The LHC, The Energy Frontier, and the Next Big Discovery

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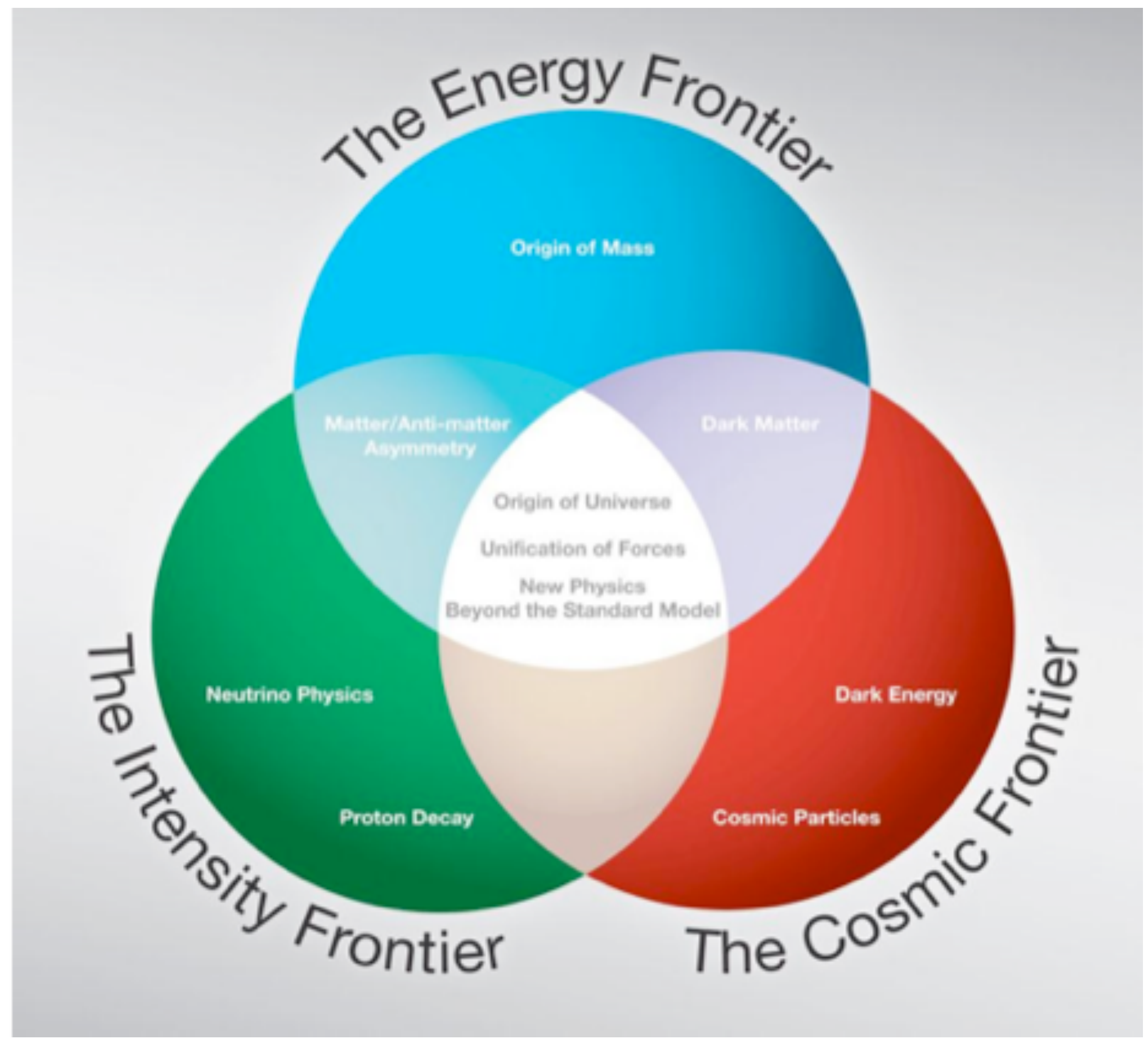
University of Washington Seattle/National Tsing Hua University

Nov 27 2013
Colloquium in NTHU

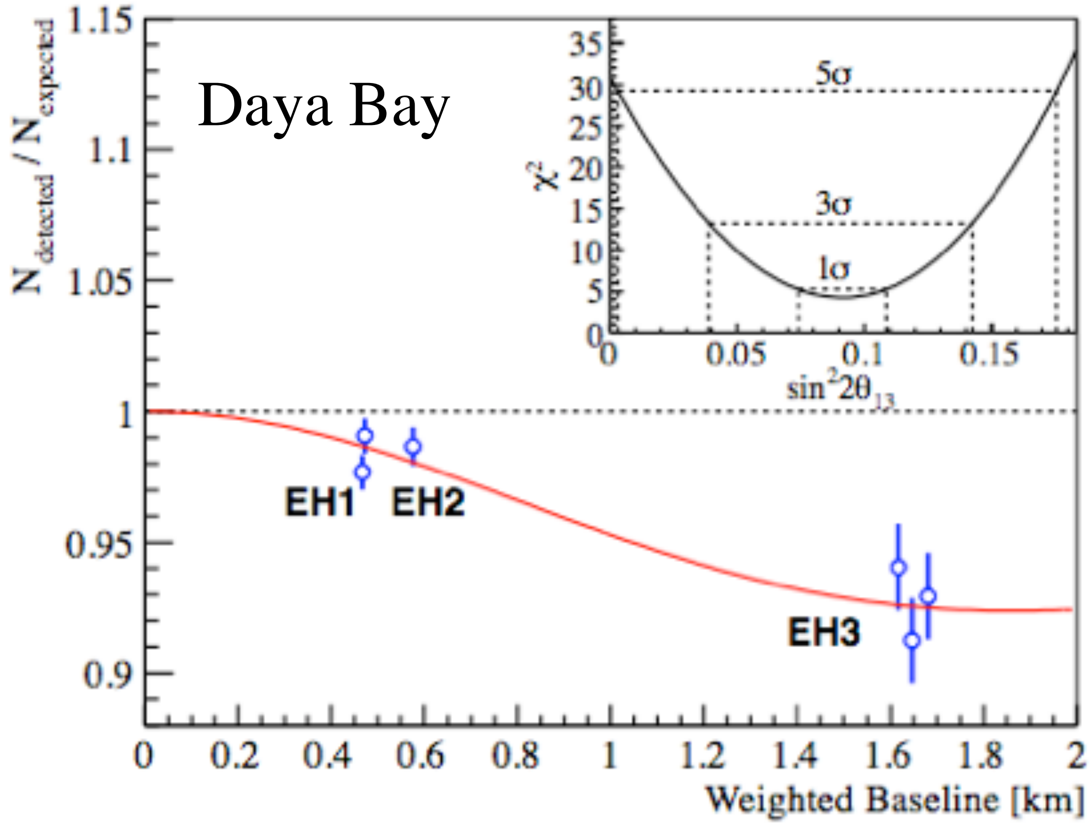
Snowmass & P5

ParticlePhysicsProjectPrioritizationPanel(P5)

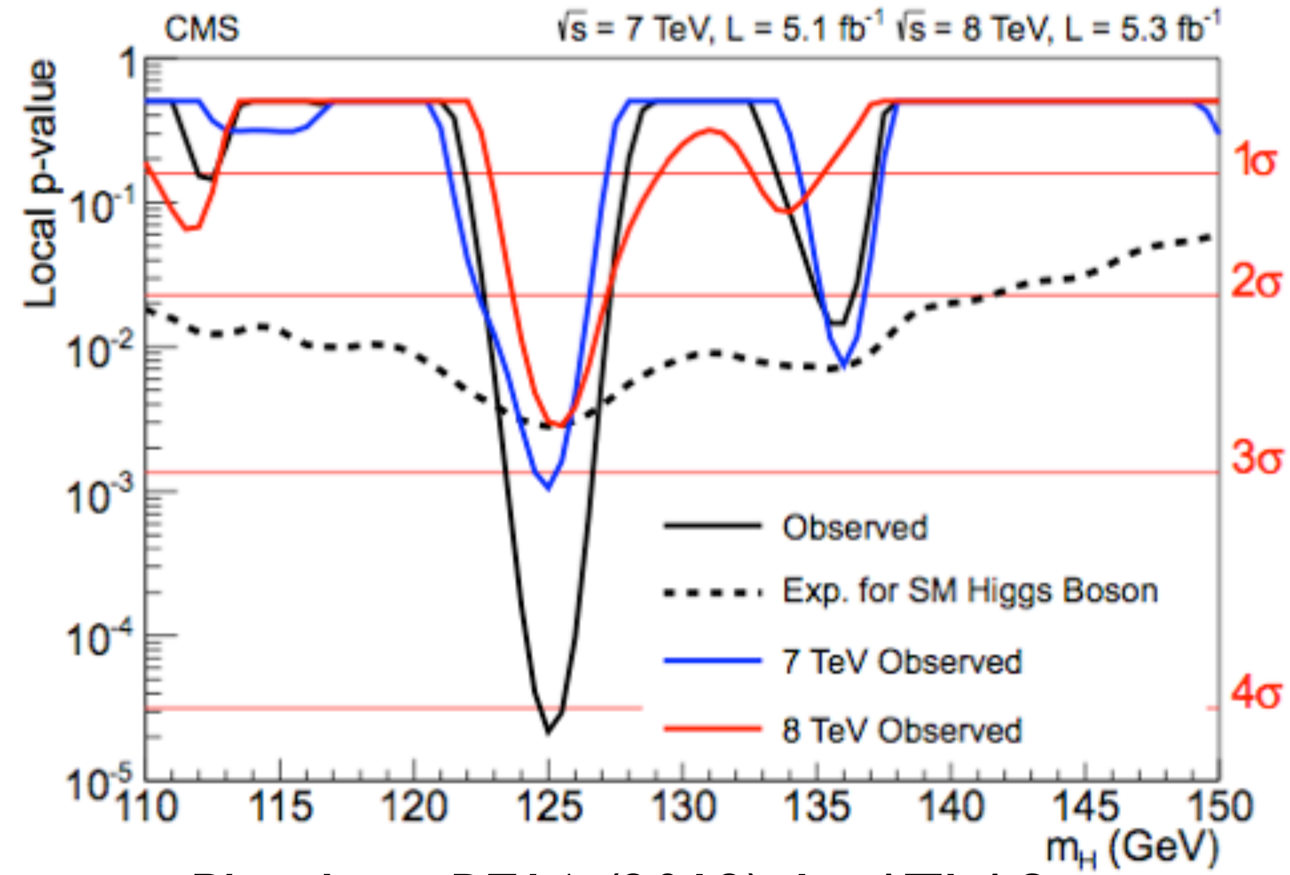
- Develop an updated strategic plan for U.S. high energy physics that can be executed over a 10-year timescale, in the context of a 20-year global vision for the field.
- Previous report in 2008
- New report to be finalized on May 2014 and based on the Snowmass input



Exciting year 2012



Phys. Rev. Lett. 108, 171803 (2012)

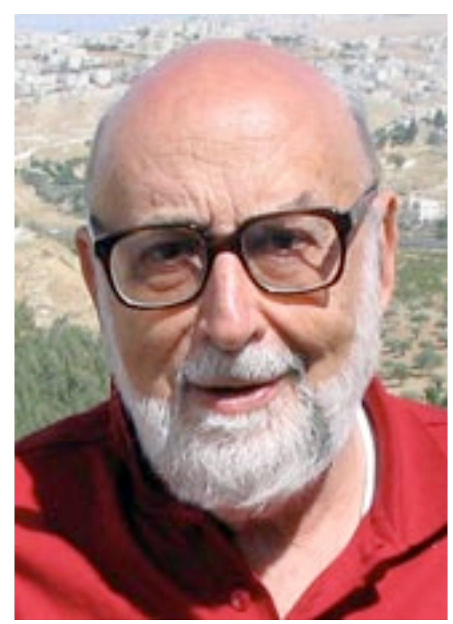


Phys.Lett. B716 (2012) 1 - ATLAS
Phys.Lett.B716(2012) 30 - CMS

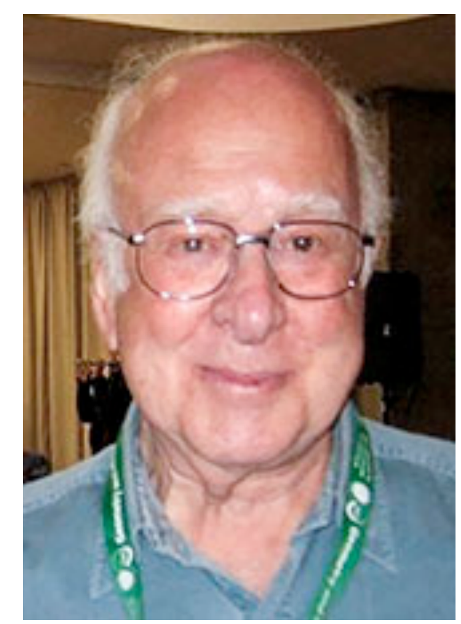
Much has changed since 2008 P5 Report

- "... a need to understand the priorities, ... under more stringent budgets ..."
- "the recent discovery of what appears to be the long-sought Standard Model Higgs boson and the observation of mixing between all three known neutrino types at unexpectedly large rates have opened up the possibility of new experiments and facilities that can address key scientific questions about the fundamental nature of the universe in new and incisive ways."

Higgs Celebration



François Englert



Peter W. Higgs

LHC after July 4 2012

LS1
INCREASE ENERGY TO 13-14 TeV

LS2
secure L ~ 10^{34} and reliability
Aiming at L ~ 2 10^{34} Start LIU

LS3 : HL-LHC New IR
leveled L ~ 5 10^{34} Experiment upgrades

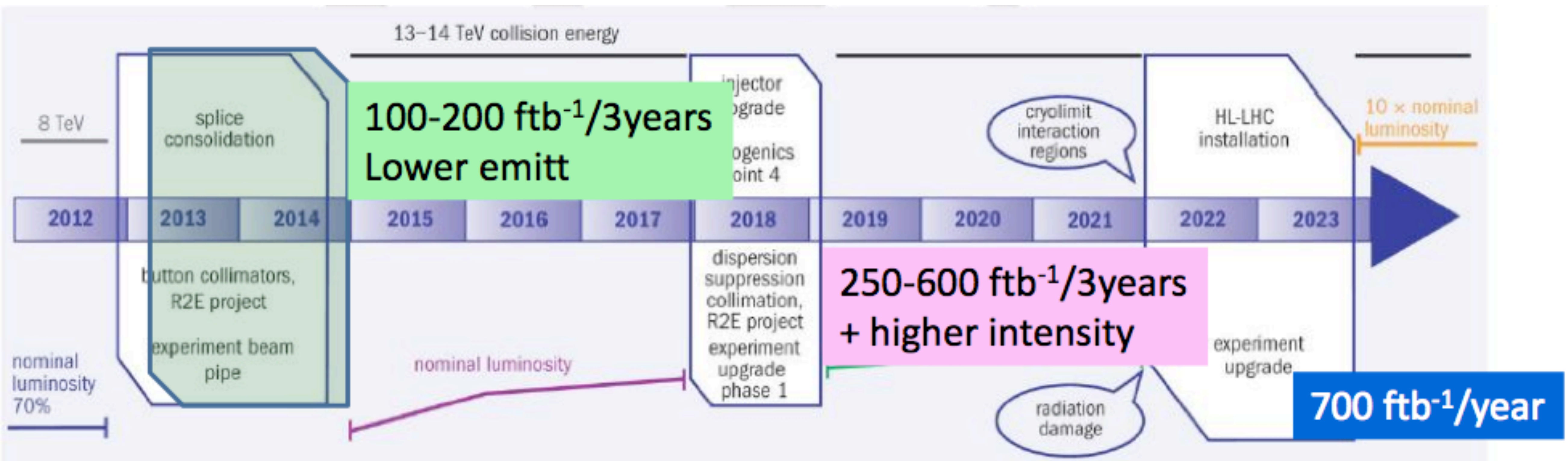
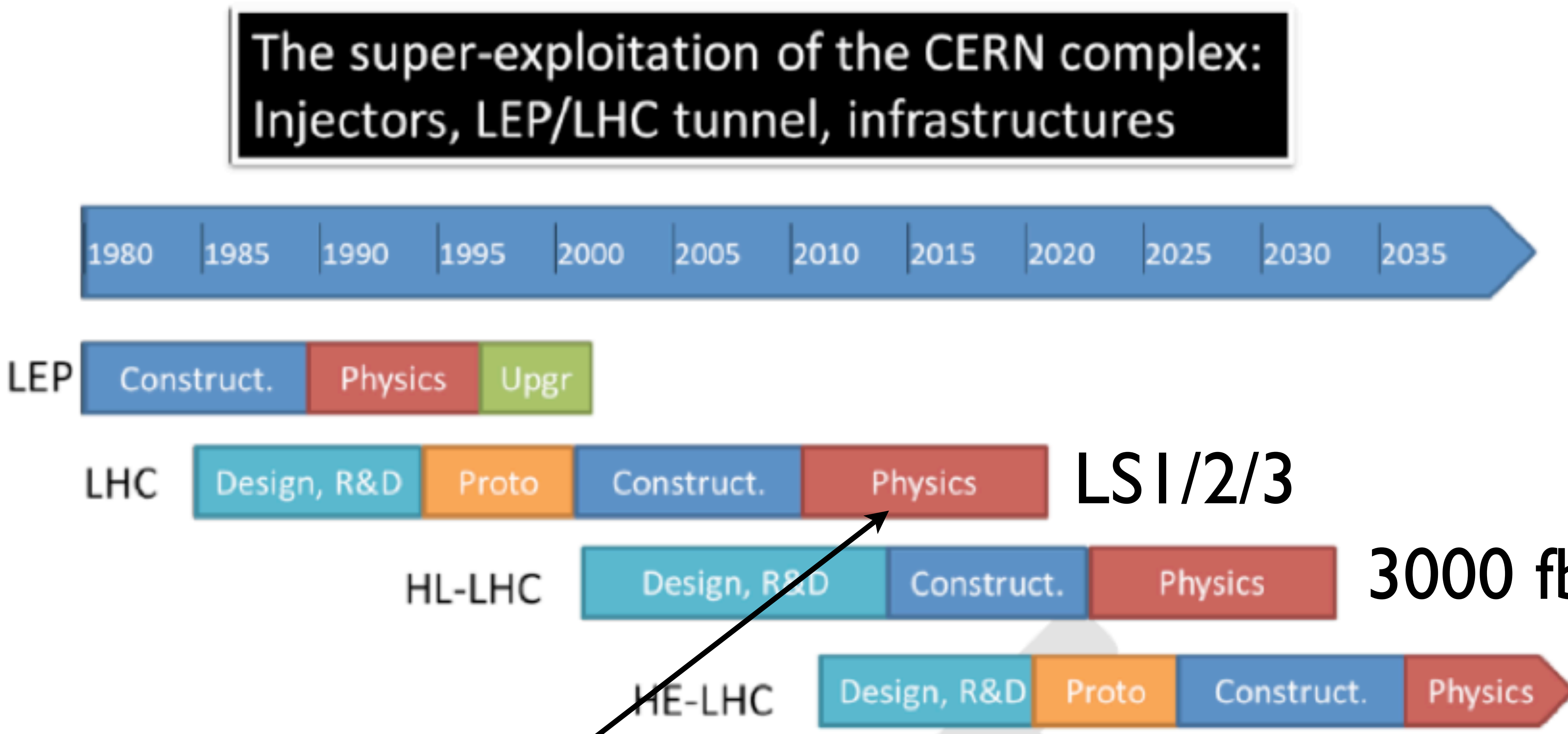


Figure 1: LHC baseline plan for the next ten years. In terms of energy of the collisions (upper line) and of luminosity (lower lines). The first long shutdown 2013-14 is to allow design parameters of beam energy and luminosity. The second one, 2018, is for secure luminosity and reliability as well as to upgrade the LHC Injectors.

LHC in Next 20 years!?



