Subnanometric resolution profiling using ion scattering and narrow resonant nuclear reactions

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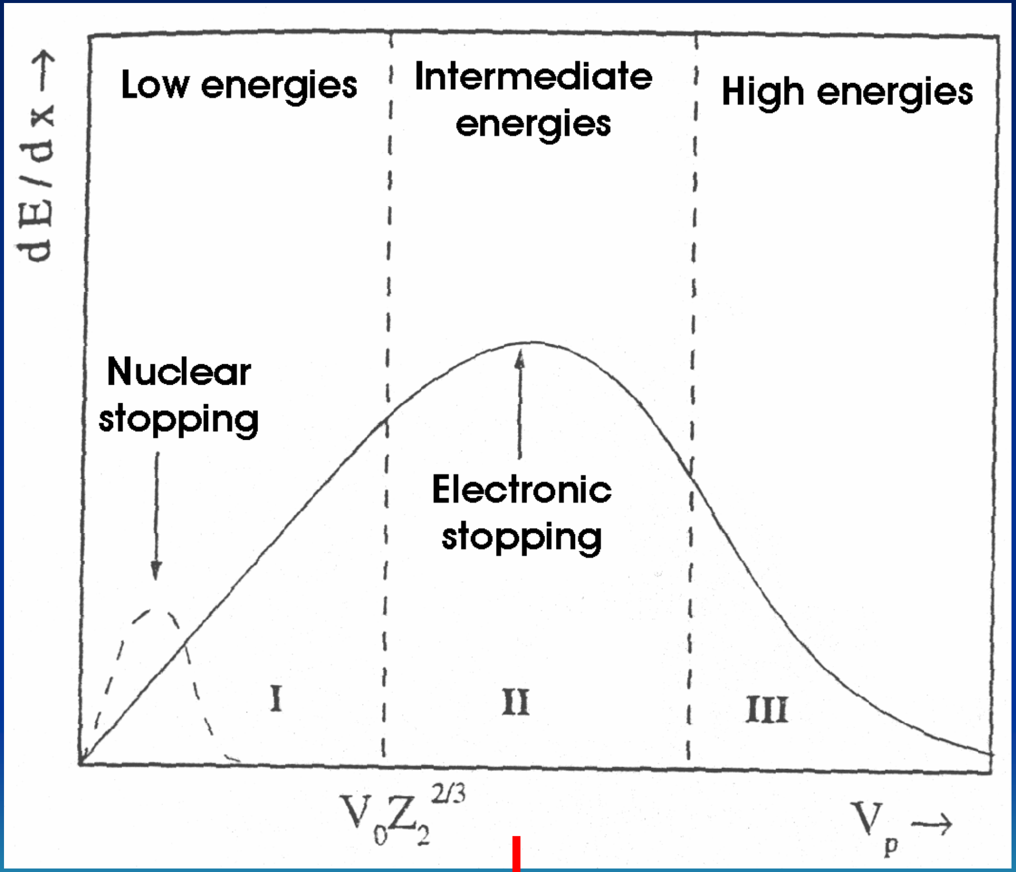
Porto Alegre

Outline

- Ion energy loss in solids
- Medium energy ion scattering
  - Modeling
  - Examples
- Narrow resonant nuclear reaction
  - Modeling
  - Examples

Working Team

Stopping power and depth resolution



Maximum stopping power

Maximum depth resolution

~ 100 keV for protons on SiO_2

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- ⇨ Medium energy ion scattering
  - – Modeling
  - – Examples
- Narrow resonant nuclear reaction profiling
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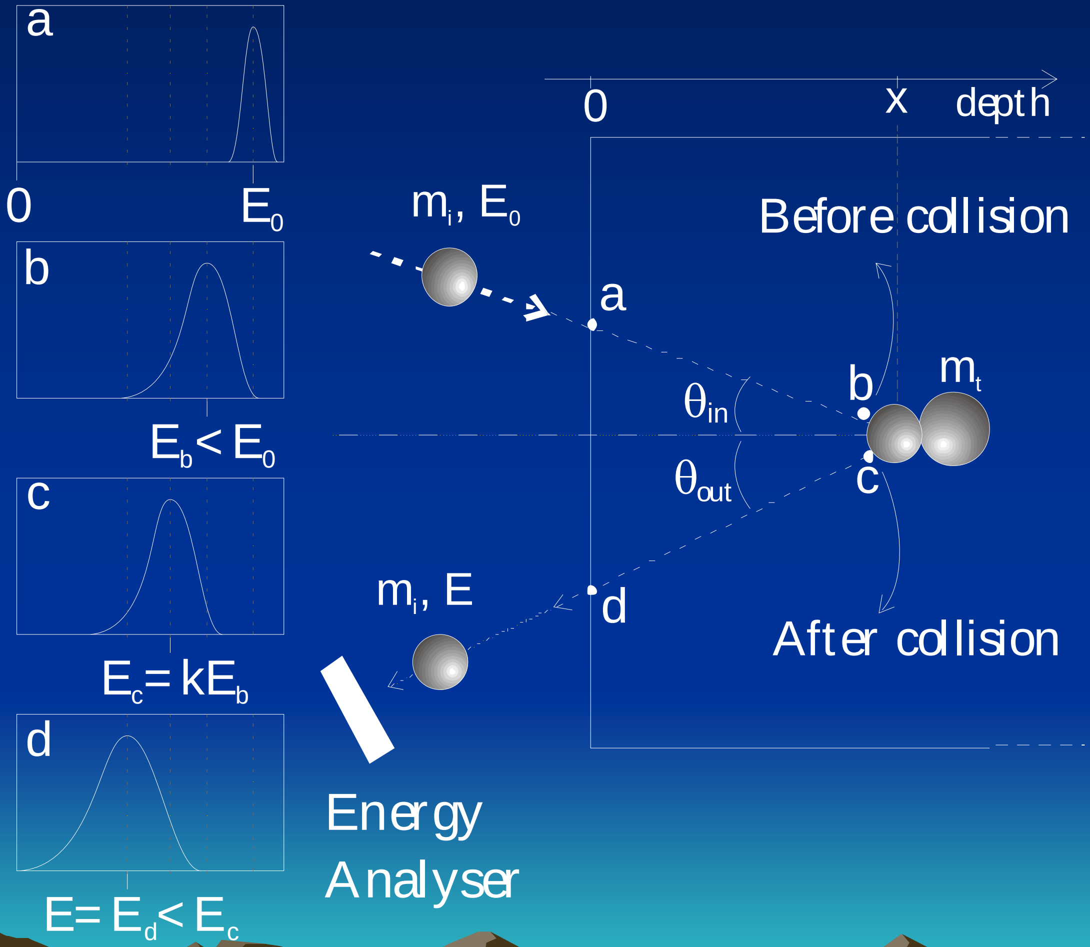
Medium energy ion scattering (MEIS)



