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Bundesamt für Eich- und Vermessungswesen

Evaluation of measurement results

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Bundesamt für Eich- und Vermessungswesen

Start of the project in spring 2002

PROPOSED EUROMET PROJECT

1. Ref. No: (please leave blank)

2. Subject Field: **water flow**

3. Type of collaboration: **Interlaboratory comparison**

4A: Partners: **BEV**, OMH, PTB, SP, UME, CMI, METAS, CETIAT (BNM), SMU, DTI, LEI, MIRS, YUSTERVESENET (institutions)

4B: CEC funded? no

5. Participating countries: **AT**, H, D, S, TR, CZ, CH, FR, SK, DK, LI, SI, N

6. Title: **Intercomparison of two electromagnetic meters DN 25**

7. Description:

0 This project shall compare the test facilities of NMIs by means of two electromagnetic meters for water, DN 25, as a robin round test. The comparison shall be performed at a temperature of 50 °C, pressure approximately 1 bar, flow range: 1 m³/h to 10 m³/h, test mode: preferably dynamic measurement.

For further details see enclosure.

Prior to the robin round test the meters are endurance tested at the BEV for long time stability and repeatability.

For the evaluation of the test results, amoung others, a Youden-plot is foreseen.

Subsequently to this EUROMET project the comparison will be extended to some test laboratories (verification laboratories) at first in Austria and also in Germany.

8. Additional remarks:
For the setup of a final schedule the interested laboratories are requested to confirm their participation.

OMH, PTB/Institute Berlin and SP have already agreed to join the project!

9. Proposer's name:
Prof. Dr. Franz Adunka
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Participating institutes in Europe

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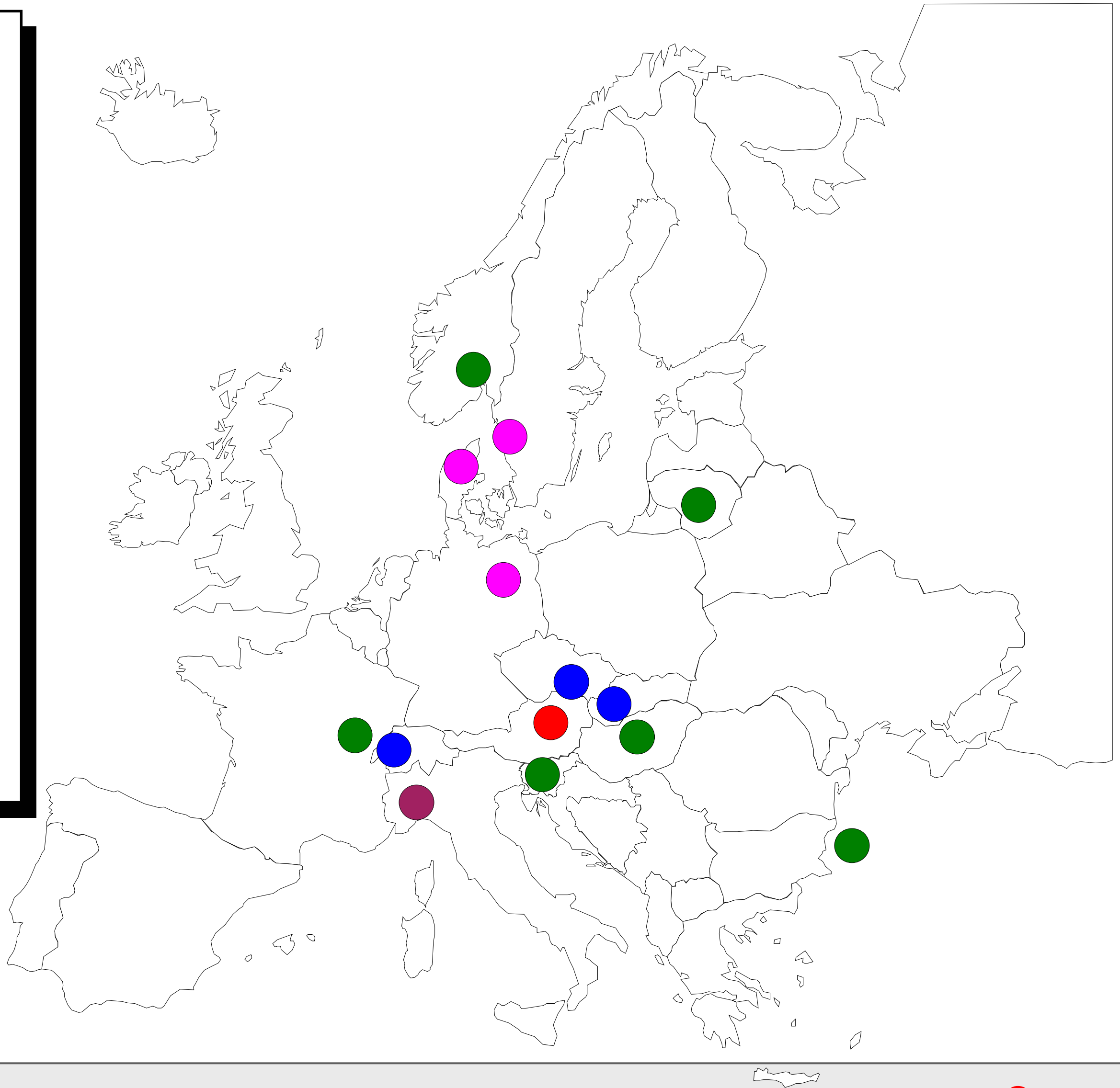
- **Austria (BEV)-pilot lab**
- Slovakia (SMU)
- Czech republik (CMI)
- Switzerland (METAS)
- Austria (BEV, 9. 2002)
- Sweden (SP)
- Denmark (DTI)
- Germany (PTB-Berlin)
- Austria (BEV, 1. 2003)
- Slovenia (JP Energetika)
- France (CETIAT)
- Norway (Justervesenet)
- Turkey (UME)
- Hungary (OMH)
- Lithuania
- Austria (BEV, 12. 2003)
- Italy
- Austria (BEV, 2. 2004)

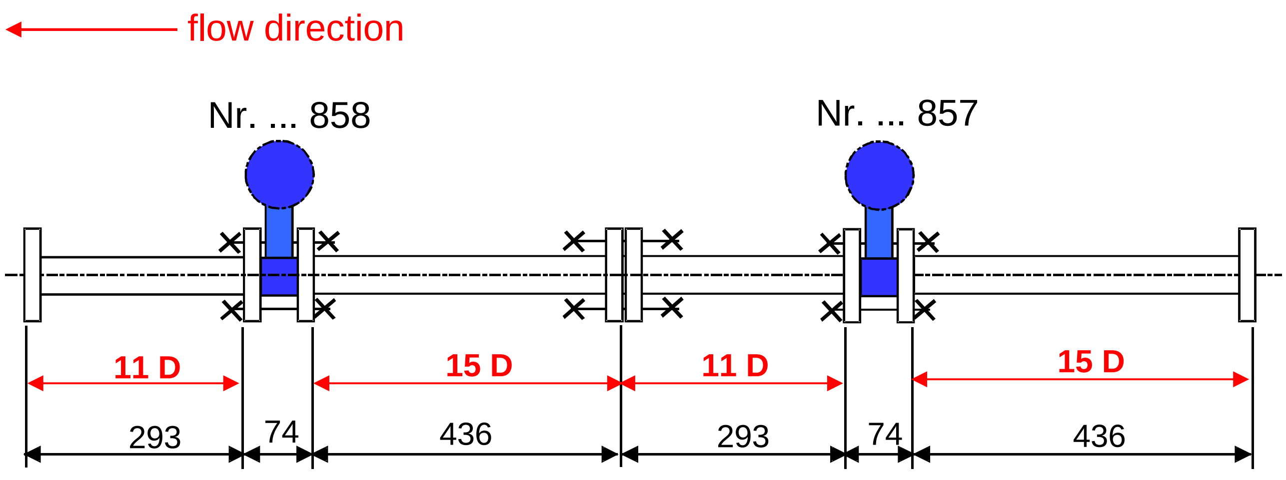
blue ... 1st cycle
violett ... 2nd cycle
green ... 3rd cycle
brown ... 4rd cycle



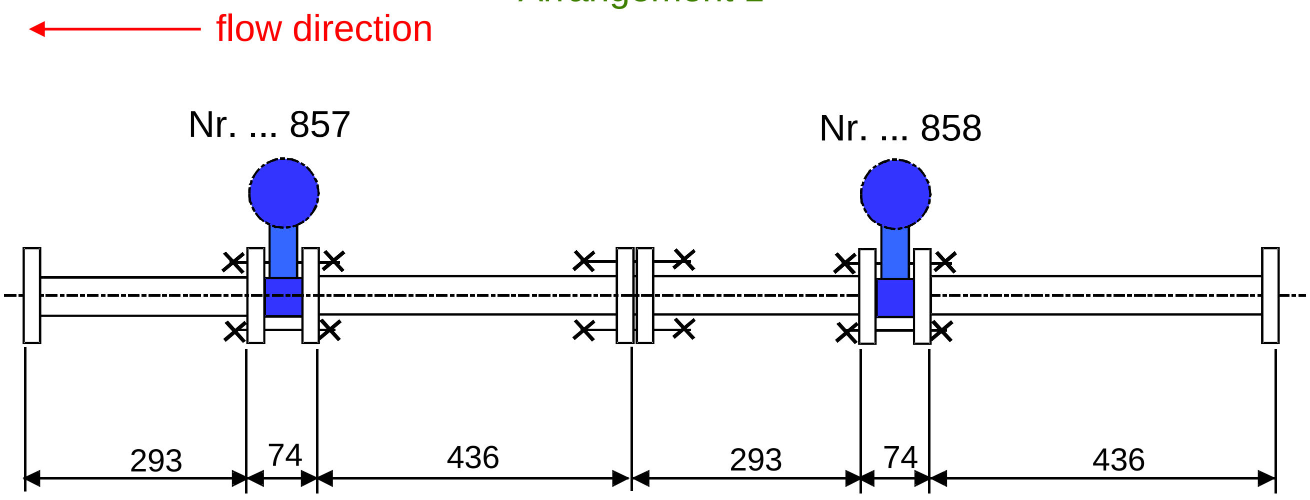
Significant data

- Medium: water
- Pressure: <1 bar downstream of the second meter (reference value: 0,6 bar)
- Temperature: 50 °C
- Flow range: 1.000 L/h ≤ ***Q*** ≤ 10.000 L/h
- pipe diameter: DN 25

Sketch of the arrangement of meters under test



Arrangement 1



Arrangement 2

Test conditions

flow rate	number of repeated measurements	Volume at the tests	temperature	pressure at the outlet
L/h	N		°C	bar
10000	≥ 10	depending of the test rig	(50 ± 0,5)	ca. 0,6
7500				
5000				
2500				
1000				

meter, straightener, transport box

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EUROMET comparison

Results of the EUROMET proj. 669 ... 857 upstream

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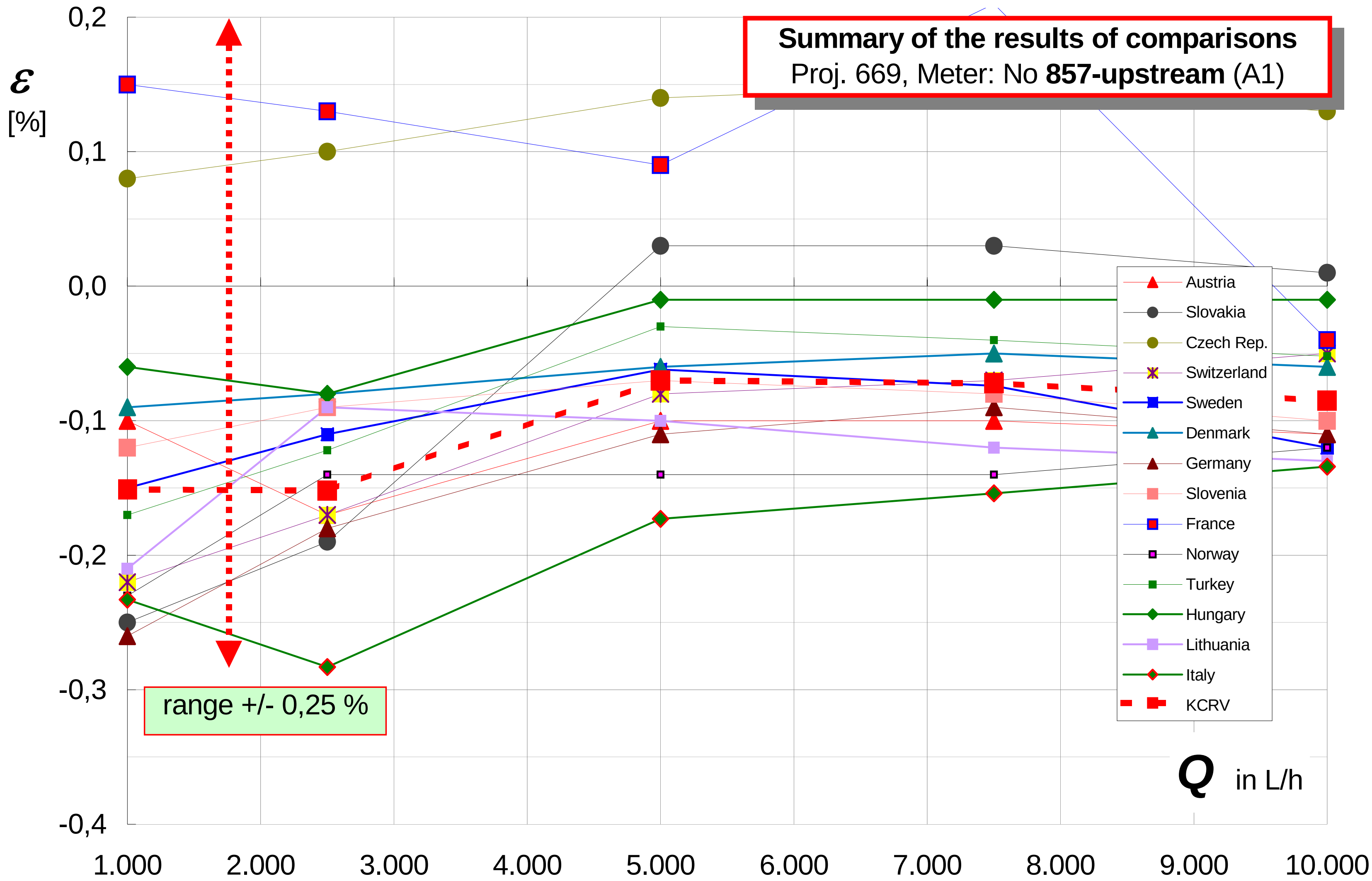

Results of the EUROMET proj. 669 ... 857 downstream

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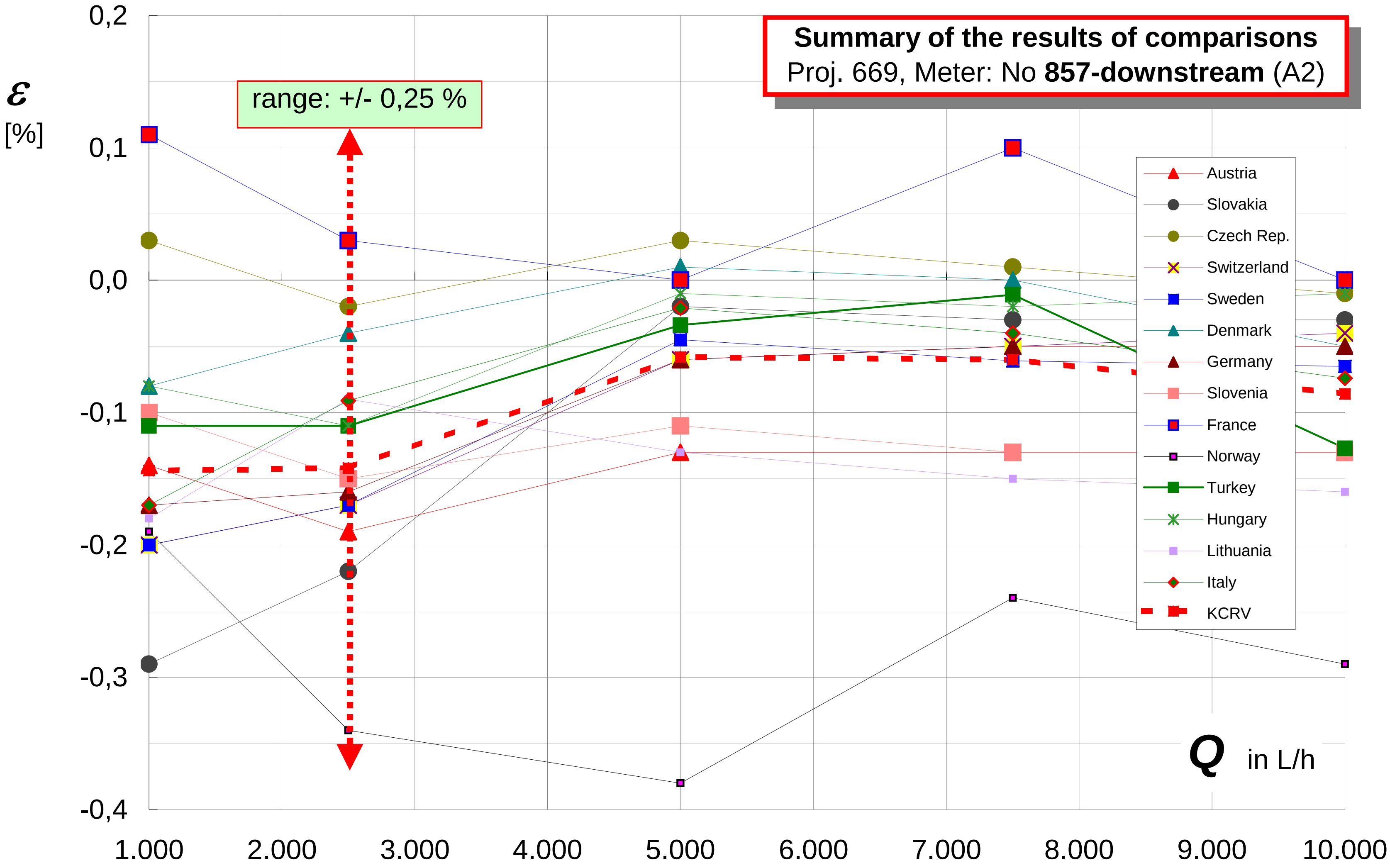

