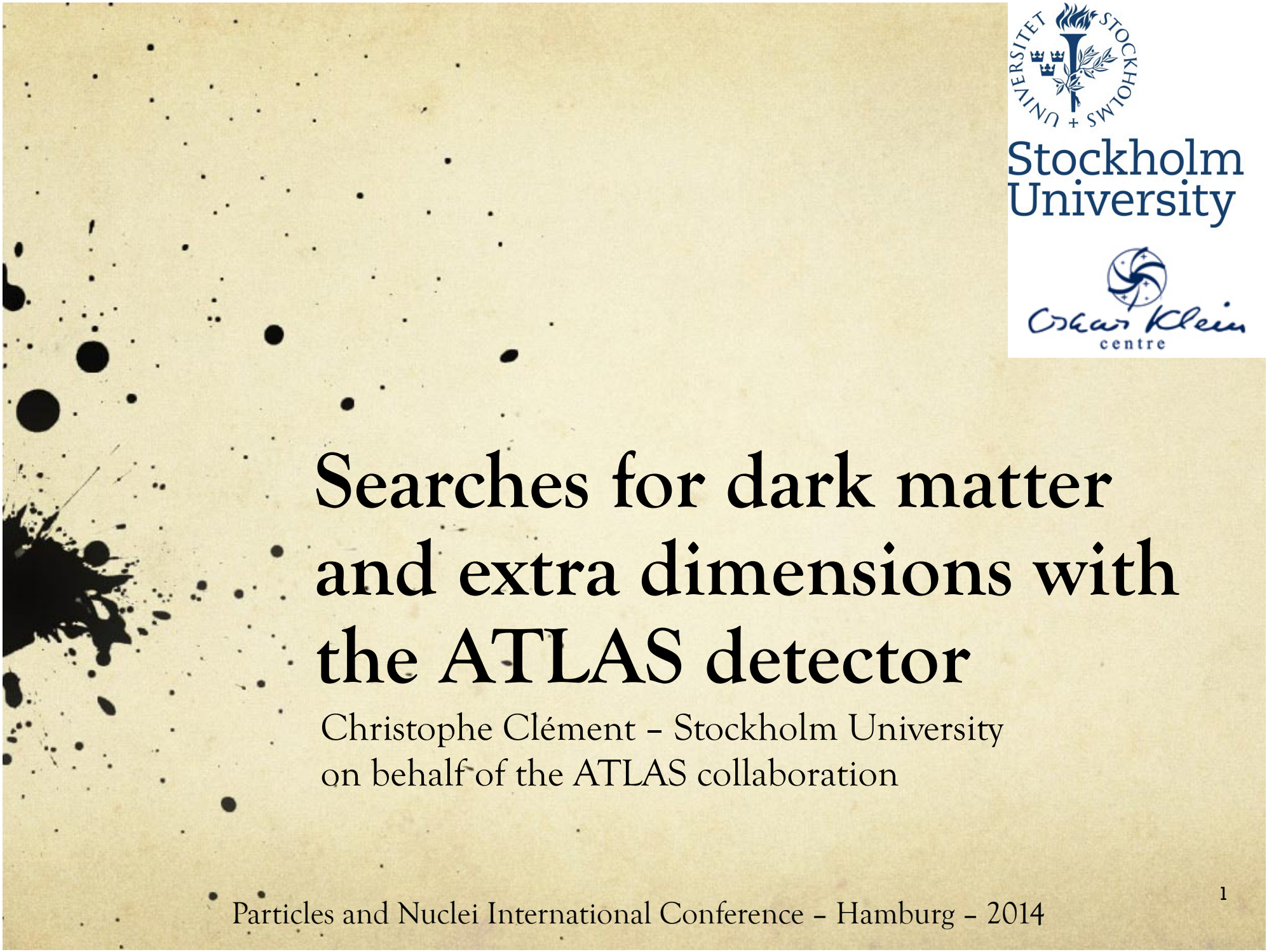


Searches for dark matter and extra dimensions with the ATLAS detector

Christophe Clément – Stockholm University
on behalf of the ATLAS collaboration

Dark Matter (DM)

- Galactic rotation curves, gravitational lensing
- DM ~25% of universe (Planck / WMAP)
- Collider search for DM particle WIMP χ complements direct/ indirect DM searches

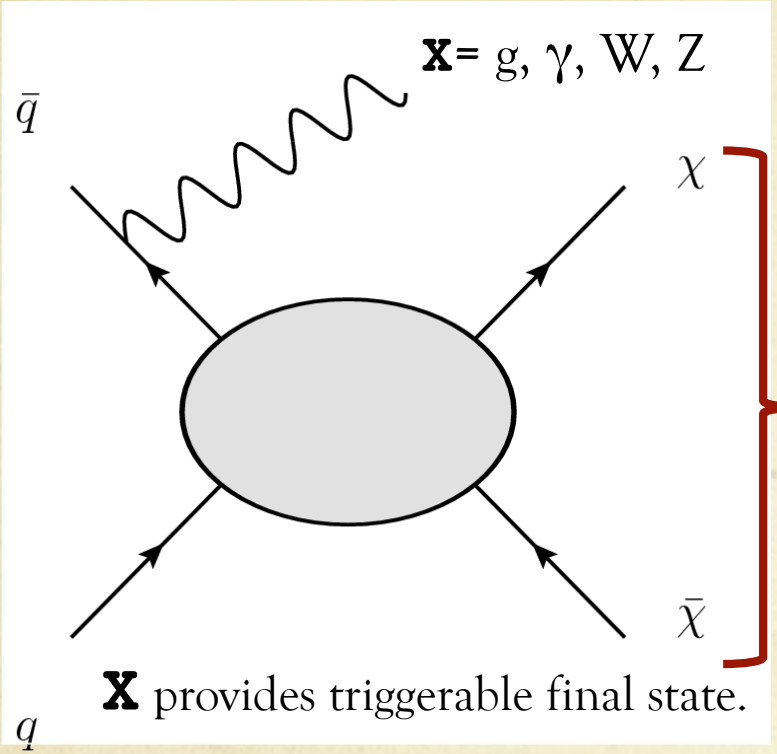
Extra Dimensions

- Possible solution to the weakness of gravitation,
- Many models, select here searches sensitive to black holes.

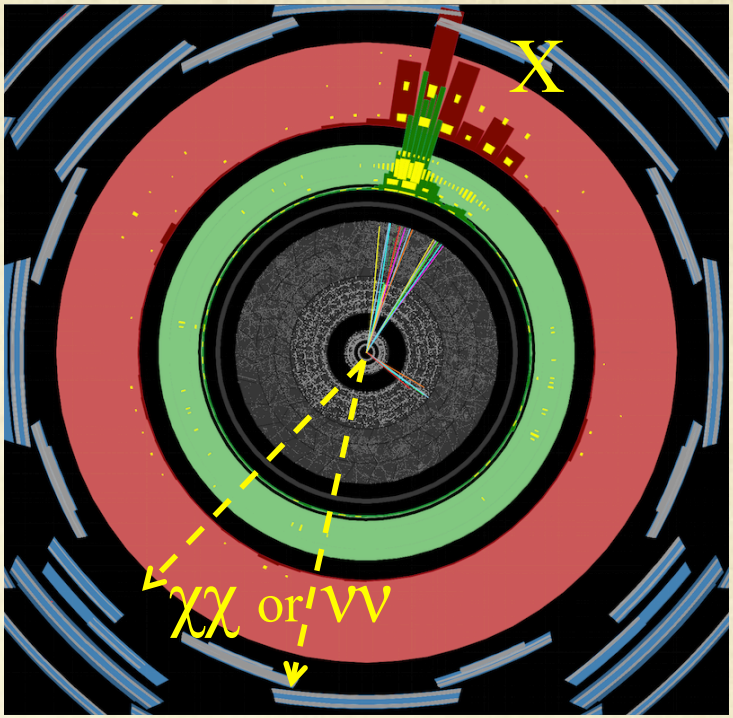
Hidden Valley

- Arises in many top-down models including string-theory constructions
- Can provide for DM candidates

