Studies Towards Design of a Small Angle Spectrometer at LHC

Ottavio Fornieri

Supervised by: Mike Albrow, Nikolai Mokhov

Fermilab

September 24, 2015

OUTLINE

- Purpose of the study: SAS physics goals

OUTLINE

- Purpose of the study: SAS physics goals
- MARS Modeling

OUTLINE

- Purpose of the study: SAS physics goals
- MARS Modeling
- Results

OUTLINE

- Purpose of the study: SAS physics goals
- MARS Modeling
- Results
- Conclusions

Purpose of the study

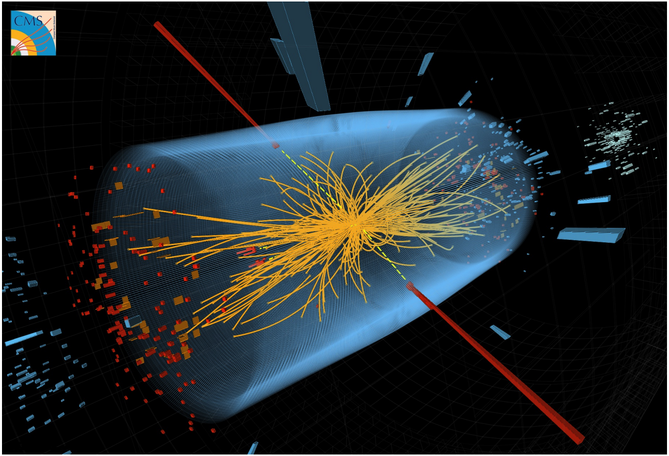
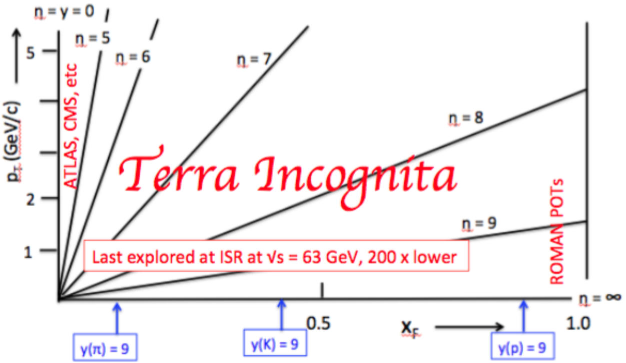


Figure 1: Particle tracks from a typical proton-proton collision in the CMS experiment.

Rapidity y in x_F-P_T plane



$x_{F,P_T=0,y=9}$ at $\sqrt{s} = 13\,TeV$

$x_{F,P_T=0} = \frac{me^y}{\sqrt{2}P_{beam}}$

Purpose of the study

Experiments all the way around LHC usually focus on detecting particles with a P_T big enough to make them hit the beam pipe within ~ 30m.

Particles produced at small angles go down the pipe and their spectra have not been measured yet, but they are important in understanding cosmic ray showers, for example.
In fact, energy of a 6.5x6.5 TeV pp collision would give a proton beam colliding with a fixed target* an energy of $\sim 10^{17}$eV, which is the order of magnitude of the cosmic rays energy.

One plausible solution seems to be the use of *channeling* with a bent crystal.

*Lorentz transformations.

MARS† Modeling

MARS is a multi-purpose particle interaction and transport Monte Carlo code.

It uses DPMJET as event generator.

Particles are tracked with MARS15 in a detailed model of IP5(*CMS*)

- $\pm 142.5\ \mu$rad horizontal crossing
- $\sigma_z = 5.6$cm

The parameter we set for our simulations are:

- 10^6 pp 6.5x6.5 TeV collisions
- tracks shown have $E_{cutoff} \geq 0.5\,TeV$
- 3 virtual detectors placed in the region appropriate for SAS: 84.3m, 107.2m, 131.2m.

