# Decays-in-flight muon polarization measurement to extract the Michel parameter $\xi'$ in $\tau$-decays at the Future Super charm-tau Factory.

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# Michel parameters

- Michel parameters of a lepton decay are bilinear combinations of coupling constants arising in the most general expression for the decay matrix element

$$M = \frac{4G_F}{\sqrt{2}} \sum_{\substack{\gamma = S,V,T \\ \varepsilon,\mu = R,L}} g^{\gamma}_{\varepsilon\mu} \langle \bar{\ell}_{\varepsilon} | \Gamma^{\gamma} | ((\nu_{\ell})_{\alpha}) \rangle \langle (\bar{\nu}_{\tau})_{\beta} | \Gamma_{\gamma} | \tau_{\mu} \rangle$$

$$\Gamma^S = 1,\, \Gamma^V = \gamma^{\mu},\;\; \Gamma^T = \frac{1}{\sqrt{2}}\sigma^{\mu\nu} = \frac{i}{2\sqrt{2}}(\gamma^{\mu}\gamma^{\nu} - \gamma^{\nu}\gamma^{\mu})$$

- Michel parameters describe the Lorentz structure of the charged currents interaction in the theory of weak interaction and can be used to test the Standard Model

- The only nonzero term in the SM theory of weak interaction: $g^V_{LL} = 1$

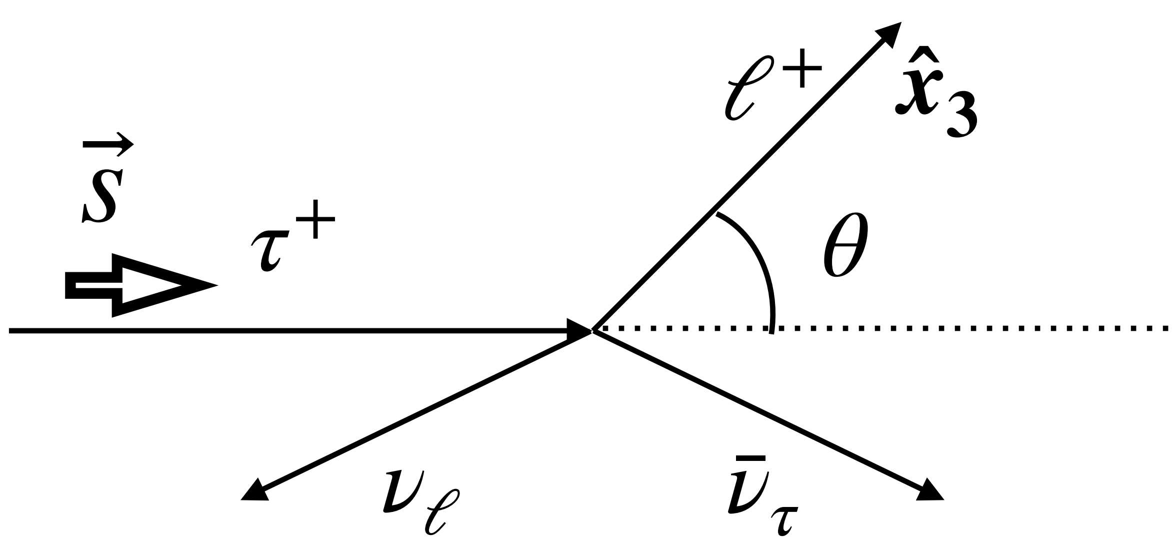
# Michel parameters (2)

- Differential width neglecting the masses of the neutrino:

$$\frac{d^2\Gamma}{dx\,d\cos\theta} = \frac{m_\tau}{4\pi^3} W_{\ell\tau}^4 G_F^2 \sqrt{x^2 - x_0^2}\left(F_{IS}(x) \pm P_\tau \cos\theta F_{AS}(x)\right)\left[1 + \hat{\boldsymbol{\xi}} \cdot \boldsymbol{P}_\ell(x,\theta)\right]$$

$$W_{\ell\tau} = \max E_\ell = \frac{m_\tau^2 + m_\ell^2}{2m_\ell},\ x = \frac{E_\ell}{\max E_\ell},\ x_0 = \frac{m_\ell}{\max E_\ell},\ P_\tau = |\boldsymbol{P}_\tau|$$

$$\boxed{\boldsymbol{P}_\ell(x,\theta) = P_{T_1}\hat{\boldsymbol{x}}_\mathbf{1} + P_{T_2}\hat{\boldsymbol{x}}_\mathbf{2} + P_L\hat{\boldsymbol{x}}_\mathbf{3}}$$




