Turbulence Measurements with Hot Wires in High Reynolds Number Boundary Layers

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and
the ICET TEAM

Data in the presentation

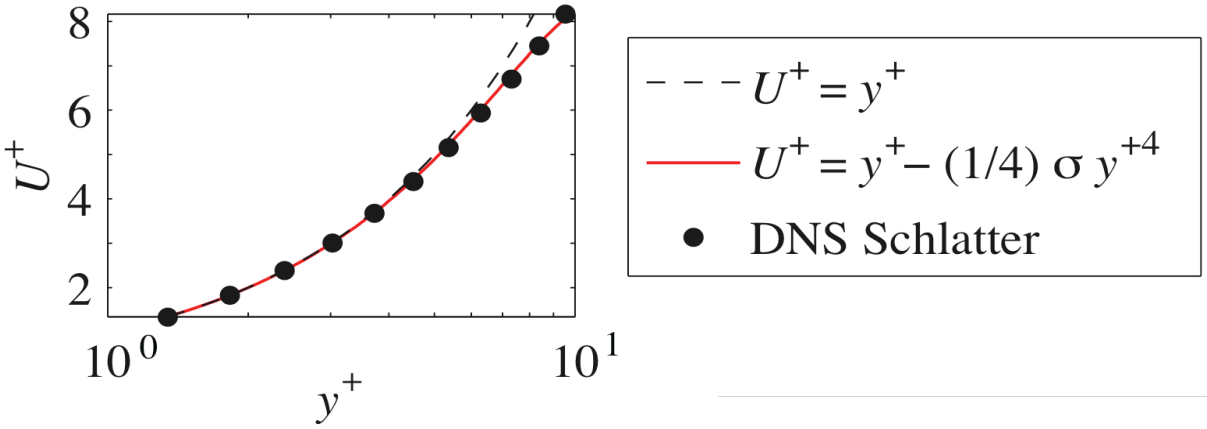
- Group@Facility
  - **MEL@KTH** (3 profiles, L+ = 27, 28, 27)
  - **MEL@MEL** (2-3 profiles, L+ = 29, 28, 23)
  - **KTH@KTH** (3 profiles, L+ = 24, 34, 45)
  - **KTH@MEL** (3 profiles, L+ = 15, 14, 12)
- Reynolds numbers
  - **L** Re = 11 800 (averaged)
  - **M** Re = 16 500 (averaged)
  - **H** Re = 21 200 (averaged)

Content of presentation

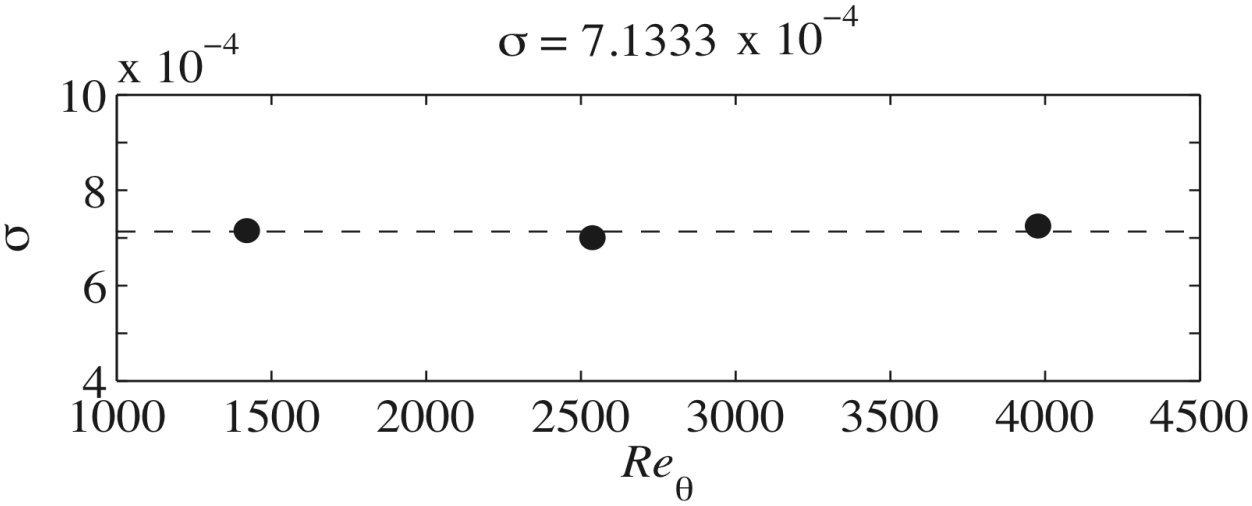
- Method of wall determination
- Re-effects on variance(u) and higher order moments
- Streamwise energy spectra and L+ effects

Method of wall determination

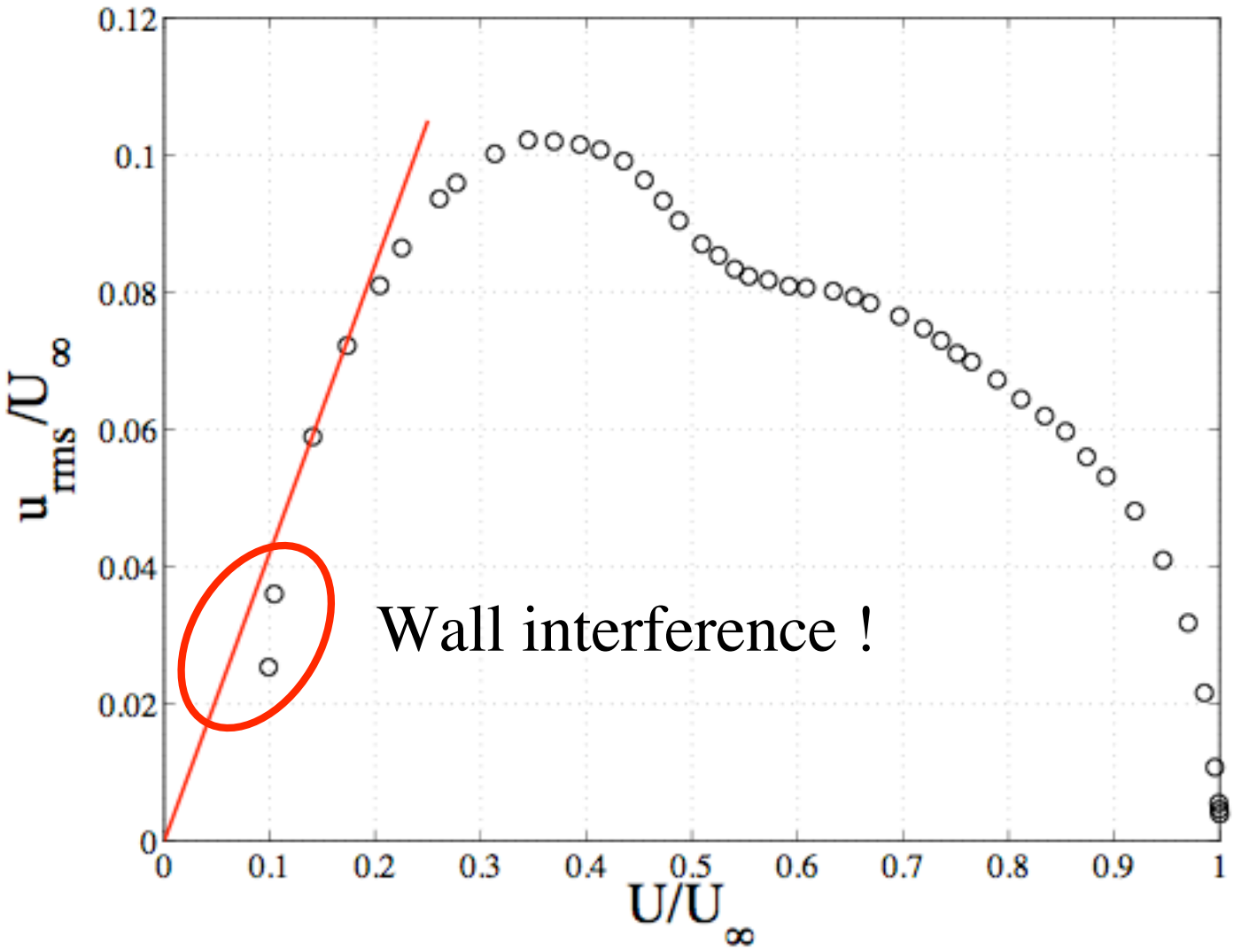
$$U^+ = y^+ - \frac{1}{4}\sigma y^{+^4} \ldots$$



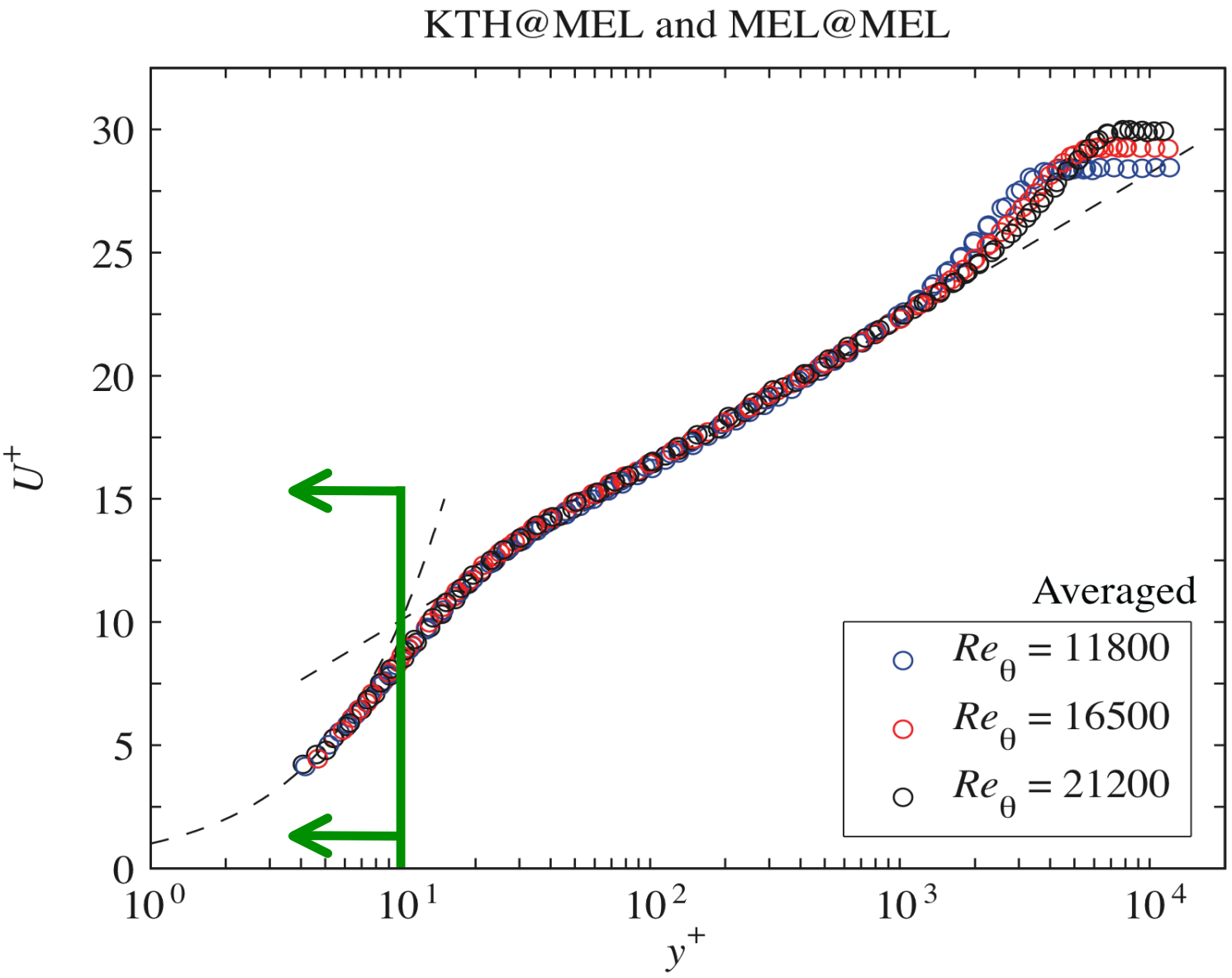
$$\sigma_{\mathrm{DNS}} = 7.1333 \times 10^{-4}$$