Stochastic Modeling

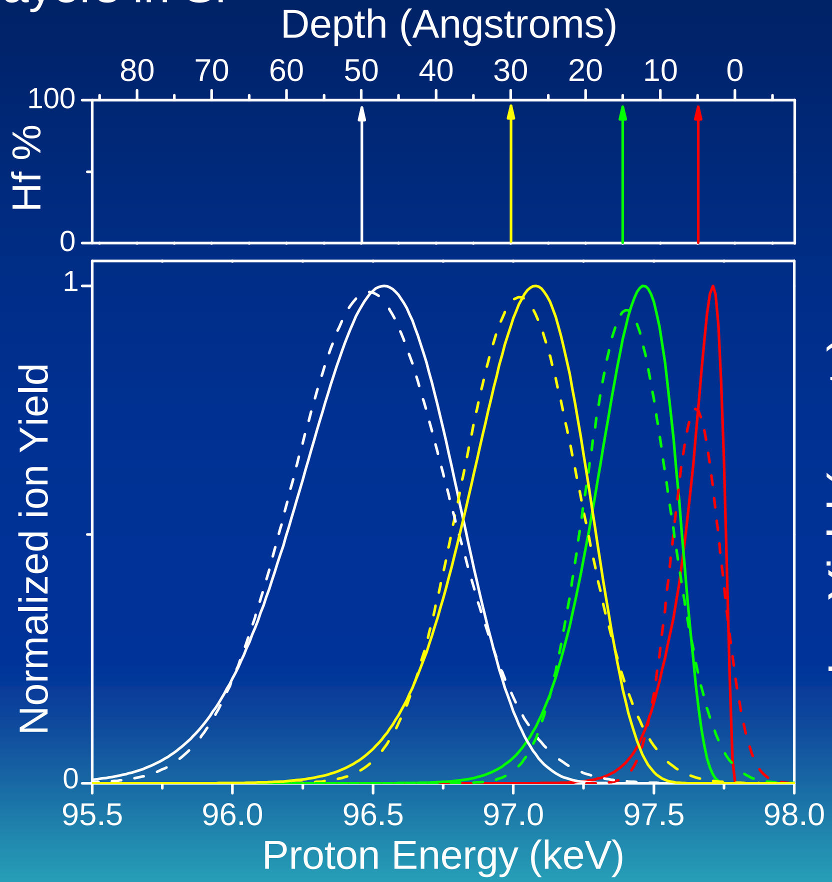
$$N_i(E) = n_0 \Omega \xi \sigma_i \int_0^\infty C_t(x) \sum_{n,l} K_n^{in} K_l^{out} f_{in}^{*n} * f_{out}^{*l}$$

