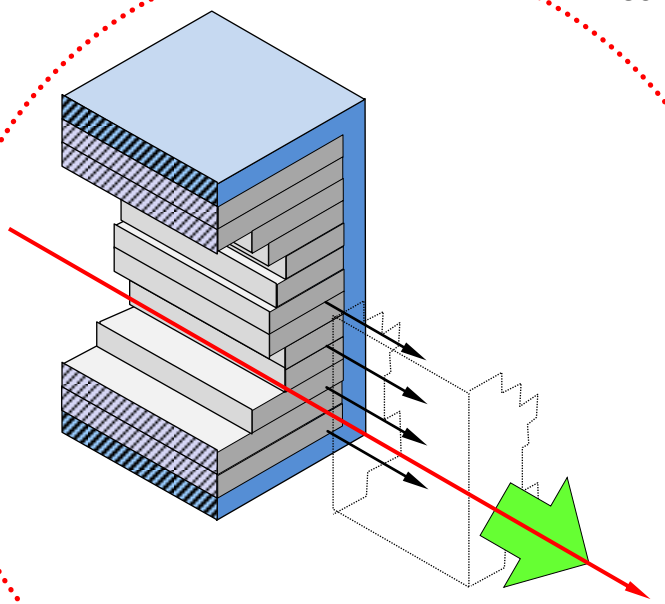
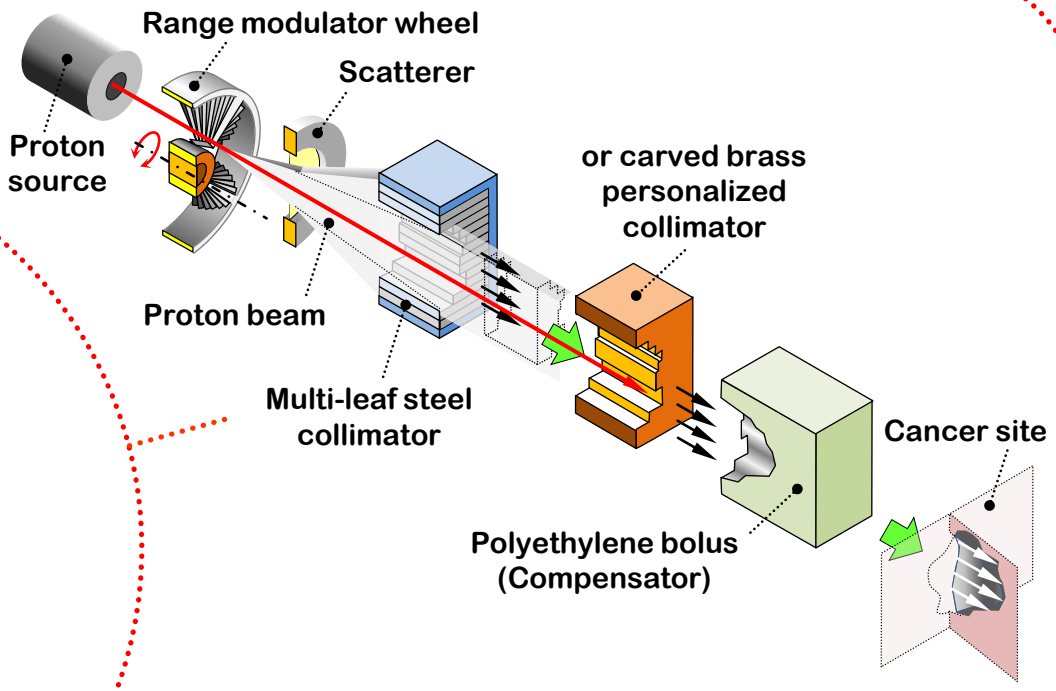
1. Segmentation

- Divide an object into independent parts.
- Make an object easy to disassemble.
- Increase the degree of fragmentation or segmentation.



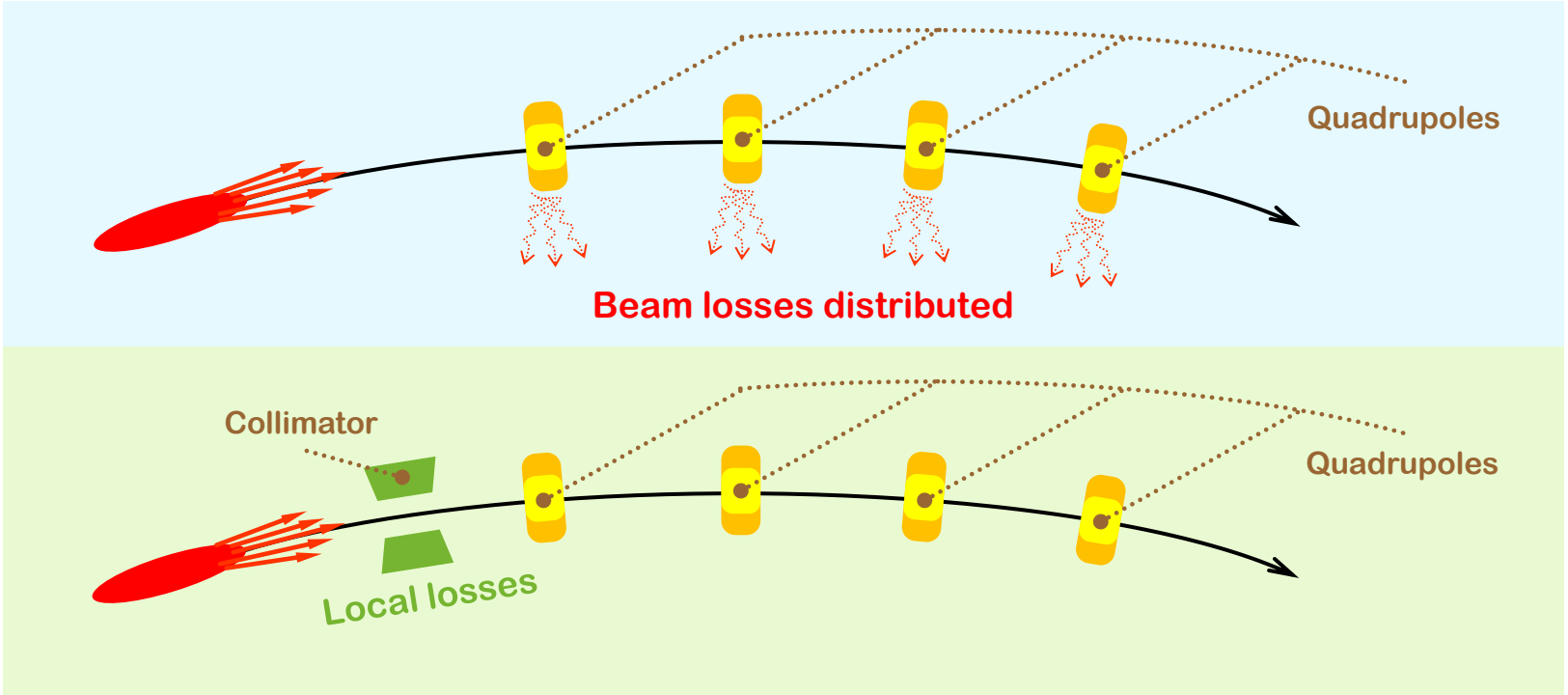
Multi-leaf steel collimator



Proton therapy

2.Taking out

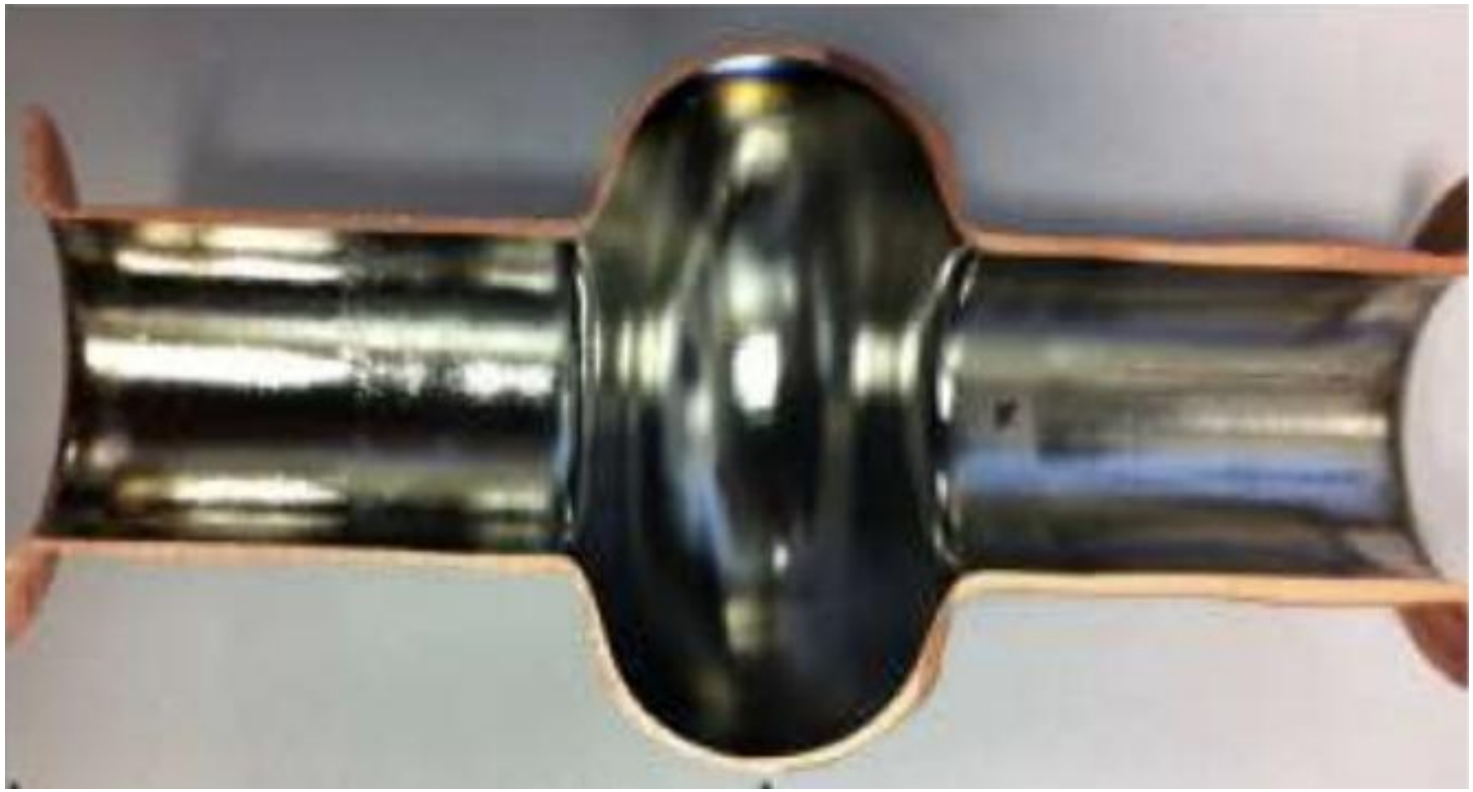
- Separate an interfering part or property from an object;
- Single out the only necessary part (or property) of an object.



Collimation of the beam to localize beam losses

3. Local quality

- Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform.
- Make each part of an object function in conditions most suitable for its operation.
- Make each part of an object fulfill a different and useful function.

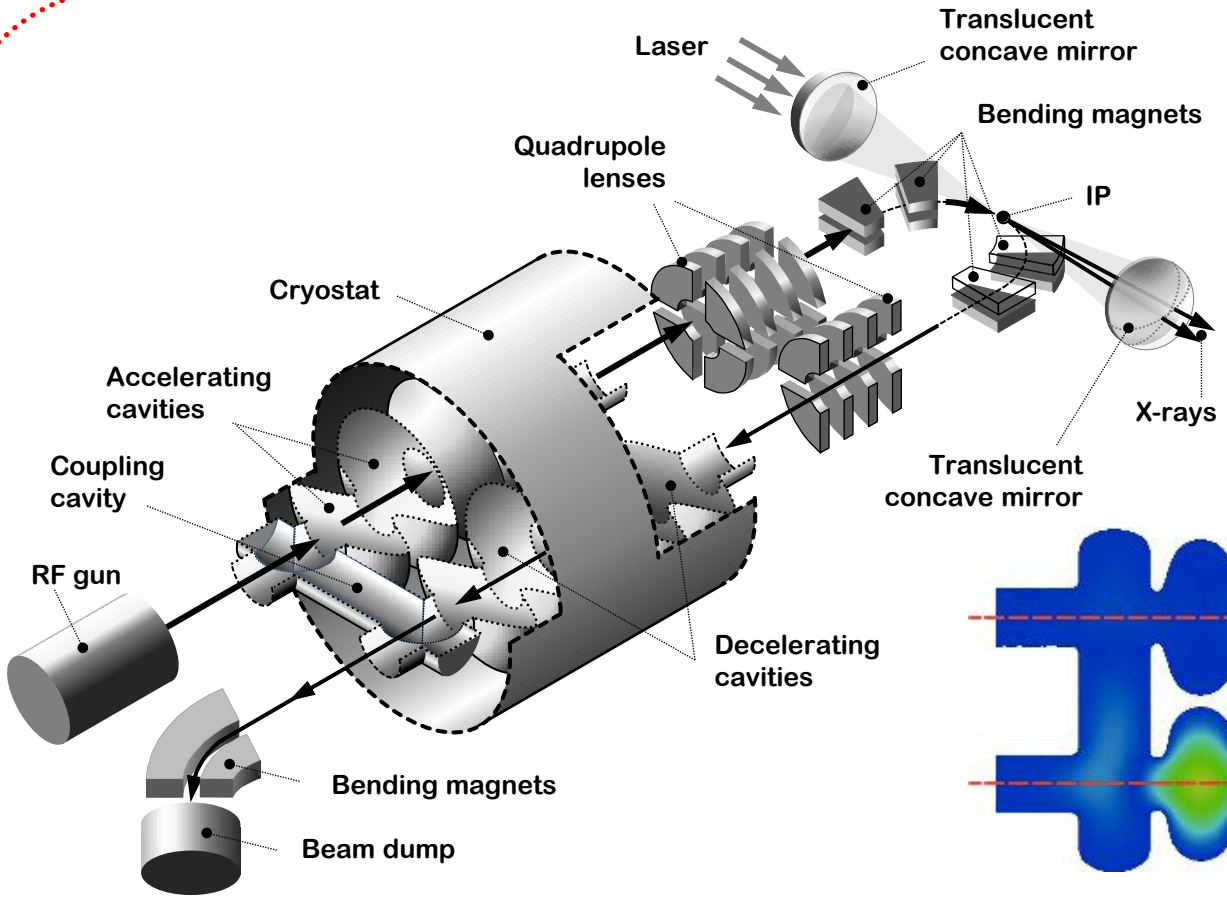


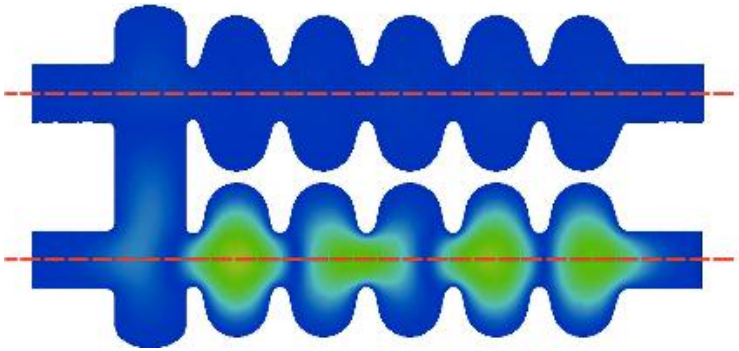
Nb coated copper cavity

Enzo Palmieri, A.A.Rossi, R. Vaglio, "Experimental Results on Thermal Boundary Resistance for Nb and Nb/Cu", Science, Oct 2014

4. Asymmetry

- Change the shape of an object from symmetrical to asymmetrical.
  - If an object is asymmetrical, increase its degree of asymmetry.