$\rho = \xi\delta = \frac{3}{4},\ \xi = 1,\ \eta = 0$ *(Measured)*

$\xi'' = \xi'$ $\qquad P_L \approx \pm 0.98\xi'$

*For SM:* $P_{T_1} \approx P_{T_2} = 0$ $\qquad \boxed{\xi' = 1}$

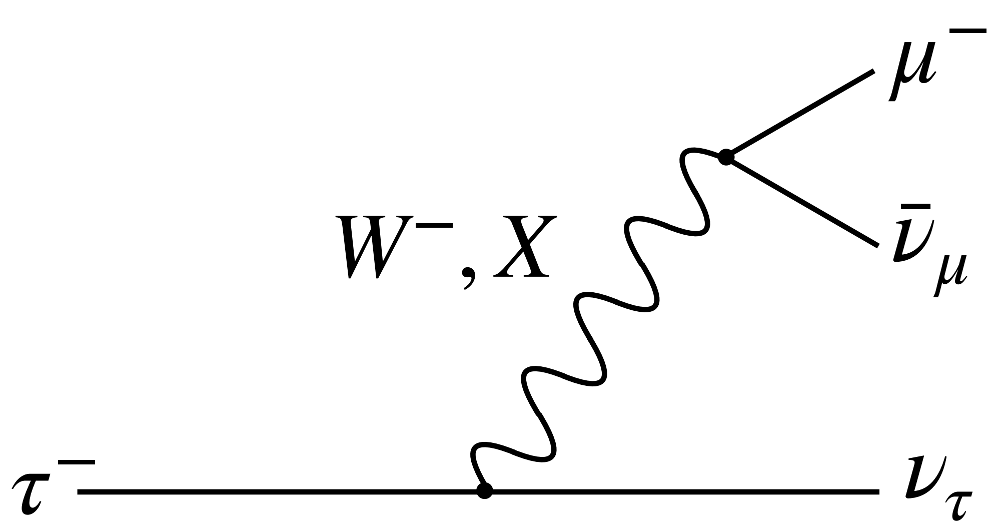
# Status of the Michel parameters

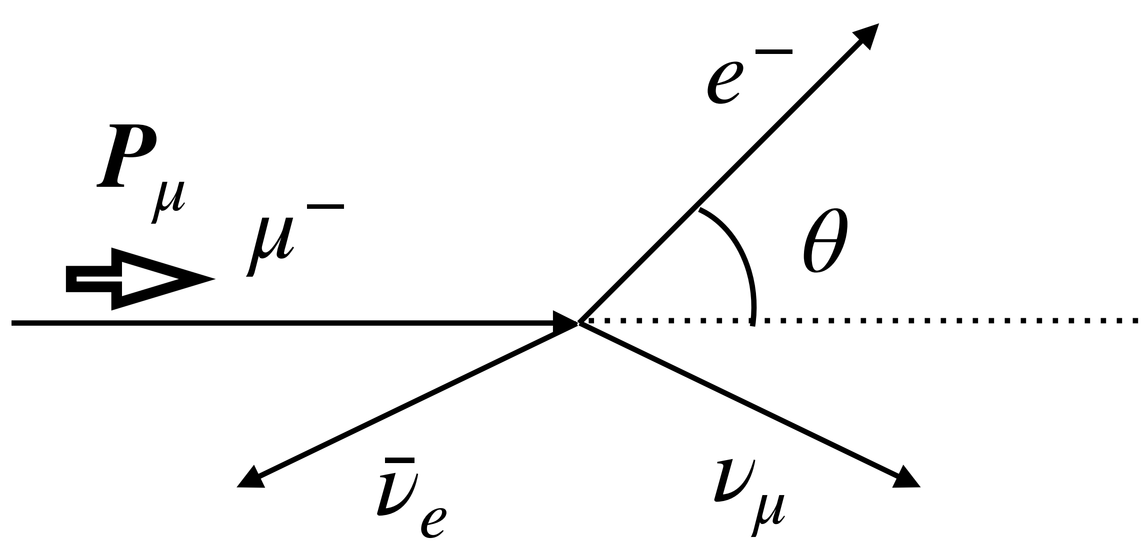
| MP (SM) | $\mu \to e\nu_e\nu_\mu$ | $\tau \to e\nu_e\nu_\tau$ | $\tau \to \mu\nu_\mu\nu_\tau$ | MP (SM) | $\mu \to e\nu_e\nu_\mu$ | $\tau \to e\nu_e\nu_\tau$ | $\tau \to \mu\nu_\mu\nu_\tau$ |
|---|---|---|---|---|---|---|---|
| $\rho\,(0.75)$ | $0.74979 \pm$ $0.00026$ | $0.747 \pm 0.010$ | $0.763 \pm 0.020$ | $\alpha'/A\,(0)$ | $-0.010 \pm 0.020$ | | |
| $\xi\,(1)$ | | $0.994 \pm 0.040$ | $1.030 \pm 0.059$ | $\beta/A\,(0)$ | $0.004 \pm 0.006$ | | |
| $\eta\,(0)$ | $0.057 \pm 0.034$ | $0.013 \pm 0.020$ | $0.094 \pm 0.073$ | $\beta'/A\,(0)$ | $0.002 \pm 0.007$ | | |
| $\xi \cdot \delta\,(0.75)$ | | $0.734 \pm 0.028$ | $0.778 \pm 0.037$ | $a/A\,(0)$ | | | |
| $\delta\,(0.75)$ | $0.75047 \pm$ $0.00034$ | | | $a'/A\,(0)$ | | | |
| $\xi \cdot \delta/\rho\,(1)$ | $1.0018^{+0.0016}_{-0.0007}$ | | | $(b'+b)/A(0)$ | | | |
| $\xi'\,(1)$ | $1.00 \pm 0.04$ | | Target | $c/A\,(0)$ | | | |
| $\xi''\,(1)$ | $0.98 \pm 0.04$ | | | $c'/A\,(0)$ | | | |
| $P_{T_1}\,(0)$ | $0.007 \pm 0.008$ | | | $\bar{\eta}\,(0)$ | $0.02 \pm 0.08$ | | $-1.3 \pm 1.7$ |
| $P_{T_2}\,(0)$ | $-0.002 \pm 0.008$ | | | $\xi\kappa\,(0)$ | | $-0.4 \pm 1.2$ | $0.8 \pm 0.6$ |
| $\alpha/A\,(0)$ | $0.000 \pm 0.004$ | | | | | | |

- There is Standard Model expectation for the Michel Parameters in brackets
- For $\tau$-lepton only leptonic decay modes are listed
- Not all listed parameters are independent!

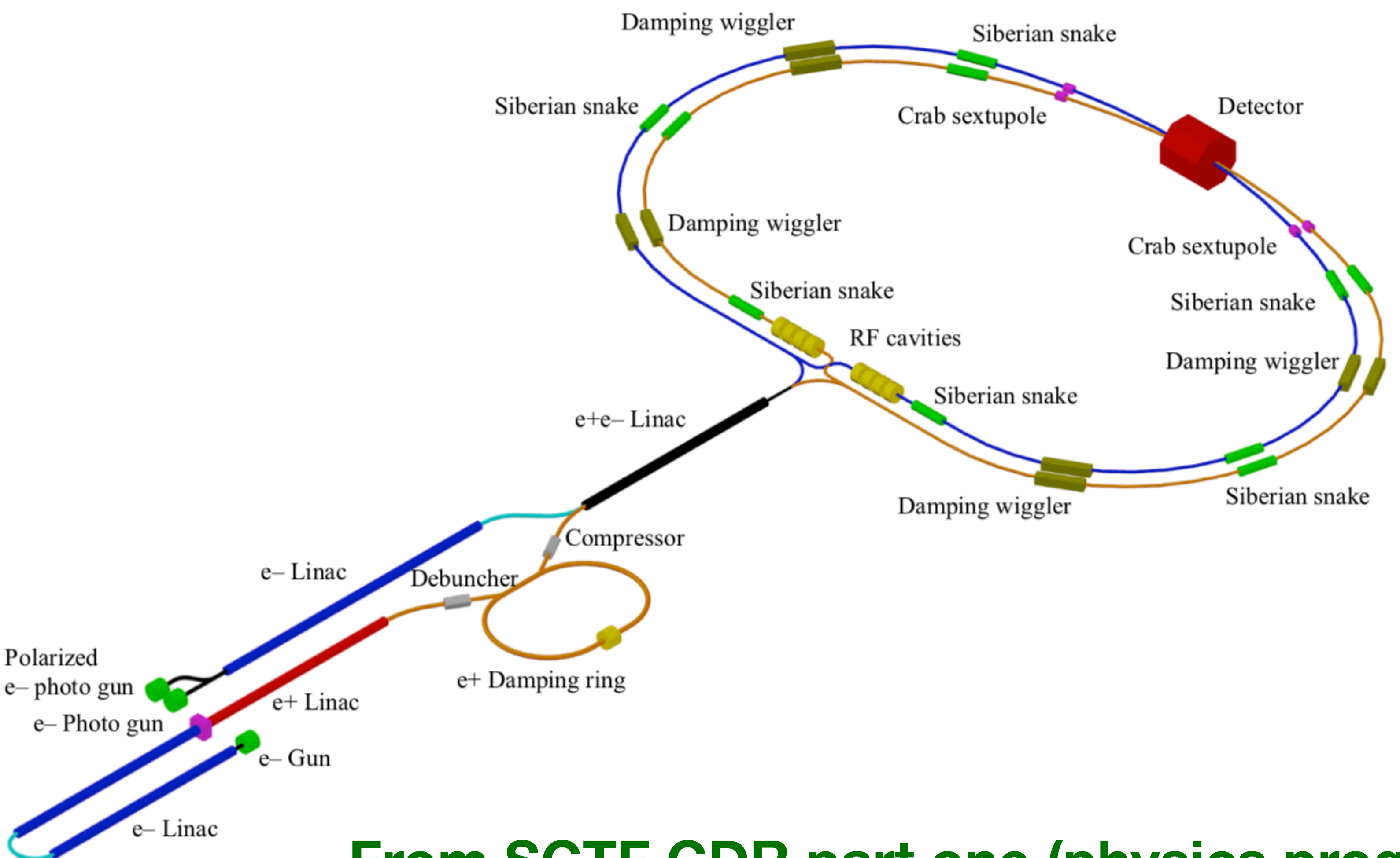
# Motivation

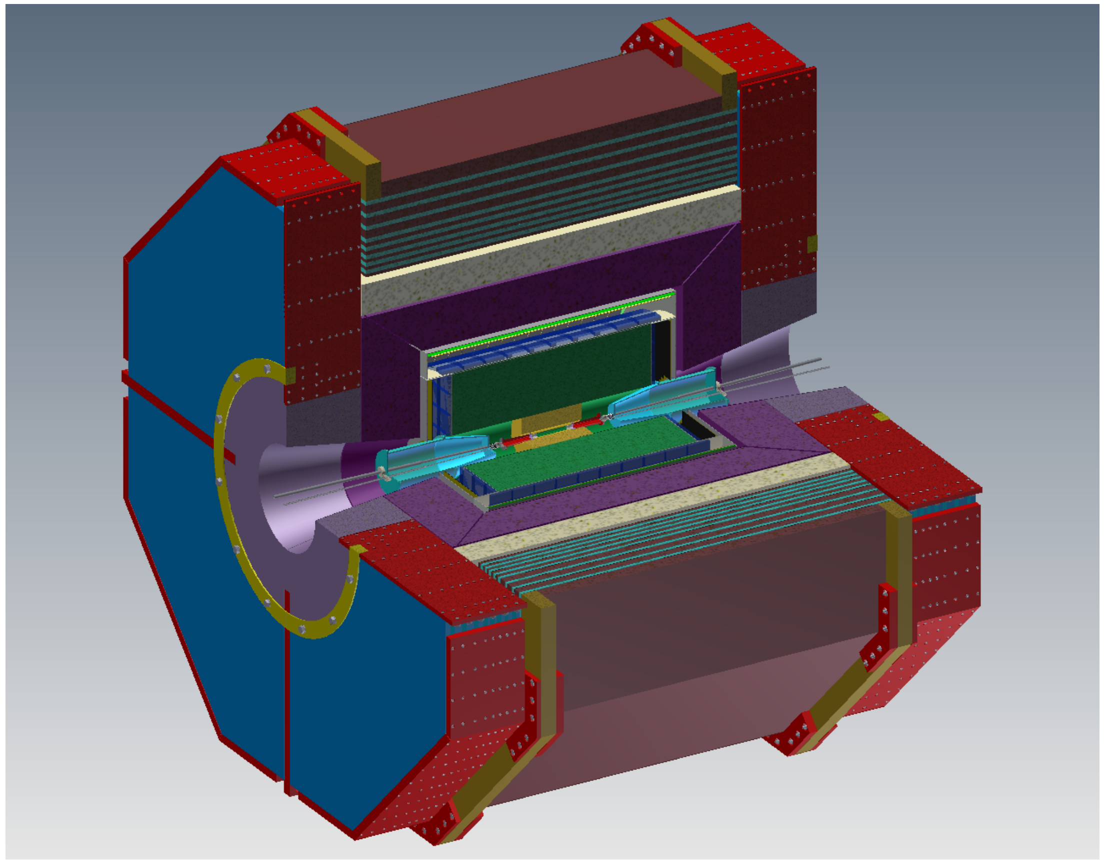
- The first measurement of the polarization of muons from $\tau$-leptons decays
- Precision measurement of the Michel parameter $\xi'$ in $\tau \to \mu \nu_\mu \nu_\tau$ decays
- In addition, indications of a lepton universality violation observed over the past 10 years in semileptonic $B$-mesons decays with $\tau$-lepton in the final state and in the electroweak penguin $B$-mesons decays
- New interactions could explain the deviations from the Standard Model predictions and reveal in $\tau$-decays



