CHANNELING projects at LNF:
From Crystal Undulators to Capillary Waveguides

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Channeling: Orientational Effects of Transmission & Radiation

Rev. Mod. Phys. 1974: 1 MeV e^- @ Cu crystal

- 1962-63:
  - Robinson & Oen: ***Prediction of anomalous penetration***
  - Piercy & Lutz: ***Experimental discovery***
- 1965:
  - Lindhard: ***Theoretical description***
  - .....
  - Andersen
  - Uggerhoj
  - Kagan
  - Kononez
  - Firsov
  - Tsyganov
  - Gibson
  - Kumakhov
  - Beloshitsky
  - Gemmel
  - Appleton
  - .....

Classical theory

Quantum theory

Prediction of channeling radiation (ChR)

Experimental confirmation: *positron channeling in diamond crystal*

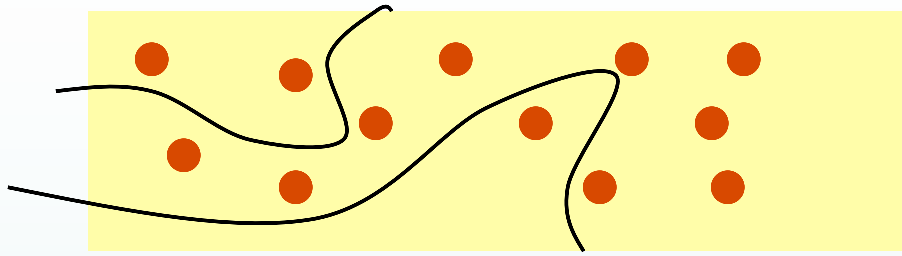
USSR-USA collaboration, SLAC 1978

JETP Lett. 1979 (Miroshnichenko, Avakyan, Figut, et al.)

more than 1000 articles + a number of monographs

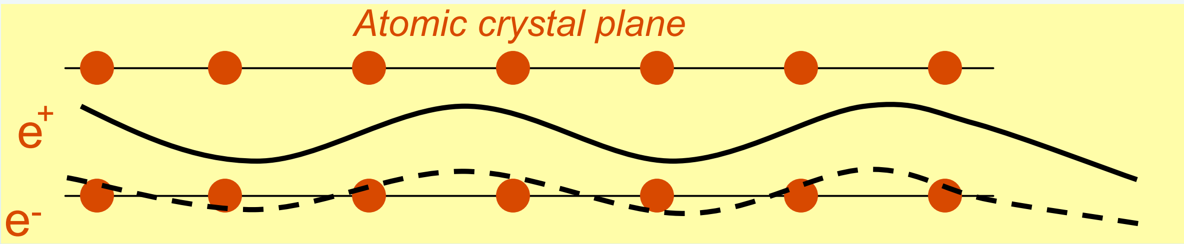
Channeling of Charged Particles

@ Amorphous:

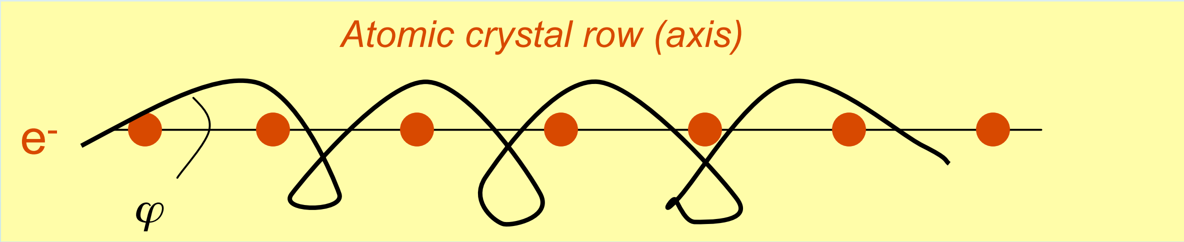


@ Channeling:

planar channeling



axial channeling



$\varphi << 1 \qquad (\varphi < \varphi_L \sim \sqrt{U/E})$ - *the Lindhard angle is the critical angle for channeling*

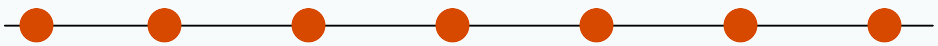
Channeling: Continuum model

$$V(r) = \frac{Z_1 Z_2 e^2}{r} \varphi(r/a)$$

screening function of Thomas-Fermi type

$$a = .8853 a_0 \left(Z_1^{1/2} + Z_2^{1/2}\right)^{-2/3}$$

screening length



$$\varphi(r/a): \quad \sum_{i=1}^{3} \alpha_i \exp(-\beta_i r/a)$$ Molier's potential

$$1 - \left[1 + \frac{Ca}{r^2}\right]^{-1/2} \qquad C^2 \approx 3$$ Lindhard potential

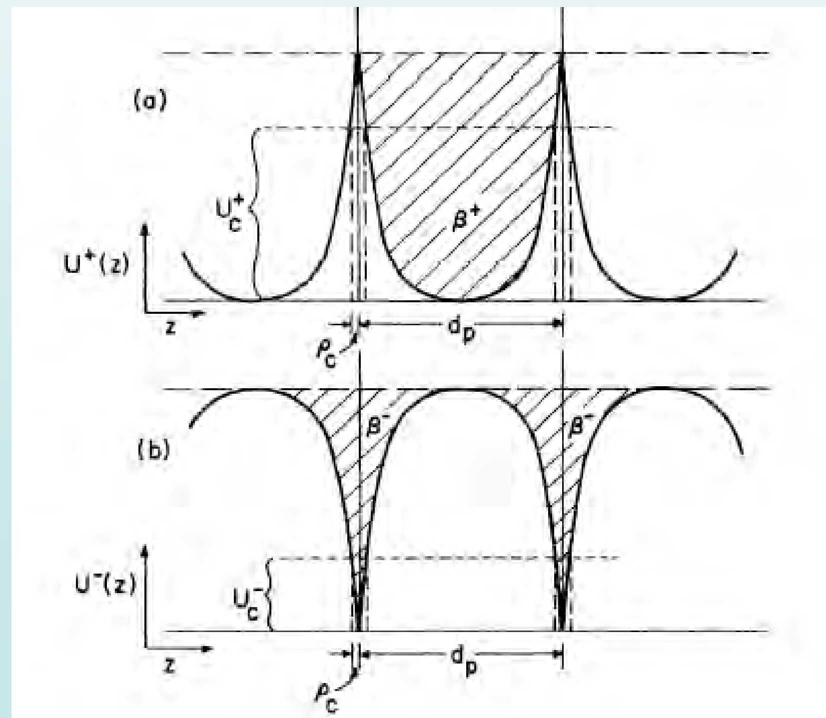
…… Firsov, Doyle-Turner, etc.

Lindhard:

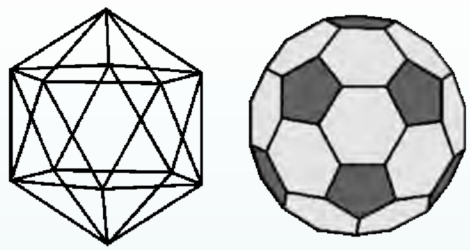
Continuum model –

continuum atomic plane/axis potential

$$V_{RS}(\rho) = \frac{1}{d} \int_{-\infty}^{+\infty} V\left(\sqrt{\rho^2 + x^2}\right) dx$$

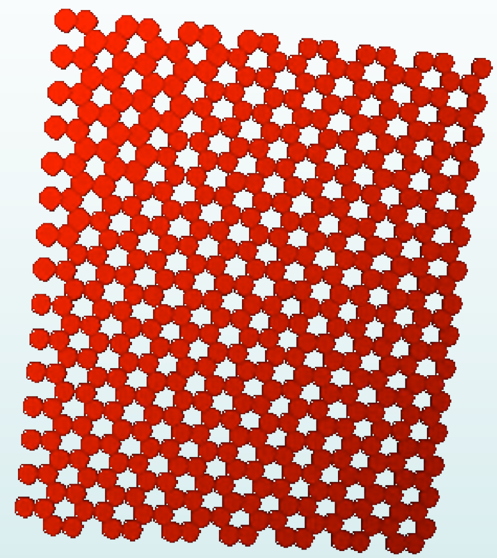


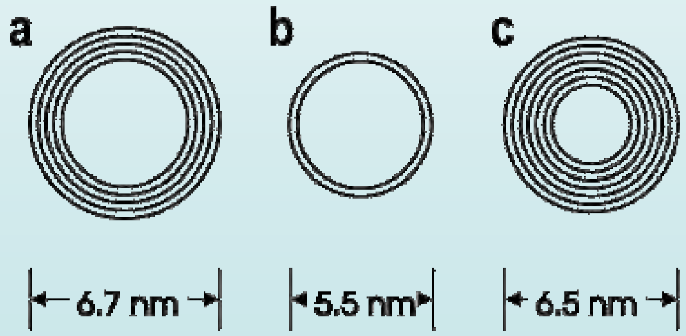
Nanotubes: continuum potential example



Base: fullerene molecule C_{60}
sphere of $d \sim 0.7$ nm

Nanosheet CC

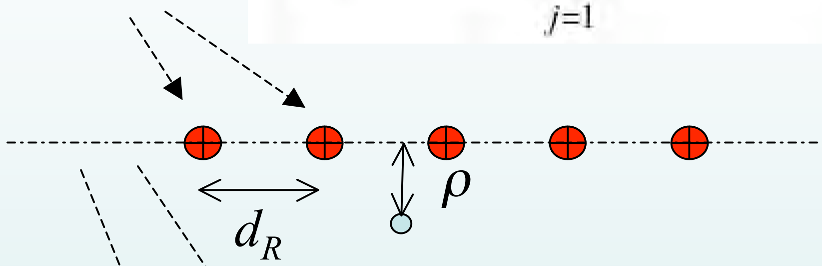




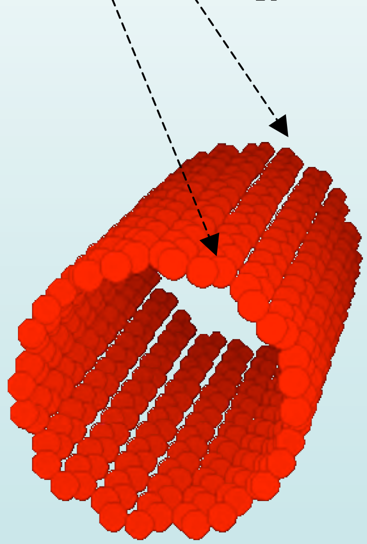
Roled graphite sheets:
nested nanotubes

Potentials: Doyle-Turner approximation

$$f(\mathbf{k}) = 4\pi Ze \sum_{j=1}^{N} a_j \exp(-k^2/4b_j^2)$$ - *form-factor for the separate fullerene*



$$V_R(\rho) = (4Ze^2/d_R) \sum_{j=1}^{N} a_j b_j^2 \exp(-b_j^2\rho^2)$$



$$U(\mathbf{r}) = \sum_i V_R(|\mathbf{r} - \mathbf{r}_i|)$$ *continuum potential as sum of row potentials*

$$U(r) = (16\pi d Ze^2/3\sqrt{3}\, l^2) \sum_{j=1}^{N} a_j b_j^2 \exp\{-b_j^2[r^2 + (d/2)^2]\} I_0(b_j^2 r d)$$

