The CERN PS ZT9 beam line simulation for the HARP experiment

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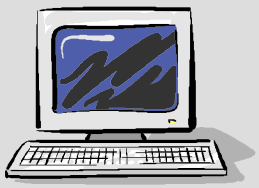
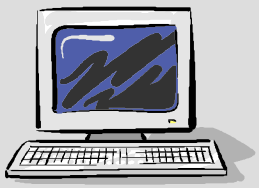


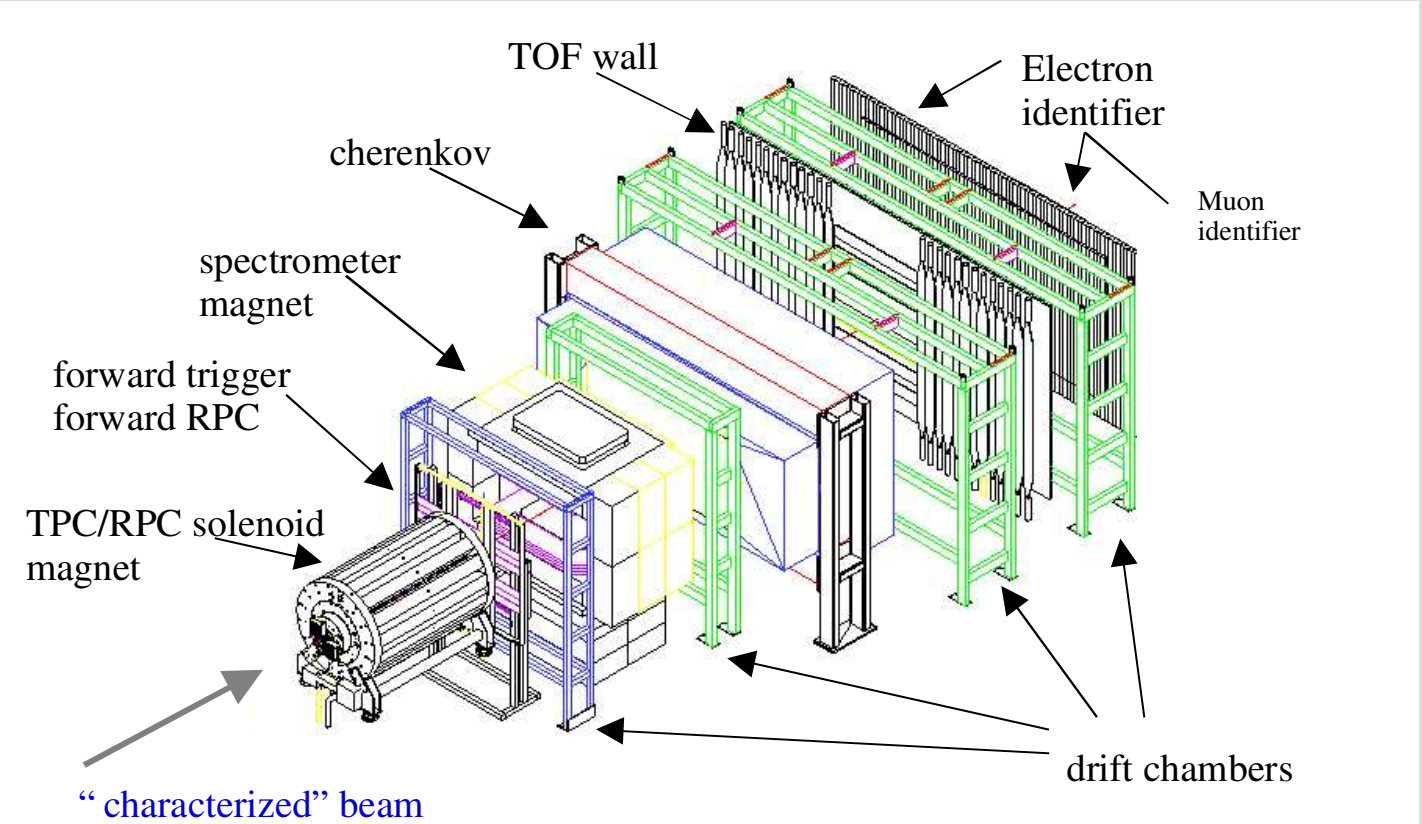
Outline

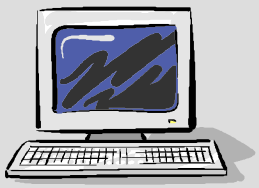
- *The HARP experiment*
- *The PS ZT9 beam line*
- *Why do we need beam simulation?*
- *Why do we need Geant4?*
- *The beam line simulation features*
- *Magnetic optics simulation*
- *Fine beam tuning*
- *Results*
- *Summary*



