Enhanced ion acceleration from a non-ideal laser pulse contrast

M. Garten[1,2], A. Huebl[3], R. Widera[1], I. Goethel[1,2], L. Obst-Huebl[3], T. Ziegler[1,2], K. Zeil[1], T. Cowan[1,2], U. Schramm[1,2], M. Bussmann[1], T. Kluge[1]

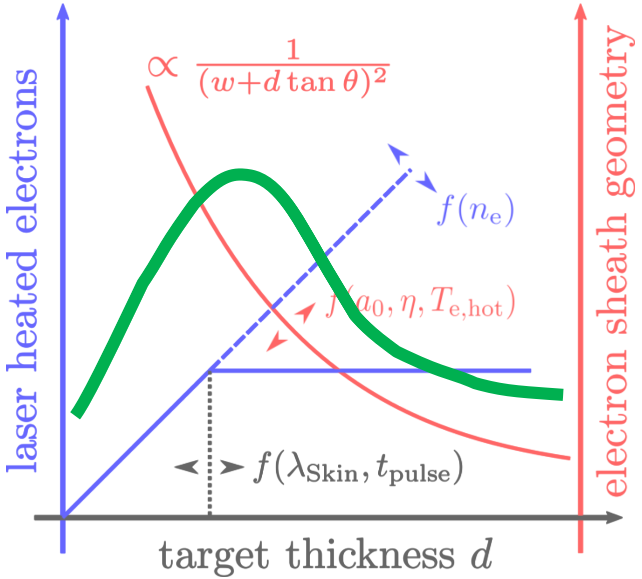
[1] Helmholtz-Zentrum Dresden – Rossendorf, Germany

[2] Technische Universität Dresden, Germany

[3] Lawrence Berkeley National Laboratory

We acknowledge PRACE for awarding us access to Piz Daint at CSCS, Switzerland.
15th PRACE call, Project ID 2016163983.

Optimum target thickness for laser-proton acceleration



- Number of available laser-acc. electrons is limited

$$N_{e,L} \propto \eta\ I\ t_p \qquad [1]$$

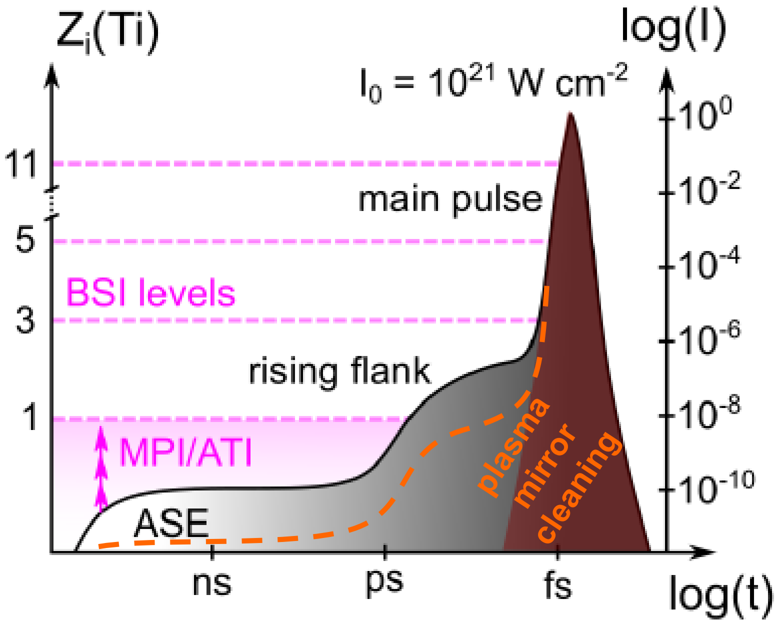
- Optimize acc. field by optimizing sheath density

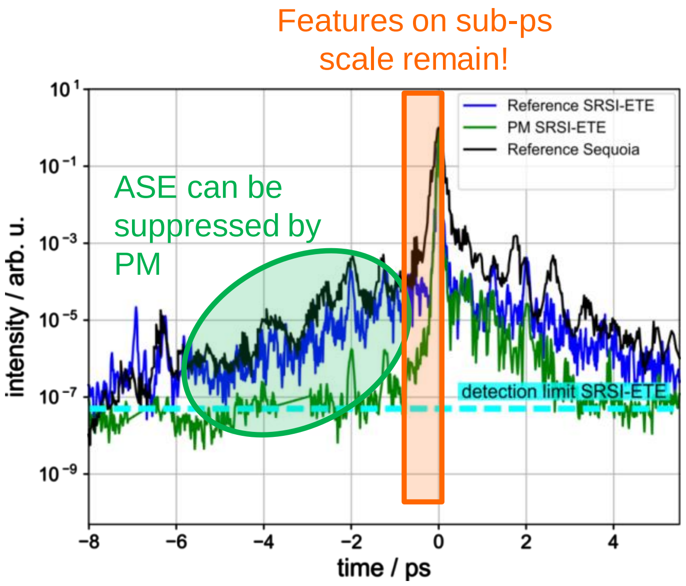
$$n_{e,S} \propto \frac{d}{(w + d\tan(\theta))^2} \qquad [1]$$