R. P. Pezzi, *et al*., Submitted to Phys. Rev. B (2005).

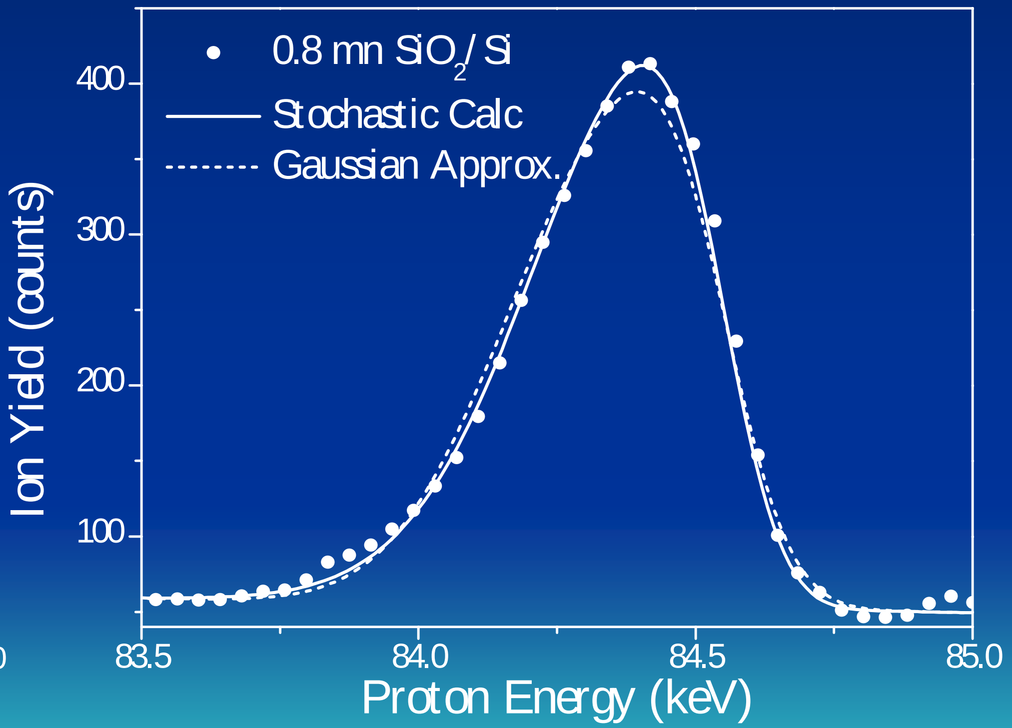
$$K_n = \frac{(mx)^n}{n!} e^{-mx}$$

Stochastic vs. Gaussian Approximation

Hf delta layers in Si

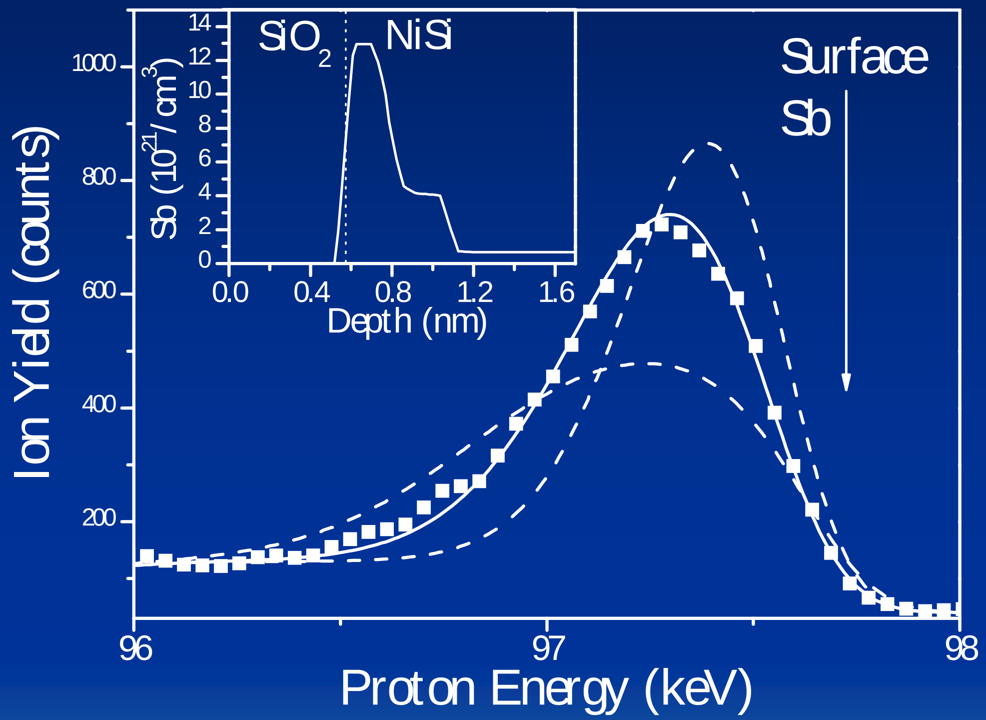


0.8 nm SiO_2 on Si



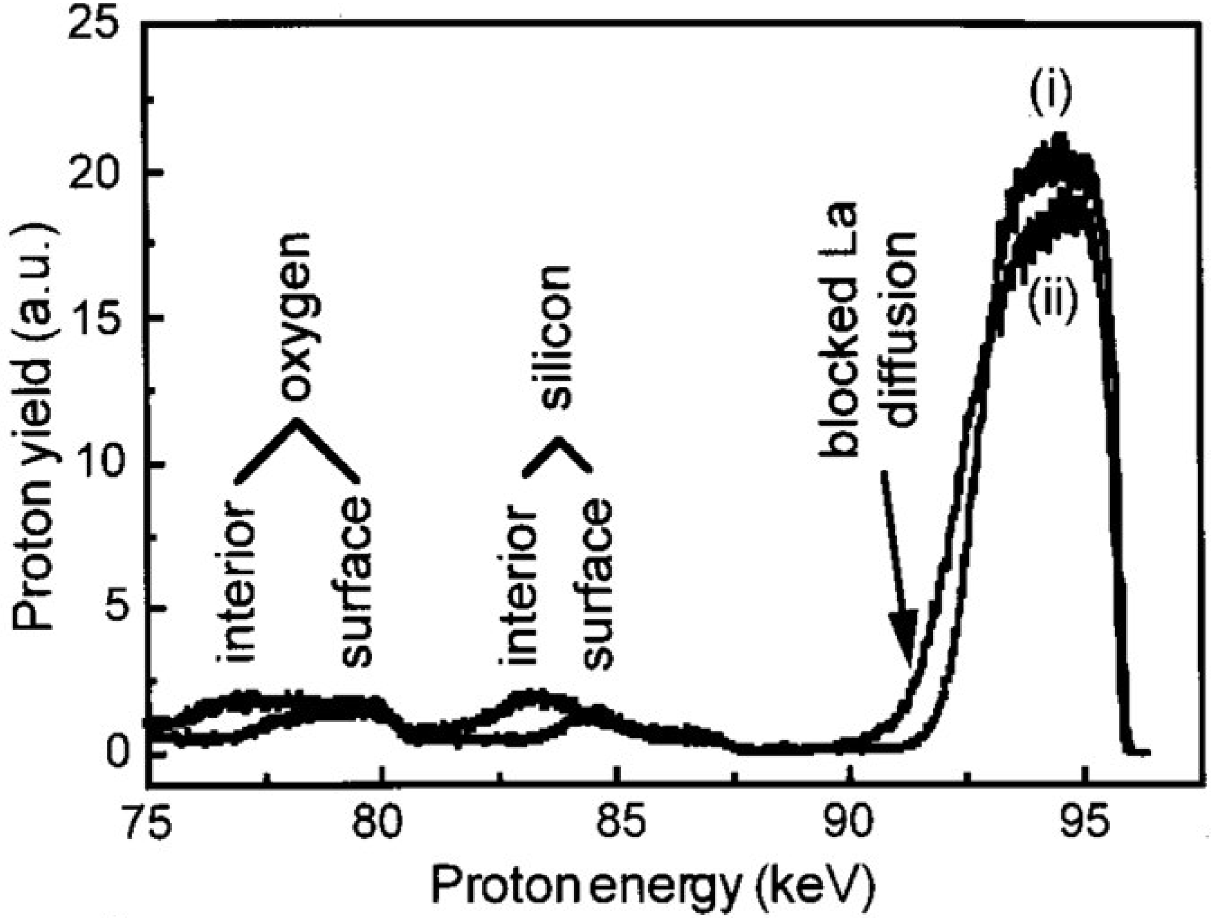
R. P. Pezzi, *et al.*, Submitted to Phys. Rev. B (2005).

Sb in advanced metal gates

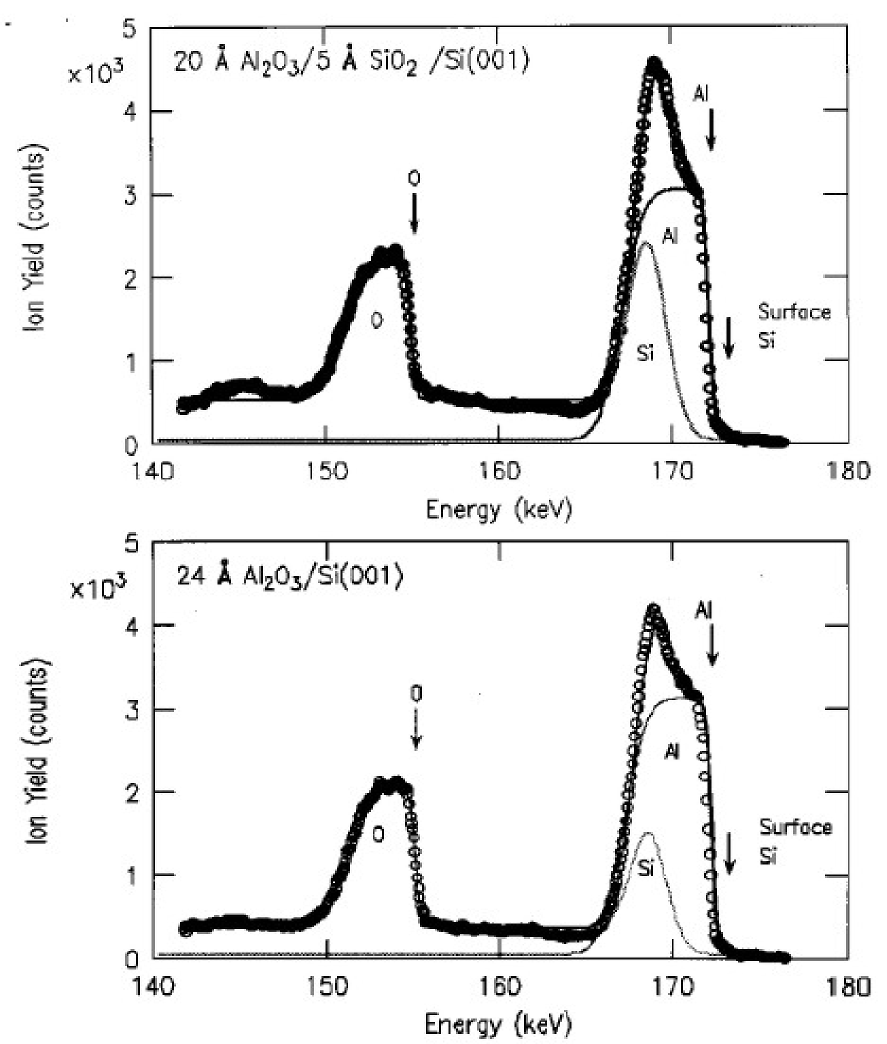


M. Copel, *et al*., Submitted to Appl. Phys. Lett. (2004).

Application for high-k dielectrics



J.-P. Maria, *et al*., J. Appl. Phys., **90**, (2001).



E. Gusev, *et al*., Appl. Phys. Lett. **76** (2000) 1.

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- ➡ Narrow resonant nuclear reaction profiling
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  - Examples


