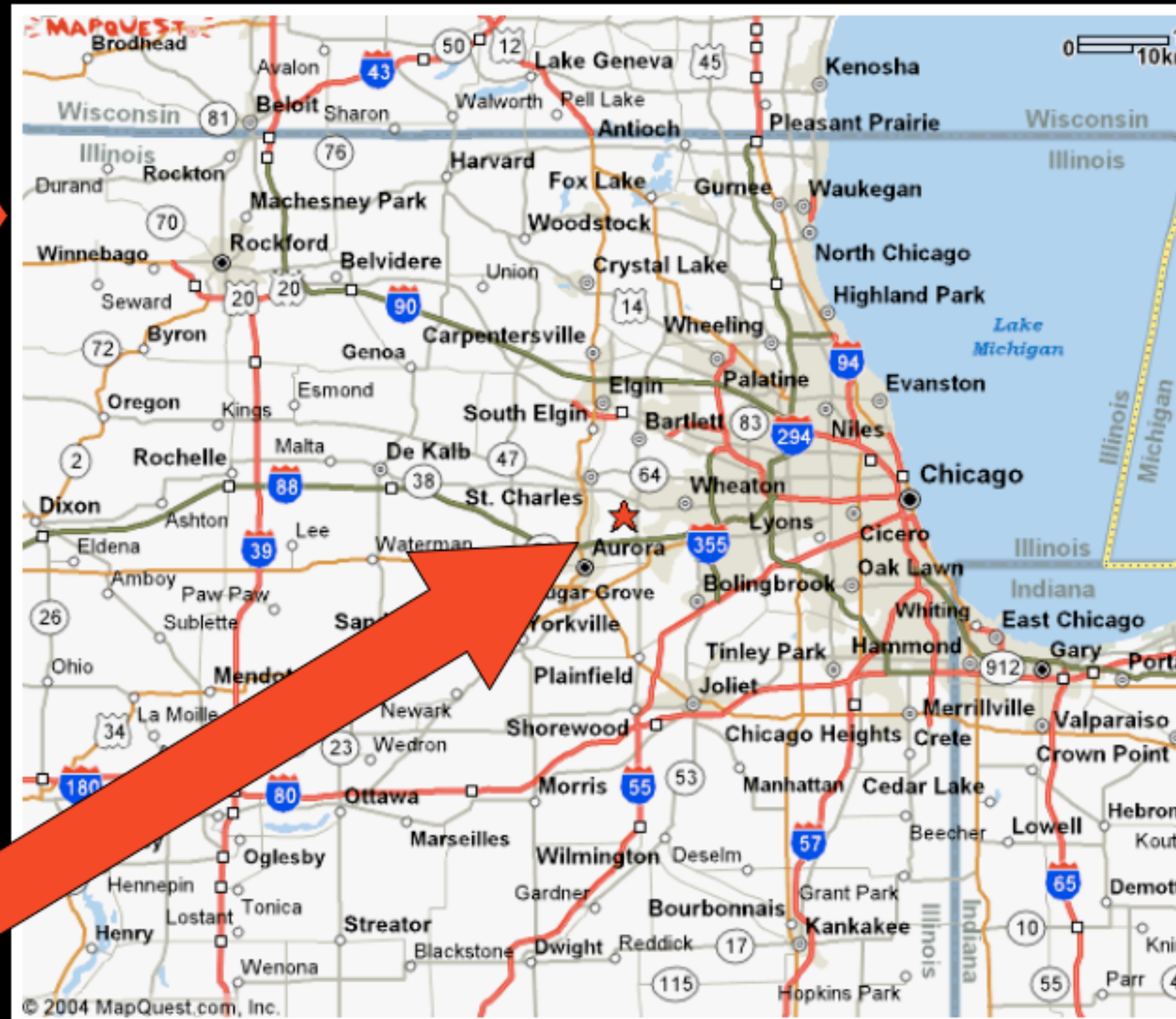
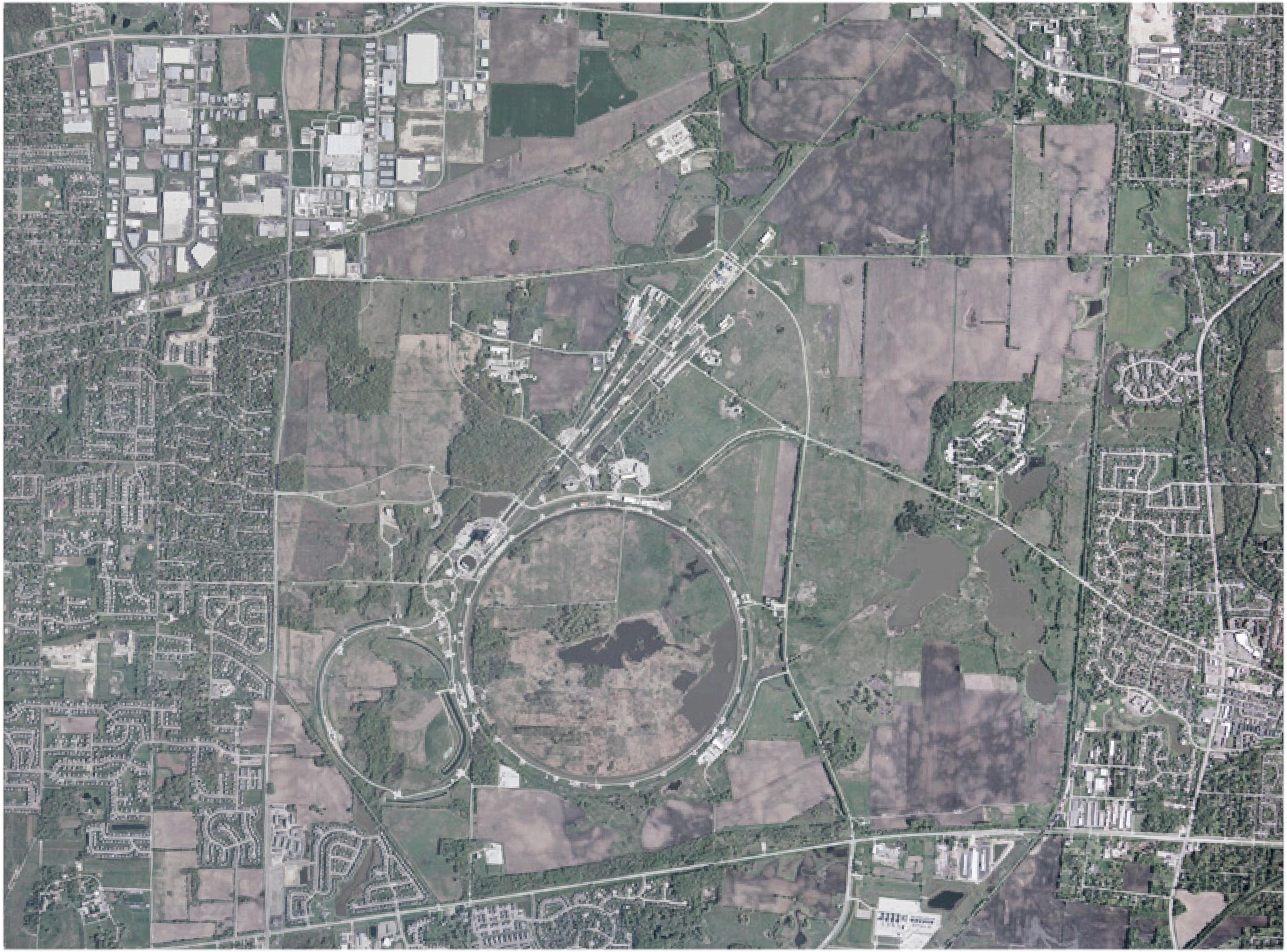
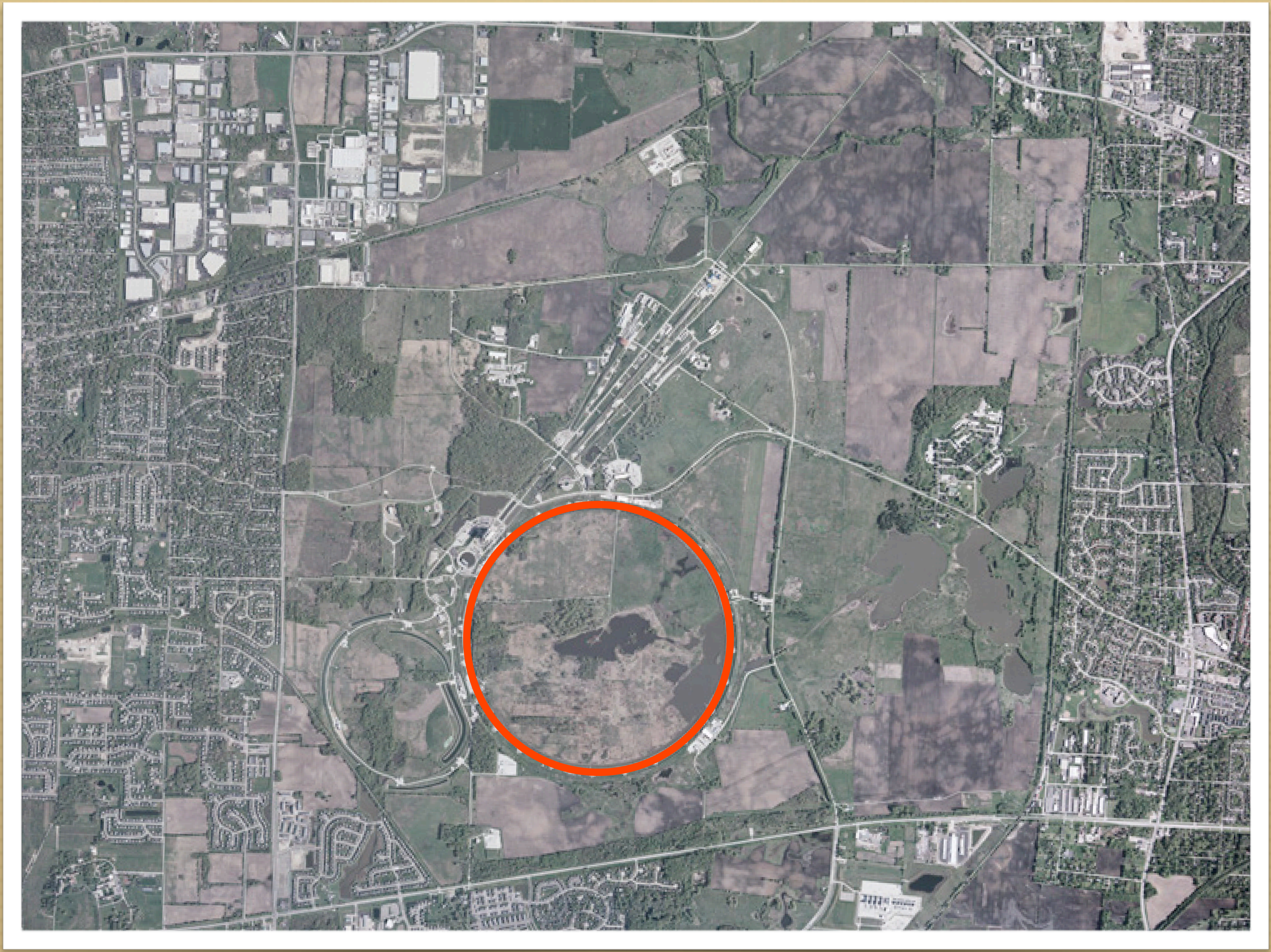
SVT

