

Auswertung von LEP-Daten (Large Electron Positron Collider)

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Juli 09



Vermittlung in der Schule

- Geschichte der Teilchenphysik (spannend !)
- Animationen, Lehr- und Lernmodule (vielfältig !) : www.teilchenphysik.de
- Exkursion zum CERN, DESY (ein Erlebnis !)
- Experiment (lehrreich !)
- Datenauswertung

Bausteine der Materie: Quarks und Leptonen



Stabile Materie: up- und down-Quark, Elektronen

LADUNG

LEPTONS

0

Electron Neutrino
Mass ~0

Muon Neutrino
~0

Tau Neutrino
~0

-1

Electron
.511

Muon
105.7

Tau
1777

QUARKS

+2/3

Up
Mass: 5

Charm
1 500

Top
~180 000

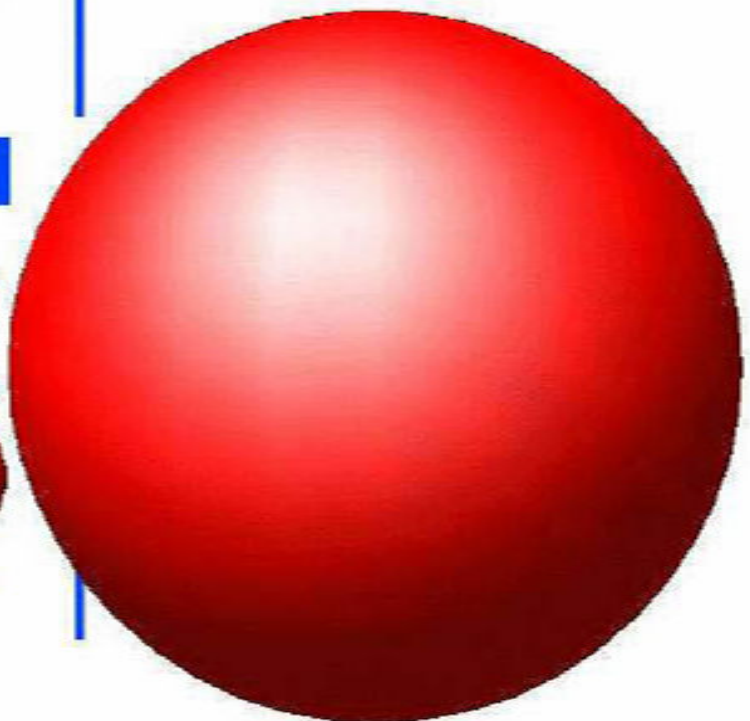
-1/3

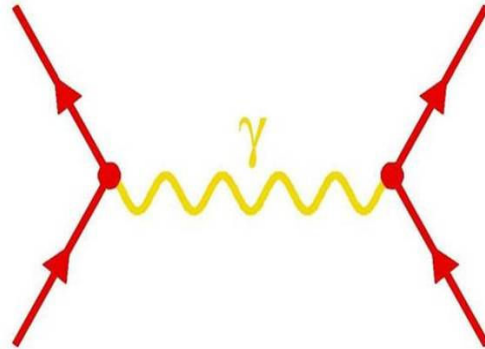
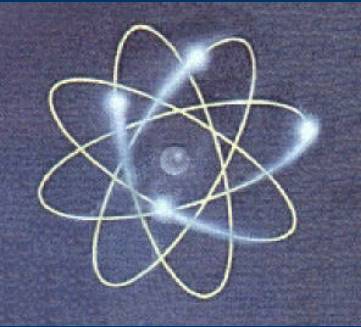
Down
8

Stronge
160

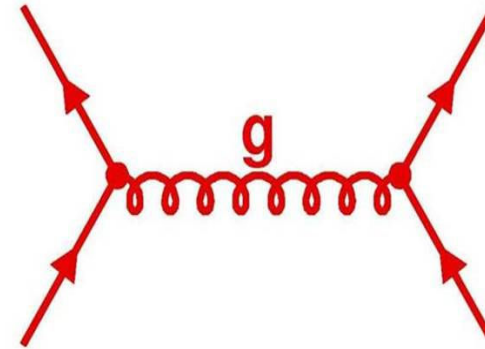
Bottom
4 250

Strukturlose, fundamentale Teilchen: Alle Leptonen
Teilchen mit innerer Struktur: Proton, Neutron,....
aufgebaut aus **Quarks**

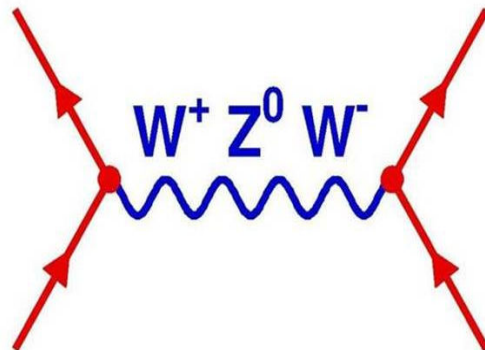
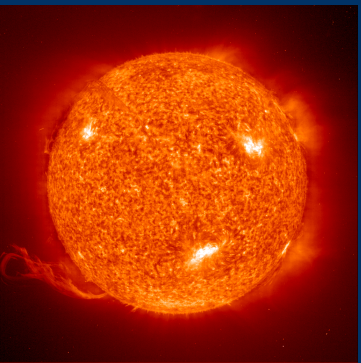
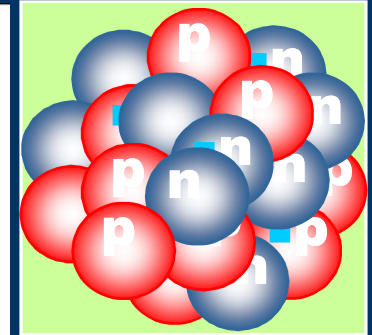




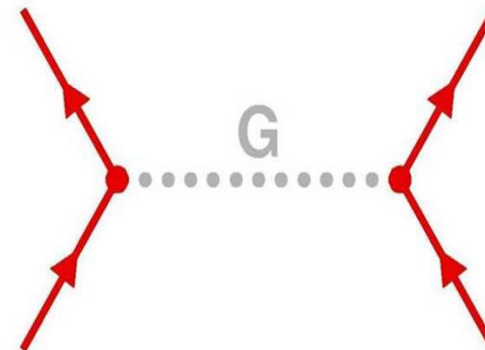
elektromagn. Kraft



starke Kraft



schwache Kraft



Gravitation



Austauschteilchen sind die Quanten der Kraftfelder



Das Standard-Modell der Teilchenphysik

- Beschreibt die fundamentalen Wechselwirkungen
 - Starke Kraft (Kernkraft)
 - Schwache Kraft (Umwandlungsprozesse von Teilchen)
 - Elektromagnetische Kraft
- Gute Beschreibung aller bekannten Prozesse
 - Zerfälle von Teilchen
 - Innere Struktur nicht fundamentaler Teilchen
- Systematik aller bekannten Teilchen
- Beruht auf Symmetrie-Prinzipien
- Sehr erfolgreiche physikalische Theorie



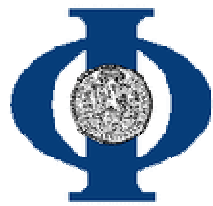
Das Standard-Modell der Teilchenphysik hat bis jetzt allen experimentellen Tests standgehalten.

Dennoch ist vieles unverstanden:

- Woher kommt die Masse (**Higgs-Teilchen**)?
- Gibt es **eine fundamentale Kraft**?
- Welche **Symmetrie** liegt unserer Welt zugrunde?
- Gibt es **zusätzliche Dimensionen**?
- Kennen wir alle Teilchen (**Supersymmetrie**)?

Um Neues zu entdecken, muss man neue Dinge tun:

Der **Large Hadron Collider** (Proton-Proton) mit den Experimenten **ATLAS** und **CMS** am Europäischen Forschungszentrum **CERN** in Genf



■ Elektron-**Positron**-Collider: **Präzisionsmessungen**

- **LEP, CERN** in Genf bis 2000

(bis 105 GeV pro Strahl)

- **ILC** (International Linear Collider) ab 2015(?)



■ Elektron-**Proton**-Collider: **Substrukturmessungen**

- **HERA, DESY** in Hamburg, bis 2007

(e: 30 GeV, p: 920 GeV)



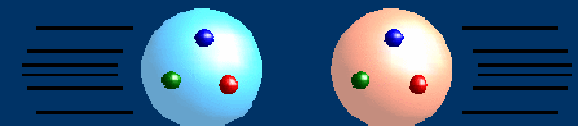
■ **Hadron-Hadron**-Collider: **Entdeckungsmaschinen**

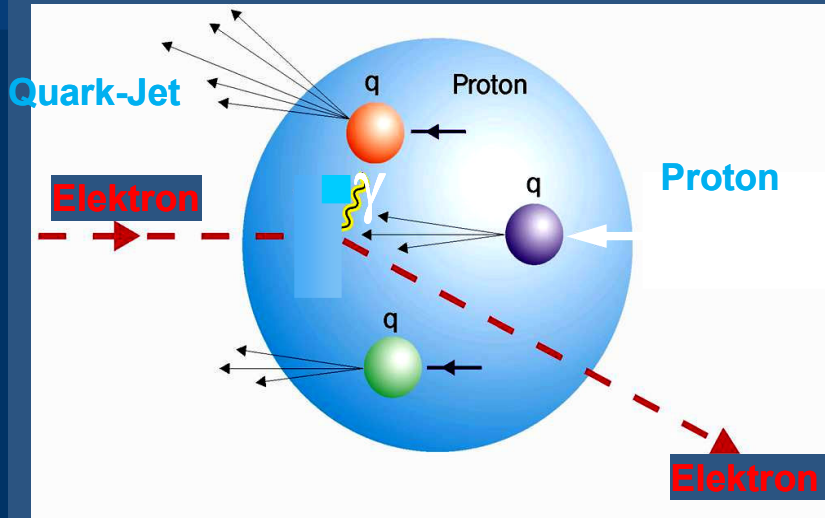
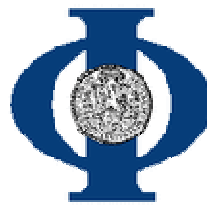
- **TEVATRON, FERMILAB** in Chicago, bis 2010

(900 GeV pro Strahl)

- **LHC, CERN** in Genf (Large Hadron Collider, Proton-Proton) ab 2009

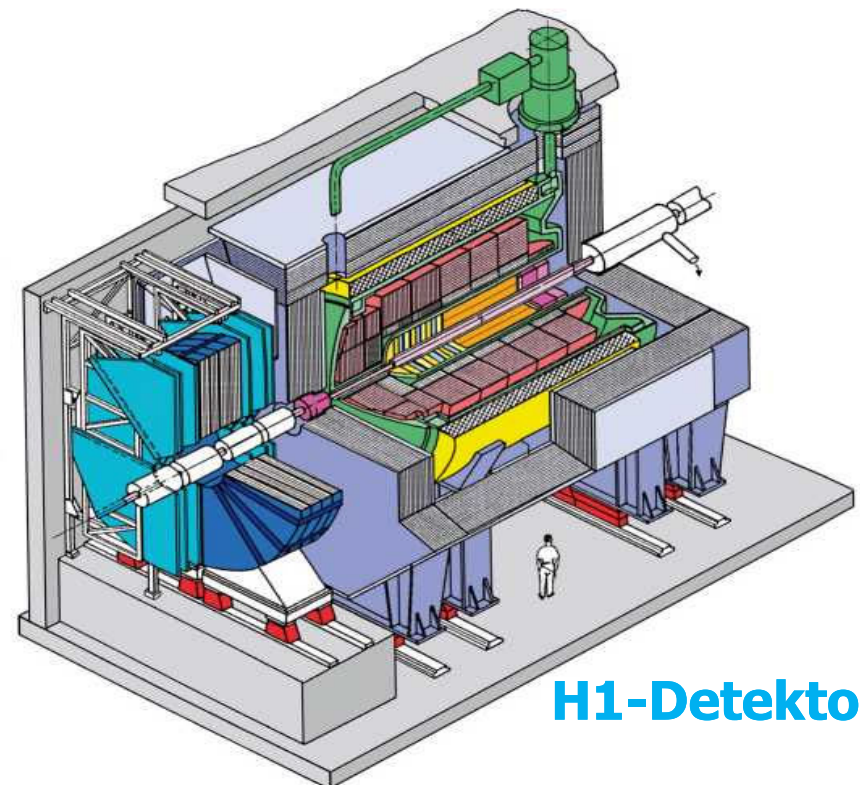
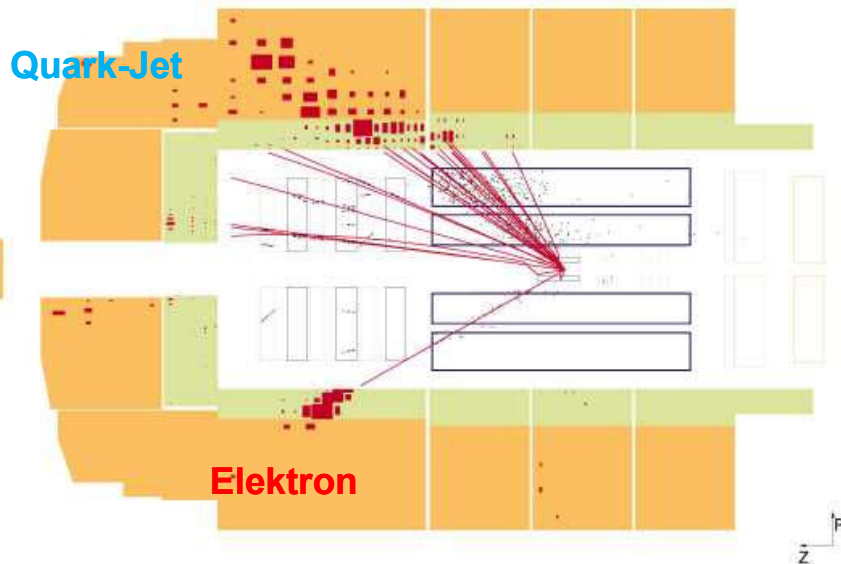
(7000 GeV pro Strahl)

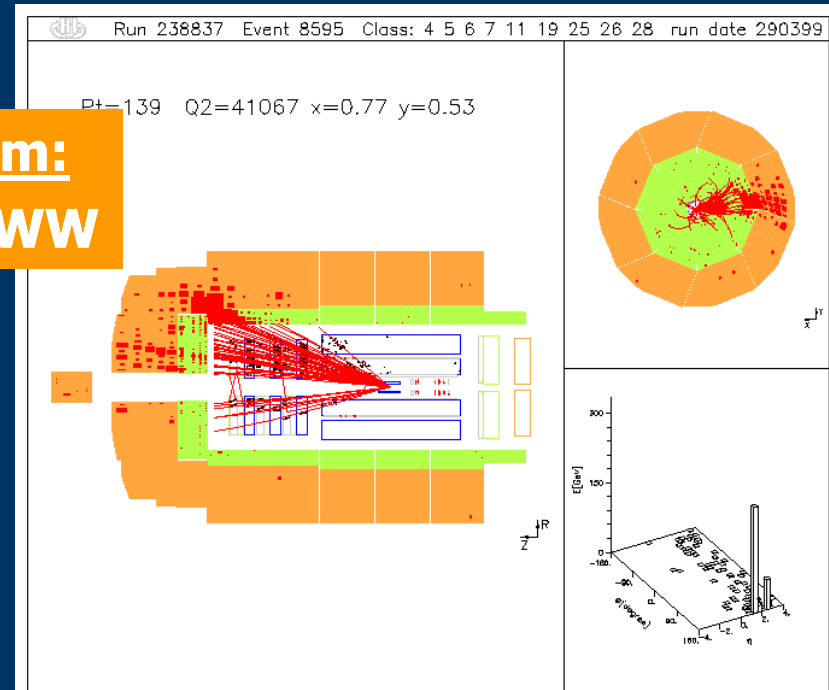
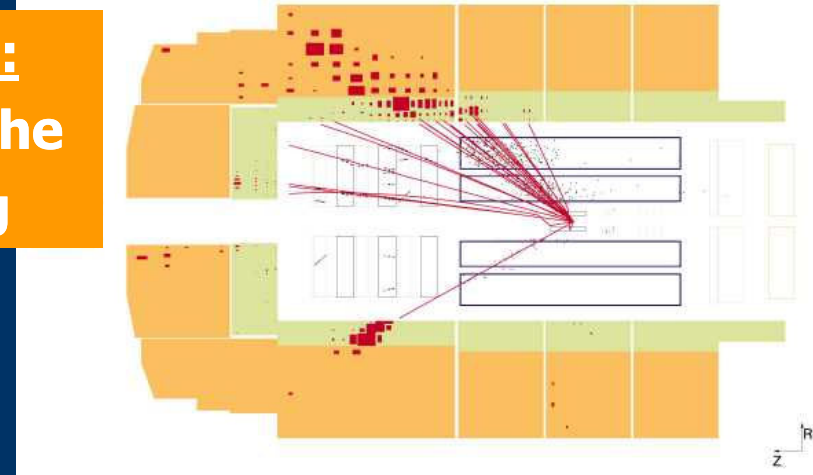
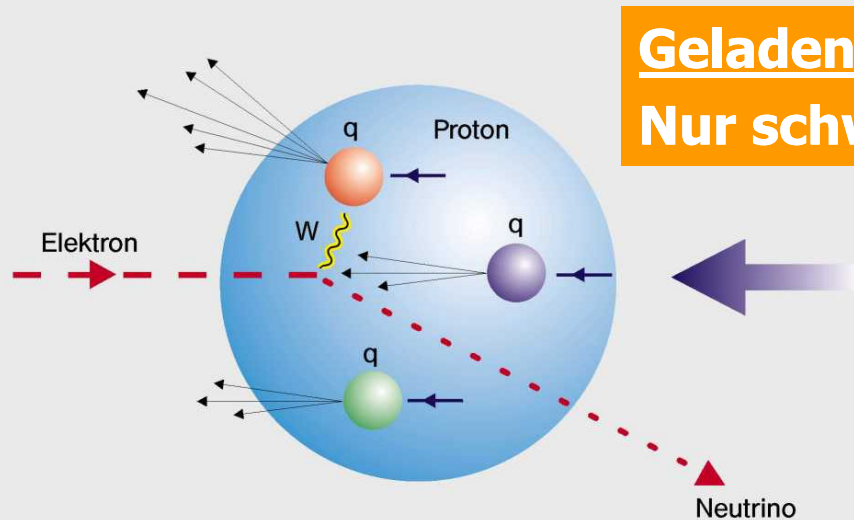
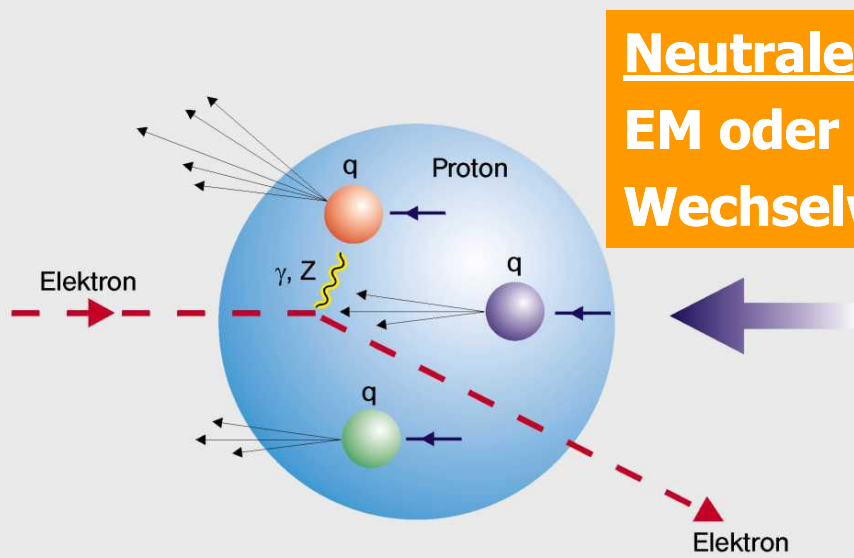
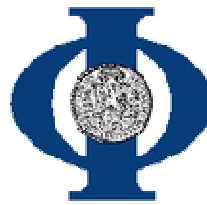




Proton-Elektron Kollisionen bei HERA (DESY):

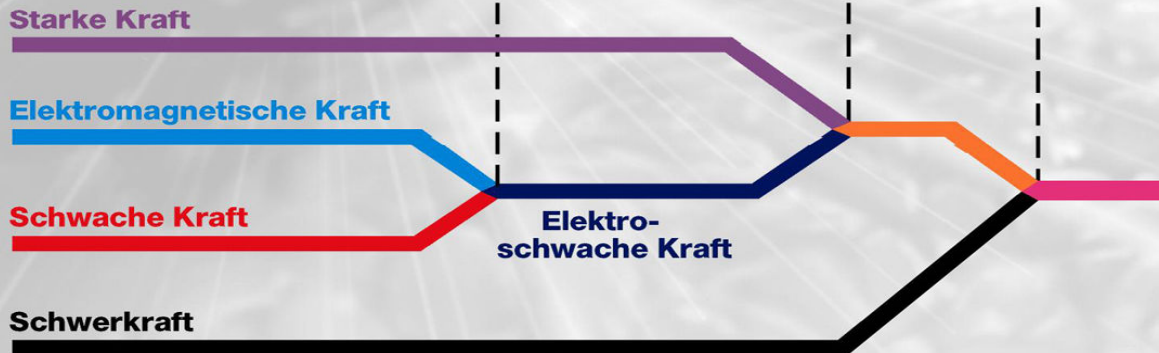
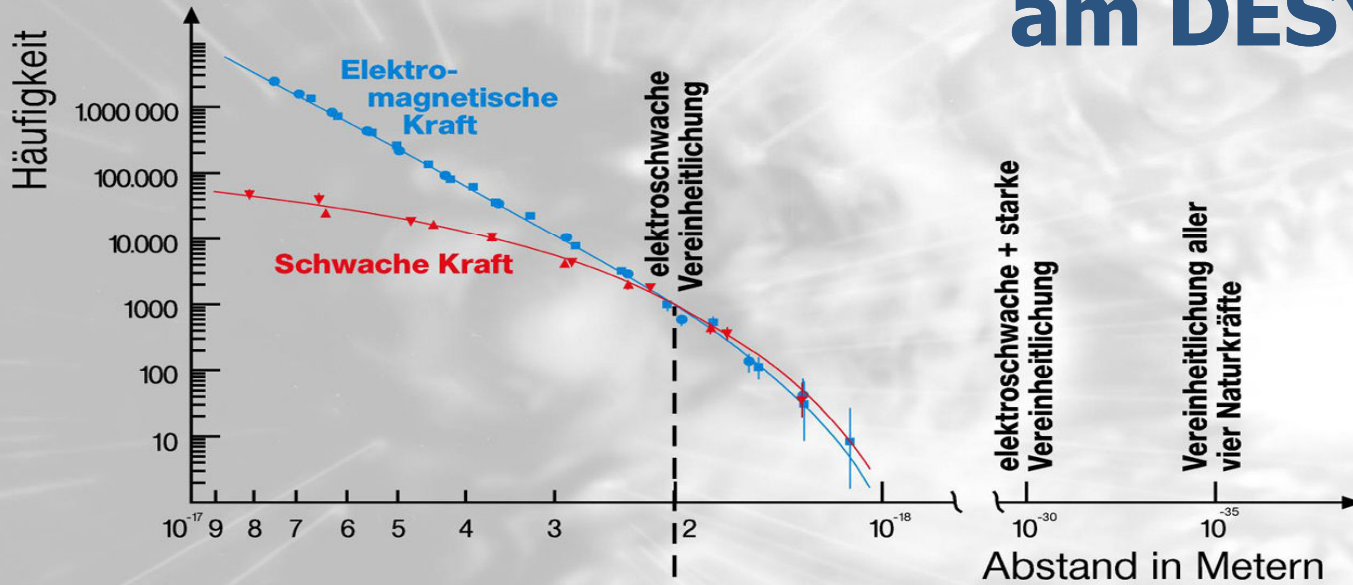
Schwerpunktsenergie von **320 GeV**
entspricht einer Ortsauflösung von **10^{-18} m**
Untersuchung der Protonstruktur



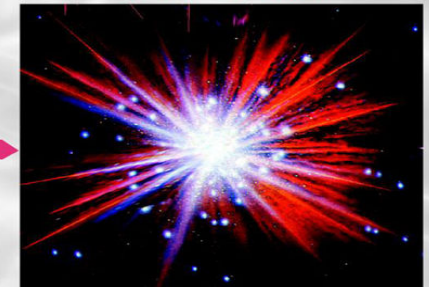


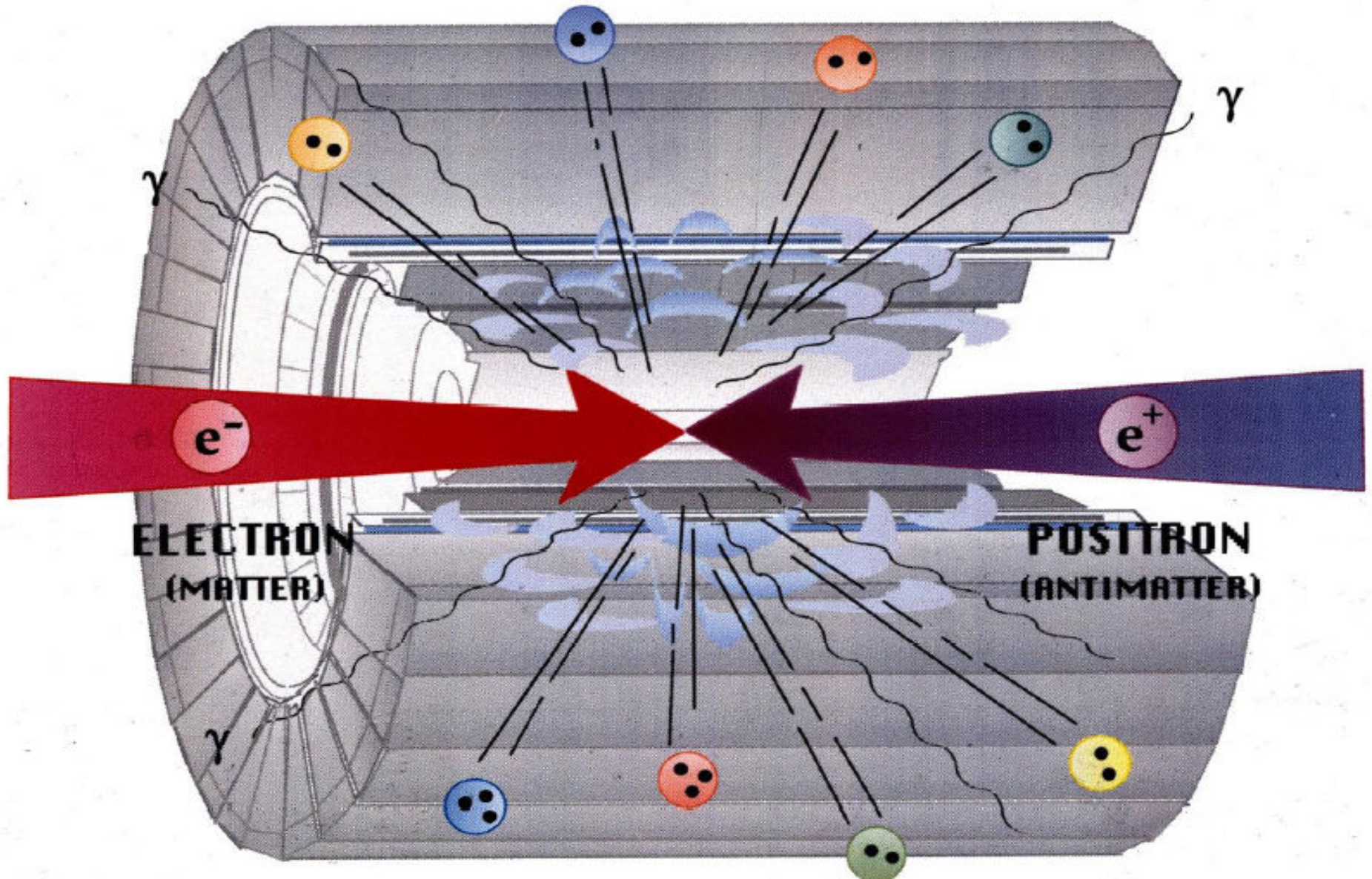


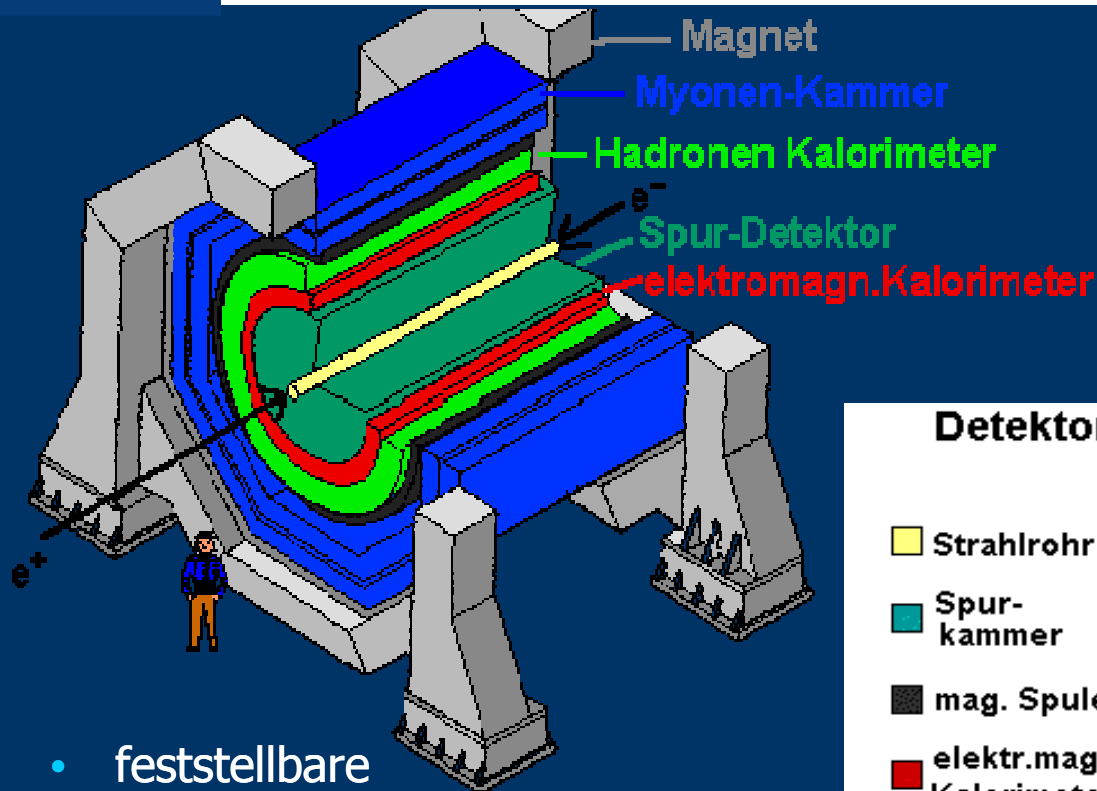
Messung bei HERA am DESY Hamburg



Urknall





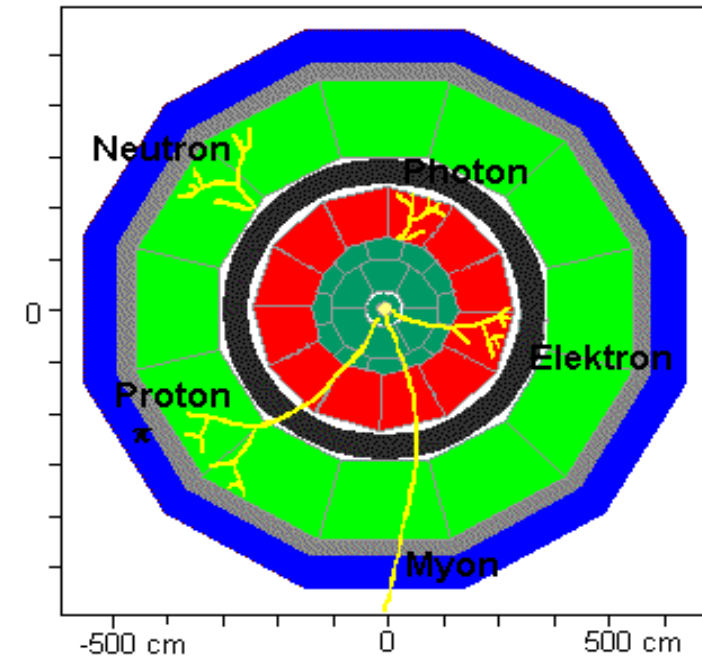


- Zwiebelschalenartiger Aufbau verschiedener Komponenten
- Jede Teilchenart hinterlässt bestimmte Kombination von Signalen in den Komponenten

