Ускорители Частиц Высоких Энергий – *Quo Vadis?*

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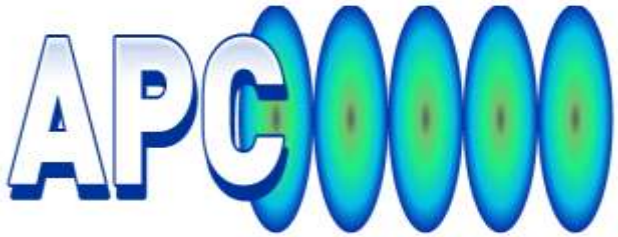
Август 2010



Содержание:

прошлое (немного)

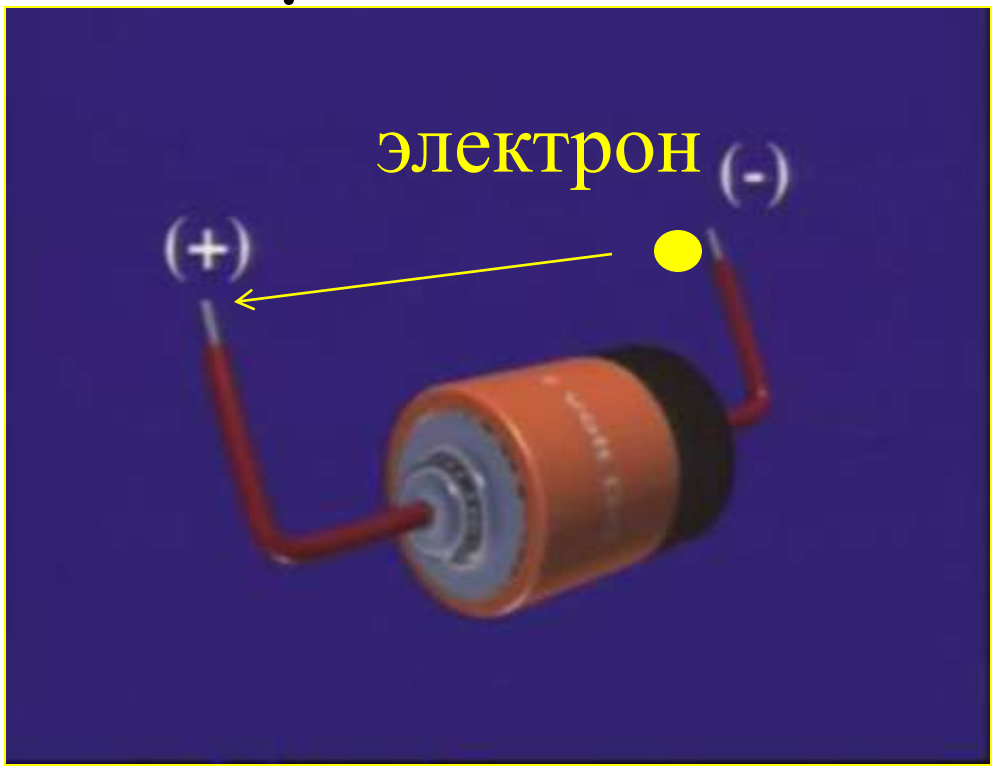
настоящее (немного)

будущее

Будущее

Ускорители Заряженных Частиц

Батарейка 1 Вольт

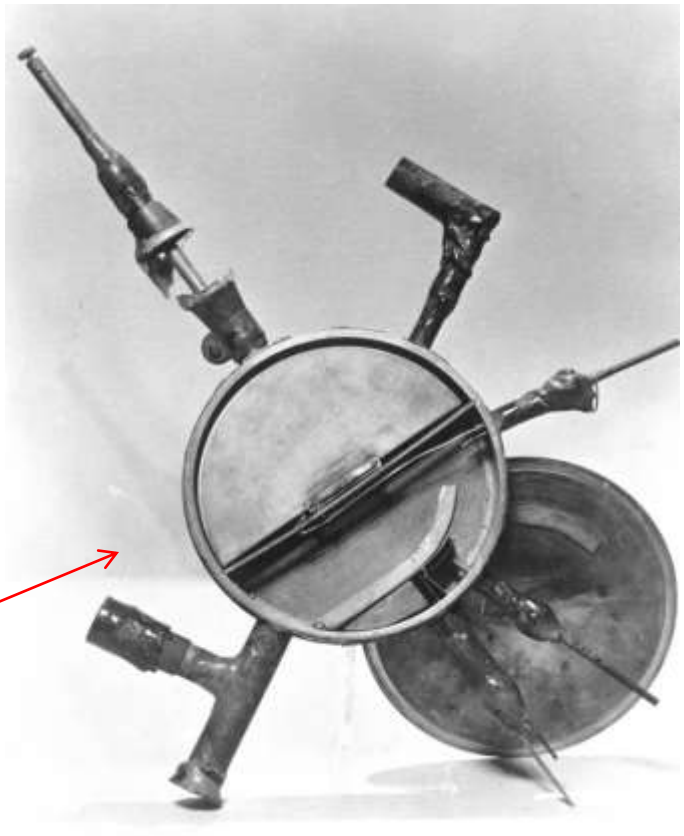


1 электрон + 1 Вольт

=1 электронВольт

Дедушка Современных Ускорителей

Эрнест Лоуренс



Циклотрон 25$

80,000 Вольт

Современный Ускоритель - 6км

1,000,000,000,000 (12 нулей!) Вольт

LHC Large Hadron Collider 27км

БАК = бак

Три Вопроса Для Физиков

Почему все имеет вес?

Почему так мало антивещества (почти нет)?

Из чего и как образовалась Вселенная?

Comparison of Particle Colliders

To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.

Следующее поколение?

Muon Collider
d=2km

LHC
d=8.4km

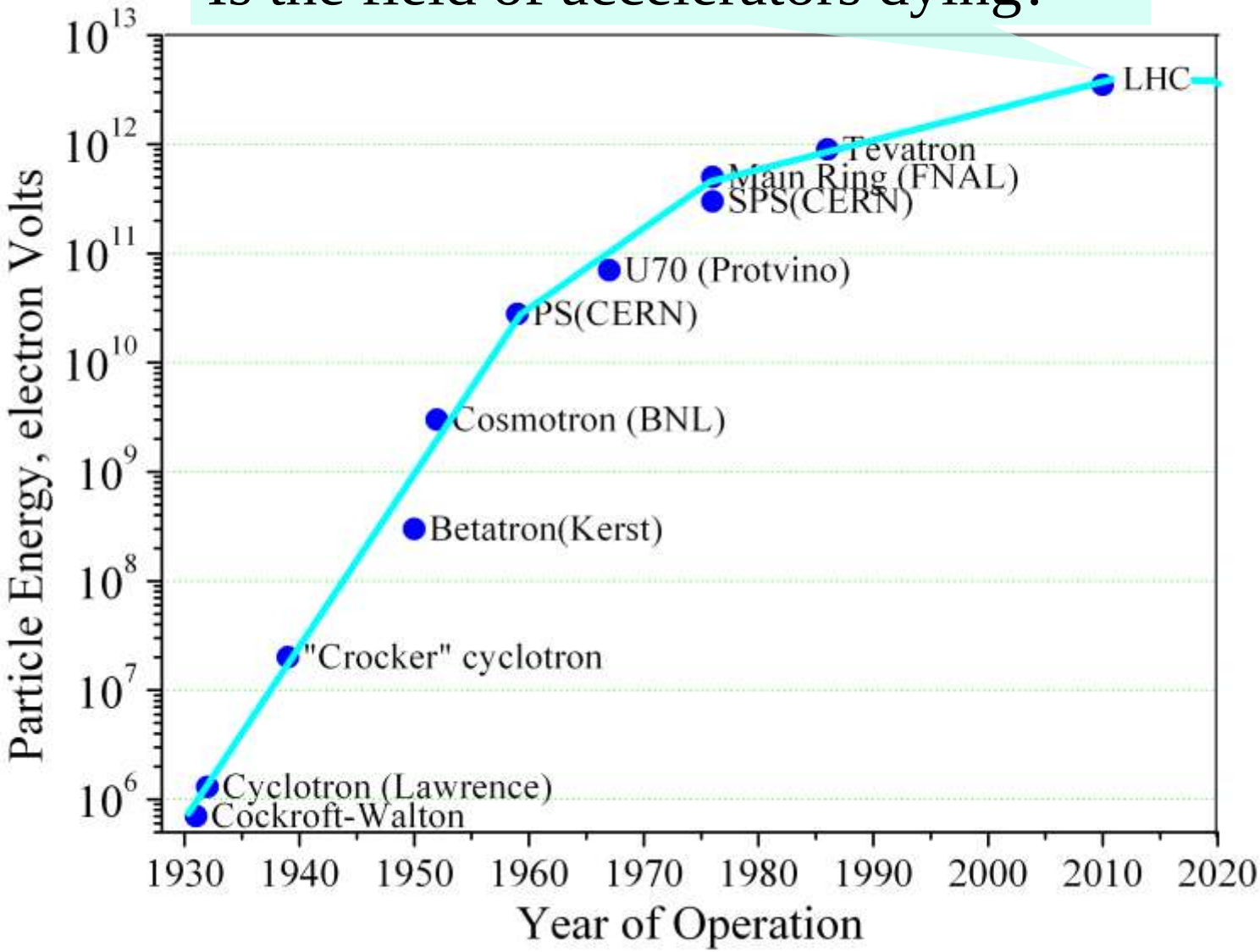
ILC
l=30km

CLIC
l=50km

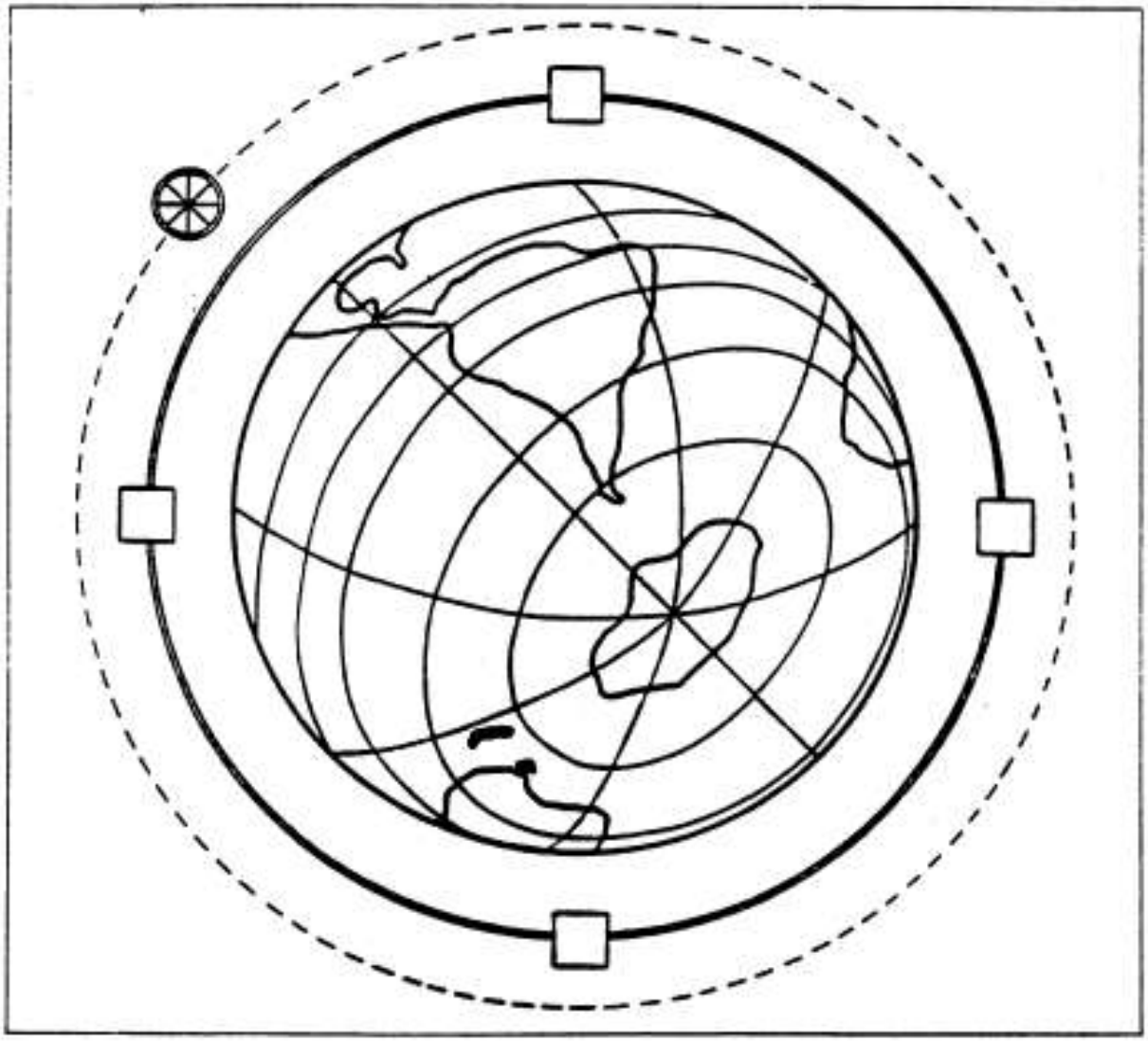
VLHC
d=74km

Причины для пессимизма

Is the field of accelerators dying?



