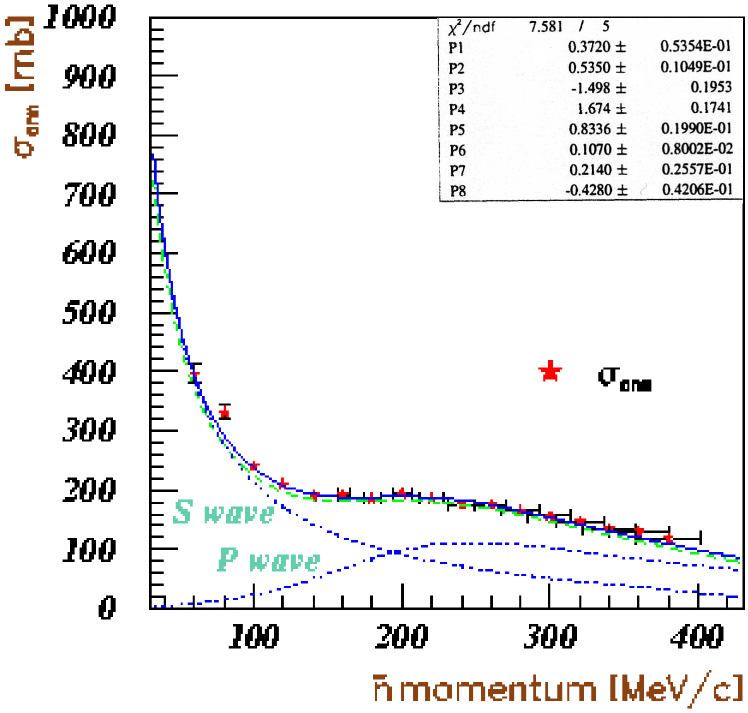
$$k^3 \cot \delta_1 = \frac{1}{b_1} - \frac{3}{2} \frac{1}{R_1} k^2$$



