

THE FUTURE

by
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1. KINDERGARTEN PARTONS

2. HIGGSTERIA

3. DARK MATTER / HIGGS

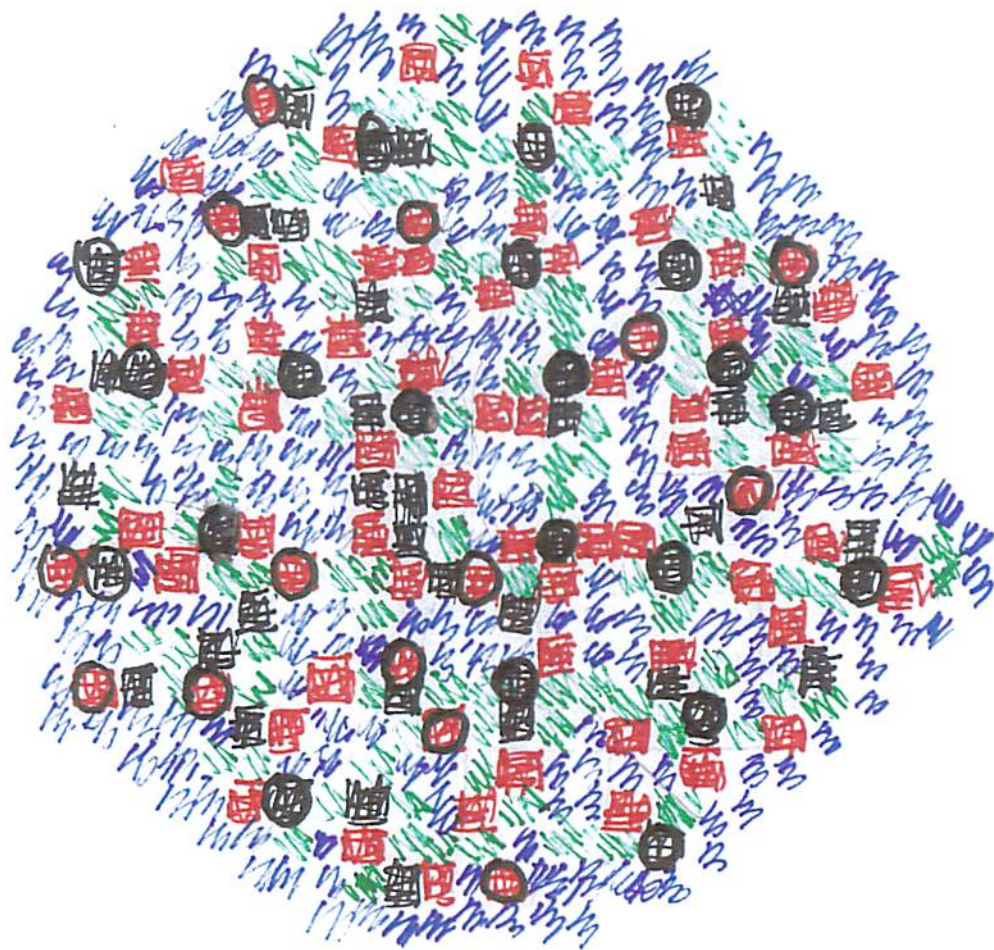
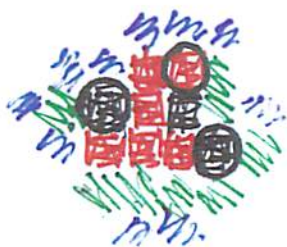
4. DARK ENERGY / DARKNESS

5. COMMENTS

PIXELIZED HADRONS (BEAM'S-EYE VIEW)

LEFT-MOVING
CARBON NUCLEUS

LEFT-MOVING
PROTON



-  $x > 0.1$
-  $0.1 \geq x > 0.03$
-  $0.03 \geq x > 0.01$
-  $0.01 \geq x \geq .001$

x = LONGITUDINAL MOMENTUM FRACTION PER NUCLEON

A PIXELIZED ION-ION COLLISION

■ × ■ → ■:

$$\sqrt{x_L x_R} \gtrsim 0.1$$

■ × ■ → ■:

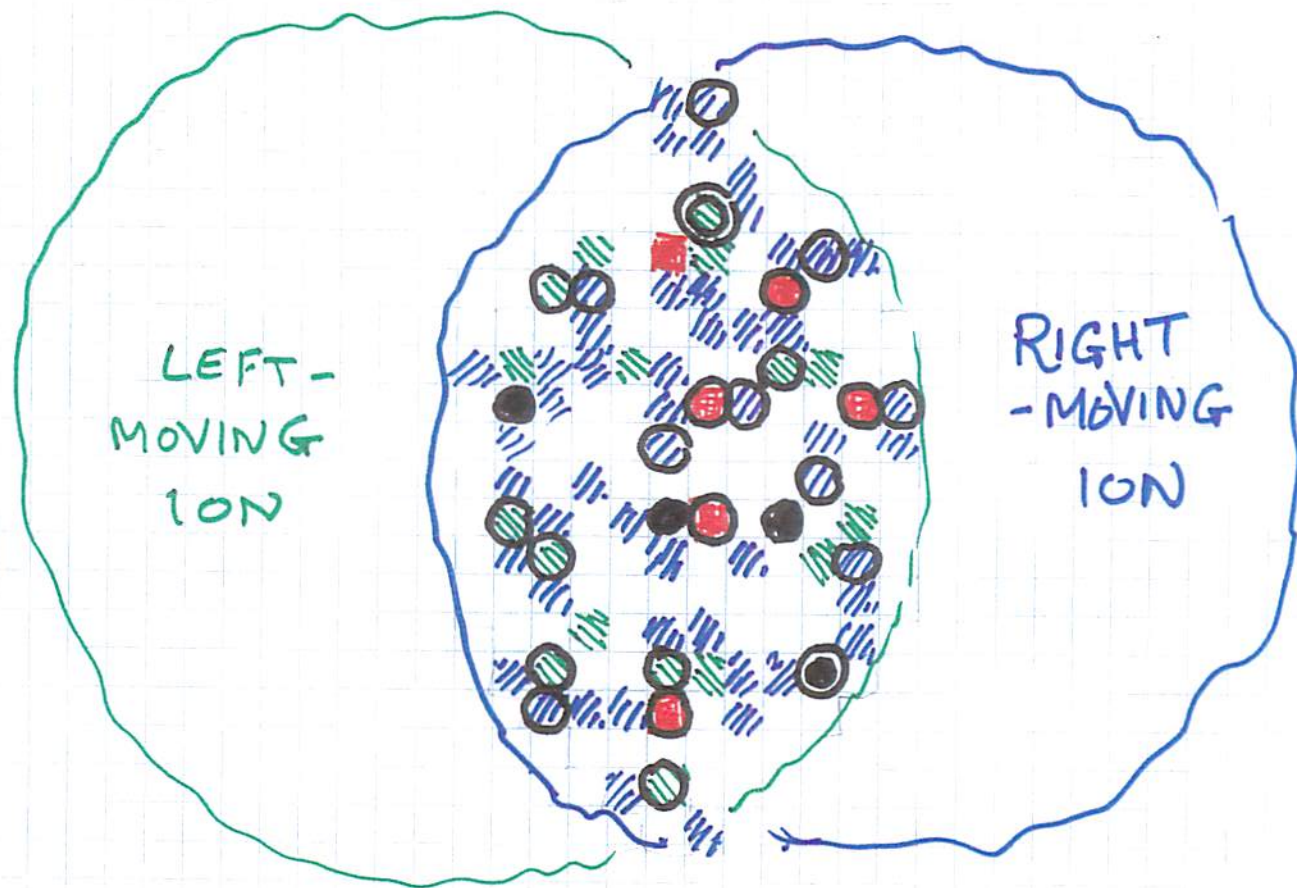
$$0.1 \gtrsim \sqrt{x_L x_R} \gtrsim 0.01$$

■ × ■ }
■ × ■ } → ■:

$$0.01 \gtrsim \sqrt{x_L x_R} \gtrsim 0.001$$

■ × ■ }
■ × ■ }
■ × ■ } → ■:

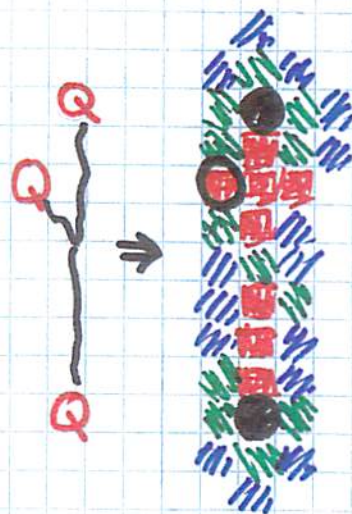
$$0.001 \gtrsim \sqrt{x_L x_R} \gtrsim 0.0001$$



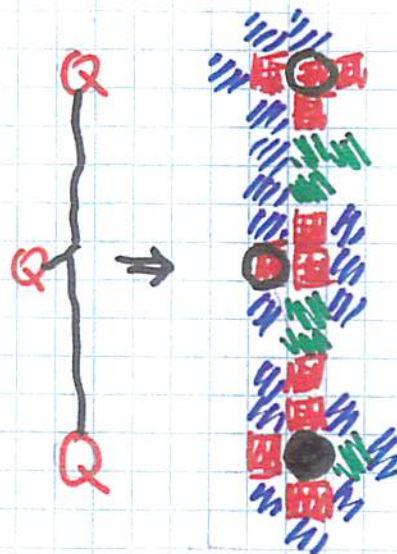
AN UNUSUAL (PIXELIZED) PP COLLISION (BEAM'S-EYE VIEWS)

S. Brodsky
F. Goldhaber
bj

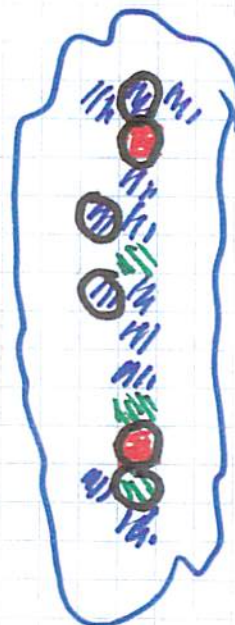
LEFT
- MOVER



RIGHT
- MOVER



COLLISION



HIGGSTERIA

Flavor symmetry $\equiv SU(6)_L \times SU(6)_R$

Family symmetry $\equiv SU(3)_L \times SU(3)_R$

family triplets: $\begin{pmatrix} u \\ c \\ t \end{pmatrix}_{L,R}$ $\begin{pmatrix} d \\ s \\ b \end{pmatrix}_{L,R}$ $\begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix}_{L,R}$ $\begin{pmatrix} \nu \\ \nu \\ \nu \end{pmatrix}_L$

family singlets: $\gamma, g, W_T^\pm, Z_T$

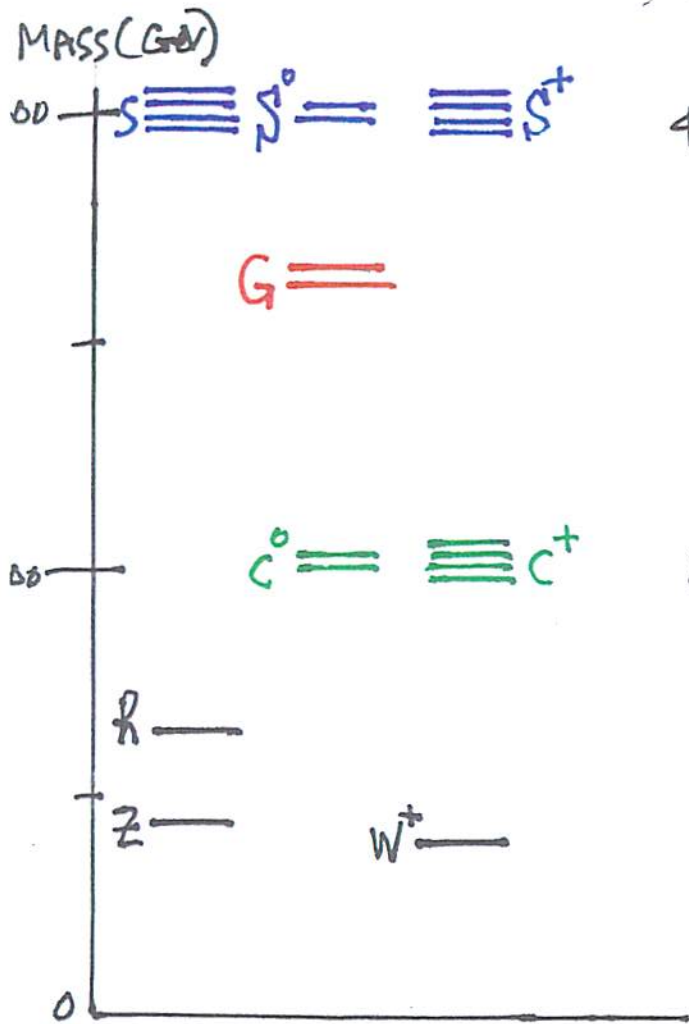
HOW SHOULD WE ASSIGN $h, W_L^\pm, Z_L$??