Results of the EUROMET proj. 669 ... 858 upstream

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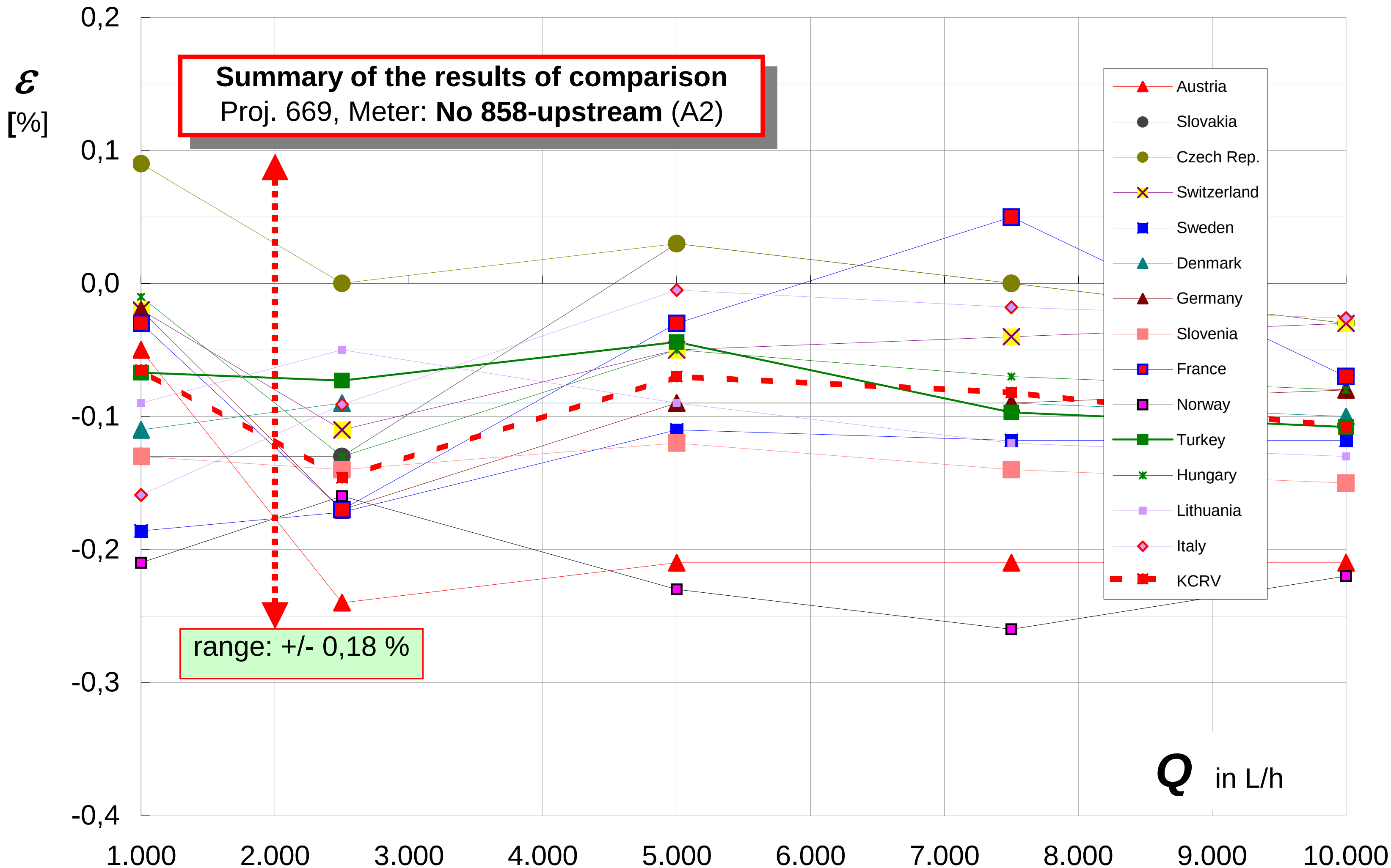
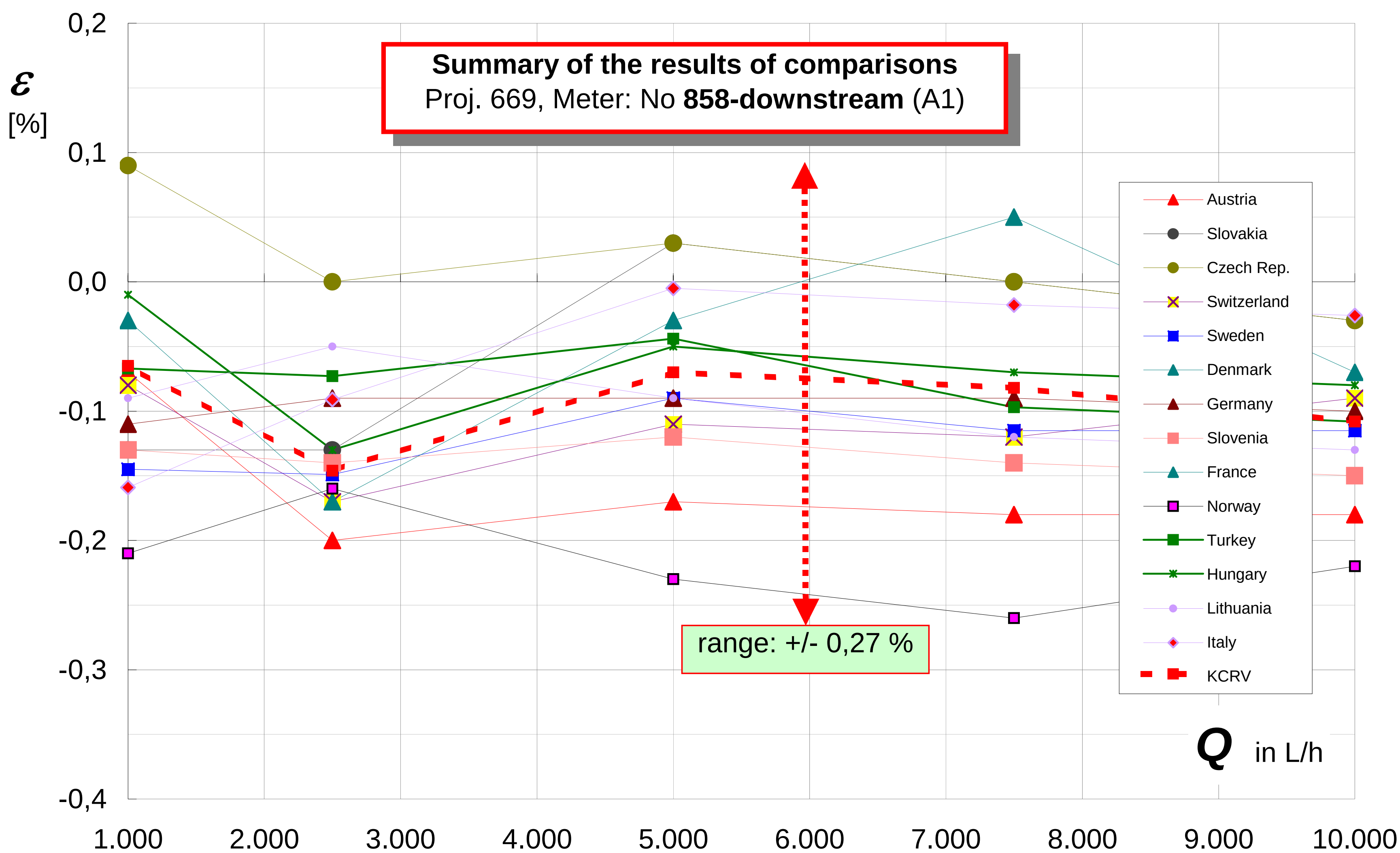


Results of the EUROMET proj. 669 ... 858 downstream



Uncertainties 857 A1 upstream

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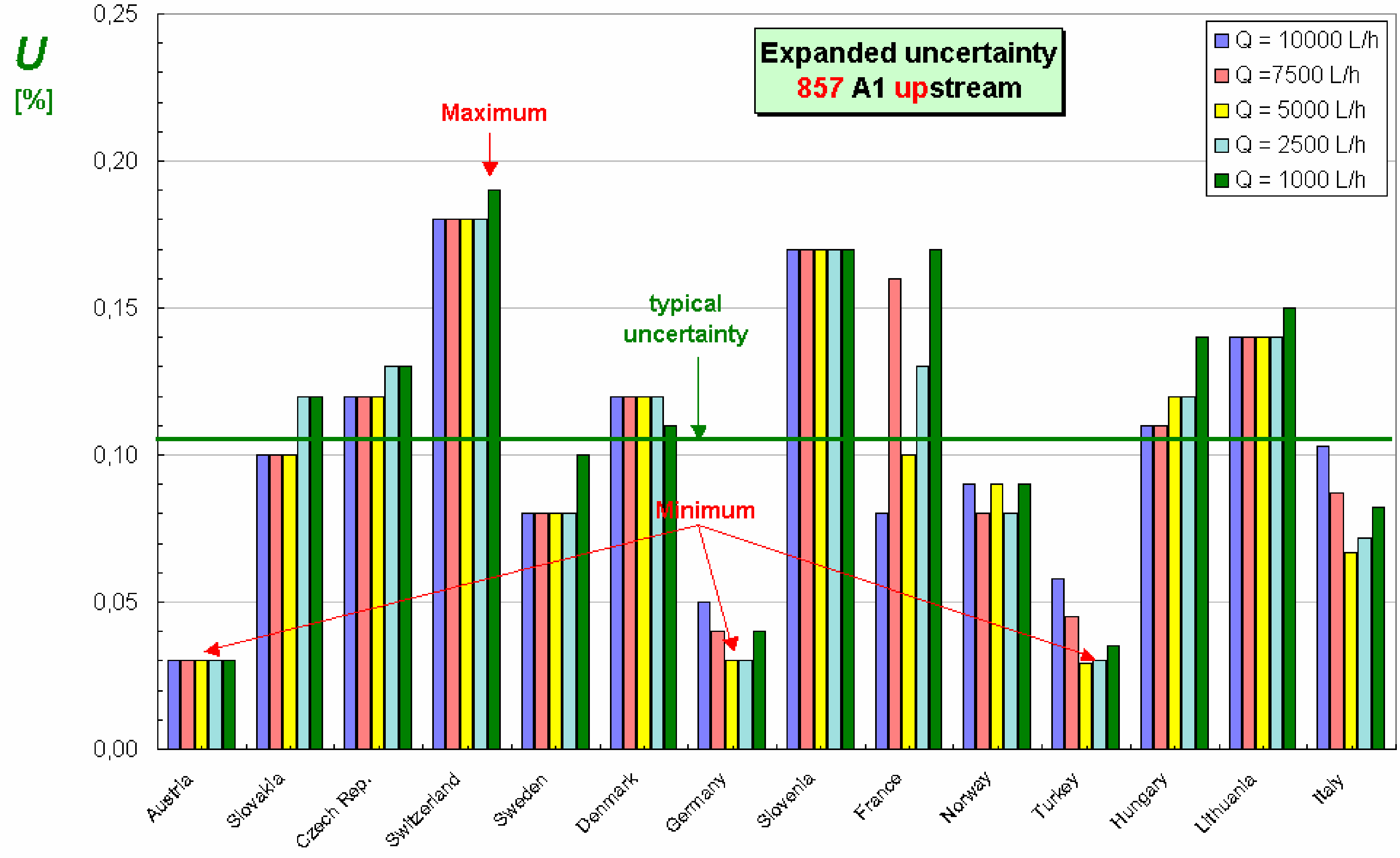
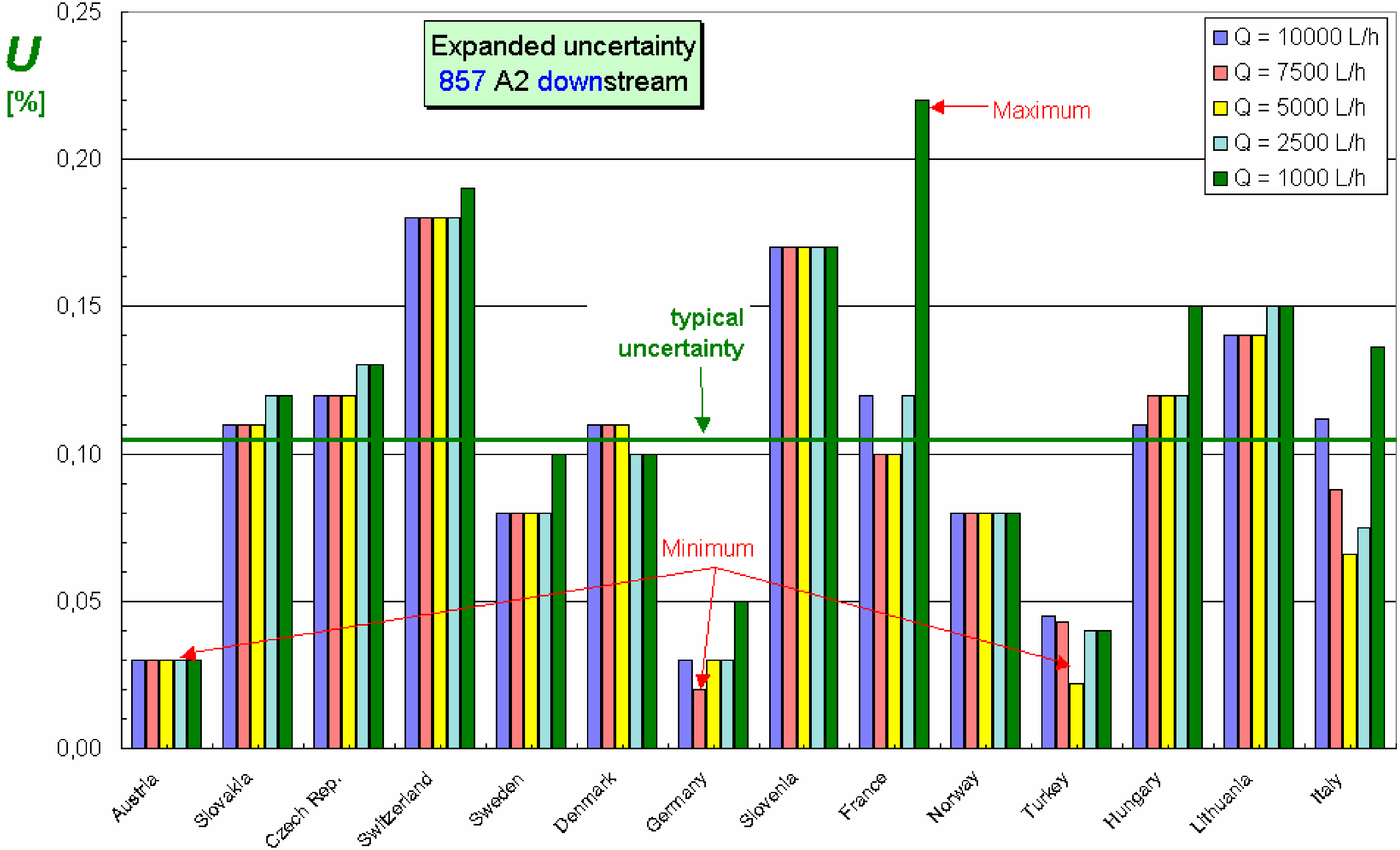
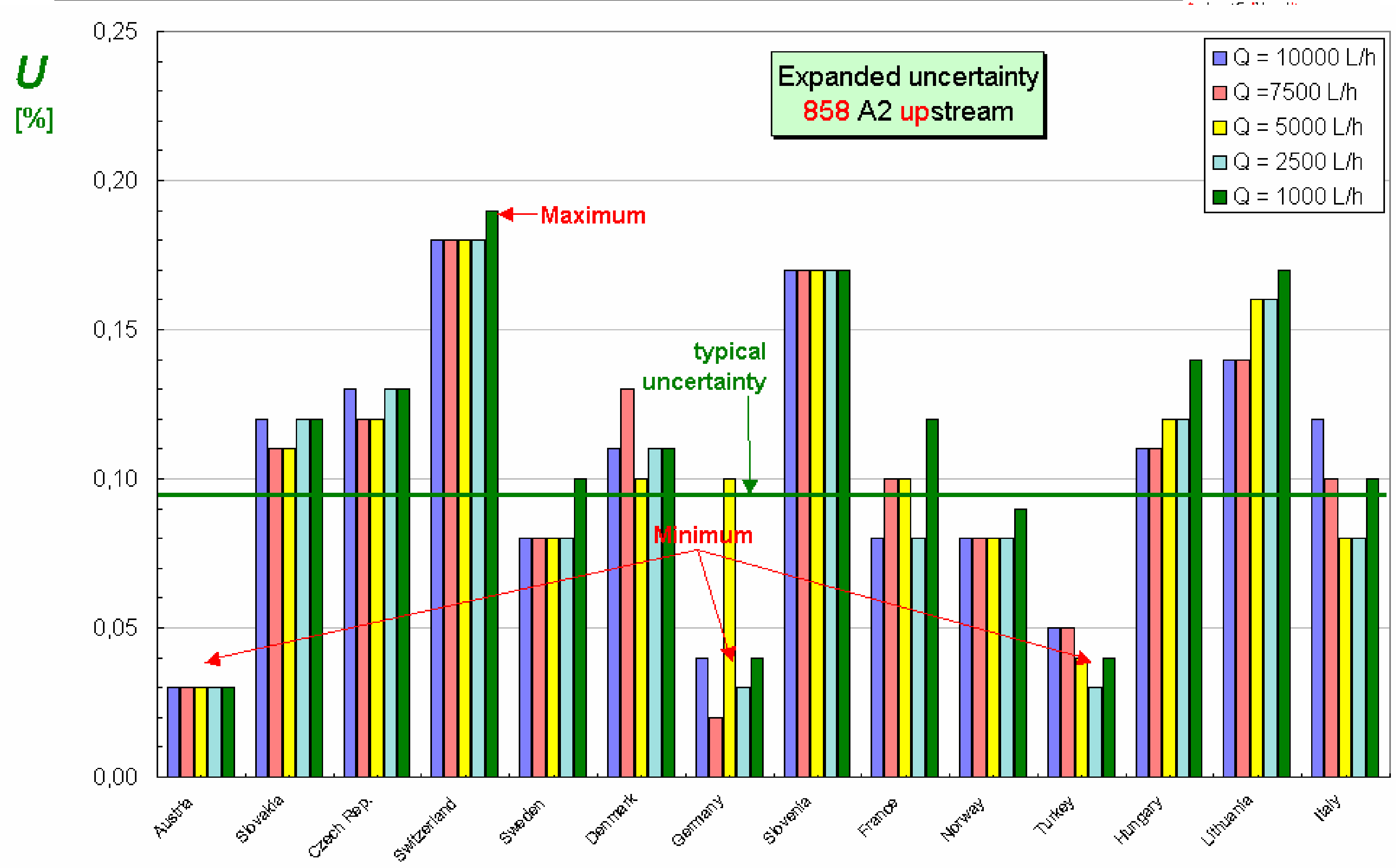


Uncertainties 857 A2 downstream

Willkommen im BEV

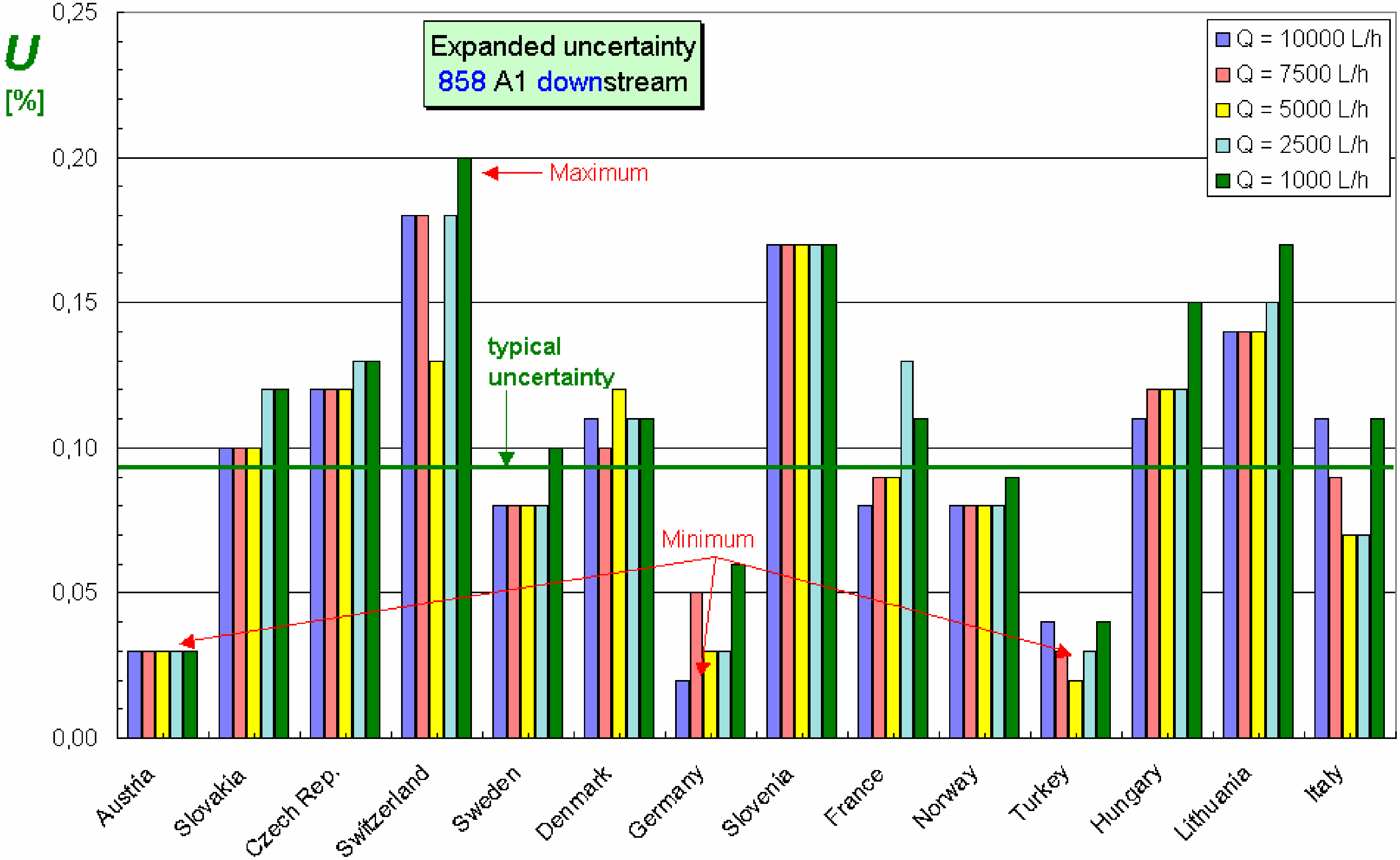


Uncertainties 858 A2 upstream



Uncertainties 858 A1 downstream

Willkommen im BEV



Test to get the KCRV: χ^2-Test

What do you do to get the best reference value ? - 1

What is the **referenz value (KCRV)** for all measurements ? ➔ the **true value**, but nobody knows the true value. We srearch for the best estimation of the true value!! There are three methods

1st approach: the mean ➔ it is the best approximation of the true value, if the measurements are normal distributed. We can evaluate the mean by the formula:

$$x_0 = \frac{1}{N}\sum_{i=1}^{N} x_i$$

2nd approach: to rate the measurements by their measurement uncertainty by the following formula

$$x_{0,B} = \frac{\sum_{i=1}^{N} p_i \; x_i}{\sum_{i=1}^{N} p_i} \quad \text{mit} \quad p_i = \frac{1}{u^2(x_i)}$$

Statistic tests -

for example: the χ^2-Tests

Situation: there are measurement results: $(x_i, y_i, u(x_i))$

On the other hand: we have an unknowned mathematical function $F(x_i, \varepsilon_1, \varepsilon_2, ...)$ with variable coefficients $\varepsilon_1, \varepsilon_2$ ..

We assume

$$\chi^2 = \sum_{i=1}^{N} \frac{(y_i - F(x_i, \varepsilon_1, \varepsilon_2, ...))^2}{u^2(x_i)}$$

Proceeding: variation of the parameters $\varepsilon_1, \varepsilon_2$ ... but χ^2 is a minimum!

