Particle Transport: Electric Field Effects and the Kernbichler/Nemov Technique

NCSX Project Meeting

January 11-12, 200

M. H. Redi

PPPL

L.P.Ku, R. B. White, M. C. Zarnstorff, Princeton Plasma Physics Lab
W. Kernbichler, Graz, Austria
S. Nemov, Ukraine

Outline

Electric Field Effects on Alpha Particles

*** Nuhrenberg Results for W7X Reactor**

*** ORBIT3D Results for W7X Reactor**

*** Conclusion - Expectations for QAS Reactor**

New Method of Particle Confinement Assessment

*** Nemov/Kernbichler Method**

*** Application to C10,C82,C93 and QAS2_40**

*** Comparison to other methods**

*** Conclusion**

- **Efforts have been made to verify improved reactor confinement with modest electric fields,**
  (Nuhrenberg Varenna '92)

  - **A -15kV electric field reduced collisional alpha transport to collisionless levels.**

- **Would apply the electric field improvement to studies of alpha particle confinement in reactor-scaled versions of the QAS designs**

- **This would be important to include in improved simulations of the TFTR confined alpha data and in future work on JET alpha simulations as well as improved ITER alpha simulations.**

  We find similar collisionless alpha losses
  - **However collisional losses are higher**
  - **No reduction in collisional losses with an electric field.**

***The simulations used a new fast Monte Carlo code, ORBIT3D, - 3D spline for speed, and**
- **simulates all alphas, both trapped and passing,**
- **with the sample size being 1000.**

*** W7X 3% beta case, run originally by Michael Drevlak.**
- **Beta was increased to 5% and the code used**
- **B=5T and R=10m and collision rates for slowing down and pitch angle scattering as in Varenna '92**
- **Initial alpha deposited at radius = 0.2a.**

- **After one slowing down time**
  - **the collisionless alpha particle loss fraction was 9%**
  - **the collisional particle loss was 21 +/-2%.**
  - **The energy loss fractions were 8% and 15%).**
- **Nuhrenberg found**
  - **collisionless particle loss 5-8% at 0.1 seconds,**
  - **collisional particle loss is ~10 +/-3%**
  - **7% collisional energy loss at one slowing down time.**

*** An electric field (+/-15keV) gave almost no change in the particle losses with ORBIT3D.**

- **The difference in the particle loss (about 2%) within the statistical error.**

*** ORBIT3D simulations may differ from Nuhrenberg simulations.**

1)ORBIT3D used a simple collision model, which approximated only the radially varying pitch angle scattering rate. ORBIT3D is being upgraded for the full NRL Formulary collision rates.

2) The magnetic configuration from the Drevlak VMEC run of 1995 (#3696) may not be as optimized as the Helias50B configuration used in the Varenna '92 paper.

- **It is hard to see how a field of 15kV can have such an effect on 3.5MeV alphas and how changes in the above can lead to Nuhrenberg's result.**

- **ORBIT3D simulations do not confirm that an electric field of the size expected will reduce alpha loss to tolerable levels.**

CONCLUSION:

If the electric field does not reduce collisional losses,

Stellarator reactors are still attractive, because of stability to disruptions, reduced needs for recirculating power and steady state operation features

Recognizing that alpha loss may be a more serious problem than estimated with collisionless losses,

methods to deal with such alpha losses need developing: alpha channelling, direct conversion, improved materials, etc

.

Collisionless α losses (Nührenberg)

