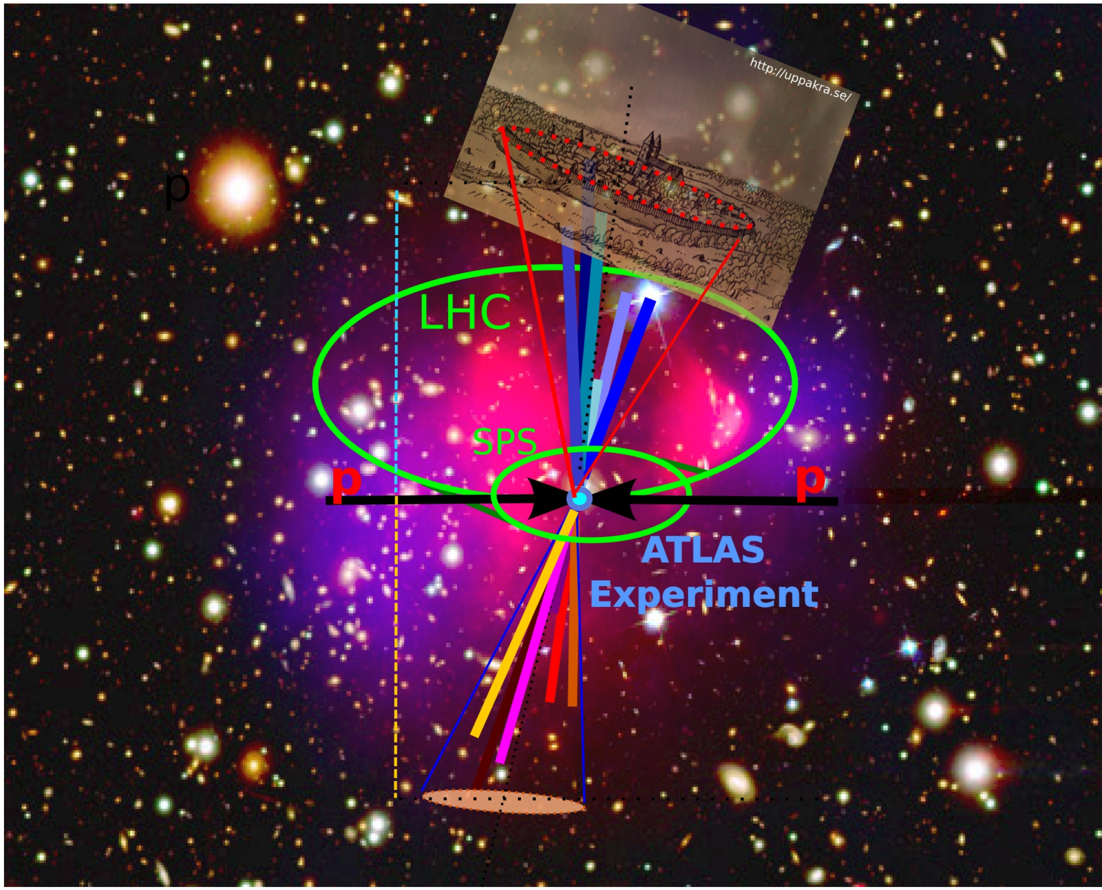


SEEKING DISCOVERIES WITH JETS AT THE LARGE HADRON COLLIDER

Caterina Doglioni,
University of Geneva
(ATLAS)

11/13/2014 – Science coffee, Lund University

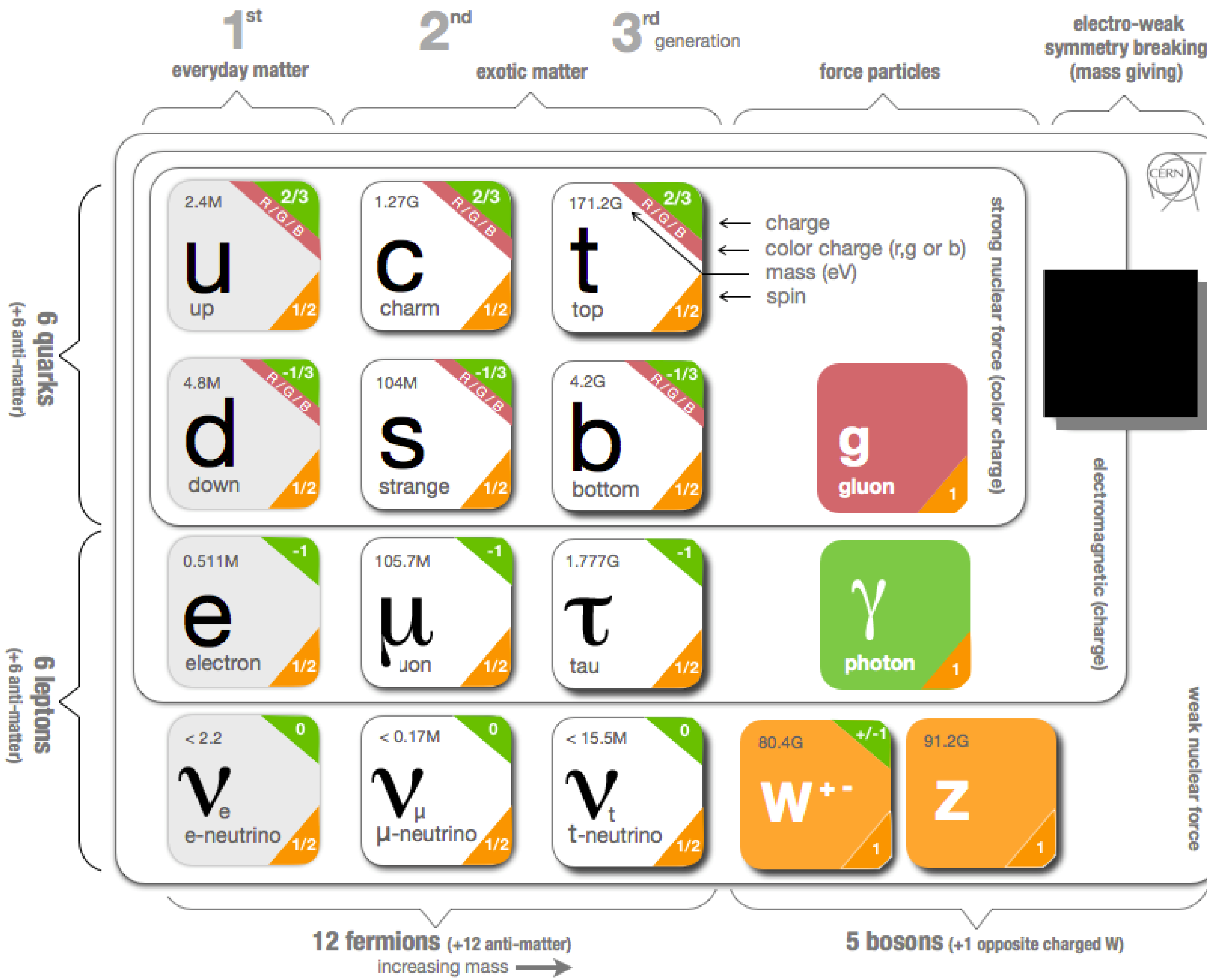
OUTLINE

Dark Matter and New Physics with hadronic jets at the LHC

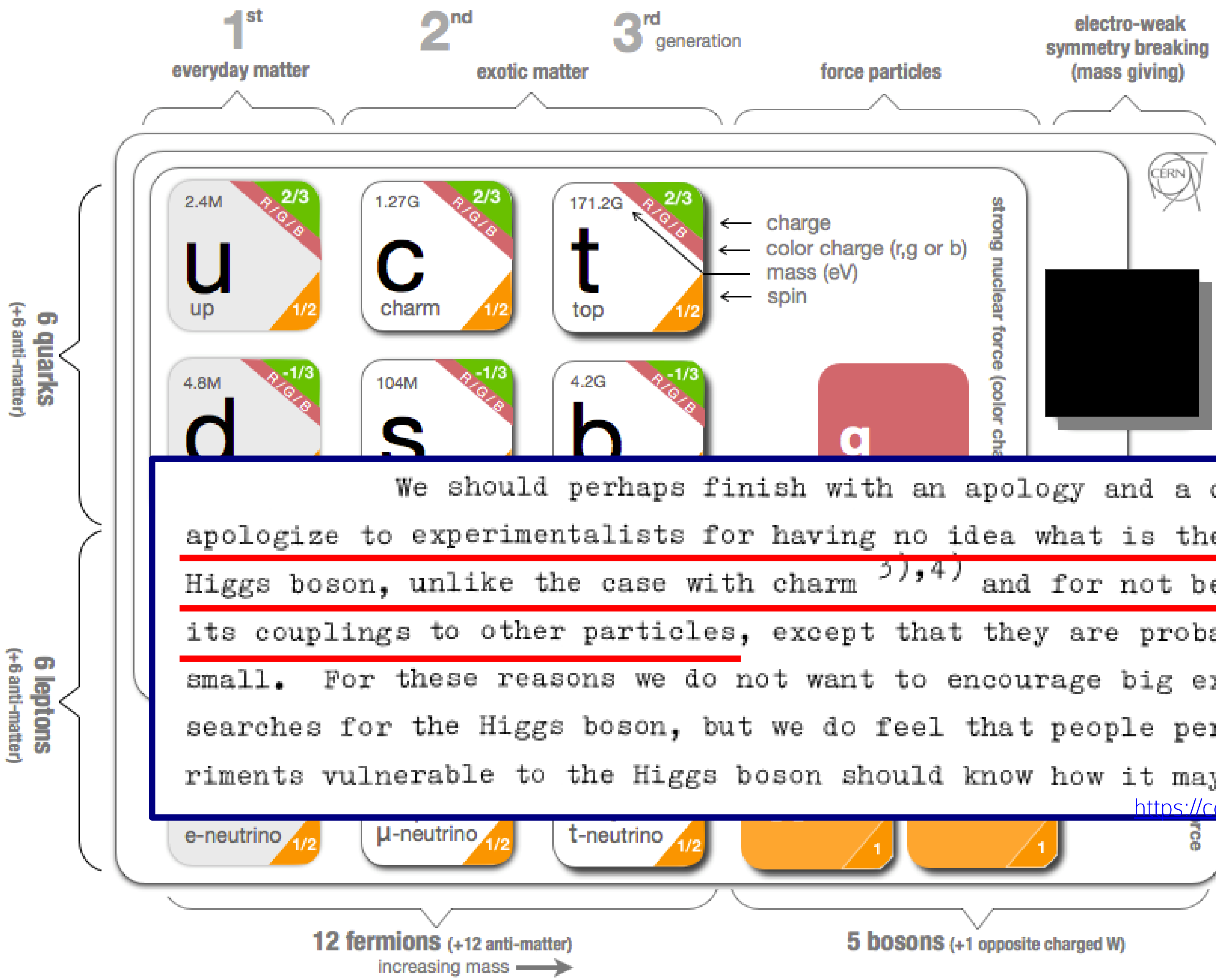
1. The heart of the matter
2. The heart of the dark matter
3. An overview of hadronic jets in ATLAS
4. New Physics searches with jets
5. A look to the future

THE HEART OF THE MATTER

THE STANDARD MODEL OF PARTICLE PHYSICS, PRE-HIGGS



THE STANDARD MODEL OF PARTICLE PHYSICS, PRE-HIGGS



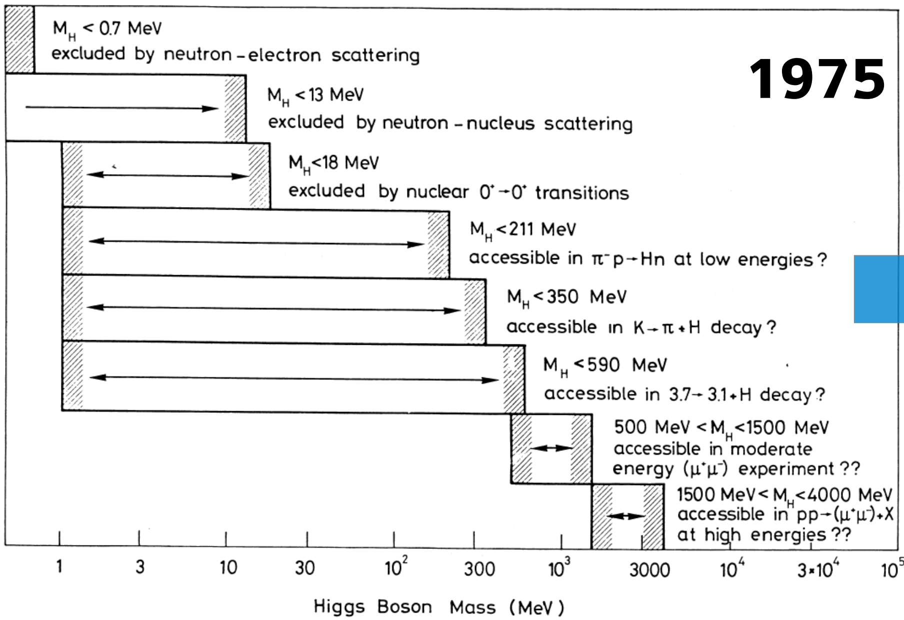
We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm[3),4)] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

https://cds.cern.ch/record/874049

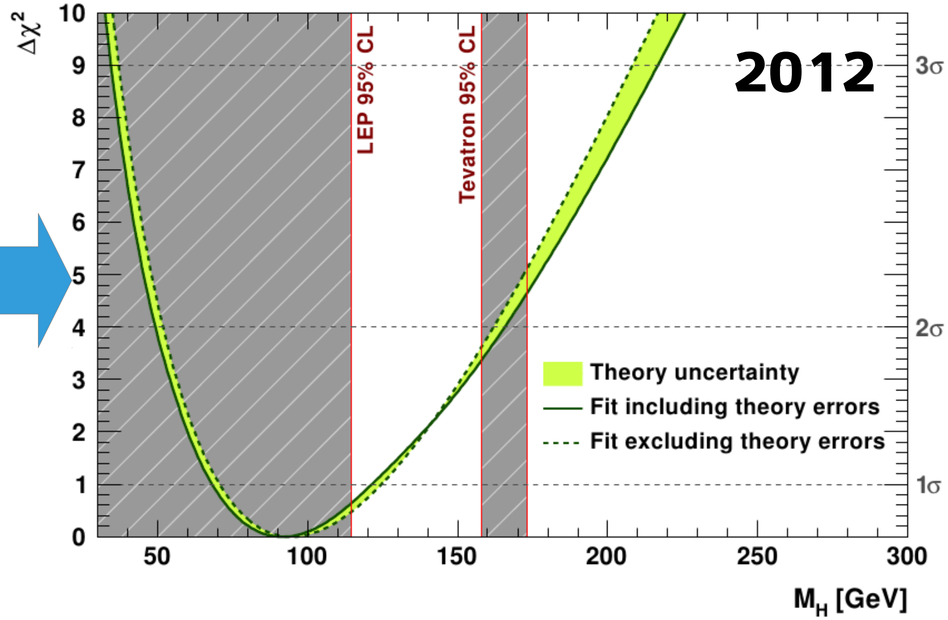
NARROWING THE SM HIGGS BOSON MASS RANGE

Strong hints of **where to search** for the new boson:

https://cds.cern.ch/record/874049



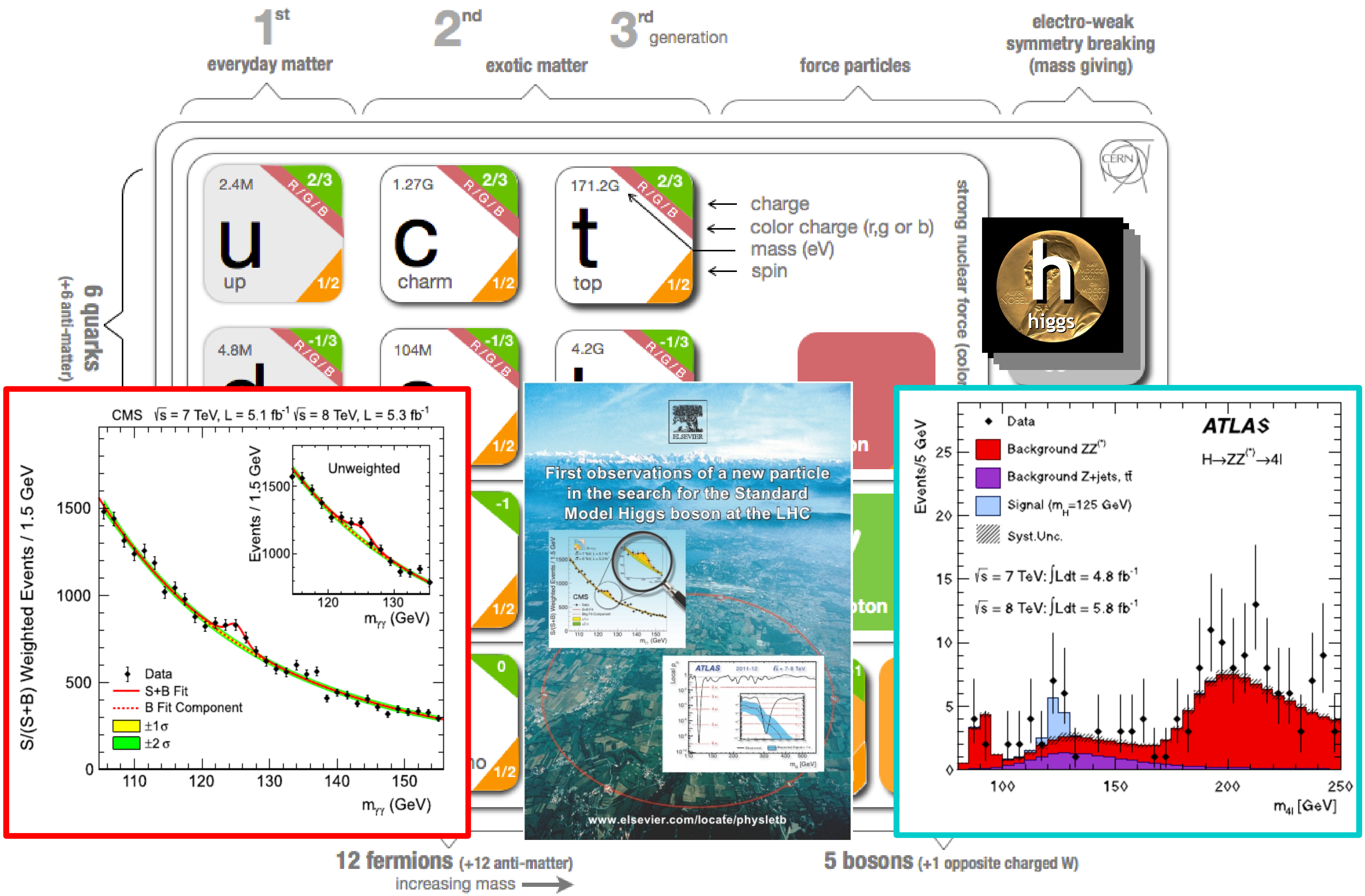
http://arxiv.org/abs/1107.0975



Given the strong performance of the LHC and its experiments, with already over 1 fb^{-1} integrated luminosity accumulated at the date of this paper, the present analysis might be among the last global electroweak fits working with Higgs limits only. In case of a Higgs discovery, the

...THEN WE FOUND THE HIGGS BOSON

THE STANDARD MODEL OF PARTICLE PHYSICS NOW



SOME MISSING PIECES OF THE STANDARD MODEL

Empirical

- Dark matter (DM)
- Dark energy
- Matter vs antimatter
- Neutrino masses
- ...

Aesthetics

- Large difference in scales of forces (hierarchy problem)
- Fine-tuning needed
- Free SM parameters
- ...

Preferred mass range for answers: **TeV-scale**

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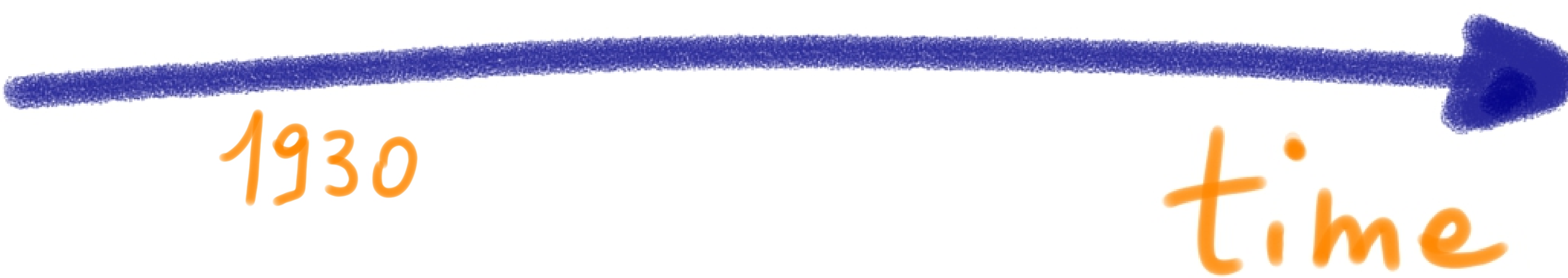
ATLAS EXPERIMENT

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

THE HEART OF THE DARK MATTER

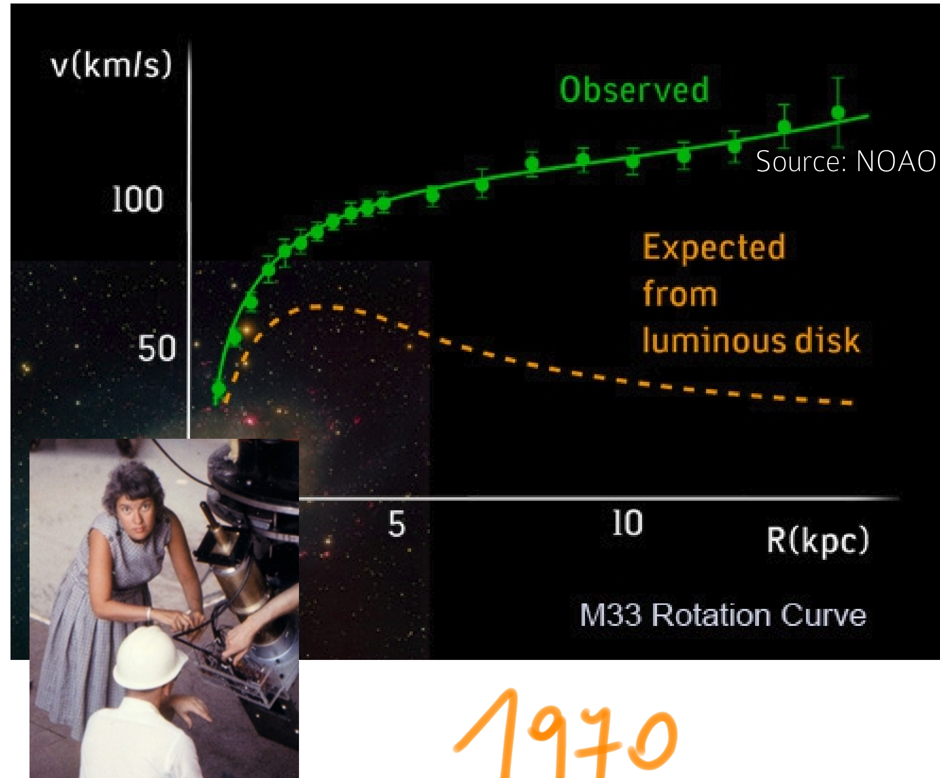
EVIDENCE FOR DARK MATTER

F. Zwicky – Coma cluster: mass vs light output



EVIDENCE FOR DARK MATTER

V. **Rubin** – Velocity of gas near Andromeda galaxy



F. **Zwicky** – Coma cluster: mass vs light output

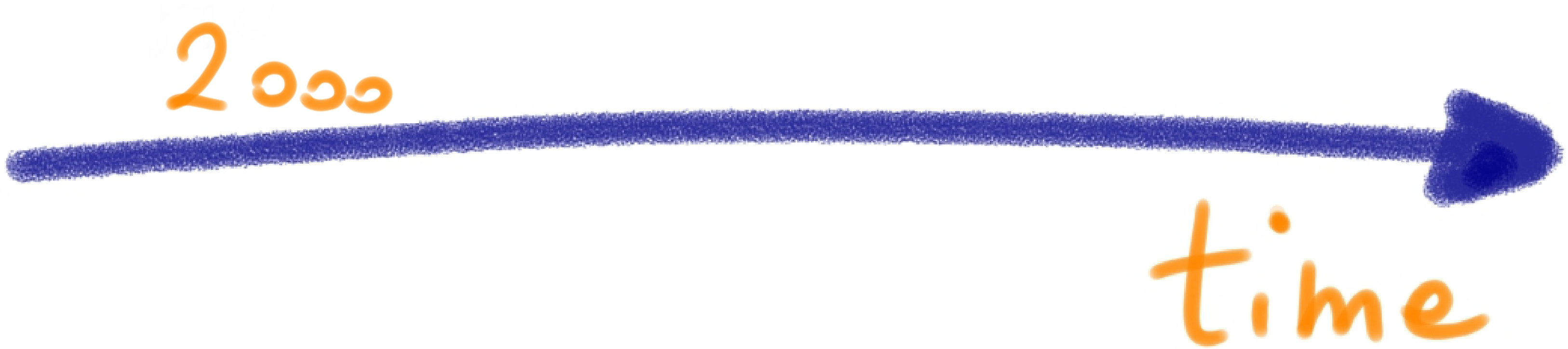
1970

1930

time

EVIDENCE FOR DARK MATTER

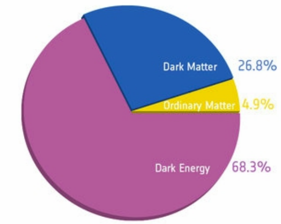
Chandra/Hubble (NASA) – Visible mass of bullet cluster vs dark mass inferred from gravitational lensing



