



EFDA

EUROPEAN FUSION DEVELOPMENT AGREEMENT

Task Force
INTEGRATED TOKAMAK MODELLING

35th EPS Plasma Physics Conference

Hersonissos, Crete 9 -13 june 2008

The European turbulence code cross-verification effort : turbulence driven by thermal gradients in magnetically confined plasmas

presented by G. Falchetto - CEA
on behalf of EFDA-TF-ITM-IMP#4

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- The Integrated Modelling Project IMP#4 on Transport processes and Micro-stability
- Cross-verification of EU turbulence codes
 - illustration of the available numerical models and main physical contents
 - definition of physically relevant test cases for both **local** and **global** codes, in **core** and **edge**
 - simulation results and discussion
 - core ion temperature gradient driven turbulence
 - adiabatic case
 - electromagnetic case
 - edge L-mode turbulence
 - **diagnostics on turbulence structure**
- Conclusions

ITM - Transport processes and Microstability Project

IMP#4 linear stability - neoclassical transport - turbulence

Objective: develop physics-based models for neoclassical and turbulent transport coefficients in all 3 plasma regions (core, pedestal, SOL)

Actual tasks (involve 11 EU Associations) :

T1 - Code Catalogue: 15 EU codes (june 2008)

T2 - Cross-Verification of turbulence codes

very uneven standards of present turbulence computational models →
cross-verification on non-trivial standard cases relevant to experiment
prerequisite to validation on experimental shots

T3 - Assess physics needs to treat ITER transport mechanisms

evolving documentation of physics and numerical standards

outstanding issues: - consistent gyrokinetic formulation including equilibrium
- zonal flow dynamics and saturation
- implementation of X-point geometry

ITM infrastructure database support essential to carry out the tasks

Participating EU turbulence codes

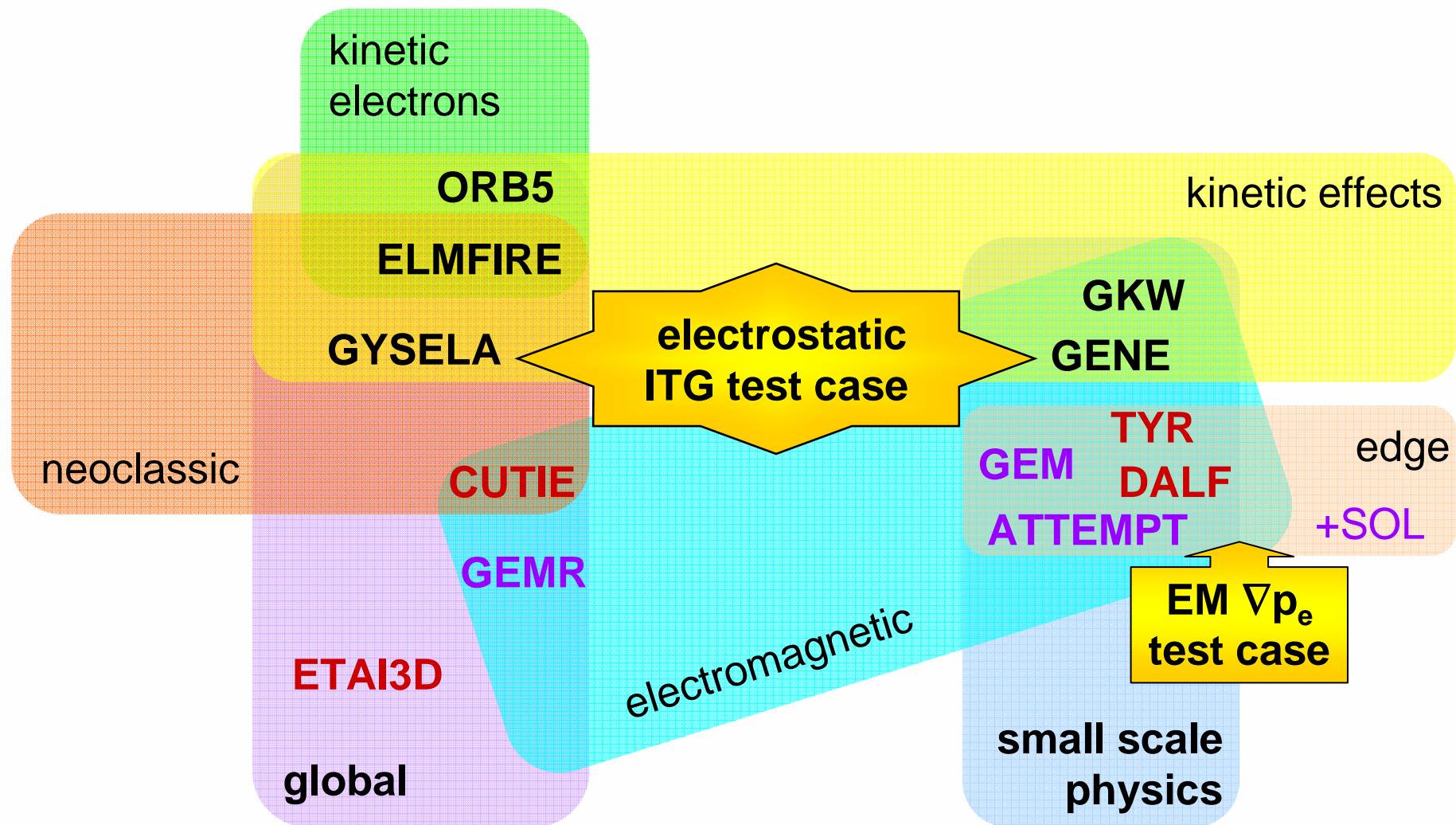
GYROKINETIC CORE CODES				
GENE IPP	GKW Warwick	ORB5 CRPP	GYSELA CEA	ELMFIRE TEKES

