Petascale Requirements of ITER

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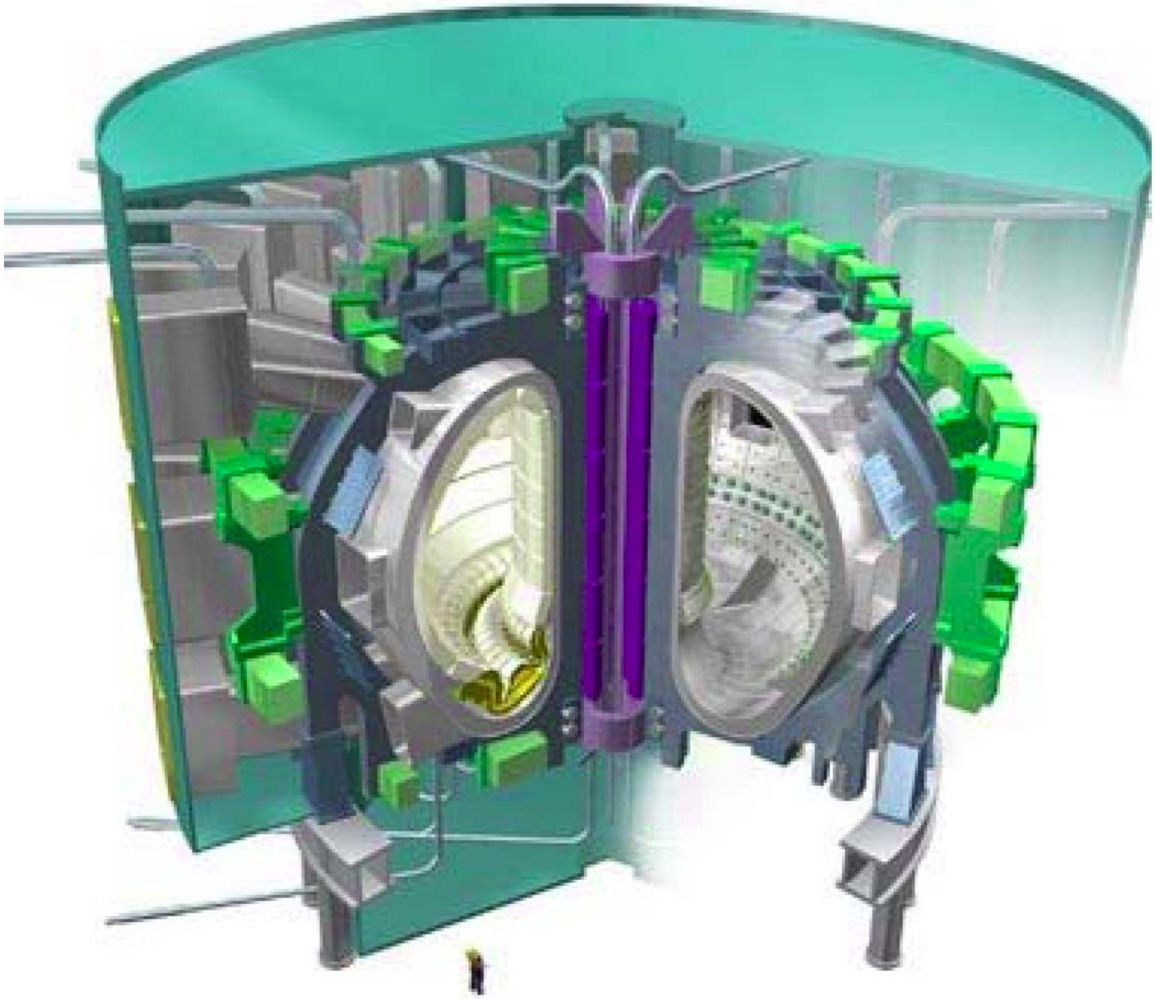
ITER project

drivers of ITER modelling needs

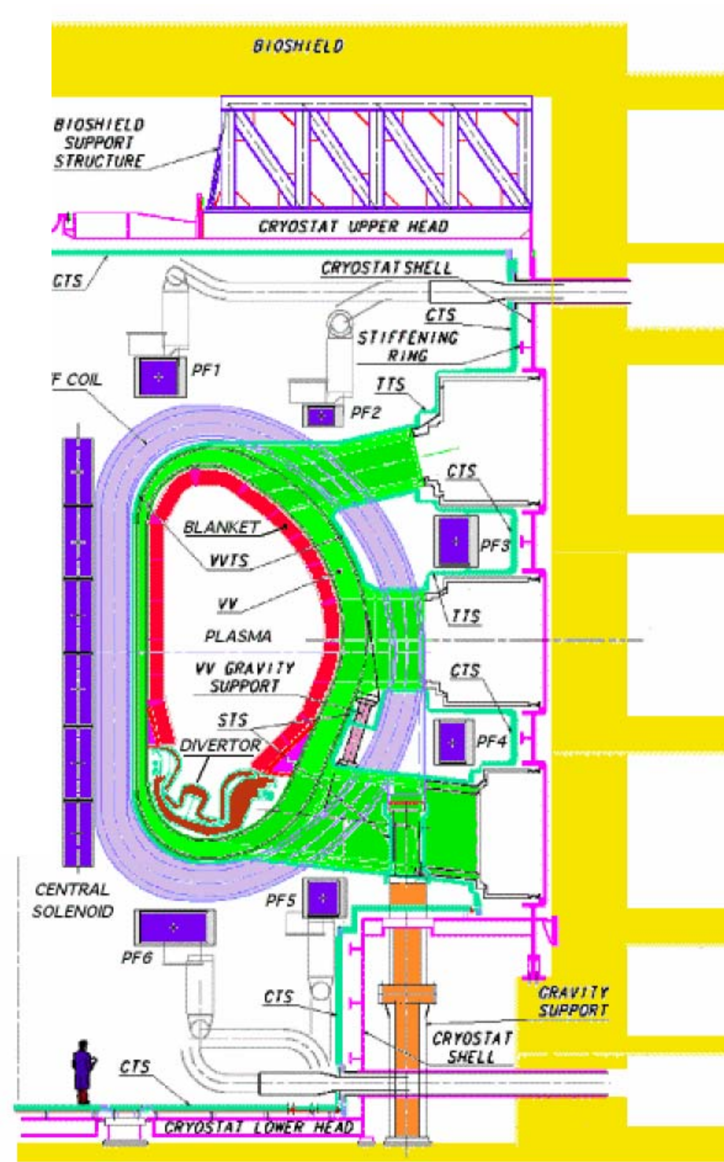
code developments for fusion plasma physics

