Early Physics Measurements at the LHC with ATLAS

Karsten Köneke

DESY

for the ATLAS Collaboration

Outline

Introduction:

- *Why was the LHC built?*
- *What is the mission of ATLAS?*

Standard Model measurements

- *First, try to measure known processes to understand the detector!*

Possible early discoveries:

- *If we are lucky, we will see something unexpected…*

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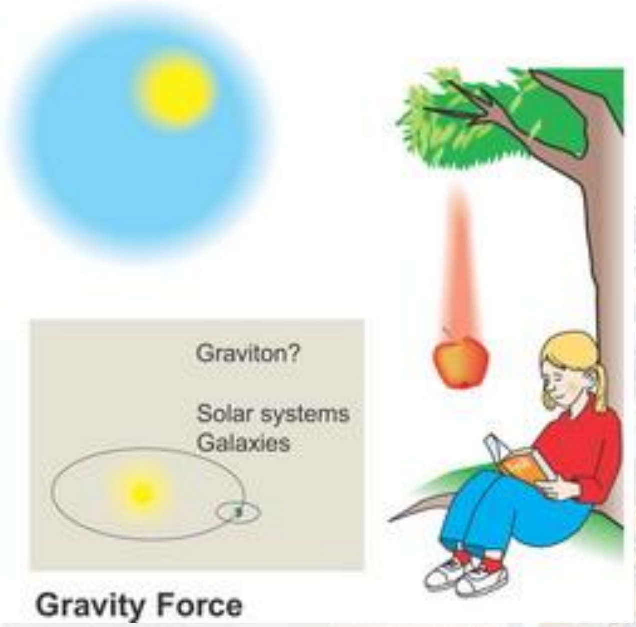
> *"Prediction is very difficult,*
> *especially if it is about the future."*
>
> *Niels Bohr*

The 4 Forces in Nature

Gravity



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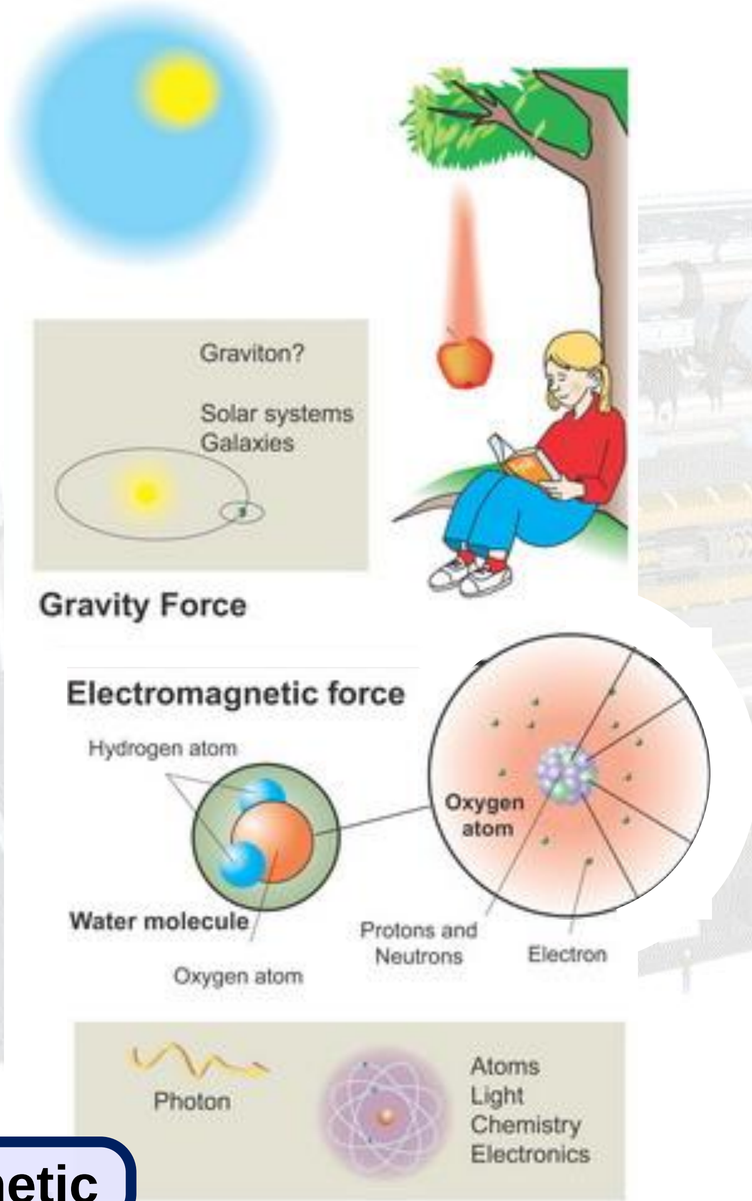
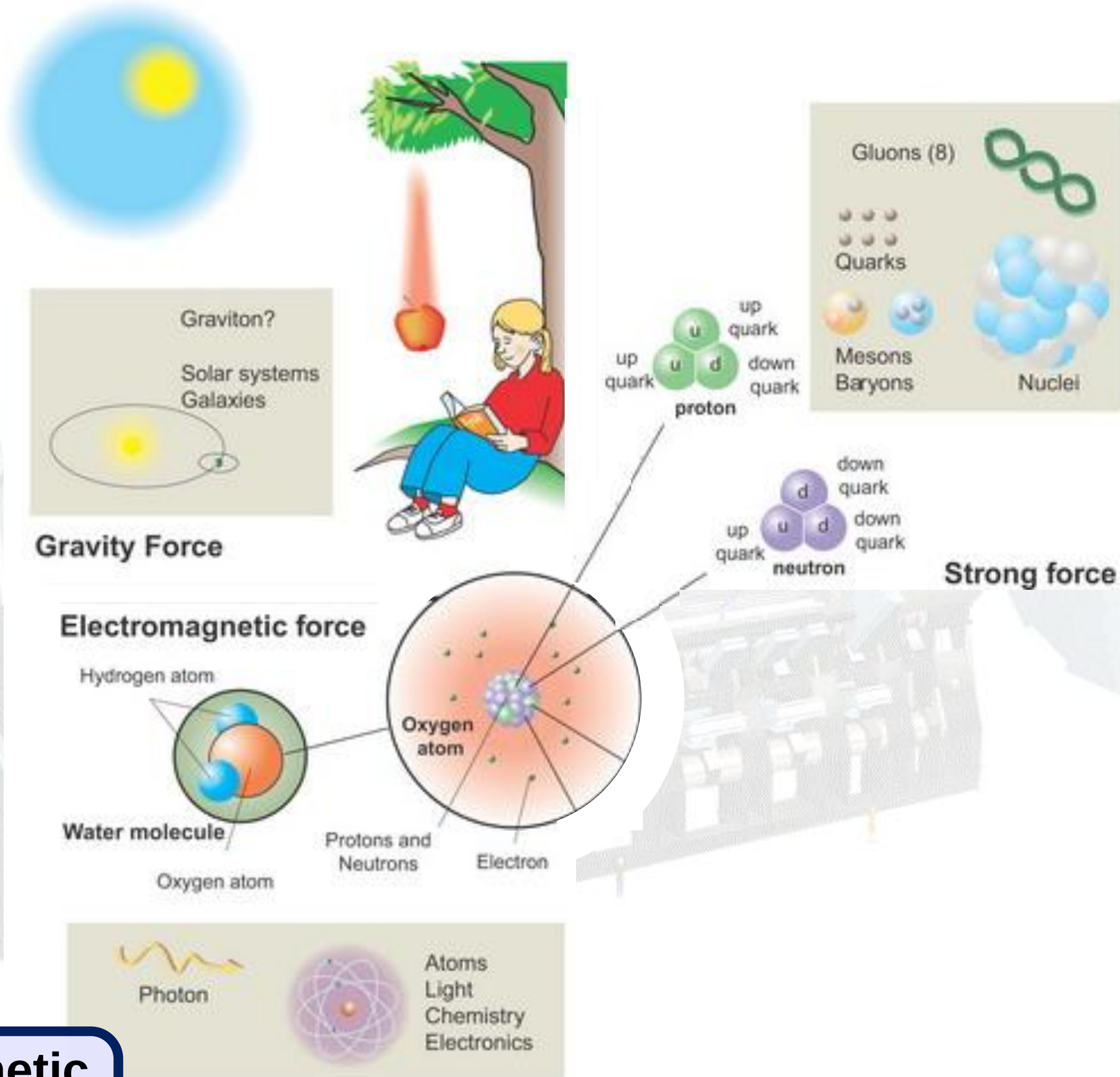


Electromagnetic

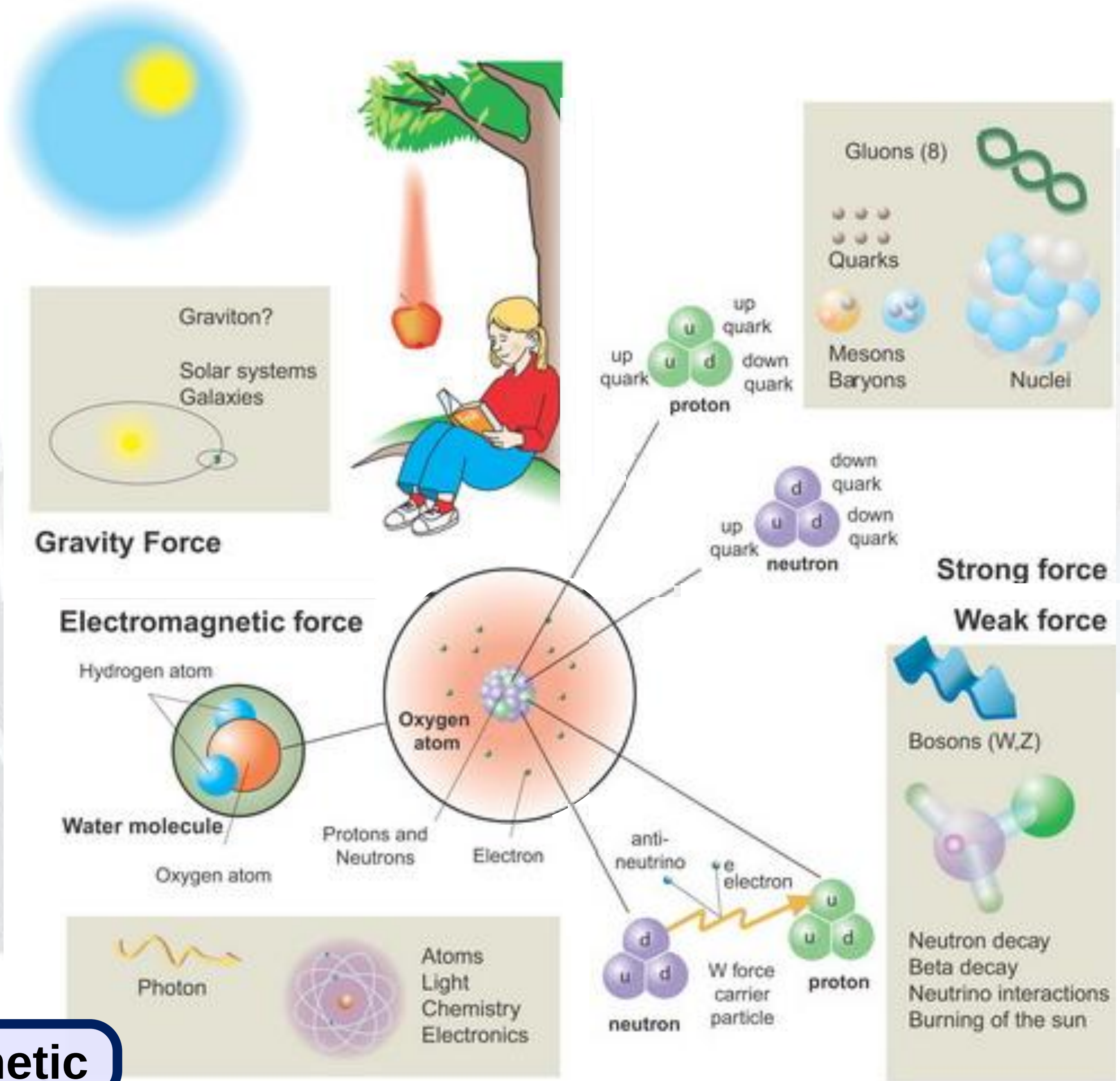
Gravity

Strong



Electromagnetic

Gravity | **Strong** | **Electromagnetic** | **Weak**



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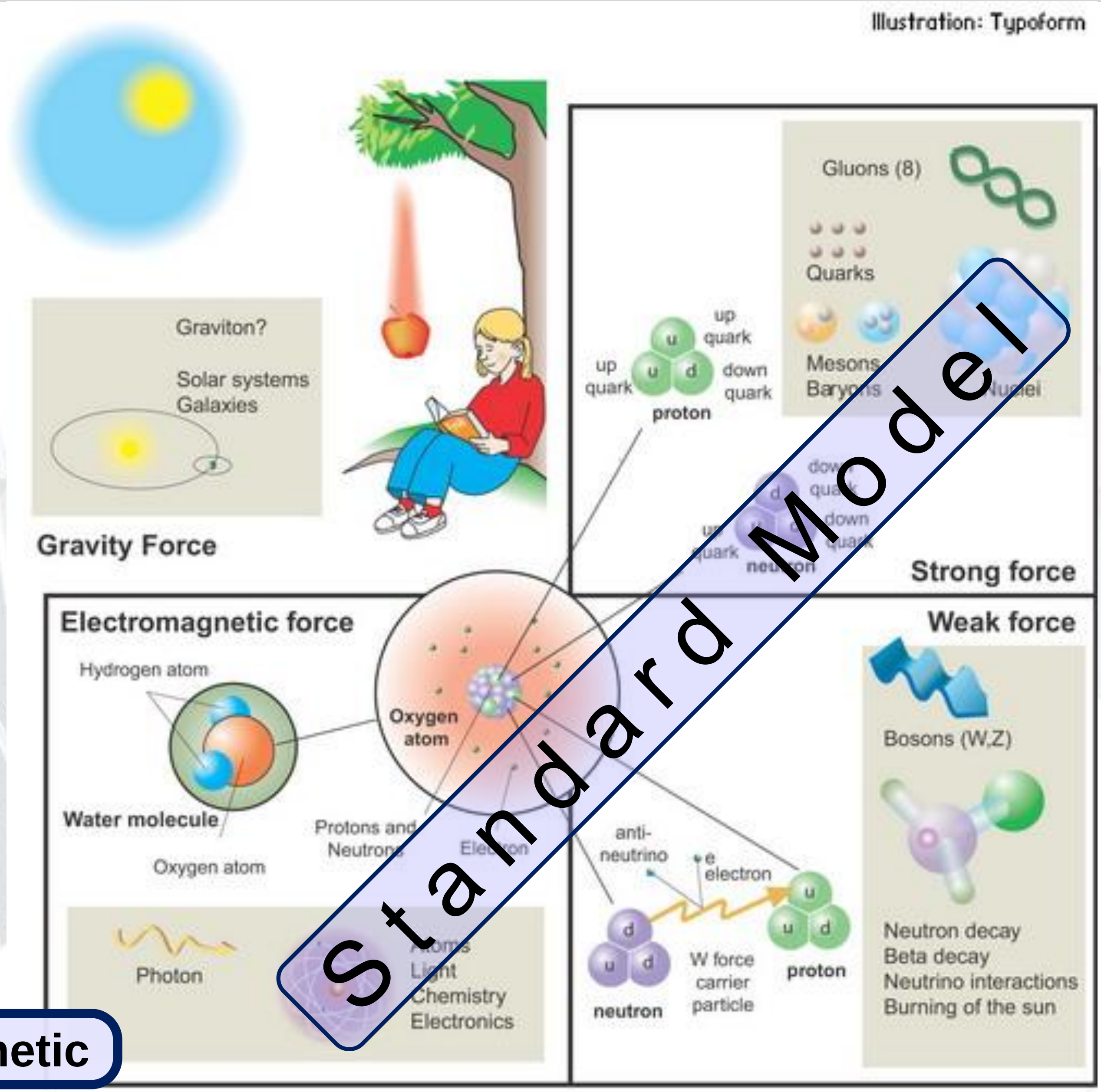
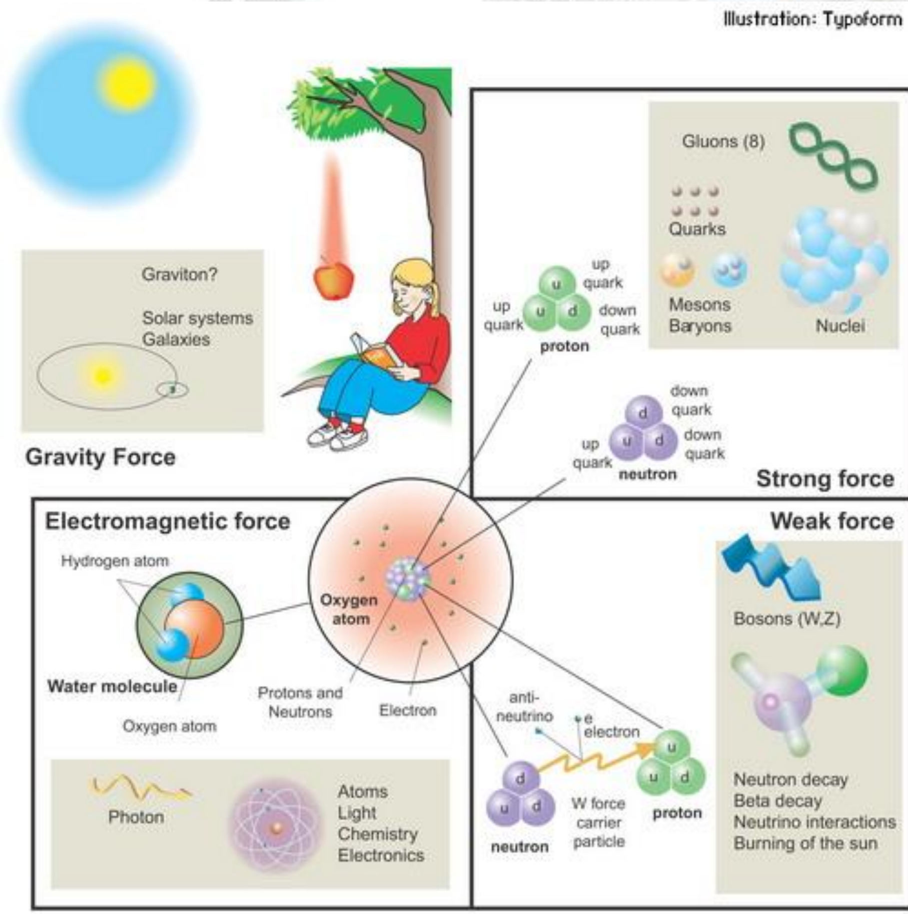


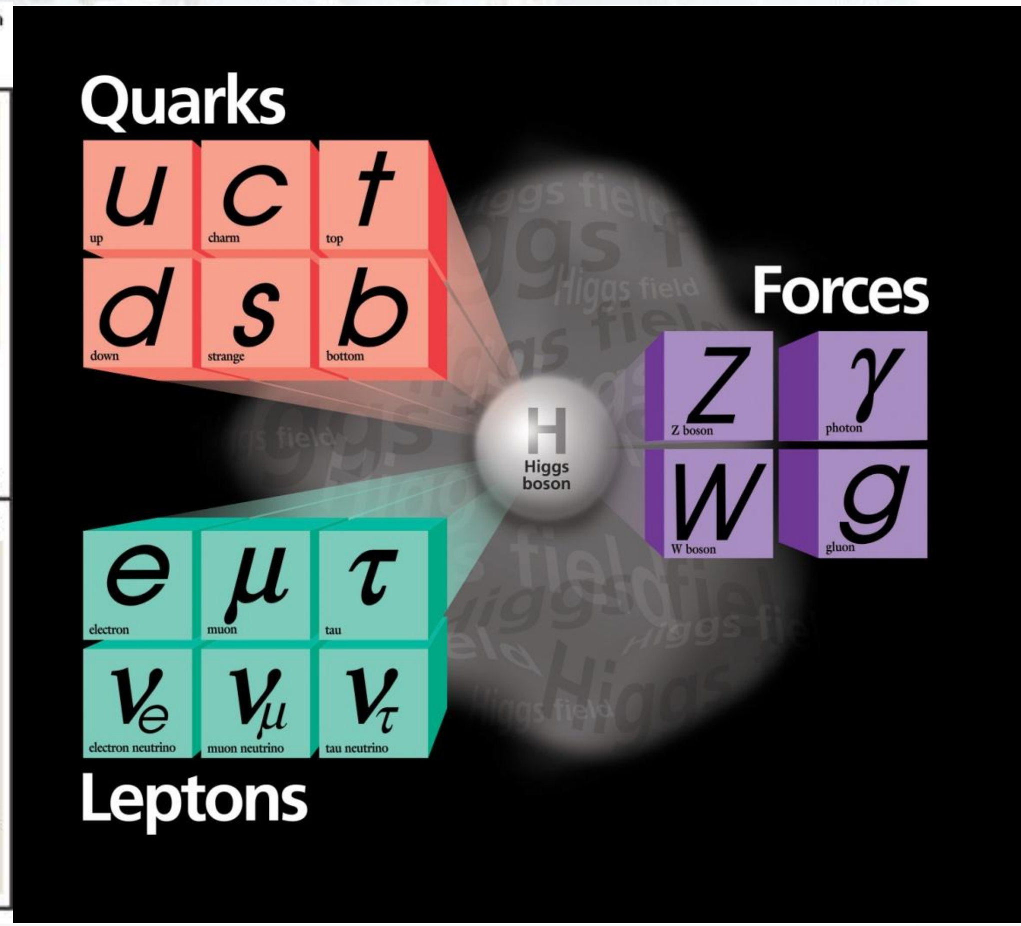
Electromagnetic

Weak

Probably the best tested theory:

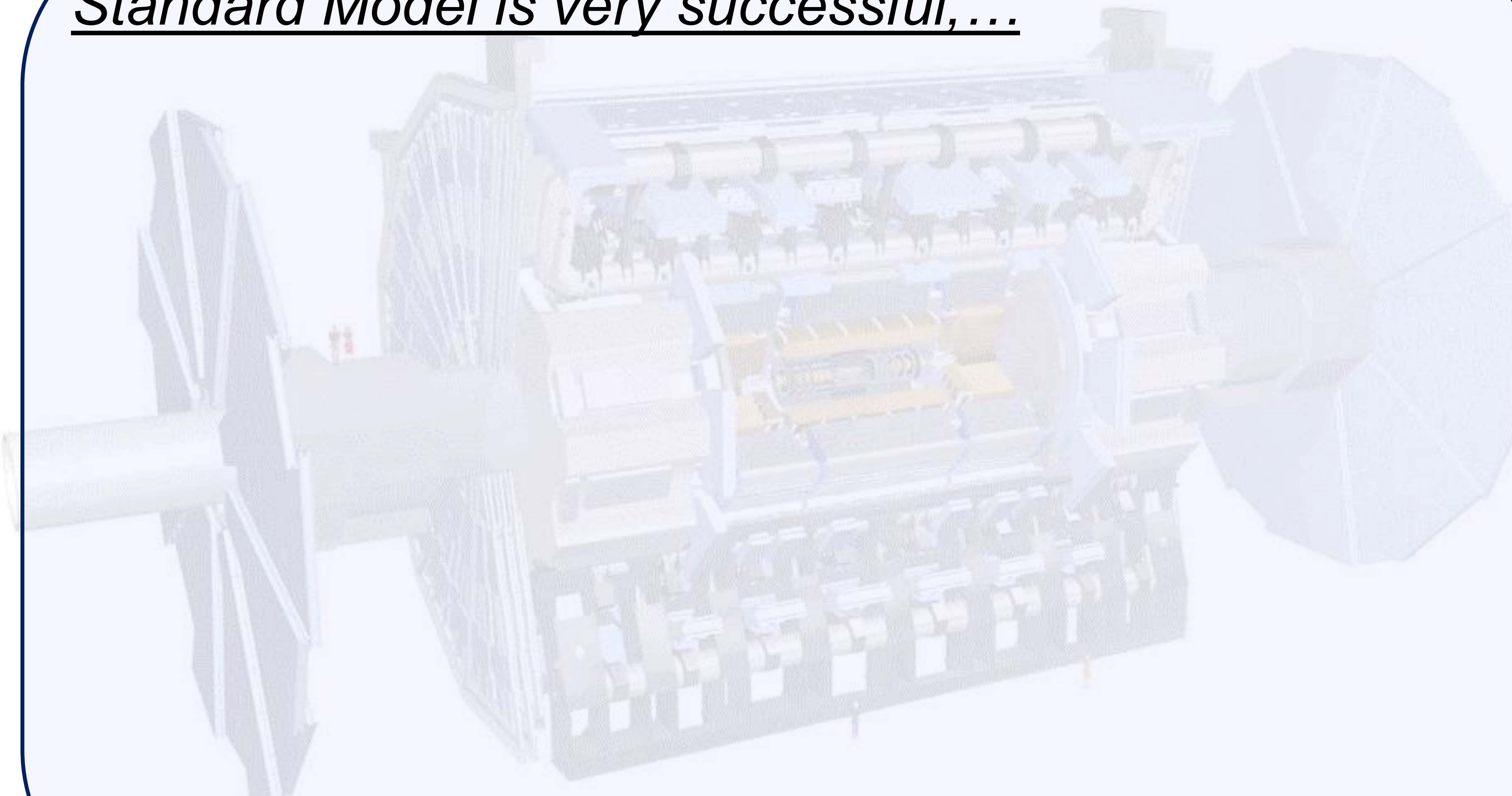
- *Describes 3 out of 4 known forces in nature.*
- *Tested in numerous experiments and sometimes incredible precission!*





What is the LHC and ATLAS build for?