# Super charm-tau Factory



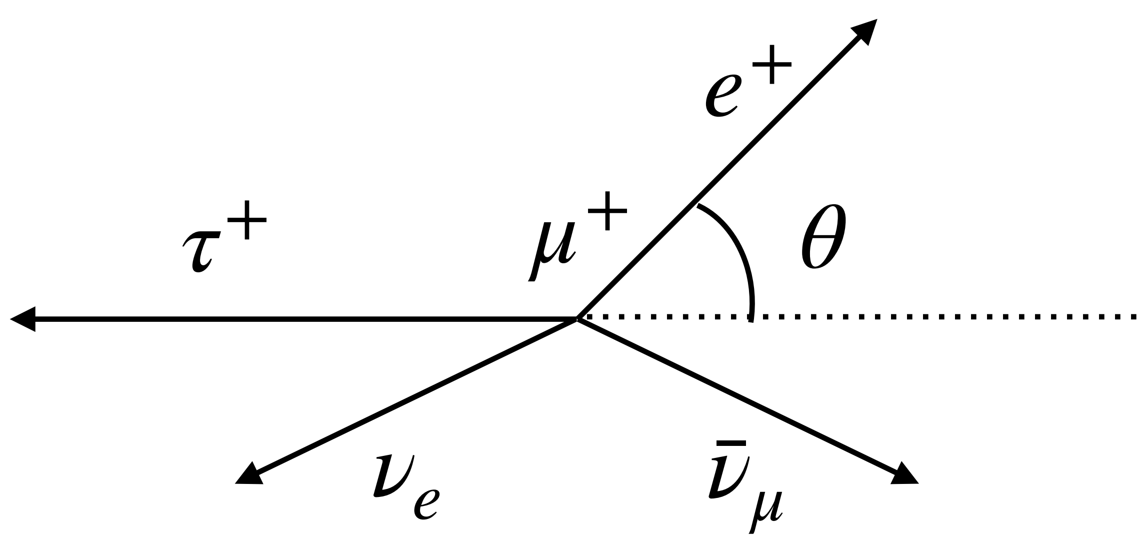
**From SCTF CDR part one (physics program and detector) 2018**

**Collider** **Detector**

| | |
|---|---|
| **Energy** | 3.78 GeV |
| **Drift chamber radius** | [20; 80] cm |
| **Drift chamber length** | [-100; 100] cm |

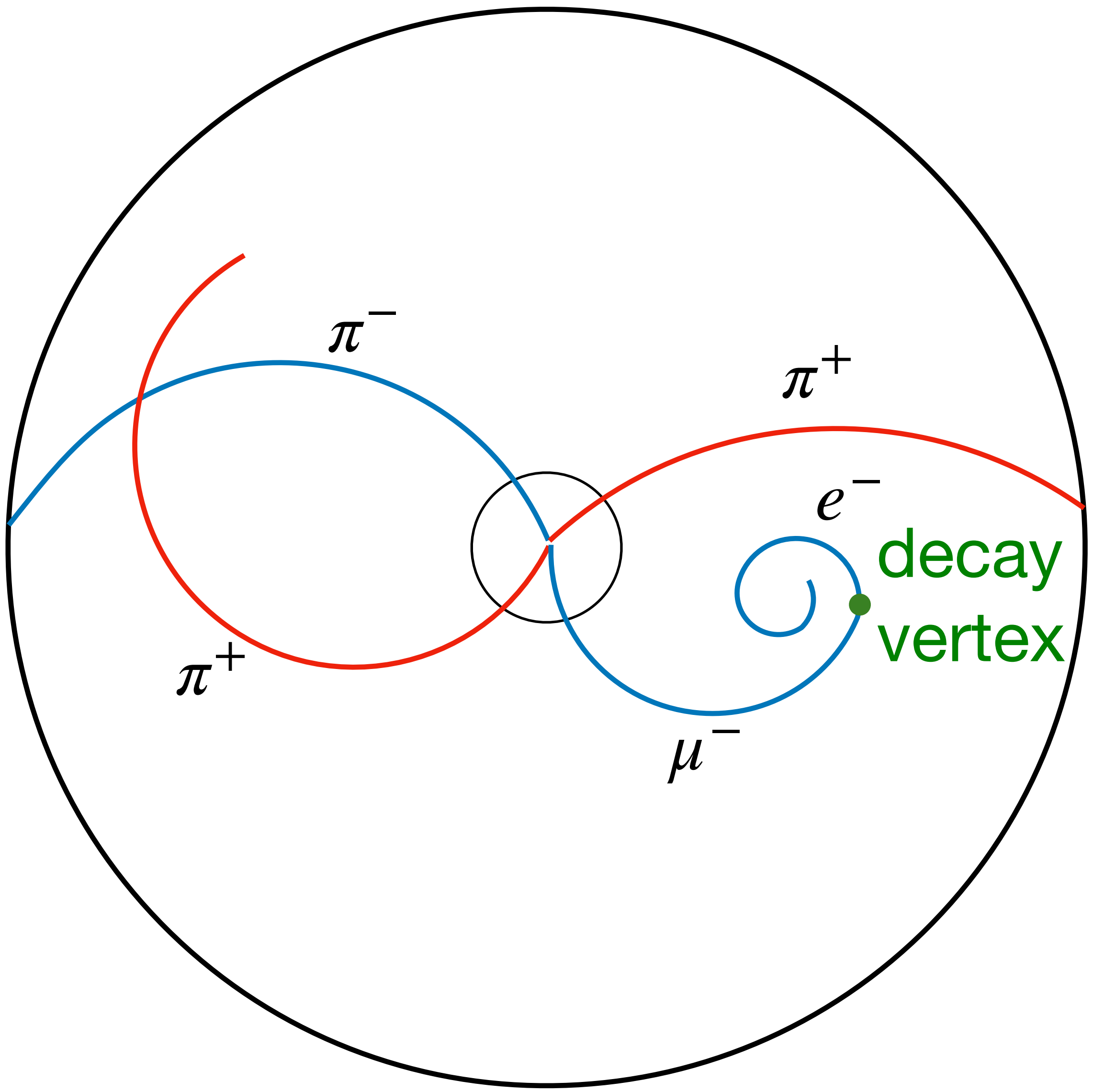
# Method of the muon polarization measurement

- Using the angular distribution of an electron in the rest frame of a decayed in the drift chamber muon