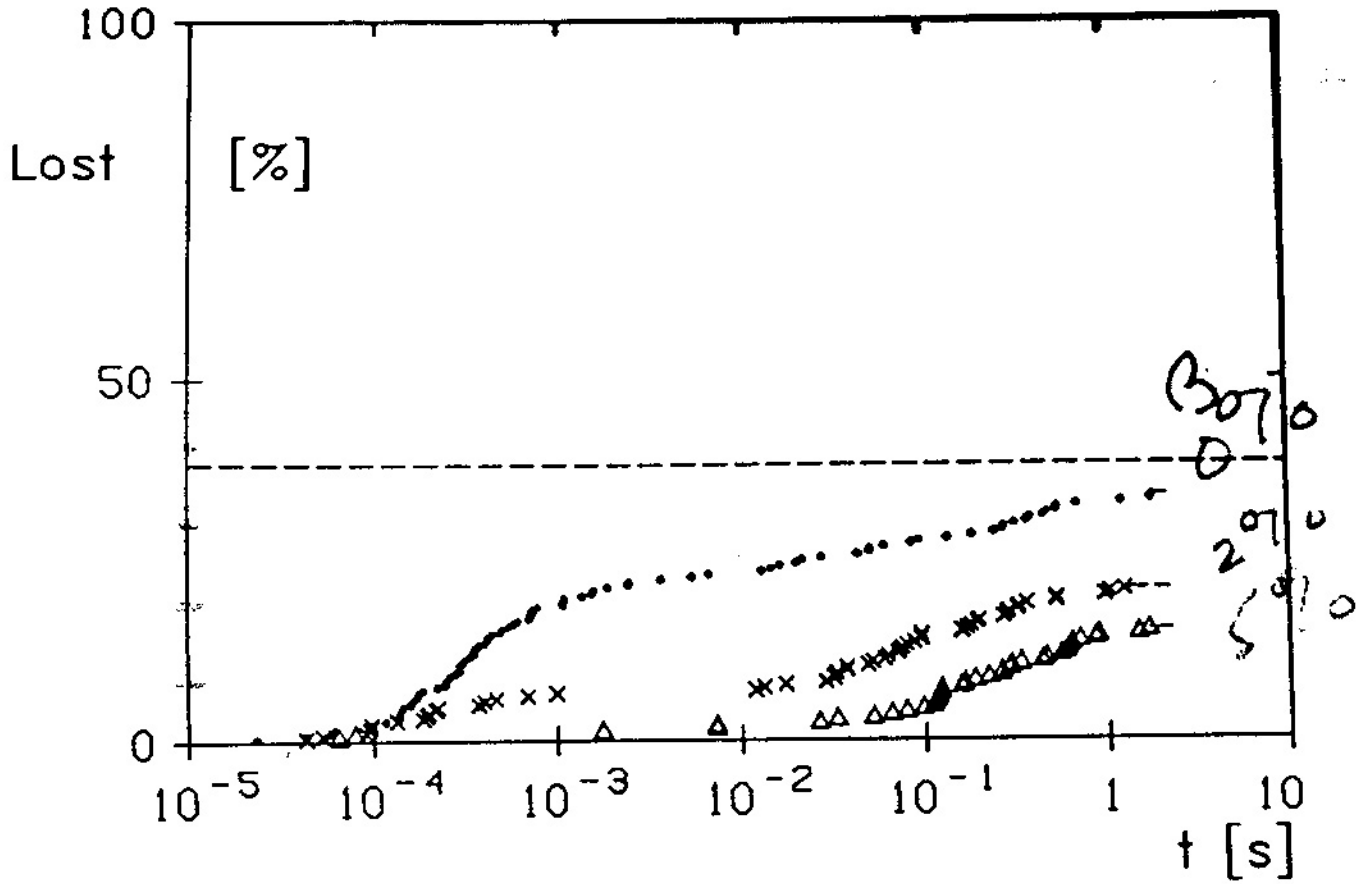


FIG. 6: α-particle losses in Helias50B (a configuration representing W7–X) for a radial α-distribution. $\langle\beta\rangle = 0$ (o), 0.024 (×), and 0.049 (Δ).

Collisional α Losses (Nuhrenberg)