- feststellbare **Teilcheneigenschaften**:
 - aus Quarks („Hadronen“)?
 - Lepton ?
 - elektr. geladen / ungeladen
 - leicht / schwer
 - Impuls und Energie

Detektorquerschnitt mit Teilchenspuren

- Strahlrohr
- Spur-kammer
- mag. Spule
- elektr.mag. Kalorimeter
- hadron. Kalorimeter
- magnet. Eisen
- Myonen Kammer





Detektorkomponenten:

• **Myon-Spektrometer:**

Toroid mit Driftröhren

• **Energiemessung:**

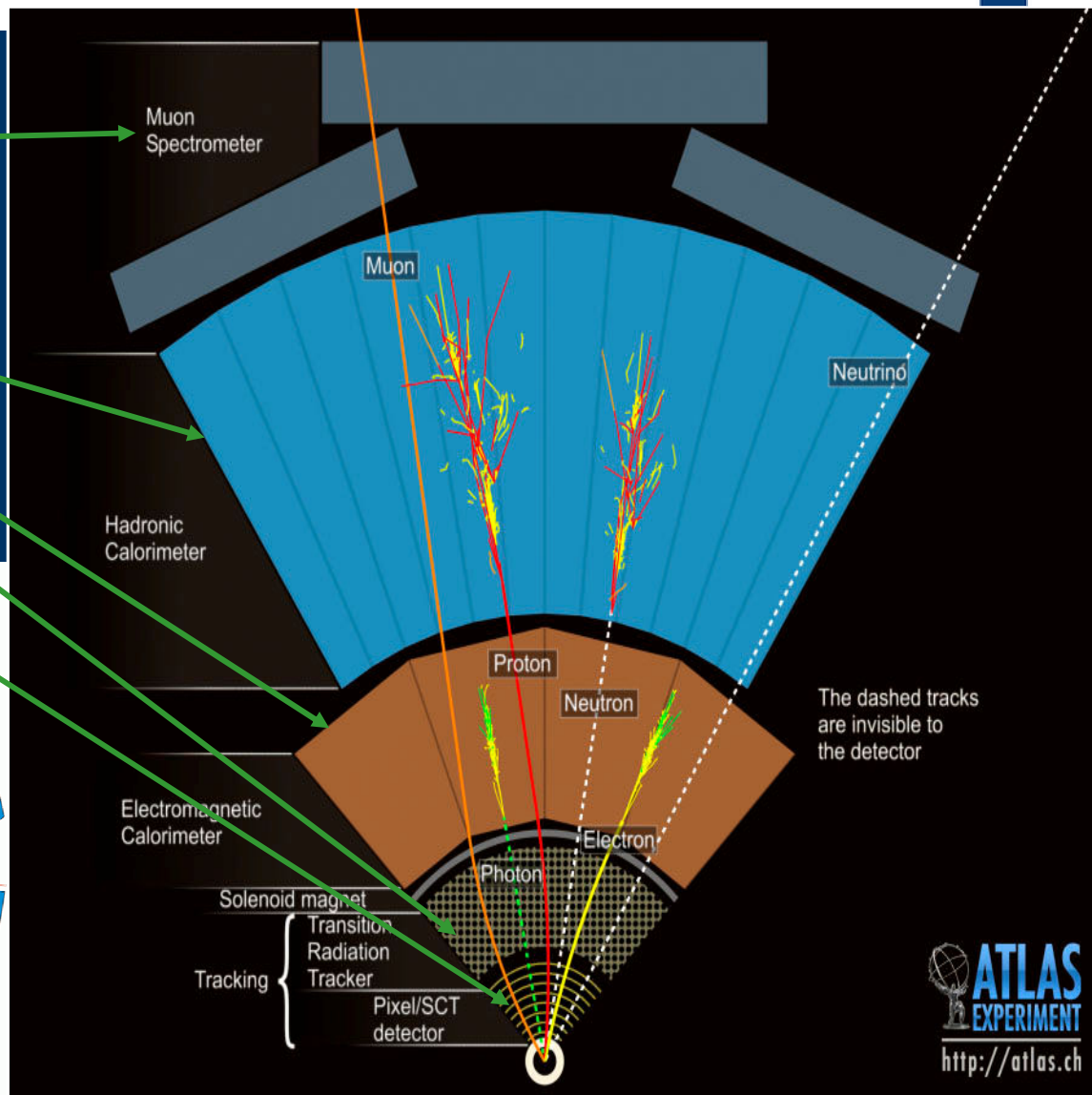
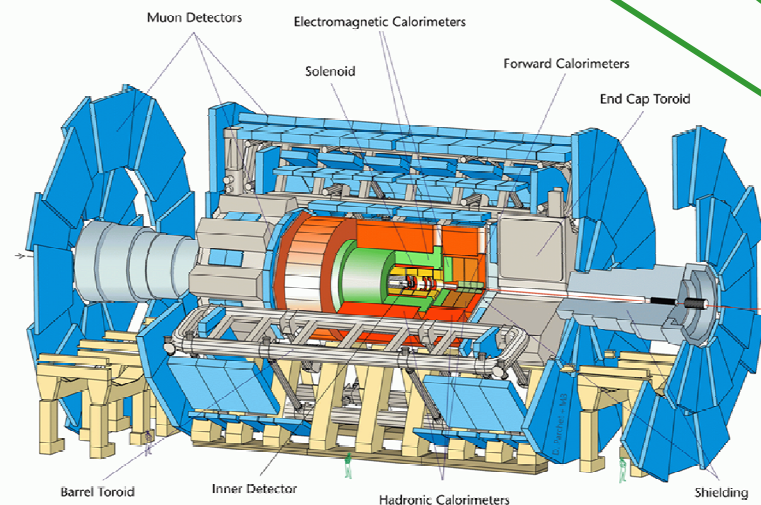
- Hadronisch

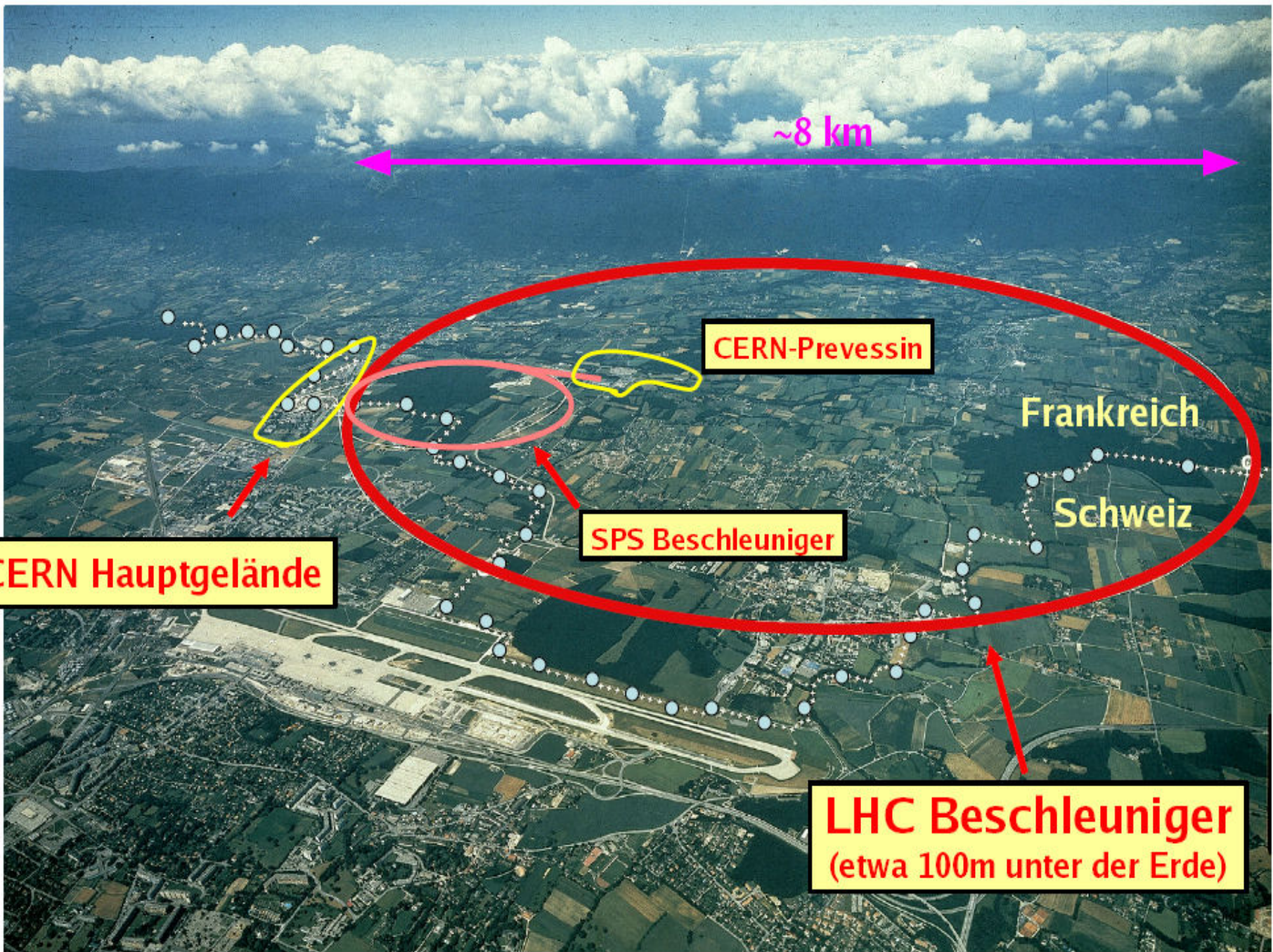
- Elektromagnetisch

• **Spurerkennung :**

- Übergangsstrahlungs-
Detektor

- Halbleiter-Detektor





~8 km

CERN-Prevessin

Frankreich

Schweiz

SPS Beschleuniger

LHC Beschleuniger
(etwa 100m unter der Erde)