GYROFLUID CORE	FLUID CORE
ETAI3D CEA	CUTIE UKAEA

GYROFLUID CORE & EDGE
GEM/GEMR IPP

FLUID EDGE CODES		
ATTEMPT FZJ	TYR RISØ	DALF IPP

European 3D turbulence codes

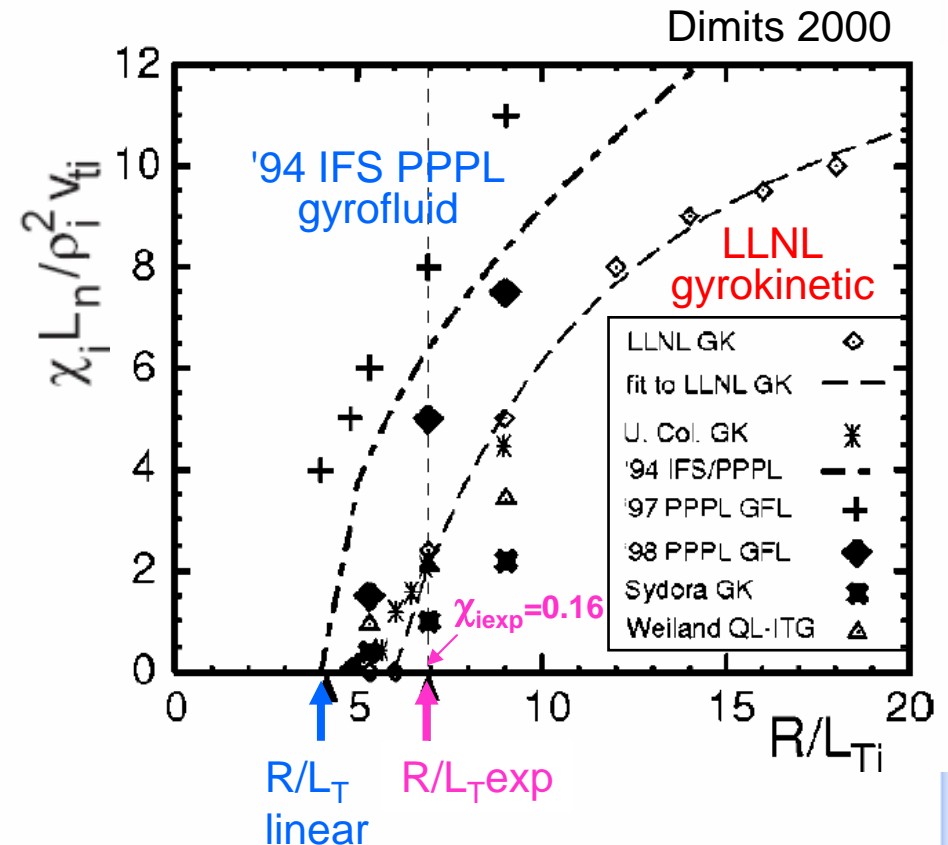


Core turbulence test case specifications

- Core turbulence
wide variety of state-of-the-art computational models benchmarked against pure ITG turbulence "CYCLONE base case"

DIII-D shot #81499 t=4 s. r/a=0.5	
$n_e (m^{-3})$	$4.5 \cdot 10^{19}$
$T_e=T_i (eV)$	$2 \cdot 10^3$
$B (T)$	1.91
$a (m)$	0.625
$R (m)$	1.7
R/L_T	6.91
L_T/L_n	0.321
q	1.4
s	0.78

