

Teilchenphysik

Status und Perspektiven

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Gliederung

- Teilchenphysik: Status, Probleme, Strategie
- Laufende und zukünftige (Groß)Projekte
- Einschub: Politik und Finanzierung
- Teilchenphysik: DESYs Strategie und zukünftige Orientierung

(mit viel Material von K. Büsser)

Eine Folie über mich

- Studium der Physik in Hamburg und München
- Diplomarbeit am CERN beim OPAL-Experiment:
“Eine Suche nach Higgs-Bosonen im 4-Jet-Kanal”
- Doktorarbeit am MPI München beim H1-Experiment bei HERA
- CERN Research Fellow (OPAL, ATLAS)
- Wissenschaftlicher Assistent (C1) an der UHH (ZEUS, CMS)
- Habilitation
- Seit 2008 Wissenschaftler bei DESY: CMS, ILC, Wissenschaftsmanagement und -administration

Gliederung

- **Teilchenphysik: Status, Probleme, Strategie**
- Laufende und zukünftige (Groß)Projekte
- Einschub: Politik und Finanzierung
- Teilchenphysik: DESYs Strategie und zukünftige Orientierung

Aus dem PR-Talk gestern

Drei Generationen
der Materie (Fermionen)

	I	II	III	
Masse →	2,3 MeV	1,275 GeV	173,07 GeV	0
Ladung →	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
Spin →	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
Name →	u up	c charm	t top	γ Photon
				H Higgs Boson
	4,8 MeV	95 MeV	4,18 GeV	0
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	d down	s strange	b bottom	g Gluon
	<2 eV	<0,19 MeV	<18,2 MeV	91,2 GeV
	0	0	0	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	ν_e Elektron- Neutrino	ν_μ Myon- Neutrino	ν_τ Tau- Neutrino	Z⁰ Z Boson
	0,511 MeV	105,7 MeV	1,777 GeV	80,4 GeV
	-1	-1	-1	±1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	e Elektron	μ Myon	τ Tau	W[±] W Boson

Eichbosonen

$$\mathcal{L}_{SM} = \mathcal{L}_{Dirac} + \mathcal{L}_{mass} + \mathcal{L}_{gauge} + \mathcal{L}_{gauge/\psi} \quad (1)$$

Here,

$$\mathcal{L}_{Dirac} = i\bar{e}_L^i \partial_\mu e_L^i + i\bar{u}_L^i \partial_\mu u_L^i + i\bar{c}_L^i \partial_\mu c_L^i + i\bar{t}_L^i \partial_\mu t_L^i + i\bar{d}_L^i \partial_\mu d_L^i + i\bar{u}_R^i \partial_\mu u_R^i + i\bar{c}_R^i \partial_\mu c_R^i + i\bar{t}_R^i \partial_\mu t_R^i \quad (2)$$

$$\mathcal{L}_{mass} = -v \left(\lambda_e^i \bar{e}_R^i e_R^i + \lambda_u^i \bar{u}_L^i u_R^i + \lambda_c^i \bar{c}_L^i c_R^i + \text{h.c.} \right) - M_W^2 W_\mu^+ W_\mu^- - \frac{M_H^2}{2 \cos^2 \theta_W} Z_\mu Z^\mu \quad (3)$$

$$\mathcal{L}_{gauge} = -\frac{1}{4} (G_{\mu\nu}^a)^2 - \frac{1}{2} W_{\mu\nu}^+ W^{-\mu\nu} - \frac{1}{4} Z_\mu Z^{\mu\nu} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \mathcal{L}_{WZA} \quad (4)$$

where

$$\begin{aligned} G_{\mu\nu}^a &= \partial_\mu A_\nu^a - \partial_\nu A_\mu^a - g_s f^{abc} A_\mu^b A_\nu^c \\ W_{\mu\nu}^\pm &= \partial_\mu W_\nu^\pm - \partial_\nu W_\mu^\pm \\ Z_{\mu\nu} &= \partial_\mu Z_\nu - \partial_\nu Z_\mu \\ F_{\mu\nu} &= \partial_\mu A_\nu - \partial_\nu A_\mu \end{aligned} \quad (5)$$

and

$$\begin{aligned} \mathcal{L}_{WZA} = & ig_2 \cos \theta_W \left[(W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) \partial^\mu Z^\nu + W_\mu^+ W_\nu^- Z^{\mu\nu} - W_\mu^- W_\nu^+ Z^{\mu\nu} \right] \\ & + ie \left[(W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) \partial^\mu A^\nu + W_\mu^+ W_\nu^- A^{\mu\nu} - W_\mu^- W_\nu^+ A^{\mu\nu} \right] \\ & + g_2^2 \cos^2 \theta_W (W_\mu^+ W_\nu^- Z^{\mu\nu} - W_\mu^- W_\nu^+ Z^{\mu\nu}) \\ & + g_2^2 (W_\mu^+ W_\nu^- A^{\mu\nu} - W_\mu^- W_\nu^+ A^{\mu\nu}) \\ & + g_2 e \cos \theta_W [W_\mu^+ W_\nu^- (Z^\mu A^\nu - Z^\nu A^\mu) - 2W_\mu^+ W_\nu^- Z_\mu A^\nu] \\ & + \frac{1}{2} g_2^2 (W_\mu^+ W_\nu^-) (W^{+\mu} W^{-\nu} - W^{+\nu} W^{-\mu}) \quad (6) \end{aligned}$$

and

$$\mathcal{L}_{gauge/\psi} = -g_s A_\mu^a J_{(3)}^{\mu a} - g_2 (W_\mu^+ J_{W^+}^\mu + W_\mu^- J_{W^-}^\mu + Z_\mu J_Z^\mu) - e A_\mu J_A^\mu \quad (7)$$

where

$$\begin{aligned} J_{(3)}^{\mu a} &= \bar{u}^i \gamma^\mu T_{(3)}^a u^i + \bar{d}^i \gamma^\mu T_{(3)}^a d^i \\ J_{W^+}^\mu &= \frac{1}{\sqrt{2}} (\bar{u}_L^i \gamma^\mu e_L^i + \bar{u}_L^i \gamma^\mu d_L^i) \\ J_{W^-}^\mu &= (J_{W^+}^\mu)^\dagger \\ J_Z^\mu &= \frac{1}{\cos \theta_W} \left[\frac{1}{2} \bar{u}_L^i \gamma^\mu u_L^i + \left(-\frac{1}{2} + \sin^2 \theta_W \right) \bar{e}_L^i \gamma^\mu e_L^i + (\sin^2 \theta_W) \bar{e}_R^i \gamma^\mu e_R^i \right. \\ & \quad \left. + \left(\frac{1}{2} - \frac{2}{3} \sin^2 \theta_W \right) \bar{u}_L^i \gamma^\mu u_L^i + \left(-\frac{2}{3} \sin^2 \theta_W \right) \bar{u}_R^i \gamma^\mu u_R^i \right. \\ & \quad \left. + \left(-\frac{1}{2} + \frac{1}{3} \sin^2 \theta_W \right) \bar{d}_L^i \gamma^\mu d_L^i + \left(\frac{1}{3} \sin^2 \theta_W \right) \bar{d}_R^i \gamma^\mu d_R^i \right] \\ J_A^\mu &= (-\frac{1}{2}) \bar{e}^i \gamma^\mu e^i + \left(\frac{2}{3} \right) \bar{u}^i \gamma^\mu u^i + \left(-\frac{1}{3} \right) \bar{d}^i \gamma^\mu d^i \quad (8) \end{aligned}$$

$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036
$m_Z [GeV]$	91.1875 ± 0.00021
$\Gamma_Z [GeV]$	2.4952 ± 0.00023
$\sigma_{had}^0 [nb]$	41.540 ± 0.037
R_t	20.767 ± 0.025
$A_{fb}^{0,l}$	0.01714 ± 0.00095
$A_l(P_\tau)$	0.1465 ± 0.0033
R_b	0.21646 ± 0.00065
R_c	0.1719 ± 0.0031
$A_{fb}^{0,b}$	0.0990 ± 0.0017
$A_{fb}^{0,c}$	0.0685 ± 0.0034
A_b	0.922 ± 0.020
A_c	0.670 ± 0.026
$A_l(SLD)$	0.1513 ± 0.0021
$\sin^2 \theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012
$m_W [GeV]$	80.450 ± 0.039
$m_t [GeV]$	174.3 ± 5.1
$\sin^2 \theta_W(\nu N)$	0.2255 ± 0.0021
$Q_W(Cs)$	-72.50 ± 0.70

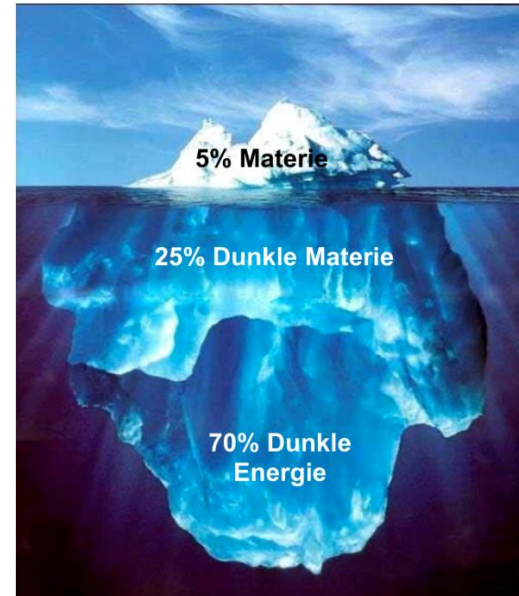
Standardmodell?



Aus dem PR-Talk gestern

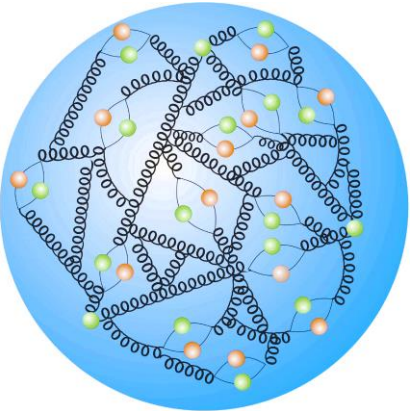
Offene Fragen ...

- ▶ Was sind der Ursprung und die Entwicklung des Universums?
 - Was geschah beim Urknall?
 - Warum besteht das Universum aus mehr Materie als Antimaterie?
- ▶ Was ist dunkle Materie?
 - Ein neues Elementarteilchen? Mehrere?
- ▶ Gibt es Supersymmetrie?
- ▶ Ist das Universum flach?
- ▶ Was geschieht in schwarzen Löchern?
- ▶ ...

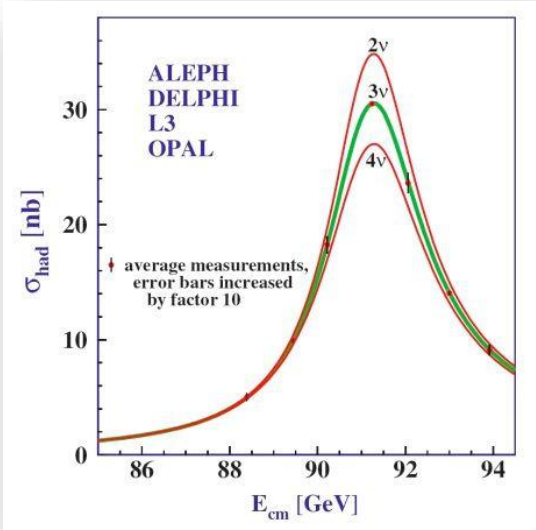


In anderen Worten

Elektron
Ladung: -1e



Proton
Ladung: +1e
Quarks mit Ladungen +2/3, -1/3

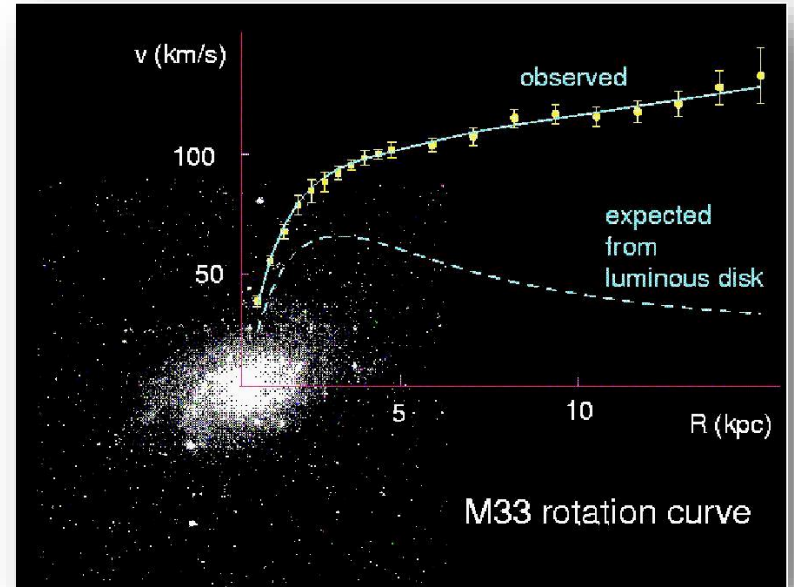
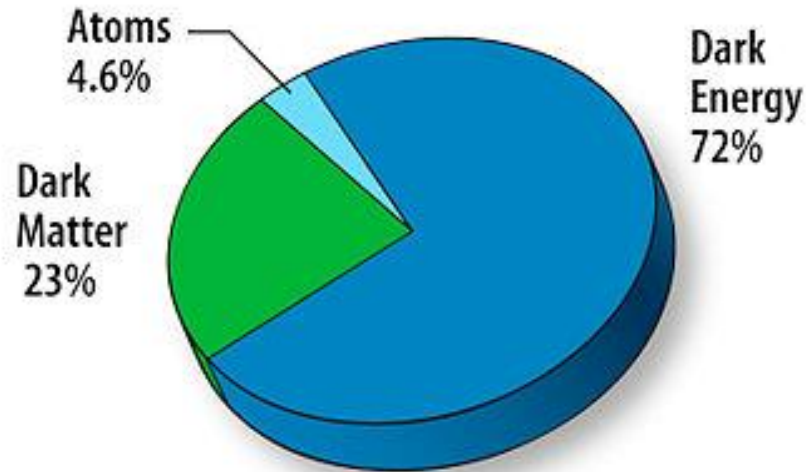


Noch dazu: ca. 30 freie Parameter?

$$\begin{aligned}
 & -\frac{1}{2}\partial_\mu g_\mu^a \partial_\nu g_\nu^a - f^{abc} g_\mu^a g_\nu^b g_\mu^c - \frac{1}{4} f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \frac{1}{2} i (\bar{q}^i \gamma^\mu q^j) g_\mu^a + \\
 & G^a \partial^\mu G^a + g_a f^{abc} \partial_\mu G^a C^b C^c - \partial_\mu W_\mu^+ \partial_\nu W_\nu^- - M^2 W_\mu^+ W_\mu^- - \frac{1}{2} \partial_\mu Z_\mu^0 \partial_\nu Z_\nu^0 - \frac{1}{2} M^2 Z_\mu^0 Z_\mu^0 - \\
 & \frac{1}{2} \partial_\mu A_\mu \partial_\nu A_\nu - \frac{1}{2} \partial_\mu H \partial_\nu H - \frac{1}{2} (H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2} \partial_\mu \phi^0 \partial_\mu \phi^0 \\
 & + \frac{1}{2} M \phi^0 \phi^0 - \beta_h [\frac{2}{3} M^2 + \frac{2}{3} H + \frac{1}{2} (H^2 + \phi^0 + \phi^0 + 2\phi^+ \phi^-)] + 2M^2 \phi^+ \phi^- - ig \partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- \\
 & - W_\nu^- W_\mu^+) - Z_\mu^0 (W_\mu^+ \partial_\nu W_\nu^- - W_\nu^- \partial_\mu W_\mu^+) + Z_\mu^0 (\partial_\nu W_\mu^+ - W_\mu^+ \partial_\nu) - i \partial_\mu (A_\mu (W_\mu^+ W_\nu^- \\
 & - W_\nu^- W_\mu^+) - A_\nu (W_\mu^+ \partial_\nu W_\nu^- - W_\nu^- \partial_\mu W_\mu^+) + A_\mu (W_\mu^+ \partial_\nu W_\nu^- - W_\nu^- \partial_\mu W_\mu^+) - \frac{1}{2} W_\mu^+ W_\nu^+ W_\mu^+ W_\nu^- \\
 & + \frac{1}{2} W_\mu^- W_\nu^- W_\mu^- W_\nu^- + g^2 (Z_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + g^2 (A_\mu W_\mu^+ A_\nu W_\nu^- \\
 & - A_\nu A_\mu W_\mu^+ W_\nu^-) + g^2 (A_\mu Z_\mu^0 (W_\mu^+ W_\nu^- - W_\nu^- W_\mu^+) - 2A_\mu Z_\mu^0 W_\mu^+ W_\nu^-) + [H^2 + \\
 & H \phi^0 \phi^0 + 2H \phi^+ \phi^-] - \frac{1}{2} A_\mu [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- \\
 & + 2(\phi^0)^2 H^2] + \frac{1}{2} M W_\mu^+ W_\nu^- H - \frac{1}{2} g \partial_\mu Z_\nu^0 (W_\mu^+ \phi^0 \partial_\nu \phi^- - \phi^- \partial_\nu \phi^0) - W_\mu^+ (\phi^0 \partial_\nu \phi^+ - \\
 & \phi^+ \partial_\nu \phi^0) + \frac{1}{2} W_\mu^- (H \partial_\nu \phi^- - \phi^- \partial_\nu H) - W_\mu^- (H \partial_\nu \phi^+ - \phi^+ \partial_\nu H) + \frac{1}{2} Z_\mu^0 (H \partial_\nu \phi^0 - \\
 & \phi^0 \partial_\nu H) - i M Z_\mu^0 (W_\mu^+ \phi^- - W_\nu^- \phi^+) + i M A_\mu (W_\mu^+ \phi^- - W_\nu^- \phi^+) - i \partial_\mu Z_\nu^0 (\phi^+ \partial_\nu \phi^- - \\
 & \phi^- \partial_\nu \phi^+) + ig \partial_\mu (A_\mu (\phi^+ \partial_\nu \phi^- - \phi^- \partial_\nu \phi^+) - \frac{1}{2} W_\mu^+ W_\nu^+ [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] - \\
 & \frac{1}{2} Z_\mu^0 Z_\nu^0 [H^2 + (\phi^0)^2 + 2(2\phi^+ \phi^-)^2 - 1]^2 \phi^+ \phi^- - \frac{1}{2} Z_\mu^0 Z_\nu^0 \phi^0 (W_\mu^+ \phi^- + W_\nu^- \phi^+) - \\
 & \frac{1}{2} Z_\mu^0 Z_\nu^0 H (W_\mu^+ \phi^- + W_\nu^- \phi^+) + \frac{1}{2} g^2 A_\mu (W_\mu^+ \phi^- + W_\nu^- \phi^+) + \frac{1}{2} i g^2 A_\mu H (W_\mu^+ \phi^- - \\
 & W_\nu^- \phi^+) - g^2 s_w^2 (2s_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - g^2 s_w^2 A_\mu A_\nu \phi^+ \phi^- - e^2 (\gamma \partial + m_e^2) e^- \\
 & - \bar{\nu} \gamma \partial \nu^+ - \bar{u}^2 (\gamma \partial + m_u^2) u^2 - d_2^2 (\gamma \partial + m_d^2) d_2^2 + i g_s u_\mu A_\mu [-(e^2 \gamma^0 u^2) - \frac{2}{3} (\bar{u}^2 \gamma^\mu u^2) - \\
 & \frac{1}{3} (e^- m_e^2)] + \frac{2}{3} Z_\mu^0 [(\bar{\nu}^2 \gamma^\mu (1 + \gamma^5) \nu^2) + (e^2 \gamma^\mu (4s_w^2 - 1 - \gamma^5) u^2) + \frac{2}{3} \gamma^\mu (\frac{4}{3} s_w^2 - \\
 & 1 - \gamma^5) u^2) + (d_2^2 \gamma^\mu (1 - \frac{8}{3} s_w^2 - \gamma^5) d_2^2)] + \frac{ig}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^2 \gamma^\mu (1 + \gamma^5) \nu^2) + (\bar{u}^2 \gamma^\mu (1 + \\
 & \gamma^5) u^2)] + \frac{ig}{2\sqrt{2}} W_\mu^- [(e^2 \gamma^\mu (1 + \gamma^5) \nu^2) + (d_2^2 \gamma^\mu (1 + \gamma^5) u^2)] + \frac{ig}{2\sqrt{2}} \frac{m_e^2}{M} [-\phi^- (\bar{\nu}^2 (1 - \\
 & \gamma^5) e^2) + \phi^- (e^2 (1 + \gamma^5) \nu^2) + \frac{g}{2} \frac{m_e^2}{M} H (e^2 e^2) + i \theta^2 (e^2 \gamma^5 e^2)] + \frac{ig}{2M\sqrt{2}} \phi^+ [-m_e^2 \frac{1}{2} C_{\lambda\kappa} (1 - \\
 & \gamma^5) d_f^2] + m_e^2 (i \lambda C_{\lambda\kappa} (1 + \gamma^5) d_f^2) + \frac{ig}{2M\sqrt{2}} \phi^- [m_e^2 (\frac{1}{2} C_{\lambda\kappa}^2 (1 + \gamma^5) u_f^2) - m_e^2 (d_f^2) C_{\lambda\kappa}^2 (1 - \\
 & \gamma^5) u_f^2] - \frac{g}{2} \frac{m_e^2}{M} (\bar{u}^2 u^2) - \frac{g}{2} \frac{m_e^2}{M} H (d_2^2 d_2^2) + \frac{ig}{2} \frac{m_e^2}{M} (\bar{u}^2 \gamma^5 u^2) - \frac{ig}{2} \frac{m_e^2}{M} (d_2^2 \gamma^5 d_2^2) + \\
 & X^+ (\partial^2 - M^2) X^+ + X^- (\partial^2 - M^2) X^- + X^0 (\partial^2 - \frac{M^2}{2}) X^0 + Y \partial^2 Y + i g_c u_\mu W_\mu^+ \partial_\nu X^- - \\
 & \partial_\mu X^+ X^0 + i g_c W_\mu^+ (\partial_\nu Y X^- - \partial_\nu X^+ Y) + i g_c W_\mu^- (\partial_\nu X^- X^0 - \partial_\nu X^+ X^-) + \\
 & i g_s W_\mu^- (\partial_\nu X^- X^0 - \partial_\nu Y X^+) + i g_c Z_\mu^0 (\partial_\nu X^+ X^- - \partial_\nu X^- X^+) + i g_s A_\mu (\partial_\nu X^+ X^- \\
 & - \partial_\nu X^- X^+) - \frac{1}{2} g M [X^+ X^+ H + X^- X^- H + \frac{1}{2} X^0 X^0 H] + \frac{1}{2\sqrt{2}} i g M [X^+ X^0 \partial_\mu \\
 & - X^- X^0 \partial_\mu] + \frac{1}{2\sqrt{2}} i g M [X^0 X^- \partial_\mu - X^+ X^+ \partial_\mu] + i g M_s w [X^0 X^- \partial_\mu - X^+ X^+ \partial_\mu] \\
 & + \frac{1}{2} i g M [X^+ X^+ \phi^0 - X^- X^- \phi^0]
 \end{aligned}$$

In anderen Worten

Wir verstehen nur 5% des Energie- und Materieinhalts des Universums.



In anderen Worten

Urknall

Symmetry

Warum existieren wir?
Wo ist all die
Antimaterie hin?