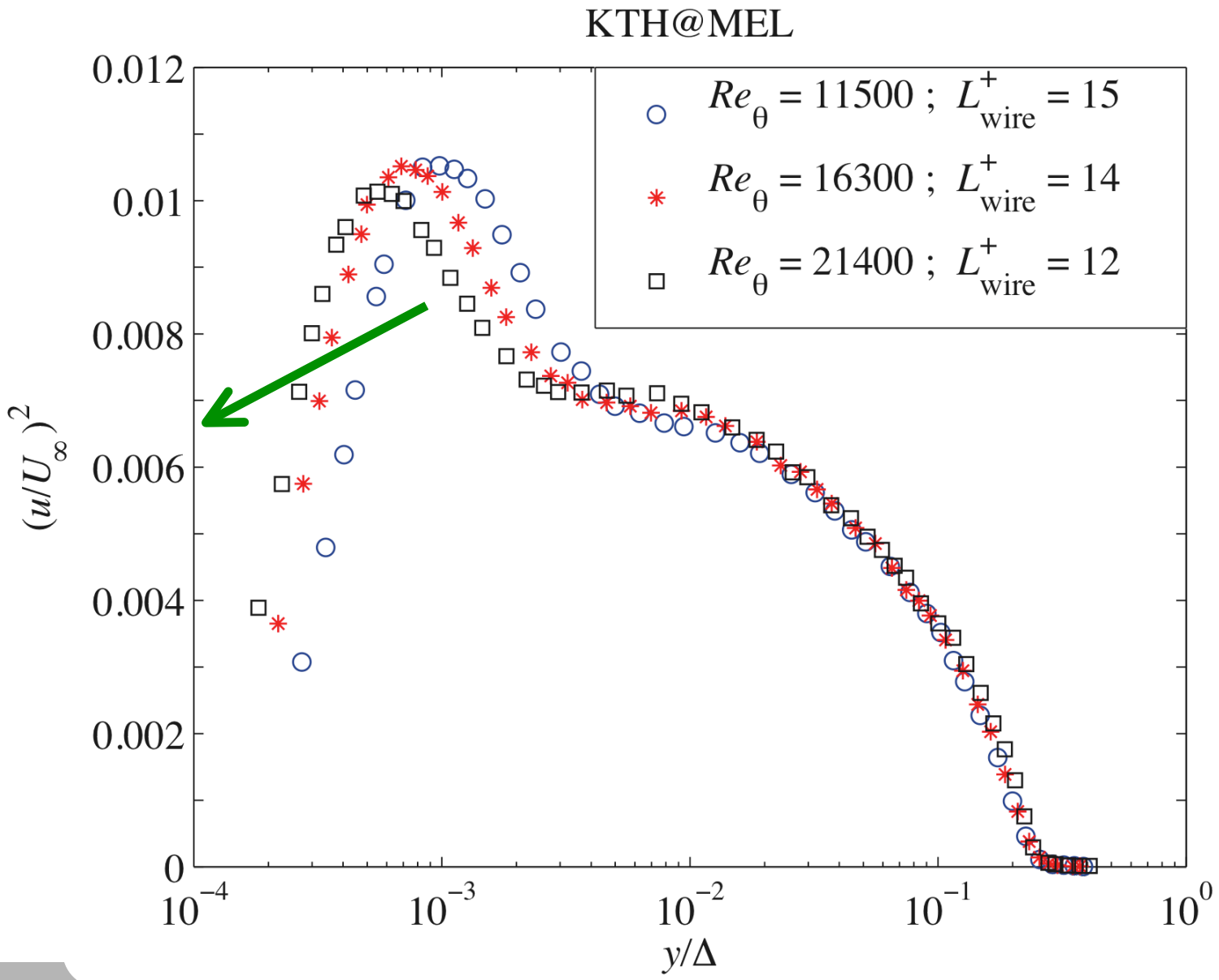
Diagnostic plot to check near wall data



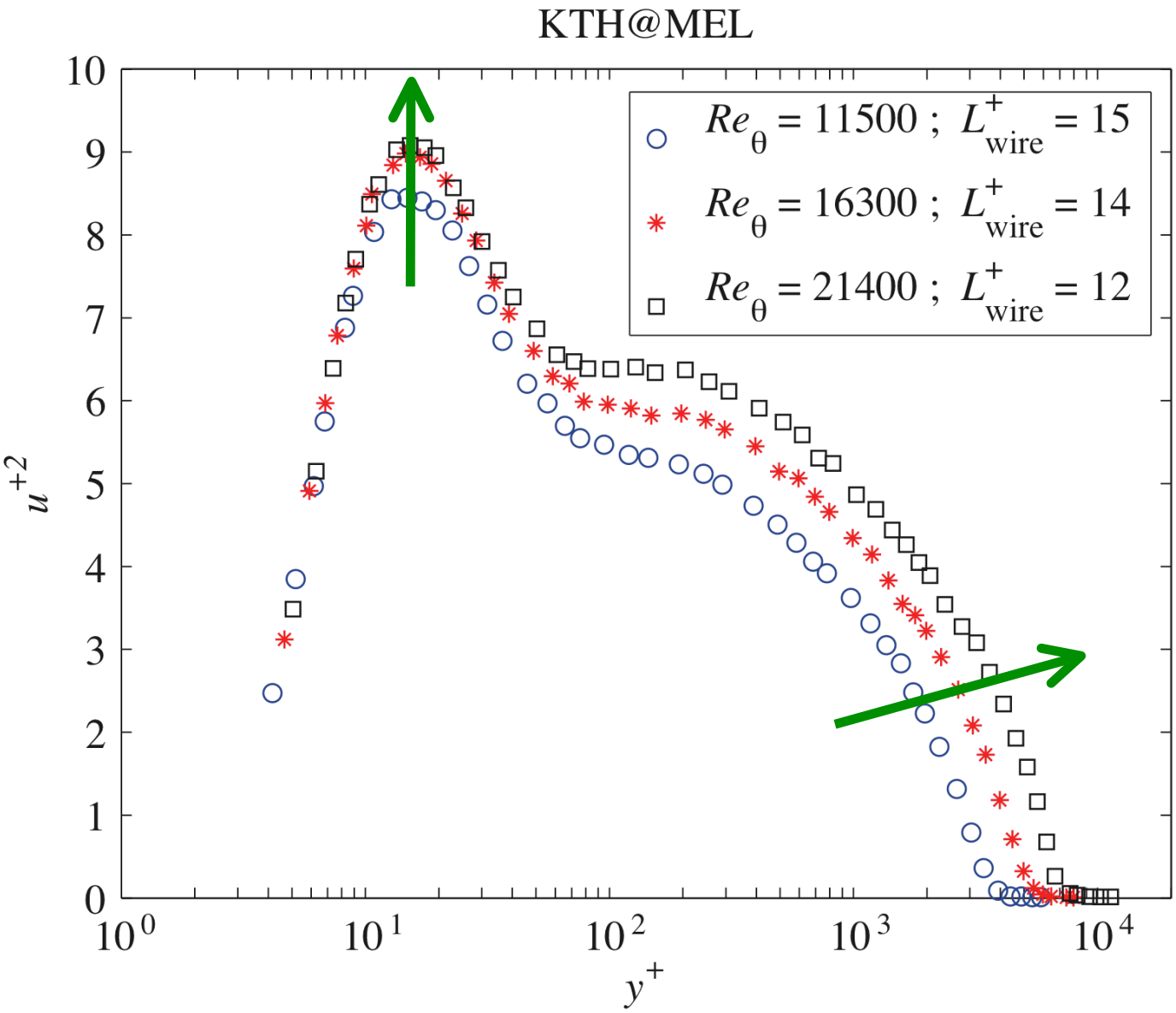
Mean velocity profiles: ALL@MEL



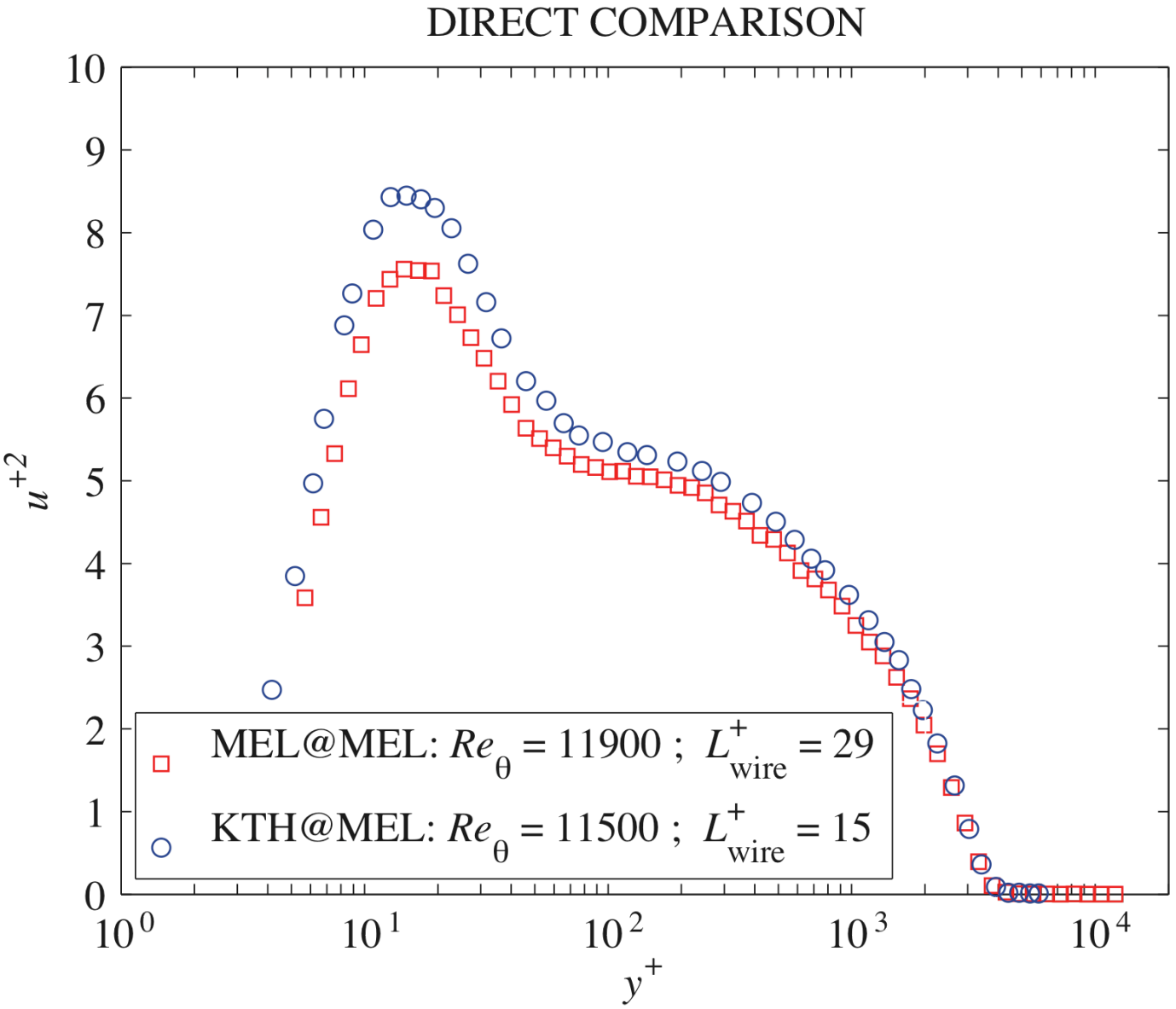
u^2 : outer scaling



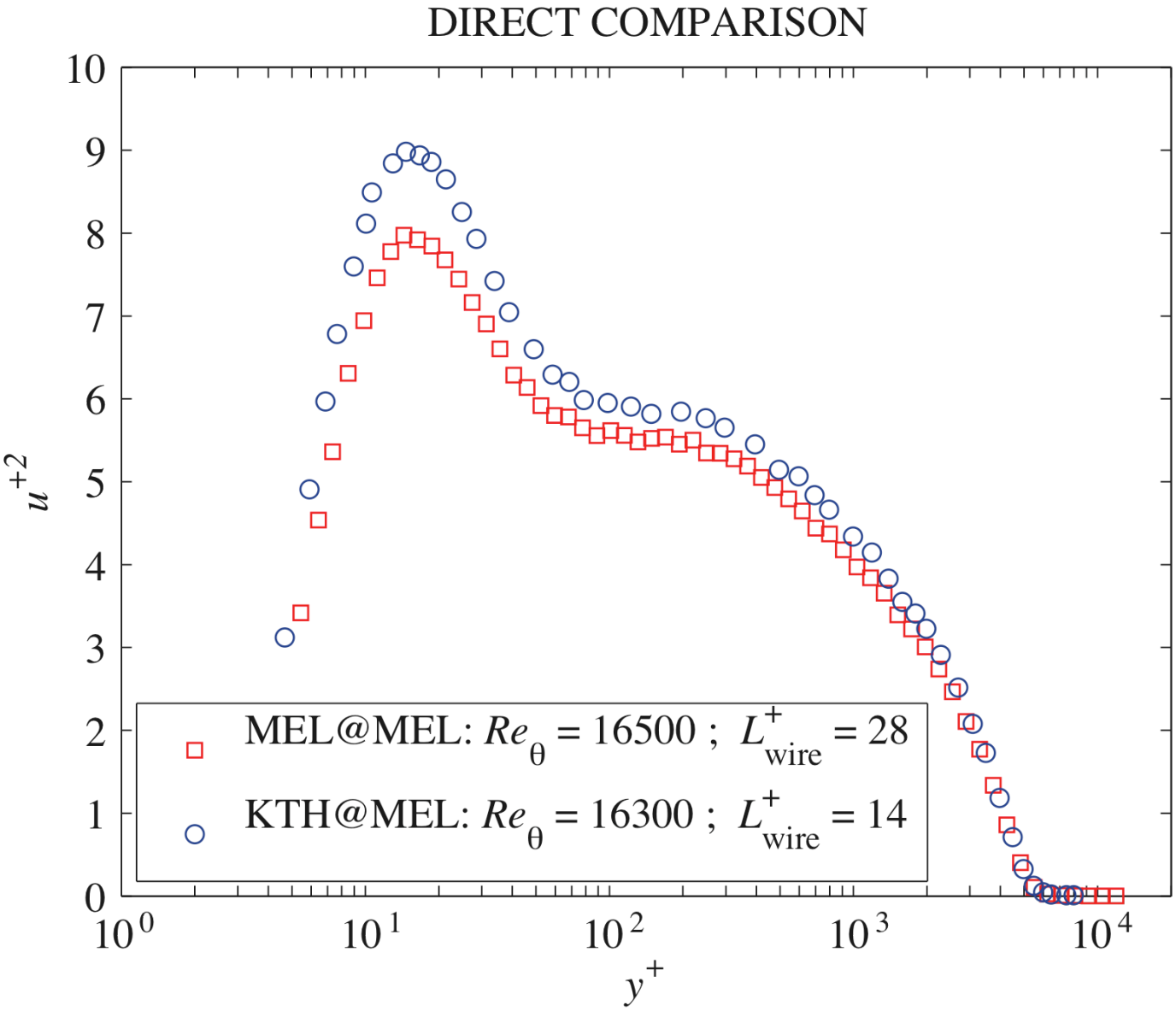