My choice is a nonet: $\begin{matrix} u & c & t \\ c & \begin{pmatrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \star \end{pmatrix} & \end{matrix} \quad \downarrow ?$

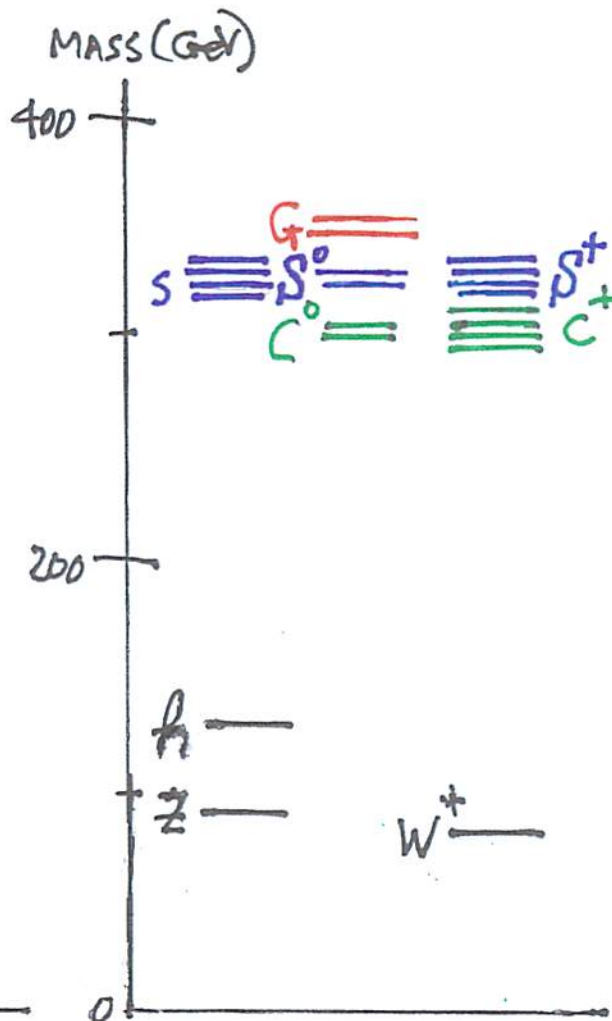
CONSEQUENCES:

- Family symmetry is spontaneously broken.
- 32 New states: masses $\sim 200-500 \text{ GeV} (?)$
- Decays are overwhelmingly to top-antitop + jets final states.