Предельный ускоритель Ферми



From a 1954 Slide by Enrico Fermi, University of Chicago Special Collections.

Тупиковый путь?

LHC & ILC = 0.5B$/km → 15B$

(hardware only 0.2B$/km)

40,000 km ring=10,000TeV = 20 T$

US GDP =15T$=15,000 B$/yr

Повод для оптимизма *Copernican Principle*

Ричард Гот (R.Gott)

Let *L* denote the lifetime of the phenomenon in question. We observe the phenomenon in progress, so

$$L = t_{past} + t_{future}$$

nature

Nature **363**, 315-319 (27 May 1993) | doi:10.1038/363315a0

Implications of the Copernican principle for our future prospects

J. Richard Gott, III

$$\frac{1}{3}t_{past} < t_{future} < 3t_{past}$$

(50% confidence level)

High Energy Particle accelerators exist for

t_{past} = 90 years

so with 50% confidence they will exists for another

t_{future}=30 to 270 years

Откуда все "...есть пошло..." (quiz)

dis?

Физика и Бог

"…Религия и естествознание нуждаются в вере в Бога. При этом для религии Бог стоит в начале всякого размышления, а для естествознания — в конце. Для одних он означает фундамент, а для других — вершину построения любых мировоззренческих принципов…"

Qualitative Advances

New Drivers/Power Sources:

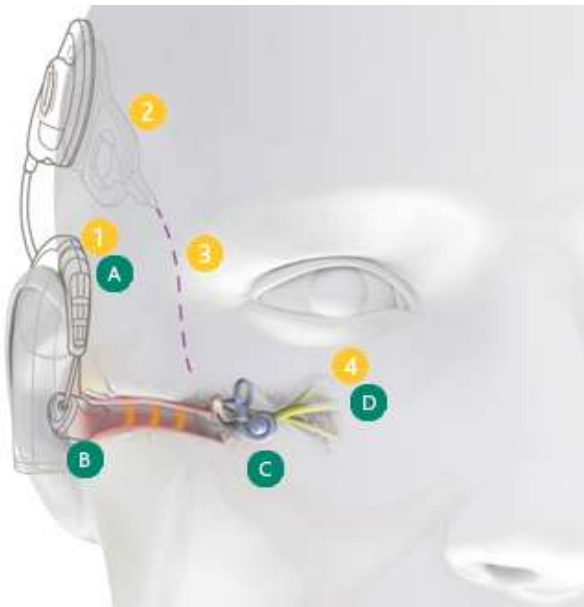
- another beam
- laser

New Accelerating Media:

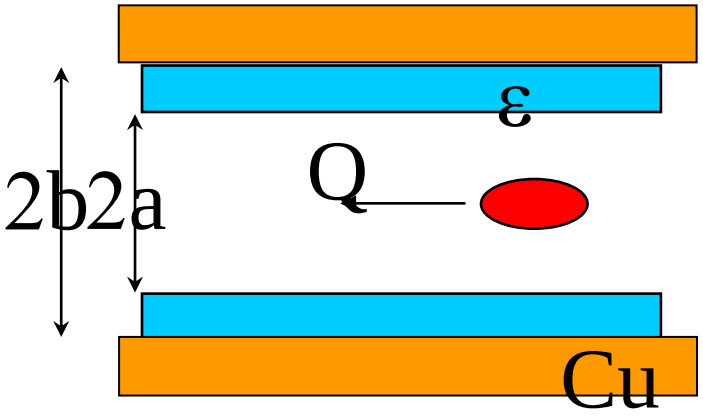
- plasma
- dielectrics
- microstructures
- crystals

Weird Schemes/Ideas

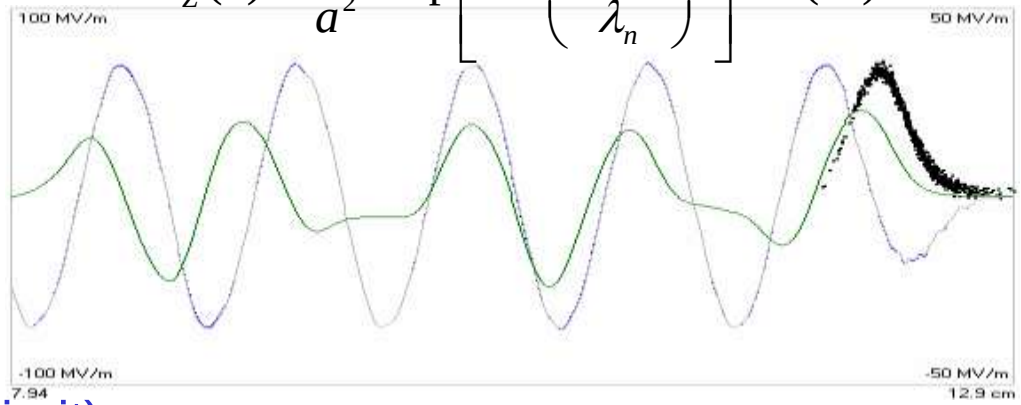
Example of Evolution: Music to Ears



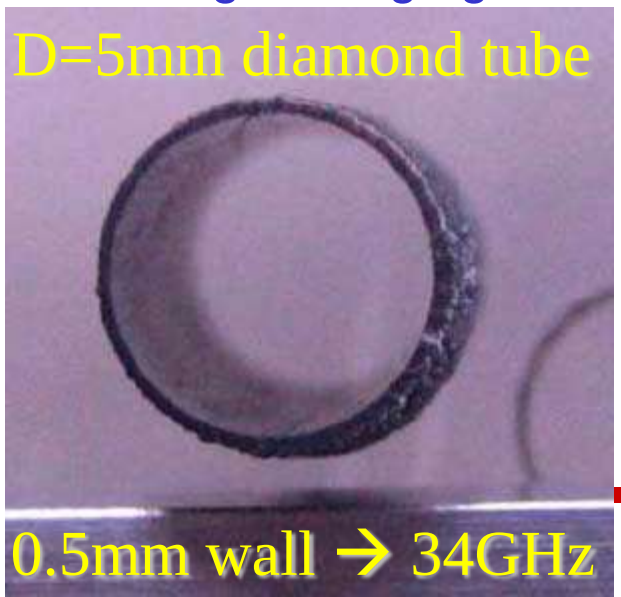
Wakefields In Dielectric Tube

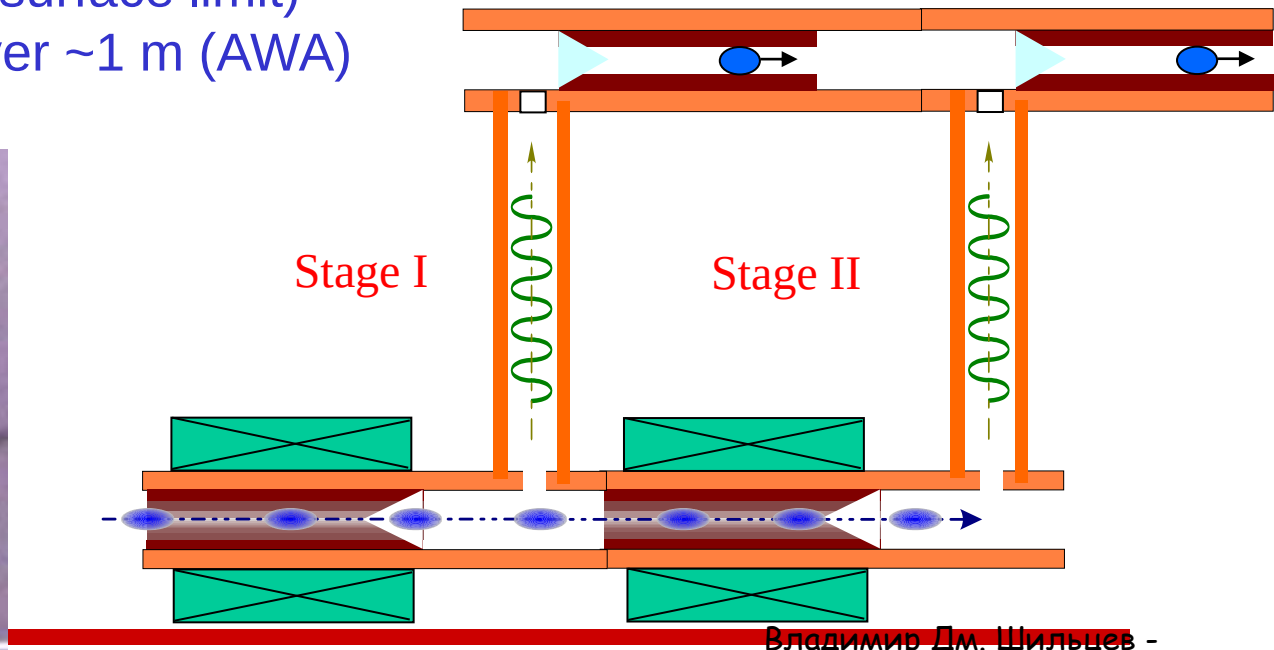


$$W_Z(z) \approx \frac{Q}{a^2} \exp\left[-2\left(\frac{\pi\,\sigma_z}{\lambda_n}\right)^2\right]\cos(kz)$$



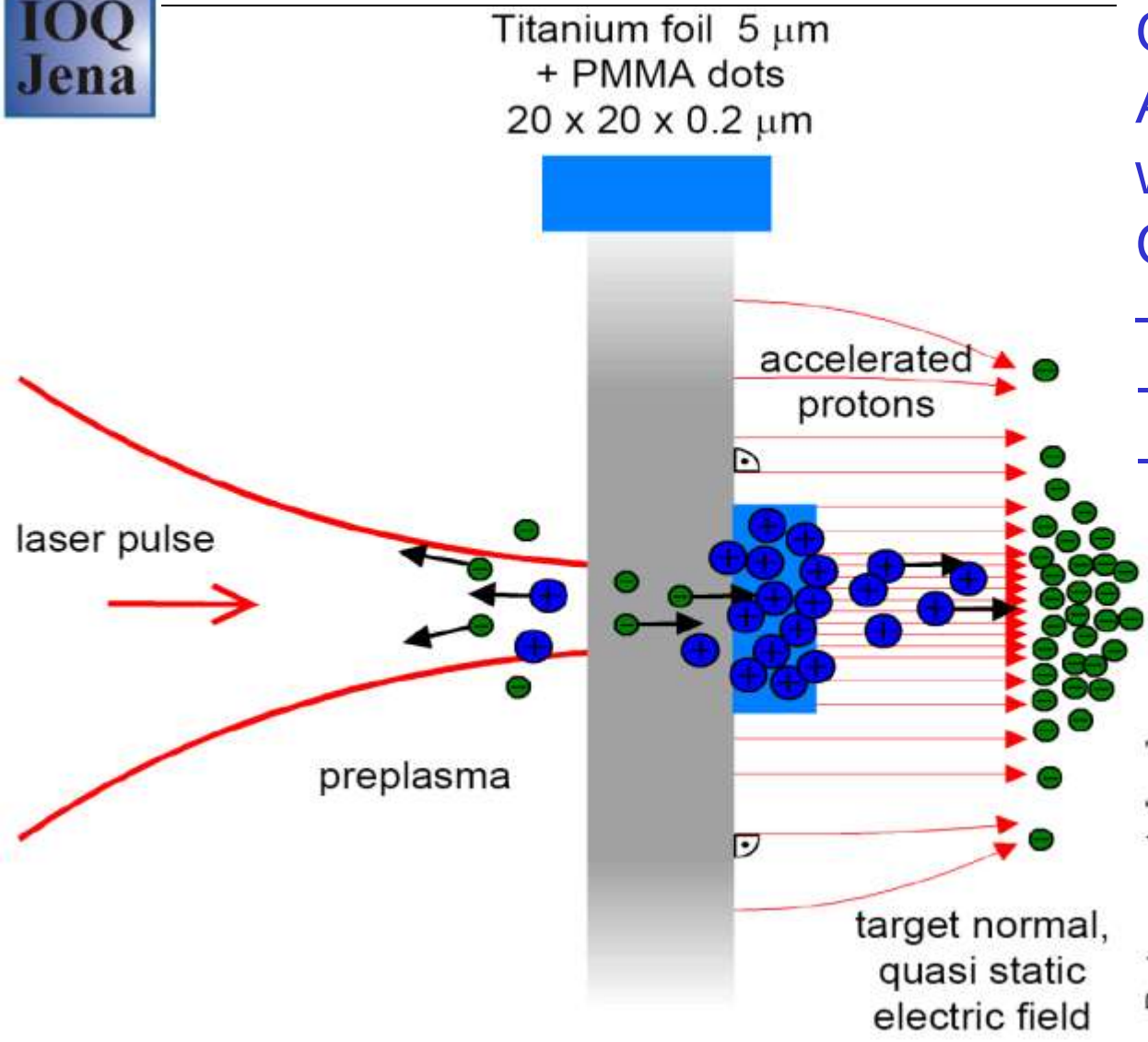
Goal ~1GV/m (diamond surface limit)
Achieved ~100 MV/m over ~1 m (AWA)
Challenge - staging



