

Introducción a los Aceleradores de partículas



Hector Garcia Morales
RHUL/CERN



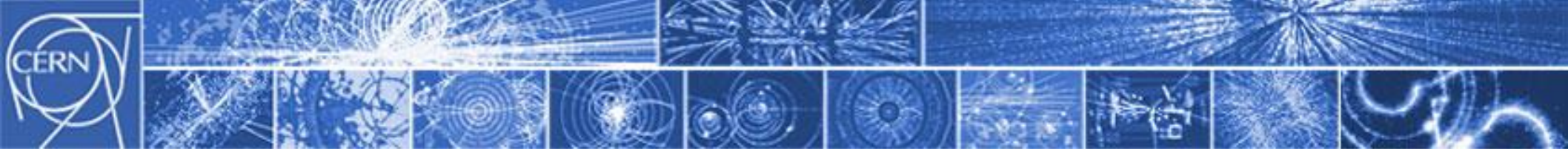
@cerntripetas



ROYAL
HOLLOWAY
UNIVERSITY
OF LONDON

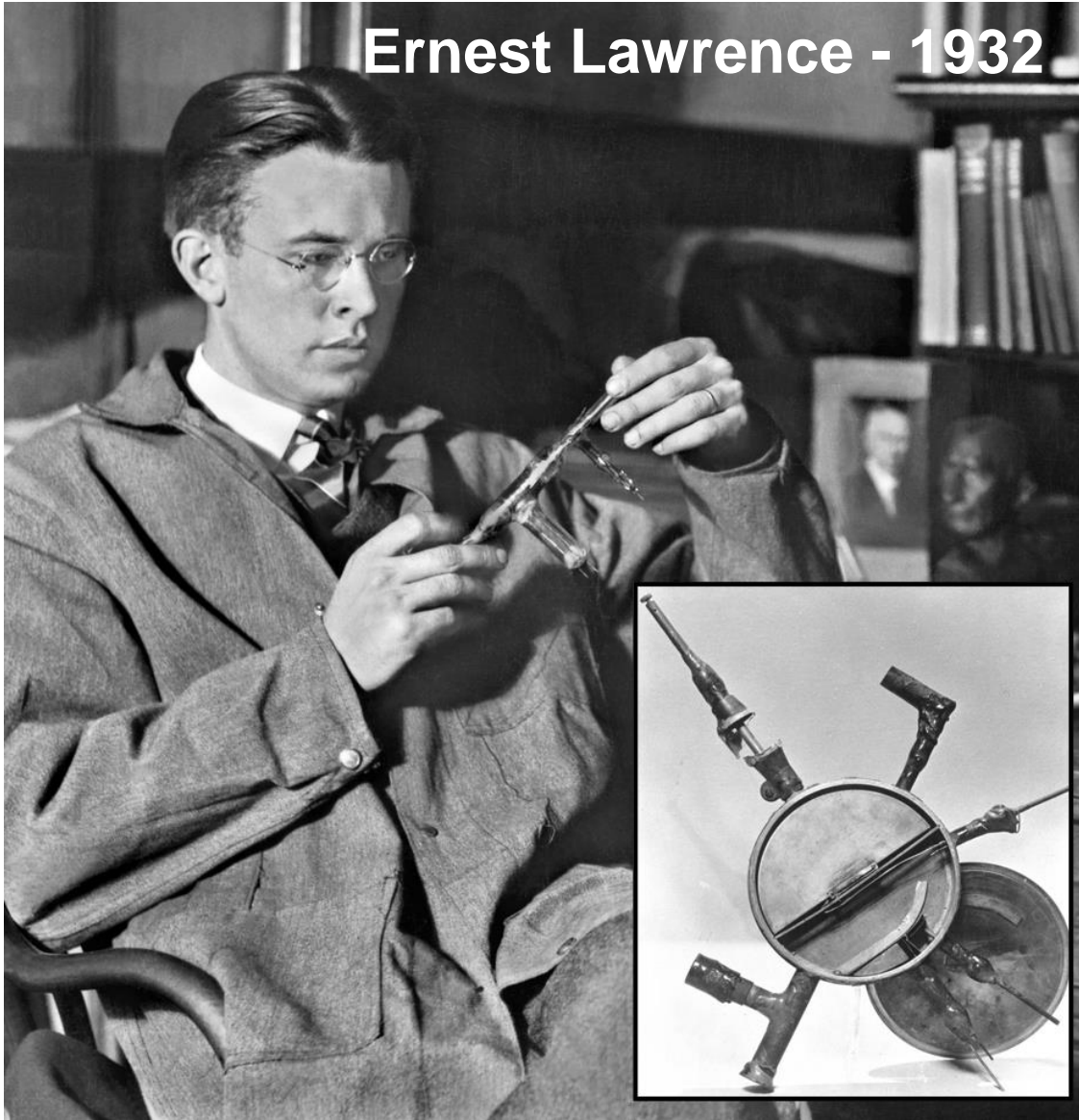


Tony Stark



Del primer ciclotrón...

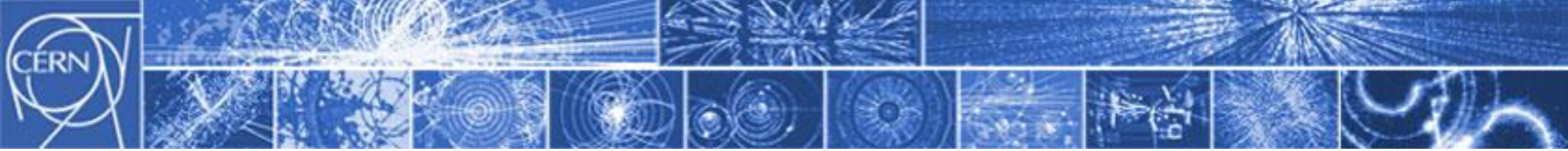
Ernest Lawrence - 1932



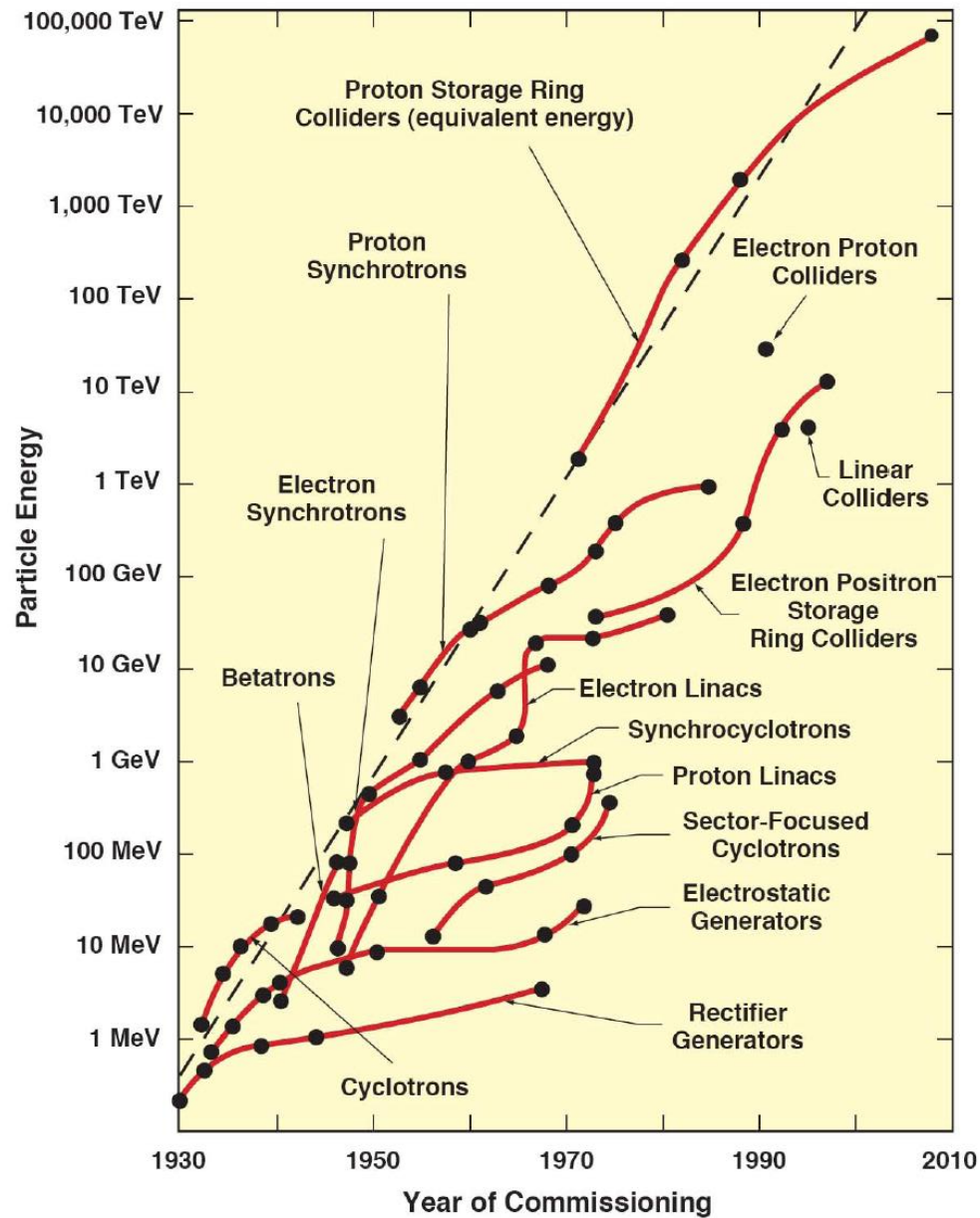


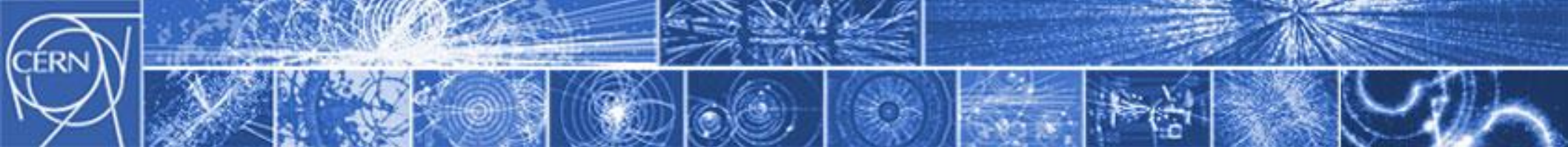
La actualidad - El LHC



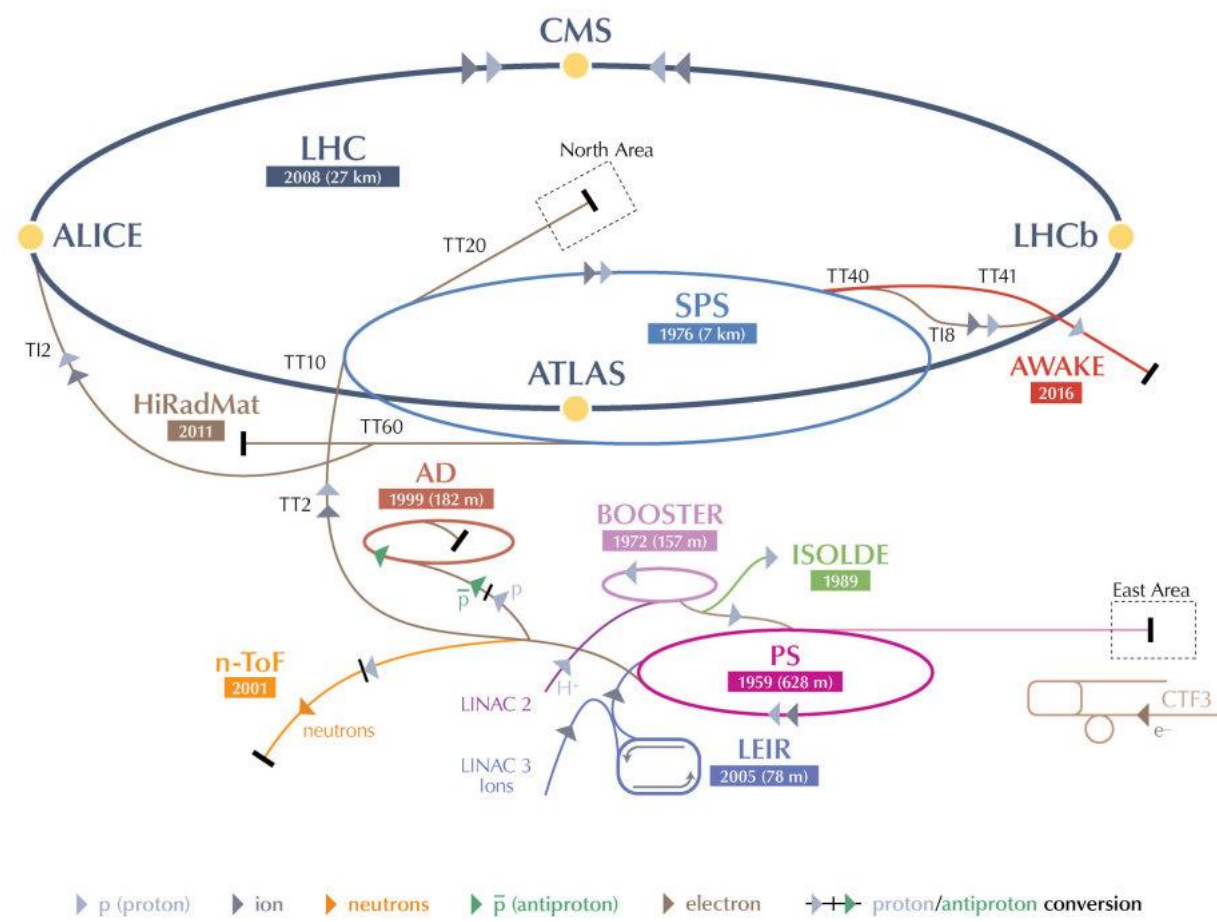


El tamaño importa





CERN's Accelerator Complex



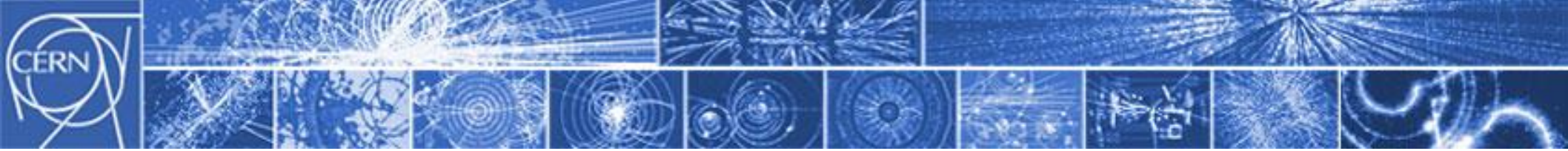
▶ p (proton) ▶ ion ▶ neutrons ▶ \bar{p} (antiproton) ▶ electron ▶ \leftrightarrow proton/antiproton conversion

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility AWAKE Advanced WAKEfield Experiment ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring LINAC LINEar ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials



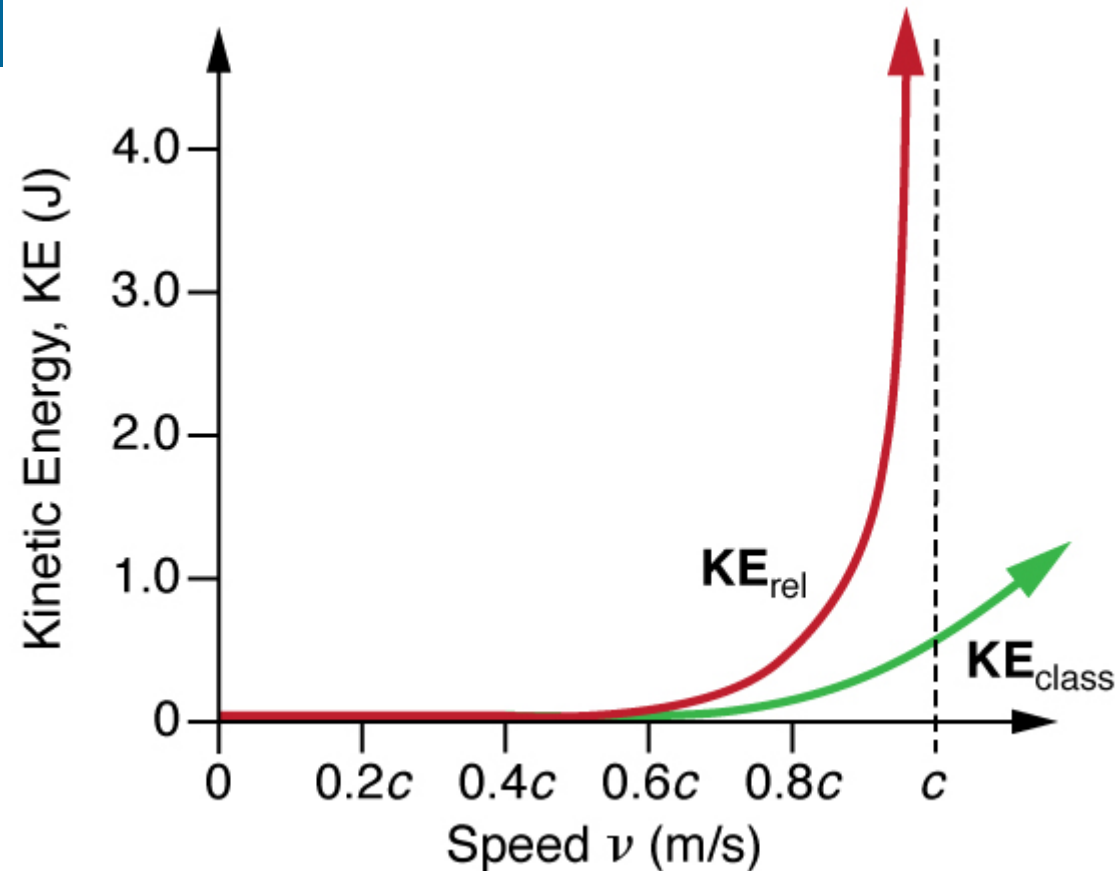


Relatividad especial

$$E = mc^2$$

$$\gamma = \frac{E}{mc^2} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Más energía significa que tenemos acceso a crear partículas más masivas