Standard Model is very successful,…



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…but incomplete! Some of the open questions are:

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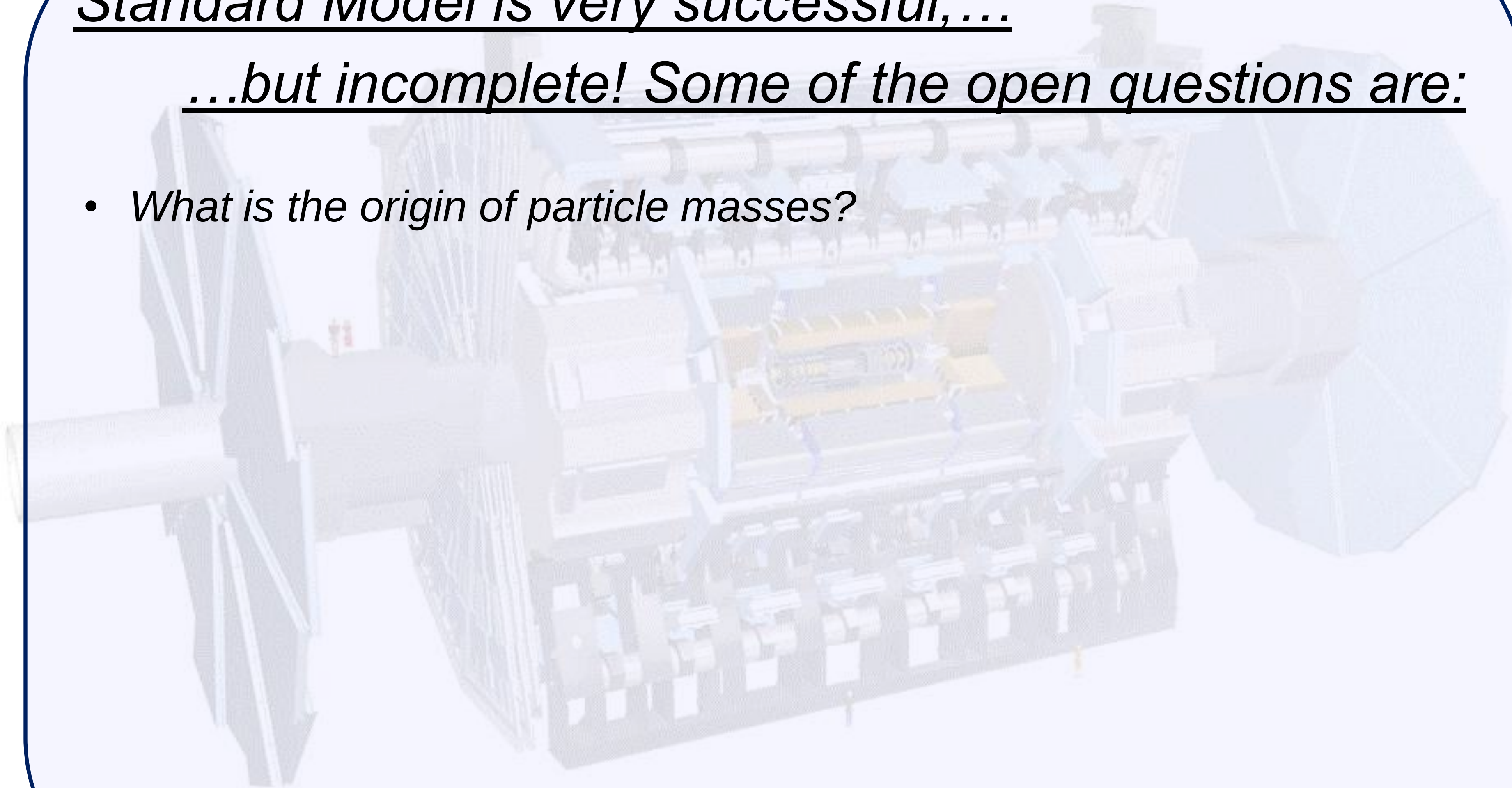

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- *What happened in the first moments of the Universe after the Big-Bang?*

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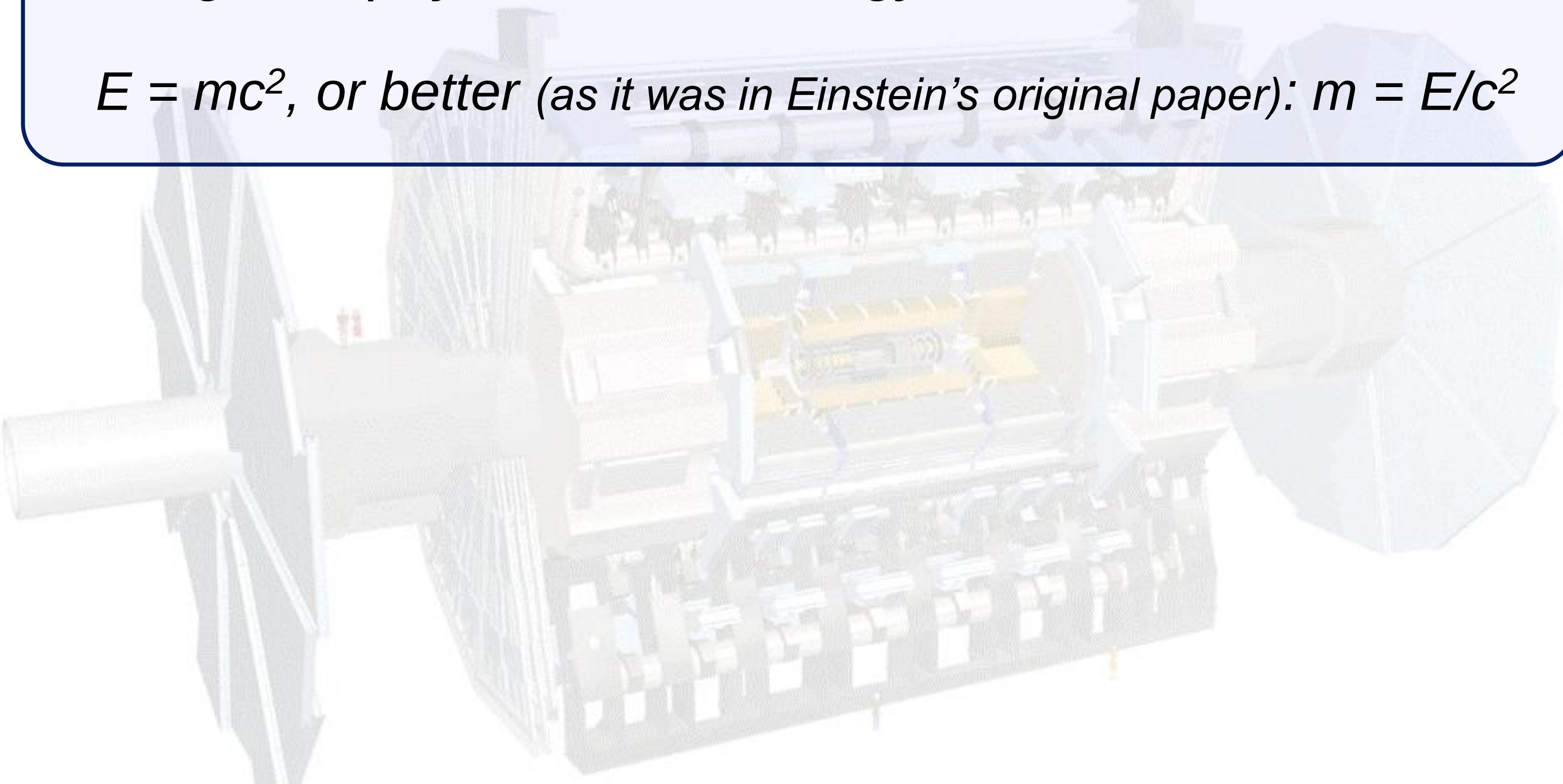
Finding new physics at the energy frontier!

$E = mc^2$, or better (as it was in Einstein's original paper): $m = E/c^2$



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New physics = measurement – known backgrounds

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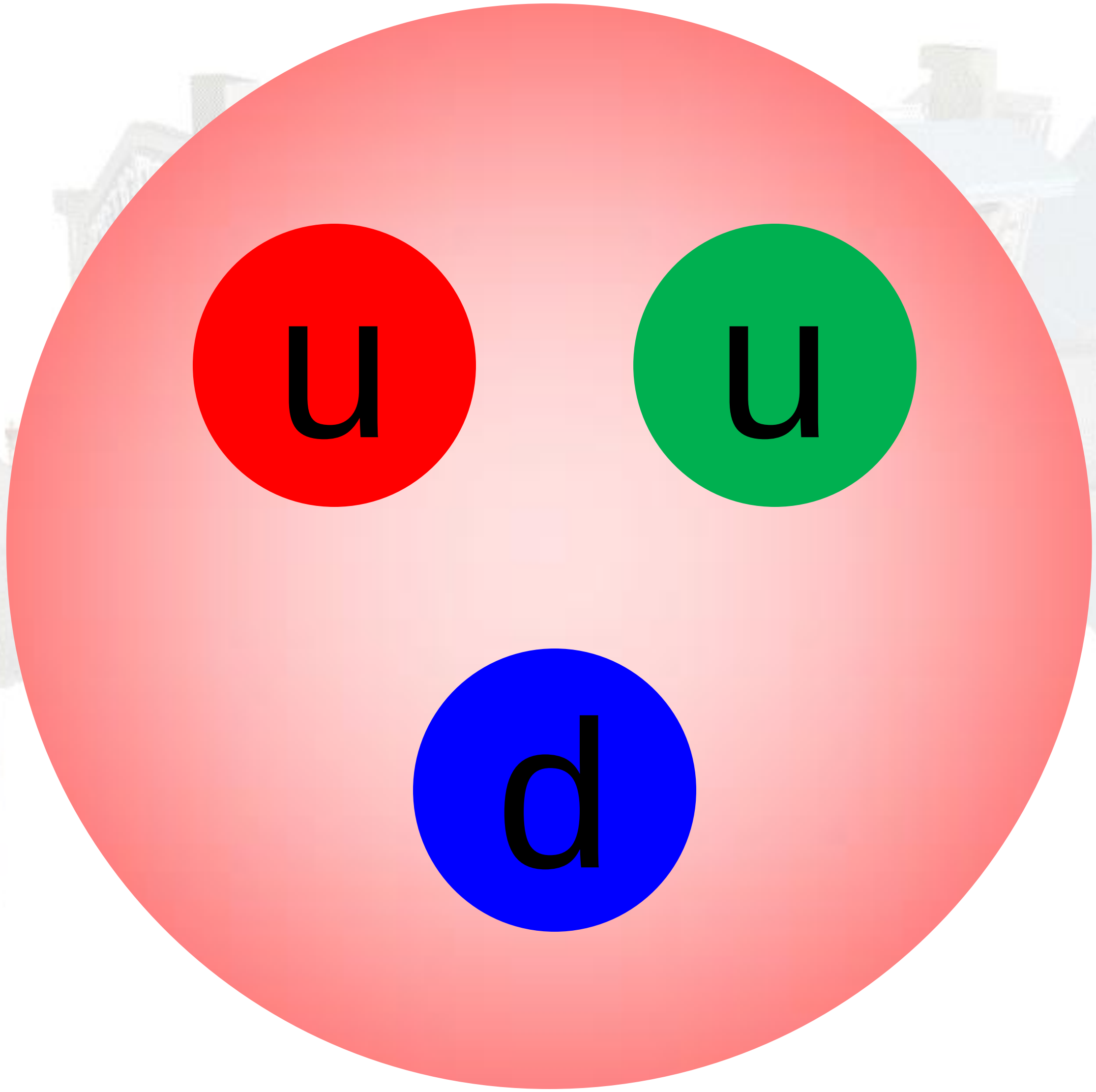
But in order to find new physics:

New physics = measurement – known backgrounds

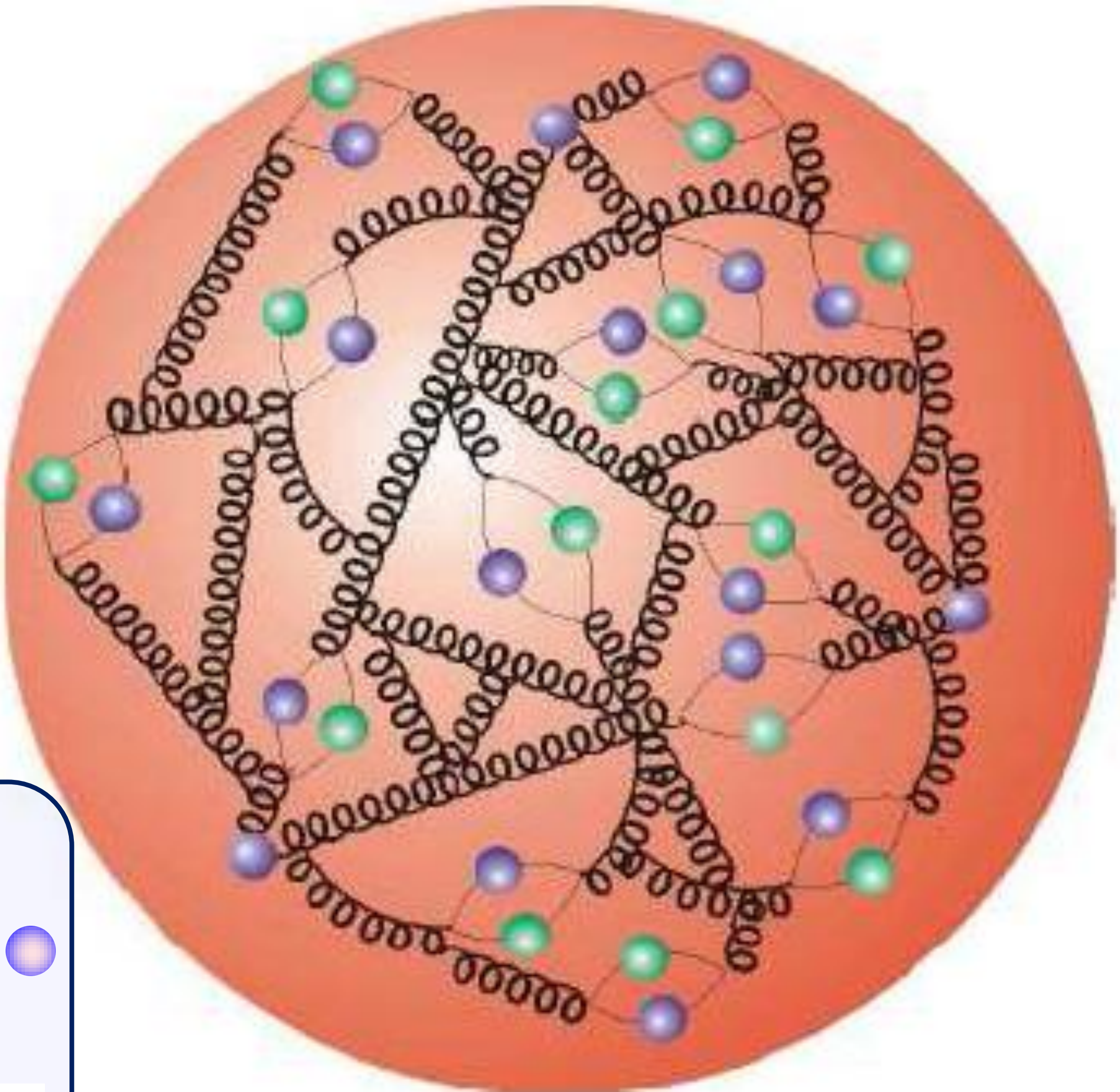
Or in other words:

Yesterday's signal is today's control sample and tomorrow's background

What does the proton look like?



What does the proton look like?



Partons =

Quarks

and

Gluons

Parton Densities

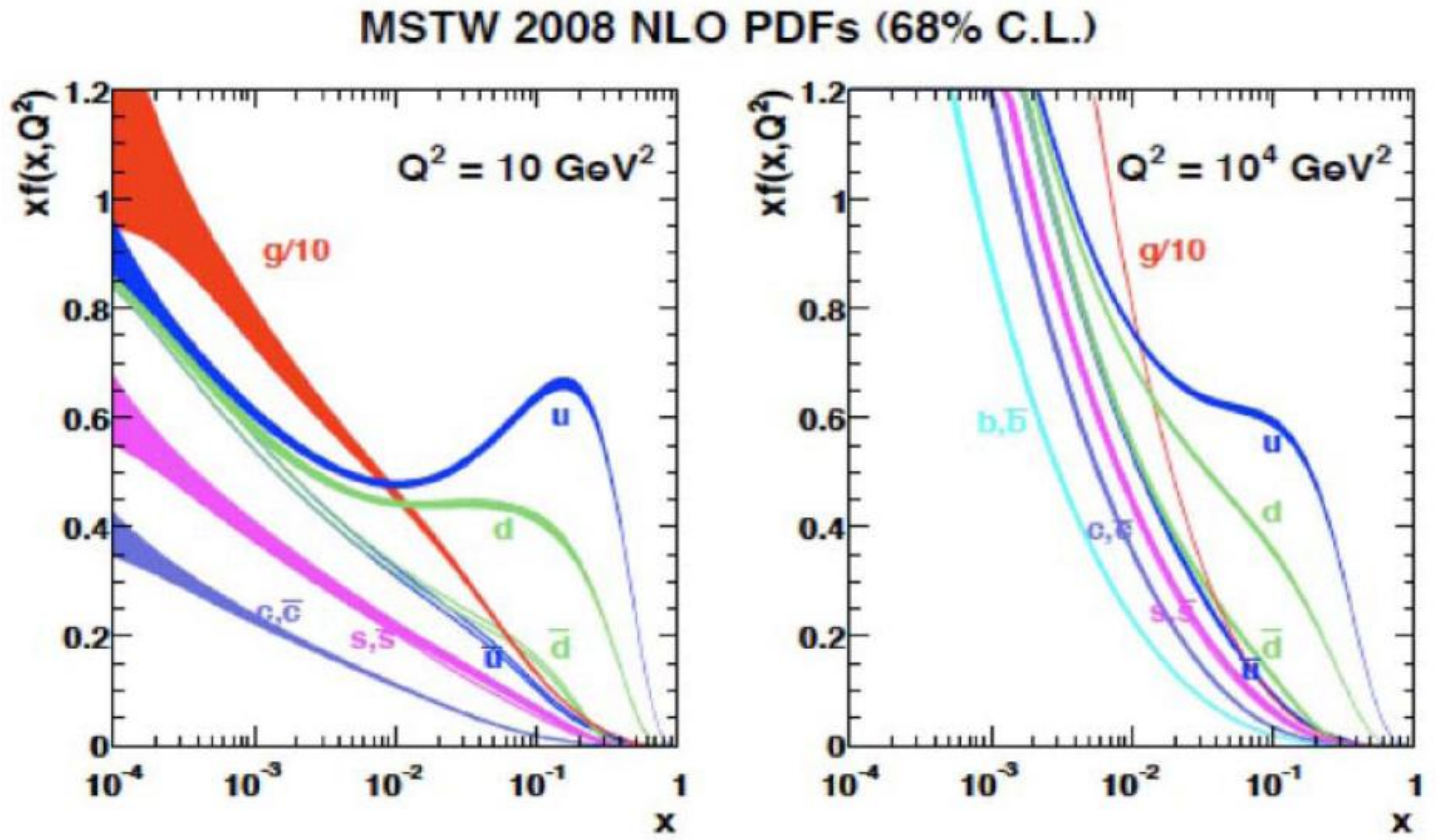
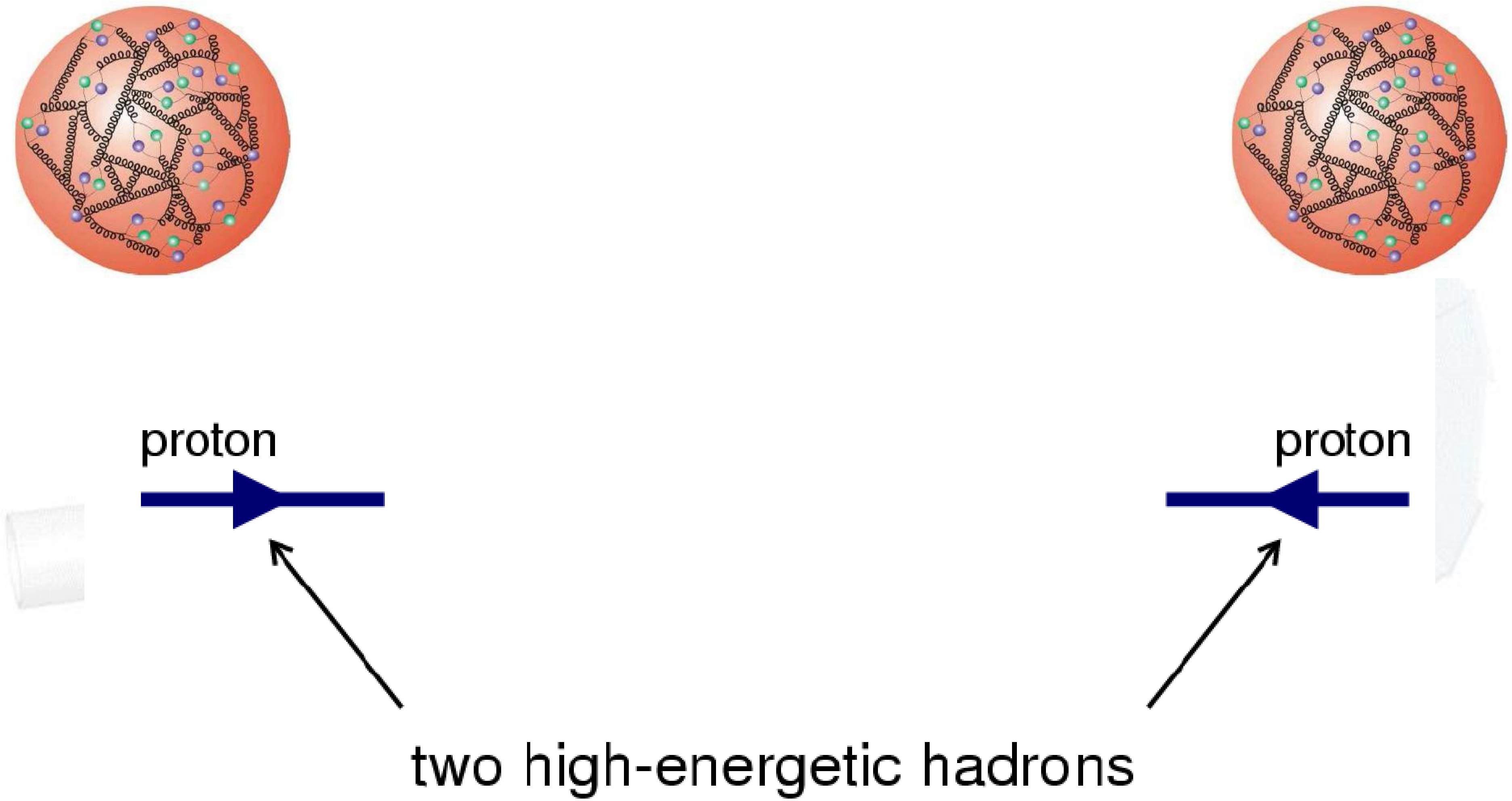
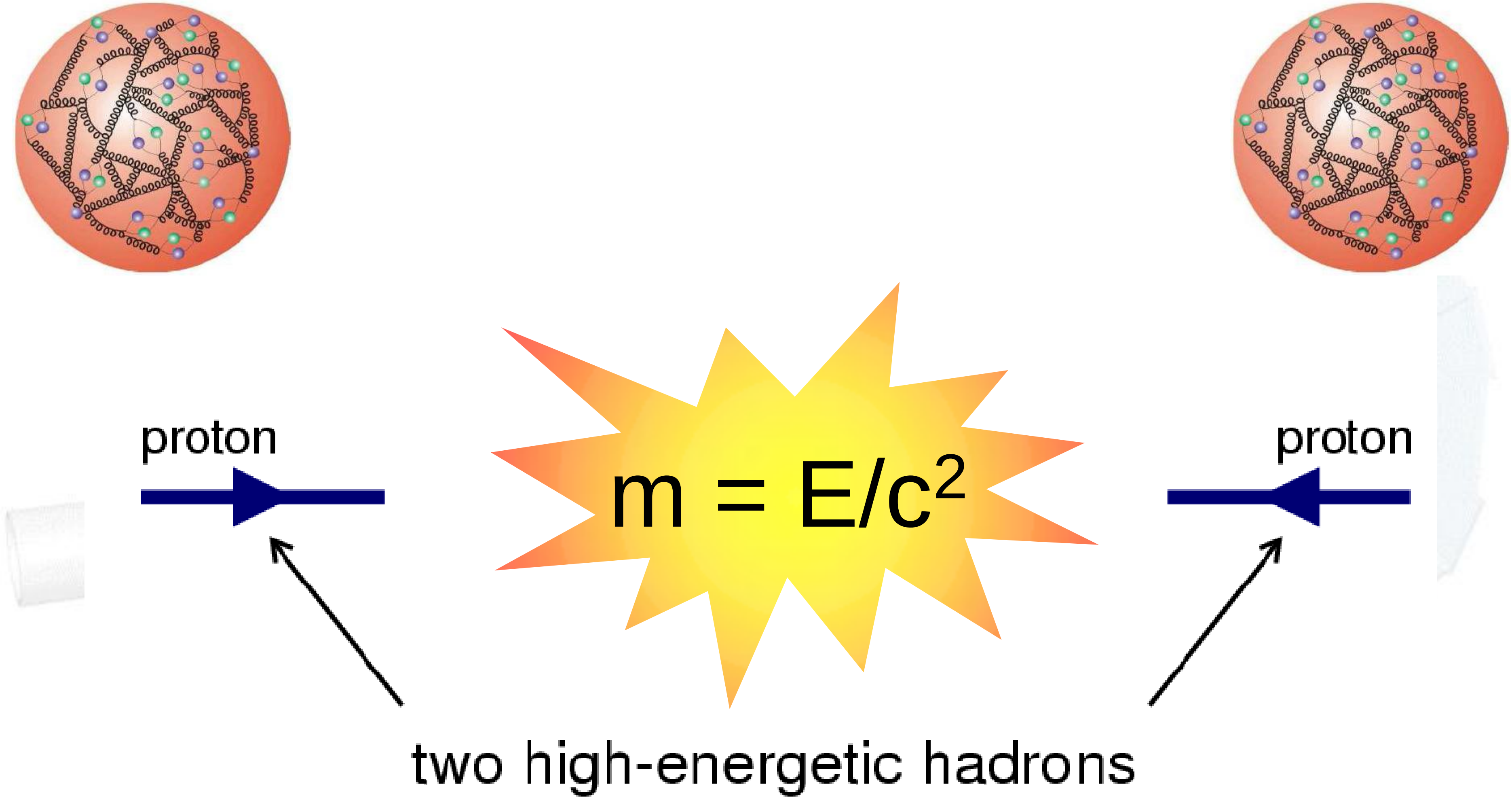


Figure 1: MSTW 2008 NLO PDFs at $Q^2 = 10$ GeV^2 and $Q^2 = 10^4$ GeV^2.

