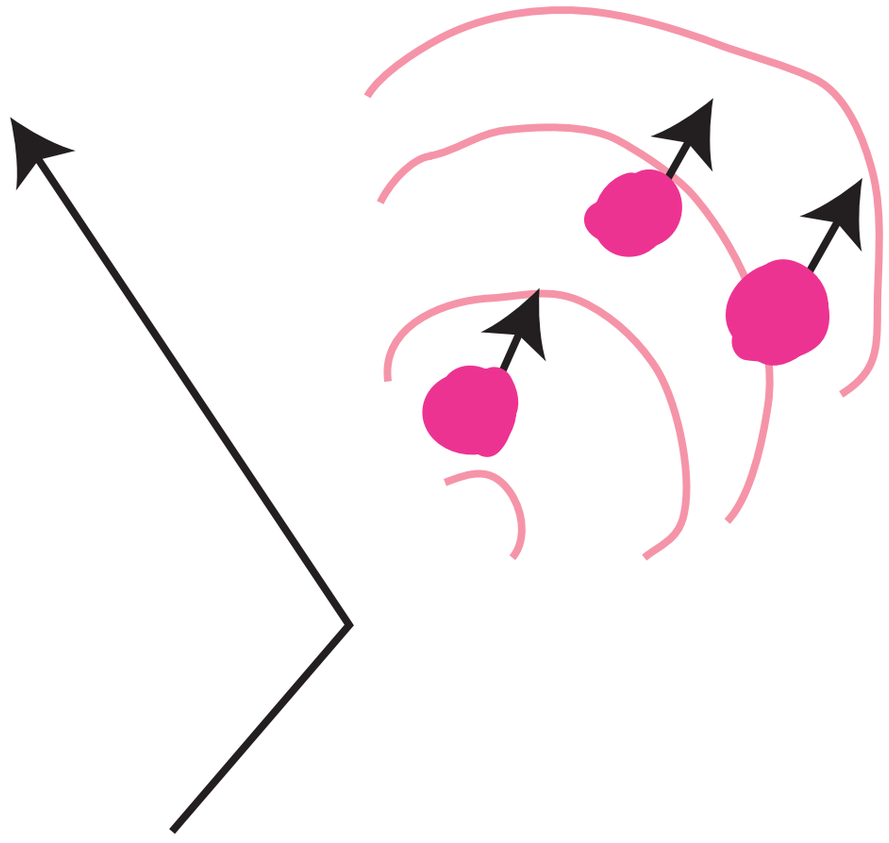
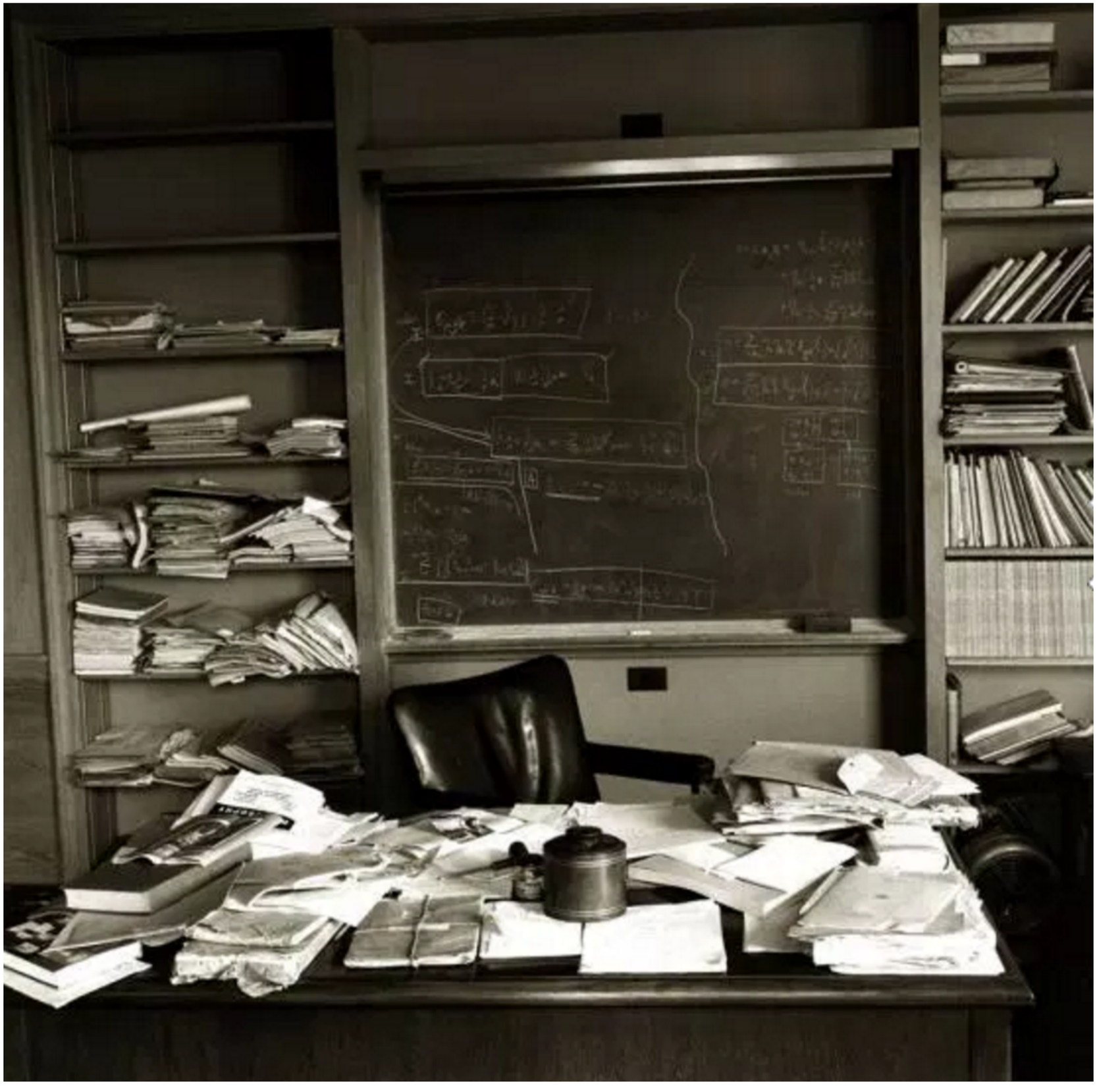
Are We Ready for a Final Theory of Physics ?



Michael E. Peskin

Aspen Winter Conference
on Particle Physics
January 2016

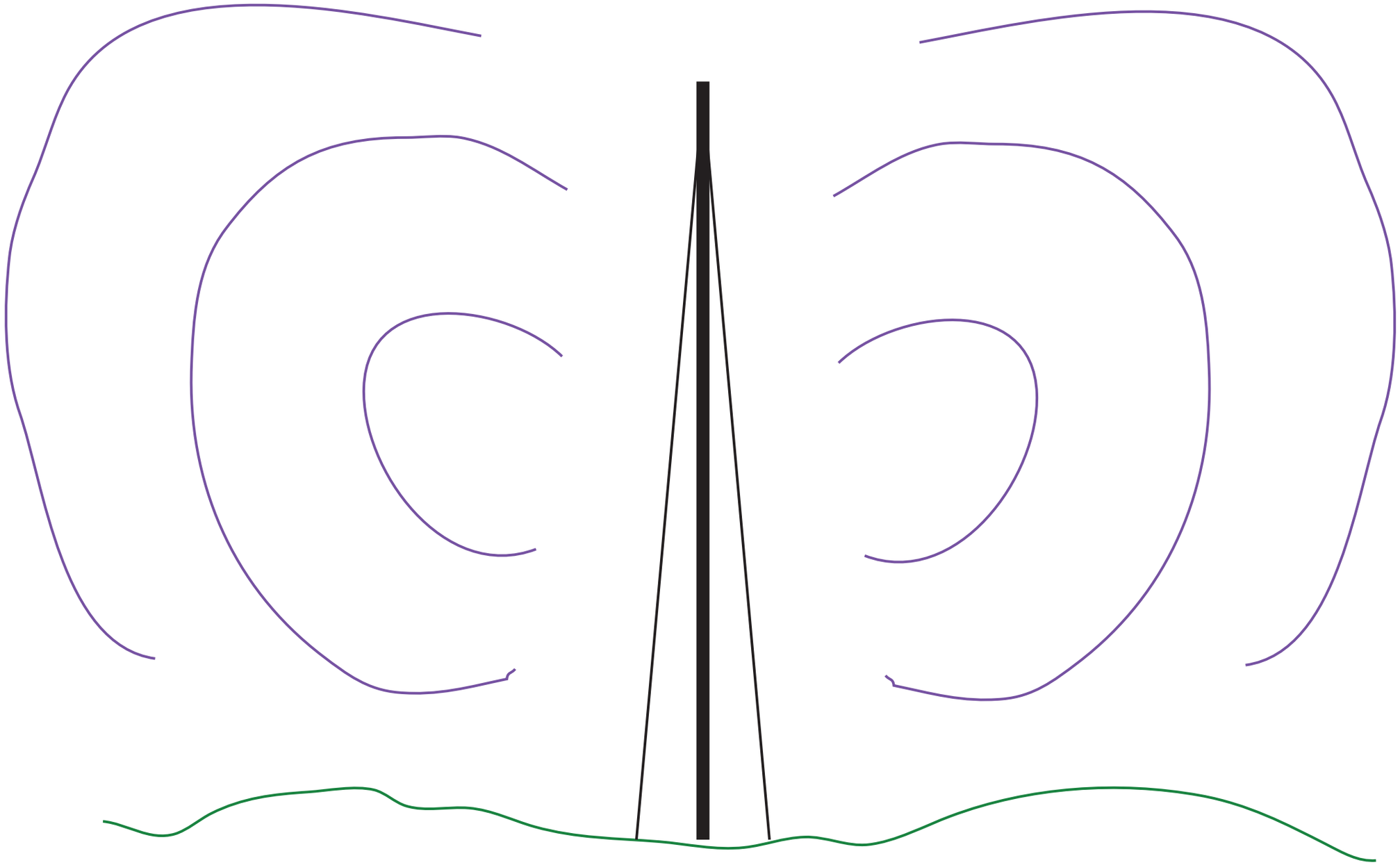


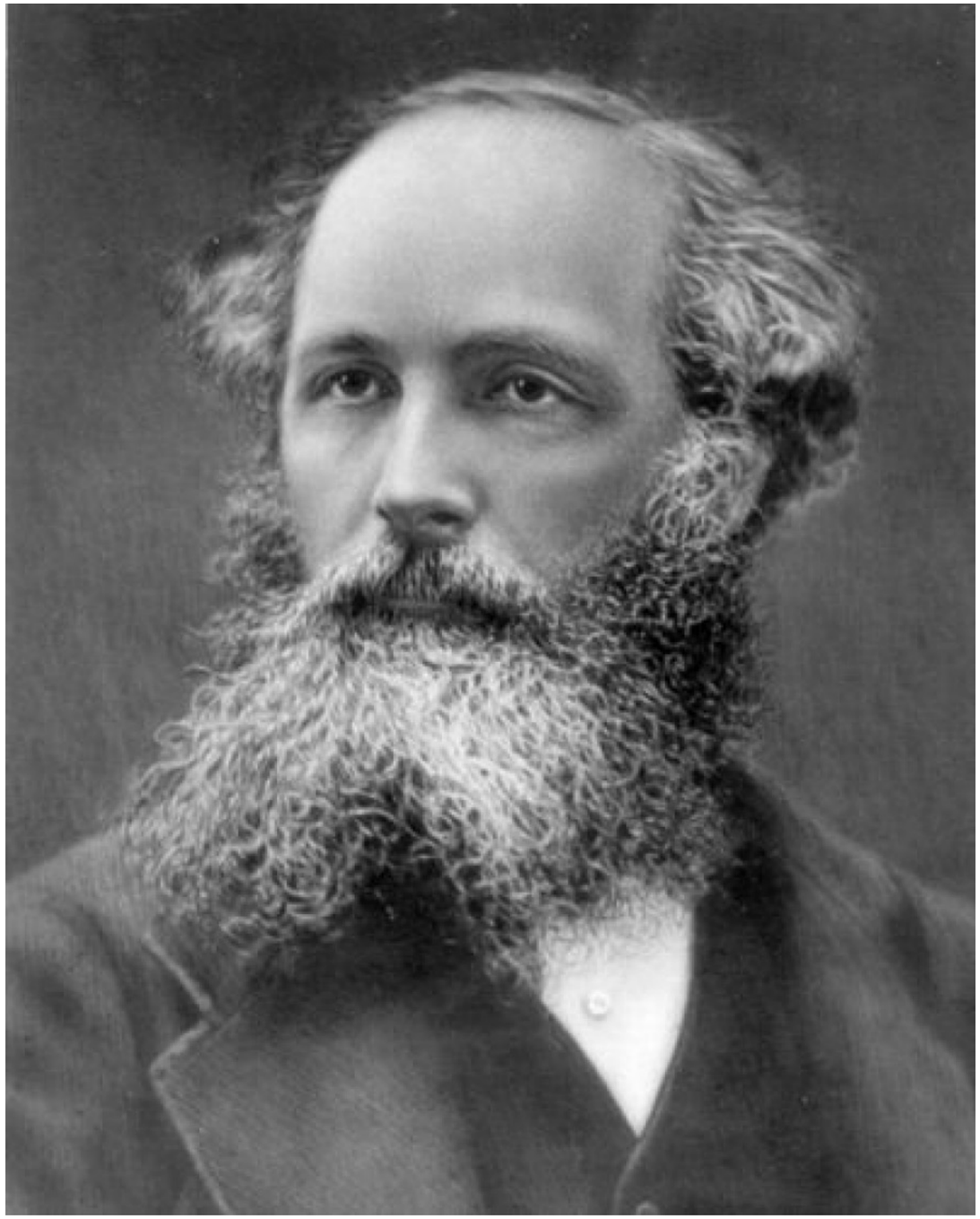
Einstein’s office on the day of his death; photo by Robert Morse for Life Magazine.

“Unified Field Theory”

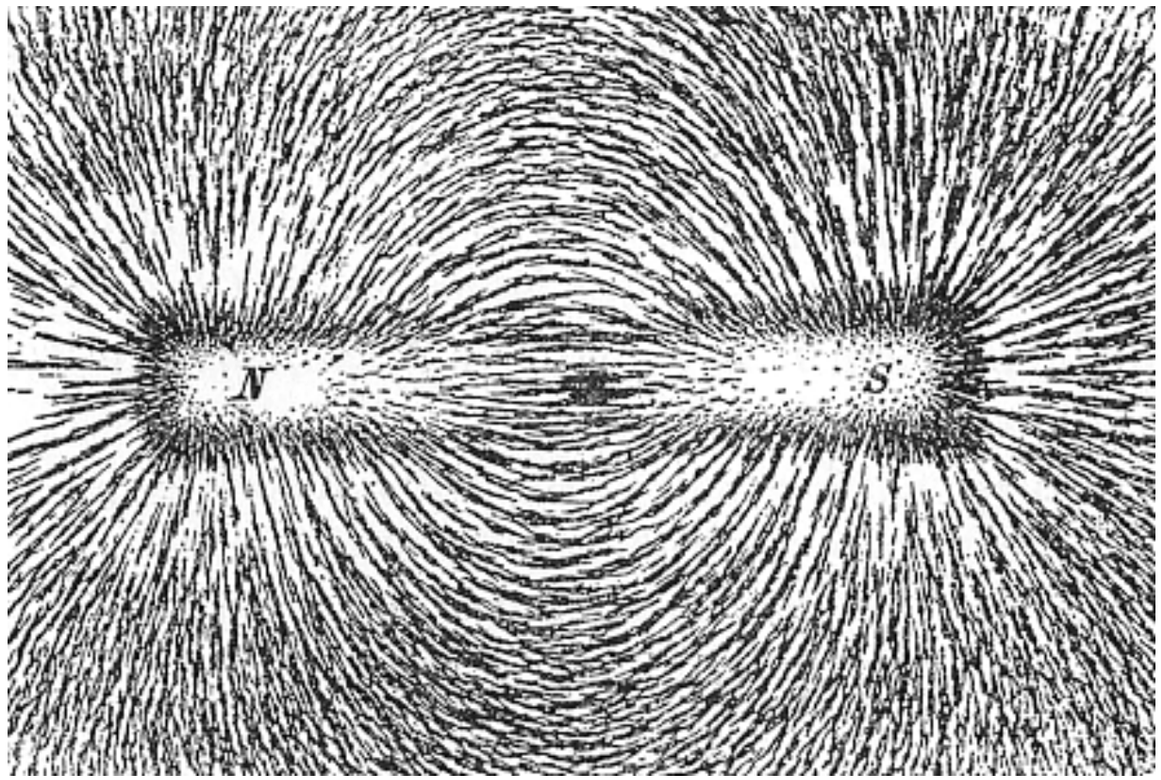
"The generalization of the theory of gravitation has occupied me unceasingly since 1916.” - Einstein, 1952

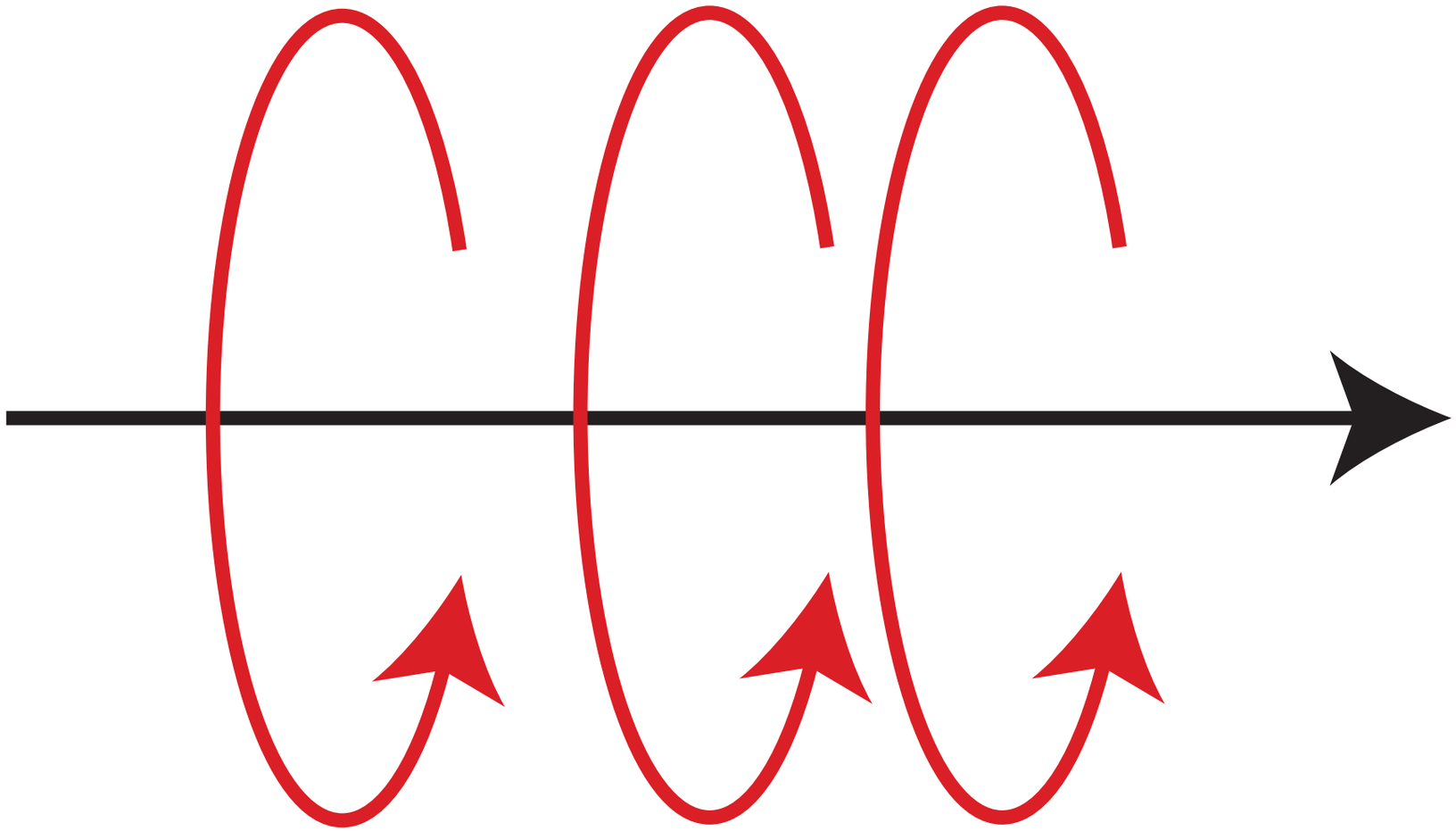

local
distant
fringe
20 miles
Vallejo
Lodi
Concord
Stockton
Berkeley
Manteca
San Francisco
Tracy
Daly City
Livermore
Modesto
Hayward
San Mateo
Fremont
Turlock
Sunnyvale
San Jose
Los Banos
Gilroy
Santa Cruz
Watsonville
Salinas
Seaside
Coverage Pattern for KXSC-FM
© 2013 radio-locator.com



