Target optimisation for the Neutrino Factory capture section (IPAC13 paper++ and updates)

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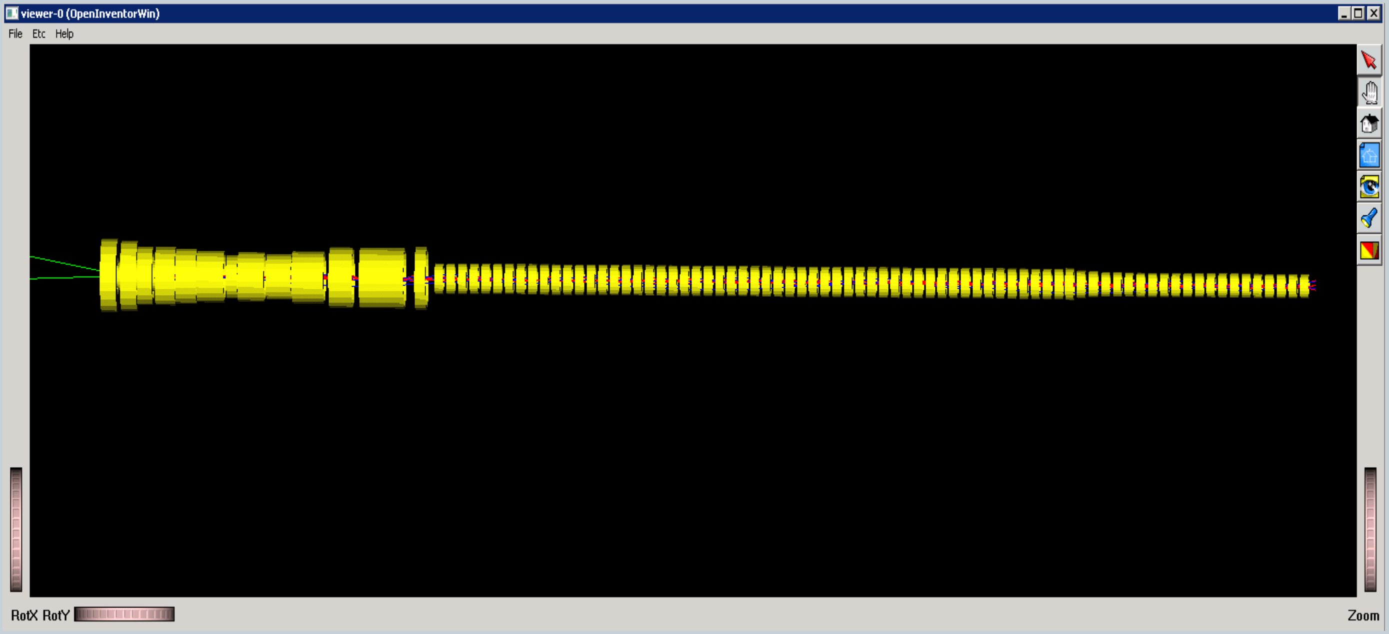
Optimisation studies

- ## MC Simulations:
  - G4beamline
- ## Method:
  - Two solenoid configurations and magnetic field tapering
    - 3SOL
    - ST2A
  - Investigating particle production and muon yield when varying the beam's entry position and entry angle on the target
  - Mercury jet target shape fluctuation in a high magnetic field
  - Investigation of the proton beam/target interaction region
  - Comparing the muon flux at z=50 m and the muon+pion flux at z= 0 m
    - MUON ACCEPTANCE CUTS ARE APPLIED, I.E. ONLY MUONS THAT WILL BE SUCCESSFULLY TRANSPORTED TO THE MUON ACCELERATOR

Solenoid layout

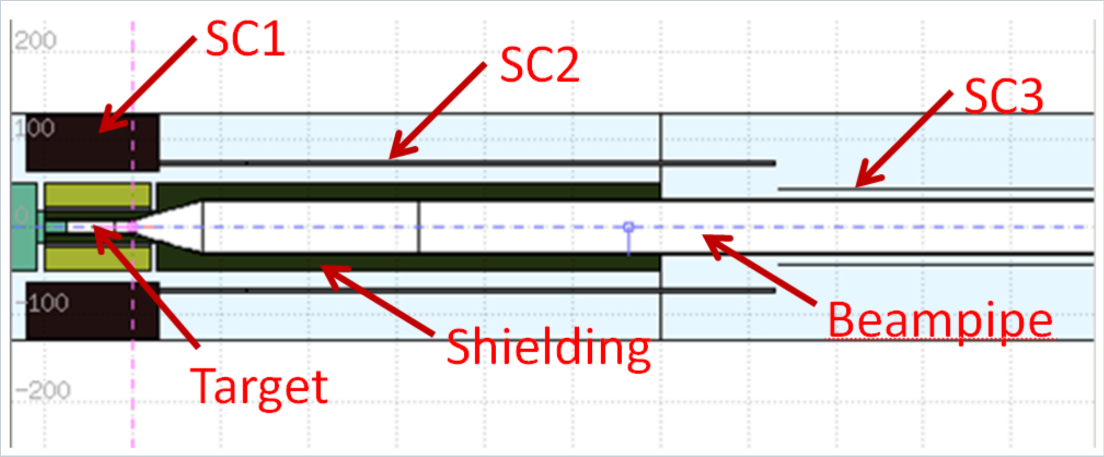
- ST2a solenoid layout, solenoids shown in yellow