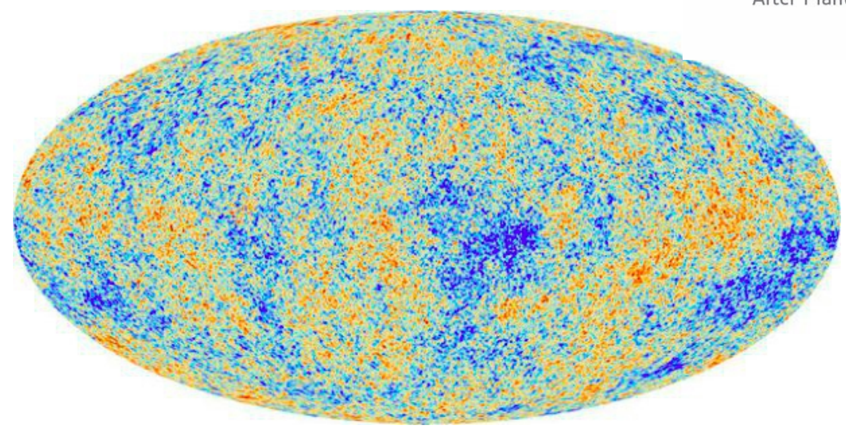
EVIDENCE FOR DARK MATTER

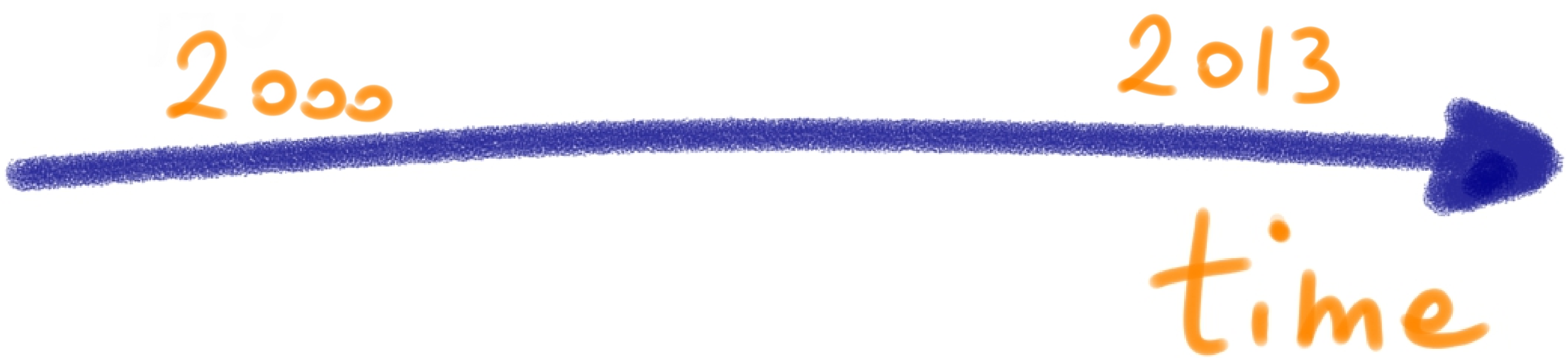
Chandra/Hubble (NASA) – Visible mass of bullet cluster vs dark mass inferred from gravitational lensing

Planck – Dark matter vs standard matter composition using Cosmic Microwave Background fluctuations



After Planck



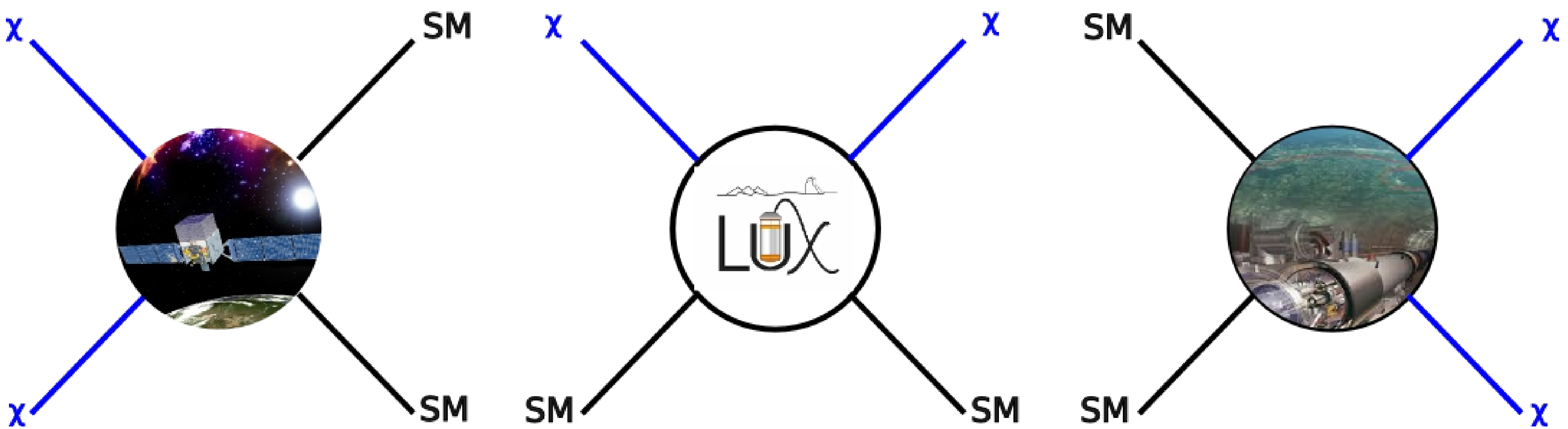


LOOKING FOR DARK MATTER

Preferred DM candidate to match observations:
dark, stable, cold, weakly interacting with SM particles,
mass of up to a few TeV

Good News! Complementary Dark Matter experiments

Indirect detection | Direct detection | Colliders



SIGNATURE-BASED SEARCHES AT COLLIDERS

Preferred mass range for answers: **TeV-scale**

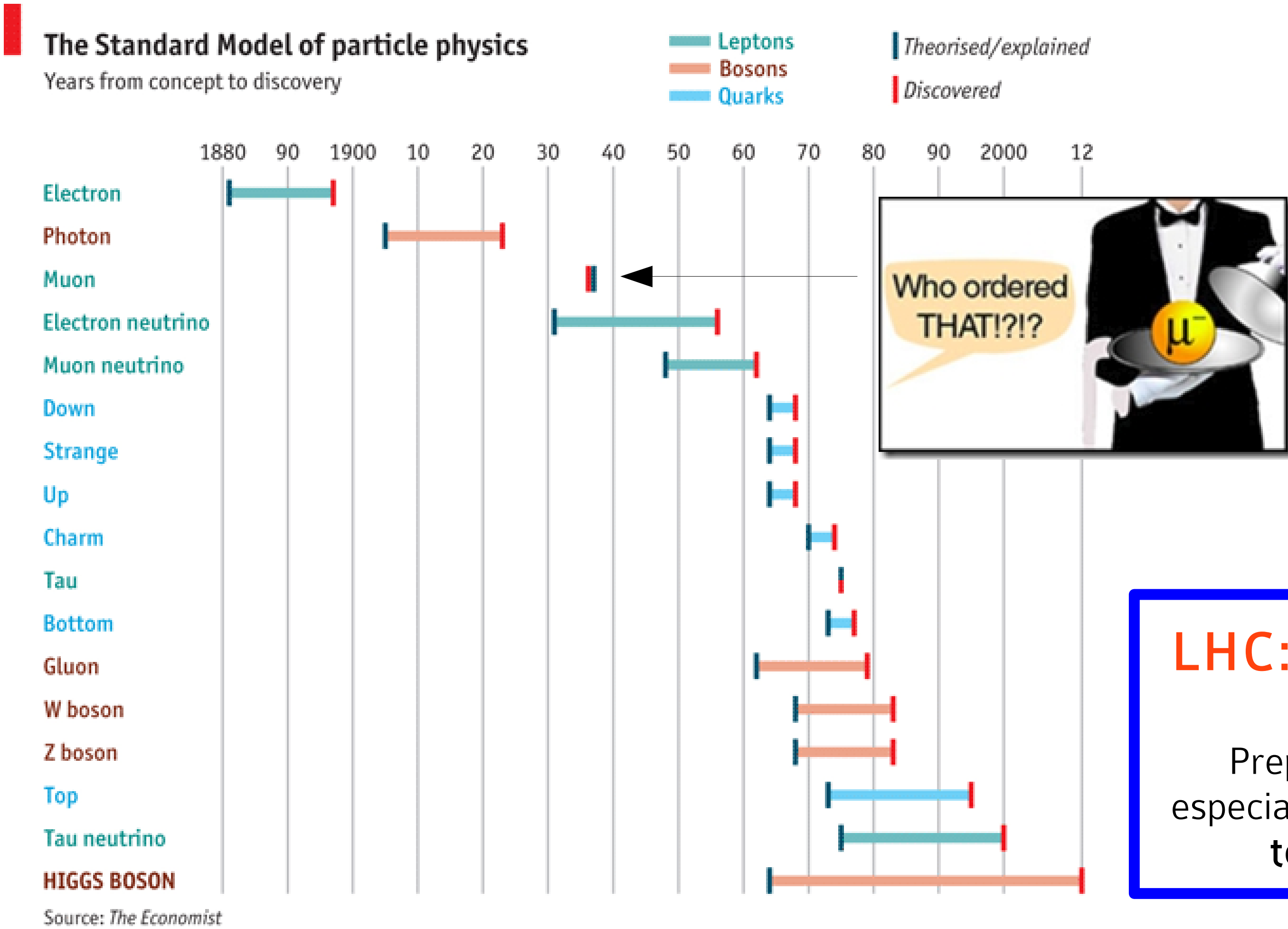
If we knew where to look,
maybe we'd do a better job

S. Worm, DM@LHC Workshop, Oxford, 2014

We have only **hints** of what we're looking for
→ design generic searches, based on **signature**
of new particles in detector,
covering one or more **generic models**

SIGNATURE-BASED SEARCHES AT COLLIDERS

Further **motivation** for **model-independent** searches:



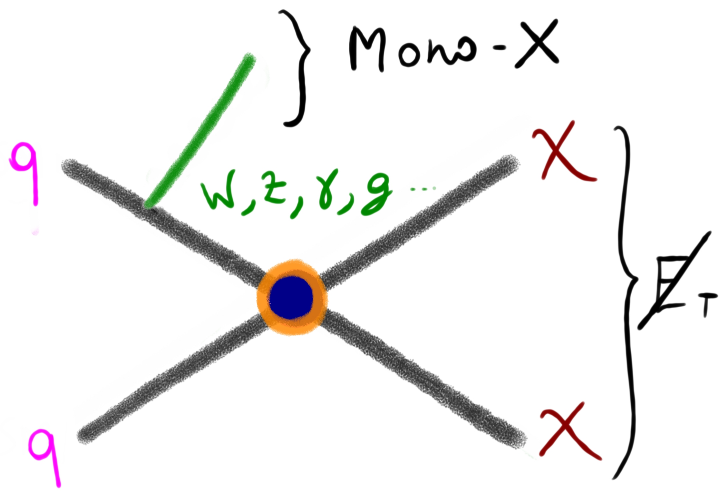
LHC: **discovery** machine

Prepare for the **unexpected**, especially if **New Physics couples to quarks and gluons**

SIGNATURES OF MISSING MATTER: *MONO-X*

Invisible DM particles **escape detection:**

tag events using **recoiling** object,
measure **missing transverse momentum** ($\not{E}_T$)



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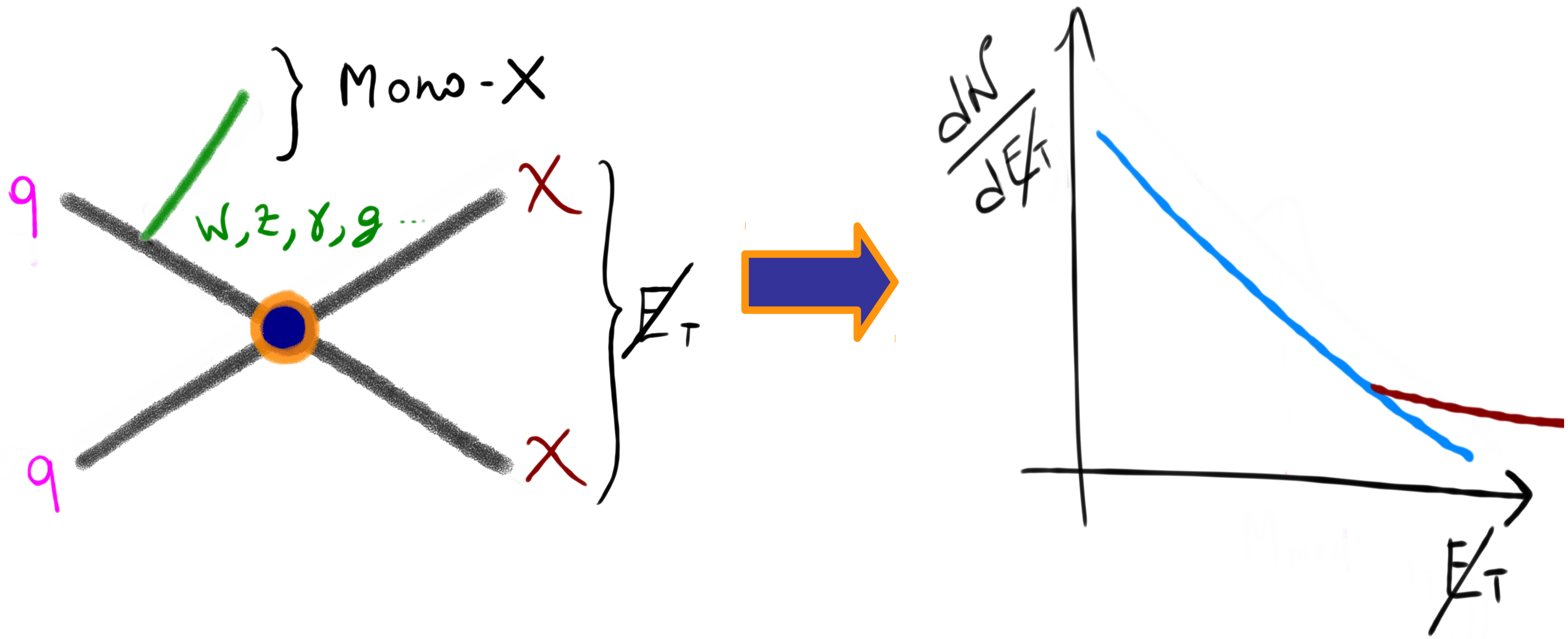
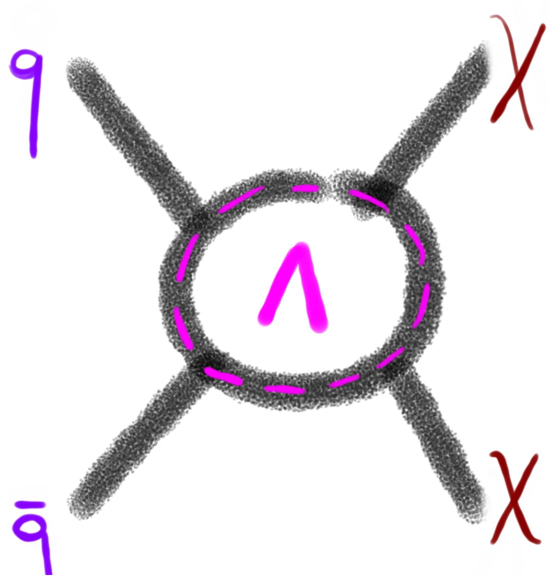


Dark Matter signature: excess in **tails of $\not\!\!E_T$ distribution**

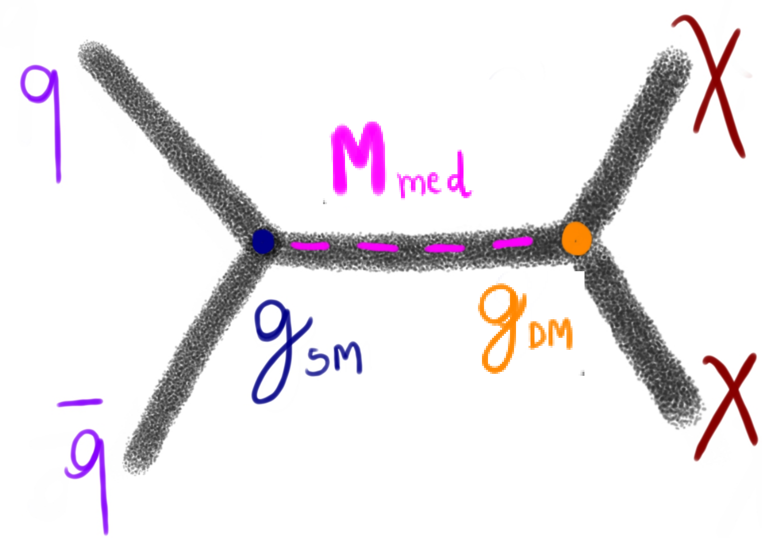
(search also sensitive to many other models!)

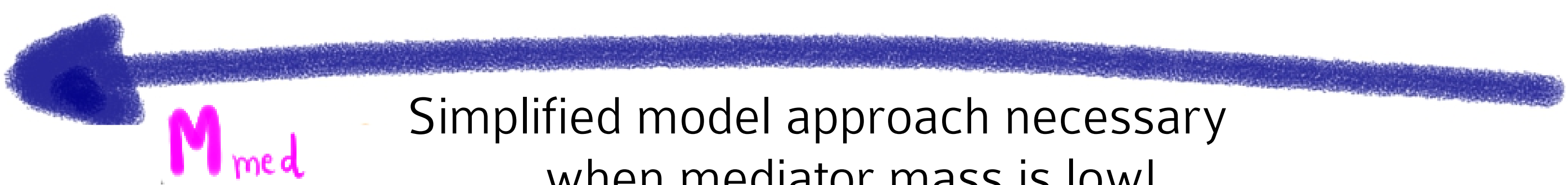
SIMPLIFIED MODELS OF DARK MATTER

Effective Field Theory:
contact interaction



Simplified model:
e.g. s-channel exchange
of mediator particle

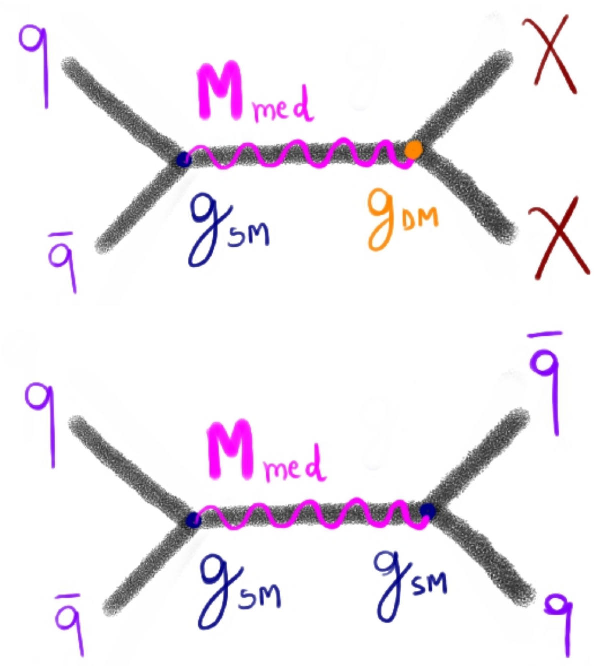




Simplified model approach necessary
when mediator mass is low!

SIGNATURES OF NEW PARTICLES: RESONANCES

Invisible DM particles can be **mediated** by other particles **coupling to quarks and gluons**



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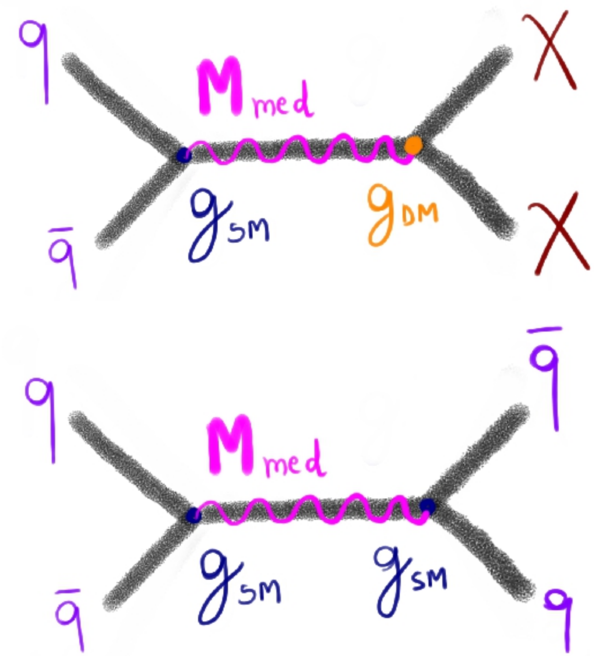
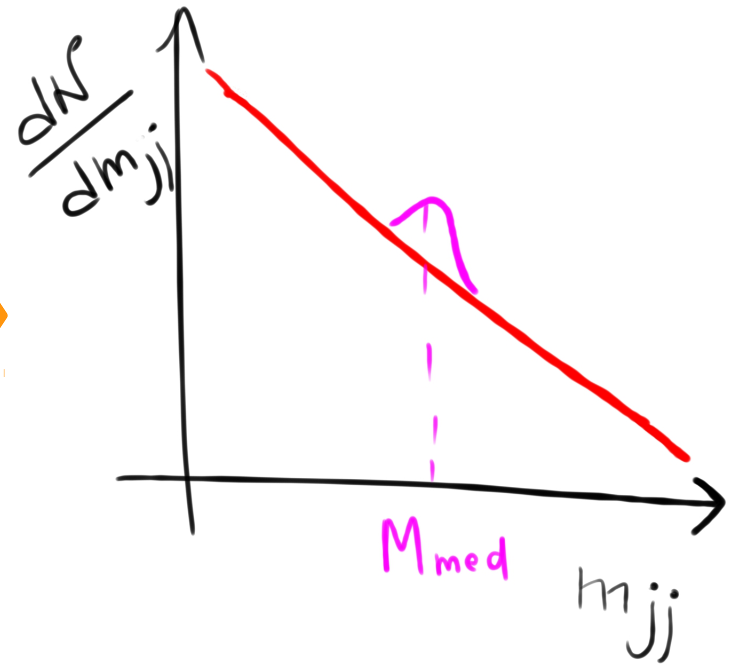


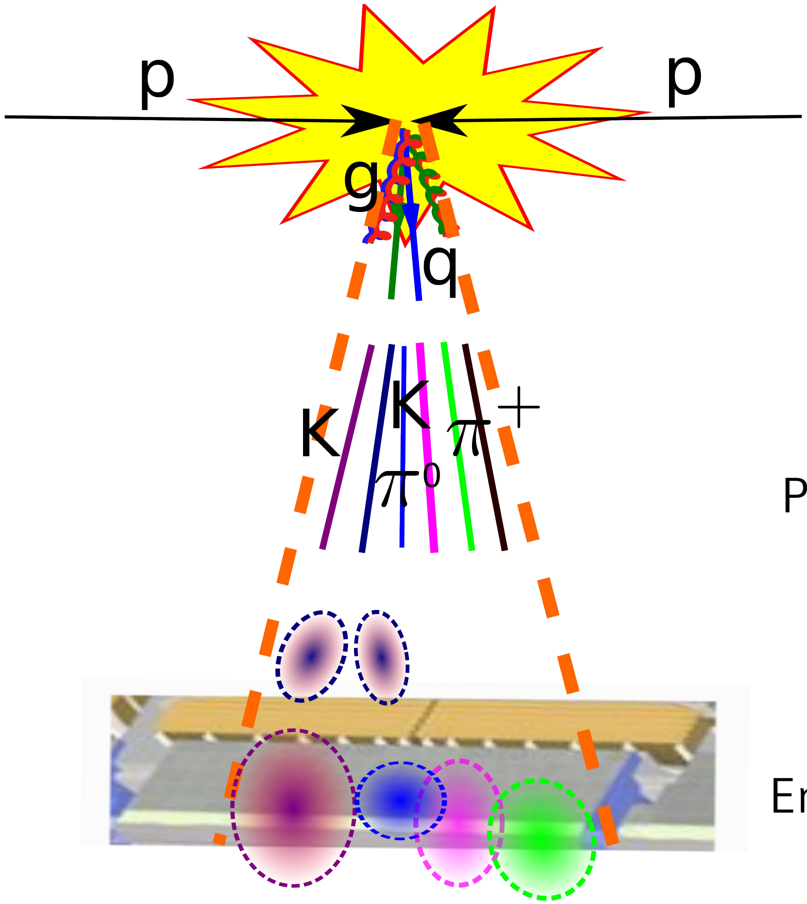


Signature of mediator: excess of central dijet events with **invariant mass = $M_{mediator}$**

(search also sensitive to many other models!)

