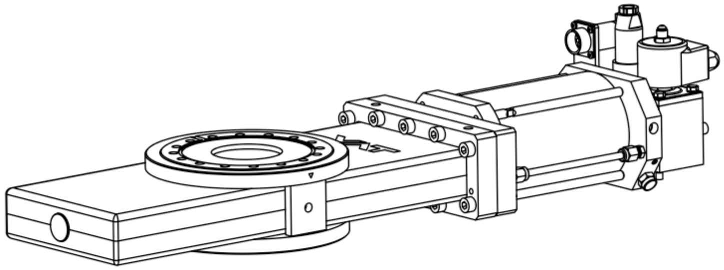
The impact of vacuum gate valves on the LHC beam



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EN / MEF

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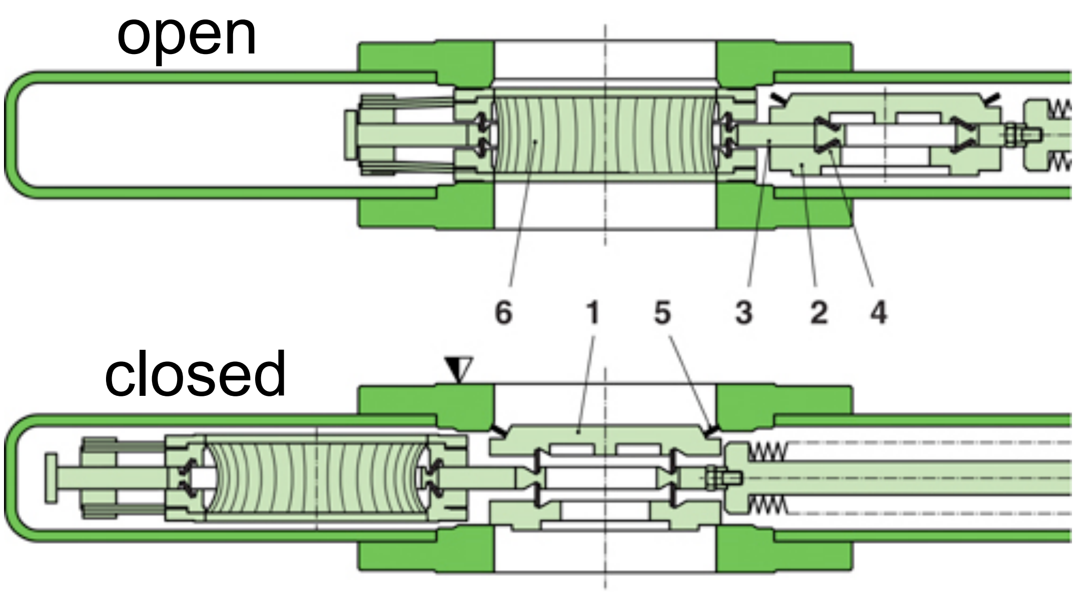
General comments

- Vacuum gates valves are located in all the LSS of the LHC ring (and not in the arcs or the DS).
- They close within 3-5 secs (depending on aperture) to sectorize the vacuum
  - This closure should trigger a beam dump request and dump the beam on a time scale very short w.r.t. valve closure time
- Need to check impact on the beam if a valve closes and does not trigger a beam dump request
- Representative valves studied in the machine to
  - Look at shower formation when a valve touches the beam halo (-> need valve before warm elements) to get peak power deposition
  - Look at formation of loss signal in subsequent BLMs
  - Check various valve-magnet-BLM geometries
  - The conclusions are **order-of-magnitude** only (errors discussed later)
- Done with FLUKA for
  - Candidate valves in IR7 for beam 1 losses
  - For 7 TeV, 5 TeV and 3.5 TeV
  - Many cases and studies made, with only key ones here (see note)
- What is not done is damage study for valve at exit of arc in front of warm collimator section (plus a detailed analysis of beam loss dists.)
  - And also a damage study of the valve itself

The gate valves : comments

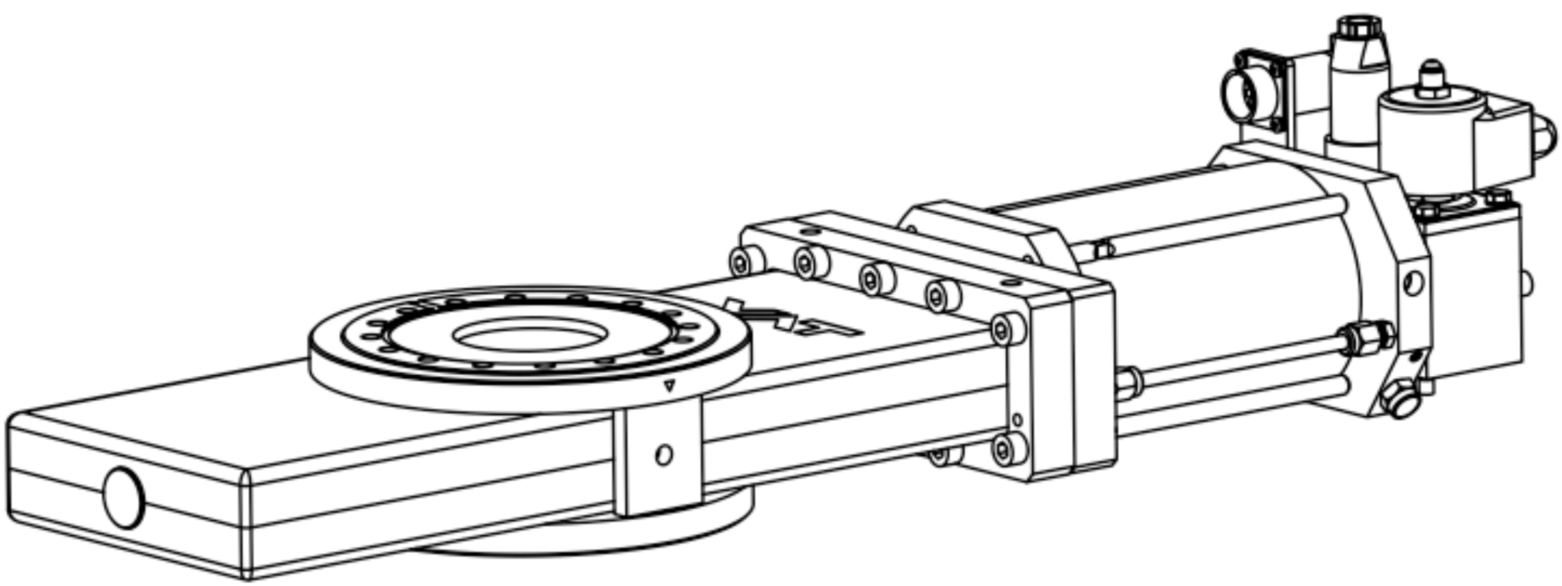
- Located in the LSSs to sectorize the LHC vacuum
  - The closure *should* issue a beam dump request
- Two variants : DN63 and DN100, referring to aperture, with a mixture of DN63's and DN100's in the machine
  - VVGST: aperture 63
  - VVGSF: aperture 63
  - VVGSH: aperture 100
  - VVGSW: aperture 100
- Closure time is ~ 3 s for a DN63, giving a speed of 20 mm/s, or 2 um in 1 turn (89 us). The closure speed is the same for the DN100 (so approx. 5 secs)
- When in the final close position, the door plate seals the beam pipe, but the beam sees a thicker 'flange' of approx. 1.8 cm of stainless steel as the valve closes
- The valves are not designed to encounter the beam at all
- The valve model is simple - 1.8 cm thickness of stainless steel, which models the real valve shown in the next few slides

Valve design

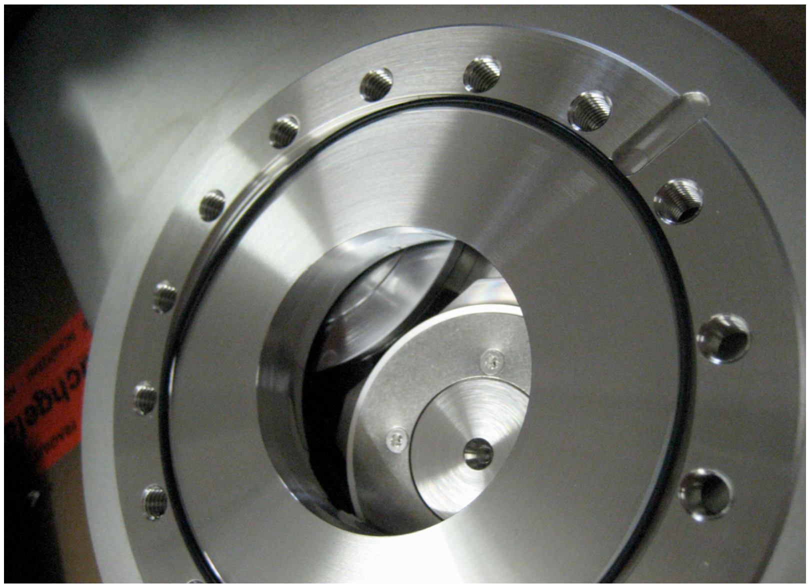


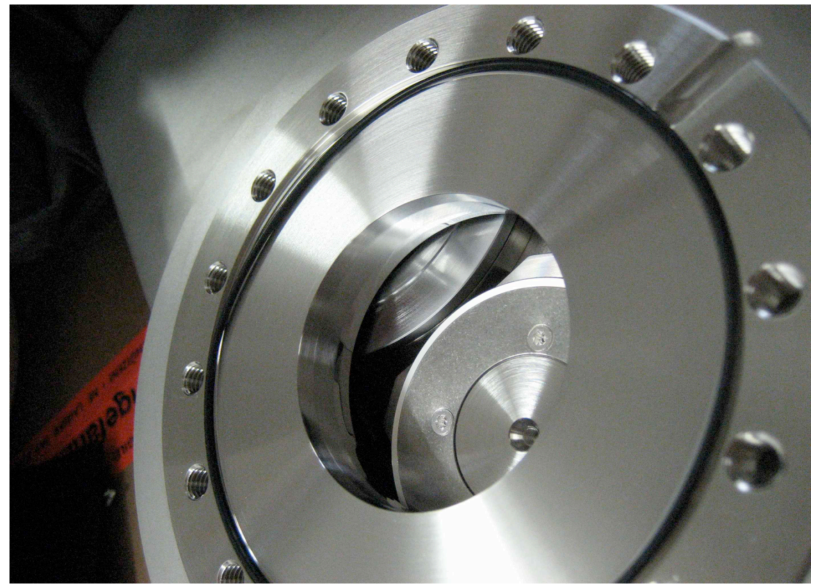
Description

- 1: valve gate
- 2: counter plate
- 3: guide plate
- 4: support
- 5: VATRING
- 6: RF-contact
- ▼: valve seat side