How do pp collisions actually look like?



M. Wobisch
Louisiana Tech University



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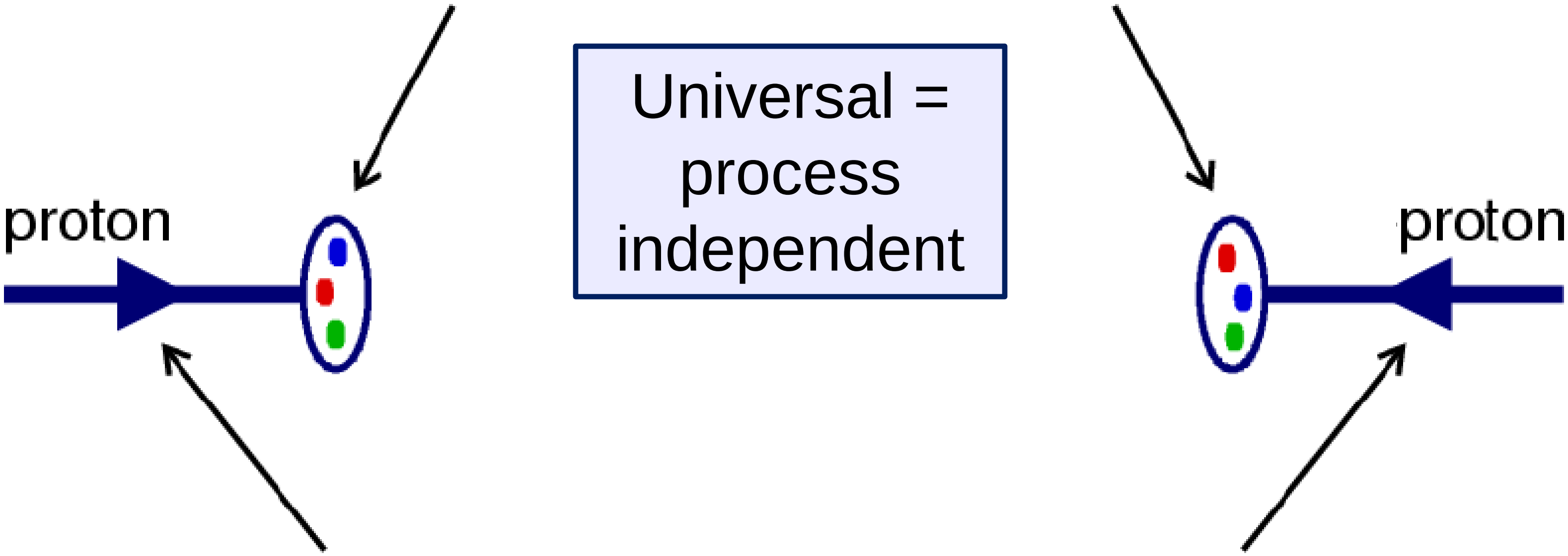
partons inside the hadrons:
parton density functions (PDFs)



two high-energetic hadrons

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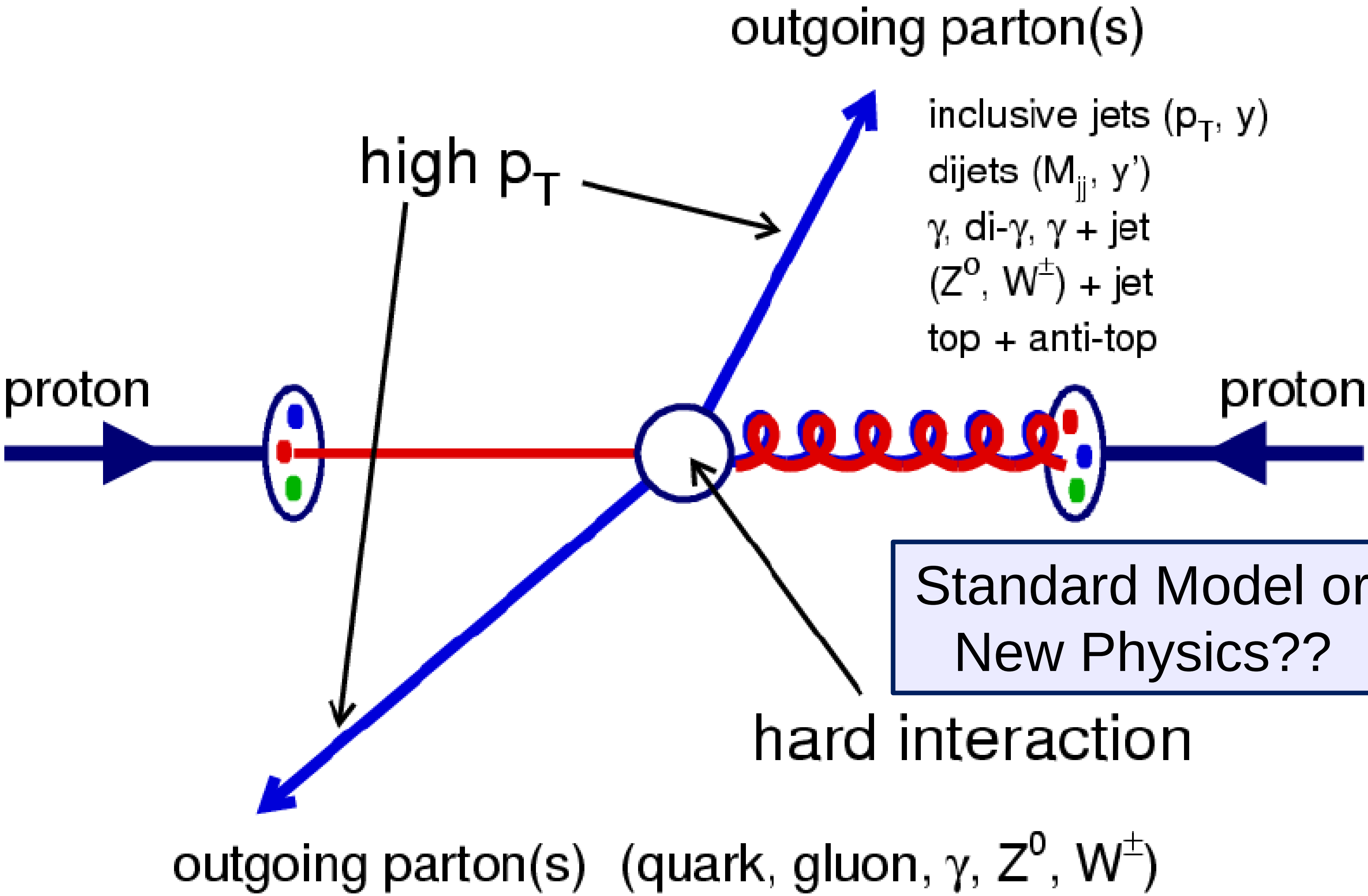

Standard Model or New Physics??

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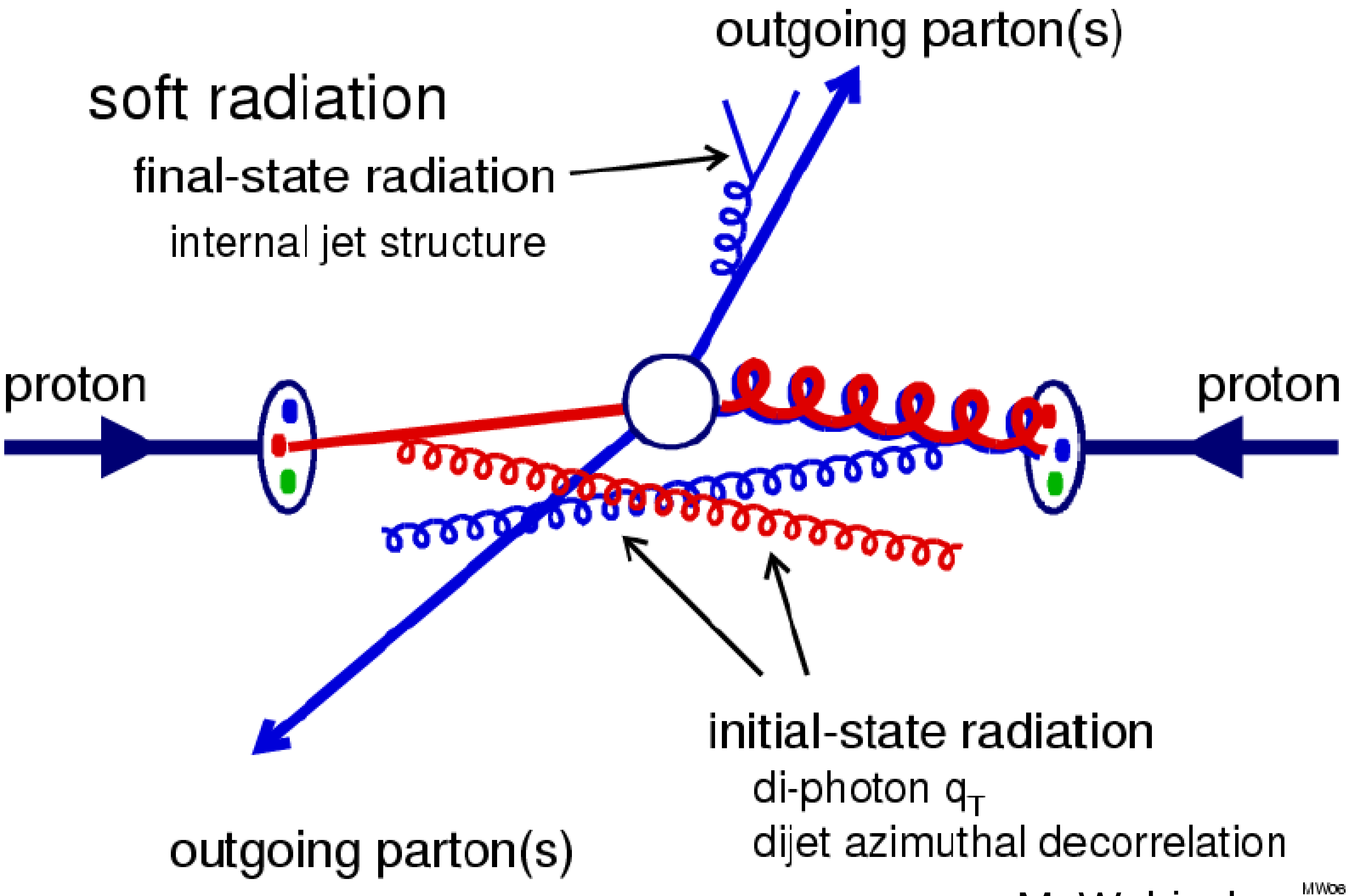

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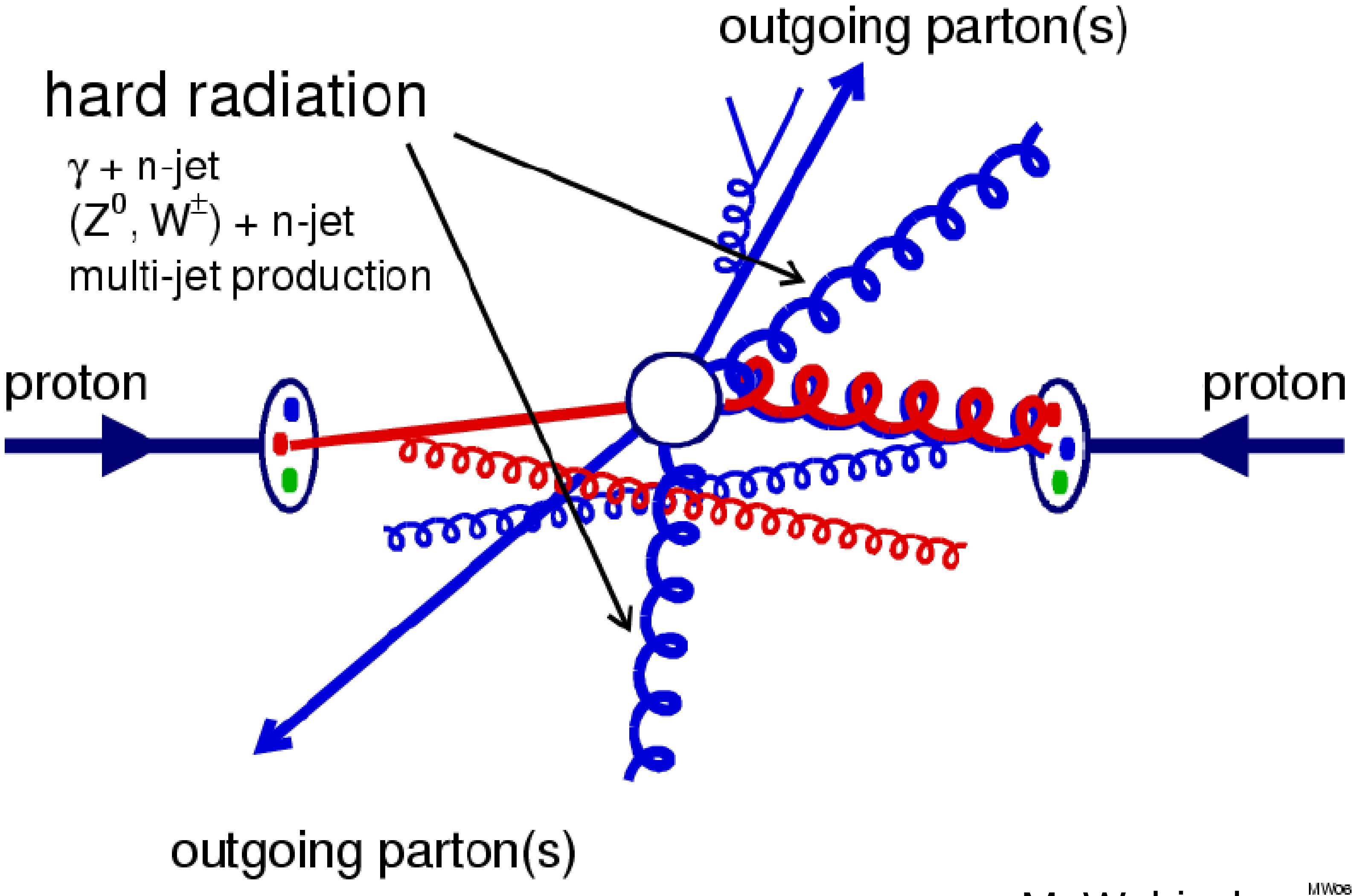

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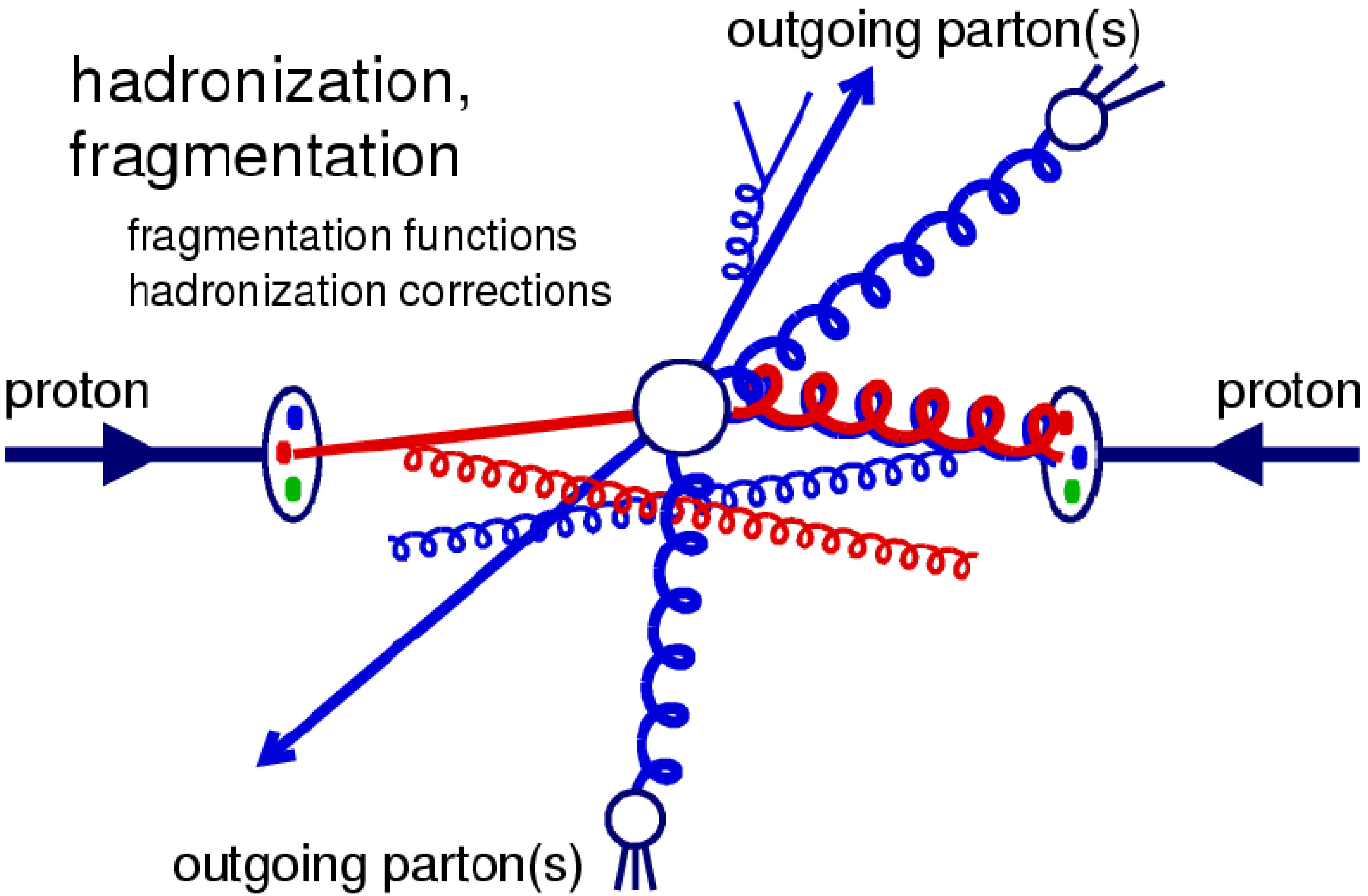

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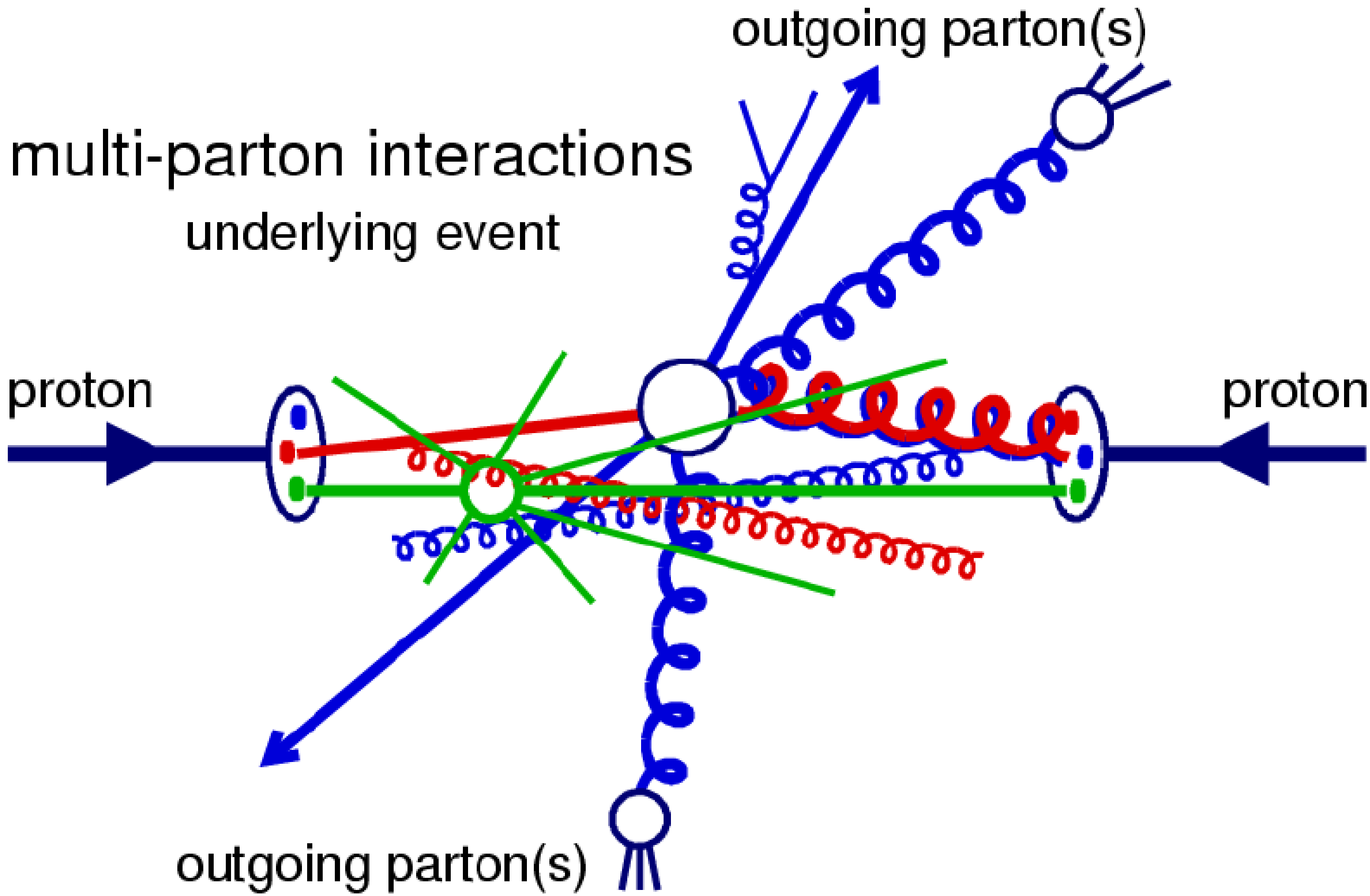