u^{+2} : inner scaling



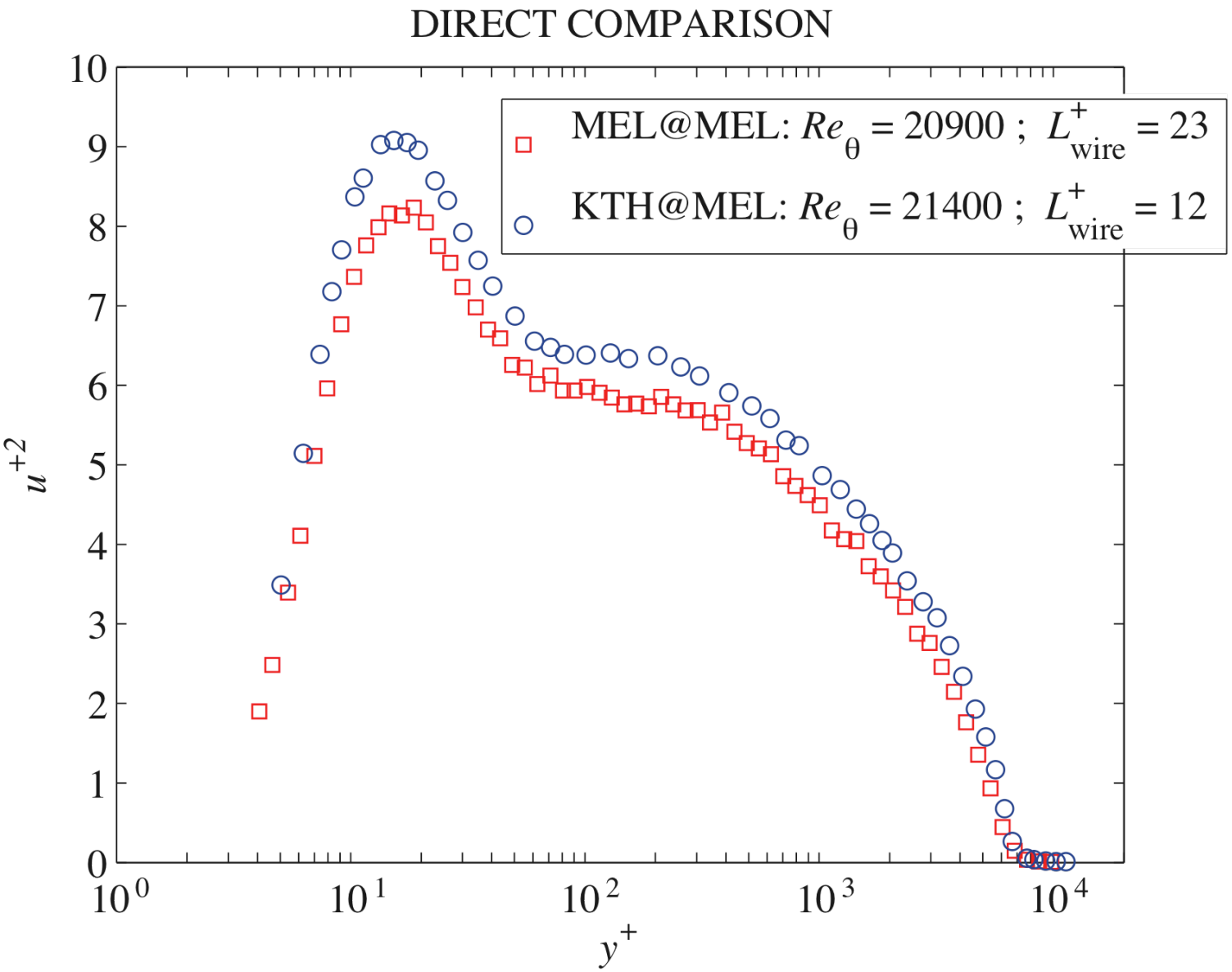
u^{+2} direct comparison: effect of spatial and/or temporal resolution



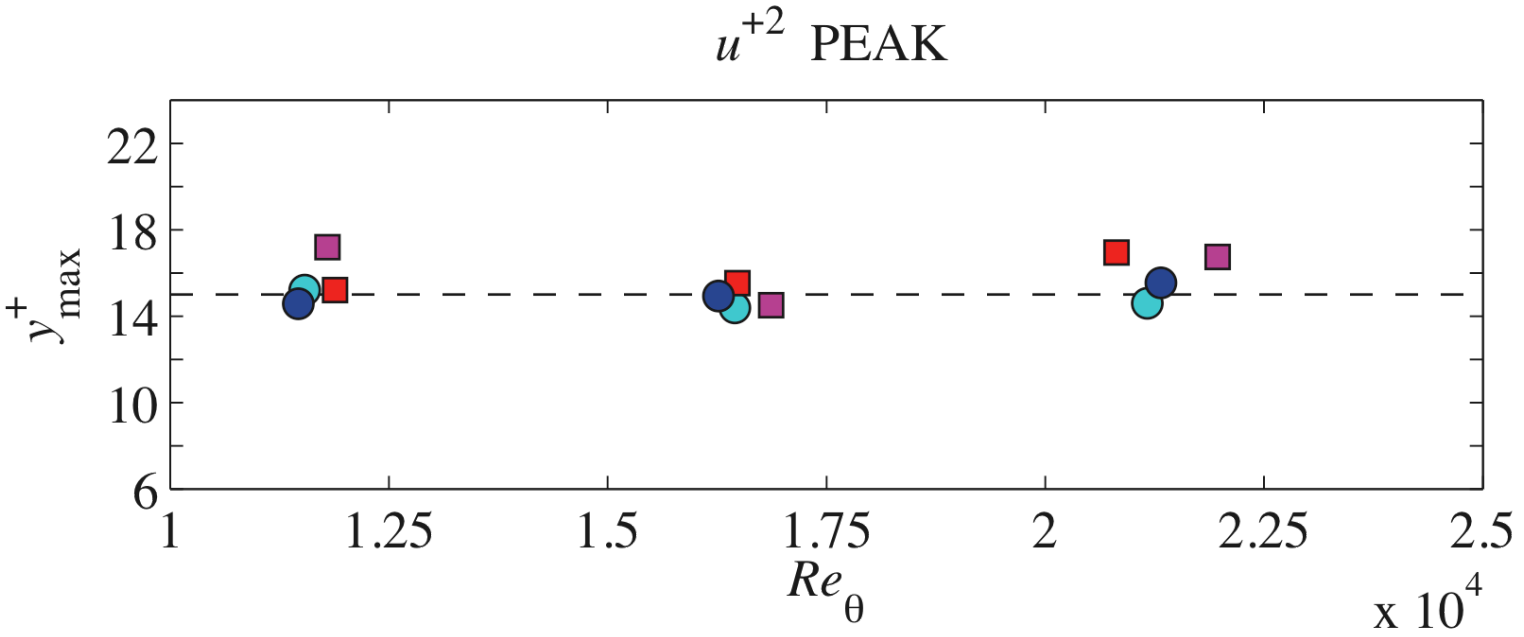
u^{+2} direct comparison: effect of spatial and/or temporal resolution