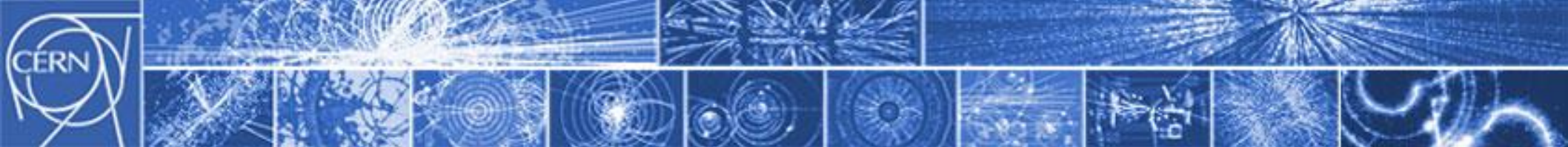


Ejemplo:

$$m_H \approx 125\text{GeV}$$

LEP: Falta de energía y de luminosidad

Tevatron: Energía suficiente pero luminosidad escasa

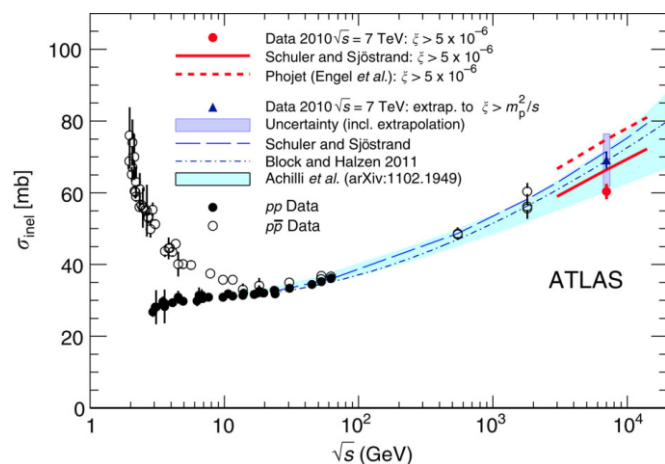


Sección eficaz

“Els guapos són els rars”
Manel

Unidad

$$1b = 10^{-24} \text{cm}^2$$

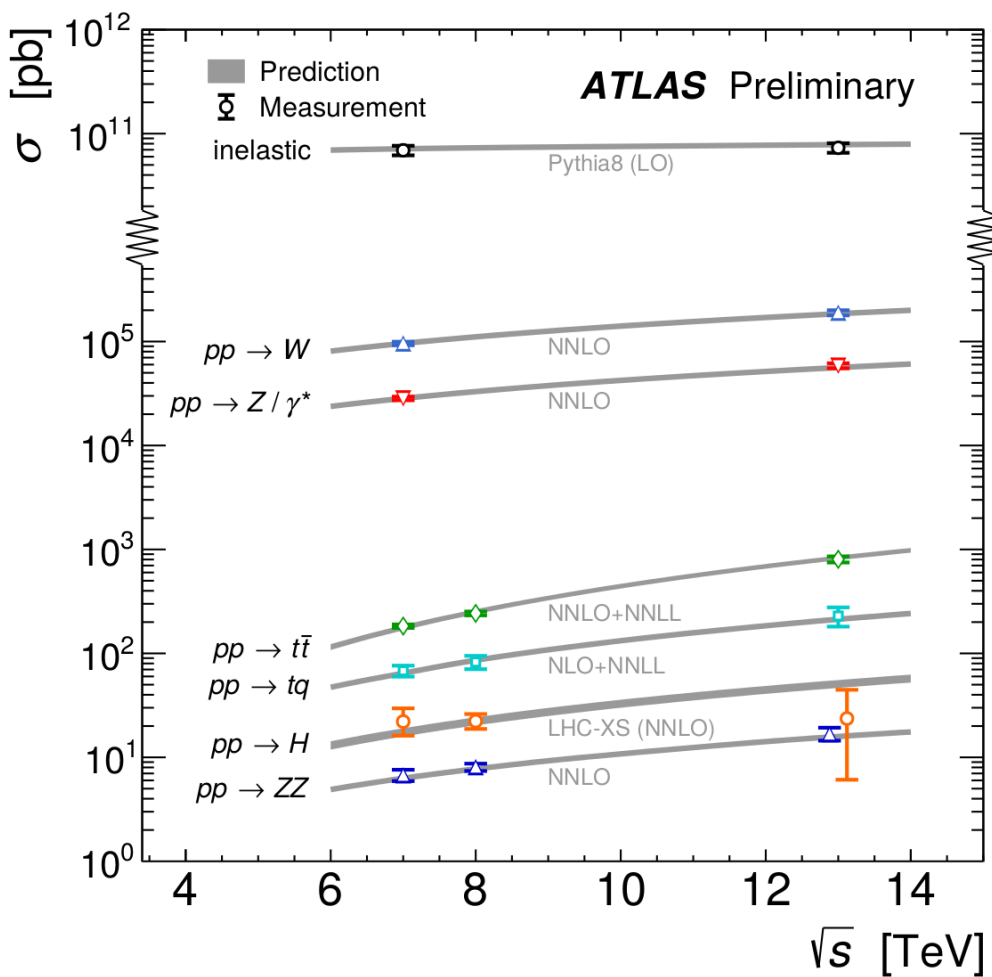


Procesos interesantes són muy raros de producir

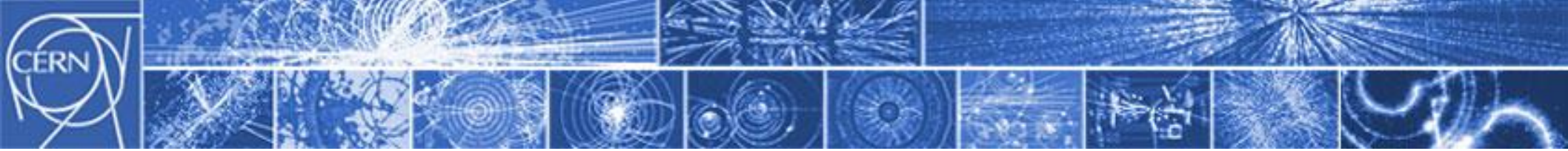
¡Por suerte, ésto no es química!

$$pp \rightarrow H$$

$$\sigma(\sqrt{s} = 8\text{TeV}) \approx 22\text{pb}$$



- σ inelastic
7 TeV, $20 \mu\text{b}^{-1}$, Nat. Commun. 2, 463 (2011)
13 TeV, $63 \mu\text{b}^{-1}$, ATLAS-CONF-2015-038
- $pp \rightarrow W$
7 TeV, 36pb^{-1} , PRD 85, 072004 (2012)
13 TeV, 81pb^{-1} , arXiv:1603.09222
- $pp \rightarrow Z/\gamma^*$
7 TeV, 36pb^{-1} , PRD 85, 072004 (2012)
13 TeV, 81pb^{-1} , arXiv:1603.09222
- $pp \rightarrow t\bar{t}$
7 TeV, 4.6fb^{-1} , Eur. Phys. J. C 74:3109 (2014)
8 TeV, 20.3fb^{-1} , Eur. Phys. J. C 74:3109 (2014)
13 TeV, 3.2fb^{-1} , ATLAS-CONF-2016-005
- $pp \rightarrow tq$
7 TeV, 4.6fb^{-1} , PRD 90, 112006 (2014)
8 TeV, 20.3fb^{-1} , ATLAS-CONF-2014-007
13 TeV, 3.2fb^{-1} , ATLAS-CONF-2015-079
- $pp \rightarrow H$
7 TeV, 4.5fb^{-1} , Eur. Phys. J. C 76 (2016)
8 TeV, 20.3fb^{-1} , Eur. Phys. J. C 76 (2016)
13 TeV, 3.2fb^{-1} , ATLAS-CONF-2015-069
- $pp \rightarrow ZZ$
7 TeV, 4.6fb^{-1} , JHEP 03, 128 (2013)
8 TeV, 20.3fb^{-1} , ATLAS-CONF-2013-020
13 TeV, 3.2fb^{-1} , PRL 116, 101801 (2016)



Luminosidad y luminosidad integrada

$$R = \mathcal{L}\sigma \quad \text{Eventos de un determinado tipo}$$

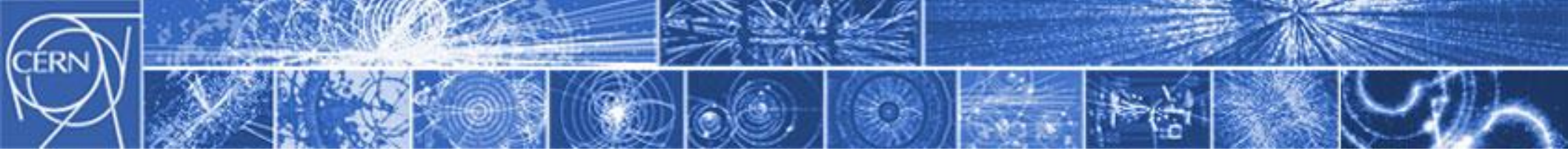
Luminosidad

$$\mathcal{L} = \frac{N^2 f_{\text{rep}} n_b}{4\pi\sigma_x\sigma_y}$$

Objetivo: maximizar la
luminosidad

Luminosidad
integrada

$$\mathcal{L}_T = \int \mathcal{L} dt$$



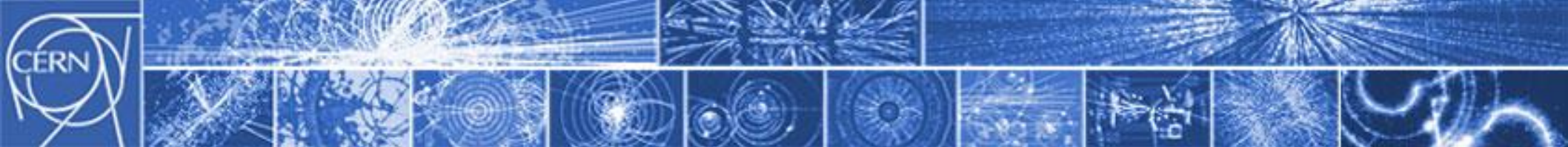
Número de partículas

Frecuencia de colisión

Número de paquetes

$$\mathcal{L} = \frac{N^2 f_{\text{rep}} n_b}{4\pi \sigma_x \sigma_y}$$

Tamaño del haz en los puntos de colisión



$$N = 1.0 \cdot 10^{11}$$

Número de partículas

$$f_{\text{rep}} = 11245 \text{ Hz}$$

Frecuencia de colisión

$$n_b = 2808$$

Número de paquetes

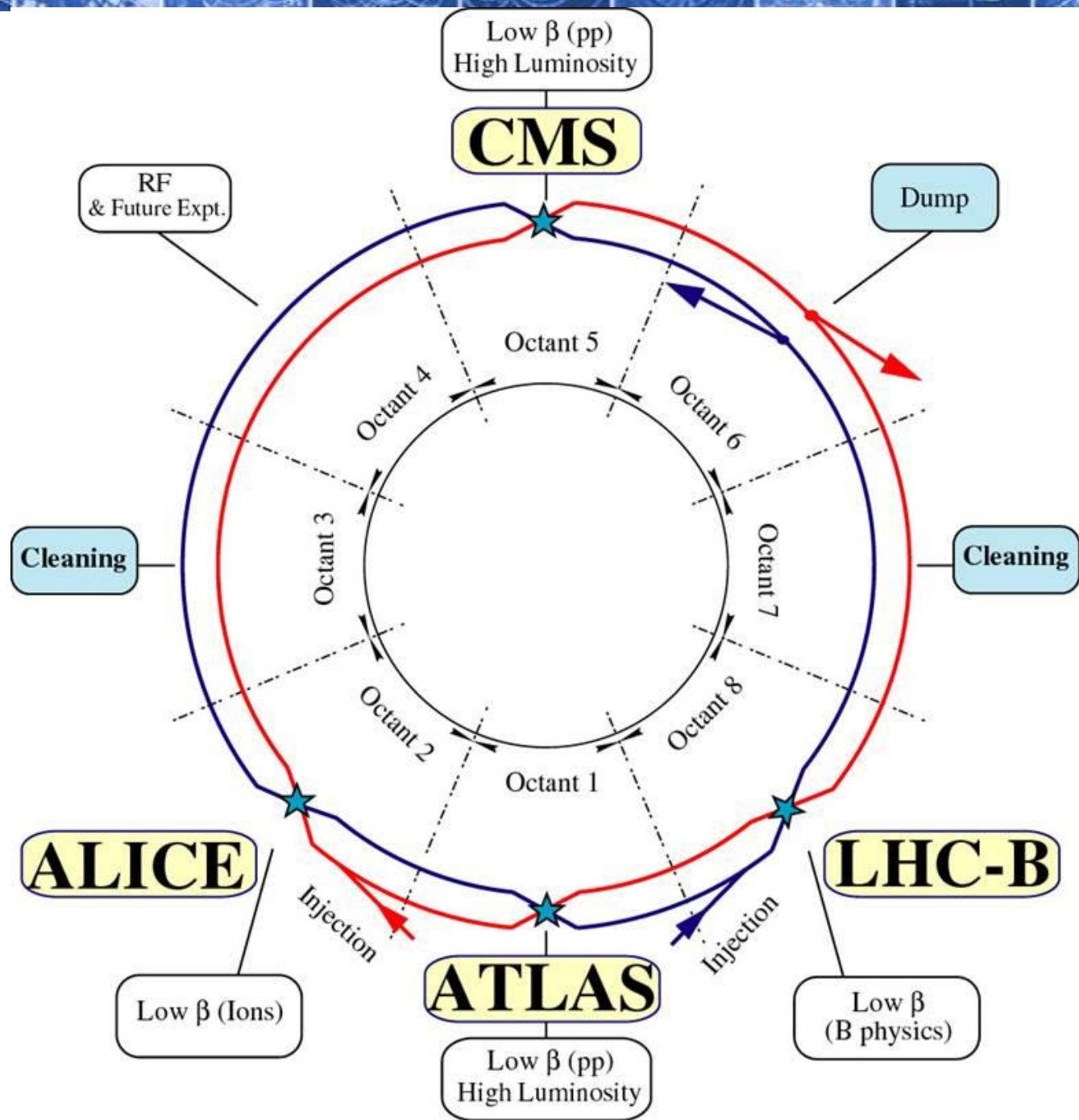
$$\mathcal{L} = \frac{N^2 f_{\text{rep}} n_b}{4\pi \sigma_x \sigma_y}$$

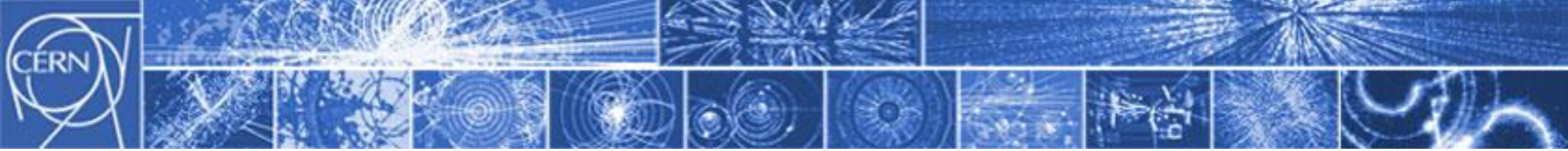
Luminosidad Nominal

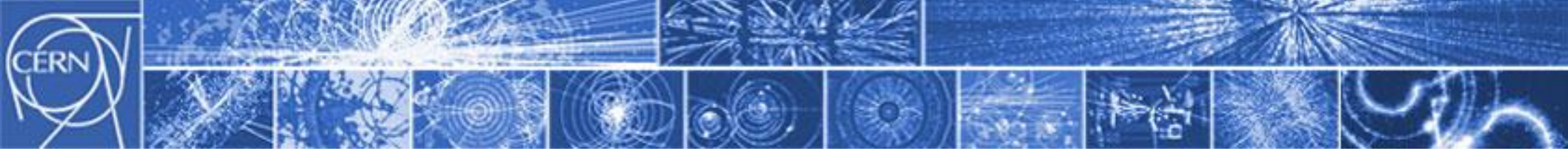
$$\mathcal{L} = 1.0 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$$