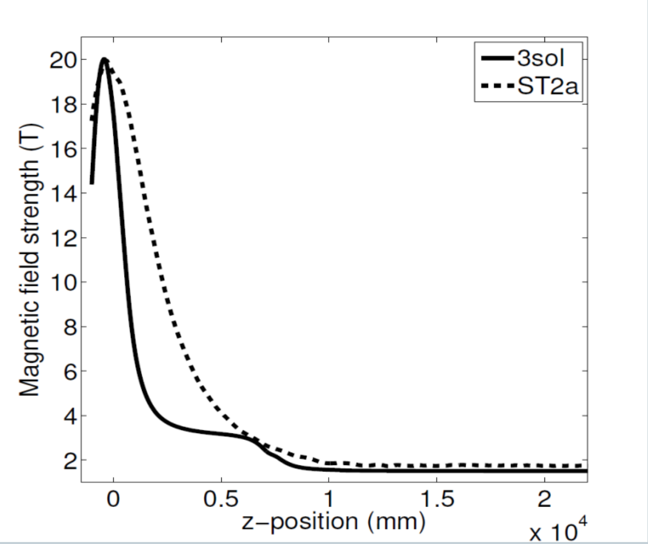


- From the G4BL-viewer

Solenoid layout

- 3sol layout and magnetic field
  - Shielding radius increases from 75 mm to 274 mm in the conical region

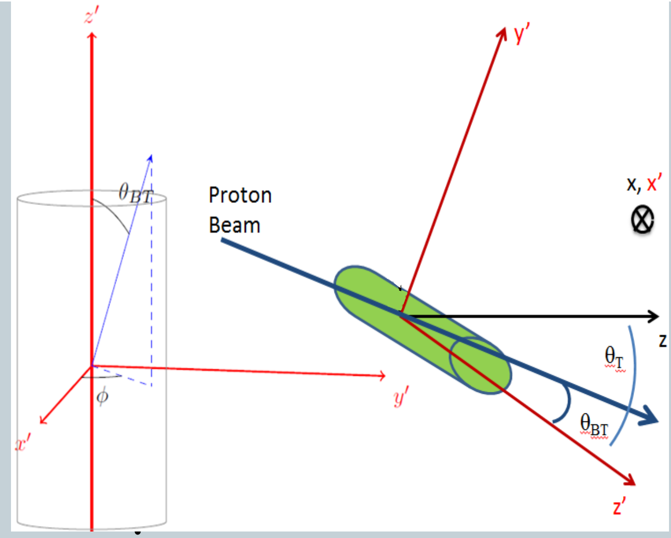




- 3sol and ST2a have 20 T capture magnets and tapers down to 1.5 T (3sol) and 1.75 T (ST2a)
  - SC1/2/3 are superconductors producing the magnetic field
  - ST2a field from standard fieldmap
  - 3sol field made from magnets and tuning currents in g4bl

Beam and Target

- 8 GeV beam kinetic energy
  - 10^5 protons on target
  - σ=1.5 mm
  - Standard definition of the beam →



- Mercury target
  - Radius=5 mm
  - Tilted θ_T=96.68 mrad with respect to the z-axis
  - The target is a long strait cylinder ~2.5 m (no gravity) centred at z=-375 mm
  - The polar angle between beam and target, θ_{BT}=30 mrad (z=-375) for the first study and varies θ_{BT}=[20, 35] mrad in the later studies
  - The azimuth angle in the target reference frame $\phi \in [0,312]$ varies in steps of 24° and is later fixed to 0°

Acceptance cuts

- Ecalc9f was used to find the "good" muons after the front-end

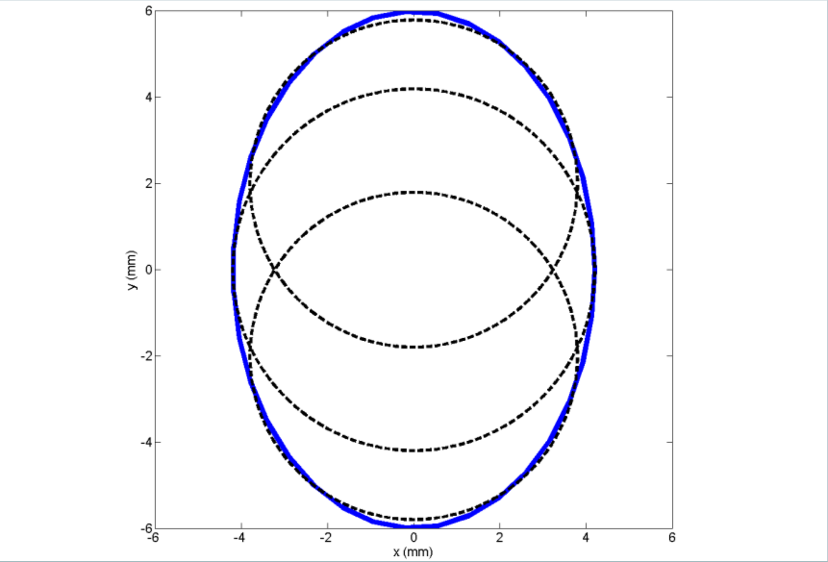
Momentum	Transverse acceptance	Longitudinal acceptance cuts
[MeV/c]	*[mrad]*	*[mrad]*
$100<p_z<300$	$A_T<0.150$	$A_L<0.030$

