EUROMET project No 669

Evaluation of a flow comparison - example

EUROMET flow project 669

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:
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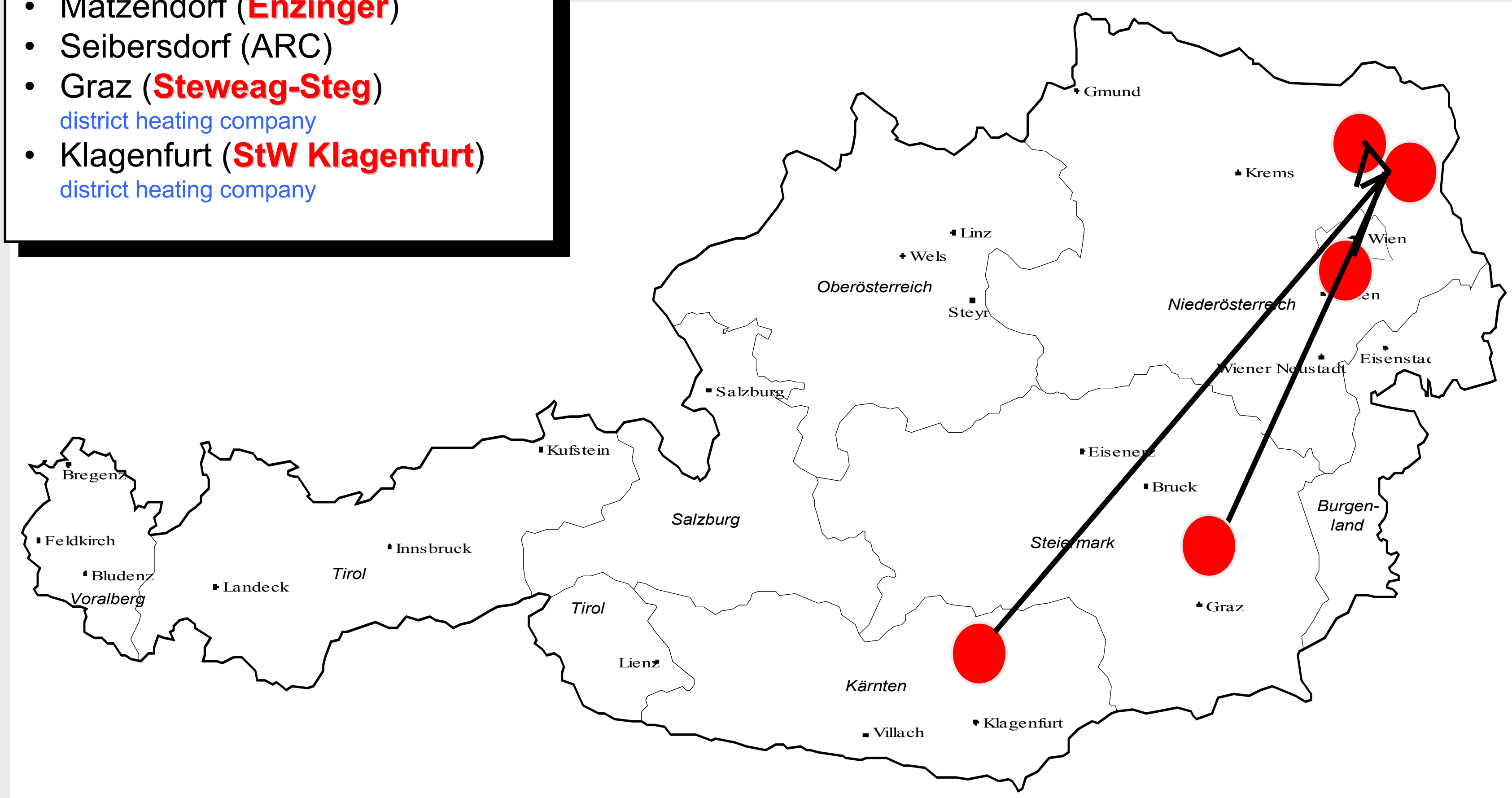
National cycle in Austria

Test laboratories in Austria

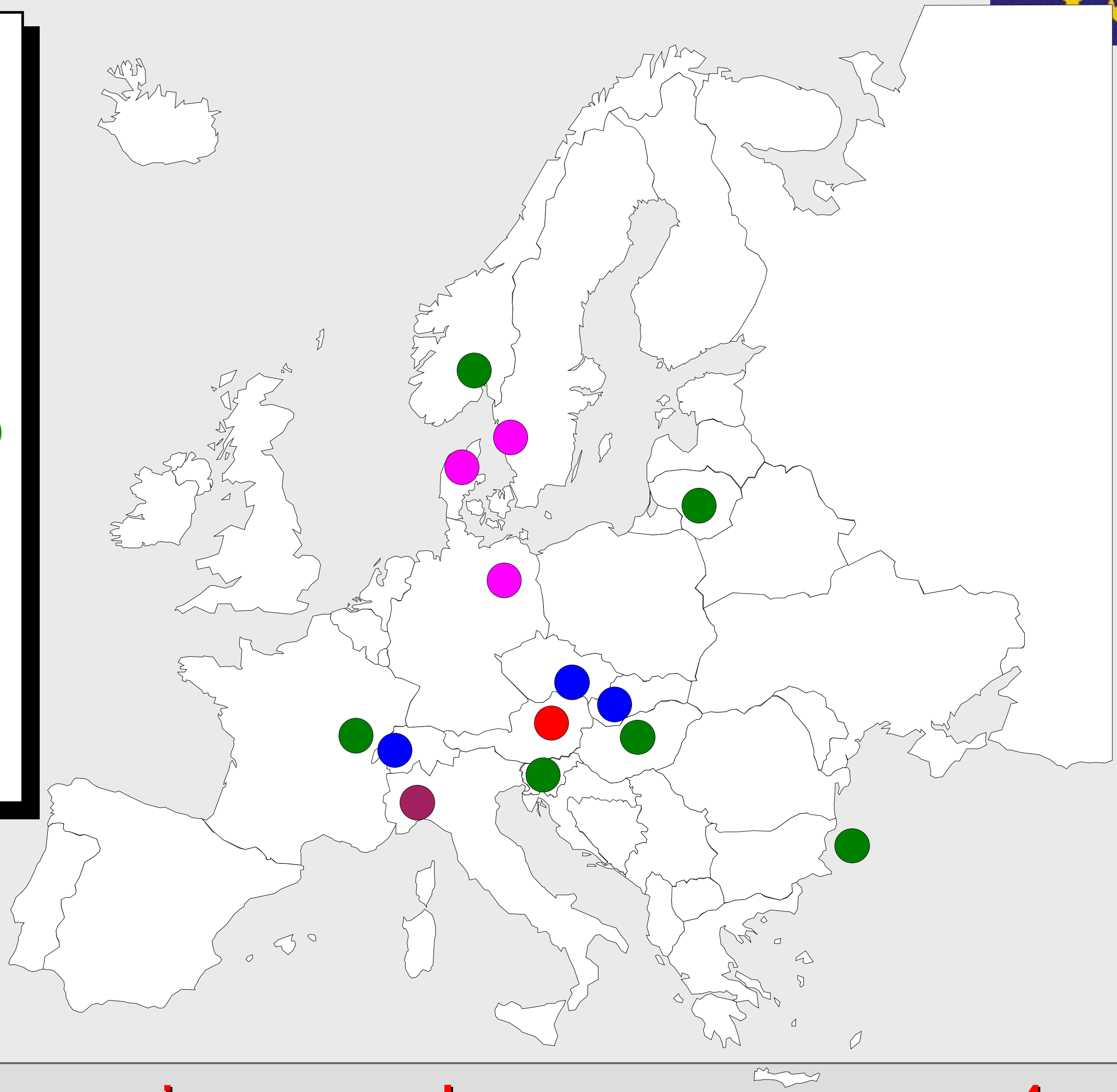
- Vienna (**BEV**, EWT, **FWW**)
- Matzendorf (**Enzinger**)
- Seibersdorf (ARC)
- Graz (**Steweag-Steg**)
  district heating company
- Klagenfurt (**StW Klagenfurt**)
  district heating company



Participating institutes in Europe

- **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)

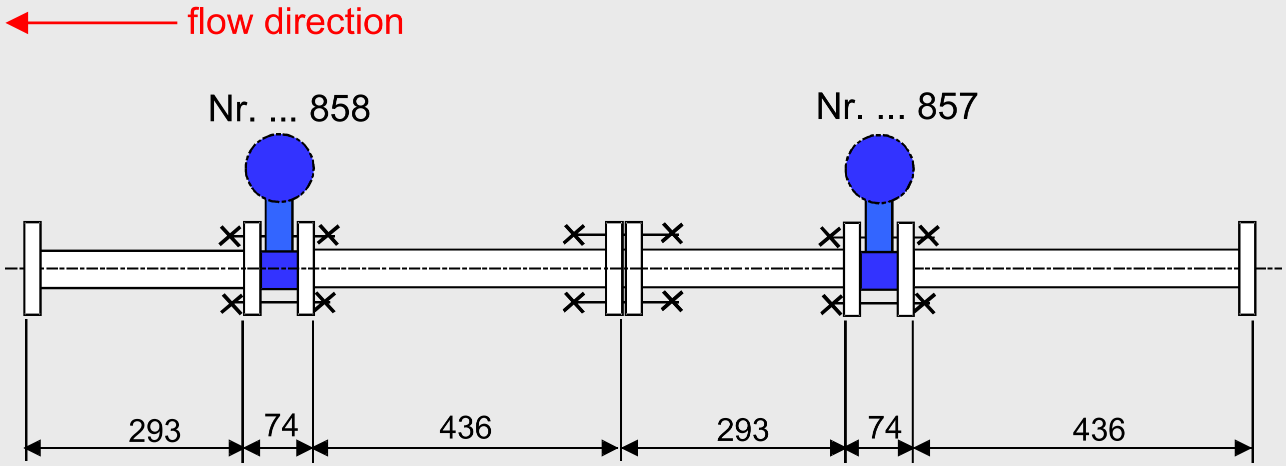
blue ... 1st cycle
violett ... 2nd cycle
green ... 3rd cycle
brown ... 4rd cycle