Tamaño del haz en los puntos de colisión

$$\sigma_x = \sigma_y = 16 \mu\text{m}$$



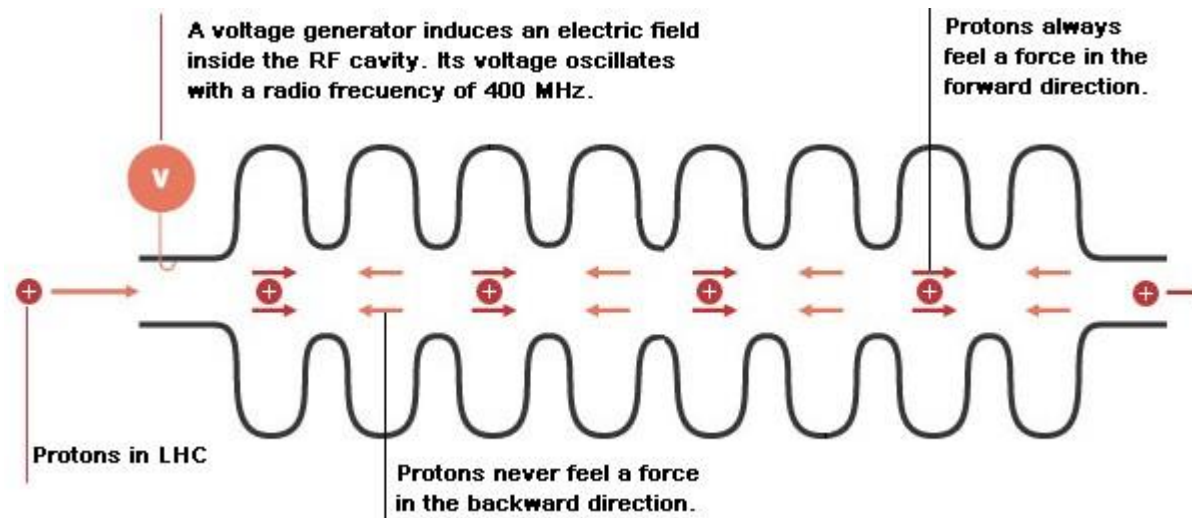
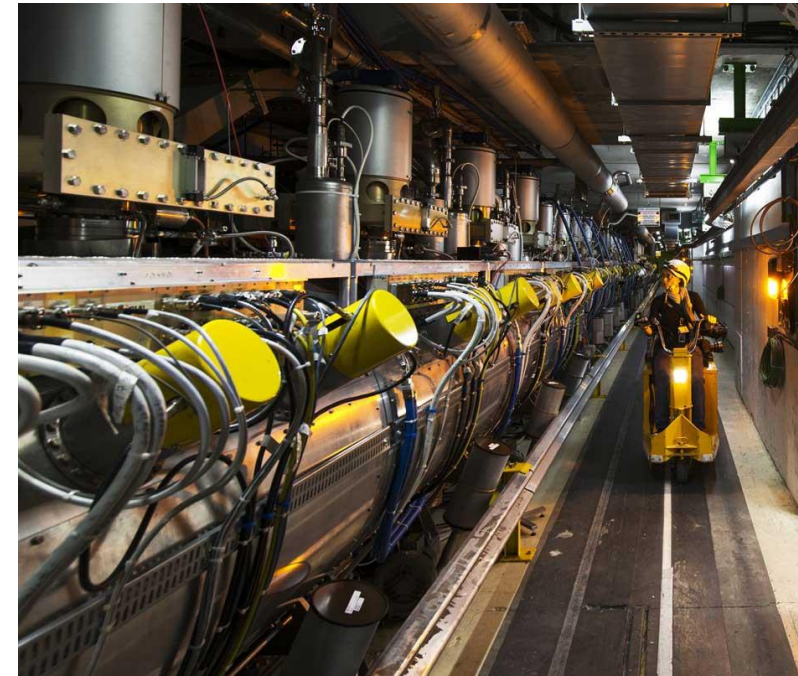


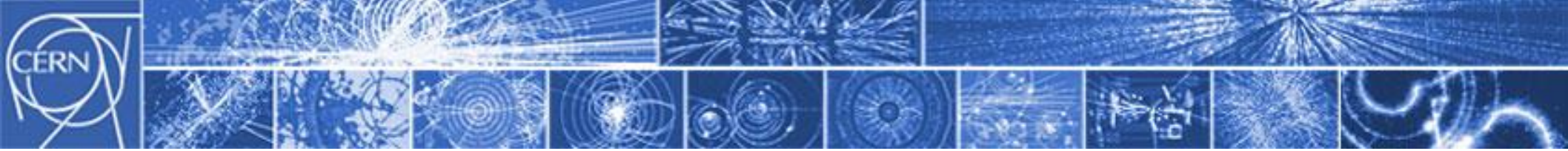


Acelerando

Fuerza de Lorentz

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

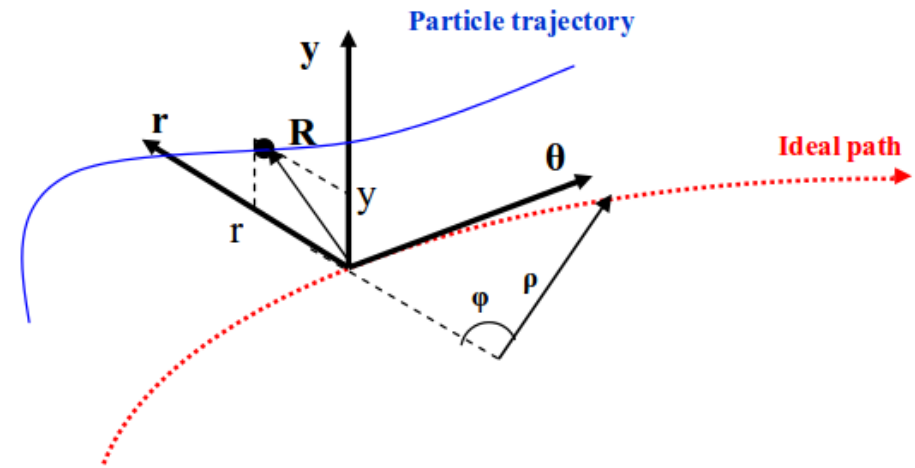




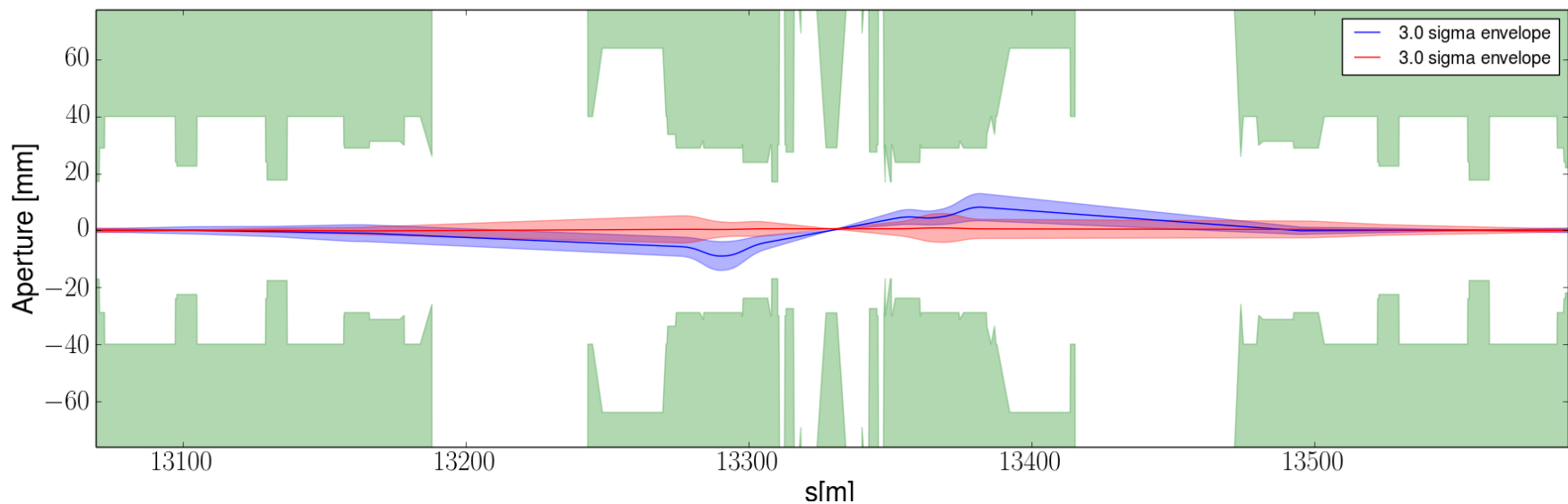
Dinámica del haz

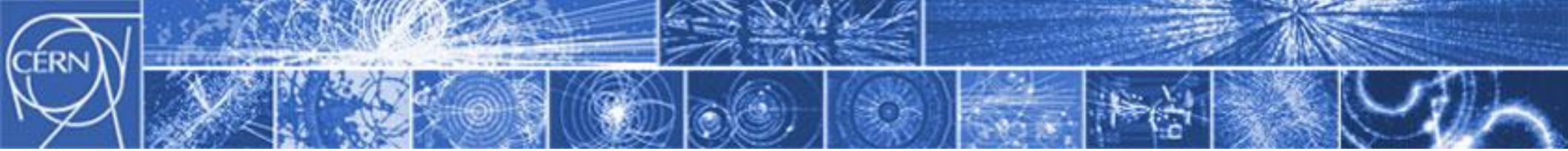
$$u'' + K(s)u(s) = 0$$

Ecuación de Hill

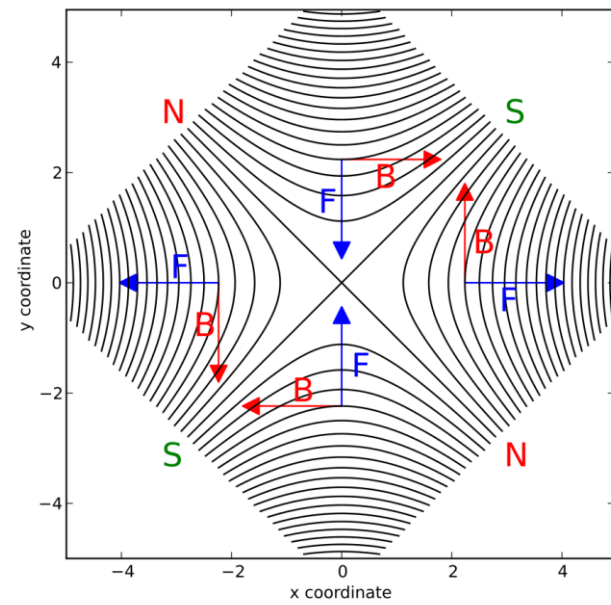
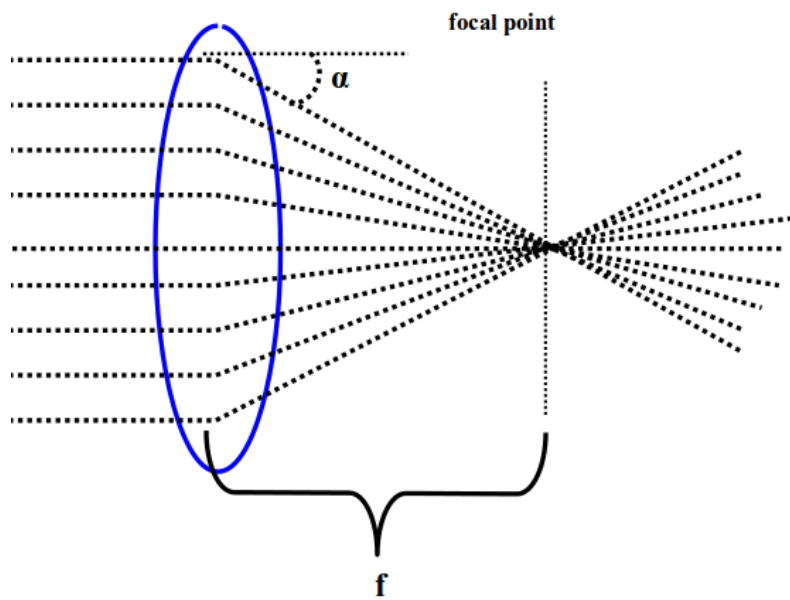


$$u = \sqrt{2J_u\beta_u(s)} \cos(\phi(s) - \phi_0)$$





Dipolos, cuadrupolos...

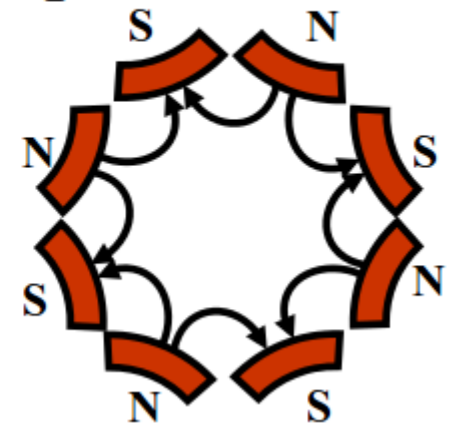
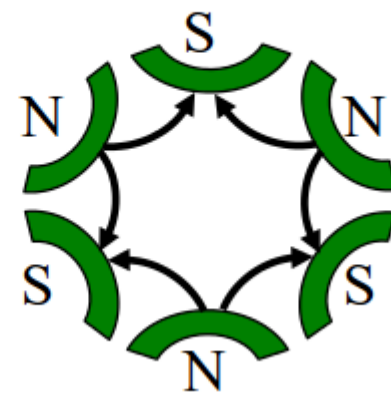
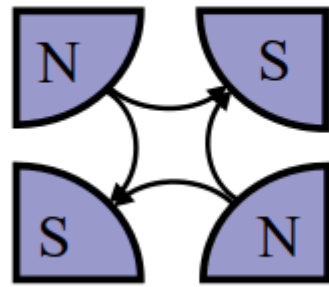
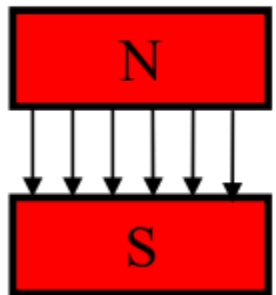


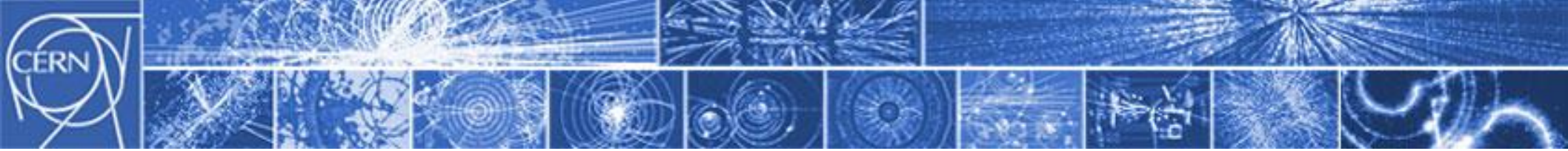
dipole

cuadrupolo

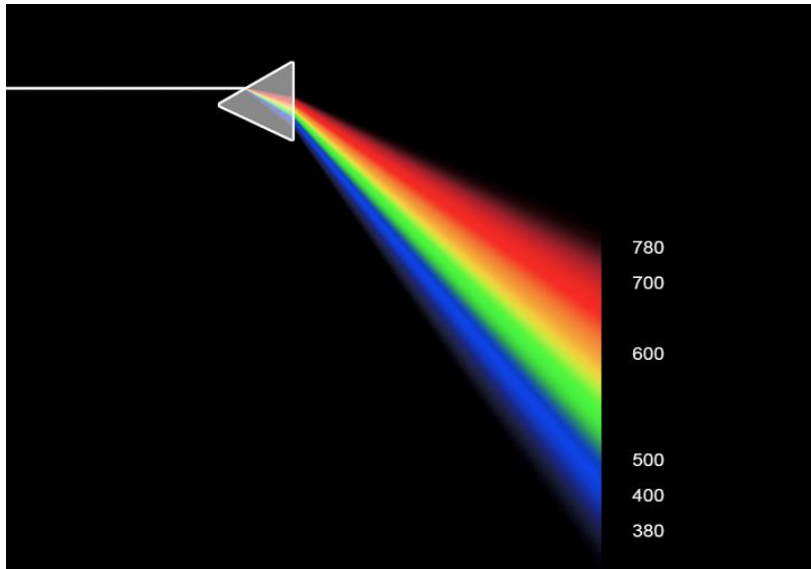
sextupolo

octupolo ...

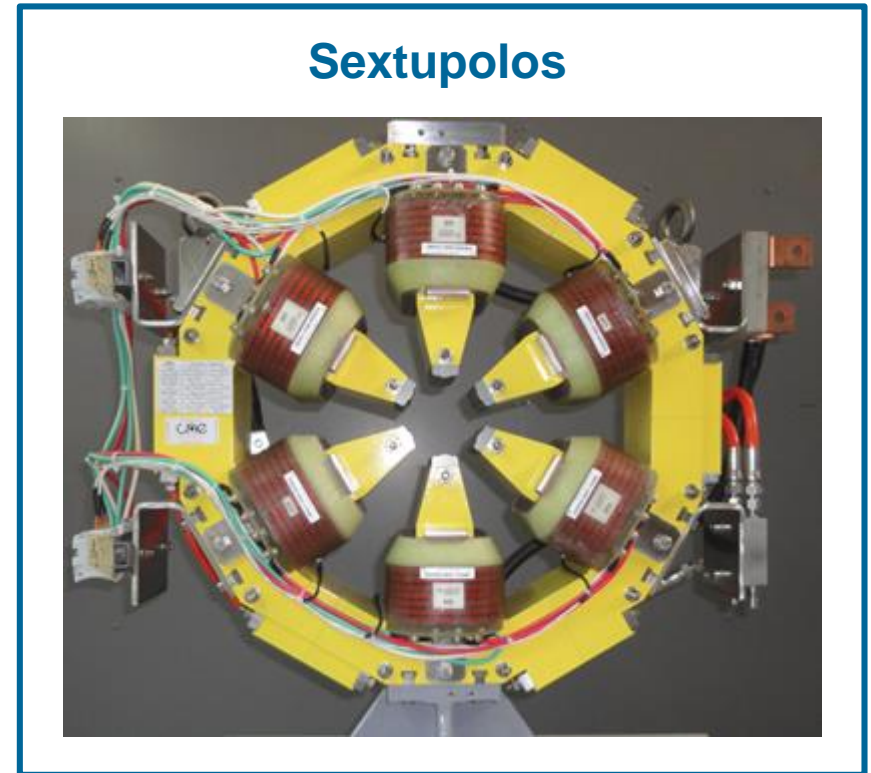
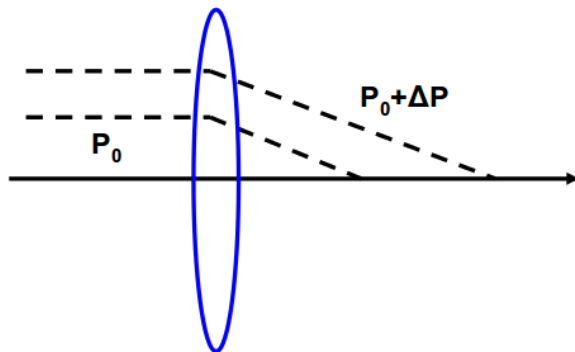