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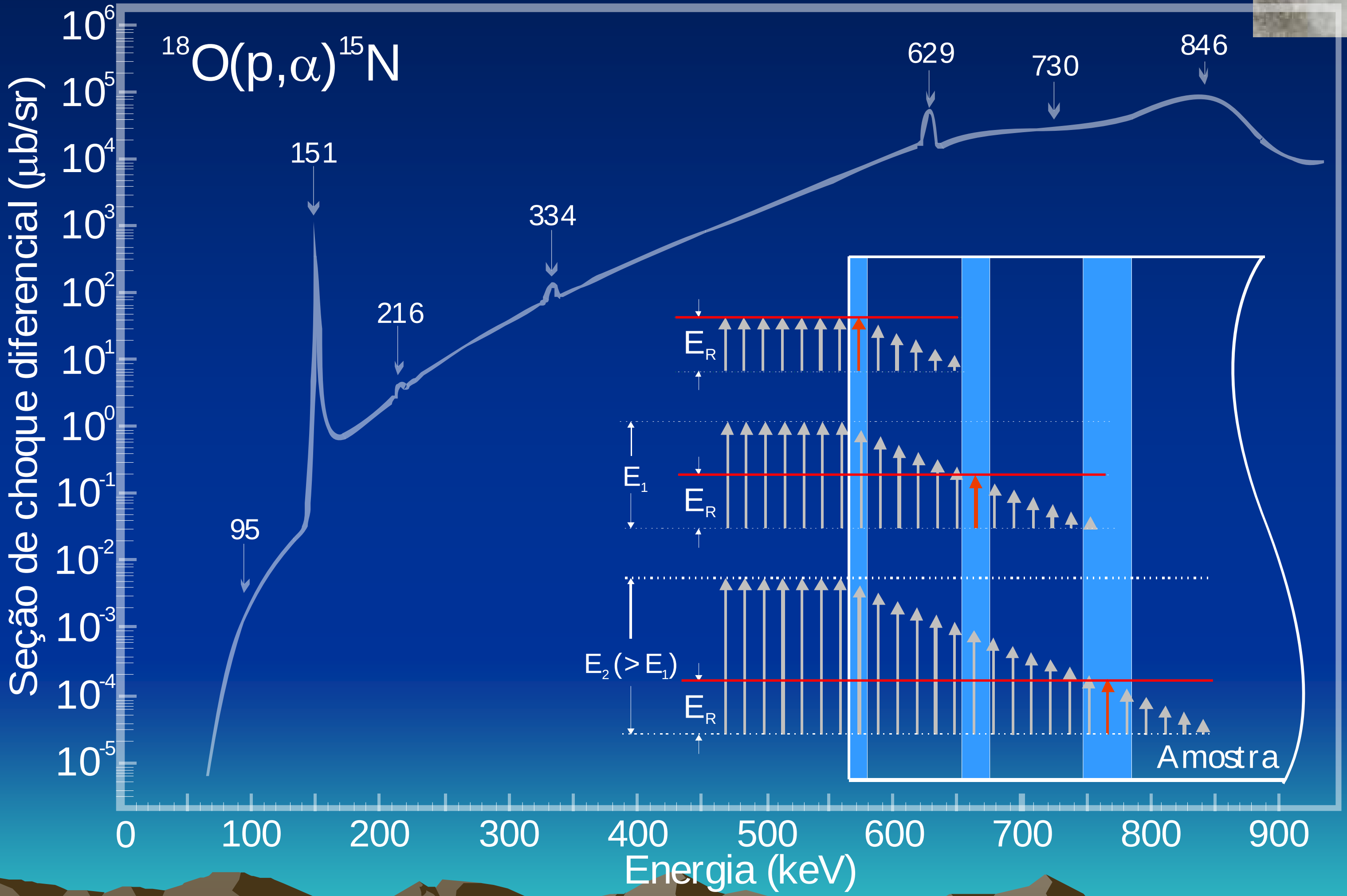
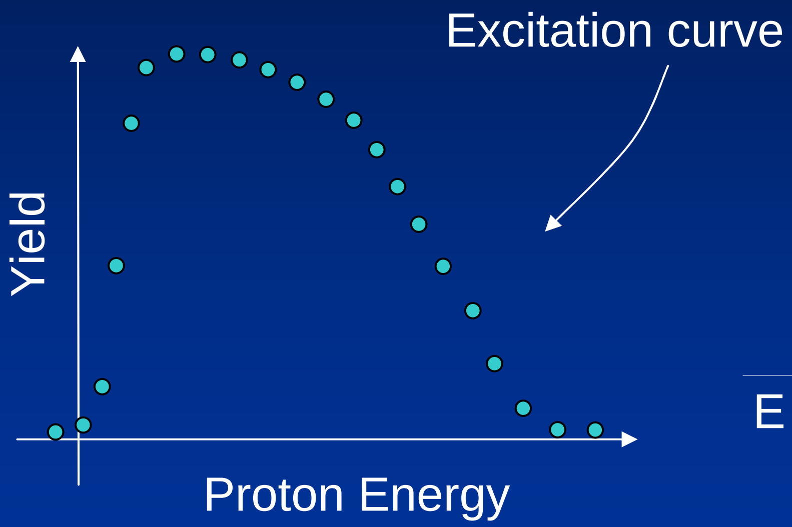
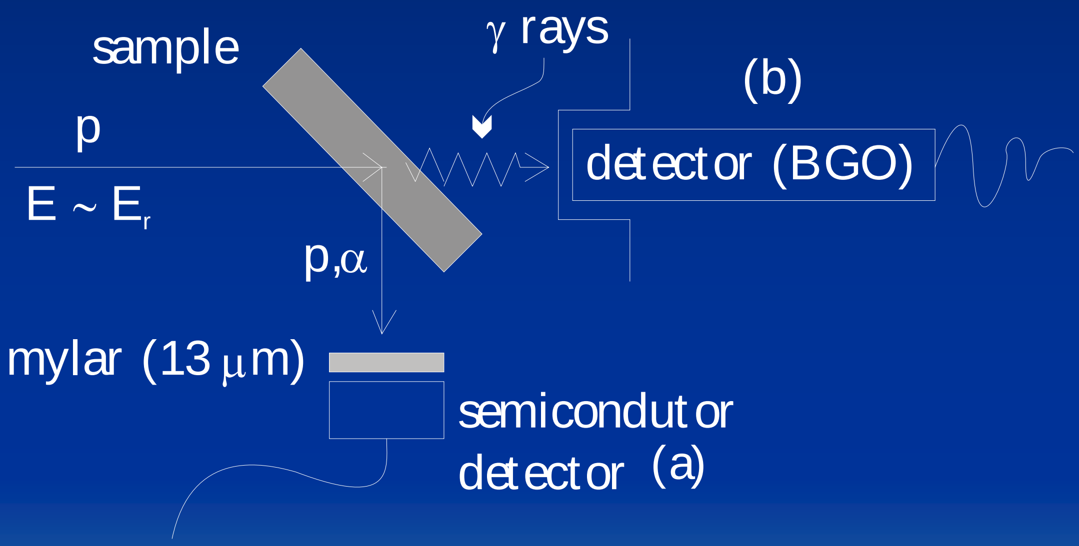
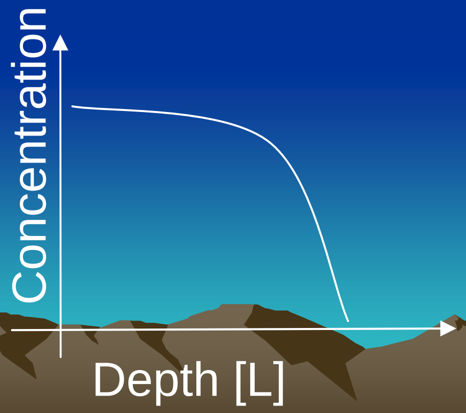
Nuclear resonances