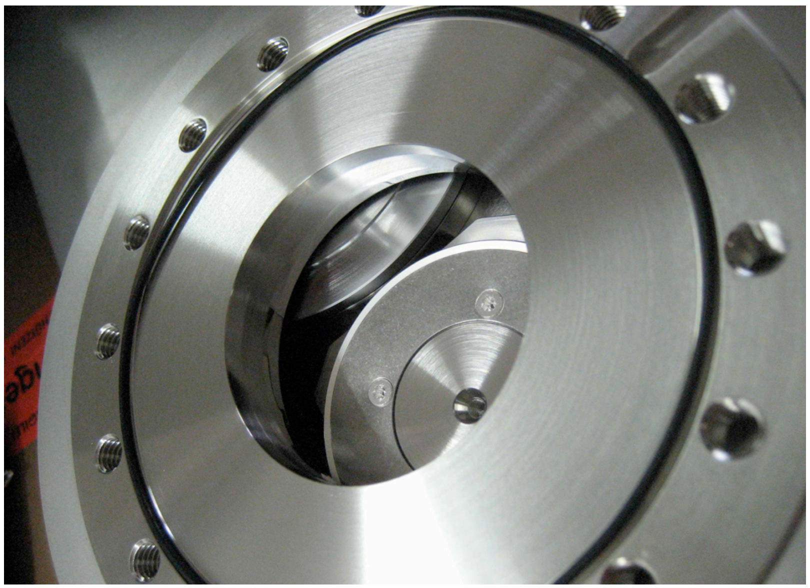


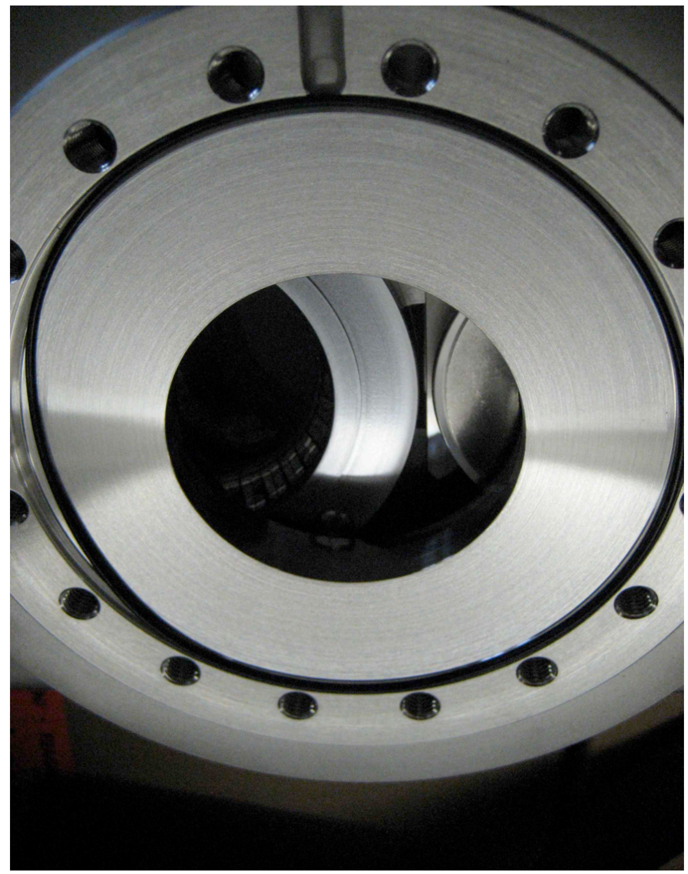
Valve pictures I



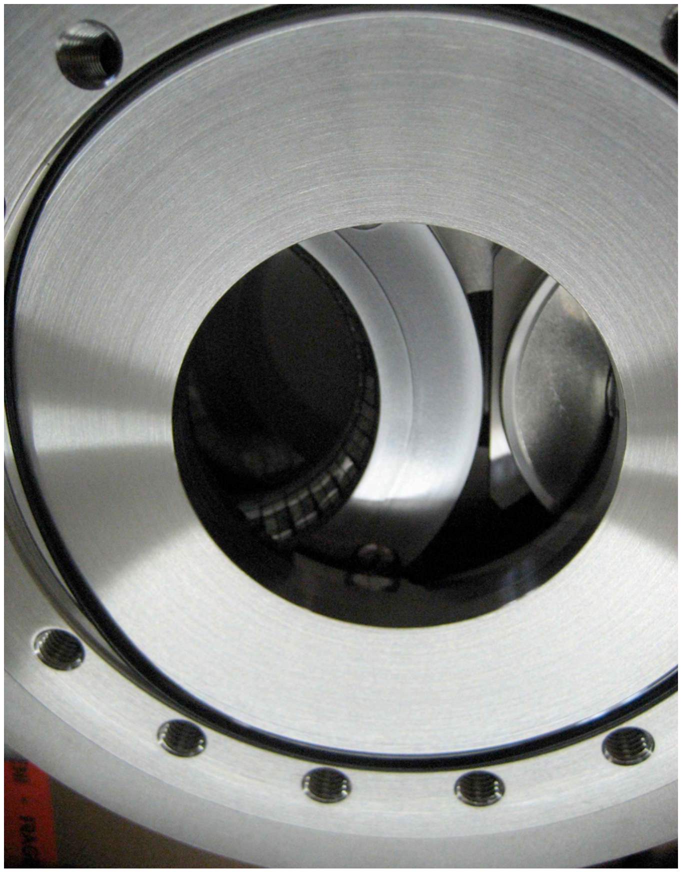


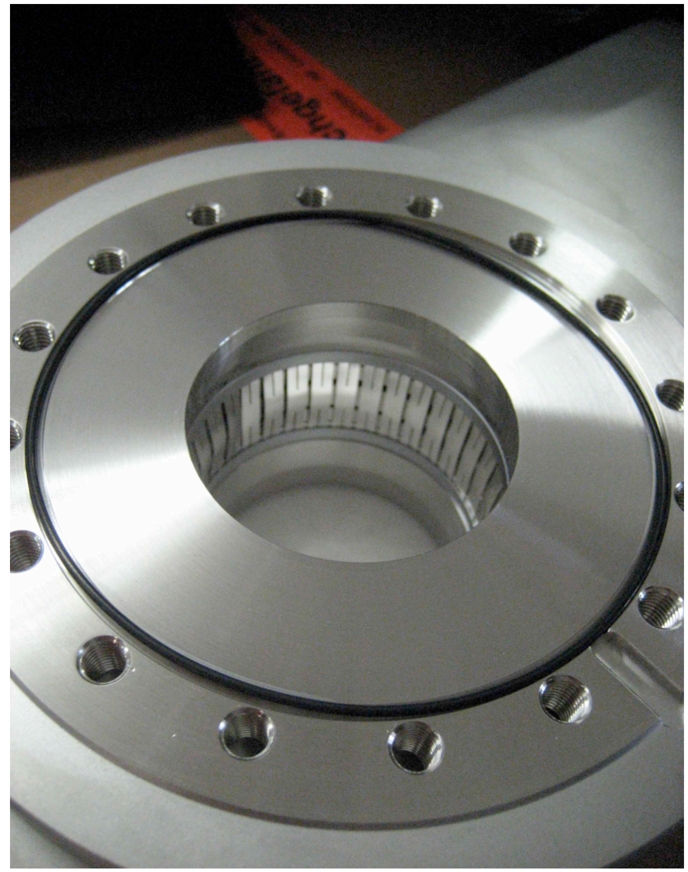
Valve pictures II



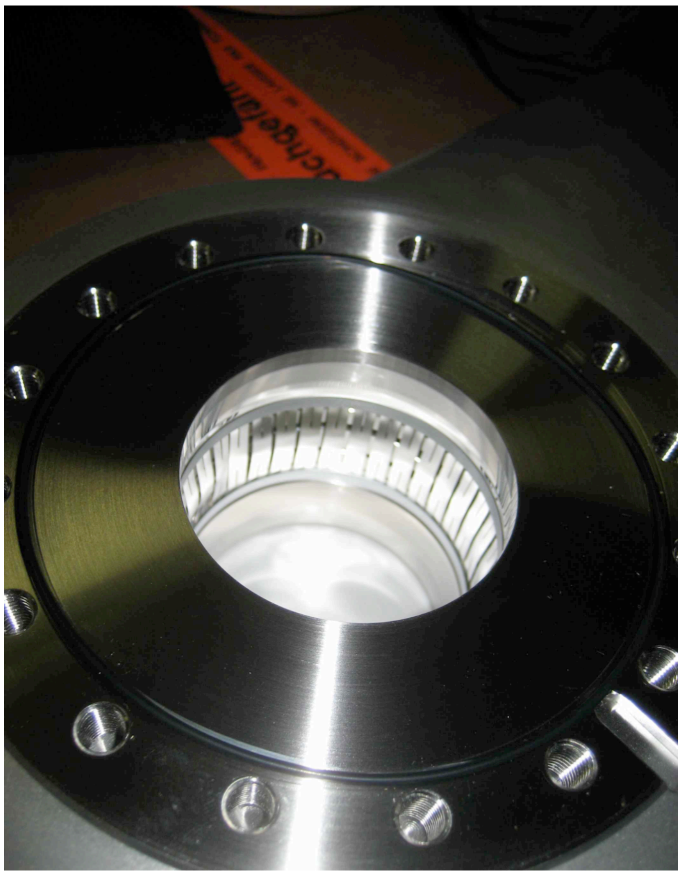


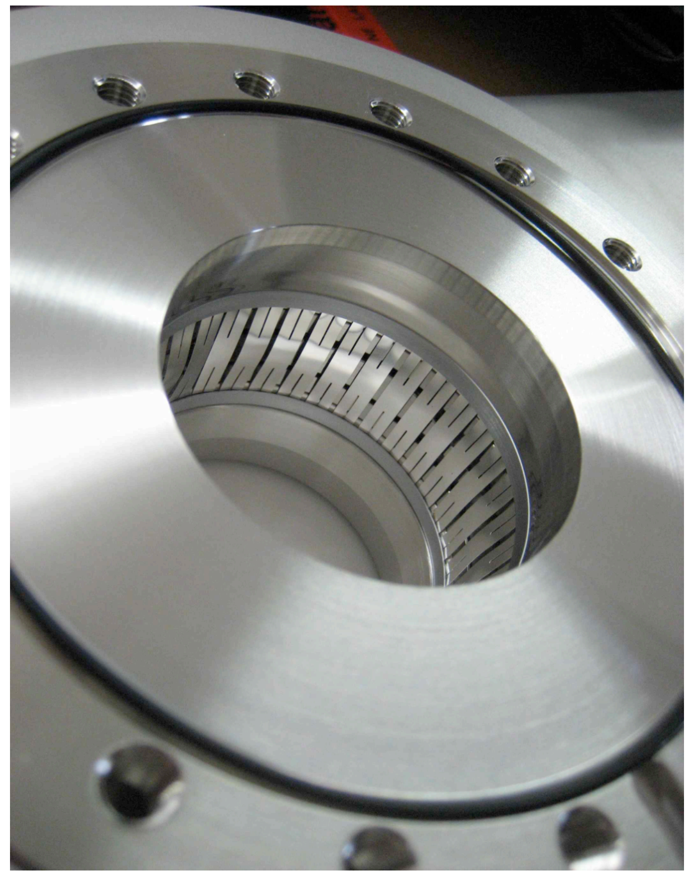
Valve pictures III





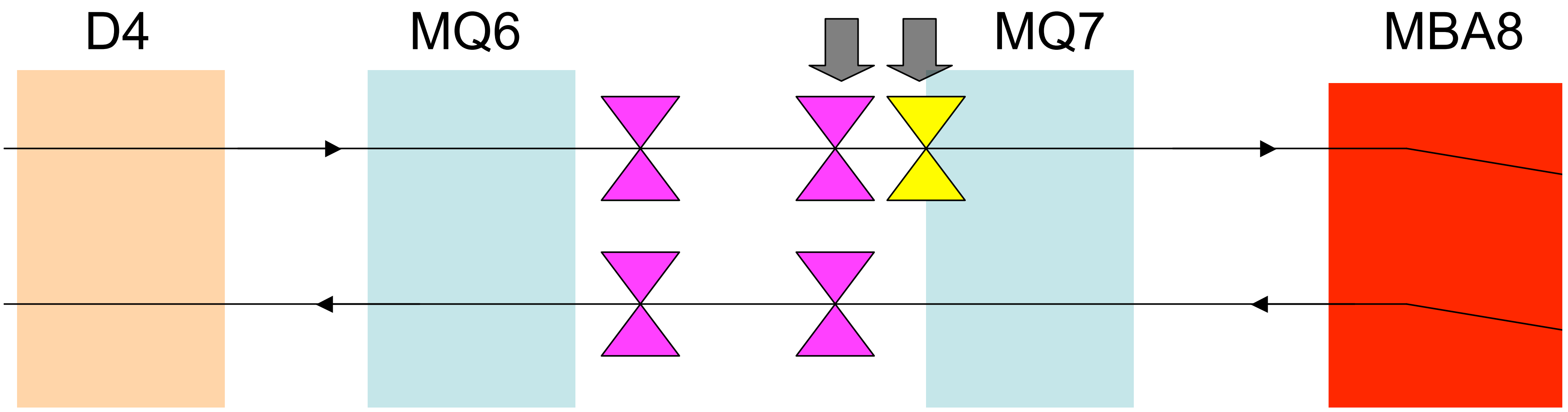
Valve pictures IV

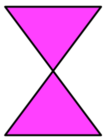




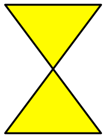