The HARP experiment

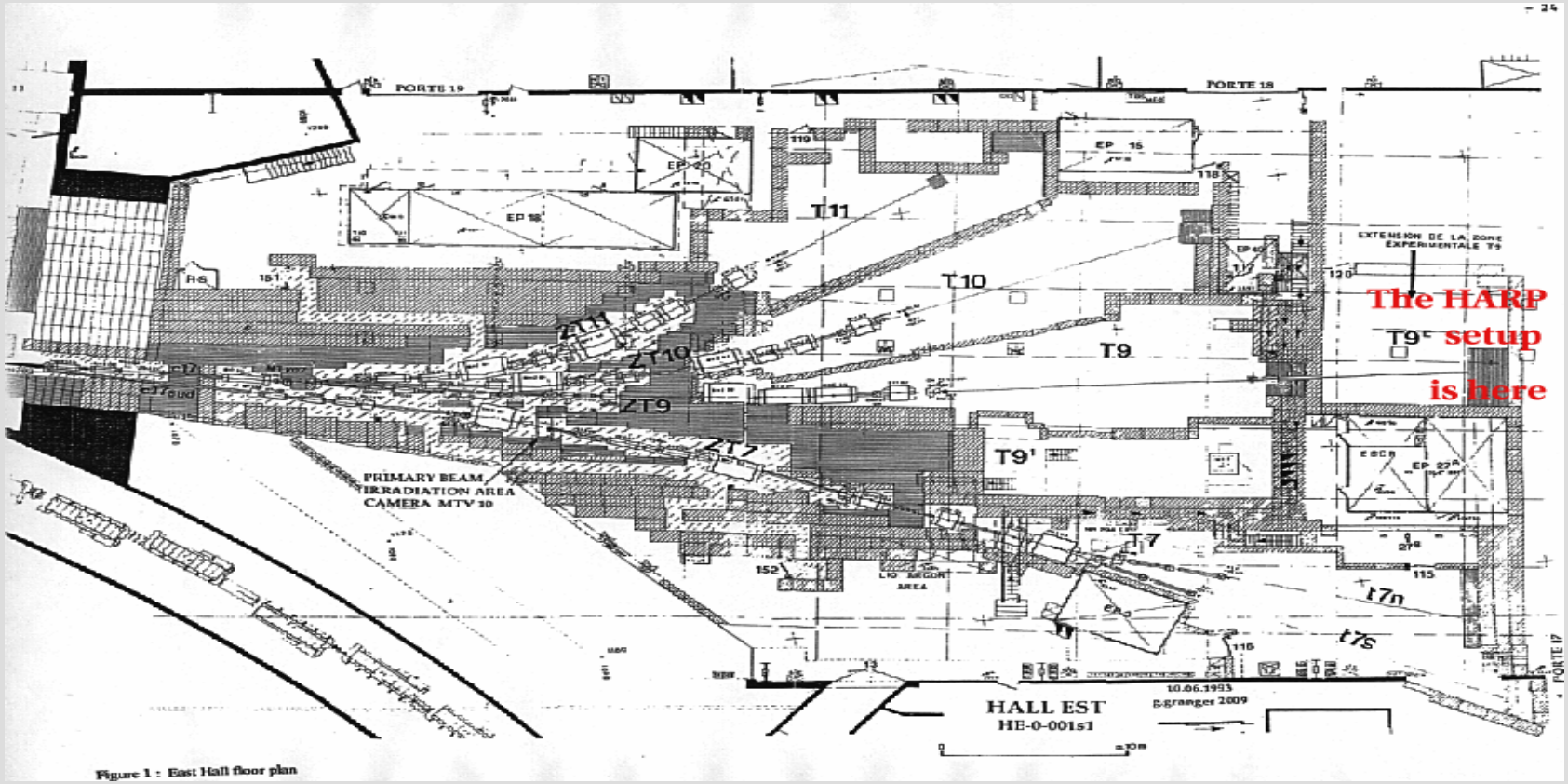
The HARP experiment is aimed to study hadron production for the neutrino factory and the atmospheric neutrino flux.





