Graz University of Technology

process & particle engineering

Flippr

Towards Simulation-based Engineering of Fibre Fractionation Equipment

OpenFOAM® for DNS – Application to Toroidal Flow

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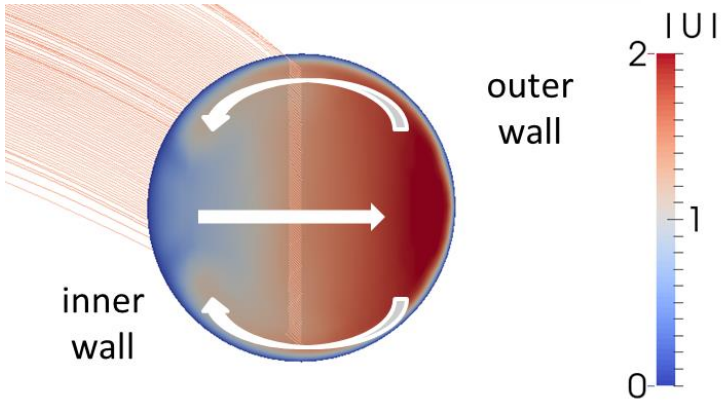
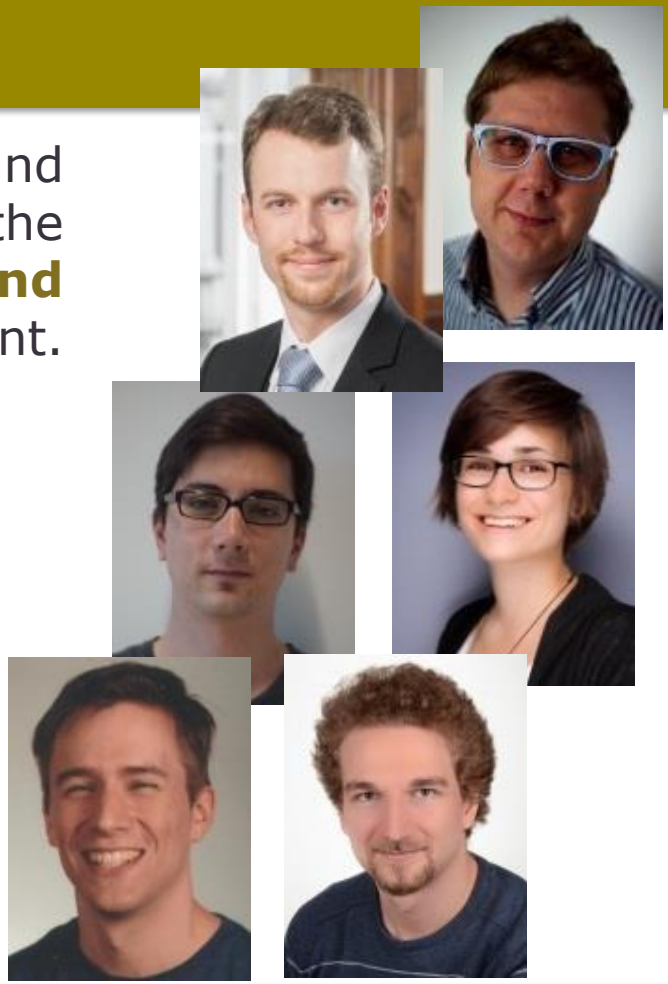
FLIPPR Group at IPPT / TUG

The mission for this project is to understand and predict particle and fibre motion for the **rational design of new separation and fractionation** equipment.