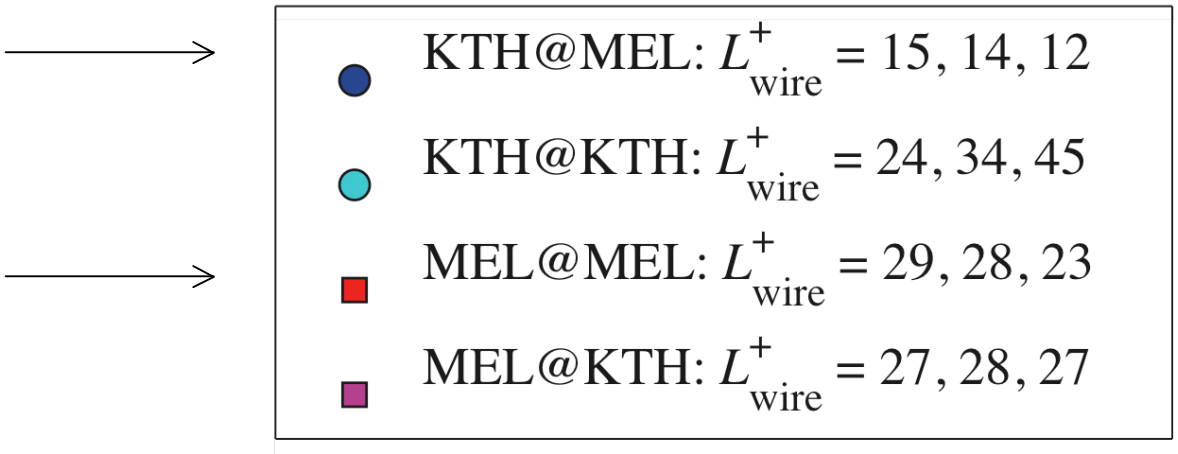


u^{+2} direct comparison: effect of spatial and/or temporal resolution

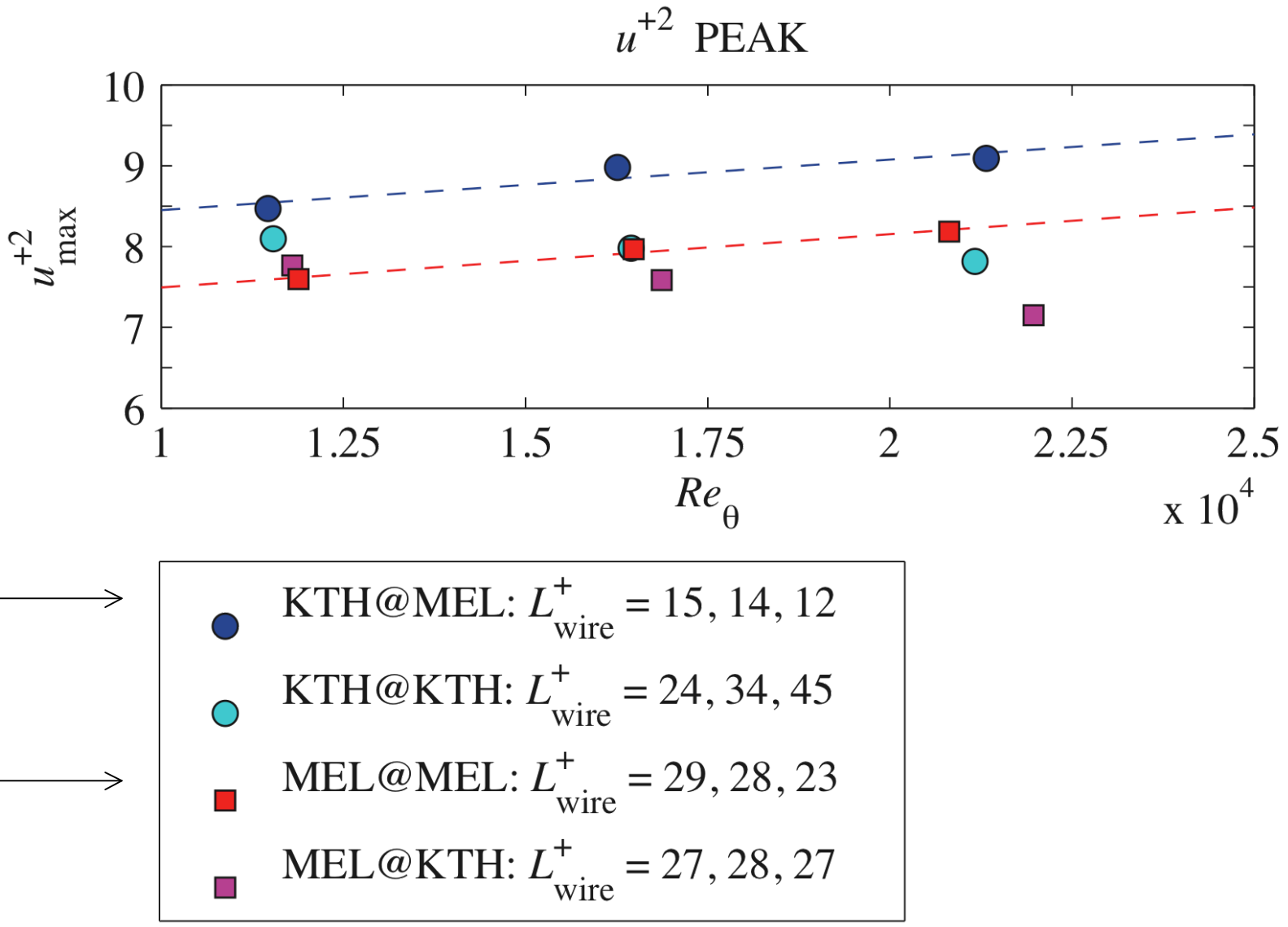


u^{+2} : inner peak location





u^{+2} : inner peak



Definitions

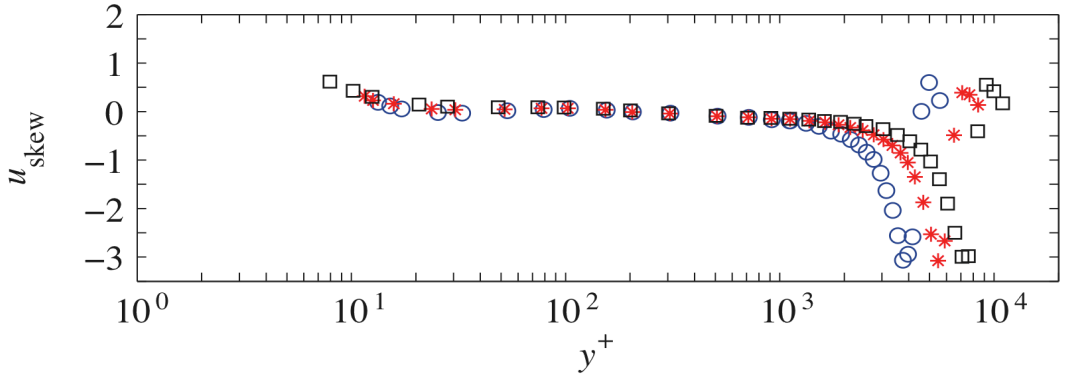
- Skewness

$$u_{\text{skew}} = \frac{\overline{(U - \overline{U})^3}}{u_{\text{rms}}^3}$$

- Flatness

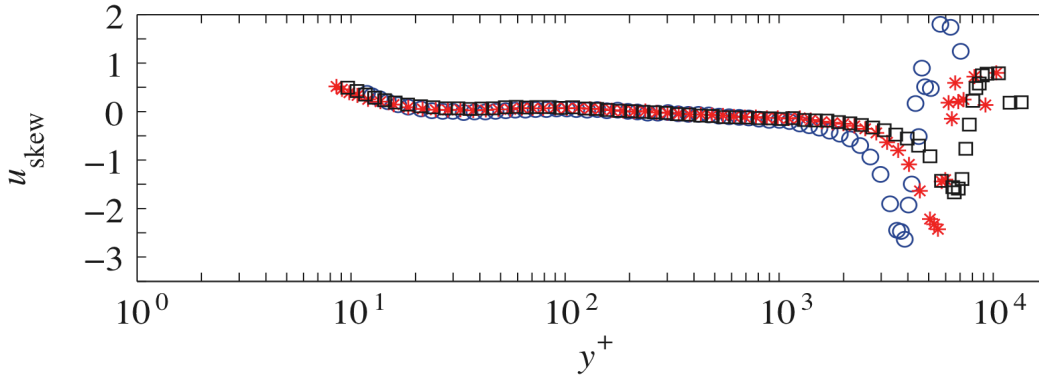
$$u_{\text{flat}} = \frac{\overline{(U - \overline{U})^4}}{u_{\text{rms}}^4}$$

KTH@KTH



$Re_\theta = 11600$; $L^+_{wire} = 24$
$Re_\theta = 16500$; $L^+_{wire} = 34$
$Re_\theta = 21200$; $L^+_{wire} = 45$

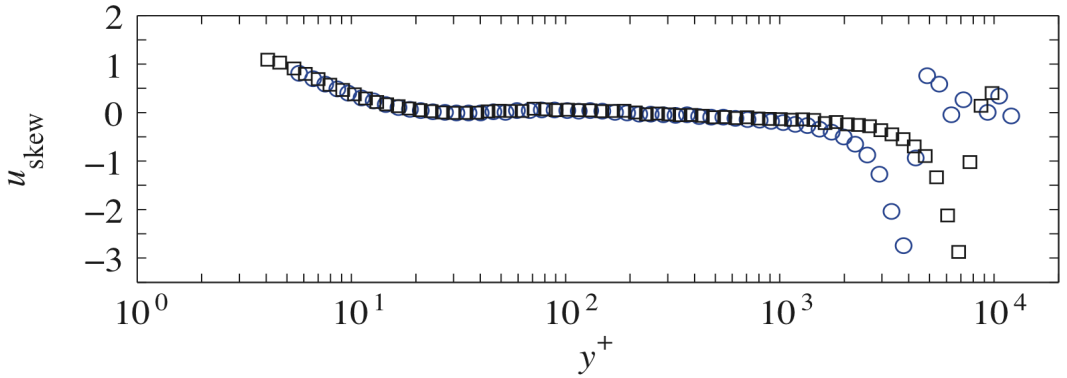
MEL@KTH



$Re_\theta = 11800$; $L^+_{wire} = 27$
$Re_\theta = 16900$; $L^+_{wire} = 28$
$Re_\theta = 22000$; $L^+_{wire} = 27$