Materie

Antimaterie

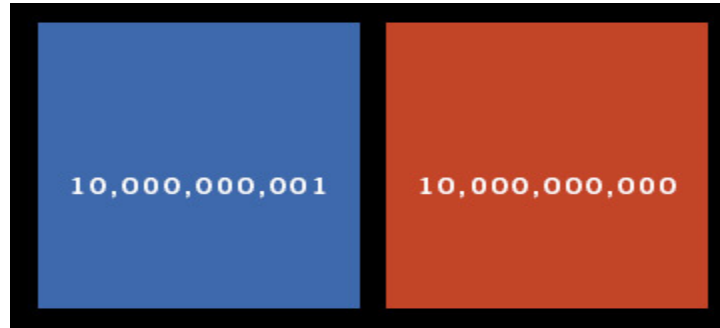
Annahme: Universum begann mit gleichen Mengen Materie / Antimaterie

In anderen Worten

Urknall



Frühes
Universum

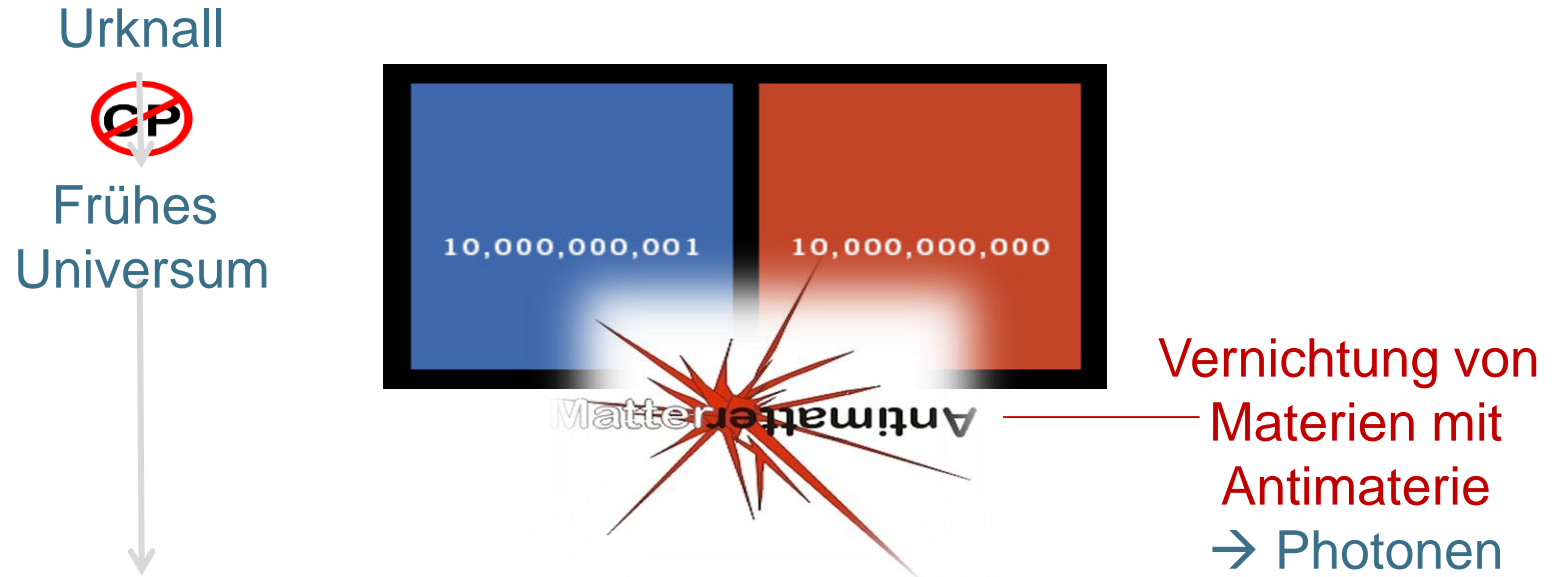


Materie

Antimaterie

Sehr schnell entwickelte sich eine Asymmetrie

In anderen Worten

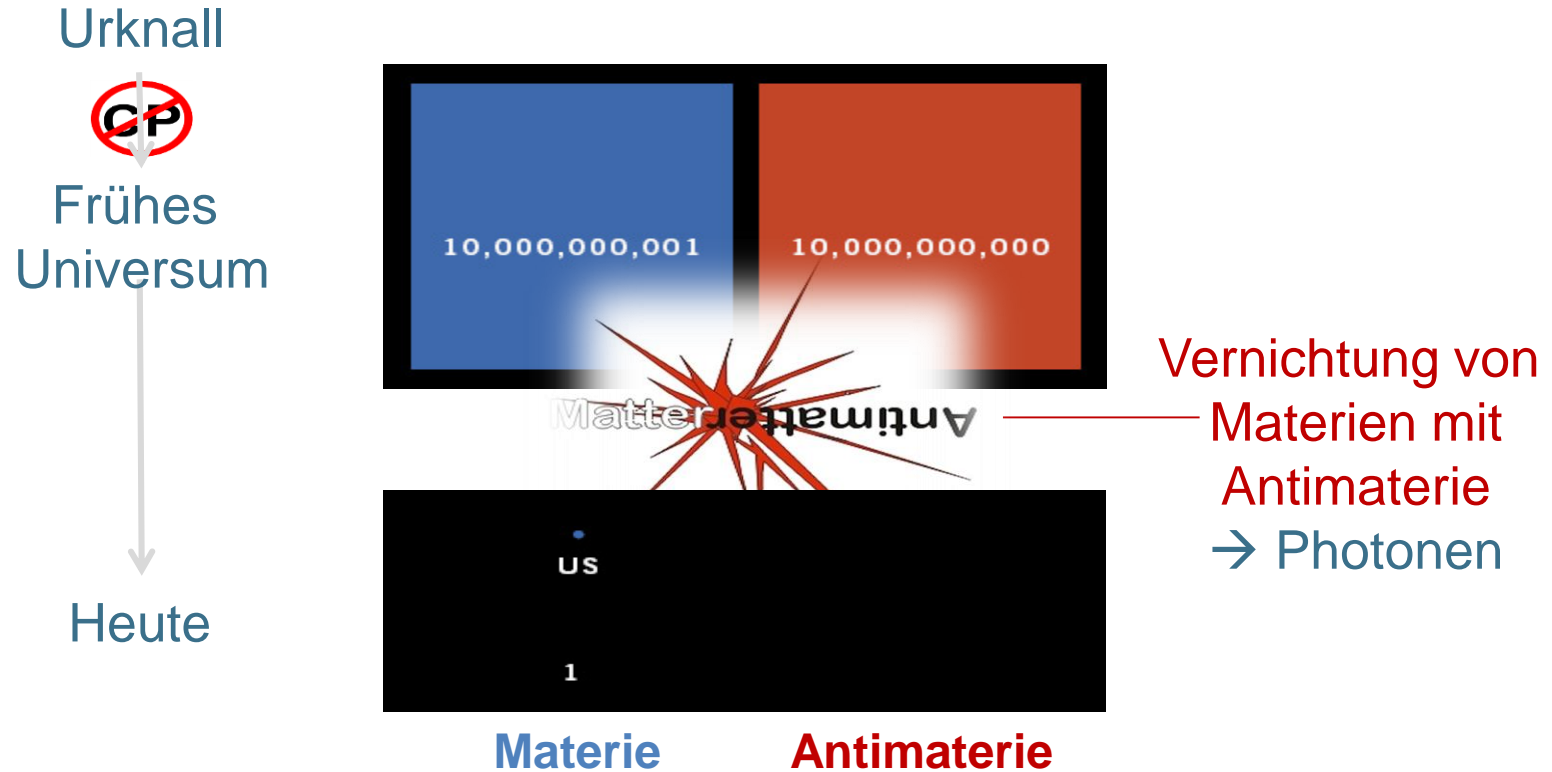


Materie

Antimaterie

Materie und Antimaterie vernichteten sich.

In anderen Worten



Heute ist nur noch Materie übrig.

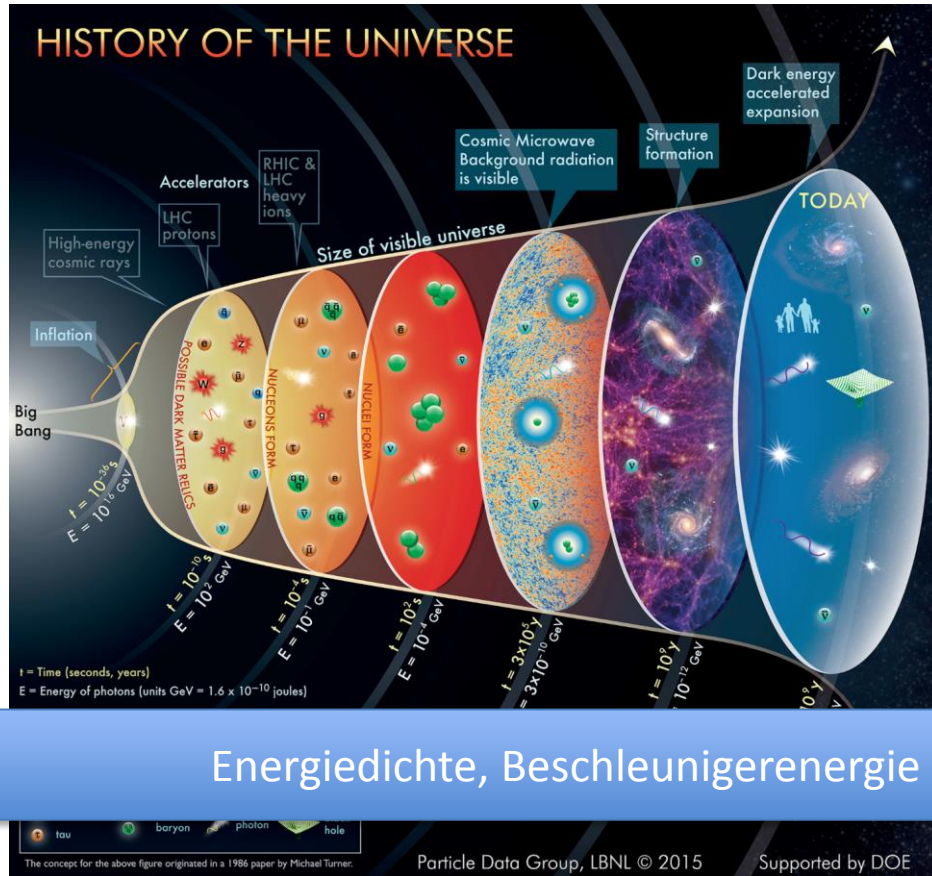
In anderen Worten



$$\eta \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma} = (6.11 \pm 0.19) \times 10^{-10}$$

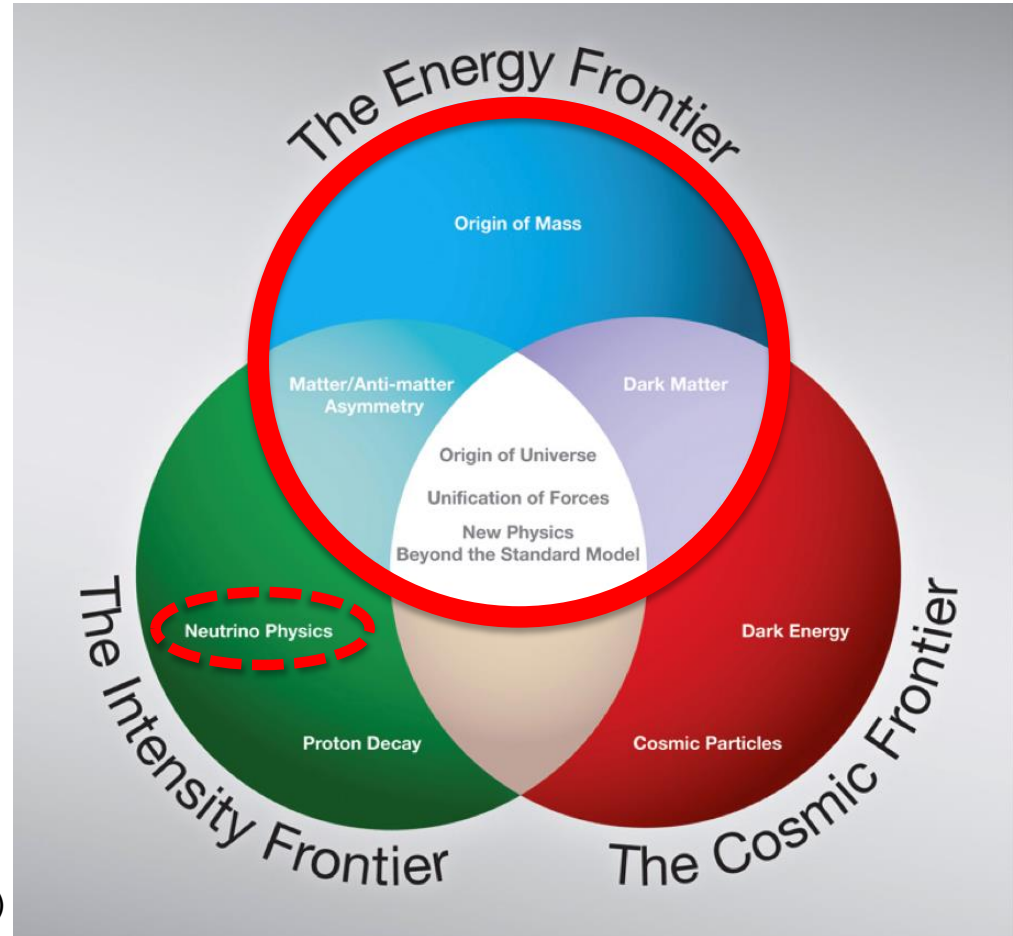
Why this strange number? Why not zero?

Geschichte des Universums

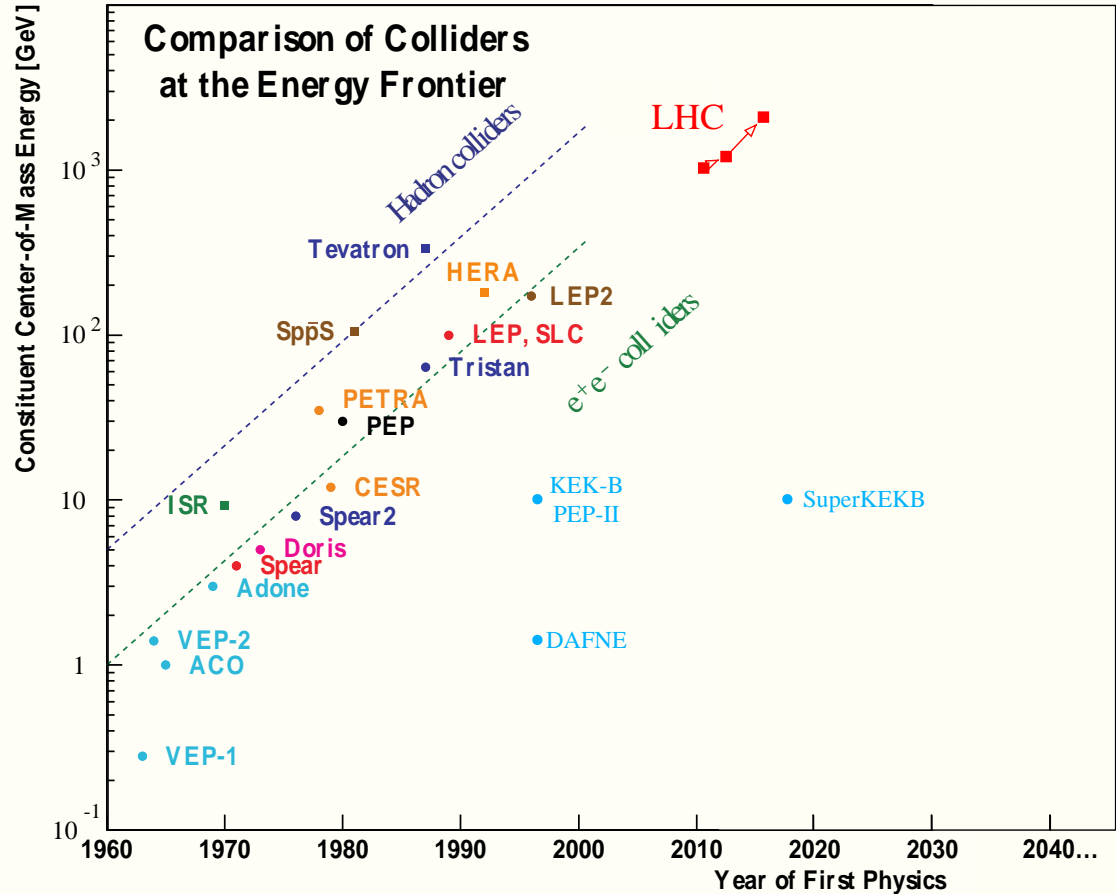


Energiedichte, Beschleunigerenergie

Die Beschleuniger-Herausforderung



Livingston-Plot



(N. Walker)

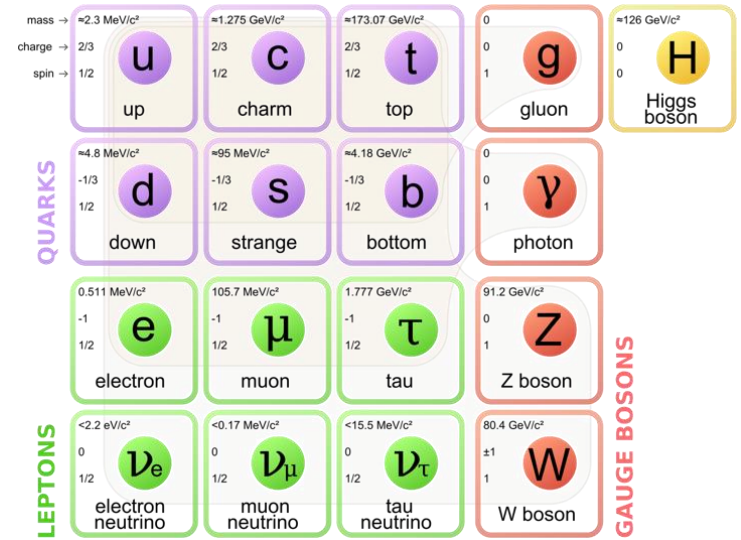
Welche Teilchen?

- Ideal:
 - Elementar
 - Geladen
 - Stabil
 - Leicht zu erzeugen
 - Großer Wirkungsquerschnitt

■ Im Standardmodell:

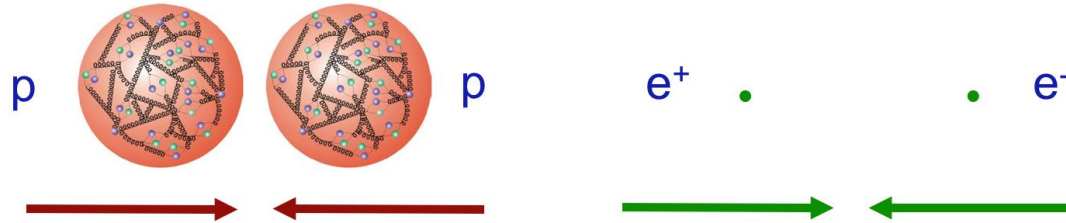
- Quarks
- Geladene Leptonen
- Neutrinos
- Z
- W
- Gluons
- Photons
- Higgs

nicht isoliert; aber Proton ok
 e ok, μ vielleicht, tau kurzlebig
 theoretisch schön, aber ...
 neutral, kurzlebig
 auch zu kurzlebig
 nur in gebundenen Zuständen
 neutral, aber vielleicht ...



Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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	*	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	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
	*	57 La	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		
	**	89 Ac	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		

Hadronen versus Leptonen



Proton (Anti-)Proton Collider	Electron Positron Collider
Energy range high (limited by bending magnets power)	Energy range limited (by RF power)
Composite particles, different initial state constituents and energies in each collision	Pointlike particles, well defined initial state quantum numbers and energies
Difficult hadronic final states	Easier final states
Discovery Machines (with some precision potential)	Precision Machines (with some discovery potential)

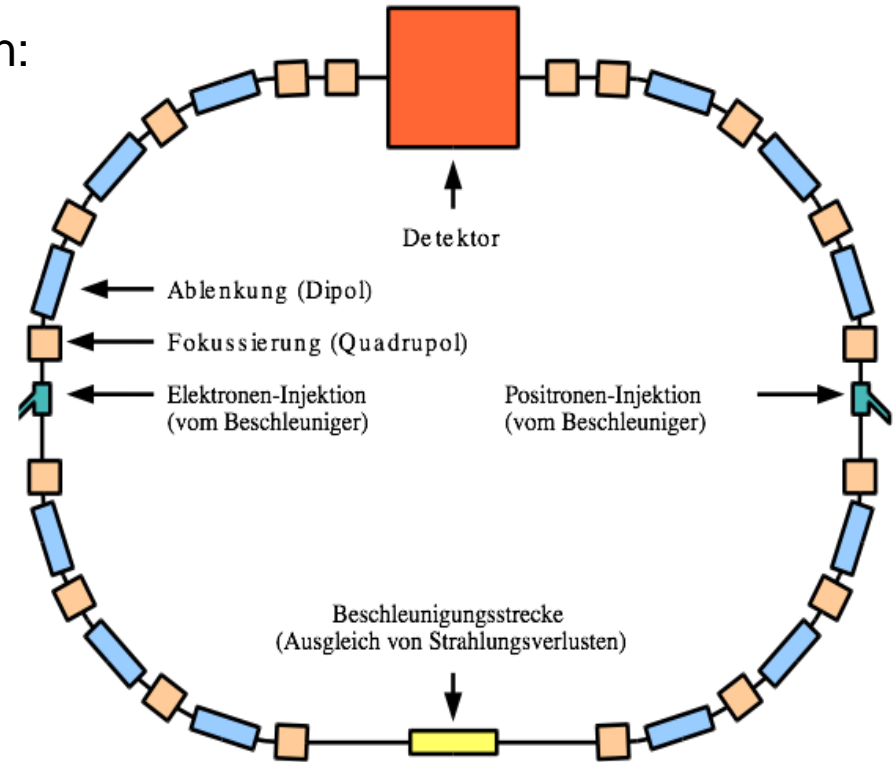
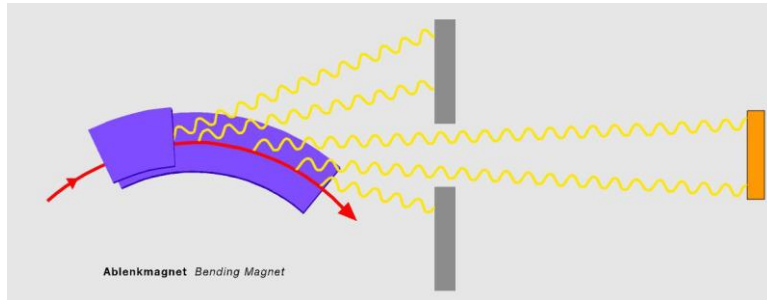
(K. Büsser)

Speicherringe



Speicherringe

- Magnete halten Teilchen auf Kreisbahn:
 - Dipolfeld $\sim E/r$
- Leichte Teilchen (Leptonen):
 - Energieverlust (Leistung) $\sim E^4/r/m^4$
- Grobe Regel:
 - Hadronmaschinen: limitiert durch Dipole
 - Elektronmaschinen: limitiert durch Beschleunigungspower



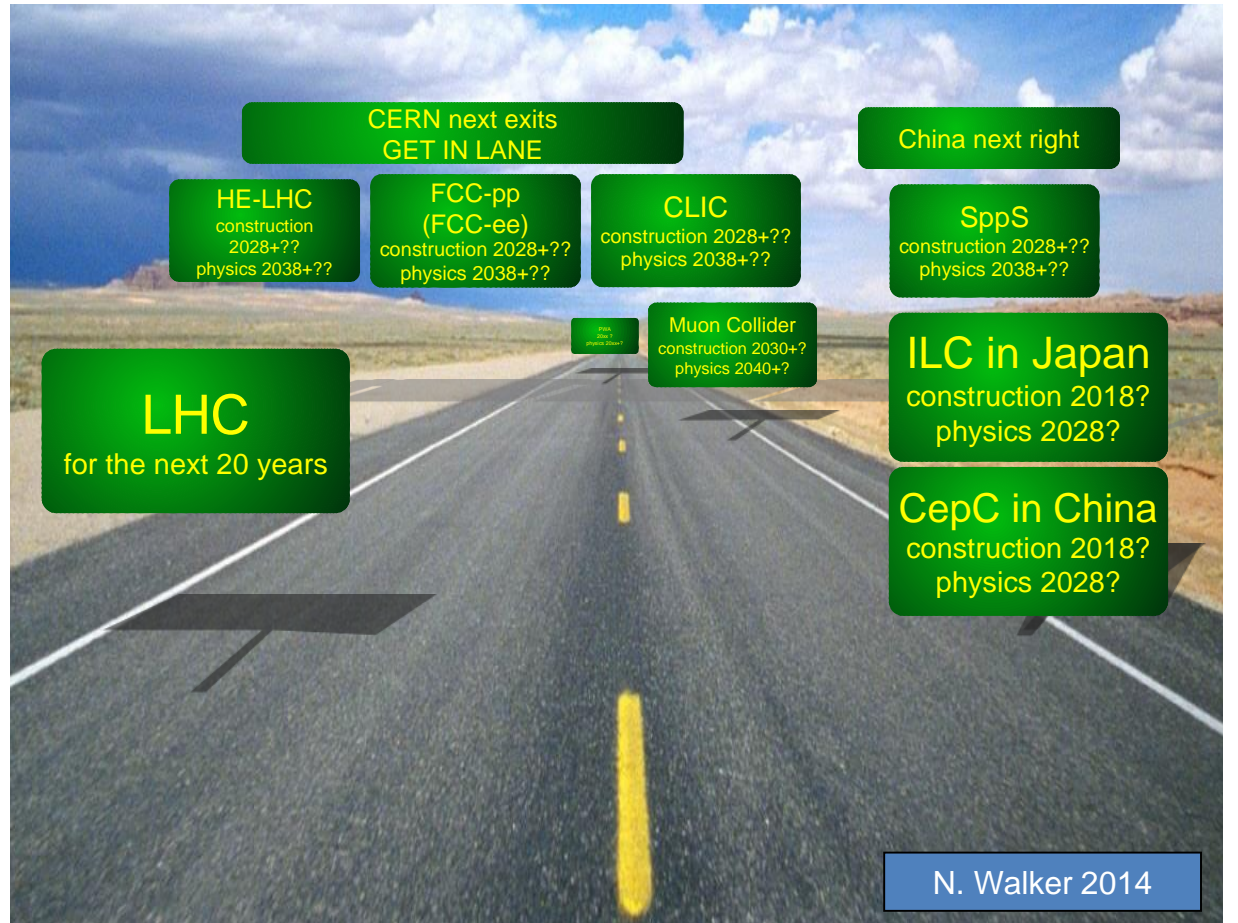
Linearbeschleuniger



Gliederung

- Teilchenphysik: Status, Probleme, Strategie
- Laufende und zukünftige (Groß)Projekte
- Einschub: Politik und Finanzierung
- Teilchenphysik: DESYs Strategie und zukünftige Orientierung
 - LHC
 - HL-LHC
 - FCC (hh und ee)
 - CepC und SppC
 - ILC
 - CLIC
 - ... und der Rest

Where to go?