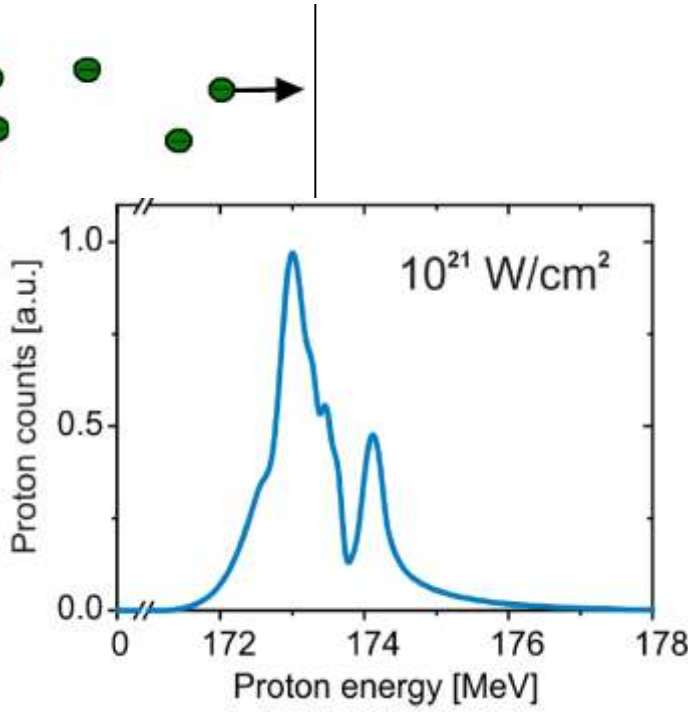


Monochromatic protons from laser jolt

IOQ Jena

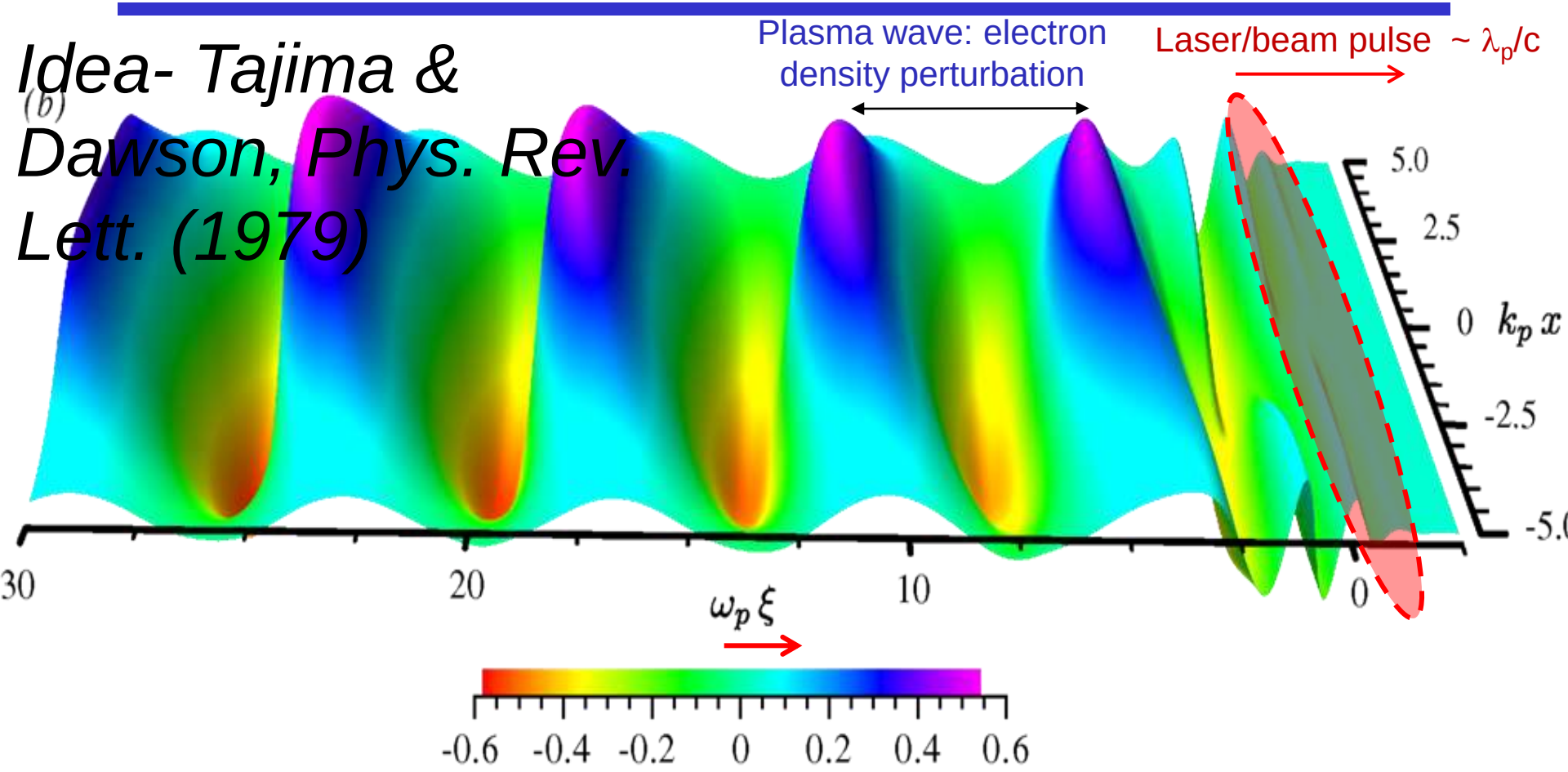


Goal ~1GeV
Achieved ~200 MeV
with dE/E<3%
Challenge s
– get high charge
-- small sizes
-- higher laser power



Excitation of Plasma Waves

Idea- Tajima & Dawson, Phys. Rev. Lett. (1979)

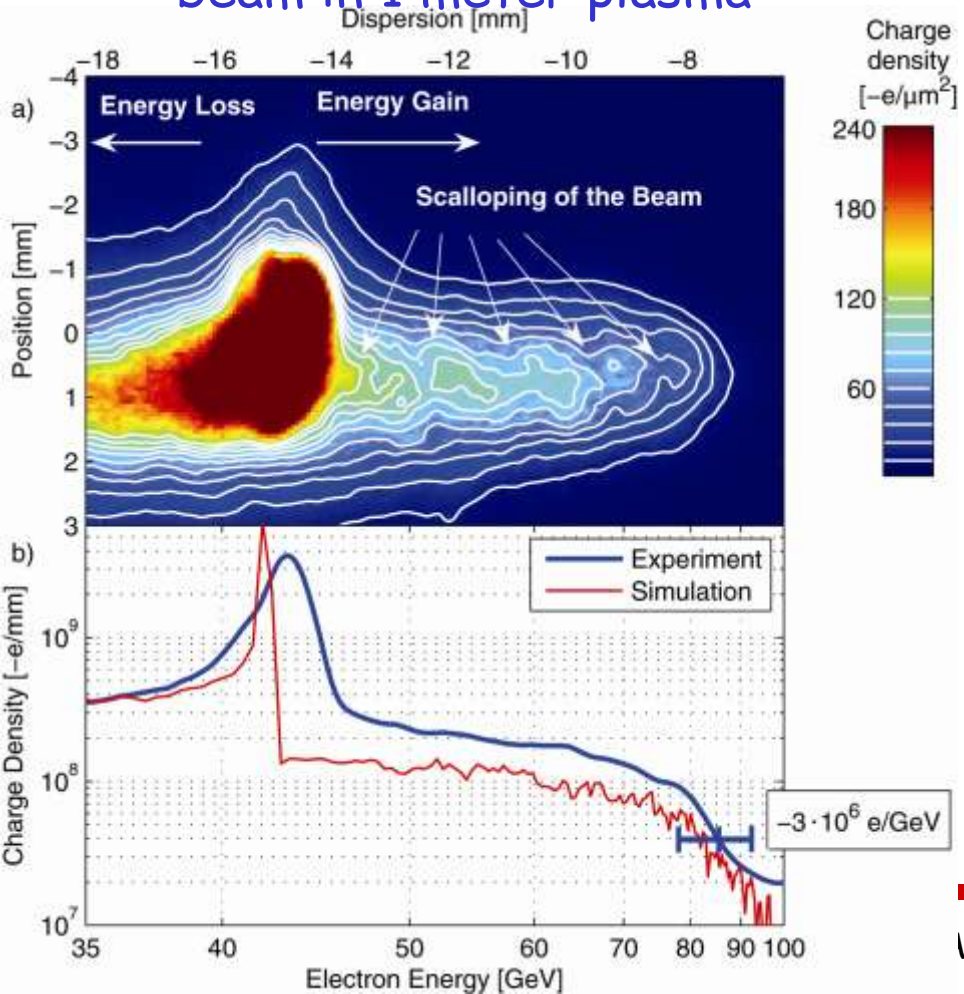


Option #1:
Short intense e-/e+/p bunch

Option #2:
Short intense laser pulse

Beam Excites Plasma

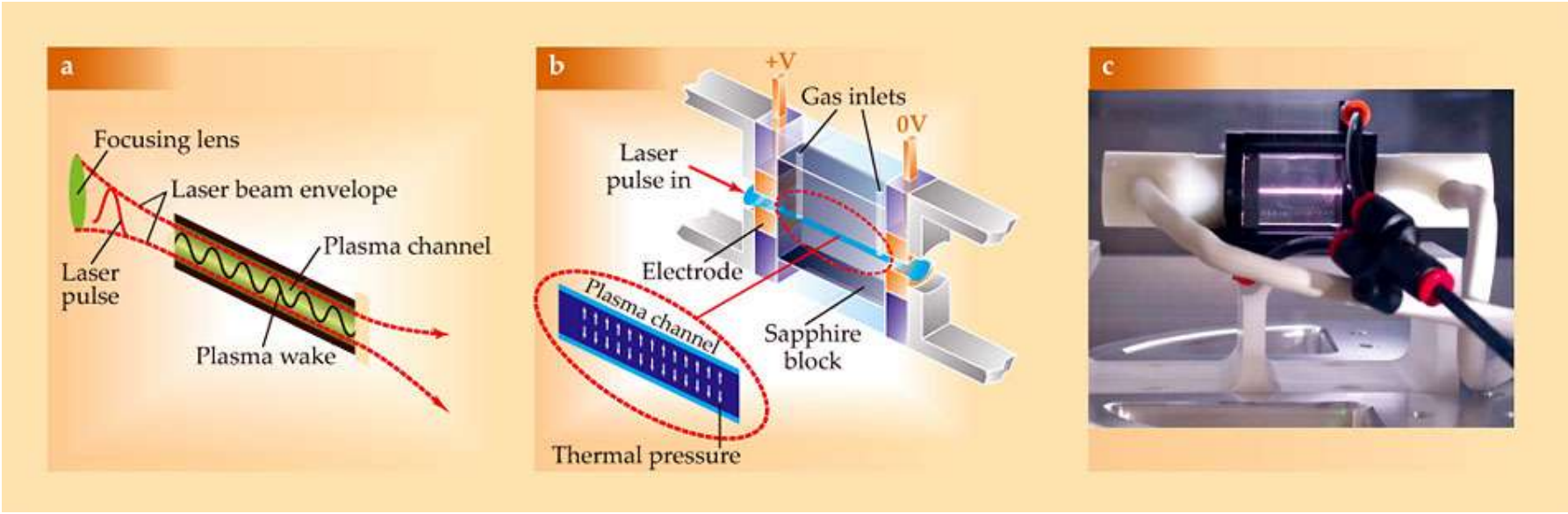
- Acceleration gradients of ~50 GV/m (3000 x SLAC)
  - Doubled energy of 45 GeV beam in 1 meter plasma

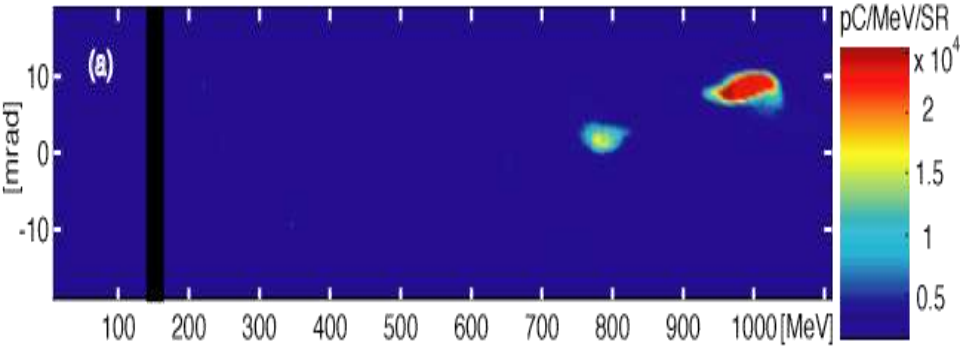


Challenges/Issues:

- small (dE/E, size) beam still to be achieved
- (FACET experiment at SLAC underway)
- needs unique drive beam
- defocuses positrons
- hard to preserve ultra small beam emittances
- thinking of using protons as a drive (even harder)

