Introduction to Coupling Simulations of Beam Impact on Accelerator Components

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LHC beams: 360 MJ (**factor of 100** above previous machines)

The energy of an 200 m long fast train at 155 km/hour corresponds to the energy of 360 MJ stored in one LHC beam.

360 MJ: the energy stored in one LHC beam corresponds approximately to…

- 90 kg of TNT
- 8 litres of gasoline
- 15 kg of chocolate

Release of this beam energy can happen in less than 100 us !

Protection is required if there are risks

To melt 1 kg of steel (copper is similar): about 800 KJ

Hazard and Risk for particle accelerators

- **Hazard:** a situation that poses a level of threat to the accelerator. Hazards are dormant or potential, with only a theoretical risk of damage. Once a hazard becomes "active“: **incident / accident**. **Consequences** and **Probability** of a hazard interact together to create **RISK**, can be quantified:

RISK = Consequences · Probability

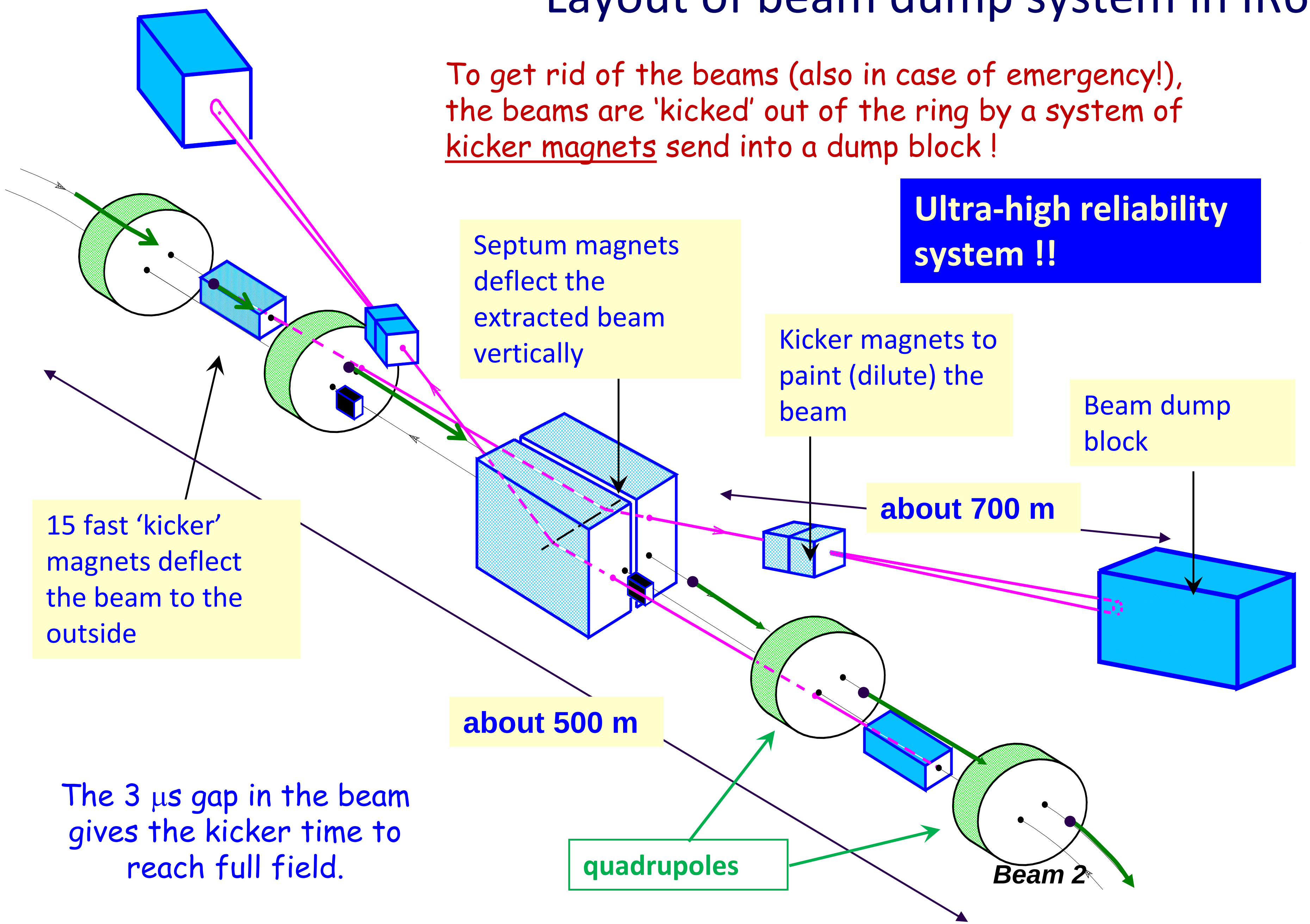
Related to accelerators

- Consequences of uncontrolled beam loss (in CHF, downtime, radiation dose to people, reputation)
- Probability of such event
- The higher the **RISK**, the more **Protection** needs to be considered
- Understanding the consequences and risk it of prime importance

Layout of beam dump system in IR6

To get rid of the beams (also in case of emergency!), the beams are 'kicked' out of the ring by a system of kicker magnets send into a dump block !

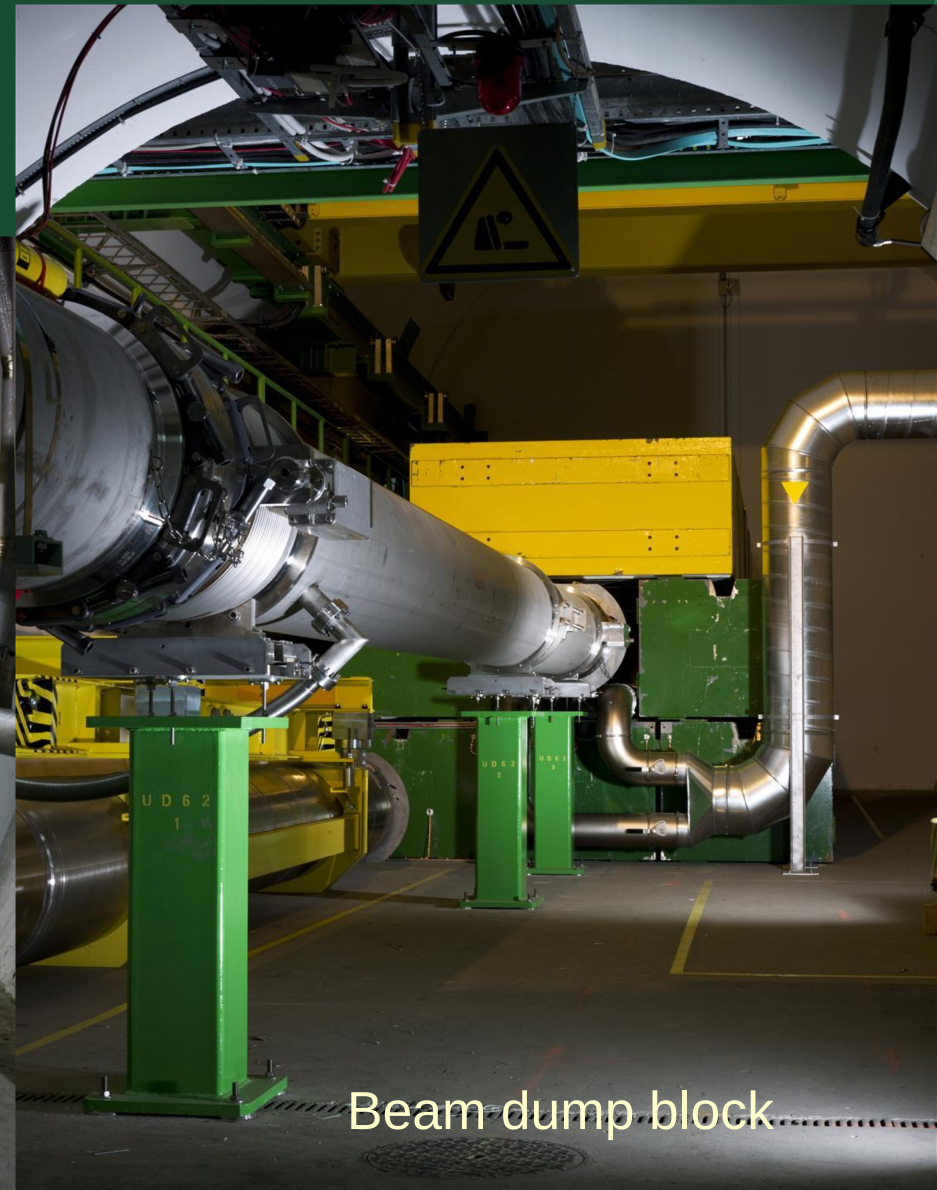
Ultra-high reliability system !!

