



# Generation of an ultrashort GeV proton bunch in an instability-free regime by a single-cycle laser pulse

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6-7 July 2016

ELI-NP Magurele - Romania



# Outline



1. Motivation and challenges of proton/ion acceleration
2. Generation of proton beam in an instability-free regime **by a single-cycle laser pulse**
3. Summary

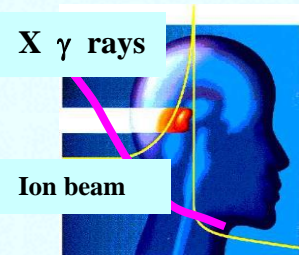
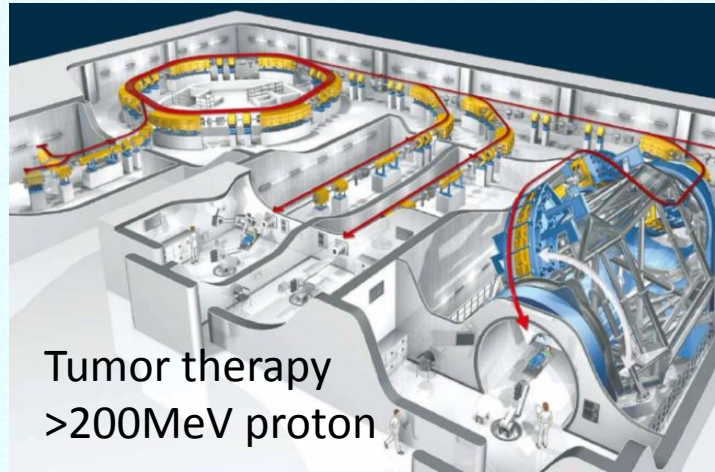
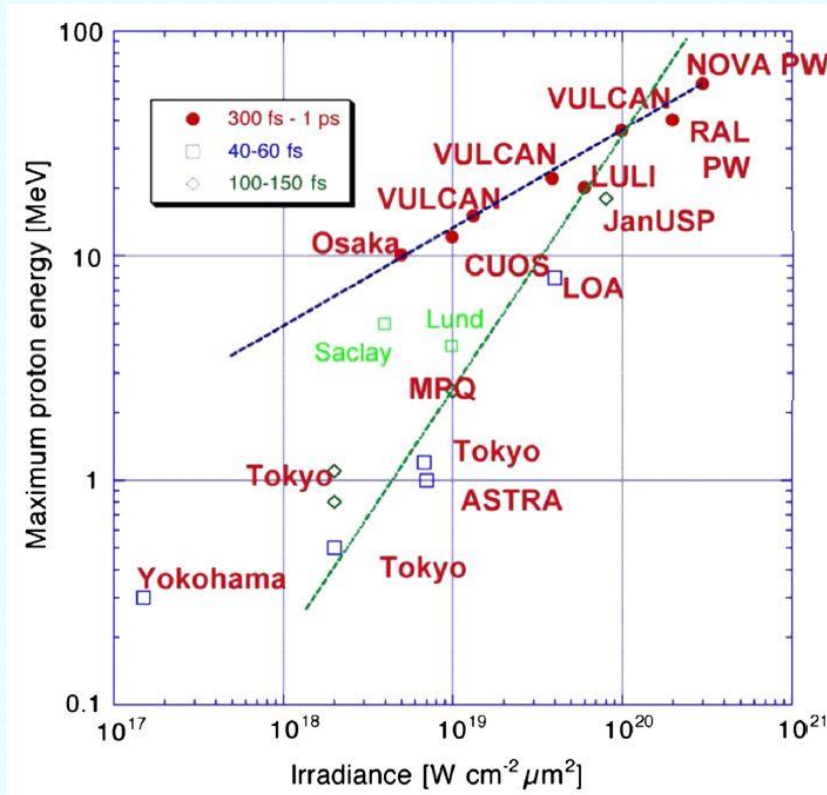


# Motivation



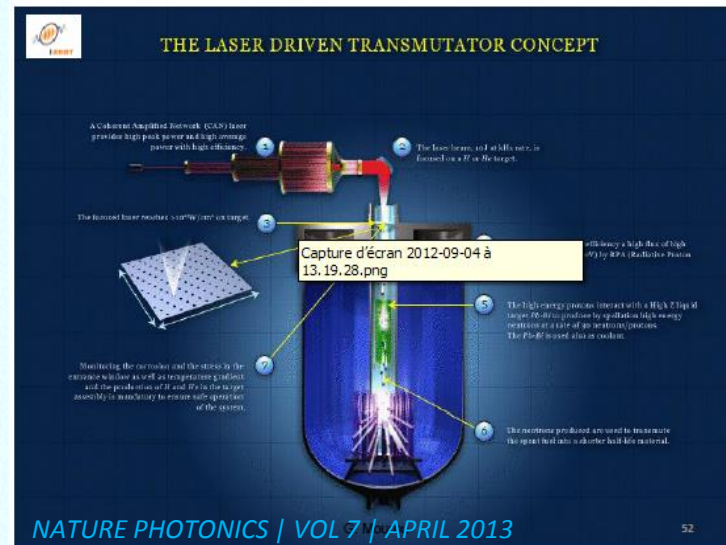
## Heavy Ion Therapy Center (HIT) in Heidelberg