Laser Excites Plasma



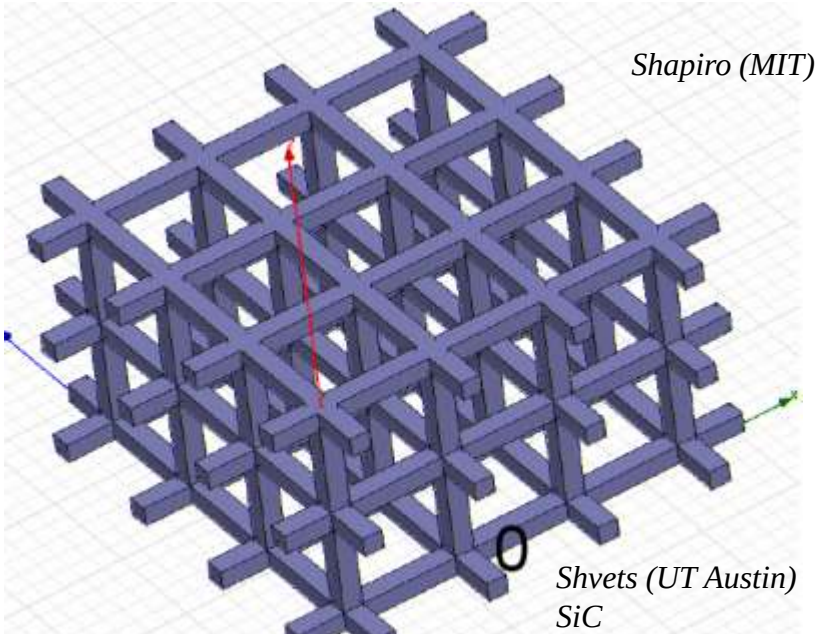


- Achieved ~30 GV/m (Berkeley)
  - 1 GeV over 3 cm
  - 40 TW laser

Challenges/Issues:

- speed of light in plasma always <c
- need many stages - hard
- BELLA experiment at LBNL with Petawatt laser (not table top!)
- low rep rate, efficiencies
- hard to preserve ultra small beams

SiC, diamond, metamaterials, etc

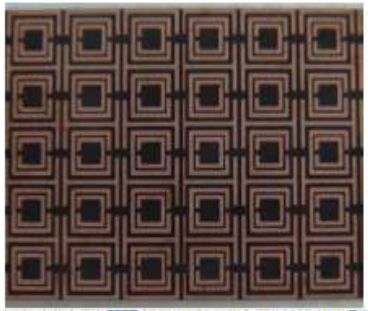


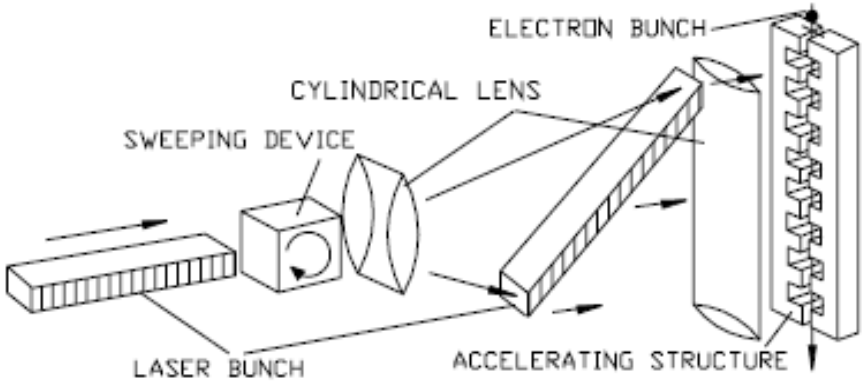
Shapiro (MIT)

Shvets (UT Austin)
SiC

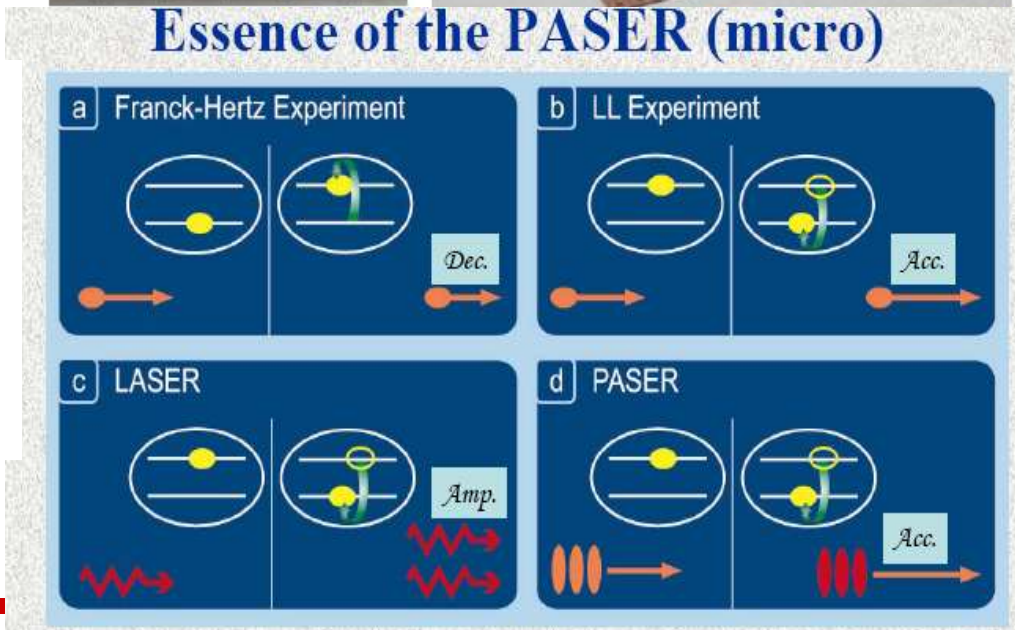
Metamaterials

Antipov (ANL)



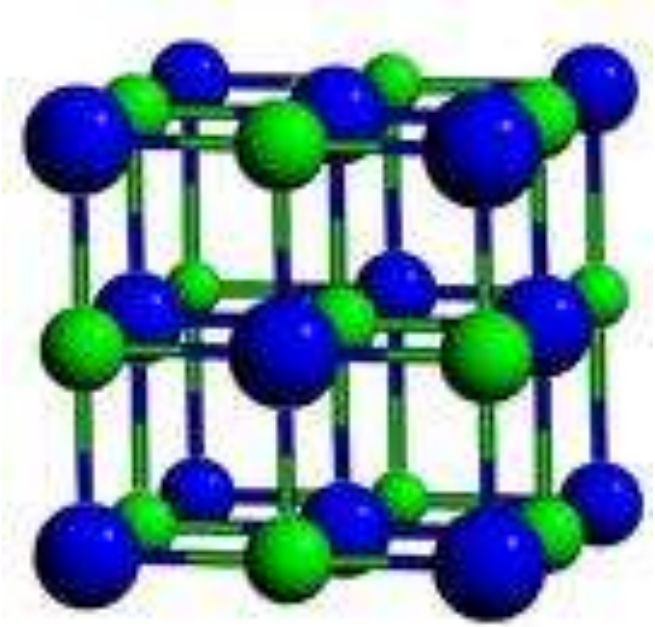


Travelling Laser Focus across Resonant Microsytructures
Mikhailichenko (Cornell)



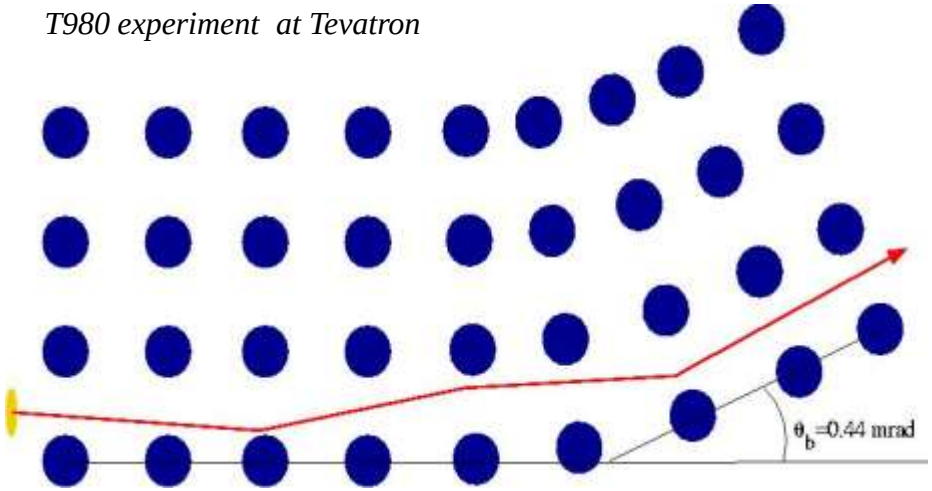
L. Schächter, Phys. Lett. A ., **205**, p. 355-358(1995).

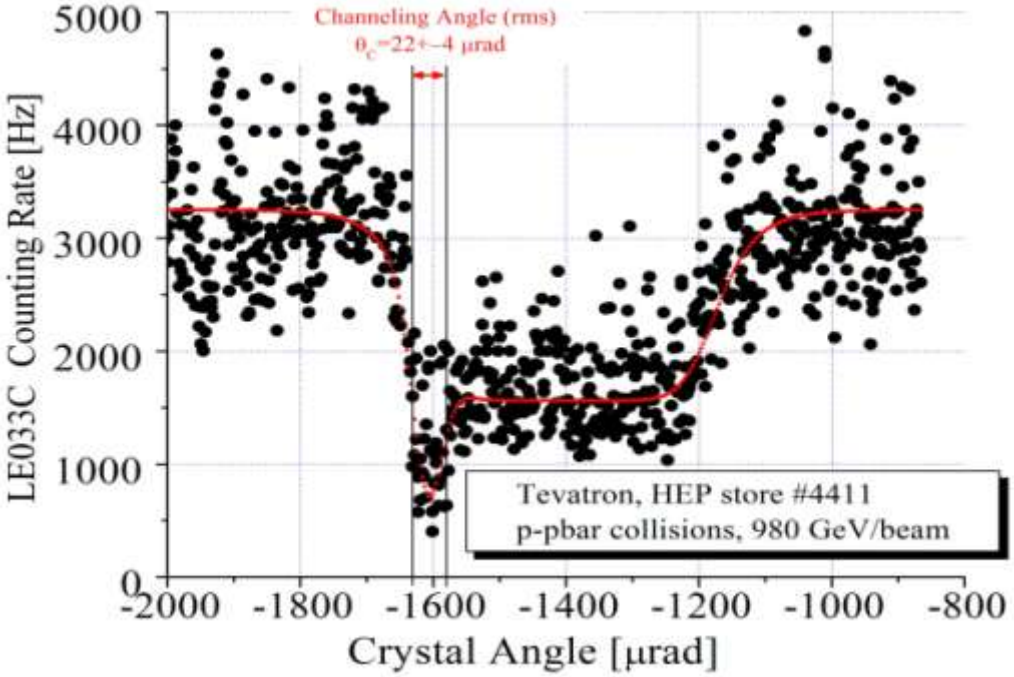
My Favorite "Theme" - Crystals



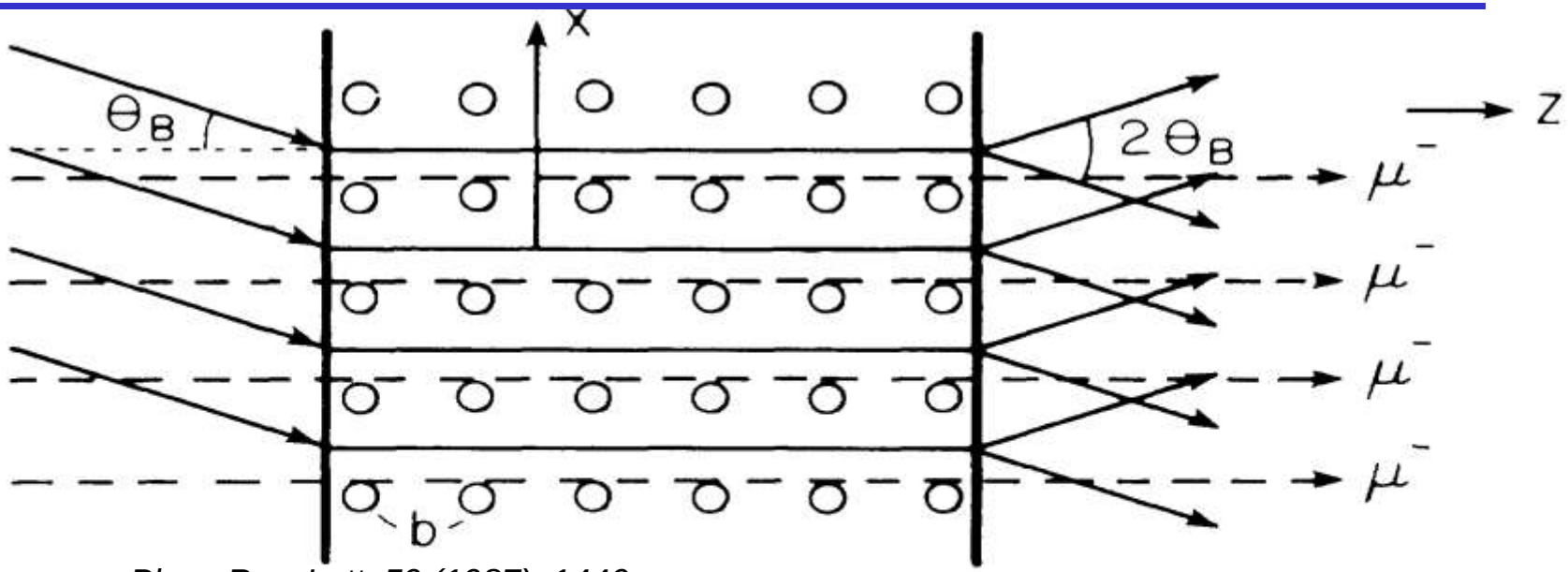
- Strong inter-planar electric fields ~10V/A=1GV/cm
- Very stable, can be used for
  - deflection/bending (*works*)
  - focusing (*works*)
  - acceleration (*if excited*)