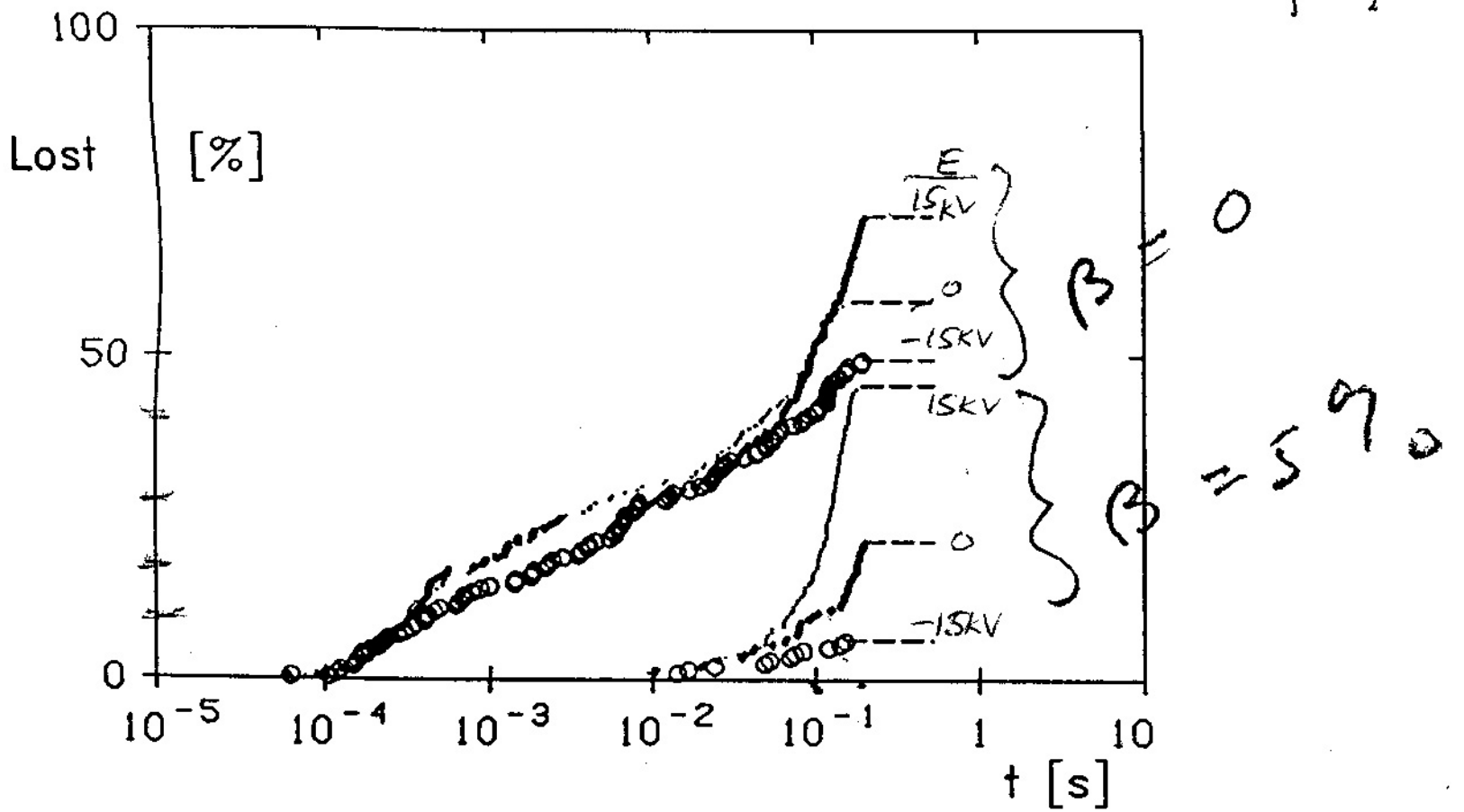
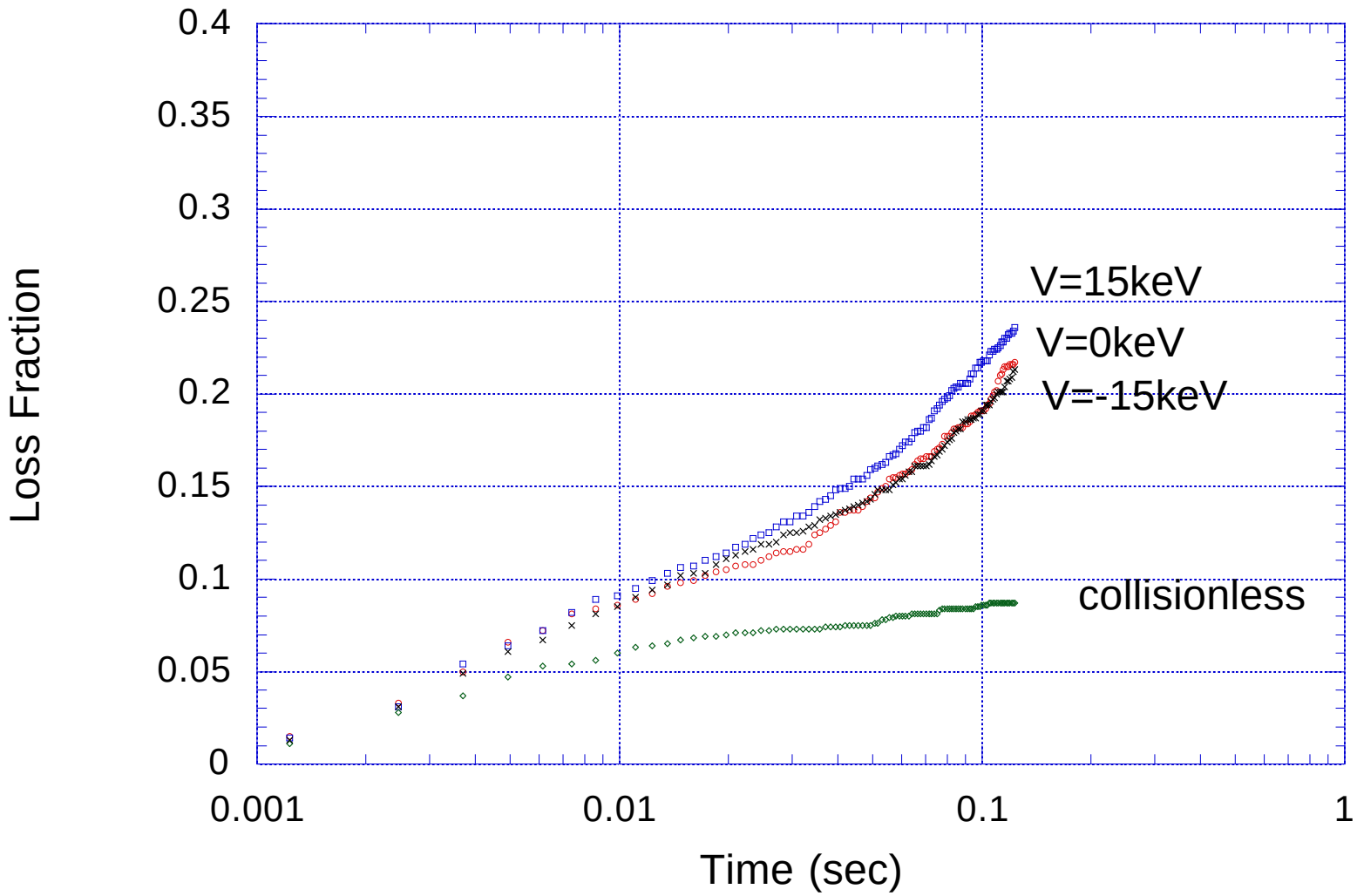