Depth profling with narrow resonanat nuclear resonances







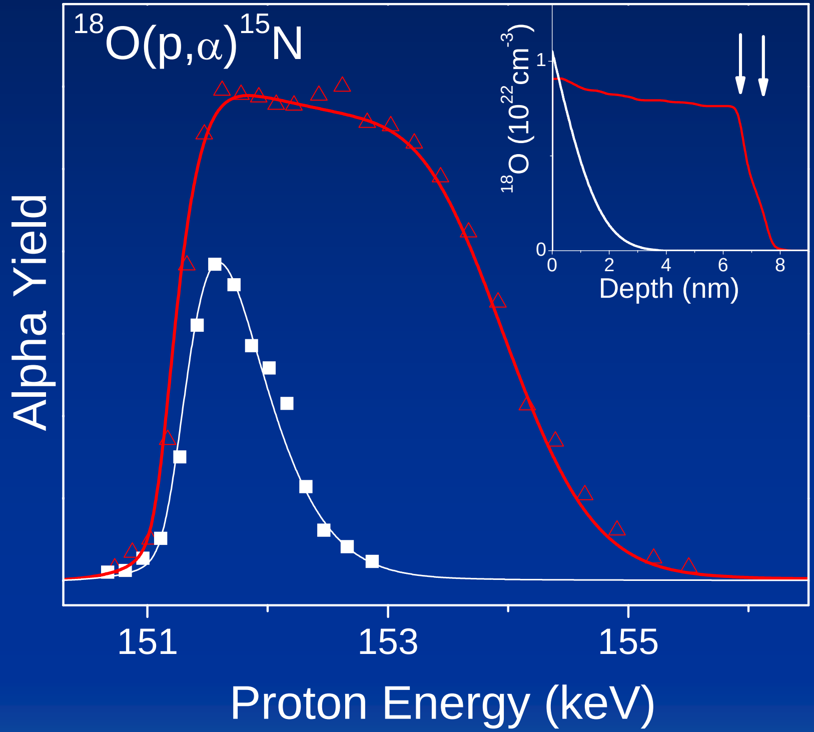
Modeling

$$N(E_0) = c.\sigma_0(E) * h(E_0) * \sum_{0}^{\infty} K_n f^{*n}(E - E_0)$$

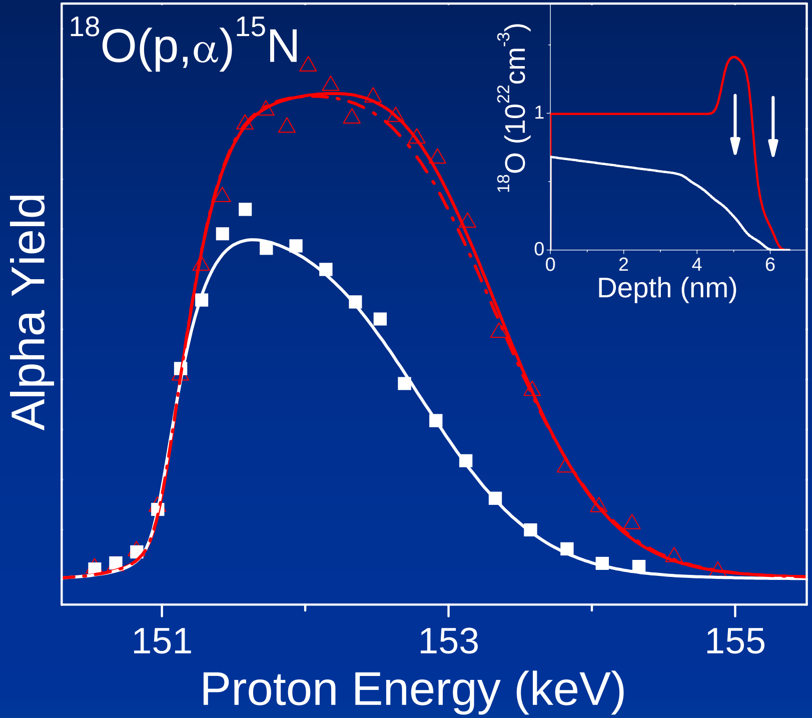
G. Amsel, et al., Nucl. Instr. Meth., v. **197, n.** 1, p. 1 (1990).

$$K_n = \int_0^{\infty} \frac{(mx)^n}{n!} e^{-mx} C(x) dx$$

Oxygen profiling



$Al_2O_3/SiO_2/Si$



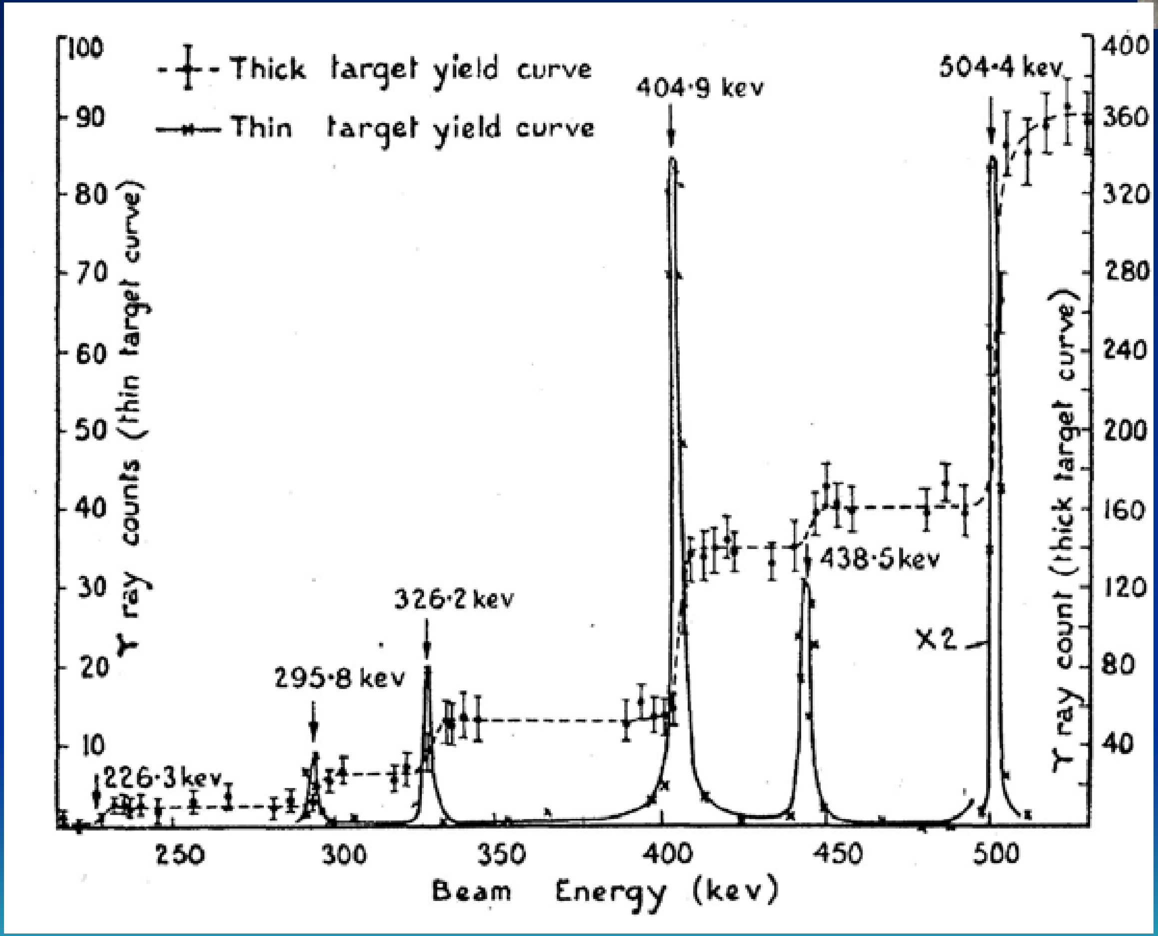
$HfO_2/SiO_2/Si$

$^{18}O_2$ anneal, 600ºC

$^{18}O_2$ anneal, 1000ºC

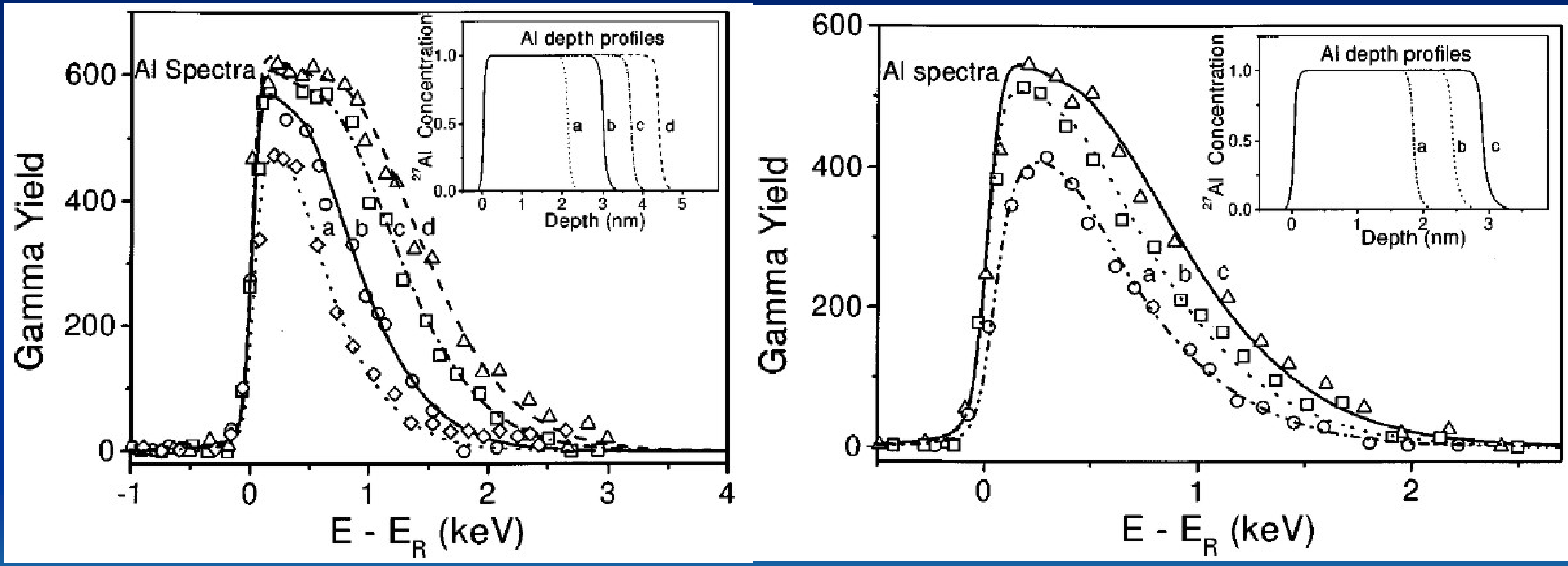
C. Driemeier *et al.*, submitted to Appl. Phys. Lett. (2005)