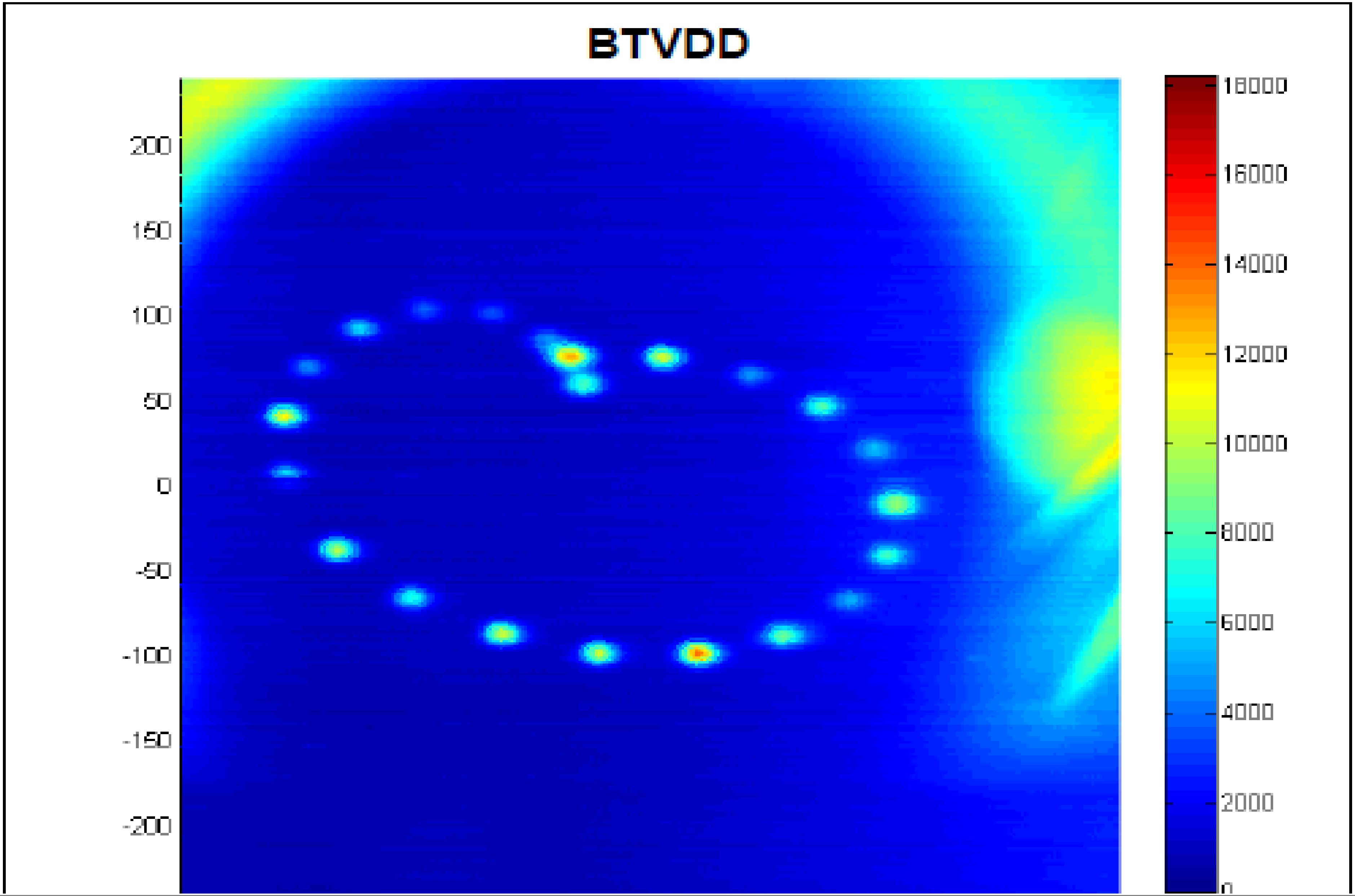


The 3 μs gap in the beam gives the kicker time to reach full field.