CERN Hauptgelände

Die CERN Teilchen-Beschleuniger: mehr als 50 km Tunnel unter der Erde

7 TeV

5 LHC

450 GeV

4 SPS

26 GeV

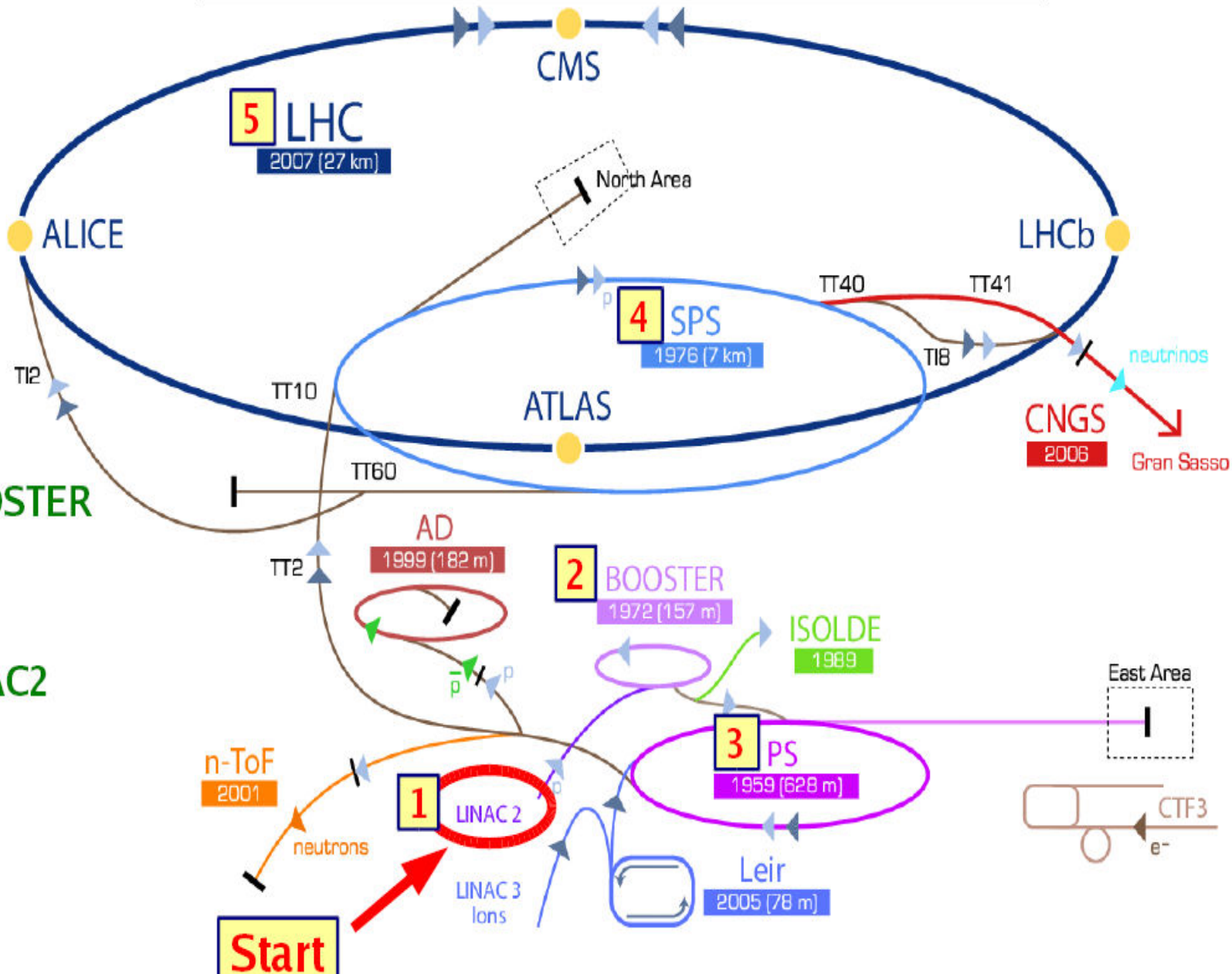
3 PS

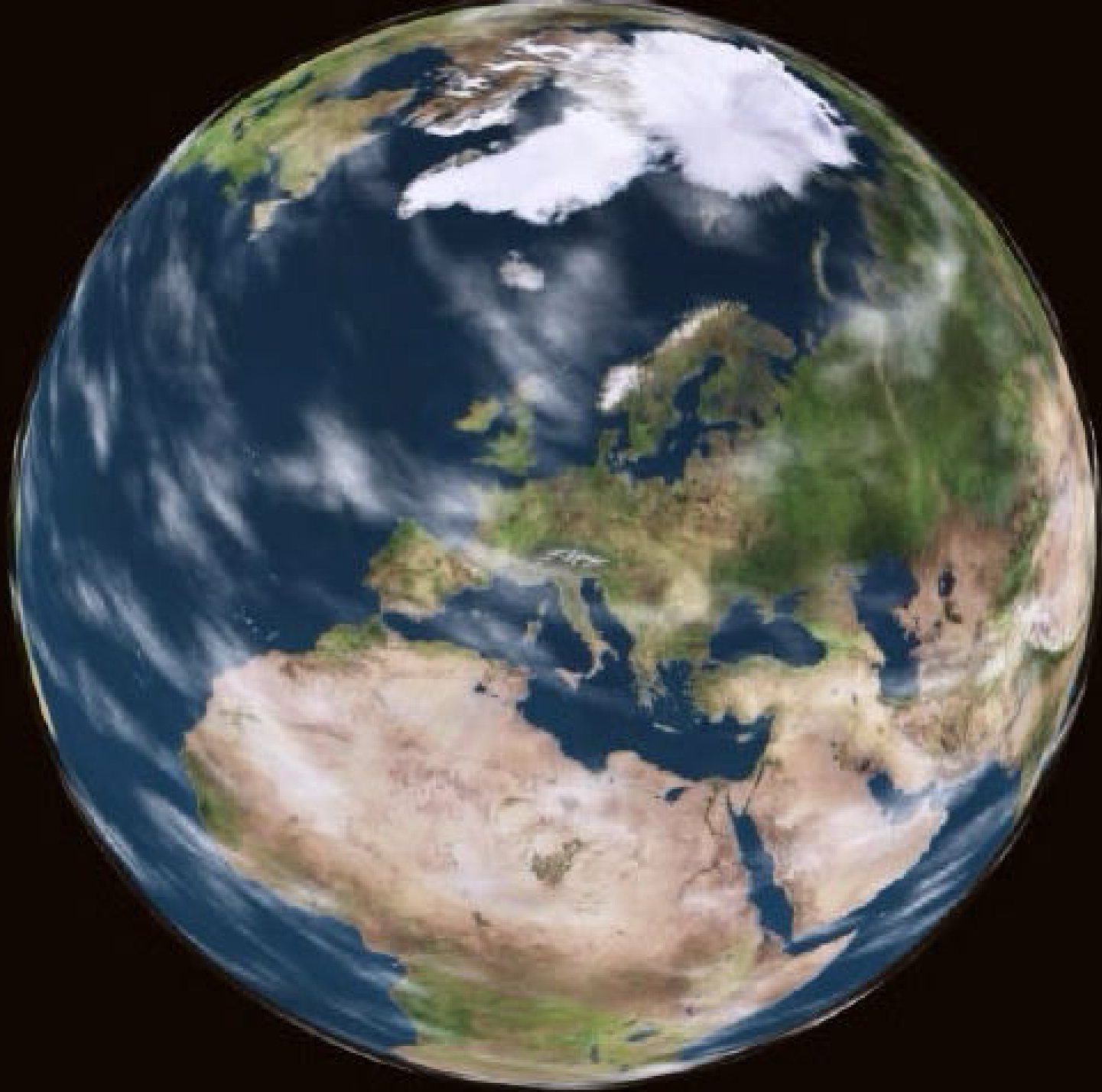
1.4 GeV

2 BOOSTER

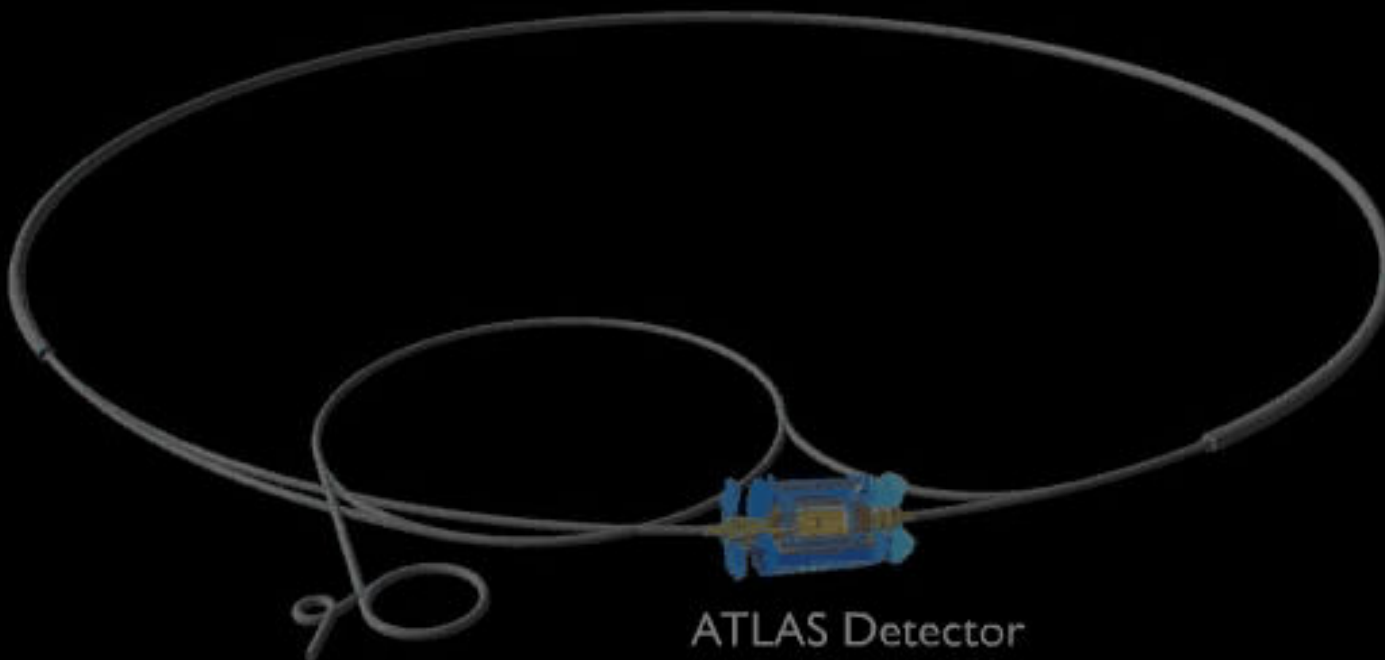
50 MeV

1 LINAC2





Large Hadron Collider

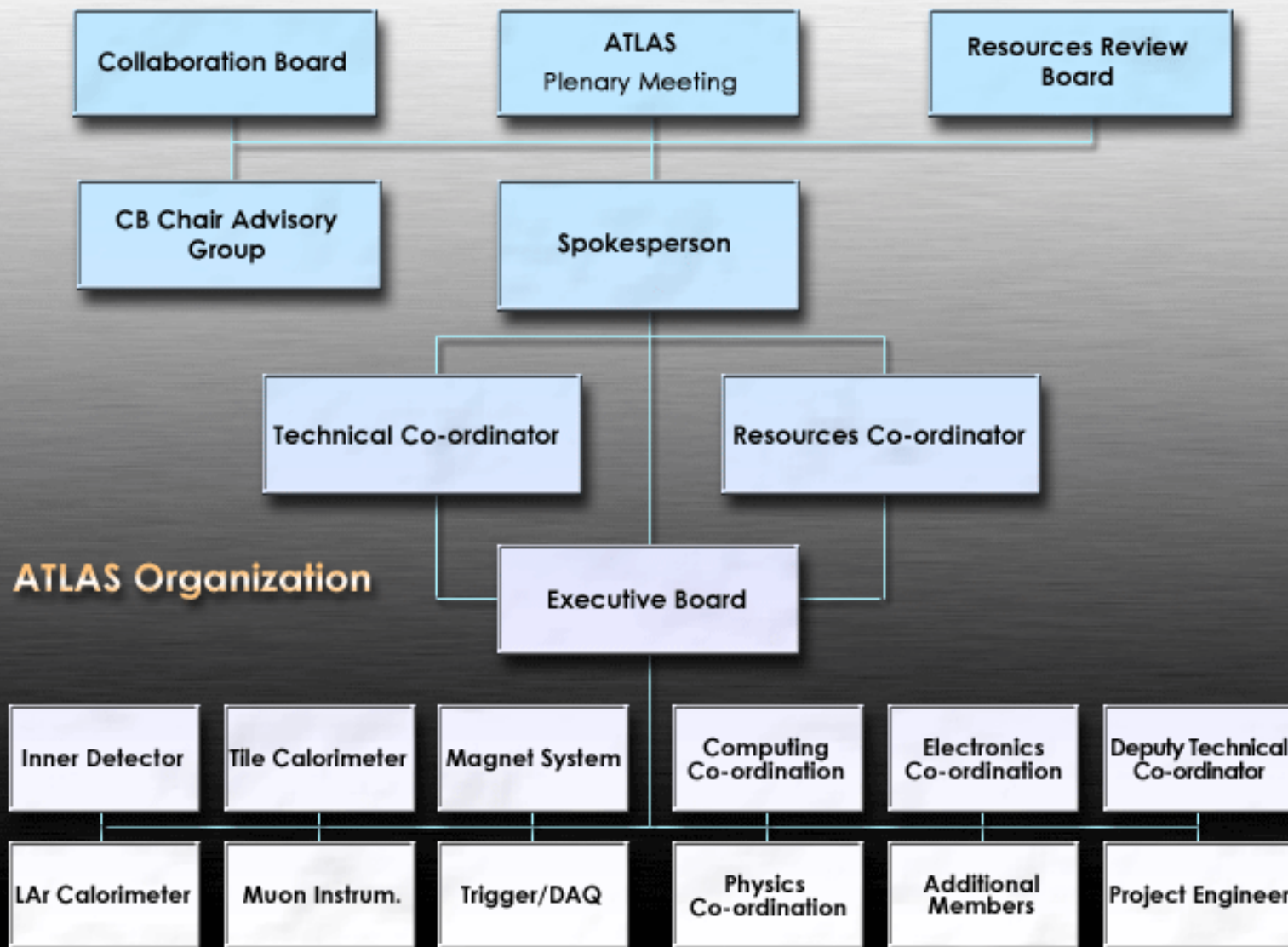


ATLAS Detector






ATLAS Organization

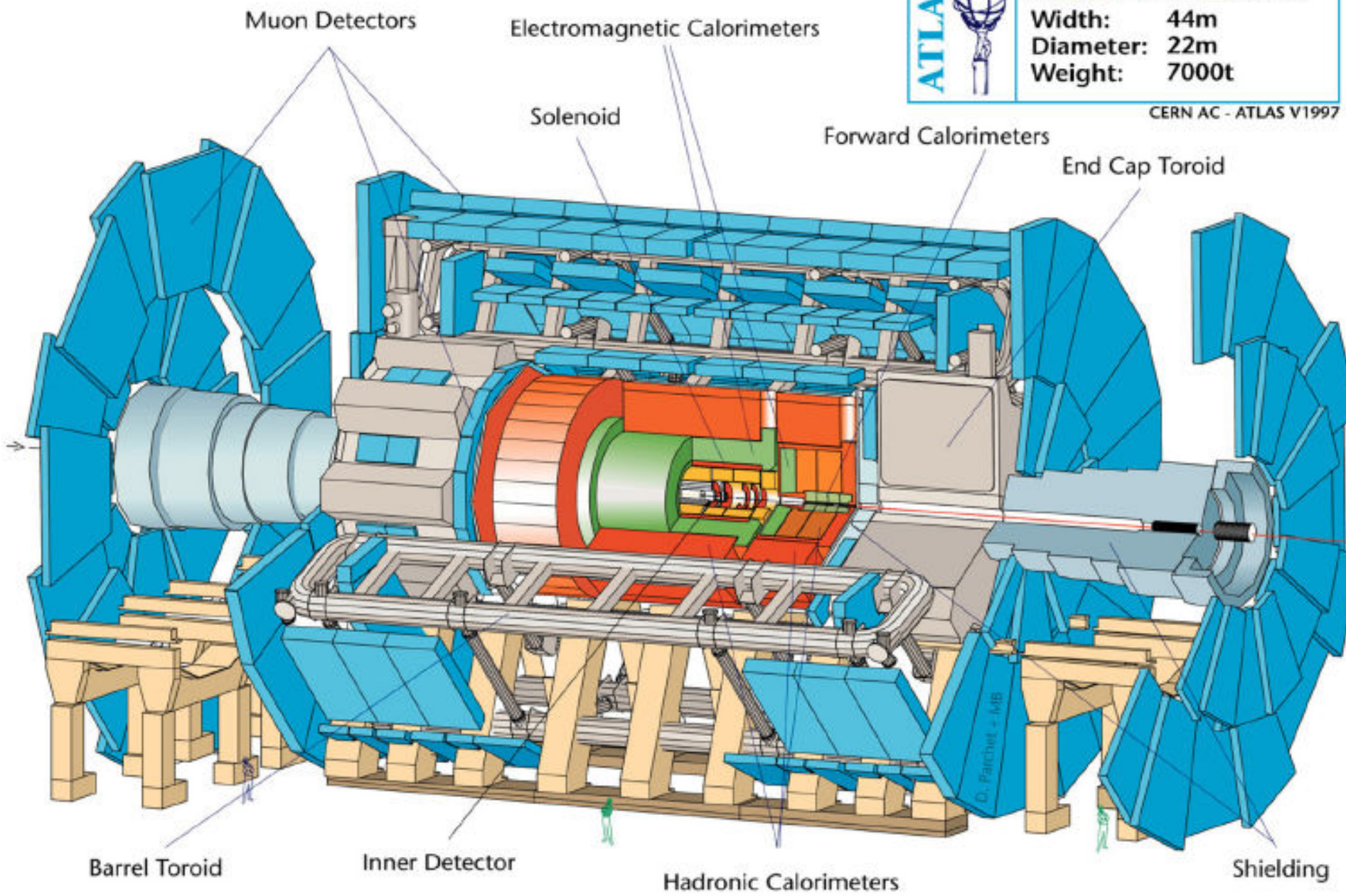




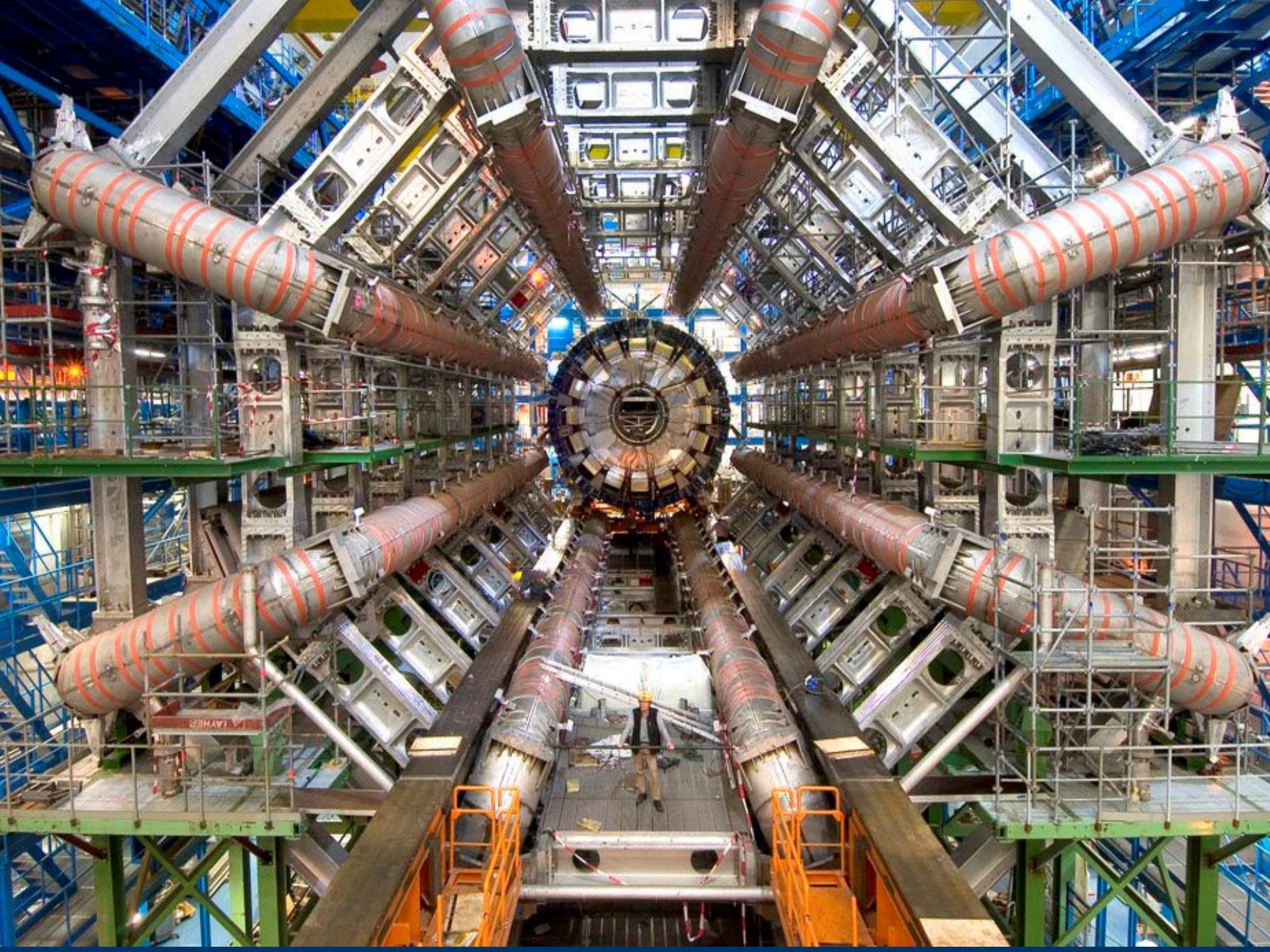
ATLAS 

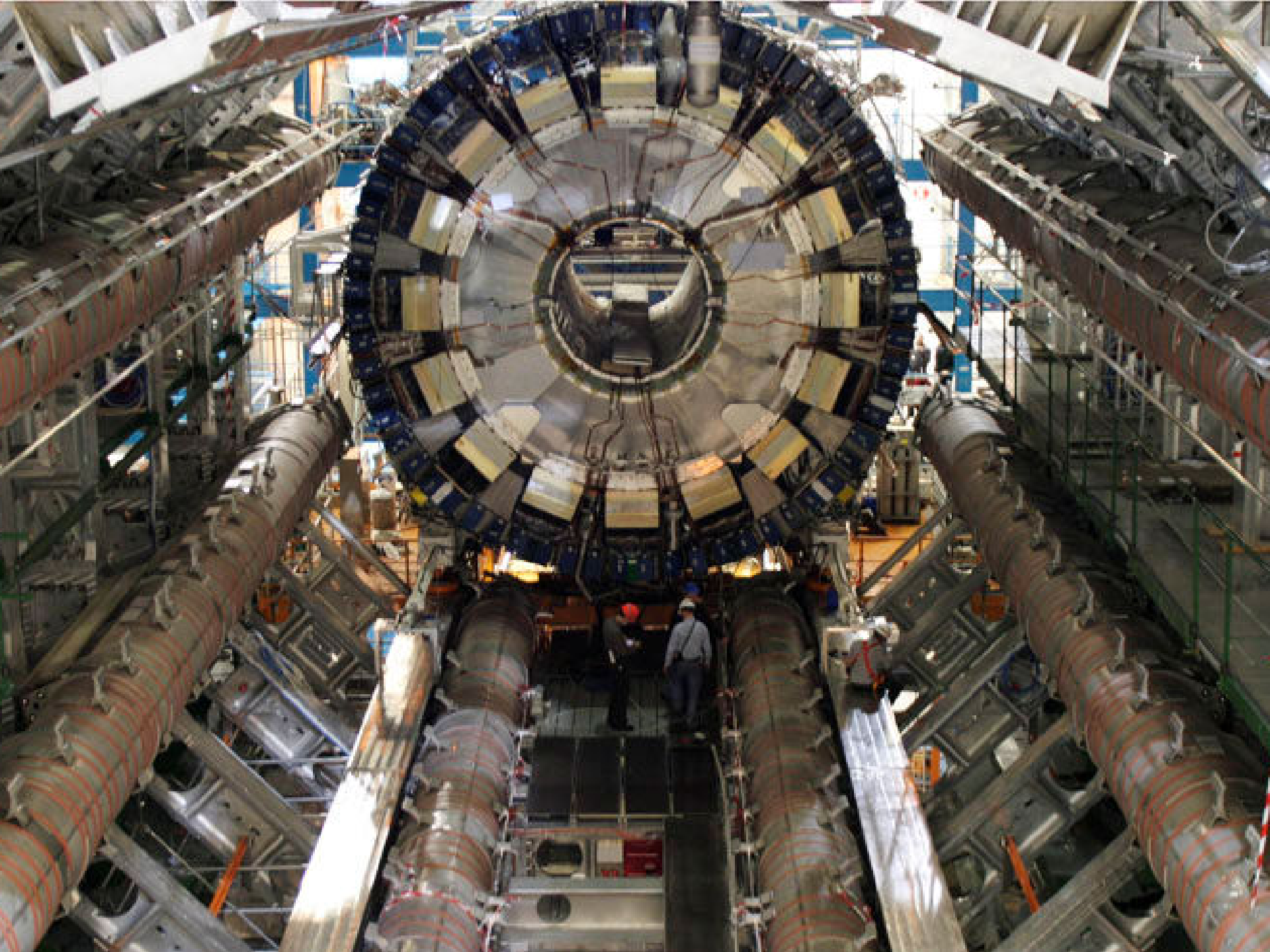
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t

CERN AC - ATLAS V1997



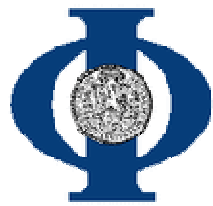
170 Unis/Institute aus 35 Ländern, 2200 Mitglieder



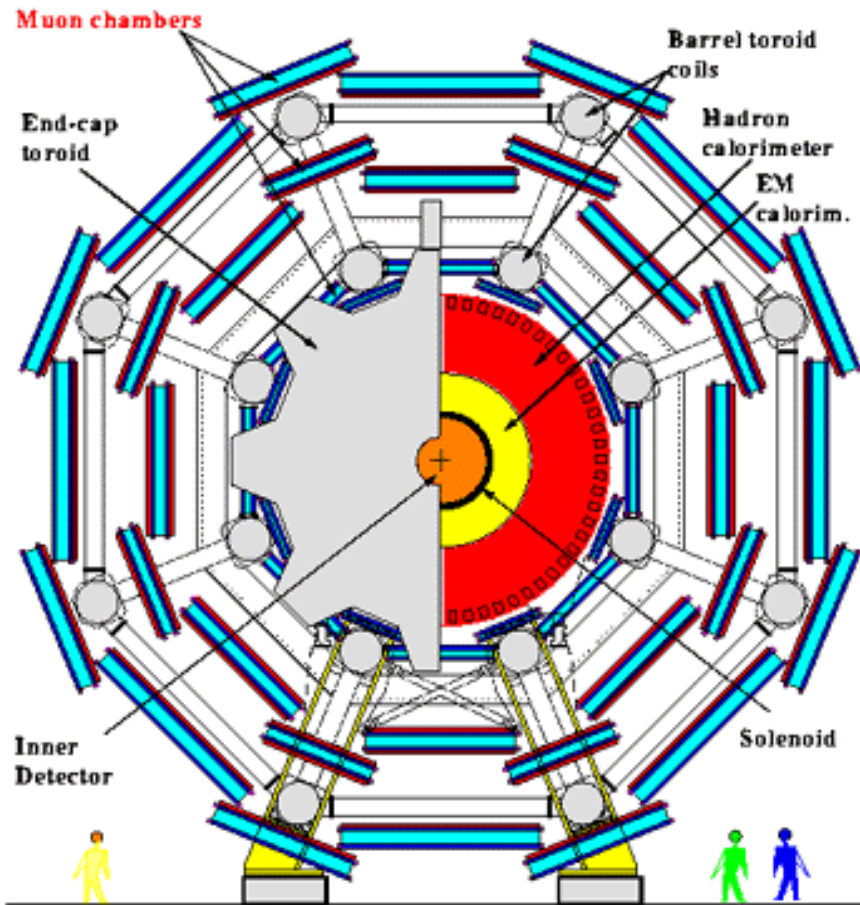




EA-01-03011



ATLAS Detector



- 5500 qm Fläche
- 1200 Präzisionskammern
- 40000 Driftrohre
- Positionierung auf 50 Mikrometer

ATLAS Trigger

• An **inner detector** with semi-conductor pixel and strip detectors for accurate measurements of the charged particle trajectories, followed by a straw-tube detector giving many hits per track and independent electron identification using transition radiation. A thin superconducting solenoid coil provides a 2 T magnetic field for the inner detector.

• A **calorimeter** with an inner cylinder using lead-LAr technology with its high resolution, calibration precision and stability, followed at large radius by an iron-scintillator tile calorimeter providing good jet energy resolution and complete coverage for measuring the missing transverse energy E_{miss} .

All systems have a large solid-angle coverage. In particular, precision measurements will be performed down to $\eta=2.5$ and calorimeter measurements down to $\eta=5$.

The initial information flow from the ATLAS detectors is reduced by a dedicated selection system, the **trigger**, based on hierarchical decision-making. A **data-acquisition** system merges the information from the trigger elements and stores it for further processing and analysis.

An object-oriented **software** system will reconstruct the data so as to access the physical properties of the produced particles and simulate ATLAS in all relevant details.

Calorimeter

Muon Spectrometer



Lead/liquid argon accordion electromagnetic calorimeter



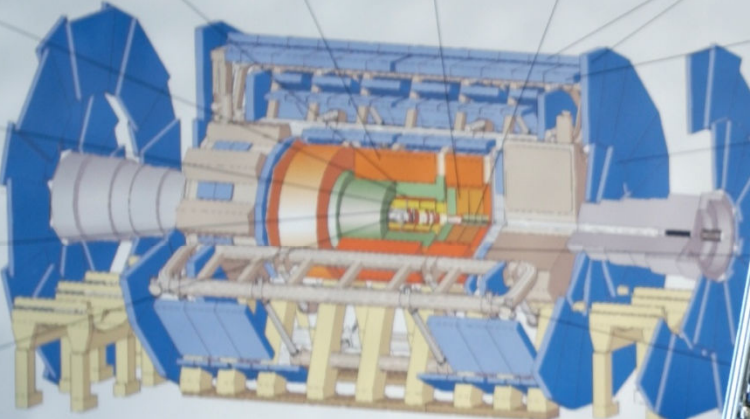
Iron/scintillator tile hadronic barrel calorimeter



Copper/liquid argon hadronic end-cap calorimeter



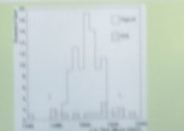
Copper/liquid argon forward calorimeter



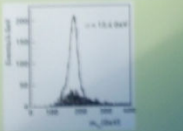
The detector is 22 meters high, 44 meters long, and the overall weight is about 14,000 tonnes.



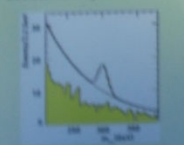
Expected $W \rightarrow Z$ signal for $\mathcal{L}_{int} = 100 \text{ fb}^{-1}$ and for an integrated luminosity of 100 fb^{-1} . The signal is shown on top of the irreducible background.



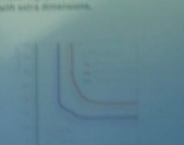
Expected signal from proton-proton production in ATLAS, with the proton decaying into electron-positron pairs, above the Standard Model background. These signals are recovered in reality with extra distributions.



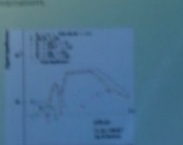
Invariant mass of a pair of jets, for example of 50 000 inclusive single-jet pairs plus jet events. The dashed histogram shows the background from wrong combinations.



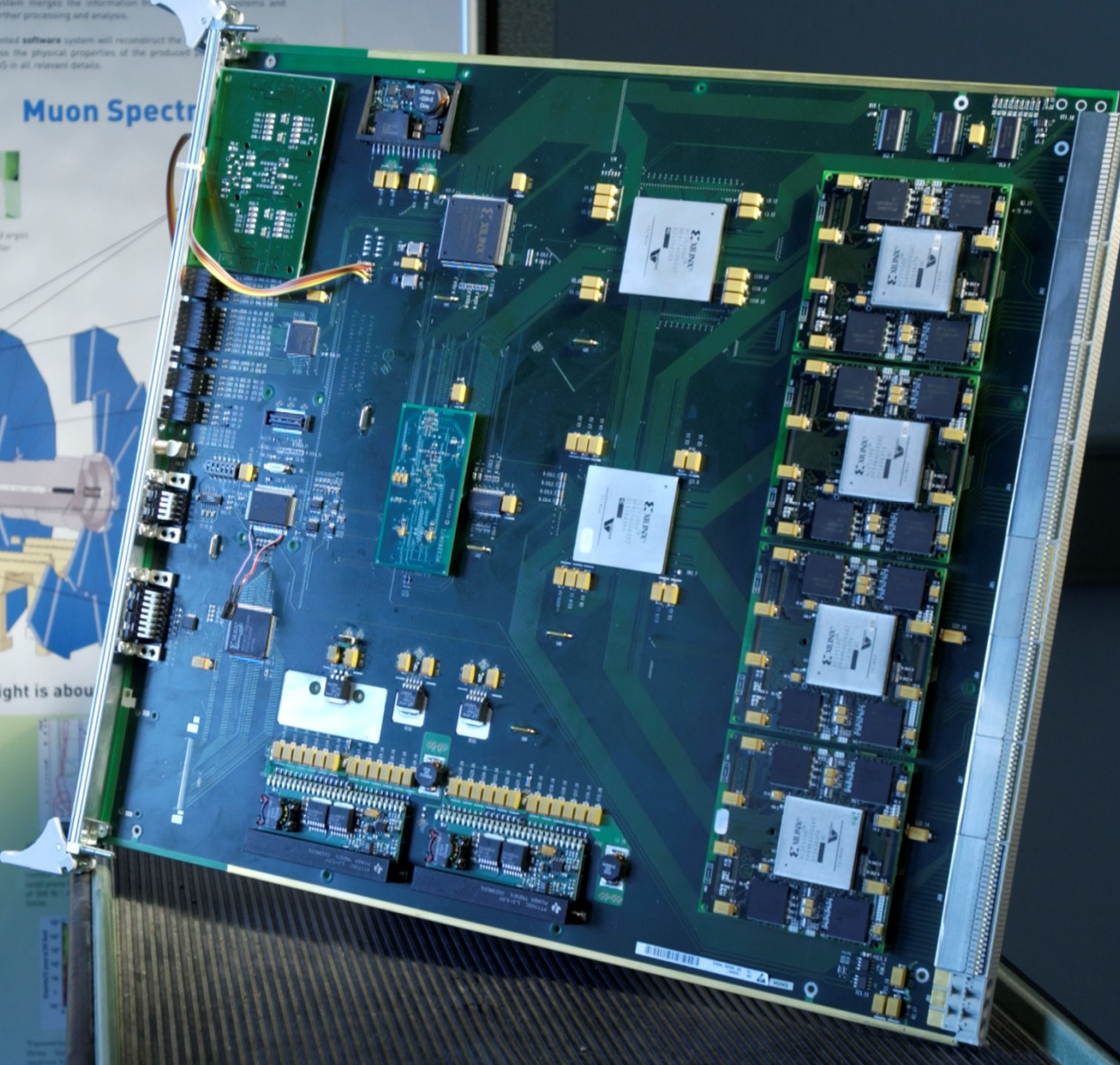
Expected signal for the production of a Standard Model Higgs boson, for an integrated luminosity of 300 fb^{-1} and for an integrated luminosity of 300 fb^{-1} . The signal is shown on top of the irreducible background.

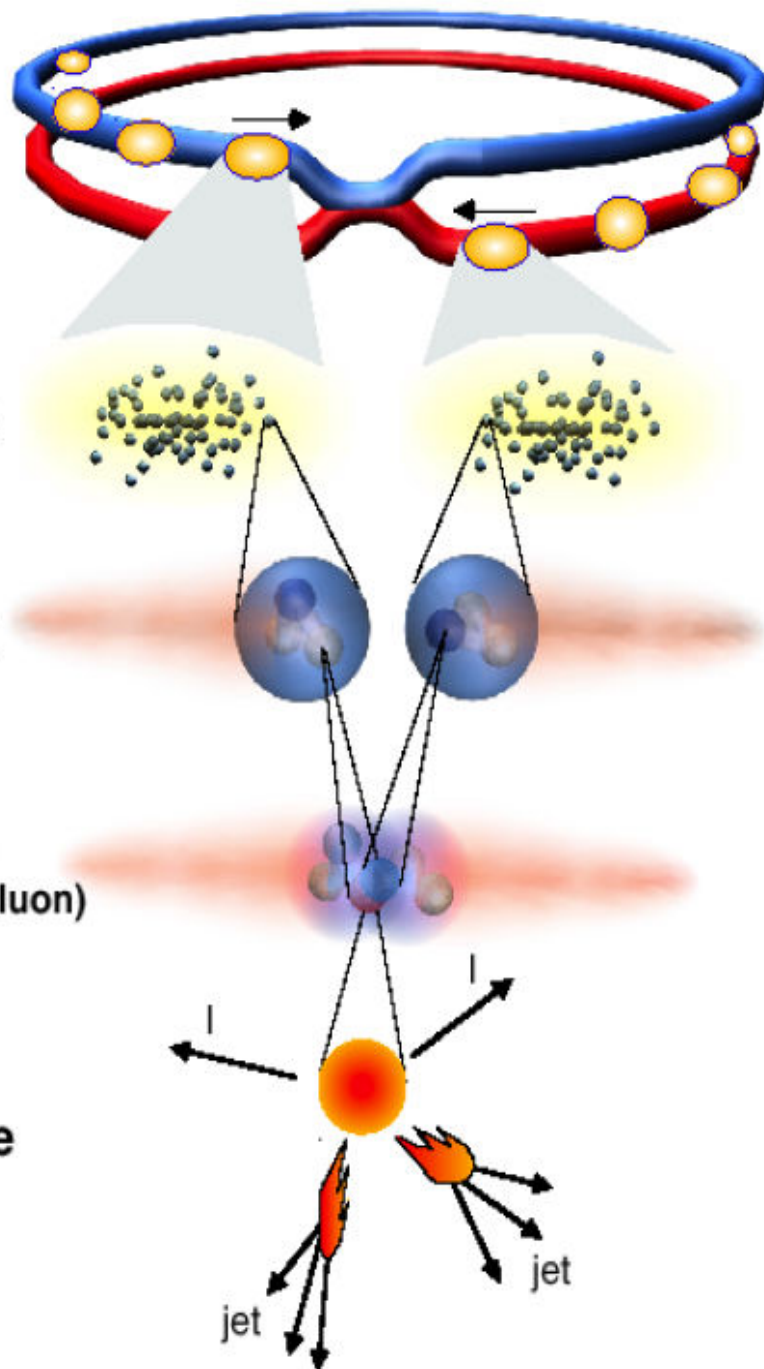


ATLAS sensitivity to search for gluino production. The regions below the curves are excluded by the absence of a signal.



ATLAS sensitivity for the discovery of a supersymmetric Higgs boson. The regions above the curves are excluded by the absence of a signal.





Proton-Proton-Kollisionen
 2835 Teilchenbündel (Bunch)

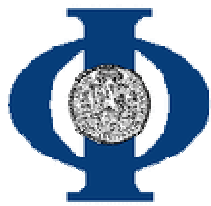
10^{11} Protonen / Bunch
 Kollisionsrate 40 MHz (25 ns)

Schwerpunktenergie 14 TeV
 (= 7400 x Ruheenergie der kollidierenden Teilchen)

Schwerpunktenergie der kollidierenden Quarks und Gluonen bis einige TeV

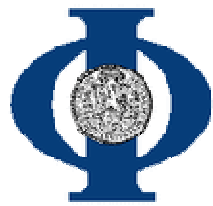
~25 pp-Kollisionen pro Bunch-Kollision

Interessante Ereignisse: 10^{-9} – 10^{-11} unterdrückt!



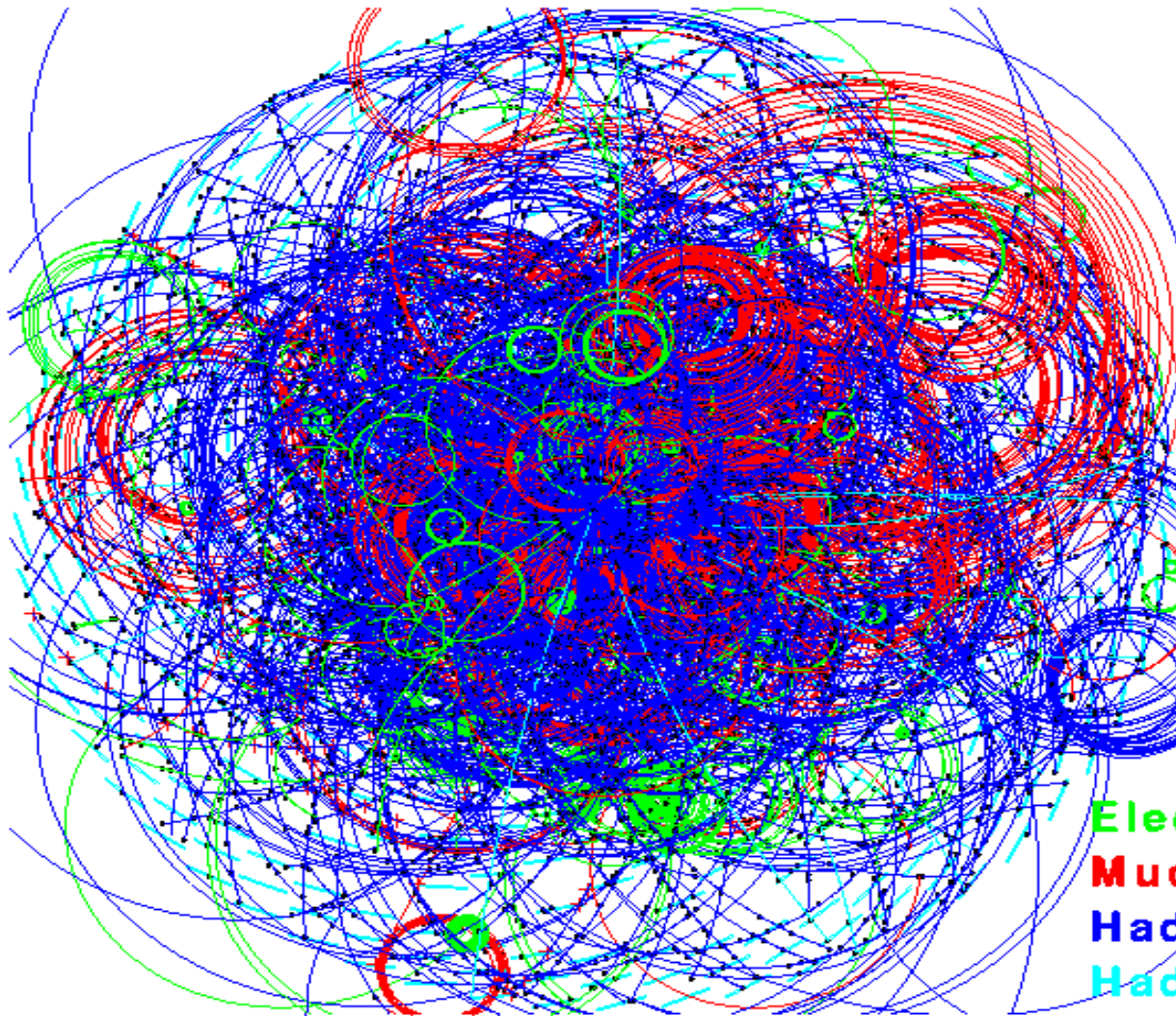
Herausforderung bei LHC

- p-p Kollisionen alle 25 Nanosekunden (40 MHz)
- Etwa 25 inelastische Ereignisse pro Kollision
- Hohe Detektorgranularität (**100 Millionen Kanäle**)
- Datenrate von 100 TByte/sec, etwa **20000 DVD's pro Sekunde** !
- Sehr effiziente Selektion in quasi Echtzeit
- Interessante Ereignisse: **~ 1 pro Sekunde**



- Nicht alle Kollisionen sind interessant
Trigger muss in 2 Mikrosekunden entscheiden !
- Eventuell interessante Ereignisse
-> Abspeichern
- Mögliche Entdeckungen
-> nur 0.0000000001%

**Was wir suchen tritt nur bei jeder
10-Milliardsten Kollision auf !**



CMS

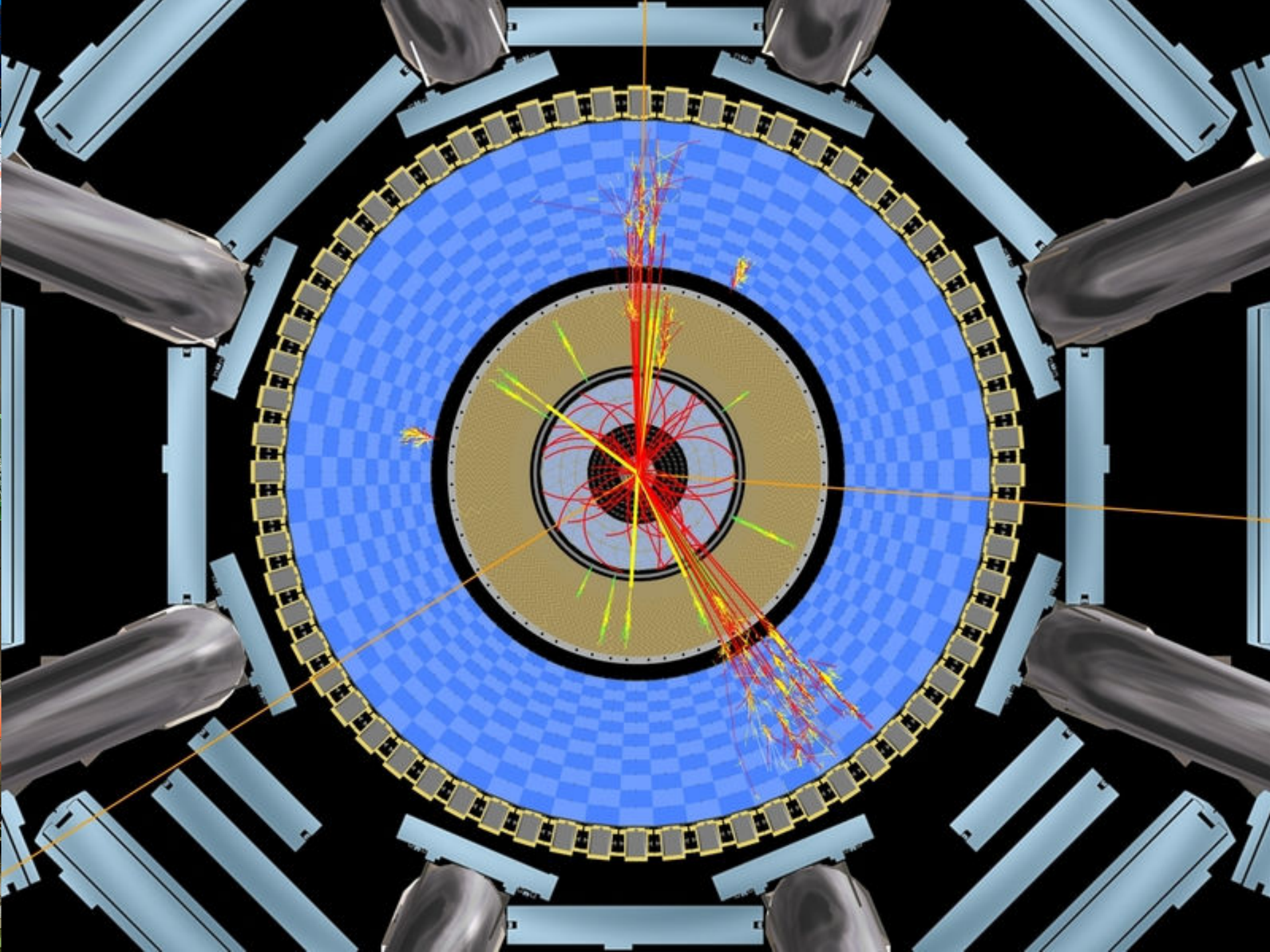
H \rightarrow $\mu\mu\mu\mu$
 $m(H)=150\text{GeV}$
+ 20 Min bias