- Particle ID was then used to find the time, momentum and position distribution of the good muons at z=0 m and z=50 m
- The muon count in these intervals of momentum, time and position is used as a measure of performance

Momentum	Transverse momentum	Time	Radius
[MeV/c]	*[MeV/c]*	*[ns]*	*[mm]*
$100<pz<300$	$p_T<50$	$160<t<240$	$r<200$

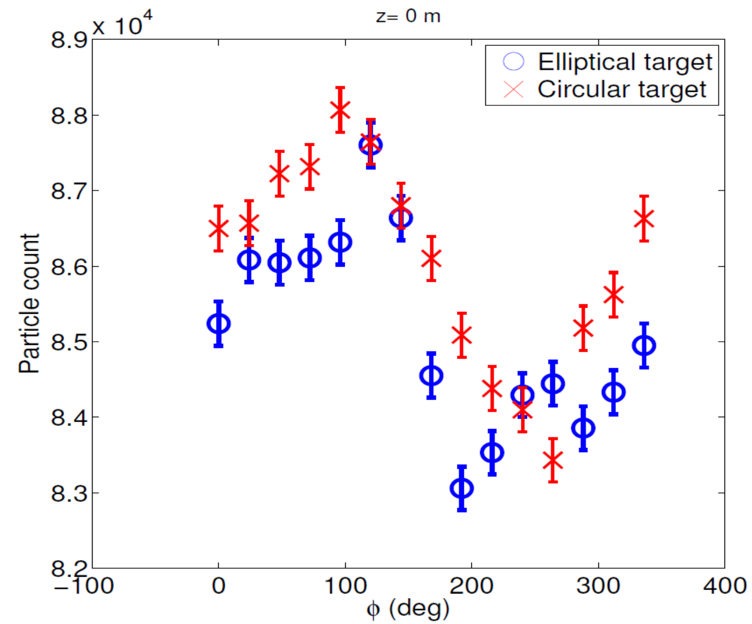
Mercury jet shape fluctuation

- The effect on particle production by changing the mercury jet shape from a cylinder to an elliptic cylinder is studied
- From mass conservation the cross sectional area of the jet is conserved
  - The height of the jet is set to be 1.2 x the radius of the cylinder, a=6 mm, and the width calculated to b=4.2 mm
  - In G4BL the elliptical cylinder is approximated by three overlapping cylinders →



Results, jet shape fluctuation

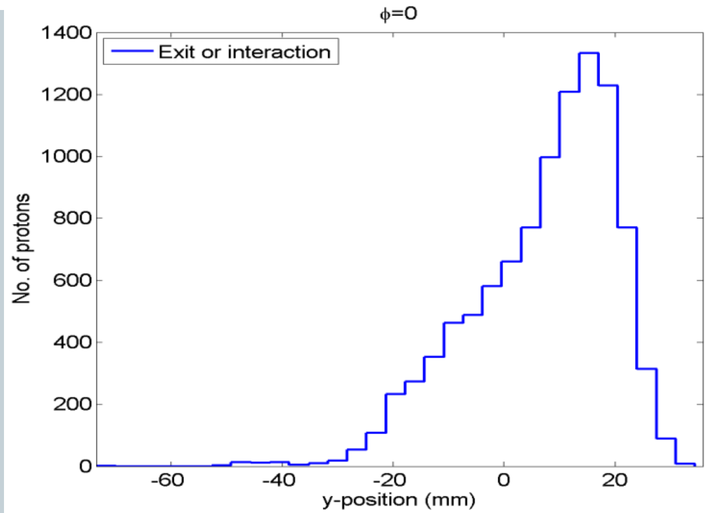
- $\phi \in [0, 312]$ in steps of 24°
- θ_{BT}=30 mrad
- The highest particle count can be found between 72° and 144°
- Slightly decreased particle count for the elliptic cylinder