- With current short pulse laser system parameters:
  t_p ~30fs, I_{max} ~ 10^{21} W/cm²
  → d_{opt} ~ 10s of nm with metal foils

[1] Schreiber et al. (2006) Phys. Rev. Lett. 97 1–4

Thin targets are sensitive to the laser contrast



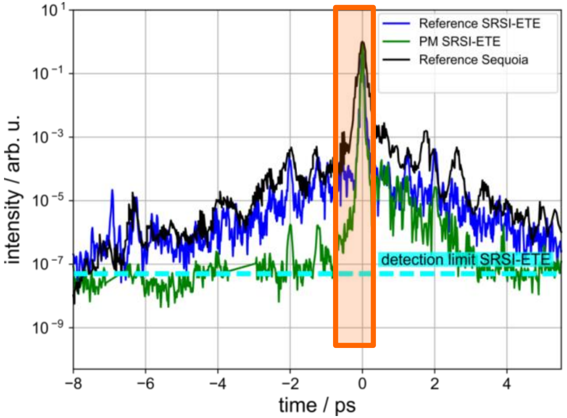


- "cleaning" of temporal contrast with plasma mirror techniques
  → can shoot thinner targets

- Shot-to-shot fluctuation
- Experimentally accessible but still challenging to measure

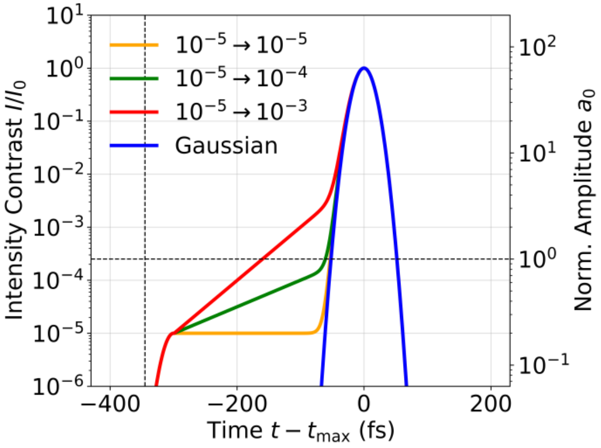
Study influence of last-ps intensity ramp with simulations

measurement



[1]

simulation



Include more realistic pulse shape into simulations of laser ion acceleration

- Extract characteristic features
- Understand interaction systematically

[1] L. Obst-Huebl PPCF (2018)

Realistic fully 3D simulations …

- resolving plasma oscillation at full density of solid foil targets
- ionization physics during ramp phase
- cover several 100 fs prior to peak of intensity
- run fast to cover parameter space of intensity ramps × target thicknesses

One of the largest allocations on European supercomputers 2017/2018

PIConGPU

openPMD

PRACE

currently 6th place on Top500 list of supercomputers & former 1st regarding GPUs until June '18

15th PRACE call, Project ID 2016163983.
We acknowledge PRACE for awarding us access to Piz Daint at CSCS, Switzerland.

PIConGPU

github.com/ComputationalRadiationPhysics/picongpu

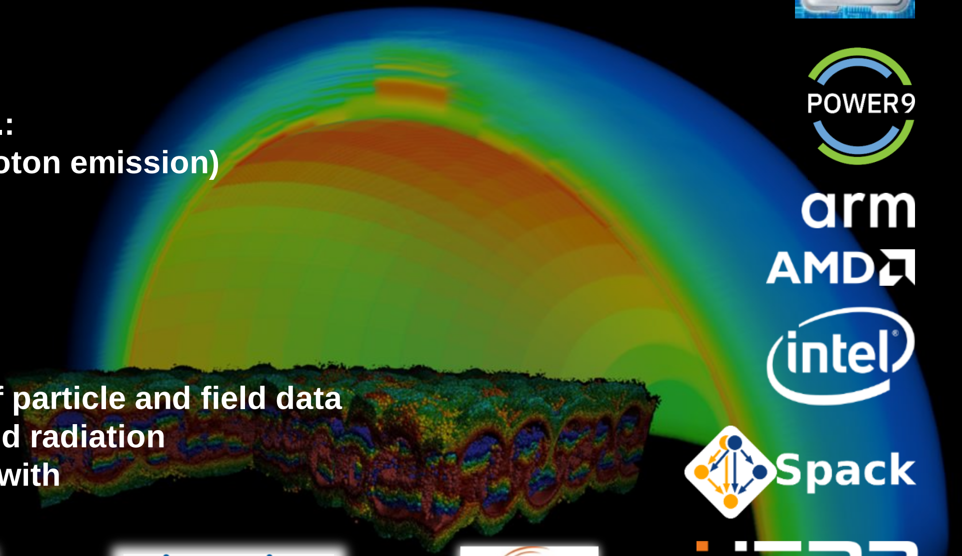
picongpu.readthedocs.io

- **Open source, fully relativistic, 3D3V, manycore, performance portable PIC code with a single code base**