Electrons

Muons

Hadrons $p_t < 2\text{GeV}$

Hadrons $p_t > 2\text{GeV}$





Hands on Particle Physics

- Schüler/innen verbringen 1 Tag an der Universität
- Einführungsvorträge von Wissenschaftlern
- Arbeit an echten Daten der Experimente
- Fundamentale Erkenntnisse aus eigenen Messungen (Z0-Zerfälle)
- 2009: 80 Institute, 23 Länder, 6000 Teilnehmer
- Jährlich jeweils während 3 Wochen im März
- 5 Masterclasses am Ende jedes Tages in Videokonferenz verbunden



Masterclass CD

- online unter <http://www.physicsmasterclasses.org>
- Offline auf masterclass CD (Auflage 7000)
- Werbematerial für Öffentlichkeit und Schule

ZIEL:

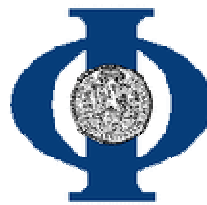
- Internationale Kollaboration von Schülern
- Eigenes Erleben der Arbeitsweise in moderner Naturwissenschaft
- Arbeiten wie Wissenschaftler an Originaldaten



Microsoft Excel - Zcombine_blank_14th

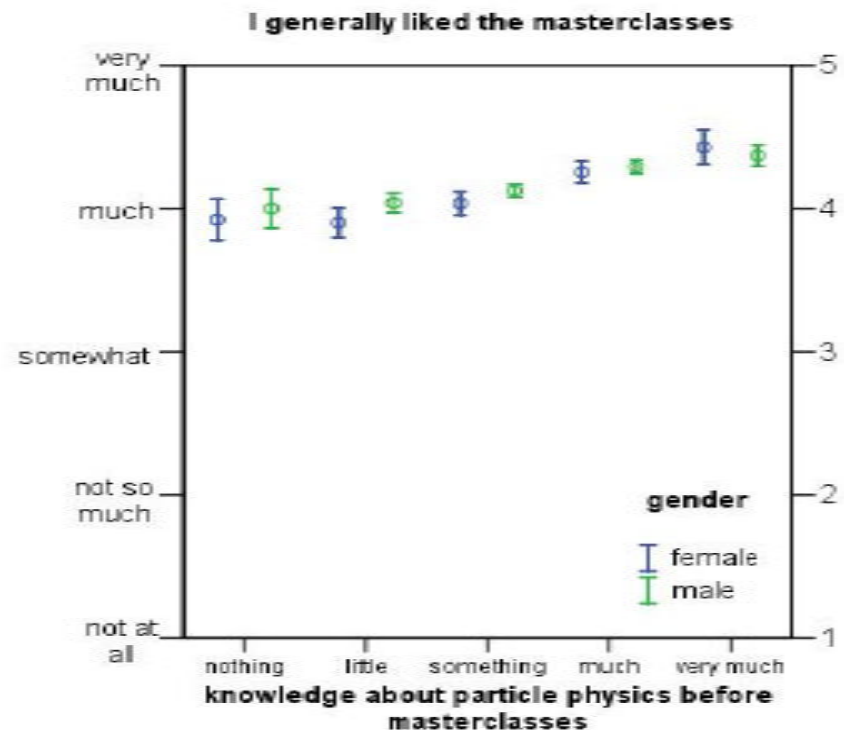
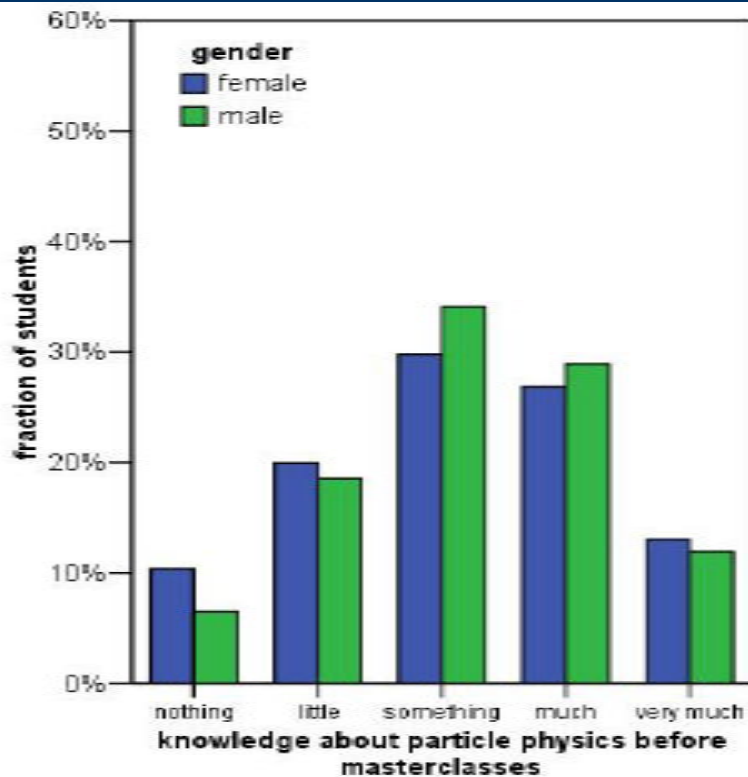
	A	B	C	D	E	F	G	H	I	J	K	L	
1	Town (COUNTRY)	0: DELPHI 1: OPAL	Electrons	Muons	Taus	Quarks		enable institutes	OPAL institute	OPAL	#e	#μ	#τ
2	Mons (BE)	0	23	24	29	523		1	0		0	0	0
3	Torino (IT)	1						0	0		0	0	0
4	Kosice Uni (SK)	1	26	41	39	894		1	1		26	41	39
5	Kosice SAS (SK)	0	32	35	76	857		0	0		0	0	0
6		0						0	0		0	0	0
7		0						0	0		0	0	0
8		0						0	0		0	0	0
9	xx(YY)							0	0		0	0	0
10			e	μ	τ	q	all	2	1	Sum	26	41	39
11	Sum (corr)		64.6	65	68	1417	1614.6			mean	26.0	41.0	39.0
12	Stat. Uncertainty		9	8	8	38							
13													
14	Fract. of Visible		e / all	μ / all	τ / all	q / all	q / ((e+μ+τ)·3)		DELPHI	#e	#μ	#τ	
15	Mons (BE)	0	0.038	0.040	0.048	0.873	20.6				23	24	29
16	Torino (IT)	1	0.000	0.000	0.000	0.000	0.0				0	0	0
17	Kosice Uni (SK)	1	0.041	0.040	0.038	0.880	22.1				0	0	0
18	Kosice SAS (SK)	0	0.000	0.000	0.000	0.000	23.2				0	0	0
19													
20													
21													
22	DELPHI	0	0.038	0.040	0.048	0.873	20.6			Sum	23	24	29
23	Statistical Uncertainty ±		0.008	0.008	0.009	0.014	2.7			mean	23.0	24.0	29.0
24	Systematic Uncertainty ±		0.000	0.000	0.000	0.000	0.0						
25	OPAL	0	0.041	0.040	0.038	0.880	22.1						
26	Statistical Uncertainty ±		0.008	0.006	0.006	0.010	2.5						
27	Systematic Uncertainty ±		0.000	0.000	0.000	0.000	0.0						
28	Combination		0.040	0.040	0.042	0.878	21.7						
29													

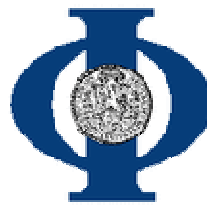
Ready



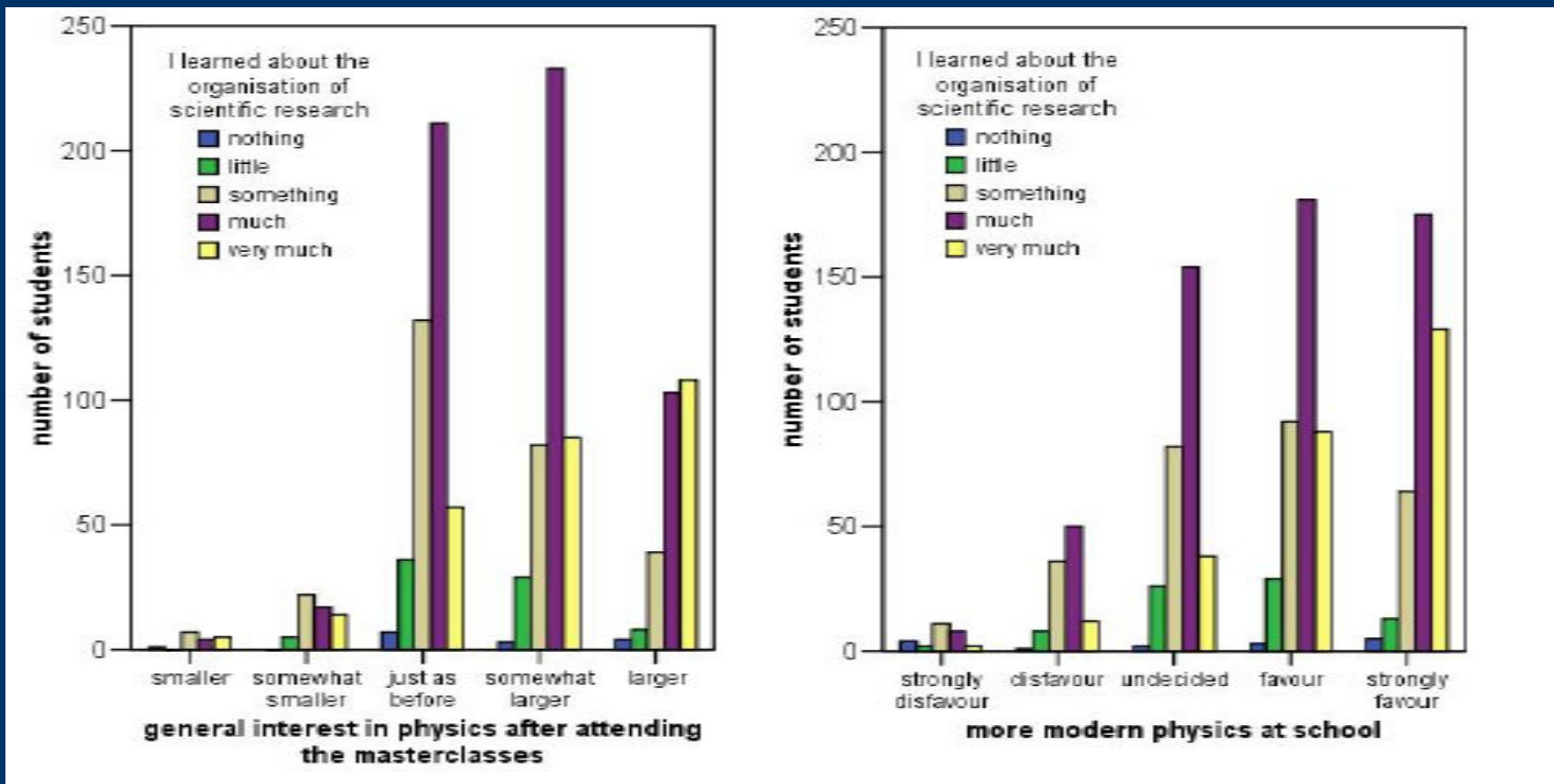
Evaluation (Physics Education 42 (2007))

- Schwierigkeitsgrad genau richtig
- Unabhängig von Vorwissen und Geschlecht





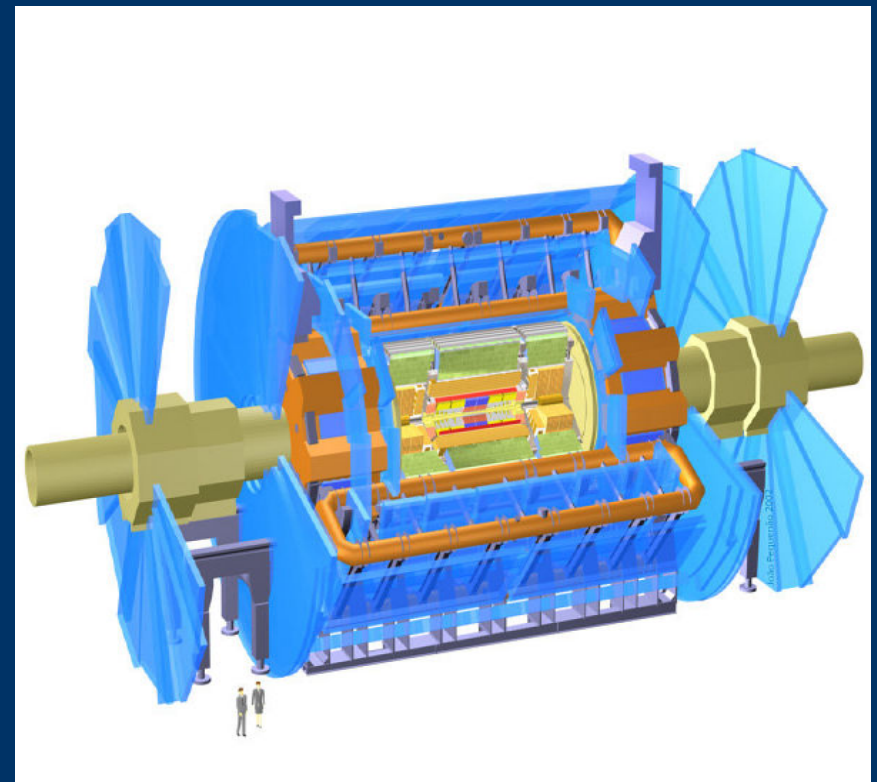
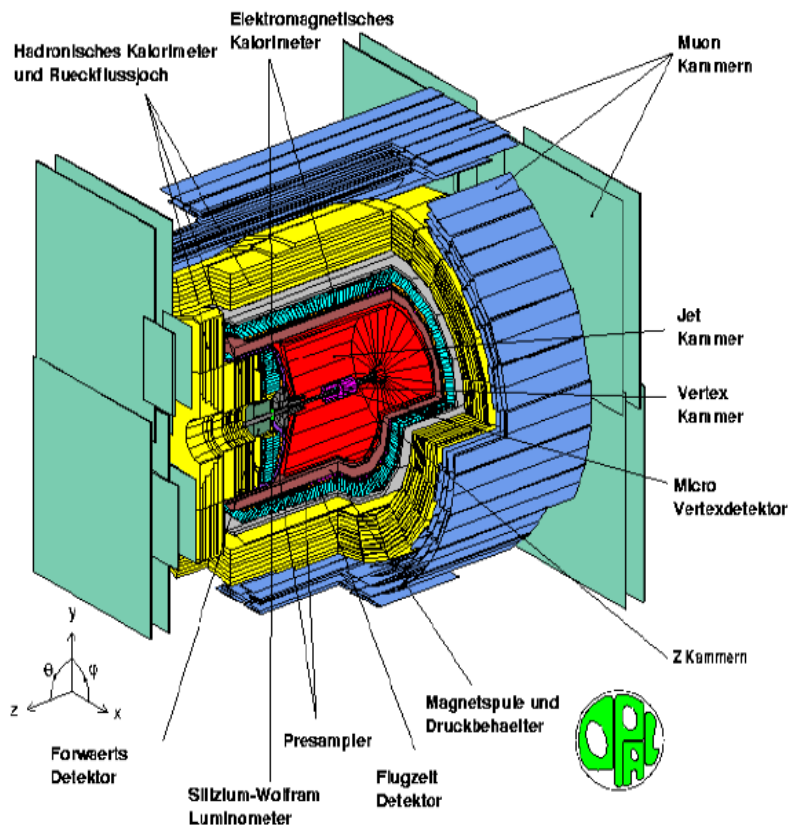
Erleben heutiger nat.wiss. Arbeitsweise erzeugt Interesse an (insbes. moderner) Physik

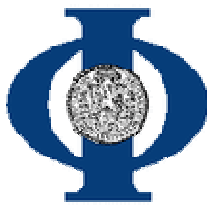


Zwiebelschalenstruktur

OPAL

ATLAS



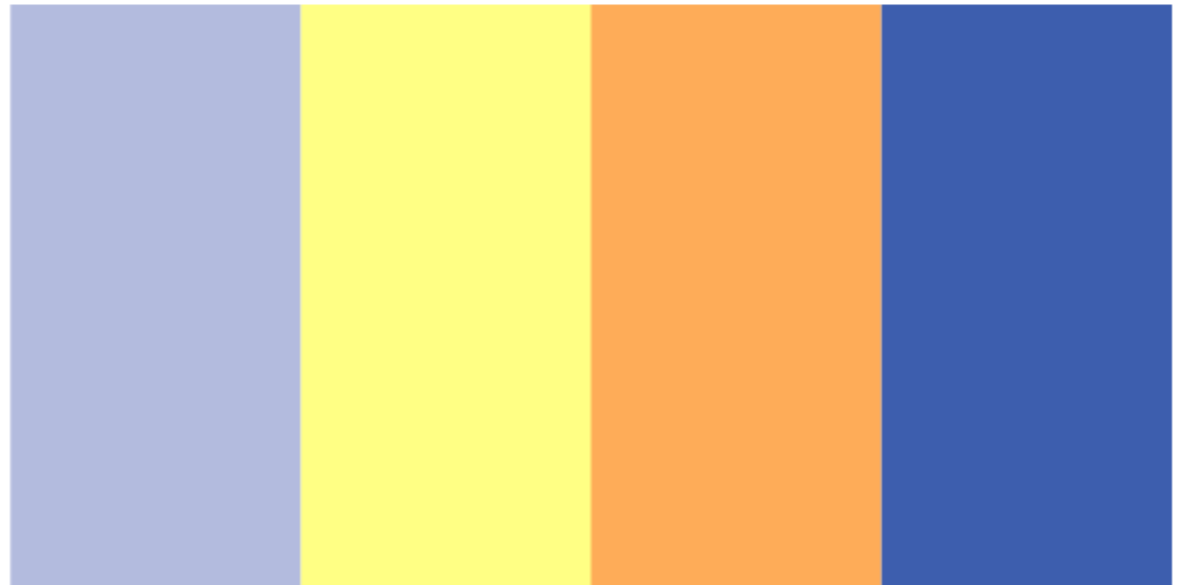


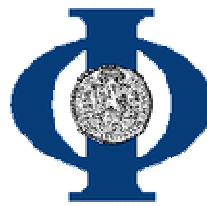
Tracking
chamber

Electromagnetic
calorimeter

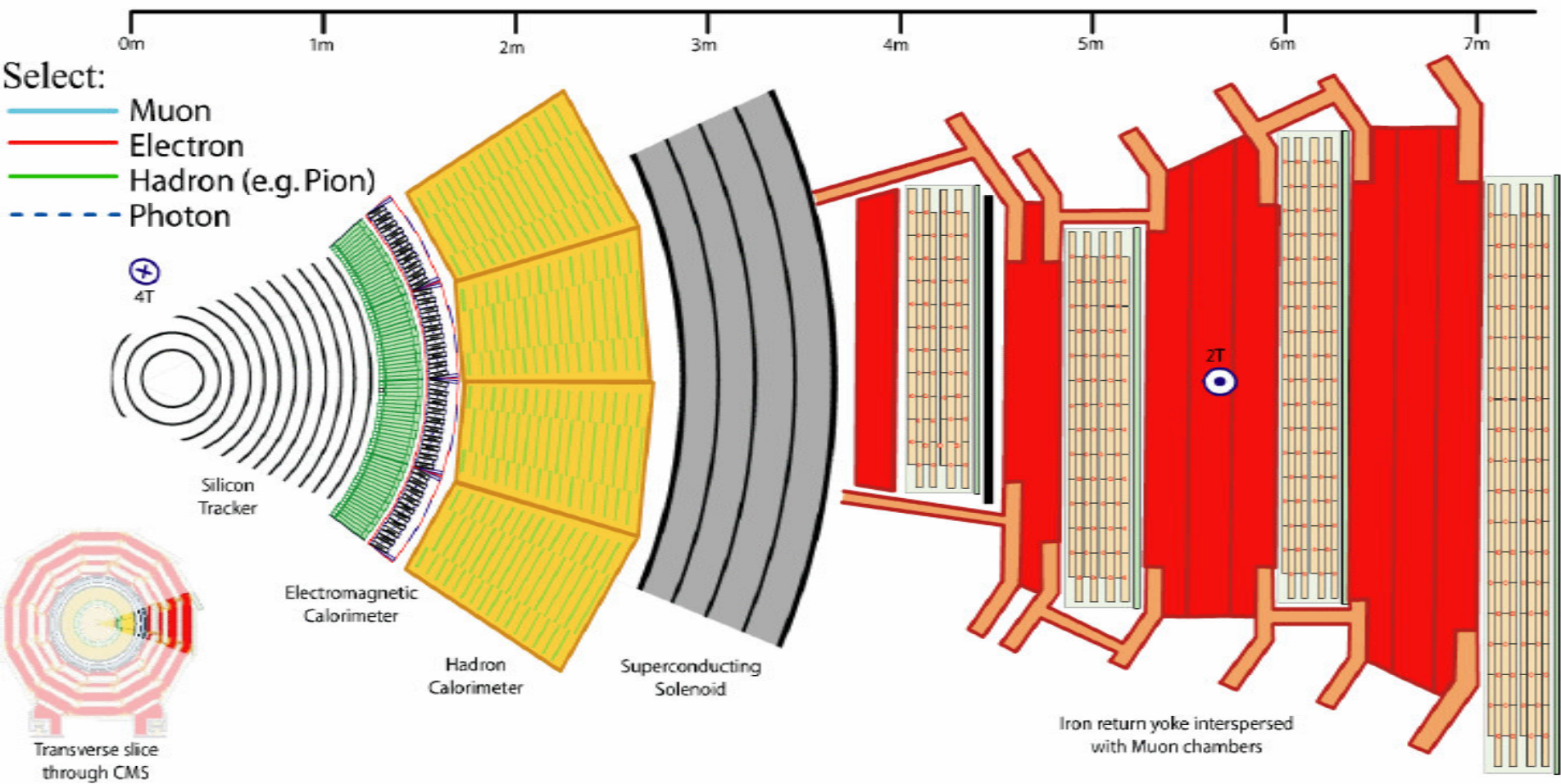
Hadron
calorimeter

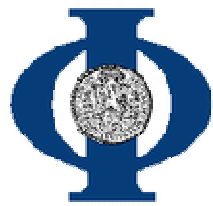
Muon
detector





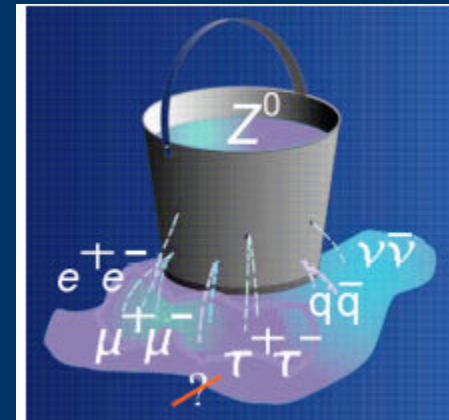
Prinzip





Untersuchung des Z-Bosons (LEP)

- Schweres Teilchen, zerfällt sofort
- Analogie zum Wassereimer:
- Je mehr Löcher der Eimer hat, desto schneller ist er leer
- Je größer das Loch ist, desto mehr Wasser fließt dadurch hinaus
- Löcher entsprechen Zerfallskanälen



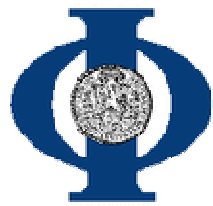
Aufgabe

- Betrachte Ereignisse mit Z-Zerfällen
- Entscheide, welcher Zerfall vorliegt
- Messe Zerfallsverhältnis

Neutrinos:

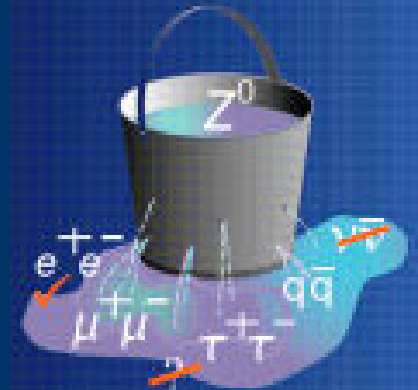
- Unsichtbar
- Verlassen den Detektor und nehmen Energie mit
- Im Detektor fehlt Energie





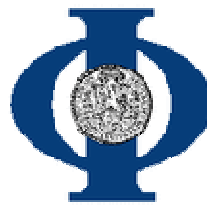
Elektronen/Positronen

- Geladen
- Spuren im Spurdetektor
- Schauer im elektromagnetischen Kalorimeter
- zerstört
 1. Verlieren ihre gesamte Energie im el.mag. Kalorimeter
 2. Impuls der geladenen Spur ist genauso groß wie Energie im el.mag. Kalorimeter (gleiche Farbe)
 3. Kein Signal im hadronischen Kalorimeter oder Myonkammern



Event: event 7579: 15784 Click(N= 1) Sump= 1.6) Ecal(N= 10) Scafi= 2.7
Ebeam 66.166 Vtx (-0.07, 0.95, 0.38) Hcal(N= 1) BcaD= 0.7) Muon(N= 0)

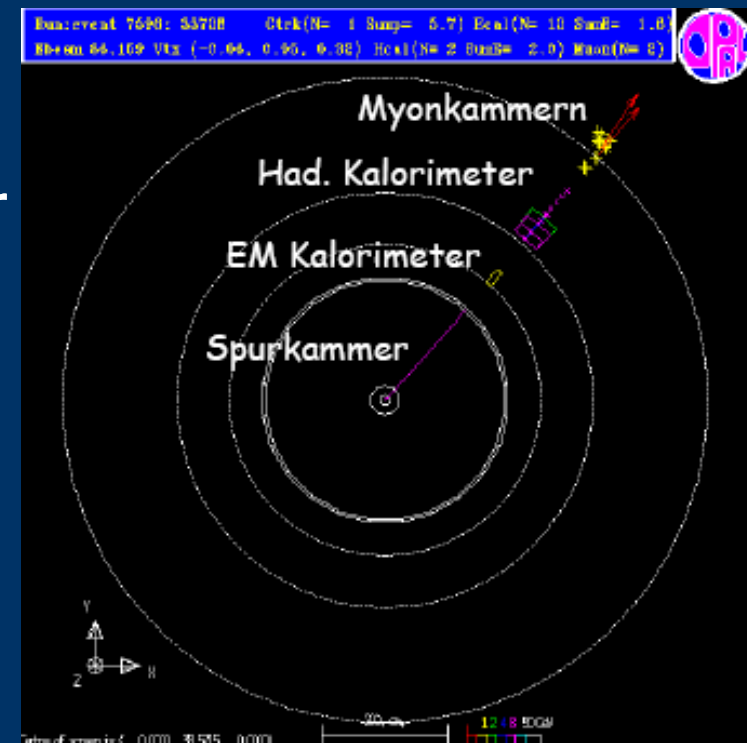


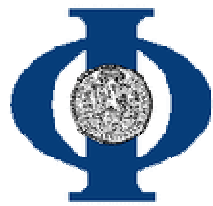


Myonen

- Geladen
- Spuren im Spurdetektor
- Energiedisposition überall
- Verlassen den Detektor und zerfallen dann, da sie instabil sind

1. Passieren den gesamten Detektor
2. Signal in der Spurkammer, sowie Energiedispositionen in beiden Kalorimetern
3. Signal in den Myonkammern



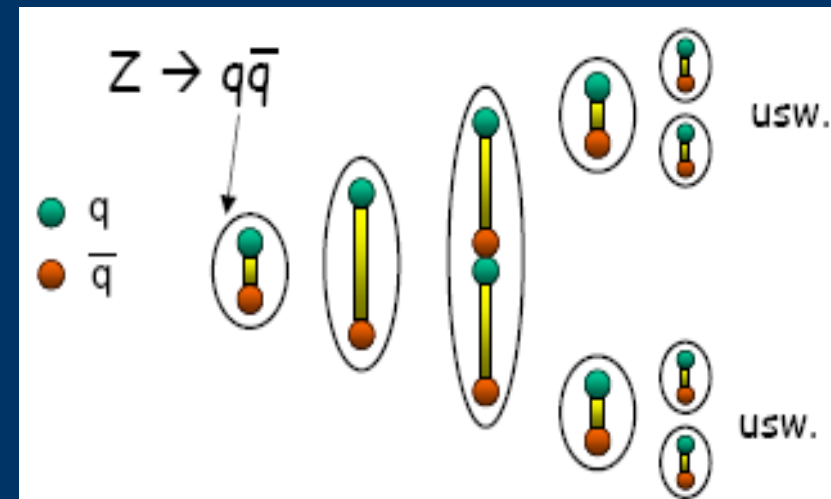


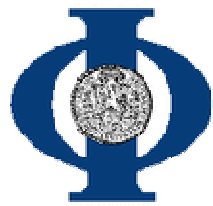
Quarks/Gluonen (bis auf top-Quark)

- Nicht einzeln messbar
- Starke Kraft erzeugt viele Teilchen entlang der Flugrichtung des Quarks/Gluons
- Im Detektor sieht man Jets=Strahlen

