Accelerators

Prof. Dr. Martin Erdmann

RWTH Aachen University

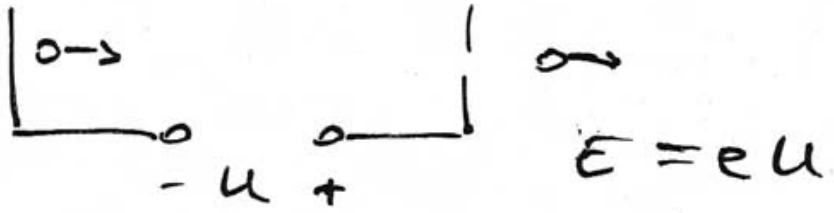
8-Oct-2010

CERN (Genf): Large Hadron Collider

27 km Circumference

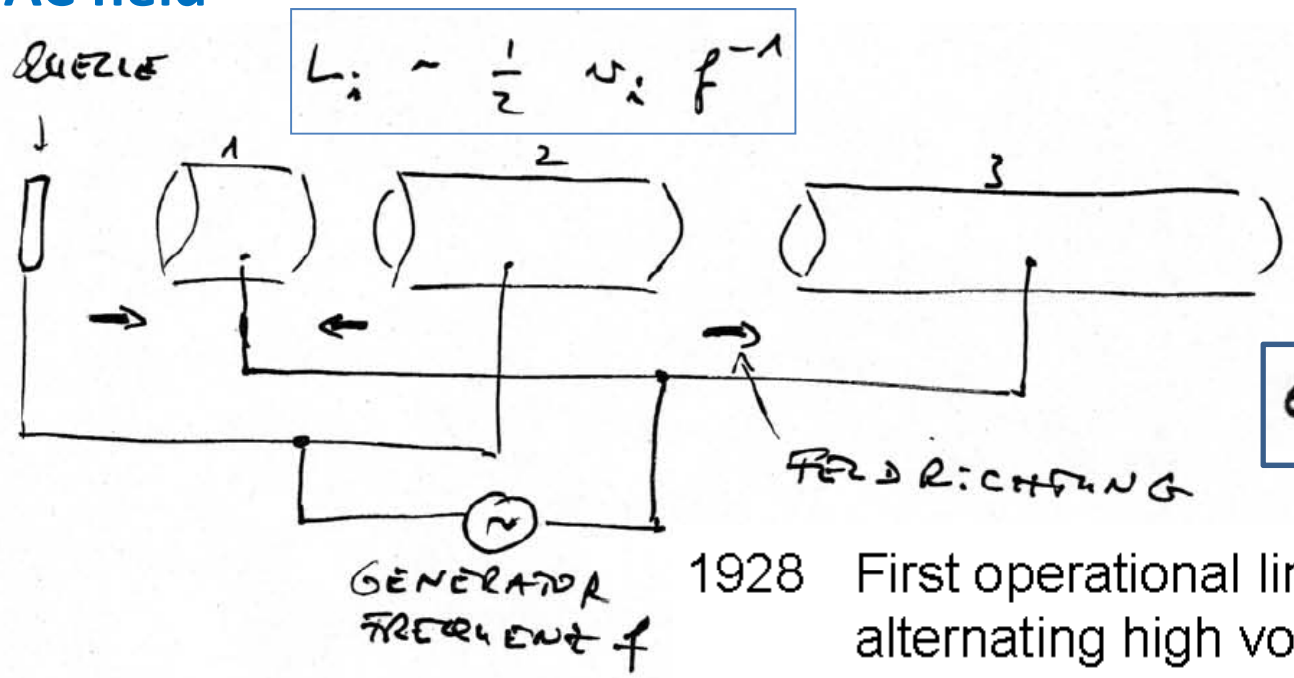
Electromagnetic Acceleration

Static field



$E \sim 10$ keV

AC field



$E \sim 50$ MeV

1928 First operational linear accelerator with alternating high voltage constructed by Rolf Wideröe at RWTH Aachen

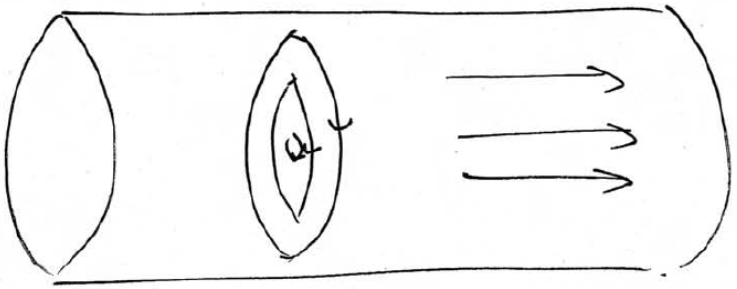
Radio Frequency Cavity

ELEKTROMAGNETISCHE WELLE MIT

LONGITUDINALER ELEKTRISCHER FELDKOMPONENTE

TM_{010} TRANSVERSALE MAGN. KOMPONENTE

PERIODE : KNOTEN AN WAND



MAGNETFELD ELEKTRISCHES FELD

MIKROWELLEN $\lambda \sim$ cm $\Leftrightarrow$ $f \sim$ 10 GHz

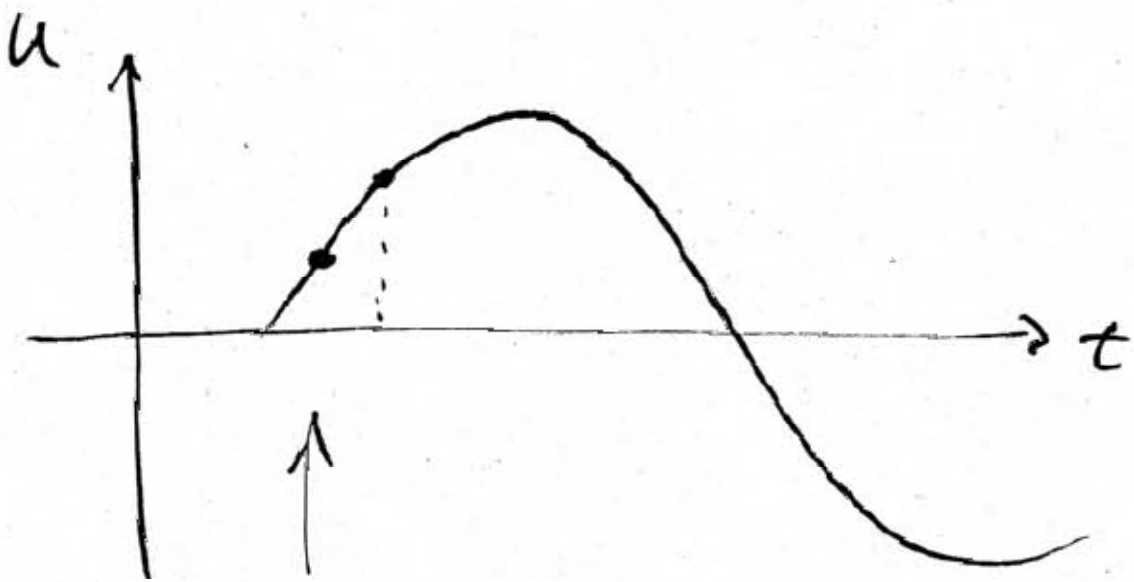
E ~ TeV

PHASENGESCHWINDIGKEIT DER WELLE AUF

TEILCHENGESCHWINDIGKEIT "ABBREMSEN" : SCHEIBEN

Longitudinal Focussing

PHASENFOKUSSIERUNG

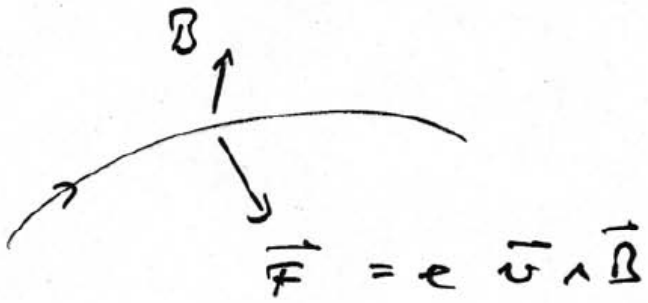


TEILCHEN ZU SCHNELL, D.H. KOMMT FRÜHER,

SIEHT WENIGER BESCHLEUNIGUNGSSPANNUNG

⇒ ANGLEICHUNG DER GESCHWINDIGKEIT

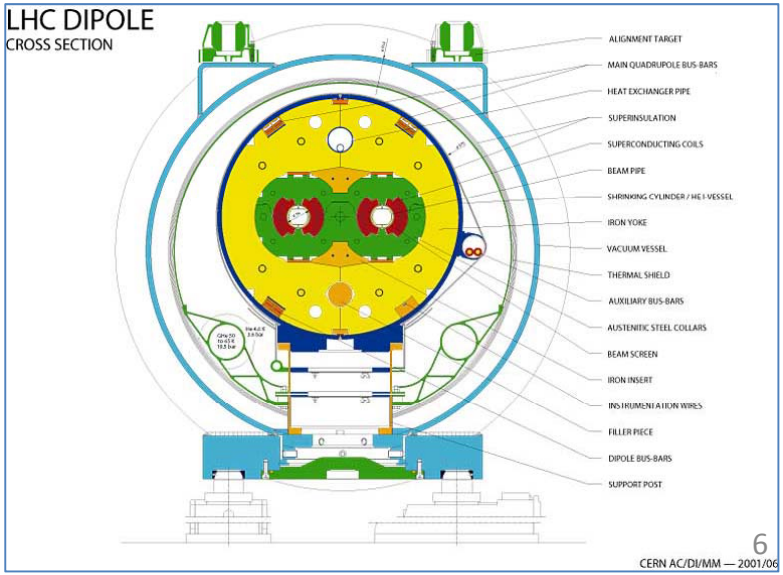
Circular Accelerator



impuls $p\,[\frac{GeV}{c}] = 0.3\;B\,[Tesla]\cdot R\,[m]$

B = 3500/0.3/[27000/(2π)] T = **5.4 T**

12m lange Supraleitende Dipolmagnete mit
10 000 t flüssigem Stickstoff auf 80 K vorgekühlt,
mit 60 t flüssigem Helium auf 1,9 K gekühlt.