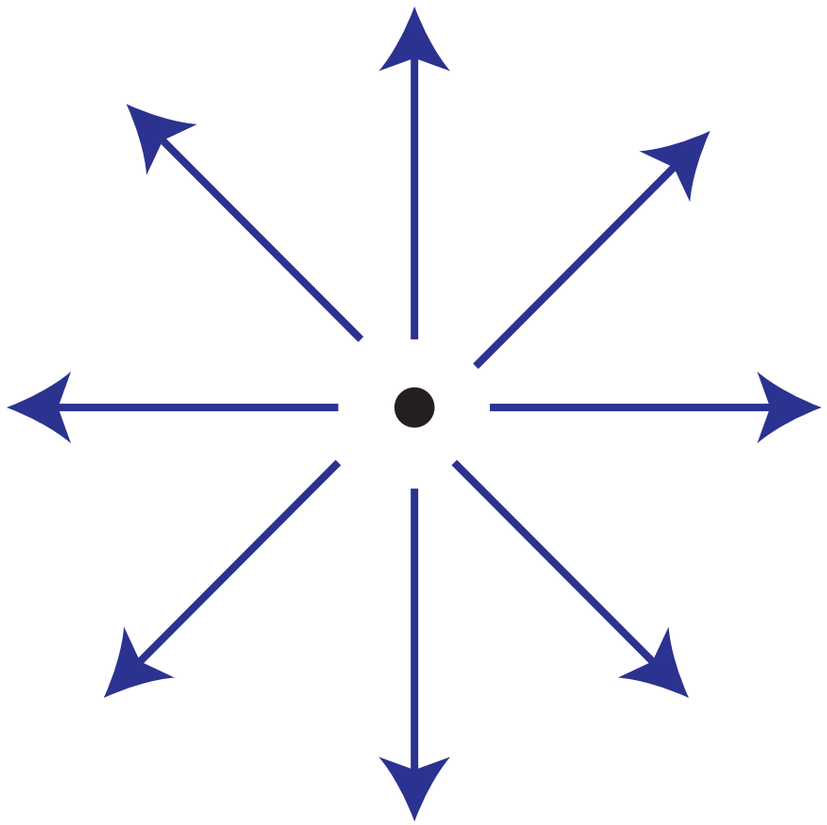


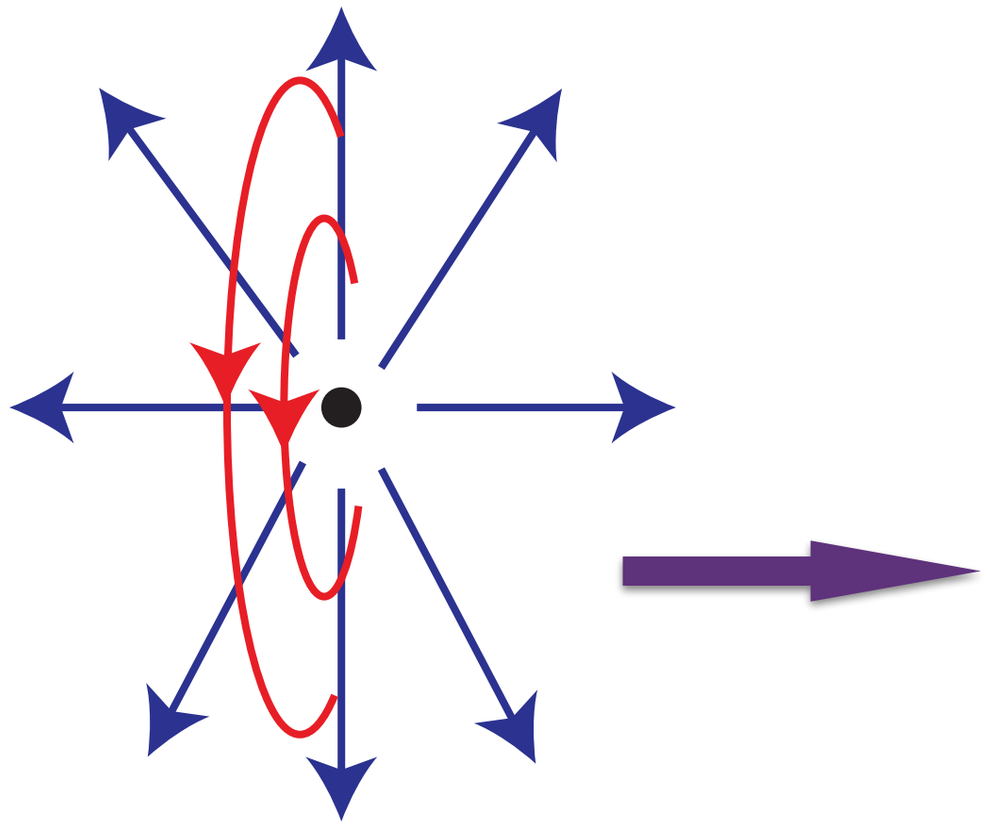
James Clerk Maxwell

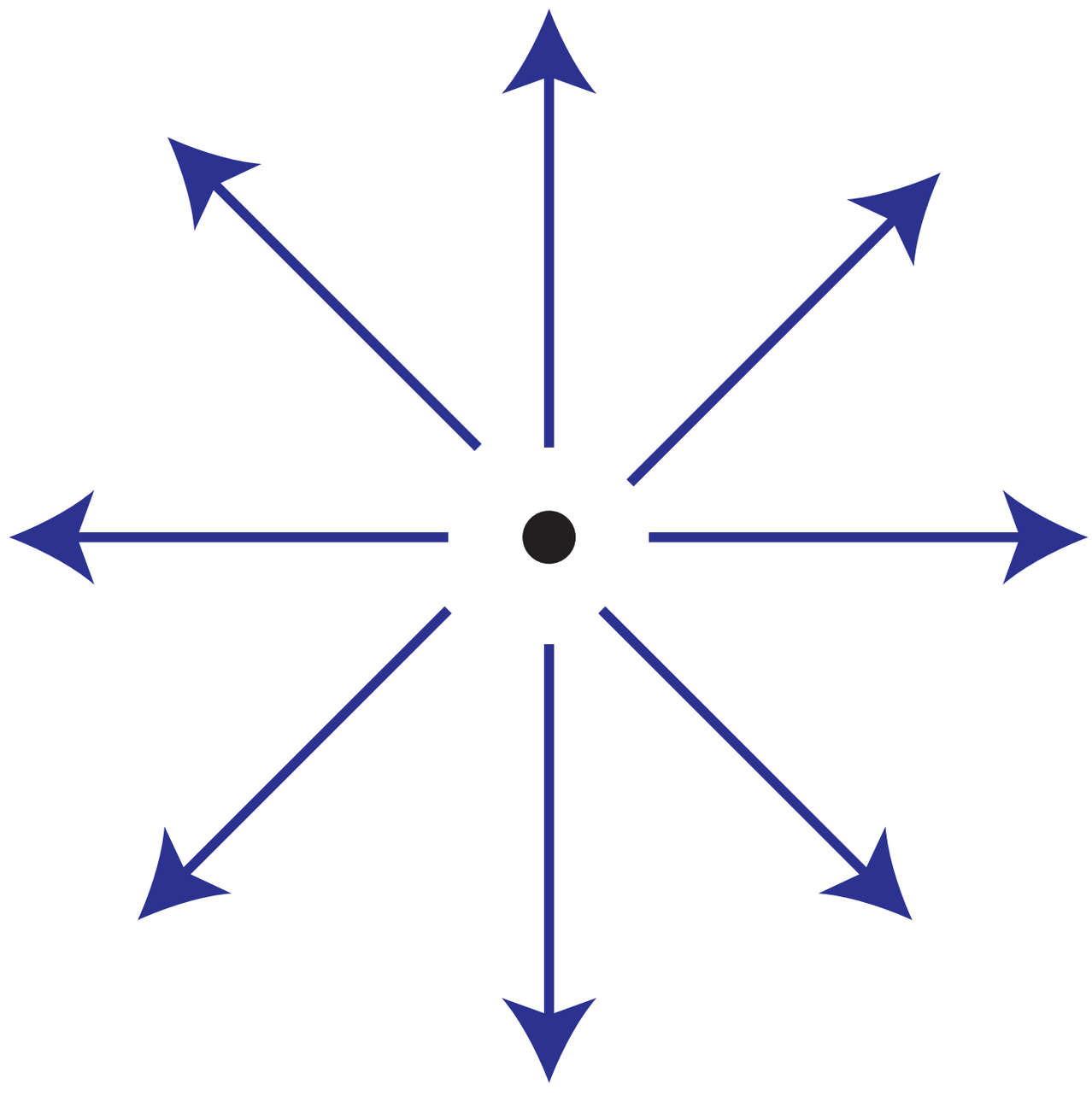

N
S



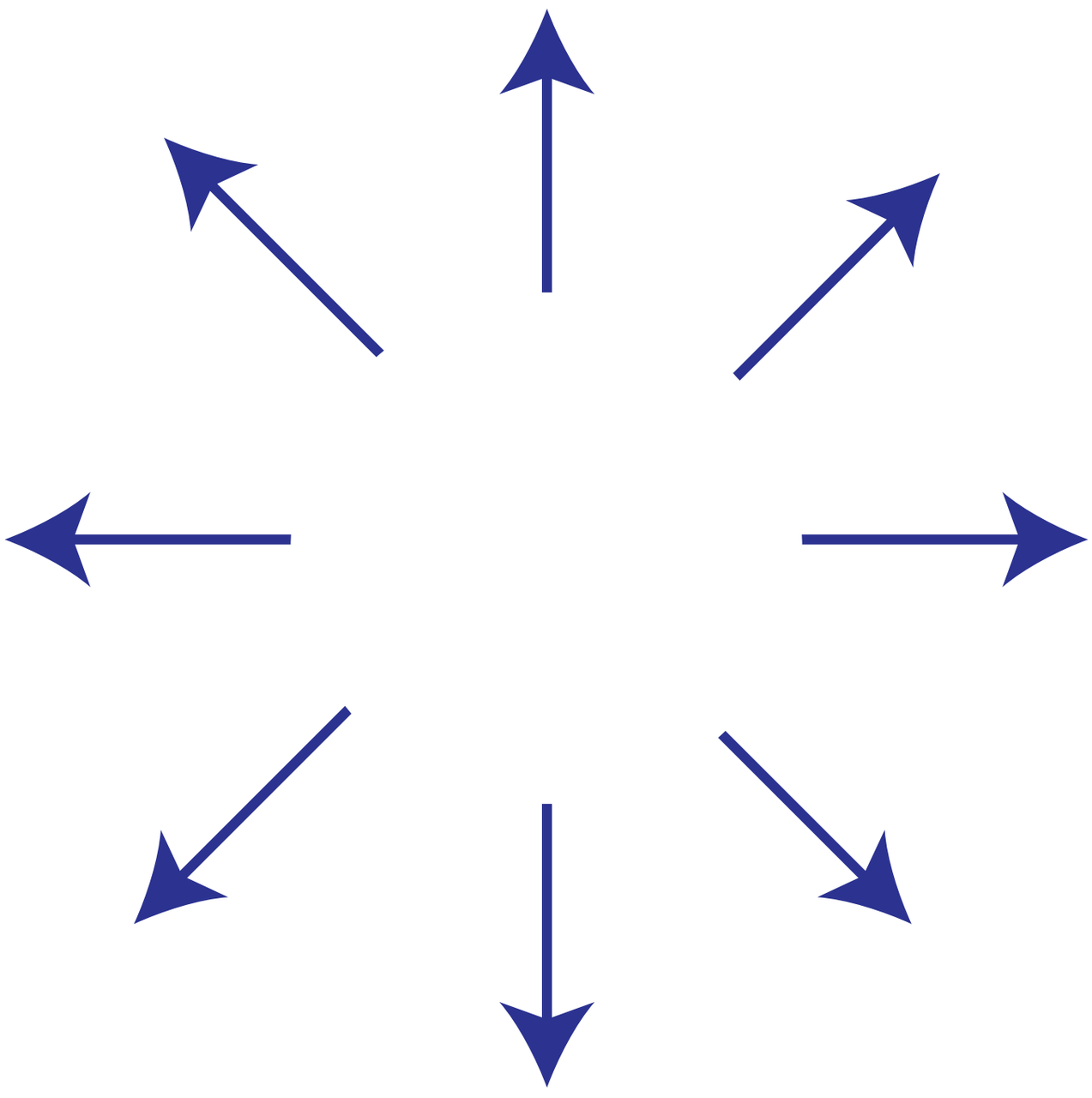
Oersted

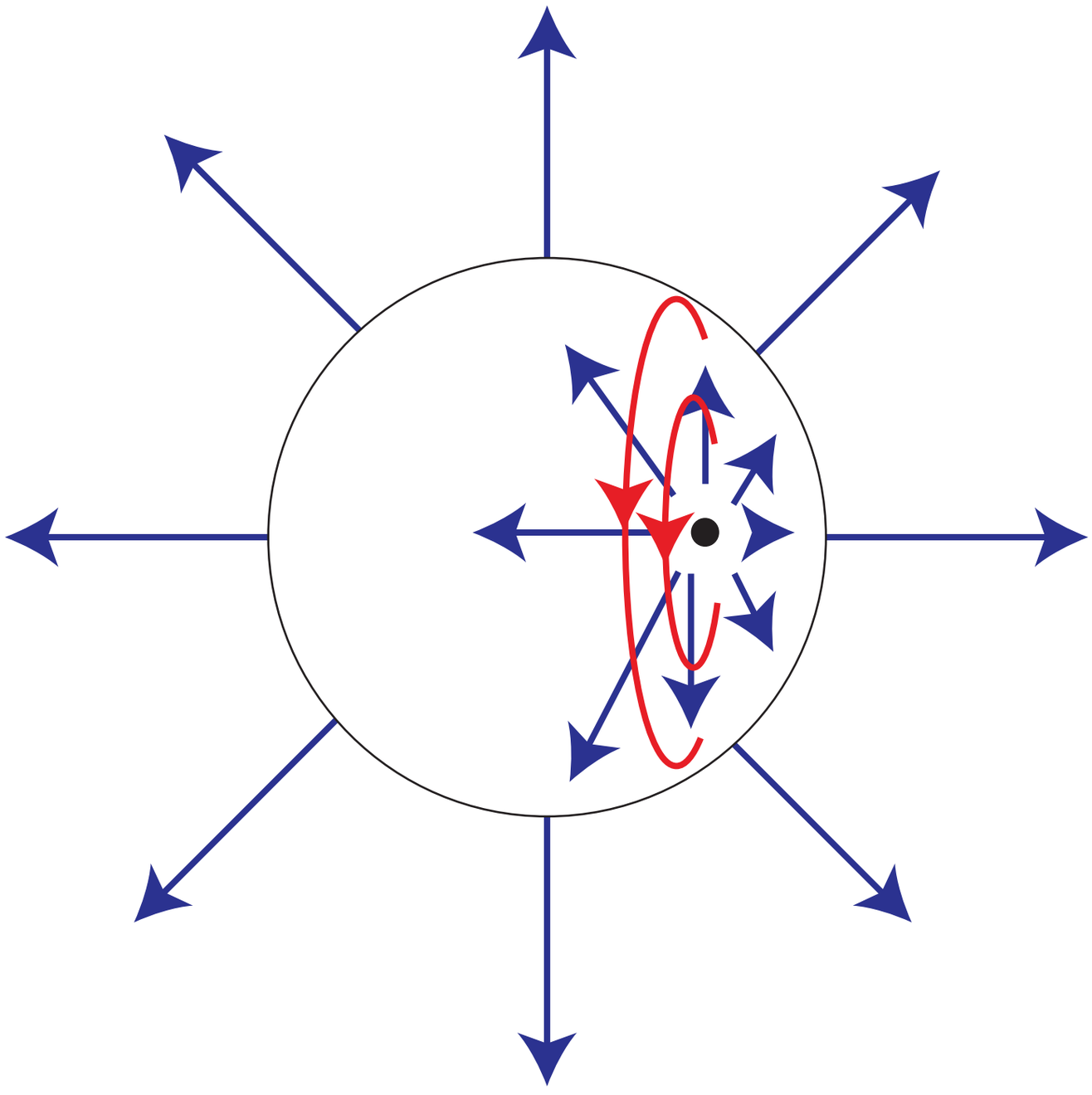


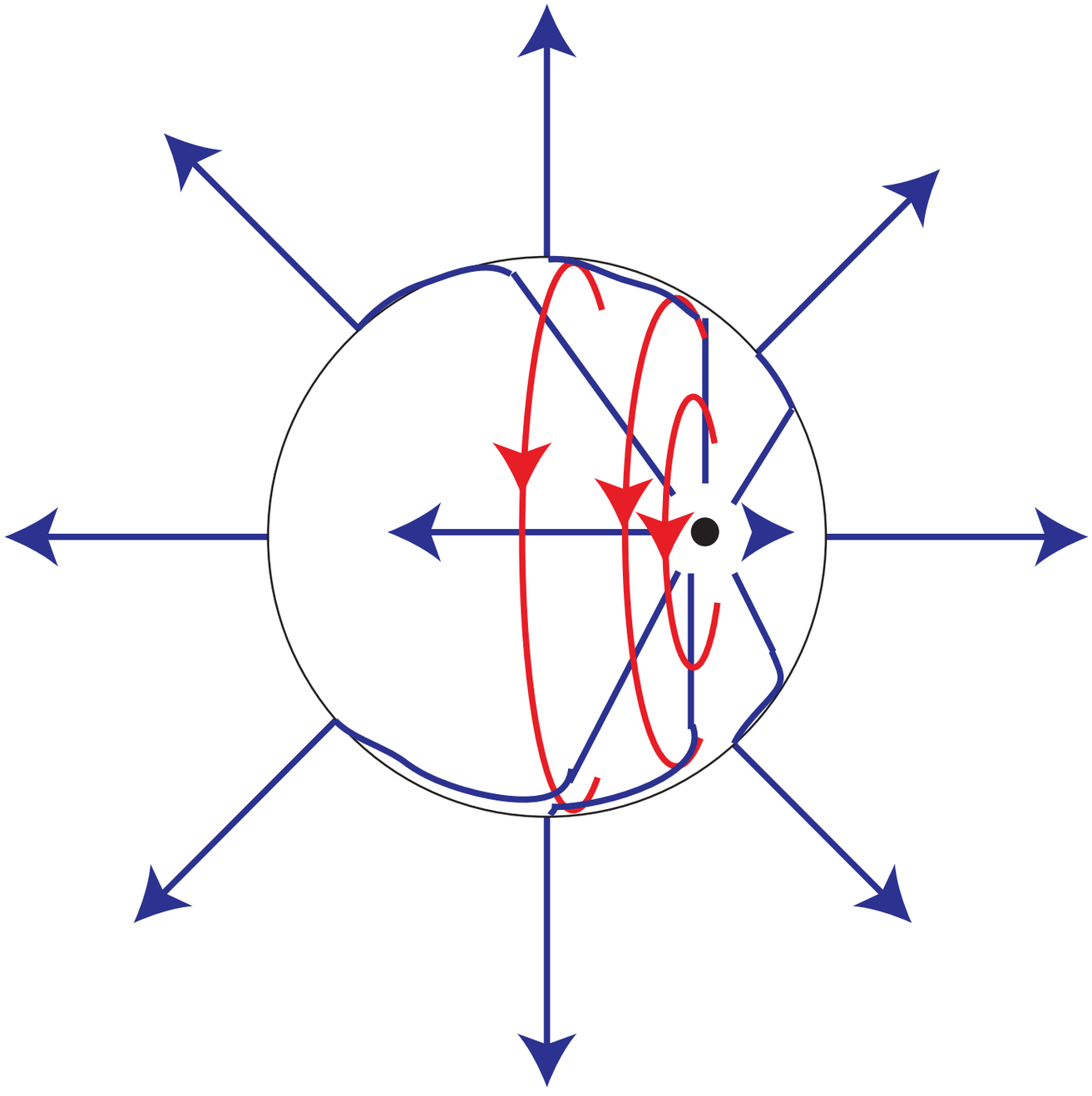


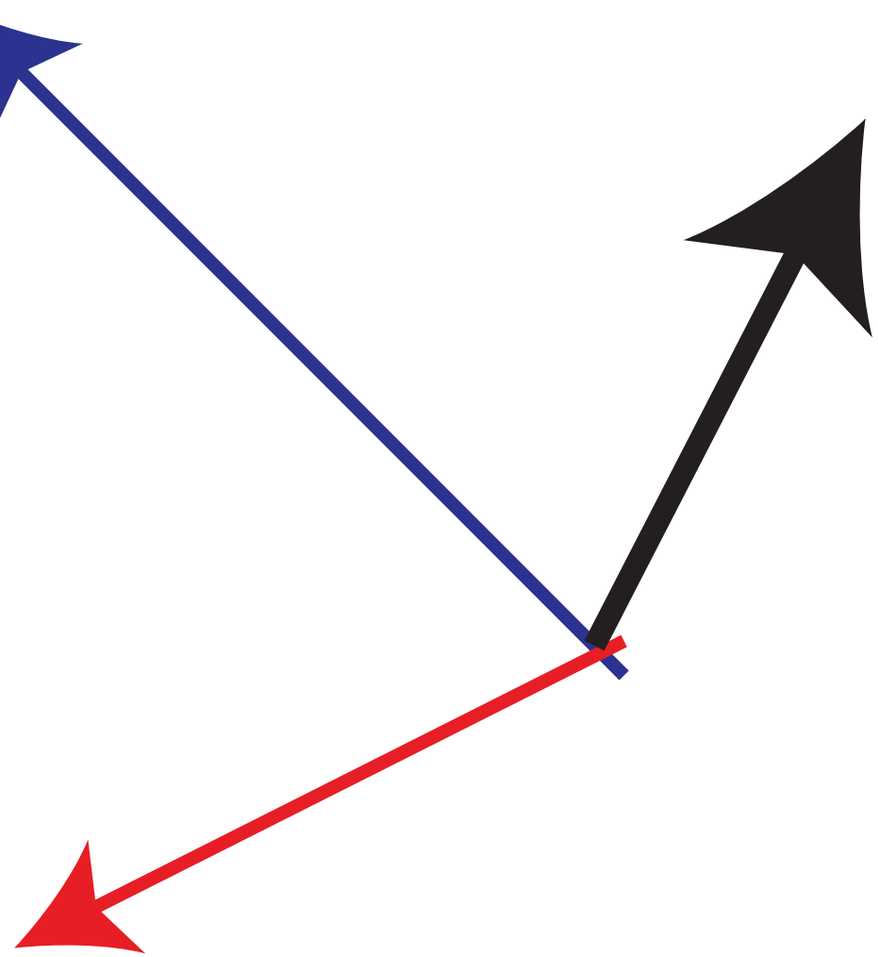


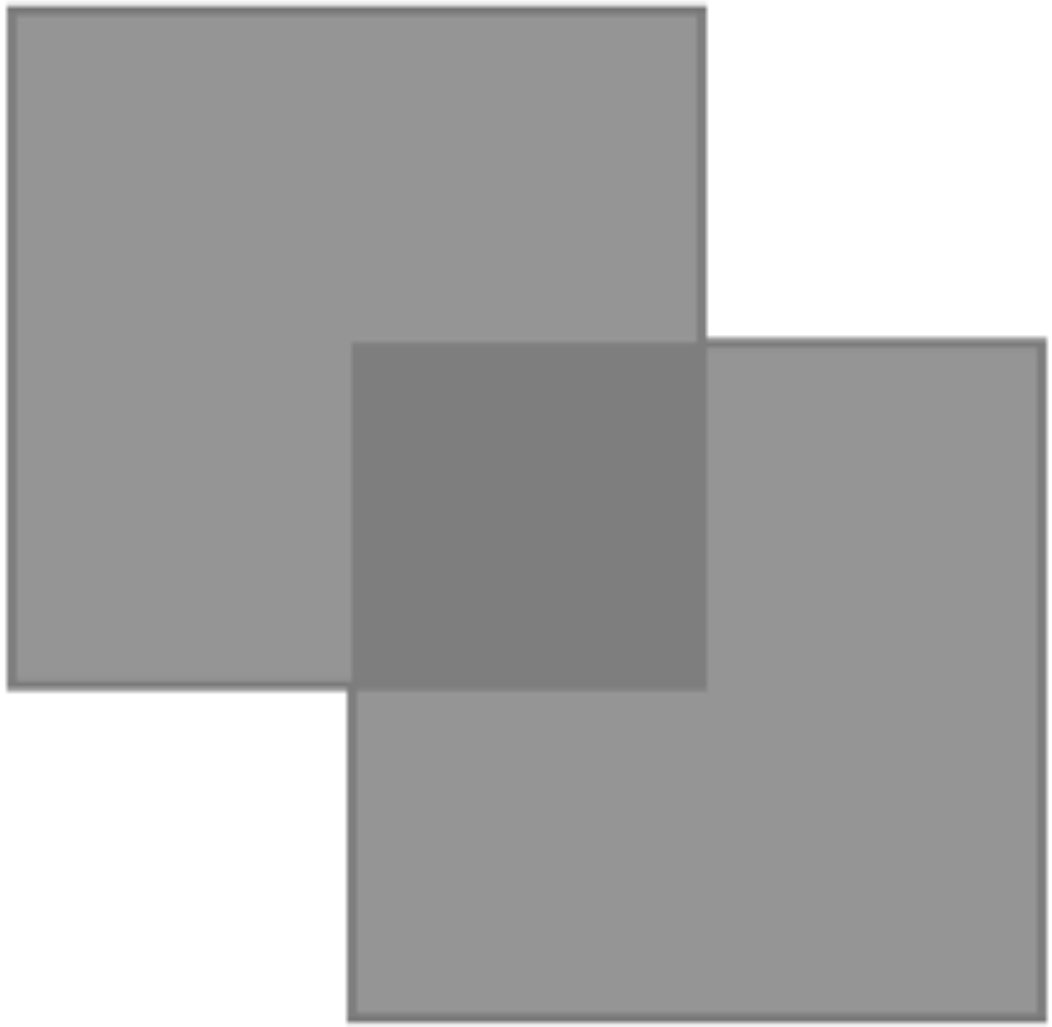
Edward Purcell



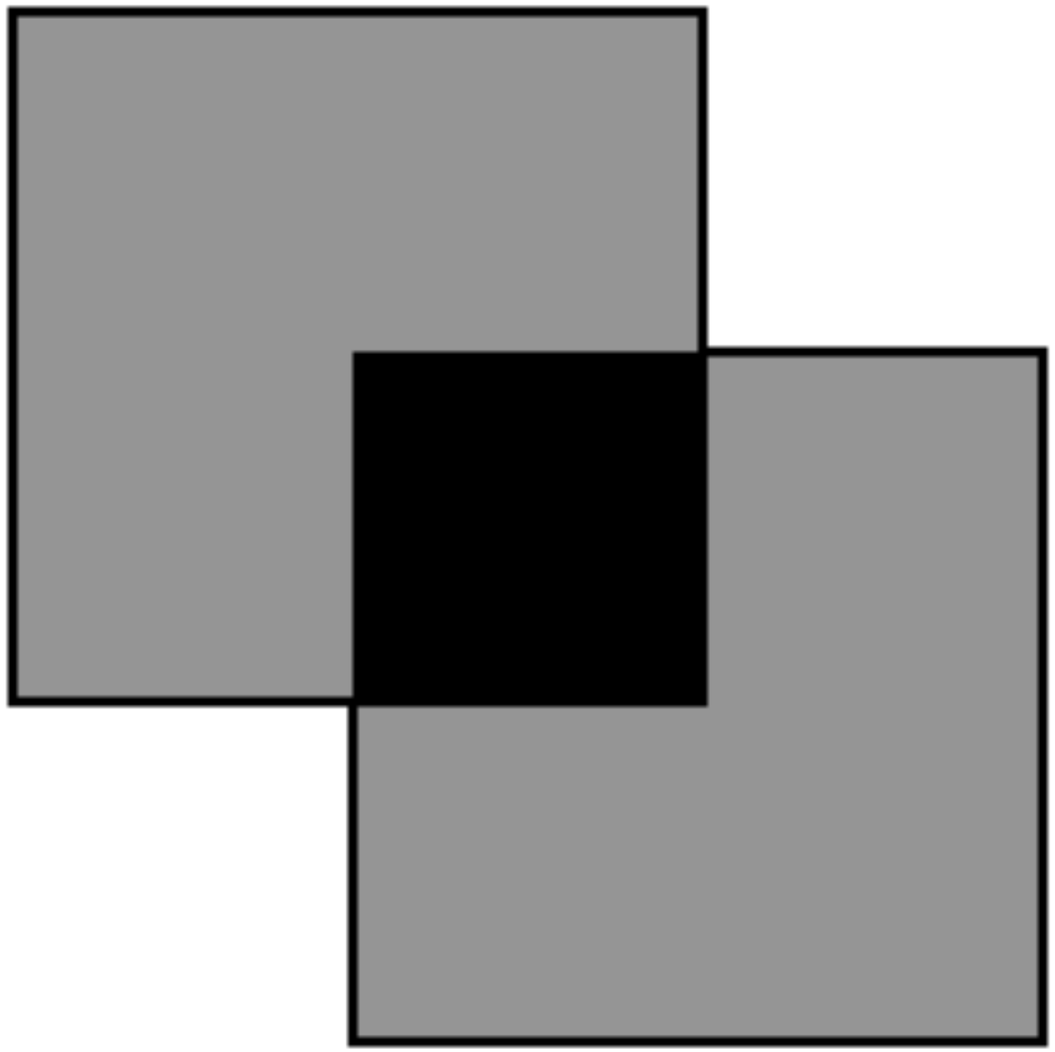






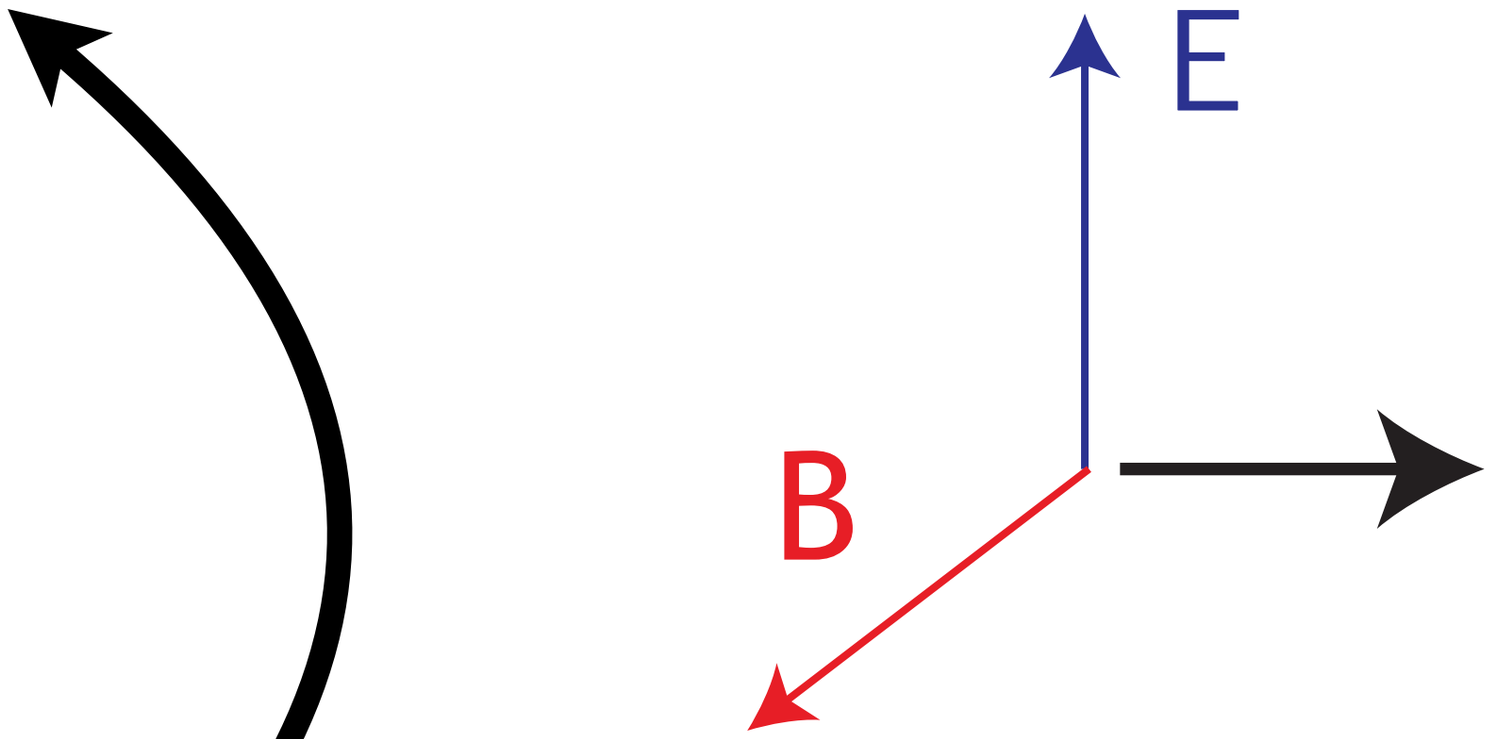


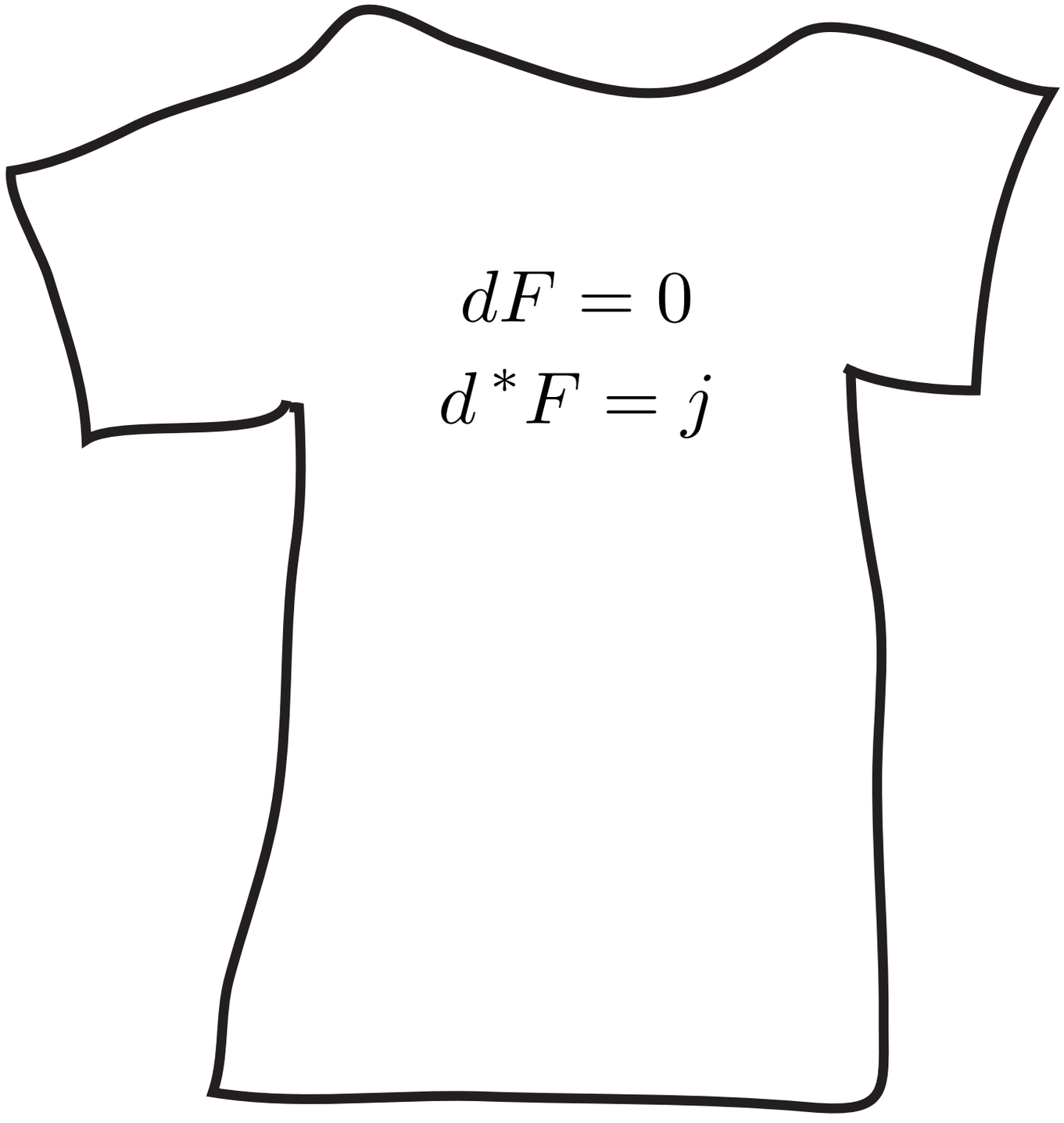
Parallel axes.



Crossed axes.