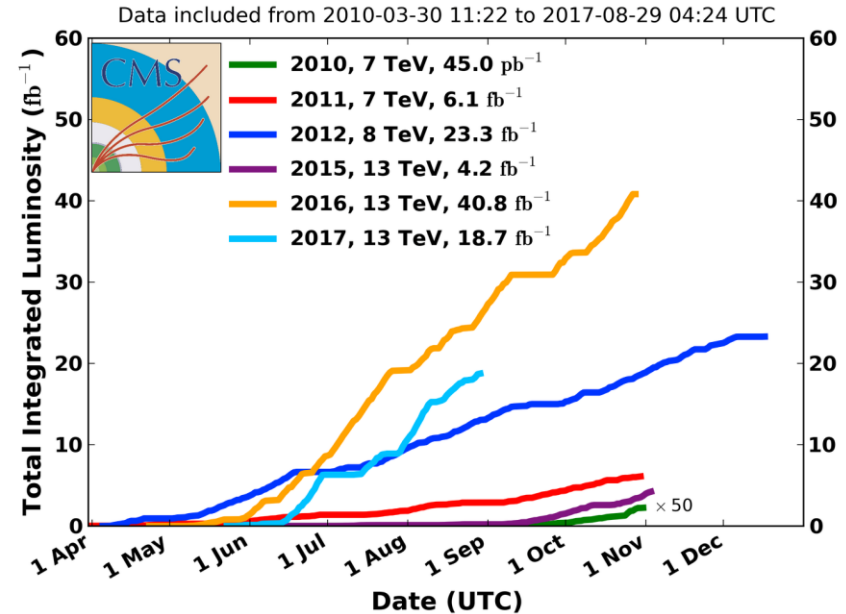
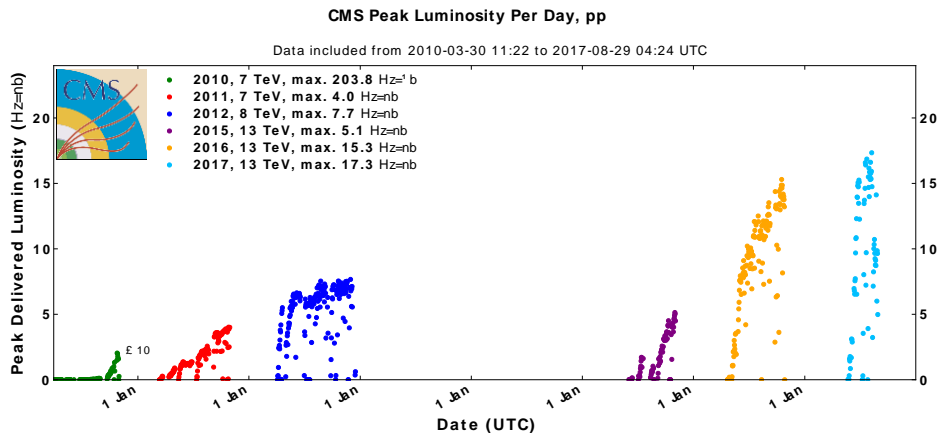


Die heutige “energy frontier”: LHC



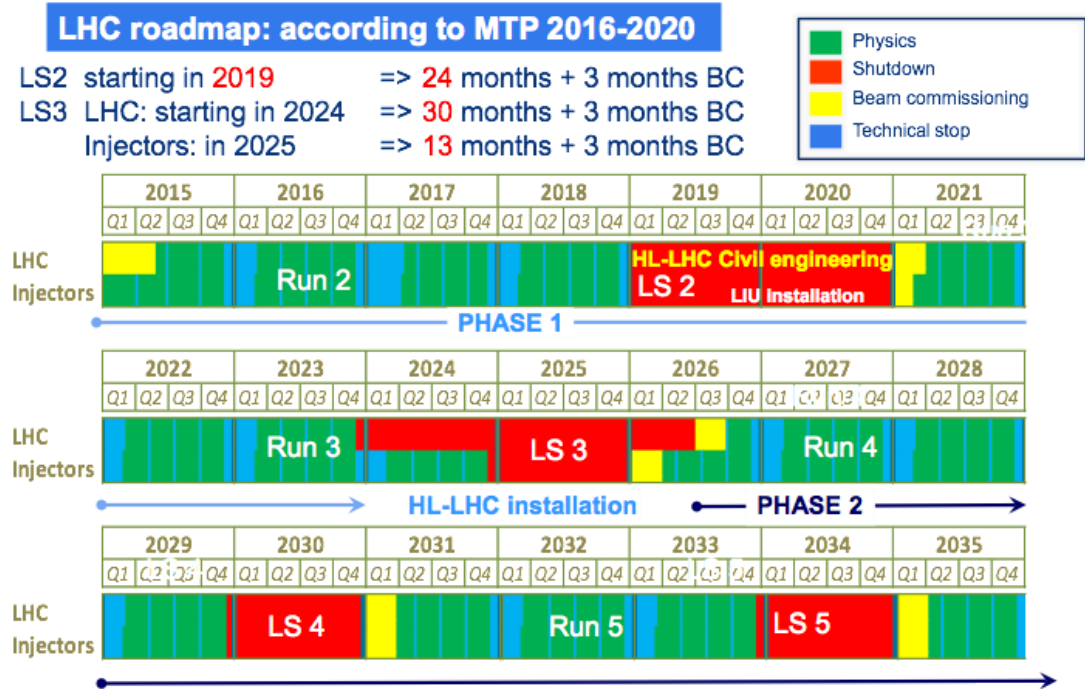
LHC-Luminosität

- Design-Lumi von $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ erreicht im July 2016
- W-Entdeckung durch UA1 am SppS nutzte integrierte Lumi von 18 nb^{-1} .
- Dafür braucht der LHC heute weniger als 5 Sekunden ...



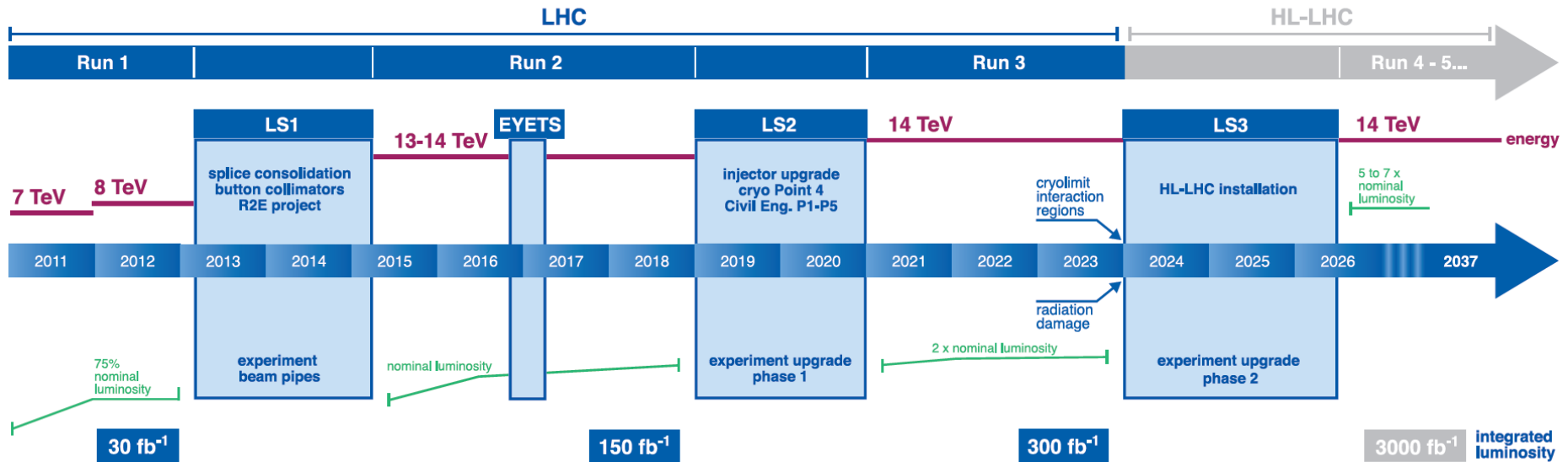
LHC-Roadmap (CERN “Medium Term Plan”)

- Phase 1: 300 fb⁻¹
- High-Lumi LHC ab Mitte 2026
- Phase 2: 3000 fb⁻¹ bis ca. 2037



LHC-Roadmap (CERN “Medium Term Plan”)

LHC / HL-LHC Plan



HL-LHC: "Physics Case"

- Ausweitung des zugänglichen Massenbereichs um Faktor 2
- Hochpräziser Test alle Higgs-Kopplungen (auch an $\mu\mu$)
- Entdeckungspotential

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: August 2016

ATLAS Preliminary

$\sqrt{s} = 7, 8, 13 \text{ TeV}$

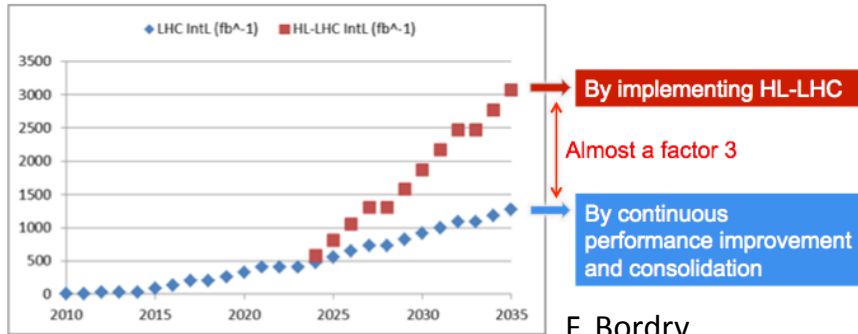
Model	$\epsilon, \mu, \tau, \gamma$	Jets	E_{T}^{miss}	$[L, d](\text{fb}^{-1})$	Mass limit		Reference			
					$\sqrt{s} = 7, 8 \text{ TeV}$	$\sqrt{s} = 13 \text{ TeV}$				
Inclusive Searches	MSUGRA/CMSSM	0-3 $e, \mu, 1-2 \tau$	2-10 jets/0 b	Yes	20.3	6.6	1.89 TeV	m $_{\tilde{g}}$ (m $_{\tilde{0}}$)	1507 05525	
	$\tilde{g}, \tilde{u}, \tilde{d}$	0	2-6 jets	Yes	13.3	4	1.35 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-078	
	$\tilde{g}, \tilde{u}, \tilde{d}$ (compressed)	mono-jet	1-3 jets	Yes	3.2	4	698 GeV	m $_{\tilde{g}}$ (m $_{\tilde{0}}$) $\leq 5 \text{ GeV}$	1804 07773	
	$\tilde{g}, \tilde{u}, \tilde{d}$	0	2-6 jets	Yes	13.3	4	1.80 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-078	
	$\tilde{g}, \tilde{u}, \tilde{d}$	0	2-6 jets	Yes	13.3	4	1.83 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-078	
	$\tilde{g}, \tilde{u}, \tilde{d}$	3 jets	4 jets	Yes	13.2	4	1.2 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-037	
	$\tilde{g}, \tilde{u}, \tilde{d}$	2 e, μ (SS)	0-3 jets	Yes	13.2	4	1.0 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-037	
	GMSB (\tilde{N} LSP)	1-2 $\tau + 0-1 l$	0-2 jets	Yes	3.2	4	2.0 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	1507 05979	
	GGM (bino NLSP)	2 γ	-	Yes	3.2	4	1.05 TeV	cr(NLSP) $\leq 0.1 \text{ mm}$	1808 09150	
	GGM (higgsino-bino NLSP)	1 b	Yes	20.3	4	1.37 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	1507 05403		
3 $^{\text{rd}}$ gen. \tilde{q} med.	GGM (higgsino NLSP)	7	2 jets	Yes	13.3	4	1.8 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-096	
	GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	4	960 GeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	1508 02050	
	Gravitino LSP	0	mono-jet	Yes	20.3	4	885 GeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	1508 01518	
	$\tilde{g}, \tilde{u}, \tilde{d}$	0	3 b	Yes	14.8	4	1.89 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-052	
	$\tilde{g}, \tilde{u}, \tilde{d}$	0-1 e, μ	3 b	Yes	14.8	4	1.69 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-052	
	$\tilde{g}, \tilde{u}, \tilde{d}$	0-1 e, μ	3 b	Yes	20.1	4	1.37 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	1407 5800	
	3 $^{\text{rd}}$ gen. squarks direct production	$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	0	2 b	Yes	3.2	4	840 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1806 08772
		$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	2 e, μ (SS)	1 b	Yes	13.2	4	325-463 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	ATLAS-COANF-2016-037
		$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	0-2 e, μ	1-2 b	Yes	4.7/13.3	4	17-170 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1200 2169, ATLAS-COANF-2016-077
		$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	0-2 e, μ	0-2 jets/1-2 b	Yes	4.7/13.3	4	90-190 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1506 08916, ATLAS-COANF-2016-077
$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$		0	mono-jet	Yes	3.2	4	99-323 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1804 07773	
$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$		2 e, μ (Z)	1 b	Yes	20.3	4	150-000 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1403 5222	
$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$		3 e, μ (Z)	1 b	Yes	13.3	4	299-780 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	ATLAS-COANF-2016-038	
$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$		1 e, μ	6 jets + 2 b	Yes	20.3	4	320-626 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1506 08616	
EW direct		$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	2 e, μ	0	Yes	20.3	4	90-335 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1403 5294
		$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	2 e, μ	0	Yes	13.3	4	840 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	ATLAS-COANF-2016-096
	$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	2 τ	0	Yes	14.8	4	580 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	ATLAS-COANF-2016-039	
	$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	3 e, μ	0	Yes	13.3	4	1.0 TeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	ATLAS-COANF-2016-096	
	$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	2-3 e, μ	0-2 jets	Yes	20.3	4	423 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1405 5994, 1402 7029	
	$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	ϵ, μ, τ	0-2 b	Yes	20.3	4	270 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1501 07110	
	$\tilde{t}_1, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}$	4 e, μ	0	Yes	20.3	4	835 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1405 5086	
	GGM (wino NLSP) weak prod.	1 $e, \mu + \gamma$	-	Yes	20.3	4	115-370 GeV	cr $\leq 1 \text{ mm}$	1507 05403	
	GGM (bino NLSP) weak prod.	2 γ	-	Yes	20.3	4	590 GeV	cr $\leq 1 \text{ mm}$	1507 05403	
	Long-lived particles	Direct \tilde{t}_1, \tilde{b}_1 prod., long-lived \tilde{t}_1, \tilde{b}_1	Disapp. trk	1 jet	Yes	20.3	4	270 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1310 3875
Direct \tilde{t}_1, \tilde{b}_1 prod., long-lived \tilde{t}_1, \tilde{b}_1		dE/dx trk	-	Yes	18.4	4	495 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1506 05332	
Stable, stopped \tilde{t} R-hadron		0-1 jets	Yes	27.9	4	800 GeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1310 3594		
Stable \tilde{t} R-hadron		trk	-	3.2	4	1.39 TeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1808 05129		
Metastable \tilde{t} R-hadron		dE/dx trk	-	3.2	4	1.87 TeV	m $_{\tilde{t}_1}$ (\tilde{b}_1)	1804 04520		
GMSB, stable $\tilde{t}, \tilde{b}_1 \rightarrow \tilde{t}, \tilde{b}_1 + \tilde{G}$		1-2 μ	-	19.1	4	537 GeV	10 4 length $\leq 5 \text{ m}$	1411 6795		
GMSB, $\tilde{t}_1 \rightarrow \tilde{t}, \tilde{b}_1 \rightarrow \tilde{b}_1 + \tilde{G}$, long-lived \tilde{t}_1, \tilde{b}_1		2 γ	-	Yes	20.3	4	440 GeV	1 τ cr $\leq 3 \text{ ns}$, SPSS model	1409 5542	
$\tilde{g}, \tilde{u}, \tilde{d} \rightarrow \tilde{g}, \tilde{u}, \tilde{d} + \tilde{G}$		displ. $\nu, \mu, \tau, \gamma, \mu, \nu$	-	20.3	4	1.0 TeV	7 cr $\leq 1 \text{ s}$ (\tilde{g}) $\leq 740 \text{ mm}$, m $_{\tilde{G}} \geq 1.3 \text{ TeV}$	1504 05162		
$\tilde{g}, \tilde{u}, \tilde{d} \rightarrow \tilde{g}, \tilde{u}, \tilde{d} + \tilde{G}$		displ. jets + vtx	-	20.3	4	1.0 TeV	8 cr $\leq 1 \text{ s}$ (\tilde{g}) $\leq 480 \text{ mm}$, m $_{\tilde{G}} \geq 1.1 \text{ TeV}$	1504 05162		
RPV		LFV $\tilde{g}, \tilde{u}, \tilde{d} \rightarrow \tilde{g}, \tilde{u}, \tilde{d} + \tilde{G}$	displ. $\nu, \mu, \tau, \gamma, \mu, \nu$	-	3.2	4	1.9 TeV	$A_{13} = 0.11, A_{23} = 0.07$	1807 08079	
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	4	1.45 TeV	m $_{\tilde{g}}$ (m $_{\tilde{0}}$)	1404 2620	
	$\tilde{g}, \tilde{u}, \tilde{d}$	4 e, μ	Yes	13.3	4	1.14 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-075		
	$\tilde{g}, \tilde{u}, \tilde{d}$	3 $e, \mu + \tau$	Yes	20.3	4	450 GeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	1405 5086		
	$\tilde{g}, \tilde{u}, \tilde{d}$	0-4-5 large-R jets	-	14.8	4	1.98 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-057		
	$\tilde{g}, \tilde{u}, \tilde{d}$	0-4-5 large-R jets	-	14.8	4	1.35 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-057		
	$\tilde{g}, \tilde{u}, \tilde{d}$	1 e, μ	8-10 jets/0-4 b	-	14.8	4	1.79 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-094	
	$\tilde{g}, \tilde{u}, \tilde{d}$	1 e, μ	8-10 jets/0-4 b	-	14.8	4	1.4 TeV	m $_{\tilde{g}}$ (\tilde{u}, \tilde{d})	ATLAS-COANF-2016-094	
	$\tilde{g}, \tilde{u}, \tilde{d}$	0	2 jets + 2 b	-	15.4	4	410 GeV	825 GeV \leq m $_{\tilde{g}}$ (\tilde{u}, \tilde{d}) $\leq 850 \text{ GeV}$	ATLAS-COANF-2016-022, ATLAS-COANF-2016-084	
	$\tilde{g}, \tilde{u}, \tilde{d}$	2 e, μ	2 b	-	20.3	4	0.4-1.0 TeV	BR($\tilde{g} \rightarrow \tilde{b}, \tilde{b} + \tilde{G}$) $\geq 20\%$	ATLAS-COANF-2015-015	
Other	Scalar charm, $\tilde{c} \rightarrow \tilde{c} + \tilde{G}$	0	2 c	Yes	20.3	4	510 GeV	m $_{\tilde{c}}$ (\tilde{c})	1501 01325	

*Only a selection of the available mass limits on new states or phenomena is shown.

10 $^{-1}$ 1 Mass scale [TeV]

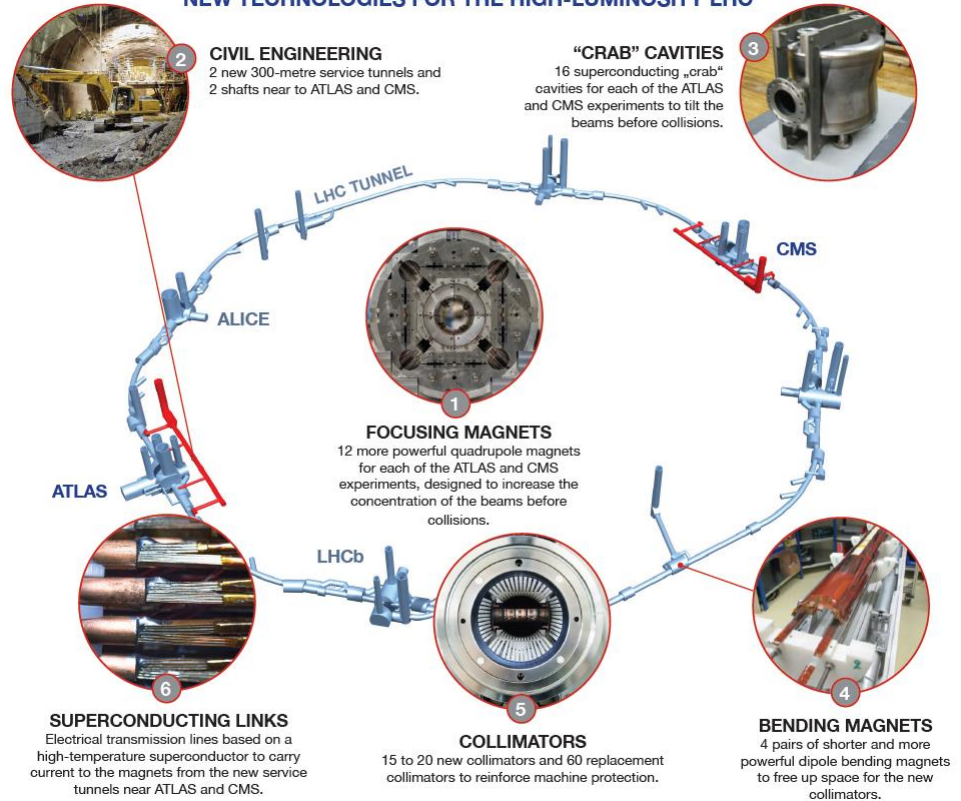
Der HL-LHC

- Erhöhung der Lumi auf $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
 - Faktor 5!
- Die volle Ausbeute des LHC ist höchste Priorität der globalen HEP-Strategie
- Massive Eingriffe auf $\sim 1,2 \text{ km}$ des LHC



F. Bordry

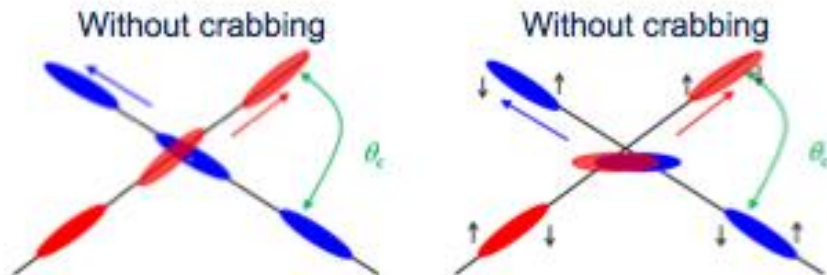
NEW TECHNOLOGIES FOR THE HIGH-LUMINOSITY LHC



Beispiel 1

Crab Cavities, Increase "Head on"

Aim: reduce the effect of the crossing angle



New crossing strategy under study to soften the pile-up density: some new schemas have interesting potential as "crab-kissing", to be discussed with all experiments



- 3 proto types available
- Cavity tests are on-going
- Test with beam in SPS foreseen in 2015-2016
- Beam test in LHC foreseen in 2017



RF-Dipole Nb prototype



4-rod in SPS1B for RF measurements



DQWR prototype
17-Jan-2013



Beispiel 2

Squeezing the beams: High Field SC Magnets

Quads for the inner triplet

Decision 2012 for low- β quads

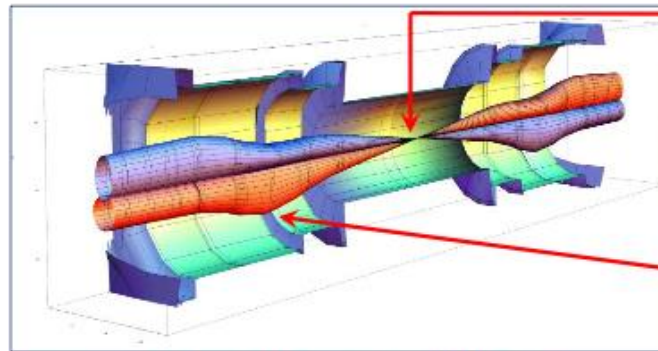
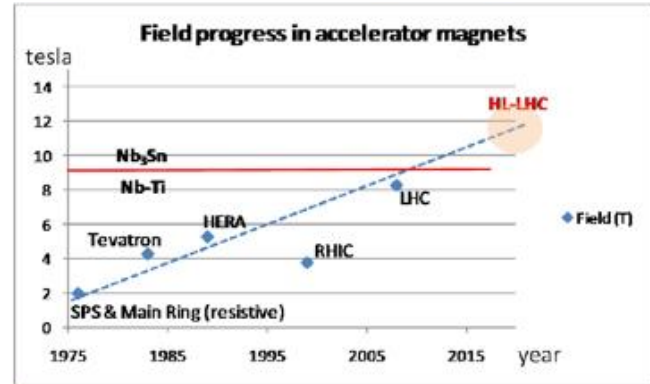
Aperture \varnothing 150 mm – 140 T/m

($B_{\text{peak}} \approx 12.3$ T)

operational field, designed for 13.5 T

=> Nb₃Sn technology

(LHC: 8 T, 70 mm)



	β_{triplet}	Sigma triplet	β^*	Sigma*
Nominal	~4.5 km	1.5 mm	55 cm	17 μm
HL-LHC	~20 km	2.6 mm	15 cm	7 μm

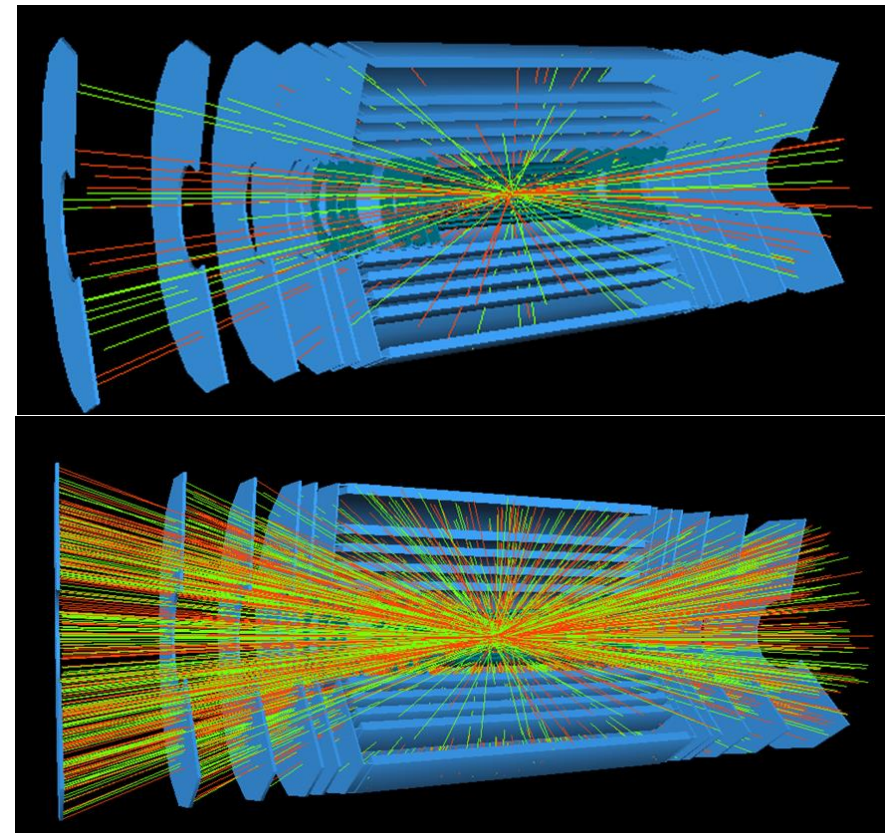


Status & prospects LHC accelerator and HL-LHC plans
High Energy Physics Advisory Panel
Frédéric Bordry
10th December 2015

