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# Timing from Target to Injection @ nuSTORM

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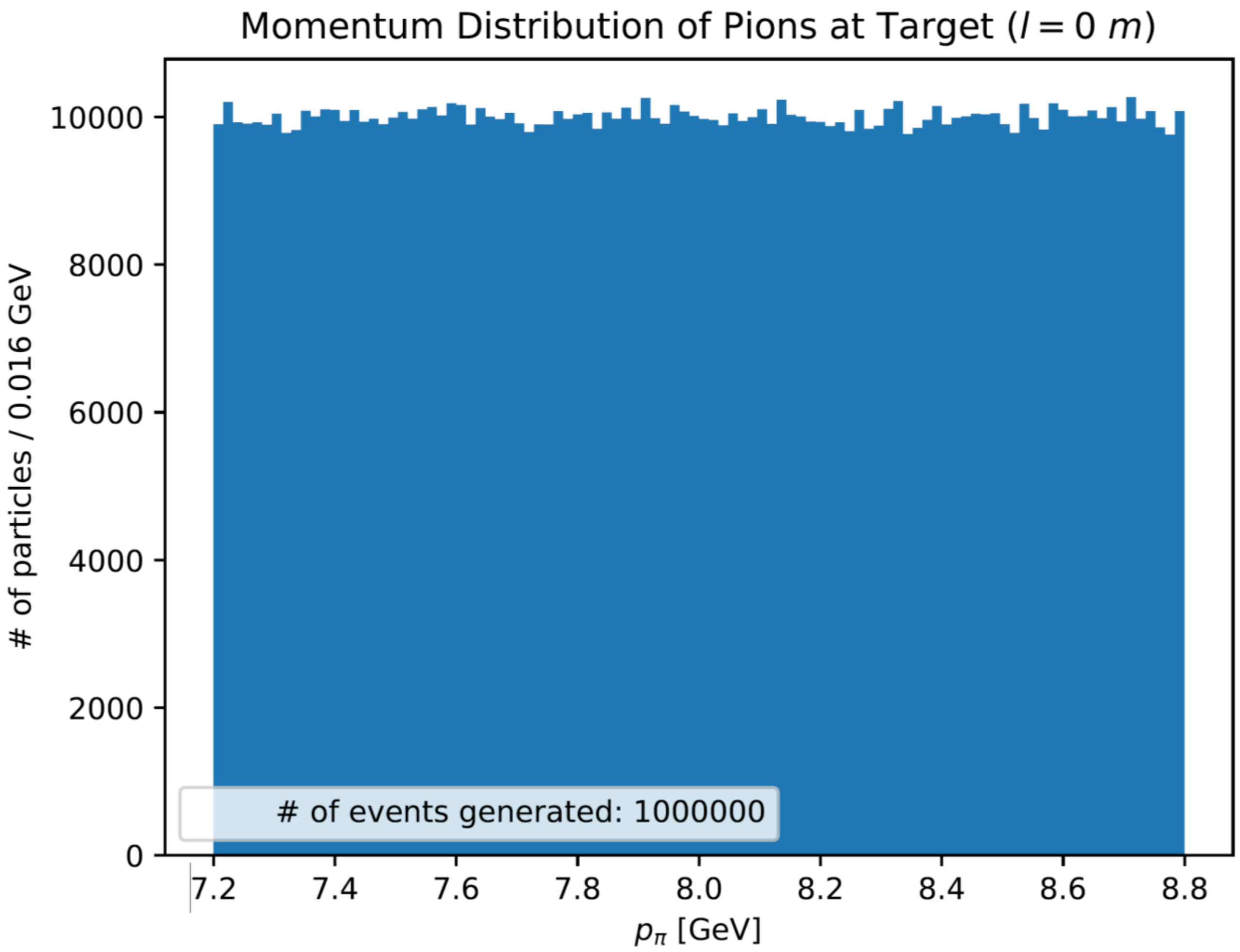
# Motivation

- To understand the timing structure and beam characteristics at the proposed nuSTORM detector, it is important to properly propagate the beam structure from the SPS on target through the whole nuSTORM set-up

- *First simple propagation of beam properties from target to decay straight* has been conducted and timing characteristics studied

- For this, the following steps were taken:
  1. Pion distributions @ target were generated:
     - Momentum distribution
     - Timing distribution (bunch length)
  2. Pion decay taken into account
  3. Pions propagated to entrance of decay straight