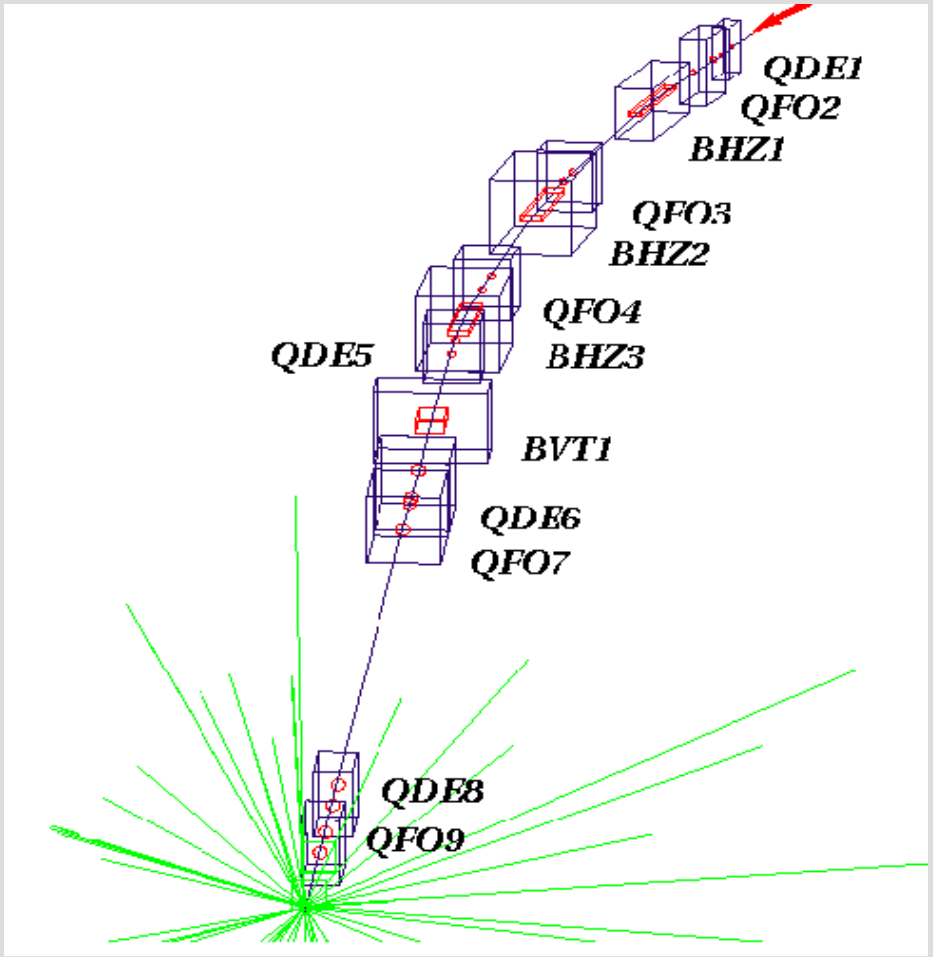
The East Area

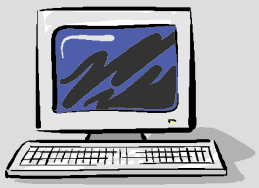
The HARP experiment is set up at the PS East Area, and uses secondary beam from CERN Proton Synchrotron



The PS ZT9 beam line

- **Length is about 77.5 m**
- **Momentum range 1.5-15 GeV/c**
- **Positive and negative beam**
- **Secondary beam :**
  protons, pions, kaons, electrons ...
- **Angular acceptance**
  is less than 5.1 mrad
- **9 quadrupole lenses**
- **4 bending magnets**
- **installed in mid 60s (!)**
  - *lack of documentation*

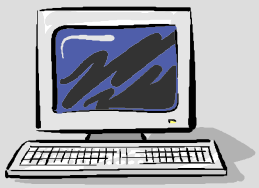




Why beam simulation?

- **For precise calculation of the cross-sections it is crucial to have absolute knowledge of the particle rate incident onto the HARP target.**
- **The beam line is rather long, so the number of pion decays will not be negligible, and therefore the reasonable rate of muons can be expected.**
- **Muon constituent of the beam could not be separated from pions directly by the HARP detector with an accuracy required.**

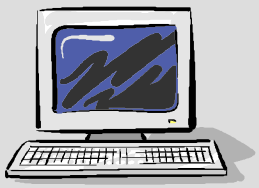
A full simulation of the PS ZT9 beam line has been carried out using GEANT4 toolkit



Why do we need Geant4?

- **Special software exists (like MAD) to provide simulation of accelerators ...**
- **... but it has different priorities.**
- **It can give**
  - ***Beam optics calculation***
  - ***Beam stability***
  - ***Beam - beam interactions***
- **And we need**
  - ***EM and hadronic interactions with matter in the beam line***
  - ***Particle decays***

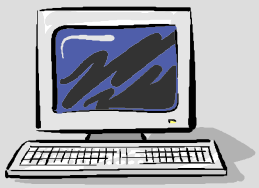
We considered Geant4 to be good for these goals



The beam line simulation features

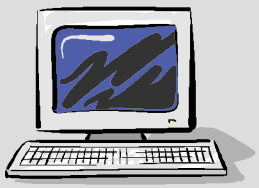
- **Sophisticated geometry –** *the beam line is a complex three-dimensional curve*
- **Very non-uniform strong magnetic field involved**
- **Magnetic field depends on the beam momentum**
- **Beam optics takes ~1/3 of the beam line length only**