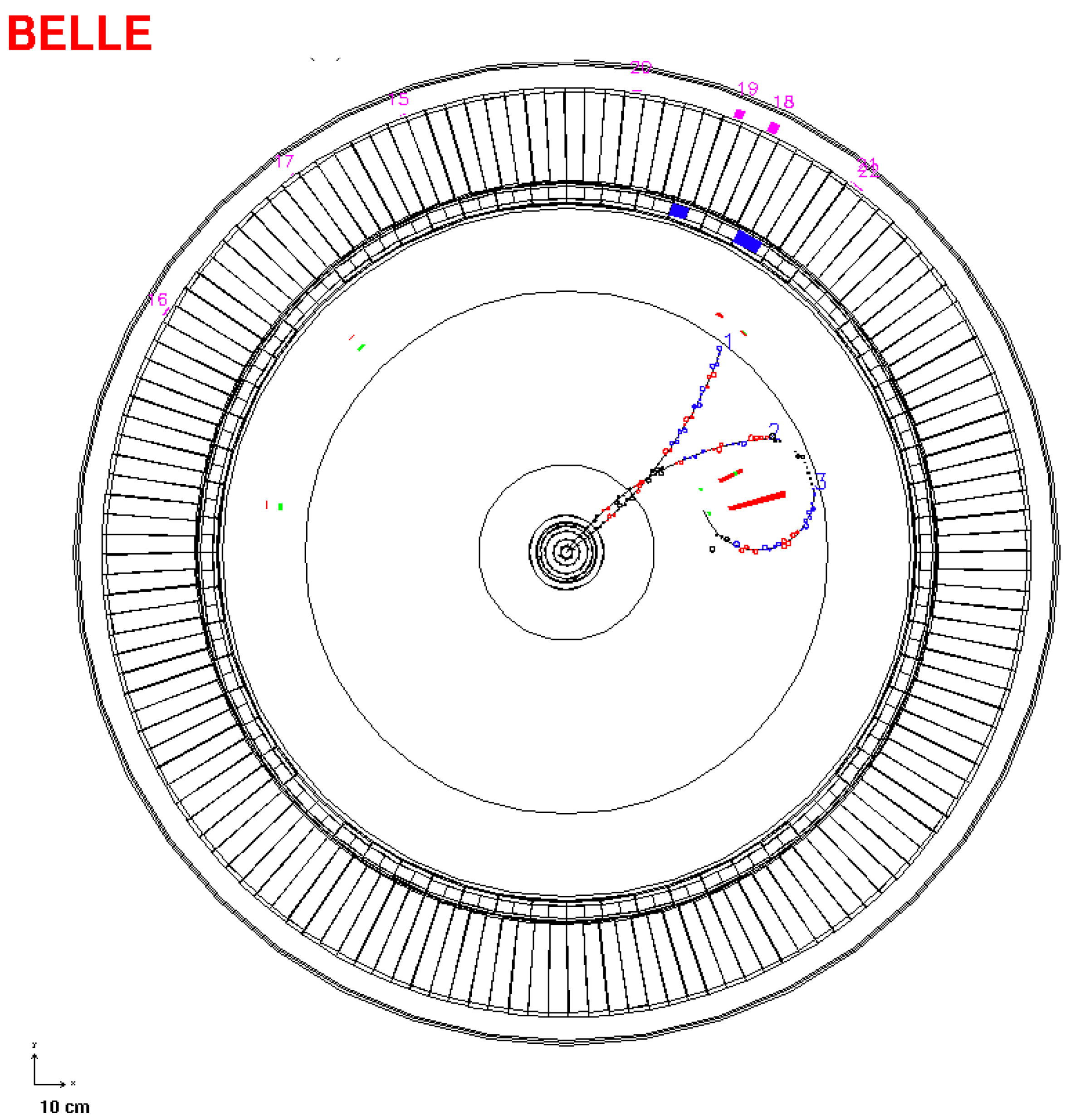

$$\frac{1}{\Gamma}\frac{d\Gamma(\cos\theta)}{d\cos\theta} = \frac{1}{2}\left(1 \pm \frac{P_L}{9}\cos\theta\right)$$

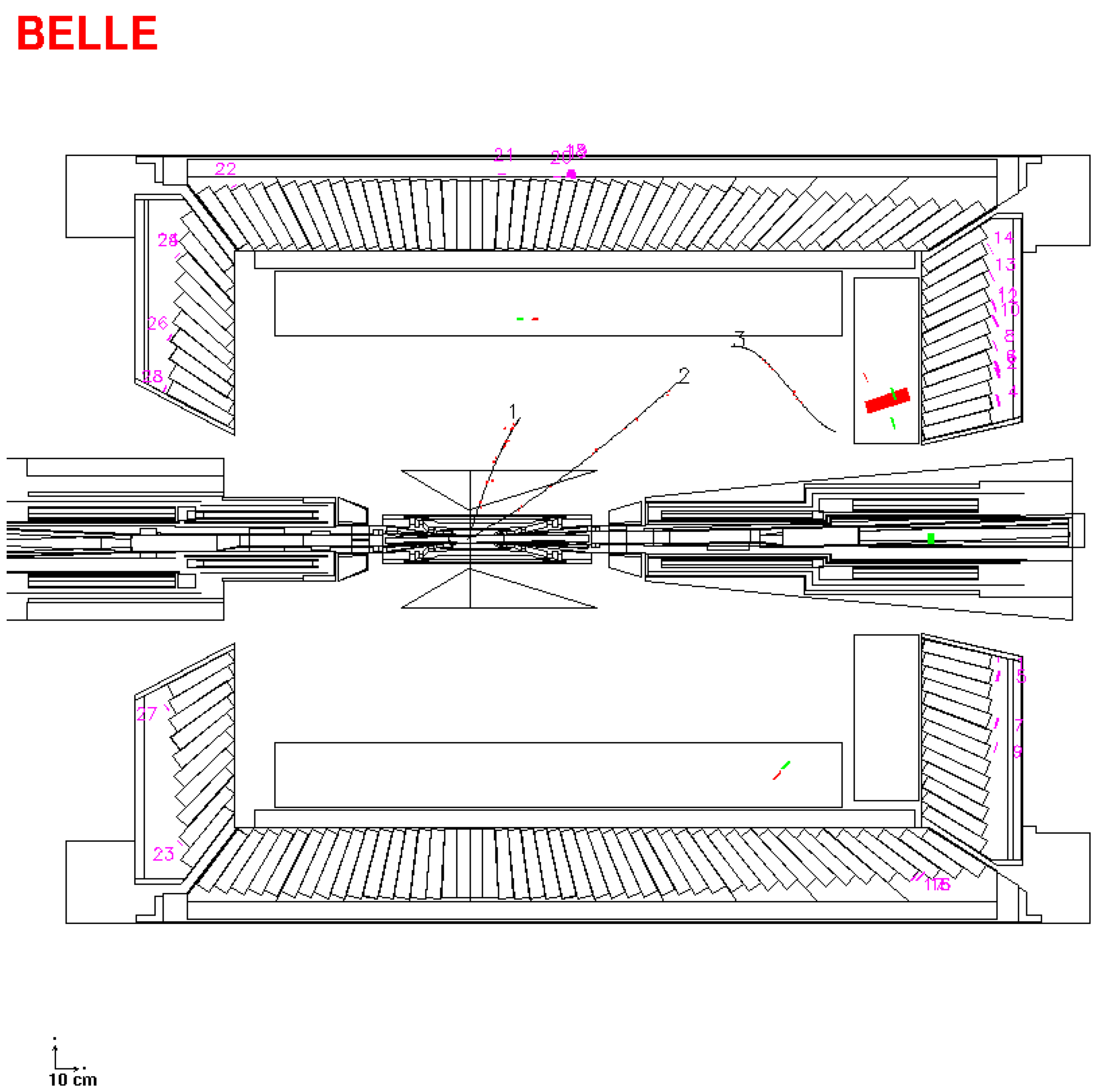
Neglecting $\tau$-lepton momentum: $P_L \to 0.97 P_L$




