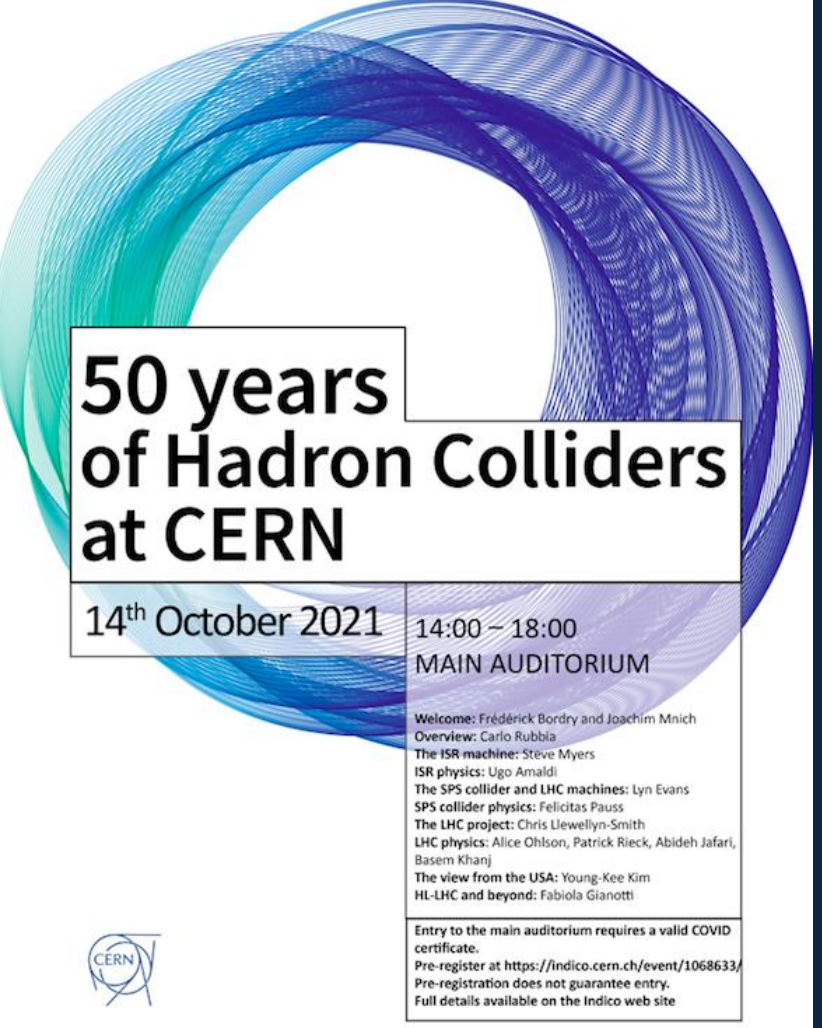


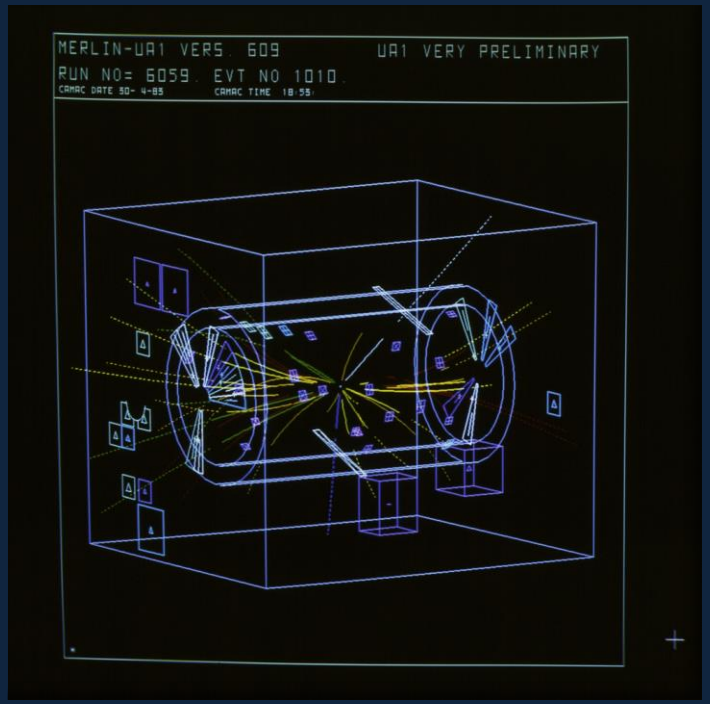
SpS̄pS Collider Physics

a very exciting time in CERN's history

Felicitas Pauss
ETH Zurich

***The** physics highlight at the proton-antiproton collider:*
the discovery of the W and Z bosons – the carrier of the weak force.

1st Z event recorded by UA1: 30 April 1983 at 18:53



First row: G. Salvini, E. Picasso, A. Leveque
Second row: A. Astbury, L. DiLella, **C. Rubbia, S. van der Meer,**
P. Darriulat, A. Kernan, D. Cline, B. Aubert

What were the big physics questions/challenges in the mid/end 1970s?

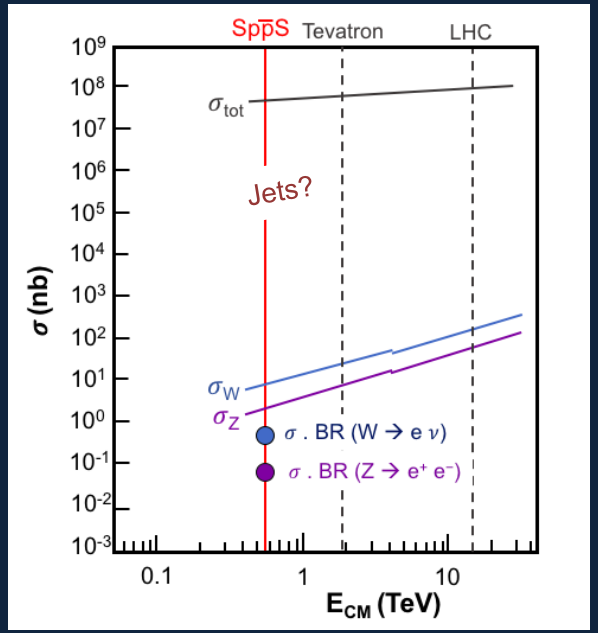
- Formulation of the electroweak theory → $m_Z = m_W / \cos \theta_W$
- 1973 discovery of neutral currents at CERN and first sin θ_W measurement → **m_W = 60-80 GeV, m_Z = 75-92 GeV**
- 1977: QCD applied for predictions of hard scattering processes
- 1977: discovery of b-quark → top quark must exist …..

Which machine for W and Z discovery?