Procedure by **Nielsen; reference value is** doubtful by $u^2(x_{ref})$:

$$\chi^2_{obs} = \frac{(x_1 - x_{ref})^2}{u^2(x_1) - u^2(x_{ref})} + \frac{(x_2 - x_{ref})^2}{u^2(x_2) - u^2(x_{ref})} + \frac{(x_3 - x_{ref})^2}{u^2(x_3) - u^2(x_{ref})} + \ldots$$

$$\ldots + \frac{(x_N - x_{ref})^2}{u^2(x_N) - u^2(x_{ref})}$$

We ask for the propability because χ^2_{obs} and $\chi^2(\nu)$ have the same distribution. Condition is:

$$P\{\chi^2(\nu) > \chi^2_{obs}\} > 5\ \%$$

Excel: $\text{chivert}(\chi^2_{obs}, \nu)$

Procedure by **Cox:** reference value $\boldsymbol{x}_{\mathrm{ref}}$ is in an interval of P ≥ 5 %

$$\chi^2_{obs} = \frac{(x_1 - x_{ref})^2}{u^2(x_1)} + \frac{(x_2 - x_{ref})^2}{u^2(x_2)} + \frac{(x_3 - x_{ref})^2}{u^2(x_3)} + \ldots + \frac{(x_N - x_{ref})^2}{u^2(x_N)}$$

Procedure by **Nielsen; reference value is** uncertain by an interval of $u(x_{\mathrm{ref}})$:

$$\chi^2_{obs} = \frac{(x_1 - x_{ref})^2}{u^2(x_1) - u^2(x_{ref})} + \frac{(x_2 - x_{ref})^2}{u^2(x_2) - u^2(x_{ref})} + \frac{(x_3 - x_{ref})^2}{u^2(x_3) - u^2(x_{ref})} + \ldots$$
$$\ldots + \frac{(x_N - x_{ref})^2}{u^2(x_N) - u^2(x_{ref})}$$

We ask for the propability because χ^2_{obs} and $\chi^2(\nu)$ have the same distribution. Condition is:

$$P\{\chi^2(\nu) > \chi^2_{obs}\} > 5\,\%$$

Excel:

$$\text{chivert}\,(\chi^2_{obs}, \nu)$$

Example: - 14 participants, ν = 13, 857 downstream

	reported values	abs deviation from mean	reported uncertainties (k = 2)	reported uncertainties included installation effects (k = 2)	reported uncertainties (k = 1) with stability uncertainty			degree of equivalence	normalized difference	by Nielsen	by Cox
Labor	x_i	d_i	$U(x_i)$	$U(x_i)$	$u(x_i)$	$x_i/u^2(x_i)$	$1/u^2(x_i)$	d_i	norm d_i	χ^2	χ^2
Austria	-0,13	0,04	0,03	0,07	0,034	-116	889	-0,04	1,16	1,35	1,12
Slovakia	-0,03	0,06	0,11	0,13	0,063	-8	255	0,06	1,06	1,12	1,06
Czech Rep.	-0,01	0,08	0,12	0,13	0,067	-2	222	0,08	1,29	1,66	1,59
Switzerland	-0,04	0,05	0,18	0,19	0,095	-4	111	0,05	0,58	0,34	0,33
Sweden	-0,07	0,02	0,08	0,10	0,050	-28	400	0,02	0,51	0,26	0,24
Denmark	-0,05	0,04	0,11	0,13	0,063	-13	255	0,04	0,73	0,53	0,50
Germany	-0,05	0,04	0,03	0,07	0,034	-44	889	0,04	1,46	2,13	1,76
Slovenia	-0,13	0,04	0,17	0,18	0,090	-16	123	-0,04	0,40	0,16	0,15
France	0,00	0,09	0,12	0,13	0,067	0	222	0,09	1,44	2,07	1,99
Norway	-0,29	0,35	0,08	0,10	0,050	-116	400	-0,20	4,07	16,57	15,28
Turkey	-0,13	0,04	0,05	0,08	0,038	-92	711	-0,04	1,02	1,04	0,90
Hungary	-0,01	0,08	0,11	0,13	0,063	-3	255	0,08	1,38	1,91	1,82
Lithuania	-0,16	0,07	0,14	0,15	0,076	-28	172	-0,07	0,87	0,76	0,74
Italy	-0,07	0,02	0,11	0,13	0,064	-17	248	0,02	0,40	0,16	0,15
mean = x_{ref}	**-0,084**				Summen =	**-487**				χ^2_{obs} =	χ^2_{obs} =
s	**0,079**				Summen =		**5152**			30,07	27,63
s_0	**0,026**							$P\{\chi^2(\nu)-\chi^2_{obs}\}$ =		**0,46%**	**1,02%**
ν =	**13**					**$u^2(x_{ref})$ = 1,941E-04**		%²		level of significance = 5 %	
x_{ref} =	**-0,095**					**$u(x_{ref})$ = 0,014**		%			

Example: - 11 participants, ν = 10 (without Cz, F, N) 857 downstream

Labor	reported values x_i	abs deviation from mean d_i	reported uncertainties (k = 2) $U(x_i)$	reported uncertainties included installation effects (k = 2) $U(x_i)$	reported uncertainties (k = 1) with stability uncertainty $u(x_i)$	$x_i/u^2(x_i)$	$1/u^2(x_i)$	degree of equivalence d_i	normalized difference norm d_i	by Nielsen χ^2	by Cox χ^2
Austria	-0,13	0,04	0,03	0,07	0,034	-116	889	-0,04	1,49	2,21	1,75
Slovakia	-0,03	0,06	0,11	0,13	0,063	-8	255	0,06	0,92	0,84	0,79
Switzerland	-0,04	0,05	0,18	0,19	0,095	-4	111	0,05	0,49	0,24	0,23
Sweden	-0,07	0,02	0,08	0,10	0,050	-28	400	0,02	0,33	0,11	0,10
Denmark	-0,05	0,04	0,11	0,13	0,063	-13	255	0,04	0,59	0,34	0,32
Germany	-0,05	0,04	0,03	0,07	0,034	-44	889	0,04	1,19	1,42	1,13
Slovenia	-0,13	0,04	0,17	0,18	0,090	-16	123	-0,04	0,50	0,25	0,24
Turkey	-0,13	0,04	0,05	0,08	0,038	-92	711	-0,04	1,30	1,68	1,40
Hungary	-0,01	0,08	0,11	0,13	0,063	-3	255	0,08	1,24	1,55	1,46
Lithuania	-0,16	0,07	0,14	0,15	0,076	-28	172	-0,07	1,00	0,99	0,95
Italy	-0,07	0,02	0,11	0,13	0,064	-17	248	0,02	0,25	0,06	0,06
mean = x_{ref}	-0,079				Summen =	-369				χ^2_{obs} =	χ^2_{obs} =
s	0,050				Summen =		4308			9,69	8,43
s_0	0,017								$P\{\chi^2(\nu)\text{-}\chi^2_{obs}\}$ =	46,84%	58,66%
ν =	10					$u^2(x_{ref})$ =	2,321E-04	%²	level of significance = 5 %		
x_{ref} =	-0,086					$u(x_{ref})$ =	0,015	%			

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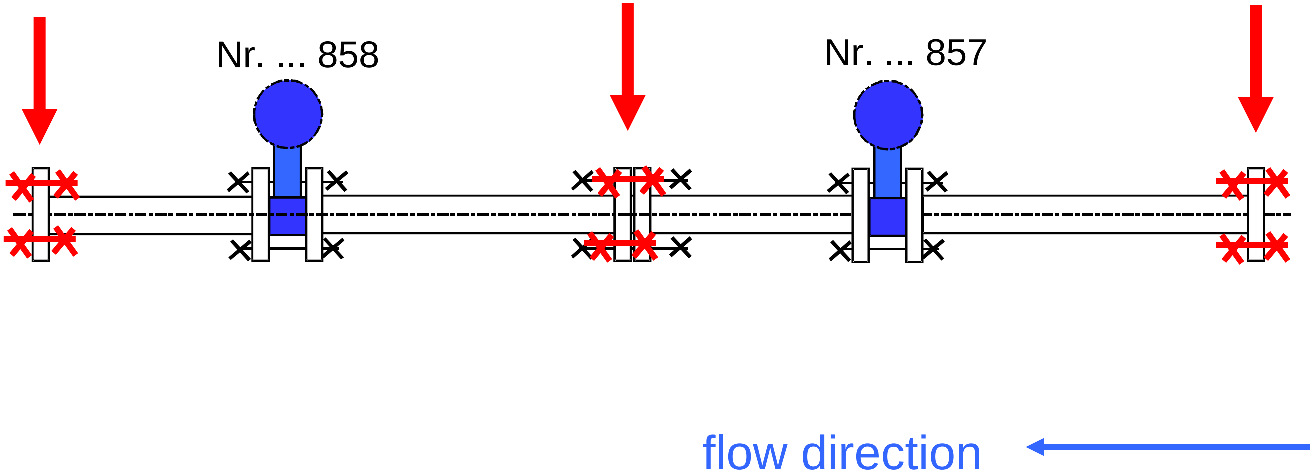
We observed that the meters depend from **installation conditions**!

Experiment: We detach the screws shown in the following picture

After that we fasten the screws again. **We do this 10 times**.

What do we get?



meter 857 at first position (upstream)

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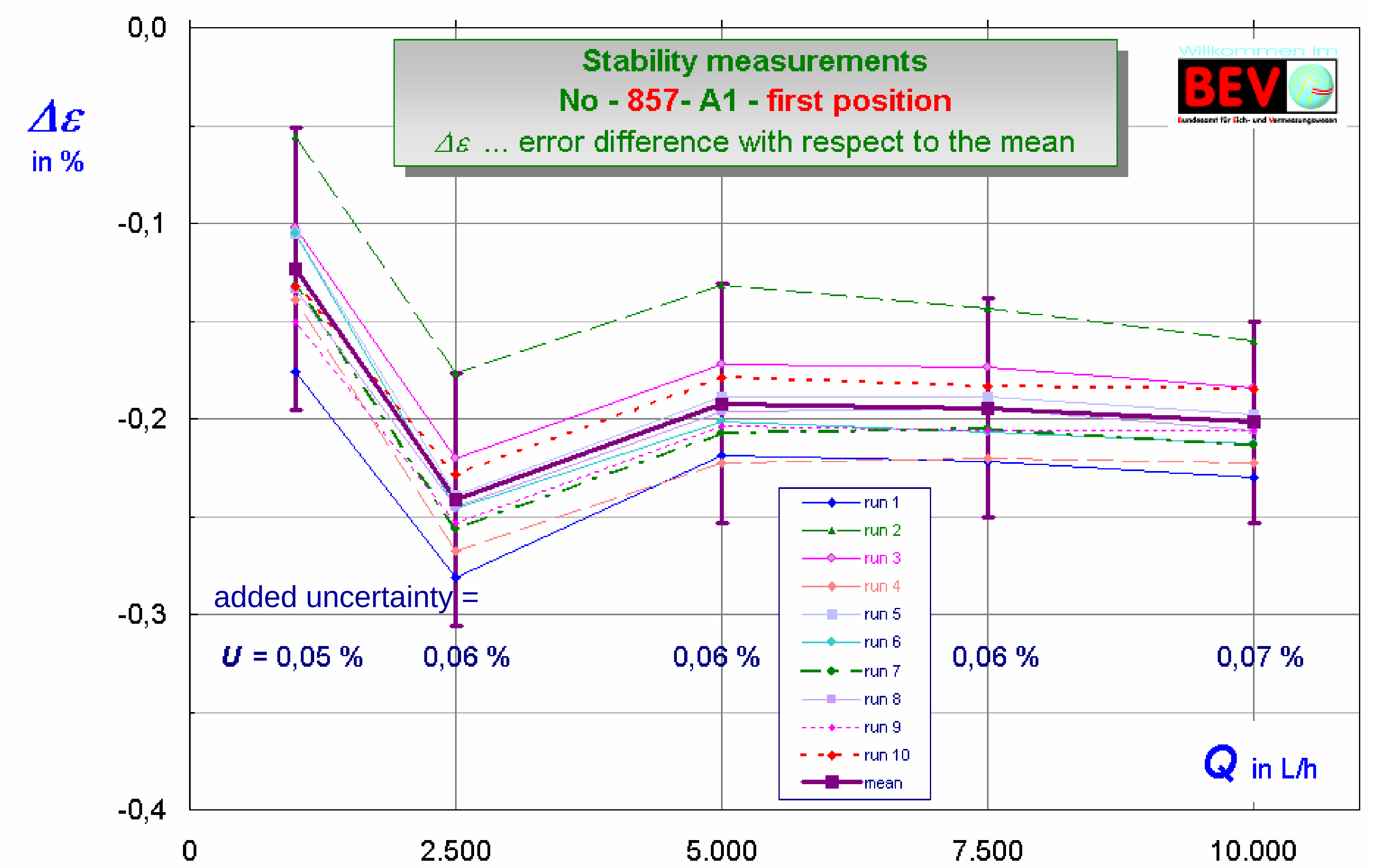
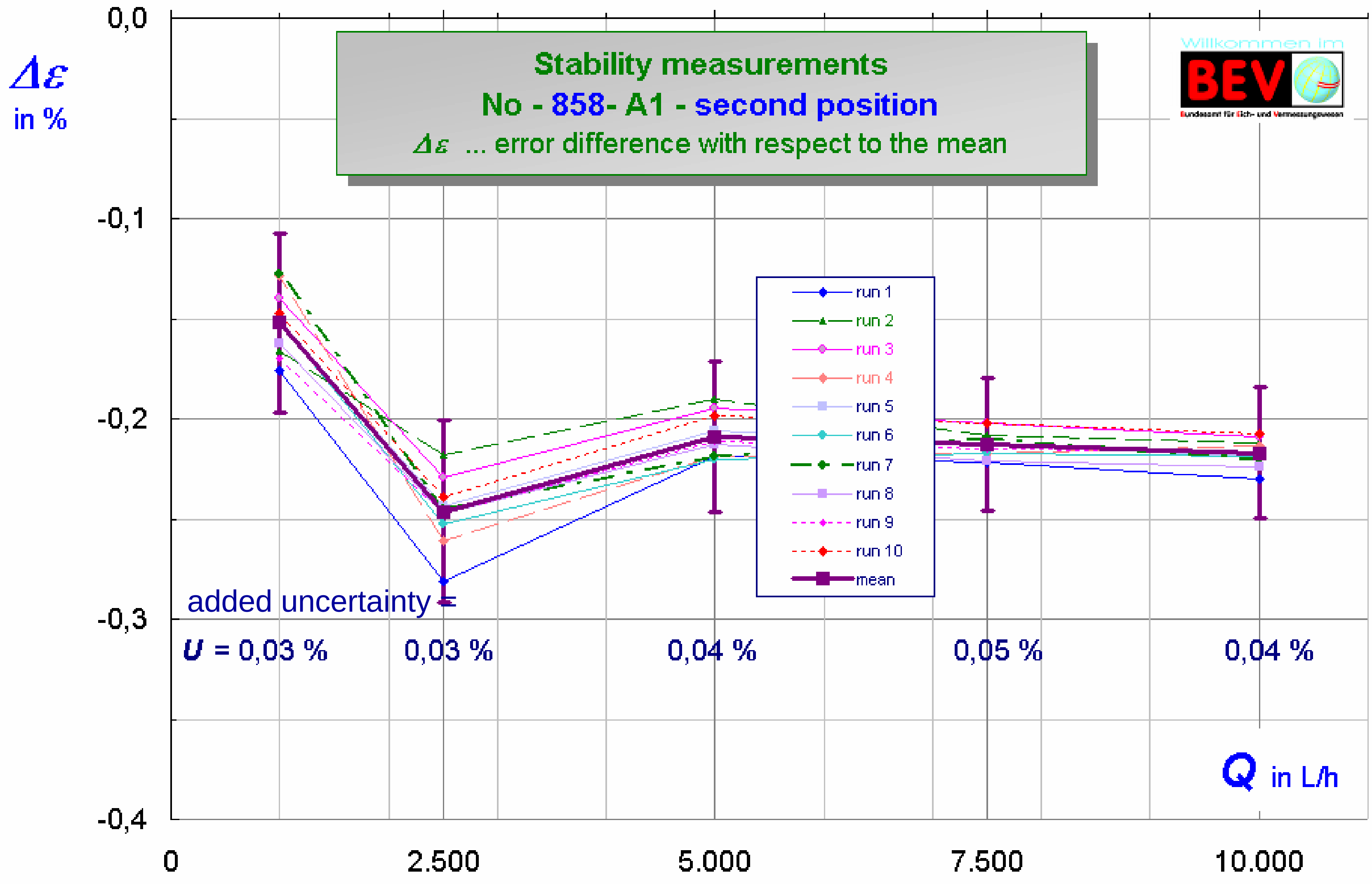


meter 857 at second position (downstream)



Uncertainty test rig and meters

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Summary:

- first position (upstream): +/- 0,6 %
- second position (downstream): +/- 0,3 %

!! We use that as a part of uncertainty which is regarded in the following Youden plots !!

Youden-plots

PLEASE REMEMBER:

- On the x-axis there is the difference between the measurement value and the KCRV for the first meter, on the y-axis there is the same for the second meter
- Zero is on both axis the **KCRV**

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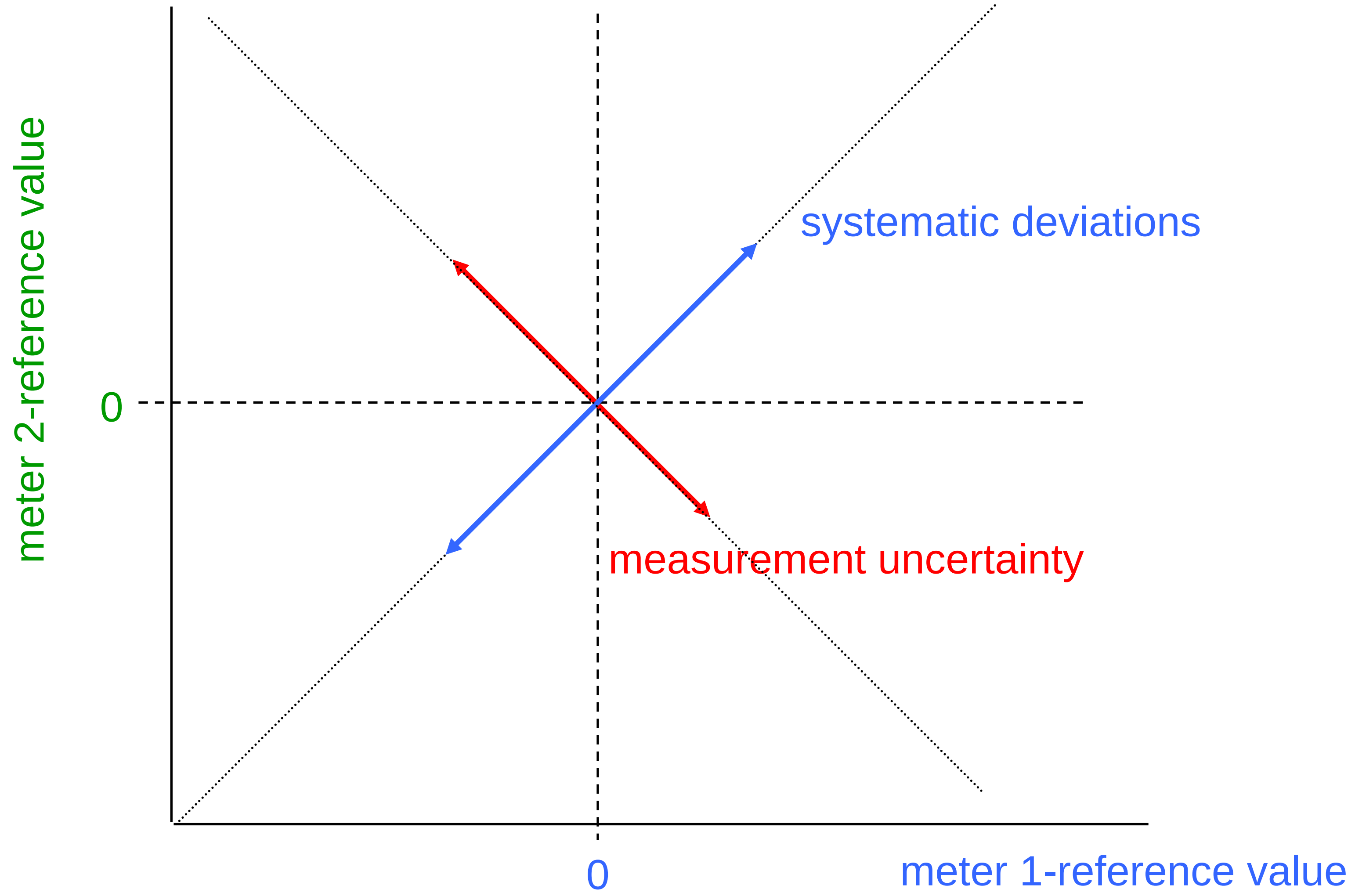
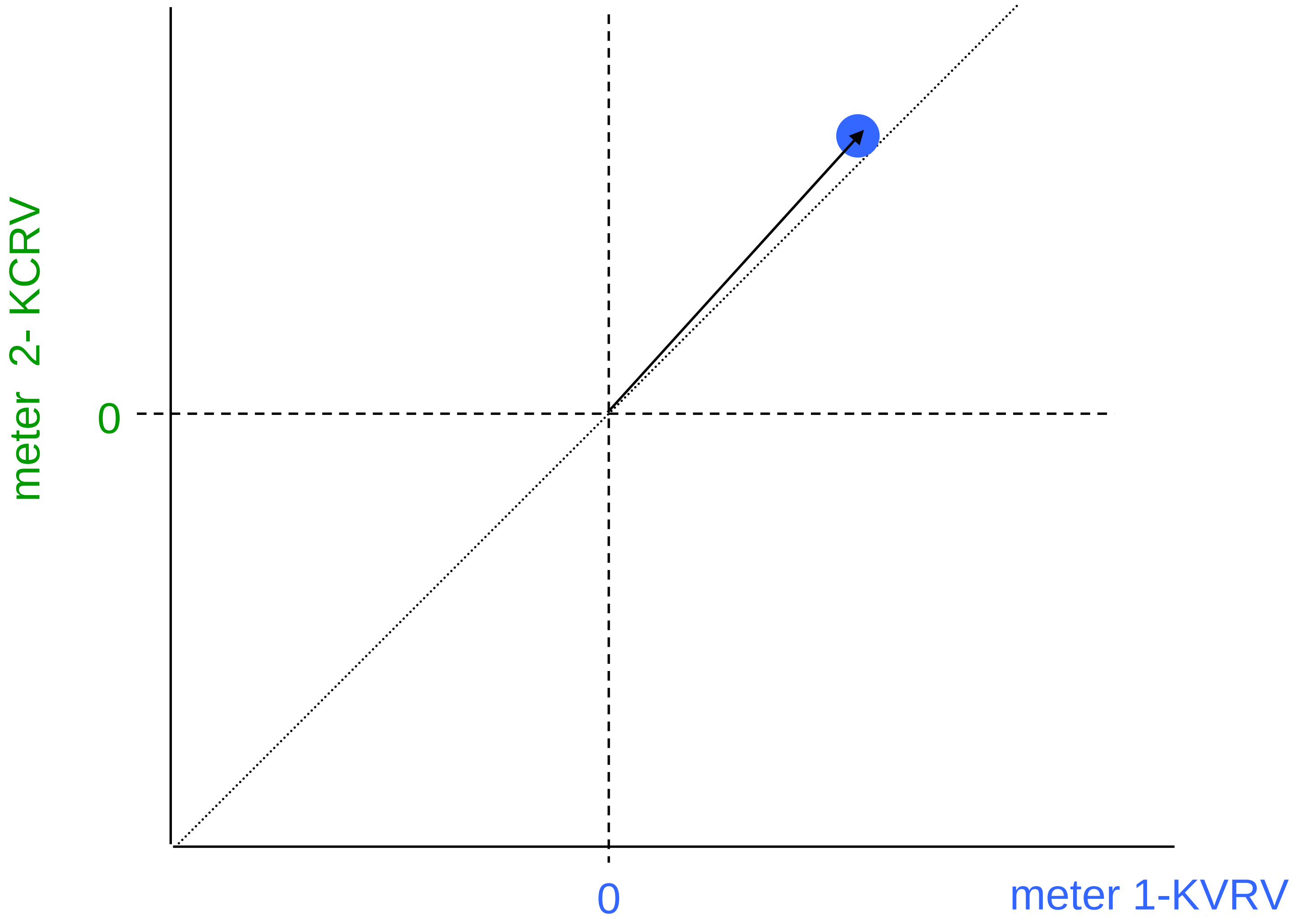