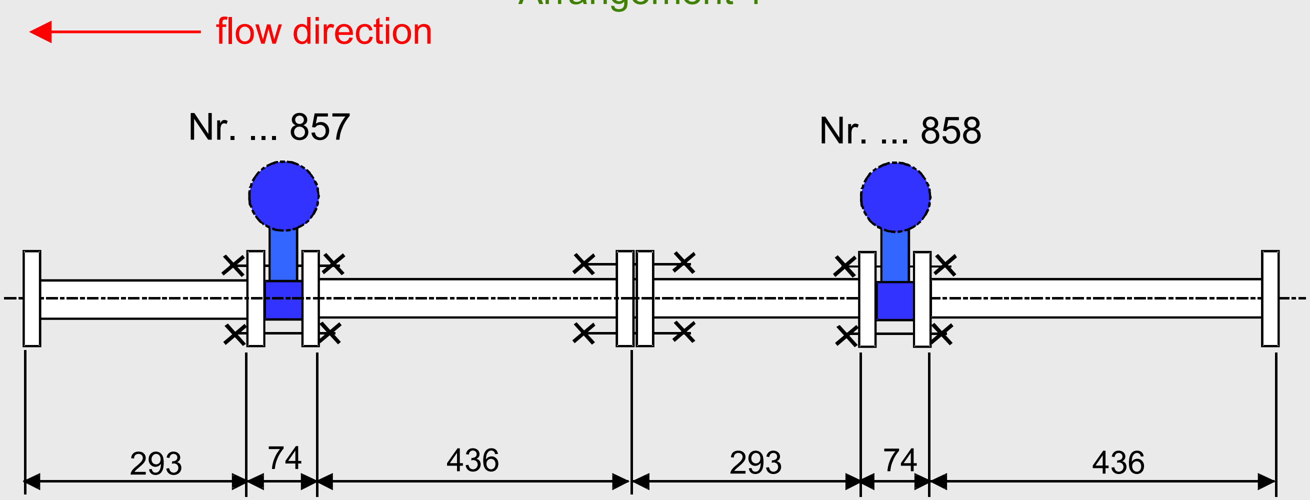
Significant data

- 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

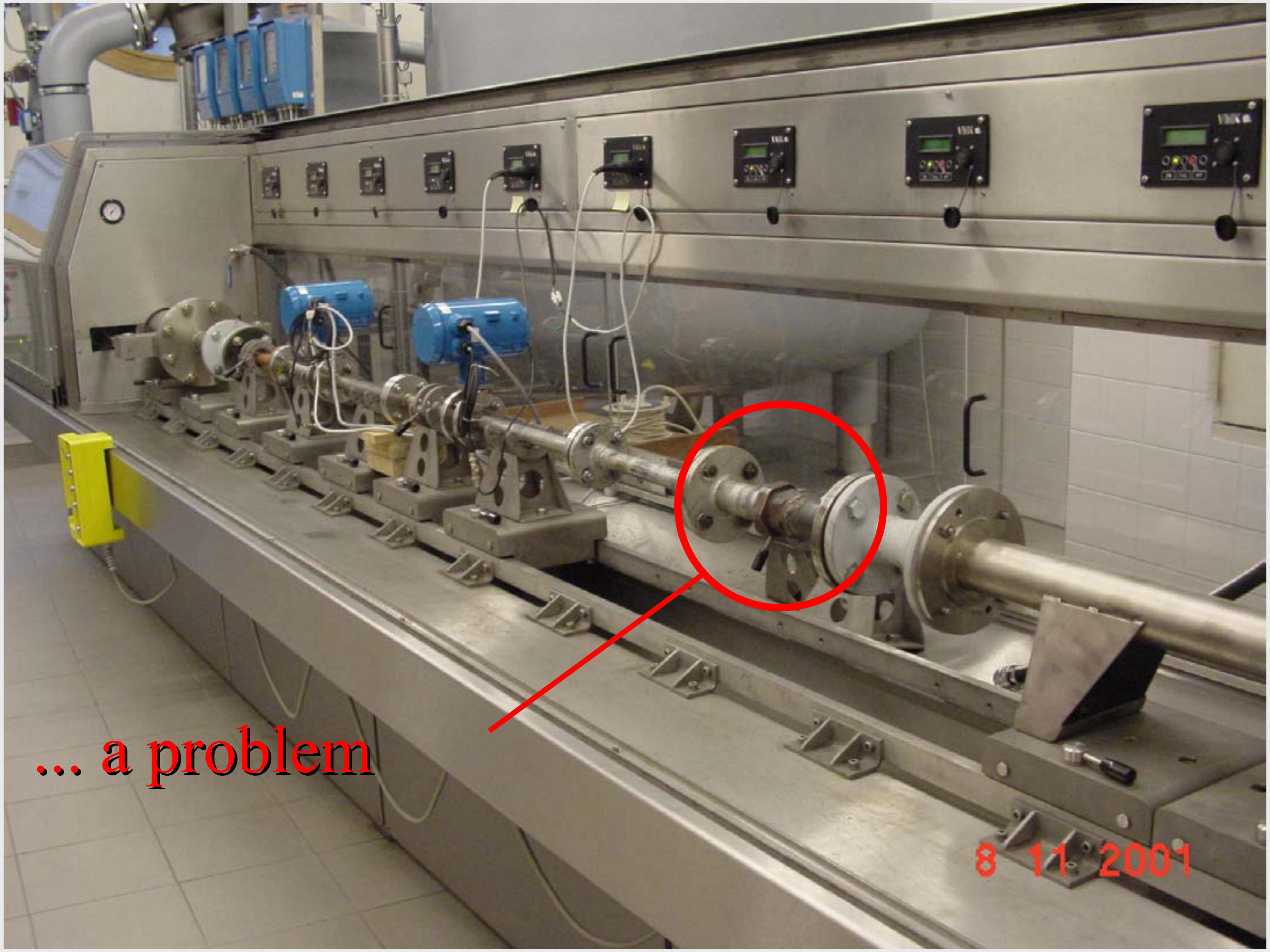


Arrangement 1



Arrangement 2

Arrangement in the test rig



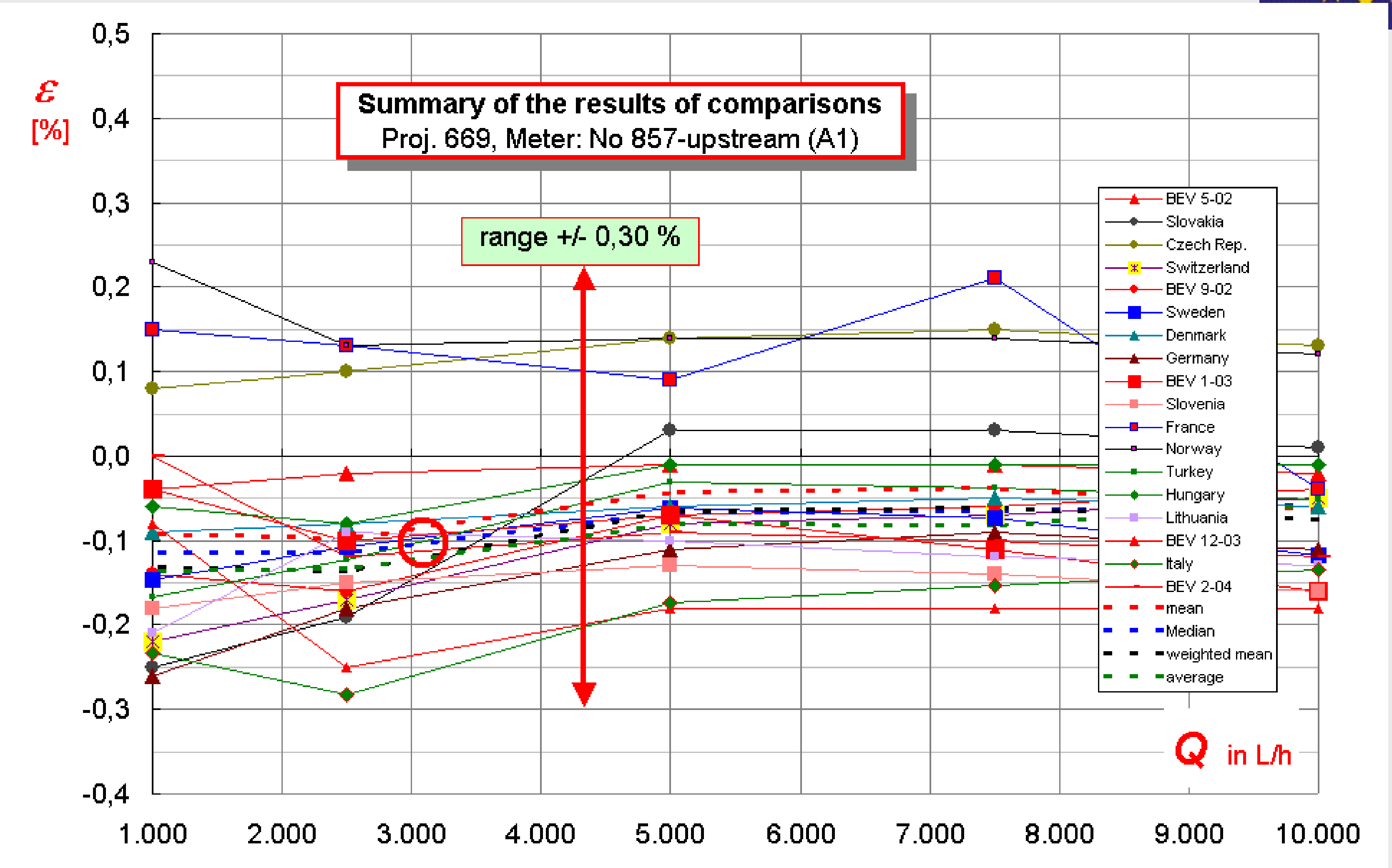
