Mono-jet searches

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on behalf of ATLAS and CMS Collaborations

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University of California Irvine
Mono-jet signature

- One of the highest sensitivity signatures for BSM, esp. for DM searches
- Search for (broad) excess in high $E_T^{\text{miss}}$ (MET) region
  - precise background estimation is vital
  - CMS: *PAS EXO-16-037* (submitted to JHEP) 13TeV (12.9 fb$^{-1}$ taken in 2016)

This talk reviews the similarity & difference of the two searches
for mono-V analysis there is a separate paper
Mono-jet Physics Model for WIMP DM

Search for pair produced DM with ISR jet which is used to tag the event

- Both experiments interpret results with Simplified models based on the suggestion from DM–Forum/Working Group to harmonize the models initial report: https://arxiv.org/abs/1507.00966
  - simplified model described by 4 parameters
    - $m_{DM}$, $m_{MED}$, $g_q$, $g_{DM(\chi)}$
    - minimal mediator width (no other invisible channel)
  - ISR jet + s–channel axial vector mediator (ATLAS)
  - ISR jet + axial–vector/vector/scalar/pseudo–scalar mediators (CMS)
Other Physics Model for mono–jet

- **Large Extra dimensions (ADD)**
  - production of KK tower of massive graviton modes
  - escape detection $\rightarrow$ MET
  - associating with high–$p_T$ jet

- **Compressed SUSY scenario**
  - squark pair production with relatively small mass gap
  - soft quark jets, MET $\rightarrow$ hard to detect out of QCD multi–jet BG
  - hard ISR jet + boosted squark pair (large MET)
The event selection and backgrounds
Baseline Event Selection Summary

Object definitions

- **Jets**: baseline: \( p_T > 20 \text{ GeV}, \mid \eta \mid < 2.8 \), JVT cut (pile up rejection), anti-\( kT \) \( R=0.4 \) based on topological clusters (ATLAS), particle flow (CMS)  
  signal: \( p_T > 30 \text{ GeV} \)

- **Electrons**: baseline: \( p_T > 20(10) \text{ GeV}, \mid \eta \mid < 2.47 (2.5) \)  
  signal: baseline + tight identification + IP cuts + track based isolation

- **Muons**: baseline: \( p_T > 10(10) \text{ GeV}, \mid \eta \mid < 2.5 (2.4) \)  
  signal: baseline + IP cuts

- (CMS) photon: \( p_T > 15 \text{ GeV} \)  
  tau: \( p_T > 18 \text{ GeV} \) used for event veto

- \( E_T^{\text{miss}} (H_T^{\text{miss}}) \): base line objects and track soft term, computed without baseline muons  
  (muons as invisible)

N.B. values in parentheses are ones for CMS

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trigger</strong></td>
<td>( E_T^{\text{miss}} ) &gt; 70 GeV</td>
<td>( E_T^{\text{miss}}, H_T^{\text{miss}} ) &gt; 90, 100, 110 GeV</td>
</tr>
<tr>
<td><strong>Leading Jet</strong></td>
<td>( p_T &gt; 250 \text{ GeV}, \mid \eta \mid &lt; 2.4 )</td>
<td>( p_T &gt; 100 \text{ GeV}, \mid \eta \mid &lt; 2.5 )</td>
</tr>
<tr>
<td><strong>( E_T^{\text{miss}} )</strong></td>
<td>( &gt; 250 \text{ GeV} )</td>
<td>( &gt; 200 \text{ GeV} )</td>
</tr>
<tr>
<td><strong>multijet BG rejection</strong></td>
<td>( \Delta \Phi(p_T^{\text{miss}}, \text{jets}(1,2,3,4)) &gt; 0.4 ) ( N_{\text{JETS}} (p_T &gt; 30 \text{ GeV}) \leq 4 )</td>
<td>( \Delta \Phi(E_T^{\text{miss}}, \text{jets}(1,2,3,4)) &gt; 0.5 ) ( N_{\text{JETS}} ) could be any</td>
</tr>
<tr>
<td><strong>NCB rejection</strong></td>
<td>Leading jet ( \mid \eta \mid &lt; 2.4 ) passes tight cleaning</td>
<td>jet energy charged &gt;10%, neutral &lt; 80%</td>
</tr>
</tbody>
</table>
Background composition overview