# Momentum Distribution @ Target



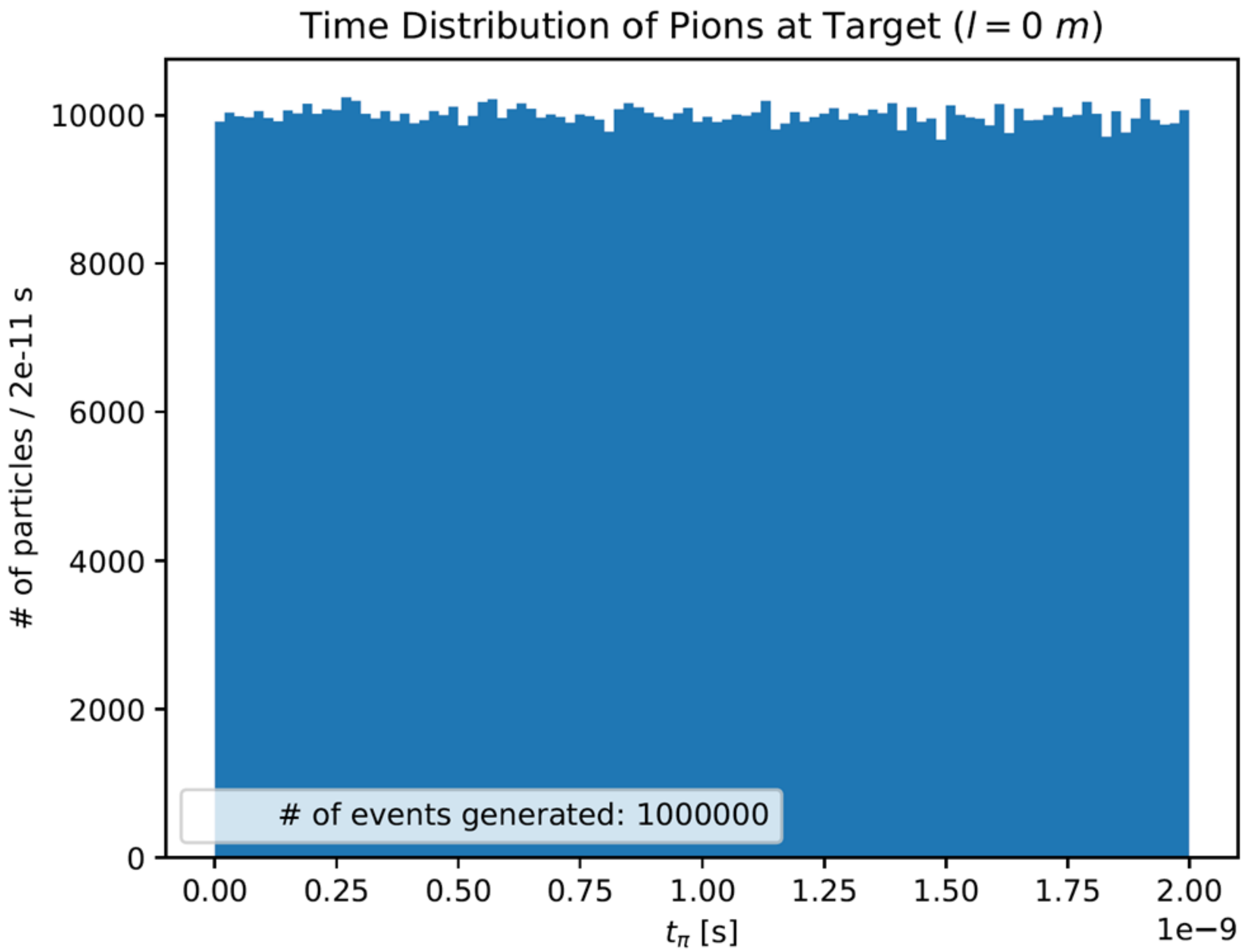

First very simple implementation:

1. Generate distributions @ target:
   - Momentum distribution
   - Timing distribution

Momentum distribution @ target (l = 0 m):