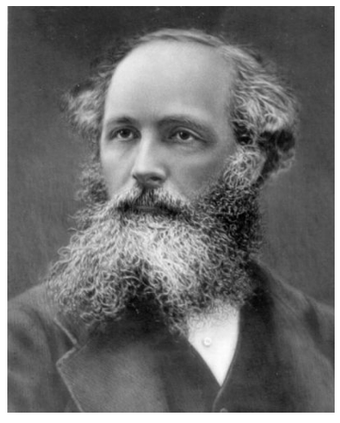
Donald Simanek

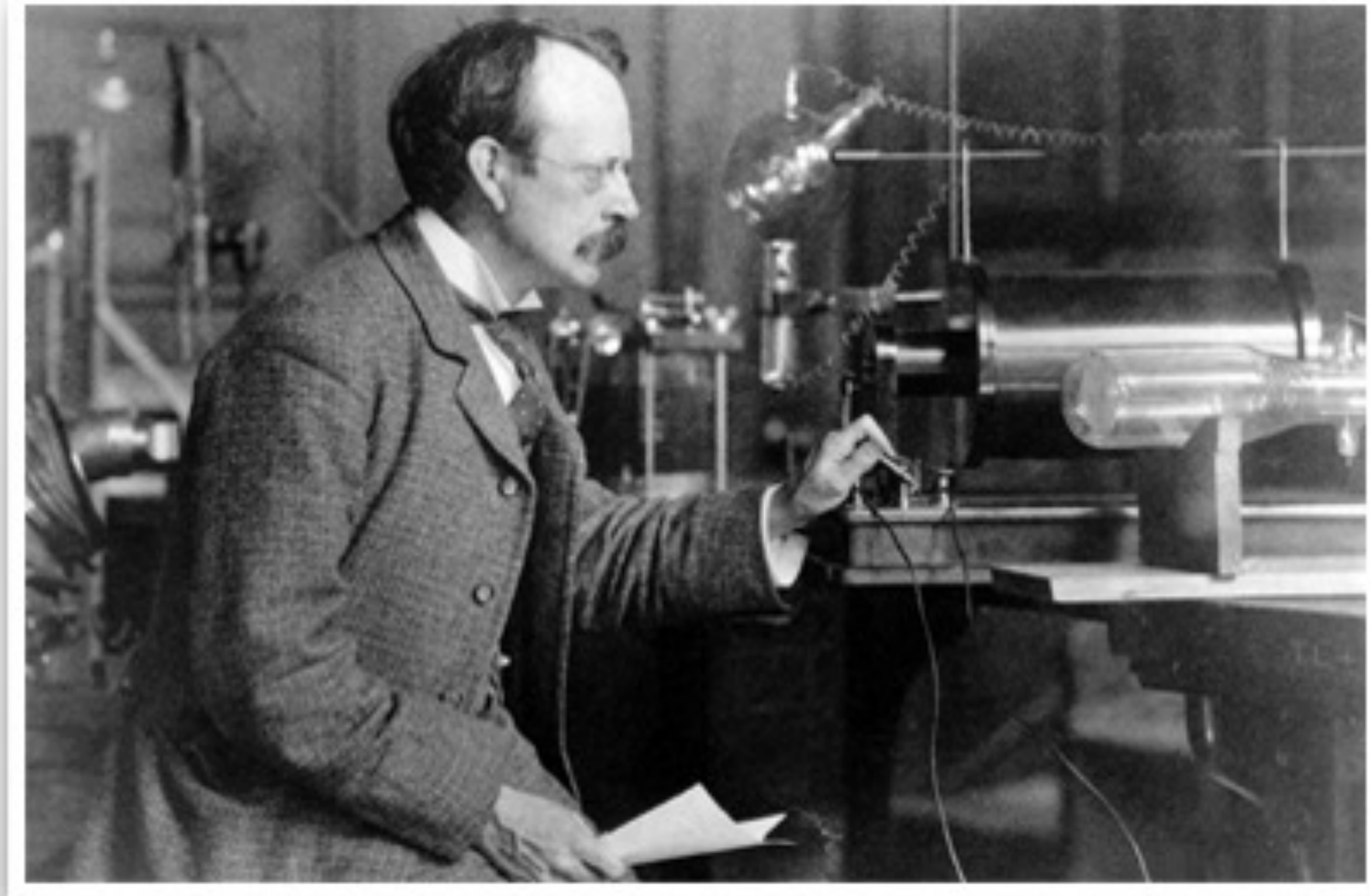

E
B


$dF = 0$
$d^*F = j$

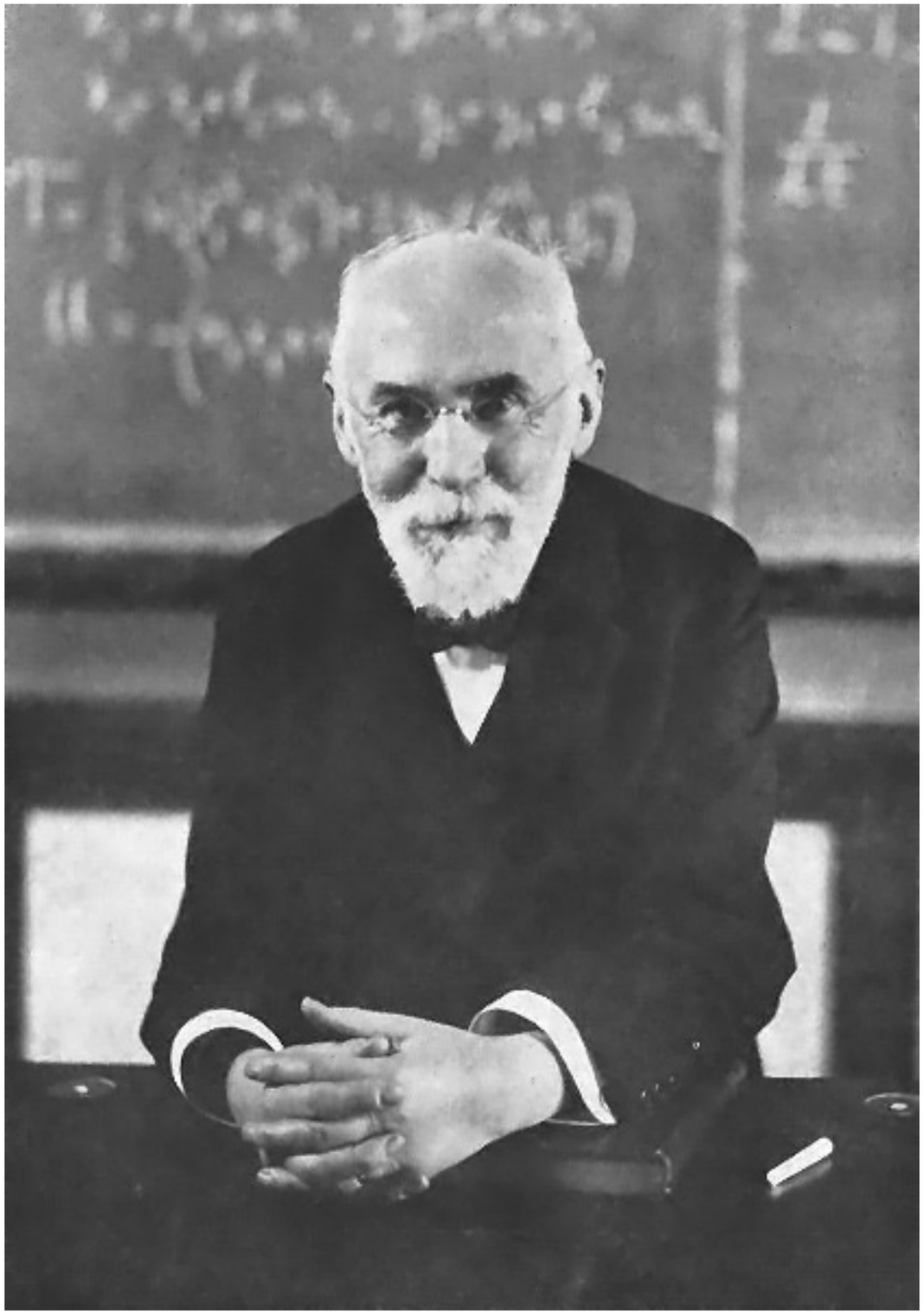
$$dF = 0$$

$$d^*F = j$$





J. J. Thomson (courtesy AIP)



Hendrik A. Lorentz

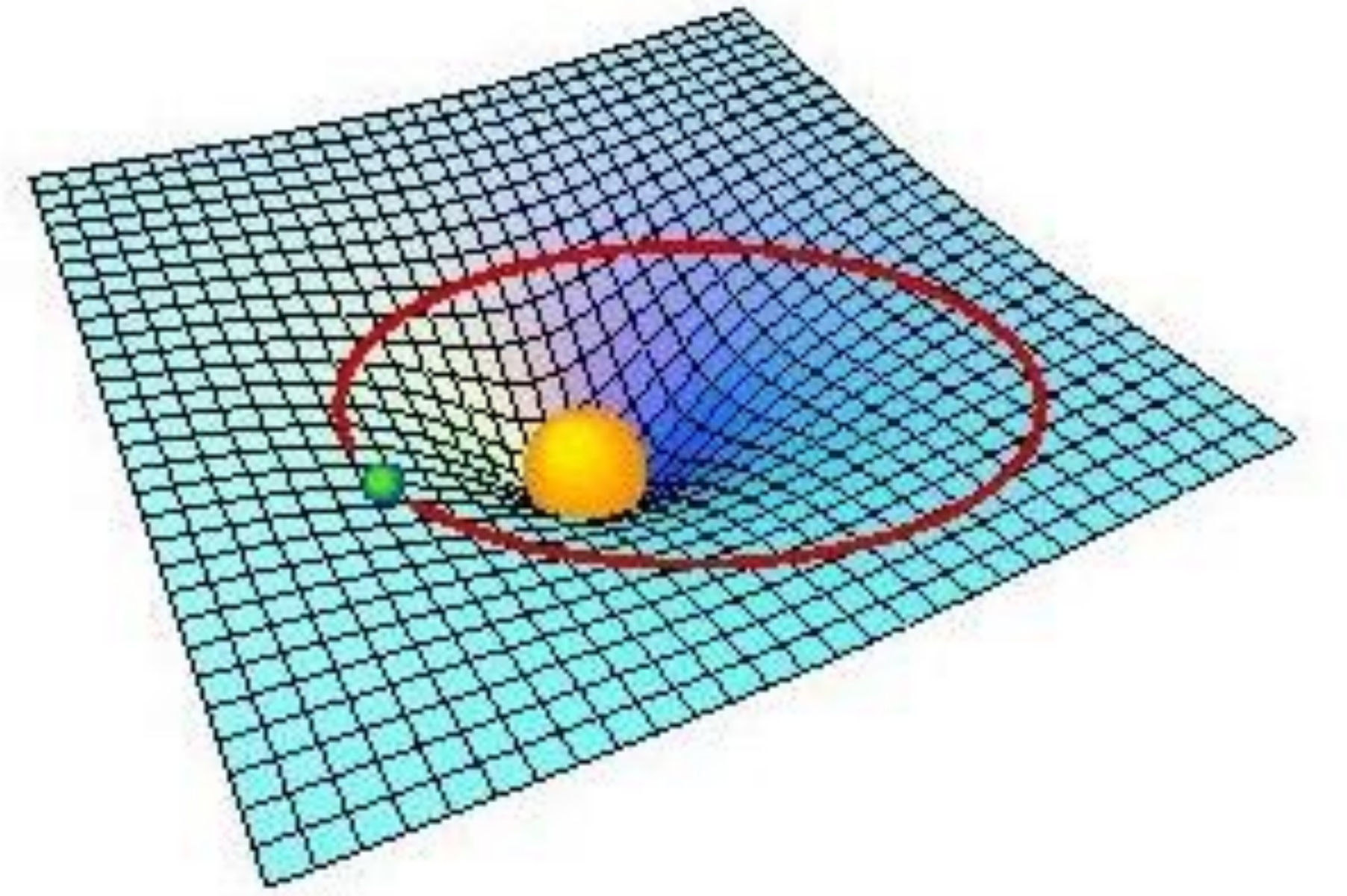
"If we want to understand the way in which electric and magnetic properties depend on the temperature, the density, the chemical composition or the crystalline state of substances, we cannot be satisfied with simply introducing for each substance these coefficients, whose values are to be determined by experiment ...

It is by this necessity that one has been led to the conception of electrons ... by whose distribution and motion we endeavor to explain all electrical and optical phenomena that are not confined to the free ether."

— Lorentz, "Theory of Electrons" 1906

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} = \kappa\, T_{\mu\nu}$$

Einstein — December 1915

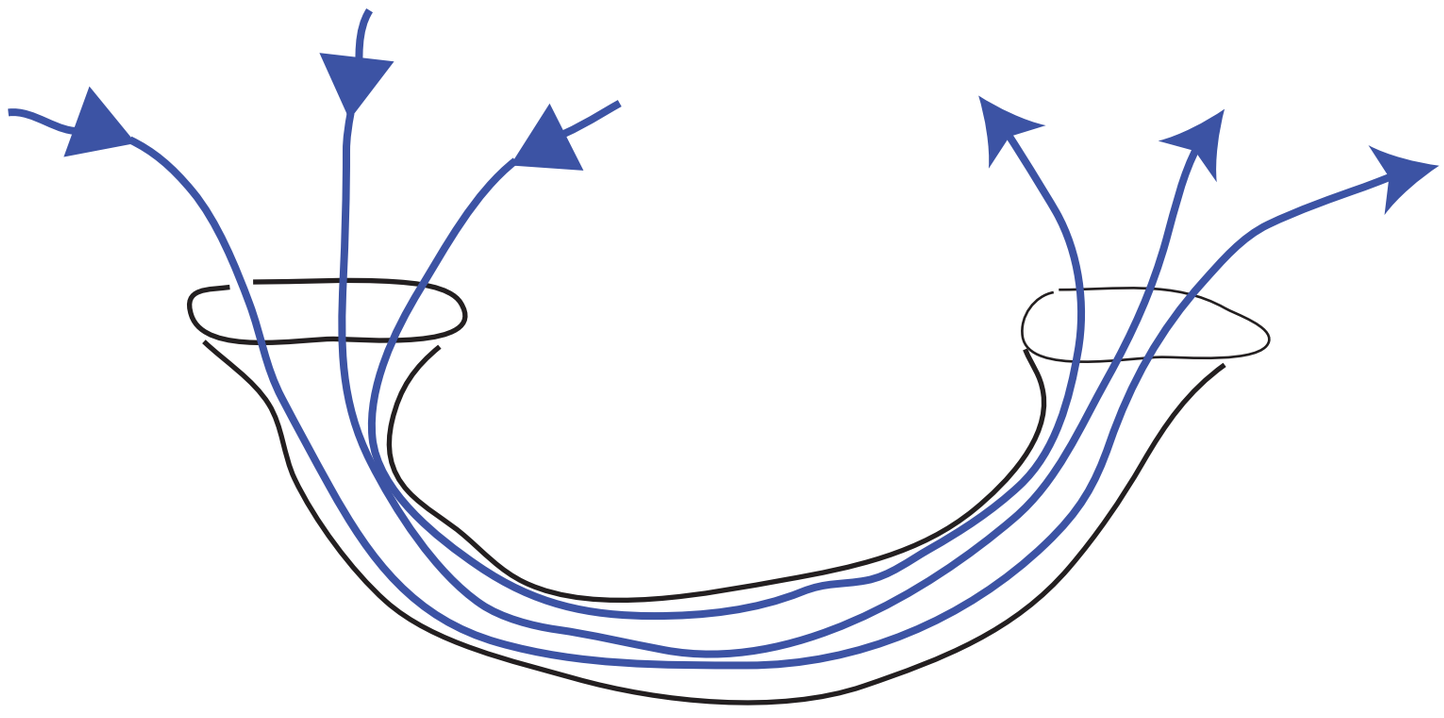


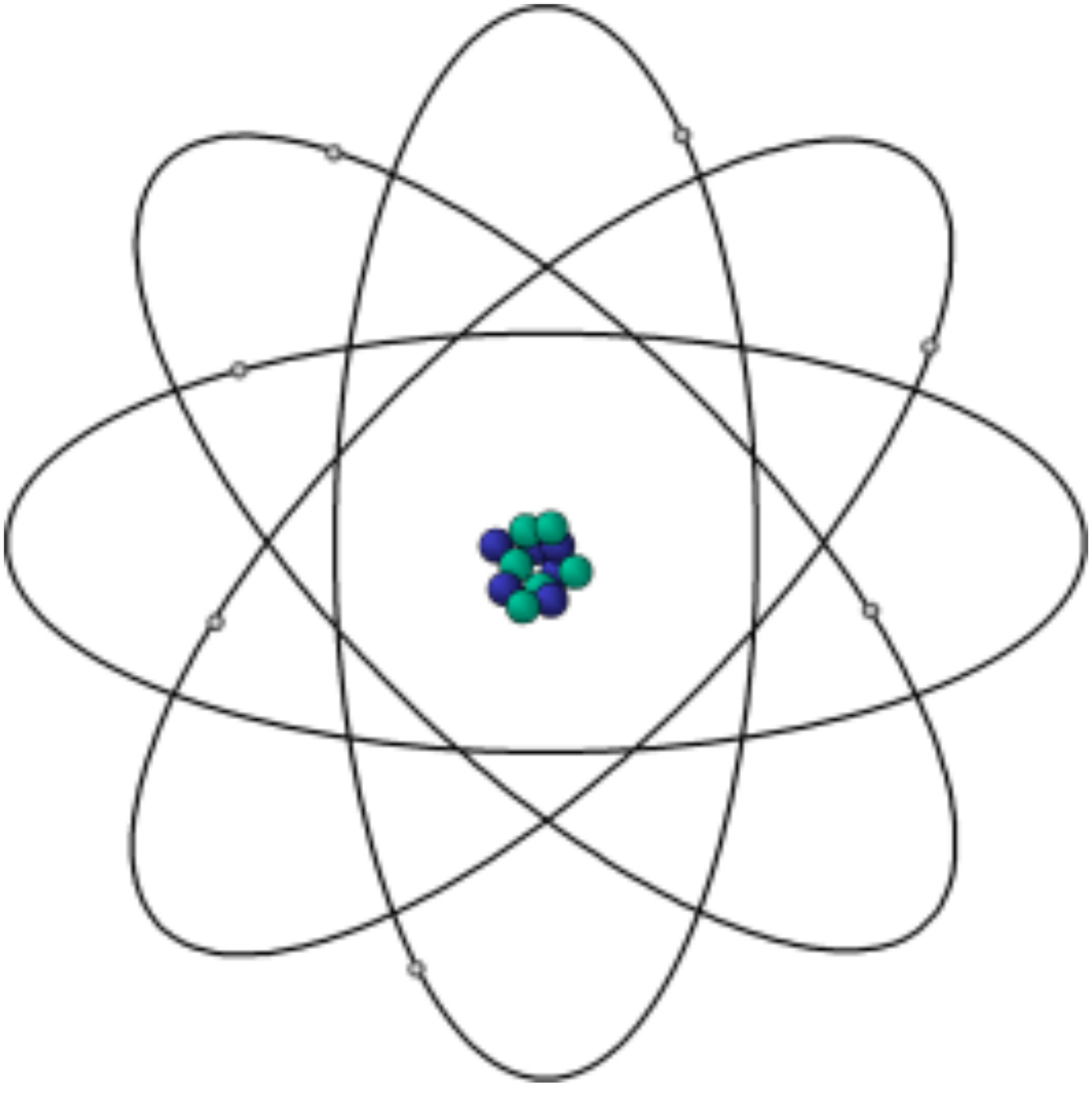
W. R. Coker, U of Texas

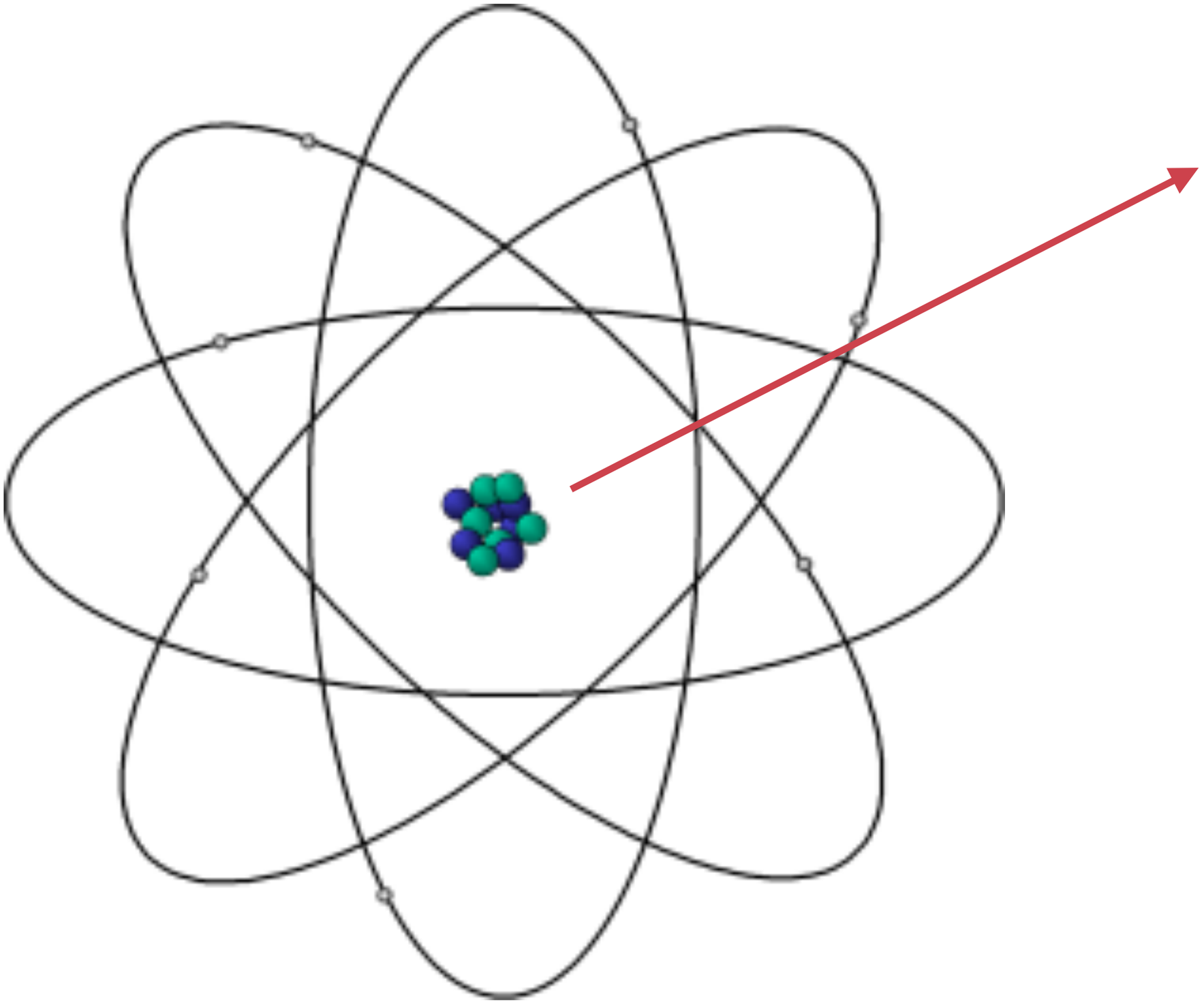
“non-symmetric field”

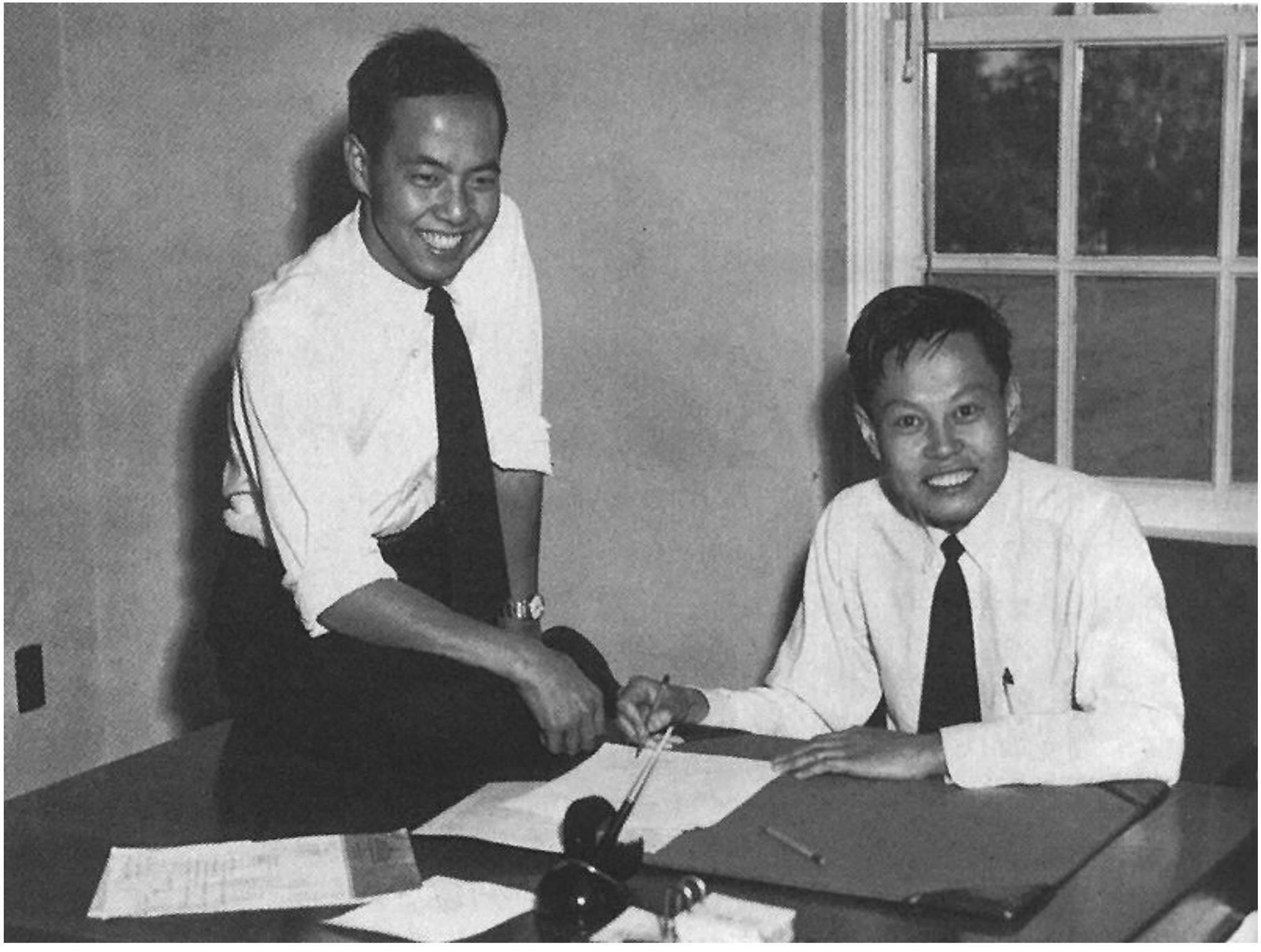
extra space dimensions

wormholes









T. D. Lee and C. N. Yang

Electromagnetic Field

Strong Interaction Field

Weak Interaction Field

for each force, a field obeying

$$DF = 0$$

$$D\,{}^*F = j$$

Glashow, Salam, Weinberg, ’t Hooft, Veltman,
Gross, Politzer, Wilczek

Matter

Force

“Fermion”

“Boson”

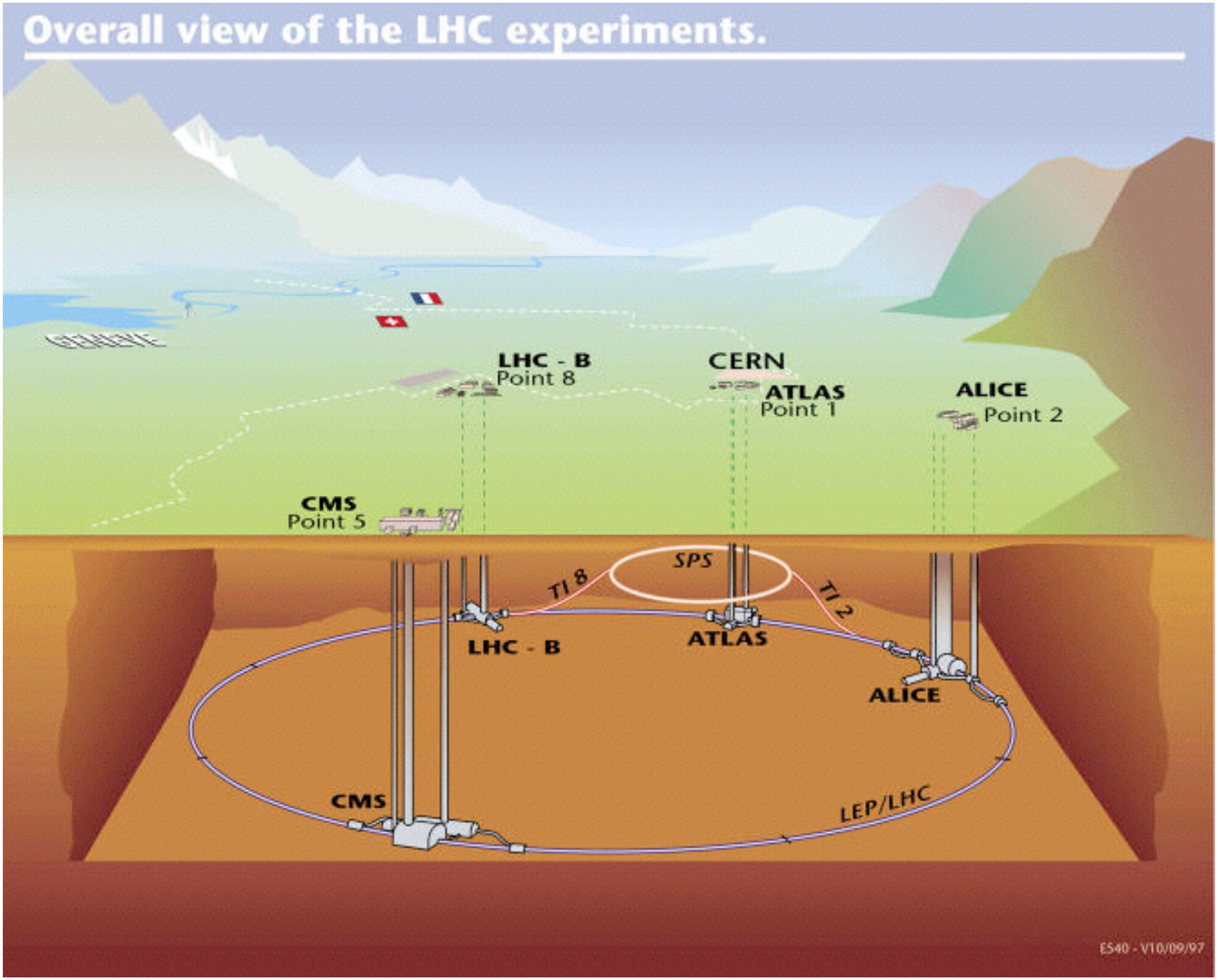
quarks, leptons

A, W, Z, gluon

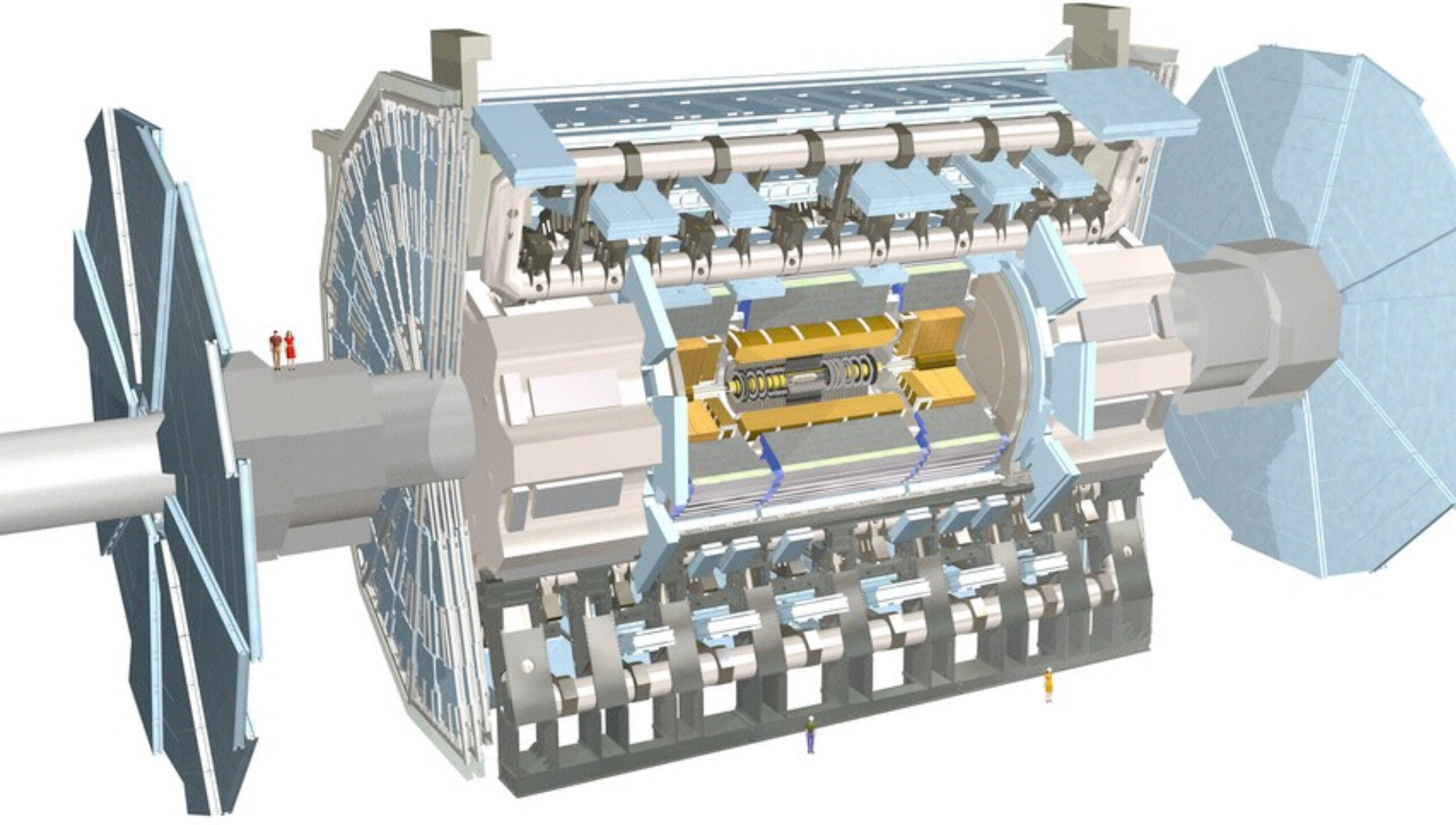
How do we know that this is true ?

Let’s talk about the Large Hadron Collider.

Overall view of the LHC experiments.