42

HL-LHC-Detektoren

- ATLAS und CMS brauchen massive Upgrades, um am HL-LHC zu bestehen
 - Spurdetektoren aufgrund von Strahlenschäden am Ende ihrer Lebensdauer
 - Faktor 10 mehr Pile-up
 - Auch Trigger, Kalorimeter ... brauchen Upgrades
- Großes Projekt für die weltweite HEP-Community bis 2025!
 - F&E läuft auf Hochtouren.
 - Produktion startet in wenigen Jahren
 - Siehe DESY-Aktivitäten am Ende des Vortrags



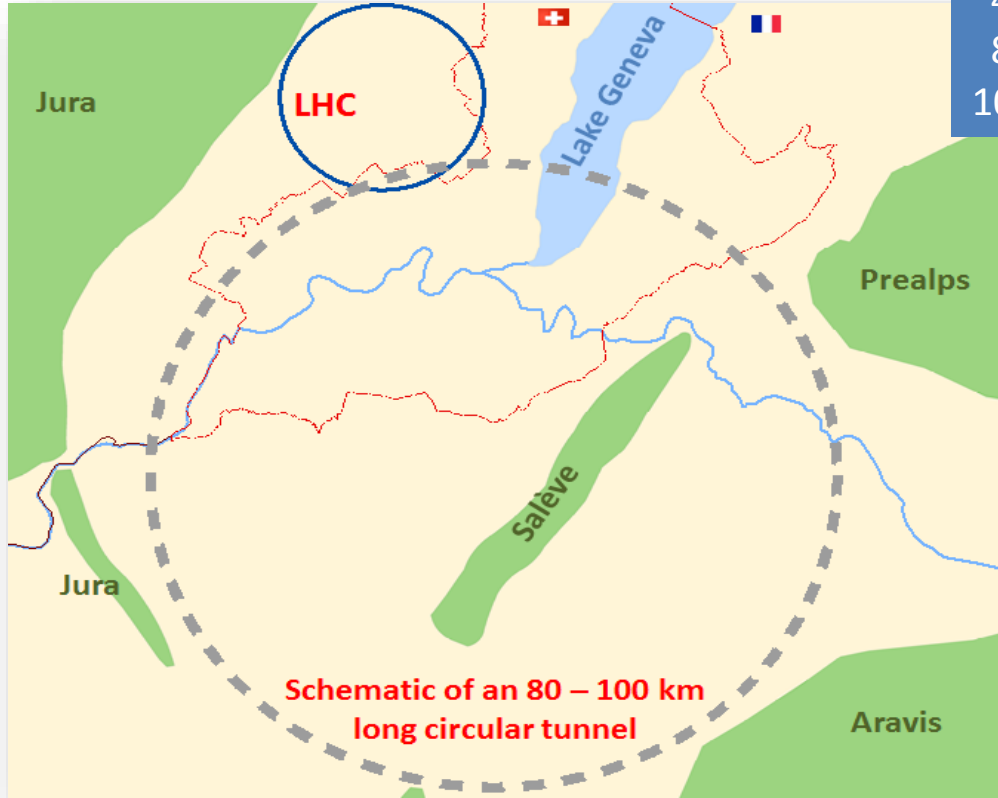
P. Vankov

FCC: Future Circular Collider

- 80-100 km Ringbeschleuniger am CERN
- pp (hh)-Kollisionen bei 100 TeV
 - Braucht Hochfeldmagnete: 16-20 T
- e^+e^- -Collider als erste Stufe?
 - Magnetentwicklung für FCC-hh braucht Zeit...
 - Hohe Luminosität (Speicherring!)
 - Energielimit bei ca. 350 GeV
 - Higgs-Top-Factory
- eh-Collider („Super-HERA“)?
- Design-Studie am CERN läuft
 - Ergebnis als Input für Europäische Strategie
- Das „next big thing“ am CERN (außer CLIC)?
- Realisierung nach 2035



FCC: Future Circular Collider



42 TeV with 8.3 T using present LHC dipoles
80 TeV with 15 T based on Nb₃Sn dipoles
100 TeV with 20 T based on HTS dipoles



Alignment Shafts Query

Choose alignment option

Tunnel elevation at centre: 322mASL

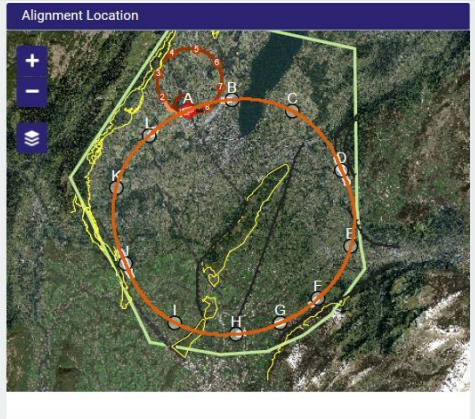
Grad. Params

Azimuth (°): -23.5
 Slope Angle x-x(%): 0.3
 Slope Angle y-y(%): 0.08

LOAD SAVE CALCULATE

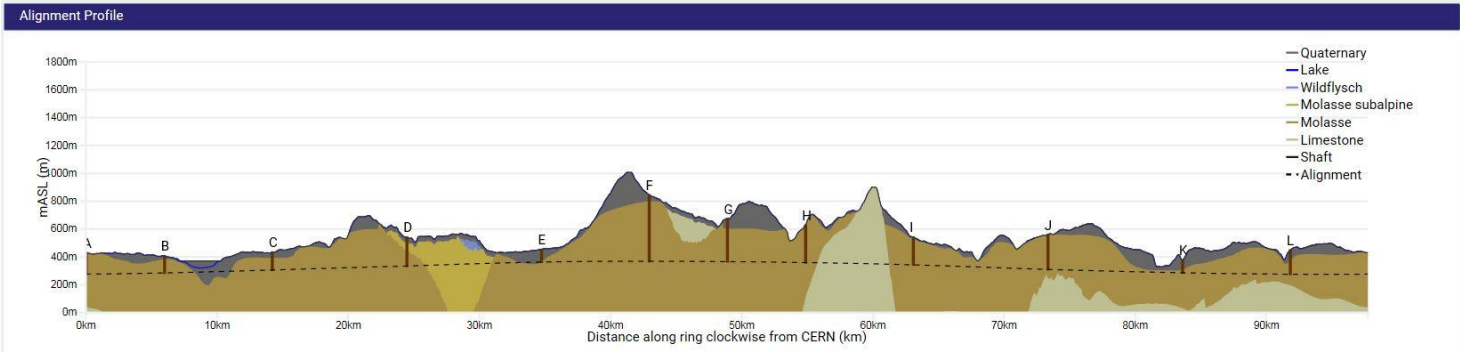
Alignment centre
 X: 2490941 Y: 1107760

	Angle	CP 1 Depth	Angle	CP 2 Depth
LHC	37°	49m	-40°	83m
SPS		121m		126m
T12		121m		126m
T18		51m		118m



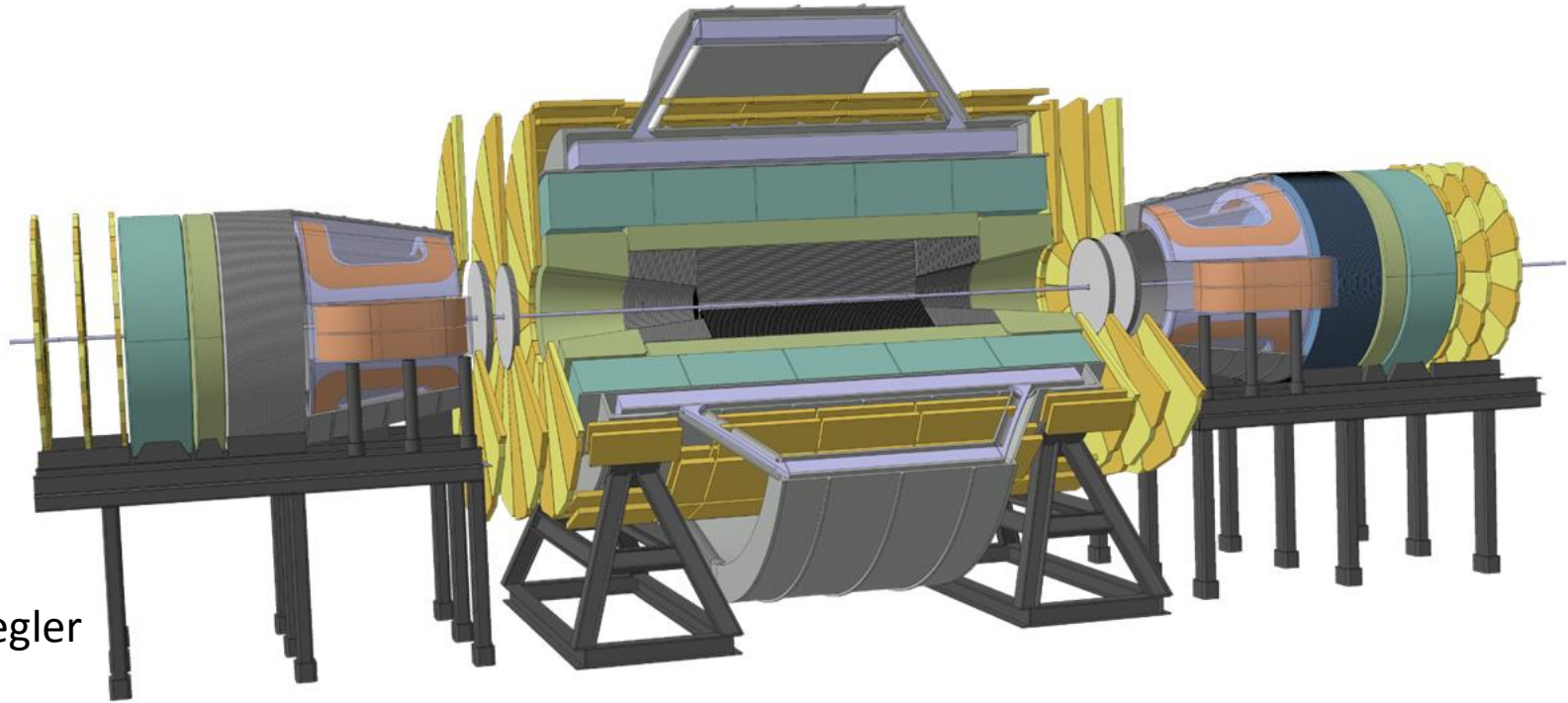
Geology Intersected by Shafts Shaft Depths

Point	Shaft Depth (m)				Geology (m)		
	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Limestone
A	152	0	0	0	152	0	0
B	121	0	0	26	95	0	0
C	127	0	0	44	83	0	0
D	205	66	0	40	100	0	0
E	89	0	0	89	0	0	0
F	476	0	0	49	427	0	0
G	307	0	0	73	234	0	0
H	266	0	0	0	266	0	0
I	198	0	0	11	187	0	0
J	248	0	0	1	247	0	0
K	88	0	0	70	18	0	0
L	172	0	0	89	83	0	0
Total	2449	66	0	492	1892	0	0



V. Mertens

FCC: Future Circular Collider



W. Riegler

FCC: Future Circular Collider

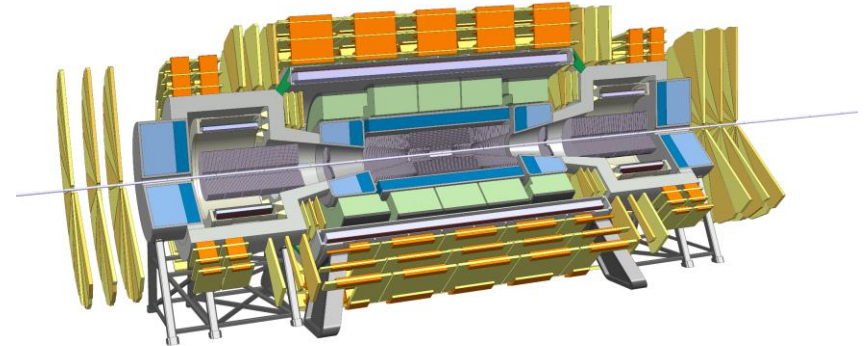
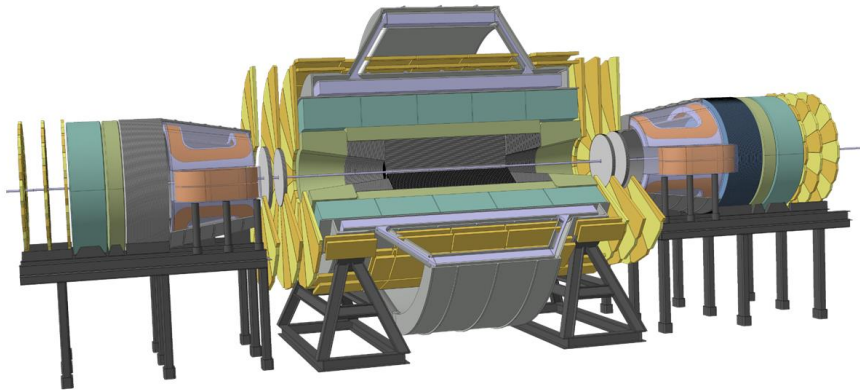
6T, 12m bore solenoid, 10Tm dipoles, shielding coil

- 65 GJ Stored Energy
- 28m Diameter
- >30m shaft
- Multi Billion project

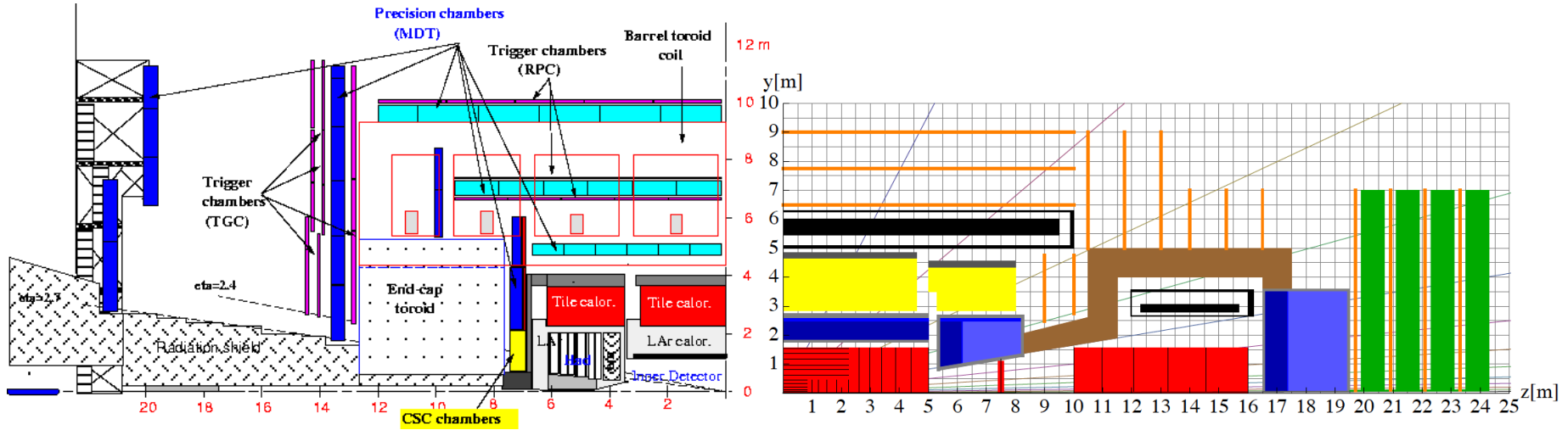


4T, 10m bore solenoid, 4T forward solenoids , no shielding coil

- 14 GJ Stored Energy
- Rotational symmetry for tracking and trigger !
- 20m Diameter (\approx ATLAS)
- 15m shaft
- \approx 1 Billion project

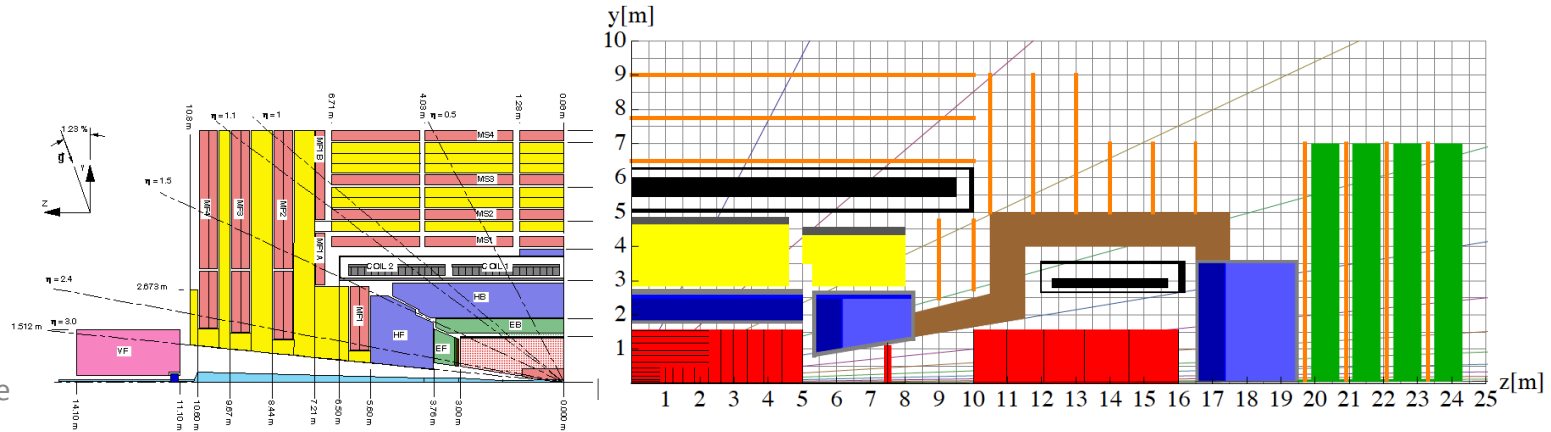


FCC: Future Circular Collider

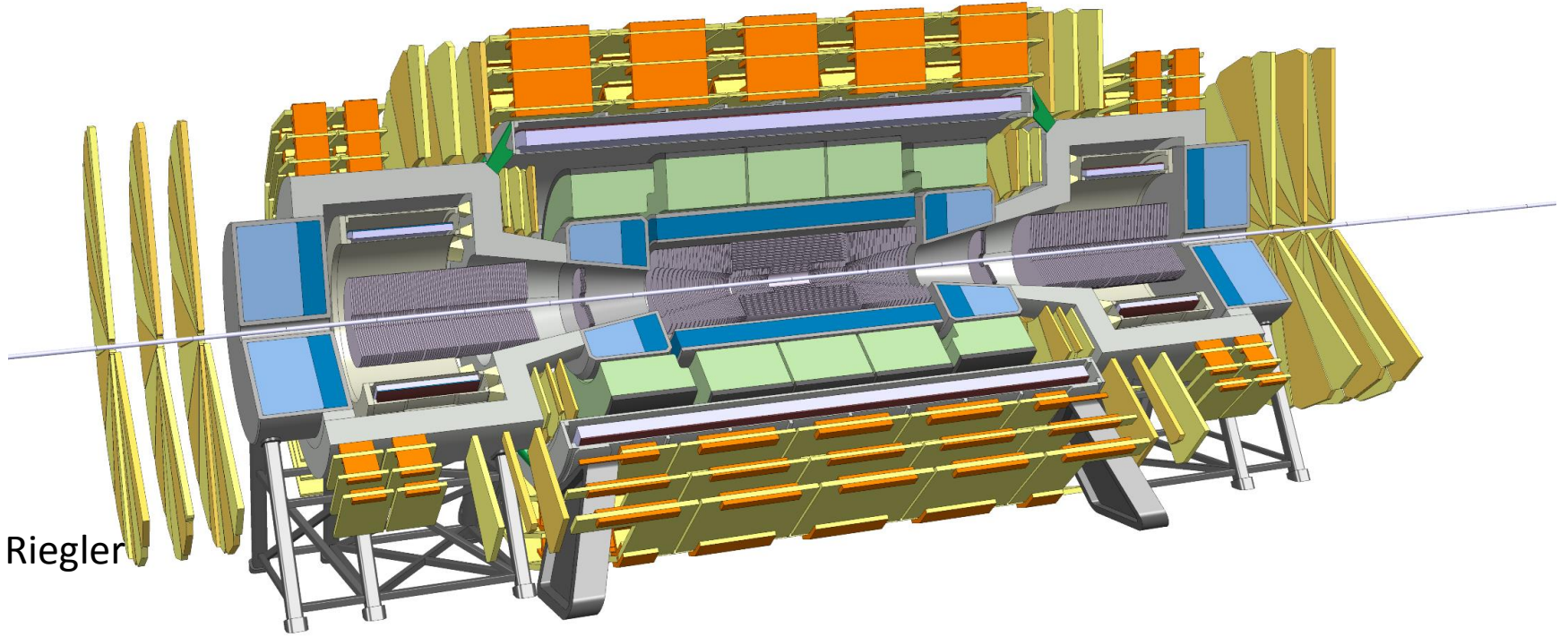


W. Riegler

NTW '17, 2. Septe



FCC: Future Circular Collider



W. Riegler

FCC: Future Circular Collider: Pile-Up 1000

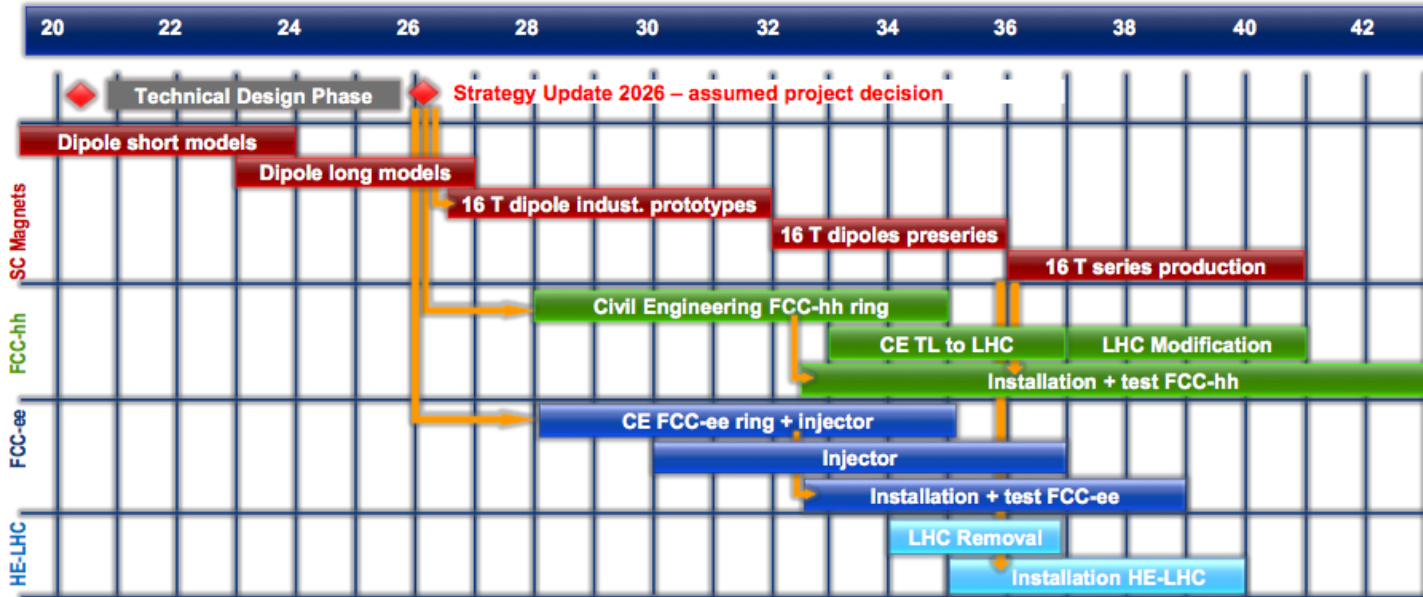


W. Riegler

FCC: Future Circular Collider



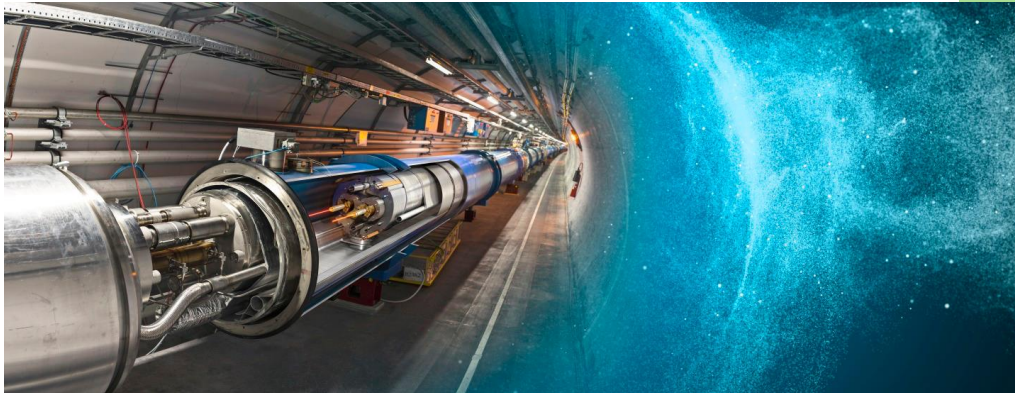
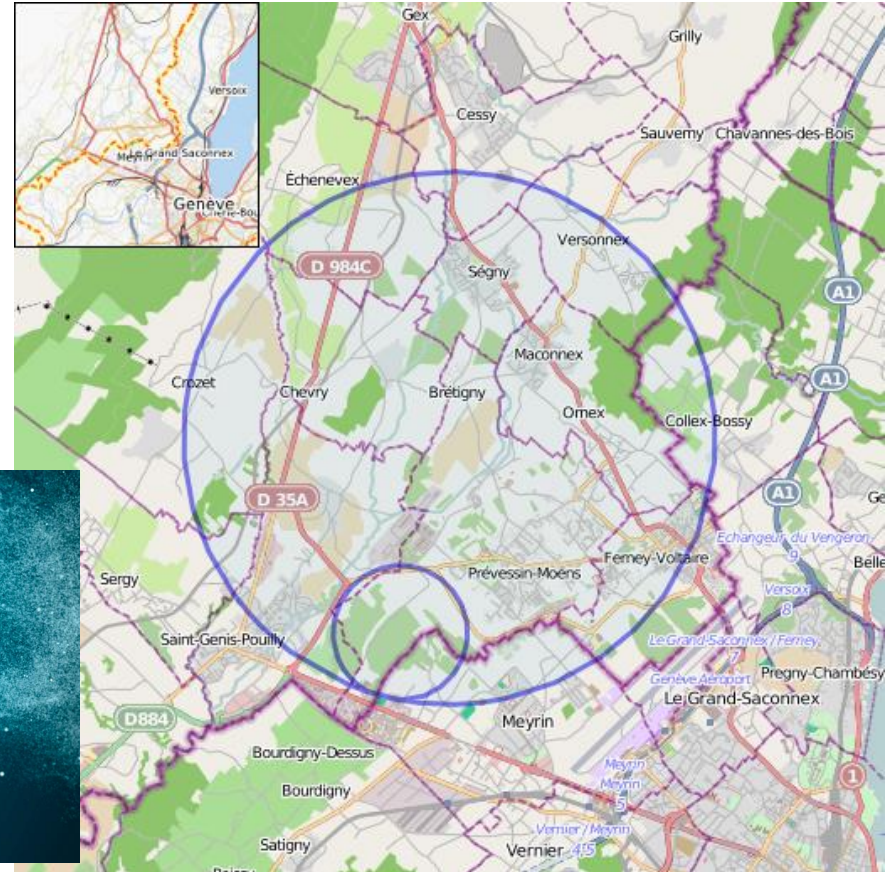
Draft Schedule Considerations



M. Benedikt

Statt dessen: High-Energy LHC?