Test conditions

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

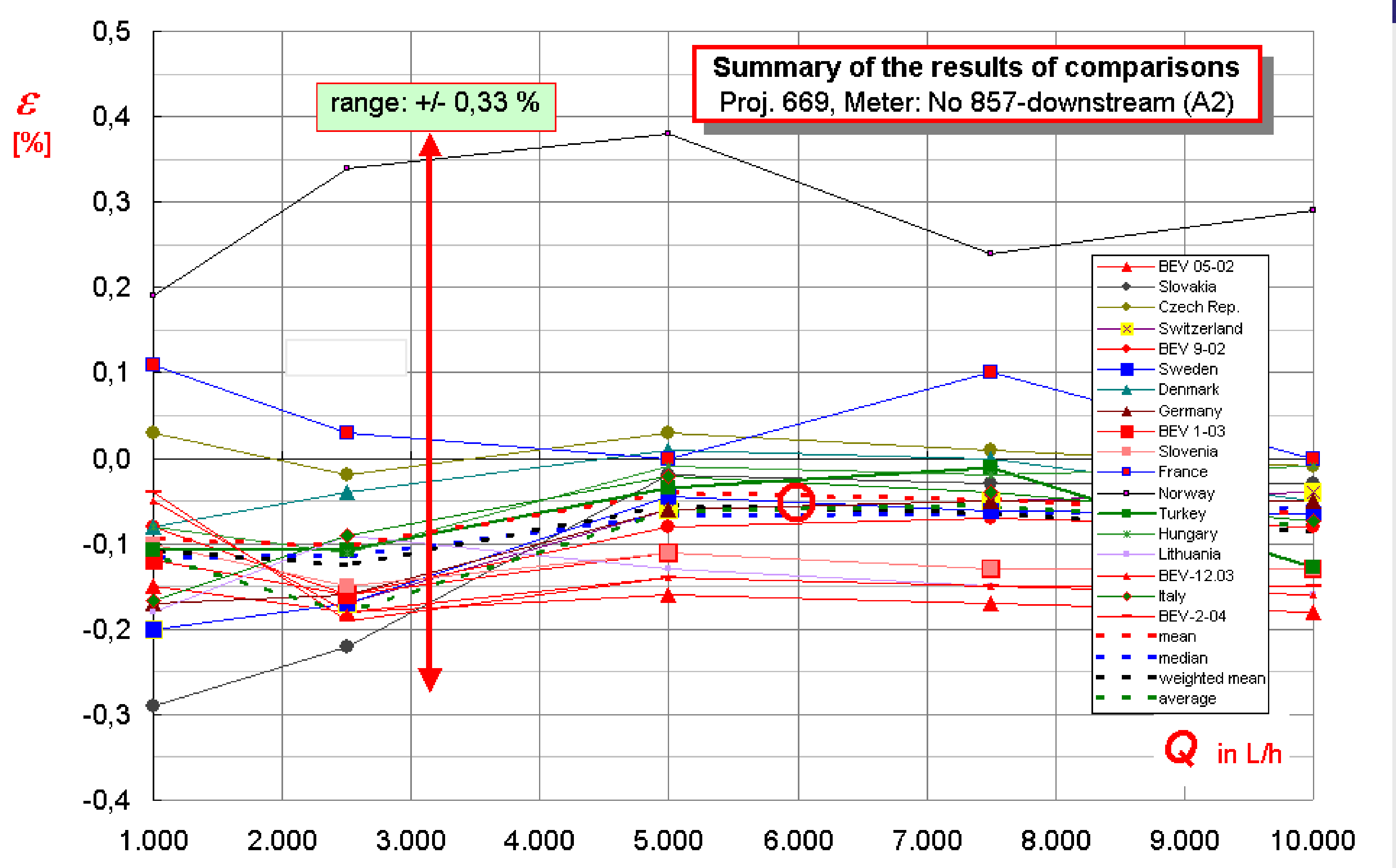
meter, straightener, transport box

EUROMET comparison

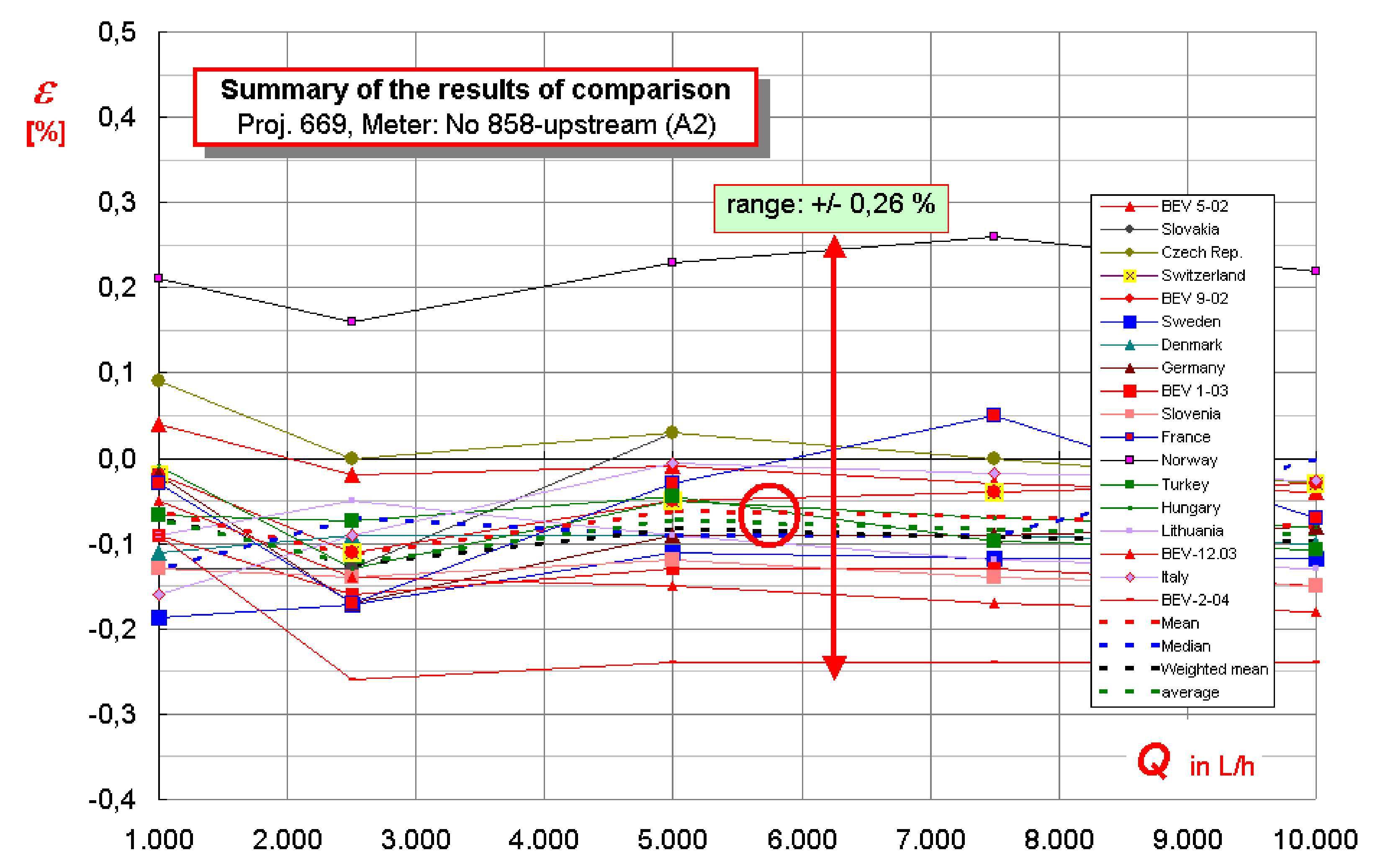
Results of the EUROMET proj. 669 ... 857 upstream