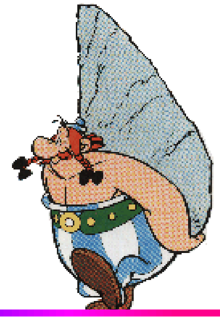


total

annihilation

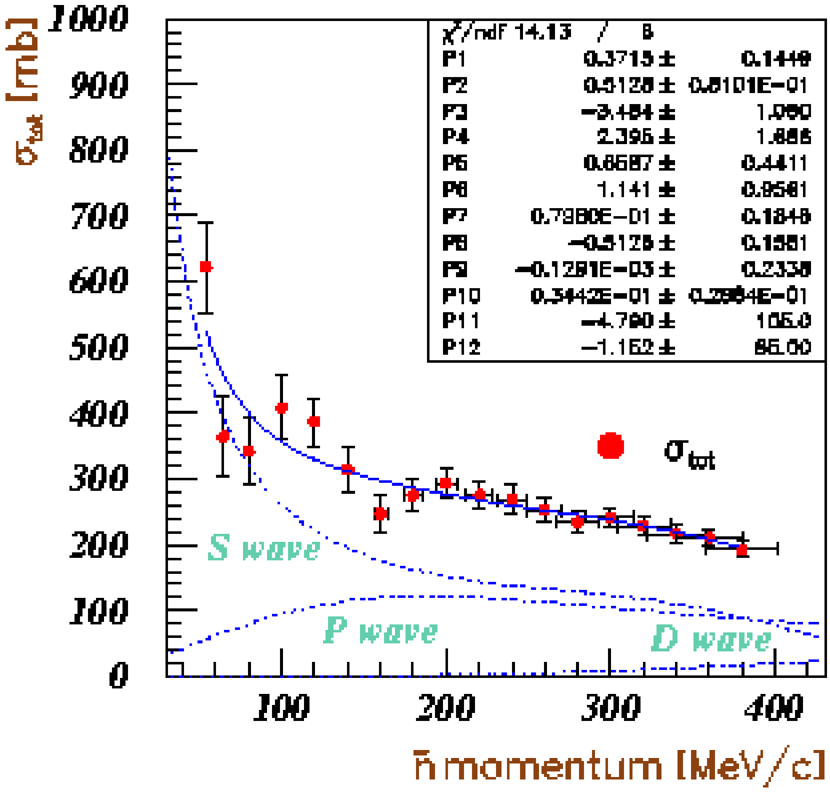


Effective range expansion



$$\sigma_{tot} = \frac{4\pi}{k^2}\sum_l (2l+1)\, Im f_l$$

$$f_l = \frac{1}{\cot\delta_l - i}$$



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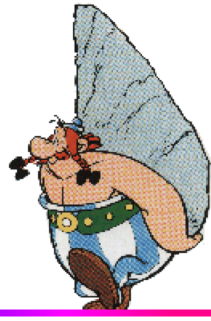
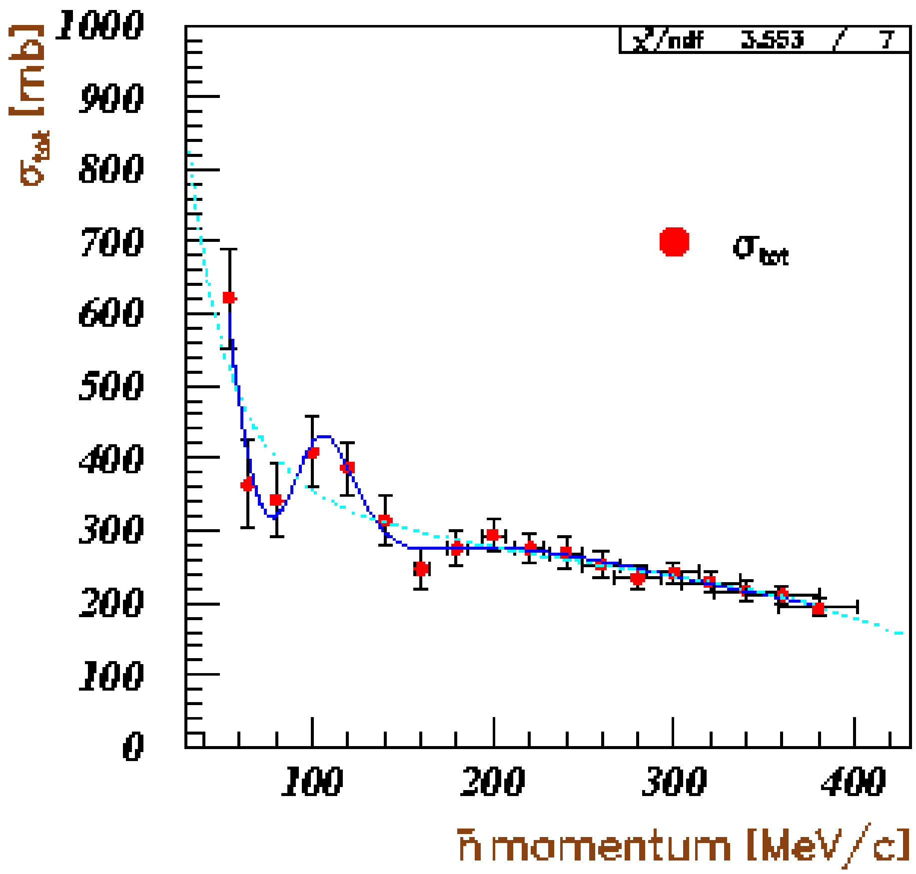
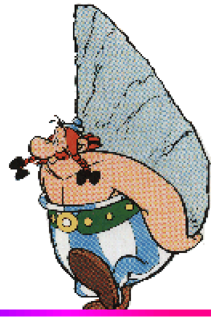


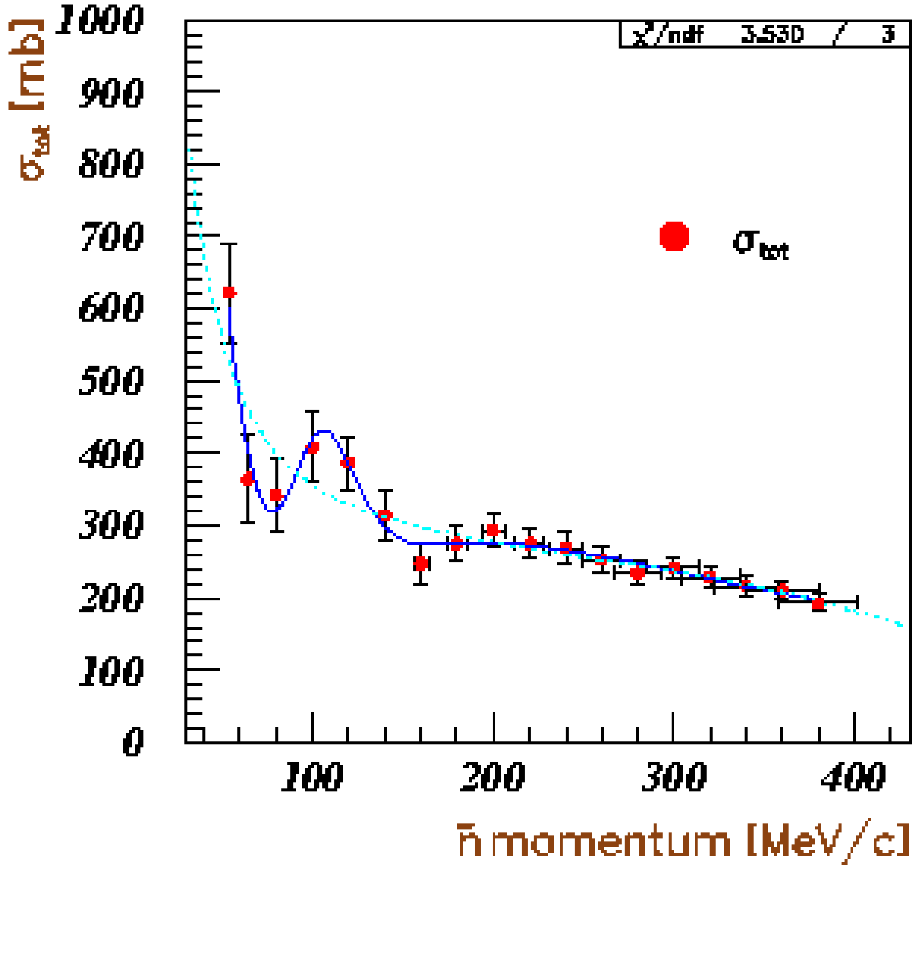
S- and P- waves + B.W.



$M_x \sim 1881$ MeV
$\Gamma_x \sim \quad 4$ MeV



S-, P- and D- waves + B.W.