- **Accurate positioning of volumes is needed --** *mis-placement should be less than 0.01%*
- **Magnetic optics simulation**
- **Fine beam optics tuning**
- **For performance reason magnetic field should not be taken into account between the magnets**

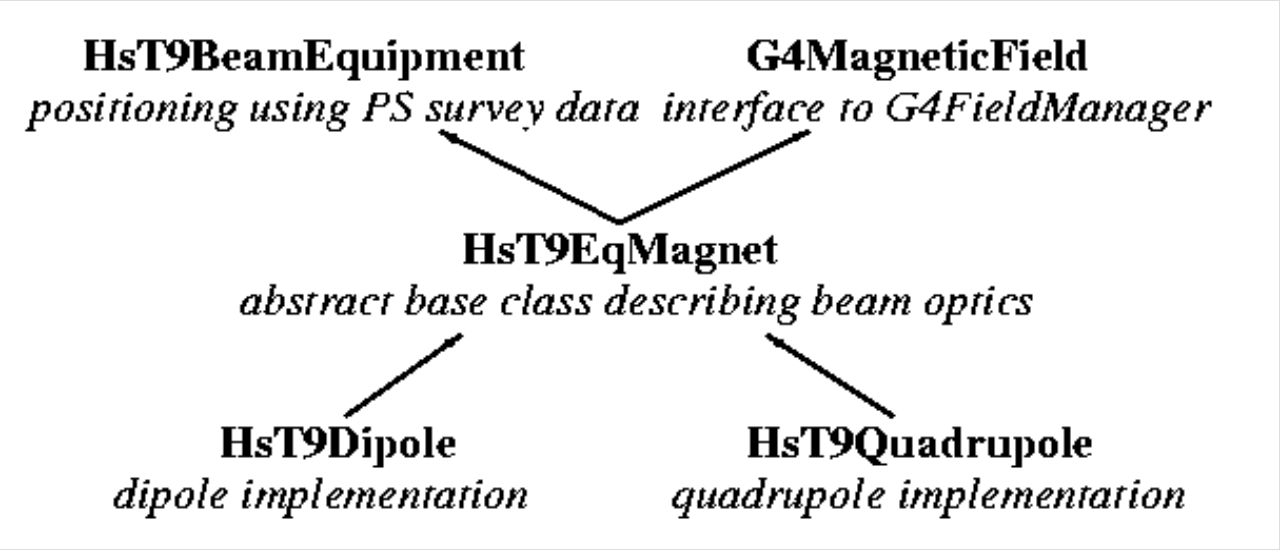


Magnetic optics simulation (I)

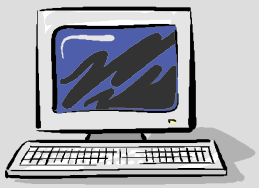
- **The PS survey data are used to position the volumes.**
- **Simple approximation is used**
  - ***Uniform magnetic field in bending magnets***
  - ***Ideal quadrupole field in quadrupole lenses***
    - ***Provides sufficient accuracy***
- **Magnetic field in magnets is set by the corresponding current value (like in a control room)**
- **It is more convenient to calculate magnetic field in the local reference system rather than in the master reference system (GEANT4 default)**



Magnetic optics simulation (II)



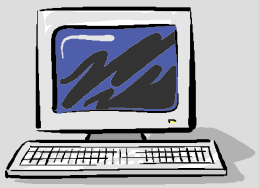
- **Each magnet is an object inherited from G4MagneticField**
- **Additional function is implemented in a UserSteppingAction to switch the field, choose the magnet responsible for the field at a given point, and give the magnet reference to G4FieldManager.**
- **Field is calculated in local reference system inside the object.**



Fine beam tuning (I)

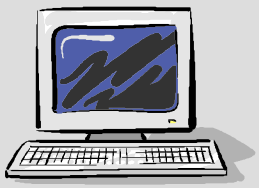
- Possible reasons of the beam line model misadjustment:
  - Lack of information about axial rotations of magnets
  - Magnet hysteresis – *what field is there at the moment* ?
  - Magnet optics approximation is quite simple
  - Inaccuracy of survey = inaccuracy of volume positioning

