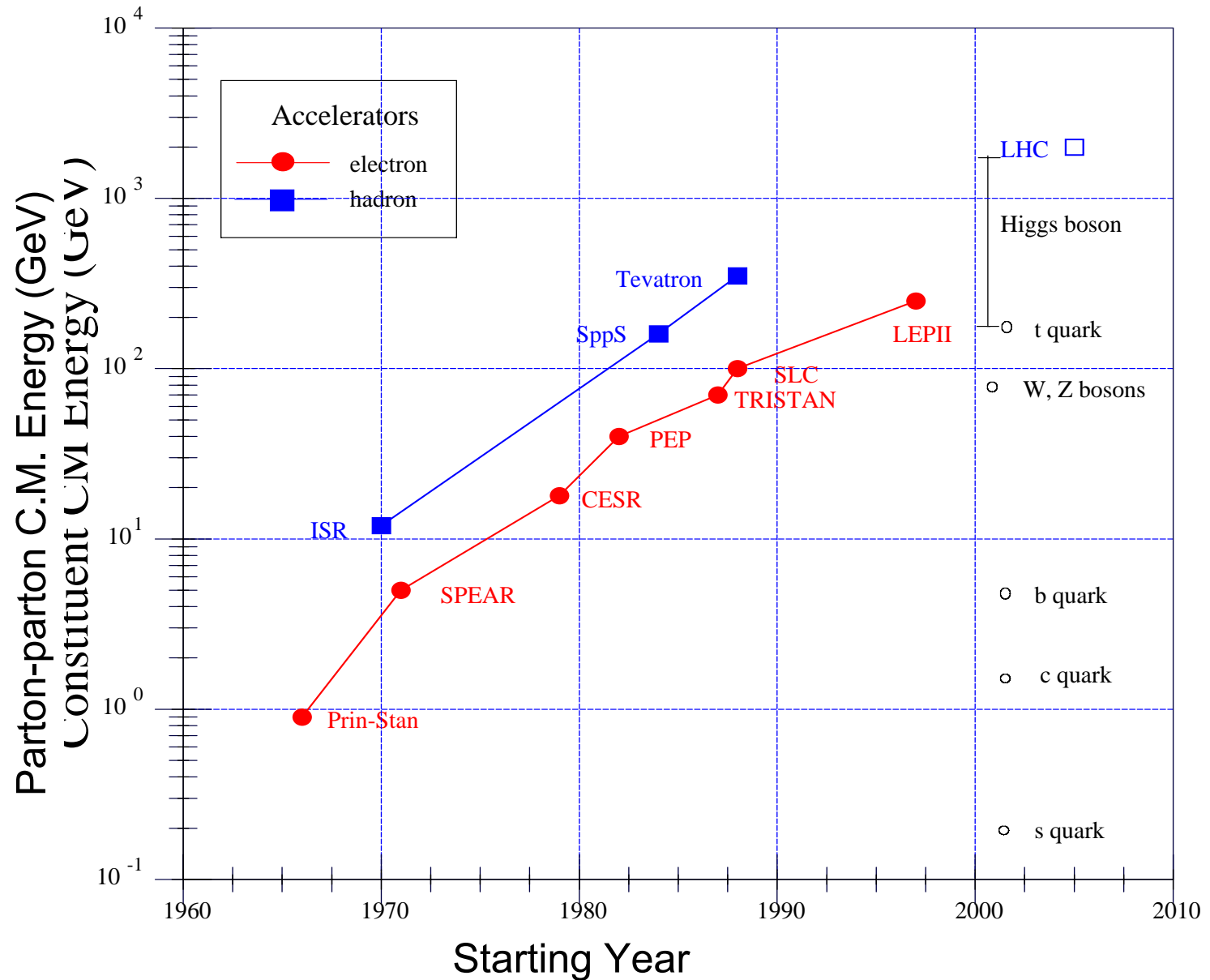


30 Years of Hadron Colliders

M. Della Negra/CERN

Islamabad, 16 December 2004

Hadron & Electron Colliders



Intersecting Storage Rings, ISR

First hadron collider (p-p)

(approved by CERN Council Dec 1965)

First collisions in Jan 1971

$$\sqrt{s} = 23, 30, 44, 53, 62 \text{ GeV}$$

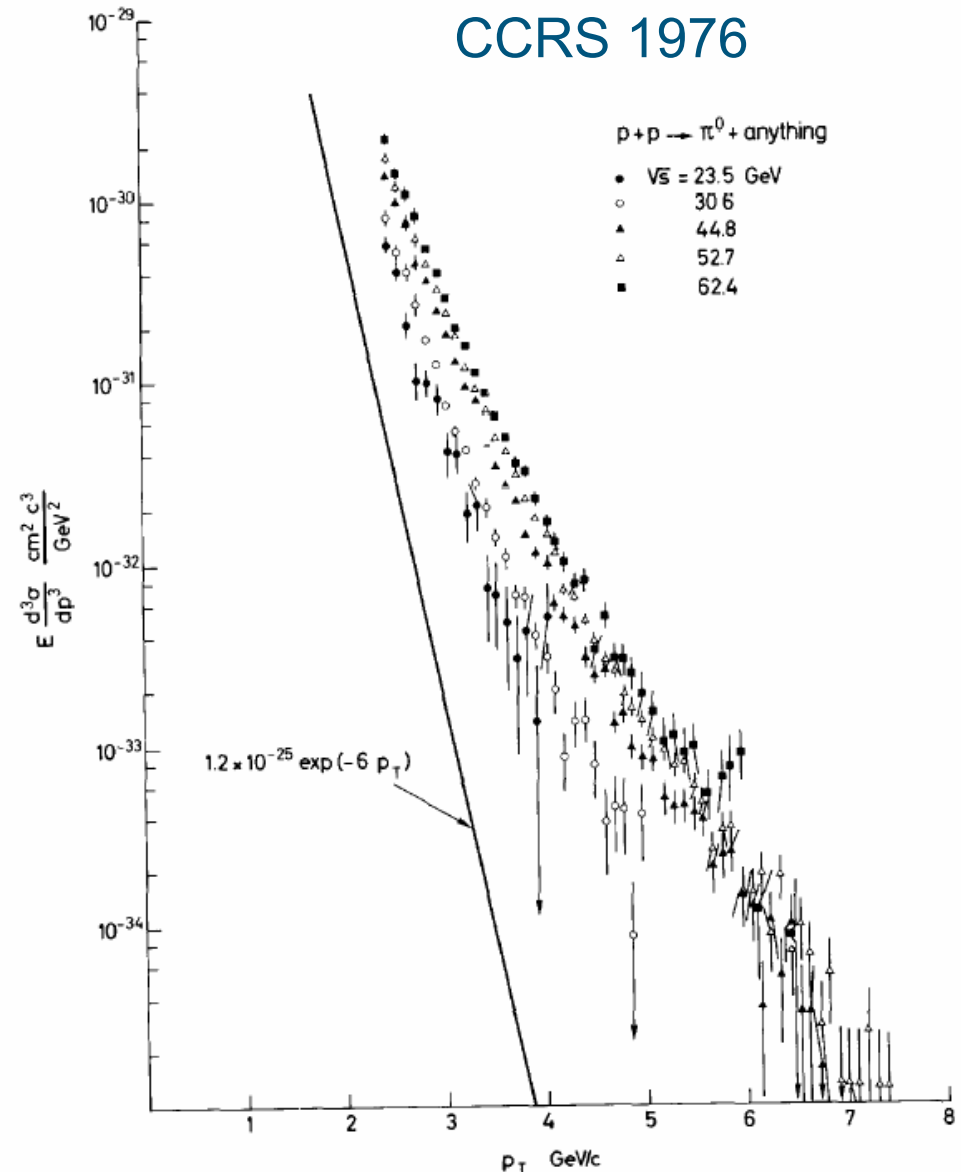
$$L \sim 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$$

Most experiments: Inclusive spectra in small solid angle spectrometers looking at forward angles. Three Collaborations looked at large angle

BS, SS, CCR (1973)

Excess at large p_T

Parton-parton collisions?



ISR: the p_T^{-8} puzzle (1)

Expectations from the parton model:

From dimension arguments the parton-parton scattering cross-section should behave as

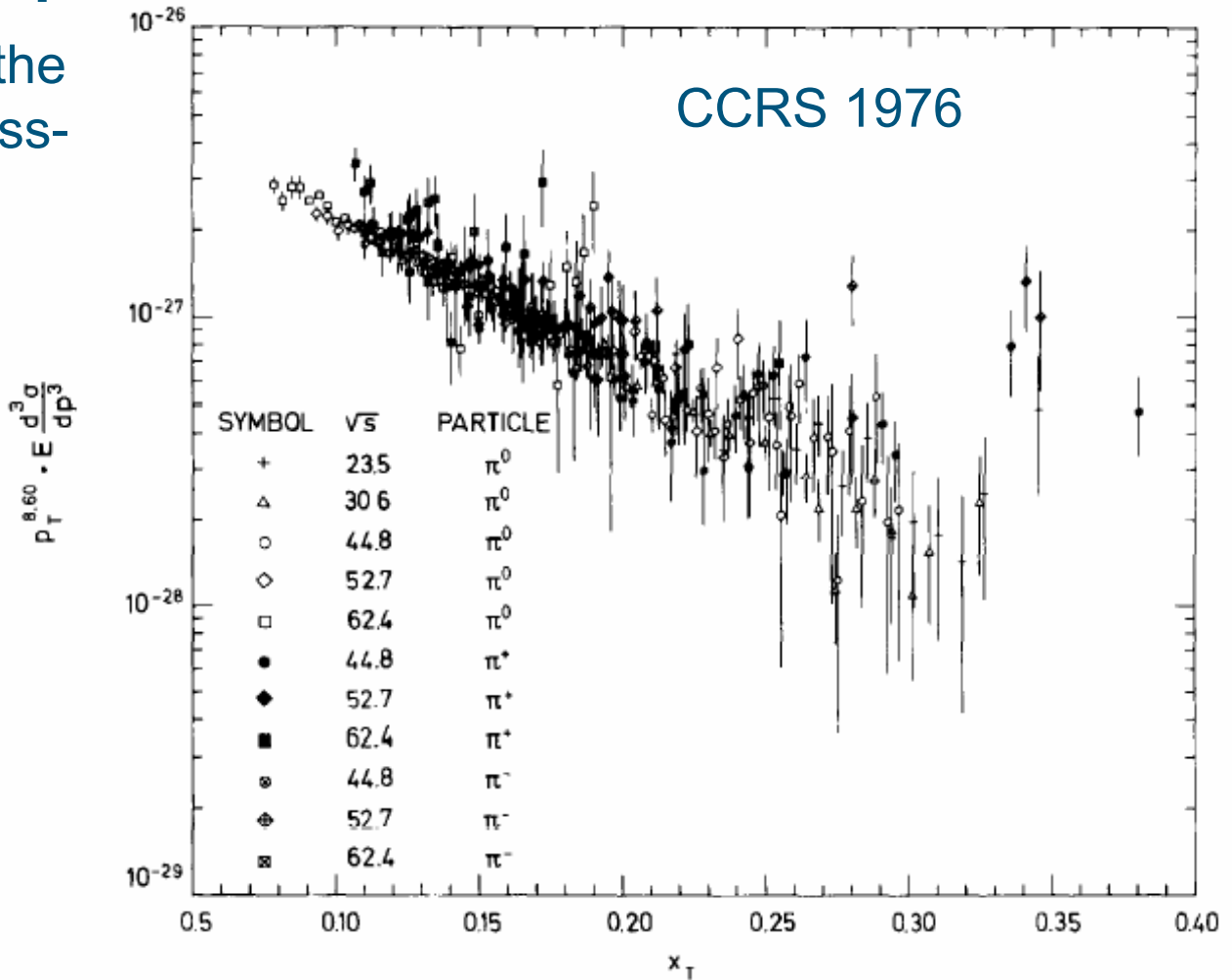
$$\frac{d\sigma}{d\hat{t}} = f(\hat{t}/\hat{s})\hat{s}^{-2}$$

Then the inclusive cross-section should behave as p_T^{-4} at fixed x_T :

$$E \frac{d^3\sigma}{dp^3} = \frac{1}{p_T^4} f(x_T, \cos\theta)$$

with
$$x_T = \frac{2p_T}{\sqrt{s}}$$

But CCRS data scale as p_T^{-8}



$$E \frac{d^3\sigma}{dp^3} \approx A \frac{1}{p_T^8} \exp(-26x_T)$$

ISR: the p_T^{-8} puzzle (2)

Force p_T^{-8} ?

meson+quark \rightarrow meson+quark (CIM)

or adhoc “black box” cross section (FF1)

$$\frac{d\sigma}{d\hat{t}} \propto \frac{1}{\hat{s}^2} \rightarrow \frac{1}{\hat{s}^4}$$

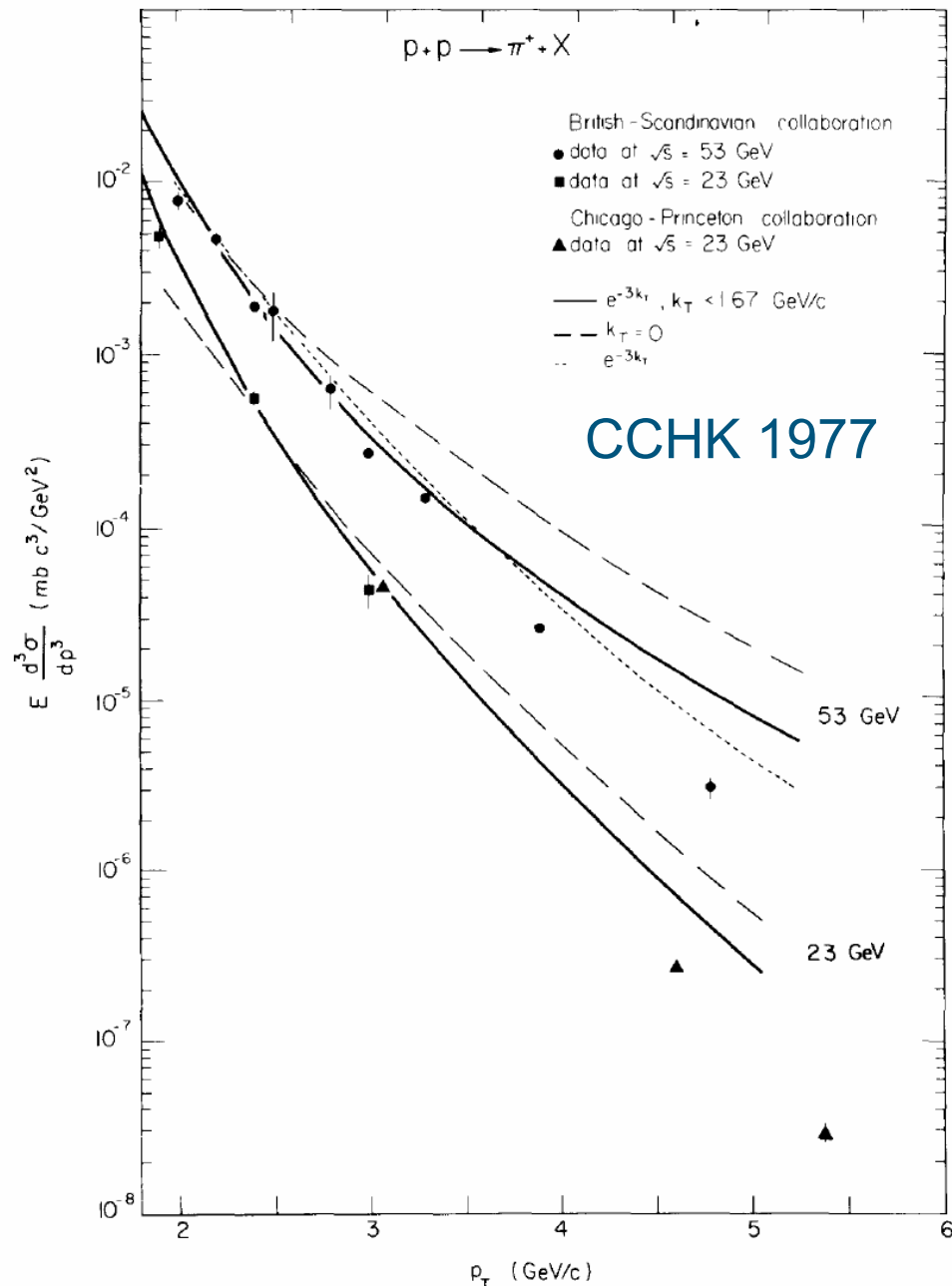
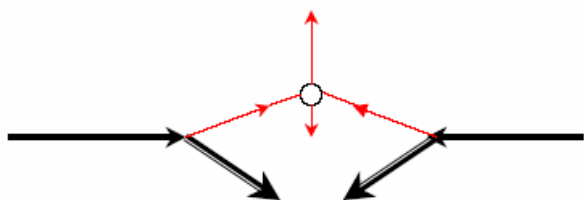
Or improve parton model :

keep natural dimensional scaling for pointlike constituents.

$$\frac{d\sigma}{d\hat{t}} \propto \frac{1}{\hat{s}^2}$$

introduce k_T smearing of partons (CCHK):

$$d\sigma(P \rightarrow q) \approx \frac{(1-x)^3}{x} e^{-Ak_T} dx dk_T^2$$

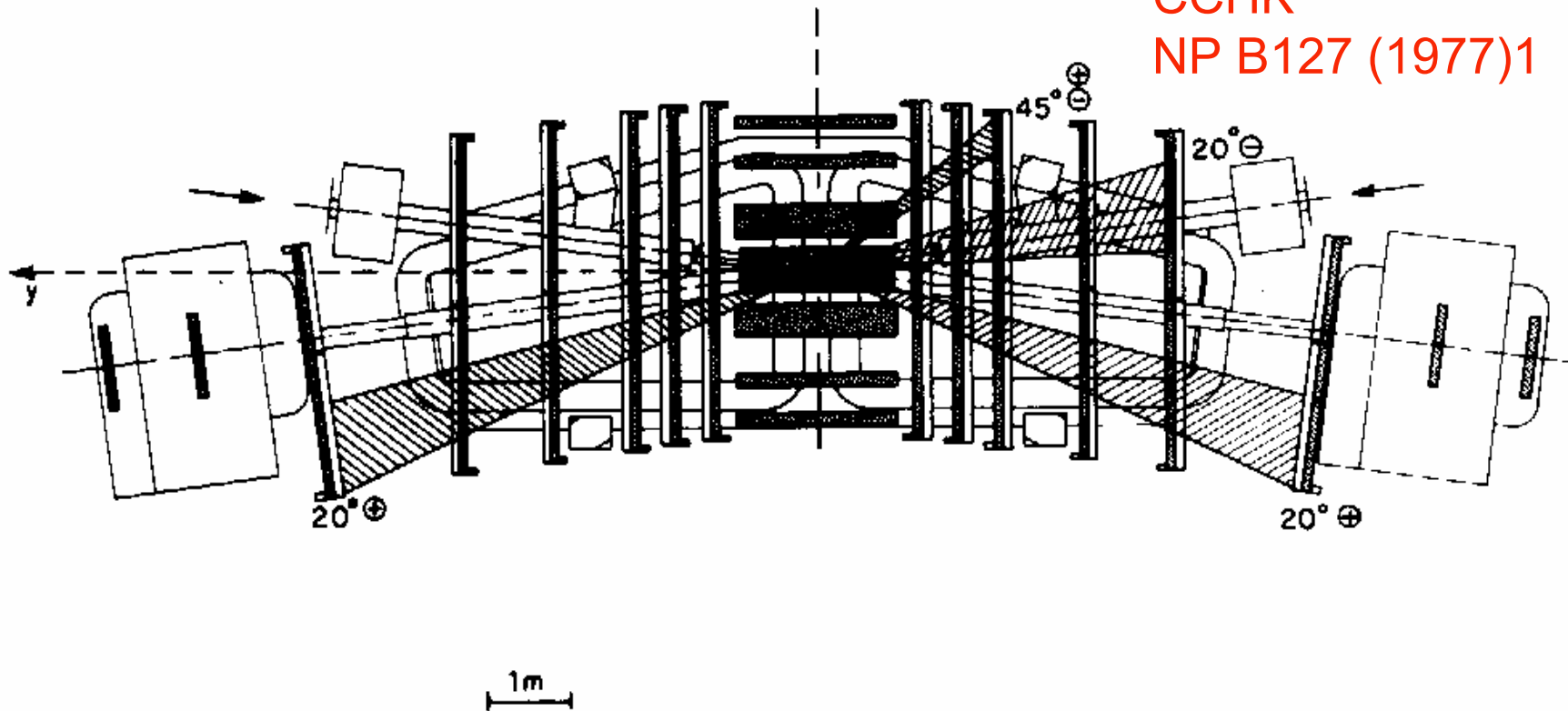


The Split Field Magnet (SFM) Detector

Can we see the parton jets?

Study full event structure: SFM the first “ 4π ” collider detector. Charged particles only! 50,000 proportional wires.