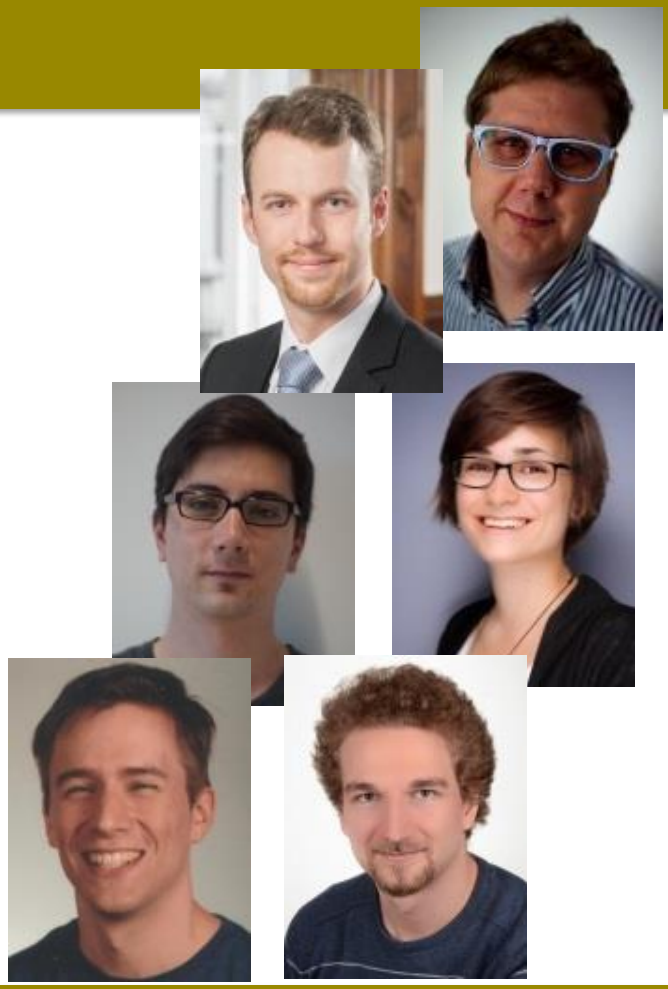


Laitinnen et.al., BioResources 6 (2011) 672-685



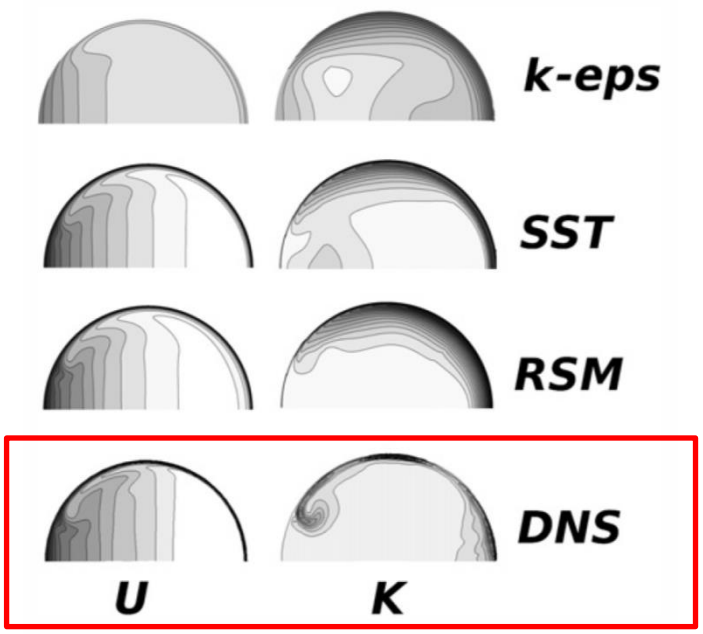
Agenda

- **Literature Review**
  - Physics of toroidal flows
- **Mesh Generation**
  - Meshing a Torus
  - A Circular Mesh
  - Mesh Quality Study
  - Domain Size
- **Schemes and Solvers**
- **Results**



Literature

DNS and standard models [1]:



Turbulent toroidal flow at
Re = 14e3, κ = 0.3

"**The computational method** was based on a finite volume coupled algebraic multigrid solver, and adopted the central interpolation scheme for the advection terms and a second-order backward Euler time-stepping algorithm." [2]

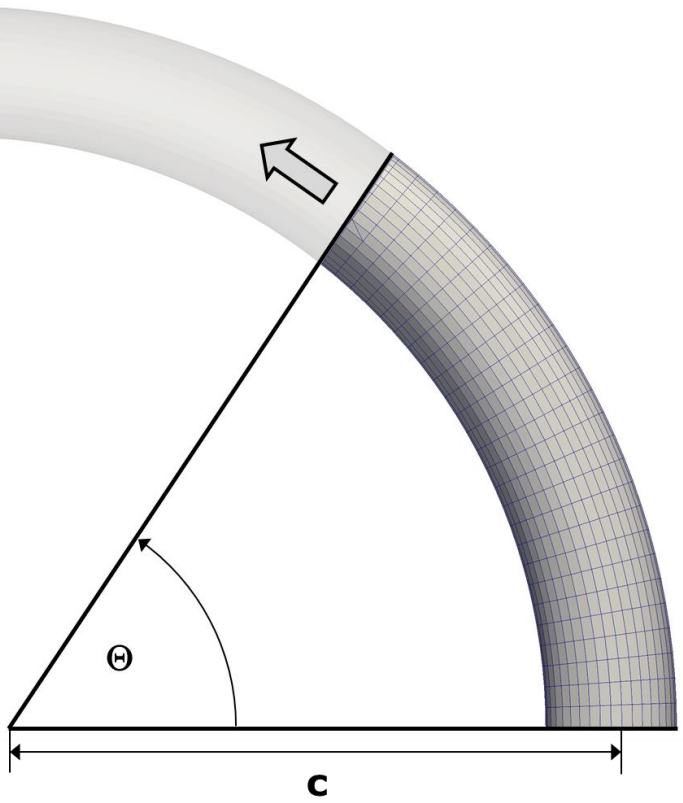
„**A finite volume method** on staggered grids is used to discretize the governing equations. It leads to central differences of second-order accuracy …" [3]

[1] Di Piazza and Ciofalo, Int. J. Therm. Sc. 49 (2010) 653-663
[2] Di Piazza and Ciofalo, J. Fluid. Mech. 687 (2011) 72-117
[3] Hüttl and Friedrich, Computers & Fluids 30 (2001) 591-605