The candidate valves:

Valves before cold magnets and an arc:
Just before the arc in IR7 right



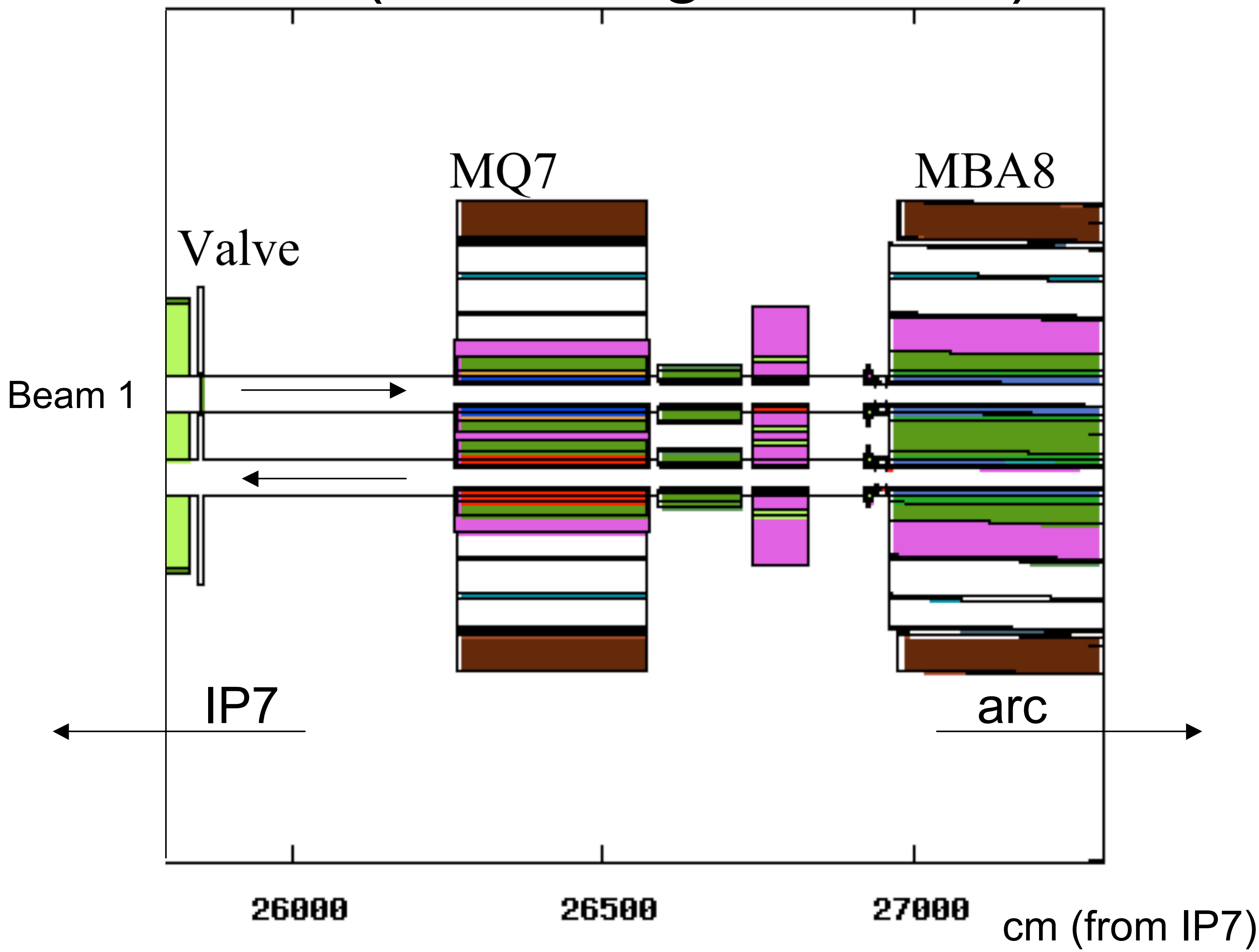


Real gate valves in the machine. All are DN63's except the bottom left which is a DN100. Nearest to Q7 is 'target valve'

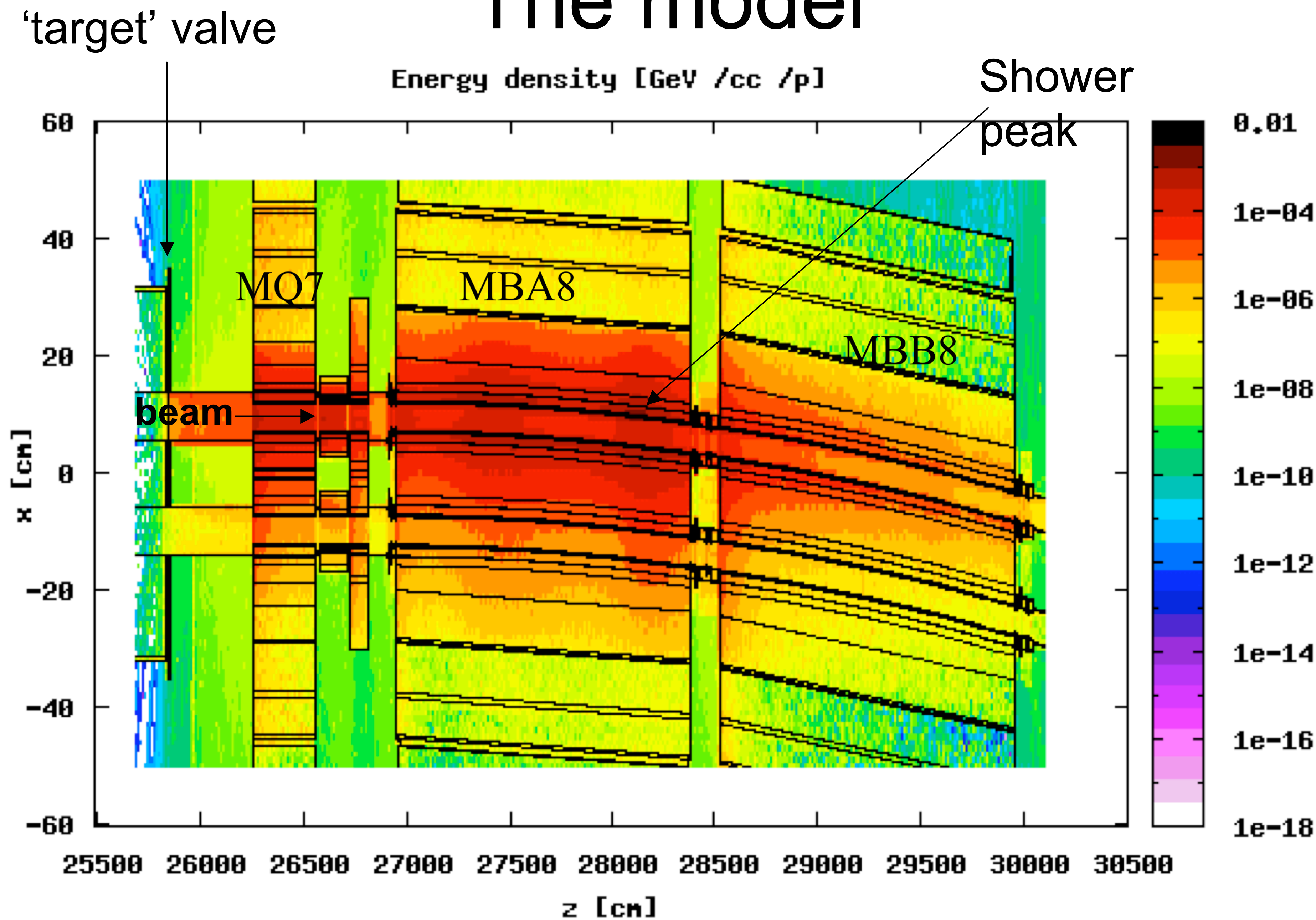


Fictitious gate valve immediately before Q7, to allow comparison to previously published magnet quench studies. 'study valve'