† http://www-ap.fnal.gov/MARS/

MARS modeling

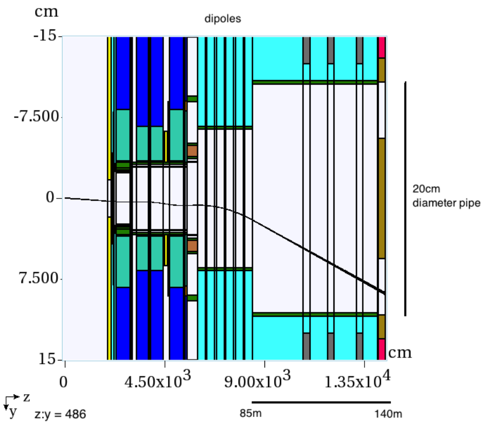


Figure 2: Primary beam on the GUI of MARS.

DPMJET Prediction

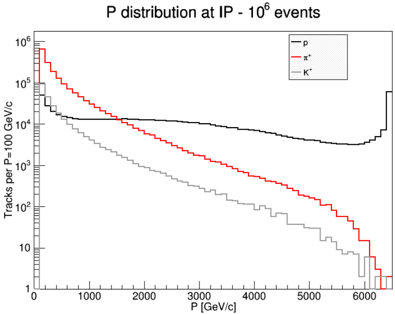


Figure 3: Positive particles

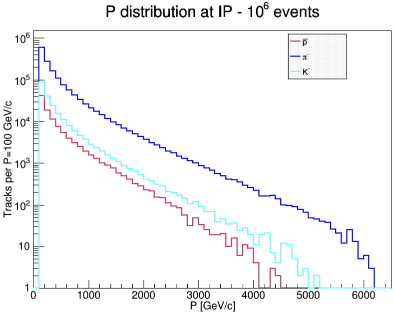


Figure 4: Negative particles

First Results

It immediately shows a very high neutral background, potentially the main responsible for crystal damaging:

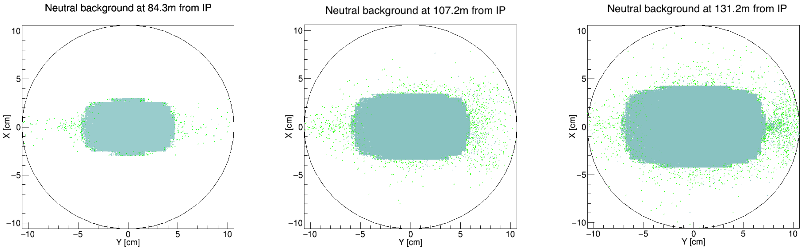


Figure 5: neutrons and γ at the 3 detectors.

Therefore the project can be split in two phases:

1. Open "detector-windows" along the pipe to detect particles which actually hit it
2. Use a bent crystal to channel highest-momentum particles

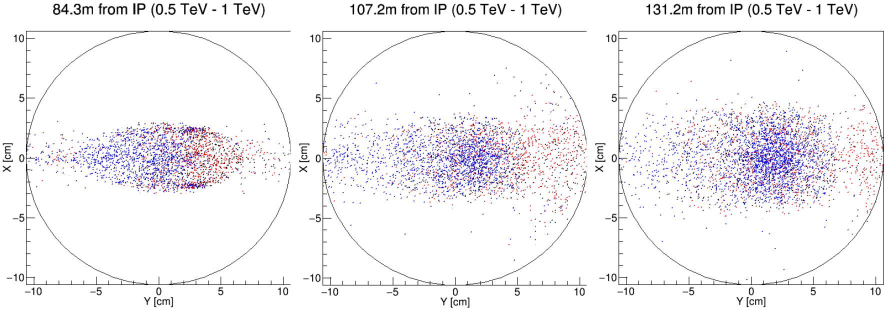
Therefore the project can be split in two phases:

1. Open "detector-windows" along the pipe to detect particles which actually hit it
2. Use a bent crystal to channel highest-momentum particles

Let us focus on phase 1.