- Realität statt Traum?
 - Aber vielleicht auch nicht wirklich billig?
- Gleiche Magnetentwicklung (16-20 T) wie für FCC
- Ca. 28 TeV, 4-mal HL-LHC-Lumi?



Oder China: SppC und CepC?

- CepC: „Circular Electron-Positron Collider“
- SppC: „Super Proton-Proton Collider“
- Phase 1: e^+e^- -Higgs-Factory, 240 GeV
- Phase 2: pp-Kollisionen bei $E_{cm}=50-90$ TeV
- 50 oder 70 km Umfang
- Timeline: Baubeginn 2021? ee 2028?
pp > 2042?



A good example is Qinhuangdao (秦皇岛)

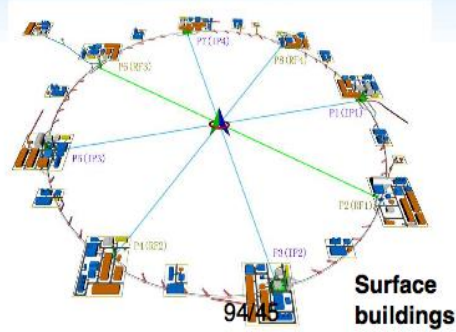
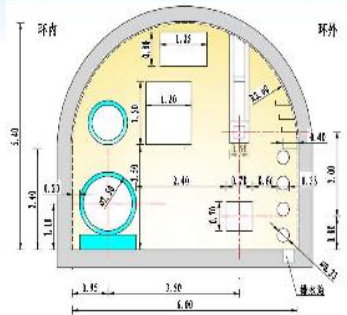
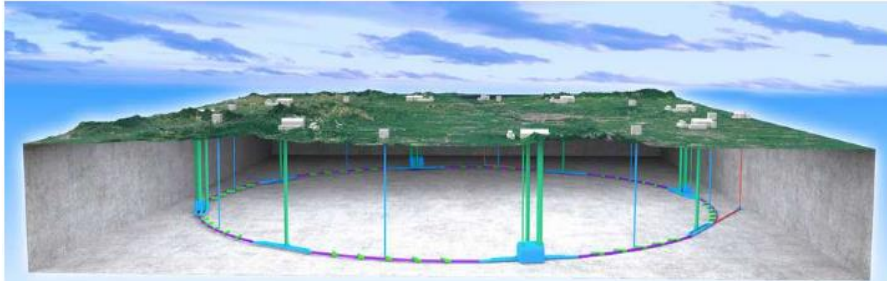


Feb. 24, 2014

Y. F. Wang

Oder China: SppC und CepC?

Civil Construction



Site selections (some main places)



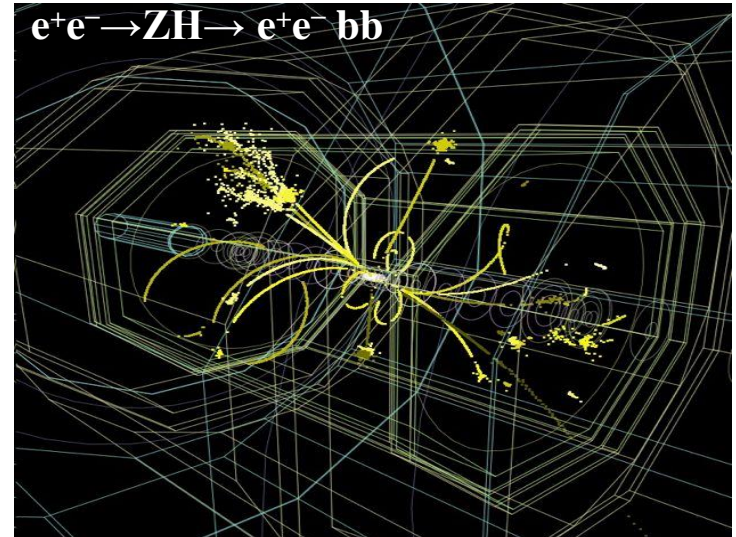
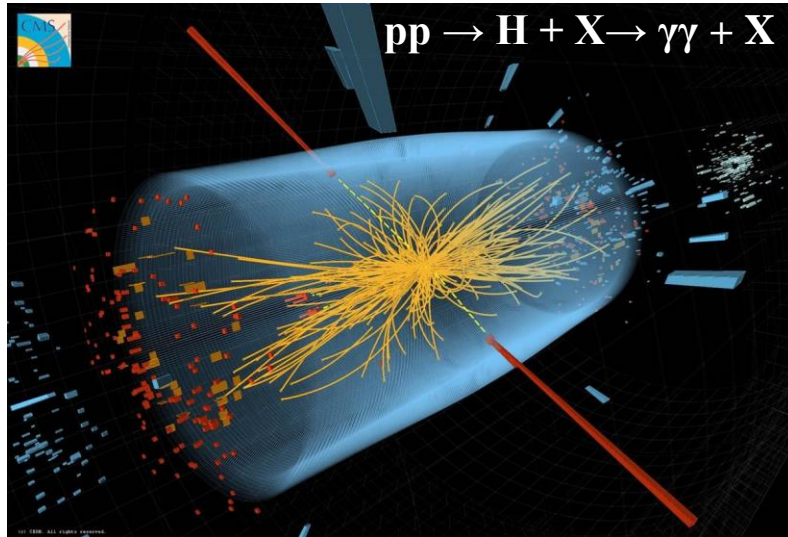
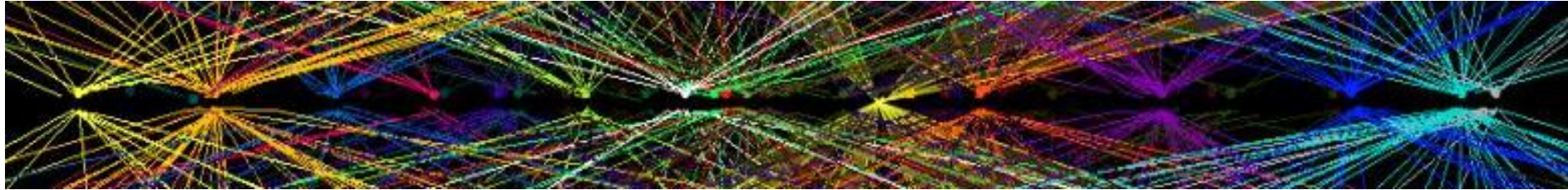
1) Qinhuangdao

2) Shanxi Province

3) Near Shenzhen and Hongkong

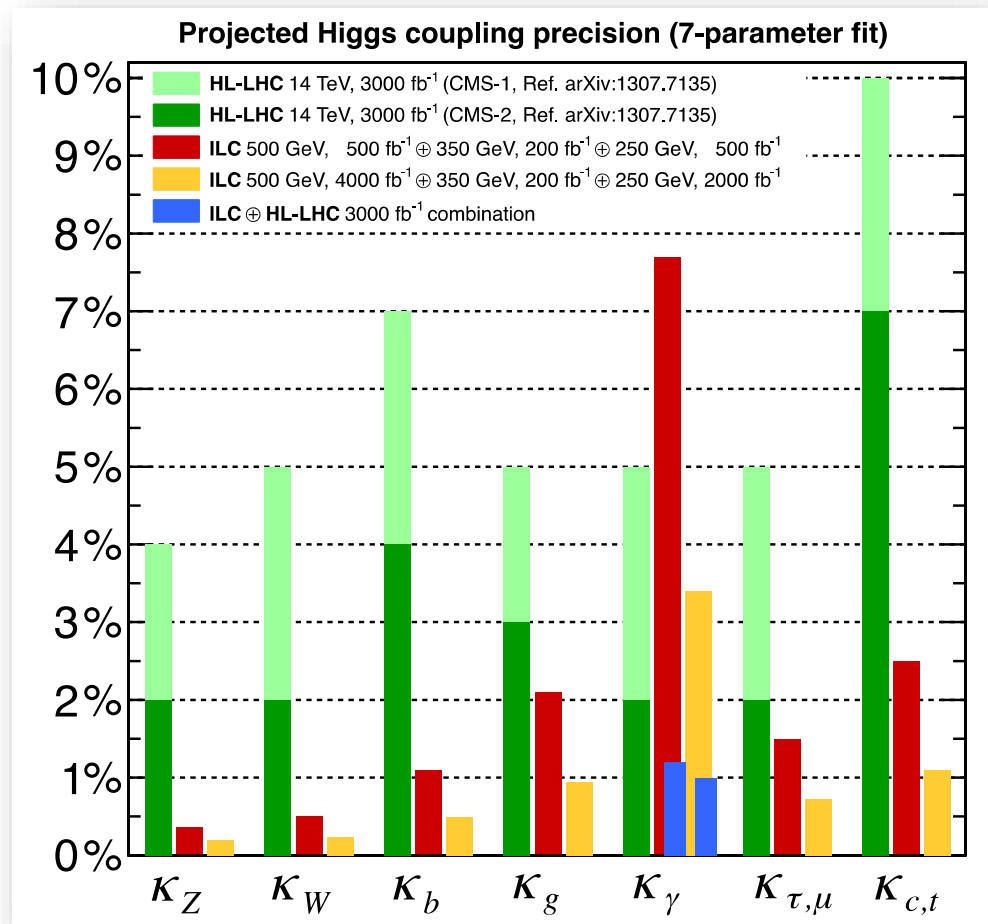
Noch mal FCC: Pile-Up 1000

W. Riegler

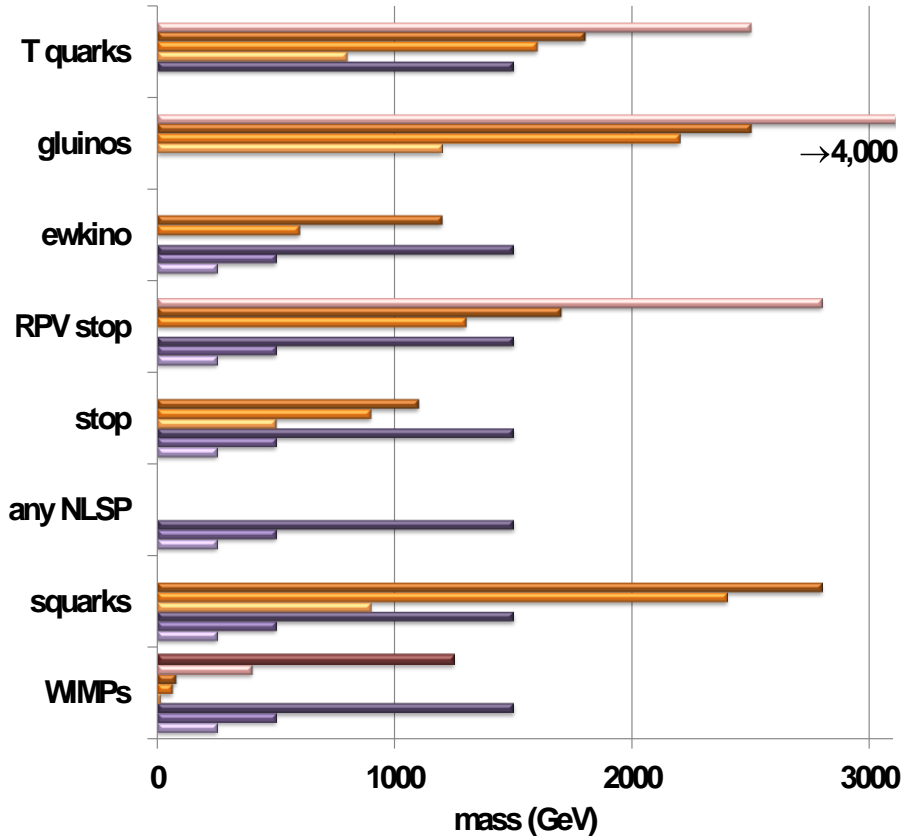


The case for e^+e^- ?

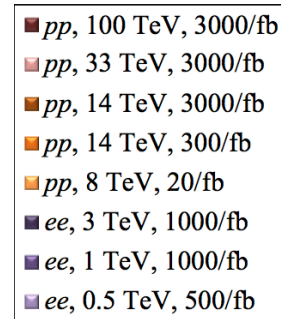
- > Höchste Präzision in der Messung der Higgs-Kopplungen nur an Lepton-Collidern.



The case for e^+e^- ?

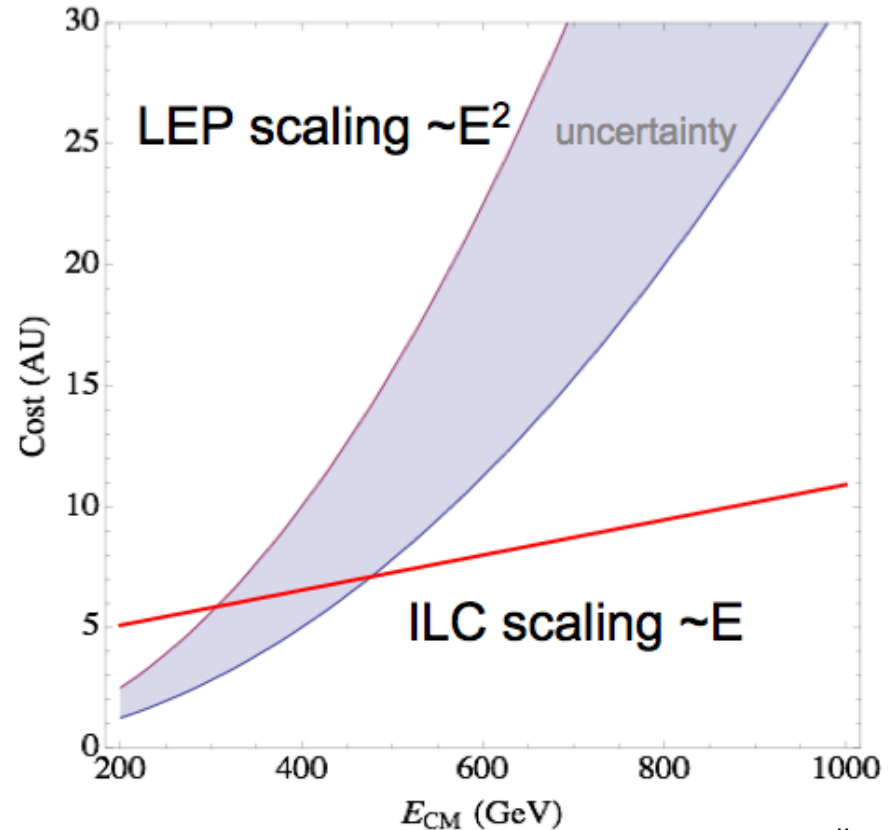


> 95%CL upper limits for masses of new particles expected from current / future machines!



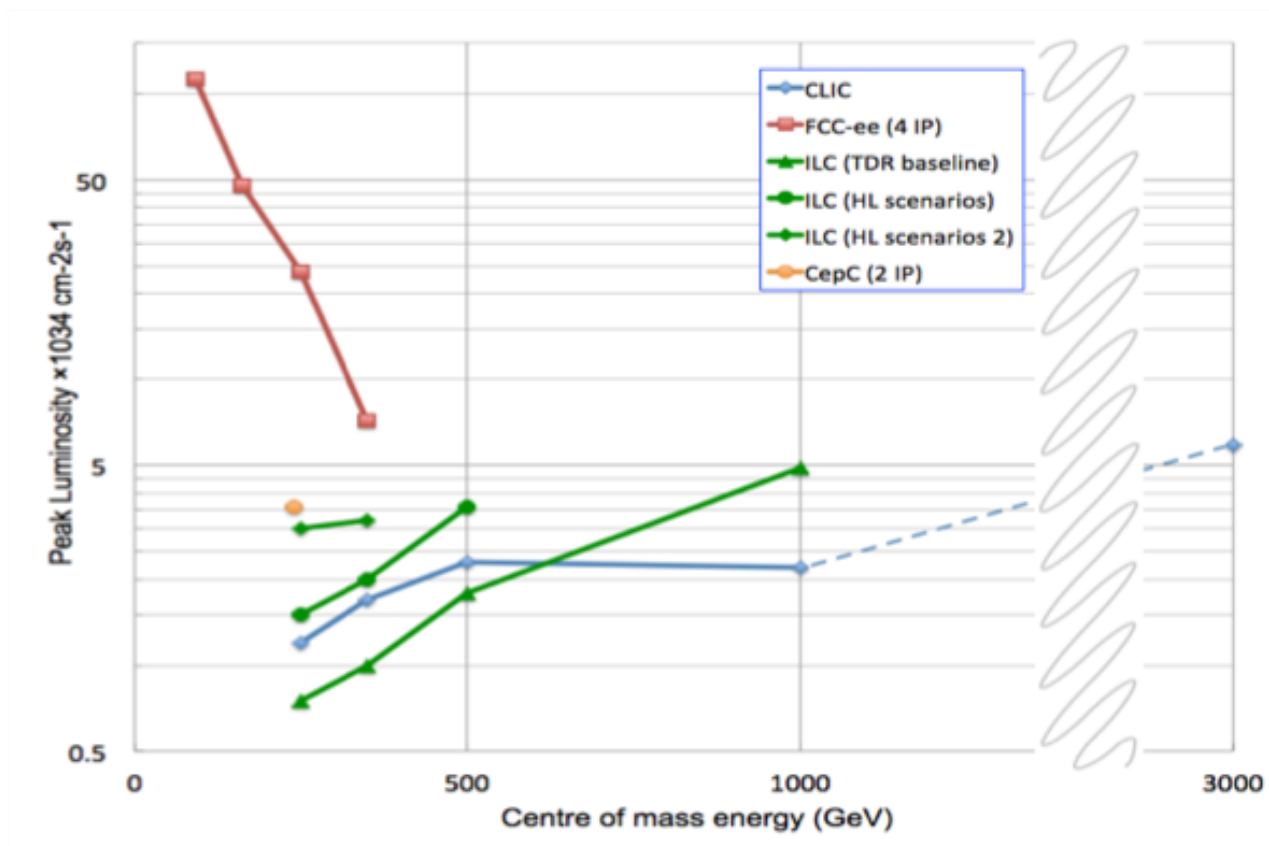
Kosten von ee-Collidern

- Kostenskalierung von ~ 200 GeV-Maschinen vor langer Zeit abgeschätzt
 - B. Richter, NIM 136 (1972) 47.
- Speicherringe skalieren mit $\sim E^2$
- Linearbeschleuniger skalieren mit $\sim E$
- Übergang bei ca. 300 GeV
 - Unklare Unsicherheiten
- Die Zukunft von ee ist (irgendwann) linear!



N. Walker

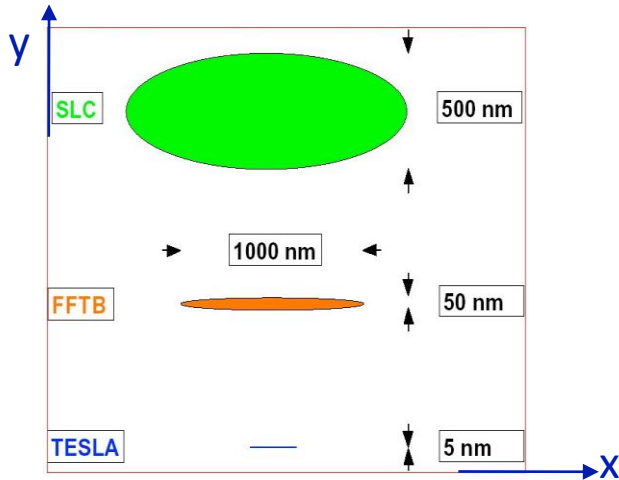
Luminosität von ee-Collidern



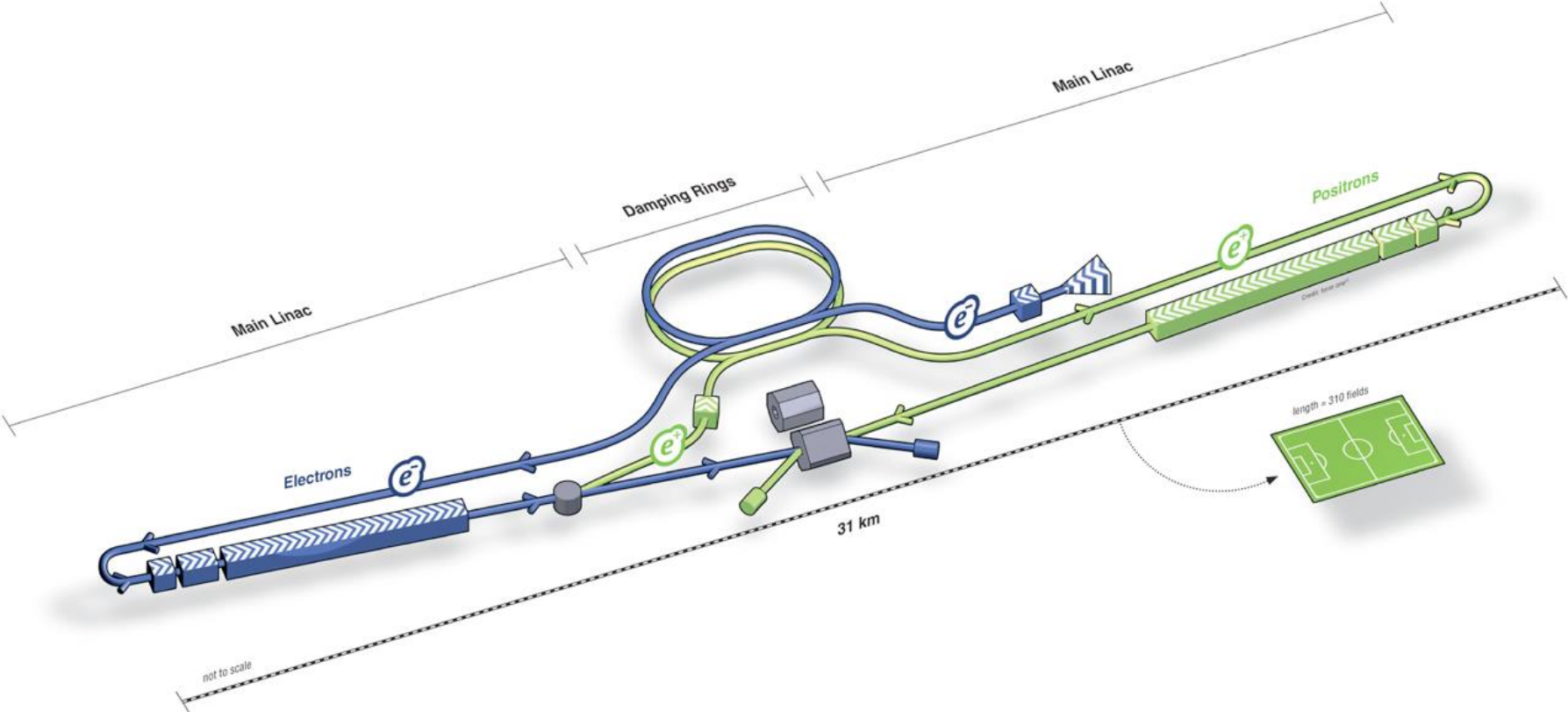
N. Walker

Der Großvater: SLAC

- Ring- versus Linearbeschleuniger:
 - f_{rep} (LEP): 44 kHz
 - f_{rep} (ILC) einige bis 100 Hz (Leistung!)
 - ➔ Faktor 1000 verloren!
 - ➔ Rettung: Beam-Größe!

