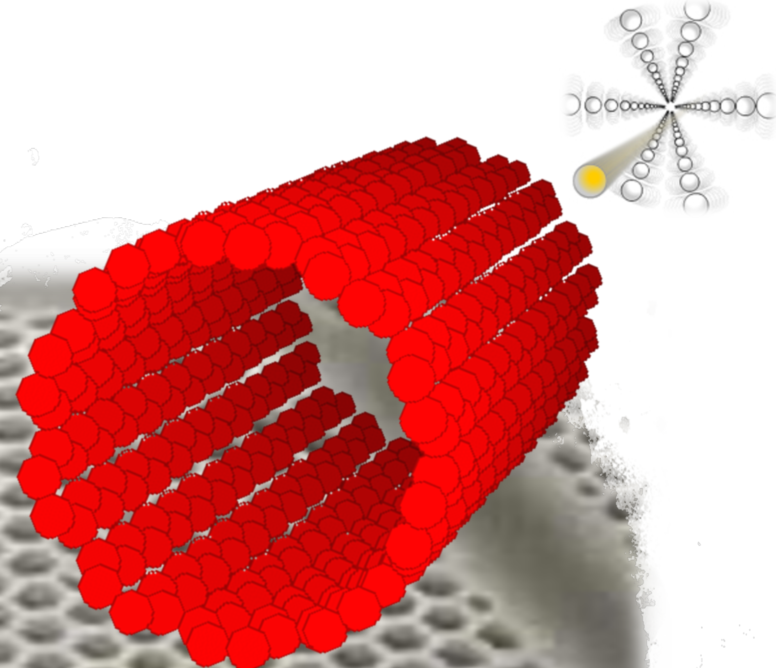


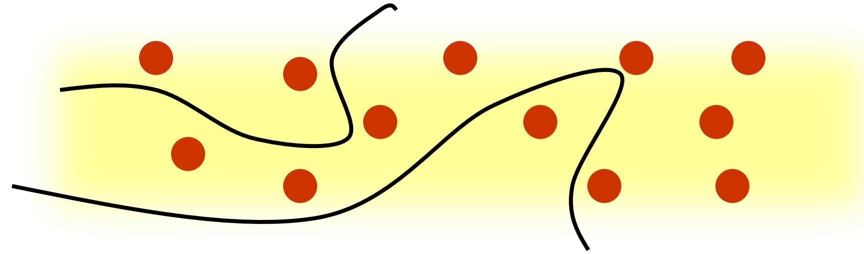
Channeling:
- highlights
- lessons
- directions

DABAGOV Sultan

INFN Lab Naz Frascati

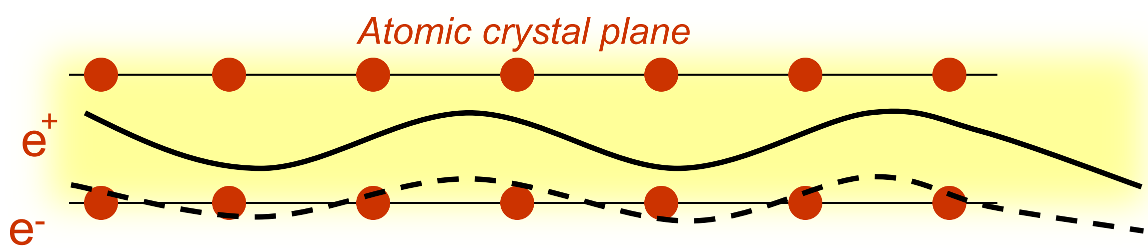
@ crystal channeling of charged particles

@ Amorphous:

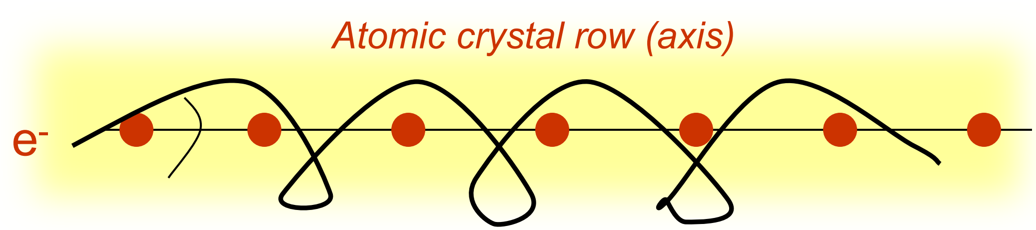


@ Channeling:

planar channeling



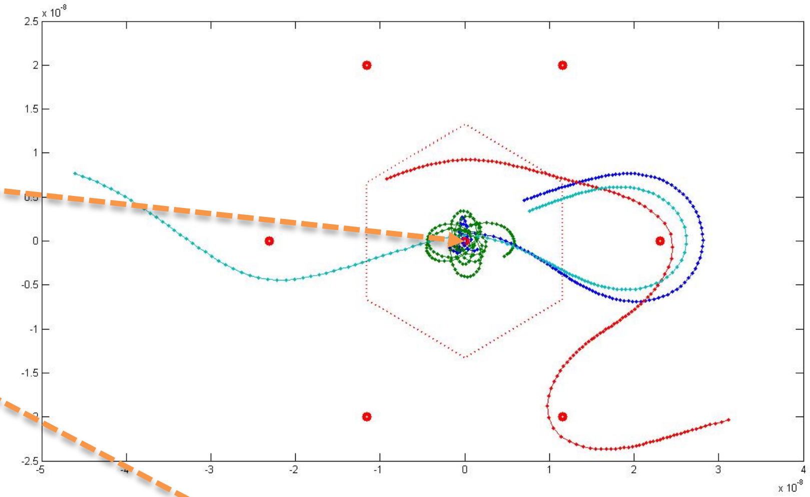
axial channeling



$\phi << 1$ $\quad (\phi < \phi_L \sim \sqrt{U/E})$ *- the Lindhard angle is the critical angle for the channeling*

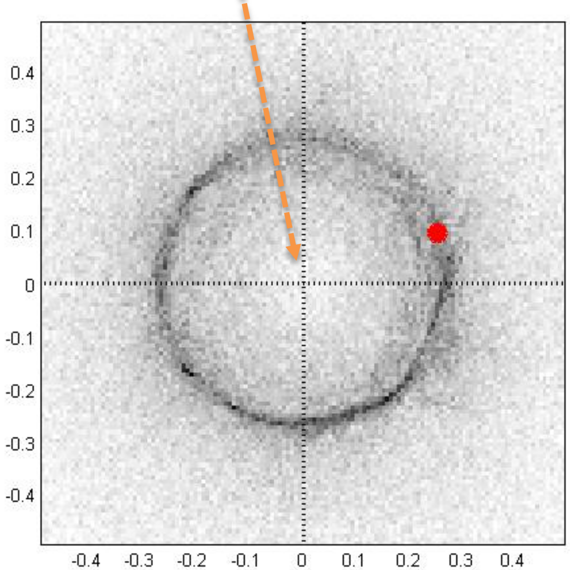
@ electron beam dynamics in crystals: simulations

Ge <111> e- 150 MeV



various trajectories transverse axis cross-section

Computer simulations for angular distribution of a beam vs depth of penetration

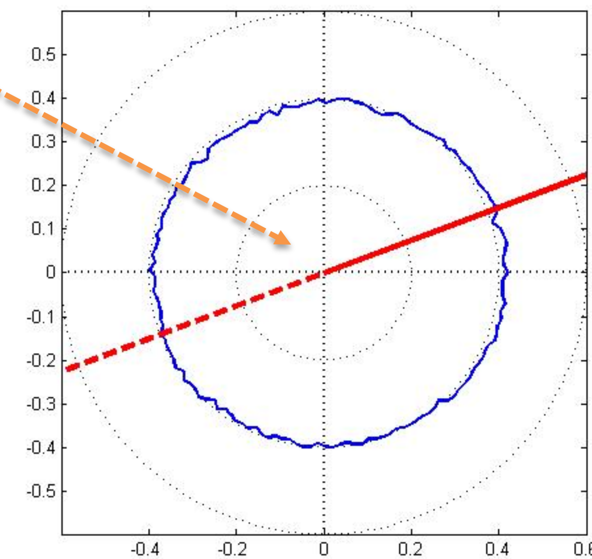


$\Delta\theta = 0$ – beam divergence

$\theta_0 = 0.25\ \theta_c$ – incidence angle

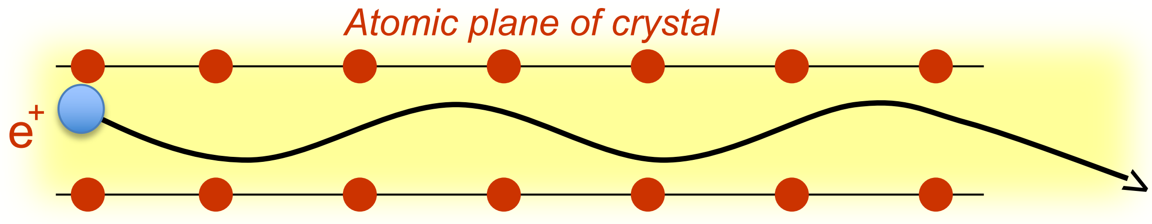
depth evolution

$\Delta t = 81\ nm \div 1.33\ \mu m$



@ channeling of charged particles & channeling radiation

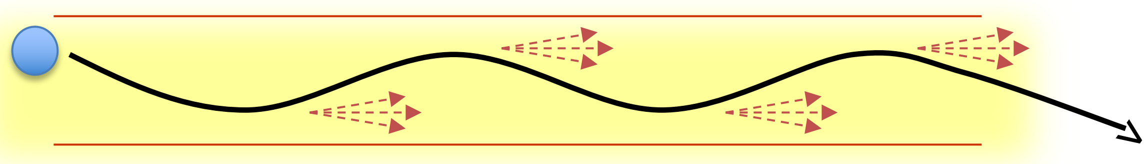
@ Channeling:



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

@ Channeling Radiation (ChR):

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

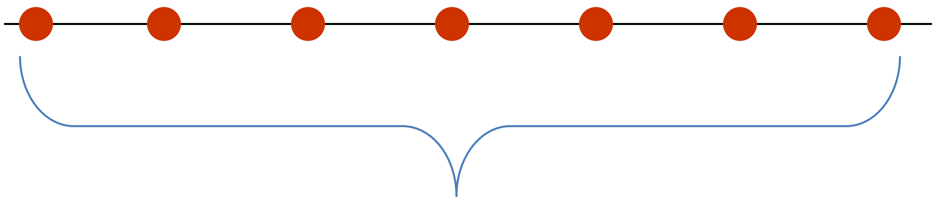


ω_{fi} - *optical frequency* → *Doppler effect* → $\omega_0\gamma^{3/2}$ - $\omega_0\gamma^2$

$(\gamma >> 1)$

Powerful radiation source of X-rays and gamma-rays:
- polarized
- Tunable (keV - MeV)
- narrow forwarded

@ channeling: continuum potential



fast motion -- averaging

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

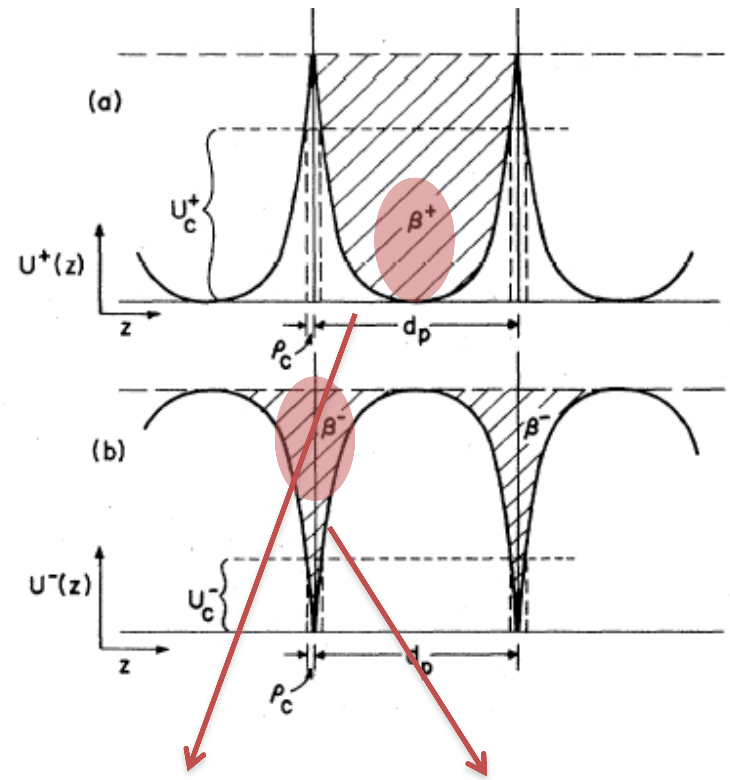
$$a = .8853 a_0 \left(Z_1^{1/2} + Z_2^{1/2}\right)^{-2/3}$$

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

Lindhard:

Continuum model –

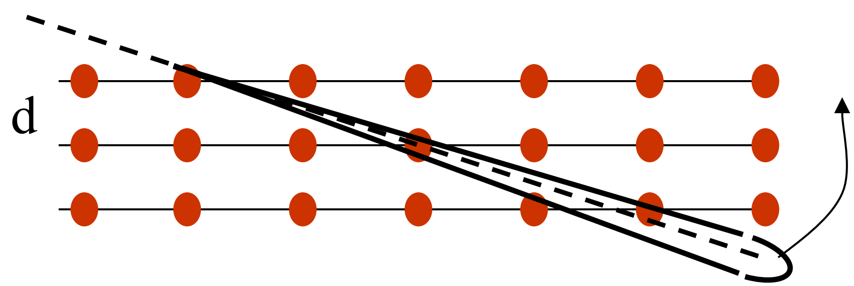
continuum atomic plane/axis potential



$$\left(\frac{\partial U}{\partial x}\right)_{plane} \ll \left(\frac{\partial U}{\partial x}\right)_{axis}$$

@ bremsstrahlung & coherent bremsstrahlung vs channeling radiation

@ crystal: $\alpha \to 0$



Channeling orientation

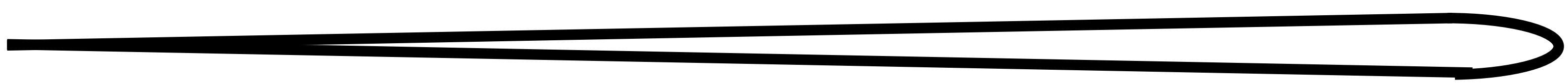
optical

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

X and γ

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

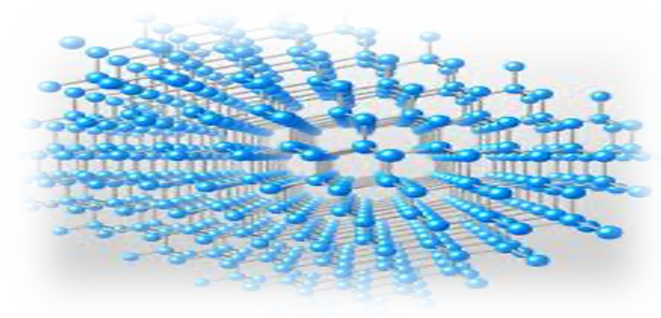
$\frac{ChR}{B} \propto \gamma^{1/2} Z^{-2/3}$ at definite conditions channeling radiation Becomes more powerful than bremsstrahlung



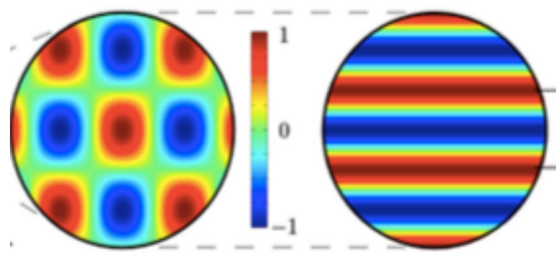
B:	CB:	ChR:
	NZe	$N \leftrightarrow \quad l_{coh} \propto \gamma^2 / \omega \quad N_{eff}$
$\propto NZ^2$	$\propto (NZ)^2$	$\propto (N_{eff} Z)^2$

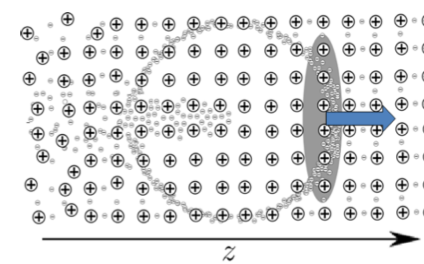
Channeling based applications for Charged Beams: from Crystal to Capillary guides

- **Crystal Channeling**
  - Beam shaping;
  - Micro-undulator;
  - Positron source

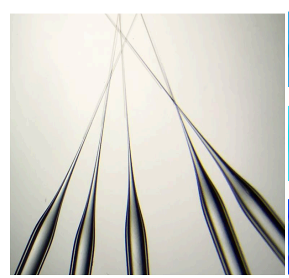


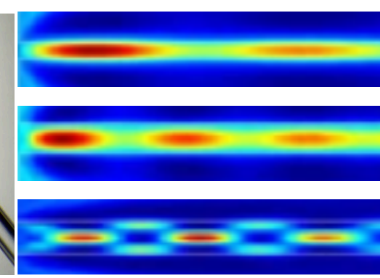
- **Laser & Plasma Channels**
  - Beam profiling for high current/luminosity;
  - Dynamics for wake field acceleration;

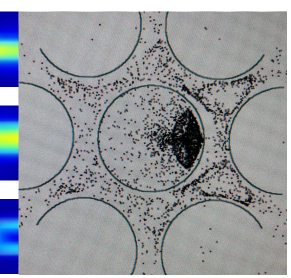




- **Capillary μ- and n-Channels**
  - beam redistribution;
  - Compact storage (?)