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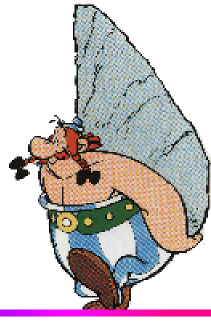
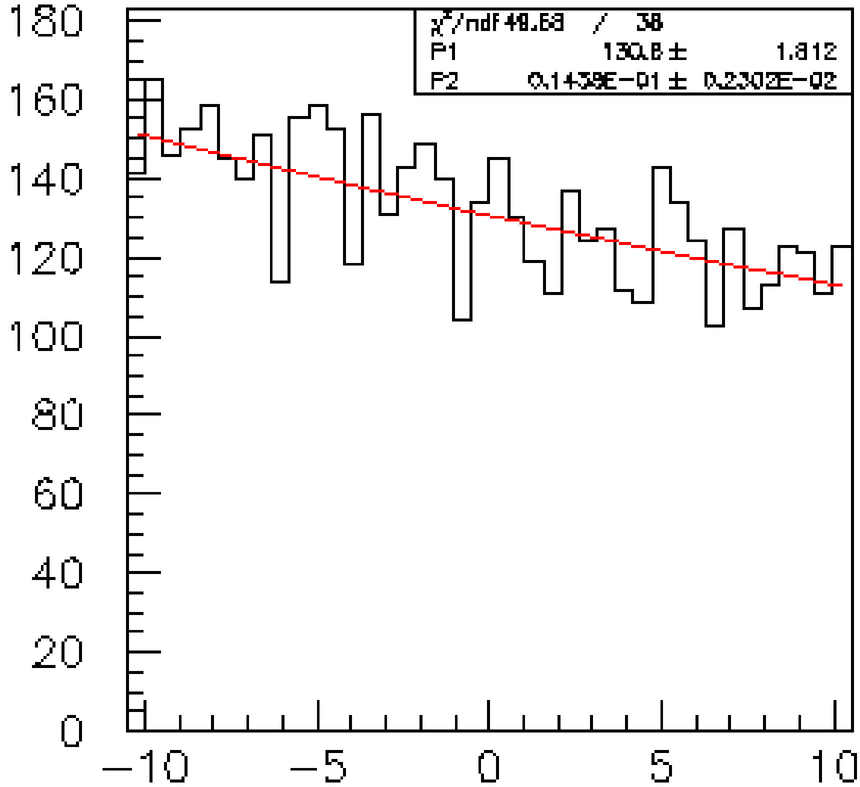
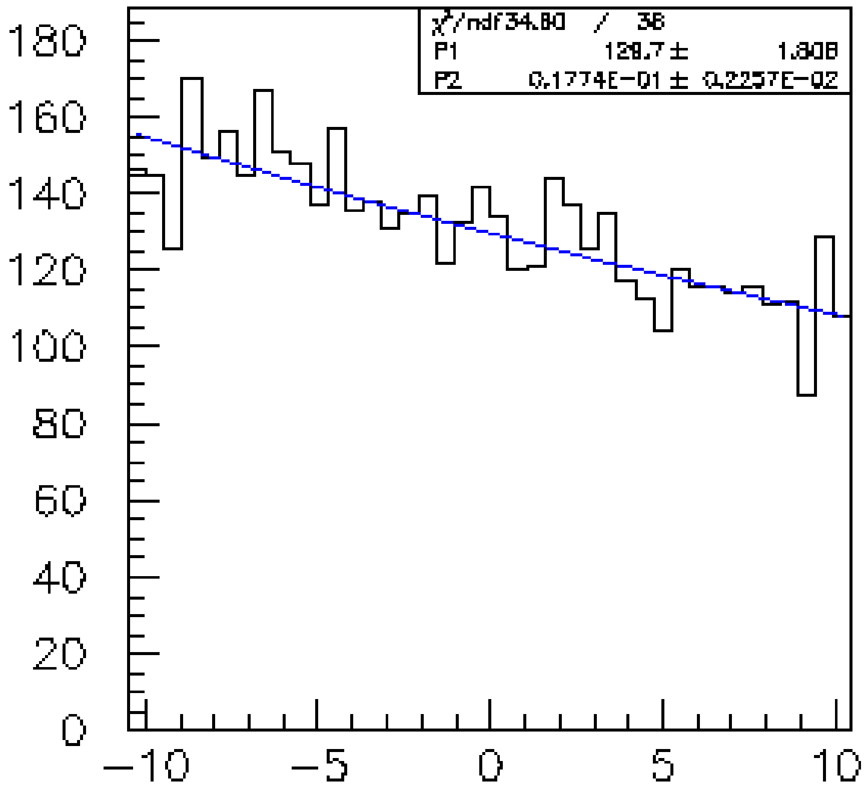




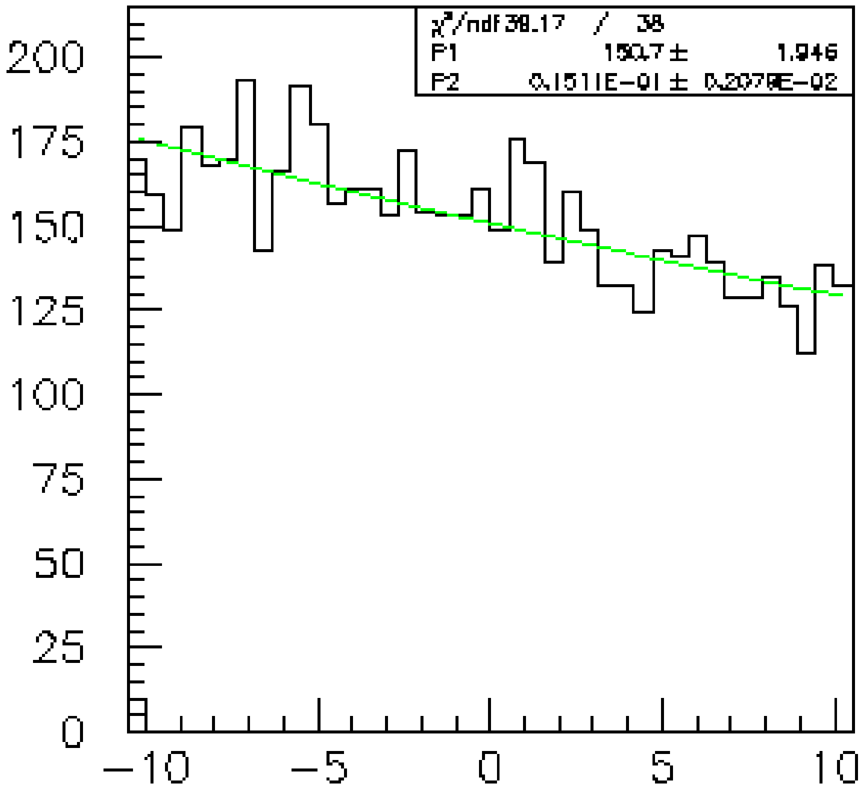
χ²/ndf 40.63 / 38
P1 130.8 ± 1.812
P2 0.1439E-01 ± 0.2302E-02
180
160
140
120
100
80
60
40
20
0
−10
−5
0
5
10