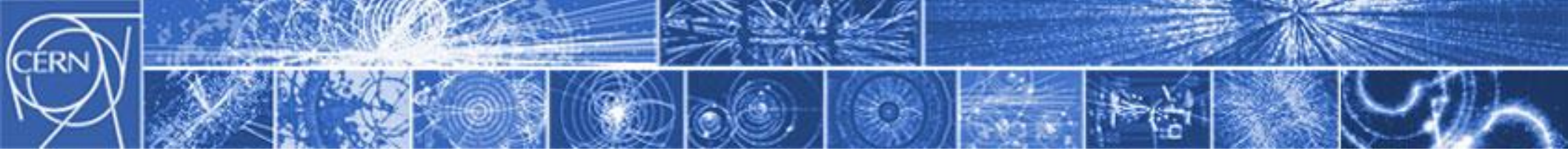


Cromaticidad



Partículas con diferente energía se focalizan en puntos diferentes





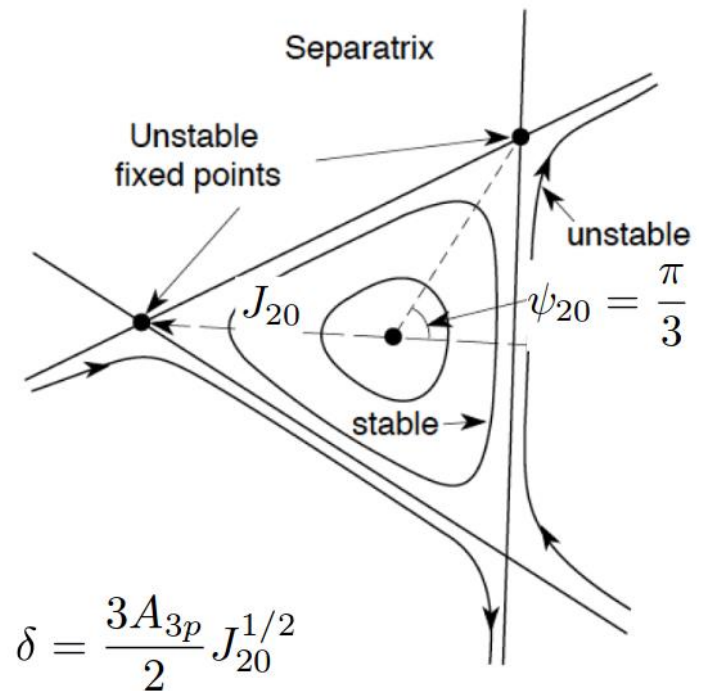
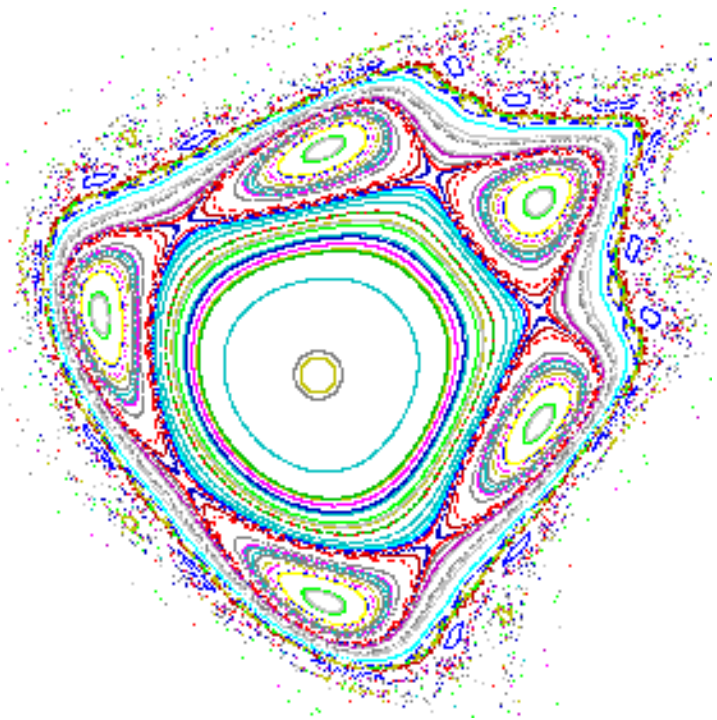
Dinámica no lineal

Términos no lineales

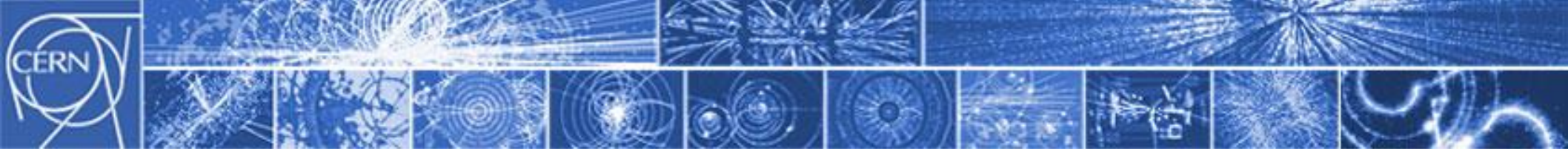
$$u'' + K(s)u(s) = 0$$

Ecuación de Hill lineal

$$u'' + K(t)u(t) = \sum a_m e^{im\omega t}$$



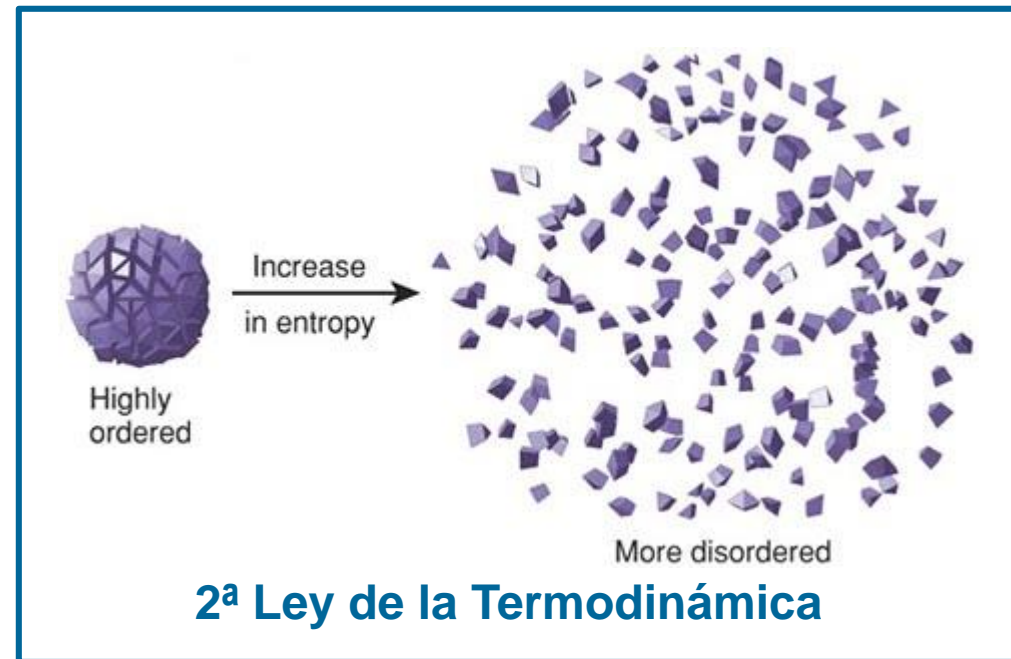
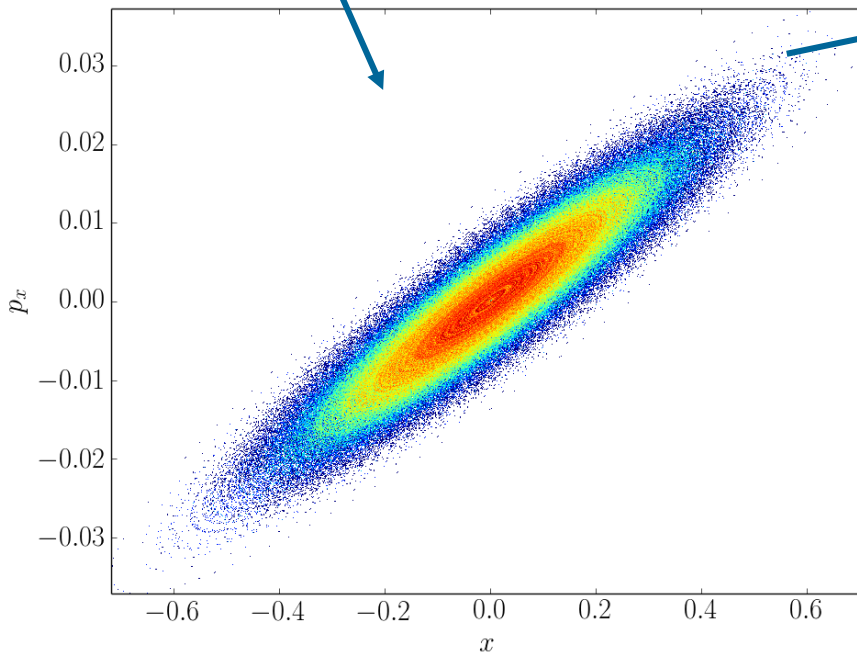
$$\delta = \frac{3A_{3p}}{2} J_{20}^{1/2}$$

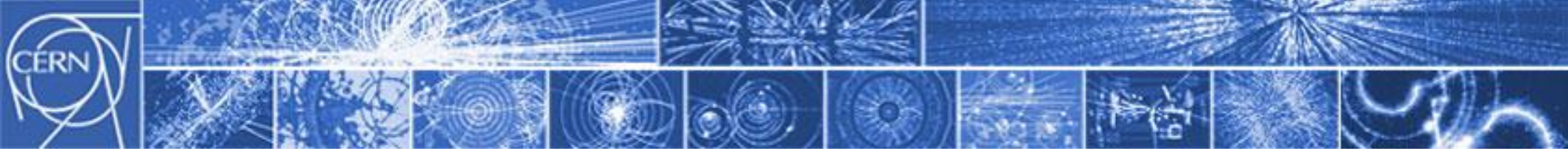


Emitancia y “cooling”

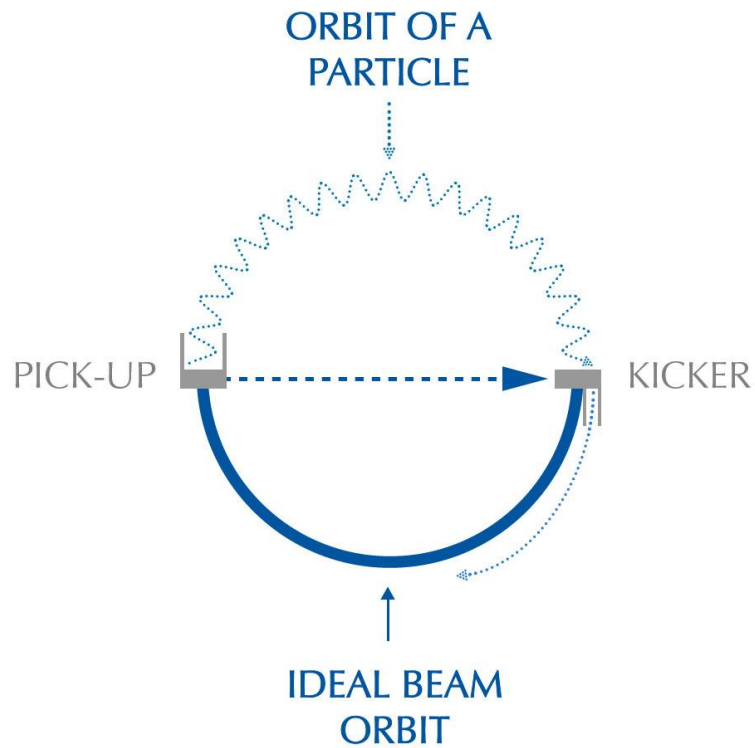
$$u = \sqrt{2J_u \beta_u(s)} \cos(\phi(s) - \phi_0)$$

$$\mathcal{L} = \frac{N^2 f_{\text{rep}} n_b}{4\pi \sigma_x \sigma_y}$$





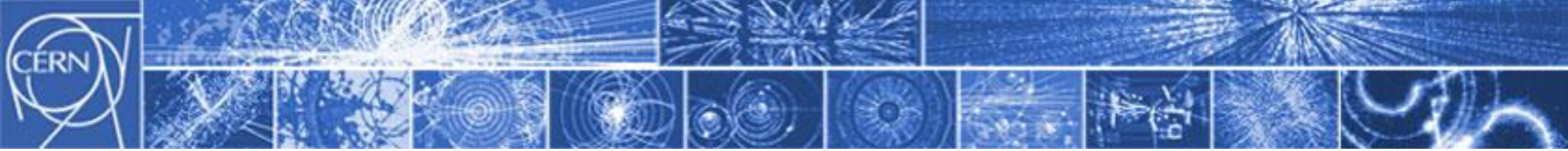
“Cooling” estocástico



Simon van der Meer

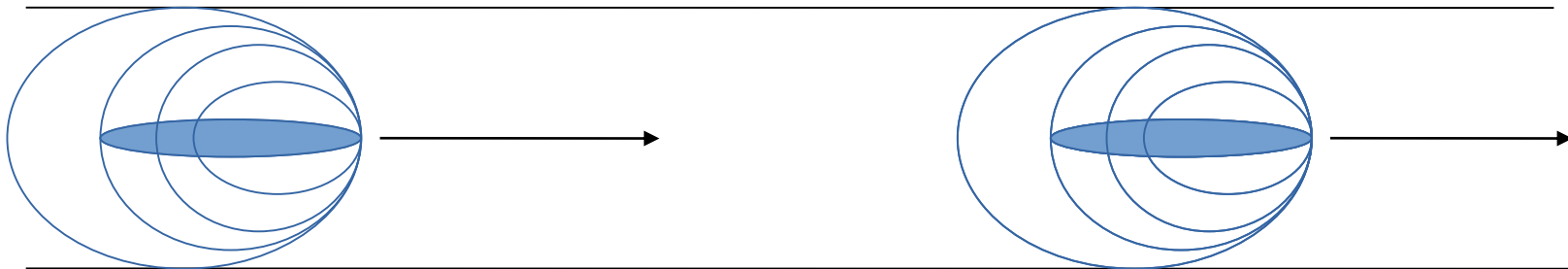


Premio Nobel 1985

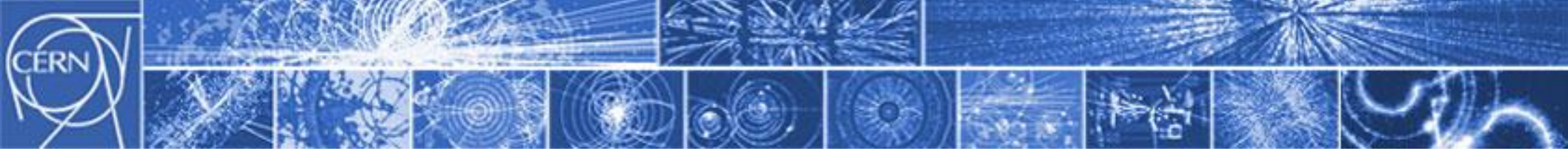


Inestabilidades

El propio haz interactúa con la cámara por donde pasa y puede afectar a otros paquetes o a sí mismo

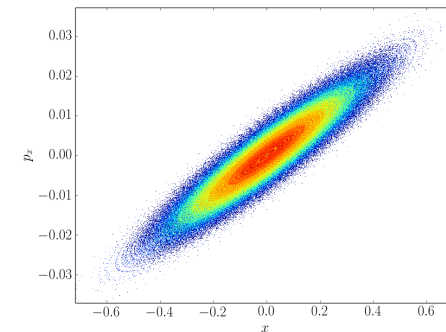
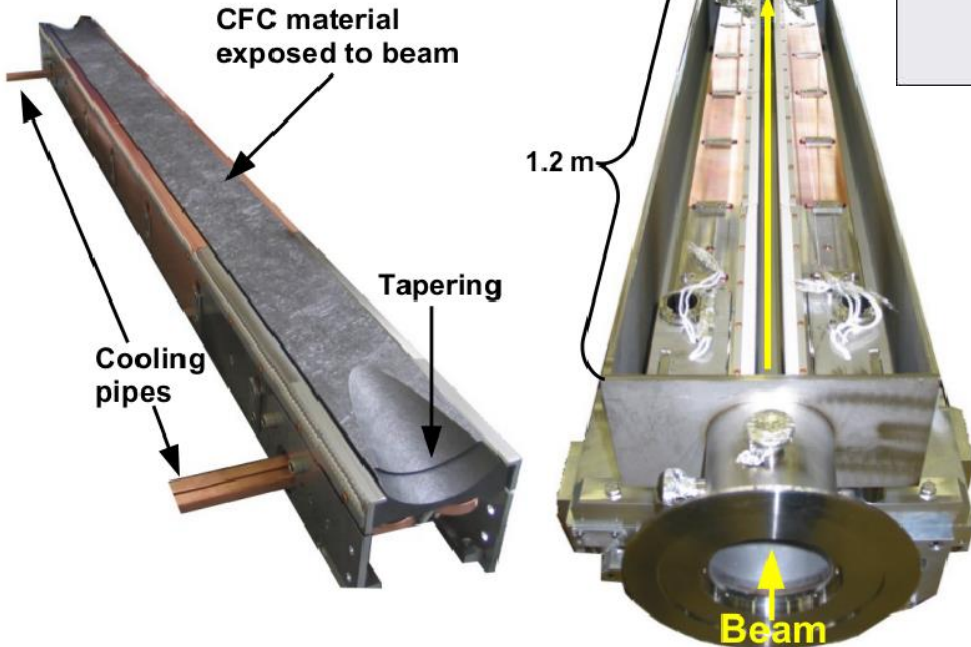
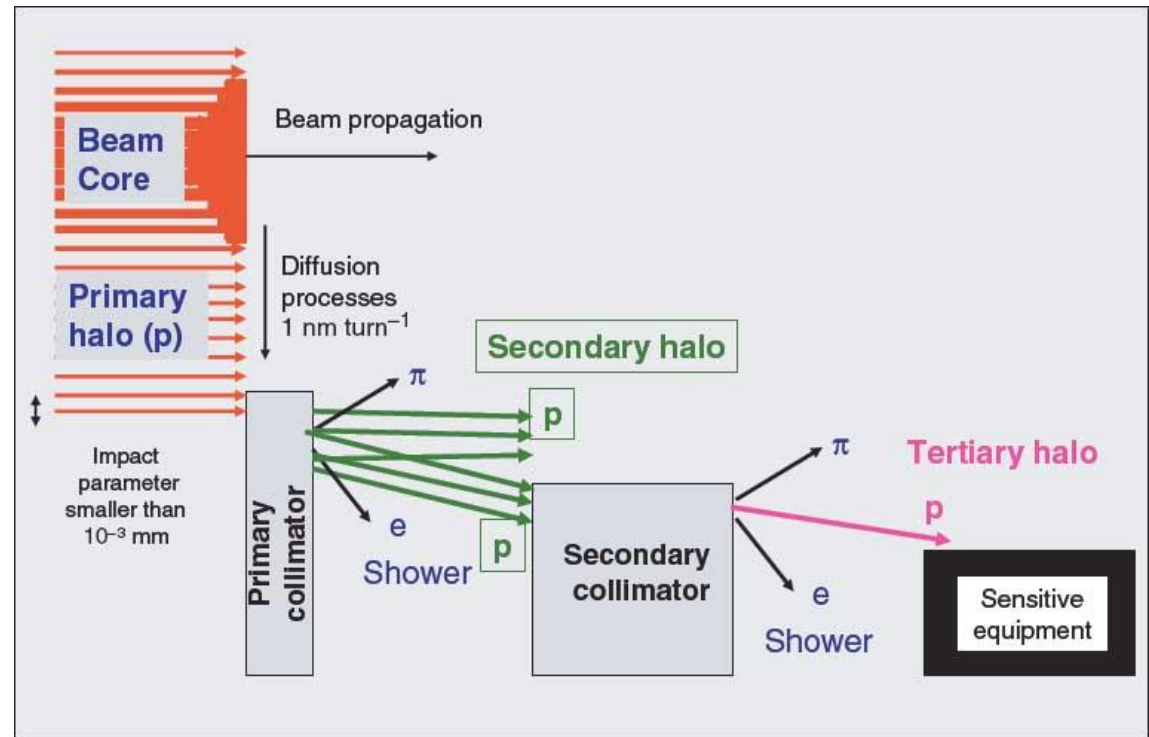