hyperscaling of turbulence simulation codes

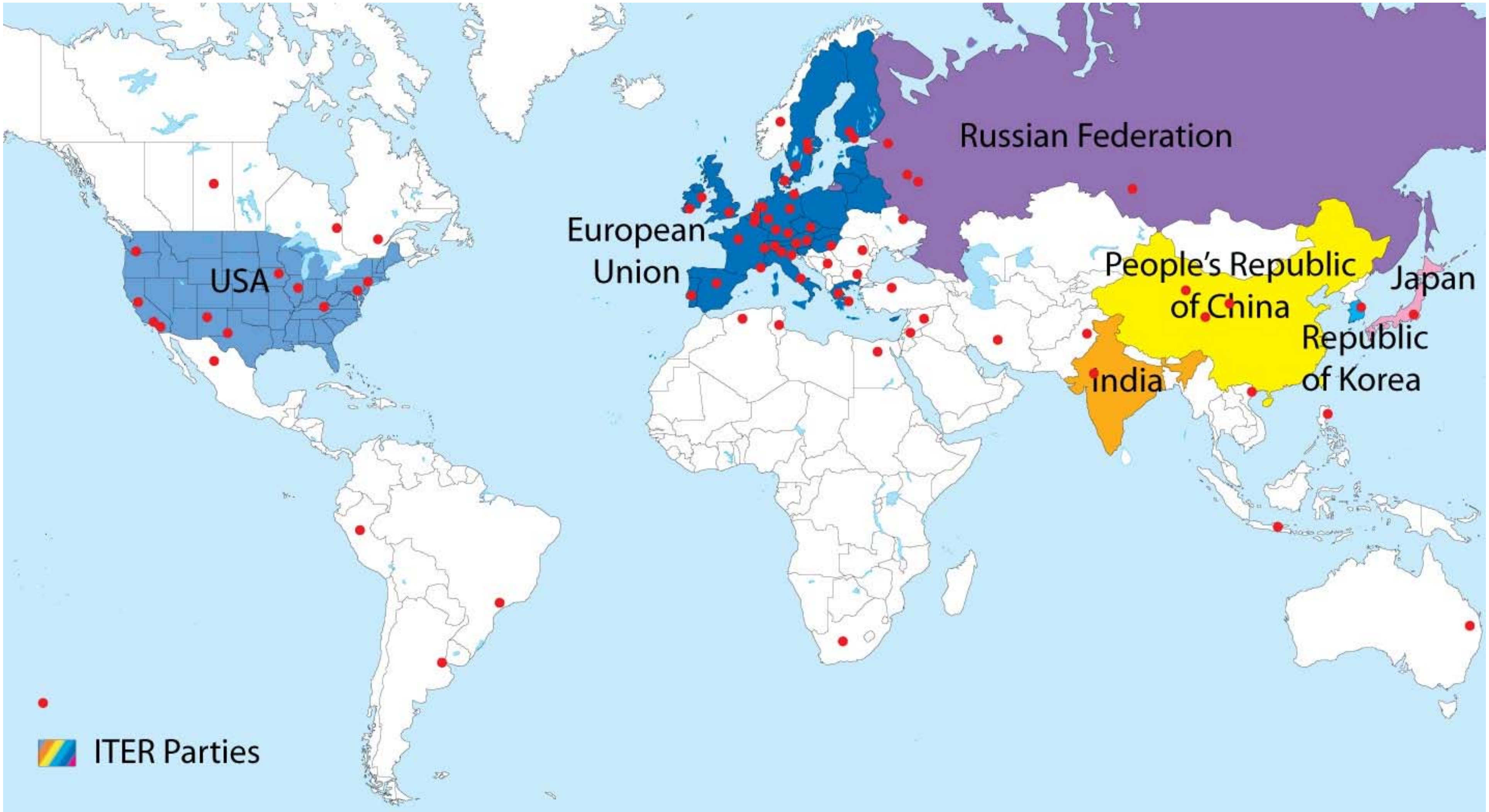
HPC plans of the EU fusion community



ITER

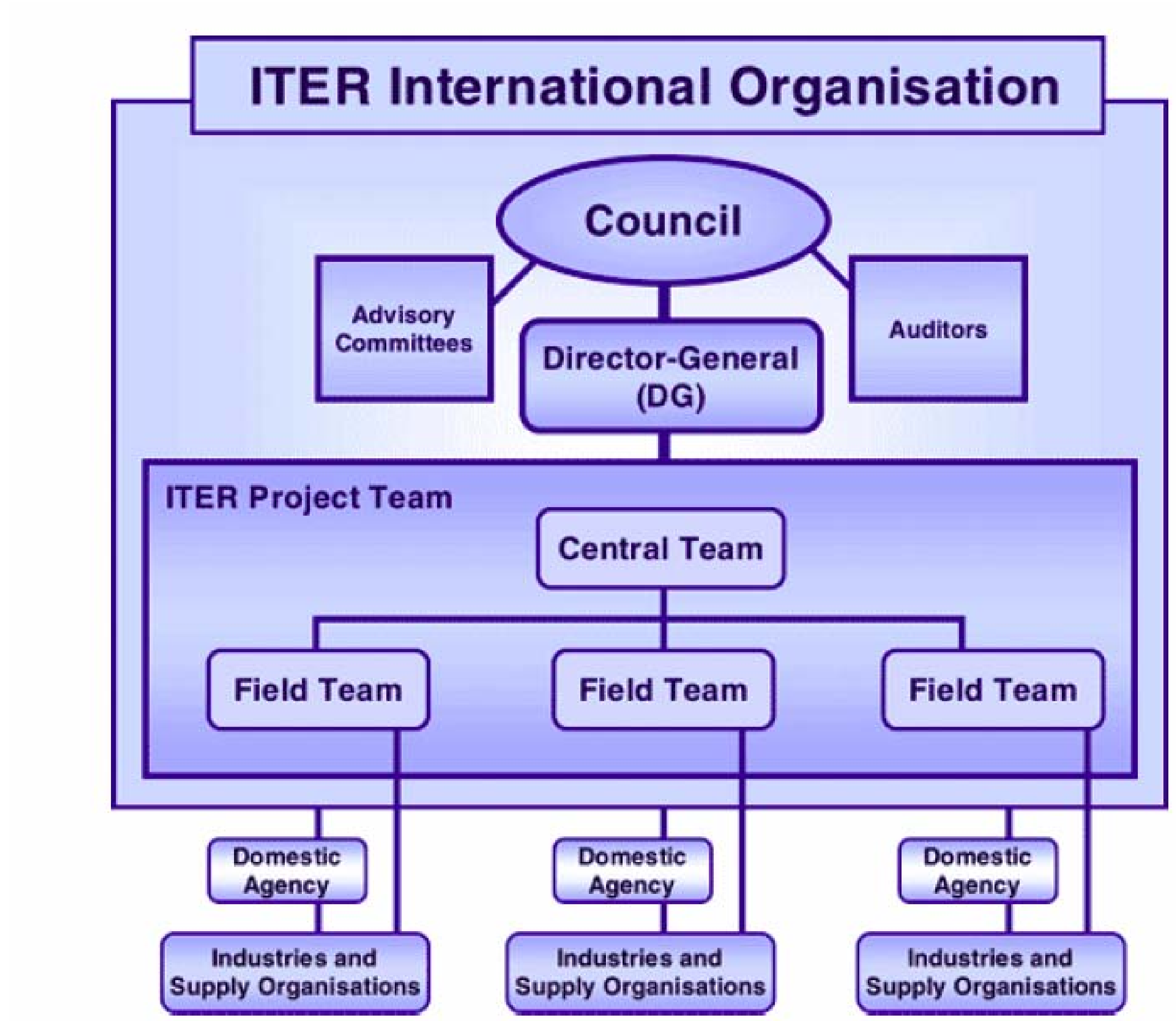


BIOSHIELD
BIOSHIELD SUPPORT STRUCTURE
CRYOSTAT UPPER HEAD
CTS
CRYOSTAT SHELL
CTS
STIFFENING RING
PF1
TF COIL
TTS
PF2
CTS
BLANKET
VVTS
PF3
VV
TTS
PLASMA
CTS
VV GRAVITY SUPPORT
STS
PF4
DIVERTOR
CENTRAL SOLENOID
PF5
PF6
CTS
GRAVITY SUPPORT
CRYOSTAT SHELL
CTS
CRYOSTAT LOWER HEAD



ITER is an international endeavor, involving ~ 4700 M€ construction cost, and 7 Parties to be constructed in Europe (France)