AN OVERVIEW OF HADRONIC JETS

THE DEVELOPMENT OF A HADRONIC JET



Parton level

Quarks and gluons
from the hard scattering

Particle level

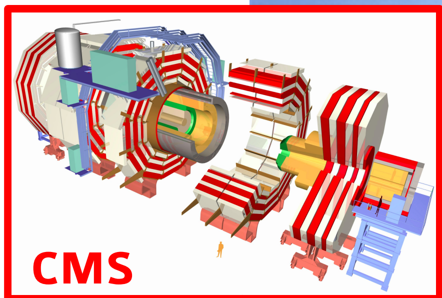
Particles from the hadronization of
quarks and gluons

Calorimeter level

Energy deposited in the calorimeters

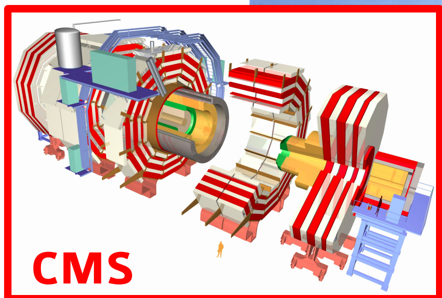
Jet finding and **calibration** needed to match kinematics at calorimeter level to underlying kinematics

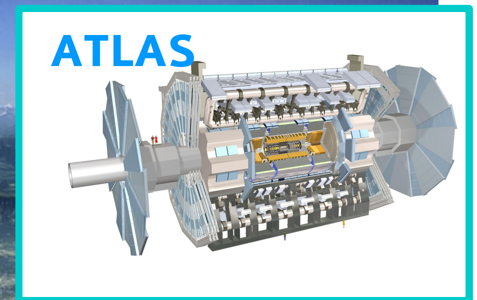
ATLAS AND CMS DETECTORS AT THE LHC

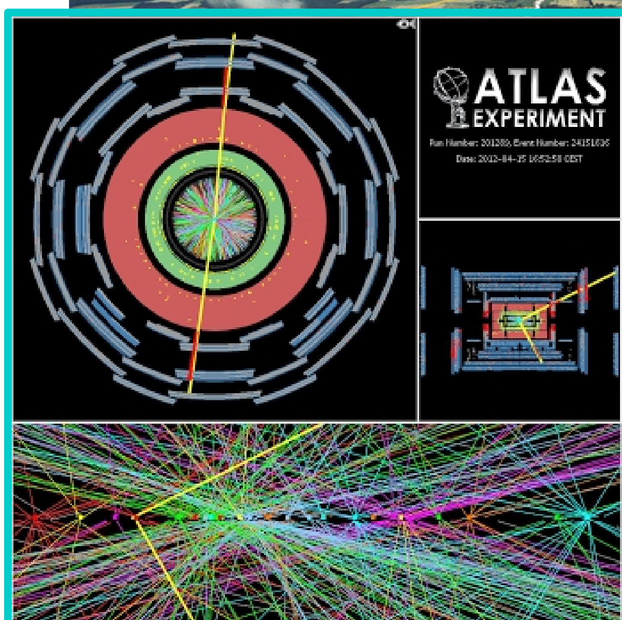


- ATLAS and CMS → physics with jets, leptons, photons
  - General-purpose experiments, covering ~ full solid angle
  - Excellent tracking, calorimetry, muon spectrometer

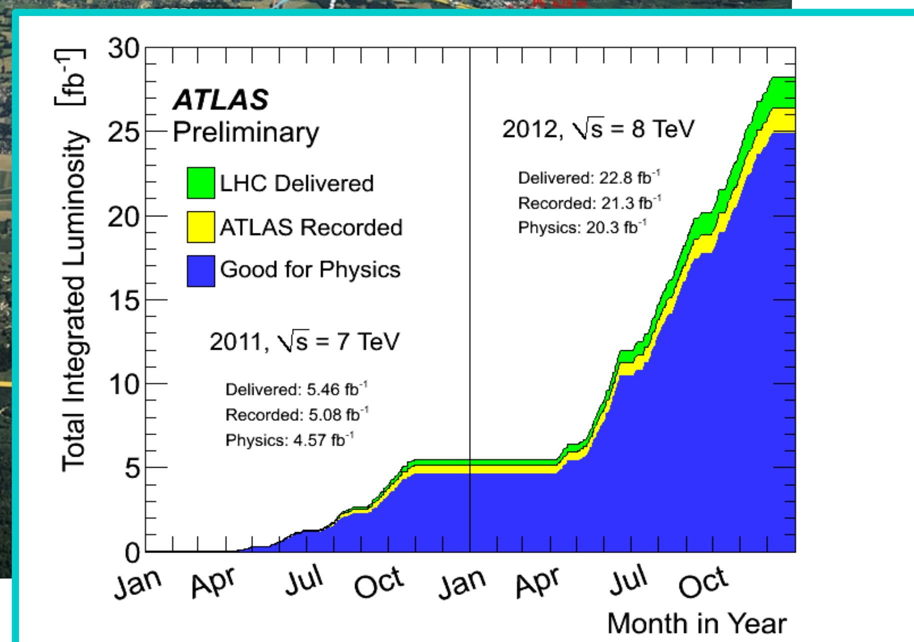
ATLAS AND CMS DETECTORS AT THE LHC







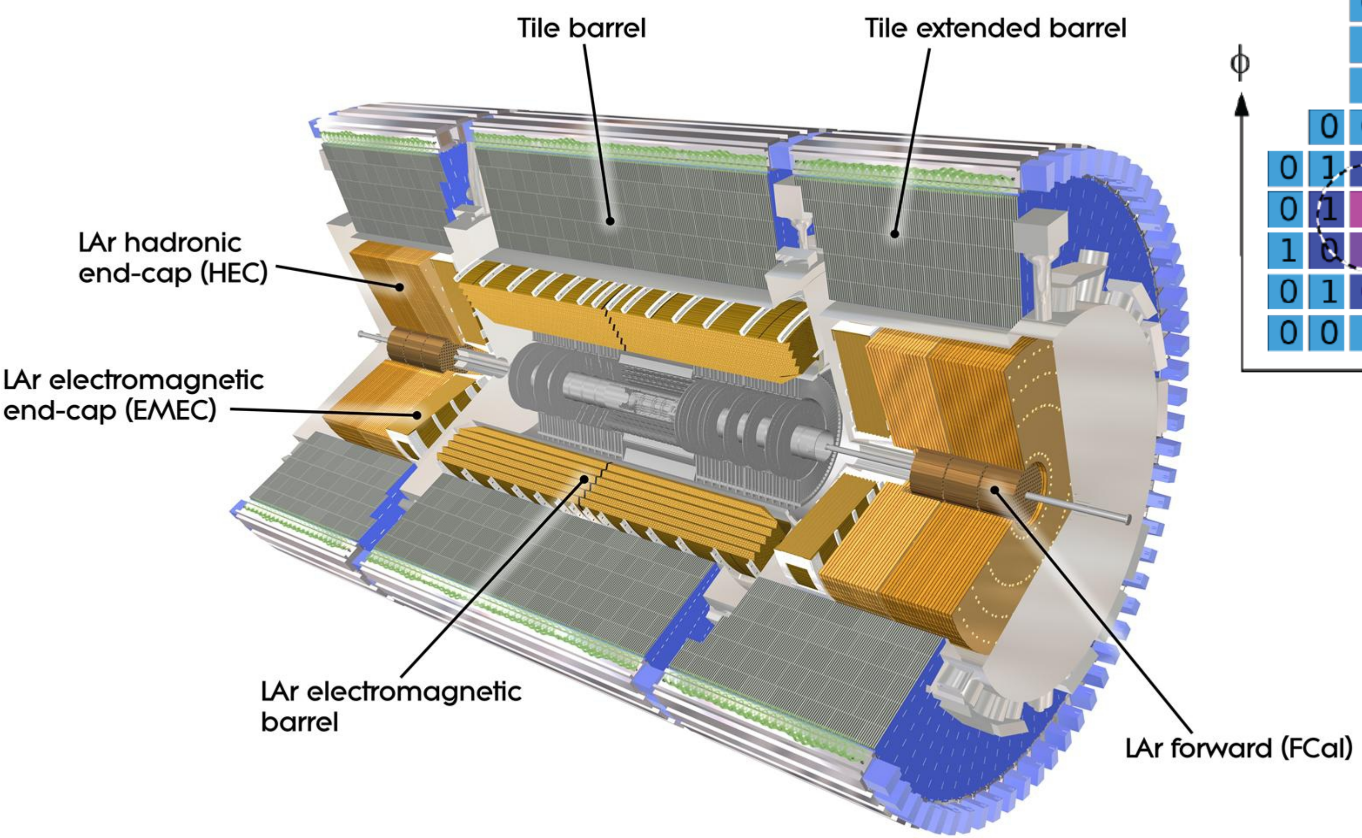
Z event with 25 reconstructed vertices

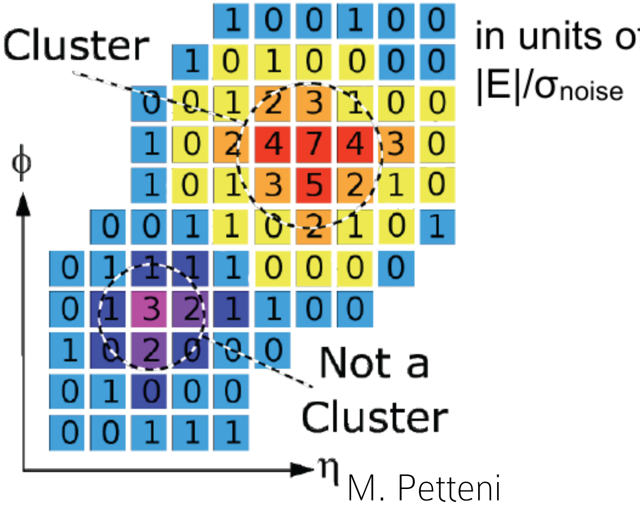


THE ATLAS CALORIMETERS

Subsystem **technology** and **granularity** follows **shower characteristics**

Energy deposits grouped in noise-suppressed **3D topological clusters**

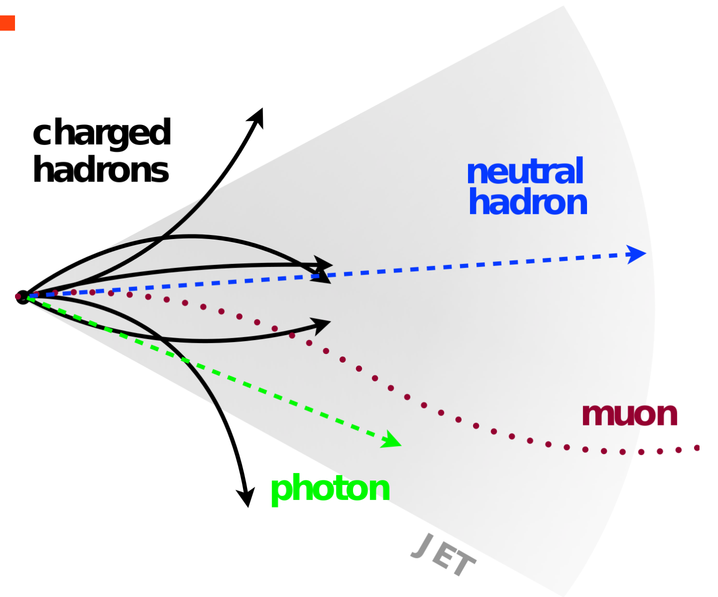




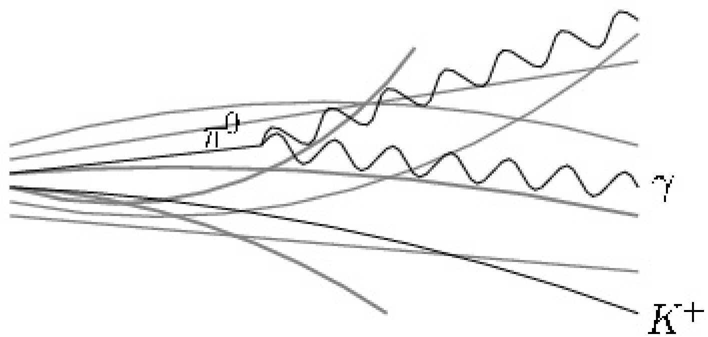
M. Petteni

JET FINDING IN ATLAS AND CMS

CMS: particle flow jets
using both tracking and calorimeter info

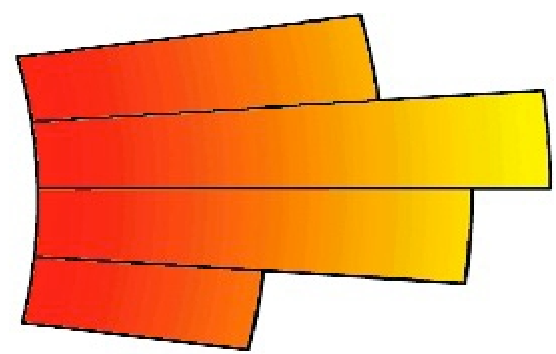


parton level jet



particle level jet

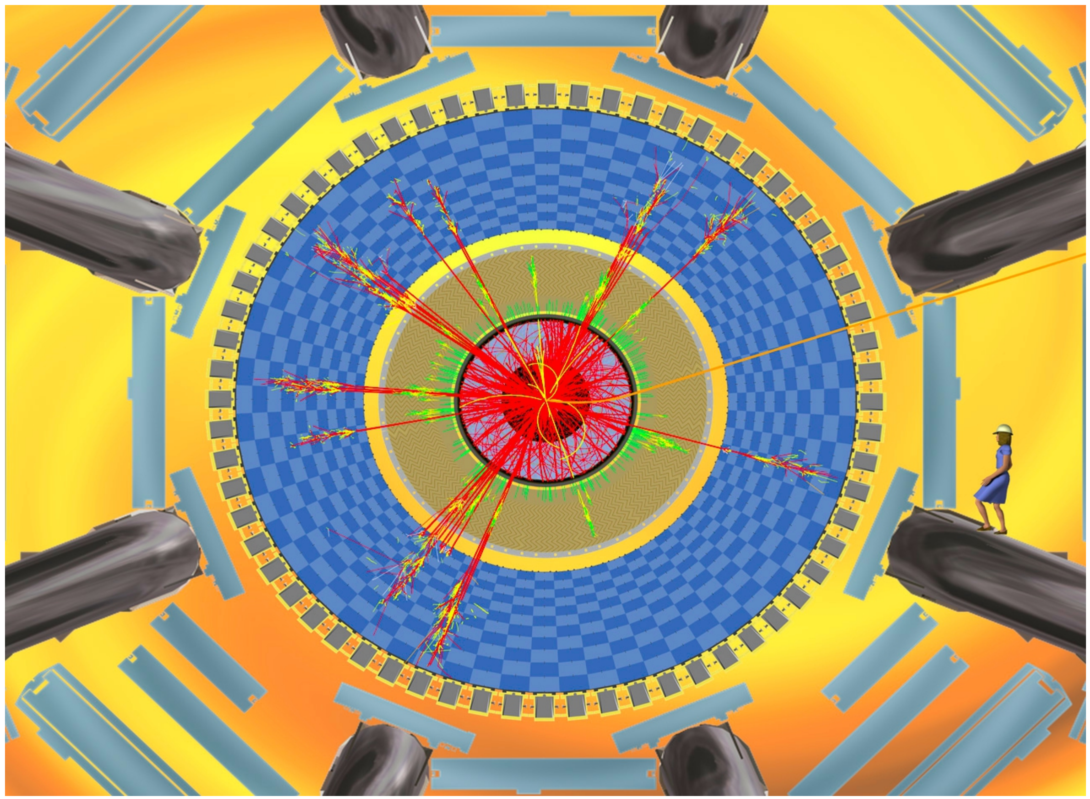
ATLAS: calorimeter jets
using topological clusters as input



calorimeter level jet

JET FINDING

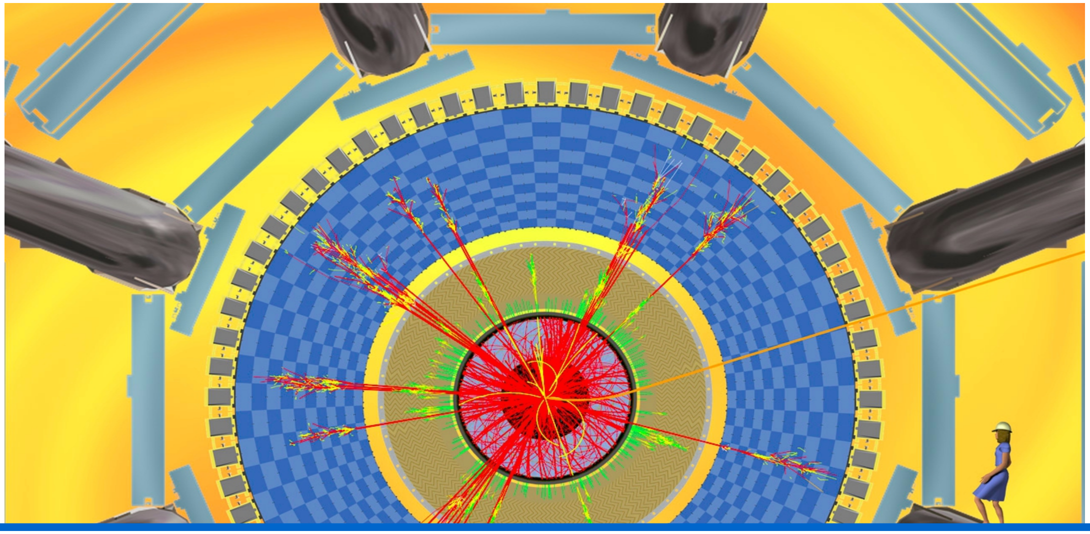
Basic algorithm: event display + physicist



everyone knows a jet
when they see it

JET FINDING

Basic algorithm: event display + physicist



Needed for communication of results:

- Specification of **algorithm** and **parameters**
- How to group input objects (**recombination scheme**)

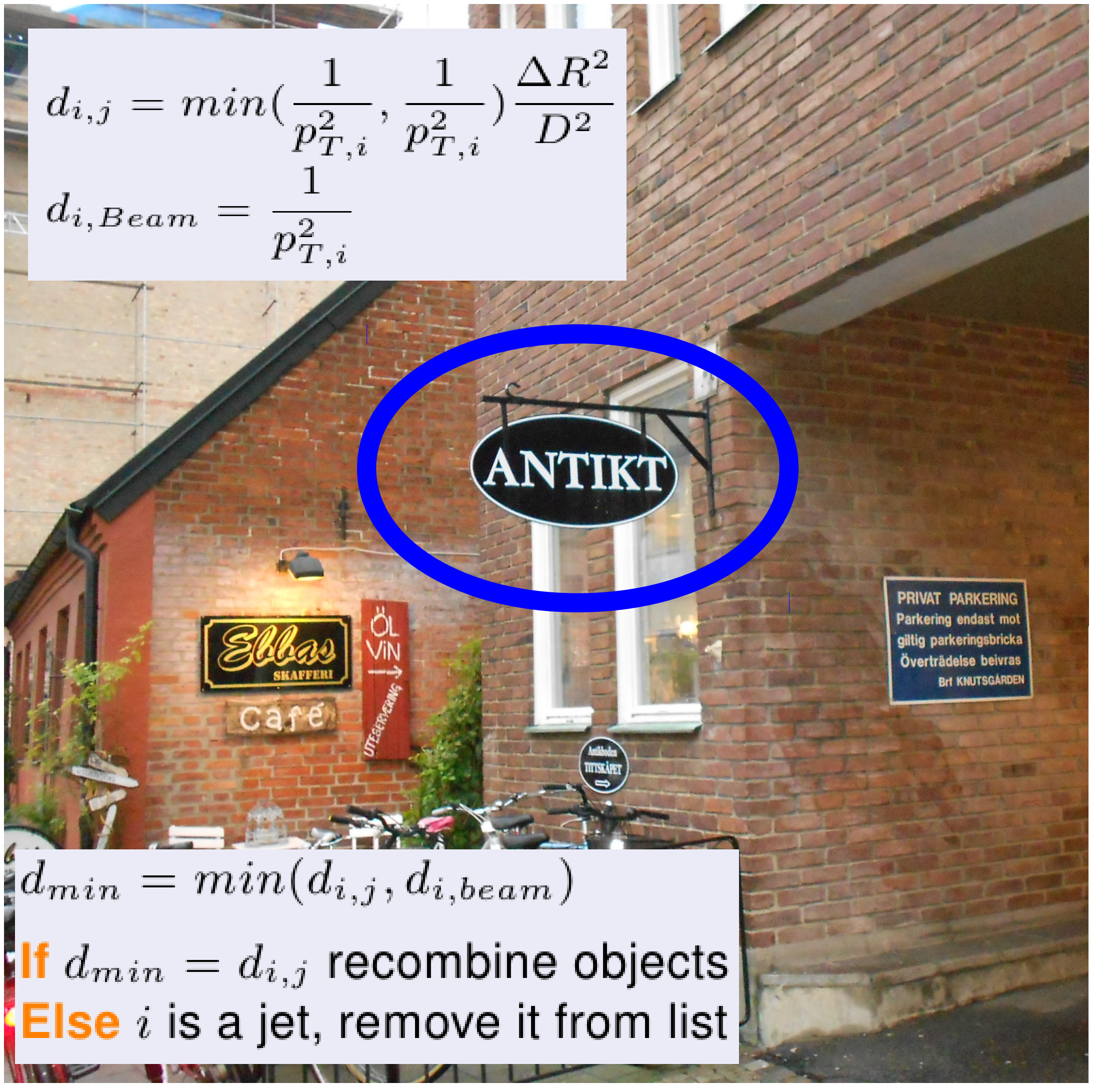
ATLAS: **Anti-k_t** algorithm as default (4-vector recombination)

Distance parameters: **R=0.4/0.6**

JET FINDING IN ATLAS (AND IN LUND)

$$d_{i,j} = min(\frac{1}{p_{T,i}^2}, \frac{1}{p_{T,i}^2})\frac{\Delta R^2}{D^2}$$

$$d_{i,Beam} = \frac{1}{p_{T,i}^2}$$

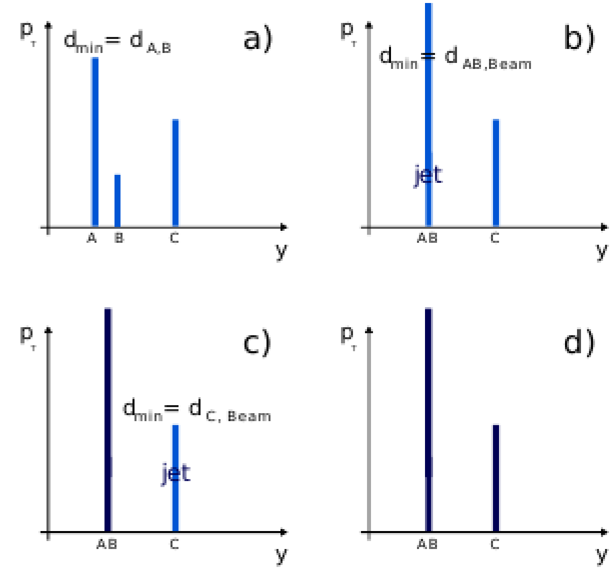


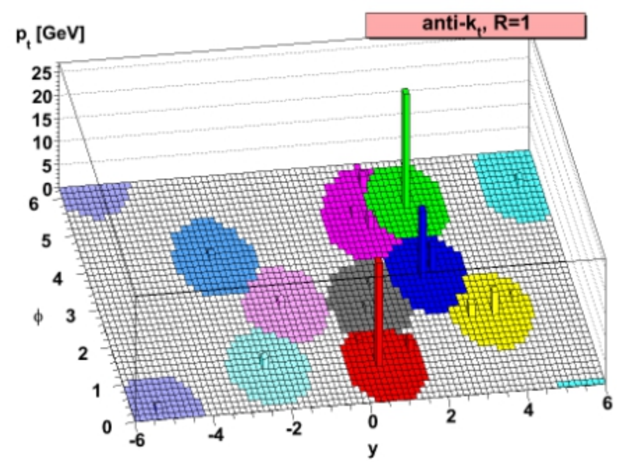
$$d_{min} = min(d_{i,j}, d_{i,beam})$$

If $d_{min} = d_{i,j}$ recombine objects

Else i is a jet, remove it from list

Idea:

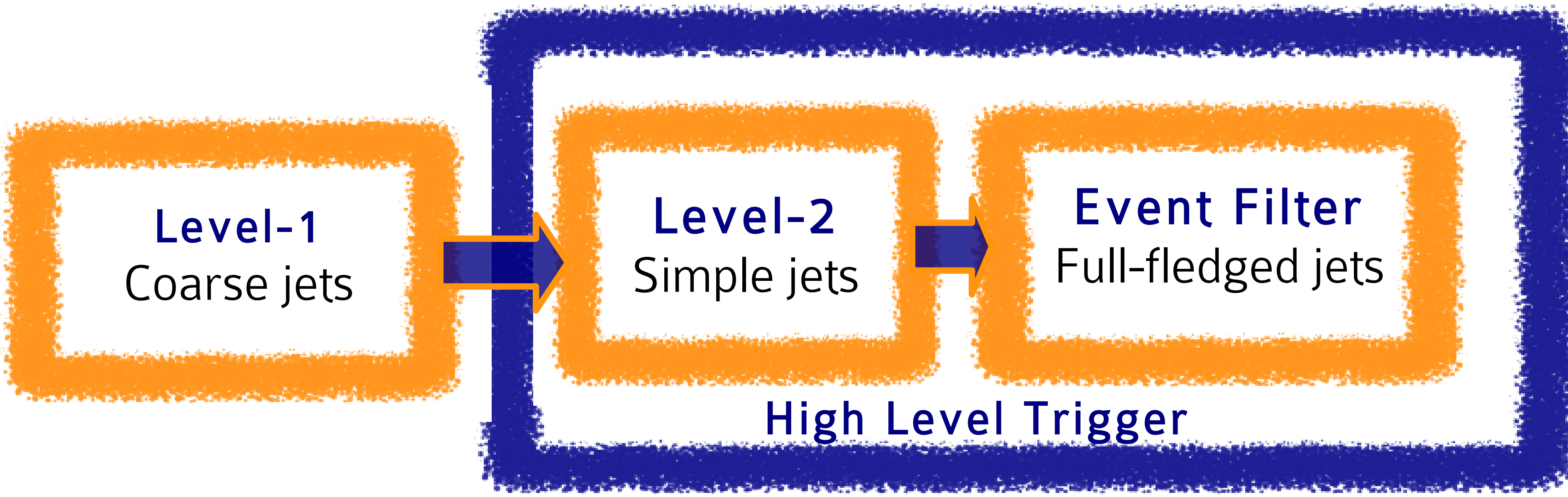




SELECTING JETS ONLINE: THE TRIGGER SYSTEM

ATLAS trigger system in 2012:

from **20 MHz** collisions to **400 Hz** recorded to disk
+ 200 Hz **delayed** stream, **recorded** but **reconstructed later**



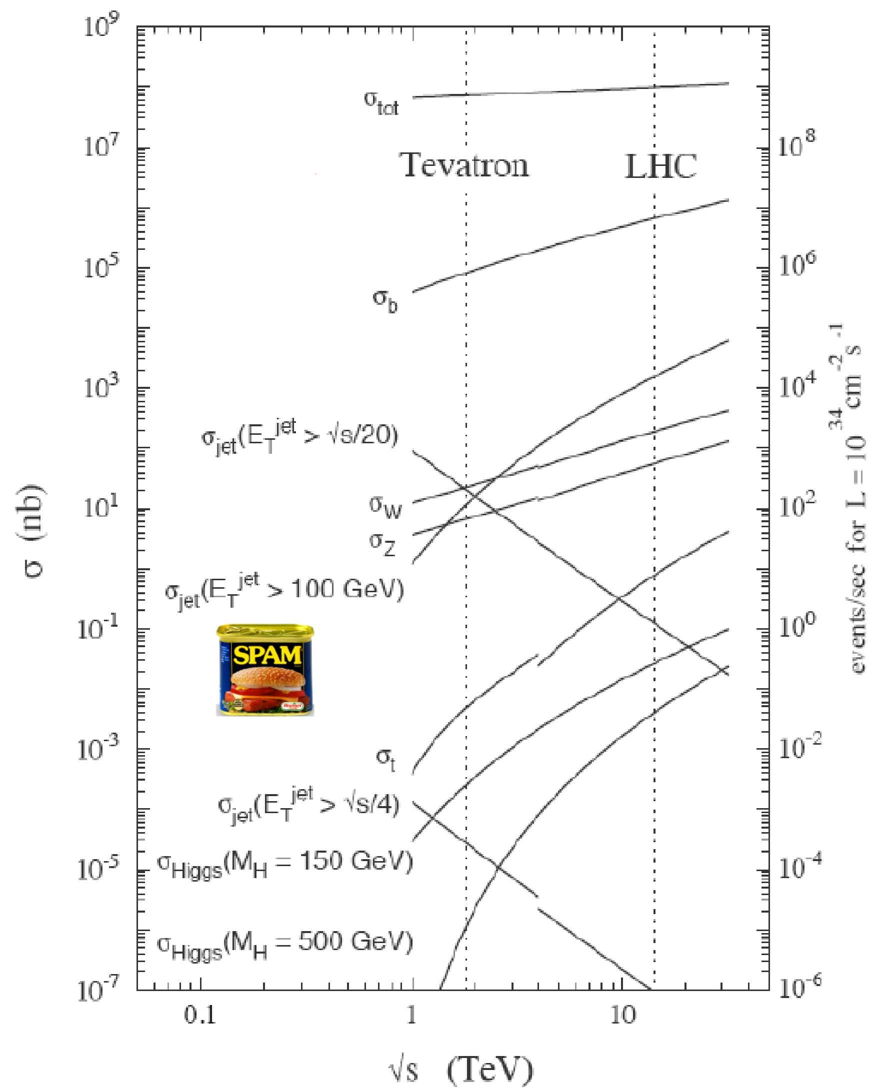
Very high QCD jet rates → use **prescales** to control total rate