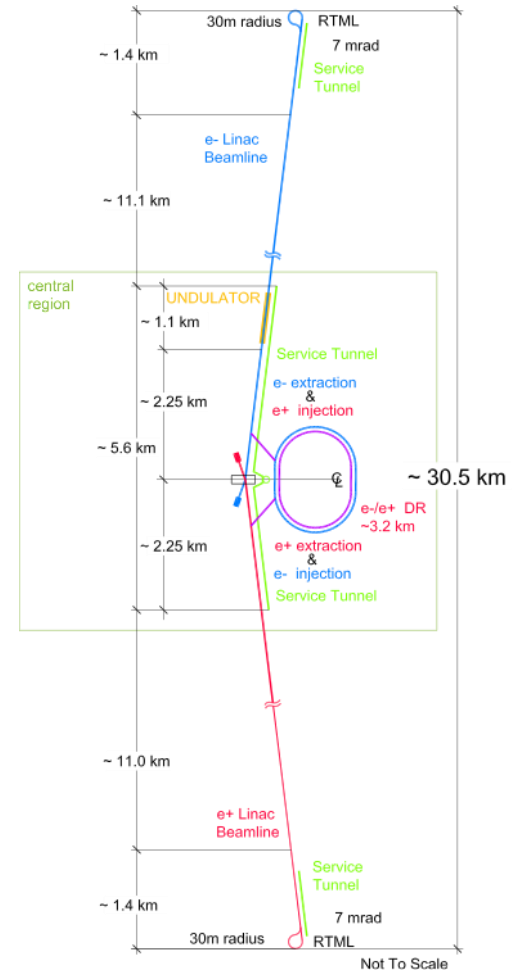


International Linear Collider (ILC)



International Linear Collider (ILC)

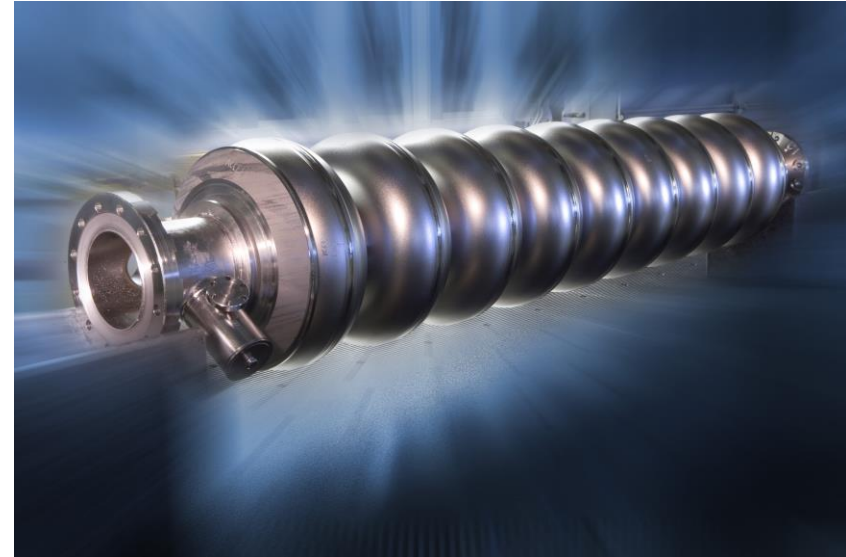
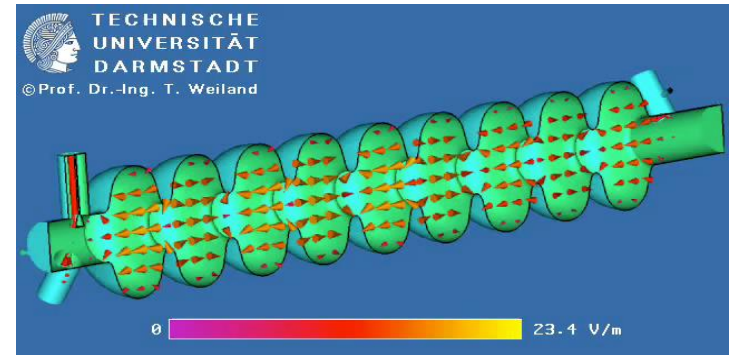
Physics	Max. E_{cm} Luminosity Polarisation (e-/e+) δ_{BS}	500 GeV $1.8 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ 80% / 30% 4.5%
Beam (interaction point)	σ_x / σ_y σ_z $\gamma\epsilon_x / \gamma\epsilon_y$ β_x / β_y bunch charge	574 nm / 6 nm 300 μm 10 μm / 35 nm 11 mm / 0.48 mm 2×10^{10}
Beam (time structure)	Number of bunches / pulse Bunch spacing Pulse current Beam pulse length Pulse repetition rate	1312 554 ns 5.8 mA 727 μs 5 Hz
Accelerator (general)	Average beam power Total AC power (linacs AC power	10.5 MW (total) 163 MW 107 MW)



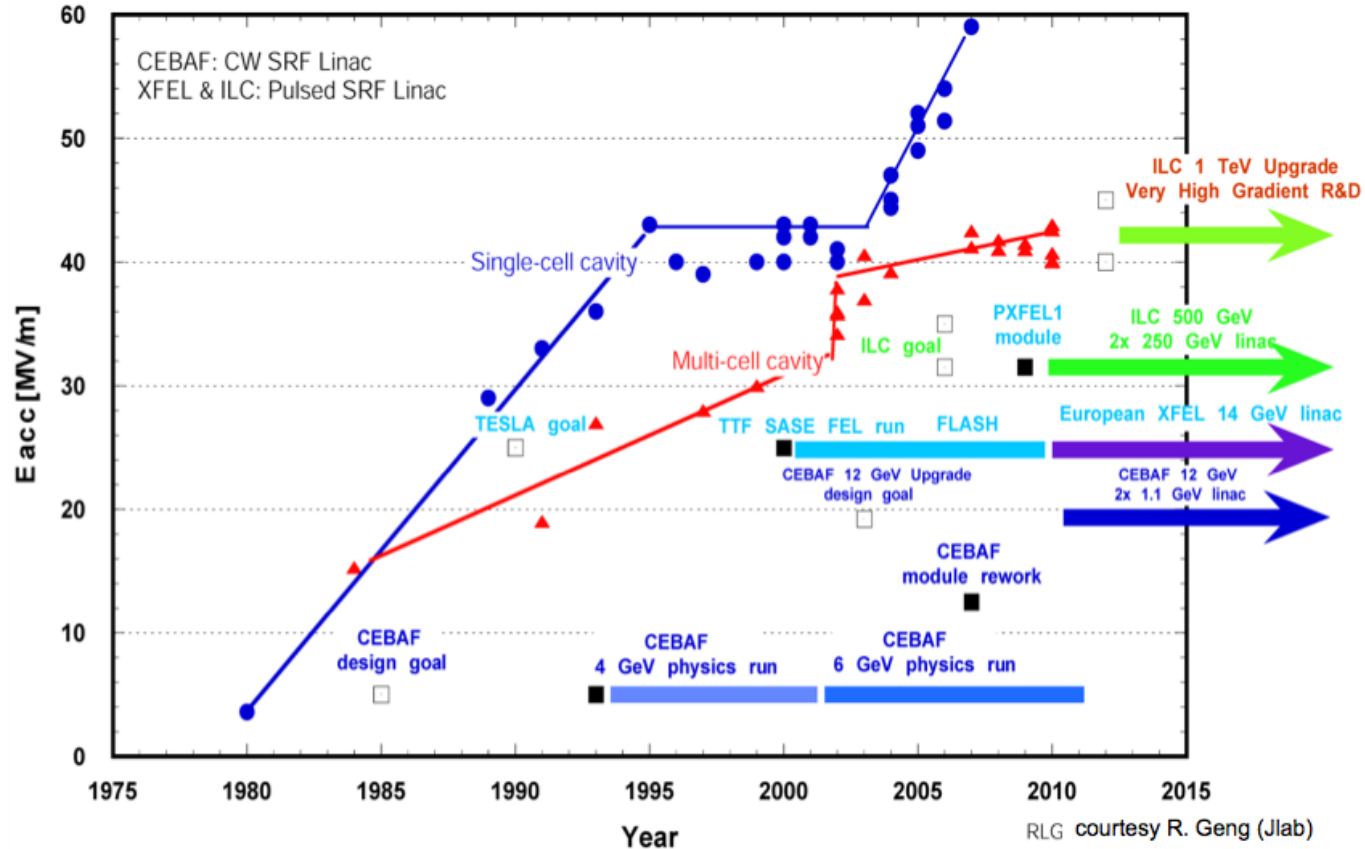
N. Walker

International Linear Collider (ILC)

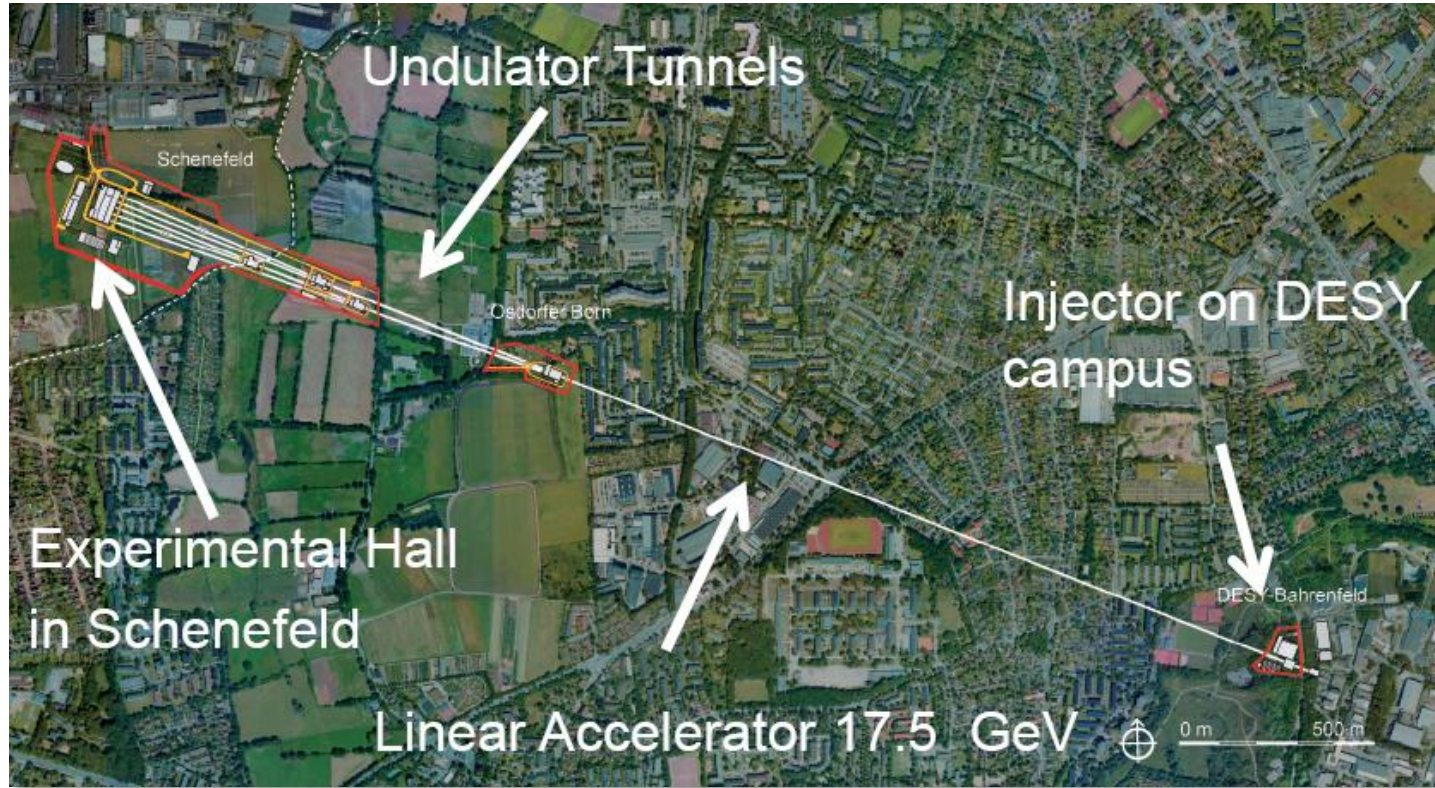
- Supraleitende Beschleunigungskavitäten
 - 2K He-gekühlt
 - 16000 Kavitäten in 1800 Kryomodulen
 - Gradient: ~ 35 MV/m – Kostentreiber
 - Q-Faktor 10^{10} !



International Linear Collider (ILC)



European XFEL



European XFEL

European XFEL

High-speed camera for the nano-world



European
XFEL



HELMHOLTZ
GEMEINSCHAFT



European XFEL

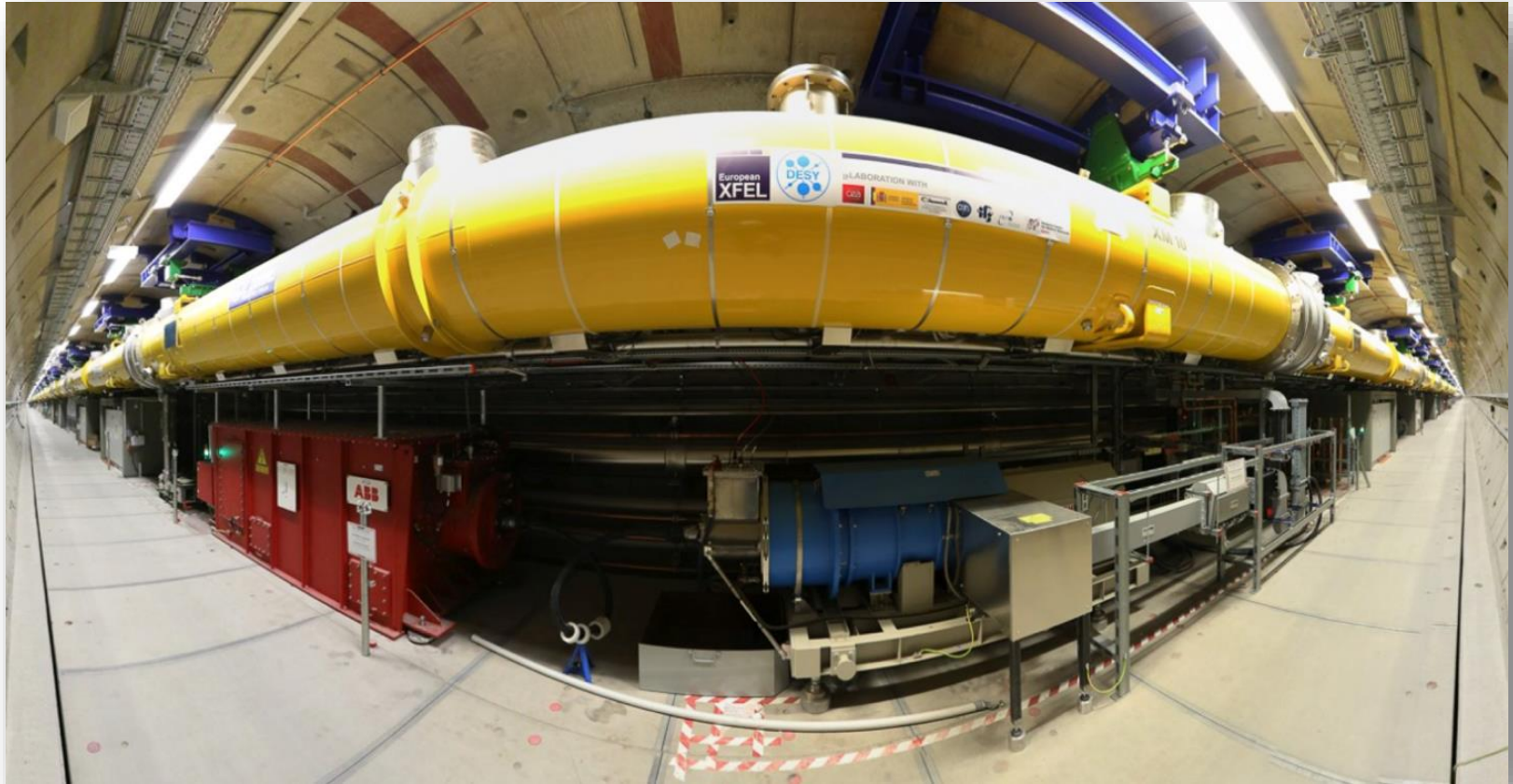
Ultrafast Science
Single Molecule Diffraction
High Energy Density Matter

2 km superconducting LINAC
17,5 GeV

1.145 Mio €

First Beam 2016

European XFEL



European XFEL

Industrialisation for XFEL

- > Mass production:
 - ☐ 100 cryomodules
 - ☐ 800 cavities
- > Largest deployment of this SCRF technology to date....
- > Large unbiased sample
 - ☐ critical for ILC

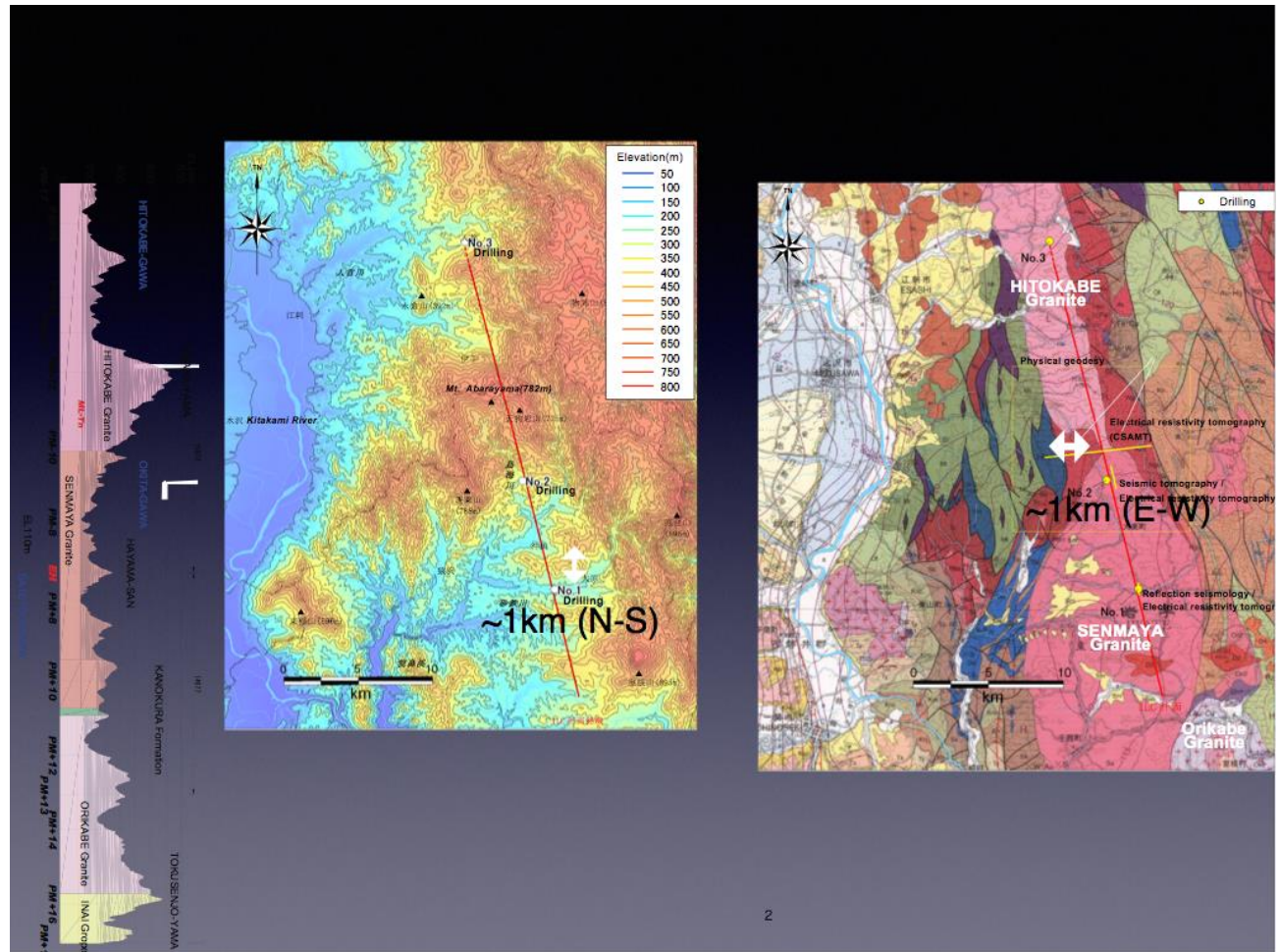


ILC in Japan?

- Japan hat Interesse am ILC angedeutet. Dieses Interesse wurde weltweit begrüßt.
- Japan hat einen möglichen Bauplatz identifiziert.
- Langwieriger politischer Prozess in Japan. Entscheidung 2018?

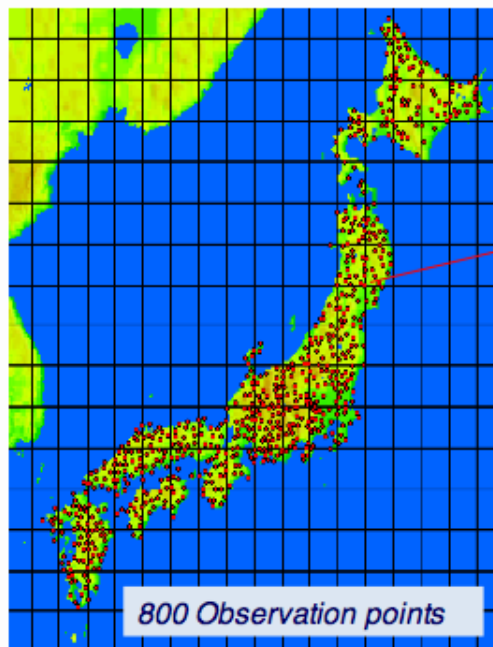


ILC in Japan?



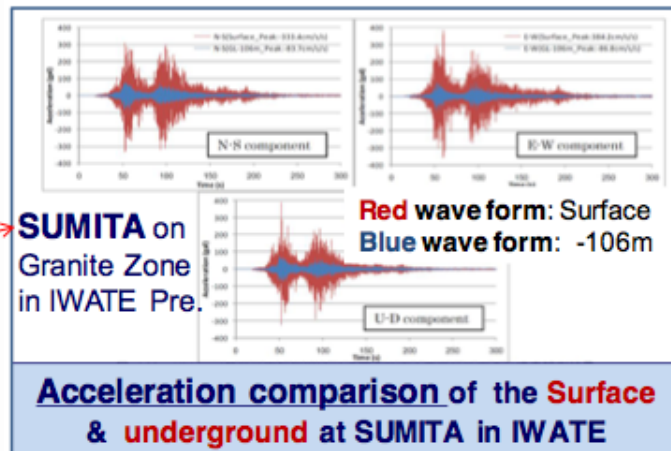
T. Sanuki

2



KiK-net Observation Network
(*Ki*ban:Bedrock, *Ky*oshin:Strong-Motion)

Data by "National Research Institute for Earth Science and Disaster Prevention"



Observation Data

Direction	Acceleration (gal)		Rate Underground /Surface
	Surface	Underground	
N-S	333.4	83.7	0.25
E-W	384.2	86.8	0.23
U-D	388.9	73.5	0.19

M. Miyahara

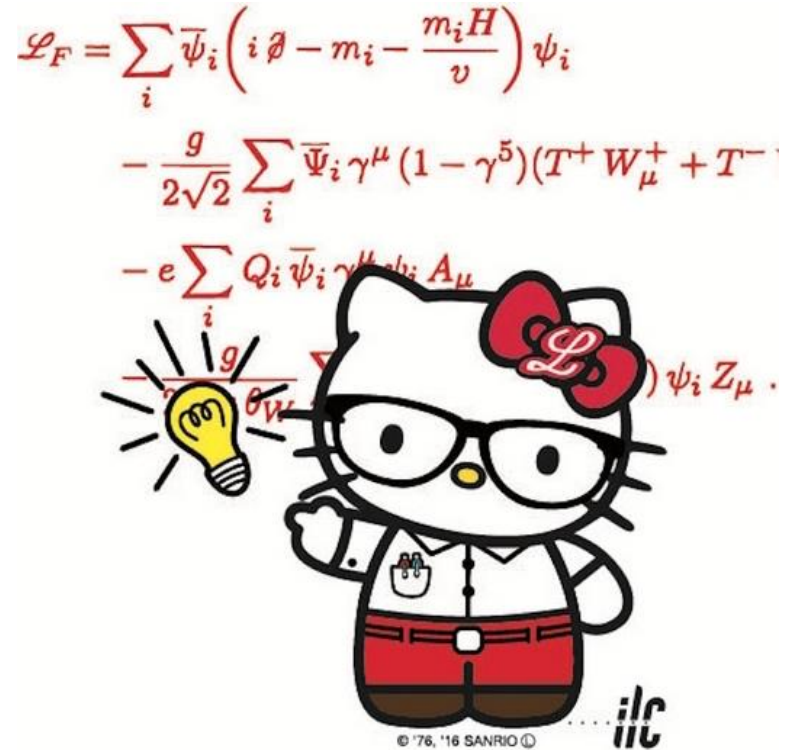
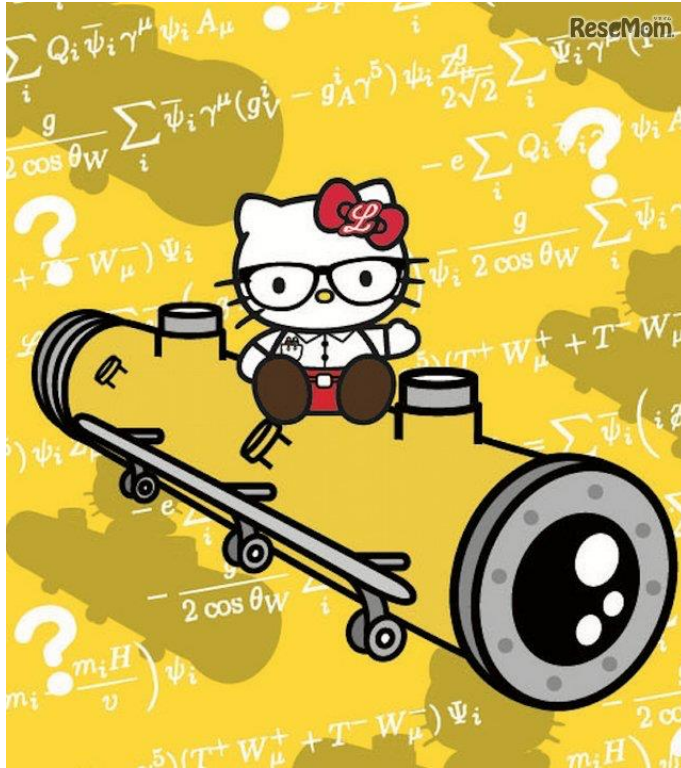
ILC in Japan?