$$\rho^* = \rho_s / a = 1/184.7$$

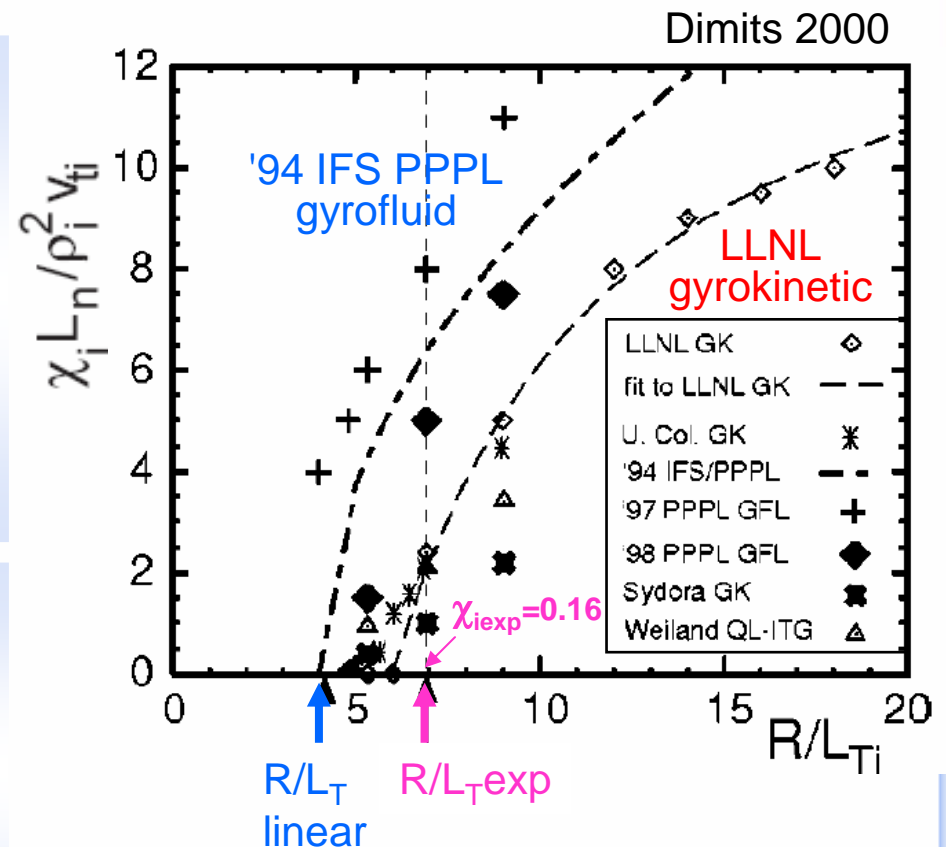


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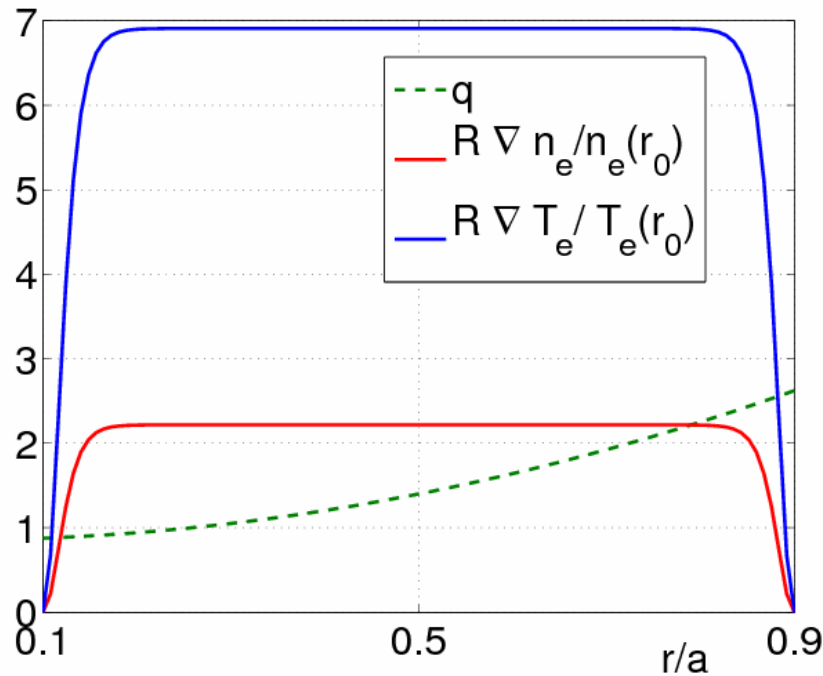
- ✓ beyond local models with fixed ∇T
- ✓ *full-f* gyrokinetic models
- ✓ global models evolving profiles
 - ➔ common prescribed global profiles
 - ➔ no sources ➔ profile relaxation
- ✓ beyond local transport coefficient vs ∇T
 - ➔ diagnostics on turbulence structure

- self-consistency of equilibrium
- numerical noise & energy conservation
- dissipation in collisionless models
- saturation / zonal flows
- ! most not known at time of first US benchmarking effort (2000)



Core test case specifications

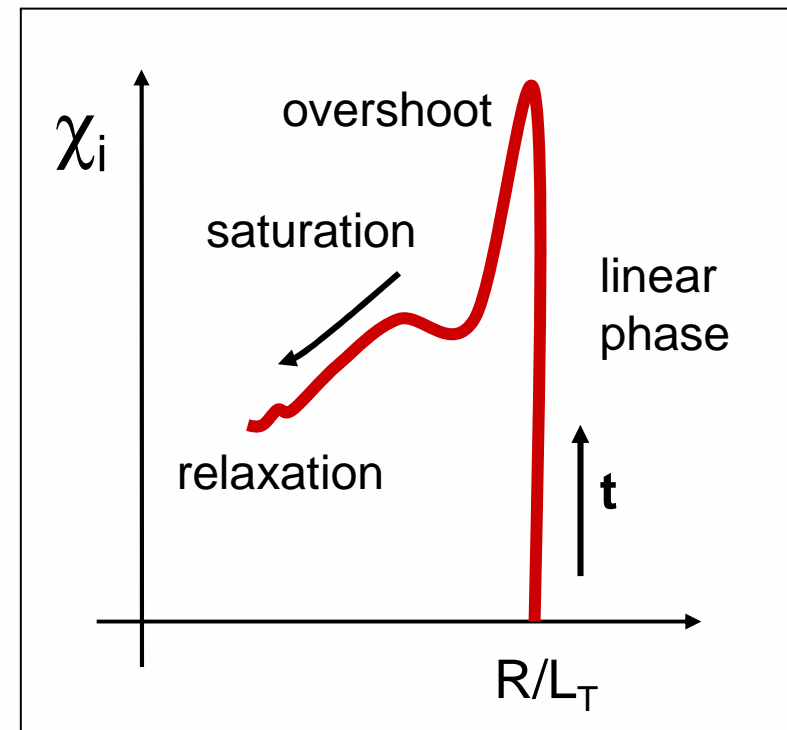
Global prescribed profiles



- nominal $\rho^* = 1/184.7$
- circular surface geometry
- adiabatic electrons
- no collisions
- no sources

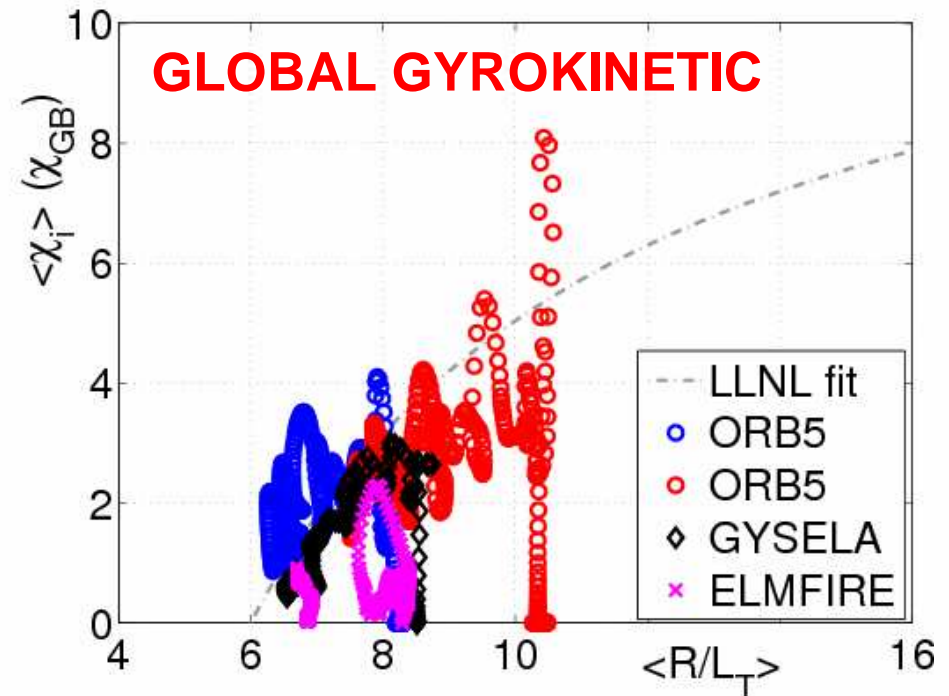
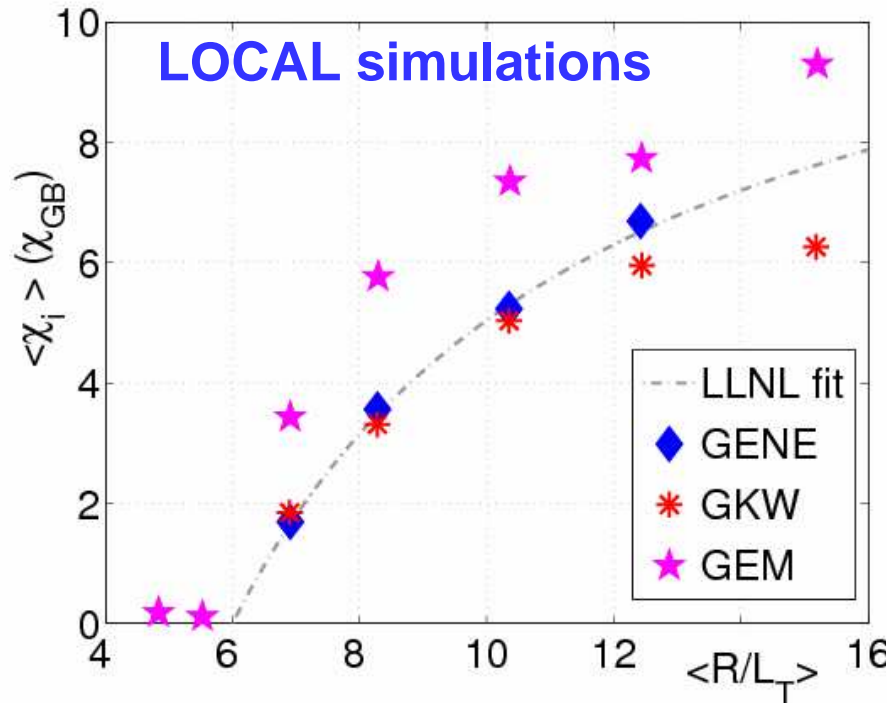
Temperature profile relaxation