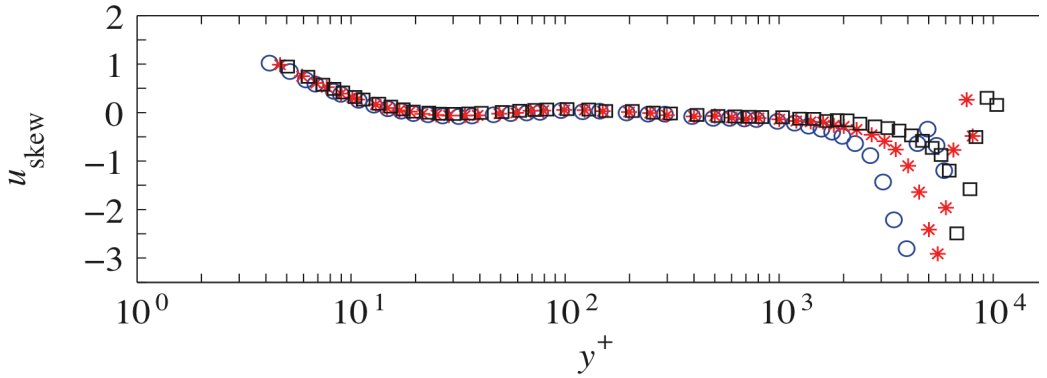
Skewness

MEL@MEL



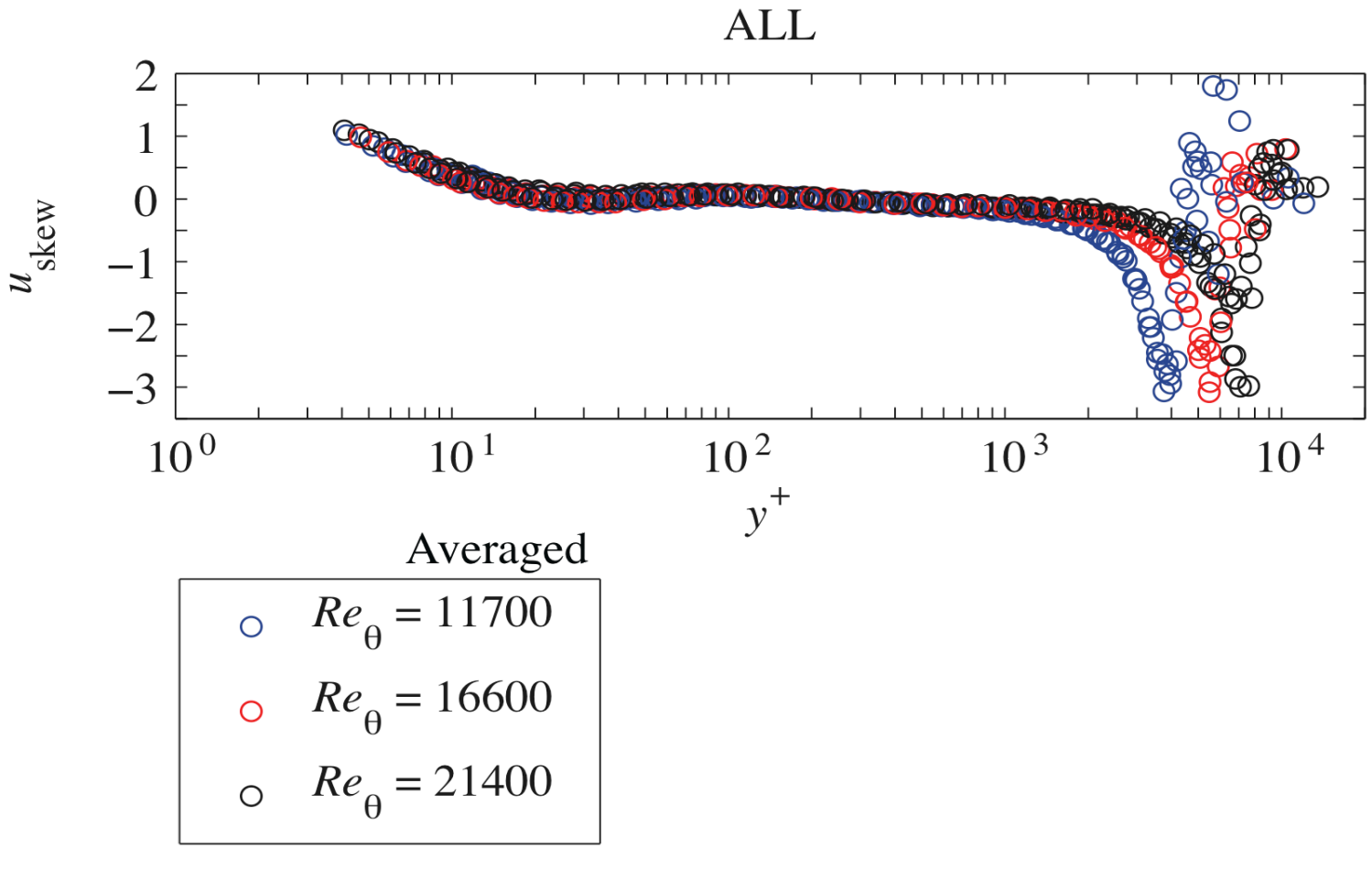
$Re_\theta = 11900$; $L^+_{wire} = 29$
$Re_\theta = 20900$; $L^+_{wire} = 23$

KTH@MEL



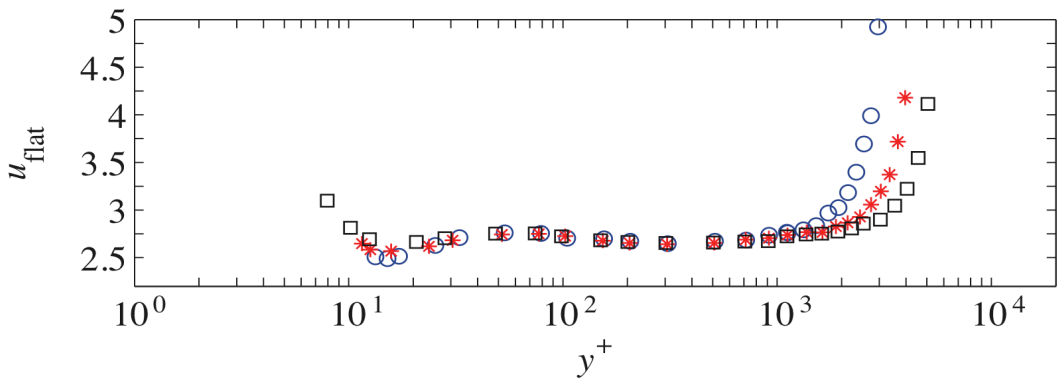
$Re_\theta = 11600$; $L^+_{wire} = 15$
$Re_\theta = 16500$; $L^+_{wire} = 14$
$Re_\theta = 21600$; $L^+_{wire} = 12$

Skewness


ALL
2
1
0
−1
−2
−3
u_{skew}
10^0
10^1
10^2
10^3
10^4
y^+
Averaged
$Re_\theta = 11700$
$Re_\theta = 16600$
$Re_\theta = 21400$