ILC in Japan?



ILC in Japan?

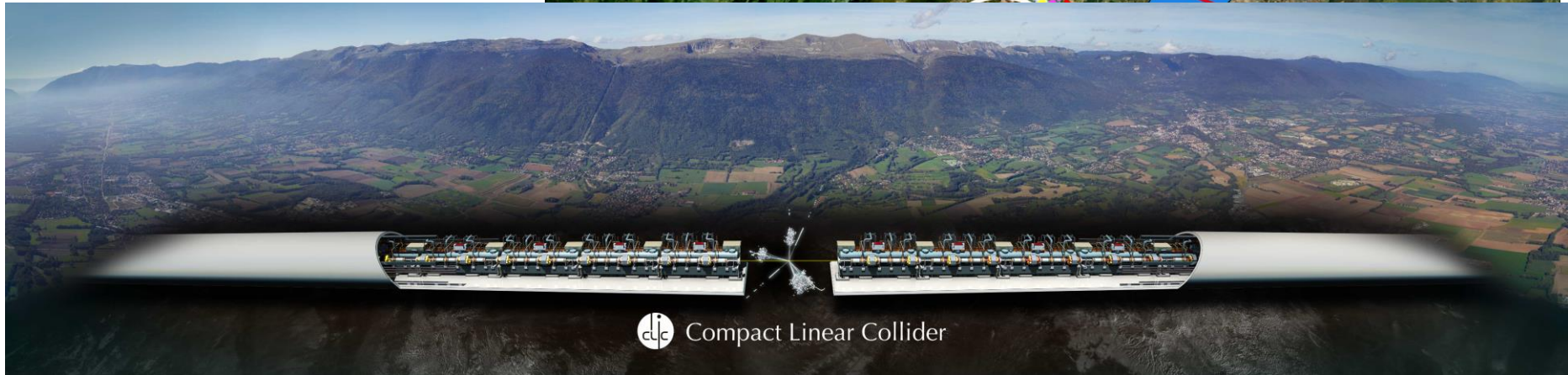
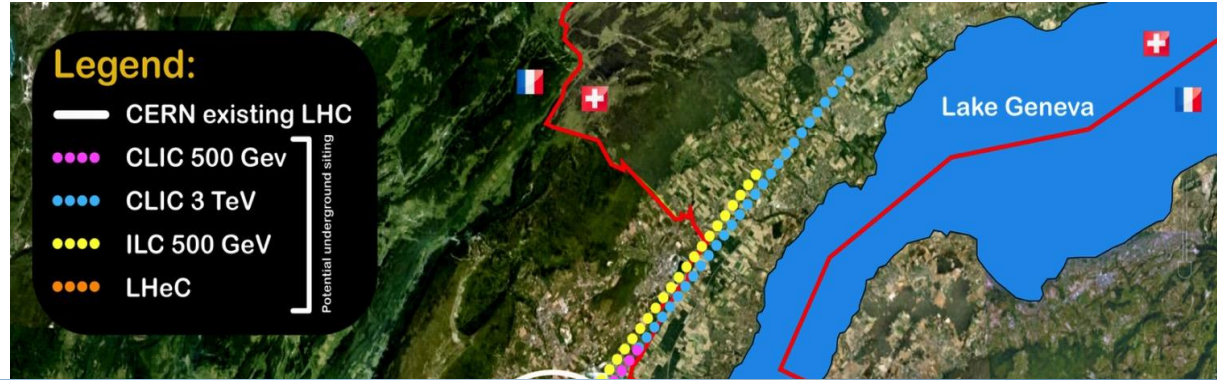


ILC in Japan?



CLIC – The Compact Linear Collider

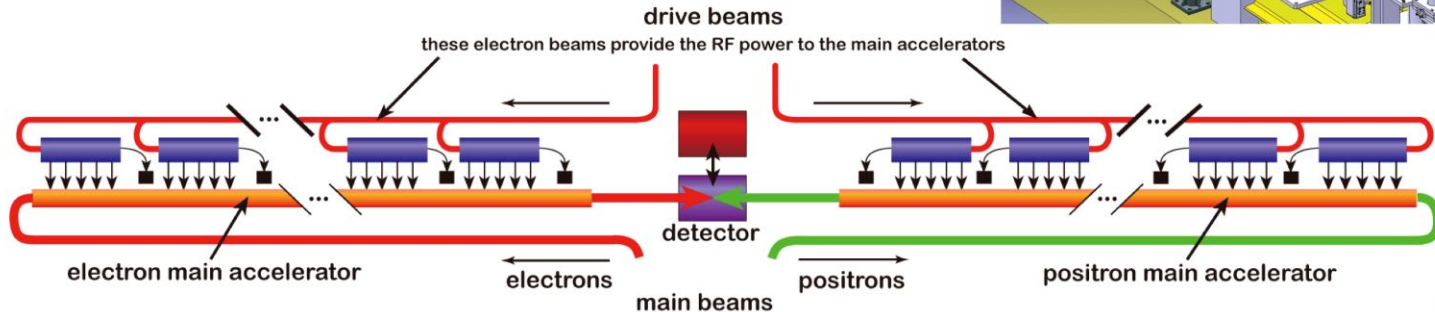
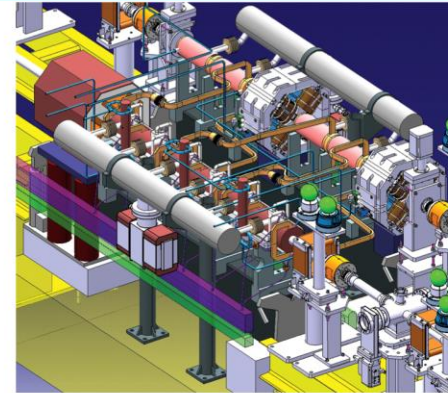
- Falls 1 TeV nicht genug?
- Höhere Gradienten nötig?
- Kalte Technologie?
- Neues Zwei-Beam-Konzept
- Design-Studie wie FCC



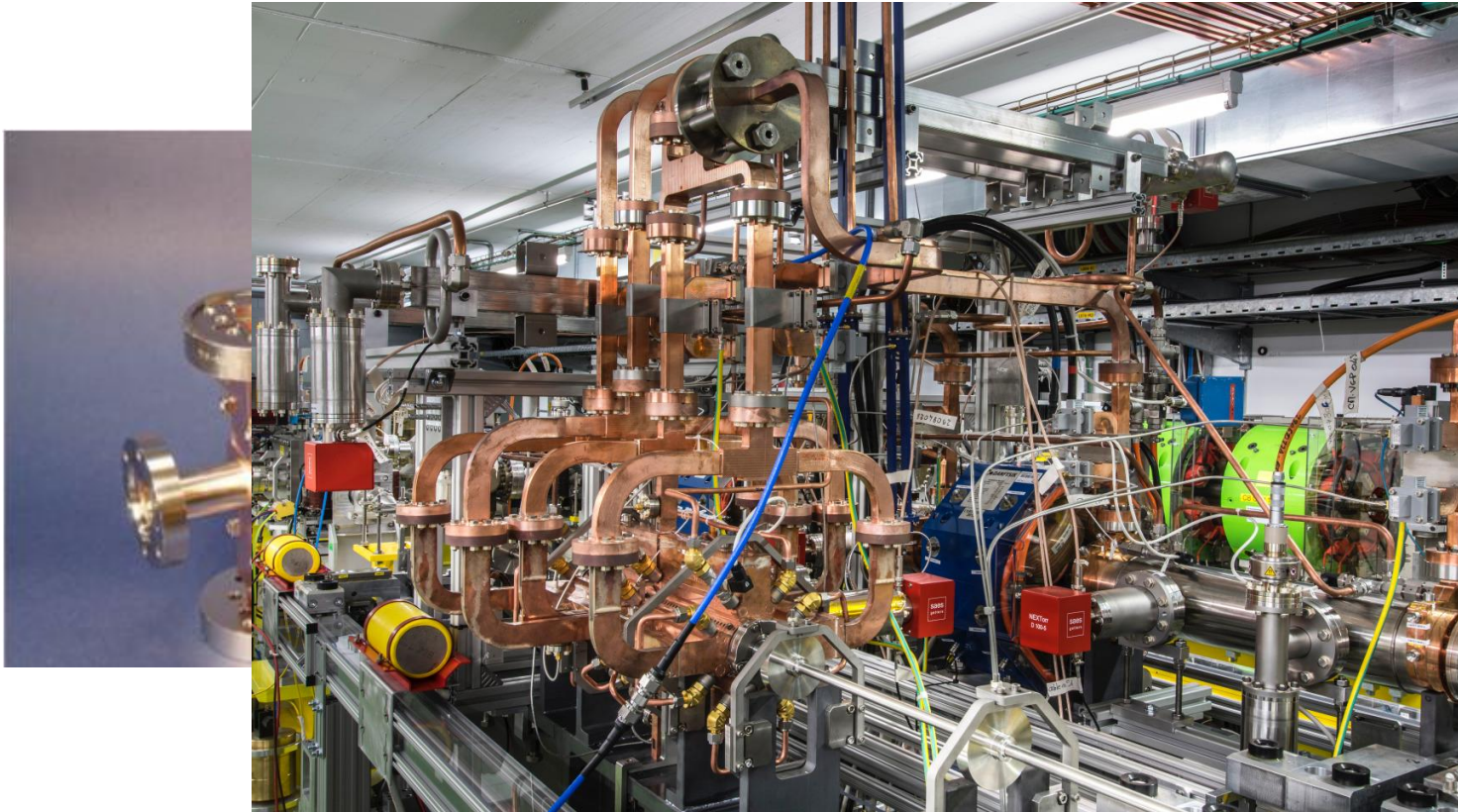
CLIC – The Compact Linear Collider

Two-Beam Acceleration Concept

- > Low energy high current beam produces RF for high-gradient accelerating cavities
- > Project technically not as advanced as ILC, i.e. is not yet „construction-ready“
 - ❓ possible „next big thing“ at CERN?



CLIC – The Compact Linear Collider



g:
~ 380 GeV

380 GeV	3 TeV
0.38	3
1.5	5.9
0.9	2.0
50	50
352	312
0.5	0.5
72	100
11	50

The Staged Linear Collider

- > In principle, a linear collider can run on any energy between ~ 90 GeV and several TeV
 - ☐ linear colliders are scalable, it is mostly a question of cost...
- > Develop a staged approach
 - ☐ start where interesting physics is guaranteed, extend to higher energies later



- > ILC₂₅₀ CLIC₃₈₀: Higgs measurements (mass, spin, couplings), EW physics, (...)
- > ILC₃₅₀ CLIC₃₈₀: Top physics, (...)
- > ILC₅₀₀: Higgs self coupling, Top-Higgs Yukawa coupling, (...)
- > ILC₁₀₀₀₊ CLIC₁₀₀₀₊: SUSY, whatever comes, (...)
- > CLIC is the only viable multi-TeV option, PWA accelerators later

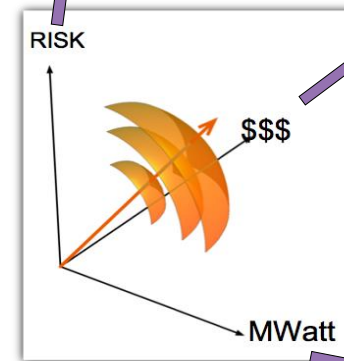
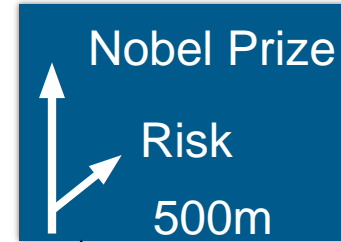
Gliederung

- Teilchenphysik: Status, Probleme, Strategie
- Laufende und zukünftige (Groß)Projekte
- **Einschub: Politik und Finanzierung**
- Teilchenphysik: DESYs Strategie und zukünftige Orientierung

Auslassung: “Plasma wakefield”-Beschleuniger und Myon-Collider

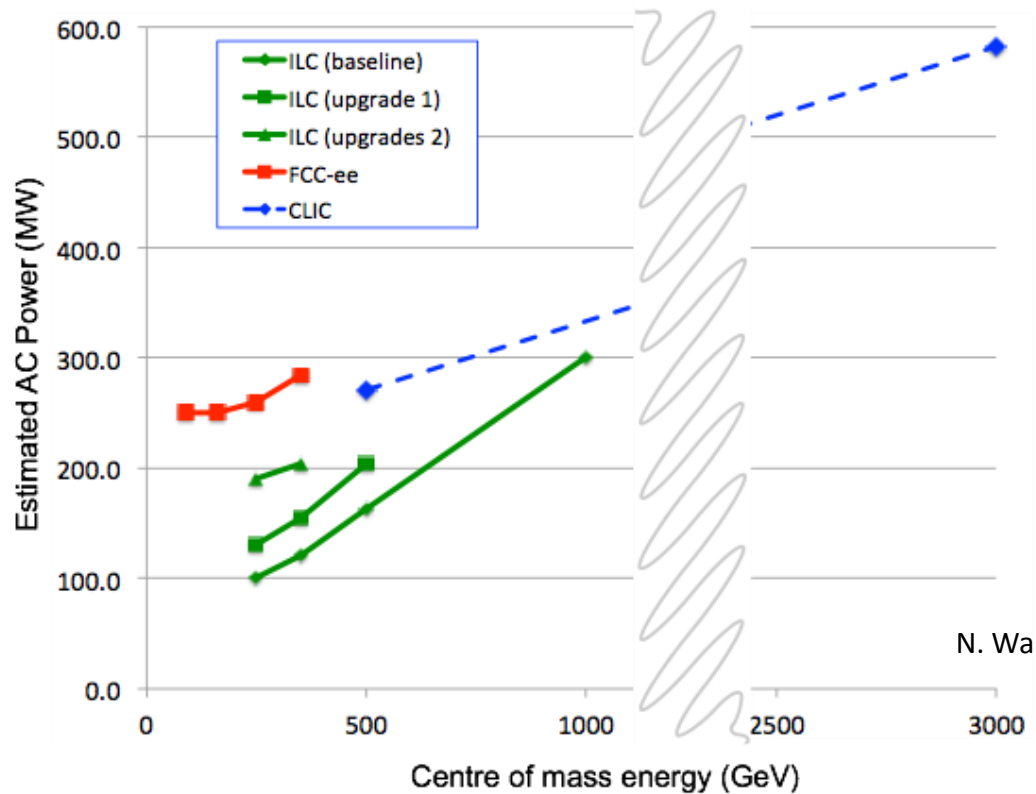
“Pushing the envelopes”

- Physik:
 - Energie und Luminosität?
- Energie als Kostentreiber:
 - Hadronen: Hochfeldmagnete
 - Leptonen: Gradient
- Luminosität treibt Leistungsverbrauch
 - Zumindest für Leptonen
 - Das treibt die Betriebskosten
 - Umweltaspekte?
- Schlussendlich: EUR / GeV!
 - Für ein bestimmtes Risikoniveau
 - Kann nur durch F&E abgemildert werden.



Leistung Leistung Leistung

LHC: < 100 MW!

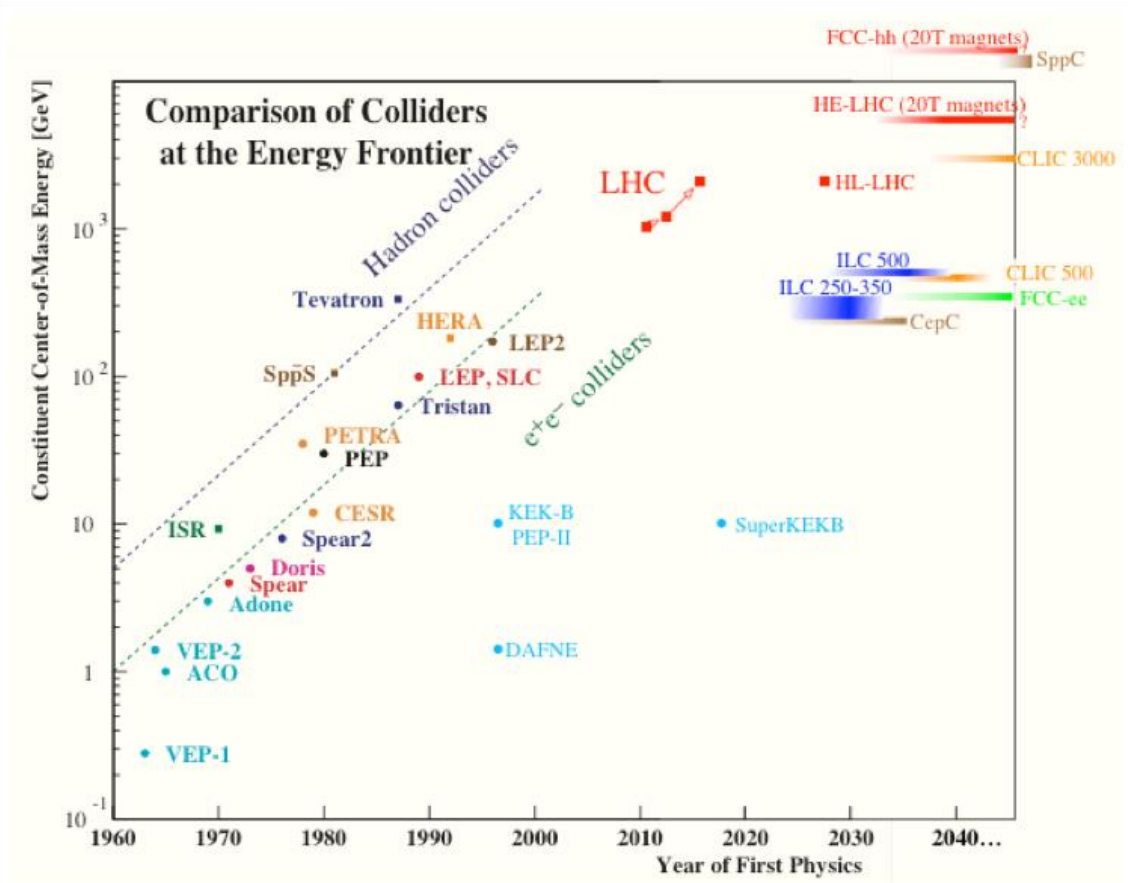


N. Walker

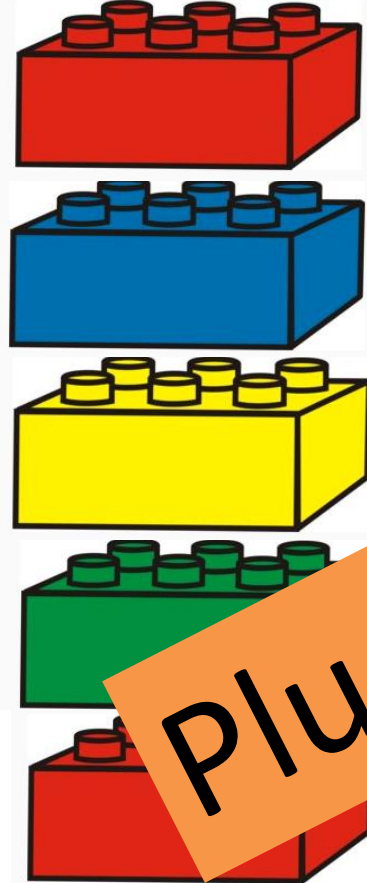
Leistung Leistung Leistung

Project	Particles	Energy	Status	Power	Cost	First Beam	Host
LHC-HL	pp (pA/AA)	14 TeV	approved	$O(100 \text{ MW})$	$\sim 975 \text{ MCHF}$ (machine)	~ 2025	CERN
LHC-HE	pp (pA/AA)	$\sim 28 \text{ TeV}$	pre-conceptual	?	?	$\gg 2035$ (post-LHC)	CERN
SppC	pp (pA/AA/ep)	50-100 TeV	pre-conceptual	?	?	> 2042	China
FCC-hh	pp (pA/AA/ep)	80-100 TeV	pre-conceptual	?	?	$\gg 2035$ (post-LHC)	CERN
FCC-ee	e^+e^-	90-350 GeV	pre-conceptual	$\sim 250\text{-}300 \text{ MW}$?	$\gg 2035$ (post-LHC)	CERN
CepC	e^+e^-	90-250 GeV	pre-conceptual	$\sim 300 \text{ MW}$?	> 2028	China
ILC	e^+e^-	0.25-1 TeV	construction-ready	120-300 MW	7.98 G\$ (500 GeV)	> 2027	Japan
CLIC	e^+e^-	0.5-3 TeV	conceptual	270-590 MW	$O(8) \text{ GCHF}$ (500 GeV)	$\gg 2035$ (post-LHC)	CERN
LBNF/DUNE	Neutrinos	60-120 GeV (p) <10 GeV (v)	„approved“	?	$O(1.5) \text{ G\$}$	2028	FNAL
Muon	$\mu^+\mu^-$	3 TeV	pre-conceptual	???	???	???	???

Leistung Leistung Leistung



Fundina



DFG (SFBs, Projekte etc.), EU, ...

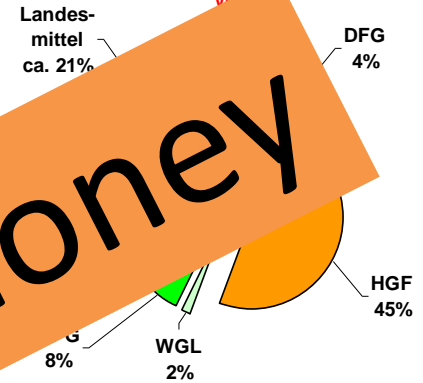
HGF ca. 30 M€/a (dazu MPG et

CERN-Beitr

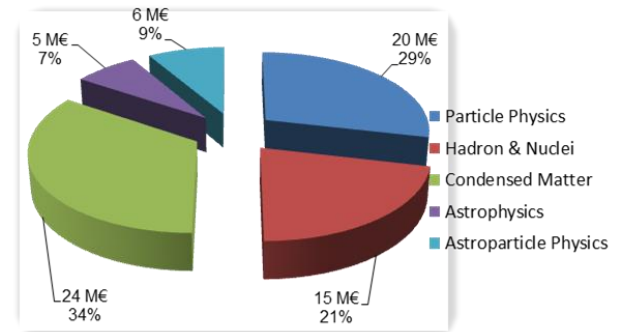
orschung (HEP: 20 M€/a)

Universitäten (finanziert über die Länder, Grundausrüstung)

Hadron&Nuclear 2012:



Average annual expenditures



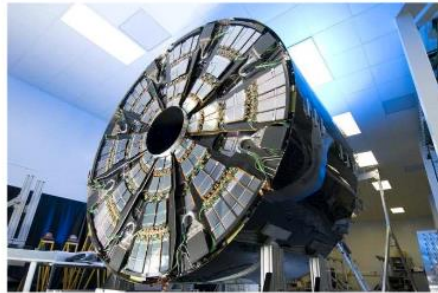
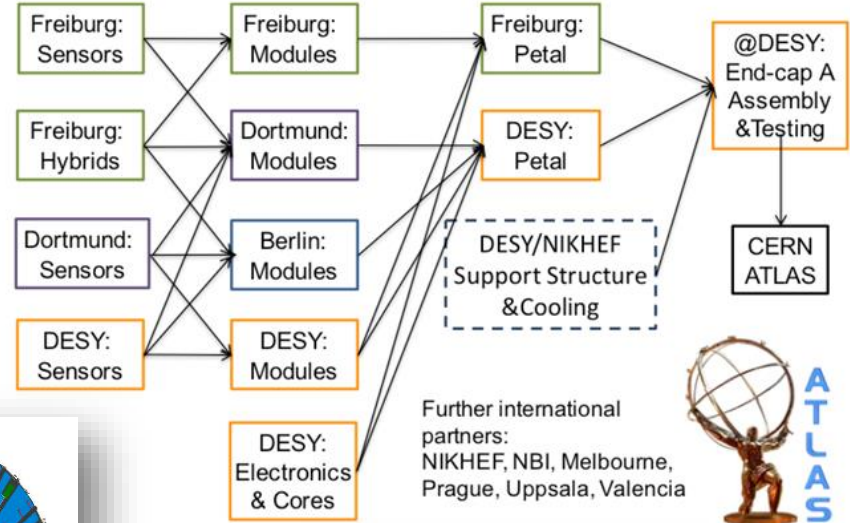
Plus: Big project money

Gliederung

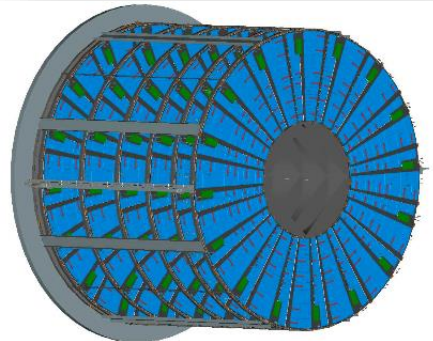
- Teilchenphysik: Status, Probleme, Strategie
- LaufendEinschub: Politik und Finanzierung
- e und zukünftige (Groß)Projekte
- **Teilchenphysik: DESYs Strategie und zukünftige Orientierung**

Projektgeld – Beispiel HL-LHC-Upgrades

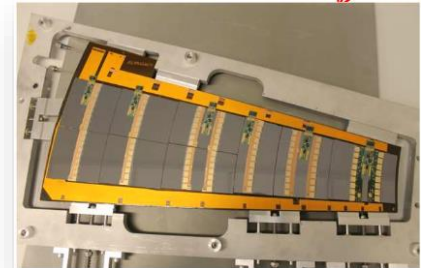
- Weltweites Projekt bis ca. 2026
- In D: Beteiligung aller relevanten Partner:
 - 90 MEUR von BMBF für die Universitäten zur Ertüchtigung von ATLAS und CMS:
 - 15.7 MEUR von HGF für DESY (und KIT / GSI)
 - 10 MEUR von DESY für die Detector Assembly Facility.