- 1976: LEP study group initiated (John Adams)
  → too long time schedule / competition in US?
- 1976: C. Rubbia, P. McIntyre and D. Cline proposed **proton-antiproton collider** using existing accelerators (ν-conference in Aachen) → see talk by L. Evans

Recall: $\sqrt{s}$ = 540 GeV: 1981 – 1983; $\sqrt{s}$ = 630 GeV: 1984 – 1990
1985-1987: upgrade of accelerator and experiments
1985: 1st pulsed run: max $\sqrt{s}$ = 900 GeV

Experimental challenges

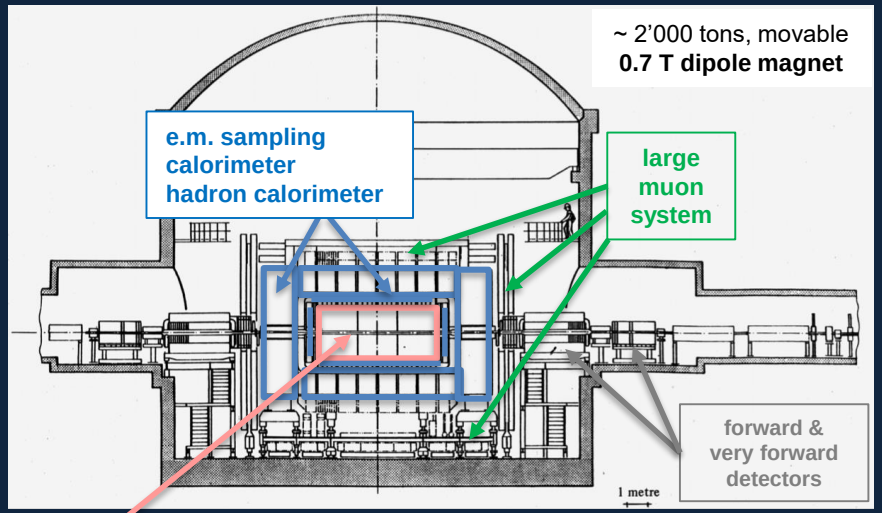


Other open questions:

- how are the experimental conditions / backgrounds from the collider?
- 4π detector concept – correct approach?

The UA1 experiment

First multi-purpose 4π (hermetic) detector in particle physics

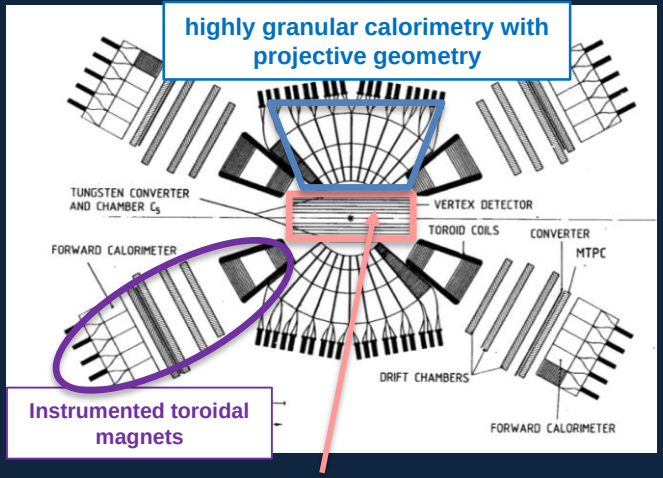


central detector: drift chamber (L=5.8 m, D=2.3 m)
cutting edge technology, the first "electronic bubble chamber"

Approved in June 1978 – first events observed in June 1981

The UA2 experiment

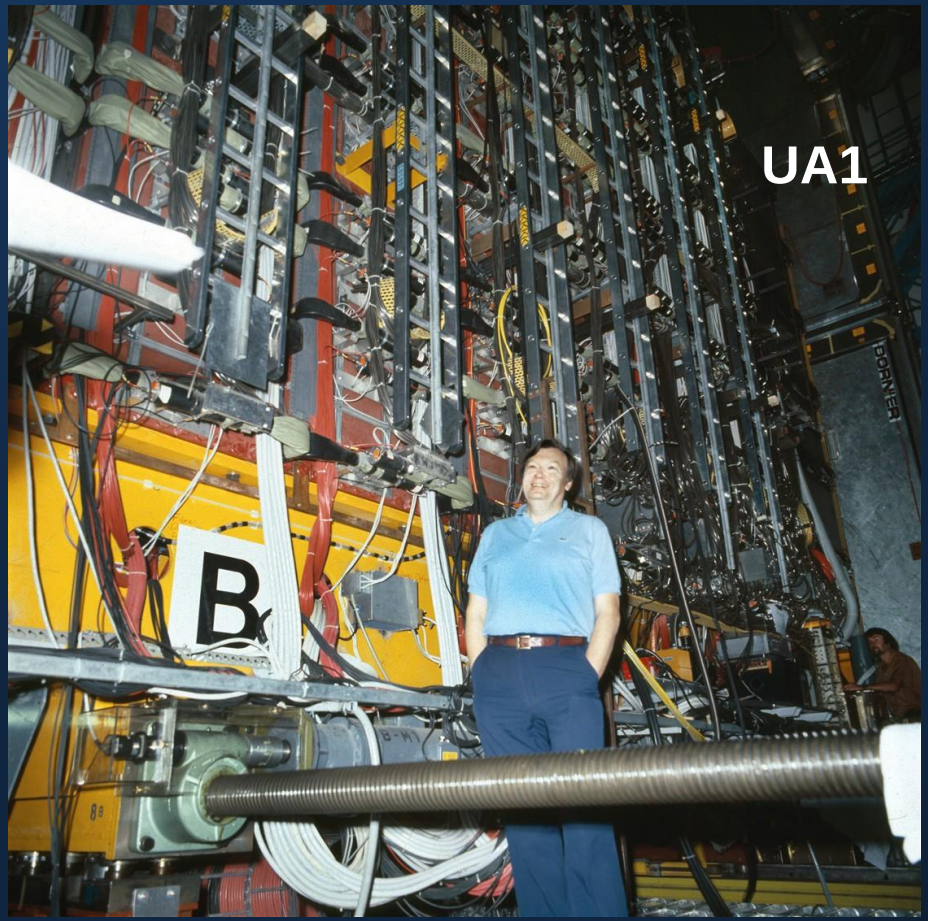
optimized for W and Z detection in electron channel
no central magnetic field, no muons

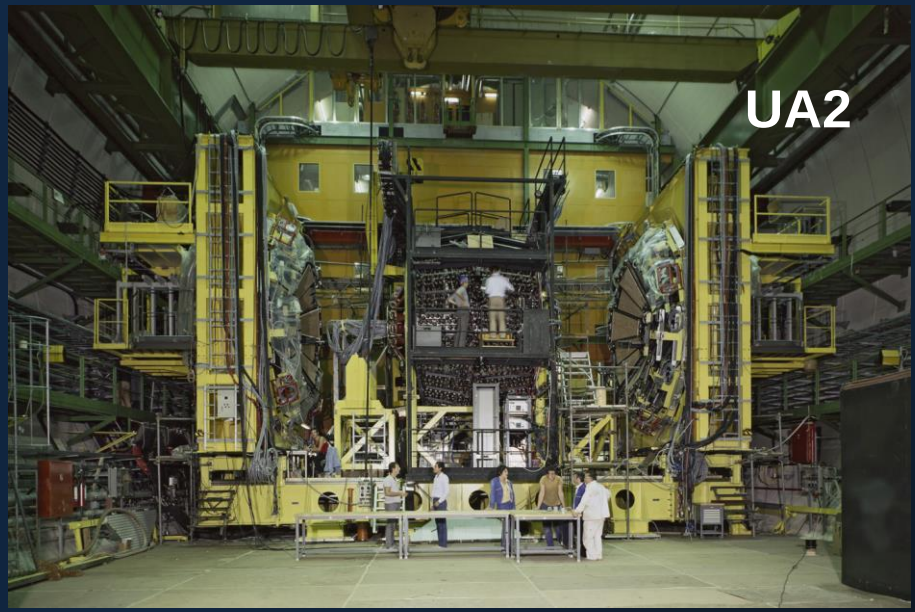


vertex detector: cylindrical drift chambers + preshower
Upgrade: inner Si pad detector → first incarnation of a Si tracker adapted to collider experiments