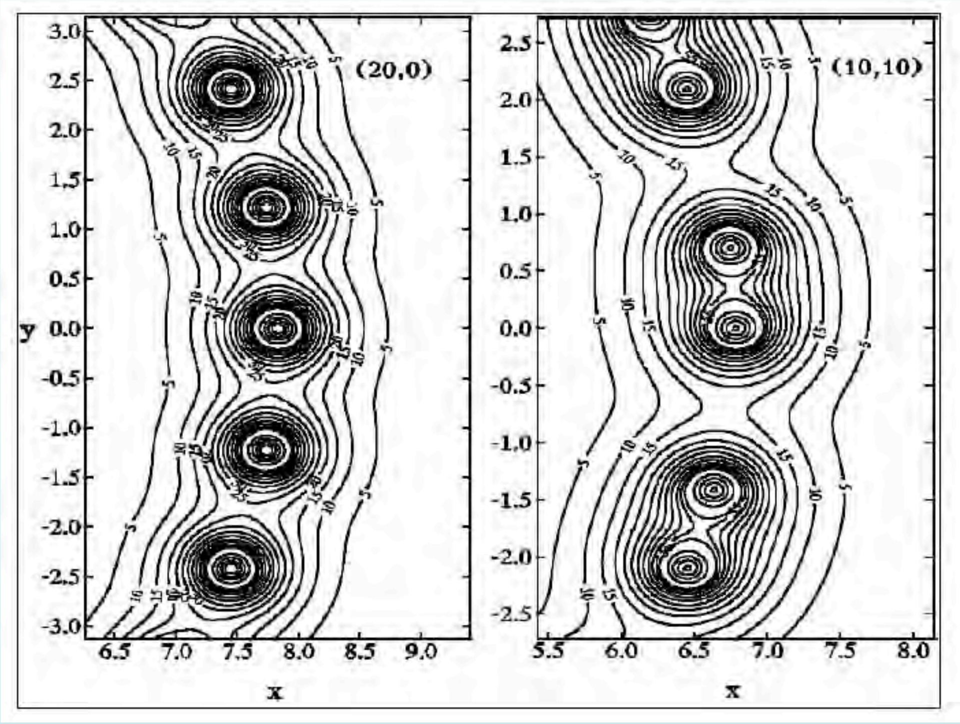
r – distance from the tube

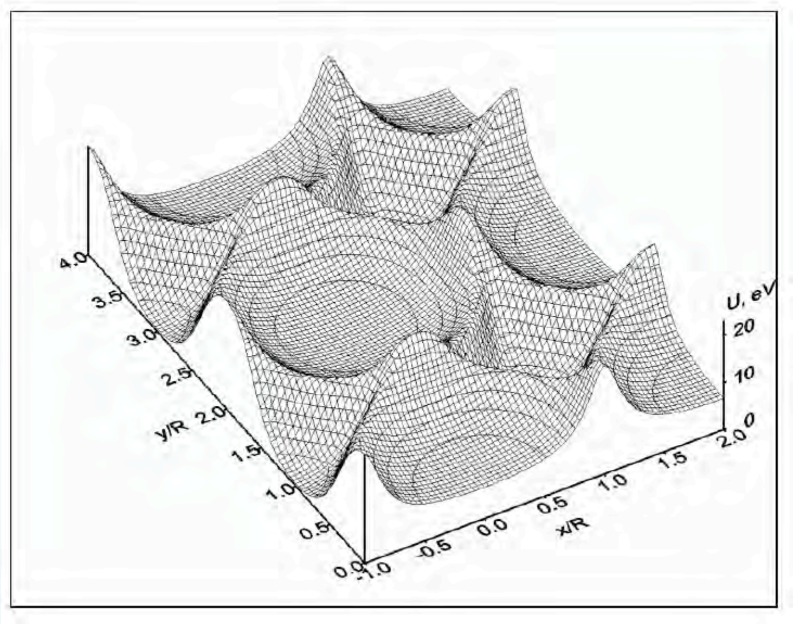
$I_0(x)$ – mod. Bessel function

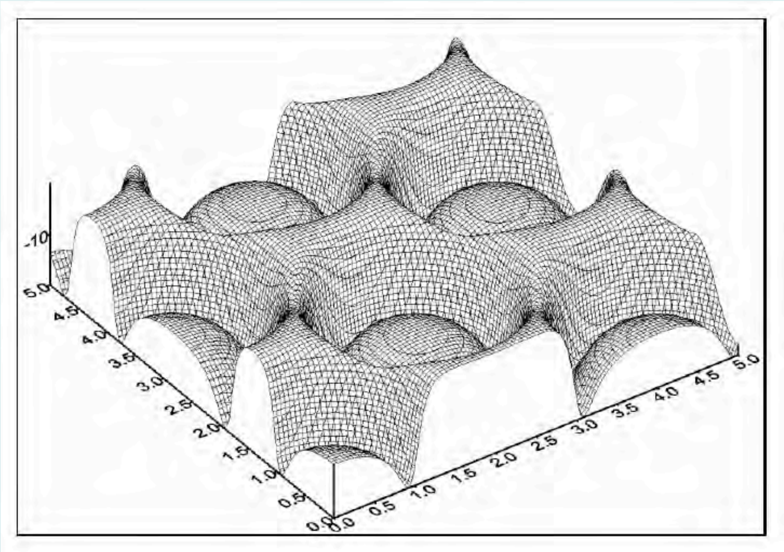
Phys. Lett. A250 (1998) 360

NIM B143 (1998) 584

Potentials: Doyle-Turner approximation







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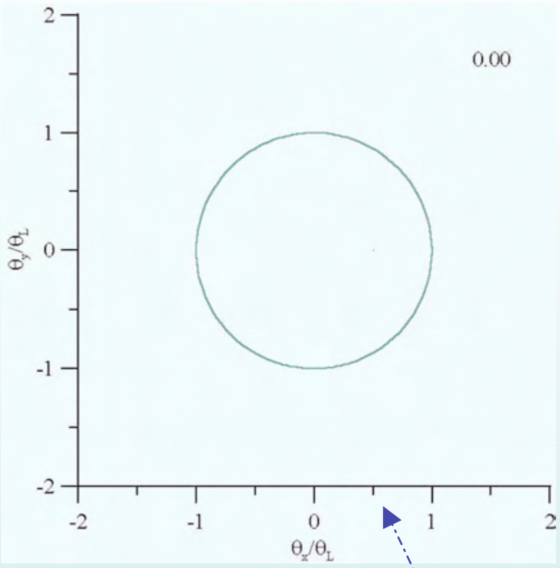
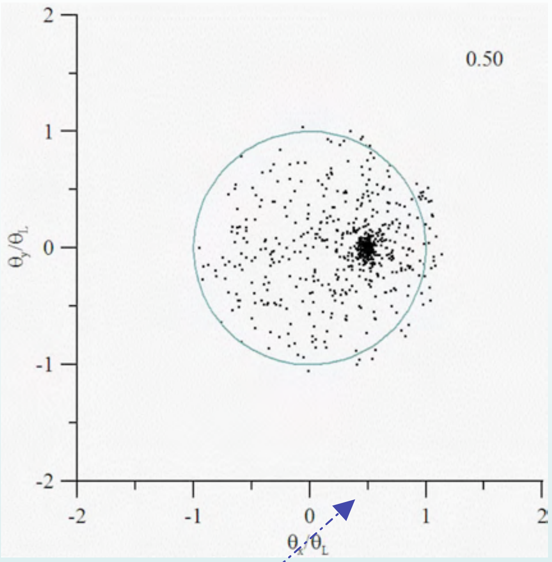
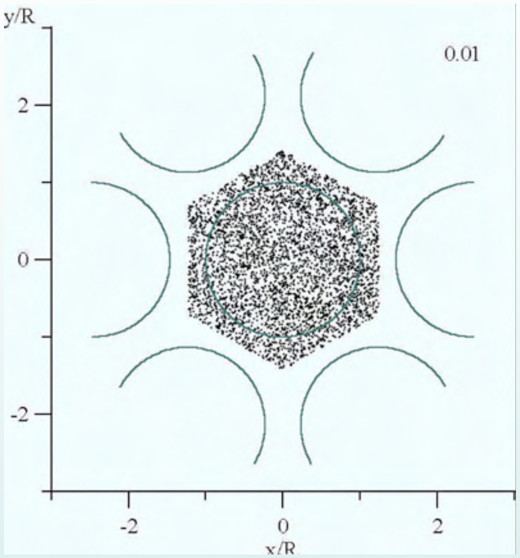
Simulations for particles channeling (straight)

Angular distributions *Spatial*







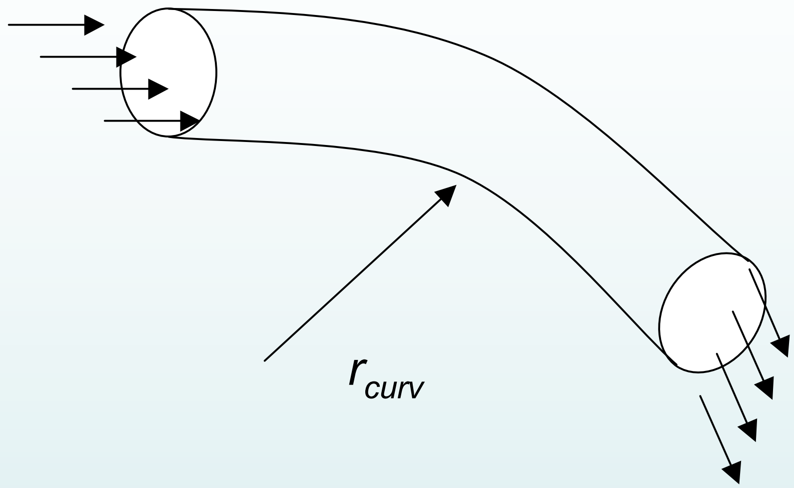
Scattering within coherence length: $0\text{-}L_c$

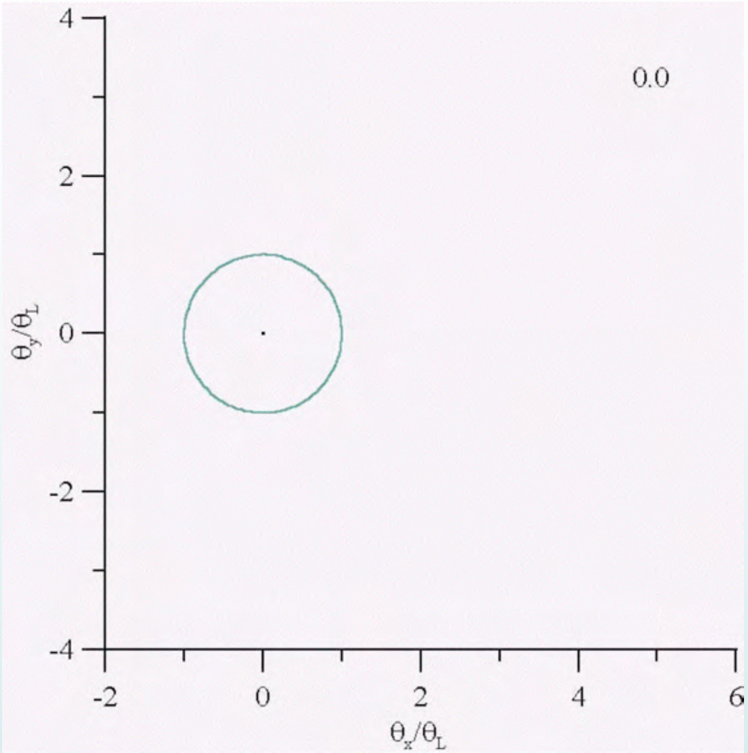
Dechanneling with propagation length: $L_c\text{-}20L_c\text{-}10^3L_c$

Flux redistribution:
Channeling & dechanneling

Angle of incidence – 0.5 critical angle of channeling

Simulations for channeling (bending)





Evolution of angular distribution

μ-capillary → n-capillary:

Strong bending effect (high efficiency!) on smaller scale

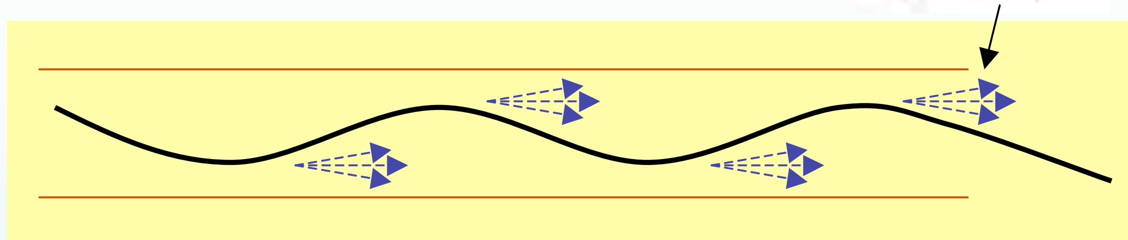
Channeling:
Electrons and Positrons

Channeling Radiation…

@ Channeling Radiation:

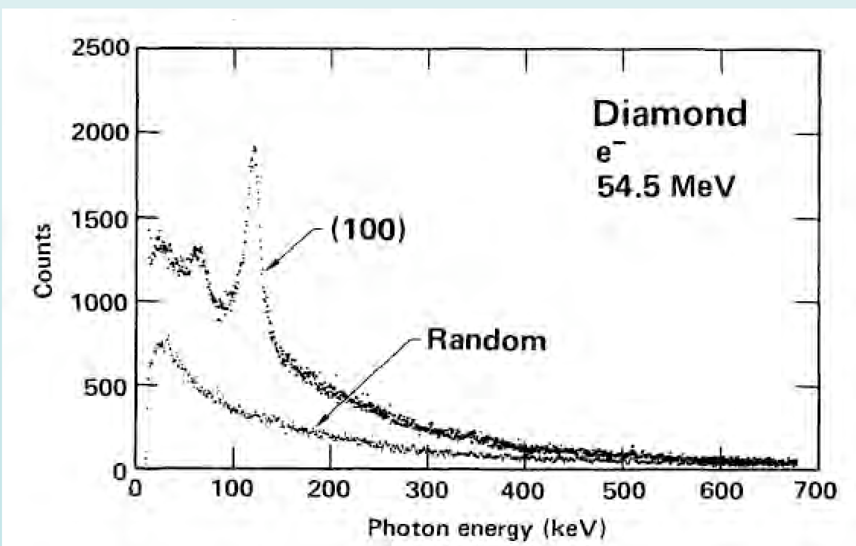
$$\Delta\vartheta \simeq \gamma^{-1}$$

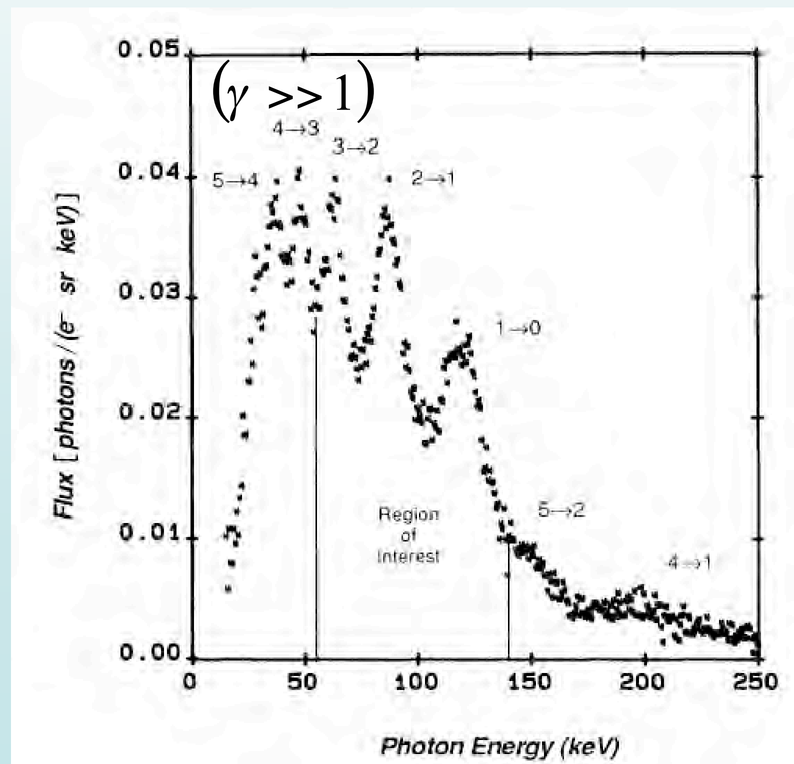
$$\omega = \omega(\theta) = \frac{\omega_{fi}}{1-\beta_{\parallel}\cos\theta}$$



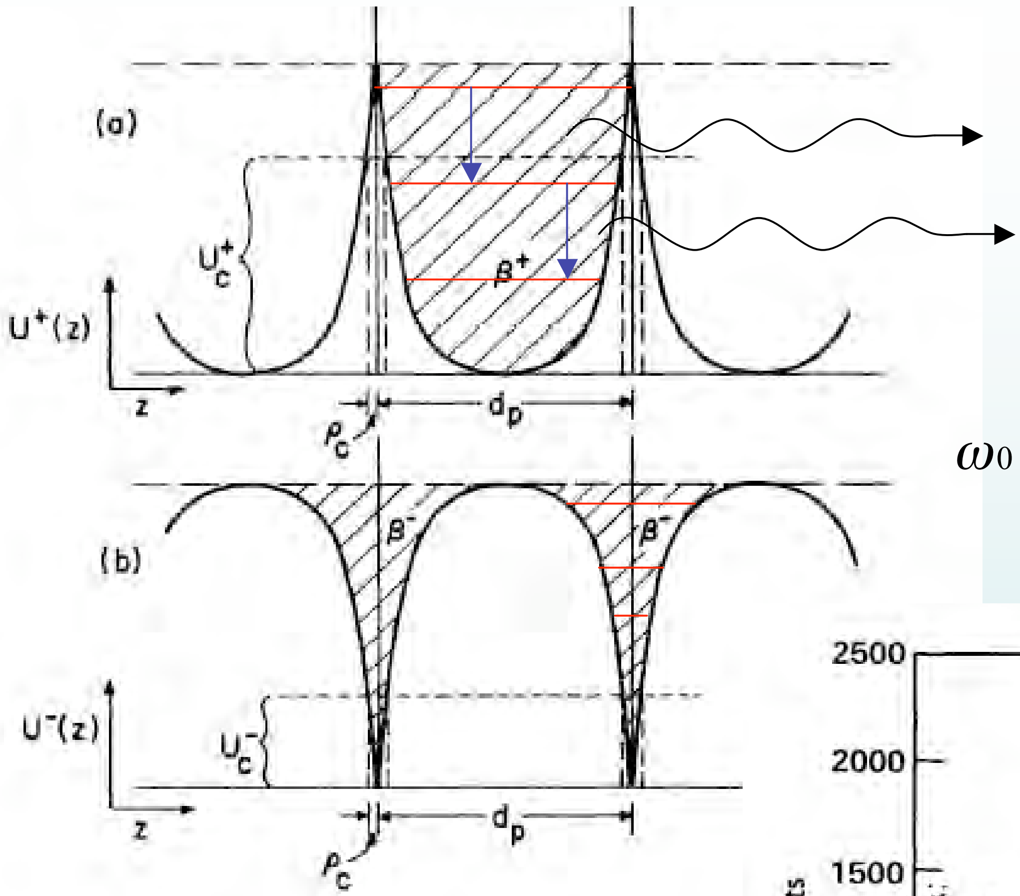
ω_{fi} - *optical frequency* ⟶ *Doppler effect* ⟶ $\omega_0\gamma^{3/2} - \omega_0\gamma^2$

Powerful radiation source of X-rays and γ-rays:
- polarized
- tunable
- narrow forwarded