Flatness

KTH@KTH

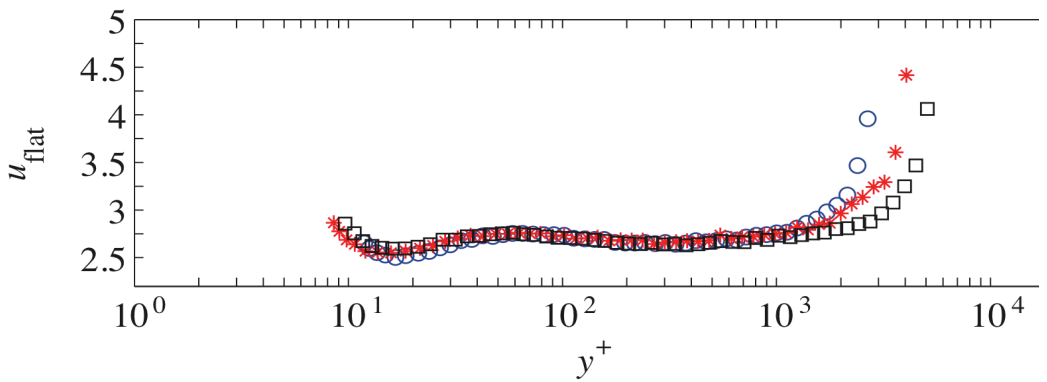


$Re_\theta = 11600$; $L^+_{wire} = 24$

$Re_\theta = 16500$; $L^+_{wire} = 34$

$Re_\theta = 21200$; $L^+_{wire} = 45$

MEL@KTH

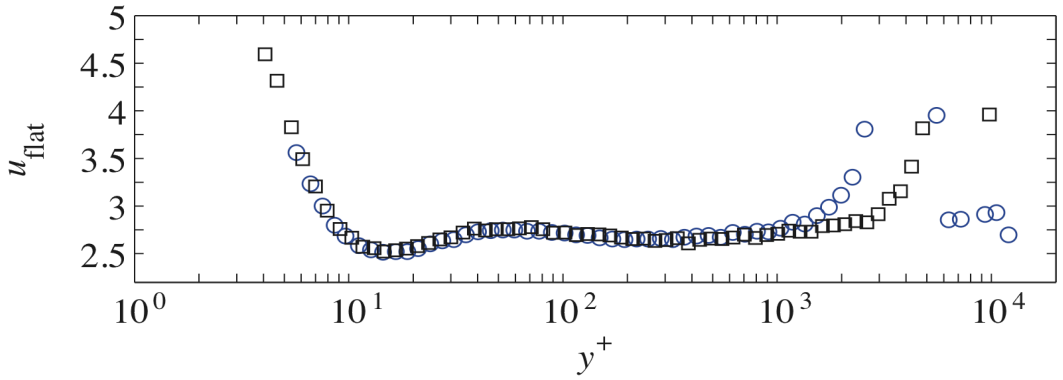


$Re_\theta = 11800$; $L^+_{wire} = 27$

$Re_\theta = 16900$; $L^+_{wire} = 28$

$Re_\theta = 22000$; $L^+_{wire} = 27$

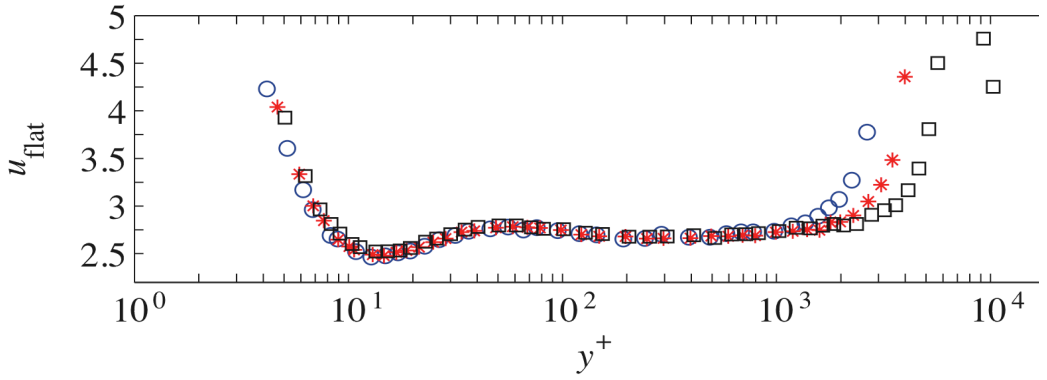
MEL@MEL



$Re_\theta = 11900$; $L^+_{wire} = 29$

$Re_\theta = 20900$; $L^+_{wire} = 23$

KTH@MEL

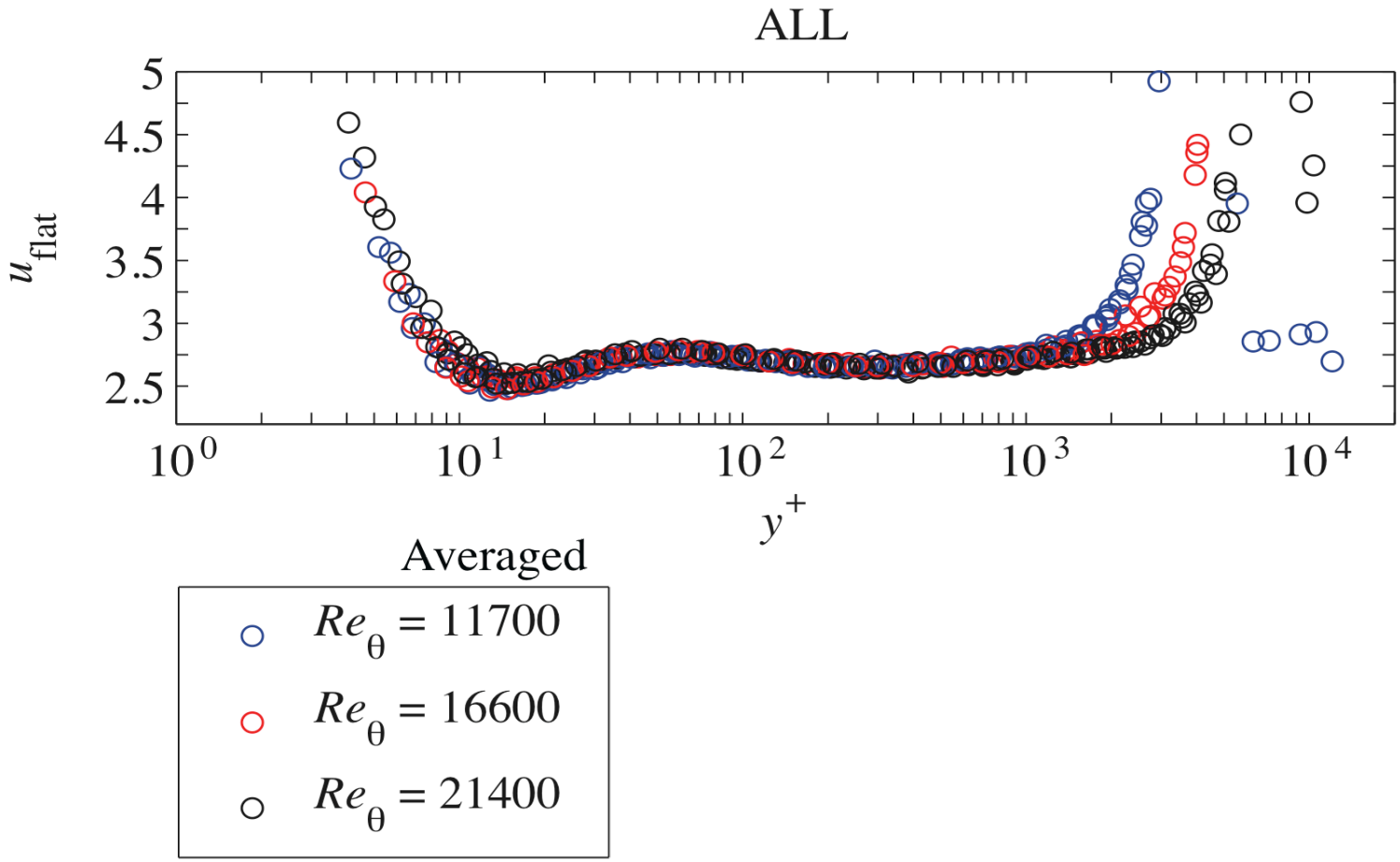


$Re_\theta = 11500$; $L^+_{wire} = 15$

$Re_\theta = 16300$; $L^+_{wire} = 14$

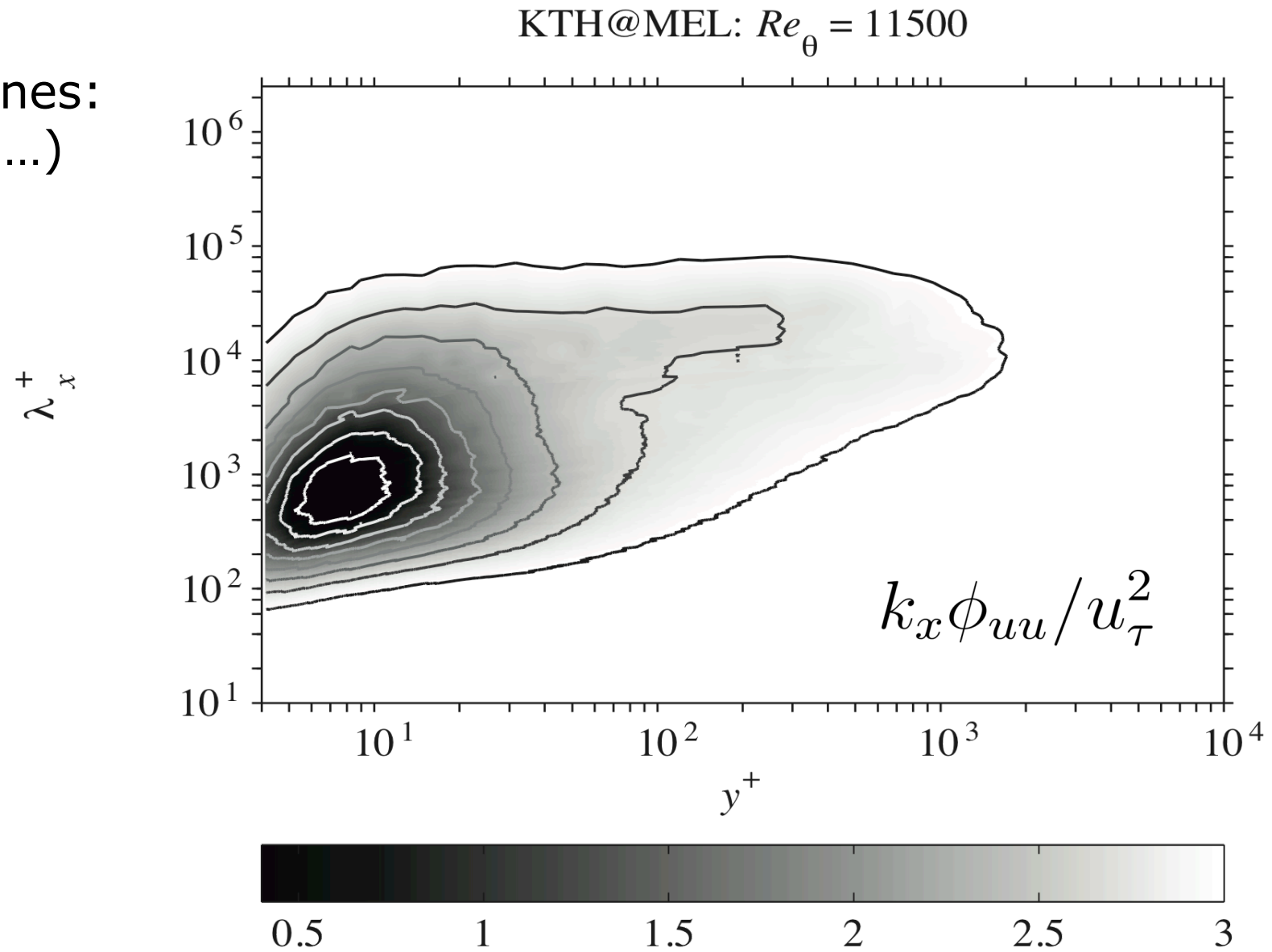
$Re_\theta = 21400$; $L^+_{wire} = 12$

Flatness


ALL
5
4.5
4
3.5
3
2.5
u_{flat}
10^0
10^1
10^2
10^3
10^4
y^+
Averaged
$Re_\theta = 11700$
$Re_\theta = 16600$
$Re_\theta = 21400$