FIG. 9: α-particle losses in Helias50B ($\langle\beta\rangle = 0,\ 0.05$) for a radial α-distribution with slowing down and pitch-angle scattering. The complete samples (initially passing and reflected particles) comprise 200 particles. Three potentials, $\Phi_0 = 0,\ \pm 15$ kV, are considered. The upper three loss histories

Electric Field Effect on Collisional Alpha Loss Fraction from W7-X Reactor (ORBIT3D)



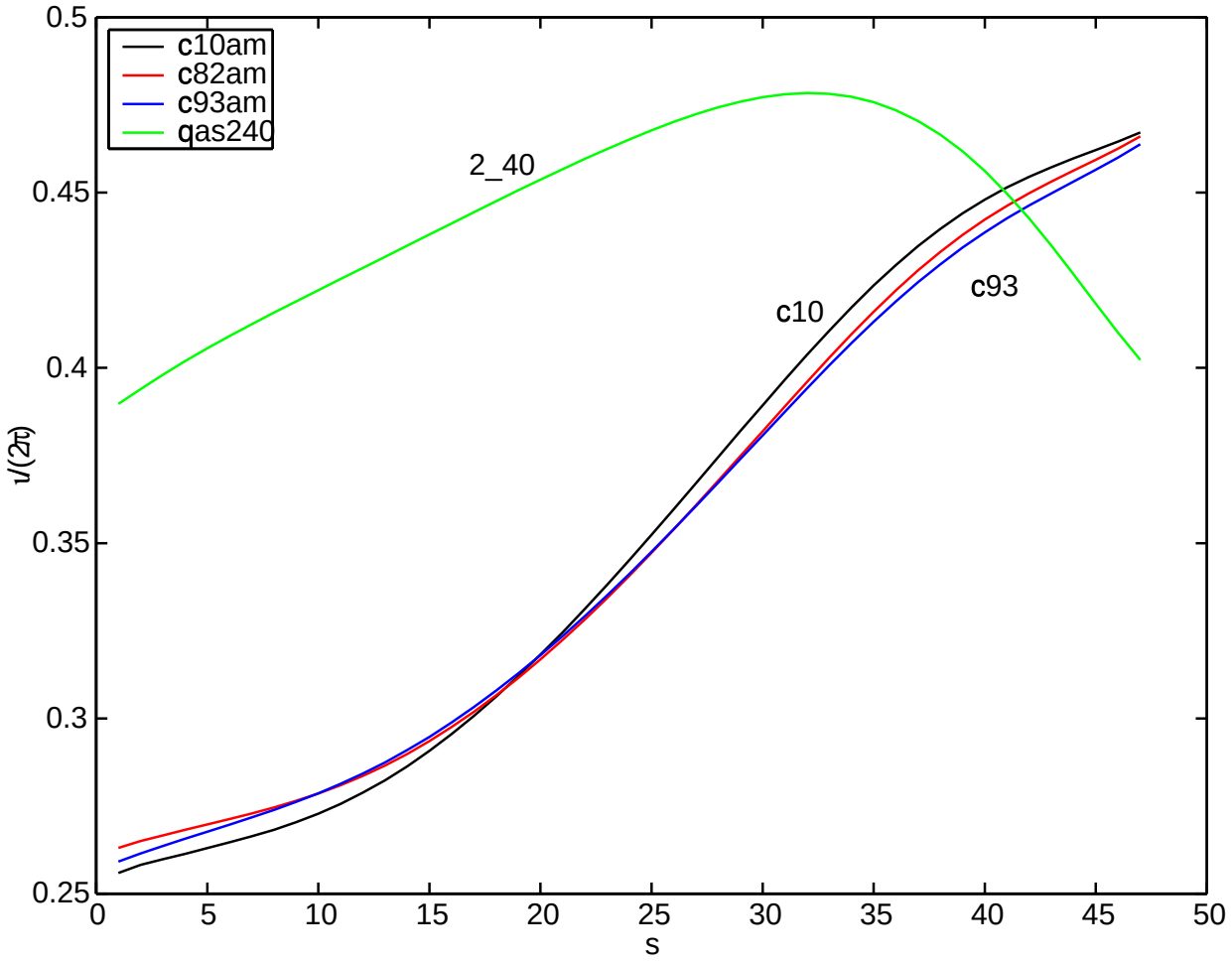
New Fast Technique for Evaluating QAS Thermal Particle Transport