El efecto se reduce con aperturas grandes y materiales especiales

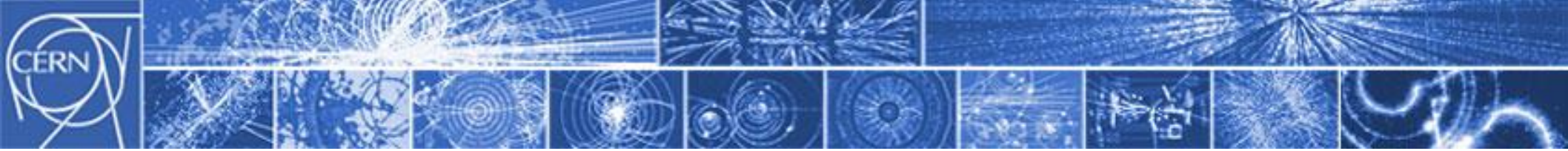


Colimación

Algunas partículas se pueden desviar demasiado de la trayectoria ideal generando mucho ruido en los detectores y poniendo en peligro la integridad del acelerador



El sistema de colimación es un sistema de triple protección para evitar pérdidas en lugares críticos

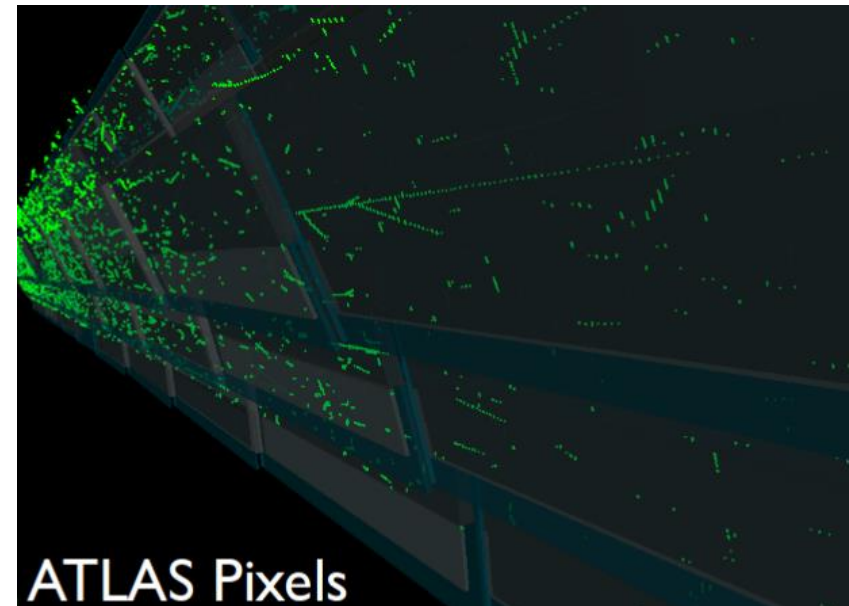
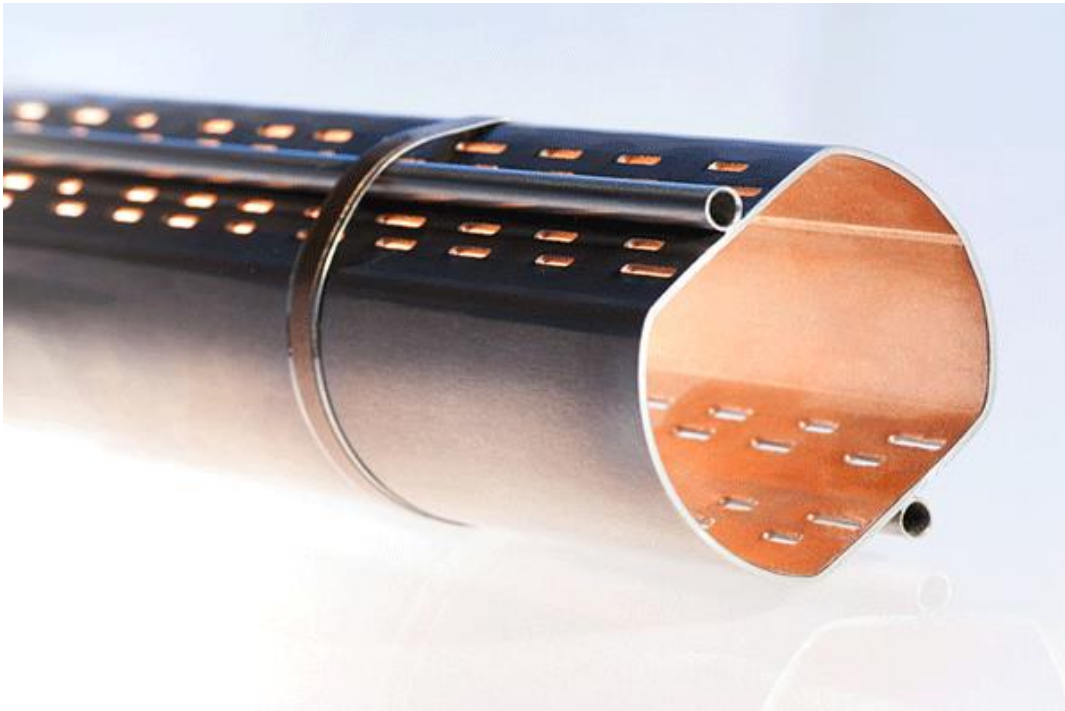


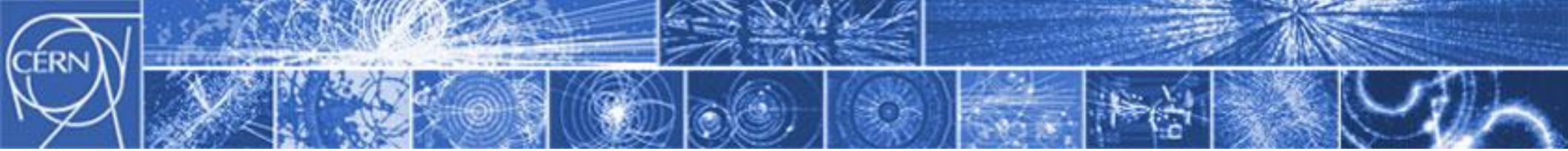
Vacío

Dentro de la cámara del LHC está tan vacío como el espacio exterior

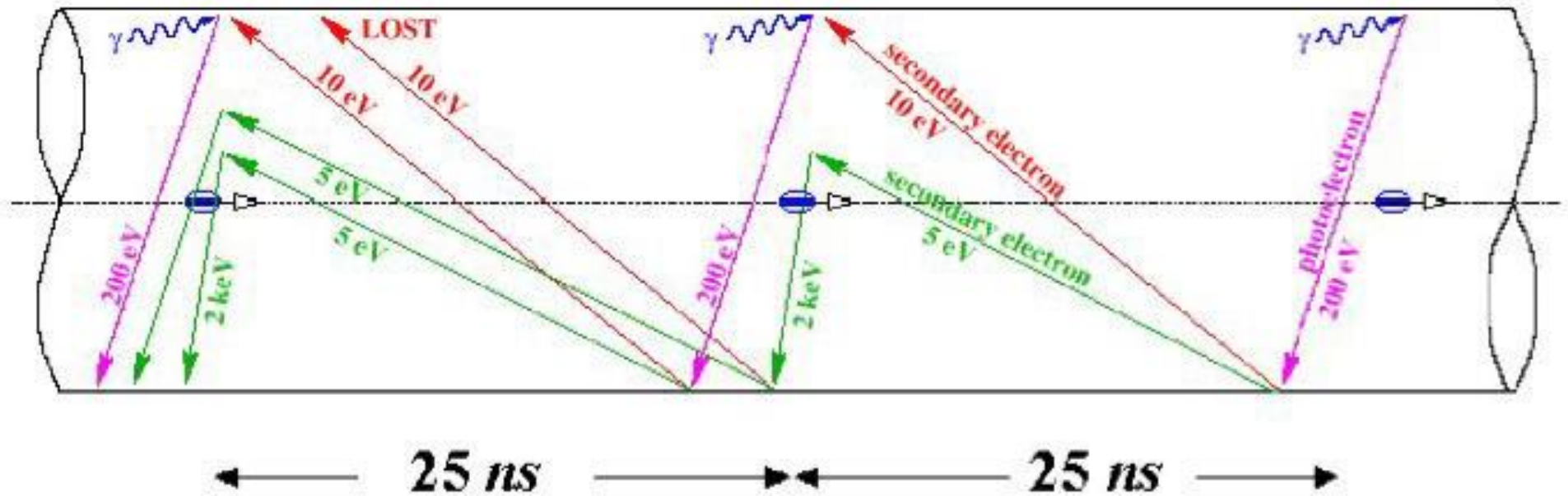
$$10^{-10} \text{ mbar}$$

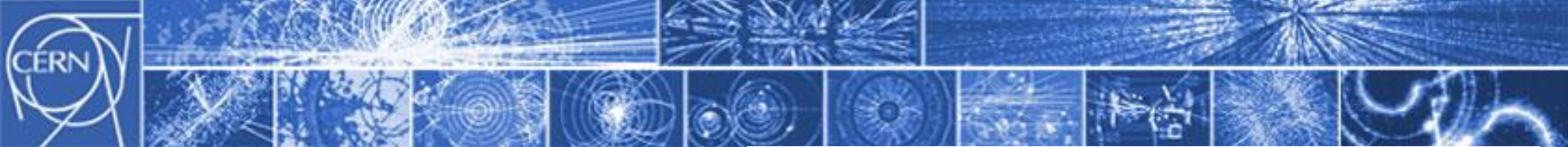
3 millones de
moléculas por
centímetro cuadrado





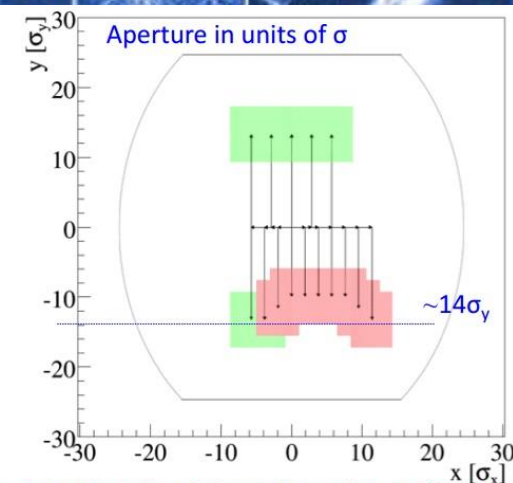
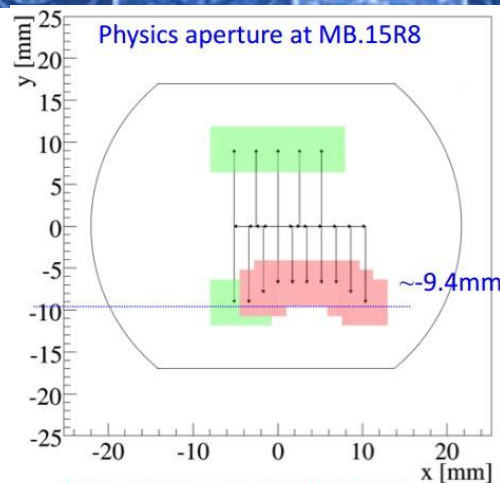
Pero no está tan vacío: “Electron cloud”





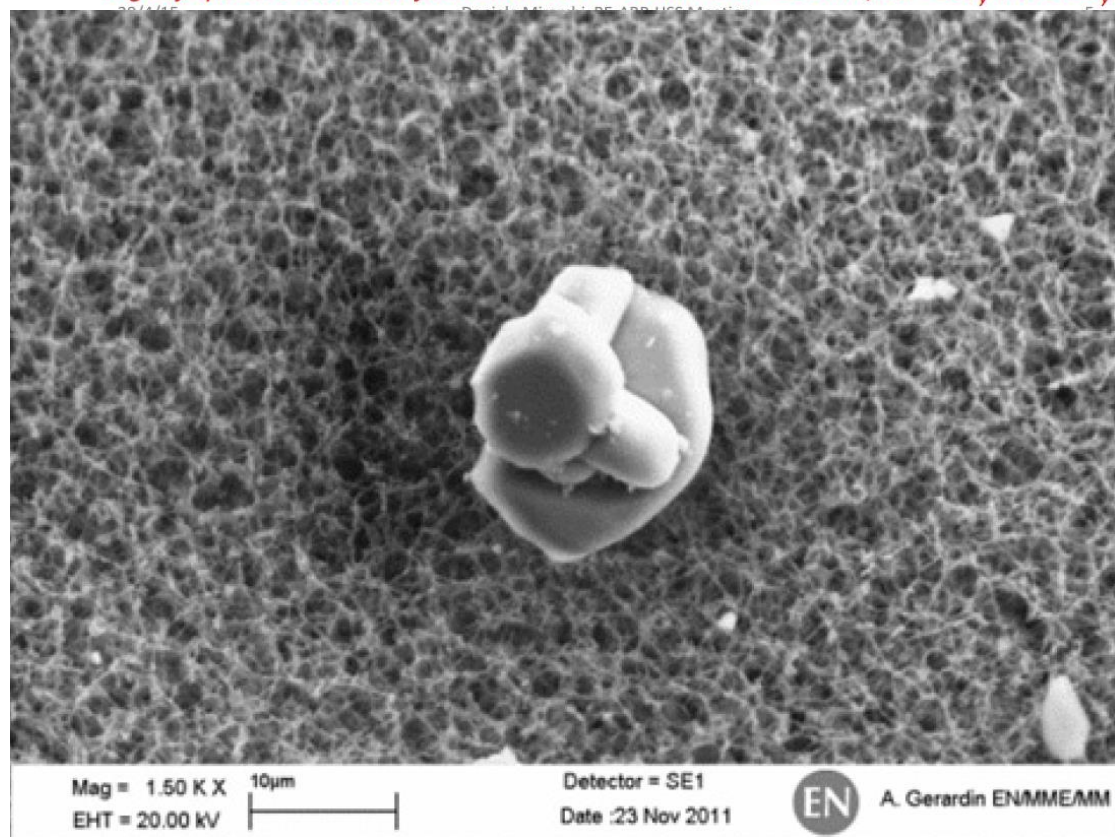
UFOs y ULOs

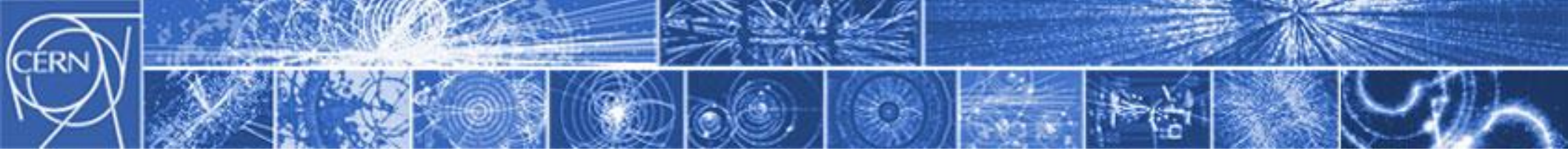
Unidentified Falling Objects
y
Unidentified Laying Objects