T980 experiment at Tevatron





Crystal Excitation by X-Rays

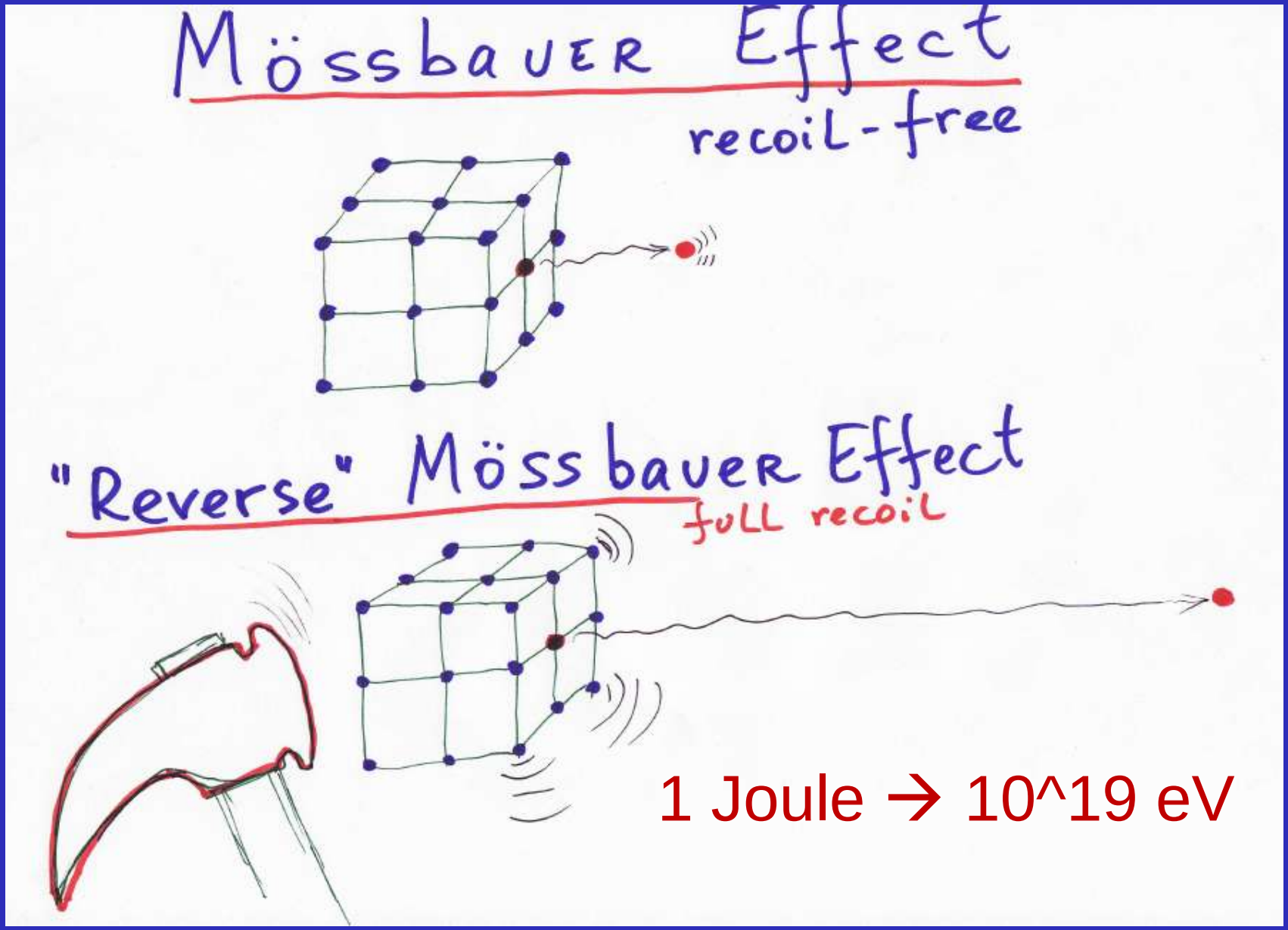


Tajima,Cavenago, Phys. Rev. Lett. 59 (1987), 1440

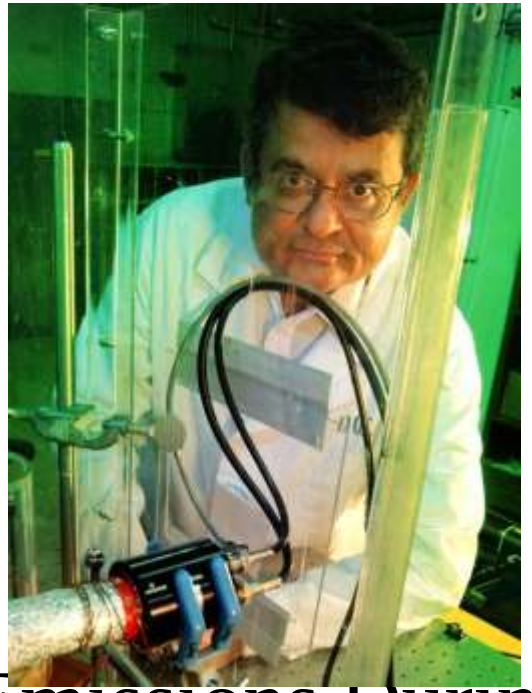
FIG. 1. Bormann anomalous transmission. When the x rays are injected at the Bragg angle, the Bormann effect takes place. Particle beams are injected along the crystal axis.

- Need 40keV high peak power x-rays
  - now available from SASE FELs like LCLS
- Gradients >1GV/cm
- Muons preferred
  - bremstrahlung
- μ+ rad length 10^9 cm
  - total energy~10^9 GeV

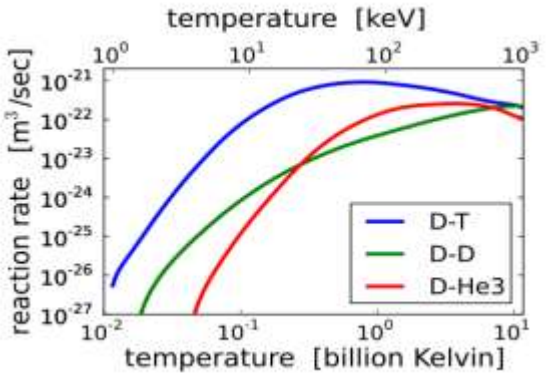
Even Better Way (…but – Fantastic)

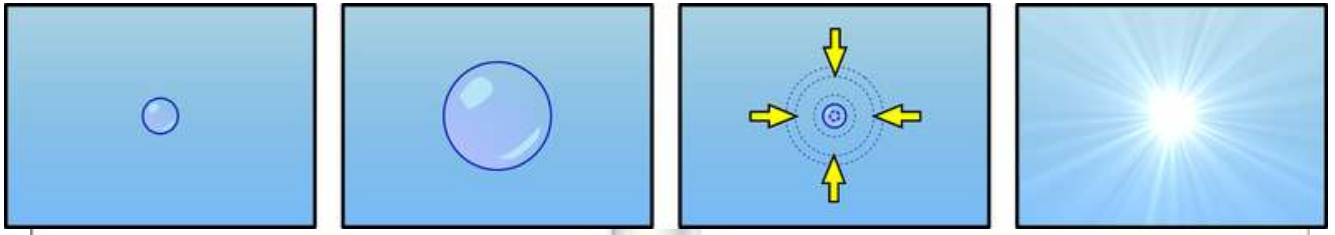


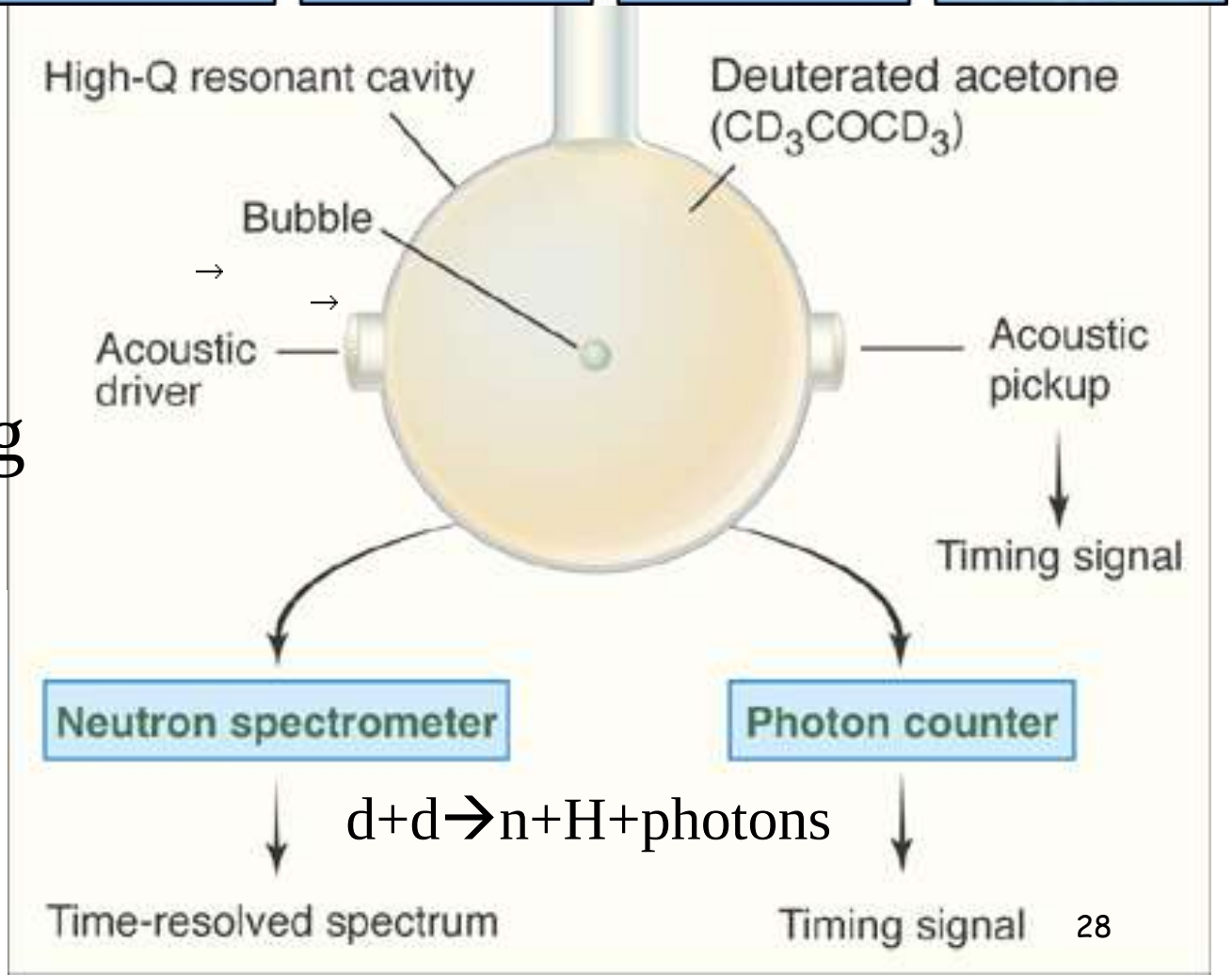
Bubble fusion: 2002→2007… RIP?