- **Implements various numerical schemes, e.g.:**
  > *Villasenor-Buneman*, *Esirkepov* and *ZigZag* current deposition
  > *NGP* (0th) to *P4S* (4th) macro particle shape orders
  > *Boris* and *Vay* particle pusher
  > *Yee* and *Lehe* field solver

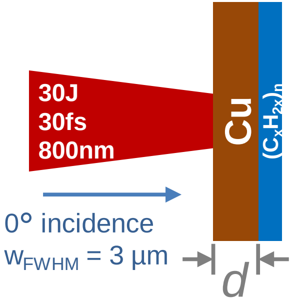
- **Available self-consistent additions to the PIC cyle, e.g.:**
  > QED synchrotron radiation and Bremsstrahlung (photon emission)
  > *Thomas-Fermi* collisional ionization
  > *ADK* and *BSI* field ionization
  > Classical radiation reaction

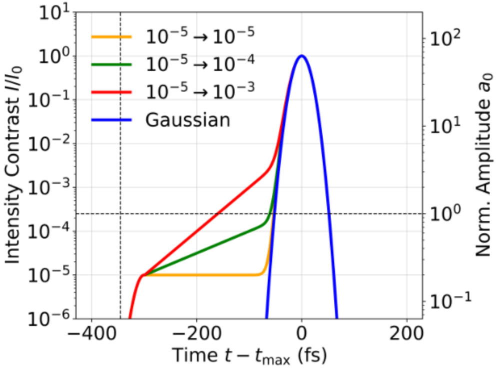
- **Tools and diagnostics, e.g.:**
  > Extensible selection of plugins for online analysis of particle and field data
  > In situ calculation of coherent and incoherent far field radiation
  > Scalable I/O for restarts and full output in openPMD with parallel *HDF5* and *ADIOS*



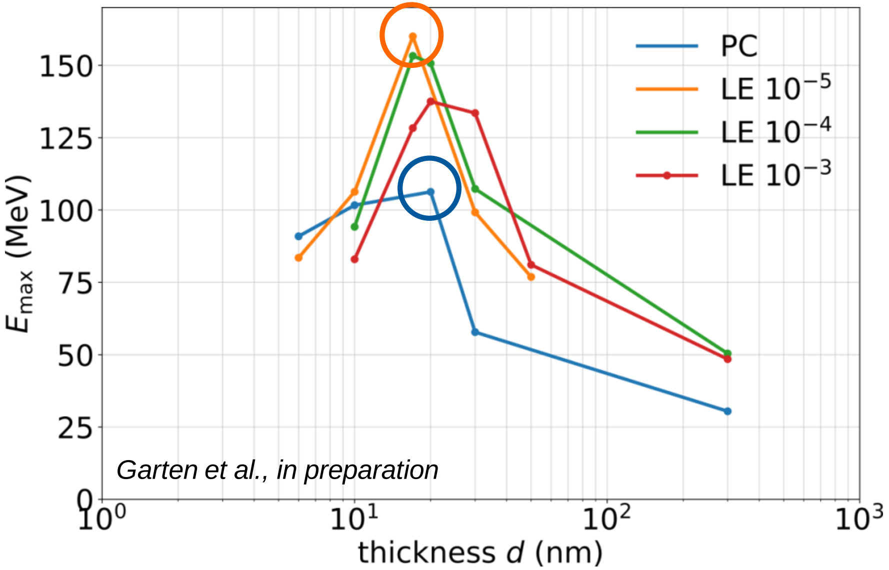
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Results from 1.6 million GPUh & 4PB of data