Beam dump line

700 m long tunnel to
beam dump block-
beam size increases





Proton bunches at the end of their life in LHC: screen in front of the beam dump block

Estimate the consequences

Calculation

- Assume that the entire beam is deflected into equipment, e.g. into a superconducting magnet
- Calculate using a simulation package (e.g. FLUKA)for the interaction and transport of particles and nuclei in matter to calculate the energy deposition, assuming simple geometry (e.g. copper cylinder)
- Calculate the expected temperature increase

Validation

- Performed at the SPS in 2004 (V.Kain PhD thesis)
- Compare the results with the simulations

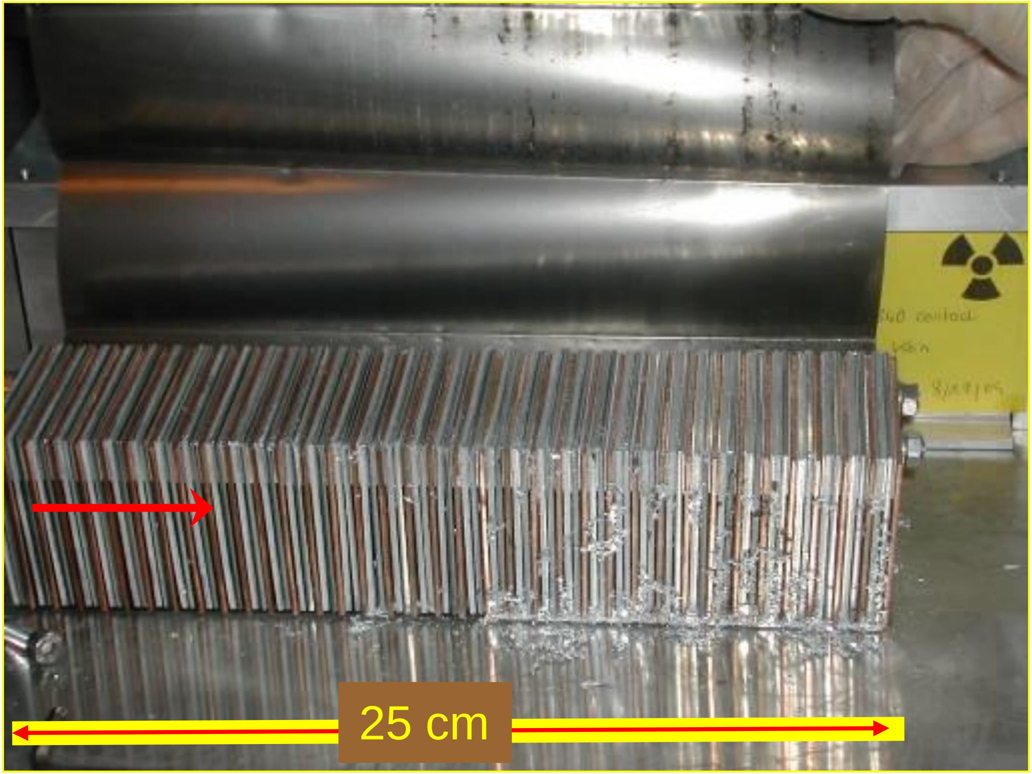
SPS experiment: Beam damage with 450 GeV protons