CCHK
NP B127 (1977)1



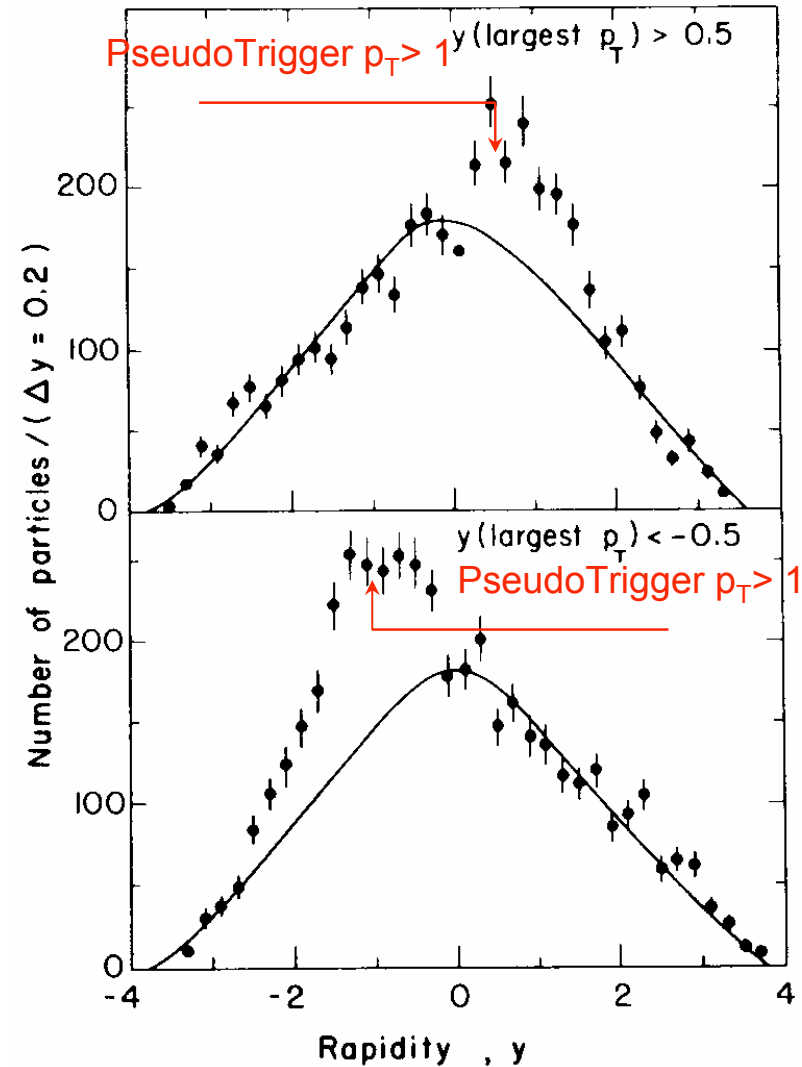
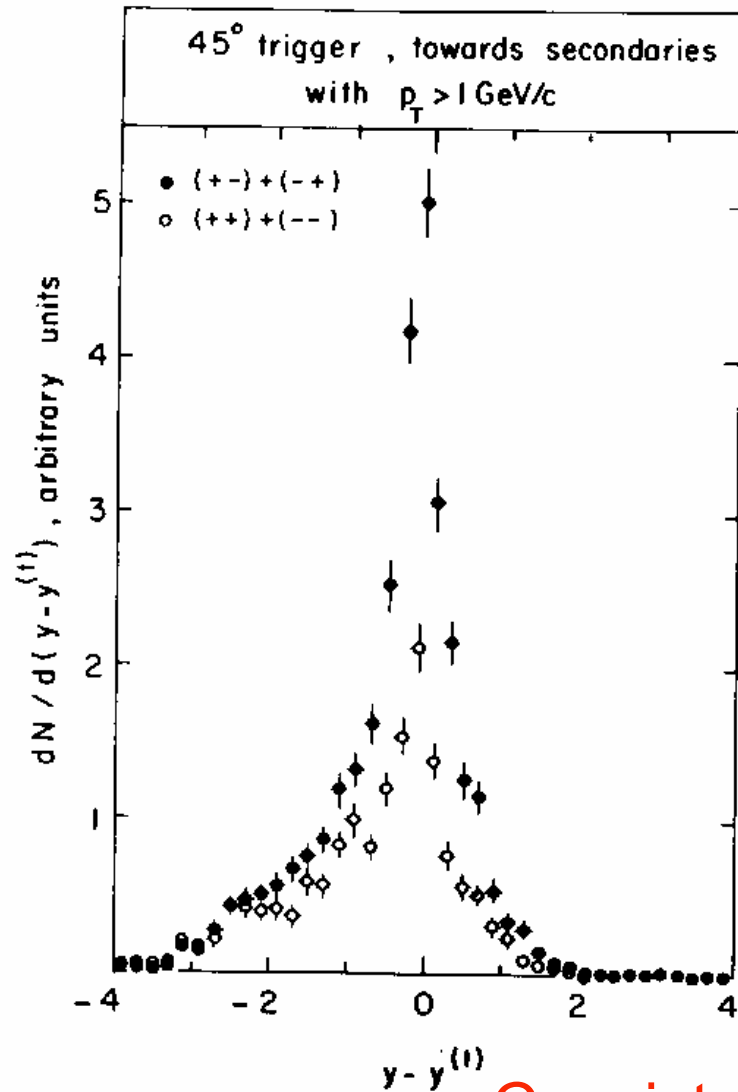
A large p_T charged particle trigger (at 20° and 45°) was implemented using the proportional chambers in self-triggering mode.

Structure of events with a large p_T trigger: $p_T > 2$ GeV

Towards

CCHK 1977

Away ($p_T > 0.8$)



Consistent with two-jet structure!

QCD and Large p_T Hadron Production

A new emerging theory giving grounds to the parton model: Quantum Chromodynamics with asymptotic freedom, **David Gross, David Politzer and Frank Wilczek (1973)**.

$$\alpha_s(Q^2) \rightarrow 0 \quad \text{as} \quad Q^2 \rightarrow \infty$$

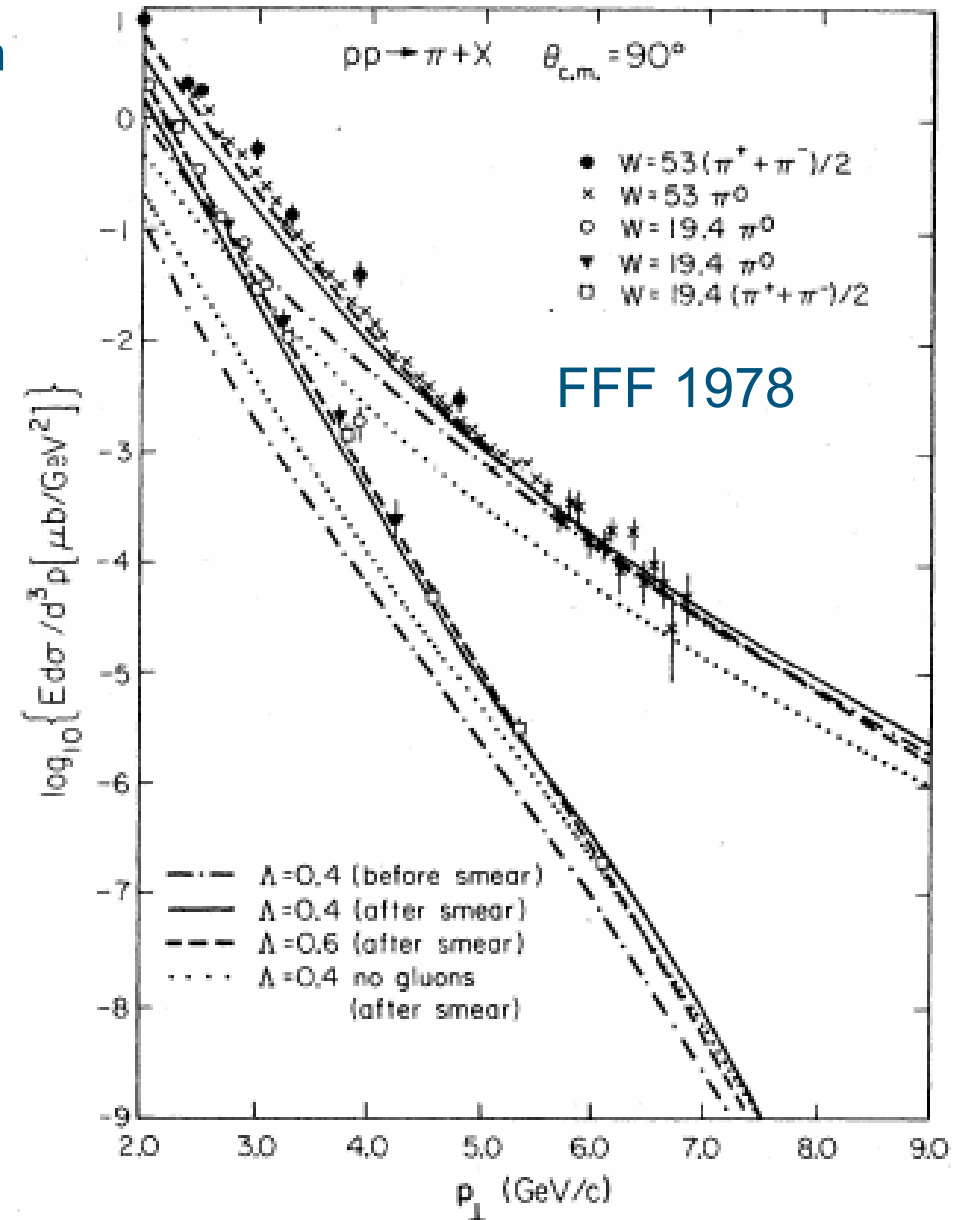
Feynman, Field and Fox (1978): QCD can fit quantitatively the ISR data!

- 1) k_T smearing a la CCHK
- 2) $2 \rightarrow 2$ process: qq, qg, gg
- 3) scaling violations

$$F(x) \rightarrow F(x, Q^2) \quad D(z) \rightarrow D(z, Q^2)$$

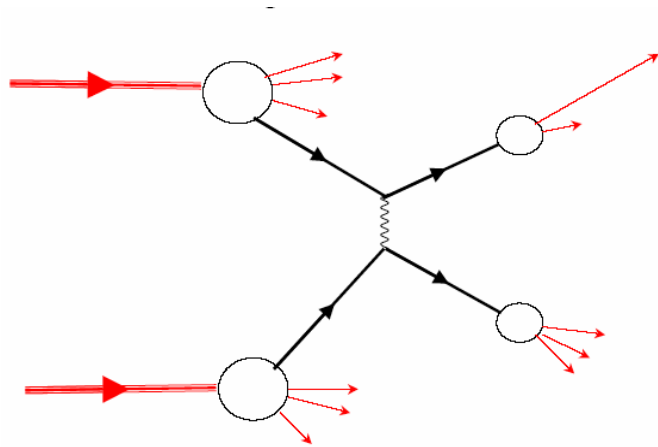
$$\alpha_s \rightarrow \alpha_s(Q^2)$$

- k_T smearing necessary to explain the data at low p_T !
- Gluon contributions are needed. ISR jets are mainly gluon jets!



Summary: Large p_T phenomena at the ISR

Large p_T phenomena observed for the first time at the ISRs are consistent with $2 \rightarrow 2$ scattering of point like constituents.



Towards jet biased by
single particle trigger

Away jet barely discernible
from the underlying event

- p_T^{-8} approximate scaling was not fundamental.
- At low p_T cannot neglect effect of k_T of partons.
- Need higher p_T s (and higher energies) to “see” jets.
- Need calorimeter trigger (unbiased jet trigger). Calo triggers also welcome higher E_T s (energy resolution). R807 with 2π calorimetry came too late (1980).

Spp̄S : a pp̄ Collider in the SPS!

In 1976 Carlo Rubbia and others pointed out that the SPS could be transformed into a proton-antiproton collider capable of reaching a centre of mass energy of 2×270 GeV and a luminosity of $\sim 10^{30} \text{cm}^{-2} \text{s}^{-1}$.

Exciting possibility: direct observation of the intermediate vector bosons: W and Z

3 working groups (1977):

1) Antiproton source

2) Initial Cooling Experiment (ICE): S. Van der Meer

3) General Purpose Detector: C. Rubbia

Sp̄pS : UA1 Proposal

The very first general purpose 4π detector (UA1) for a hadron collider was proposed in January 1978

C replacema
PROPOSAL



CM-P00043779

CERN/SPSC/78-06
SPSC/P92
30 January 1978

A 4π SOLID ANGLE DETECTOR FOR THE SPS USED AS A PROTON-ANTIPROTON
COLLIDER AT A CENTRE OF MASS ENERGY OF 540 GeV

A. Astbury⁸, B. Aubert², A. Benvenuti⁴, D. Bugg⁶, A. Bussi ere², Ph. Catz²,
S. Cittolin⁴, D. Cline^{**})⁴, M. Corden³, J. Colas², M. Della Negra²,
L. Dobrzynski⁵, J. Dowell³, K. Eggert¹, E. Eisenhandler⁶, B. Equer⁶,
H. Faissner¹, G. Fontaine⁵, S.Y. Fung⁷, J. Garvey³, C. Ghesquiere⁵,
W.R. Gibson⁶, A. Grant⁴, T. Hansl¹, H. Hoffmann⁴, R.J. Homer³, M. Jobs³,
P. Kalmus⁶, I. Kenyon³, A. Kernan⁷, F. Lacava^{**})⁴, J.Ph. Laugier⁹,
A. Leveque⁹, D. Linglin², J. Mallet⁹, T. McMahon³, F. Muller⁴, A. Norton⁴,
R.T. Poe⁷, E. Radermacher¹, H. Reithler¹, A. Robertson⁸, C. Rubbia[†])⁴,
B. Sadoulet⁴, G. Salvini^{**})⁴, T. Shah⁶, C. Sutton⁶, M. Spiro⁹,
K. Sumorok³, P. Watkins³, J. Wilson³, R. Wilson^{***})⁴

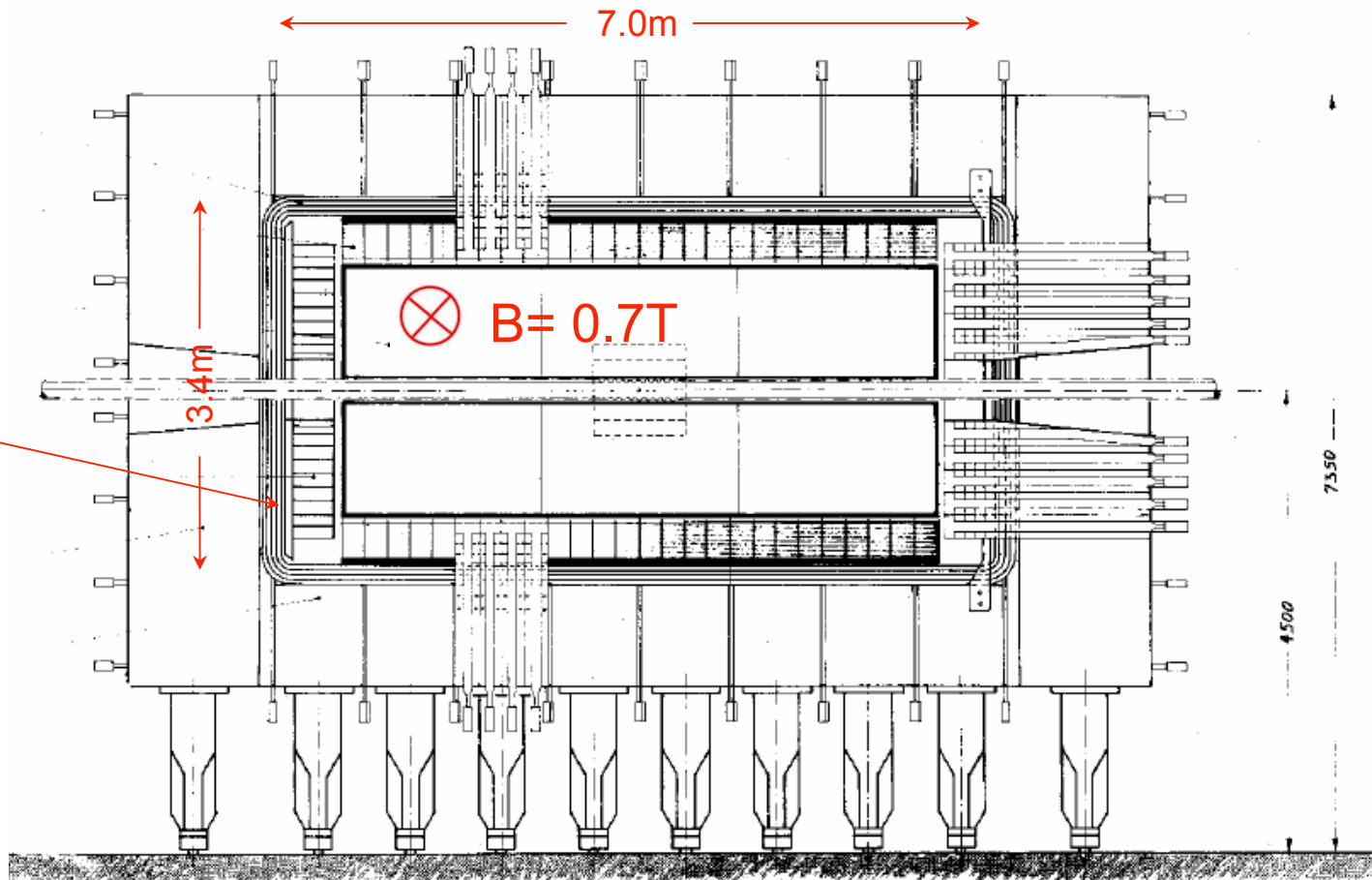
(52 authors)

UA1 Design

Magnetic Field: $B=0$ (UA2) or $B \neq 0$ (UA1) ?

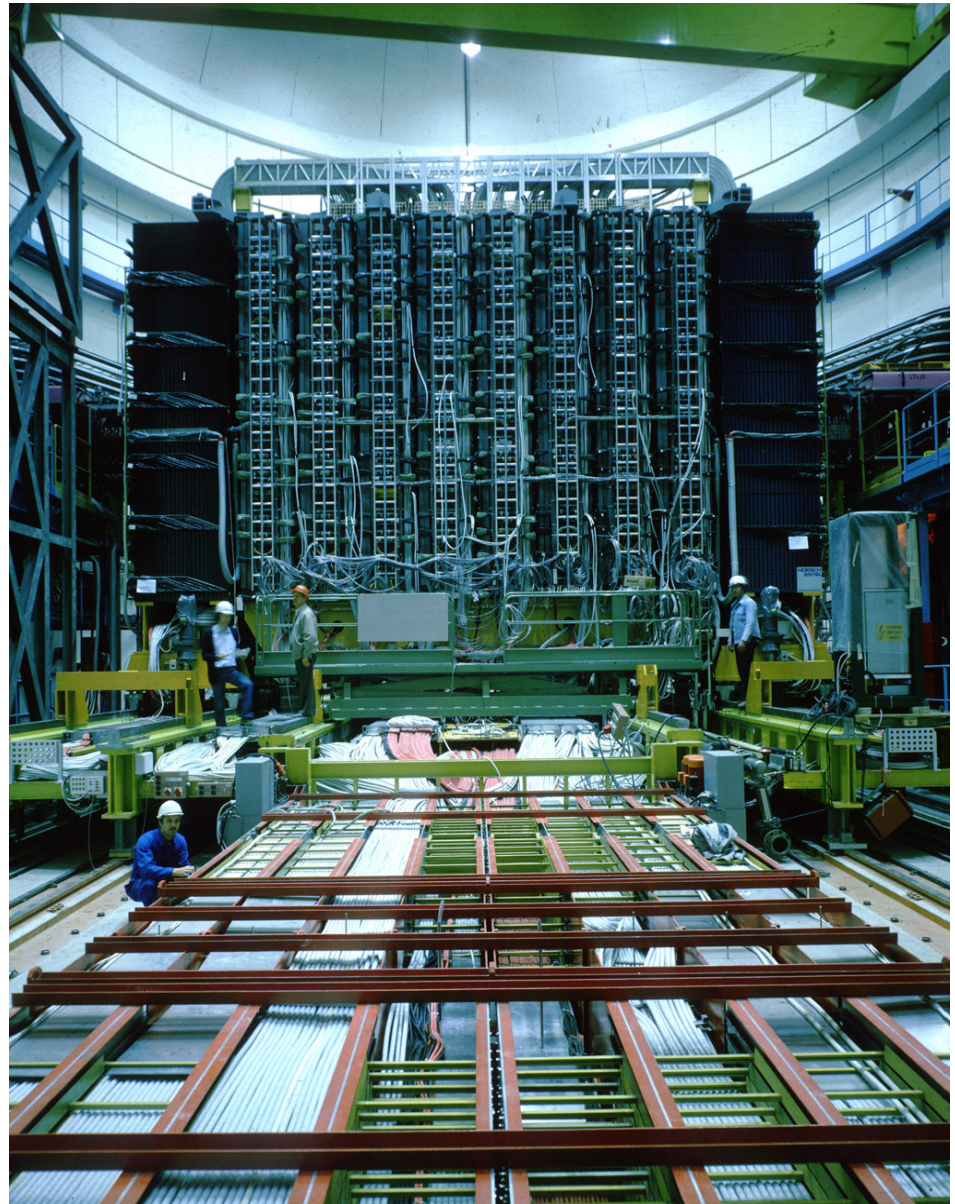
Choice of Magnet: Solenoid or Dipole? Difficult choice. Dipole selected for better forward tracking (hadron collider \neq electron collider).

(Cheap) warm magnet with Al Coil

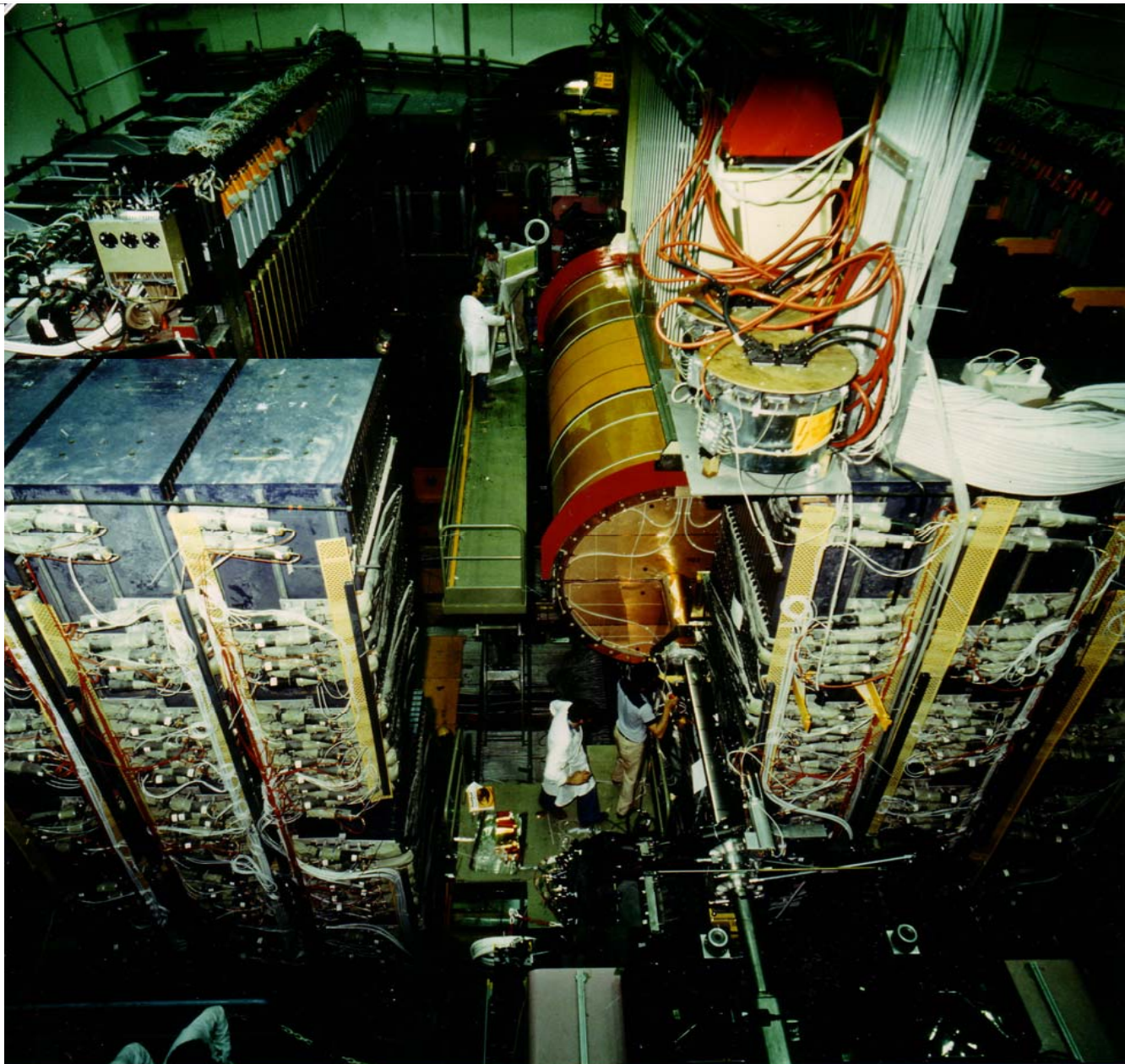


UA1 Detector

UA1 was built in less than 4 years!