typical: small uncertainty, large systematic error



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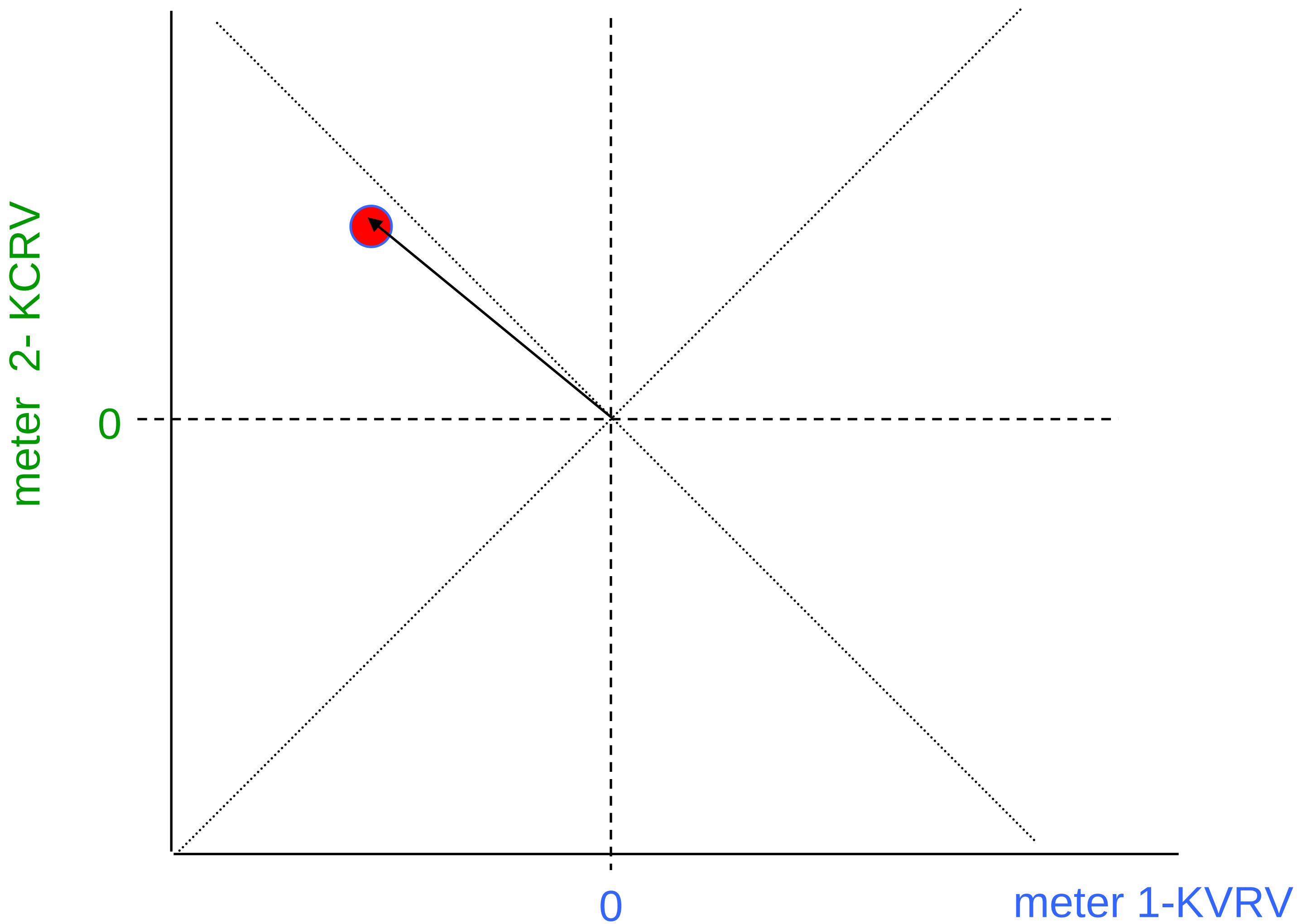
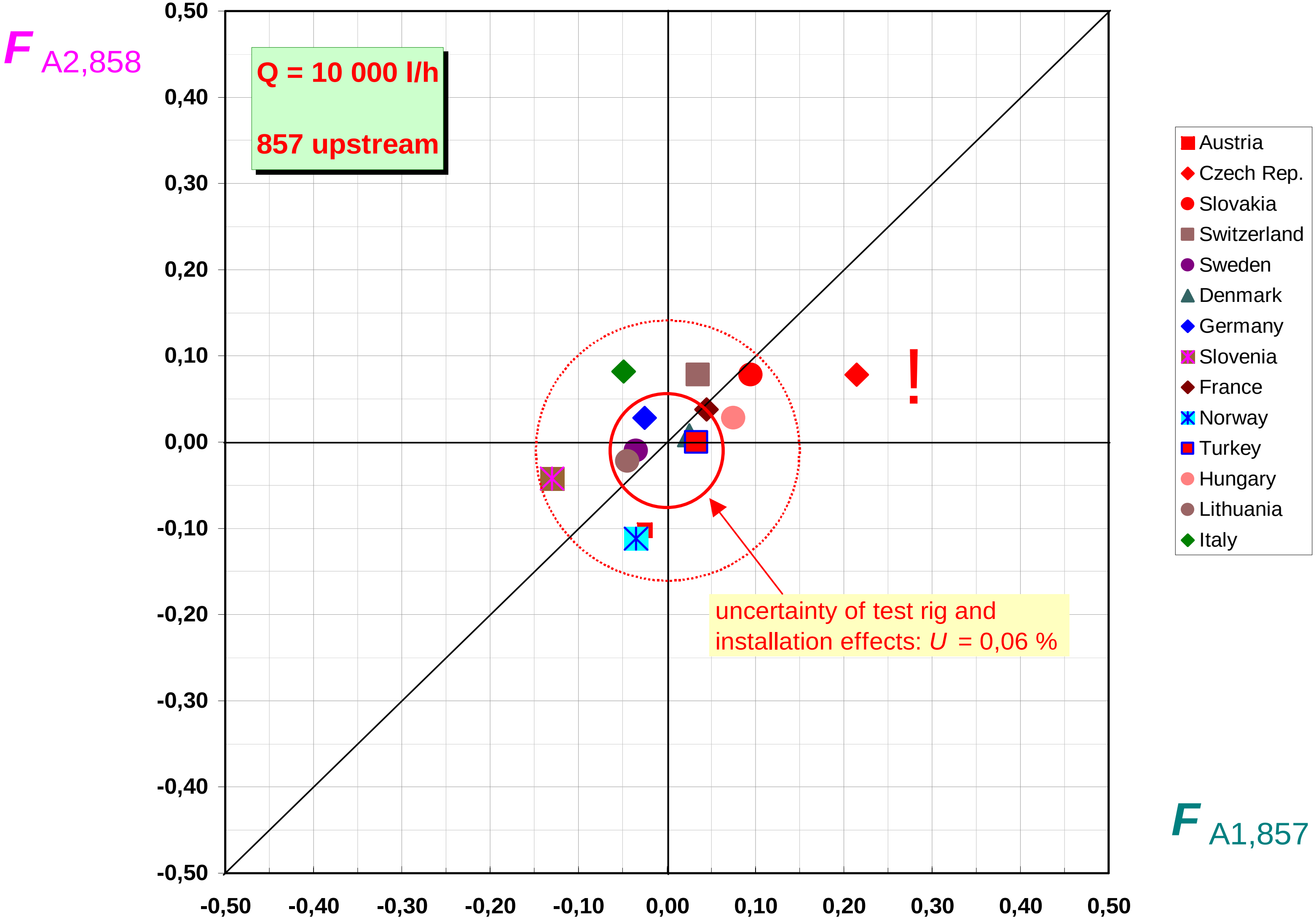


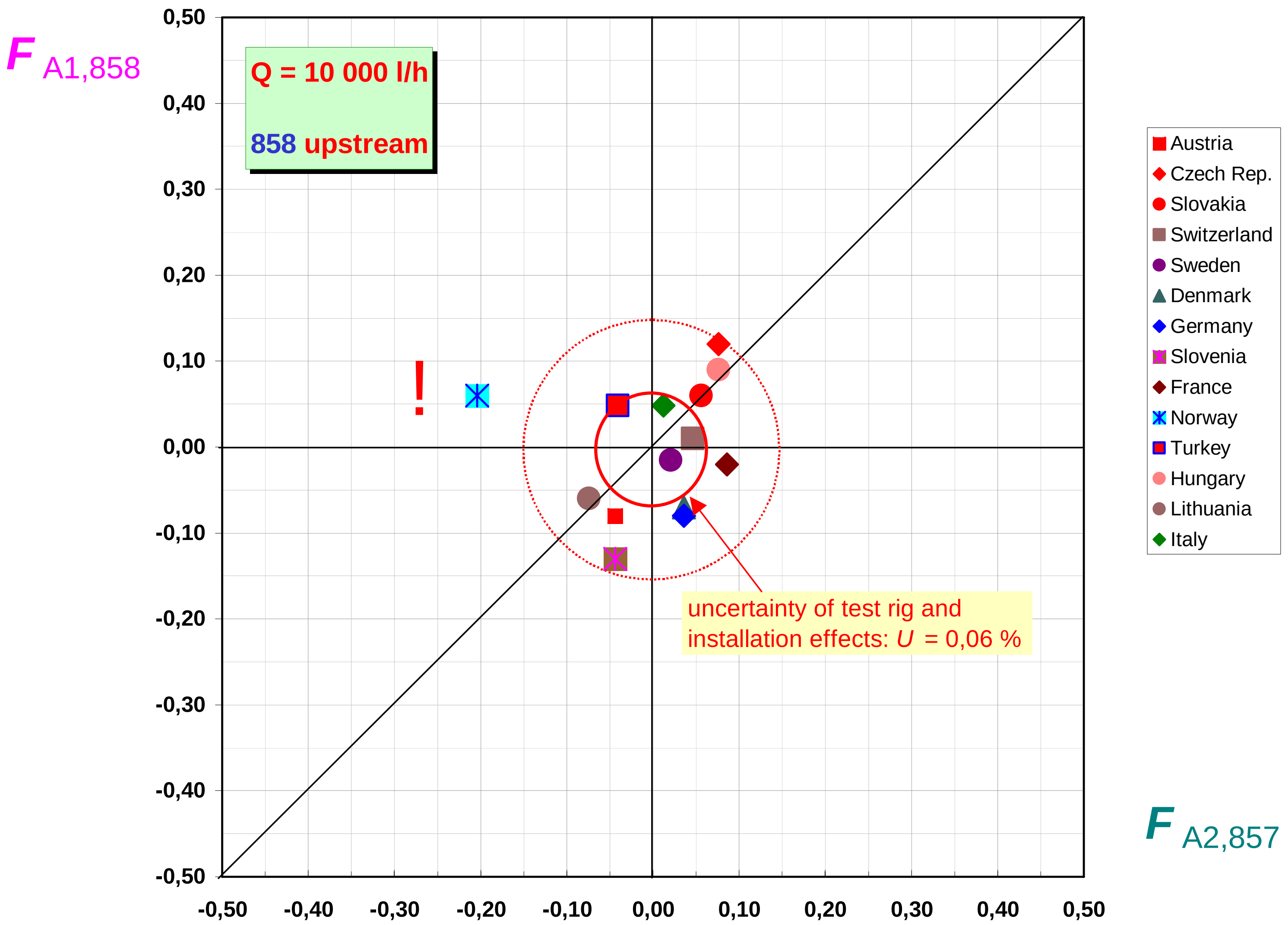
Results of the EUROMET comparisons

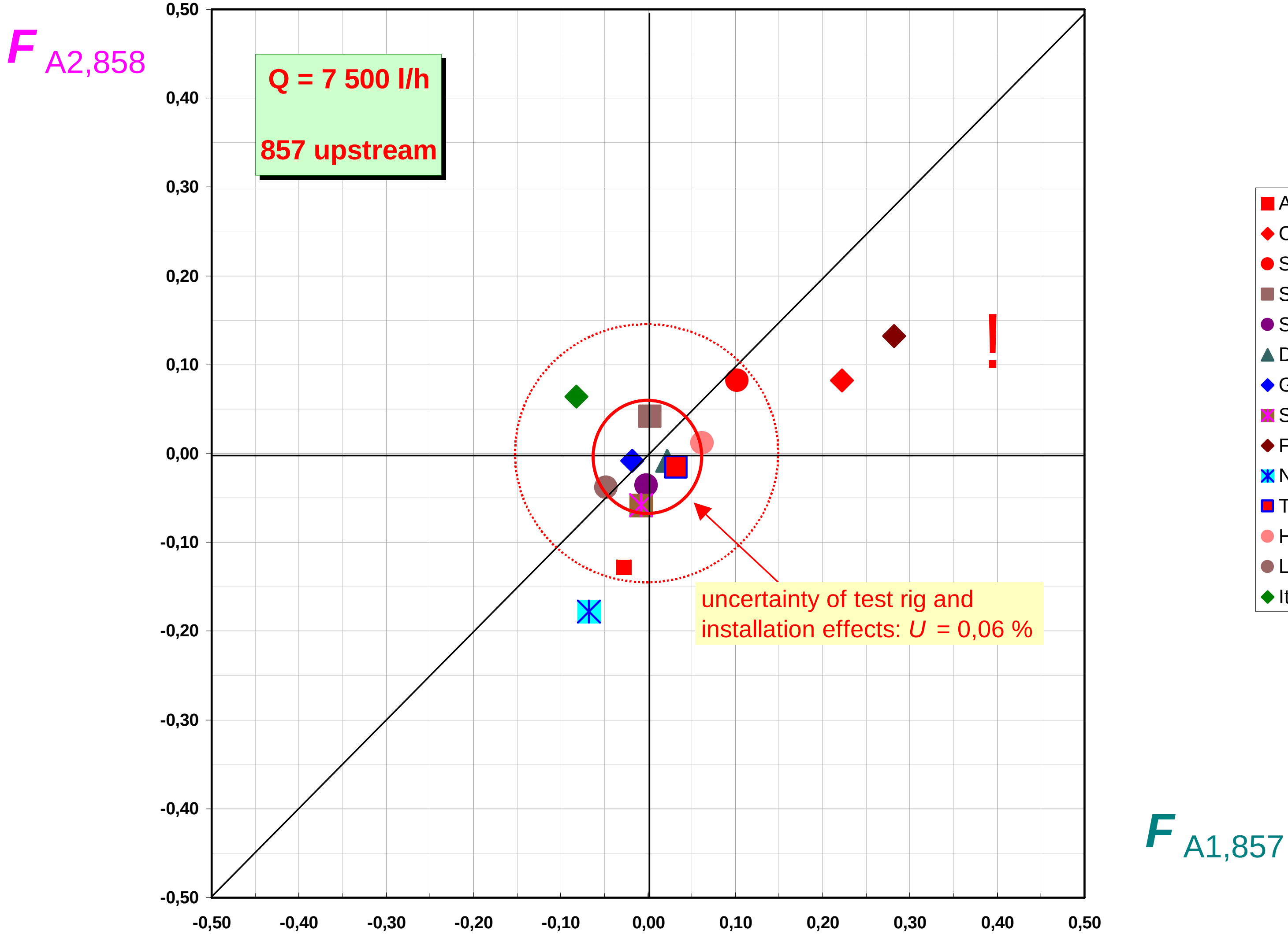
reference: KCRV (method ➔ Lau, 2003)

Q = 10 000 L/h, 857 upstream

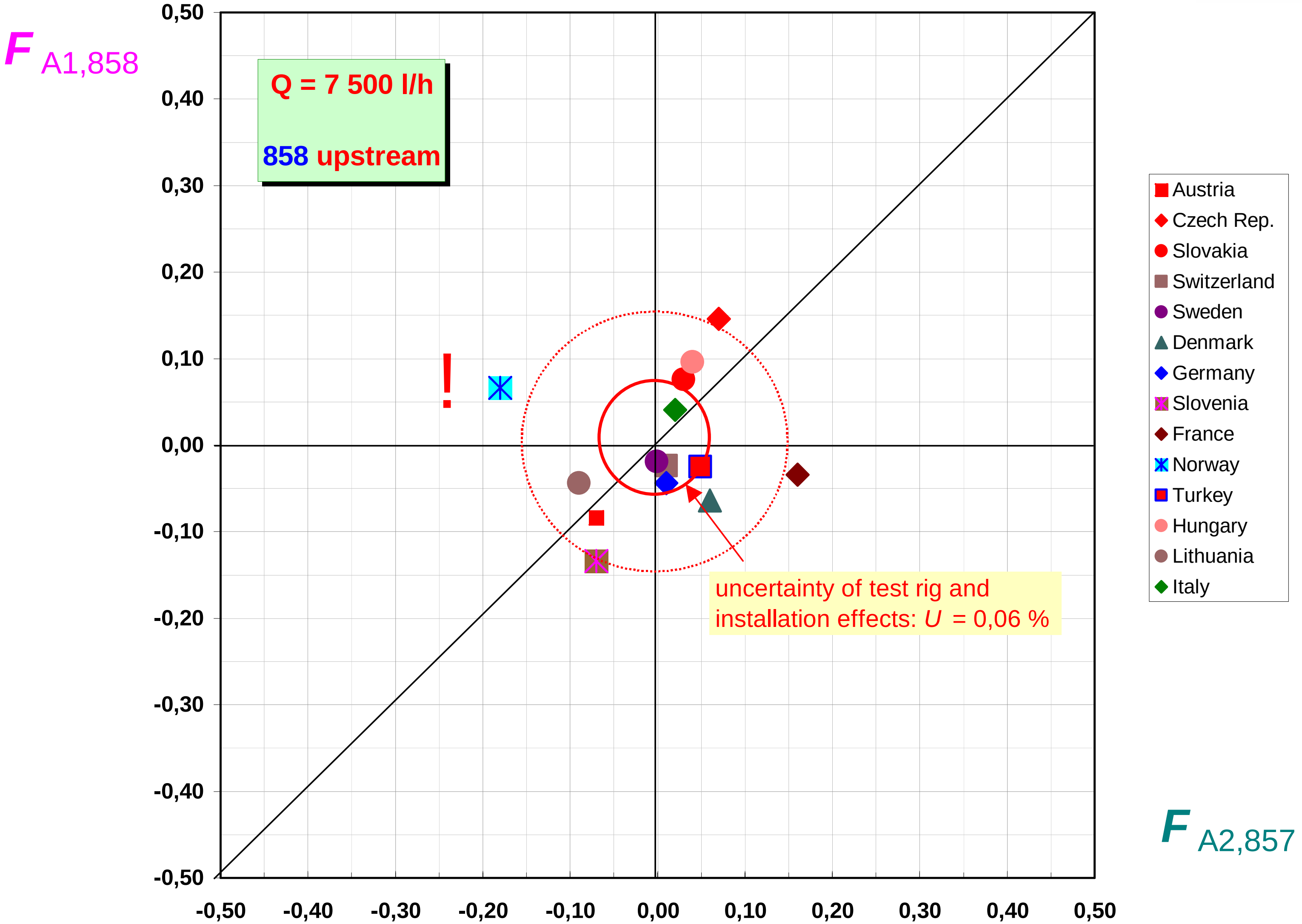


Q = 10 000 L/h, 858 upstream

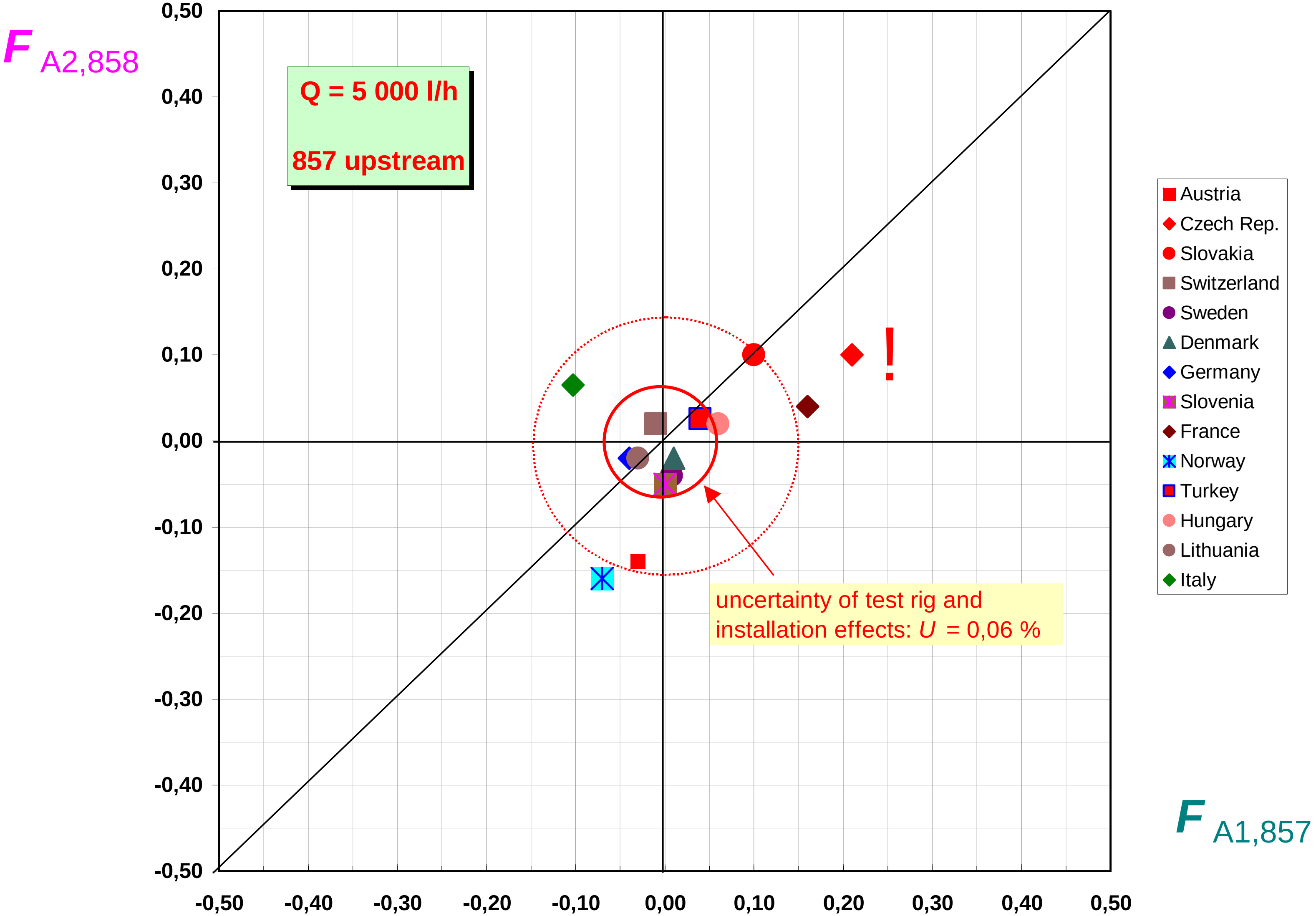



$F_{A2,858}$
Q = 7 500 l/h
857 upstream
!
uncertainty of test rig and installation effects: U = 0,06 %
0,50
0,40
0,30
0,20
0,10
0,00
-0,10
-0,20
-0,30
-0,40
-0,50
-0,50
-0,40
-0,30
-0,20
-0,10
0,00
0,10
0,20
0,30
0,40
0,50
Austria
Czech Rep.
Slovakia
Switzerland
Sweden
Denmark
Germany
Slovenia
France
Norway
Turkey
Hungary
Lithuania
Italy
$F_{A1,857}$