LS1/2/3

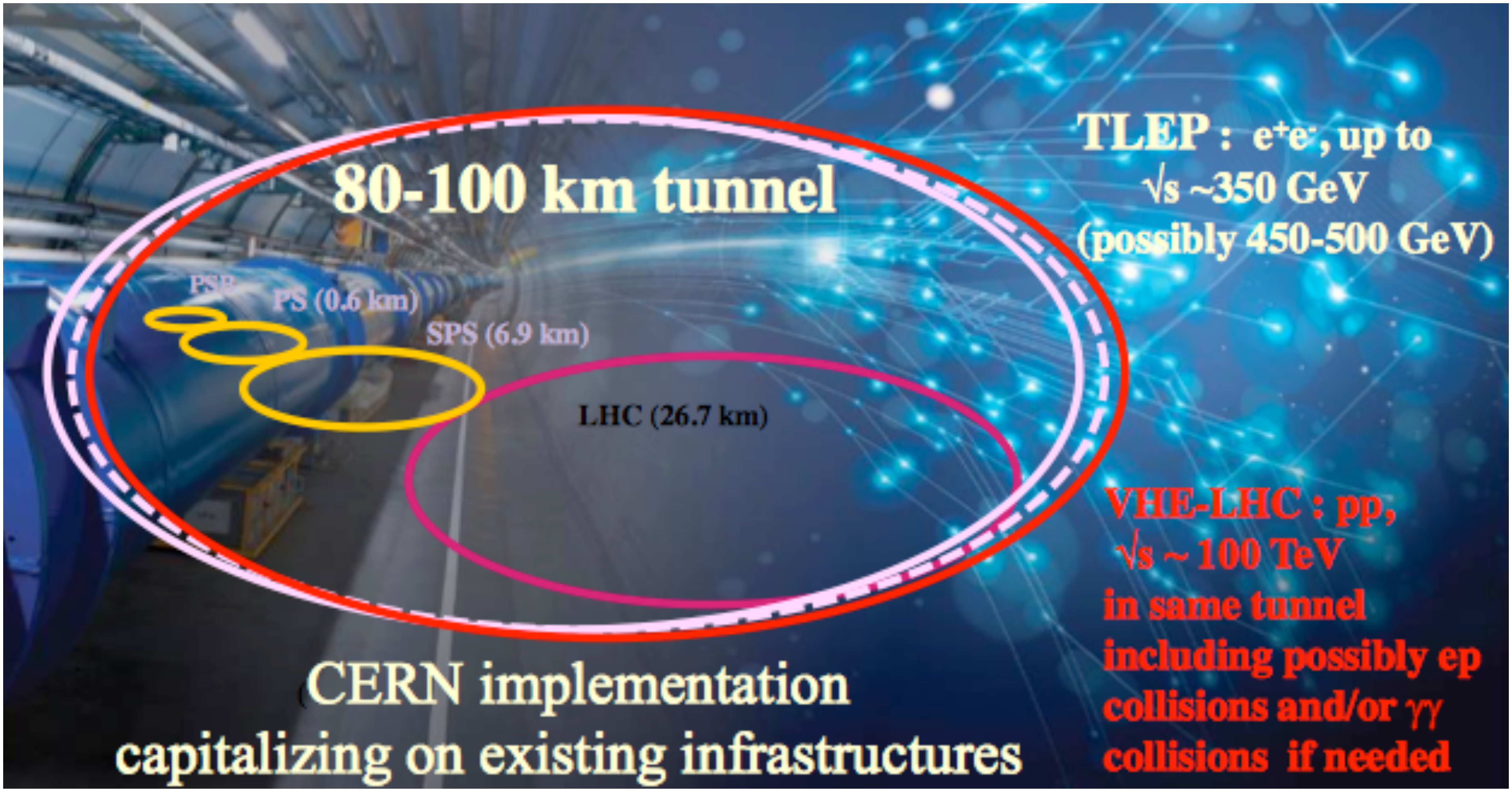
3000 fb-1

33 TeV

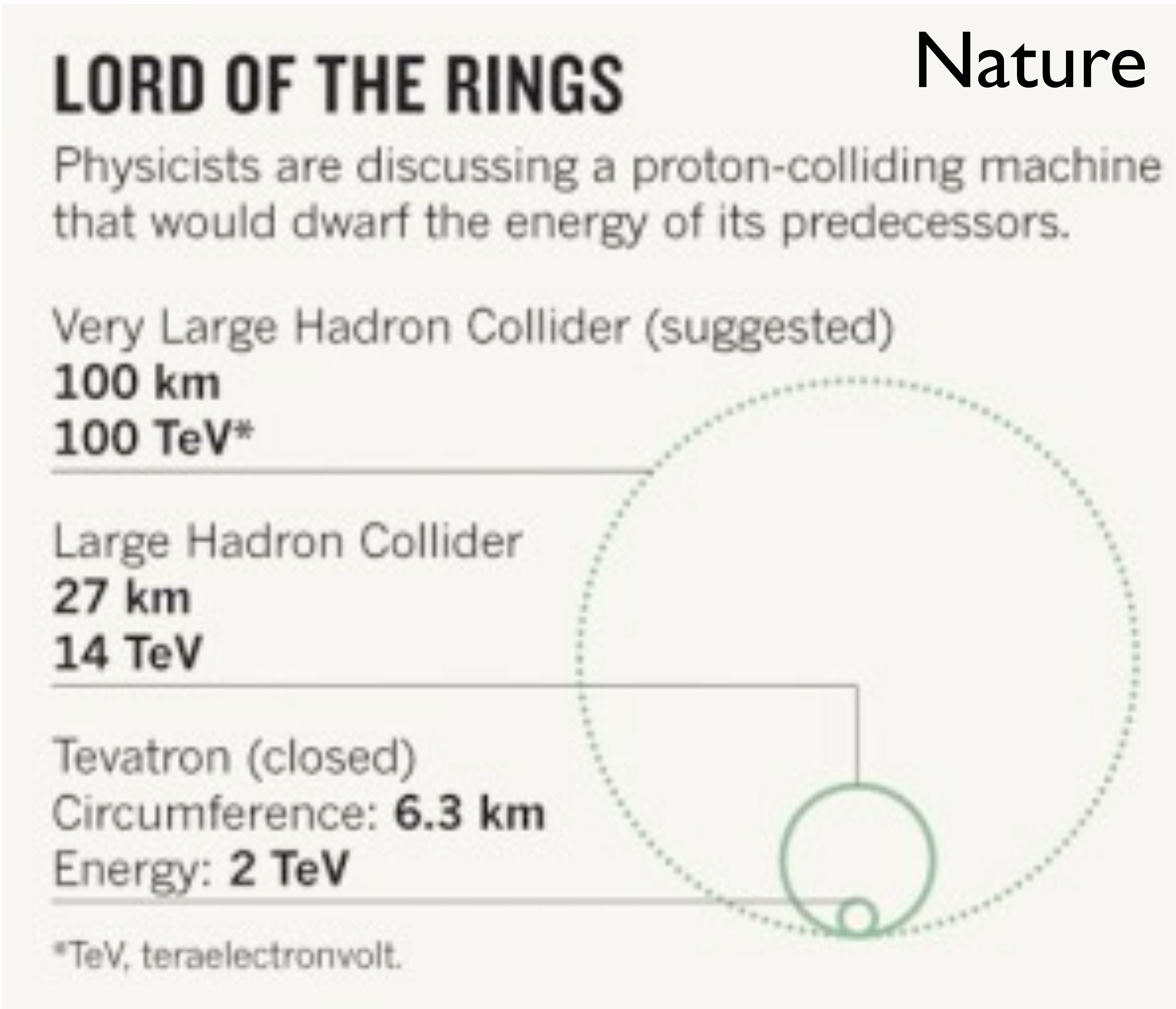
My talk today focus on LHC and preparation for 2018

TLEP

Stage approach toward (V)HE-LHC at CERN



Other names

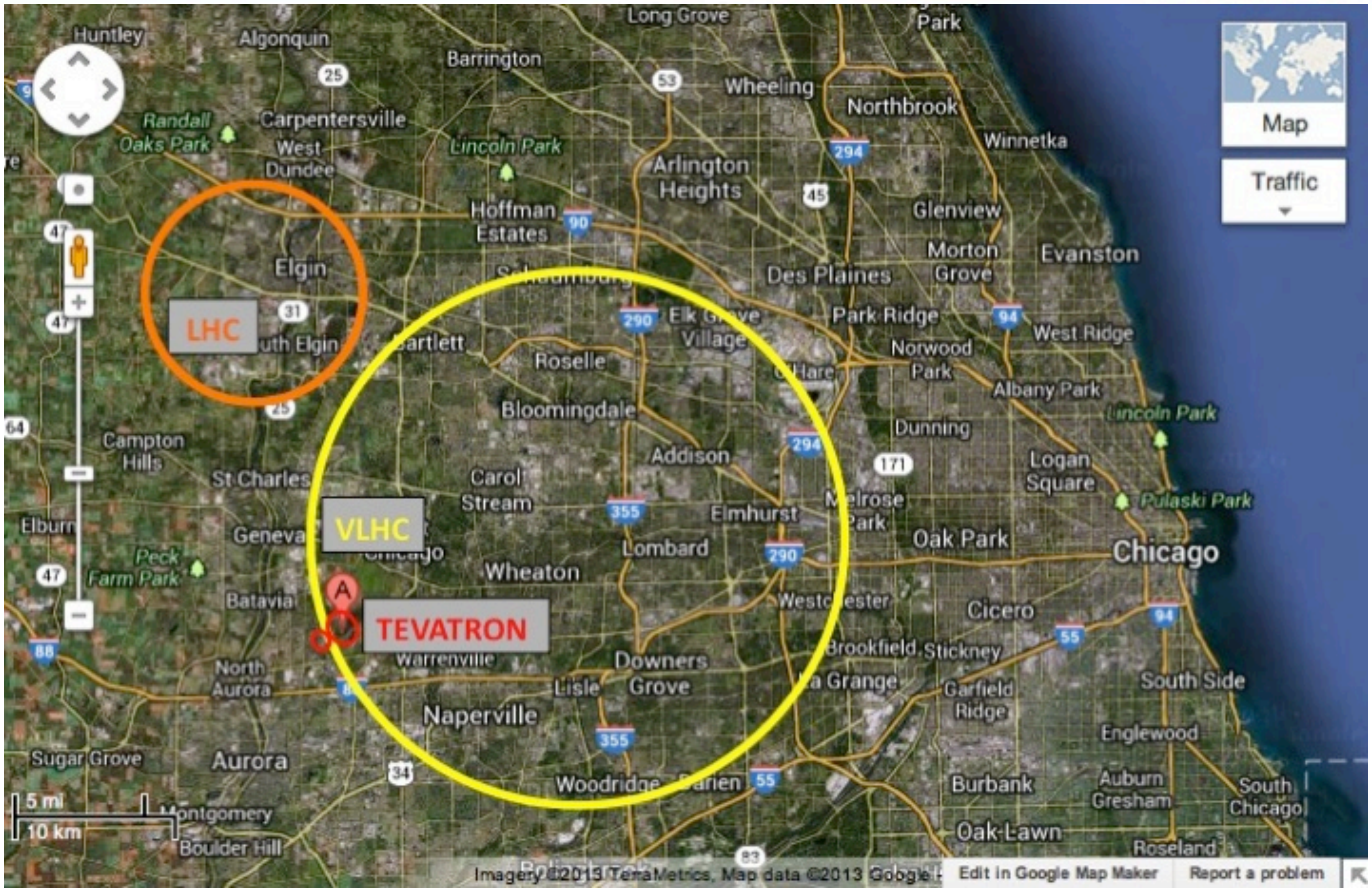


Super Duper Hadron Collider
Ludicrously Large Hadron Collider
Space Smoothie Maker
Big Banger
Quark Fountain
The Doughnut of Physics
Megahadrosaurousen
Huge Hadron Collider
Large Hadron Collider 2: Electric Boogaloo
The Hadronator: The Destroyer of Atoms

BBC Richard Fisher

Global Interests

USA



China

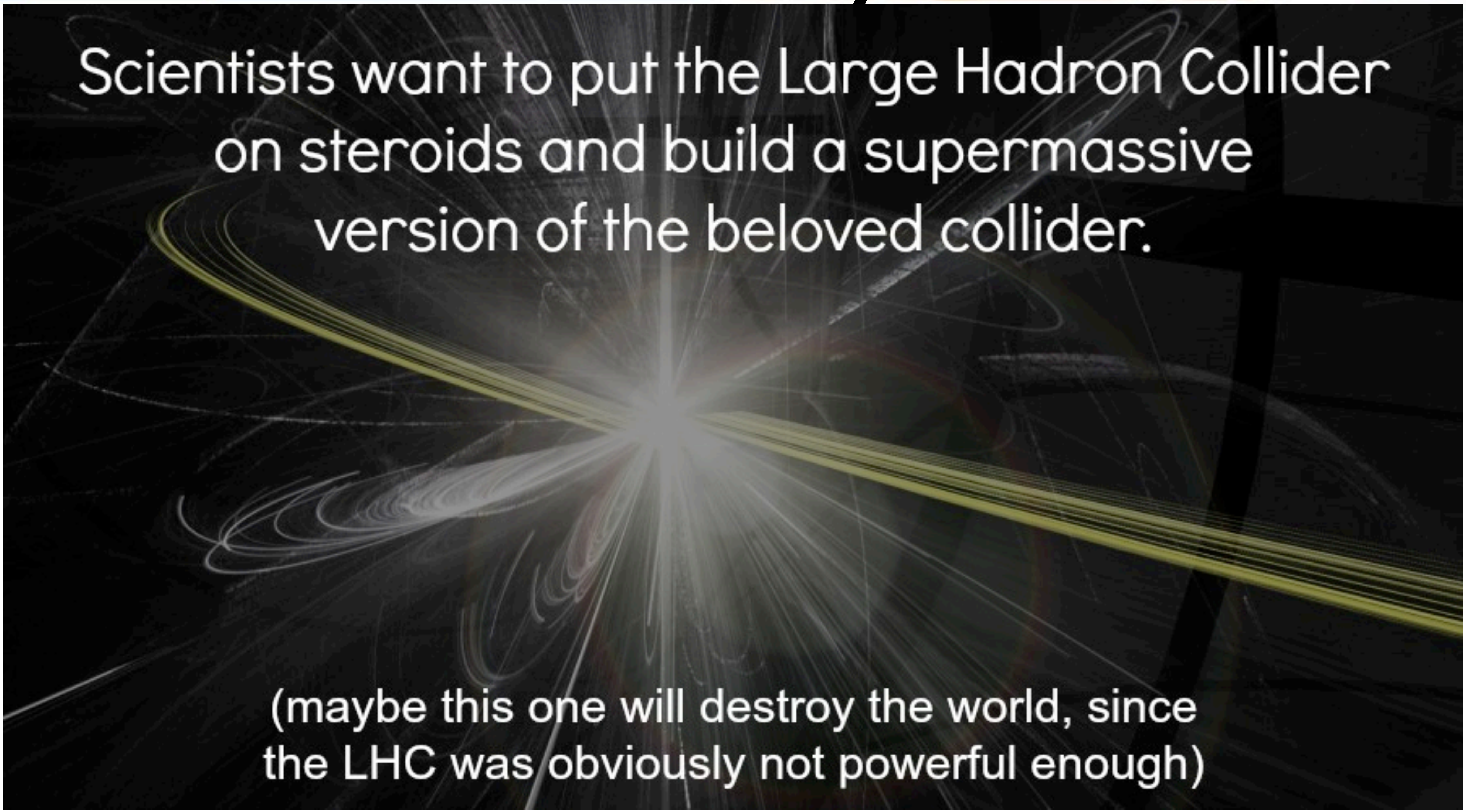
Center for Future High Energy Physics

FHEP

Director: Nima Arkani-Hamed (IAS, USA)
Deputy Director: Cai-Dian Lu (IHEP, China)

高能物理前沿研究中心

From Layman



LHC Collision via Michael Taylor/ Shuttershock

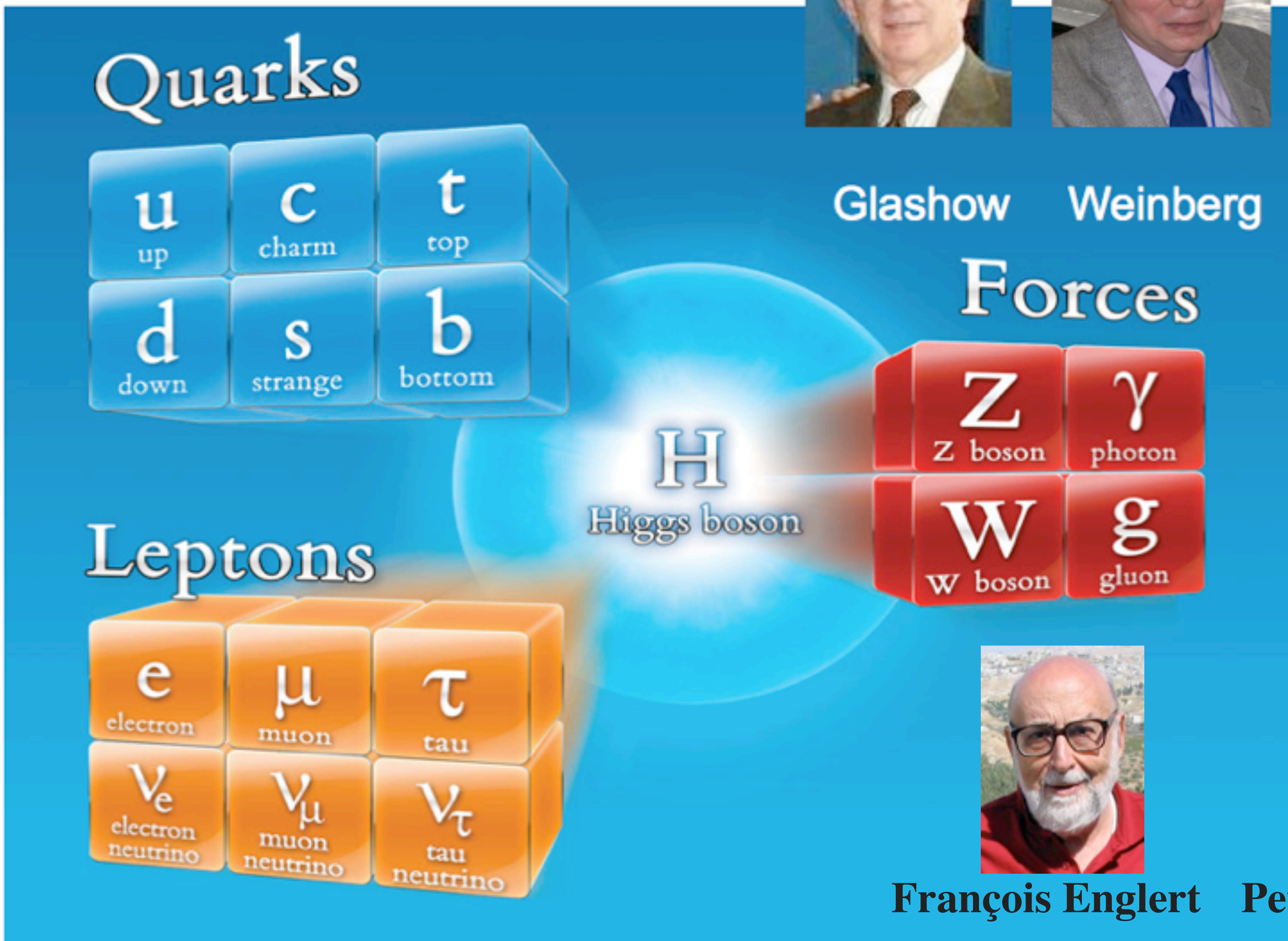
Thousands year curiosity

Philosophy

Empedocles
(490–430 BC)

The Standard Model

Applying Higgs mechanism to generate masses!