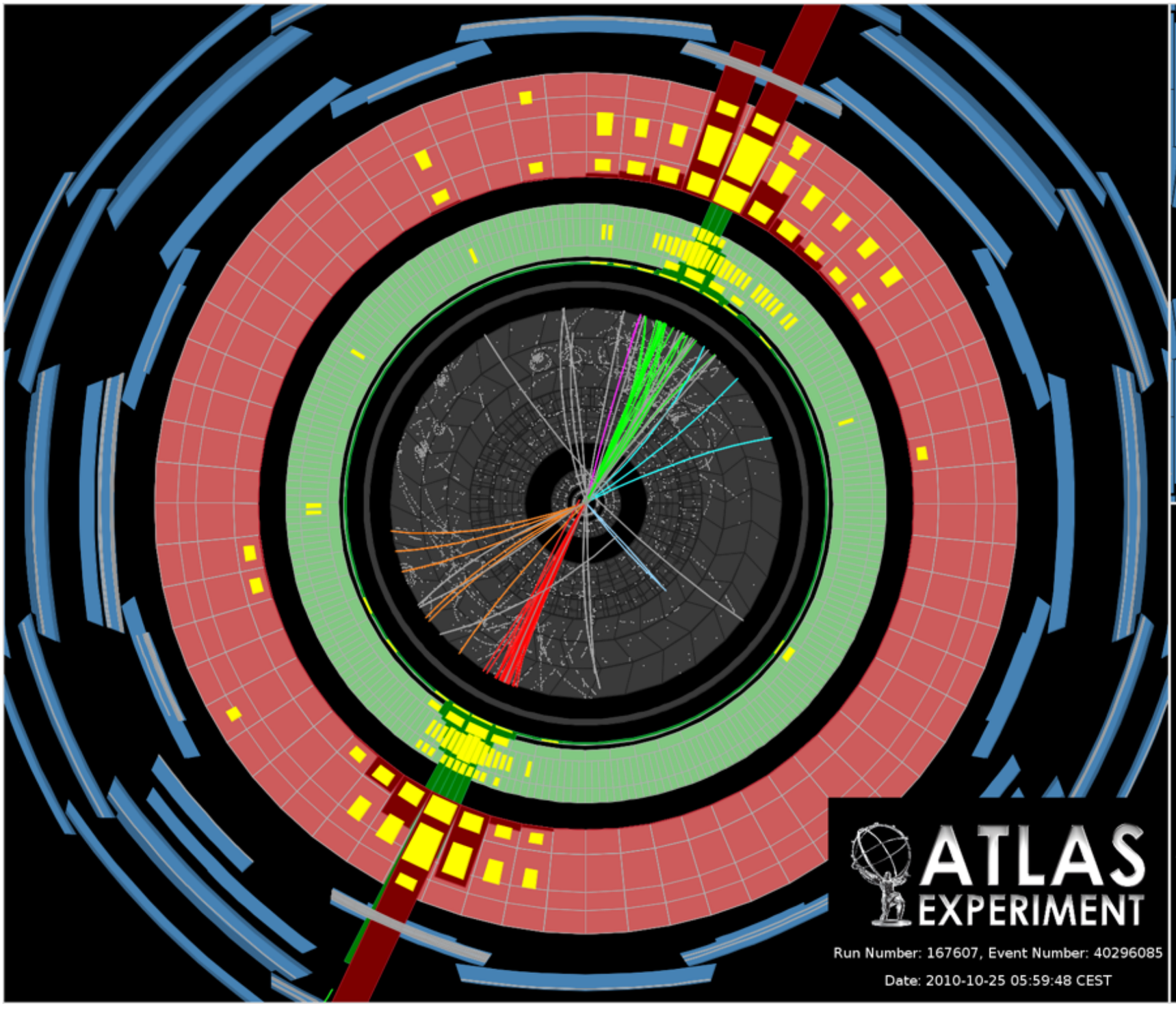


CERN



the ATLAS experiment

CERN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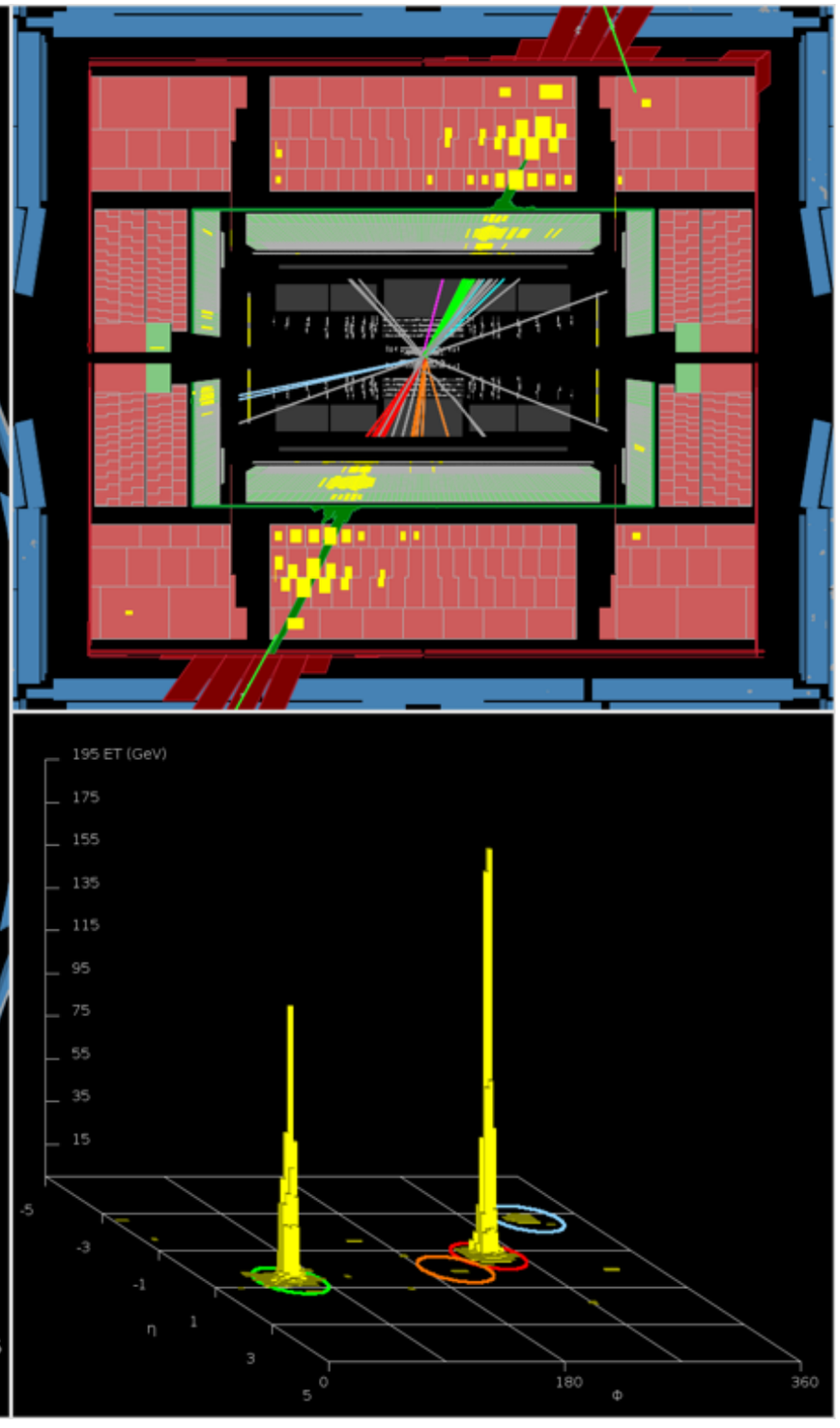
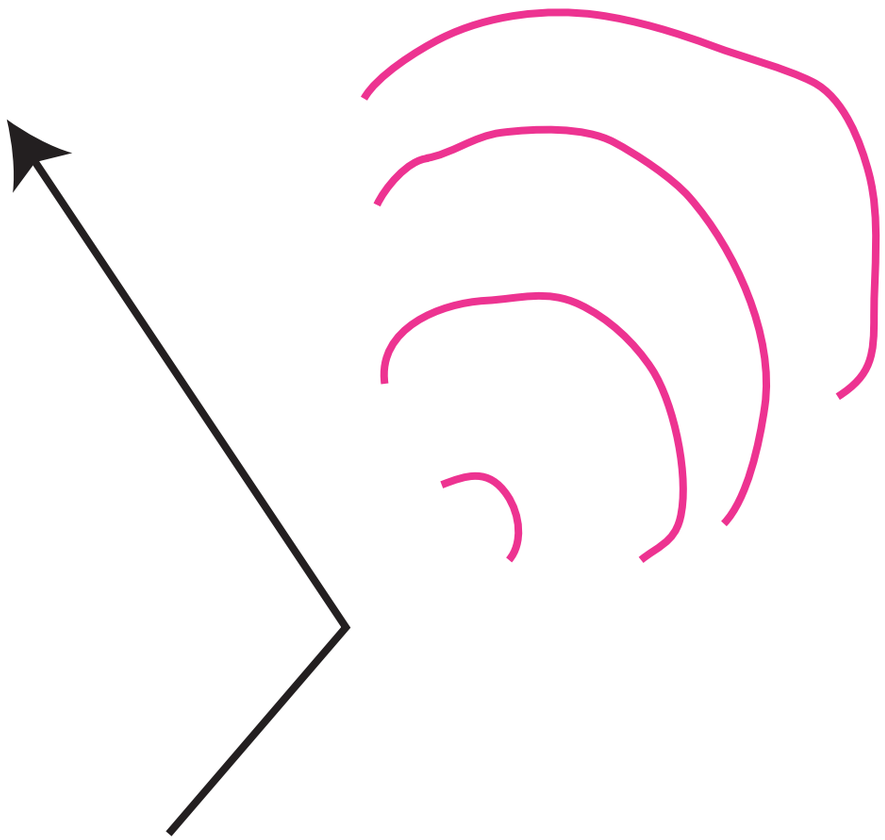
EXPERIMENT
Run Number: 167607, Event Number: 40296085
Date: 2010-10-25 05:59:48 CEST

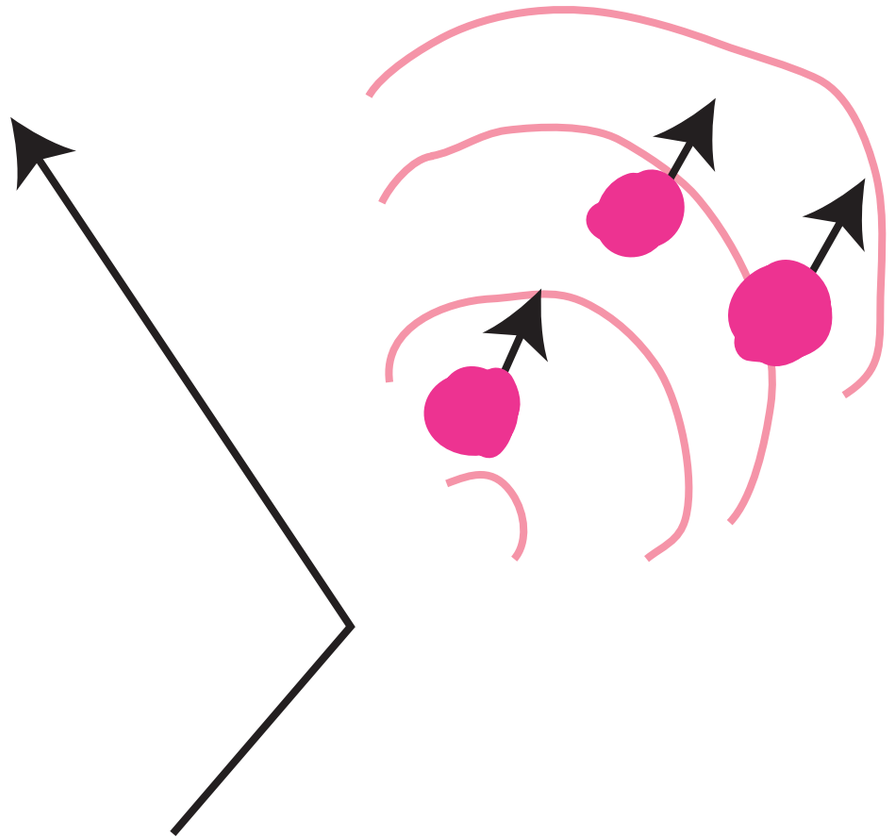

195 ET (GeV)
175
155
135
115
95
75
55
35
15
-5
-3
-1
1
3
5
η
0
180
360
Φ

40 million collisions / second

200 pictures recorded / second

2 billion pictures recorded / year





"Coherent State" — field become particles

$$\frac{Prob(1)}{Prob(0)} = \lambda$$

$$Prob(n) = \frac{\lambda^n}{n!} e^{-\lambda}$$

Poisson distribution

"Coherent State" — field become particles

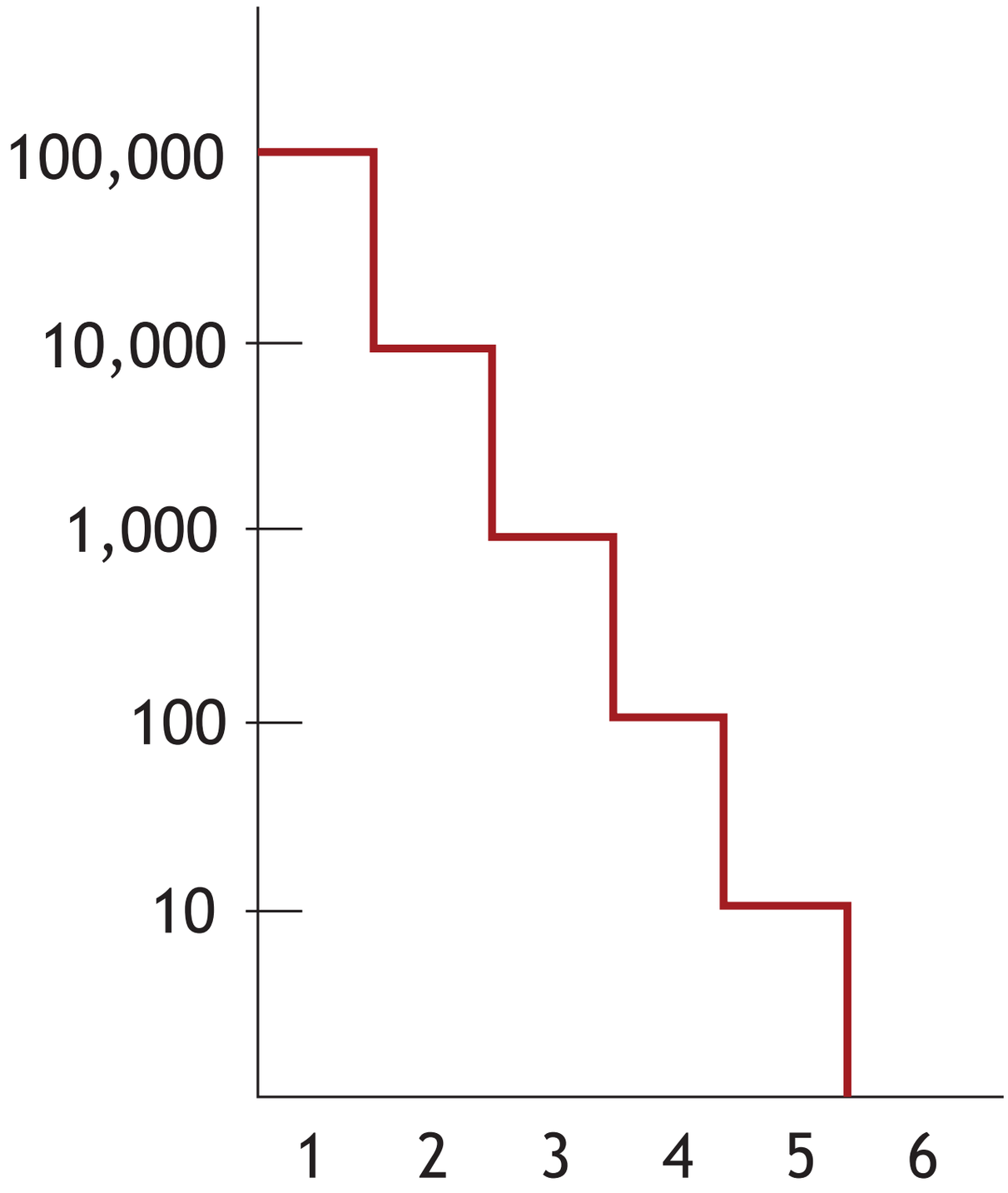
$$\frac{Prob(1)}{Prob(0)} = \lambda$$

$$Prob(n) = \frac{\lambda^n}{n!} e^{-\lambda}$$

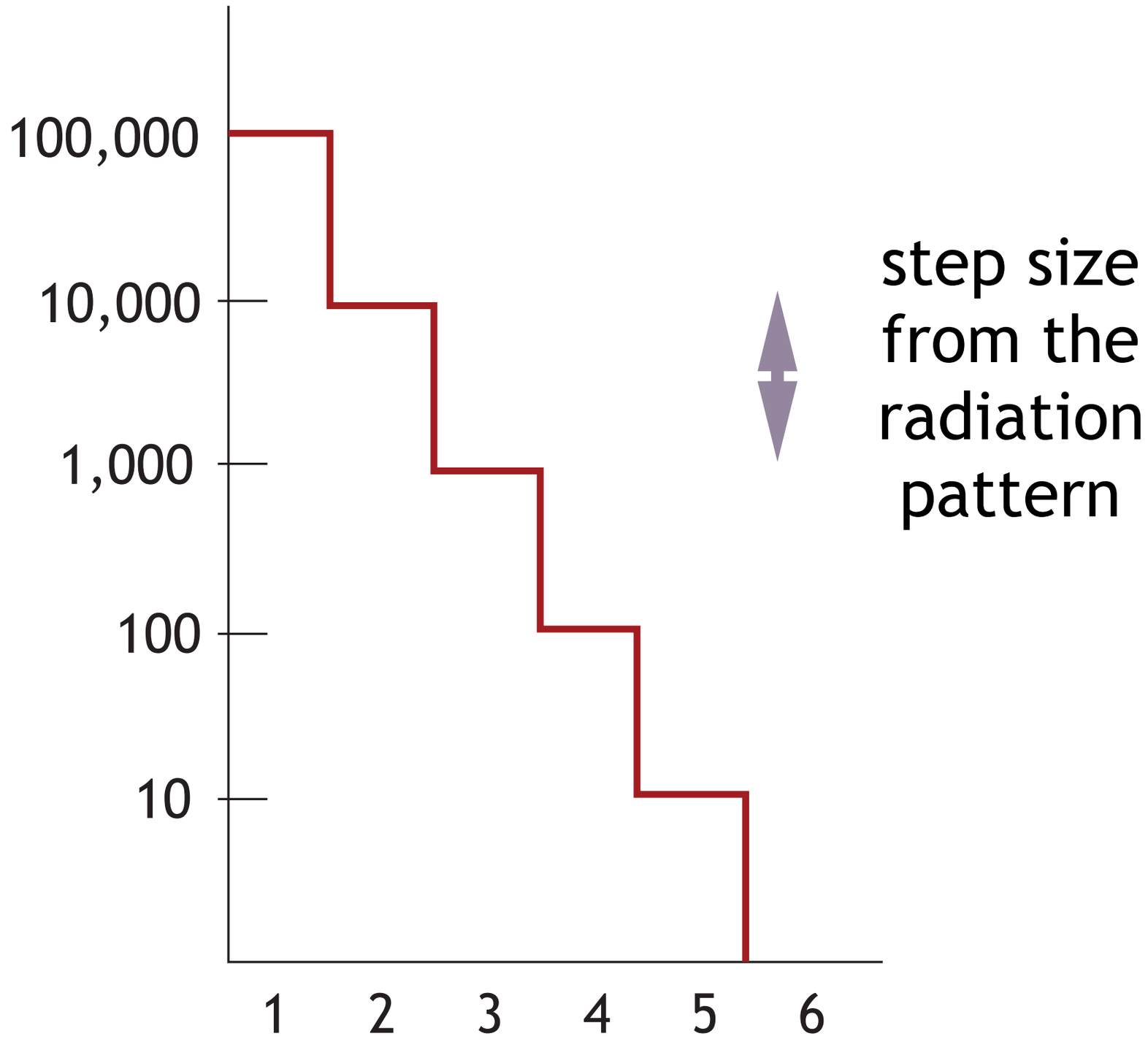
Poisson distribution

$$\frac{Prob(n+1)}{Prob(n)} \approx \lambda$$

LHC Iconography: the "Staircase"

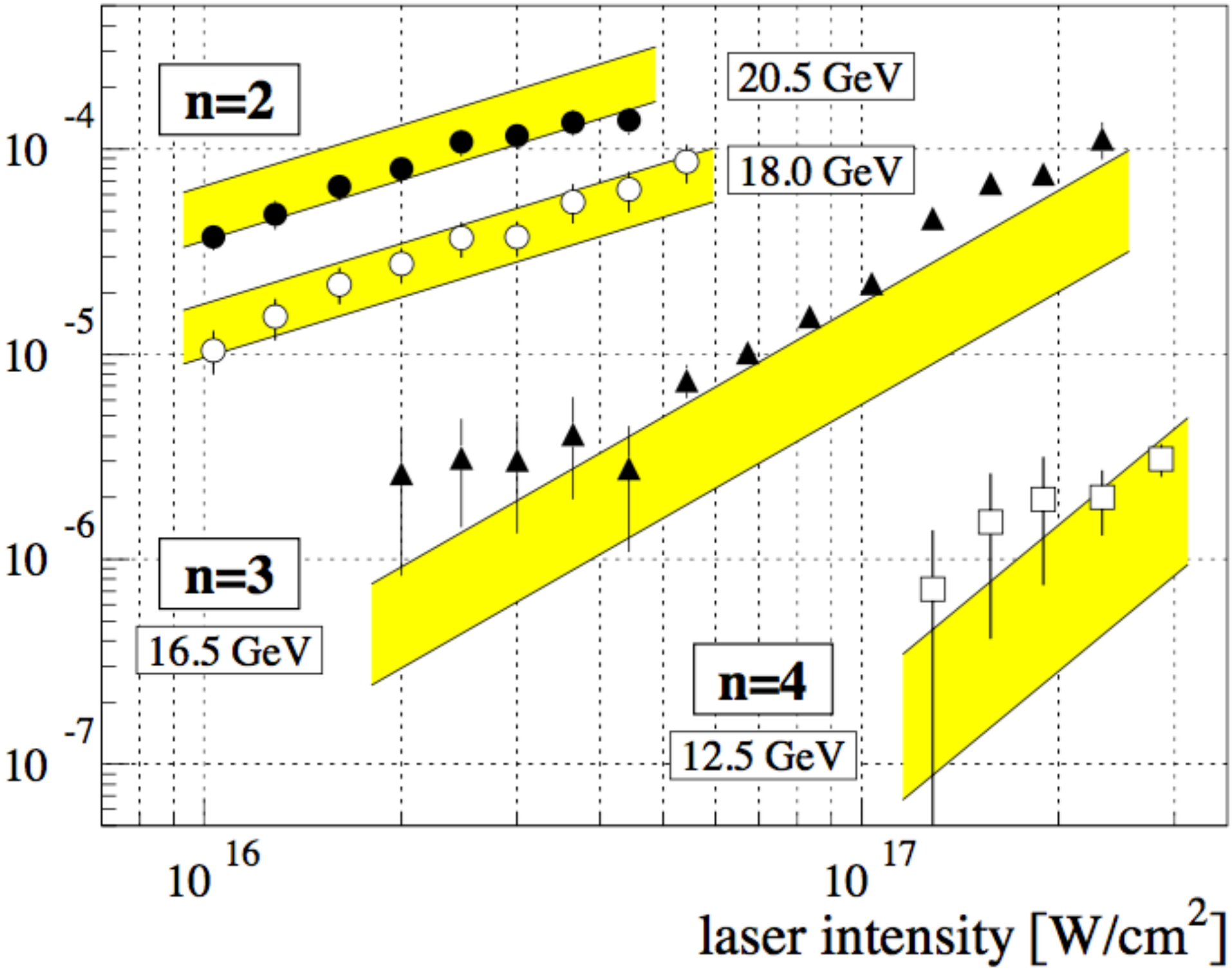


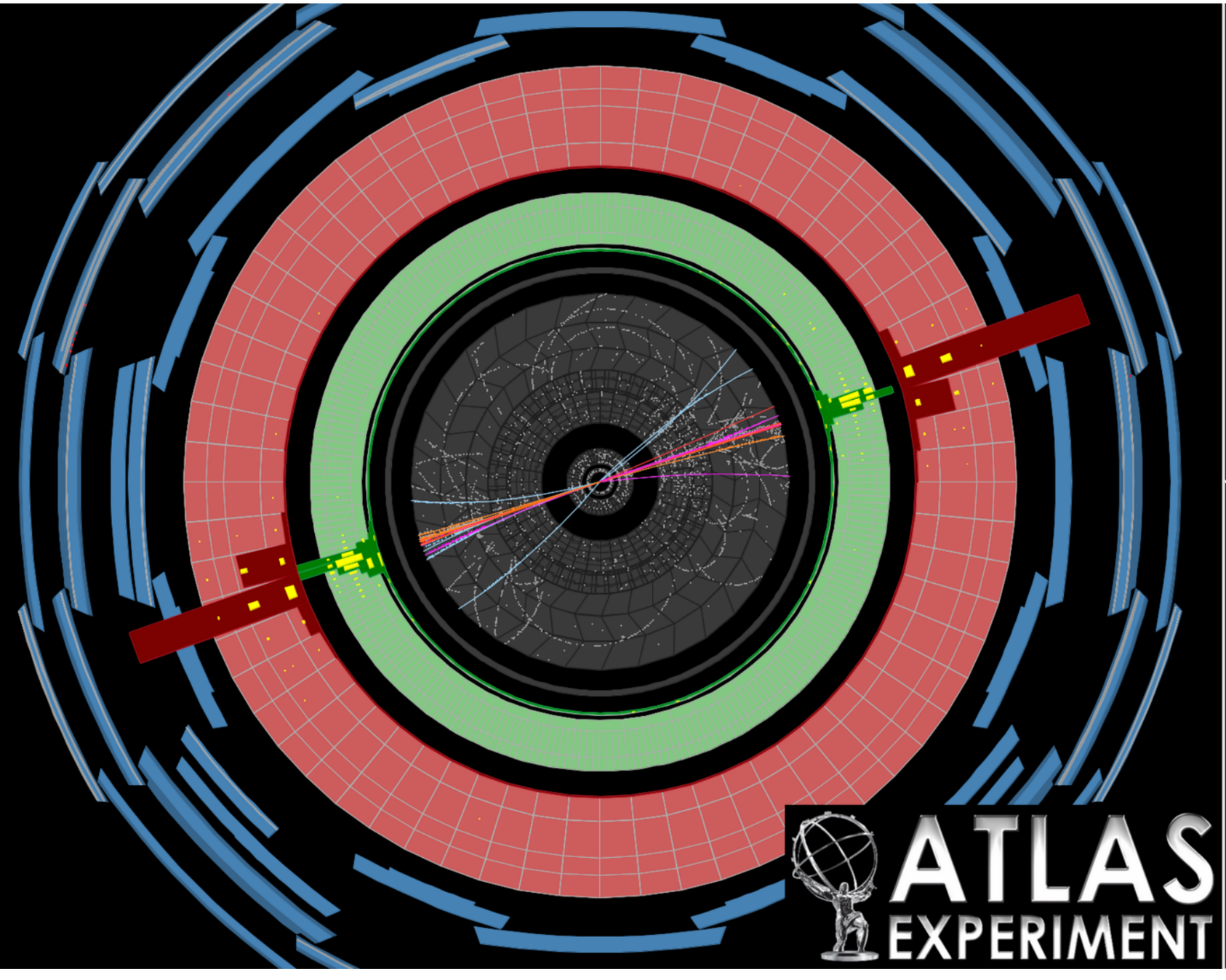
LHC Iconography: the "Staircase"

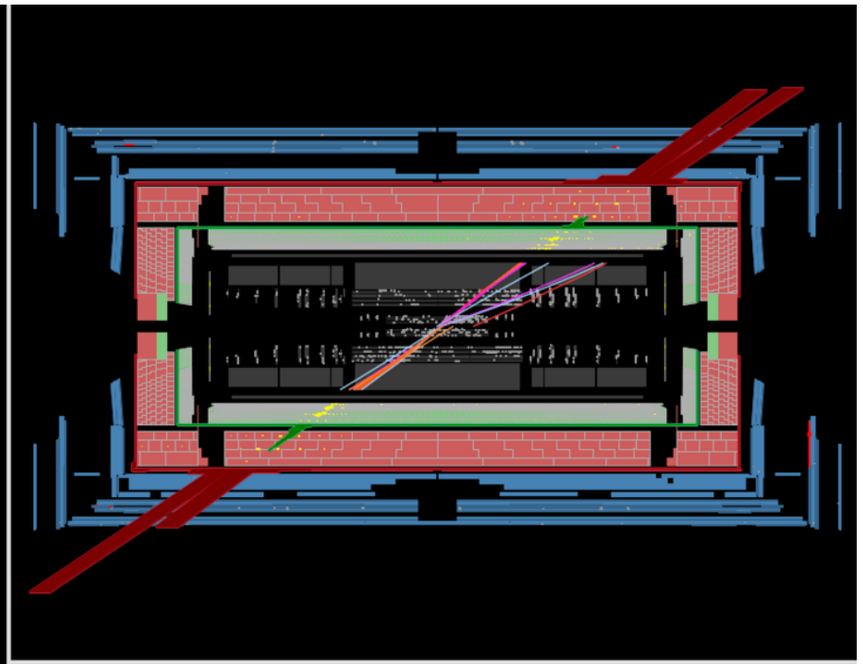


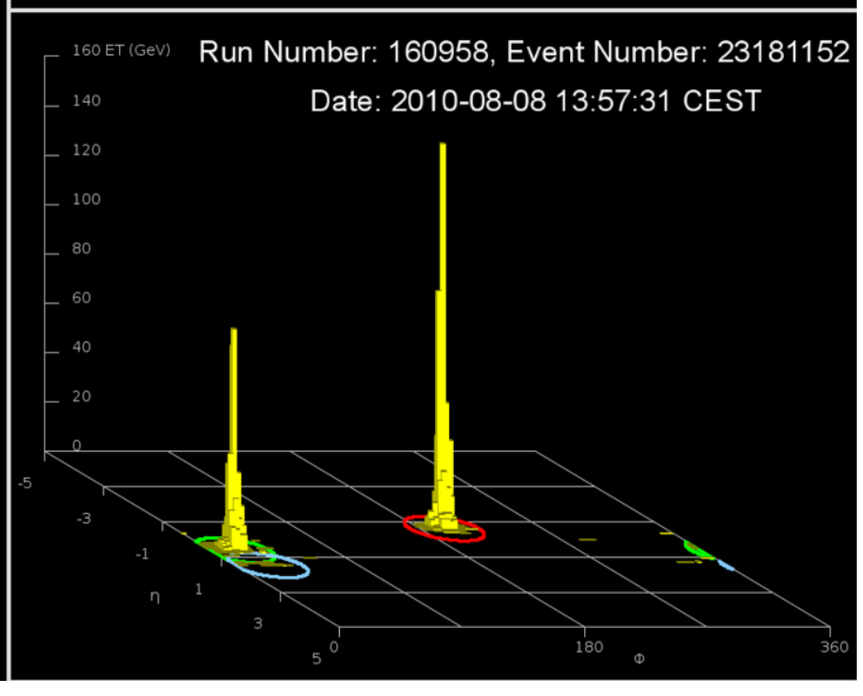
C. Bula et al. (Princeton-Rochester-SLAC-Tennessee)

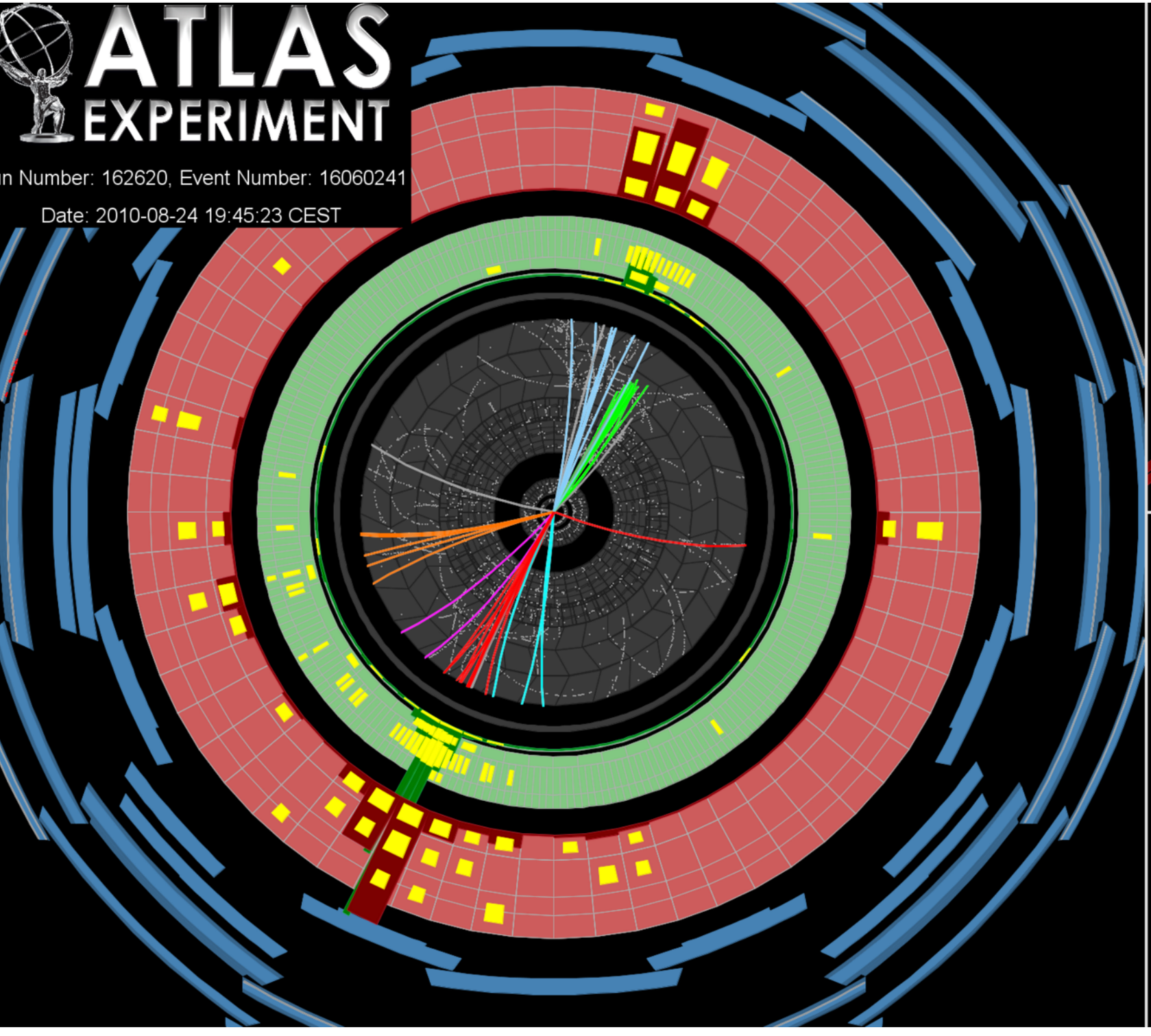
Final Focus
Test Beam
Experiment


n=2
20.5 GeV
18.0 GeV
n=3
16.5 GeV
n=4
12.5 GeV
10 -4
10 -5
10 -6
10 -7
10 16
10 17
laser intensity [W/cm2]