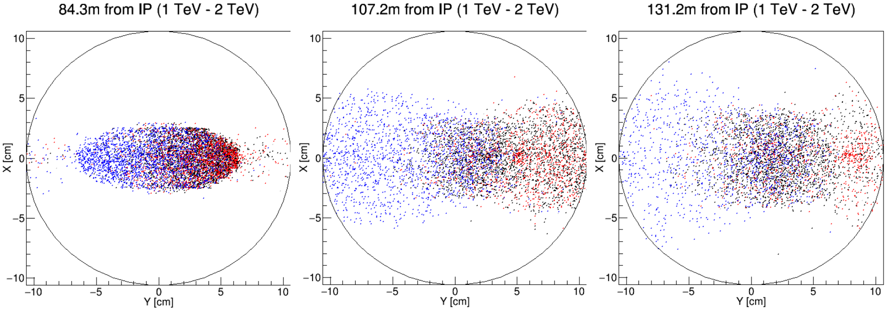
MARS simulation: 0.5 TeV $< E <$ 1 TeV

- π^+
- π^-
- p
- K^+

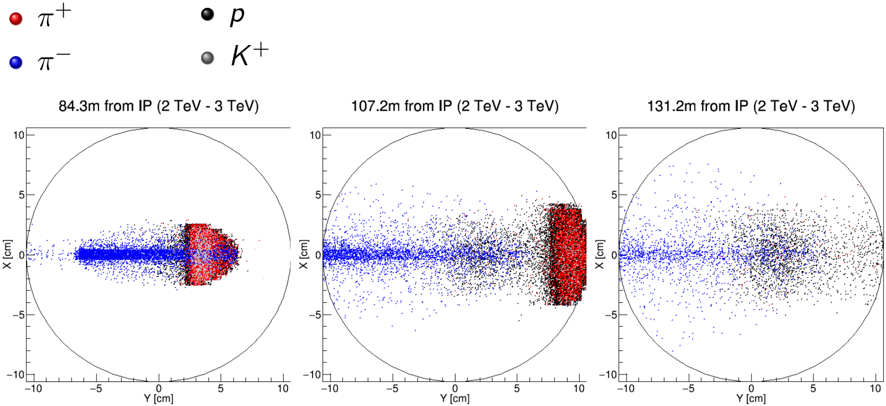


MARS simulation: 1 TeV $< E <$ 2 TeV

- π^+
- π^-
- p
- K^+



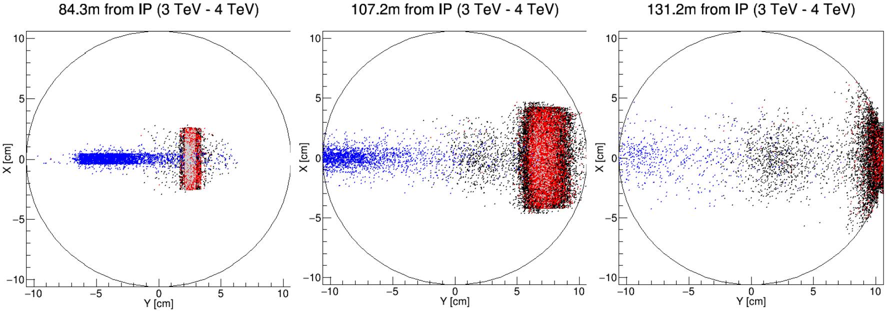
MARS simulation: 2 TeV $< E <$ 3 TeV



Rectangular shapes are due to the F/D quad field for given energy slice.