- **Dominant BG:** MC + global fit
  - Z (νν) + jets
    - irreducible, dominant esp. in high MET
  - W(lν) + jets
    - irreducible when leptons are out of acceptance or from the detector inefficiency

- **Other BG:**
  - Z/γ*(ll) + jets: MC+global fit (ATLAS uses MC for Z/γ*(ee))
  - ttbar, single top, di–boson: MC only
  - QCD multi–jet, Non–collision BG: data driven estimate

*ATLAS*  |  CMS
---|---
(250 GeV)  | 
Others  | 3% W+jets
6% W+jets  | 34%
Z+jets  | 63%
(750 GeV)  | 
Others  | 3% W+jets
11% W+jets  | 16%
22% W+jets  | 22%
Z+jets  | 81%
58% W+jets  | 35%
The Analysis Strategy
Strategy for mono-jet in ATLAS

• **Signal Regions**

<table>
<thead>
<tr>
<th>Inclusive signal region</th>
<th>IM1</th>
<th>IM2</th>
<th>IM3</th>
<th>IM4</th>
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<td>$E^\text{miss}_{T}$ (GeV)</td>
<td>&gt; 250</td>
<td>&gt; 300</td>
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<td>[300–350]</td>
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<td>[400–500]</td>
<td>[500–600]</td>
<td>[600–700]</td>
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7 exclusive SRs

• SR (7 MET bin) accompany 3 x CR each

**SR**

veto on baseline leptons

**di- muon CR**

- exactly two $\mu$, no e
- 66 GeV < $M_{\mu\mu}$ < 116 GeV
- target BG: $Z/\gamma^* (\mu\mu)$+jets

**single electron CR**

- exactly one isolated e, no $\mu$
- target backgrounds: $W(e\nu)$+jets, $W(\tau\nu)$+jets, $Z/\gamma^* (\tau\tau)$+jets

**single muon CR**

- exactly one $\mu$, no e
- 30 GeV < $M_T$ < 100 GeV
- target BGs: $W(\mu\nu)$+jets, $Z(\nu\nu)$+jets

perform global fit and derive 3 scale factors to normalize EW backgrounds
Analysis strategy in ATLAS (cont’d)

3x $E_T^{\text{miss}}$ dependent normalization factors
($f_{W \to e}^{\text{bin}}$, $f_{W \to \mu}^{\text{bin}}$, $f_{Z \to \mu\mu}^{\text{bin}}$) used to constraint the EW backgrounds in each CR

<table>
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<tr>
<th>Control Regions</th>
<th>background process</th>
<th>norm. factor</th>
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<tr>
<td>$W \to e\nu$ (single-e)</td>
<td>$W(e\nu)$+jets, $W(\tau\nu)$+jets, $Z/\gamma^* (\tau\tau)$+jets</td>
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<td>$Z \to \mu\mu$ (di-muon)</td>
<td>$Z/\gamma^* (\mu\mu)$+jets</td>
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$W, Z$ boson events are generated with Sherpa-2.1.1, up to 2 (4) -parton at NLO (LO)

$Z(\nu\nu)$ + jets

- transfer distribution from $W(\mu\nu)$ CR
- statistical power (7x $Z(\mu\mu)$+jets), partial systematic cancelation

\[
N_{\text{signal}}^{Z(\nu\nu)} = \frac{N_{\text{data, control}}^{W(\to \mu\nu)} - N_{\text{non-W, control}}^{W(\to \mu\nu)}}{N_{\text{MC, control}}^{Z(\nu\nu)}} \times \frac{N_{\text{MC, signal}}^{Z(\nu\nu)}}{N_{\text{MC, control}}^{W(\to \mu\nu)}}
\]
Objective: performed global fit to derive scale factor for EW backgrounds

$E_T^{\text{miss}}$ calculation includes EM cluster, and not corrected for muon

$W(e\nu)$ CR: $W(e\nu)$+jets, $W(\tau\nu)$+jets, $Z/\gamma^*$ ($\tau\tau$)+jets

$W(\mu\nu)$ CR: $W(\mu\nu)$+jets, $Z(\nu\nu)$+jets

Data 2015
- Standard Model
- $Z(\nu\nu)$+jets
- $W(\rightarrow e\nu)$+jets
- $W(\rightarrow \mu\nu)$+jets
- Dibosons
- $t\bar{t}$+single top