Magnetic spectrometer: Upgrade: replaced by calorimeter

Approved in Dec 1978 – first data taking in Dec 1981

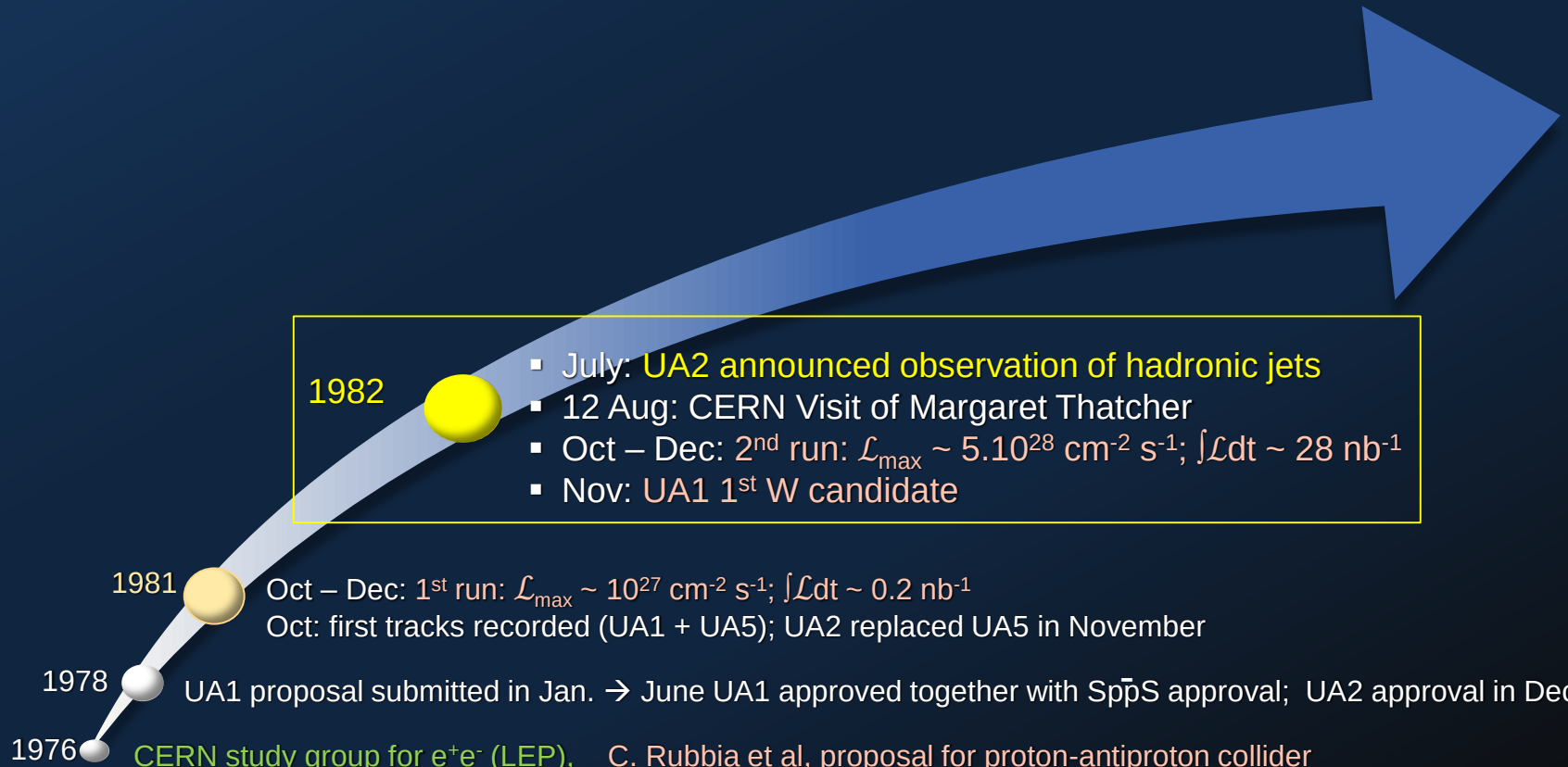




Collider offered also other experiments to exploit this new energy domain: e.g.:

- UA4: σ_{tot} measurement using Roman pots, 40 m from UA1-IP
- UA5: large streamer chamber allowing to detect charged particles down to < 1^{o}, (a few days of data taking before UA2 was rolled into the tunnel in Nov 1981)

The Timeline of Discoveries



1982

- July: UA2 announced observation of hadronic jets
- 12 Aug: CERN Visit of Margaret Thatcher
- Oct – Dec: 2nd run: $\mathcal{L}_{max} \sim 5.10^{28}$ cm^{-2} s^{-1}; $\int \mathcal{L} dt \sim 28$ nb^{-1}
- Nov: UA1 1st W candidate

1981

Oct – Dec: 1st run: $\mathcal{L}_{max} \sim 10^{27}$ cm^{-2} s^{-1}; $\int \mathcal{L} dt \sim 0.2$ nb^{-1}
Oct: first tracks recorded (UA1 + UA5); UA2 replaced UA5 in November

1978

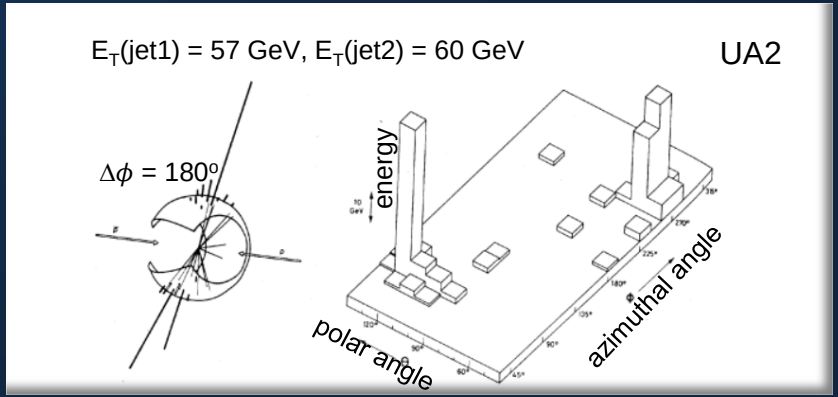
UA1 proposal submitted in Jan. → June UA1 approved together with $Sp\bar{p}S$ approval; UA2 approval in December

1976

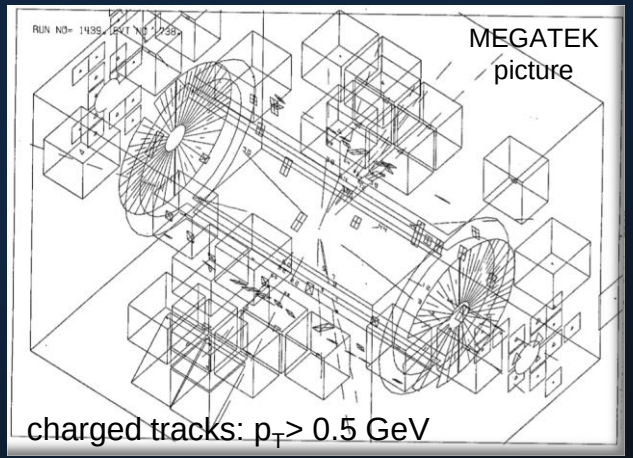
CERN study group for e^+e^- (LEP), C. Rubbia et al, proposal for proton-antiproton collider