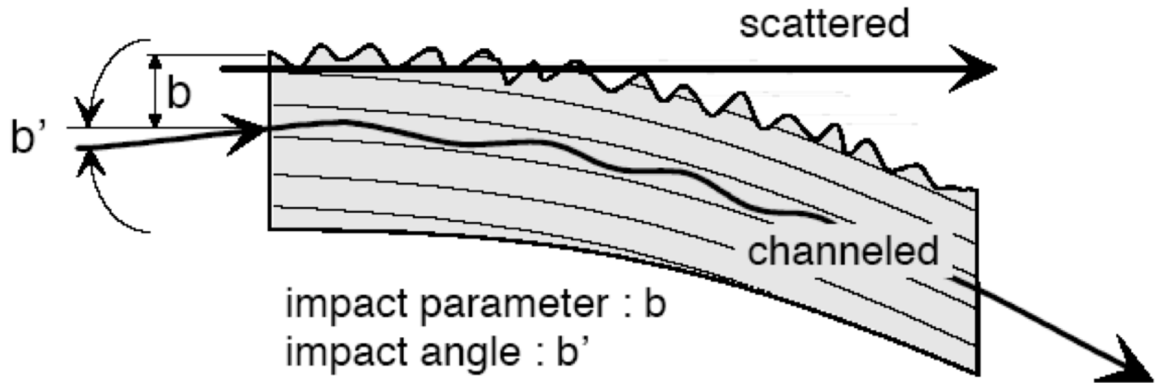


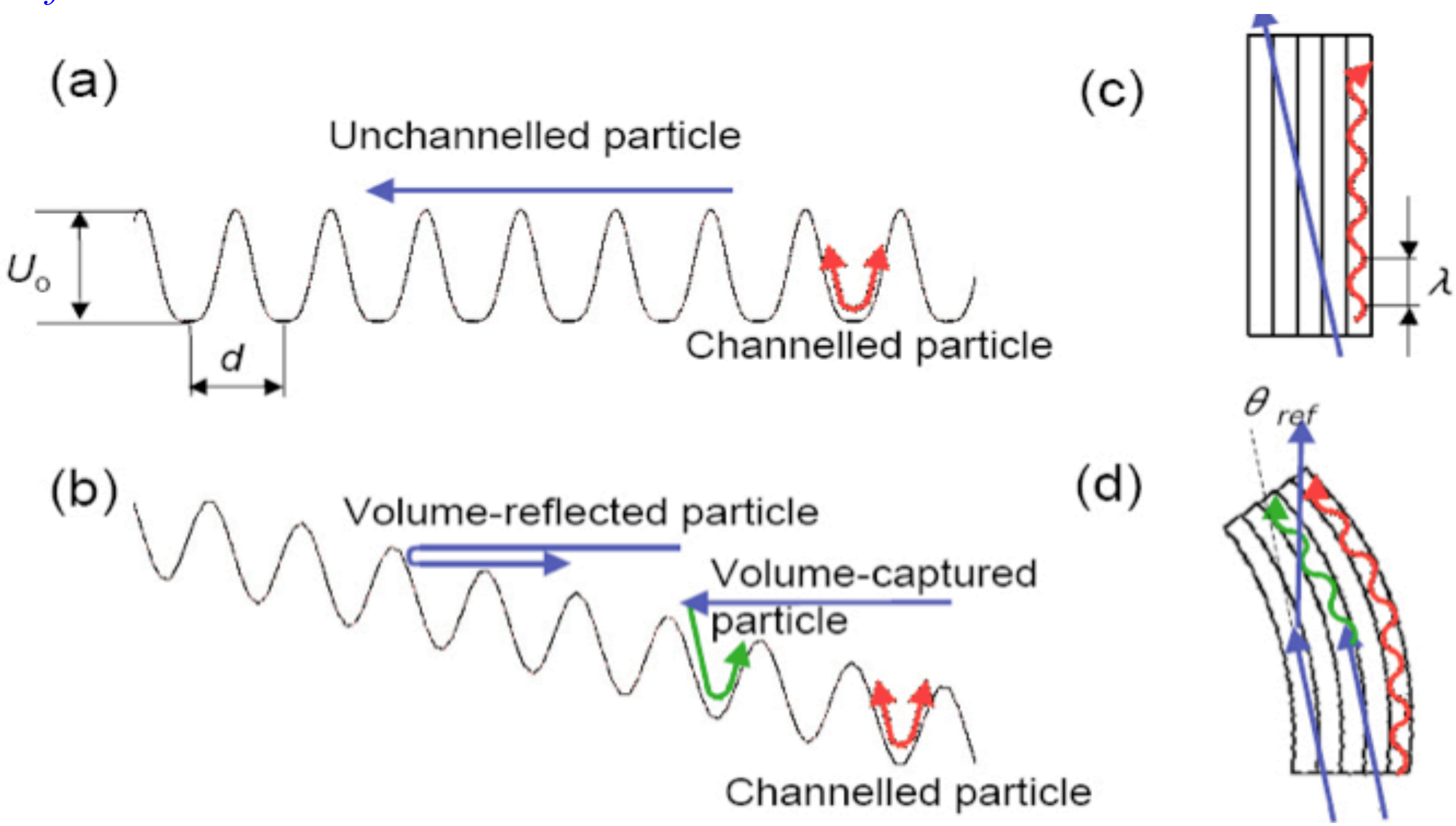
@ Beam Steering & Coherent Radiation

@ beam steering by crystal

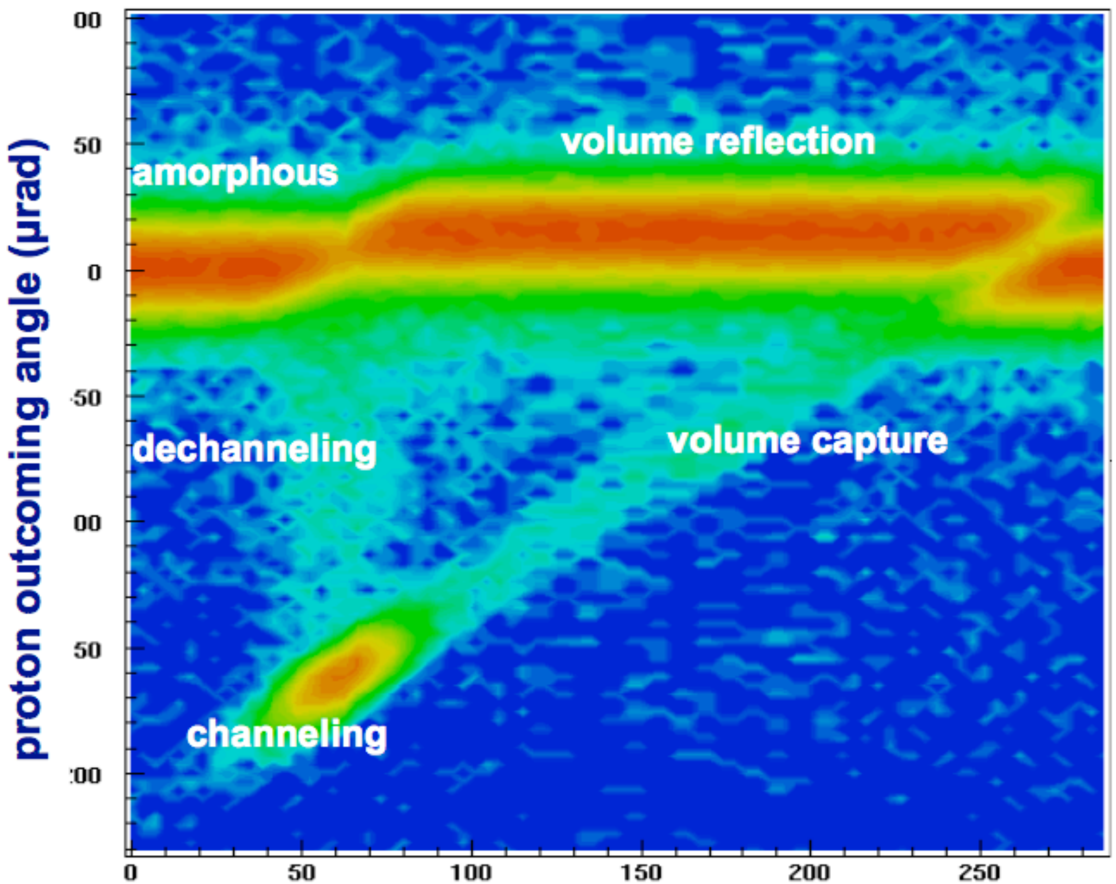
Possible processes:

- multiple scattering
- channeling
- volume capture
- de-channeling
- *volume reflection*

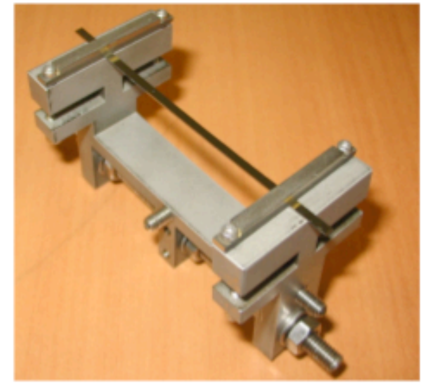




@ first observation: 400 GeV/c CERN



Single strip crystal



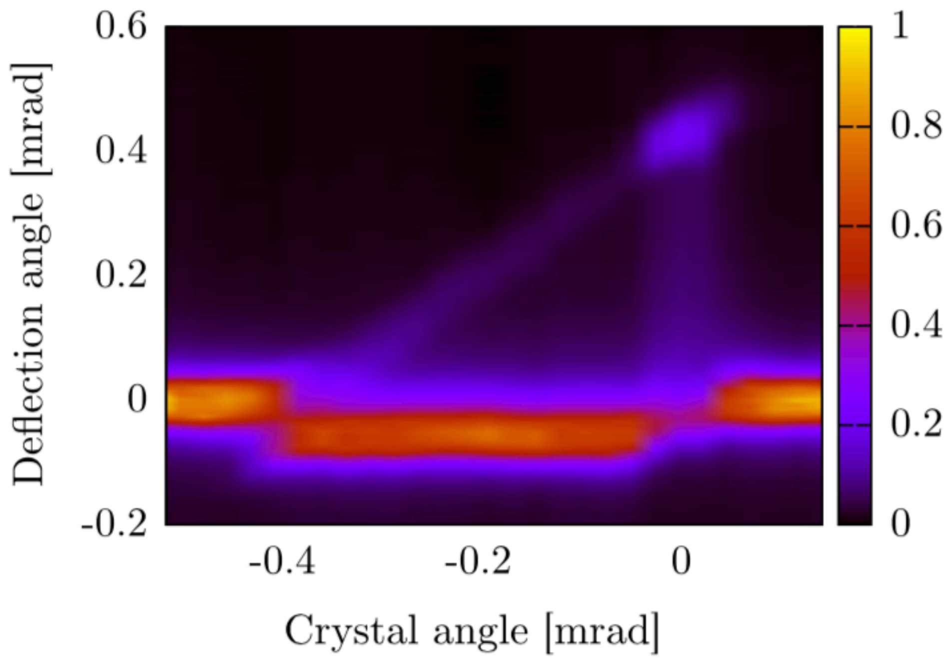
- ***First measurement*** **of the volume reflection effect with a proton beam of 400 GeV/c**

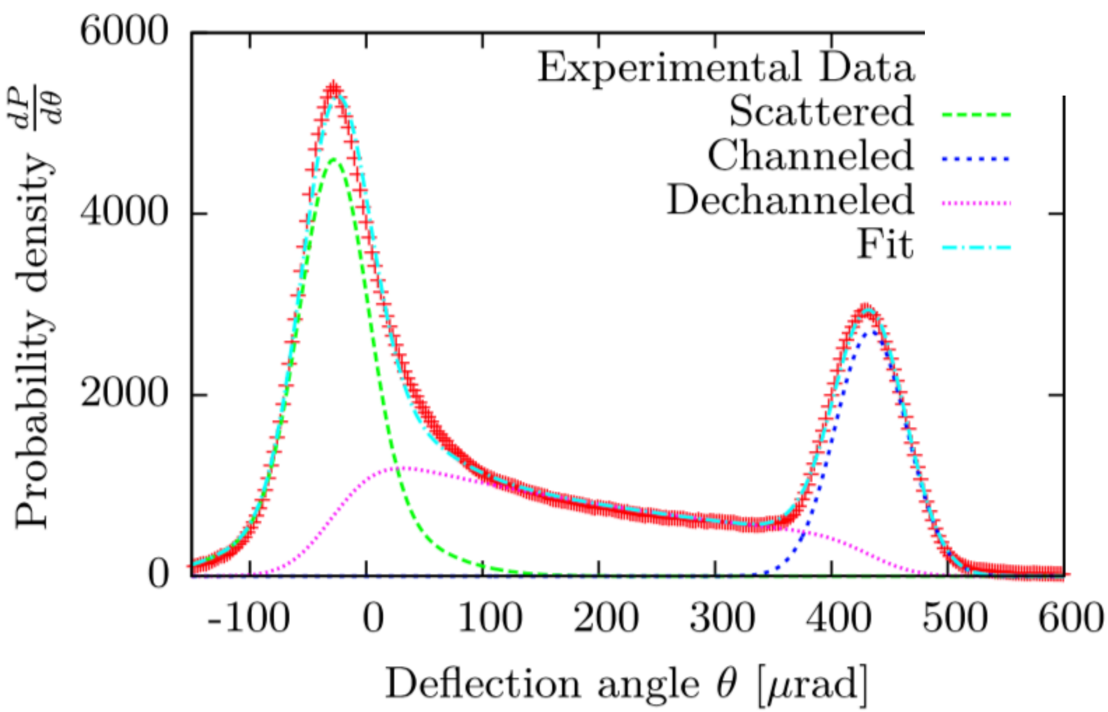
EFFICIENCY	VALUE
VOLUME REFLECTION	98.2 ± 0.1%
CHANNELING	51.2 ± 0.7%
VOLUME CAPTURE	1.3 ± 0.1%
DECHANNELING	5.0 ± 0.4%

Multi-strip technique is under strong investigation /several assembled crystals/

@ ultra-high γ beam steering: 10.5 GeV e⁻ SLAC

Deflected beam angular distribution





Distribution at channeling orientation

Spin precession in bent crystals

- Firstly predicted by **Baryshevsky** (1979)

V.G. Baryshevsky, Pis'ma Zh. Tekh. Fiz. 5 (1979) 182.

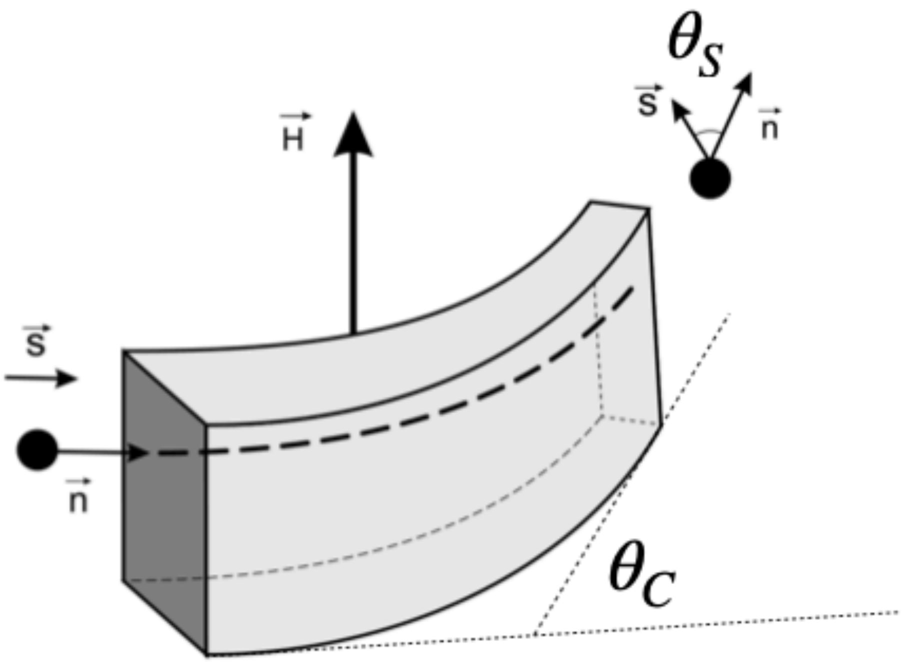


Fig. 1. Spin rotation in a bent crystal.