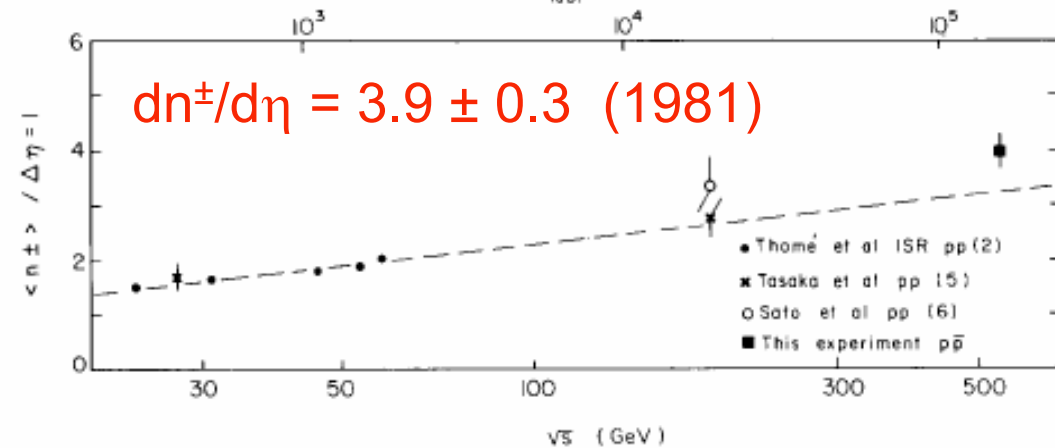
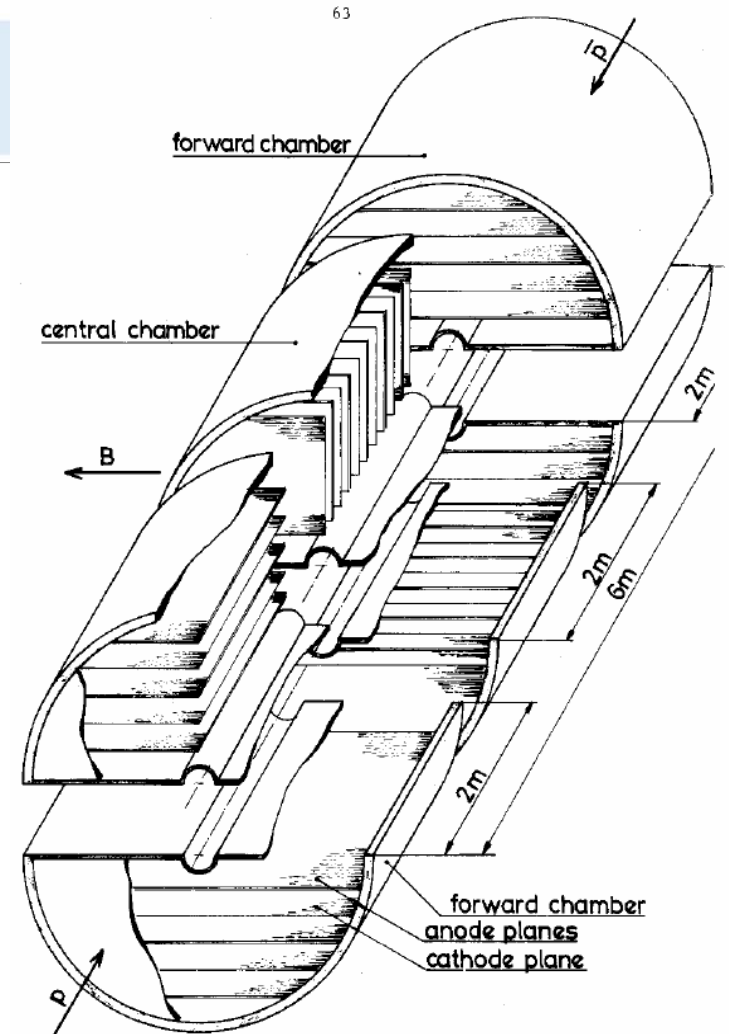
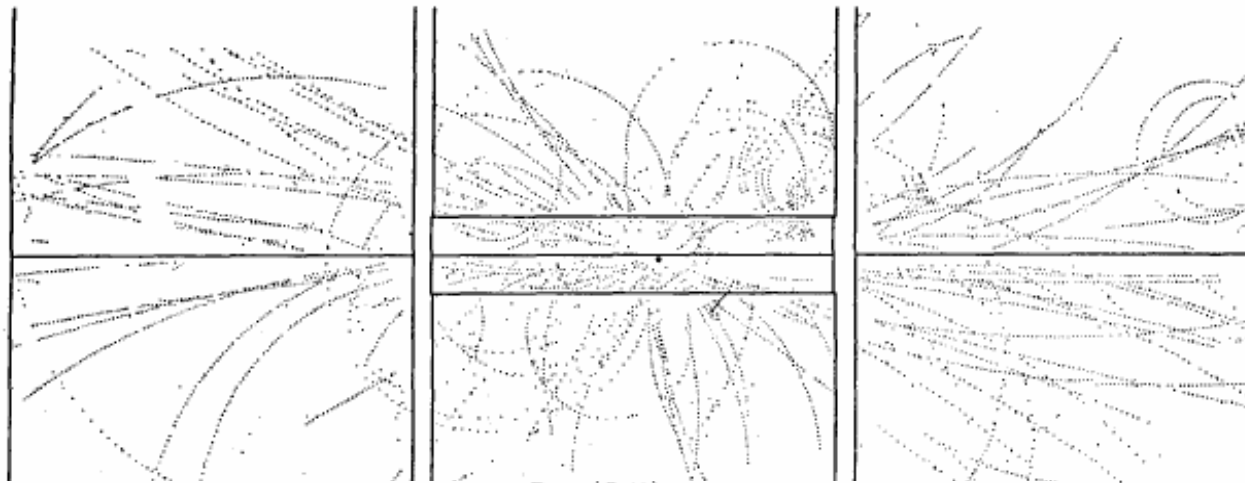


UA1 Central Tracking



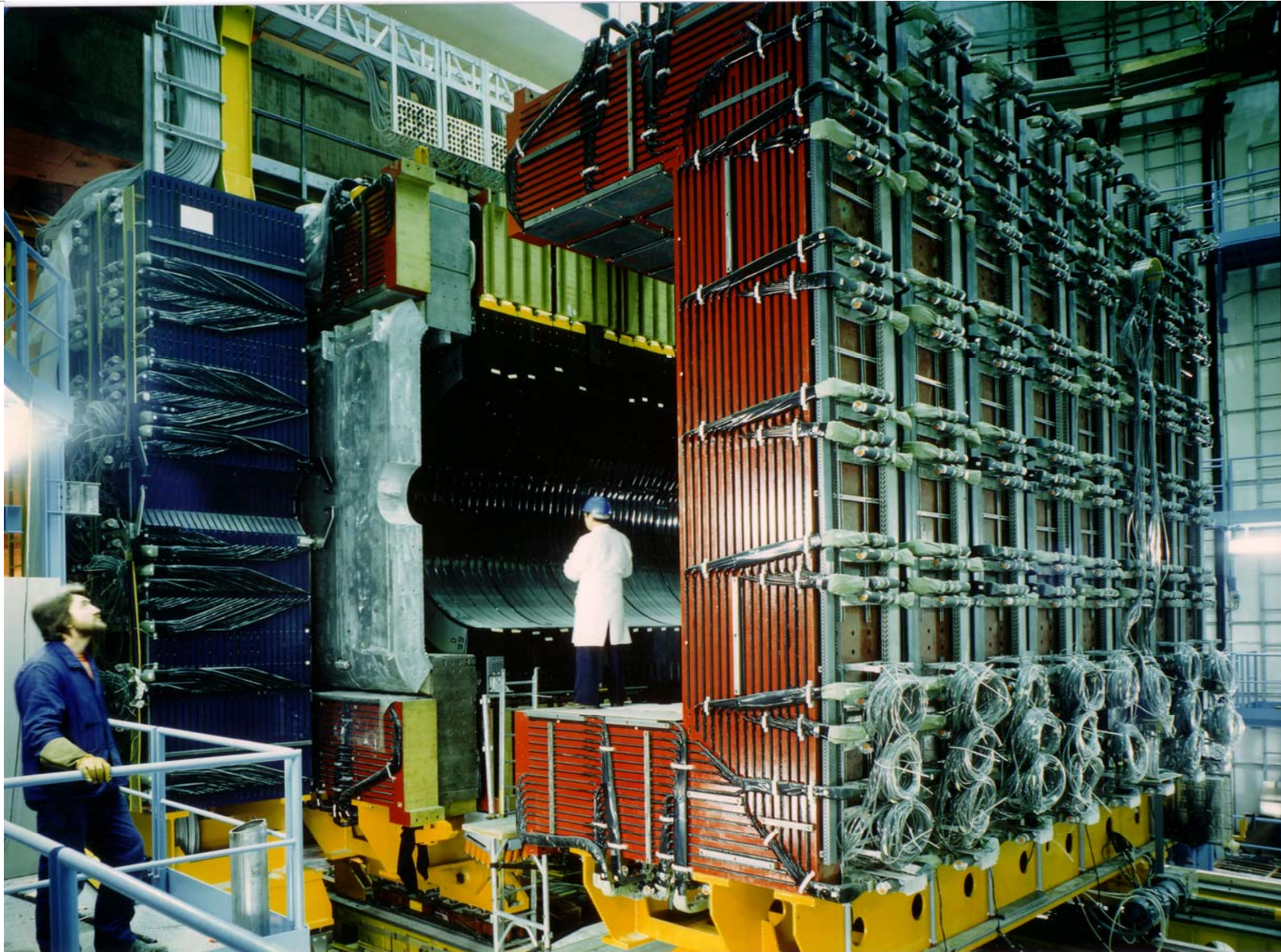
UA1 Central Tracking

Image Chamber (drift chamber): Bubble chamber picture quality! (10,700 wires, 20cm drift length, 4 μ s max drift time, ~ 300 μ m accuracy)



First collisions at $\sqrt{s} = 540$ GeV observed in a pilot run in Oct 1981!
(less than 4 years after the proposal)
at $L \sim 2 \times 10^{25} \text{ cm}^{-2}\text{s}^{-1}$

UA1 Calorimetry



UA1 Calorimetry

First Physics Run in Dec 1981 at 10^{26} Luminosity.

UA1 and UA2 started to turn on calorimeter triggers:

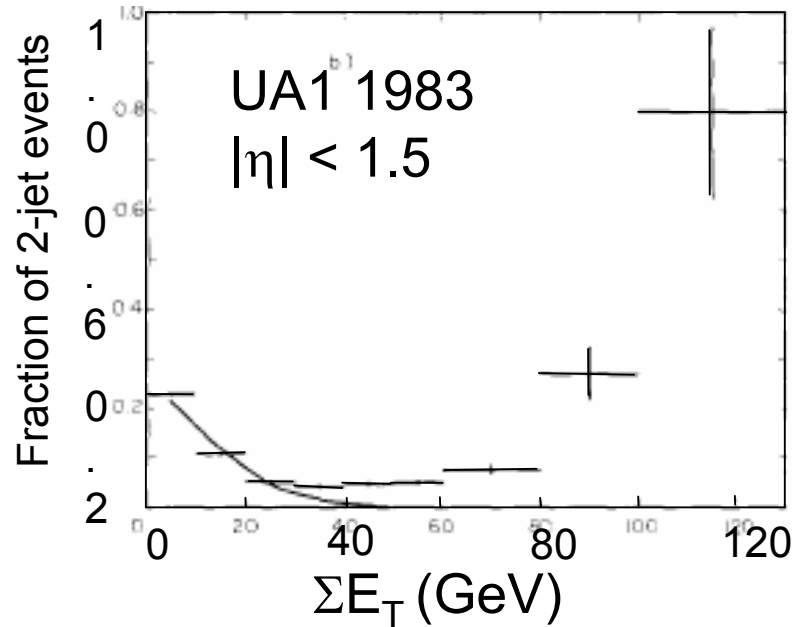
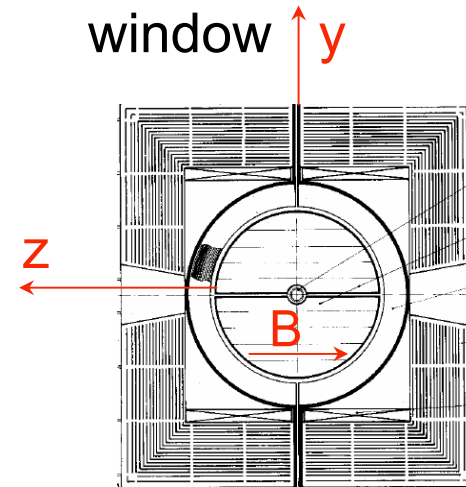
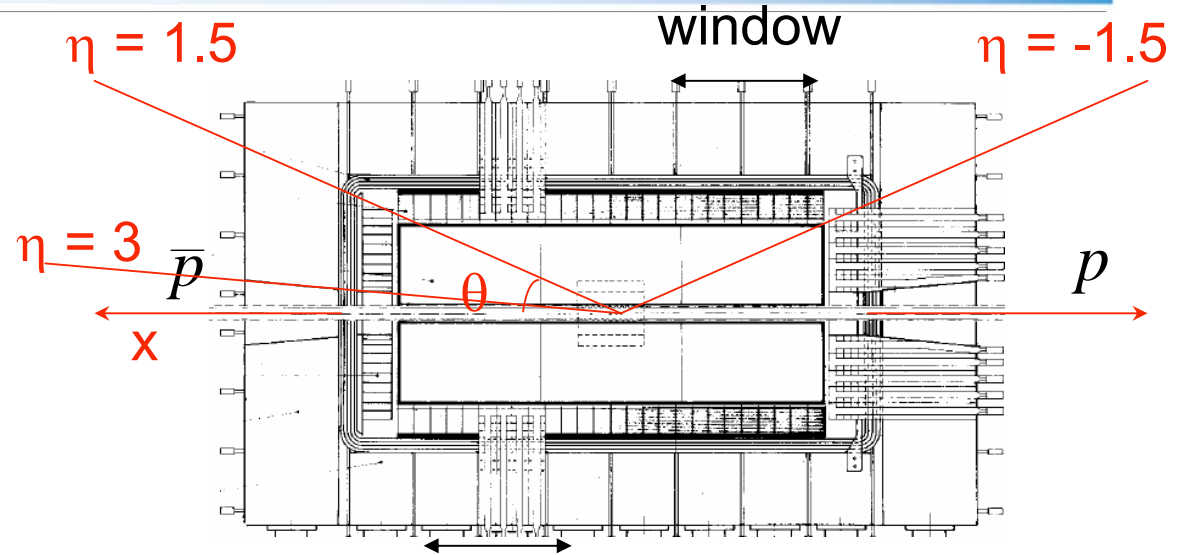
ΣE_T triggers instead of Jet trigger!

UA1: ΣE_T in $|\eta| < 3$

UA2: ΣE_T in $|\eta| < 1.5$ (no endcaps!)

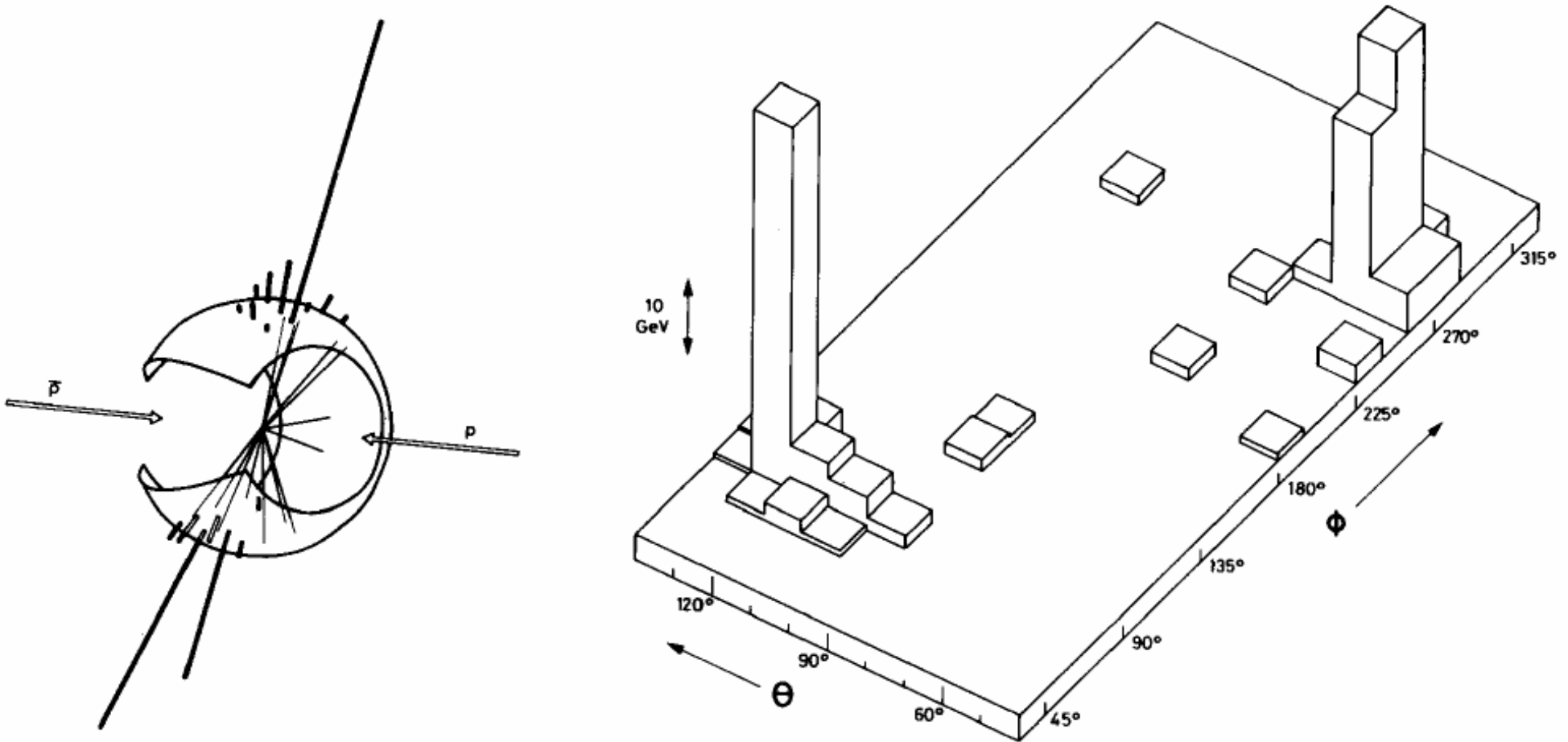
UA2 saw the jets first !