Al profiling - $^{27}Al(p,\gamma)^{28}Si$

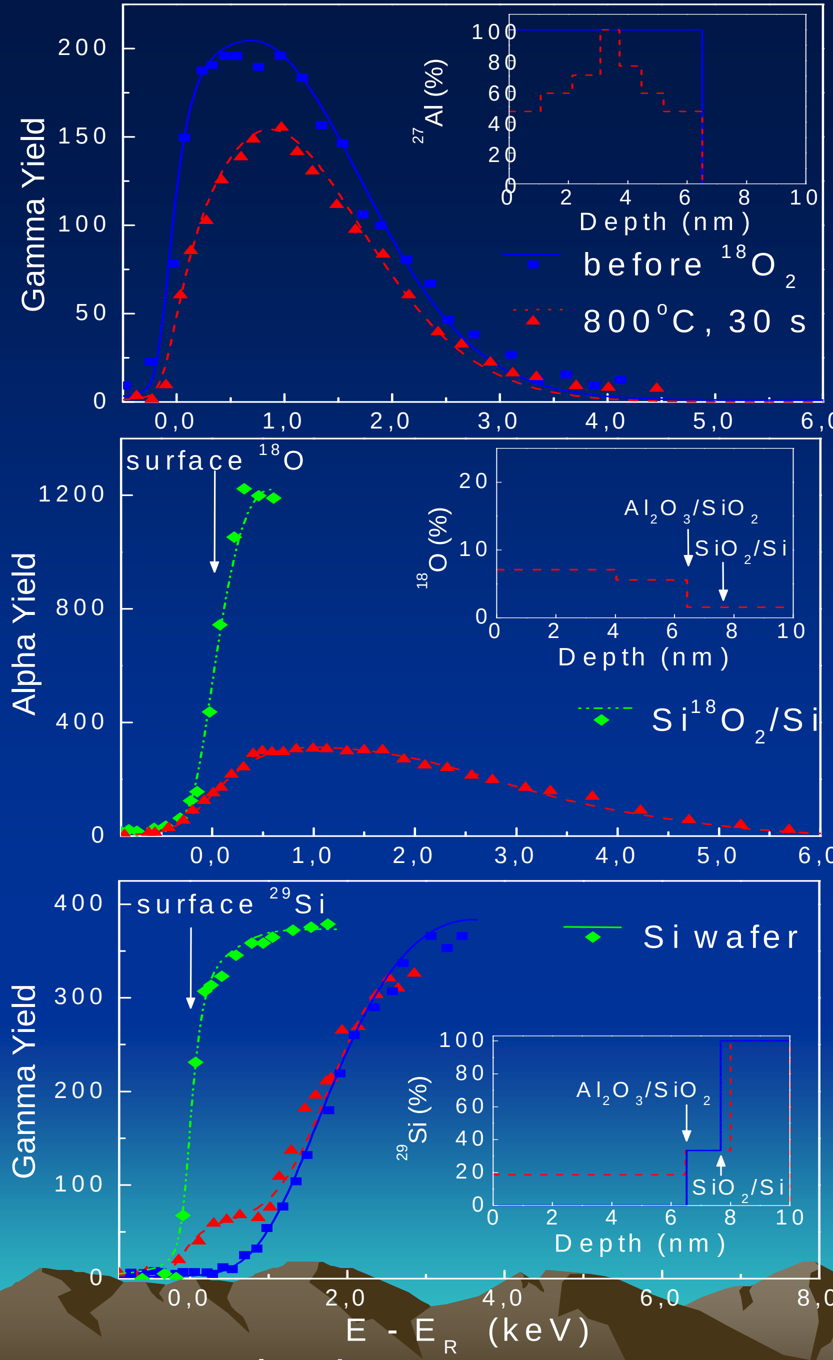


S. E. Hunt, *et al*., Phys. Rev., **89**, 1283 (1953).

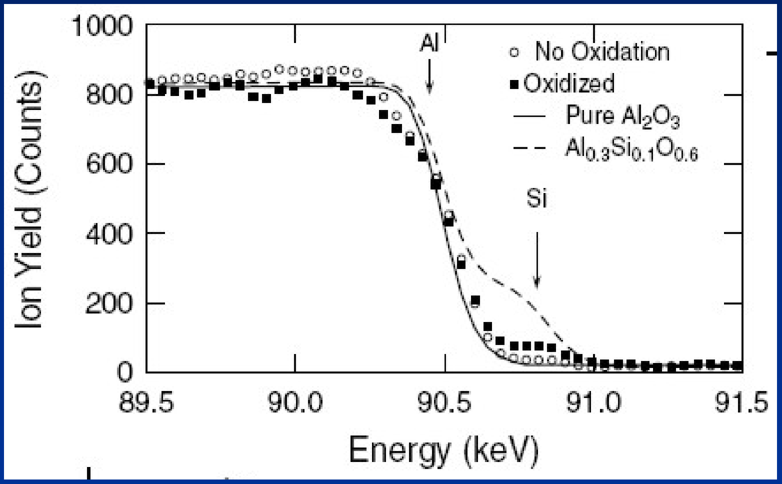
Al_2O_3/Si



E. Gusev, *et al.*, Appl. Phys. Lett. **76** (2000) 1).

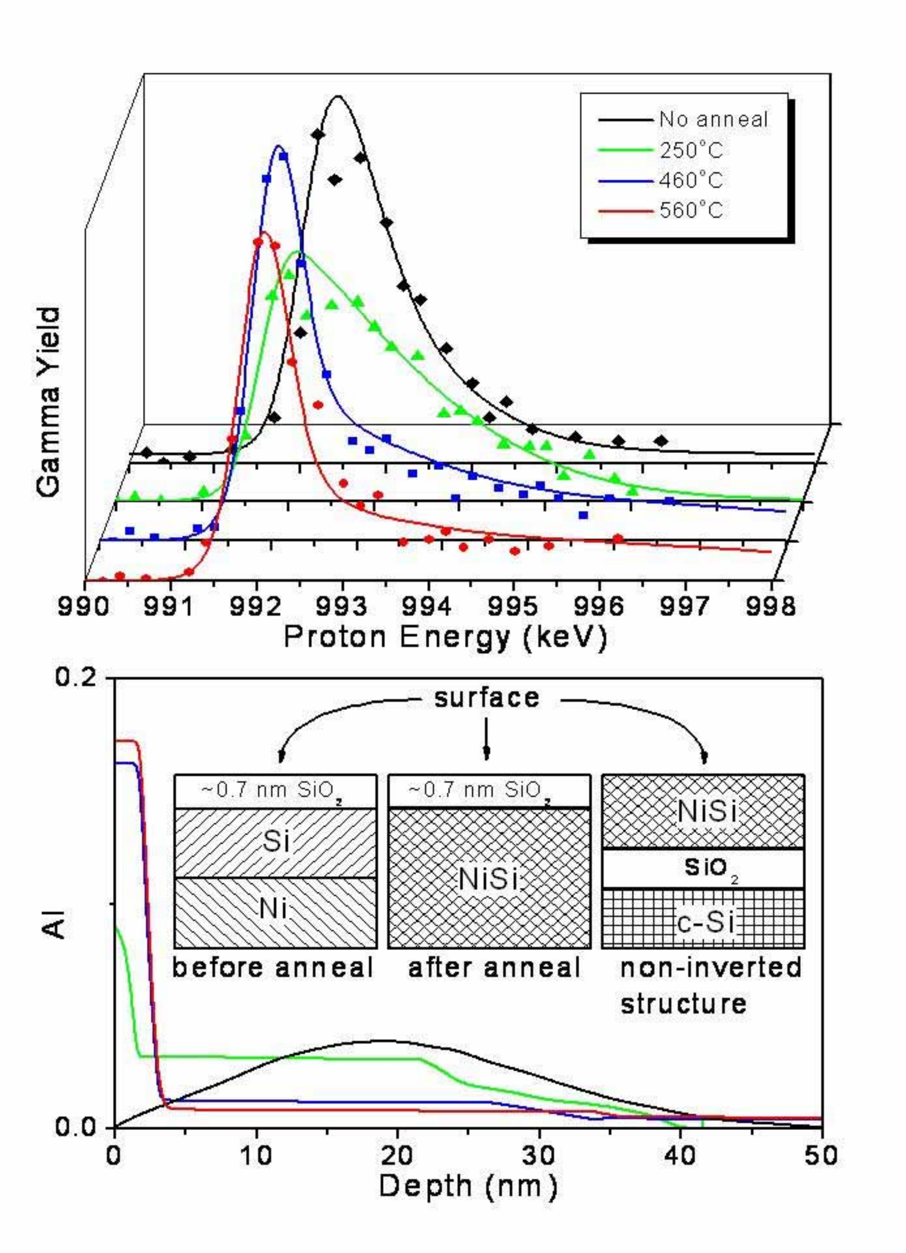


$^{29}Si(p,\alpha)^{30}P$
414 keV

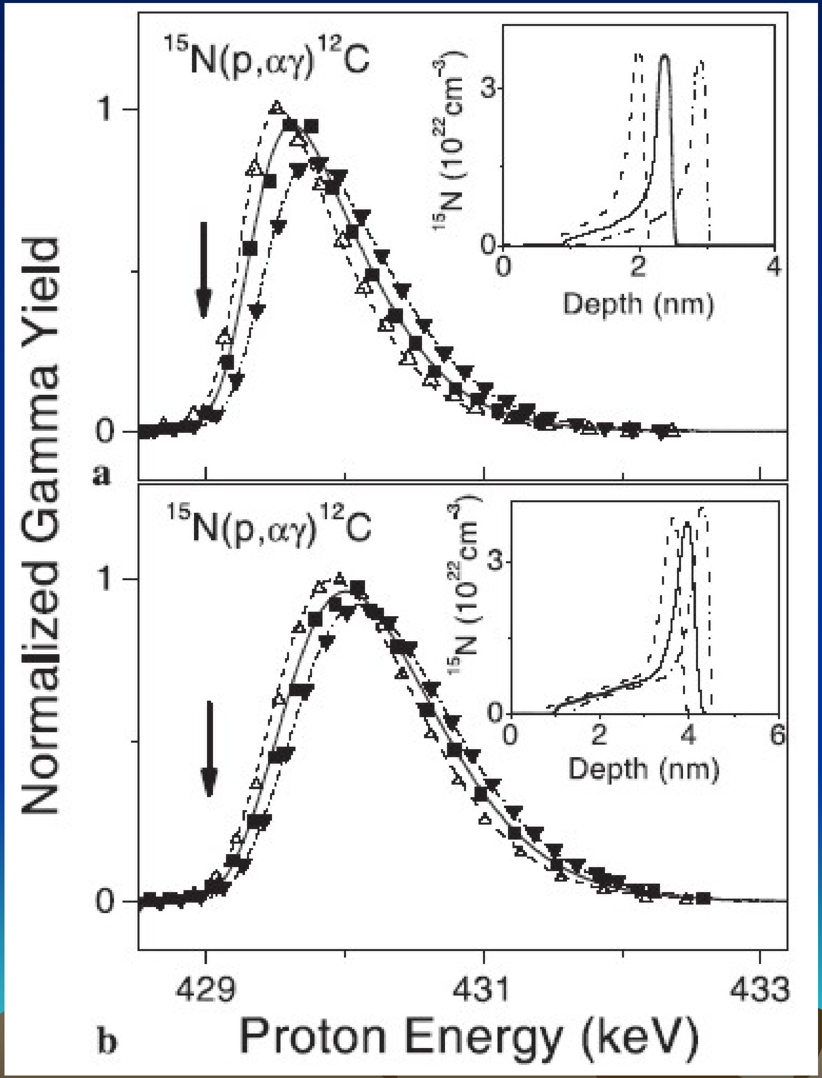


MEIS by M. Copel,
Phys. Rev. Lett., **86**, 4713 (2001)

C. Krug, *et al.*, Phys. Rev. Lett., **86**, 4564 (2001)