**Example of the event**

# Example of a muon decay in CDC



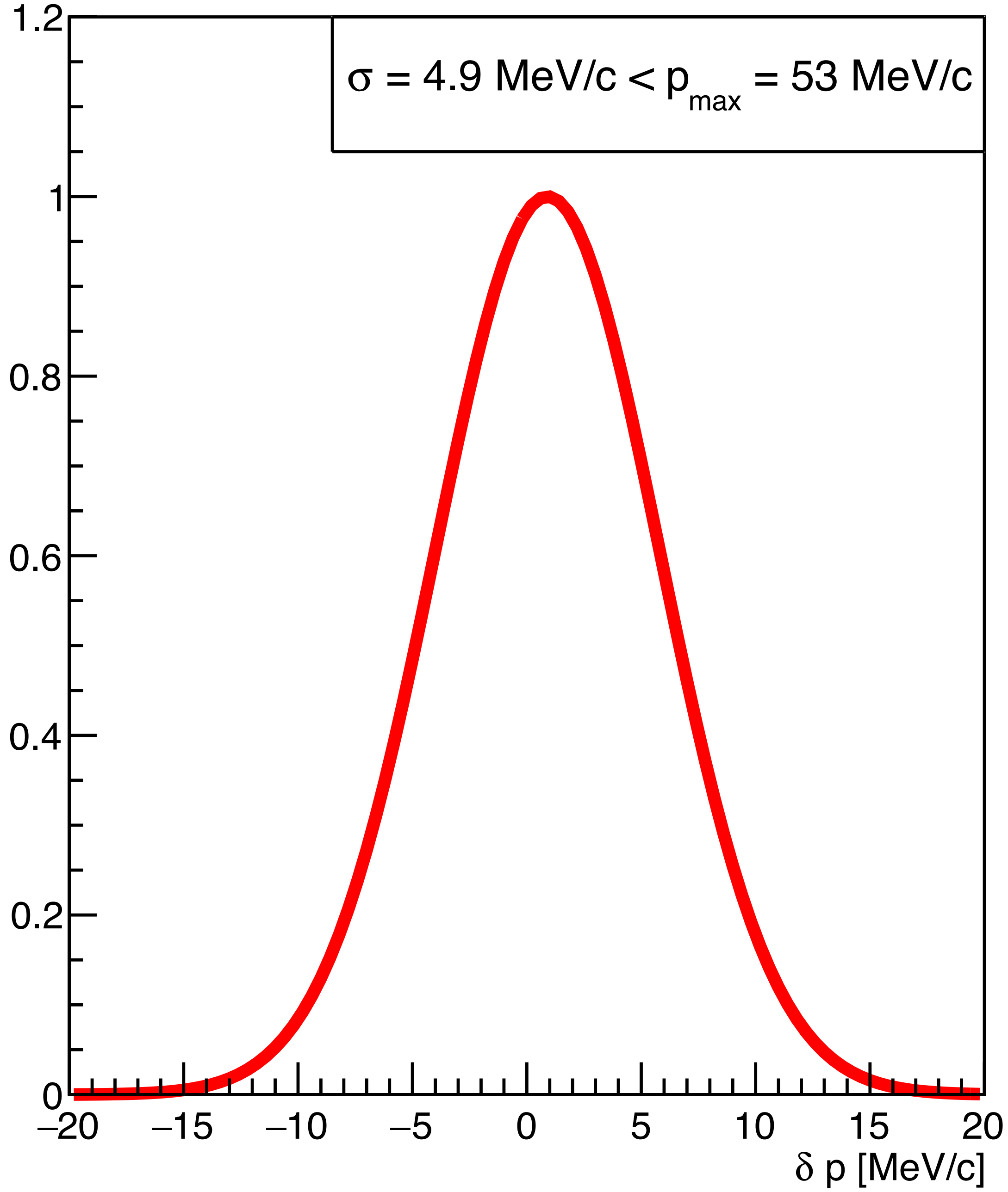

We used the Belle CDC for the MC simulation, as spatial resolution and size are comparable. The assumed beam parameters for the SCT factory were used.

# Estimated number of reconstructed events

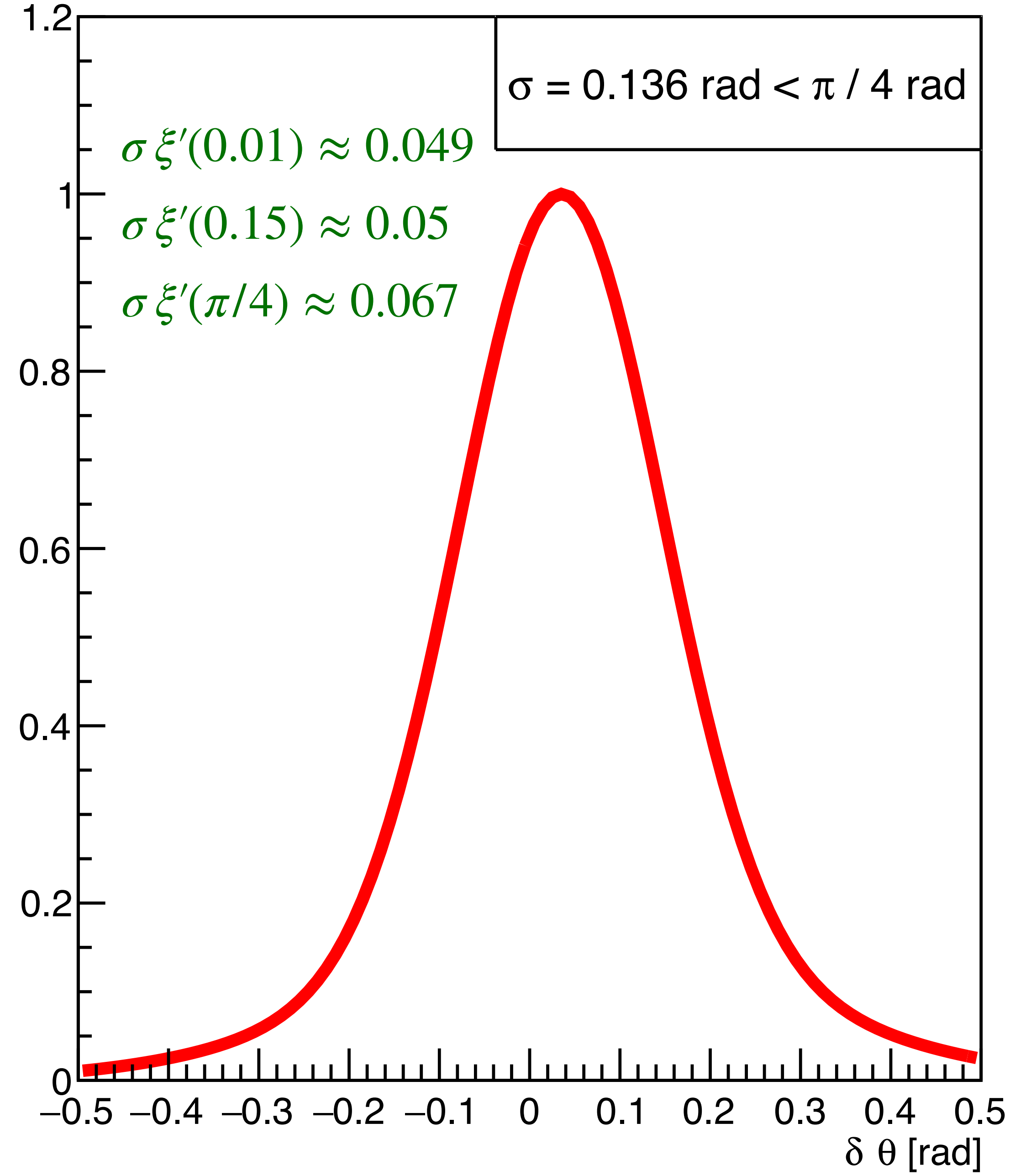
| | Events |
|---|---|
| **Number of tau-pairs** | $\sim 2.1 \times 10^{10}$ * |
| **Decays in the SCT drift chamber** | $\sim 1.1 \cdot 10^{6}$ |
| **Muon and electron tracks could be reconstructed (number of hits for each track > 9)** | $\sim 2.5 \cdot 10^{5}$ |