* Kernbichler and Nemov (Austria and Ukraine)
  - Evaluate effective ripple, D for singly and multiply trapped ions
  - Only trapped ions and non-axisymmetric transport
  - Flux surface calculation time is 30 seconds per flux surface
  - 4 flux surfaces per configuration a good estimate possible
  - Radial profiles of effective ripple vary considerably among QAS
* Technique roughly agrees

  with C82 worse than C10 and that

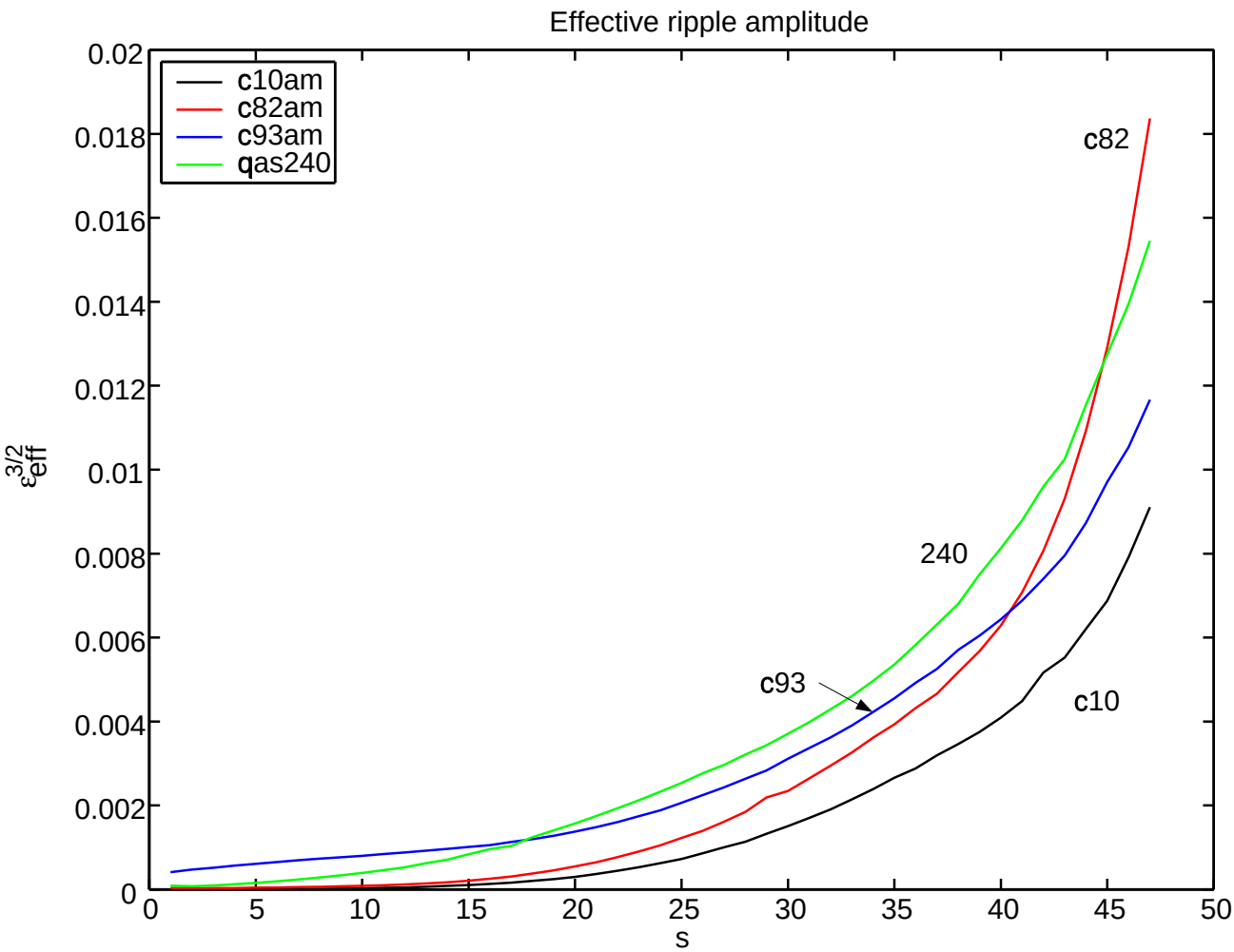
  QAS2_40 has worse transport than C10, (ORBITMN)
* Still need to calculate D and benchmark with GC3, DKES etc
* Looks promising to include in the configuration optimizer

iota (=1/q)


c10am
c82am
c93am
qas240
2_40
c10
c93
ι/(2π)
s
0.5
0.45
0.4
0.35
0.3
0.25
0
5
10
15
20
25
30
35
40
45
50