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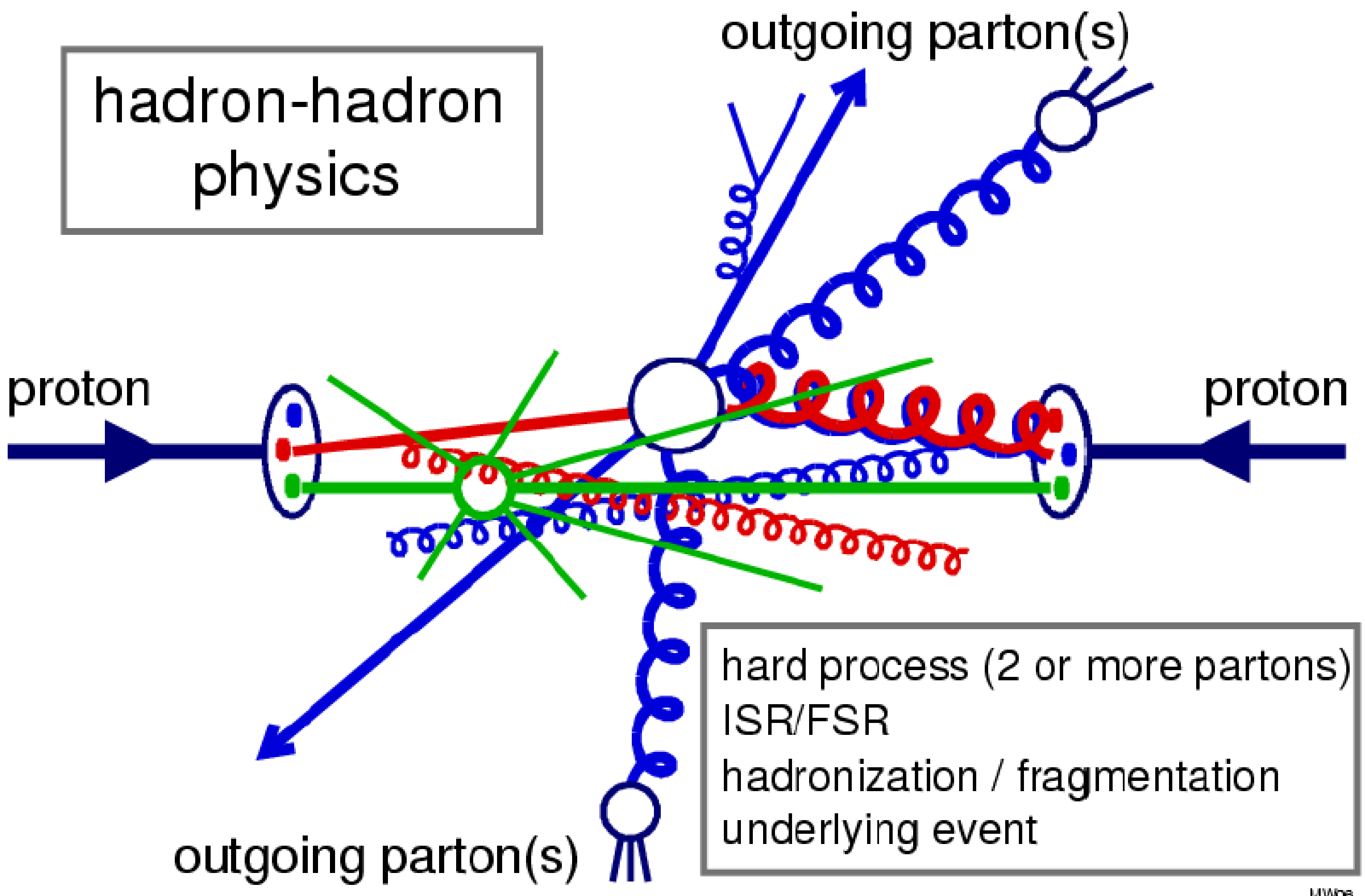

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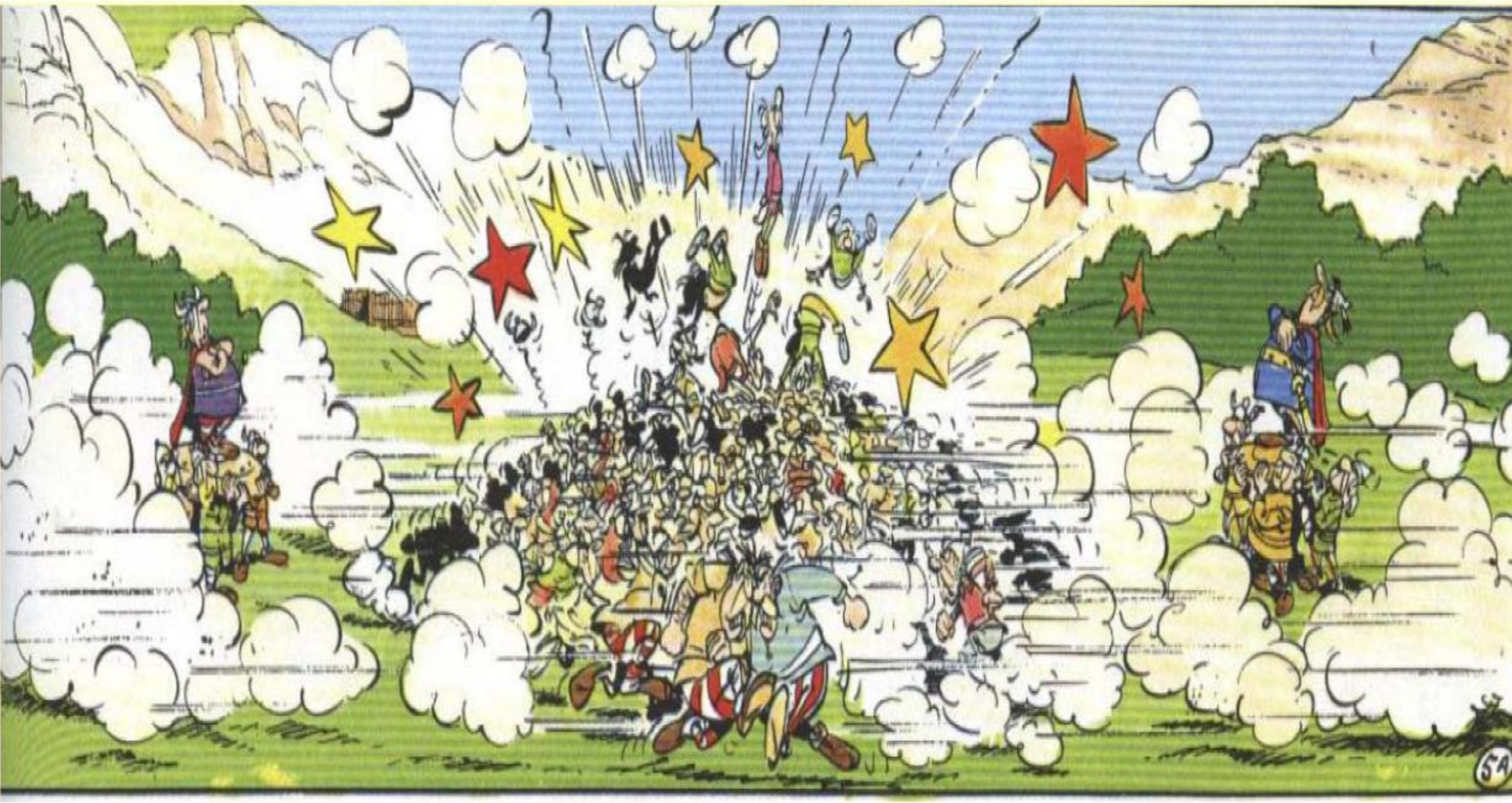


It is really a big mess!!

LHC schedule for 2009/2010

First beam:

- *Mid/end of November 2009*

First collissions:

- *At injection energy, i.e., 900 GeV center-of-mass energy*
- *For a short time (few days?)*

First high-energy collissions:

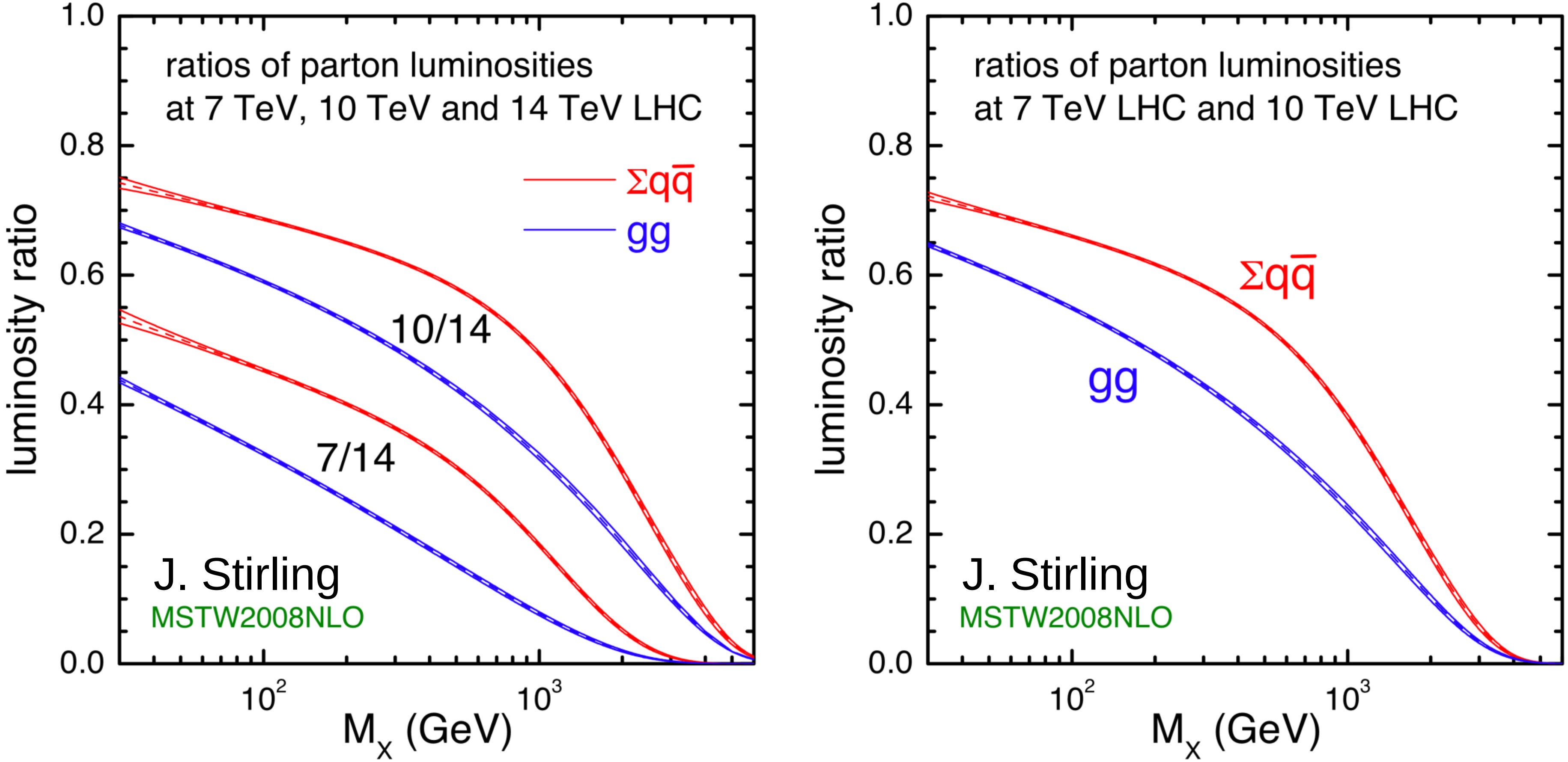
- ***7 TeV** center-of-mass energy, i.e., 3.5 TeV per beam*
- *For a few months, to take a good amount of data for*

First high-energy collissions:

- ***10 TeV** center-of-mass energy, i.e., 5 TeV per beam*
- *For another few months.*
- *Total integrated luminosity is planned to be around 200 pb-1*

1 Month of heavy ion running towards the end of the running period (November 2010)

7 TeV vs. 10 TeV vs. 14 TeV



Examples of cross section suppression in going from 14 TeV to 7 TeV:

- *W, Z ~ 45%*
- *H (120 GeV) ~ 30%*
- *Z' (1 TeV) ~ 18%*

few pb^{-1}

↓

~10 pb^{-1}

↓

~100 pb^{-1}

Understanding the detector and reconstruction algorithms:

- *Beyond the current understanding based on simulations, test beam, and cosmics data*

Rediscovery of the Standard Model

- *Establish how pp collisions at the LHC really look like*
- *Later on: precision measurements*

Search for new physics:

- *And determine what new model can actually describe the data*

Expected data samples

Channel (example)	Expected event in ATLAS after cuts ($\sqrt{s}$ = 10 TeV, 100 pb^{-1})
$J/\psi \rightarrow \mu\mu$	~ 10^6
$\Upsilon \rightarrow \mu\mu$	~ $5\ 10^4$
$W \rightarrow \mu\nu$	~ $3\ 10^5$
$Z \rightarrow \mu\mu$	~ $3\ 10^4$
$tt \rightarrow W b W b \rightarrow \mu\nu + X$	~ 350
QCD jets $p_T > 1$ TeV	~ 500
Gluino, squark m~1 TeV	~ 5

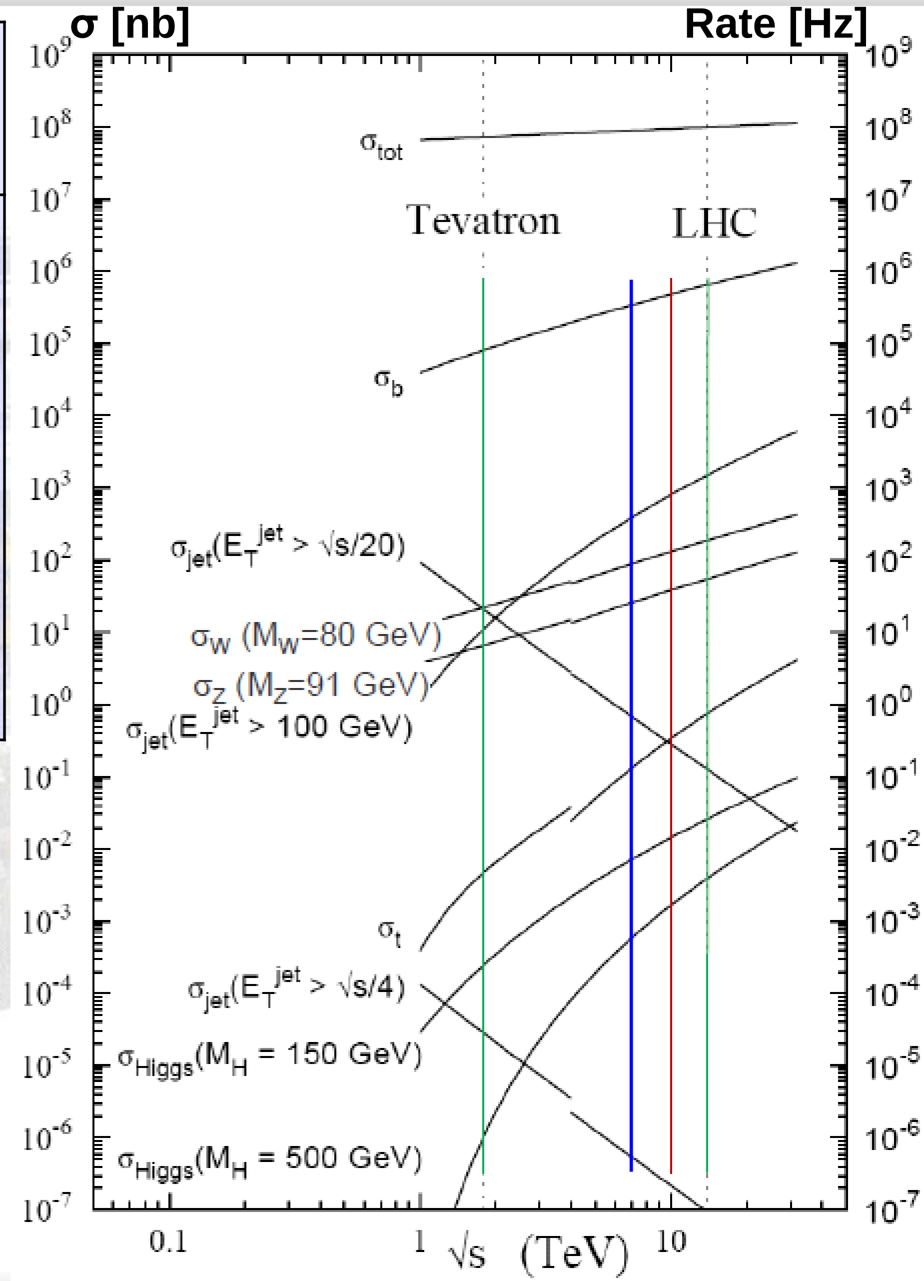
__Commission and calibrate detector__

- *J/ψ, $Z \rightarrow ee, \mu\mu$; $tt \rightarrow bl\nu\ bjj$*

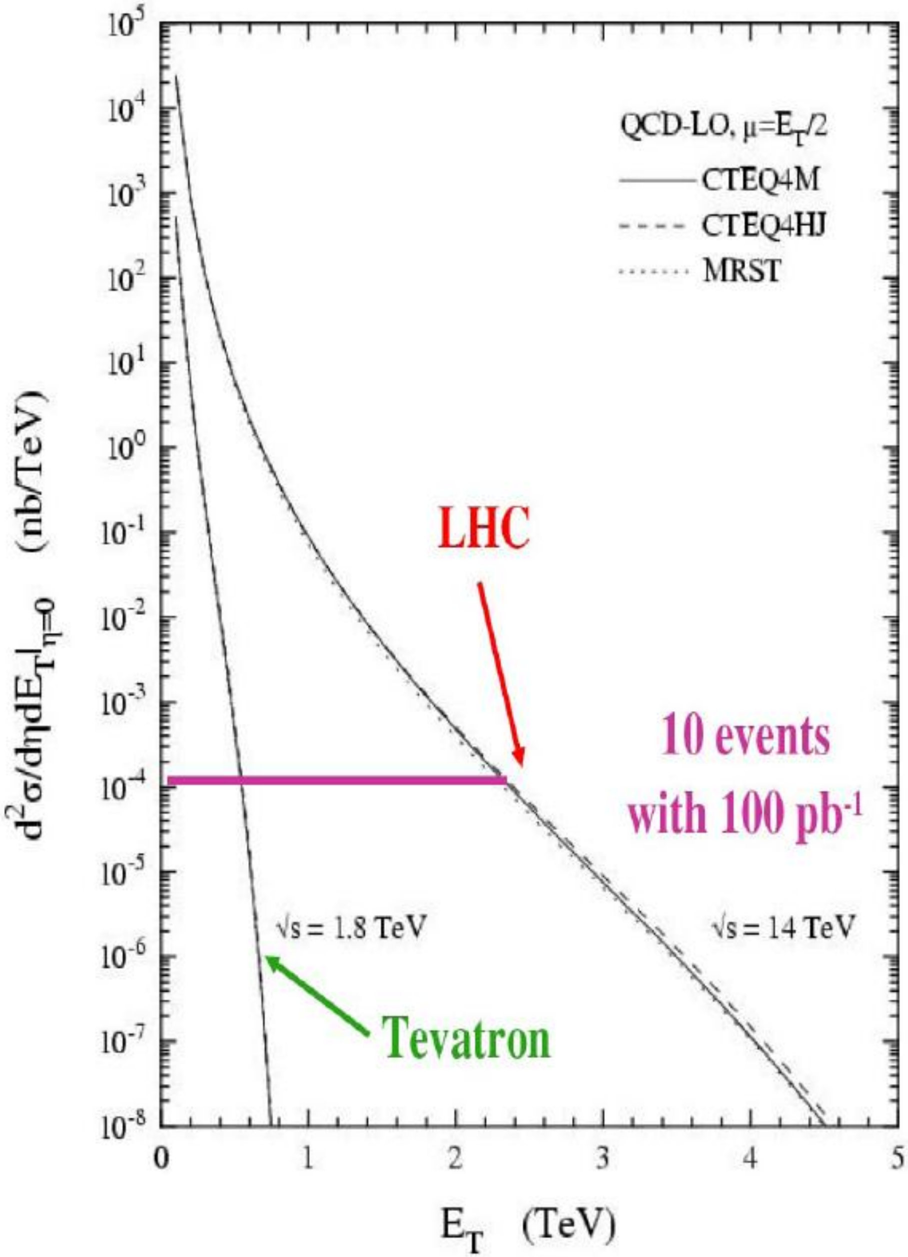
__Rediscover Standard Model__

__Early discoveries?__

- *Z', SUSY, … or???*



Jet measurements

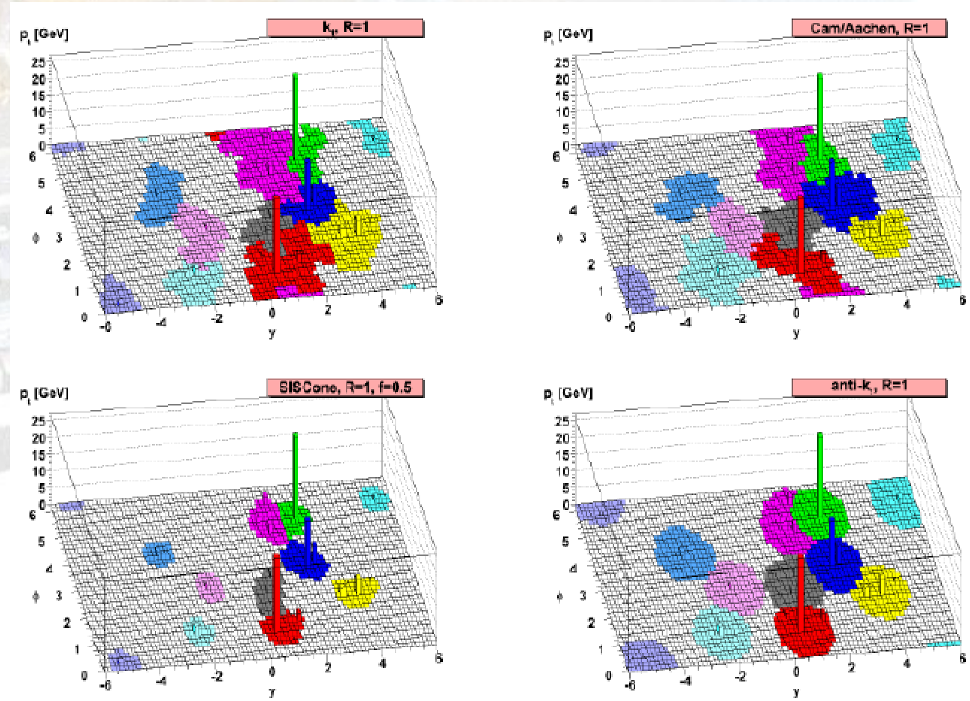


What is actually a jet?