Mesh Generation - Meshing a Torus

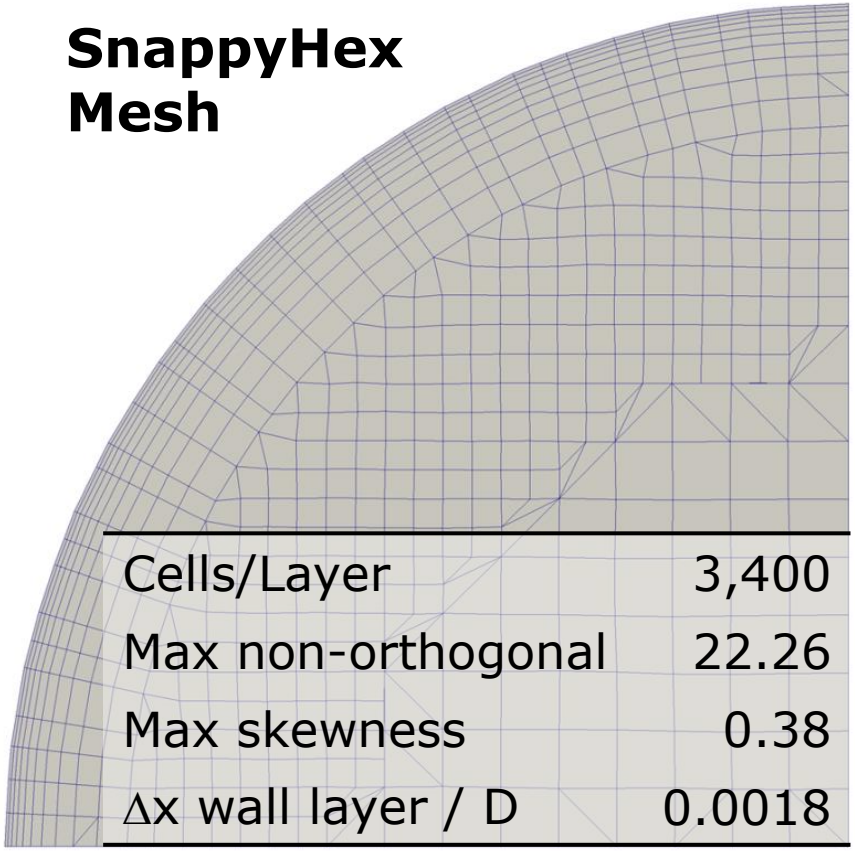
- Toroidal mesh is generated by circular extrusion from a **patch**.
- For that the OpenFOAM utility extrudeMesh was modified.

```
extrudeModel        spiral;

nLayers               200;
expansionRatio        1; // by default 1, leave it like that for spiral

patchName outlet;

spiralCoeffs
{
    axisPt          (0 5 0); // from patch face, direction which then is
    axis             (1 0 0);
    angle           -200;
    pitch            0;
}
```



Mesh Generation - A Circular Mesh

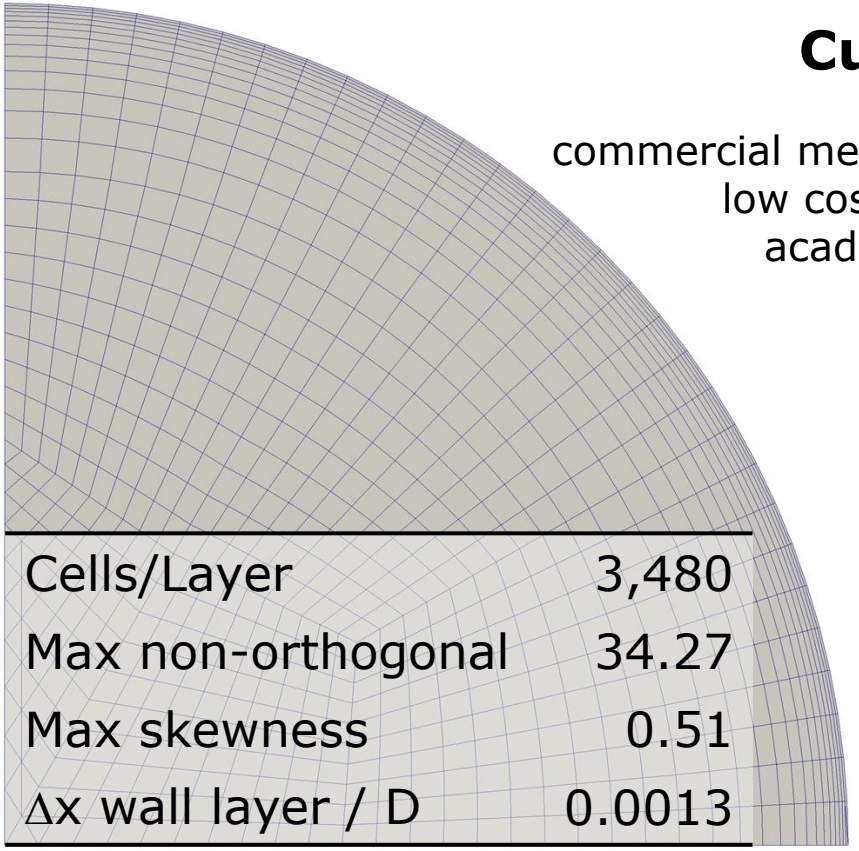
SnappyHex Mesh



Cells/Layer	3,400
Max non-orthogonal	22.26
Max skewness	0.38
Δx wall layer / D	0.0018

Cubit

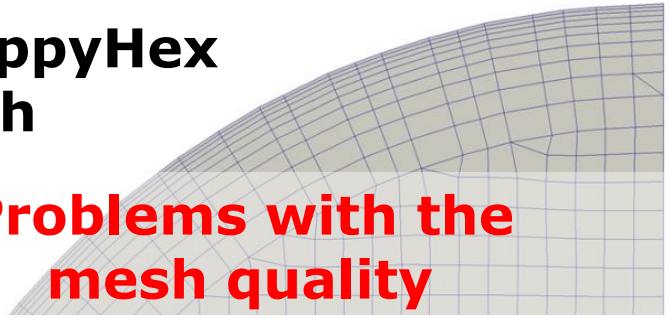
commercial mesher, low cost for academia