(Paris, ICHEP1982):



$|\eta| < 1.5$ versus $|\eta| < 3$, wont see jets for $|\eta| < 3$ until $\Sigma E_T > 300$ GeV

UA2 first clear evidence for jets (Paris 1982)

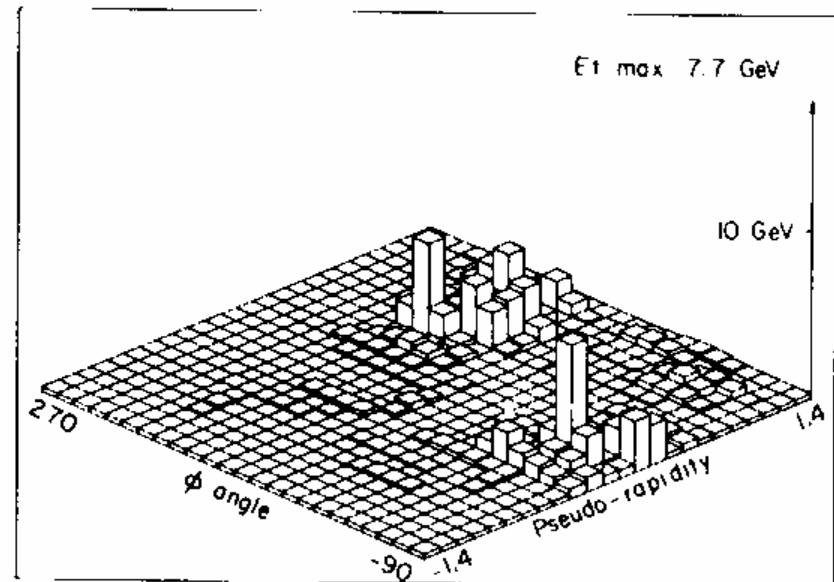
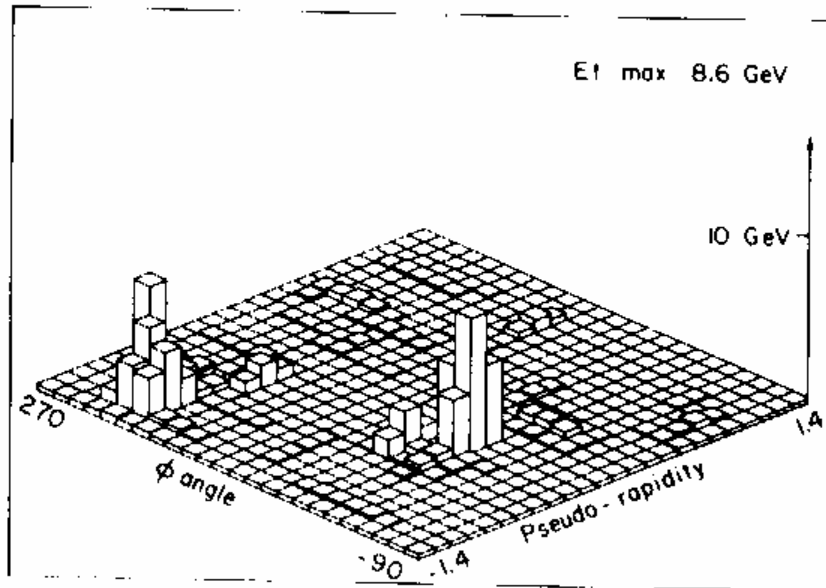
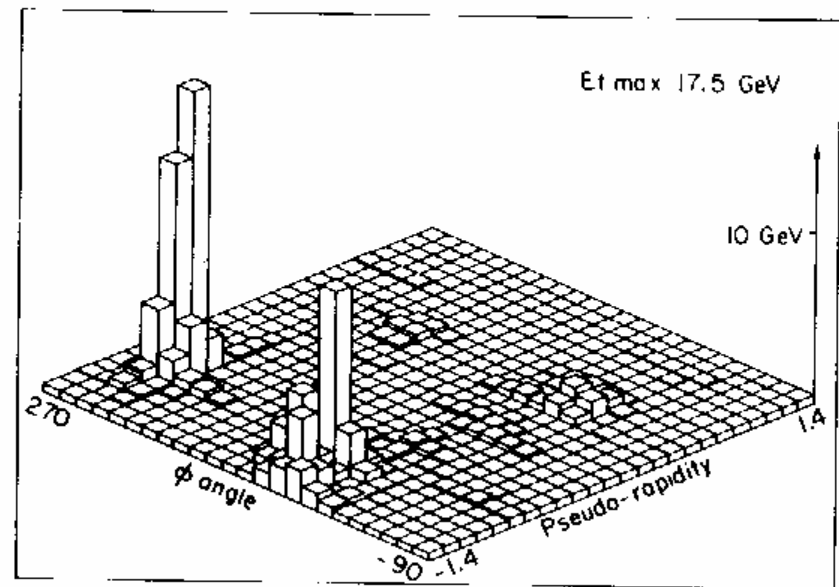
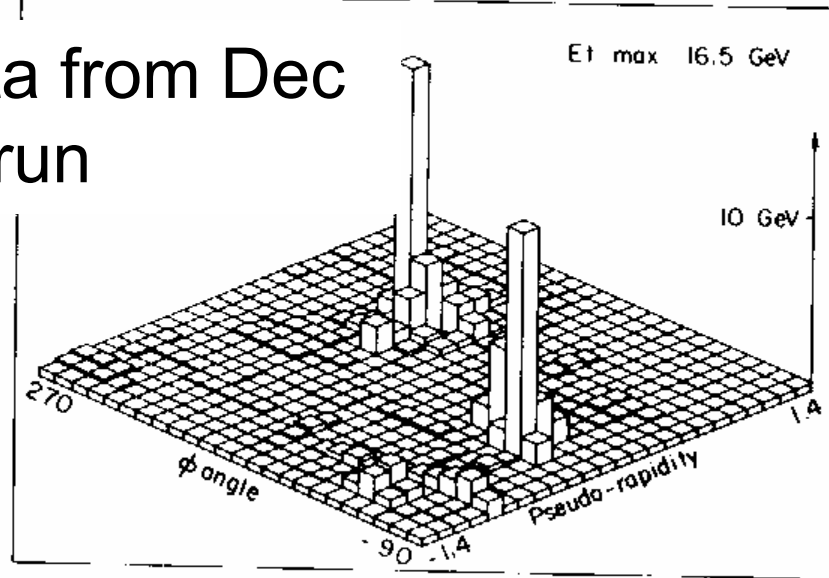


UA2 event with the largest ΣE_T ($|\eta| < 1.5$): $\Sigma E_T = 127 \text{ GeV}$

(Dec 1981 run, $79 \mu\text{b}^{-1}$)

UA1: All Events are jet-like for $\Sigma E_T > 100$ GeV in $|\eta| < 1.5$

Data from Dec 81 run



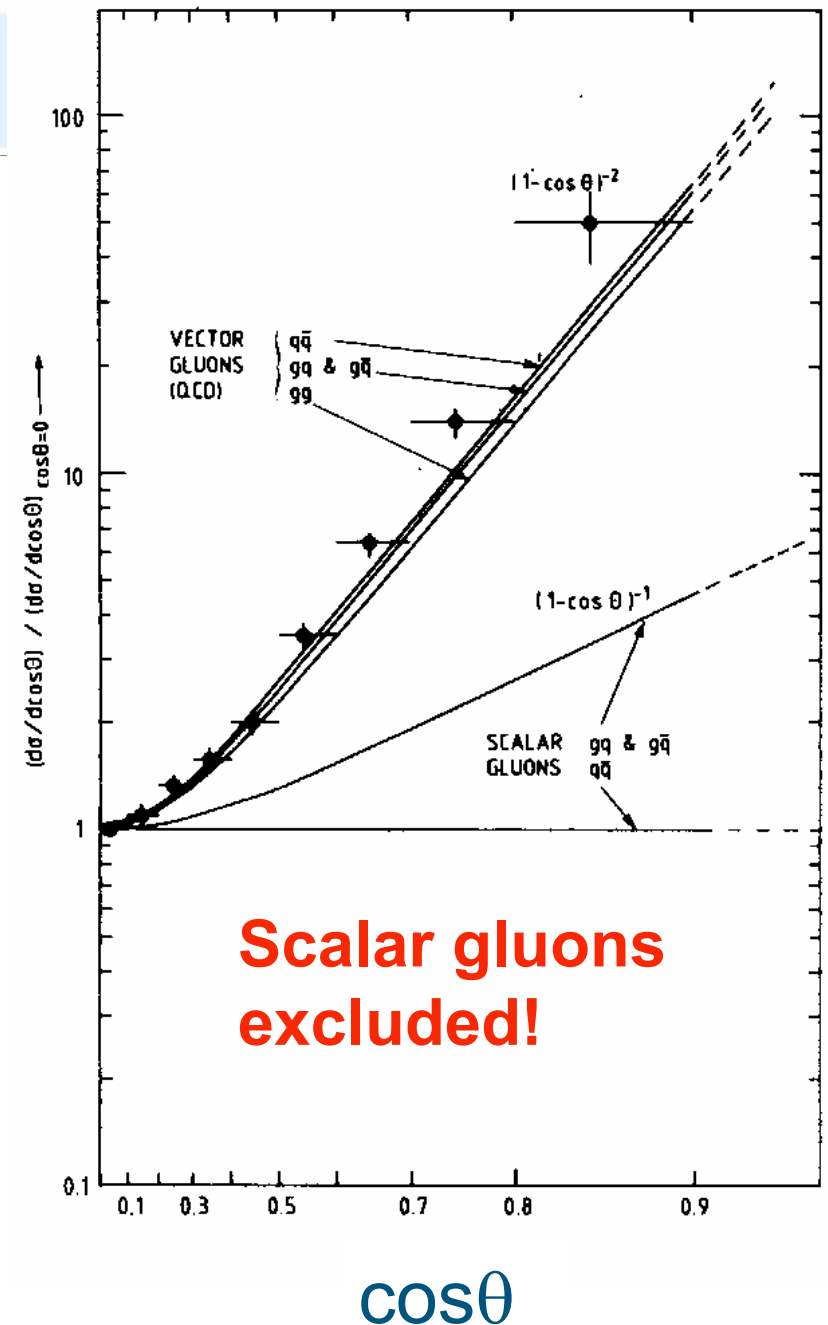
dN/dcosθ for 2-jet events

For the 1982 runs (Oct-Dec, 14 nb^{-1} at $L = 5 \times 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$) localised energy jet triggers were used instead of ΣE_T triggers.

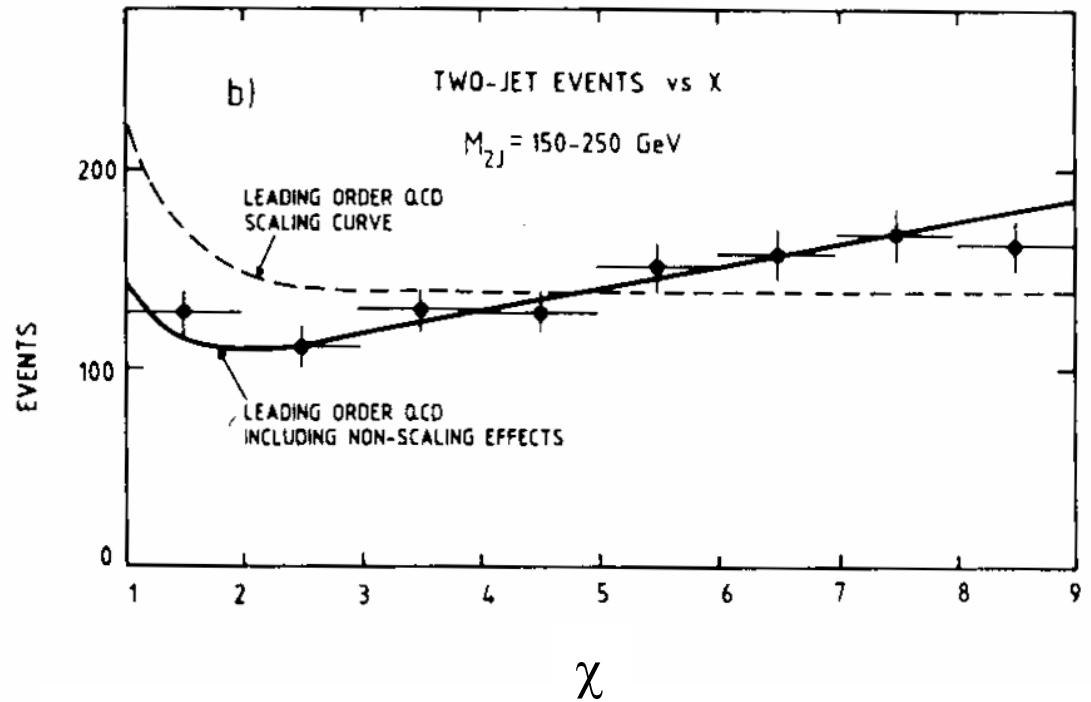
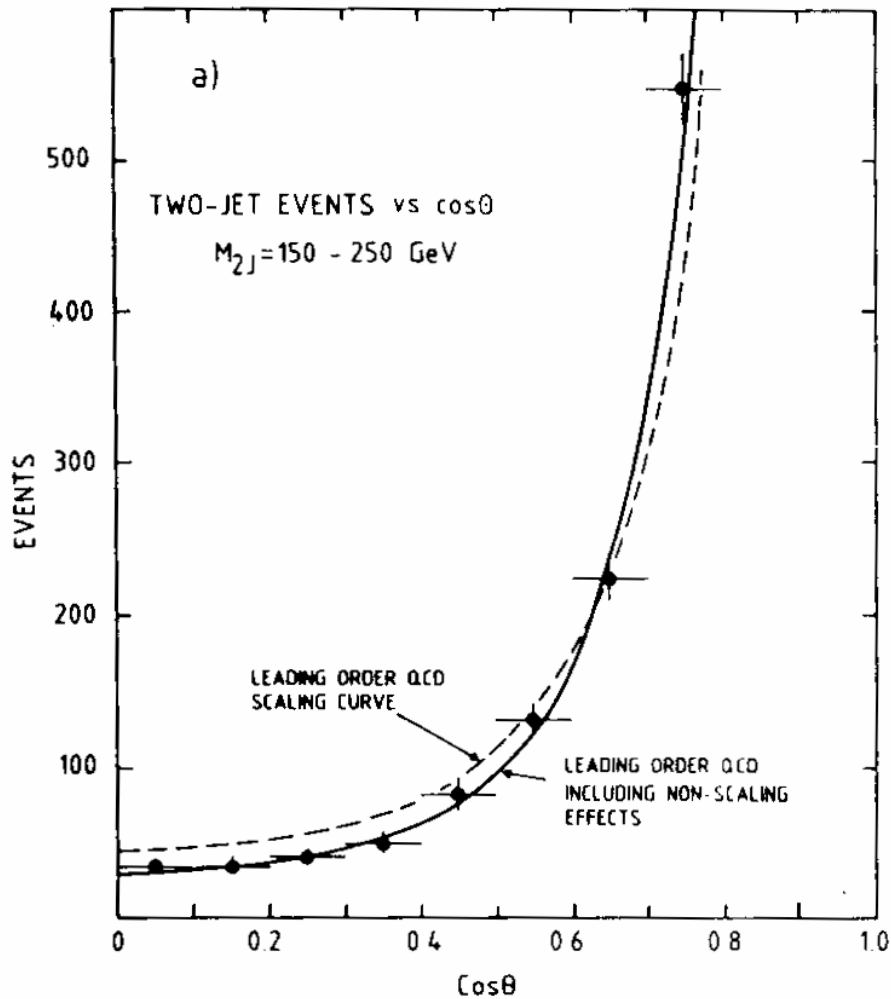
A large collection of 2-jet events with $E_T > 25 \text{ GeV}$ (both jets) in $|\eta| < 3$ was collected.

From the jet observables one can reconstruct the kinematics of the parton-parton scattering and extract x_1 , x_2 and $\cos\theta$

Partons inside protons do scatter a la Rutherford (vector gluon exchange): $1/(1 - \cos\theta)^2$



Angular distribution for 2-jet events



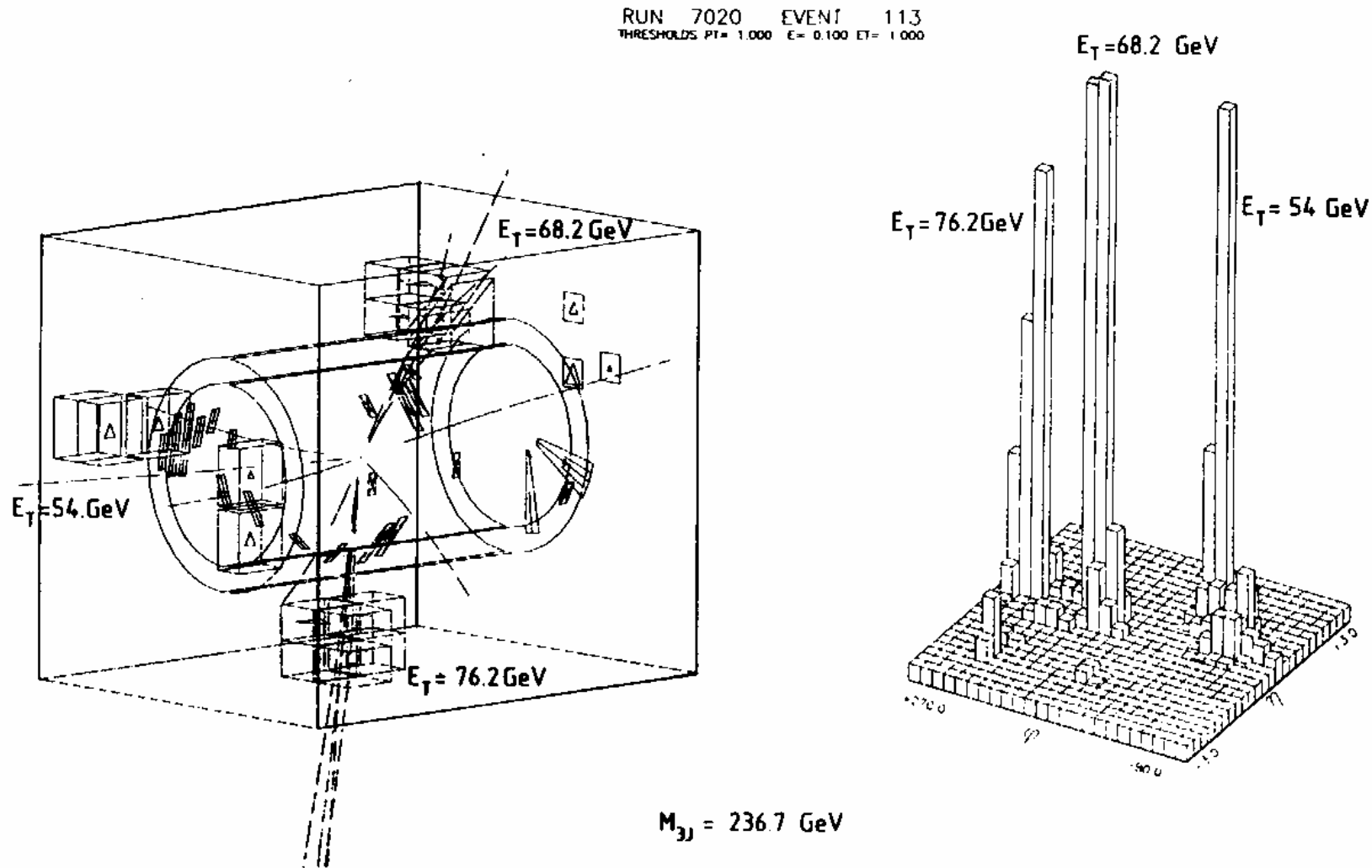
$$\chi = (1 + \cos\theta)/(1 - \cos\theta)$$

$$d\chi = 2 d \cos\theta / (1 - \cos\theta)^2$$

Scaling violations are visible

Three-Jet events are also there

Direct Evidence for Gluon Bremsstrahlung



First observation of W's

Main goal of UA1 (and UA2!) was to observe W's and Z's as predicted by the Weinberg Salam theory. In 1982 the mass of the IVBs were predicted to be:

$$\sin^2 \theta_w = 0.23 \pm 0.01 \quad M_W = 82 \pm 2.4 \text{ GeV} \quad M_Z = 94 \pm 2.5 \text{ GeV}$$

The W/Z production cross-sections at $\sqrt{s} = 540 \text{ GeV}$ were computed in LO QCD

$$\sigma(p\bar{p} \rightarrow W^\pm \rightarrow e^\pm \nu) \approx 0.5 \text{ nb} \quad (u\bar{d} \rightarrow W^+ \text{ or } \bar{u}d \rightarrow W^-)$$

$$\sigma(p\bar{p} \rightarrow Z^0 \rightarrow e^+e^-) \approx 0.05 \text{ nb} \quad (q\bar{q} \rightarrow Z^0)$$

Hence for the Nov-Dec 1982 run of 14 nb^{-1} , ~ 7 W's were expected and < 1 Z⁰!

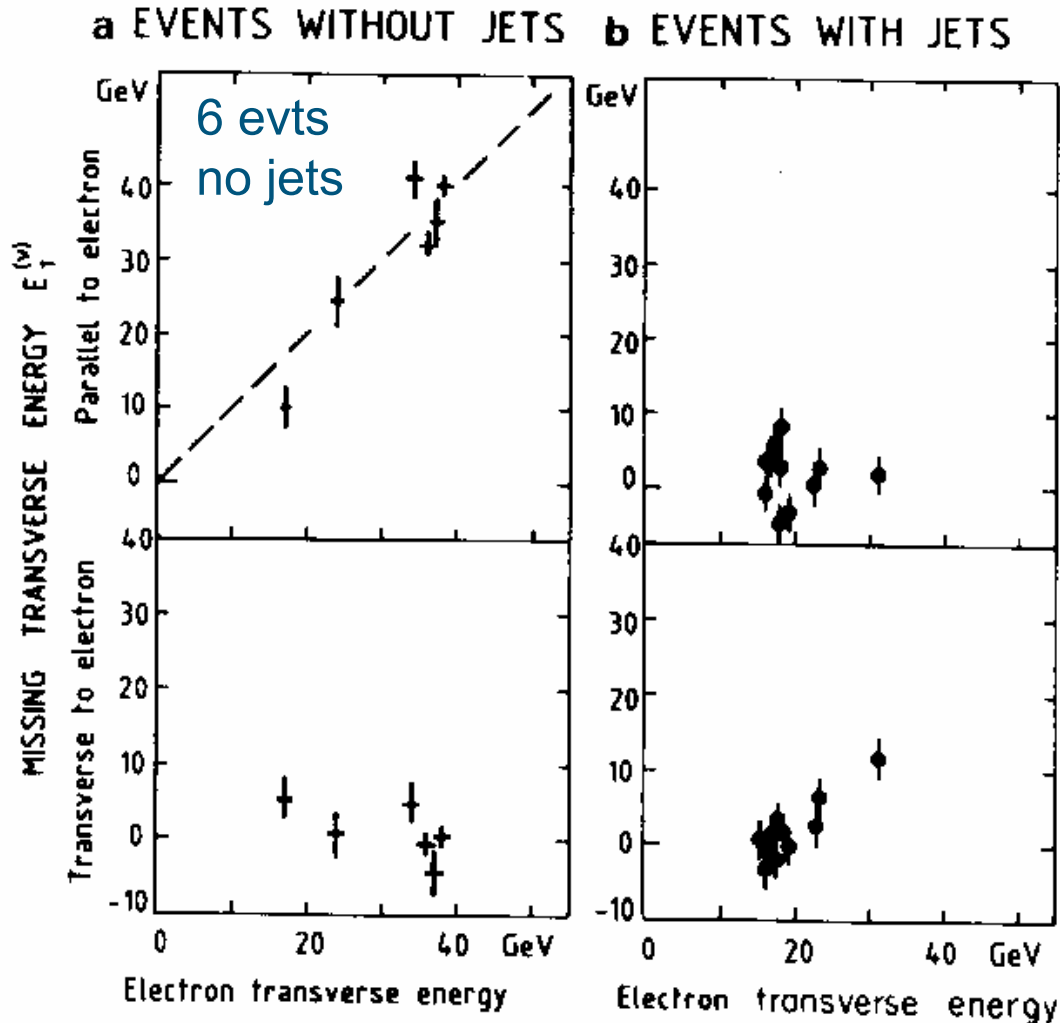
Indeed 6 W events were found in UA1 and published Feb 1983

UA1: Phys. Lett. 122B (1983) 103

And so did UA2!