Data/SM vs. $E_T^{\text{miss}}$ [GeV]

- $\sqrt{s} = 13$ TeV, 3.2 fb$^{-1}$
- $p_\perp > 250$ GeV, $E_T^{\text{miss}} > 250$ GeV

Data and prediction for IM1 (MET>250GeV) selection
after the fit in exclusive MET bins, gray band: stat. + syst. errors after the fit
Di-muon CR in ATLAS (post fit)

- objective: estimate \(Z(\mu\mu)+\text{jets}\) in SR
  \(E_T^{\text{miss}}\) is not corrected for muons (muons considered as invisible)
- performed global fit to derive scale factor for EW backgrounds

\[ N(\text{signal muon}) = 2, \quad N(\text{base electron}) = 0 \]

\(66 \text{ GeV} < m_{\mu\mu} < 116 \text{ GeV}\)

data and prediction for IM1 (\(\text{MET}>250\text{GeV}\)) selection after the fit in exclusive MET bins
gray band: stat. + syst. errors after the fit
Other backgrounds in ATLAS

MC based estimation
- Z(ee)+jets
- ttbar, single top, di–boson

Multi-jet BG
- fake $E_T^{\text{miss}}$, from mis–measured jets
- estimated from jet smearing & inverted dΦ (jet, MET)
- negligible in high MET

NCB (Non Collision BG )
- Cosmic or Beam–induced background
- jet cleaning reduction < 0.1 %
- residual events can be tagged by matching calorimeter and muon segment
- almost negligible contributions in SR
Analysis strategy in CMS

- Signal region
  - mono-jet (\& mono-V category)
- 5x Control regions for each SR
  - 5 CRs to constrains 2 major BGs ($Z(\nu\nu)+\text{jets}$, $W(l\nu)+\text{jets}$)

\begin{itemize}
  \item $\gamma + \text{jets CR}$
  \item $Z(\nu\nu) + \text{jets BG}$
  \item $Z(ll) \text{ CR } l = e, \mu$
  \item $W(l\nu) + \text{jets BG}$
  \item $W(l\nu) \text{ CR } l = e, \mu$
\end{itemize}

pass the V-tag (AK8, mass, etc)
see backup slide
Analysis strategy in CMS

- Transfer factor to translate recoil (in CR) to missing $E_T$ (in SR)
- Global likelihood fit simultaneously to SR+5CR regions in all $E_T^{\text{miss}}$ bins

\[
\mathcal{L}_k(\mu^{Z(\nu\bar{\nu})}, \mu, \theta) = \prod_i \text{Poisson} \left( d_i^i | B_i^i(\theta) + \frac{\mu_i^{Z(\nu\bar{\nu})}}{R_i^i(\theta)} \right) \\
\times \prod_i \text{Poisson} \left( d_i^{\mu\mu} | B_i^{\mu\mu}(\theta) + \frac{\mu_i^{Z(\nu\bar{\nu})}}{R_i^{\mu\mu}(\theta)} \right) \\
\times \prod_i \text{Poisson} \left( d_i^{ee} | B_i^{ee}(\theta) + \frac{\mu_i^{Z(\nu\bar{\nu})}}{R_i^{ee}(\theta)} \right) \\
\times \prod_i \text{Poisson} \left( d_i^{\mu} | B_i^{\mu}(\theta) + \frac{f_i(\theta) \mu_i^{Z(\nu\bar{\nu})}}{R_i^{\mu}(\theta)} \right) \\
\times \prod_i \text{Poisson} \left( d_i^{e} | B_i^{e}(\theta) + \frac{f_i(\theta) \mu_i^{Z(\nu\bar{\nu})}}{R_i^{e}(\theta)} \right) \\
\times \prod_i \text{Poisson} \left( d_i | B_i(\theta) + (1 + f_i(\theta)) \mu_i^{Z(\nu\bar{\nu})} + \mu S_i(\theta) \right)
\]

\[\mu_i^{W\rightarrow ll} \rightarrow f_i(\theta) \cdot \mu_i^{Z\rightarrow \nu\bar{\nu}} \quad \mu_i : \text{yields} \quad R_i : \text{transfer factor}\]