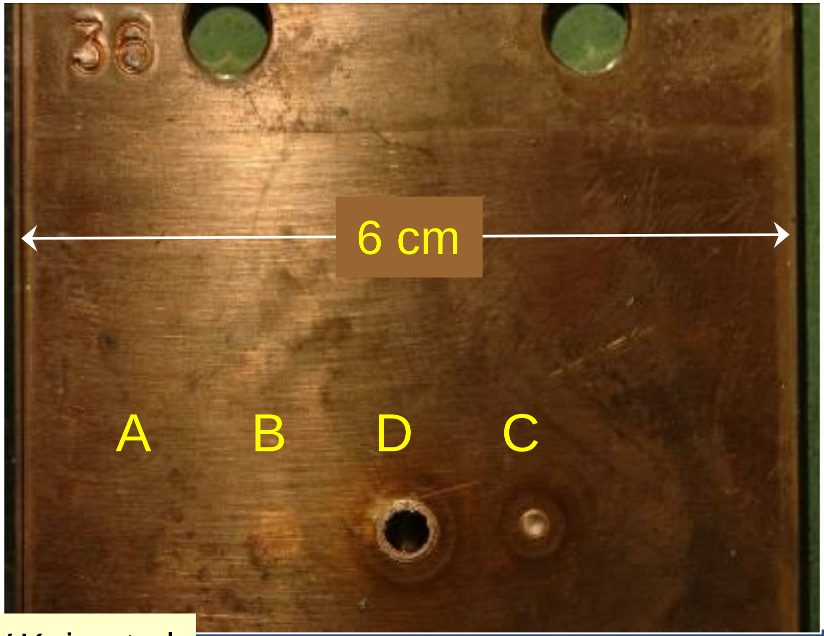
Controlled SPS experiment

- $8 \cdot 10^{12}$ protons clear damage
- beam size $\sigma_{x/y}$ = 1.1mm/0.6mm

stainless steel no damage

- $2 \cdot 10^{12}$ protons



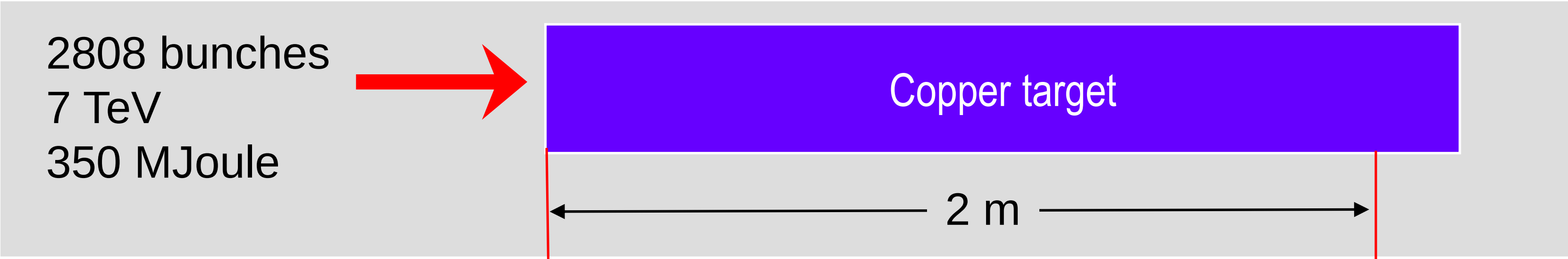


- 0.1 % of the full LHC 7 TeV beams
- factor of three below the energy in a bunch train injected into LHC
- damage limit ~200 kJoule