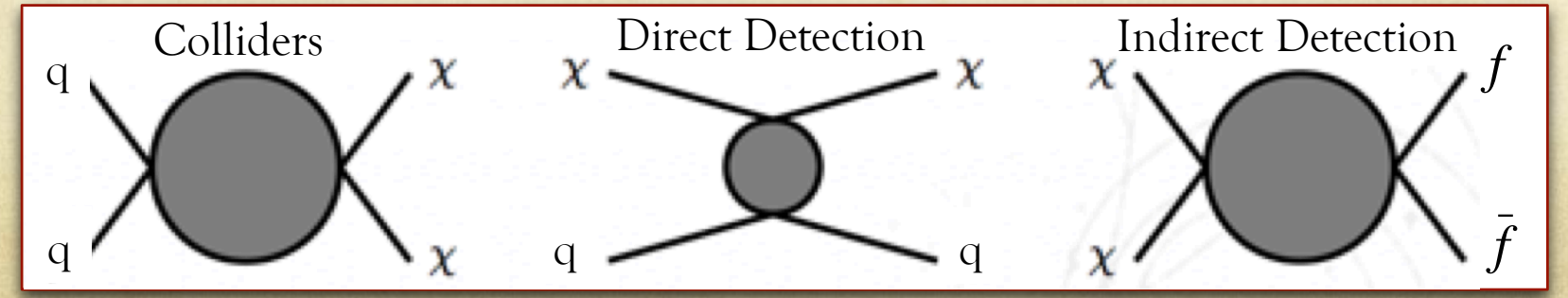
Dark Matter Search with Mono-X Signatures



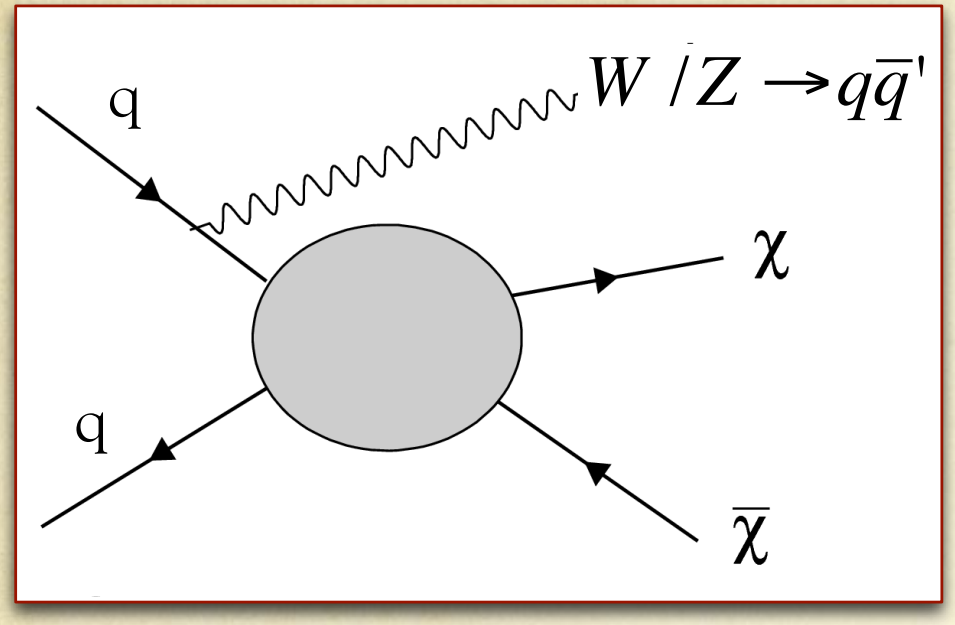
Effective Theory (EFT) approach for interpretation with m_χ and M* and DM.



Display of a high p_T jets recoiling against missing transverse energy E_T(miss).



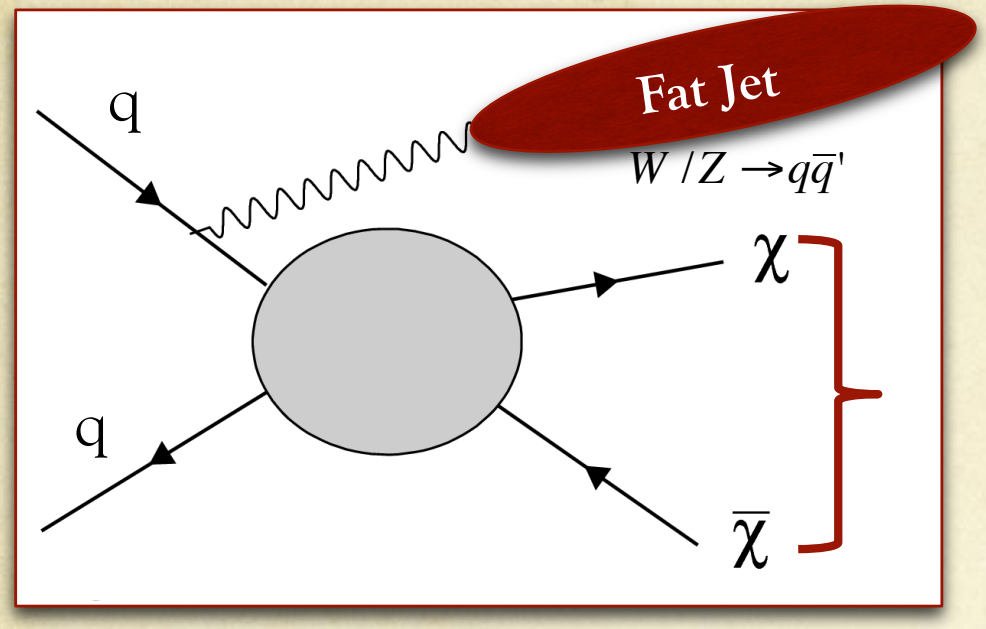
Mono-W/Z Searches – hadronic W/Z decay



Hadronic W/Z decay observed as massive jet.

Phys. Rev. Lett. 112, 041802 (2014)

Mono-W/Z Searches – hadronic W/Z decay



Hadronic W/Z decay observed as massive jet.

E_T(miss)

With W production, sensitive to the sign of **DM coupling** to the up- and down-quarks:

- Constructive interference if C(u)=-C(d)
- Destructive interference if C(u)=C(d)

=> Several order of magnitudes variation on the WIMP-nucleon cross section

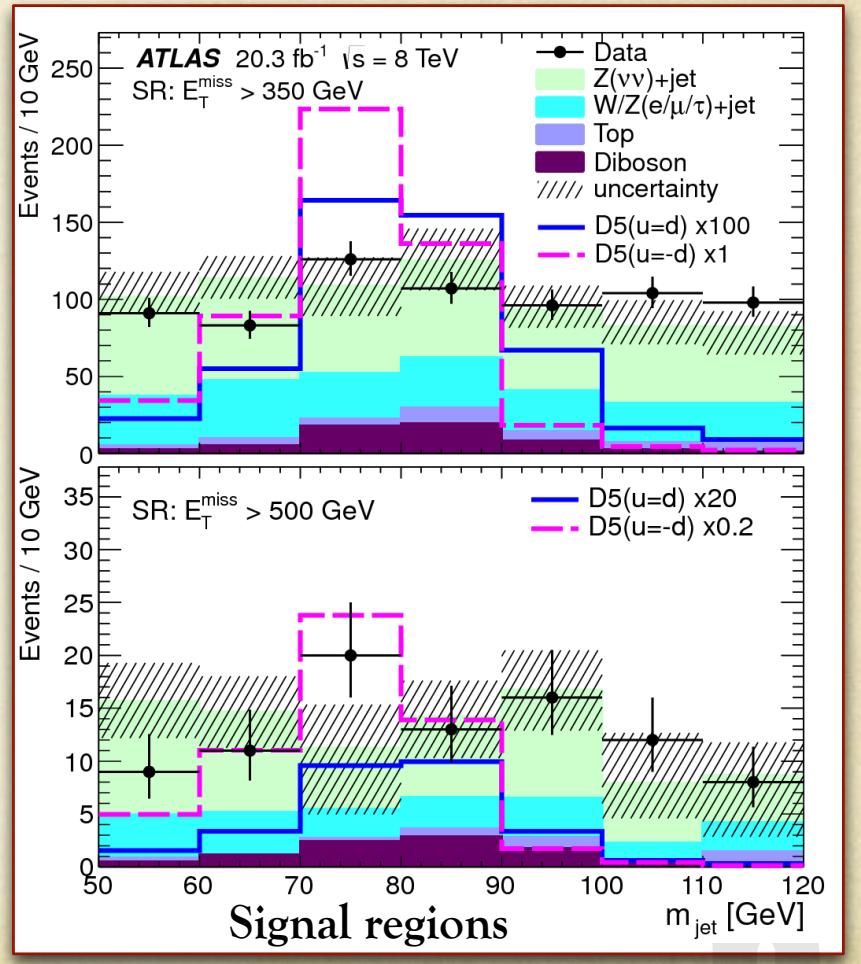
Phys. Rev. Lett. 112, 041802 (2014)