SELECTING JETS ONLINE: THE TRIGGER SYSTEM

Very high QCD jet rates
→ use **prescales** to control total rate of jet events

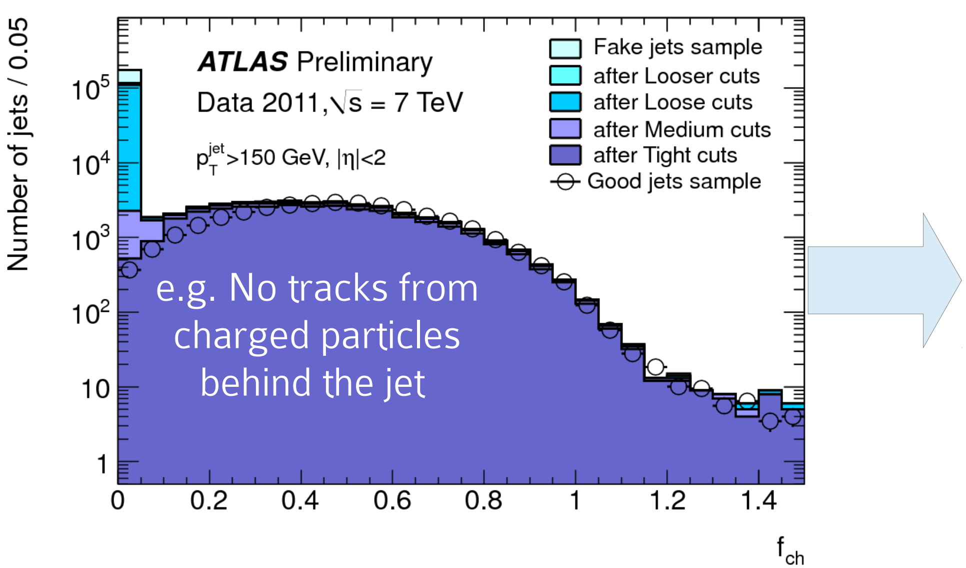
Only save a fraction of events above a given E_T threshold
(smaller fraction for lower thresholds)

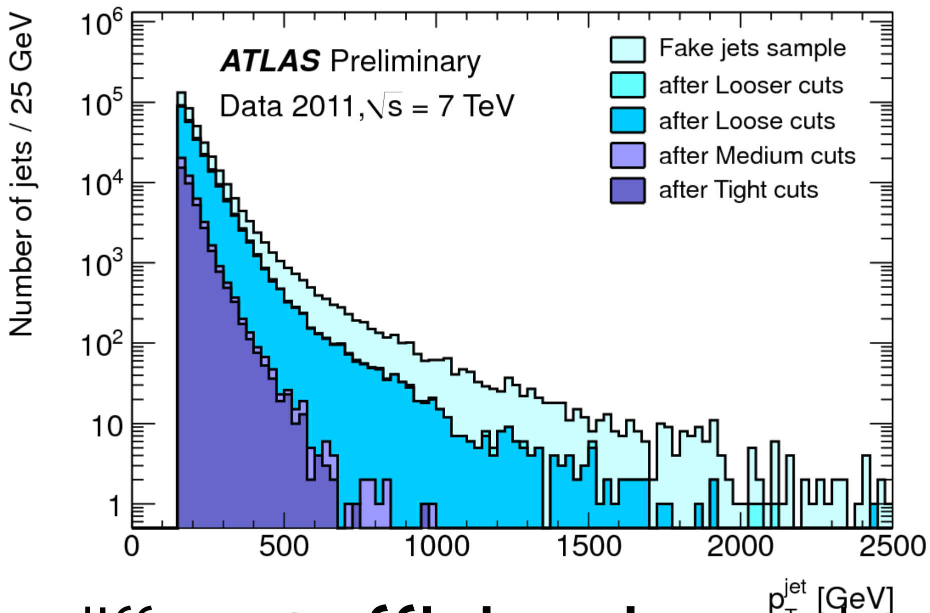
1/fraction = prescale weight
(statistical power suffers)



IDENTIFYING JETS

Energy deposits in calorimeters → jet
But: energy deposits in calorimeters != always real jets
→ experiments need criteria to **remove fake jets**



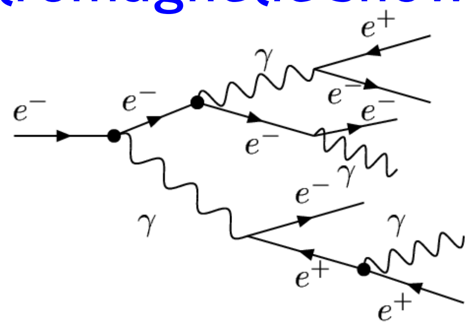


ATLAS: various cut definitions, different **efficiencies** and **purities** + rejection of **jets from pile-up**

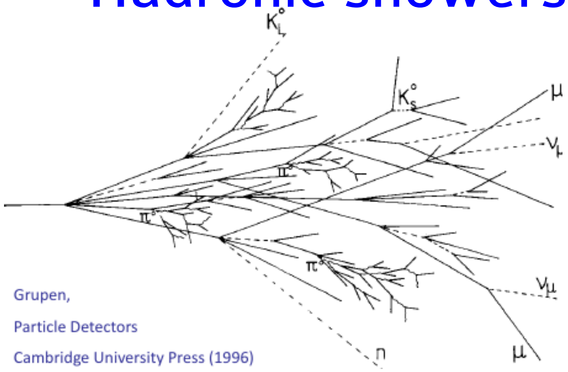
ATLAS JET CALIBRATION

Hadronic component of showers of particles in jets involves **invisible** particles/processes (to non-compensating calorimeters)

Electromagnetic showers

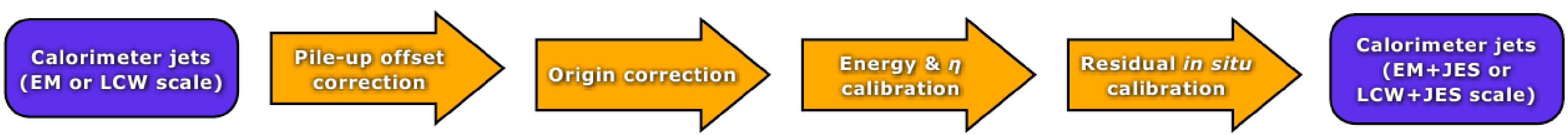


Hadronic showers



Grupen,
Particle Detectors
Cambridge University Press (1996)

→ calibration needed to restore jet energy scale



arXiv:1406.0076

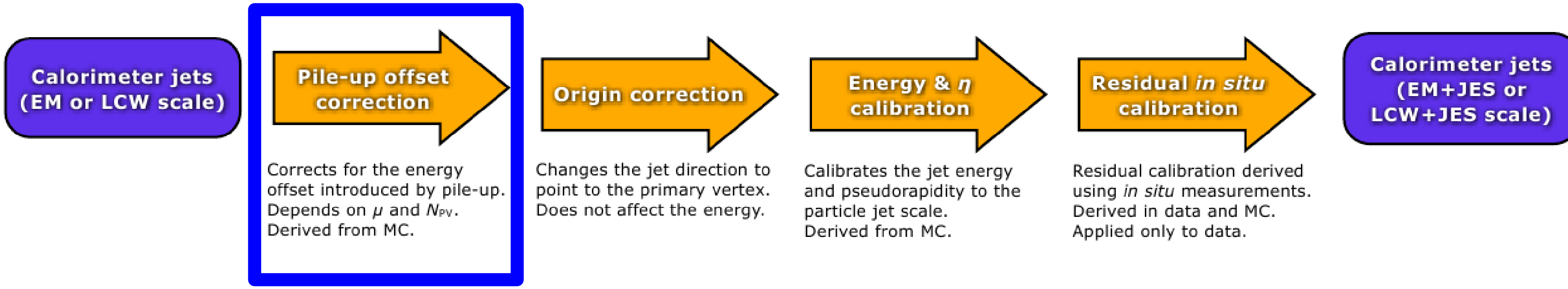
Corrects for the energy offset introduced by pile-up. Depends on μ and N_{PV}. Derived from MC.

Changes the jet direction to point to the primary vertex. Does not affect the energy.

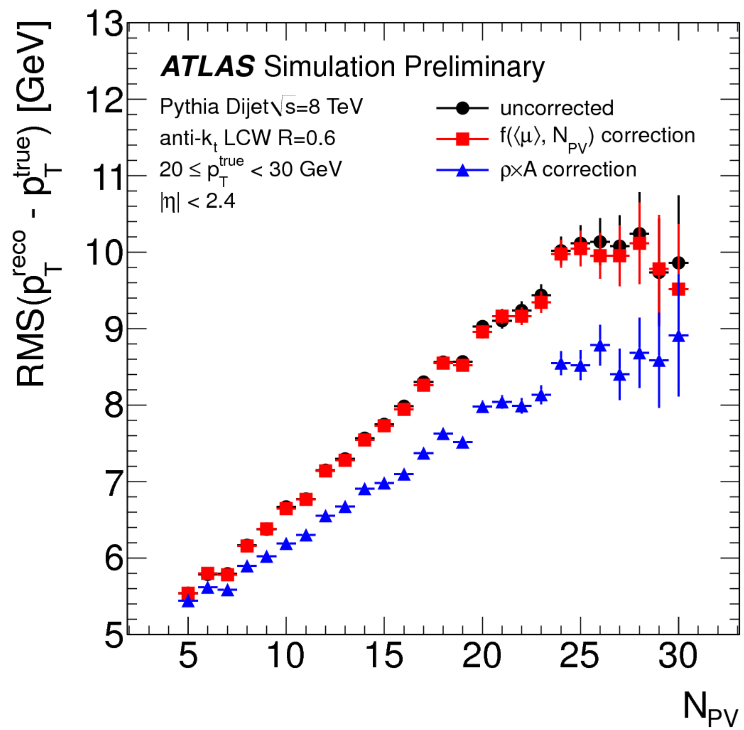
Calibrates the jet energy and pseudorapidity to the particle jet scale. Derived from MC.

Residual calibration derived using *in situ* measurements. Derived in data and MC. Applied only to data.

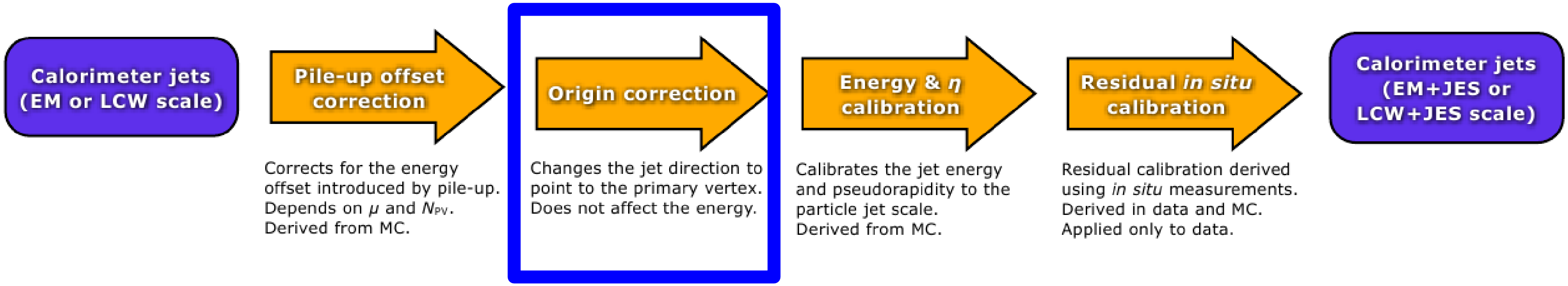
PILE-UP SUBTRACTION



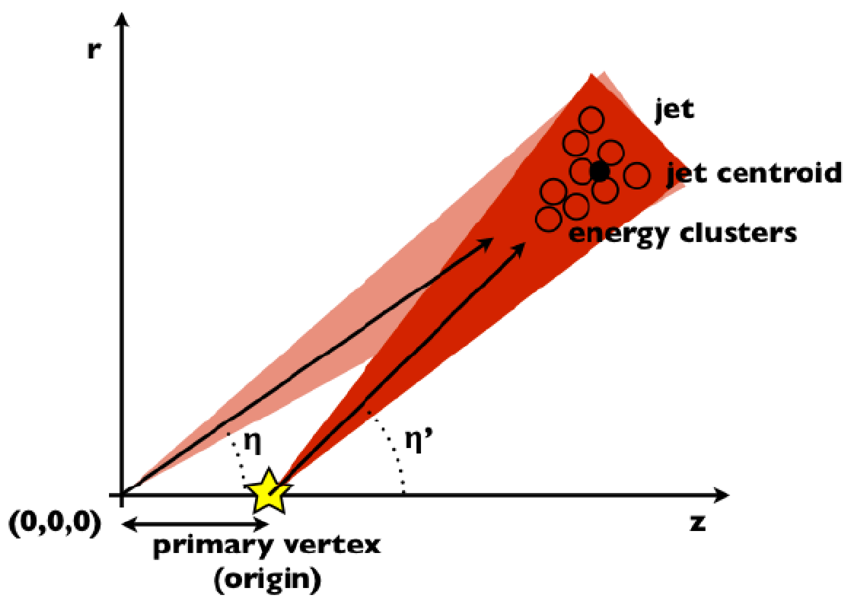
- **Pile-up:** effects of **additional interactions** within the same or neighboring bunch crossing
  → Need to **restore jet/MET energy scale and resolution**
  - Event-by-event calibrations for jets and MET (based on **jet areas/tracks**)
  - Identification of jets from pile-up: **J**et **V**ertex **F**raction



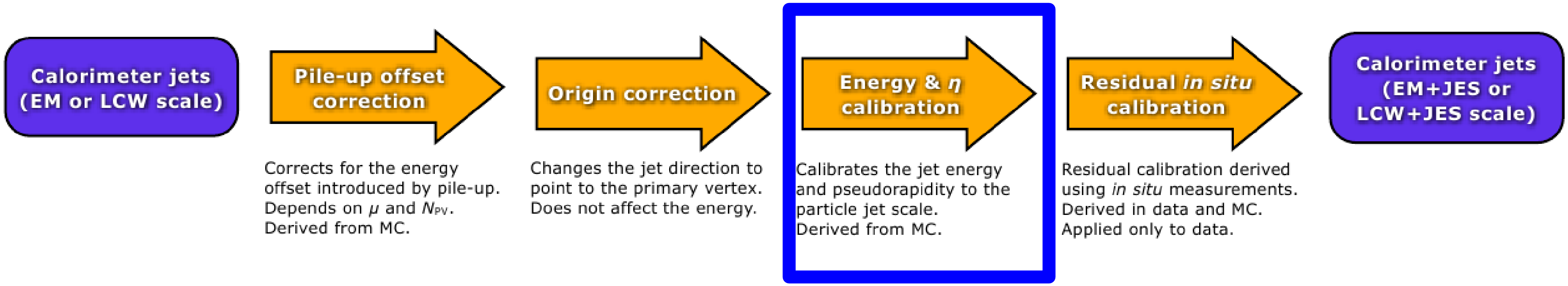
ORIGIN CORRECTION



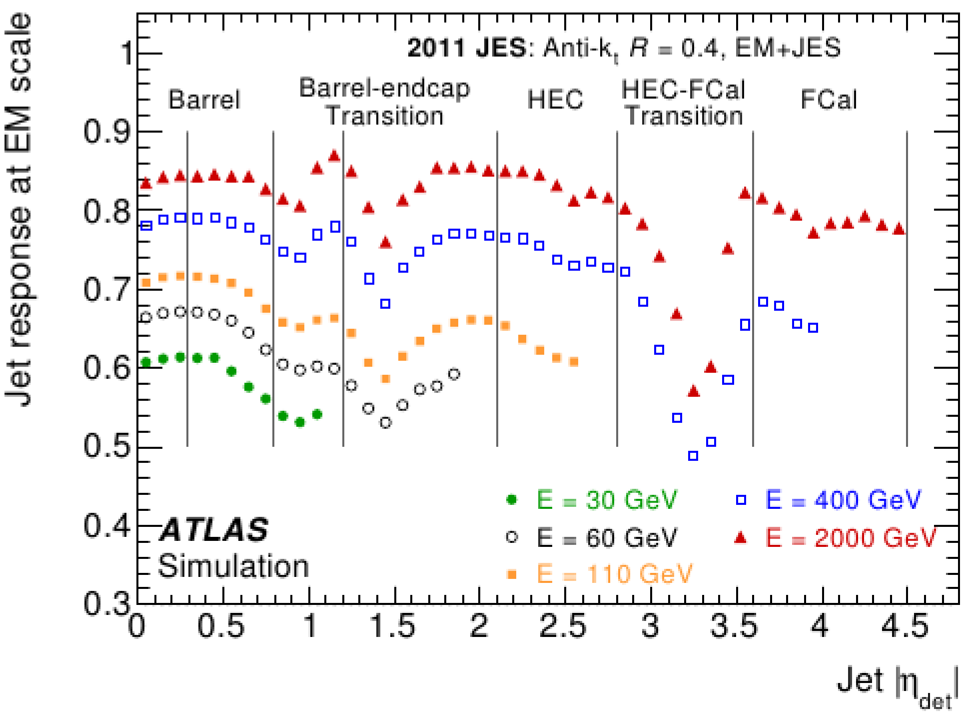
Point the jet to the **primary collision vertex**, rather than to the center of the detector

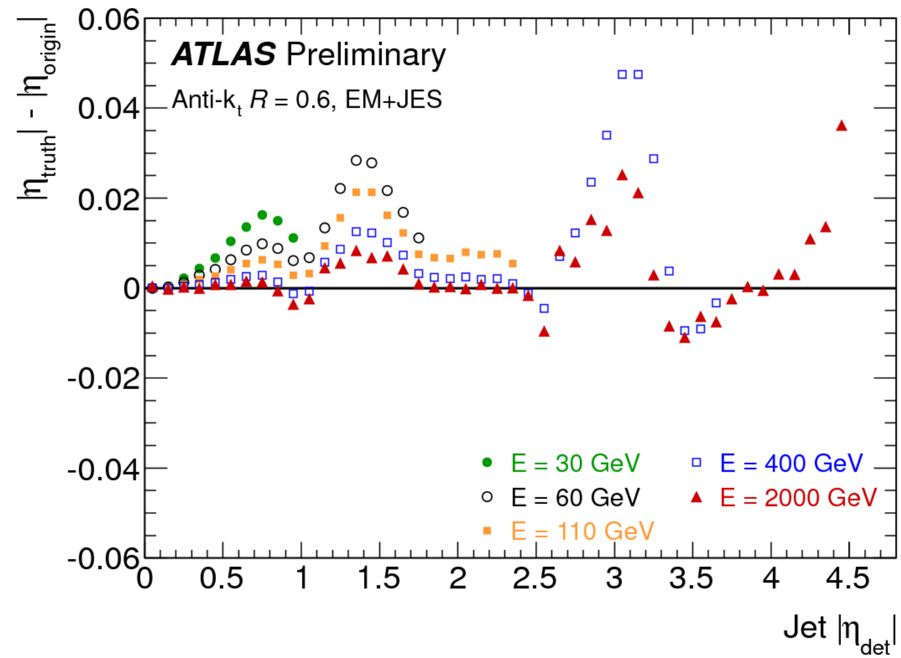


ENERGY AND ETA CALIBRATION



Compensate for energy losses in e.g. out-of-cone, dead material...





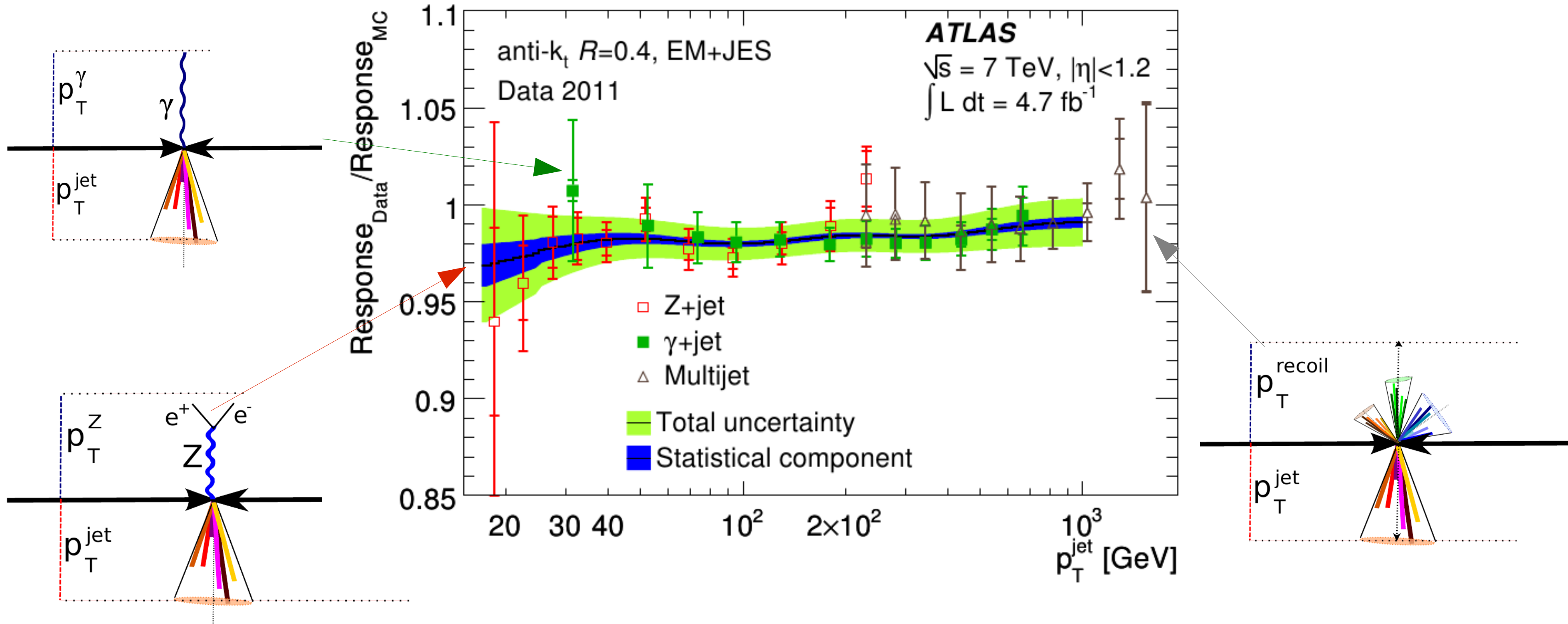
RESIDUAL IN-SITU CALIBRATION

Calorimeter jets (EM or LCW scale) → **Pile-up offset correction** → **Origin correction** → **Energy & η calibration** → **Residual *in situ* calibration** → **Calorimeter jets (EM+JES or LCW+JES scale)**

- **Pile-up offset correction:** Corrects for the energy offset introduced by pile-up. Depends on μ and N_{PV}. Derived from MC.
- **Origin correction:** Changes the jet direction to point to the primary vertex. Does not affect the energy.
- **Energy & η calibration:** Calibrates the jet energy and pseudorapidity to the particle jet scale. Derived from MC.
- **Residual *in situ* calibration:** Residual calibration derived using *in situ* measurements. Derived in data and MC. Applied only to data.