70 < p < 90

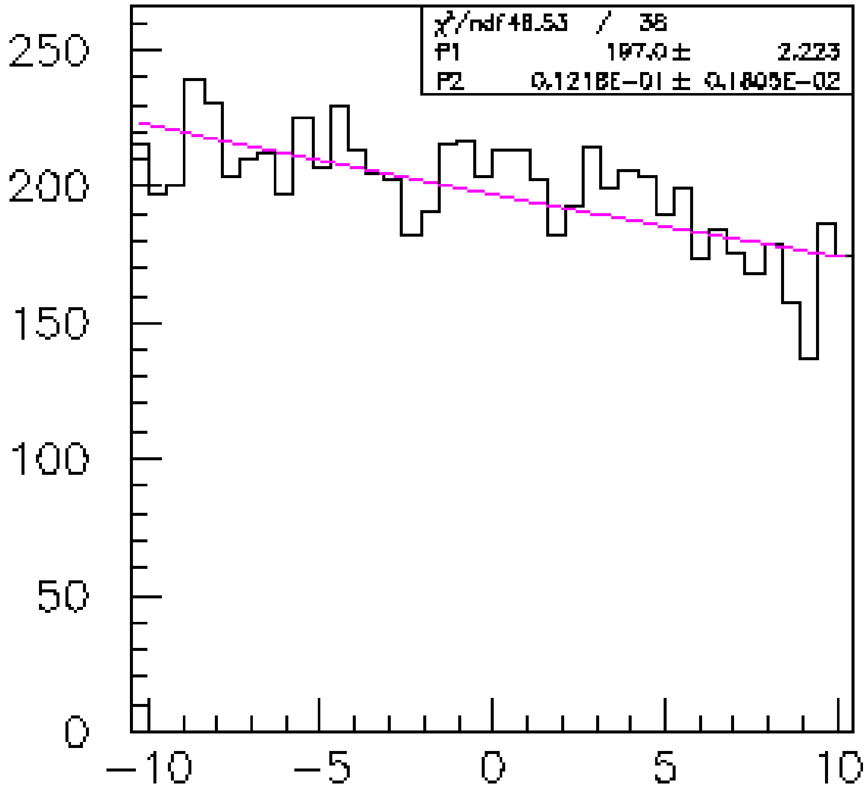


χ²/ndf 34.80 / 38
P1 128.7 ± 1.808
P2 0.1774E−01 ± 0.2257E−02
180
160
140
120
100
80
60
40
20
0
−10
−5
0
5
10

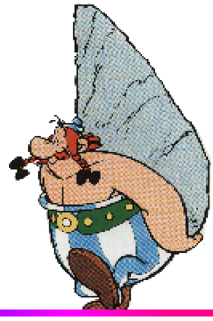
$90 < p < 110$

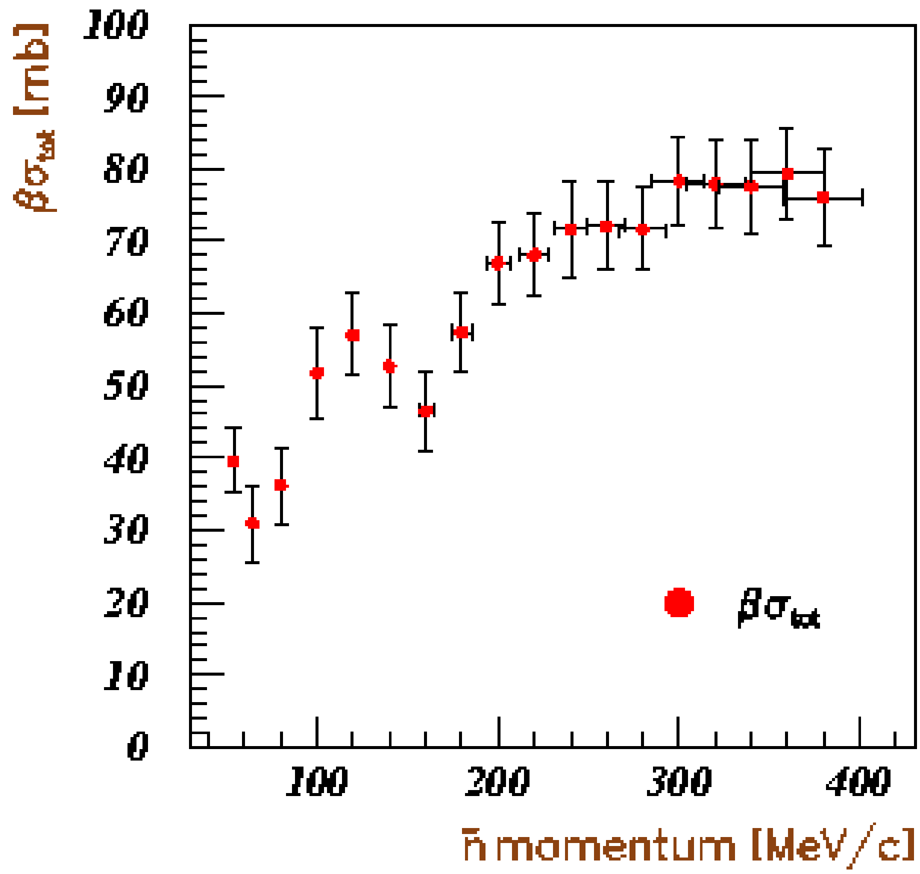

χ²/ndf 38.17 / 38
P1 150.7 ± 1.946
P2 0.1511E-01 ± 0.2079E-02
200
175
150
125
100
75
50
25
0
−10
−5
0
5
10