### Laser ion acceleration experiments data



*Th. Haberer et al., Radiother. Oncol. 73(2), 186 (2004).  
Reviews of Accelerator Science and Technology Vol. 2 201–228 (2009)*

### Accelerator driven sub-critical clean nuclear energy System ~GeV proton



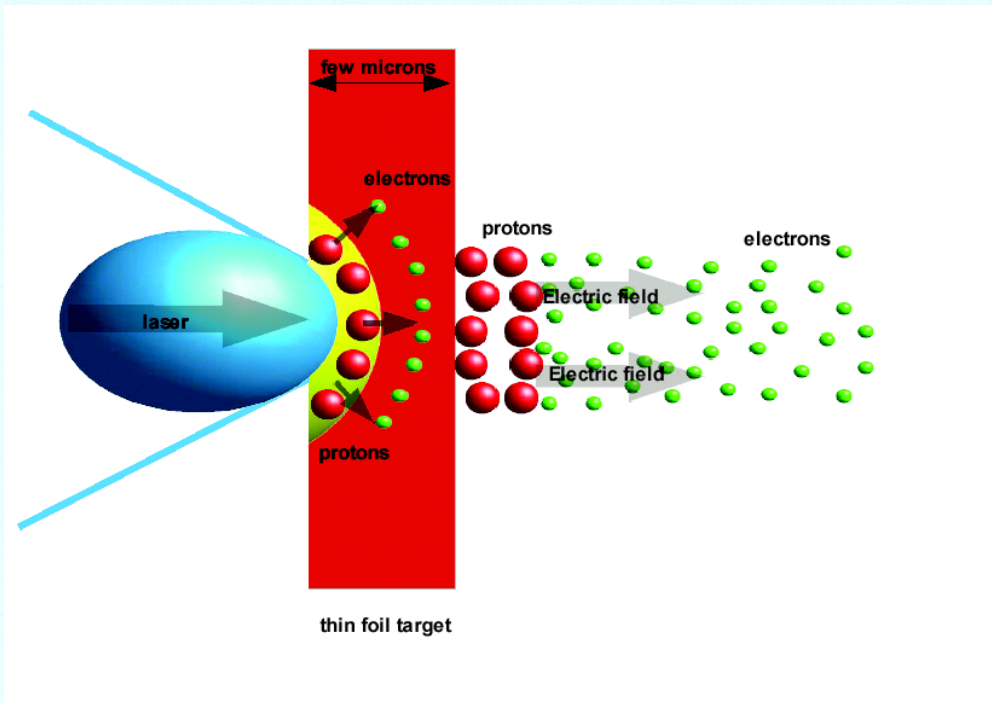
Maximum proton energy from laser irradiated solid targets as a function of the laser irradiance and for three ranges of pulse durations, reporting experiments up to 2008.

*Borghesi, M., et al., Plasma Phys. Controlled Fusion 50,124040(2008)*



# Ion acceleration mechanisms

## TNSA(target normal sheath acceleration)



Large divergence

Energy spread: ~100%

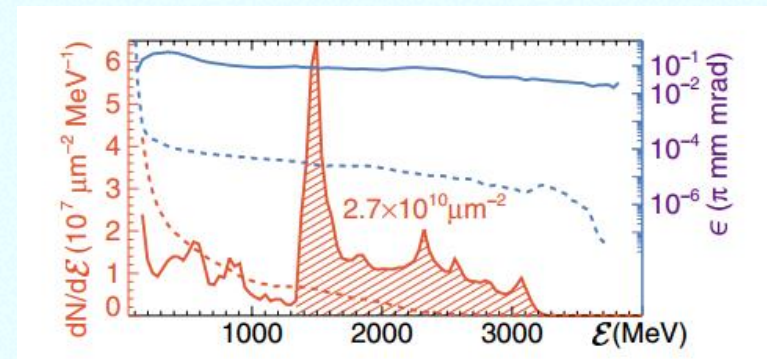
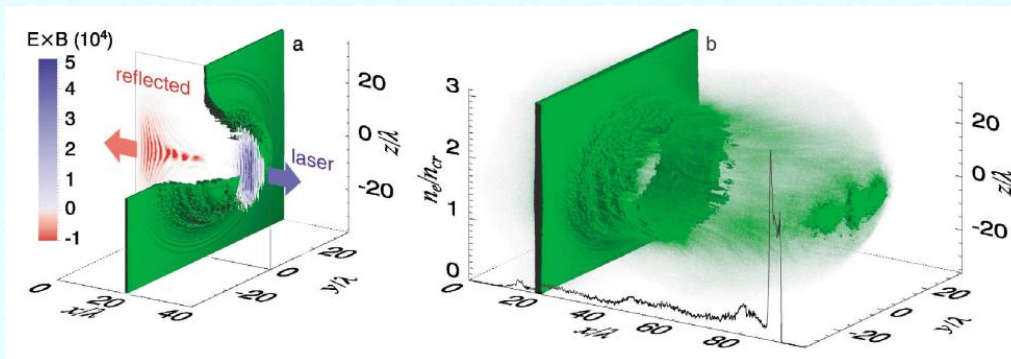
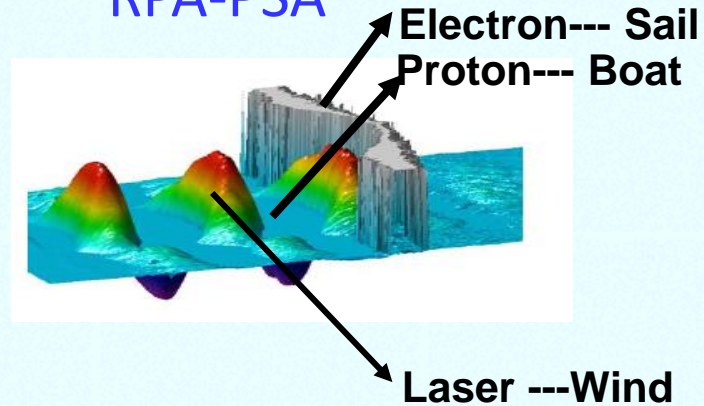
Low conversion efficiency