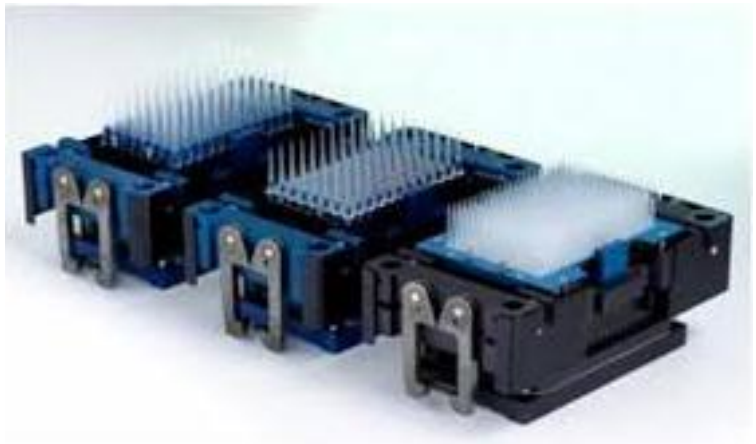
Cavities are slightly different to resonate on the main mode but be decoupled for all higher order modes

R. Ainsworth, G. Burt, I. V. Konoplev, A. Seryi, arXiv:1509.03675, 2015

5. Merging

- **Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations.**
- **Make operations contiguous or parallel; bring them together in time.**

Single-channel and Multi-channel (8- and 12-) pipettes

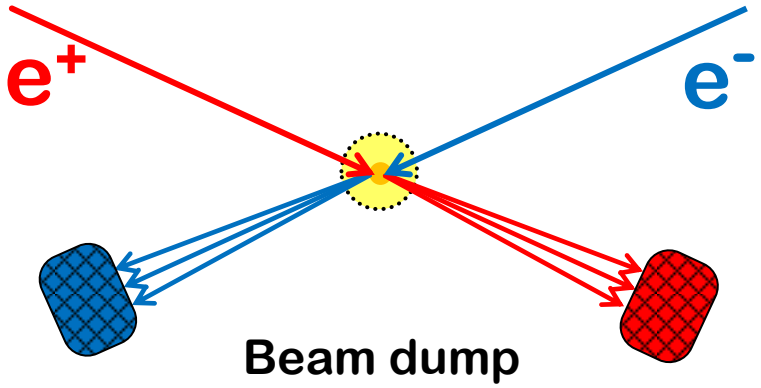


96- or 384-channel Modular Dispense Technology™ (MDT) dispense heads. PerkinElmer Janus.

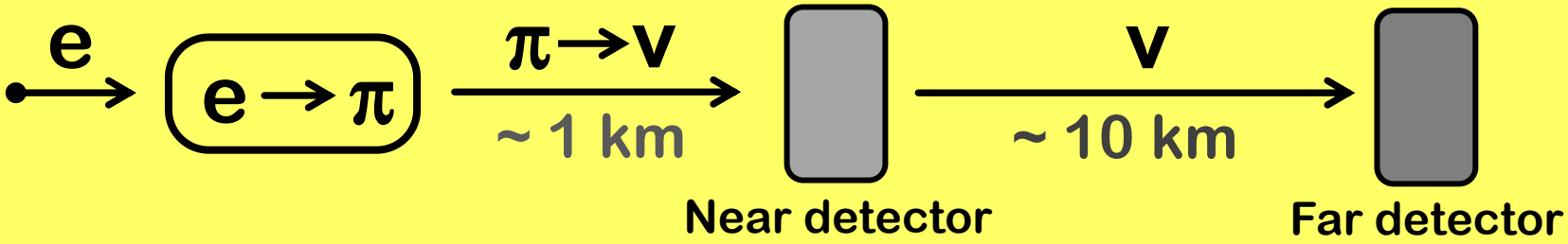
Illustration: PerkinElmer

6. Universality

- Make a part or object perform multiple functions; eliminate the need for other parts.



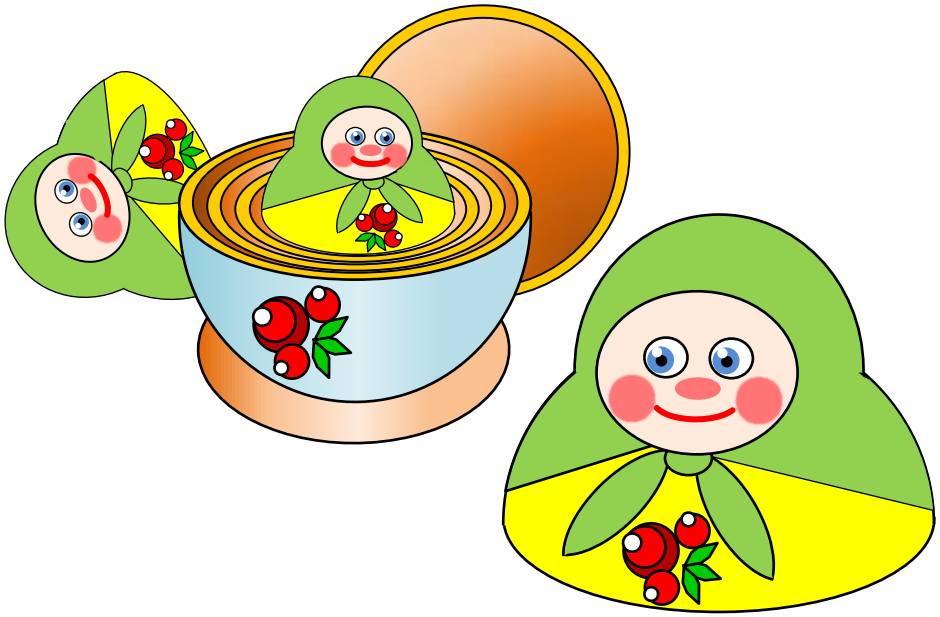
Make beam dump of linear collider to be sub-critical reactor to generate power or make neutrino factory out of it

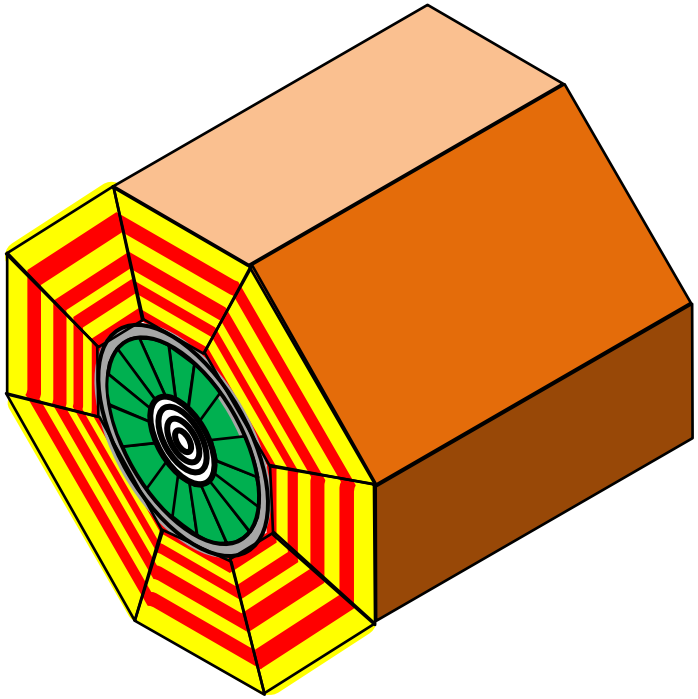


I.F. Ginzburg, arXiv:1411.3295, 2014

7. Nested doll

- Place one object inside another; place each object, in turn, inside the other.
- Make one part pass through a cavity in the other.

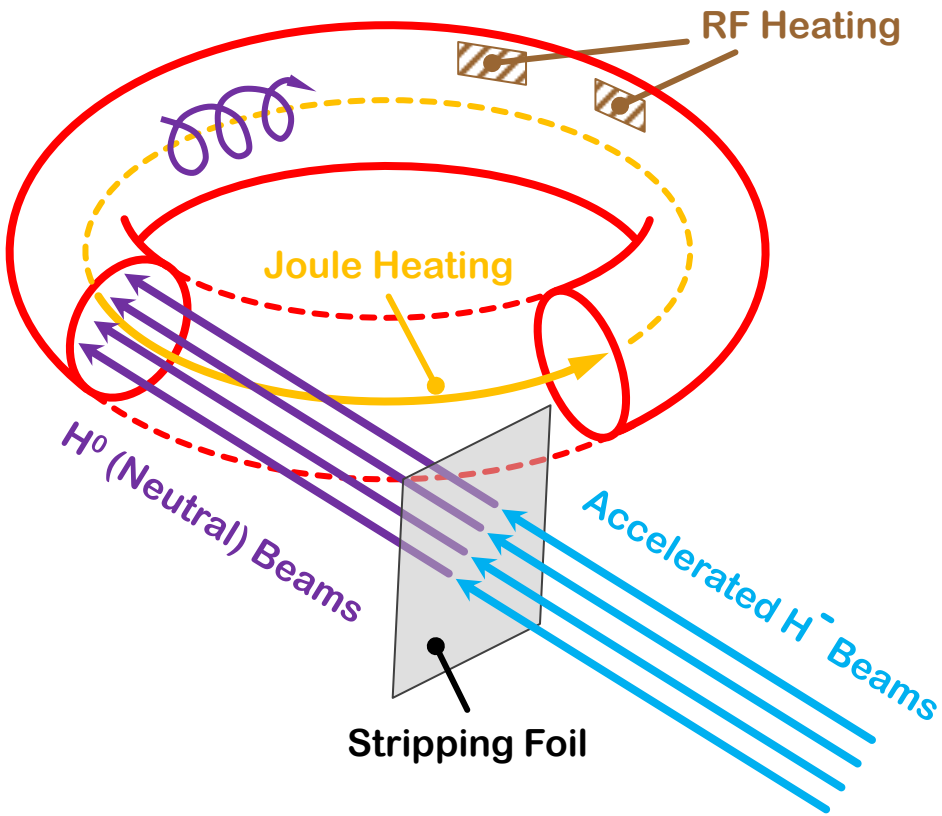




High energy physics detectors

8. Anti-~~weight~~ force

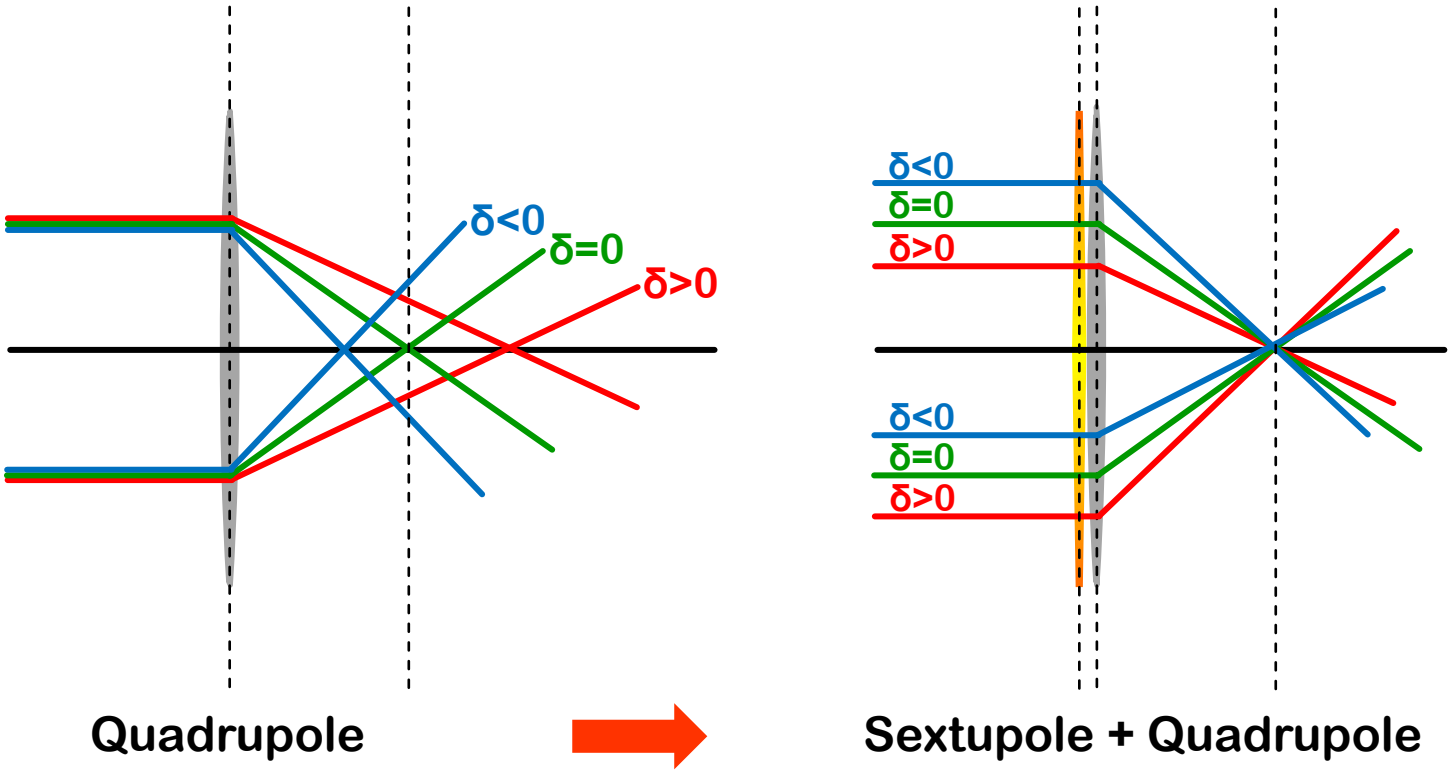
- To compensate for the ~~weight of~~ force on an object, merge it with other objects that provide compensating force.
- To compensate for the ~~weight of~~ force on an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).



Heating of plasma with neutral beams

9. Preliminary anti-action

- If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.
- Create beforehand stresses in an object that will oppose known undesirable working stresses later on.