Settings of current in coils differ in the simulation and in the control room

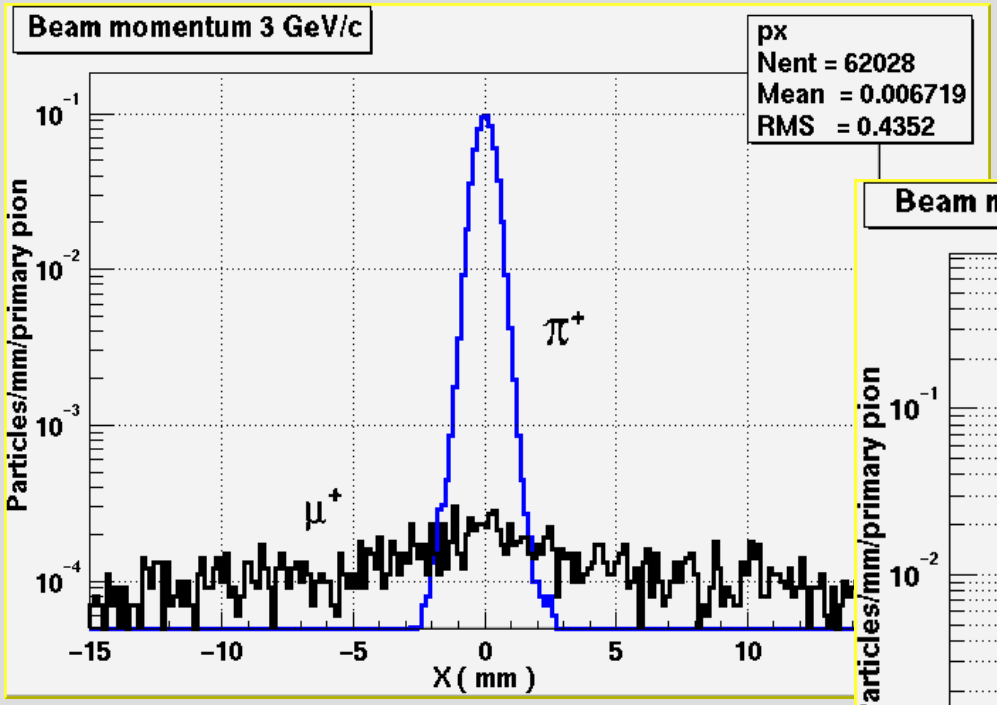


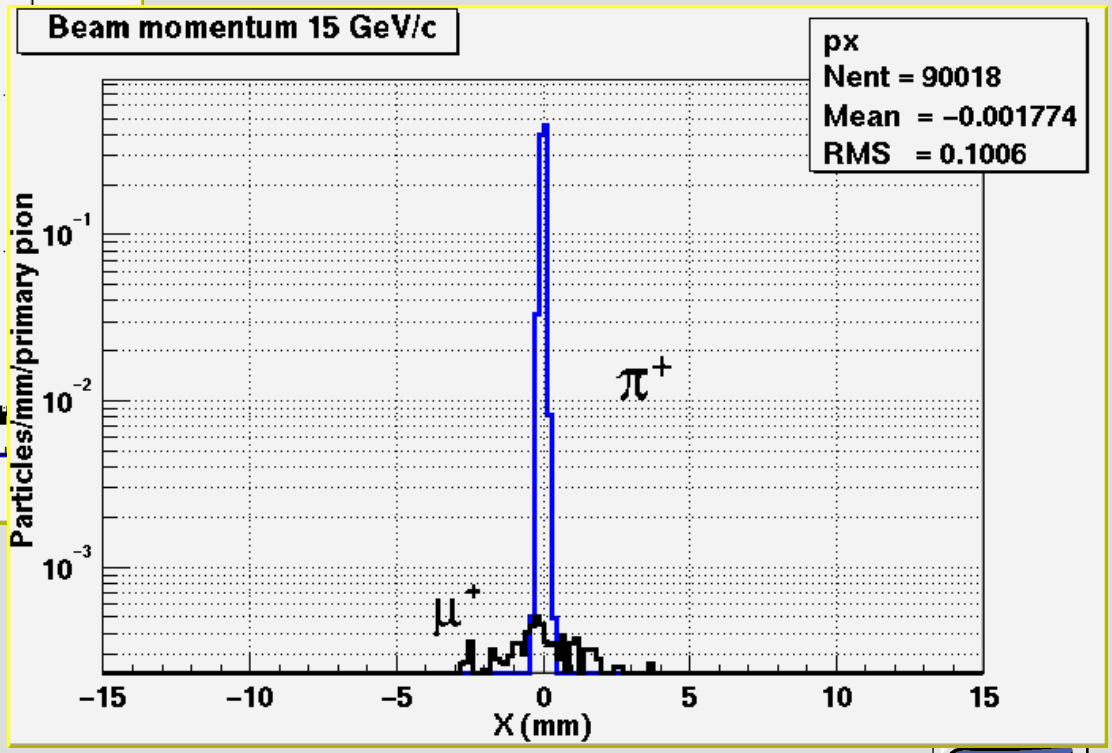
Fine beam tuning (II)