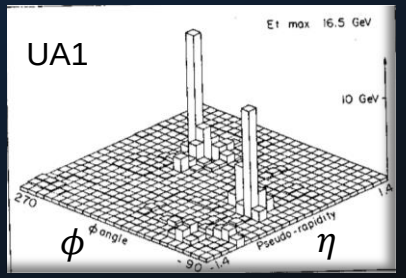
1982: in July (Paris Conference) UA2 announced observation of hadronic jets

UA2: a pragmatic approach:
select the highest E_T events, simply "look at" the energy flow in the calorimeter



6th European Symposium: 30 August - 3 September 1982
in Santiago de Compostela, Spain
→ **celebration of collider jets**





MEGATEK: interactive event display facility

UA1: first looked at correlations of tracks in the central detector
then used tracks or cells for jet algorithm:
$R_{cone}=\sqrt{(\Delta\phi)^2+(\Delta\eta)^2}$, $\eta = -\ln(\tan\theta/2)$
e.g.: θ=40° → η =1.0 θ=5° → η=3.0

1982

Margaret Thatcher, Prime Minister UK visits CERN in August 1982

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

DIRECTOR-GENERAL

CERN
CH-1211 GENEVA 23
SWITZERLAND

Mrs Margaret THATCHER
Prime Minister
10 Downing Street

LONDON

20 Dec 1982

Geneva, 20 December 1982

Dear Prime Minister,

In presenting you with my respects and best wishes for the New Year, I am ever mindful of the promise I made on the occasion of your visit to CERN, in August of this year, that I would report to you immediately and directly on the day CERN obtained confirmed experimental evidence for the existence of the "intermediate boson" (W^+, W^- and Z^0) for which we are actively searching.

I should have liked to combine seasonal greetings with the report that such a discovery had indeed been made, but, in the absence of incontrovertible evidence, I am nevertheless pleased to inform you, in strict confidence, that results recently obtained point to the imminence of such a discovery. Indeed, a few events have been seen containing one electron and missing energy on the opposite side, compatible with the decay mode $W^+ \rightarrow e^+ + \nu$.

As soon as final and irrefutable evidence is available, I shall immediately communicate the news to you.

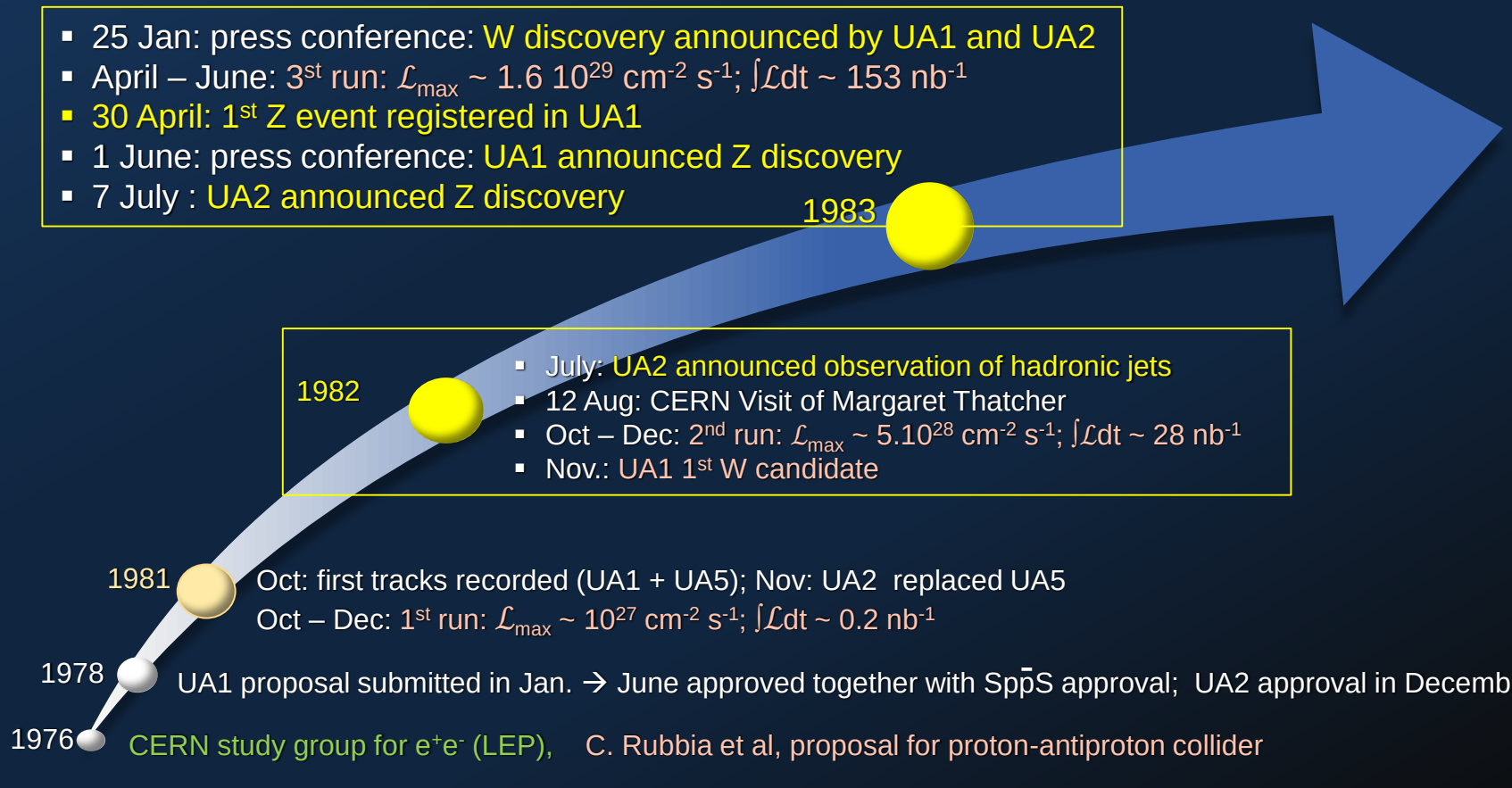
Meanwhile, I have the honour to remain, dear Prime Minister,
Very respectfully

Yours,

cc.: Sir Alec Merrison

*"…. … I am… pleased to inform you, **in strict confidence**, that the results recently obtained point to the imminence of such a discovery. Indeed, a few events have been seen compatible with the decay mode $W^+ \rightarrow e^+ + \nu$ ……."*

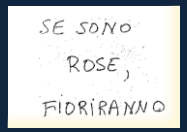
The Timeline of Discoveries



1983: W discovery
in e-channel

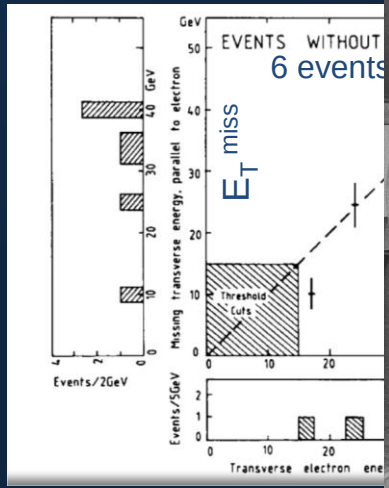
introduction of E_T^{miss} signature as new analysis tool:

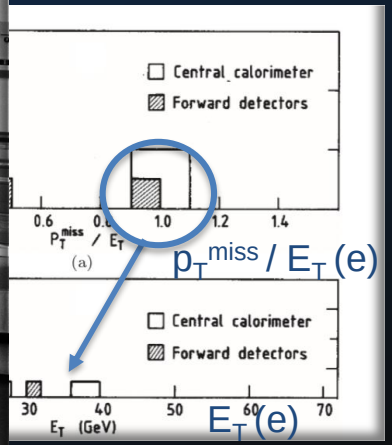
$$\vec{E}_T^{miss} + \sum_{cells} \vec{E}_T = 0$$



- 12-14 Jan: Rome meeting: W-candidates shown by UA1 and UA2
- CERN Seminar:
  20 Jan 1983, Ca
  21 Jan 1983, Lu

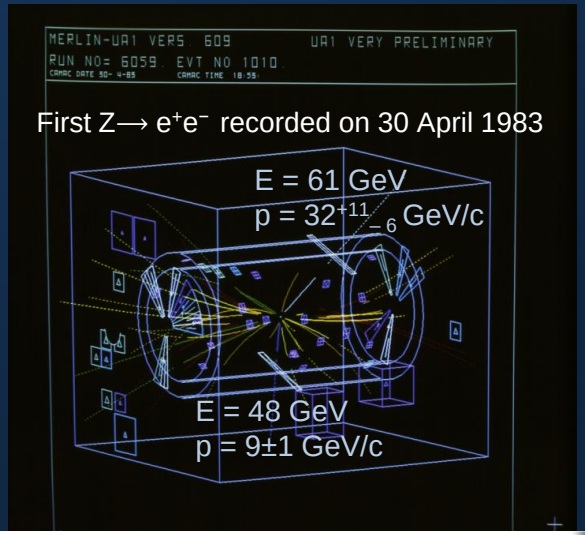
following week:
s, they feel like Ws, they smell
t be Ws"





$m_W = 80\ ^{+10}_{-6}$ GeV

1983: Z discovery – UA1



- 27 May: seminar at CERN by Carlo Rubbia: first Z events (e^+e^- and $\mu^+\mu^-$)
- 1 June: press conference announcing Z discovery
- 6 June: paper submitted for publication (Phys.Lett.B)

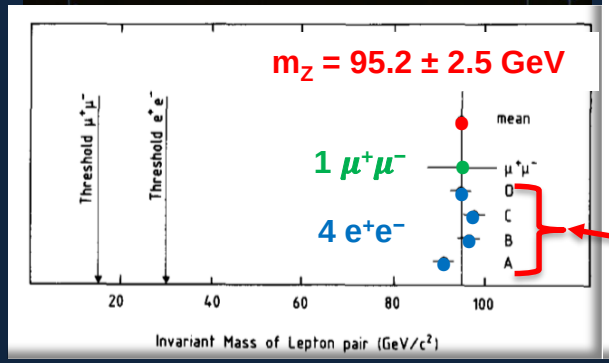
The New York Times

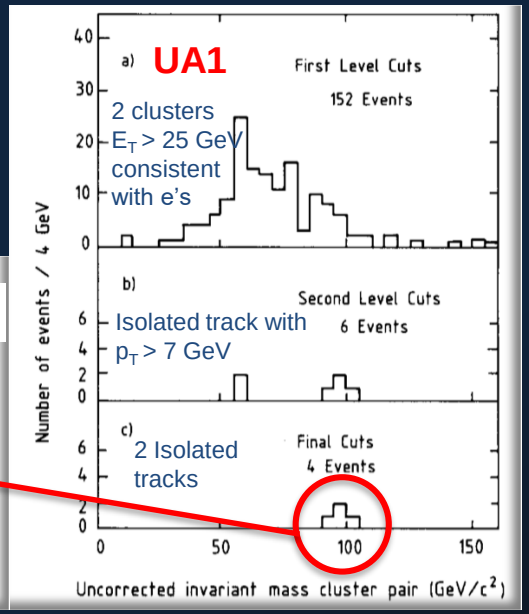
6 June 1983

Europe 3, U.S. Not Even Z-Zero

A team of 126 scientists at the CERN accelerator in Geneva reports proof of an important new subatomic particle, the Z-zero. The discovery carries two messages. The good news is that it confirms a major theory about the fundamental forces of nature. The bad news is that Europeans have

American physicists blame lack of Federal support. But some observers, like the President's science adviser, George Keyworth, blame the physicists for routinely spreading funds among the three major American research centers. "Our world leadership in high energy physics has been displaced,"



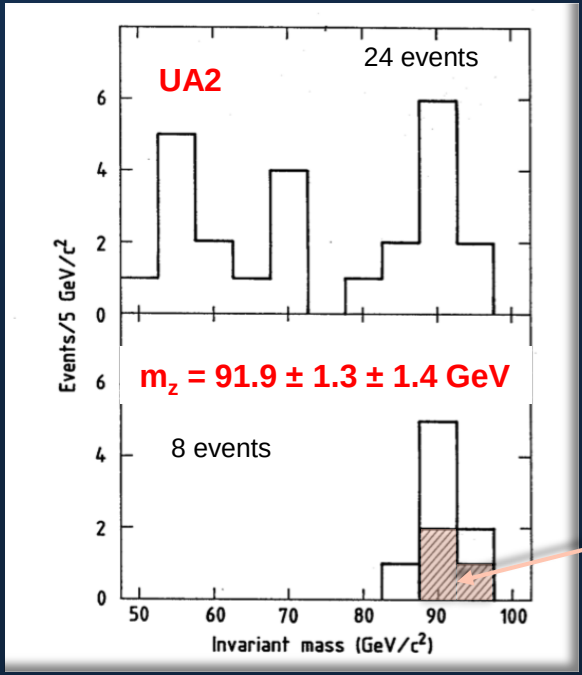


1 June 1983: CERN press conference announcing the Z discovery

1983: Z discovery – UA2

7 July 1983: CERN seminar by P. Darriulat to announce Z discovery

11 August: paper submitted for publication (Phys.Lett.B)

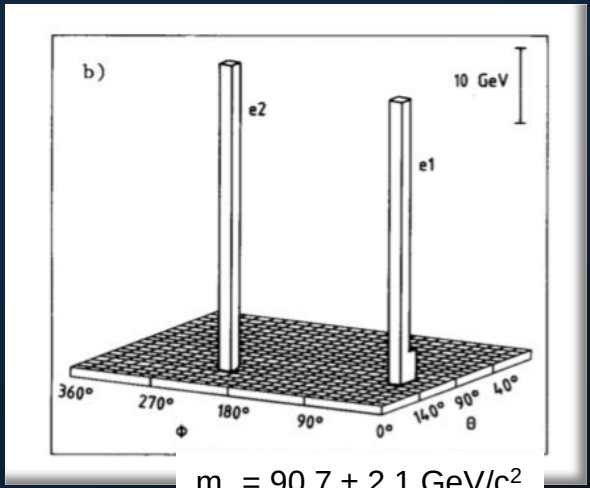


Two energy clusters with E_T > 25 GeV, consistent with electrons → 24 events

A track identified as an isolated electron pointing to at least one of the two clusters → 8 events