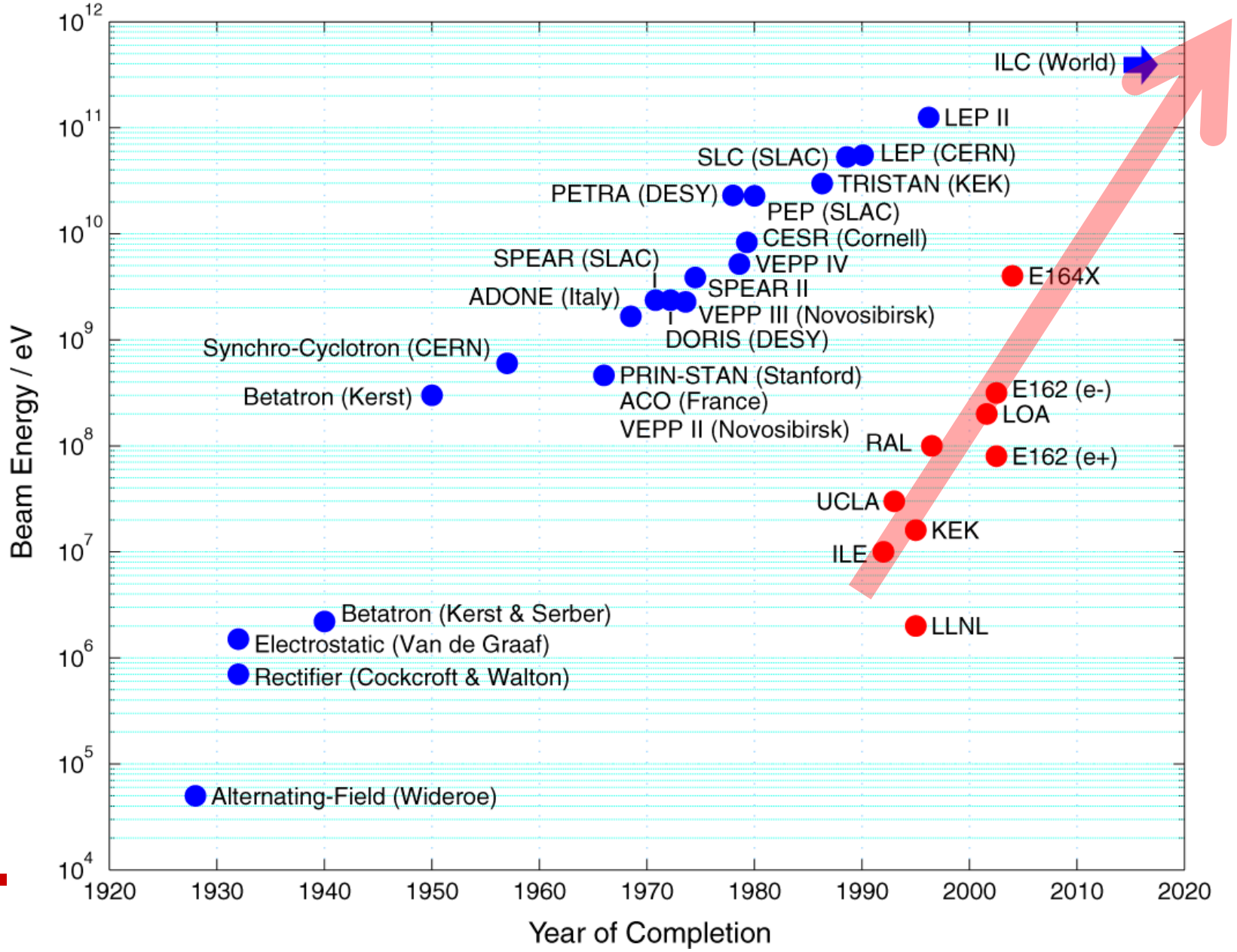
Emissions During Acoustic







Progress Feeds Dreams



Plasma-Accelerator-Based Linear Collider

Leemans & Esarey, Physics Today (March 2009)

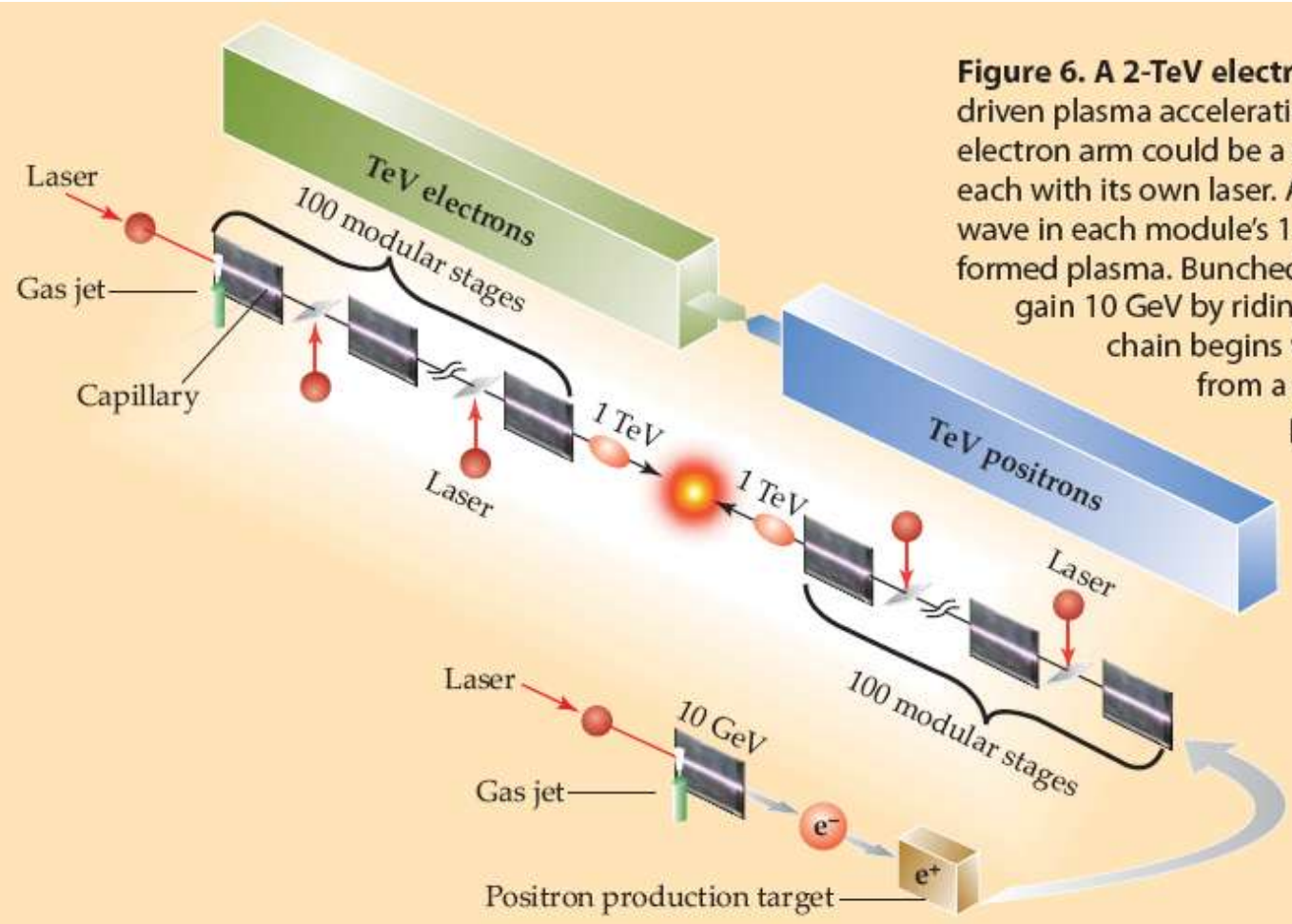


Figure 6. A 2-TeV electron–positron collider based on laser-driven plasma acceleration might be less than 1 km long. Its electron arm could be a string of 100 acceleration modules, each with its own laser. A 30-J laser pulse drives a plasma wave in each module's 1-m-long capillary channel of pre-formed plasma. Bunched electrons from the previous module gain 10 GeV by riding the wave through the channel. The chain begins with a bunch of electrons trapped from a gas jet just inside the first module's plasma channel. The collider's positron arm begins the same way, but the 10-GeV electrons emerging from its first module bombard a metal target to create positrons, which are then focused and injected into the arm's string of modules and accelerated just like the electrons.

F.Bacon

“Knowledge ∝ Power”
“Power ∝ Money”…
literally so for accelerators:

Tevatron (2TeV)	20 MW
LHC (7+ TeV)	120 MW
μμ Collider(4TeV)	140 MW
ILC(0.5TeV)	230 MW
CLIC(3TeV)	420 MW
LaserPlasma *x*TeV	?? GW

Проблема коллайдеров: L vs E

What do HEP folks want?

$\sigma_{QED} = \frac{90fb}{s} \rightarrow \mathcal{L} \propto E_{cm}^2$

$1\,TeV \rightarrow 10^{32}$

$10^3\,TeV \rightarrow 10^{38}$

What Accelerator geniuses can (suggest)?

x

MANY

$\mathcal{L} = \frac{f_{rep} \cdot N_{bunches} \cdot N_p^2}{4\pi\sigma^2} = \frac{[\gamma f_{rep} \cdot N_p \cdot N_b]}{4\pi\beta^*} \cdot \left[\frac{N_p}{\varepsilon}\right]$

Beam power — Brightness

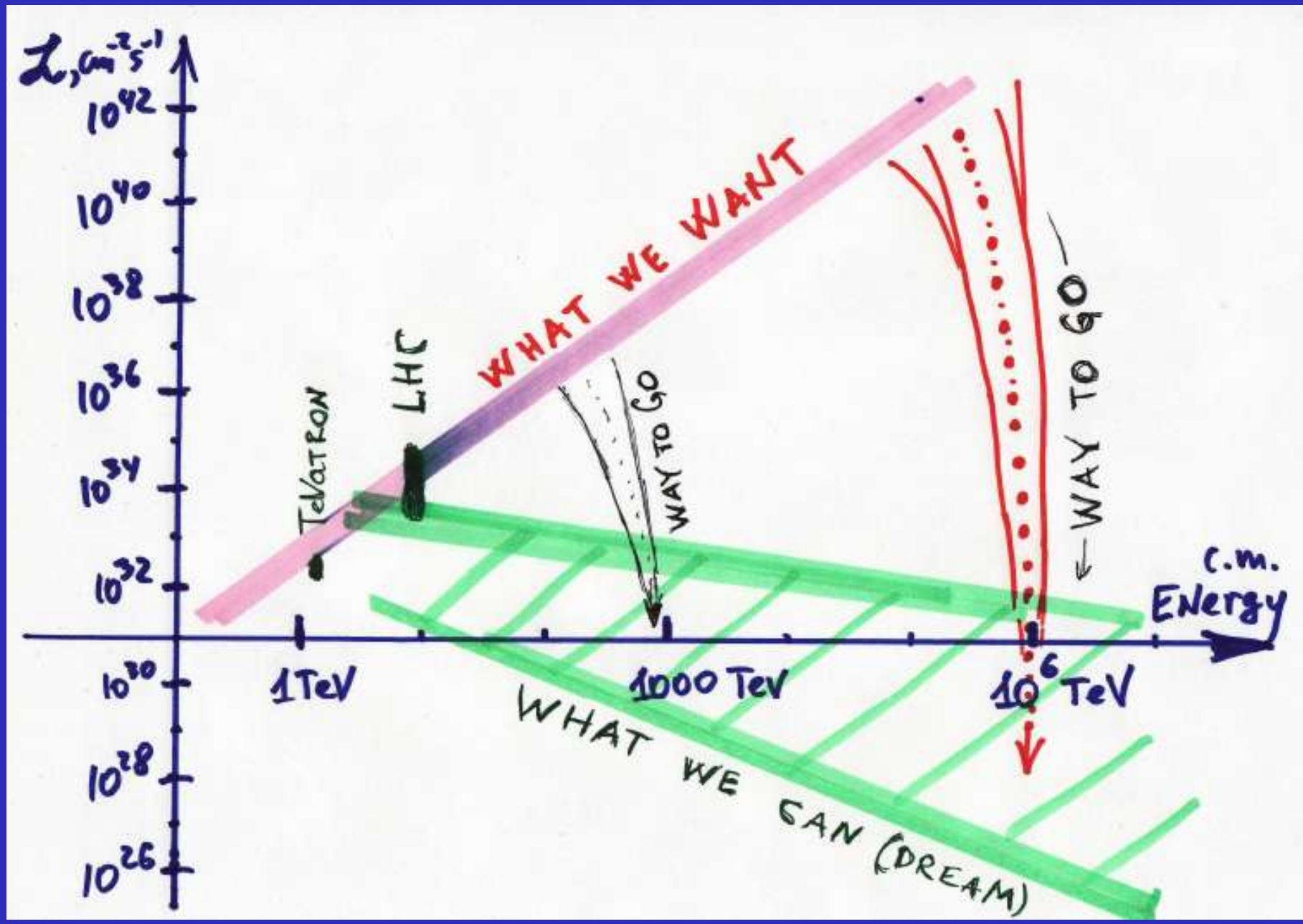
$P_{power} = \eta \cdot P_{WALL}$

$\rightarrow P_{WALL} \leq (MAX)$, $\eta \propto E_{cm}^{-1/3 \ldots -1/5}$

$\rightarrow$ [Brightness] ~ CONST

Best case $\mathcal{L} = 1\,kHz \cdot \frac{(10^5\,particles)^2}{(1\,\text{Å})^2} = 10^{27}\,cm^{-2}s^{-1}$

That Leads to New Paradigm



Возможное решение (подход)