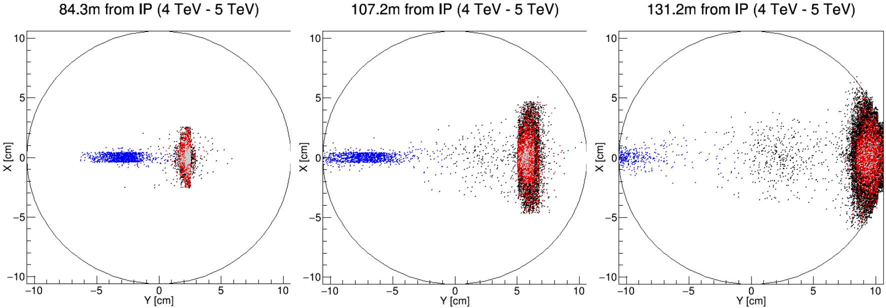
MARS simulation: 3 TeV $< E <$ 4 TeV

- π^+
- π^-
- p
- K^+



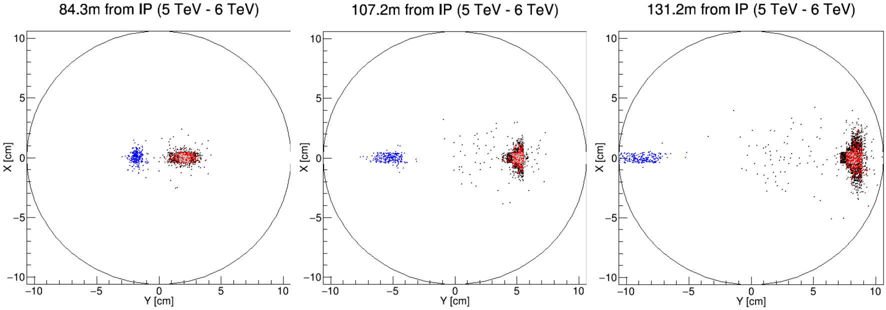
MARS simulation: 4 TeV $< E <$ 5 TeV

- π^+
- π^-
- p
- K^+



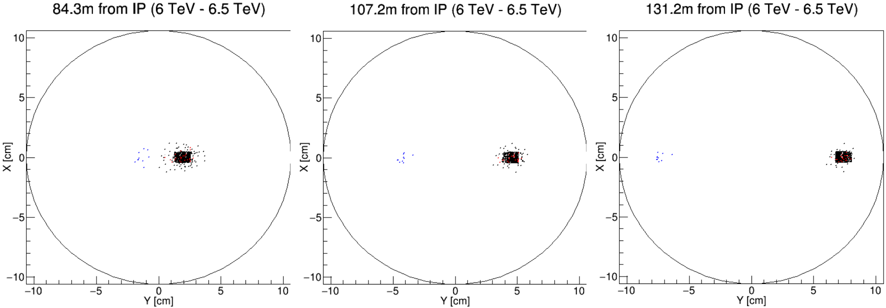
MARS simulation: 5 TeV $< E <$ 6 TeV

- π^+
- π^-
- p
- K^+



MARS simulation: 6 TeV $< E <$ 6.5 TeV

- π^+
- π^-
- p
- K^+



Essentially only primary beam and diffractive protons!

Comments

- <u>Low-Energy slices:</u>

$$0.5\,TeV - 1\,TeV$$
$$1\,TeV - 2\,TeV$$

tracks are spread all over the pipe on the y-z plane.

- <u>High-Energy slices:</u>

$$5\,TeV - 6\,TeV$$
$$6\,TeV - 6.5\,TeV$$

they go down the pipe, which makes us not able to detect them (unless bent crystals deflect them by a few *mrad*).

- Middle-Energy slices:

$$2\,TeV - 3\,TeV$$
$$3\,TeV - 4\,TeV$$
$$4\,TeV - 5\,TeV$$

trajectories have well defined shapes.
Momenta and energy (in a calorimeter) can be measured.

- Middle-Energy slices:

$$\begin{gathered} 2\,TeV - 3\,TeV \\ 3\,TeV - 4\,TeV \\ 4\,TeV - 5\,TeV \end{gathered}$$

trajectories have well defined shapes.
Momenta and energy (in a calorimeter) can be measured.