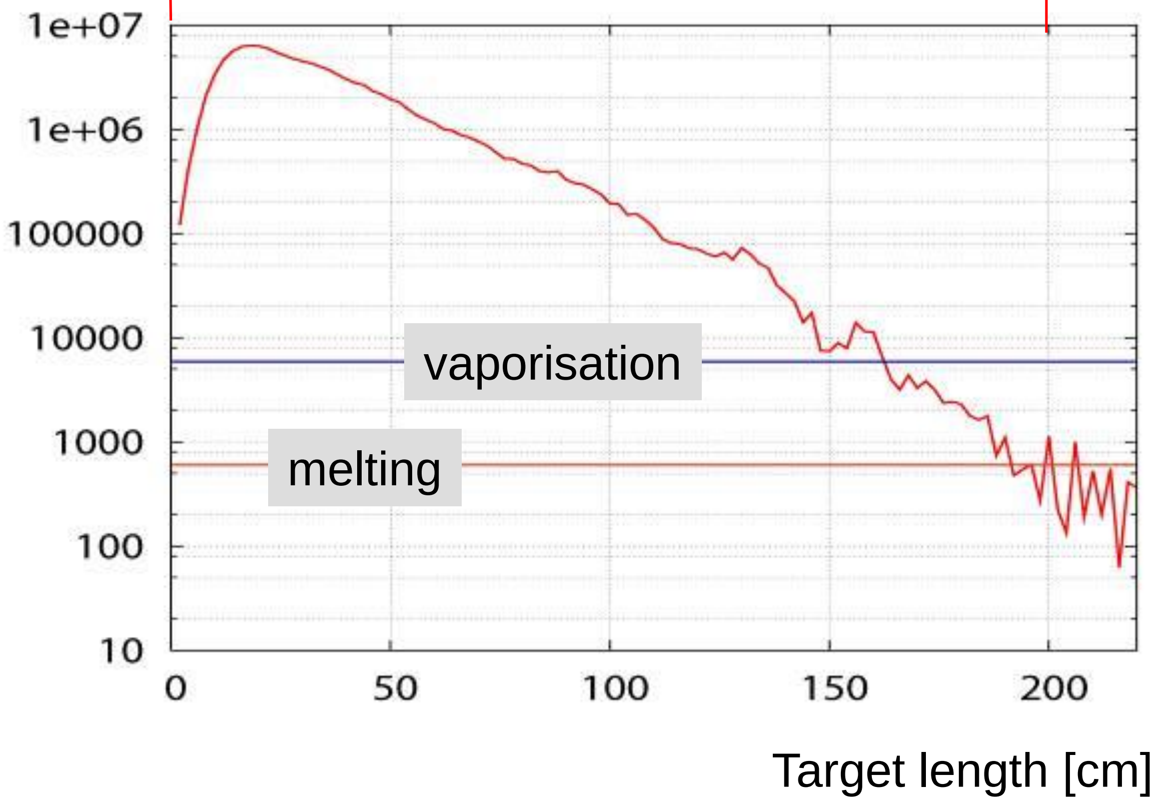
V.Kain et al

What happens if the beam has 1000 times more energy, and dimensions that are 10 times less ?

Full LHC beam deflected into copper target



Energy density
[GeV/cm³]
on target axis



Hydrodynamic tunnelling

- The beam impacts on a target, e.g. due to a failure of the injection of extraction kicker
- For LHC, bunches arrive every 25 or 50 ns
- The time structure of the beam plays an essential role
- The first bunches arrive, deposit their energy, and lead to a reduction of the target material density
- Bunches arriving later travel further into the target since the material density is reduced (predicted for SSC, N.Mokhov et al.)
- LHC: **tunnelling of the beam through about 30 m** is expected