transport curve in decay simulation



- volume averaged diffusivity:
 - outer $3/4$ radial domain

Core test case (1) adiabatic : ion heat diffusivity

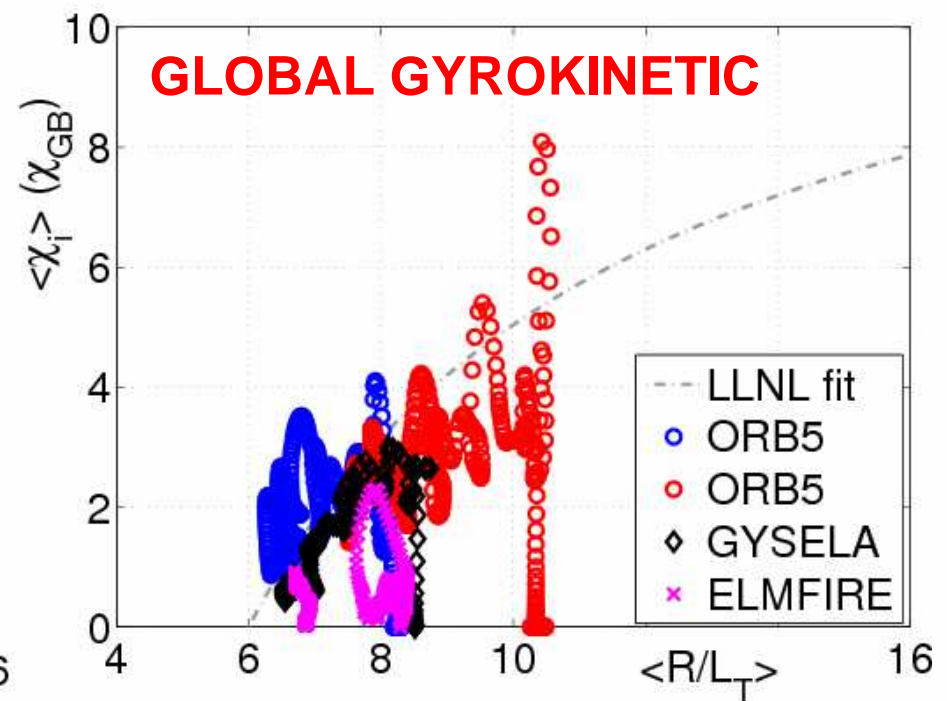
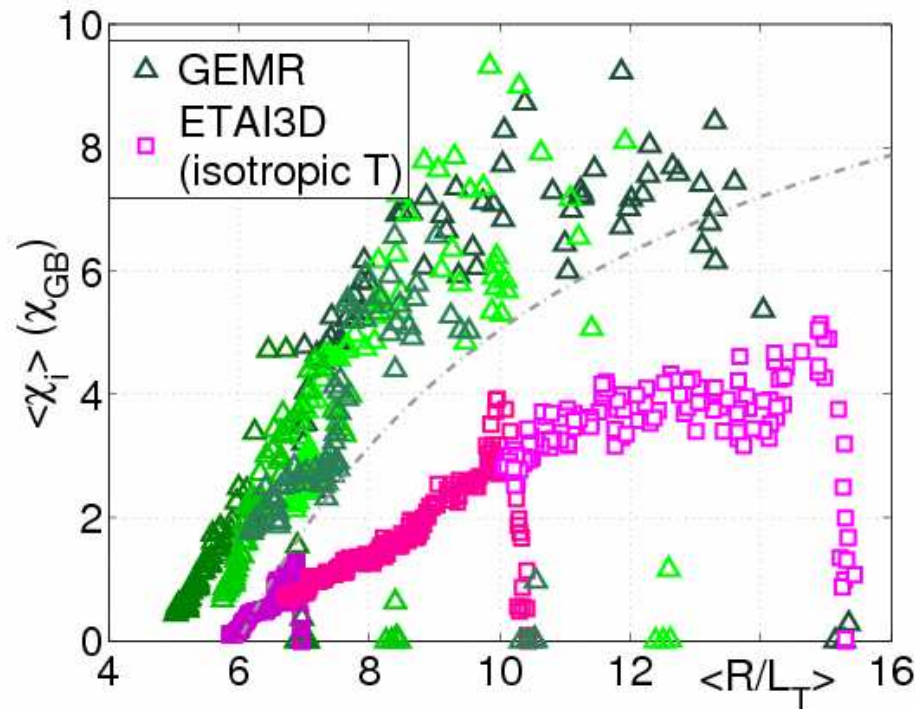