110 < p < 130

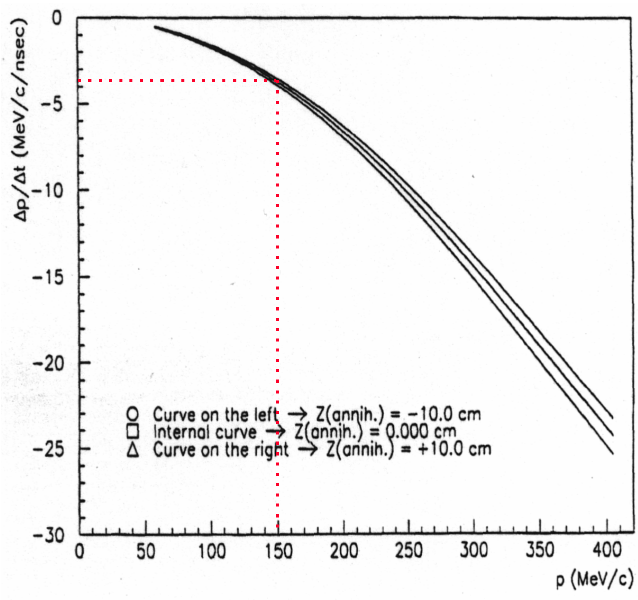

χ²/ndf 48.53 / 38
P1 197.0 ± 2.223
P2 0.1218E-01 ± 0.1809E-02
250
200
150
100
50
0
−10
−5
0
5
10

130 < p < 150

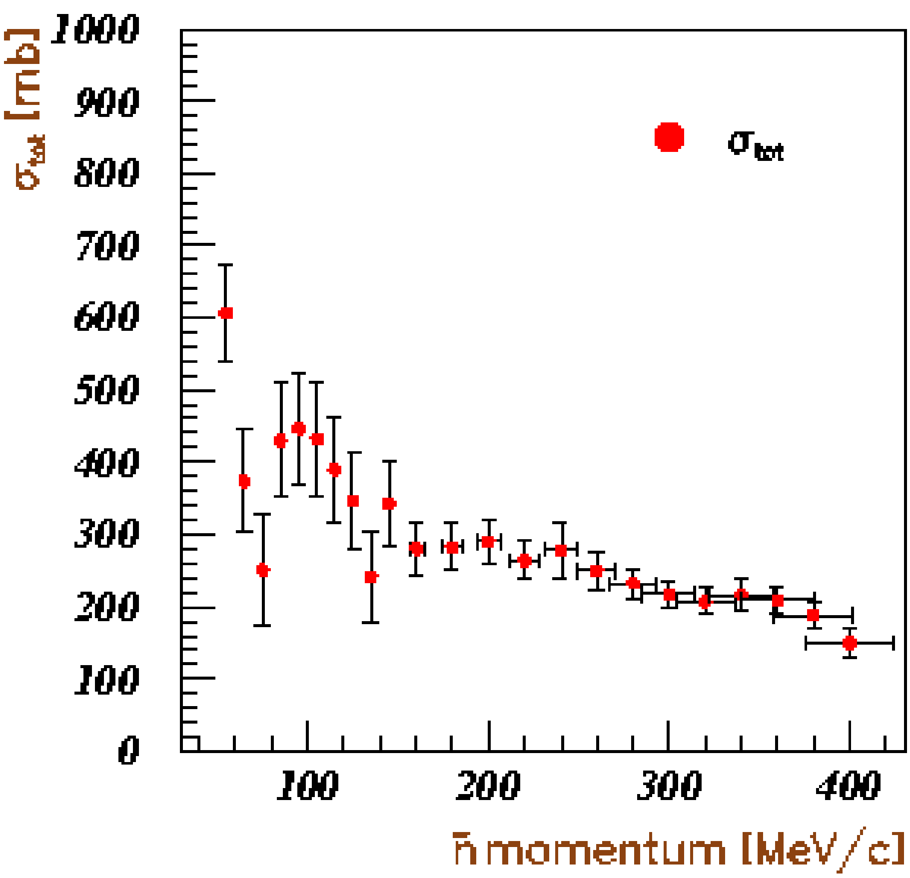




βσtot [mb]
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
n̄ momentum [MeV/c]
βσtot

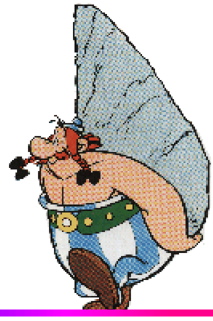


Δp/Δt (MeV/c/nsec)
p (MeV/c)
O Curve on the left → Z(annih.) = −10.0 cm
□ Internal curve → Z(annih.) = 0.000 cm
Δ Curve on the right → Z(annih.) = +10.0 cm



σtot [mb]
σtot
n̄ momentum [MeV/c]