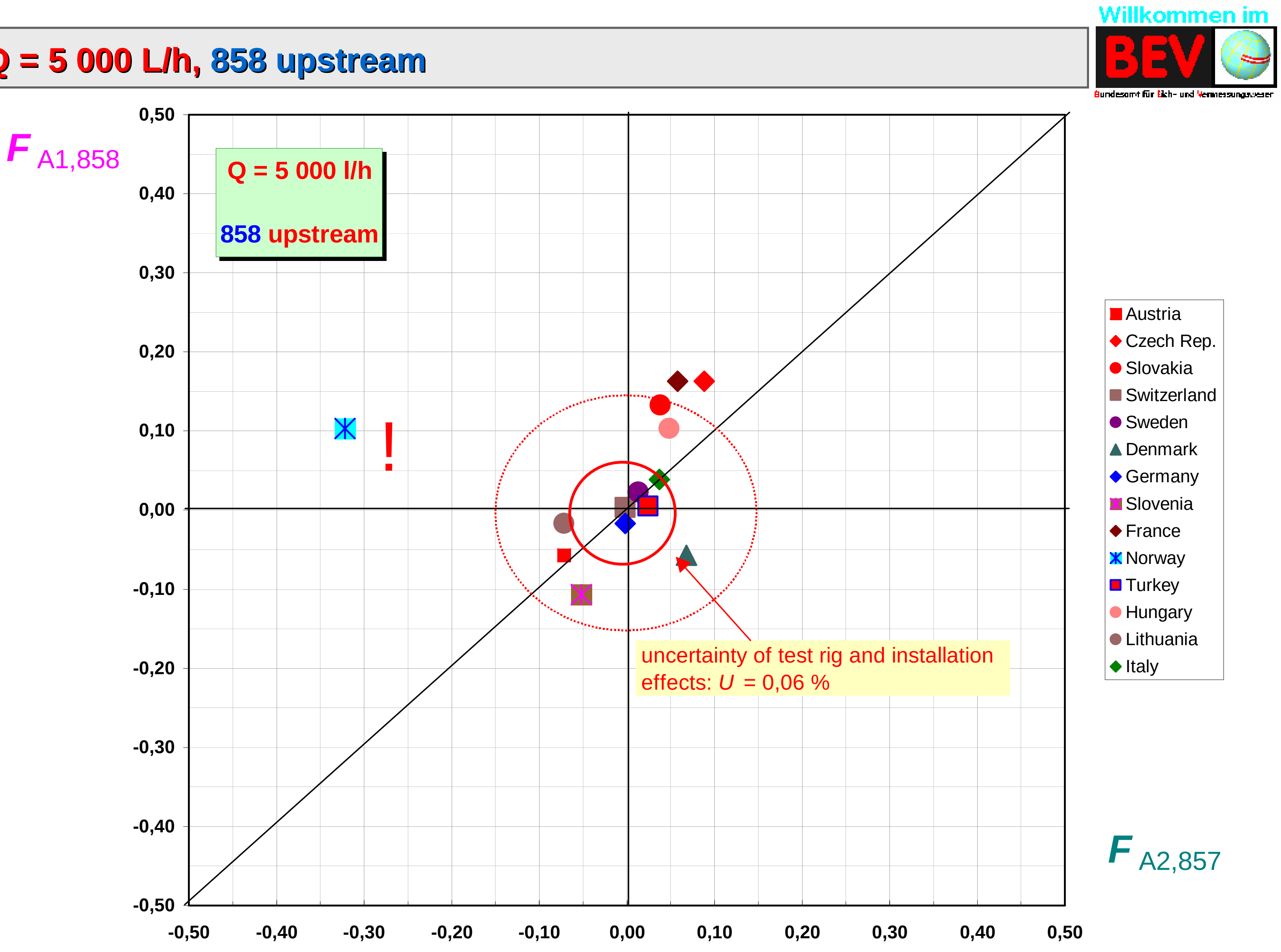
Q = 7 500 L/h, 858 upstream



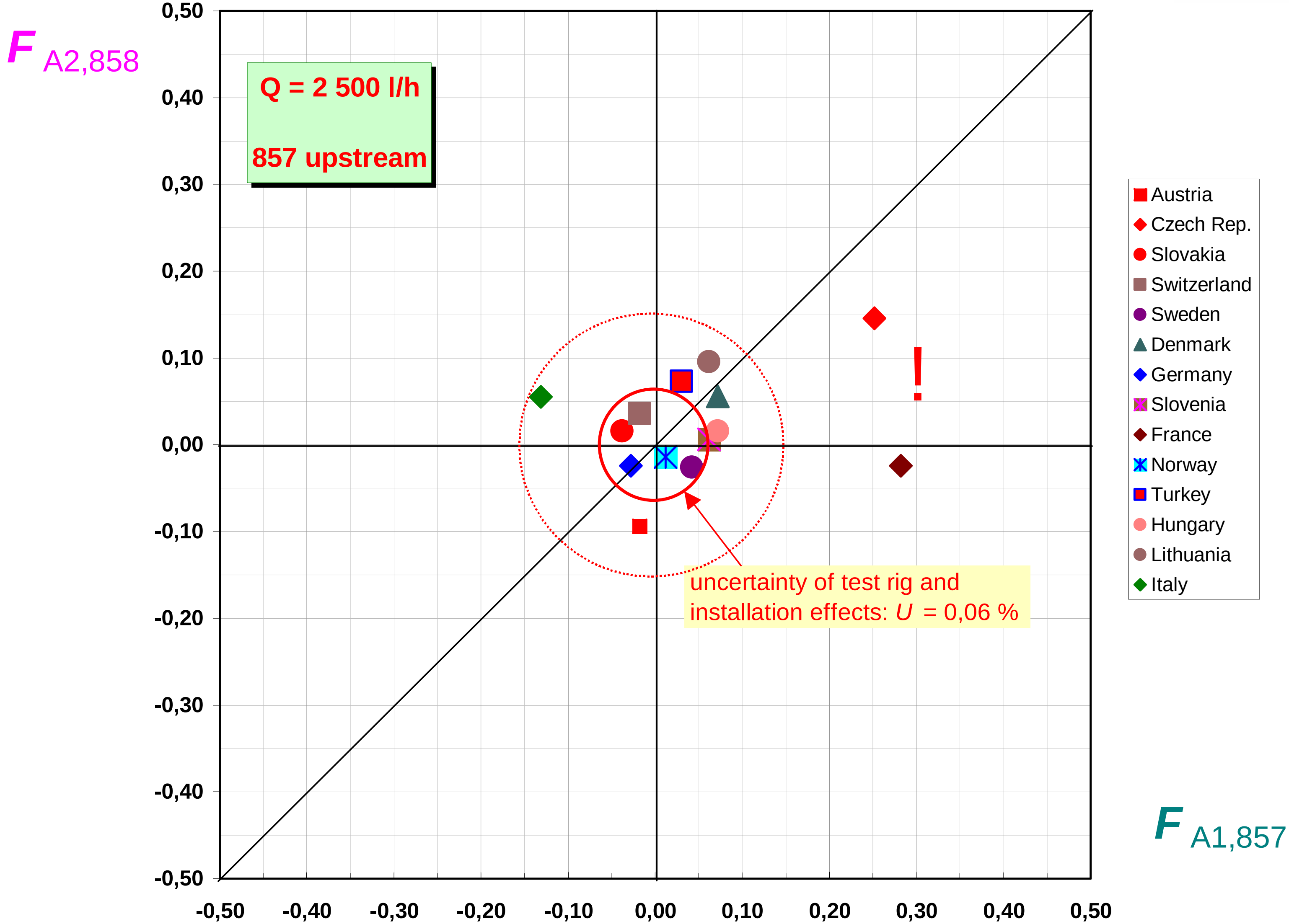
Q = 5 000 L/h, 857 upstream



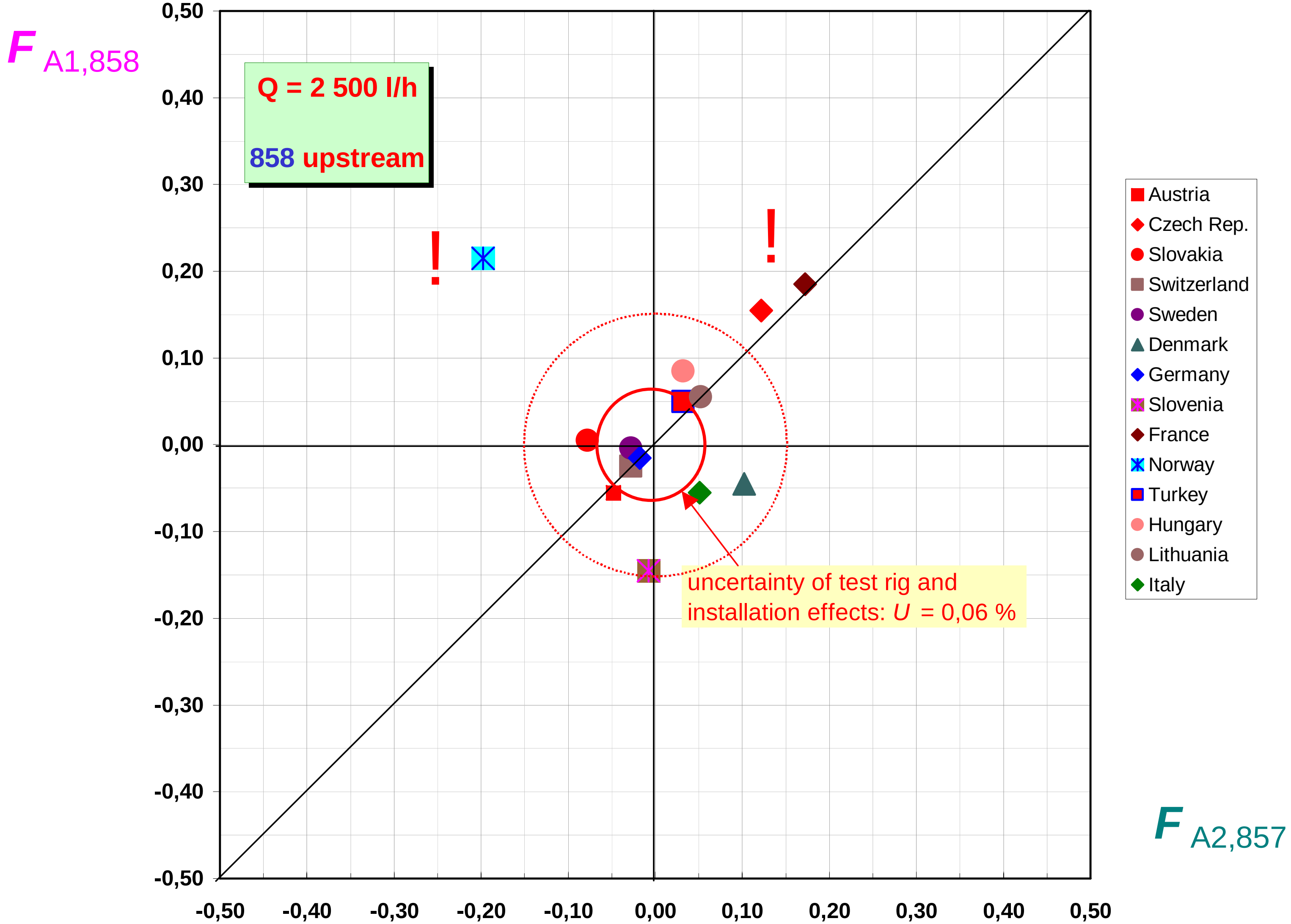
Q = 5 000 L/h, 858 upstream



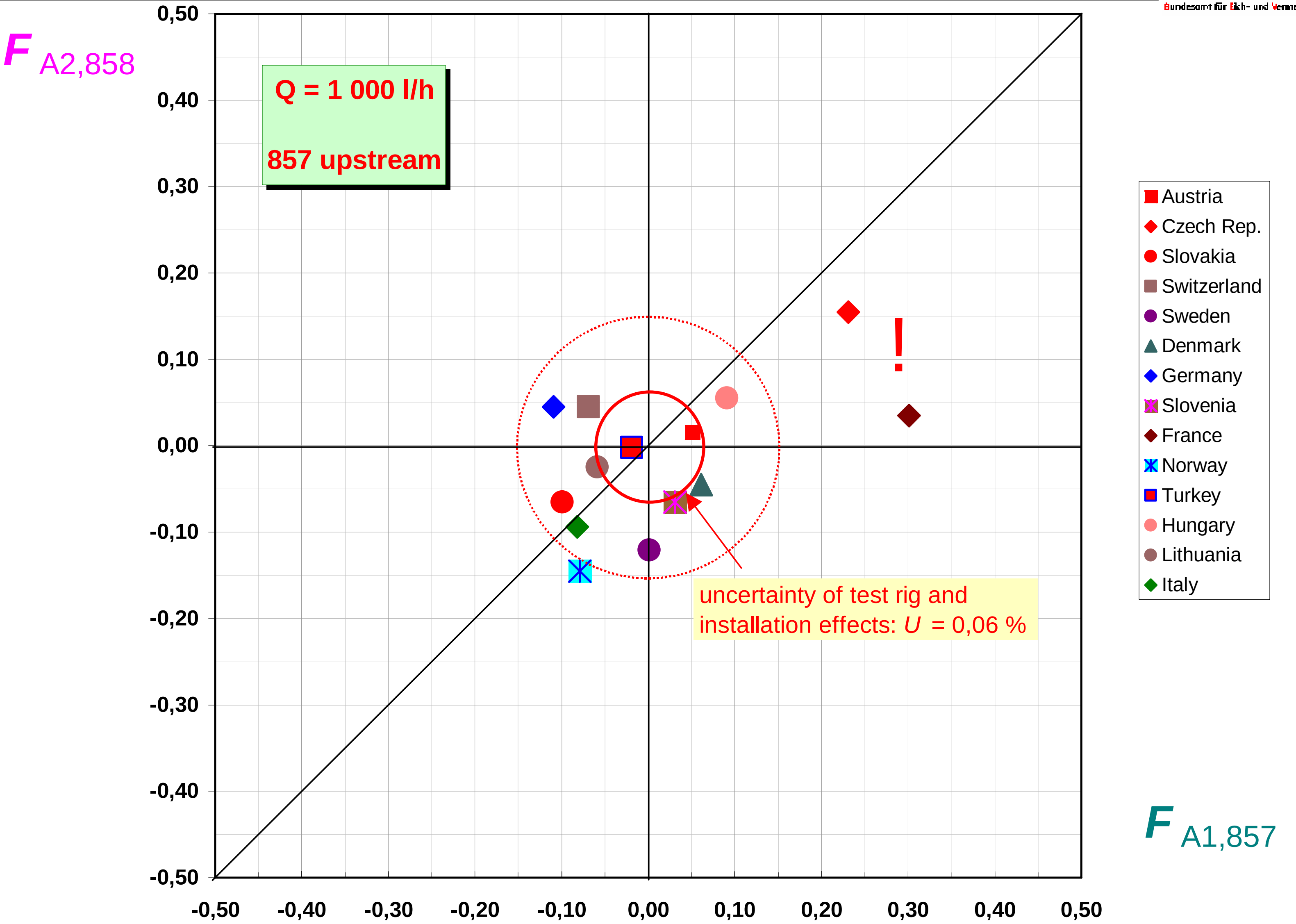
Q = 2 500 L/h, 857 upstream



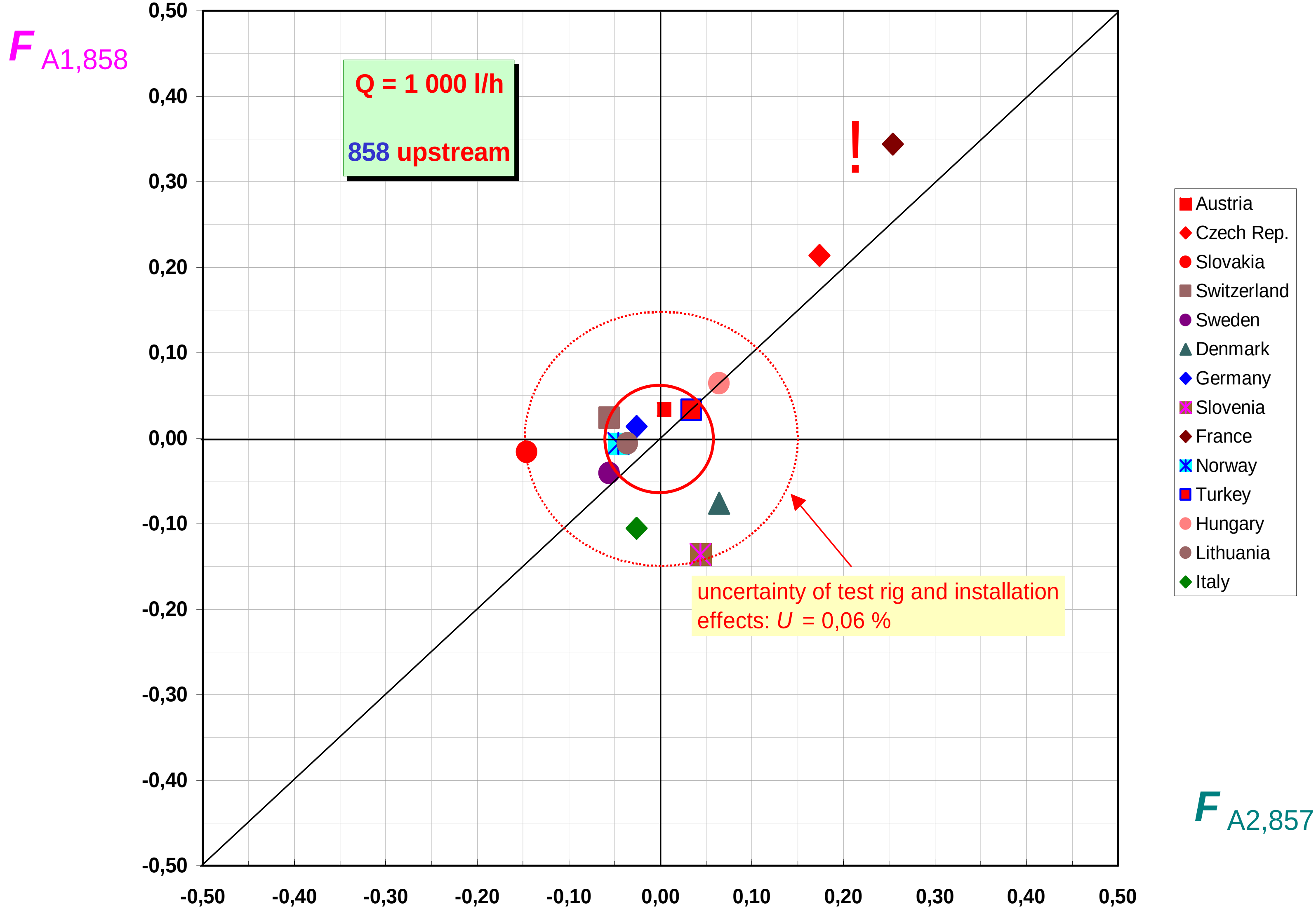
Q = 2 500 L/h, 858 upstream



Q = 1 000 L/h, 857 upstream



Q = 1 000 L/h, 858 upstream



What is to do: for determination of KCRV ➔elimination of the outsiders

➔ criteria: P(χ^2) > 5 %

Results

- measurement uncertainties of participants are extremly different: ➔ (0,02 % bis 0,20 %)
- if measurement uncertainty of a NMI very small ➔ the measurement results dominate the KCRV
- if measurement uncertainty of a NMI large ➔ only a small contribution to KCRV evaluation
- please remember: installation effects are **not neglectable**