Constraints from transfer factors, only one free parameter to fit
Transfer factors in CMS

1. $Z(\mu\mu)$ CR $\rightarrow$ $Z(\nu\nu)$

2. $\gamma +$ jets CR $\rightarrow$ $Z(\nu\nu)$

3. $W(\mu\nu)$ CR $\rightarrow$ $W(l\nu)$

4. $W(l\nu) \rightarrow Z(\nu\nu)$

factorization/renormalization scale

- $\gamma +$ jets CR
- $\times R^\gamma_i$
- $\times f_i(\theta) \cdot \mu^{Z\rightarrow\nu\nu}_i$
- $Z(\nu\nu) +$ jets
- $W(l\nu) +$ jets
- $\times R^Z_i$
- $\times R^W_i$

Events are generated with MadGraph (LO) and corrected to NLO from DM WG public meeting 19 Sep 2016
CR distributions in CMS (1)

- post-fit predictions match well with data in all CRs
CR distributions in CMS (2)

- Post-fit predictions match well with data in all CRs

**single-muon CR**

**single-electron CR**
Systematics uncertainties in ATLAS

Background theoretical uncertainties
- Normalization, factorization, PS–ME matching scale, PDFs
  - for Sherpa W/Z 1.1 – 1.3 %
  - for top backgrounds 2.7 – 3.3 %
- Diboson generator difference: 0.05 – 0.4%
- Multi-jet background: 0.2 %

W/Z+jets modeling (Z(vv) in SR)
- lepton rec, eff, acceptance 3% flat uncertainties for all MET bins
- NLO EW radiative corrections: 1.9% for IM1, 5.2% for IM7

Experimental uncertainties
- jet, MET scale: 0.5 – 1.6 %
- jet quality requirements, pile-up description/correction to jet/MET: 0.2–0.9%
- lepton ID, reconstr Eff., energy scale/resolutions: 0.1–2.6% in IM7
- luminosity: 5%
- statistical uncertainties for CRs: 2.5 – 10%

Signal uncertainties
- jet/MET reconstruction, energy scale, resolution, luminosity
- gluon radiation model: shower parameters, $\alpha_s$, renom./factor. scale
- jet quality requirement < 1%

Overall uncertainties (stat. + sys.): 4.0%(IM1), 6.8%(IM5), 12% (IM7)
Systematics uncertainties in CMS

**Background theoretical uncertainties**

- top backgrounds: relative 10%
  - b–veto: 6%
- Diboson generator difference: relative 20%
  - b–veto: 2%
- Multi–jet background: relative 50–150%

**Experimental uncertainties**

- luminosity: 6.2%
- $E_T^{\text{miss}}$ modeling (jet energy scale): 5%
- lepton reconstruction: 1%
  - selection: 2%

**W/Z/γ+jets modeling**

- $\gamma$+jets to Z+jets, W+jets to Z+jets differential cross section ratios
  - renormalization (10–15%)
  - factorization (1–10%)
  - PDF (negligible)
- NLO EW corrections
  - $\gamma$+jets (2–14%), W+jets (1–9%)
The Results
Results (Signal Region) in ATLAS

- $\sqrt{s} = 13$ TeV, 3.2 fb$^{-1}$
- Signal Region $p_T > 250$ GeV, $E_{T}^{miss} > 250$ GeV

Table:

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<tr>
<td>Observed events (3.2 fb$^{-1}$)</td>
<td>21447</td>
<td>11975</td>
<td>6433</td>
<td>3494</td>
<td>1170</td>
<td>423</td>
<td>185</td>
</tr>
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<td>SM prediction</td>
<td>$21730 \pm 940$</td>
<td>$12340 \pm 570$</td>
<td>$6570 \pm 340$</td>
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<tr>
<td>Observed events (3.2 fb$^{-1}$)</td>
<td>9472</td>
<td>5542</td>
<td>2939</td>
<td>2324</td>
<td>747</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>SM prediction</td>
<td>$9400 \pm 410$</td>
<td>$5770 \pm 260$</td>
<td>$3210 \pm 170$</td>
<td>$2260 \pm 140$</td>
<td>$686 \pm 50$</td>
<td>$271 \pm 28$</td>
<td></td>
</tr>
</tbody>
</table>