Effective range expansion



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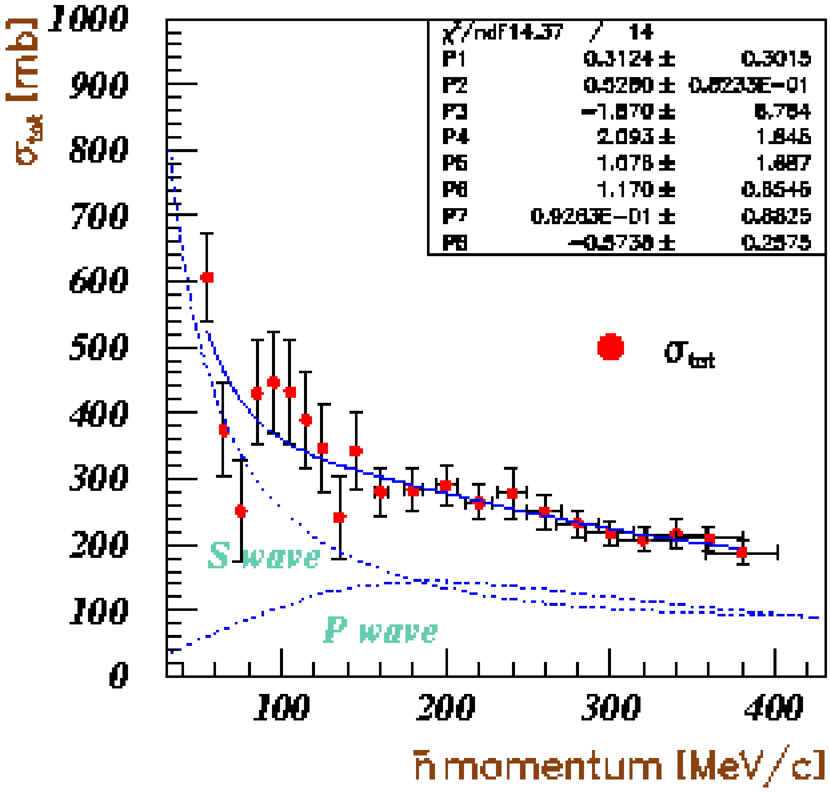
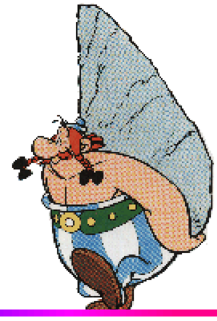


$$k \cot\delta_0 = \frac{1}{a_1} + \frac{1}{2} r_1 k^2$$

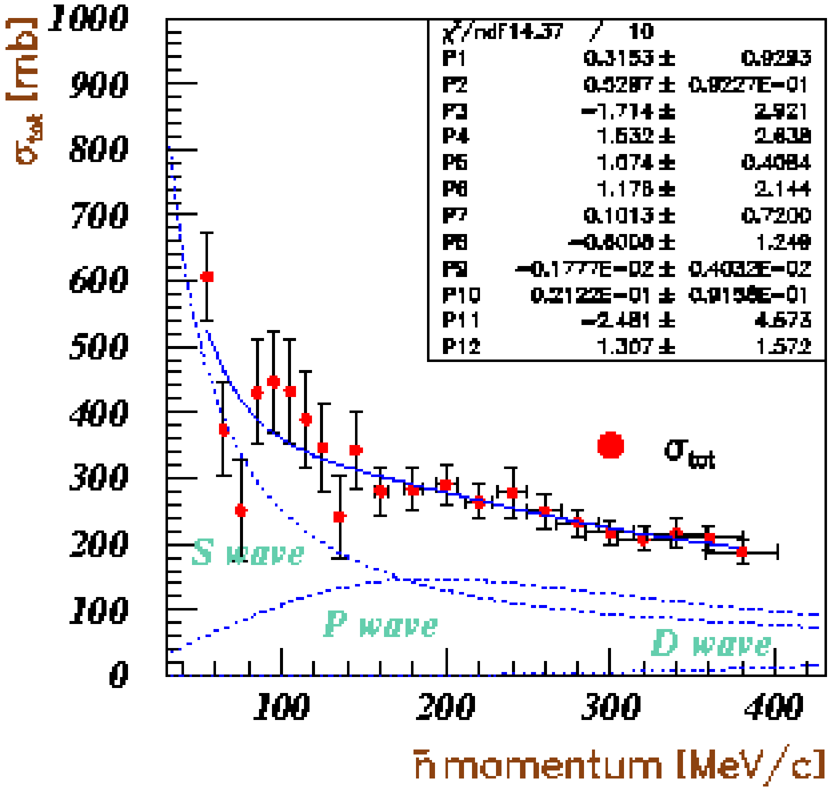
$$k^3 \cot\delta_1 = \frac{1}{b_1} - \frac{3}{2}\frac{1}{R_1} k^2$$