- **Fine beam tuning has been carried out**
  - ***dipole field was adjusted according to the beam spot position at reference focus***
  - ***quadrupole field was tuned to reach the reference beam spot size and conform with the beam parameters provided by accelerator experts.***
- **Transportation efficiency achieved is better than 75%**
  - ***Good correspondence with accelerator simulations***
- **Momentum selection is solved at primary generator level rather than by implementing a collimator**
  - ***mainly for performance reason***

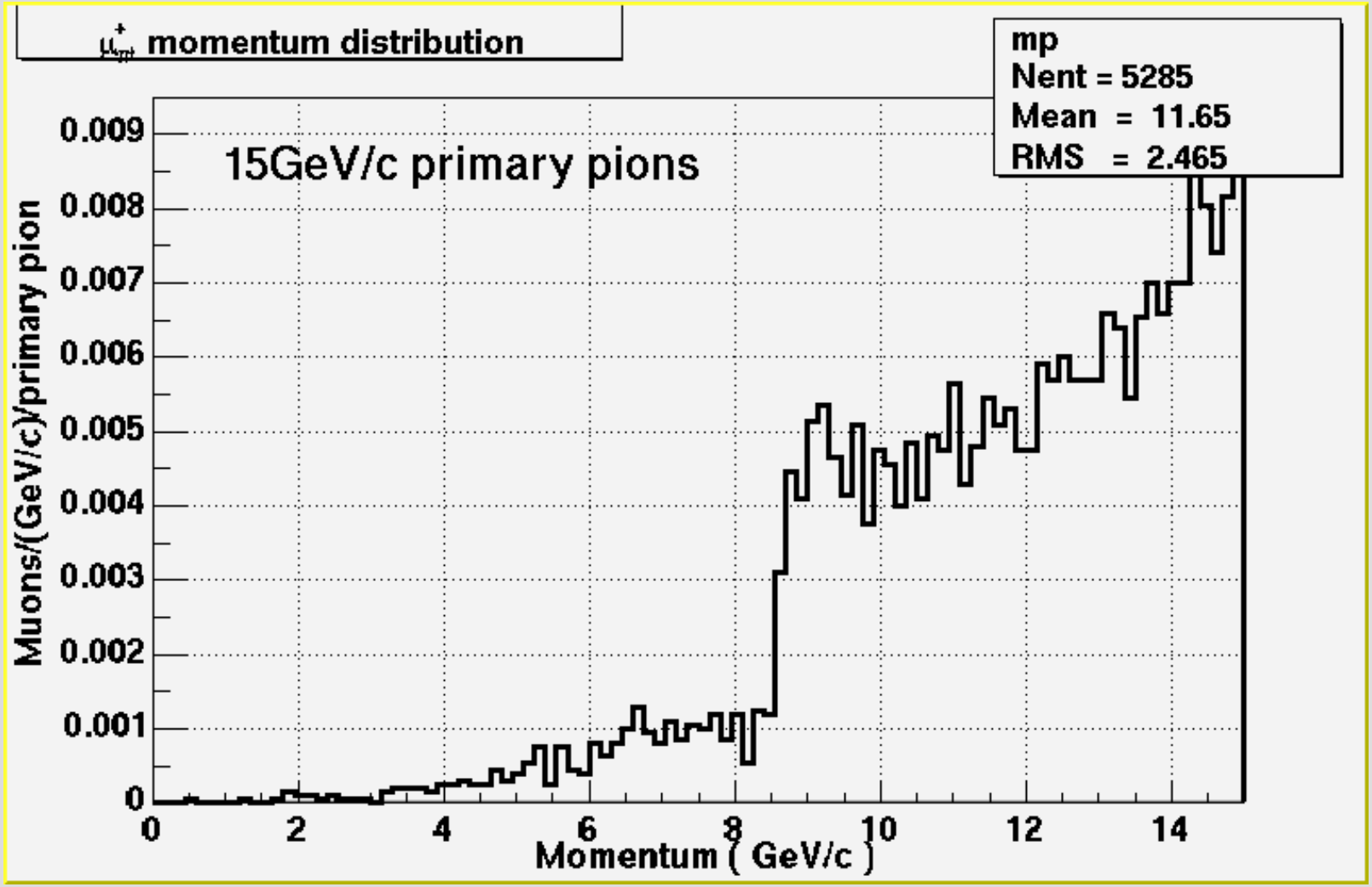


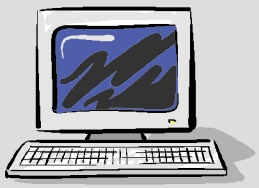
Horizontal beam profiles at the HARP target