Graphs:

- Data 2015
- Standard Model
- $Z(\rightarrow \nu\nu) +$ jets
- $W(\rightarrow \nu\nu) +$ jets
- $W(\rightarrow l\nu) +$ jets
- $Z(\rightarrow l l) +$ jets
- Dibosons
- $t\bar{t} +$ single top
- $m(D, Z) = (350, 345)$ GeV
- $(m_{out}, M_{med}) = (150, 1000)$ GeV
- ADD, $n=3$, $M_{DM}=5600$ GeV

ATLAS leading jet $p_T$ [GeV]

ATLAS Data / SM

ATLAS no significant excess observed
Results in ATLAS

post-fit predictions match well with data in SR/CRs

<table>
<thead>
<tr>
<th>Signal channel</th>
<th>$\langle \sigma \rangle_{\text{obs}}^{95}$ [fb]</th>
<th>$S_{\text{obs}}^{95}$</th>
<th>$S_{\text{exp}}^{95}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IM1</td>
<td>553</td>
<td>1773</td>
<td>1864$^{+829}_{-548}$</td>
</tr>
<tr>
<td>IM2</td>
<td>308</td>
<td>988</td>
<td>1178$^{+541}_{-348}$</td>
</tr>
<tr>
<td>IM3</td>
<td>196</td>
<td>630</td>
<td>694$^{+308}_{-204}$</td>
</tr>
<tr>
<td>IM4</td>
<td>153</td>
<td>491</td>
<td>401$^{+168}_{-113}$</td>
</tr>
<tr>
<td>IM5</td>
<td>61</td>
<td>196</td>
<td>164$^{+63}_{-45}$</td>
</tr>
<tr>
<td>IM6</td>
<td>23</td>
<td>75</td>
<td>84$^{+32}_{-23}$</td>
</tr>
<tr>
<td>IM7</td>
<td>19</td>
<td>61</td>
<td>48$^{+18}_{-13}$</td>
</tr>
</tbody>
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- model independent 95% C.L. upper limits on
  - signal events
  - visible cross sections for each $E_T^{\text{miss}}$ bin
- 553 — 19 fb obtained
Results (Signal Region) in CMS

The last bin is an overflow.

post combined fit only in CRs

gray band: post fit uncertainty

no signal excess (small non-significant deficits)
DM Interpretations
DM interpretation (Mediator mass vs. WIMP (DM) mass)

• In ATLAS (L=3.2 fb\(^{-1}\)), observed (expected) limit on Mediator mass at 1.0 TeV (1.2 TeV) for WIMP mass below 250 GeV (300 GeV) at 95% CL

• In CMS (L=12.9 fb\(^{-1}\)), observed (expected) limit on Mediator mass at 1.95 TeV (1.7 TeV) for WIMP mass below 450 GeV (600 GeV) at 95% CL
DM interpretation (DM–nucleon scattering cross–sections)

Axial vector mediator $g_q=0.25$, $g_{DM}=1.0$

**ATLAS**

- $\sqrt{s} = 13$ TeV, $3.2 \text{ fb}^{-1}$

**CMS**

- Axial-vector med, Dirac DM, $g_q = 0.25$, $g_{DM} = 1$

- 12.9 fb$^{-1}$ (13 TeV)

---

for WIMP masses **below 10 GeV** with **90% CL**,

- In ATLAS, WIMP–nucleon spin dependent cross sections above $10^{-42} \text{ cm}^2$ excluded
- In CMS, WIMP–proton spin dependent cross sections above $10^{-43} \text{ cm}^2$ excluded

---

Other interpretations in ATLAS

- SUSY: interpreted in terms of stop pair production in a compressed scenarios
  stop masses **below 323 GeV** are excluded in 95% C.L.
  (sbottom/squark mass below 323/608 GeV are excluded in 95% C.L.)