Effective range expansion



$$\sigma_{tot} = \frac{4\pi}{k^2}\sum_l (2l+1)\, Im f_l$$

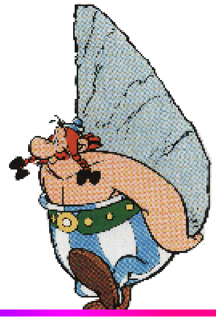
$$f_l = \frac{1}{\cot\delta_l - i}$$



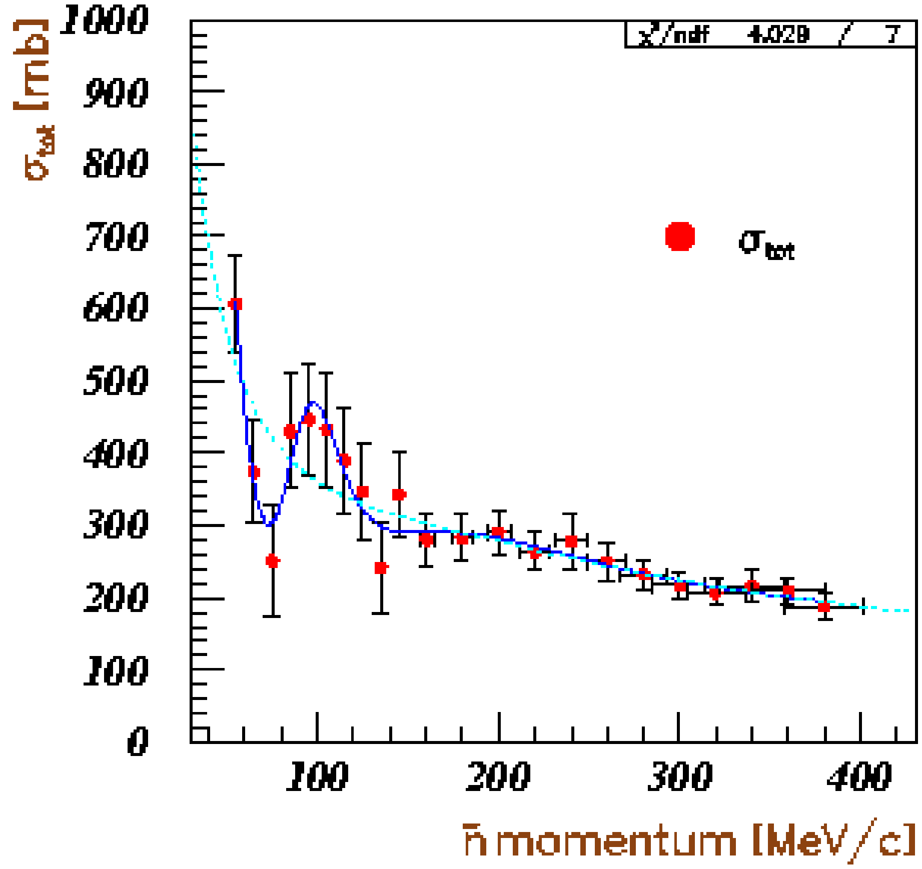
$$k\cot\delta_0 = \frac{1}{a_1} + \frac{1}{2} r_1 k^2$$

$$k^3\cot\delta_1 = \frac{1}{b_1} - \frac{3}{2}\frac{1}{R_1} k^2$$

$$k^5\cot\delta_2 = \frac{1}{c_1} + \frac{5}{2}\frac{1}{\rho_1^3} k^2$$



S-, *P*- and *D*- waves + B.W.