## RPA (radiation pressure acceleration)

Sailboat



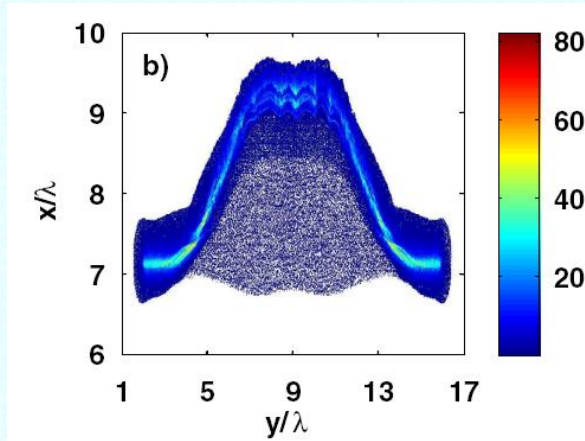
RPA-PSA



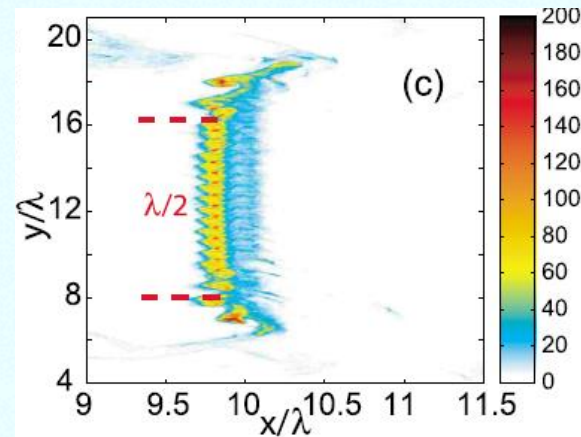


# Sail broken by “violent storm” of laser

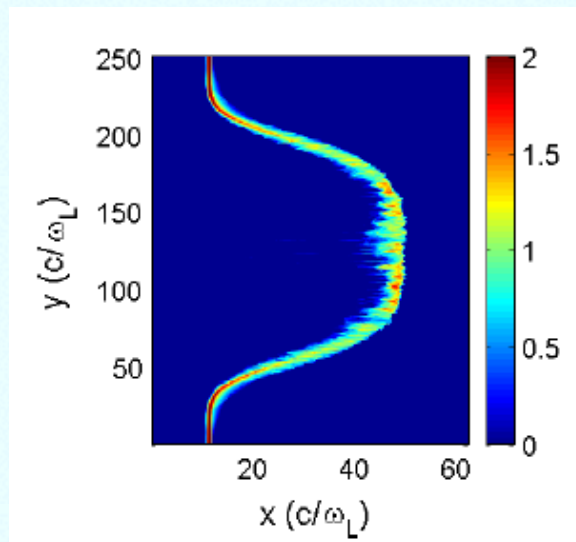
Hole boring and *Instabilities* are not gentle breeze



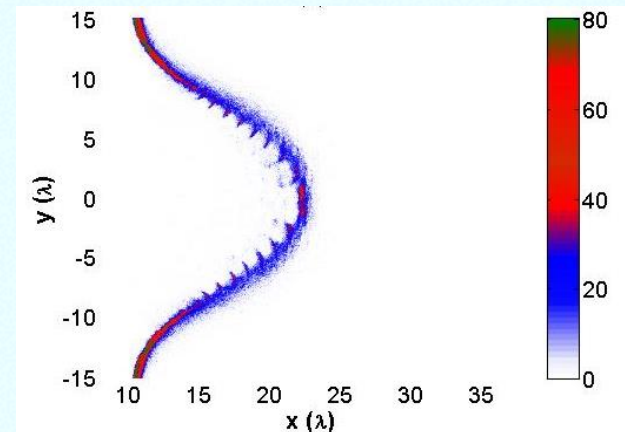
*Klimo et al, Phys. Rev. STAB 11, 031301 (2008)*