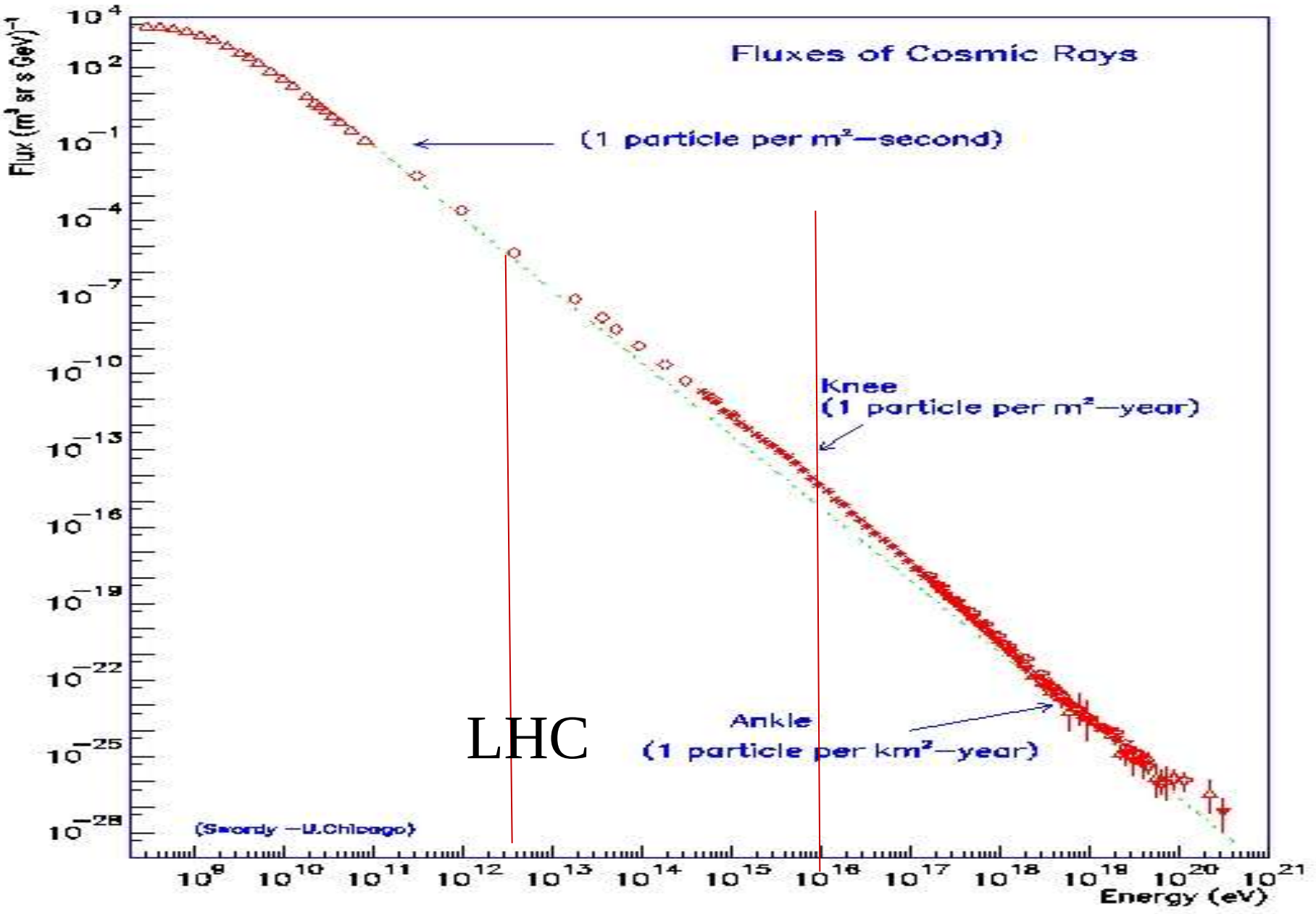
Отказ от пучков = 1+1 частица

Получить надо только Энергию

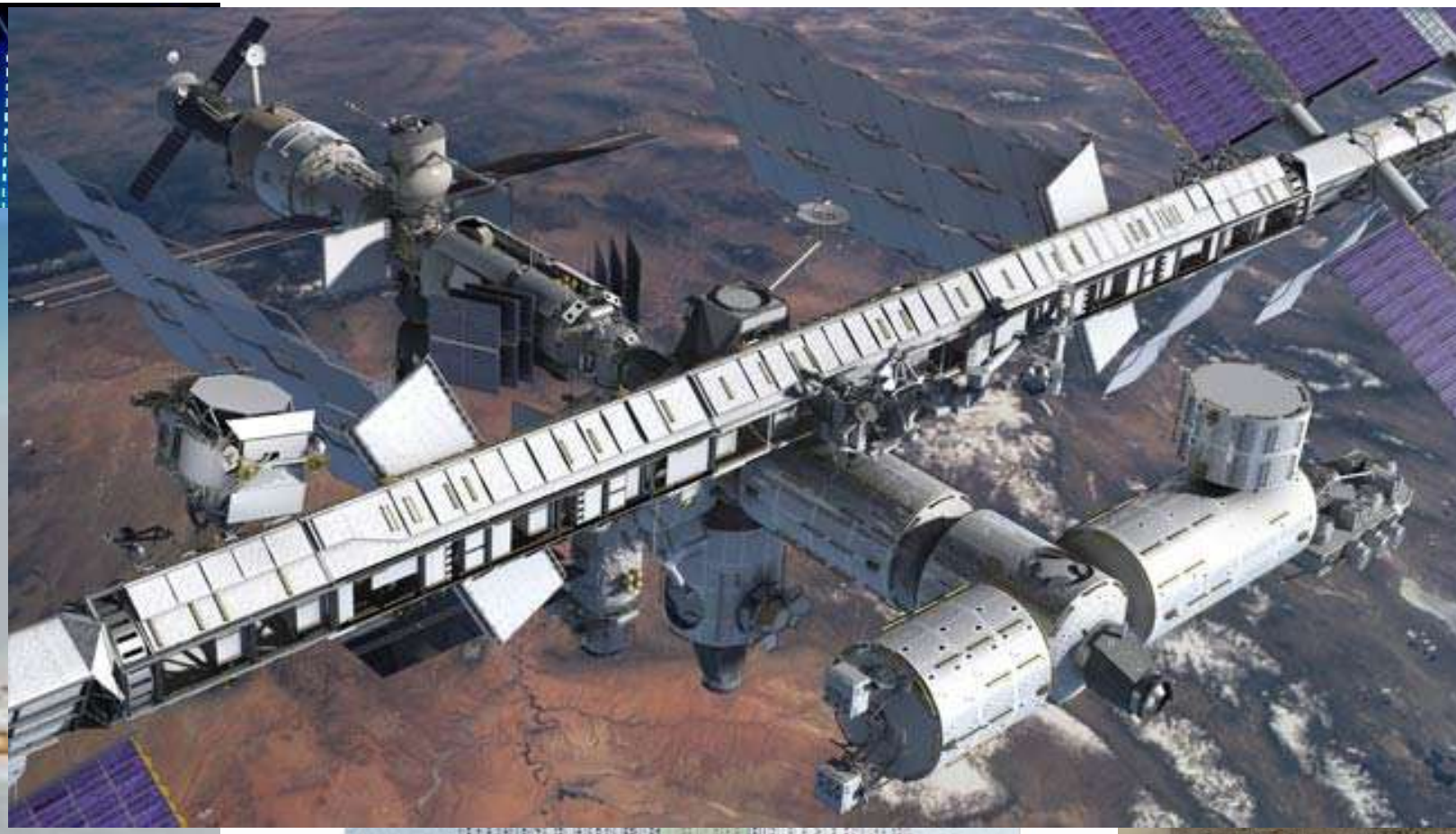
Скажем 10,000 TeB+10,000 TeB

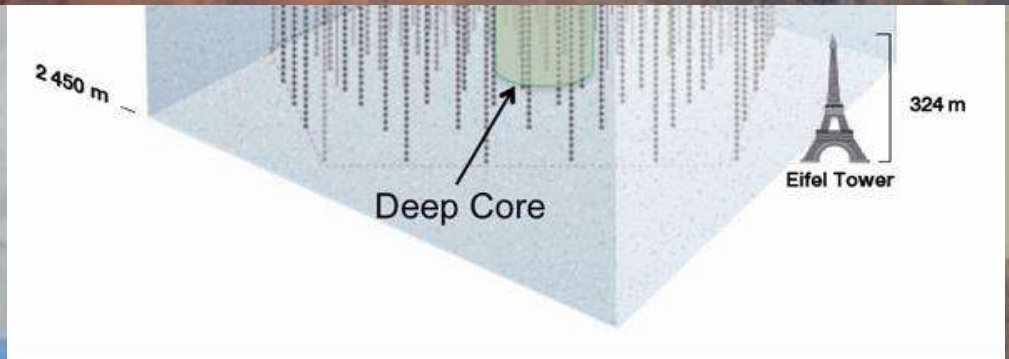
Маленький ускоритель+большой детектор (атмосф или лед)

Подсказка от "Mother Nature"

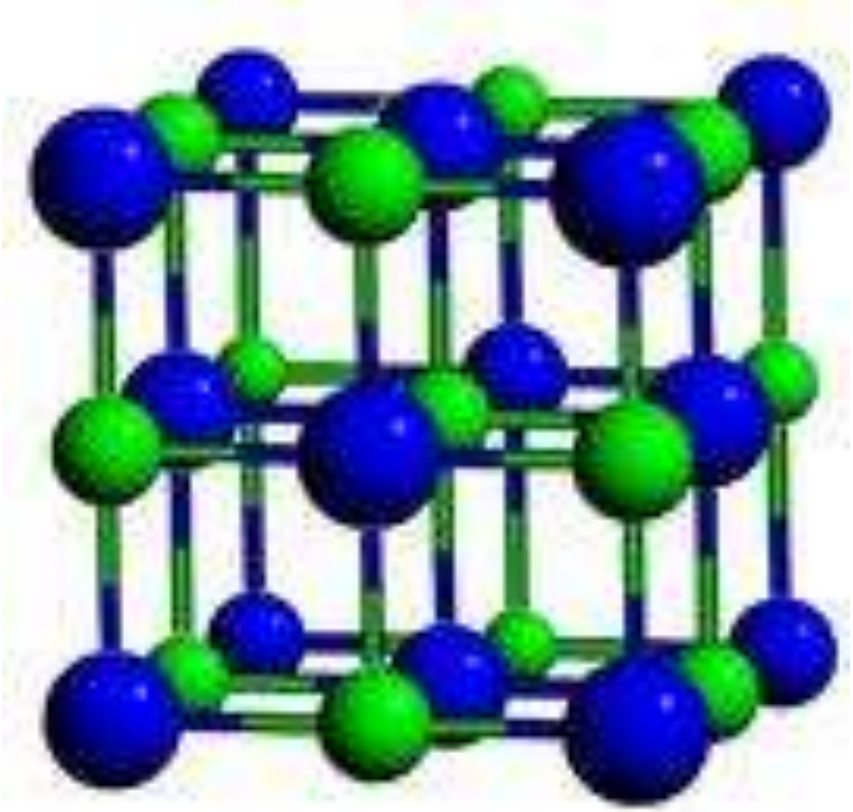


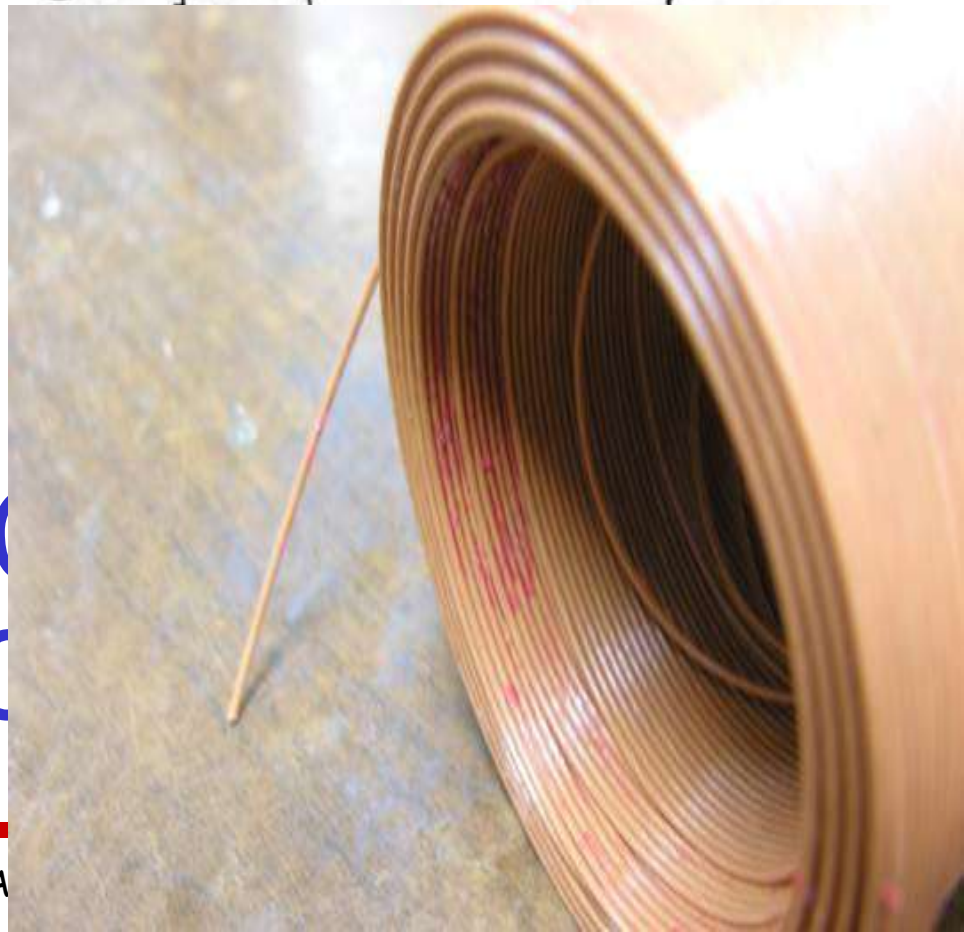
Детекторы Космических Частиц





Микро(Нано) Ускоритель





20В/Ангстрем=(

50км для 1(

Возможно ли это?

Надо пробовать... Или искать другие пути...