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

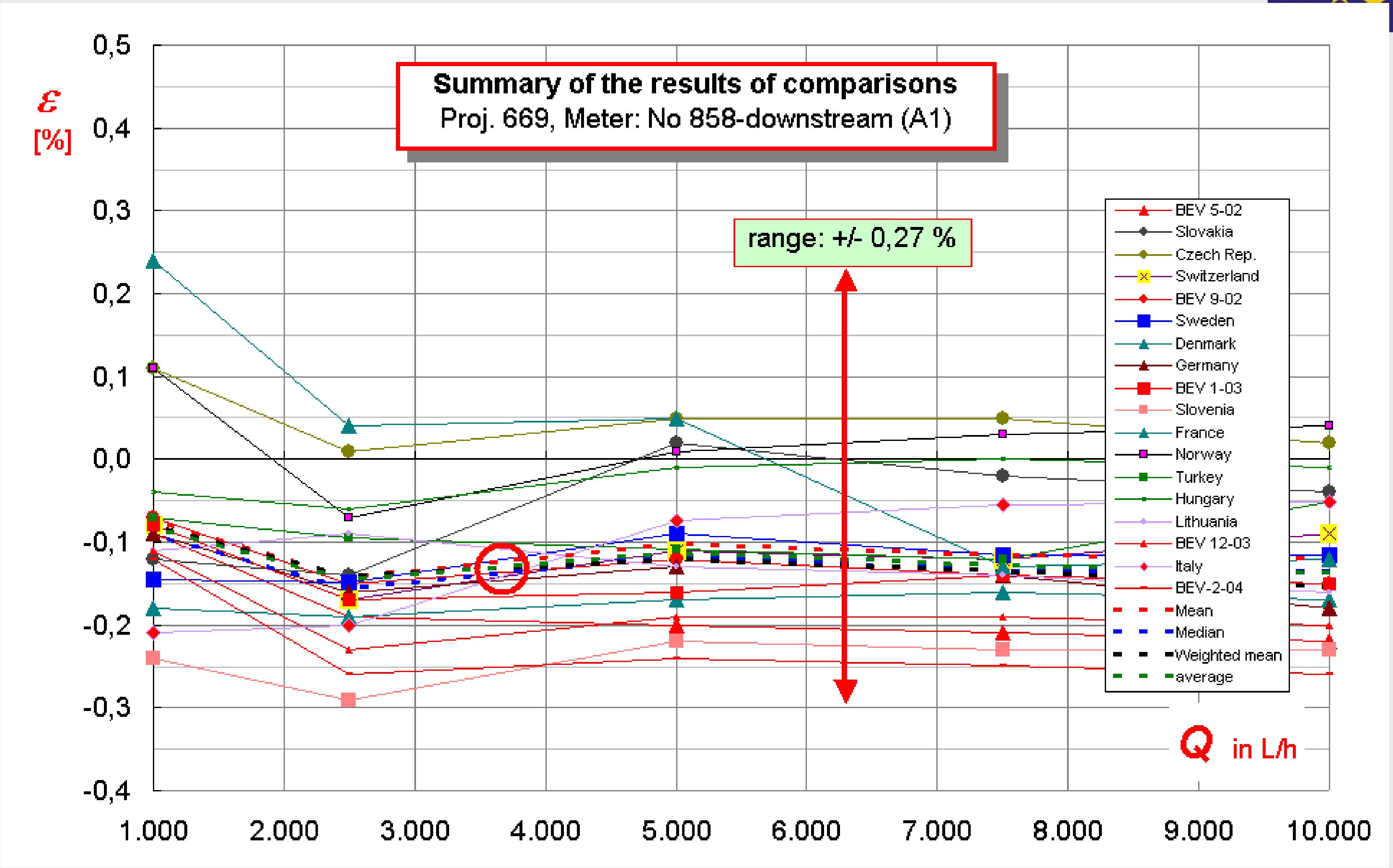


Results of the EUROMET proj. 669 ... 858 upstream

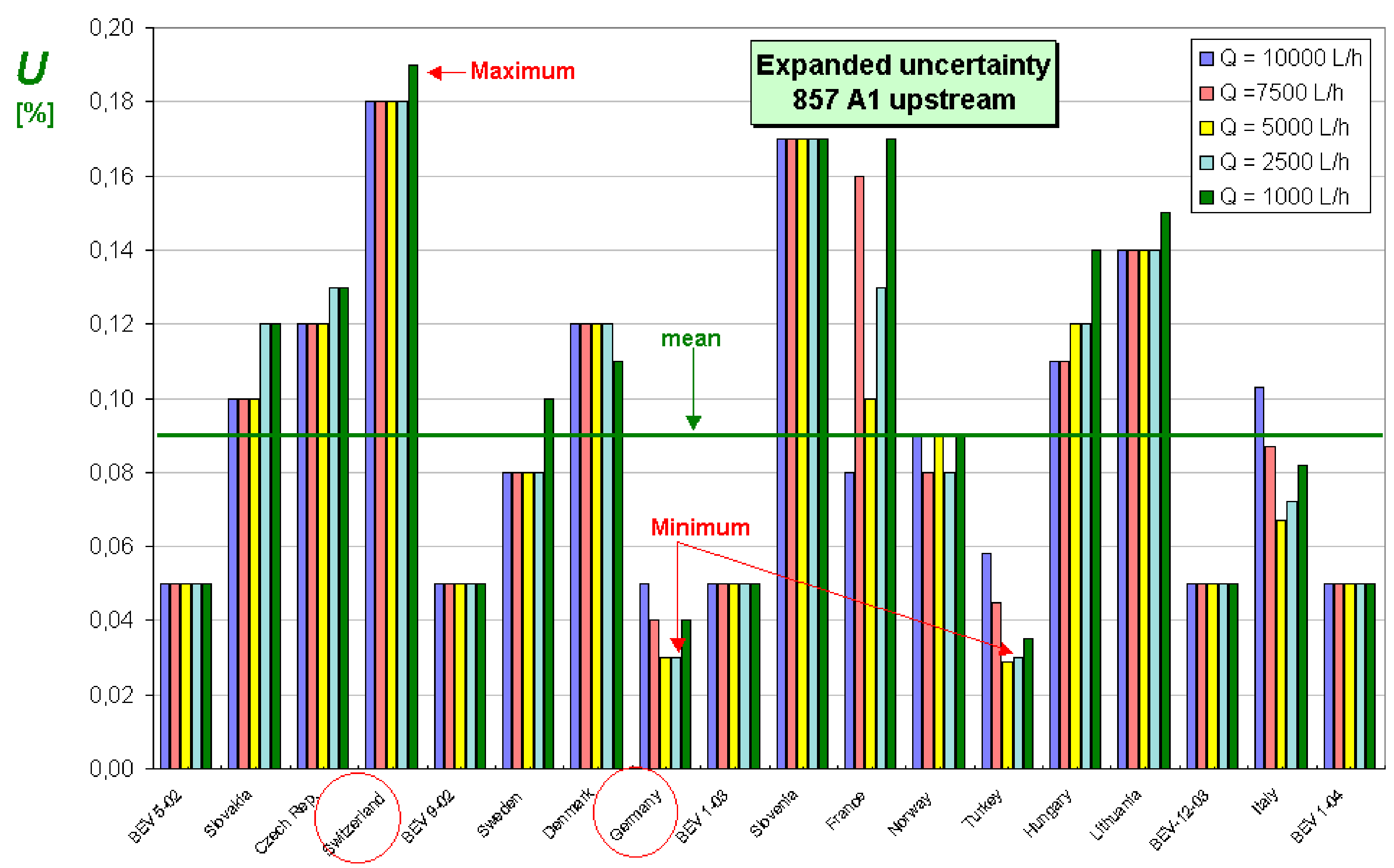


Evaluation of a flow comparison - example

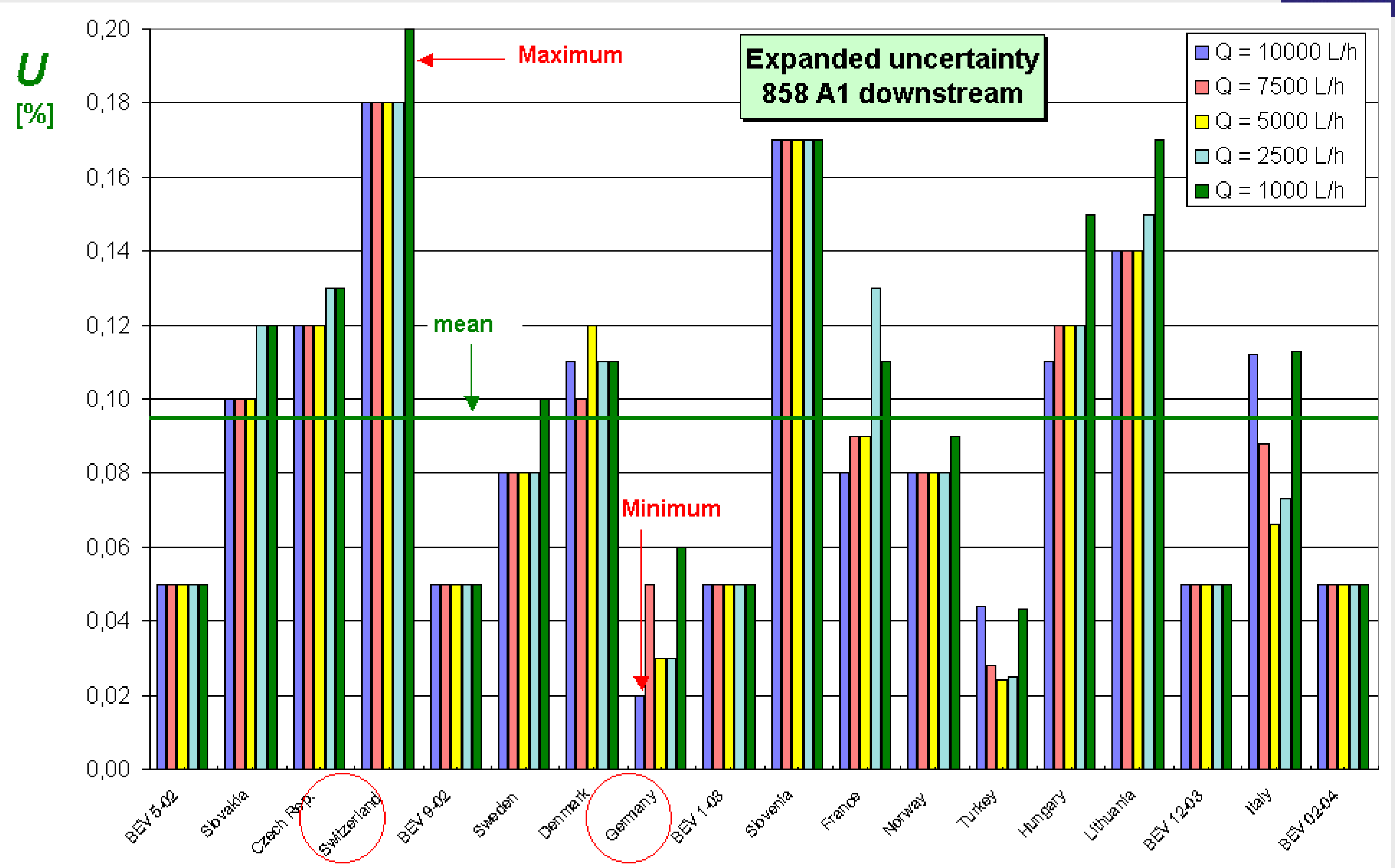
Results of the EUROMET proj. 669 ... 858 downstream



Uncertainties 857 A1 upstream



Uncertainties 858 downstream



The KCRV

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

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

What do you do to get the best reference value ? - 2

3rd approach: the **median –** we get the median by adjusting the measurements by its size: the value in the middle is the median. In praxis the median is a very realistic estimation for the true value

Question: What is the best estimation if we don´t know the distribution of the measurement results?

to 1st: We don´t know if the measurement results are normal distributed. The assumption is that there are no systematic contributions at the measurement results!!

to 2nd: The **rated mean** is also problematic, because the measurement result on a participant is depending of the measurement uncertainty and the person which evaluate the uncertainty.
If the are great differences in measurment uncertainty, the rated mean is very problematically.

to 3rd: The **median**: it is acquaint in praxis, that the mediangives the best results!

!! To give a decision by statistic tests !!

Statistic tests: the χ^2-test

What is the „Chisquare-test“?

To compare the results of different laboratories we use the **Chisquare-test !**
There ate two hypothesis:

H_0 – Zero-hypothesis: the measurement results of all laboratories are standard distributed. There are not systematic contributions of the measurement results. It this proposal not correct the zero hypothesis is exploded ➔

H_1 – Antithesis: There are no consistency in the datas

Minimum χ^2-procedure

Situation: measurement result can by wiritten as y = (x_i, y_i, $u(x_i)$)

On the other side there exist a mathematical function $F(x_i, \varepsilon_1, \varepsilon_2, ...)$ with coefficients ε_1, ε_2 ..

assume:

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

Performance: variation of the parameters ε_1, ε_2 ... χ^2 ➔ minimum!

Take the difference between the observed (χ^2_{obs}) and the theoretical distribution ($\chi^2(\nu)$). Compare this difference with $u^2(x_i)$!