- ✓ local flux-tube models perfectly agree with LLNL local PIC code fit
- ✓ global gyrokinetic codes in good agreement among each other & on local gyrokinetic threshold
- ✓ ion heat diffusivity from gyrofluid runs reproduces variability of global gyrokinetic runs

$$\chi_{GB} = \rho_s^2 c_s / a$$

Core test case (1) adiabatic : ion heat diffusivity

GLOBAL GYROFLUID

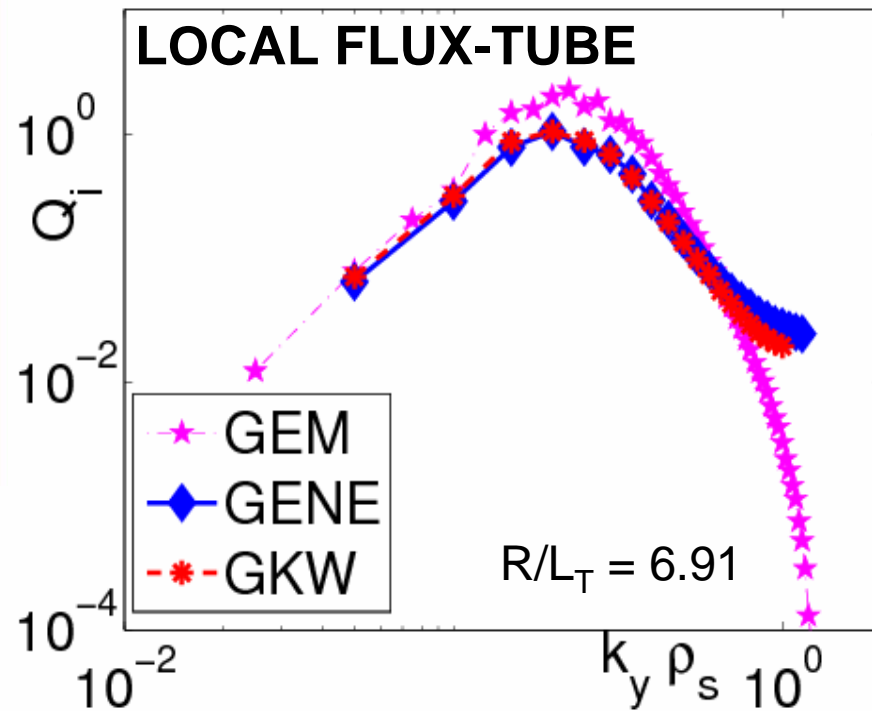


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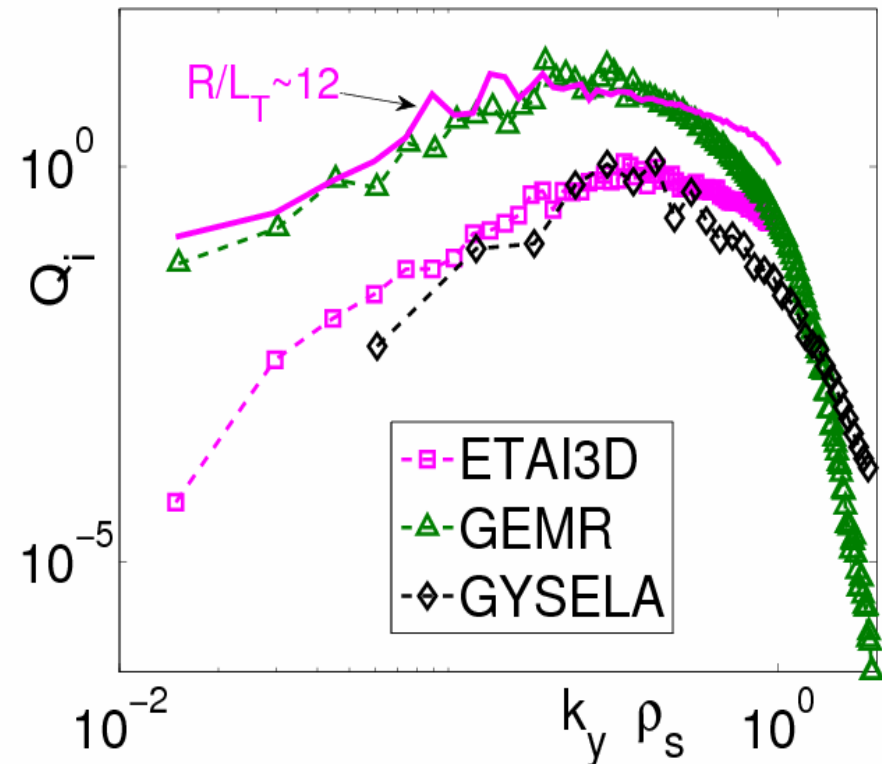
$$\chi_{GB} = \rho_s^2 c_s / a$$

Core test case adiabatic : ion heat flux spectra

GLOBAL



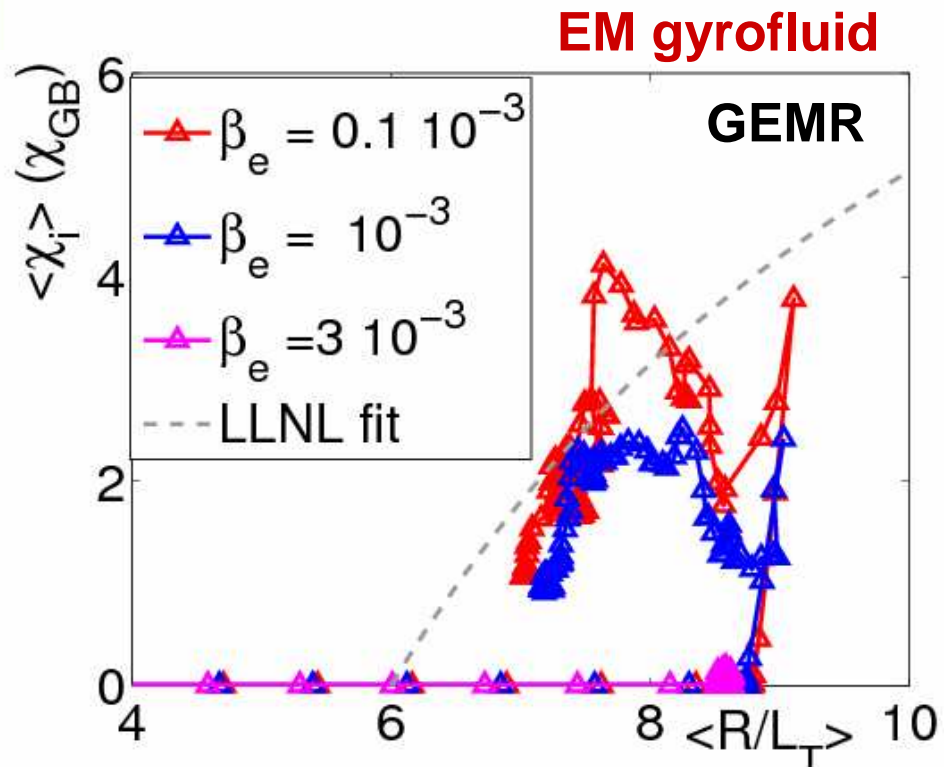
- local flux-tube codes
close spectra up to high k_y