Current Endcap of the CMS tracking detector in the TIF at CERN

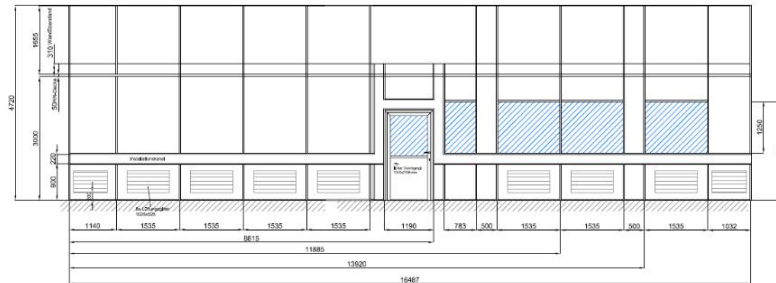
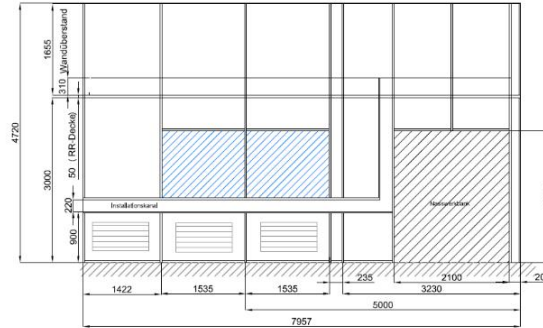
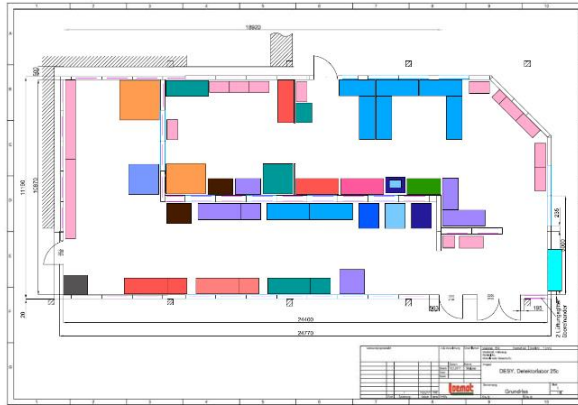


Planned endcap of the ATLAS Silicon-Tracker

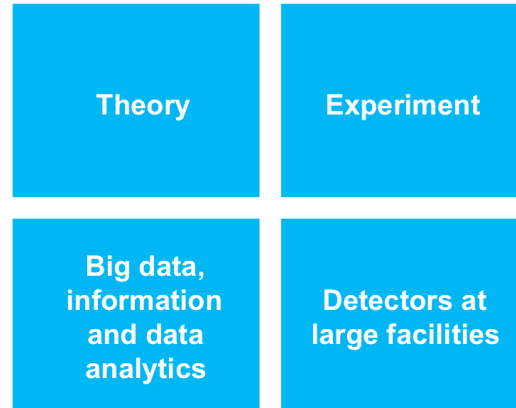
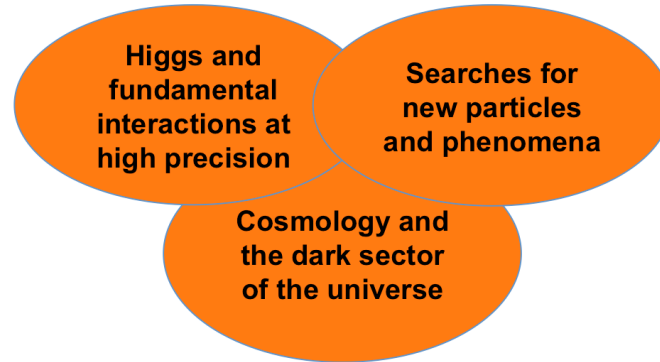


Detector Assembly Facility

Building 25c - Cleanroom Planning



DESY-Strategie in HEP



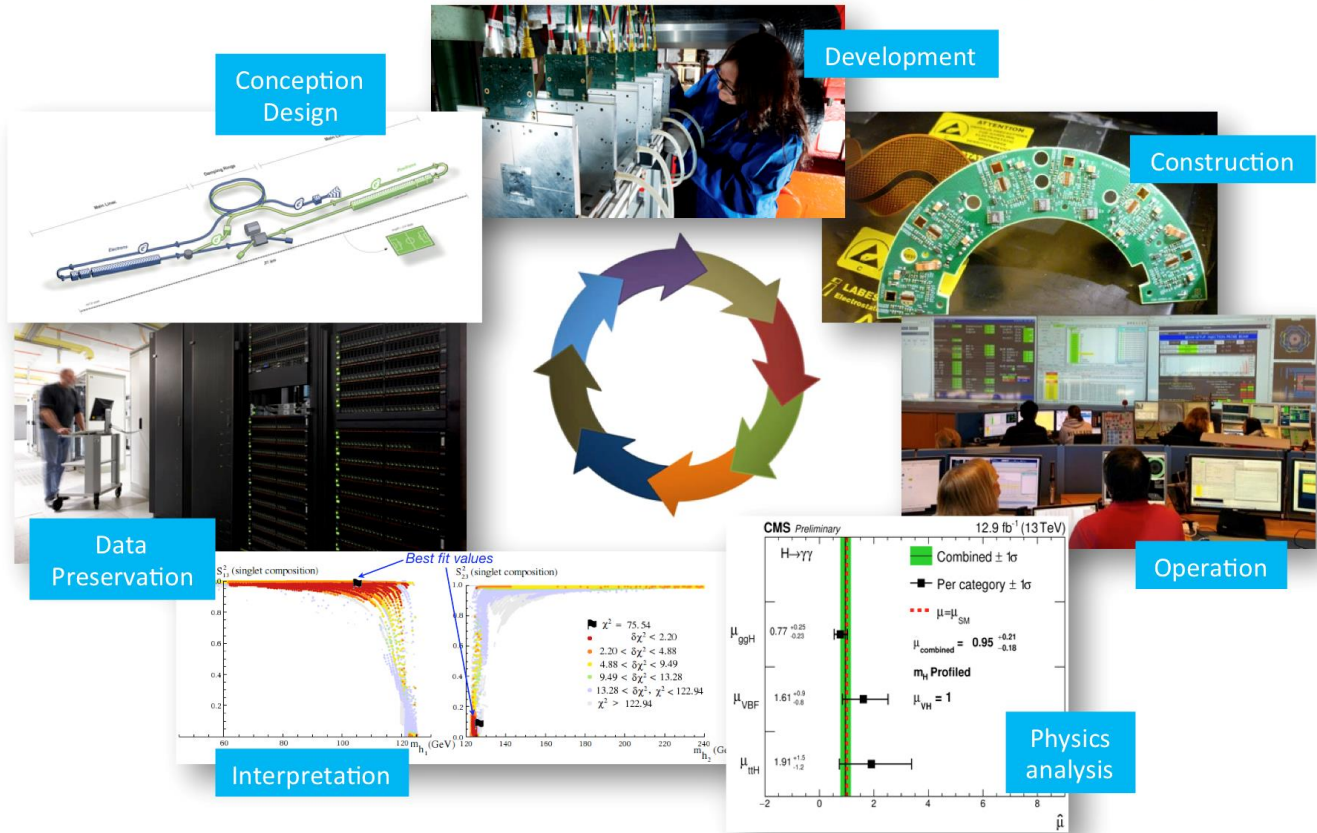
Activities:

- Data analysis
- Interpretation
- Guidance
- New directions

Tools:

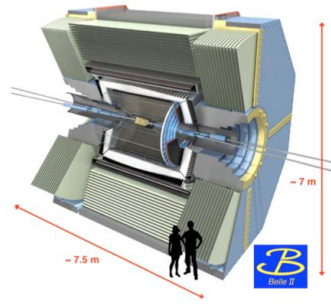
- Data analytics
- Grid & cloud and HPC
- Strategic planning, design, construction, operation

“Lifecycle Competence”



Portfolio

Theory

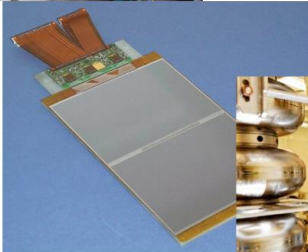


Belle /
Belle II

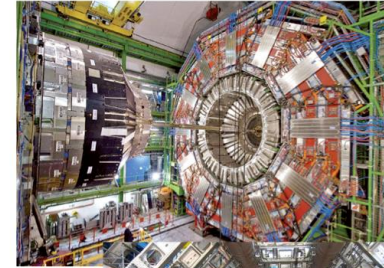
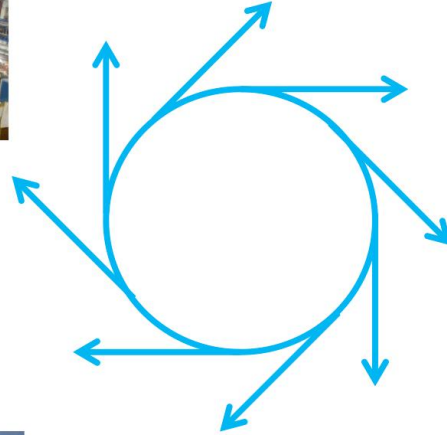
ALPS



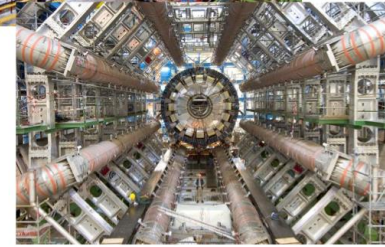
Olympus



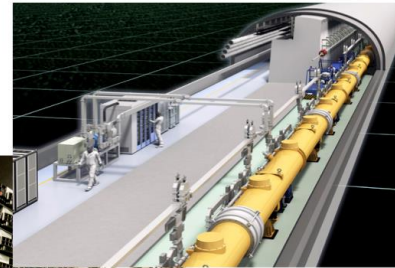
Detector / accelerator R&D



CMS



ATLAS



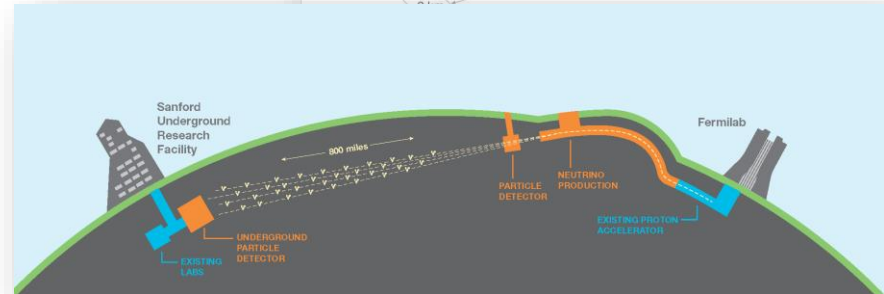
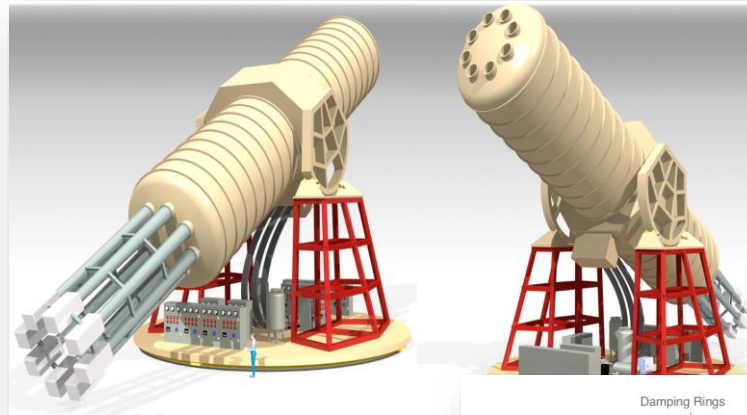
ILC / ILD



Computing

2025?

- HL-LHC läuft an
- Belle II läuft langsam aus
- ALPS II ist durch
- IAXO?
- MADMAX?
- ILC?
- DUNE
- Beschleuniger- und Detektor-R&D
- ?????

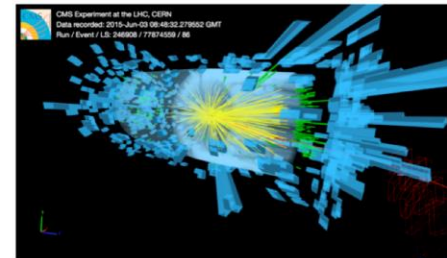
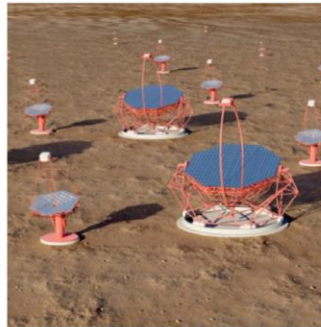
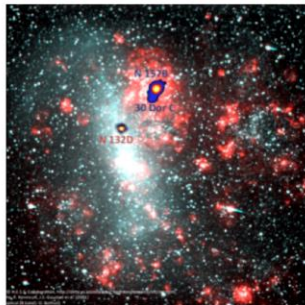
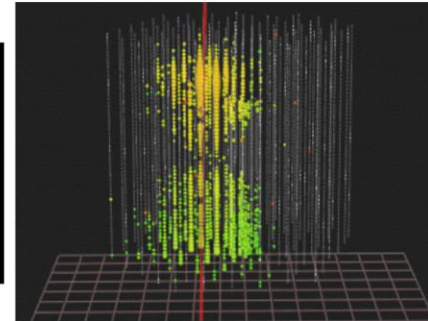
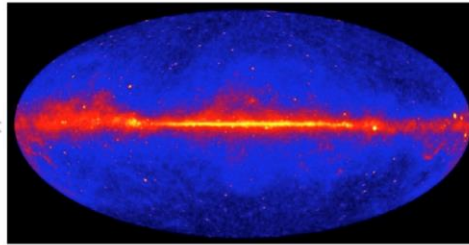
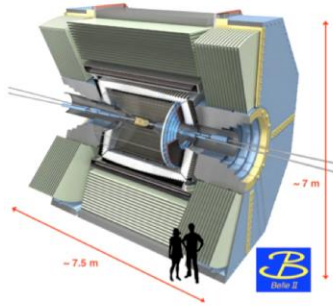


Schlussfolgerungen

- Higgs-Entdeckung: Eine neue Energieskala für neue Beschleuniger!
 - 200-500 GeV: Masse, Quantenzahlen, Kopplungen, Top
 - Bis ~ 1 TeV: Higgs-Potenzial
 - Präzision und Energie: Die Suche nach dem Unbekannten ...
- LHC / HL-LHC als einzige genehmigte Projekte
 - LBNF/DUNE das einzige weitere konkrete große HEP-Projekt
 - Was dann? \rightarrow Was ist das Narrativ der Teilchenphysik?
- Elektron-Positron könnte den LHC komplementieren
 - Linearcollider können am ehesten in die leptonische TeV-Welt eintauchen
 - Große Speicherringe sind bis 350 GeV interessant (CepC, FCC-ee)
- Große Hadron-Collider für bis zu 100 TeV sind in Diskussion (SppC, FCC)
 - Kein “physics case” – Schuss ins Blaue
 - Magnet-F&E nötig
 - Myon-Collider, PWA?
- Think about money!
- “Take home”-Botschaft: Es dauert, es ist teuer, und es braucht die ganze Welt!

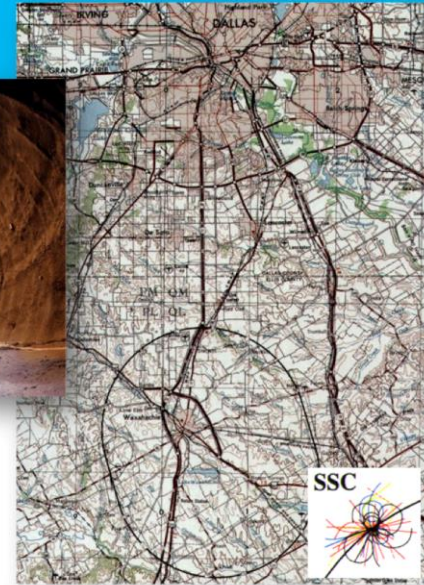
Needed: Combination of different sources of information

- > Colliders provide only part of the information we need to unravel the mysteries.
 - Need hadron colliders, lepton colliders, low-energy / high-intensity machines, neutrinos, astroparticles and cosmological observations – and all must fit!



But beware ...

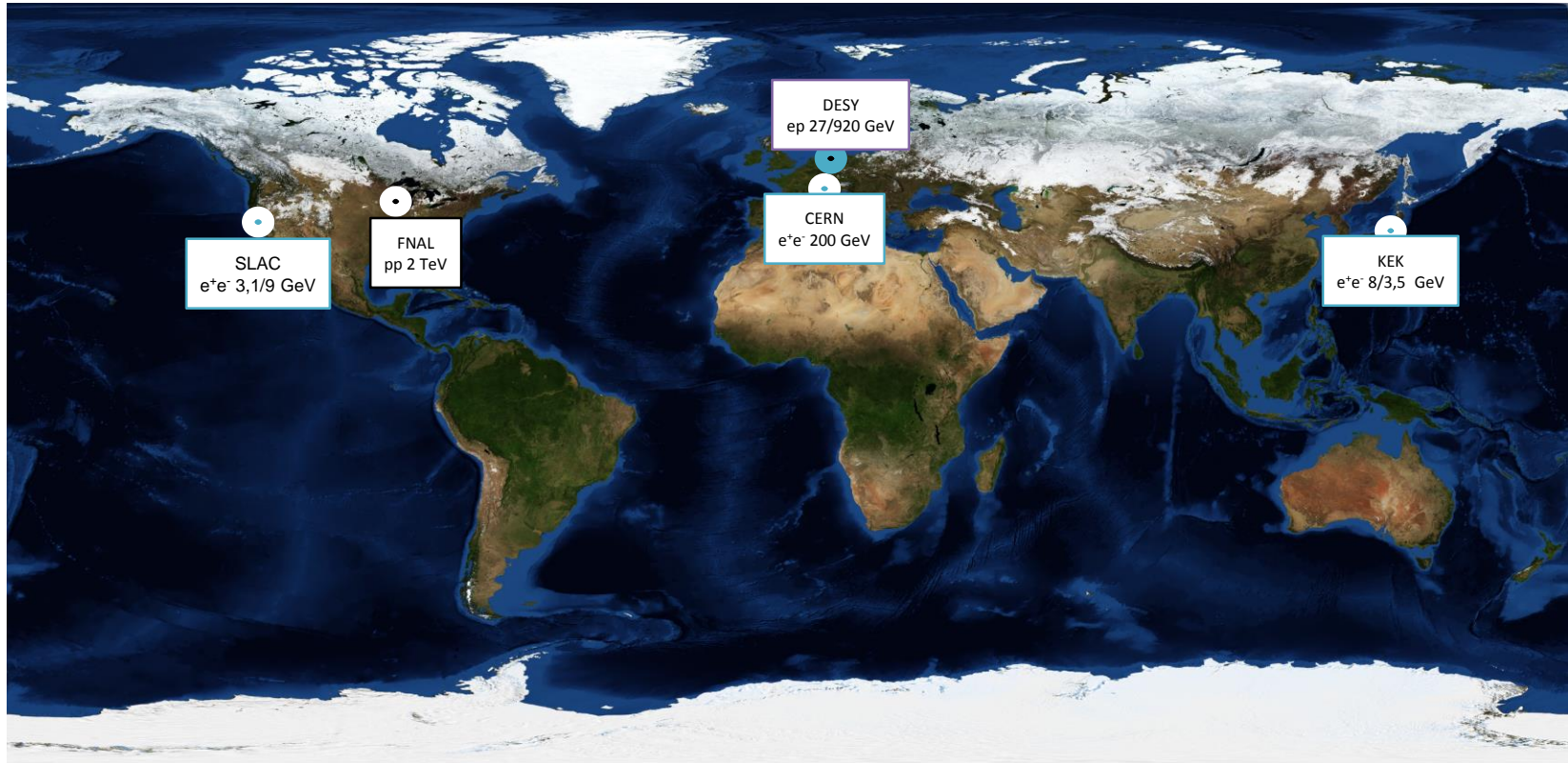
- Others tried to think big before!
- Super-conduction Super Collider SSC (USA)
 - pp collider in 87 km tunnel
 - first ideas in 1983, construction since 1987,
 - stopped in 1993 by Congress, with half the tunnel ready. Reason: Cost increase...
- UNK in Serphukov: 21 km pp storage ring with up to 6 TeV CMS energy (planned 1983)
 - later de-staged to a 2*600 GeV machine (U-600).
 - in 1998, 75% of the U-600 dipoles available and mostly tested. A quarter of the ring ready for installation.
 - complete stop in 1998; since then tunnel and equipment kept under safe conditions.



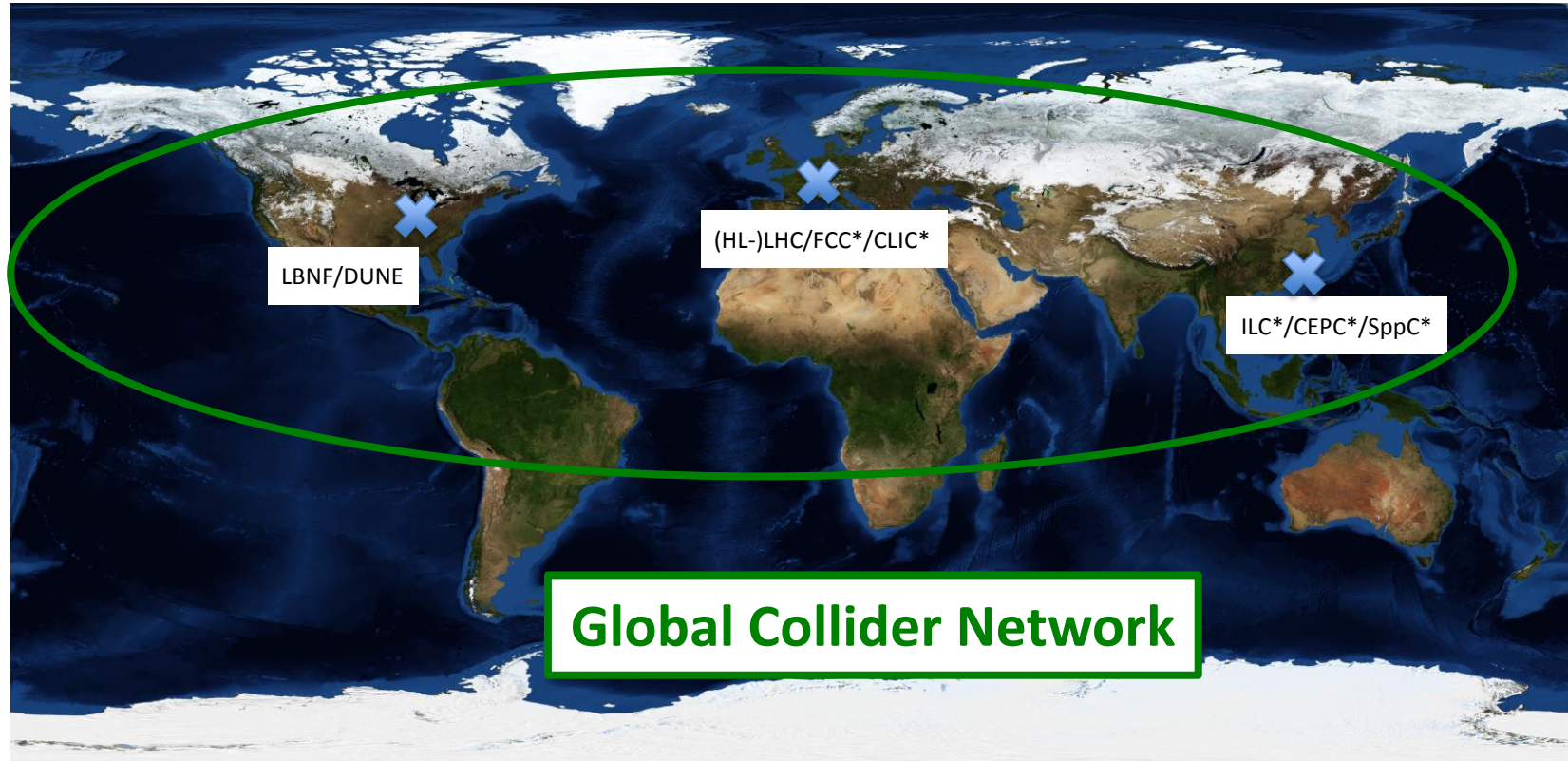
<http://a-a-ah.com/accelerator>



Im Jahr 2000 ...



Im Jahr 2030 ...?



Not covered ...

- Flavour-Physik (Belle II)
- Neutrino-Physik (LBNF/DUNE, Hyper-K)
- Axion-Physik etc. (ALPS II etc.)
- ...