- So far: uniform distribution
- 8 GeV central momentum
- 10% momentum spread

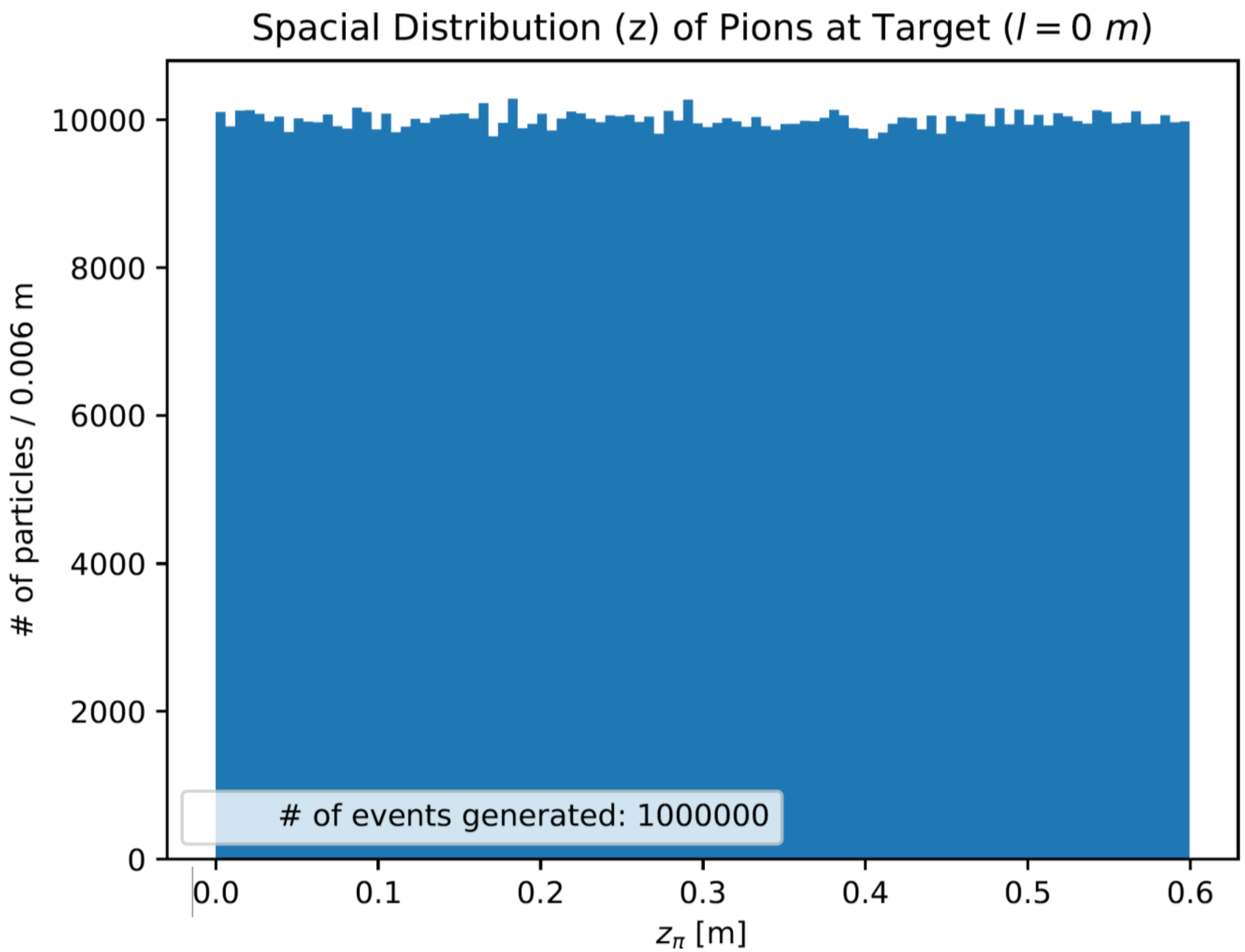
# Time Distribution @ Target




Time distribution @ target (l = 0 m):

- Uniform distribution
- 2 ns bunch length

# Spatial Bunch Distribution @ Target

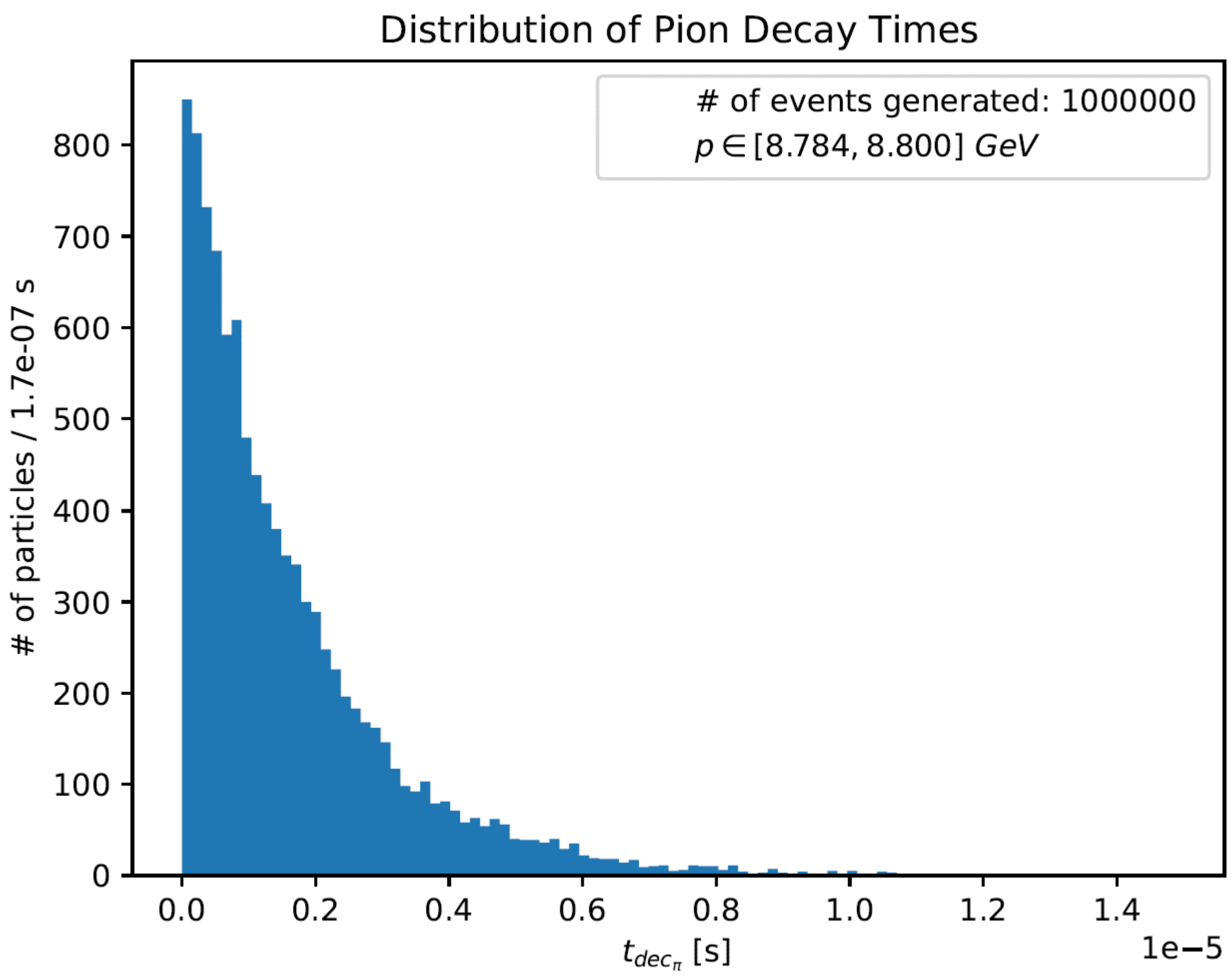



Spatial Bunch distribution @ target (l = 0 m):