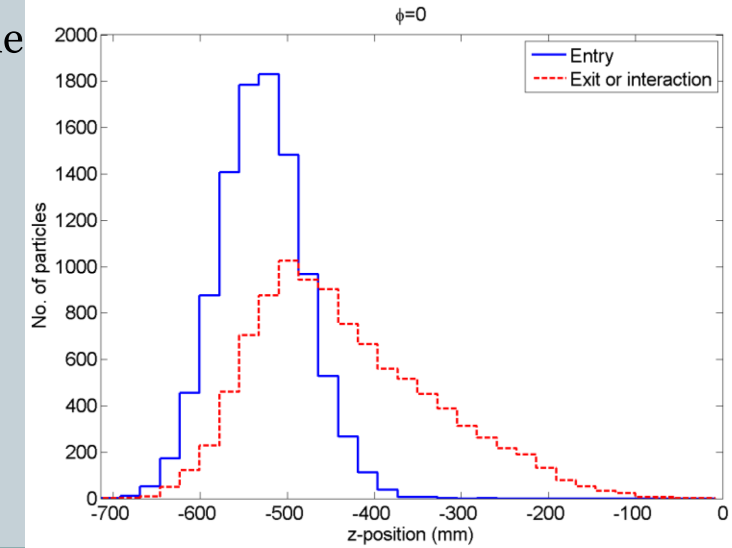


- The maximum difference when varying ϕ is 5.5 % for both cases
- Error bars are statistical

Proton beam trajectory in the jet

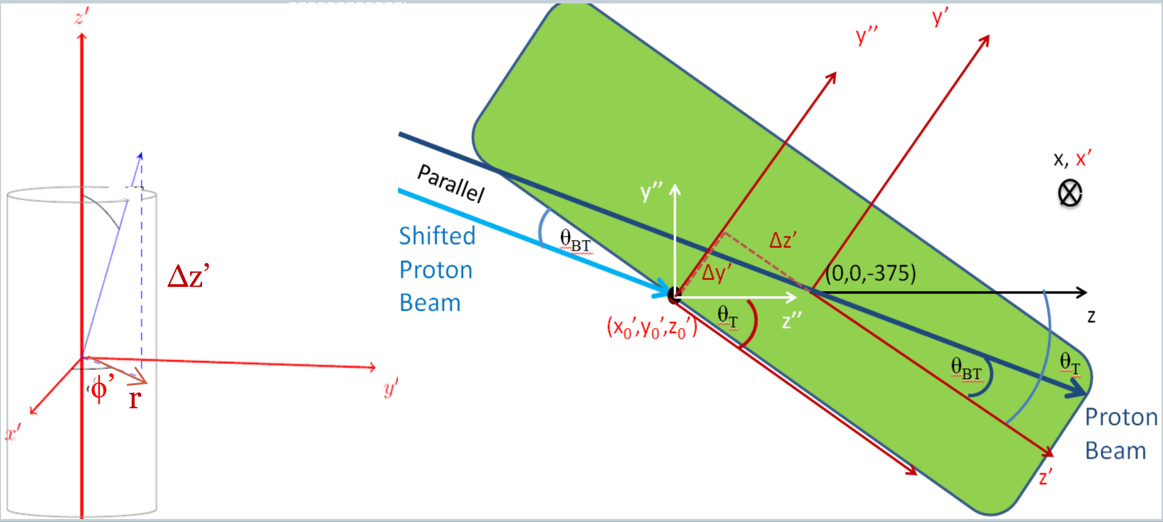
- Jet is now cylindrical
  - These figures show the case from the previous slide for φ=0°
- Beam initial z-position is -750 mm
  - Upper figure shows the proton/jet interaction distribution in the y-direction (vertical)
  - Lower figure shows where each individual proton enters and exits or interacts with the jet
  - Beam starts interacting already at z~680 mm, which gives the skew and off centred distribution in y, because of the tilted jet
- Fix: move distribution peak closer to the origin (beam pipe centre)