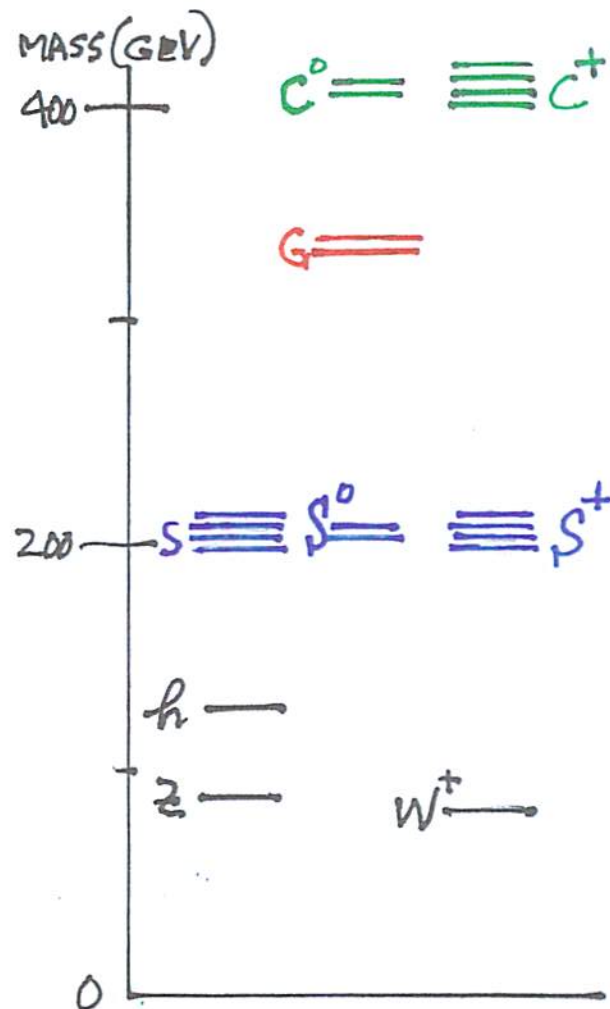
A HIGGS FAMILY



OPTION A



OPTION B



OPTION C

DECAYS:

$$C, G \rightarrow t \bar{t} \quad S, S^0 \rightarrow \begin{cases} t \bar{t} b \bar{q}' \\ b \bar{q} \bar{t} q' \end{cases}$$

$$[q \neq q' = u, d, s, \text{ or } c]$$

THEORY STATUS : INCOMPLETE

- For vanishing CKM mixing, theory is OK.
- For nonvanishing CKM mixing, problems remain:
 - "Parameter of difficulty" is $(\frac{m_b}{m_t})^2 |V_{cb}| \sim 3 \times 10^{-5}$.
 - Additional family multiplets are probably needed.
- LHC search phenomenology appears robust — no matter what,

HOW BIG IS THE HIGGS SECTOR ?

GUT $SO(10) \Rightarrow \begin{cases} 36 \text{ Goldstones} \\ \text{Many massive modes} \end{cases}$

My present working hypothesis is $SO(16)$

$$SO(16) \supset SO(10) \times SO(6)$$

$\downarrow$
GUT $SU(5)$ $\downarrow$ $SU(3)$ Family??

$\downarrow$ Standard-model particles $\downarrow$ Low mass dark matter sector ??

RAW MATERIAL FOR THE MODEL

$$\frac{16 \times 15}{2} = 120$$

"Adjoint Higgs"

$$\phi_{[ij]}$$

$$16 \times 16 = 256$$

"Frame Higgs"

$$\psi_i^A$$

- "Frame-field" tactic not well-explored (?)
- Motivations: "Rotating mass matrix" [Hong Mo Chan et al. arXiv/2006.0199]
"Vierbein" in first-order GR

DARK ENERGY & DARKNESS

GR defines two extreme scales:

$$G_{\text{Newton}} \sim \frac{1}{M_{\text{Pl}}^2} \sim (10^{33} \text{ cm})^2$$

$$\Lambda \equiv \frac{H^2}{3} \sim (10^{28} \text{ cm})^{-2}$$

These induce an intermediate scale:

$$\text{Dark-energy density } \rho_{\text{DE}} \sim H^2 M_{\text{Pl}}^2 \sim [10^3 \text{ cm}]^{-4}$$

Is there another intermediate scale?

$$\text{"Darkness" (or dark-topology density) } \rho_{\text{D}} \sim H M_{\text{Pl}}^2 \sim [10^{12} \text{ cm}]^{-3}$$

MATTERS OF GRAVITY

(16) Einstein-Hilbert

$$g_{\mu\nu}$$

$$S_{EH} \sim M_{pl}^2 \int d^4x \sqrt{g} R$$

(24+16) Einstein-Cartan

$$\begin{aligned} \omega_\mu^{AB} \gamma_A \gamma_B &\equiv \omega_\mu \\ e_\mu^A \gamma_A \gamma_5 &\equiv e_\mu \end{aligned}$$

$$S_{EC} \sim M_{pl}^2 \int d^4x \text{Tr} \gamma_5 e e R$$

(40) MacDowell-Mansouri

$$A_\mu \equiv H e_\mu + \omega_\mu$$

$$S_{MM} \sim \frac{M_{pl}^2}{H^2} \int d^4x \text{Tr} \gamma_5 F_\Lambda F^\Lambda$$

$$S_{MM} \sim \int d^4x \text{Tr} \gamma_5 \left[\overset{\text{Topological}}{\downarrow} \frac{M_{pl}^2}{H^2} R_\Lambda R^\Lambda + \overset{\text{GR}}{\downarrow} M_{pl}^2 e e_\Lambda e^\Lambda R + \overset{\text{DE}}{\downarrow} H^2 e_\Lambda e^\Lambda e e^\Lambda \right]$$