- evidence of non-linear cascade:
downshift of peak for stronger
turbulence (higher R/L_T)
- **discrepancy in steepness**

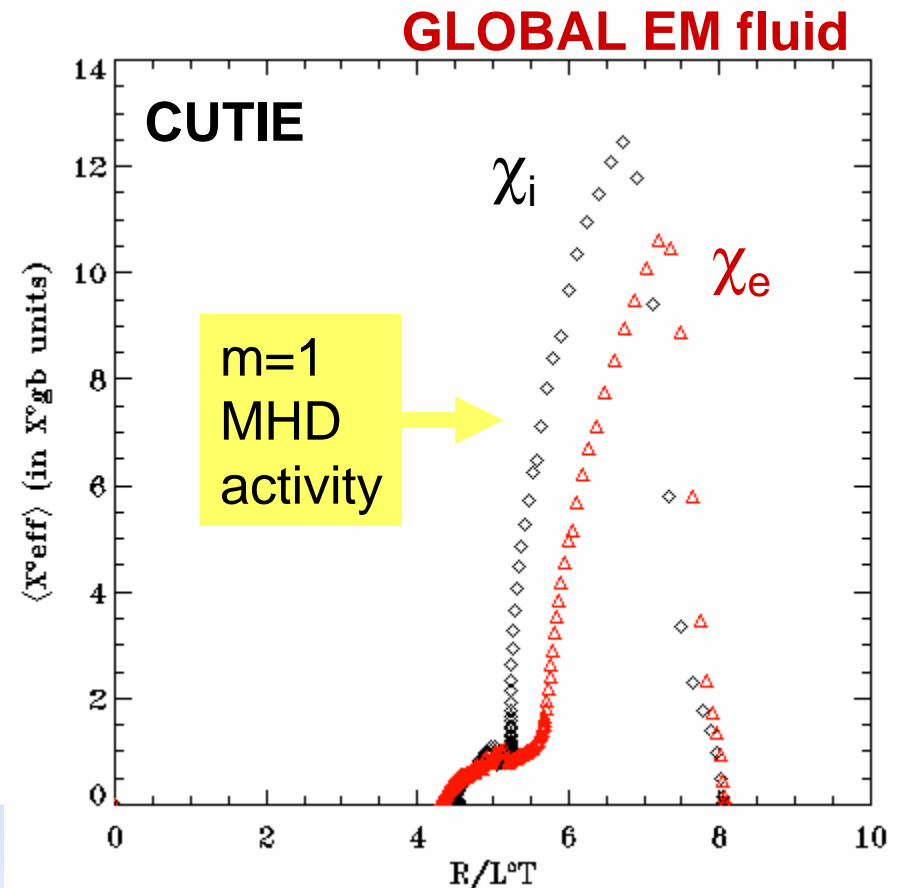
Core test case (2): EM simulations

- set-up of EM simulation essential to turbulence saturation mechanism and transport level prediction



! tearing mode switched off

- strong conductivity drop for $\beta_e > 10^{-3}$
- KBM appears @ β_e nominal value



! ($m=0, n \neq 0$) & ($n=0, m \neq 0$)
couplings not included

Core test case results: summary

- **ITG turbulence test case with adiabatic electrons**
 - ✓ reasonable agreement of transport predictions among gyrofluid and gyrokinetic codes
 - ! gyrofluid simulations would fail in trapped electron regime
 - ✓ comparisons of turbulence structure
 - ✓ reasonable agreement
 - ✓ measuring differences → basis for future advances
 - validation on experimental data
 - ! collisionless global gyrokinetic models :
 - ✓ coupling of fluctuations and equilibrium essential to dynamics
 - ! dissipation less in absence of collisions
- electromagnetic (gyro)fluid test case
 - ! critical since chosen profile $q(0) < 1$
 - ! not comparable simulations → future test case with exp q profile
 - electromagnetic gyrokinetic test lies in future

Edge turbulence test case specifications

- Edge turbulence

electromagnetic 4-field (gyro)fluid models mutually validated on generic medium tokamak edge L-mode test case

sweeping a wide range of collisionality ν_e and β_e values

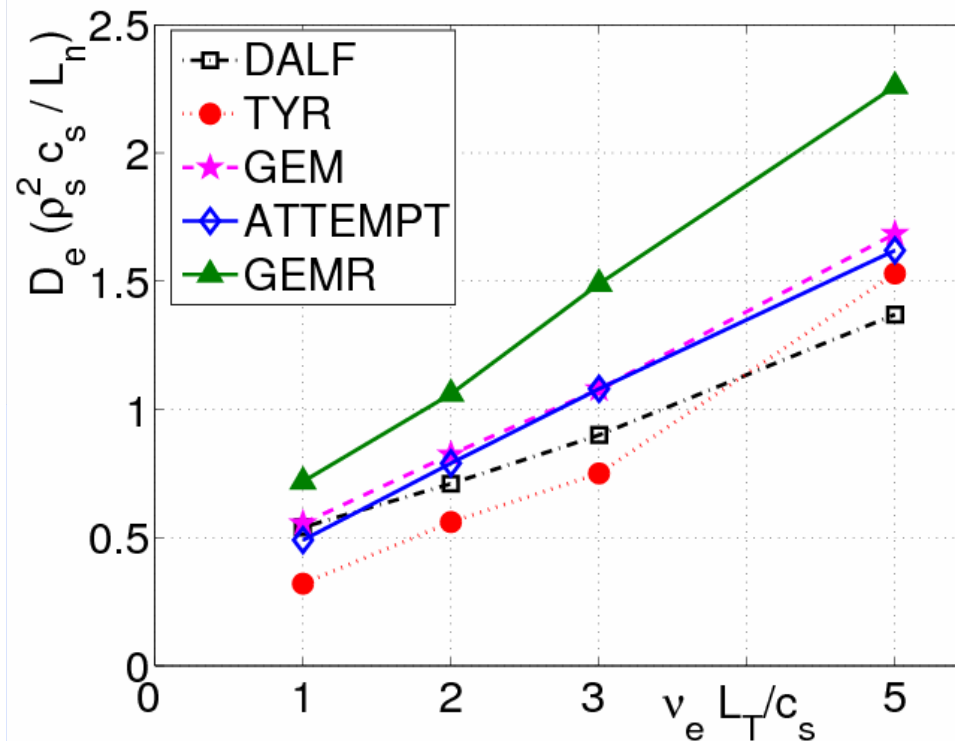
L-mode edge parameters	
$n_e \text{ (m}^{-3}\text{)}$	$2 \cdot 10^{19}$
$T_e \text{ (eV)}$	70
$B \text{ (T)}$	2
$a \text{ (m)}$	0.5
$R \text{ (m)}$	1.65
$R/L_T = R/L_n$	40
q	3.5
s	1