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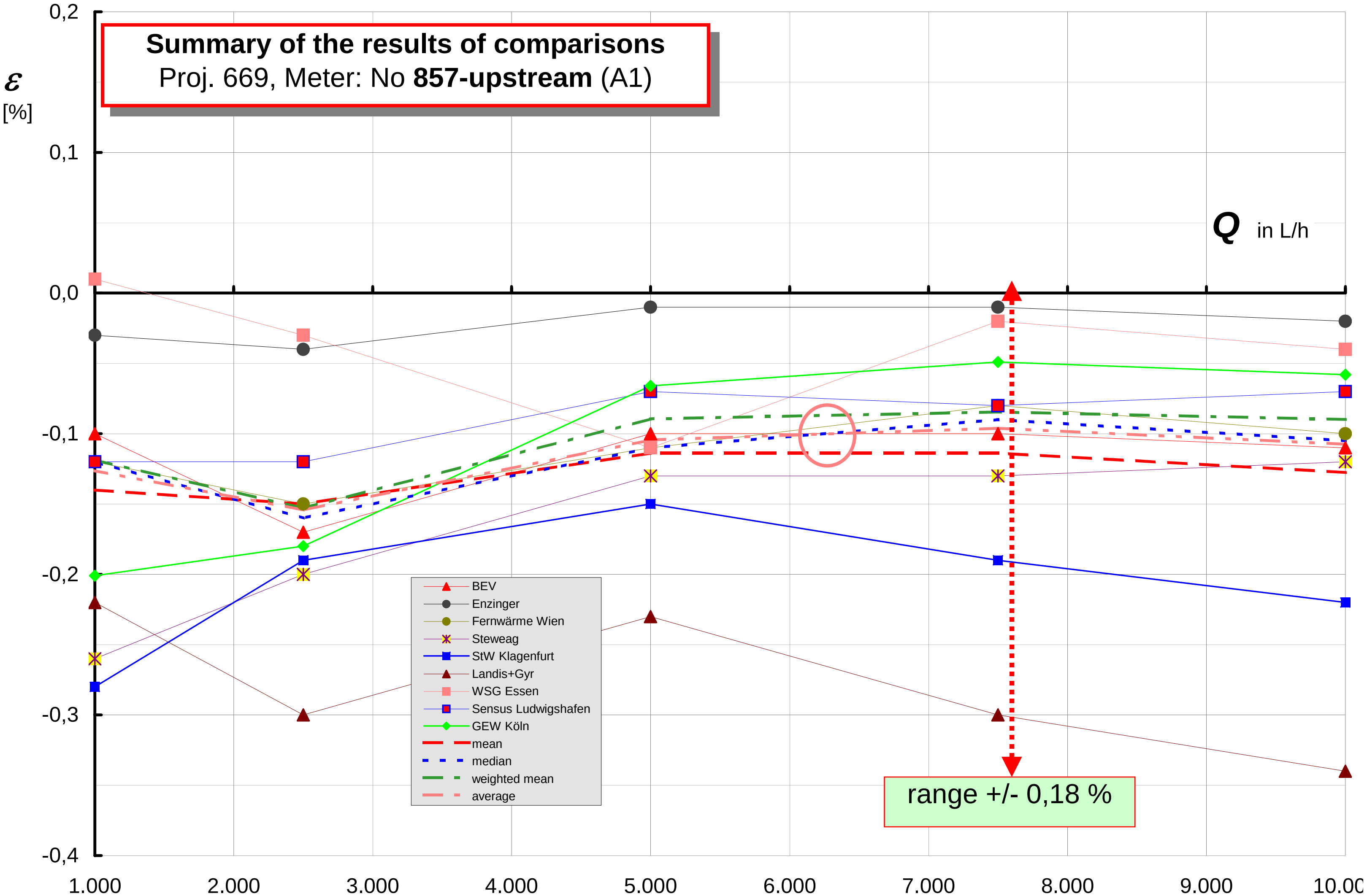
Results of the measurements:

- 10 participant (77 %) lie in a range of ± 0,15 %
- 1 participant (7,6 % lies in a range of ± 0,25 %
- 1 participant (7,6 %) lies in a range of ± 0,30 %
- 1 participant (7,6 %) lies in a range of ± 0,32 %

Results in Verification offices

No 857- upstream



No 857 - downstream

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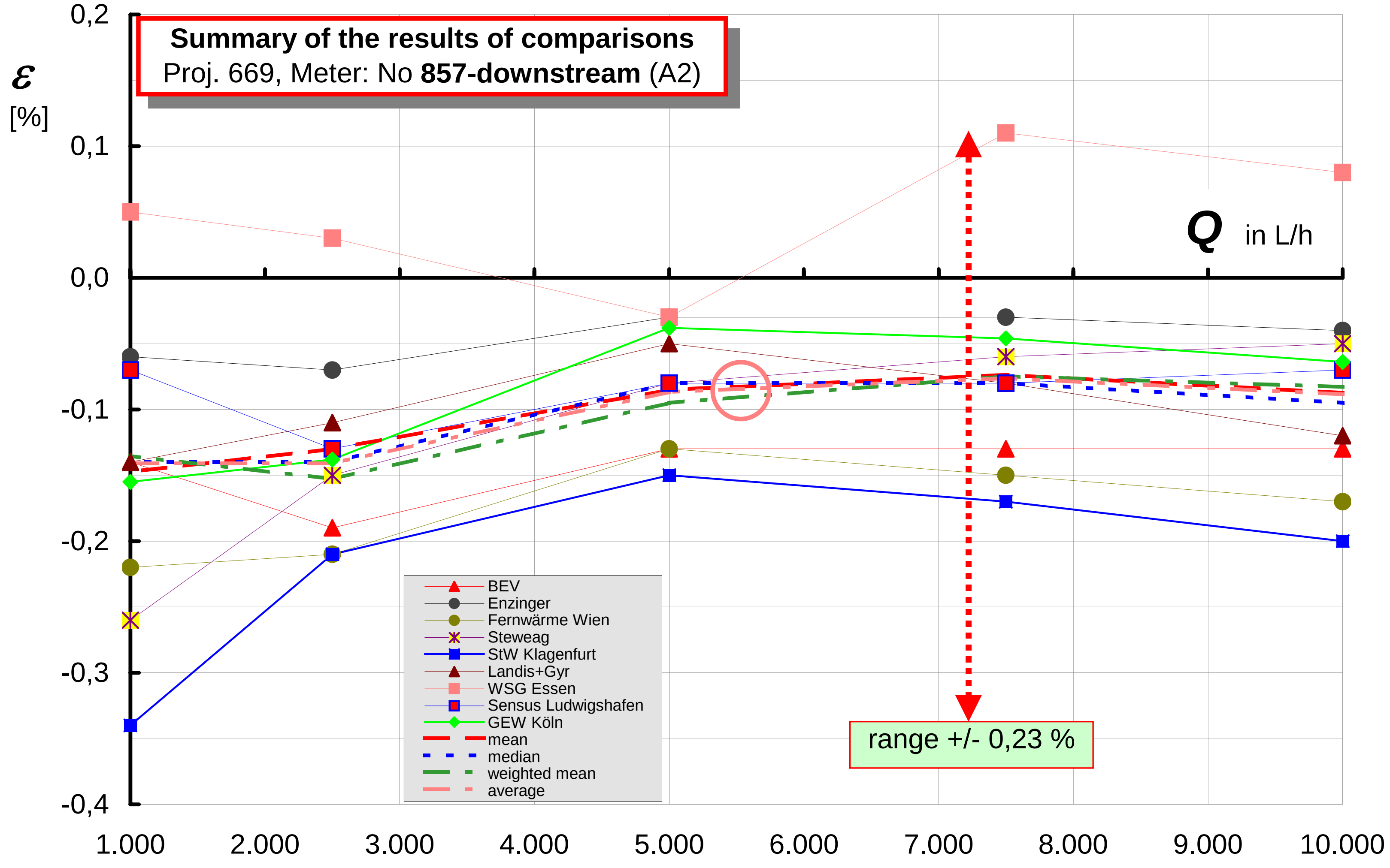
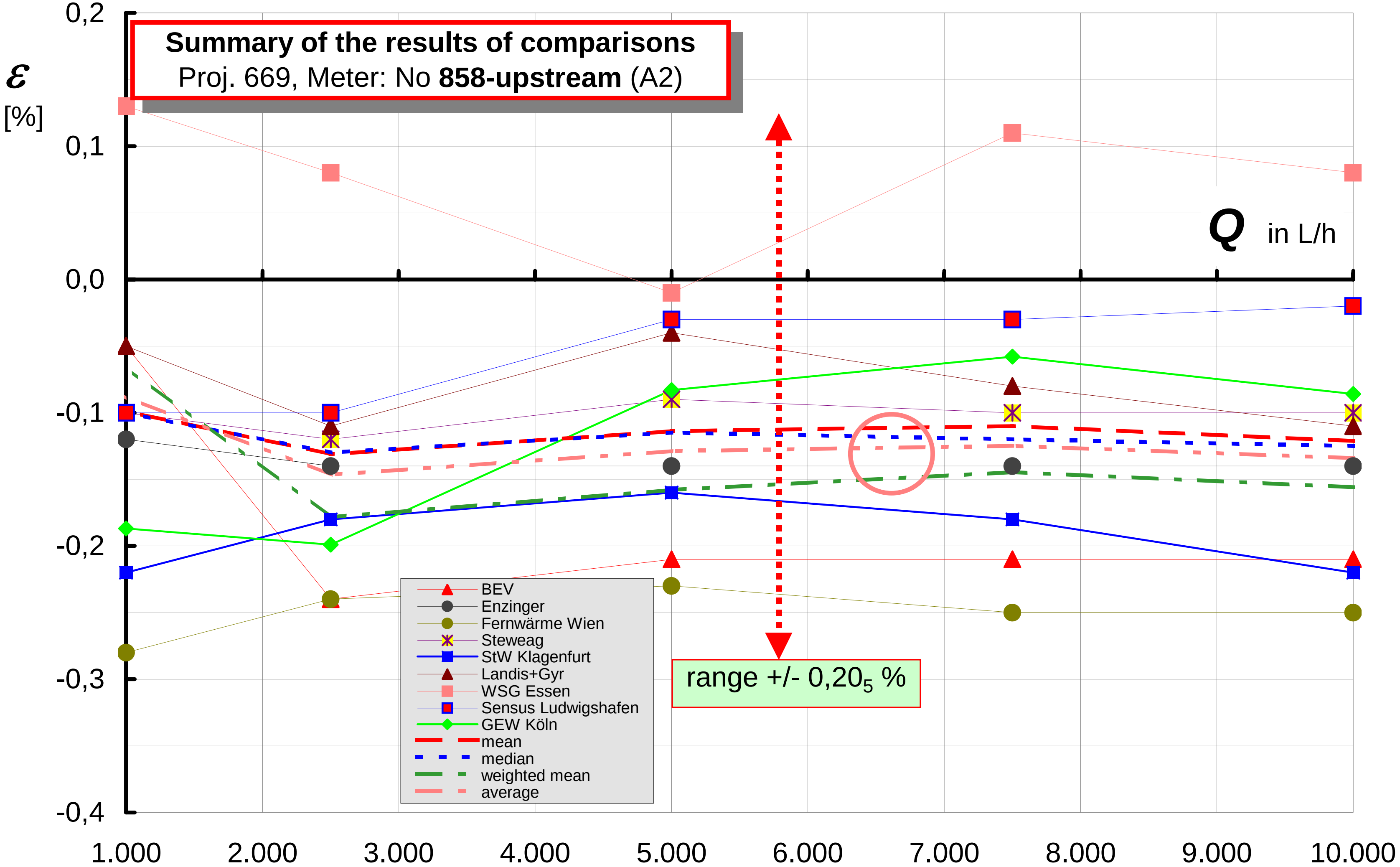
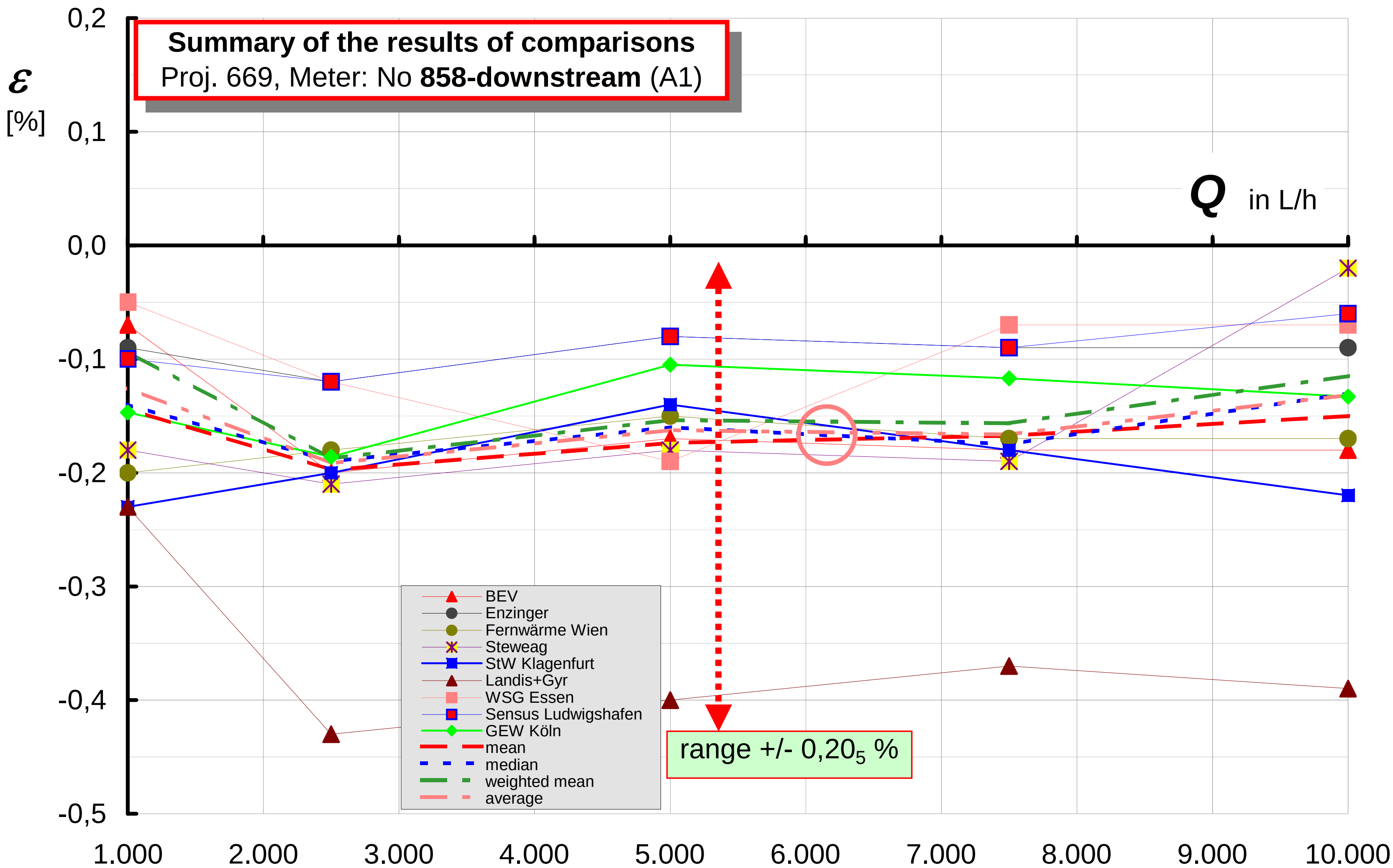


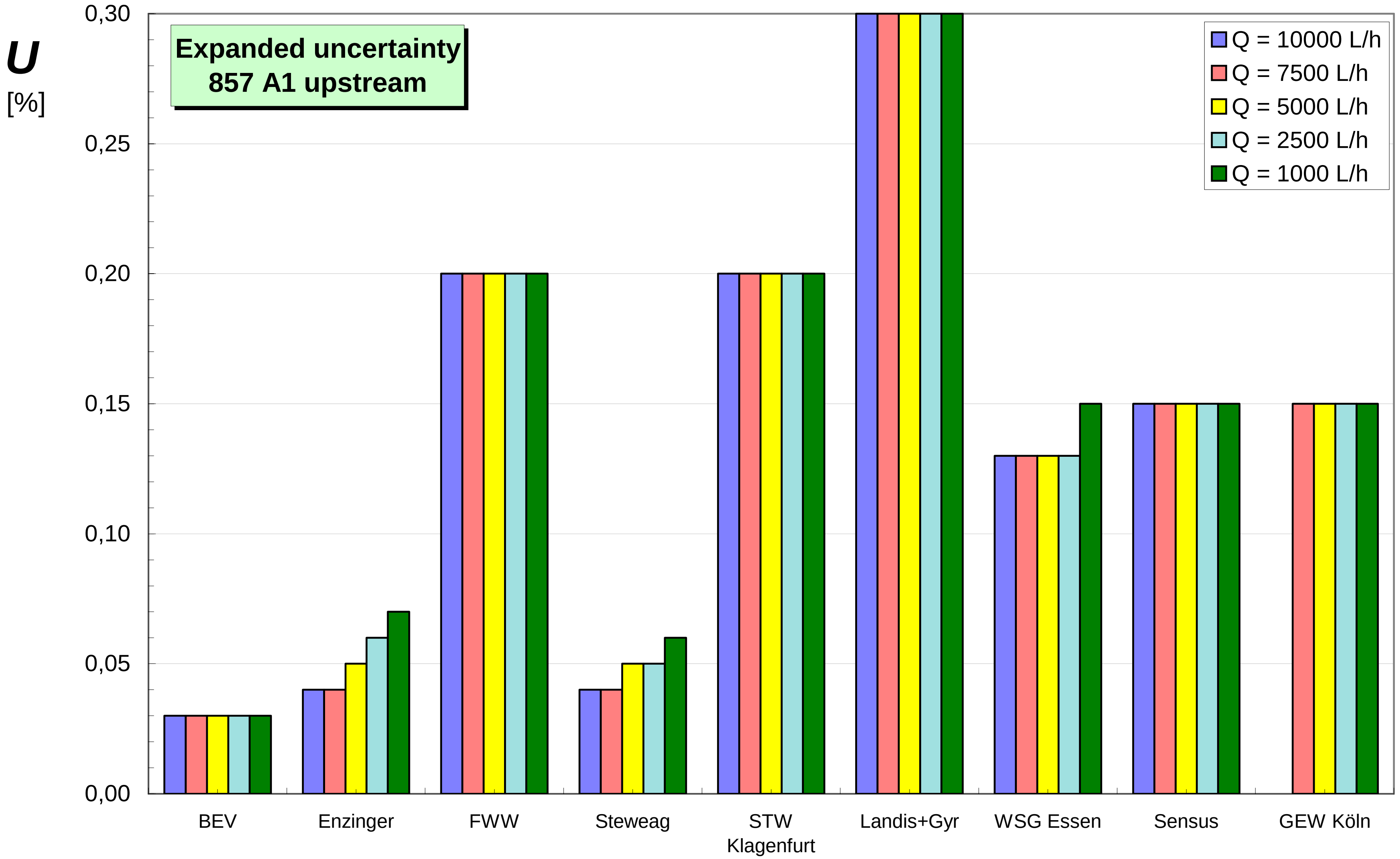


Summary of the results of comparisons
Proj. 669, Meter: No 858-upstream (A2)
ε
[%]
0,2
0,1
0,0
-0,1
-0,2
-0,3
-0,4
Q in L/h
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
BEV
Enzinger
Fernwärme Wien
Steweag
StW Klagenfurt
Landis+Gyr
WSG Essen
Sensus Ludwigshafen
GEW Köln
mean
median
weighted mean
average
range +/- 0,205 %