ATLAS
EXPERIMENT




Run Number: 160958, Event Number: 23181152
Date: 2010-08-08 13:57:31 CEST
160 ET (GeV)
140
120
100
80
60
40
20
0
-5
-3
-1
η
1
3
5
0
180
360
Φ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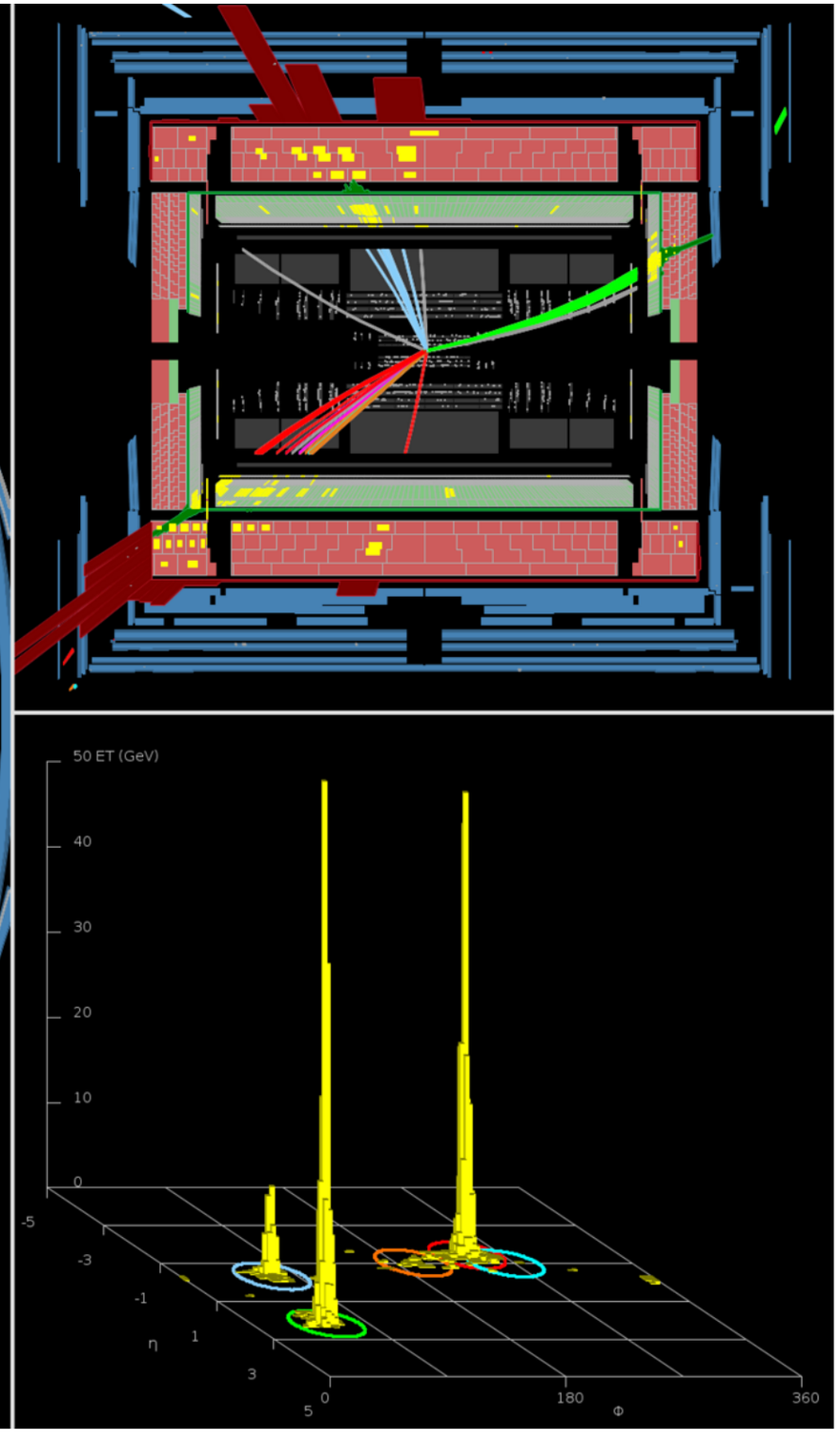
Date: 2010-08-24 19:45:23 CEST

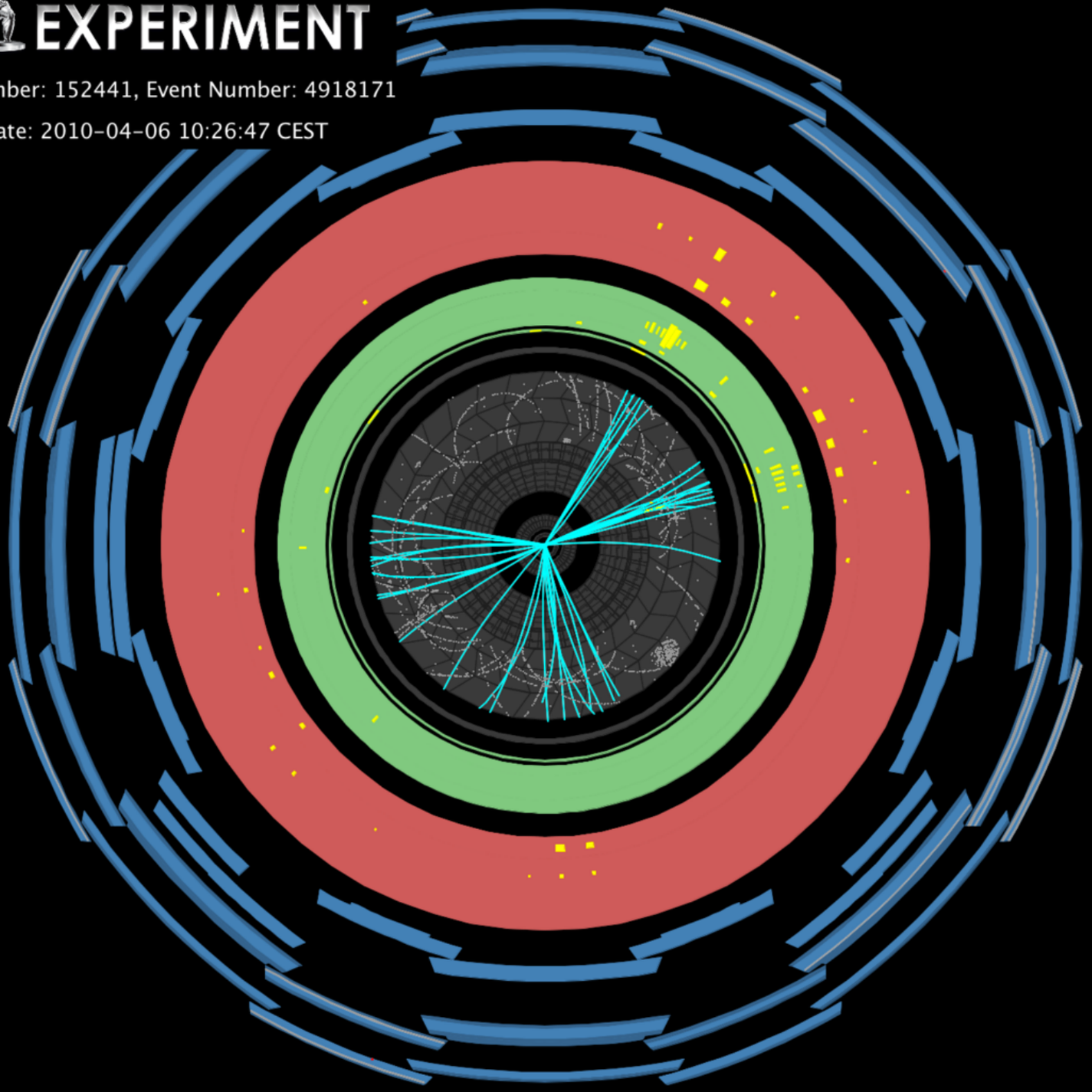

50 ET (GeV)
40
30
20
10
0
-5
-3
-1
η
1
3
5
0
180
360
Φ

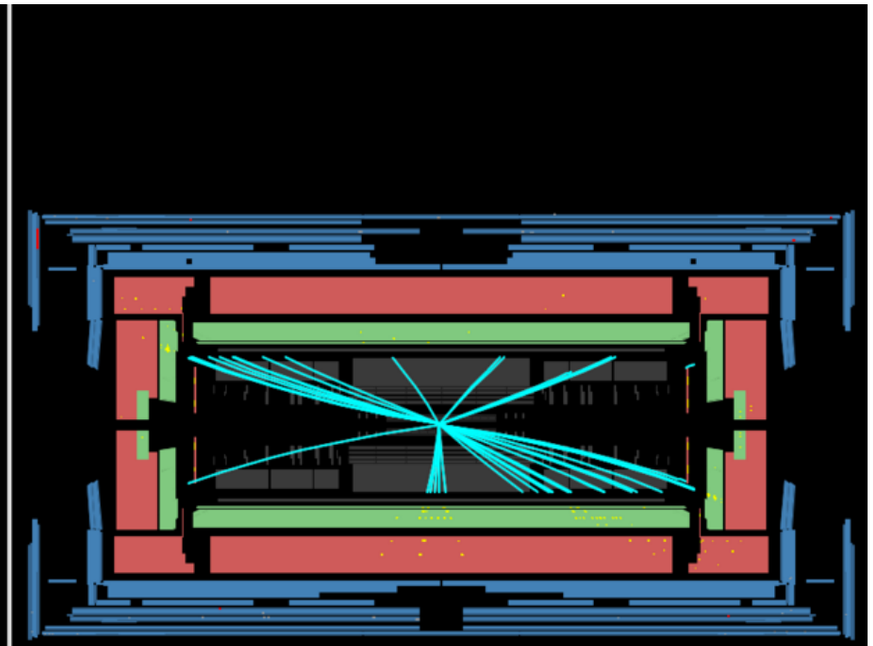
m(jj) = 3.1 TeV

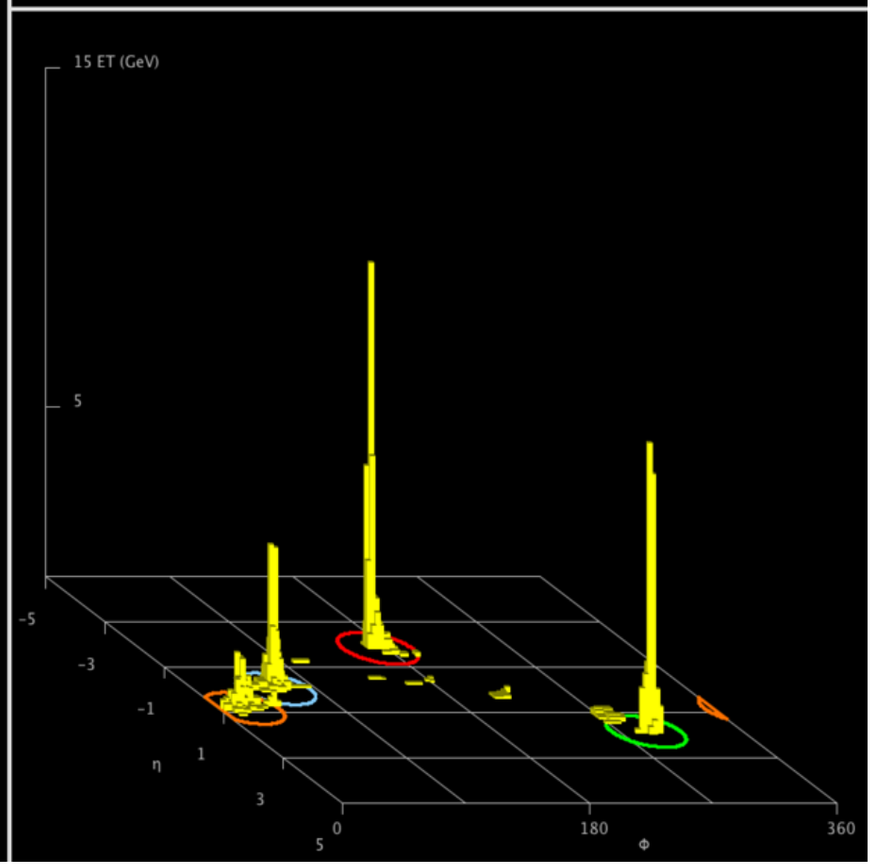
ATLAS
EXPERIMENT

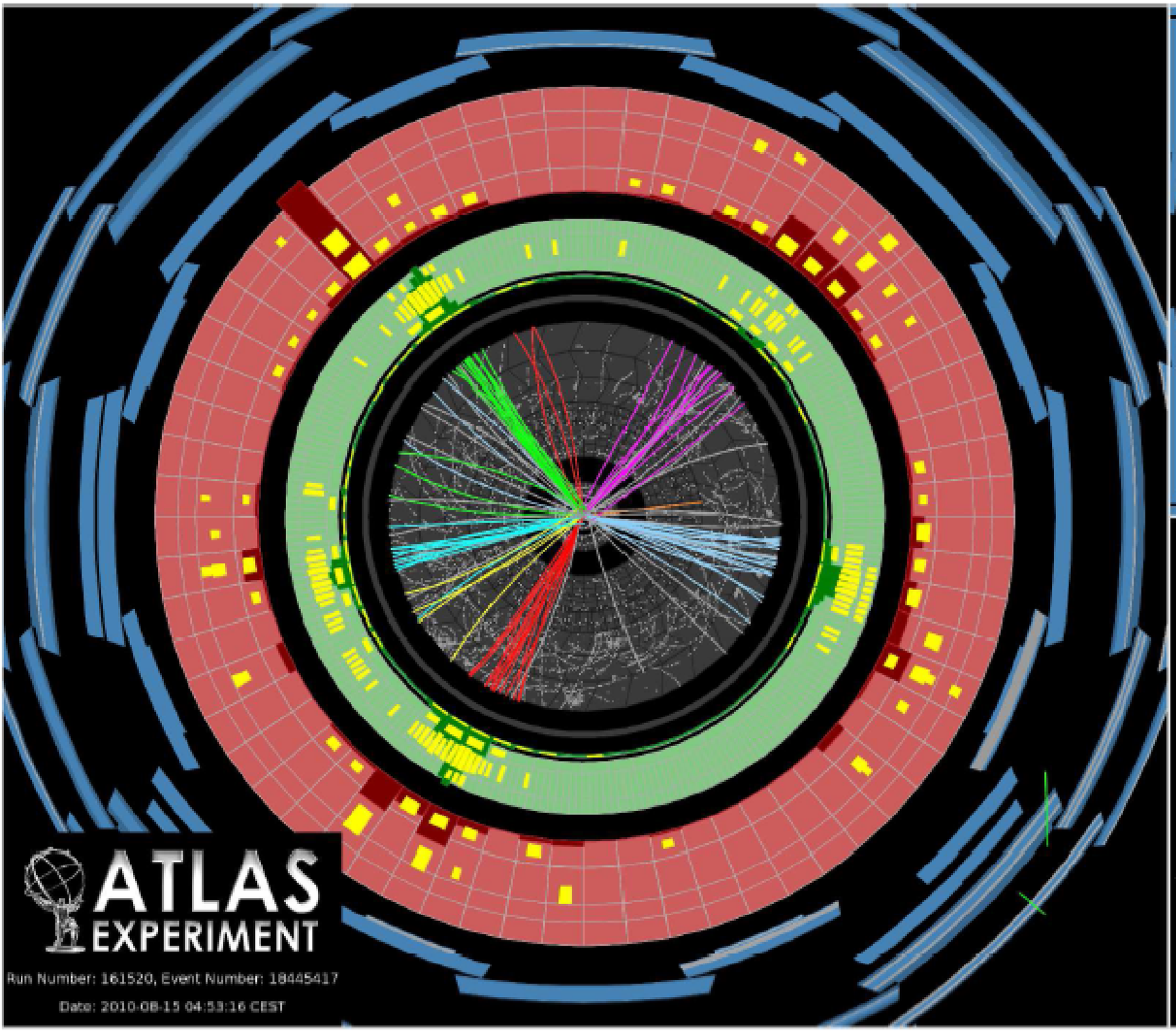
un Number: 152441, Event Number: 4918171

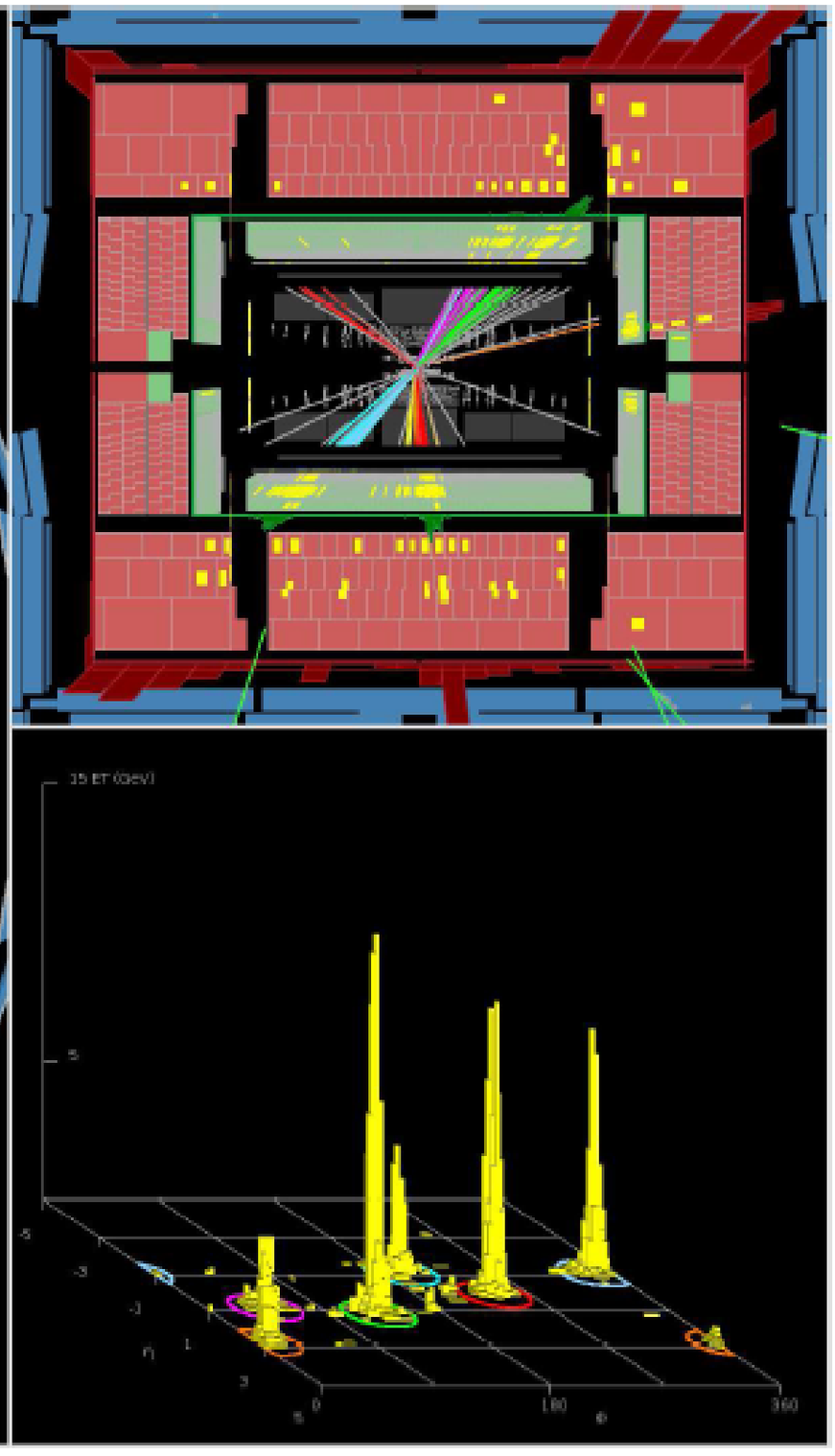
Date: 2010-04-06 10:26:47 CEST



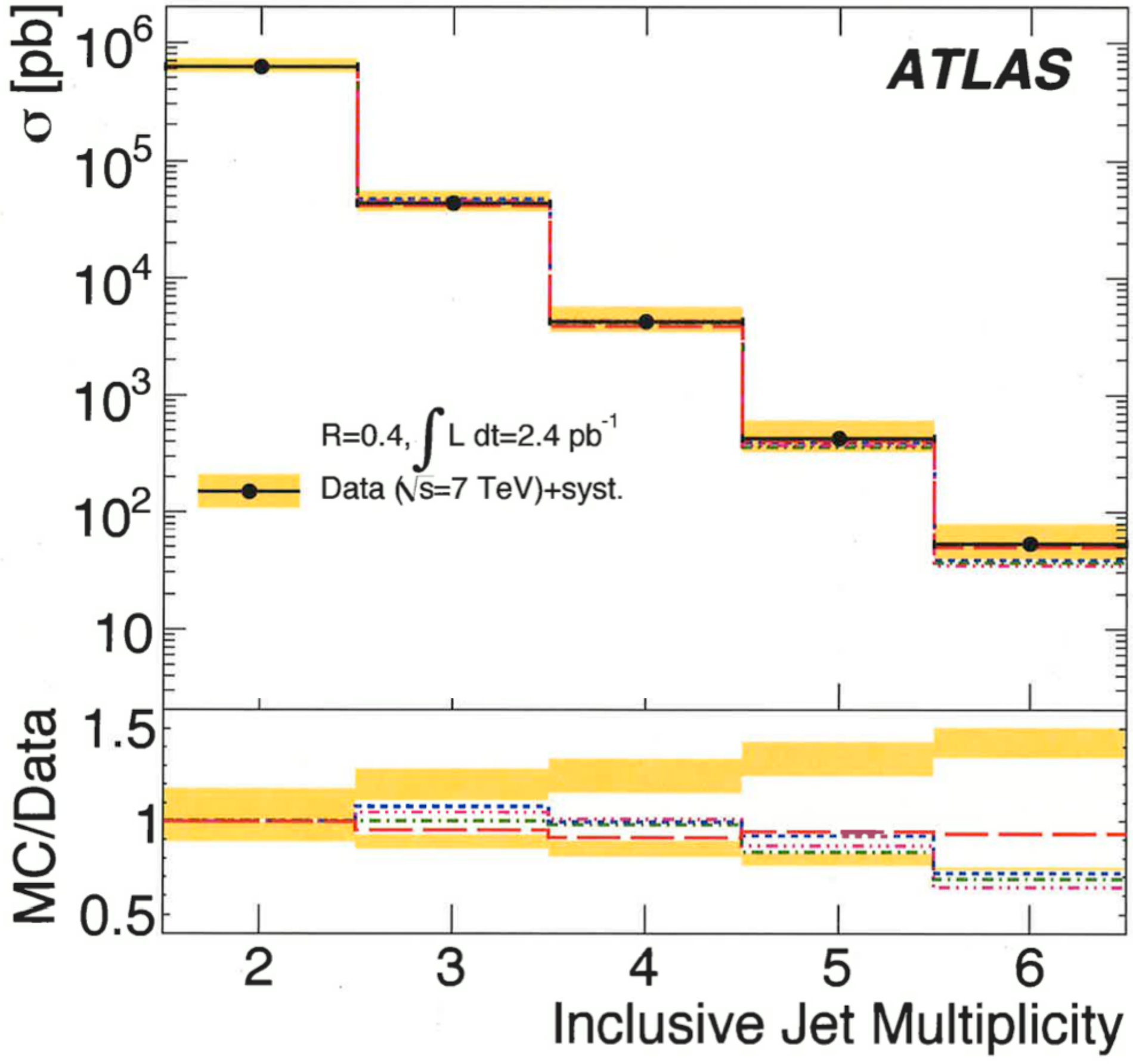




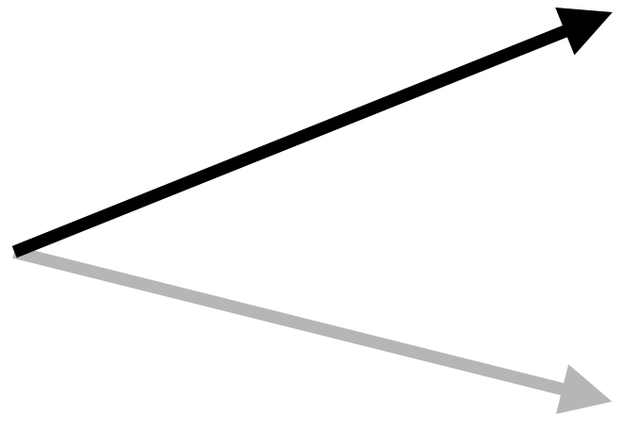




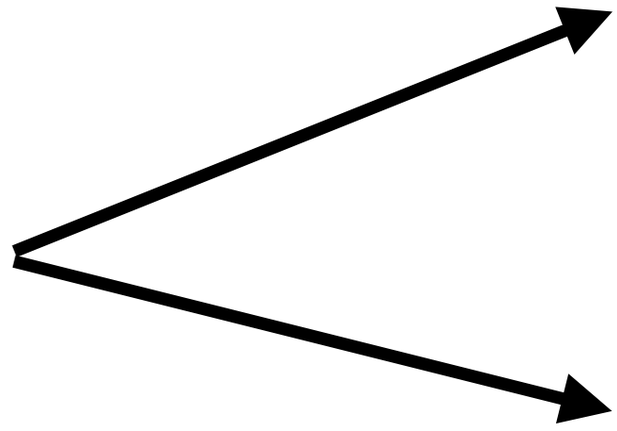
ATLAS 6-jet event


ATLAS
σ [pb]
10^6
10^5
10^4
10^3
10^2
10
R=0.4, $\int$ L dt=2.4 pb^{-1}
Data ($\sqrt{s}$=7 TeV)+syst.
MC/Data
1.5
1
0.5
2
3
4
5
6
Inclusive Jet Multiplicity

$$W \rightarrow e\ \nu$$



$$Z \rightarrow e^+\ e^-$$



ATLAS
EXPERIMENT

Run Number: 152409, Event Number: 5966801

Date: 2010-04-05 06:54:50 CEST

W→eν candidate in
7 TeV collisions

$p_T(e+) = 34$ GeV

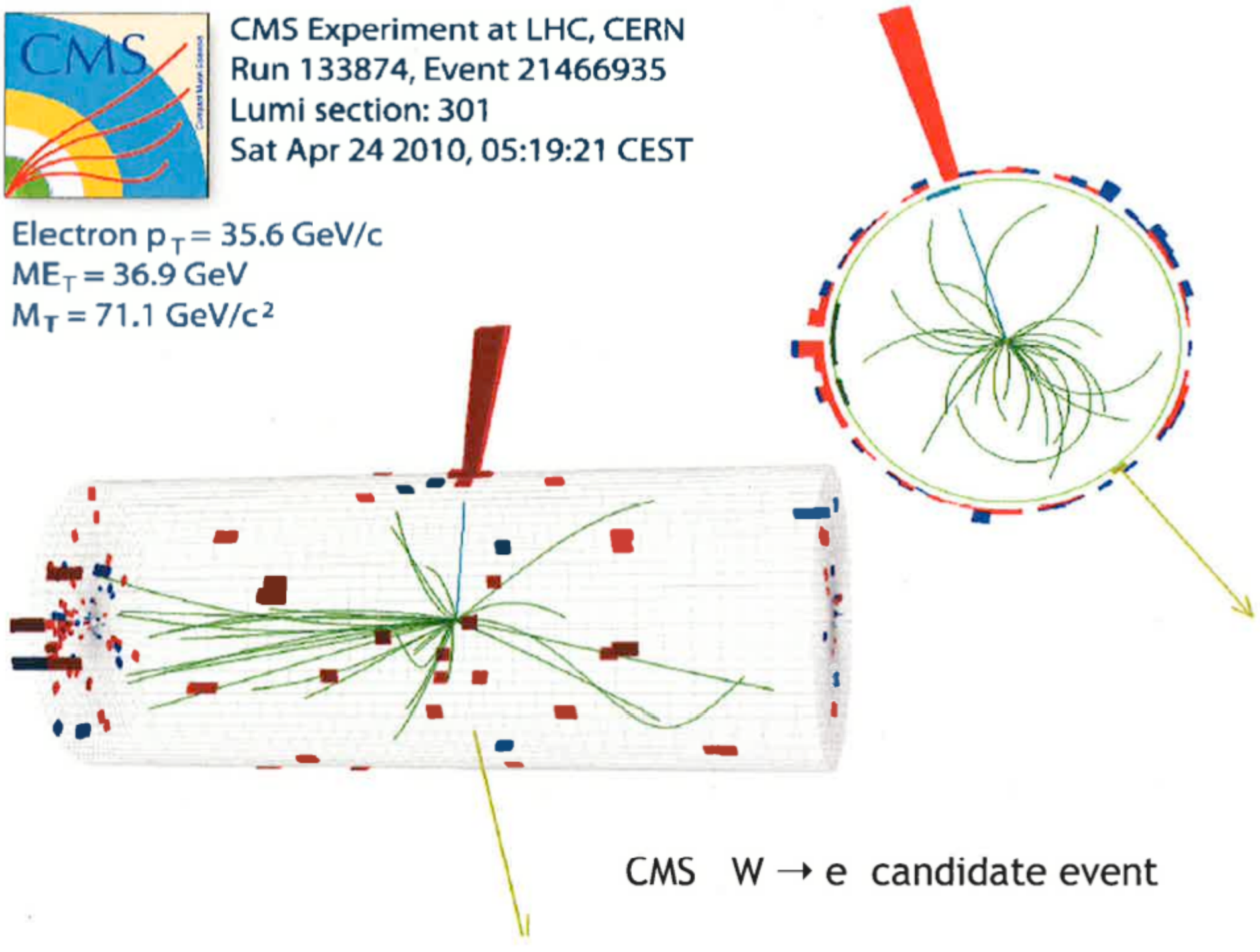
$\eta(e+) = -0.42$

$E_T^{miss} = 26$ GeV

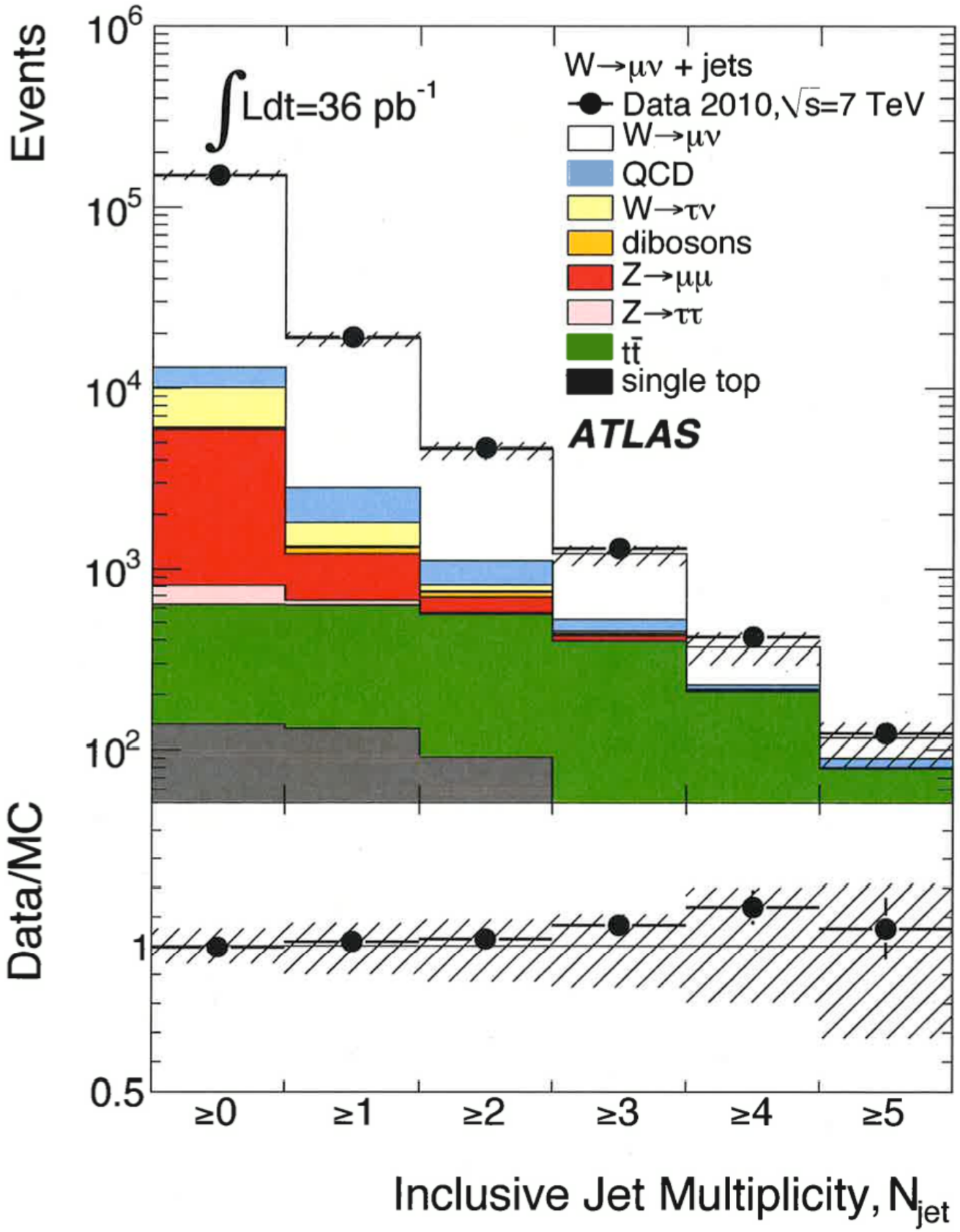
$M_T = 57$ GeV

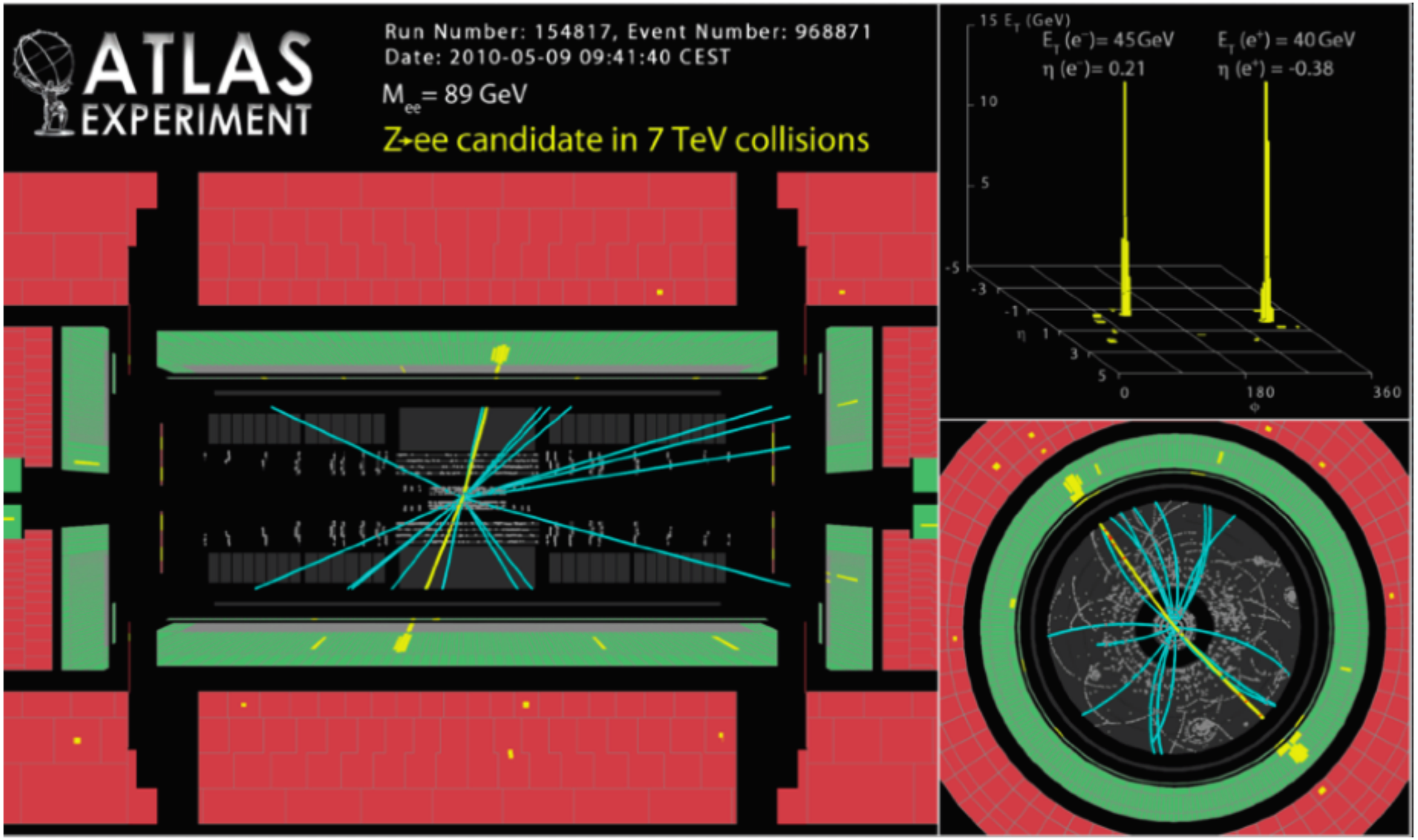
CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2