Maximum Proton Energy

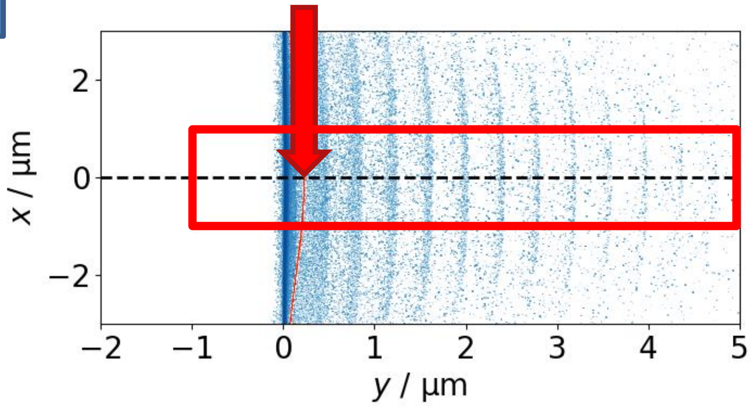


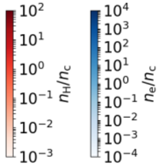
Optimum thickness exists in each case

Perfect contrast setup does not deliver the highest proton energies

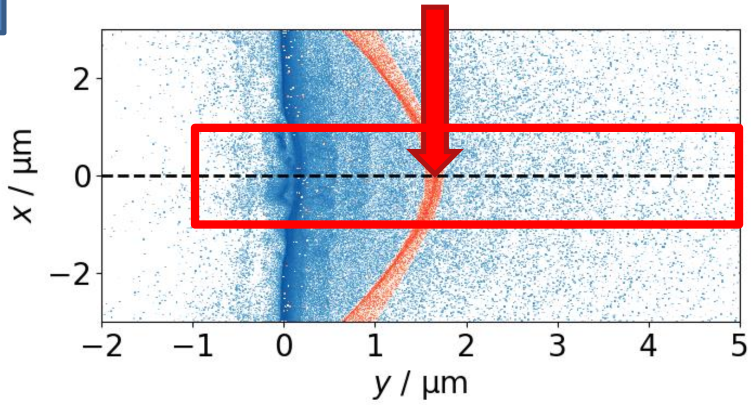
Target at maximum laser intensity

no ramp





with ramp



- Proton and electron density (Cu and C not shown)
- Proton layer in ramp case significantly pre-expanded

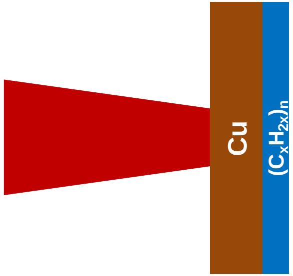
Now we look more closely at densities and accelerating fields

Densities & accelerating fields

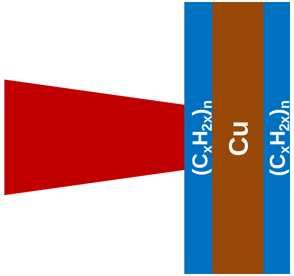
Slides 9-14 removed,

for access requests please write a mail
to m.garten@hzdr.de.

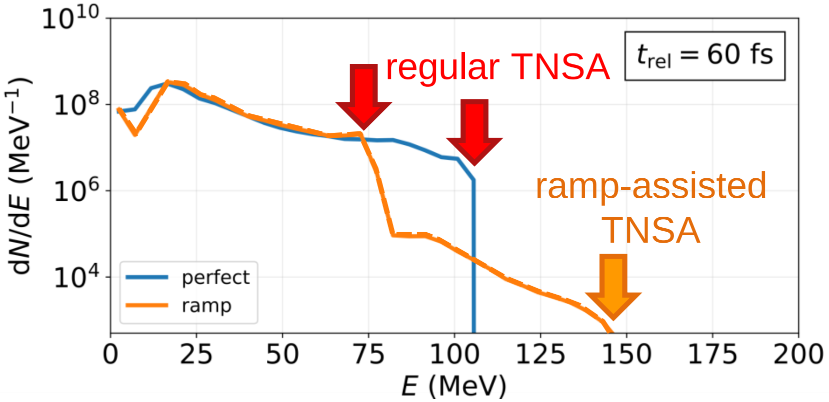
Can the number of protons at high energies be increased?