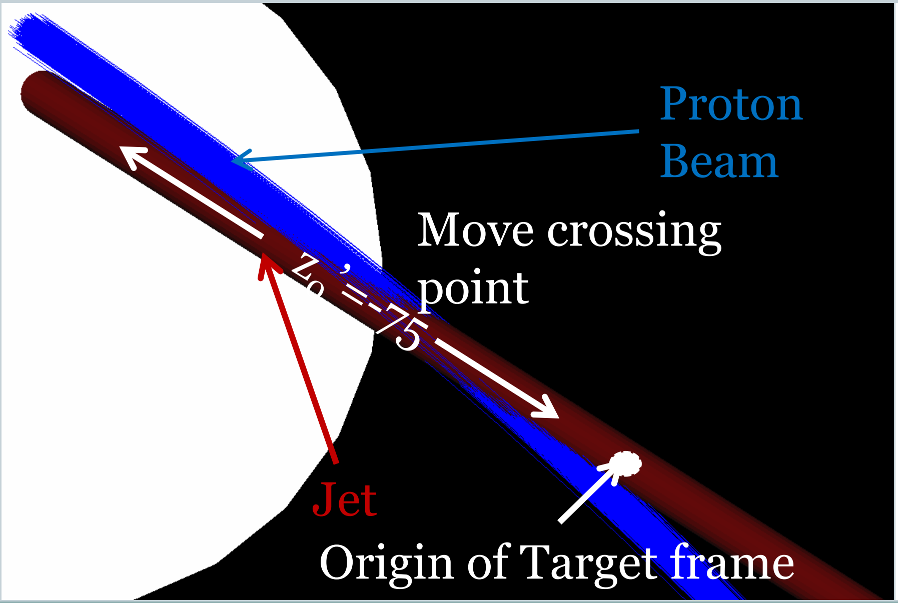
Redefining the beam

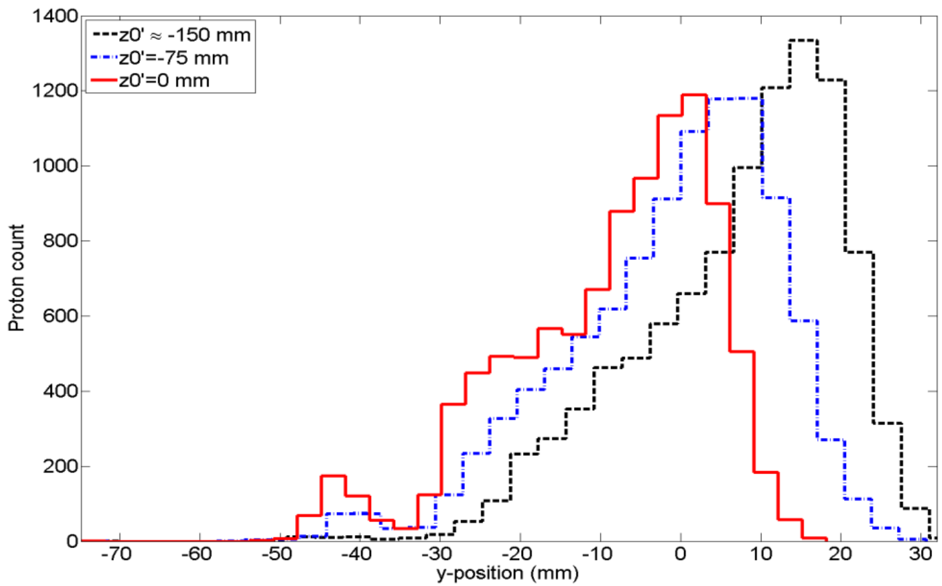
- The vector definition of the beam can readily be shifted in space
  - Assume perfectly defined point-size proton
- Select a point on the surface of the target for the protons to hit, (x_o', y_o', z_o') in the target reference frame
  - $r=\sqrt{\Delta x'^2 + \Delta y'^2}$ is the radius of the target and the length from the target frame origin is Δz'
  - Do a rotation around the x'-axis to find the coordinates of (x_o, y_o, z_o), in the Neutrino Factory reference frame, and shift the initial position of the beam accordingly
- The angles ϕ, θ_T and θ_{BT} are now the angles at the surface of the target instead of the centre
- ϕ' defines the azimuth angle for finding (x_o', y_o')



Proton/jet interaction y-position distribution

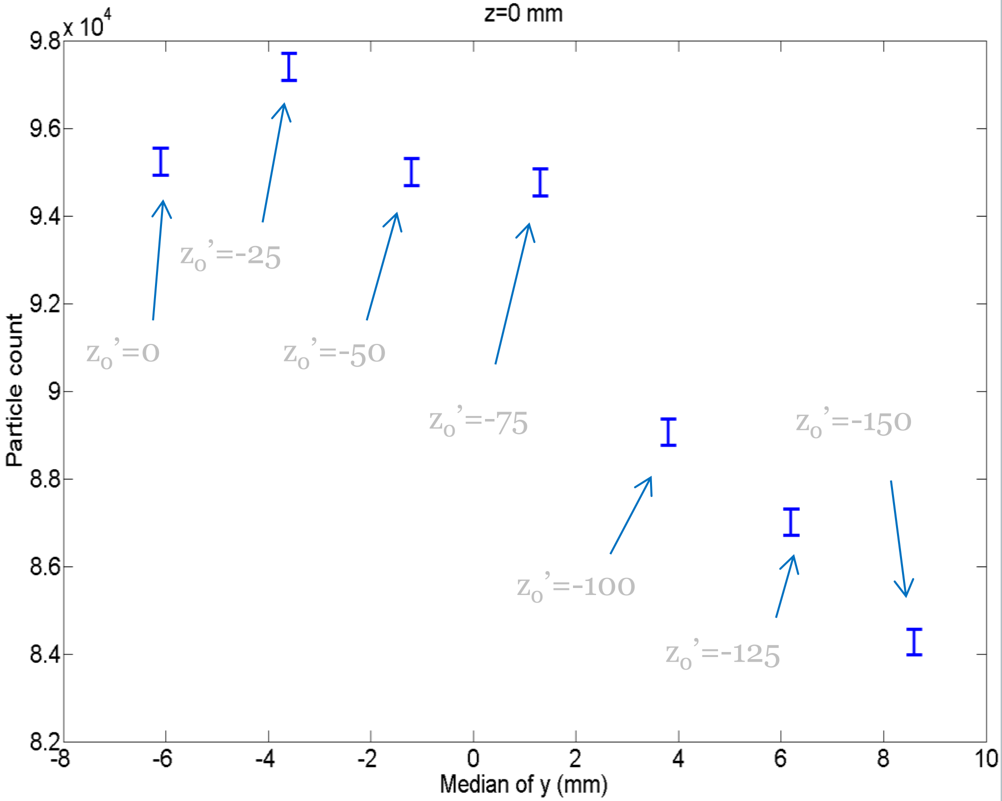
- θ_{BT}=30 mrad, φ=0° , φ'=90° hit on top of the jet (x_0=0, y_0= r), z_0' varies ϵ [-150, 0] mm
- Left: z_0'=-75 mm, shows where the beam hits the jet
- Right: three settings for z_0', the "original" z_0'≈-150 mm is shown in black and the peak is off-centred by about 15 mm
- The two other histograms (red and blue) show how the peak is shifted with increasing z_0'