edge regime dimensionless parameters
$\hat{\mu} \equiv (m_e/m_i) (qR/L_T)^2 = 5$
$\hat{\beta} \equiv \beta_e (qR/L_T) = 2$
$C \equiv 0.51 \nu_e (L_T/c_s) \hat{\mu} = 7.65$

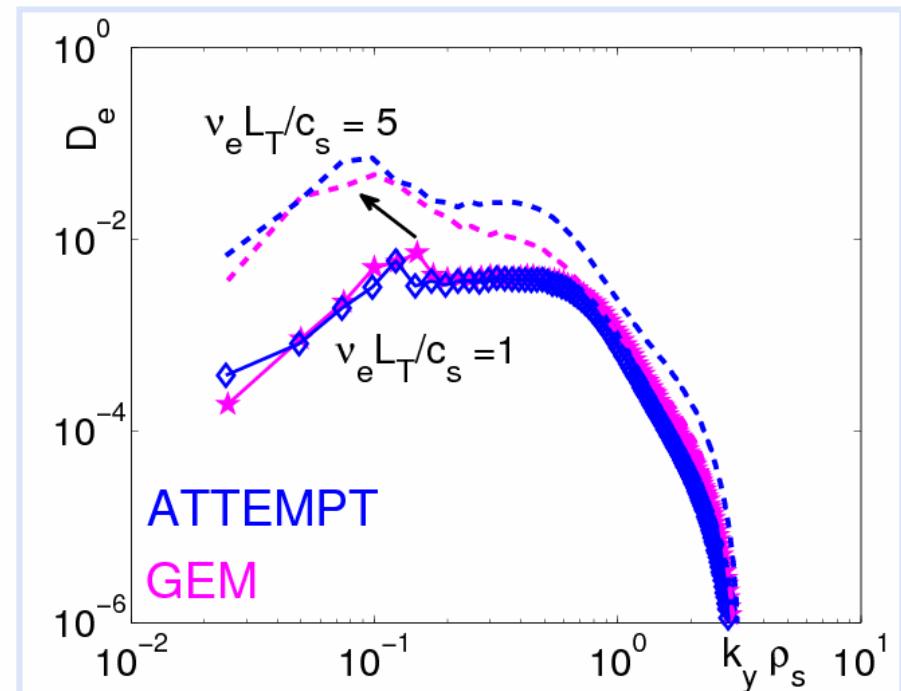
- circular surface geometry
- feedback control of profiles

Edge test case : particle transport vs. collisionality

- v_e scan @ fixed $\beta_e(qR/L_T) = 1$



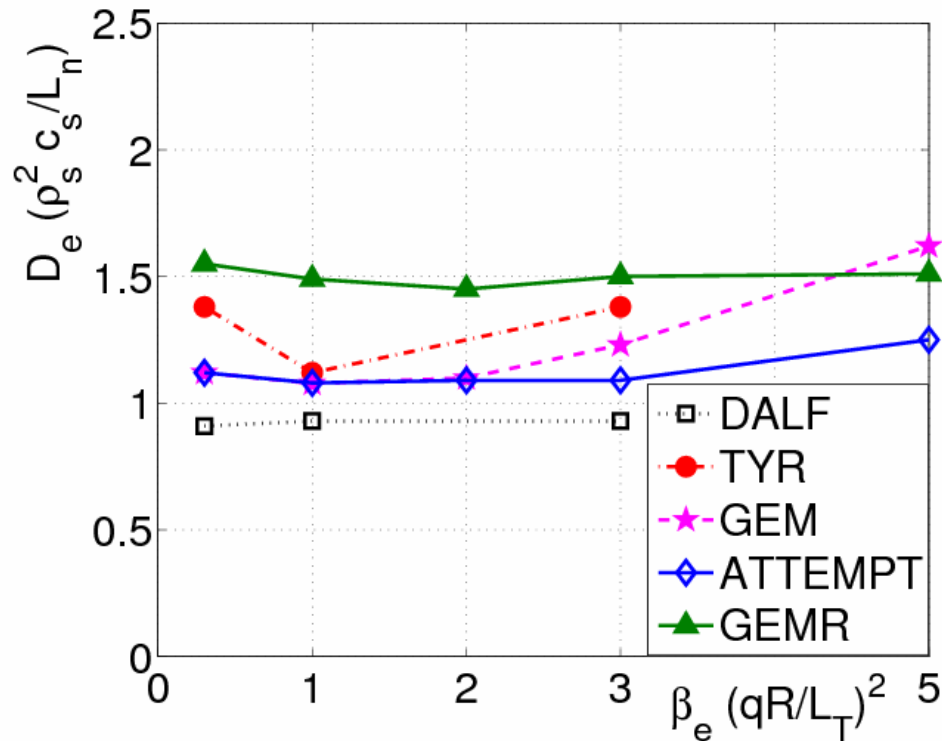
All codes agree in trend:
 increased electron particle diffusivity
 with increased collisionality