UA2: Phys. Lett. 122B (1983) 476

First observation of W's



Inclusive electron selection
 $E_T > 15$ GeV: **find 6 events with no jet** and hence large missing transverse energy, E_T^{miss} ! Events with jets have no E_T^{miss}

Experimental aspects

Magnetic tracking is a fundamental tool for electron id:
 Isolated track in CD

$$|1/p_{CD} - 1/E_{calo}| < 3\sigma$$

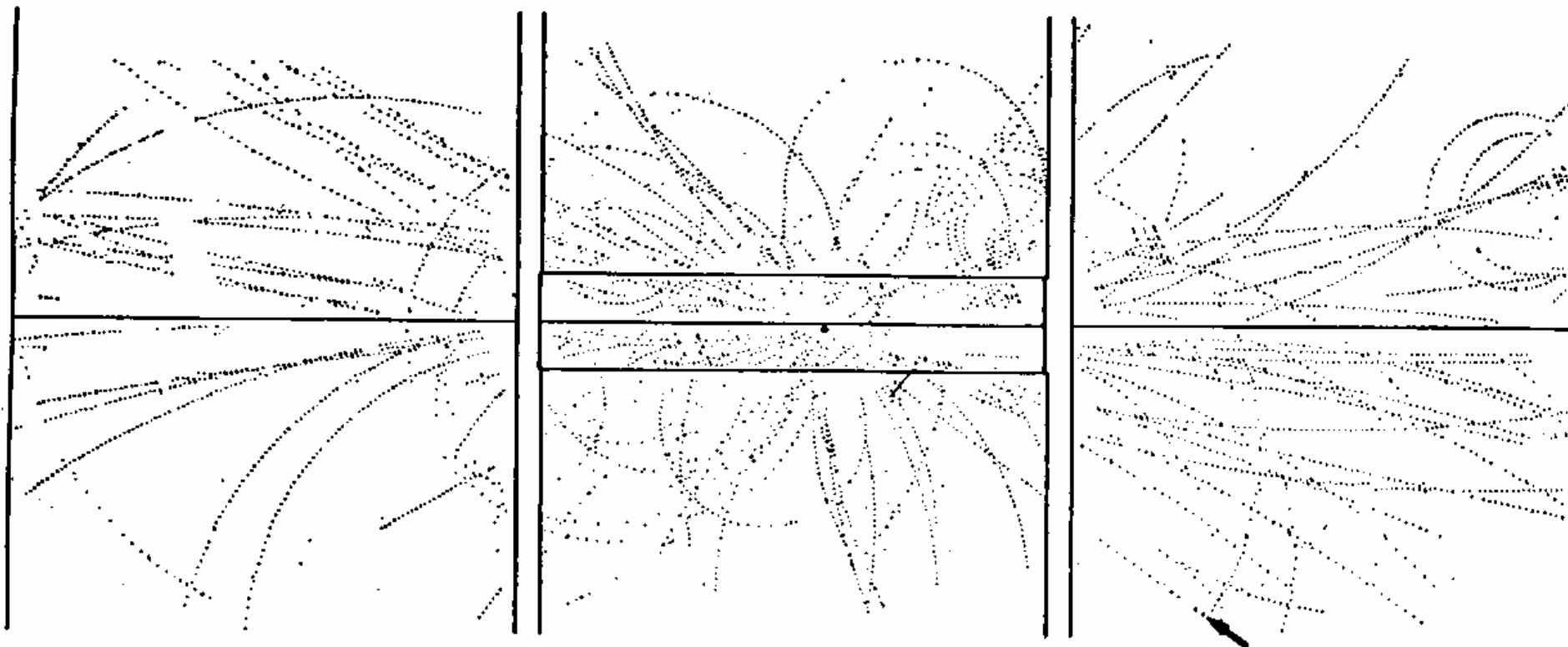
B field, 0.7T, a bit weak

$$\Delta p/p = \pm 20\% \text{ at } p_T = 40 \text{ GeV}$$

Hermetic Calorimetry is a fundamental tool for E_T^{miss} measurement.

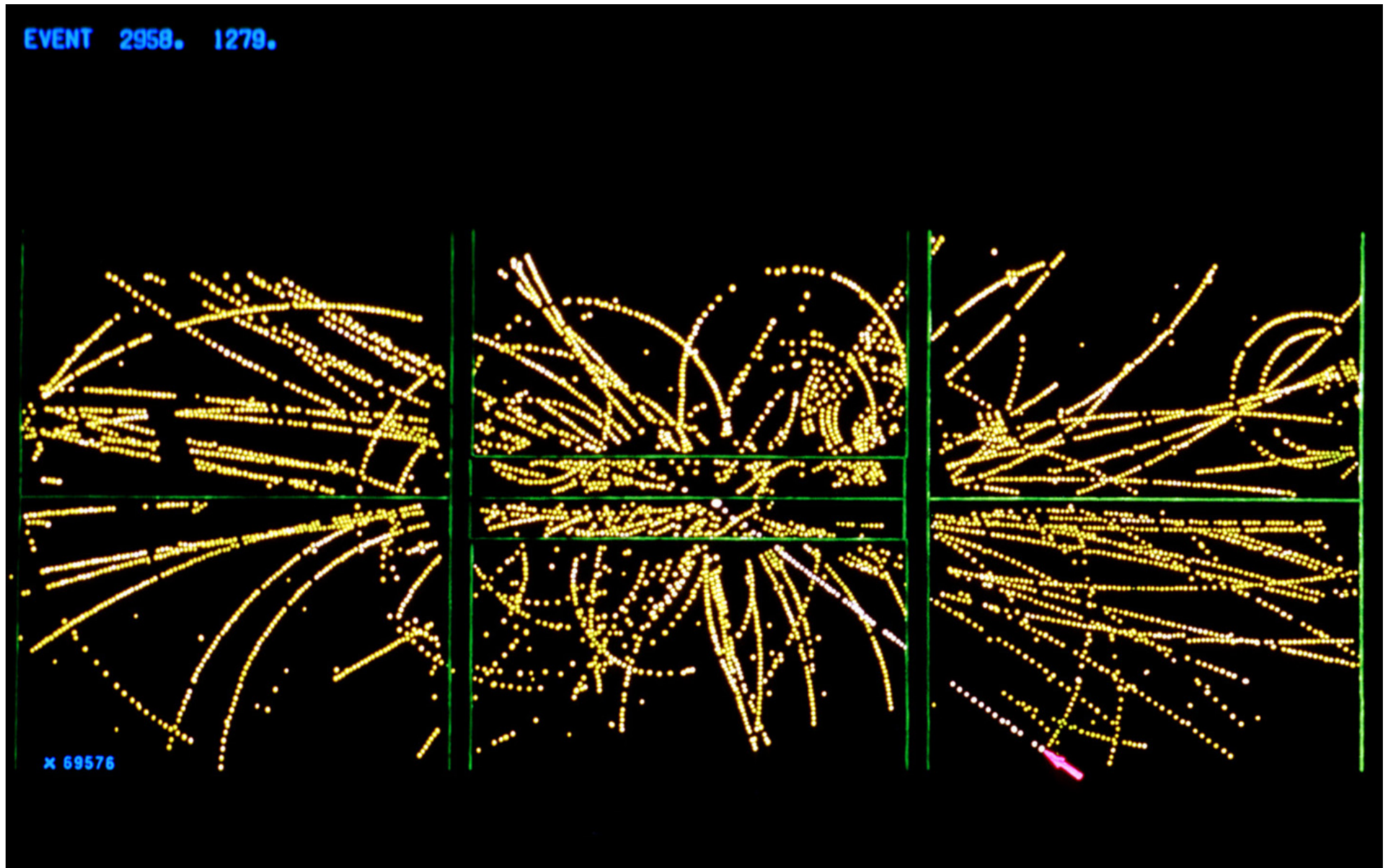
A busy W event

No visible jet on the away side!



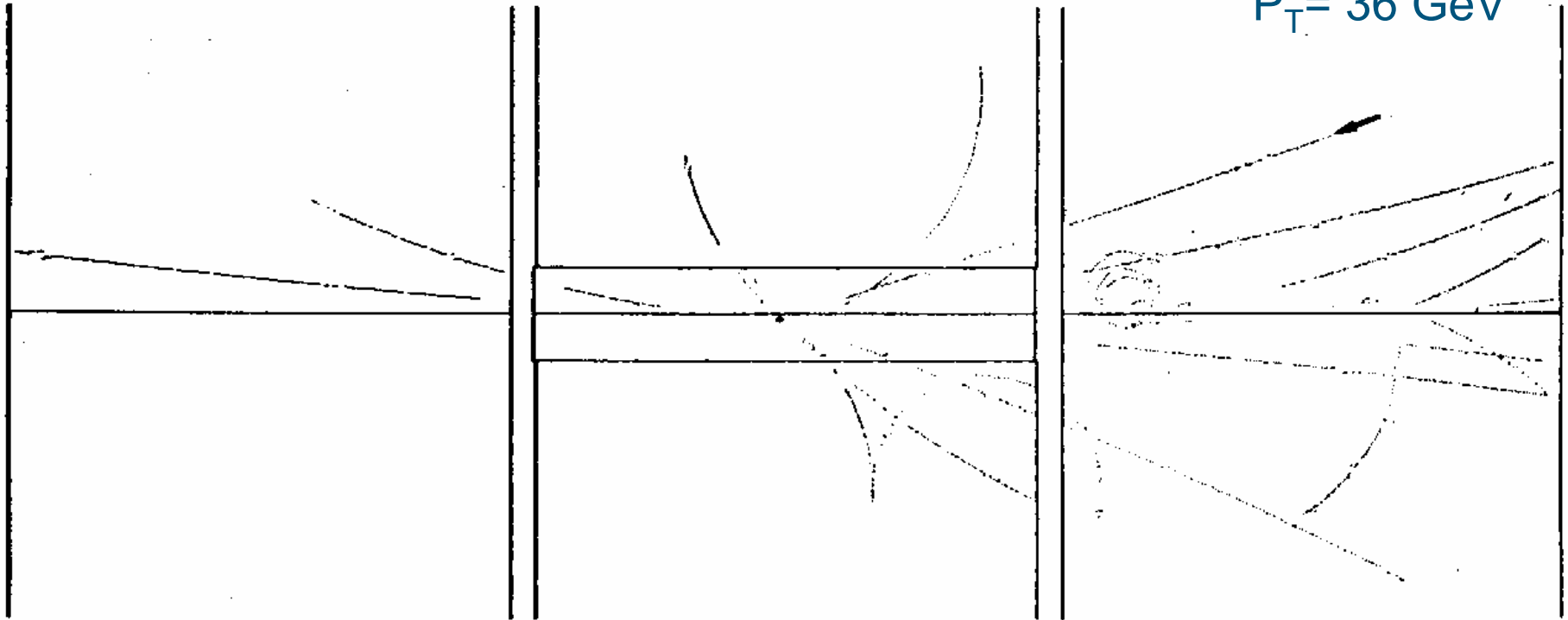
Electron
 $P_T = 24 \text{ GeV}$

Same busy W event (in color!)



A Quiet W Event

Electron
 $P_T = 36 \text{ GeV}$

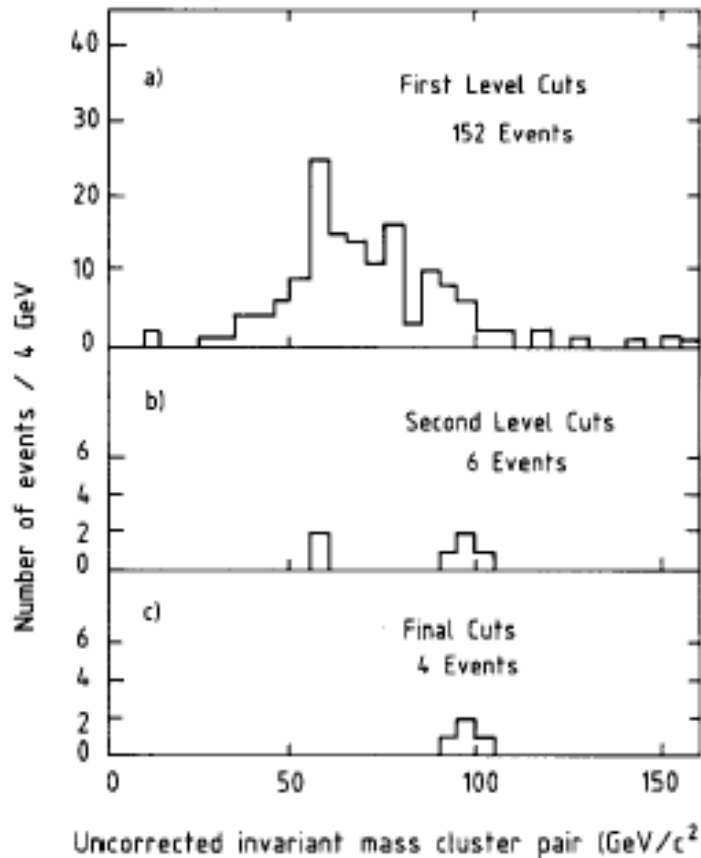


No visible jet on the away side!

First observation of Zs

April-May 1983 run: 55nb^{-1}

Race open for the first observation of Zs!

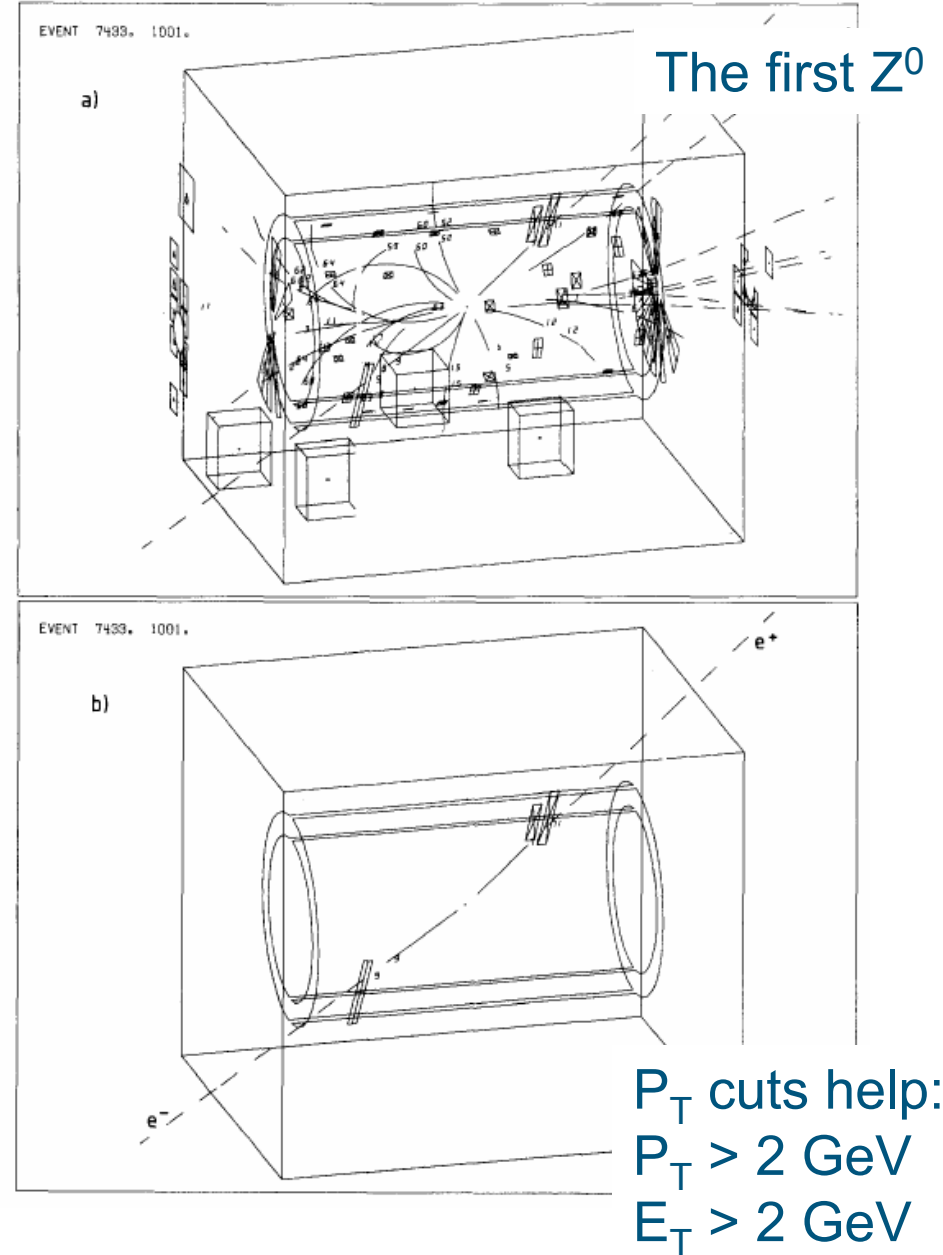


2 elm clusters
 $E_T > 25 \text{ GeV}$

1 charged
track in CD
 $P_T > 7 \text{ GeV}$

2 charged
tracks

“Four e^+e^- events survive the cuts with a common value of e^+e^- invariant mass”

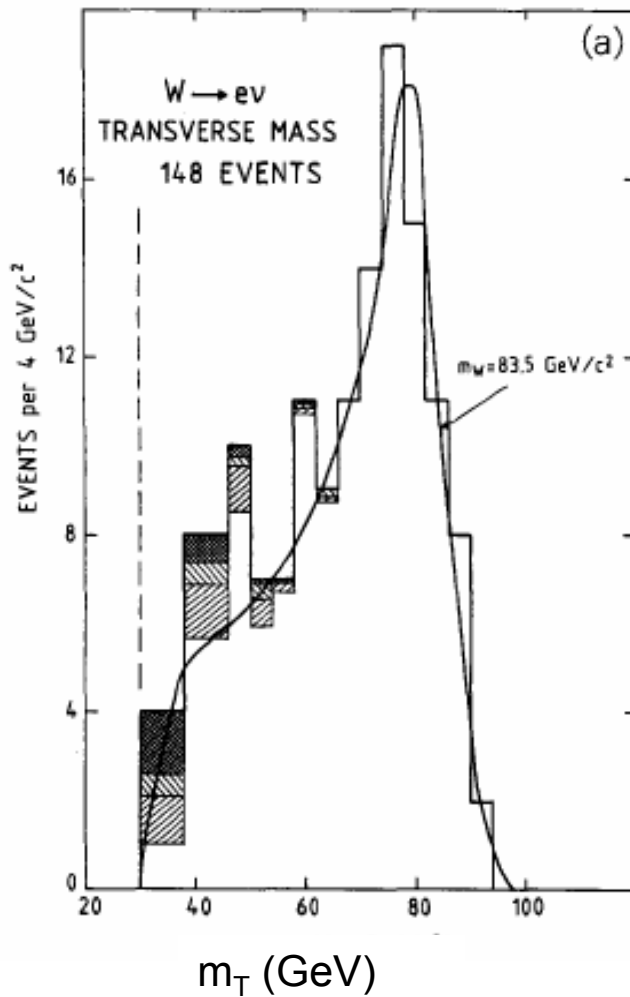


UA1: Phys. Lett. 126B (1983) 398

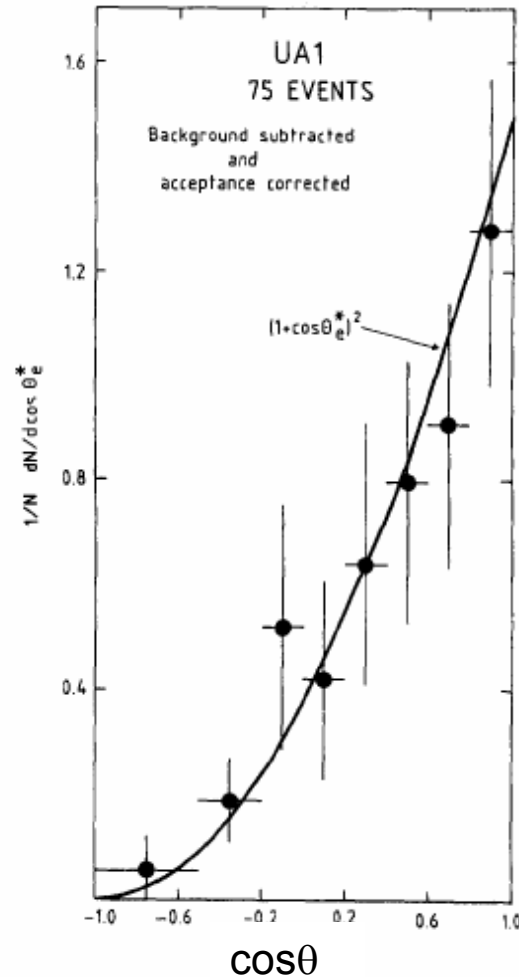
UA2: Phys. Lett. 129B (1983) 130

W/Z Mass and Spin

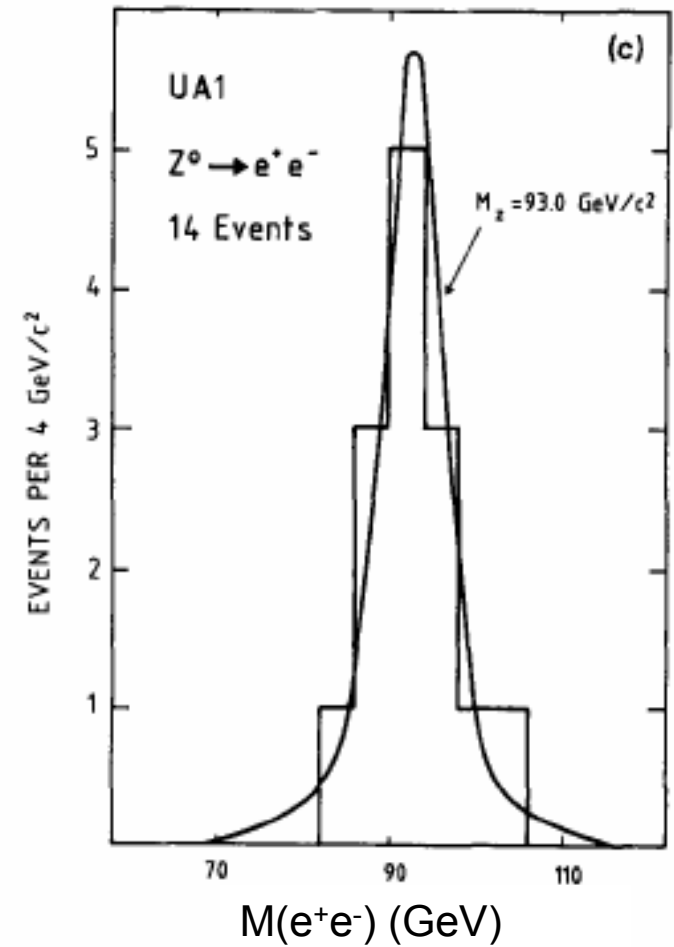
W mass



W Spin



Z mass



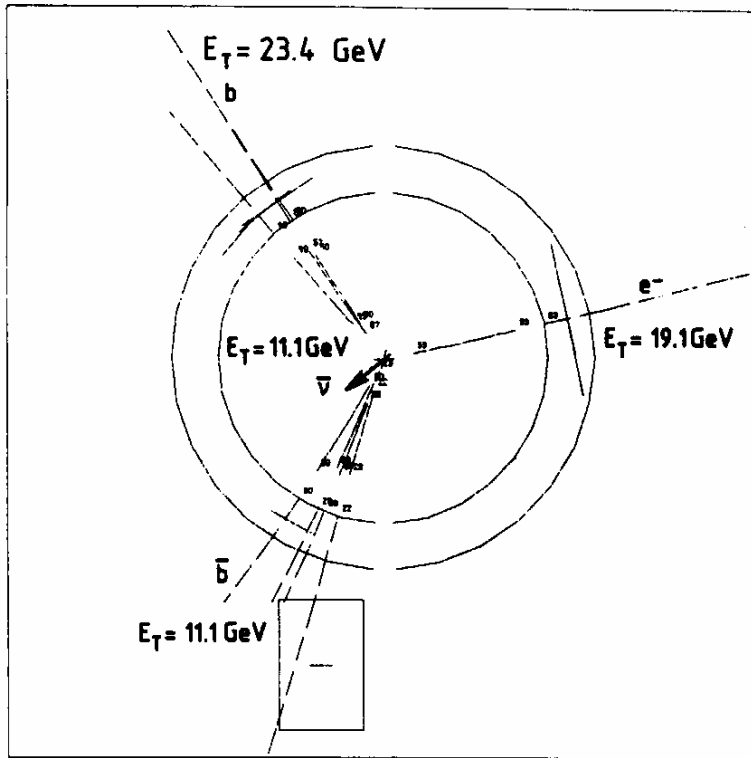
1983 + 1984 data, 400 nb⁻¹: study W/Z properties

Top in UA1?