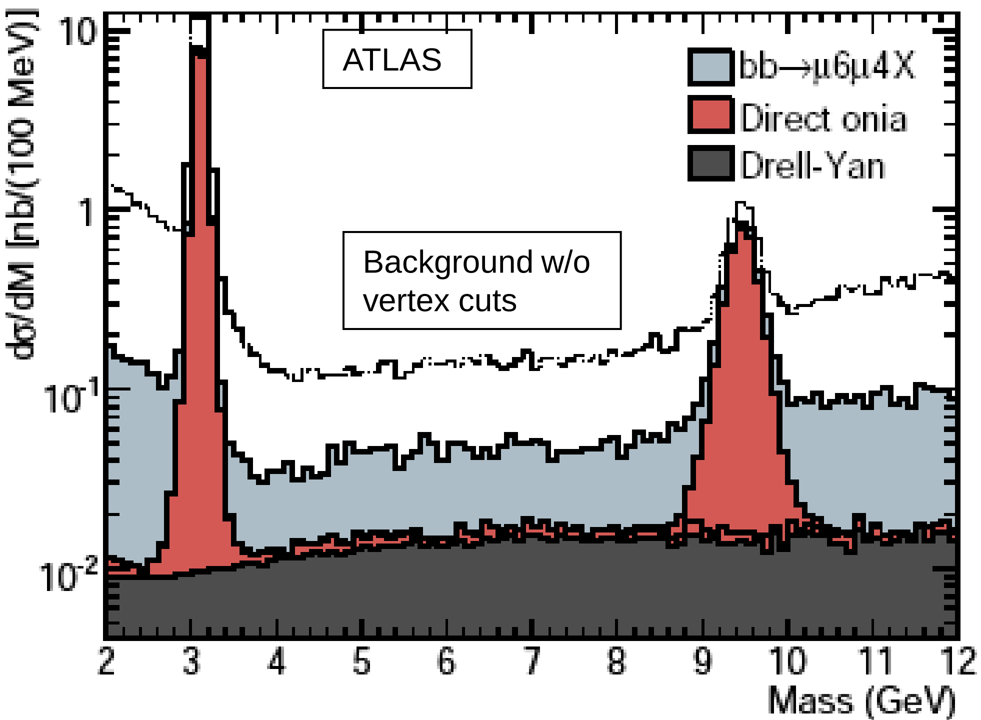
- *Different jet algorithms give somewhat different results*

Challenge:

- *Jet energy scale determination and resolution.*



J/ψ and Upsilon measurements



J/ψ → μμ

Y → μμ

__Estimated number of events after cuts per pb^{-1}:__

- *At 10 TeV:*
  - *~10000 J/ψ → μμ*
  - *~500 Y → μμ*
  - *~2000 J/ψ → ee*
  - *~400 Y → ee*
- *At 7 TeV:*
  - *~7000 J/ψ → μμ*

__Besides the cross-section measurement, this is useful for:__

- *Muon spectrometer and inner detector alignment, ECAL calibration, energy/momentum scale of full detector, lepton trigger and reconstruction efficiencies,…*

Z boson measurement

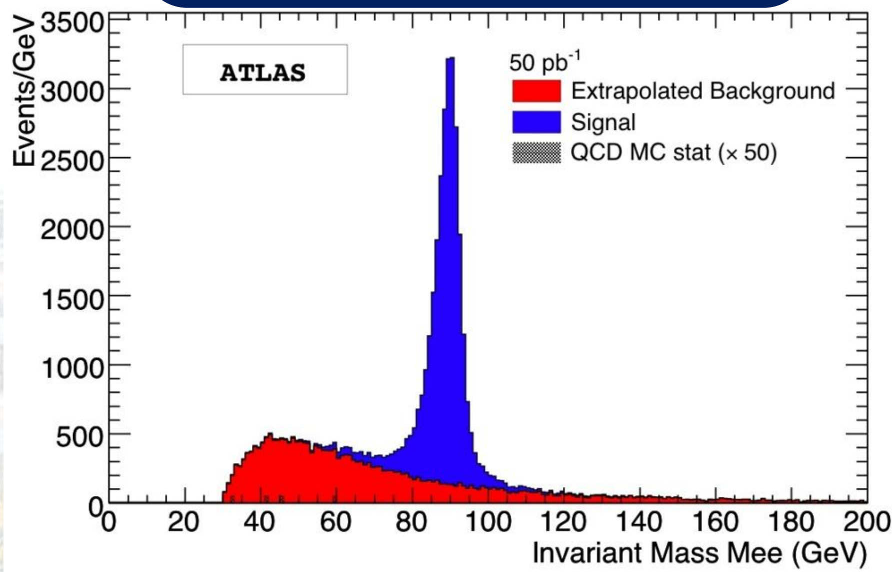
Z → ee, 50 pb^{-1}, 14 TeV

Selection:

- *2 electrons with E_T > 15 GeV*
- *Loose identification criteria*

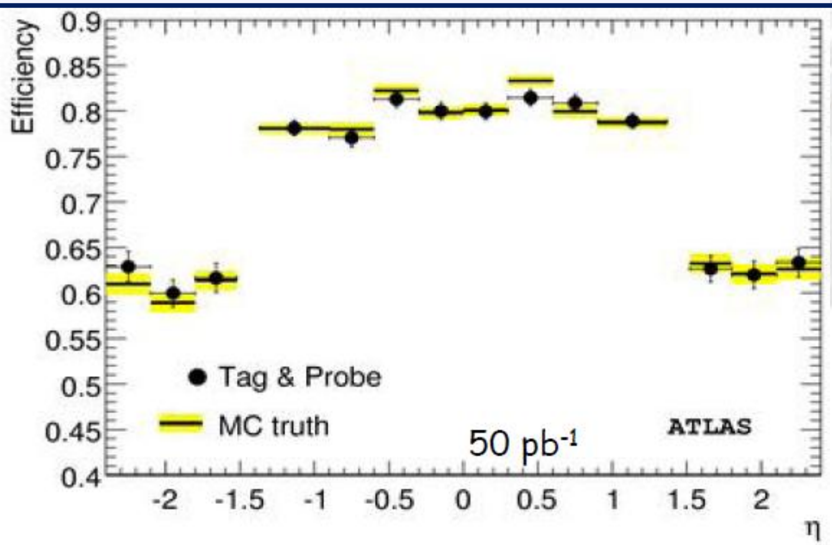
Accuracy on inclusive cross section (no lumi):

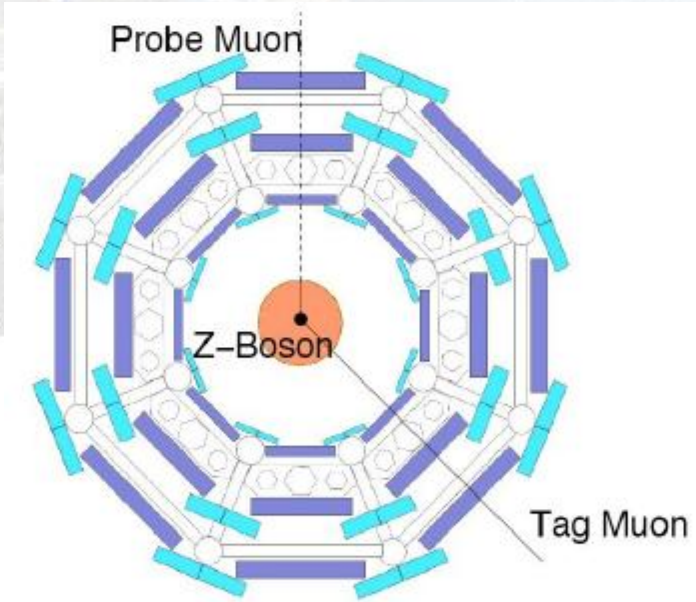
- *2-4% (stat.) and 2-4% (syst.)*



Measure e and μ efficiencies:

- *In data: Tag&Probe with Z events*

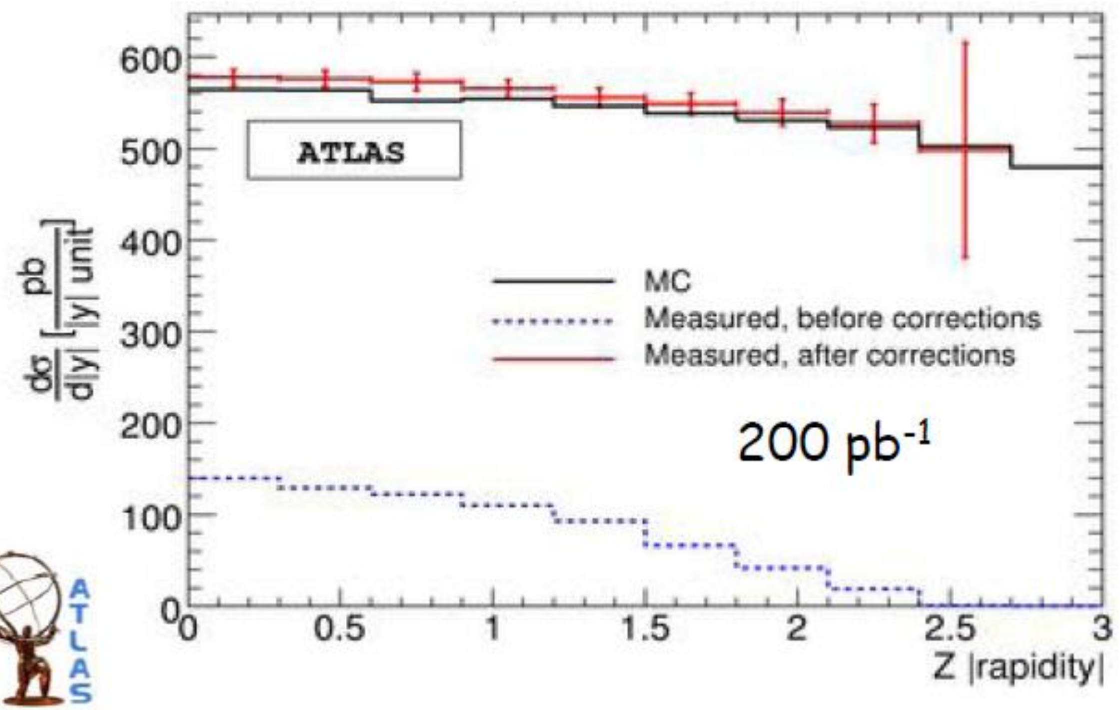




Measure differential pp → Z cross-section:

- *As a function of Z rapidity and of Z p_T*
- *More data needed. ~ 200 pb^{-1}*
- *Interesting for constraining the parton density functions*

Z → ee, 200 pb^{-1}, 14 TeV

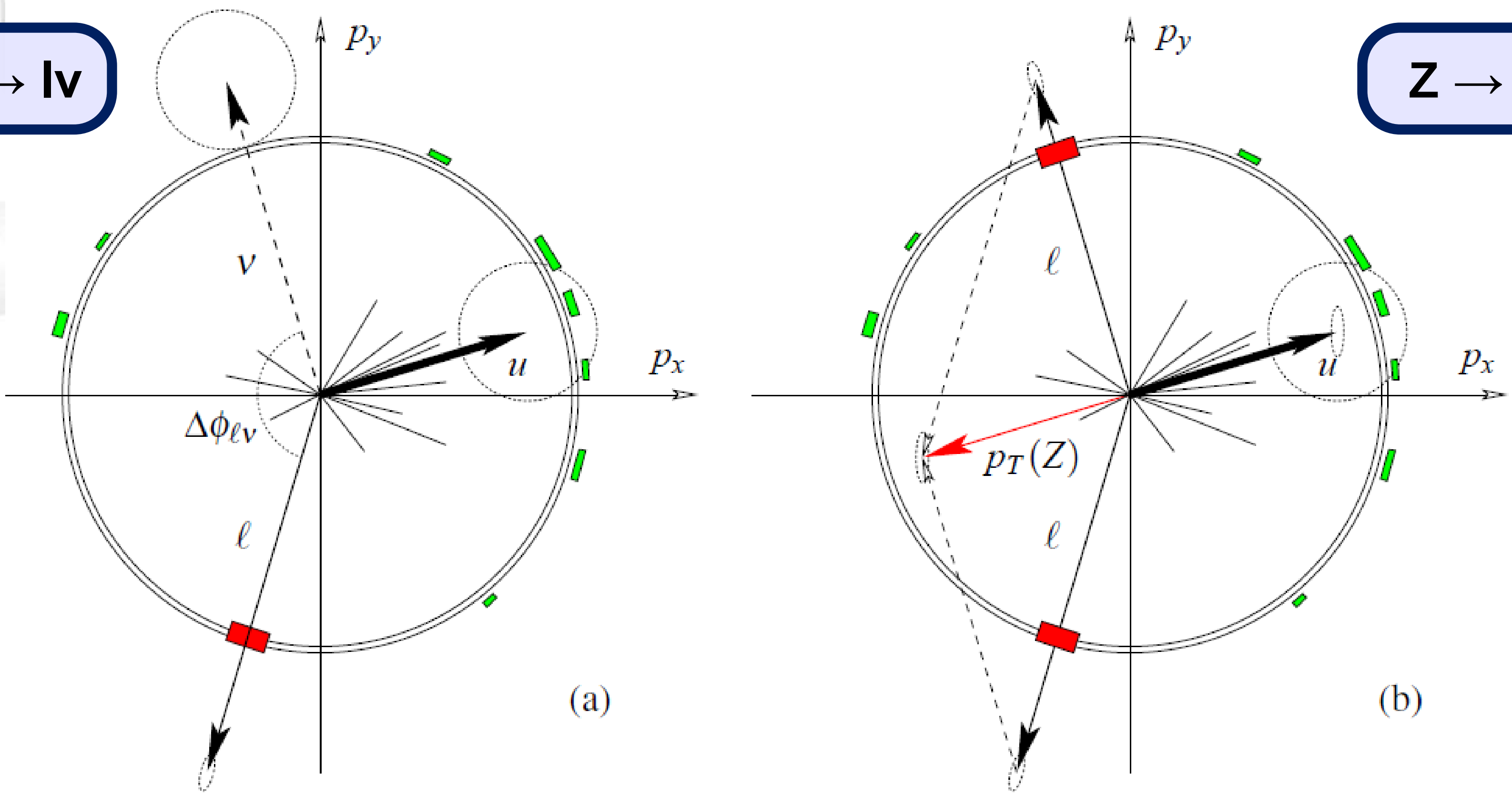


Measure missing E_T efficiency:

- Not easy to determine, lots of event cleaning needed (e.g. cosmic muons, hot cells in calorimeters,…)
- Use Z events and replace one lepton to measure missing E_T with data

W → lν

Z → ll

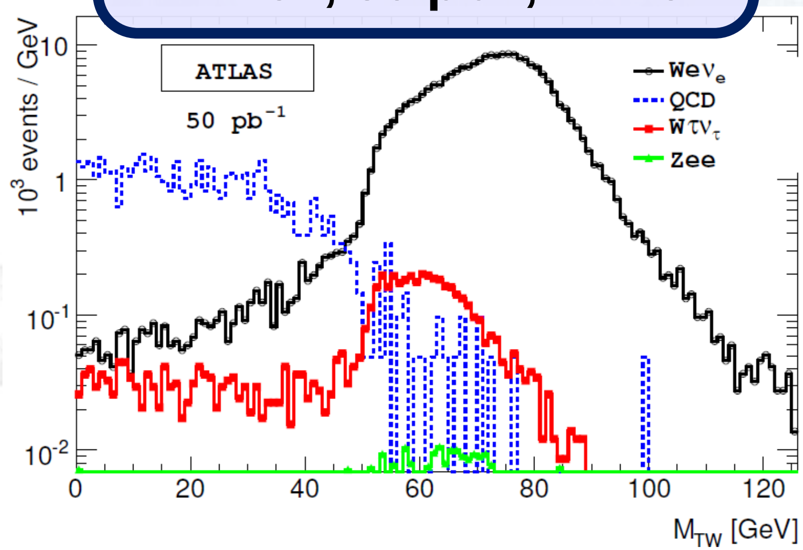


W boson measurement – cross section

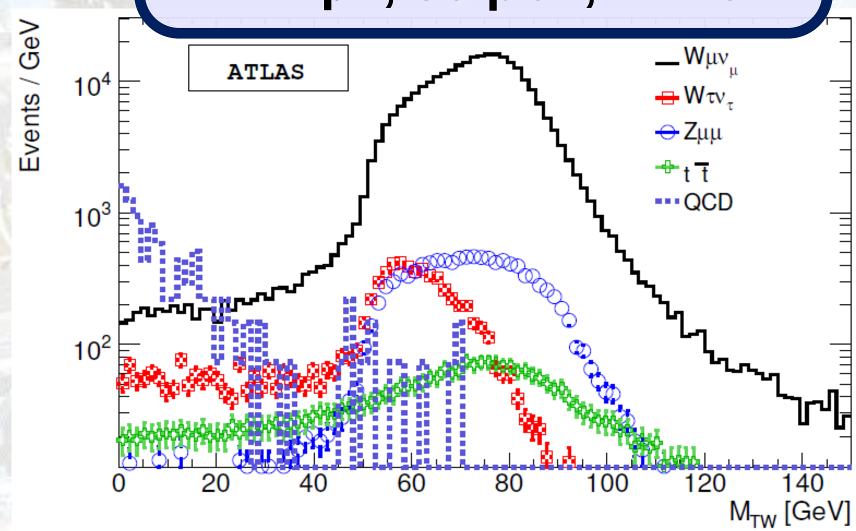
Selections:

- *Single isolated lepton with $|\eta| < 2.5$ and $p_T > 25$ GeV*
- *Missing $E_T > 25$ GeV*
- *Transverse mass* $m_T^W = \sqrt{2 p_T^l p_T^\nu (1 - \cos\Delta\phi)}$ *> 40 GeV*

$W \rightarrow e\nu$, 50 pb^{-1}, 14 TeV



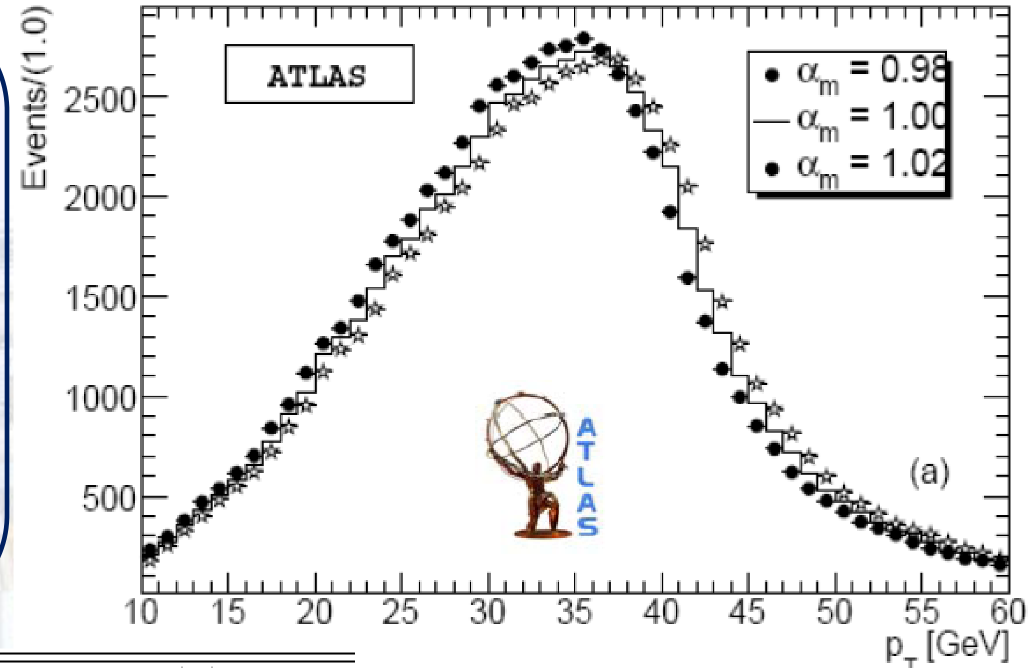
$W \rightarrow \mu\nu$, 50 pb^{-1}, 14 TeV



Process	$N(\times 10^4)$	$B(\times 10^4)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$W \rightarrow e\nu$	22.67 ± 0.04	0.61 ± 0.92	0.215	0.023	0.02	$20520 \pm 40 \pm 1060$
$W \rightarrow \mu\nu$	30.04 ± 0.05	2.01 ± 0.12	0.273	0.023	0.02	$20530 \pm 40 \pm 630$
$Z \rightarrow ee$	2.71 ± 0.02	0.23 ± 0.04	0.246	0.023	0.03	$2016 \pm 16 \pm 83$
$Z \rightarrow \mu\mu$	2.57 ± 0.02	0.010 ± 0.002	0.254	0.023	0.03	$2016 \pm 16 \pm 76$

Two methods:

1. Lepton p_T measurement
   - M_W ± 120 (stat.) ± 117 (syst.)
   - Energy scale dominates
2. Transverse mass measurement
   - M_W ± 57 (stat.) ± 231 (syst.)
   - Recoil modeling dominates



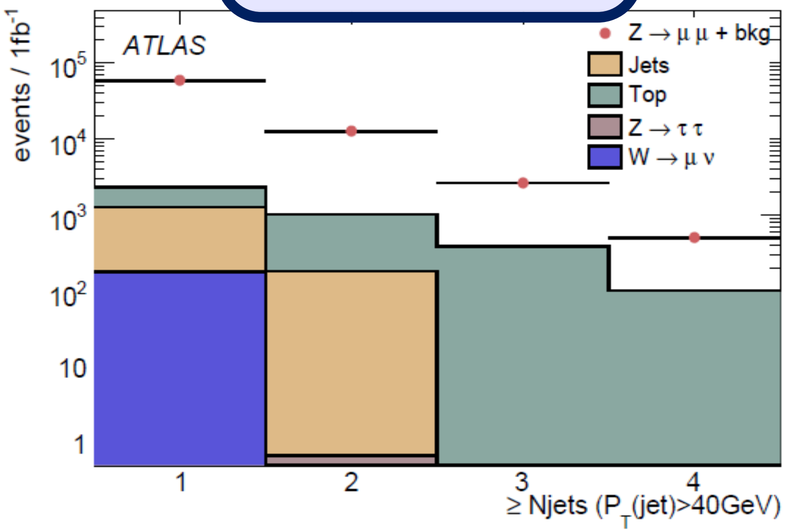
Method	$p_T(e)$ [MeV]	$p_T(\mu)$ [MeV]	$M_T(e)$ [MeV]	$M_T(\mu)$ [MeV]
δm_W (stat)	120	106	61	57
δm_W (α_E)	110	110	110	110
δm_W (σ_E)	5	5	5	5
δm_W (tails)	28	< 28	28	< 28
δm_W (ε)	14	–	14	–
δm_W (recoil)	–	–	200	200
δm_W (bkg)	3	3	3	3
δm_W (exp)	114	114	230	230
δm_W (PDF)	25	25	25	25
Total	167	158	239	238

With 15 pb^{-1}:

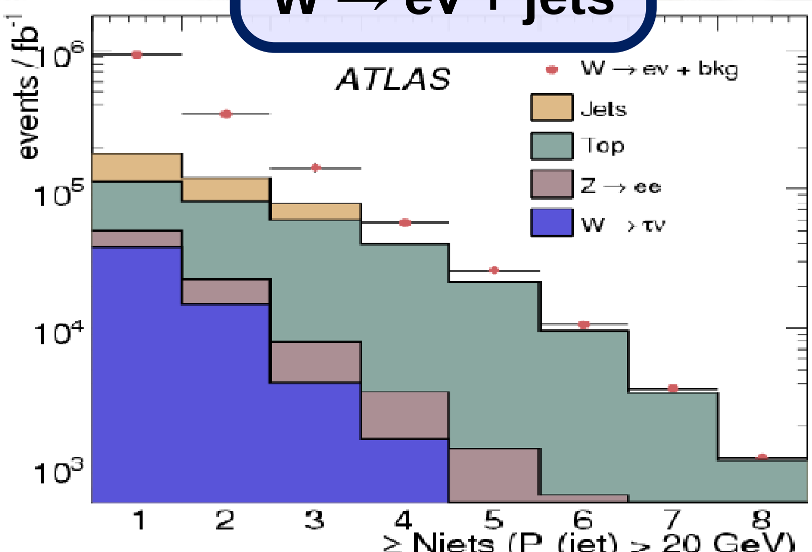
- Use of template fits
- Shown is a W mass change of 2%