- ADD Large Extra Dimension Model:
  **6.58 TeV at n=2** is excluded

- significant improvement against Run–1 result
Other interpretations in CMS

- WIMP–nucleon spin independent cross sections above $10^{-42}\text{cm}^2$ for WIMP masses below 10 GeV excluded at 90% C.L. with **Vector type mediator**
- WIMP–nucleon spin independent cross sections above $10^{-45}\text{cm}^2$ for WIMP masses below 10 GeV excluded at 90% C.L. with **Scalar type mediator**
Summary of mono-jet searches

- Mono-jet is one of the most powerful channel in searching for DM by collider experiments
- ATLAS and CMS performed searches for mono-jet signature using different approaches
- No excesses were observed, limits were set accordingly
- The results were interpreted with DM models, limits on
  - mediator & DM masses
  - nucleon scattering cross sections, were obtained
Extra materials
V-tagging in CMS

- Events are classified into mono-V or mono-jet
- Mono-V selection:
  - MET > 250 GeV
  - leading AK8 (anti-kT distant parameter 0.8) jet > 250 GeV
  - jet mass between 65 and 105 GeV
    - after pruning
  - \( \tau_N \) (N sub-jettiness variable): \( \tau_2/\tau_1 < 0.6 \)
- Mono-jet
  - the events which failed mono-V selection
 EVENT YIELDS IN SRs (ATLAS)

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TABLE VIII. Data and SM background predictions in the signal region for the different selections. For the SM predictions both the statistical and systematic uncertainties are included.

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</tr>
<tr>
<td>SM prediction</td>
<td>9400 ± 410</td>
<td>5770 ± 260</td>
<td>3210 ± 170</td>
<td>2260 ± 140</td>
<td>686 ± 50</td>
<td>271 ± 28</td>
</tr>
</tbody>
</table>
Table 1: Expected event yields in each $E_T^{\text{miss}}$ bin for various background processes in the mono-jet signal region. The background yields and the corresponding uncertainties are obtained after performing a combined fit to data in all the control samples, but excluding data in the signal region. The observed event yields in the monojet signal region are also reported.