Mono-W/Z →Hadrons – Selections & Backgrounds

"Fat Jet" capturing the hadronic W/Z decay
- large R=1.2 Cambridge-Aachen jet p_T>250GeV,
- $|\eta|$<1.2
- $\sqrt{y} = \min(p_{T1}, p_{T2})\Delta R / m_{jet} > 0.4$
- $50 < m_{jet} < 120$ GeV

Veto
Leptons, photons, light jets

Signal Regions:
$E_T(miss)$ > 350, 500 GeV



Main backgrounds, from data control regions

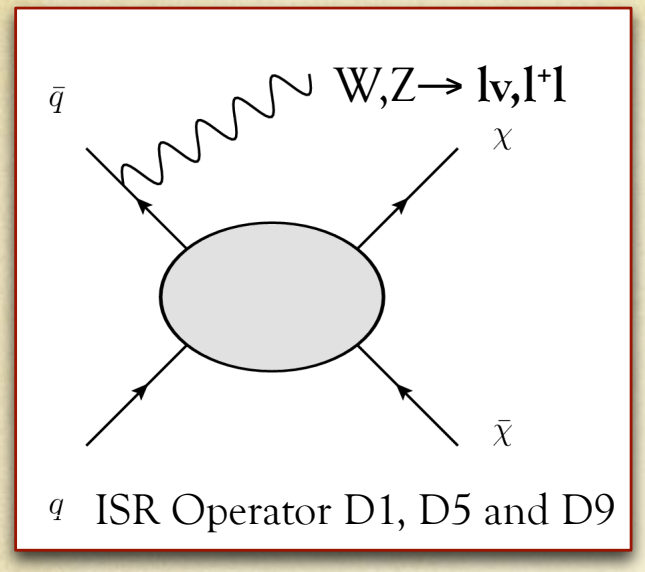
$(Z \rightarrow \bar{\nu}\nu) + jets$

$W/Z + jets$ with misidentified lepton(s)

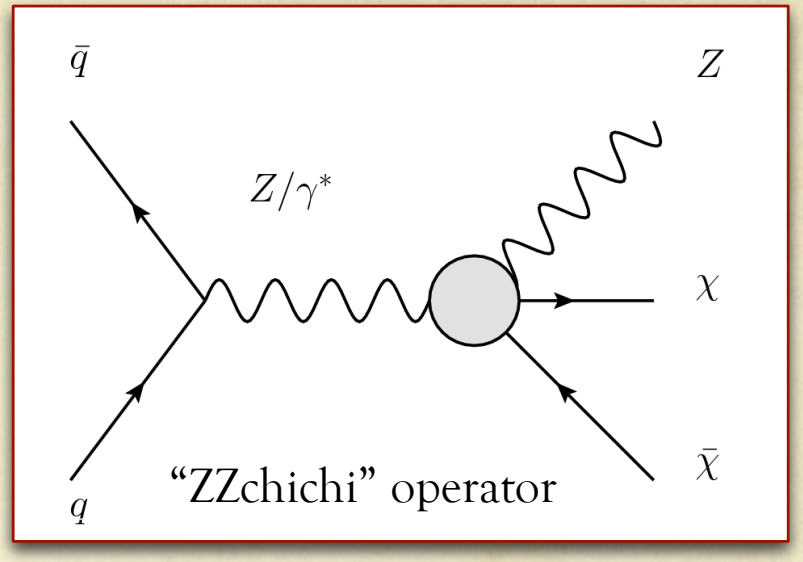
Secondary backgrounds

Top and diboson production from Monte Carlo simulation.

Mono-Z→ l^+l^- and Mono-W→ lν – Selections



ISR Operator D1, D5 and D9



"ZZchichi" operator

Mono-Z Signal Region e^+e^-, $\mu^+\mu^-$
- p_T> 20 GeV, mll ∈ [76, 106] GeV
- $|\eta_{ll}|$ <2.5

Back to back & balanced
- $\Delta\phi$ (E_T(miss),$p_T$ll) >2.5
- $|p_T ll - E_T(miss)|/p_T ll < 0.5$
- E_T(miss)>150, 250, 350, 450 GeV

Mono-W Signal Region eν, μν
- e-channel p_T> 125 GeV
- μ-channel p_T> 45 GeV

Balanced
- e-channel E_T(miss)> 125 GeV
- μ-channel E_T(miss)> 45 GeV

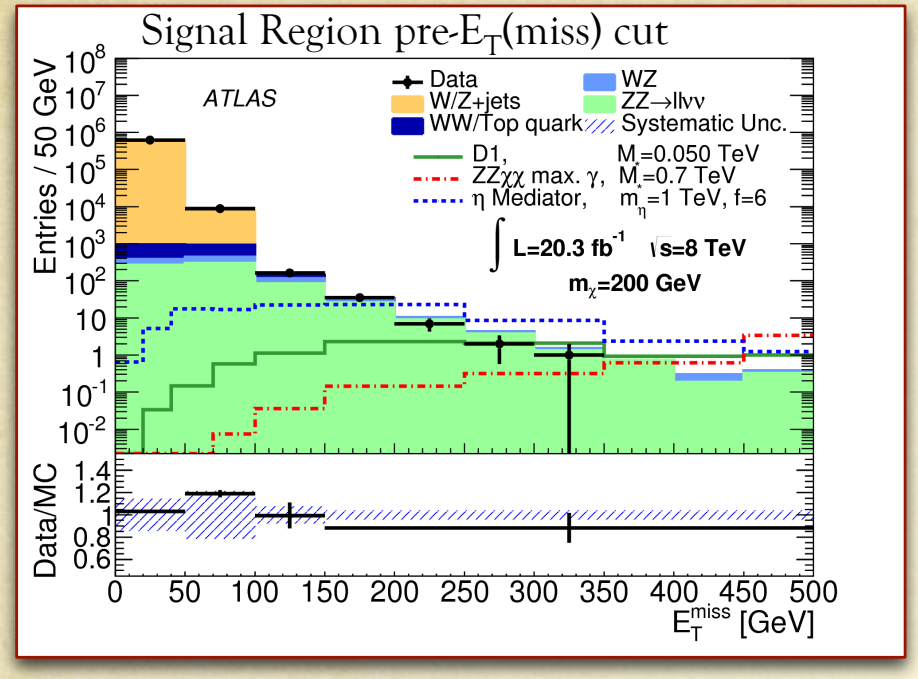
Final

$$m_T = \sqrt{2 p_T E_T(miss)(1-\cos\varphi_{lv})} > m_{T\,\min}$$

where the optimal value of m_{Tmin} is optimised for each model.

Mono-Z Phys. Rev. D 90, 012004 (2014)
Mono-W arXiv:1407.7494 [hep-ex] accepted by JHEP