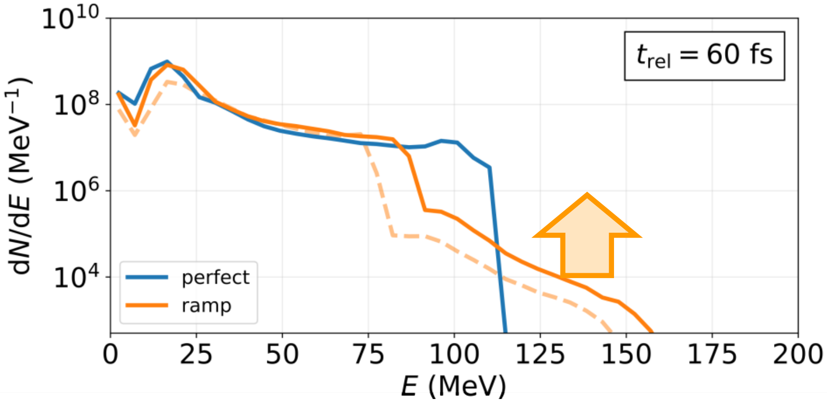


rear-only
contaminant



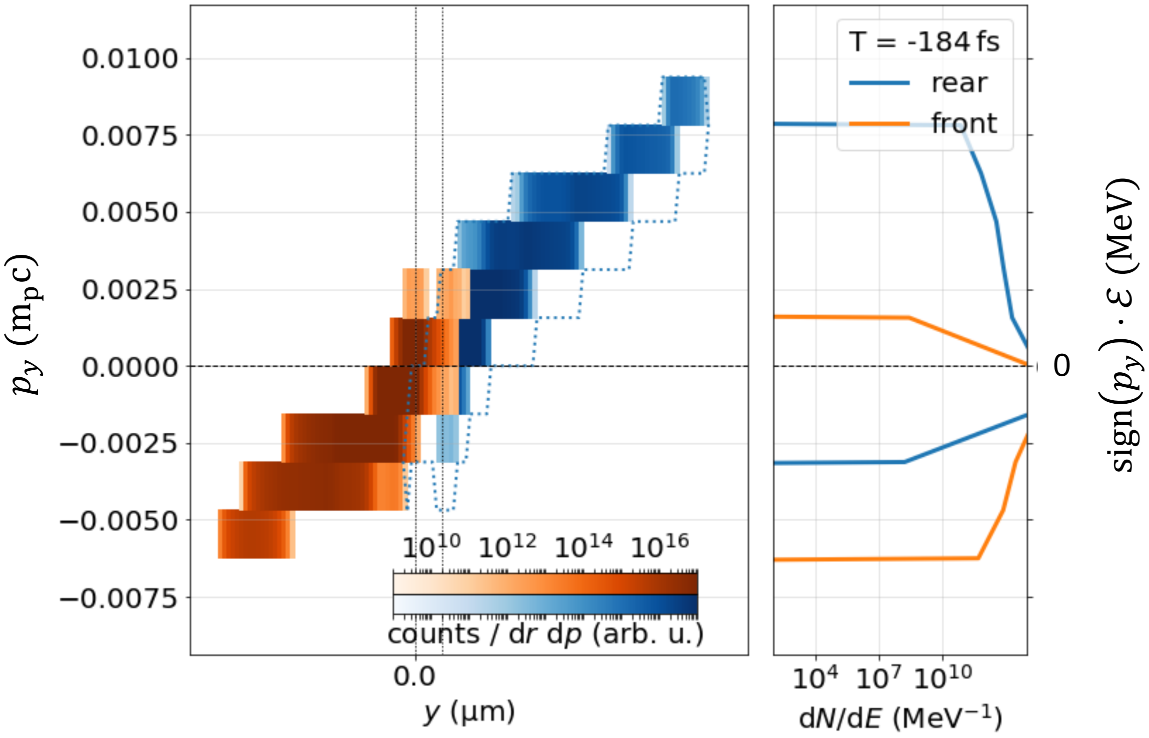
front + rear
contaminant





Adding a front-side contaminant increases no. of protons at high energies by an order of magnitude!

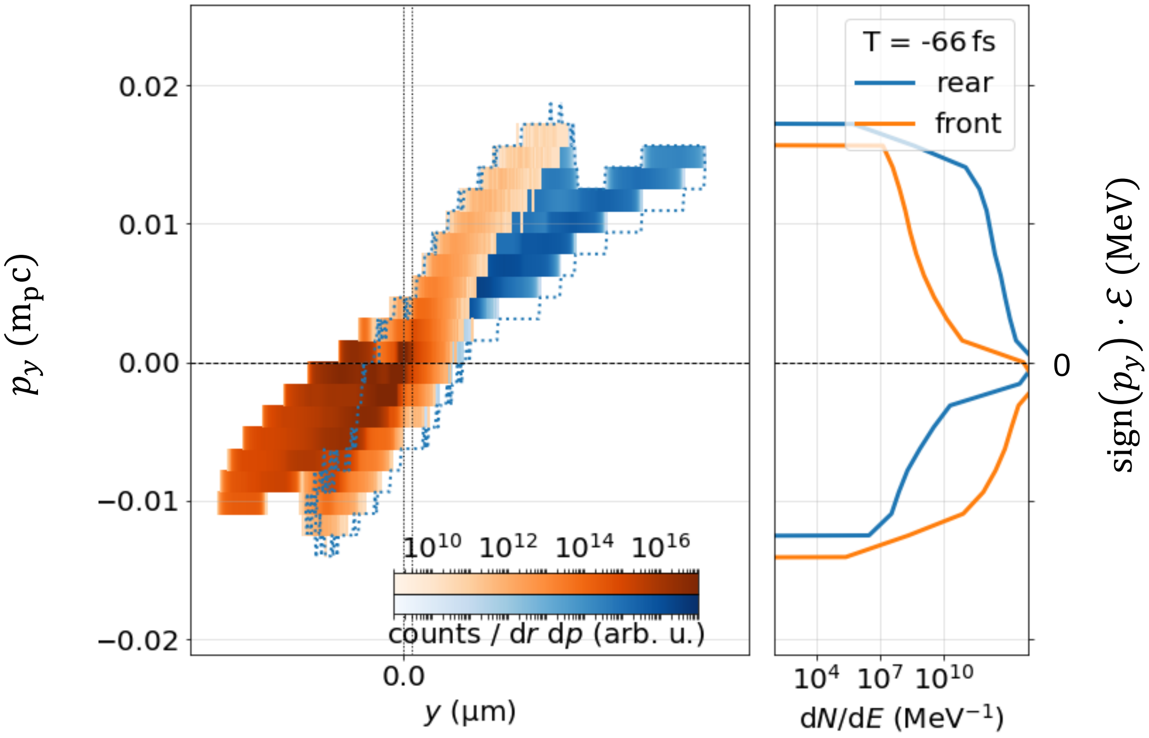
Origin of the ramp-assisted TNSA protons