ν Is the degree of freedom = N - 1

2 possible procedure:

Cox proposed: the **KCRV** χ_{ref} lies in an intervall of 5 % if:

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

Nielsen proposed:

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

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

What is the propability for the accordance of the actual and theoretical distribution: χ^2_{obs} and $\chi^2(\nu)$. The condition is:

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

Excel:

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

Example: comparison - 11 participants, ν = 10

Labb	reported values xi	abs deviation from mean di	reported uncertain-ties (k=2) U(xi)	reported uncertain-ties (k=1) u(xi)		$xi/u^2(xi)$	$1/u^2(xi)$		degree of equiva-lence di	normalized difference norm di		Nielsen χ^2	Cox χ^2	
BEV 5-02	-0,04	0,07	0,15	0,08		-7,11	177,78		0,14	1,84		3,39	3,30	
Slovakia	-0,25	0,14	0,12	0,06		-69,44	277,78		-0,07	1,25		1,57	1,51	
Czech Rep.	0,08	0,19	0,13	0,07		18,93	236,69		0,26	4,01		16,09	15,55	
Switzerland	-0,22	0,11	0,19	0,10		-24,38	110,80		-0,04	0,46		0,21	0,21	
BEV 9-02	-0,14	0,03	0,15	0,08		-24,89	177,78		0,04	0,49		0,24	0,23	
Sweden	-0,15	0,04	0,1	0,05		-58,80	400,00		0,03	0,60		0,36	0,34	
Denmark	-0,09	0,02	0,11	0,06		-29,75	330,58		0,09	1,61		2,58	2,46	
Germany	-0,28	0,18	0,034	0,02		-979,24	3460,21		-0,11	8,79		77,34	39,37	
BEV 1-03	-0,04	0,07	0,05	0,03		-64,00	1600,00		0,14	6,20		38,47	29,74	
Slovenia	-0,18	0,07	0,17	0,09		-24,91	138,41		0,00	0,04		0,00	0,00	
France	0,15	0,26	0,17	0,09		20,76	138,41		0,33	3,88		15,03	14,74	
mean = x_{ref}	**-0,105**			$\sum \frac{x_i}{u^2(x_i)}$		**-1242,8**			$d_i = x_i - x_{ref}$	$\frac{x_i - x_{ref}}{\sqrt{u^2(x_i) - u^2(x_{ref})}}$			$\chi^2_{obs} = \sum \frac{(x_i - x_{ref})^2}{u^2(x_i) - u^2(x_{ref})}$	
stdeviation	**0,135**				$\frac{1}{u^2(x_{ref})} = \sum \frac{1}{u^2(x_i)}$		**7048**				χ^2_{obs}	**101,80**	**107,47**	
stdeviation of mean	**0,045**		**weighted mean (KCRV)**		$x_{ref} = \frac{\sum \frac{x_i}{u^2(x_i)}}{\sum \frac{1}{u^2(x_i)}}$		**-0,176**		**P{χ2(ν)-χ2$_{obs}$}** **degree of freedom**	**10**		0,00%	0,00%	**level of significan %**
			variance of weighted mean			$u^2(x_{ref})$	0,000							
		uncertainty of weighted mean (KCRV, k=1)				$u(x_{ref})$	0,0119							

Example: comparison - 9 participants, $\nu = 8$ (ohne G+Cz)

	reported values	abs deviation from mean	reported uncertainties (k=2)	reported uncertainties (k=1)			degree of equivalence	normalized difference	Nielsen	Cox
Labor	**xi**	**di**	**U(xi)**	**u(xi)**	**$x_i/u^2(x_i)$**	**$1/u^2(x_i)$**	**di**	**norm di**	χ^2	χ^2
BEV 5-02	-0,04	0,07	0,15	0,08	-7,11	177,78	0,04	0,61	0,37	0,35
Slovakia	-0,25	0,14	0,12	0,06	-69,44	277,78	-0,17	2,88	8,32	7,63
Switzerland	-0,22	0,11	0,19	0,10	-24,38	110,80	-0,14	1,45	2,11	2,04
BEV 9-02	-0,14	0,03	0,15	0,08	-24,89	177,78	-0,06	0,76	0,58	0,55
Sweden	-0,15	0,04	0,1	0,05	-58,80	400,00	-0,06	1,34	1,79	1,57
Denmark	-0,09	0,02	0,11	0,06	-29,75	330,58	-0,01	0,11	0,01	0,01
BEV 1-03	-0,04	0,07	0,05	0,03	-64,00	1600,00	0,04	2,45	6,01	3,14
Slovenia	-0,18	0,07	0,17	0,09	-24,91	138,41	-0,10	1,15	1,32	1,27
France	0,15	0,26	0,17	0,09	20,76	138,41	0,23	2,82	7,93	7,60

mean = x_{ref}: **-0,106**

$\sum \frac{x_i}{u^2(x_i)}$: **-282,525**

$d_i = x_i - x_{ref}$

$\frac{x_i - x_{ref}}{\sqrt{u^2(x_i) - u^2(x_{ref})}}$

stdeviation: **0,121**

$\frac{1}{u^2(x_{ref})} = \sum \frac{1}{u^2(x_i)}$: **3351,532**

$\chi^2_{obs} = \sum \frac{(x_i - x_{ref})^2}{u^2(x_i) - u^2(x_{ref})}$

χ^2_{obs}: Nielsen **13,16**, Cox **12,14**

stdeviation of mean: **0,040**

weighted mean (KCRV) $x_{ref} = \frac{\sum \frac{x_i}{u^2(x_i)}}{\sum \frac{1}{u^2(x_i)}}$: **-0,0843**

P{χ2(ν)-χ2obs}
degree of freedom 14

Nielsen: **21,5%**, Cox: **27,6%**

level of significance 5 %

variance of weighted mean $u^2(x_{ref})$: 0,000

uncertainty of weighted mean (KCRV, k=1) $u(x_{ref})$: 0,0173

A special tool:

the Youden-plot

The concept of „Youden plot“

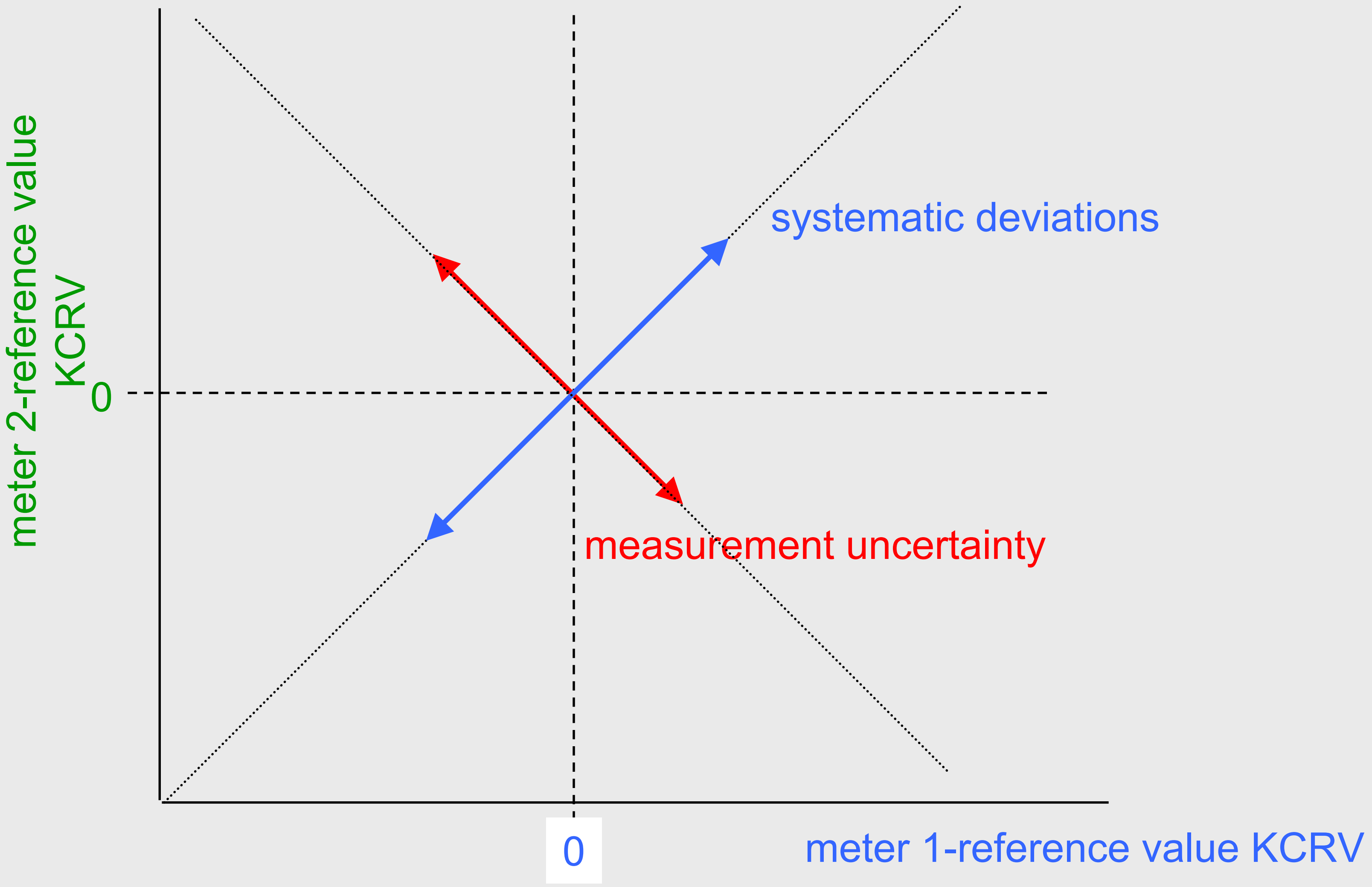
On the x-axis there is the difference between the measurement value and the KCRV for the first meter, on the y-axis is the same for the second meter

On both axis the KCRV is the zero.