in an organisational frame relying heavily on a distributed system and contributions in kind



Modelling needs of ITER
associated with

engineering level (incl. safety) planning of ITER discharges

- plasma is an essential subsystem
- done by ITER Central Team
- little HPC requirements

physics based selection of ITER operating scenarios

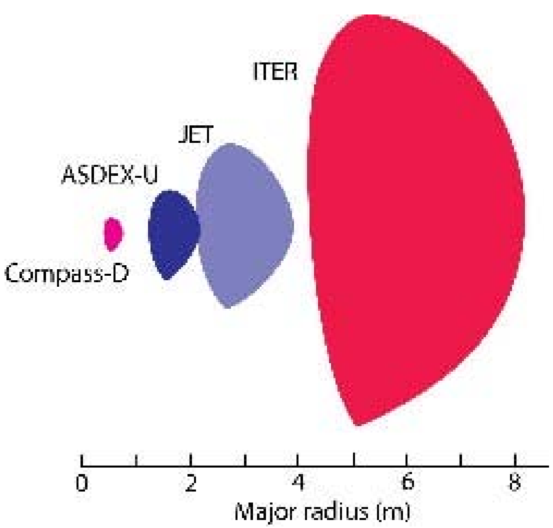
- based on best available, ab-initio physics models
- reflect differing ITER-role seen by partners - competitive
- top-level HPC requirements

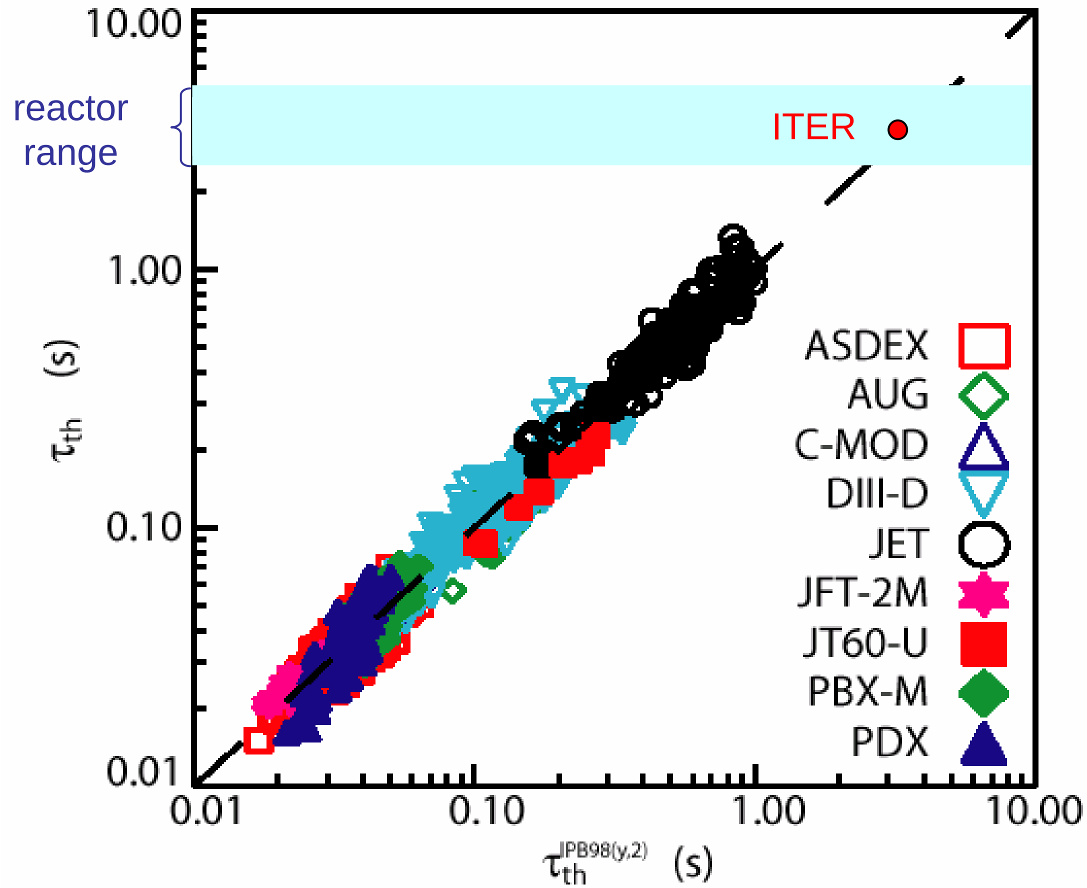
preparing the design base of a (DEMO) fusion power plant