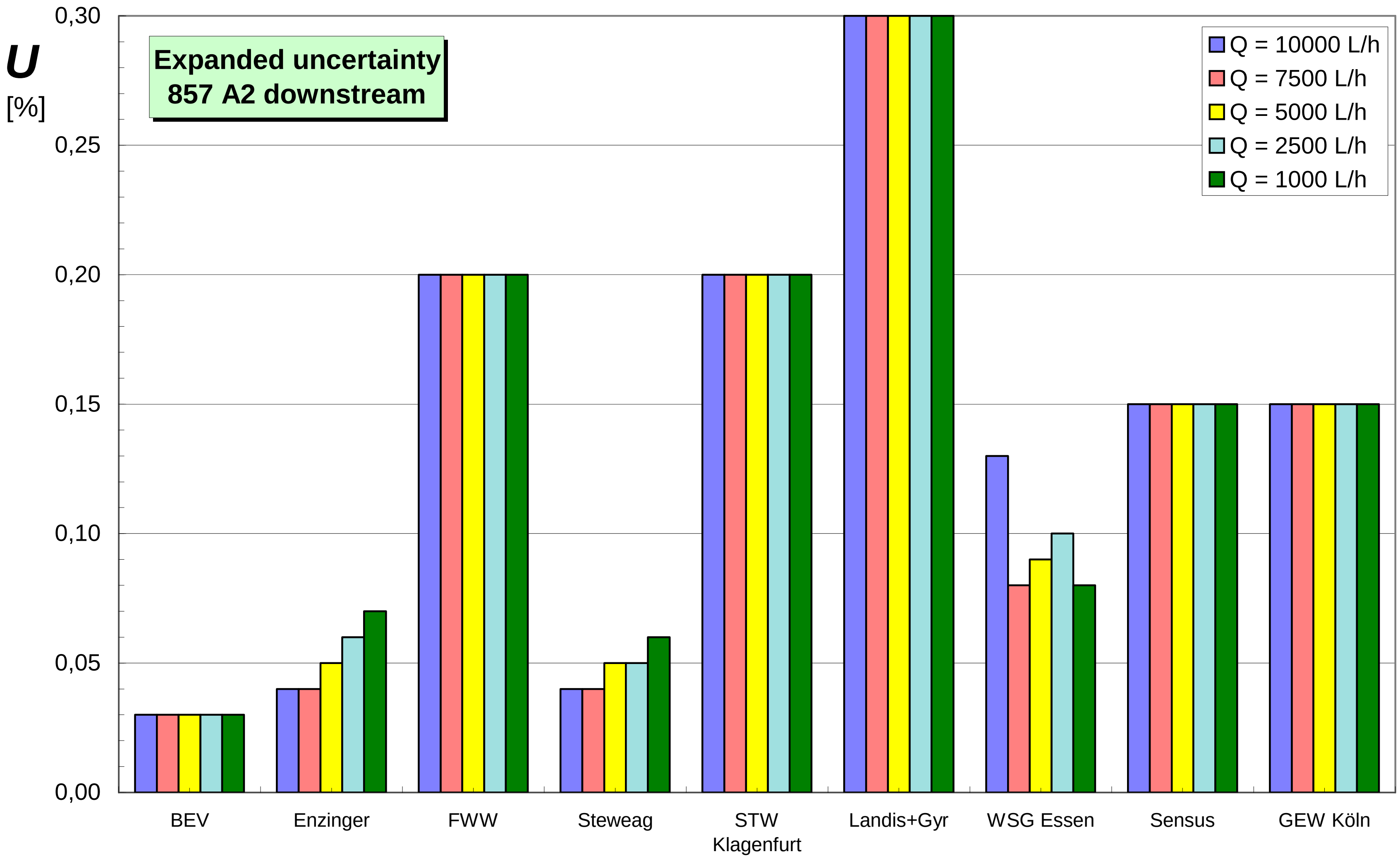
No 858 - downstream

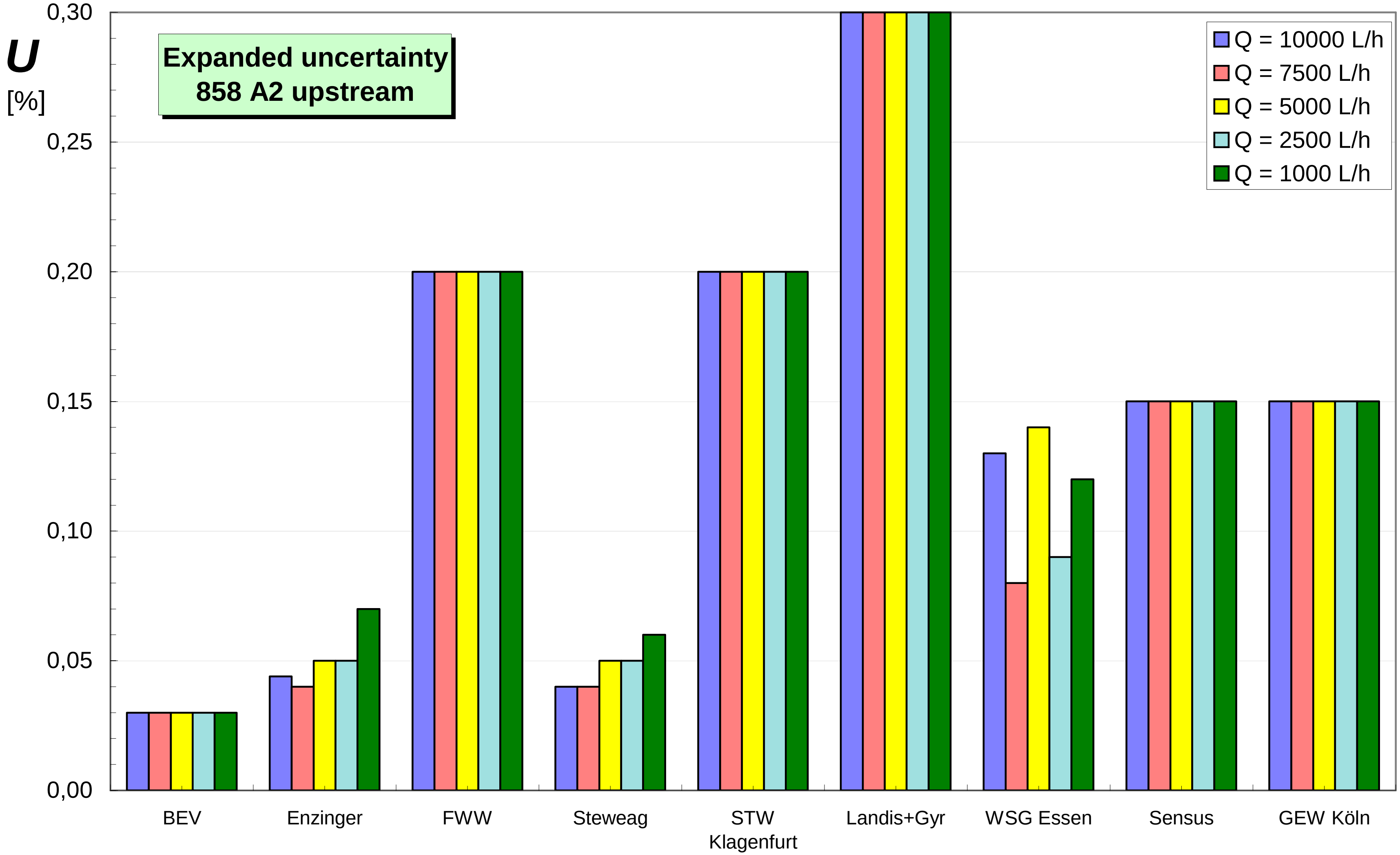


857 - upstream

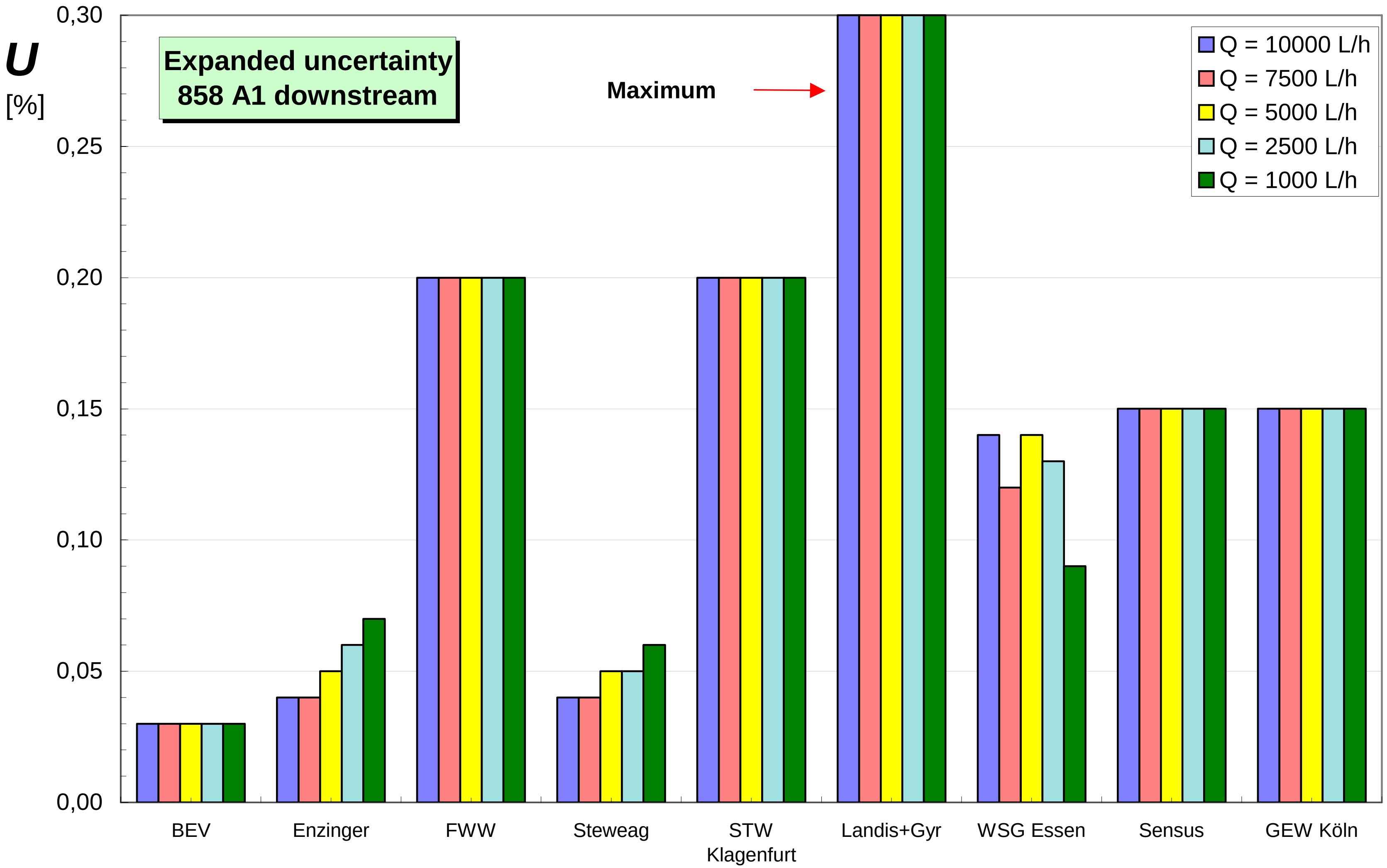


857 - downstream



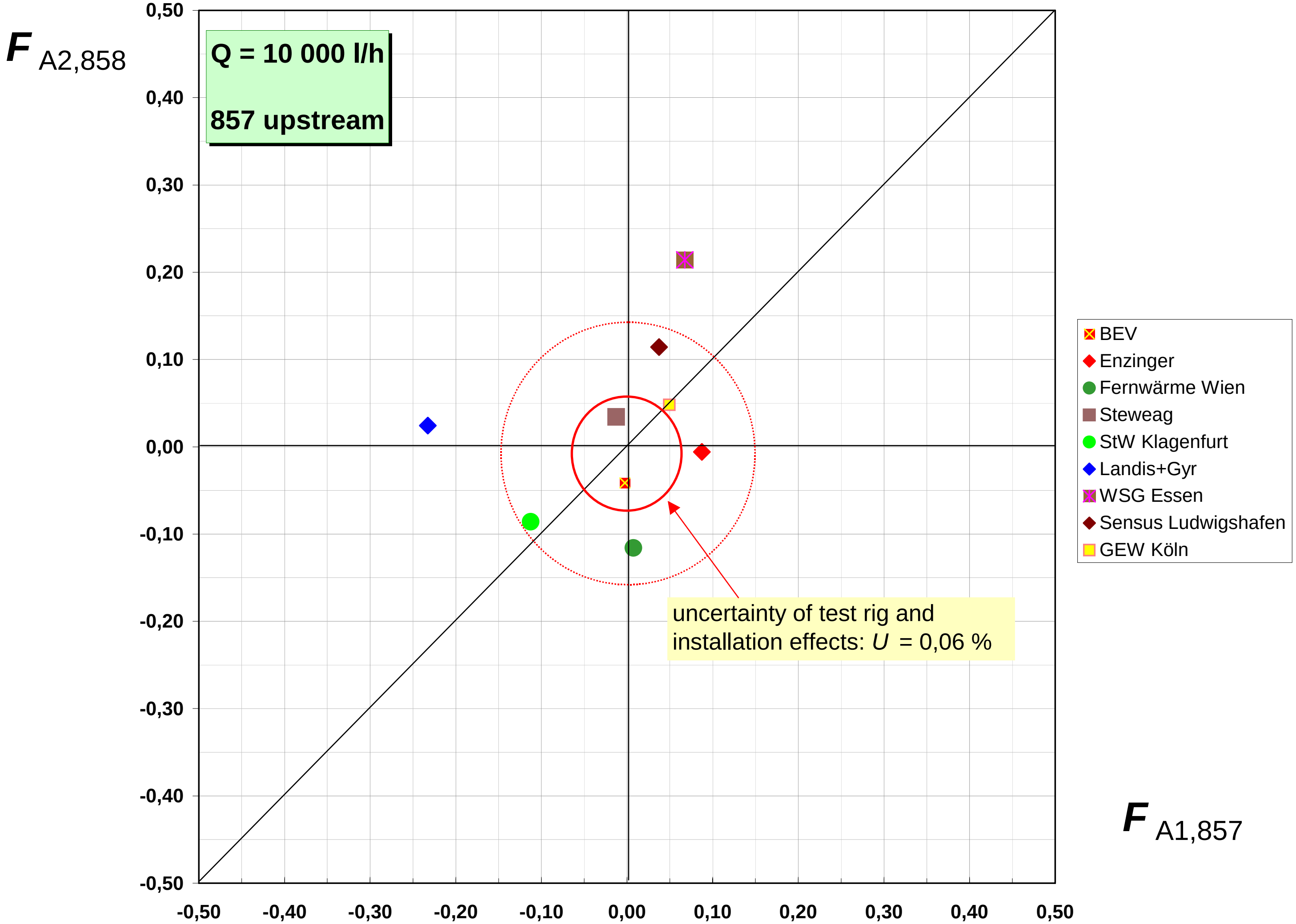


U
[%]
Expanded uncertainty
858 A2 upstream
0,30
0,25
0,20
0,15
0,10
0,05
0,00
Q = 10000 L/h
Q = 7500 L/h
Q = 5000 L/h
Q = 2500 L/h
Q = 1000 L/h
BEV
Enzinger
FWW
Steweag
STW Klagenfurt
Landis+Gyr
WSG Essen
Sensus
GEW Köln



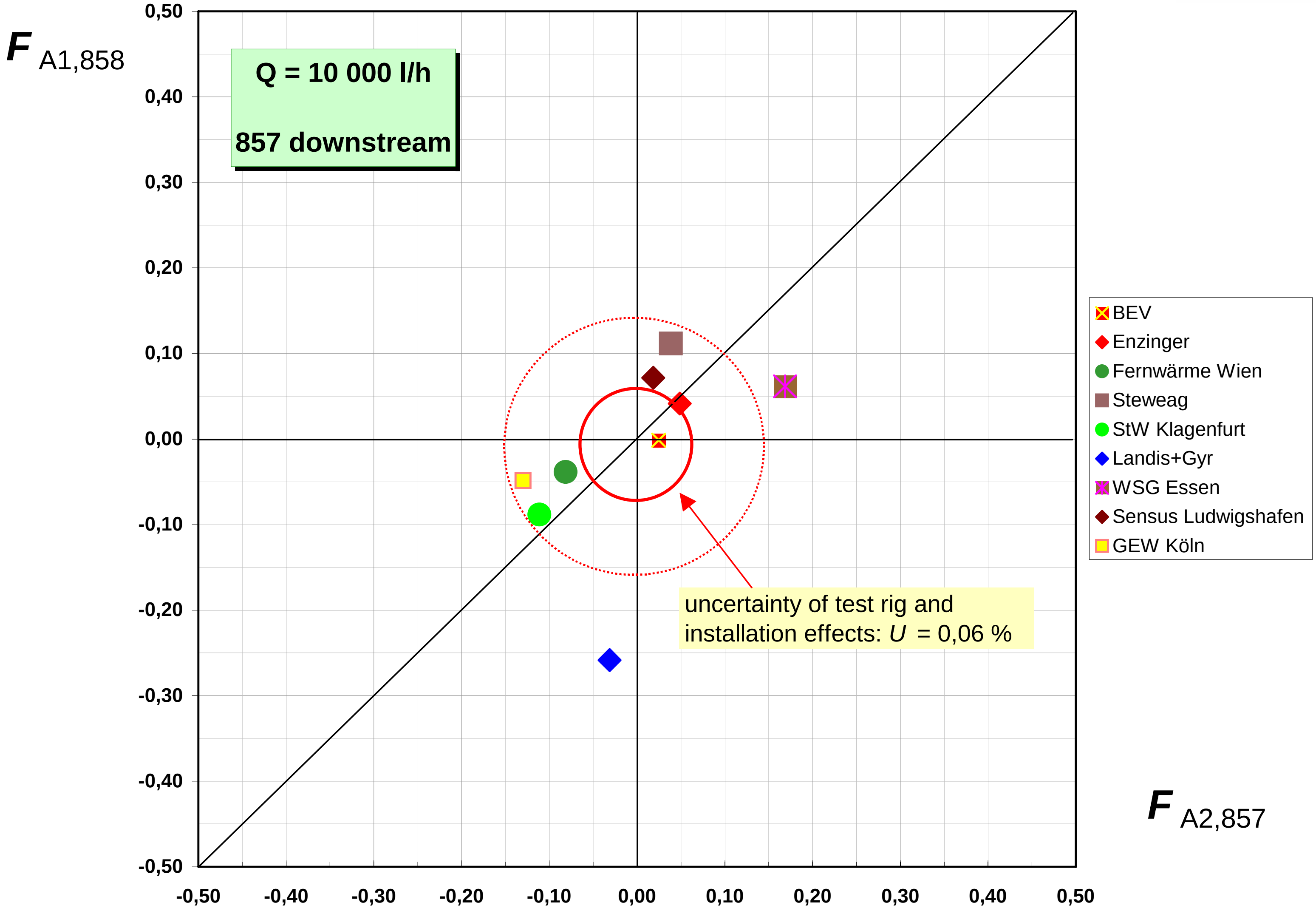
U
[%]
0,30
0,25
0,20
0,15
0,10
0,05
0,00
Expanded uncertainty
858 A1 downstream
Maximum
Q = 10000 L/h
Q = 7500 L/h
Q = 5000 L/h
Q = 2500 L/h
Q = 1000 L/h
BEV
Enzinger
FWW
Steweag
STW Klagenfurt
Landis+Gyr
WSG Essen
Sensus
GEW Köln

Youdenplot 10.000 l/h

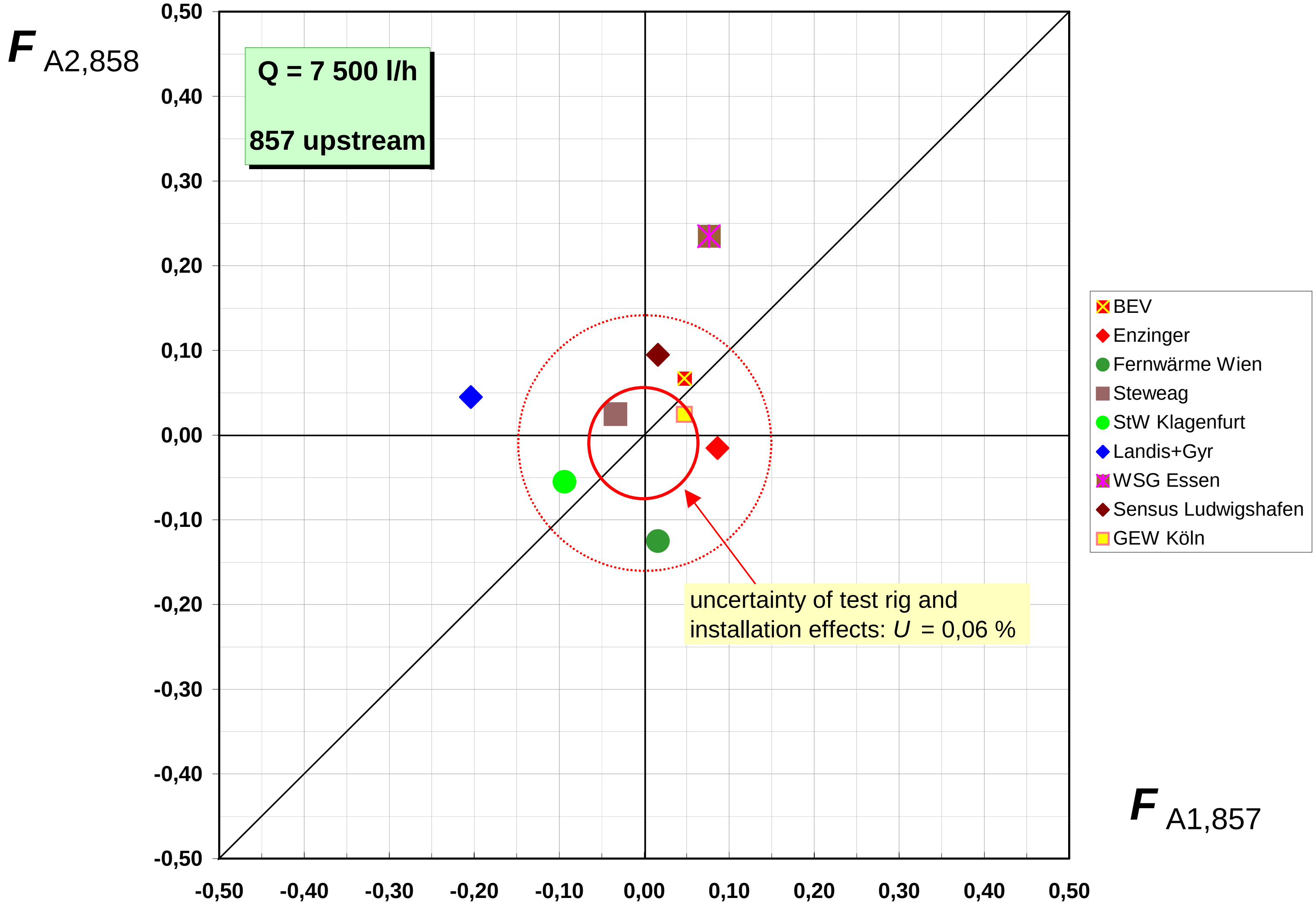


Youdenplot 10.000 l/h

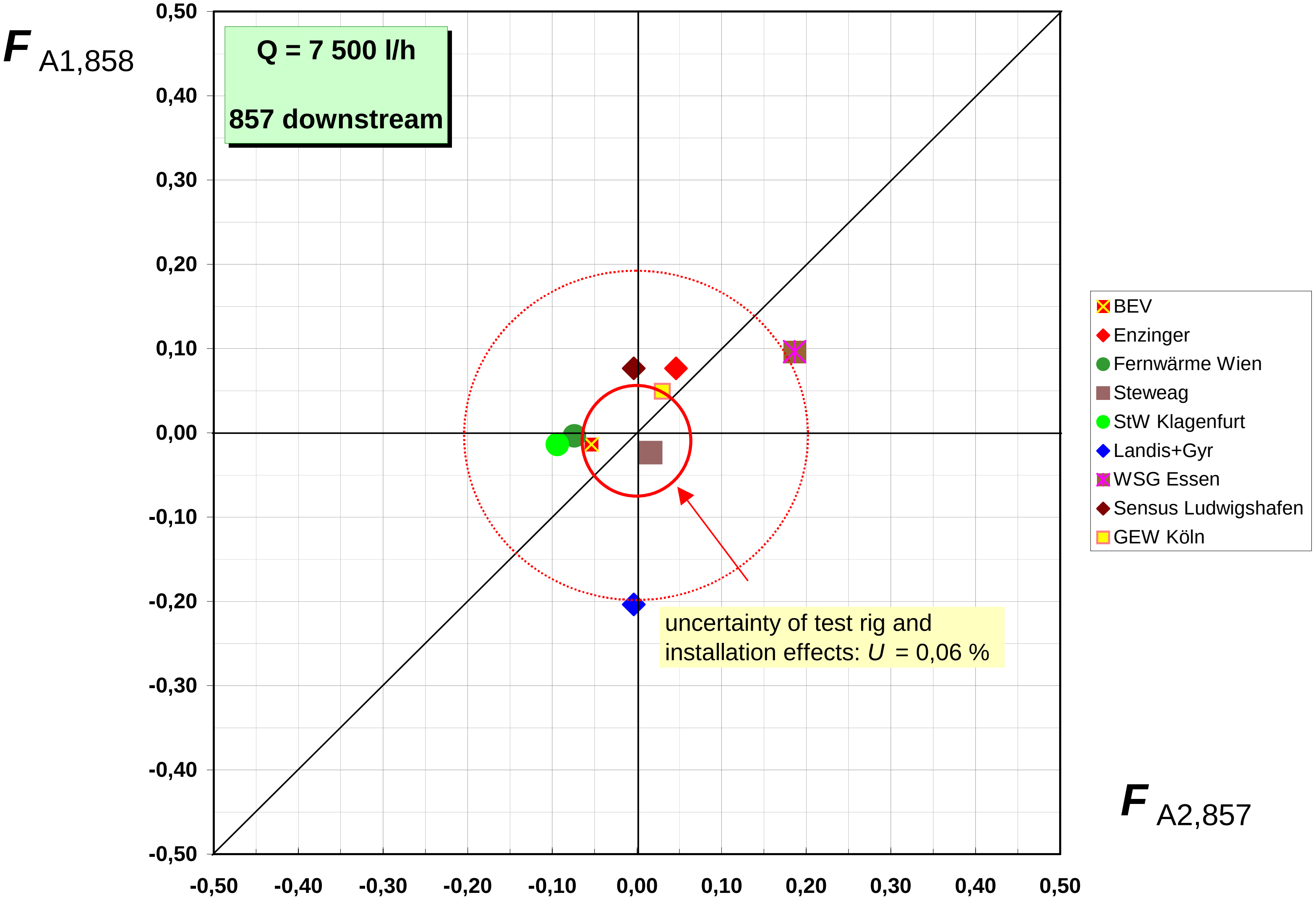
Willkommen im BEV
Bundesamt für Eich- und Vermessungswesen