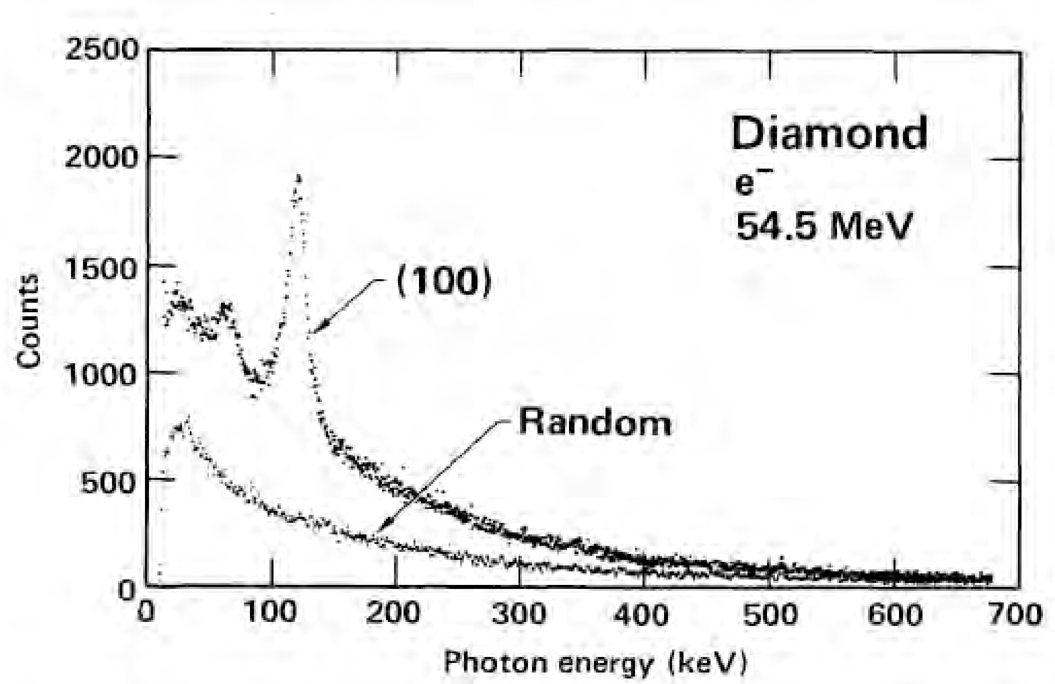


Channeling Radiation…strong Doppler effect



$$\omega_0 \propto 10 \quad eV$$

$$\omega_0 \rightarrow 2\gamma^2 \max \quad forward \rightarrow 200 \quad keV$$



Bremsstrahlung & Coherent Bremsstrahlung vs Channeling Radiation

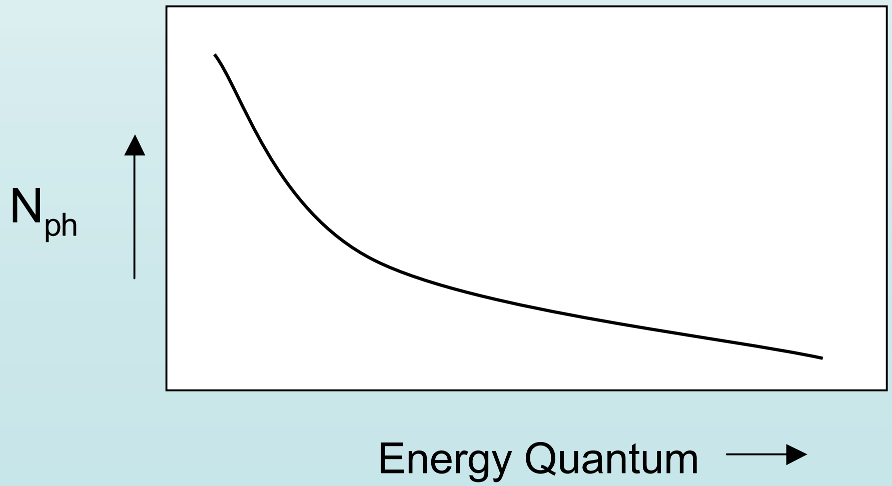
Bremsstrahlung (Deutsch, Sommerfeld) – brake radiation

@ amorphous - electron:

- Radiation as sum of independent impacts with atoms
- Effective radius of interaction – a_{TF}
- Coherent radiation length $l_{coh} >> a_{TF}$
- Deviations in trajectory more than effective radiation angles:

$$\Delta\theta \propto a_{TF} / p \qquad \Delta\vartheta \simeq \gamma^{-1}$$

$$\left(\frac{d^2 I}{d\omega\Omega}\right)_{BR} \simeq (\pi L_R)^{-1}\gamma^2 \frac{1+\gamma^4\theta^4}{(1+\gamma^2\theta^2)^4} \longrightarrow \left(\frac{dI}{d\omega}\right)_{BR} \simeq \frac{4}{3} L_R^{-1}$$



Bremsstrahlung & Coherent Bremsstrahlung vs Channeling Radiation

@ interference of consequent radiation events:

phase of radiation wave → $(\omega t - \mathbf{kr}(t))$

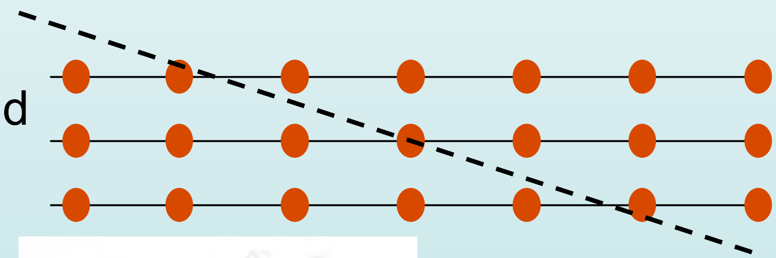
Radiation field as interference of radiated waves:

$$l_{coh} \approx \frac{v}{\omega - \mathbf{kr}} = \frac{\lambda\beta}{1 - \beta cos\theta} \longrightarrow l_{coh} \propto \gamma^2\lambda$$

Coherent radiation length can be rather large even for short wavelength

@ crystal: $l_1 = n l_{coh}$ $\quad l = d/\sin\alpha \quad l_1 = \dfrac{n\lambda\beta}{1 - \beta\cos\theta} \quad \omega_0 \equiv \beta/l_1$

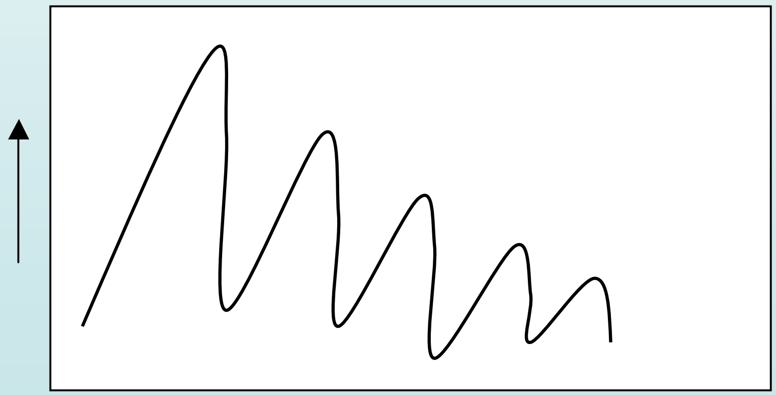
d



$$\omega = \frac{n\omega_0}{1 - \beta\cos\theta}$$

$$\left(\frac{d^2I}{d\omega\Omega}\right)_{CBR} \propto \delta\left(\omega(1 - \beta\cos\theta) - n\omega_0\right)$$

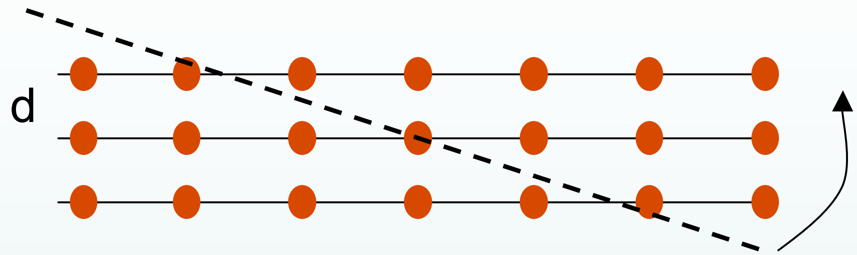
N_{ph}



Energy Quantum →

Bremsstrahlung & Coherent Bremsstrahlung vs Channeling Radiation

@ crystal: $\alpha \to 0$



→ channeling

$$\omega = \frac{\omega_{fi}}{1 - \beta_{||} \cos\theta}$$

$$\left(\frac{dI}{d\omega}\right)_{CR} \propto \omega \left[1 - 2\left(\frac{\omega}{\omega_m}\right) + 2\left(\frac{\omega}{\omega_m}\right)^2\right], \quad \omega \le \omega_m \simeq 2\gamma^2 \omega_{fi}$$

$$\frac{ChR}{B} \propto \gamma^{1/2} Z^{-2/3}$$

at definite conditions channeling radiation can be significantly powerful than bremsstrahlung

B:	CB:	ChR:
	NZe	$N \leftrightarrow \quad l_{coh} \propto \gamma^2 / \omega \qquad N_{eff}$
$\propto NZ^2$	$\propto (NZ)^2$	$\propto (N_{eff} Z)^2$

SPARC

R&D program towards high brightness e⁻beam & SASE-FEL experiment

(150 MeV e- : $\lambda \sim 500$ nm)

SPARX Phase I - SPARXINO

R&D towards an X-ray FEL-SASE source (1.25 GeV : $\lambda < 10$ nm)

S ource

P ulsed

Self A mplified

R adiation

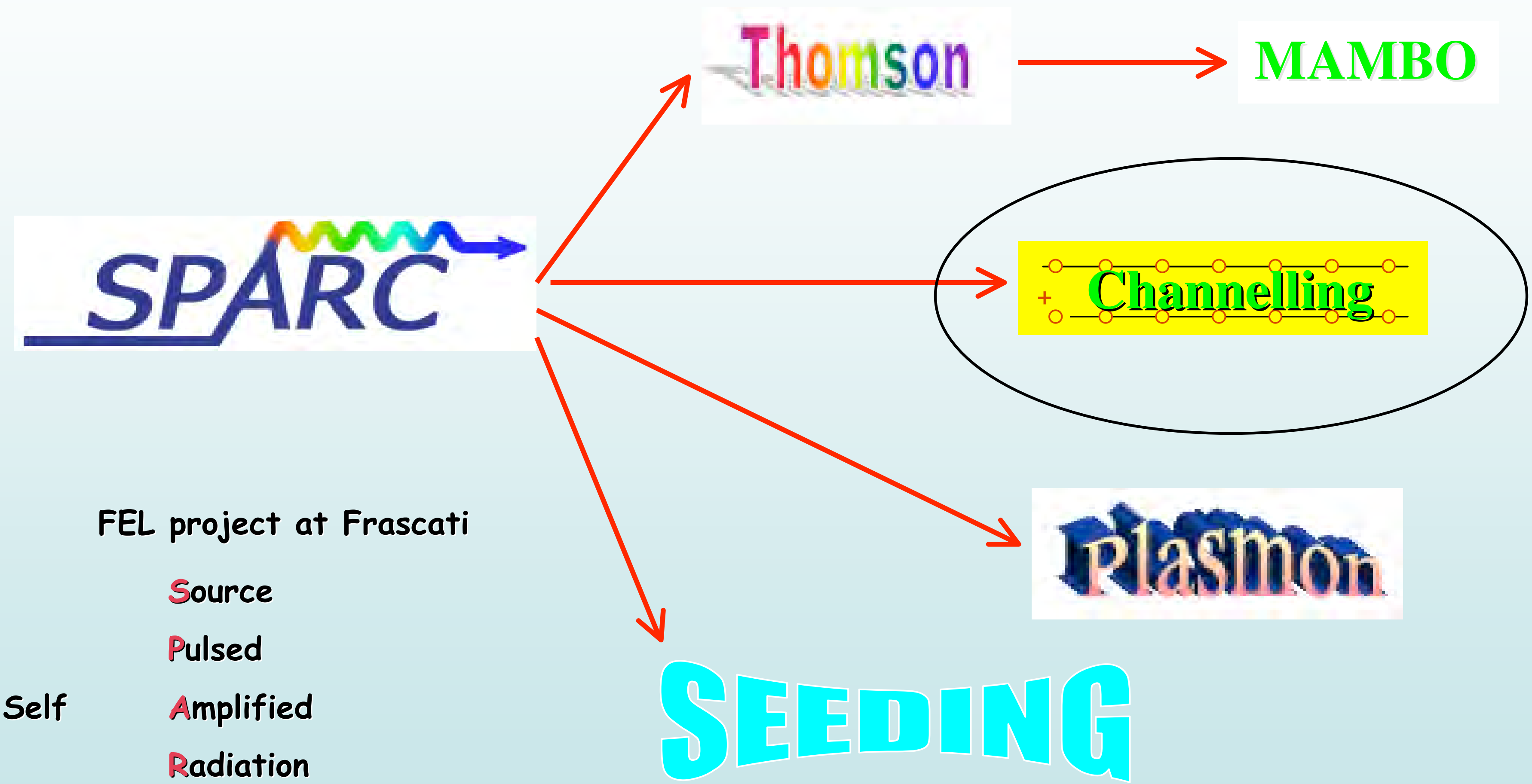
X

SPARX

(2.5 GeV e- : $\lambda = 13.5 - 1.5$ nm)

Self-Amplified Pulsed X Radiation Source

Channeling Radiation & Coherent Bremsstrahlung

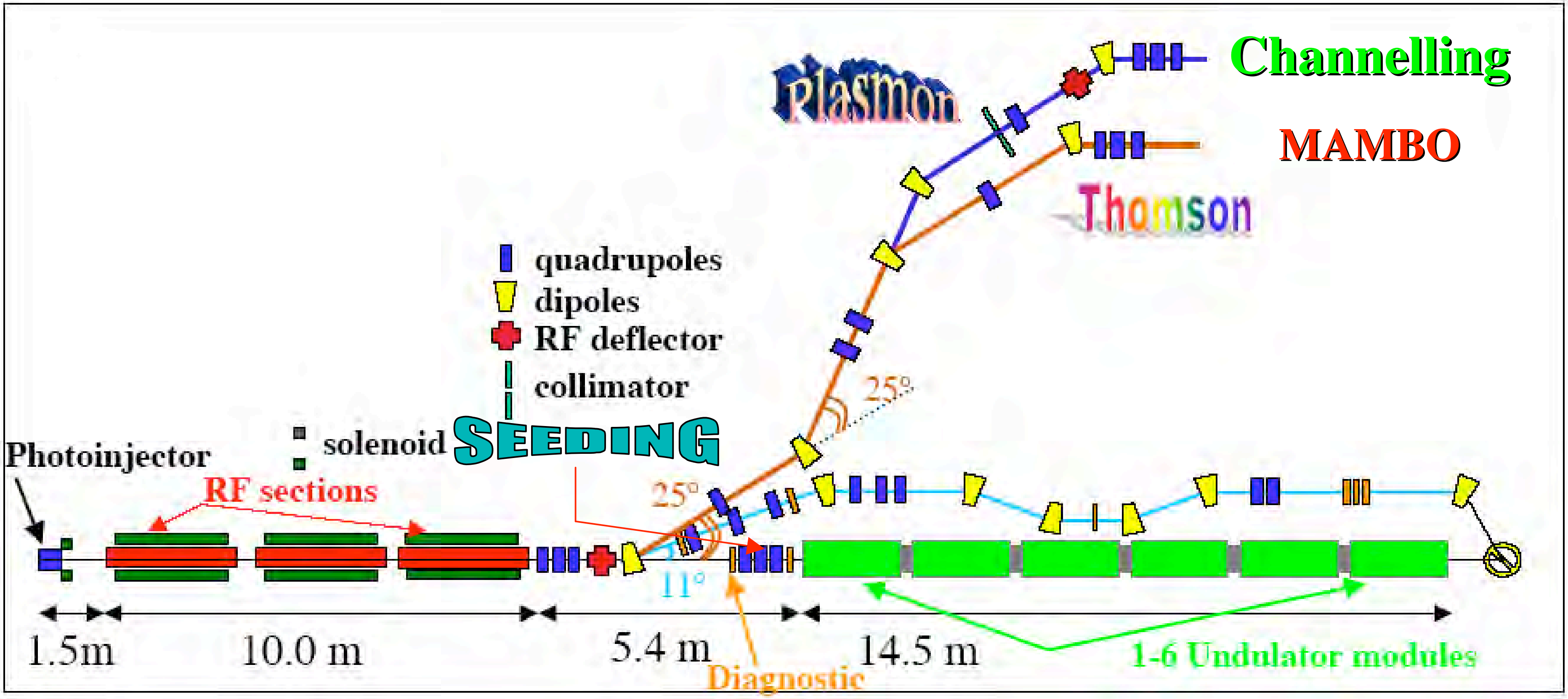


FEL project at Frascati

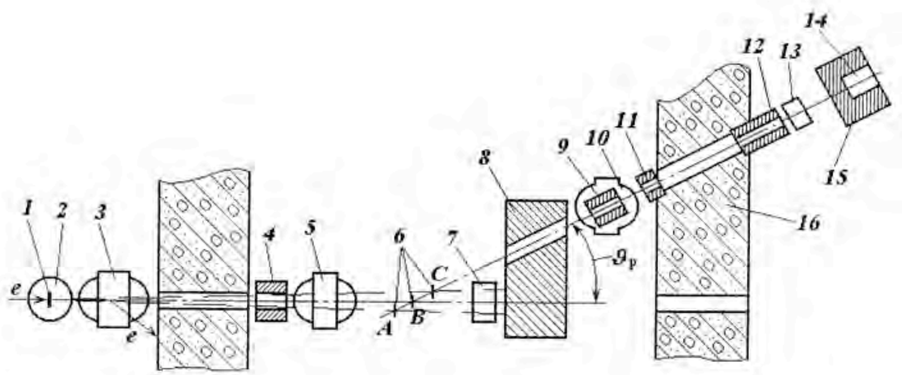
Source
Pulsed
Self Amplified
Radiation
Coherent