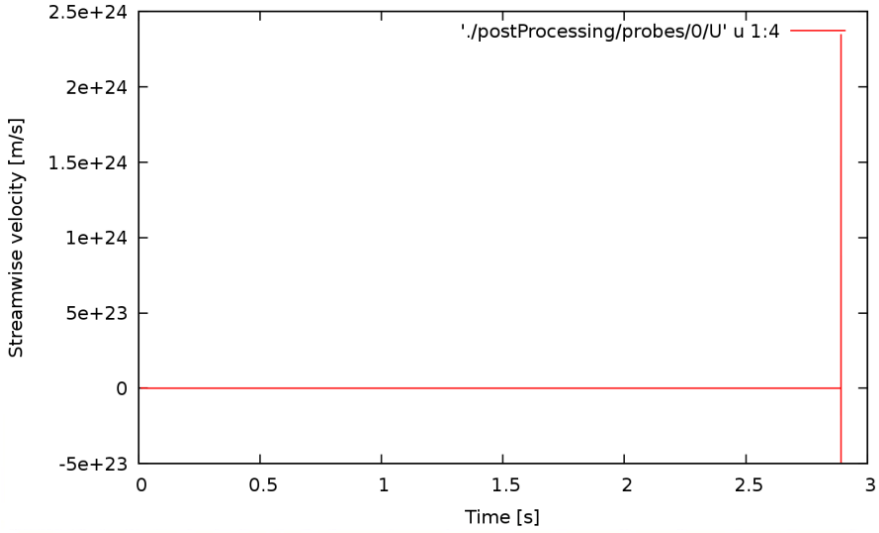
Cells/Layer	3,480
Max non-orthogonal	34.27
Max skewness	0.51
Δx wall layer / D	0.0013

Mesh Generation - A Circular Mesh

SnappyHex Mesh



Problems with the mesh quality



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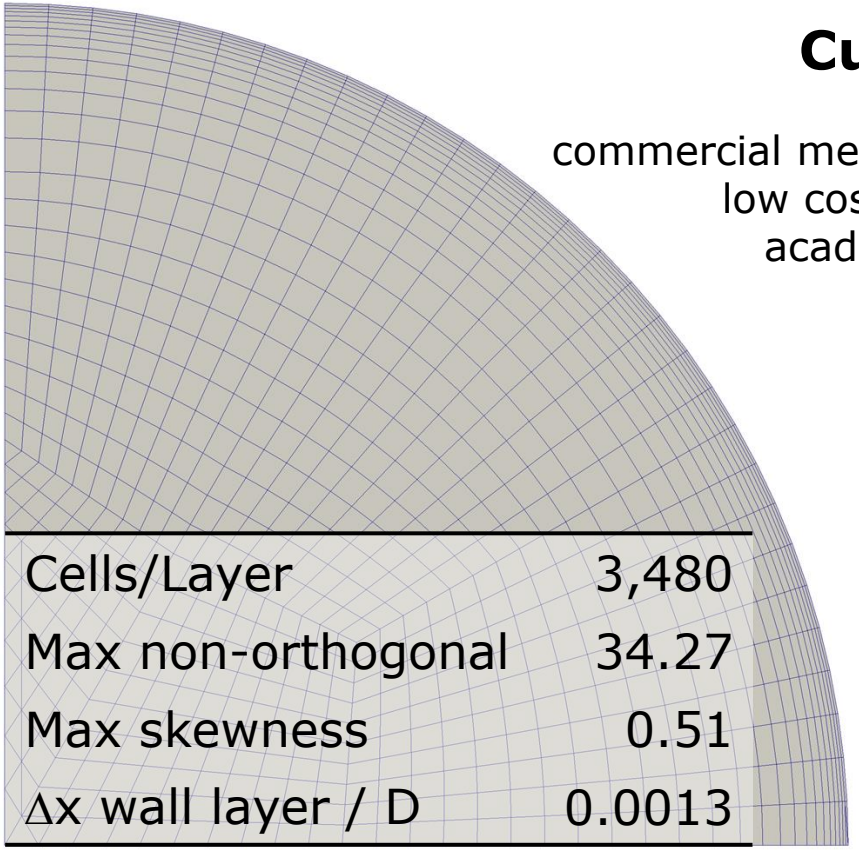

Cells/Layer	3,480
Max non-orthogonal	34.27
Max skewness	0.51
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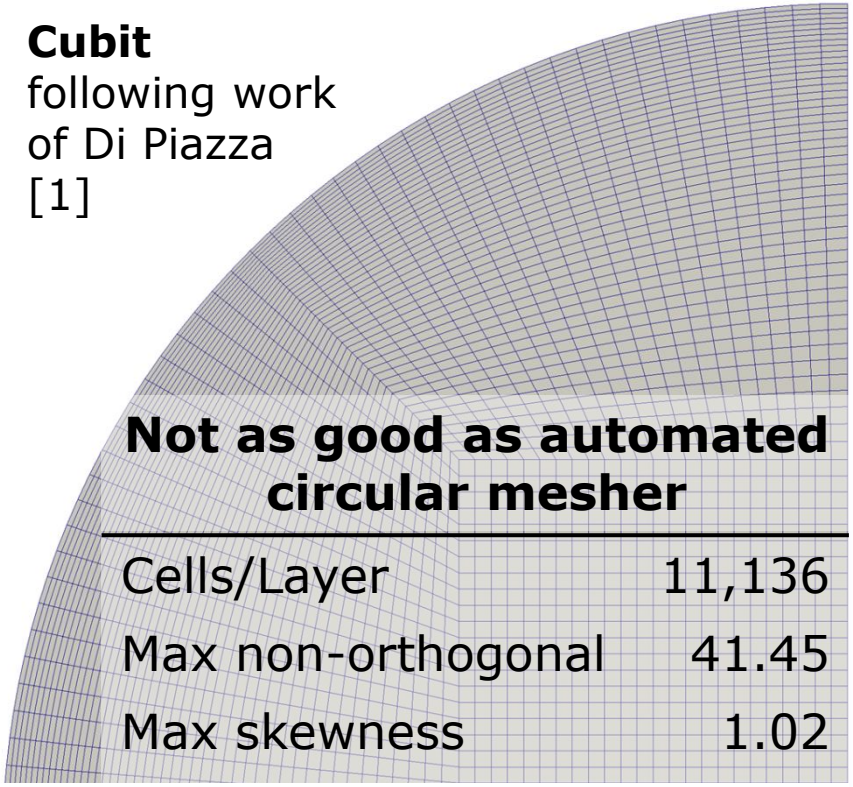
Mesh Generation - A Circular Mesh