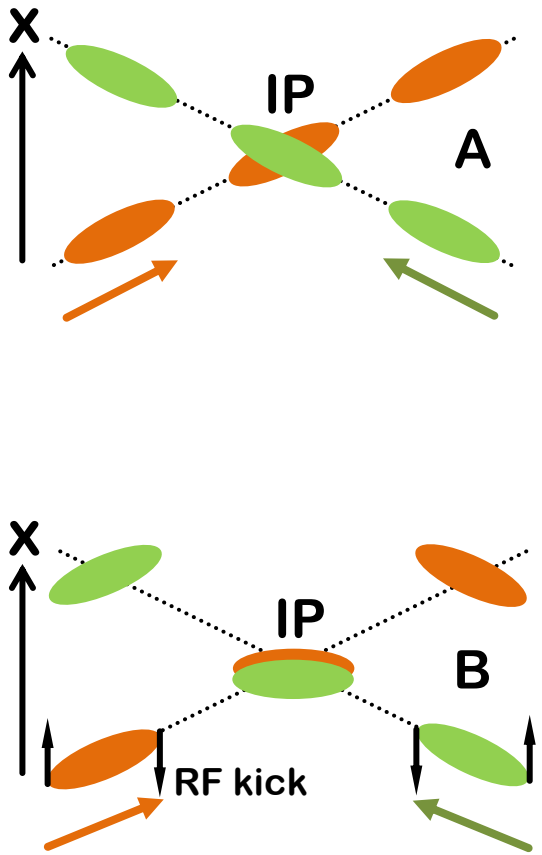
Quadrupole → Sextupole + Quadrupole

Local chromatic correction

P. Raimondi, A. Seryi, PRL, 86, 3779 (2001)

10. Preliminary action

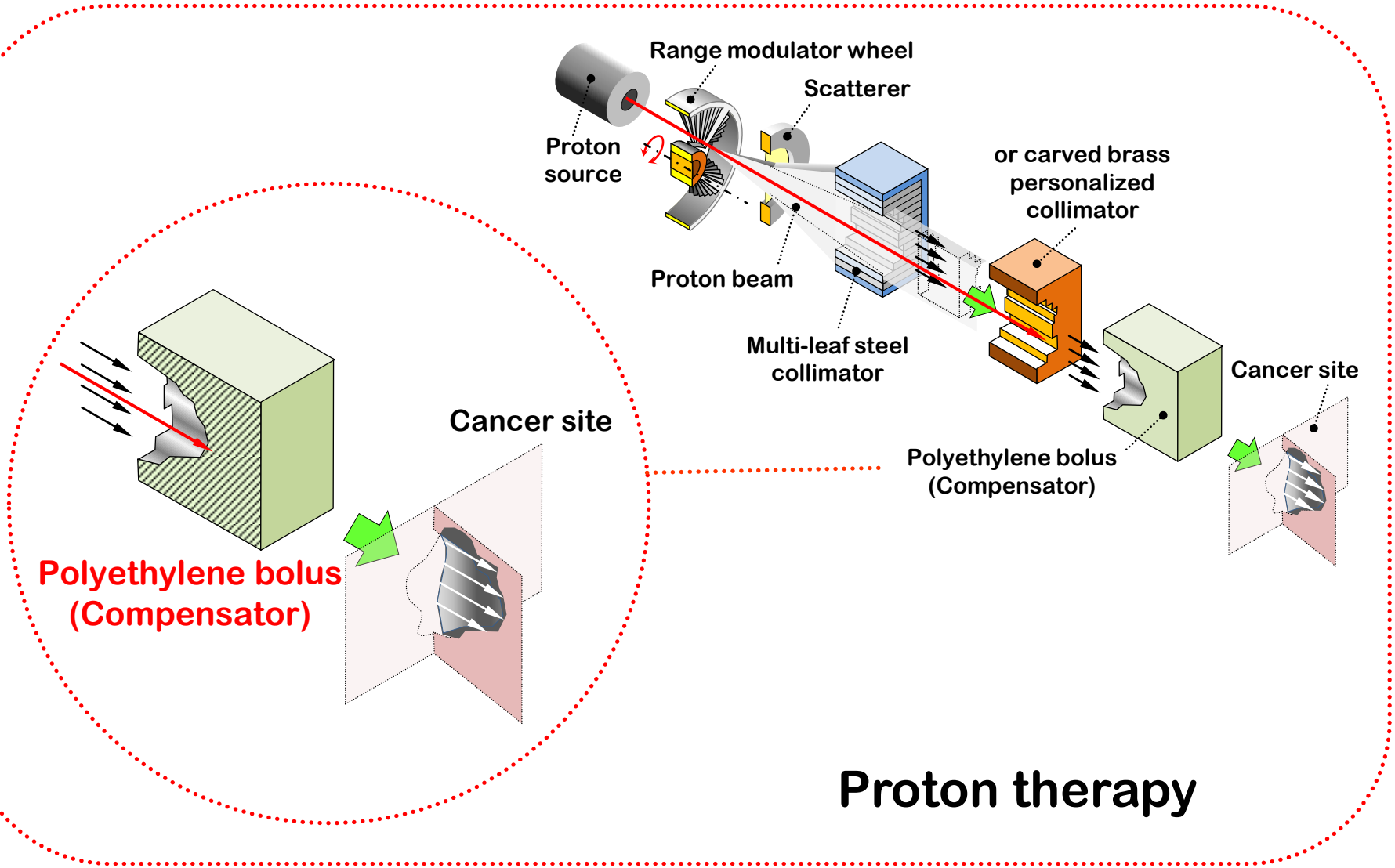
- Perform, before it is needed, the required change of an object (either fully or partially).
- Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.



Crabbed collisions

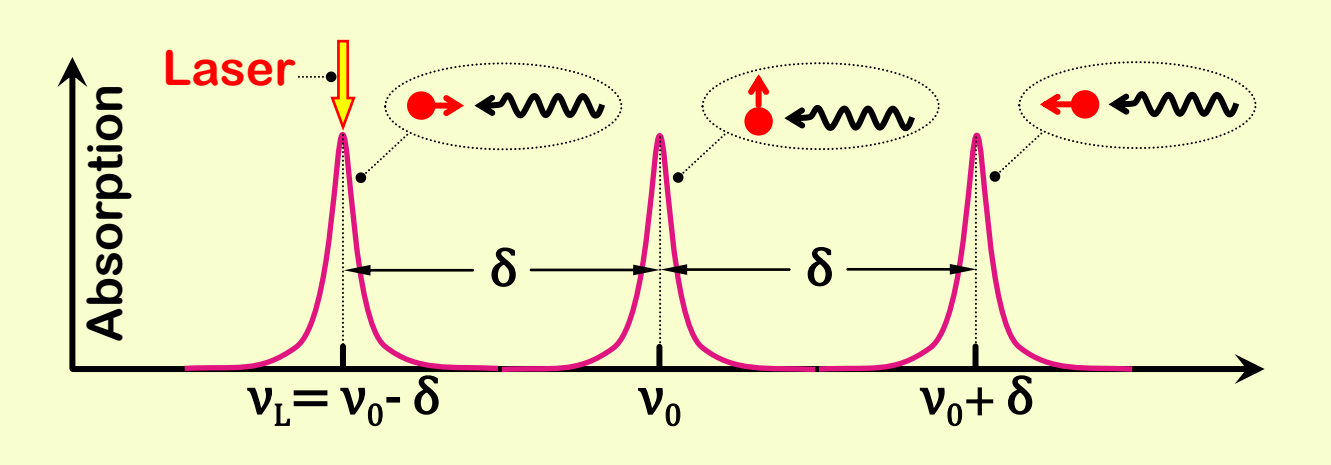
11. Beforehand cushioning

- **Prepare emergency means beforehand to compensate for the relatively low reliability of an object.**



12. Equipotentiality

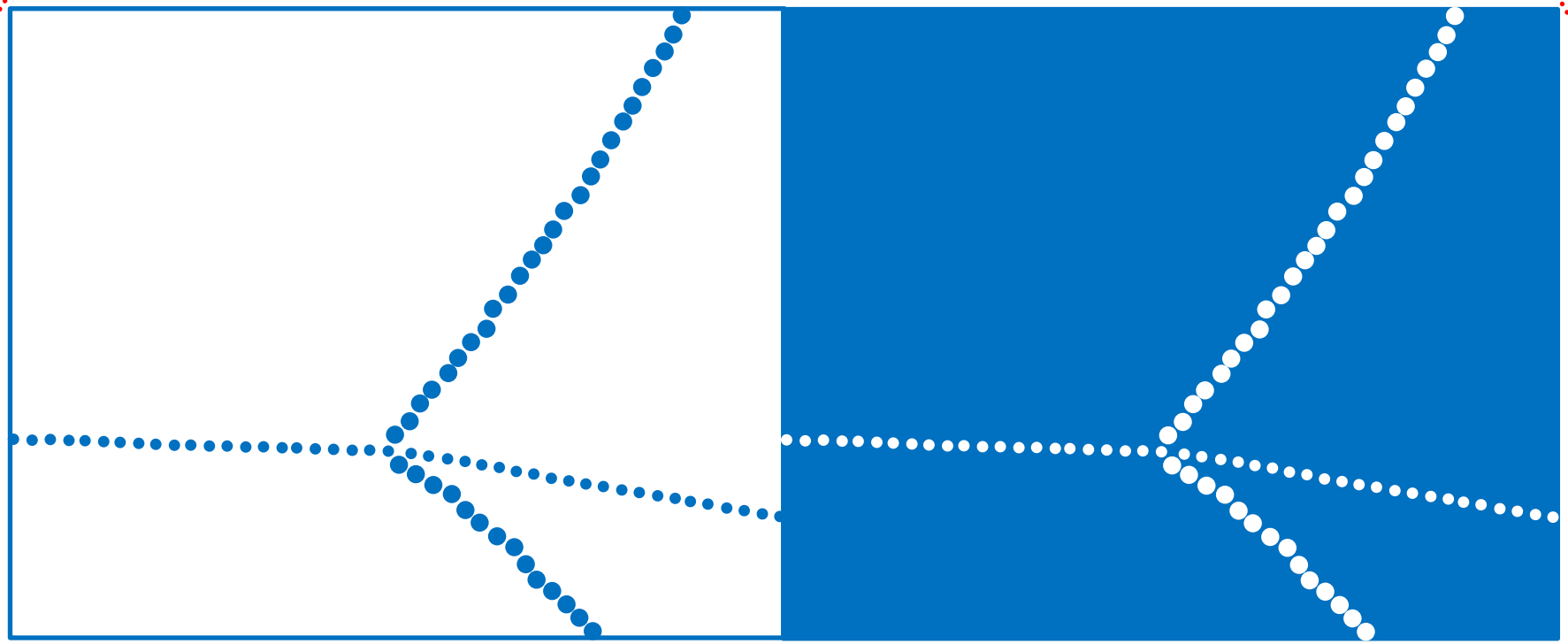
- In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field).



Laser cooling

13. The other way round

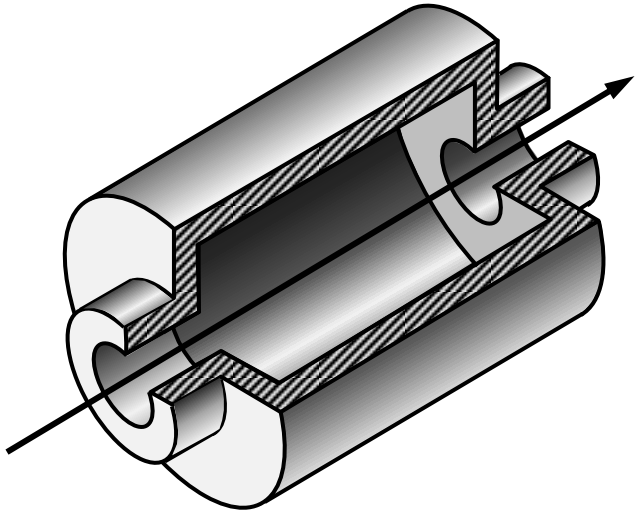
- Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).
- Make movable parts (or the external environment) fixed, and fixed parts movable.
- Turn the object (or process) “upside down”.

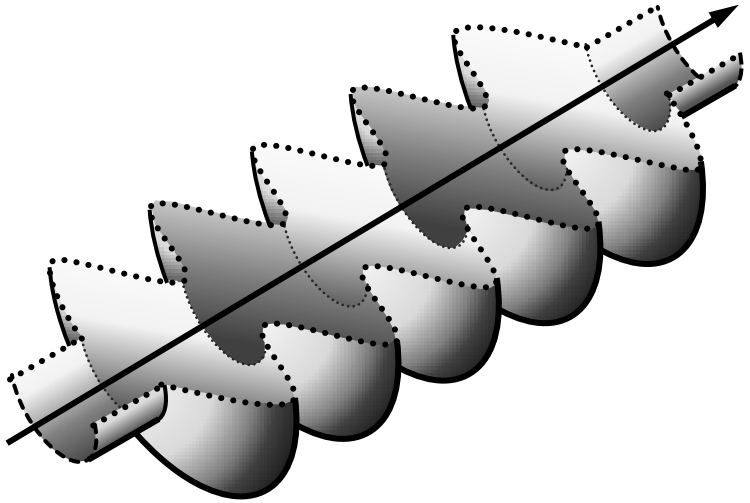


Cloud and bubble chambers

14. Spheroidality – Curvature

- Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures.
- Use rollers, balls, spirals, domes.
- Go from linear to rotary motion, use centrifugal forces.

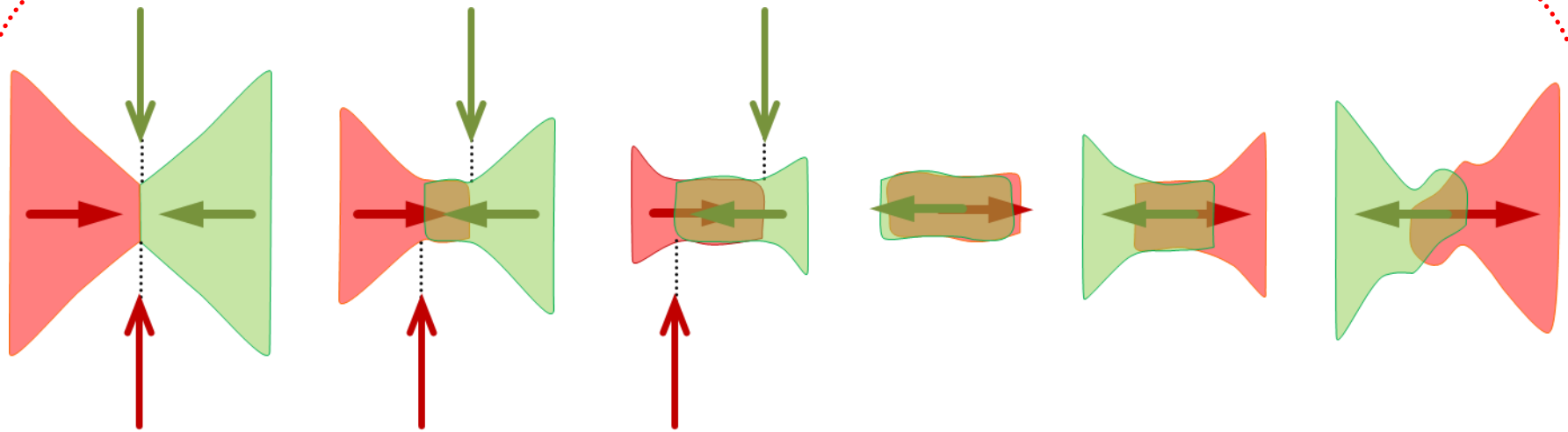




Pill-box and crab-cavity

15. Dynamics

- Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
  - Divide an object into parts capable of movement relative to each other.
  - If an object (or process) is rigid or inflexible, make it movable or adaptive.