- based on above ab-initio physics models, tested on experiment
- integrated into “fusion physics core” of a design code: “numerical tokamak”
- top-level HPC requirements

ITER parameters decided by empirical scaling

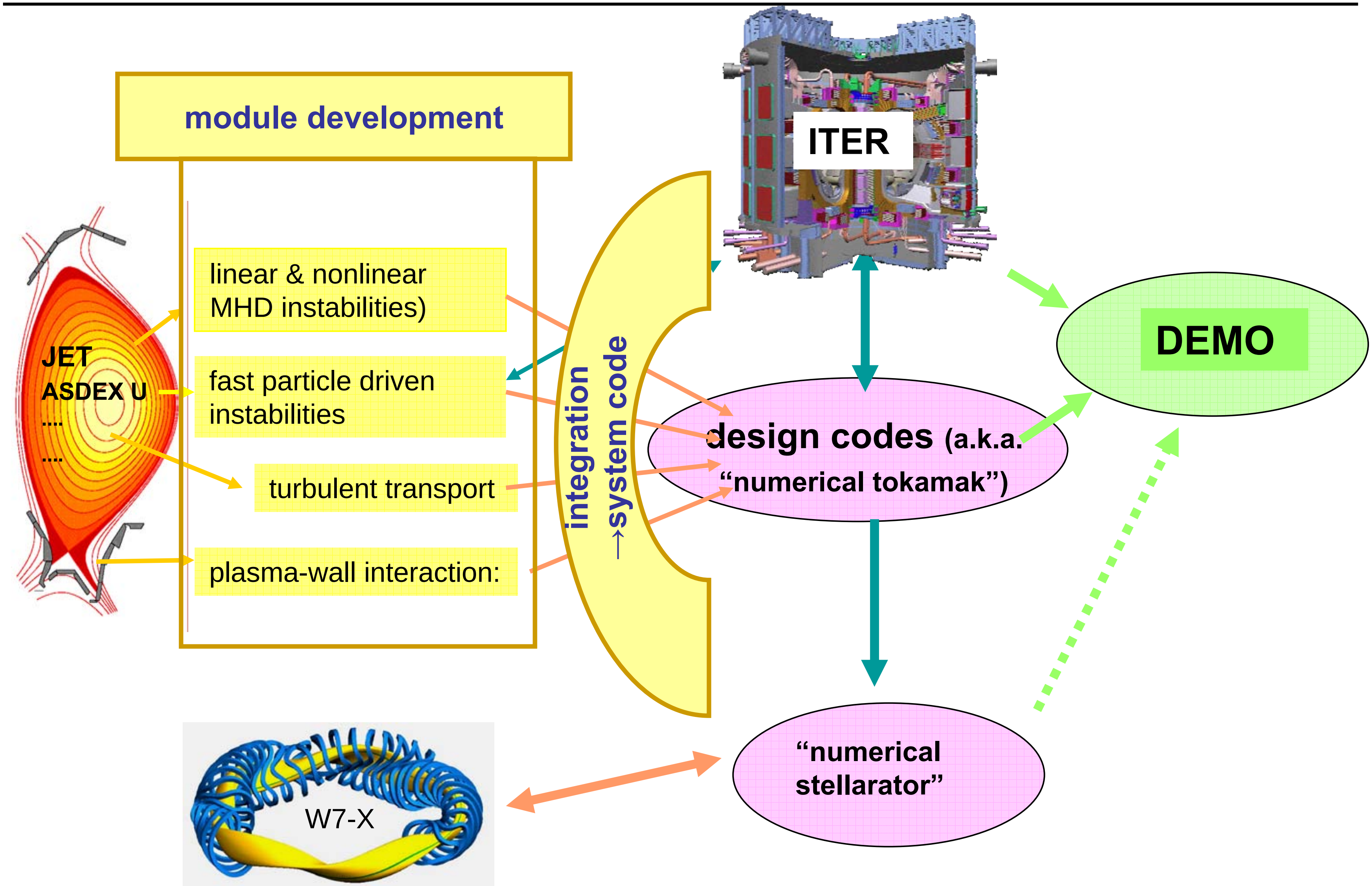
Main ITER Parameters	
Total Fusion Power (MW)	500
Q - Fusion Power/Auxiliary Heating Power	10
Average (1 MeV) neutron wall loading (MW/m2)	0.57
Plasma major radius (m)	6.2
Plasma minor radius (m)	2.0
Plasma Current (MAmpere)	15
Toroidal Field at 6.2 m radius(T)	5.3
Plasma Volume (m3)	837
Installed auxiliary heating/current drive power (MW)	73