- Determine particle gyromagnetic factor from BMT equation

V.L. Lyuboshits, Sov. J. Nucl. Phys. 31 (1980) 509.

$$\theta_S = \frac{g-2}{2}\gamma\theta_C$$

θ_S = spin rotation angle

θ_C = crystal bending angle

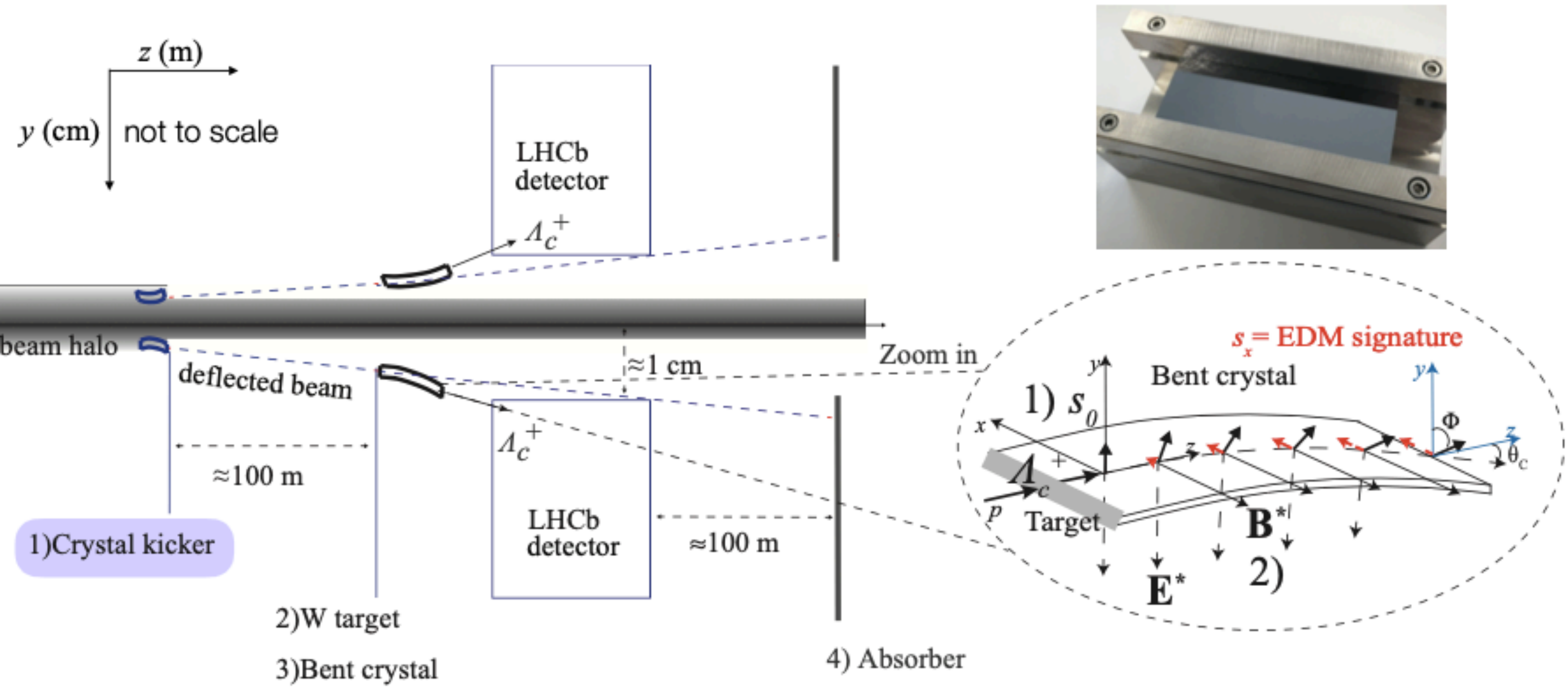
g = gyromagnetic factor

γ = Lorentz boost

Courtesy of Neri

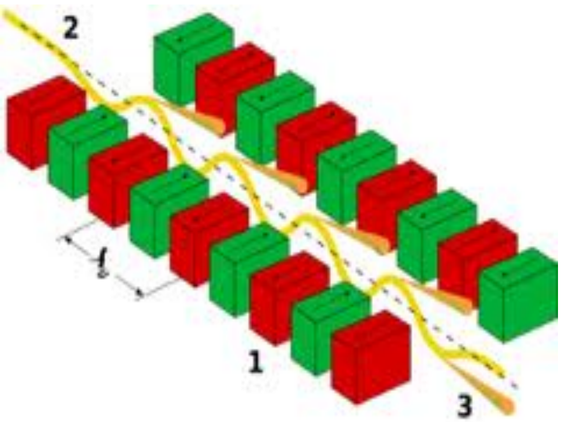
Novel fixed-target experiment at LHC for charm baryons

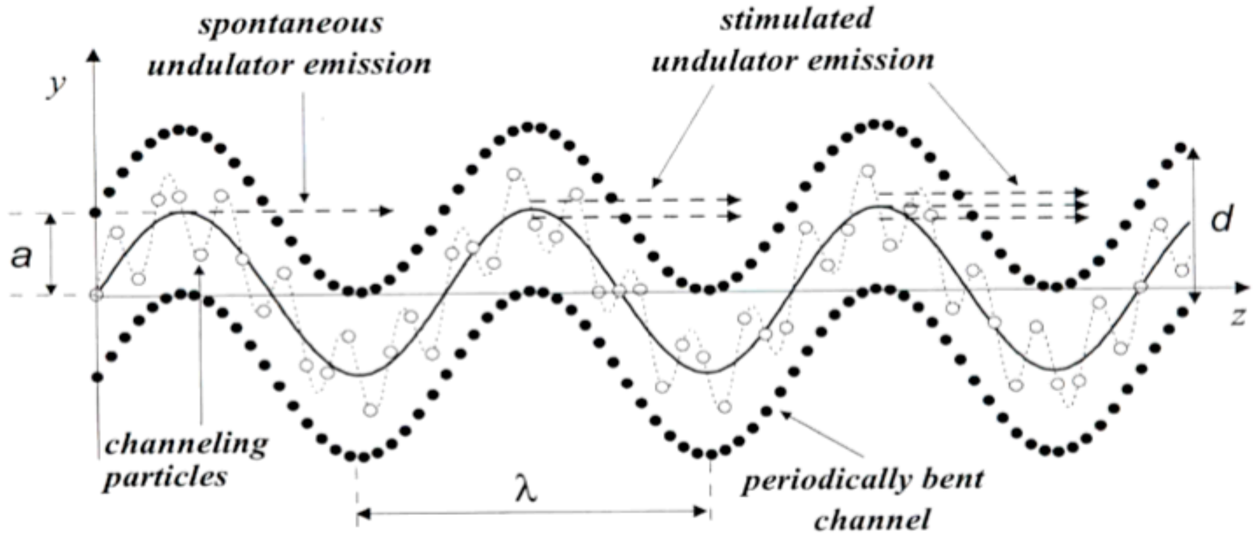
- EDM/MDM from spin precession of channeled baryons in **bent crystals**



Courtesy of Neri

@ crystal/crystalline undulator - i



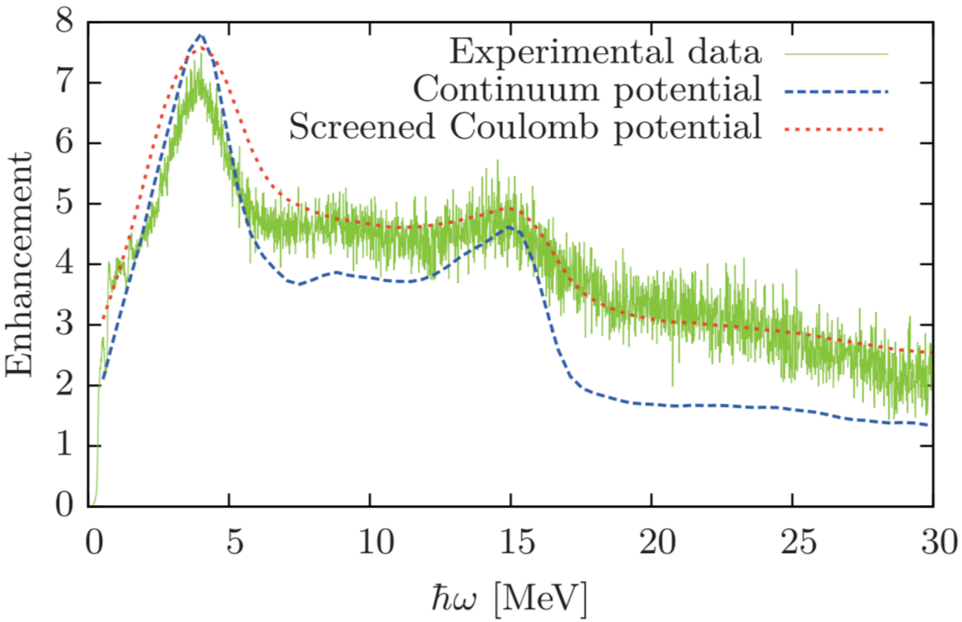


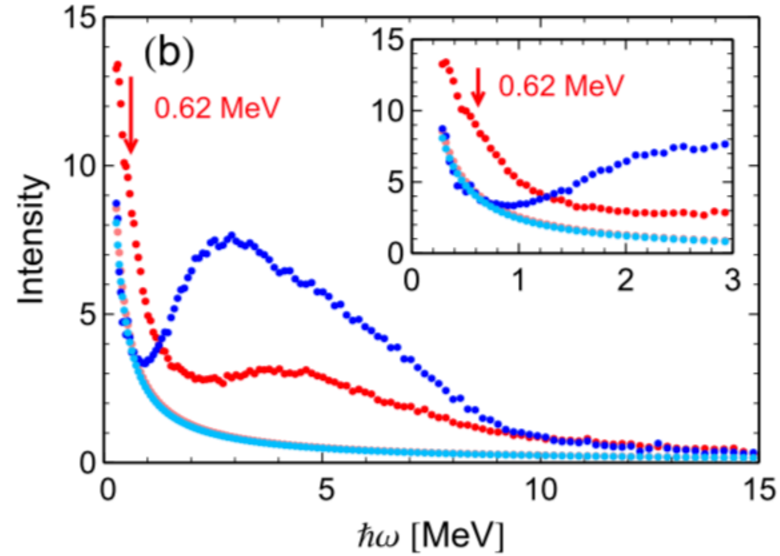
SCALE FACTOR – several orders more compact!

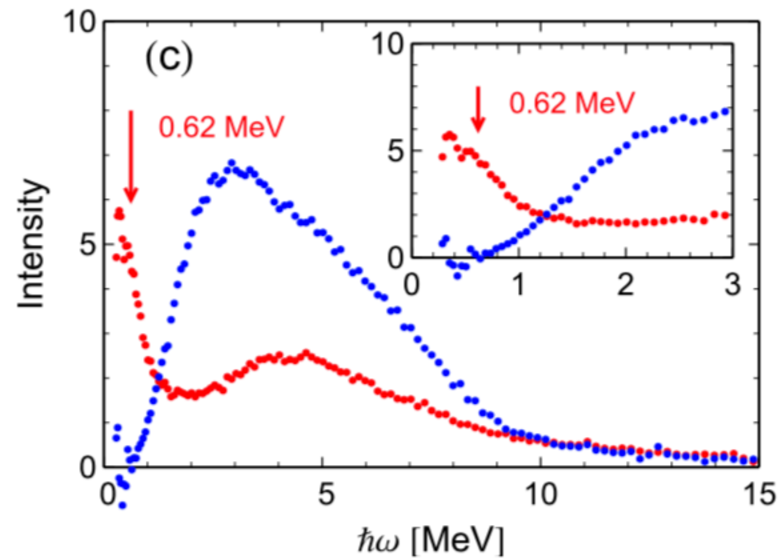
- A Crystalline Undulator may play the same role as a conventional magnetic undulator.
- It can be built with millimetric-submillimetric period, increasing the energy of radiated photons than in a magnetic undulator with the same beam energy.
- An operating CU could produce highly monochromatic X- and γ-ray beam, with energies up to 1 MeV or higher.

H2020-RISE PEARL (2016-2020)
(consortium with several institute that work in the subject of radiation in oriented crystals such as ESRF, MAMI, INP MINSK, AARHUS, INFN & UNIFE)

@ crystal/crystalline undulator - ii



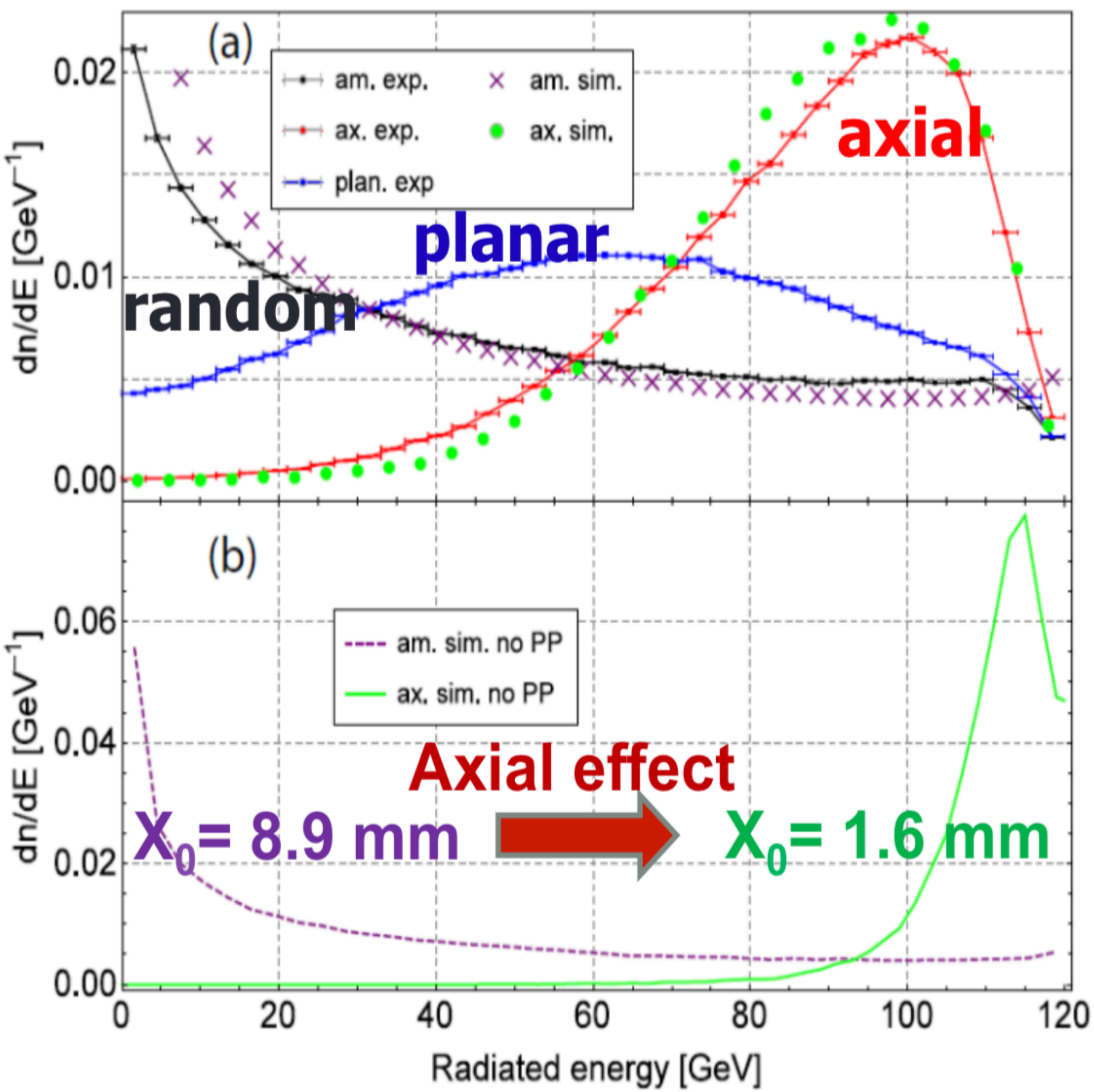




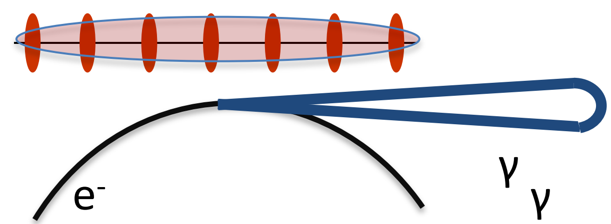
A comparison of the theoretical and experimental results for 855 MeV electrons penetrating a 10-period crystalline undulator with period 0.4 μm and planar oscillation amplitude 0.12 Å.