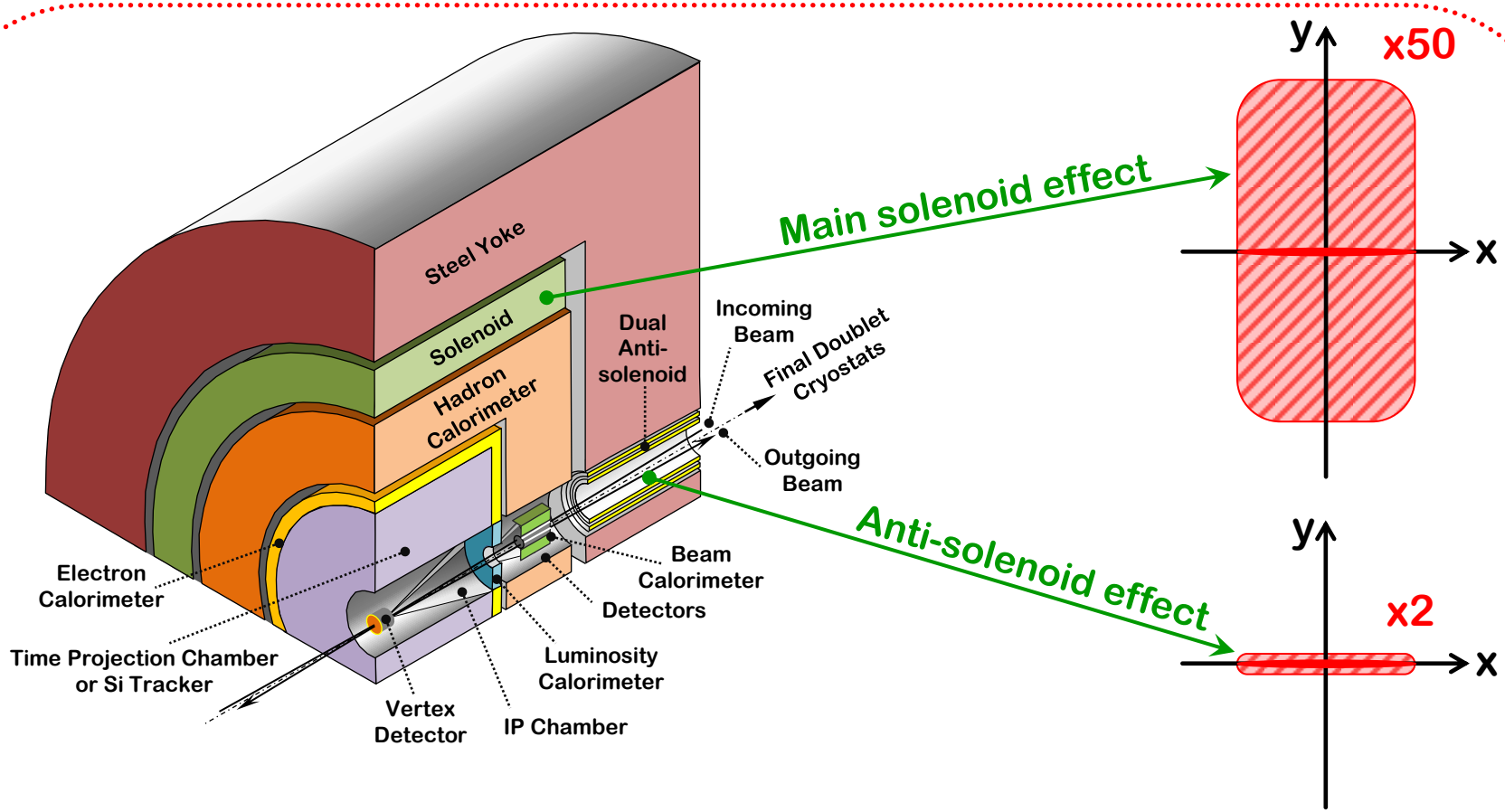


Travelling focus

V. Balakin, 1991

16. Partial or excessive actions

- If 100 percent of an object is hard to achieve using a given solution method then, by using "slightly less" or "slightly more" of the same method, the problem may be considerably easier to solve.

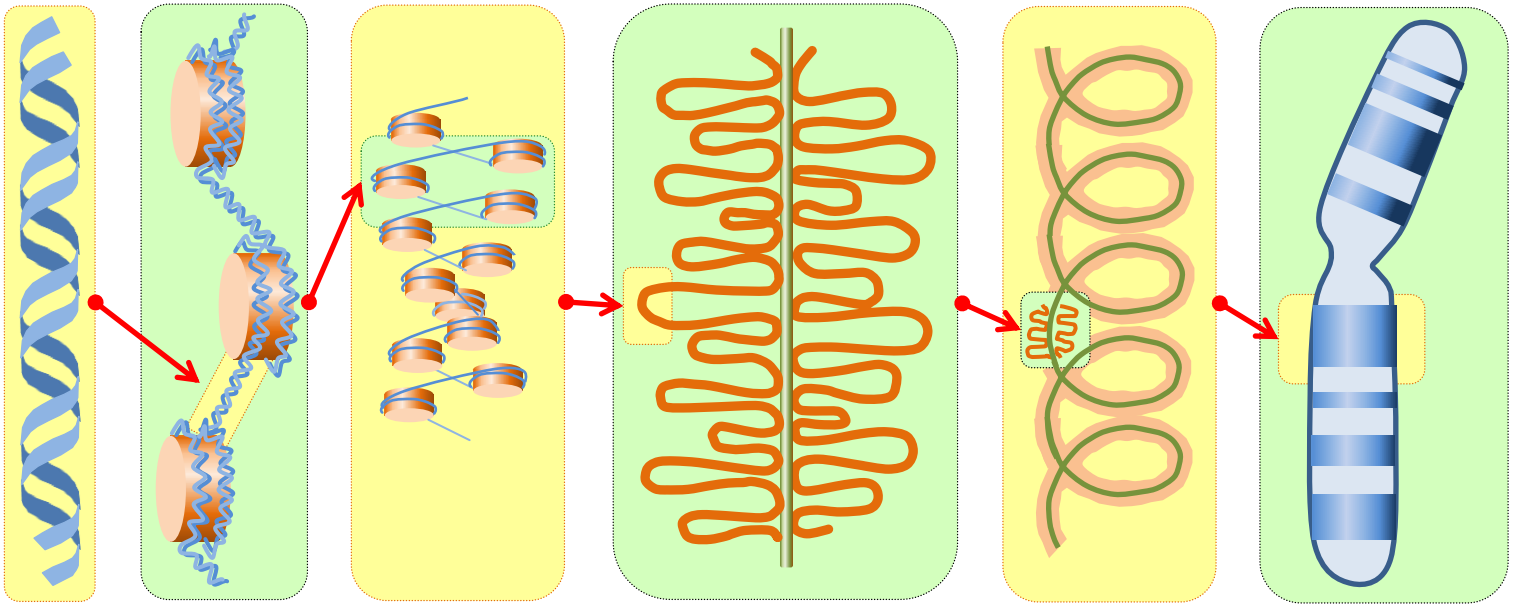


Huge coupling due to overlap of solenoid with Final Doublet quads
=> partial compensation by weak anti-solenoid

Y. Nosochkov, A. Seryi, PRSTAB, 8, 021001 (2005)

17. Another dimension

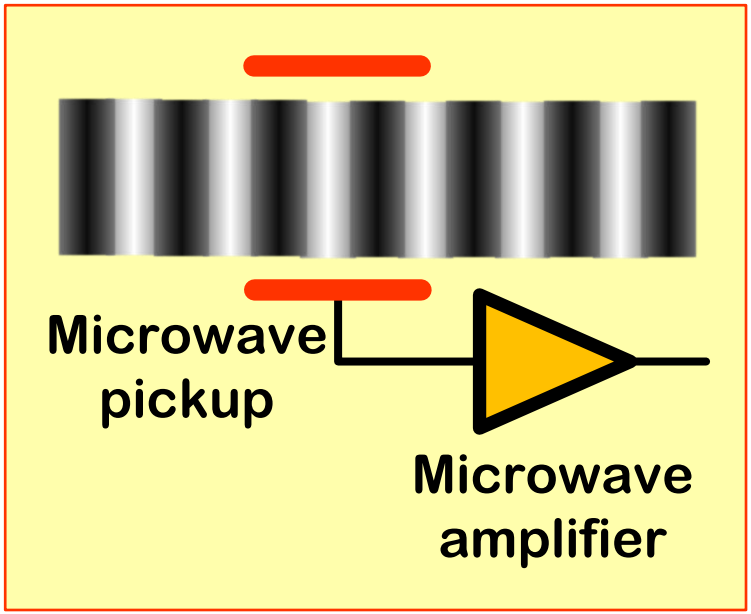
- To move into an additional dimension.
- Use a multi-story arrangement of objects instead of a single-story arrangement.
- Tilt or re-orient the object, lay it on its side.
- Use “another side” of a given area.

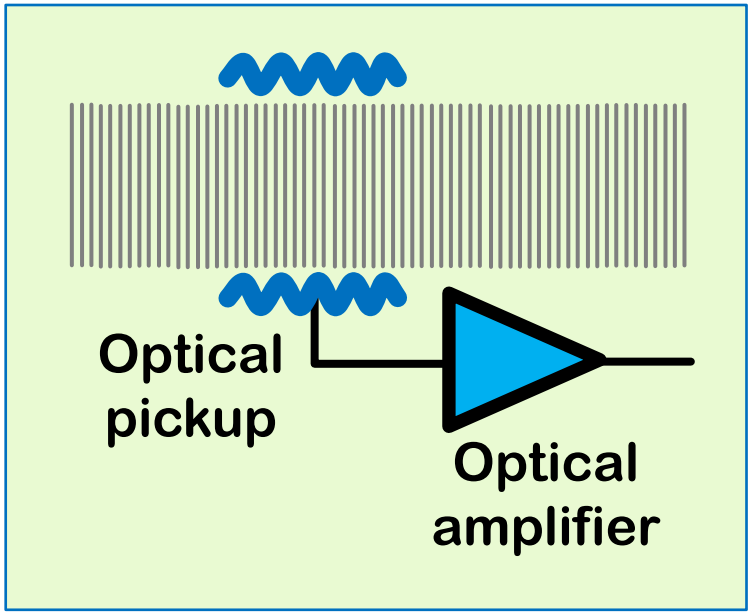


DNA packaging levels

18. ~~Mechanical vibration~~ Oscillations and resonances

- Cause an object to oscillate or vibrate.
- Increase its frequency (~~even up to the ultrasonic~~ from microwave to optical).
- Use an object's resonant frequency.
- Use piezoelectric vibrators instead of mechanical ones.
- Use combined ultrasonic and electromagnetic field oscillations.

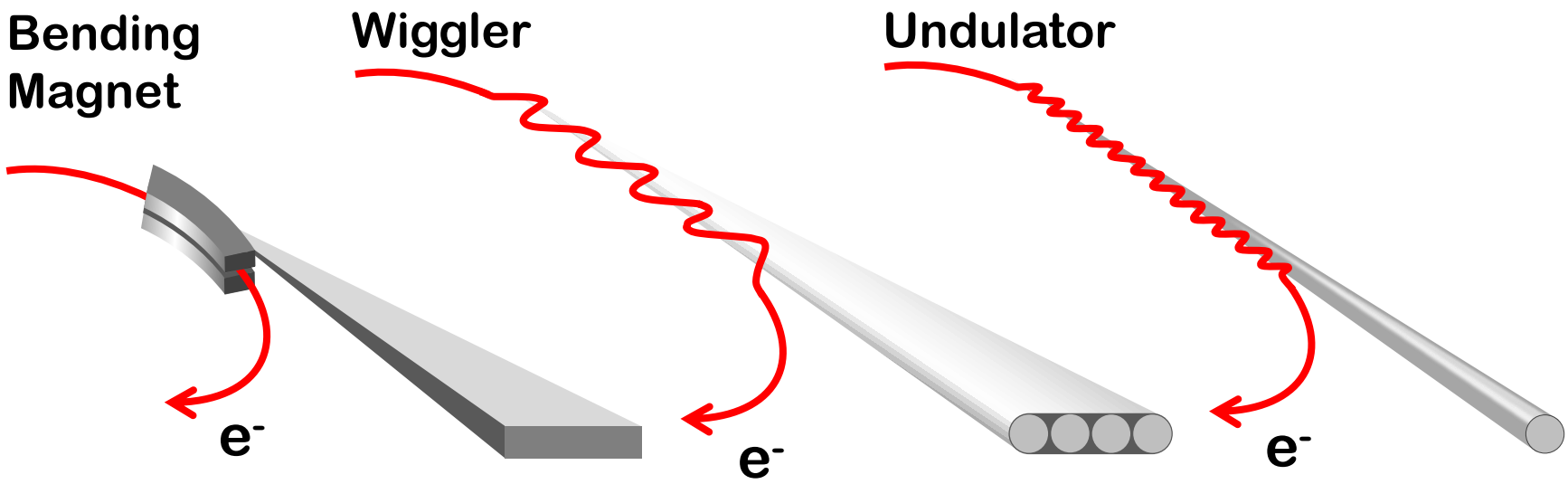




Stochastic cooling => optical stochastic cooling

19. Periodic action

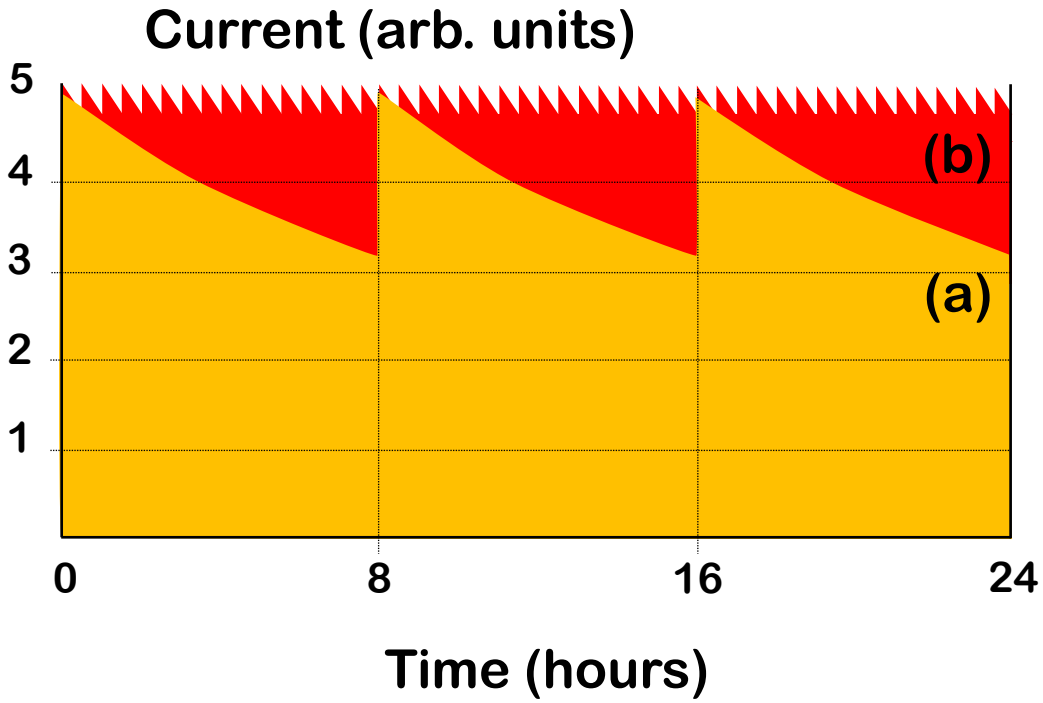
- Instead of continuous action, use periodic or pulsating actions.
- If an action is already periodic, change the periodic magnitude or frequency.
- Use pauses between impulses to perform a different action.