<table>
<thead>
<tr>
<th>$E_T^{\text{miss}}$ [GeV]</th>
<th>$Z(\nu\nu) + \text{jets}$</th>
<th>$W(\ell\nu) + \text{jets}$</th>
<th>Top quark</th>
<th>Dibosons</th>
<th>Other</th>
<th>Total bkg.</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>200–230</td>
<td>71300 ± 2200</td>
<td>54600 ± 2300</td>
<td>2140 ± 320</td>
<td>1320 ± 220</td>
<td>2470 ± 310</td>
<td>132100 ± 4000</td>
<td>140642</td>
</tr>
<tr>
<td>230–260</td>
<td>39500 ± 1300</td>
<td>27500 ± 1200</td>
<td>1060 ± 160</td>
<td>790 ± 130</td>
<td>1090 ± 130</td>
<td>69900 ± 2200</td>
<td>73114</td>
</tr>
<tr>
<td>260–290</td>
<td>21900 ± 670</td>
<td>13600 ± 550</td>
<td>440 ± 65</td>
<td>364 ± 61</td>
<td>498 ± 65</td>
<td>36800 ± 1100</td>
<td>38321</td>
</tr>
<tr>
<td>290–320</td>
<td>12900 ± 400</td>
<td>7300 ± 290</td>
<td>210 ± 31</td>
<td>235 ± 40</td>
<td>216 ± 30</td>
<td>20780 ± 630</td>
<td>21417</td>
</tr>
<tr>
<td>320–350</td>
<td>8000 ± 280</td>
<td>4000 ± 170</td>
<td>107 ± 16</td>
<td>145 ± 24</td>
<td>124 ± 18</td>
<td>12340 ± 400</td>
<td>12525</td>
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<tr>
<td>350–390</td>
<td>6100 ± 220</td>
<td>2800 ± 130</td>
<td>74 ± 11</td>
<td>111 ± 19</td>
<td>87 ± 13</td>
<td>9160 ± 320</td>
<td>9515</td>
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<tr>
<td>390–430</td>
<td>3500 ± 160</td>
<td>1434 ± 66</td>
<td>30.1 ± 4.5</td>
<td>58.4 ± 9.9</td>
<td>33.4 ± 5.3</td>
<td>5100 ± 200</td>
<td>5174</td>
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<tr>
<td>430–470</td>
<td>2100 ± 98</td>
<td>816 ± 37</td>
<td>16.6 ± 2.5</td>
<td>42.4 ± 7.1</td>
<td>16.3 ± 2.7</td>
<td>3000 ± 120</td>
<td>2947</td>
</tr>
<tr>
<td>470–510</td>
<td>1300 ± 66</td>
<td>450 ± 20</td>
<td>7.4 ± 1.1</td>
<td>24.6 ± 4.1</td>
<td>9.6 ± 1.6</td>
<td>1763 ± 79</td>
<td>1777</td>
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<tr>
<td>510–550</td>
<td>735 ± 39</td>
<td>266 ± 13</td>
<td>5.2 ± 0.8</td>
<td>18.5 ± 3.1</td>
<td>7.0 ± 1.3</td>
<td>1032 ± 48</td>
<td>1021</td>
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<tr>
<td>550–590</td>
<td>513 ± 31</td>
<td>152 ± 8</td>
<td>2.4 ± 0.4</td>
<td>13.5 ± 2.3</td>
<td>1.1 ± 0.3</td>
<td>683 ± 37</td>
<td>694</td>
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<tr>
<td>590–640</td>
<td>419 ± 23</td>
<td>120 ± 6</td>
<td>1.5 ± 0.2</td>
<td>10.6 ± 1.8</td>
<td>2.1 ± 0.4</td>
<td>554 ± 28</td>
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<tr>
<td>640–690</td>
<td>246 ± 16</td>
<td>62.8 ± 3.8</td>
<td>1.3 ± 0.2</td>
<td>11.4 ± 1.9</td>
<td>1.0 ± 0.2</td>
<td>322 ± 19</td>
<td>339</td>
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<tr>
<td>690–740</td>
<td>139 ± 11</td>
<td>34.2 ± 2.4</td>
<td>0.6 ± 0.1</td>
<td>4.2 ± 0.7</td>
<td>0.20 ± 0.07</td>
<td>178 ± 13</td>
<td>196</td>
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<tr>
<td>740–790</td>
<td>97.2 ± 7.2</td>
<td>22.7 ± 1.7</td>
<td>0.22 ± 0.03</td>
<td>1.4 ± 0.2</td>
<td>0.63 ± 0.12</td>
<td>122 ± 8</td>
<td>123</td>
</tr>
<tr>
<td>790–840</td>
<td>59.8 ± 5.8</td>
<td>12.9 ± 1.2</td>
<td>0.13 ± 0.02</td>
<td>1.5 ± 0.3</td>
<td>0.05 ± 0.02</td>
<td>74.5 ± 6.6</td>
<td>80</td>
</tr>
<tr>
<td>840–890</td>
<td>64.3 ± 6.4</td>
<td>12.3 ± 1.1</td>
<td>0.24 ± 0.04</td>
<td>0.92 ± 0.1</td>
<td>0.03 ± 0.01</td>
<td>77.8 ± 7.2</td>
<td>68</td>
</tr>
<tr>
<td>900–960</td>
<td>31.5 ± 4.3</td>
<td>6.0 ± 0.7</td>
<td>0.21 ± 0.03</td>
<td>0.74 ± 0.1</td>
<td>0.01 ± 0.01</td>
<td>38.4 ± 4.8</td>
<td>37</td>
</tr>
<tr>
<td>960–1020</td>
<td>20.8 ± 3.0</td>
<td>3.4 ± 0.5</td>
<td>—</td>
<td>0.94 ± 0.2</td>
<td>0.01 ± 0.01</td>
<td>25.1 ± 3.4</td>
<td>23</td>
</tr>
<tr>
<td>1020–1090</td>
<td>16.3 ± 2.6</td>
<td>3.1 ± 0.5</td>
<td>0.04 ± 0.01</td>
<td>1.6 ± 0.3</td>
<td>0.01 ± 0.01</td>
<td>21.1 ± 3.0</td>
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<tr>
<td>1090–1160</td>
<td>8.1 ± 1.8</td>
<td>1.3 ± 0.3</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>9.4 ± 1.9</td>
<td>7</td>
</tr>
<tr>
<td>&gt;1160</td>
<td>18.6 ± 2.7</td>
<td>2.7 ± 0.4</td>
<td>—</td>
<td>1.3 ± 0.2</td>
<td>—</td>
<td>22.6 ± 3.0</td>
<td>26</td>
</tr>
</tbody>
</table>
Systematic error direct comparison