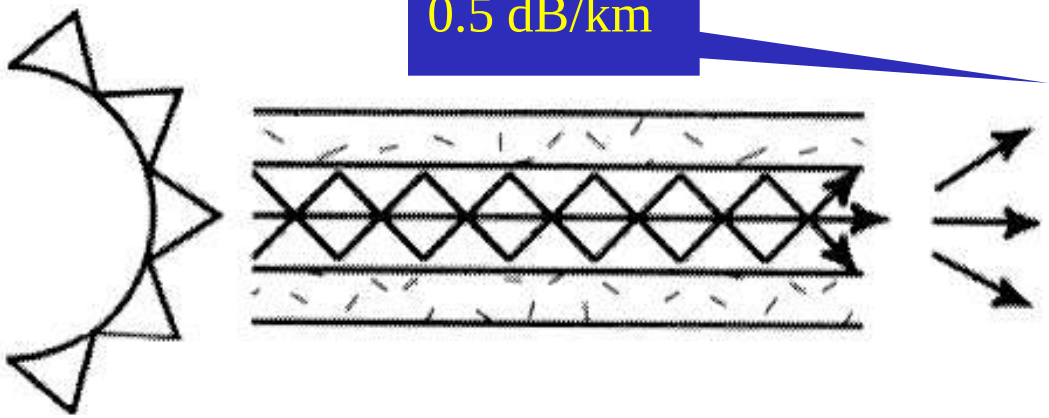
Кому любопытно проверить?

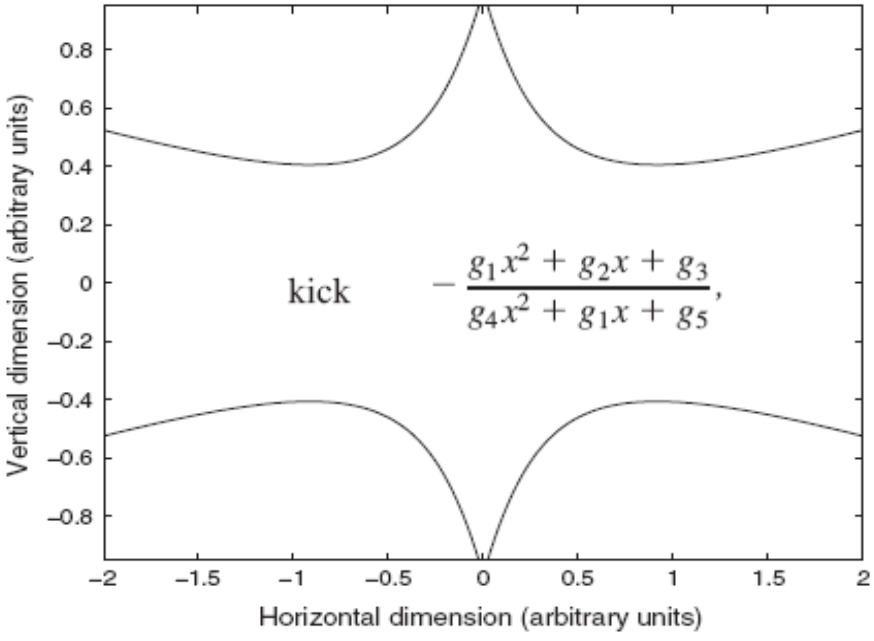

If you can dream it,
you can achieve it.
Bent Objects

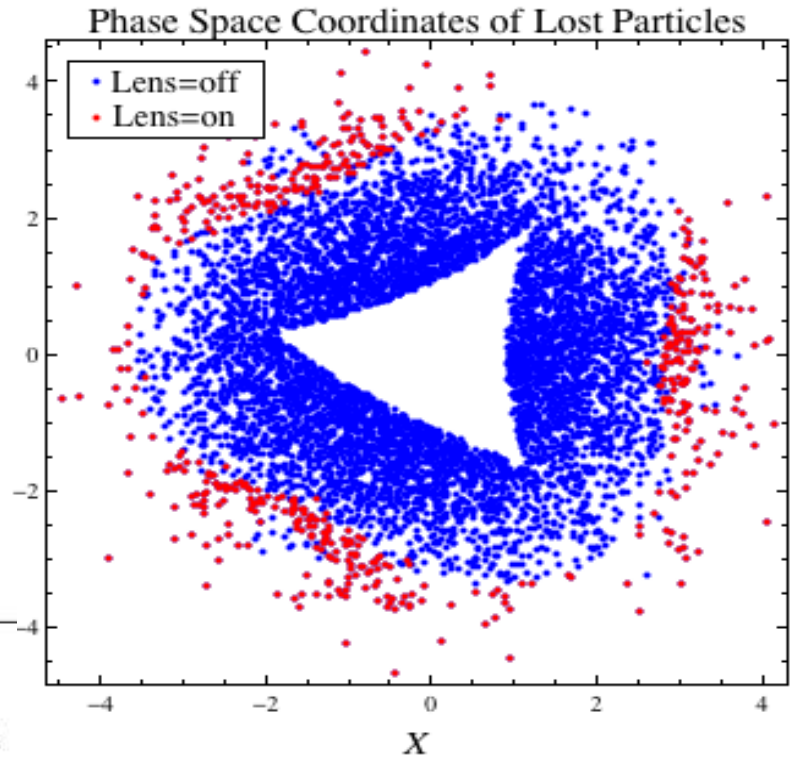
BACK UP

Another Neat Idea: Integrable Optics

0.5 dB/km







PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 11, 114001 (2008)

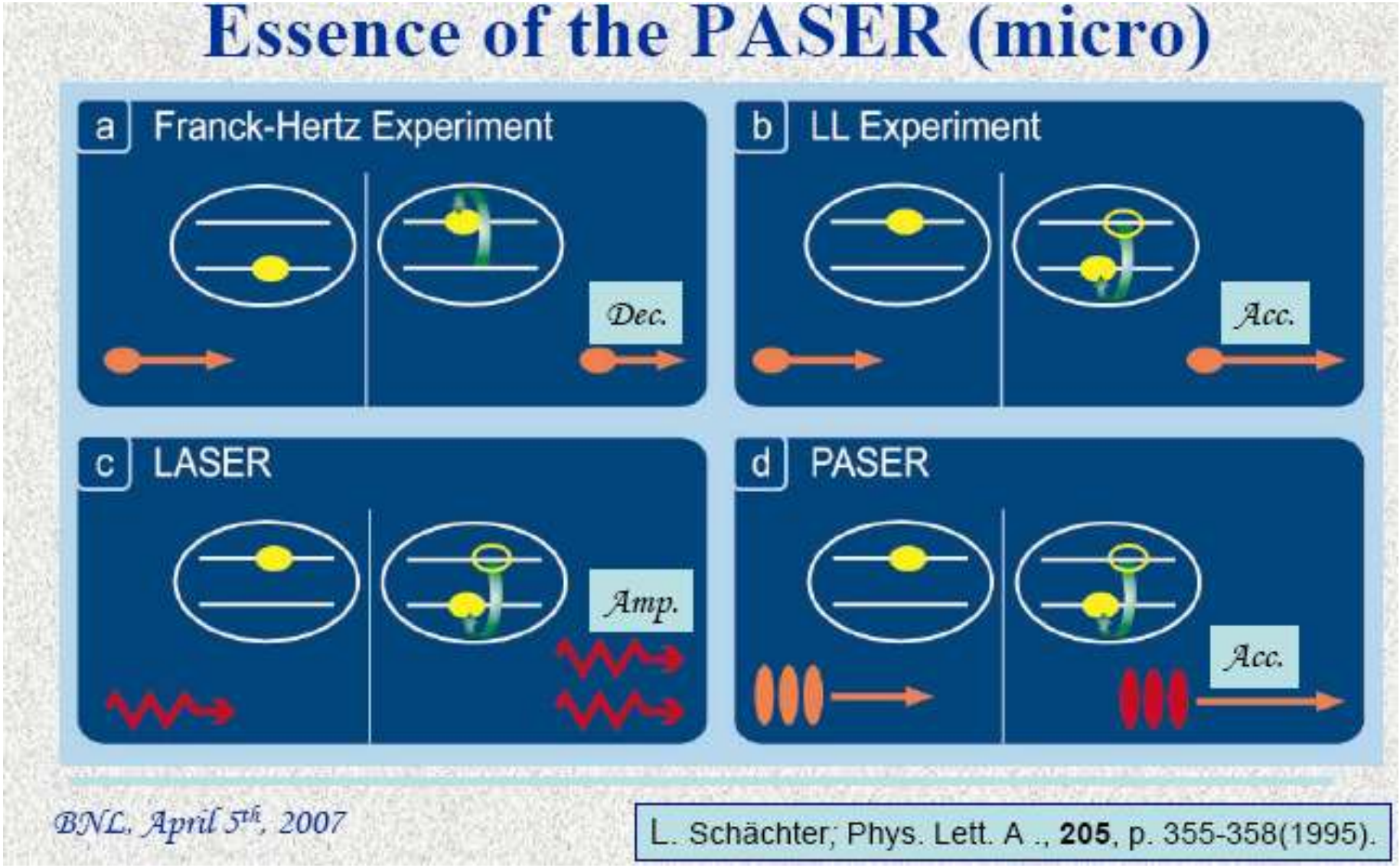
Practical solutions for nonlinear accelerator lattice with stable nearly regular motion

V. Danilov

Spallation Neutron Source Project, Oak Ridge National Laboratory, Building 8600, Oak Ridge, Tennessee 37830, USA

(Received 21 August 2008; published 20 November 2008)

Beam in Active(Excited) Media

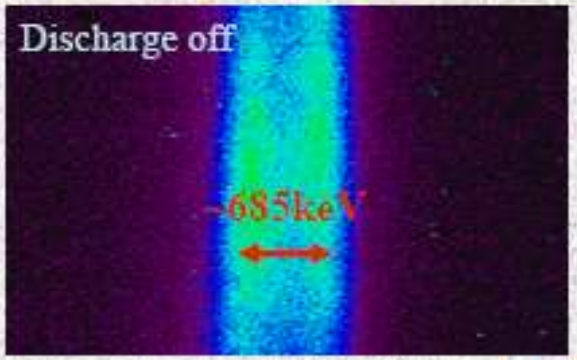


MC vs CLIC: M&S+Labor

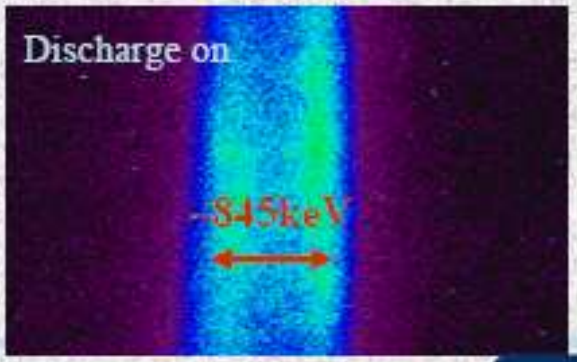
Experiment
Experiment

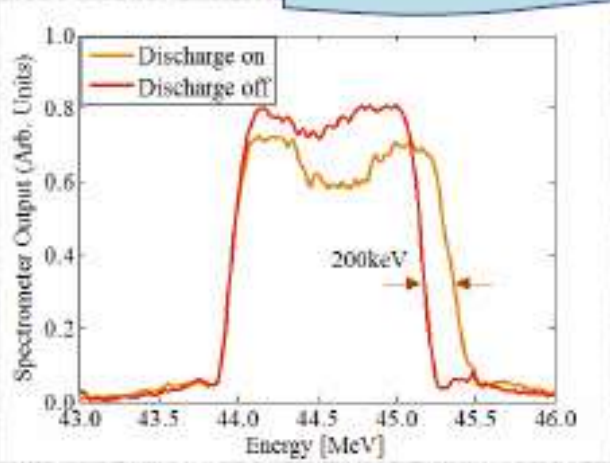
2,000,000 collisions !!

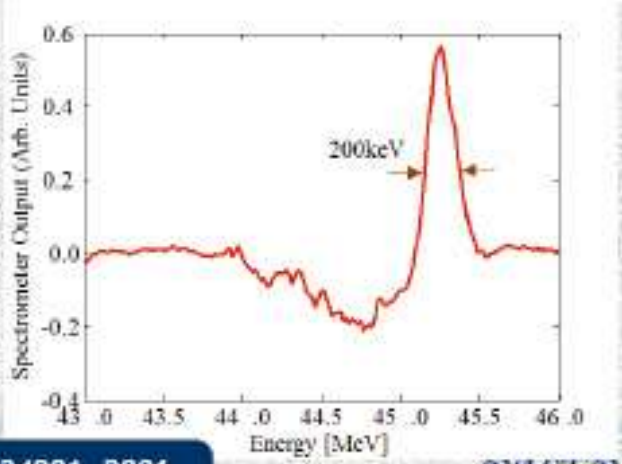
1.5% peak-to-peak energy modulation



Direction of increasing energy







Banna et al., PRL 97, 134801, 2006

Future Colliders Comparison Table

	ILC	MC	CLIC
com Energy TeV	0.5	1.5-4	3
Acceleration feasible (techn.)	~yes	yes by 2013*	yes by 2011
Performance (L) feasible now?	~yes x(1/10-1)	? x1/1000	? x1/100
Cost : known?	~16B$	by 2013*	by 2011
Hi-Tech length	36km	14-20km	~60km
wall power, MW	230	120-200	380-430
Complexity # of elements	~24,000	~6,000	~220,000

Прогресс и перспективы