W/Z + jets

Z → μμ + jets

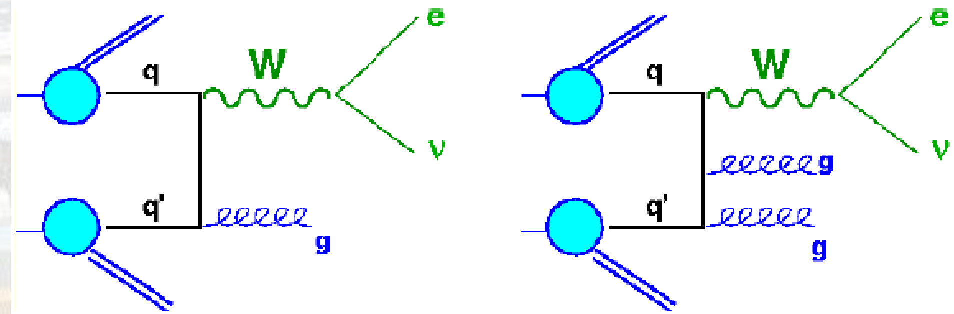


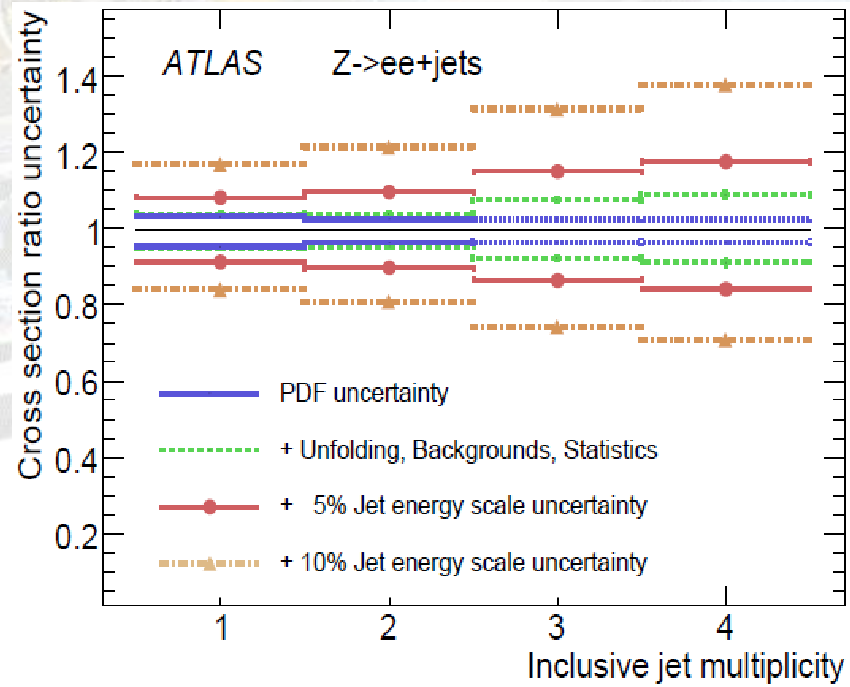
W → eν + jets



Background for many processes:

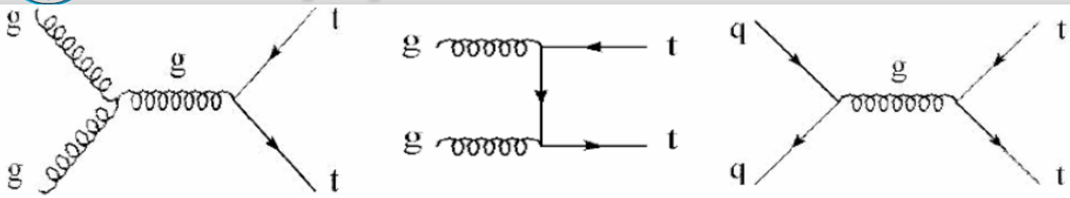
- *Top measurements, SUSY searches,…*

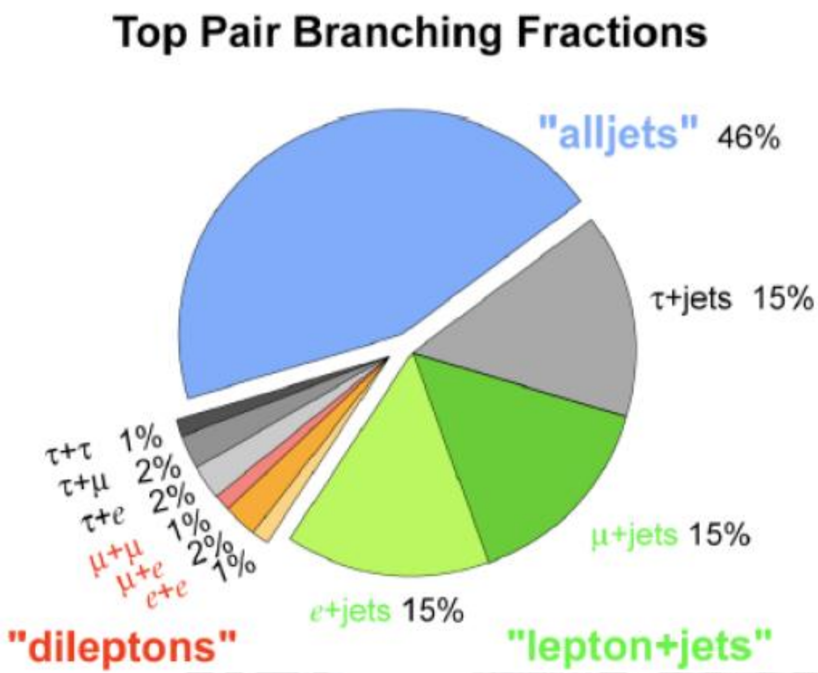


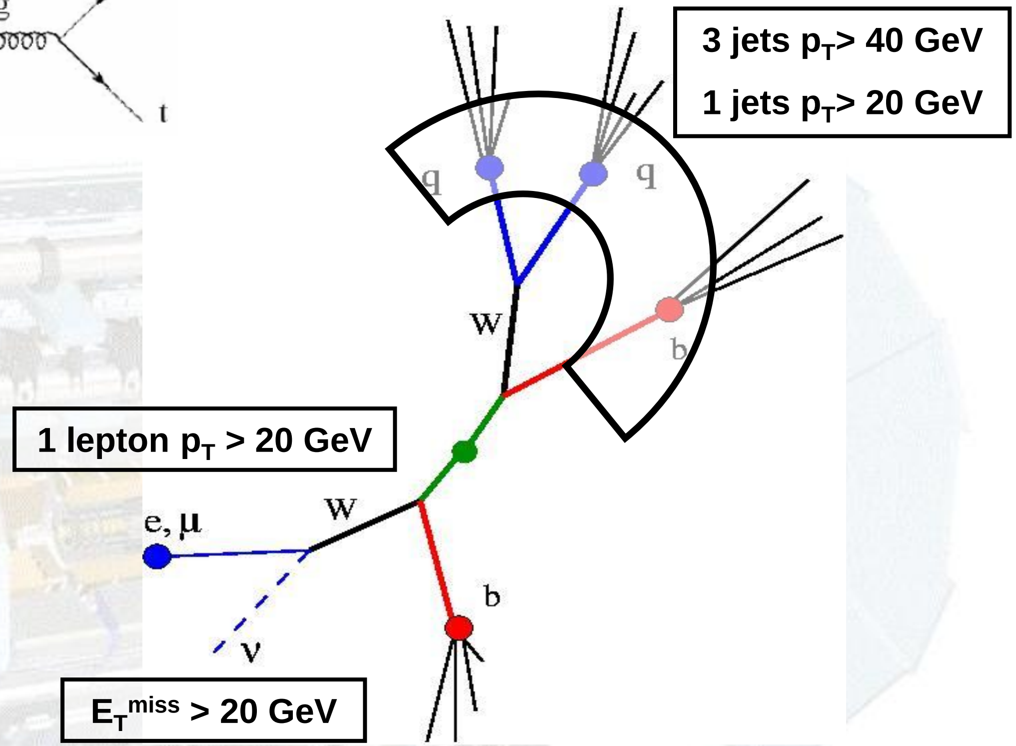


Top pair events

tt → bW bW → blν bjj







After cuts in μ-channel:

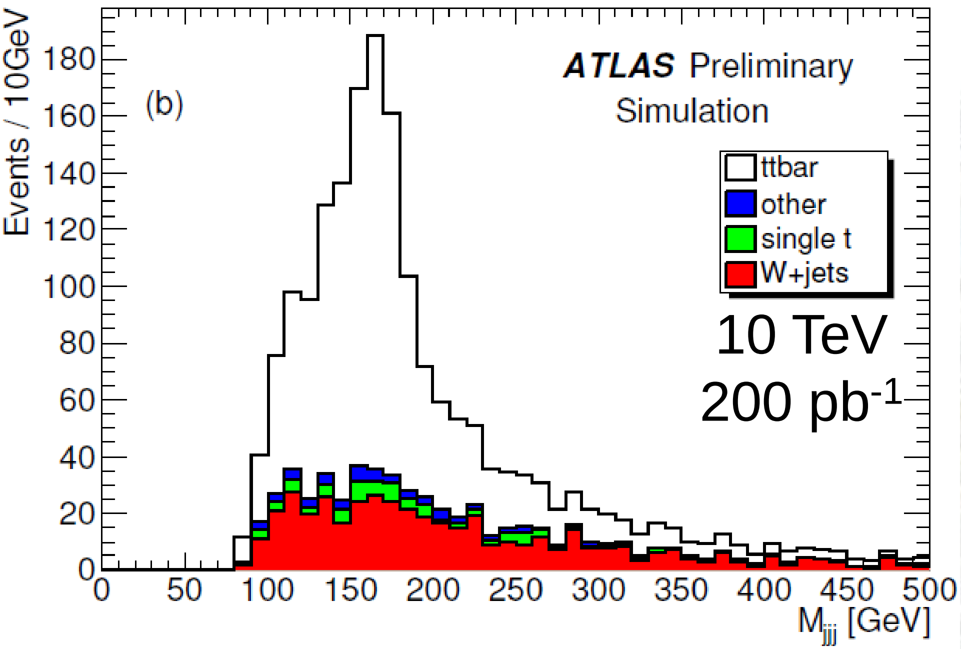
- *10 TeV: ~1600 events*
- *7 TeV: ~600 events*
- *Uncertainty on cross section < 20% (+lumi)*

Contains most physics objects:

- *Leptons, jets, b-jets, missing E_T*
- *Background to almost all searches*
- ***When top is measured, experiment is ready for discovery physics!***

First top quarks in Europe

tt → bW bW → beν bjj



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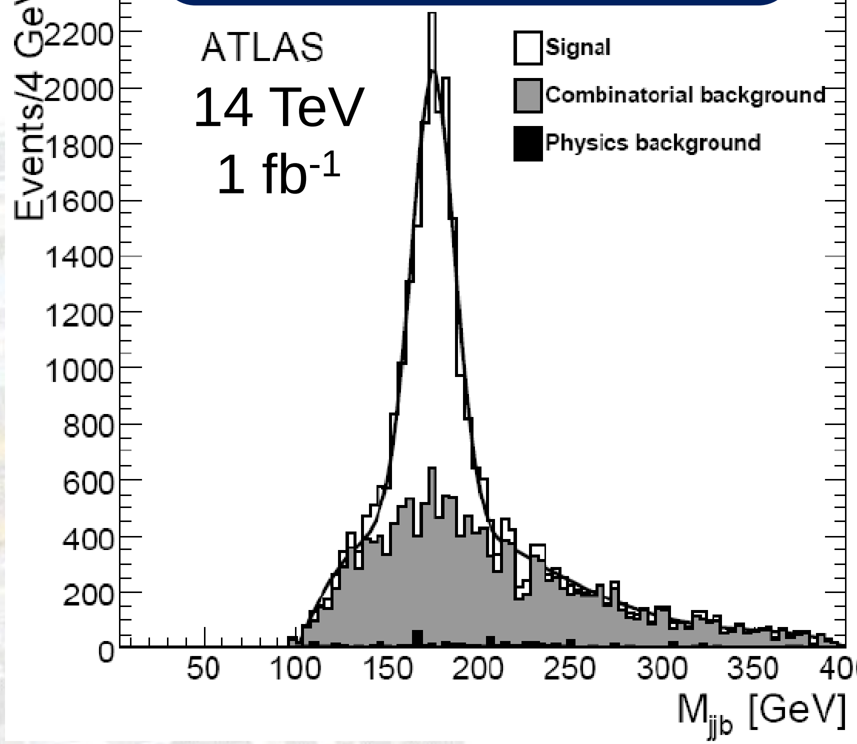


Cross section:

- *Semi-leptonic channel*
- *No b-tagging!*
- *Precision expected on Δσ/σ:*

  3(stat.) ⊕15(syst.) ⊕22(lumi)

Top mass:

- *Semi-leptonic channel*
- *With b-tagging!*
- *Precision: 1 - 3.5 GeV*

  for absolute scale knowledge 1 – 5%

BSM theory landscape (Murayama)

To find a deviation is easy…

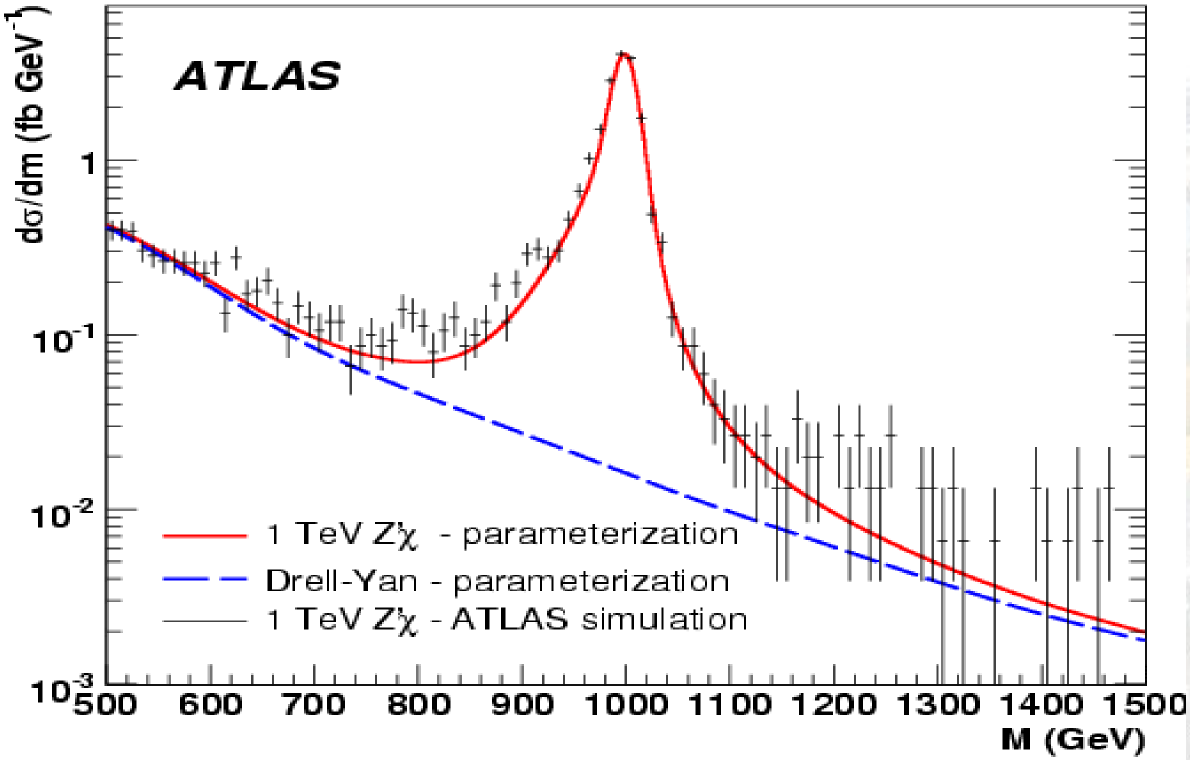
- *To prove that is comes from new physics is much harder!*
- *Simple-minded recipe:*
  - *Find variable(s) discriminating between signal and background*
  - *Cut away most background (maximize signal significance)*
  - *Estimate remaining background events and look at event yield in data*

Need to worry and care about:

- *Is the detector behavior really understood?*
  - *Efficiencies, fake rates, energy and momentum scales, non-gaussian resolutions,…*
  - *Try to obtain as much information as possible from data*
- *Is the Standard Model prediction really understood?*
  - *Cross sections, kinematic distributions, underlying event,…*
  - *Must know sources of uncertainties on these!*

Possible early on: Z' with mass ~1 TeV

Z' → ee, 14 TeV, 1 fb^{-1}



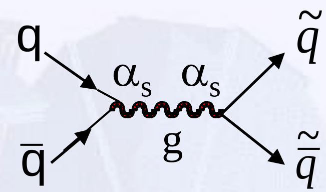
New forces or new dimensions of space?

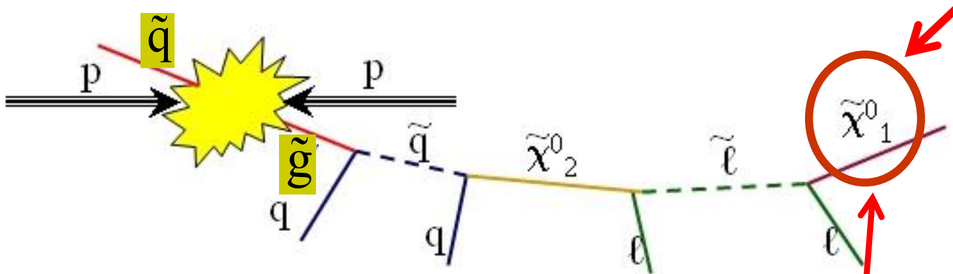
- *From angular distribution of leptons can disentangle Z' (spin=1) from Graviton (spin=2)*
- *Requires more data…*

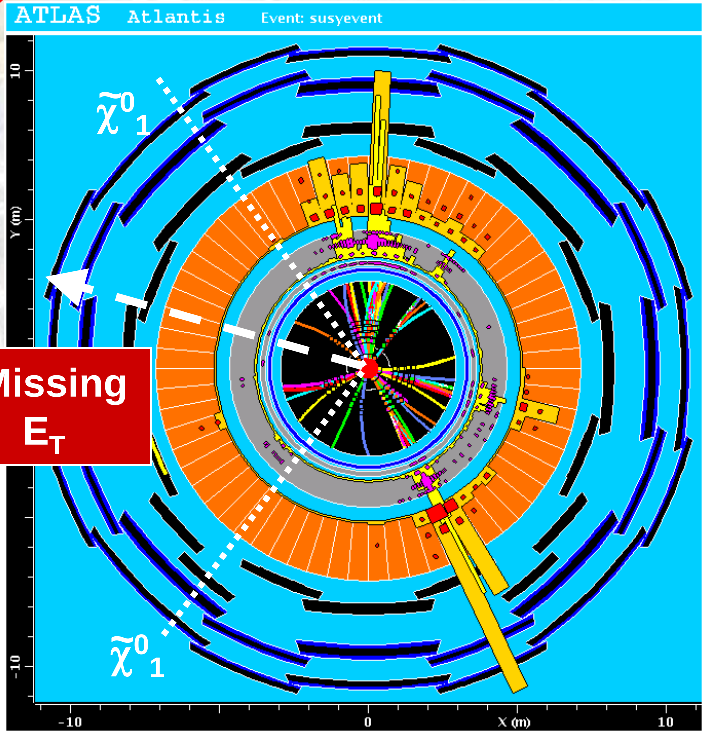
- *Signal is (narrow) mass peak above small and smooth SM background*
- *Does not require ultimate EM calorimeter performance*
- *Sensitivity beyond Tevatron limits with 200 pb^{-1} at 7 TeV (100 pb^{-1} at 10 TeV)*
- *Perhaps sometime in 2010, if we are lucky???*

If it is at TeV scale, it could be found "quickly"… due to:

- *Huge production cross section for* $\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}$
- *If* $m(\tilde{q}, \tilde{g})$ *~ 1 TeV:*
  expect 1 event every 5 days at L = 10^{31} cm^{-2} s^{-1}
- *Spectacular final states (many jets, leptons, missing transverse energy)*



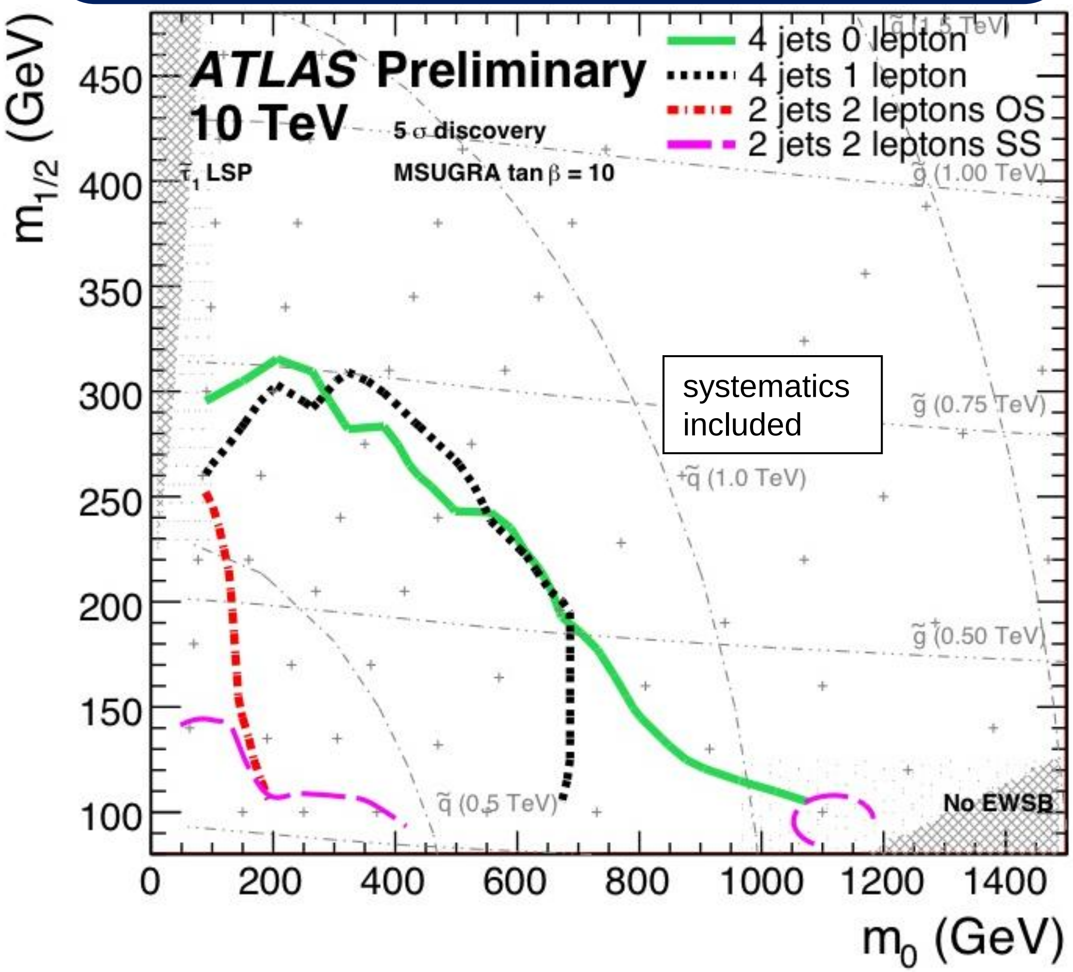




Missing E_T

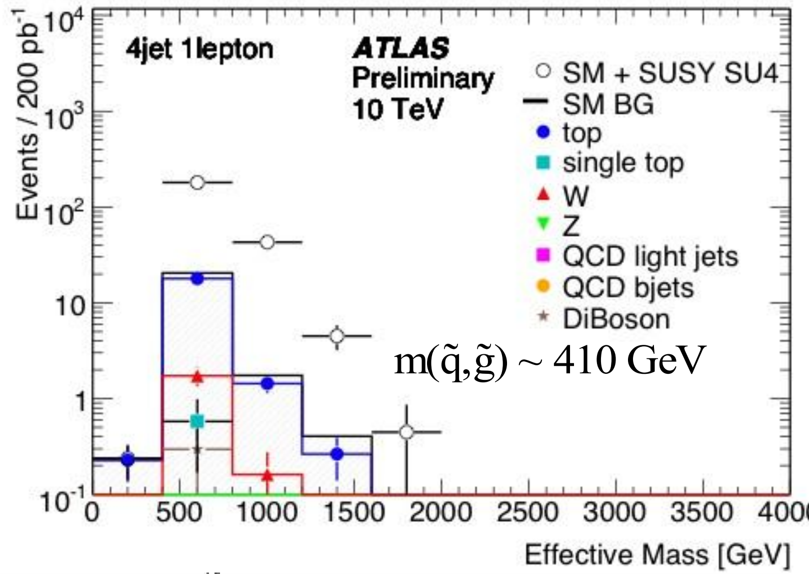
dark matter candidate

5σ discovery reach, 10 TeV, 200 pb^{-1}



- *Jets + E_T^{miss} channel: highest reach*
- *1-lepton channel: more robust*

Jets + missing ET + lepton 10 TeV, 200 pb^{-1}

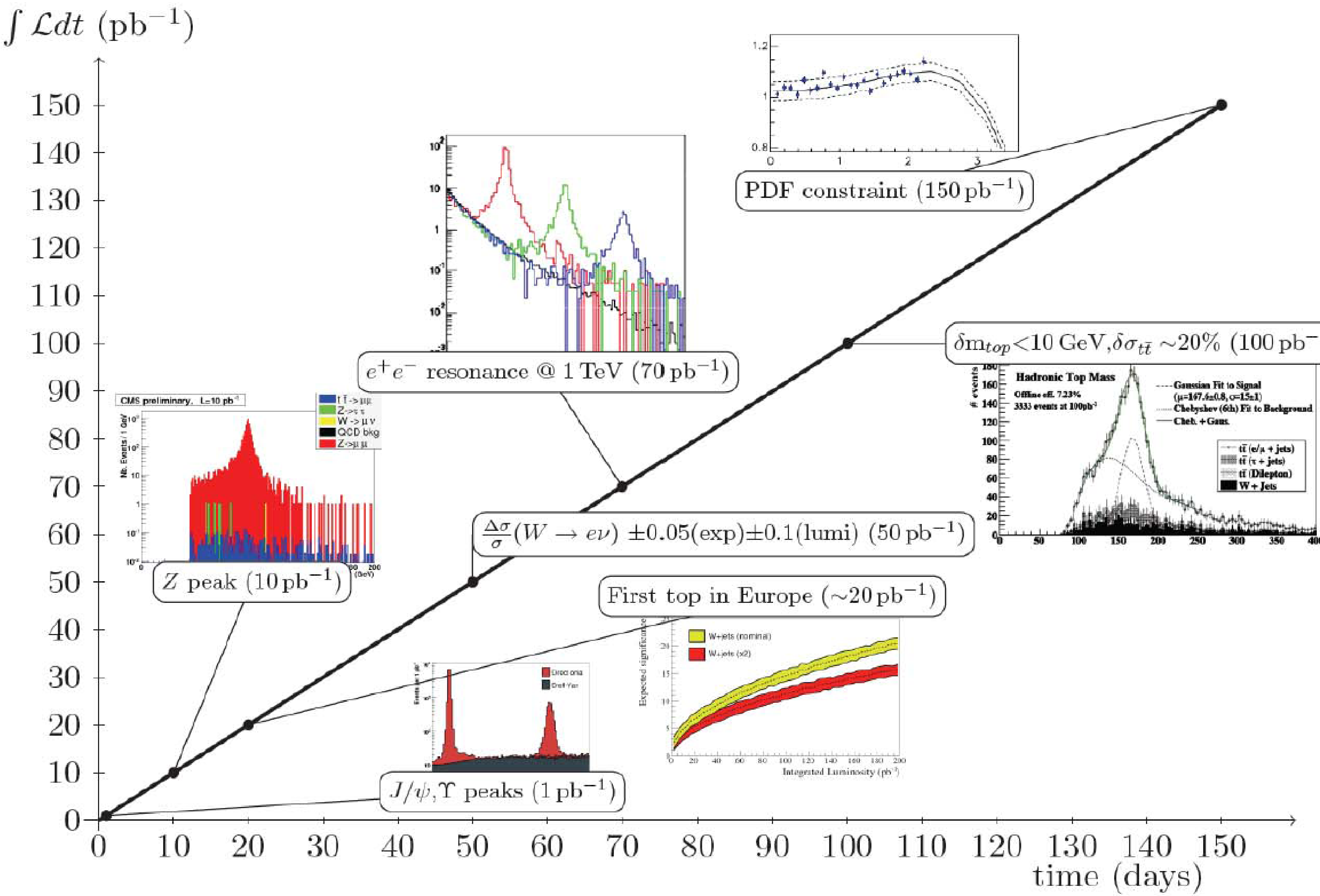


$$M_{\mathrm{eff}} \equiv \sum_{i=1}^{4} p_T^{\mathrm{jet},i} + \sum_{i=1} p_T^{\mathrm{lep},i} + E_T^{\mathrm{miss}}$$