*** — from SCTF CDR part one (physics program and detector) 2018, chapter 1.6**

# Momentum and angular resolution

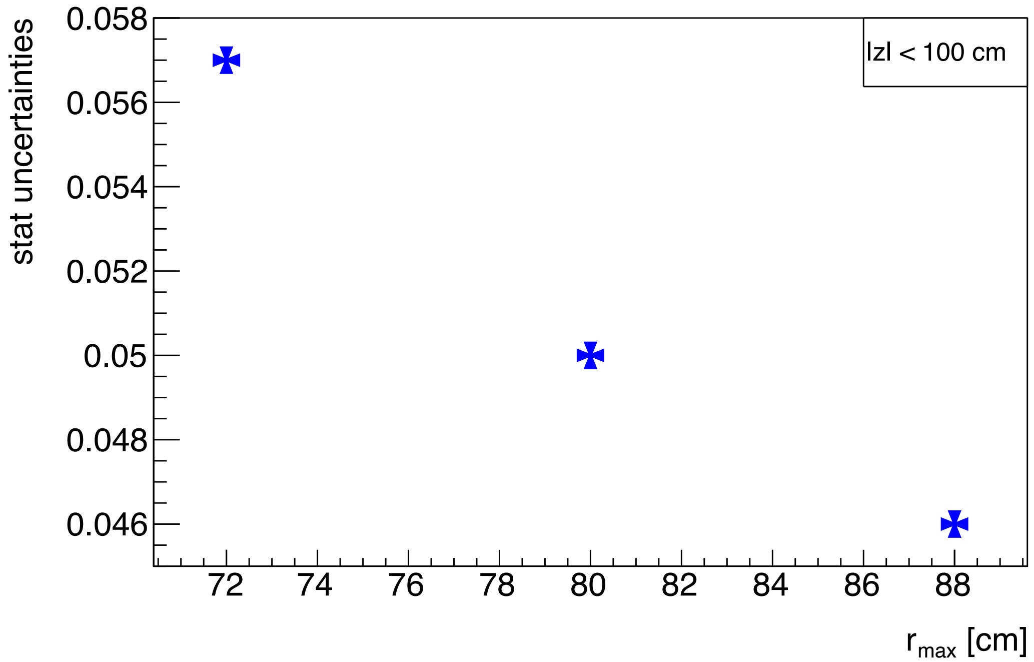


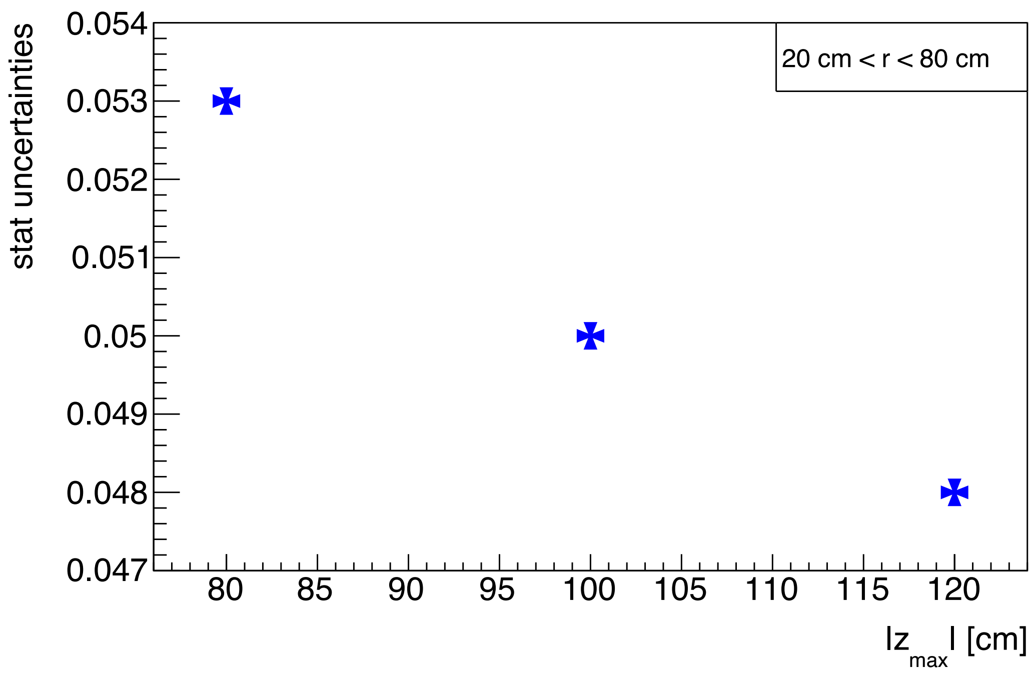

**Electron momentum resolution in the muon rest frame**



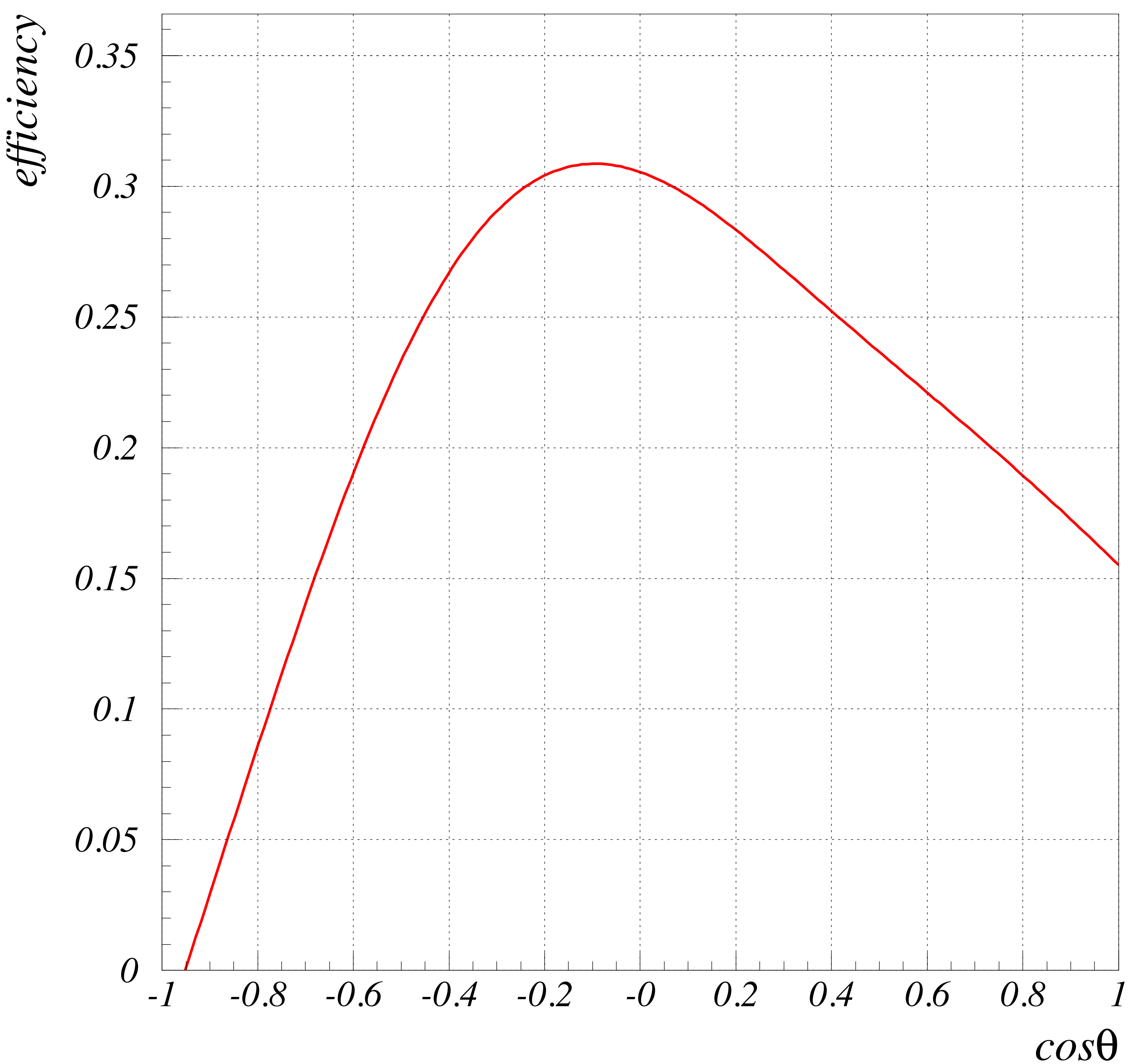

**Electron angular resolution in the muon rest frame**

# Estimated reconstruction efficiency



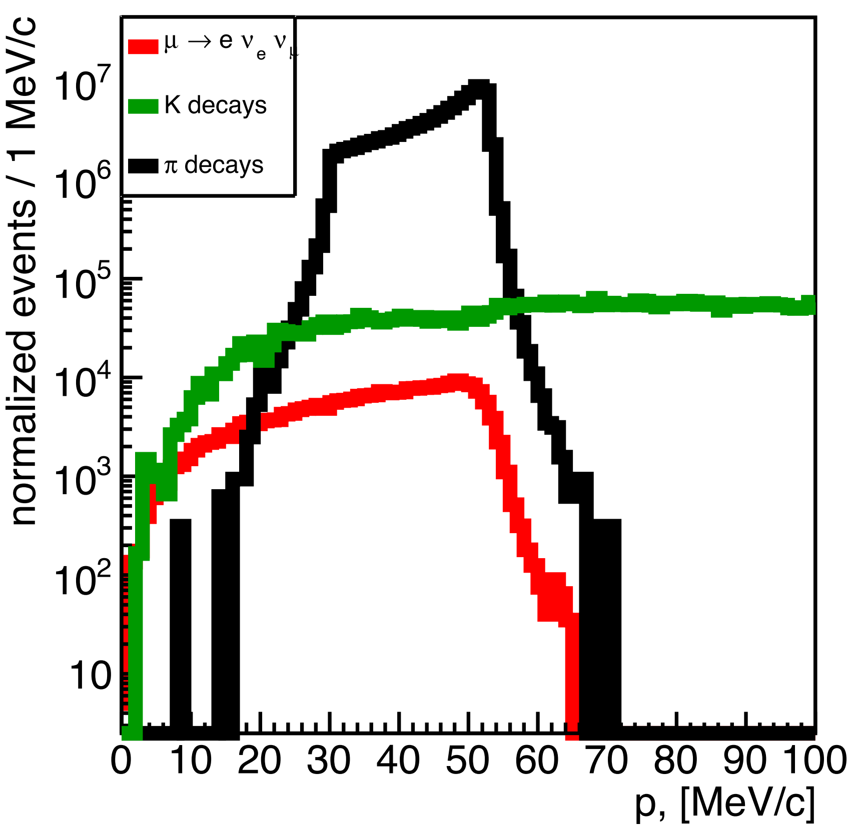

The dependence of statistical uncertainties on the drift chamber size.