Glashow


Weinberg

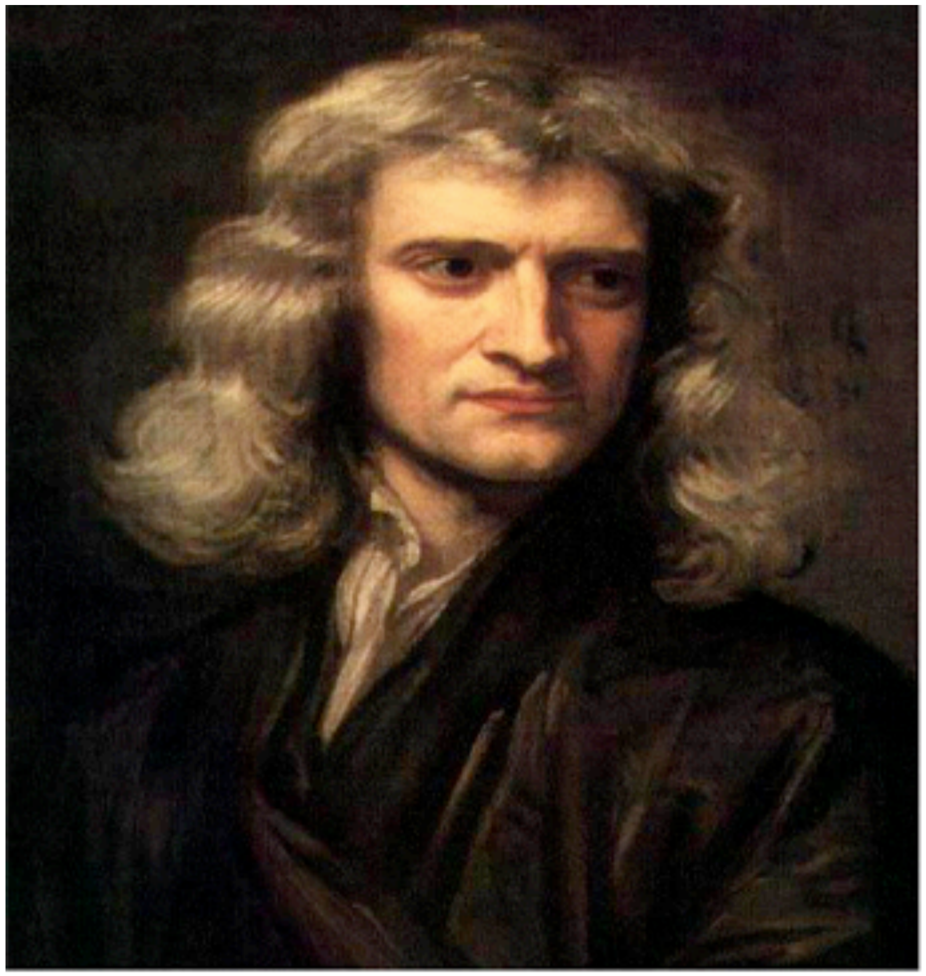

Salam

François Englert


Peter W. Higgs

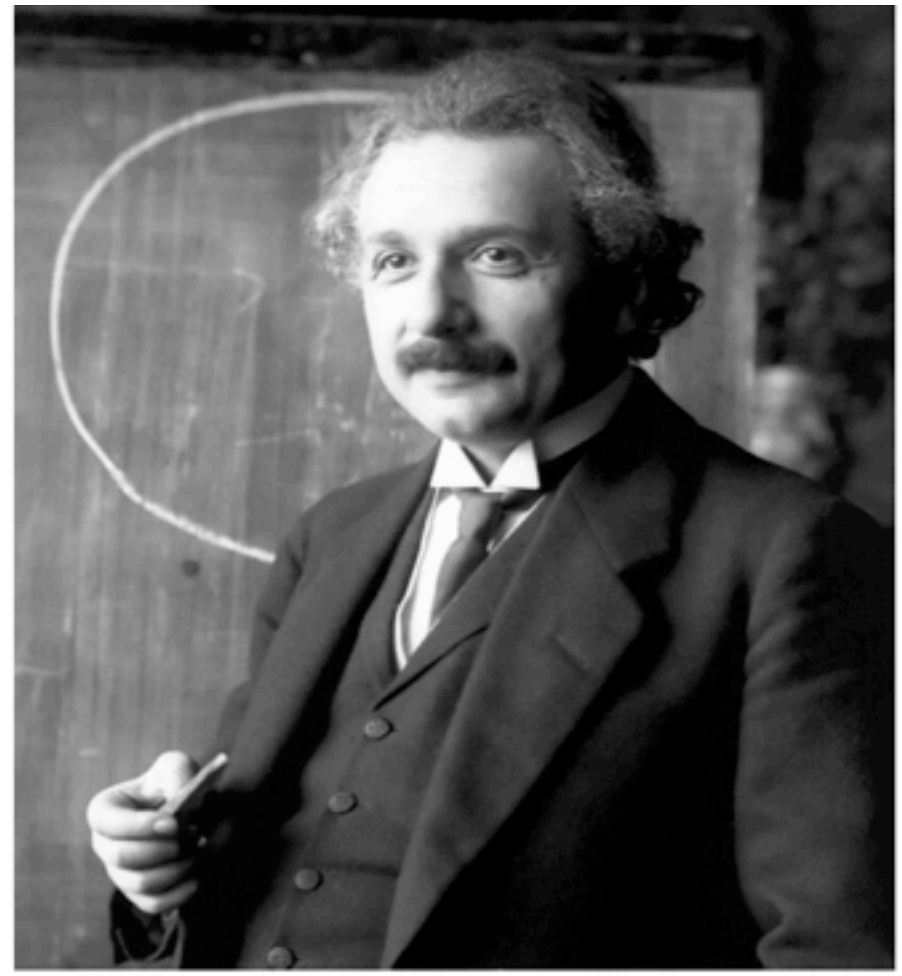
A Massive Problem!?

A quest since 18th century



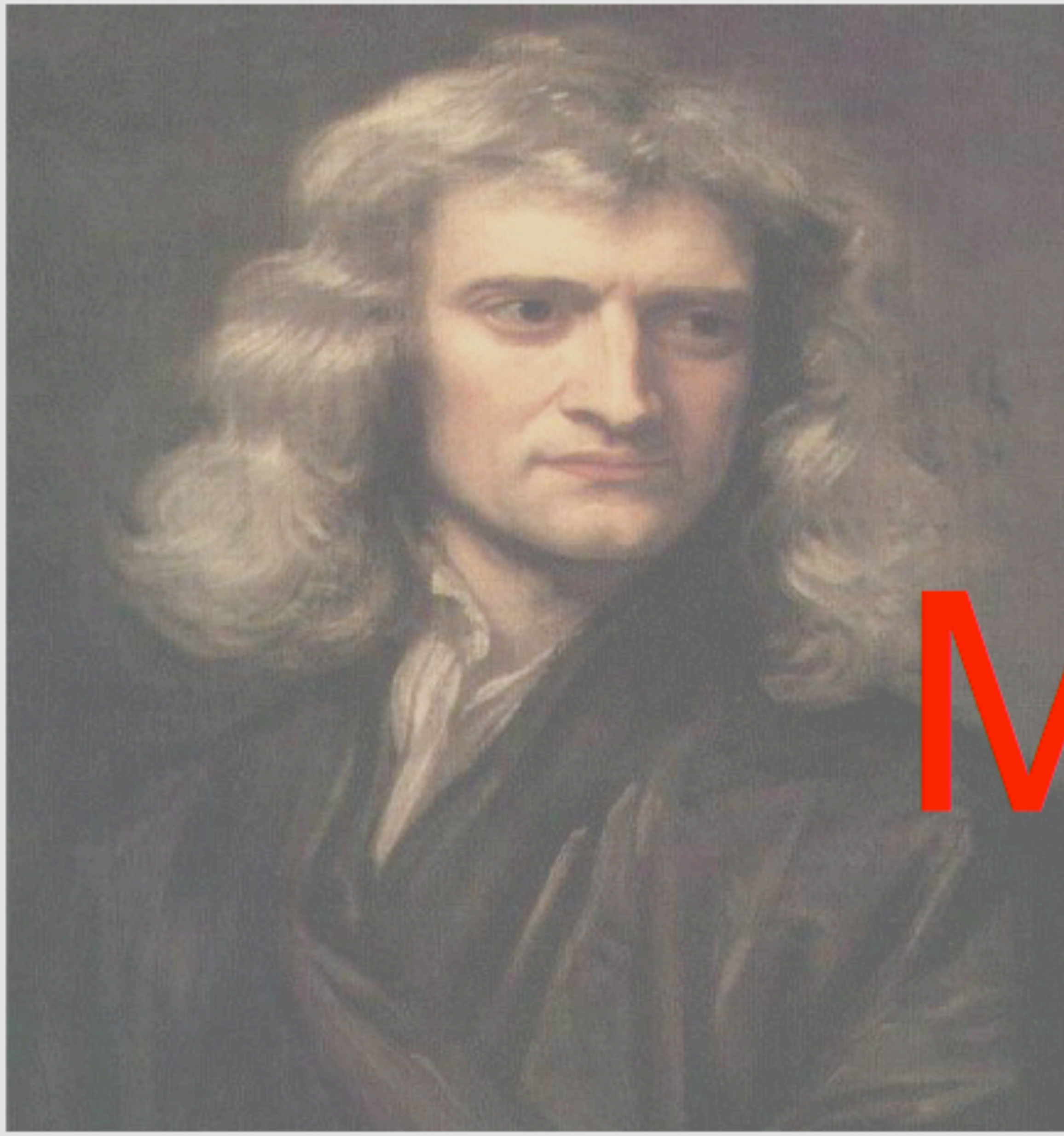
Newton

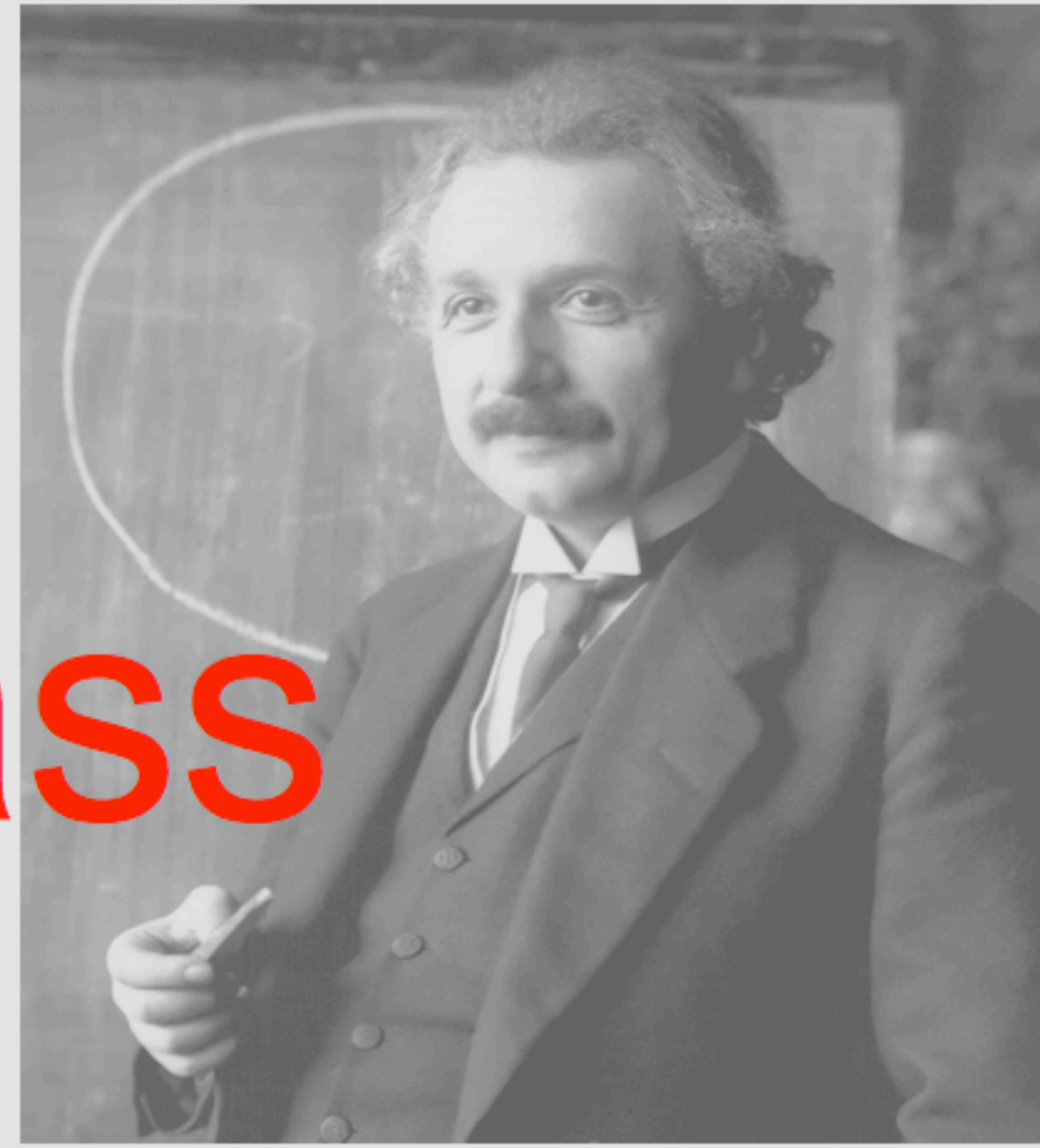
$F=ma$



Einstein

$E=mc^2$





Mass

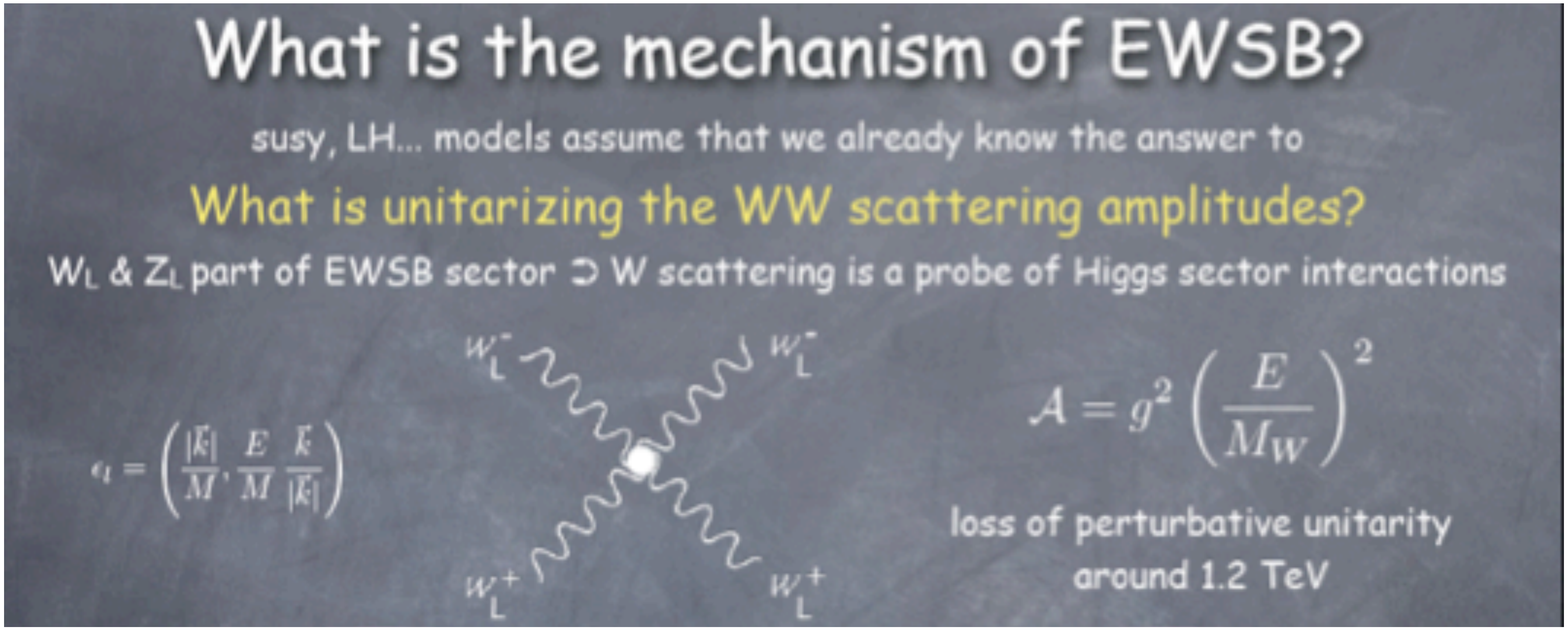
Newton

$F=ma$

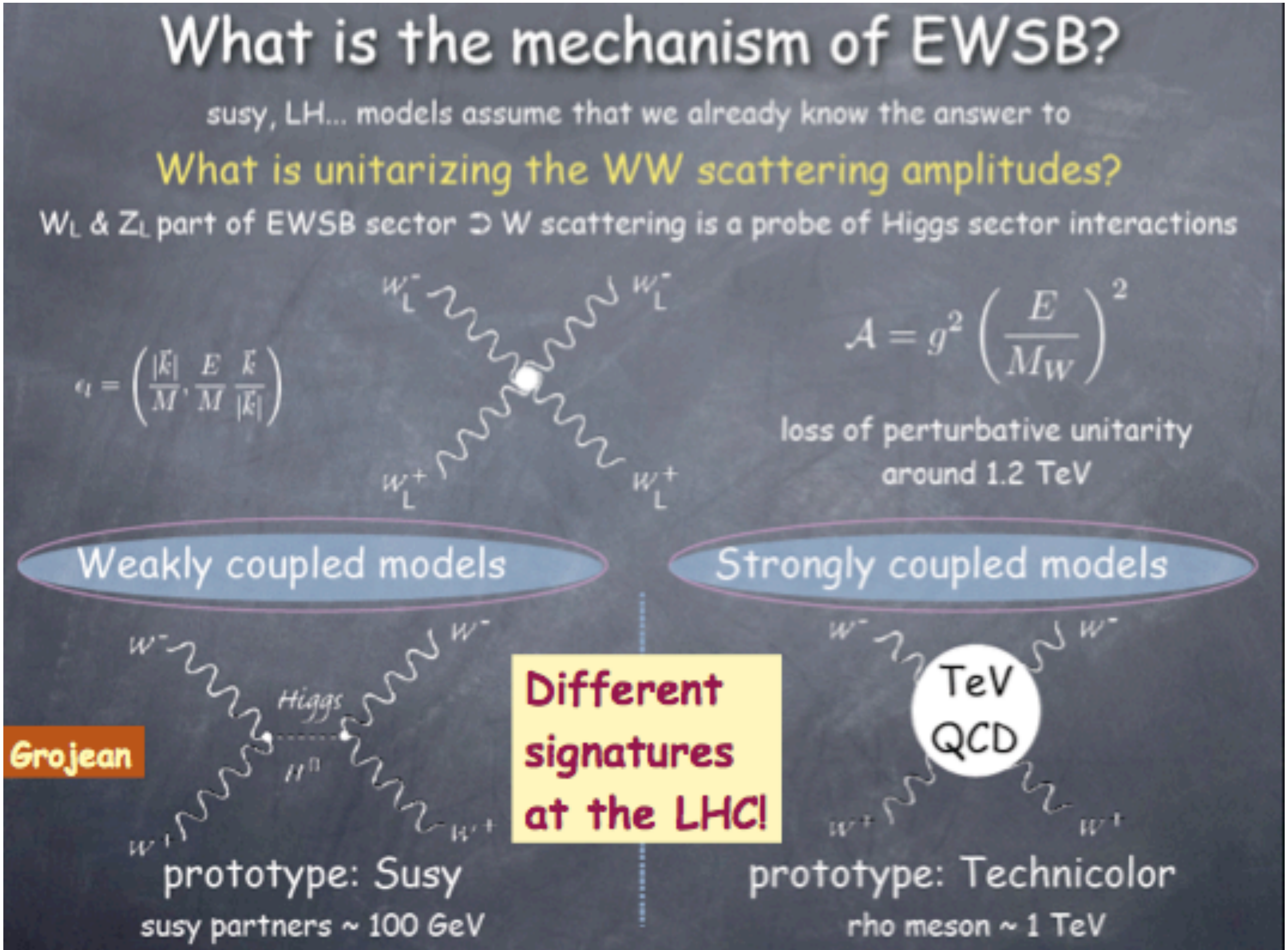
Einstein

$E=mc^2$

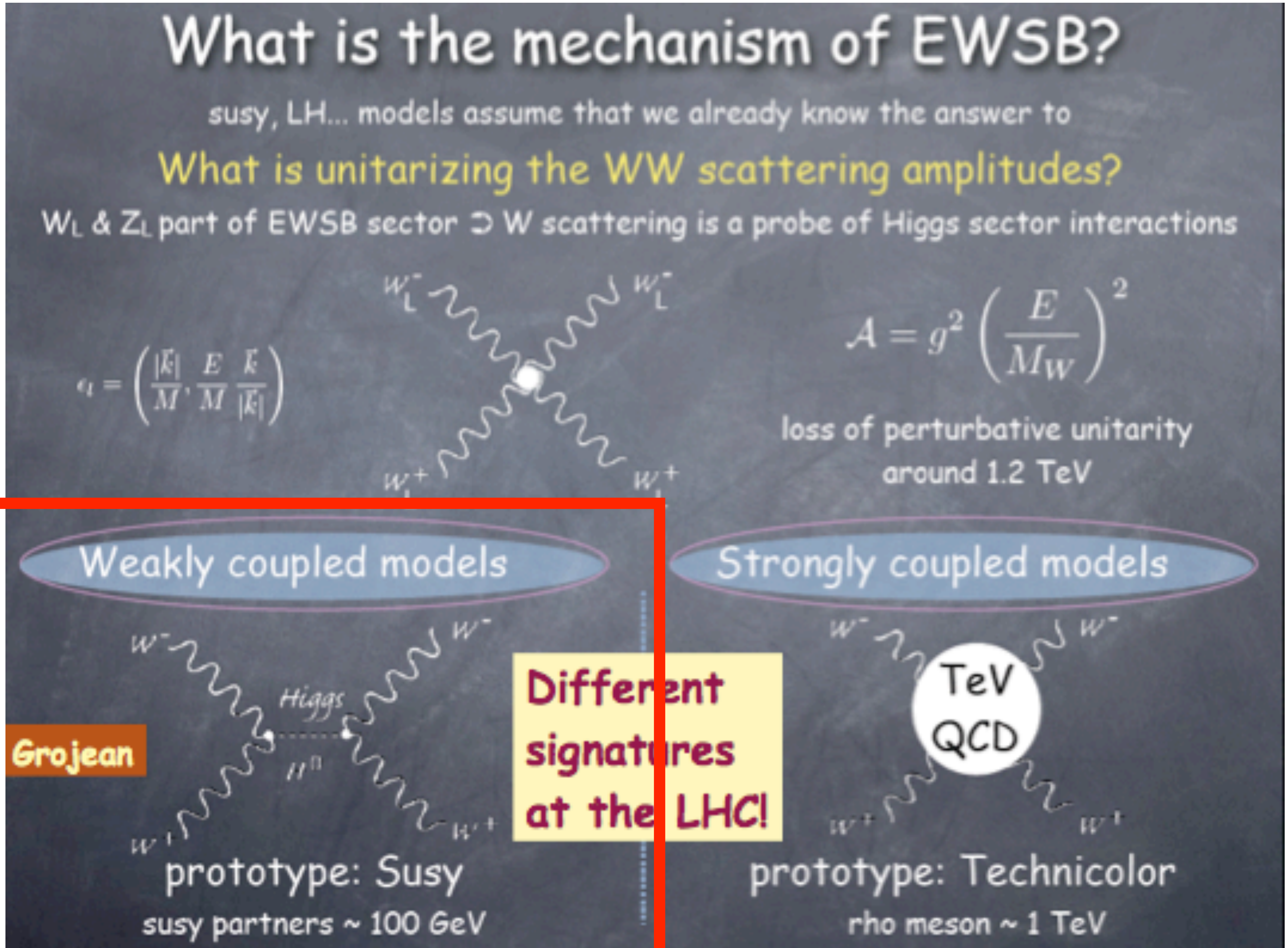
Mission of the LHC



Mission of the LHC



Mission of the LHC



Higgs Discovery

Post-Higgs Discovery

Scenario 1: Strongly dynamics

NO HIGGS PARTICLE: **HIGGSLESS** MODEL (almost) killed by LHC

Possibly a mixture between authentic Higgs with the "impostor", e.g. dilaton, radion