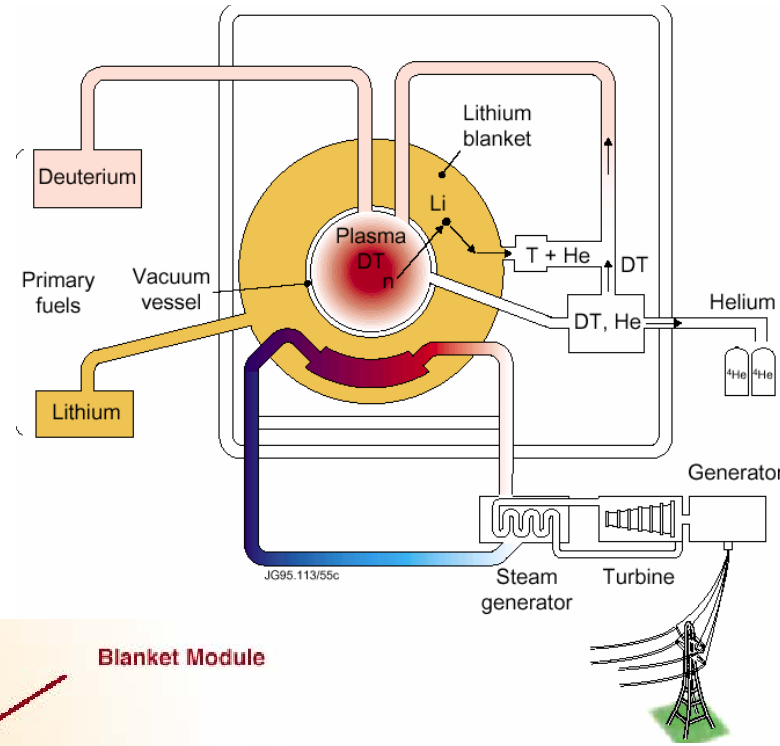


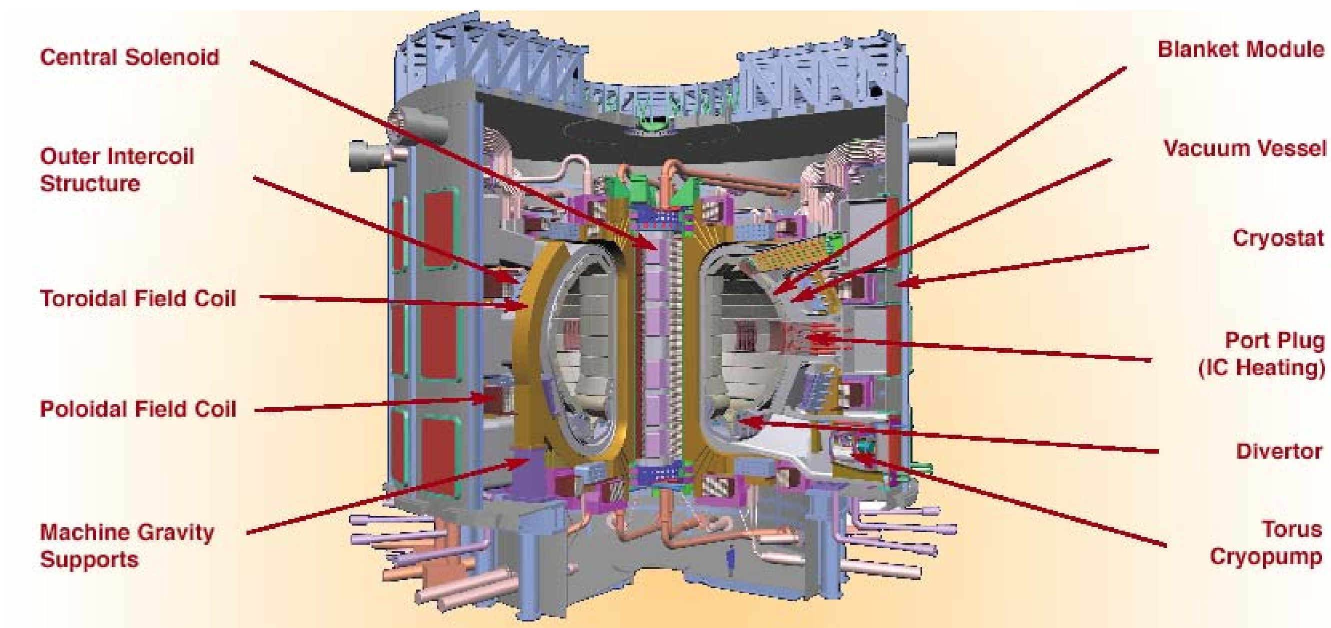
$$\tau_{th,98y2} = 0.0562\, I_p^{0.93} B_t^{0.15} n_{19}^{0.41} P_l^{-0.69} R^{1.97} \varepsilon^{0.58} \kappa^{0.78} \mu^{0.19} \sim \frac{a^2 B_t}{T} \cdot \frac{1}{\rho_*^{0.7} \beta^{0.9} \nu_*^{0.01}}$$

integrated modelling of fusion plasmas: the vision

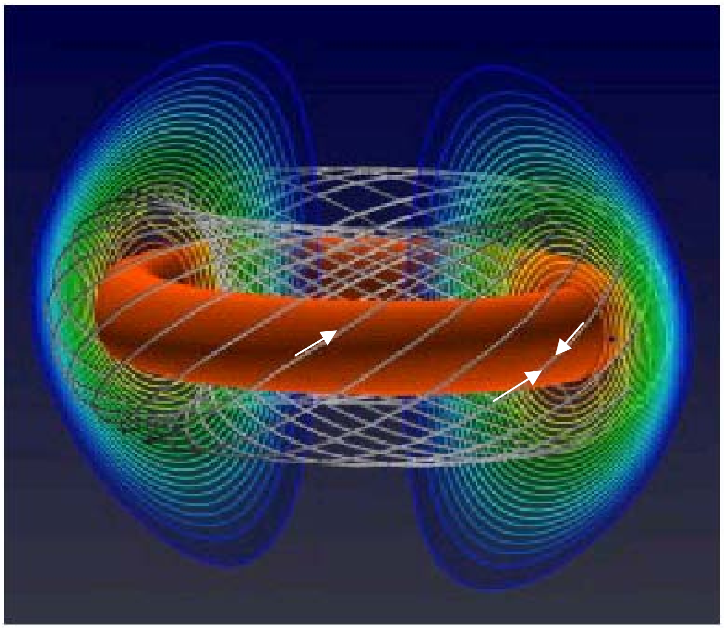


the PLASMA: the core and the innovative subsystem of a Fusion Power Plant





toroidally confined high-temperature plasmas



$$\beta = \frac{p}{B_p^{\,2}/2\mu_o} \approx O(1) \Rightarrow \textit{strong effect on field topol.}$$