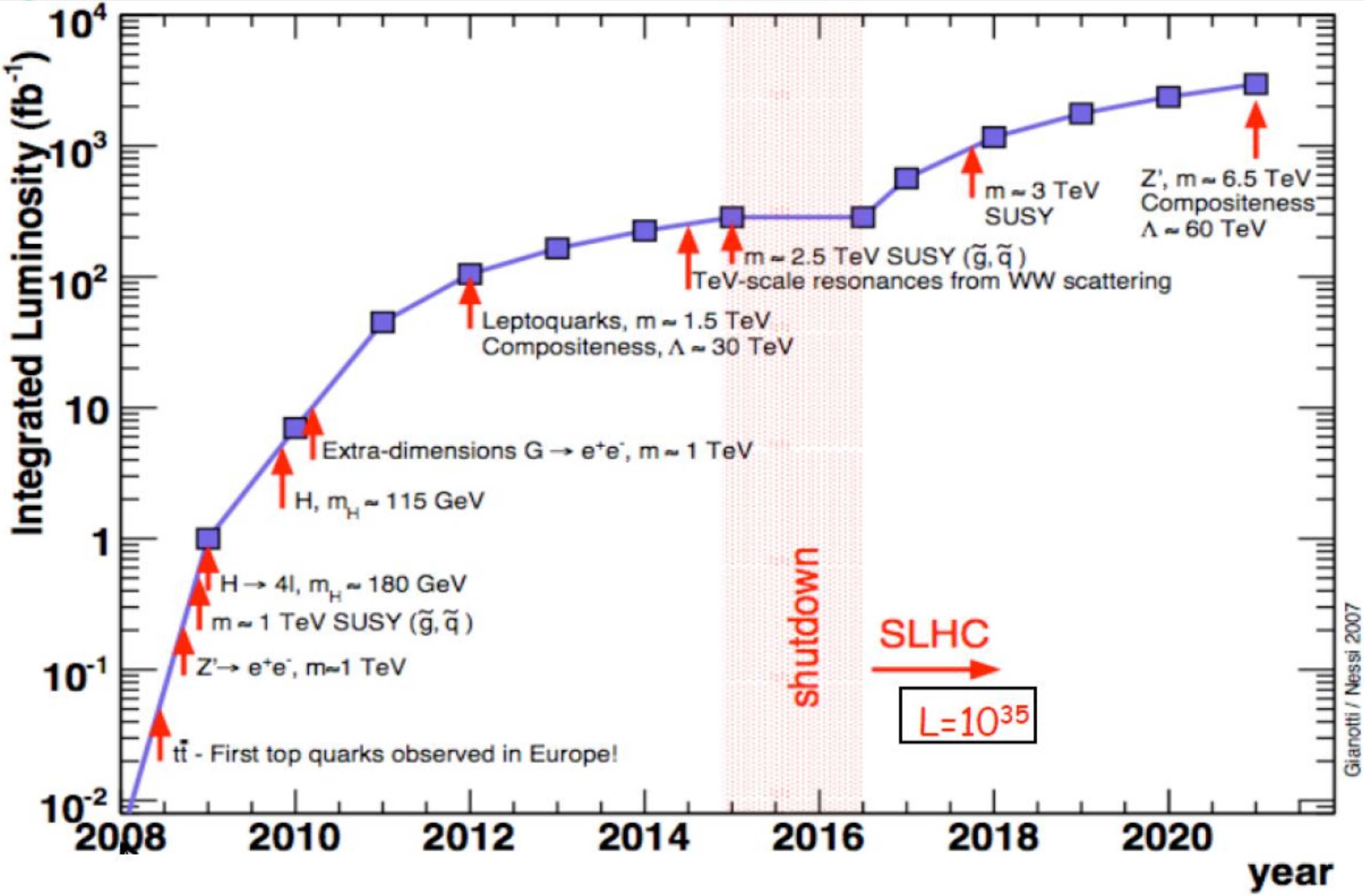
- *With 200 pb-1 at 7 TeV reach beyond Tevatron (~400 GeV)*
- *Tricky: understanding the background, i.e., missing E_T*
- *Ultimate LHC reach: ~ 3 TeV*