$$z_i = v_i \cdot t_{0,i}$$

- Uniform distribution
- Spatial (z) bunch length: $\Delta z \approx 59.95$ cm

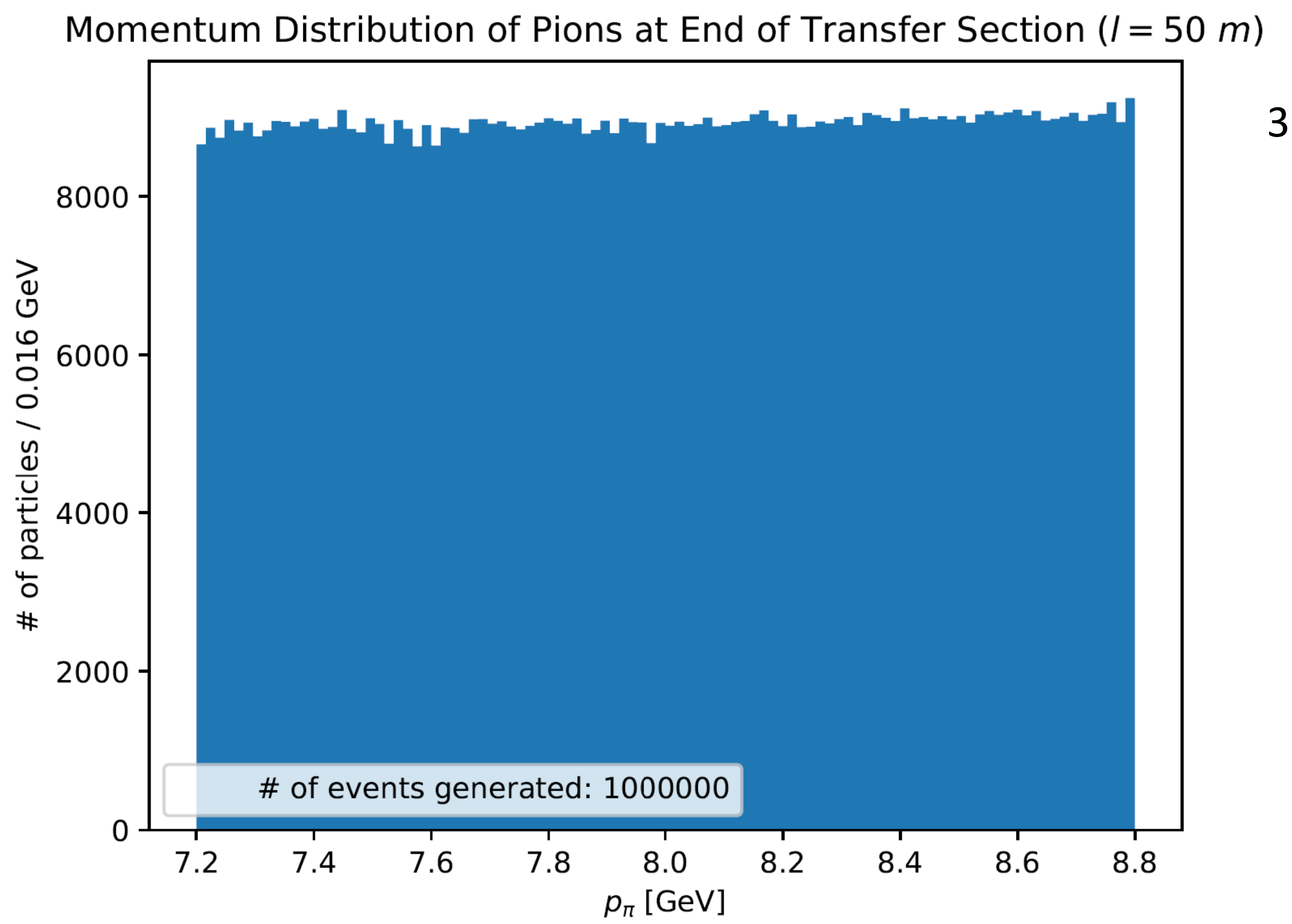
# Pion Decay




2. Take pion decay into account:

- Exponential random distribution for number of pions of each bin (bin width: 16 MeV) with $\tau$ dilated by $\gamma$ of bin central momentum
- One $t_{decay}$ gets assigned to each pion