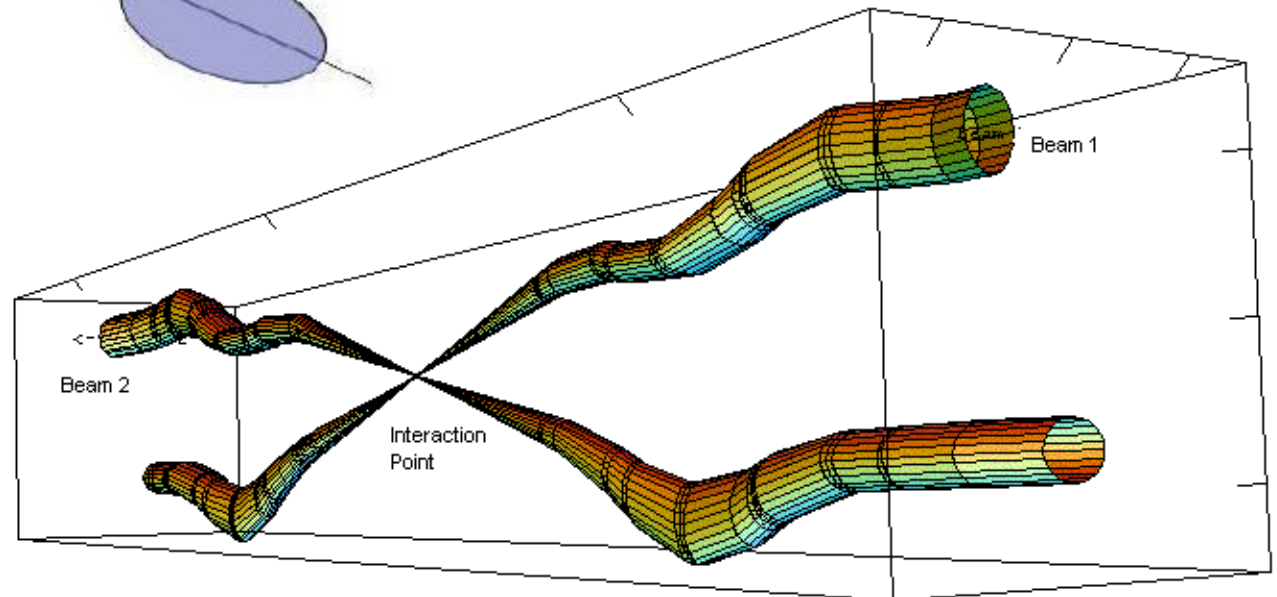
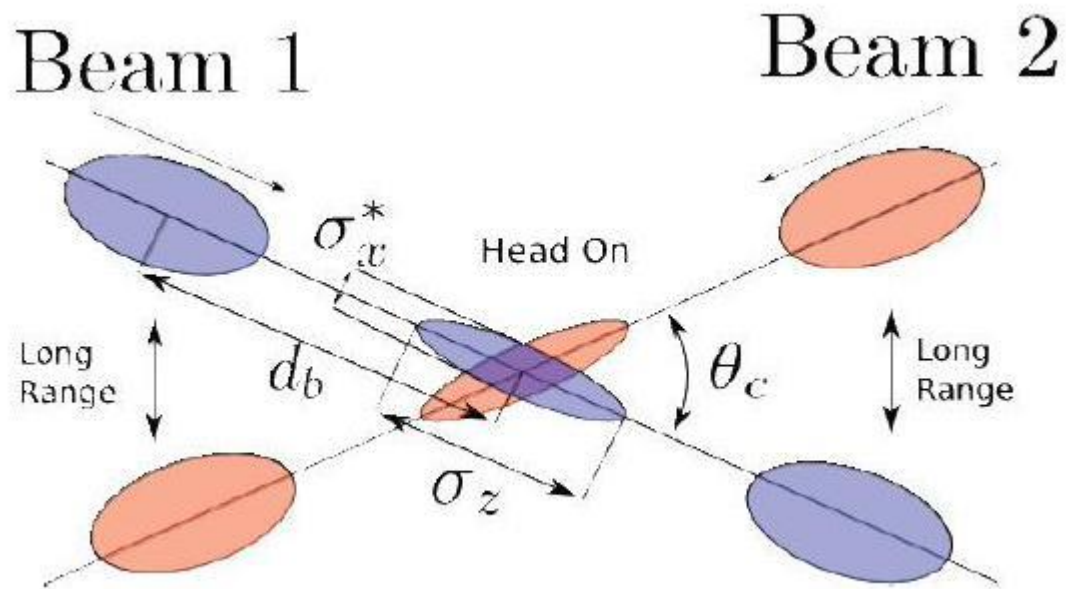
Edge of aperture restriction found between $\sim -8.4\text{mm}$ and $\sim -9.4\text{mm}$, i.e. $\sim 12\sigma_y$ and $\sim 14\sigma_y$

Actualmente uno de los principales causantes de fallos durante la operación del LHC

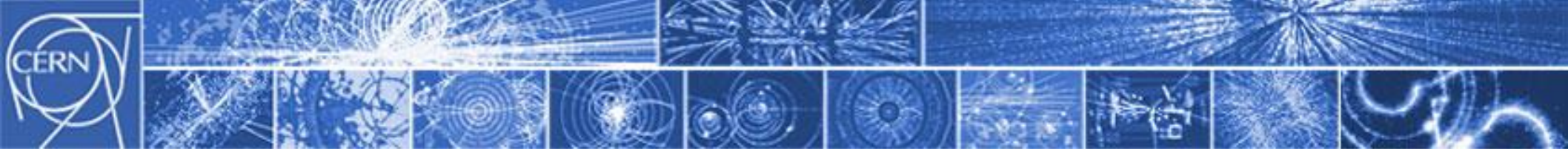




Ángulo de cruce y “beam-beam effects”

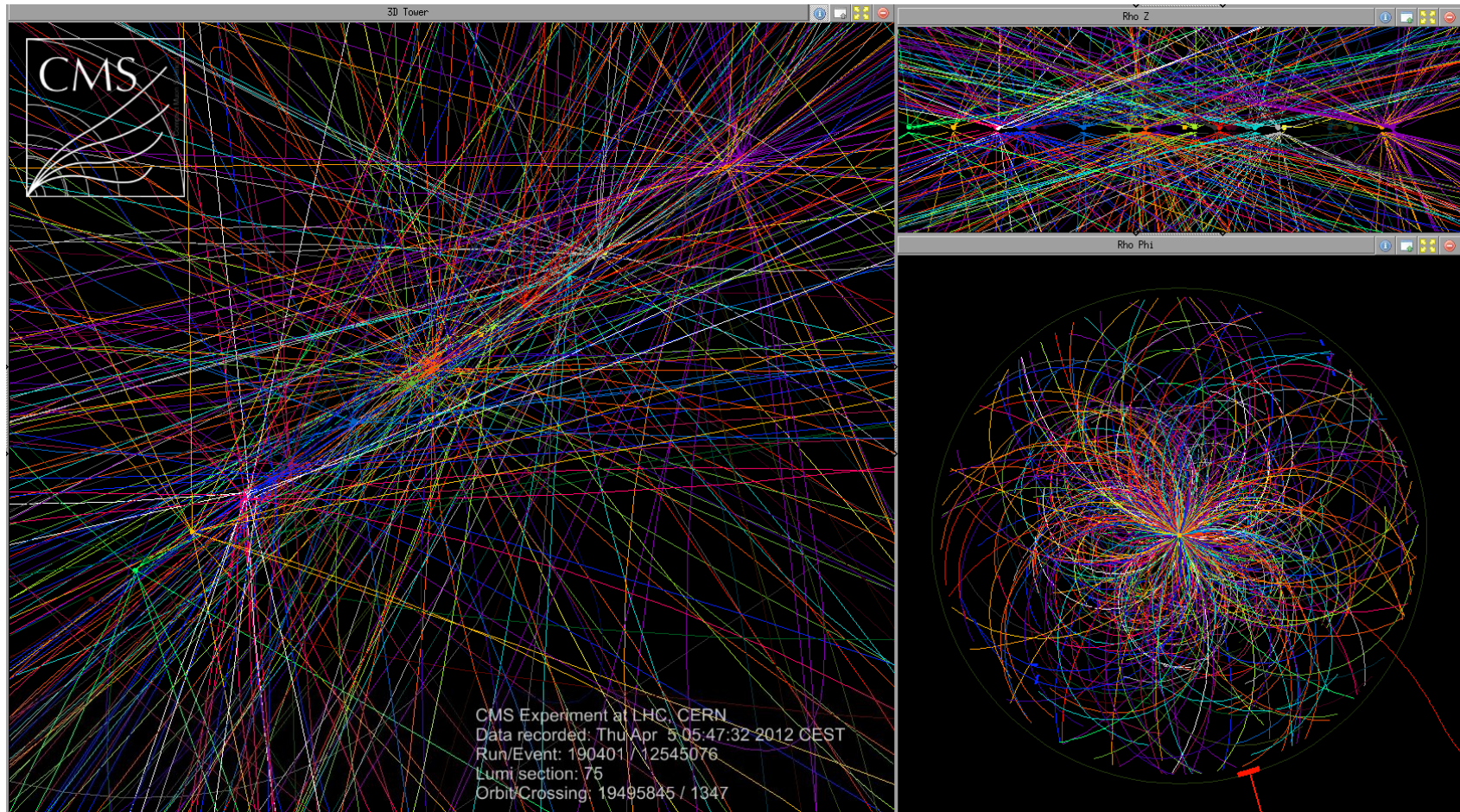


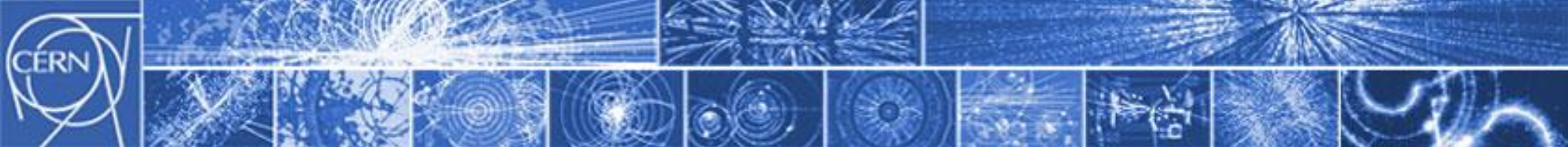
Relative beam sizes around IP1 (Atlas) in collision



“Pile up”

O de cómo los detectores tienen dificultades para gestionar tantas colisiones cada segundo





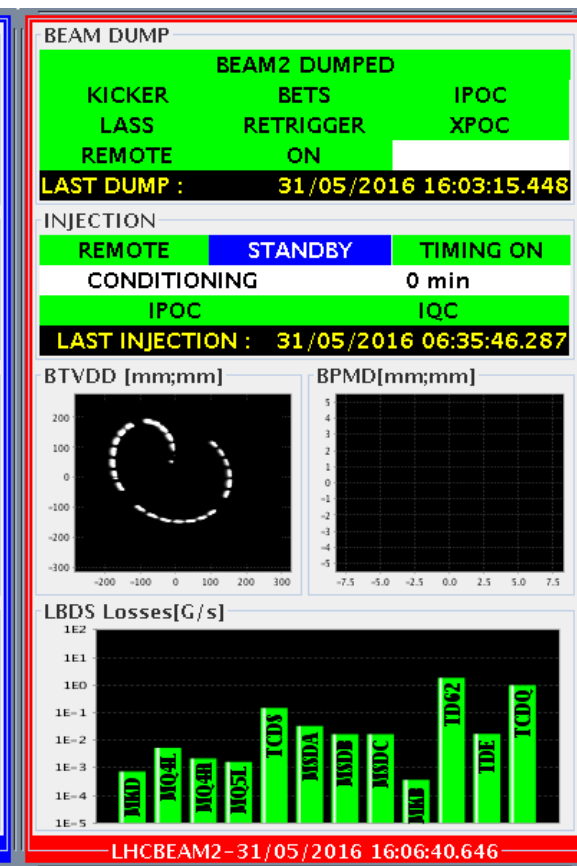
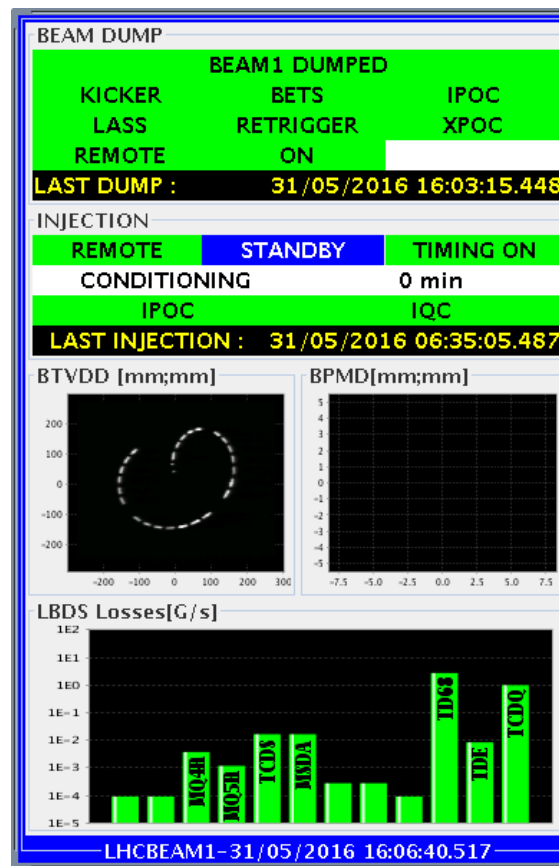
Diagnóstico y “Beam dump”

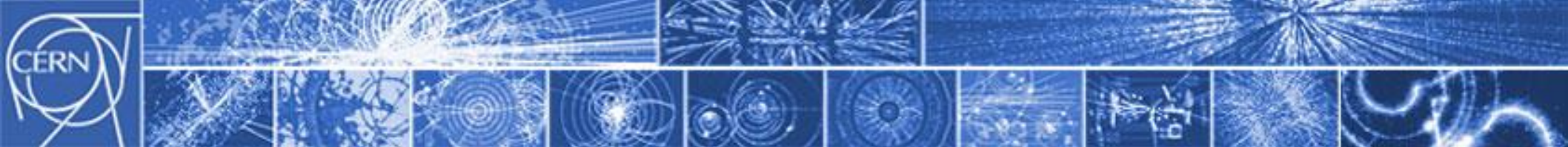


Wire scanner

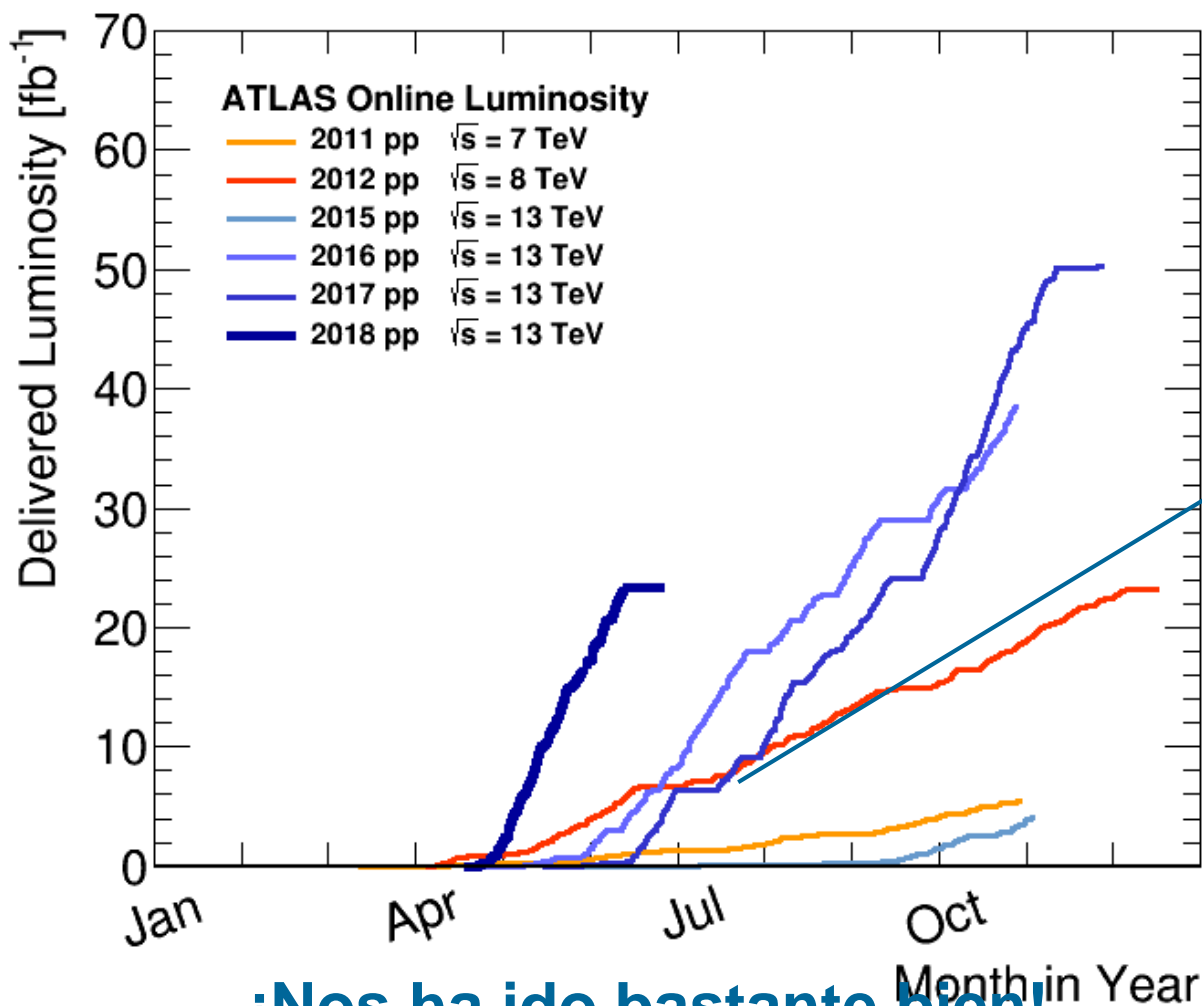
Estamos preparados para cualquier eventualidad

Una gran diversidad de dispositivos de diagnóstico nos permiten saber las características del haz en cada instante