Effective Ripple Amplitude verus Radius

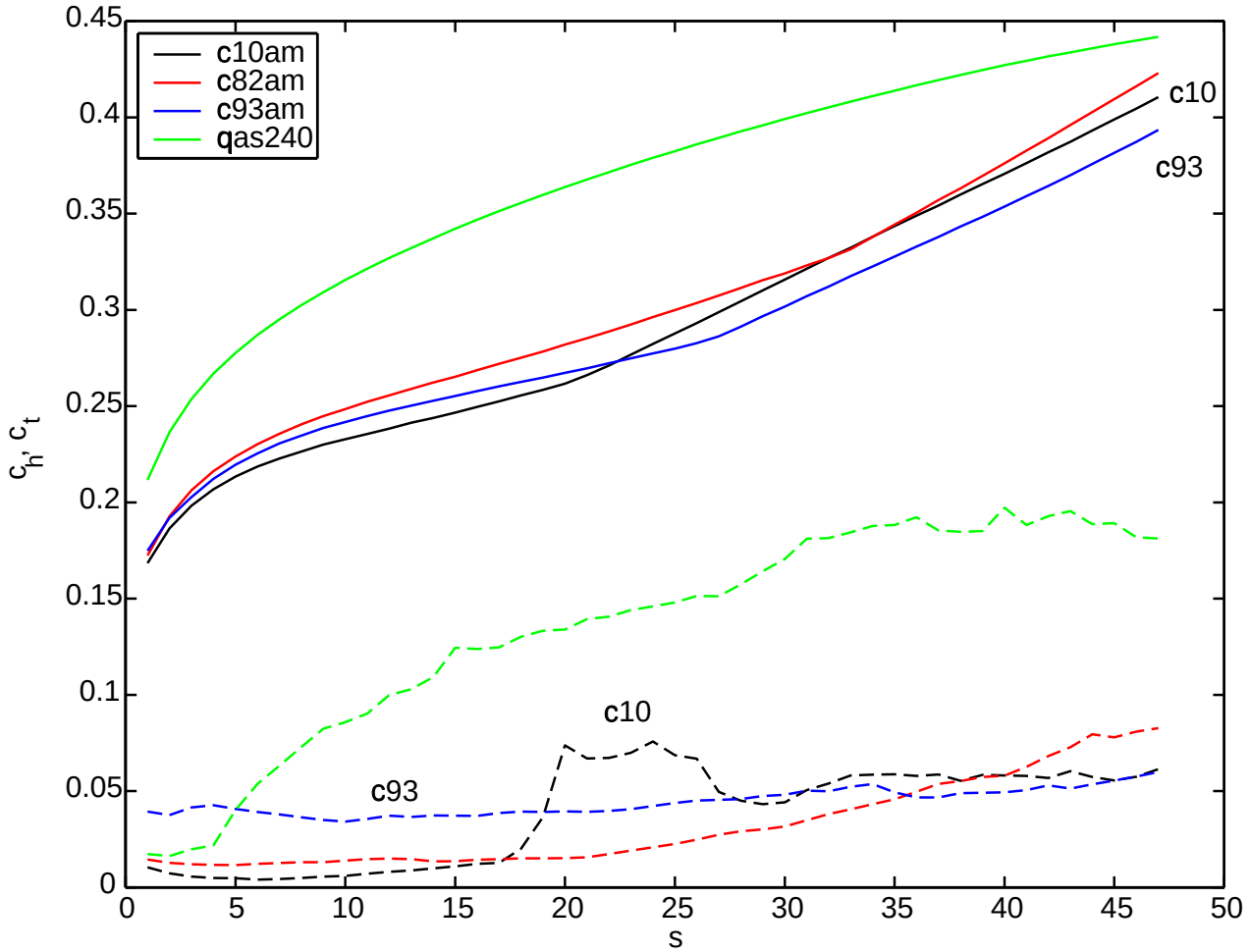
Largest for QAS3_C82, QAS2_40, QAS3_C93
compared to QAS3_C10