Synchrotronstrahlung

PRO UMLAUF ABGESTRAHLTE ENERGIE

$$\Delta E = \frac{4\pi e^2}{3R}\left(\frac{E}{mc^2}\right)^4$$

Elektronen

$$\Delta E\,[\mathrm{keV}] = 88.5\,\frac{E^4\,[\mathrm{GeV}^4]}{R\,[\mathrm{m}]}$$

LEP II $\Delta E\,[\mathrm{keV}] = 1\,\mathrm{GeV}$ *Large!*

Protonen

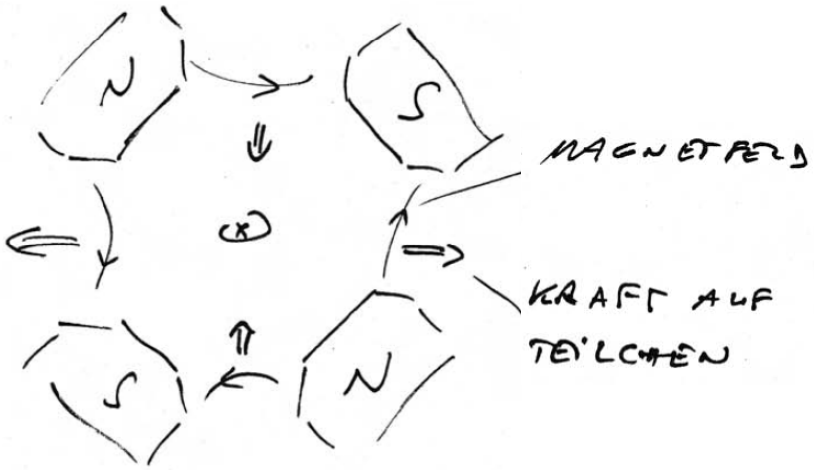
$$\left(\frac{m_e}{m_p}\right)^4 \sim \left(\frac{0.5\cdot 10^{-3}\,\mathrm{GeV}}{1\,\mathrm{GeV}}\right)^4 \sim 10^{-13}$$

LHC (7TeV)

$$\Delta E\,[\mathrm{keV}] = 88.5\,\frac{3500^4}{5\,10^3}\,10^{-13} = 0.27\ \mathrm{keV}$$ *small.*

Transverse Focussing

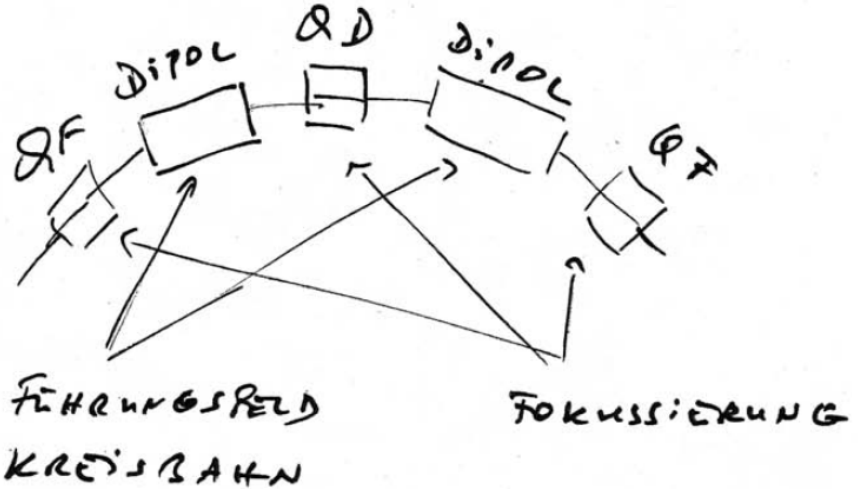
Quadrupolmagnet



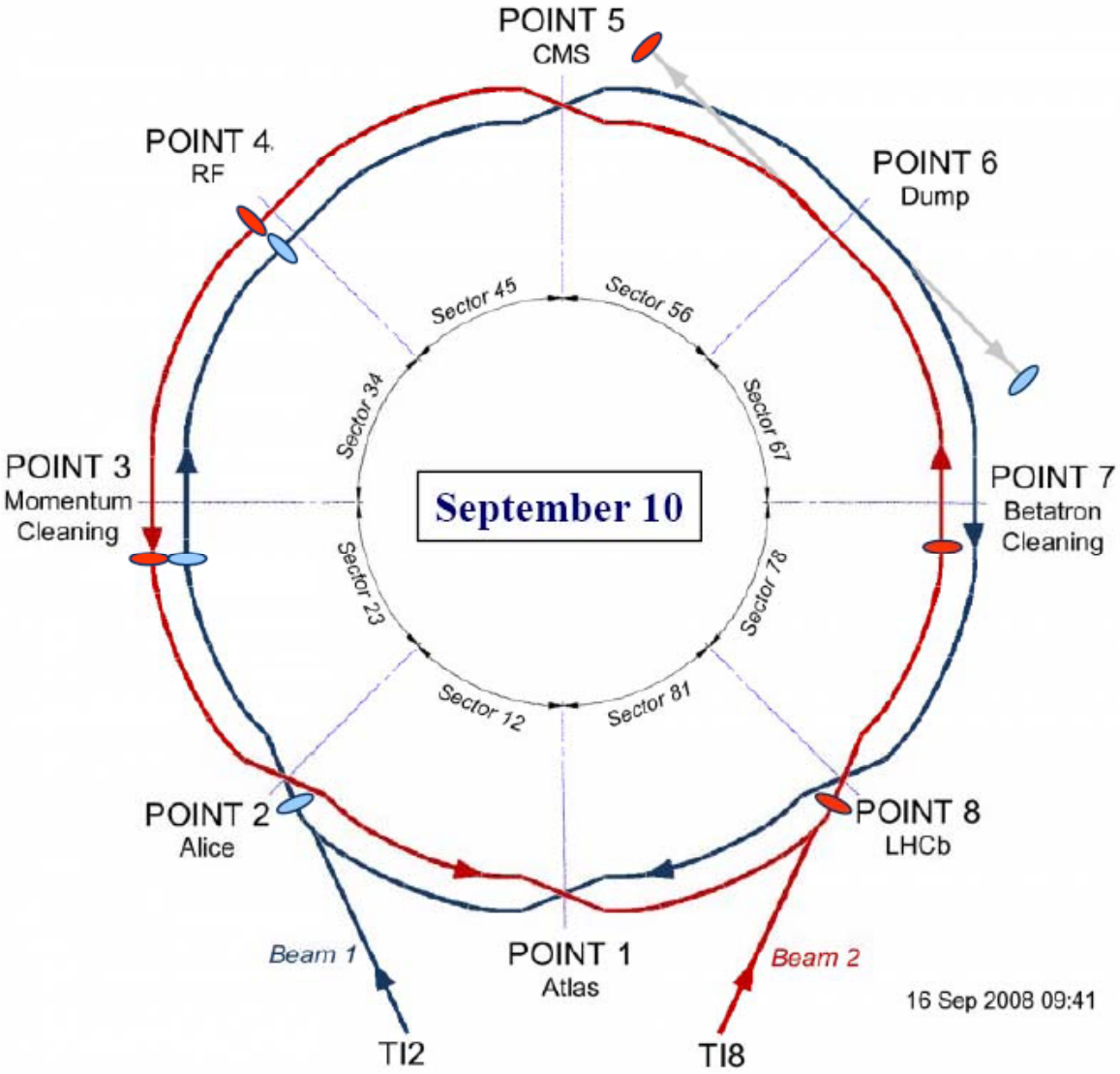
FOKUSSIERT IN EINER EBENE "F"

DEFOKUSSIERT IN ANDERER EBENE "D"