Jets

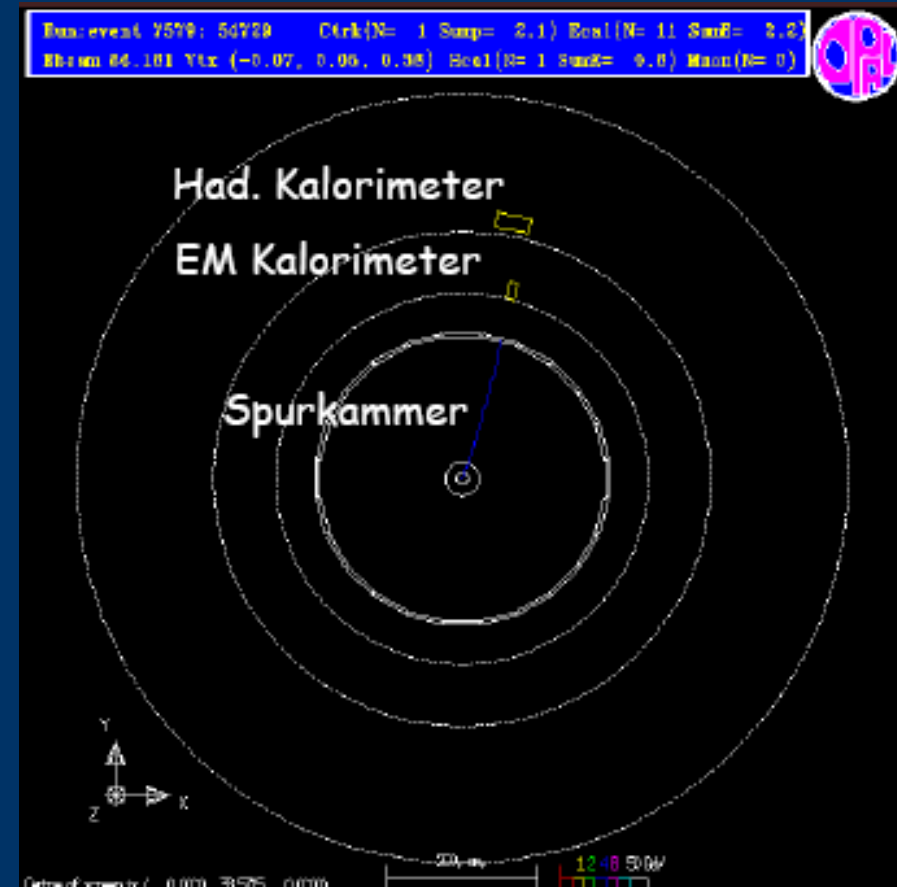
- Geladene und neutrale Hadronen
- Viele Spuren im Spurdetektor
- Schauer (meist) in beiden Kalorimetern
- Zerstört
- Jet=Strahl von Hadronen





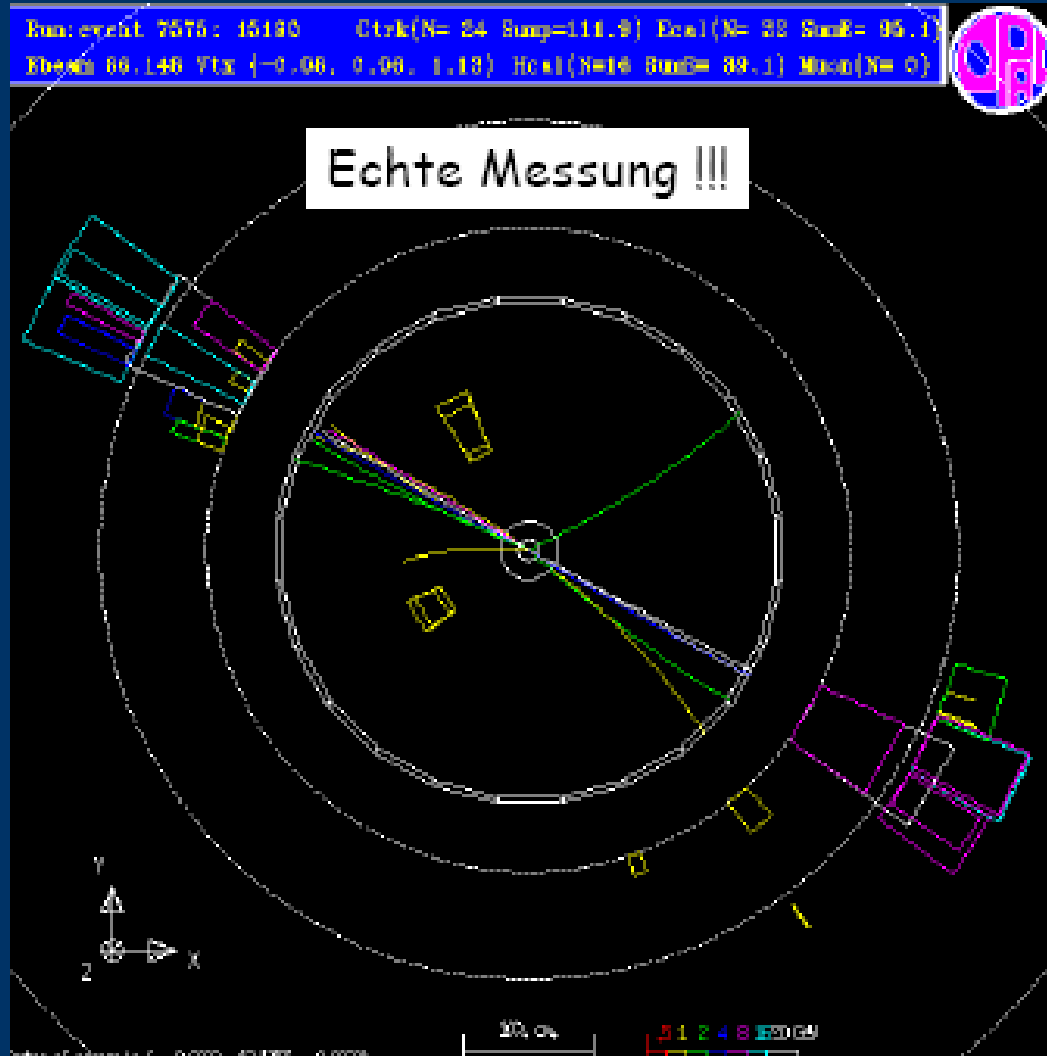
Hadronen

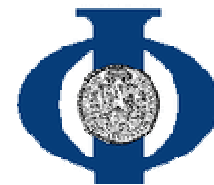
1. Kein Signal in den Myonkammern
2. Signal in der Spurkammer (meist) sowie Energiedisposition in beiden Kalorimetern





Jets (meist sehr viele Hadronen)





Run: event 7708: 23918 Ctrk(N= 1 SumE= 4.8)ecal(N= 7 SumE= 1.0)
 Kbeam 86.149 Tex (-0.05, 0.08, 0.00) Hcal(n= 2 SumE= 2.7) Muon(N= 1)

Signale in Muon-Kammern

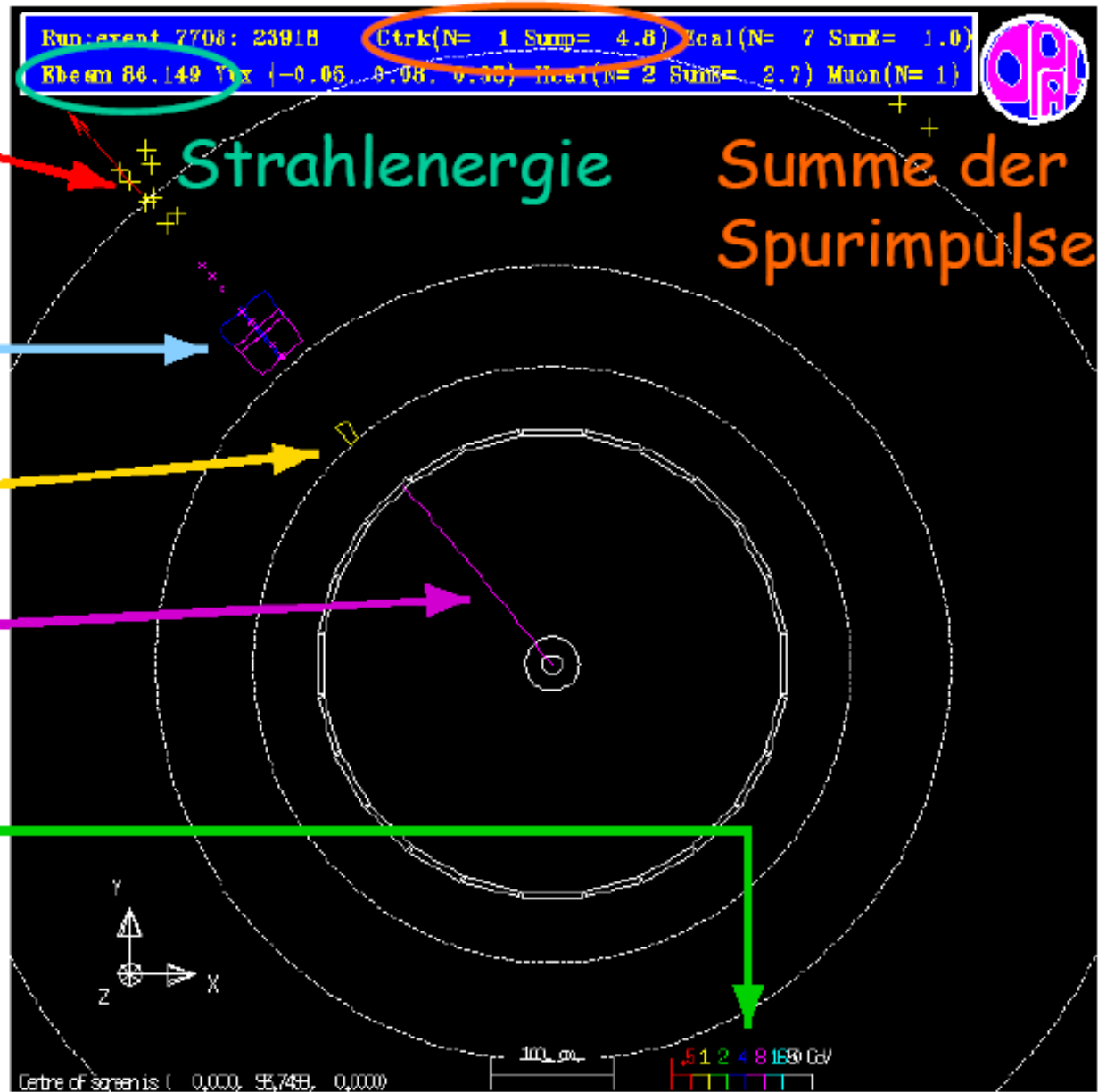
Signal im hadronischen Kalorimeter

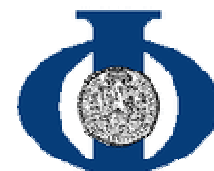
Signal im elektromagnetischen Kalorimeter

Spur eines geladenen Teilchens

Farbcode der Teilchenenergie :

- < 0.5 GeV
- 0.5 - 1.0 GeV
- 1.0 - 2.0 GeV
- 2.0 - 4.0 GeV
- 4.0 - 8.0 GeV
- 8.0 - 16.0 GeV
- > 16 GeV





```
Run: event 7708: 23918 Ctrk(N= 1 Sump= 4.8) Cal(N= 7 SumE= 1.0)
Kbeam 66.149 Vtx (-0.06, 0.04, 0.65) Bcal(N= 2 SumE= 2.7) Muon(N= 1)
```



Signale in Muon-Kammern

Strahlenergie

Summe der
Spurimpulse

Signal im hadronischen
Kalorimeter

Signal im elektromagnetischen
Kalorimeter

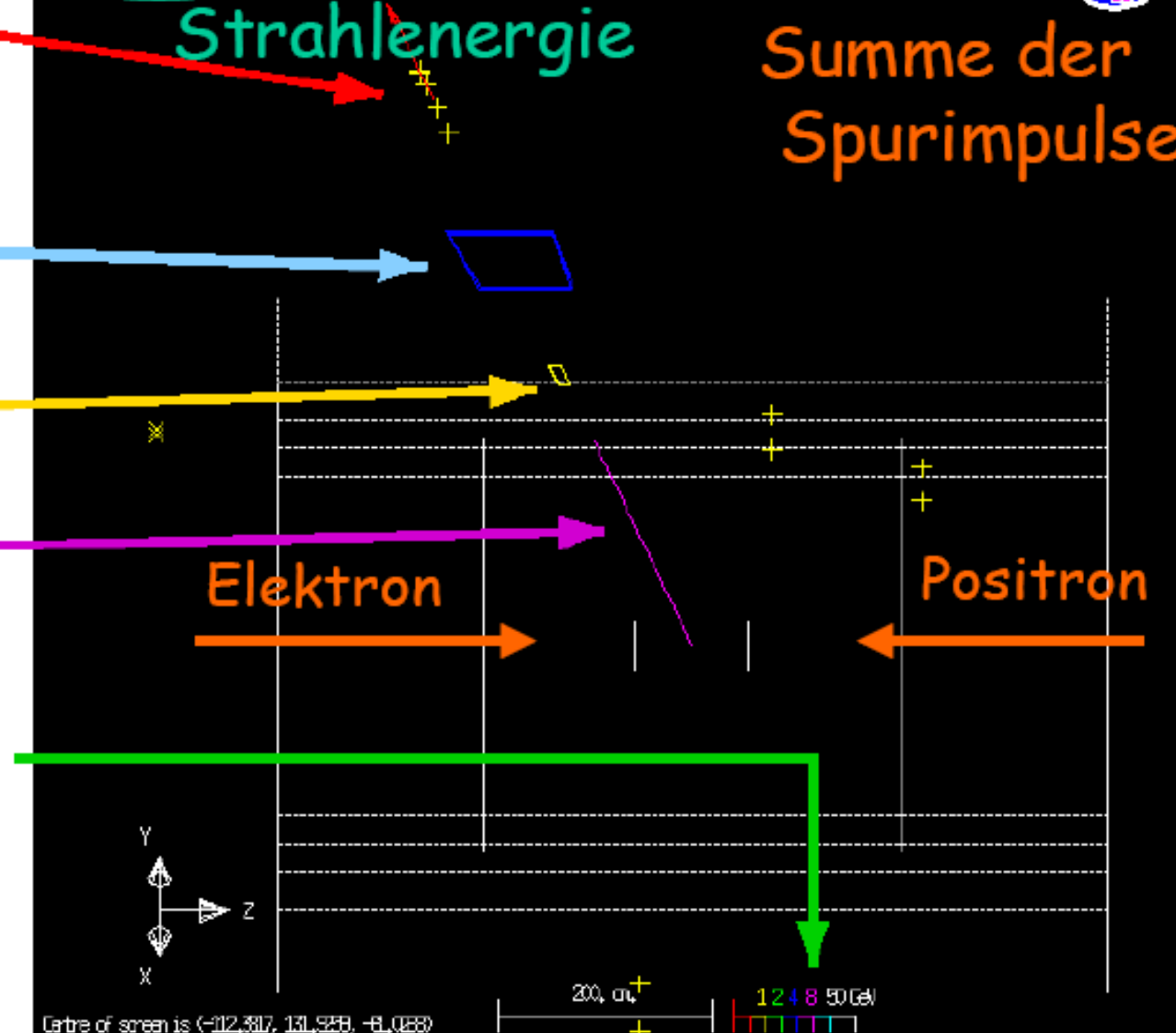
Spur eines geladenen
Teilchens

Elektron

Positron

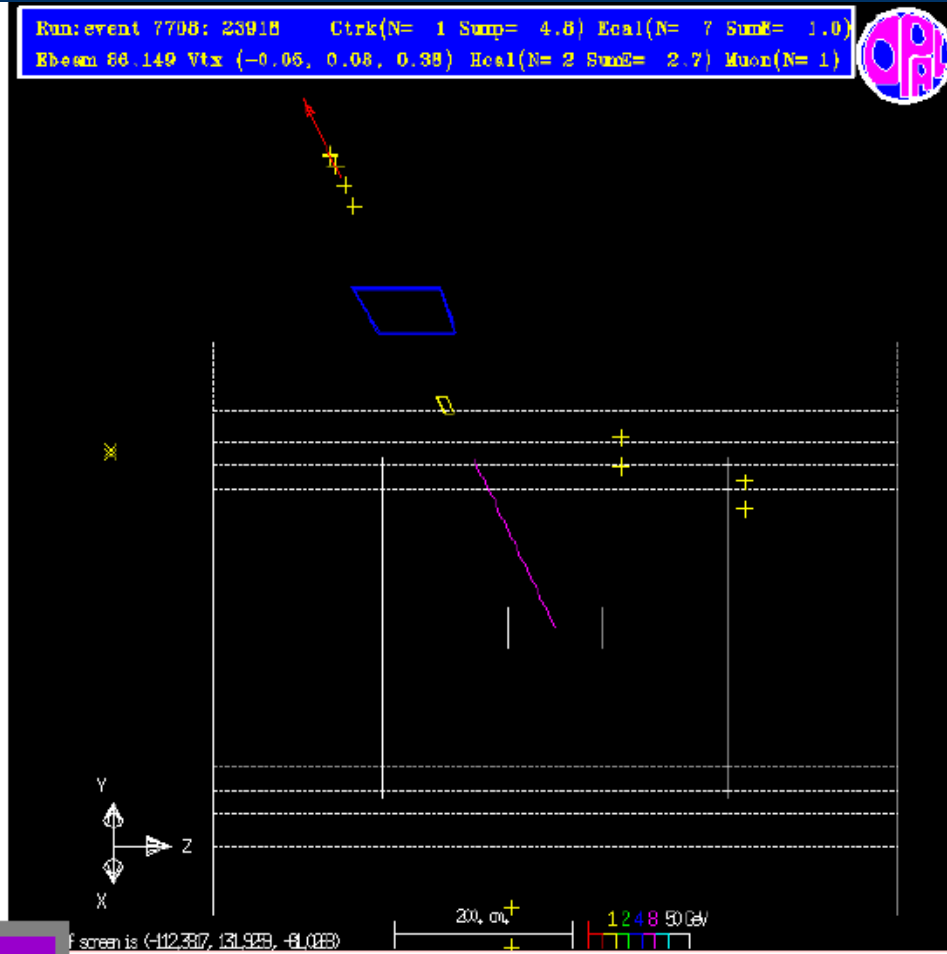
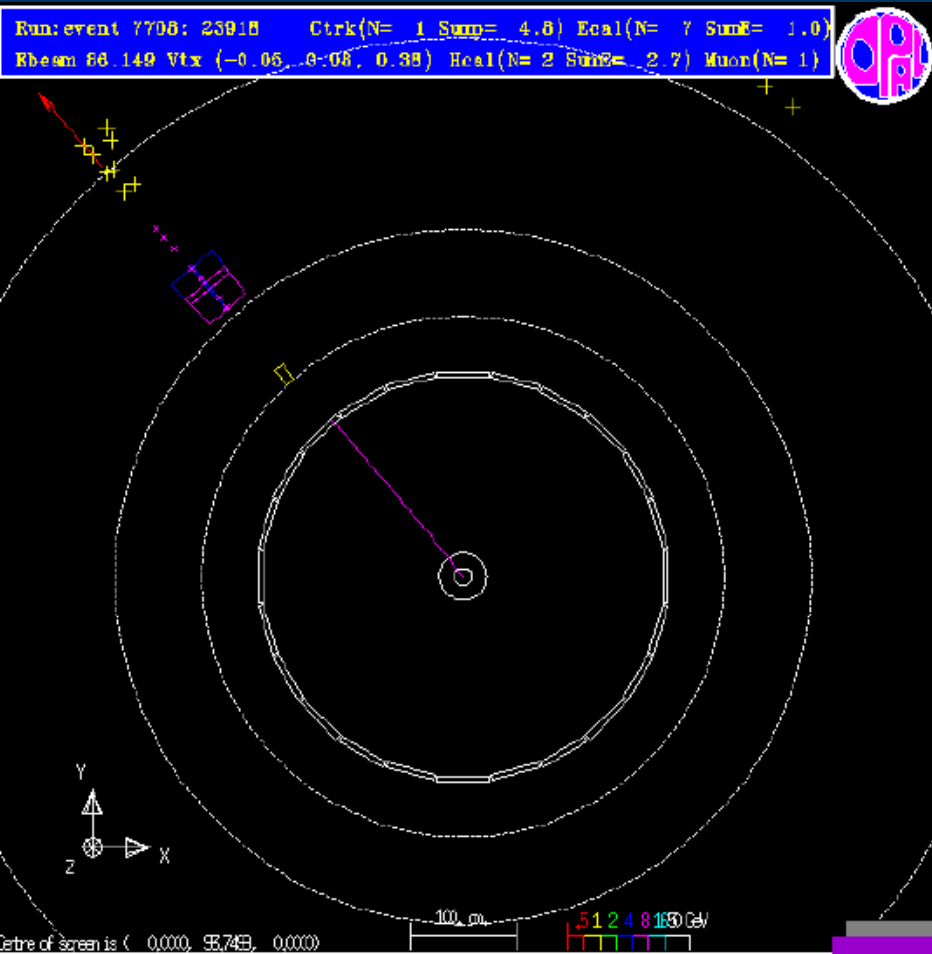
Farbcode der Teilchenenergie :

- < 0.5 GeV
- 0.5 - 1.0 GeV
- 1.0 - 2.0 GeV
- 2.0 - 4.0 GeV
- 4.0 - 8.0 GeV
- 8.0 - 16.0 GeV
- > 16 GeV





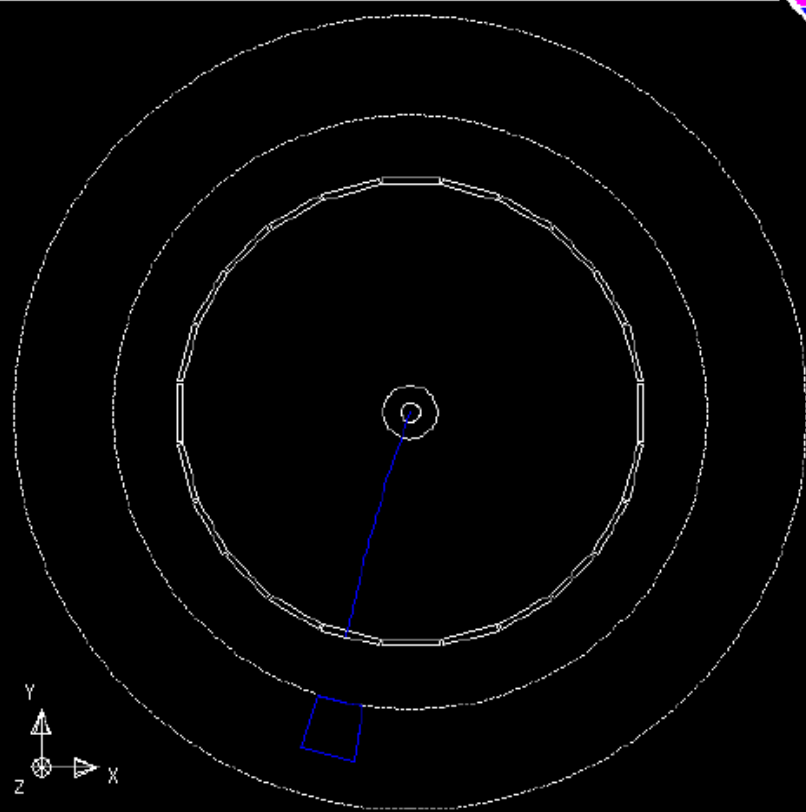
Myon





Elektron

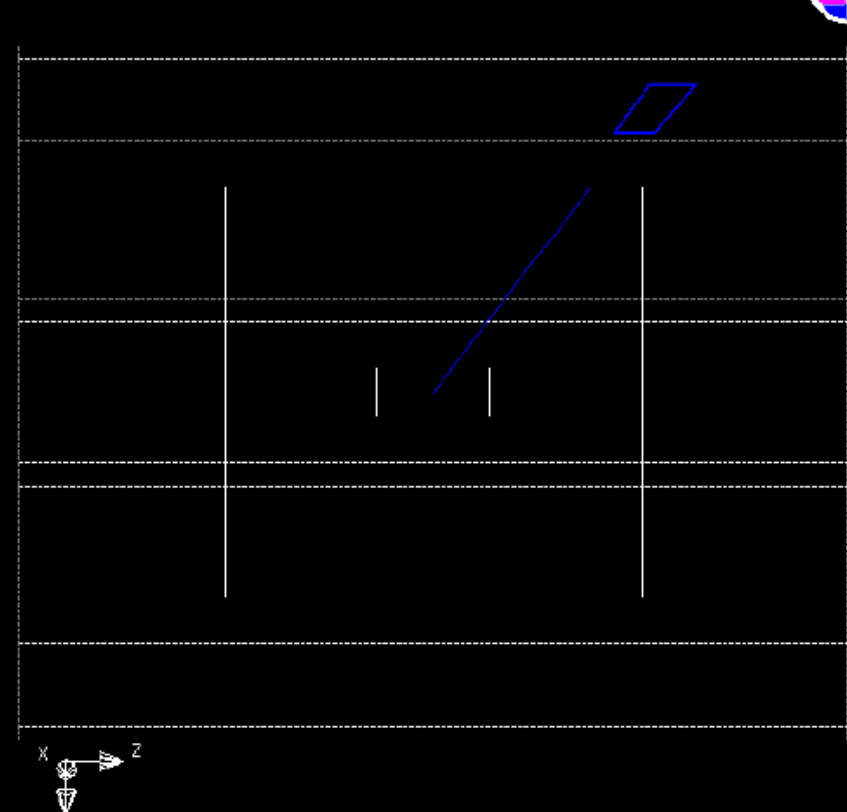
Run: event 7579: 31933 Ctrk(N= 1 Sump= 2.0) Ecal(N= 7 SumE= 3.4)
 Ebeam 86.180 Vtx (-0.07, 0.06, 0.38) Hcal(N= 0 SumE= 0.0) Muon(N= 0)



Centre of screen is (0.000, 11.885, 0.000)

100, cm 5 1 2 4 8 16 30 GeV

Run: event 7579: 31933 Ctrk(N= 1 Sump= 2.0) Ecal(N= 7 SumE= 2.4)
 Ebeam 86.180 Vtx (-0.07, 0.06, 0.38) Hcal(N= 0 SumE= 0.0) Muon(N= 0)



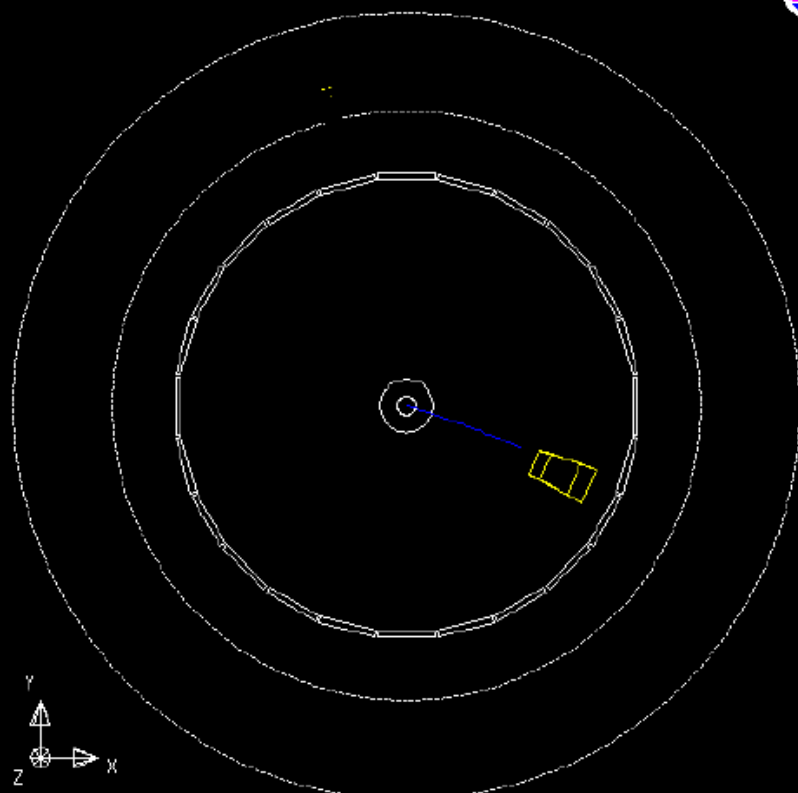
0.485 1.546, 0.000)

100, cm 5 1 2 4 8 16 30 GeV

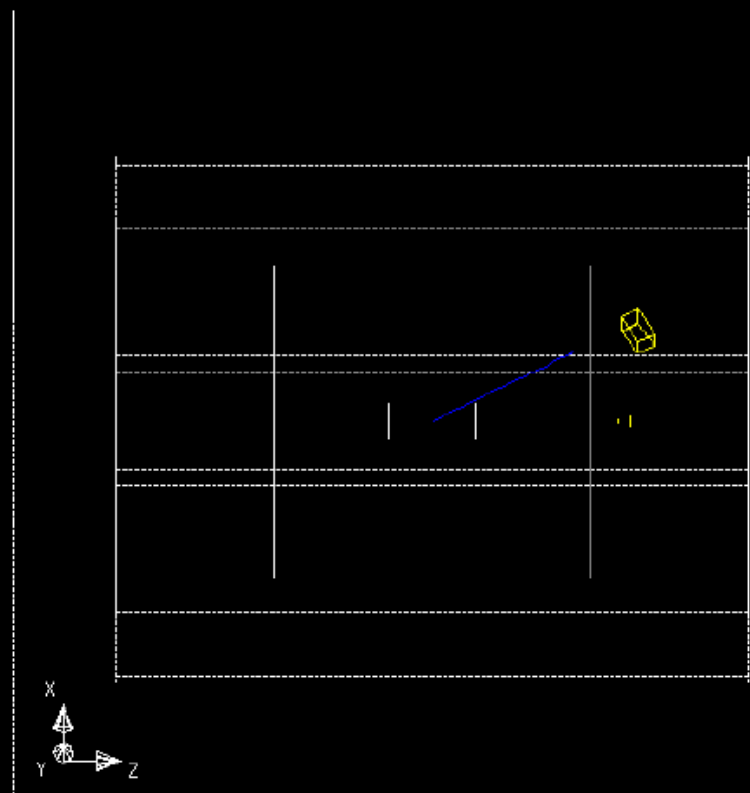


Hadron

Run: event 7022: 56657 Ctrk(N= 6 Sump= 2.3) Ecal(N= 14 SumE= 3.1)
 Ebeam 69.166 Vtx (-0.06, 0.06, 0.47) Hcal(N= 0 SumE= 0.0) Muon(N= 0)