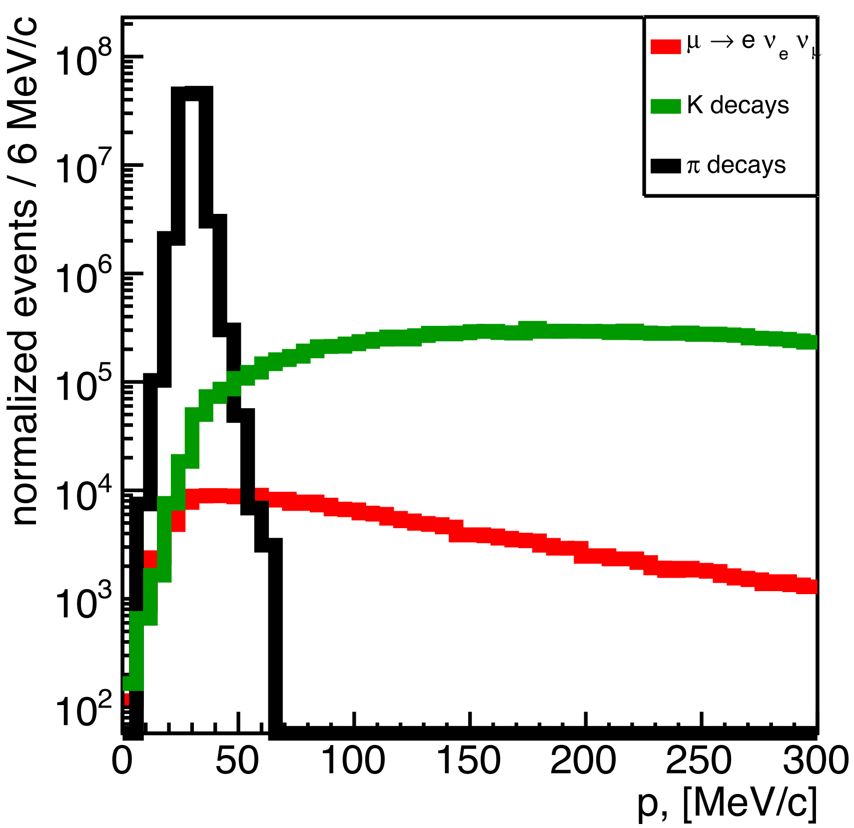

The reconstruction efficiency depends on the electron direction in the muon rest frame.

# Background suppression

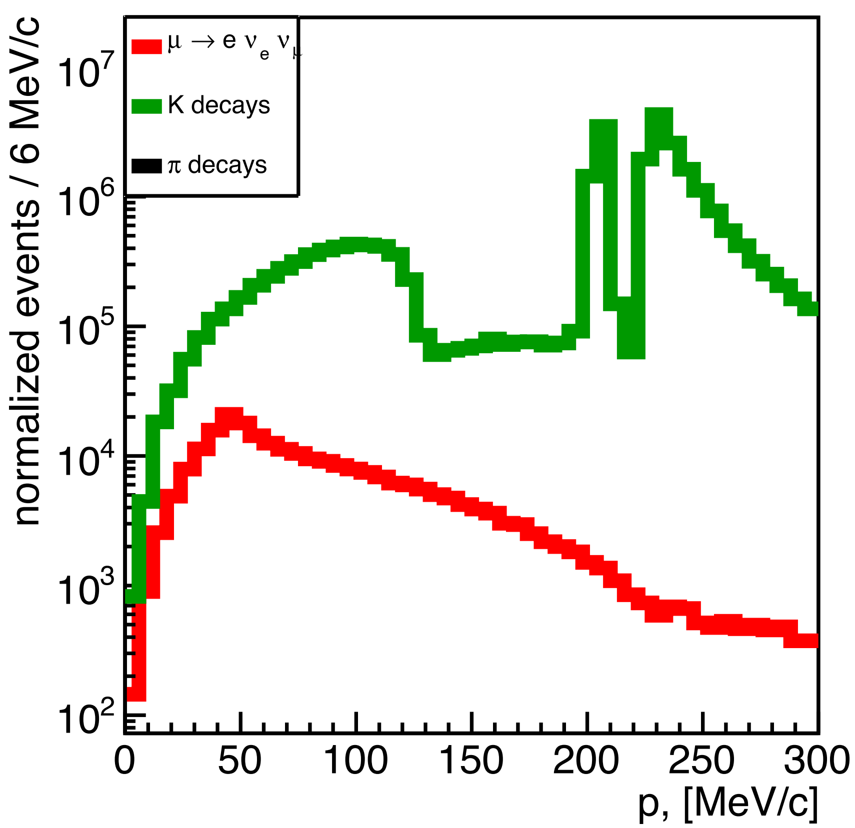
- Particle identification and decay kinematics are used. Mesons decay mainly into two monochromatic particles
- Daughter particle (y) momentum in the rest frame of decayed one (x) depends on the mass hypothesis


**Electron and muon mass hypotheses**




**Muon and pion mass hypotheses**




**Pion and kaon mass hypotheses**

# Conclusion

- This study proves the possibility of measuring the polarization of muons from the decays of tau-leptons for the first time at the Super charm-tau Factory.
- The statistical and systematic precision of the proposed measurement strongly depends on the Hardware and Software requirements for the SCT detector.

| $\xi'_\mu$ | $\xi'_\tau$ |
|---|---|
| $1.00 \pm 0.04$ | $\sim 1.00 \pm 0.05$ |

Currently measured parameter for muon from M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D 98, 030001 (2018) and 2019 update

Depends on background suppression efficiency

# Requirements for SCT

- A large drift chamber, as a number of decayed muons depends on the maximum flight distance
- The best hits spatial resolution and good *dE/dx* resolution
- Big statistics of the tau-pairs events at the threshold
- The reconstruction algorithm assumes reconstruction of decayed-in-flight charged particles in a drift chamber together with their daughters and decay vertex

Thank you for attention!

# Backup

# Michel parameters

# Michel parameters

$$
\begin{aligned}
\rho =&\frac{3}{4}-\frac{3}{4}\left\{(|g^V_{RL}|^2+|g^V_{LR}|^2)+2(|g^T_{LR}|^2+|g^T_{RL}|^2)+Re(g^S_{RL}g^{T*}_{RL}+g^S_{LR}g^{T*}_{LR})\right\}\\
\eta =&\frac{1}{2}Re\left\{g^V_{RL}(g^{S*}_{LR}+6g^{T*}_{LR})+g^V_{LR}(g^{S*}_{RL}+6g^{T*}_{RL})+g^V_{RR}g^{S*}_{LL}+g^V_{LL}g^{S*}_{RR}\right\}\\
\eta'' =&\frac{1}{2}Re\left\{3g^V_{RL}(g^{S*}_{LR}+6g^{T*}_{LR})+3g^V_{LR}(g^{S*}_{RL}+6g^{T*}_{RL})-g^V_{RR}g^{S*}_{LL}-g^V_{LL}g^{S*}_{RR}\right\}\\
\xi =&4Re(g^S_{LR}g^{T*}_{LR}-g^S_{RL}g^{T*}_{RL})+|g^V_{LL}|^2-|g^V_{RR}|^2+3(|g^V_{LR}|^2-|g^V_{RL}|^2)+\\
&+5(|g^T_{LR}|^2-|g^T_{RL}|^2)+\frac{1}{4}(|g^S_{LL}|^2-|g^S_{RR}|^2+|g^S_{RL}|^2-|g^S_{LR}|^2)\\
\xi\delta =&\frac{3}{16}(|g^S_{LL}|^2-|g^S_{RR}|^2+|g^S_{RL}|^2-|g^S_{LR}|^2)+\frac{3}{4}(|g^V_{LL}|^2-|g^V_{RR}|^2-|g^T_{LR}|^2+\\
&+|g^T_{RL}|^2+Re(g^S_{LR}g^{T*}_{LR}-g^S_{RL}g^{T*}_{RL}))\\
\xi' =&-\{3\left(|g^T_{RL}|^2-|g^T_{LR}|^2\right)+\left(|g^V_{RR}|^2+|g^V_{RL}|^2-|g^V_{LR}|^2-|g^V_{LL}|^2\right)+\\
&+\frac{1}{4}\left(|g^S_{RR}|^2+|g^S_{RL}|^2-|g^S_{LR}|^2-|g^S_{LL}|^2\right)\}\\
\xi'' =&1-\frac{1}{2}(|g^S_{RL}|^2+|g^S_{LR}|^2)+2(|g^V_{RL}|^2+|g^V_{LR}|^2+|g^T_{RL}|^2+|g^T_{LR}|^2)+\\
&+4Re(g^S_{RL}g^{T*}_{RL}+g^S_{LR}g^{T*}_{LR})\\
\alpha =&8Re\left\{g^V_{RL}(g^{S*}_{LR}+6g^{T*}_{LR})+g^V_{LR}(g^{S*}_{RL}+6g^{T*}_{RL})\right\}\\
\alpha' =&8Im\left\{g^V_{LR}(g^{S*}_{RL}+6g^{T*}_{RL}-g^V_{RL}(g^{S*}_{LR}+6g^{T*}_{LR}))\right\}\\
\beta =&-4Re\left\{g^V_{RR}g^{S*}_{LL}+g^V_{LL}g^{S*}_{RR}\right\}\\
\beta' =&4Im\left\{g^V_{RR}g^{S*}_{LL}-g^V_{LL}g^{S*}_{RR}\right\}.
\end{aligned}
$$