Fraction of trapped particles

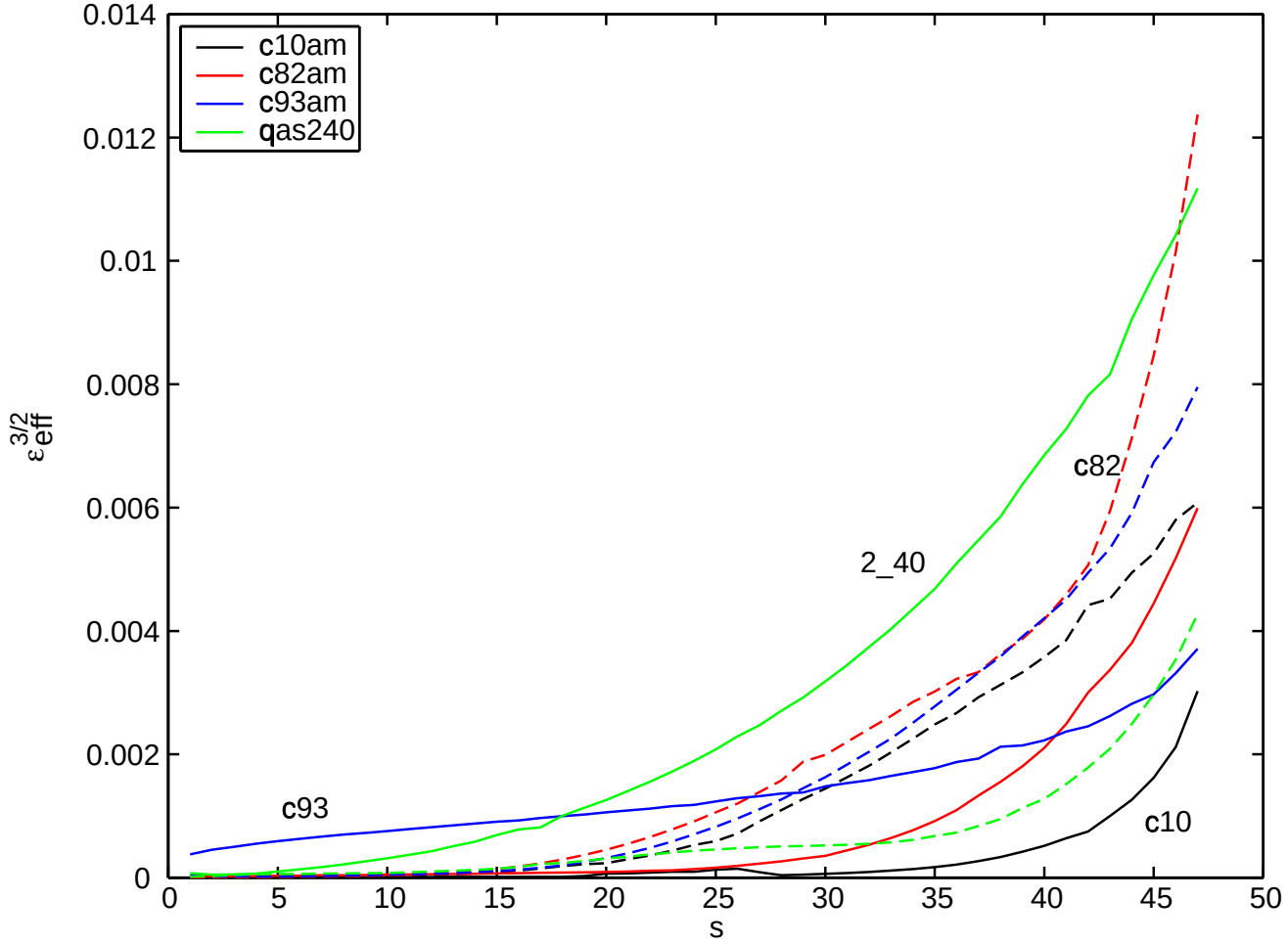
- total − solid; highest for 2_40,C82,C10,C93

- within single well − dotted;
  highest for 2_40 and C93 (throughout),C82 (at edge)