Run: event 7022: 56657 Ctrk(N= 6 Sump= 2.3) Ecal(N= 14 SumE= 3.1)
 Ebeam 69.166 Vtx (-0.06, 0.06, 0.47) Hcal(N= 0 SumE= 0.0) Muon(N= 0)



Centre of screen is (0.000, 11.883, 0.000)

100, cm 51 2 4 8 150 GeV

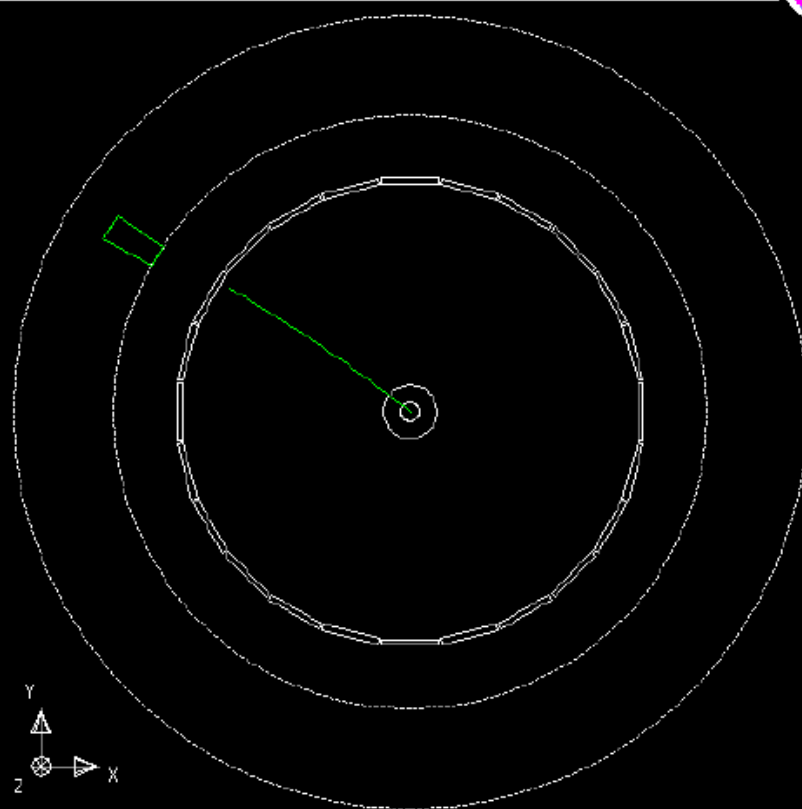
is (33.971, 8.882, 0.000)

200, cm 12 48 50 GeV



Elektron

Run: event 7579: 41259 Ctrk(N= 1 Sump= 1.7) Ecal(N= 9 SumE= 2.6)
 Ebeam 66.180 Vtx (-0.07, 0.06, 0.38) Hcal(N= 0 SumE= 0.0) Muon(N= 0)

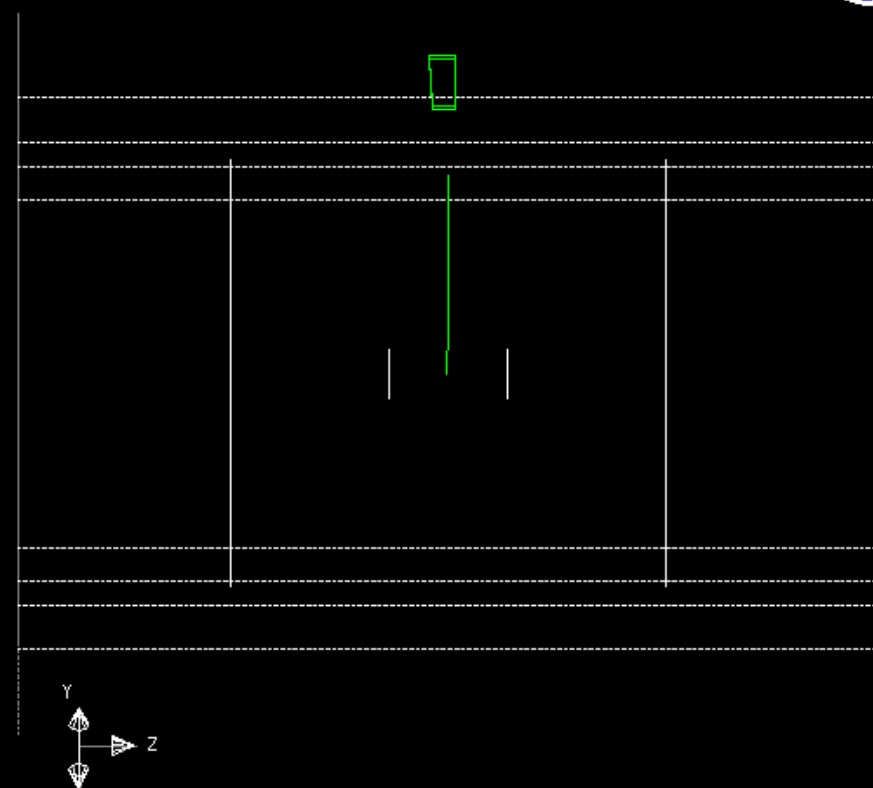


Centre of screen is (0.000, 11.855, 0.000)

100, cm

51 2 4 8 16 30 GeV

Run: event 7579: 41259 Ctrk(N= 1 Sump= 1.7) Ecal(N= 9 SumE= 2.6)
 Ebeam 66.180 Vtx (-0.07, 0.06, 0.38) Hcal(N= 0 SumE= 0.0) Muon(N= 0)



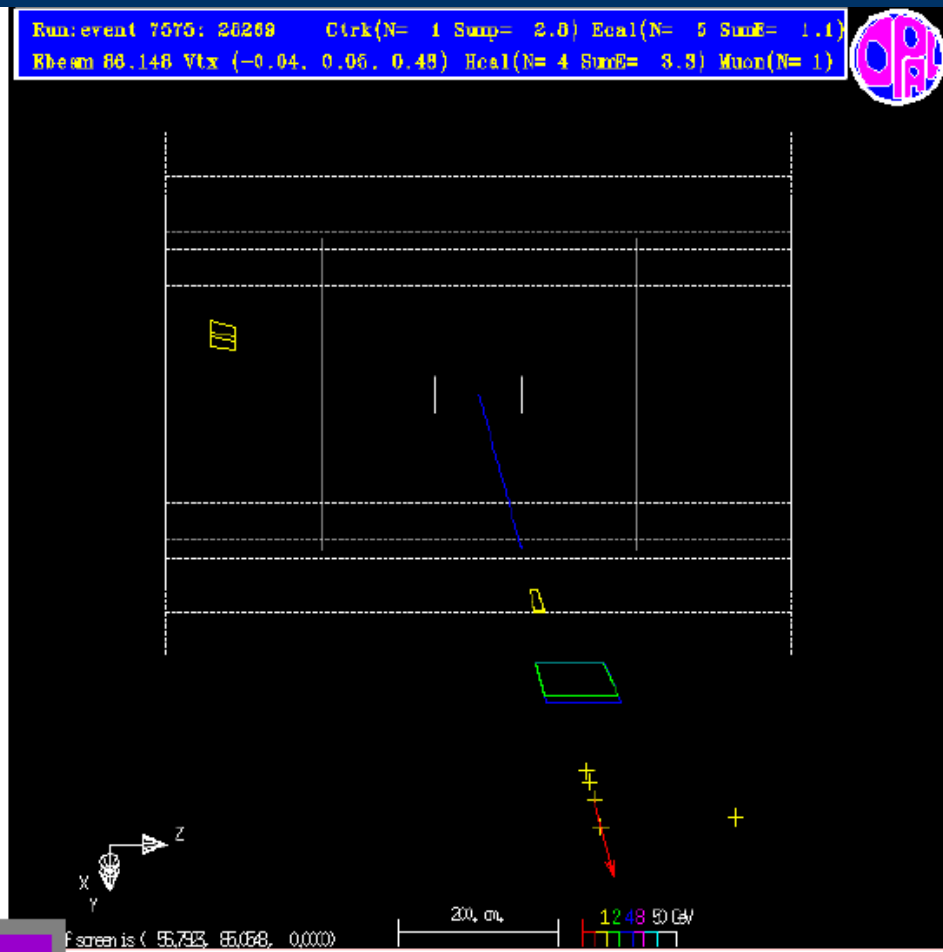
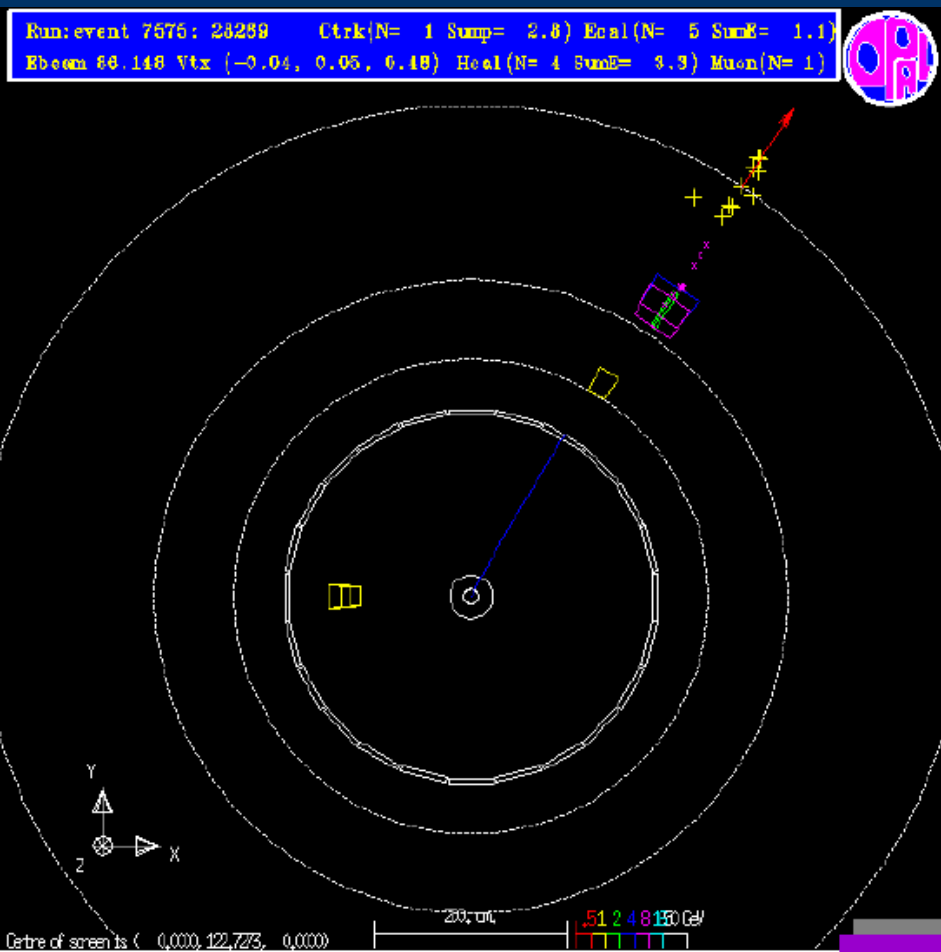
1787, -1503, 0.000

100, cm

51 2 4 8 16 30 GeV

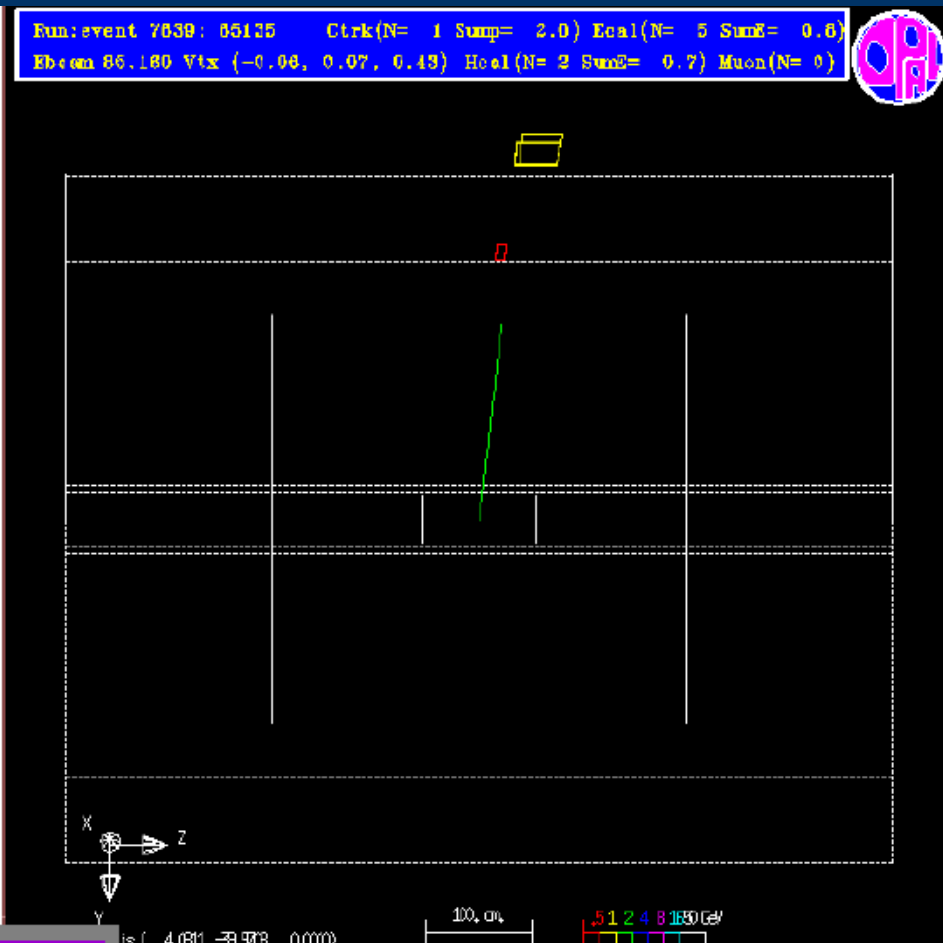
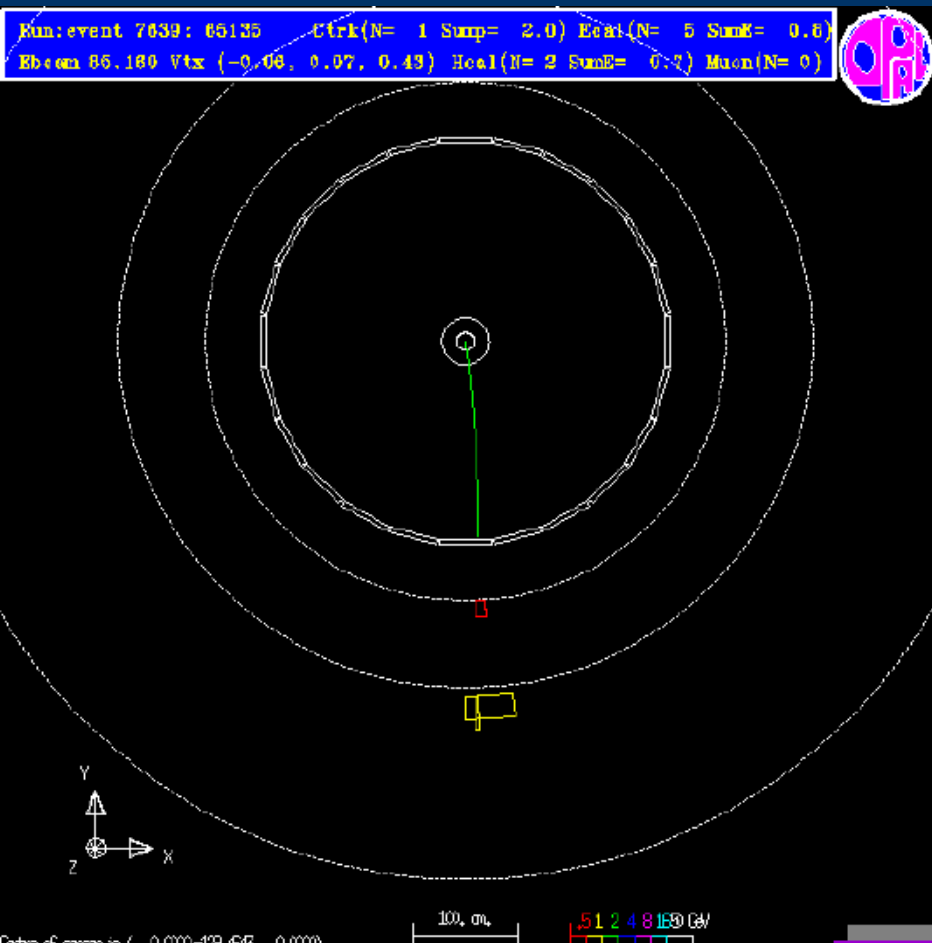


Myon





Hadron



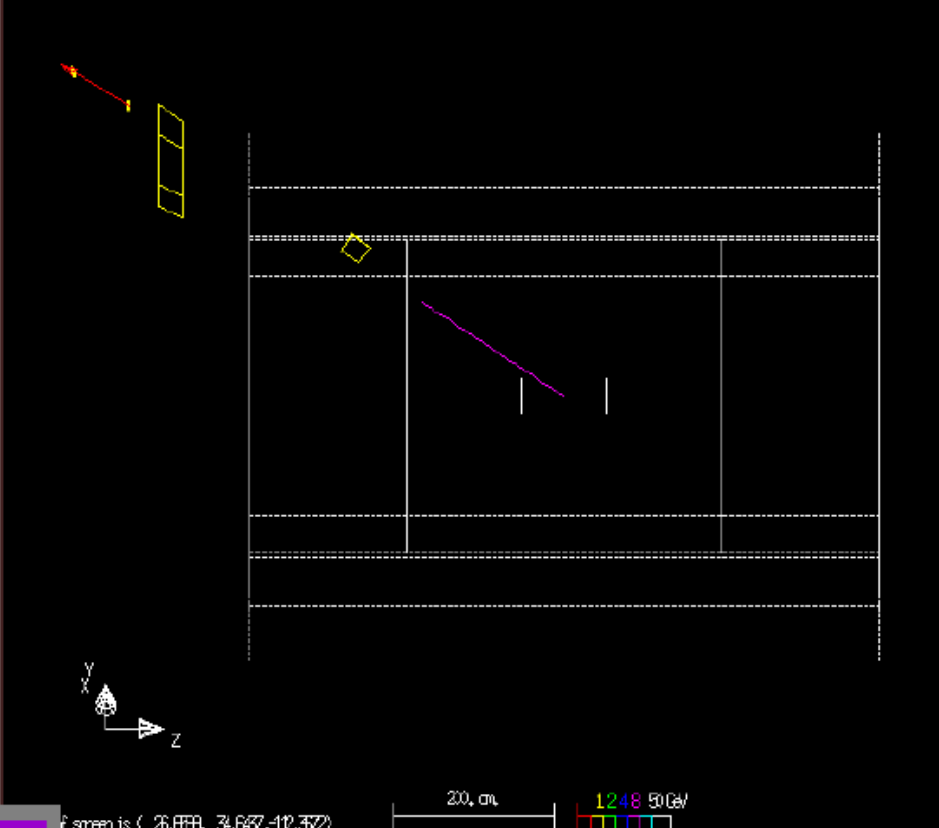
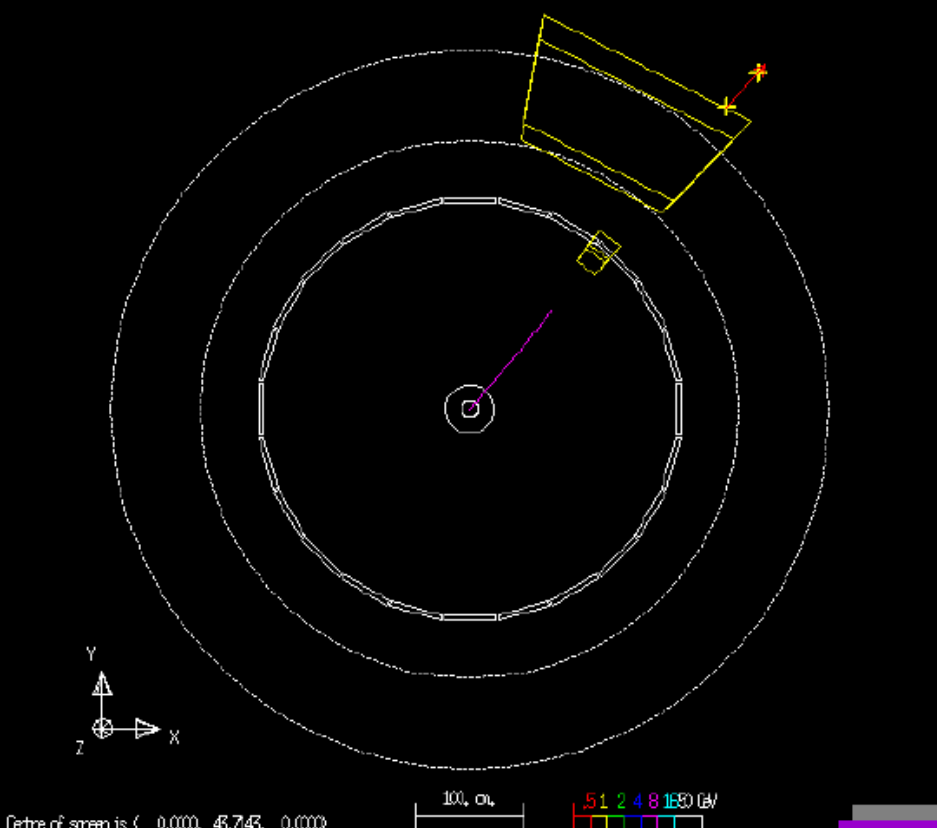


Myon

Run: event 7010: 60147 Ctrk(N= 1 SumE= 5.5) Ecal(N= 5 SumE= 1.3)
 Ebeam 86.136 Vtx (-0.04, 0.06, 0.40) Hcal(N= 2 SumE= 0.4) Muon(N= 1)



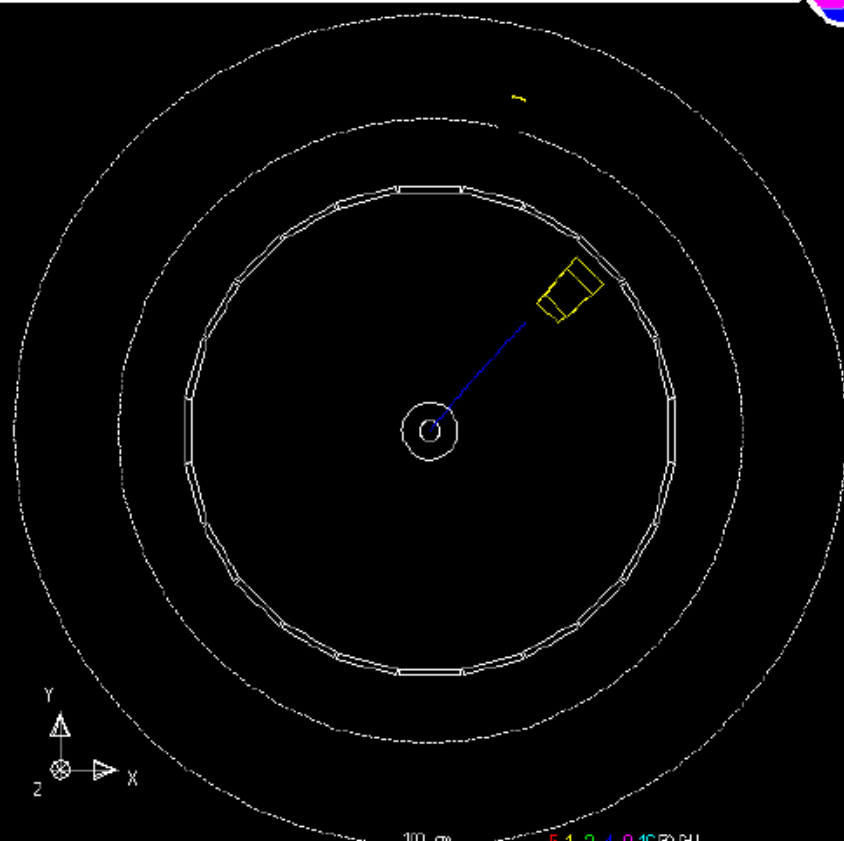
Run: event 7010: 60147 Ctrk(N= 1 SumE= 5.5) Ecal(N= 5 SumE= 1.3)
 Ebeam 86.136 Vtx (-0.04, 0.06, 0.40) Hcal(N= 2 SumE= 0.4) Muon(N= 1)





Hadron

Run: event 7635: 36802 Ctrk(N= 1 Stmp= 2.7) Ecal(N= 15 SumE= 2.6)
 Ebeam 86.180 Vtx (-0.06, 0.06, 0.43) Hcal(N= 1 SumE= 0.0) Muon(N= 0)

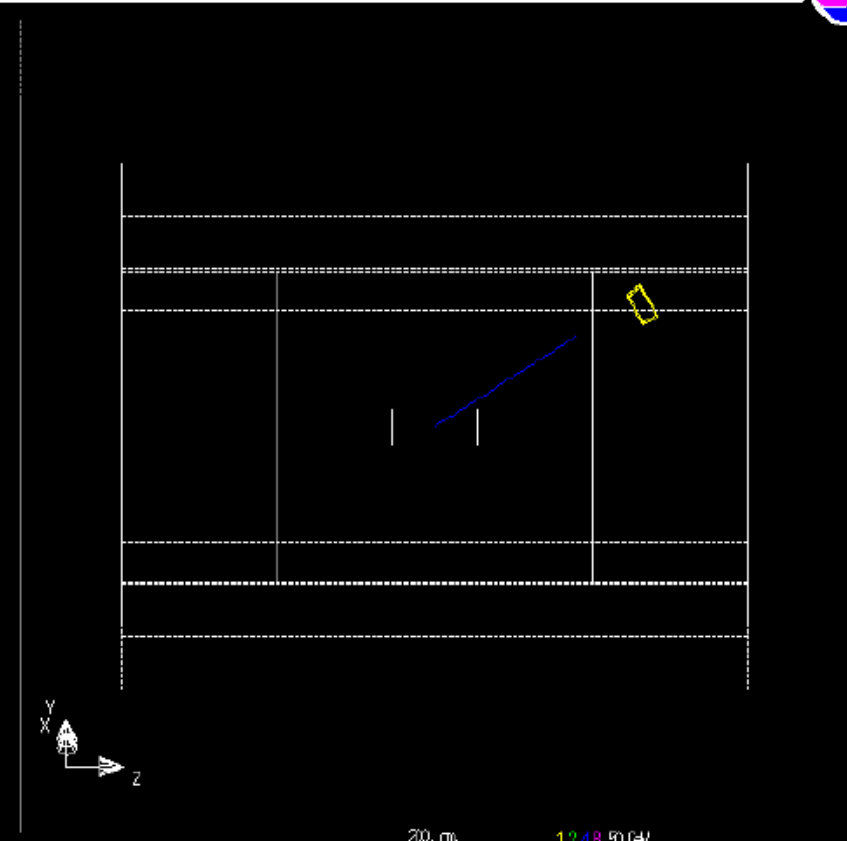


Centre of screen is (0.000, 26.154, 0.000)

100. cm

5 1 2 4 8 16 50 100

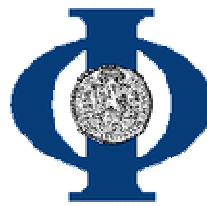
Run: event 7635: 36802 Ctrk(N= 1 Stmp= 2.7) Ecal(N= 15 SumE= 2.6)
 Ebeam 86.180 Vtx (-0.06, 0.06, 0.43) Hcal(N= 1 SumE= 0.0) Muon(N= 0)



Centre of screen is (20.553, 28.473, 0.000)

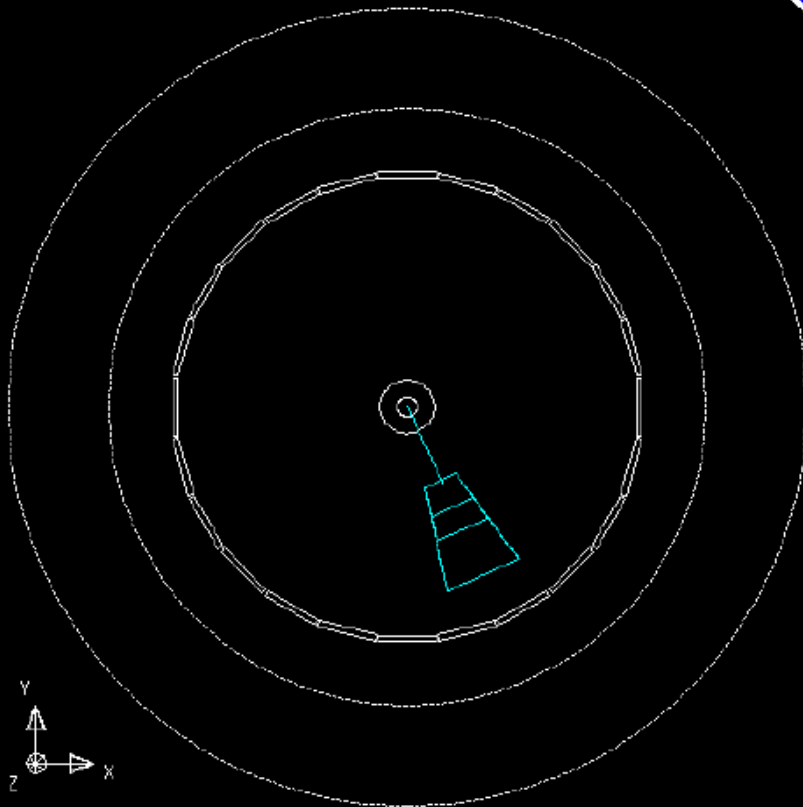
20. cm

12 48 50 100



Elektron

Run: event 7581: 42018 Ctrk(N= 2 Sump= 10.6) Ecal(N= 8 SumE= 18.7)
Ebeam 88.154 Vtx (-0.07, 0.08, 0.47) Hcal(N= 1 SumE= 1.8) Muon(N= 0)