EFFEKTIV FOKUSSIEREND

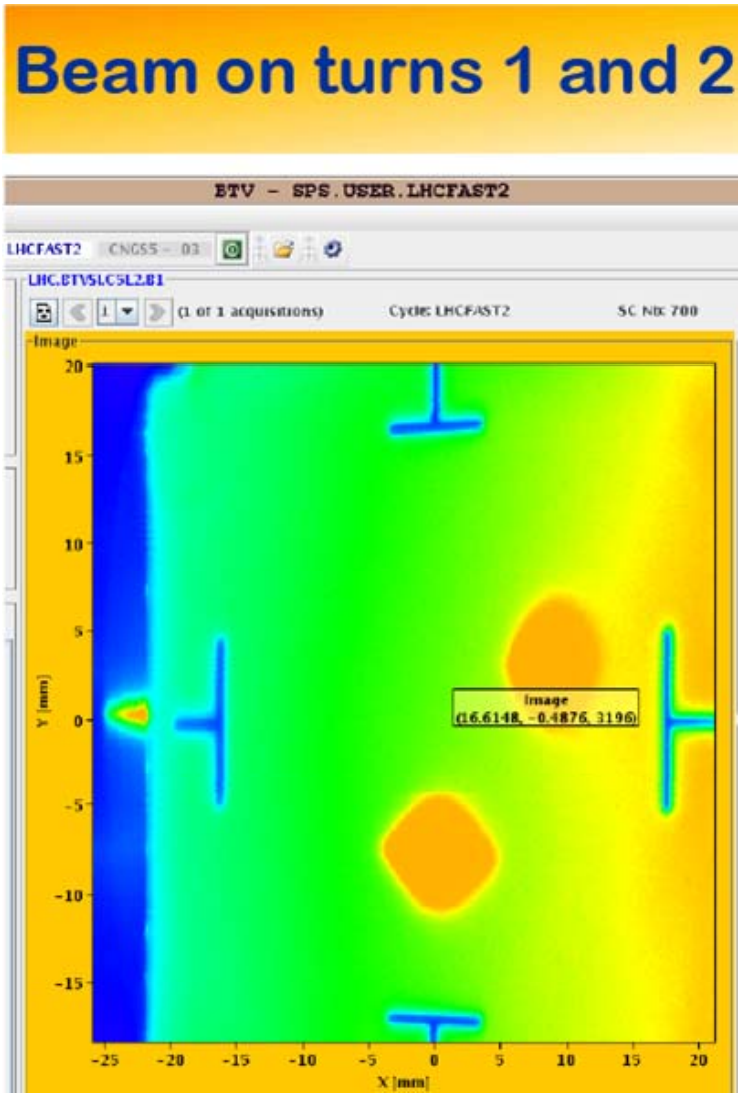


LHC 2009: First Injection E=450GeV



Der Strahl nach ersten 2 Umrundungen

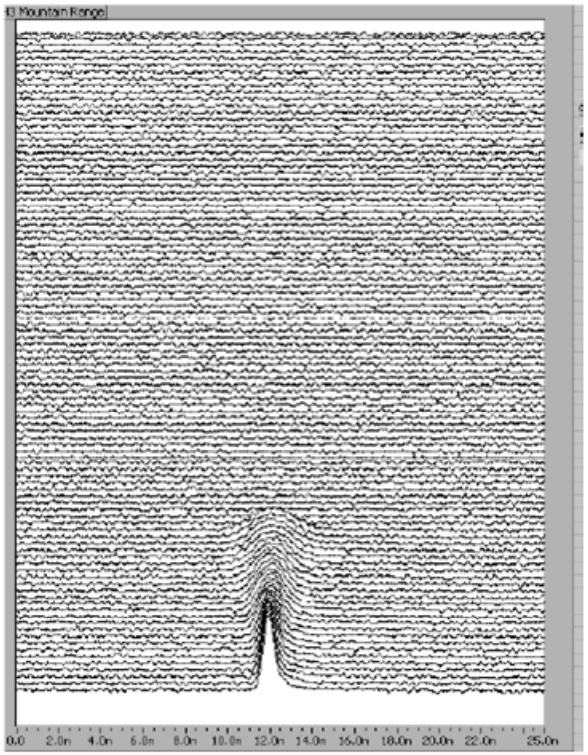
2009

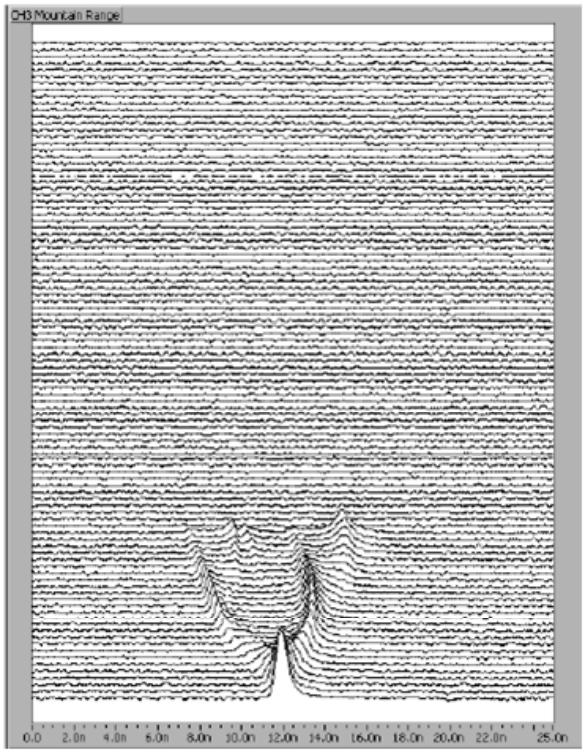


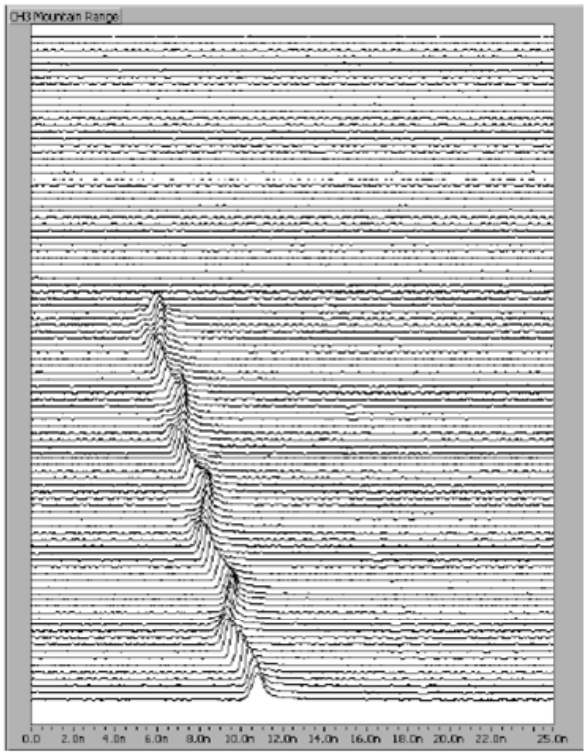
Proton-Paket-Einfang

2009

debunching in ~ 25*10 turns
roughly 25 mS



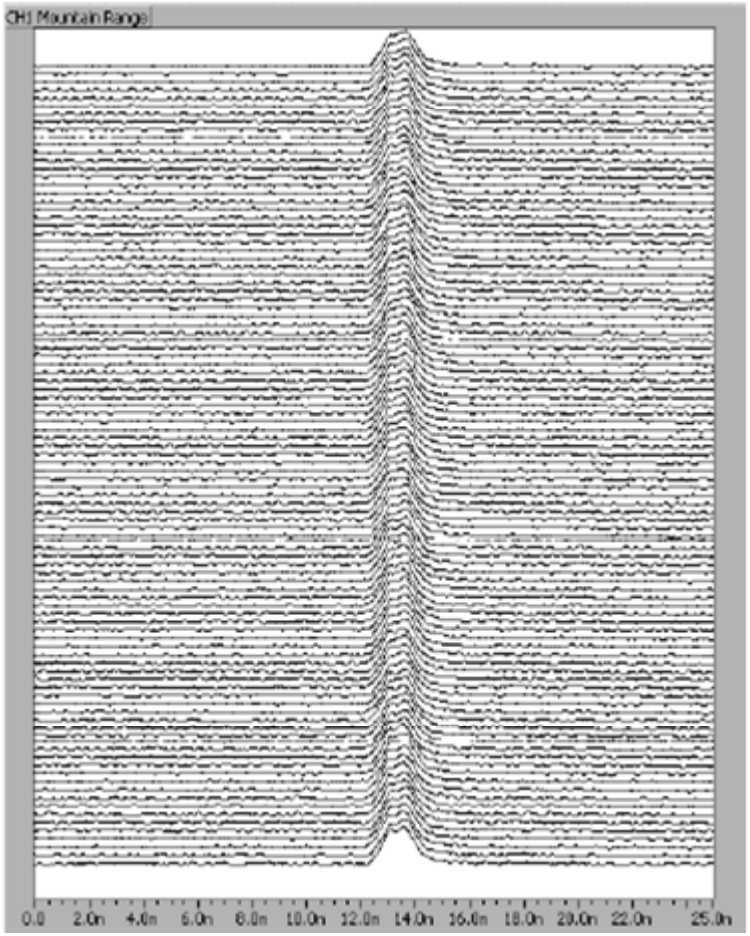




Versuch 1 Versuch 2 Versuch 3

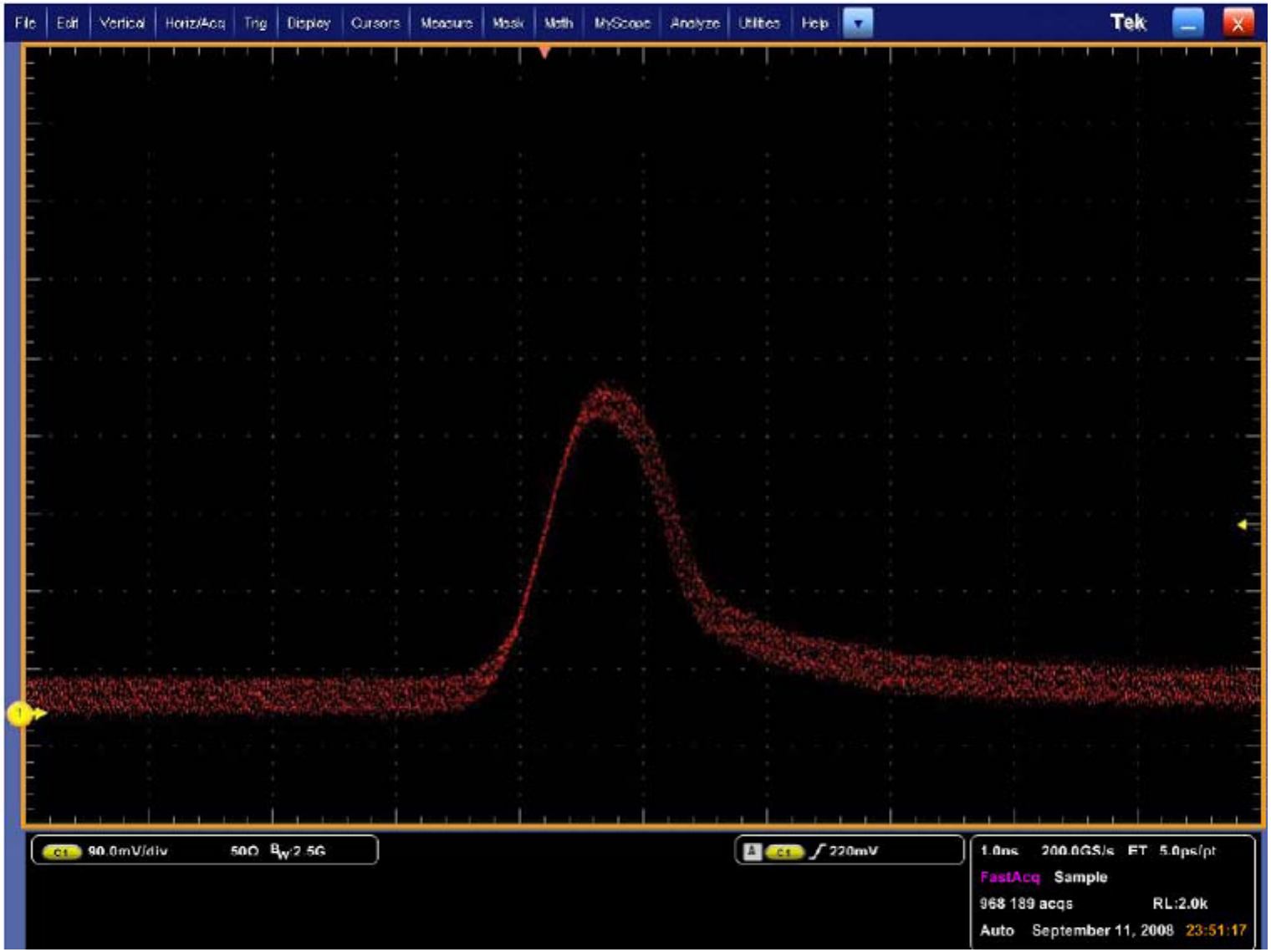
Protonen erfolgreich eingefangen

2009



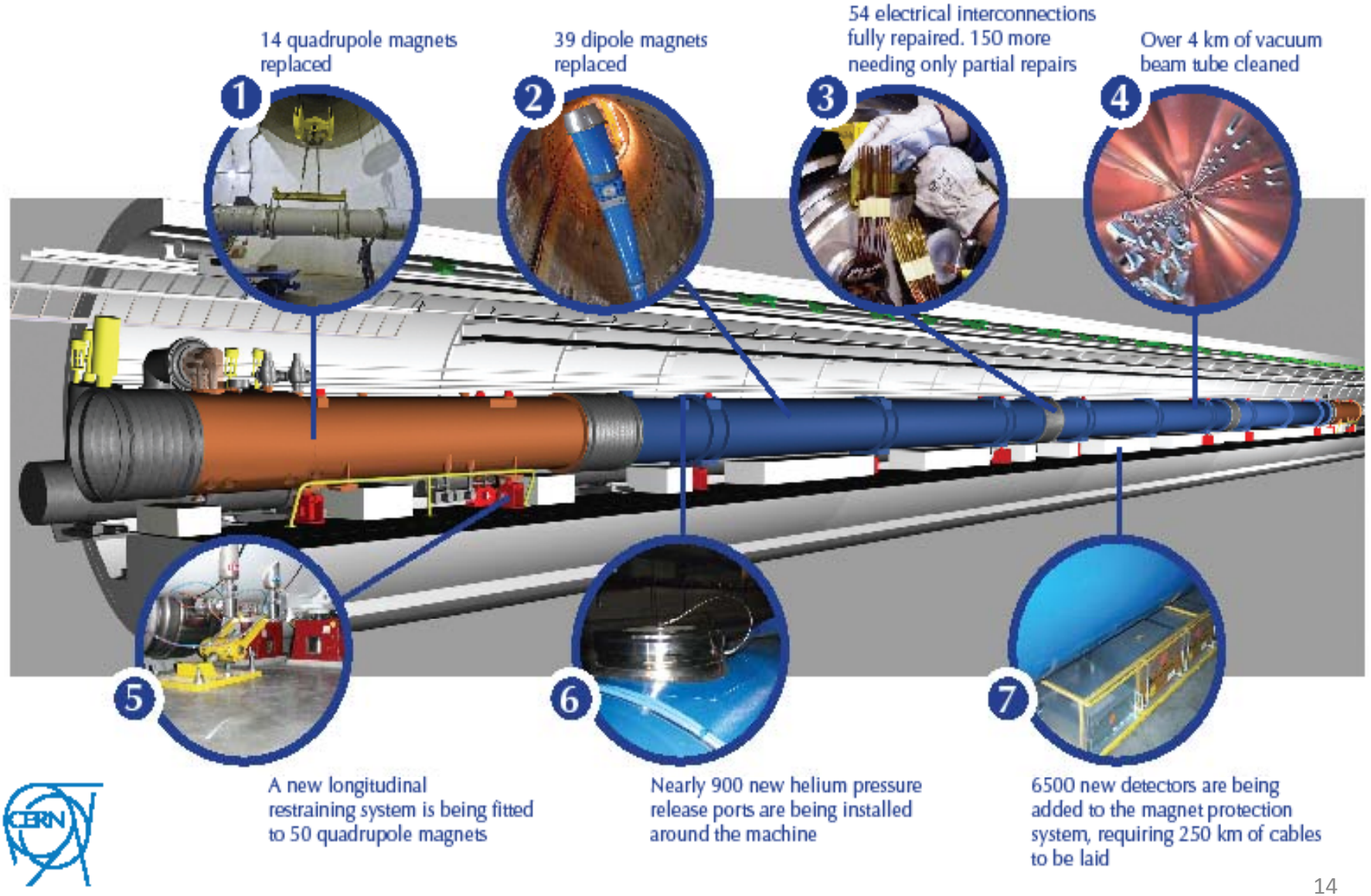
LHC longitudinal bunch profile Beam 2

2009



The LHC repairs in detail

From Steve Myers (CERN, ICHEP2010)