Mono-Z→ l+l



Signal Regions

E_T(miss)>150, 250, 350, 450 GeV

Irreducible backgrounds

$ZZ \rightarrow \ell^+\ell^-\bar{\nu}\nu$

$W^+W^- \rightarrow \ell^+\nu\ell^-\bar{\nu}$

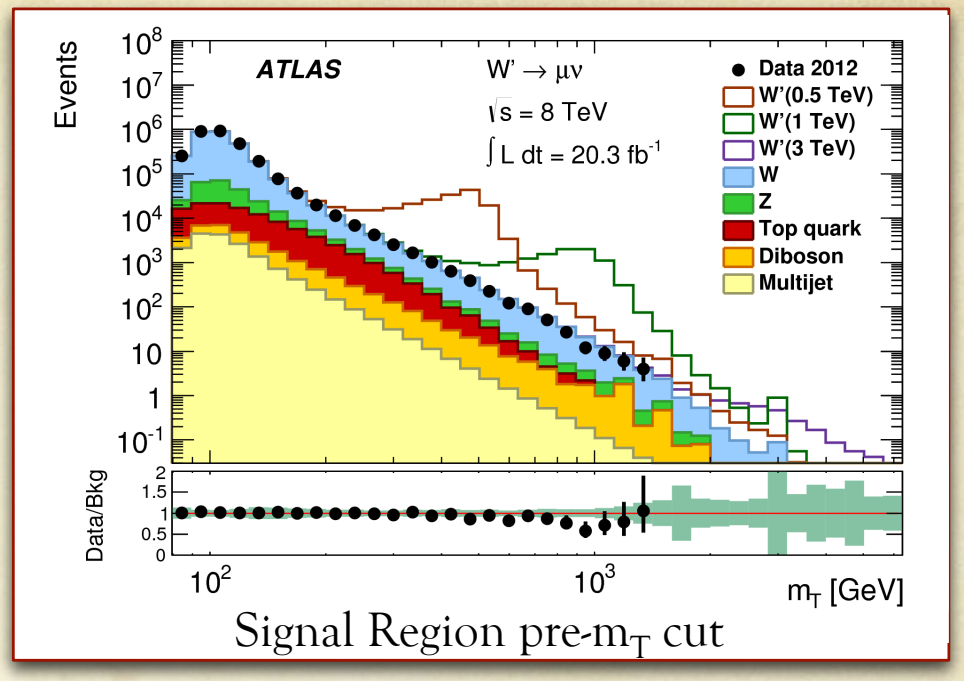
From MC with NLO generator

Reducible backgrounds

WW, top, Z→ττ from eμ data

Z+jets and W+jets from data CR.

Mono-W→ lν



Signal Regions

$m_T > m_{T\,\mathrm{min}} = 252$GeV and higher bins

Main backgrounds

Tail of the m_T distribution in W+jets

Z+jets with one non-reconstructed lepton

From NLO event generators+NNLO cross sections+higher order EW corrections K-factors per mass bin.

Additional backgrounds

top, diboson <10 %, from simulation.

Mono-Jet Based on L=10.5 fb^{-1}

One jet recoiling against missing energy

"Mono-jet"
- Leading jet with $|\eta|<2.5$
- ≤ 2 jets with $p_T>30$ GeV and $|\eta|<4.5$
- Veto events with leptons

Back to back & balanced configuration
- $\Delta\phi$(jet, E_T(miss)) > 0.5
- Same cut value on the jet p_T and E_T(miss)

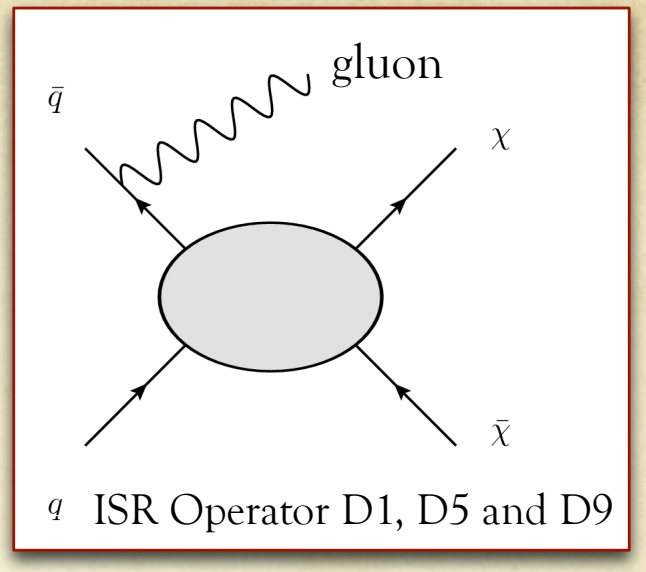
Signal Regions
p_T(jet1), E_T(miss)> 120, 220, 350, 500 GeV

Leading backgrounds

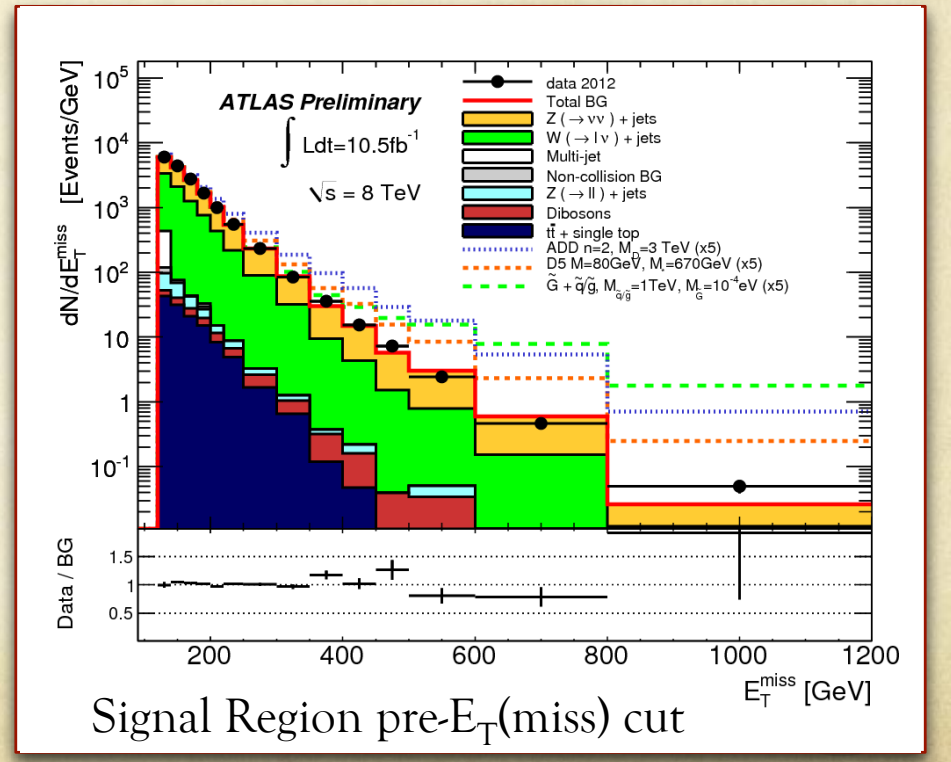
$(Z \rightarrow \bar{\nu}\nu) + jets$
$W/Z + jets$