Cubit
following work of Di Piazza [1]



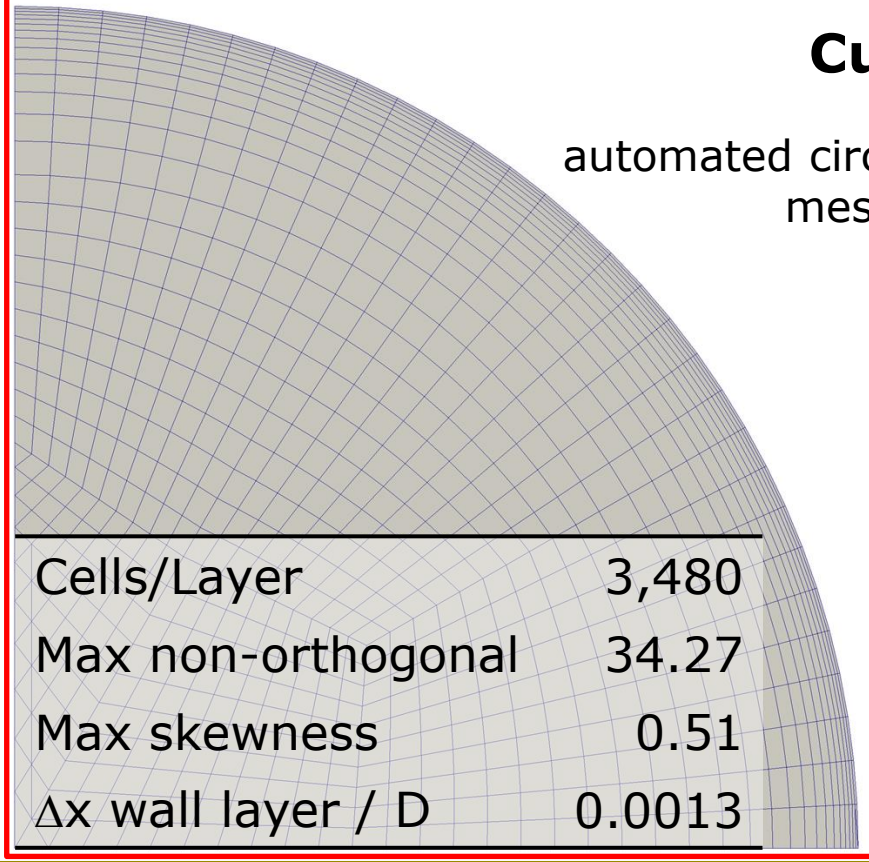
Not as good as automated circular mesher

Cells/Layer	11,136
Max non-orthogonal	41.45
Max skewness	1.02

[1] Di Piazza and Ciofalo, Int. J. Therm. Sc. 49 (2010) 653-663

Cubit

automated circular meshing



Cells/Layer	3,480
Max non-orthogonal	34.27
Max skewness	0.51
Δx wall layer / D	0.0013

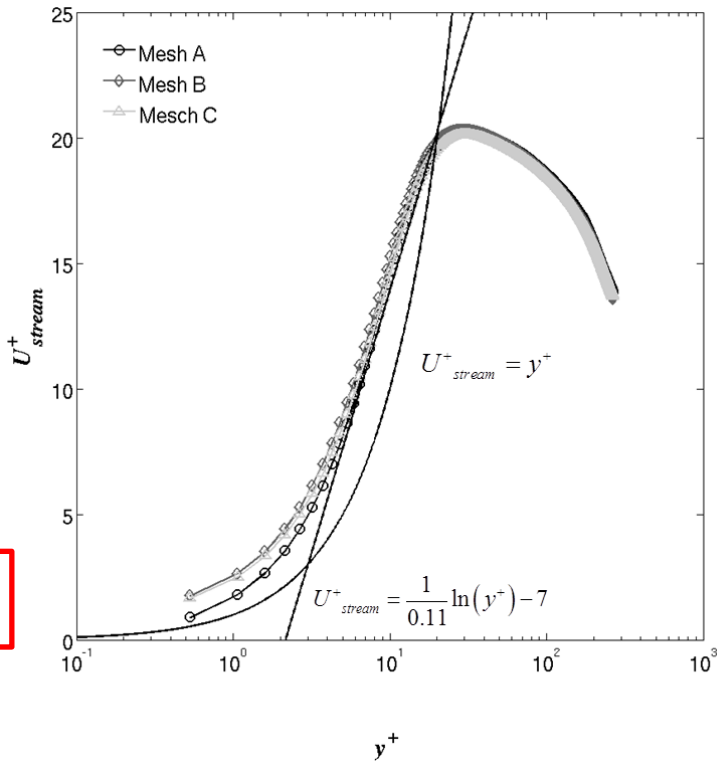
Mesh Generation - Mesh Quality Study

Mesh study follows the work of Di Liberto [1].