# Momentum Distribution @ Decay Straight Entrance



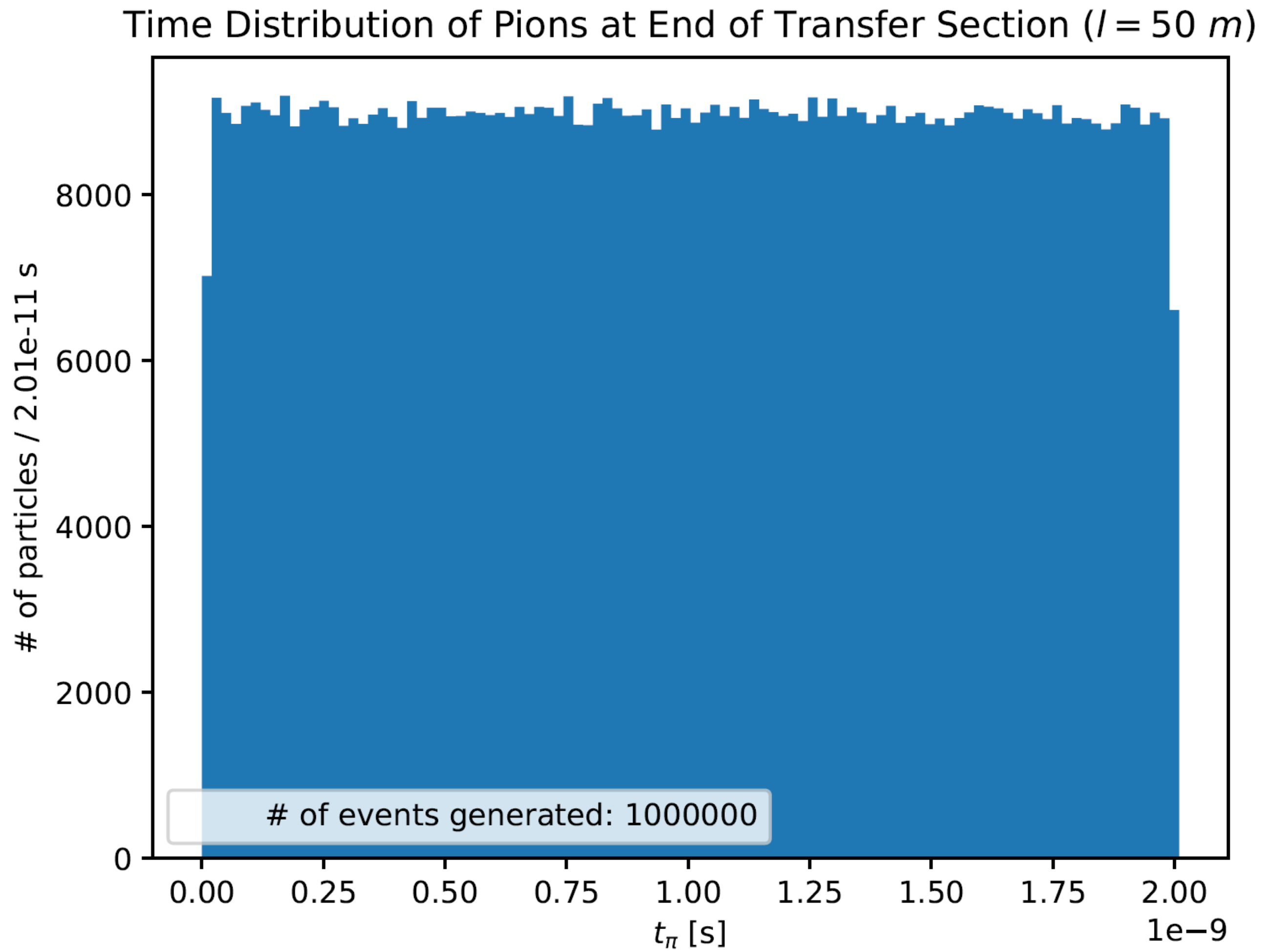

3. Propagate distributions to decay straight entrance
   - Cut on $t_{decay}$
   - Each pion propagates with its own velocity $v_i$
   - Momentum loss negligible over $l = 50$ m

Momentum distribution @ Decay straight entrance ($l = 50$ m):

- Approx. 1% of pions have decayed
- Predominantly pions with smaller momentum have decayed

→ slight positive slope visible

# Time Distribution @ Decay Straight Entrance

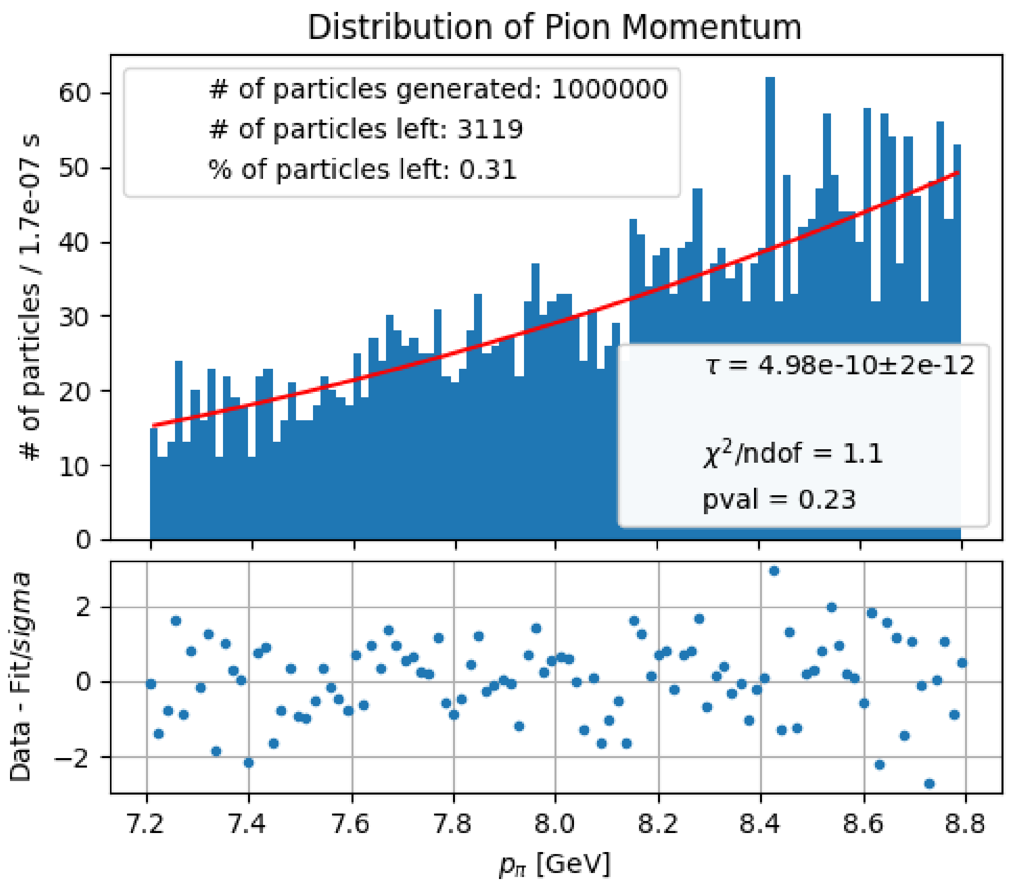



Time distribution @ Decay straight entrance (l = 50 m):