CMS $W \rightarrow e$ candidate event

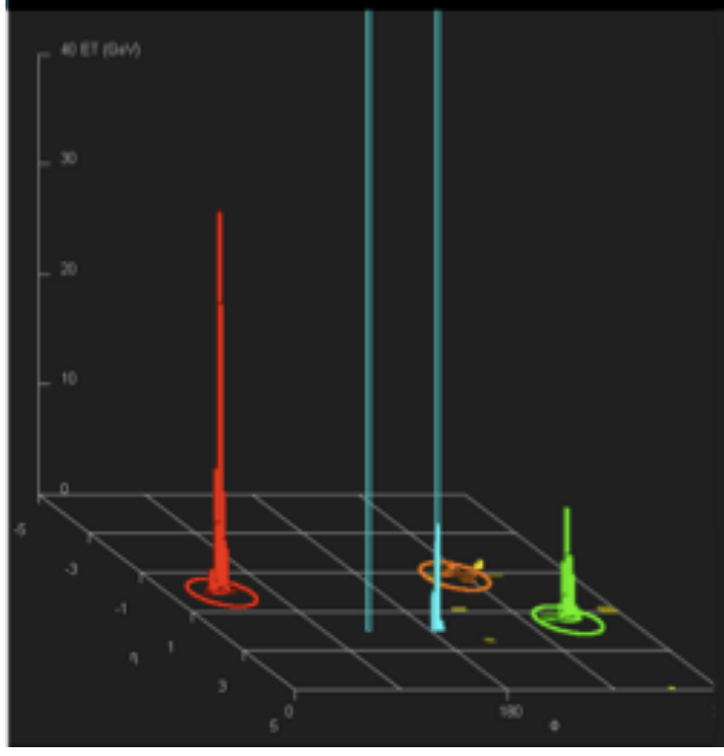

Events
10^6
10^5
10^4
10^3
10^2
1
0.5
$\int$Ldt=36 pb^{-1}
W→μν + jets
Data 2010,√s=7 TeV
W→μν
QCD
W→τν
dibosons
Z→μμ
Z→ττ
tt̄
single top
ATLAS
Data/MC
≥0
≥1
≥2
≥3
≥4
≥5
Inclusive Jet Multiplicity, N_{jet}

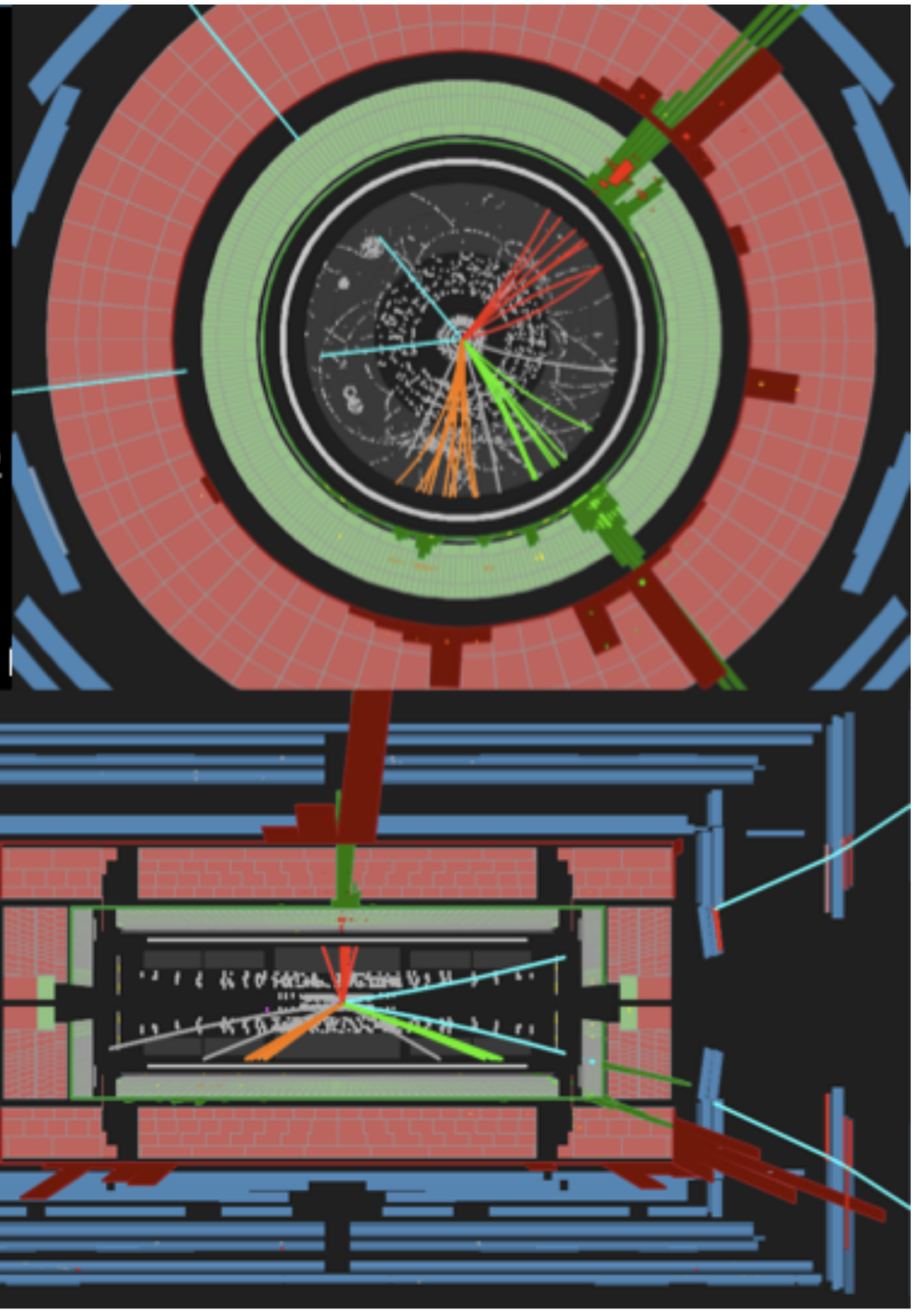

ATLAS
EXPERIMENT
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST
M_ee = 89 GeV
Z→ee candidate in 7 TeV collisions
15 E_T (GeV)
E_T (e⁻)= 45GeV
η (e⁻)= 0.21
E_T (e⁺) = 40GeV
η (e⁺) = -0.38
10
5
-5
-3
-1
η 1
3
5
0
180
360
φ

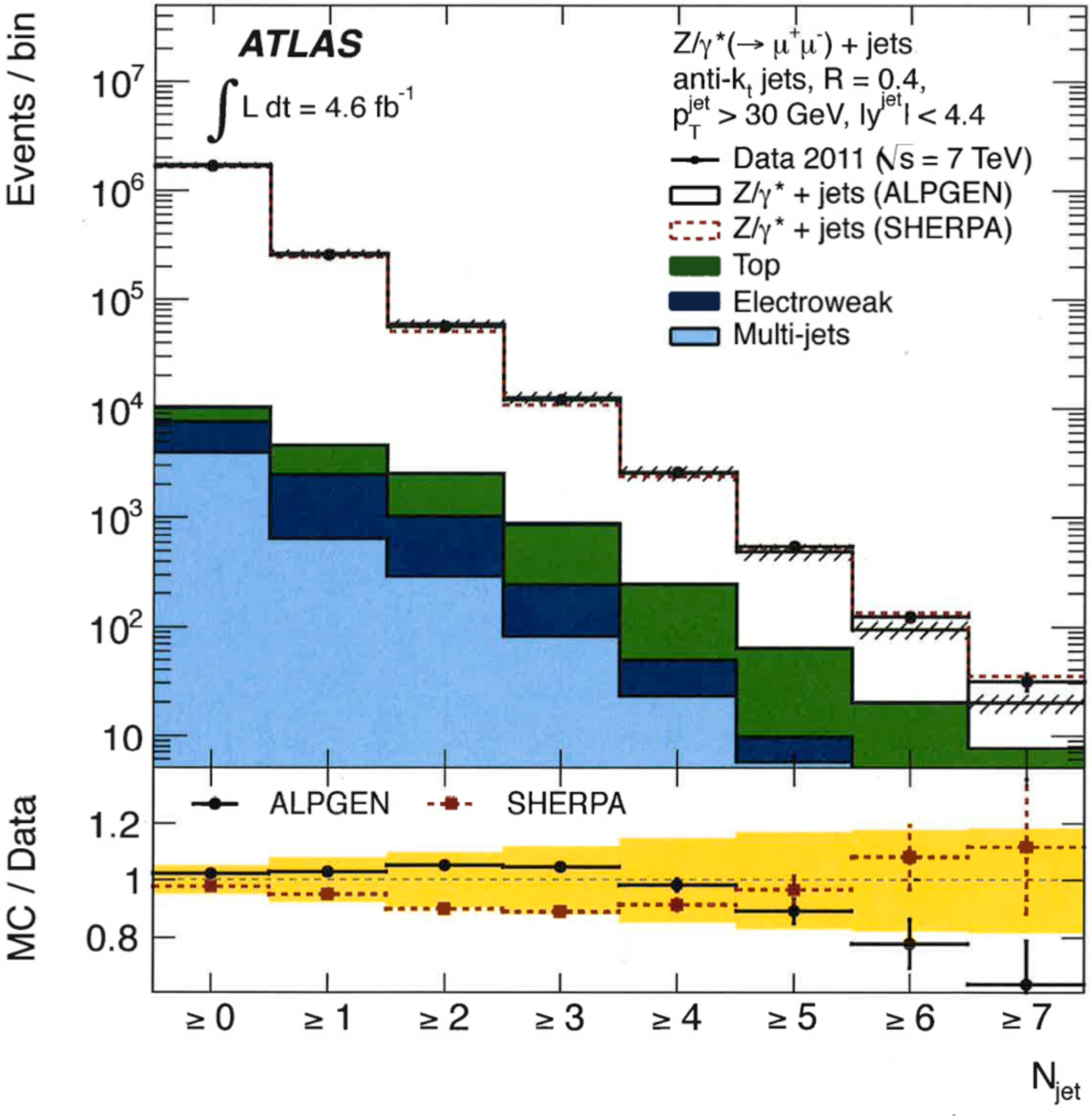
ATLAS EXPERIMENT

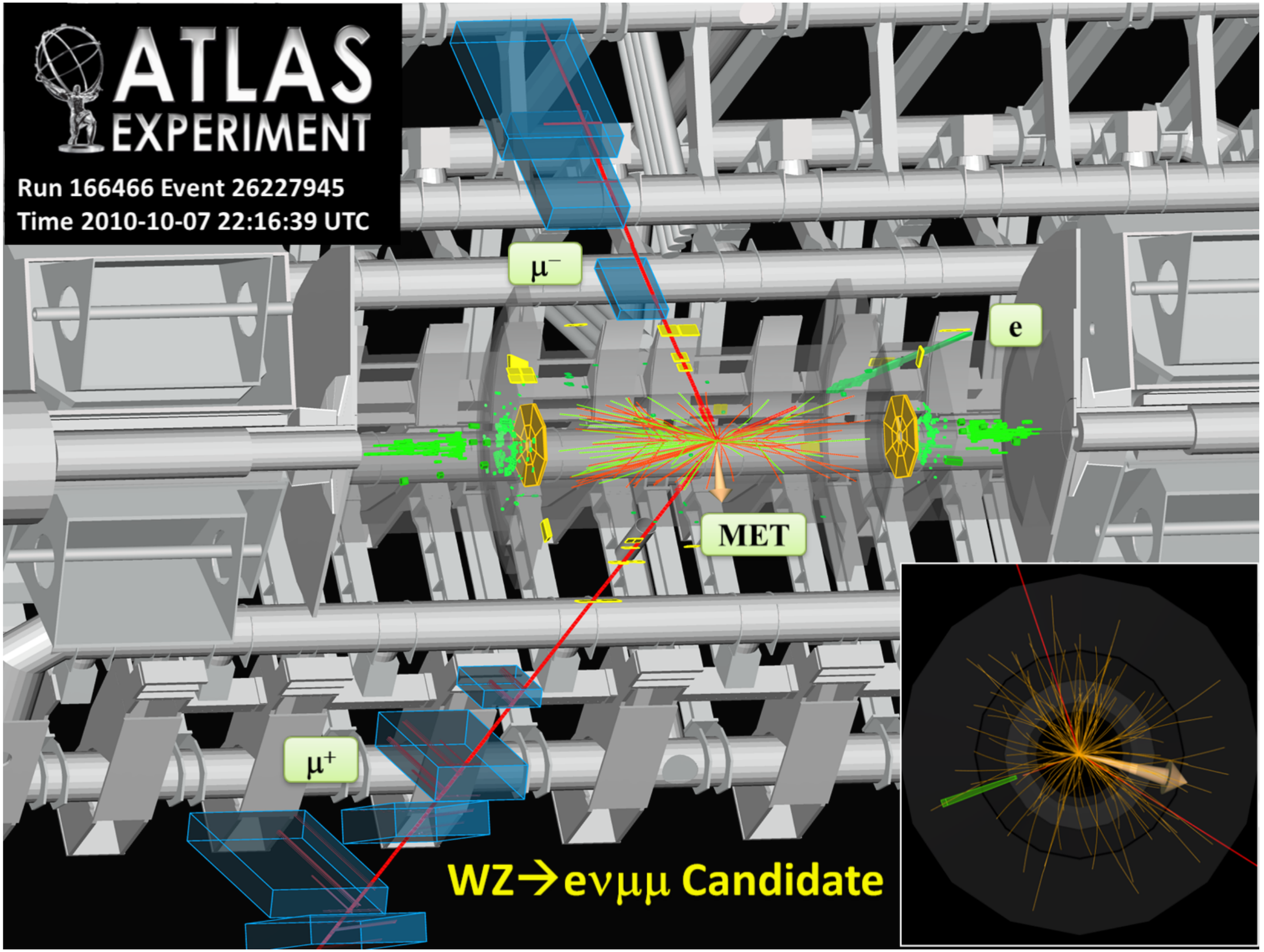
$Z \rightarrow \mu^- \mu^+ + 3$ jets

Run Number 158466, Event Number 4174272
Date: 2010-07-02 17:49:13 CEST

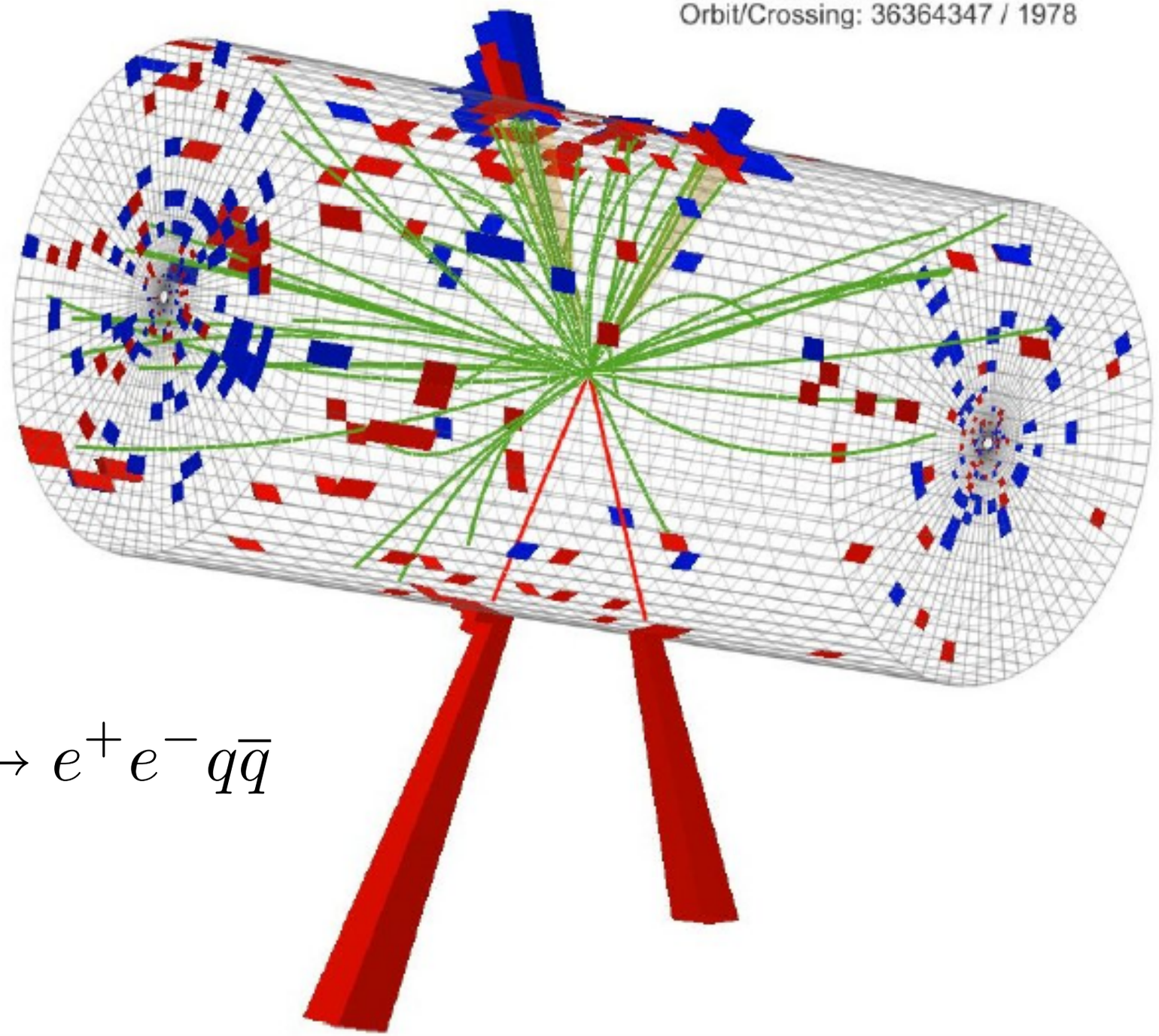





ATLAS
∫ L dt = 4.6 fb-1
Z/γ*(→ μ+μ-) + jets
anti-kt jets, R = 0.4,
pTjet > 30 GeV, |yjet| < 4.4
Data 2011 (√s = 7 TeV)
Z/γ* + jets (ALPGEN)
Z/γ* + jets (SHERPA)
Top
Electroweak
Multi-jets
Events / bin
10^7
10^6
10^5
10^4
10^3
10^2
10
ALPGEN
SHERPA
MC / Data
1.2
1
0.8
≥ 0
≥ 1
≥ 2
≥ 3
≥ 4
≥ 5
≥ 6
≥ 7
Njet


ATLAS
EXPERIMENT
Run 166466 Event 26227945
Time 2010-10-07 22:16:39 UTC
μ⁻
e
MET
μ⁺
WZ→eνμμ Candidate

CMS Experiment at LHC, CERN
Data recorded: Sun Jun 12 04:43:37 2011 CEST
Run/Event: 166864 / 145883149
Lumi section: 139
Orbit/Crossing: 36364347 / 1978



$$pp \to ZZ \to e^+e^-q\bar{q}$$

CMS Preliminary

Dec 2015

Production Cross Section, σ [pb]

10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}

7 TeV CMS measurement (L ≤ 5.0 fb^{-1})
8 TeV CMS measurement (L ≤ 19.6 fb^{-1})
13 TeV CMS measurement (L ≤ 1.3 fb^{-1})
Theory prediction
CMS 95%CL limit

W | ≥1j | ≥2j | ≥3j | ≥4j | Z | ≥1j | ≥2j | ≥3j | ≥4j | Wγ | Zγ | WW | WZ | ZZ | EW qqW | EW qqZ | γγ→ WW | EW ssWW | EW Zγjj | WVγ | tt | 1j | 2j | 3j | $t_{t\text{-ch}}$ | tW | $t_{s\text{-ch}}$ | ttγ | ttW | ttZ | ggH | VBF qqH | VH | ttH

EW: W→lν, Z→ll, l=e,μ

All results at: http://cern.ch/go/pNj7

Th. $\Delta\sigma_H$ in exp. $\Delta\sigma$

2

0

1

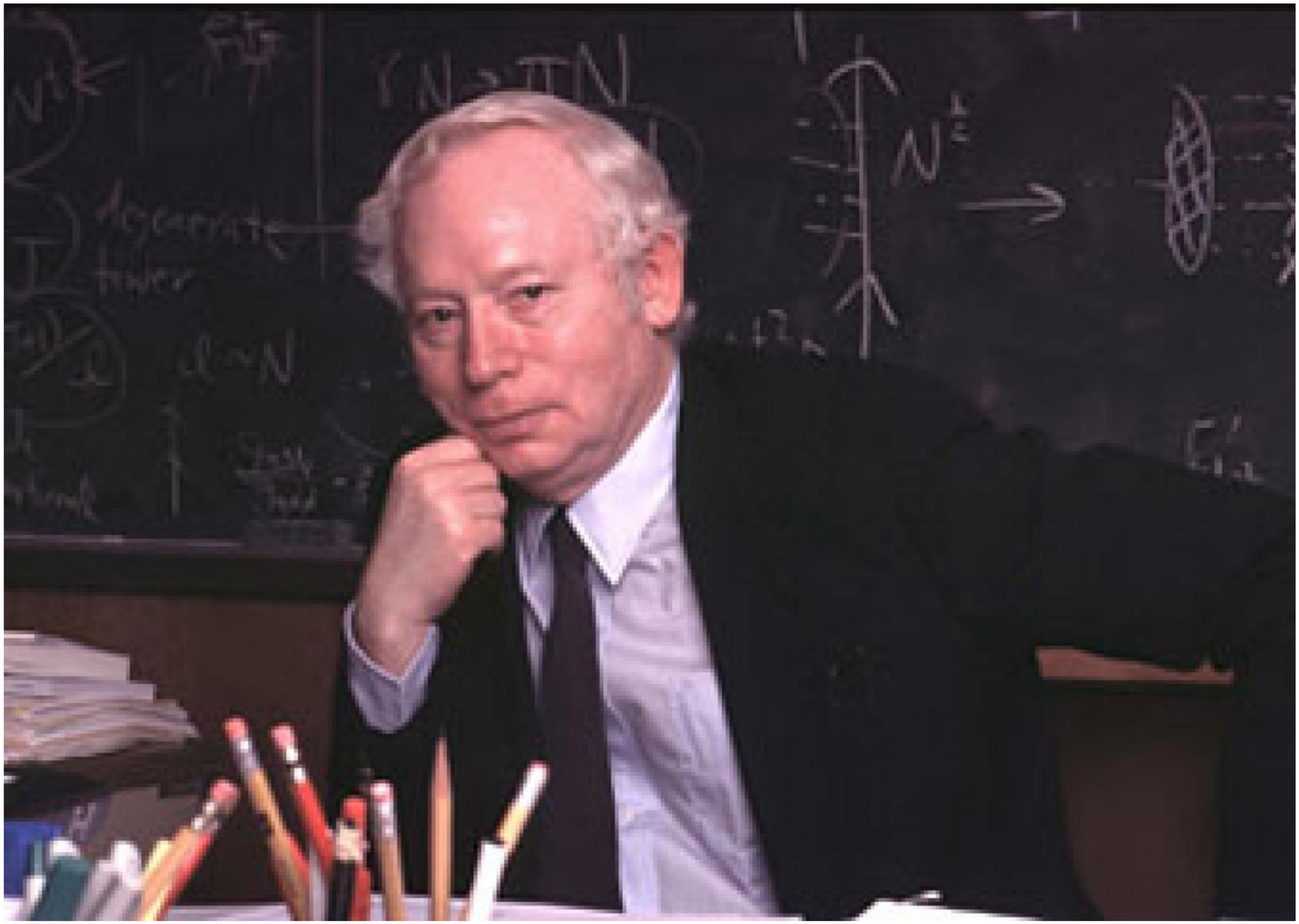
2

3

W
≥1j
≥2j
≥3j
≥4j
Z
≥1j
≥2j
≥3j
≥4j
Wγ
Zγ
WW
WZ
ZZ
EW qqW
EW qqZ
γγ→ WW
EW ssWW
EW Zγjj
WVγ

All results at: http://cern.ch/go/pNj7

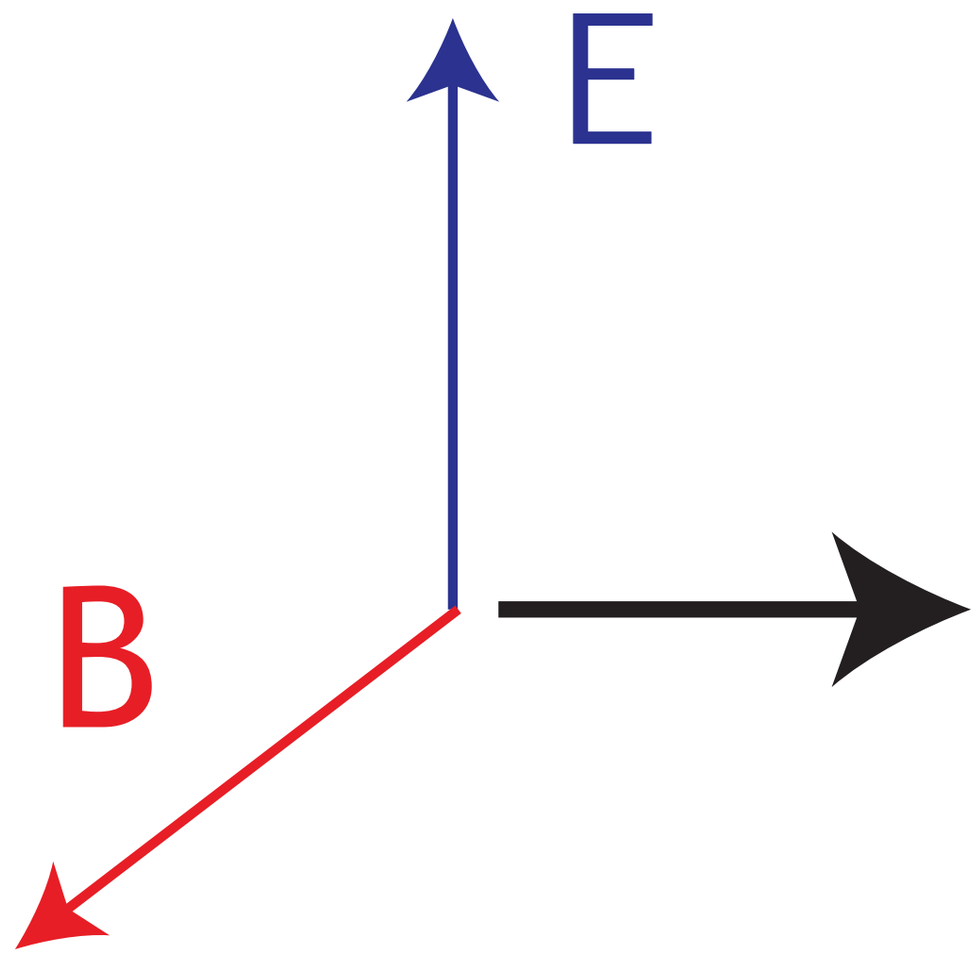
EW: W→lν, Z→ll, l=e,μ

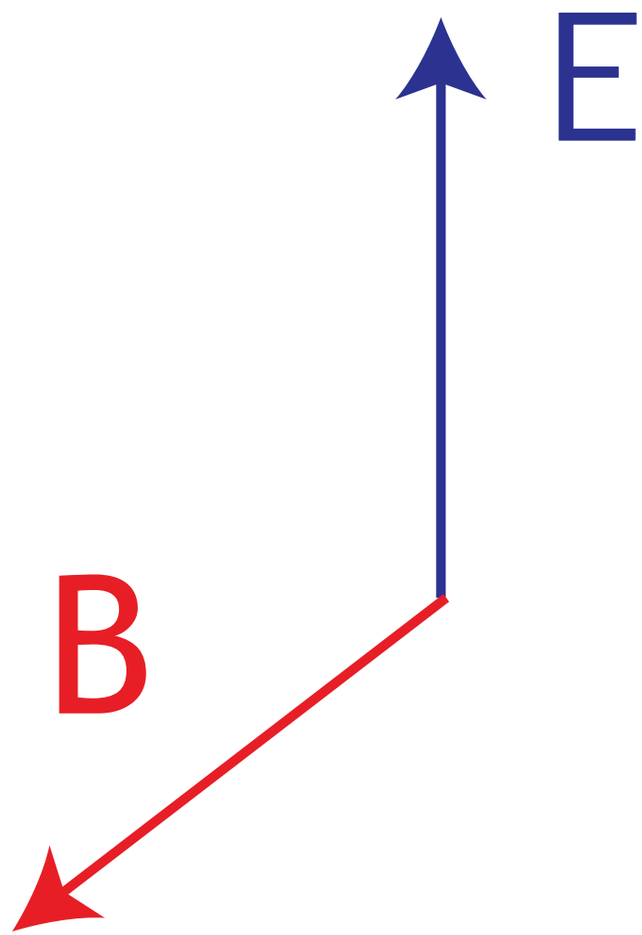


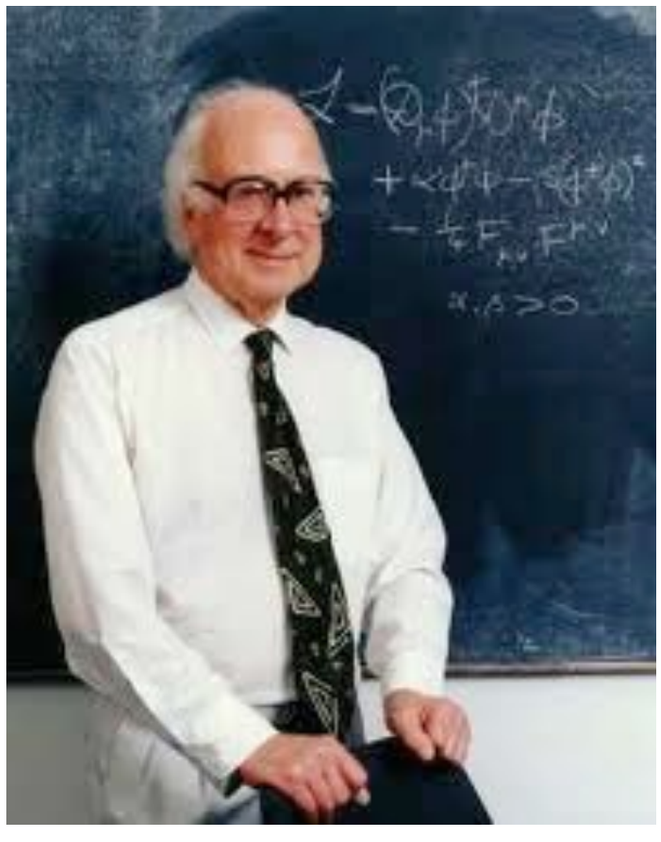
Steven Weinberg (courtesy U T News)

“We certainly do not have a final theory yet, and we are not likely to discover it soon. But from time to time we catch hints that it is not so far off. Sometimes in discussions among physicists, when it turns out that mathematically beautiful ideas are actually relevant to the real world, we get the feeling that there is something behind the blackboard, some deeper truth foreshadowing a final theory, that makes our ideas turn out so well.”