$Si_{1-x}Ge_x$ undulator //
4-period with a period length 9.9 μm

@ strong radiation regime at channeling: 120 GeV e^- CERN



PWO –
lead tungstate $PbWO_4$ crystal
4 mm



- Synchrotron-like radiation at channeling

$\gamma \gg 1 \rightarrow \Sigma N \rightarrow N_{eff} \gg N$
scattering by "single atom"

- Strong reduction of radiation length

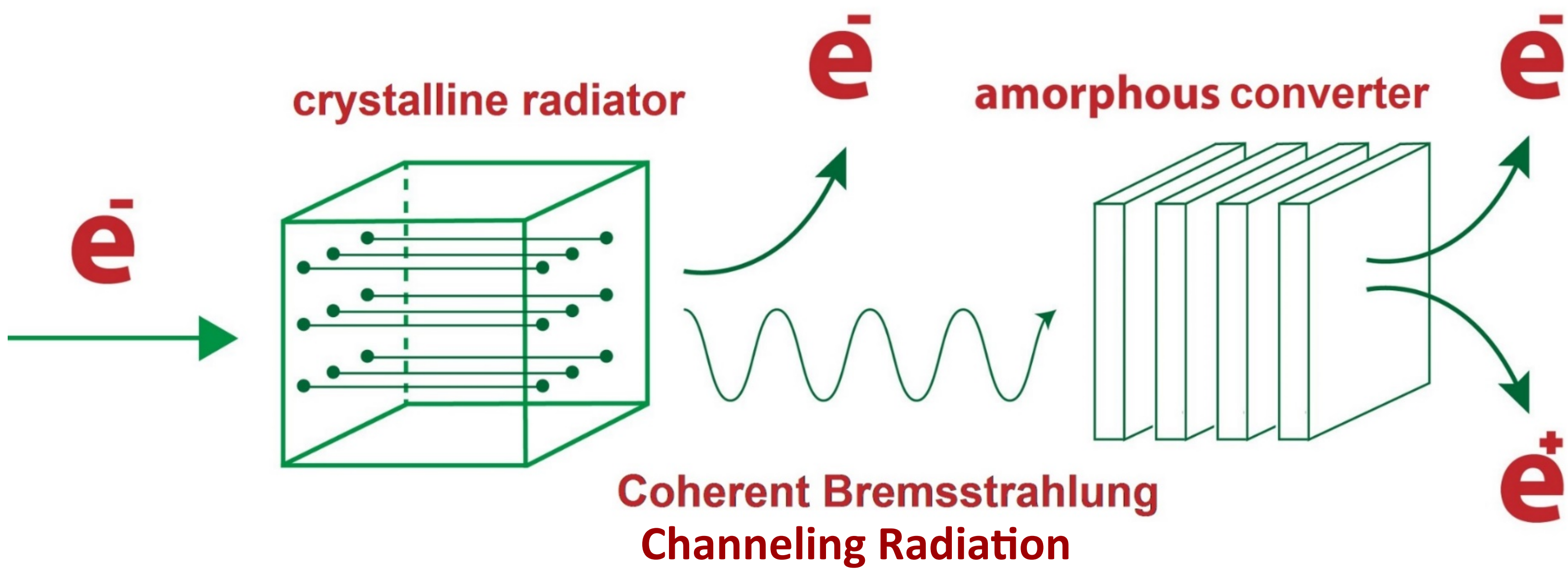
Courtesy of Bandiera

@ hybrid scheme for crystal based positron source

- **Undulator+converter**
- **The scheme of hybrid positron source using CR or CB from primary electron beam**

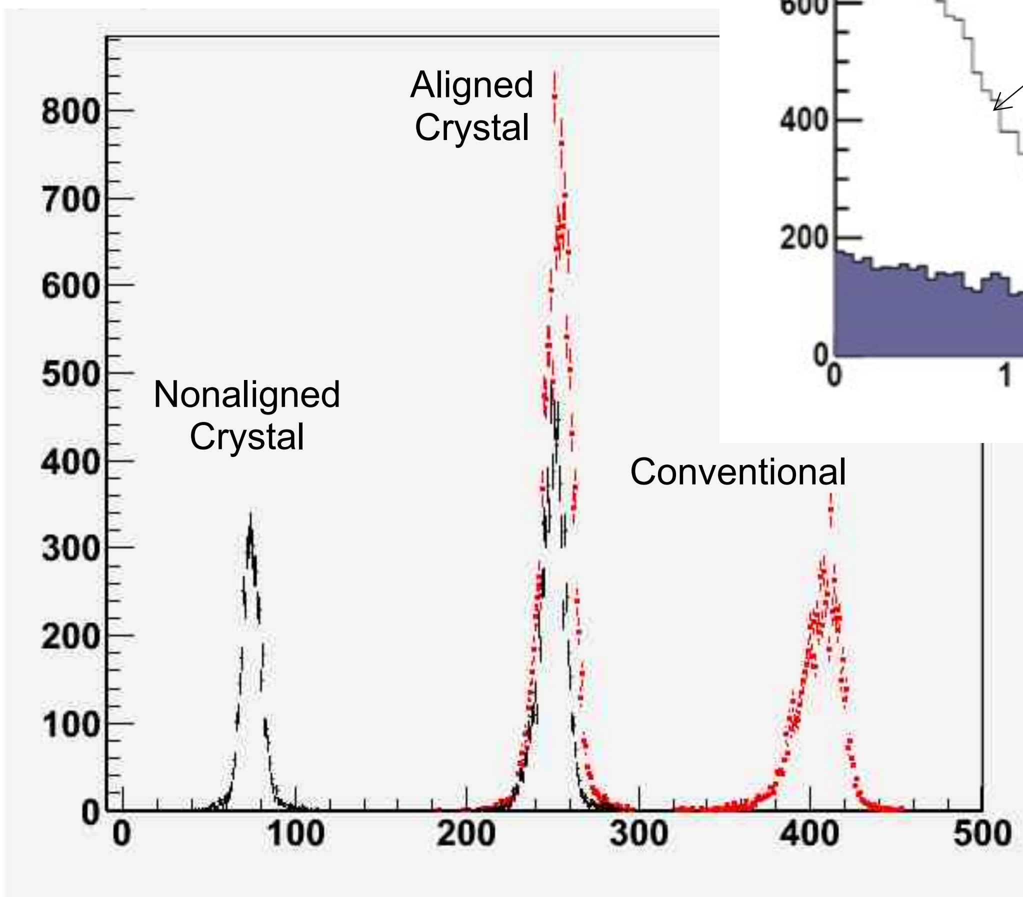
Channeling Radiation – efficient for sub GeV – essential increase for higher electron energy **200 MeV – and higher**

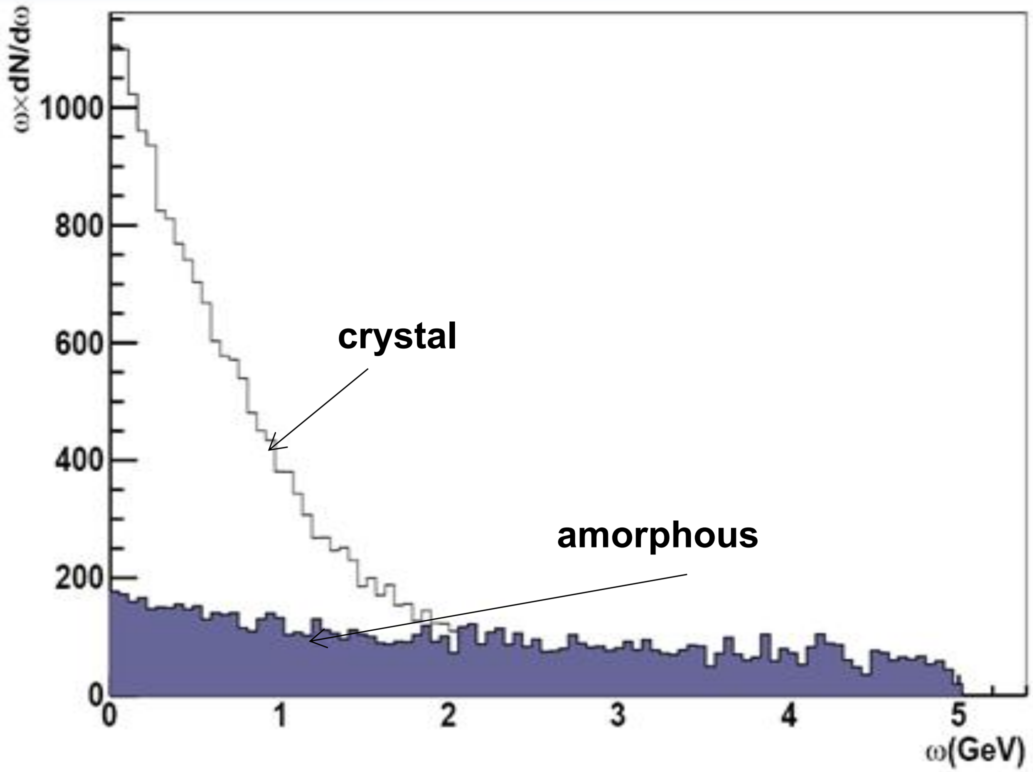
Coherent Bremsstrahlung – efficient even for MeV energies **10 – 100 MeV**



@ channeling radiation at axial e- channeling in W

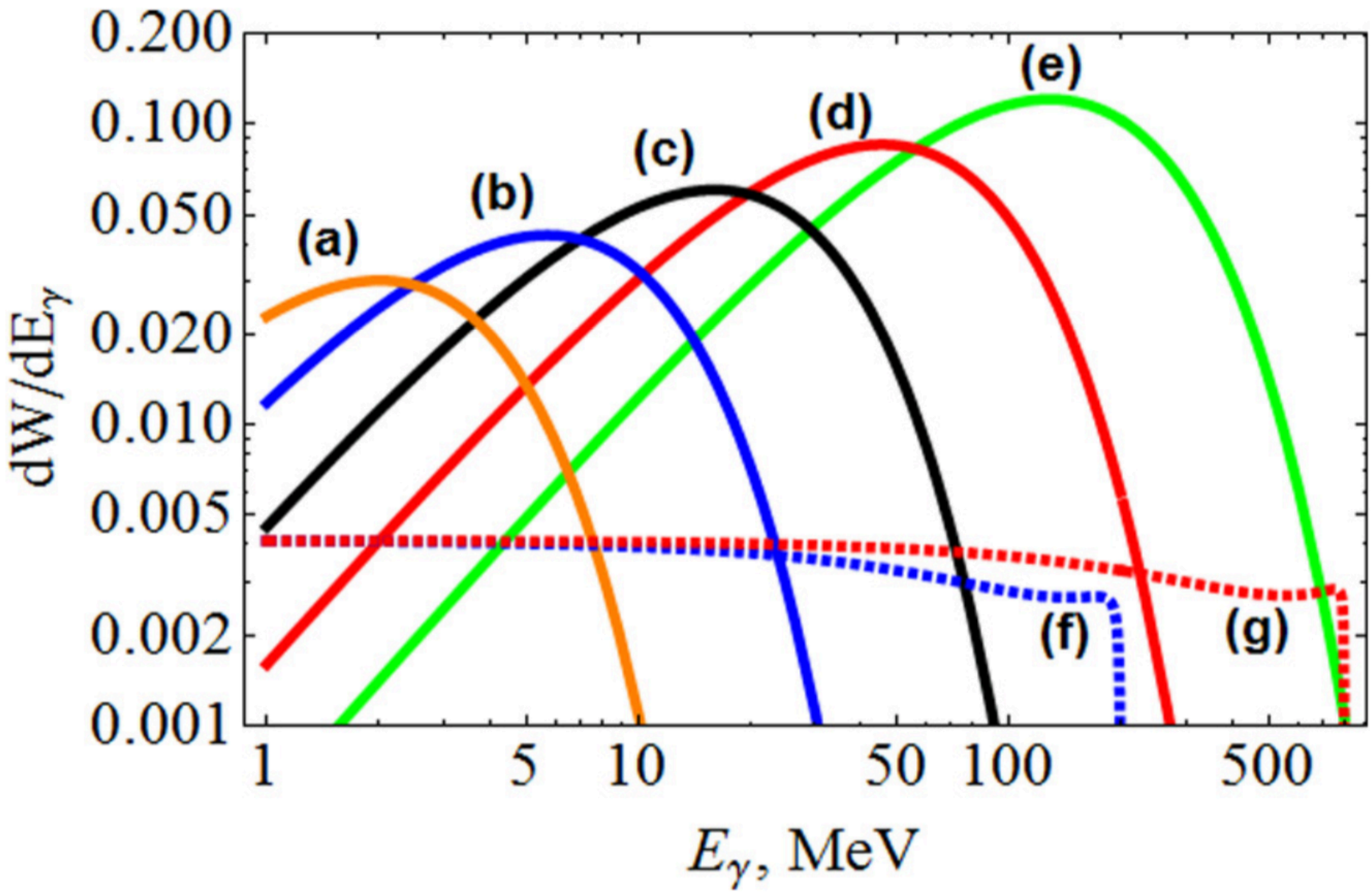
e+ yield for aligned
and misaligned crystals





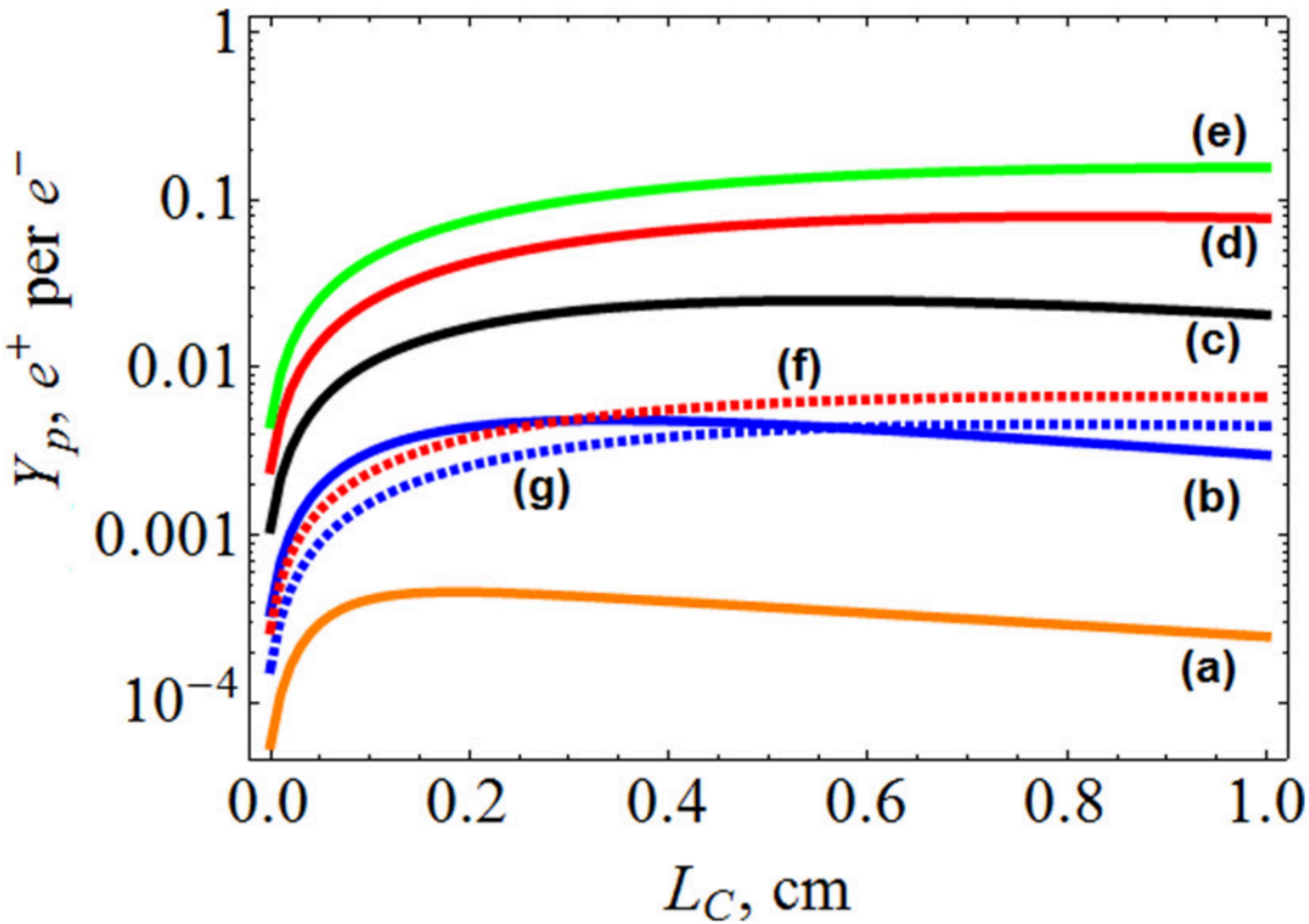
intensity of γ-ChR becomes much higher over B with primary e^- energy increase

@ channeling radiation vs bremsstrahlung



<1 0 0> axial channeling radiation energy spectra (dW/dEc) from (a) 0.1 GeV, (b) 0.2 GeV, (c) 0.4 GeV, (d) 0.8 GeV and (e) 1.6 GeV electrons and energy spectra of bremsstrahlung from (f) 0.2 GeV and (g) 0.8 GeV electrons in L = 10 mm W.

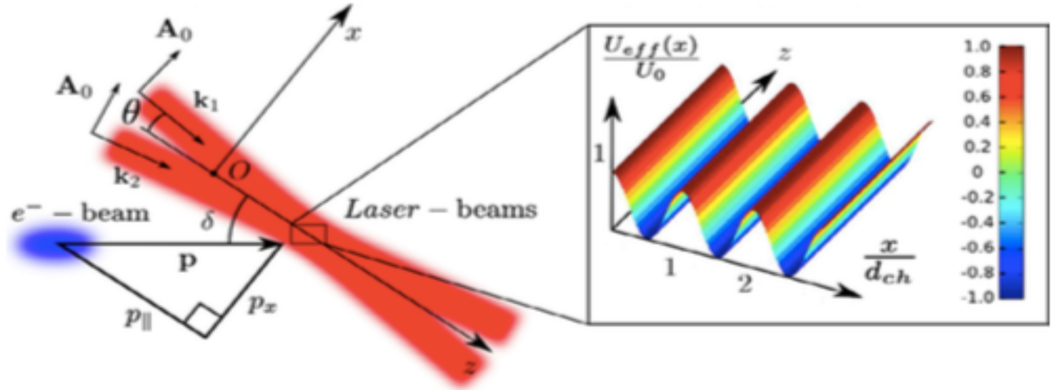
@ total yield of e^+ per e^-



Total yield of positrons Yp (e+ per e%) produced by the <100> CR from (a) 0.1GeV, (b) 0.2GeV, (c) 0.4GeV, (d) 0.8GeV and (e) 1.6GeV electrons and bremsstrahlung from (f) 0.2 GeV and (g) 0.8 GeV electrons in L = 10 mm W as the function of Lc – the W converter thickness (cm).