Scenario 2: SU(2)LxU(1)Y linear + strong dynamics

Composite Higgs: Pseudo-goldston boson, strongly interactive light Higgs

Scenario 3: SU(2)LxU(1)Y linear + Perturbativity

Elementary Higgs:

a) Fine-tuned: Unnature Higgs, extreme high scale fundamental theory

b) Nature: low-energy SUSY, in-existence of hierarchy problem: warped extra dimension,

A Higgs or The Higgs

Coupling strength: 5 parameters

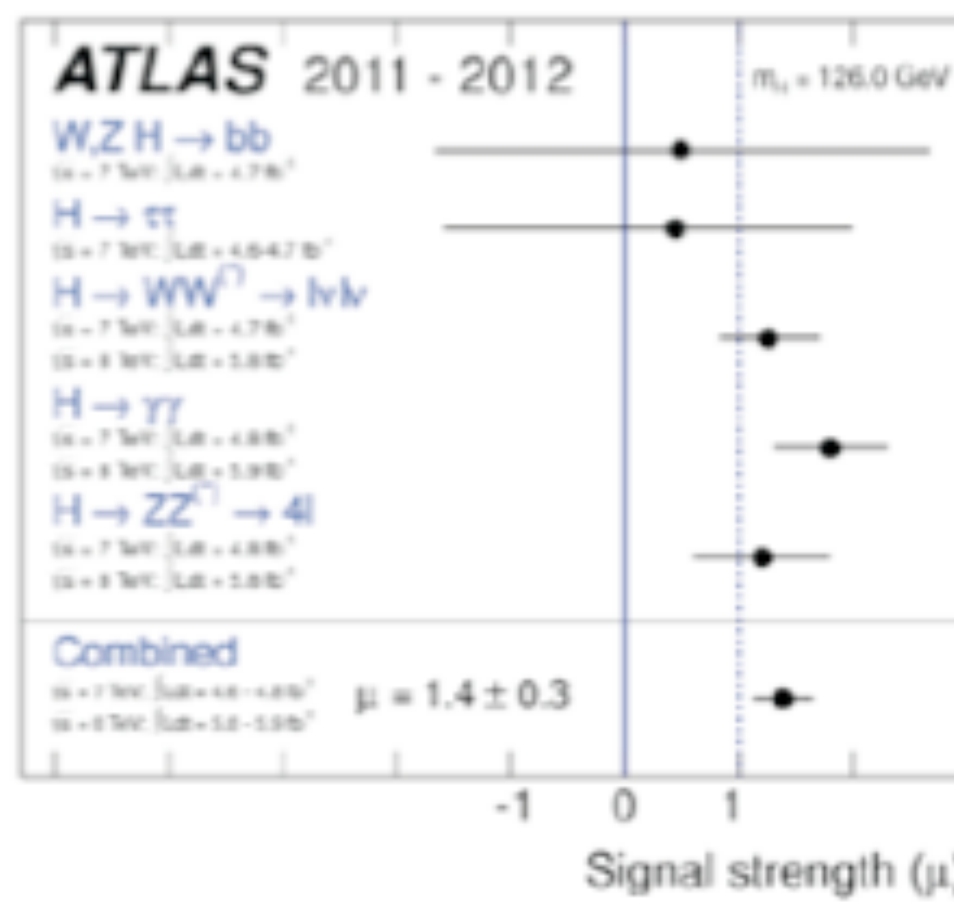
In the SM all 5 $c = 1$ and $\mathcal{L}(h \to inv) \approx 0$

$$\mathcal{L}^{eff}_{<m_h} \approx c_V\left(\frac{2m_W^2}{v} W^+_\mu W^-_\mu + \frac{m_Z^2}{v} Z^2_\mu\right)h + c_b \frac{m_b}{v}\bar{b}bh + c_\tau \frac{m_\tau}{v}\bar{\tau}\tau h$$
$$+ c^\gamma \frac{2\alpha}{9\pi v} F^2_{\mu\nu} h + c^g \frac{\alpha_S}{12\pi v} G^2_{\mu\nu} h$$
$$+ \mathcal{L}(h \to inv)$$

BARBIERI, ICHEP2012

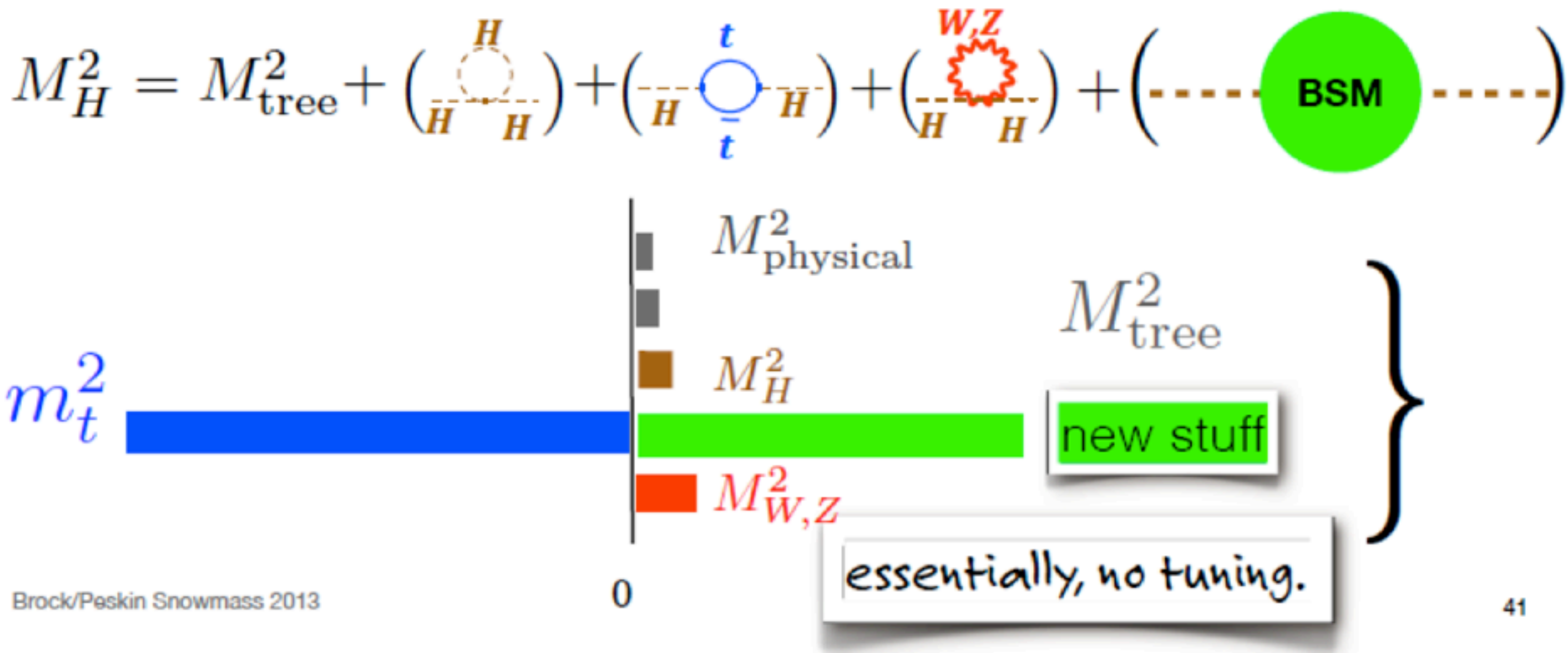
$$c^\gamma = c_t + \frac{9}{2}\delta c^\gamma$$
$$c^g = c_t + \delta c^g$$

Sping/CP: Need more statistics

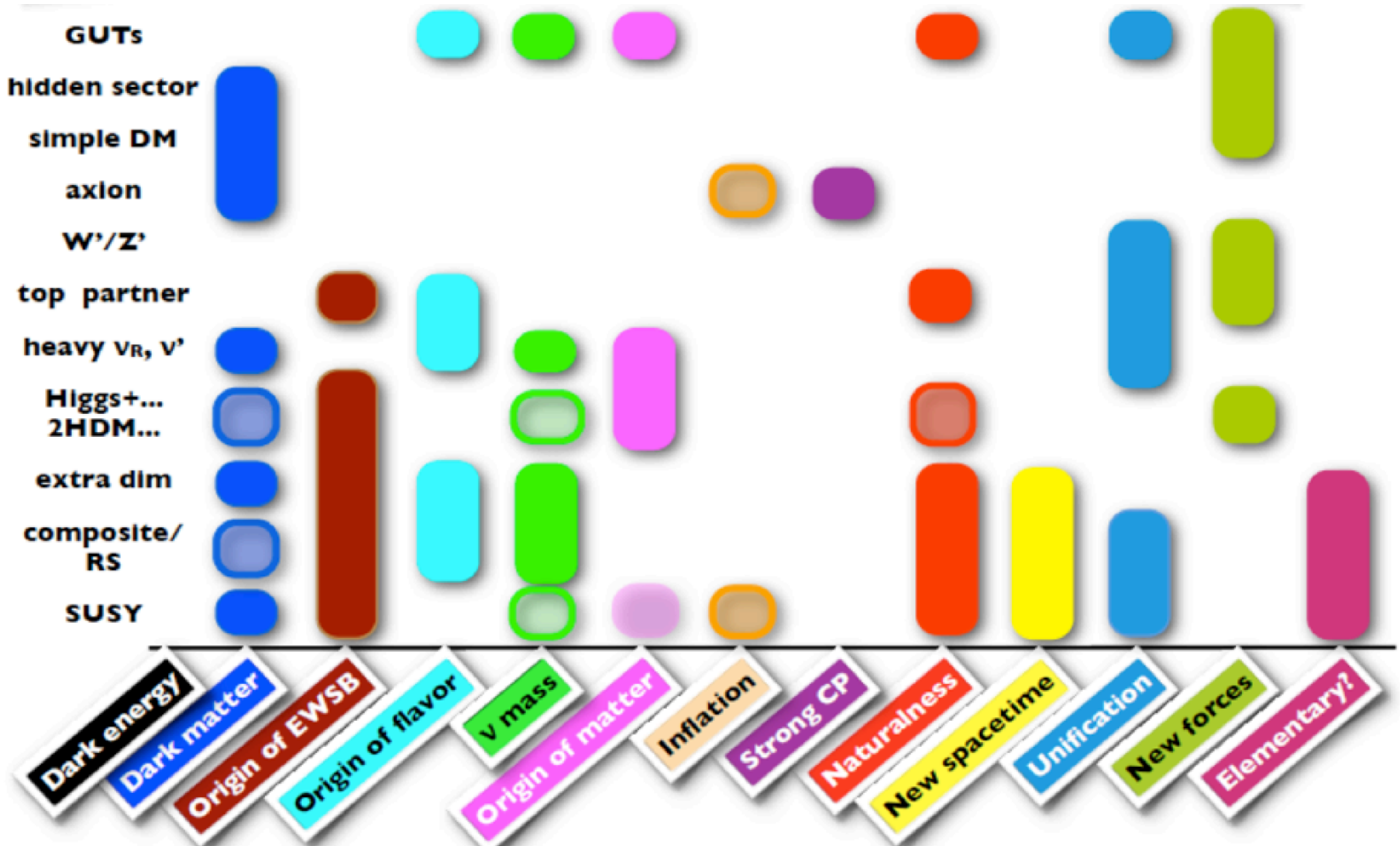


Natural Higgs

Divergence of the Higgs mass correction



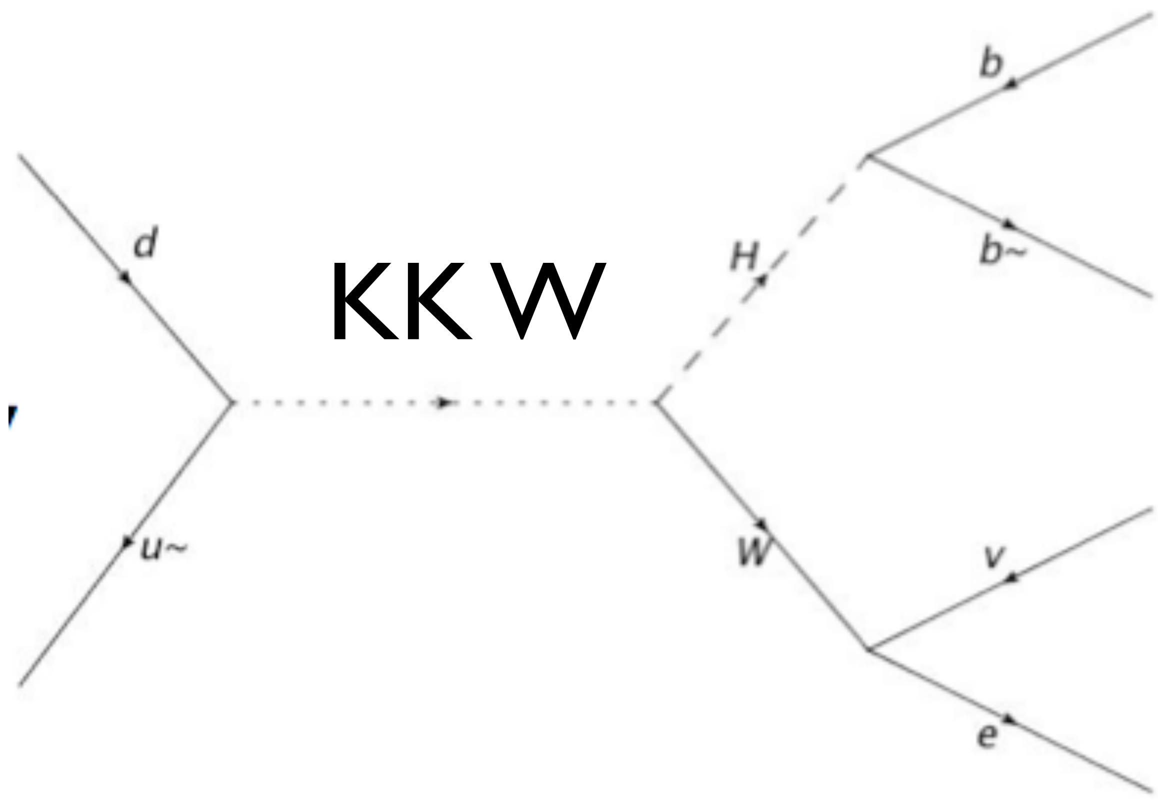
Big Questions

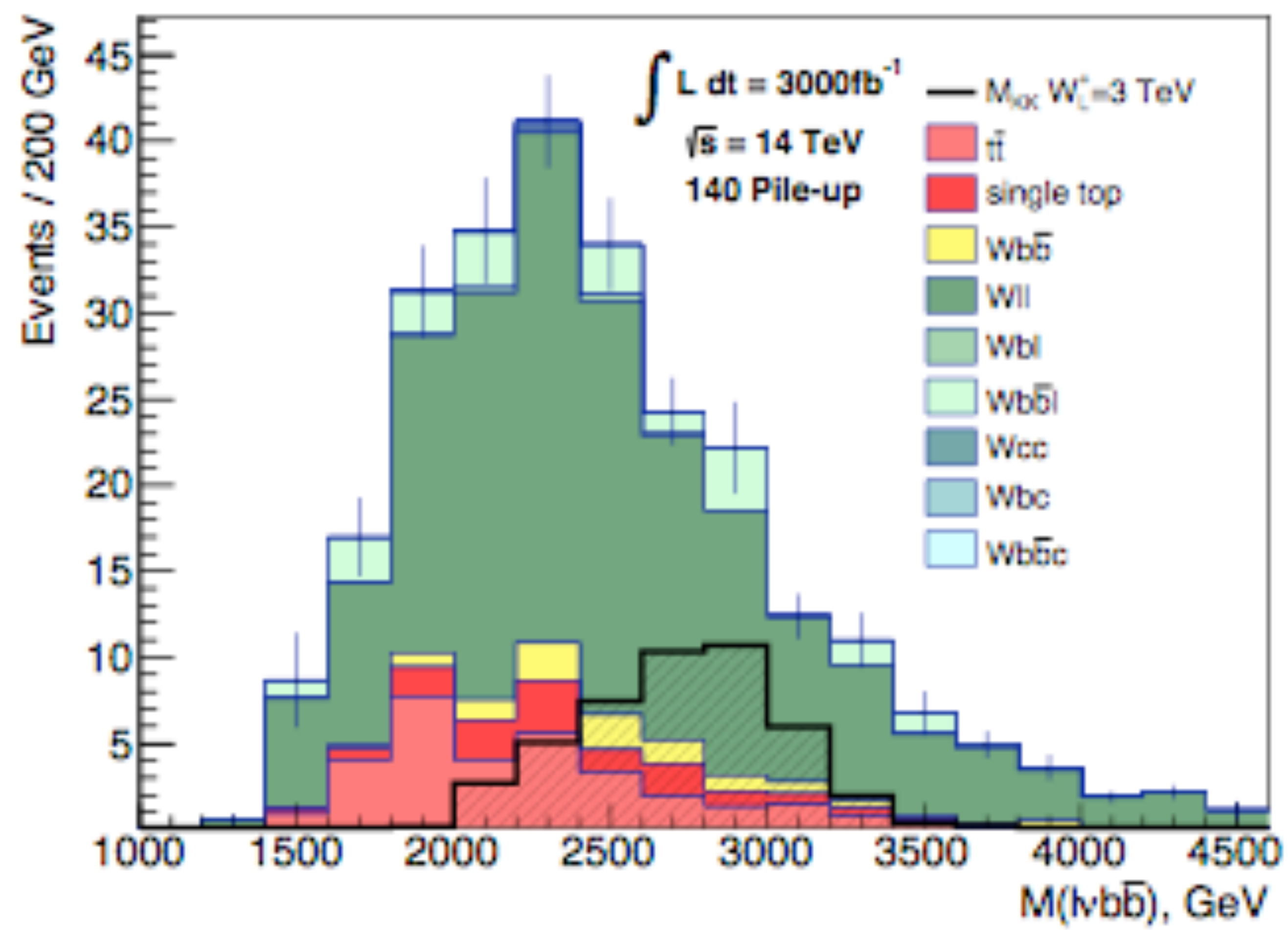


Warped Extra Dimension Search

arXiv:1309.7847

New Physics at high mass scale!