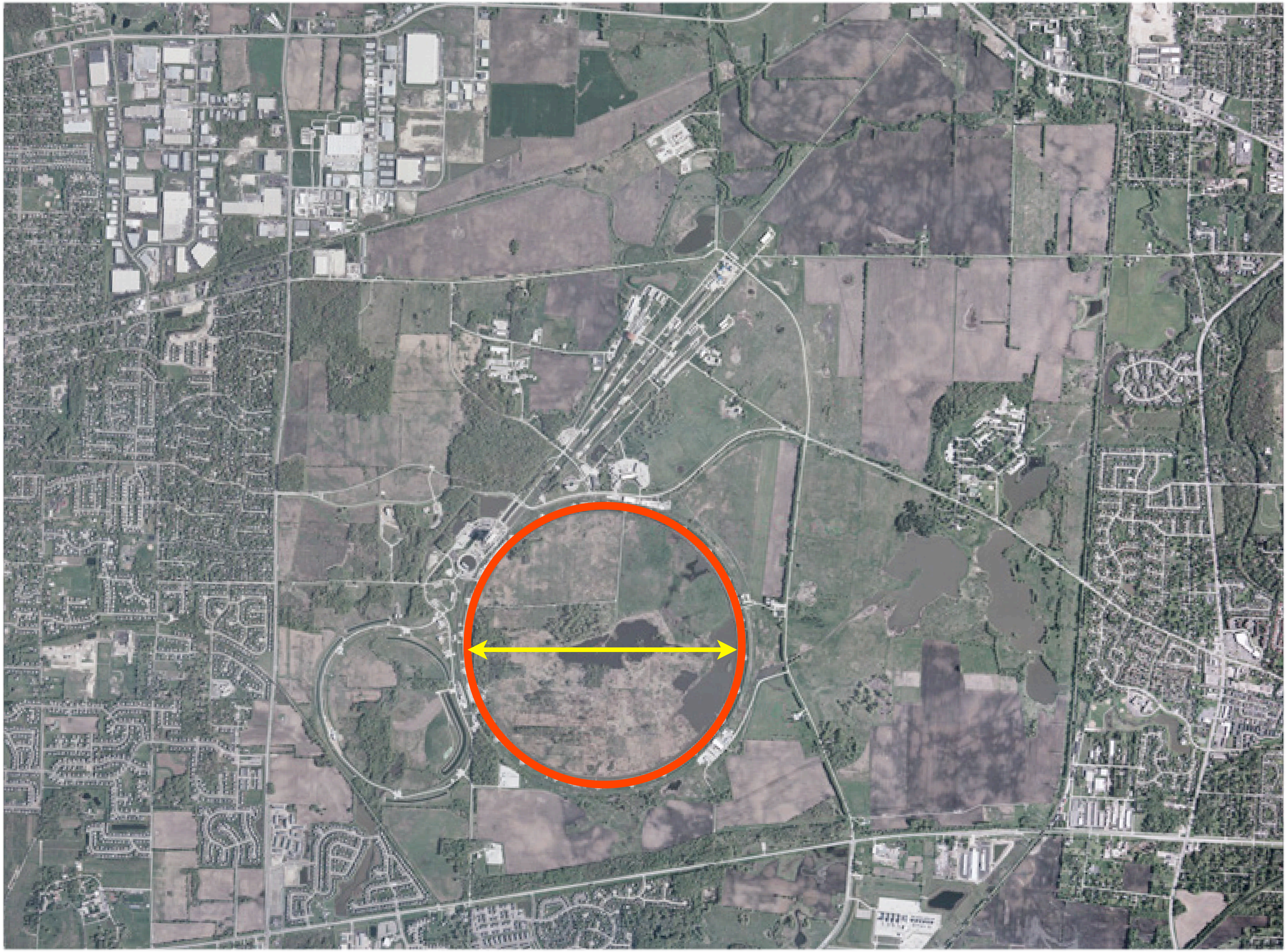
Luciano Ristori - 5 Dicembre 2008

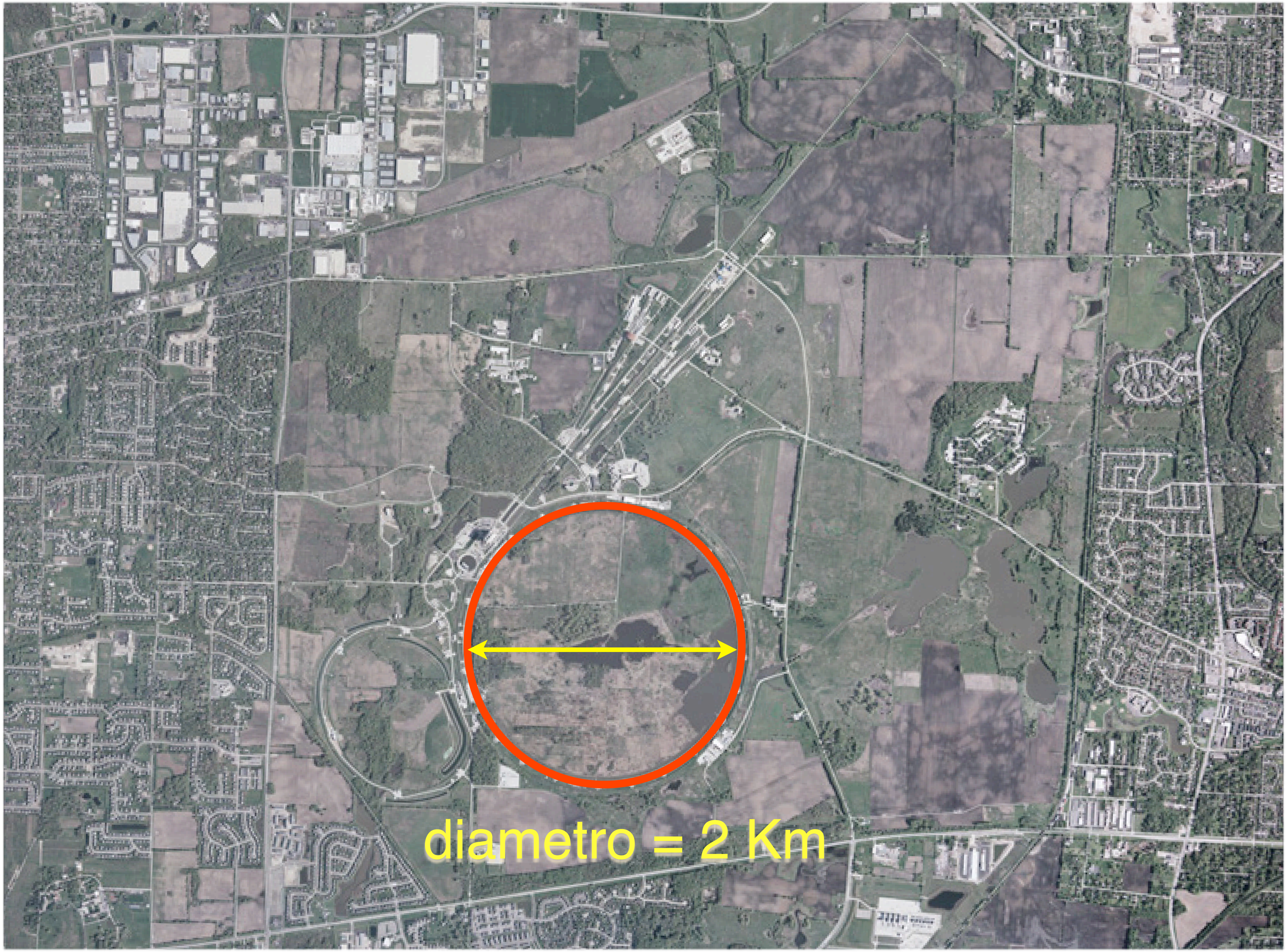


Fermi
National
Accelerator
Laboratory



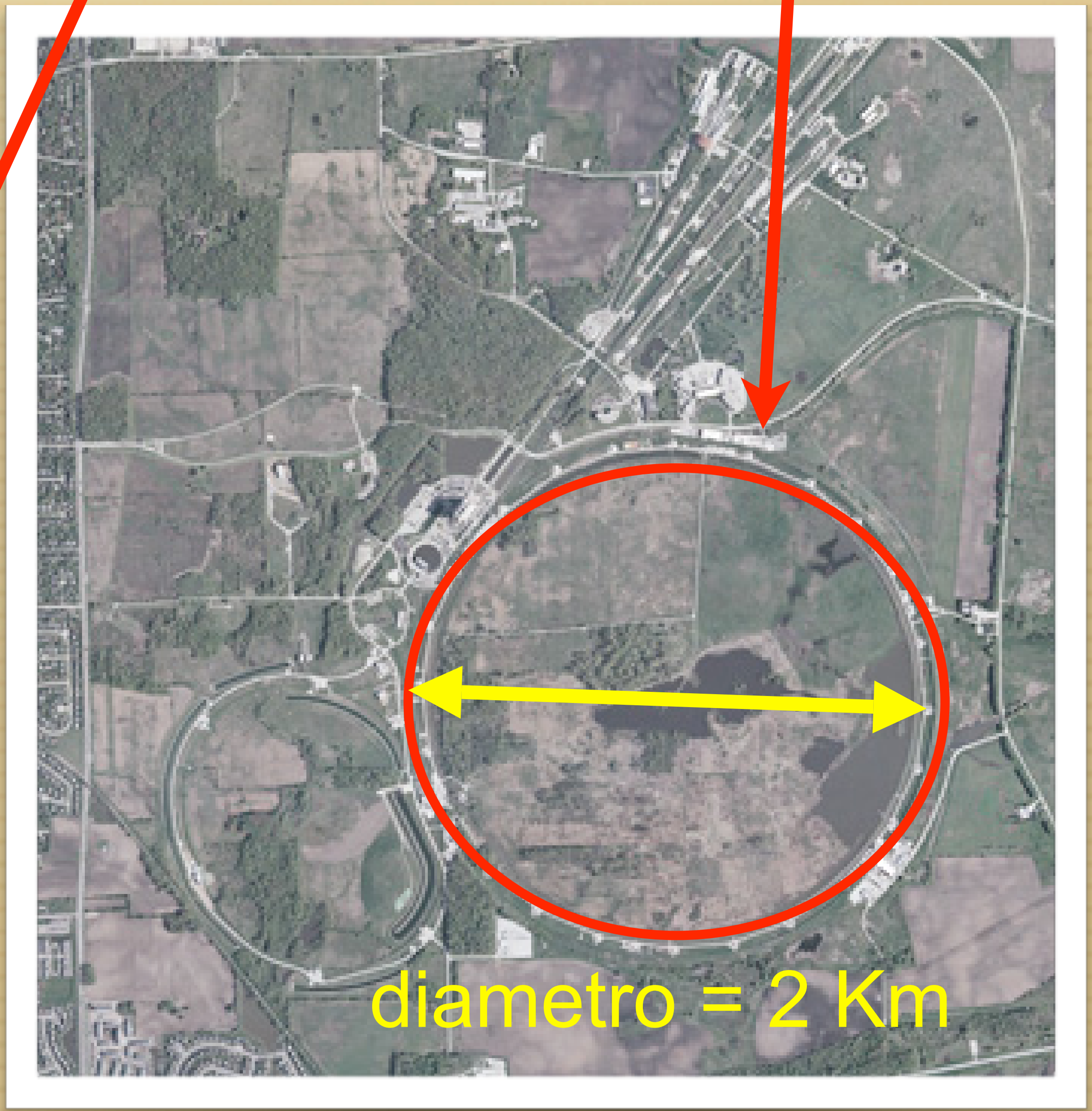




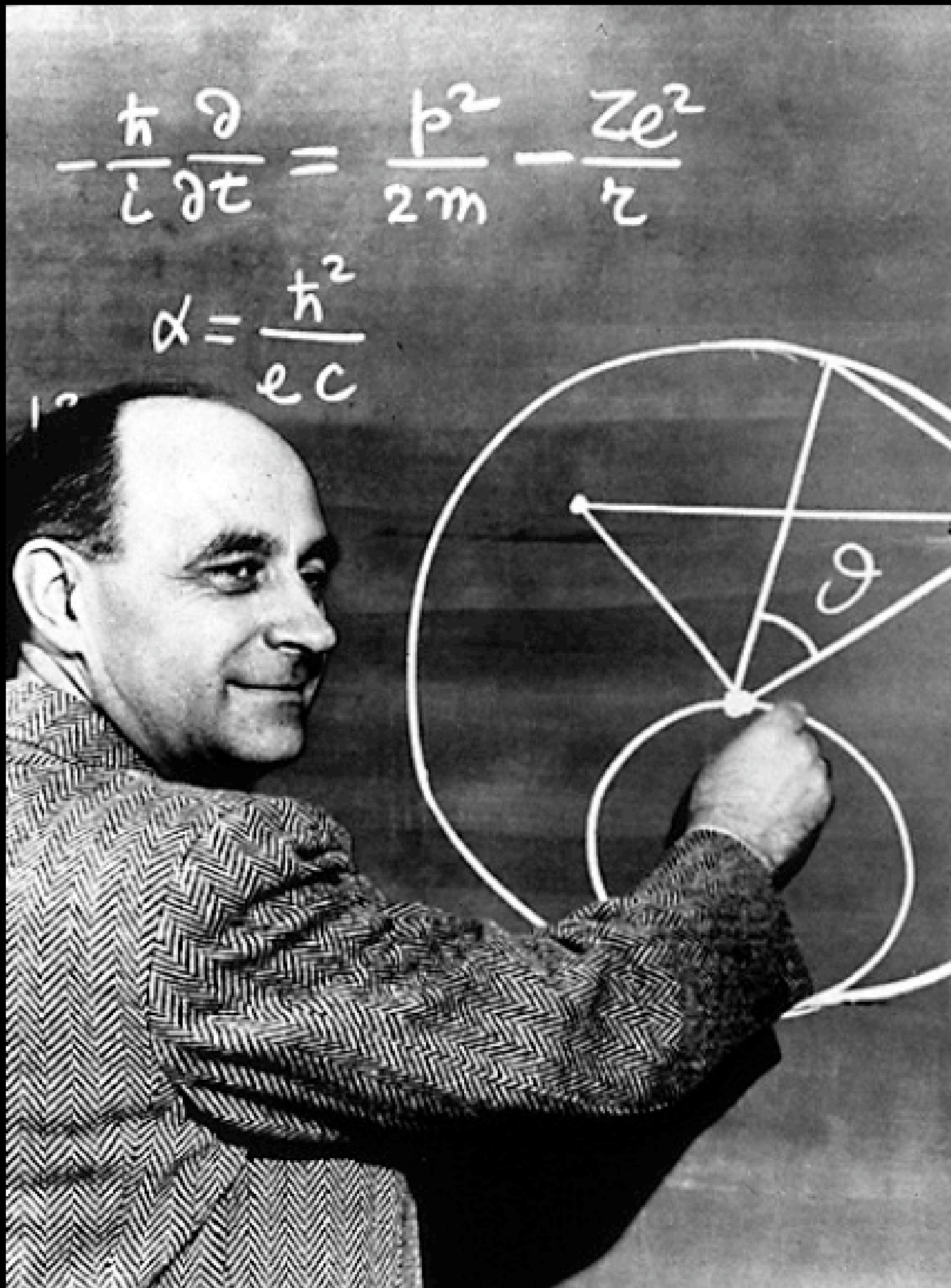

diametro = 2 Km

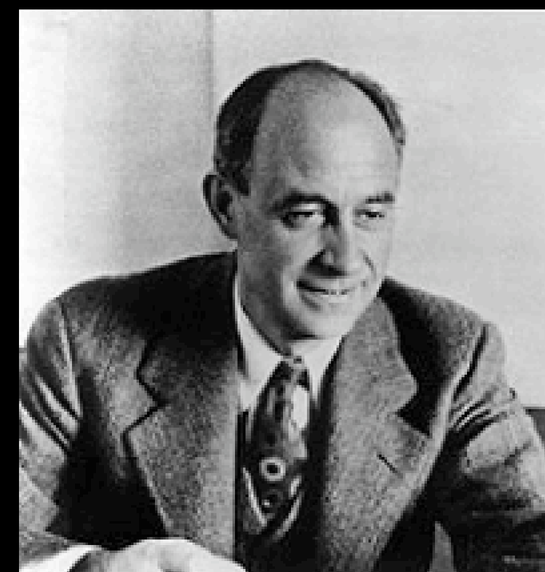
il primo acceleratore ... e l’ultimo

Ernest Lawrence - 1930



Enrico Fermi

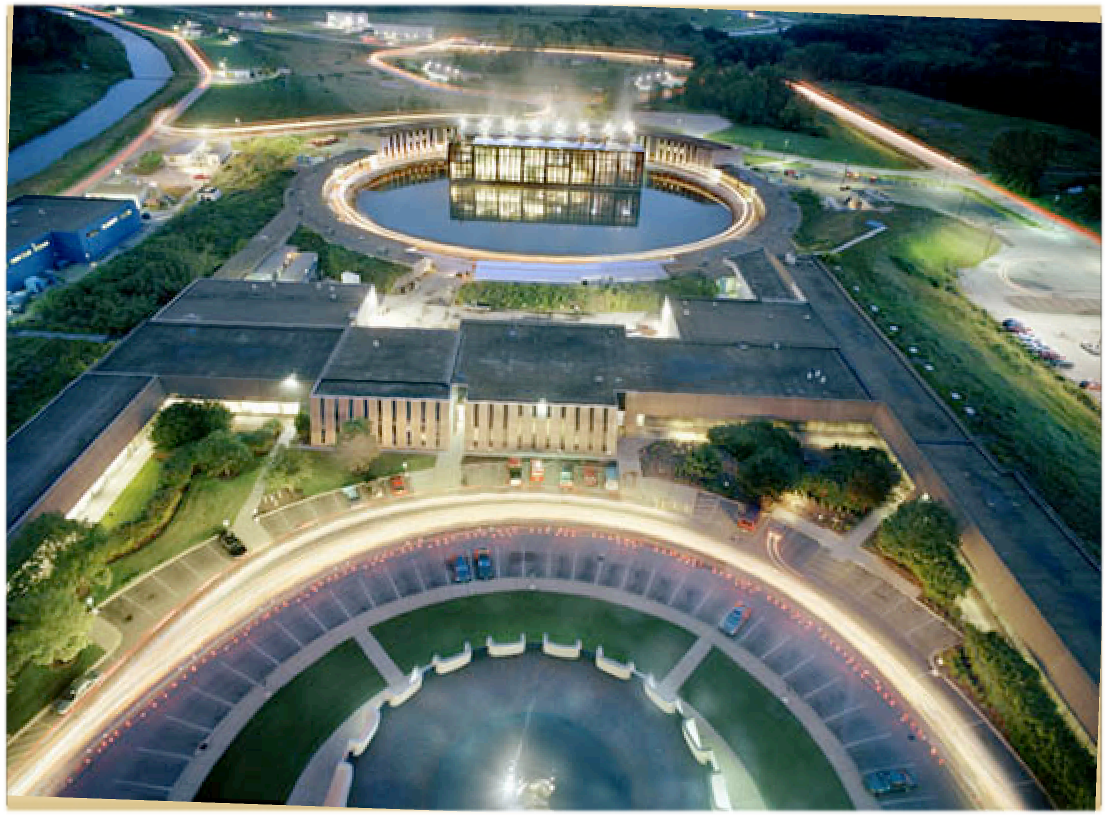


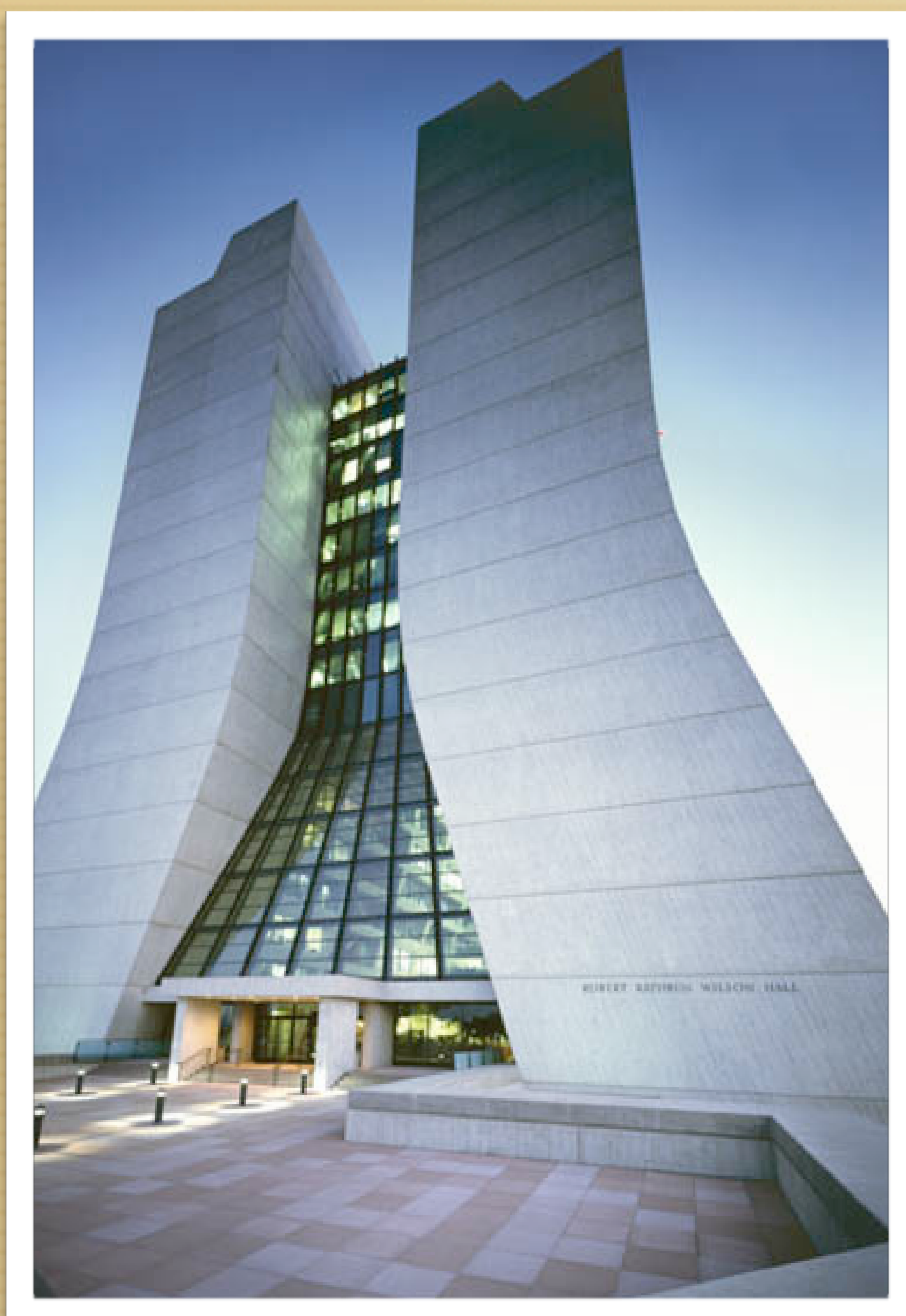


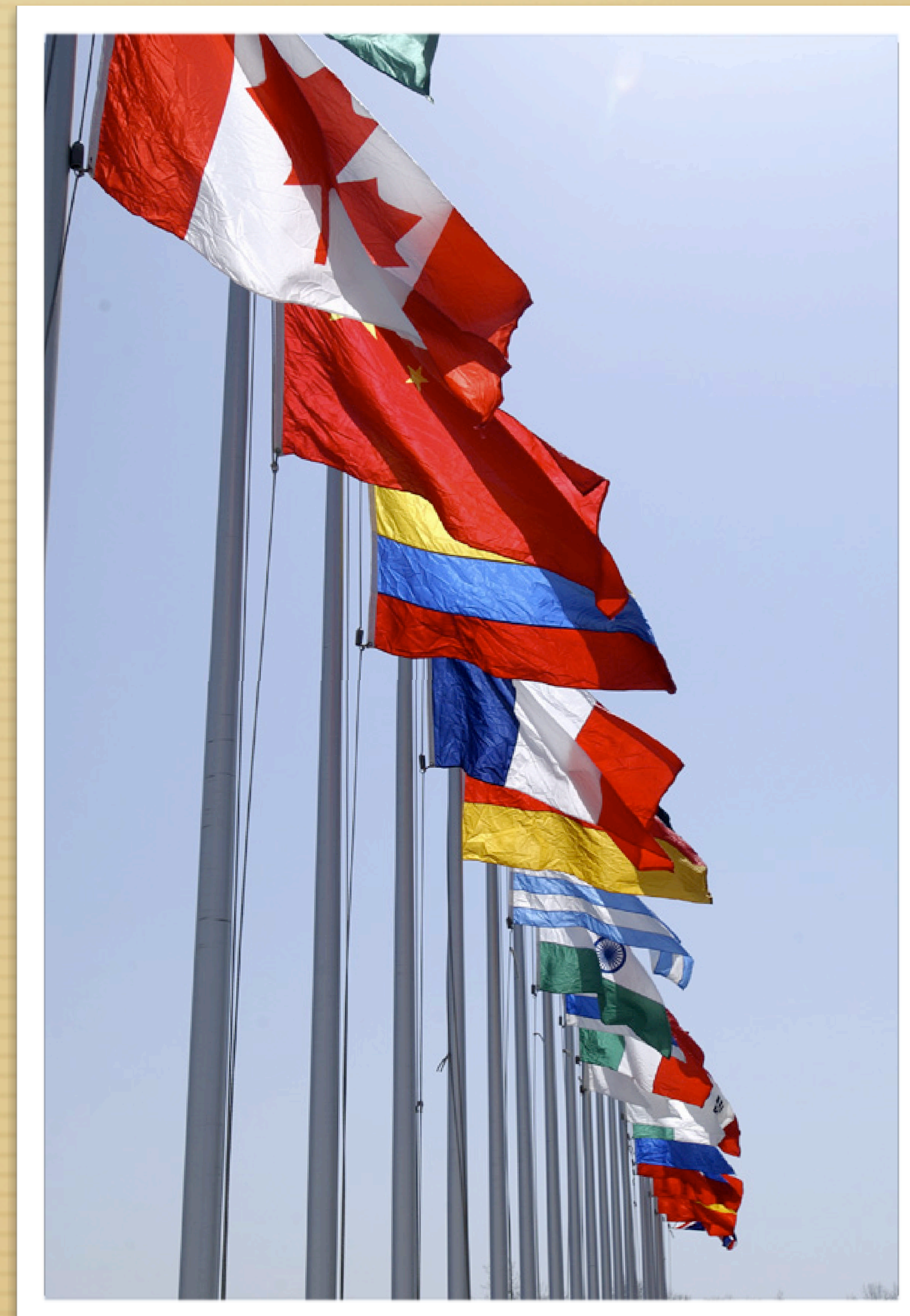
1901 - 1954

Premio Nobel
per la Fisica
nel 1938


Fermilab



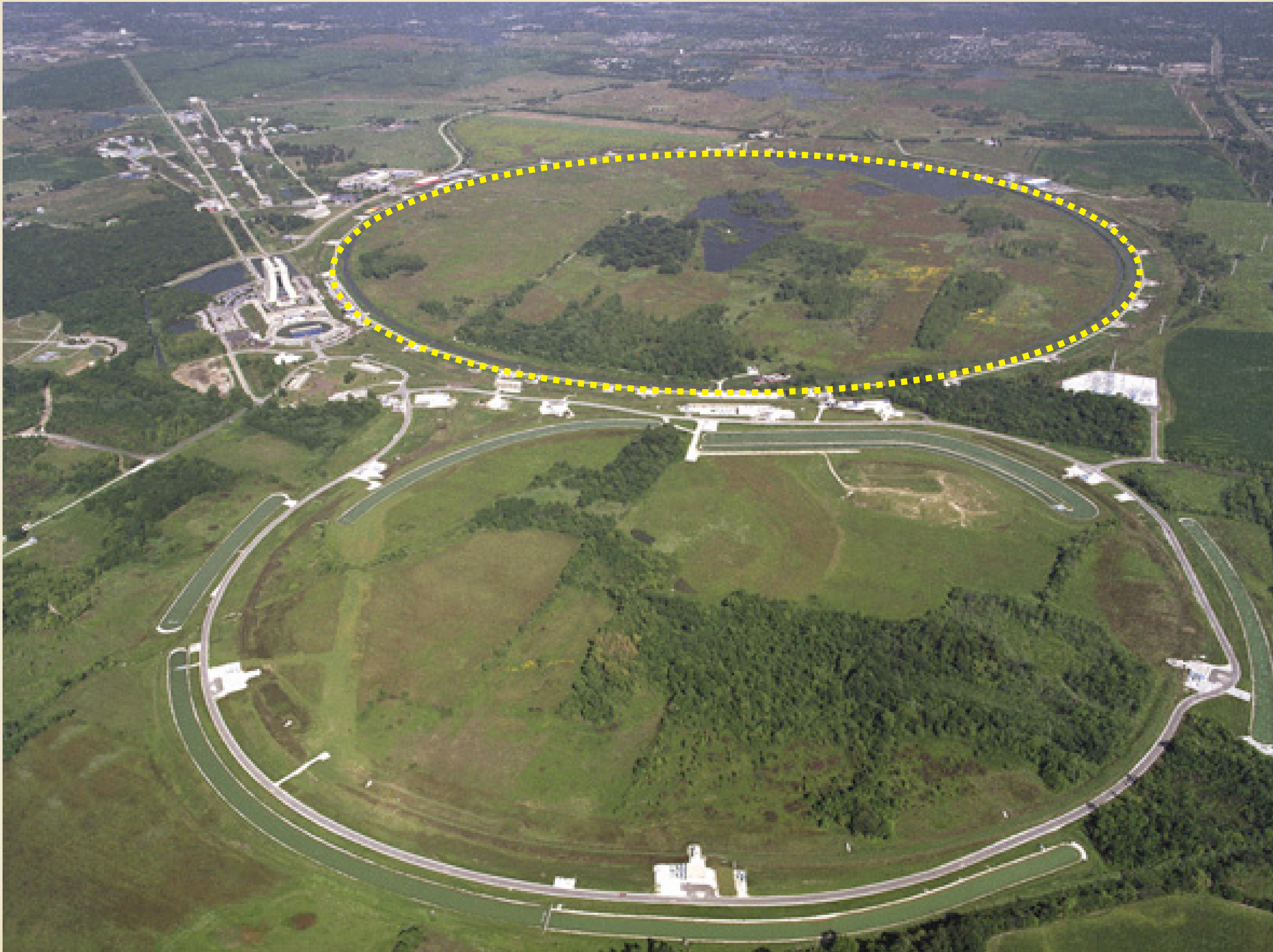


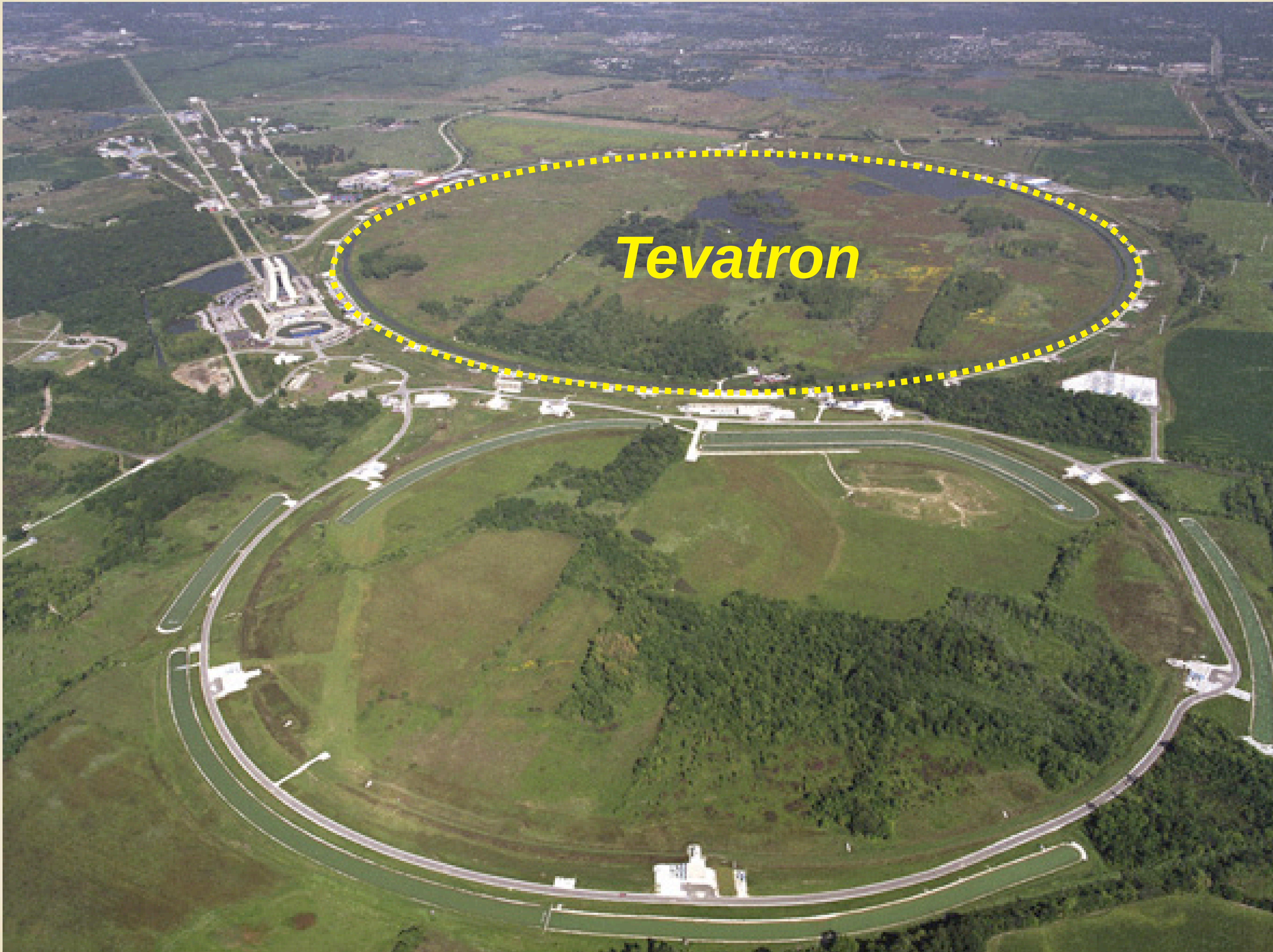


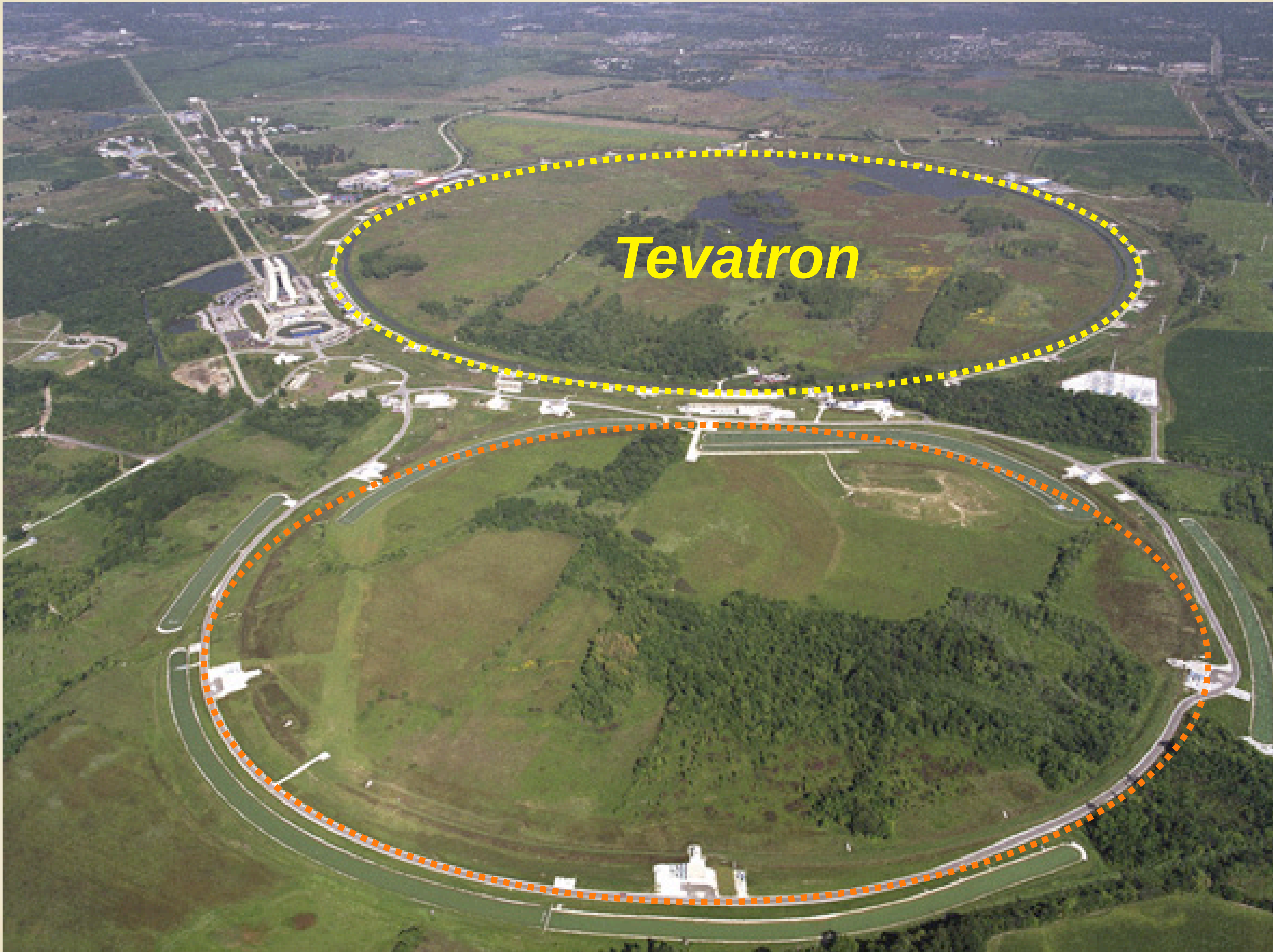
Fermilab

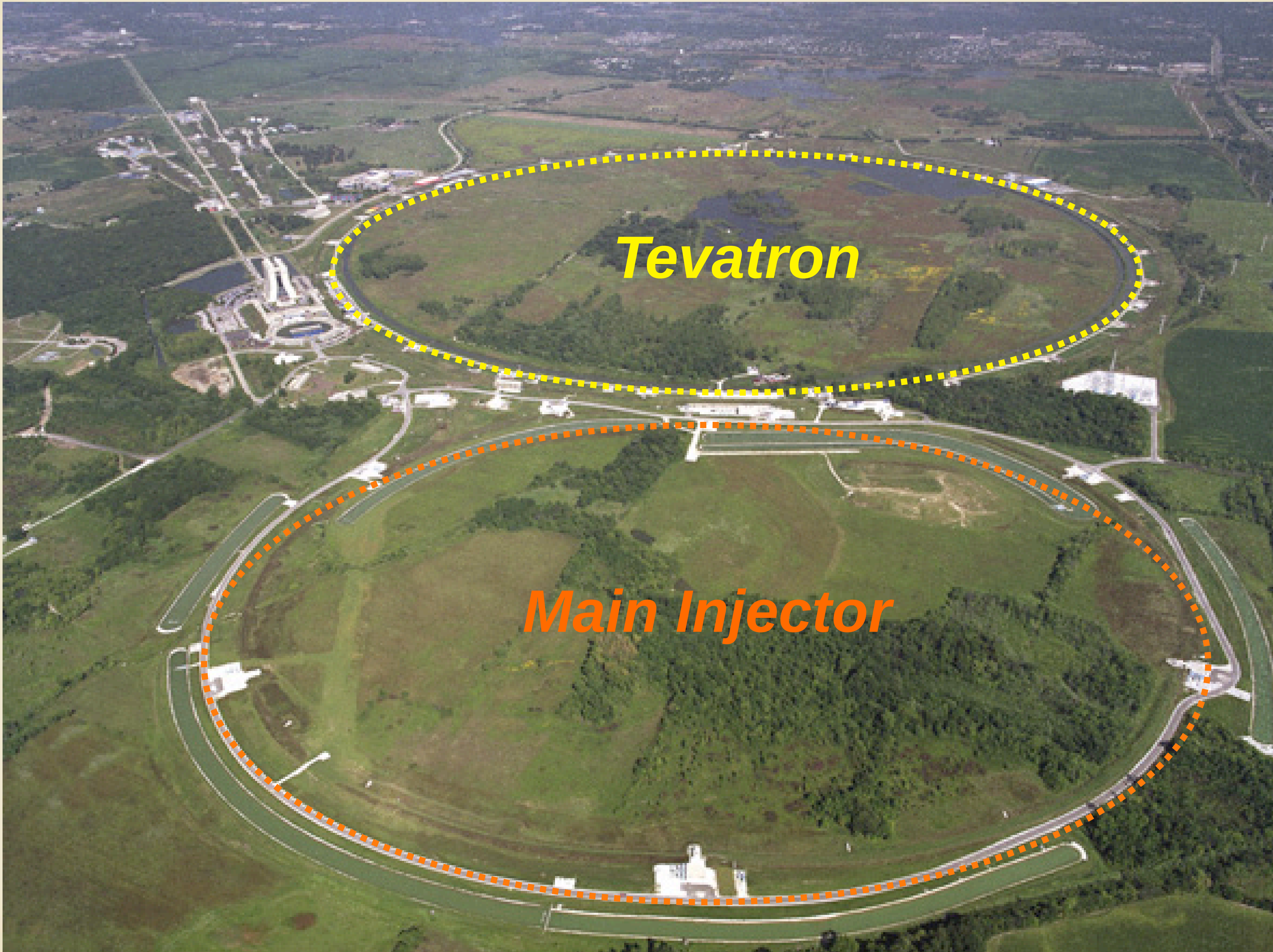
Fermilab


Fermilab

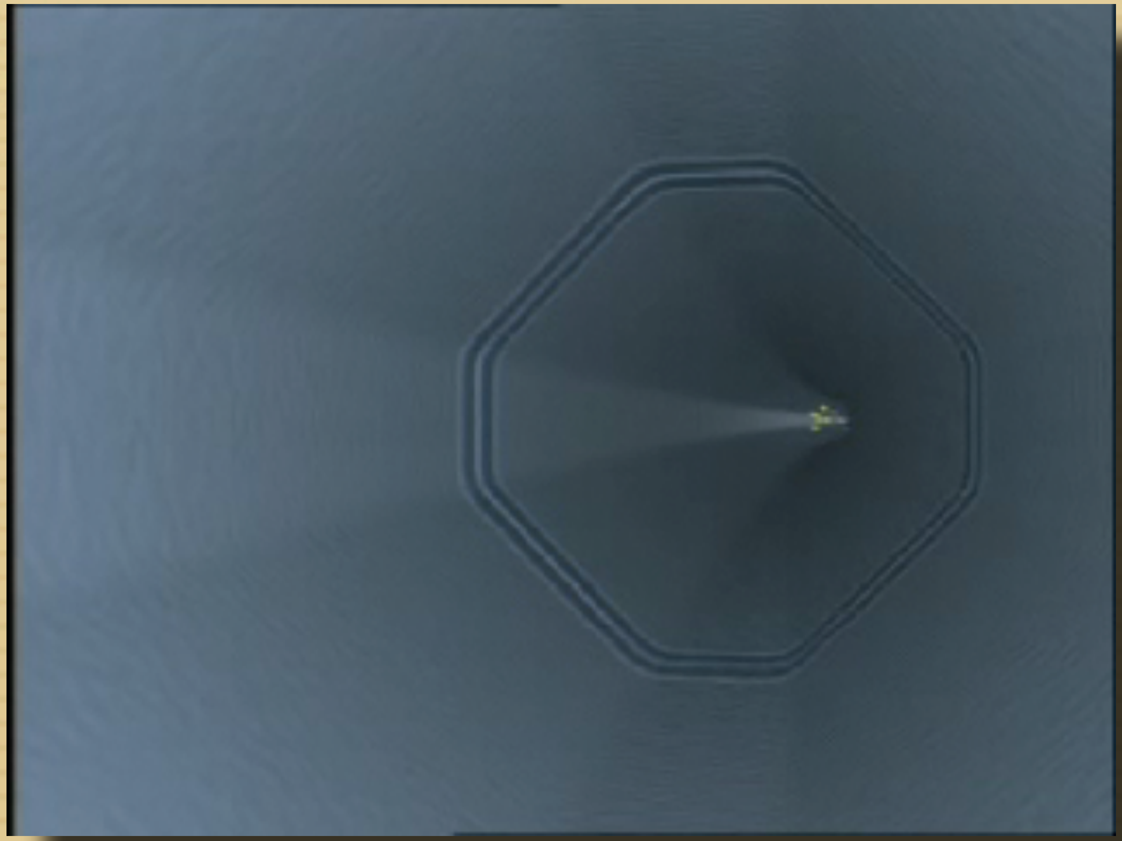


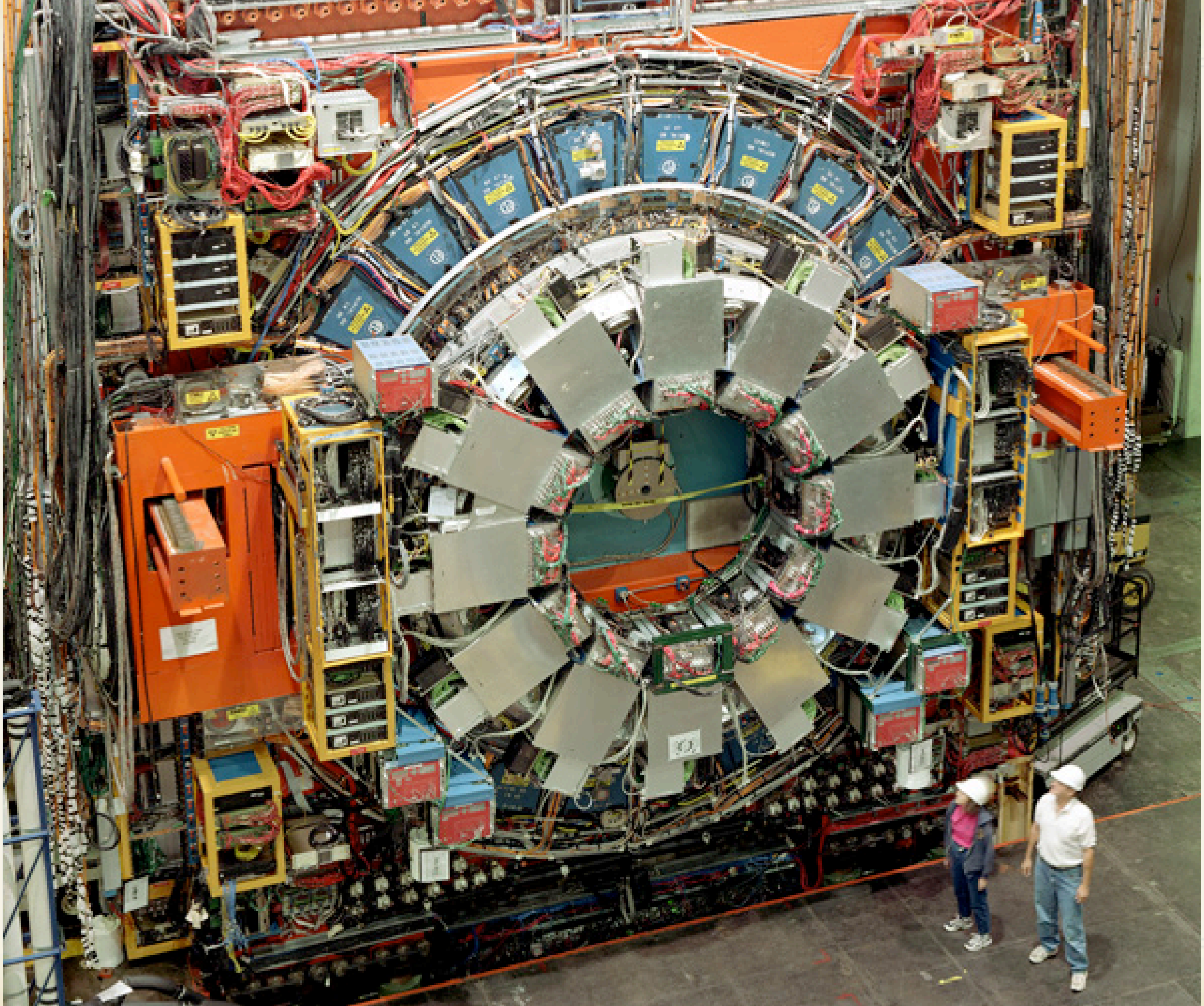

Tevatron

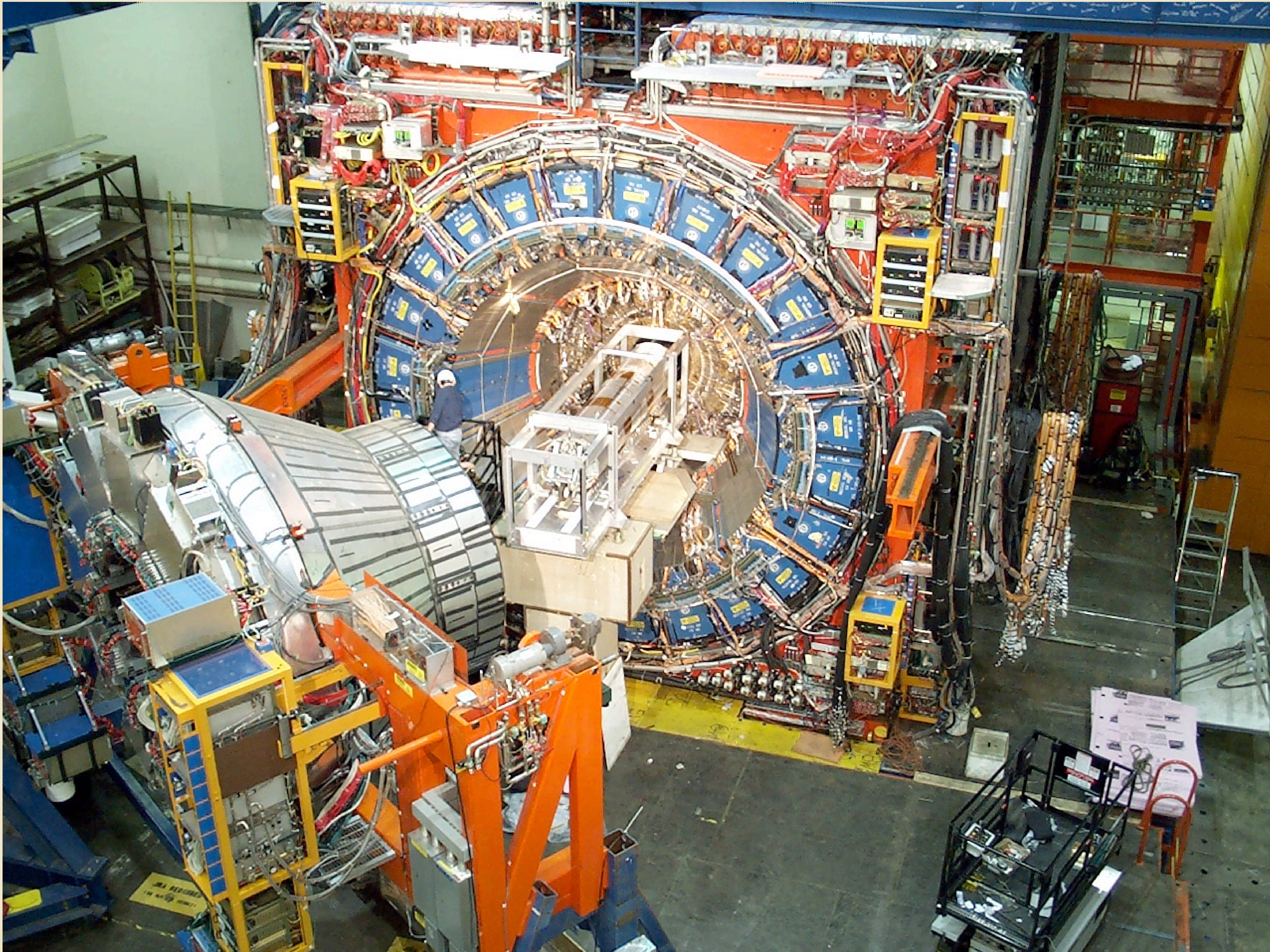

Tevatron

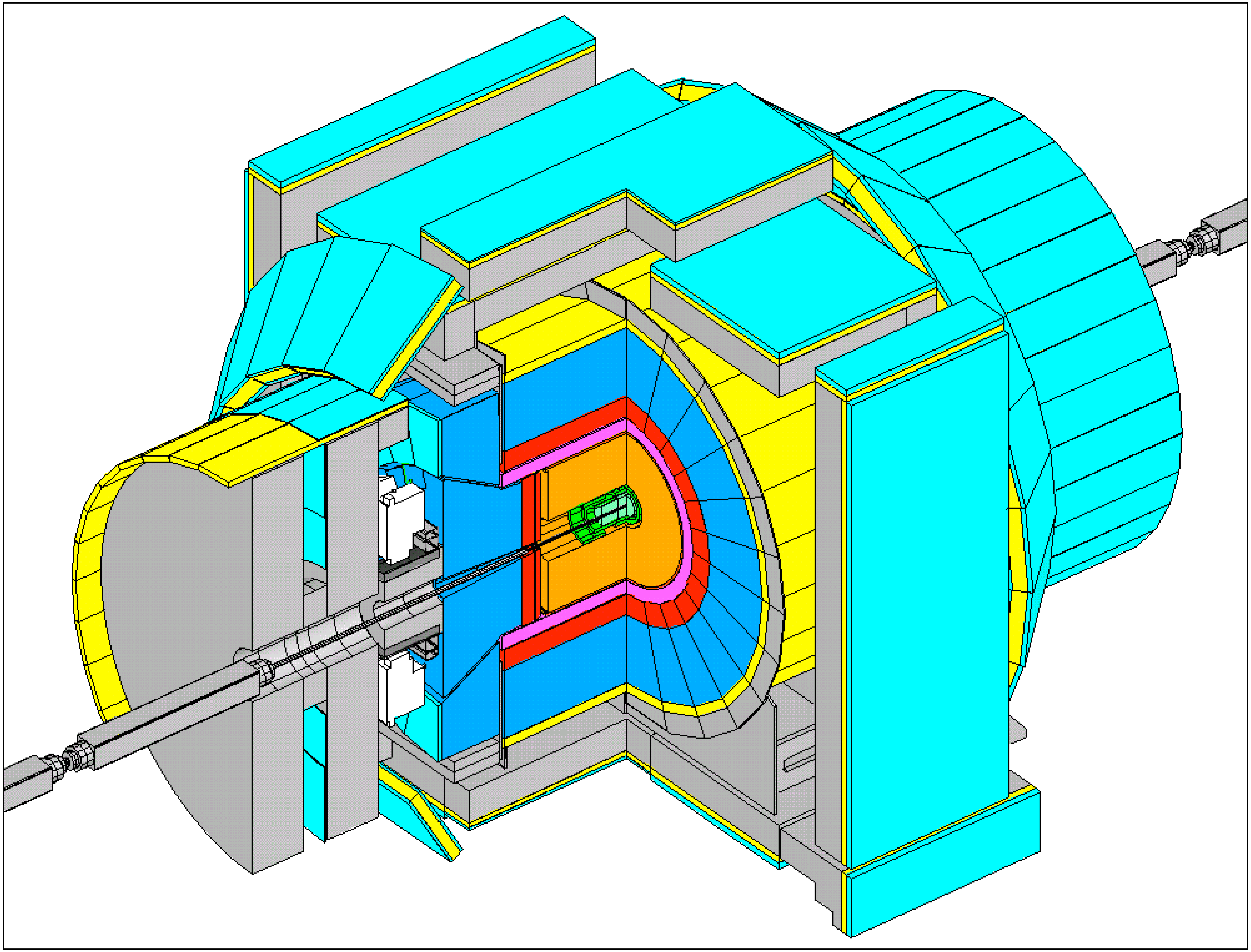


Tevatron
Main Injector

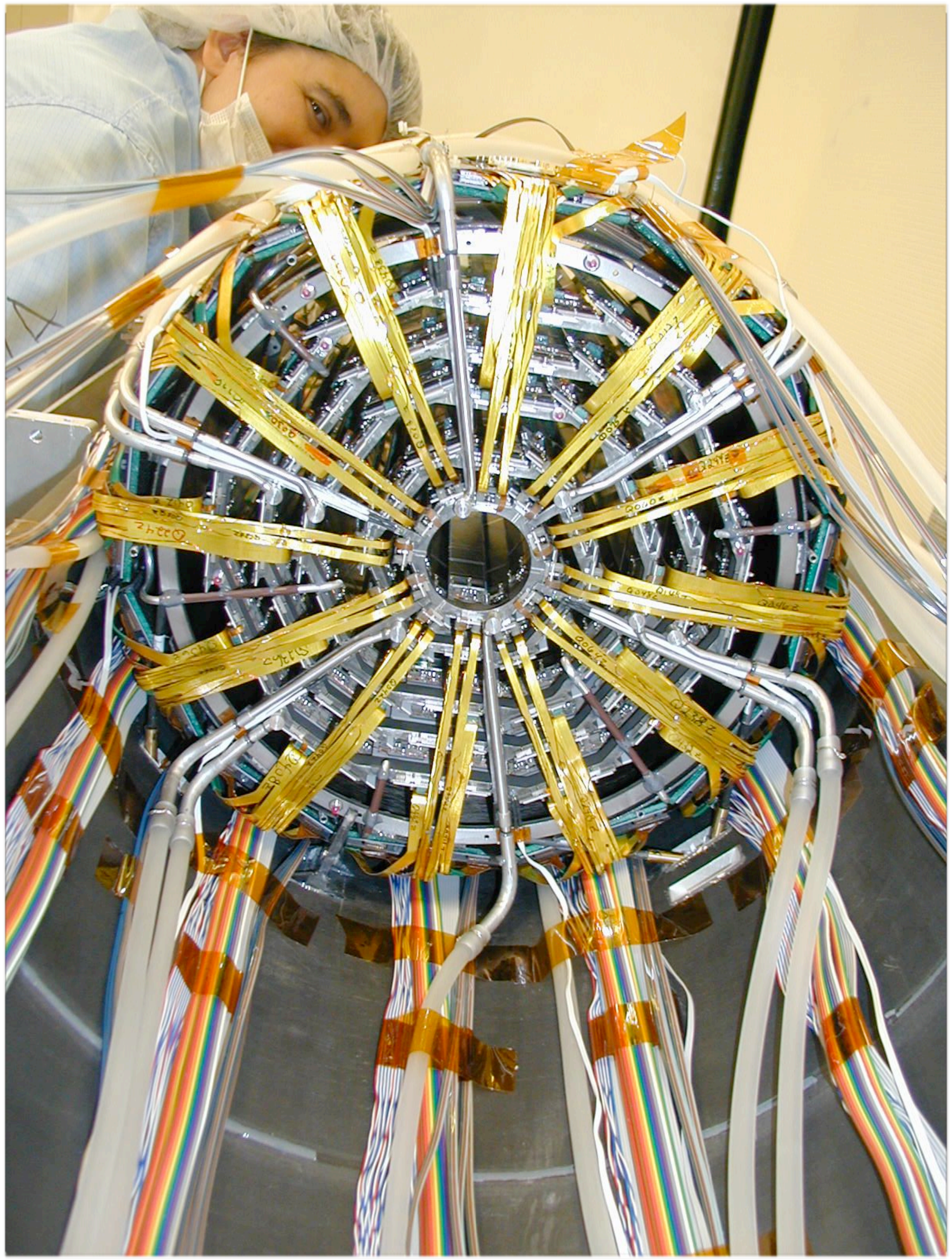


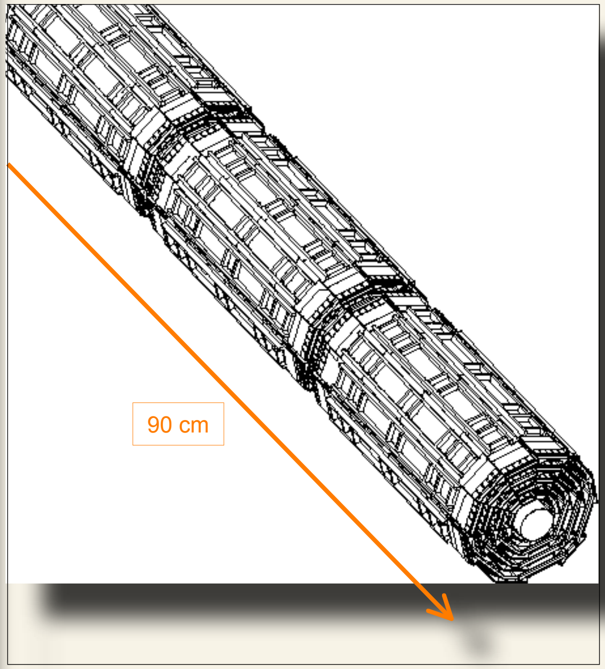


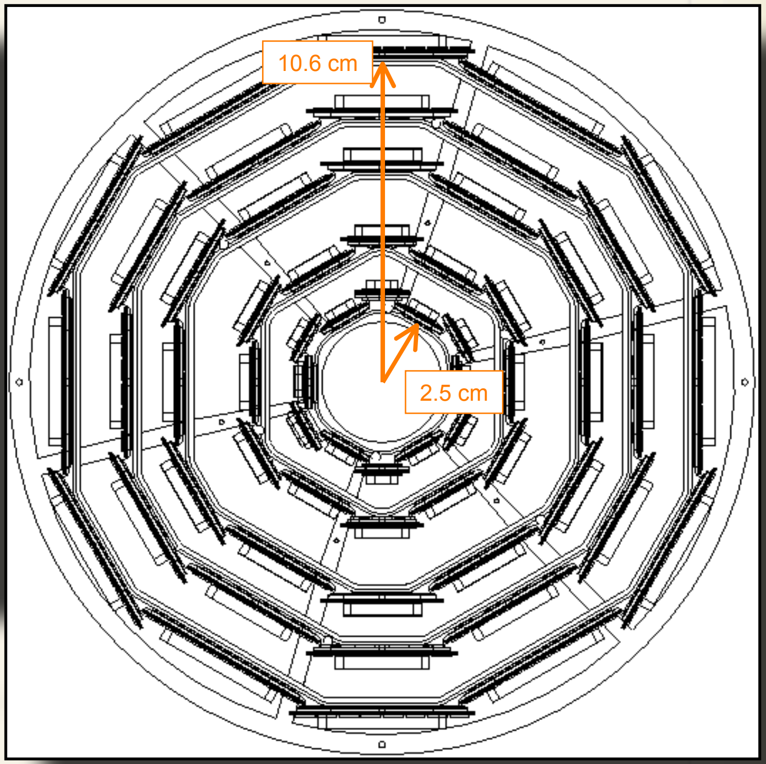




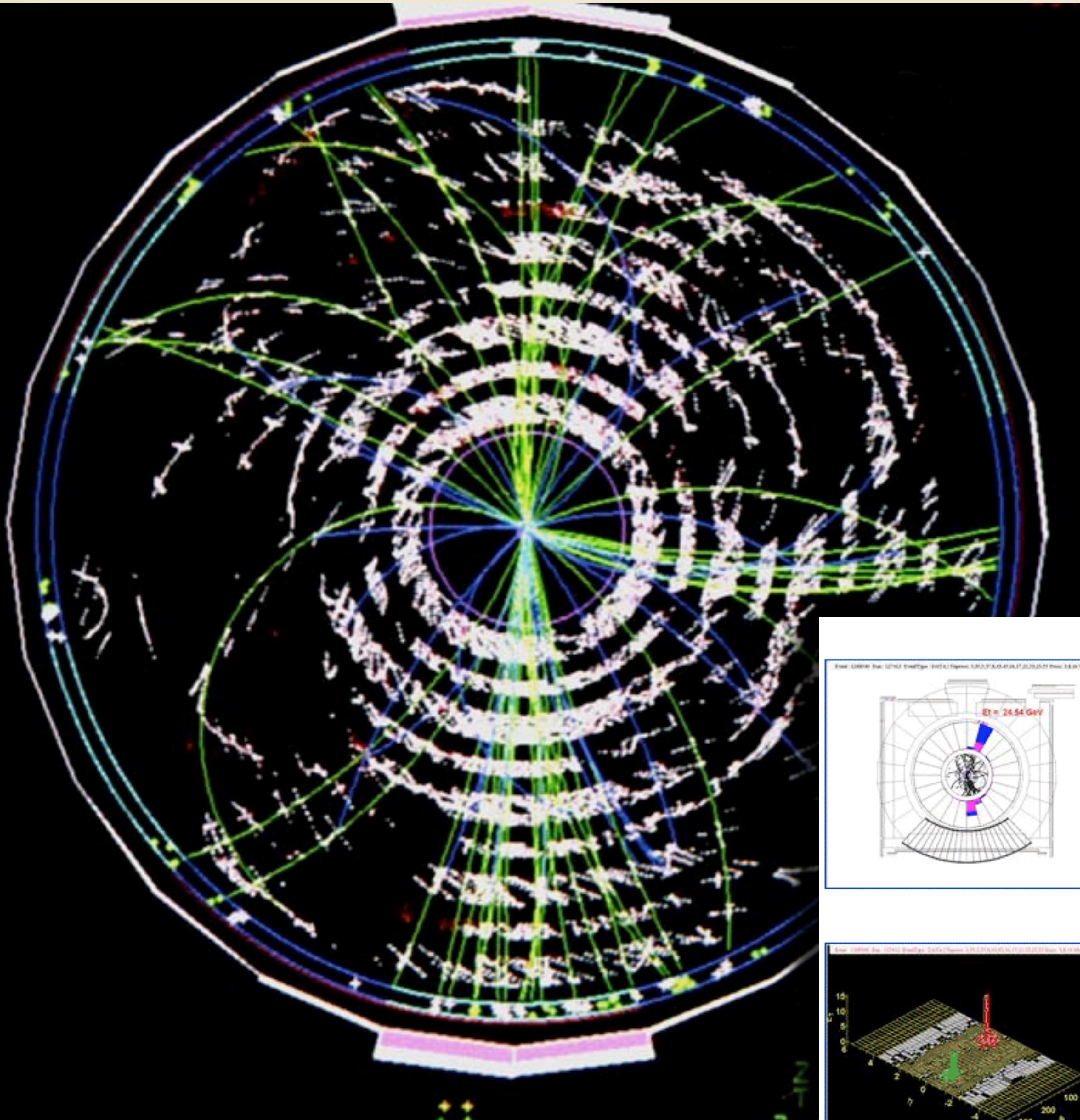
Silicon Vertex Detector

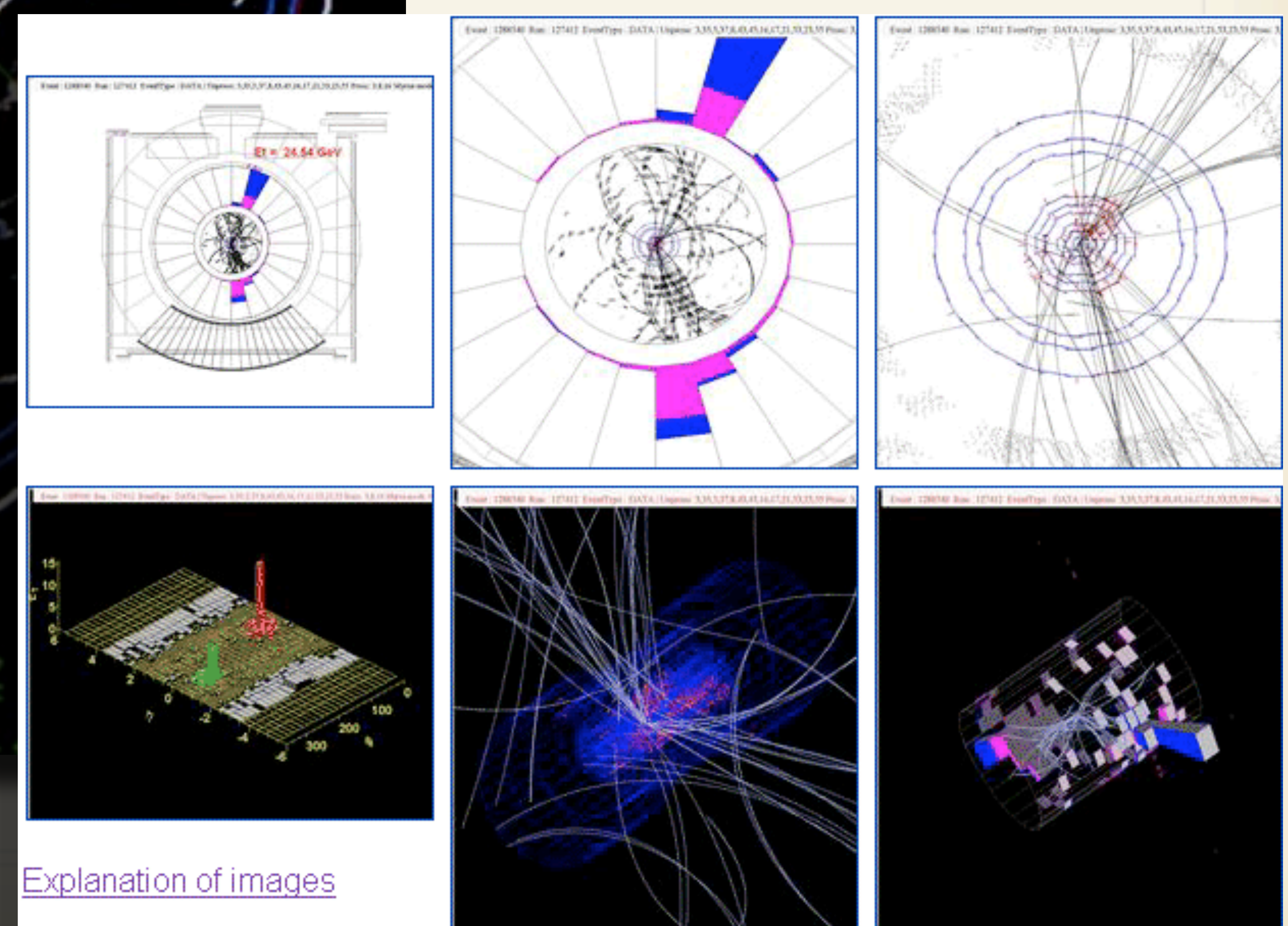






ricostruzione
delle
collisioni





quanti dati?

- il rivelatore si comporta come una sofisticata macchina fotografica digitale che registra le particelle prodotte in una collisione
- 2.5 milioni di collisioni al secondo
- circa mezzo milione di bytes per collisione
- 1250 miliardi di bytes al secondo