Following meshes are compared against each other.

Re = 6926, κ = 0.1

Mesh	N_{CS}	N_S	N_{total}	N ($y^+ \leq 5.5$)	y^+_{max}
A	5640	402	2.27e6	5	0.656
B	11970	503	6.02e6	6	0.556
C	20586	804	16.55e6	9	0.371



[1] Di Liberto, rt.al, Computers & Fluids 88 (2013) 452-472

Mesh Generation - Domain Size

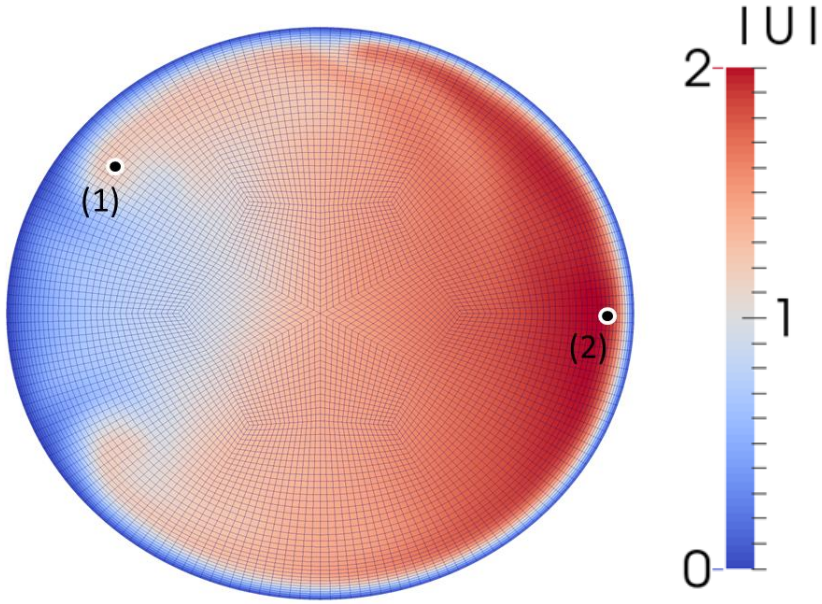
A too short torus length might suppress oscillating behavior [1].

We compared **velocity fluctuations** at position of the Dean vortex (1) and high speed region (2) for:

Full Torus

Half Torus

Quarter Torus

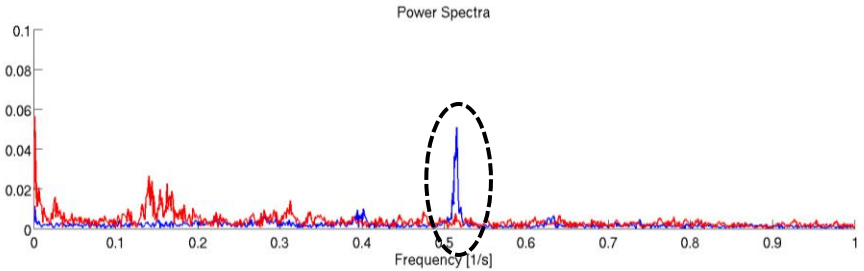


Recording time 650 (20 Letots)

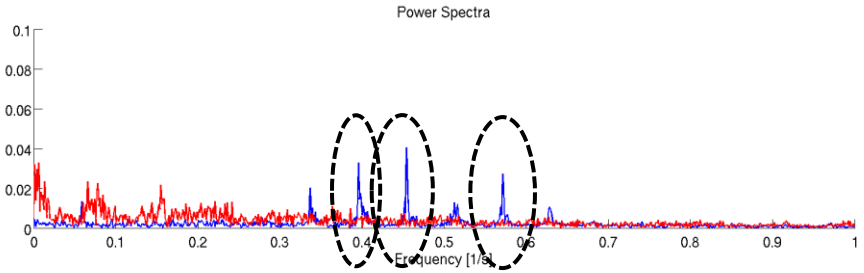
[1] Di Piazza and Ciofalo, J. Fluid. Mech. 687 (2011) 72-117

Mesh Generation - Domain Size

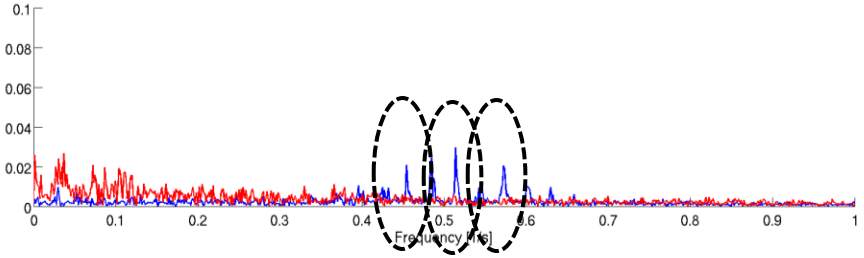
Quarter Torus



Half Torus



Full Torus



Mesh Generation - Domain Size

Bulk velocity is 1 m/s.