1983 data (108 nb^{-1}): Observe 5 isolated electrons + ≥ 2 Jets events (SM background: 0.1 fake e + 0.15 bbg) consistent with

$$W \rightarrow t\bar{b} \rightarrow e\nu b\bar{b} \quad (m_t \approx 40 \text{ GeV})$$

1983-85 data (715 nb^{-1}): Observe 7 isolated electrons + ≥ 2 Jets events consistent with SM background of 6.7 evts



	Monte Carlo					Data
	Overlap and Conversions	W/Z γ	$D.Y.$ J/ψ	$b\bar{b}$ $c\bar{c}$	Total	
$e + 0 \text{ jets}$	3 ± 0.2 ± 0.5	26.9 ± 2 ± 1.73	2.1 ± 0.4 ± 0.72	1.8 ± 0.4 ± 0.45	33.8 ± 2.1 ± 2.0	34
$e + 1 \text{ jets}$	5.5 ± 0.3 ± 1.0	5.3 ± 0.3 ± 0.34	4.3 ± 0.5 ± 1.5	1.6 ± 0.35 ± 0.4	16.7 ± 0.7 ± 1.9	19
$e + \geq 2 \text{ jets}$	2.6 ± 0.3 ± 0.5	0.8 ± 0.2 ± 0.06	1.1 ± 0.3 ± 0.38	2.2 ± 0.45 ± 0.55	6.7 ± 0.6 ± 0.7	7
$e + \geq 1 \text{ jets}$	8.1 ± 0.5 ± 1.5	6.1 ± 0.4 ± 0.4	5.4 ± 0.6 ± 1.9	3.8 ± 0.6 ± 0.95	23.4 ± 0.9 ± 2.7	26

Top in UA1?

Upgrade of the machine. New antiproton collector ACOL. $L = 2 \times 10^{30} \text{cm}^{-2} \text{s}^{-1}$

Upgrade of UA1? New em calorimeters U-TMP not ready. Old em calos removed.

UA1 1988-1989: 4.7 pb^{-1} of data muons only.

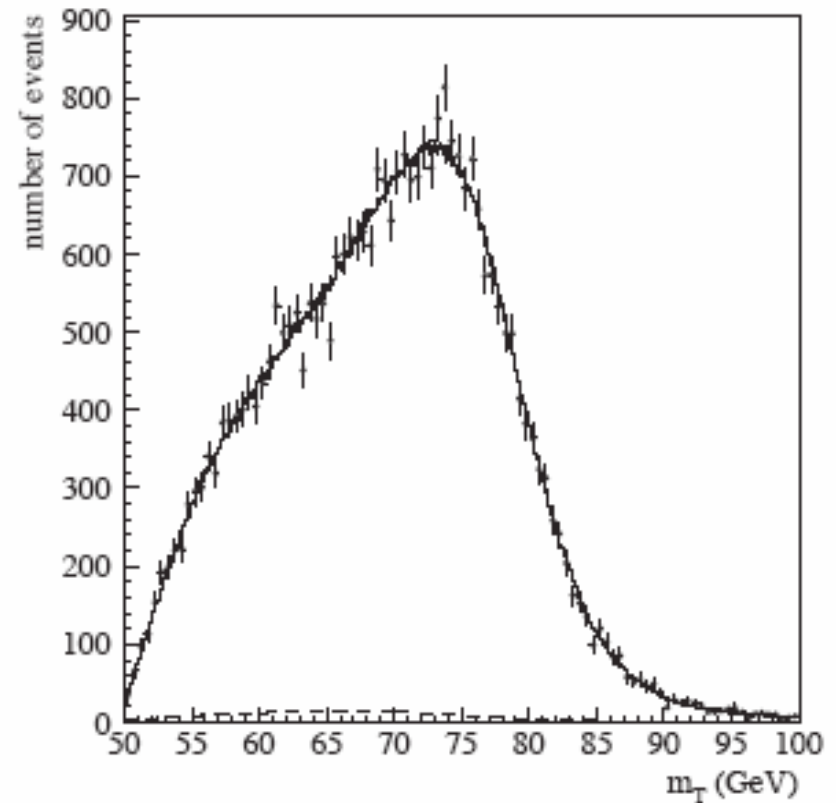
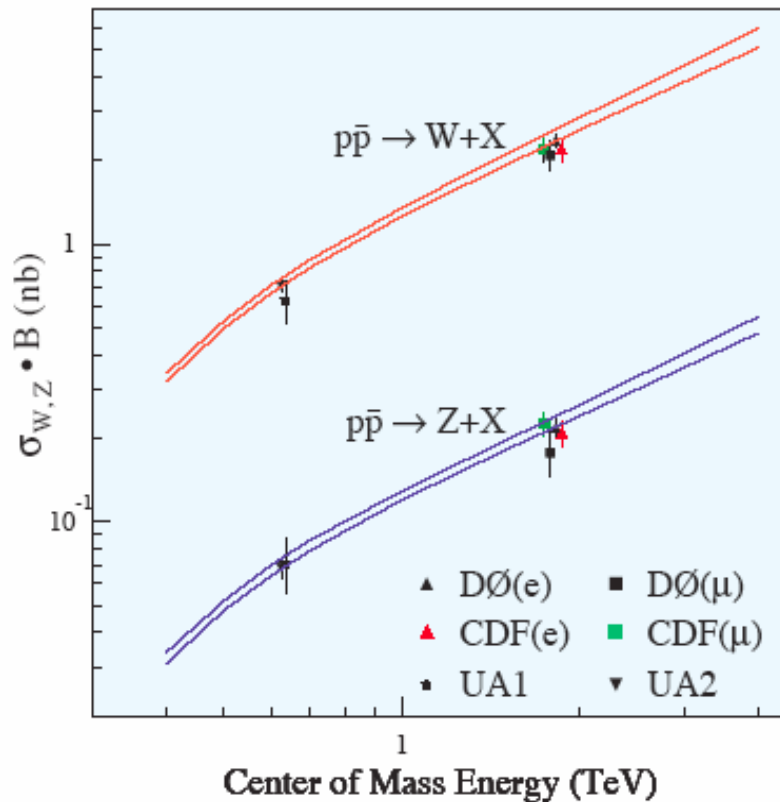
Table 5. Summary of t -quark searches in different data samples. Sources of uncertainties are discussed in Sect. 4 and summarized in Tables 6 and 7 for the background estimate and top expectations respectively

	Data	Background	Expected number of top events				95% CL limit on m_t [GeV/c ²]
			$m_t = 40$ [GeV/c ²]	$m_t = 50$ [GeV/c ²]	$m_t = 60$ [GeV/c ²]	$m_t = 70$ [GeV/c ²]	
Electrons plus jets (1983–1985)	26	26.0	11.7	8.5	4.1	1.5	41
Muons plus jets (1983–1985)	10	11.4	7.9	4.7	2.3	0.8	40
Muons plus jets (1988–1989)	2	2.8	6.7	6.2	3.3	0.9	52
Dimuon (1983–1989)	2	4.5	6.2	3.9	1.9	0.7	46

Combining all UA1 data (5.4 pb^{-1}): $m_t > 60 \text{ GeV}$ (95% CL).

But... CDF (Tevatron) had already started its search for the top and was getting already a better limit: $m_t > 77 \text{ GeV}$ (95% CL).

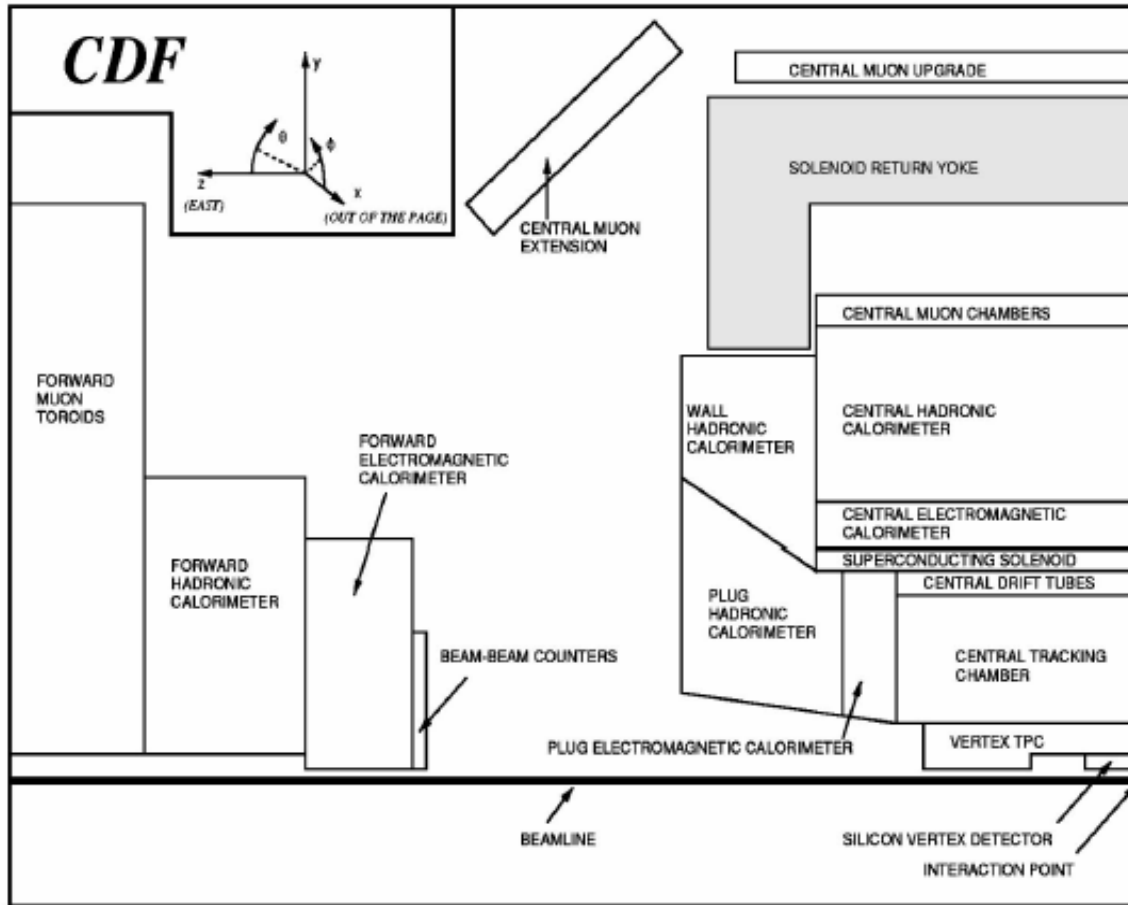
The Tevatron era



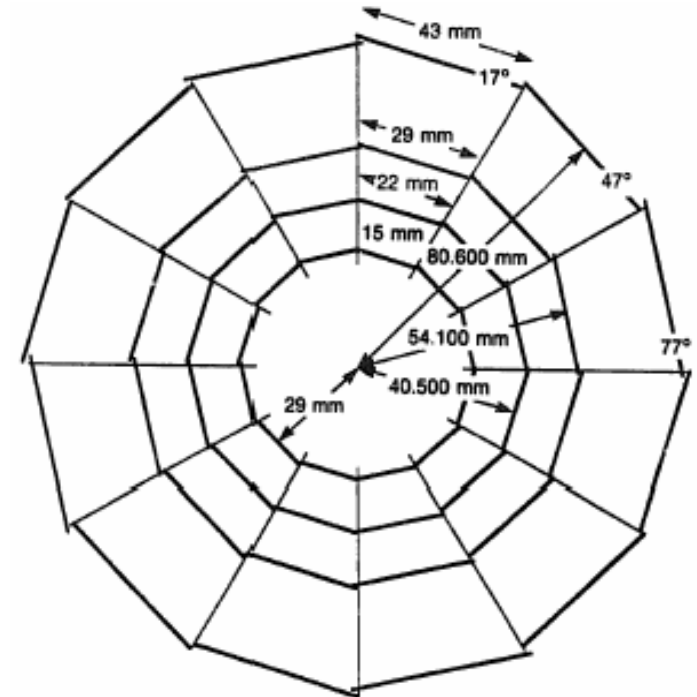
Higher Energy: Increase the production cross-section for massive particles

Higher Luminosity:
 SPS $10^{30} \rightarrow$ Tevatron 10^{32}
 Huge samples available
 DØ: 30,000 Ws
 $M_W = 80.482 \pm 0.091$

The CDF detector



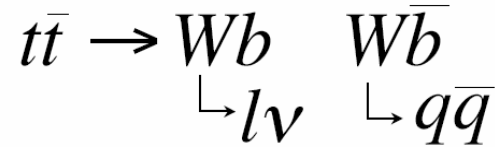
The Silicon Vertex Detector of CDF



With a Silicon Vertex Detector (SVD) CDF has demonstrated that b tagging is possible at a hadron collider!

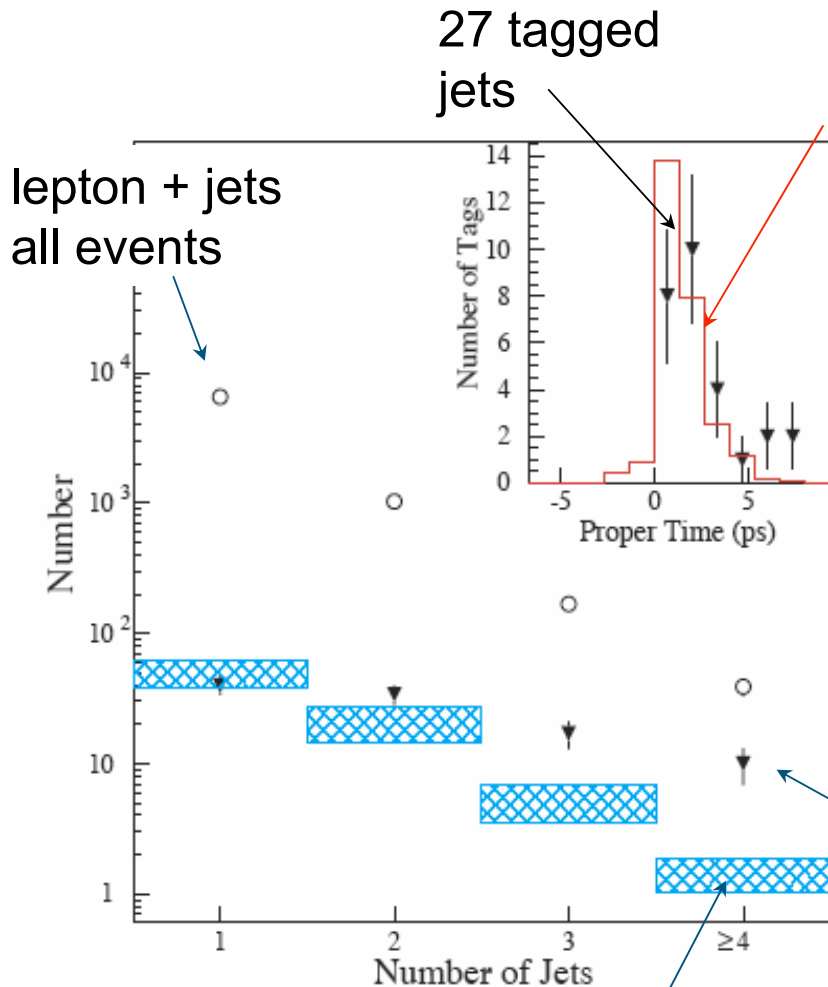
Tevatron: the Top

CDF 1995



Look for leptons (e or μ) + ≥ 3 jets

Important feature of the CDF Detector:
the Silicon Vertex Detector allows to
SEE the b quarks (b tag).



Expected for
b from t

27 tagged
jets

lepton + jets
all events

lepton + jets
b tag only

Background
(fake b-tags)

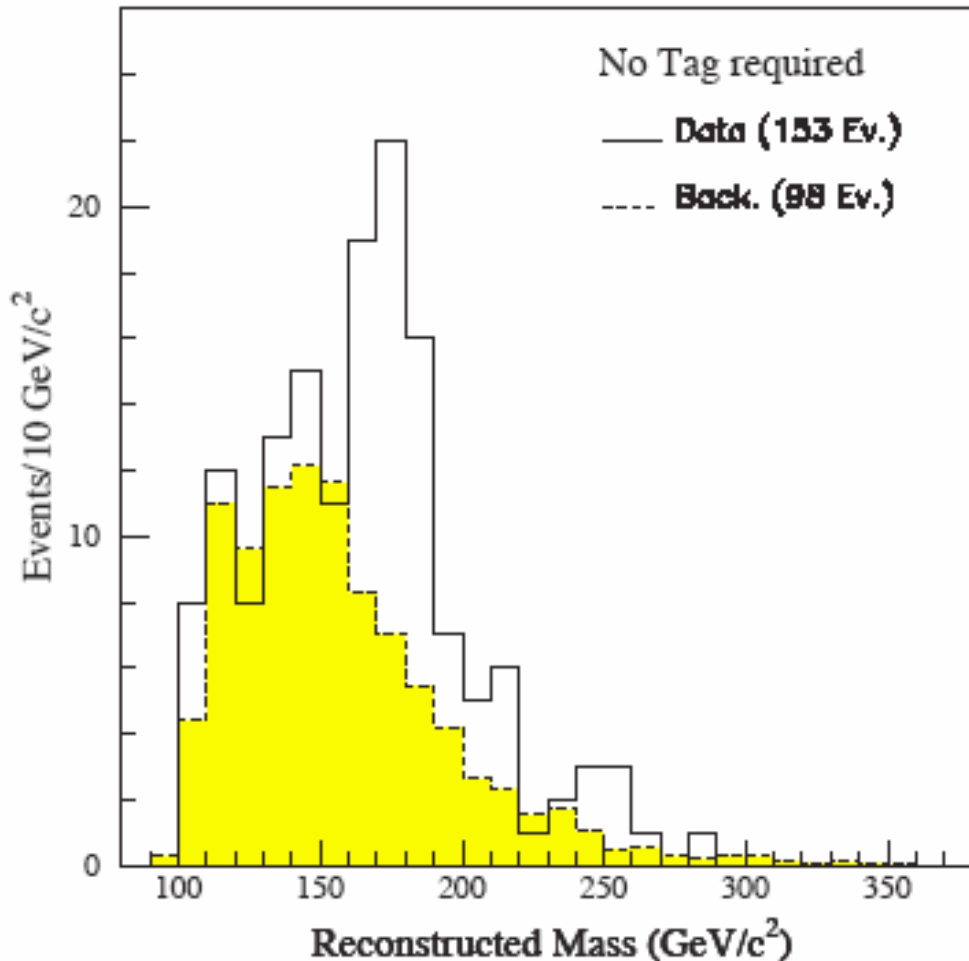
The Top is Heavy 175 GeV!

Without b tag

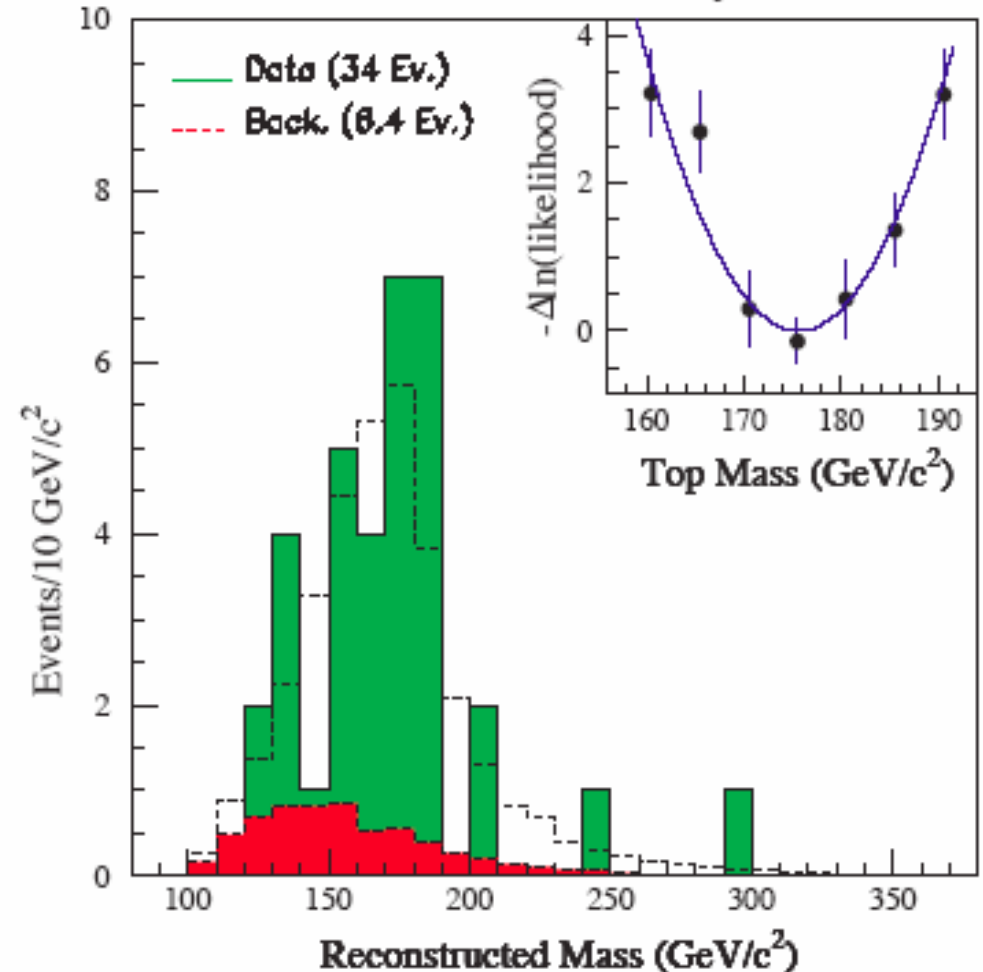
CDF 1995
Run I

With b tag

CDF PRELIMINARY (110pb⁻¹)



CDF PRELIMINARY (110 pb⁻¹)
 $M = 175.6 \pm 5.7(\text{stat}) \pm 7.1(\text{syst}) \text{ GeV}$