$$\nu^* = \frac{2\pi R}{\lambda_{90^o}} << 1 \Rightarrow \textit{kinetic description}$$

$$\rho_i \leq \Delta x_j \leq a \;\Rightarrow \textit{to be resolved}$$

$$\chi_{//} / \chi_\perp > 10^{10} \Rightarrow \textit{heat flux pollution}$$

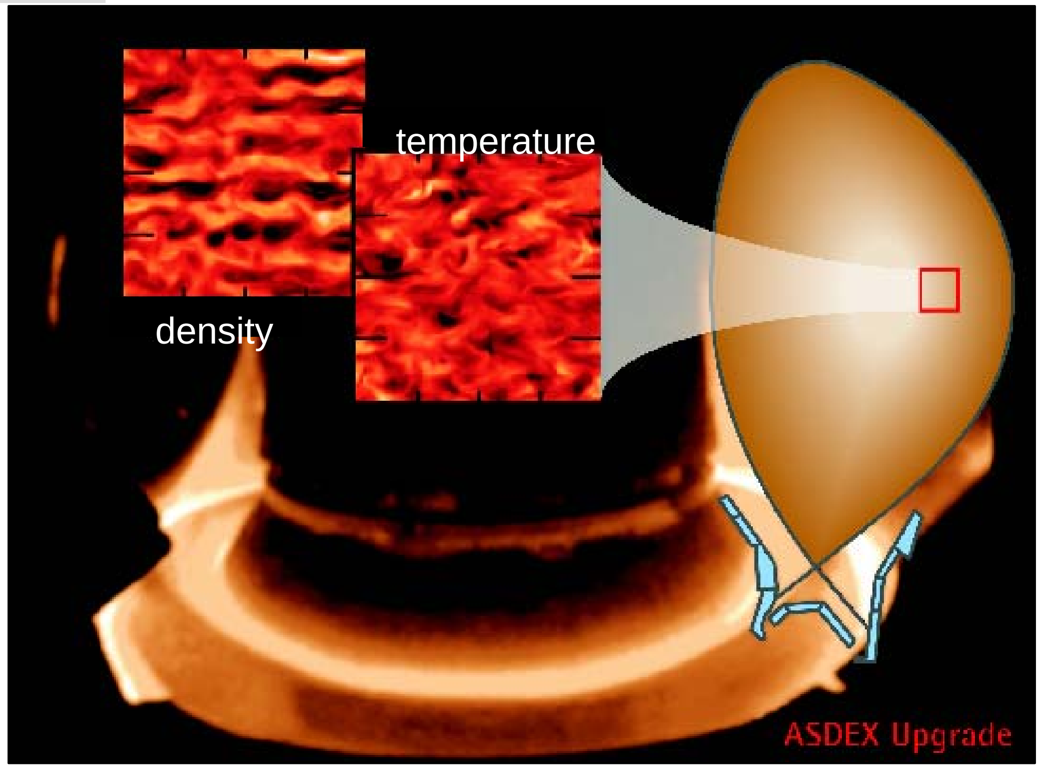
kinetic description in 6 d : Fokker - Planck + Maxwell equs.

$$\frac{\partial f_\alpha}{\partial t} + \vec{v} \cdot \nabla_r f_\alpha + \frac{q_\alpha}{m_\alpha}\left(\vec{E} + \vec{v} \times \vec{B}\right) \cdot \nabla_v f_\alpha = \left(\frac{\partial f_\alpha}{\partial t}\right)_{coll.}$$

Simulating Turbulent Transport

Full scale ab-initio modelling of total plasma, including all relevant time/space scales

- •realistic mid term prospect
- •necessity for describing system component *"Plasma"* of a fusion reactor with engineering level confidence



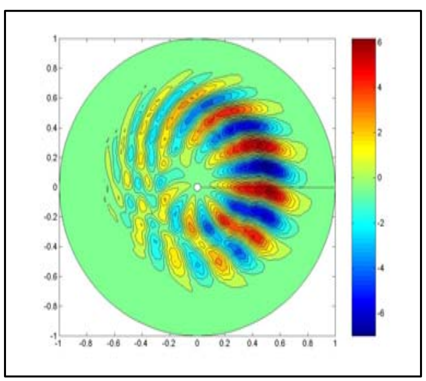
Ultimately required

spatial scale range: ρ_i <–> a

•a few 100 to 1000

time scale range: $L_\perp/c_s$ <–>τ_E

•order a few million



modelling turbulence

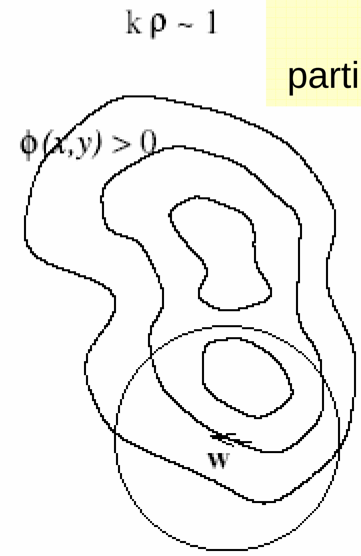
Complexity of problem

ambition of aim (quantitative instead of qualtiative) results

difficulty to verify intermediate results experimentally

justify:

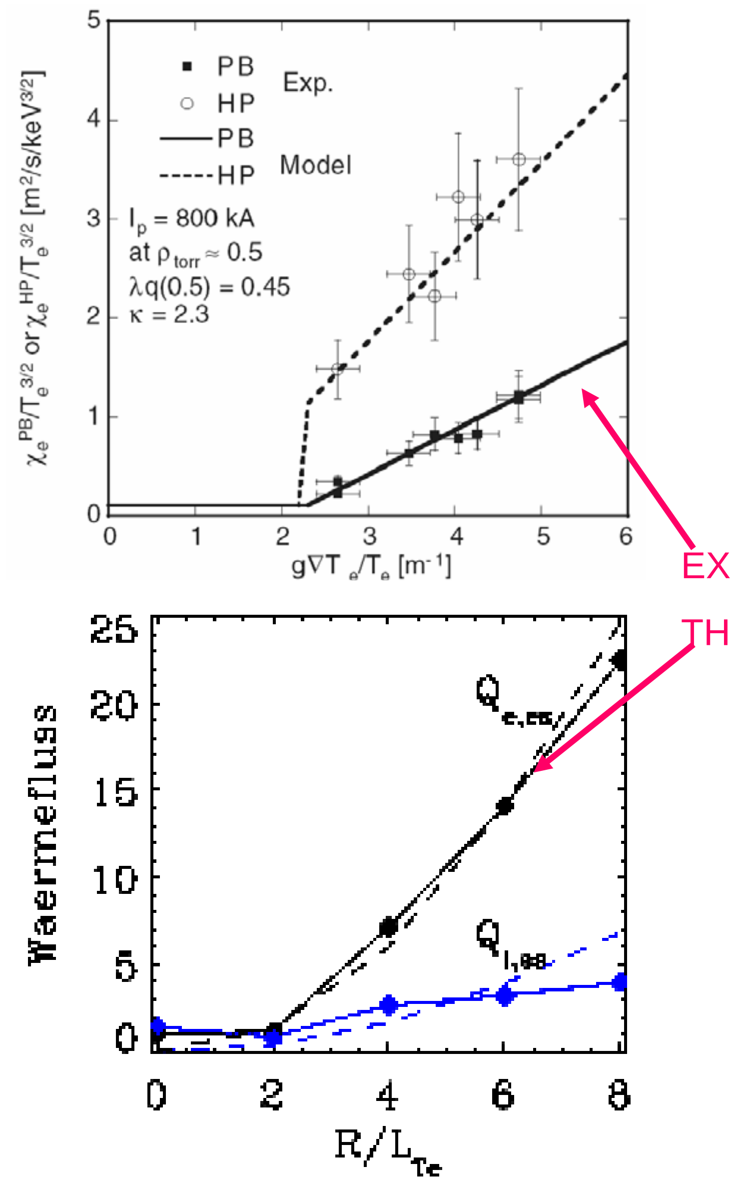
- multiple models
- parallel (competing) developments within given model



Gyrokinetics:
particle = ring of charge

- fluid: simple, link to homogeneous turbulence work
- gyrofluid: effort 1 - 2 orders magnitude reduced (results 3 - 6 years earlier)
- gyrokinetic: the most consistent model
  - continuum (a.k.a. Vlasov, Eulerian) models: ultimately best convergence properties
  - PIC: effective mix of velocity and space-space, adapted to parallel computers

gyrokinetic GENE Code:



ab-initio turbulence modelling codes give quantitative agreement with (as yet) selected experimental results

further increase in code applicability

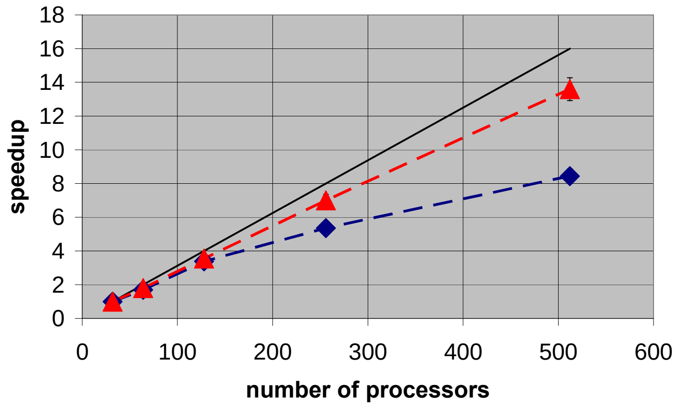
- more detailled physics,
- larger computational domain/non-local effects
- larger devices (bigger scale range)

connected to use of more processors ↔ hyperscaling

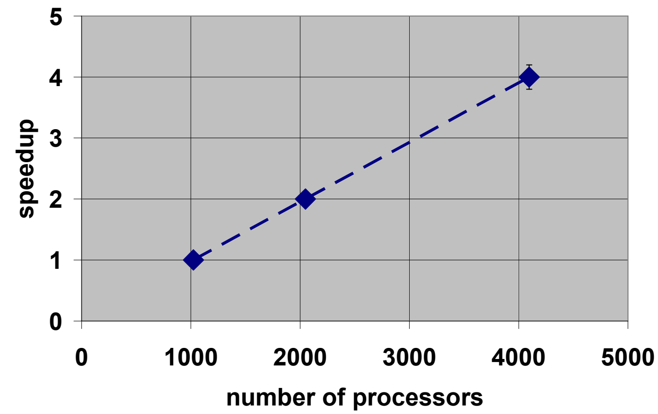
hyperscaling:

6-dimensions (species + 3 space coord. + 2 velocity coord., e.g. 2 x 128 x 128 x 128 x 8 x 32) available for parallelisation

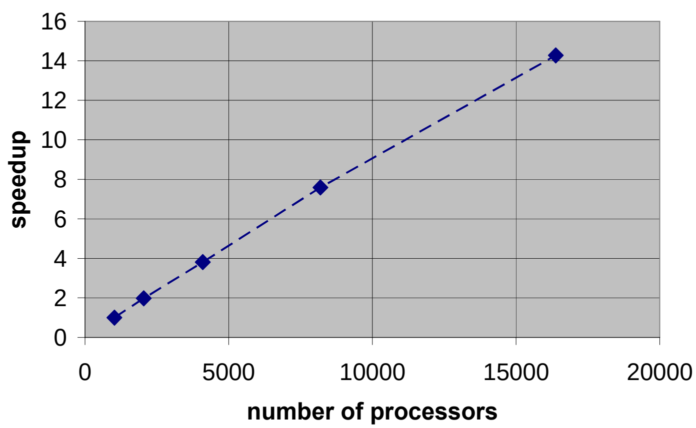
hyperscaling of plasma turbulence codes (GENE)