laser prop. direction

- **- 184 fs:** a_0 << 1, thermal motion & mixing of species

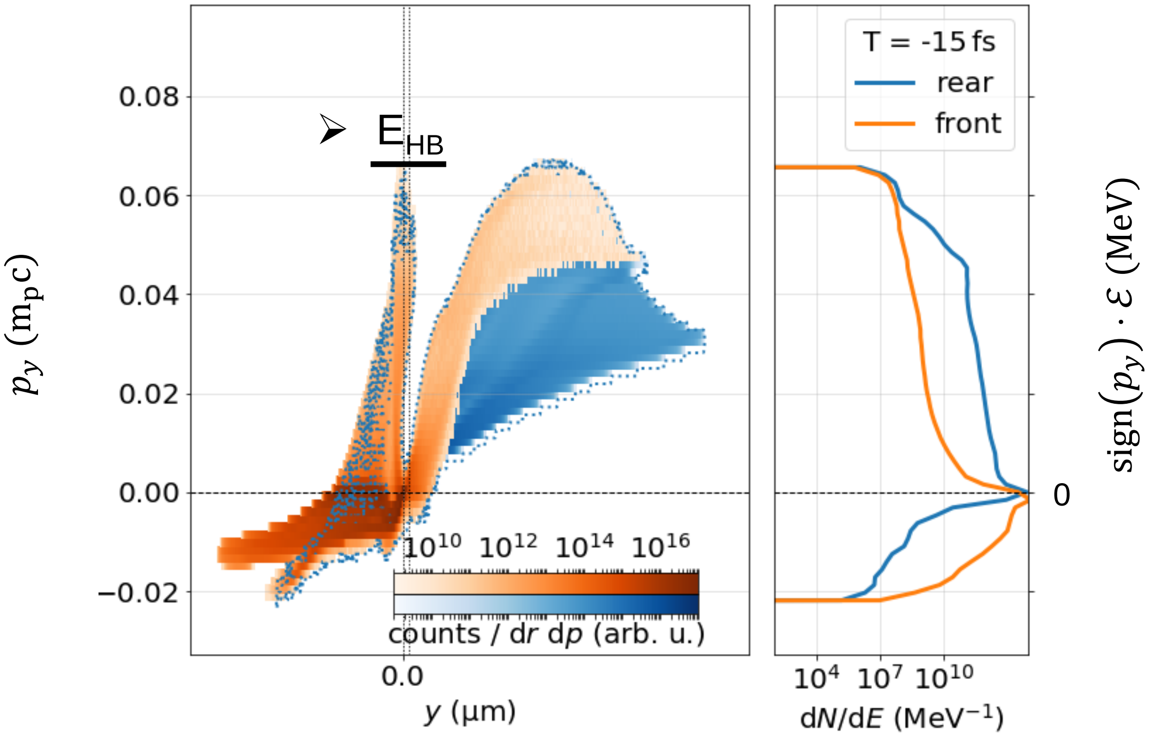
Origin of the ramp-assisted TNSA protons



laser prop. direction

- **- 184 fs:** a_0 << 1, thermal motion & mixing of species
- **- 66 fs:** TNSA towards both sides

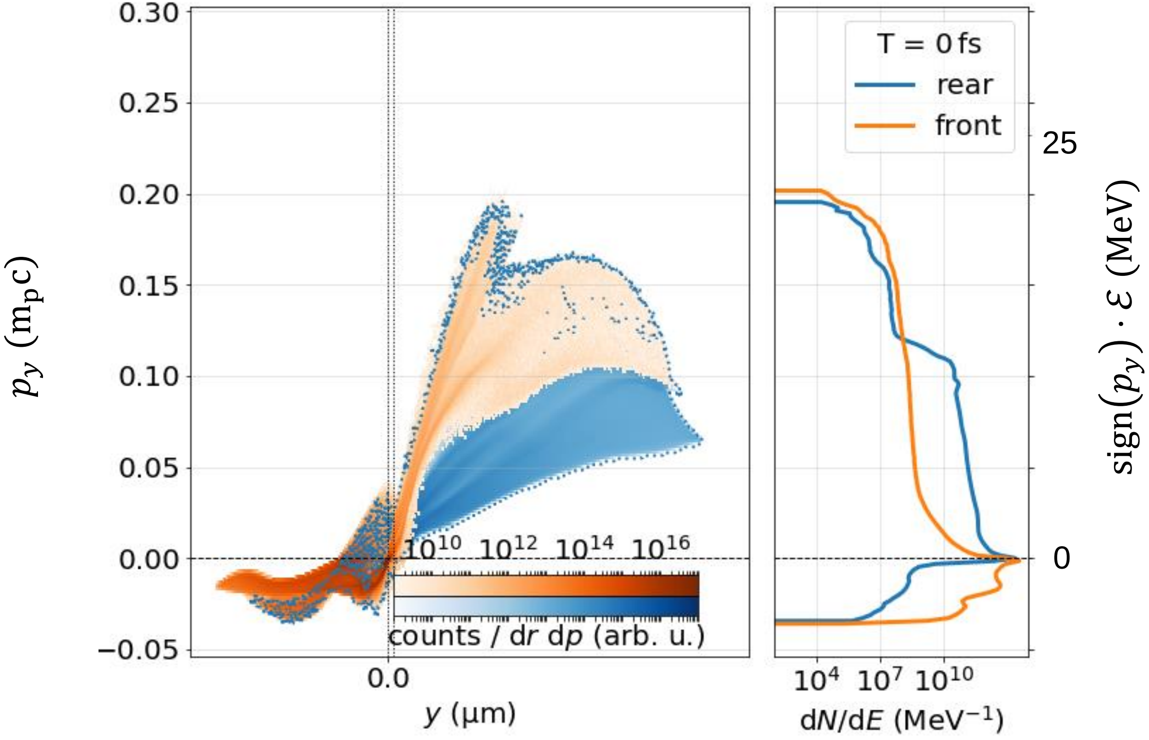
Origin of the ramp-assisted TNSA protons