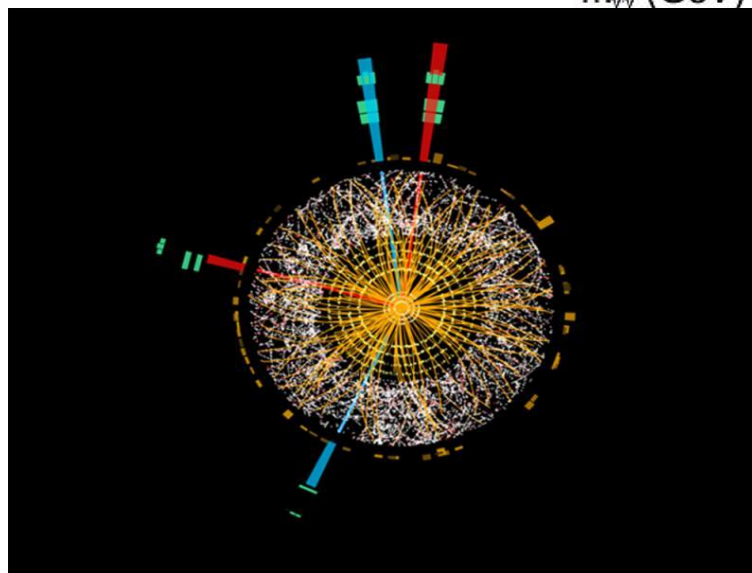
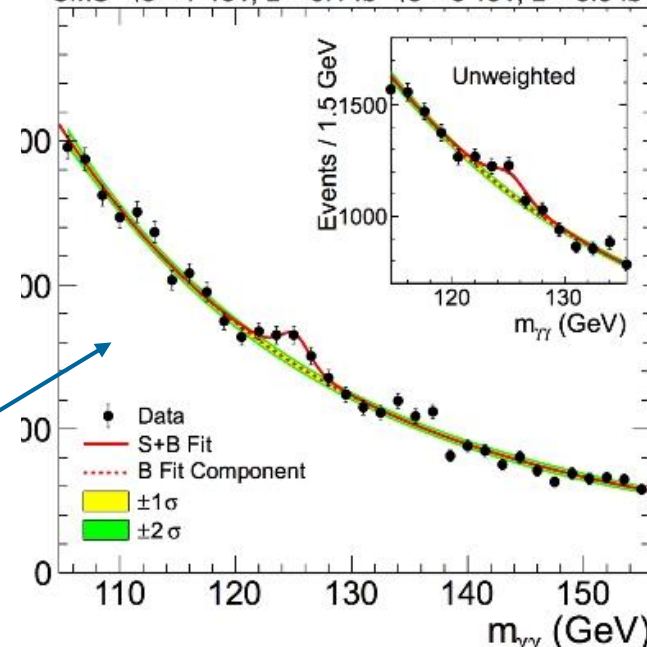


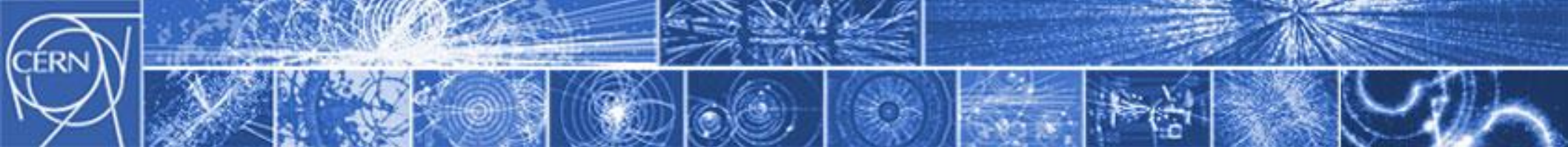
¿Cómo nos ha ido hasta el momento?



¡Nos ha ido bastante bien!

CMS $\sqrt{s} = 7$ TeV, $L = 5.1 \text{ fb}^{-1}$ $\sqrt{s} = 8$ TeV, $L = 5.3 \text{ fb}^{-1}$

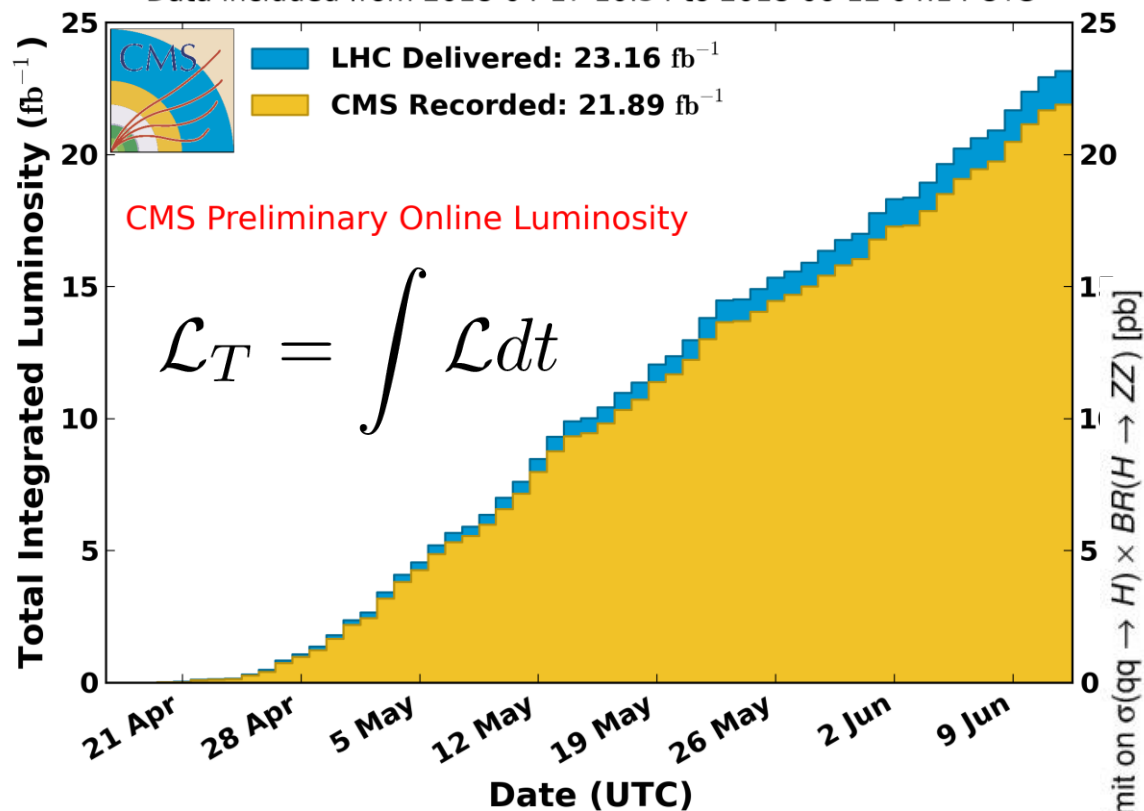




¿Cómo nos ha ido hasta el momento?

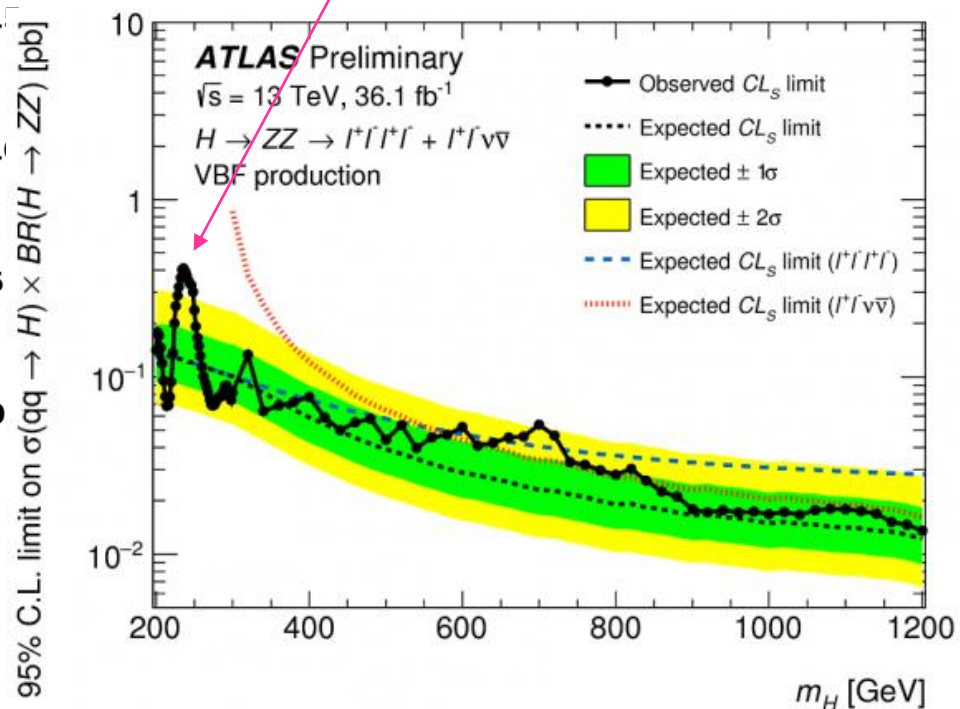
CMS Integrated Luminosity, pp, 2018, $\sqrt{s} = 13$ TeV

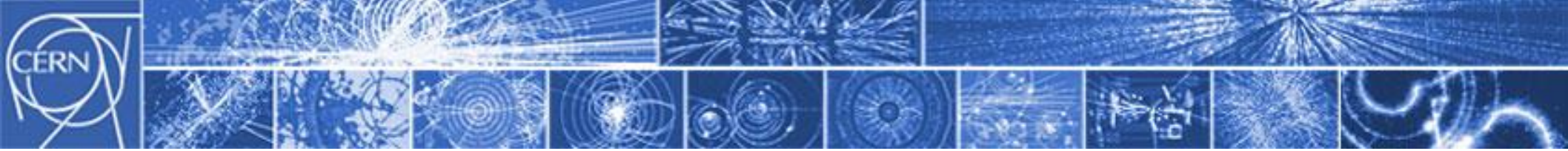
Data included from 2018-04-17 10:54 to 2018-06-12 04:14 UTC



$$\mathcal{L} = \frac{N^2 f_{\text{rep}} n_b}{4\pi\sigma_x\sigma_y}$$

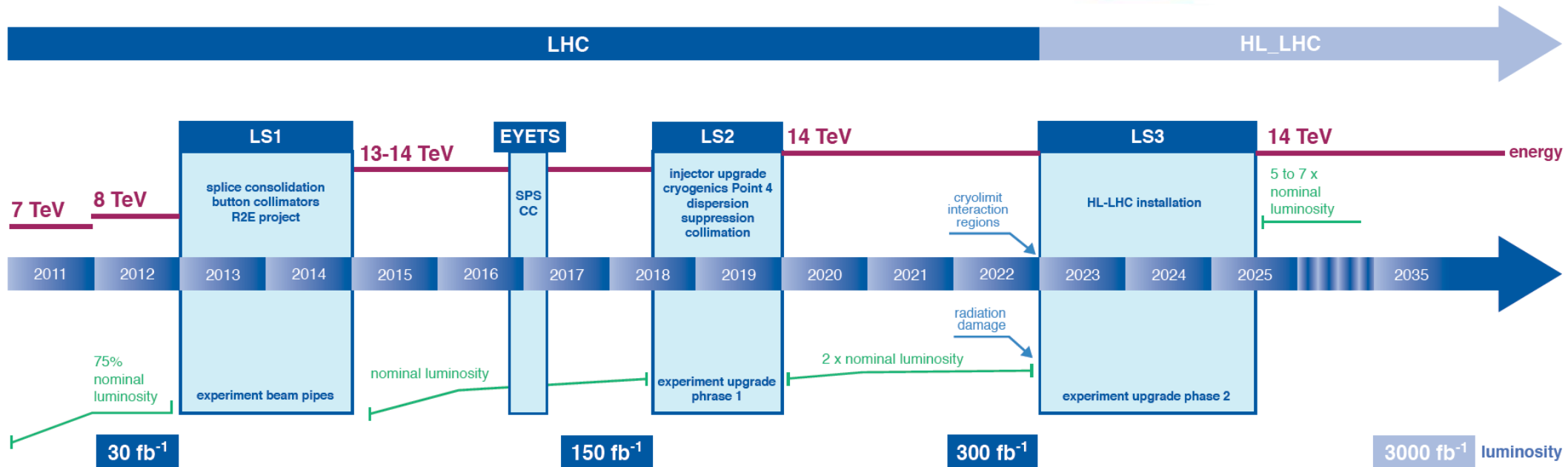
¿Qué es esto?

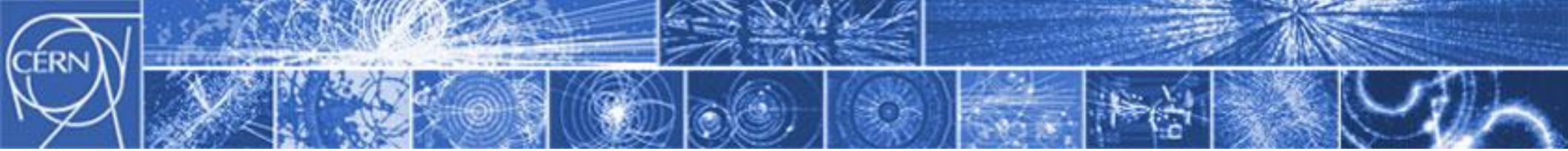




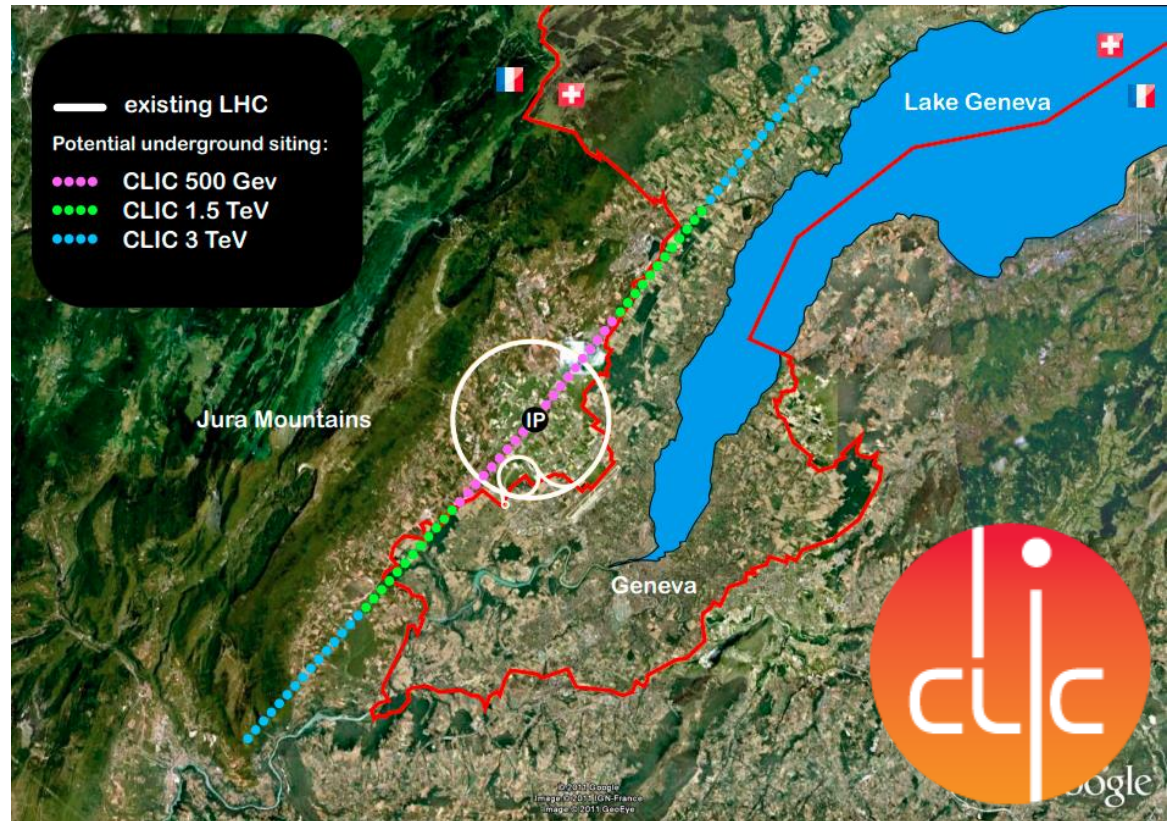
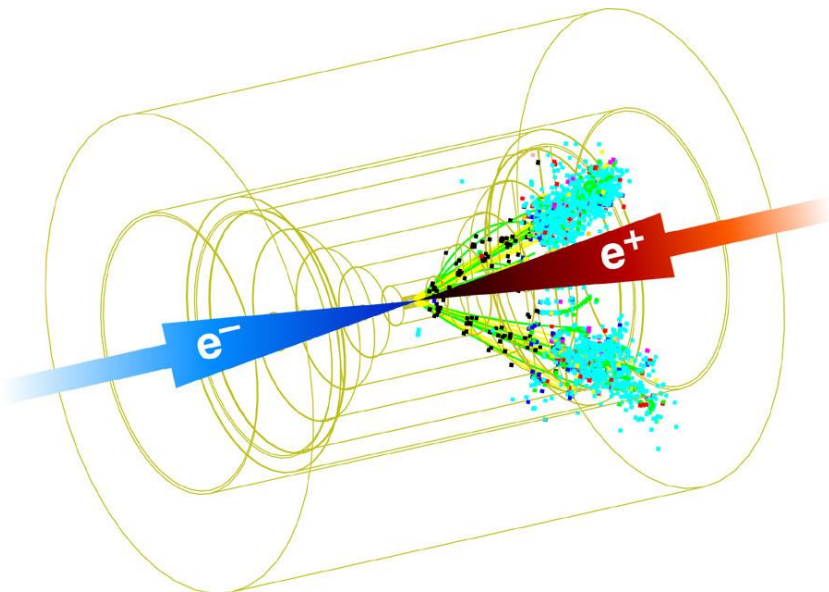
Mejorando el LHC