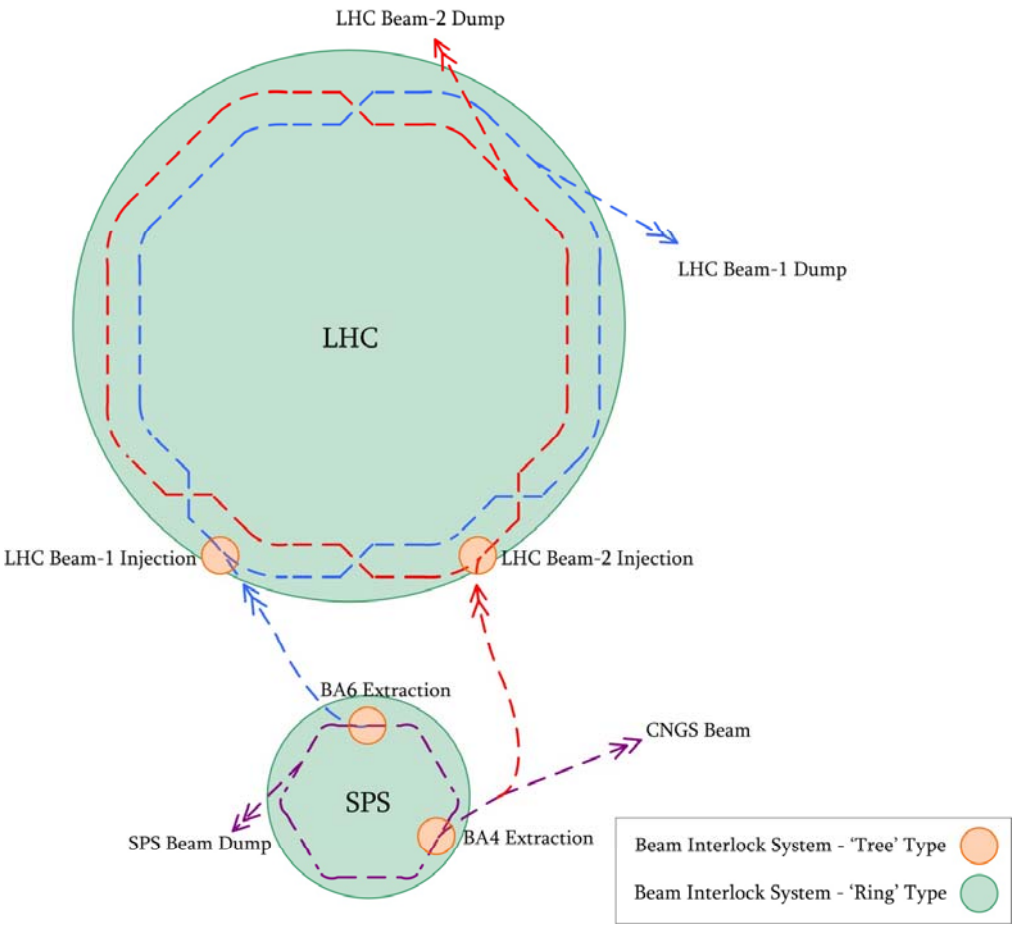
LHC today at 7 TeV

5.10.2010

2 10^{13} Protonen pro beam

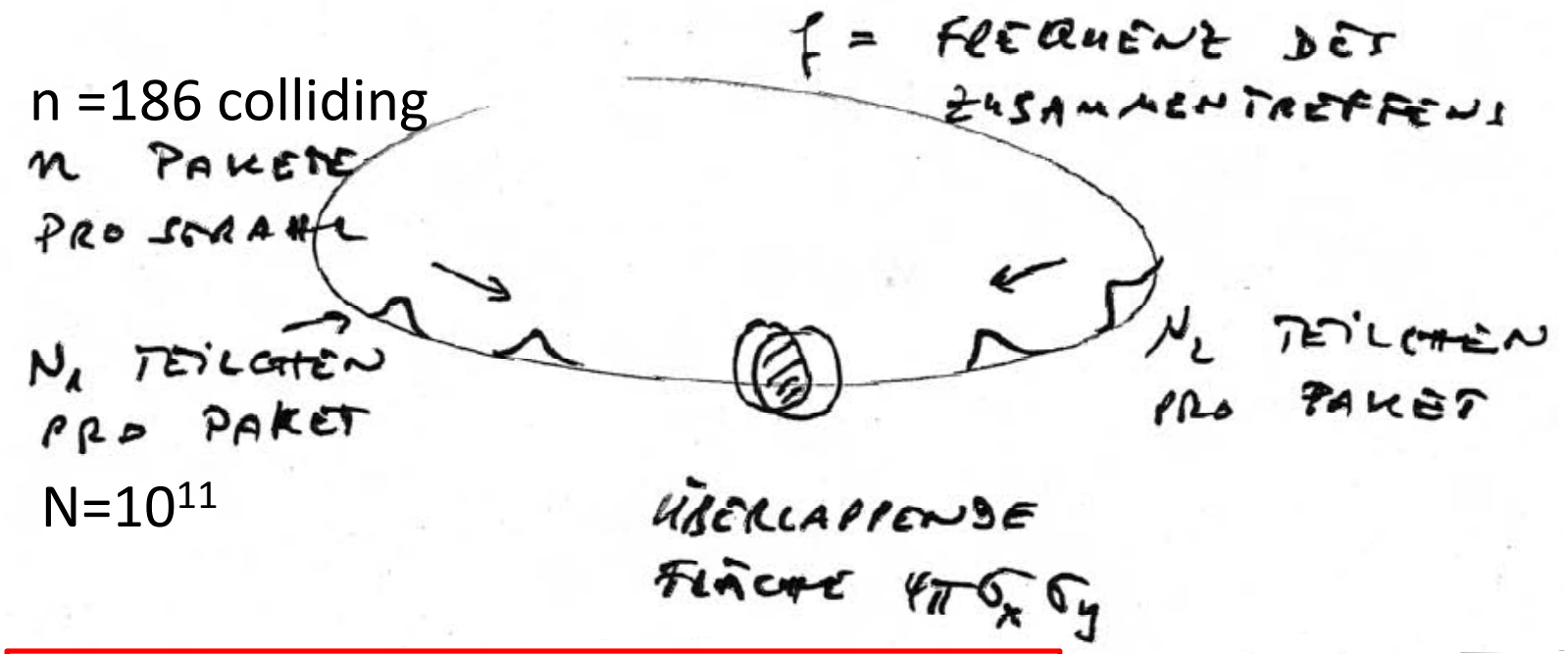
11.2 MJ pro Beam

Safety: Beam Dump
within 3 Turns



Luminosity

n =186 colliding



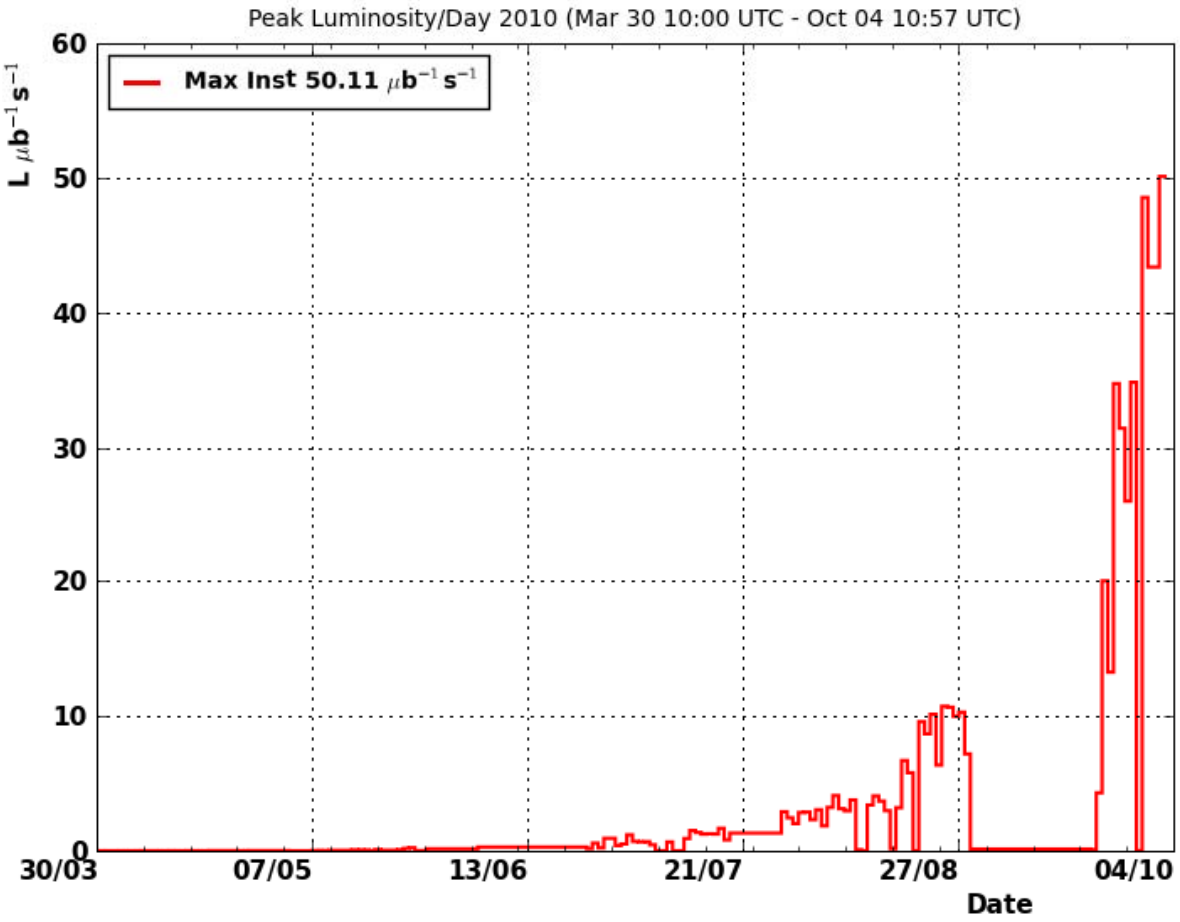
$N=10^{11}$

$$\mathcal{L} = \frac{N_1 N_2 \, n \, f}{4\pi \, \sigma_x \, \sigma_y} = \frac{7\,10^{31}}{\mathrm{cm}^2\,\mathrm{s}}$$

event rate with total cross section $\sigma \sim 100$ mb

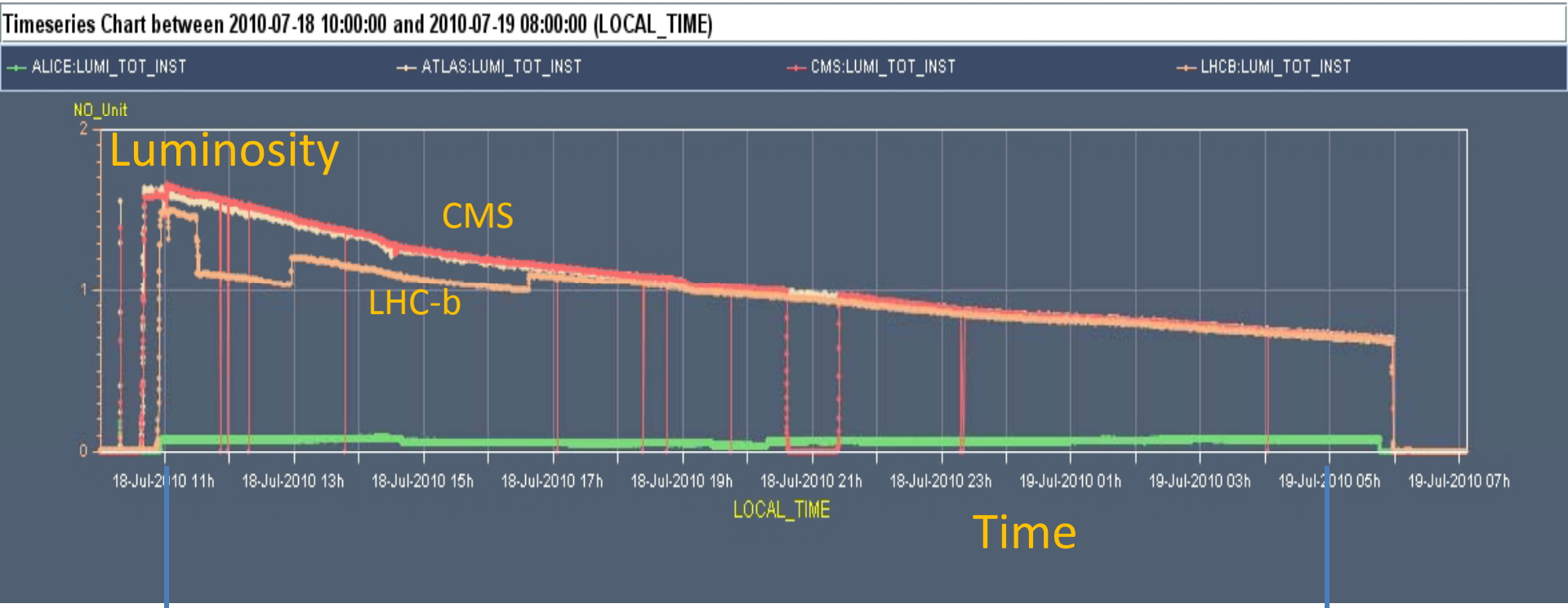
$$\frac{N}{t} = \sigma \, \mathcal{L} = 10^{-25}\,\mathrm{cm}^2 \, \frac{7\,10^{31}}{\mathrm{cm}^2\,\mathrm{s}} = 7\ \mathrm{MHz}$$