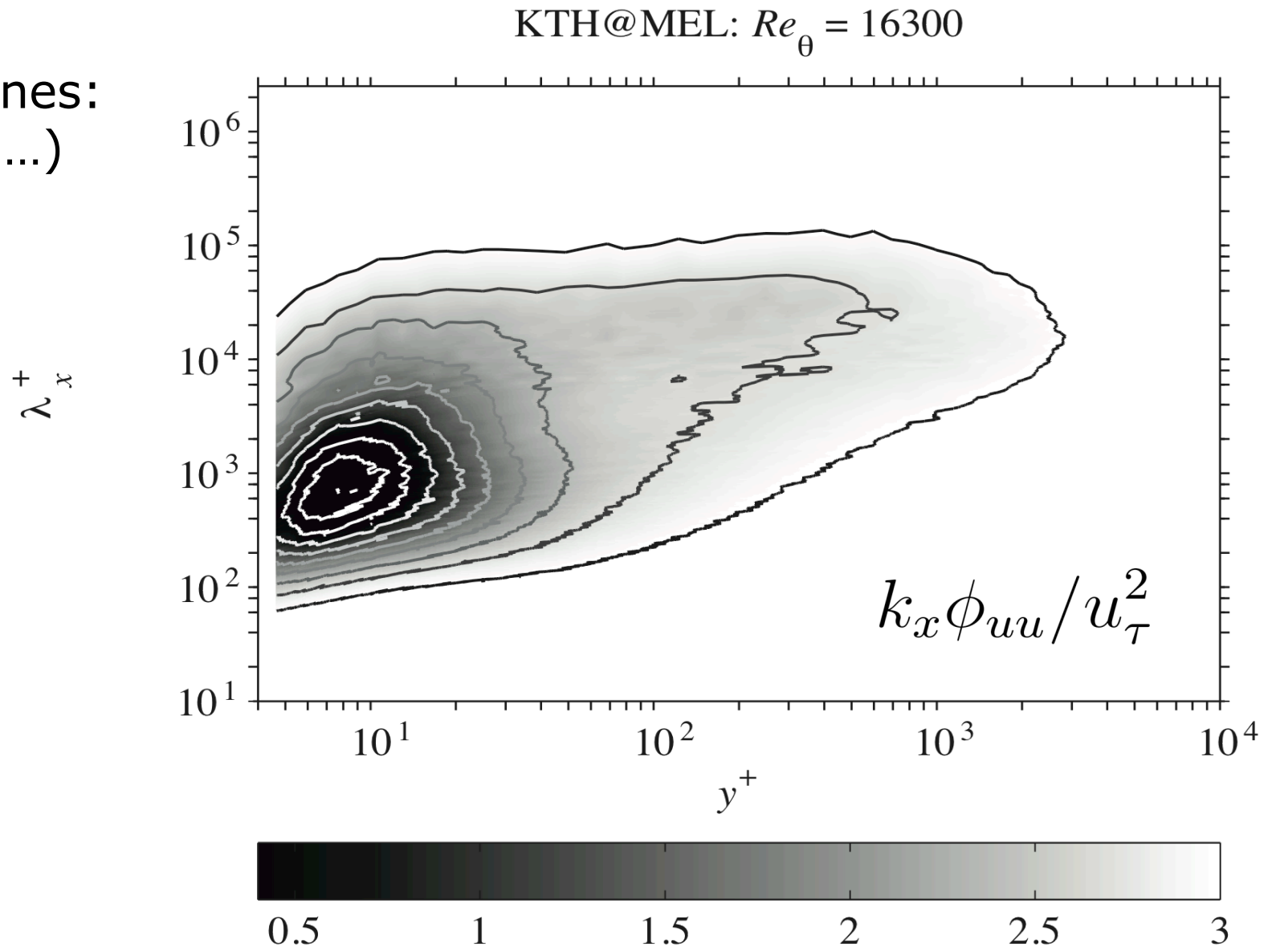
Energy spectrum: KTH@MEL, L-Re

Contour lines:
(0.4:0.4: …)



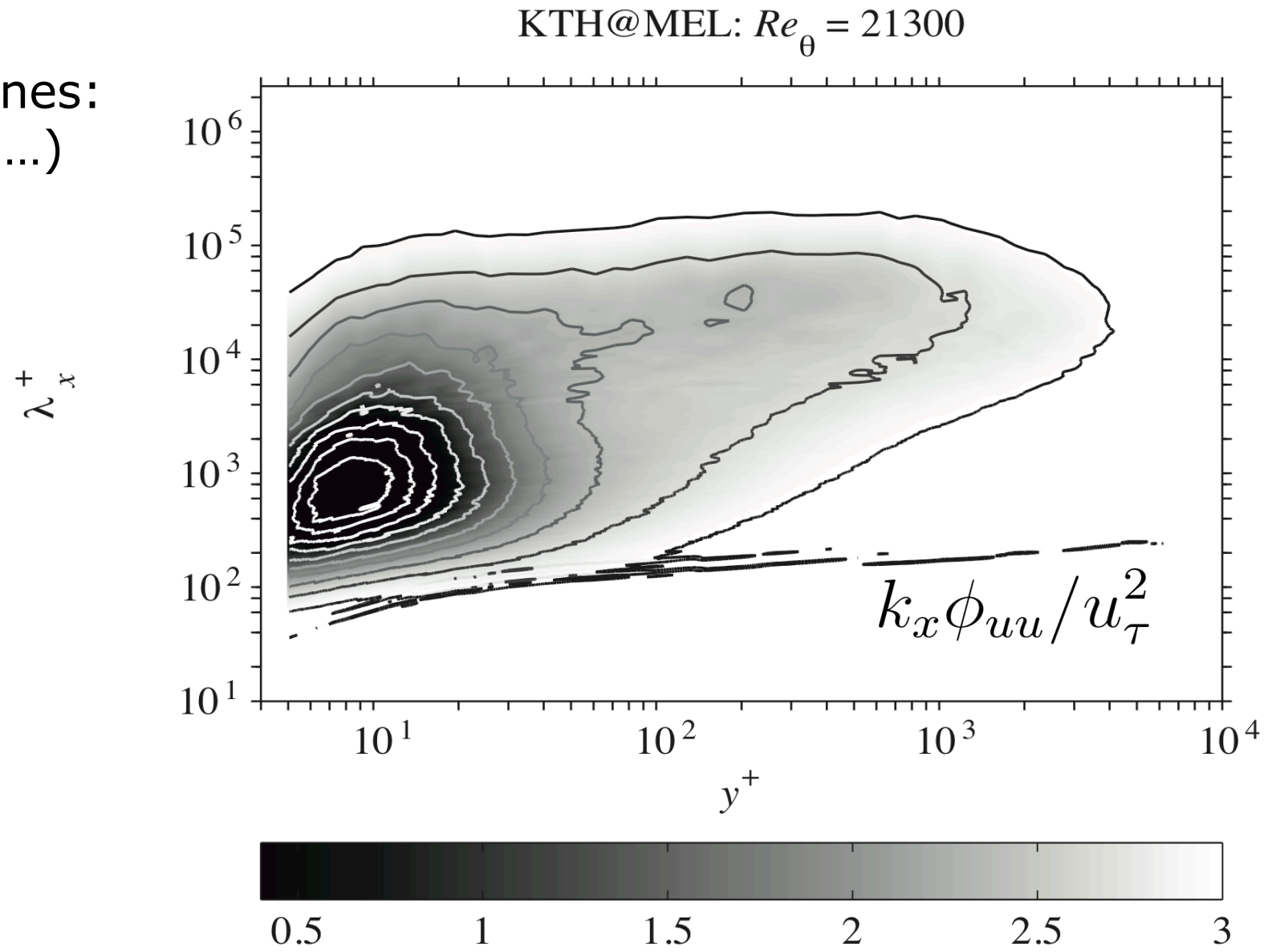
Energy spectrum: KTH@MEL, M-Re

Contour lines:
(0.4:0.4: …)



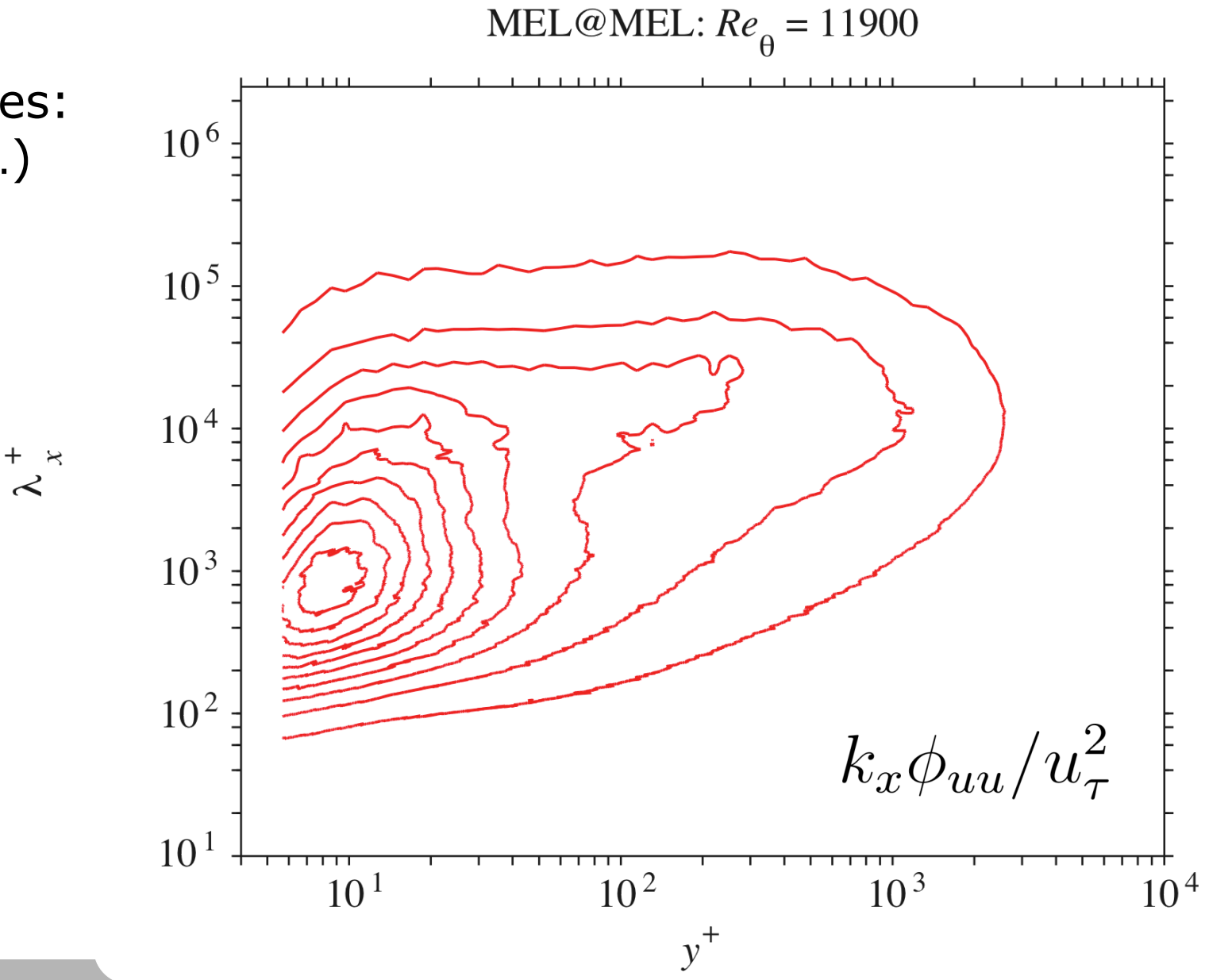
Energy spectrum: KTH@MEL, H-Re

Contour lines:
(0.4:0.4: …)