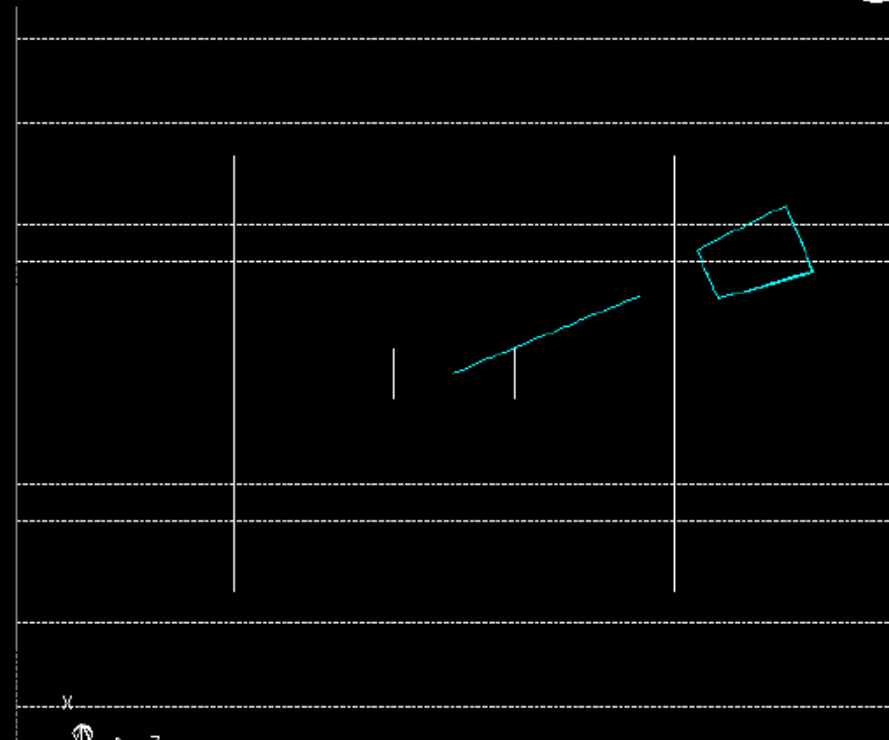


Rate of spurs (0.000 1.15E-05 0.000)

100, cm

.51 2 4 8 16 30 GeV

Run: event 7581: 42018 Ctrk(N= 2 Sump= 10.6) Ecal(N= 8 SumE= 18.7)
Ebeam 88.154 Vtx (-0.07, 0.08, 0.47) Hcal(N= 1 SumE= 1.8) Muon(N= 0)



-0.988 2.1E0 0.000

100, cm

.51 2 4 8 16 30 GeV

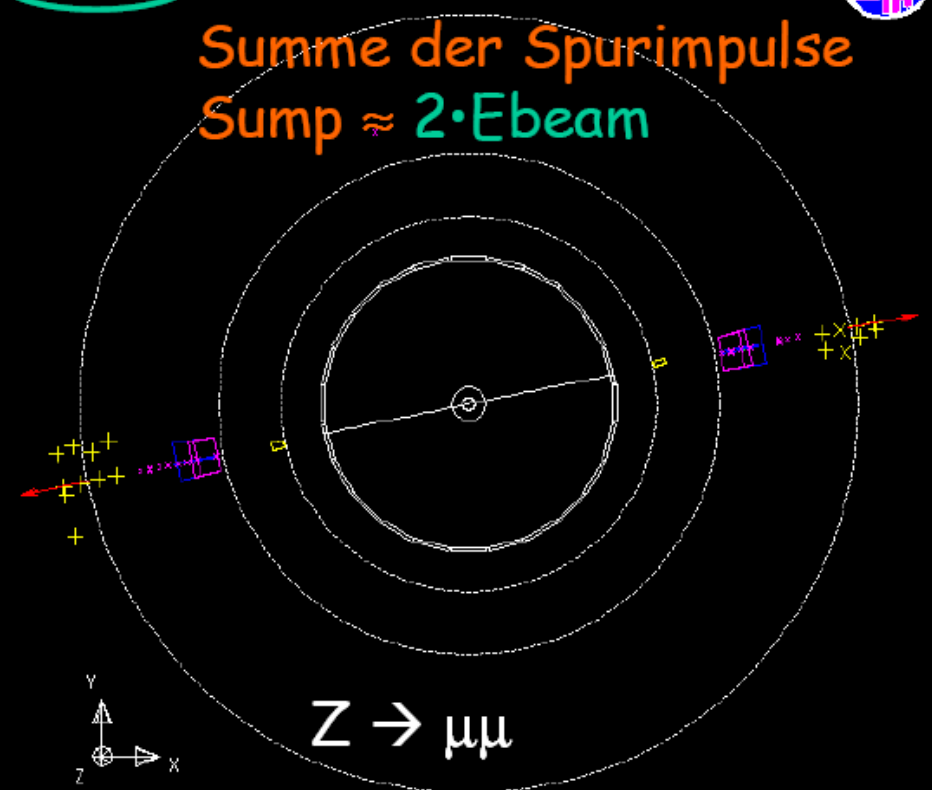


Beispielzerfälle Z-Boson

Run: event 7592: 63783 Cirk(N= 2 Sump=159.0) Ecal(N= 7 SumE= 1.4)
Ebeam 86.187 Vtx (-0.06, 0.06, 0.35) Hadr(N= 6 SumE= 0.2) Muon(N= 2)



Summe der Spurimpulse
Sump $\approx 2 \cdot E_{\text{beam}}$

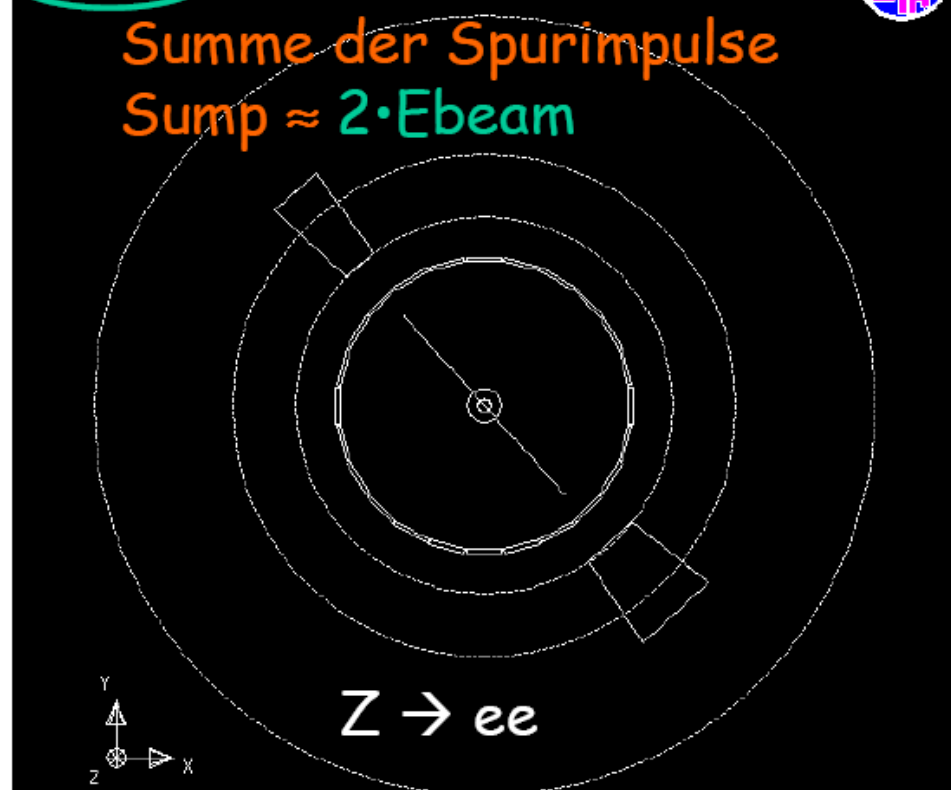


Centre of screen is (0,000, 19,573, 0,000) 200, cm 1248 50 GeV

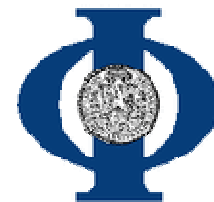
Run: event 7576: 13612 Cirk(N= 2 Sump=140.6) Ecal(N= 16 SumE=175.3)
Ebeam 86.148 Vtx (-0.06, 0.06, 0.48) Hadr(N= 0 SumE= 0.0) Muon(N= 0)



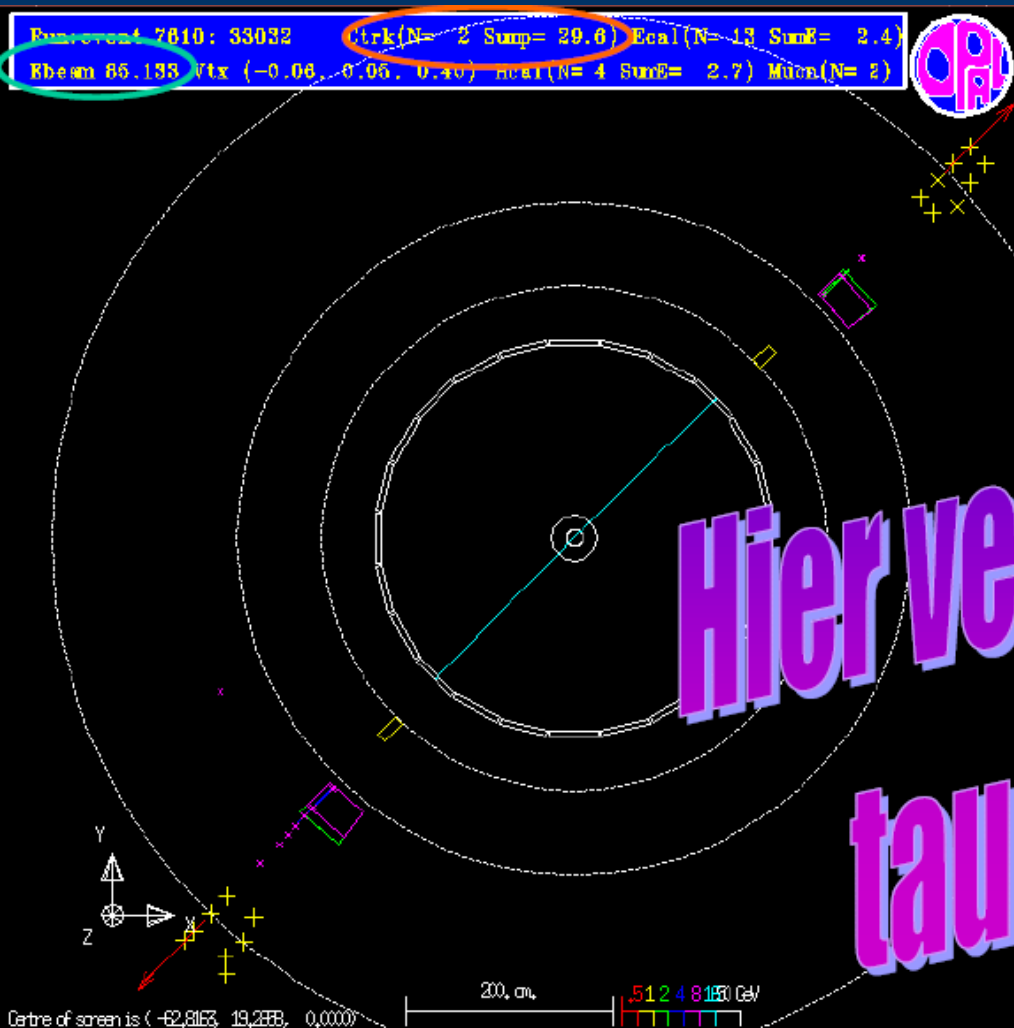
Summe der Spurimpulse
Sump $\approx 2 \cdot E_{\text{beam}}$



Centre of screen is (0,000, 19,297, 0,000) 200, cm 1248 50 GeV



Was ist das ?



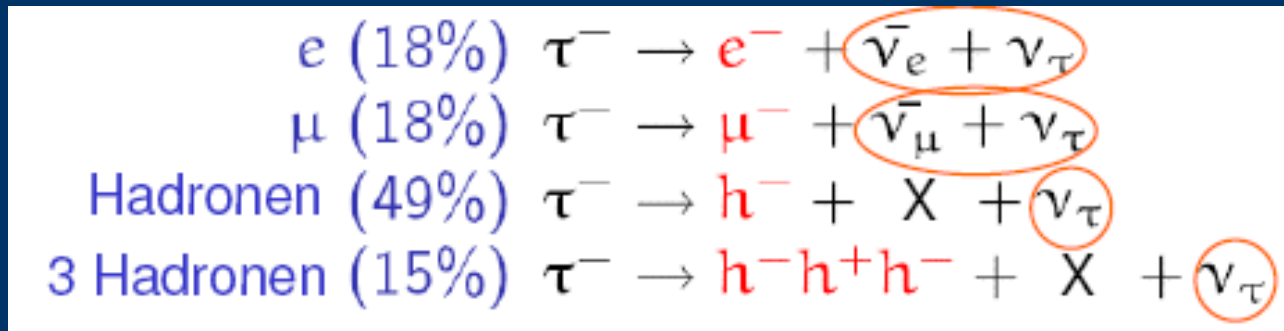
2 eindeutige Myonen, aber
Summe der Spurimpulse
 $Sump \ll 2 \cdot E_{beam}$

Hier verstecken sich
tau-Zerfälle!



Tau-Lepton

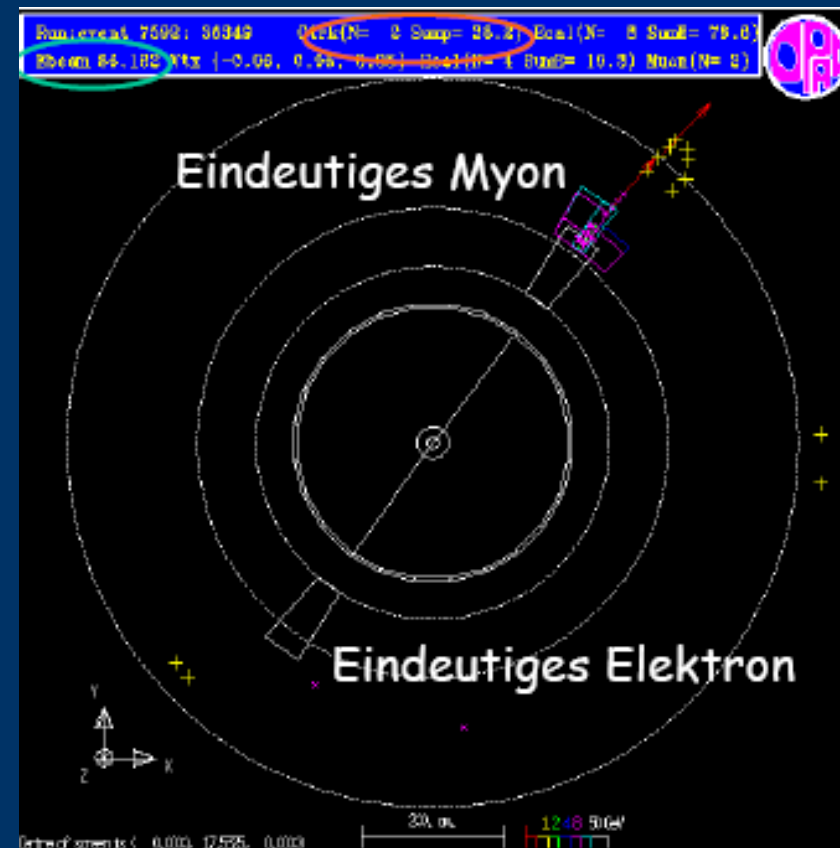
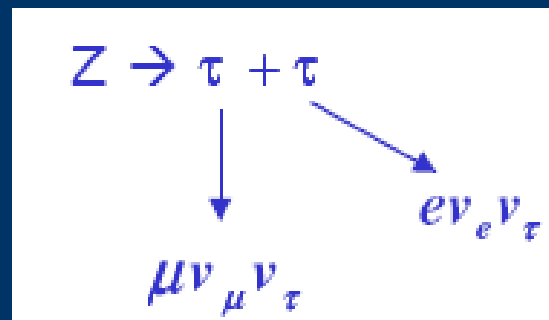
- Tau ist ein Herausforderung für Teilchenphysiker !
- Tau hat mehrere Möglichkeiten zu zerfallen, man sieht nur die Zerfallsprodukte, nicht das tau selbst

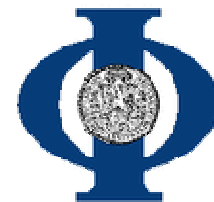


- Hauptmerkmal: Neutrinos -> fehlende Energie
- Achtung: Der Z-Zerfall hat 2 Tau, die unabhängig voneinander zerfallen

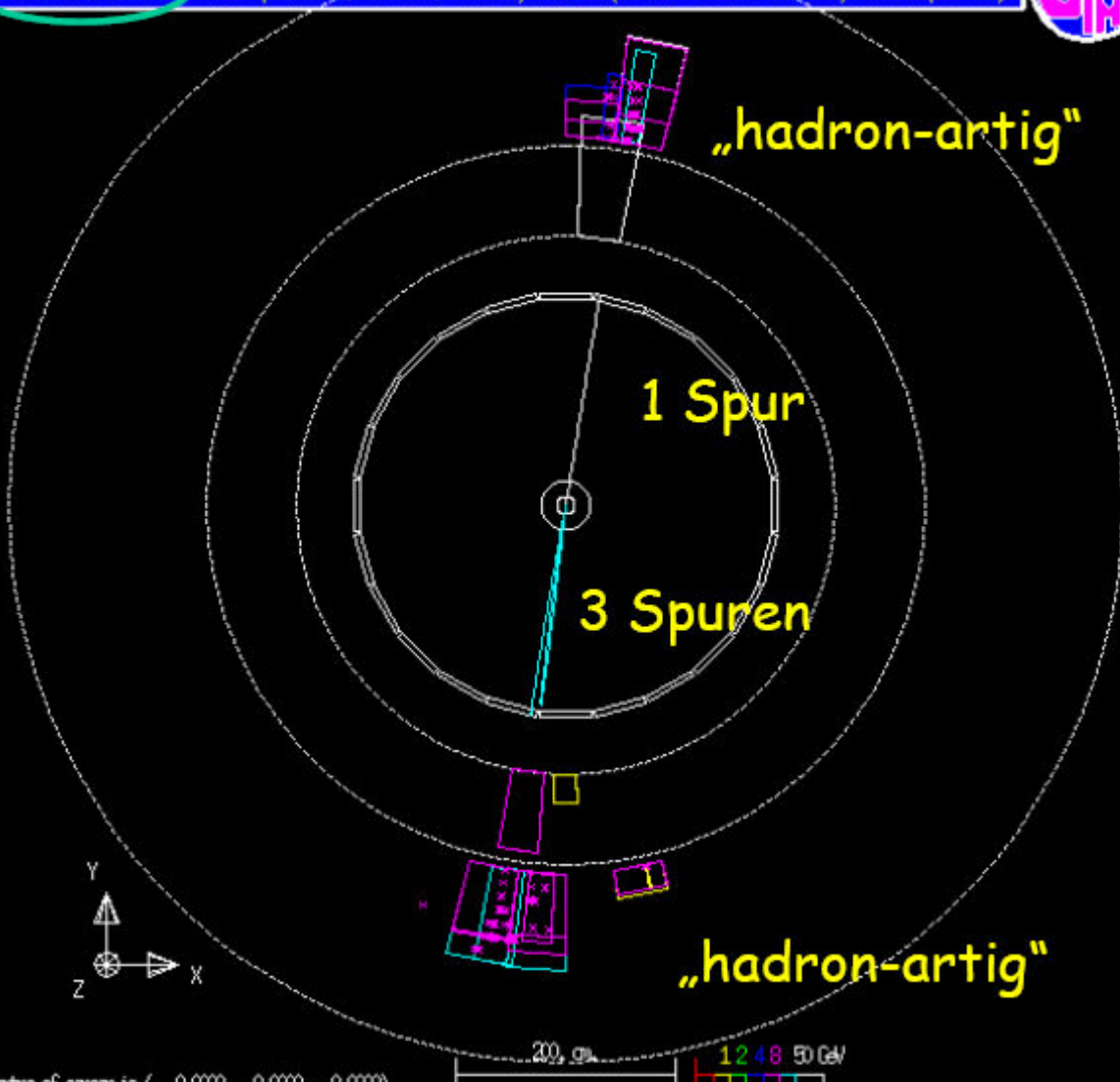
Z -> tau tau

- Summe der Spurimpulse
Sump << 2 x Ebeam
- 4 Neutrinos tragen
Energie aus dem
Detektor

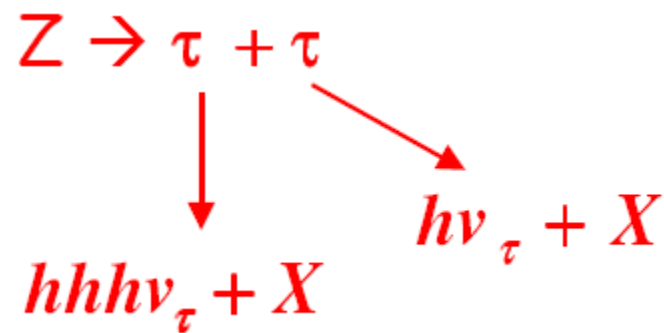


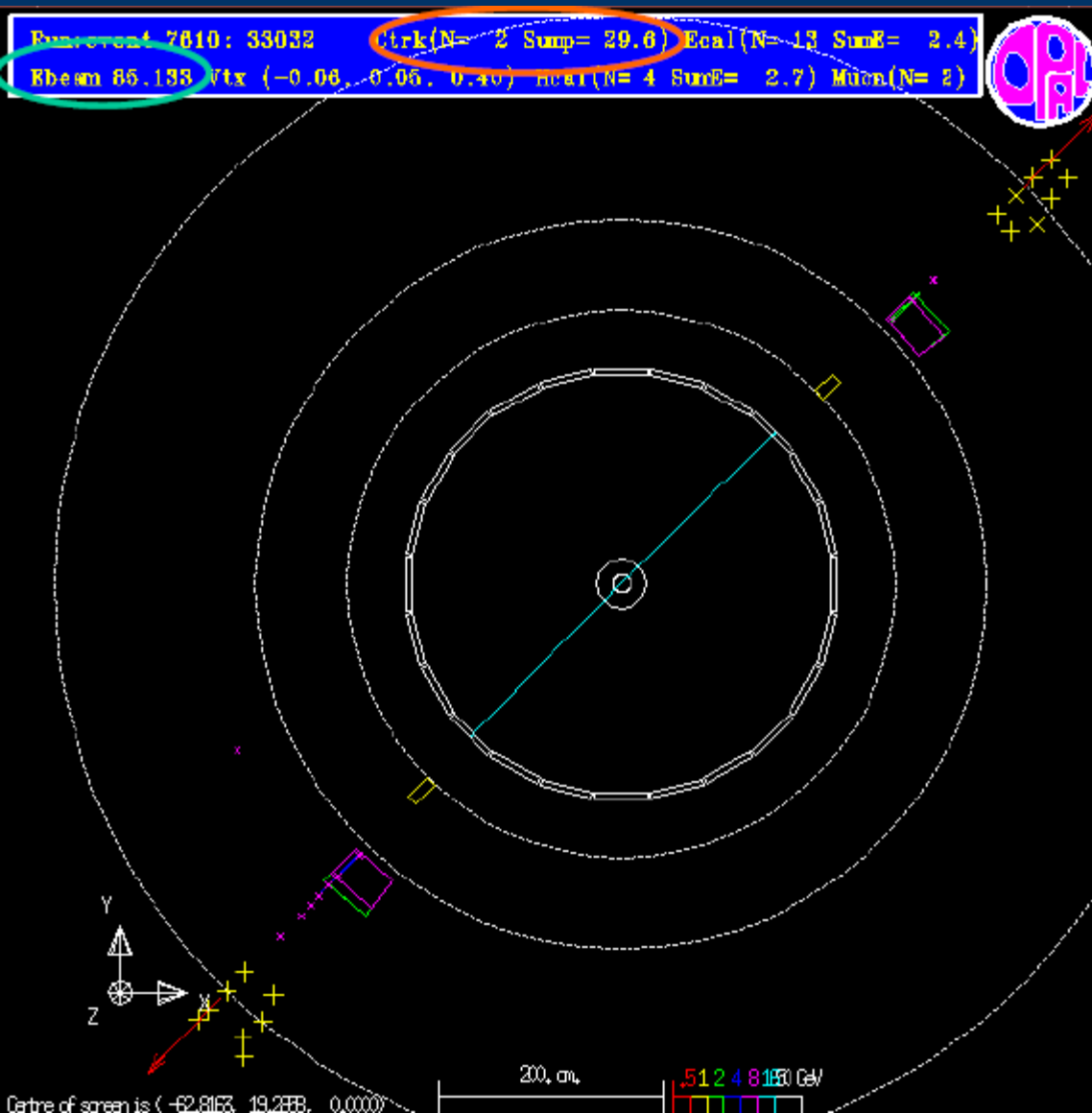
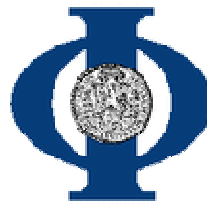


Run: event 7624: 27103 Ctrk(N= 4 SumE= 49.9) Ecal(N= 18 SumE= 49.3)
Ebeam 86.170 Vtx (-0.08, -0.28, -0.42) Hcal(N=10 SumE= 49.4) Muon(N= 0)

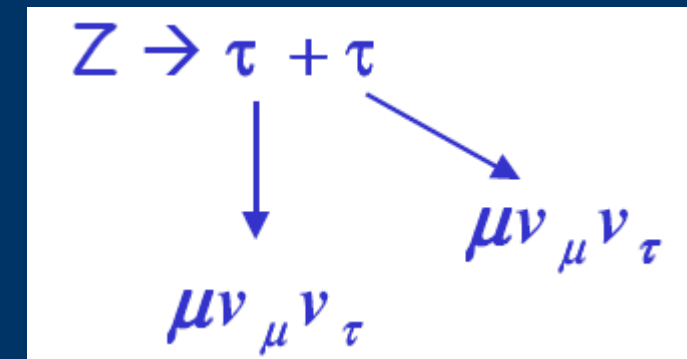


- Nur wenige Spuren
- Fehlende Energie



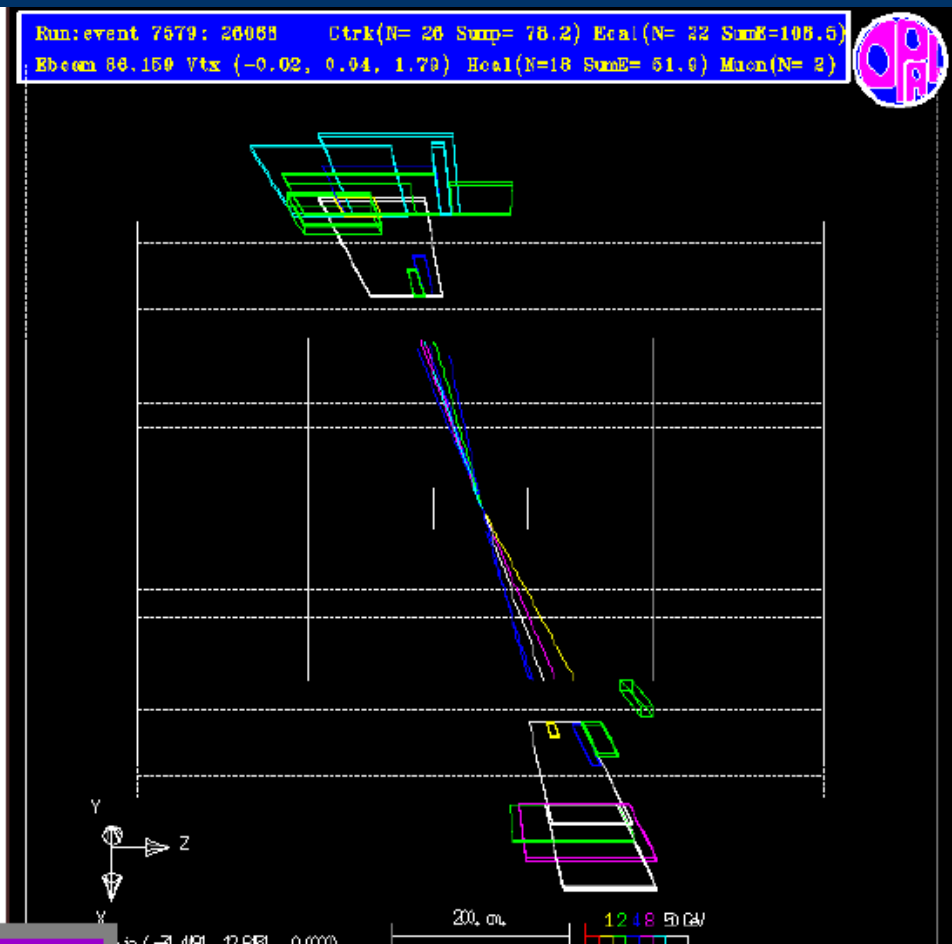
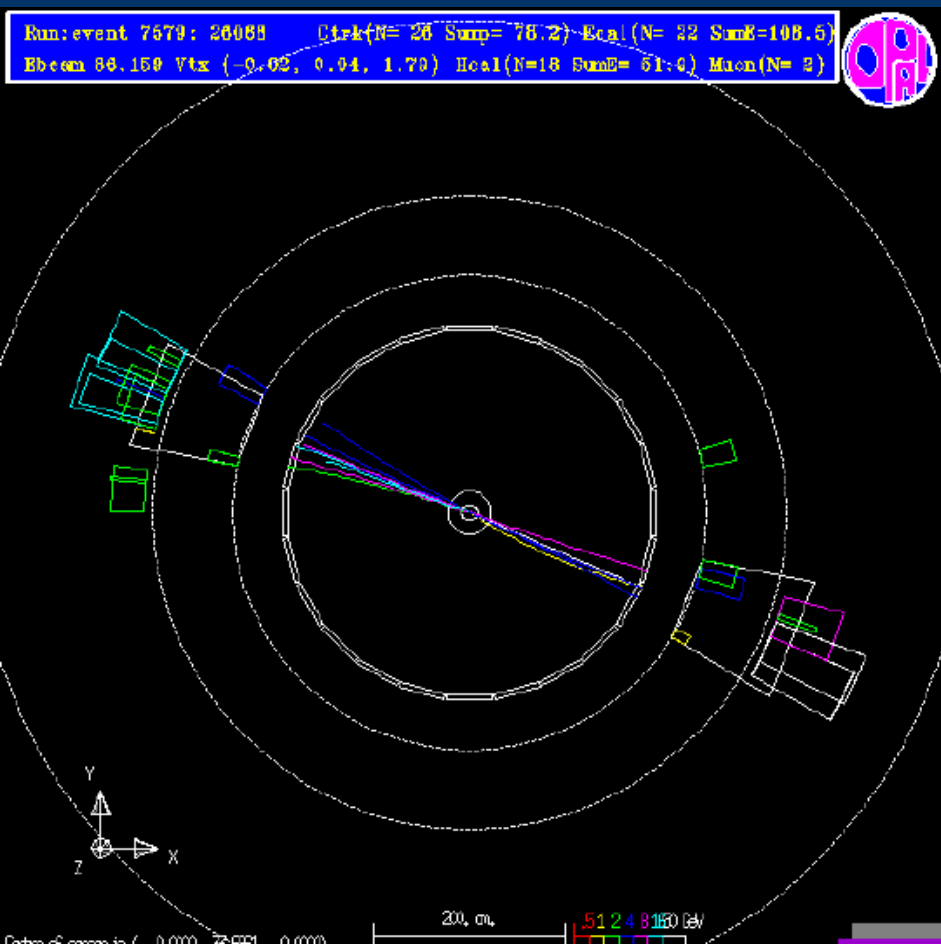