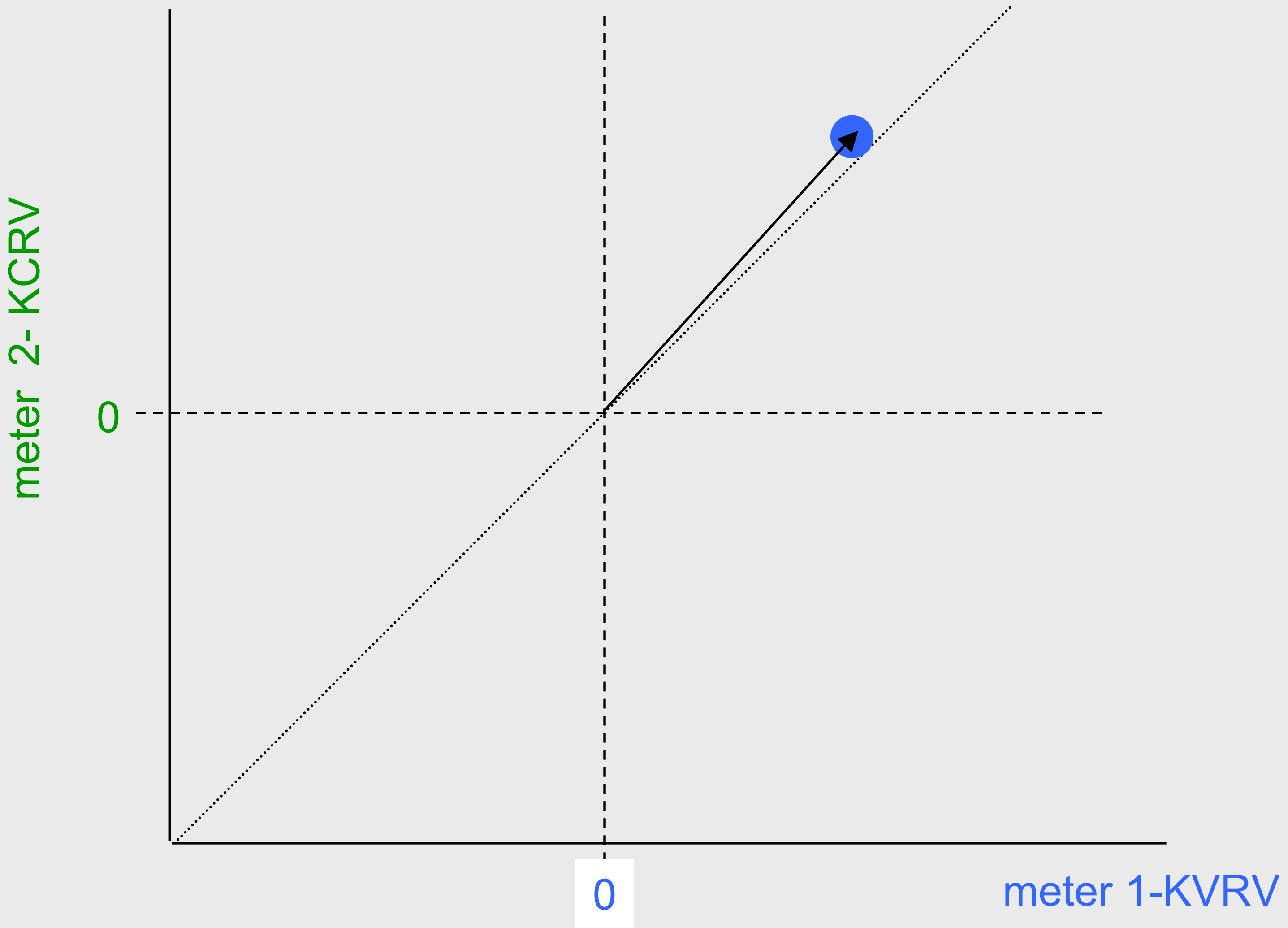
In the following diagrams there are:

ε ... excentricity of an intended ellipse
σ_s ... mean of the uncertainty of the test rigs
σ_m ... mean of the uncertainty of the meters