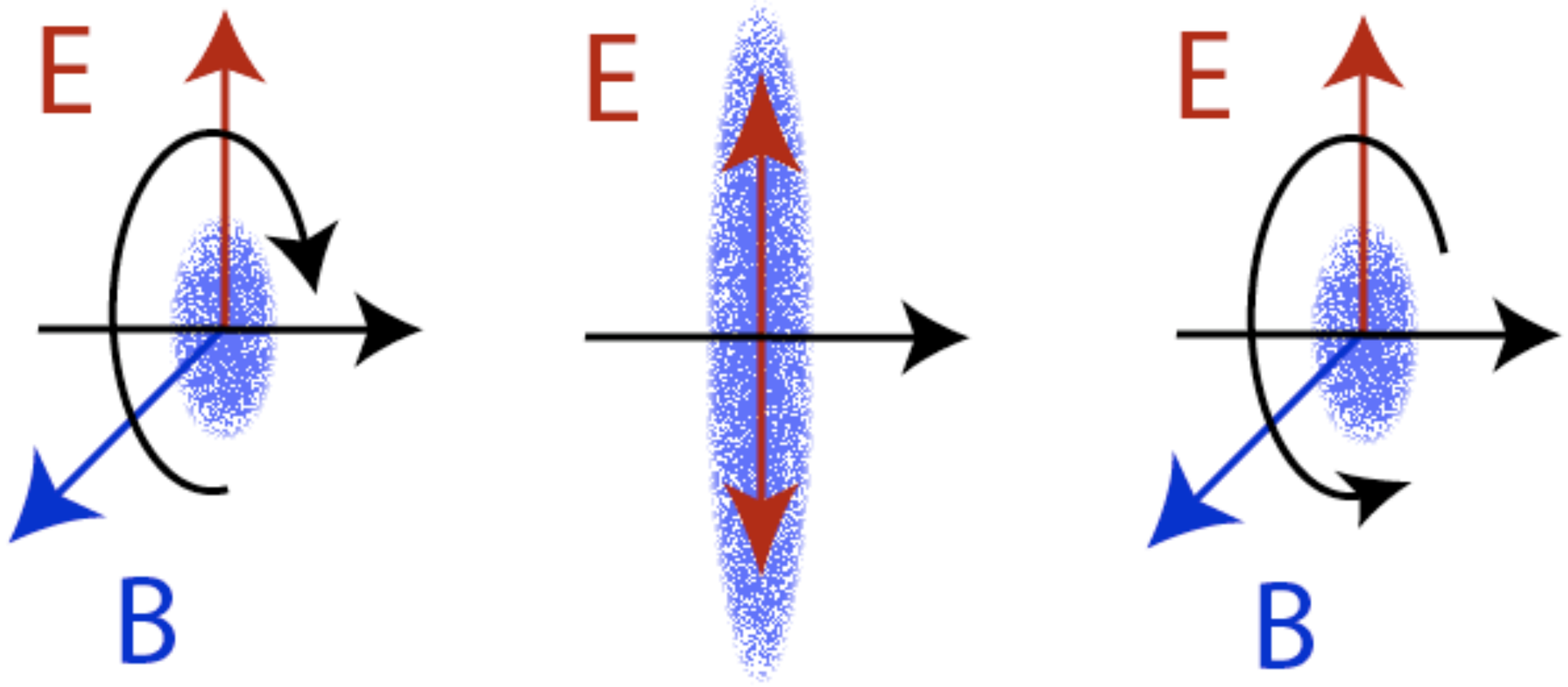
— S. Weinberg “Dreams of a Final Theory” 1993

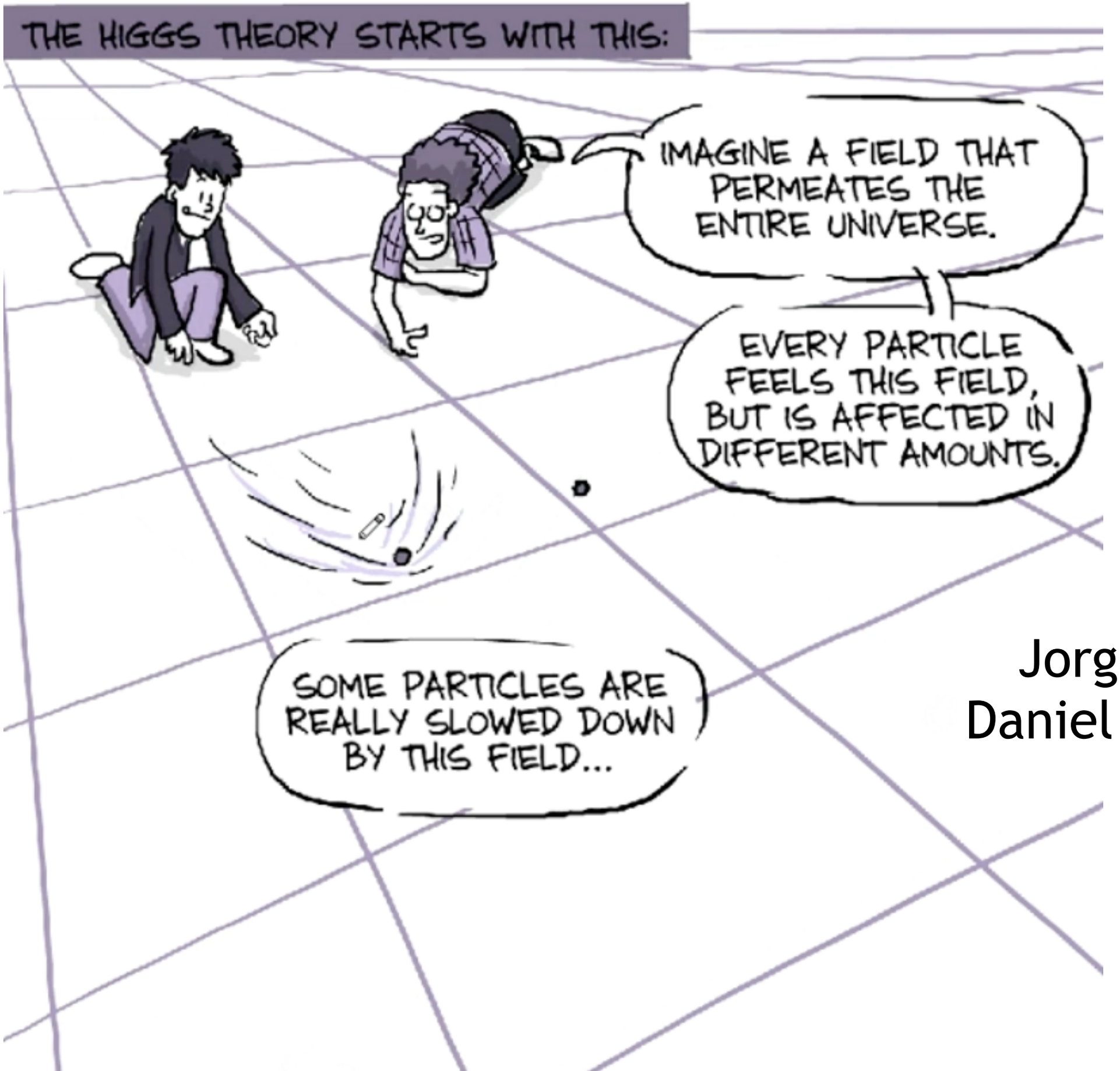

E
B


E
B



Yoichiro Nambu, Peter Higgs,
Tom Kibble, Gerald Guralnik,
Carl Hagen, Francois Englert,
Robert Brout

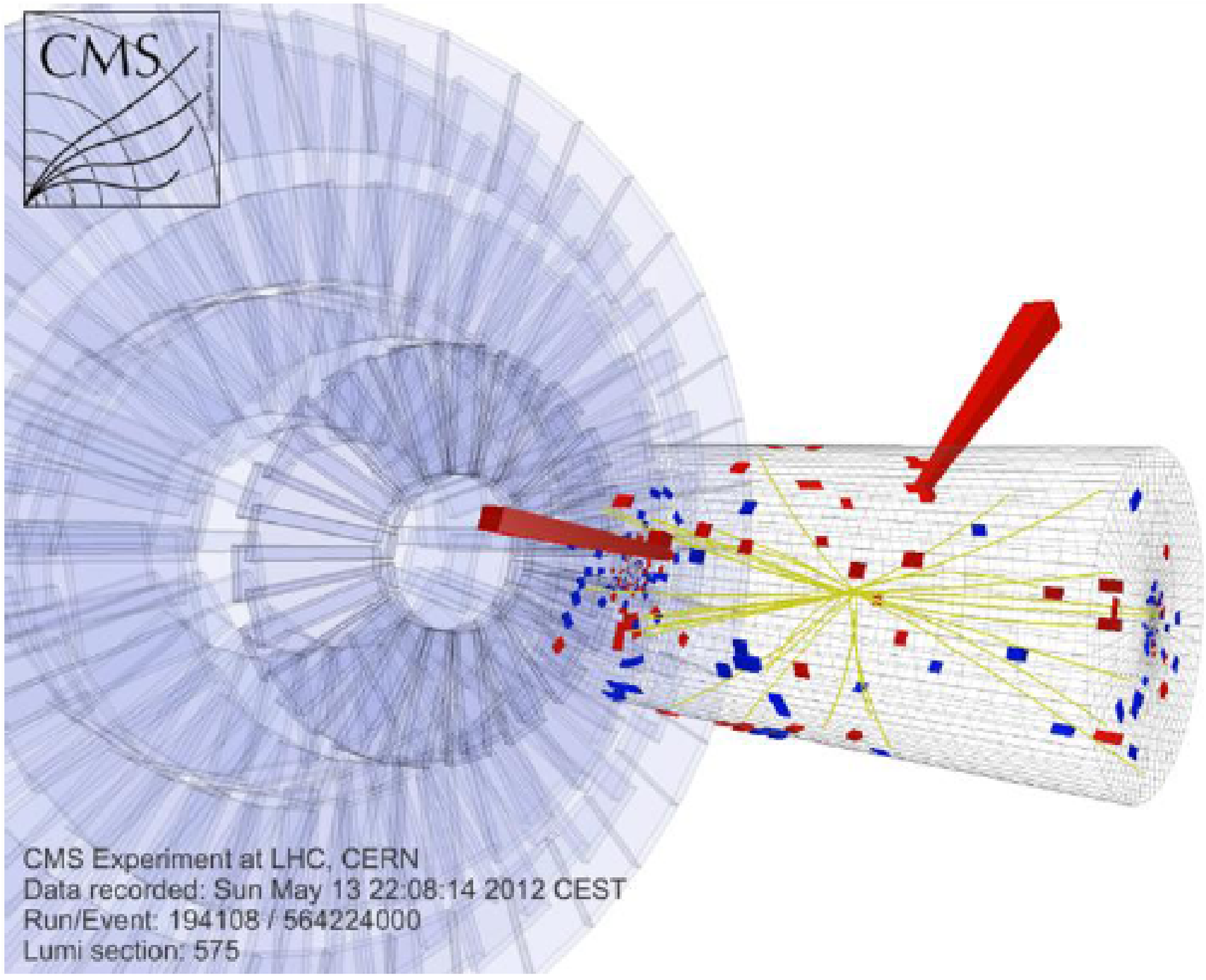

E
B
E
E
B

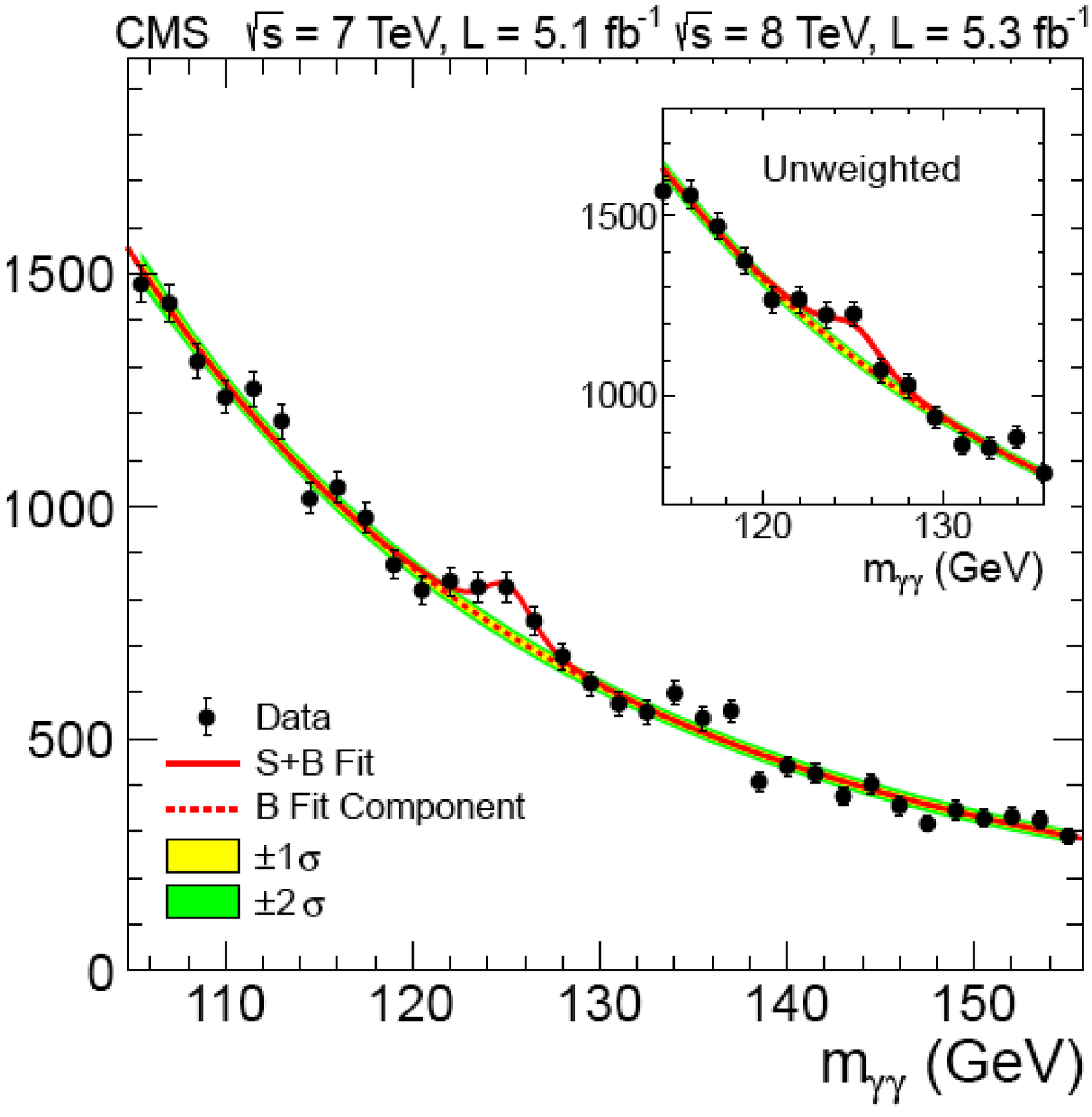


Jorge Cham
Daniel Whiteson

CMS candidate

$$h^0 \to \gamma\gamma$$

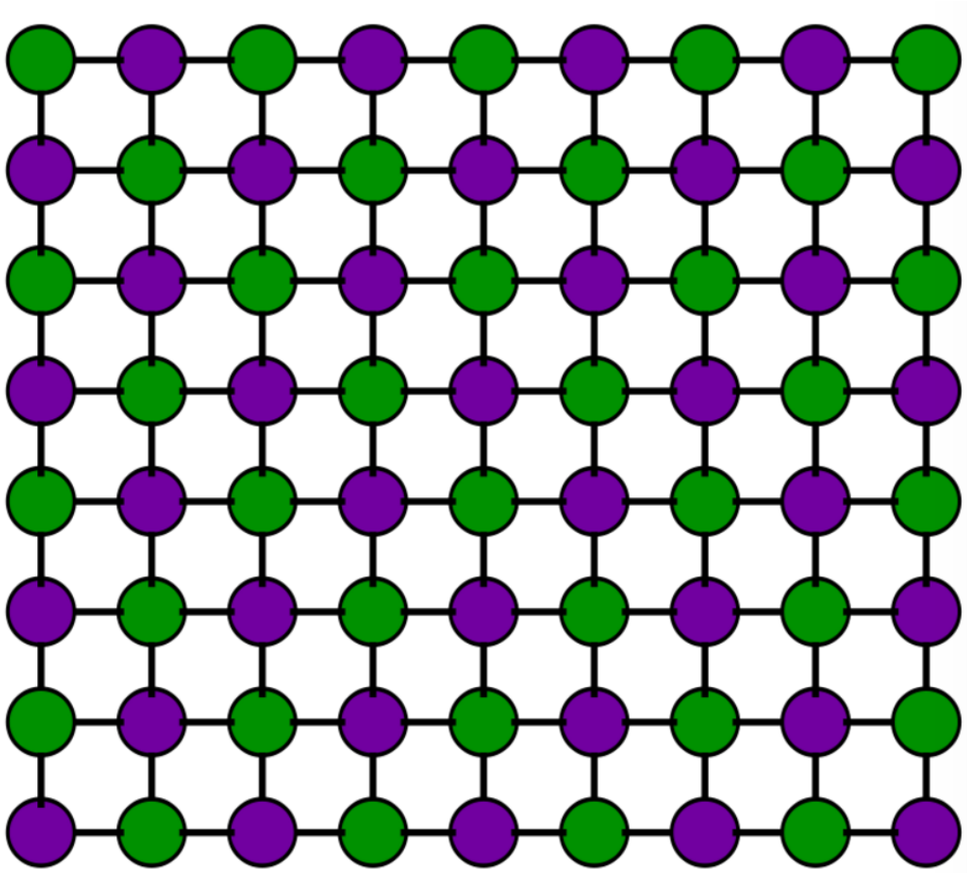


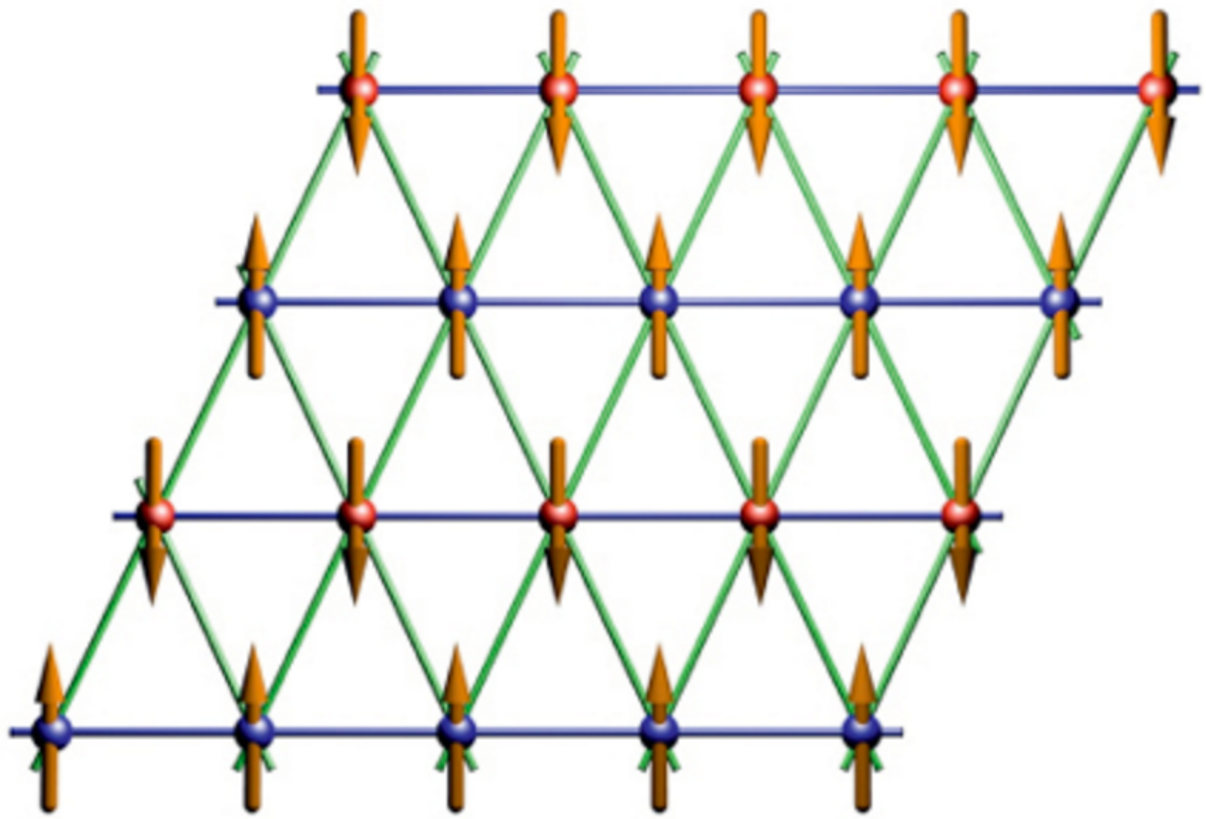

CMS √s = 7 TeV, L = 5.1 fb-1 √s = 8 TeV, L = 5.3 fb-1
Unweighted
1500
1000
120
130
mγγ (GeV)
1500
1000
500
0
Data
S+B Fit
B Fit Component
±1σ
±2σ
110
120
130
140
150
mγγ (GeV)

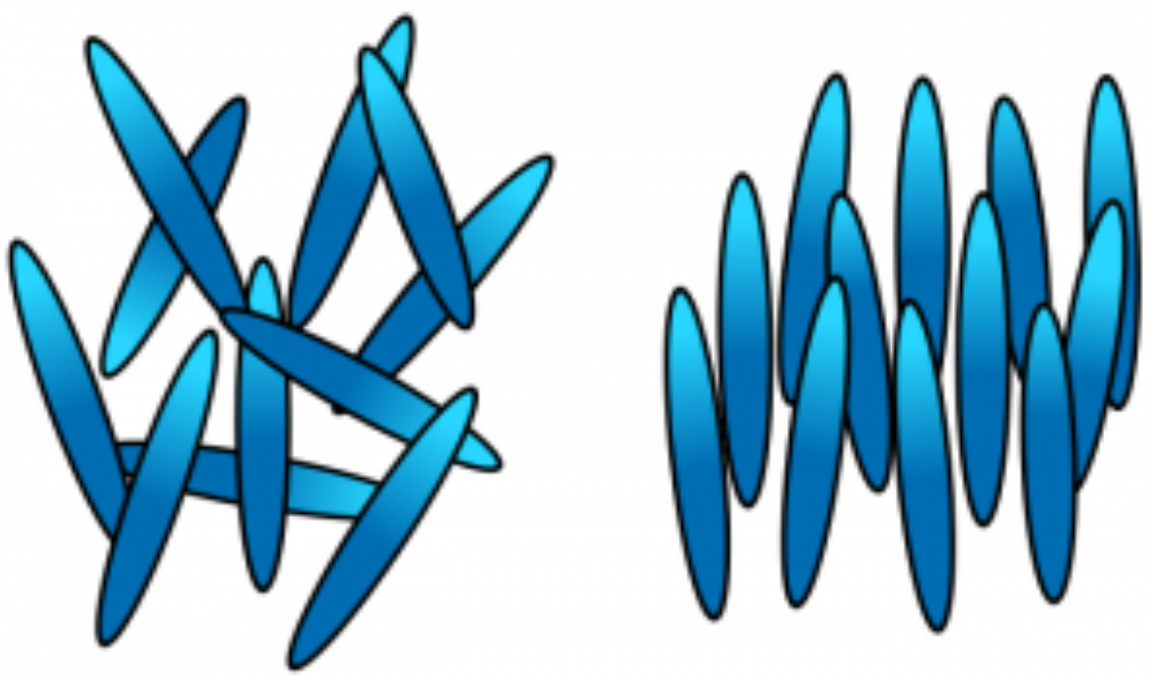
The Higgs field must exist.

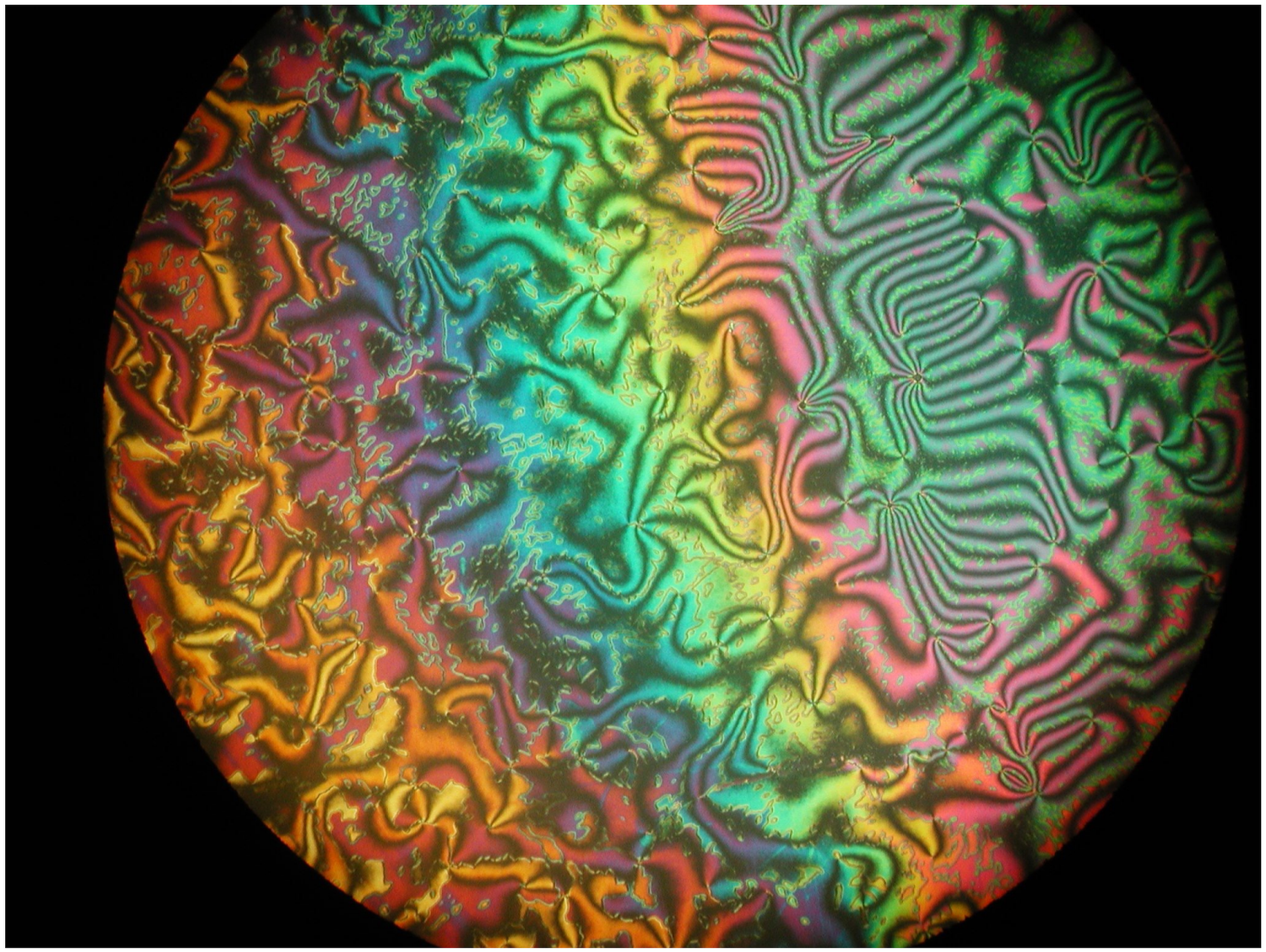
But, what is it ?

Why does it fill space ?