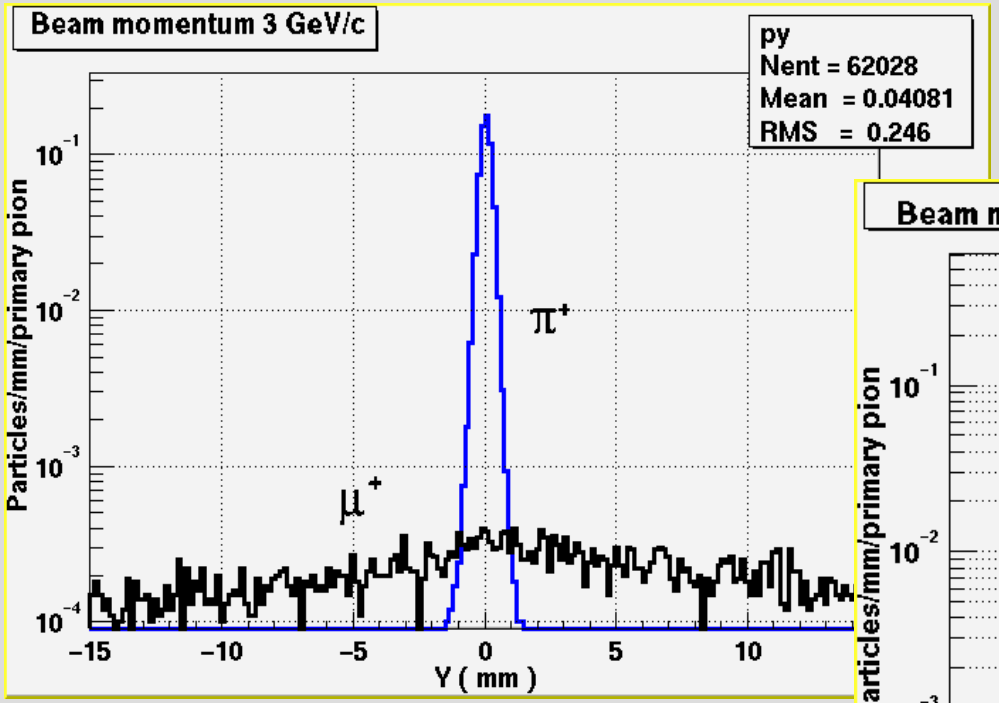


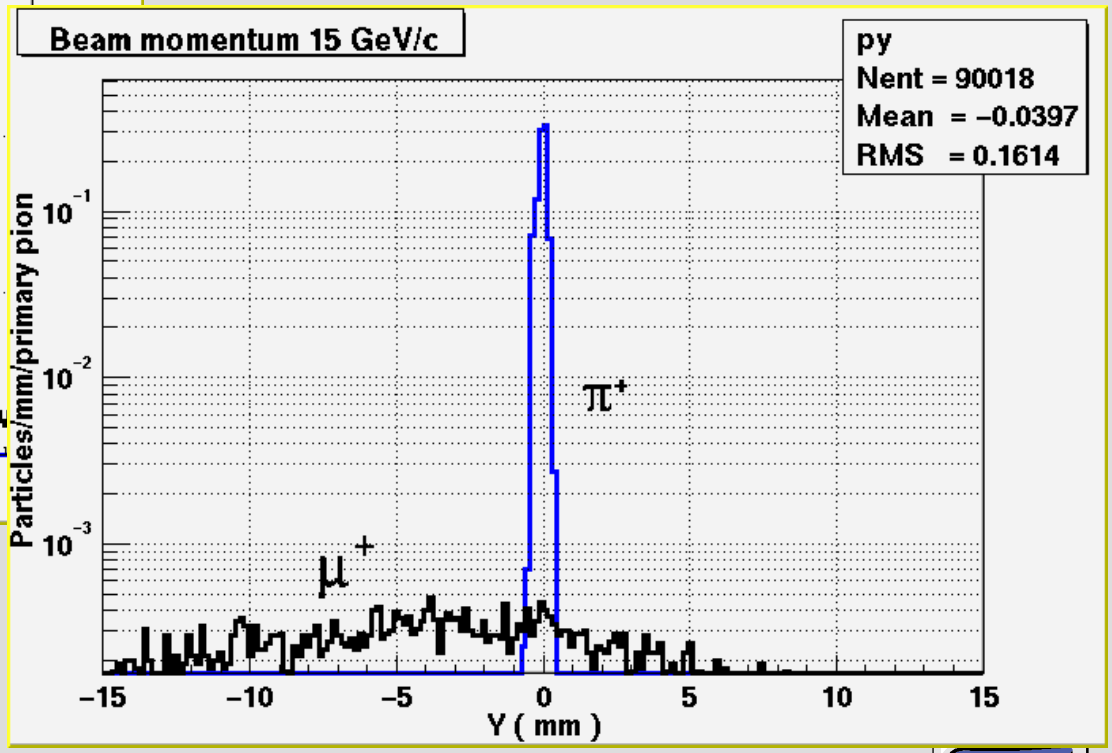
Muon momentum distribution



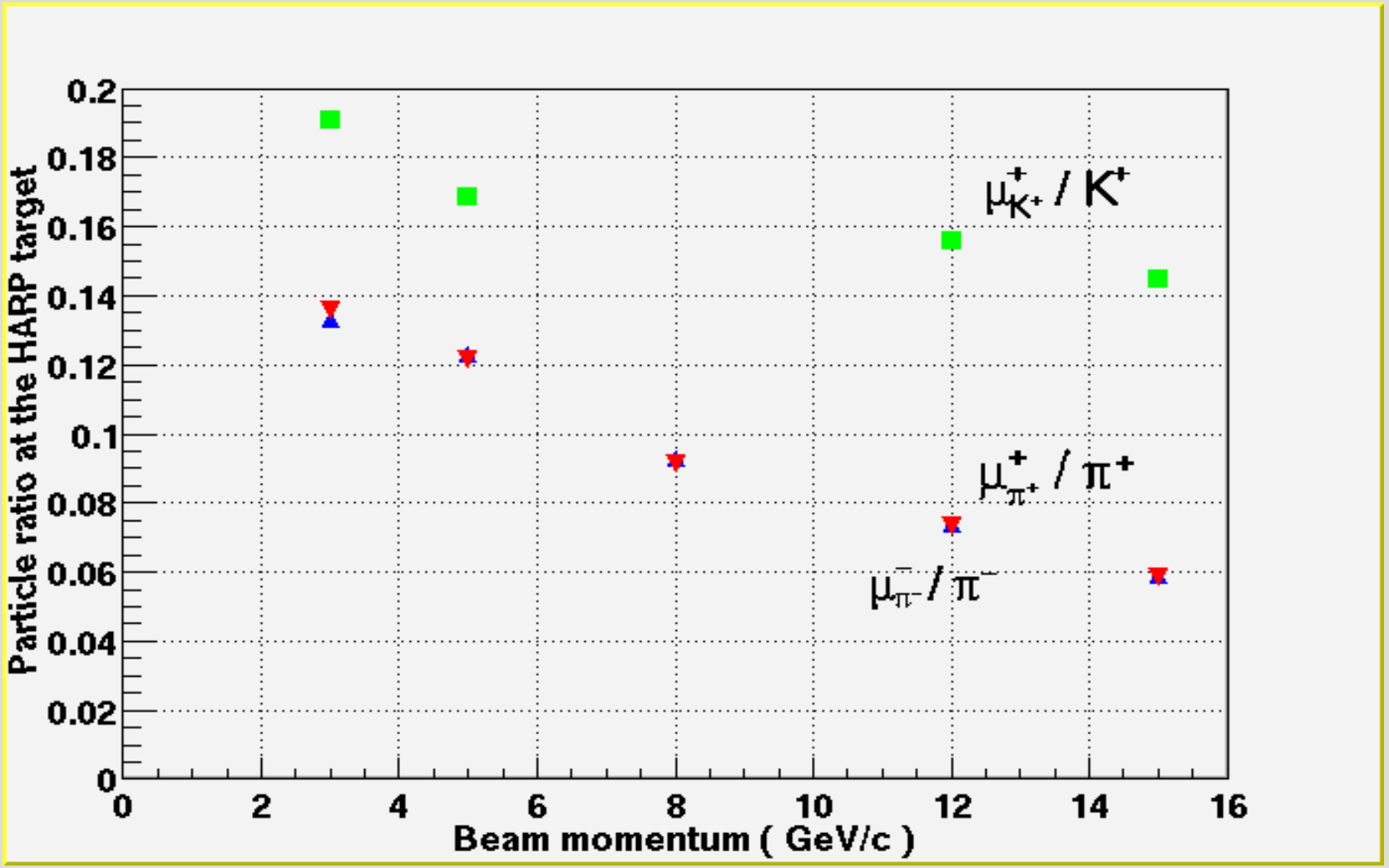


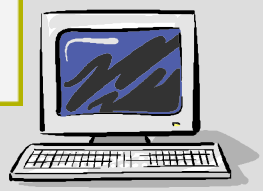
Vertical beam profiles at the HARP target





Muon constituent of the beam





Summary

- The CERN PS ZT9 beam line simulation has been carried out, to provide muon background calculations for the HARP experiment.
- The beam simulation has been also integrated into the HARP detector simulation as a primary generator.
- Geant4 proved out to be a good tool for simulation of physical aspects of beam lines.
- **Question to G4 team**: it would be nice to be able to bind the magnetic field together with a volume in a standard way ...

The authors would like to express their sincere thanks to A.-S.Mueller for providing the beam line related information and valuable discussions.