$\longrightarrow$ **Possibility to create window in the pipe with the following sizes along the x-axis:**

LEFT SIDE $d_{x,L} = \pm 2cm$ RIGHT SIDE $d_{x,R} = \pm 5cm$

Suggestion for SAS

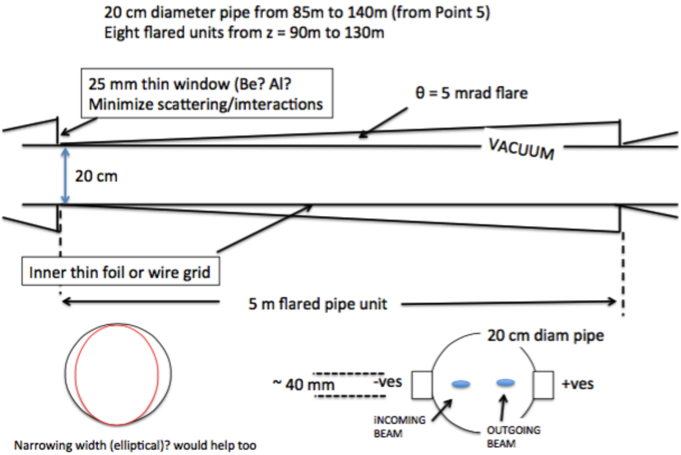


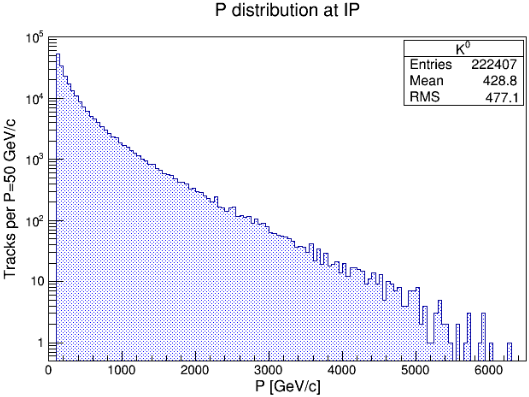
Figure 6: Beam pipe design for small angle spectrometer (very schematic)

MARS takes into account all physics processes in the region of interest, including:

- Scattering
- Decay
- Production of Showers from particles hitting the pipe.

Analysis of these processes could lead to significant background.

DECAY: example with $K^{0\ddagger}$



$$c\tau = \begin{cases} K^0_S = 2.68cm \\ K^0_L = 15.34m \end{cases}$$

$\gamma \approx 10^3$, $\bar{P} \simeq 430\,GeV$

$\lambda_D = \gamma c\tau \quad \Rightarrow$

$$\Rightarrow \begin{cases} \lambda_{D,K^0_S} \simeq 26.8m \\ \cancel{\lambda_{D,K^0_L} \simeq 15.3km} \end{cases}$$

‡ http://pdg.lbl.gov/2014/tables/rpp2014-tab-mesons-strange.pdf

DECAY: example with K^0

Most common decay channel for K_S^0:

$$K_S^0 \to \pi^+\pi^- \quad \text{with} \quad 68,20\%$$

- on average, the two pions take half momentum per each from the kaon: $P_{\pi^\pm} \approx 215\,GeV$
- on MARS simulations we put a cutoff on the lower energy of $E_{cutoff} \geq 0.5\,TeV$

$\longrightarrow$ Those pions will not be seen!

But, given the huge flux of K^0 with P above the mean value,

Decay could be one important source of background pions.