laser prop. direction

- **- 184 fs:** $a_0 \ll 1$, thermal motion & mixing of species
- **- 66 fs:** TNSA towards both sides
- **- 15 fs:** hole-boring pushes protons through foil

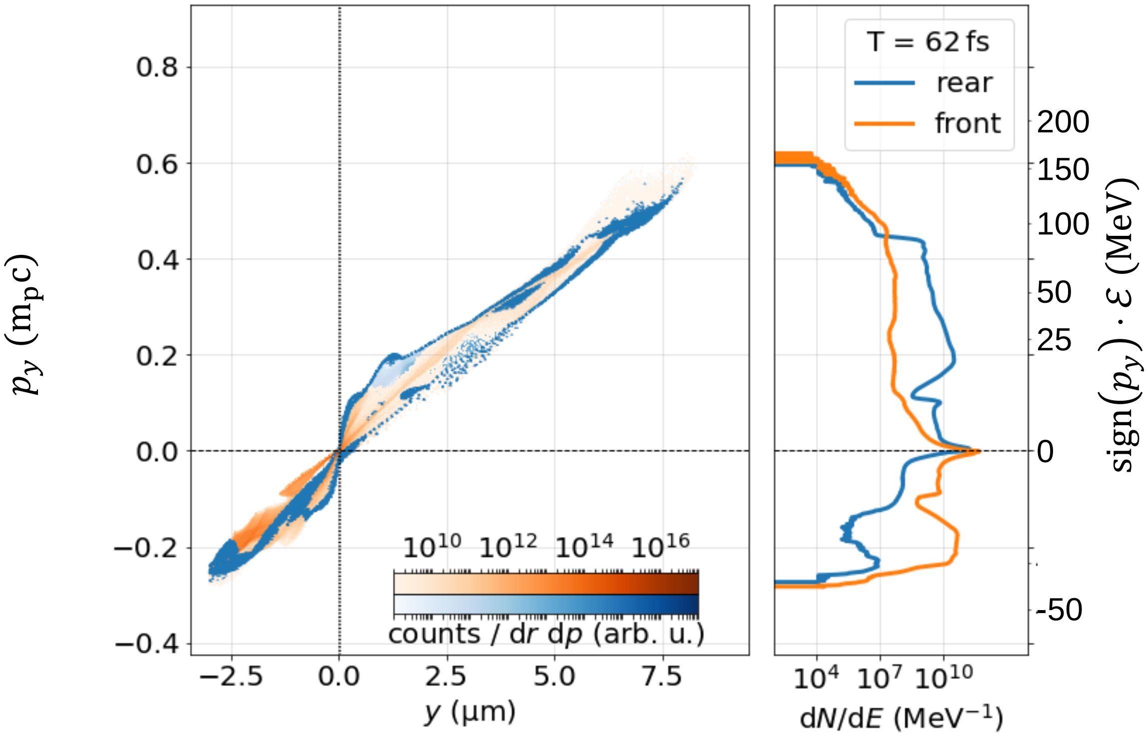
Origin of the ramp-assisted TNSA protons



laser prop. direction

- **- 184 fs:** $a_0 << 1$, thermal motion & mixing of species
- **- 66 fs:** TNSA towards both sides
- **- 15 fs:** hole-boring pushes protons through foil
- **0 fs:** protons detach from front, are injected into TNSA sheath