} derived from a data W/Z control region with leptons

ATLAS CONF Note
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-147/

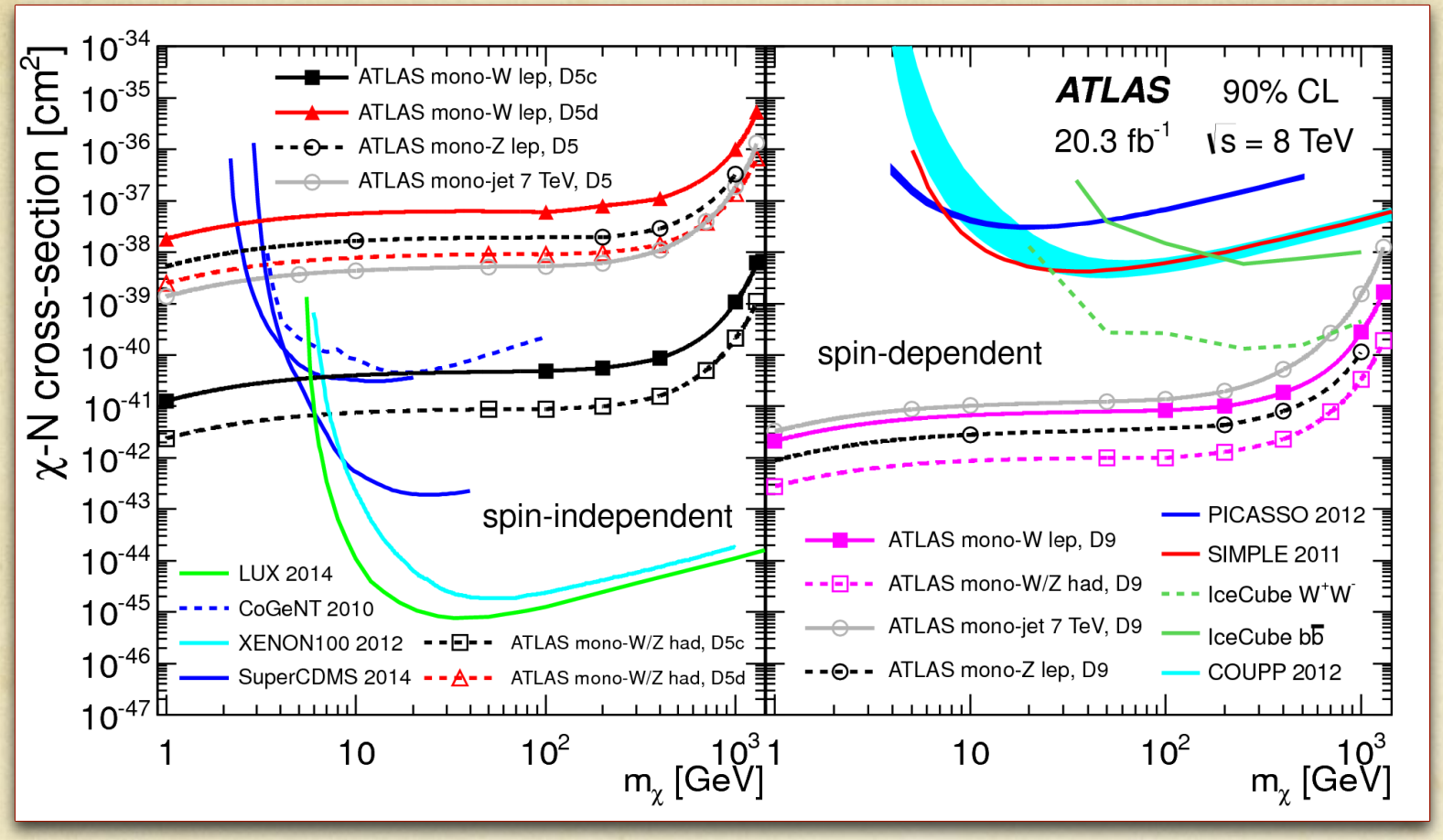


q ISR Operator D1, D5 and D9



Signal Region pre-E_T(miss) cut

Dark Matter mono-X Summary



Sensitivity of the signal regions at low m_χ is independent on m_χ.

Powerful spin-dependent limits over entire mass range

Powerful spin-independent at low mass.

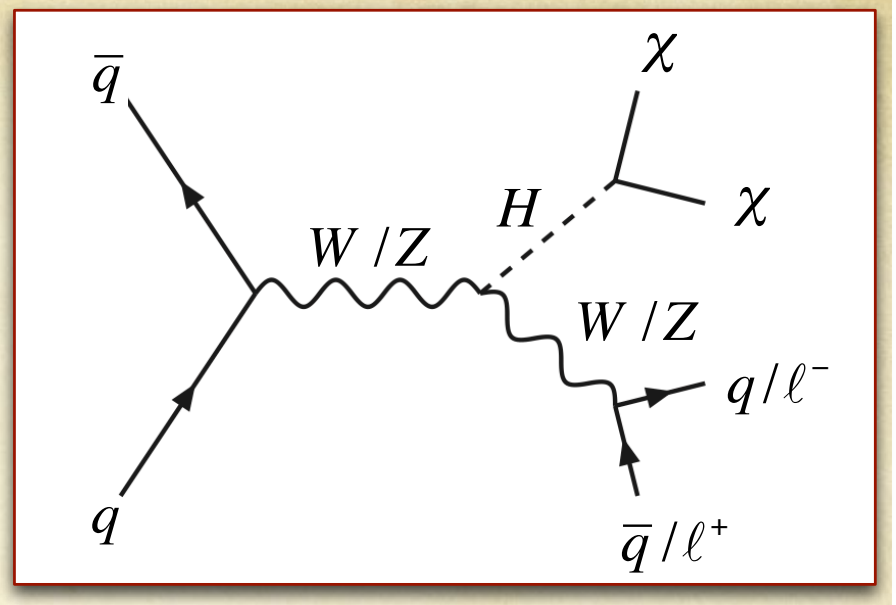
Validity of effective theory and effect on limits is under study in ATLAS.

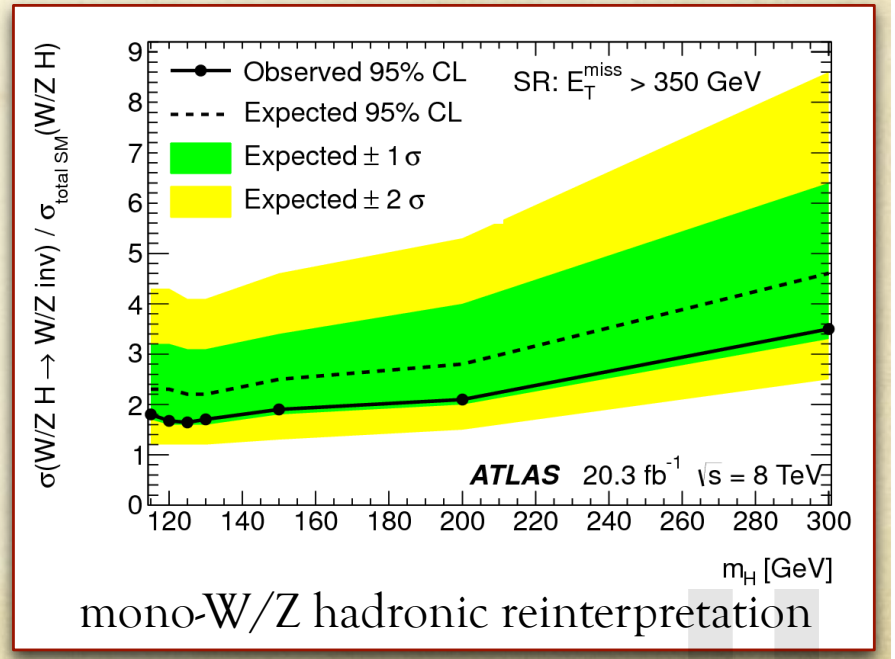
Invisible Higgs Search $H \to \chi\bar{\chi}$

DM particles search with $m_\chi < m_H/2$

1) Reinterpretation of mono-W/Z hadronic
   Phys. Rev. Lett. 112, 041802 (2014)

2) Dedicated search with $Z \to \ell^+\ell^-$
   Phys. Rev. Lett. 112, 201802 (2014)
   Selections close but not identical to that of mono-Z with leptonic decay.