Charged particles - 200 Collisions
$\beta^* = 0.55m$, $\sqrt{s} = 13\,TeV$

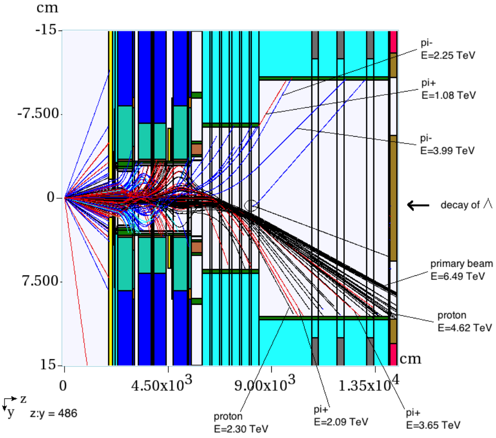


Figure 7: Sample simulation on the GUI of MARS.

We are interested in measuring only spectra of the primary particles

In a real experiment, with windows along the pipe

- in most cases particles hitting the pipe would not produce showers, as they would go through thin windows to be detected
- background coming from the decay would still be present

One way to ***emulate*** the switching off of decay and shower processes would be to take into account only data coming from the first detector (84.3m) and let the particles spread out as straight lines, since there is no magnetic field in that region.

This approach, let us call it *Ray Analysis*, already produces some changes, mostly for low-energy slices:

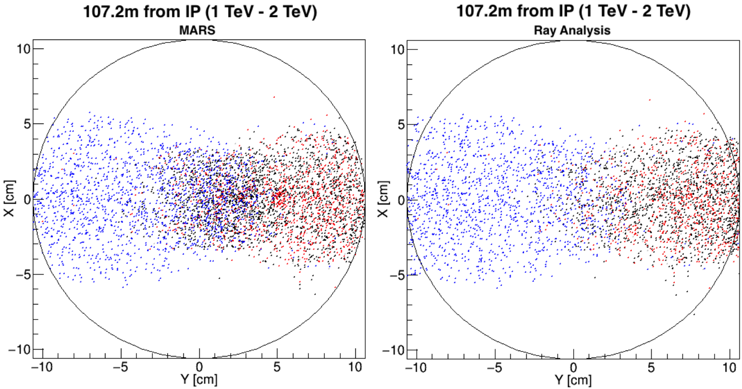


Figure 8: Graphical visualization purpose: comparison between the scatter plots produced with data from MARS (left) and from a fictitious detector (right), $1\,TeV < E < 2\,TeV$, 107,2m from IP.

However, it does not affect at all the region before the first detector. Here, sources of background are still present.

Then, out of all the particles detected, tracks reconstruction will be necessary to see which ones are coming from the original collision

$$(x_0, y_0, z_0, P_x, P_y, P_z, Q) \quad \longleftrightarrow \quad (x, y, z, \theta_x, \theta_y, E)$$

Fortunately, MARS also produces a file with all the information about the particles produced at the collision point; so it is very instructive, for a quantitative analysis, to look at the distribution of P_T within the energies of interest:

$$\begin{aligned} E: &\quad 2\,TeV - 3\,TeV \\ E: &\quad 3\,TeV - 4\,TeV \\ E: &\quad 4\,TeV - 5\,TeV \end{aligned}$$