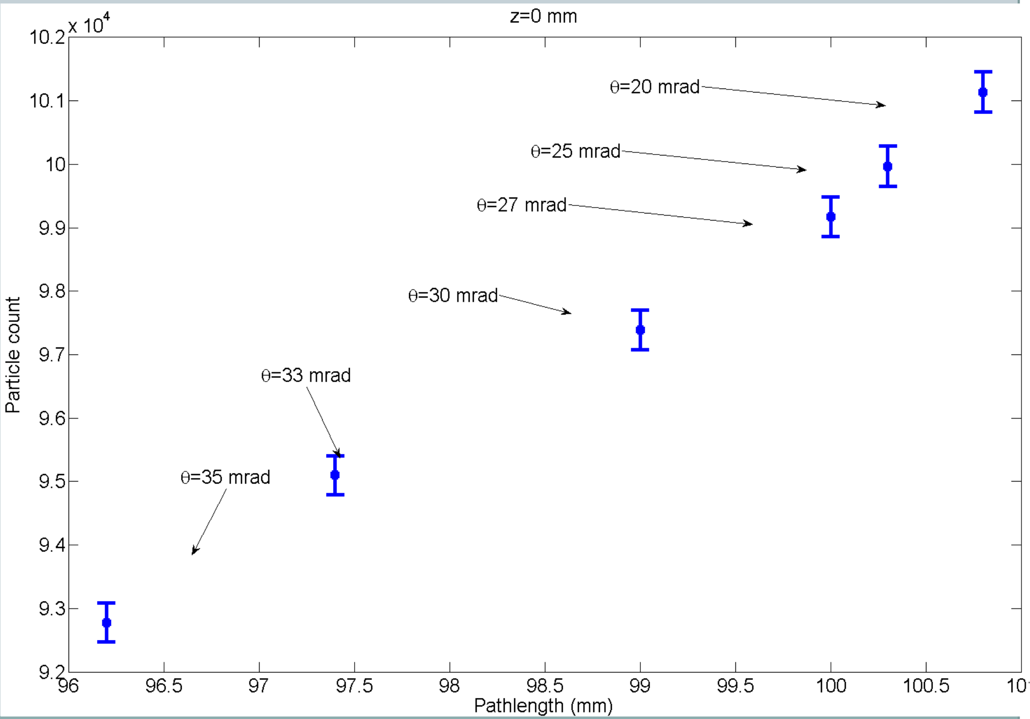
Proton/jet interaction region

- The median is used as a measure of the central tendency of the distribution since it's skewed
- The highest particle count at z=0 mm is found when the median is ≈-4 mm
- The increased particle count is 10.5%
  - Increasing z_o' brings the detector closer to the interaction points and an increased particle count should be expected by the fact itself
- Therefore → Acceptance cuts