# Michel parameters (2)

$$\frac{d^2\Gamma}{dx\, dcos\vartheta} = \frac{m_\mu}{4\pi^3} W_{e\mu}^4 G_4^2 \sqrt{x^2 - x_0^2}$$
$$\times \left(F_{IS}(x) \pm P_\mu cos\vartheta F_{AS}(x)\right)$$
$$\times \left[1 + \hat{\boldsymbol{\varsigma}} \cdot \boldsymbol{P}_e(x, \vartheta)\right]$$

$W_{e\mu} = \max(E_e) = \frac{m_\mu^2 + m_e^2}{2m_\mu}$, $x = \frac{E_e}{W_{e\mu}}$, $x_0 = \frac{m_e}{W_{e\mu}}$,

$P_\mu = \left|\boldsymbol{P}_\mu\right|$

For $\tau$ decay replace: $\mu \rightarrow \tau, e \rightarrow \mu$

# Michel parameters (3)

$$F_{IS}(x) = x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x)$$

$$F_{AS}(x) = \frac{1}{3}\xi\sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\delta\left(4x - 3 + \left(\sqrt{1 - x_0^2} - 1\right)\right)\right]$$

$$\boldsymbol{P}_e(x, \vartheta) = P_{T_1} \cdot \hat{\boldsymbol{x}}_1 + P_{T_2} \cdot \hat{\boldsymbol{x}}_2 + P_L \cdot \hat{\boldsymbol{x}}_3$$

# Michel parameters (4)

$$P_{T_1}(x,\vartheta) = \frac{P_\mu sin\vartheta \cdot F_{T_1}(x)}{F_{IS}(x) \pm P_\mu cos\vartheta \cdot F_{AS}(x)}$$

$$P_{T_2}(x,\vartheta) = \frac{P_\mu sin\vartheta \cdot F_{T_2}(x)}{F_{IS}(x) \pm P_\mu cos\vartheta \cdot F_{AS}(x)}$$

$$P_L(x,\vartheta) = \frac{\pm F_{IP}(x) + P_\mu cos\vartheta \cdot F_{AP}(x)}{F_{IS}(x) \pm P_\mu cos\vartheta \cdot F_{AS}(x)}$$

# Michel parameters (5)

$$F_{T_1}(x) = \frac{1}{12}\left\{-2\left[\xi'' + 12\left(\rho - \frac{3}{4}\right)\right](1-x)x_0 - 3\eta(x^2 - x_0^2) + \eta''(-3x^2 + 4x - x_0^2)\right\}$$

$$F_{T_2}(x) = \frac{1}{3}\sqrt{x^2 - x_0^2}\left\{\frac{3\alpha'}{A}(1-x) + \frac{2\beta'}{A}\sqrt{1 - x_0^2}\right\}$$

$$F_{IP}(x) = \frac{1}{54}\sqrt{x^2 - x_0^2}\left\{9\xi'\left(-2x + x + \sqrt{1 - x_0^2}\right) + 4\xi\left(\delta - \frac{3}{4}\right)\left(4x - 4 + \sqrt{1 - x_0^2}\right)\right\}$$

$$F_{AP}(x) = \frac{1}{6}\left\{\xi''(2x^2 - x - x_0^2) + 4\left(\rho - \frac{3}{4}\right)(4x^2 - 3x - x_0^2) + 2\eta''(1-x)x_0\right\}$$

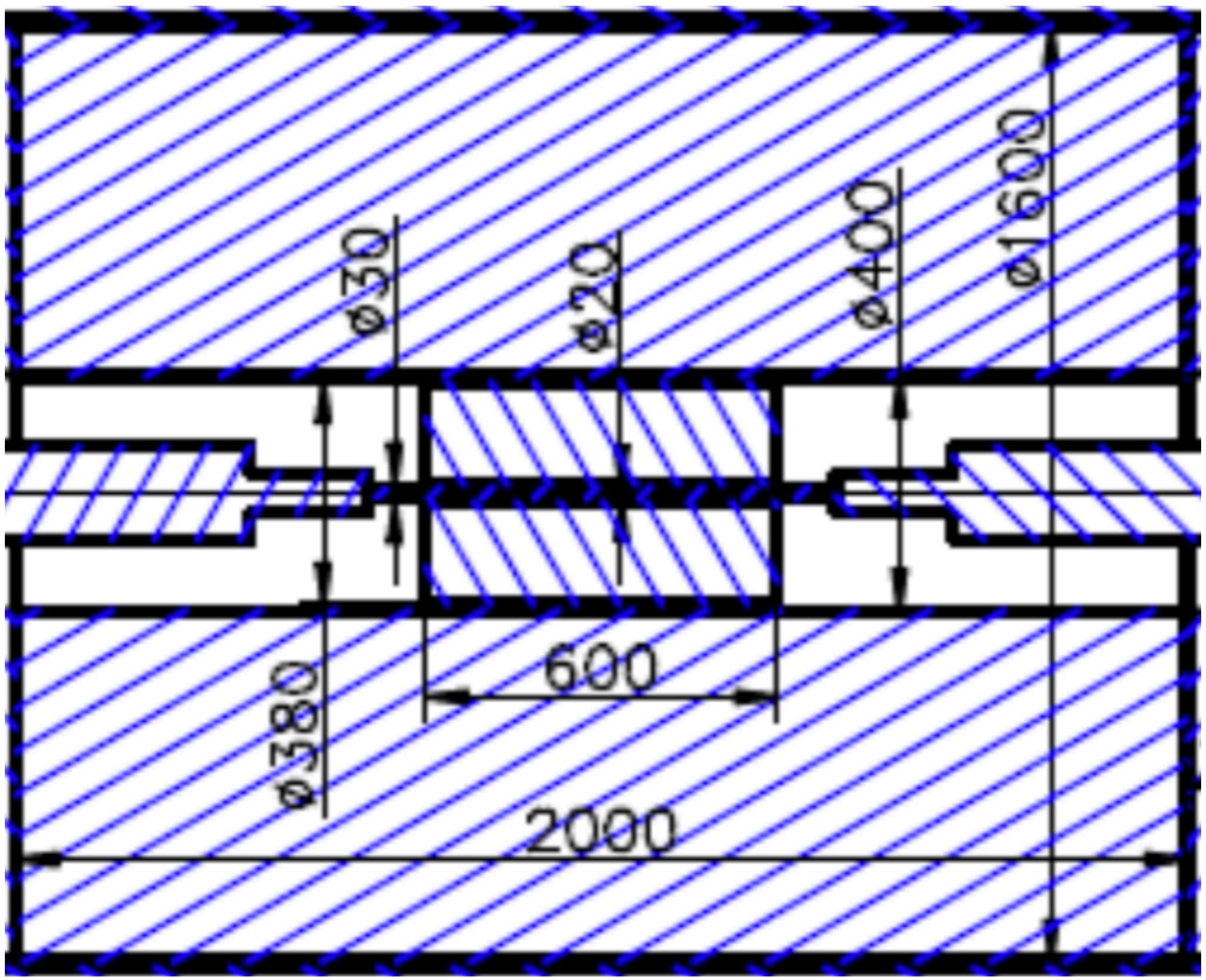
# Parameters for MC simulation

# Parameters for the Monte Carlo generator

| | |
|---|---|
| **Energy** | 3.78 GeV |
| **Energy spread** | 1.86 MeV |
| **Bunch length** | 1 cm |
| **Horizontal beam size at IP** | 17.8 $\mu$m |
| **Vertical beam size at IP** | 0.178 $\mu$m |
| **Crossing angle** | 60 mrad |
| **Detector** | *Belle* |

- $\tau$-pairs production is simulated by KKMC generator
- Decays of $\tau$-leptons are simulated by TAUOLA generator
- Detector is simulated in GEANT3

# Drift chamber size




**SCT drift chamber**