Copper or carbon target

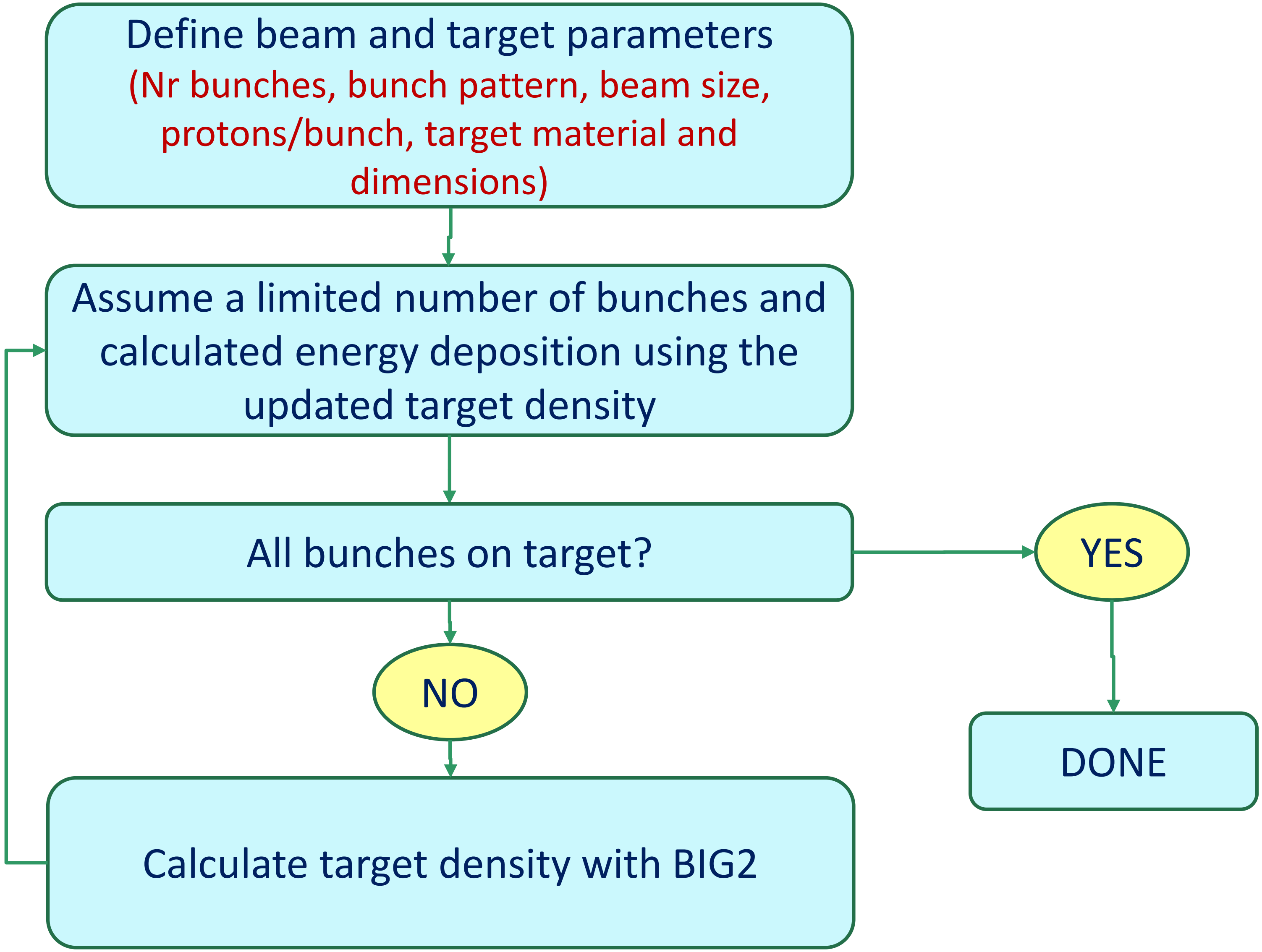
Collaboration with GSI, Naeem Tahir

- Competence in Plasma Physics required
- Established contact via Technical University Darmstadt with N.Tahir, GSI in 2003
- Started simulation work – using FLUKA and BIG2
  - FLUKA: particle shower code
  - BIG2: hydrodynamic code

1st static phase of calculations: Calculated energy deposition with FLUKA, and hydrodynamic response with BIG2 – extrapolation led to tunnelling depth for LHC between 35 m and 40 m

2nd dynamic phase: next page, refined results gave similar estimations

Calculation of hydrodynamic tunneling

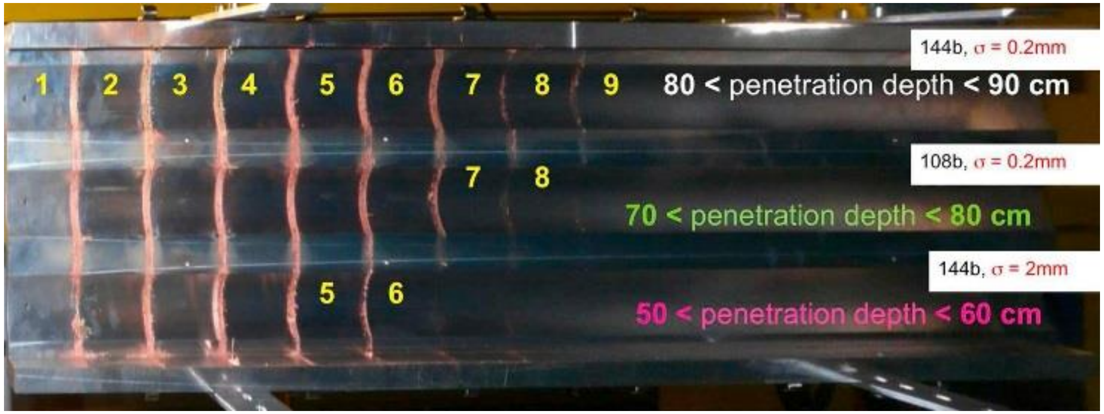


Validation at HiRadMat with SPS beam

- 144 bunches from SPS on copper target
- Compared with simulation results
- Good agreement

(b)

(c)



Using other tools

- At CERN, there is substantial experience with commercially available tools, in particular with Autodyn
- It is of interest to see, if identical results can be obtained with such tools

The end….

- More than 14 years of effort to understand the impact of high intensity proton beam on targets, with simulations and experiments
- Provided important input to estimate risk, and required level of protection

- Lot of work, very little CERN staff involvement (N.Tahir from GSI, and a number of PhD students and fellows over the years)

- Recently, another tool has been tried out (Autodyn), the results were compared with previous work
- Promising! Not to forget, a deep understanding of the underlying physics is further required

Thanks, and have a excellent workshop

….and be critical with results of simulations