Layout in FLUKA model (Valve region detail)



The model

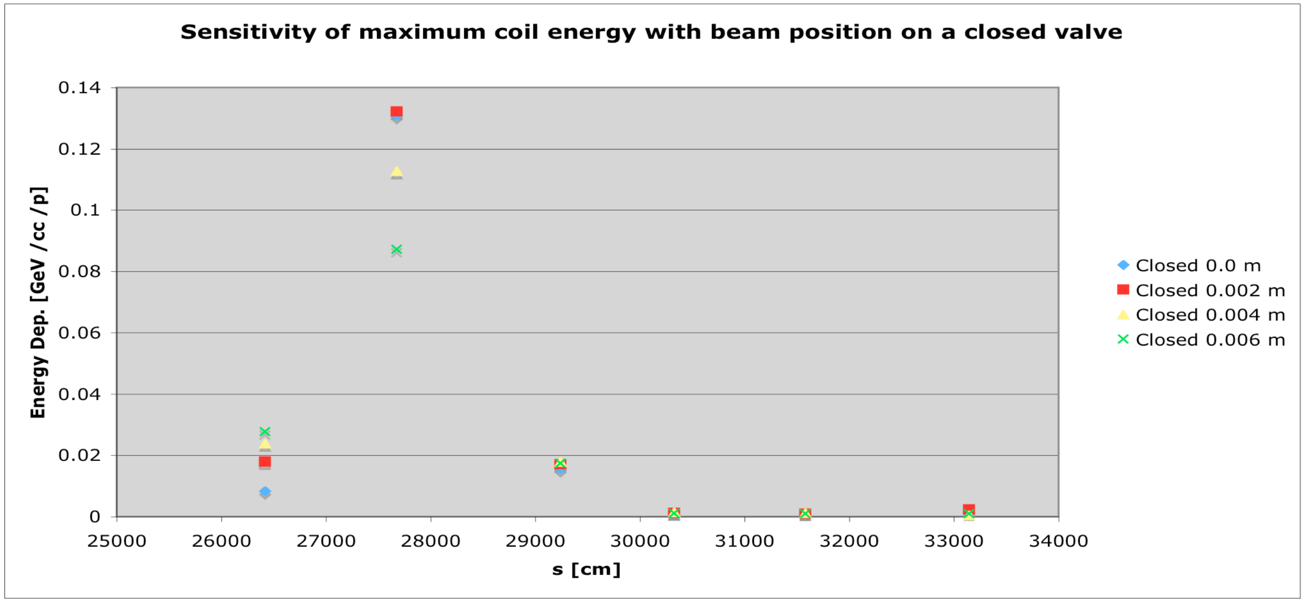


'target' valve
Energy density [GeV /cc /p]
Shower peak
MQ7
MBA8
MBB8
beam
60
40
20
0
-20
-40
-60
x [cm]
25500
26000
26500
27000
27500
28000
28500
29000
29500
30000
30500
z [cm]
0.01
1e-04
1e-06
1e-08
1e-10
1e-12
1e-14
1e-16
1e-18

Method and assumptions

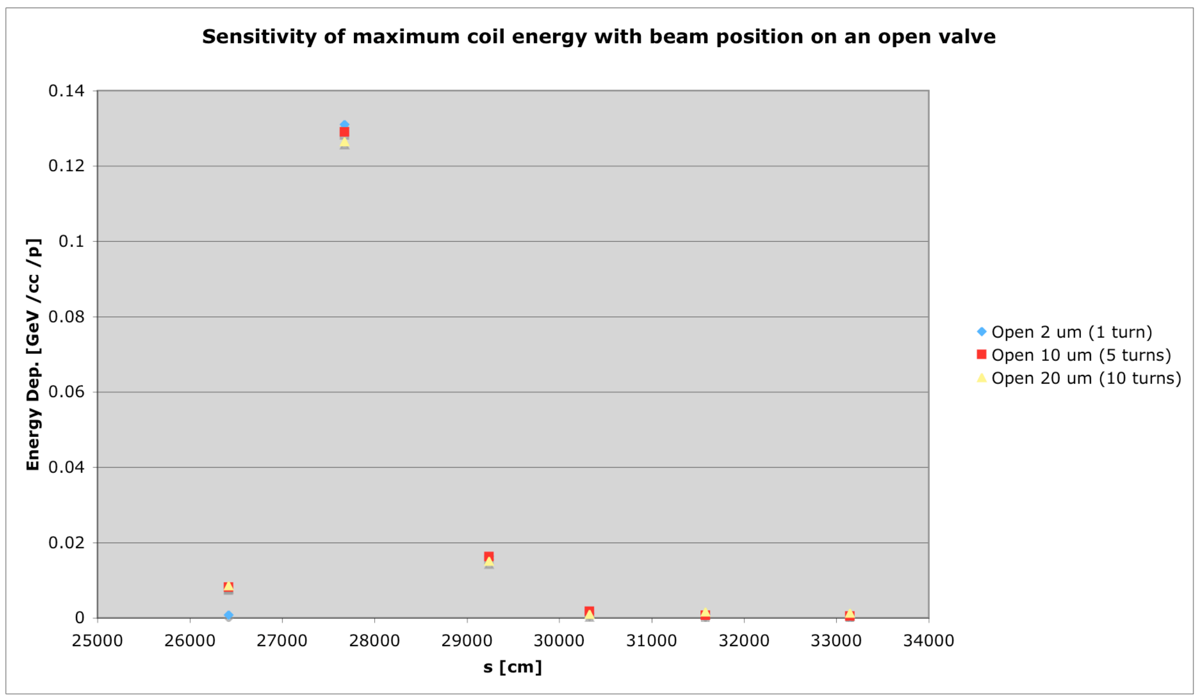
1. The cascade is modelled for a proton beam incident on the valve (about 10% interact) for
   - a beam incident on a closed valve with varying position and angle
   - A beam scraping a partially closed valve for variable impact parameter
2. The beam incident on the valve is modelled as a pencil beam, so the distribution is ignored. This gives correctly the position and order of magnitude of the energy deposition peak, and the order of magnitude of the BLM signal.
   - This needs to be relaxed to study heating and damage to the valve itself
3. The study is time independent, so the shower from proton impact on the valve is calculated, the peaks in the coil energy deposition studied and the charge seen in the BLMs calculated from the energy flow
4. The peaks in the SC magnet coils are inverted, to give the number of incident protons to give a quench, knowing the quench level, and in turn the normalised BLM charge for this number of incident protons
5. The BLMs are modelled as N_2 BLMs (standard) located along the length of an element ('theoretical' BLMs).
   - BLM detection threshold is 1 pC and typical charge at the quench level is O(nC), which can be compared to the quench thresholds set by the BLM team (more later)
6. The transient quench limits were taken to be 1 mJ /cc at 7 TeV, 3 mJ /cc at 5 TeV and 9 mJ /cc at 3.5 TeV.
   - The results scale with these assumptions
7. Previous quadrupole quench studies found a pencil proton beam incident on a target inside a SC quad required 1E7 - 1E8 protons incident to quench at 7 TeV
   - This is a known result to test the model for loss on the study valve

Sensitivity study I : (study valve)

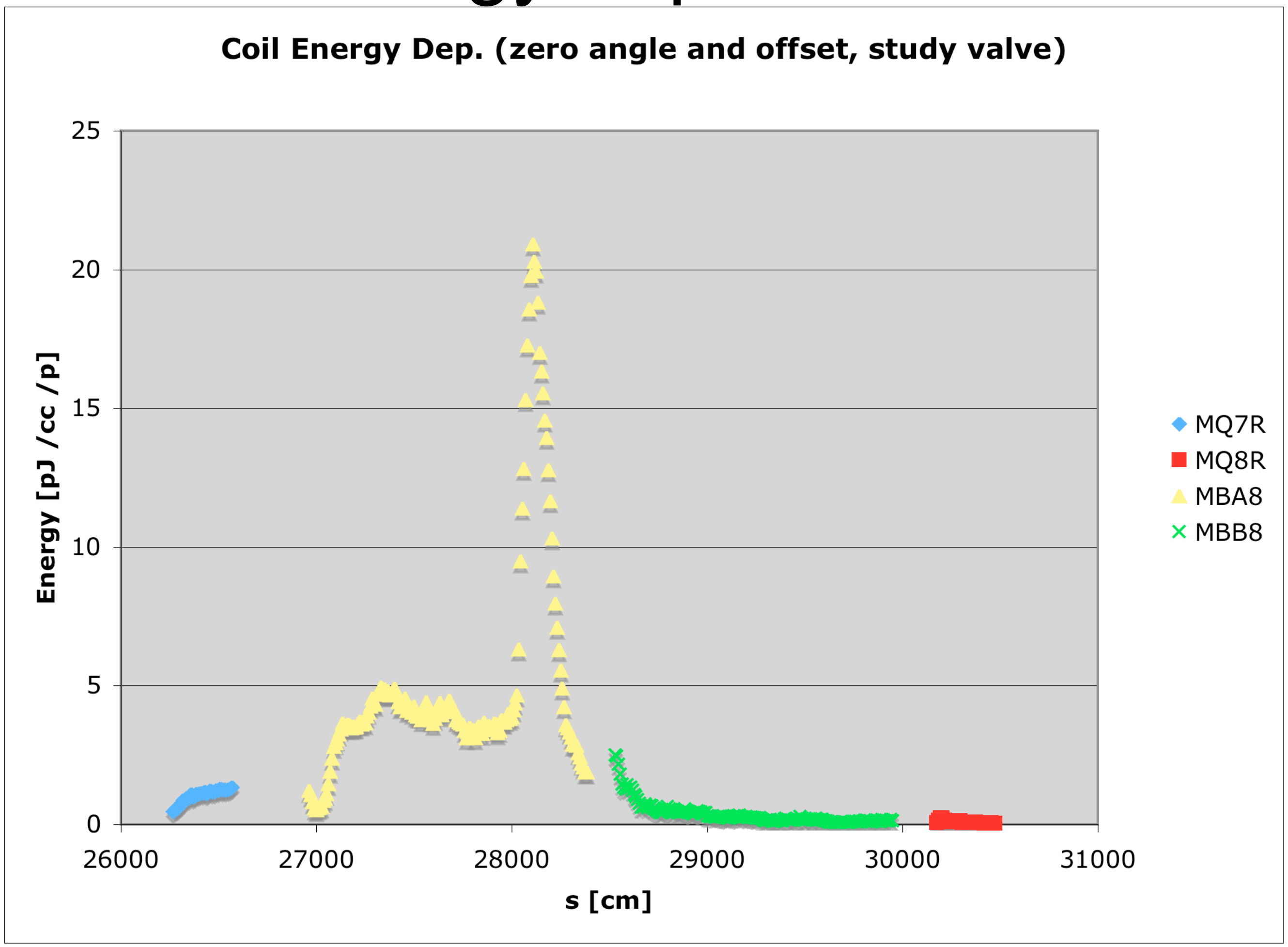


Pencil beam incident on a closed valve at variable x position. The position of the peak is fixed, and only reduces for a (large) 6 mm displaced beam.