Contribution to effective ripple amplitude

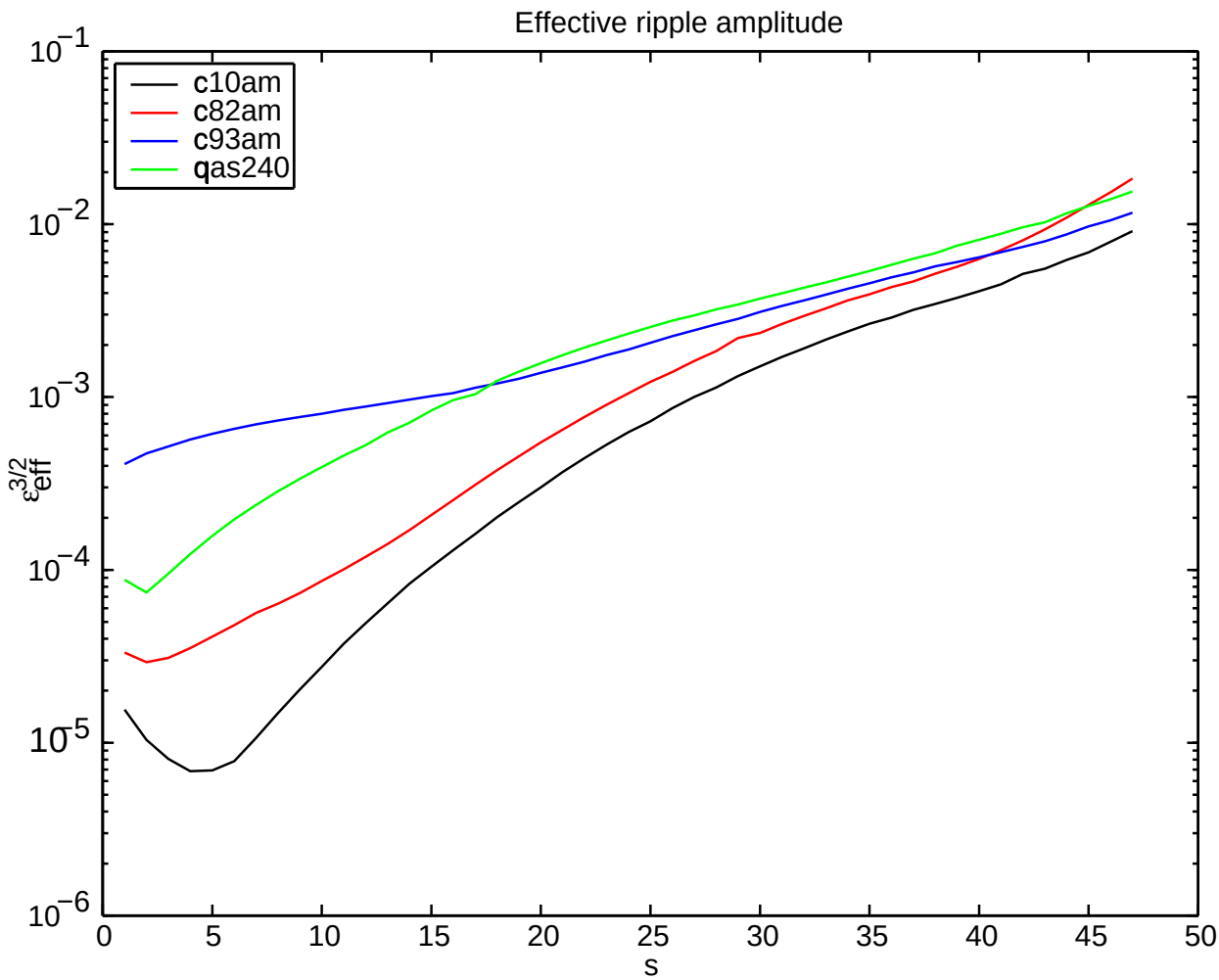
single trapped − solid, largest for C82,C93(throughout),C10
multiple trapped − dotted, largest for C82, C93,C10



Effective Ripple Amplitude versus Radius for Four QAS

Effective ripple differs by

- two orders of magnitude near the magnetic axis
- a factor of two at the plasma edge



BENCHMARKING of PARTICLE TRANSPORT METHODS for OPTIMIZER

A) Comparison of Γ_11 for C82, C93 and C10 calculated with DKES

S=0.3

ν/v	C82	C93	C10	Ratio
0.1	6.9376e-1	6.4547e-1	7.5484e-1	1:0.93:1.09
0.01	2.9163e-1	2.8416e-1	3.0832e-1	1:0.97:1.06
0.001	8.0538e-2 8.0559e-2	8.8614e-2 8.9054e-2	8.0316e-2 8.0320e-2	1:1.10:1.00
0.0001	1.5000e-2 1.5524e-2	1.4696e-2 1.5859e-2	1.4735e-2 1.5160e-2	1:1.00:0.98

S=0.5

ν/v	C82	C93	C10	Ratio
0.1	4.5914e-1	4.3630e-1	4.7973e-1	1:0.95:1.04
0.01	1.8091e-1	1.8973e-1	1.8583e-1	1:1.05:1.03
0.001	5.2714e-2 5.3002e-2	6.2875e-2 6.4582e-2	5.1070e-2 5.1354e-2	1:1.20:0.97
0.0001	1.4850e-2 1.8415e-2	1.3685e-2 1.7771e-2	1.2781e-2 1.6229e-2	1:0.95:0.87

B) The ratio, taken from GTC calculations for global confinement times, is 1:0.95:0.90. Thus, a reasonable correlation among the three cases is obtained only for $\nu/v \leq 0.0001$ at S=0.5.

C) Kernbichler/Nemov technique has found effective ripple which gives roughly
flux ~ $\varepsilon^{3/2}$, with c10 having the lowest effective ripple and the c82 and c93 curves intersecting so that a calculation of Flux or τ is still needed.

Deliverables 3/1/00

1. **Stellarator fast ion transport code**

   A new faster code, ORBIT3D (White), is operational and benchmarked against ORBITMN.

   It includes now the electric field potential and is being used to check the W7X alpha transport. Initial studies completed.

   A new collisional module is written and needs to be debugged/benchmarked. Likely complete by 3/1/00.

2. **Particle Transport Targeting in Optimizer**

   The Kernbichler/Nemov technique is operational with our Bmns, initial results look promising. Could be fully benchmarked and installed by 3/1/00.

3. **MHD Stability Code Comparisons**

   C. Nuhrenberg now has CAS3D.f90 and is doing benchmarking comparisons with TERPSICHORE for broad and peaked pressure profile cases. Initial benchmarking will be complete by 3/1/00.