- Bunch length: $\Delta t \approx 2.010$ ns

→ Bunch length increased by approx. 0.5%

# Verification of Decay Code – Exponential Fit




Decayed distribution:

$z = 50$ m

**true $\tau = 5 \cdot 10^{-10}$ s**

Idea:

- Generate decayed distribution with artificial $\tau$
- Fit distribution with a function of p
- Calculate lifetime from fit parameters

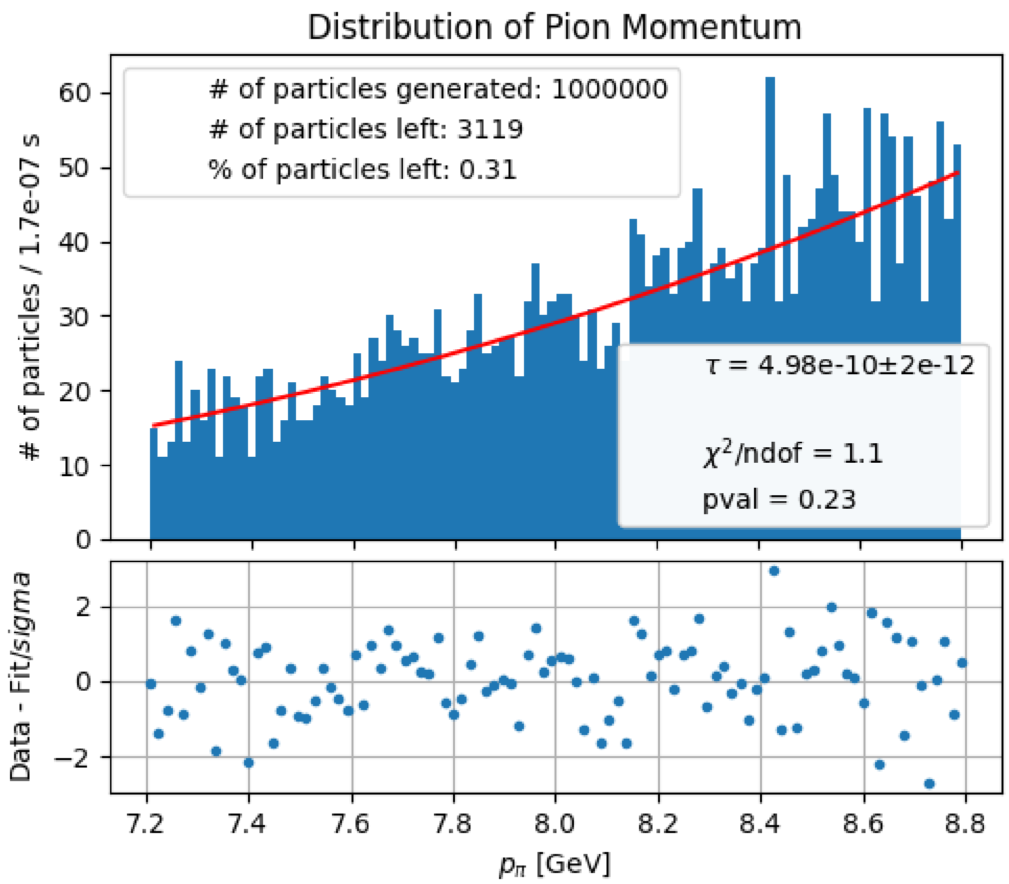
→ Consistency check

PDF:

$$f(p) = N_{bin\ average(@z=0m)} \times \exp\left(-\frac{m_\pi \cdot z}{p \cdot \tau}\right)$$

- $N_{bin\ average(@z=0m)}$: average number of entries in bins at the target
- $m_\pi$: mass of pion
- $z$: location of the decayed distribution
- $\tau$: particle lifetime
- $p$: particle momentum (fitted)

# Verification of Decay Code – Exponential Fit




Decayed distribution:

**true**

Inputs to generate distribution:

- $z\ =\ 50$ m
- $m_\pi = 0.1395$ GeV (PDG value)

- $\boldsymbol{\tau_{input} = 5 \cdot 10^{-10}}$ **s**

Fit outputs:

- $\boldsymbol{\tau_{fit} = (4.98 \pm 0.02) \cdot 10^{-10}}$ **s**
- Reduced $\chi^2$ and p value are good