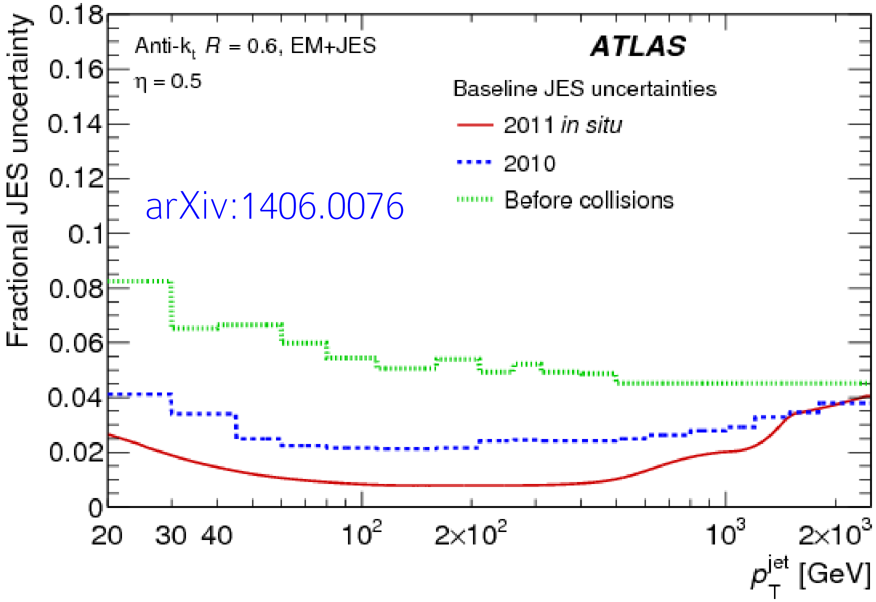
Use **well-measured objects** to **check the scale** of the **calibrated jets**

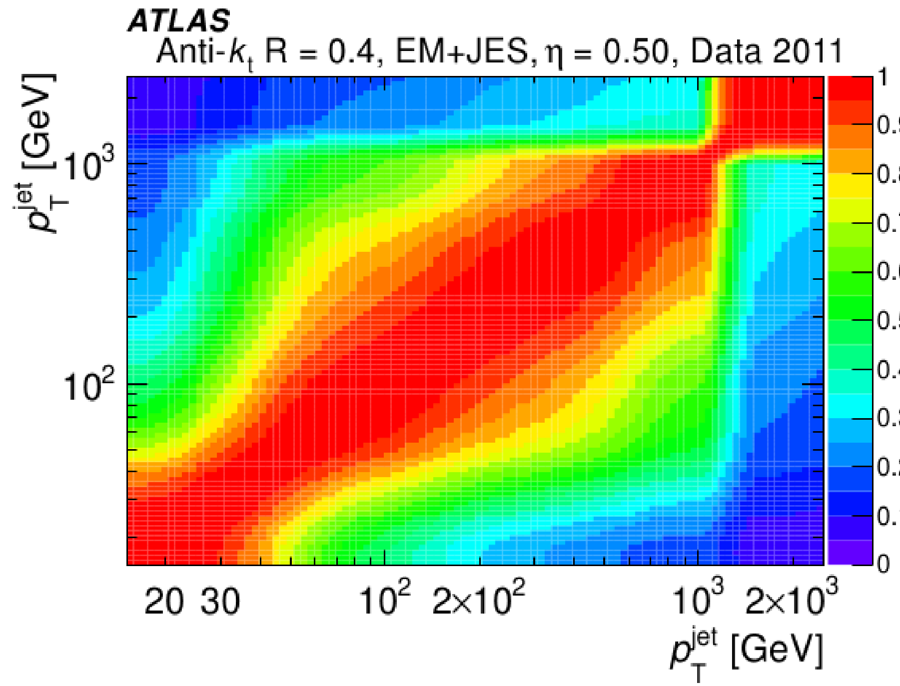
Compare balance in data and MC → combine, correct for differences



JET ENERGY SCALE UNCERTAINTY

Milestone of **1% baseline JES uncertainty** reached by ATLAS and CMS **after 1 year of data**





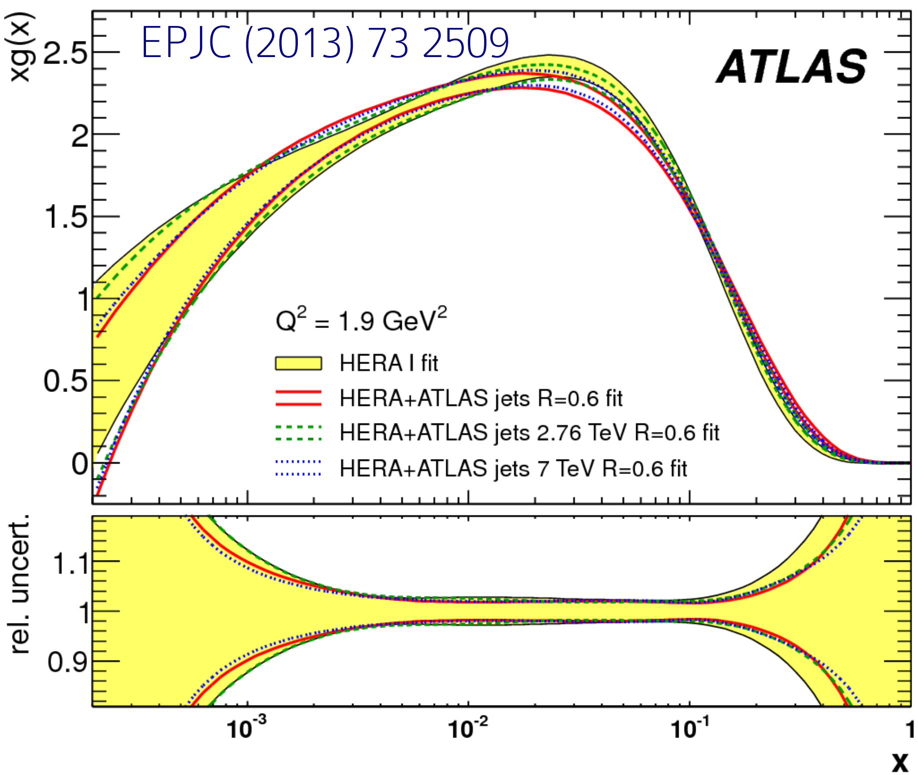
Full set of **bin-by-bin correlations** available
(also: R=0.4/0.6, 2010 vs 2011 datasets…)

Correlations with CMS available ATL-PHYS-PUB-2014-020

JES UNCERTAINTY FOR PRECISION PHYSICS

Knowledge of JES uncertainty correlations crucial for:

Fits of Parton Distribution Functions



C. Doglioni, Springer Theses

LHC/Tevatron NOTE

ATLAS-CONF-2014-008
CDF Note 11071
CMS PAS TOP-13-014
D0 Note 6416

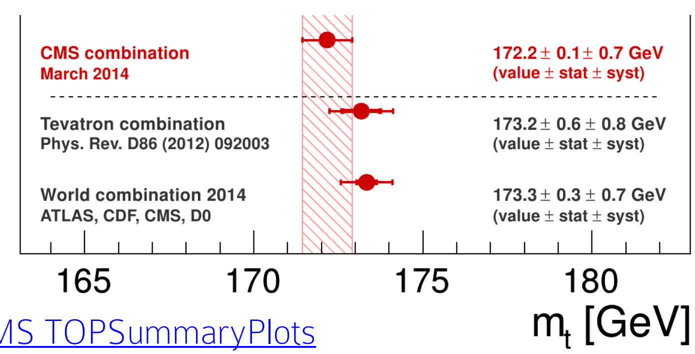
March 17, 2014

Combinations of top measurements

http://arxiv.org/abs/1403.4427

First combination of Tevatron and LHC measurements of the top-quark mass

M_{top} = 173.3±0.3(stat)±0.7(syst) GeV



CMS TOPSummaryPlots

M_{top} = 172.2±0.1(stat)±0.7(syst) GeV

http://arxiv.org/abs/1405.1756

FERMILAB-PUB-14-123-E

Precision measurement of the top-quark mass in lepton+jets final states

M_{top} = 175.0±0.6(stat)±0.5(syst) GeV

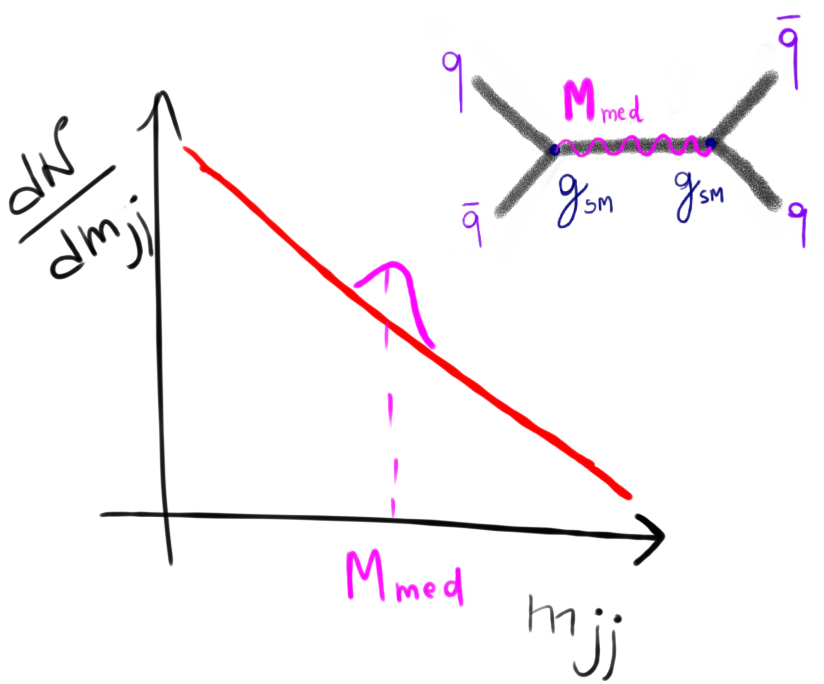
JETS IN NEW PHYSICS SEARCHES

SEARCHES WITH JETS

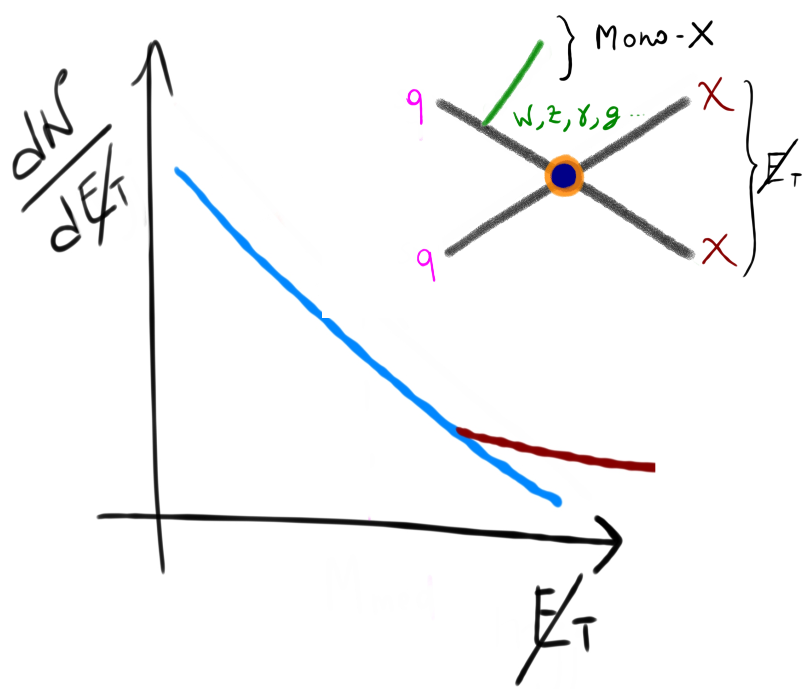
Once we have jets and uncertainties under control: **search!**

Many ATLAS searches with jets have been published, shown here: generic, **model-independent searches**

DIJET RESONANCE SEARCH



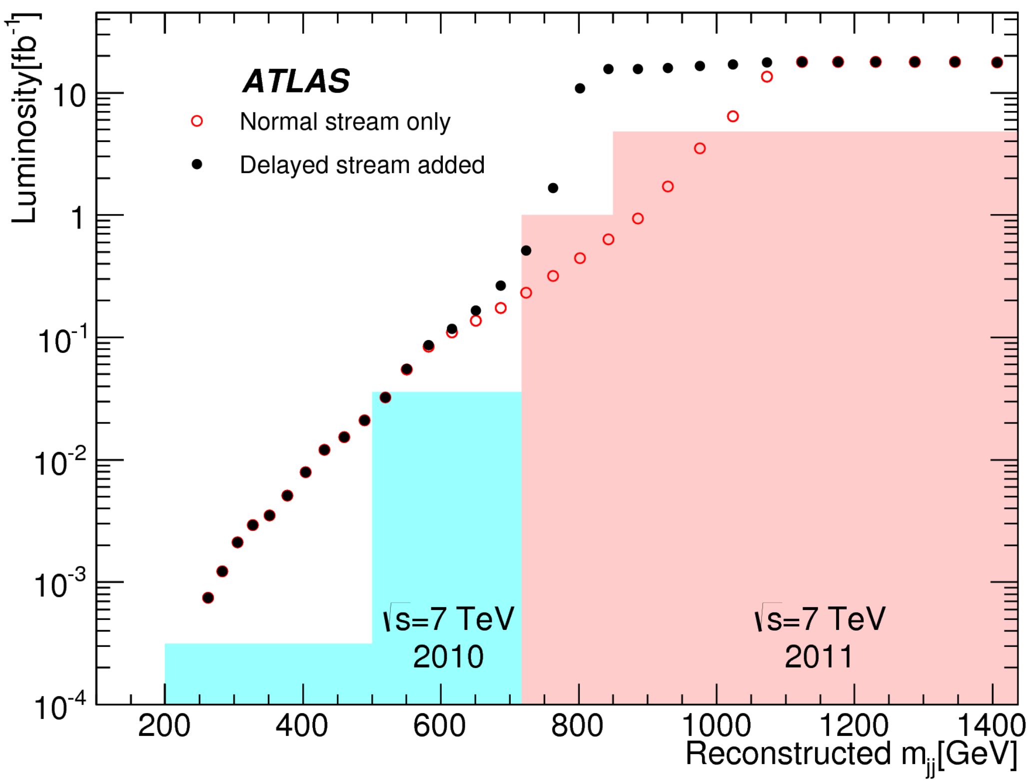
MONO-X SEARCHES



DIJET RESONANCE SEARCH: 8 TEV RESULTS arxiv: 1407.1376

Observable: central, back-to-back **dijet mass spectrum**

Use delayed stream data to increase low-mass statistics



DIJET RESONANCE SEARCH: 8 TEV RESULTS arxiv: 1407.1376

Observable: central, back-to-back **dijet mass spectrum**

Data-driven background estimation:
fit to empirical function motivated by LO QCD,
unable to accommodate local bumps

$$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x}$$

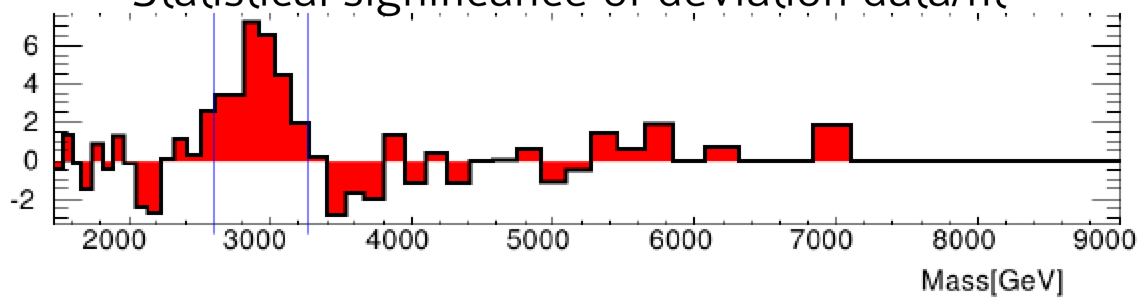
DIJET RESONANCE SEARCH: 8 TEV RESULTS arxiv: 1407.1376

Observable: central, back-to-back **dijet mass spectrum**

Data-driven background estimation

Search phase: is there a local excess?

Statistical significance of deviation data/fit



DIJET RESONANCE SEARCH: 8 TEV RESULTS

arxiv: 1407.1376

Observable: central, back-to-back **dijet mass spectrum**

Data-driven background estimation

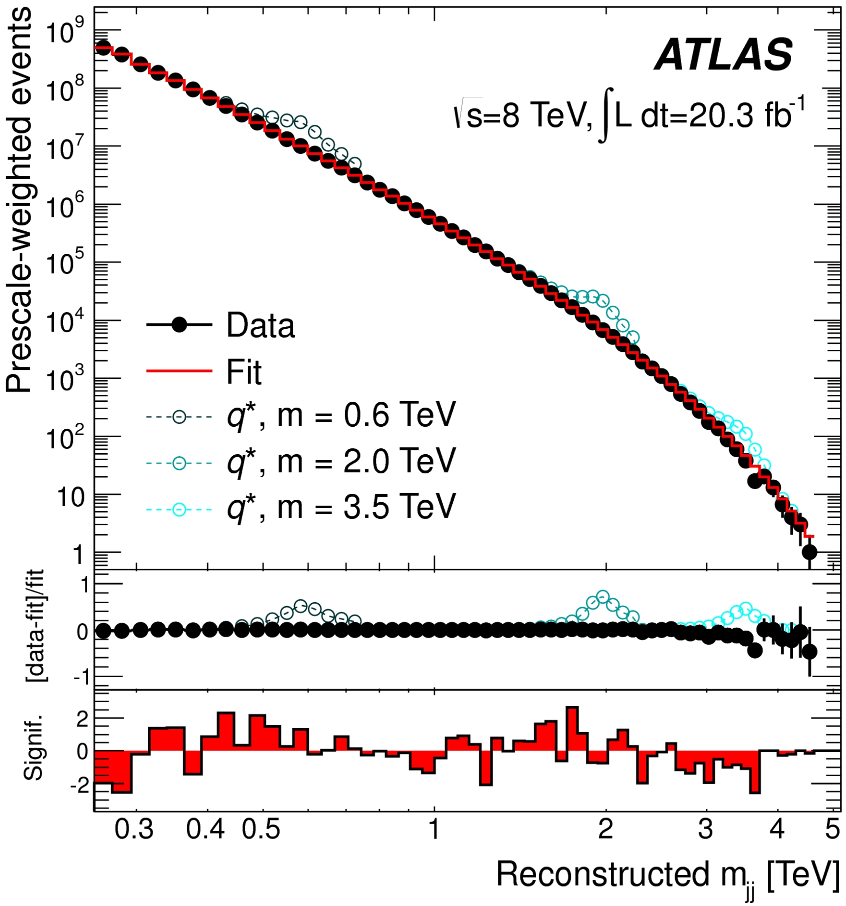
Search phase: is there a local excess?

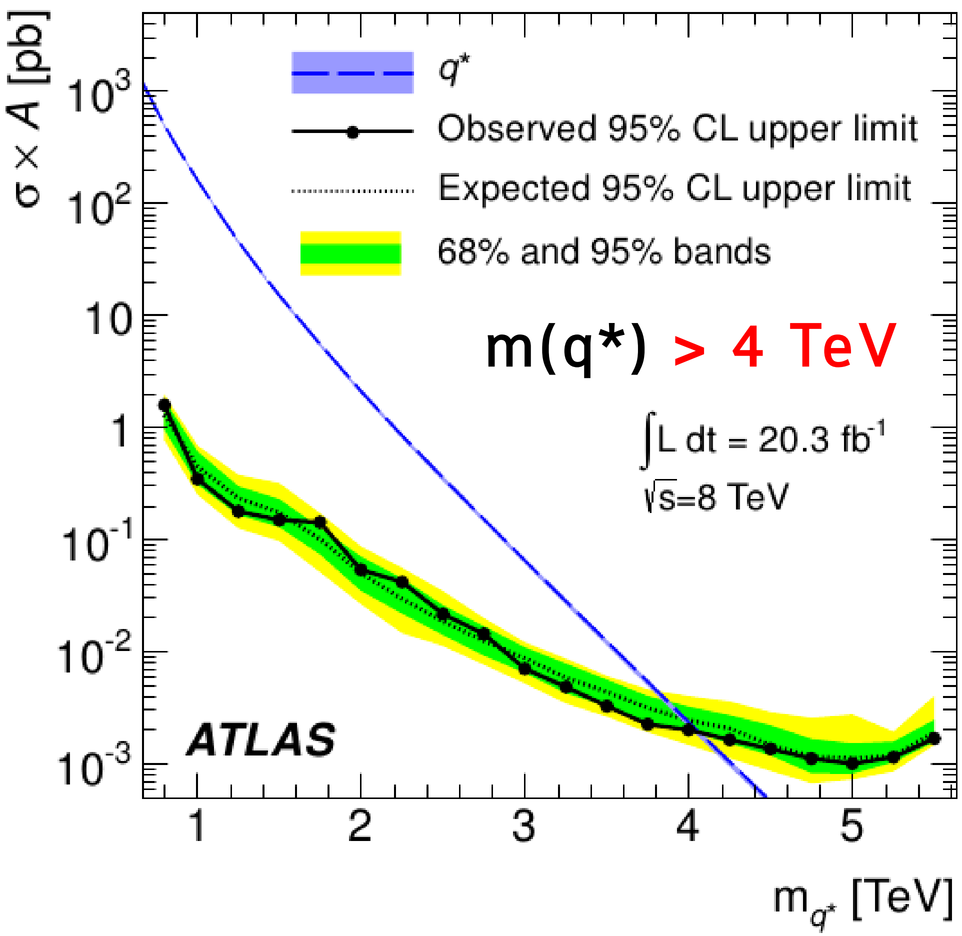
If not, set **limits on various resonances**

Systematic uncertainties:
fit function, JES uncertainty, luminosity

Model and Final State	95% CL Limits [TeV] Expected	Observed
$q^* \to qg$	3.99	4.09
$s8 \to gg$	2.83	2.72
$W' \to q\bar{q}'$	2.51	2.45
Leptophobic $W^* \to q\bar{q}'$	1.93	1.75
Leptophilic $W^* \to q\bar{q}'$	1.67	1.66
QBH black holes (q and g decays only)	5.82	5.82
BLACKMAX black holes (all decays)	5.75	5.75

DIJET RESONANCE SEARCH: 8 TEV RESULTS arxiv: 1407.1376

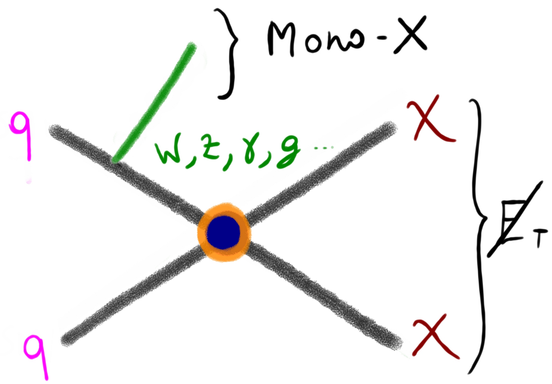




No discoveries yet → **limits** on many new resonant physics models

Reinterpretable results on **generic resonances**

SEARCHES FOR DARK MATTER IN ATLAS



- Monojet (jets+MET)
- Monophoton (photon+MET)
- Mono-W/Z (vector boson + MET)
  - W/Z, Hadronic decays
  - W: Leptonic decays
  - Z: Leptonic decays:
- Heavy flavor quarks + MET

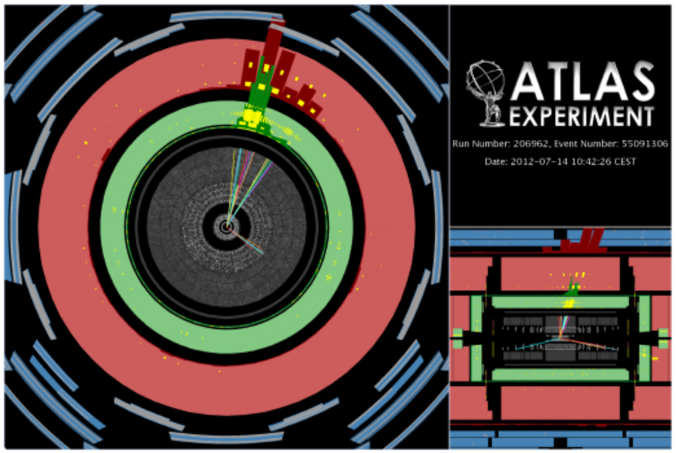
No discoveries yet

- **limits** set on **dark matter candidates**
- Work with **theorists** on **models** and **interpretations**
- Initiate **discussions** with **astroparticle community** → establish common ground for **complementarity**

THE ATLAS MONOJET SEARCH

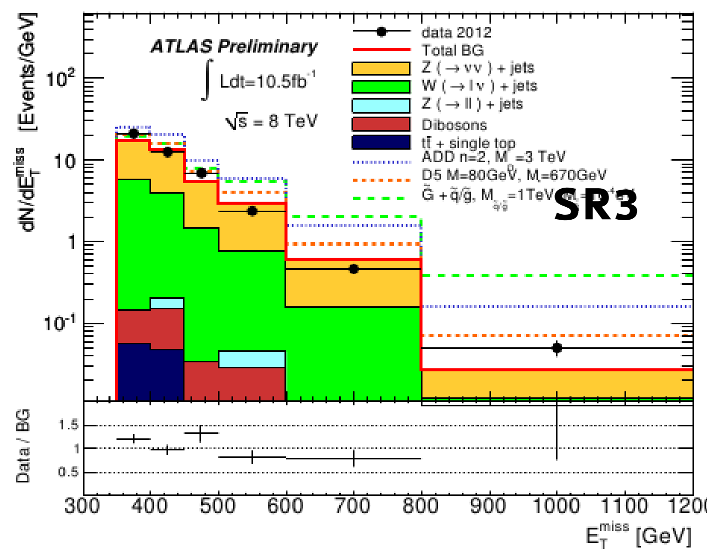
ATLAS-CONF-2012-147
arXiv: 1210.4491

Mono-jet: look for excess of events with high pT jet(s), high missing transverse momentum



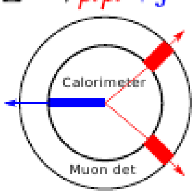
Dominant systematics:
JES uncertainty
Theory uncertainties
MC statistics (8 TeV, 10 inv fb)

Signal regions:
Cut and count analysis,
varying jet pT and MET thresholds
(e.g. SR4: pT > 350 GeV, MET > 350 GeV)

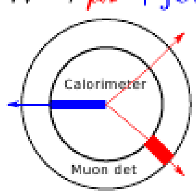


Background estimation (main: Zvv+jets):
use transfer factors from W/Z data control regions