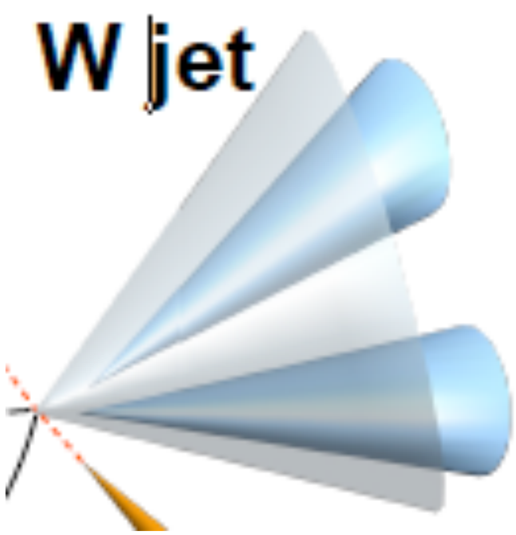


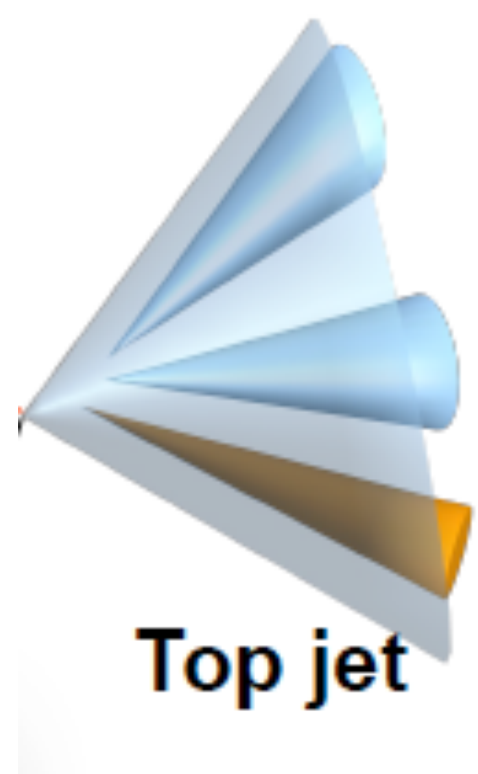


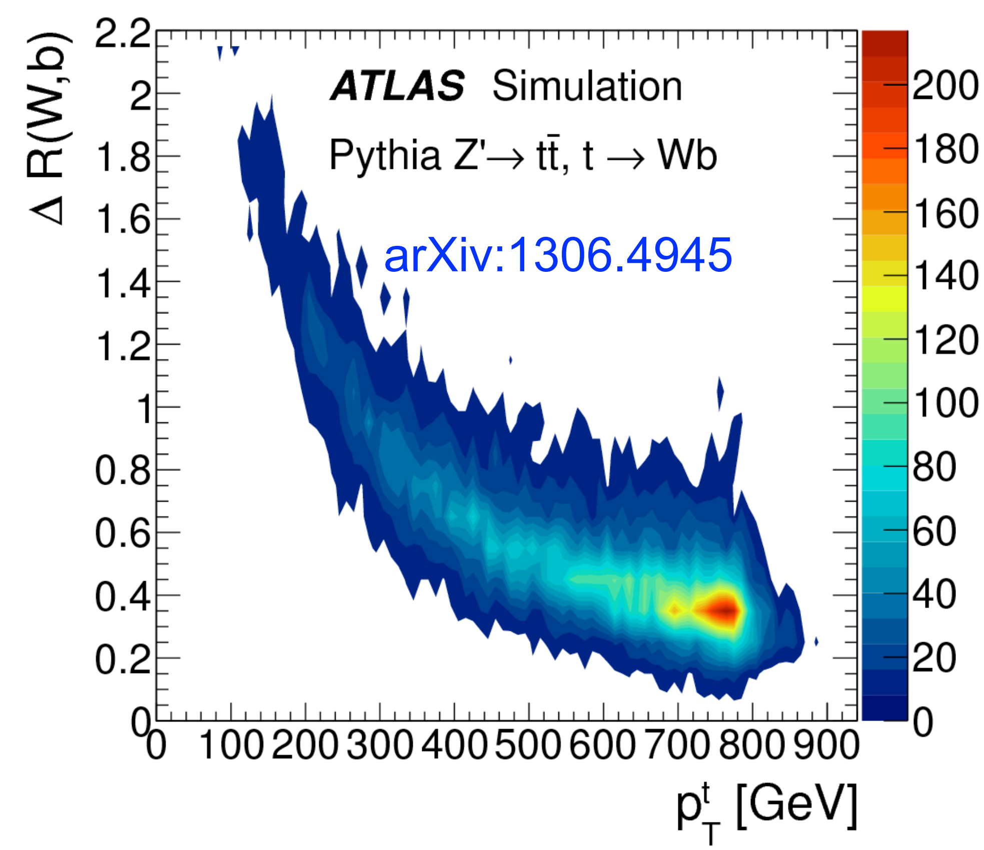
$$\Delta R < \frac{2m}{p}$$

Boosted Objects

Many BSM predicts new particles at TeV scale decaying to top, W, Z or Higgs final states.

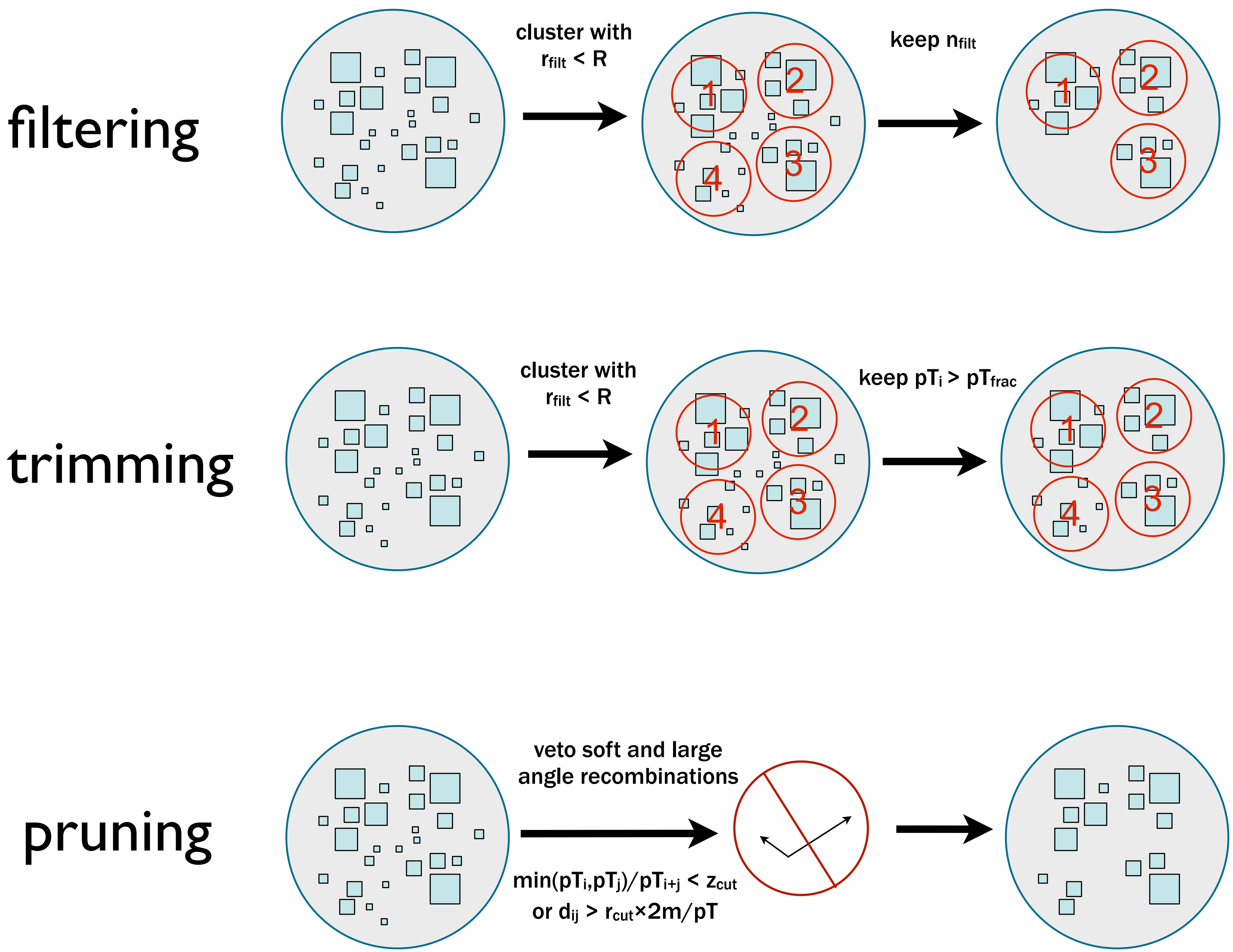






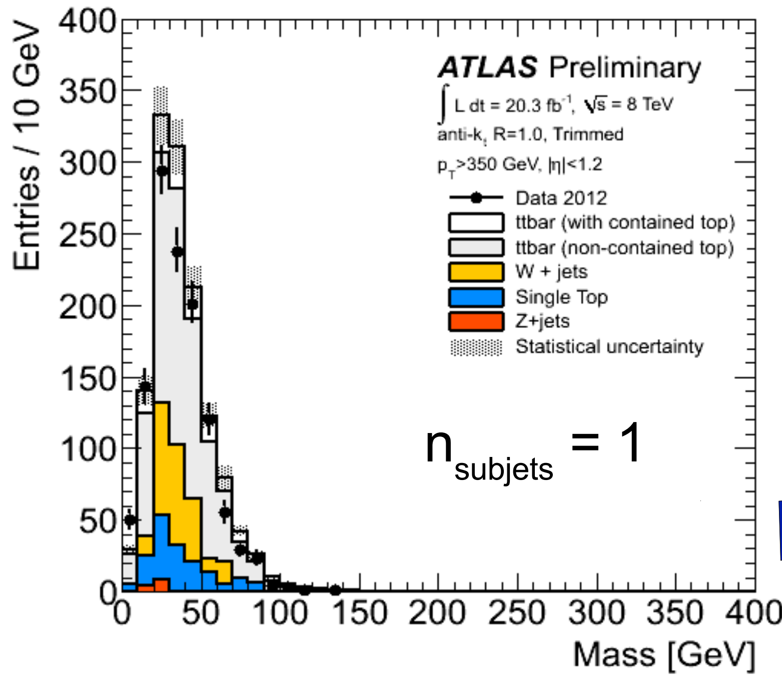
Hadronic final states are merged into one jet due to limited calorimeter resolutions.

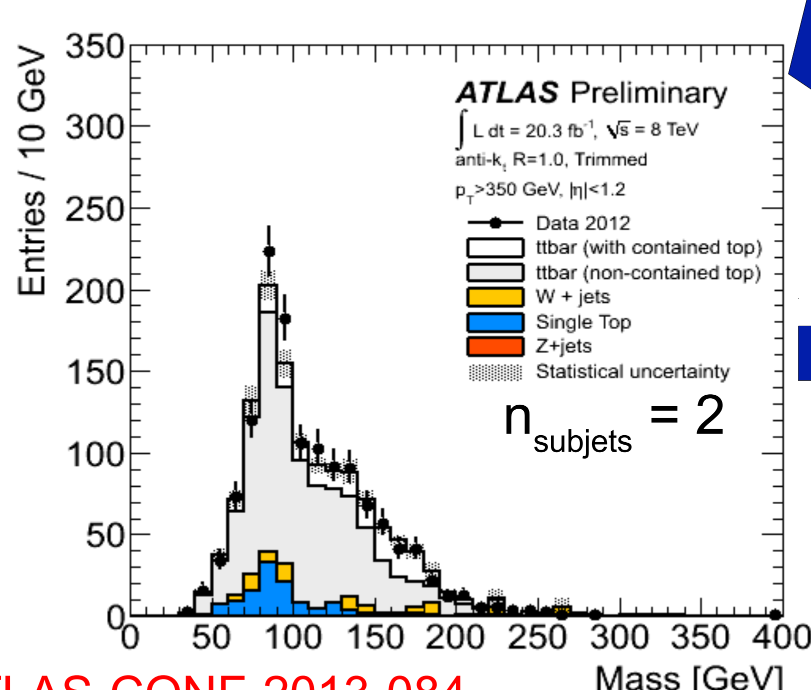
Jet Grooming



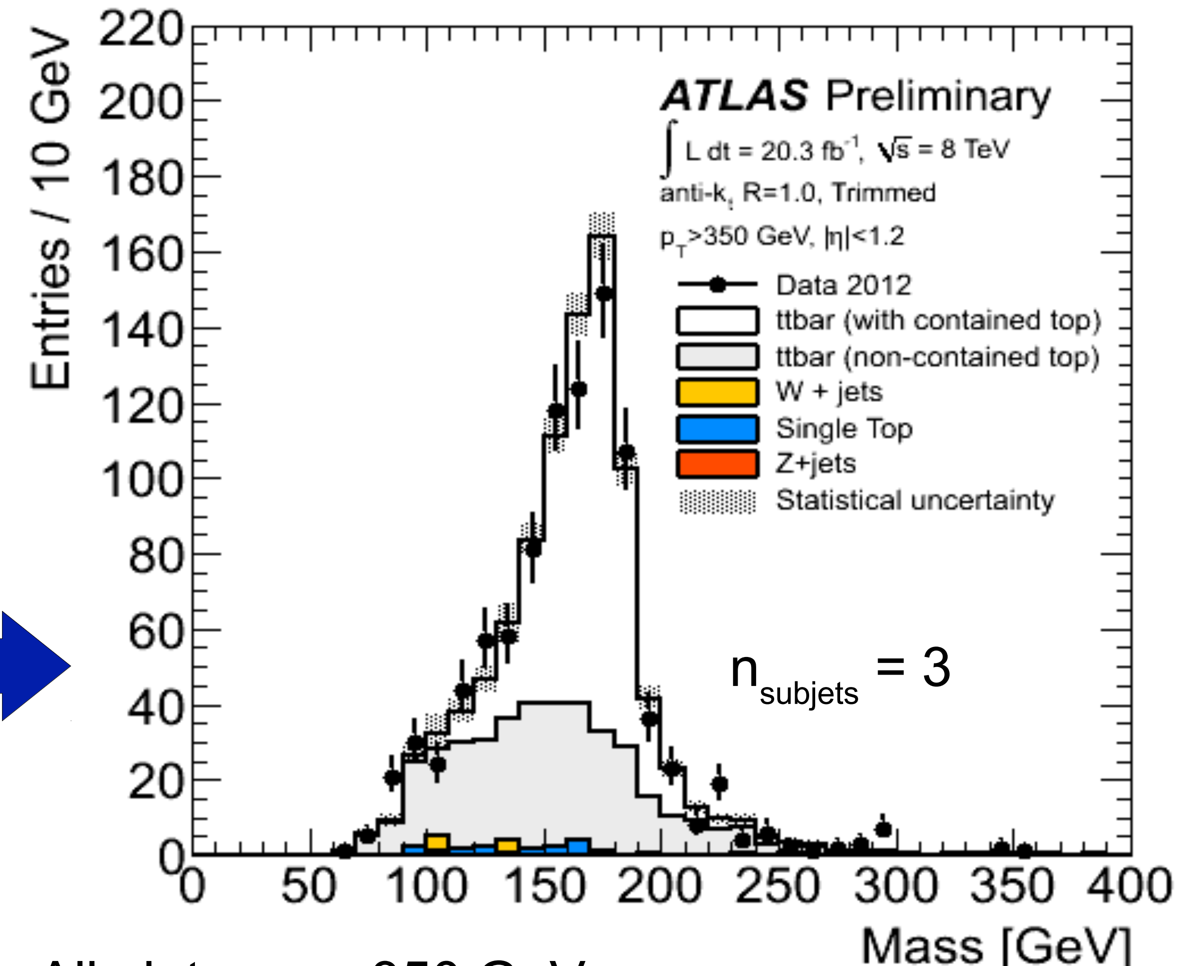
N subjets

- Nice peak at top mass in 3 subjet bin and at W mass in 2 subjet bin.
- Backgrounds mostly in 1 subjet bin.
- Recall: JMS uncertainty 4-5%





ATLAS-CONF-2013-084

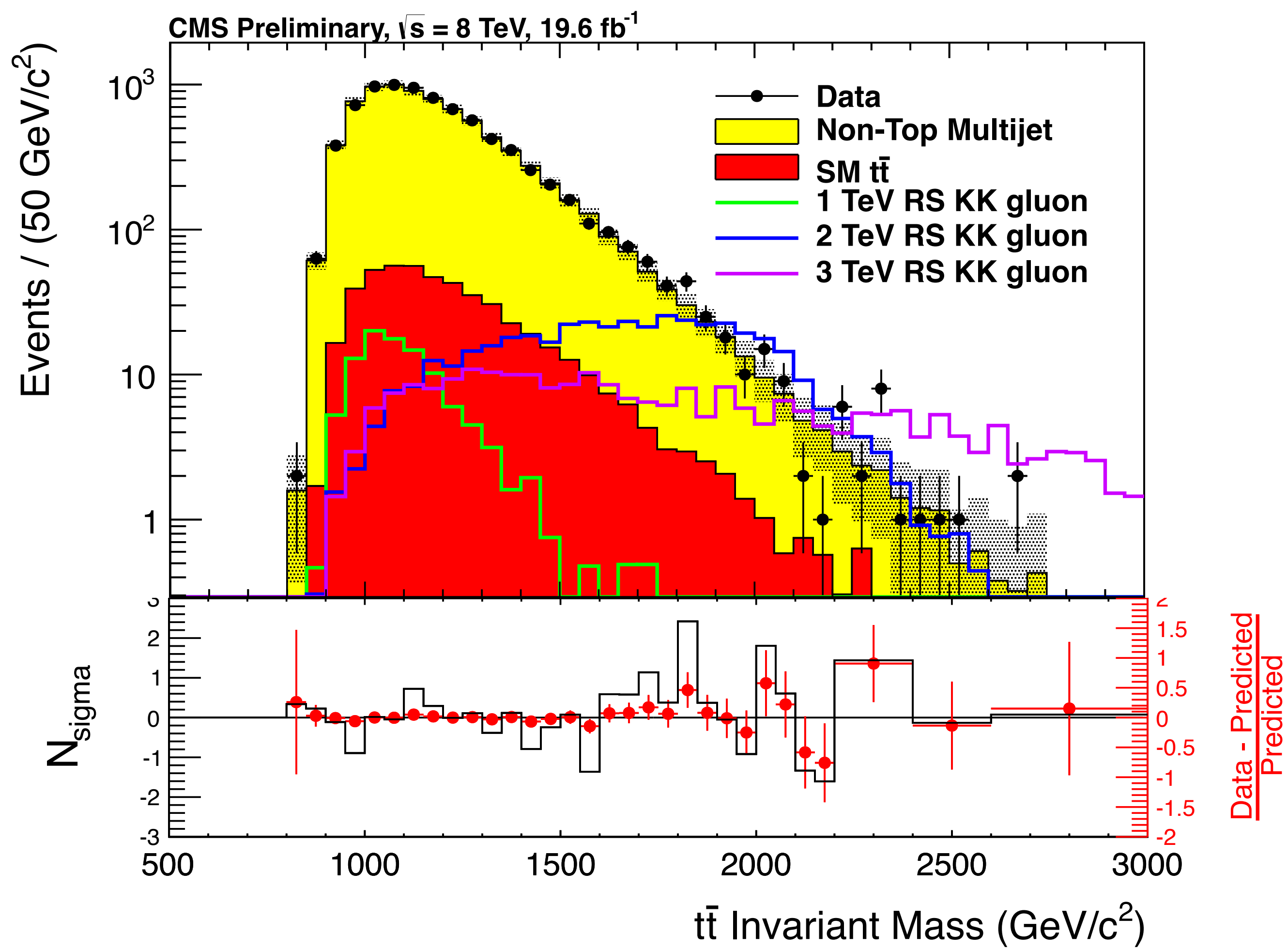


All plots: $p_T > 350$ GeV

Top Tagger Application

[CMS PAS B2G-12-005]