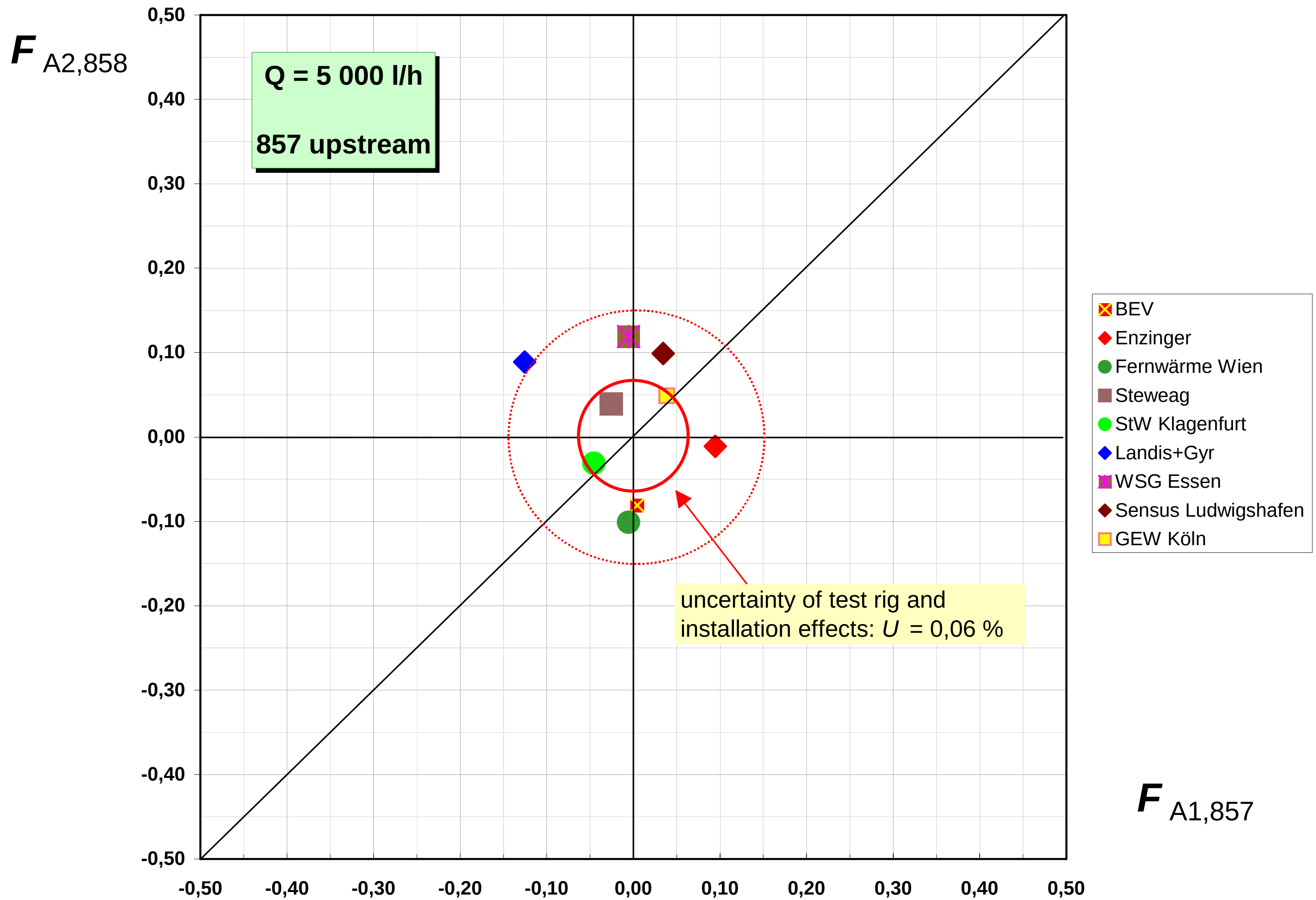
Youdenplot 7.500 l/h



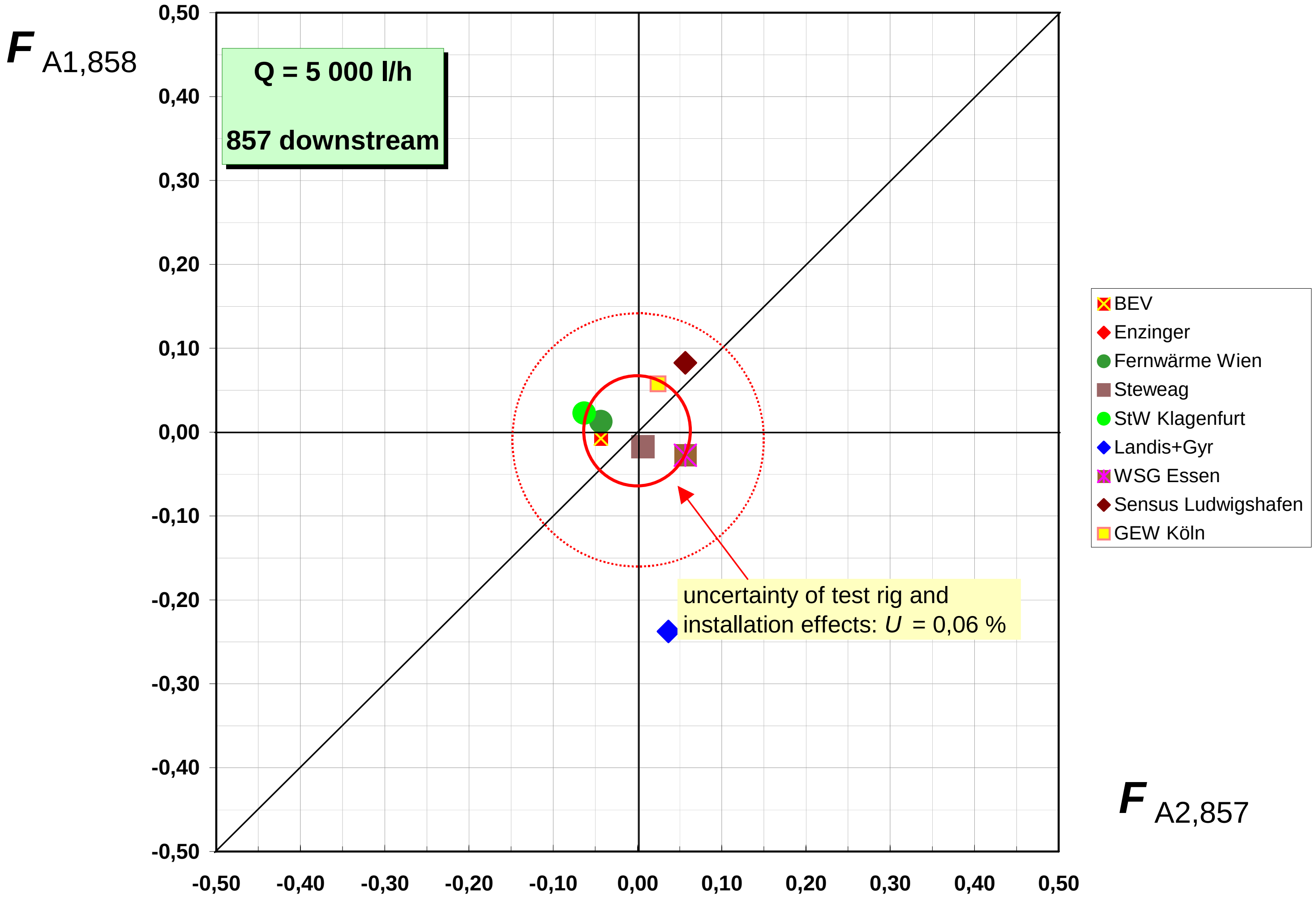
Youdenplot 7.500 l/h



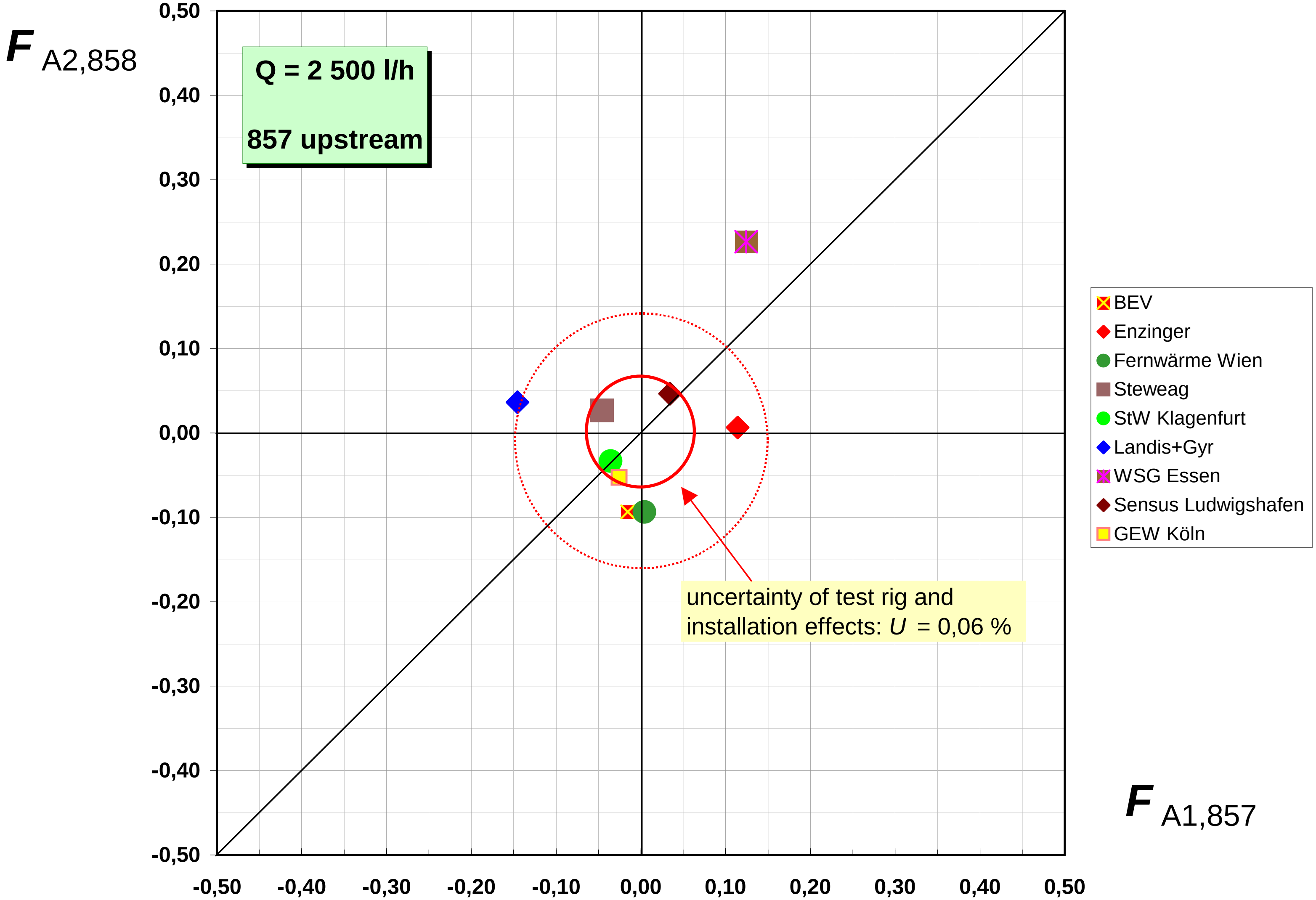
Youdenplot 5.000 l/h



Youdenplot 5.000 l/h



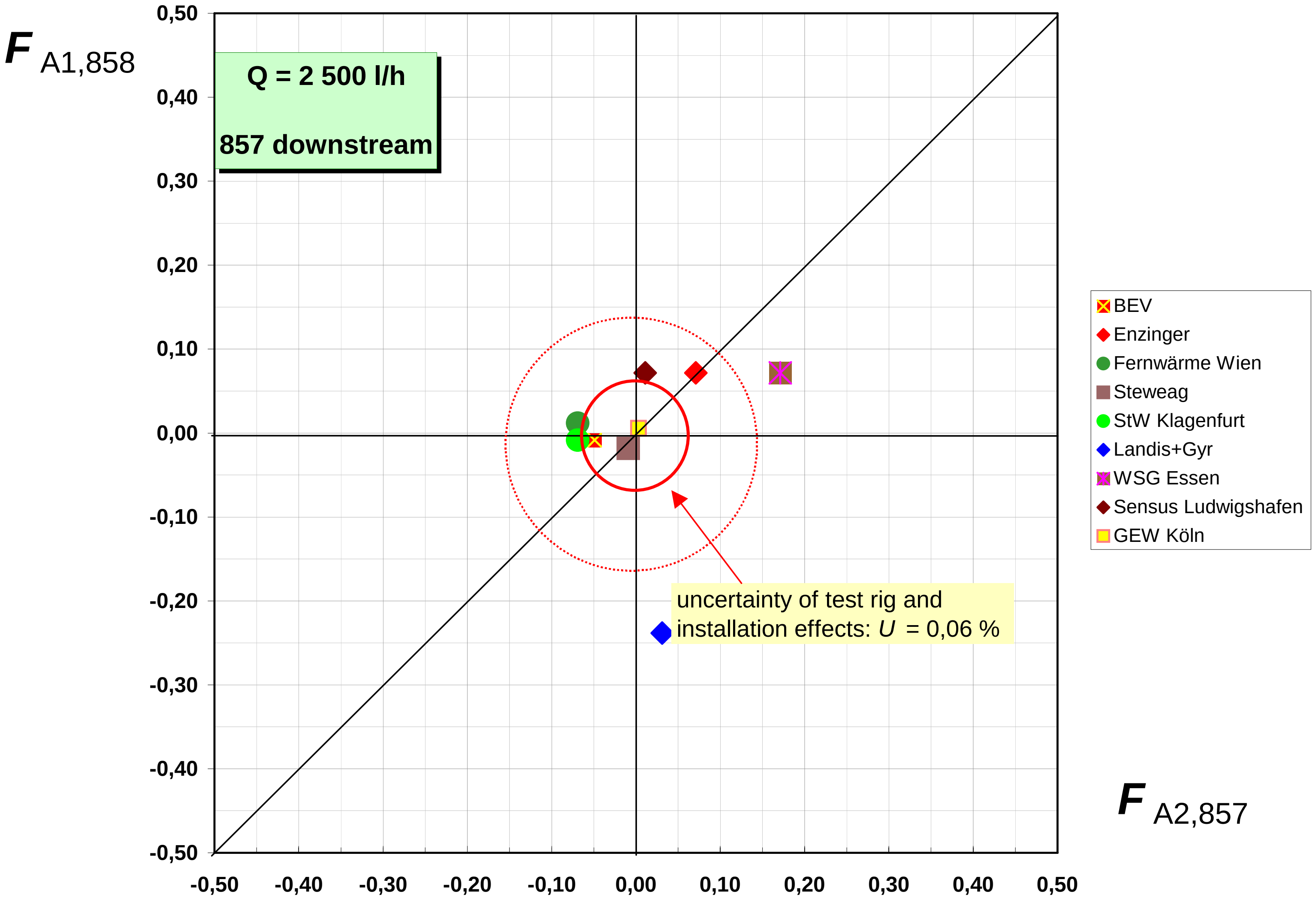
Youdenplot 2.500 l/h



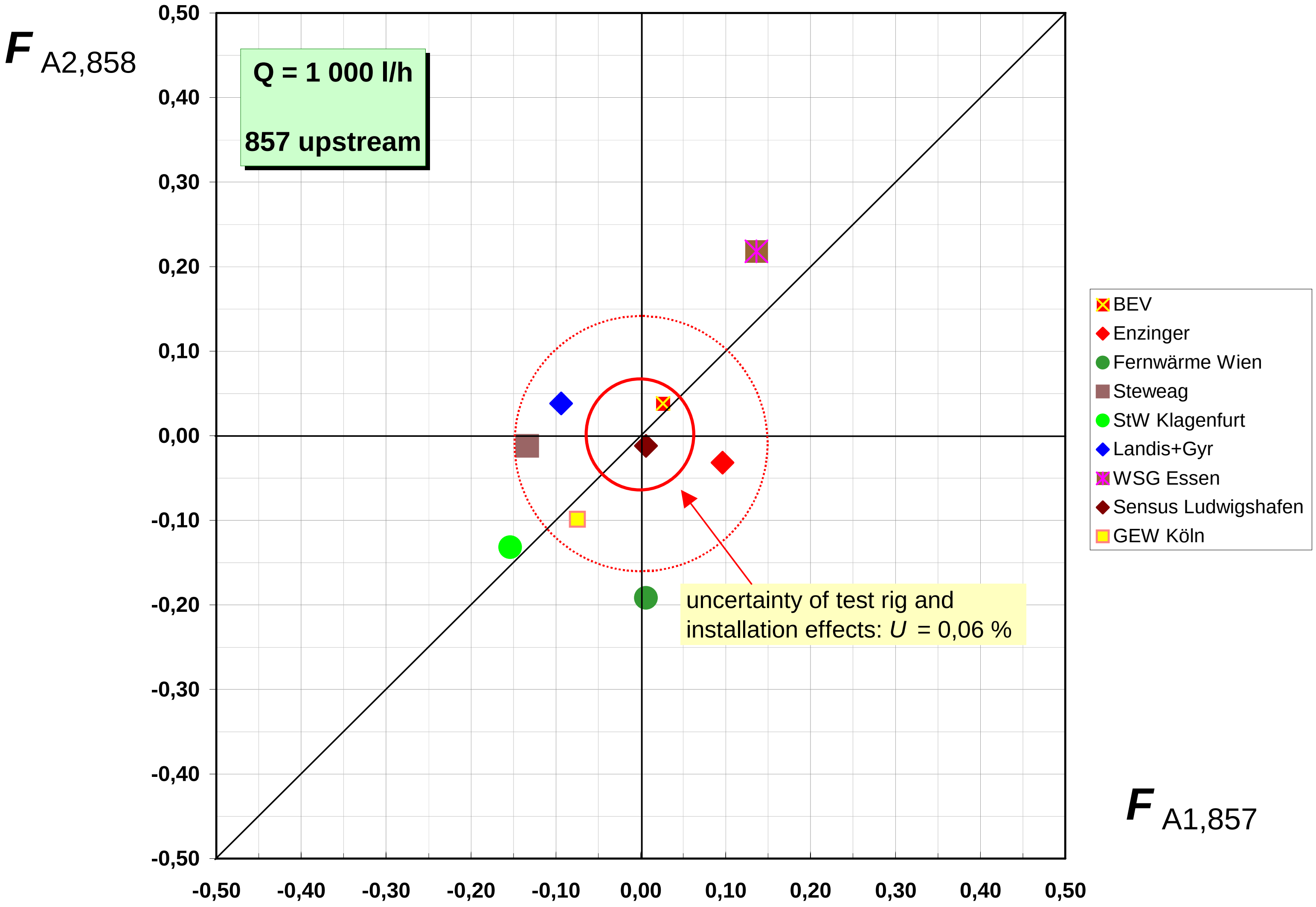
Youdenplot 2.500 l/h

Willkommen im BEV

Bundesamt für Eich- und Vermessungswesen



Youdenplot 1.000 l/h



Youdenplot 1.000 l/h