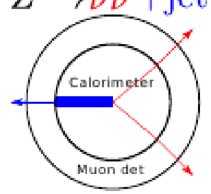
$Z \rightarrow \mu\mu + \text{jet}$



$W \rightarrow \mu\nu + \text{jet}$



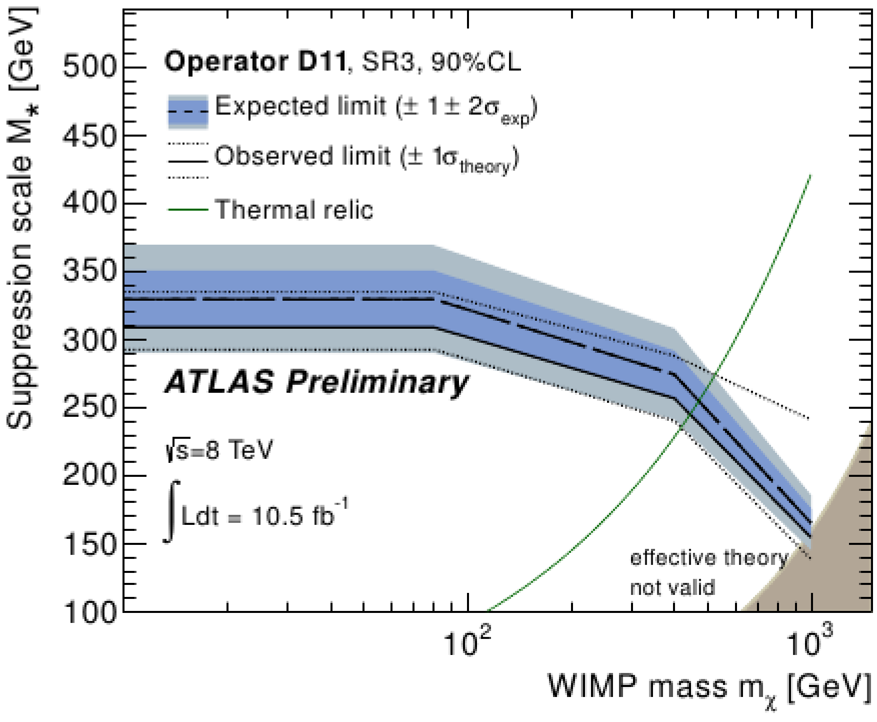
$Z \rightarrow \nu\nu + \text{jet}$



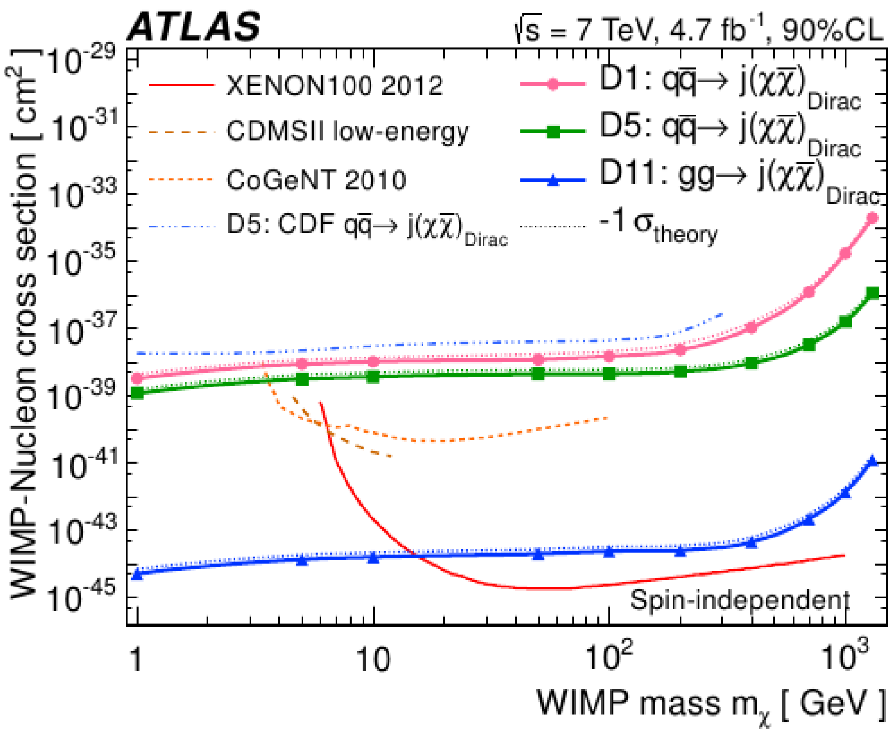
THE ATLAS MONOJET SEARCH

ATLAS-CONF-2012-147
arXiv: 1210.4491

No excesses → set limits on new physics models
Model-independent and interpretations: ADD, gravitino, WIMP (EFT)



Limit on suppression scale of EFT M*

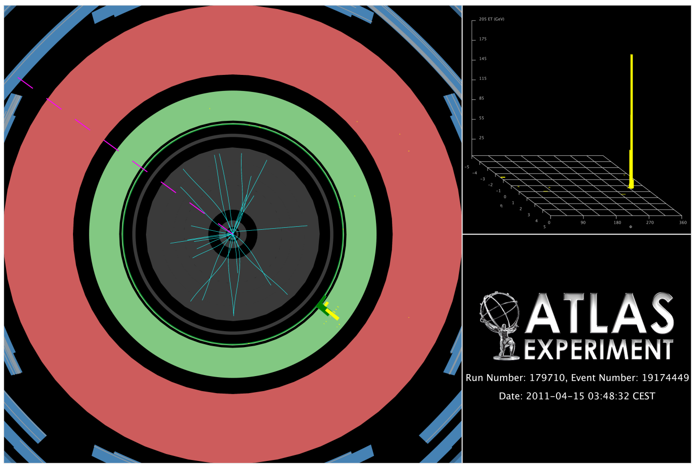


Comparison to DD experiments assuming EFT framework (from 7 TeV)

$$\sigma_0^{D11} = 3.83 \times 10^{-41}\ \mathrm{cm}^2 \left(\frac{\mu_\chi}{1\ \mathrm{GeV}}\right)^2 \left(\frac{100\ \mathrm{GeV}}{M_*}\right)^6$$

THE MONOPHOTON SEARCH ATLAS-CONF-2014-051

Mono-photon: look for excess of events with high pT photon, high missing transverse momentum

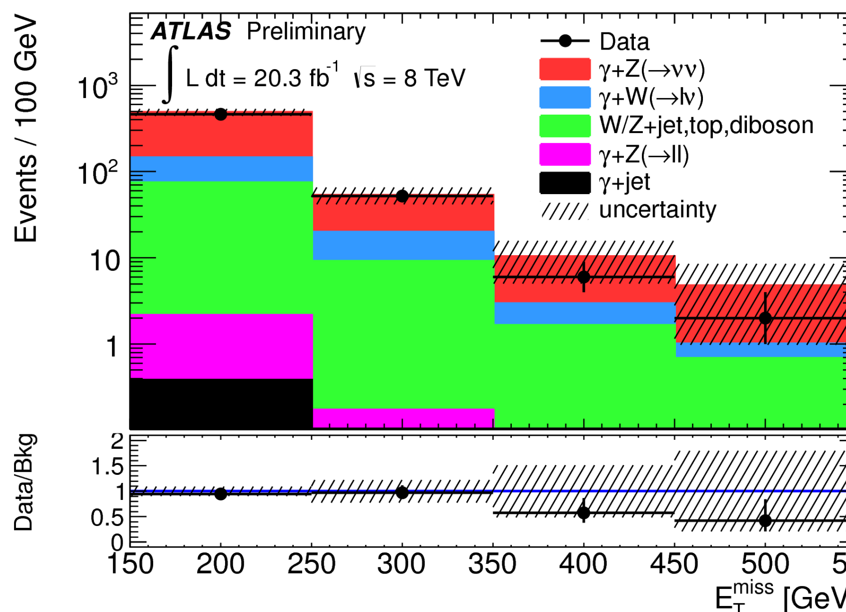


Background estimation (main: Zνν+γ):
combined fit with control regions estimates
Data-driven fake photon estimation
Validation region (VR)

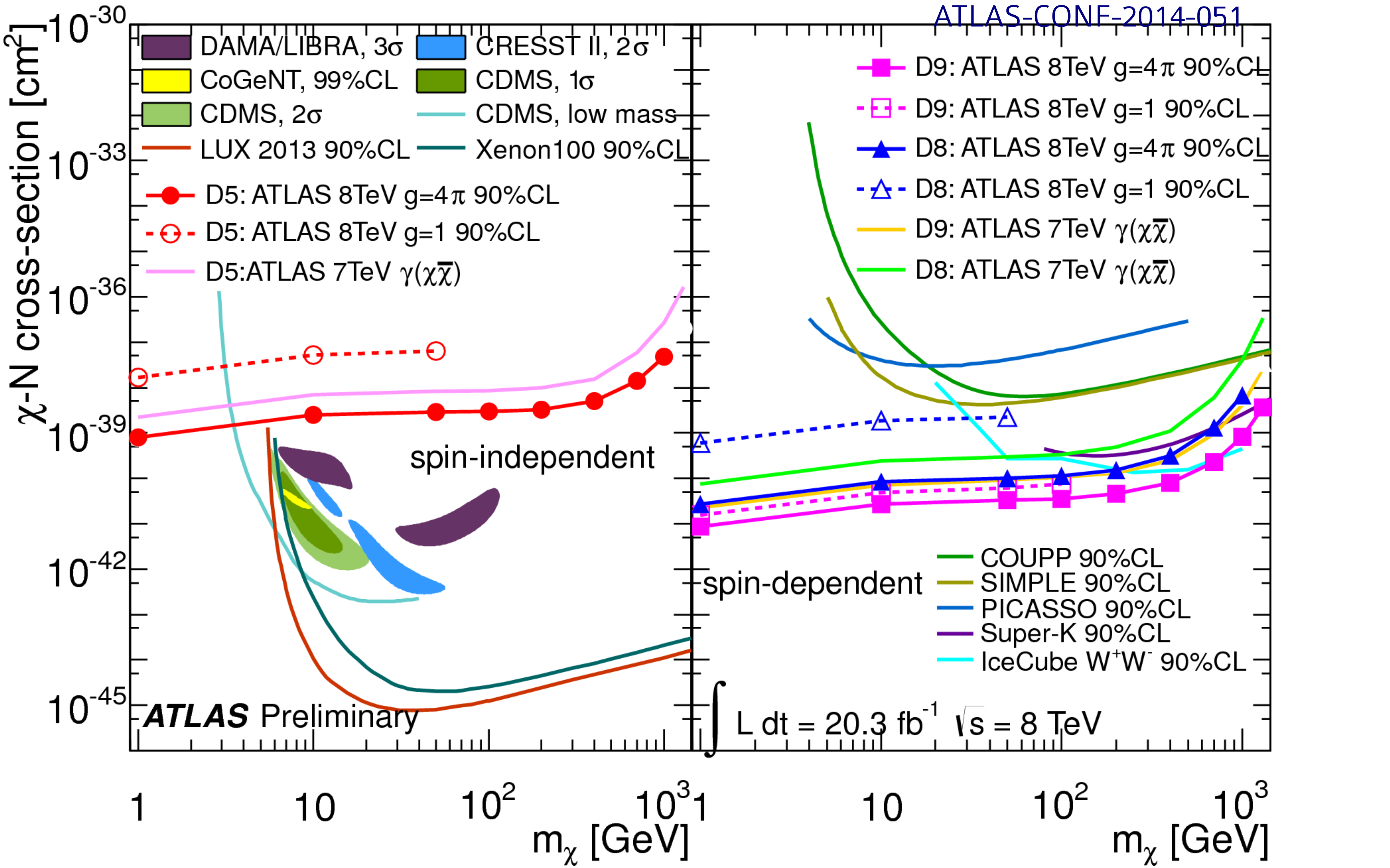
Dominant systematics:
Fake rates, MC modelling
(large SR statistical uncertainties)

Signal region (SR):
Cut and count analysis,
pT(γ) > 150 GeV, MET > 150 GeV)

Process	Event yield (SR)	Event yield (VR)
$Z(\to \nu\nu) + \gamma$	$389 \pm 36 \pm 10$	$153 \pm 16 \pm 10$
$W(\to \ell\nu) + \gamma$	$82.5 \pm 5.3 \pm 3.4$	$67 \pm 5 \pm 5$
W/Z + jet, $t\bar{t}$, diboson	$83 \pm 2 \pm 28$	$47 \pm 2 \pm 14$
$Z(\to \ell\ell) + \gamma$	$2.0 \pm 0.2 \pm 0.6$	$2.9 \pm 0.3 \pm 0.6$
γ + jet	$0.4^{+0.3}_{-0.4}$	$2.5^{+4.0}_{-2.5}$
Total background	$557 \pm 36 \pm 27$	$272 \pm 17 \pm 14$
Data	521	307



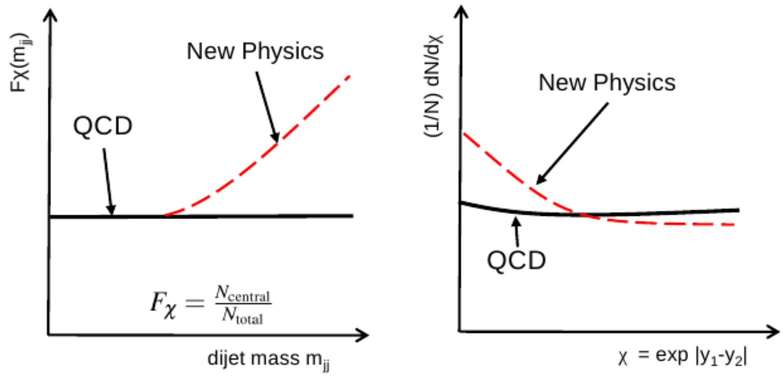
THE MONOPHOTON SEARCH



More interpretations: Extra Dimensions, SUSY, WIMP simplified model

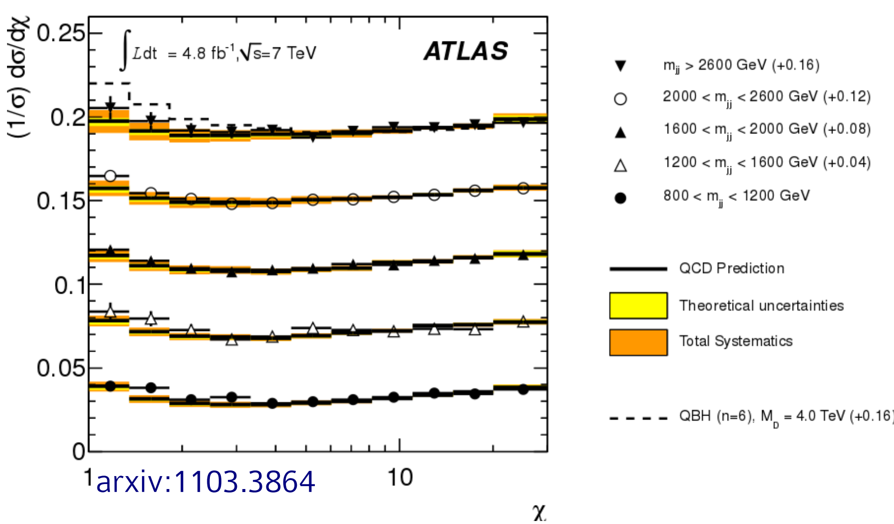
NOT JUST MONO-X: EFT WIMPS WITH DIJETS
(SEARCHES IN DIJET ANGULAR DISTRIBUTIONS)

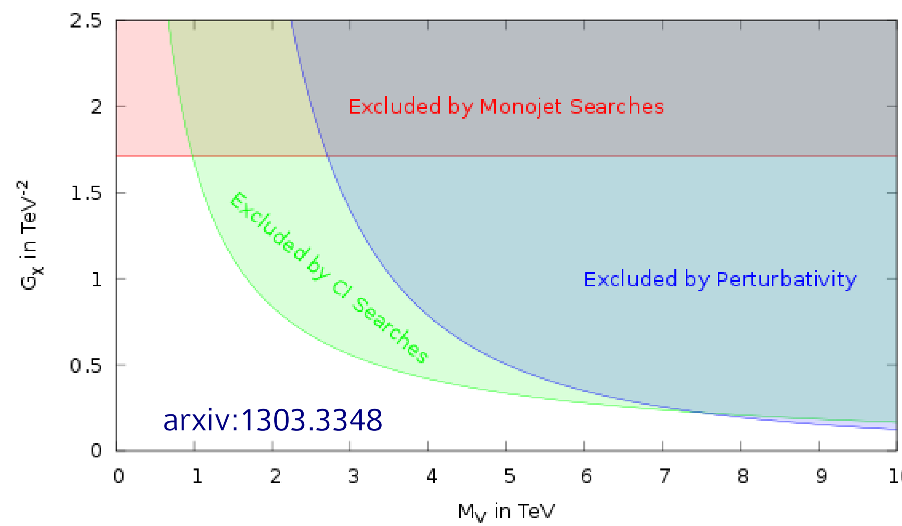
Analysis of **dijet angular distributions** probes contact interactions

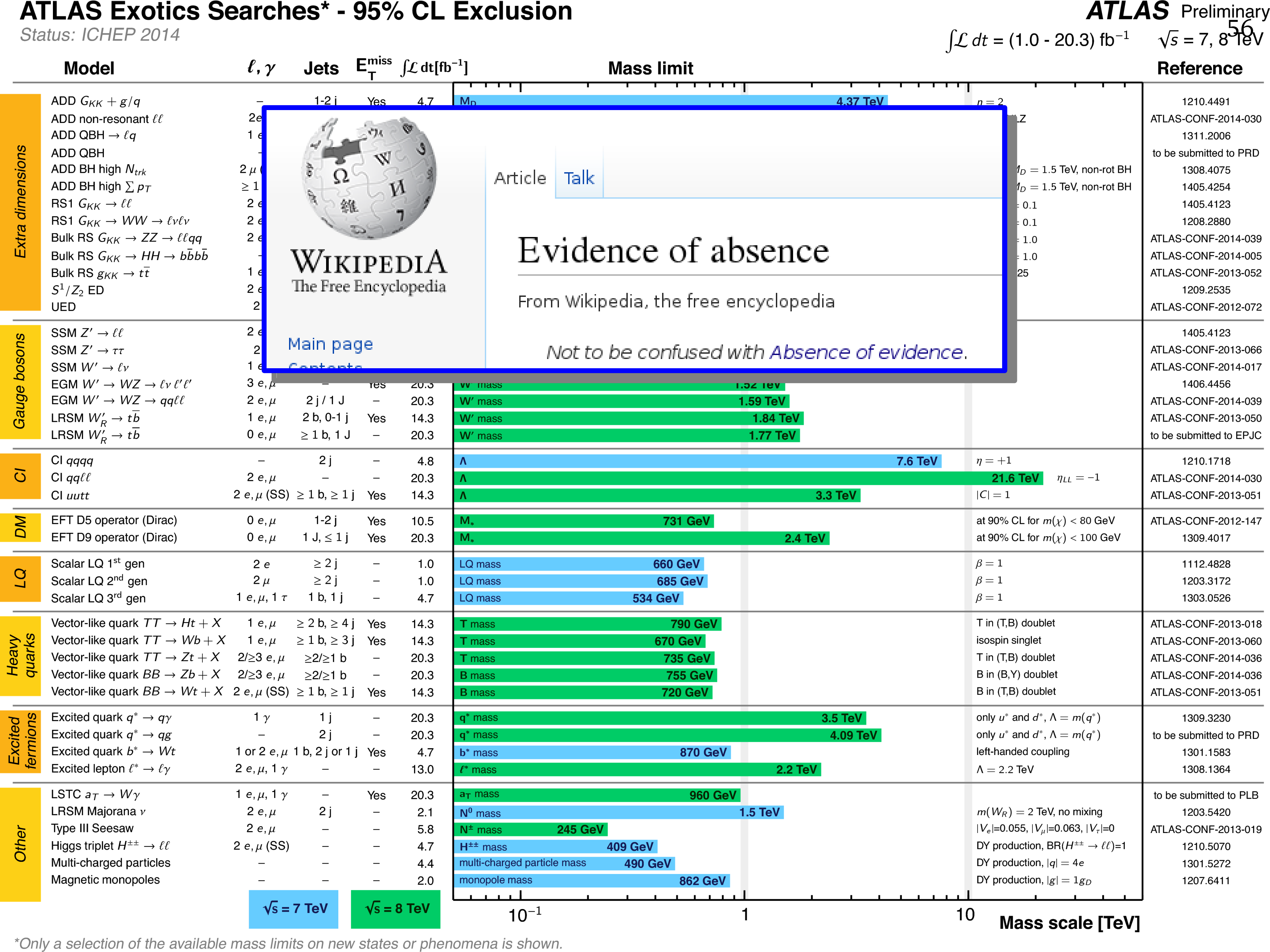


[F. Ruehr, LPCC Workshop on Higgs/BSM]

→ can **reinterpret** constraints in terms of **EFT framework for DM**







ATLAS Exotics Searches* - 95% CL Exclusion
Status: ICHEP 2014
ATLAS Preliminary
$\int \mathcal{L} dt = (1.0 - 20.3)$ fb^{-1}
$\sqrt{s}$ = 7, 8 TeV
Model
ℓ, γ
Jets
E_T^{miss}
$\int \mathcal{L} dt [fb^{-1}]$
Mass limit
Reference
Extra dimensions
ADD $G_{KK} + g/q$
ADD non-resonant $\ell\ell$
ADD QBH $\to \ell q$
ADD QBH
ADD BH high N_{trk}
ADD BH high $\sum p_T$
RS1 $G_{KK} \to \ell\ell$
RS1 $G_{KK} \to WW \to \ell\nu\ell\nu$
Bulk RS $G_{KK} \to ZZ \to \ell\ell qq$
Bulk RS $G_{KK} \to HH \to b\bar{b}b\bar{b}$
Bulk RS $g_{KK} \to t\bar{t}$
S^1/Z_2 ED
UED
1210.4491
ATLAS-CONF-2014-030
1311.2006
to be submitted to PRD
1308.4075
1405.4254
1405.4123
1208.2880
ATLAS-CONF-2014-039
ATLAS-CONF-2014-005
ATLAS-CONF-2013-052
1209.2535
ATLAS-CONF-2012-072
Gauge bosons
SSM $Z' \to \ell\ell$
SSM $Z' \to \tau\tau$
SSM $W' \to \ell\nu$
EGM $W' \to WZ \to \ell\nu\,\ell'\ell'$
EGM $W' \to WZ \to qq\ell\ell$ | 2 e, μ | 2 j / 1 J | – | 20.3 | W′ mass 1.59 TeV
LRSM $W'_R \to t\bar{b}$ | 1 e, μ | 2 b, 0-1 j | Yes | 14.3 | W′ mass 1.84 TeV
LRSM $W'_R \to t\bar{b}$ | 0 e, μ | ≥ 1 b, 1 J | – | 20.3 | W′ mass 1.77 TeV
1405.4123
ATLAS-CONF-2013-066
ATLAS-CONF-2014-017
1406.4456
ATLAS-CONF-2014-039
ATLAS-CONF-2013-050
to be submitted to EPJC
CI
CI qqqq | – | 2 j | – | 4.8 | Λ 7.6 TeV | η = +1 | 1210.1718
CI qqℓℓ | 2 e, μ | – | – | 20.3 | Λ 21.6 TeV | $\eta_{LL} = -1$ | ATLAS-CONF-2014-030
CI uutt | 2 e, μ (SS) | ≥ 1 b, ≥ 1 j | Yes | 14.3 | Λ 3.3 TeV | |C| = 1 | ATLAS-CONF-2013-051
DM
EFT D5 operator (Dirac) | 0 e, μ | 1-2 j | Yes | 10.5 | M* 731 GeV | at 90% CL for $m(\chi) < 80$ GeV | ATLAS-CONF-2012-147
EFT D9 operator (Dirac) | 0 e, μ | 1 J, ≤ 1 j | Yes | 20.3 | M* 2.4 TeV | at 90% CL for $m(\chi) < 100$ GeV | 1309.4017
LQ
Scalar LQ 1st gen | 2 e | ≥ 2 j | – | 1.0 | LQ mass 660 GeV | β = 1 | 1112.4828
Scalar LQ 2nd gen | 2 μ | ≥ 2 j | – | 1.0 | LQ mass 685 GeV | β = 1 | 1203.3172
Scalar LQ 3rd gen | 1 e, μ, 1 τ | 1 b, 1 j | – | 4.7 | LQ mass 534 GeV | β = 1 | 1303.0526
Heavy quarks
Vector-like quark $TT \to Ht + X$ | 1 e, μ | ≥ 2 b, ≥ 4 j | Yes | 14.3 | T mass 790 GeV | T in (T,B) doublet | ATLAS-CONF-2013-018
Vector-like quark $TT \to Wb + X$ | 1 e, μ | ≥ 1 b, ≥ 3 j | Yes | 14.3 | T mass 670 GeV | isospin singlet | ATLAS-CONF-2013-060
Vector-like quark $TT \to Zt + X$ | 2/≥3 e, μ | ≥2/≥1 b | – | 20.3 | T mass 735 GeV | T in (T,B) doublet | ATLAS-CONF-2014-036
Vector-like quark $BB \to Zb + X$ | 2/≥3 e, μ | ≥2/≥1 b | – | 20.3 | B mass 755 GeV | B in (B,Y) doublet | ATLAS-CONF-2014-036
Vector-like quark $BB \to Wt + X$ | 2 e, μ (SS) | ≥ 1 b, ≥ 1 j | Yes | 14.3 | B mass 720 GeV | B in (T,B) doublet | ATLAS-CONF-2013-051
Excited fermions
Excited quark $q^* \to q\gamma$ | 1 γ | 1 j | – | 20.3 | q* mass 3.5 TeV | only u^* and d^*, $\Lambda = m(q^*)$ | 1309.3230
Excited quark $q^* \to qg$ | – | 2 j | – | 20.3 | q* mass 4.09 TeV | only u^* and d^*, $\Lambda = m(q^*)$ | to be submitted to PRD
Excited quark $b^* \to Wt$ | 1 or 2 e, μ | 1 b, 2 j or 1 j | Yes | 4.7 | b* mass 870 GeV | left-handed coupling | 1301.1583
Excited lepton $\ell^* \to \ell\gamma$ | 2 e, μ, 1 γ | – | – | 13.0 | ℓ* mass 2.2 TeV | Λ = 2.2 TeV | 1308.1364
Other
LSTC $a_T \to W\gamma$ | 1 e, μ, 1 γ | – | Yes | 20.3 | a_T mass 960 GeV | | to be submitted to PLB
LRSM Majorana ν | 2 e, μ | 2 j | – | 2.1 | N^0 mass 1.5 TeV | $m(W_R)$ = 2 TeV, no mixing | 1203.5420
Type III Seesaw | 2 e, μ | – | – | 5.8 | $N^\pm$ mass 245 GeV | $|V_e|$=0.055, $|V_\mu|$=0.063, $|V_\tau|$=0 | ATLAS-CONF-2013-019
Higgs triplet $H^{\pm\pm} \to \ell\ell$ | 2 e, μ (SS) | – | – | 4.7 | $H^{\pm\pm}$ mass 409 GeV | DY production, BR($H^{\pm\pm} \to \ell\ell$)=1 | 1210.5070
Multi-charged particles | – | – | – | 4.4 | multi-charged particle mass 490 GeV | DY production, |q| = 4e | 1301.5272
Magnetic monopoles | – | – | – | 2.0 | monopole mass 862 GeV | DY production, $|g| = 1g_D$ | 1207.6411
$\sqrt{s}$ = 7 TeV
$\sqrt{s}$ = 8 TeV
10^{-1}
1
10
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown.
Wikipedia
The Free Encyclopedia
Main page
Article
Talk
Evidence of absence
From Wikipedia, the free encyclopedia
Not to be confused with Absence of evidence.

THE FUTURE...