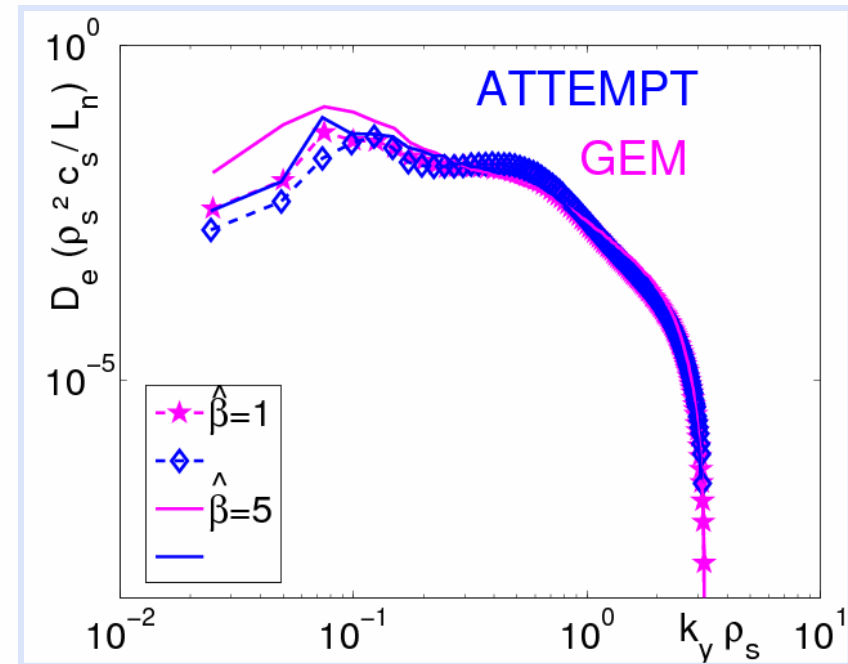
- non-linear cascade:
downshift of peak for higher v
(higher diffusivity)

Edge test case : particle transport vs. beta

- β scan @ fixed collisionality ($\nu_e L_T / c_s$) = 3



very low variation with beta
of electron particle diffusivity



- All codes also benchmarked
- ✓ D_e timetraces
 - ✓ fluctuation spectra & timetraces
 - ✓ poloidal envelopes
 - ✓ x profiles

Conclusions and perspectives

- Cross-verification of a **variety of turbulence codes** on **prescribed common global test cases** for **core** and **edge** tokamak plasma
- ➔ prerequisite to validation on experimental data
 - ➔ define numerical standards / exclude non-physical results
 - ➔ gain higher degree of confidence on transport predictions
 - ✓ consistent transport predictions among all codes for core and edge
 - ✓ verification on turbulence structure
 - ✓ good agreement among edge codes
 - ✓ differences open the way to future advances

Open questions and future issues to be addressed in IMP4:

- self-consistent neoclassical equilibrium
- gyrokinetic electromagnetic simulations
- trapped electrons / X-point geometry / ...more...

- P1.017 A. Casati *CEA* *QuaLiKiz* *GYSELA*
 - *Towards an improved first principle based transport model*
- P1.019 B.F. McMillan *CRPP* *ORB5*
 - *Avalanche-like bursts in global gyrokinetic simulations*
- P1.038 M.J. Pueschel *IPP*
 - *GENE simulations on the beta dependence of tokamak core turbulence*
- O4.047 A.G. Peeters *GKW* *Warwick Univ.* Thursday 12 @ 11h40
 - *The Coriolis drift effect*
- P4.033 P. Angelino *CEA* *ORB5* (*CRPP*)
 - *Effects of plasma current on drift wave-zonal flow turbulence*
- P4.045 S. Janhunen *TEKES*
 - *Transport dynamics of the Cyclone Base case on ELMFIRE*
- P5.030 B.D. Scott *IPP* *FEFI*
 - *Fully Nonlinear Electromagnetic Gyrokinetic Computations*
- P5.039 T.T. Ribeiro, B. Scott *IPP* *GEM GEMR*
 - *Drift wave vs. interchange turbulence geometrical effects on the ballooning threshold*

Core turbulence codes

GYROKINETIC					(GYRO)FLUID		
GENE IPP	GKW Warwick	ORB5 CRPP	GYSELA CEA	ELMFIRE TEKE	GEM/GEMR IPP	CUTIE UKAEA	ETAI3D CEA
δf Eulerian	δf Eulerian	δf -PIC	full-f semi- Lagrangian	full-f PIC	gyrofluid 6 moments	2-fluid Braginskji	gyrofluid 3-field isotropic
MHD equilibria	general geometry	MHD equilibria	circular concentric	field-aligned circular concentric	flux-tube / general geometry	circular concentric	
E.M. gyrokinetic electrons		E.S. kinetic trapped electrons	E.S. adiabatic electrons	E.S. drift-kinetic electrons	E.M. non-adiabatic electrons	E.M.	E.S. adiabatic electrons
collisions: pitch angle & energy scattering		collisionless		binary collision model			Landau damping closure
periodic BC		thermostatting	thermal bath	recycling outflowing particles	sources	sources	flux driven

! no complete overlap of this large number of codes

Edge turbulence codes

(Gyro)fluid electromagnetic flux-tube codes				
GEMR IPP	GEM IPP	ATTEMPT FZJ	TYR RISØ	DALF IPP
gyrofluid	gyrofluid	4-field fluid		
warm ions		cold ions		
global	local	local		
edge + SOL		edge + SOL (limiter)	edge	
high wavenumber subgrid dissipation				
feedback control of profiles				

! only 1 warm-ion model
 ! No edge PIC code available

Core test case

	L_x	L_y	L_s	N_x	N_y	N_s	$v_{\parallel max}$	μ_{max}	$N_{v\parallel}$	$N_{v\perp}$
GENE	$127\rho_s$	$126\rho_s$	$2\pi qR$	128	48	16	$\pm 3v_{th}$	$9\mu_{th}$	32	8
GKW	$128\rho_s$	$128\rho_s$	$2\pi qR$	83	21	16	$3 v_{th}$	$3 v_{th}$	32	8
GYSELA			$2\pi/4$	256	512	64	$\pm 6v_{th}$	$7\mu_{th}$	64	8
	N_{part}								Δm	
ORB5	$320M$		2π	128	512	256	$\pm 5v_{th}$	$\pm 5v_{th}$	5	
ELMFIRE	$450M$		2π	91	150	8				
GEM	$100\rho_s$	$251\rho_s$	$2\pi qR$	64	128	16				
ETAI3D				512	256	128				
CUTIE				100	128	32				

Edge test case

domain $20\pi\rho_s \times 80\pi\rho_s \times 2\pi qR$ in $\{x, y, \bar{s}\}$
 grid $64 \times 256 \times 16$