*M.Chen et al, PoP, 15, 113103, 2008*



*A P L Robinson, et al, New J. Phys. 10.1(2008)*



*X.Yan, et al., PRL, 103, 135001, (2009)*





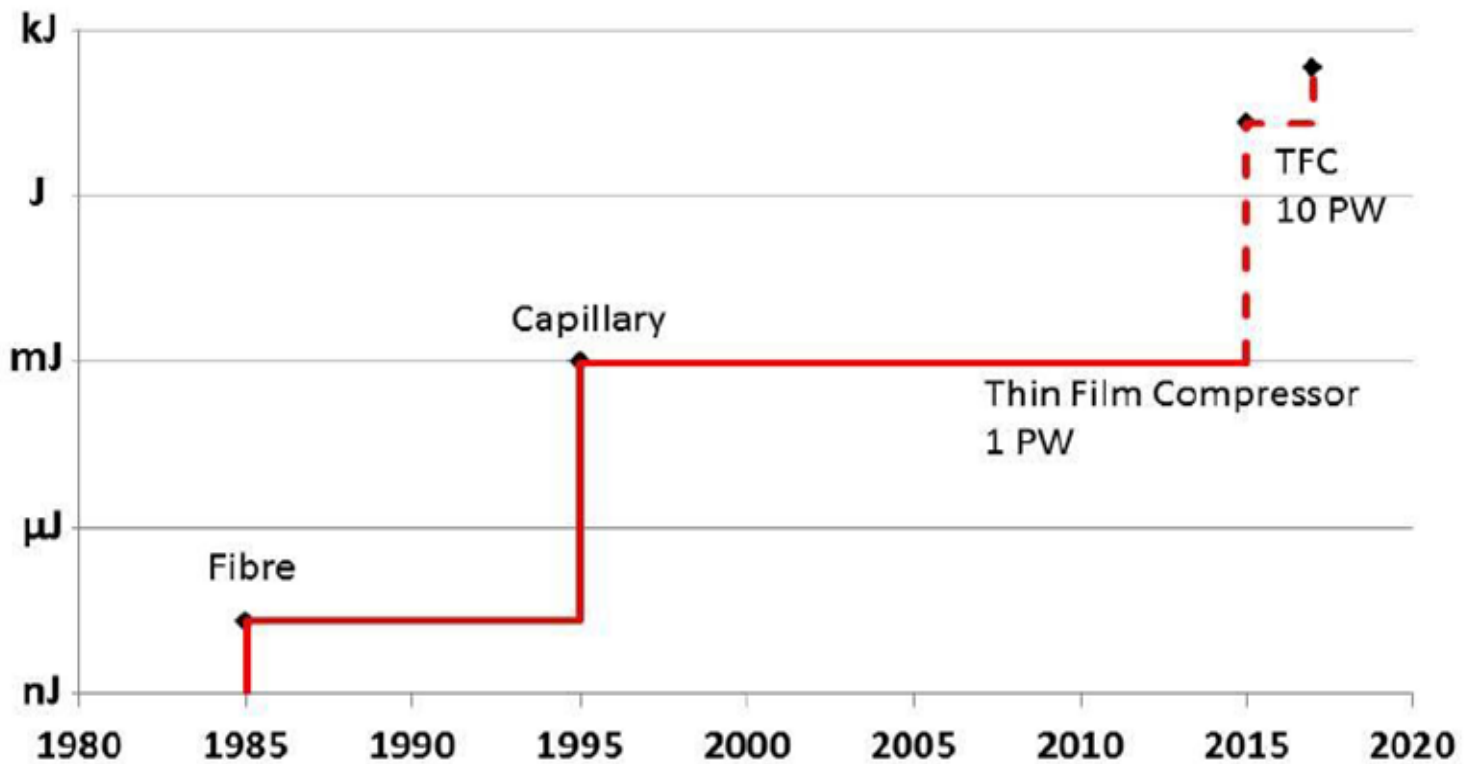
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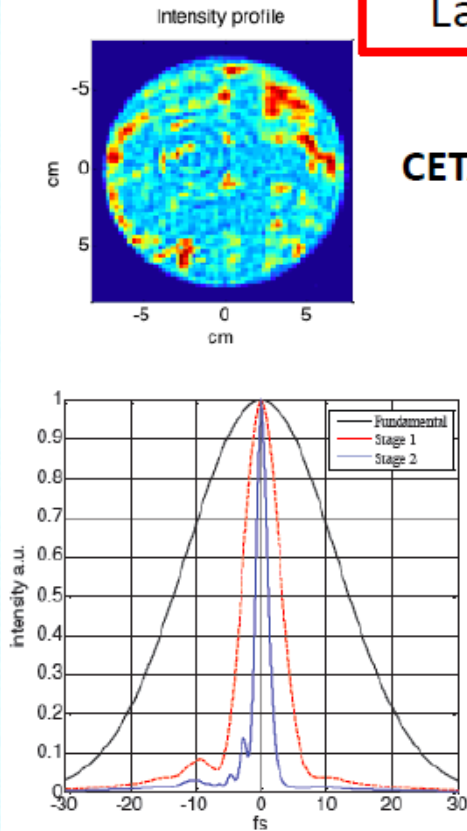
# Single Cycle Compression of High Energy Pulse: History