Summary – Early physics potential at ATLAS

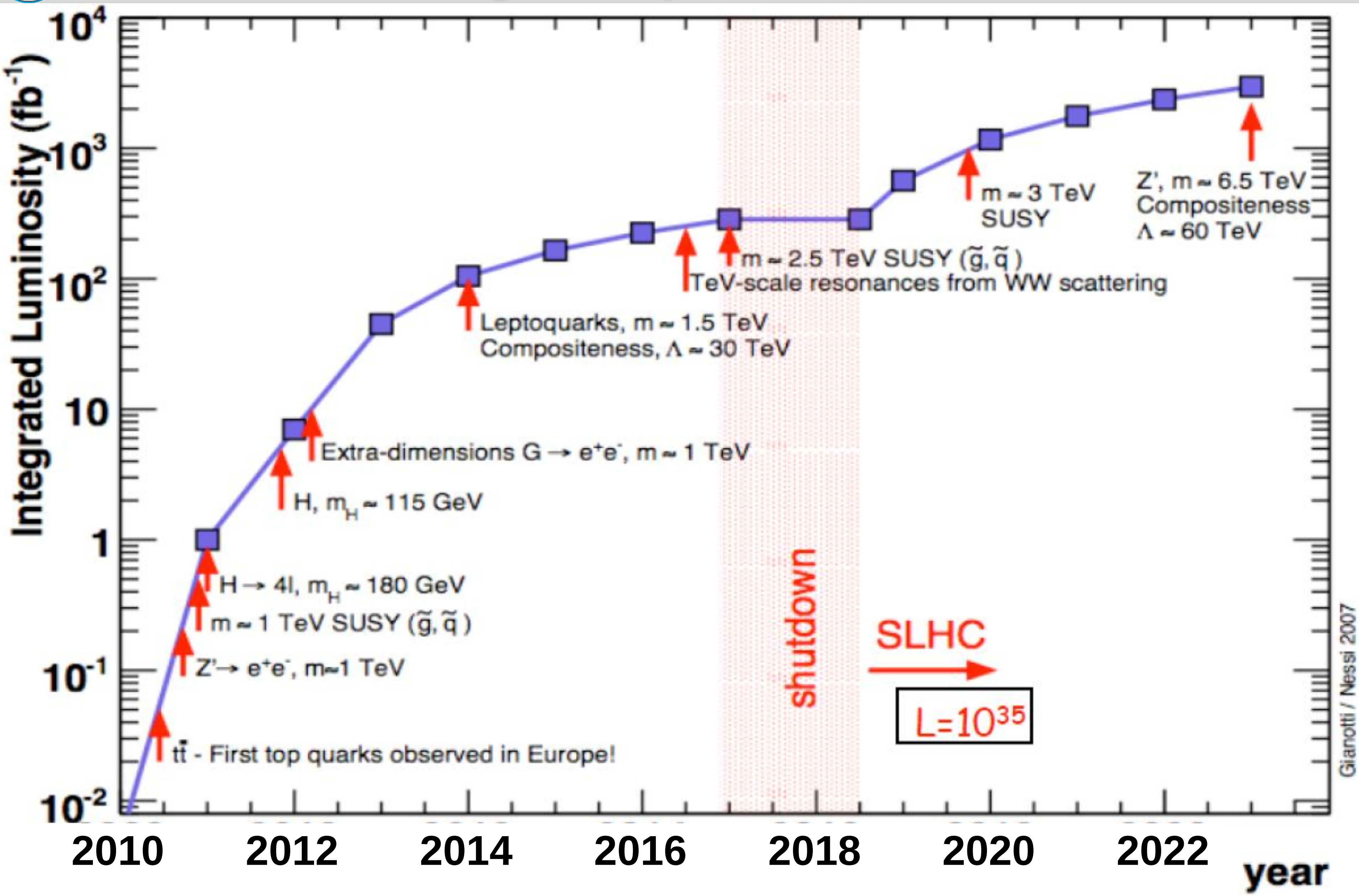
ATL-PHYS-CONF-2008-015

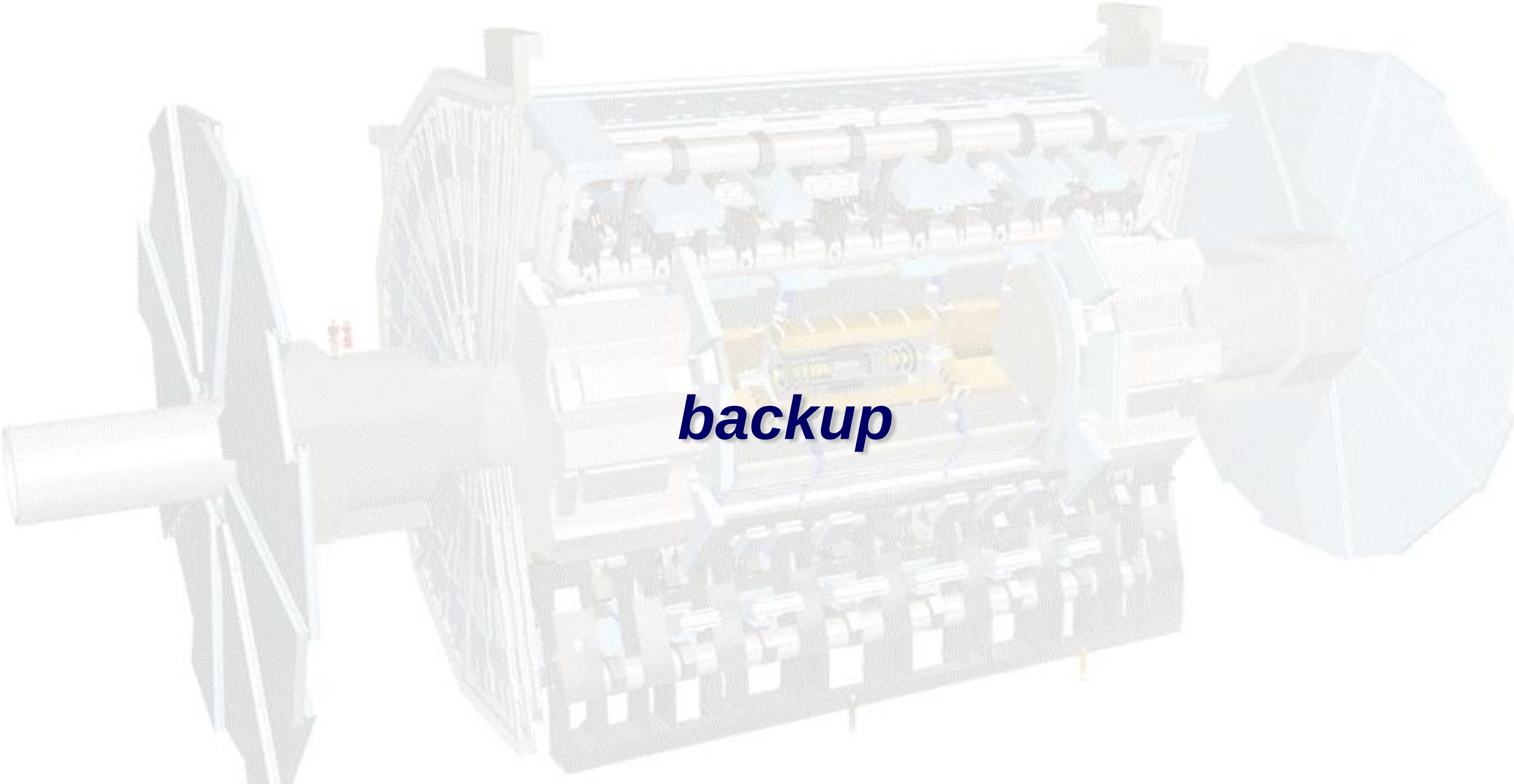


Outlook – long term potential



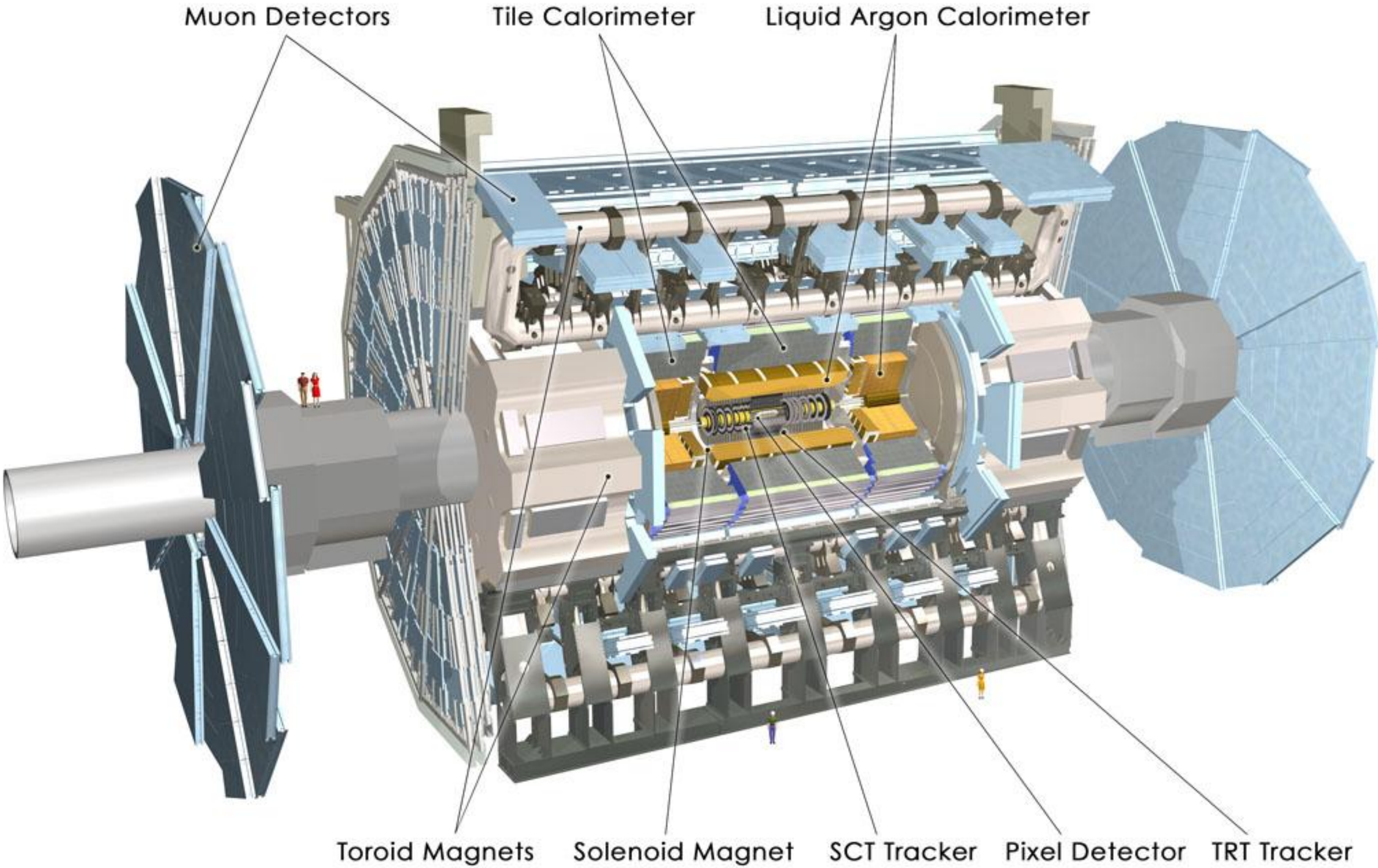
Outlook – long term potential



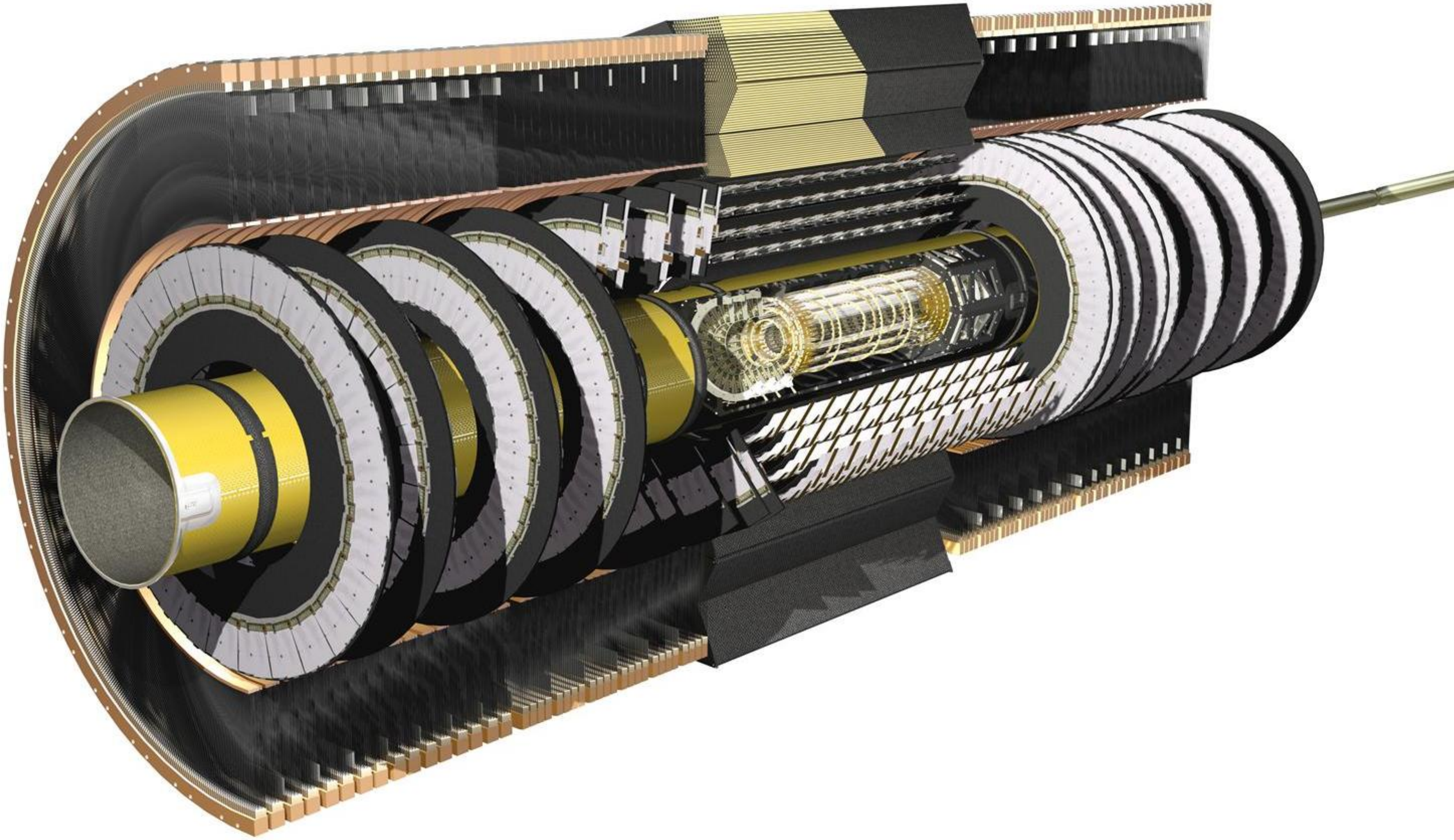


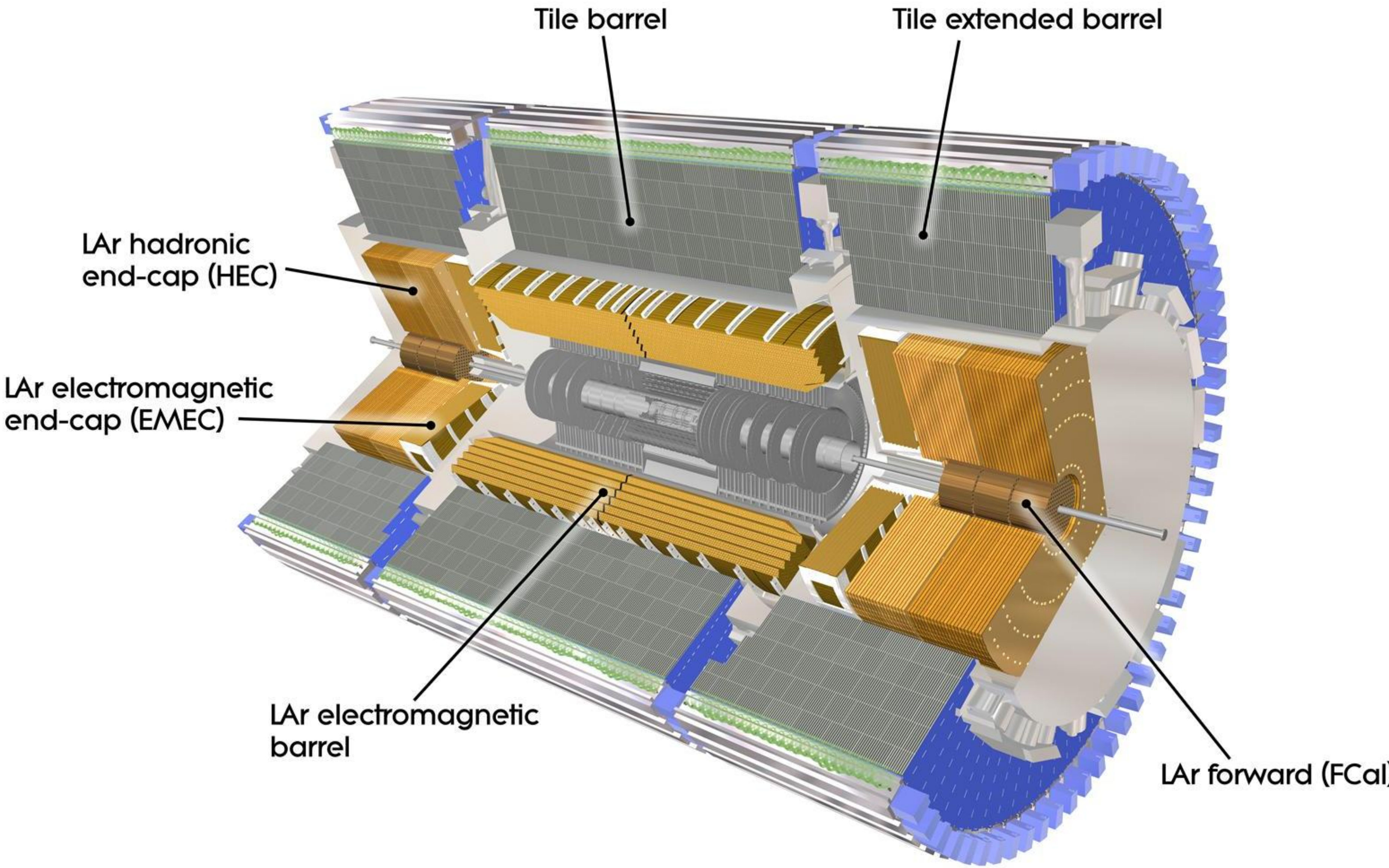
backup

The ATLAS Detector

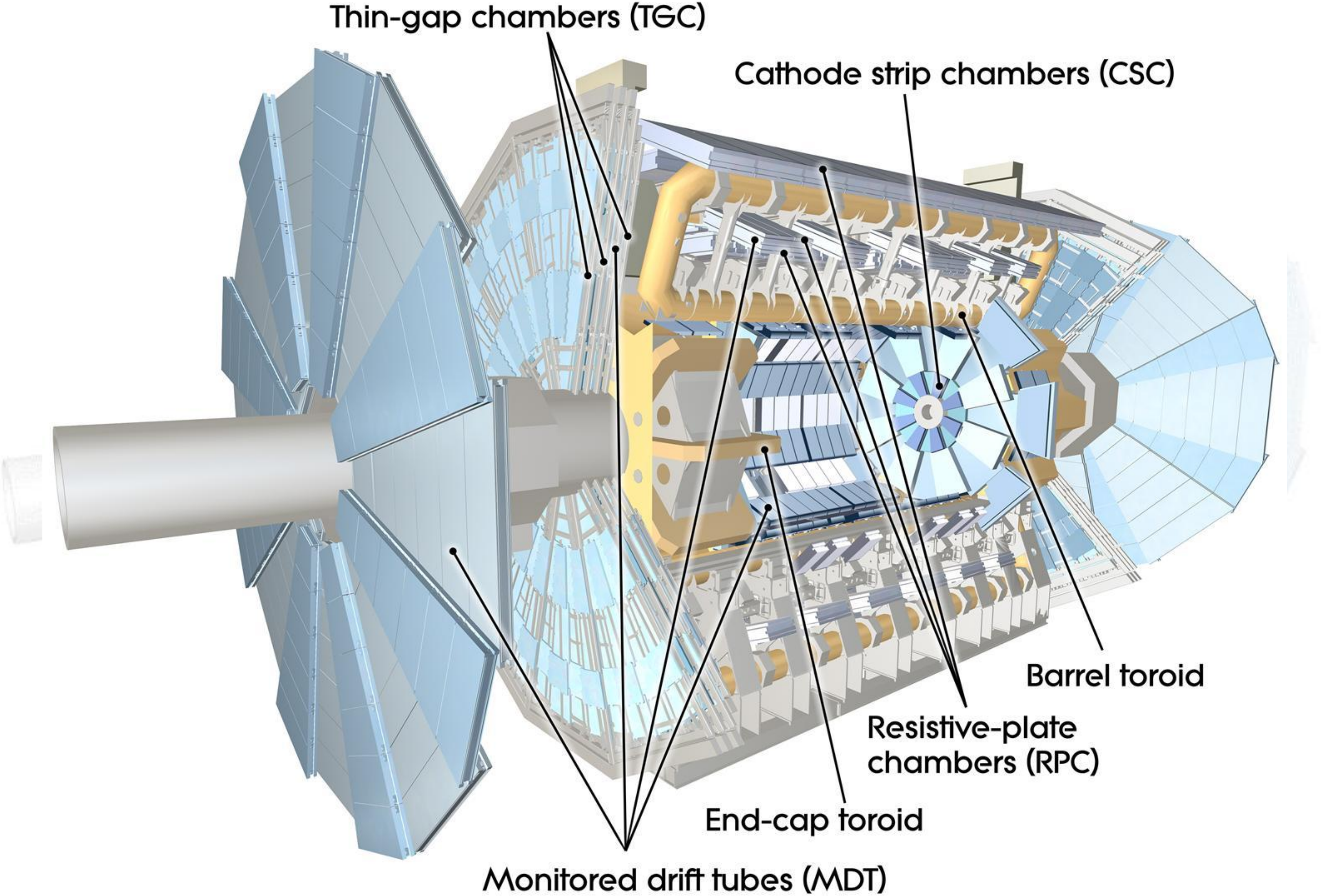


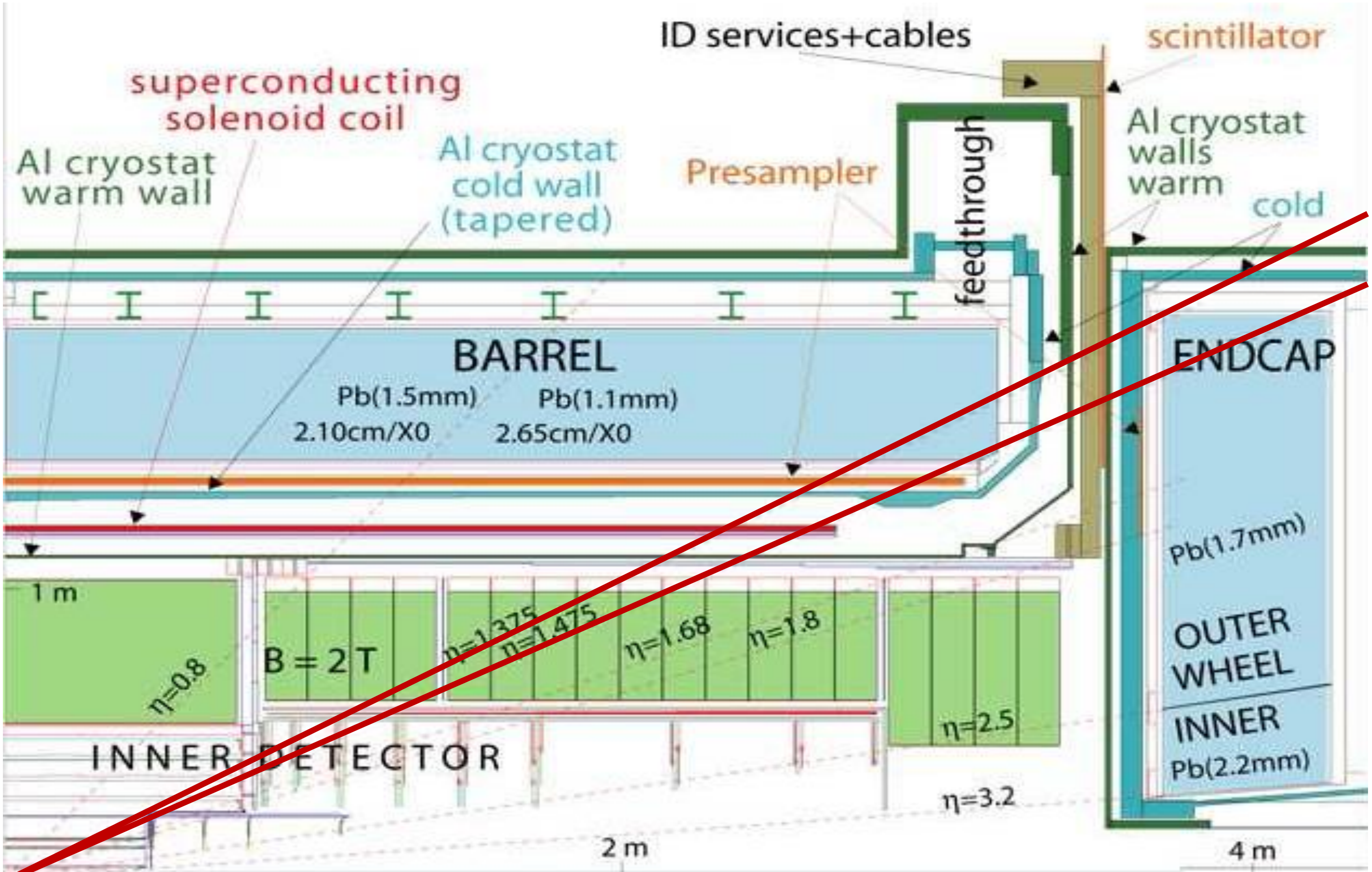
The ATLAS Inner Detector Tracking




Tile barrel
Tile extended barrel
LAr hadronic
end-cap (HEC)
LAr electromagnetic
end-cap (EMEC)
LAr electromagnetic
barrel
LAr forward (FCal)

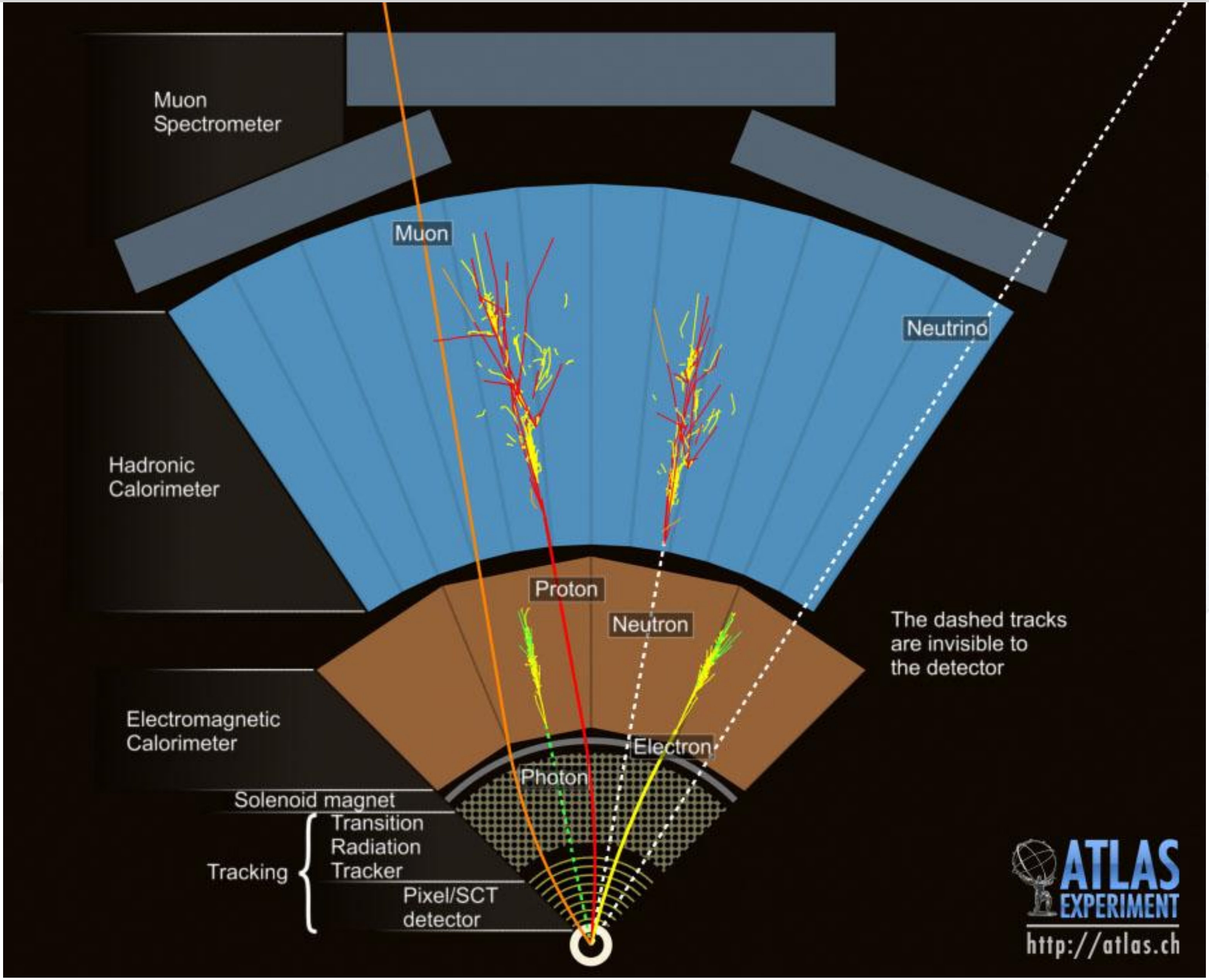
The ATLAS Muon System



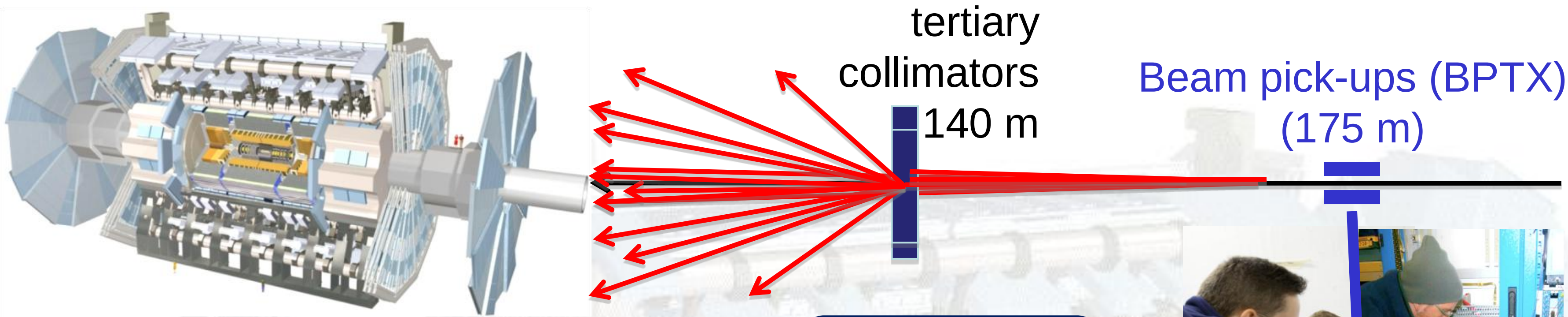


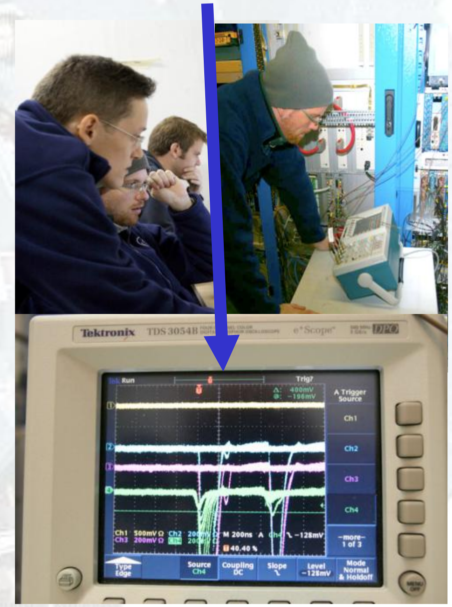
ID services+cables
scintillator
superconducting solenoid coil
Al cryostat warm wall
Al cryostat cold wall (tapered)
Presampler
feedthrough
Al cryostat walls warm
cold
BARREL
Pb(1.5mm)
Pb(1.1mm)
2.10cm/X0
2.65cm/X0
ENDCAP
Pb(1.7mm)
OUTER WHEEL
INNER
Pb(2.2mm)
1 m
B = 2 T
η=0.8
η=1.375
η=1.475
η=1.68
η=1.8
η=2.5
η=3.2
INNER DETECTOR
2 m
4 m

Interaction of different particles in ATLAS



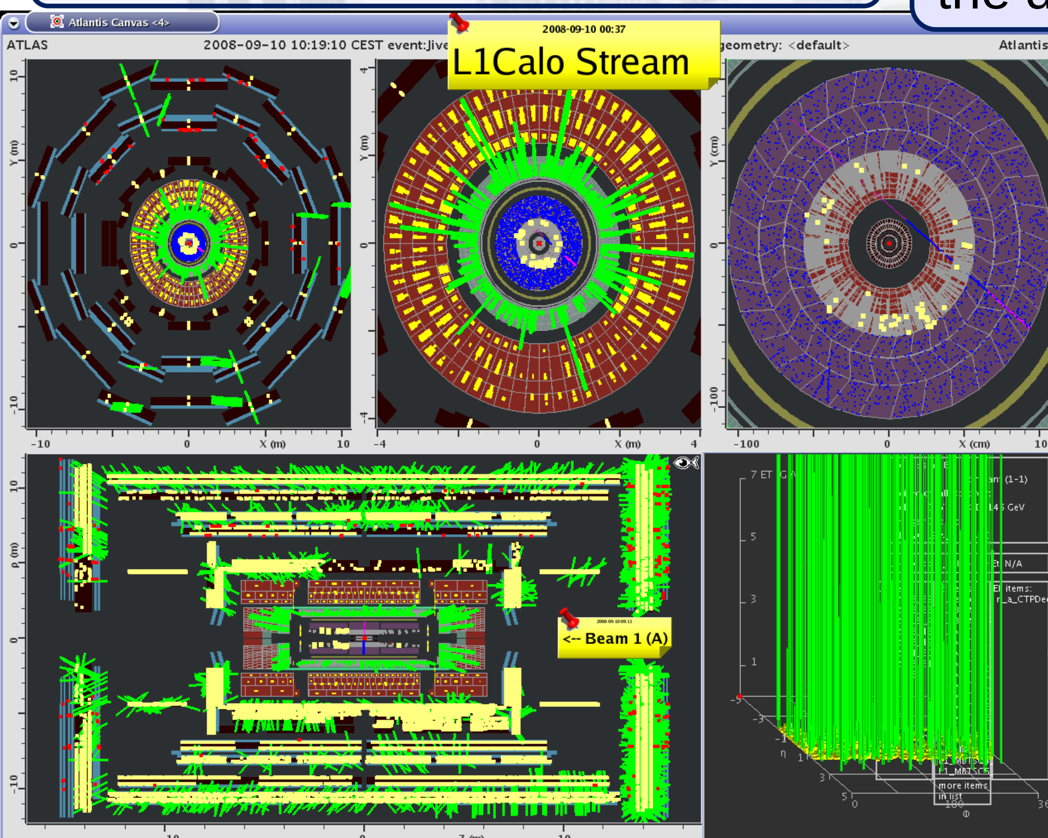
First ATLAS "beam splash event" recorded





September 10^{th}, 10:19 am:

~ 100 TeV in the detector!



Beam bunches ($2x10^9$ protons at 450 GeV) stopped by (closed) collimators upstream of experiment
"splash" events in the detector
(debris are mainly muons)

First top quarks in Europe

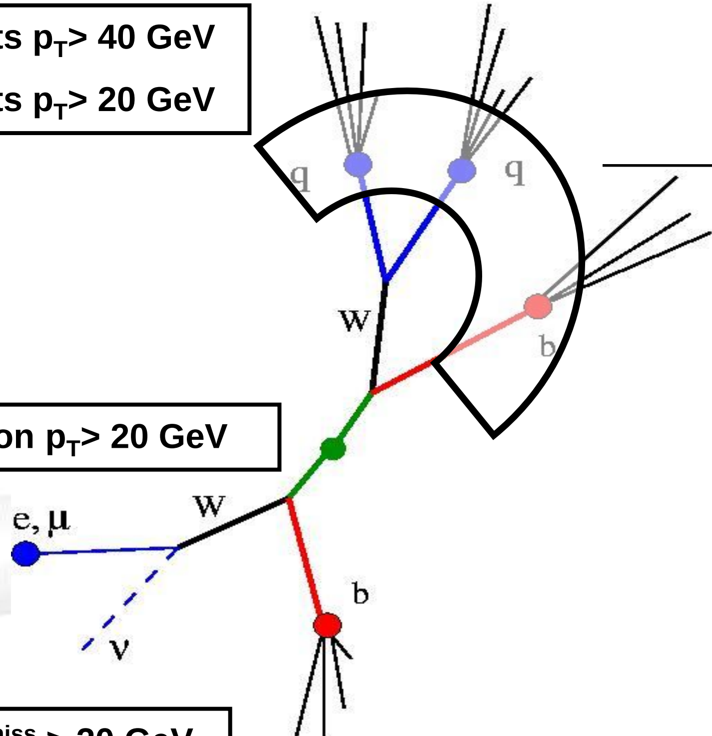
tt → bW bW → blν bjj

3 jets p_T> 40 GeV

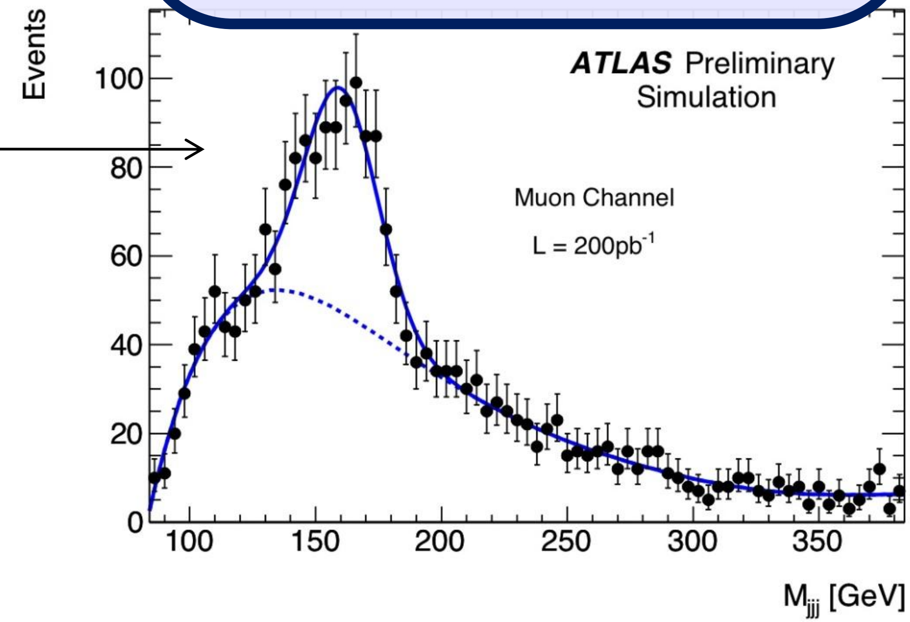
1 jets p_T> 20 GeV

1 lepton p_T> 20 GeV

E_T^{miss} > 20 GeV



Tri-jet mass
10 TeV, 200 pb^{-1}, μ-channel
No b-tagging!



Contains most physics objects:

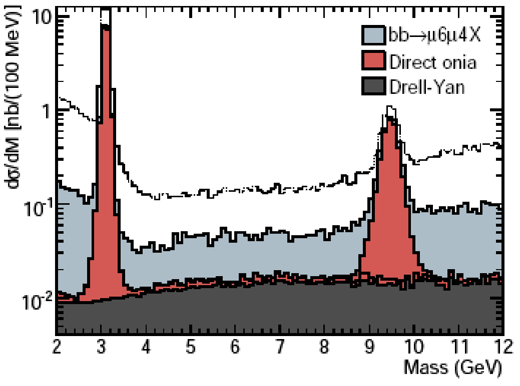
- *Leptons, jes, b-jets, missing E_T*
- *Background to almost all searches*

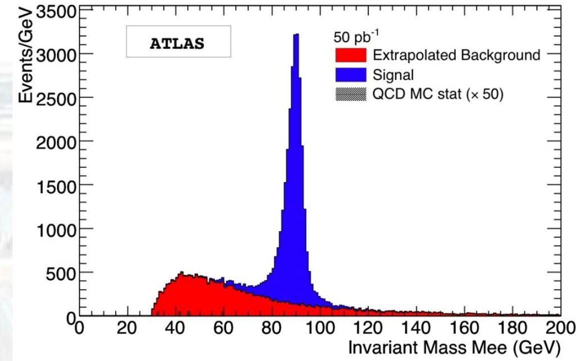
After cuts in μ-channel:

- *10 TeV: ~1600 events*
- *7 TeV: ~600 events*
- *Uncertainty on cross section < 20% (+lumi)*

When top is measured, experiment is ready for discovery physics!

Early Physics Measurements at the LHC with ATLAS





Karsten Köneke

DESY

for the ATLAS Collaboration