→ Input and output are consistent

# Summary & Outlook

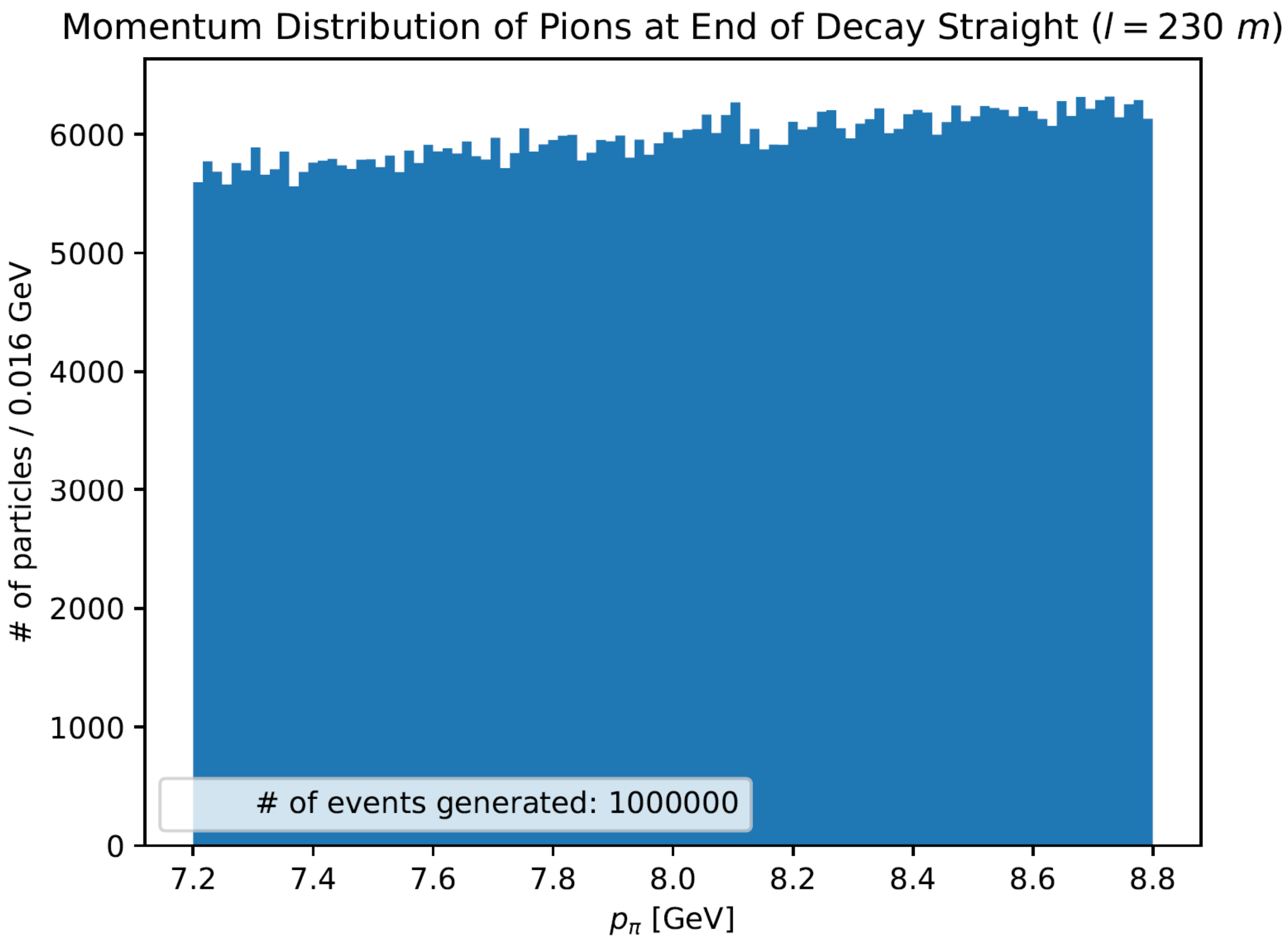
- To understand the timing structure and beam characteristics at the proposed nuSTORM detector, it is important to properly propagate the beam structure from the SPS on target through the whole nuSTORM set-up

- *First simple propagation of beam properties from target to decay straight* has been conducted and timing characteristics studied:
  - Approx. 1% of pions have decayed (predominantly ones with smaller momentum)
  - Bunch length increased by approx. 0.5% ($\Delta t \approx 2.000$ ns → $\Delta t \approx 2.010$ ns)
  - Code works well (as shown by consistency check)

- Next steps:
  - Implementation of pion decay for each particle seperately with its corresponding momentum (so far: decay spectrum per momentum bin with bin central momentum)
  - Implementation of stand-alone code in nuSIM software package
  - Later – further improvemet of code:
    - More realistic pion distrubition @ target
    - Generating full 3D beam profile (so far: only z-coordinate)