Pencil beam incident on a partially open valve at increasing x impact parameter. The position of the peak is fixed, and the magnitude is sensitive. The open valve peak position and size agrees with a closed valve



7 TeV beam on closed study valve: Energy deposition



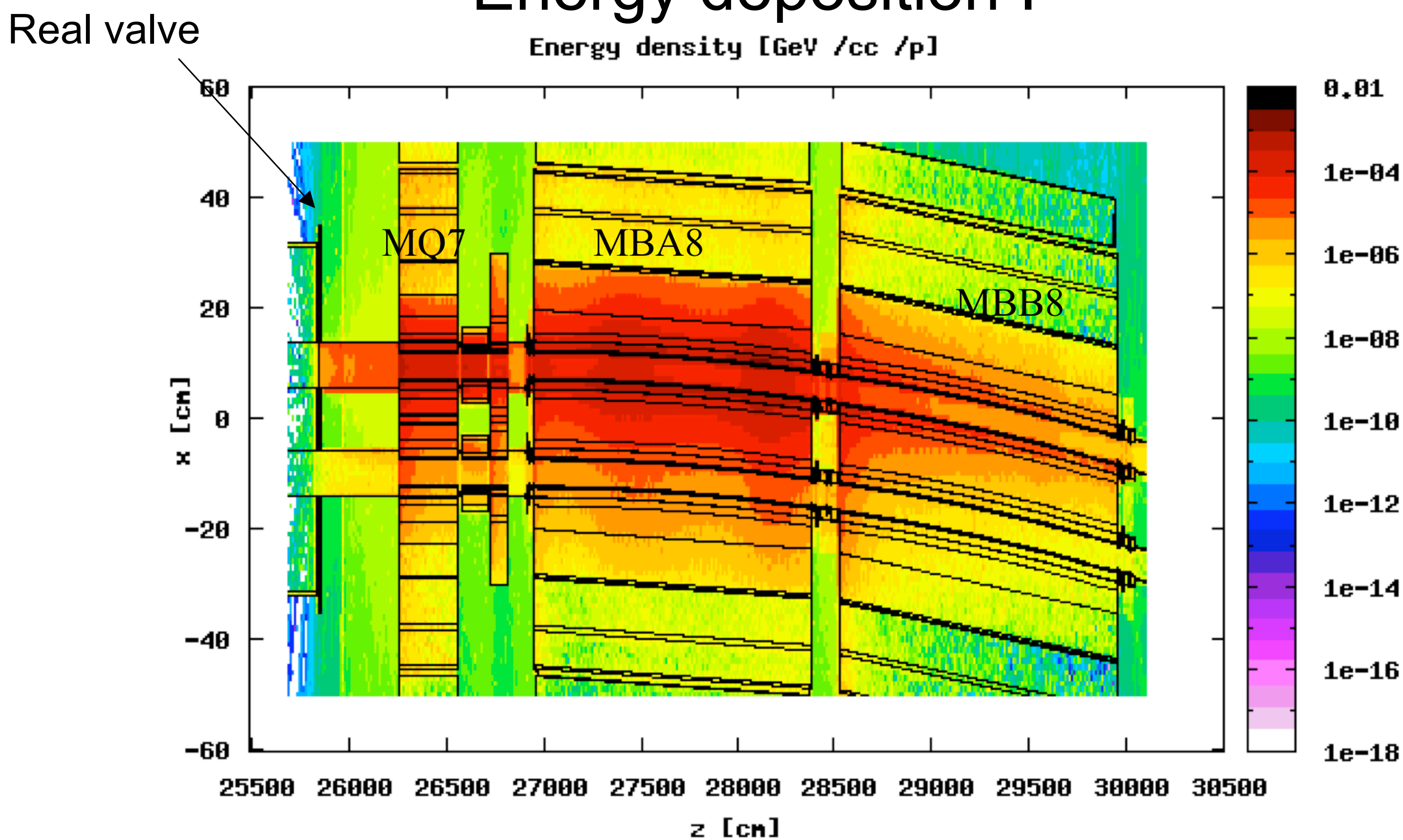
Source is a pencil beam at x=0 on the closed valve

Energy deposition peak is seen in MBA8, at 20.9 pJ /cc /proton (error 2.6%)

-> Quench limit of 1 mJ /cc reached when **5E7** protons incident on the valve

-> Good consistency with previous quench calculations of loss inside a quadrupole

7 TeV beam on closed **target** valve: Energy deposition I

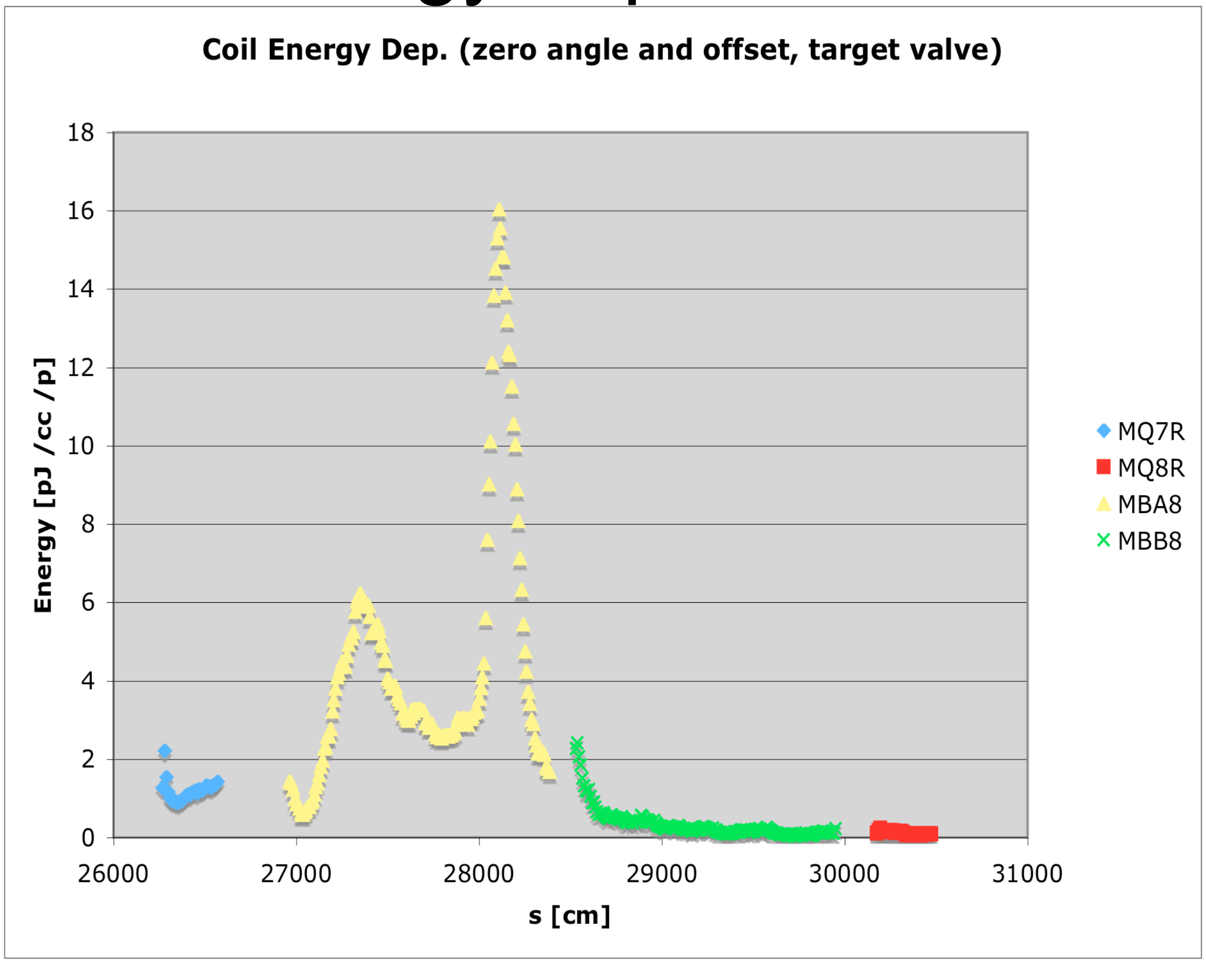


Source is a pencil beam at x=0 on the closed target valve

Energy deposition peak is seen in MBA8, at 16.1 pJ /cc /proton (error 3.6%)