Devices for generation of synchrotron radiation

20. Continuity of useful action

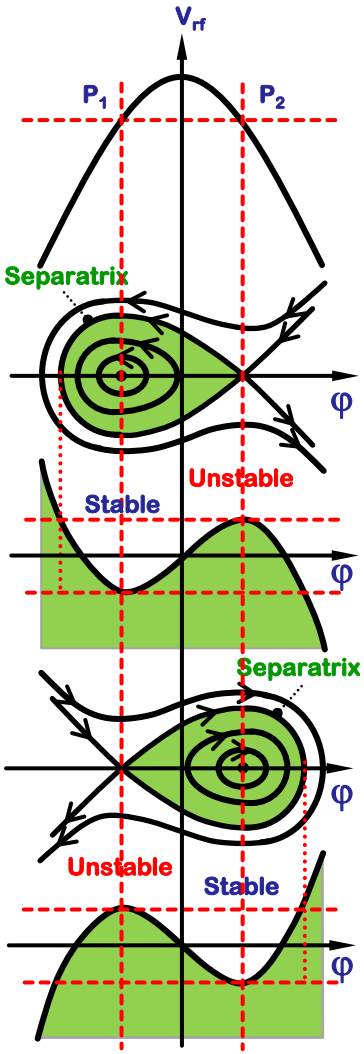
- Carry on work continuously; make all parts of an object work at full load, all the time.
- Eliminate all idle or intermittent actions or work.

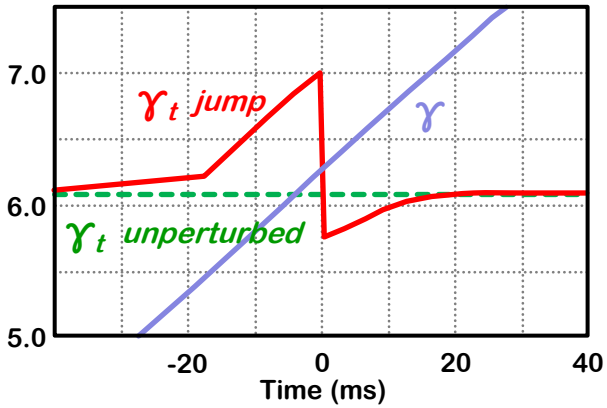


Top off injection

21. Skipping

- Conduct a process , or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.

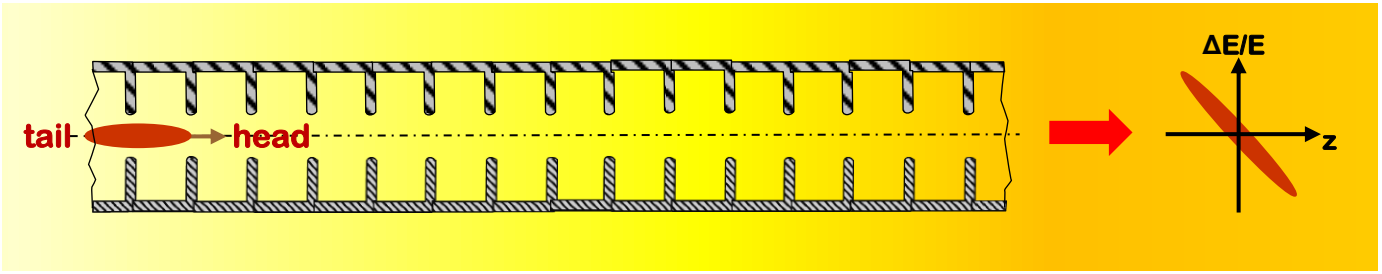




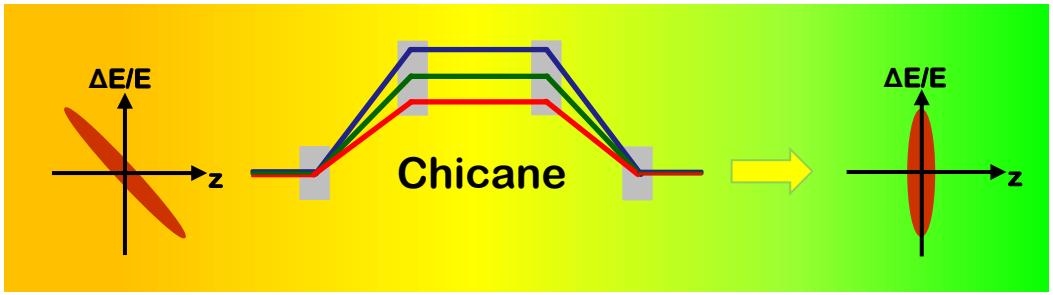
Crossing transition energy with γ_t jump technique

22. "Blessing in disguise" or "Turn Lemons into Lemonade"

- Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.
- Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.
- Amplify a harmful factor to such a degree that it is no longer harmful.



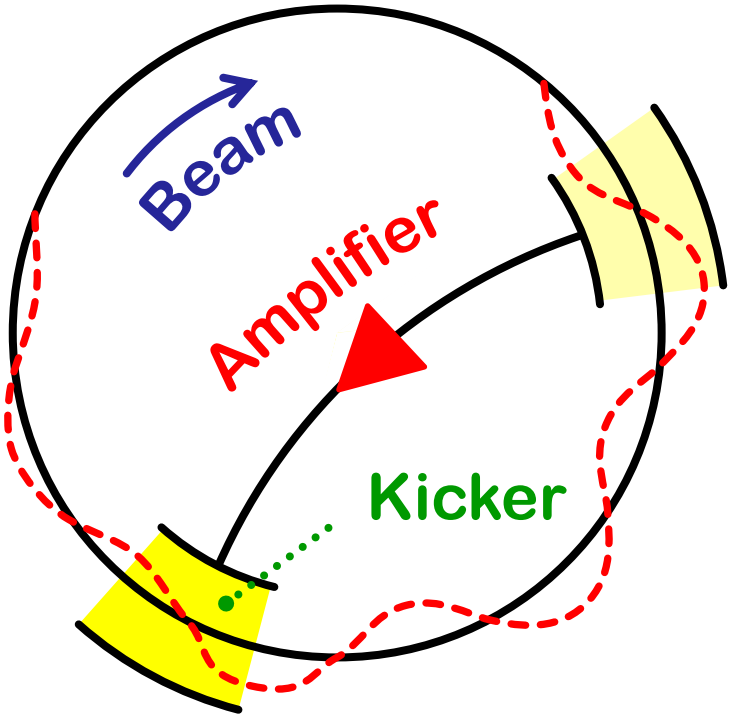
Wakefields in long Linac are harmful.
They can be made useful by compressing bunch for use in FEL.



Linac wake for FEL use

23. Feedback

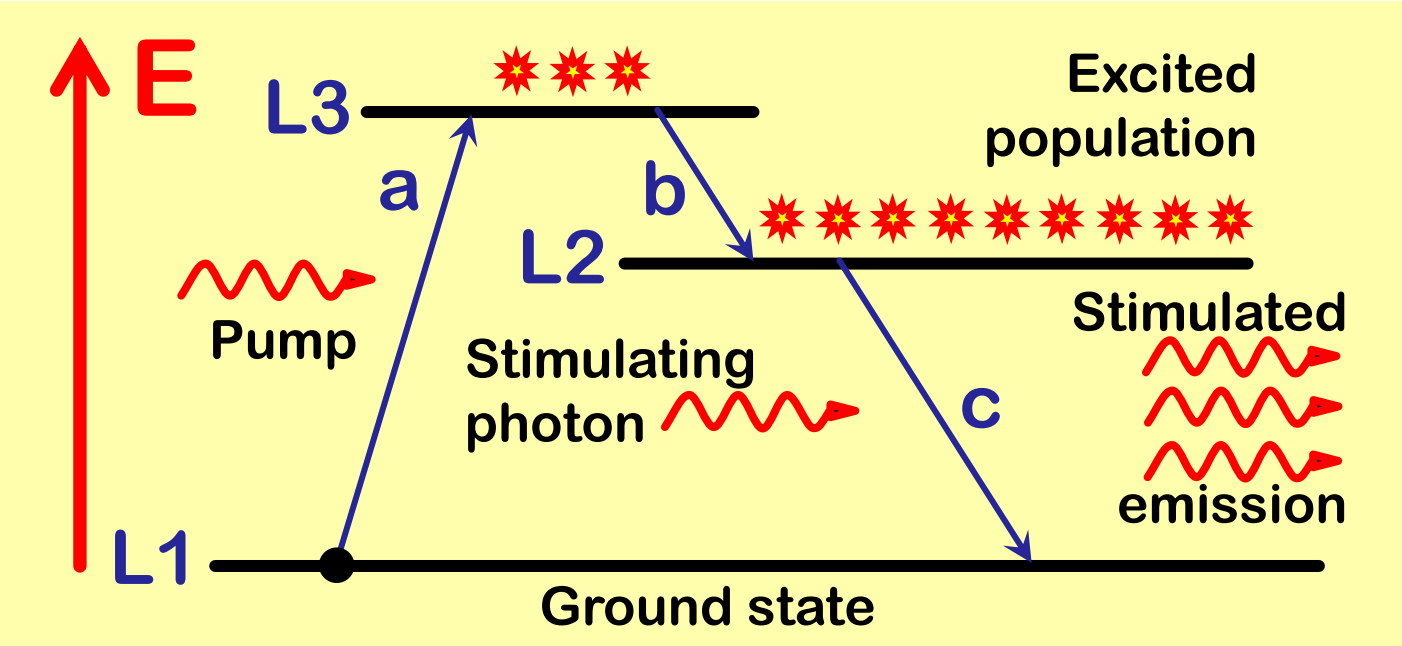
- Introduce feedback (referring back, cross-checking) to improve a process or action.
- If feedback is already used, change its magnitude or influence.



Stochastic cooling

24. Intermediary

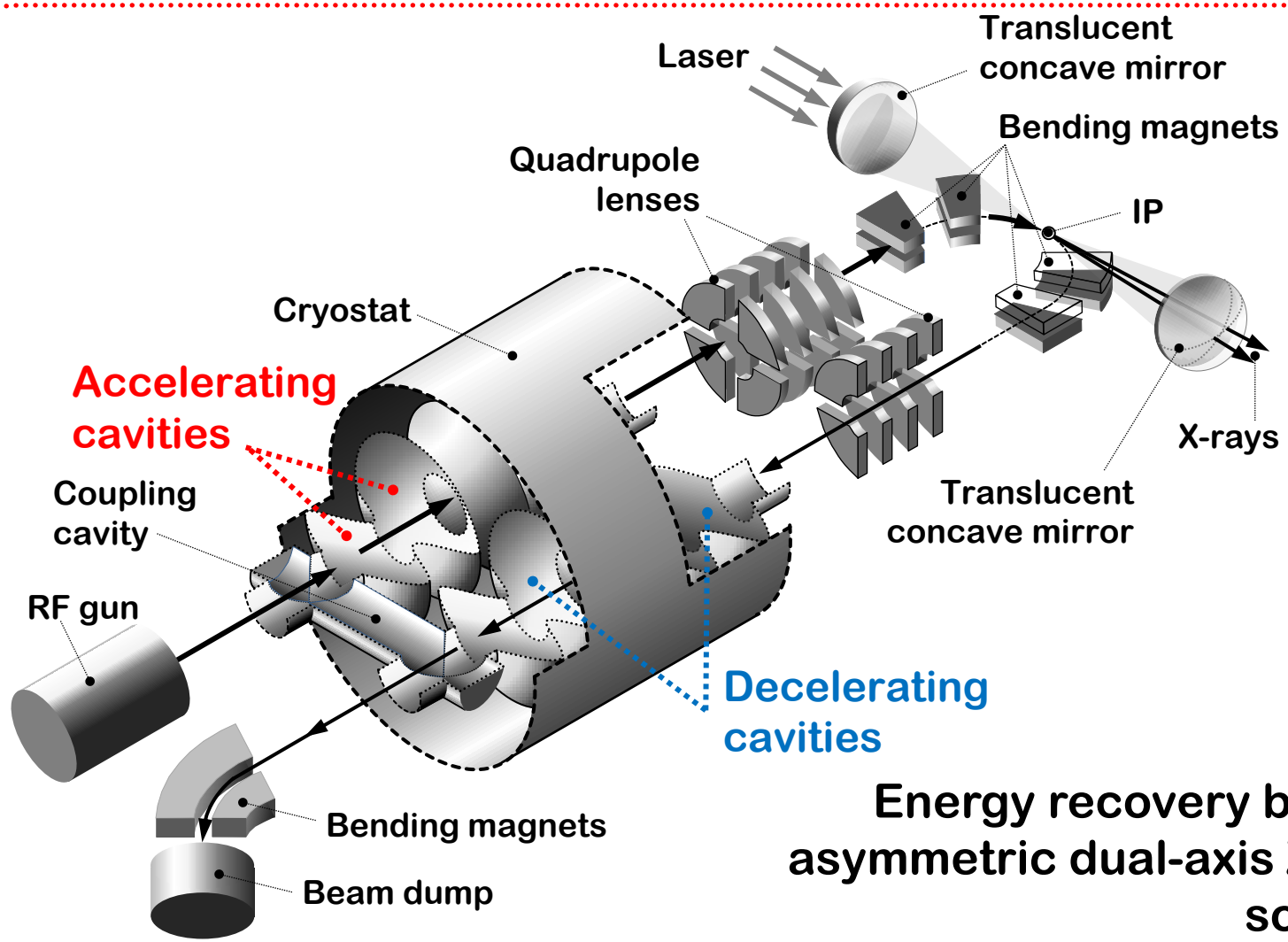
- Use an intermediary carrier object or intermediary process.
- Merge one object temporarily with another (which can be easily removed).



Three-level laser

25. Self service

- Make an object serve itself by performing auxiliary helpful functions
- Use waste resources, energy, or substances.