Instantaneous Luminosity



$$\frac{5\ 10^{31}}{cm^2\ s}$$

Lifetime of LHC Luminosity



18-Jul-2010, 11:00

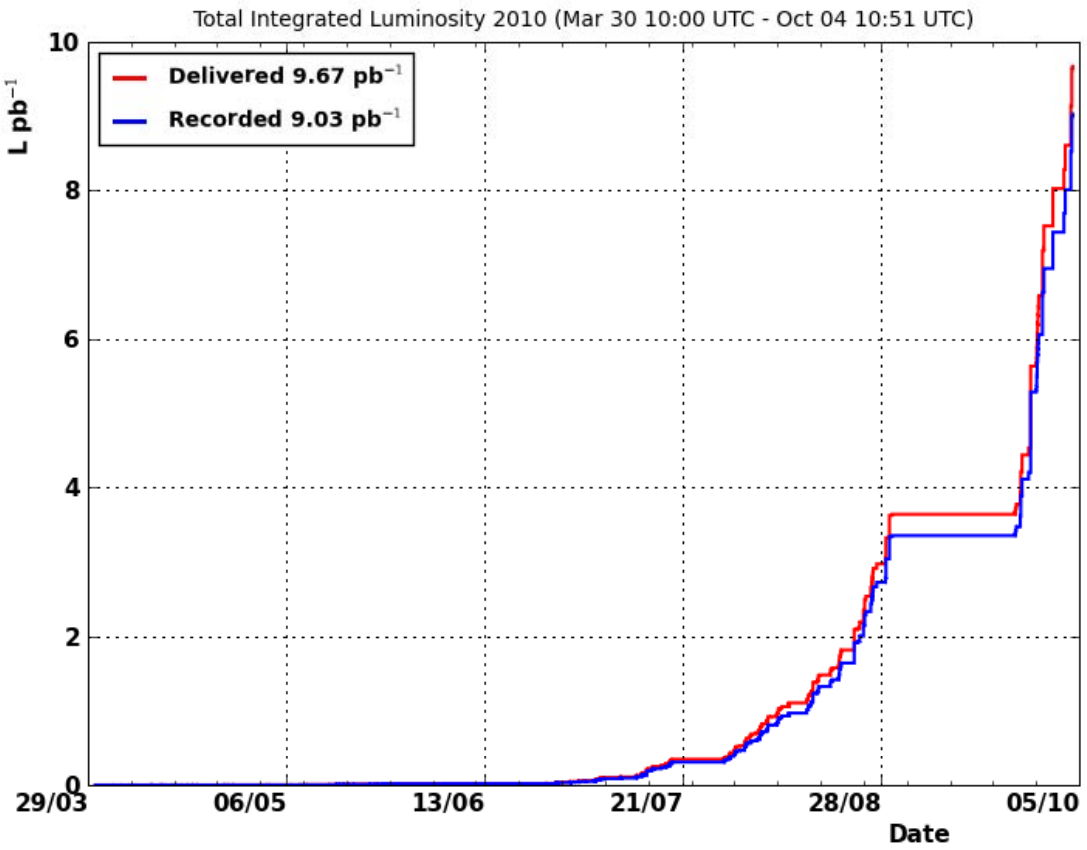
19-Jul-2010, 5:00

outstanding

Time integrated Luminosity

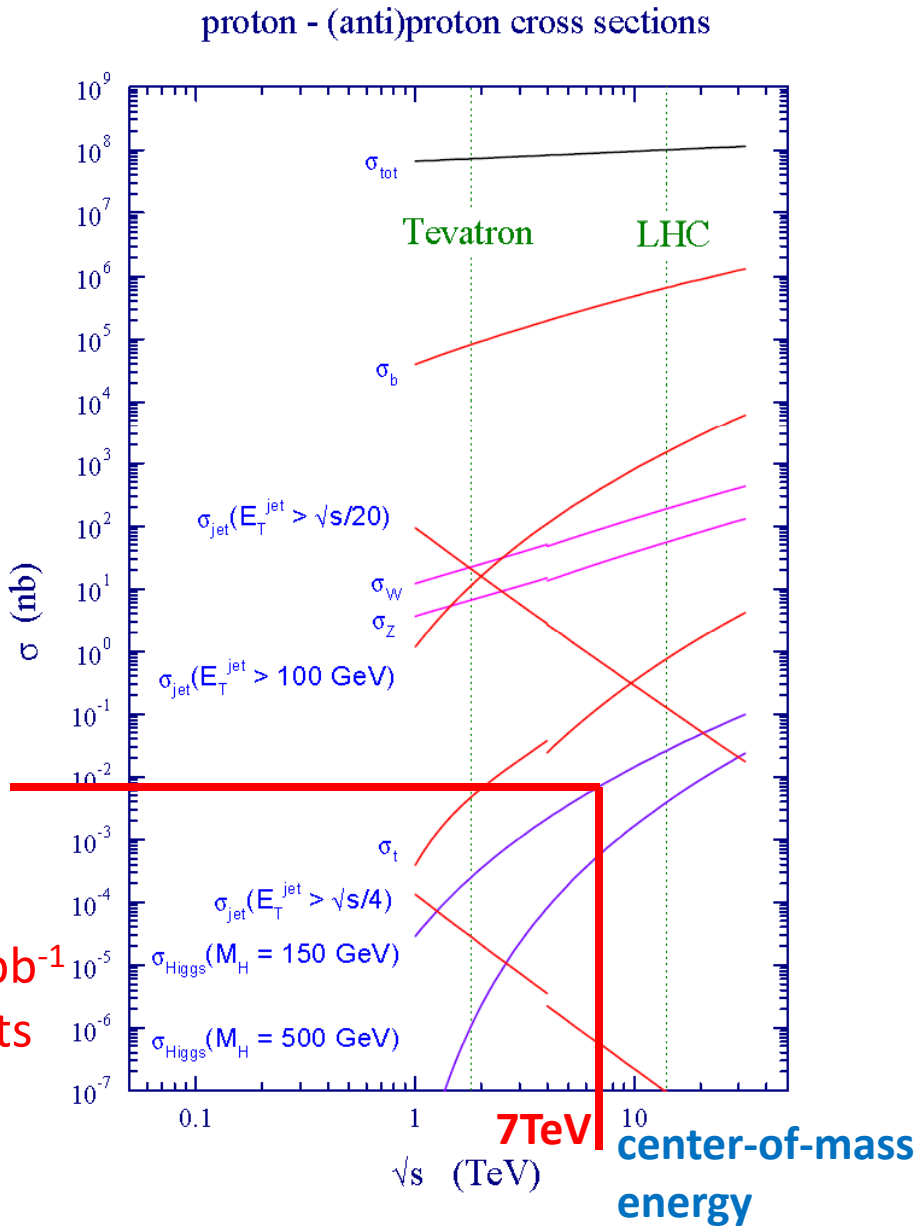
$$\frac{N}{t} = \sigma \mathcal{L}$$

$$N = \sigma \int L \, dt$$



Number of Events

Cross section σ



Total number of Events:

$$N = \sigma \int L \, dt$$

time integrated Luminosity

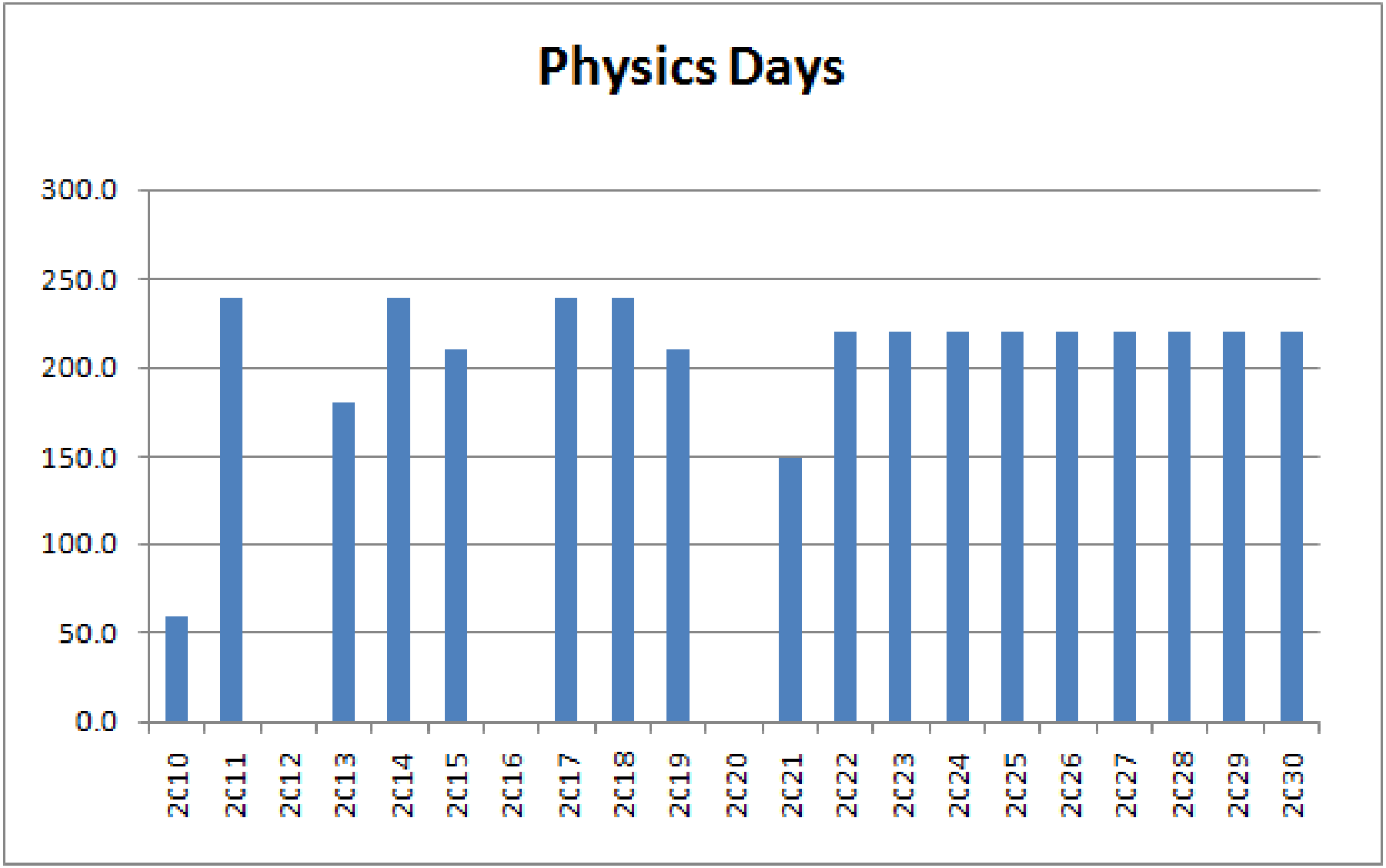
if exists:

σ(Higgs)=8pb

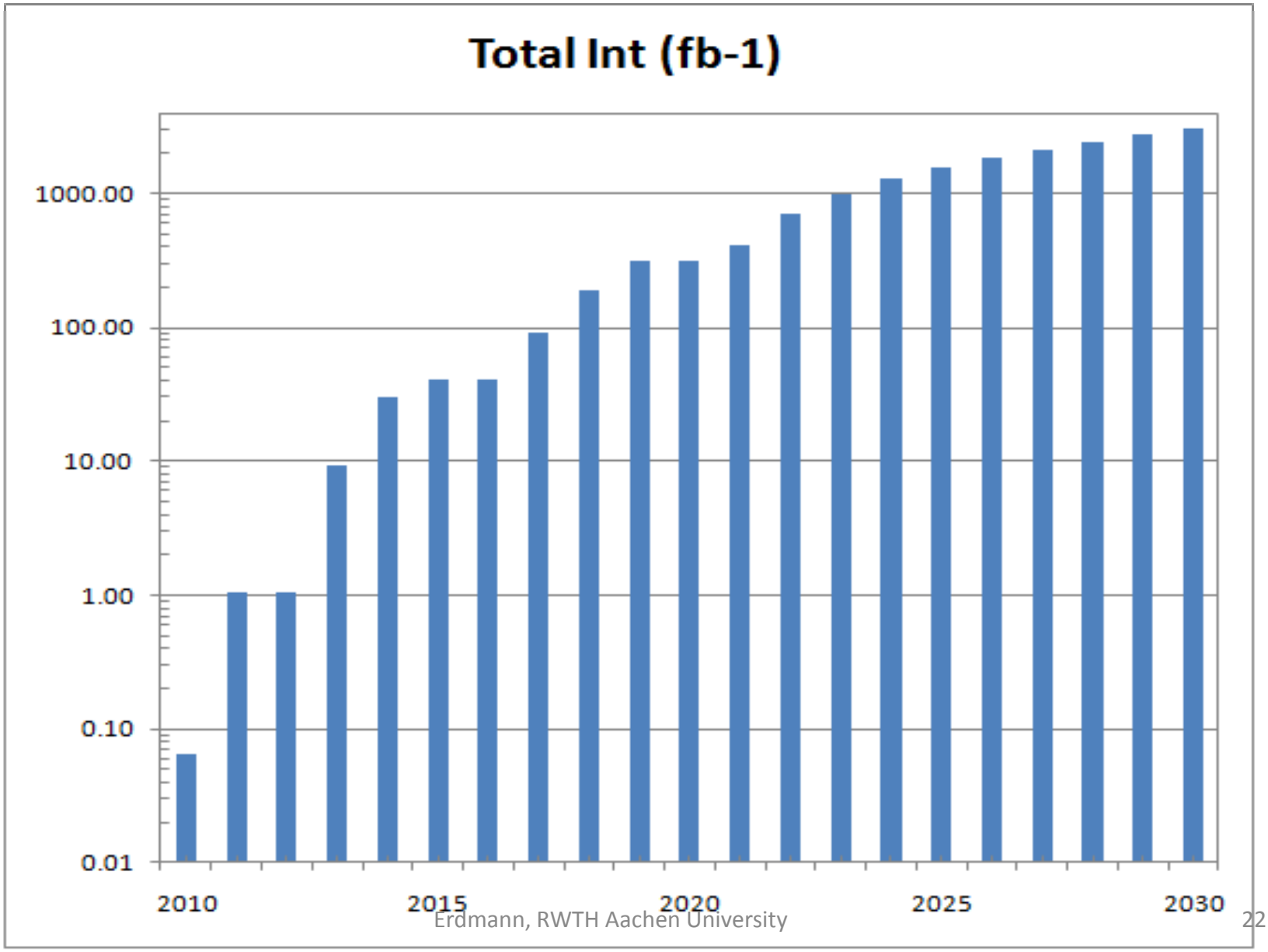
expect:

N(Higgs)= 8pb*10pb^{-1}
= 80 Events

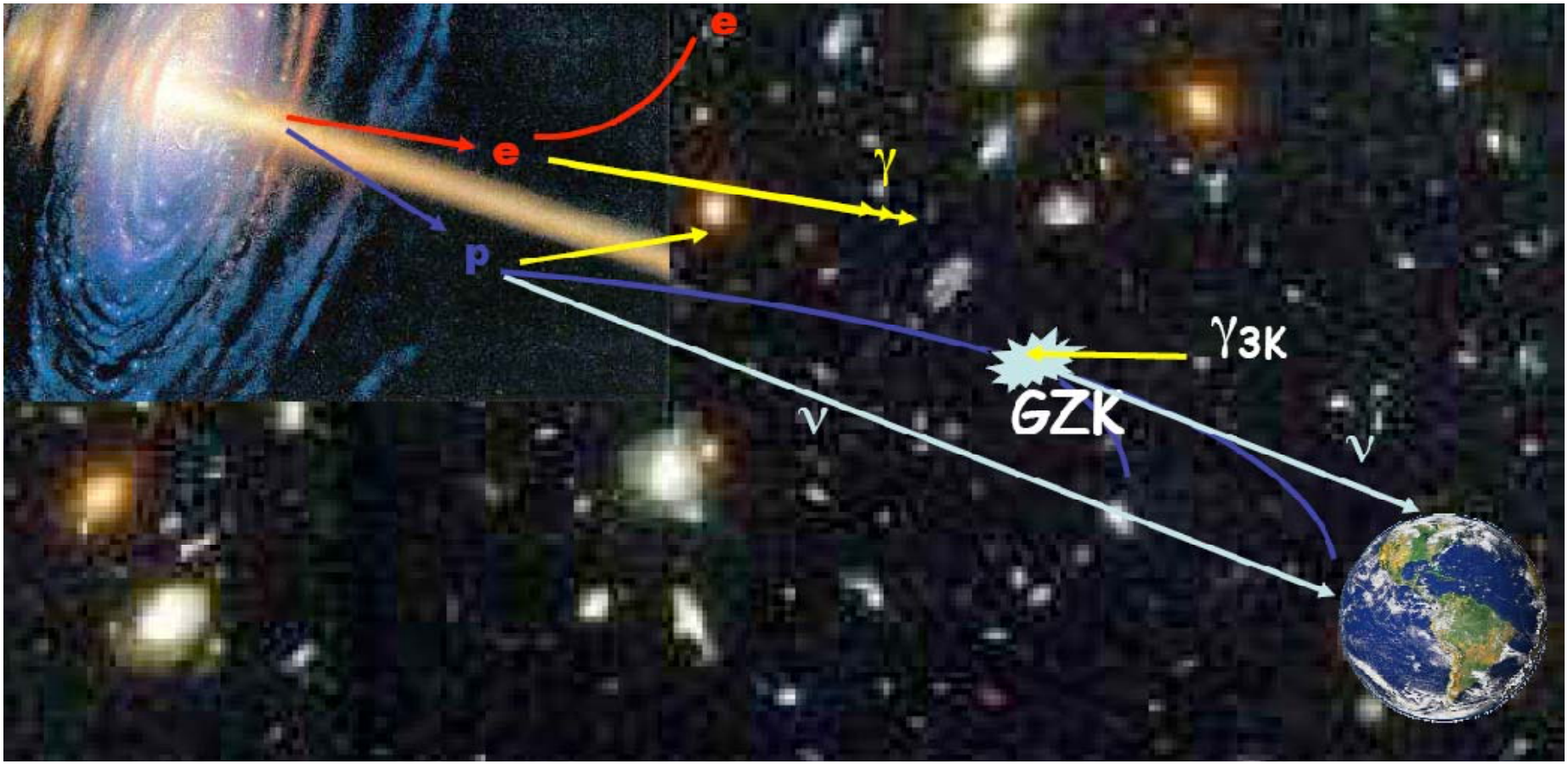
The 20 year physics plan



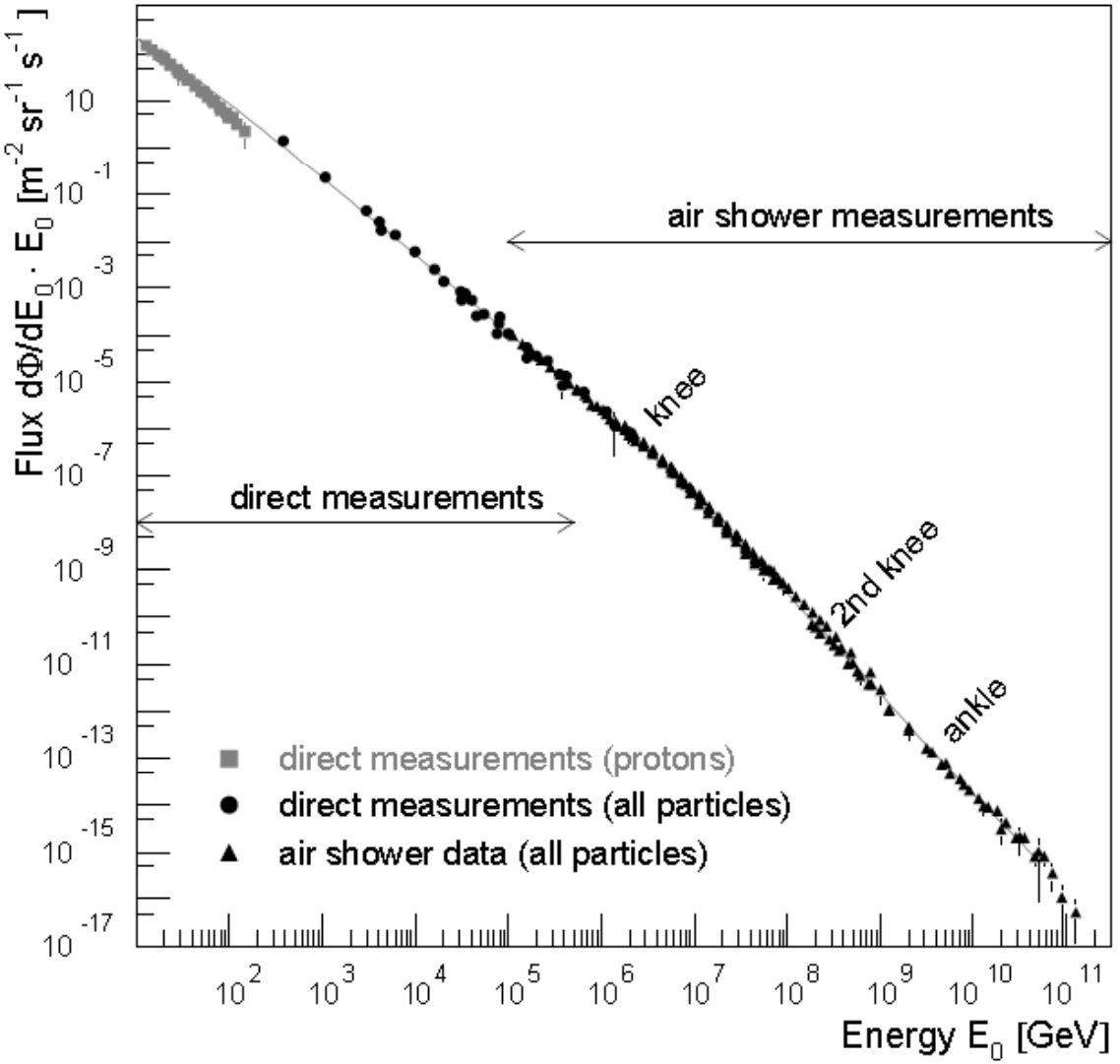
Preliminary Long Term Predictions



Cosmic Accelerators



Cosmic Ray Spectrum



Hillas Diagram: Source Candidates

Einschluss geladenes
Teilchens in Magnetfeld

nicht-relativistisch

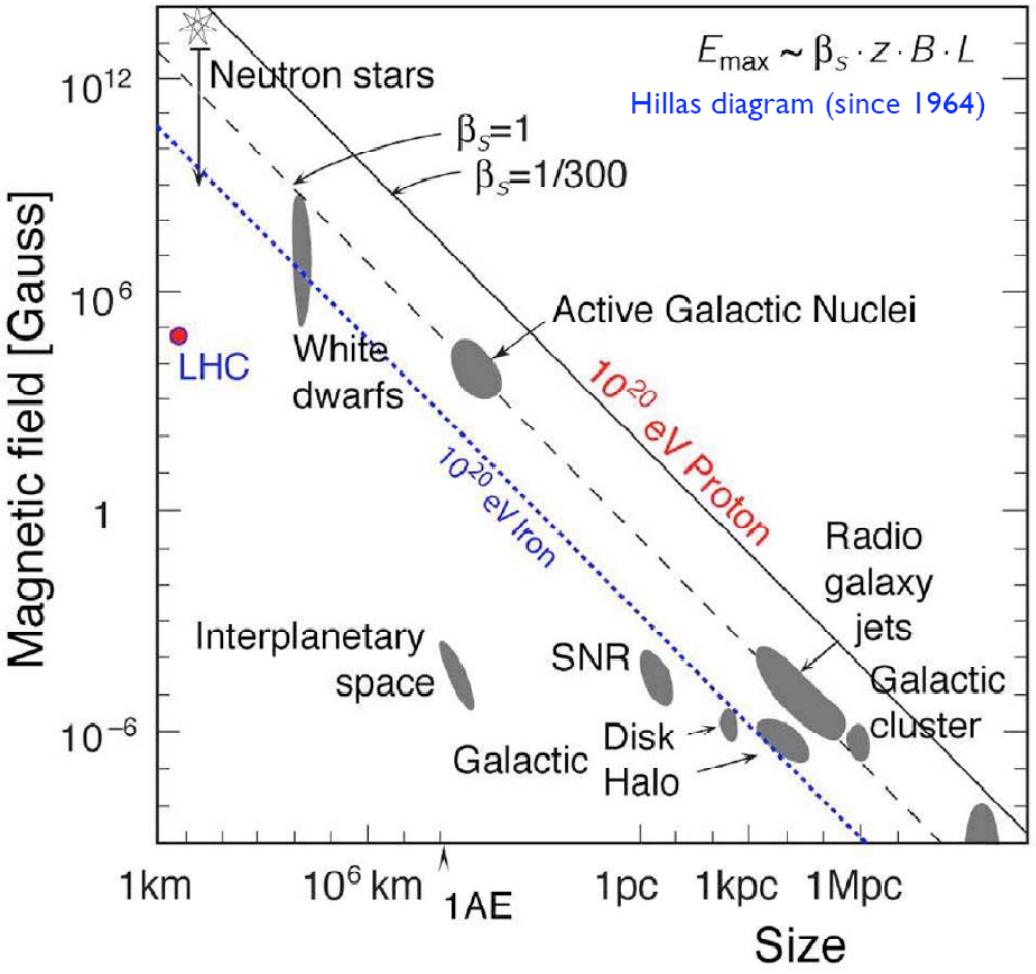
Lorentzkraft = Zentripetalkraft

$$Z\,e\,|\,\vec{v}\,\wedge\,\vec{B}\,| = \frac{m\,v^2}{r}$$

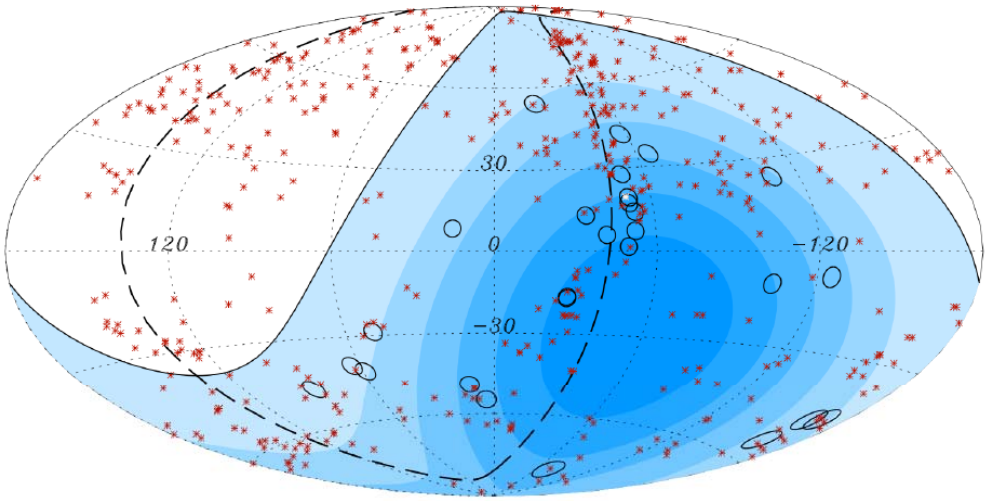
$$B = \frac{p}{Z\,e\,r}$$

$$\lg B = -\lg r + \lg p - \lg(Z\,e)$$

1 Gauss = 10^{-4} Tesla



UHECR Anisotropy

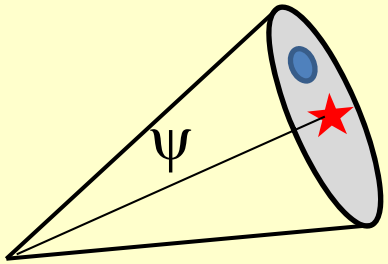


Pierre Auger Collab.

AP 29 (2008) 188

Science 318 (5852) 938

UHECR: Energy, Angular direction

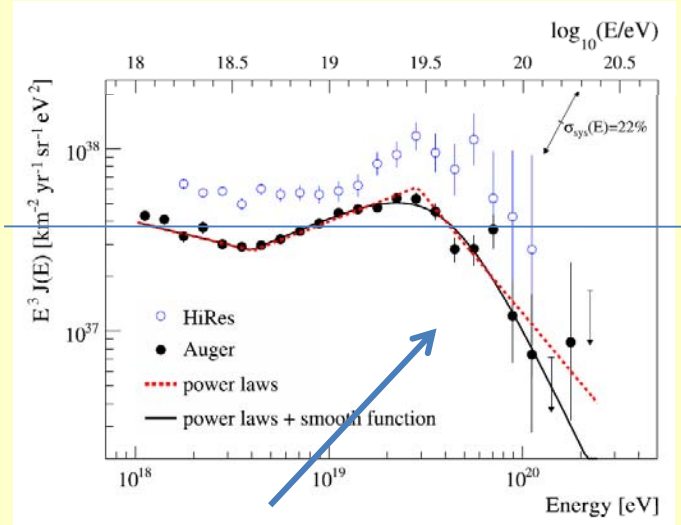


Reference distribution

Veron Cetty and Veron - AGN catalogue

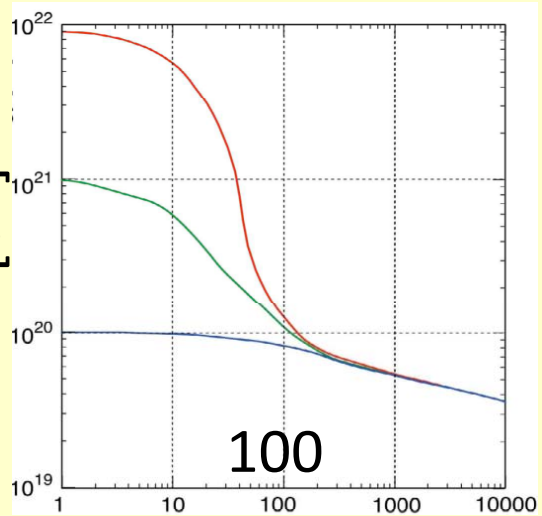
VC Catalogue Pre-Selection

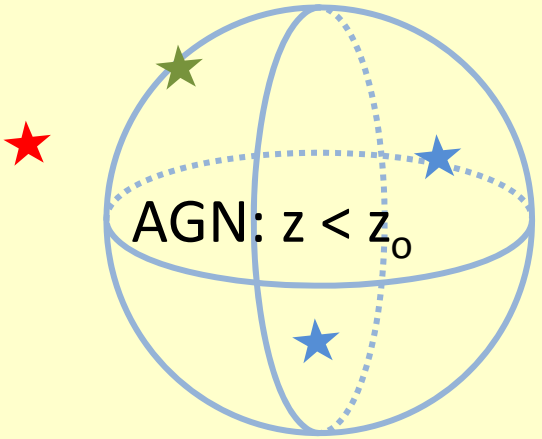
Energy distribution of UHECR



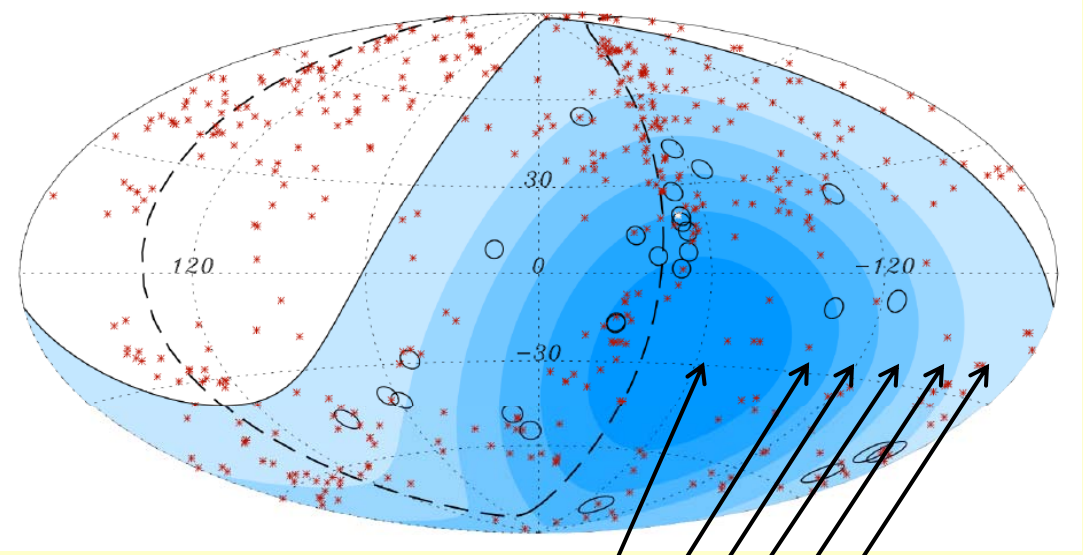
Suppression expected from GZK

Expected energy loss



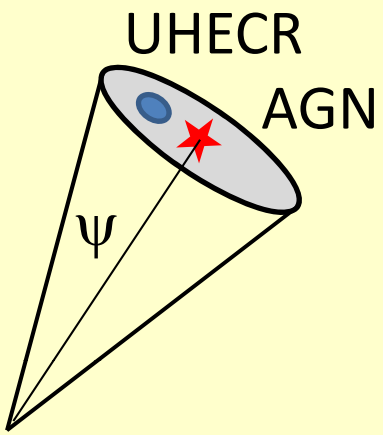


Pierre Auger Observatory: Aperture



Aperture fraction	Sky fraction	Number of AGN
1/6	0.08	25
1/6	0.08	24
1/6	0.09	46
1/6	0.10	27
1/6	0.12	63
1/6	0.23	107