problemi?

- troppi dati da memorizzare
  - una unità disco moderna che può contenere fino a 1 TB non basterebbe nemmeno per un secondo
- troppi dati da elaborare
  - "ricostruire" un evento è un processo complicato e richiede tipicamente qualche secondo di tempo di calcolo, occorrerebbero quindi milioni di computers per analizzare tutte le collisioni

cosa si può fare?

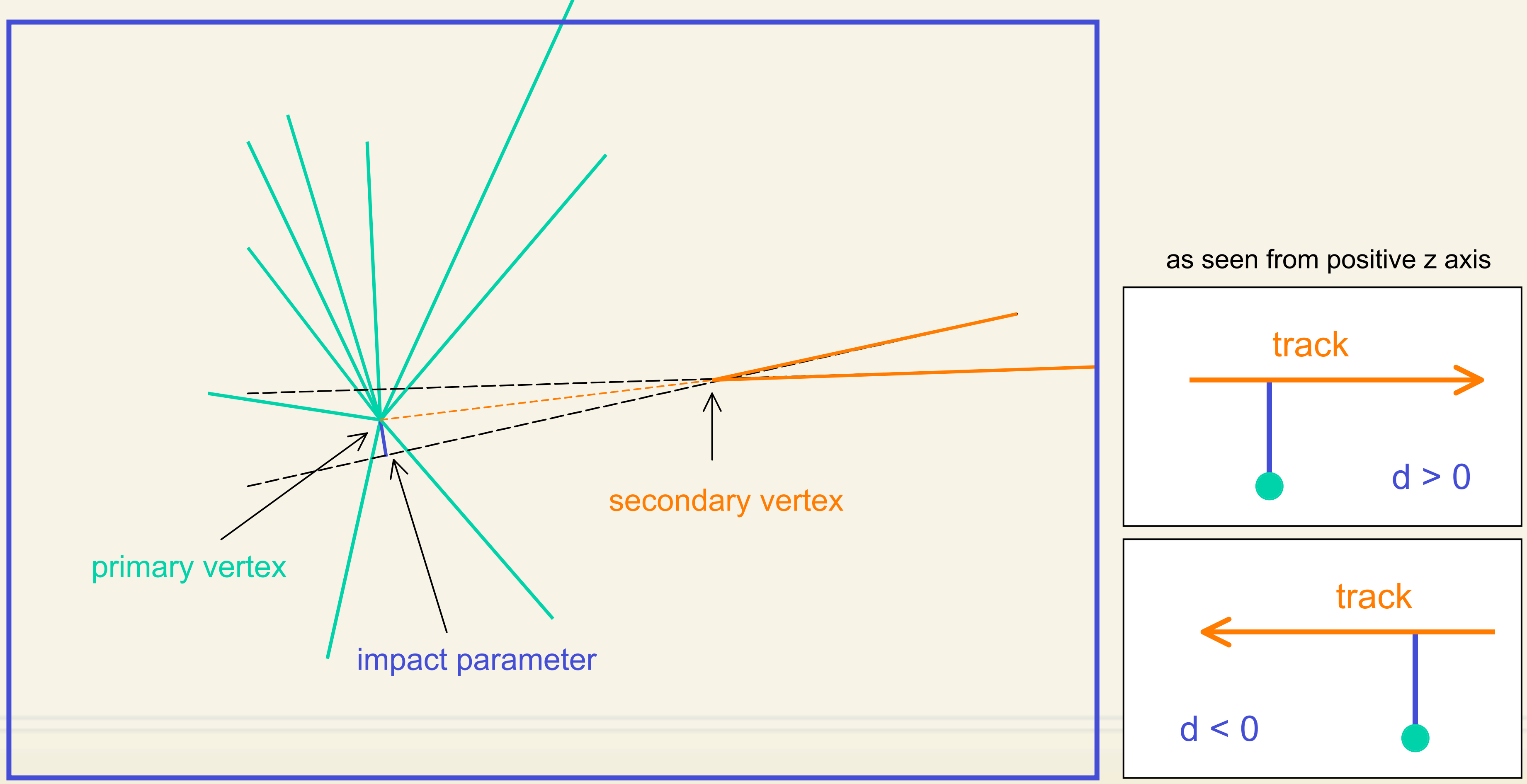
- milioni di computers no, ma mille sì
  - si possono ricostruire circa mille collisioni al secondo, una su 2500. Ma quali?
- come possiamo scegliere le collisioni interessanti?
  - occorre poter esaminare 2.5 milioni di collisioni al secondo e decidere quali vale la pena di ricostruire
  - una volta ricostruita una collisione è relativamente facile decidere se vale la pena di memorizzarla in modo permanente o se si può scartare

il Trigger

- serve una macchina in grado di elaborare i dati di una collisione, magari in modo approssimato, ma in un tempo molto più breve di qualunque calcolatore commerciale
- in gergo un dispositivo di questo genere viene chiamato “trigger”
- la qualità del trigger, ad un acceleratore come il Tevatron, determina in modo fondamentale i fenomeni che si possono osservare e le misure che si possono fare

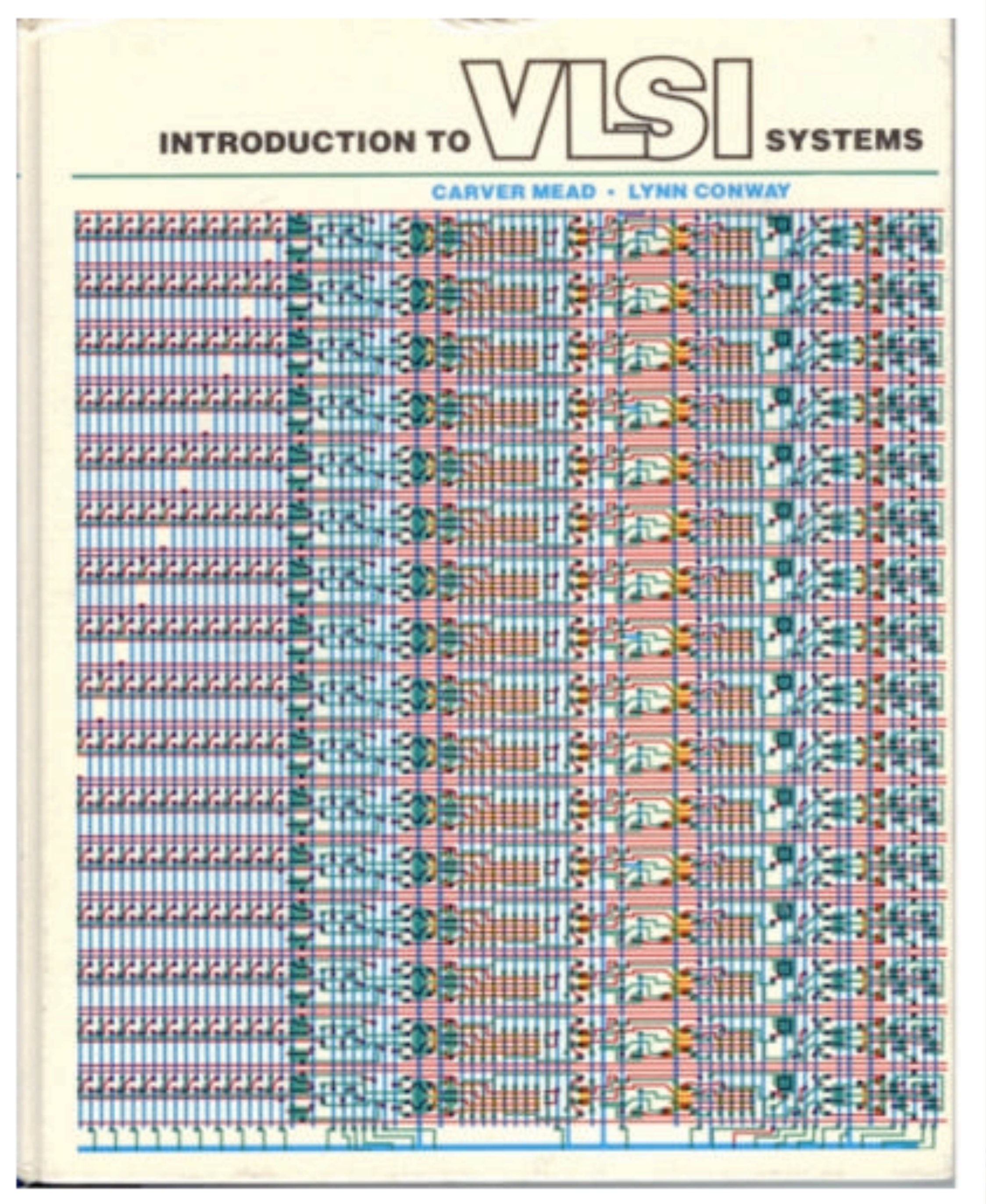
la fisica degli “heavy flavors”

- appare importante studiare le proprietà dei quarks *charm* e *bottom*
- la loro principale caratteristica è una vita media relativamente lunga che crea vertici secondari a distanze dell’ordine di millimetri