Self-Amplified Pulsed Coherent Radiation Source

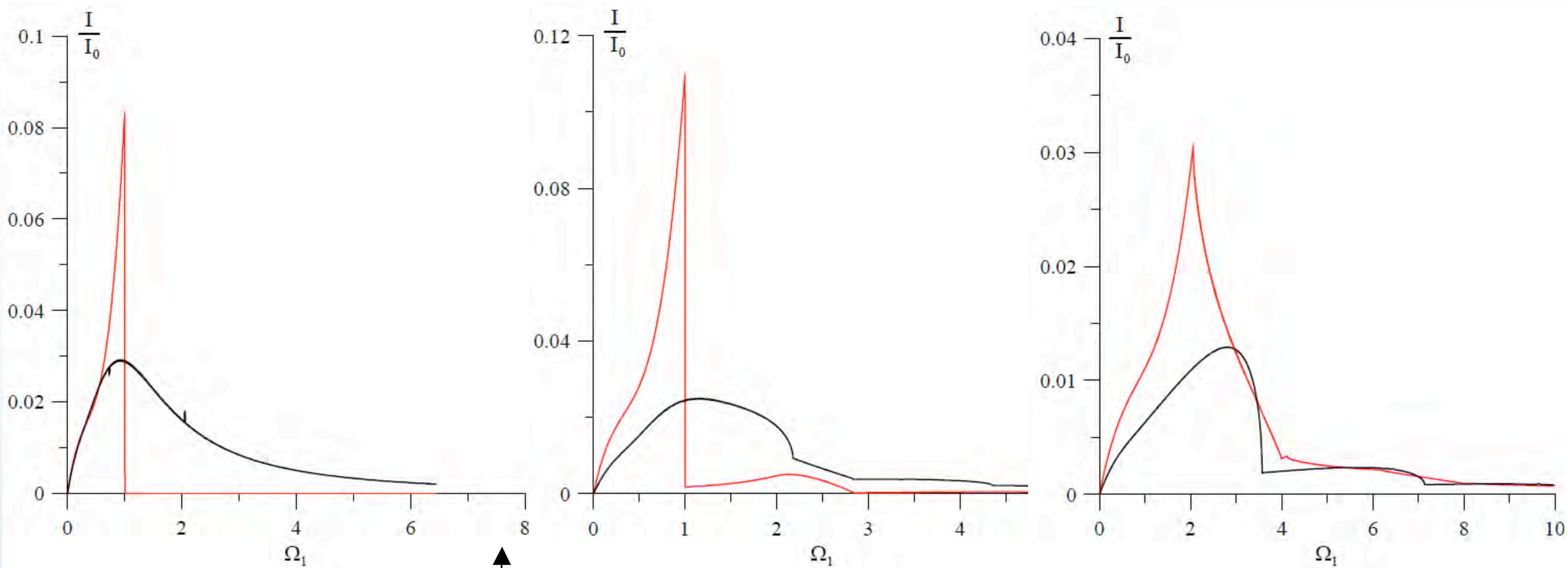
Experimental scheme



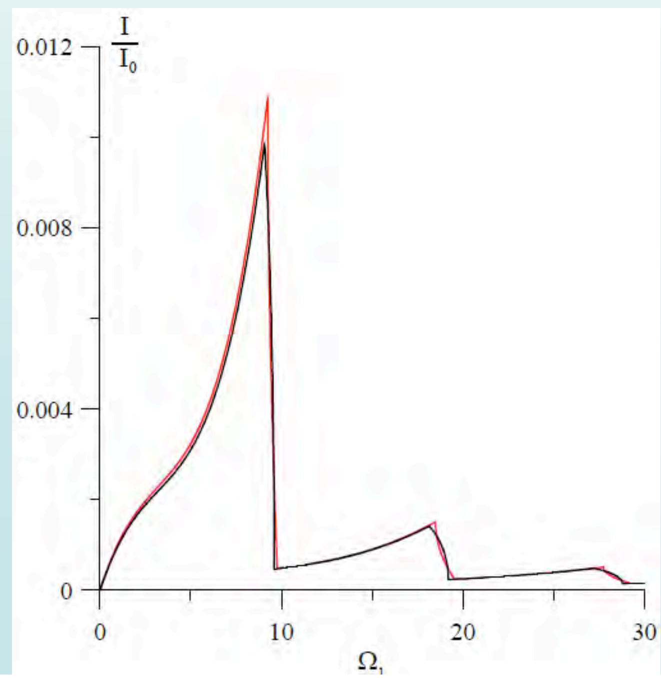
"Channeling" line layout
by Kharkov group



Calculation of ChR spectra



Channeling Radiation
vs
Coherent Bremsstrahlung



Channeling Radiation vs Thomson Scattering

$$\omega_{lab}^{ChR} \approx \frac{2\gamma^2}{1+\theta^2\gamma^2}\omega_0^{ChR}$$ $\propto \gamma^{3/2}$

- radiation frequency -

$$\omega_{lab}^{TS}\left\{\begin{array}{c}\vartheta = 0\\ \vartheta = \pi/2\\ \vartheta = \pi\end{array}\right\} \simeq \left\{\begin{array}{c}1\\2\\4\end{array}\right\}\frac{\gamma^2}{1+\vartheta^2\gamma^2}\omega_0^{TS}$$ $\propto \gamma^2$

$$\left(\frac{dN_{ph}}{dt}\right)_{ChR} \propto \gamma^{1/2}$$

- number of photons per unit of time -

$$\left(\frac{dN_{ph}}{dt}\right)_{TS} \propto Const$$

$$P \propto \gamma^2$$

- radiation power -

$$P \propto \gamma^2$$

@ comparison factor: $f \simeq \frac{\mathbf{A}_{Ch}^2}{\mathbf{A}_{TS}^2}\frac{L_{Ch}}{L_{TS}}$ $\quad L_{Ch}(z) \simeq \int_0^z N_{ch}(z)\,dz$

→ Laser beam size & mutual orientation

@ strength parameters – crystal & field:

	Si ⟨110⟩	C ⟨100⟩	W ⟨111⟩
$\mathbf{A}_{Ch}^2$, eV/Å^3	~ 520	~ 580	~ 10000

$\mathbf{A}_{TS}^2$ ~ 700 eV/Å^3 for the 10 TW laser with a beam diameter of 0.1 mm

By Carrigan R. et al.

Channeling Radiation vs Thomson Scattering

For X-ray frequencies: **100 MeV** electrons **channeled** in 105 μm Si (110) emit ~ 10^{-3} ph/e^-

corresponding to a Photon Flux ~ 10^8 ph/sec

ChR – effective source of photons in very wide frequency range:

- in x-ray range – higher than B, CB, and TS
- however, TS provides a higher degree of monochromatization and TS is not undergone incoherent background, which always takes place at ChR

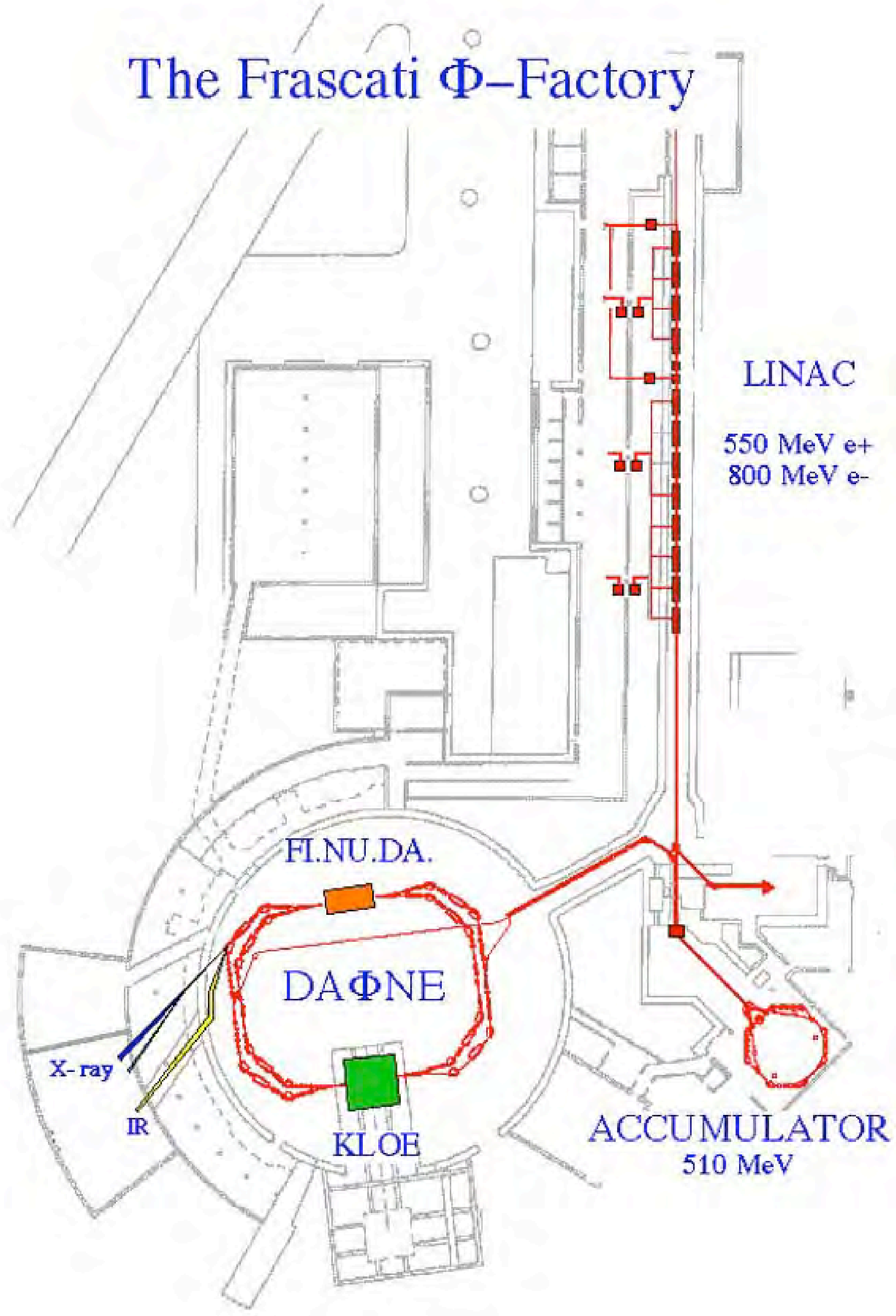
SPARX-ino proposal

• Upgrade the DAFNE Linac to drive a 5-10 nm SASE-FEL

• Beam energy : 1.2 - 1.5 GeV

• Upgrade the injector to a RF photo-injector (SPARC-like)