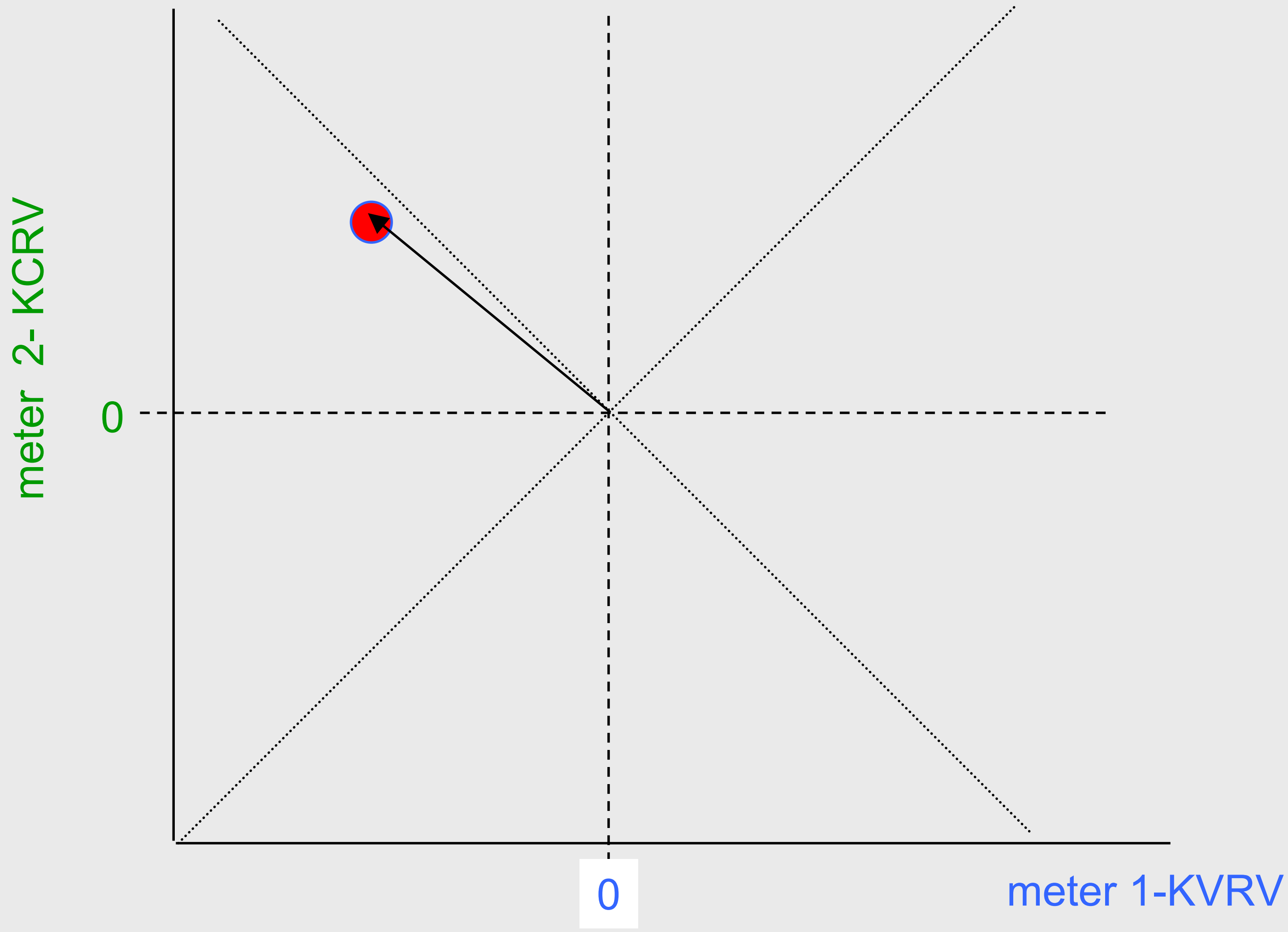
The sence of Youden-plot



Typical: small uncertainties, large systematic errors



Typical: large uncertainties, small systematic errors



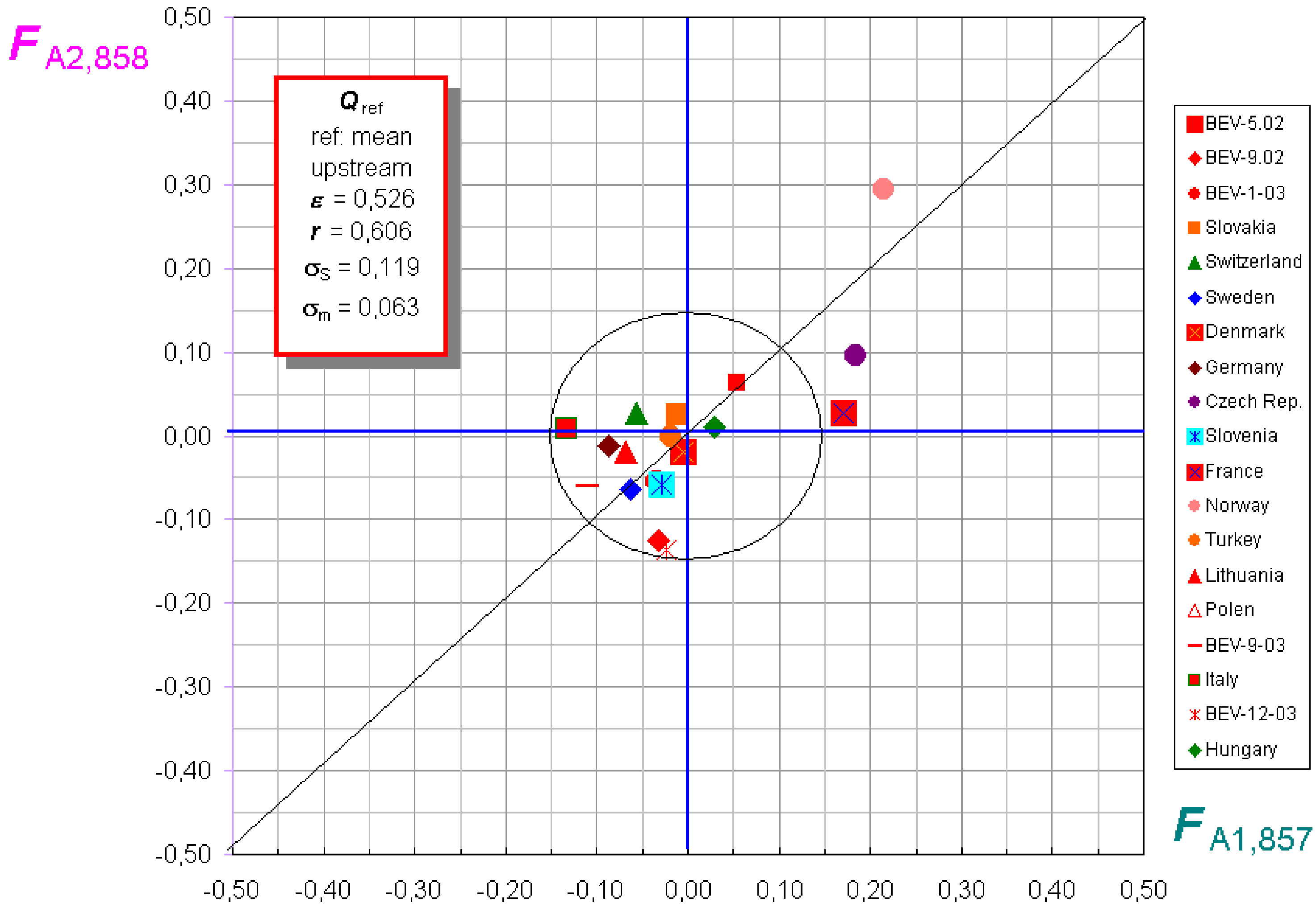
Definition of a reference flow rate

5 flow rates: 1000 l/h; 2500 l/h; 5000 l/h; 7500 l/h and 10000 l/h

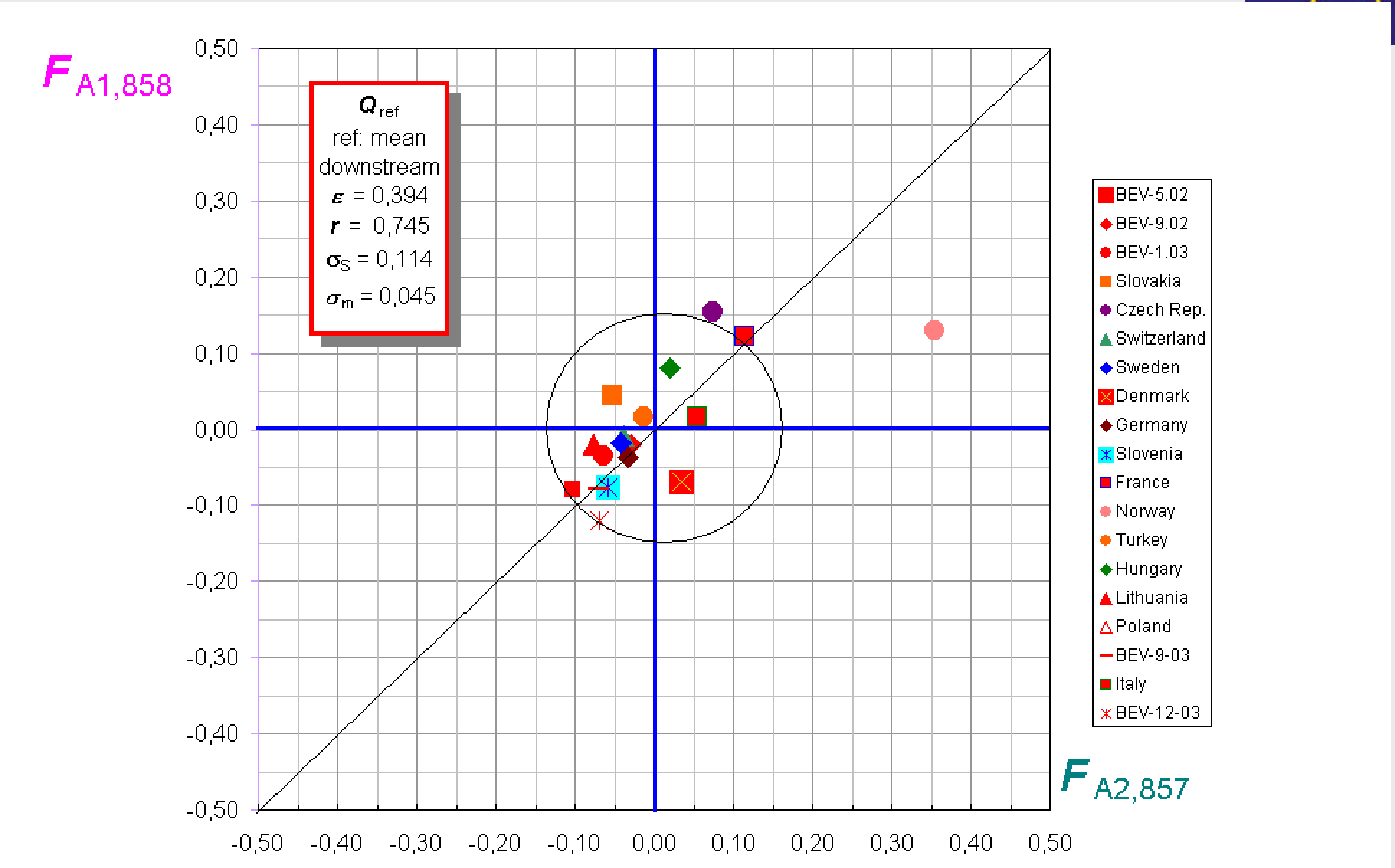
$$Q_{ref} = \frac{1}{5} \times \sum_{i=1000}^{10\,000} Q_i$$