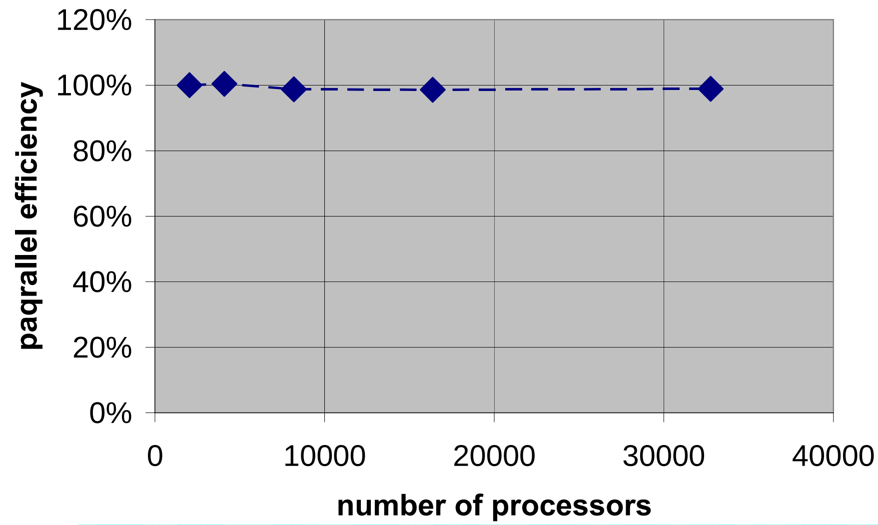
strong scaling of GENEv9 and v10 on IBM p690@1.3 GHz



strong scaling of GENEv10 on Cray XT3 at ORNL

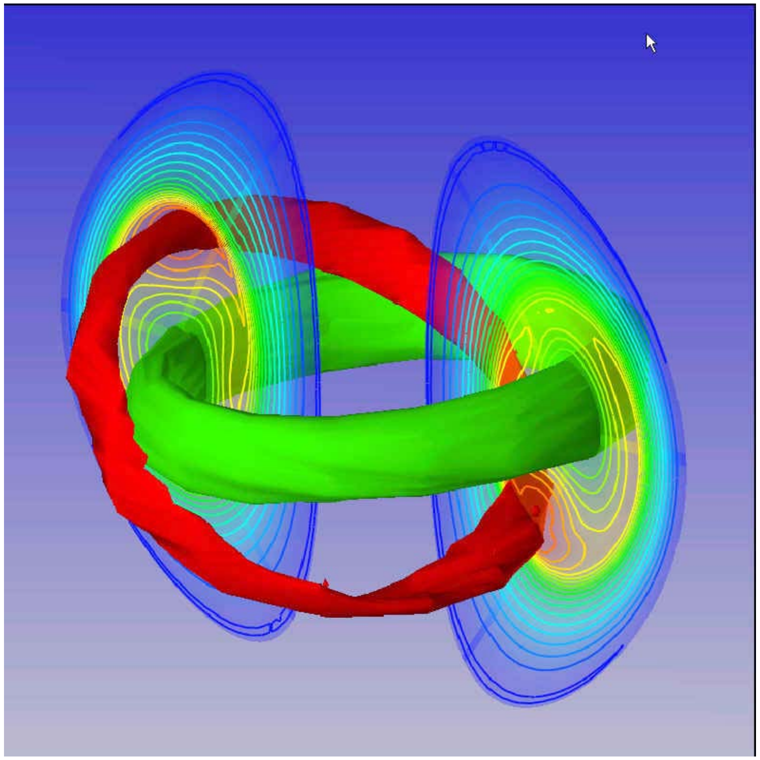


strong scaling of GENEv11+ on Blue Gene /L at IBM Watson Research Center; *measurements in co-processor mode*

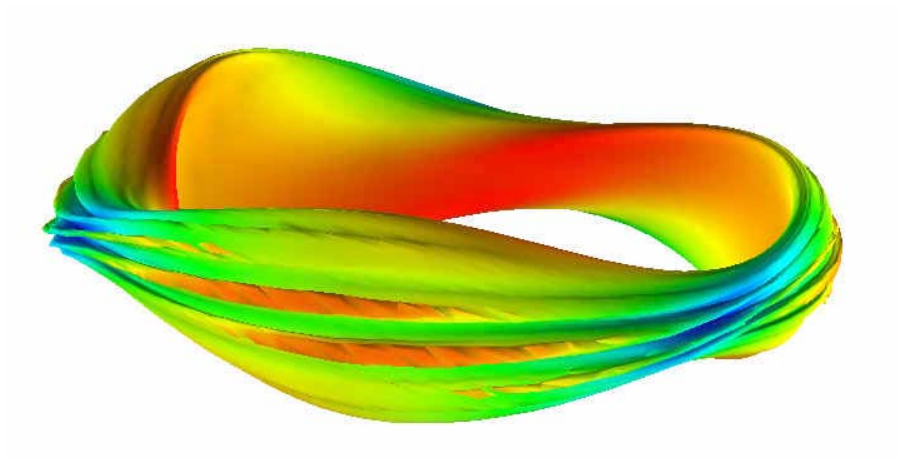


weak scaling of GENEv11+ on Blue Gene /L at IBM Watson Research Center; *measurements in virtual node mode*

macroscopic plasma deformation (linear & nonlinear MHD instabilities)



Sawtooth in NSTX computed by M3D



Stellarator ballooning mode computed by M3D

HPC plans of the EU Fusion Community

	the projected *) needs	**existing comitments**	**proposals for filling the gaps**
	flux-tube on ASDEX-Up. 10ns – several ms sev. Tf/s for 1d	case-by case access to HPCs through associations	
2007	full torus AUG or segment JET 10ns – 100 ms 50 Tf/s for 1d – 1w		
2010	up to full torus ITER 10 ns – few s. 5 Pf/s for 1d – 1w		dedicated EU fusion HPC ~100Tf/s
2013		dedicated HPC in EU-JA Fusion Simulation Centre (“broader approach initiative”) > 2 Pf/s	

***) “production – not demonstration runs”;**
example: gyrokinetic turbulence simulation