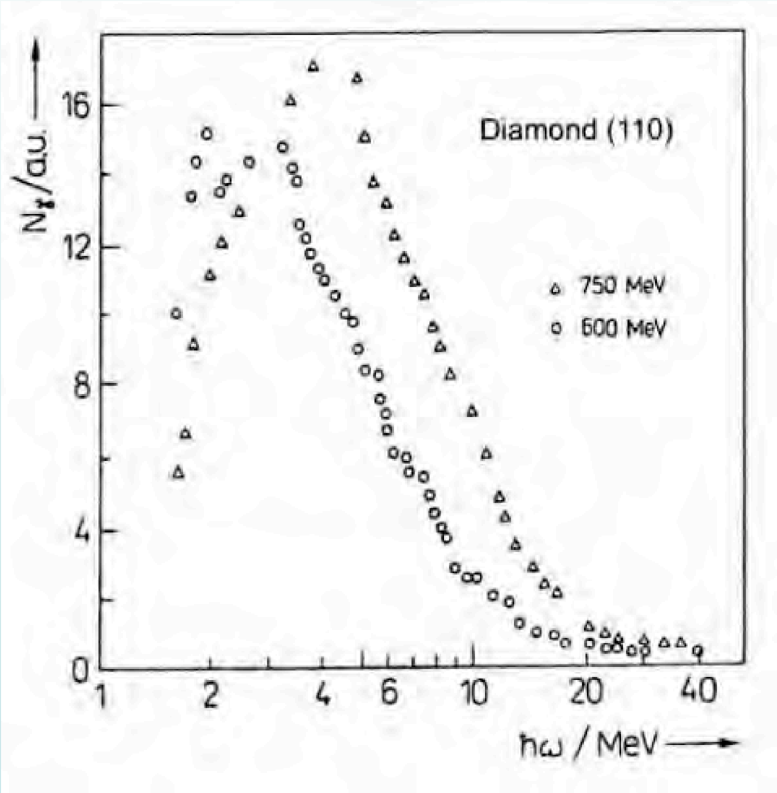
• Proposal in preparation

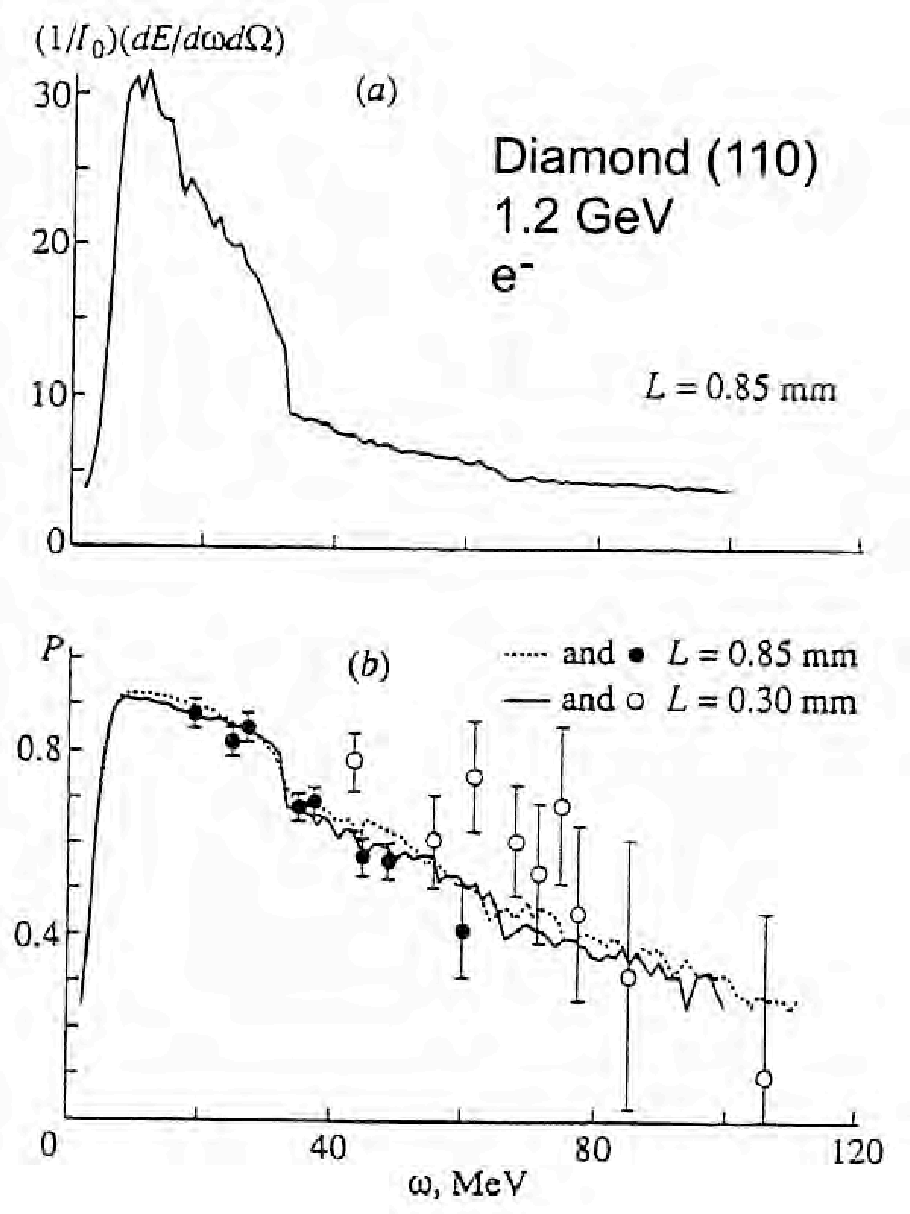


Spectra for e+/e- channeling

Channeling Radiation

0.5 – 1.2 GeV





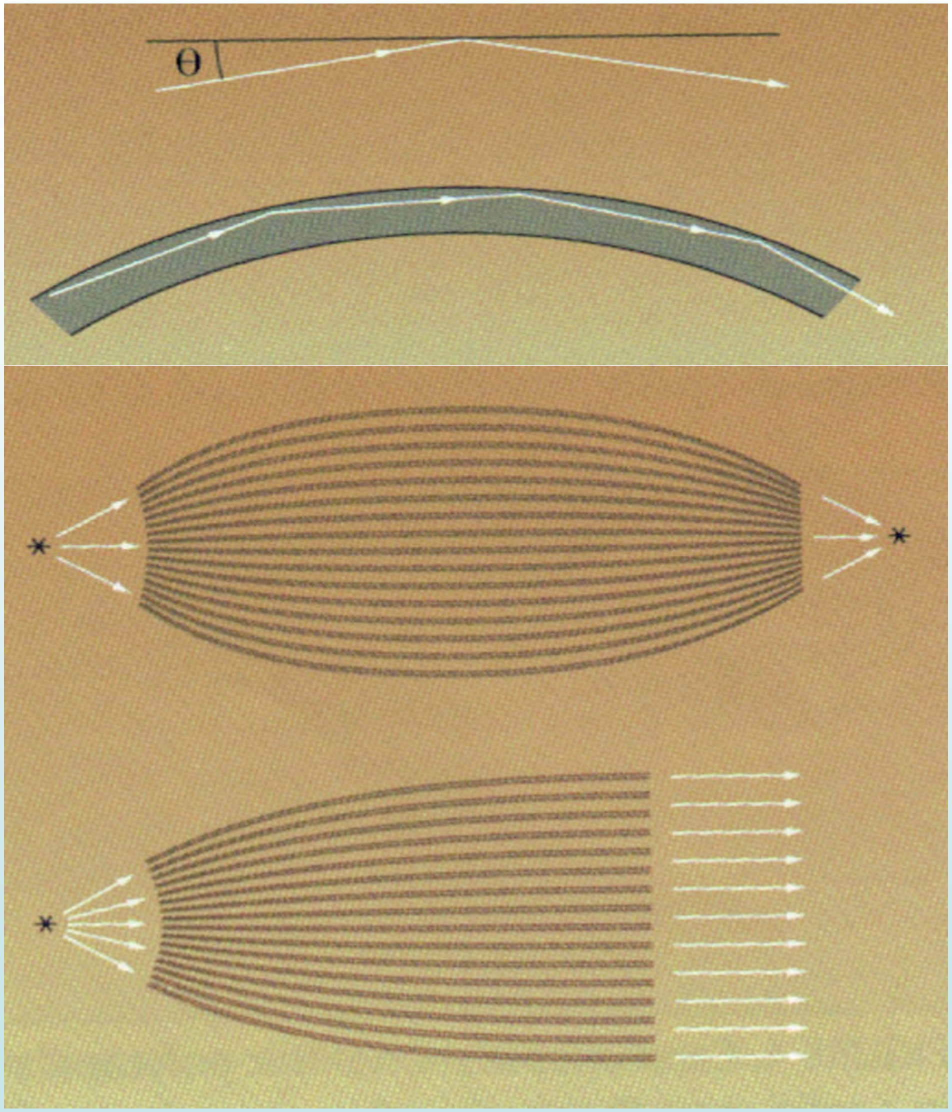
Comparison: Channeling Radiation vs Bremsstrahlung

		Diamond (110)					Si (110)				
U_0	eV	23.46					21.28				
d	Å	1.2611					1.9201				
I_{BH}	cm^{-1}	0.11					0.14				
		E	θ_L	ω_1	I_0	I_0/I_{BH}	E	θ_L	ω_1	I_0	I_0/I_{BH}
		MeV	mrad	MeV	cm^{-1}		MeV	mrad	MeV	cm^{-1}	
		150	0.559	0.302	34.89	317	150	0.533	0.189	19.80	141
		450	0.323	1.567	60.43	549	450	0.308	0.980	34.29	245
		750	0.250	3.372	78.02	709	750	0.238	2.109	44.27	316
		1000	0.217	5.192	90.09	819	1000	0.206	3.248	51.11	365
		1200	0.198	6.825	98.69	900	1200	0.188	4.269	55.99	400

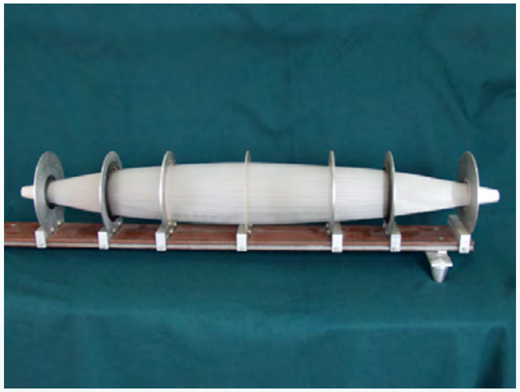
Channeling:
X-Rays and Neutrons

X-ray and neutron capillary optics

@ Basic idea of **polycapillary optics** is very close to the phenomenon of charged **particle channeling**



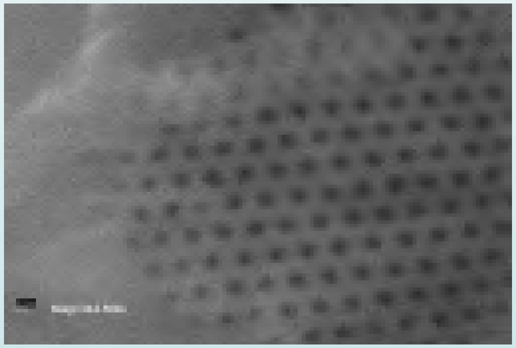
X-ray & Neutron Channeling: samples of capillary optics



1st generation:
[m]

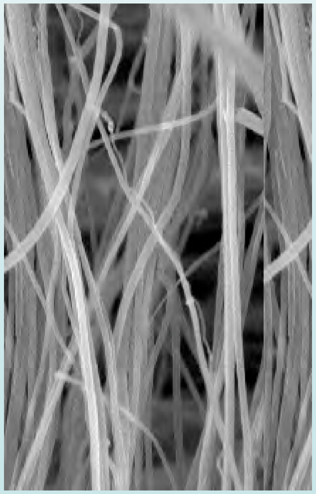
2d generation:
[cm]

3d & 4th generations:
[mm]



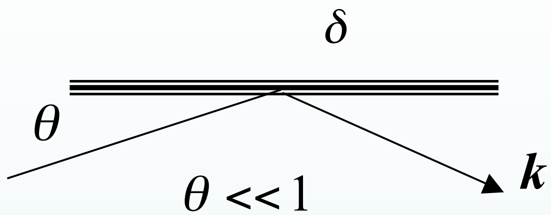
5th generation:
[μm – nm]

http://www.unisantis.com
http://www.iroptic.com



?n-capillaries?

Quantum base



$\theta << 1$

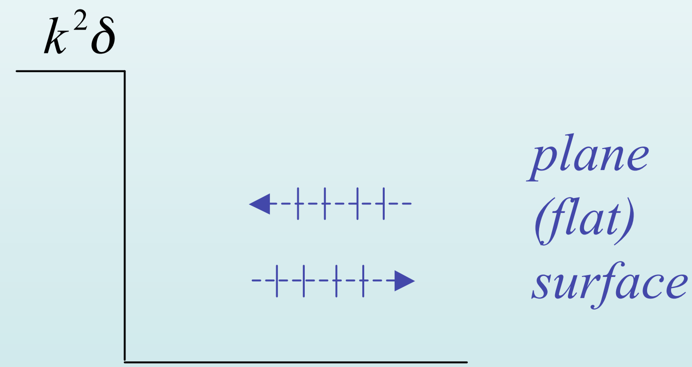
$k_\perp \approx k\theta$

1st order: $\Delta\varepsilon(\vec{r}) = 0$ *- no roughness*

Wave equation:

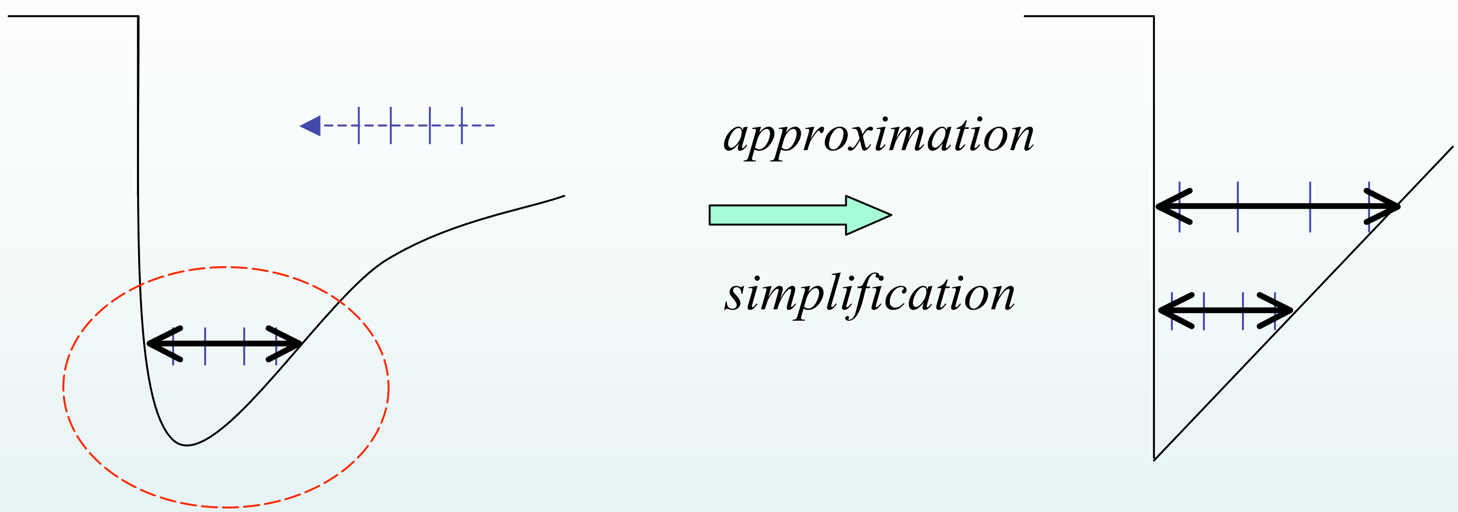
$$\left(-\nabla^2 + \underbrace{k^2\delta(\vec{r}_\perp) - k_\perp^{\,2}}_{V_{eff}}\right)E(\vec{r}_\perp) = 0$$

$$k^2\left(\delta(\vec{r}_\perp) - \theta^2\right) = \begin{cases} -k^2\theta^2, & r_\perp < r_1 \\ \underbrace{k^2\left(\delta_0 - \theta^2\right)} & r_\perp \geq r_1 \end{cases}$$



Total external reflection $V_{eff} \equiv 0 \Rightarrow \theta_c \equiv \theta \approx \sqrt{\delta_0}$

Quantum base (2) - curvature



additional term to

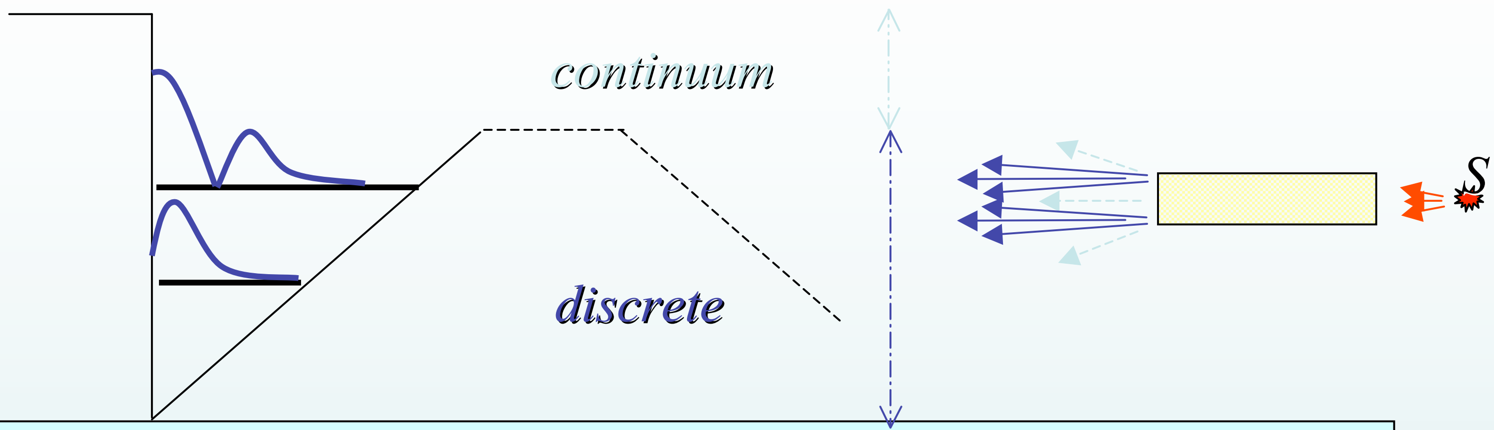
$$V_{eff} \longrightarrow 2\frac{-k^2 r_\perp}{r_{curv}}$$

"potential energy": angular momentum of photon

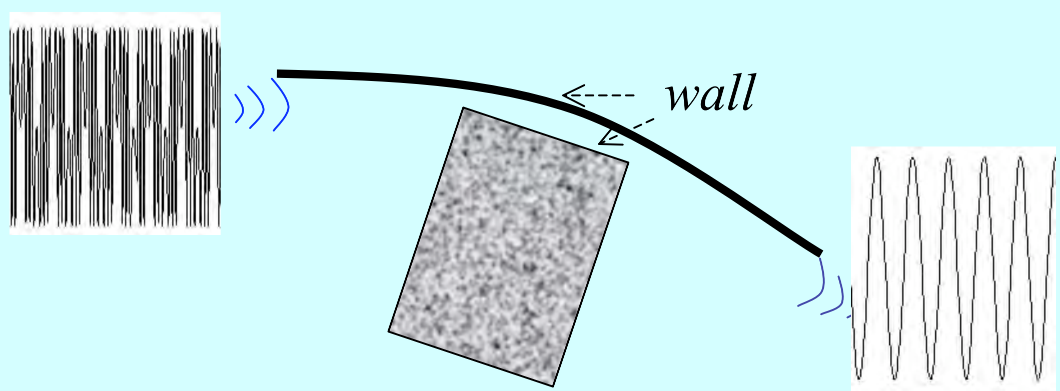
$$k r_{curv} \varphi$$

$$V_{eff} = k^2 \left(\delta\left(\vec{r}_\perp\right) - \theta^2 - 2\frac{r_\perp}{r_{curv}} \right)$$

Surface channeling - "whispering X gallery"



*** Whispering:**



APPLIED PHYSICS LETTERS VOLUME 78, NUMBER 19 7 MAY 2001

Divergence behavior due to surface channeling in capillary optics

G. Cappuccio
CNR—Istituto di Strutturistica Chimica, P.O. Box 10, I-00016 Montelibretti Sc., Italy
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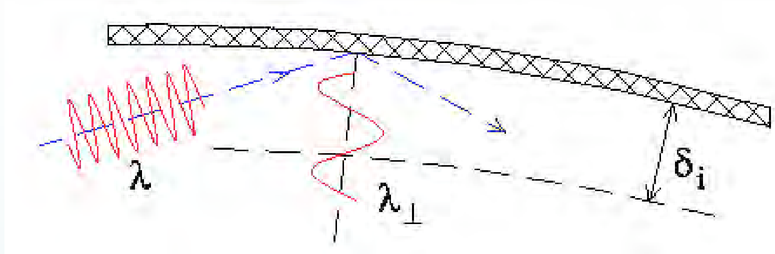
C. Gramaccioni and A. Pifferi
CNR—Istituto di Strutturistica Chimica, P.O. Box 10, I-00016 Montelibretti Sc., Italy