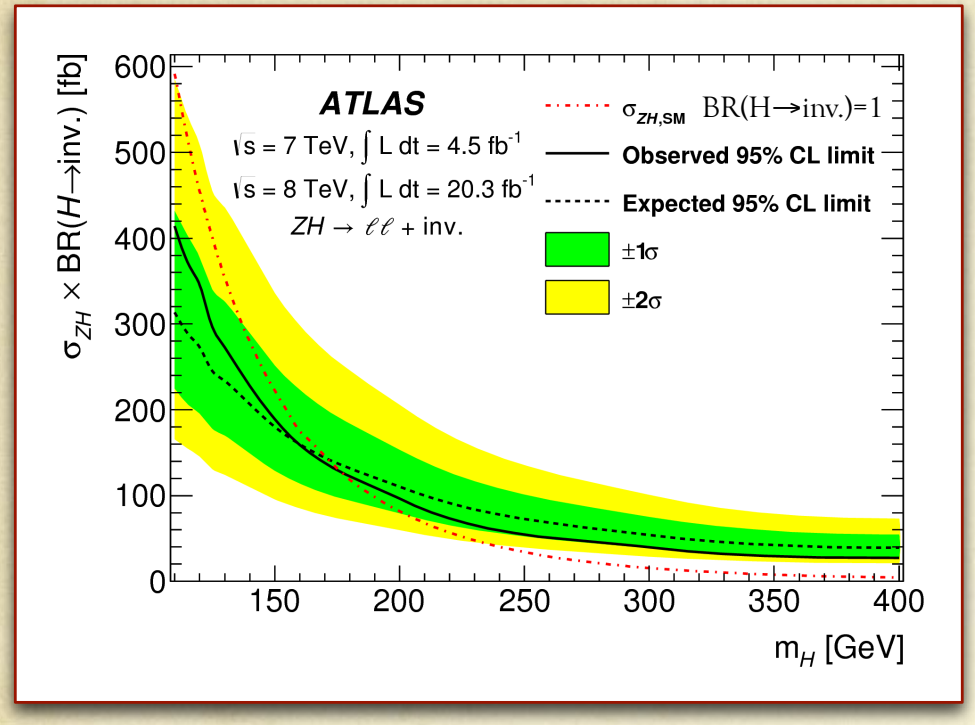


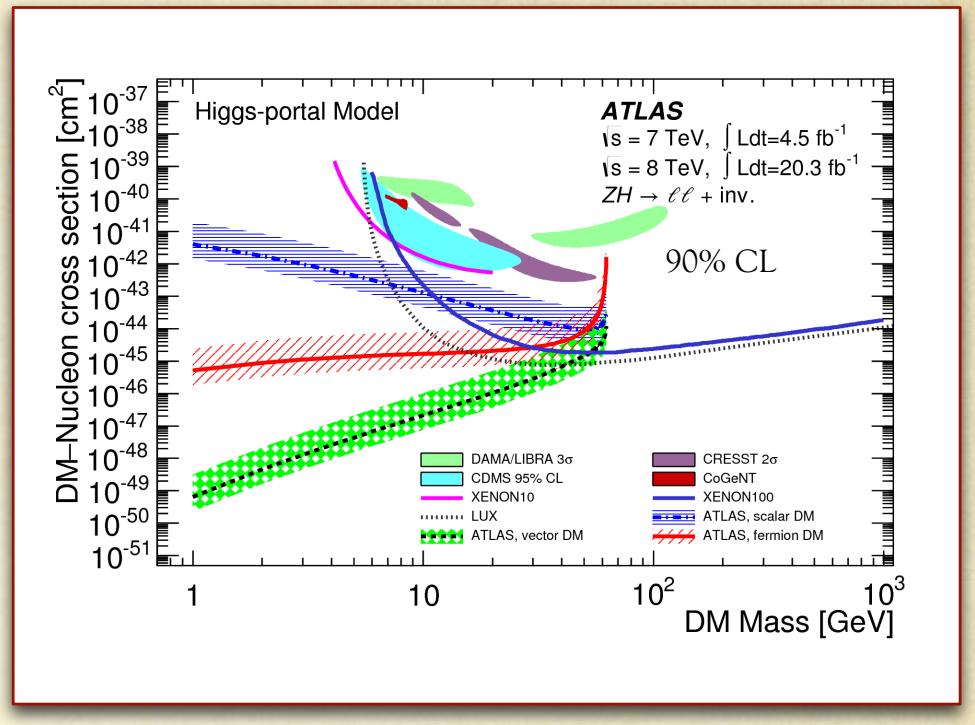


mono-W/Z hadronic reinterpretation

σ (W/Z+H $\to$ W/Z+inv.) / $\sigma_{W/Z+H}$ <1.6 for a Higgs mass of 125 GeV.

Invisible Higgs search $pp \rightarrow (Z \rightarrow \ell^+\ell^-)(H \rightarrow \chi\bar{\chi})$





95% CL upper limits on $\sigma_{ZH} \times$ BR(H $\rightarrow$inv.) in the mass range $110 < m_H < 400$ GeV

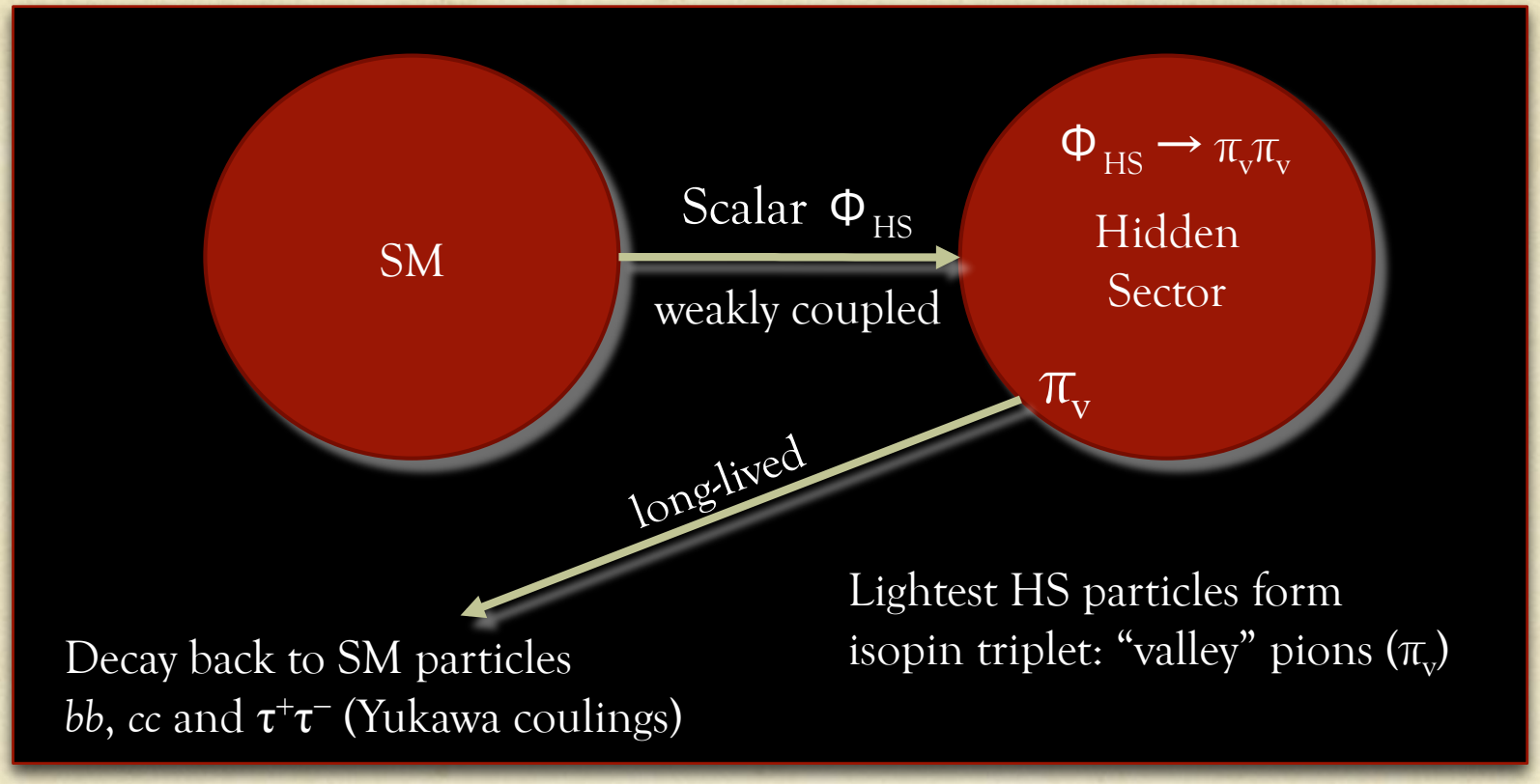
Upper limit of BR(H$\rightarrow$inv.)=0.75 at 95% CL
(Expected limit of 0.62 at 95% CL)

Higgs-portal DM scenario
Higgs boson is mediator between DM and SM.

Upper limit on the DM–nucleon scattering cross section.

DM candidate=
Scalar, vector or a Majorana fermion.

Searches for Hidden Sector (HS) with long-lived particles



Benchmark Model

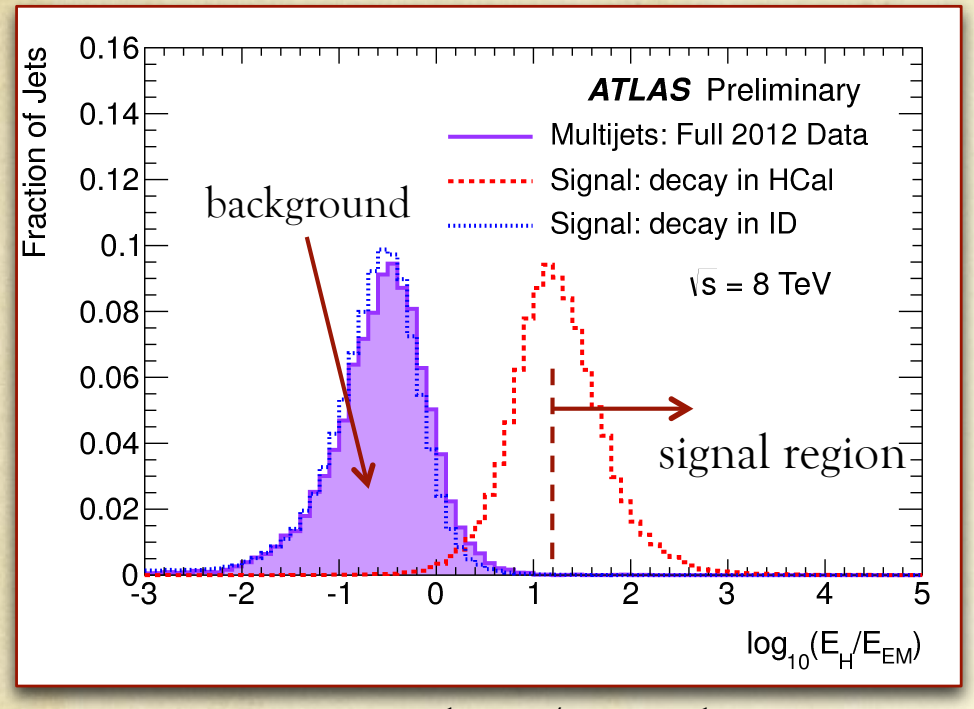
Scalar Φ_{HS} couples to mass in the same manner as the Higgs.
Confining gauge in HS => v-hadrons.