THE GAUSS - BONNET (EULER) TERM

$$S_{GB} = \frac{M_{pl}^2}{H^2} \int d^4x \text{Tr} \gamma_5 R_\lambda R = 2\pi \int dt \left(\frac{dN}{dt} \right)$$

- It is a topological term; it does not contribute to the Einstein equations of motion.
- In FRW cosmology, N is an extensive variable.
- In cosmic voids, $\frac{N}{V} \sim H M_{pl}^2 \sim 10^{39}/\text{liter}$
- In early universe, $\frac{N}{V} \sim M_{pl}^3$ when $T \sim 50 \text{ MeV}$.
- Just outside protons, lead nuclei, neutron stars, $\frac{N}{V} \sim M_{pl}^3$

WHAT DOES THIS MEAN?

- I don't know
- At best, MacDowell-Mansouri is an effective field theory description, only valid when the distance scale is $> \Lambda_Z^{-1} \sim 10^{-12} \text{ cm}$.
- BUT maybe the darkness scale links, via vacuum couplings, to

Λ_{QCD}
Lepton/quark mass scale
Higgs-sector mass scale (??)
Dark-matter mass scale

MASSSES & MIXINGS

$$m \equiv 7 \text{ MeV}$$

FIRST GENERATION:

$$m_u \lesssim m = 7 \text{ MeV}$$

$$(2.3 \pm 0.6 \text{ MeV})$$

$$m_d \lesssim m = 7 \text{ MeV}$$

$$(4.8 \pm 0.5 \text{ MeV})$$

$$m_e = m^2/m_\mu = .44 \text{ MeV}^*$$

$$(0.51 \text{ MeV})$$

SECOND GENERATION:

$$m_c = \sqrt{m m_t} = 1.1 \text{ GeV}^{**}$$

$$(1.3 \text{ GeV})$$

$$m_s = \sqrt{m m_b} = 170 \text{ MeV}^{**}$$

$$(100 \pm 30 \text{ MeV})$$

$$m_\mu = \sqrt{m m_\tau} = 110 \text{ MeV}^{**}$$

$$(106 \text{ MeV})$$

CKM MIXING:

$$|V_{cb}| = \sqrt{m/m_b} = .040^{**}$$

$$(.04i)$$

$$|V_{td}| = m/\sqrt{m_b m_s} = .0080^*$$

$$(.0081)$$

$$|V_{ub}| = m/\sqrt{m_b m_c} = .0032^*$$

$$(.0039)$$

UNITARITY TRIANGLE
VERTEX ANGLE:

$$\alpha = \frac{\pi}{2}$$

$$(89^\circ \pm 4^\circ)$$

COMMENTS

1. Pay more attention to the family problem.
2. Are there (LHC-accessible) Higgs families?
3. $SO(10)$ GUT already implies a big Higgs sector.
4. Should family symmetry be gauged?
5. Is there a "dark Higgs" subsector?
 - "Dark gluons"
 - "Dark confinement"

6. Third generation masses $\Leftrightarrow$ GUT physics ?

$$m_t : 10 \times 10 \times (5)_{\text{Higgs}}$$

$$m_b, m_\tau : 10 \times 5 \times (5)_{\text{Higgs}}$$

$$m_{\text{Dirac } \nu} : 1 \times 5 \times (5)_{\text{Higgs}}$$

7. 1st & 2nd generation masses & mixings depend on a low mass scale (e.g. 10-100 MeV)?

8. Does that low mass scale (& Λ_{QCD}) have something to do with "darkness"?

9. Never give up.

FUTURE FACILITIES

- LHC discovery potential at low mass scales is still high.
- ILC looks very attractive.
- Dark-matter sector may { be complex.
contain low-mass states.
- Think big (≥ 100 TeV) - now!
- In all this, QCD remains of central importance.