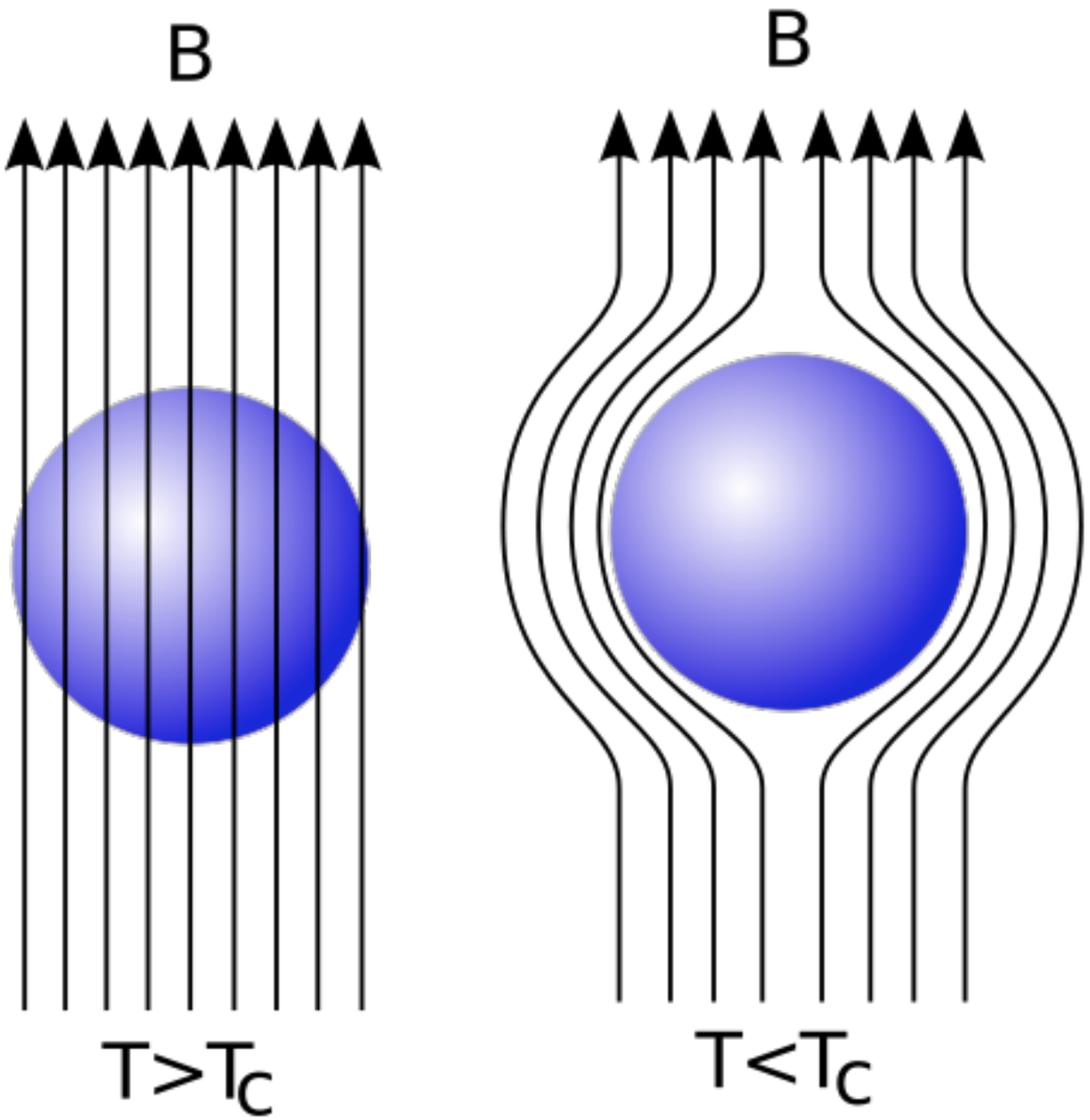


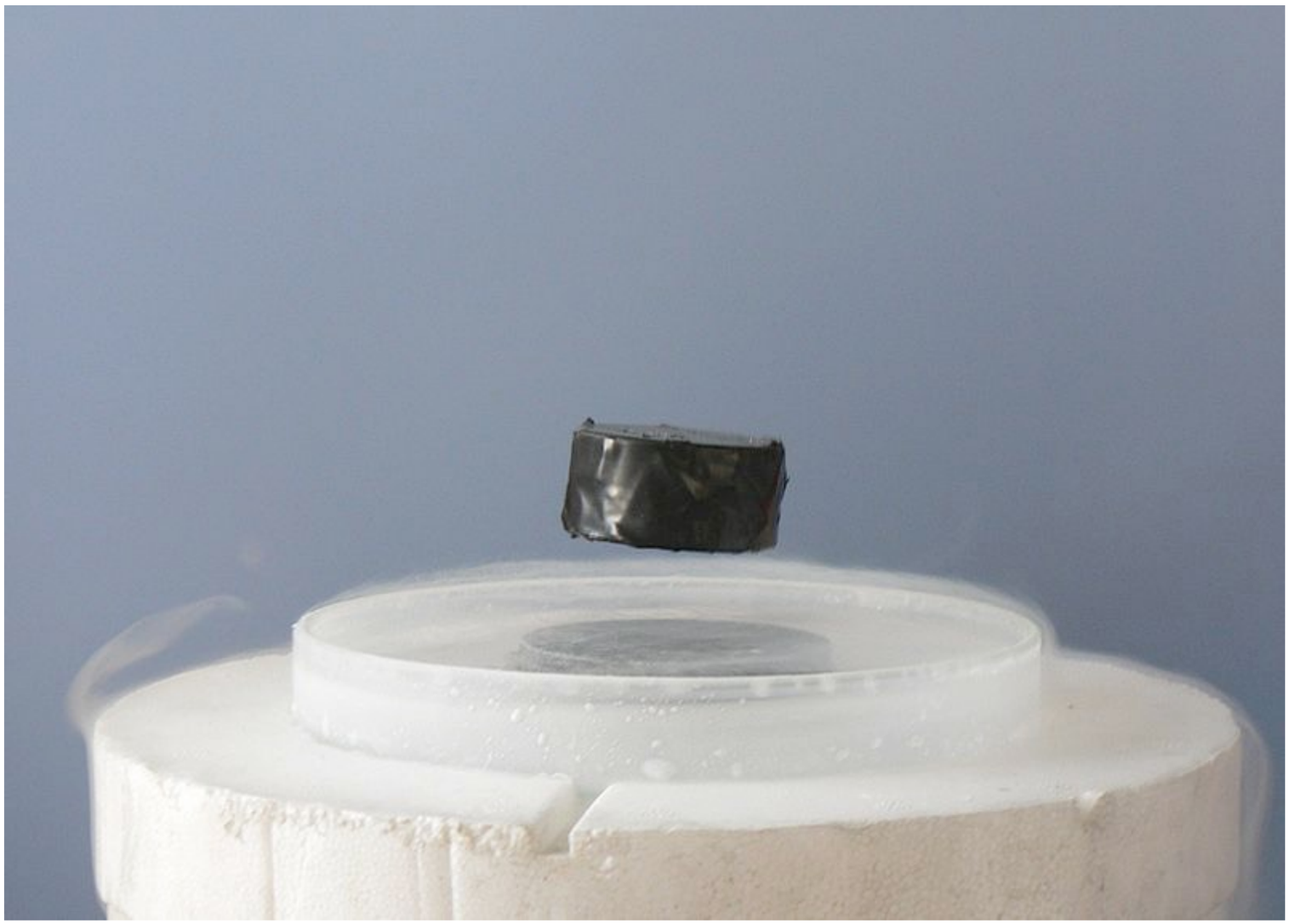






Charles Rosenblatt
Case Western


B
B
T>T_C
T<T_C



KNOWN SUPERCONDUCTIVE ELEMENTS

- BLUE = AT AMBIENT PRESSURE
- GREEN = ONLY UNDER HIGH PRESSURE

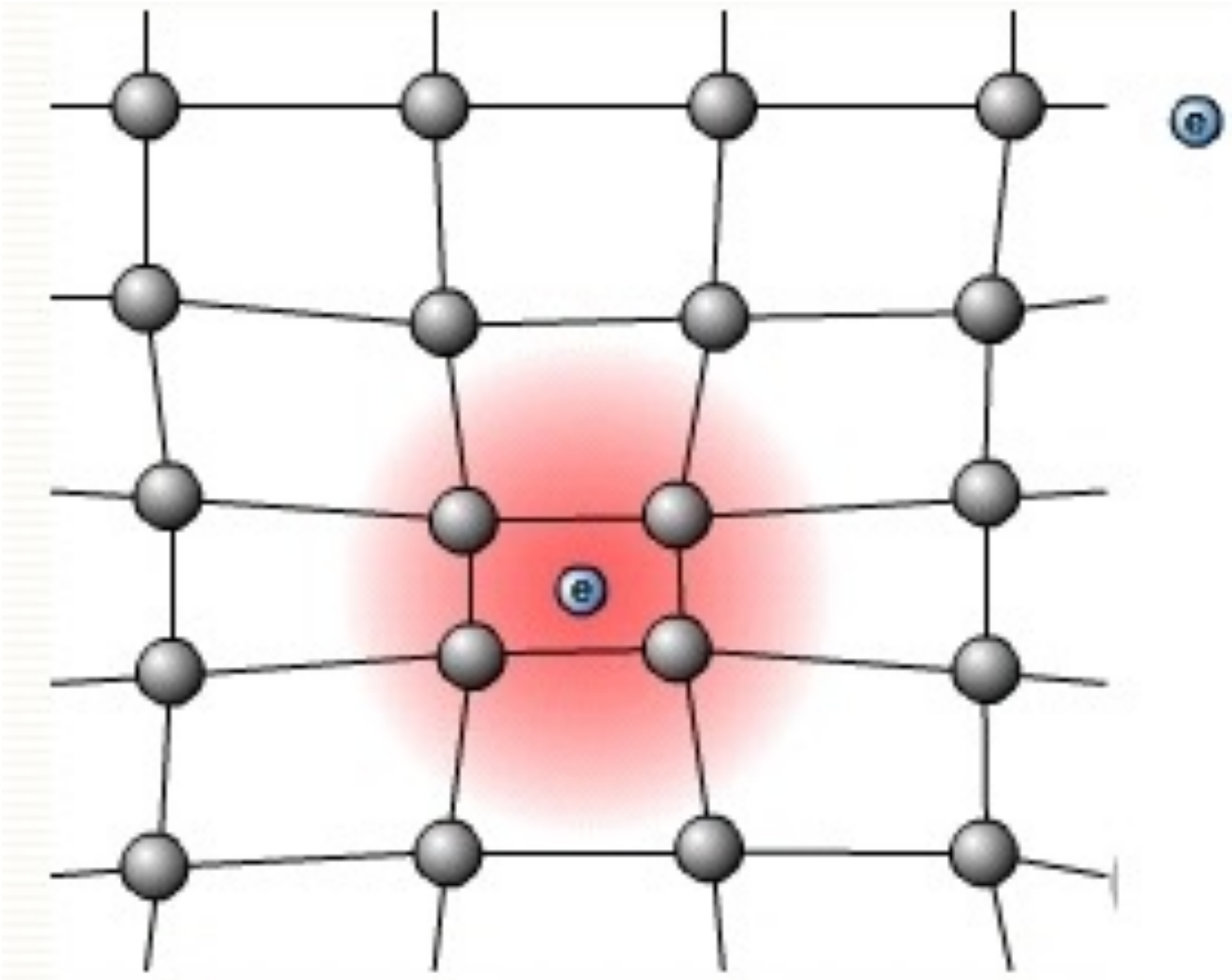
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	—— VII ——	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H															2 He
2	3 Li	4 Be									5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg									13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 106	107 107	108 108	109 109	110 110	111 111	112 112						

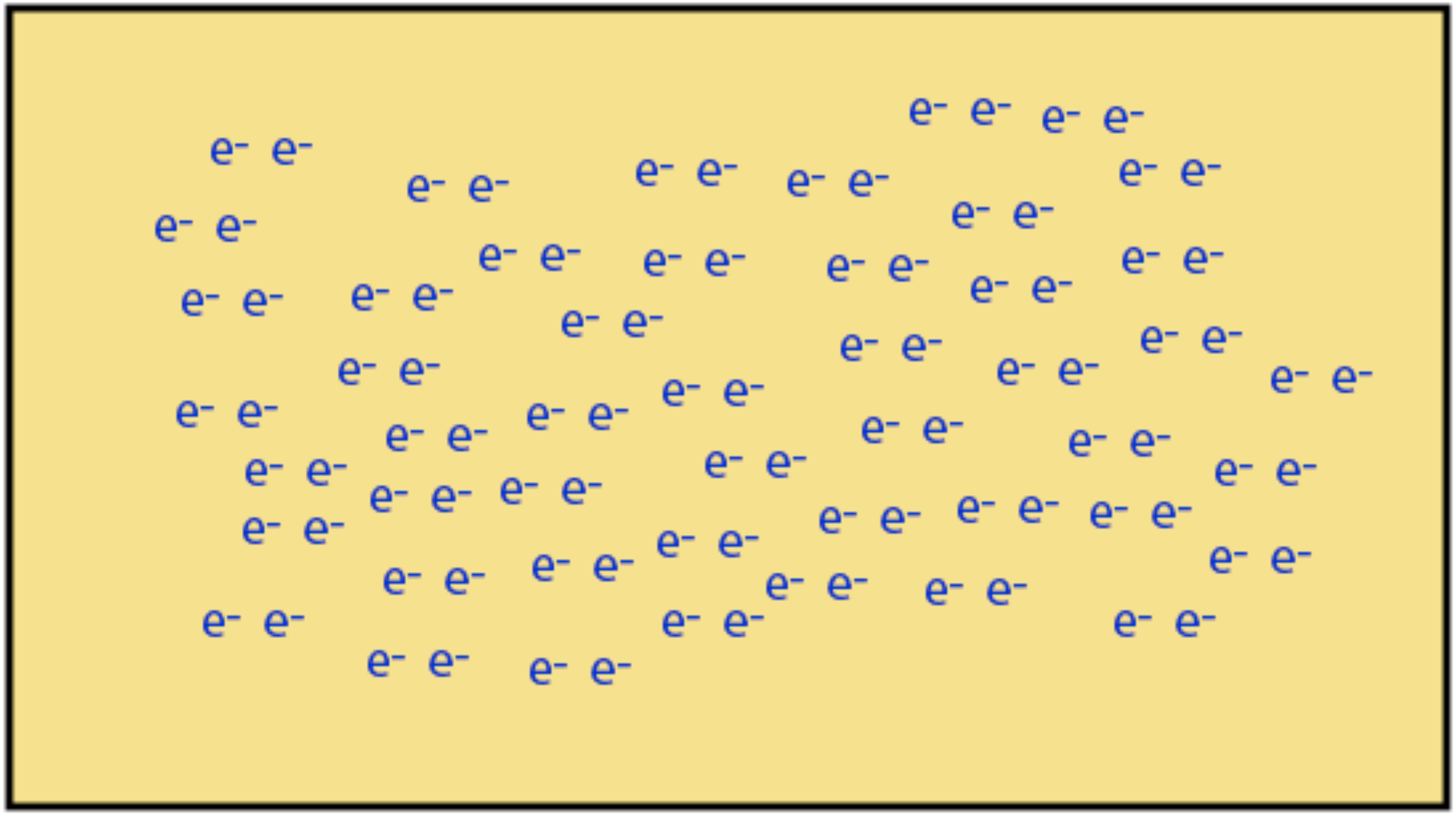
SUPERCONDUCTORS.ORG

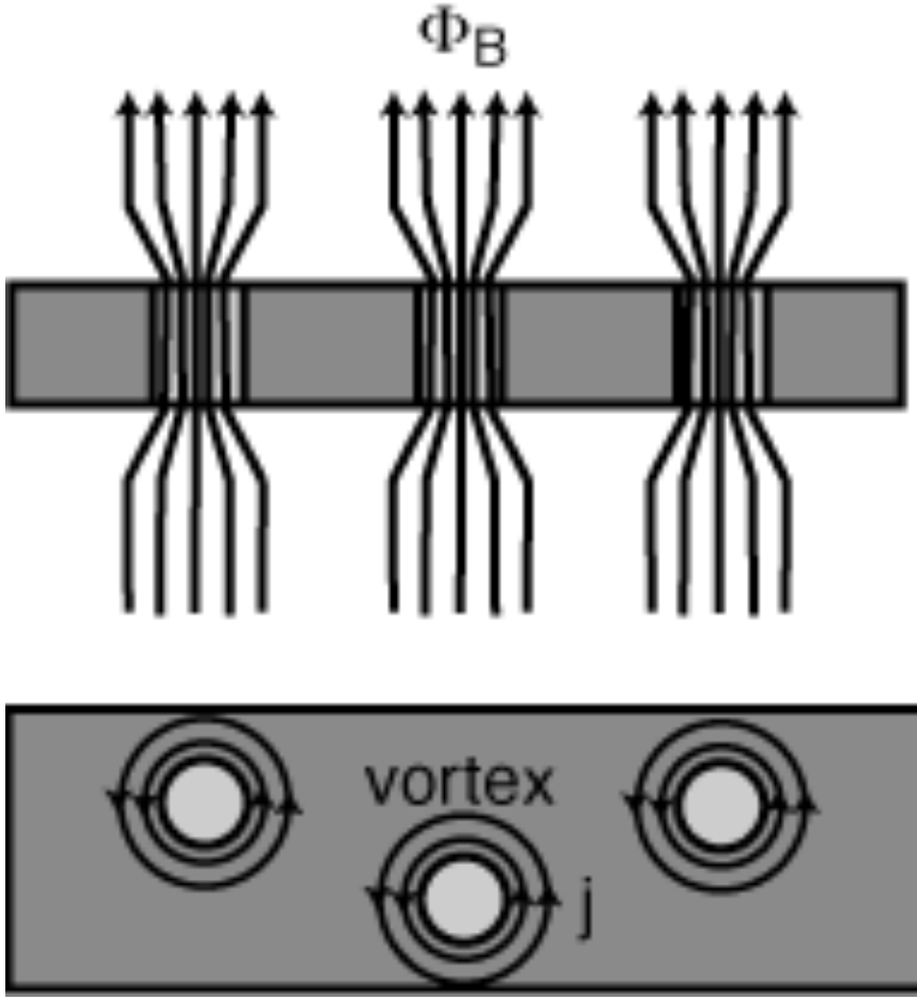
* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

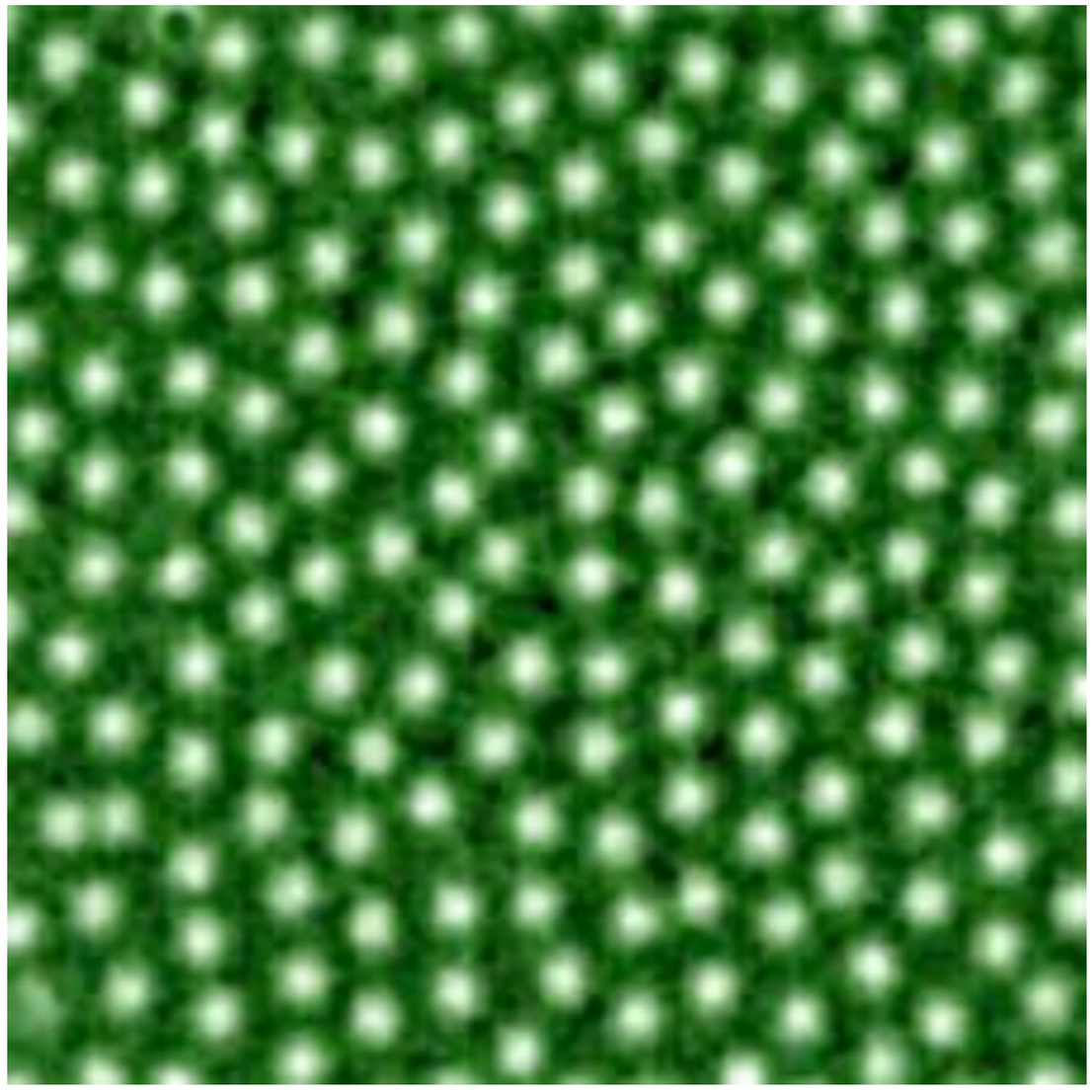
Leon Cooper

w. John Bardeen and Robert Schrieffer (BCS)


e
e







Philip Hofmann

University of Oslo

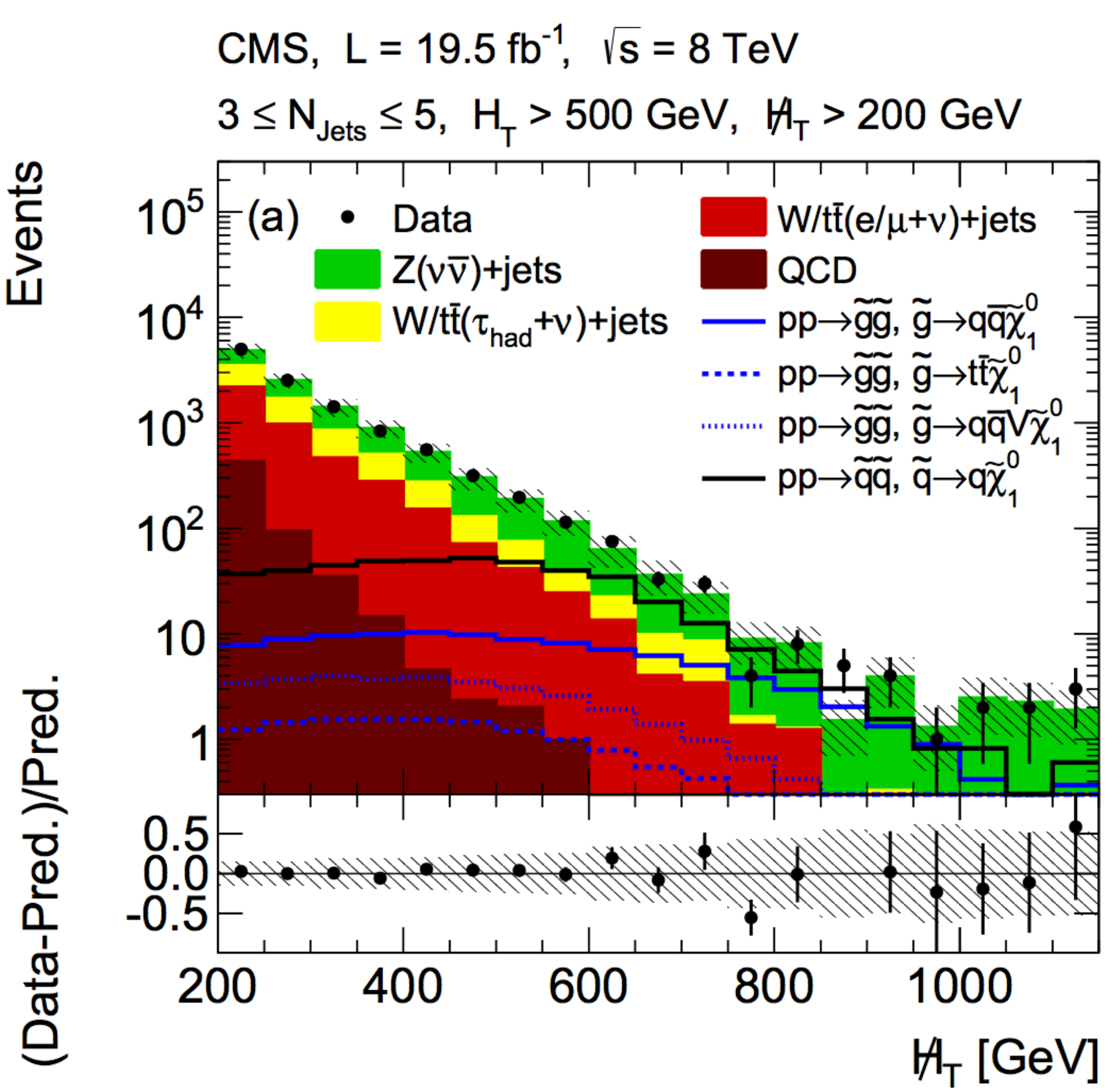
For Higgs,

what are the “electrons” ?

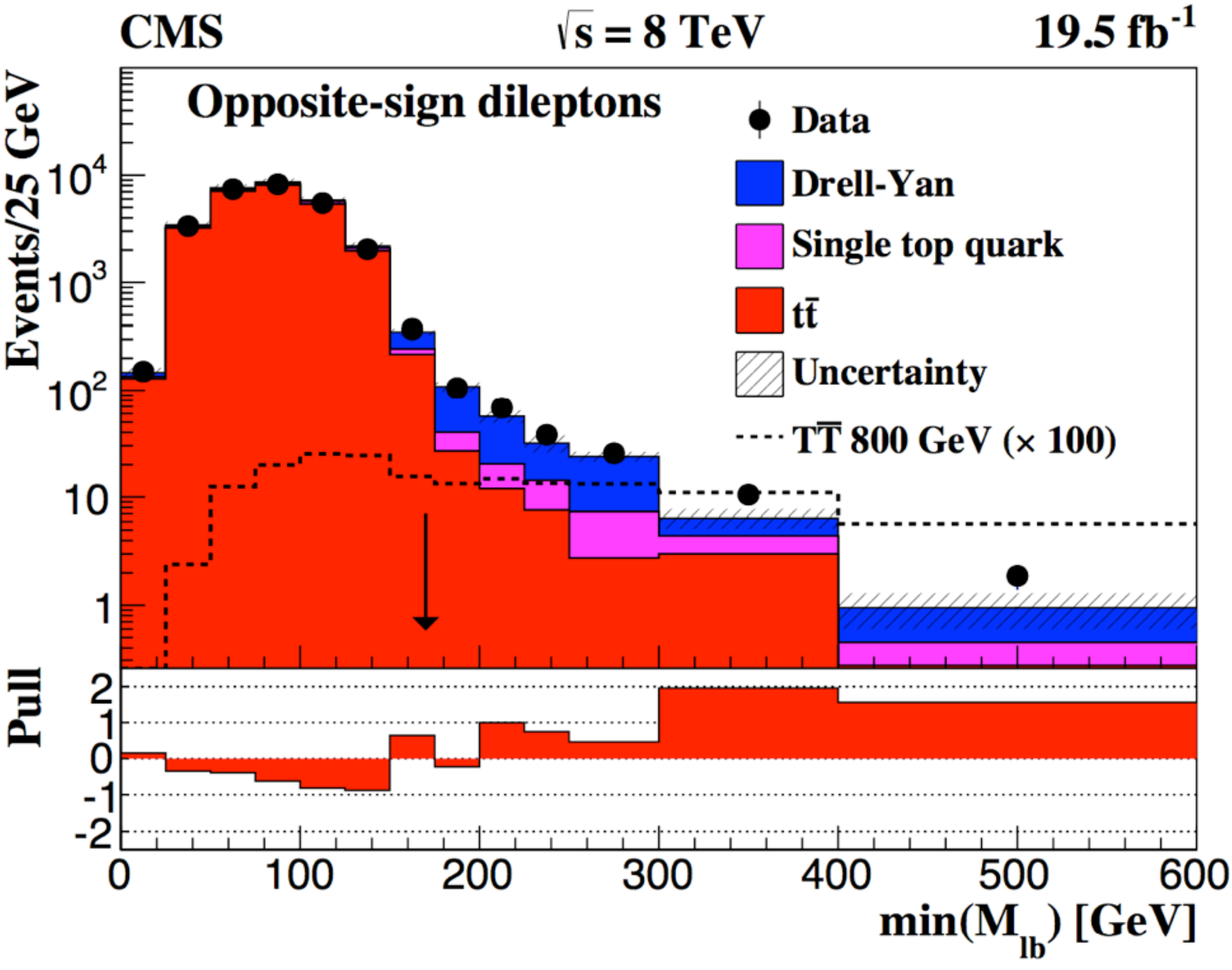
what new force pulls them together ?

what impels them to fill space ?

how are they connected to W, Z, quarks, leptons ?

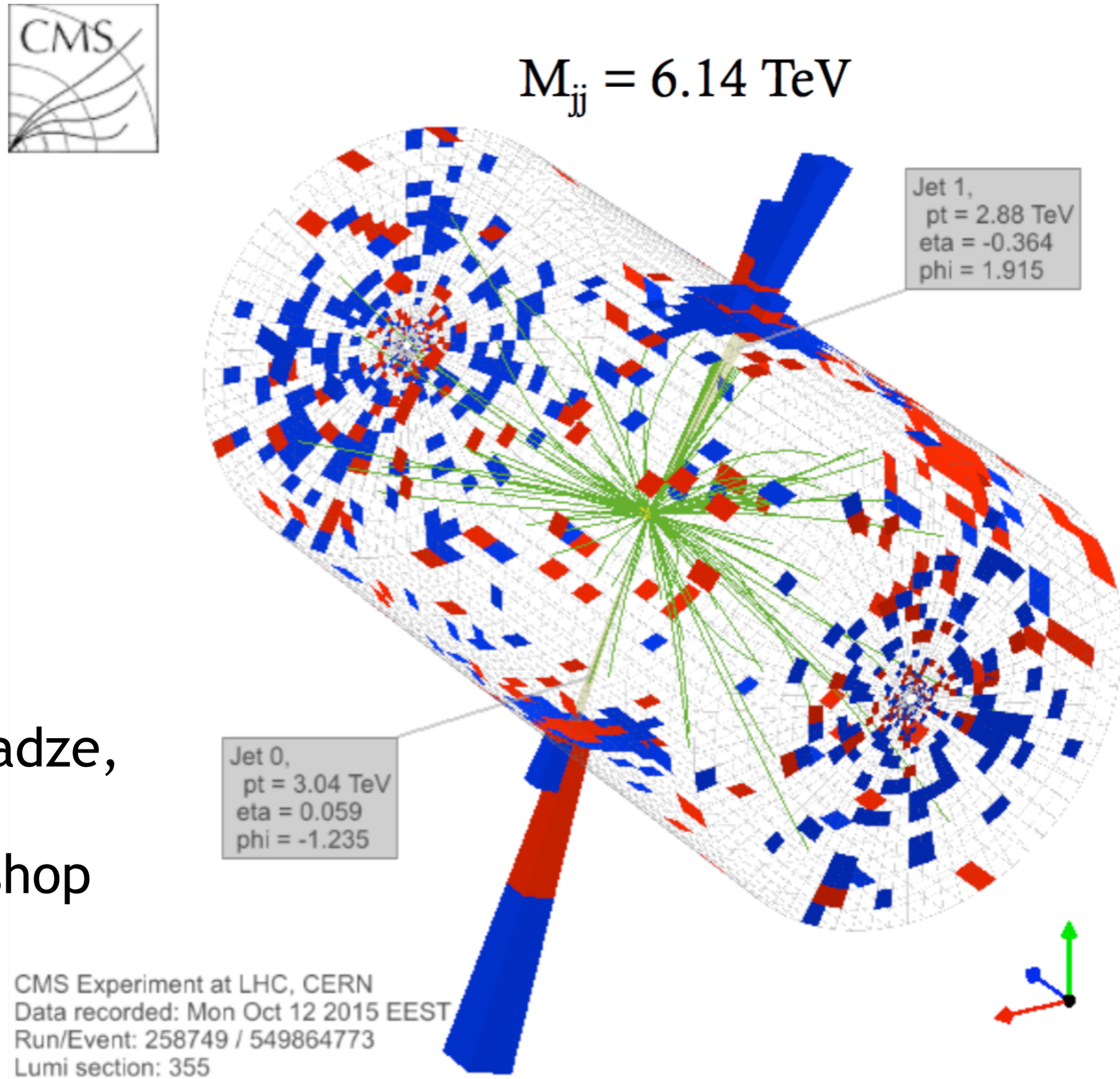

CMS, L = 19.5 fb^{-1}, $\sqrt{s}$ = 8 TeV
$3 \leq N_{Jets} \leq 5$, $H_T > 500$ GeV, $\not{H}_T > 200$ GeV
Events
(a)
Data
Z(νν̄)+jets
W/tt̄(τ$_{had}$+ν)+jets
W/tt̄(e/μ+ν)+jets
QCD
pp→g̃g̃, g̃→qq̄χ̃$^0_1$
pp→g̃g̃, g̃→tt̄χ̃$^0_1$
pp→g̃g̃, g̃→qq̄Vχ̃$^0_1$
pp→q̃q̃, q̃→qχ̃$^0_1$
(Data-Pred.)/Pred.
$\not{H}_T$ [GeV]

search for $T \to W^+ b$



“What really interests me is whether God had any choice in the creation of the world.”

— Albert Einstein, to Ernest Strauss



K. Kaadze, Aspen Workshop

Thank you for your attention.