@ Laser Channels → Optical Lattice

@ channeling in OL



Equation for slow motion particle wave function

$$i\hbar\frac{\partial\bar{\psi}}{\partial t}=\left(-\frac{\hbar^2}{2\gamma_{\|}m}\nabla^2+U_{eff}\right)\bar{\psi}$$

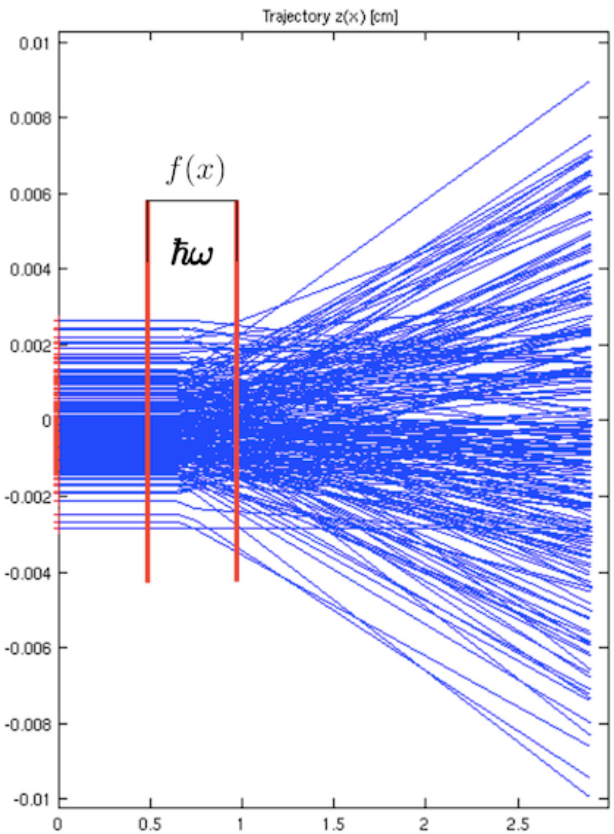
Effective potential[1]

$$U_{eff}=\frac{e^2A_2^2}{4\gamma_{\|}mc^2}-\frac{\hbar^2}{2\gamma_{\|}m}\overline{(\nabla\ln\chi)^2}-\frac{i\hbar e}{\gamma_{\|}mc}\overline{(\mathbf{A},\nabla\ln\chi)}+$$

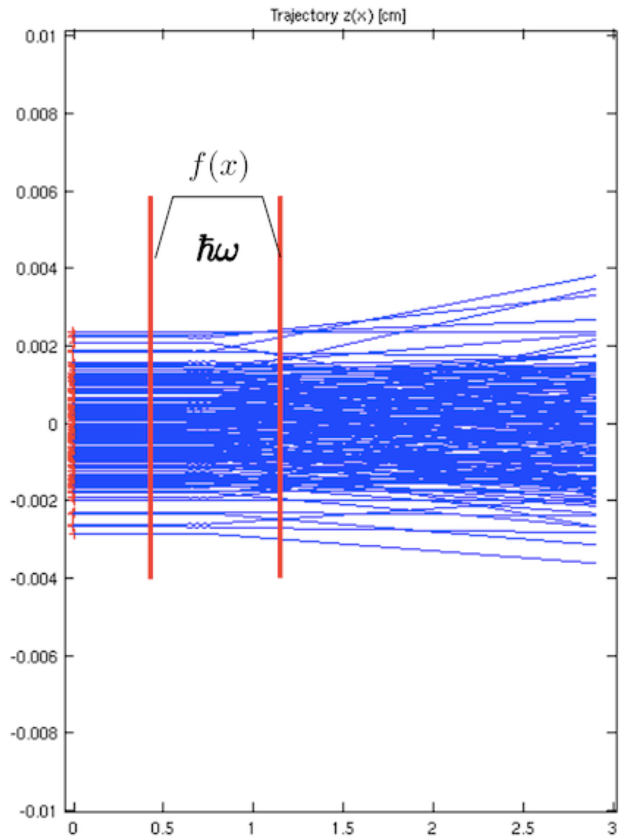
$$+\frac{\hbar^2}{2\gamma_{\|}mc^2}\left[\overline{\left(\frac{\partial}{\partial t}\ln\chi\right)^2}-2\beta_{\|}c\overline{\frac{\partial}{\partial t}\ln\chi\frac{\partial}{\partial\zeta}\ln\chi}+\beta_{\|}^2c^2\overline{\left(\frac{\partial}{\partial\zeta}\ln\chi\right)^2}\right]$$

here $\zeta=z-\beta_{\|}ct$, $\omega=\omega_0-\beta_{\|}k_z$ - oscillation frequency of χ, A_2 - slowly changing term of the field $\mathbf{A}$, U_{eff} - complex function, $\mathrm{Im}U_{eff}\sim\frac{e^2A^2}{(\gamma_{\|}mc^2)^2}\left(\nabla\bar{\psi}\right)^2$

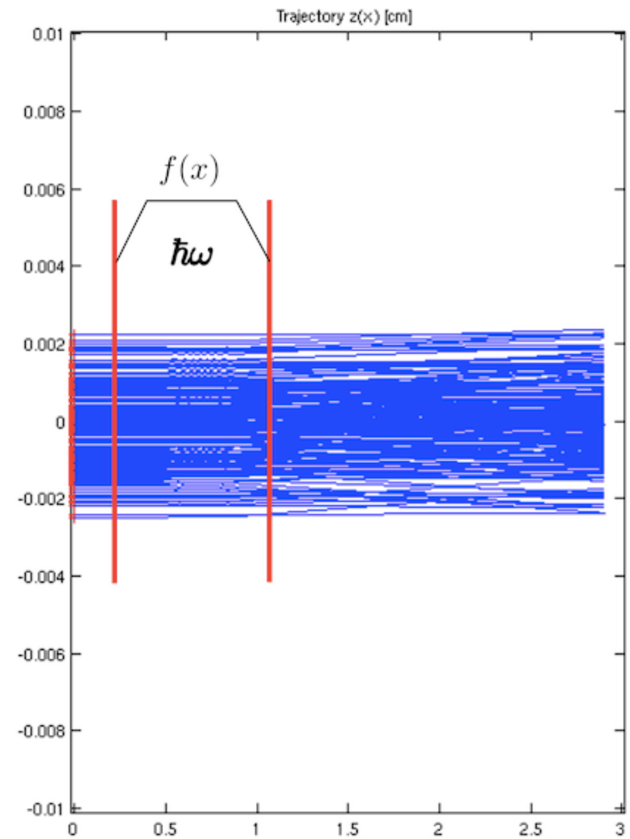
@ optical lattice time structure for beam profiling



Scattering - defocusing

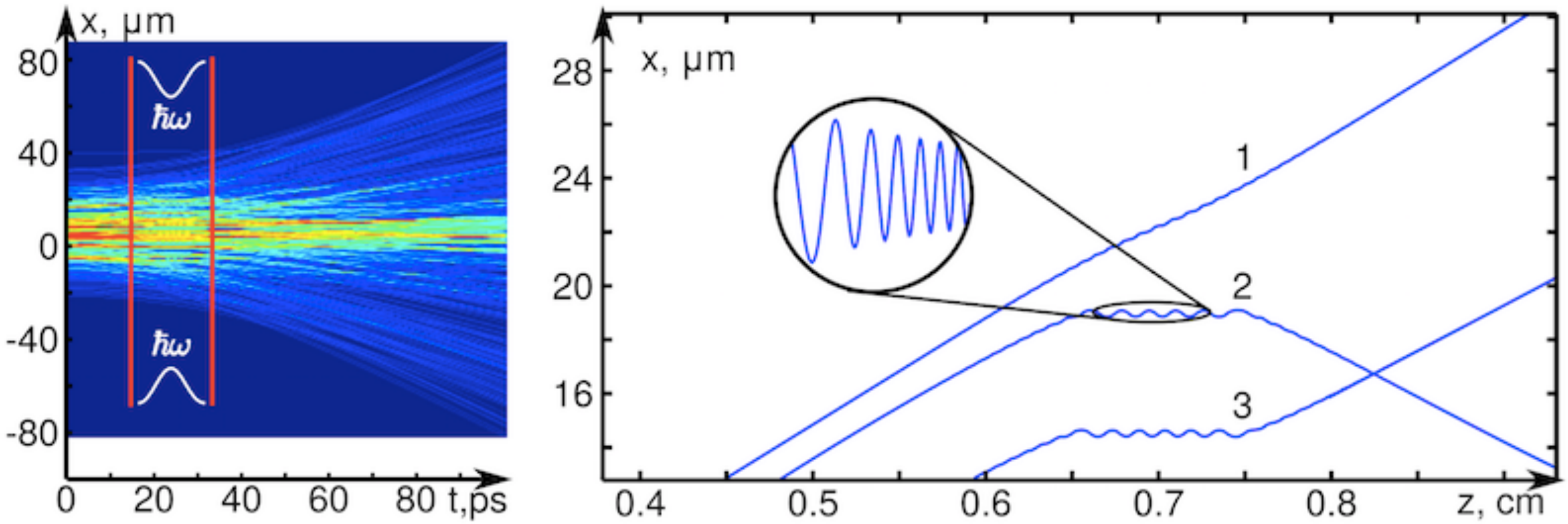


Focusing



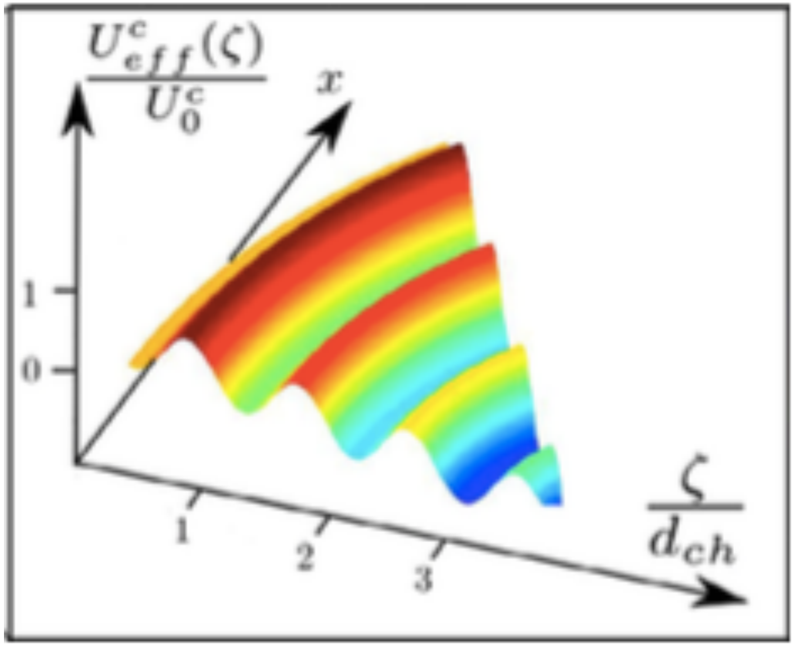
Condensing

@ beam flux-peaking vs space charge



Numerical simulations (presented above) show that 0.8 pC 1.9 MeV Gaussian electron beam with zero initial divergence might be partially trapped by optical lattice, formed by two counter propagating laser beams with electrical field intensity 10^5 CGS units each. The laser beams have Gaussian transverse profile with σ_z=1mm and are positioned at 23 ps from initial beam position. Density color plot of the beam passing through optical lattice (left) depicts particle distribution over time. While the majority of electrons was trapped by optical lattice potential channel, there were some with transverse energy big enough to escape from it

@ effective potential of curved laser channels



$$\rho_{cr} = \frac{4(m\bar{\gamma}c^2)^2}{e^2 A_0^2 k\psi} \approx 1.6 \cdot 10^{-8} \left(\frac{m\bar{\gamma}c^2}{e}\right)^2 \frac{\omega_0}{\psi I}$$

critical radius for e- steering in curved laser field

$$U^c_{eff}(\bar{\zeta}) = \frac{e^2 A_0^2}{8mc^2\bar{\gamma}} \cos\left(2k\psi\bar{\zeta}\right) - \frac{\bar{\gamma} m v_0^2 \bar{\zeta}}{\rho_0}$$

effective potential of curved laser channel

@ radiation features

The photon radiated frequency of spontaneous particle transition from state (σ_i ,n_i) to state (σ_f ,n_f) has the same form as in classical description (σ,n-quantum number of channeling motion and number of absorbed photons) :

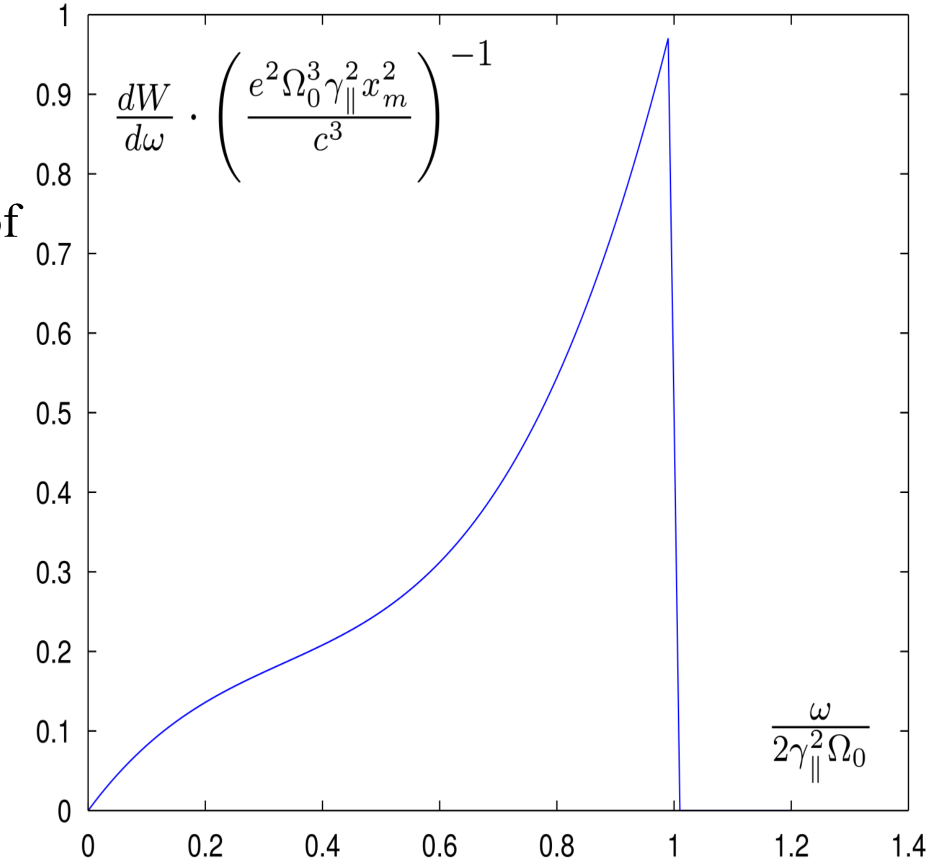
$$\omega_\lambda = \frac{(n_i - n_f)\omega_1}{1 - \beta_\parallel \cos\theta} + \frac{(\sigma_i - \sigma_f)\Omega_0}{1 - \beta_\parallel \cos\theta}$$

$$\omega_1 = \omega_0(1 - \beta_\parallel \sin\alpha)$$

Frequency of small fast oscillation of classical particle

$$\omega_\lambda = \frac{(\sigma_i - \sigma_f)\Omega_0}{1 - \beta_\parallel \cos\theta}, \quad n_i = n_f$$

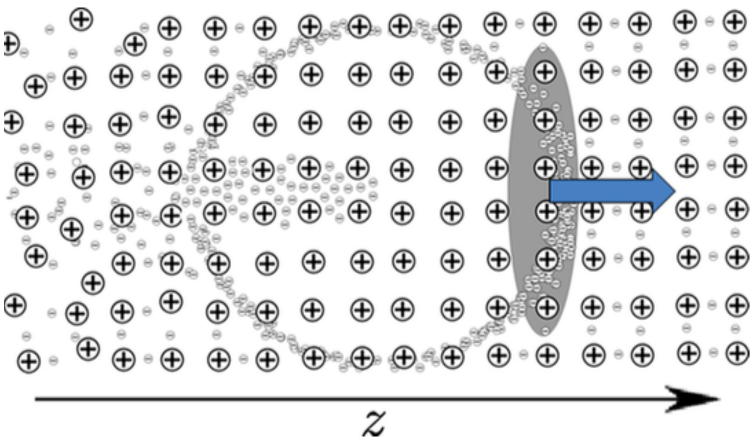
Channeling radiation frequency



Channeling radiation spectra has the same form as a classical particle in dipole approximation

classical $\longrightarrow$ $x_m^2 = \hbar\sigma/(2\gamma_\parallel m\Omega_0)$ $\longleftarrow$ quantum

@ laser based plasma channel: i



buble propagates creating behind a positively charged channel

$$\frac{dp_z}{dt} \approx -2\pi e^2 n_0 (z - v_l t),$$

$$\frac{d\mathbf{p}_\perp}{dt} \approx -2\pi e^2 n_0 \mathbf{r}_\perp,$$

$$\begin{cases} \mathbf{A} \approx 0, \\ \varphi = -\pi n_0 e r_\perp^2 \end{cases}$$

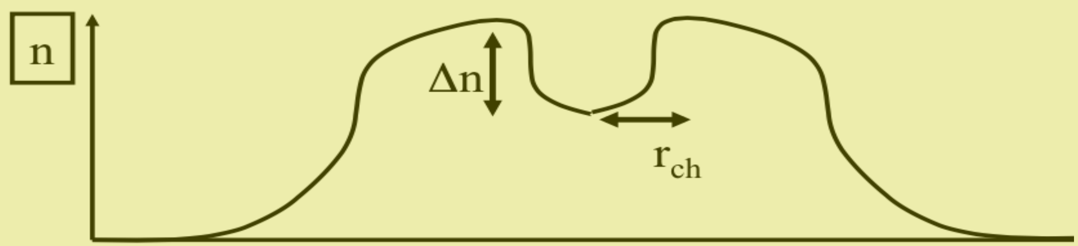
for an infinite cylindrical channel containing 'frozen' ions

relativistic electron motion

down to the ion channel

$$H = E_z + \frac{c^2 p_\perp^2}{2E_z} - e\varphi$$

$$E_z = c\sqrt{p_z^2 + m^2 c^2}$$



$$w_0 = \left[r_{ch}^2 / (\pi r_e \Delta n) \right]^{1/4}; \quad r_e = e^2 / mc^2$$