Modes of channeling along curved surfaces

$$\vec{\mathbf{k}} = (\mathbf{k}_\perp, \mathbf{k}_{||})$$

$$k_\perp \simeq k\theta \; (\theta < \theta_c)$$

$$\lambda_\perp = \lambda/\theta >> \lambda$$



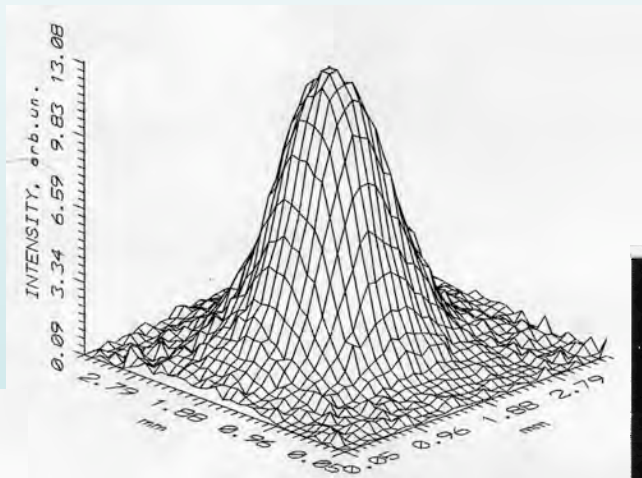
Effective guide channel → $\delta_i(\theta) \simeq \lambda_\perp(\theta)$

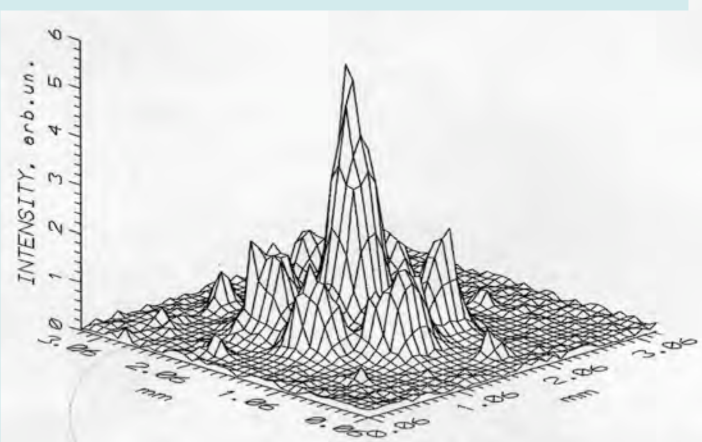
$$\boxed{(r_{curv})_i \theta^3 \sim \lambda}$$

$$(r_{curv})_i = 1\,cm \div 1\,m$$

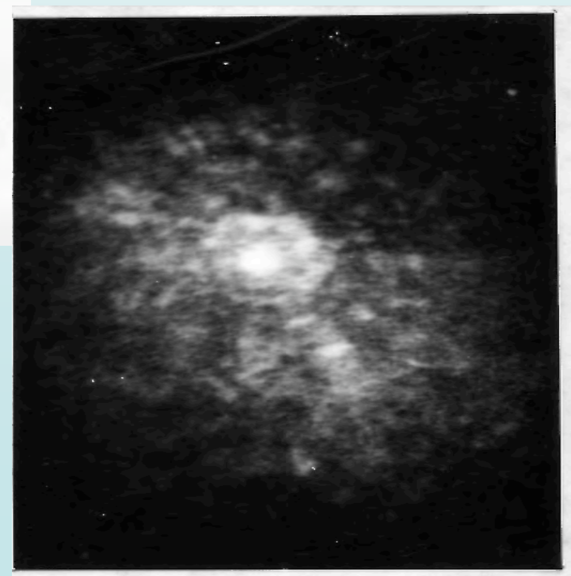
$$\theta \simeq 10^{-3} rad$$

$$\lambda \simeq 0.1 \div 10\,\text{Å}$$

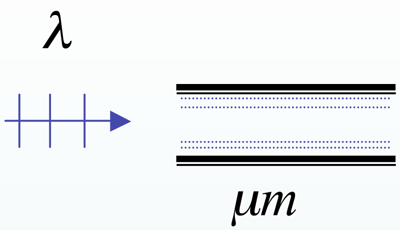




J.Synchrotron. Rad. 1995
Phys. Lett. A 1995



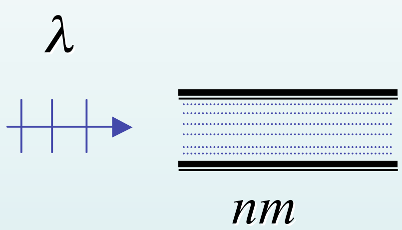
Down to bulk photon and neutron channeling



$\theta << 1 \quad (\theta_c \sim 10^{-3})$: *grazing incidence optics*

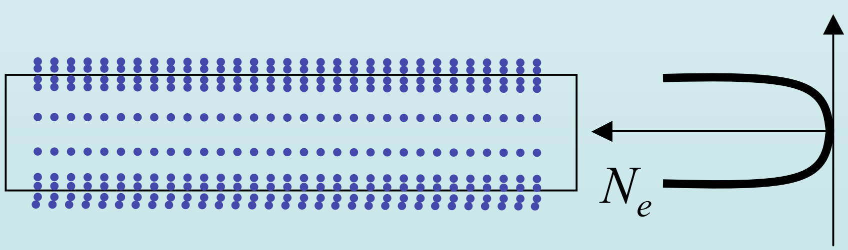
$\lambda \quad \rightarrow \quad \lambda_\perp >> \lambda$: *from nm to μm*

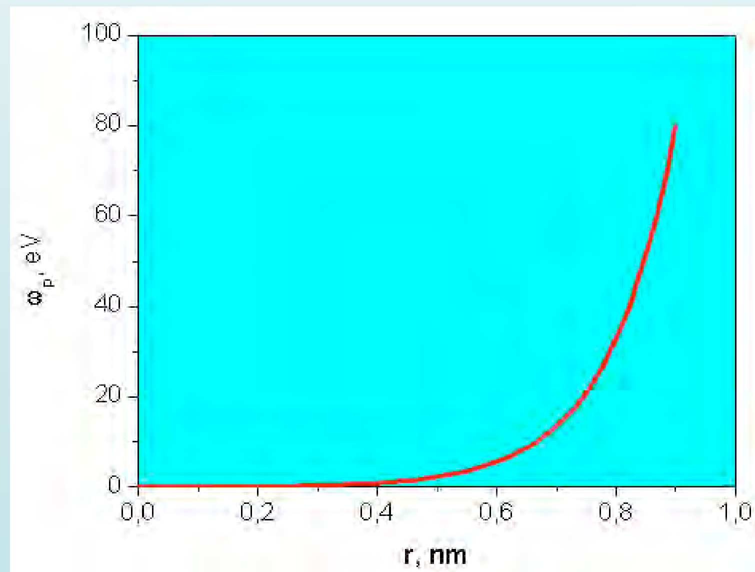
$d_0 \sim 1\mu m \div 10\mu m : \quad \lambda_\perp << d_0$: ***surface channeling***



$\theta_d = \lambda / d_0 \sim \theta_c$: *diffraction angle approaches Fresnel angle*

$\lambda_\perp / d_0 \sim 1$: ***bulk channeling***





Usp. Fiz. Nauk – Physics Uspekhi 2003

X-Ray channeling in nanotubes

JETP Letters, Vol. 81, No. 1, 2005, pp. 34–38. Translated from Pis'ma v Zhurnal Éksperimental'noĭ i Teoreticheskoĭ Fiziki, Vol. 81, No. 1, 2005, pp. 37–42.

Orientational Effect of the Texture of a Carbon-Nanotube Film on the Intensity of CK_α Radiation

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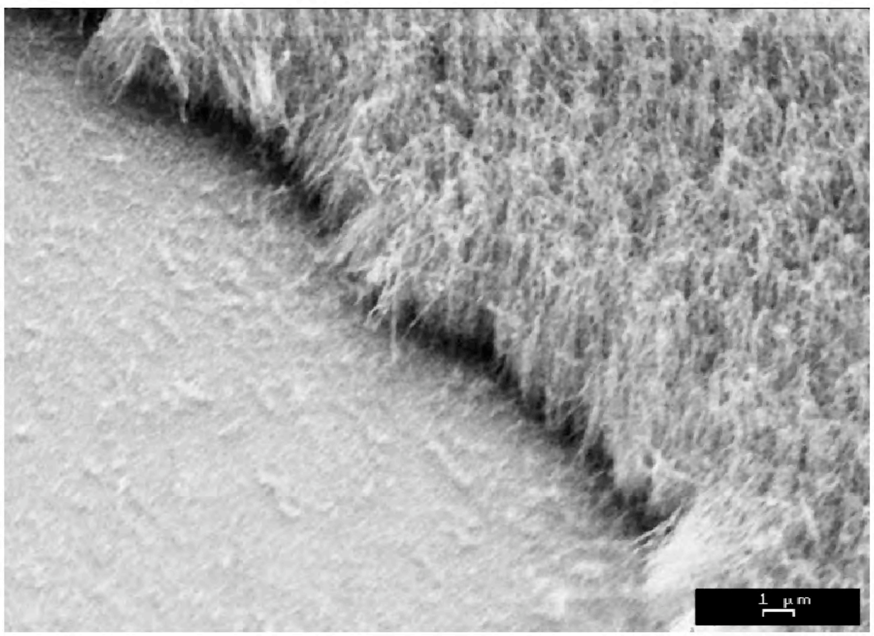
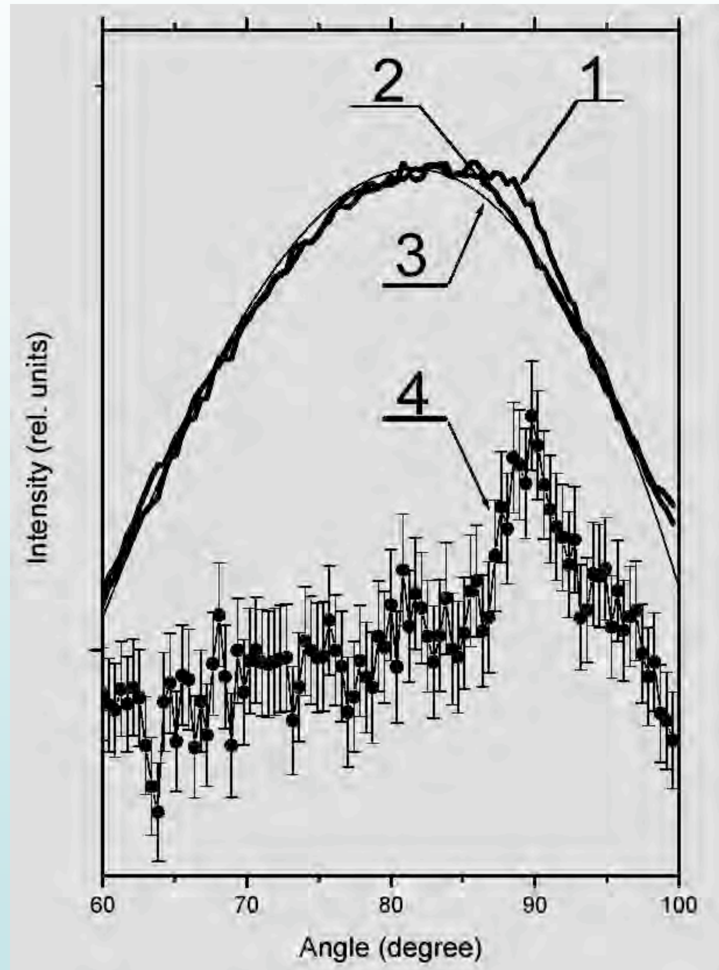
Received September 16, 2004; in final form, December 6, 2004

The angular dependence of the intensity of CK_α radiation measured from a film of oriented carbon nanotubes shows an increase in the yield of x-ray fluorescence along the growth direction of nanotubes. The angular distribution of the intensity of scattered x rays is close in magnitude to the angular distribution of the directivity of nanotubes in the film, which is determined by analyzing an electron-microscope image. To explain the propagation of radiation along the nanotubes, two mechanisms are proposed on the basis of reflection from inner walls of a tube (channeling) and an anomalous dispersion of CK_α photons in the carbon medium. © 2005 Ple-





Channeling 2004 – Channeling 2006

@ "**Channeling 2004**"
Workshop on Charged and Neutral Particles
Channeling Phenomena
(Frascati 2-6 November 2004)
http://www.lnf.infn.it/conference/channeling

- Radiation of relativistic charged particles in periodic structures
- Coherent scattering of electrons and positrons in crystals
- Channeling radiation of electrons and positrons in crystals
- Channeling of X-rays and neutrons in capillary systems (micro- and nano-channeling)
- Novel types of sources for electromagnetic radiation (FEL, powerful X-ray sources)
- Applications of channeling phenomena (novel radiation sources, X-ray waveguides, capillary/polycapillary optics)

@ **"Channeling 2006"**
International Conference on Charged and Neutral Particles
Channeling Phenomena
(LNF INFN, June 2006)

…with extended subjects for topics…

Collaboration & Acknowledgements

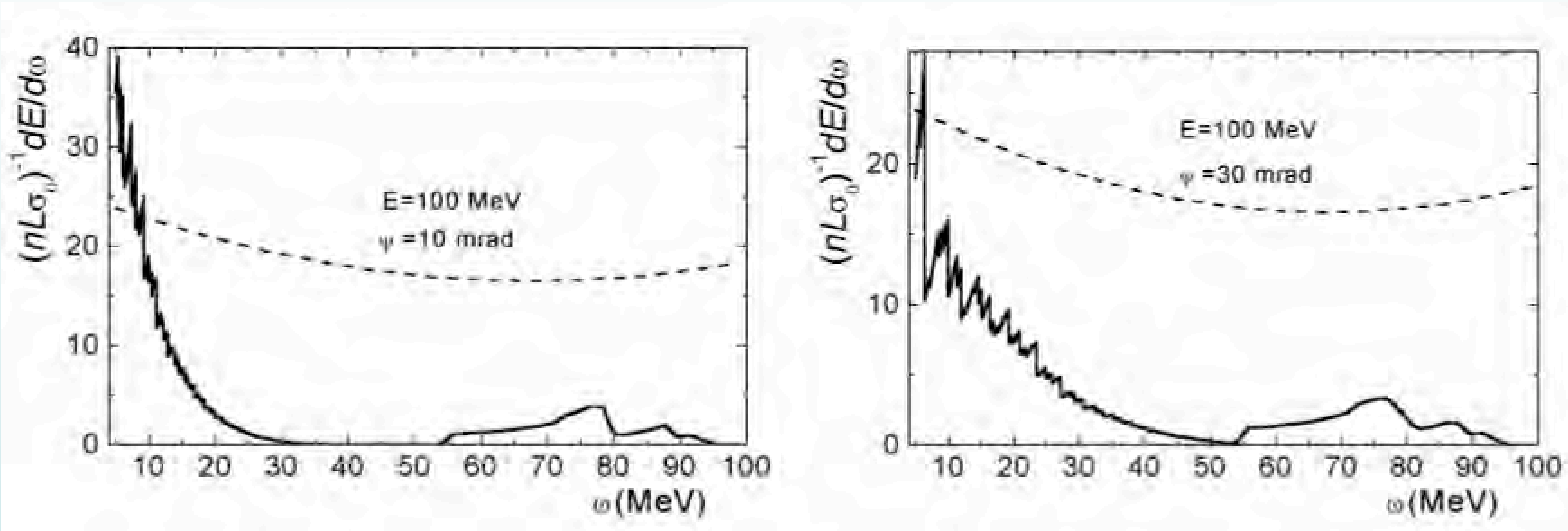
We have started collaboration with groups from:

Italy, Russia, USA, France, Germany, Switzerland, Ukraine, Belarus, Armenia

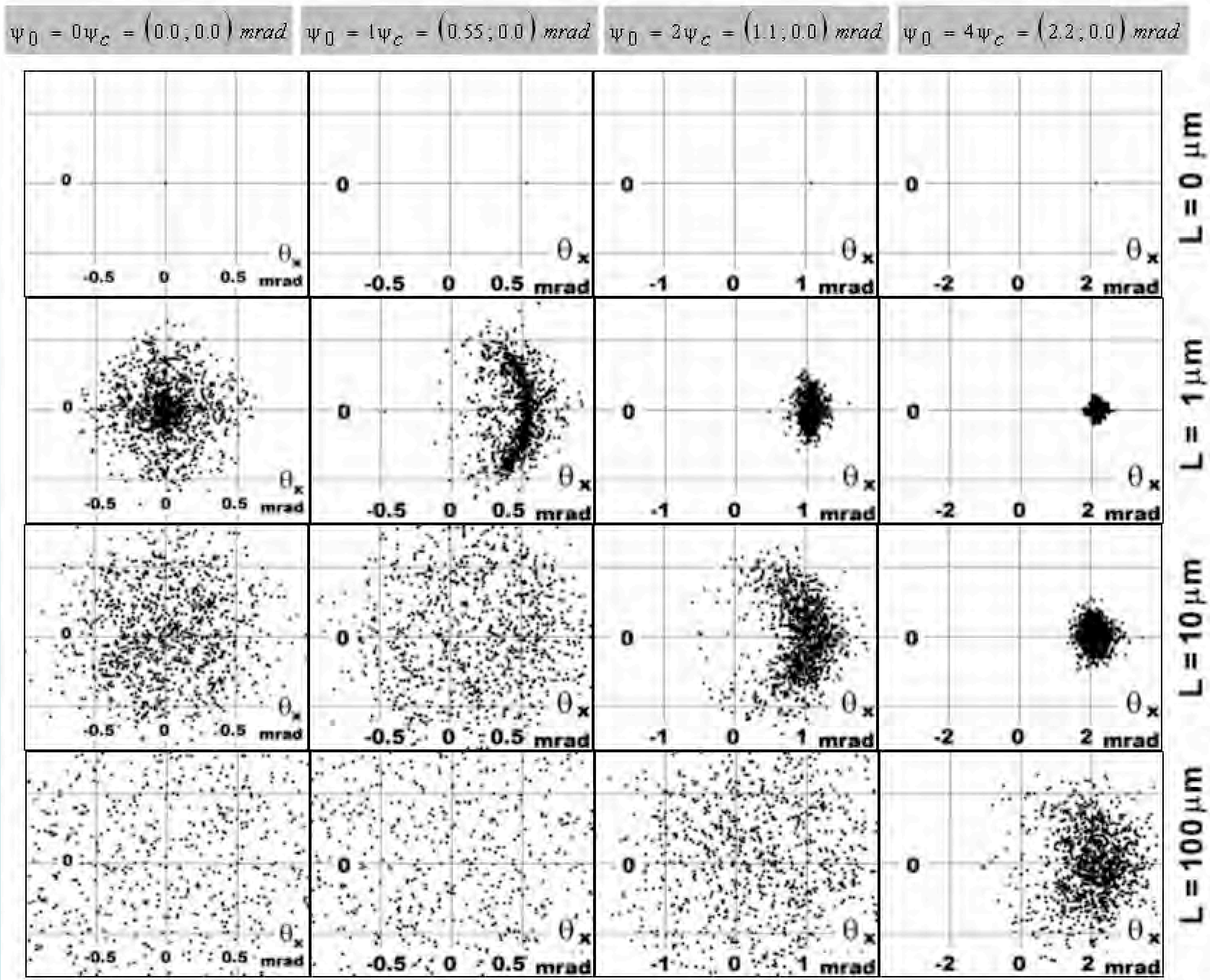
…list will be extended…

Appendix

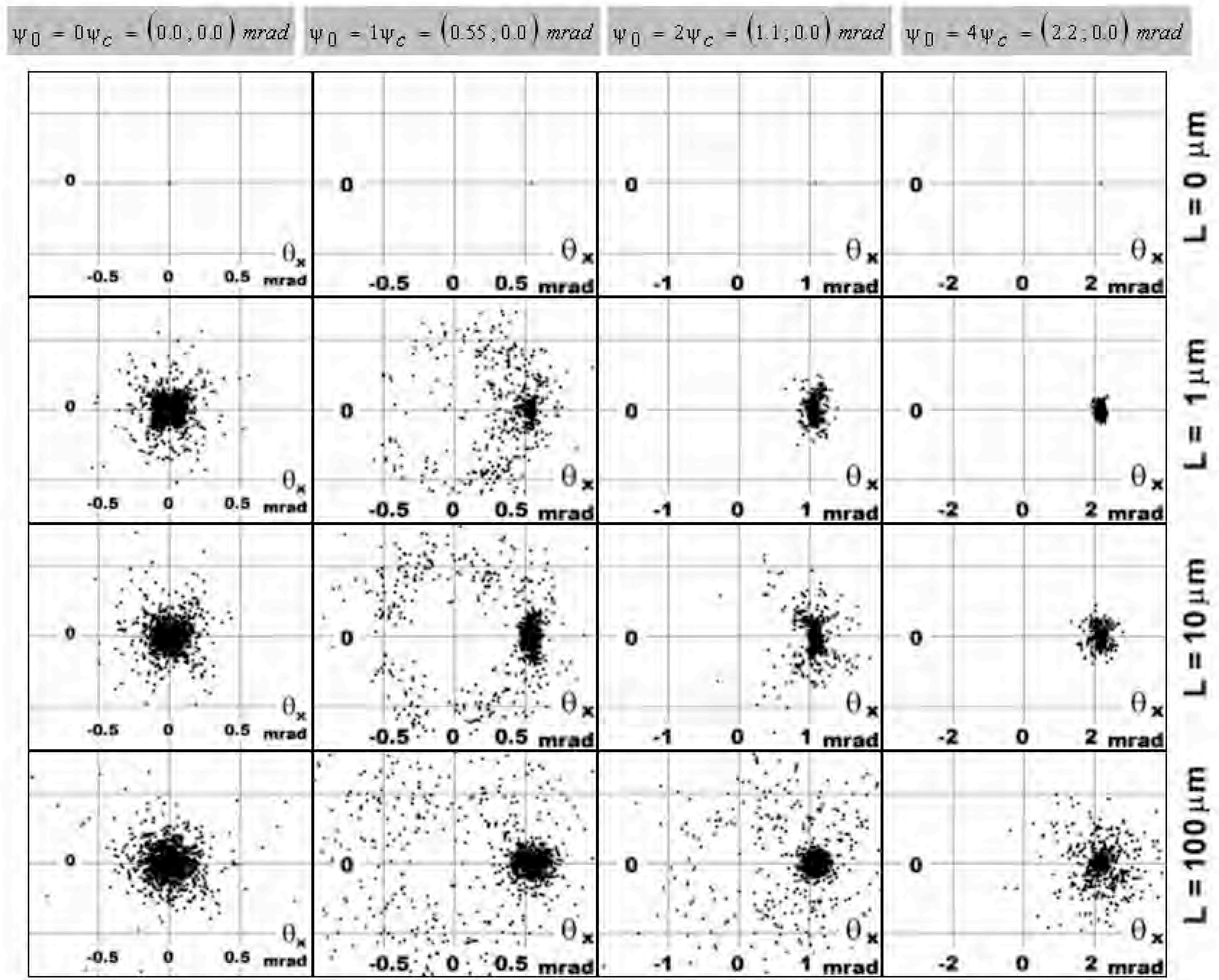
Additional material



(nLσ0)^-1 dE/dω
E=100 MeV
ψ =10 mrad
ω(MeV)
(nLσ0)^-1 dE/dω
E=100 MeV
ψ =30 mrad
ω(MeV)



$\psi_0 = 0\psi_c = (0.0; 0.0)$ mrad
$\psi_0 = 1\psi_c = (0.55; 0.0)$ mrad
$\psi_0 = 2\psi_c = (1.1; 0.0)$ mrad
$\psi_0 = 4\psi_c = (2.2; 0.0)$ mrad
L = 0 µm
L = 1 µm
L = 10 µm
L = 100 µm
θ_x
mrad



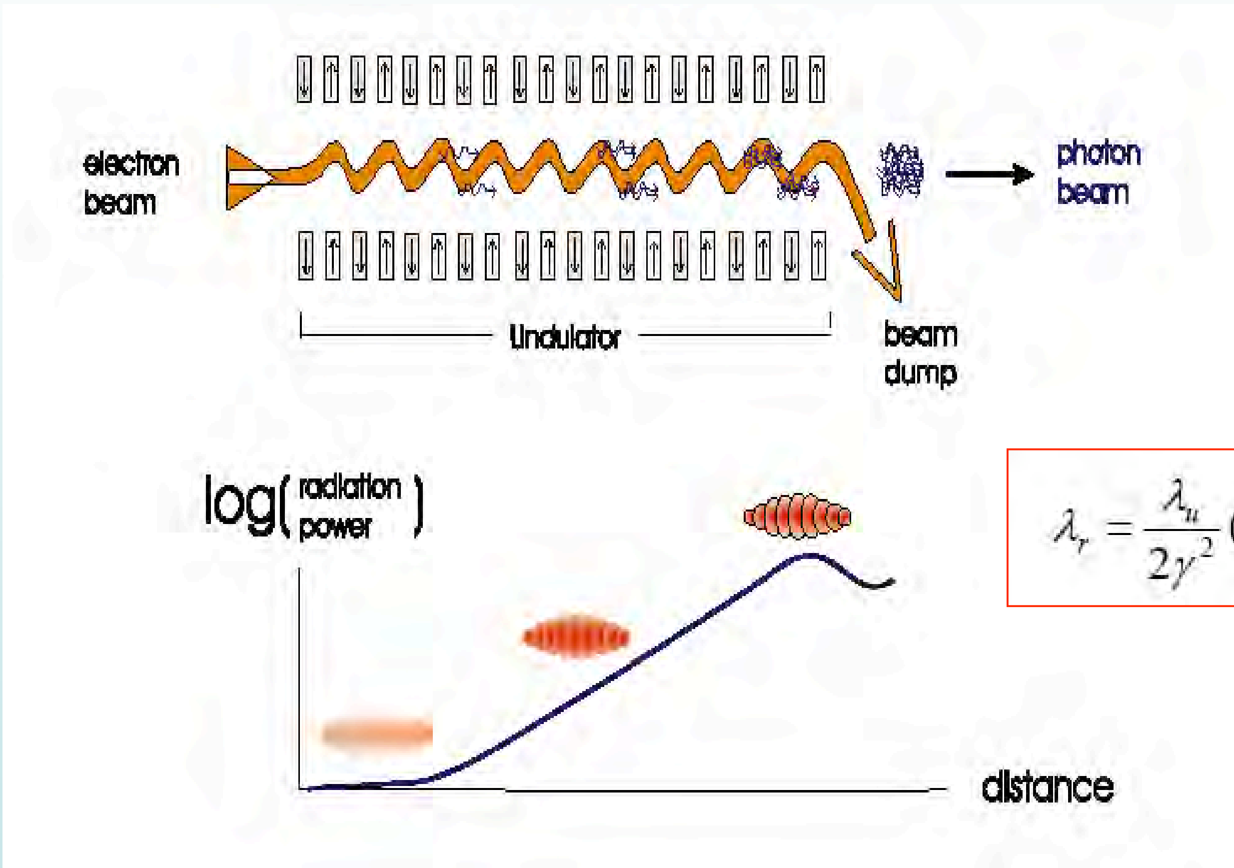
$\psi_0 = 0\psi_c = (0.0 ; 0.0)$ mrad
$\psi_0 = 1\psi_c = (0.55 ; 0.0)$ mrad
$\psi_0 = 2\psi_c = (1.1 ; 0.0)$ mrad
$\psi_0 = 4\psi_c = (2.2 ; 0.0)$ mrad
L = 0 µm
L = 1 µm
L = 10 µm
L = 100 µm
θ_x
-0.5 0 0.5 mrad
-1 0 1 mrad
-2 0 2 mrad

The Scientific Case in the 10 nm ⇒ 1 nm range:

High Peak Brightness (> 10^{30}) Ultra-short (< 100 fs) radiation pulses are of great interest in various areas

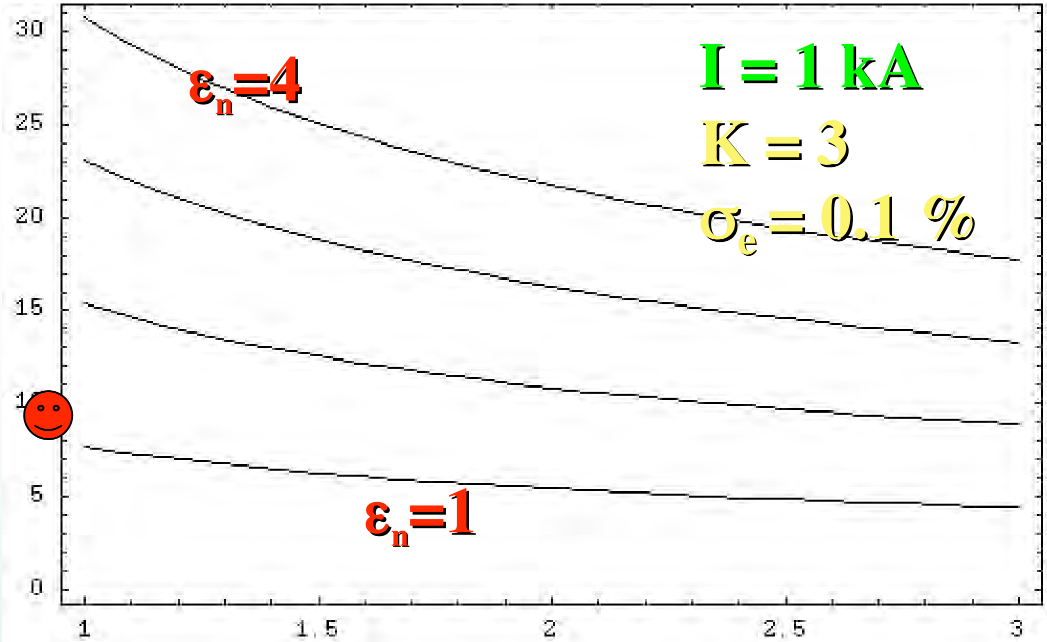
- **molecular physics** (vibrational modes, bond breaking and formation at λ=10-1 nm)
- **physics of the clusters** (phase transitions at λ=10-1 nm,)
- **surface and interfaces** (real time dynamics and phase transitions, λ=10-1 nm)
- **time resolved chemical reactions** (metastable and transition states, magnetic scattering, confined systems, λ=10-1 nm)

Free Electron Laser
Self-Amplified-Spontaneous-Emission
(No Mirrors - Tunability - Harmonics)



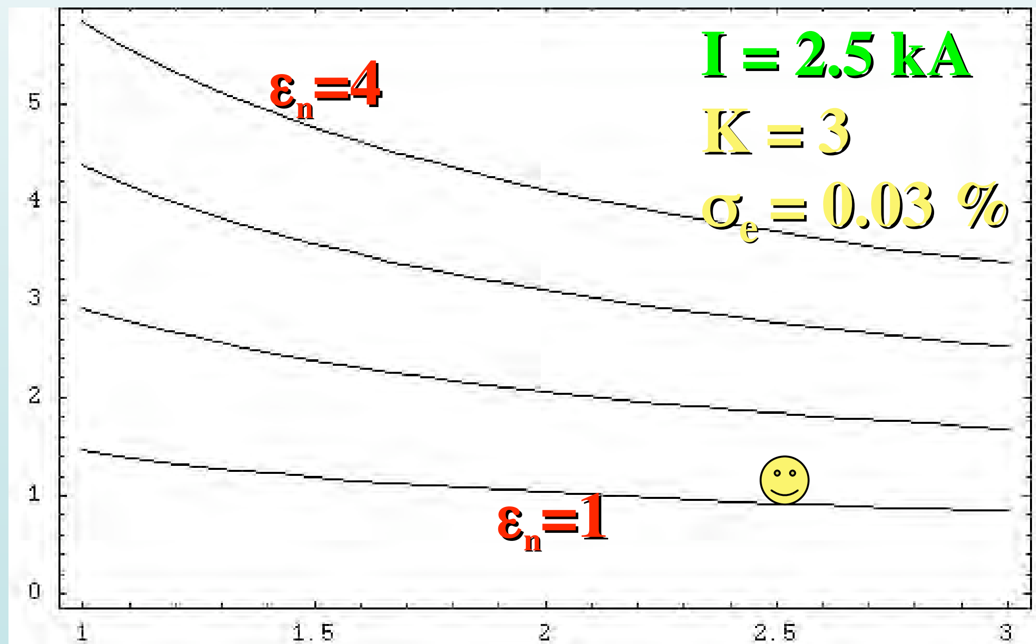
$$\lambda_r = \frac{\lambda_u}{2\gamma^2}(1 + a_u^{\,2} + \gamma^2\theta^2)$$

The SPARX-ino opportunity



Energy [GeV]

λcr [nm]



Energy [GeV]