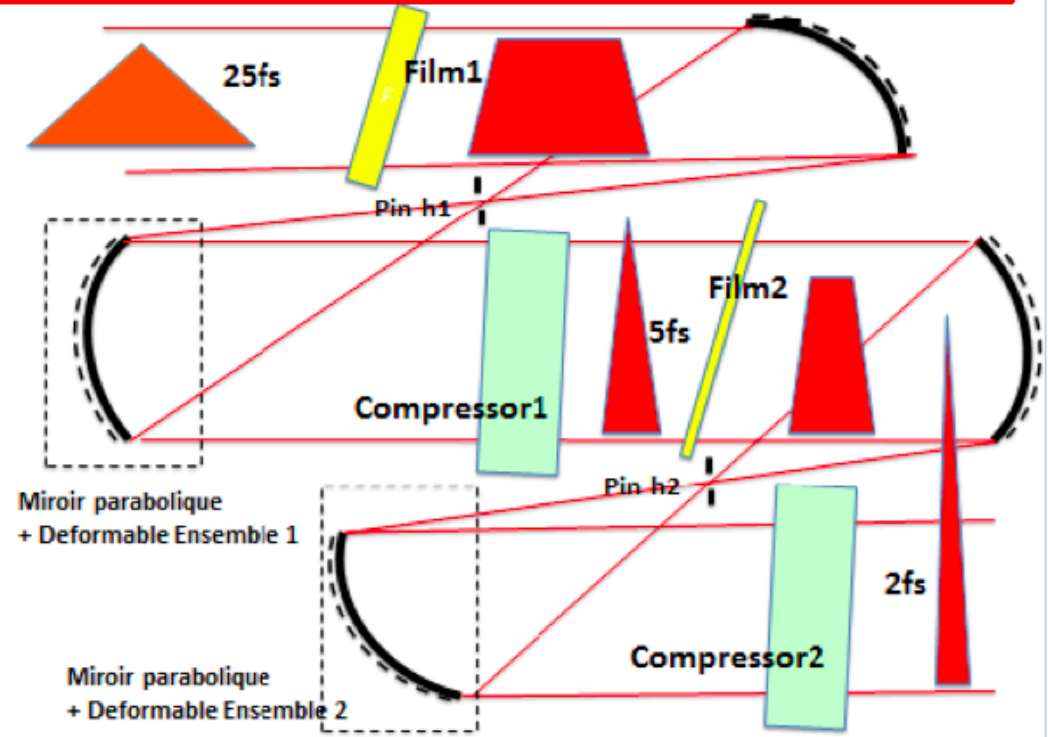


# Single Cycle Thin Film Compressor

## Laser with Uniform beam Amplitude and Phase

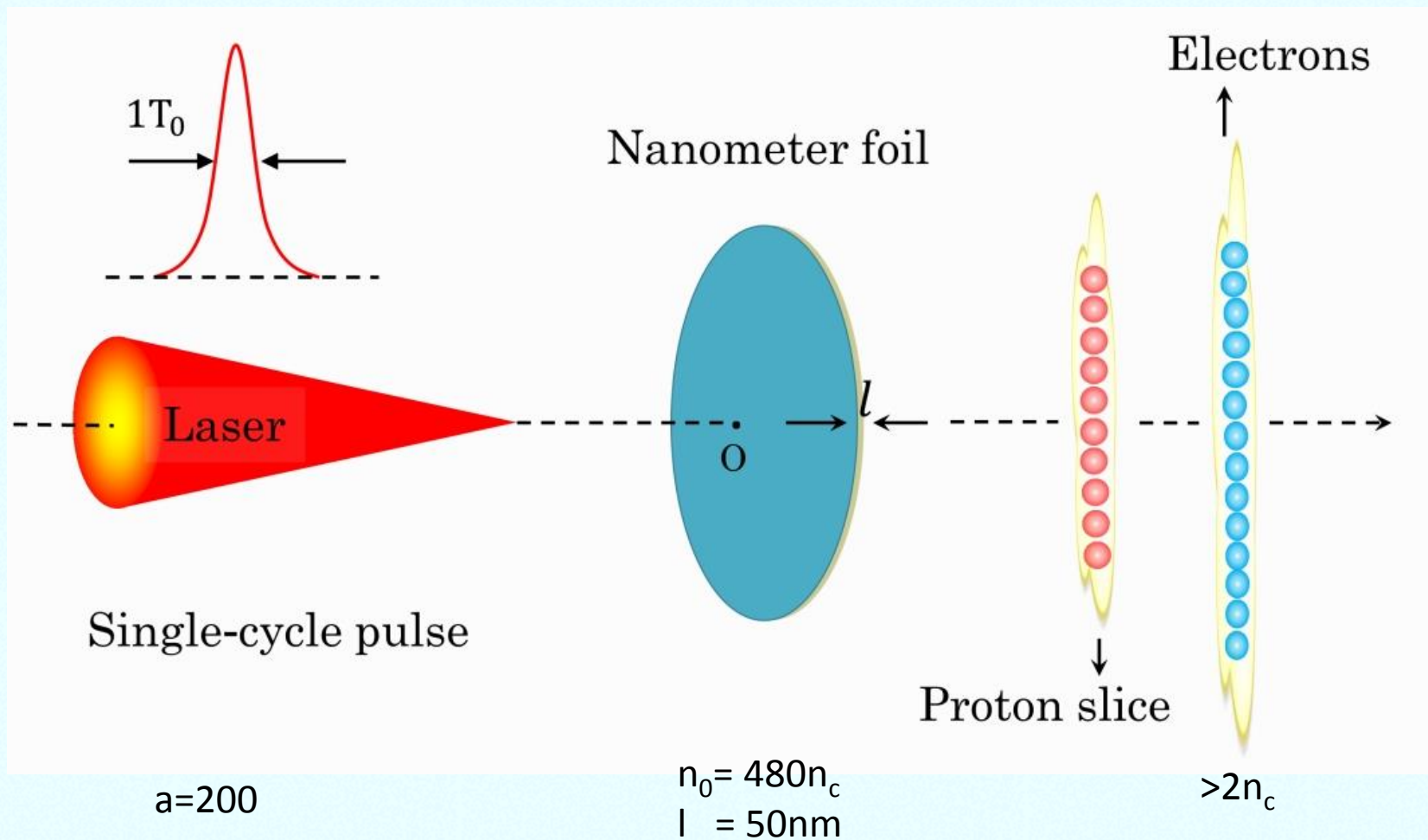


CETAL



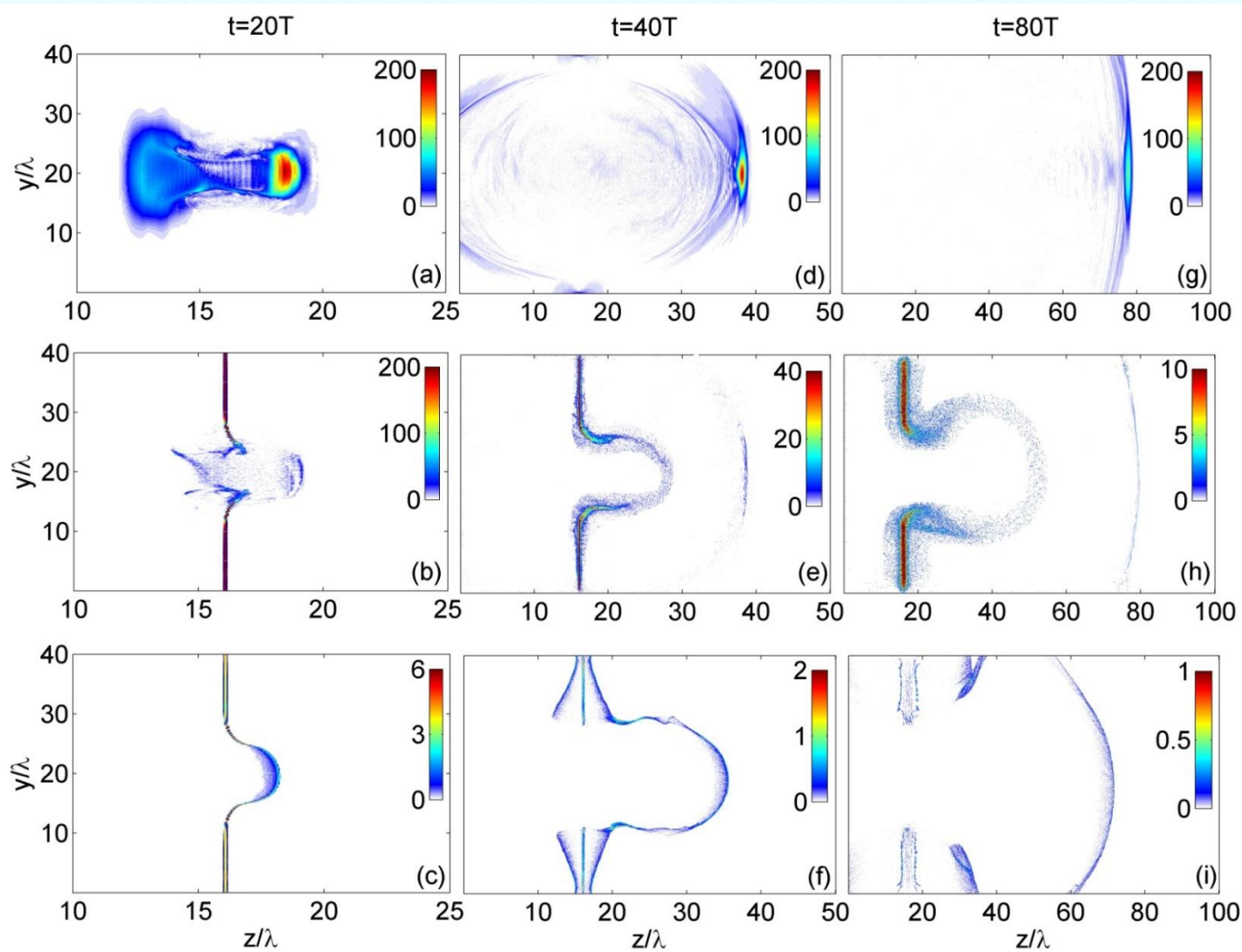
G. Mourou, S. Mironov, E. Khazanov and A. Sergeev, Single cycle thin film compressor opening the door to Zeptosecond-Exawatt Physics, Eur. Phys. J. Special Topics, 223, 1181(2014)

# The schematic view of single cycle pulse ion acceleration regime





# The evolution of Transverse electric field electrons density proton density



lack of  
instabilities!