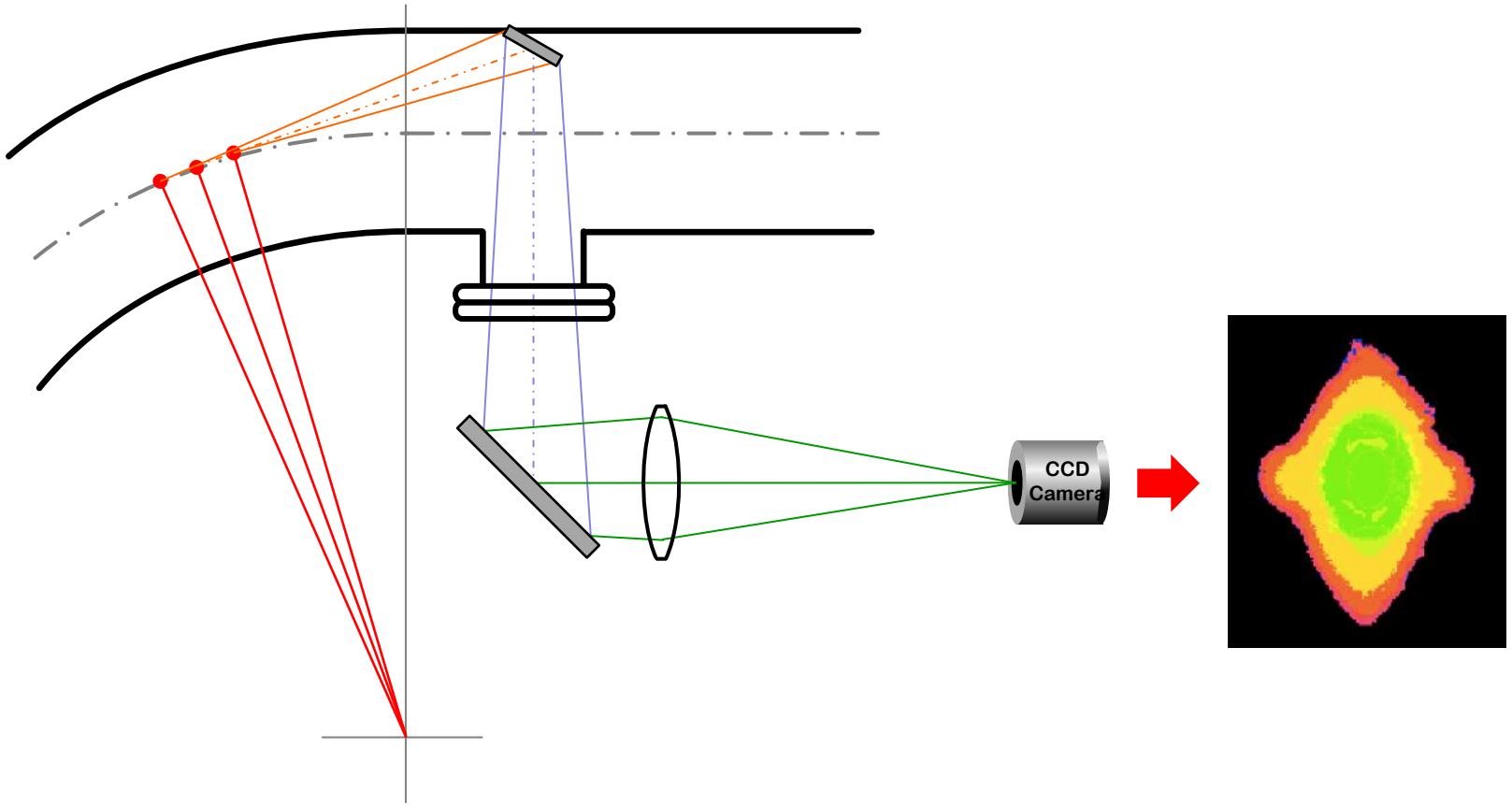


Energy recovery based asymmetric dual-axis X-ray source

R. Ainsworth, G. Burt, I. V. Konoplev, A. Seryi, arXiv:1509.03675, 2015

26. Copying

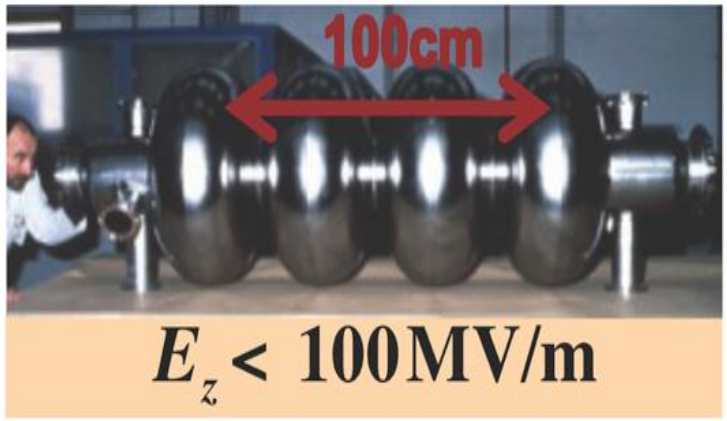
- Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.
- Replace an object, or process with optical copies.
- If visible optical copies are already used, move to infrared or ultraviolet copies.



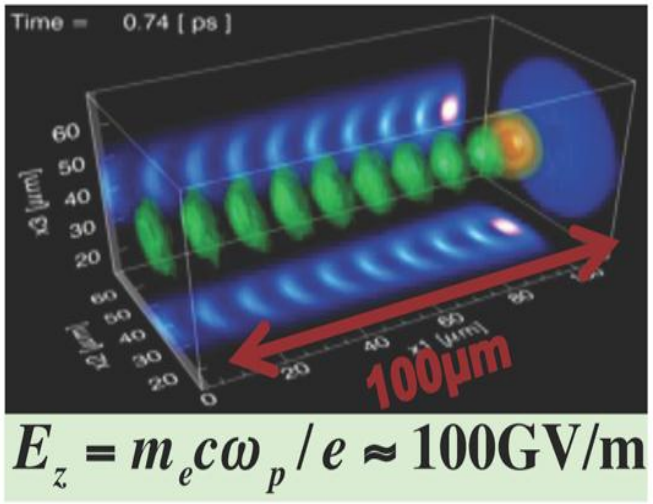
Synchrotron radiation profile monitor

27. Cheap short-living objects

- Replace an expensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).



Accelerating structure, metal (normal conductive or super-conductive)

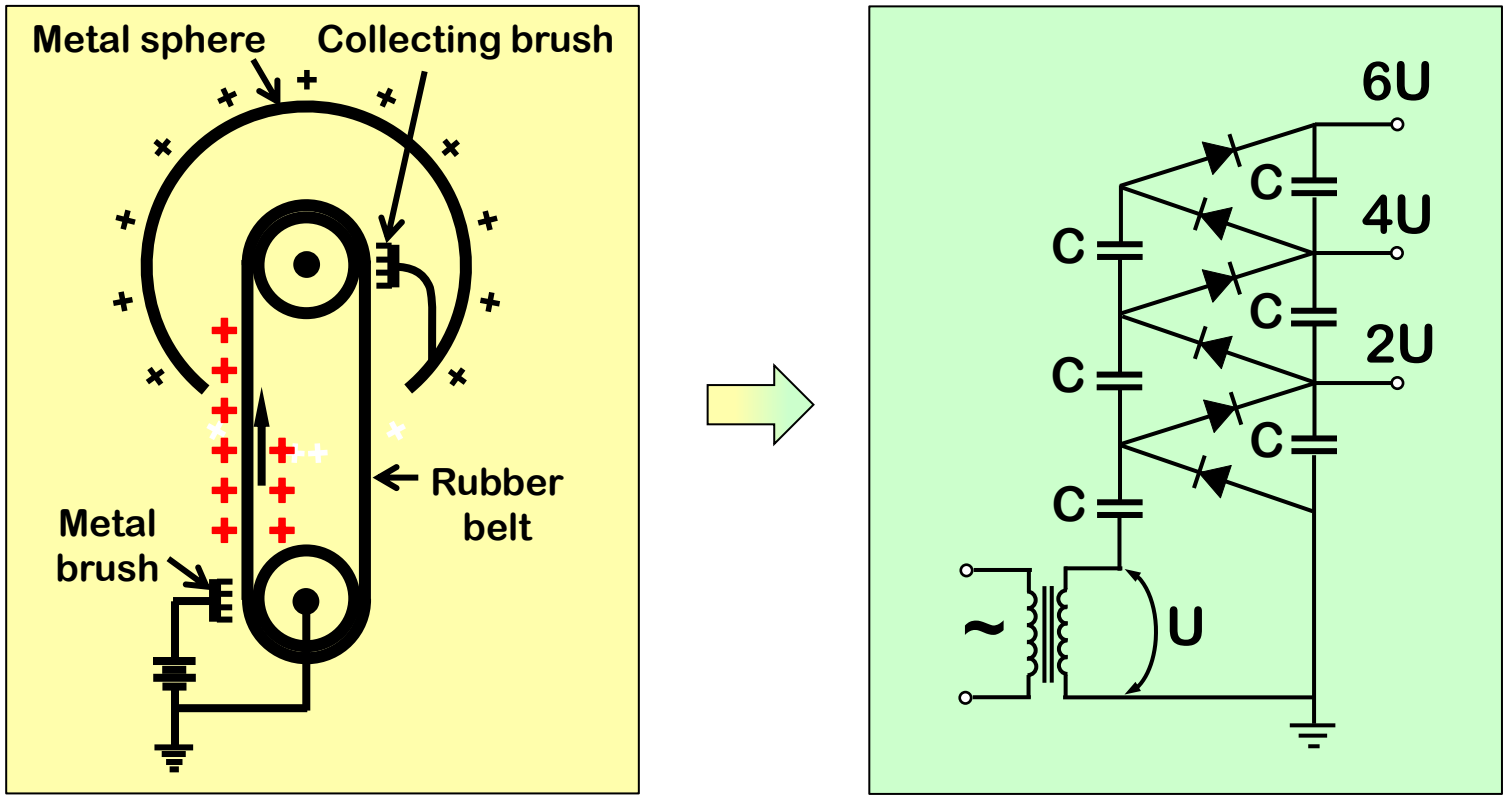


"Accelerating structure" produced on-the-fly in plasma by laser pulse

Plasma acceleration

28. Mechanics substitution

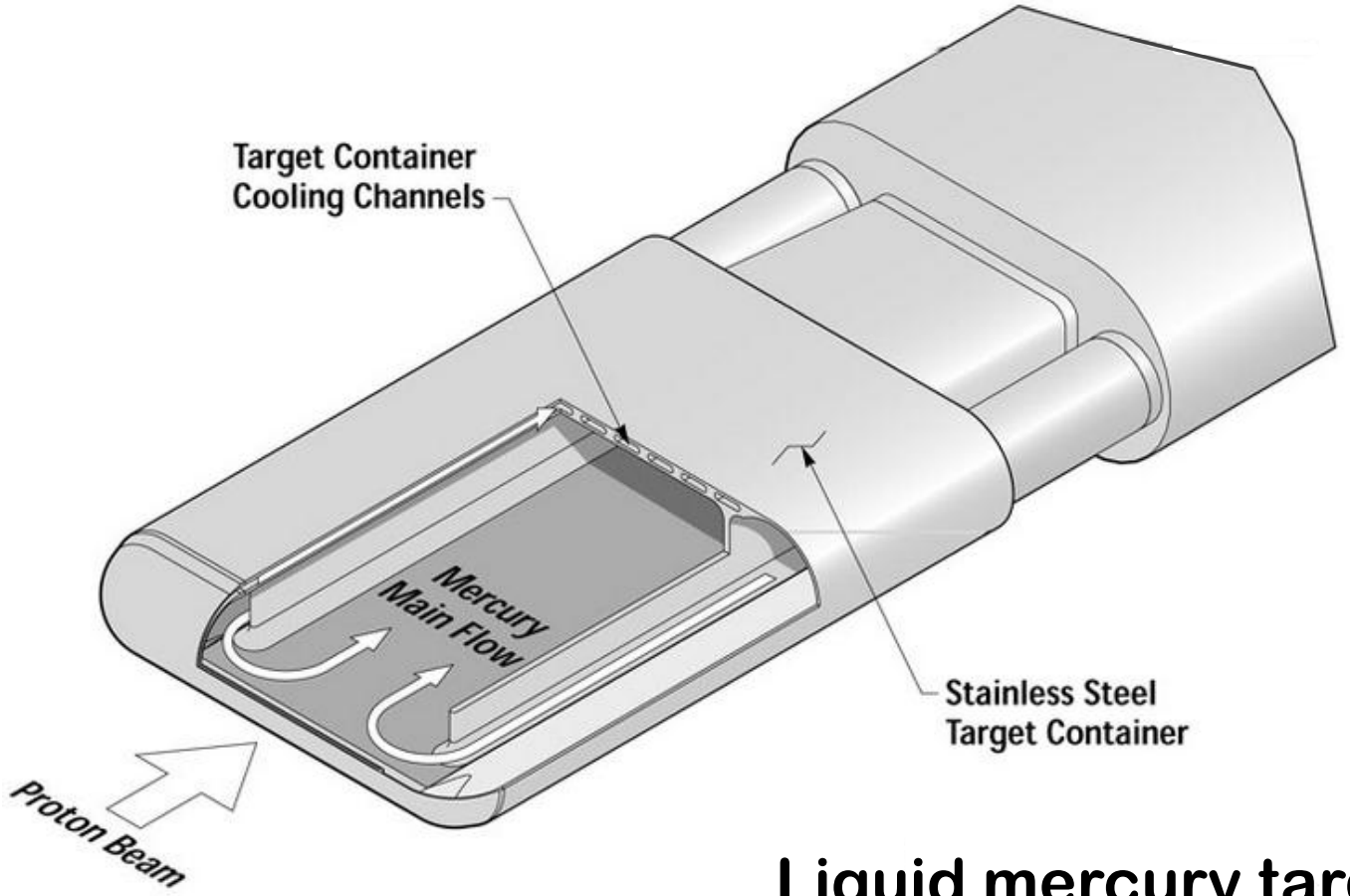
- Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.
- Use electric, magnetic and electromagnetic fields to interact with the object.
- Change from static to movable fields, from unstructured fields to those having structure.
- Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.