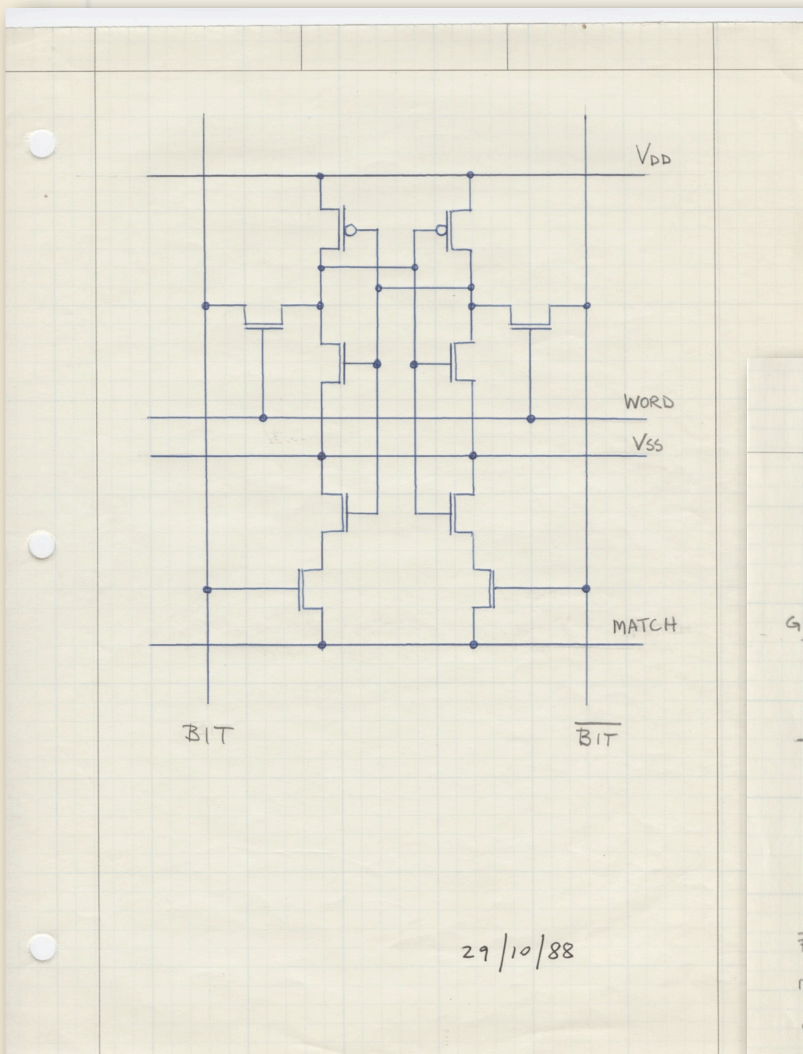


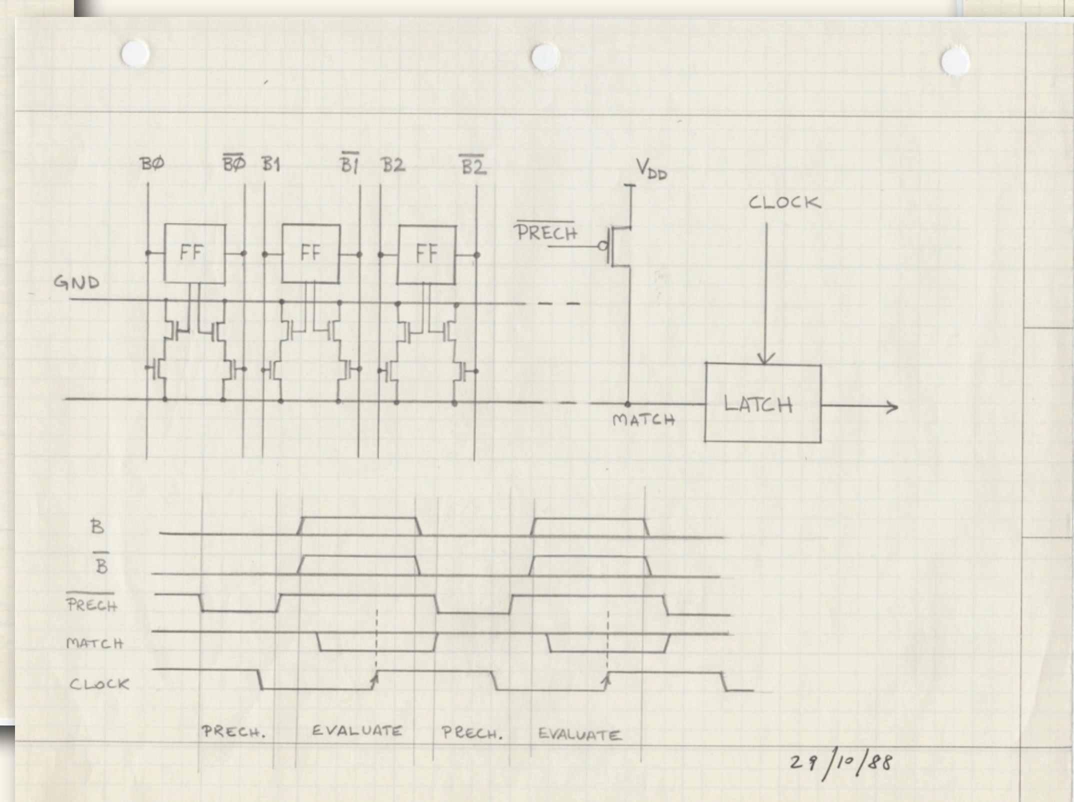
Very Large Scale Integration
la rivoluzione

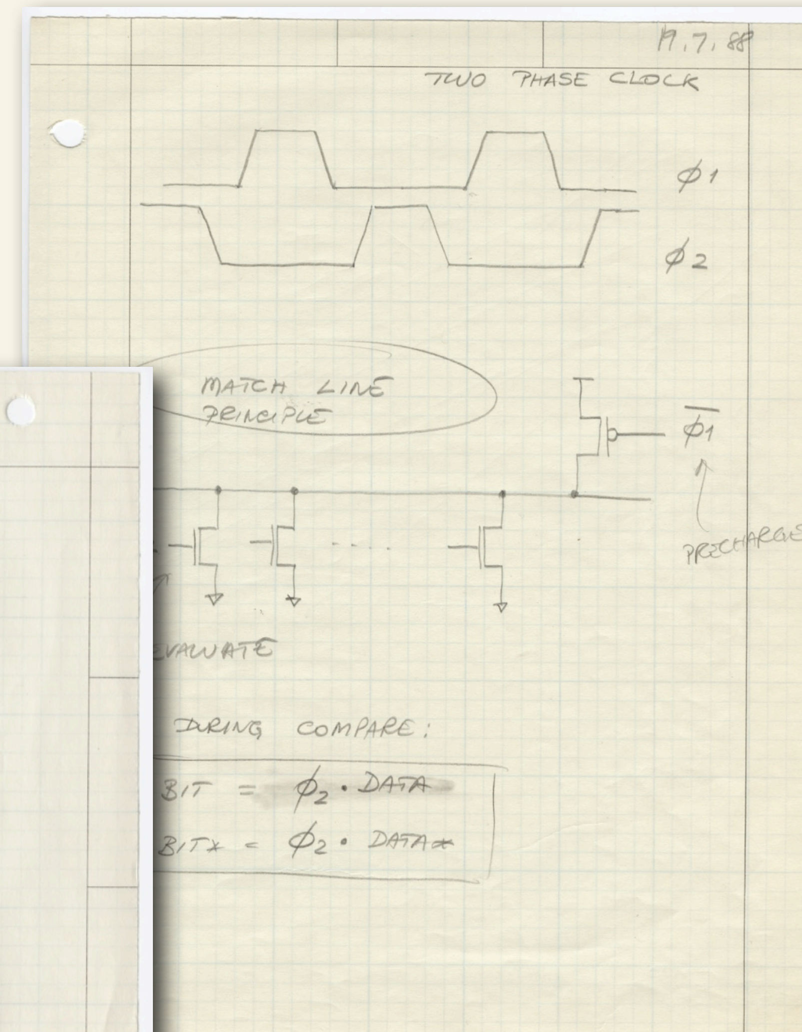
Carver Mead & Lynn Conway



negli anni '80 la progettazione VLSI cessa di essere una tecnologia alla portata esclusiva della grande industria e diventa accessibile ai laboratori di ricerca e alle università nasce l'idea di usare la tecnologia VLSI per risolvere il problema del *pattern recognition* e ricostruire le tracce nei rivelatori in tempi estremamente brevi







Ottobre 1988: lapis, gomma e carta quadrettata…

Nuclear Instruments and Methods in Physics Research A278 (1989) 436–440
North-Holland, Amsterdam

VLSI STRUCTURES FOR TRACK FINDING

Mauro DELL'ORSO
Dipartimento di Fisica, Università di Pisa, Piazza Torricelli 2, 56100 Pisa, Italy

Luciano RISTORI
INFN Sezione di Pisa, Via Vecchia Livornese 582a, 56010 S. Piero a Grado (PI), Italy

Received 24 October 1988

We discuss the architecture of a device based on the concept of *associative memory* designed to solve the track finding problem, typical of high energy physics experiments, in a time span of a few microseconds even for very high multiplicity events. This "machine" is implemented as a large array of custom VLSI chips. All the chips are equal and each of them stores a number of "patterns". All the patterns in all the chips are compared in parallel to the data coming from the detector while the detector is being read out.