# Backup

# Momentum Distribution @ End of Decay Straight

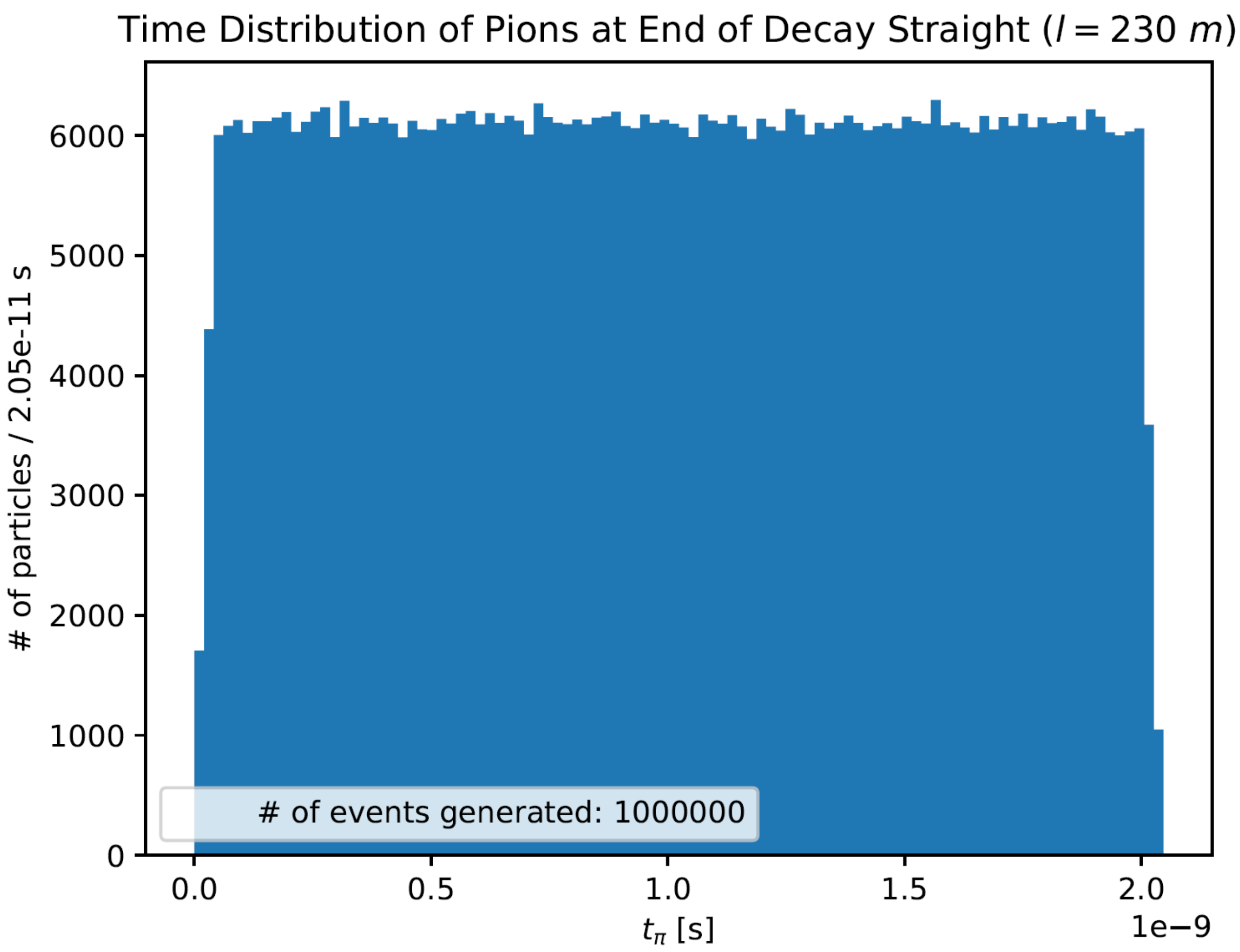



Momentum distribution @ Decay straight entrance (l = 230 m):

- Approx. 4% of pions have decayed

→ Slope increased

# Time Distribution @ Decay Straight Entrance

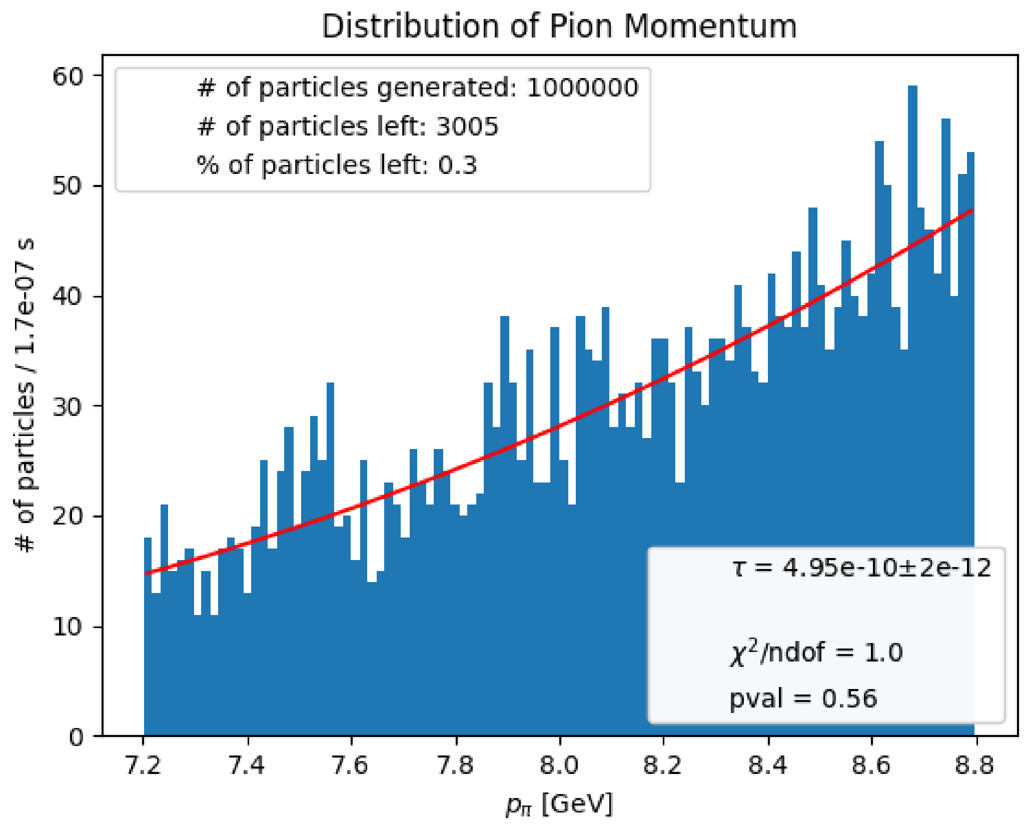



Time distribution @ Decay straight entrance (l = 230 m):

- Bunch length: $\Delta t \approx 2.047$ ns

→ Bunch length increased by approx. 2.4%

# Verification of Decay Code – Calculation




Probability that a particle survives for time t before decaying:

$$P(t) = \exp\left(-\frac{t}{\gamma \cdot \tau}\right) = \exp\left(-\frac{m \cdot v \cdot t}{p \cdot \tau}\right) \qquad \gamma = \frac{\vec{p}}{m\vec{v}} = \frac{p}{mv}$$

$$P(z, p) = \exp\left(-\frac{m \cdot z}{p \cdot \tau}\right)$$

PDF:

$$f(p) = N_{bin\ average(@z=0m)} \times \exp\left(-\frac{m_\pi \cdot z}{p \cdot \tau}\right)$$