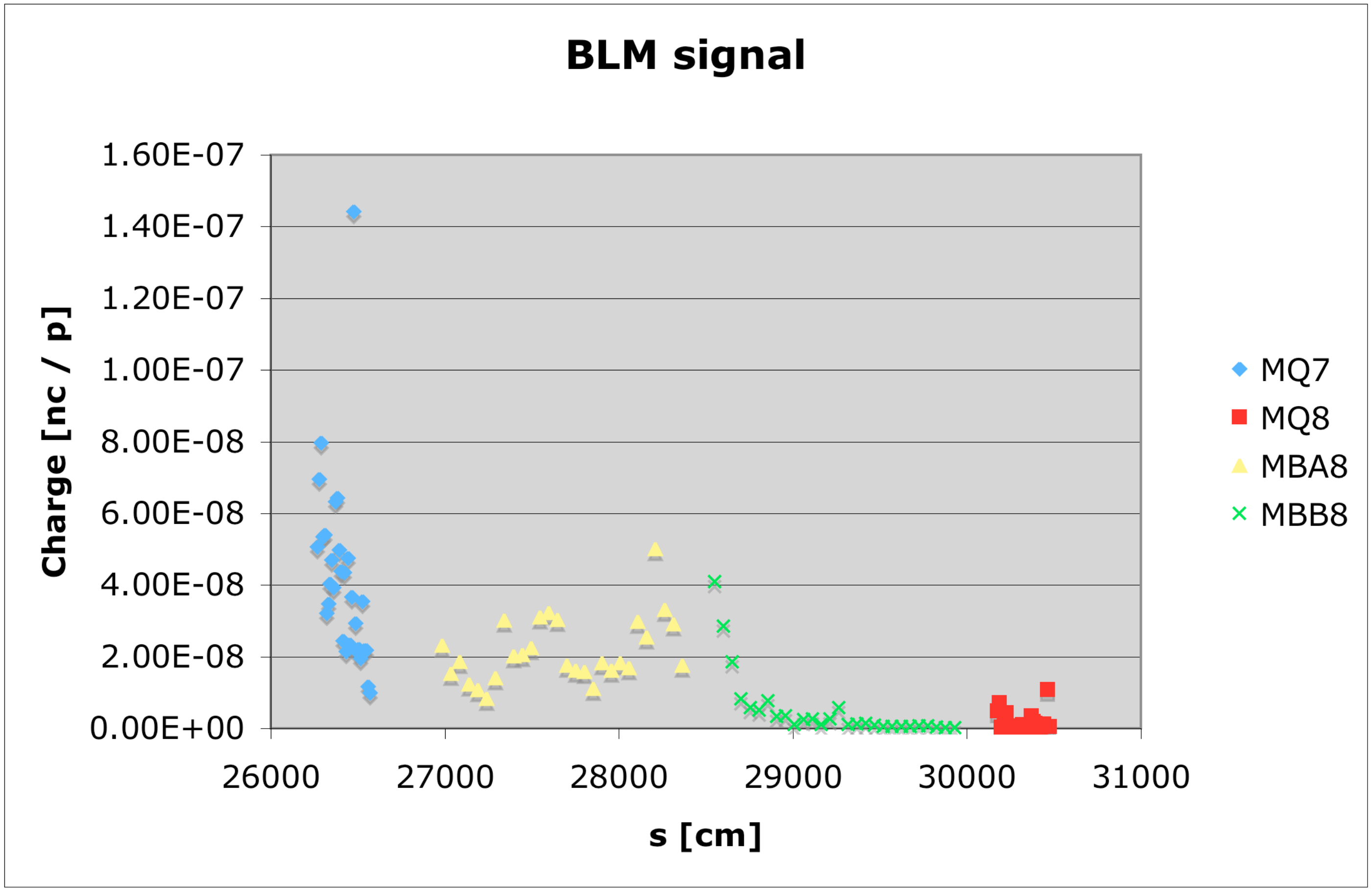
-> Peak in MBA8 is reduced and peak in MQ7 is increased w.r.t. the study valve

7 TeV beam on closed target valve: Energy deposition II



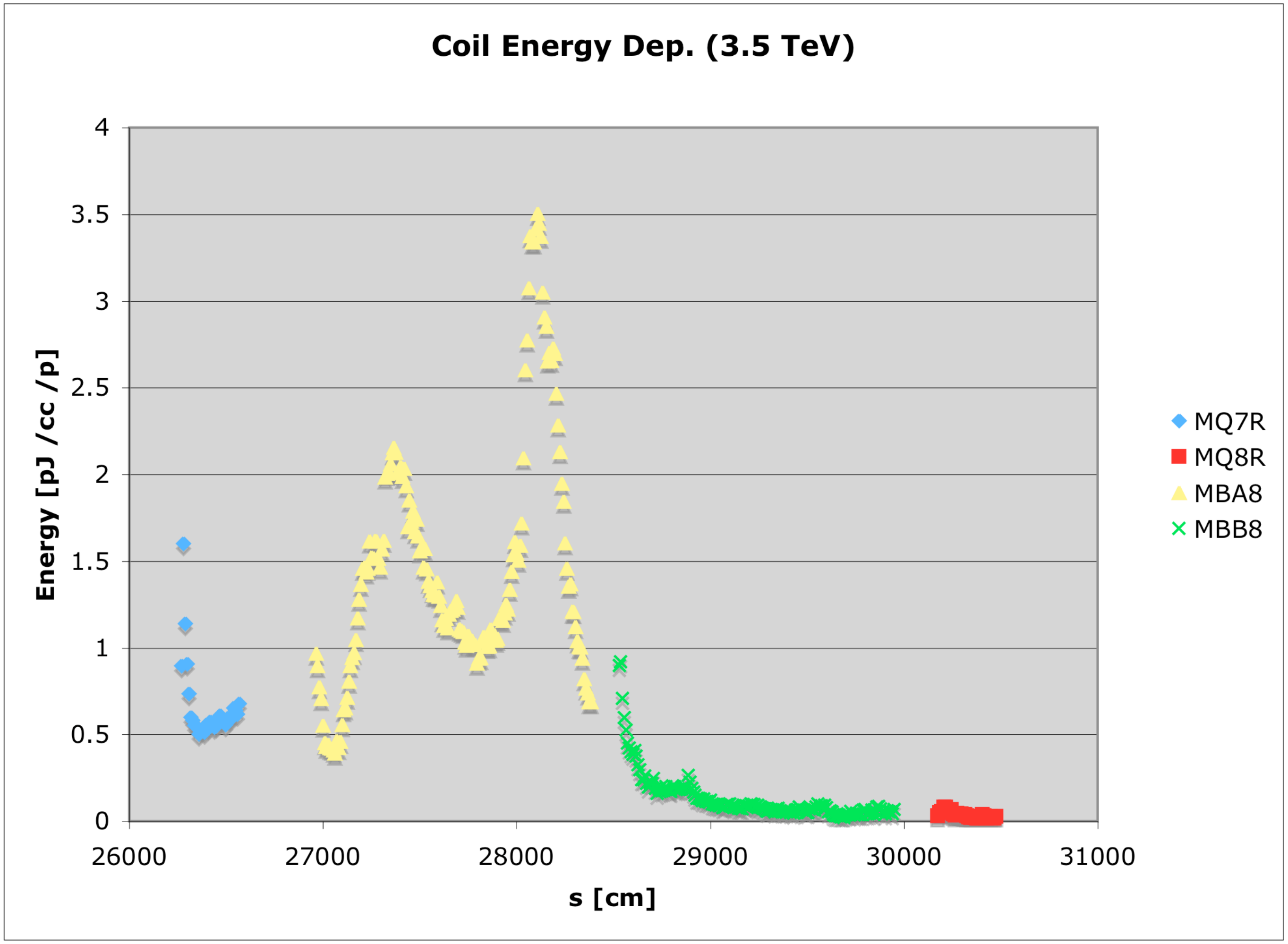
Source is a pencil beam at x=0 on the closed target valve
Energy deposition peak is seen in MBA8, at 16.1 pJ /cc /proton (error 3.6%)
-> Peak in MBA8 is reduced and peak in MQ7 is increased w.r.t. the study valve
-> Quench limit of 1 mJ /cc reached when **6E7** protons incident on the valve.

7 TeV beam on closed target valve: BLM signal



BLM peaks seen in the ‘theoretical BLMs of MQ7 and MBA8.
-> BLM in MQ7 sees a peak of 1E-7 nC /proton (order of magnitude)
-> At the quench level (6E7) the MQ7 BLM gets 9.0 nC, MBA8 BLM gets 3.1 nC
The numbers are essentially the same for 1 um impact parameter on an open valve
-> This is consistent with the BLM quench thresholds set the BLM team and > 1 pC
-> So the BLM can see a signal and detect the quench

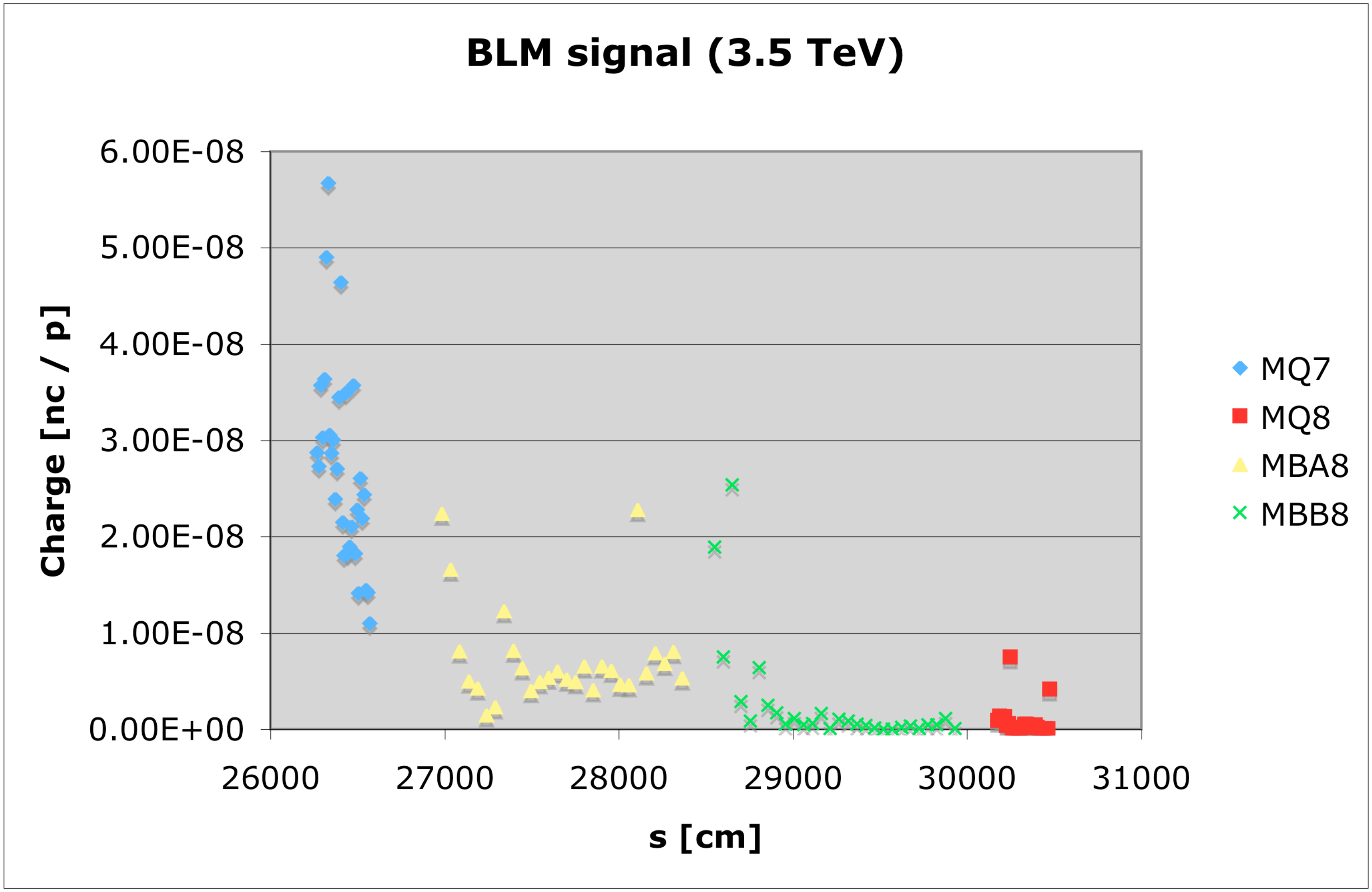
3.5 TeV beam on closed target valve: Energy deposition



Source is a pencil 3.5 TeV beam at x=0 on the closed target valve
Energy deposition peak is seen in MBA8, at 3.5 pJ /cc /proton (error 2.8%)

-> Quench limit of 9 mJ /cc reached when **3E9** protons incident on the valve.