Potential for neutral particles: Moliere approximation

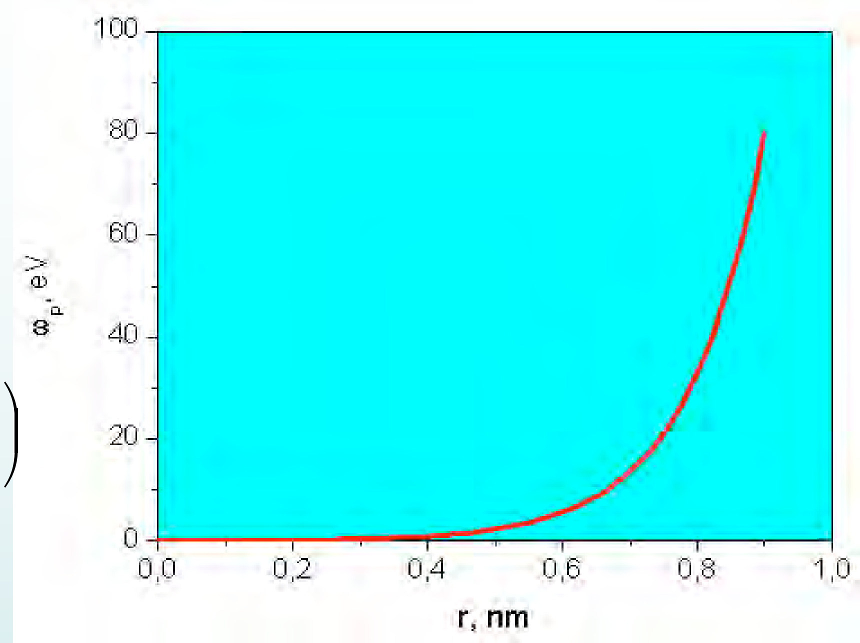
$$N_e(r) = \frac{Z}{4\pi a^2 r}\sum_{i=1}^{3}\alpha_i\beta_i^2\exp\left(-\frac{\beta_i r}{a}\right)$$

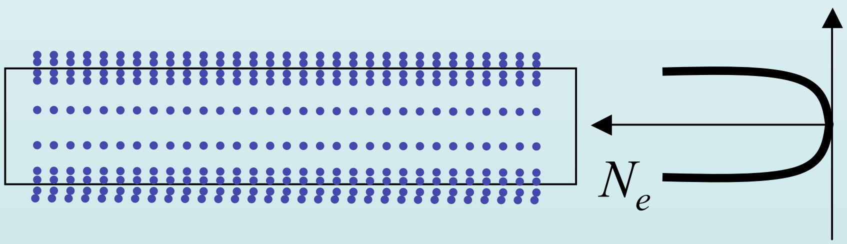
$$C: \quad Z = 6$$

$$a \approx 0.05Z^{-1/3} - \quad screening \quad length$$

$$\overline{N}_e(r) \approx \frac{r_{curv} n_a Z}{\pi a^2}\sum_i \alpha_i\beta_i^2\int_0^{\pi} d\theta\, K_0\left(\frac{\beta_i\rho}{a}\right)$$

$$\rho = \left(r^2 + r_{curv}^2 - 2 r r_{curv}\cos\theta\right)^{1/2}$$





"Continuous filtration"

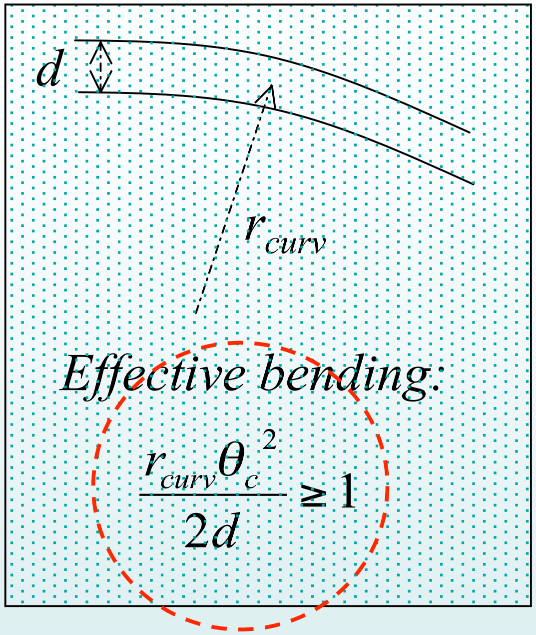
Phys. Lett. ***A250*** *(1998) 360*
NIM ***B143*** *(1998) 584*

Nanocapillary: Bending efficiency

$$n = \sqrt{1-\theta_c^{\,2}} \approx \sqrt{1-\frac{\omega_p^{\,2}}{\omega^2}}$$

$$\omega_p = \sqrt{\frac{4\pi \; N_e e^2}{m}} - \quad plasma \quad frequency$$

$$\omega - \quad photon \quad frequency$$



μ-capillary: 10^0-30^0 through 10-20cm

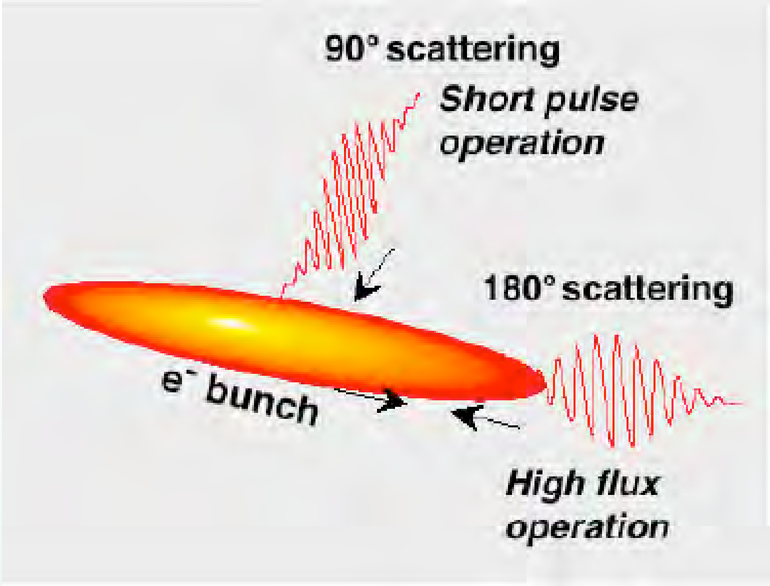
n-capillary:the reduce of the dimensions by several orders with much higher efficiency

*Nuovo Cimento **B116** (2001) 361*

Thomson

$$E_x \cong 2\gamma^2 E_{las}\,(1-\cos\psi)$$

$$N_X \propto \Sigma_T f \frac{N_{e^-} N_{h\nu}}{\sigma_{coll}^2} = 2 \cdot 10^{9/11}$$



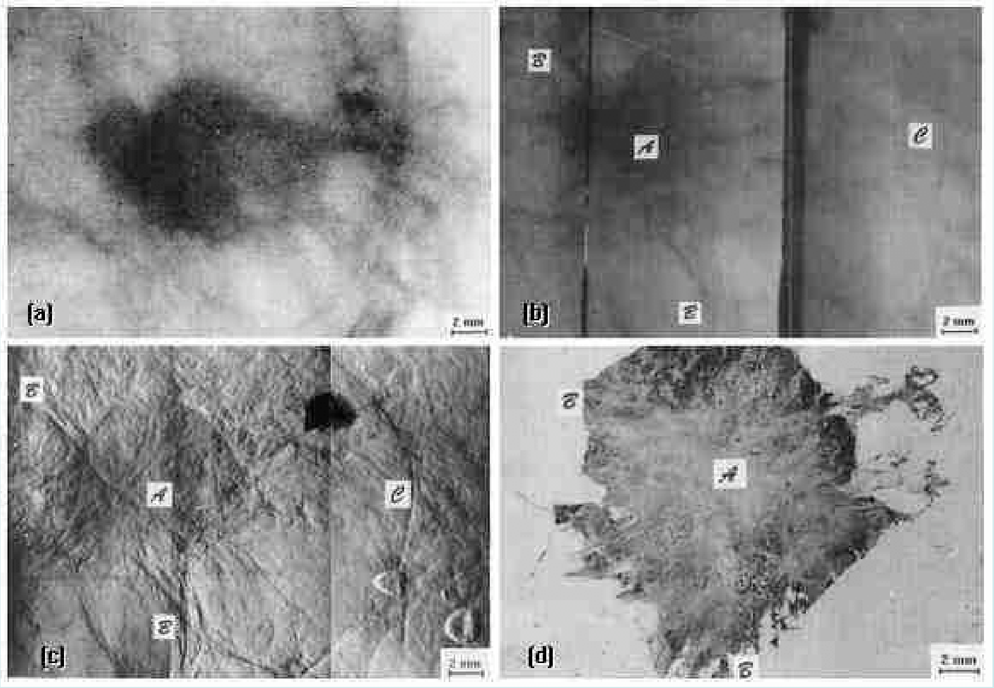
- Produzioni di impulsi X :

  10^9 fotoni/s, durata 3 ps, **monocromatici** tunabili nel range **20 keV - 1 MeV**.

  Raggiungimento di **10^{11} fotoni/s** con spot focali all'interazione di **5 μm**.
- Studi di tecniche di **mammografia** (e **angiografia coronarica**) con X monocromatici.
- Studi di **single molecule protein cristallography**.

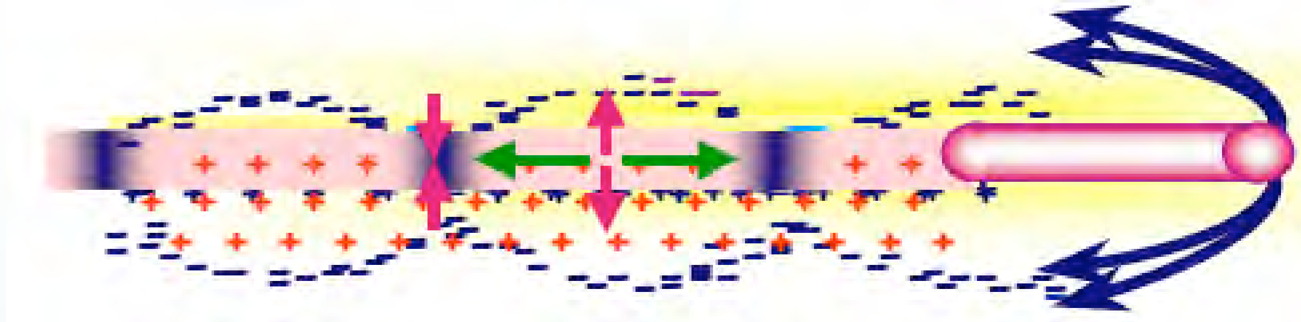
MaMBO Experiment:
Mammography Monochromatic Beam Outlook

La realizzazione di una immagine (su superficie 18x24 cm^2) in tempi di **2600 s** scende a **2.6 s** con l'upgrade previsto su SPARC che porta il num. di fotoni a 2.5 10^{11} γ/s



The constrast (sensitivity to tissue density variations) goes from 8% to 0.1%, while the spatial resolution goes from 0,15 -0,3 mm to 0.01-0.015 mm. This means the capability to detect a tumor 30 times smaller in volume, i.e. a 2 year earlier detection of the tumor.

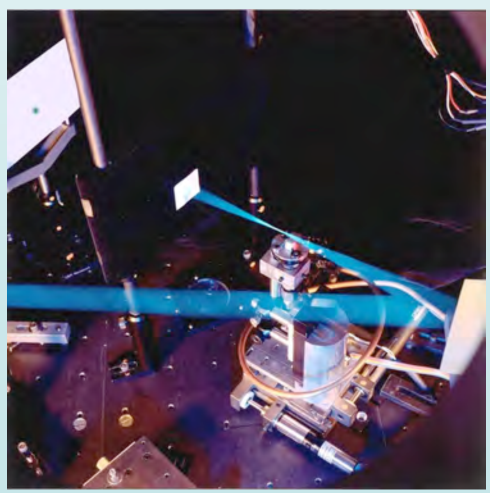
Plasmon



Accelerazione a plasma di pacchetti di elettroni (**25 pC**) da **100 MeV a 130 MeV** con spread energetico < 5%, emitt. < 1 μm, con laser non guidato (5 mm acc. length).

Accelerazione con laser guidato (**5 cm**) fino a 400 MeV, **gradienti > 5 GV/m**.

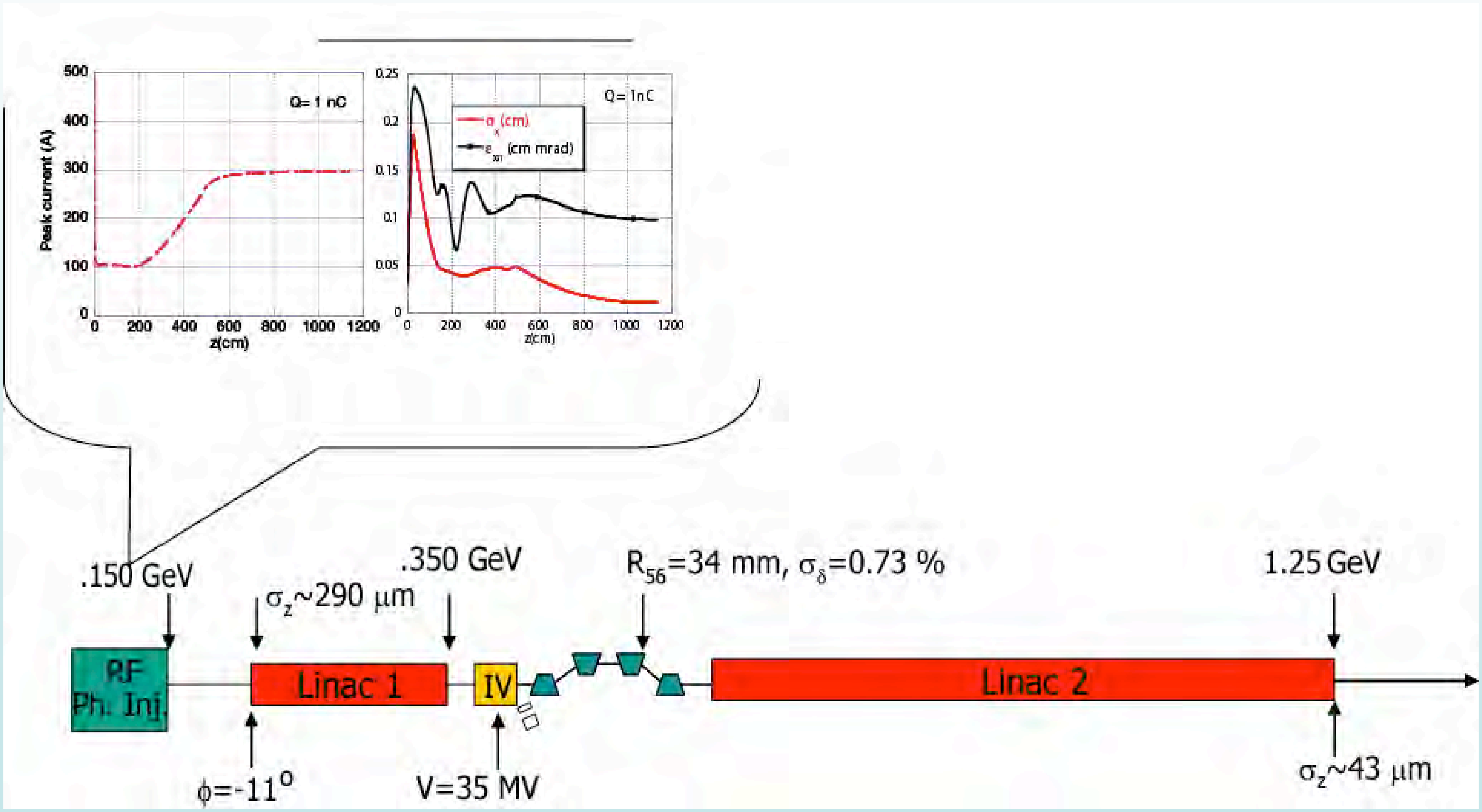
$$\varepsilon_n \le \sqrt{\gamma \frac{\Delta n_p}{n_p} \frac{\lambda_p}{2\pi}}$$



$$\Phi_p \approx 50 \quad \mu m$$

$$\lambda_p \approx 30 - 100 \quad \mu m$$

SPARC Injector + DAFNE Linac
SPARX-ino
a 5-10 nm SASE FEL source at LNF



SPARC & SPARX & SPARXINO

- The SPARC project engineering has been completed

- The LINAC is entering, on schedule, the installation phase

- First beam delivery in 2006

- The SPARX project has been funded

- With an up-grade of Dafne Linac the region of a few nm would be achievable.