π_V is long-lived (LL)

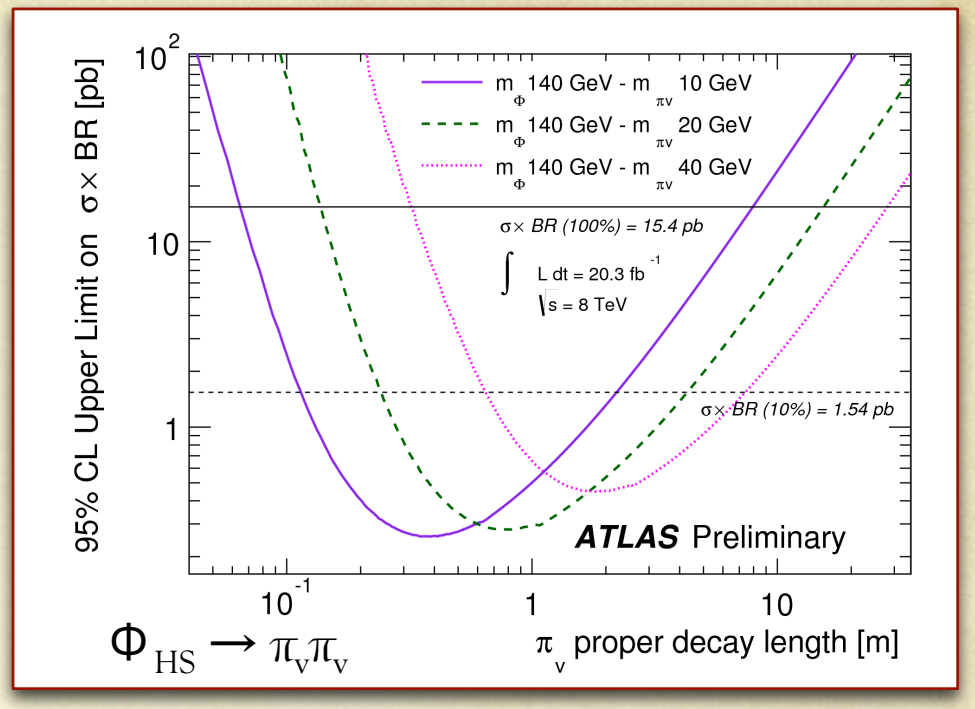
here present a search for π_v decays in the hadronic calorimeter or near the outer edge of the electromagnetic calorimeter.

ATLAS CONF Note
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2014-041/

CalRatio trigger looks for π_V decay near the outer radius of ECal or within the HCal.



energy ratio Hadron / EM calorimeter



exclusion limit on $\sigma \times BR$ for $m_{\Phi HS}$=140 GeV

Signal selection

Two jets must satisfy $\log_{10}(E_H/E_{EM}) > 1.2$

E_T(jet1)>60 GeV

No tracks close to the jets

E_T(miss) < 50 GeV

Main background= multijet, derived from data

Results for $m_{\Phi HS}$=126 GeV

MC sample m_Φ, $m_{\pi v}$ [GeV]	excluded range 30% BR $\Phi_{HS} \rightarrow \pi_v\pi_v$ [m]	excluded range 10% BR $\Phi_{HS} \rightarrow \pi_v\pi_v$ [m]
126, 10	0.10 - 4.38	0.13 - 2.30
126, 25	0.27 - 10.01	0.37 - 5.12
126, 40	0.54 - 12.11	0.86 - 5.62

Black Holes

Predicted in models with *n* extra dimensions. SM particles confined to 3+1 dimensions.

Fundamental gravity scale M_D given by $M_D^{2+n} = M_{Pl}^2 R^{-n}/8\pi$ could be O(1TeV)

Quantum

- BH most likely produced close to the production threshold M_{th}.
- Regime where M_{th} close to M_D, below classical BH regime => 2-particle states
- Strong gravity => more transverse (p_T) than background.
- Low particle multiplicity, possible decay to quark + lepton => violation of B and L.
- Look for lepton+jet signature, localised excess in **M(l,jet)**

Accepted by JHEP http://arxiv.org/abs/1405.4254

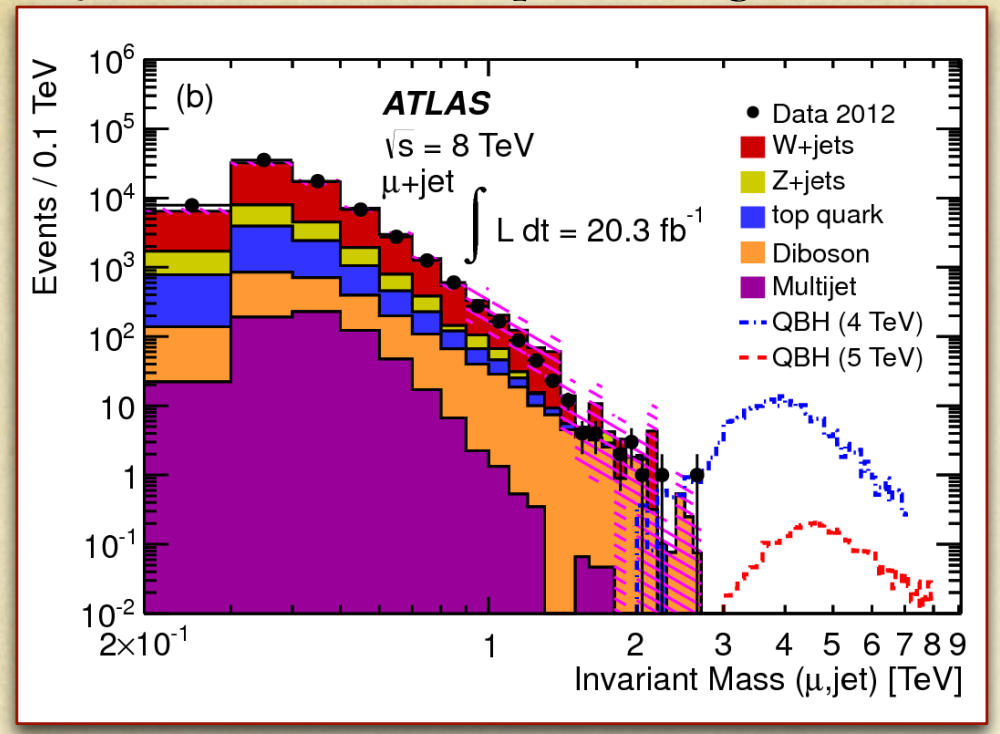
Classical

- Semiclassical, thermal black holes, approximation valid for $M_{th} >> M_D$
- Lose mass and angular momentum via Hawking radiation
- All types of SM particles are emitted
- Signature of high multiplicity of high p_T particles
- 1 high-p_T isolated lepton e/μ & ≥2 objects with p_T>100 GeV

$$\sum p_T = \sum_{\substack{i=leptons,\,jets \\ p_{T,i}>60\mathrm{GeV}}} p_{T,i} > 2000 \ \mathrm{GeV}$$

Phys. Rev. Lett. 112, 091804 (2014)