3.5 TeV beam on closed target valve: BLM signal



BLM peaks seen in the ‘theoretical BLMs of MQ7, MBA8 and MBB8.
-> BLM in MQ7 sees a peak of 6E-8 nC /proton (order of magnitude)
-> At the quench level (3E9) the MQ7 BLM gets 146 nC, MBA8 BLM gets 65 nC
The numbers are essentially the same for 1 um impact parameter on an open valve
-> So the BLM can see a signal and detect the quench

Estimation of BLM-quench time lag

- As the valve closes onto a beam, the BLM will see a signal before the quench limit of the nearby magnets is reached…can we estimate this time lag…roughly?
- If we assume a Gaussian beam (a big assumption) then we can integrate over the distribution to find the physical distance into the beam when
  - The BLM receives it's threshold of 1 pC
  - The quench limit is reached for the first magnet
- Difference/speed gives time lag **order of magnitude** only

- Doing this for the cases considered, the time lag is a few ms

  -> for example 7 TeV beam onto the target valve, the lag is 2.6 ms

  -> Enough time for the beam dump to be triggered

  -> So the BLMs can detect the quench, and there is a margin prior to the quench

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BLM Applied thresholds	7 TeV Applied, uGy	7 TeV, Applied, nC
MB	21	1.1
MQ 1	75	4.1
MQ 2	24	1.3

Can compare BLM signals to the applied (~ 1/3 of maximum) BLM quench thresholds (remember we talk of orders of magnitude)

For loss in MQ7, BLM in MB sees 1.9 nC

For loss in front of MQ7, BLM in MQ sees 9 nC

-> calculations consistent with threshold (cross-check)

-> calculations in excess of the applied thresholds

Summary table for all energies

Valve	Config	E, TeV	Peak	pJ /cc /p	Error %	Qunech Level mJ /cc /p	P's to quench	BLM sig.	BLM sig. nC /p	nC	Time ms
Study	Closed	7	MBA8	20.9	2.6	1	5E7	MBB8	4E-8	1.9	2.3
Study	Open	7	MBA8	21.0	2.0	1	5E7	MQ7	6E-8	2.9	2.4
Target	Closed	7	MBA8	16.1	3.6	1	6E7	MQ7	1E-7	9.0	2.6
Target	Closed	3.5	MBA8	3.5	2.8	9	3E9	MQ7	6E-8	146	4.1
Target	Closed	5	MBA8	7.8	2.5	5	4E8	MQ7	8E-8	32	3.3
Far	Closed	7	MQ7	5.4	8.2	1	2E8	Coll.	8E-8	15	3.0

Key 7 TeV case

Not all cases shown, but representative ones

Key 3.5 TeV case

Summary and conclusion I

1. The LHC gate vacuum valves should trigger a beam dump when they close, and we've checked the impact on the beam if this request is not made.

2. A candidate set of valves was modelled in FLUKA in the right side of IR7, in the region before the cold MQ7 and the arc dipoles.

3. A pencil beam incident on the valve cascaded through the downstream magnets, and the energy deposition into SC magnet coils and BLMs scored.

4. For the case of a study valve located immediately before MQ7
    1. The position and magnitude of the peaks were insensitive to the position and angle of the beam on a valve in the open or closed position
    2. The number of incident protons to quench MQ7 agreed with previous studies
    3. The BLM current seen at the quench level was consistent with BLM quench thresholds

5. For the case of the beam striking the DN63 in the drift before MQ7

    1. The shower peak is seen in MBA8, which sees 16.1 pJ /cc /proton the valve
    2. At the quench level of 1 mJ, 6E7 protons are incident on valve.
    3. At this level, the BLM receives 9 nC, and receives 1 pC 2.6 ms before the quench level is reached
    4. So the BLM sees a signal, can detect a quench and there is a margin before the higher damage level

6. For the same valve at 3.5 TeV, the loss pattern is the same, and the BLM receives 1 pC 4.1 ms before the quench level of 9 mJ /cc is reached.

Summary and conclusion II

1. The conclusion that the BLM sees a signal before the quench level is reached and the signal at the quench level is consistent with the BLM quench levels set the by the BLM team is valid for all energies and valves studied.
    1. **The BLM can see a signal and can detect a quench**

2. The uncertainties in this study:
    1. Statistical: small for the energy deposition peak, larger (order of magnitude) for the BLM signal
    2. Systematic:
        1. MB beam pipe is modelled piece-wise, rather than continuous
        2. Pencil beam assumption versus real beam distribution
        3. The reality is a very small impact parameter, where larger uncertainties are inherent

3. To complete the study, a check will be made with the vacuum group of the logic conditions which would cause a valve to enter the beam (e.g. power-cut), which could become new protection interlocks for additional protection

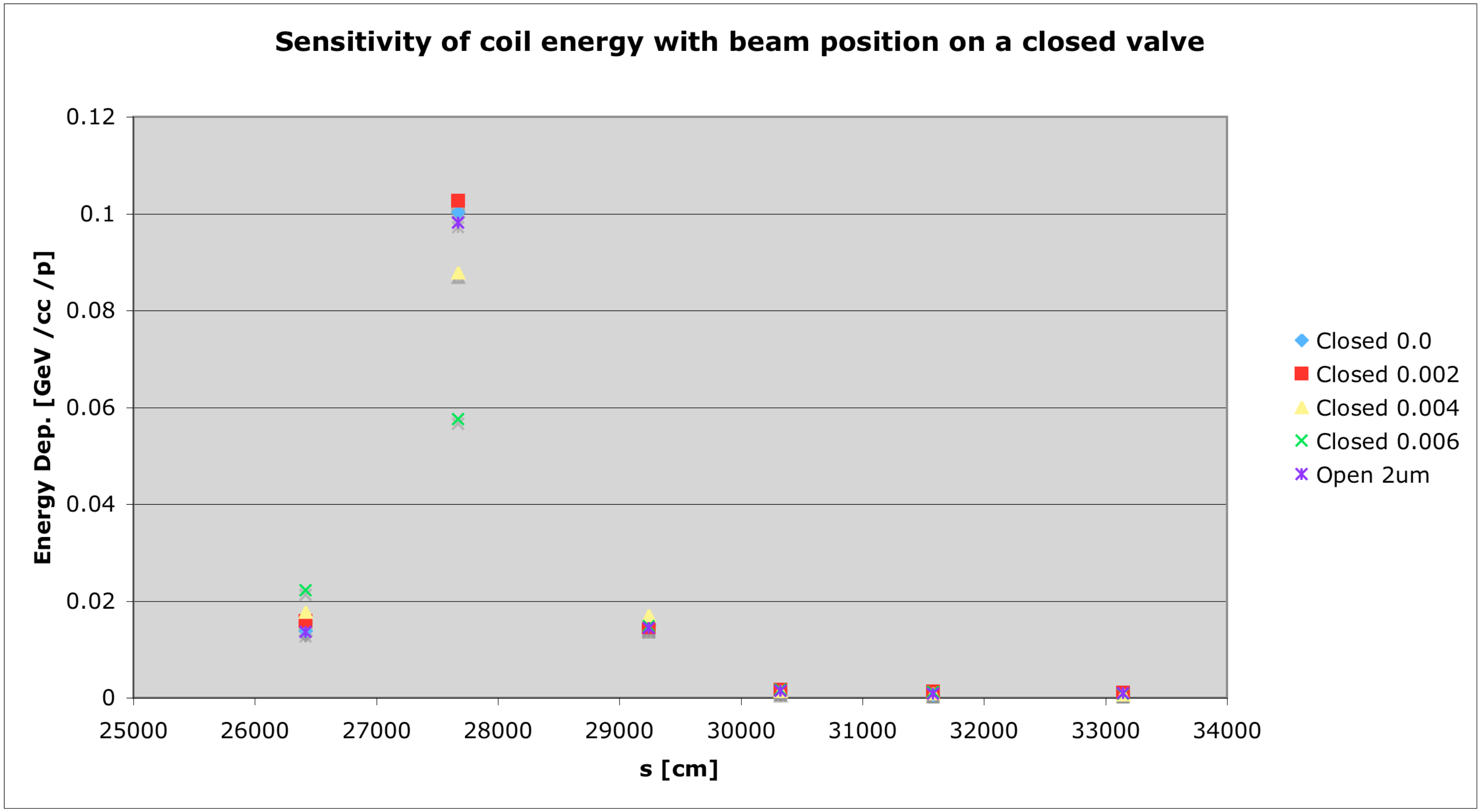
4. This study looked at quench levels, and not element or valve damage levels
    1. What about a valve closing before a warm section full of collimators (with higher BLM thresholds)?
    2. What about damage to the valve itself?

5. Finally, there is an interlocked gate valve either side of the experiments, between the TAS and Q1, and positioned very close to Q1
    1. If the experiments are interested in checking any possible impact of this valve closure with beam, we can provide all the necessary information