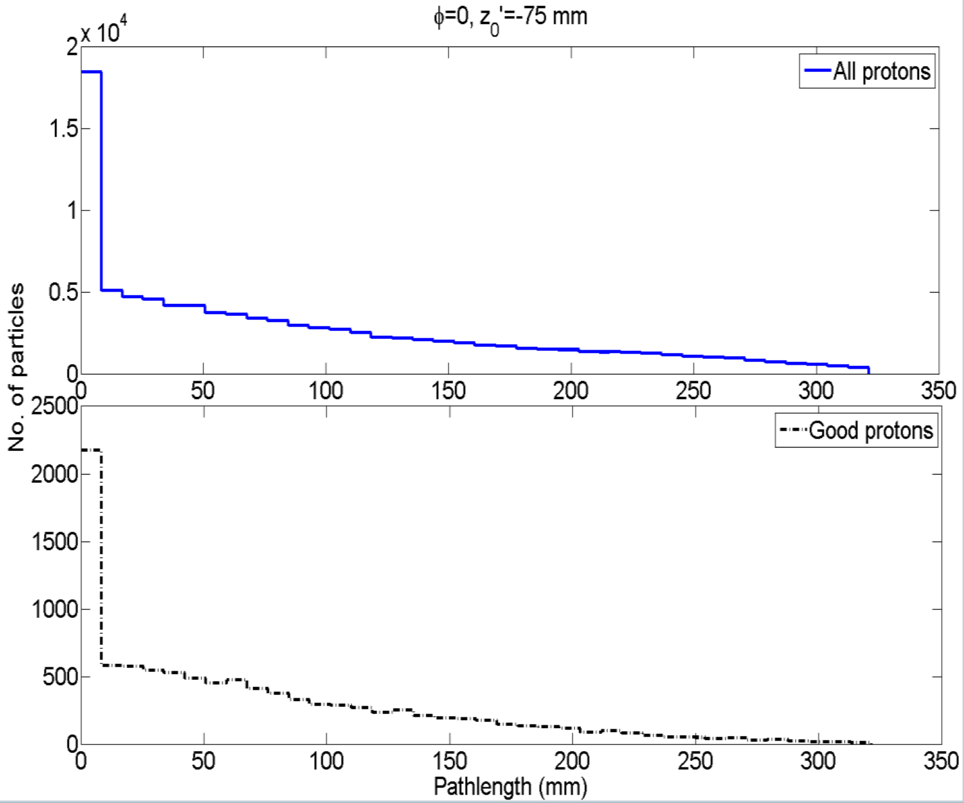
Increasing the pathlength

- Fix z_o'=-25 mm, which gives the median of -4 mm and the highest particle count
- Variation of $\theta_{BT} \in [20, 35]$ mrad
- A longer proton trajectory in the jet (*pathlength*) does increase the particle count at z=0 mm
- Particle count increase of 6.8%



Increasing the pathlength (cont.)

- The pathlength in the jet is shown on the right for z_o'=-75 mm
- Most of the protons interact with the jet at the jet-surface, pathlength=0 mm



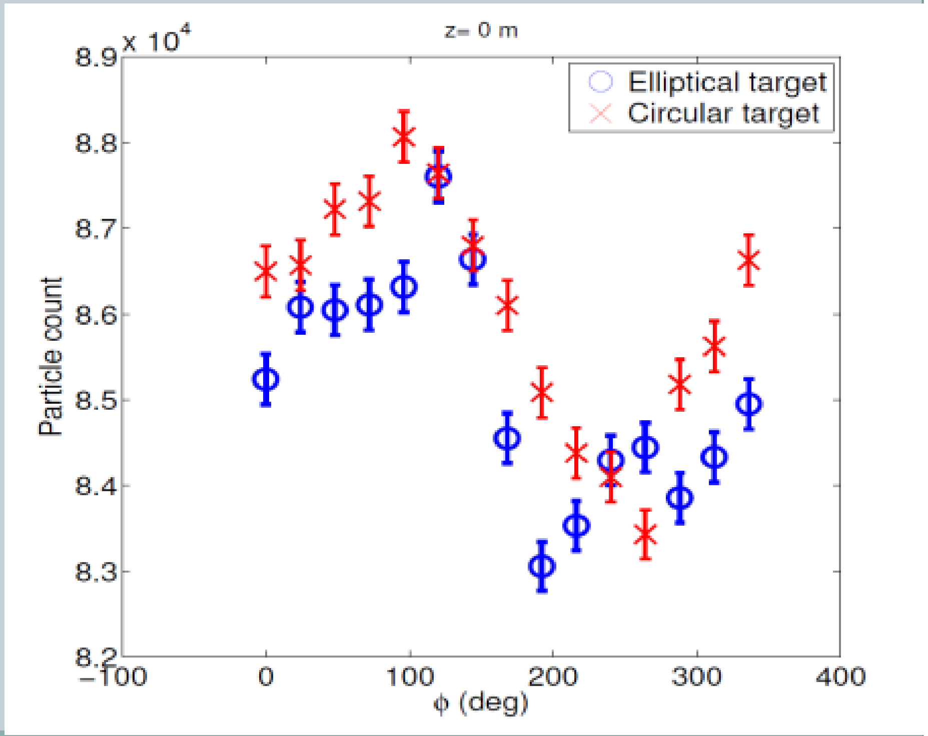
Short summary

- The production of the secondary particles has been centred in the beam pipe and the pathlength was increased
- The increase of the particle count is 6.8 % (from centring) and 10.5 % (from increased pathlength) giving a total increase of 17.3% at z=0 mm without considering acceptance cuts (good muons)