Van der Graaf to Cockroft-Walton generator

29.Pneumatics and hydraulics

- **Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).**

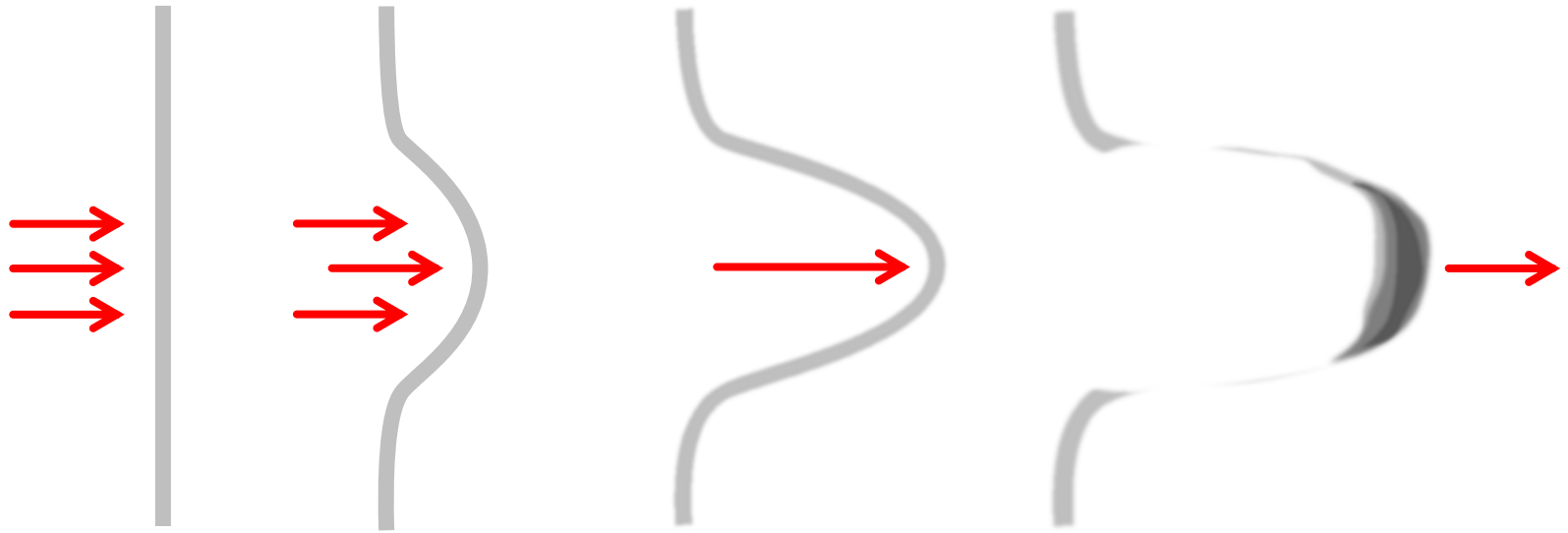


Liquid mercury target

Illustration: ORNL

30. Flexible shells and thin films

- Use flexible shells and thin films instead of three dimensional structures
- Isolate the object from the external environment using flexible shells and thin films.



Light sail laser-plasma ion acceleration

31. Porous materials

Make an object porous or add porous elements (inserts, coatings, etc.).
If an object is already porous, use the pores to introduce a useful substance or function.

Membranes made with ion beams

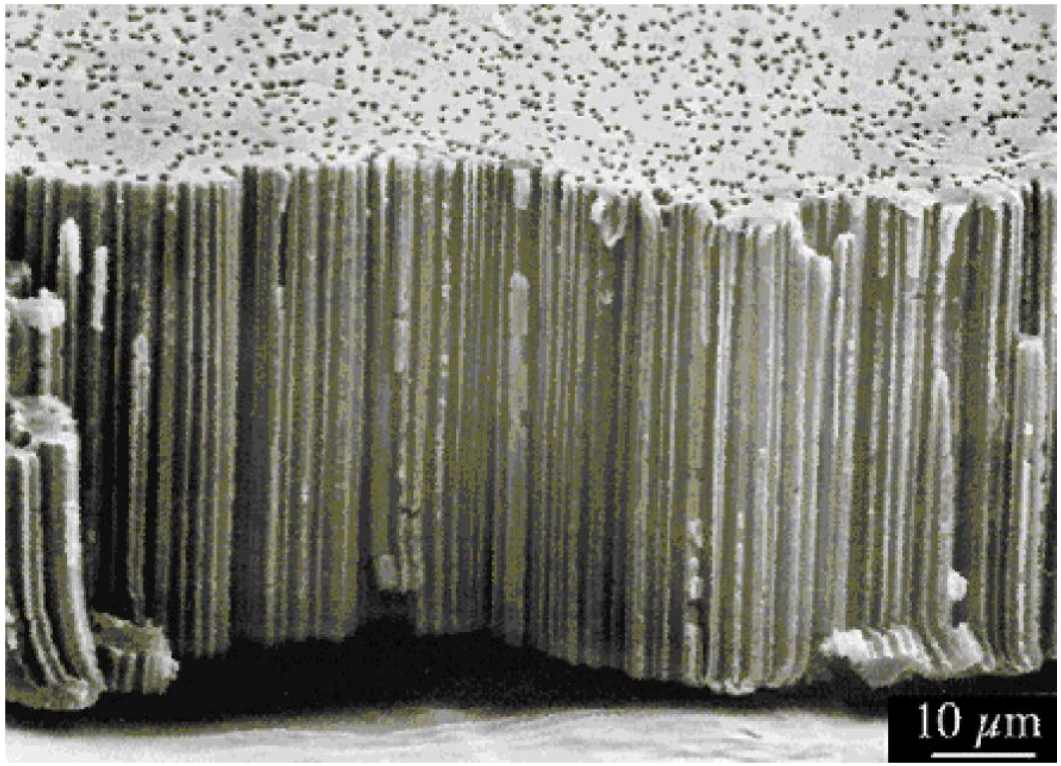
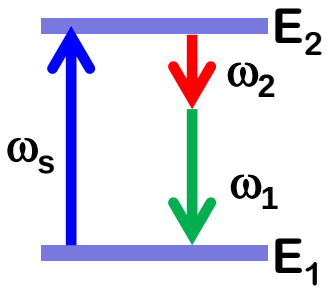


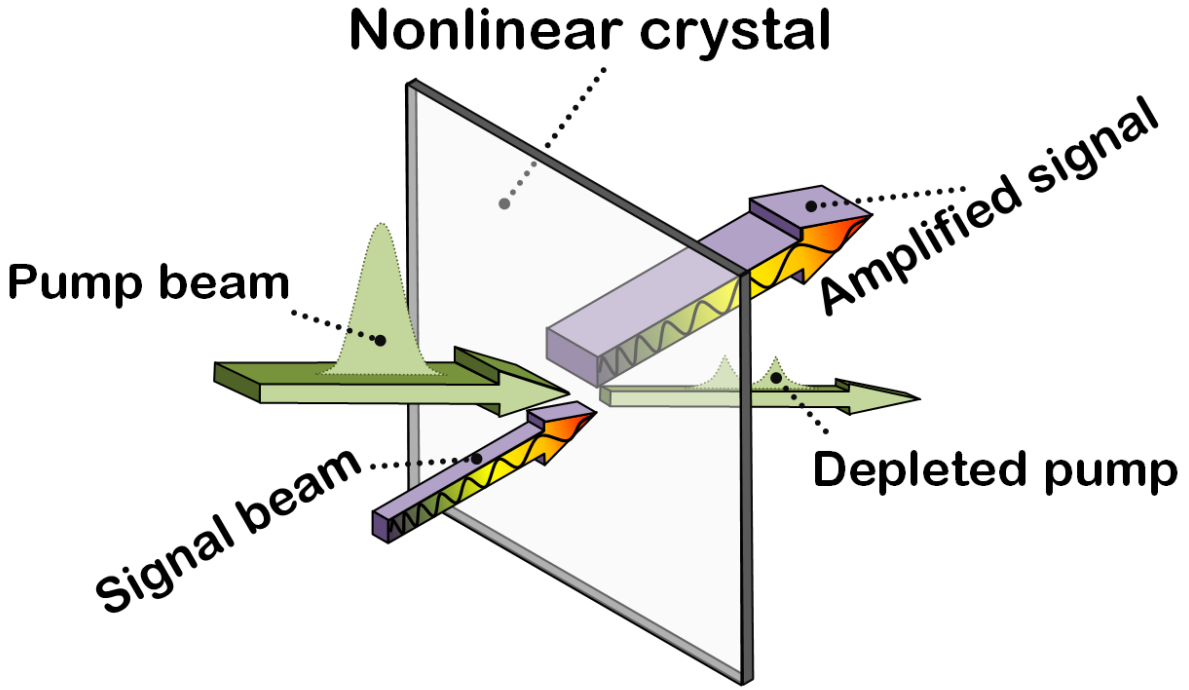
Illustration from "Engines of Discovery: A Century of Particle Accelerators", A. Sessler and T. Wilson, 2007

32. Color changes

- Change the color of an object or its external environment.
- Change the transparency of an object or its external environment.
- To improve observability of things that are difficult to see, use colored additives or luminescent elements.
- Change the emissivity properties of an object subject to radiant heating.



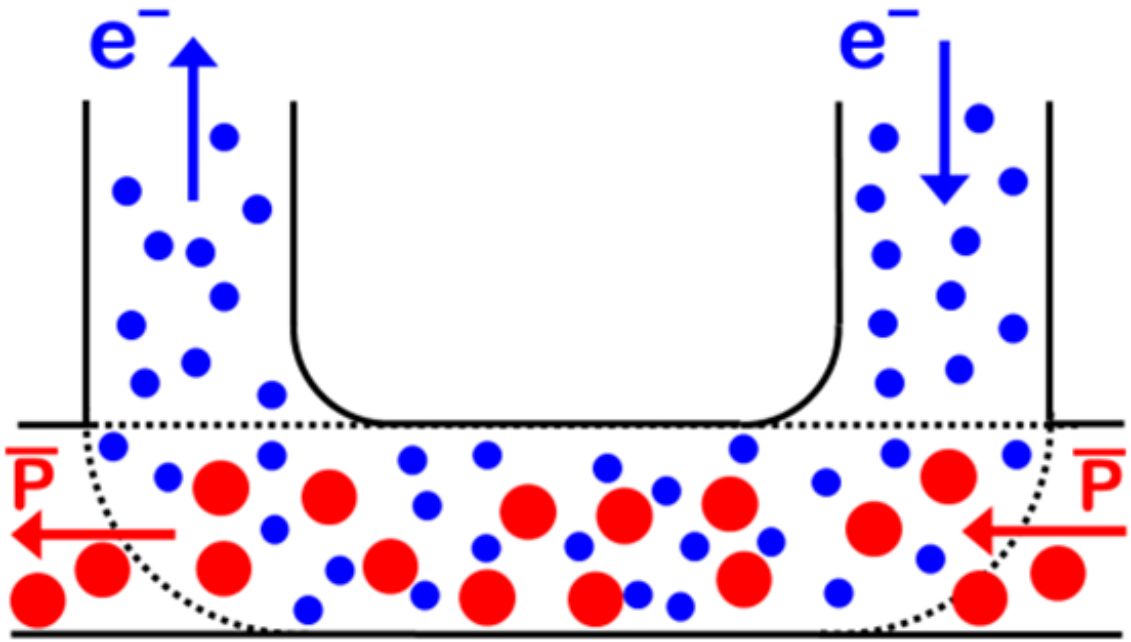
Optical Parametric process



Optical Parametric Chirped Pulse Amplification - OPCPA

33. Homogeneity *(Similia similibus curantur)*

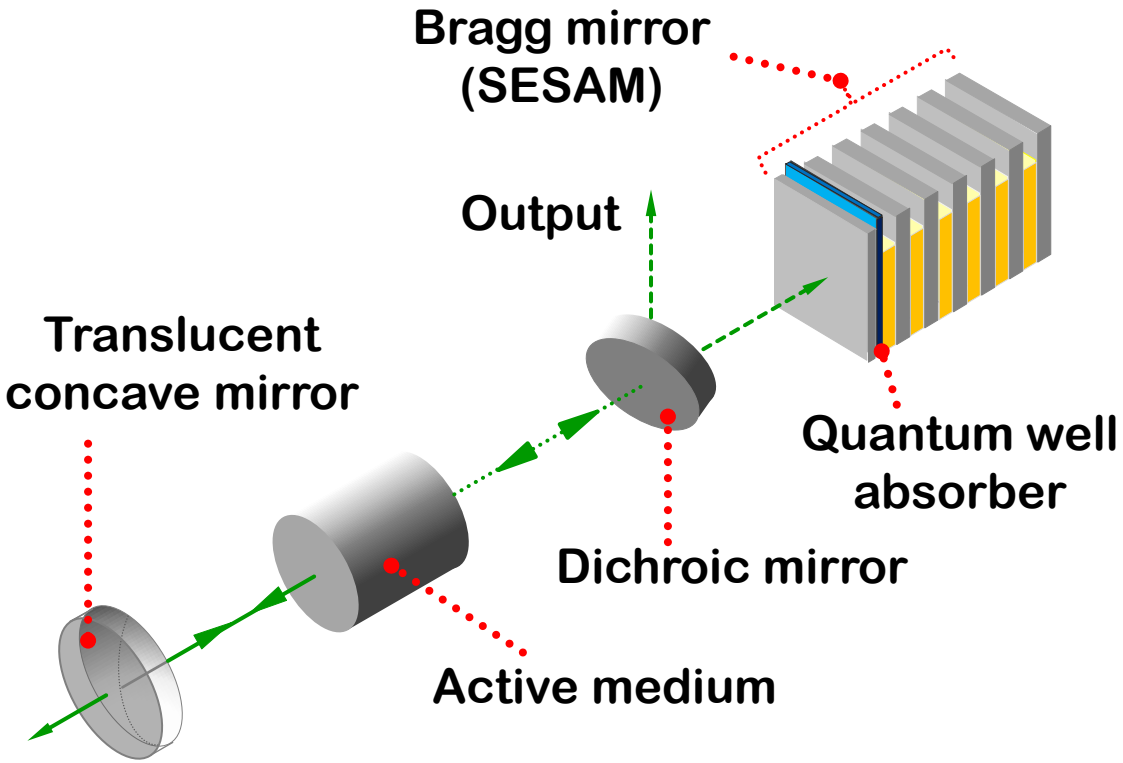
- **Make objects interacting with a given object of the same material (or material with identical properties).**



Electron cooling

34.Discarding and recovering

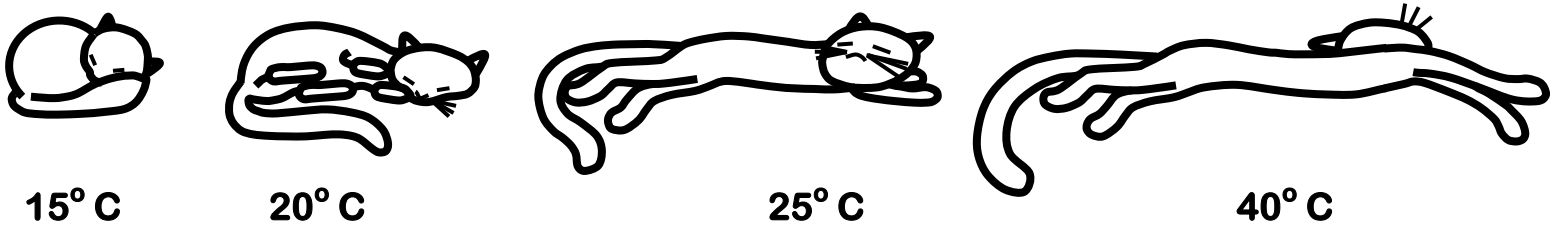
- Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.
- Conversely, restore consumable parts of an object directly in operation.