For the analysis we compared the length of the travelling oscillation of the Dean vortex and

compared it to the length of the torus segment

Frequency [1/s]		0.382	0.446	0.510	0.575
Torus	Length [m]	Multiple			
Quarter	7.85	3.000	3.503	4.006	4.516
Half	**15.71**	**6.000**	**7.006**	**8.011**	**9.032**
Full	31.42	12.001	14.012	16.022	18.064

Schemes and Solvers

- Invested / spent some time changing numerical schemes and solver settings
- resulting to use best practice settings after all [1].

ddtSchemes	backward	Pimple Solver	
gradSchemes	Gauss linear	nOuterCorrectors	1
divSchemes	Gauss linear	nCorrectors	2
laplacianSchemes	Gauss linear corrected	nNonOrthogonalCorrectors	1
interpolationSchemes	Linear		
snGradSchemes	corrected		

[1] Guerrero, Introductory OpenFOAM® Course, University of Genoa, 2013

Schemes and Solvers

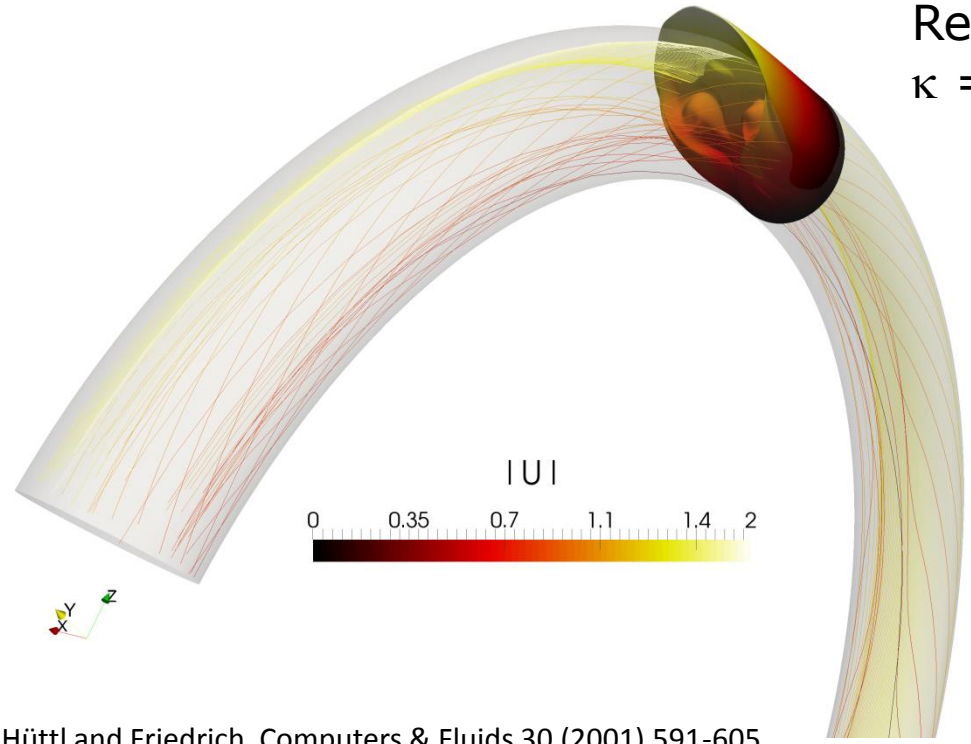
Cyclic boundary conditions at the inlet and outlet of the half torus.

Modified momentum source used to to drive the flow in toroidal domains.

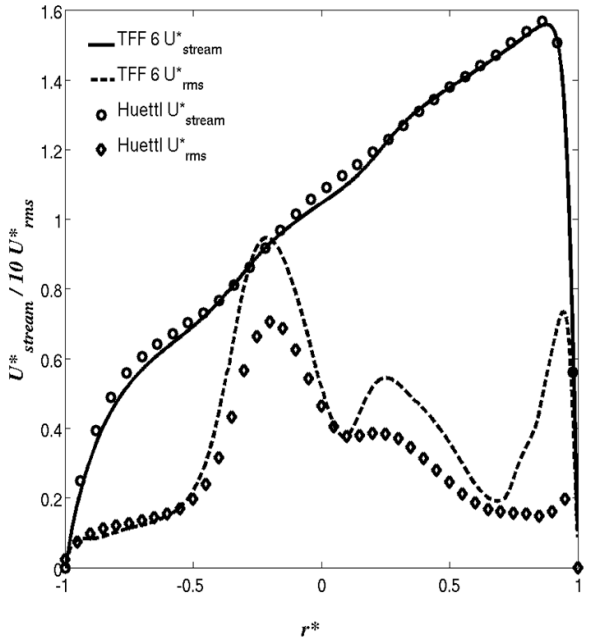
Good to go/run

```
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

libs
(
    "libfvOptionsIPPT.so"
);

momentumSource
{
    type            pressureGradientTorus;
    active          on;             //on/off switch
    selectionMode   all;        //cellSet // points //cellZone

    pressureGradientTorusCoeffs
    {
        fieldNames  (U);
        Ubar        1.00;
        axis        (1  0  0);
        origin      (0  5  0);
    }
}

// ************************************************************************
```