Summary Hadron Colliders

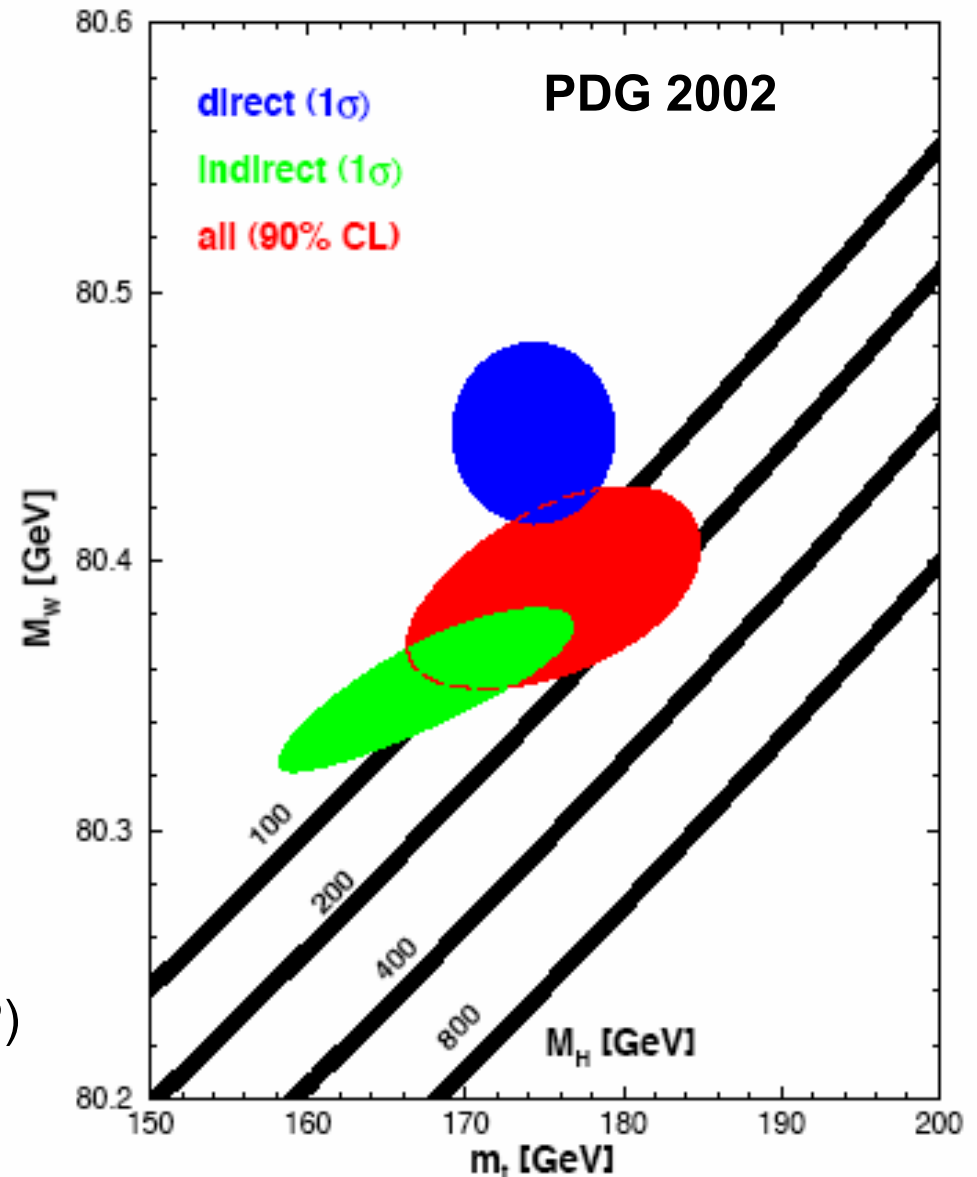
- QCD looks like the theory of strong interactions
- W and Z properties as expected
- All the known/expected fermions are there
- All is well with the Standard Model

PDG 2002

$m_t = 174.3 \pm 5.1$ GeV (CDF, D0)

$m_W = 80.454 \pm 0.060$ GeV (CDF, D0, UA2)

$m_W = 80.451 \pm 0.033$ GeV (CDF, D0, UA2, LEP)



Higgs Mass (SM, PDG2002)

Experimental Limits

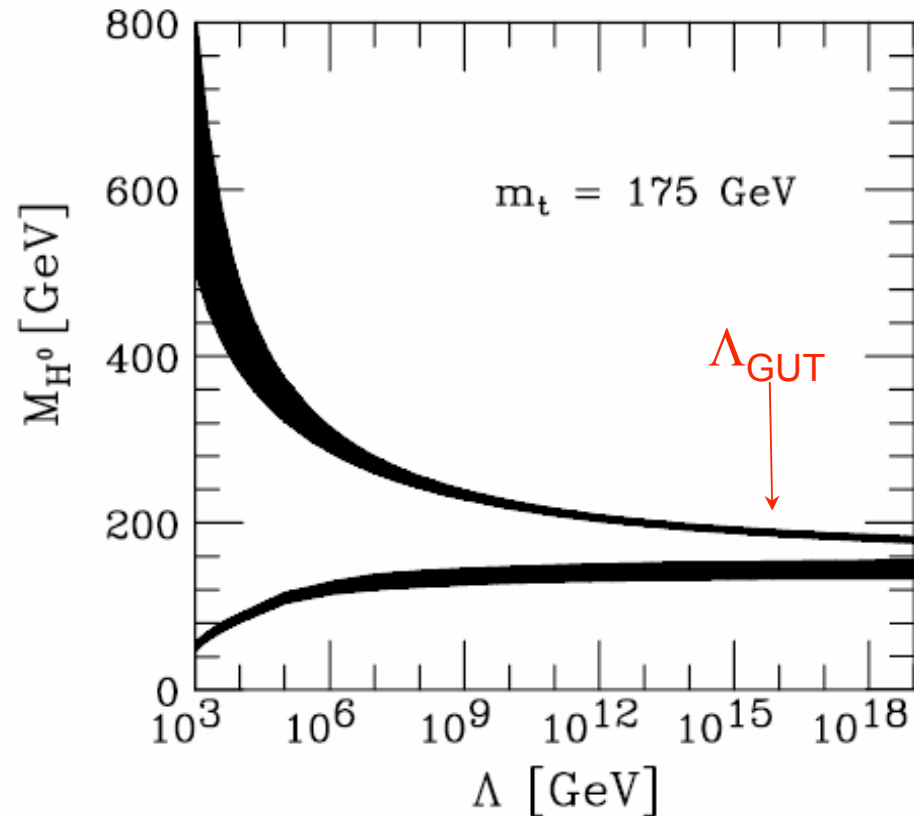
Direct Search at LEP

$m_H > 114.1 \text{ GeV}$ (95% CL)

Indirect experimental bound
radiative corrections EW
data, m_t and m_W

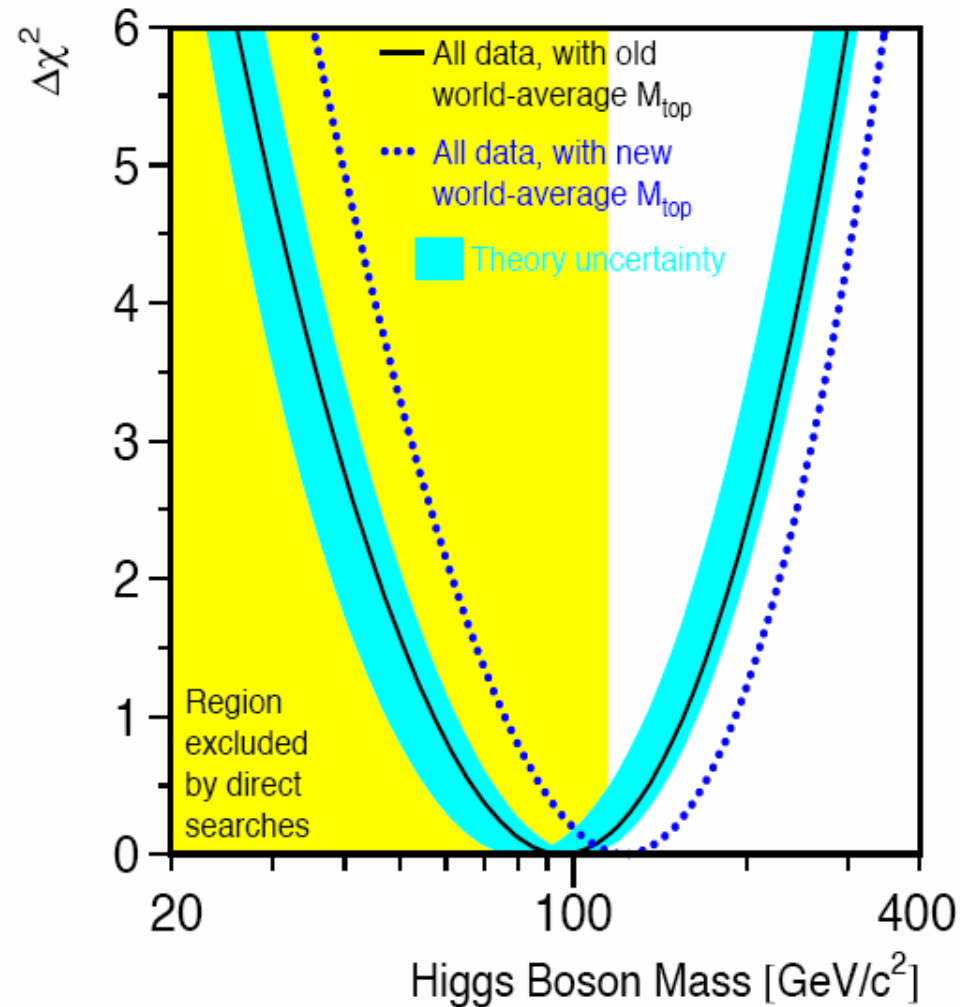
$m_H < 196 \text{ GeV}$ (95% CL)

Theoretical Limits



SM self consistent up to $\Lambda_{\text{GUT}} \approx 10^{16} \text{ GeV}$
implies: **$130 \text{ GeV} < m_H < 190 \text{ GeV}$**

New top mass from Tevatron



The top mass is drifting up!

New value of top mass CDF Run II

http://www-cdf.fnal.gov/people/links/KoheiYorita/TopMassDLM_public.html

$m_t = 177.8 +4.5-5.0$ (stat.) ± 6.2 (syst.) GeV

New analysis of D0 Run I:

http://moriond.in2p3.fr/EW/2004/transparencies/2_Tuesday/2_1_morning/2_1_3_Kulik/Kulik.pdf

$m_t = 180.1 \pm 3.6$ (stat) ± 3.9 (syst) GeV

Favors slightly higher Higgs mass

LEPEWWG'04

Assume standard model global fit

$$\Rightarrow M_H = 117_{-45}^{+67} \text{ GeV}$$

WW Scattering

Lee, Quigg and Thacker, PRD16 (1977) 1519

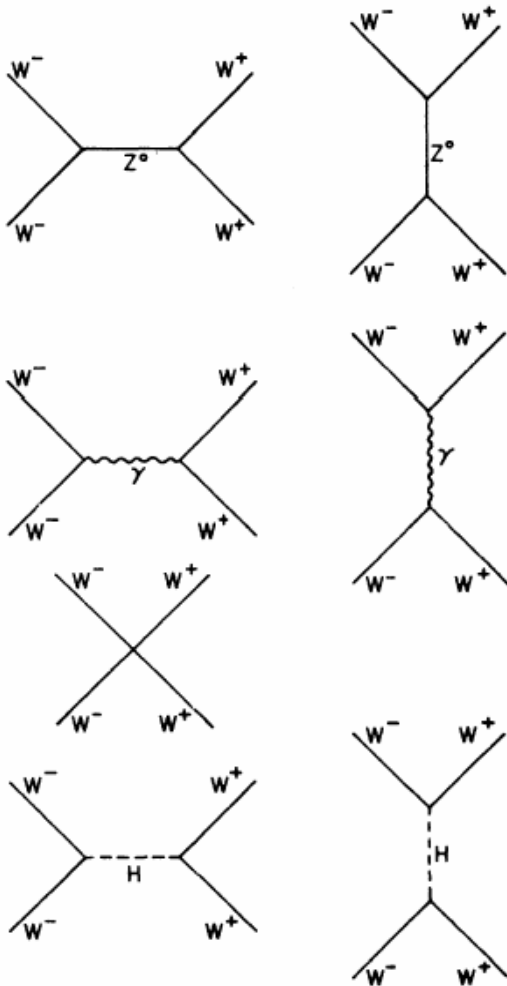
- 1) Need H exchange to cancel divergences at large s
- 2) Partial wave unitarity bounds lead to limits on Higgs mass:

$$m_H^2 \leq \frac{8\pi\sqrt{2}}{3G_F} \Rightarrow m_H \leq 1 \text{ TeV}$$

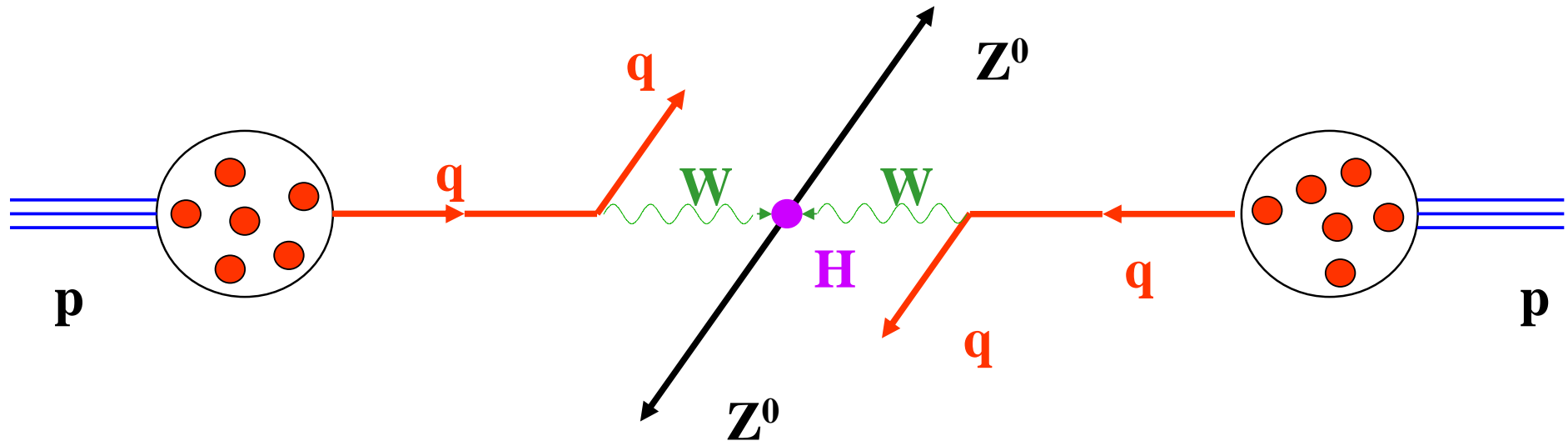
G_F is the Fermi constant: $G_F^{-1/2} \approx 300 \text{ GeV}$

No lose theorem:

An accelerator able to probe WW scattering up to $\sqrt{s} \approx 1 \text{ TeV}$ will necessarily elucidate the Higgs mechanism in the Standard Model.



Higgs Production in pp Collisions



$$M_H \sim 1000 \text{ GeV}$$

$$\leftarrow E_W \geq 500 \text{ GeV}$$

$$\leftarrow E_q \geq 1000 \text{ GeV (1 TeV)}$$

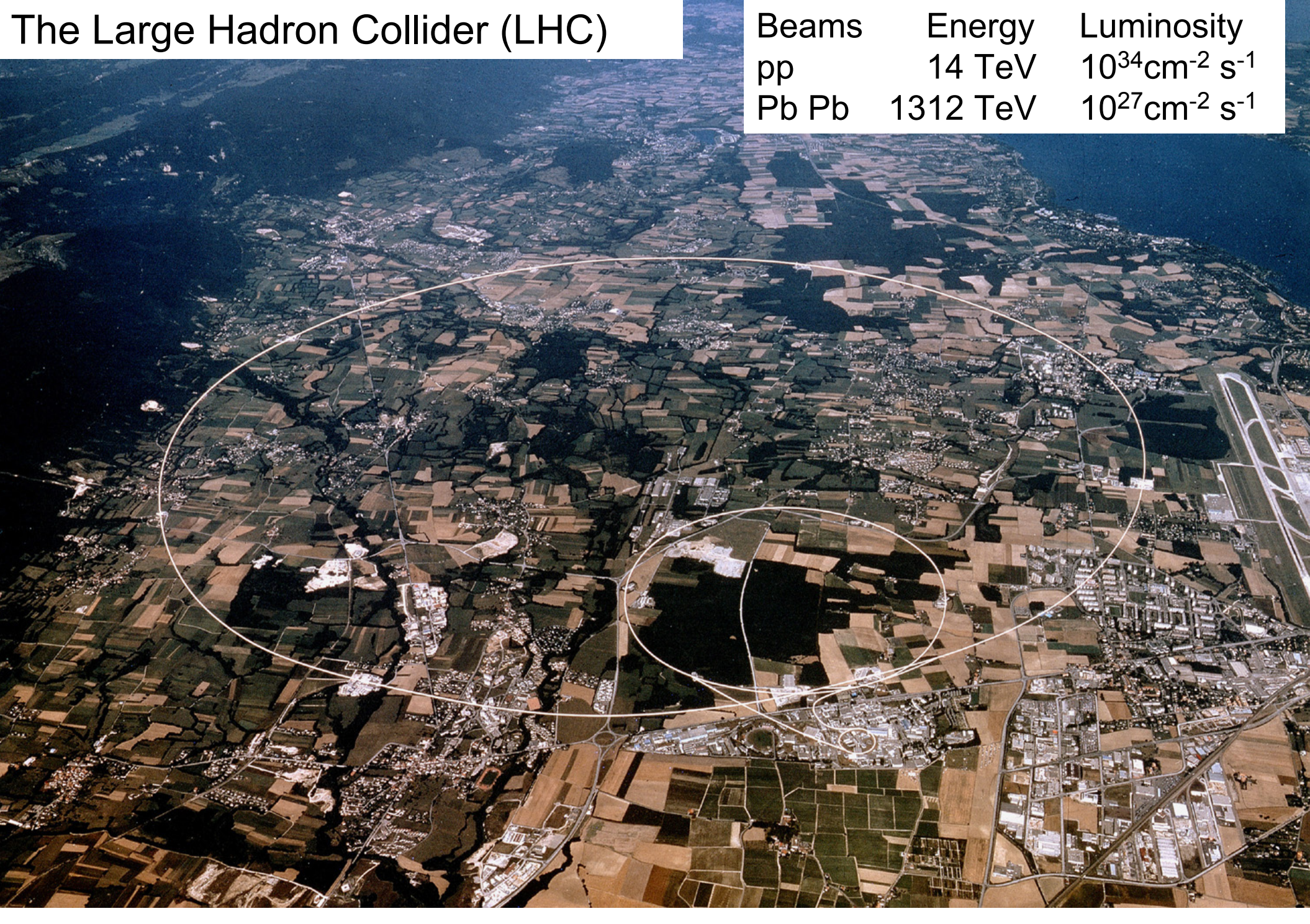
$$\leftarrow E_p \geq 6000 \text{ GeV (6 TeV)}$$



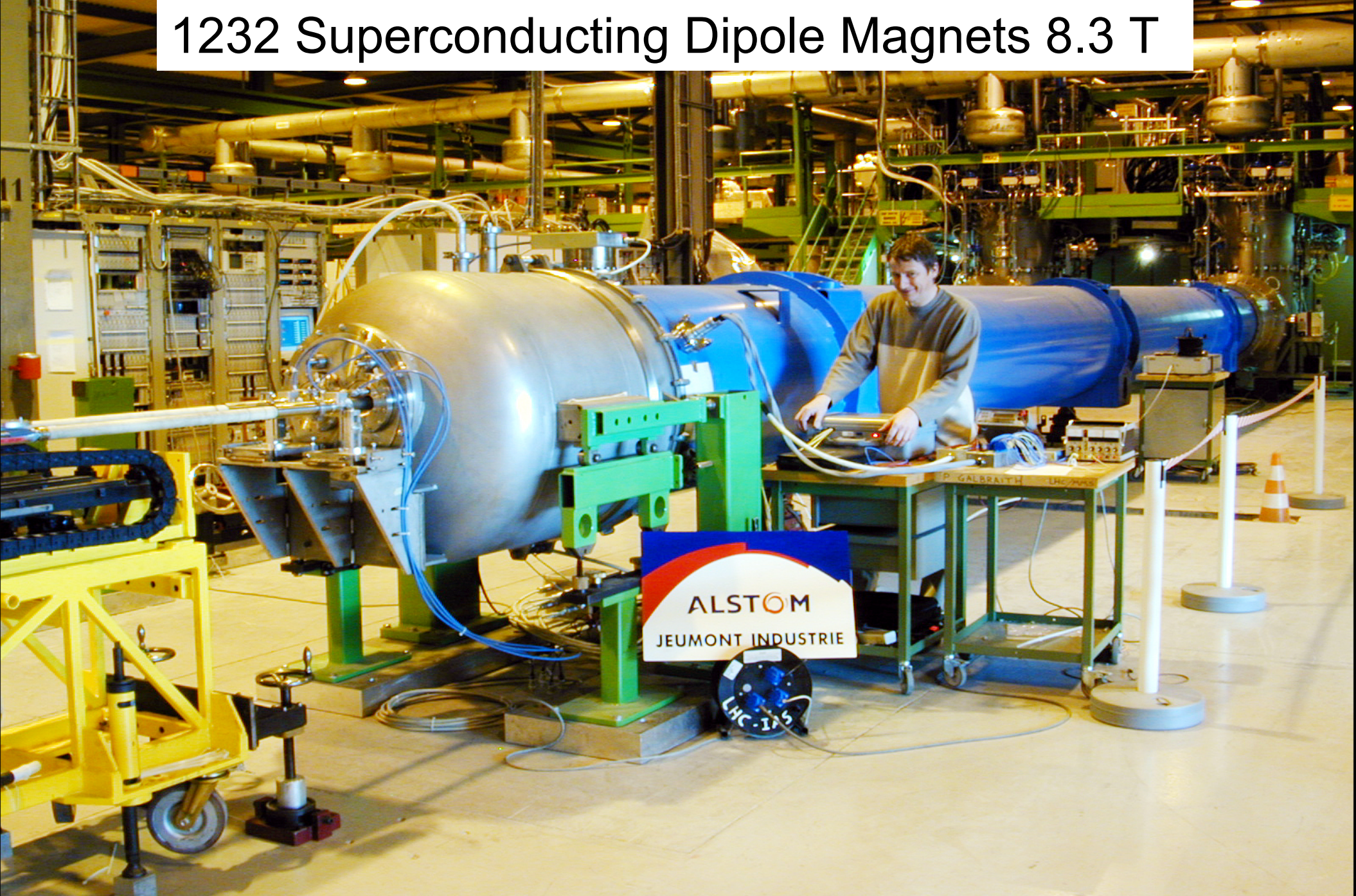
**Proton Proton Collider $E_p \geq 7 \text{ TeV}$
@ $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ Luminosity**

The Large Hadron Collider (LHC)