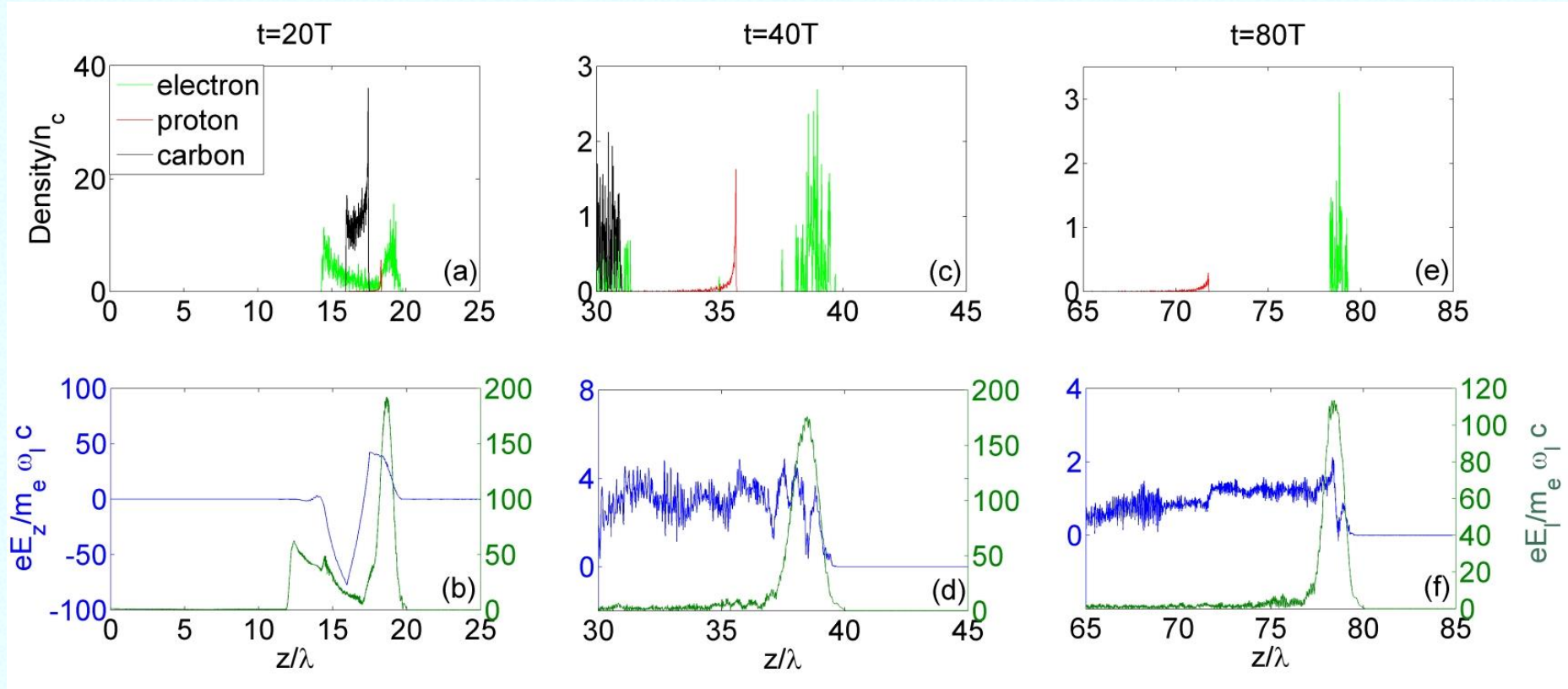
the electrons do not  
spread out in a short  
time, but generate a  
much **compressed**  
**leading slice**

**a thin and coherent**  
**proton slice** forms  
behind the electron  
layer





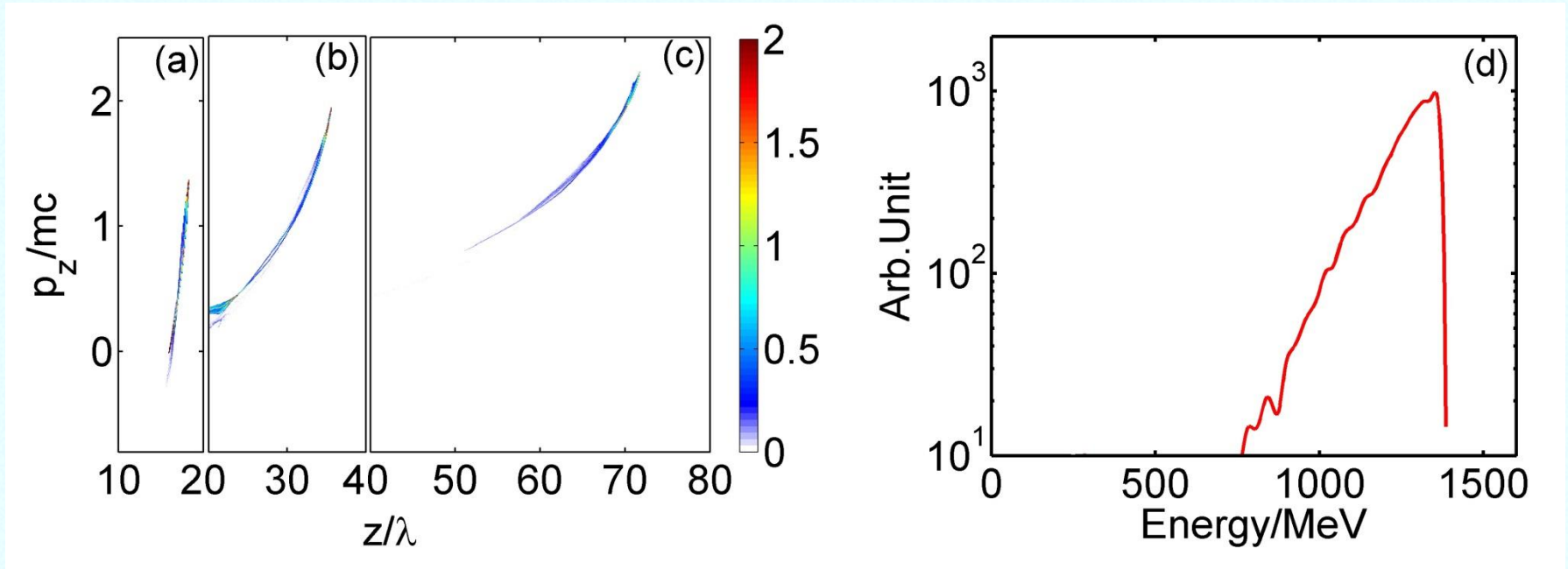
# particle density longitudinal electric field transverse electric field