2 eindeutige Myonen,
aber Summe der
Spurimpulse 29.6
GeV \ll 170 GeV



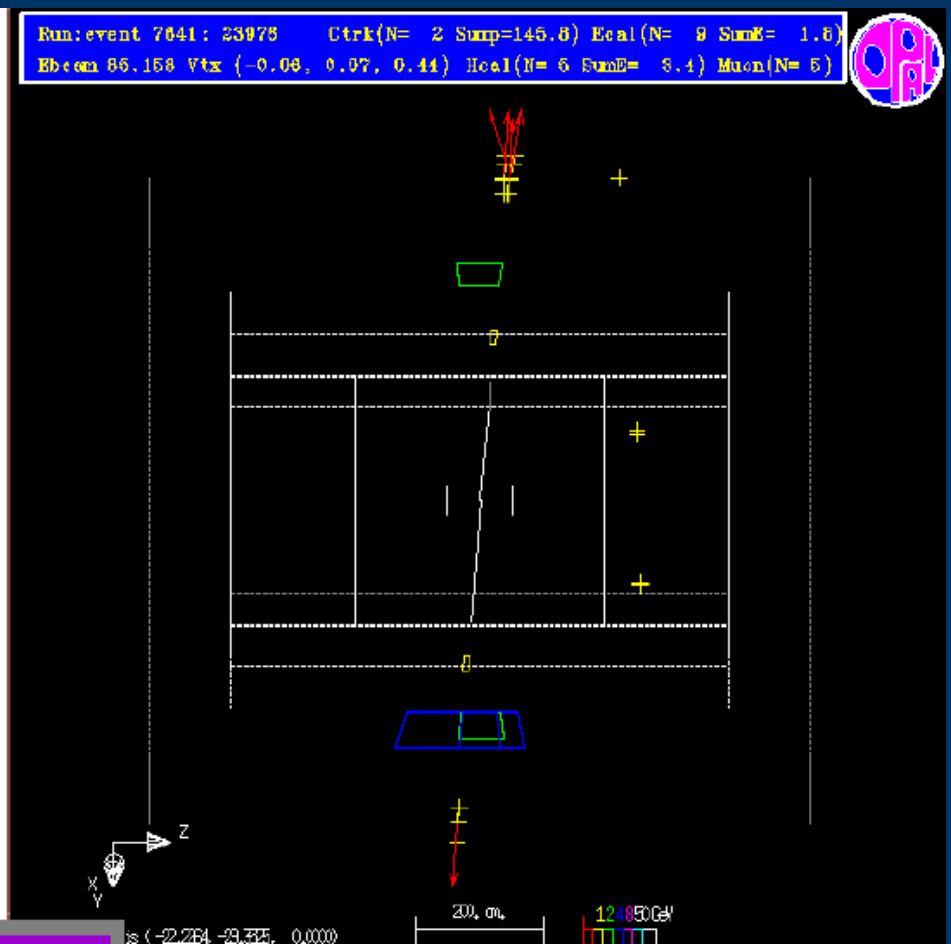
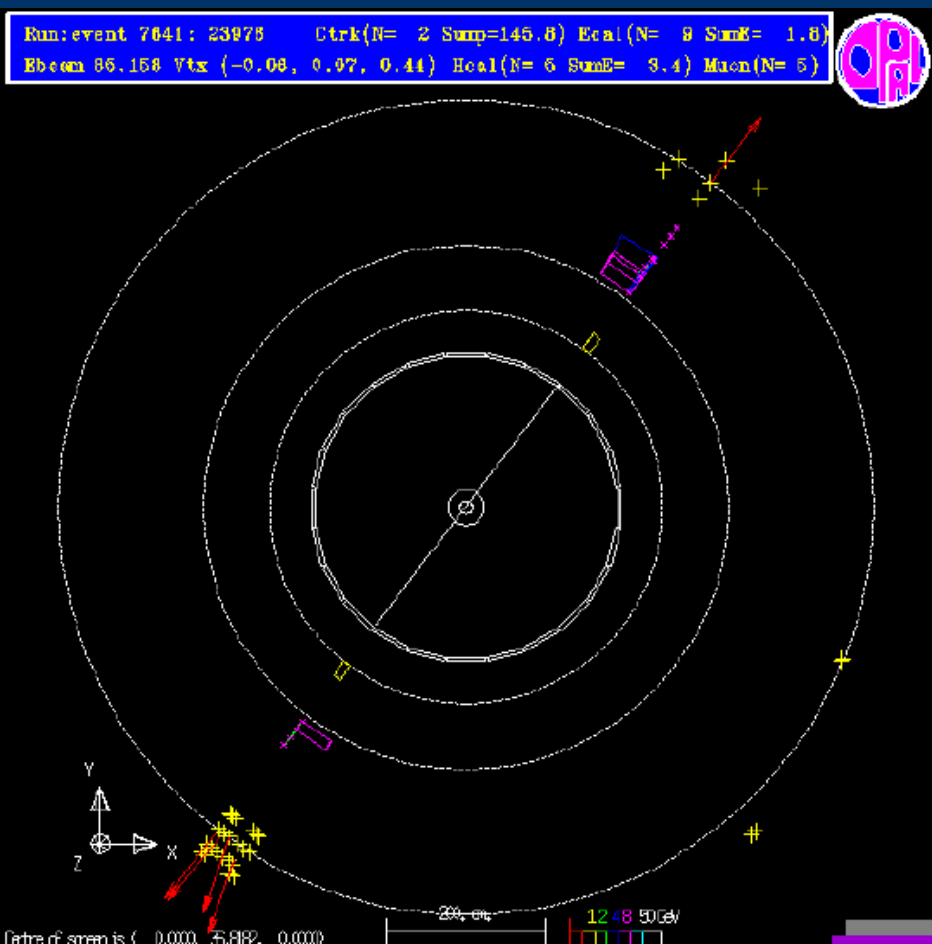


Z-> q q





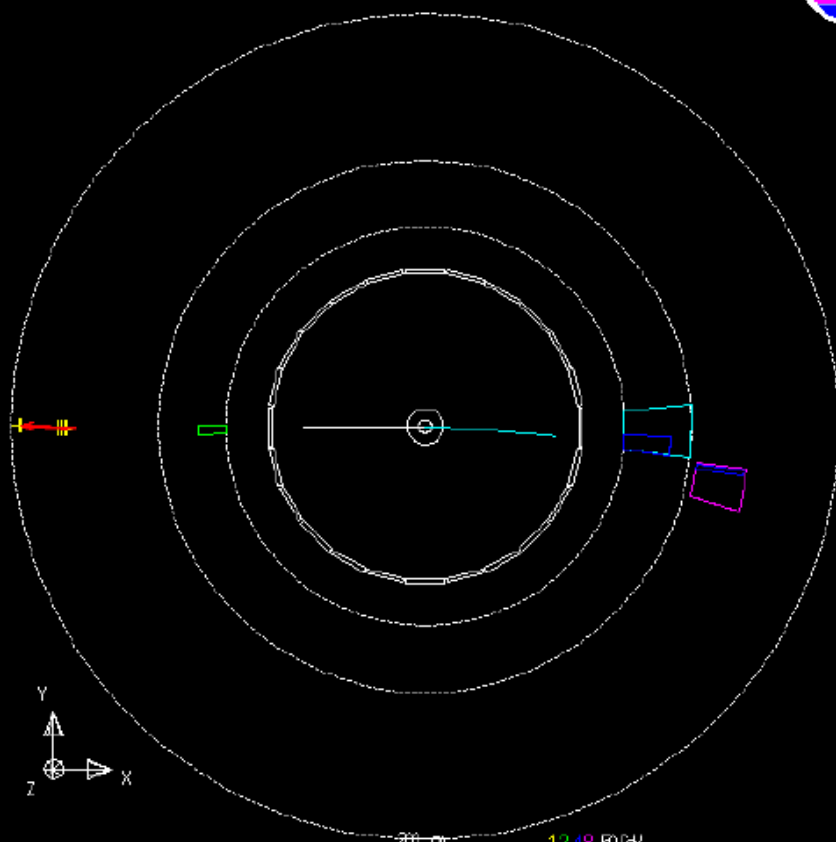
Z -> mu mu





Z -> tau tau -> mu nu nu + h nu

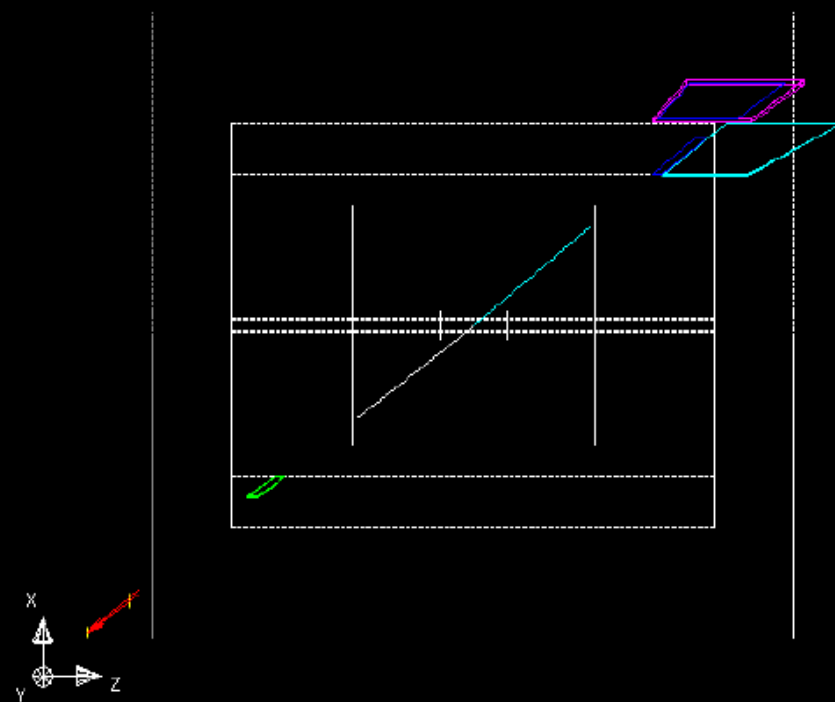
Run: event 7579: 10951 Ctrk(N= 2 Sump= 36.1) Ecal(N= 16 SumE= 17.6)
Ebeam 86.153 Vtx (-0.07, 0.06, 0.38) Hcal(N= 2 SumE= 4.4) Muon(N= 8)



Centre of screen is (0,000, 35,069, 0,000)

20, cm 12.48 50 GeV

Run: event 7579: 10951 Ctrk(N= 2 Sump= 36.1) Ecal(N= 16 SumE= 17.6)
Ebeam 86.153 Vtx (-0.07, 0.06, 0.38) Hcal(N= 2 SumE= 4.4) Muon(N= 8)



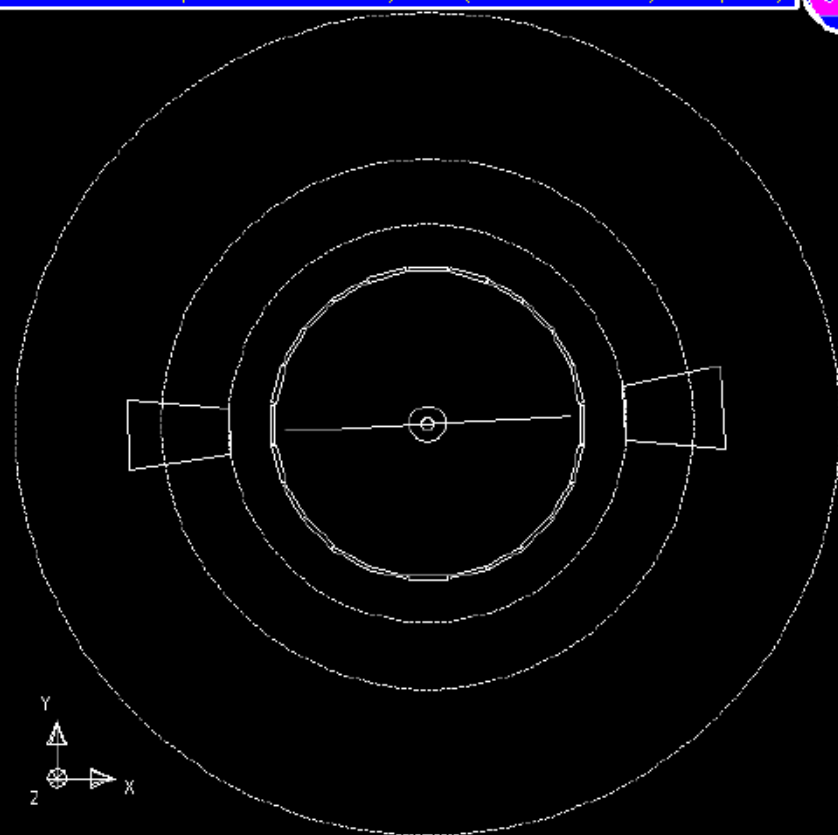
25719

20, cm 12.850 GeV



Z -> e e

Run: event 7575: 19535 Ctrk(N= 3 Sump=174.9) Ecal(N= 21 SumE=157.6)
Ebeam 88.148 Vtx (-0.06, 0.05, 0.48) Hcal(N= 1 SumE= 1.2) Muon(N= 0)

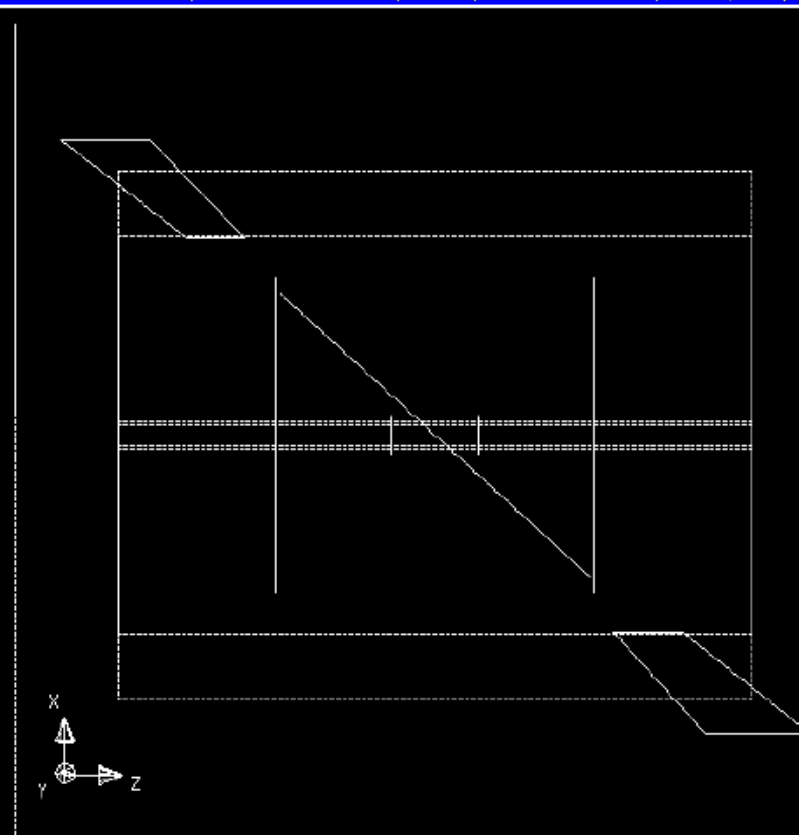


Centre of screen is (0.000, 19.258, 0.000)

200, cm

1248 50GeV

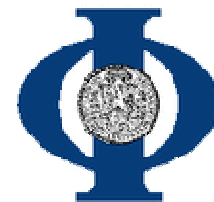
Run: event 7575: 19535 Ctrk(N= 3 Sump=174.9) Ecal(N= 21 SumE=157.6)
Ebeam 88.148 Vtx (-0.06, 0.05, 0.48) Hcal(N= 1 SumE= 1.2) Muon(N= 0)



Centre of screen is (3.780, 1.905, 0.000)

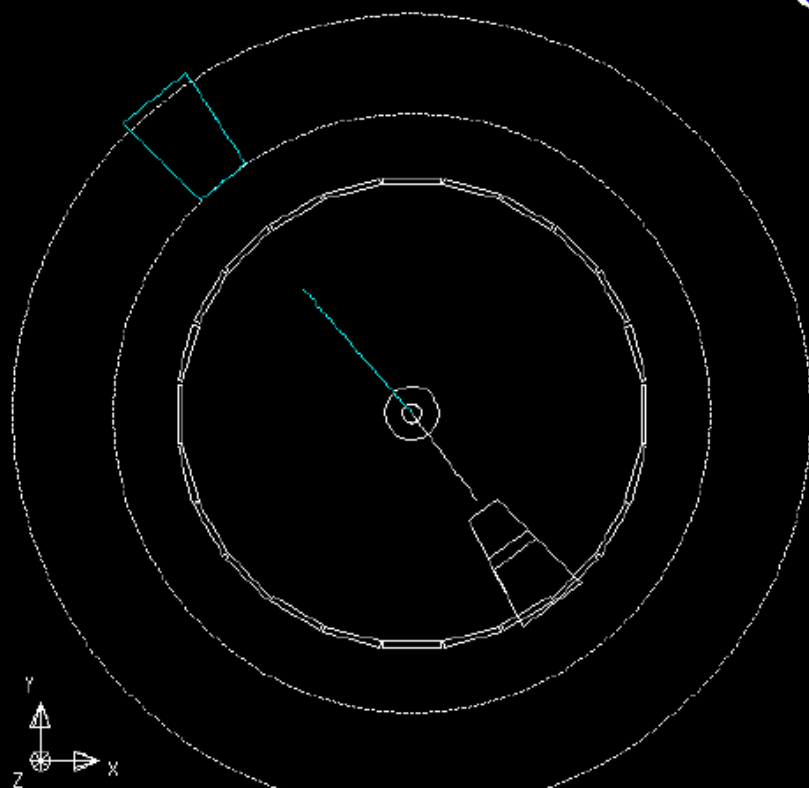
200, cm

1248 50GeV



$Z \rightarrow \tau \tau \rightarrow e \nu \nu + e \nu \nu$

Run: event 7610: 65108 Ctrk(N= 2 Sump= 34.4) Ecal(N= 2 SumE= 35.5)
Ebeam 65.140 Vtx (-0.06, 0.06, 0.40) Hcal(N= 1 SumE= 0.0) Muon(N= 0)

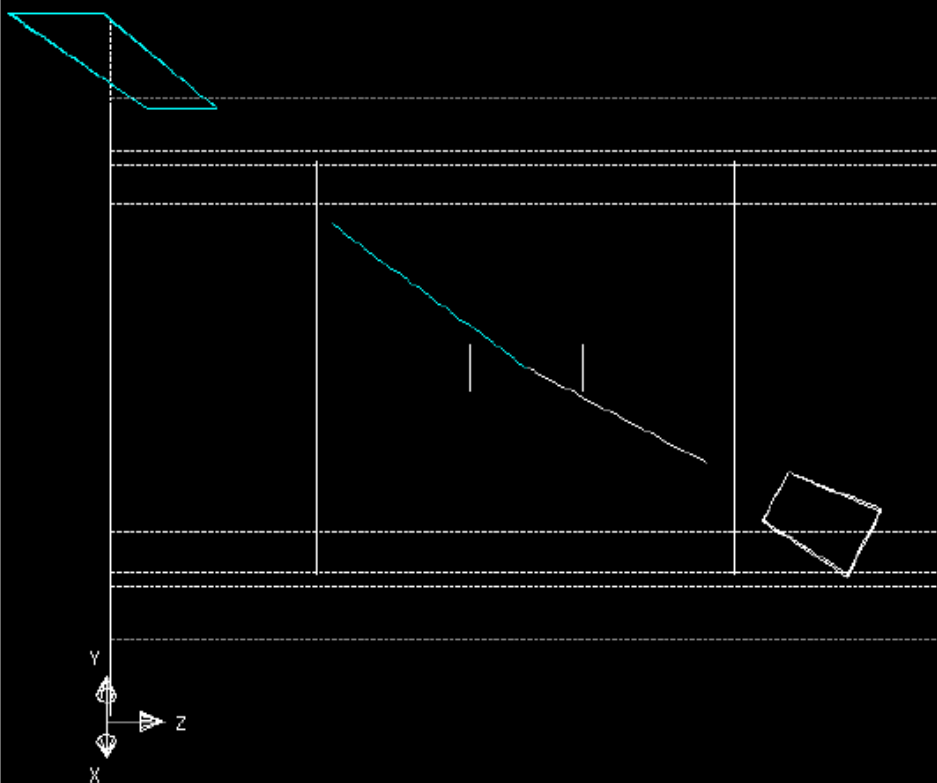


Centre of screen is (0.000, 19.287, 0.000)

100 cm

51 2 4 8 16 32 64

Run: event 7610: 65108 Ctrk(N= 2 Sump= 34.4) Ecal(N= 2 SumE= 35.5)
Ebeam 65.140 Vtx (-0.06, 0.06, 0.40) Hcal(N= 1 SumE= 0.0) Muon(N= 0)

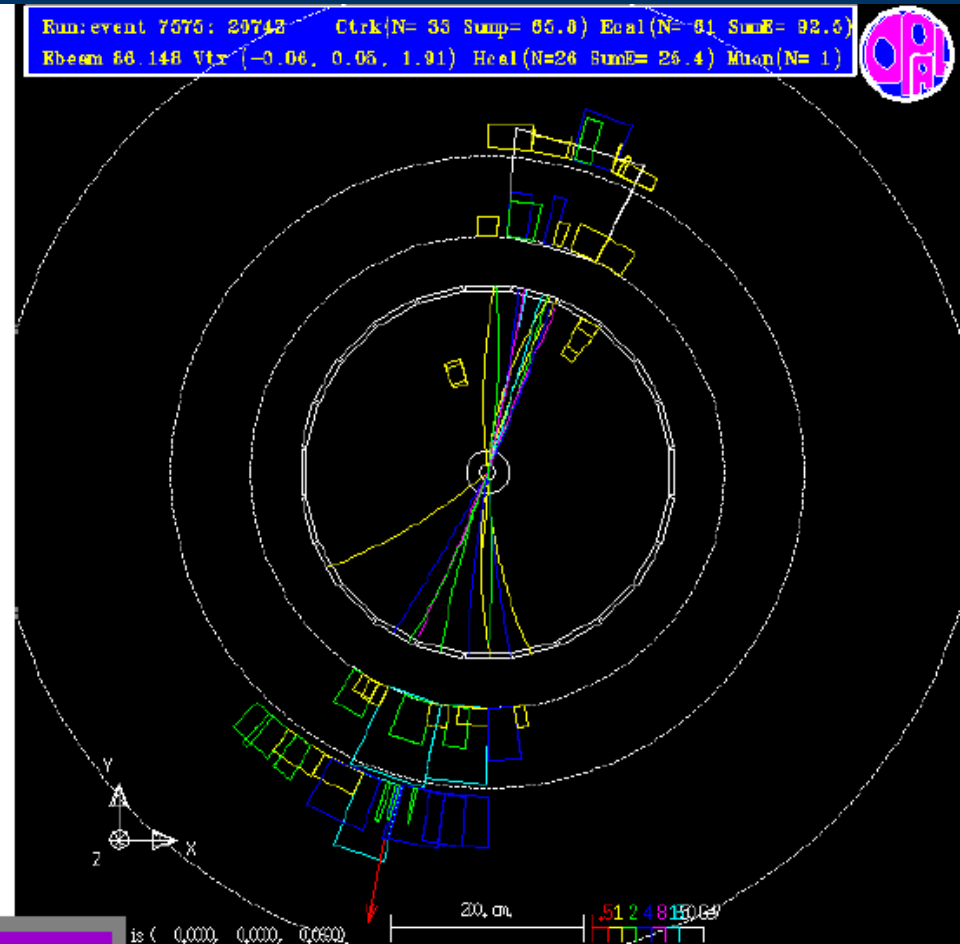
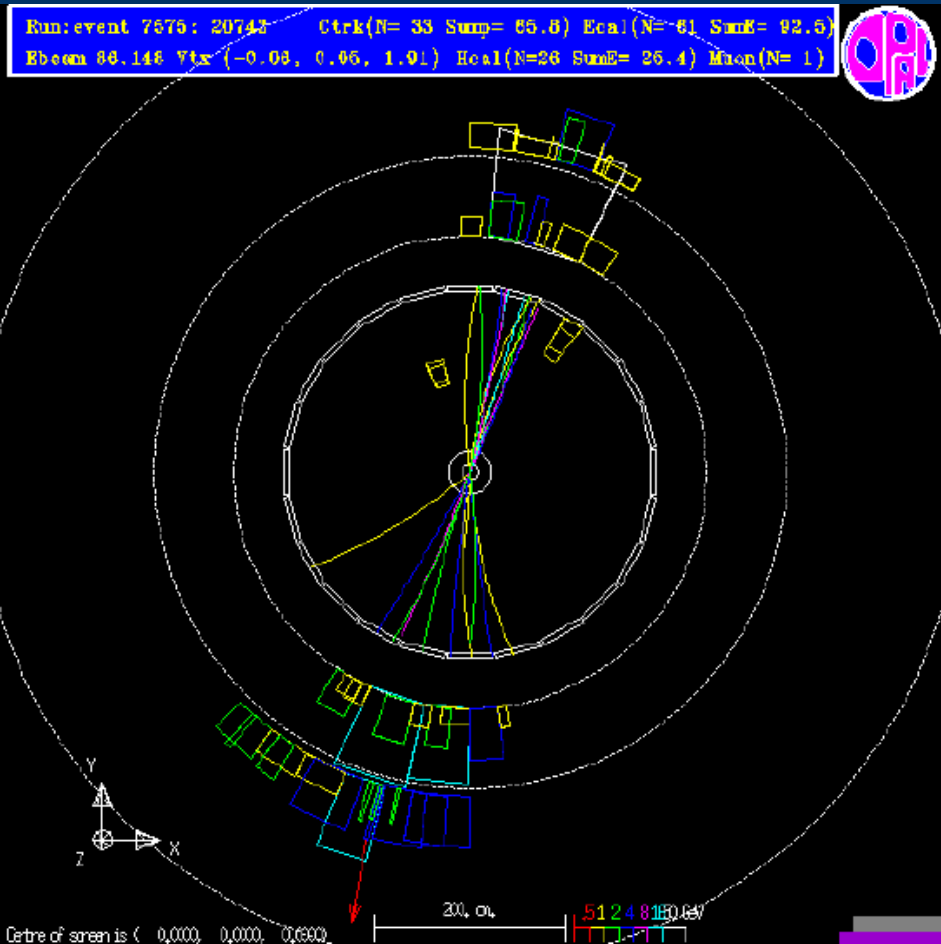


200 cm

51 2 4 8 16 32 64



Z -> qq





CD -> index.html -> Identifying Particles



Hands on Particle

International Masterclasses for High Energy Physics

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 - **Ident. Particles**
 - Particle Physics
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 - Le Monde des Particules
 - KworkQuark
 - Teilchentour I
 - Teilchentour II
 - LHC
 - Unischule
- Links
- Institutes
- Imprint

Hands on Particle Identifying Particles

(T. Wyatt et al, Manchester)

The purpose of these web pages is to provide an interesting particle physics experiment that can be seen using an experiment that has been performed. The experiment ran from 1989 to 2000 and was installed in the LEP tunnel. The emphasis is very much on learning a few important things about particle physics and the different types of events that can be seen. You play the role of a "particle physicist" and identify different types of events.

English

German

Greek

[jump
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[jump

Inhalt

Besser nochmal lesen

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- NEW** [Der ATLAS-Detektor und die Ereignisbilder](#)
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Erste Herausforderung: Eine fundamentale Messung

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- NEW** [Die Aufspüren von \$Z^0\$ Zerfällen am LHC](#)

[Wie man Ereignisse identifiziert, die ein Paar von W-Teilchen beinhalten](#)

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Zweite Herausforderung: Eine andere fundamentale Messung

[Messung von W-Zerfällen](#)

[Wie man etwas komplizierteren Ereignistypen identifiziert](#)

[Fünfte Übung](#)



Messung

- Standardmodell macht Voraussagen über Häufigkeiten der Kanäle
- Messung bei OPAL war wichtiger Test des Standardmodells
- WIR WIEDERHOLEN HEUTE DIESE MESSUNG
- 1000 Ereignisse auf der CD
- 100 Ereignisse/Laptop
- Kombination der Ergebnisse