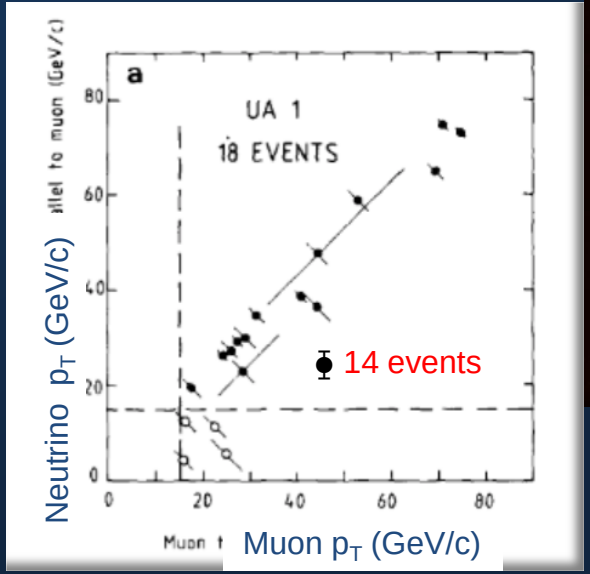
Shaded area: Tracks identified as an isolated electron pointing to both energy clusters
→ 3 events

UA2 Z-candidate

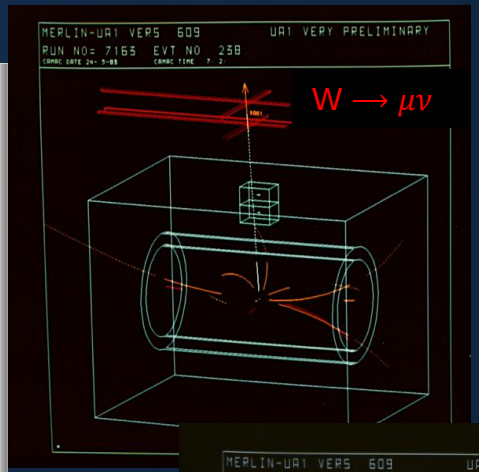


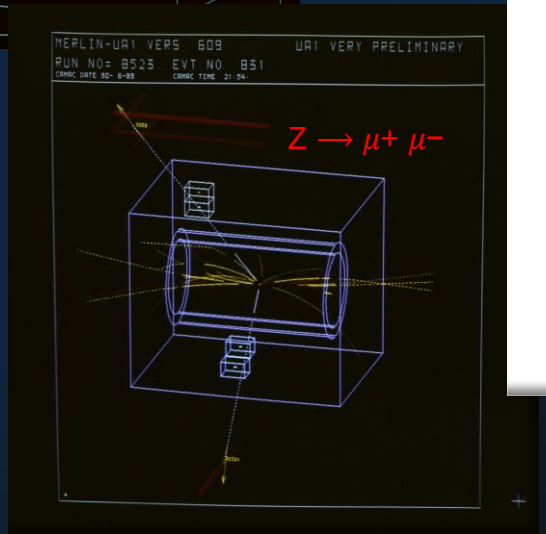
m_z = 90.7 ± 2.1 GeV/c²

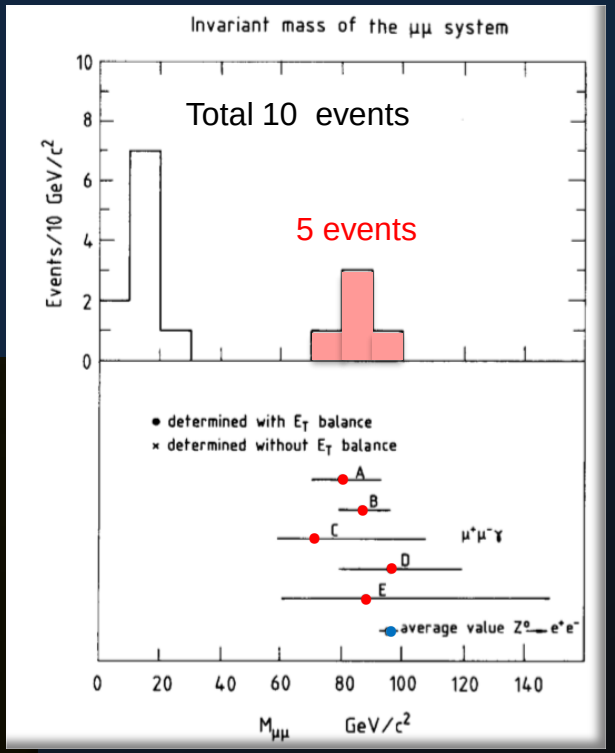
UA1: analysis of 1983 data: W ⟶ $\mu\nu$ and Z ⟶ μ+ μ− events



$m_W = 81\ ^{+6}_{-7}$ GeV







$m_Z = 85.8\ ^{+7.0}_{-5.4}$ GeV

Compared to 43 W ⟶ e ν events

Very exciting time!
Not much sleep!