Acceleration distance:  $\sim 60\mu\text{m}$



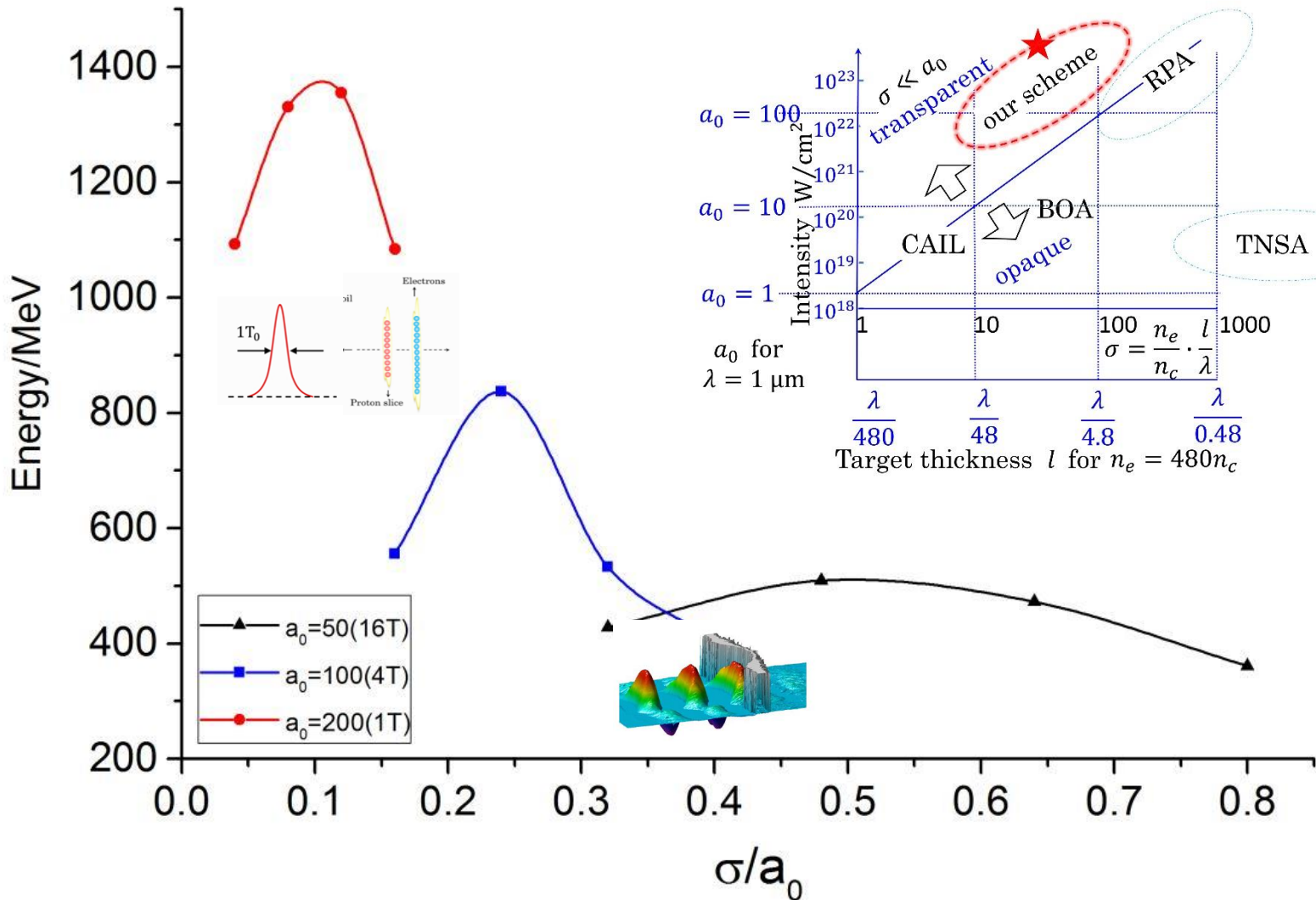
# Proton phase space and spectrum



The thickness of the isolated central slice is no more than 1  $\mu\text{m}$ , an ultrashort proton bunch corresponding to a few fs.



# TNSA, RPA and our regime







# Summary



- With a single cycle pulse and simple thin planar foil, the acceleration structure is stable, avoiding transverse instabilities, which is the bottle neck happened in RPA.
- the optimal value of  $\sigma/a$  is much smaller (0.1) than the traditional value, more efficient acceleration!
- Obtain a quite short protons pulse (less than 1 micrometer).
- Such proton beams could be used in proton cancer therapy or ADS.



Thanks for your attention