1. Introduction

The quality of results from present and future high energy physics experiments depends to some extent on the implementation of fast and efficient track finding algorithms. The detection of *heavy flavor* production, for example, depends on the reconstruction of secondary vertices generated by the decay of long lived particles, which in turn requires the reconstruction of the majority of the tracks in every event.

Particularly appealing is the possibility of having detailed tracking information available at trigger level even for high multiplicity events. This information could be used to select events based on impact parameter or secondary vertices. If we could do this in a sufficiently short time we would significantly enrich the sample of events containing heavy flavors.

Typical events feature up to several tens of tracks each of them traversing a few position sensitive detector layers. Each layer detects many hits and we must correctly correlate hits belonging to the same track on different layers before we can compute the parameters of the track. This task is typically time consuming; it is

2. The detector

In this discussion we will assume that our detector consists of a number of layers, each layer being segmented into a number of *bins*. When charged particles cross the detector they *hit* one bin per layer. No particular assumption is made on the shape of trajectories: they could be straight or curved. Also the detector layers need not be parallel nor flat. This abstraction is meant to represent a whole class of real detectors (drift chambers, silicon microstrip detectors etc.). In the real world the coordinate of each hit will actually be the result of some computation performed on "raw" data: it could be the center of gravity of a cluster or a charge division interpolation or a drift-time to space conversion depending on the particular class of detector we are considering. We assume that all these operations are performed upstream and that the resulting coordinates are "binned" in some way before being transmitted to our device.

3. The pattern bank

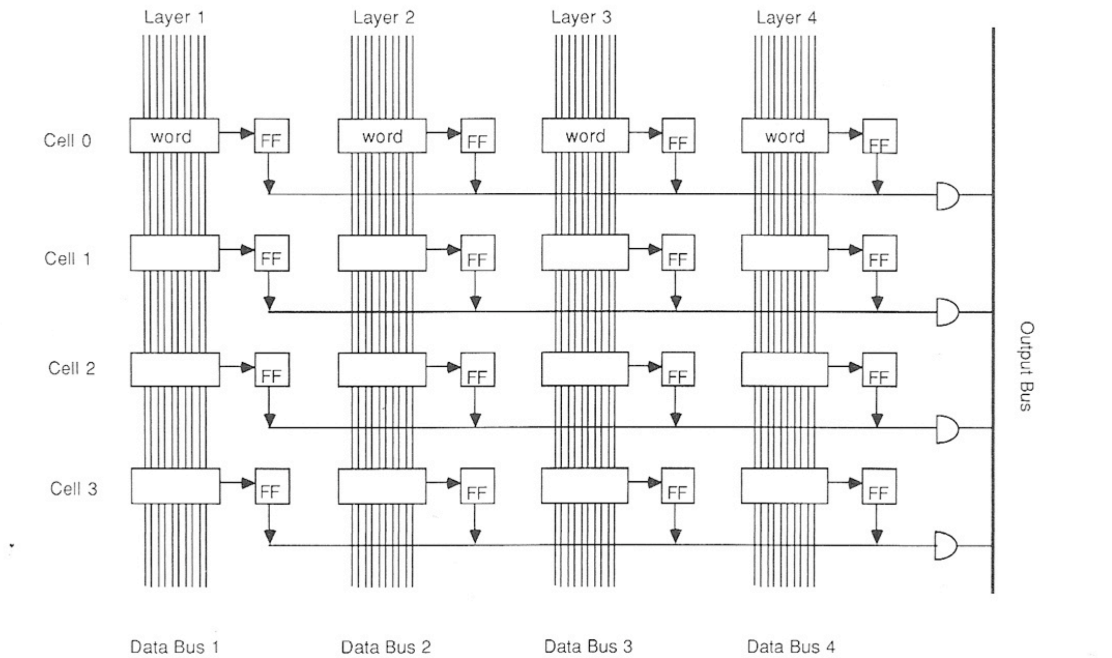


Fig. 3. Associative memory architecture.

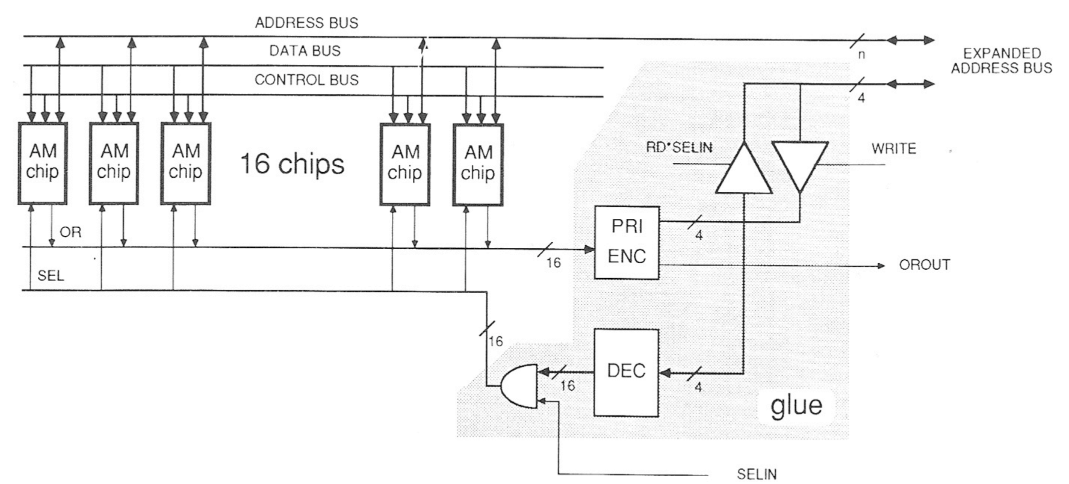


Fig. 5. 16 AM chips tied by the "glue".

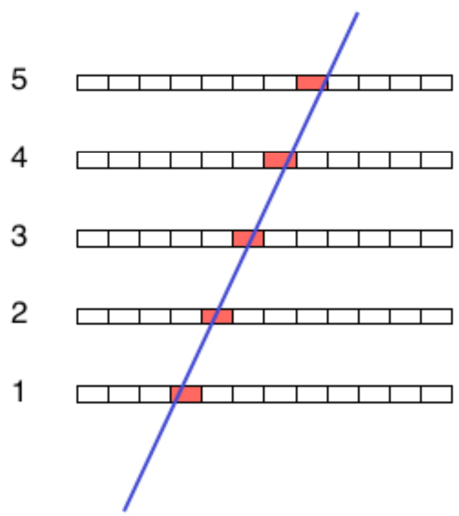
We discuss the architecture of a device based on the concept of *associative memory* designed to solve the track finding problem, typical of high energy physics experiments, in a time span of a few microseconds even for very high multiplicity events. This "machine" is implemented as a large array of custom VLSI chips. All the chips are equal and each of them stores a number of "patterns". All the patterns in all the chips are compared in parallel to the data coming from the detector while the detector is being read out.

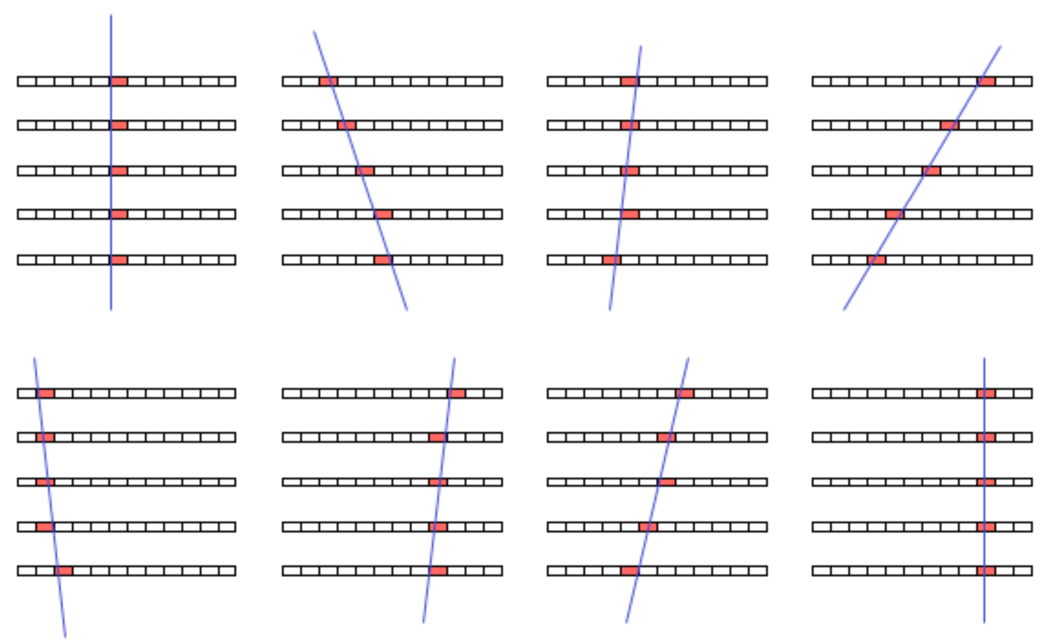
Building the “Pattern Bank”

SVT

Instead of looking for hit combinations such that *f(x1,x2,x3,…) = 0*

1. Build a database with all patterns corresponding to “good” tracks
2. Compare hits in each event with all patterns to find track candidates





In this example:
Straight lines, 5 layers, 12 bins/layer

⇨ Total number of patterns ~ $(12)^2*(5-1) = 576$

CDF/DOC/TRIGGER/PUBLIC/1421

SVT
THE SILICON VERTEX TRACKER

Luciano Ristori

May 1, 1991

INTRODUCTION

This note describes the architecture of a device we believe we can build to reconstruct tracks in the Silicon Vertex Detector (SVX) with enough speed and accuracy to be used at trigger level 2 to select events containing secondary vertices originated by B decay. We name such a device *Silicon Vertex Tracker* (SVT).

The use of SVT as part of the CDF trigger would allow us to collect a large sample of B's (> 10^7 events) in a 100 pb^{-1} run.

B production at 2 TeV in the c.m. is abundant: Isajet predicts that, in the central region, 6.5% of two-jet events with Pt>20 GeV/c contain a B pair. Thus we need a trigger with a relatively modest rejection factor (10 ÷ 20) not necessarily requiring the presence of very high P_T tracks.

It turns out that the simple requirement of a single track with an impact parameter greater than a given threshold might do the job.

The possibility to use the output of SVT to actually reconstruct secondary vertices is left open and it's not discussed here.

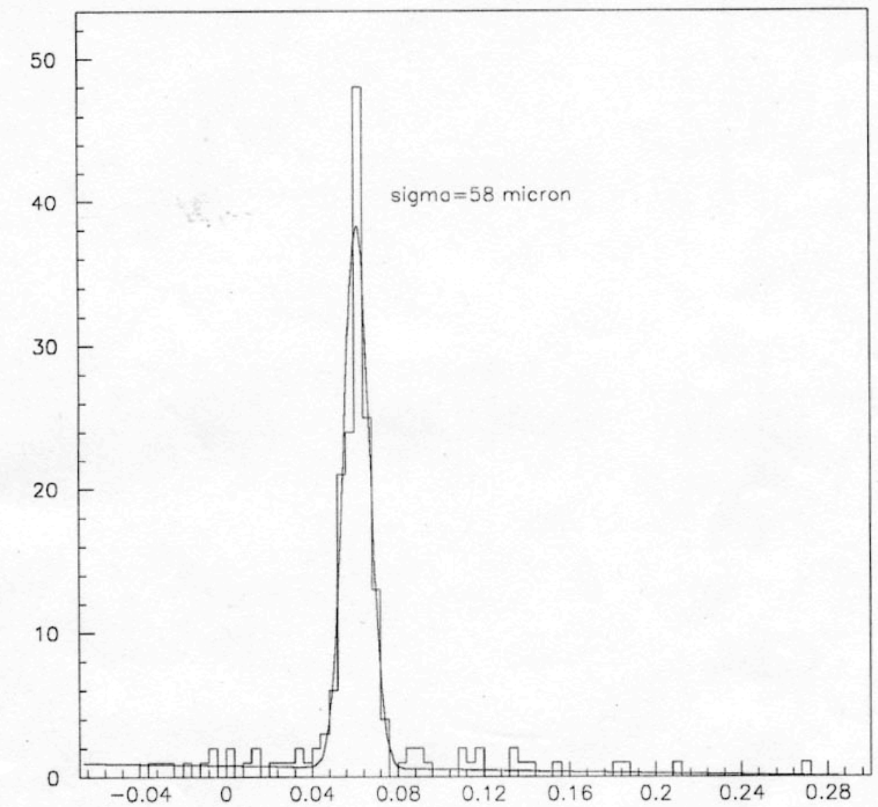
In Section 1 we report the results of some simple simulations we have done to show the efficacy of the impact parameter cut, in Section 2 we overview the overall architecture of SVT, in Section 3 we describe the different parts SVT is made of and how they relate to the different stages the track finding process goes through.

1. SIMULATION RESULTS

1.1 Impact Parameter Cut

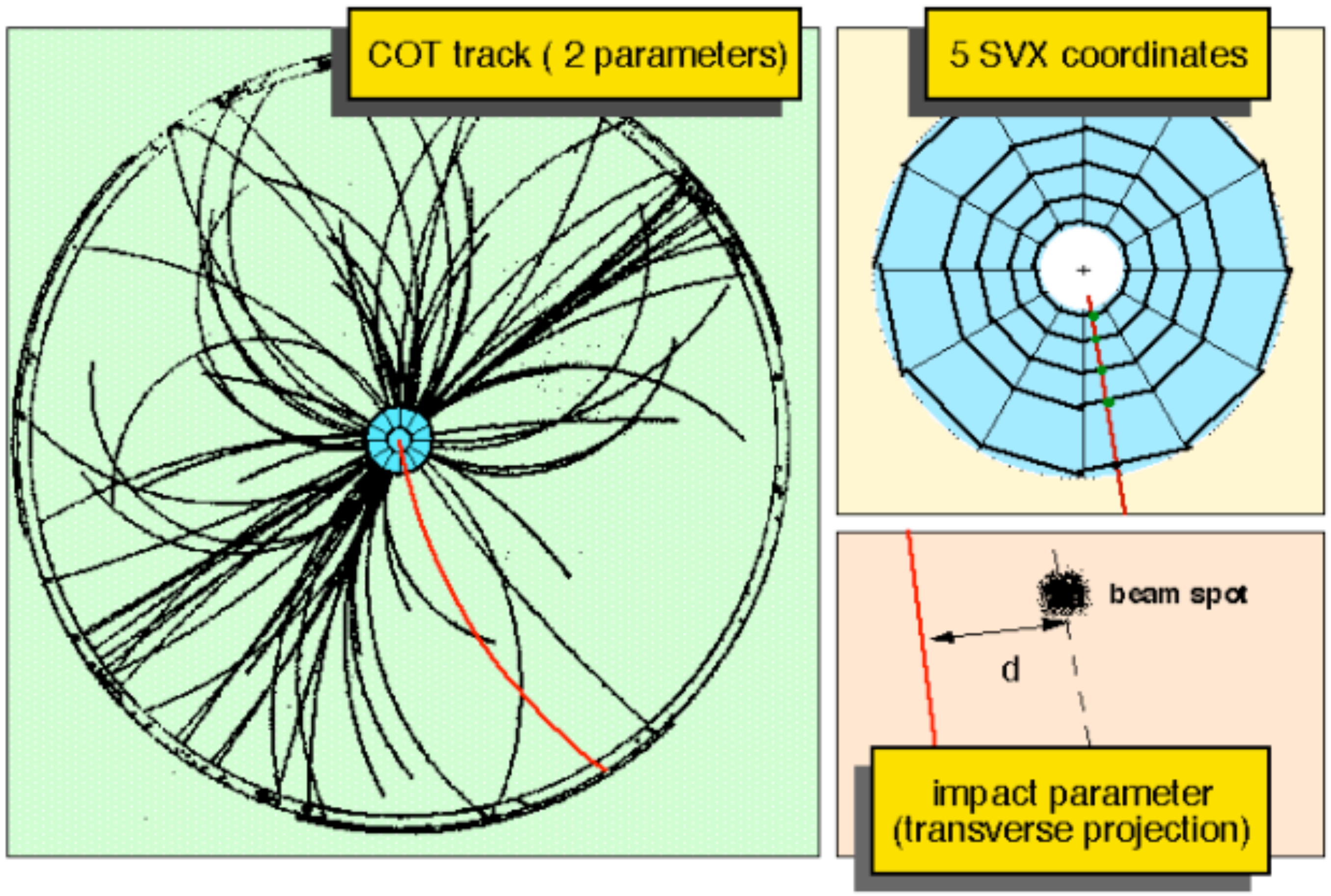
The impact parameter *s* of each track is defined as the minimum

real data + SVT simulation



Transverse profile of the Tevatron luminous region obtained feeding real data from SVX into the simulation of SVT. The sigma of this curve (58 μm) is the result of the folding of spot size with impact parameter resolution.

Nov 17, 1992



Inputs:

- L1 tracks from XFT (ϕ, p_T)
- digitized pulse heights from SVX II

Functionalities:

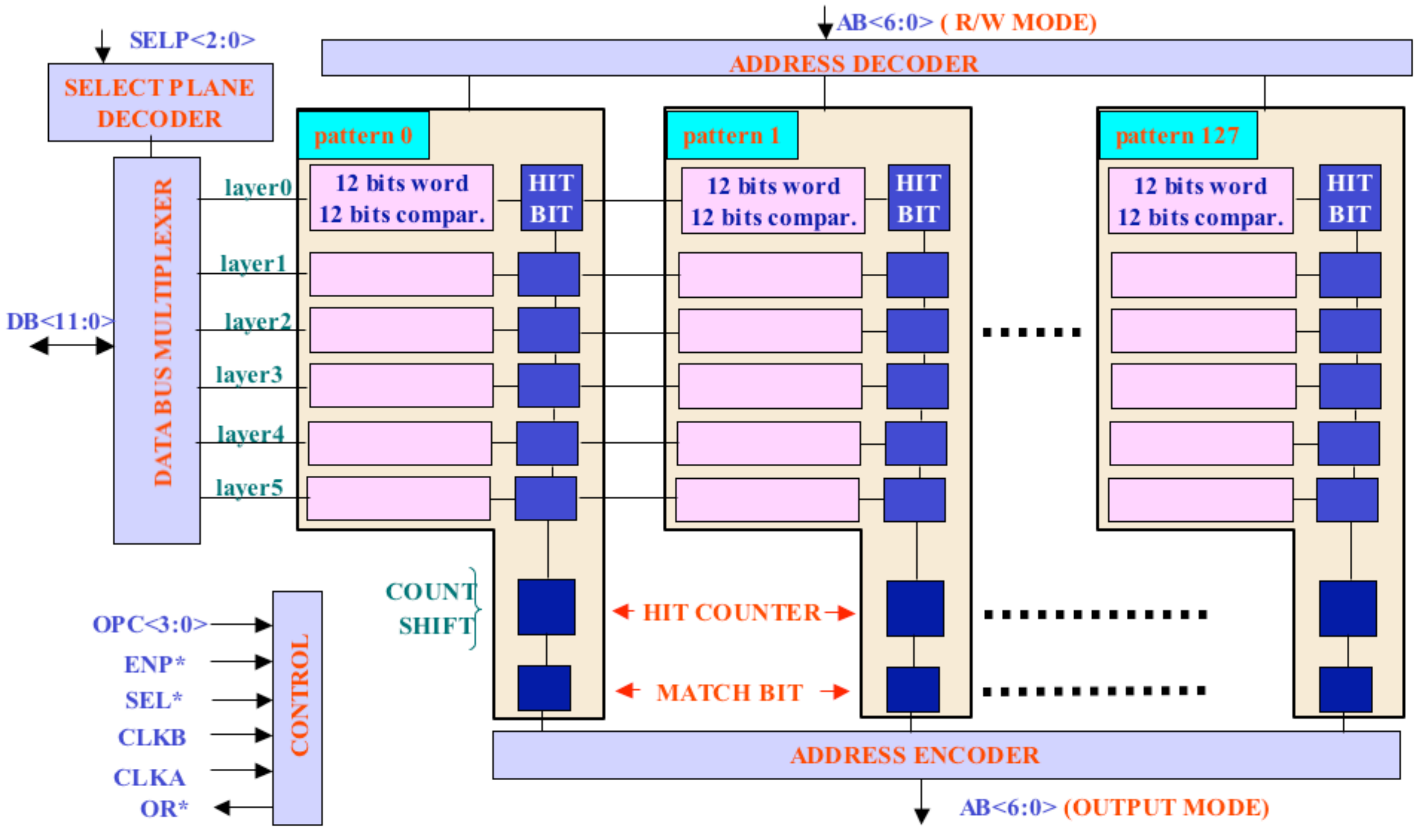
- hit cluster finding
- pattern recognition
- track fitting

Outputs:

- reconstructed tracks (d, ϕ, p_T)

AM chip internal structure

SVT



Constraint surface

SVT

6 coordinates: x_1, x_2, x_3, x_4, x_5 (P_T), x_6 (ϕ)

3 parameters to fit: P_T , ϕ , d

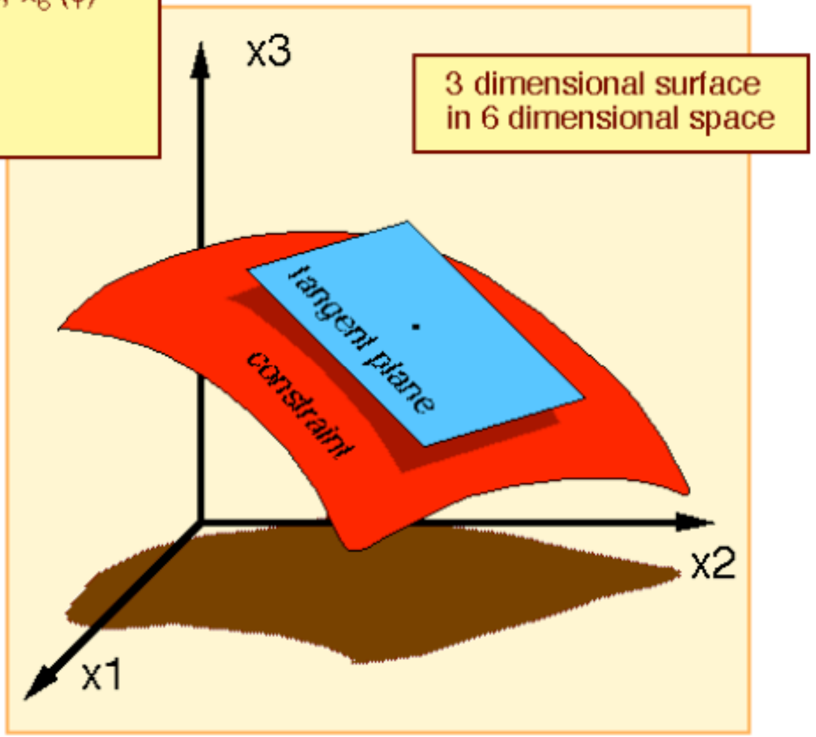
3 constraints

tangent plane:

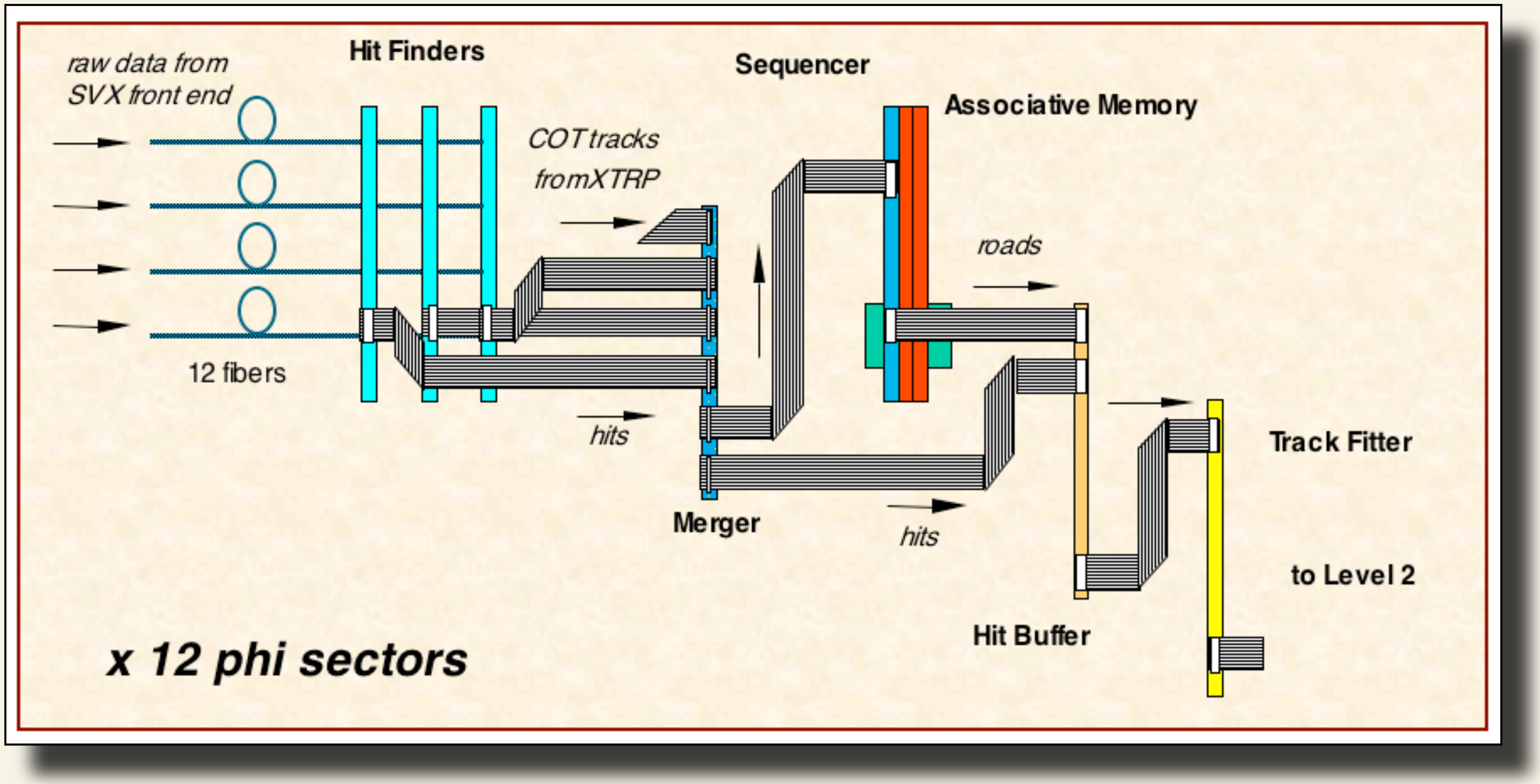
$$\sum_{1}^{6} a_i x_i = b$$

track parameters:

$$d \approx c_0 + \sum_{1}^{6} c_i x_i$$



Linear approximation is so good that a single set of constants is sufficient for a whole detector wedge (30° in ϕ)


raw data from
SVX front end
Hit Finders
Sequencer
Associative Memory
COT tracks
fromXTRP
roads
12 fibers
hits
Track Fitter
Merger
hits
to Level 2
Hit Buffer
x 12 phi sectors

FERMI NATIONAL ACCELERATOR LABORATORY
P.O. Box 500
Batavia, Illinois 60510

CDF
Mail Station 318

January 5, 1994

Professor Giorgio Bellettini
INFN, Pisa

Dear Giorgio,

We are writing to encourage you and your colleagues to continue development of the SVT system for CDF. The studies of quark mixing and CP violation in B decay are important long term goals of CDF and the Fermilab Tevatron Collider program in general. For many years a popular view in the high energy physics community was that this physics could not be done at hadron colliders. Because B production is a very small fraction of the total cross section, it was argued, triggering was only possible for those decays containing leptons. The work of Luciano Ristori *et al* has shown that this is not the case. Their proposal of a fast trigger that finds tracks from a secondary vertex is viewed broadly as extremely important. CDF plans on using the SVT in run II and beyond to greatly broaden our physics opportunities. We have been officially encouraged to proceed with this work by the Fermilab Director and his Physics Advisory Committee. We thus hope that you are able to develop the SVT as quickly as possible. When the design work is completed, we look forward to a joint Italy--U.S. construction effort.

Sincerely yours,

Mel Shochet

Bill Carithers

Co-spokesmen, CDF Collaboration

CDF/DOC/TRIGGER/PUBLIC/3108

SVT

Silicon Vertex Tracker

TECHNICAL DESIGN REPORT

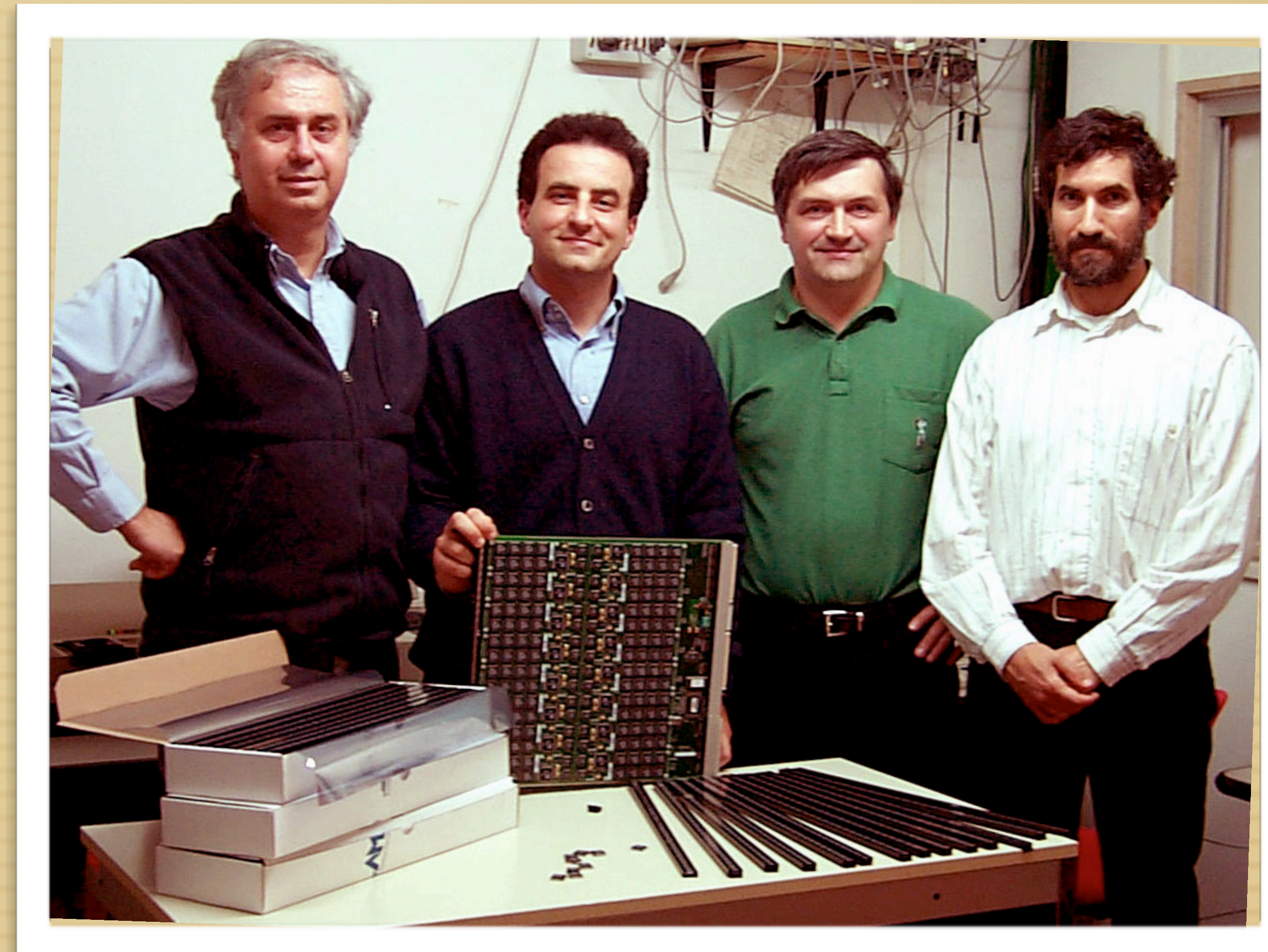
Version 2.1 - November 22, 1994

The following people have contributed to the development of the SVT project and to the writing of this document:

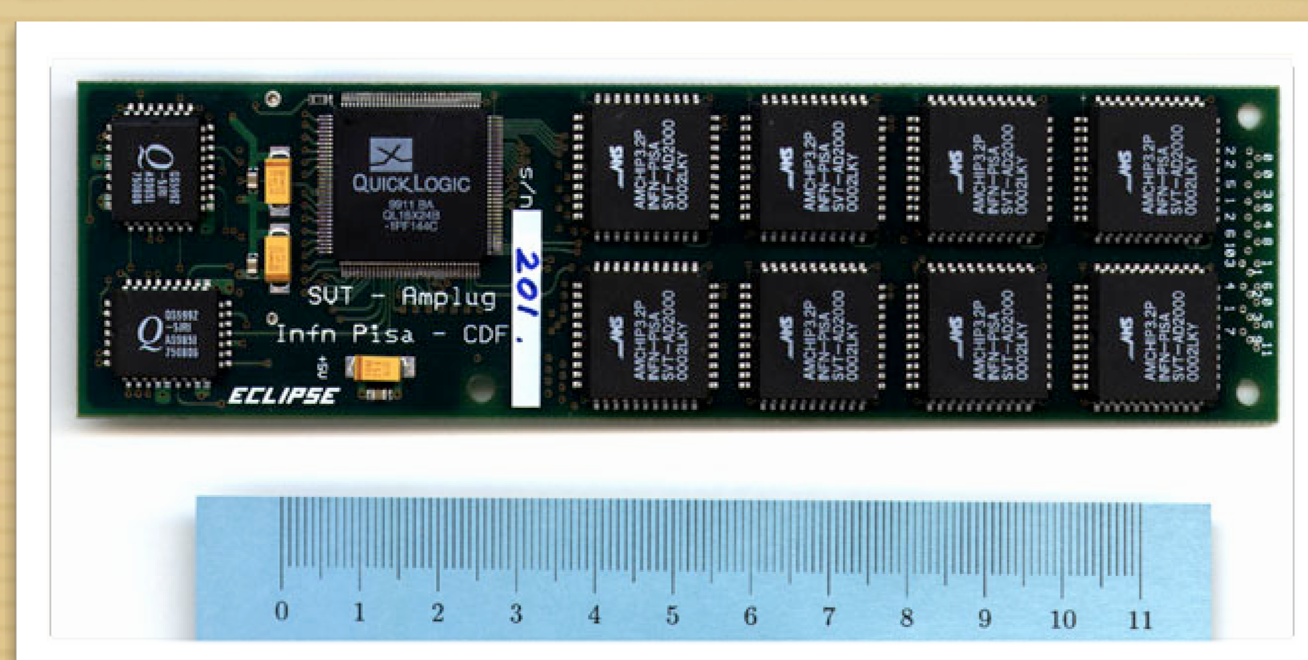
S. Belforte, M. Dell'Orso, S. Donati, G. Gagliardi, S. Galeotti, P. Giannetti, N. Labanca, F. Morsani, D. Passuello, G. Punzi, L. Ristori, G. Sciacca, N. Turini, A.M. Zanetti

Fabio

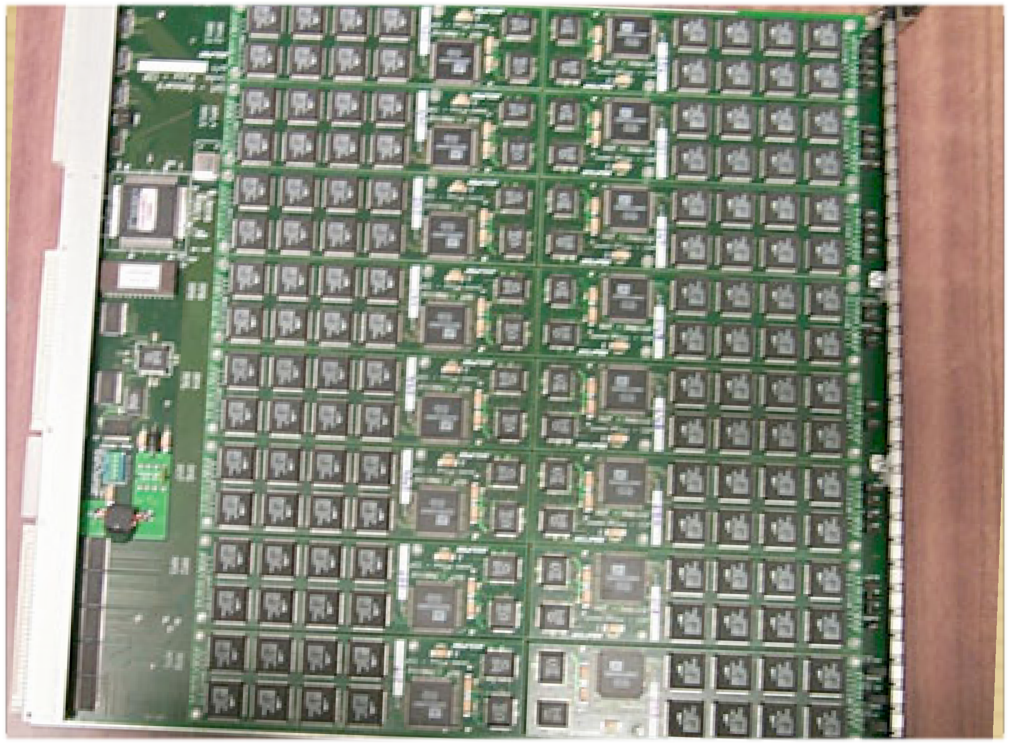
Luciano Giovanni Alexei Fabio



Associative Memory chip

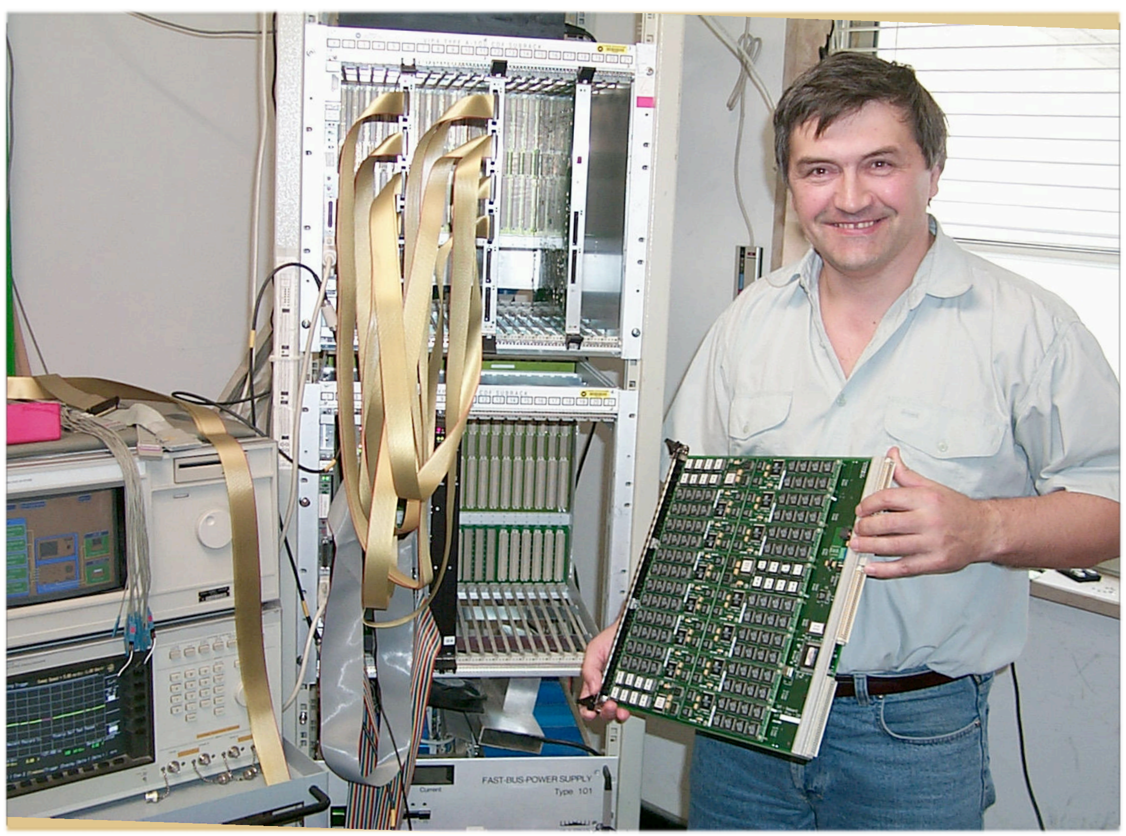


Associative Memory plug

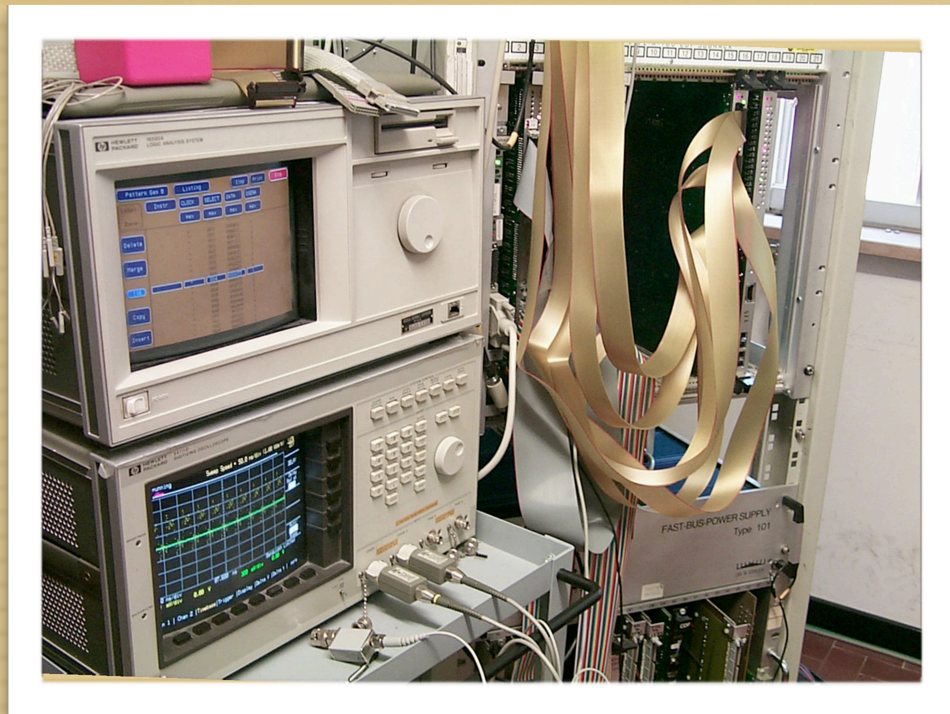


Associative Memory board

Gianfranco

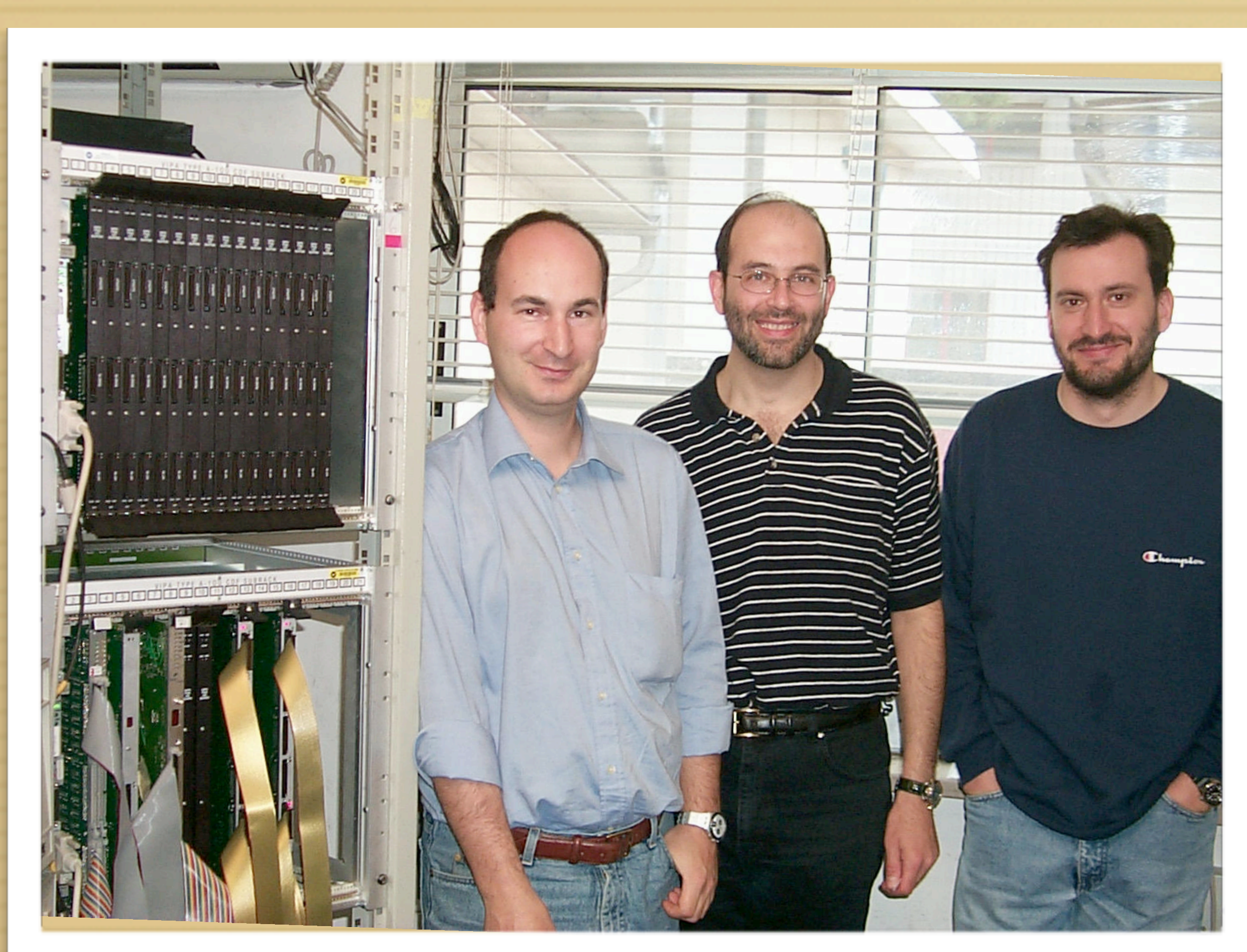


Alexei



Test Stand

Stefano

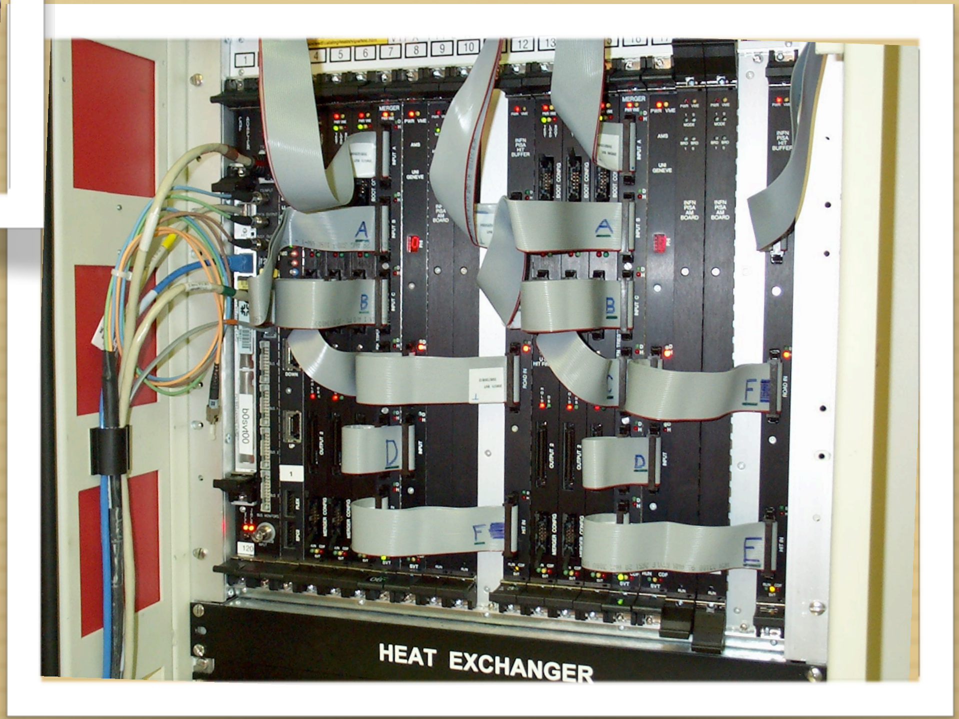


Franco Stefano Simone

Hit Buffers

31 Agosto 2000

Tutti i crates installati a Fermilab



31 Agosto 2000

Tutti i crates installati a Fermilab


SVT was born on Halloween night 2000

From: Giovanni Punzi <giovanni.punzi@tiscalinet.it>
Subject: **Tracks in SVT !!!**
Date: November 1, 2000 6:16:39 AM CST
To: World SVT <svt@fnal.gov>
Reply-To: giovanni.punzi@tiscalinet.it