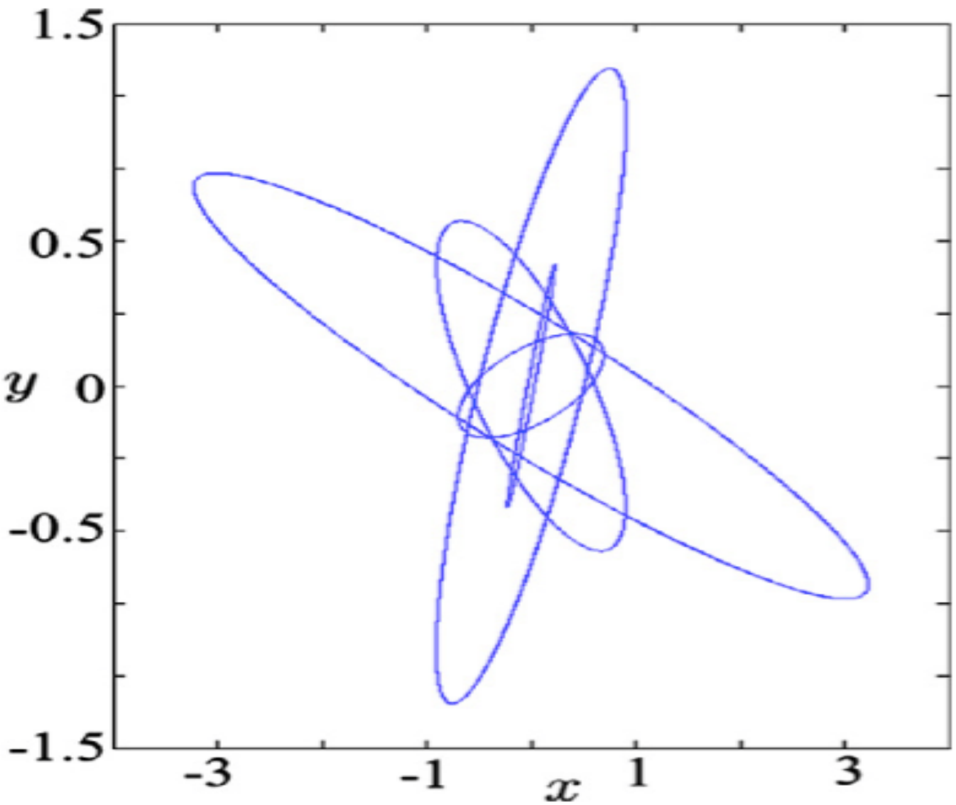
@ laser based plasma channel: ii

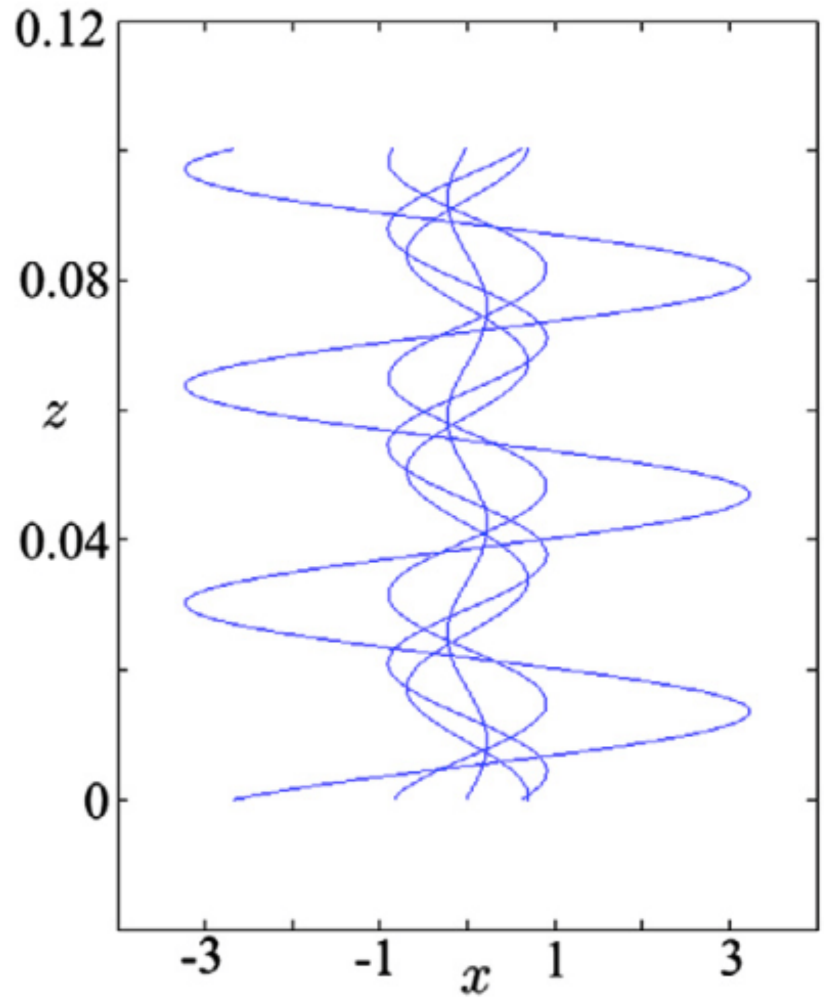
...channeling method simplifies calculations...

trajectory of a plasma channeled particle

$$z(t) = at + b\sin(2\omega_0 t + \alpha), \quad \mathbf{r}_\perp(t) = \mathbf{r}_0\cos(\omega_0 t) + \mathbf{v}_0\sin(\omega_0 t)/\omega_0$$

$$\omega_0^2 = \frac{2\pi e^2 n_0 c^2}{E_z}$$



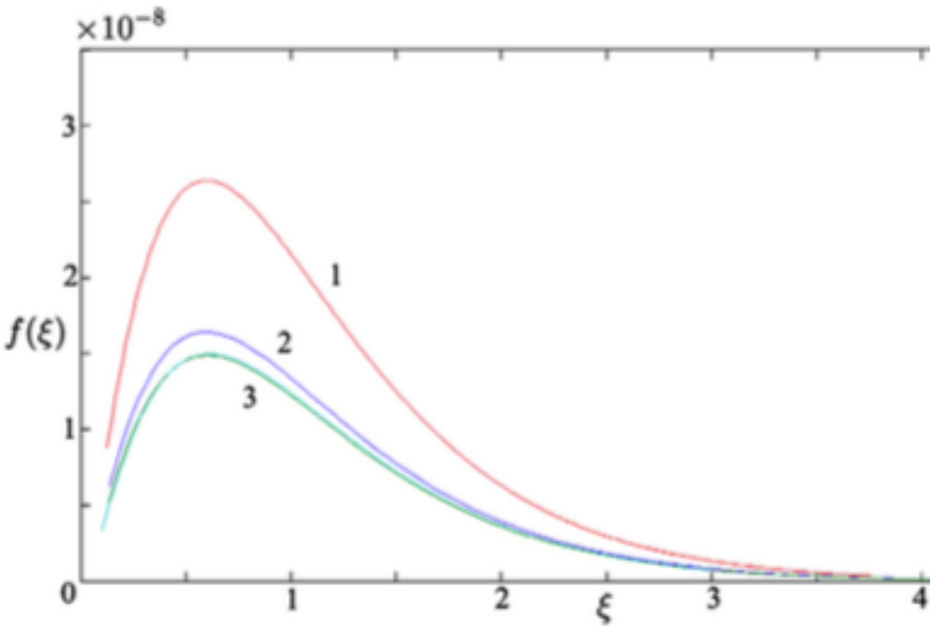


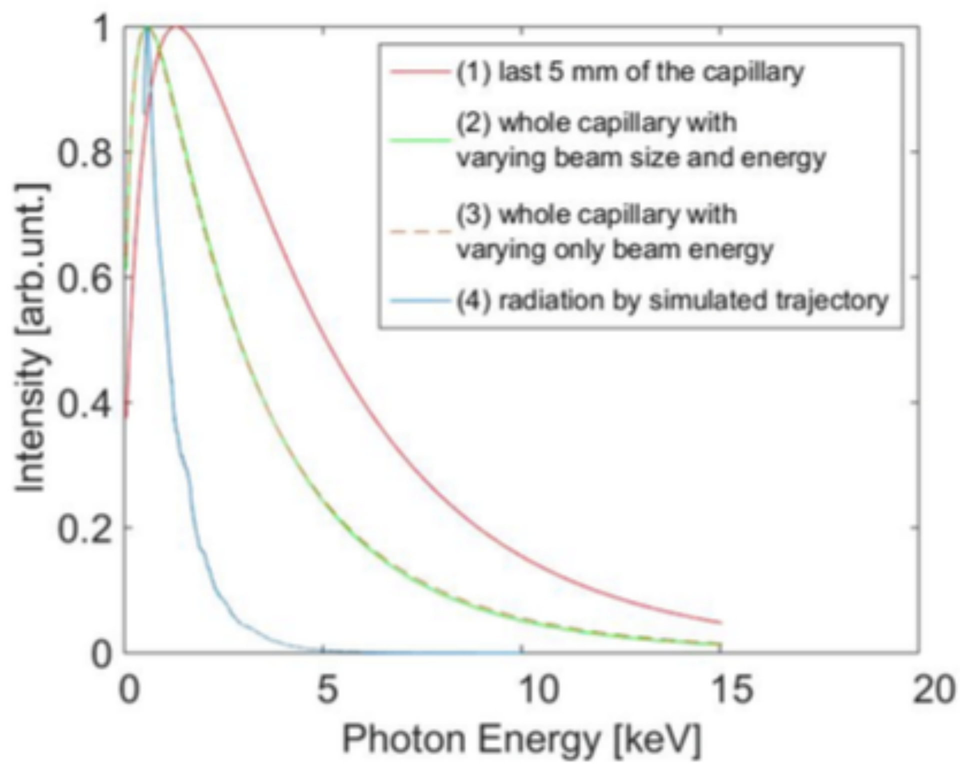
@ laser based plasma channel: radiation

$$\frac{dI(\theta=0)}{d\omega} = \frac{e^2\gamma_z^4\omega'^2}{3\pi^3 c\omega_0}\left(\frac{3\omega_0}{\omega'}\right)^{2/3} f\left(\frac{\omega}{\omega'}\right),$$

$$f(\xi) = \xi^2\left((2a_1+a_2)\left(K_{1/3}(\xi) - \left(\frac{3\omega_0}{\omega'}\right)^{1/3} K_{2/3}(\xi)\right)K_{1/3}(\xi) + a_1\left(\frac{3\omega_0}{\omega'}\right)^{2/3} K_{2/3}^2(\xi)\right),$$

$$a_1 = \frac{r_0^2\omega_0^2 + v_0^2}{4c^2}, \quad a_2 = \frac{r_0^2\omega_0^2 - v_0^2}{2c^2}\cos\alpha + \frac{\omega_0(\mathbf{r}_0,\mathbf{v}_0)}{c^2}\sin\alpha, \quad \omega' = 3\gamma_z^3\omega_0\sqrt{a_1},$$





@ Capillary Micro- & NanoChannels

@ e^- channeling in a capillary

$$i\hbar\frac{\partial\Psi(\mathbf{R},t)}{\partial t}=\left(\hat{H}^0+\hat{V}_{ip}-e^2\int\rho_e(\mathbf{r},t)G\left(\mathbf{R}-\mathbf{r}\right)d^3r\right)\Psi(\mathbf{R},t)$$

$$G\left(\mathbf{r}\right)=\int\tilde{G}\left(\mathbf{r}_\perp,q_z\right)e^{iq_zz}dq_z$$

Green function for a capillary

$$\tilde{G}\left(\mathbf{r}_\perp,q_z\right)=4\pi\begin{cases}\frac{1}{(2\pi)^2}\ln|\mathbf{r}_\perp|, & q_z=0\\ \frac{\pi}{|q_z|}e^{-|q_z||\mathbf{r}_\perp|}, & q_z\neq 0\end{cases}$$

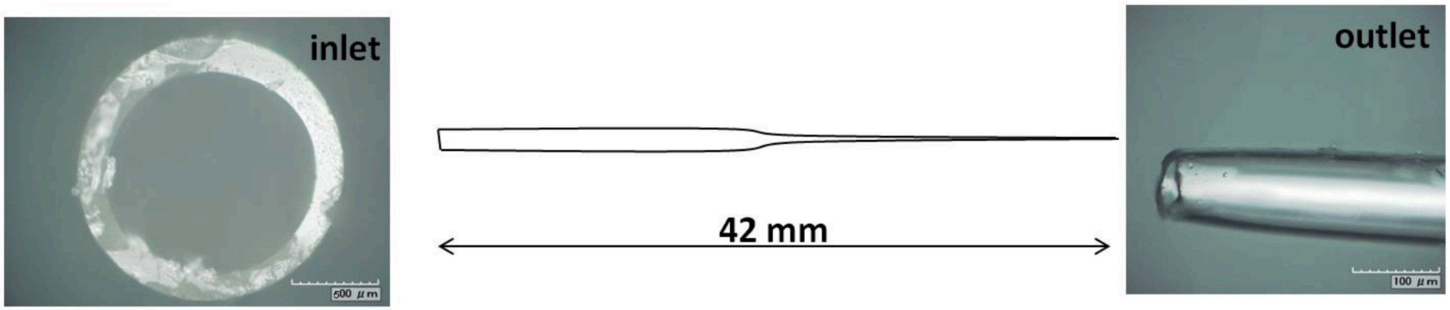
$$\bar{V}\left(R_\perp\right)=-AR_0\frac{e^2}{2\pi}\int_0^{2\pi}\tilde{G}\left(\mathbf{R}_\perp,\mathbf{R}_0\right)d\phi=$$

$$=-AR_0\frac{e^2}{2\pi}\ln\left(\frac{R_\perp^2+R_0^2+\sqrt{(R_\perp^2+R_0^2)^2-4R_\perp^2R_0^2}}{2R_0^2}\right)$$

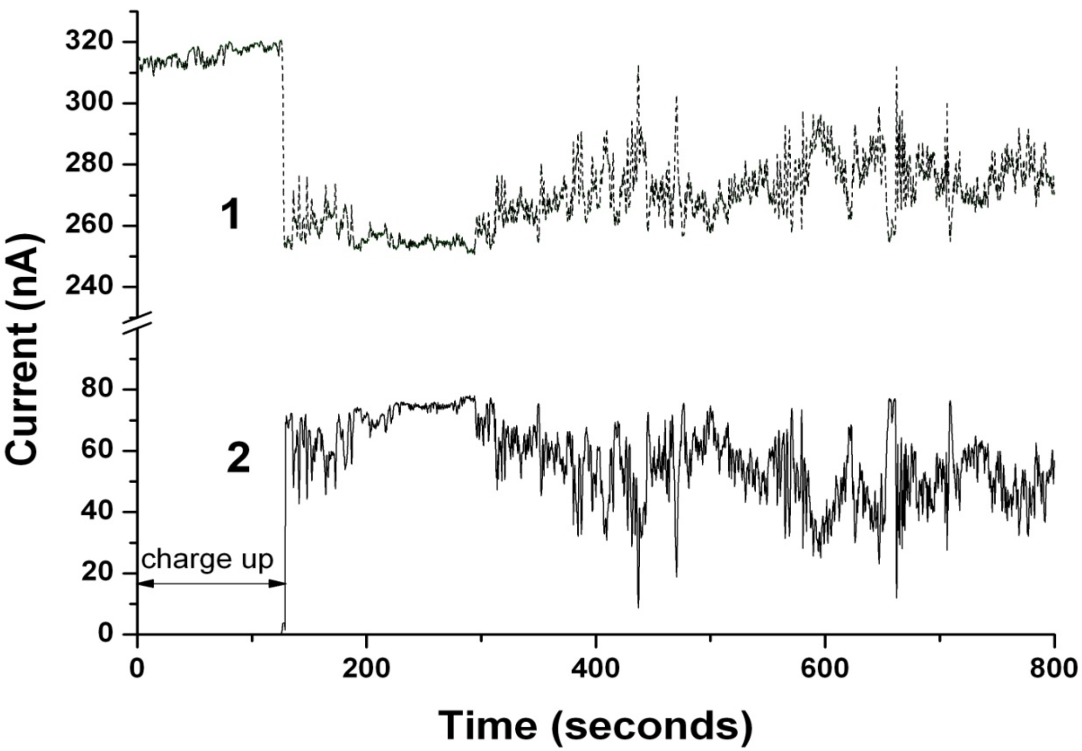
Potential of interaction for
a channeled electron in a capillary:

simple approximation

@ effective low-energy e⁻ guiding by tapered capillary

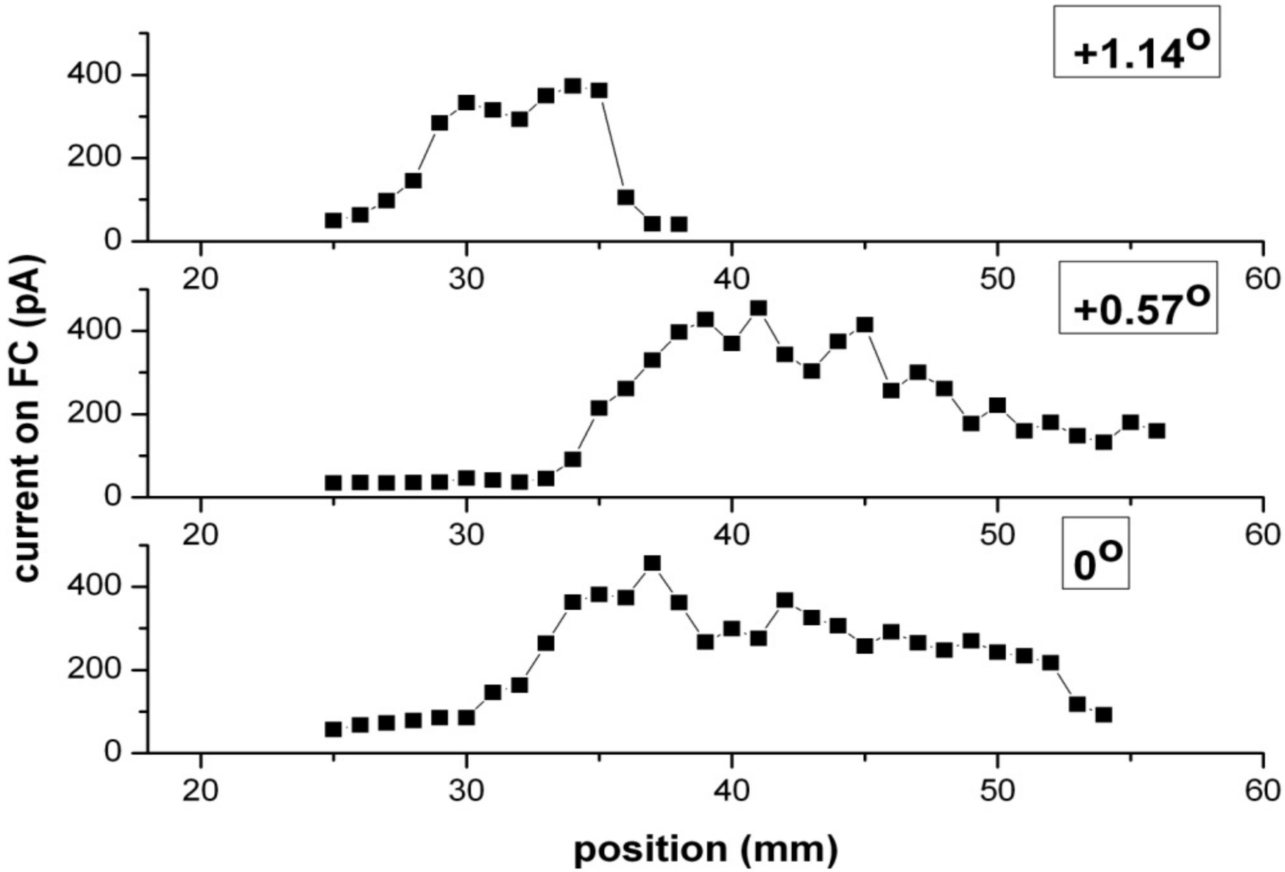


The draft image of the capillary and the photos of its inlet and outlet (inner diameters: inlet - 1.11±0.02 mm, outlet - 57±5 μm)