- Next slides: only good muons are accepted

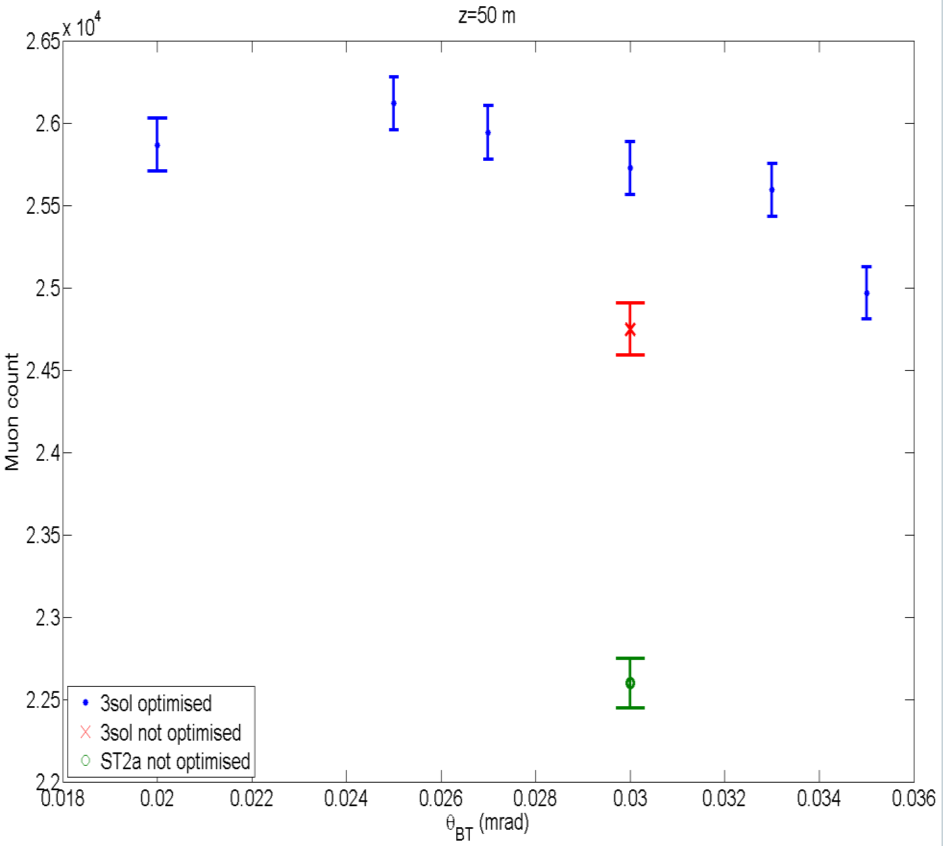
Short reminder

- 3sol setup used and compared with the ST2a
- 'not-optimised' means the maximum values when only ϕ was varied, jet circular and θ_{BT}=30 mrad



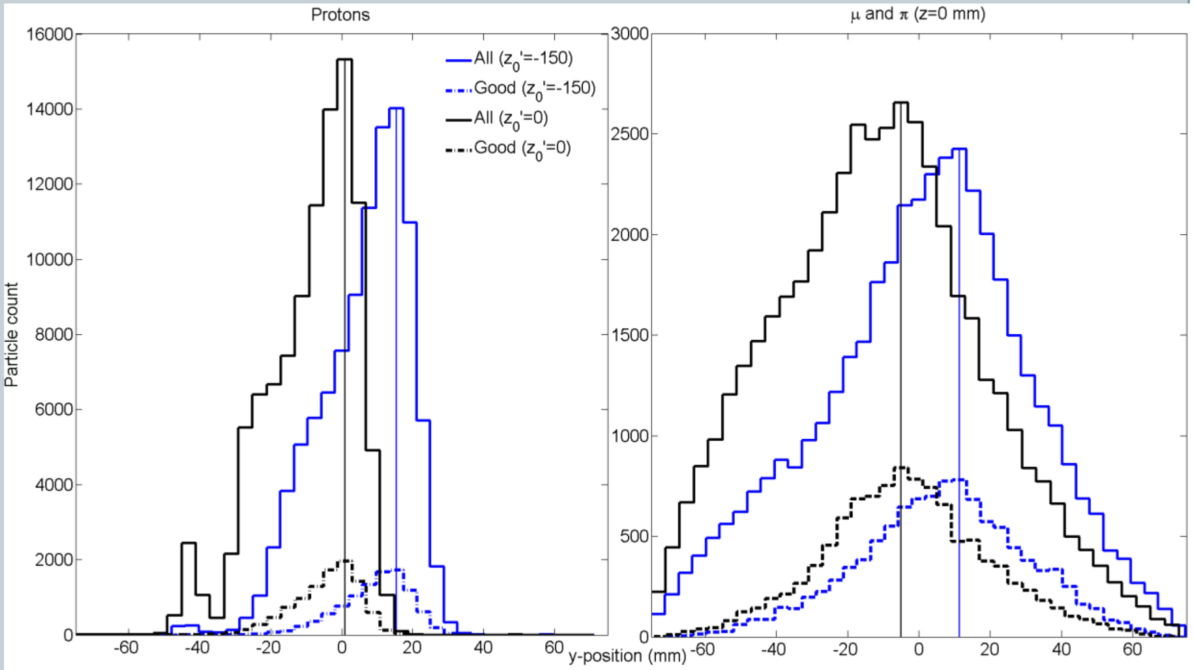
The muon yield

- Increase of 5.5% (16%) on the muon yield compared to the non-optimised 3sol (ST2a)
- The maximum muon yield is found when θ_{BT}=25 mrad
- Increase of 5.5% (16%) on the muon yield compared to the non-optimised 3sol (ST2a)



Updates, production and muon beam centre

- Centring the particle production also centres the pions and muons in the beam pipe
- The distribution maximum for all protons and muons + pions coincide with the distribution maximum for the good particles
- The solid lines show all particles and dashed lines show good particles
- Both distributions have heavier left tales, but the muon + pion distribution is less negative skew (explained by the pathlength plot where the majority of pions are produce at the jet-surface)



Future

- More work on the pathlength study
  - Let the beam enter the jet from other directions
  - Change jet shape to include gravity
- Energy deposition study - 3sol vs. ST2a