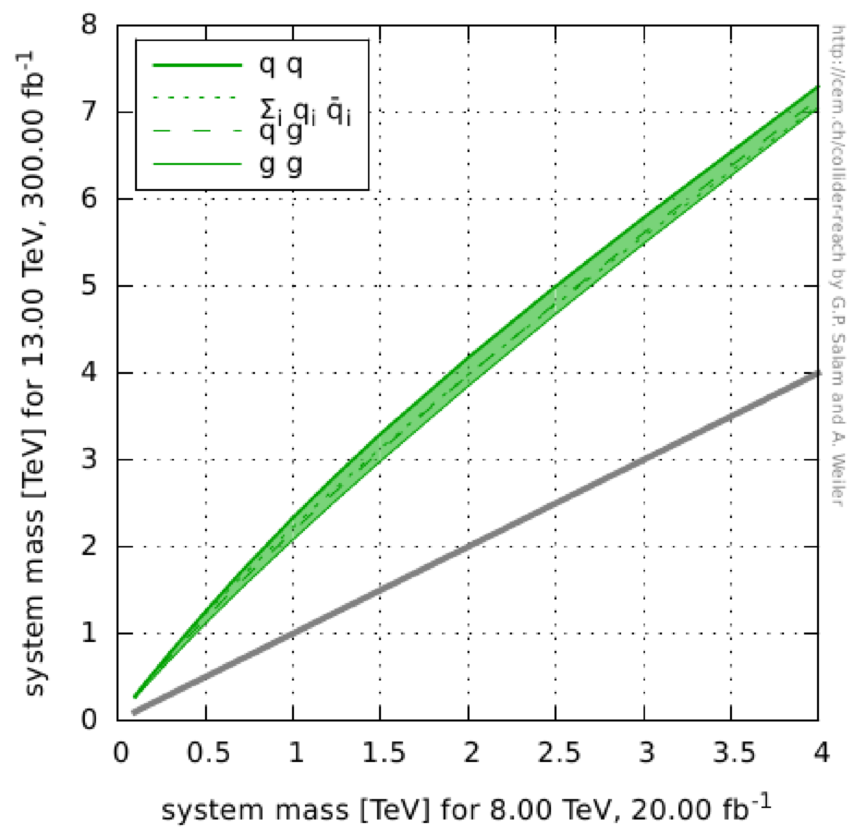
SEARCHES AT THE LHC RUN-II

LHC Run-II, $\sqrt{s}$ = 13 TeV, o(100) fb^{-1}

Increased **center of mass energy**: higher reach for **new massive particles and scales of new interactions**

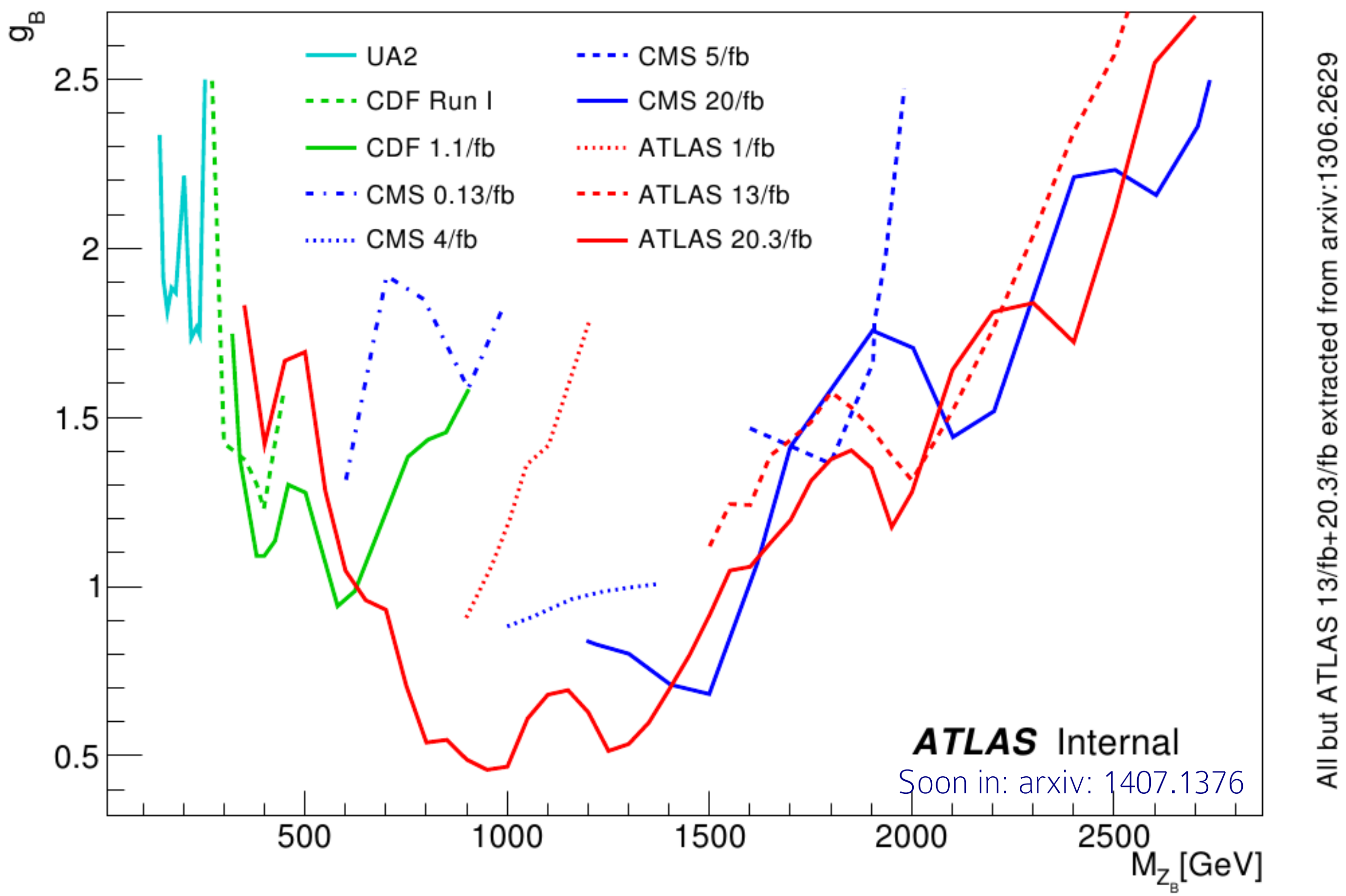
Larger dataset:
more sensitive to **rare** processes

Comparison of (new physics) mass reaches with full 8 and 13 TeV datasets



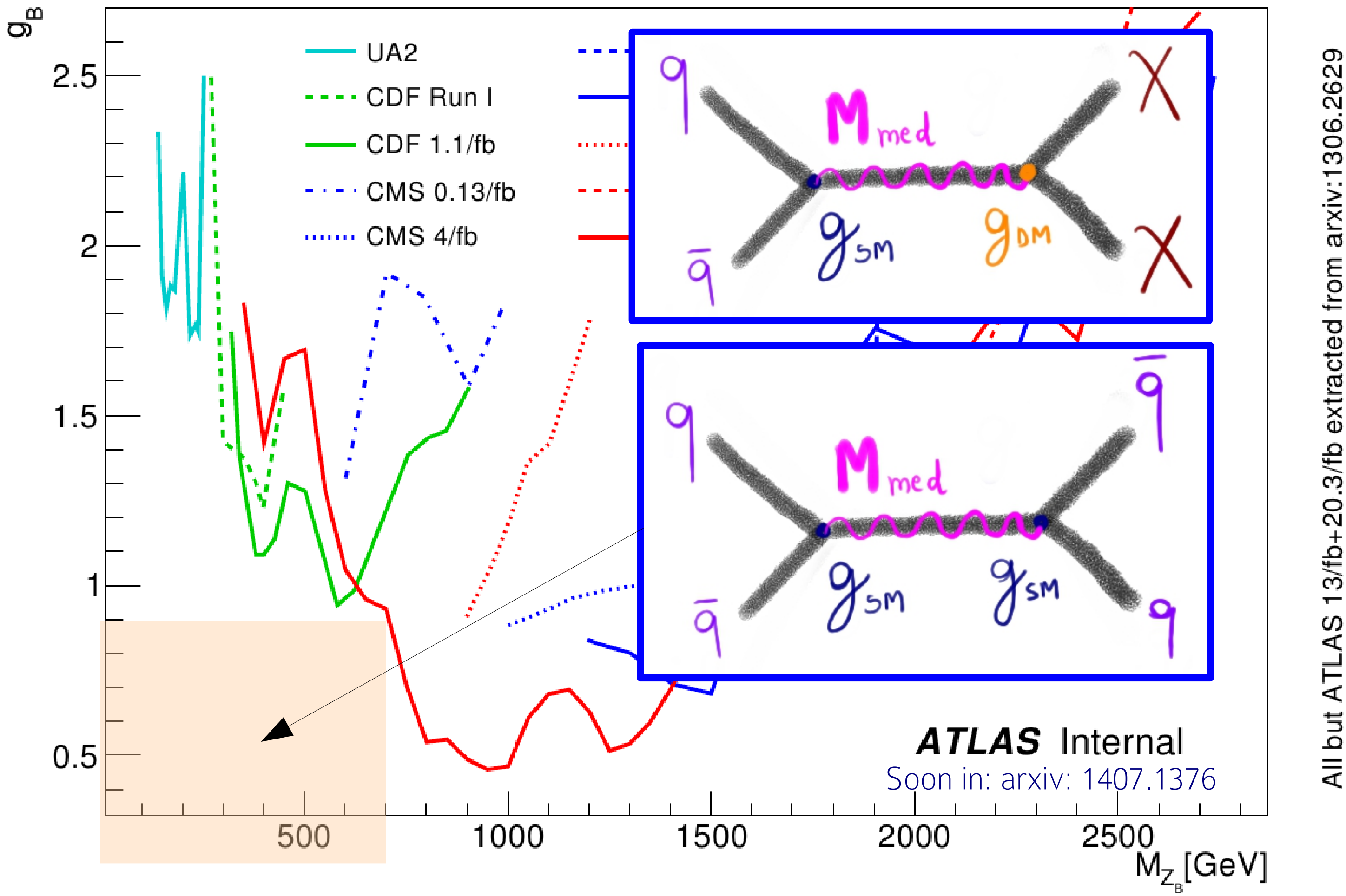
KEEP SEARCHING AT LOWER DIJET MASSES

Coupling vs mass limits for generic leptophobic Z'



Sensitivity at low masses driven by **available statistics**

KEEP SEARCHING AT LOWER DIJET MASSES



Blind spot (due to jet trigger rates and prescales), but promising for **DM mediator searches**

DATA SCOUTING AND TRIGGER-LEVEL ANALYSIS

Use **Event Filter jets** for dijet resonance search:

Bandwidth = rate * event size → decrease event size, increase rate

Advantages:

1) spot new physics early (**data scouting** mode)

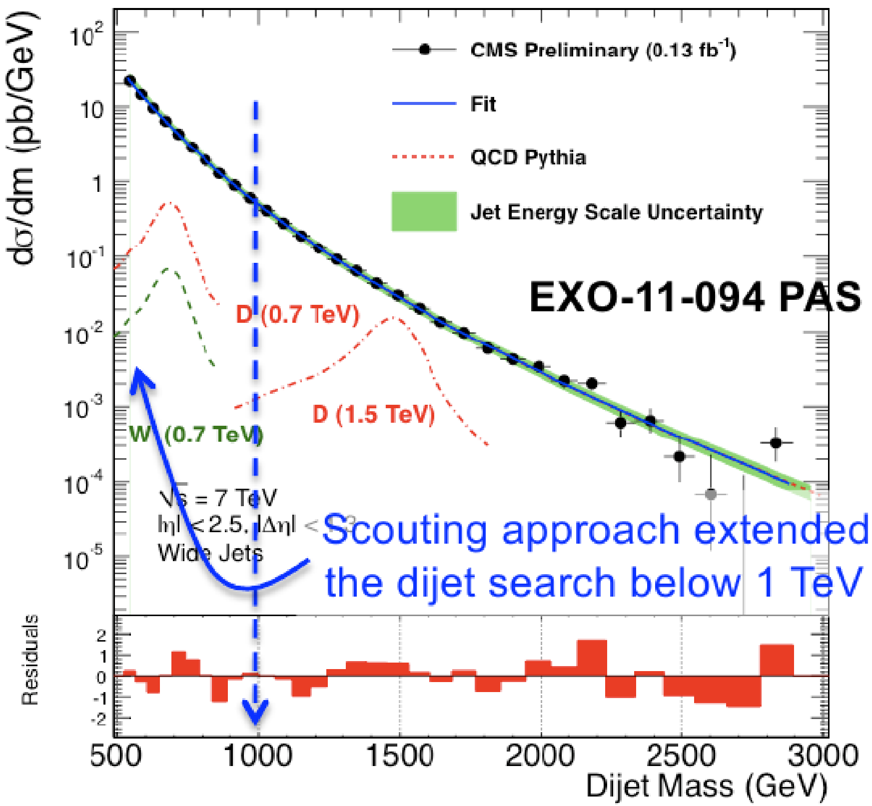
CMS-DP-2012-022

2) gain sensitivity in blind spot

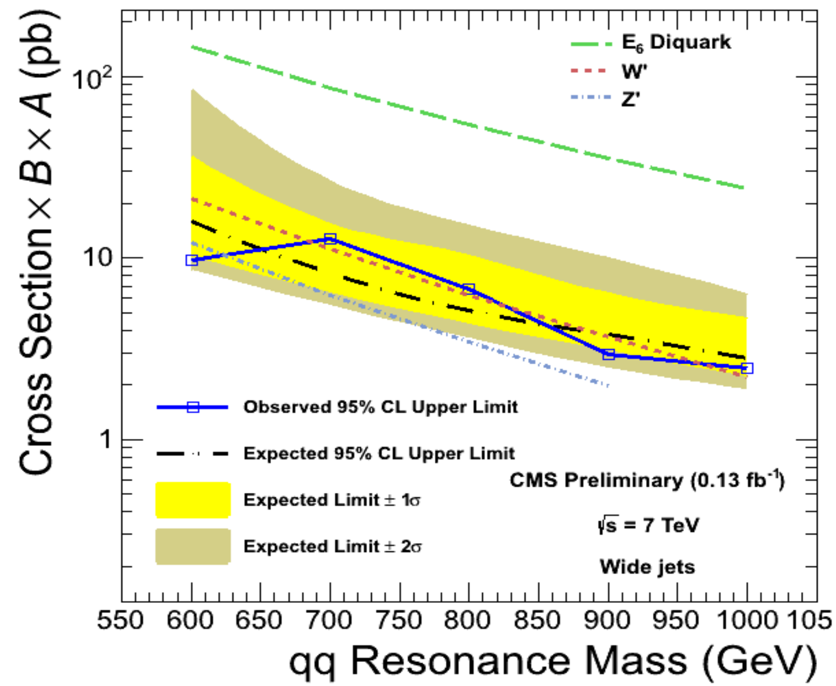
DATA SCOUTING: CMS RESULTS

CMS-DP-2012-022

Test Feasibility of Data Scouting in 2011:
Dijet Resonance Search (0.13 fb^{-1})



CMS : data parking (from 2012)
data scouting (from end of 2011)

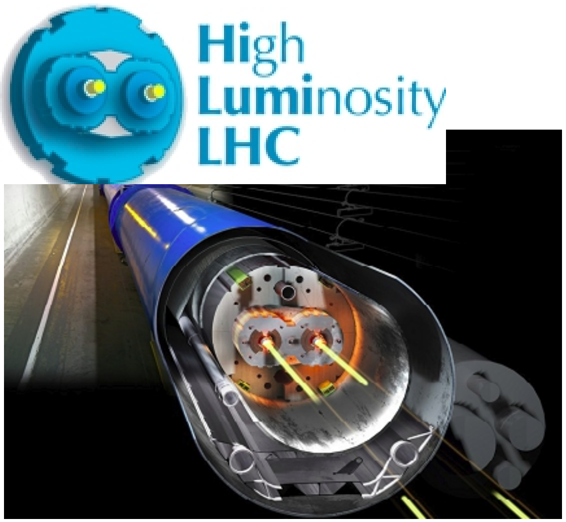


CMS-PAS-EXO-11-094

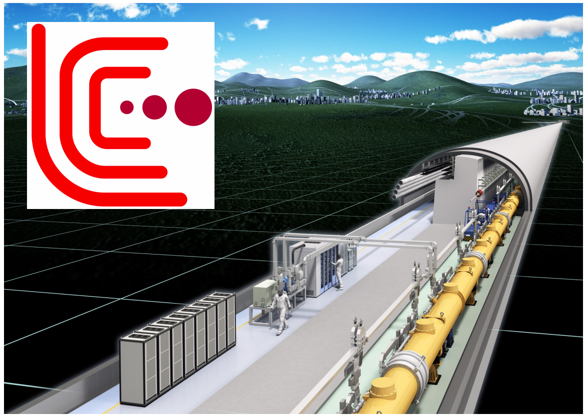
last two days of 2011 data
using **data scouting**

THE FUTURE OF COLLIDERS

Future machines will depend on **LHC discoveries** (or lack of)



HL-LHC website



Linear Collider website

FCC Website

time

Start thinking about **benchmarks, jets, calorimeters** now to answer the questions still left open by the LHC

CONCLUSIONS

A wealth of **physics results** brought to the HEP community by LHC **Run-I** data taking (only a small subset from ATLAS searches shown)

Higgs boson discovered, **Dark Matter** still at large
→ looking for a DM particle candidate at the LHC

Model-independent searches needed for LHC discoveries:
hadronic jets promising signatures at hadron colliders

Performance of jets and objects used crucial for searches, now and in the future

CONCLUSIONS

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the new particles unlike the case with the Higgs and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do ~~not~~ want to encourage big experimental searches for new particles , but we do feel that people performing experiments vulnerable to new particles should know how they may turn up.

Soon ready to analyse **a larger dataset** at a **higher center of mass energy** with **upgraded detectors**

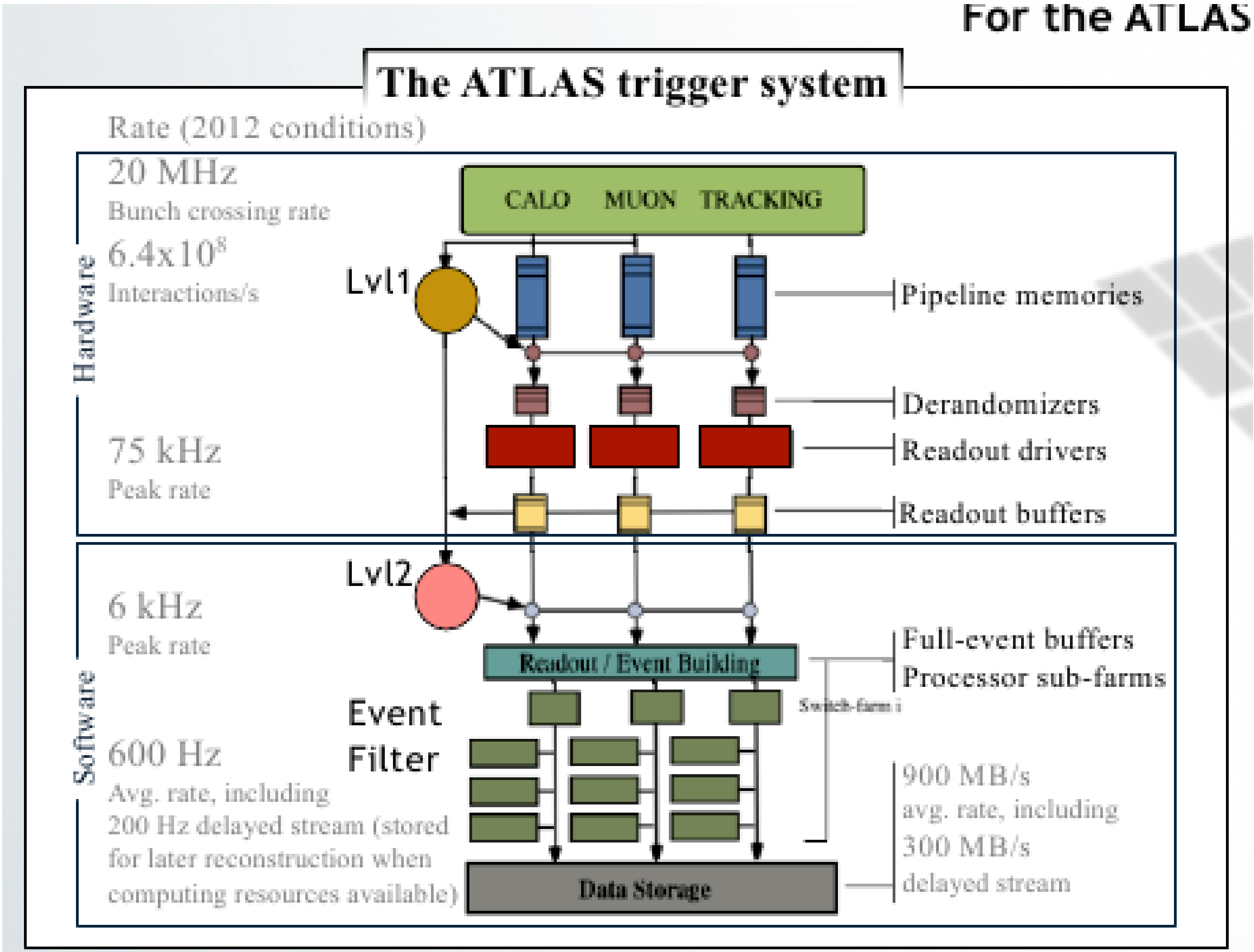
Run-II discoveries will show the path to **future colliders!**

THANK YOU FOR YOUR ATTENTION!

(LOOKING FORWARD TO JOINING THE LUND ATLAS GROUP!)

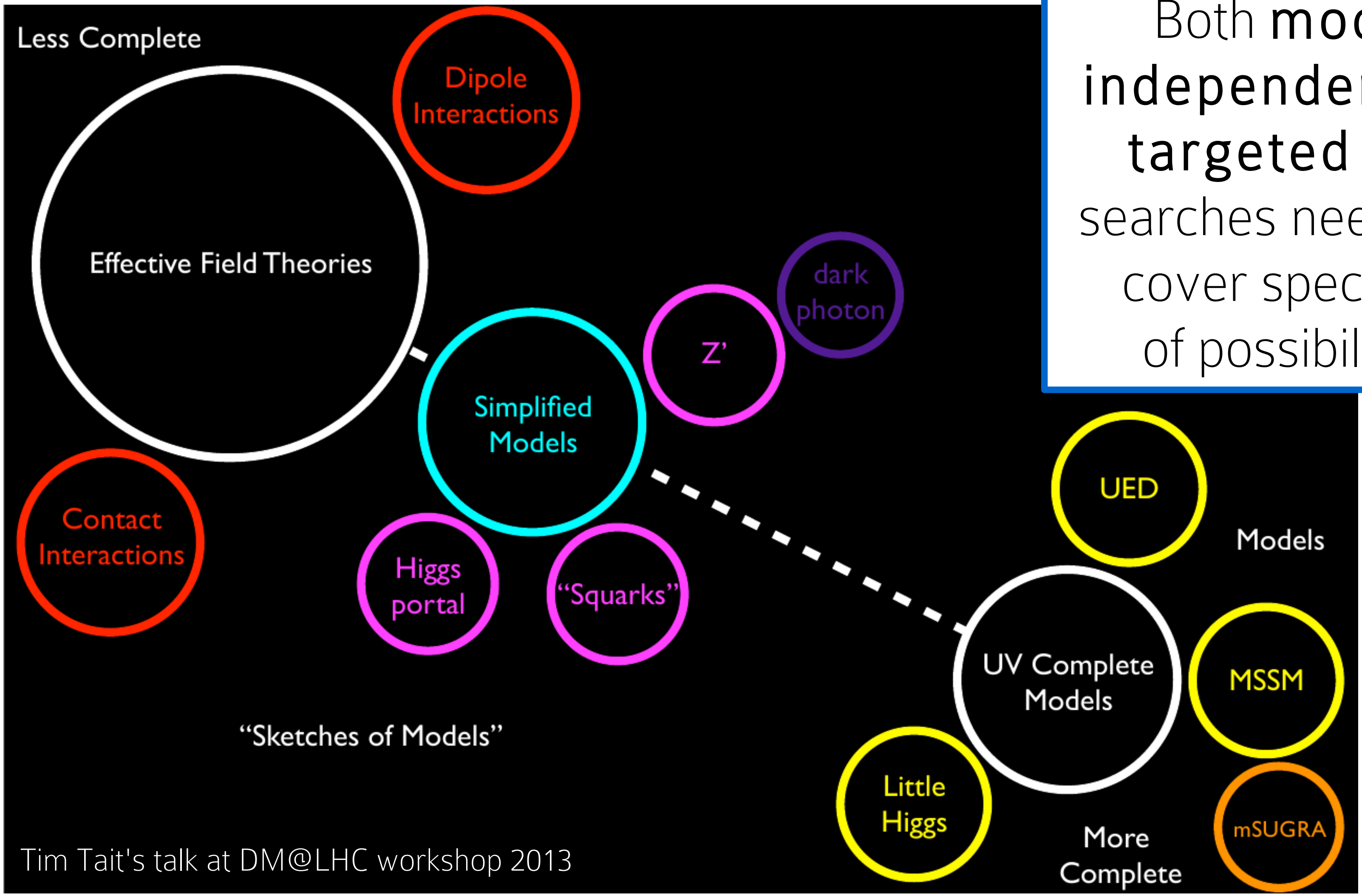
BACKUP SLIDES

SELECTING JETS ONLINE: THE TRIGGER SYSTEM



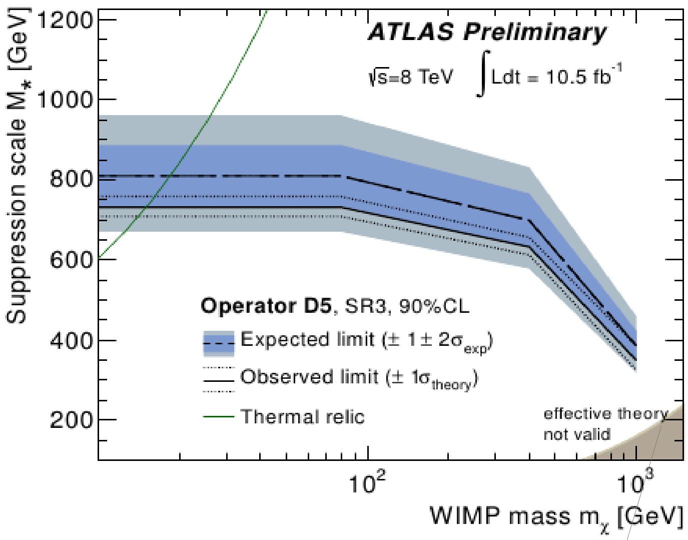
A. Sfyrla

MANY MODELS OF DARK MATTER



Both **model-independent** and **targeted** LHC searches needed to cover spectrum of possibilities

DISPLAYING EFT VALIDITY



A **truncation** procedure can be implemented (e.g. before converting EFT limits to DM-nucleon cross-section plot)

Fraction of events in EFT validity region

$$R_\Lambda^{\rm tot} \equiv \frac{\sigma_{\rm eff}\big|_{Q_{\rm tr}<\Lambda}}{\sigma_{\rm eff}}$$