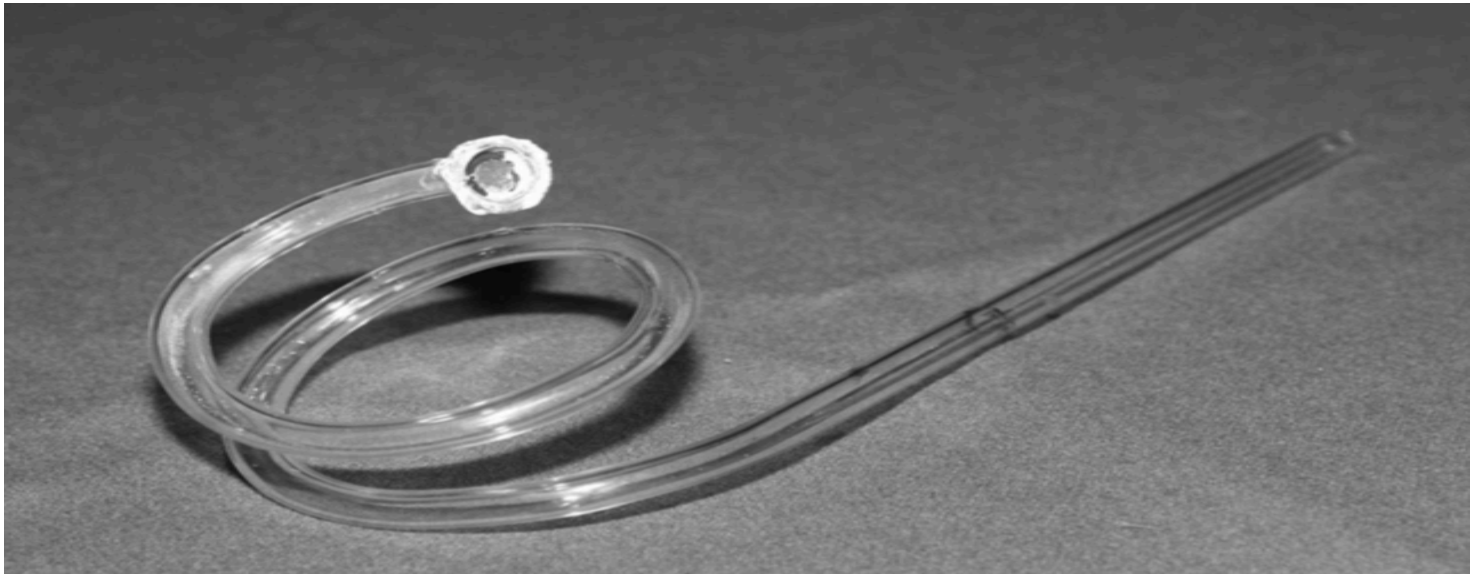
Time dependence of the current on mask (1) and the current transmitted through the capillary of 42 mm length and the inlet/outlet ratio – 1.11/0.057 (2)

@ beam profiling by tapered capillary



The profiles of transmitted current (average) for three tilt angles of the capillary relative to the beam axis (inlet/outlet – 1mm/15μm, length – 30 mm)

@ high I channeling of electrons in strongly bent capillaries

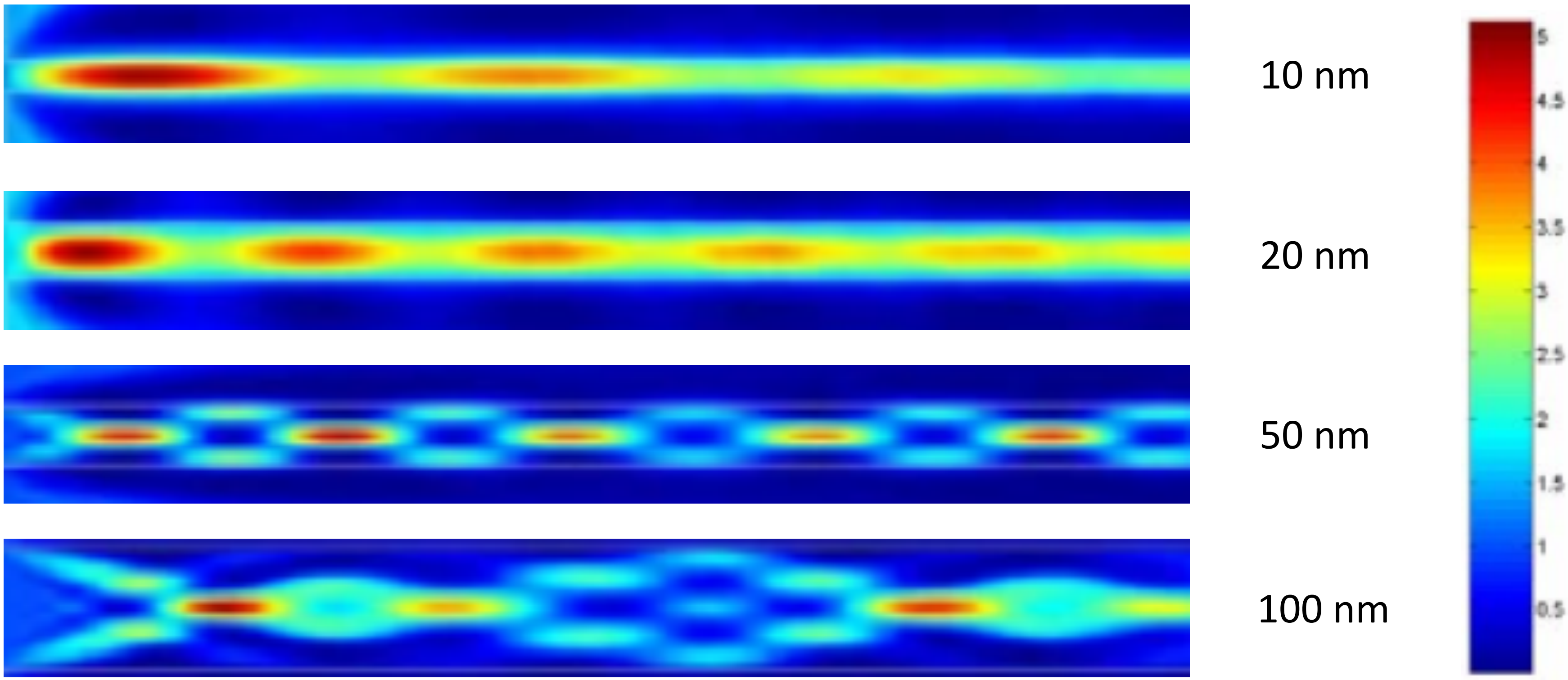


E = 10-20 keV –> 10 MeV e^-
R = 15-20 cm

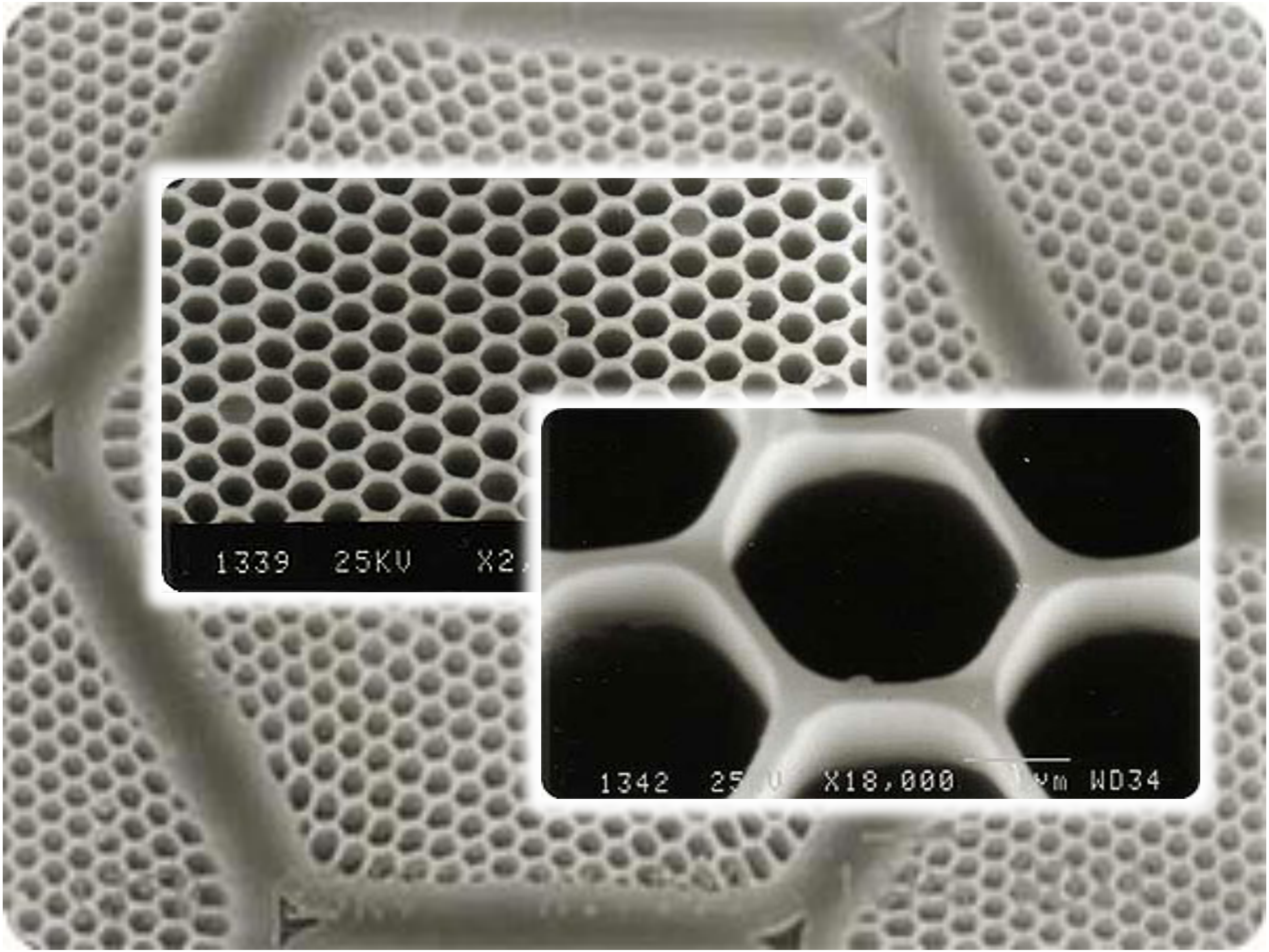
Glass capillary → ~ 100 kV/mm
d ~ 3mm // r ~ 3 mm

Declaration for ~100% channeling by strongly bent capillary (several complete turns)

@ nanoguides for electrons

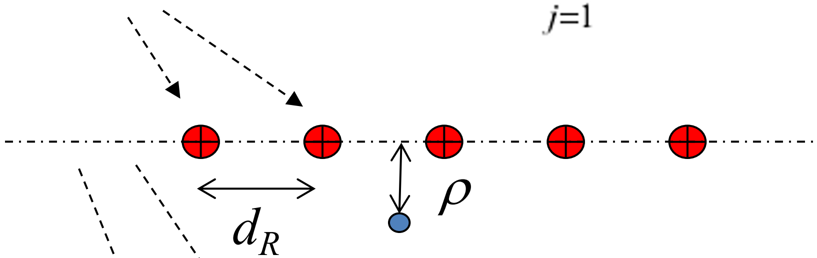


Flux peaking due to beam channeling as an effective focusing tecnique → self-focusing

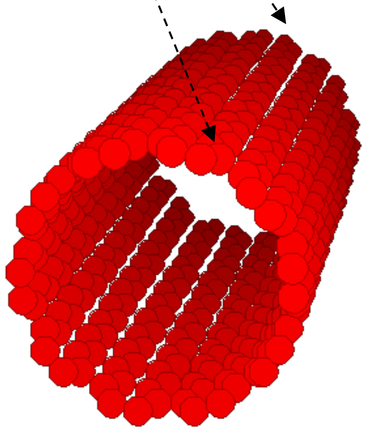

1339 25KV
1342
X18,000
WD34

@ channeling in nanotubes

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



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



$$U(\mathbf{r}) = \sum_{i} V_R(|\ \mathbf{r} - \mathbf{r}_i\ |)$$

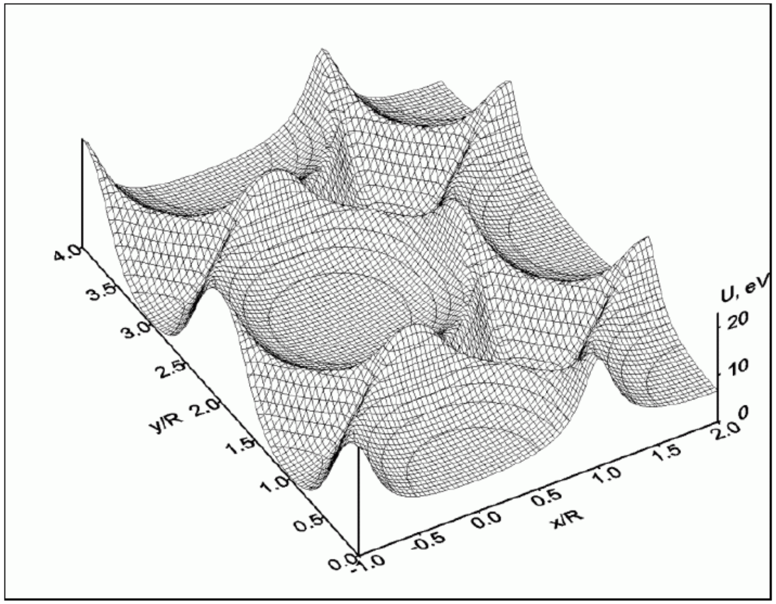
continuum potential
as sum of row potentials