Quantum BH – two-particle signature



Signal Region

e or μ with p_T>130 GeV

≥1 jet with p_T>130 GeV

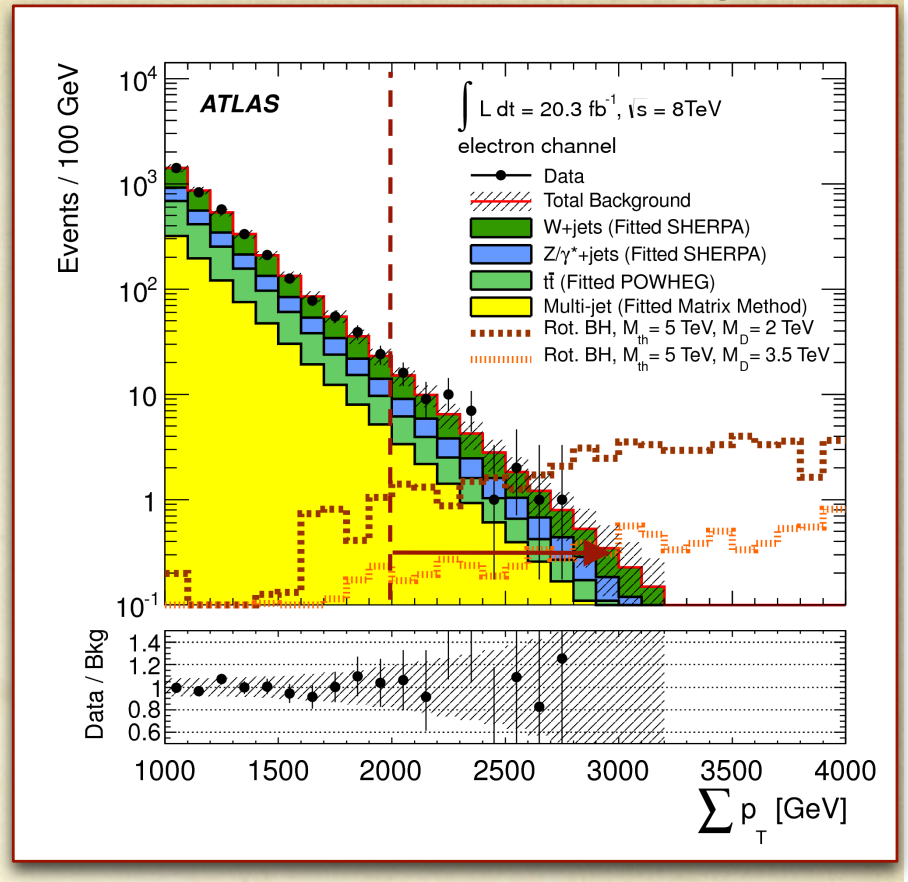
M(l,jet) > M_{min} with

e-channel M(l,jet) = $0.9M_{th}$

μ-channel M(l,jet) = $[0.95 - 0.05M_{th}/1TeV]M_{th}$

Multijet and EW background templates fitted to E_T(miss) (e-channel) and d0 (μ-channel) data distributions.

Classical BH – multiparticle signature



Signal region

e or μ with p_T>130 GeV

$\sum p_T > 2000$ GeV

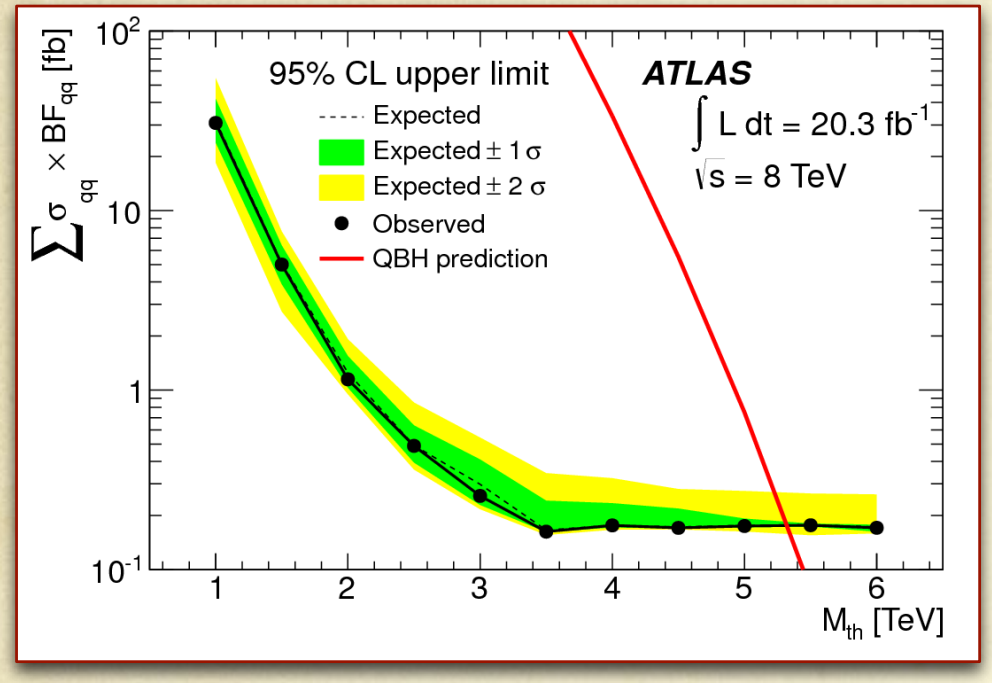
W/Z+jets and top background derived from control regions in data

Excellent agreement b/w data and prediction

Black Holes limits

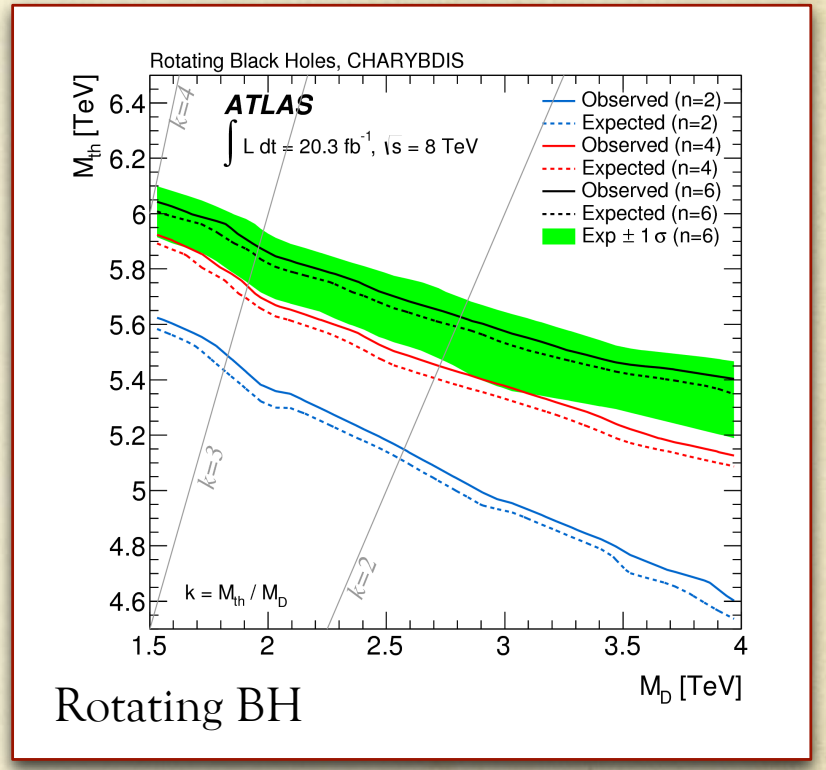
Quantum BH – two-particle signature

Upper limit on the QBH prediction from qq pairs



QBH excluded up to 5.5 TeV.

Classical BH – multiparticle signature



Rotating BH

eg. M_{th}=5.9 TeV excluded if M_D=2 TeV

ATLAS Classical BH limits cover:
- n=2,4,6 (non)-rotating BH
- string balls,
- high/low multiplicity remnants,
- **BLACKMAX**, **CHARYBDIS**
- 2 models of BH production losses.

Conclusions

ATLAS has set new stringent limits on Dark Matter production using multiple final states.

Particularly powerful in *spin-dependent case at all masses* and *low mass spin-independent*.

Hidden Valley search based on displaced particle decays was presented, uses dedicated triggers.

Classical and *Quantum black* hole searches have been performed in multiple scenarios.