$t\bar{t}$ Resonances: All-hadronic



- $m_{t\bar{t}}$ distribution after likelihood maximization
- overwhelming background from QCD dijet production (could be reduced using advanced b-tagging techniques on subjets)
- broad resonances from KK gluon excitations

New Analysis Techniques

ATLAS-CONF-2013-087

Q-Jet: A new approach to parton shower

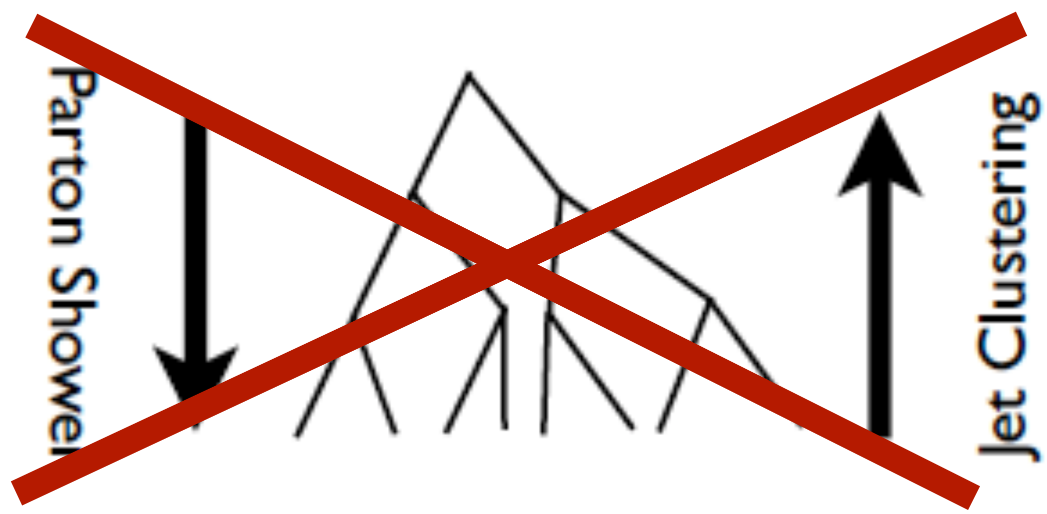
arXiv:1201.1914
ATLAS-CONF-2013-087

A typical jet clustering is to inverse the parton shower

Q-Jet: A new approach to parton shower

arXiv:1201.1914
ATLAS-CONF-2013-087

A typical jet clustering is to inverse the parton shower

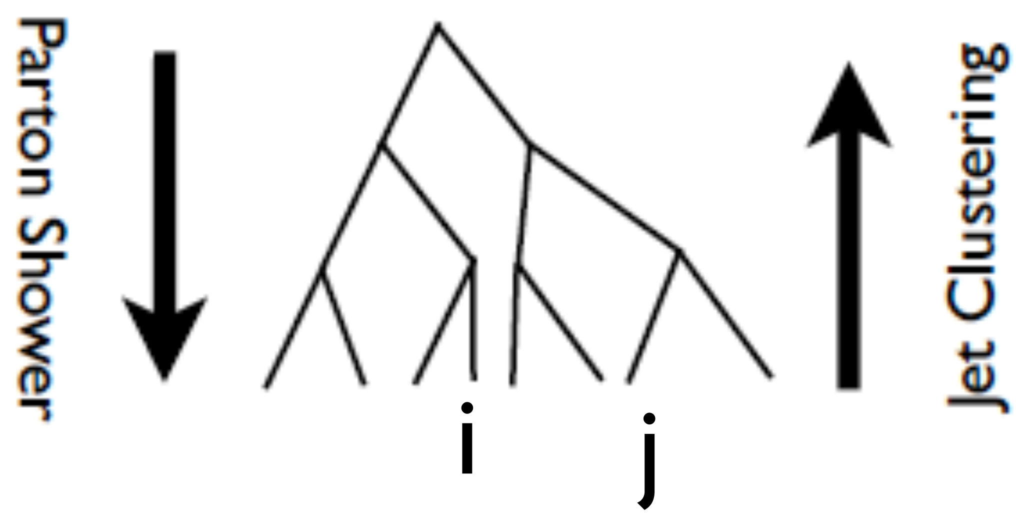


But the parton shower is not really invertible
Many parton shower can produce the same jet
Q-jet asks: study all possible inverse parton shower path.

Q-Jet: A new approach to parton shower

arXiv:1201.1914
ATLAS-CONF-2013-087

A typical jet clustering is to inverse the parton shower

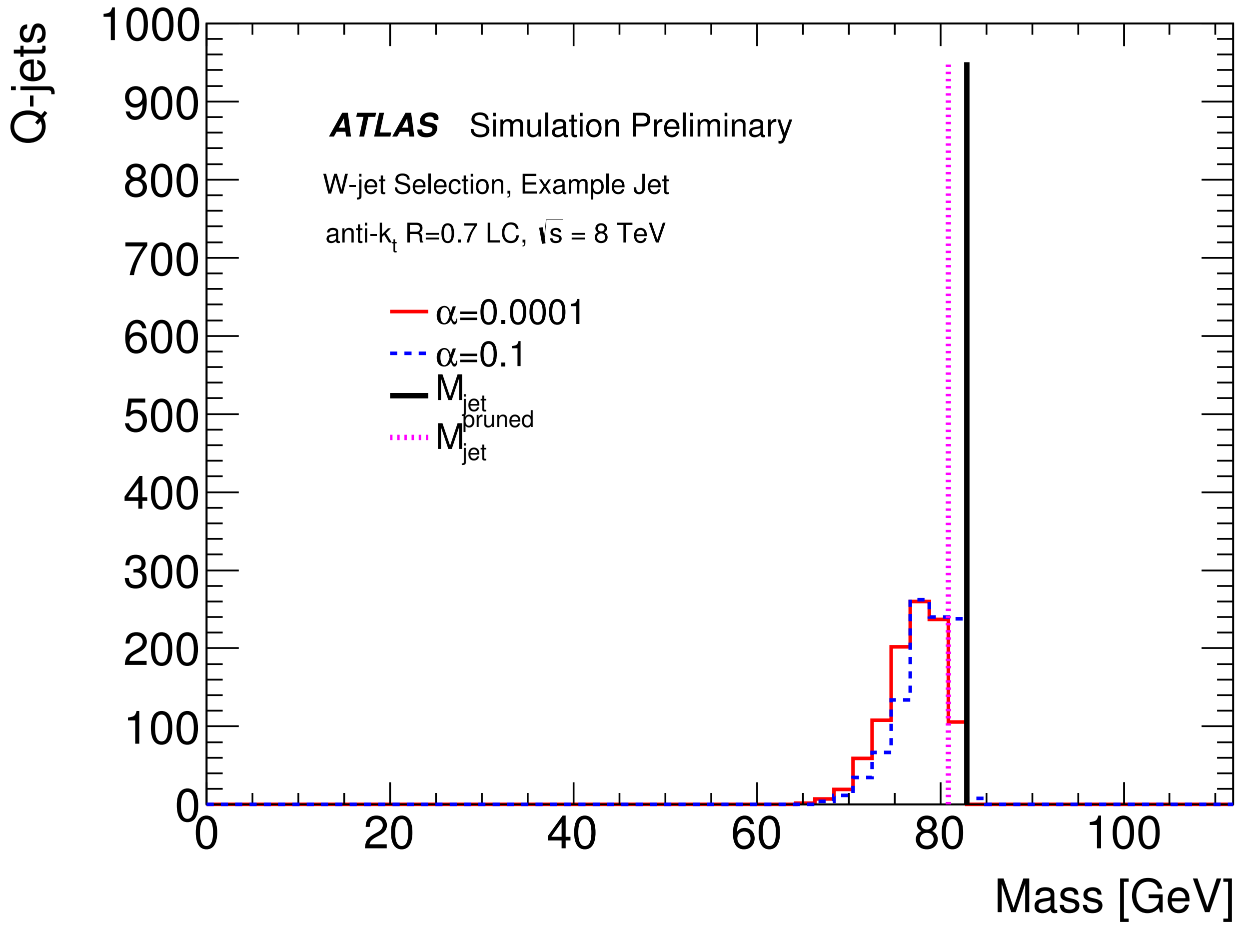


Choose a random pair ij, using the weights:

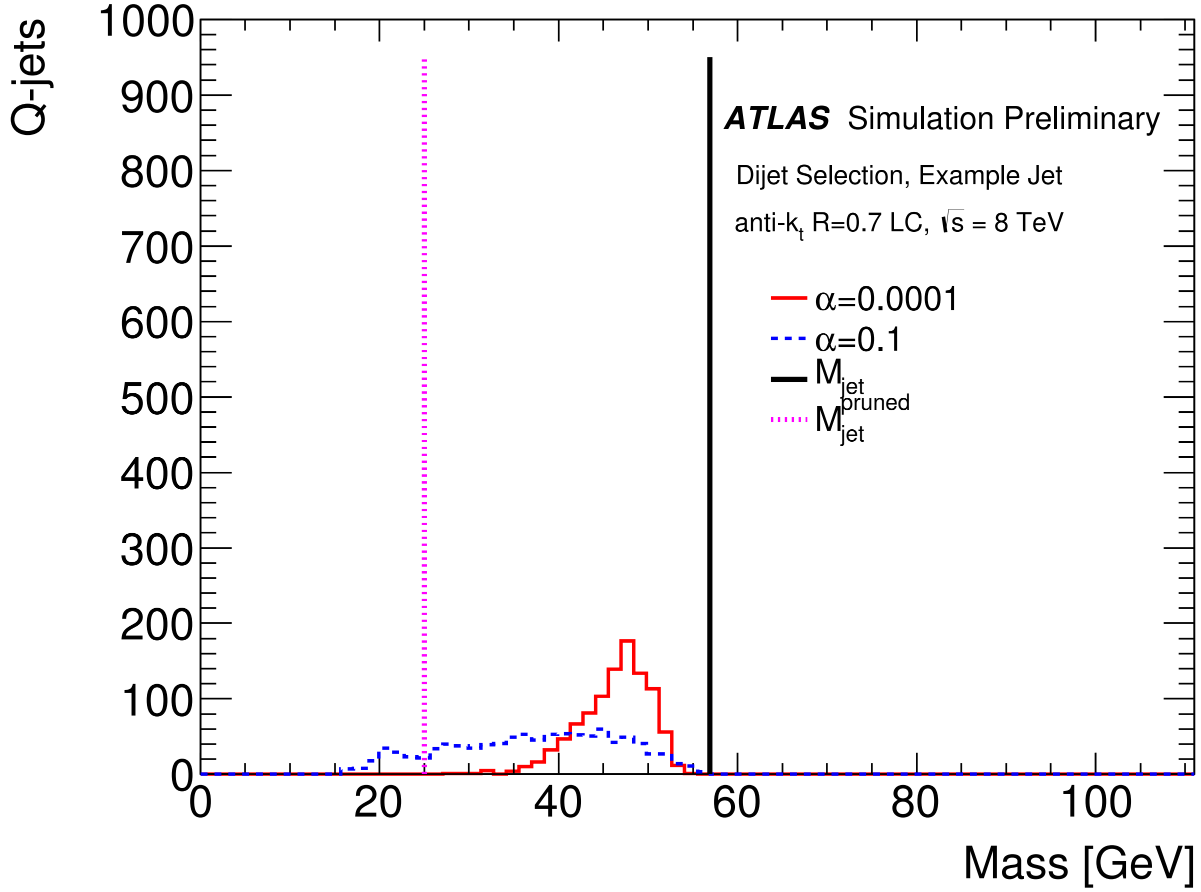
$$\omega_{ij}^{(\alpha)} = \exp\left\{-\alpha \frac{d_{ij} - d^{min}}{d^{min}}\right\}$$

Each combinatorial tree sequence is a representation of parton jet
Consider random combinatorial of trees

Example Jets



W-jet

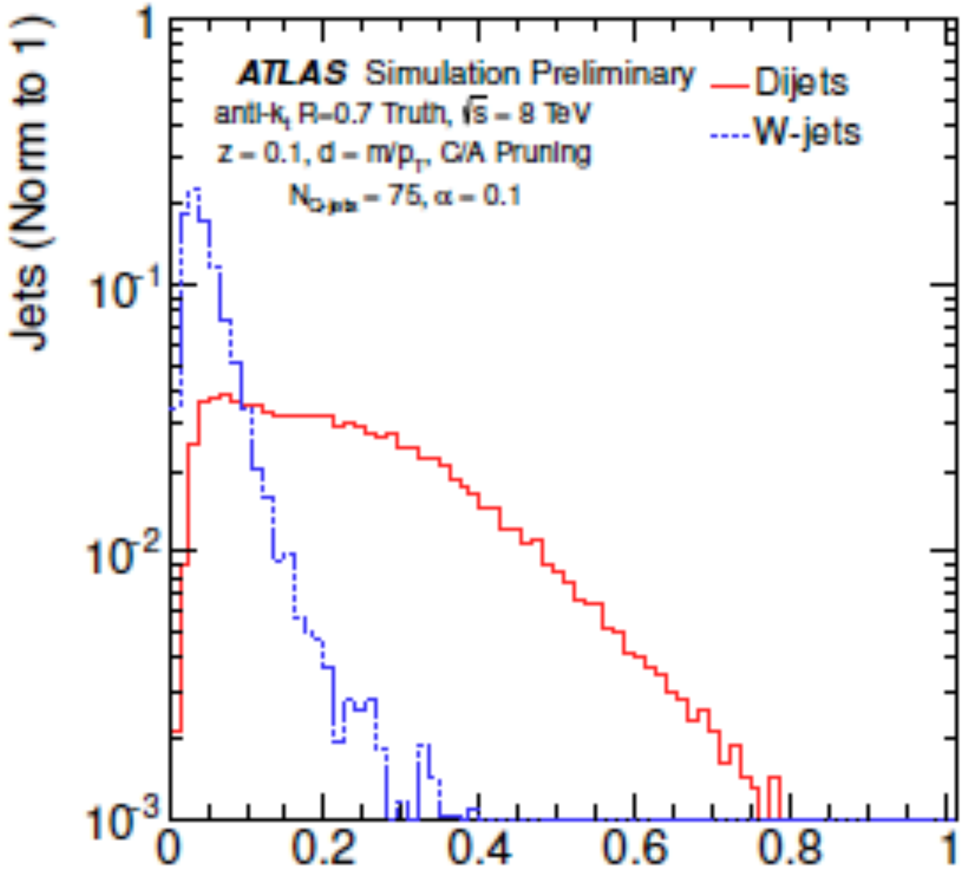


QCD-jet

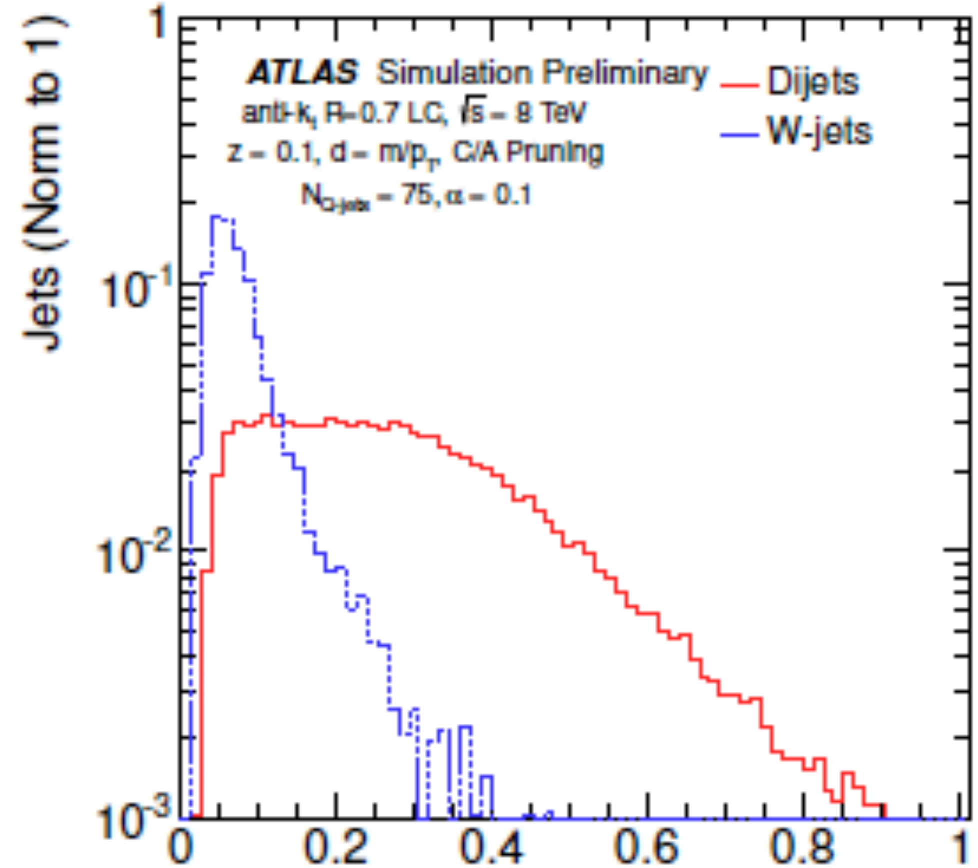
- A W-jet has a **small spread** in masses for its Q-jets: a QCD jet has a **very large spread** in masses for its Q-jets

Q-Jet Volatility

- Inspired by the previous plots, define $\nu = \Gamma / \langle m \rangle$, where Γ = RMS



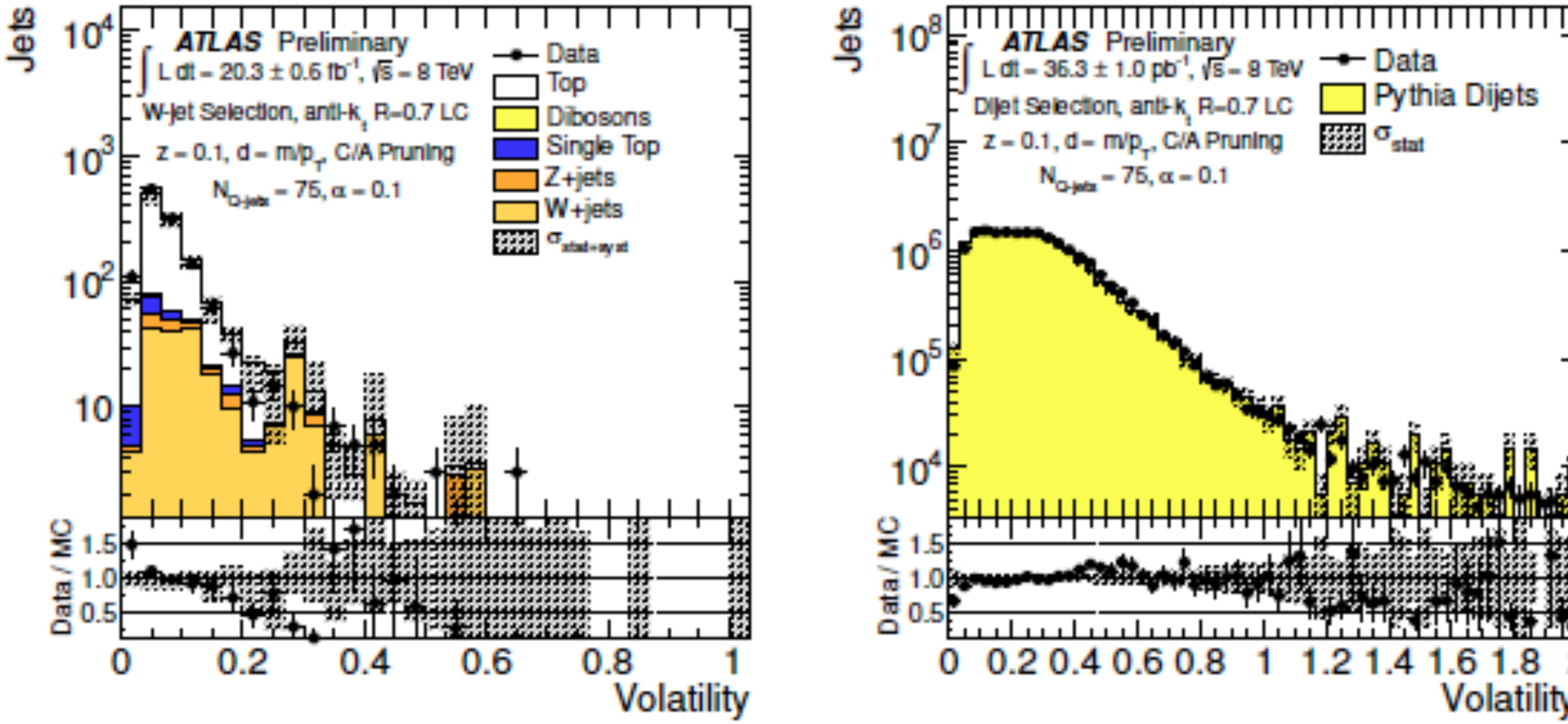
Truth Hadrons



Reconstructed

- Volatility, with $N_{Qjets} = 75$ and $\alpha = 0.1$, for W-jets and QCD-jets
  - Truth-jets on left, reconstructed jets on right
- See **very good discrimination** between signal and background!