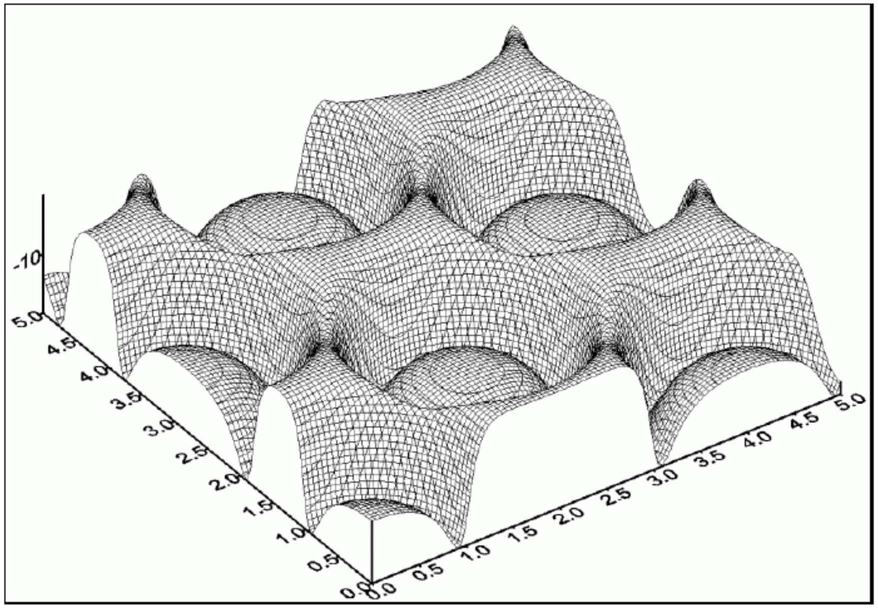
$$U(r) = (16\pi d Ze^2/3\sqrt{3}\, l^2) \sum_{j=1}^{N} a_j b_j^2 \exp\{-b_j{}^2[r^2 + (d/2)^2]\} I_0(b_j^2 r d)$$

r – distance from the tube
$I_0(x)$ – mod. Bessel function

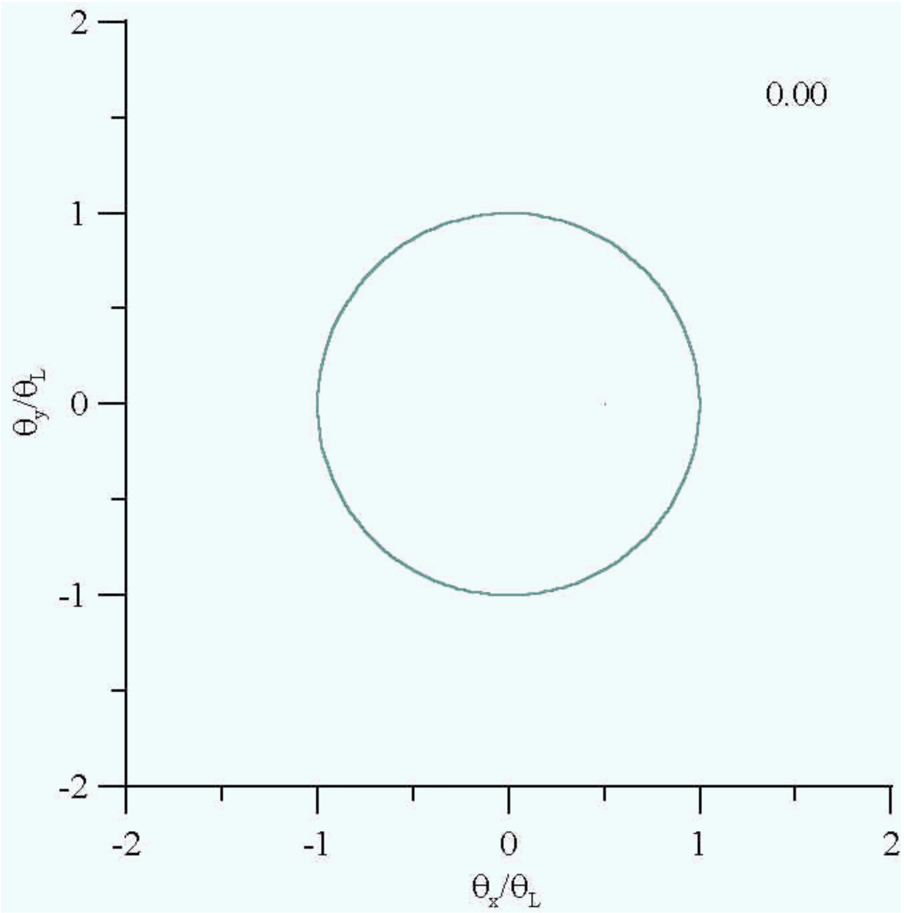
@ continuous potentials: Doyle-Turner approximation

Continuum potential in C60 fullerite: [100] and [110] after averaging of the wall potential

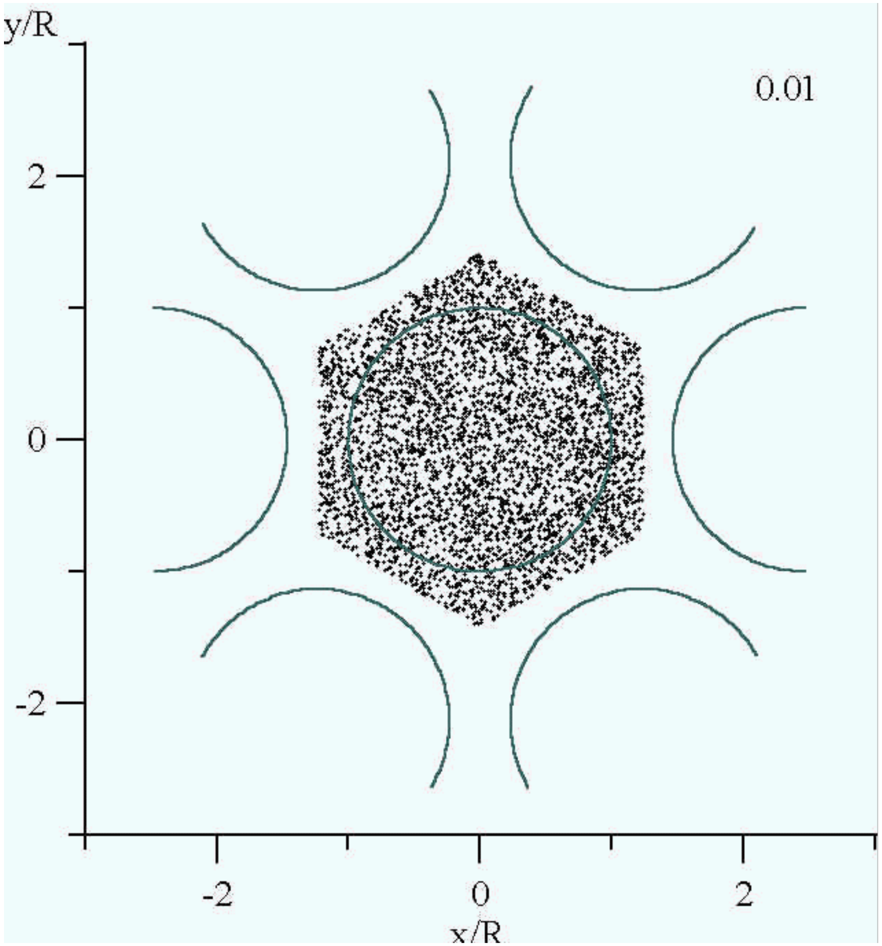




@ simulations for nanotube channeling: *angular distribution*

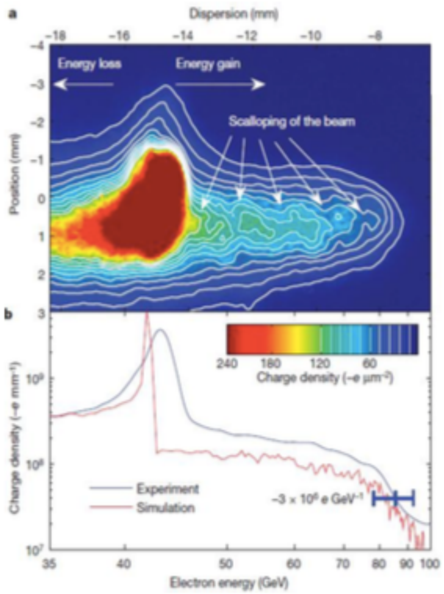


@ simulations for nanotube channeling: *spatial distribution*



@ micro/nano-channeling

Gas-State Plasma

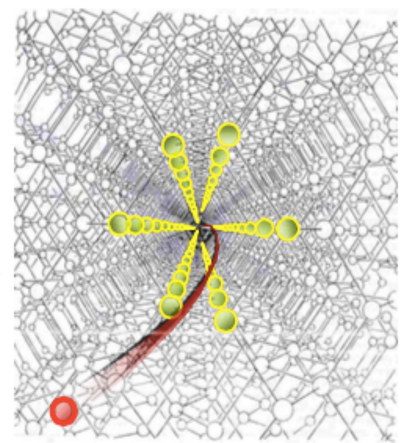


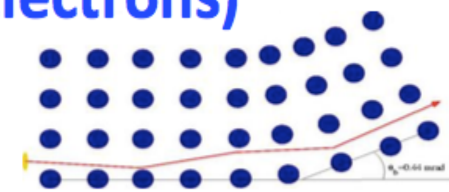
$10^{16} – 10^{18} cm^{-3}$ → 10 ~ 100 GeV/m

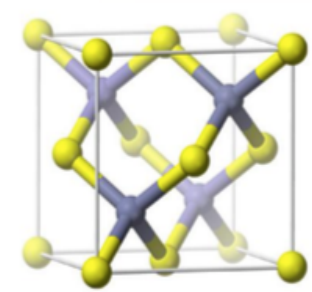
Nature 445, 741-744 (2007)

Energy Doubling: ~ 52 GV/m (@ 42 GeV)

Solid-State Plasma (Conduction Electrons)







$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$

$10^{20} – 10^{23} cm^{-3}$ → 1 ~ 30 TeV/m

courtesy of Shin

@ channeling for acceleration: i

$$\Delta E_{\max} = \left(\frac{M_b}{M_p}\right)^2 (\Lambda G)^{1/2} \left(\sqrt{\frac{G}{z^3 \times 1000[GV/cm]}}\right) \cdot 10^5 [TeV]^*$$

(M_b *and* M_p are the mass of the beam particle and mass of the proton respectively, Λ is the de-channeling length per unit of energy, G is the accelerating gradient, and z is the charge of the beam particle)

- 0.3 TeV for electrons/positrons,

- 10^4 TeV for muons,

- 10^6 TeV for protons

*P. Chen and R.J. Noble, in: Relativistic Channeling, eds. R.A. Carrigan, Jr and J.A. Ellison (Plenum, New York, 1987) p. 517.

@ channeling for acceleration: ii

	Dielectric based	Plasma based	Crystal channeling
Accelerating media	micro-structures	ionized plasma	solid crystals
Energy source: option 1 option 2	optical laser e^- bunch	e^- bunch optical laser	x-ray laser particle beam
Preferred particles	any stable	e^-, μ	μ^+, p^+ ($e+$, $e-$)
Max acc gradient	1-3 GV/m	30-100 GV/m	0.1-10 TV/m
c.m. energy in 10 km	3-10 TeV	3-50 TeV	10^3-10^5 TeV
# stages/10 km: option 1 option 2	10^5 - 10^6 10^4 – 10^5	~100 10^3 - 10^4	~ 1

- V. Shiltsev, Physics-Uspekhi (2012)
- F. Zimmermann, "The future of highest energy accelerators", CERN, Geneva, Switzerland

@ Channeling … future …

- Beam Shaping (deflection, collimation, extraction)
- Crystal Channeling & Channeling related Radiation Phenomena
- Channeling in Combined Laser fields
- Channeling based phenomenology of known physical processes

(μ- & n-giudes, laser & plasma based acceleration)

- Channeling of Beams in Micro- & Nano-Structures

(compact accelerator, compact storage rings)

channeling …

… nice for "imagination" and useful in applications …

@ Channeling: papers - i

Review papers related to this presentation (for general basic principles):

- S.B. Dabagov, and Yu.P. Gladkikh, Advanced Channeling Technologies for X-ray Applications (invited review), Radiation Physics and Chemistry 154 (2019) 3-16.
- S.B. Dabagov, Advanced Channeling Technologies in Plasma and Laser Fields (invited review), European Physical Journal Web Conferences 167 (2018) 01002.
- S.B. Dabagov, and N.K. Zhevago, “On radiation by relativistic electrons and positrons channeled in crystals” (invited review), La Rivista del Nuovo Cimento 31 (9) (2008) 491-529.
- S.B. Dabagov, “Channeling of Neutral Particles in Micro- and Nanocapillaries” (Reviews of Topical Problems), Physics Uspekhi 46 (10) (2003) 1053-1075.

@ Channeling: papers - ii

Proceedings of Channeling meetings (for complete activity list):

- S.B. Dabagov, Ed., "Channeling 2018", Proc. of the 8th International Conference "Charged and Neutral Particles Channeling Phenomena" (Ischia (Napoli), September 23-28, 2018), Physical Review: Accelerators and Beams (2019) - in processing.
- S.B. Dabagov, Ed., "Channeling 2016", Proc. of the 7th International Conference "Charged and Neutral Particles Channeling Phenomena" (Sirmione-Desenzano del Garda, September 25-30, 2016), Nuclear Instruments and Methods in Physics Research B402 (2017) 392 pp.
- S.B. Dabagov, Ed., "Channeling 2014", Proc. of the 6th International Conference "Charged and Neutral Particles Channeling Phenomena" (Capri, October 5-10, 2014), Nuclear Instruments and Methods in Physics Research B355 (2015) 402 pp.
- S.B. Dabagov, Ed., "Channeling 2012", Proc. of the 5th International Conference "Charged and Neutral Particles Channeling Phenomena" (Alghero, September 23-28, 2012), Nuclear Instruments and Methods in Physics Research B309 (2013) 280 pp.
- S.B. Dabagov, L. Palumbo, and V. Guidi, Eds., "Channeling 2010", Proc. of the 4th International Conference "Charged and Neutral Particles Channeling Phenomena" (Ferrara, October 3-8, 2010), Nuovo Cimento C 34 (4) (2011) 560 pp.
- S.B. Dabagov, and L. Palumbo, Eds., Charged and Neutral Particles Channeling Phenomena - "Channeling 2008", Proc. of the 51st Workshop of the INFN Eloisatron Project, World Scientific, (2010) 823 pp.
- S.B. Dabagov, Ed., "Channeling 2006", Proc. of the International Conference on Charged and Neutral Particles Channeling Phenomena (Frascati, July 3-7, 2006), Proc. of SPIE 6634 (2007) .
- S.B. Dabagov, Ed., "Channeling 2004", Proc. of the International Conference on Charged and Neutral Particles Channeling Phenomena (Frascati, November 2-6, 2004), Proc. of SPIE 5974 (2005) 506 pp.

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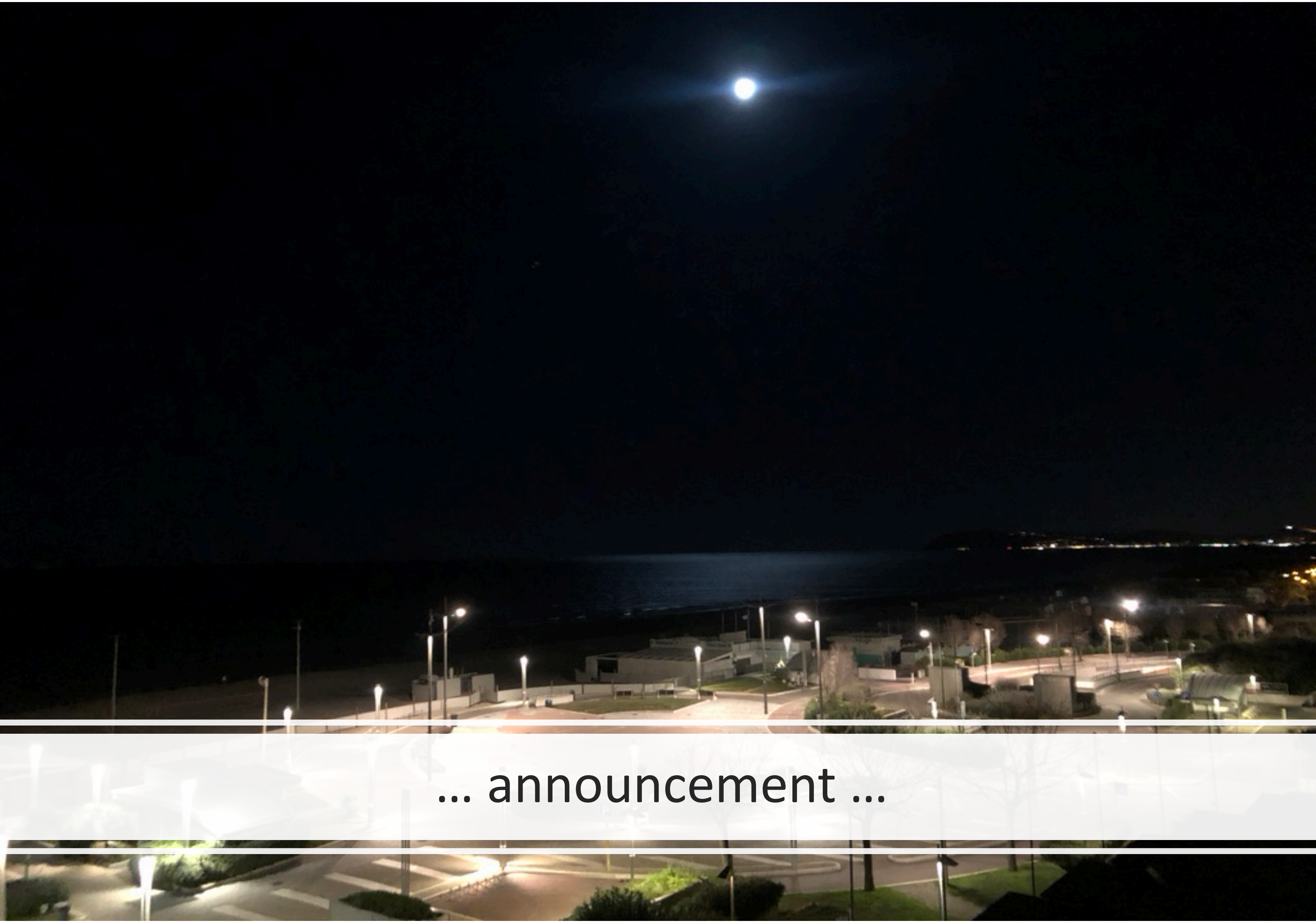
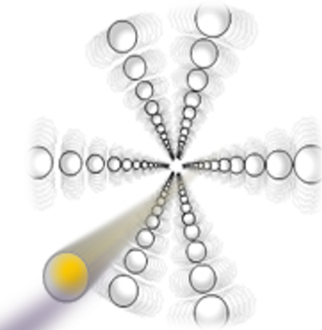
LPI & MEPHI & TPU & BSU (Russia), KhPTI (Ukraine)

Special acknowledgements for their exciting results on channeling physics!

Thank you for attention!


… announcement …



The 9th International Conference

CHARGED & NEUTRAL PARTICLES

CHANNELING PHENOMENA

CHANNELING 2020

20-25 September 2020

Riccione (Rimini), Italy


CORALLO






ATTIBASSI
ESPRESSO
ITALIANO


You are welcome to take part in our meeting:

Channeling 2020

-

in a time and a place

but much in advance

to contact us with your ideas and proposals

channeling2020@lists.lnf.infn.it