Method: Binomial Counting



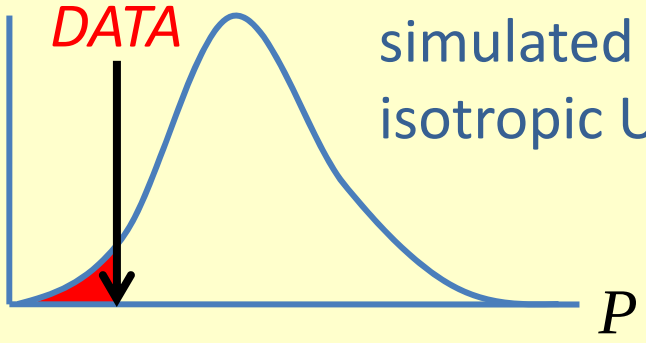
for hypothesis of *isotropic* UHECR distribution:
Probability UHECR within cone by chance

N UHECR events

$$P = \sum_{j=k}^{N} \binom{N}{j} p^j (1-p)^{N-j}$$

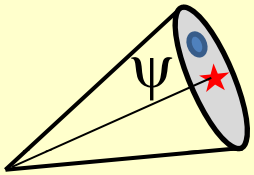
j or more UHECR are within cone

Probability for UHECR data to originate from isotropic distribution:
α < 1% reject isotropy

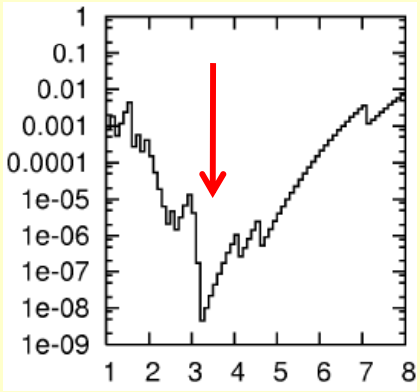


Parameters: Example Scan

Max.angular distance

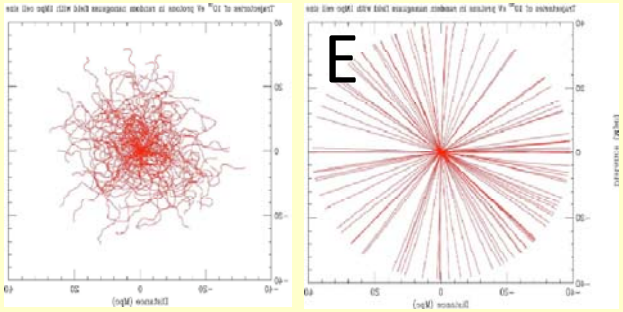


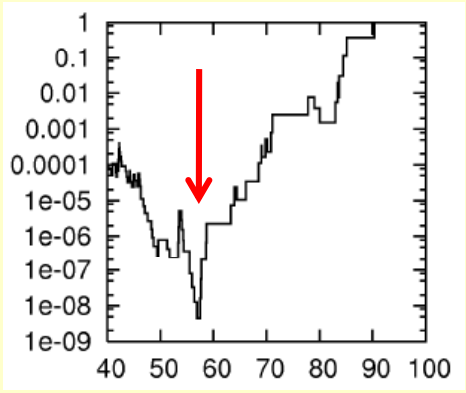
Probability



ψ [deg]

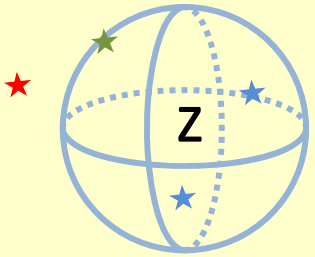
Min. UHECR energy

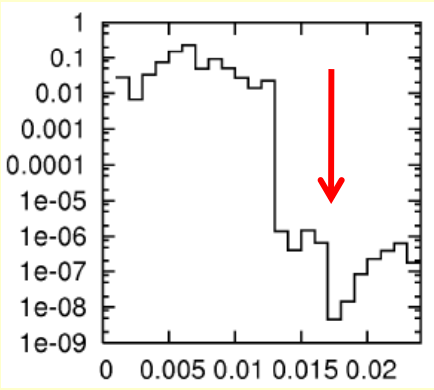




E_{min} [EeV]

AGN max. redshift





z_{max}

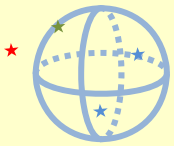
Training & Test Event Samples

- **Training**

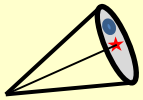
Data Set 1
1.1.04-27.5.06

→

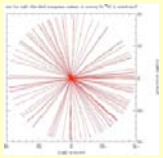
Fix scan parameters



z<0.018



$\psi < 3.1°$



E>56EeV

UHECR events

min. UHECR within AGN cones
to reject isotropy α<1%

N	4	6	**8**	10	12	...	30
k_{min}	4	5	**6**	7	8	...	14

- **Test**

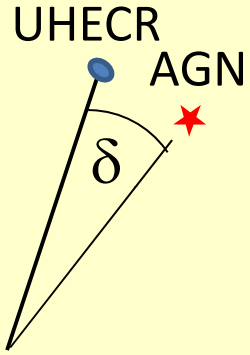
Data Set 2
28.5.06-31.8.07

→

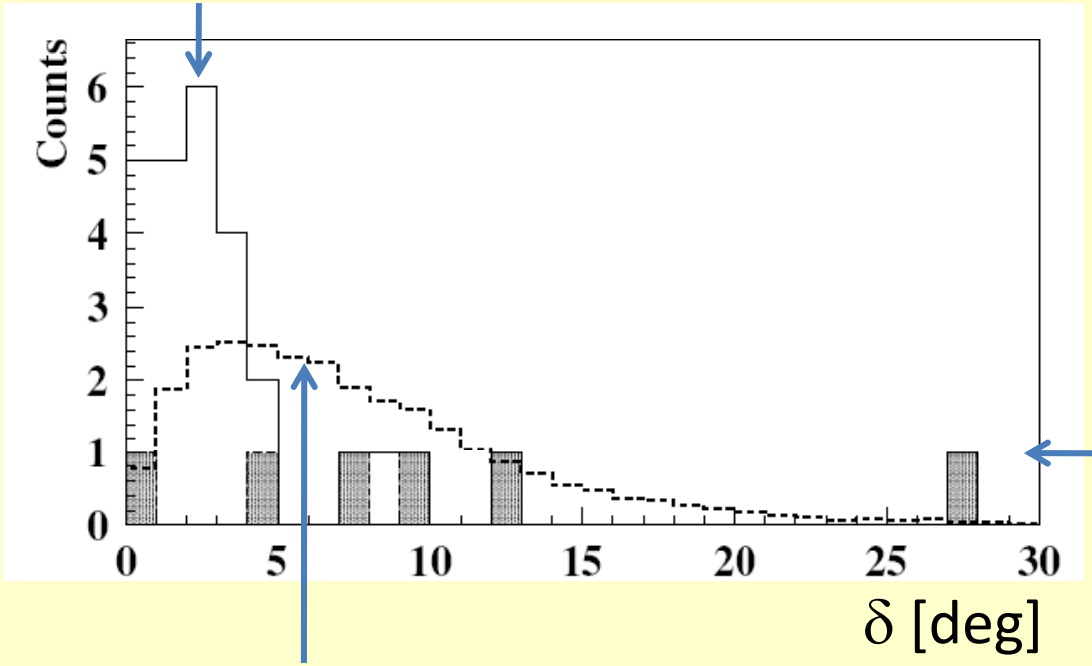
Test hypothesis of isotropic distribution

25.5.2007
reject isotropy

Angle Distance UHECR - AGN

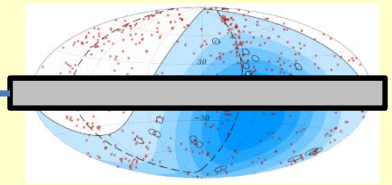


UHECR DATA

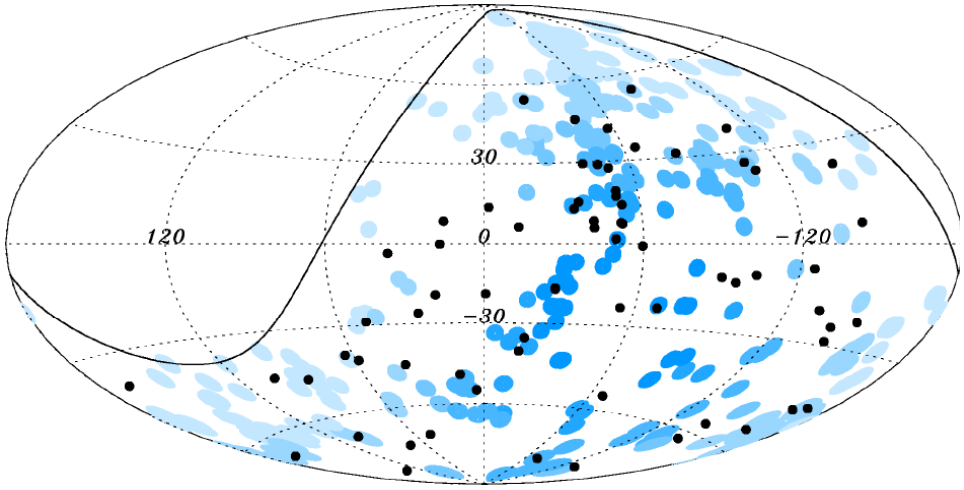


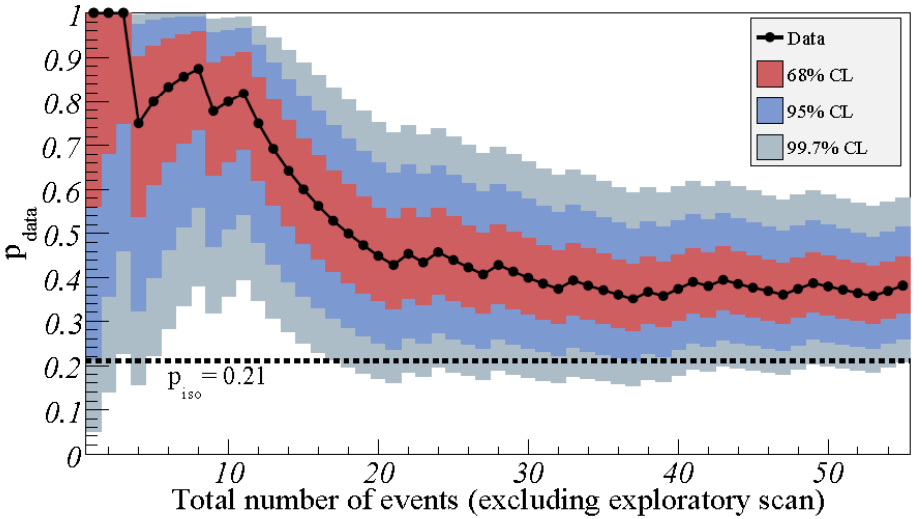
UHECR simulated isotropic distribution

UHECR within 12deg of galactic plane



Time Development





Blue circles of radius 3.1◦ are centred at the positions of the 318 AGNs in the VCV catalog that lie within 75 Mpc and that are within the field of view of the Observatory.

Most likely value of the degree of correlation p_data = k/N . Horizontal dashed line shows the isotropic value p_iso = 0.21. The current estimate of the signal is (0.38+0.07−0.06).

interpretation of correlation: one signal of UHECR anisotropy

Summary

- Earth bound accelerator LHC works remarkable well.
- World record cosmic accelerators still not identified.