Data/MC agreements



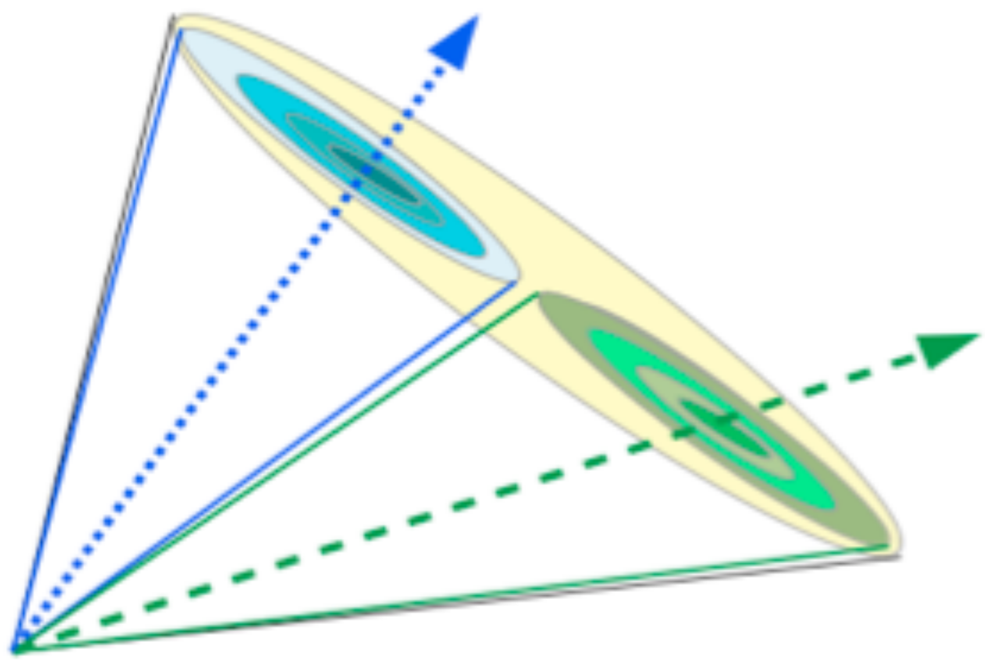
- **Generally very good agreement** seen in data/MC!
  - W-jet events have slightly worse agreement: data has lower values of volatility

Telescoping-Jet

Yang-Ting Chien arXiv:1304.5240

Idea: jet algorithms with multiple R's

Close collaboration iwth Yang-Ting



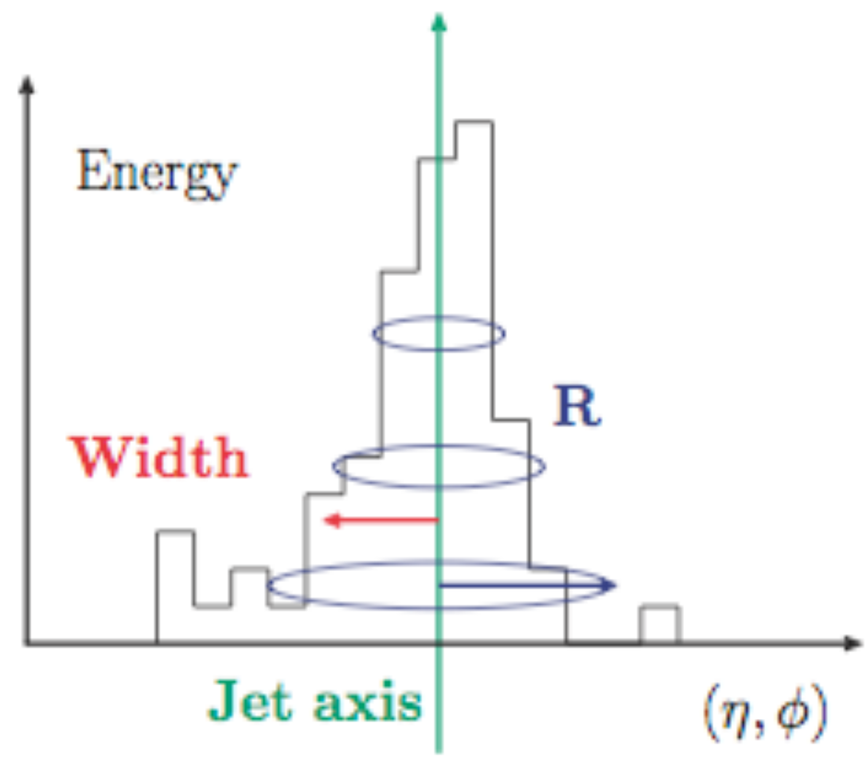


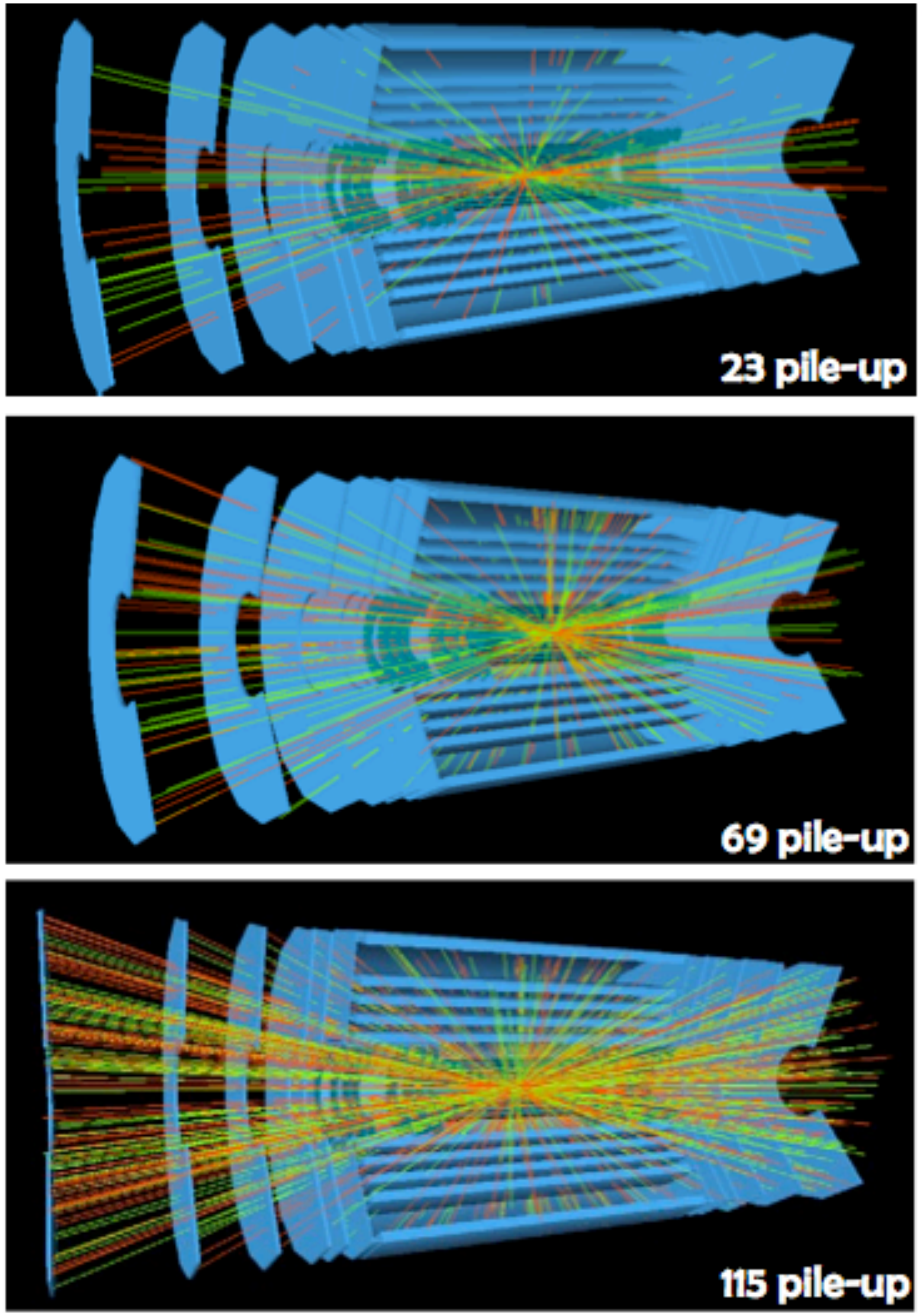
Figure: A cartoon calorimeter plot distinguishing the width of the localized energy distribution of a jet from the parameter R

New Experimental Challenges

Experimental Challenge

- Increased luminosity
  - Higher hit-rate capability
  - Higher segmentation
  - Higher radiation hardness
  - Lighter detectors

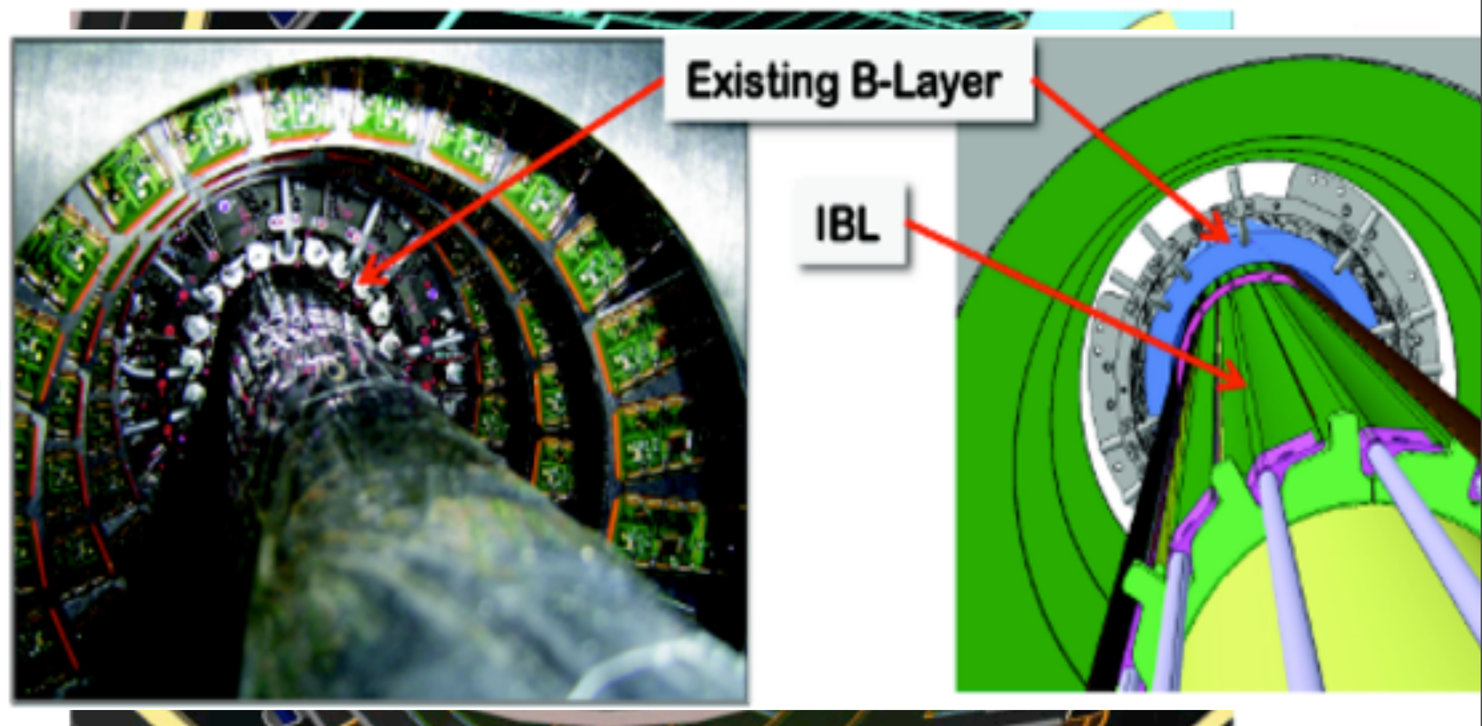
- Radiation hardness for the innermost layer at 3cm to 4cm
  - Phase 1: $1 \cdot 10^{15}\ n_{eq}cm^{-2}$
  - Phase 2: $5 \cdot 10^{15}\ n_{eq}cm^{-2}$
  - HL-LHC: $2 \cdot 10^{16}\ n_{eq}cm^{-2}$



ATLAS Pixel Upgrade

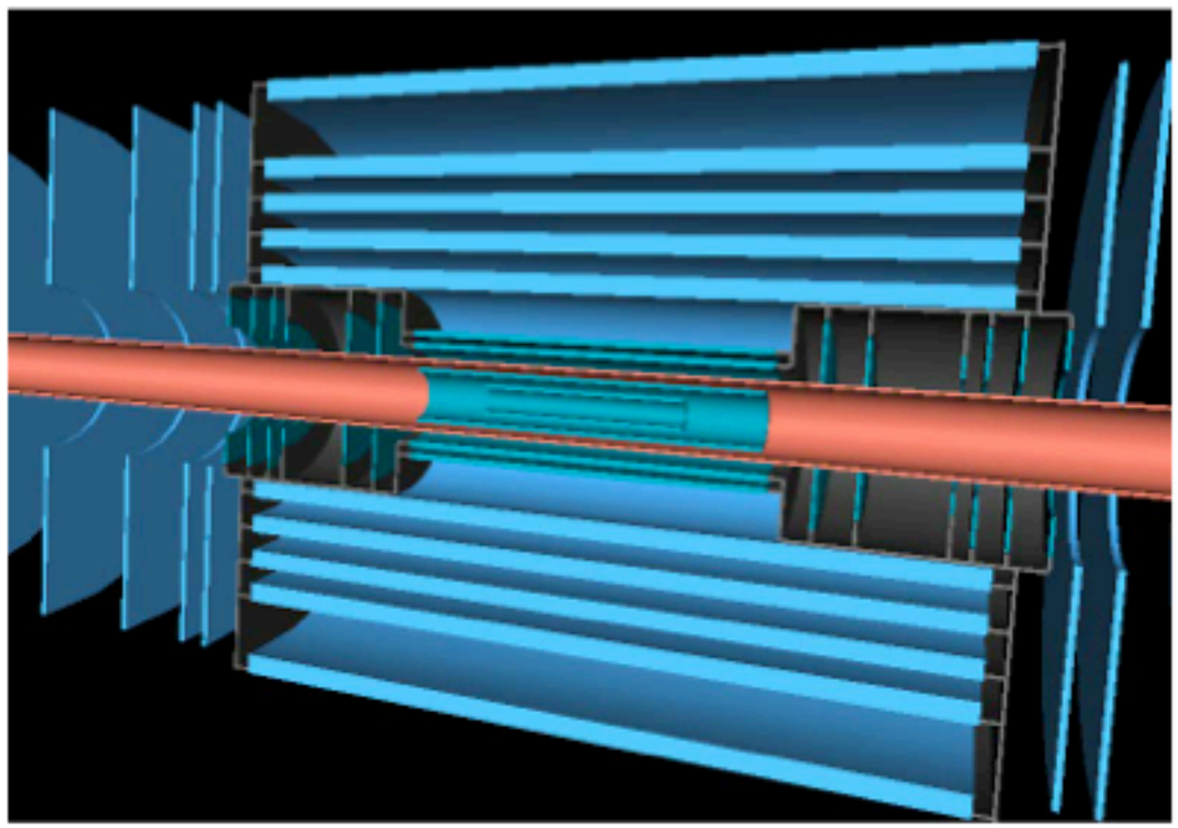
- **Phase 0 Upgrade**

  The new IBL will extend the pixel detector system to a 4-layer system with finer segmentation and at a smaller radius



- **Phase 2 Upgrade**

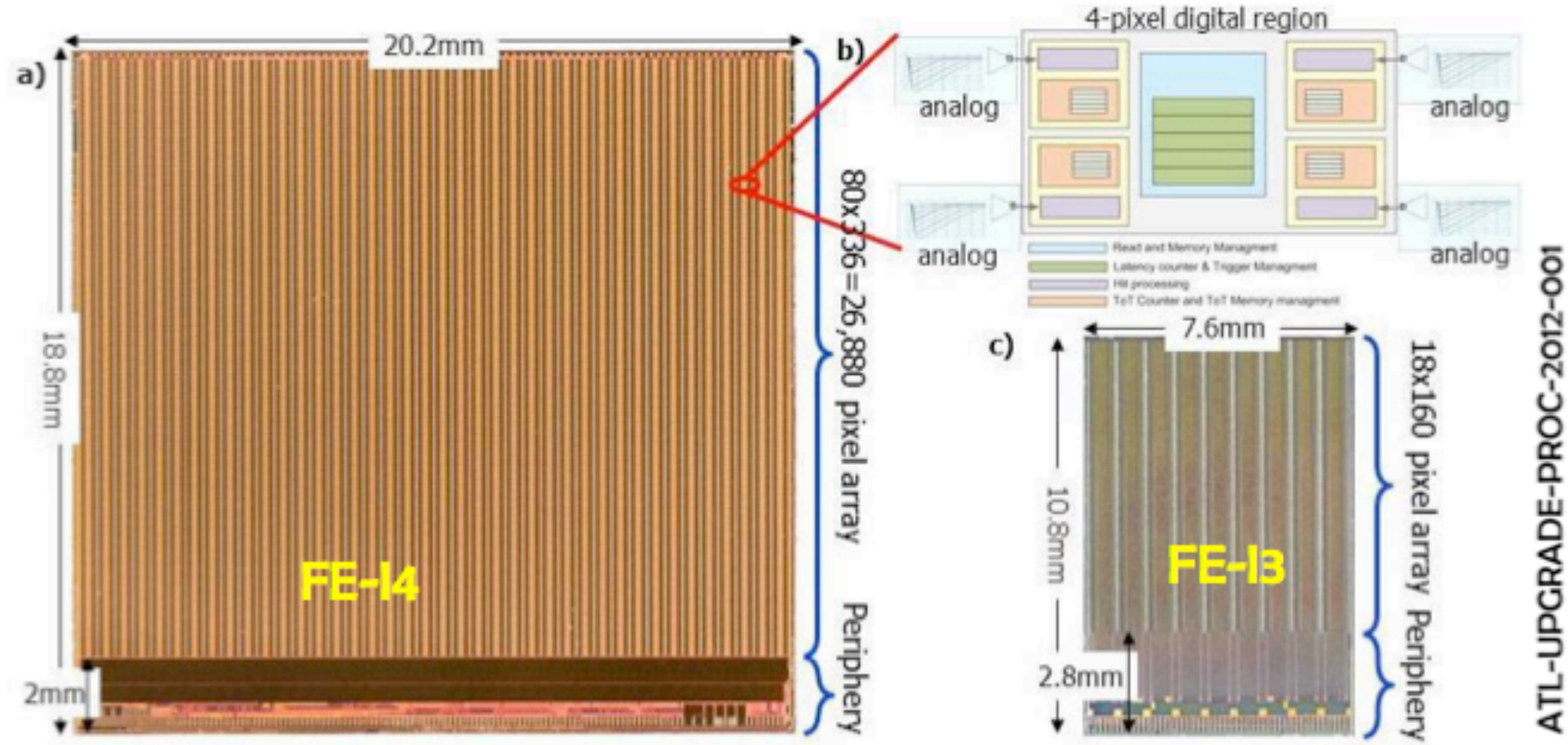
  Complete new ATLAS tracker for pixels and strip detectors