1984 till 1990: Tests of SM and Searches for Physics Beyond the SM

1985 – 1987: upgrade accelerator & experiments

1983
Discovery of W and Z

1990

End of data taking

1982
hadronic jets

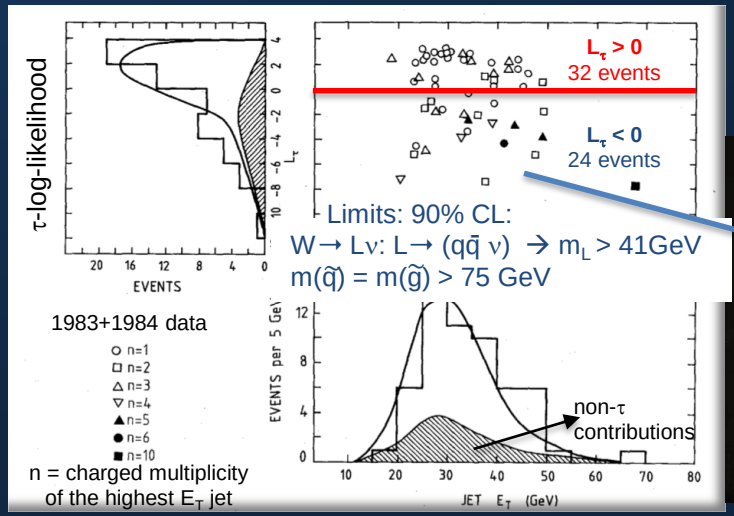
1981

1978

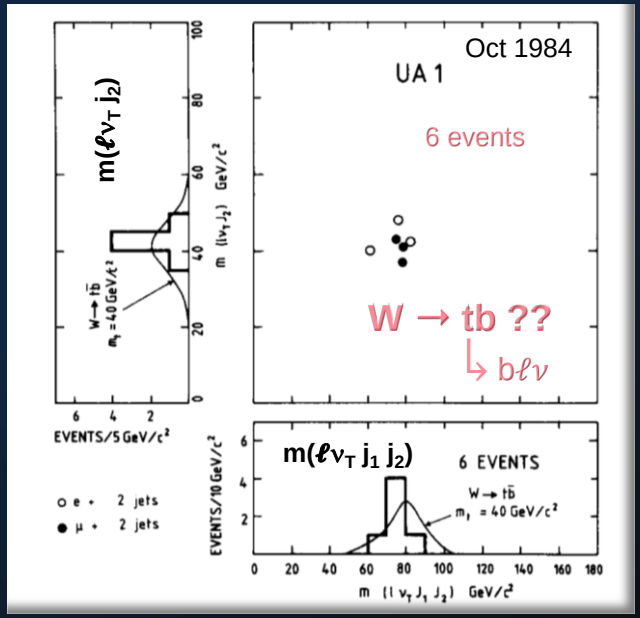
1976

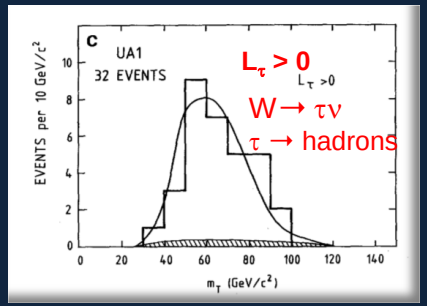
1984 till 1990: Searches for Physics Beyond the SM and the Top Quark

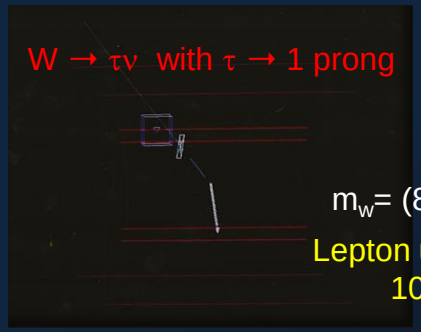
UA1: Events with jet(s) and large E_T^{miss}



UA1: Events with an isolated, large p_T lepton (e or μ) and 2 jets







m_W= (89±3±6) GeV

Lepton universality tested to 10% at $Q^2 = m_W^2$

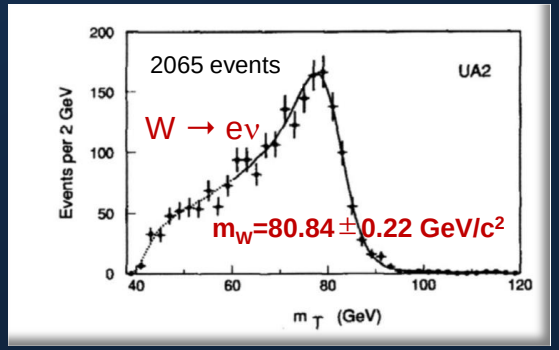
in 1990: limits placed at the 95% C.L.:
UA1: $m_{top} > 60$ GeV/c²
UA2: $m_{top} > 69$ GeV/c²

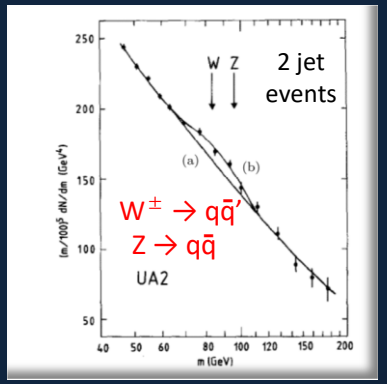
1984 till 1990: Tests of SM Predictions

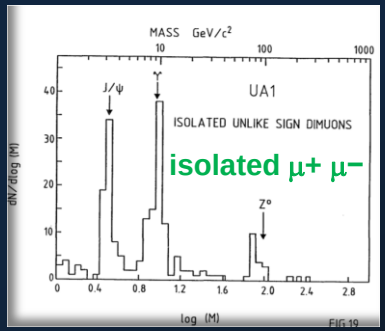
First measurements of B^o-$\bar{B}^o$ oscillations by UA1:
count B^o meson decaying in "wrong-sign" non-isolated muon:

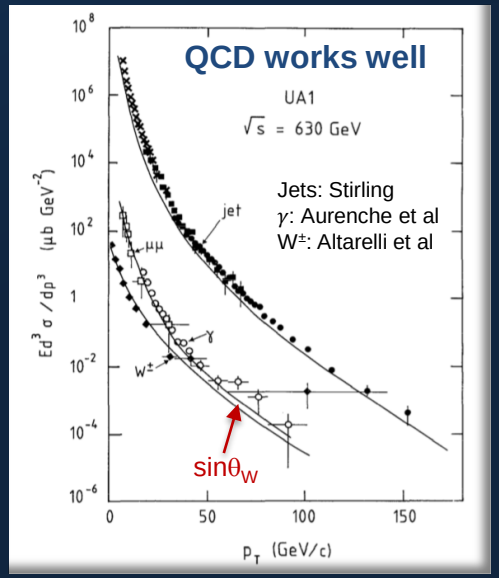
$$\frac{N(++)+N(--)}{N(+-)} = 0.42 \pm 0.07 \pm 0.03$$