Show in M

Hello SVTers,
we have got clear tracks in SVT from run 102831 !!!! This is in spite of the lack of XFT information !
I thought the easiest way to show you this was to simply display the whole of my Mathematica session with all plots and comments:

first tracks in SVT

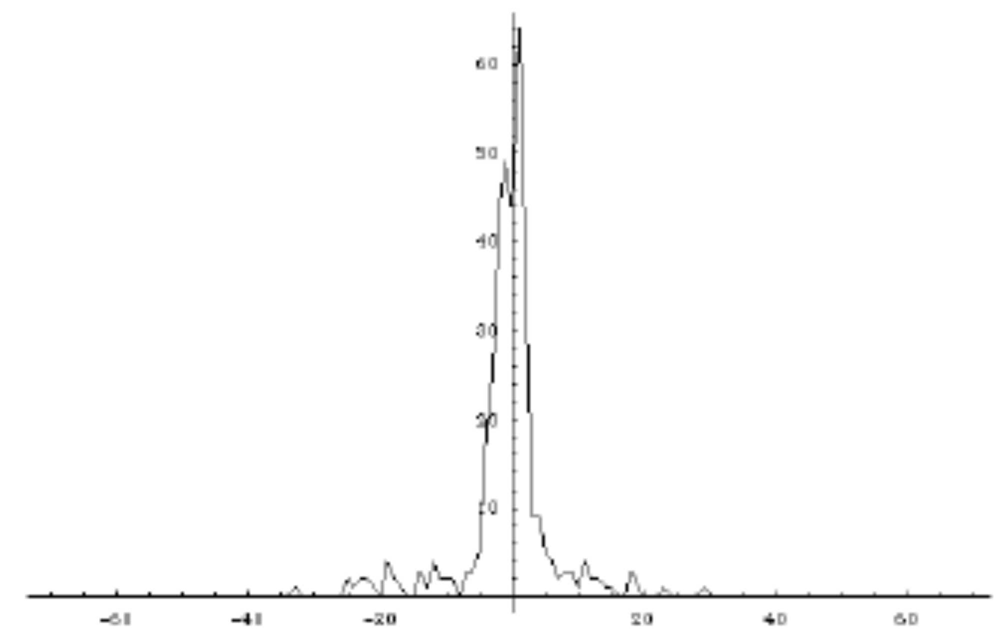
Enjoy !

Giovanni

dieci anni di ricerca
nel profondo della foresta
oggi grandi risate
sulla riva del lago

Soen

SVT_first_.nb 11/02/200



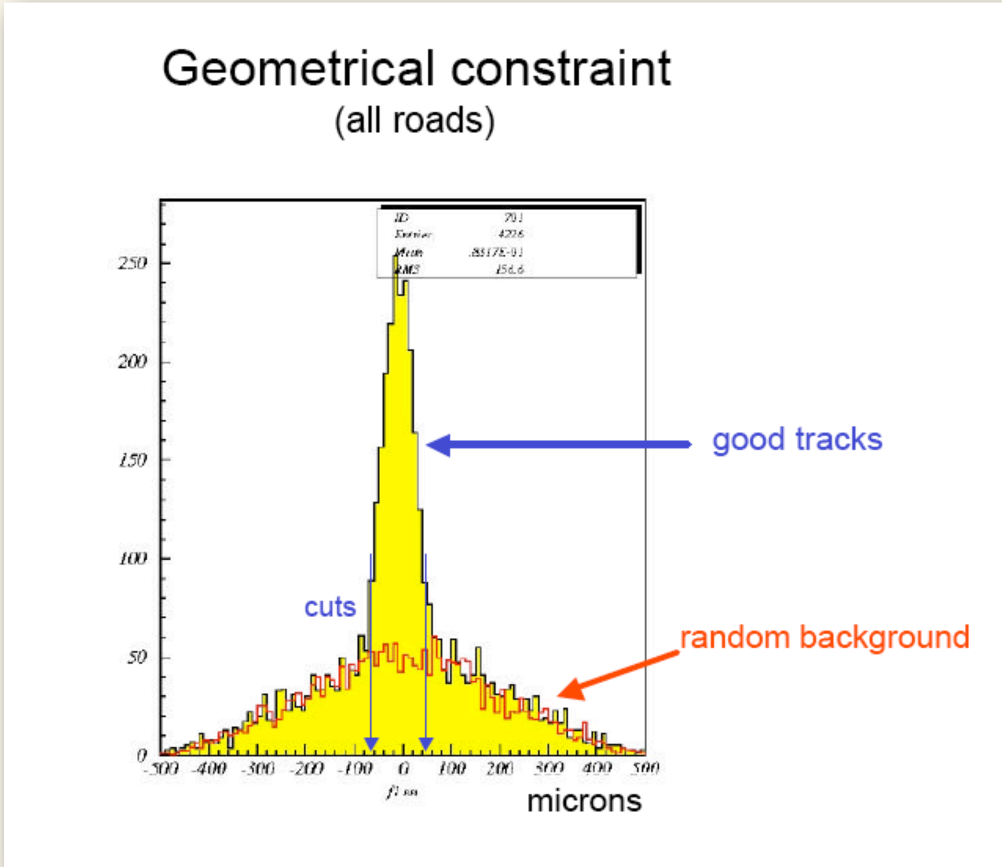
Out[295]= - Graphics -

This is VERY CLEAN now !!! The beam constraint cleans up the sample a lot !!!
Note that Kernel and d are basically uncorrelated, as they should:

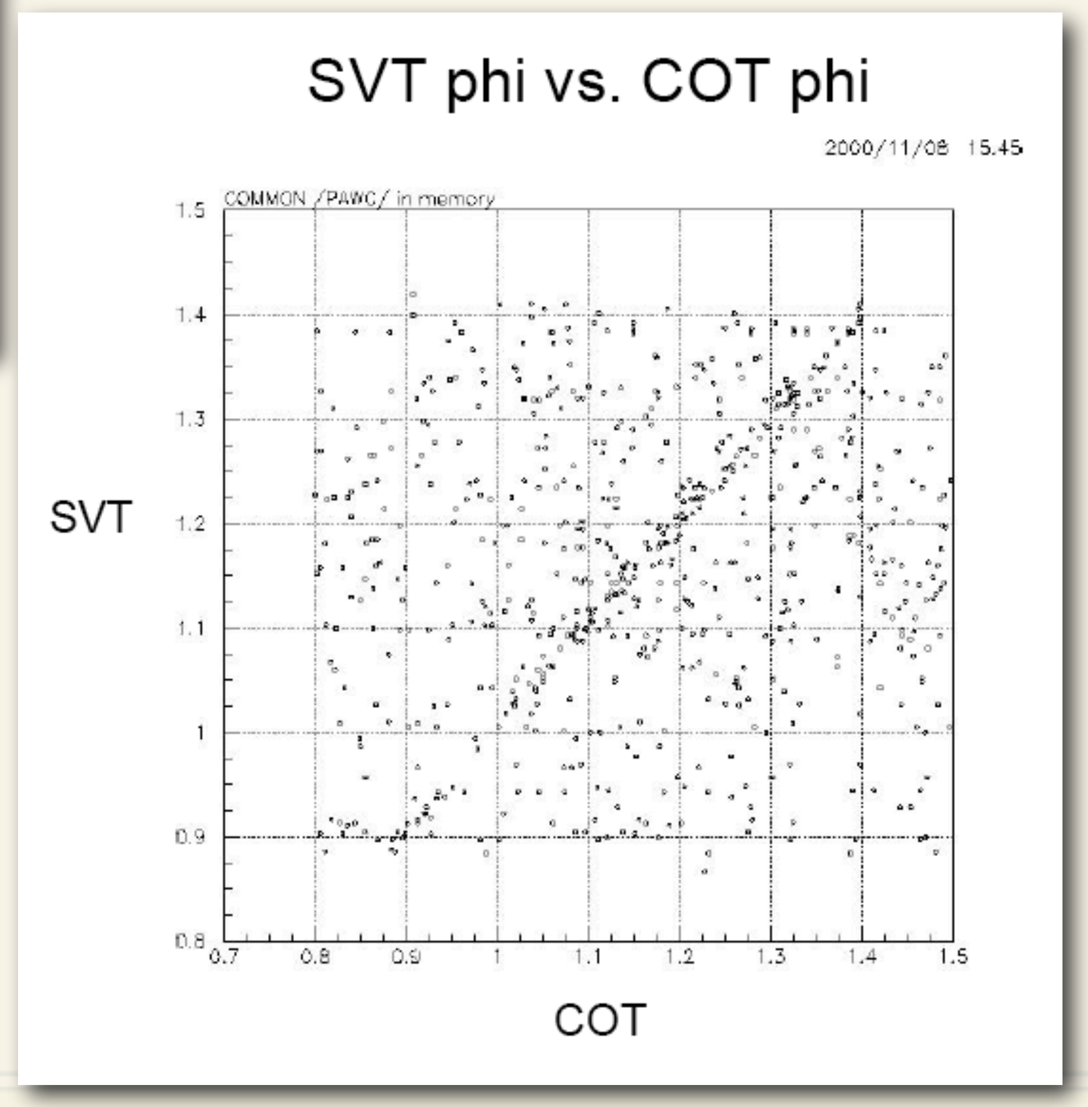
In[296]:= K.Dsub / Sqrt[K.K *Dsub.Dsub]

Out[296]= -0.0529577

...so there is no trick,the correlation between the two variables is given by physics!!!



abbiamo la prova che le tracce rivelate da SVT sono reali

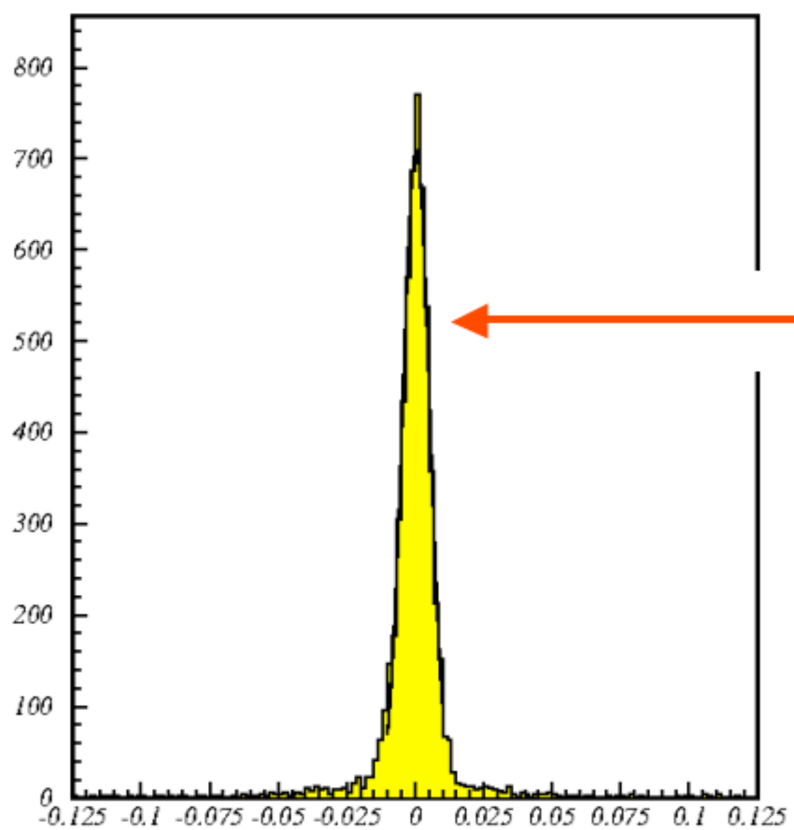


la precisione della misura del parametro di impatto è quella prevista

SVT: beam profile

SVT

Impact parameter distribution



This distribution is interpreted as the convolution of the actual transverse size of the beam spot with the impact parameter resolution of the SVT

sigma ~ 48 um ~ 42 um $\oplus$ 23 um

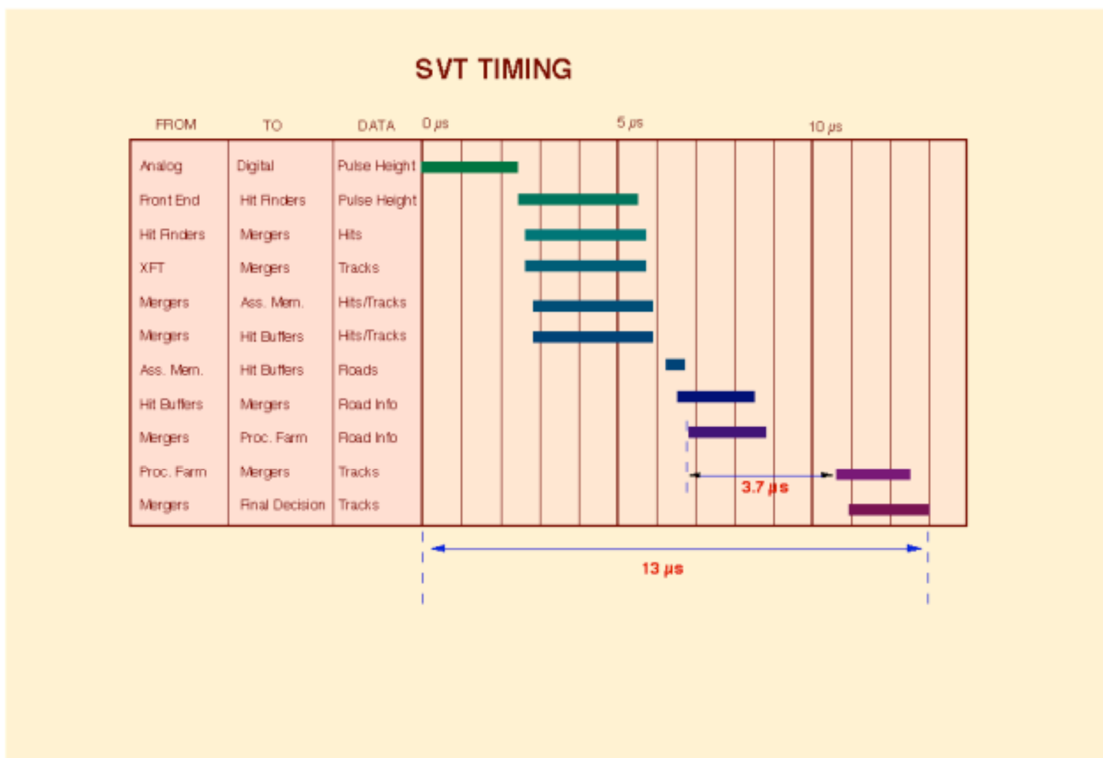
SVT resolution   beam spot size

	beam	*SVT*	*Total*
sigma	23	42	48
rms	23	51	56

anche il tempo di elaborazione è molto vicino a quello previsto

Timing

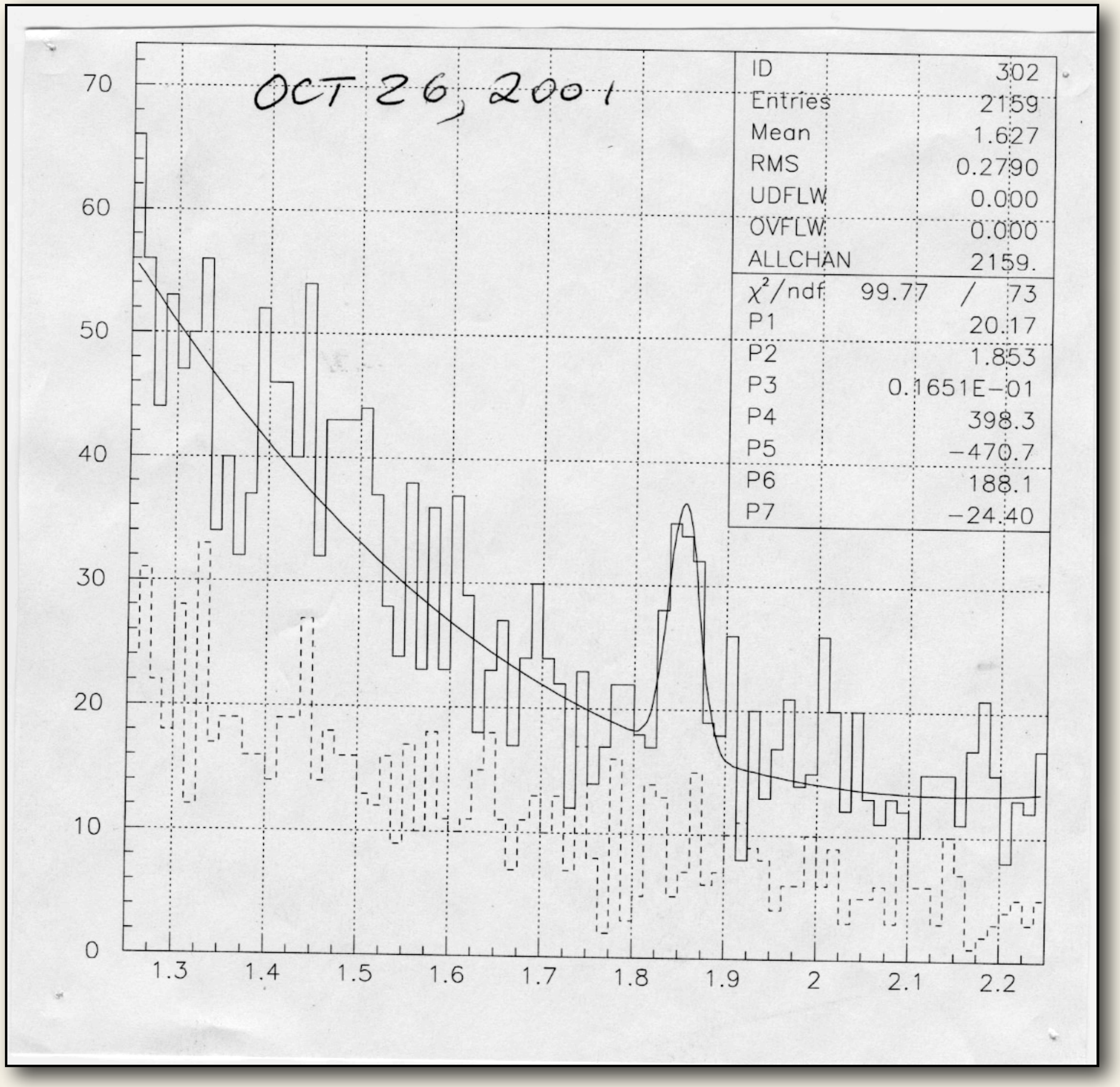
SVT



Prediction of SVT execution time from design document CDF3108 – Nov 1994

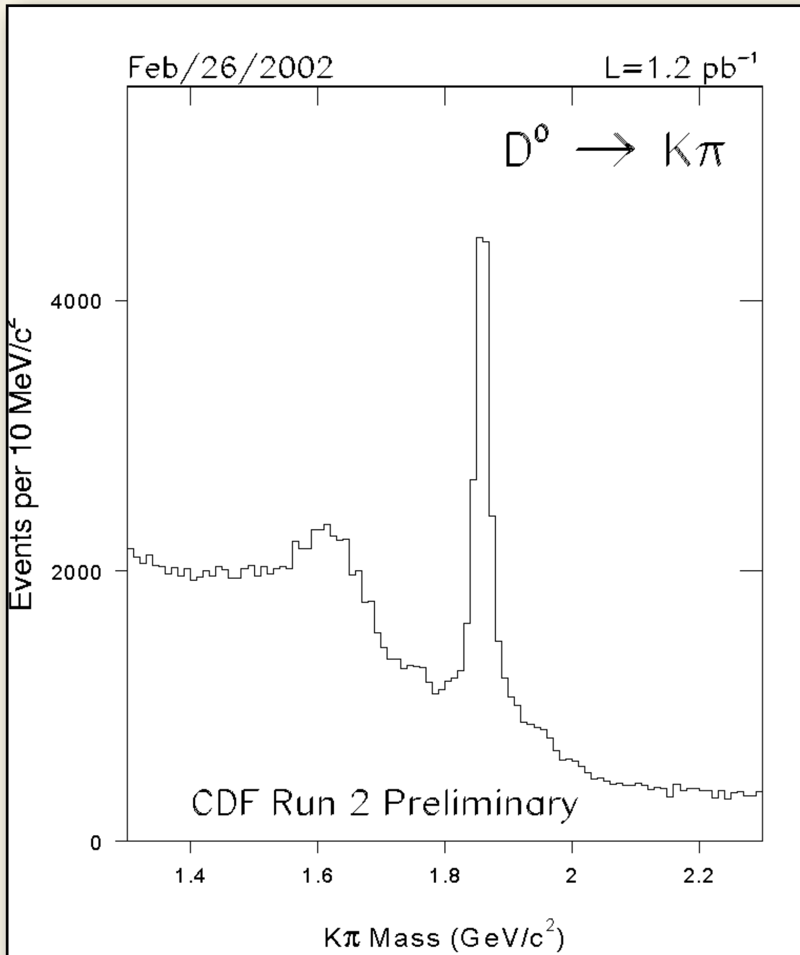
SVX readout	SVT proc.	Total (us)	
2.5	10.5	13	predicted
9	13	22	actual