10^6 collisions - P_T distribution at the IP $2\,TeV < E < 3\,TeV$

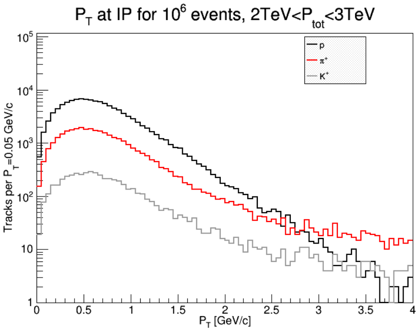


Figure 9: Positive particles

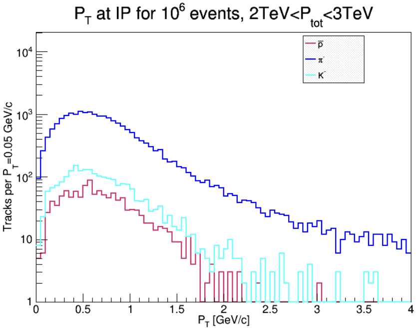


Figure 10: Negative particles

10^6 collisions - P_T distribution at the IP $3\,TeV < E < 4\,TeV$

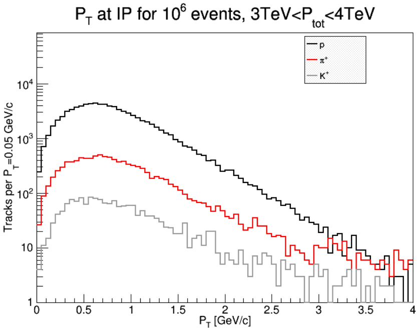


Figure 11: Positive particles

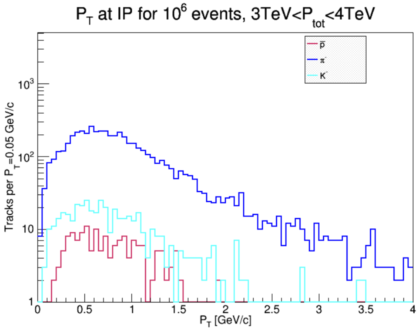


Figure 12: Negative particles

10^6 collisions - P_T distribution at the IP $4\,TeV < E < 5\,TeV$

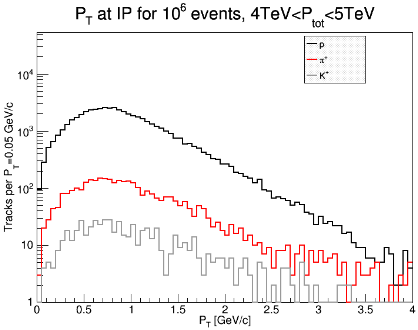


Figure 13: Positive particles

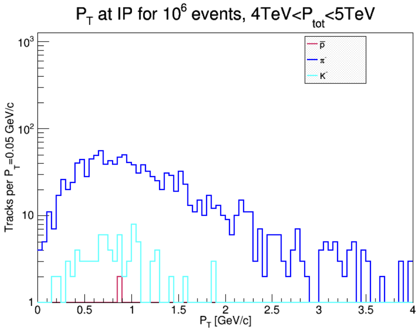


Figure 14: Negative particles

Conclusions

- Data from MARS Simulations gave very helpful information for the development of the idea of **New Detector-Windows** along the beam pipe

Conclusions

- Data from MARS Simulations gave very helpful information for the development of the idea of **New Detector-Windows** along the beam pipe
- First step without any bent crystal would be already informative, as it allows the measurement of spectra for low-P_T particles within certain ranges of energy

Conclusions

- Data from MARS Simulations gave very helpful information for the development of the idea of **New Detector-Windows** along the beam pipe
- First step without any bent crystal would be already informative, as it allows the measurement of spectra for low-P_T particles within certain ranges of energy
- A lot of experimental work required, in order to reconstruct tracks coming from the original collision

Conclusions

- Data from MARS Simulations gave very helpful information for the development of the idea of **New Detector-Windows** along the beam pipe
- First step without any bent crystal would be already informative, as it allows the measurement of spectra for low-P_T particles within certain ranges of energy
- A lot of experimental work required, in order to reconstruct tracks coming from the original collision
- Second step with crystals, only needed for the highest momenta.

Thanks for attending!

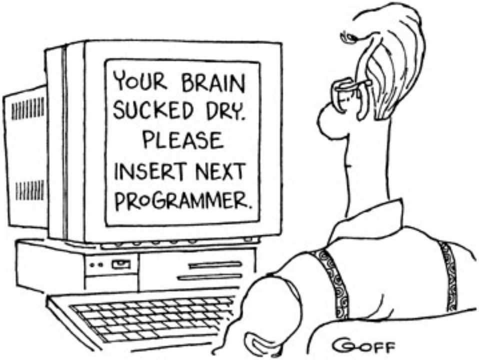


Figure 15: Me.