No anneal
250°C
460°C
560°C
Gamma Yield
990
991
992
993
994
995
996
997
998
Proton Energy (keV)
0.2
0.0
Al
surface
~0.7 nm SiO2
Si
Ni
before anneal
~0.7 nm SiO2
NiSi
after anneal
NiSi
SiO2
c-Si
non-inverted structure
0
10
20
30
40
50
Depth (nm)

^{15}N profiling - $^{15}N(p,\alpha\gamma)\ ^{12}C$



429 keV

Samples

HfSiON (top) or HfSiO (bottom)	HfSiON ^{15}N enriched layer	Si

As-deposited (dash)

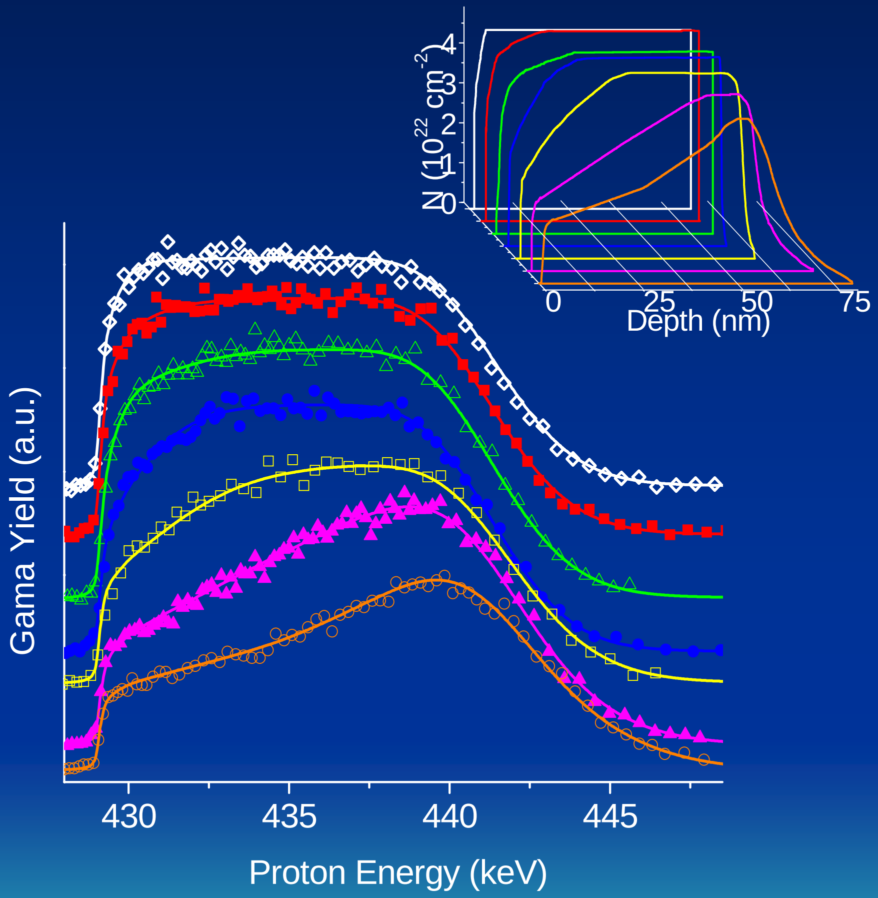
N_2+O_2 annealed (solid)