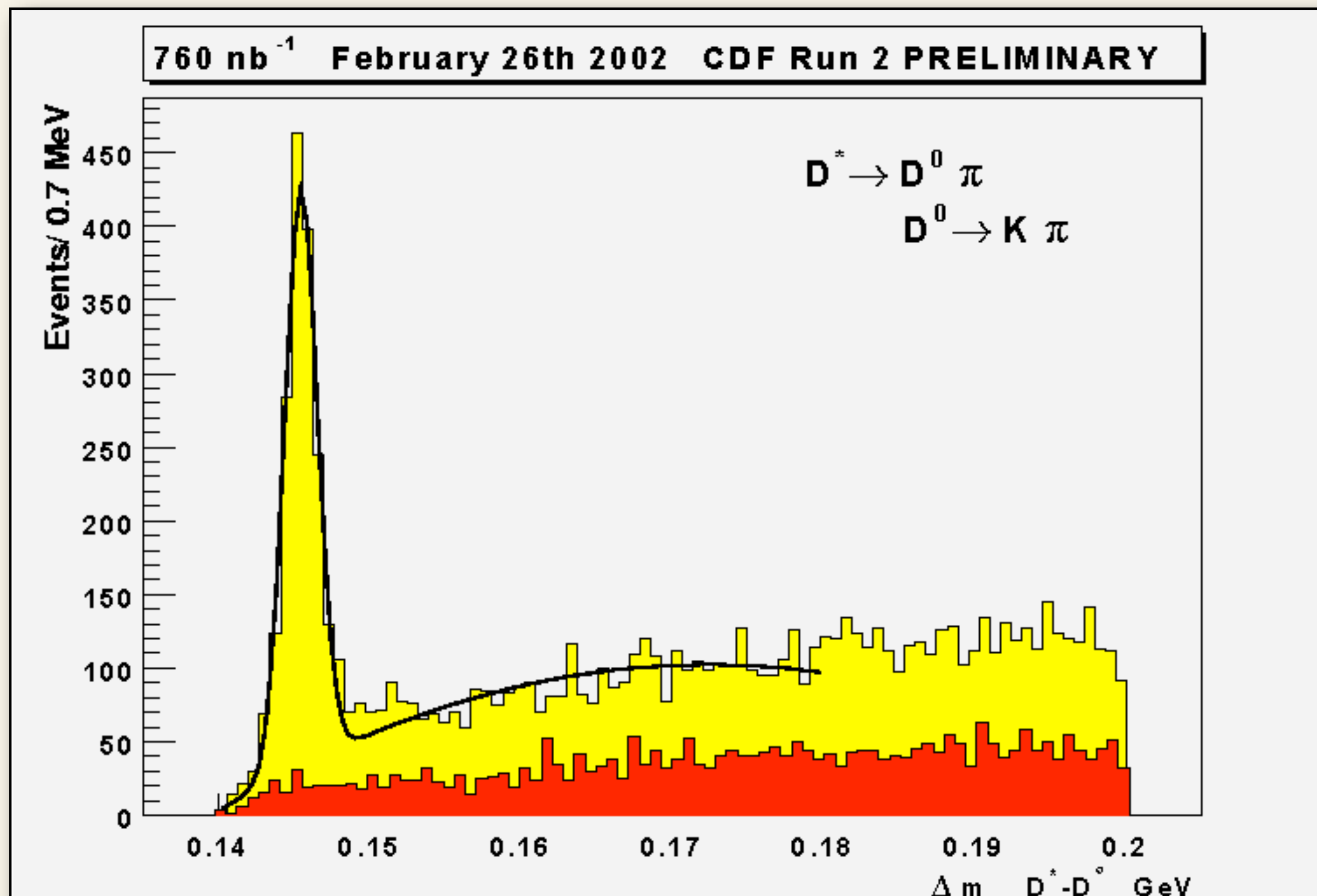
Ottobre 2001: un’altra tappa importante:



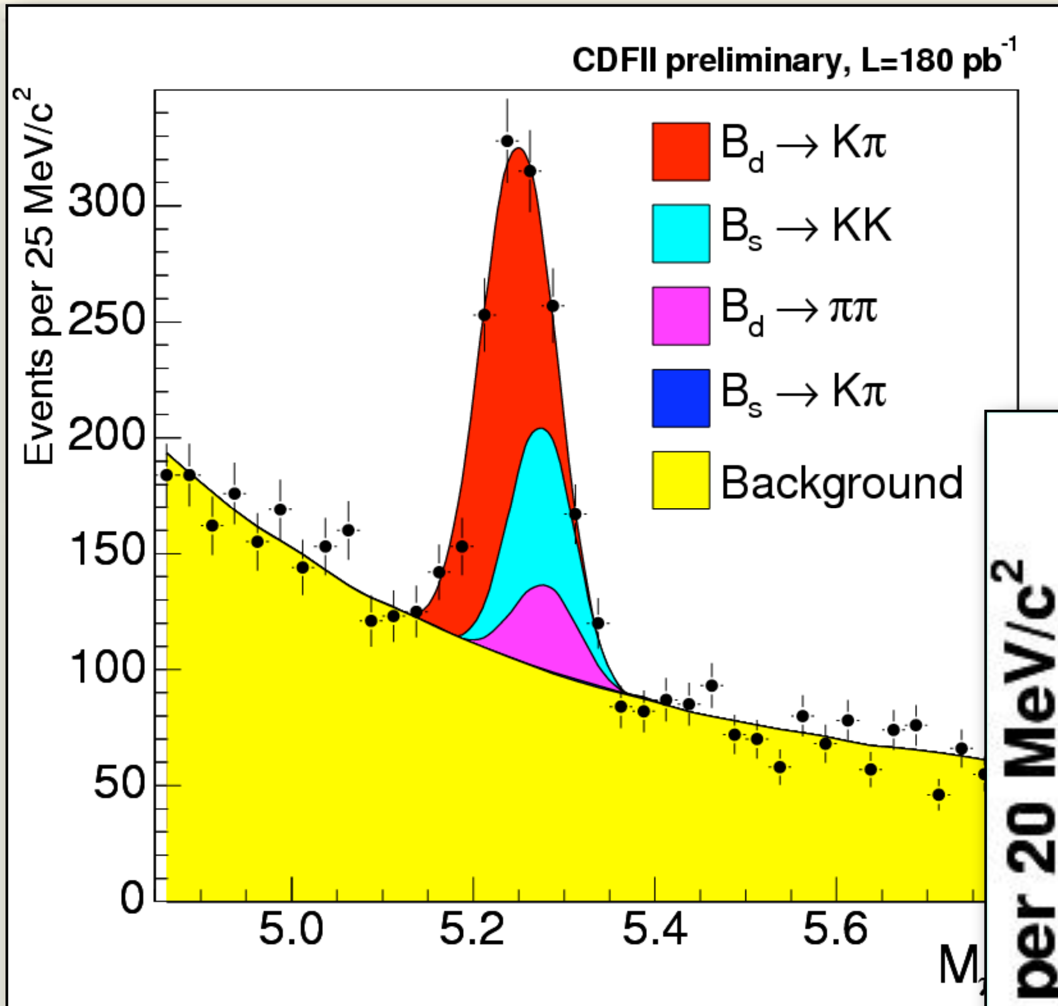
negli eventi selezionati con SVT ci sono i D^0

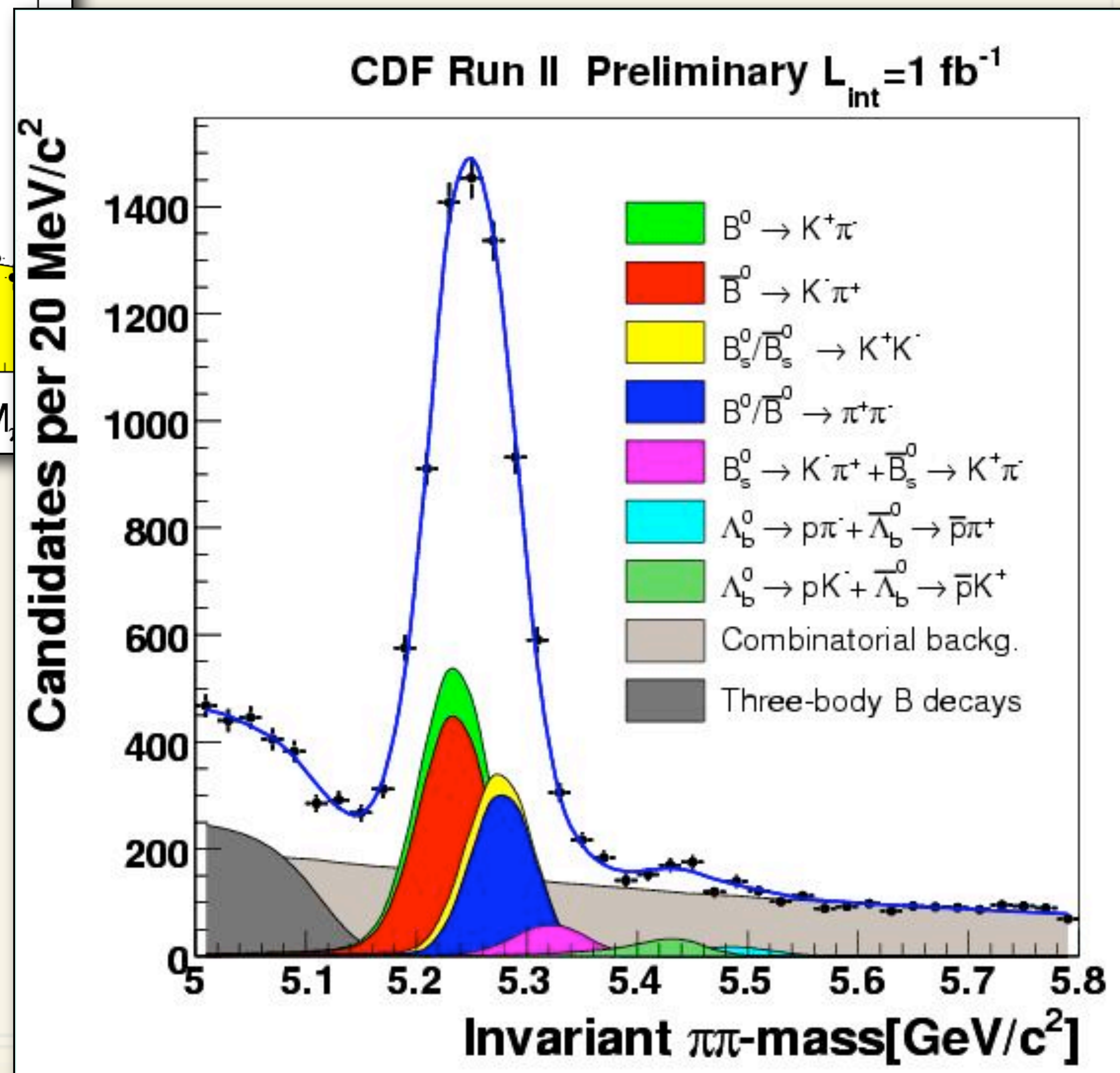
Febbraio 2002: abbiamo molti D^0 e D^*





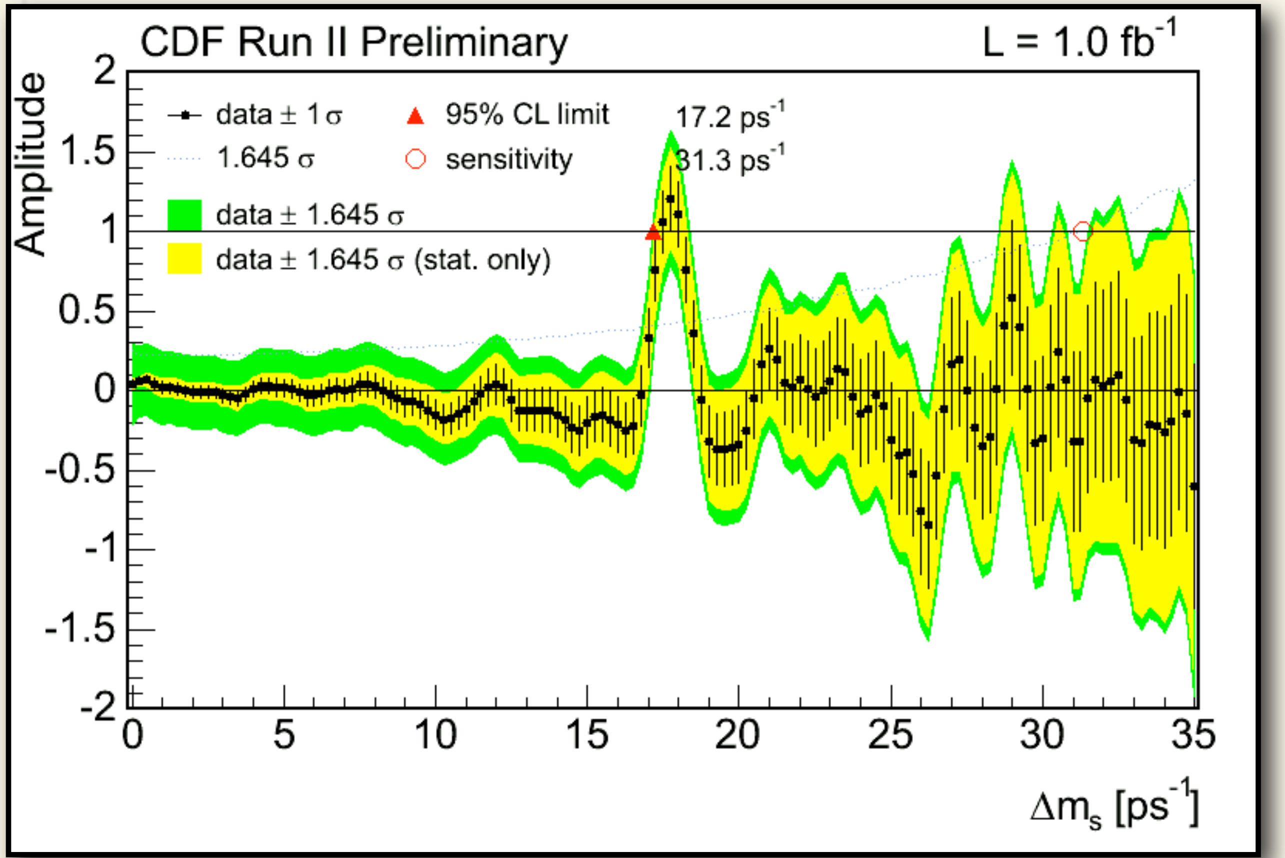
ed infine...
il picco di massa del B → h⁺h⁻



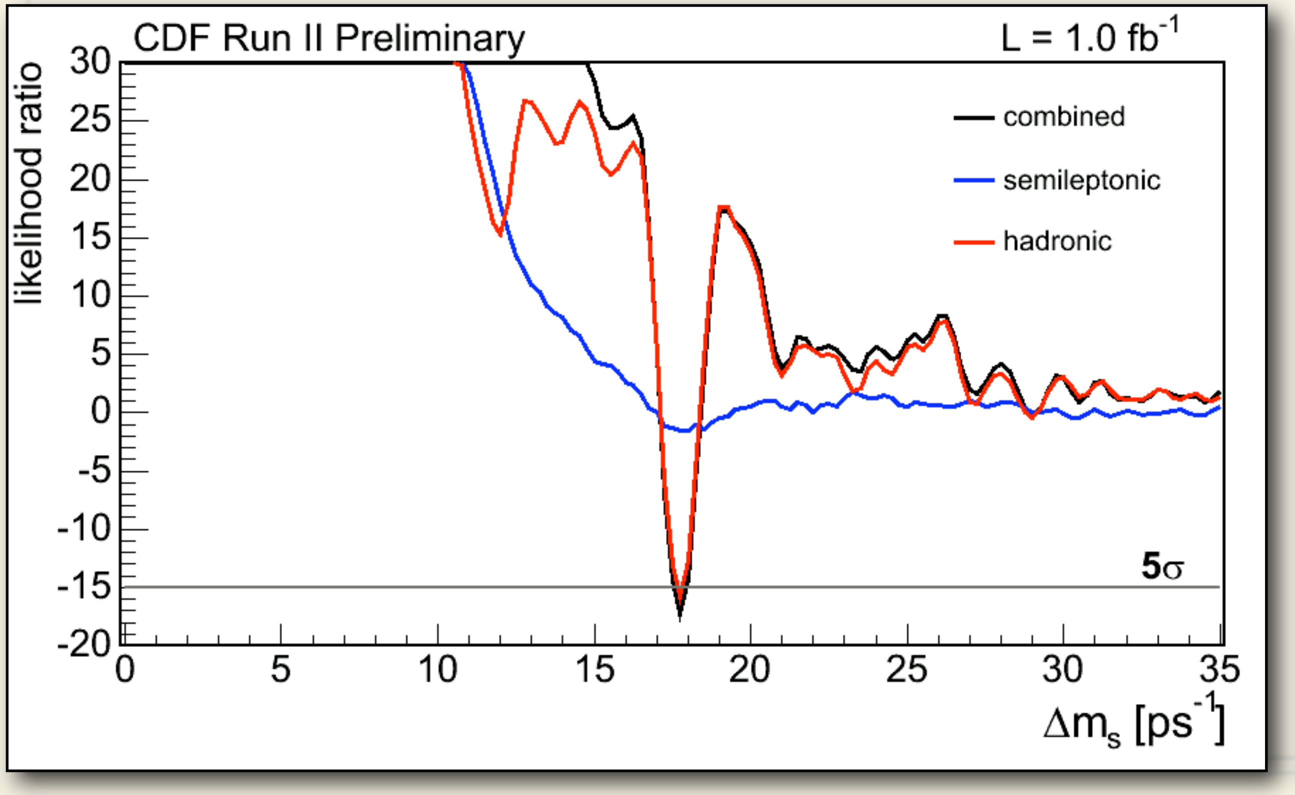


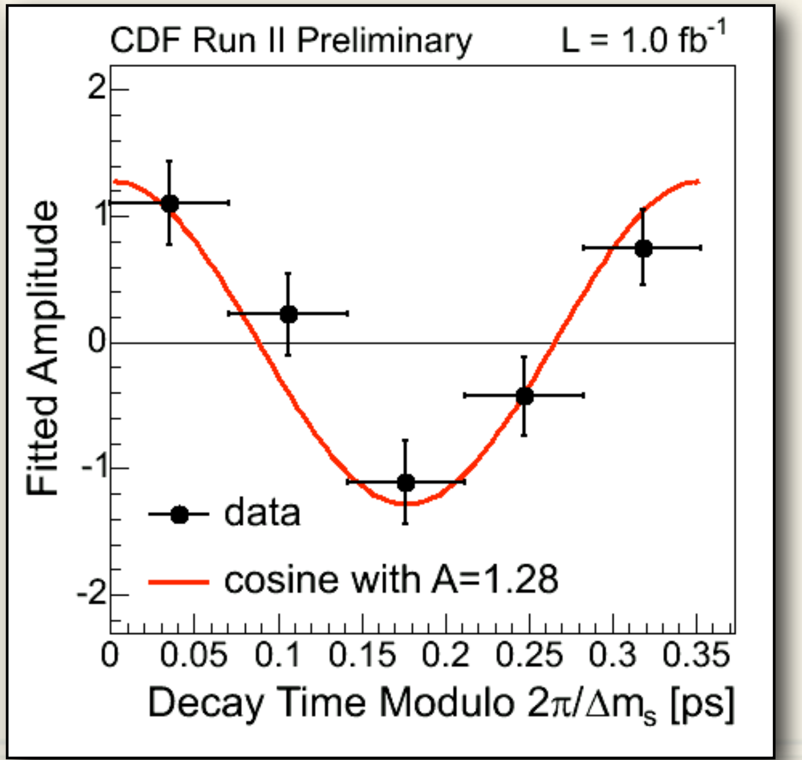
più pulito delle nostre più ottimistiche previsioni

Observation of B_s^0-$\bar{B}_s^0$ Oscillations



la qualità di questa misura dipende in modo determinante dai canali di decadimento adronici raccolti con il trigger di SVT





articoli di fisica basati su dati raccolti con il trigger di SVT

References

[1] T. Aaltonen *et al.* [CDF Collaboration], "First Measurement of the Ratio of Branching Fractions $B(\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu)/B(\Lambda_b^0 \to \Lambda^+ c \pi^-)$," arXiv:0810.3213 [hep-ex].

[2] T. Aaltonen *et al.* [CDF Collaboration], "First observation of $\bar{B}_s^0 \to D_s^\pm K^\mp$ and measurement of the ratio of branching fractions $B(\bar{B}_s^0 \to D_s^\pm K^\mp / B(\bar{B}_s^0 \to D_s^+ \pi^-)$," arXiv:0809.0080 [hep-ex].

[3] T. Aaltonen *et al.* [CDF Collaboration], "Evidence for D0-D0bar mixing using the CDF II Detector," Phys. Rev. Lett. **100** (2008) 121802 [arXiv:0712.1567 [hep-ex]].

[4] T. Aaltonen *et al.* [CDF Collaboration], "Observation of Orbitally Excited B_s Mesons," Phys. Rev. Lett. **100** (2008) 082001 [arXiv:0710.4199 [hep-ex]].

[5] T. Aaltonen *et al.* [CDF Collaboration], "First observation of the decay $B_s^0 \to D_s^- D_s^+$ and measurement of its branching ratio," Phys. Rev. Lett. **100** (2008) 021803.

[6] T. Aaltonen *et al.* [CDF Collaboration], "First observation of heavy baryons Σ_b and Σ_b^*," Phys. Rev. Lett. **99** (2007) 202001 [arXiv:0706.3868 [hep-ex]].

[7] A. Abulencia *et al.* [CDF Collaboration], "Measurement of the ratios of branching fractions B(B/s0 -¿ D/s- pi+ pi+ pi-)/B(B0 -¿ D- pi+ pi+ pi-) and B(B/s0 -¿ D/s- pi+)/B(B0 -¿ D- pi+)," Phys. Rev. Lett. **98** (2007) 061802 [arXiv:hep-ex/0610045].

[8] A. Abulencia *et al.* [CDF Collaboration], "Observation of B/s0 anti-B/s0 oscillations," Phys. Rev. Lett. **97** (2006) 242003 [arXiv:hep-ex/0609040].

[9] A. Abulencia *et al.* [CDF Collaboration], "Observation of B^0 $(s) \to K^+K^-$ and Measurements of Branching Fractions of Charmless Two-body Decays of B^0 and B_s^0 Mesons in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$-TeV," Phys. Rev. Lett. **97** (2006) 211802 [arXiv:hep-ex/0607021].

[10] A. Abulencia *et al.* [CDF - Run II Collaboration], "Measurement of the $B_s^0 - \bar{B}_s^0$ Oscillation Frequency," Phys. Rev. Lett. **97** (2006) 062003 [arXiv:hep-ex/0606027].

[11] A. Abulencia *et al.* [CDF Collaboration], "Measurement of the ratio of branching fractions B(D0 $\to K^+\pi^{-)}$ / B(D0 $\to K^-\pi^{+)}$ using the CDF II Detector," Phys. Rev. D **74** (2006) 031109 [arXiv:hep-ex/0605027].

[12] A. Abulencia *et al.* [CDF Collaboration], "Measurement of mass and width of the excited charmed meson states D10 and D2*0," Phys. Rev. D **73** (2006) 051104 [arXiv:hep-ex/0512069].

[13] A. Abulencia *et al.* [CDF Collaboration], "Measurement of the ratios of branching fractions $B(B_s^0 \to D_s^- \pi^+)/B(B^0 \to D^-\pi^+)$ and $B(B^+ \to \overline{D}^0\pi^+)/B(B^0 \to D^-\pi^+)$," Phys. Rev. Lett. **96** (2006) 191801 [arXiv:hep-ex/0508014].

[14] D. E. Acosta *et al.* [CDF Collaboration], "Search for $\Lambda_b \to p\pi$ and $\Lambda_b \to pK$ decays in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV," Phys. Rev. D **72** (2005) 051104 [arXiv:hep-ex/0507067].

[15] D. E. Acosta *et al.* [CDF Collaboration], "First evidence for $B_s^0 \to \phi\phi$ decay and measurements of branching ratio and A_{CP} for $B^+ \to \phi K^+$," Phys. Rev. Lett. **95** (2005) 031801 [arXiv:hep-ex/0502044].

[16] D. E. Acosta *et al.* [CDF Collaboration], "Measurement of partial widths and search for direct CP violation in D^0 meson decays to K^-K^+ and $\pi^-\pi^+$," Phys. Rev. Lett. **94** (2005) 122001 [arXiv:hep-ex/0504006].

[17] D. E. Acosta *et al.* [CDF II Collaboration], "Measurement of the mass difference $m(D_s^+) - m(D^+)$ at CDF II," Phys. Rev. D **68** (2003) 072004 [arXiv:hep-ex/0310043].

[18] D. E. Acosta *et al.* [CDF Collaboration], "Measurement of prompt charm meson production cross sections in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV," Phys. Rev. Lett. **91** (2003) 241804 [arXiv:hep-ex/0307080].

[19] D. E. Acosta *et al.* [CDF Collaboration], "Search for the flavor-changing neutral current decay $D^0 \to \mu^+\mu^-$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV," Phys. Rev. D **68** (2003) 091101 [arXiv:hep-ex/0308059].