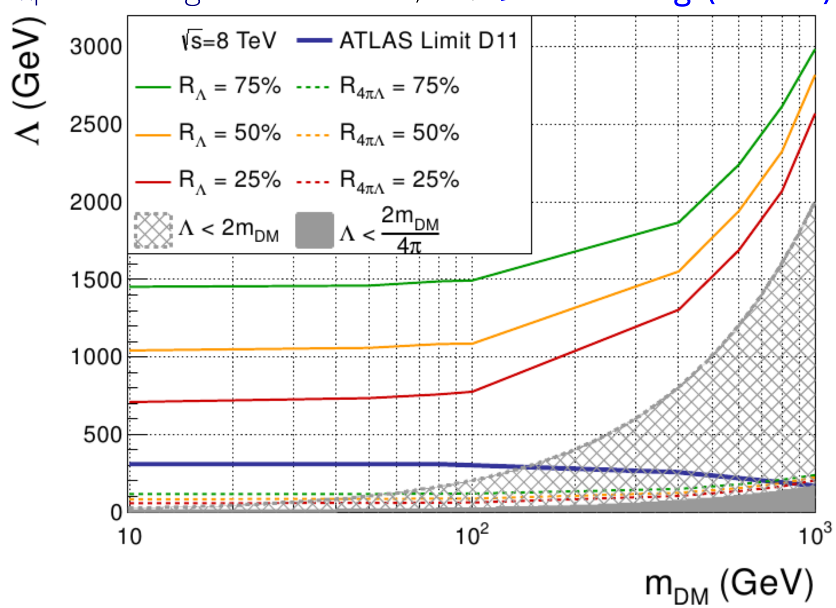
This region only considers validity due to kinematic constraints and theory perturbativity

More appropriate (stronger) **constraint:**

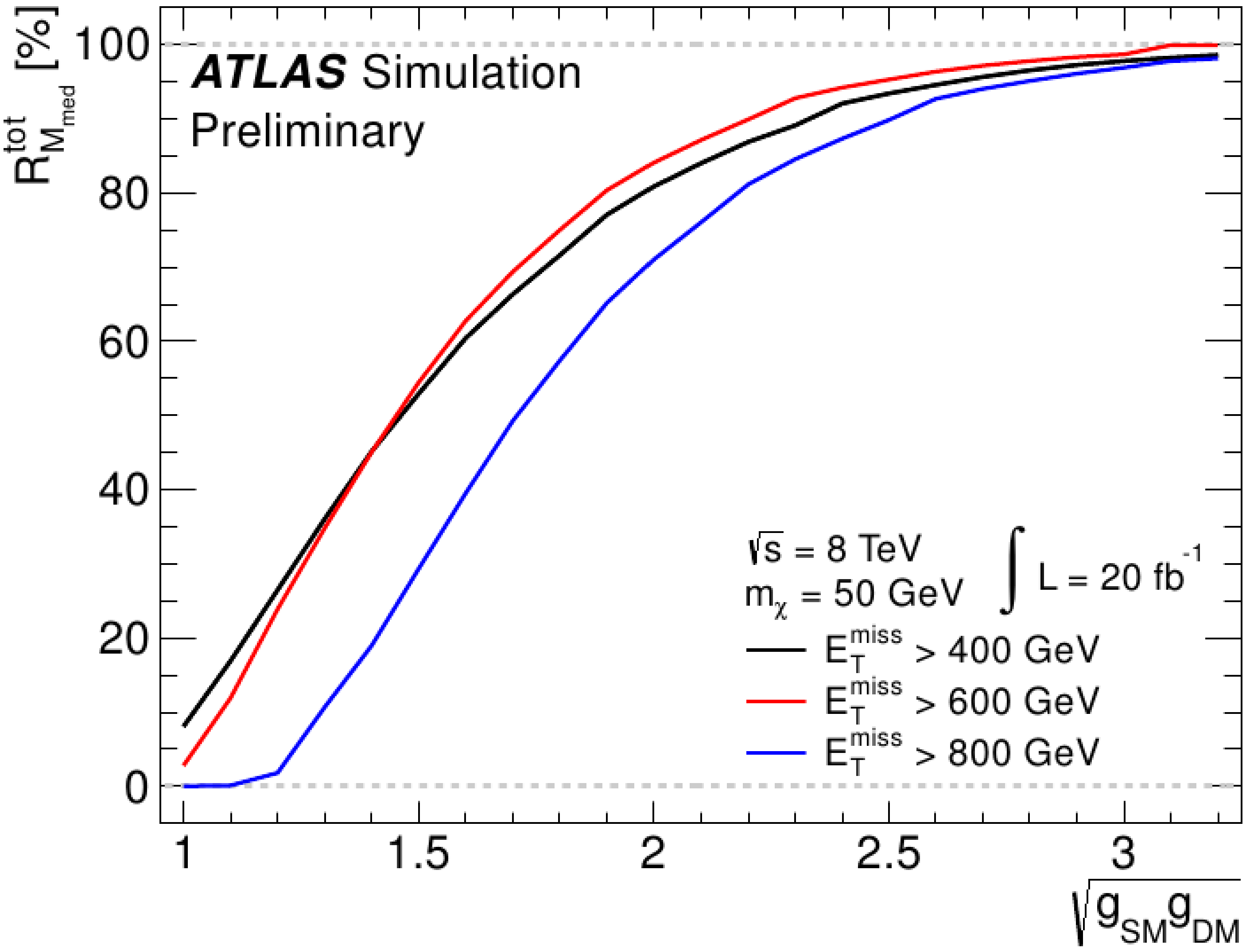
$$Q_{\rm tr}^2 < \Lambda^2$$

(coupling/operator-dependent statement)

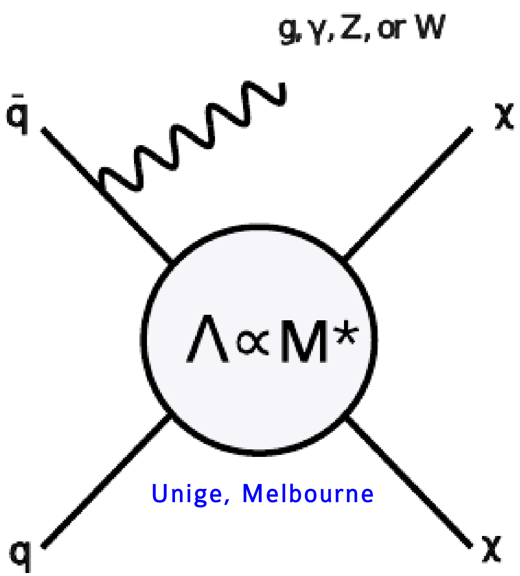
http://arxiv.org/abs/1402.1275, with J. Gramling (UniGe)



EXAMPLE: EFT VALIDITY FOR D5 OPERATOR



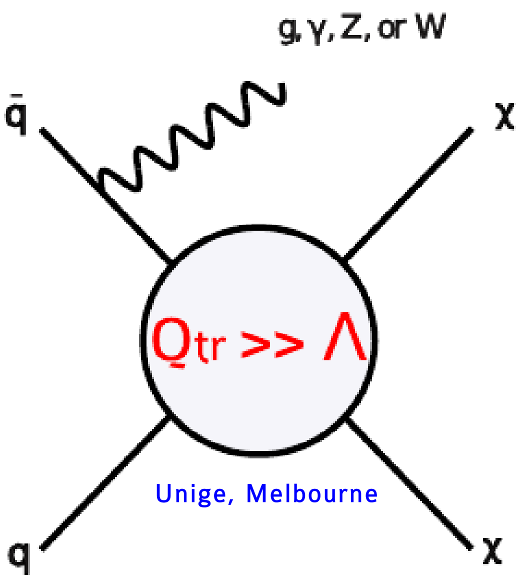
QUESTIONING THE EFT VALIDITY



Mono-X topology: MET + a recoiling high-p_T object

- Effective Field Theory: interaction between SM and DM particles mediated by very heavy particle → simplest possible model, governed by scale M^*
- Simplified models: adding an explicit mediator to the theory: parameterize theory via couplings, m_{DM}, m_{med} → Active collaboration experiments/theorists, e.g. 8 TeV Mono-Z paper
- Specific, UV-complete theories: e.g. SUSY, with Lightest Supersymmetric Particle as DM candidate → optimise sensitivity for certain models

QUESTIONING THE EFT VALIDITY



Problems with EFT: momentum transfer surpasses cut-off scale

- Effective Field Theory: interaction between SM and DM particles mediated by very heavy particle → simplest possible model, governed by scale M^*

Caveat on Effective Field Theories:

validity problems due to high momentum transfer at colliders, problematic when comparing to complementary direct/indirect detection experiments

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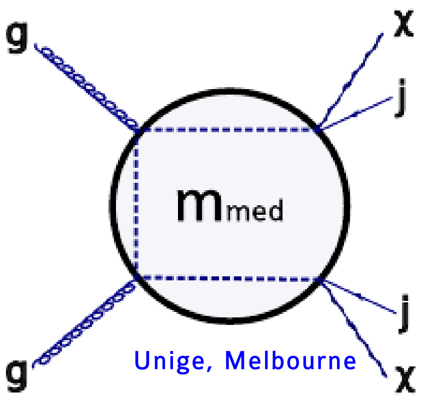

Solution: simplified models with mediator mediator could bring in additional signatures

- Effective Field Theory: interaction between SM and DM particles mediated by very heavy particle → simplest possible model, governed by scale M^*

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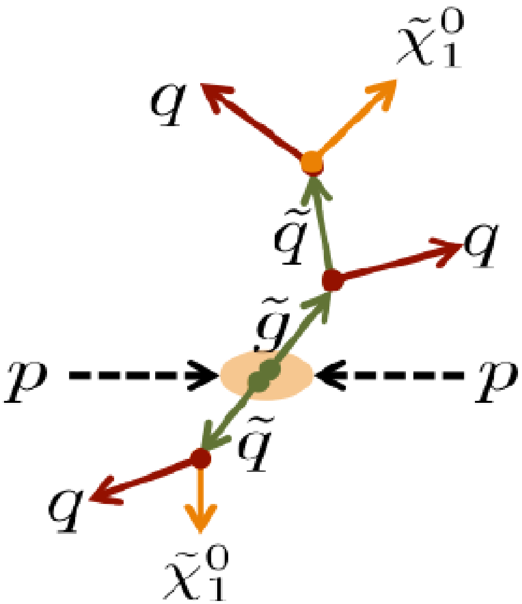
QUESTIONING THE EFT VALIDITY

Cambridge
(see TJ Khoo's talk)



Full SUSY models: not covered here

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Caveat on Effective Field Theories:

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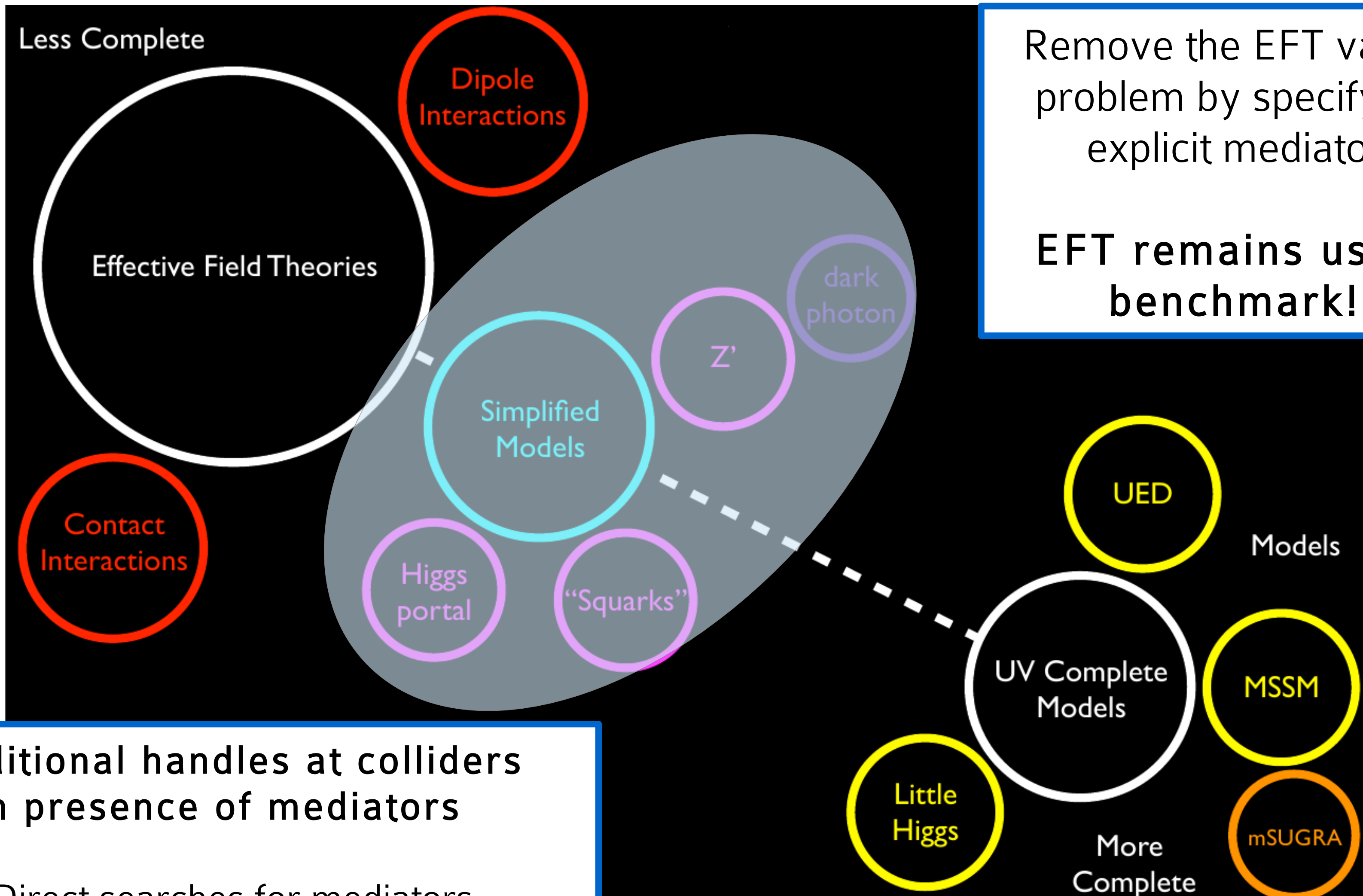
MOVING TO SIMPLIFIED MODELS



Remove the EFT validity problem by specifying explicit mediator

EFT remains useful benchmark!

Additional handles at colliders in presence of mediators

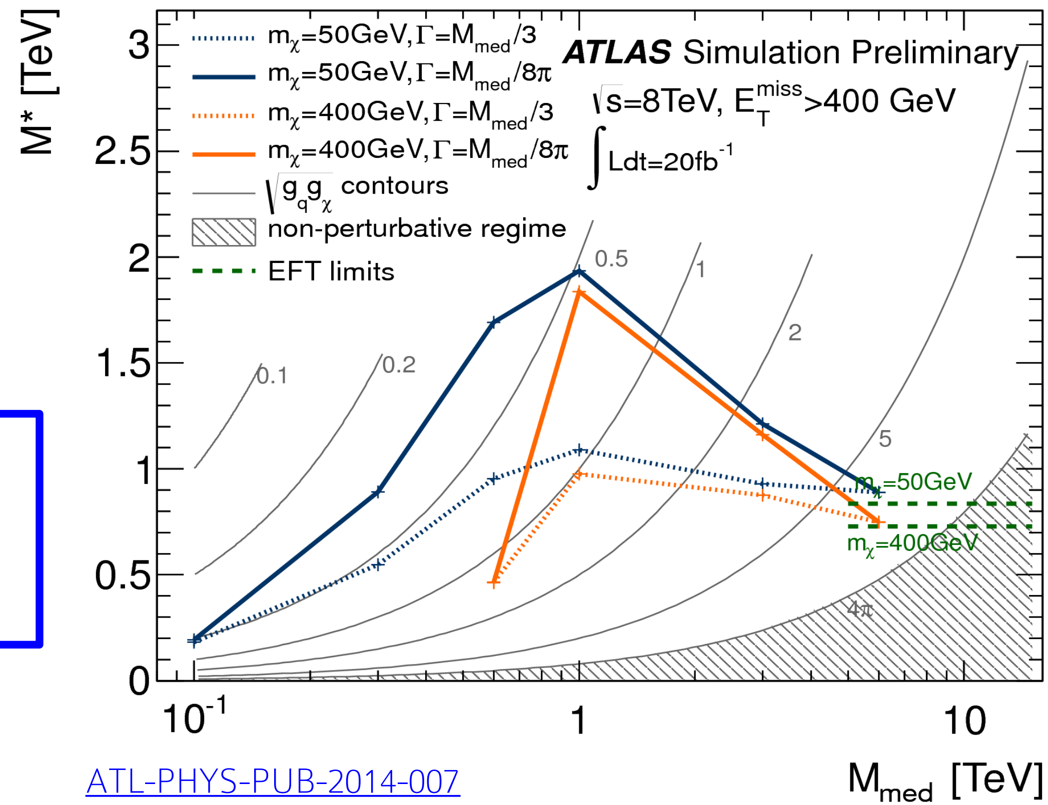
- Direct searches for mediators
- Existing constraints on existing mediators
- More signatures (e.g. dijet+MET)

SIMPLIFIED MODELS OF DARK MATTER

Many possibilities for building blocks:
- qq/gg initial state
- s-channel/t-channel exchange
- Scalar or fermion or vector DM, real or complex
- Scalar or vector mediator

Currently prioritizing studies on fermion DM:
- qq initial state
- s-channel, vector mediator
- t-channel, scalar mediator

Correspondence between EFT operators and simplified models (e.g. vector mediator, s-channel vs D5 EFT operator)



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Other interesting possibility:
- Higgs as SM/DM mediator
(**Higgs portal**)

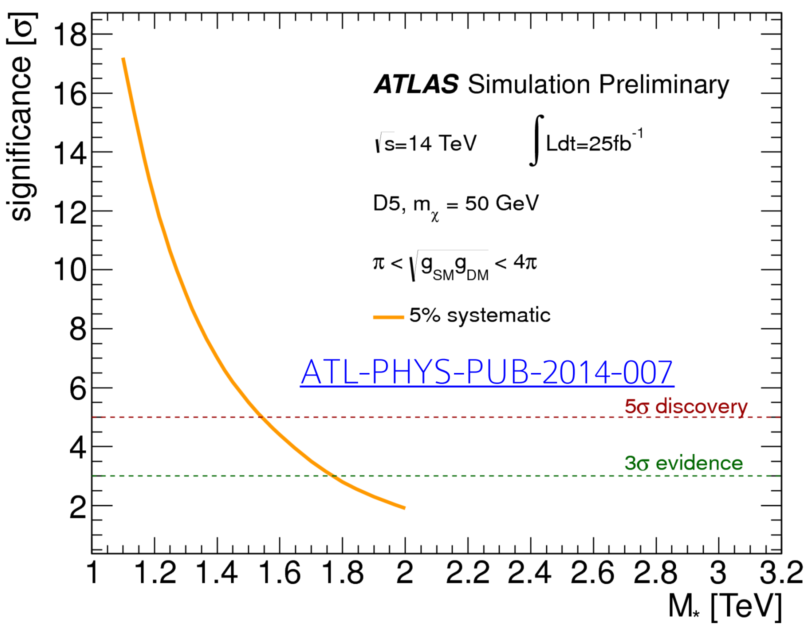
MONOJET PROSPECTS

Early DM searches: what do we gain/lose from CoM increase?

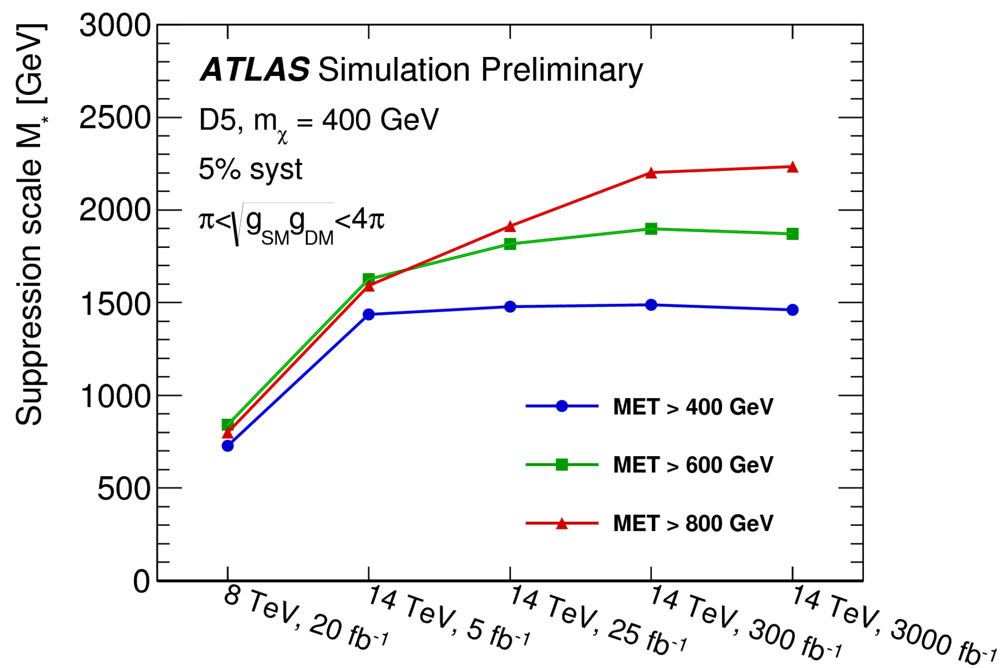
- Current monojet analysis: systematically limited at low MET, statistically limited at high MET $\rightarrow$ How high can we reach in $M*$ at 14 TeV?
- Will we have problems with the EFT validity at a higher CoM energy?

Increase of CoM energy → increase in reach (MET cut)

Marginal increase with luminosity (but decrease of syst. unc. needs time/statistics!)



Discovery potential for 50 GeV D5 WIMP



Limit on suppression scale for 50 GeV D5 WIMP

MONOJET PROSPECTS

ATL-PHYS-PUB-2014-007

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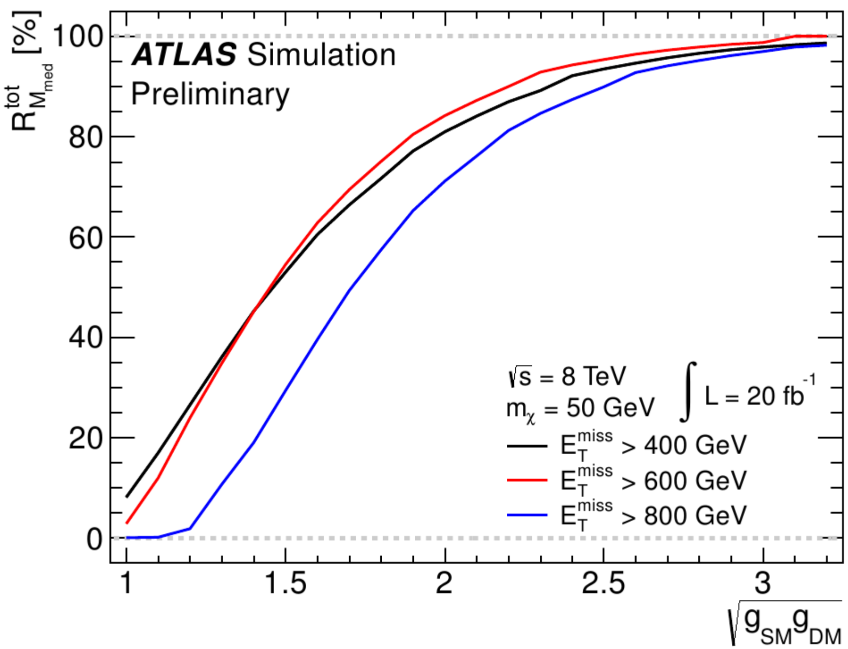
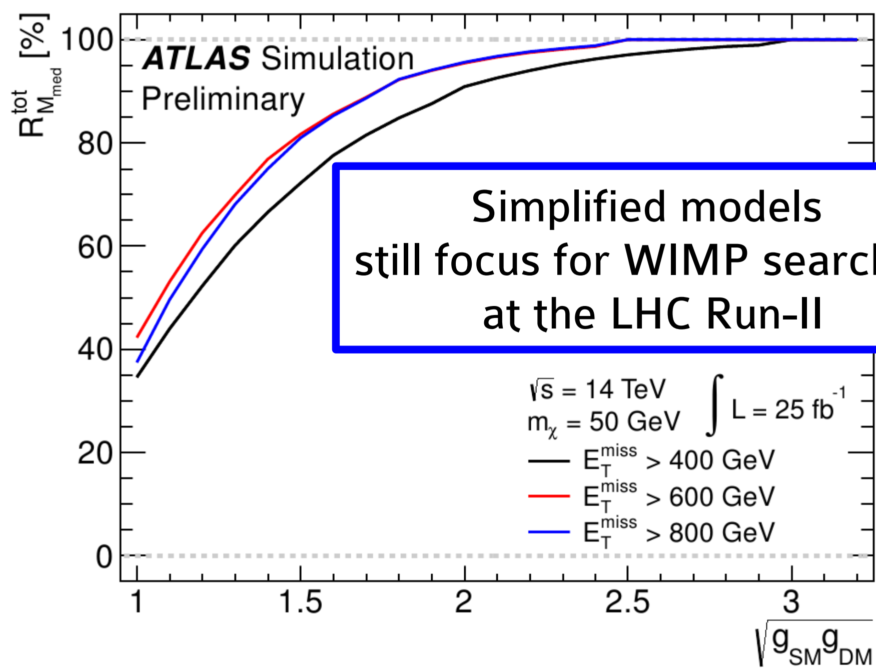
Somehow counterintuitive results! **Competing effects**: $Q_{\rm tr} < \sqrt{g_{\rm SM} g_{\rm DM}} M^*$

- Higher MET → higher Q_{tr} (weak correlation: MET smeared by detector)
- Increase of reach in M* → higher limits to start with → increased validity





Simplified models still focus for WIMP searches at the LHC Run-II

MONO-X SEARCHES IN ATLAS: REFERENCES

- Monojet (jets+MET): ATLAS-CONF-2012-147
- Monophoton (photon+MET): ATLAS-CONF-2014-051
- Mono-W/Z (vector boson + MET)
  - W/Z, Hadronic decays: PRL 112, 041802 (2014)
  - W: Leptonic decays: JHEP 09 (2014) 037
  - Z: Leptonic decays: PRD 90, 052005 (2014)
- Heavy flavor quarks + MET: In preparation (public results)