BACKUP

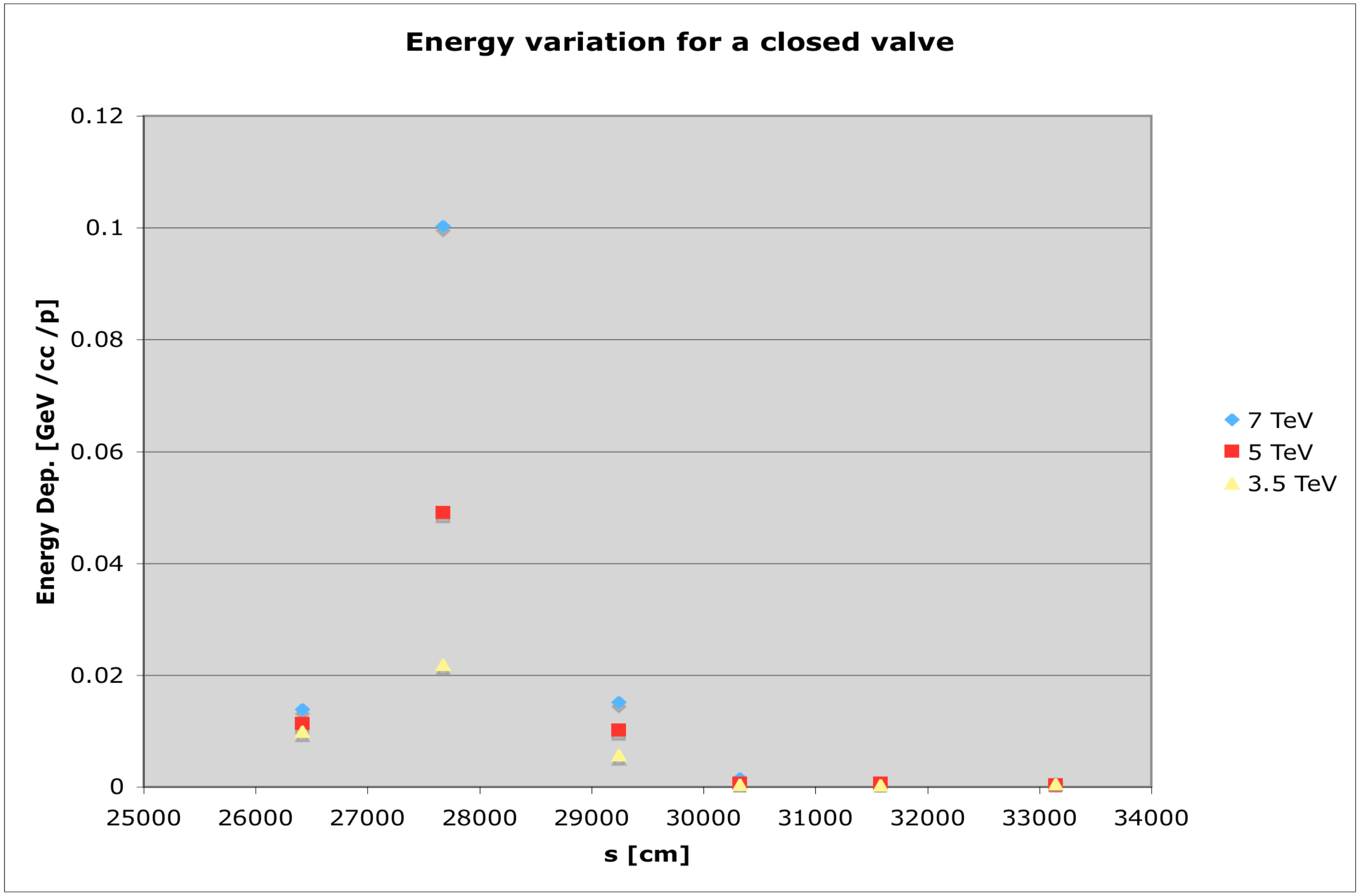
Sensitivity study : (target valve)

Now switching to the **target valve** located in the drift before MQ7



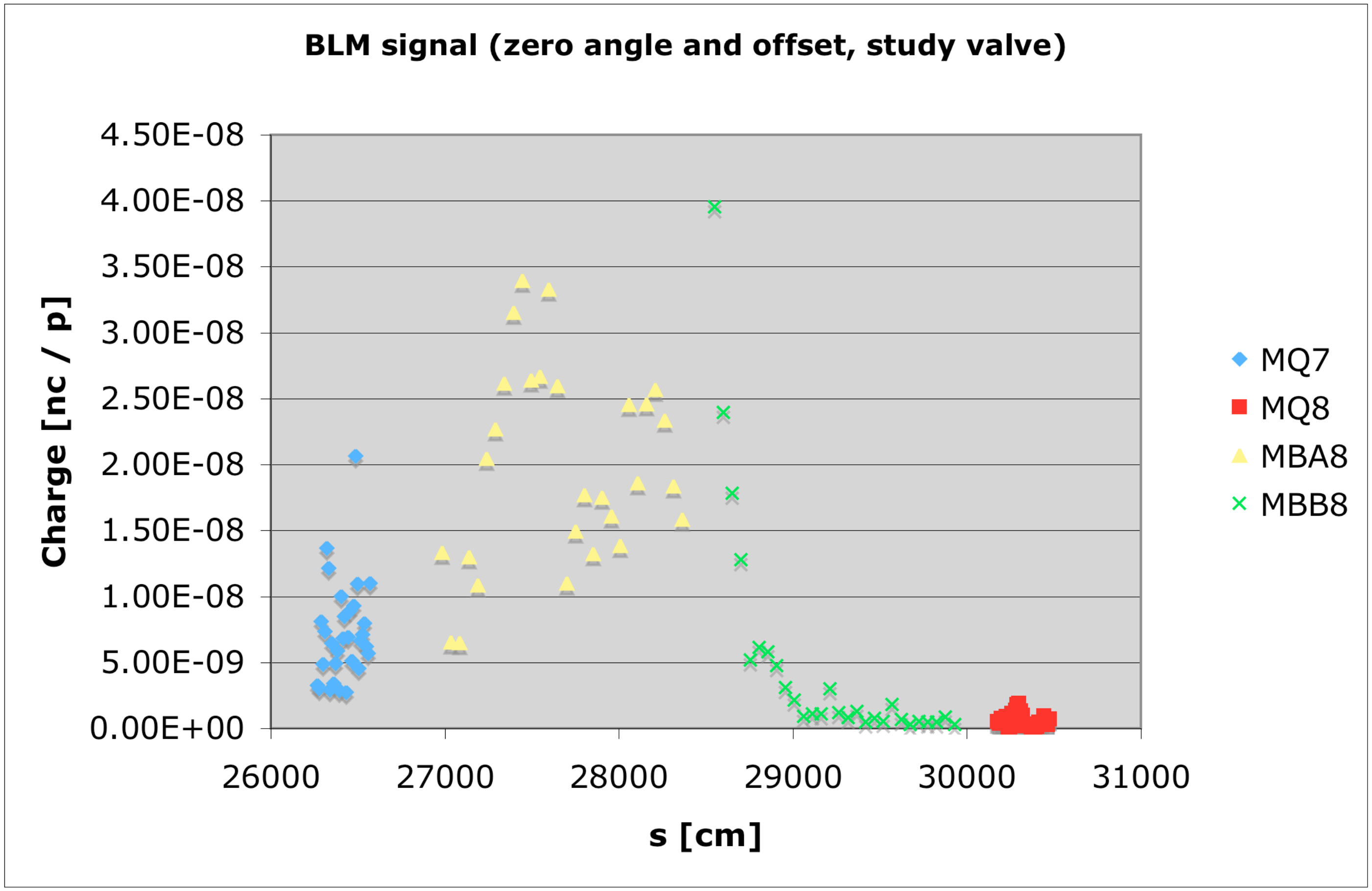
Remake sensitivity study of variable beam position on a closed valve and a 1 turn impact parameter on an partially open valve….everything okay

Energy variation of shower peak magnitude

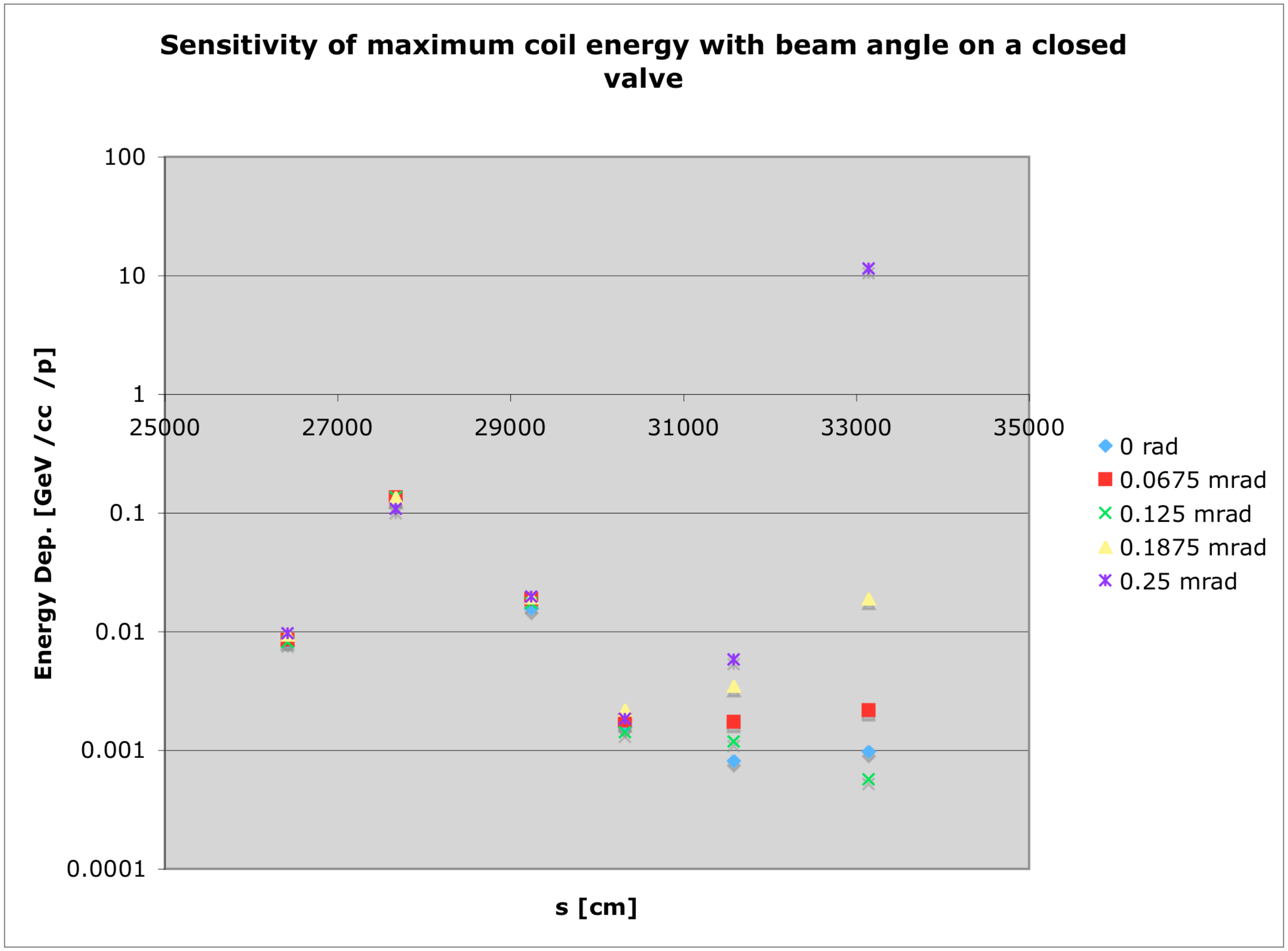


Source is a pencil beam at x=0 on the closed target valve at varying beam energy
Energy deposition peak is always seen in MBA8, with smaller peaks in MQ7 and MBB8
-> Peak magnitude at lower beam energy reduced w.r.t. 7 TeV

7 TeV beam on closed study valve: BLM signal



Sensitivity study II : (study valve)



Source is a pencil beam at x=0 on the closed valve, from and increasing x'.

-> Energy deposition peak position and size insensitive to angle at small angles

-> At larger angles, see peak in MBB9 - beam core (angle many σ's)