Results



Case 6
Re = 5626
κ = 0.1



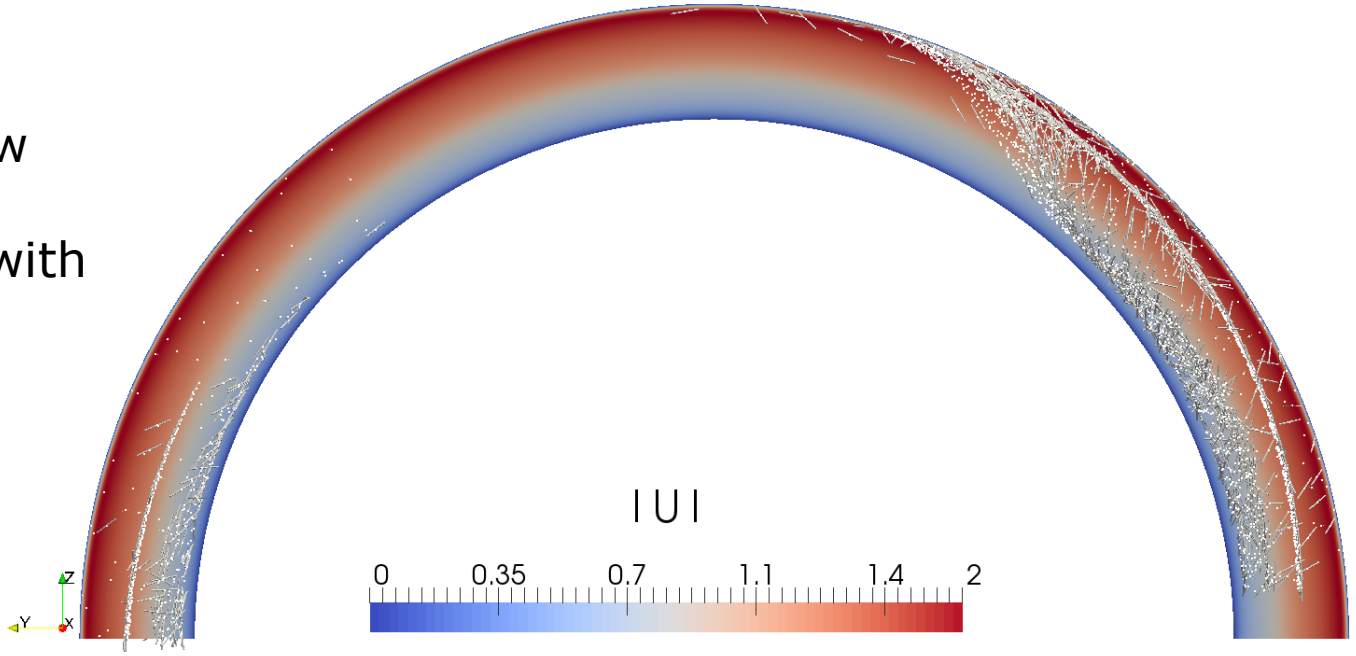
[1] Hüttl and Friedrich, Computers & Fluids 30 (2001) 591-605

Results – Sneak Preview to CFDEM Simulation

CFDEM Simulation:

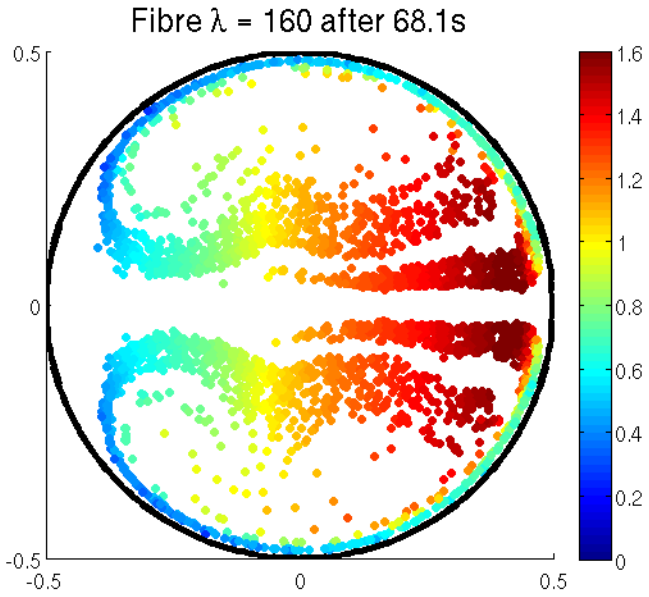
- Re = 3316
- κ = 0.1
- Stationary flow

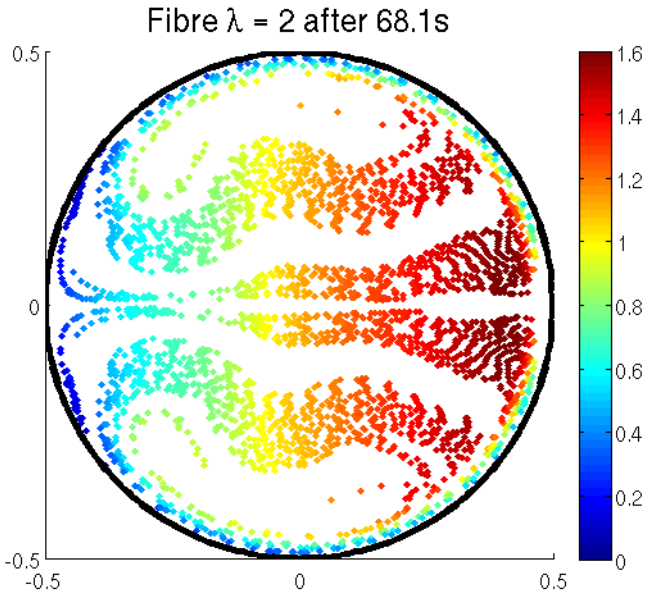
- 3 fibre types with AR 160, 40, 2



Results – Sneak Preview to CFDEM Simulation

Fibre position in the cross section. Fibres are colored by their stream wise velocity





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FUNDING PARTNERS

The K-Project Flippr ° is within the scope of COMET - Competence Centers for Excellent Technologies sponsored by BMVIT, BMWFJ, Province of Styria and Carinthia. The COMET program is managed by FFG

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