Results of the EUROMET comparisons

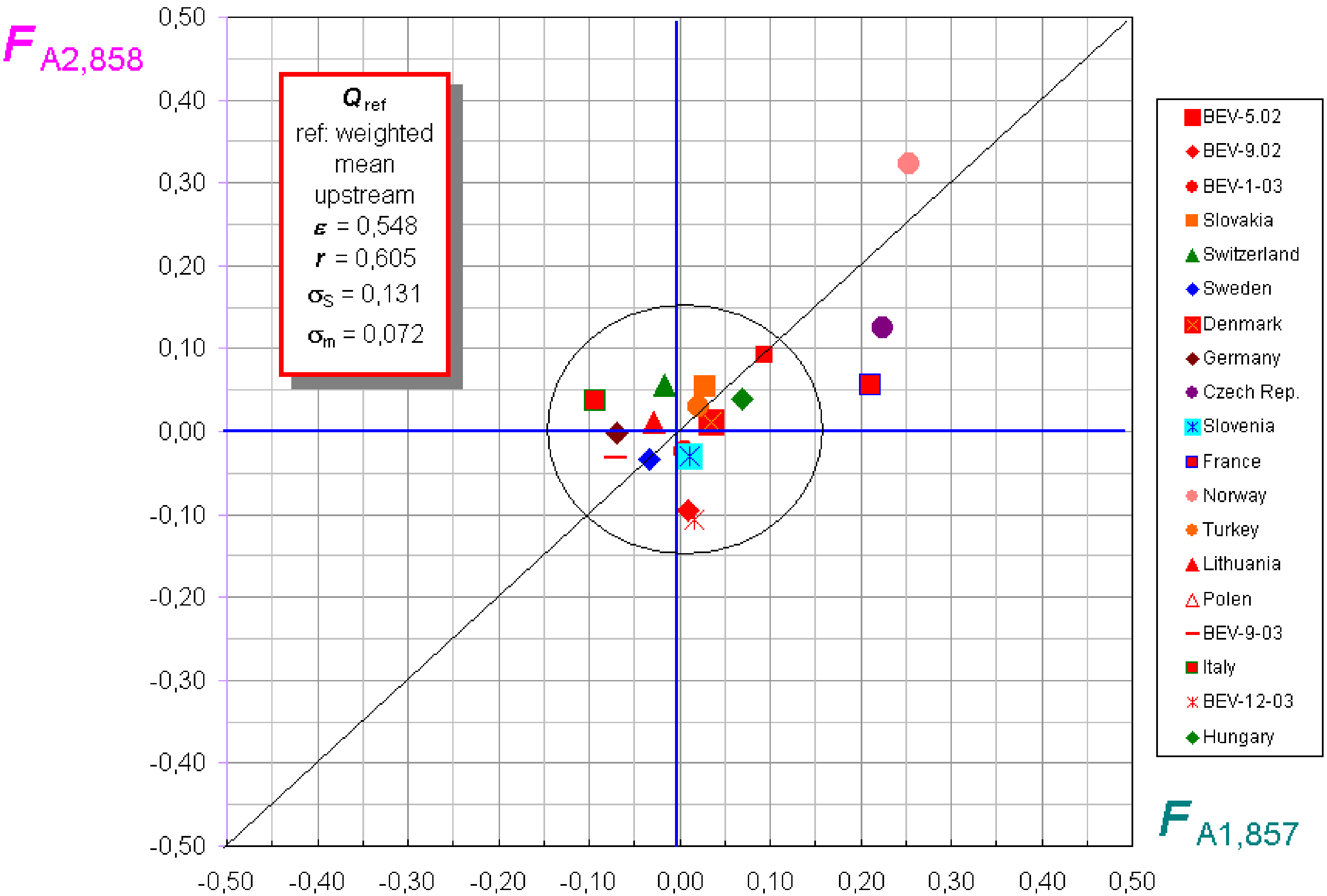
reference: mean - upstream



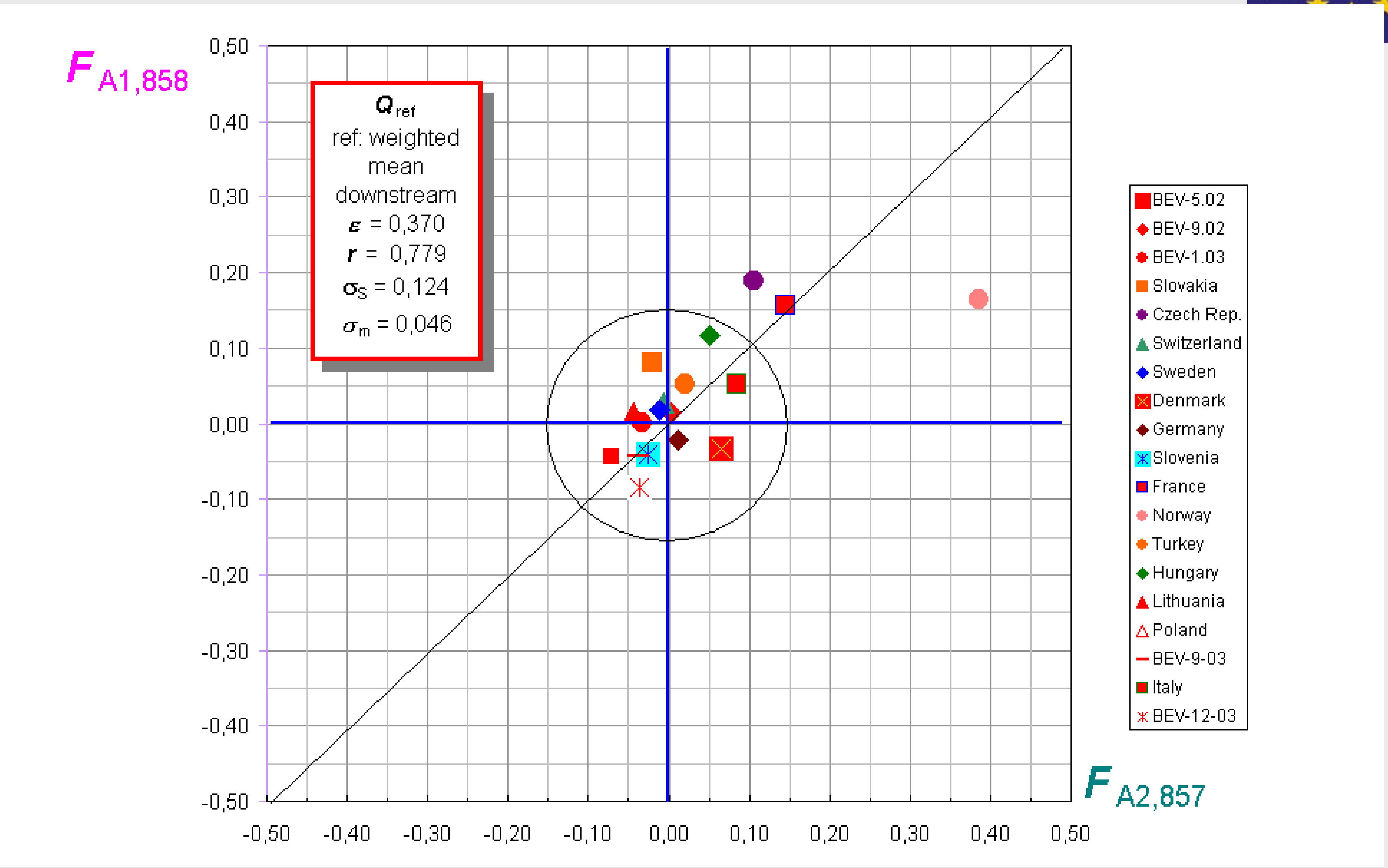
reference: mean - downstream



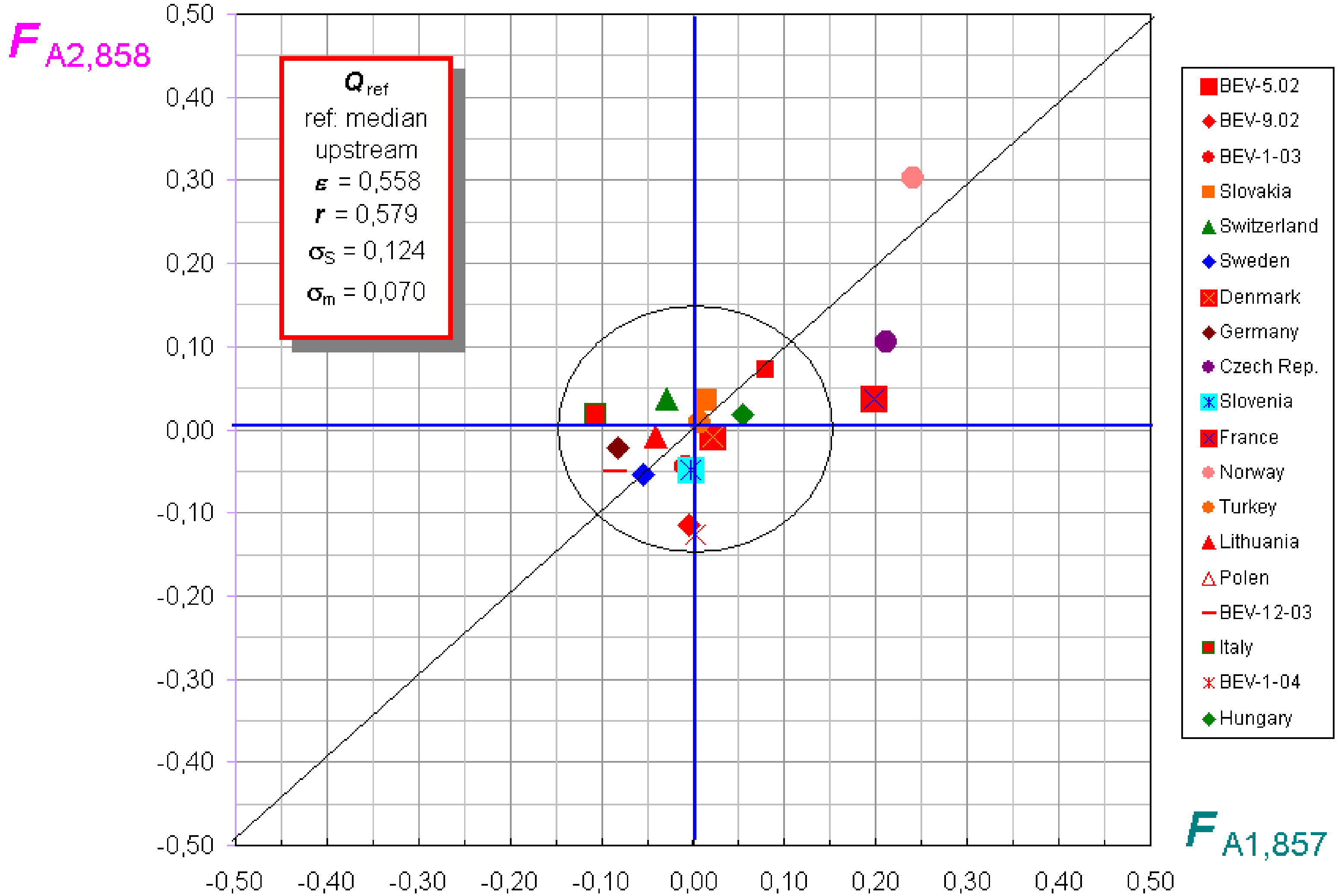
reference: weighted mean - upstream



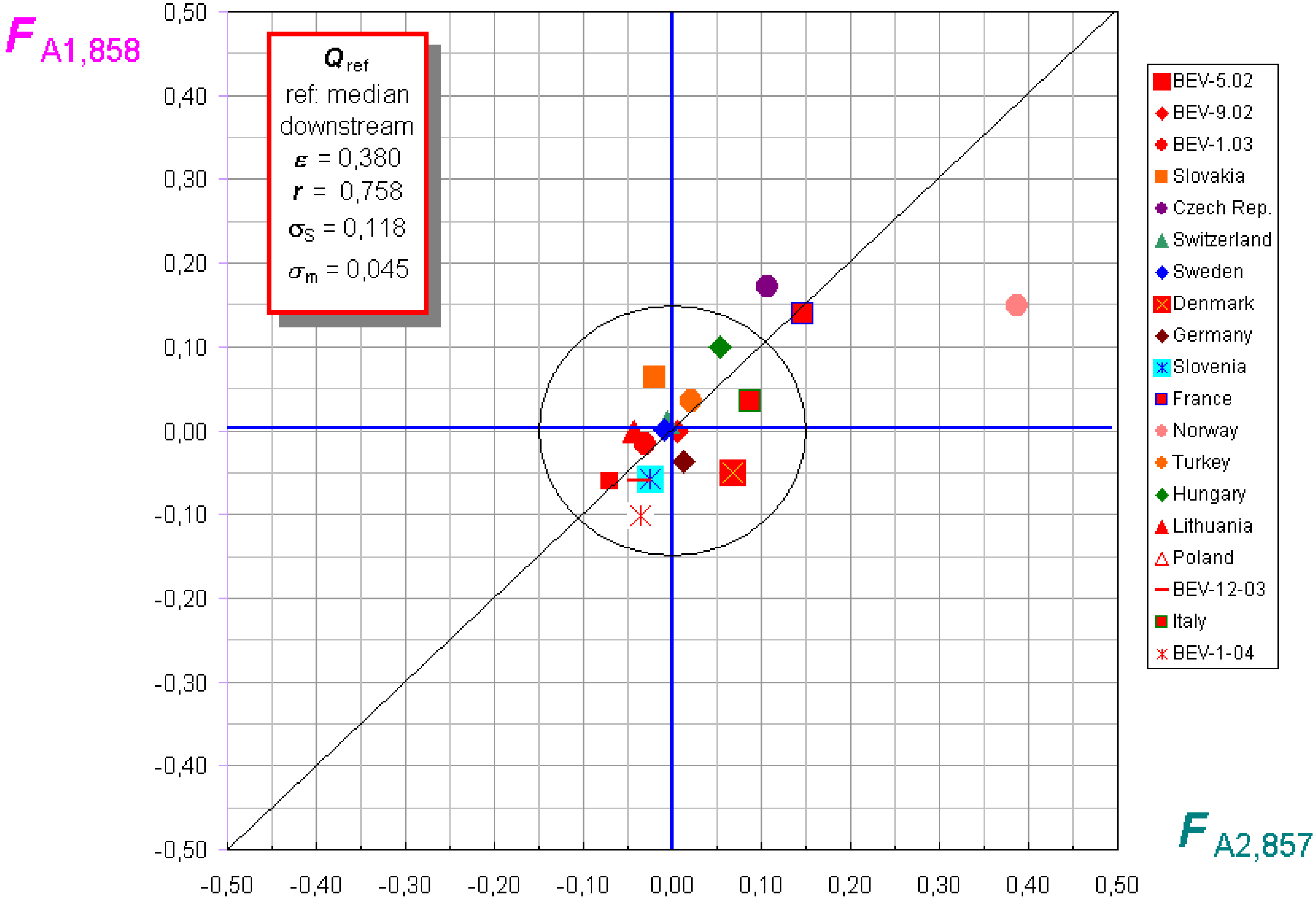
reference: weighted mean -downstream



reference: median - upstream



reference: median - downstream



What is to do?

elimination of the outsiders ➔ criteria: $P(\chi^2) > 5$ %

- main problem: measurement uncertainties of participants are extremly different: ➔ (0,02 % bis 0,20 %)
- if measurement uncertainty of a NMI very small ➔ these measurements results dominate the KCRV
- if measurement uncertainty of a NMI large ➔ only a small contribution to KCRV evaluation

Reason of the differences ... perhaps:

- measurement uncertainty was not evaluated by GUM but by empiric estimation
- there are wrong measurement uncertainty contributions or wrong assumptions (example: the relevant quantities are not correlated)
- not all contributions to uncertainty are regarded (example: contributions are not acquainted ... or: some contributions are forgetted)

The End