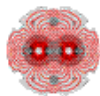
Beams	Energy	Luminosity
pp	14 TeV	$10^{34} \text{cm}^{-2} \text{s}^{-1}$
Pb Pb	1312 TeV	$10^{27} \text{cm}^{-2} \text{s}^{-1}$



1232 Superconducting Dipole Magnets 8.3 T



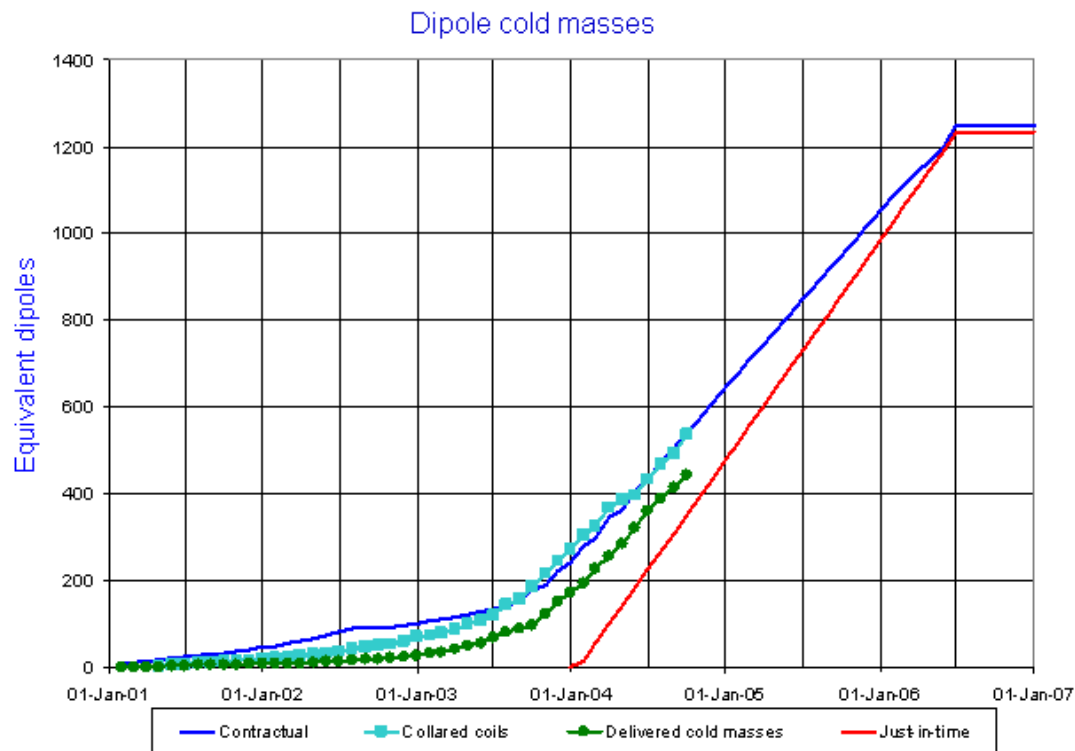
Machine Schedule



LHC Progress
Dashboard



- **Official schedule:**
Collisions in Summer 2007
- **Dipole production is not critical**
~400 dipoles (32%) cold tested ready for installation.
- **Critical Path:**
Repair and Installation of Cryogenic lines.
- **New Machine Schedule:**
Dec 04



Updated 30 Sep 2004

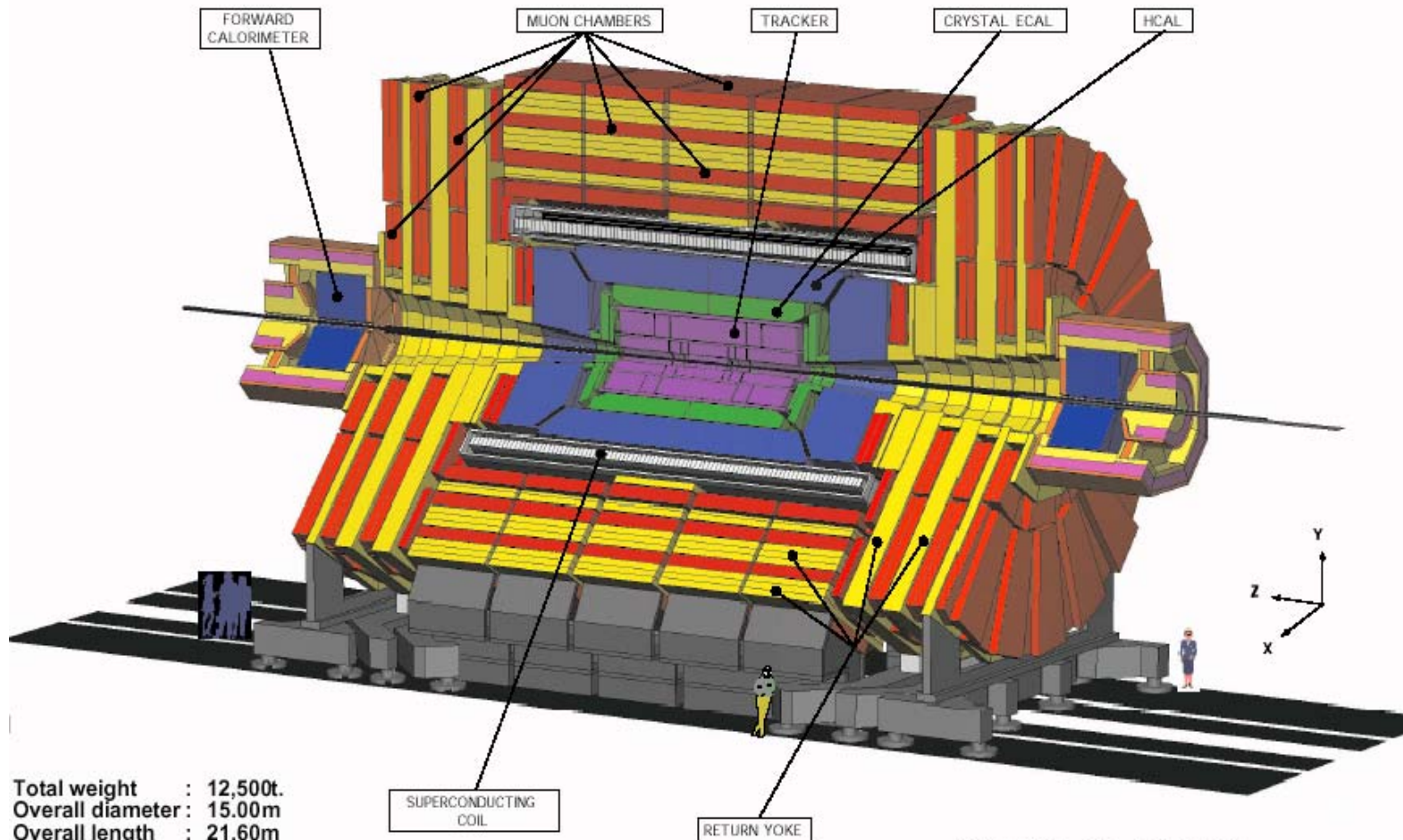
Data provided by P. Lienard AT-MAS

Design of LHC Detectors

- Two specialised detectors: Alice (Heavy Ions) and LHCb (B physics)
- Two general purpose detectors: ATLAS and CMS
 - Not clear that a general purpose detector could work at 10^{34} luminosity:
 - Fast detectors (25ns between bunch crossings)
 - Radiation Hard (more than 10 Mrad forward)
 - Very high granularity: minimize cell occupancy and pile-up
 - Event size and rate, trigger selection, bandwidth of readout network
- R&D started in ~1990 (Aachen workshop).

The CMS Detector

CMS A Compact Solenoidal Detector for LHC



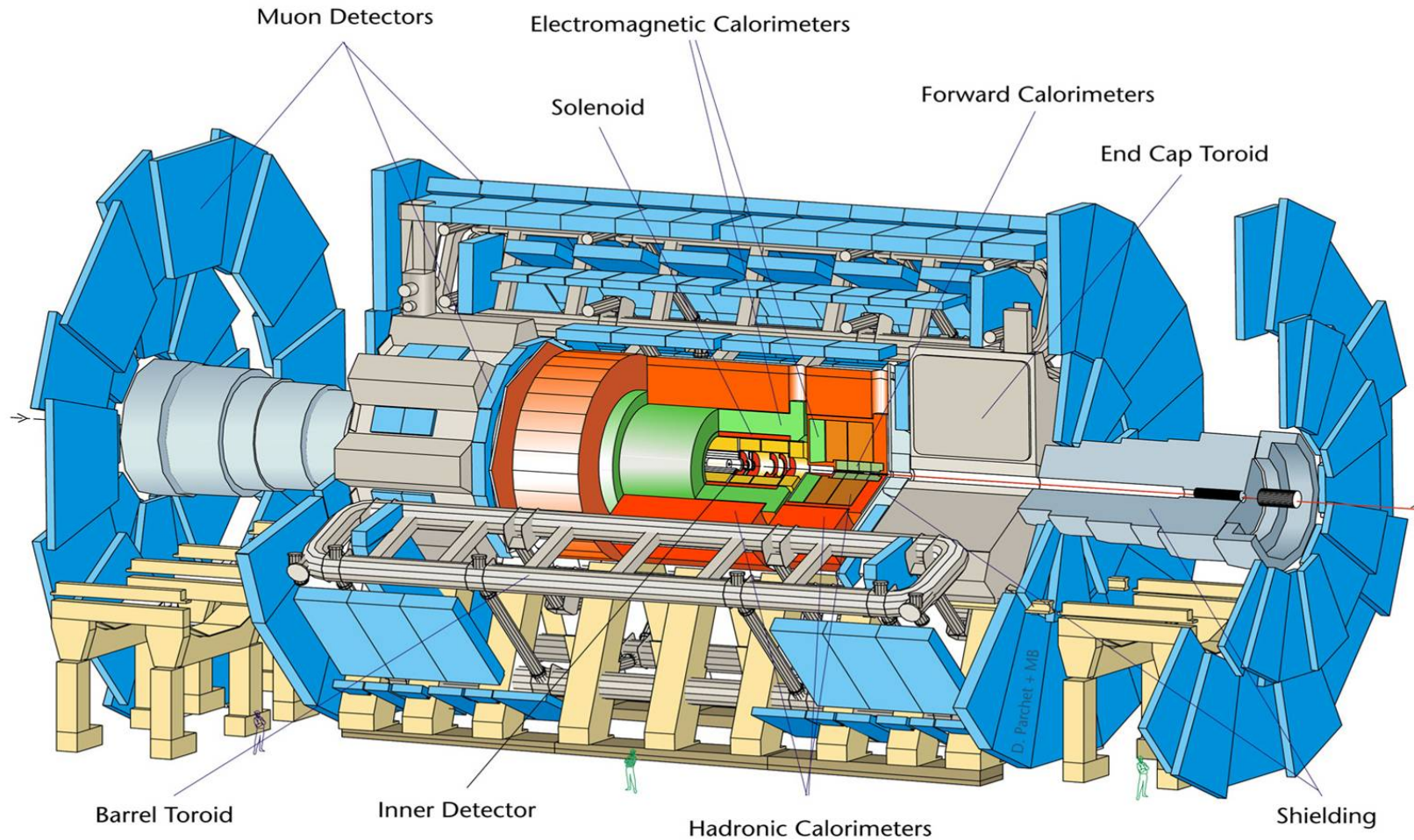
Total weight : 12,500t.
Overall diameter : 15.00m
Overall length : 21.60m
Magnetic field : 4 Tesla

CMS-PARA-001-11/07/97

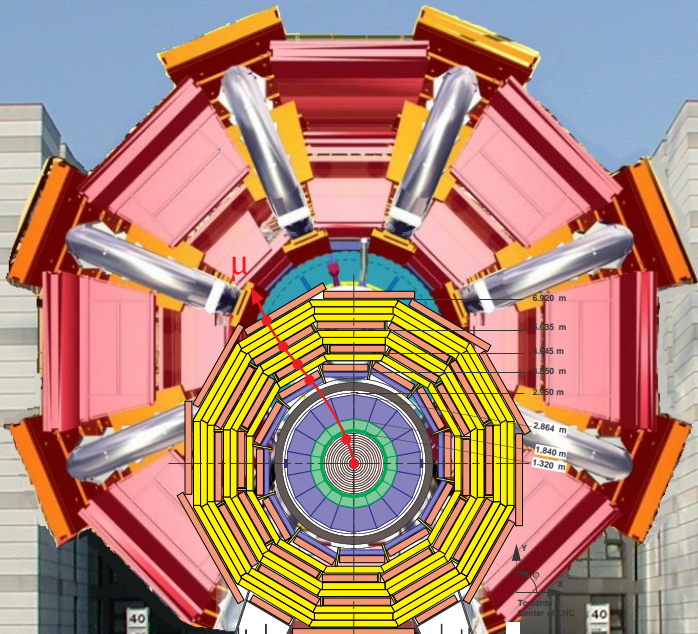
JLB.PP

The ATLAS Detector

D712/mb-26/06/97



<i>Diameter</i>	<i>25 m</i>
<i>Barrel toroid length</i>	<i>26 m</i>
<i>End-cap end-wall chamber span</i>	<i>46 m</i>
<i>Overall weight</i>	<i>7000 Tons</i>



40

40

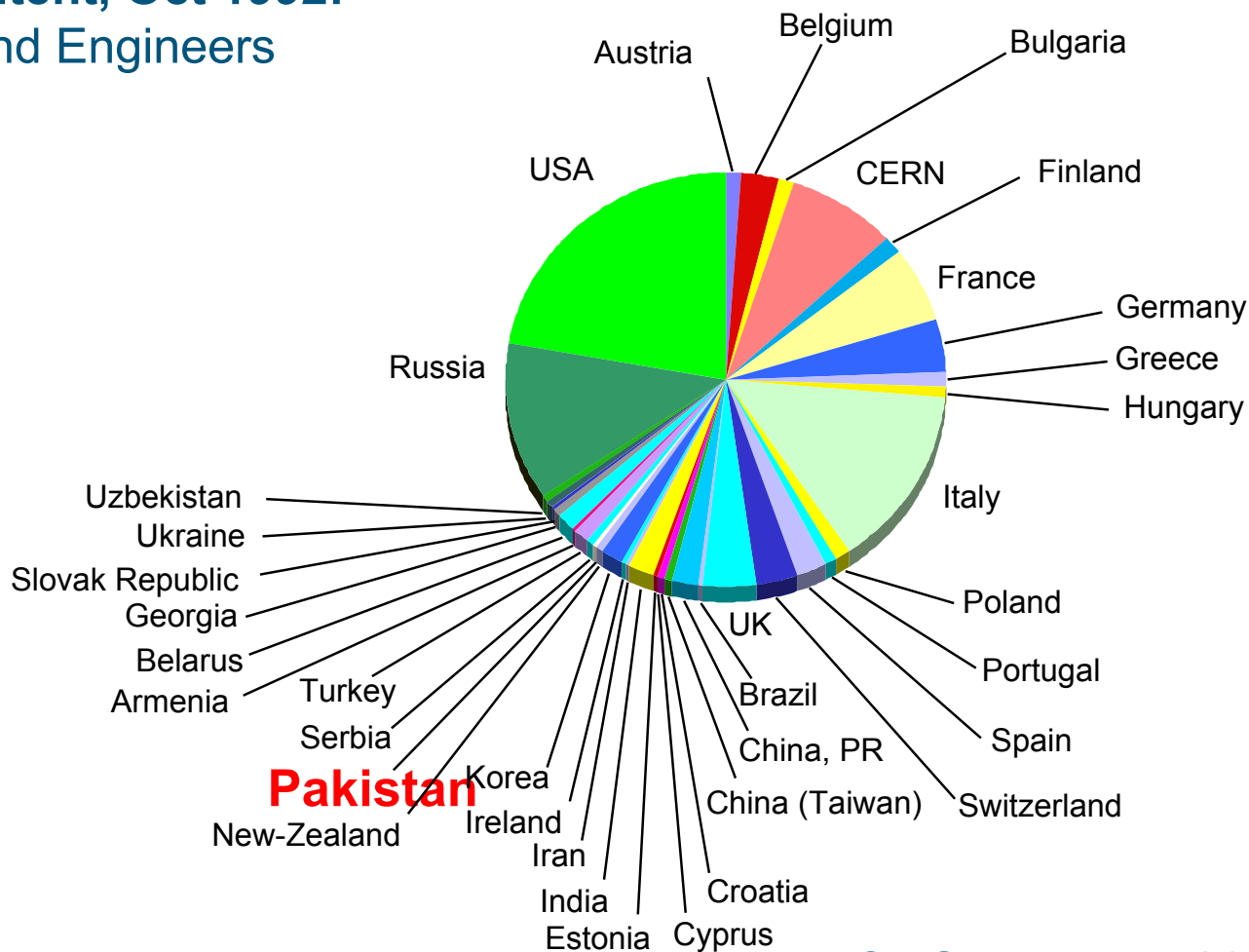
CMS Collaboration

CMS Letter of Intent, Oct 1992:

443 Physicists and Engineers

23 Countries

49 Institutions



CMS RRB Apr 2004

1976 Physicists and Engineers

36 Countries

153 Institutions

April, 05 2004/gm

<http://cmsdoc.cern.ch/pictures/cmsorg/overview.html>

LHC Detector Innovations

LHC challenges have led to dramatic detector progress

- Precise and fast Electromagnetic Calorimeters; high granularity (~100,000 channels), radiation hard.
 - ATLAS: Liquid Argon – “accordeon” for high speed operation
 - CMS: PbWO₄ – fast crystal calorimetry, radiation resistant; more precise than Lar, but more difficult to calibrate.
- Huge Supraconducting Magnets
 - CMS: 4T Solenoid – HPD, APD photodetectors working at 4T
 - ATLAS: Muon Toroids – precision momentum over an enormous volume.
- All silicon tracking – 200 m² (10 M strips, 60 M pixels)
- Silicon pixels at p-p colliders for b tagging.
- Deep Submicron (0.25μm) electronics – radiation hard
- Optical data transfers – fast, hermetic - Gigabit Optical Links.

Physics at Startup

ATLAS and CMS will be ready for first collisions in 2007.

Example SM Higgs Discovery Reach (5σ): ATLAS +CMS

At $L_0 = 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

1 month $\sim 0.7 \text{ fb}^{-1}$

At $L_0 = 3 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

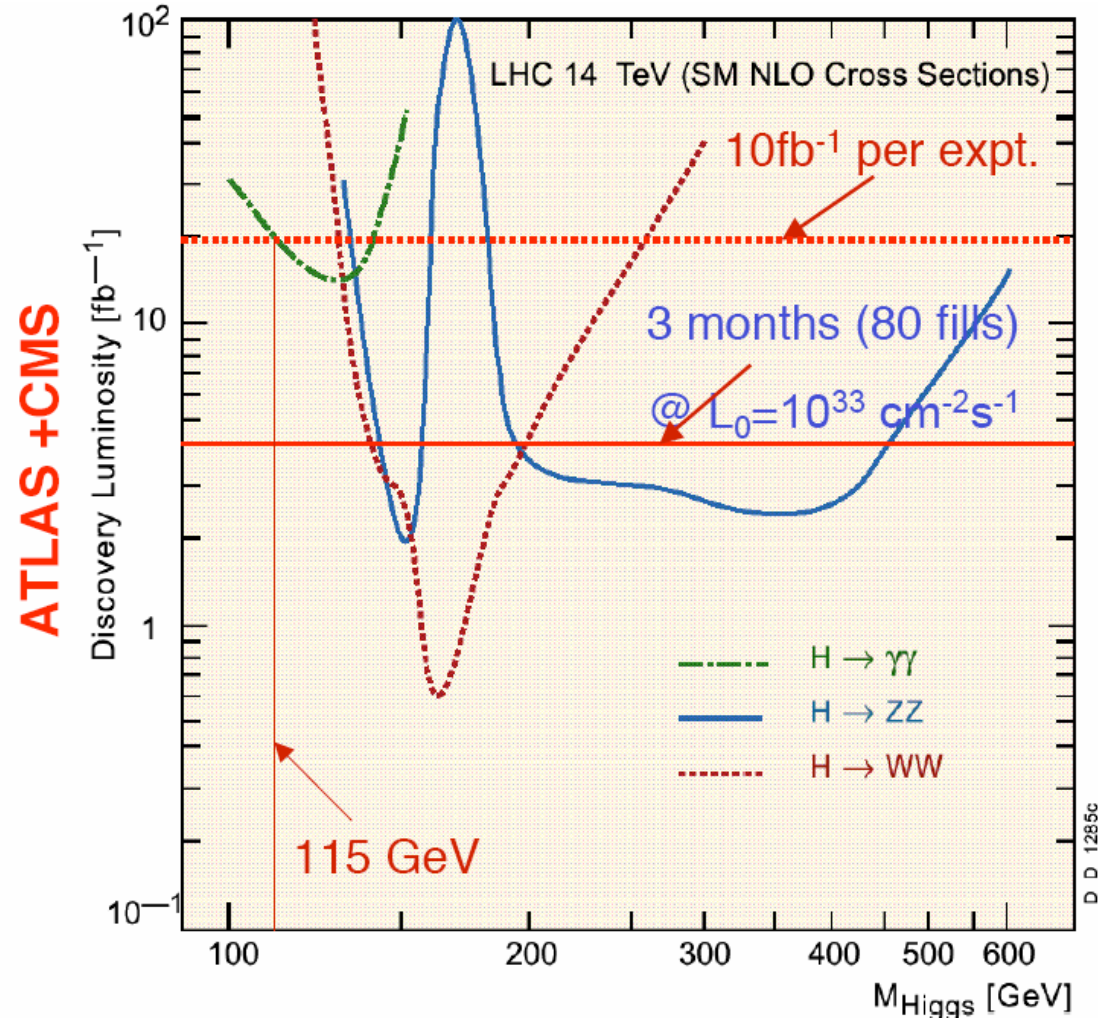
1 month $\sim 2 \text{ fb}^{-1}$

Assumptions: 14hr run

and 10hr to refill

i.e. 1 fill/day

$t_L \sim 20 \text{ hr}$, Efficiency of 2/3



Conclusion

Hadron Colliders are discovery machines.

- **ISR:** large PT phenomena, first indications of strong parton-parton interactions.
- **Sp \bar{p} S UA1/UA2:** Jet Physics establish QCD as theory of strong interactions. Confirmation of the EW theory with the observation of the IVBs (Ws and Zs) and the study of their properties.
- **Tevatron CDF/D0:** Discovery of the Top quark. The top is heavy!
- **LHC CMS/Atlas:** Probe the 1 TeV mass scale for the first time. The Standard Model has been precisely tested at LEP. Theory needs experimental input.

There are no firm predictions: Higgs? Supersymmetry? Extra-dimensions? Something new will be discovered, we don't know exactly what and this is very exciting.

Rendez-vous in 2007 for the first collisions at LHC