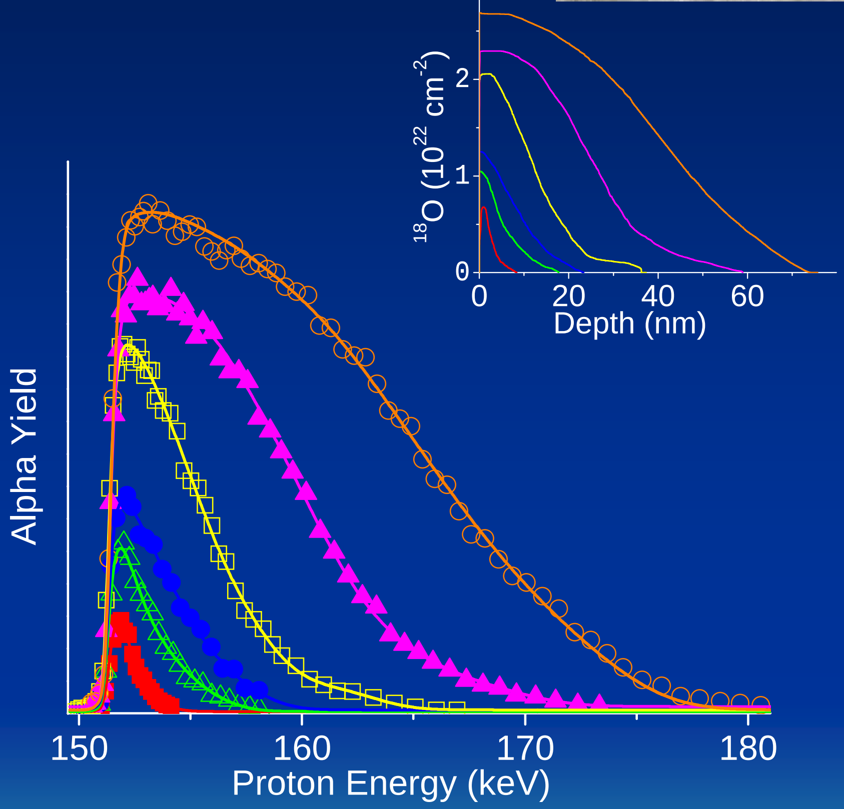
O_2 annealed only (dash-dot)

→ Position of ^{15}N layer

C. Driemeier *et al.*, Appl. Phys. A, **80**, 1045, (2005)

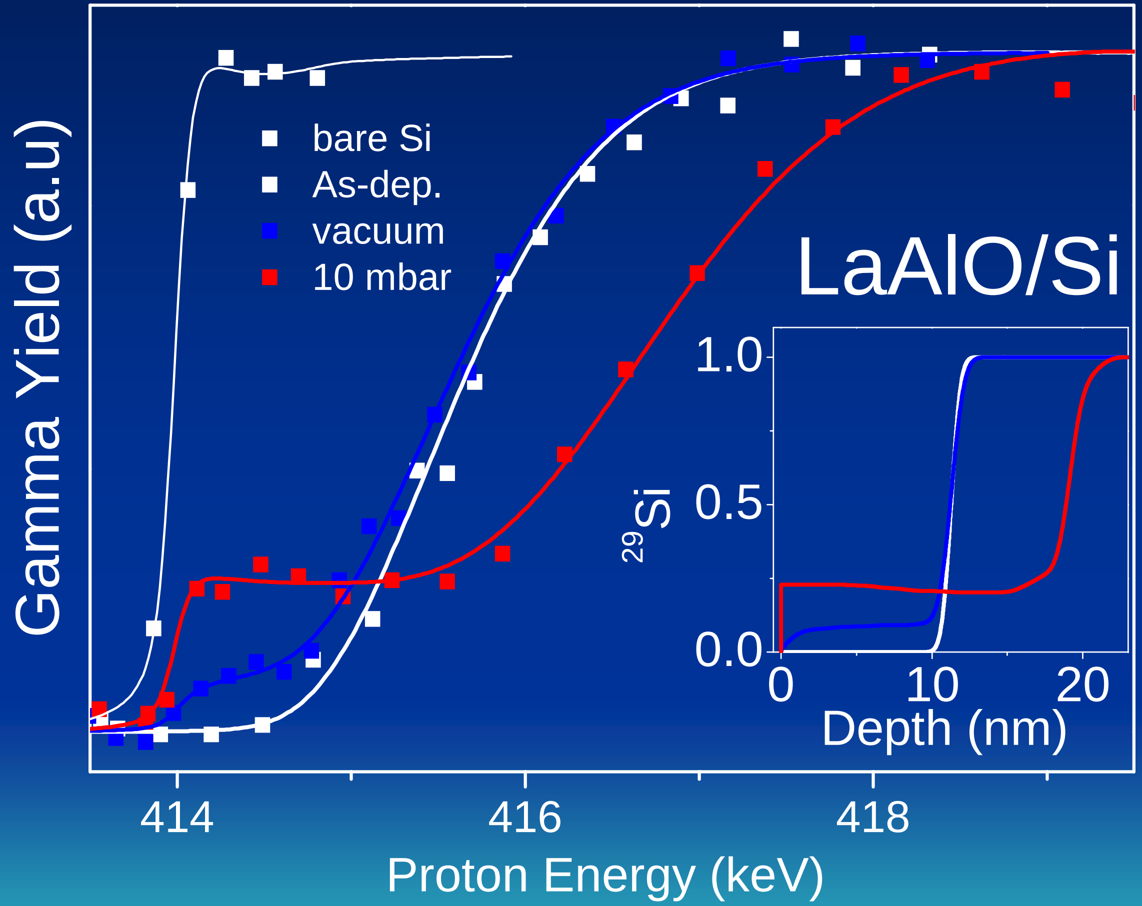
HfSiON annealed in $^{18}O_2$





L. Miotti, *et al.*, Appl. Phys. Lett., **85**, 4460 (2004).

Si Profiling – $^{29}\mathrm{Si}(p,\gamma)^{30}\mathrm{P}$

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Any cooperation proposal is welcome !

Thank you

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Depth profiling by ion beams: limiting facts for depth resolution

- Stopping power of ions in matter
  - *e.g.* ~ 120 eV/nm for protons on SiO_2
- Energy analyzer resolution (MEIS) - ~150 eV
- Appropriate simulation of the ion-matter interaction phenomena.
- Straggling
- Beam spread + Doppler effect - ~ 100 eV

Depth profiling by ion beams: limiting facts for depth resolution

- Stopping power of ions in matter
  - *e.g.* ~ 120 eV/nm for protons on SiO_2
- Resonance width (NRP) - 40 - 120 eV
  Straggling
- Appropriate simulation of the ion-matter interaction phenomena.
- Beam spread + Doppler effect - ~ 100 eV