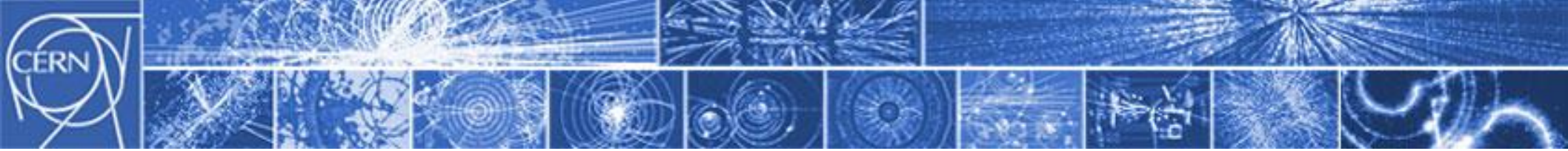
LHC / HL-LHC Plan





Linear Colliders

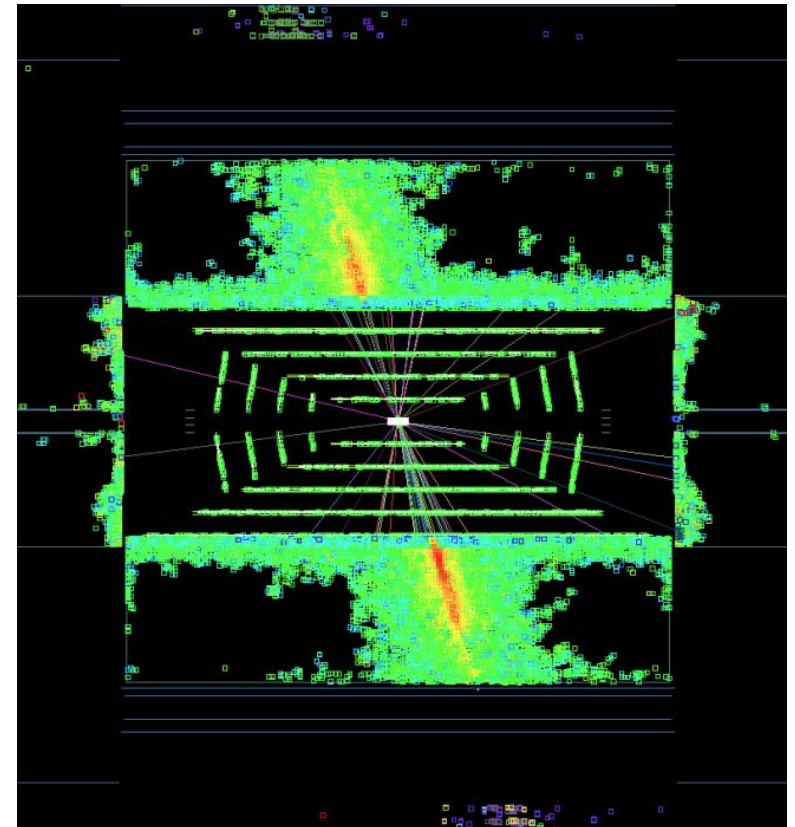
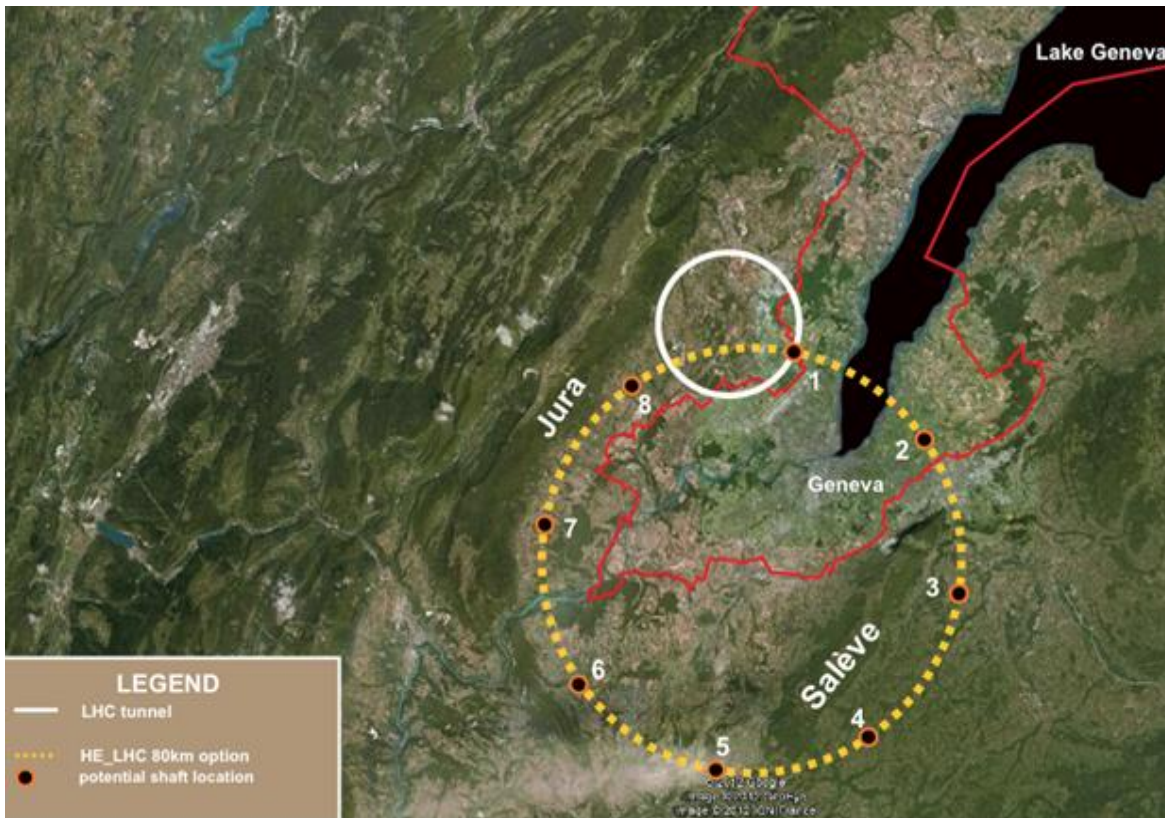


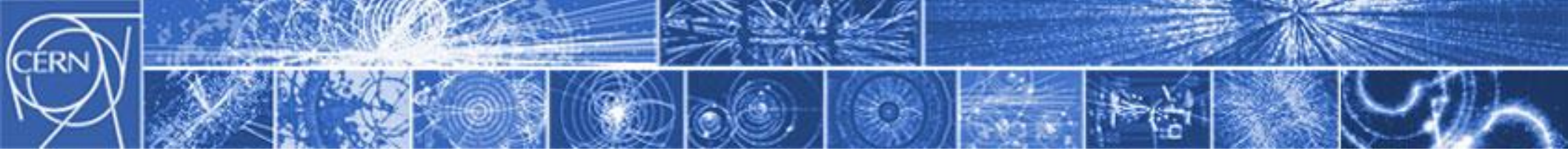


Future Circular Collider

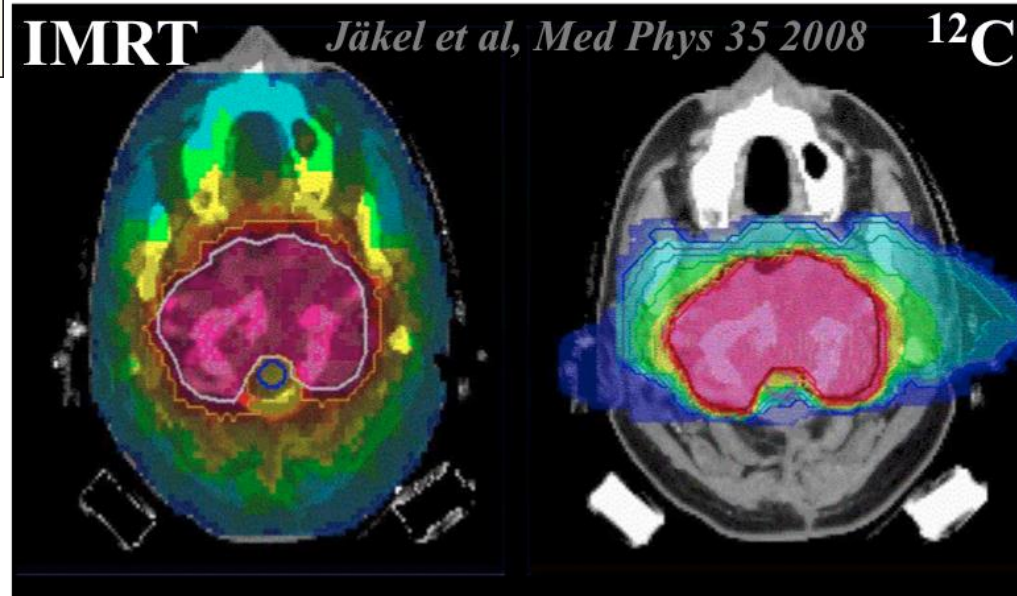
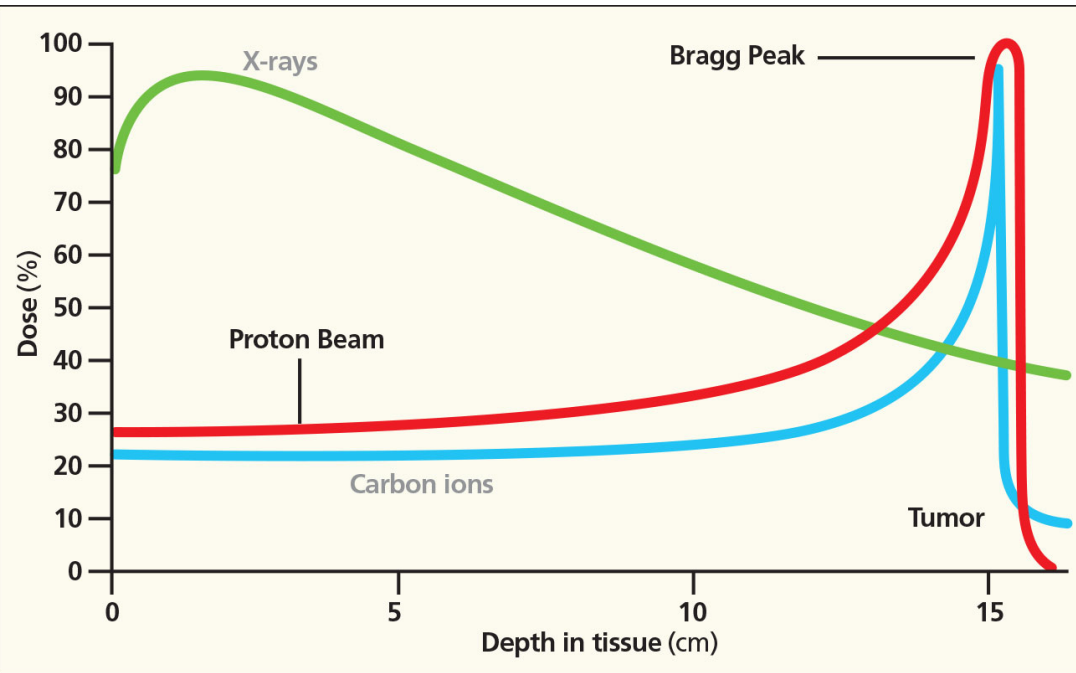


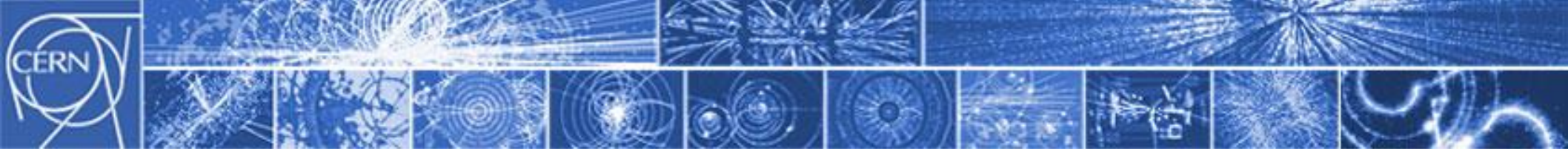
- Energía de colisión: 100 TeV
- Tunnel = 100 km



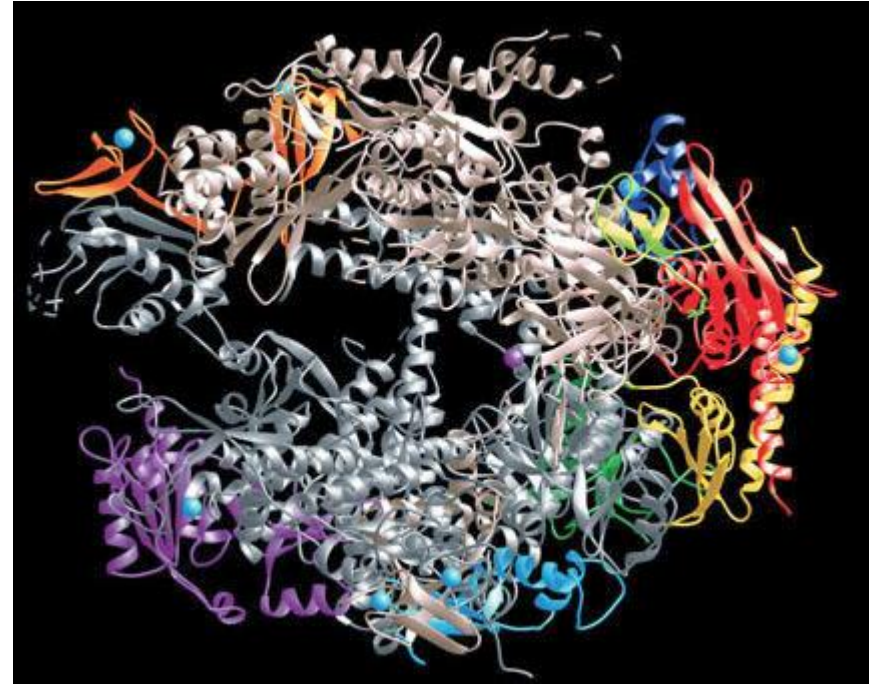
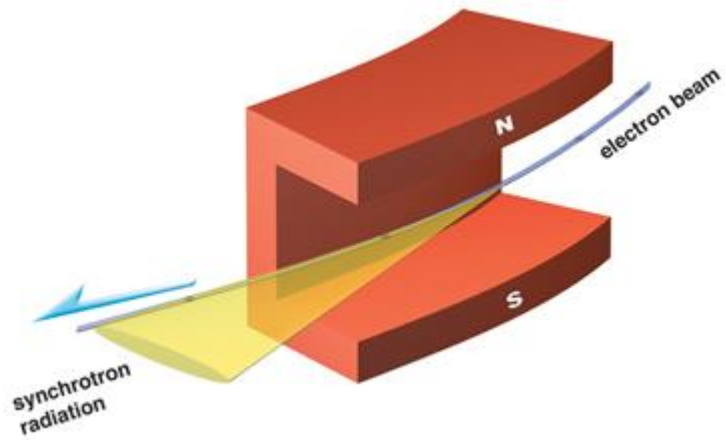


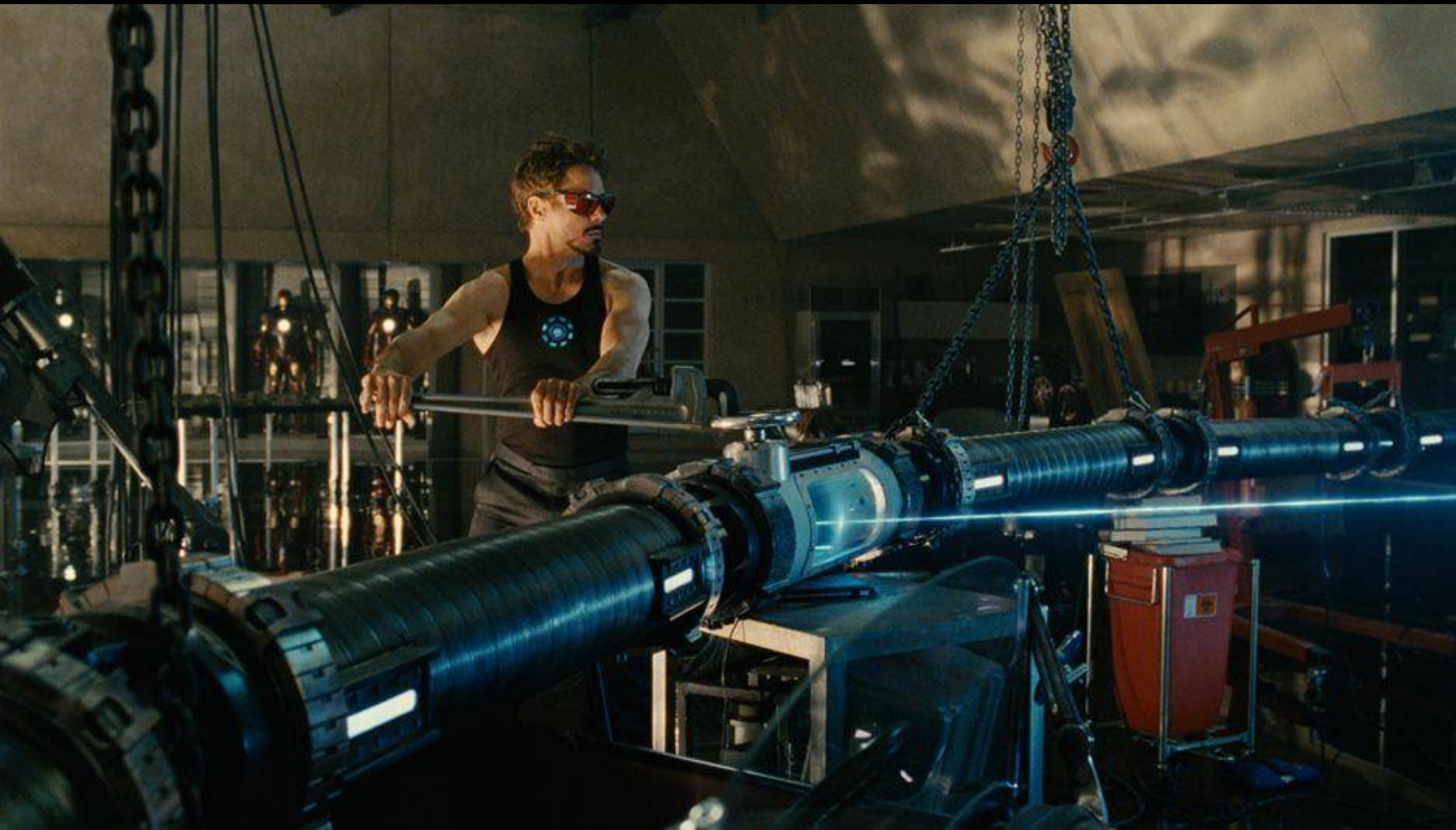
Aceleradores para medicina





Radiación de sincrotrón







Muchas
gracias