FE I4: Largest HEP Chip

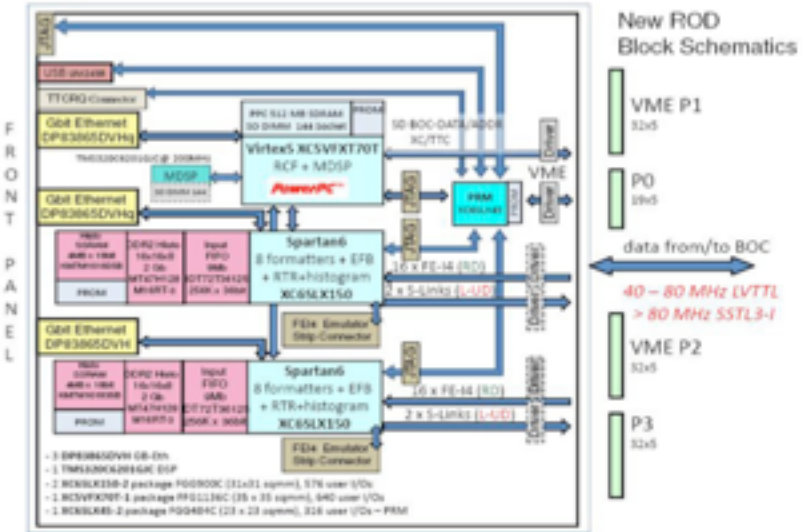
- Smaller pixels (50·250 μm²)
- Lower noise and threshold operation
- Compatibility for higher data rates
- Column drain architecture with local hit storage
- IBM 130nm process

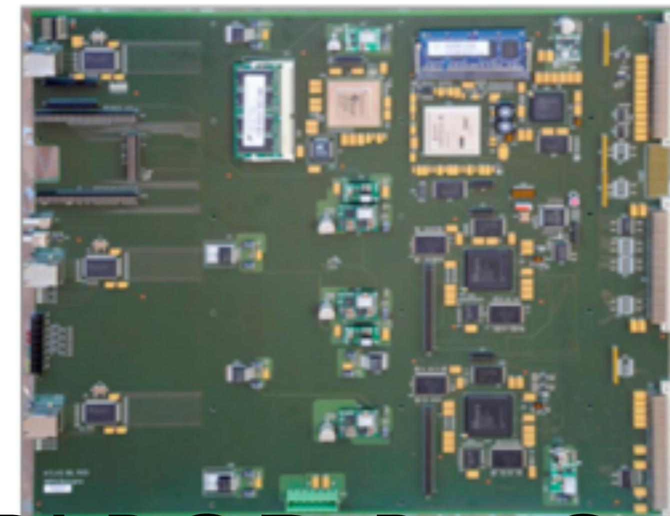
- Largest chip to date in HEP:
  - maximize active area and reduce bump-bonding costs
- array size: 80 col. x 336 rows => 26880 pixels, 8×10^7 transistors
- average hit rate at 1% inefficiency => 400 MHz cm^{-2}; max. trigger rate:



IBLROD DAQ

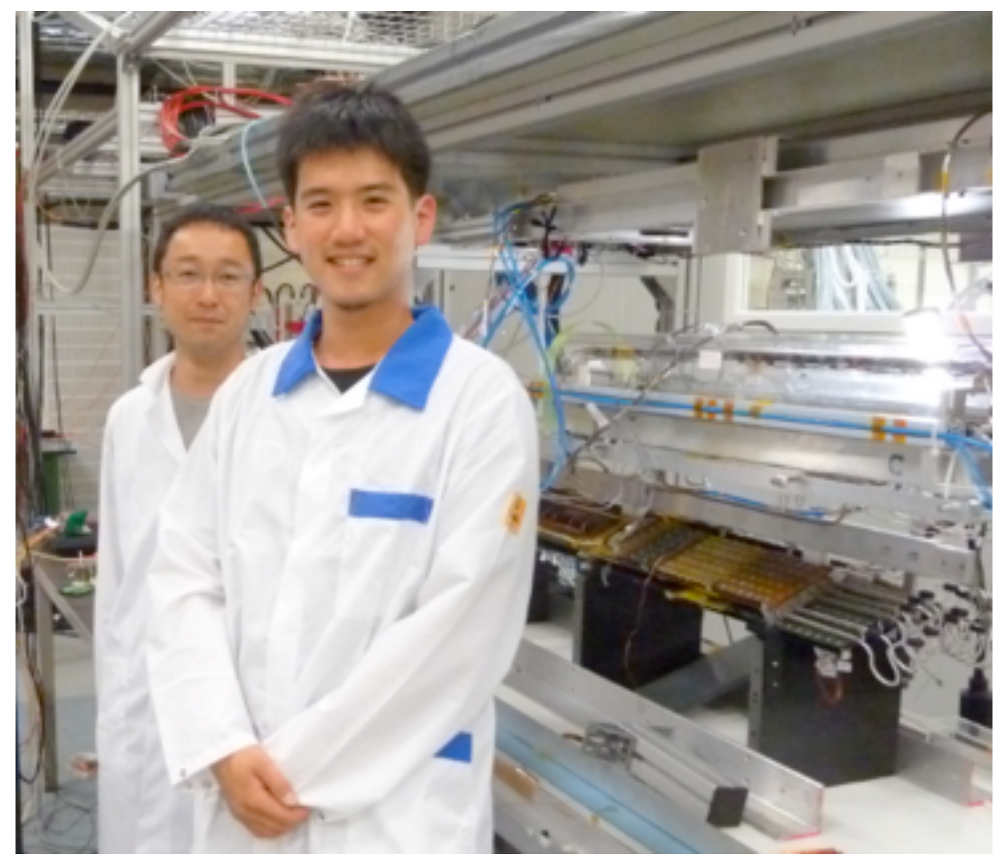
My team is responsible for firmware/software development of the VME based Read Out Driver to double readout speed!





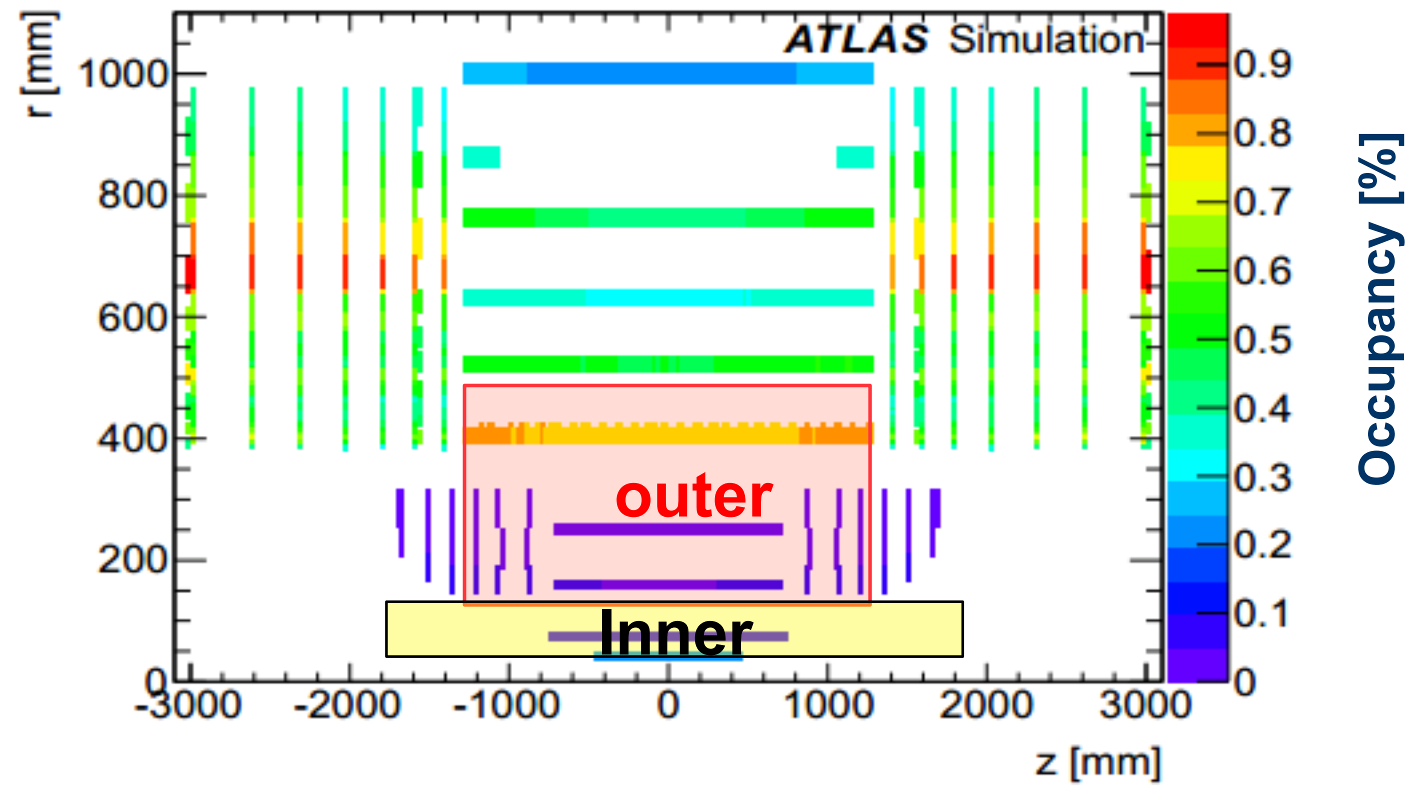
IBLROD RevC

Lynn Marx (UW physics postdoc)



Shawpin (Bin) Chen (UW EE master)

PhaseII Upgrade: Design Consideration



Detector:	Silicon area [m^2]	Channels [10^6]
Pixel barrel	5.1	445
Pixel end-cap	3.1	193
Pixel total	**8.2**	**638**
Strip barrel	122	47
Strip end-cap	71	27
Strip total	**193**	**74**

ATLAS Phase II Letter of Intent

Inner layers (r ~ 3 to 15 cm)

1. low power
2. low material budget
3. occupancy / bandwidth
4. resolution

hybrid pixels (65nm)
new sensor developments

Outer layers (r > ~ 15 cm)

1. low cost
2. low power
3. low material budget
4. resolution / bandwidth

low cost hybrid pixels or monolithic pixels
wafer scale processes are needed

ATLAS Pixel R&D

- sensor materials
  - planar Si sensors (PPS collaboration)
  - 3D Si sensors (3D collaboration and IBL coll.)
  - CVD diamond (RD42 and DBM collaborations)

  IBL and DBM are the best sensor test benches

- IC development
  - 65 nm → within RD53 collaboration
  - 3D integration (within AIDA framework)
- stave + powering + link
  - mechanics R&D (stave: France, Germany, US, disks: UK)
  - powering schemes (serial powering, DC-DC)
  - GBT link
- new concepts
  - towards more monolithic CMOS pixels
    → HVMAPS and (fully) depleted DMAPS

The Next Generation

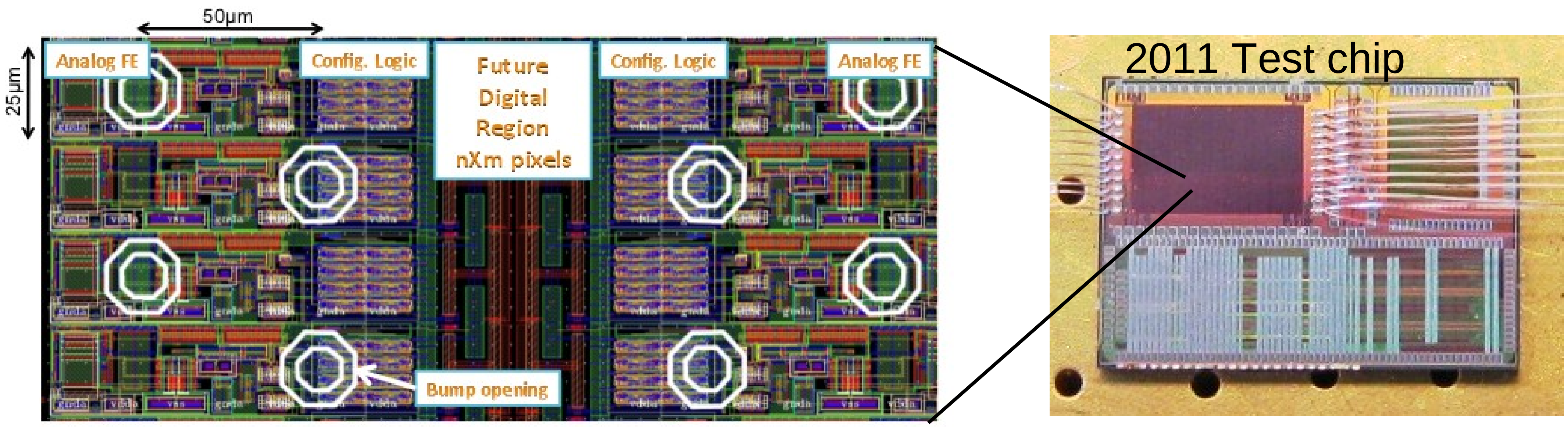
Sensor thickness (planar or 3D):	100 – 150 µm -> MIP signal ~ 10 ke$^-$ before irrad.
Pixel size:	~ 25 x 150* µm^2
Threshold:	~ 1 ke$^-$
Threshold dispersion:	~ 100 e$^-$
Noise:	< 200 e$^-$ @ C_{IN}^* = 400 fF, I_{LEAK}^* = 100 nA
Power dissipation:	3.5 mW / mm^2
Hit rate:	~ 1GHz / cm^2 => ~ 30 kHz / pixel
Hit loss:	< 0.5 % (rather 0.1 %)
Radiation tolerance:	1 Grad, 2×10^{16} neutrons
Technology:	65 nm

M. Garcia-Sciveres,

Future pixel chips design meeting 19th February 2013

* Parameters which are not yet clear

First 65nm Prototyping
(LBNL, Bonn)



- Fabricated 2011, 3 x 4 mm^2
  - ~500 pixel matrix, analog + configuration only (no digital region)
  - Pixel size 25um x 100um (estimate 25 x 150 with digital region)
  - Bump inputs staggered to maintain 50um bump spacing
- Irradiated in Los Alamos in 2011, CERN PS 2012, CERN x-ray 2013

radiation does effect is fine only upto 4MGy (Need 10MGy)

RD53: Work Plan

Goal is to have a full chip design in 65nm in 2-3 years.

Title	Scope	Year 1	Year 2	Year 3
WG1	Qualification of technology to 10 MGy TID, 10^{16} n.eq./cm^2	IR	FR	
Radiation	transistor simulation models after irradiation		FD	
	evaluation of logic cell libraries after irradiation	IR	FR(*)	
WG2	Design methodology & verification of 5×10^8 transistor IC	P	FD	
Top Level	Analog integration in large digital chip, power distribution	P	P	FD
Design	Synthesis constraints, clock distribution and optimization	P	P	FD
WG3	System Verilog simulation and Verification framework	P	FD	
Simulation	Optimization of global architecture/pixel regions/pixel	-	FR	
Test Bench	External system and external physics data	-	P	FD
	Verification of test chips and evolving designs	-	OA	OA
WG4	Definition of readout and control interfaces (e.g LPGBT)	IR	FR	
I/O	Definition of standardized I/O protocols and performance	IR	FR	
	Implementation of readout and control interface blocks	-	P	P
WG5	Evaluate and compare alternate amplifier designs	-	IR	FR
Analog	Evaluate and compare charge ADC techniques	-	IR	FR
Design	vs. number of bits (TOT, shared ADC, etc.)			
	Define common requirements for IP block design	FR		
WG6	Evaluate, document, and keep library of IP blocks	-	OA	OA
IP Blocks	Generate overview and recommendations		IR	IR
	Each block will have its own prototyping milestones	P	P	P

Milestone Key: IR=Interim Report, FR=Final Report, P=Prototype, FD=Final deliverable, OA=Ongoing Activity.

(*) *Add 1 year if a custom logic library must be developed*

Detector R&D

Vertex: the pitch & the radiation hardness

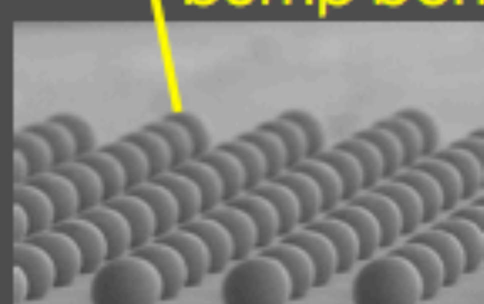
requirement from Physics: better granularity

- increase in the number of pile-up events up to 200 per bunch-crossing @ 5×10^{34} $cm^{-2}s^{-1}$
- Identification of heavy flavours @ ILC, SuperB, Belle II
- 2-tracks separation in the core of hadronic jets

today pitch
50 – 100s µm

Hybrid

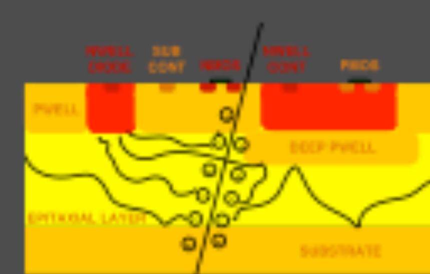
bump bonding



tomorrow 50 – 25 µm

→ R&D on connectivity
- bb facilities
- Through Silicon Vias
- micro bb

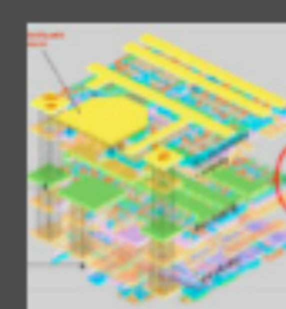
→ MONOLITHIC



less X_0

day after tomorrow
25 µm and less

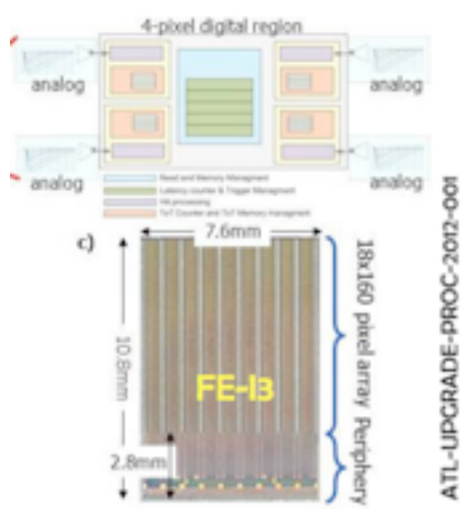
→ Invest on R&D on
- Monolithic
- 3D vertical integration



Krakow, 11 Sept. 2012 4 A. Cattai

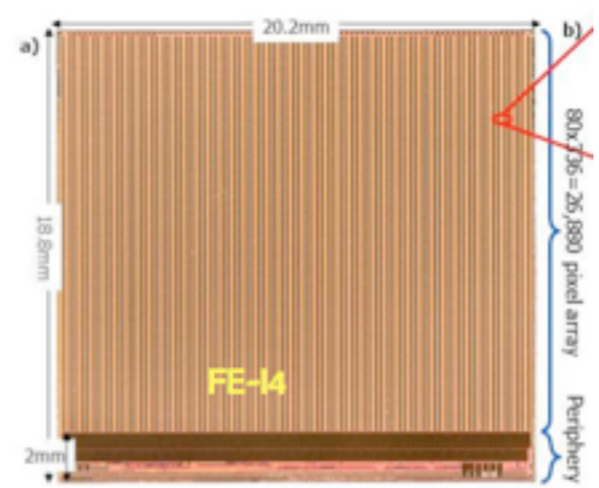
My Involvements

pixel FEI3
(50x400um)
IBM130nm
40colx160row
60MHz max RDO



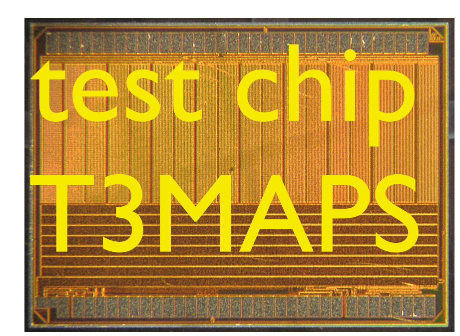
PixelROD DSP

pixel FEI4
(50x250um)
IBM130nm
80colx336row
400MHz max RDO
Largest chip to date



IBLROD DAQ

CMOS MAPS
(25x50um?)
TSMC 65nm?
Rad Hard?
Cheaper?



T3MAPS DAQ system

Summary

- The LHC
  Fully exploration of TeV scale physics

- The Energy Frontier
  Go beyond TeV Scale

- The Next Big Discovery
  To be enabled by new techniques
  + brave thinkers!

Backup

Approximate Timelines of HE projects