Origin of the ramp-assisted TNSA protons

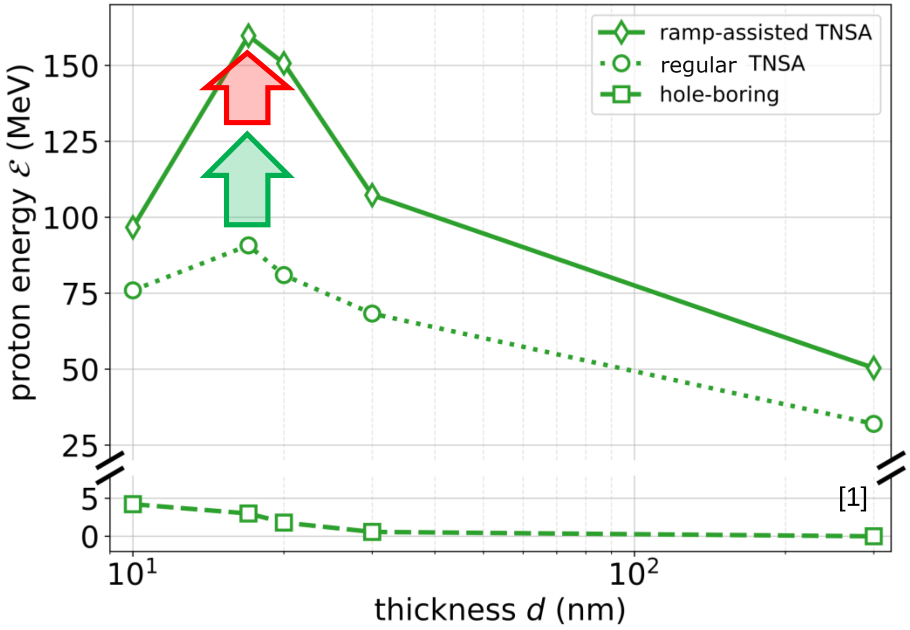


laser prop. direction

- **- 184 fs:** $a_0 << 1$, thermal motion & mixing of species
- **- 66 fs:** TNSA towards both sides
- **- 15 fs:** hole-boring pushes protons through foil
- **0 fs:** protons detach from front, are injected into TNSA sheath
- **62 fs:** large number of ramp-assisted TNSA protons from front-surface at high energies

Energy contributed per acceleration mechanism

10^{-5} (-300fs) → 10^{-4} (-100fs) contrast setting

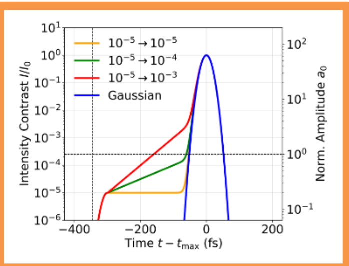


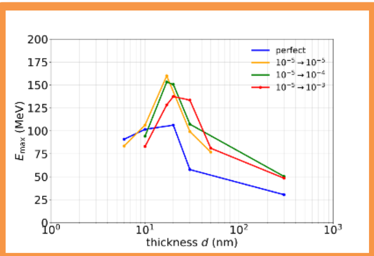
- Energy gain from protons running down the full sheath potential after being injected into it at right place & right time
- Additional energy gain from overall increased acc. field
- Contribution from front-side acceleration (hole-boring) is minimal

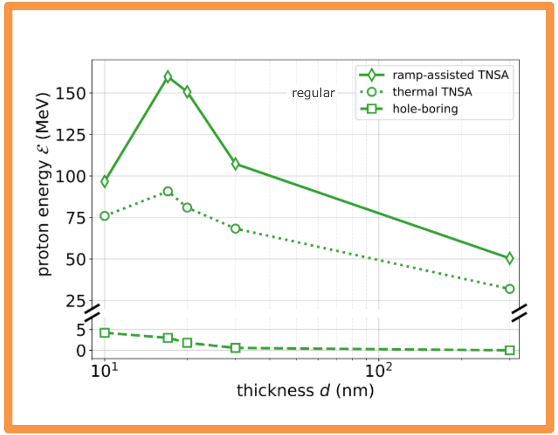
[1] *Garten et al., in preparation*

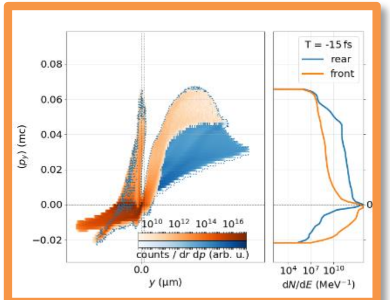
Summary & Conclusion

- **Ps-ramp significantly influences acceleration performance**
- **Optimal proton energies at “non-optimal” laser contrast**
- **Inject protons into sheath field at right moment**
- **Benefit from full acceleration potential of TNSA process**









Acknowledgments

This project has been enabled by many people in open-source and open-science communities. Great thanks to the communities and developers of: PIConGPU, Jupyter, yt, the SciPy ecosystem, ADIOS, HDF5, CMake, openPMD, Spack, ...

This project has received funding from the European Unions Horizon 2020 research and innovation programme under grant agreement No 654220.

We acknowledge PRACE for awarding us access to Piz Daint at CSCS, Switzerland. 15th PRACE call, Project ID 2016163983.

Thank you for your attention and thank you to the organizing committee!