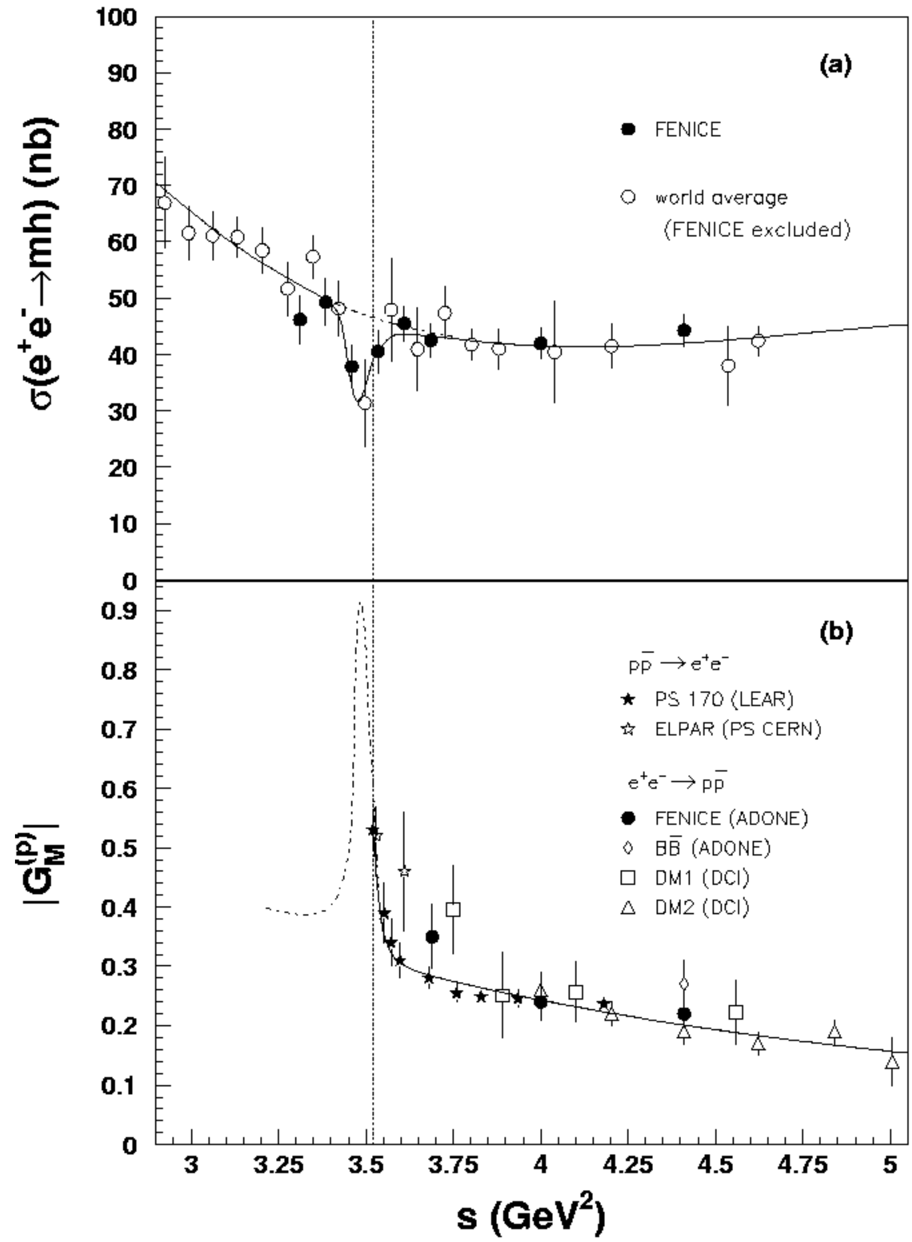


$M_x \sim 1880$ MeV

$\Gamma_x \sim 3$ MeV

FENICE experiment

$e^+e^- \to$ *hadrons*



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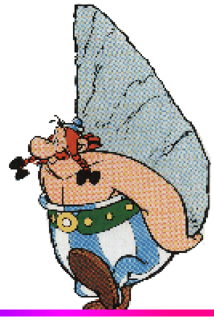
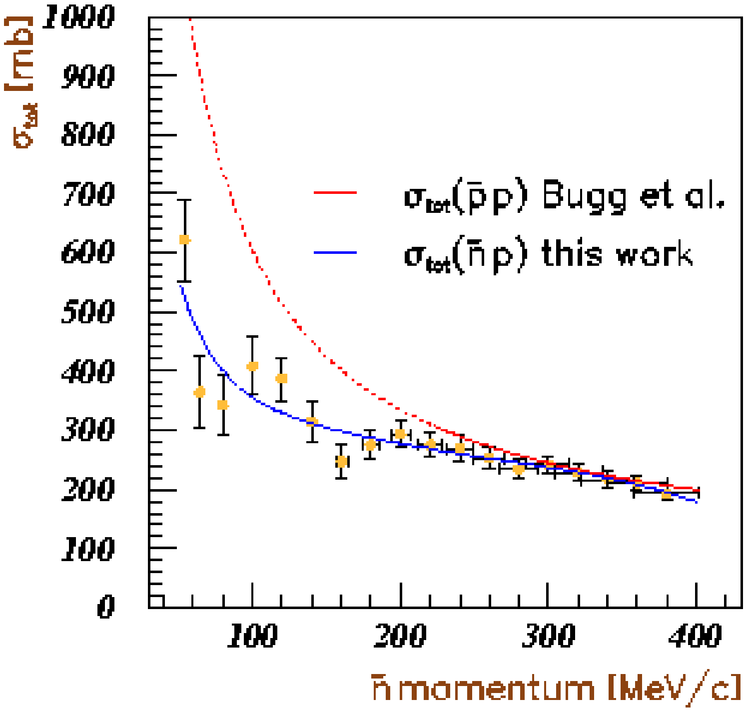
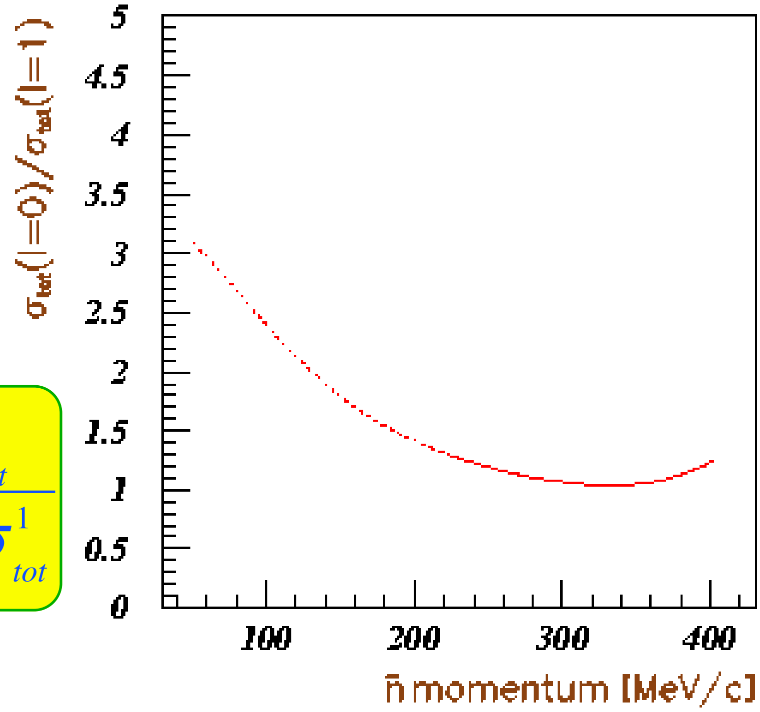
$$M_x = (1.87 \pm 0.01)\ \mathrm{GeV}$$
$$\Gamma_x = (10 \pm 5)\ \mathrm{MeV}$$

Isospin dependence

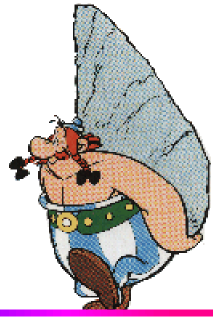




$$R_{tot} = \frac{\sigma_{tot}(\bar{n}p)}{\sigma_{tot}(\bar{p}p)} = \frac{2\sigma^1_{tot}}{\sigma^0_{tot} + \sigma^1_{tot}}$$



Conclusion



- $\bar{n}p$ σ_{tot} and σ_{ann} measured for the first time:
  - ❶ down to 50 MeV/*c*
  - ❷ with high statistics
- impossible to disentangle the I=0 and the I=1 contributions, due to the lack of $\bar{p}p$ σ_{tot} data below 200 MeV/*c*
- confirmation of the abnormally large *P*-wave contribution in some low-energy $\overline{N}N$ interactions
- indication of a narrow (quasi-nuclear ?) state

  (as usual, much more work needed)