Prediction: R = 0.26 ± 0.03

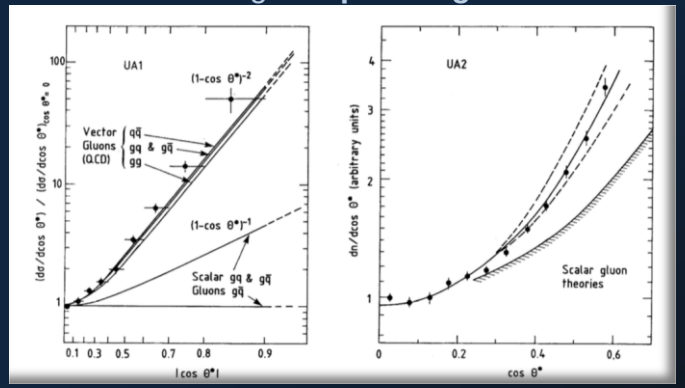


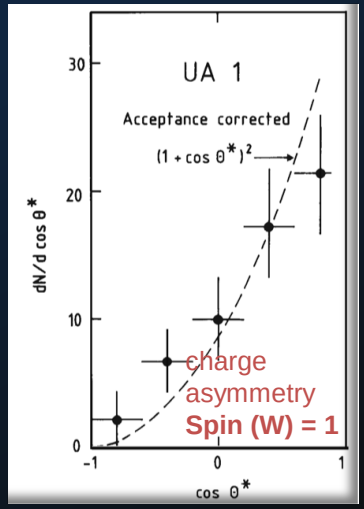




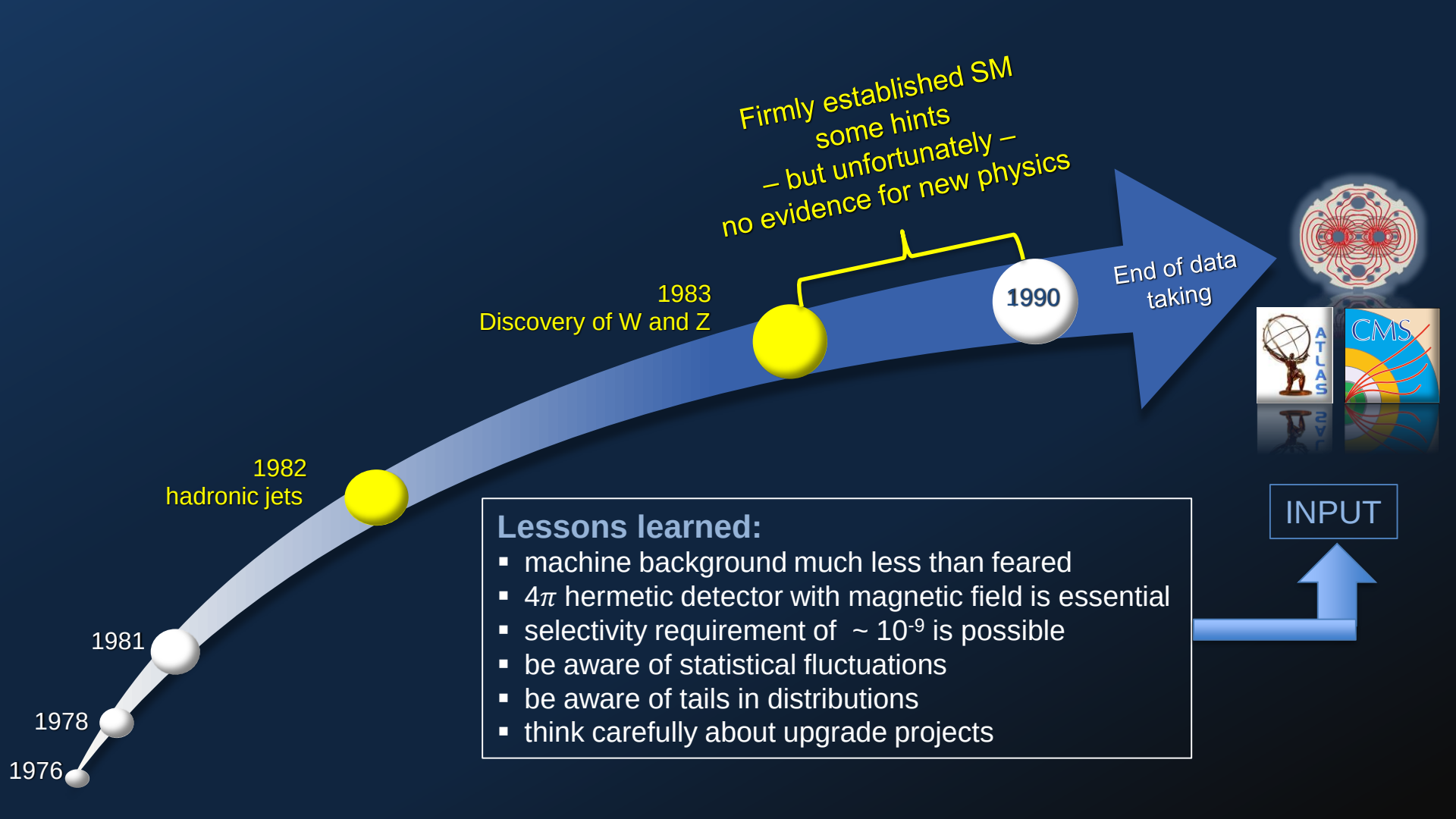


Angular distribution of parton-parton scattering for **spin = 1 gluons**





And many more results
:
:


Firmly established SM
some hints
– but unfortunately –
no evidence for new physics
1983
Discovery of W and Z
1990
End of data taking
1982
hadronic jets
1981
1978
1976
ATLAS
CMS
Lessons learned:
machine background much less than feared
4π hermetic detector with magnetic field is essential
selectivity requirement of ~ 10-9 is possible
be aware of statistical fluctuations
be aware of tails in distributions
think carefully about upgrade projects
INPUT

A big thank you to all my friends and colleagues from **UA1** and **UA2** for contributing to this very rich physics output at CERN's $p\bar{p}$ collider and sharing this exciting time with me !

EXPERIMENTAL OBSERVATION OF LEPTON PAIRS OF INVARIANT MASS AROUND 95 GeV/c^2 AT THE CERN SPS COLLIDER

UA1 Collaboration, CERN, Geneva, Switzerland

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Received 6 June 1983

EVIDENCE FOR $Z^0 \to e^+e^-$ AT THE CERN $\bar{p}p$ COLLIDER

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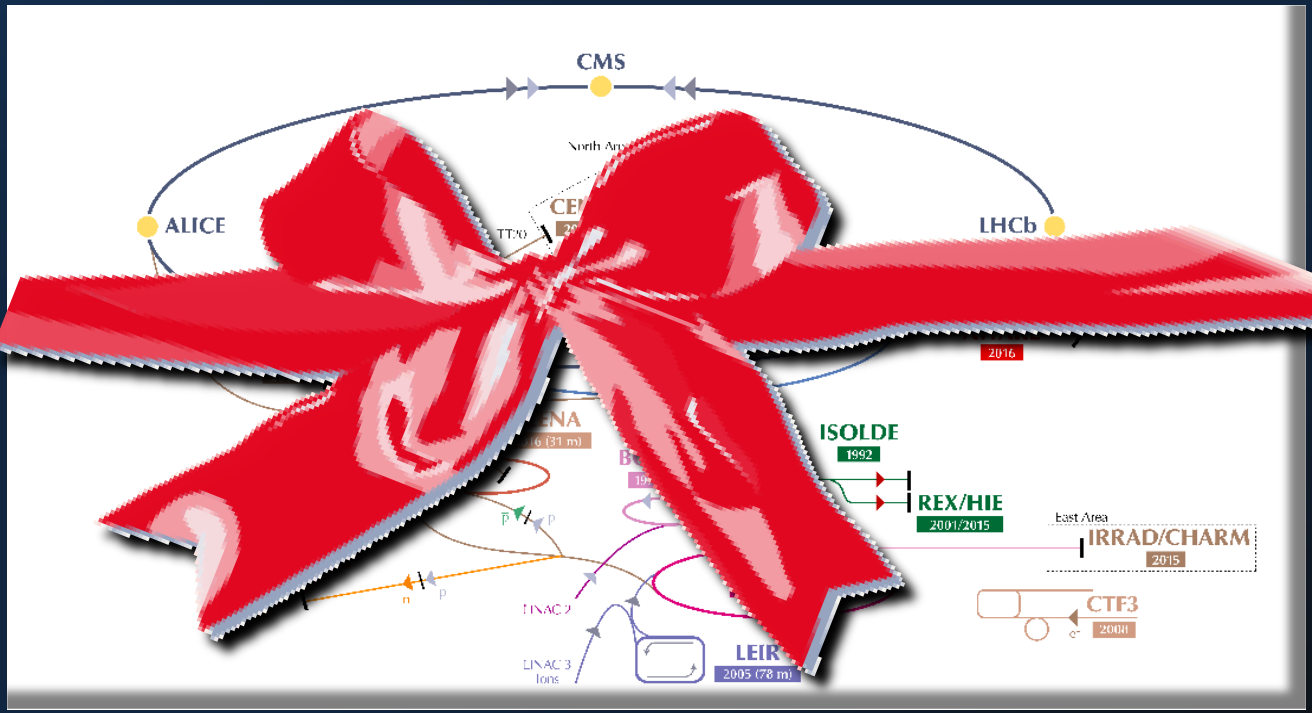
Received 11 August 1983

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