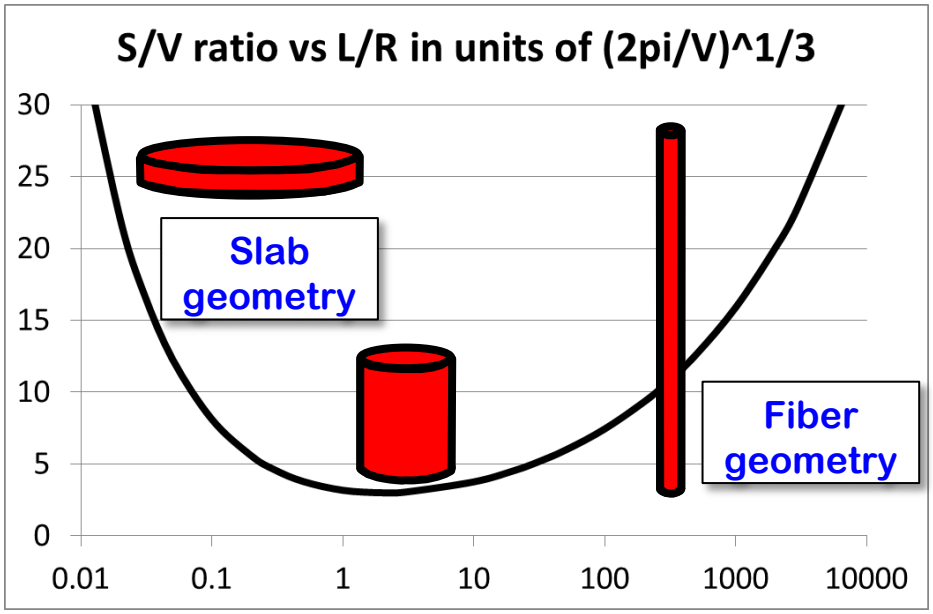


Semiconductor Saturable Absorber Mirror - SESAM

35. Parameter changes

- Change an object's physical state (e.g. to a gas, liquid, or solid.)
- Change the concentration or consistency.
- Change the degree of flexibility.
- Change the temperature.

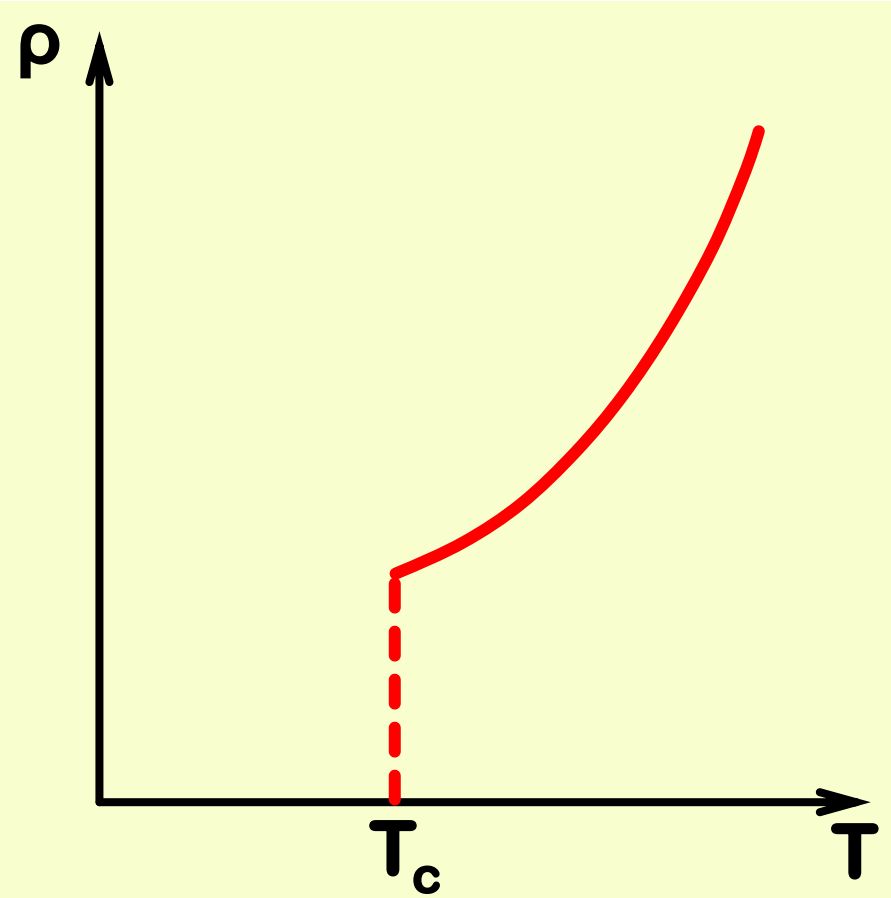




Fiber lasers

36. Phase transitions

- Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).

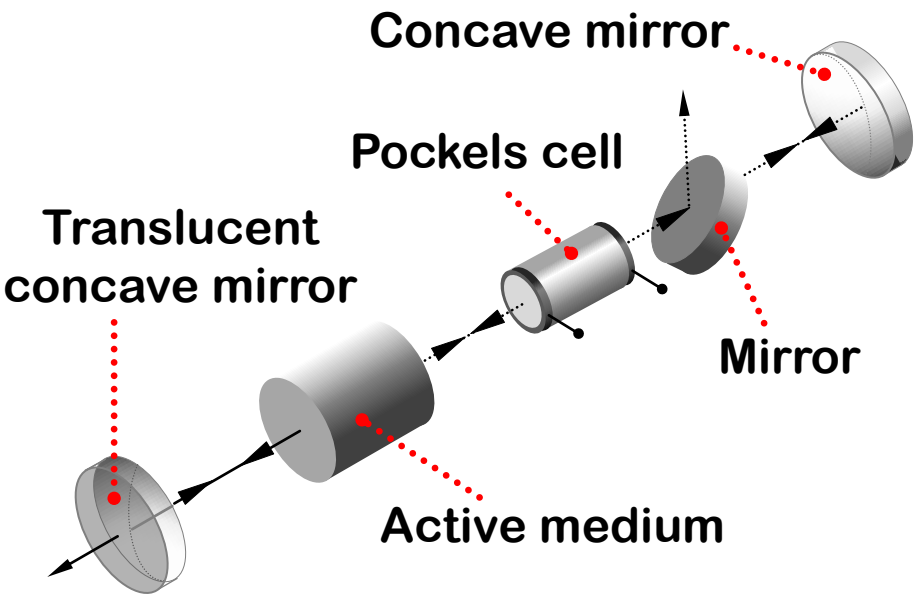


Phase transition

Superconductivity

37. Thermal or electrical expansion or property change

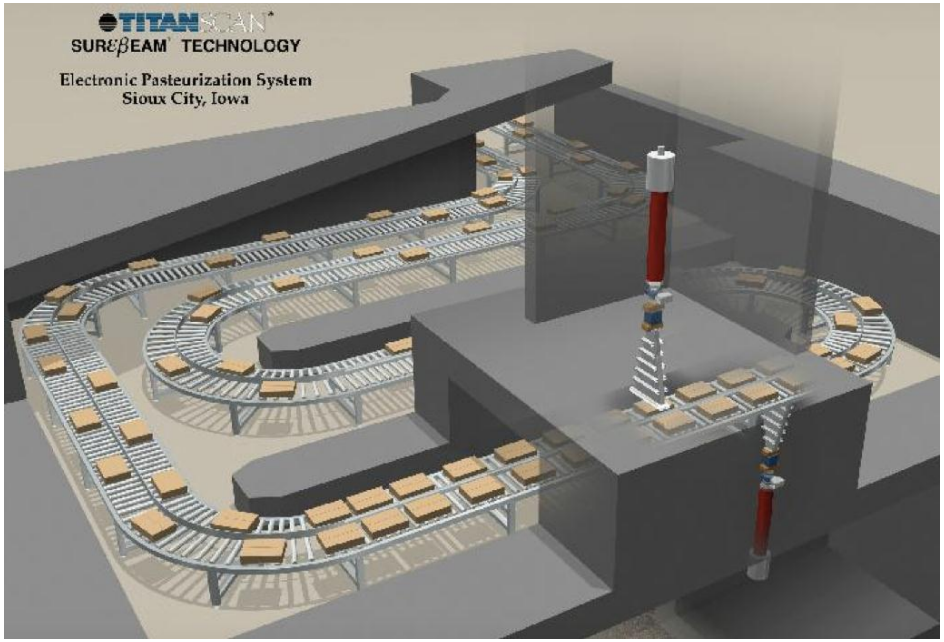
- Use thermal or electrical expansion (or contraction) or other property change of materials.
- If thermal or electrical expansion (property change) is being used, use multiple materials with different coefficients of thermal expansion (property change).



Electro-optic effect — dependence of optical properties of objects such as absorption or refraction (Pockels effect) on the applied electric field

38. Strong oxidants

- Replace common air with oxygen-enriched air.
- Replace enriched air with pure oxygen.
- Expose air or oxygen to ionizing radiation.
- Use ionized oxygen.
- Replace ozonized (or ionized) oxygen with ozone.



TITANSCAN*

SURεβEAM TECHNOLOGY

Electronic Pasteurization System

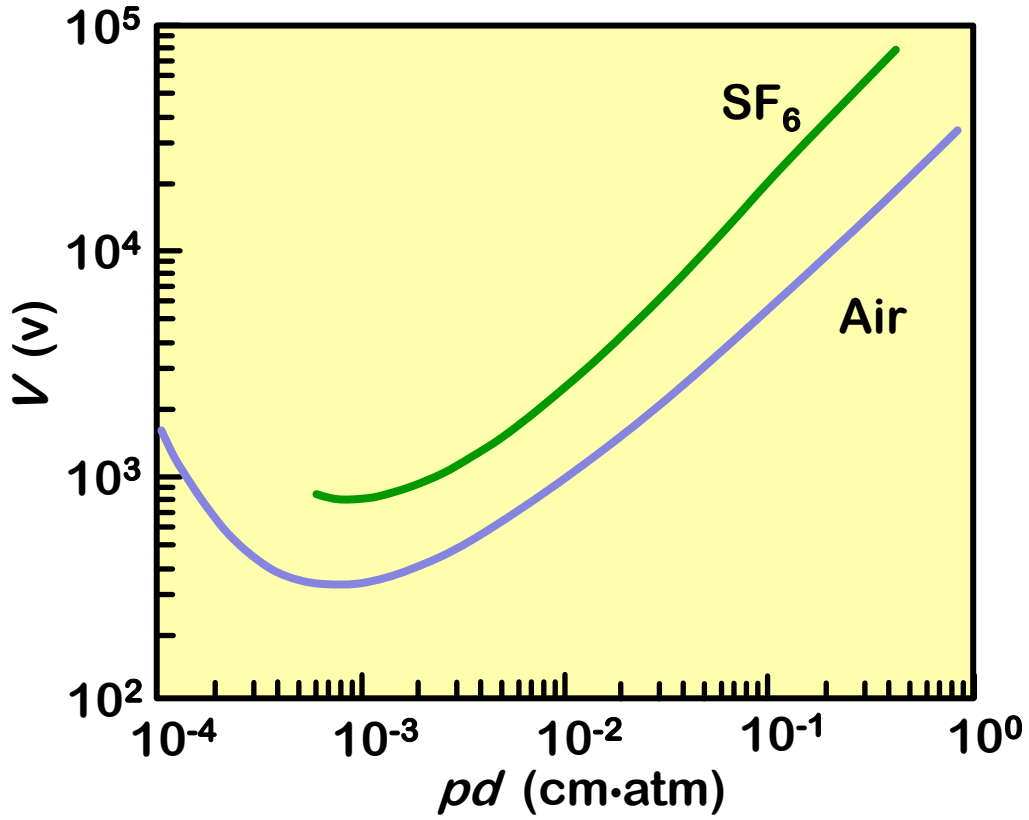
Sioux City, Iowa

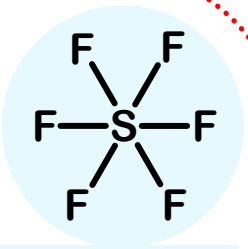
Irradiation of food for sterilisation

Illustration: TITANSCAN

39. Inert atmosphere

- Replace a normal environment with an inert one.
- Add neutral parts, or inert additives to an object.





Sulfur hexafluoride (SF6 or Elegas) is a colorless non-flammable gas with excellent electric insulating and arc-quenching capacity. It is widely used in the fields of electric, laser, medical, meteorological, freezing, fire-fighting, chemical, military, space aviation, nonferrous metallurgy and physical research areas.

40. Composite materials

- Change from uniform to composite (multiple) materials.

Ion beam surface treatment
Hardening an artificial knee joint using ion implantation

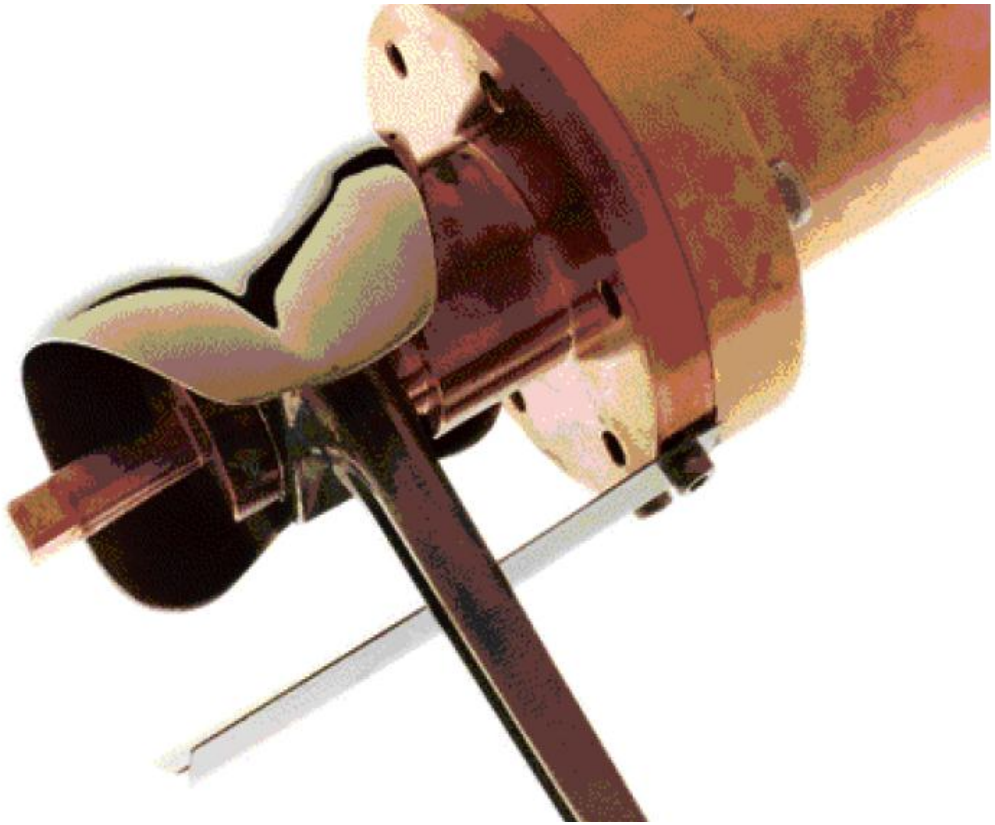


Illustration from "Engines of Discovery: A Century of Particle Accelerators"
A. Sessler and T. Wilson, 2007