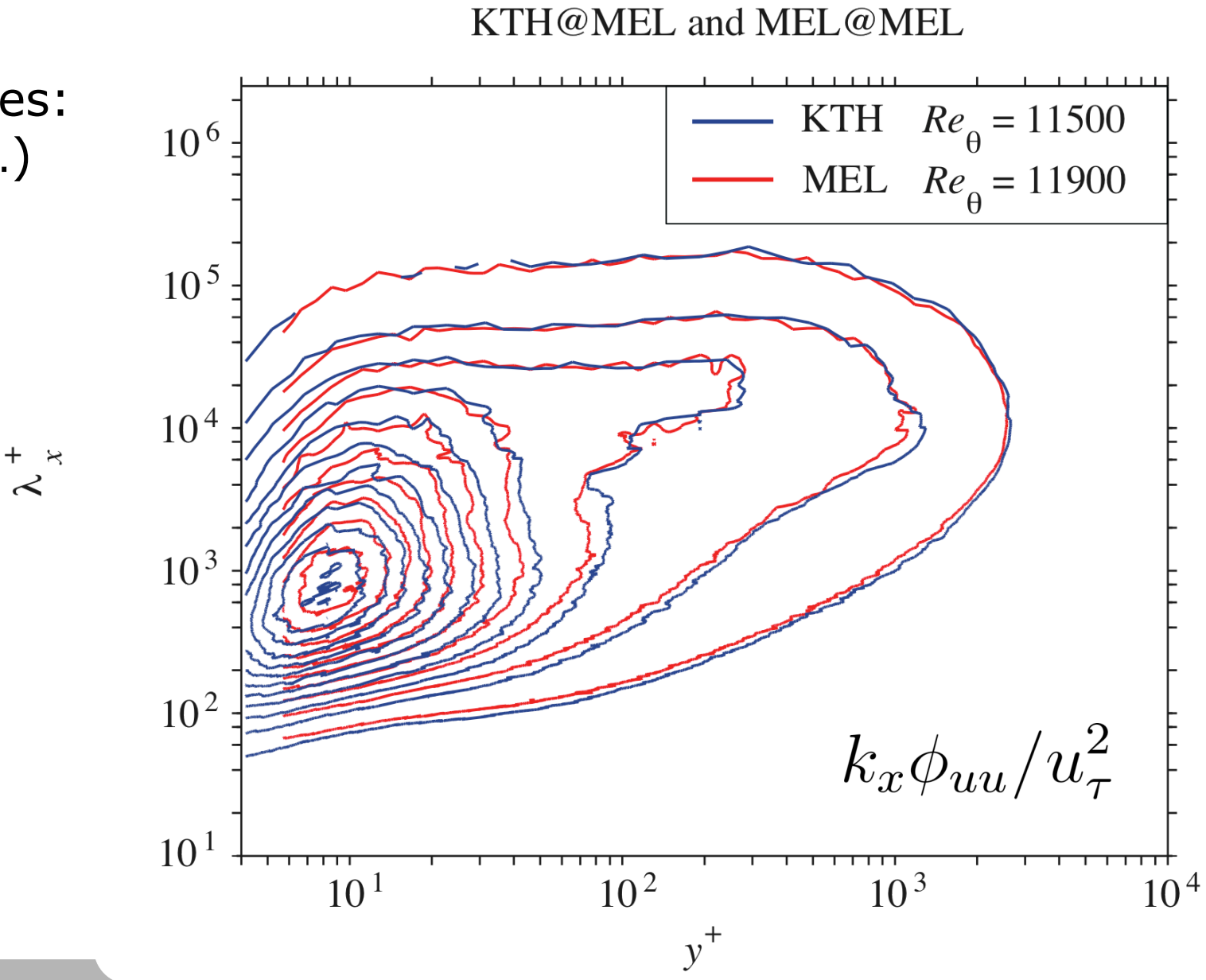
Energy spectrum: MEL@MEL, L-Re

Contour lines:
(0.2:0.3: …)



Energy spectra: @MEL, L-Re

Contour lines:
(0.2:0.3: …)

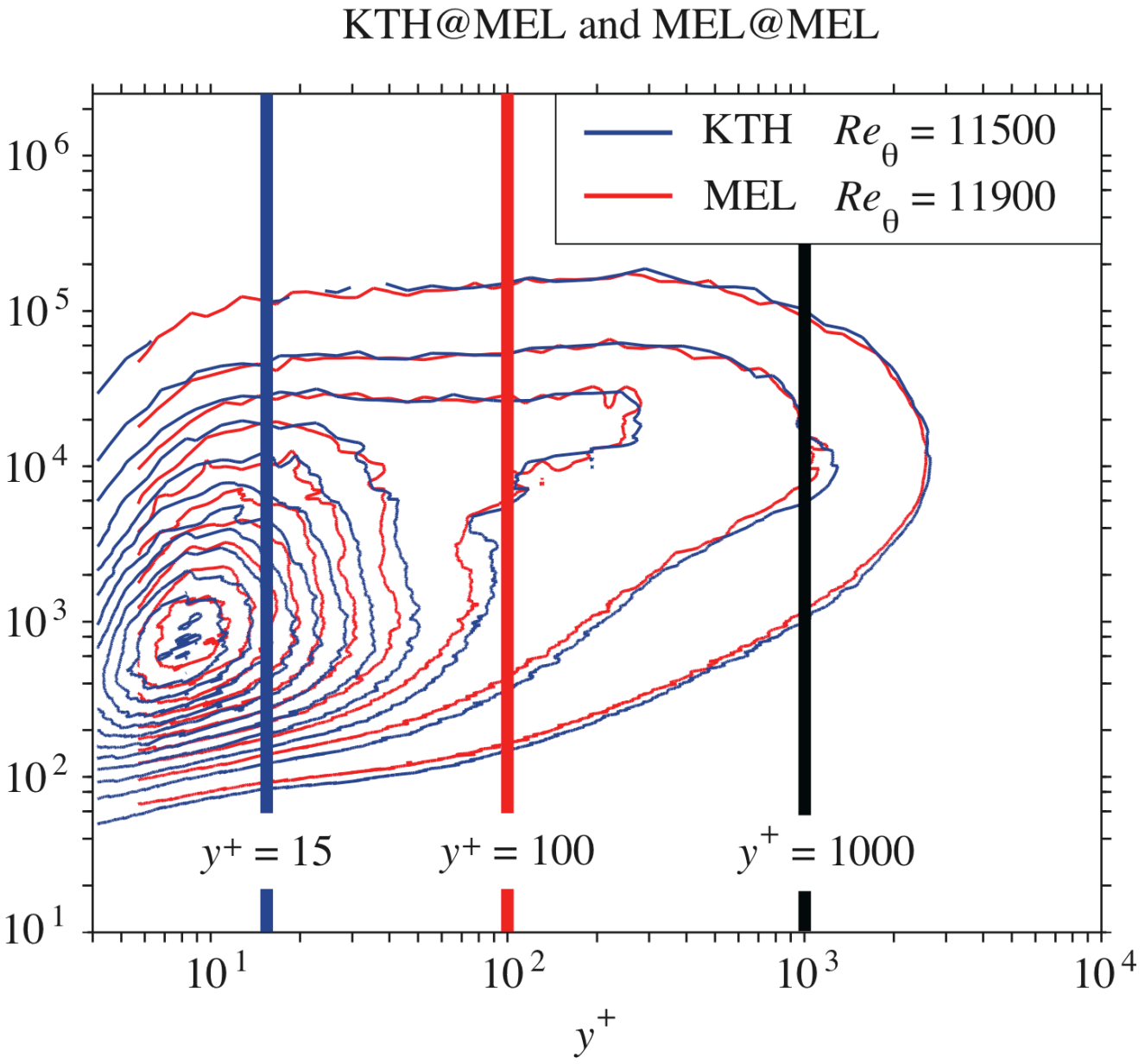


Energy spectra: @MEL, L-Re

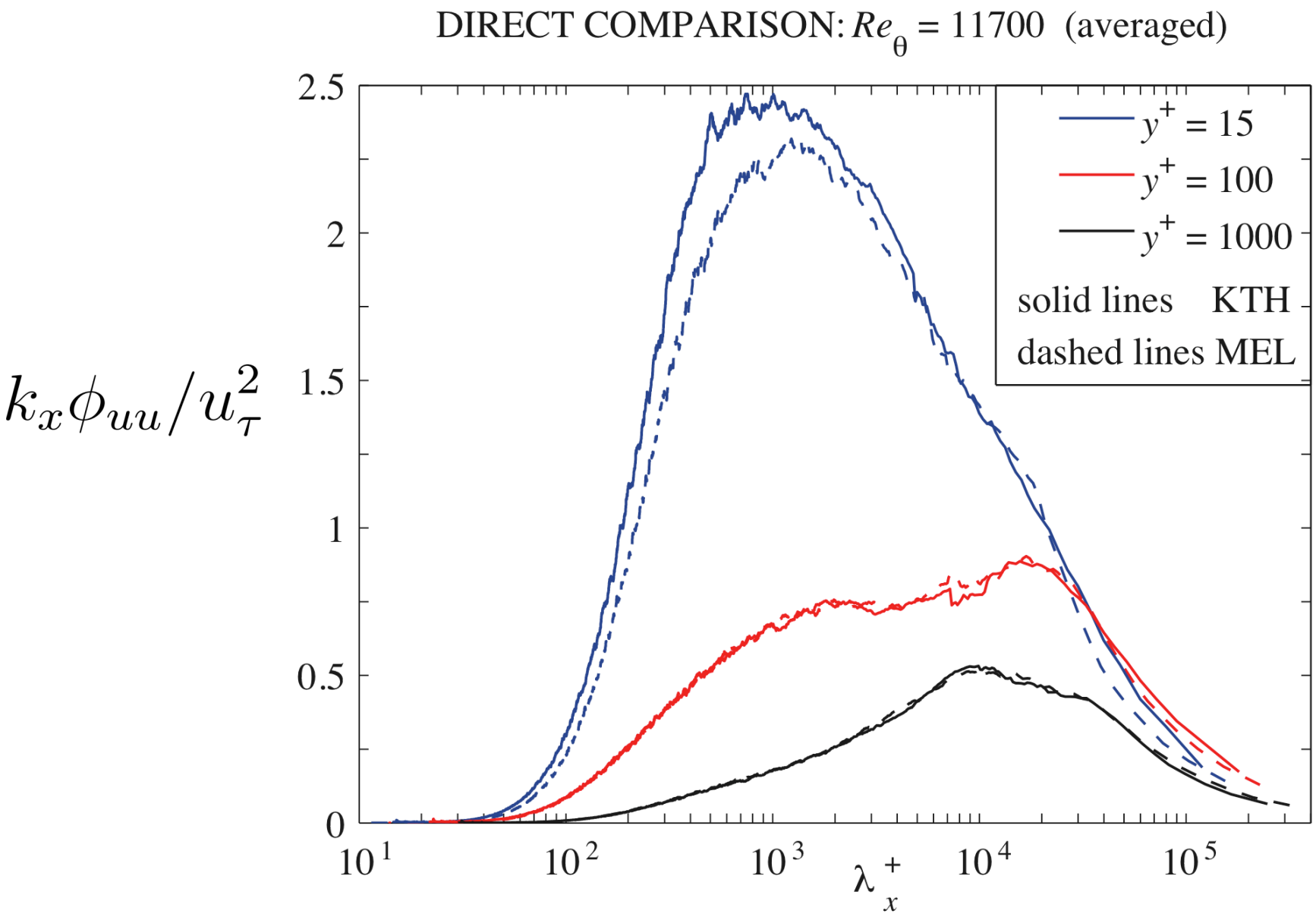
Contour lines:
(0.2:0.3: …)

$k_x\phi_{uu}/u_\tau^2$

λ_x^+



Energy spectra: @MEL, L-Re



Conclusions

- Method of wall determination necessary if qualitative measures are analysed
- Inner scaling:
  - urms peak increases with Re
  - urms: some differences between KTH and MEL groups, L^+ effects …
  - Skewness and Flatness (“universal”), anything will look good …
- Outer scaling:
  - urms peak decreases with Re and approaches the wall
- Pre-multiplied energy spectra show a single inner peak around

$$(y^+,\ \lambda_x^+) \approx (10^1, 10^3)$$

- Direct comparison between spectra compare relatively well. Discrepancies due to L^+ effects and/or temporal attenuation
- Large facilities preferred for near wall data analyses