Effective weak mixing angle($\sin^2\theta_{eff}^{f}$) measurement at the CEPC

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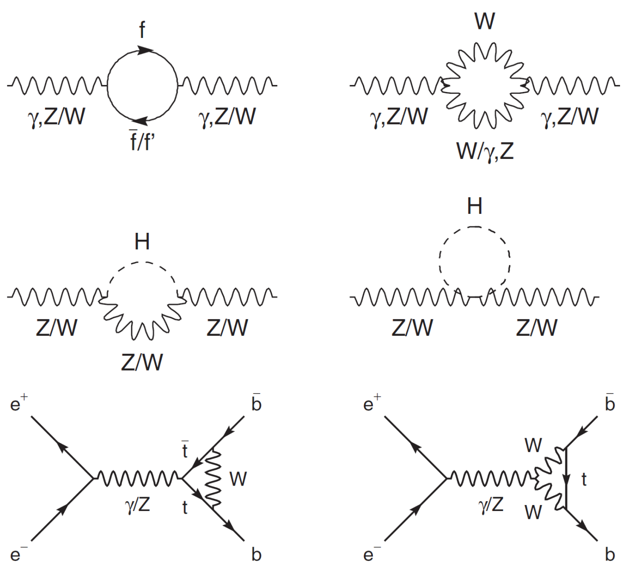
Electroweak Precision measurements and $\sin^2\theta_{eff}^{f}$

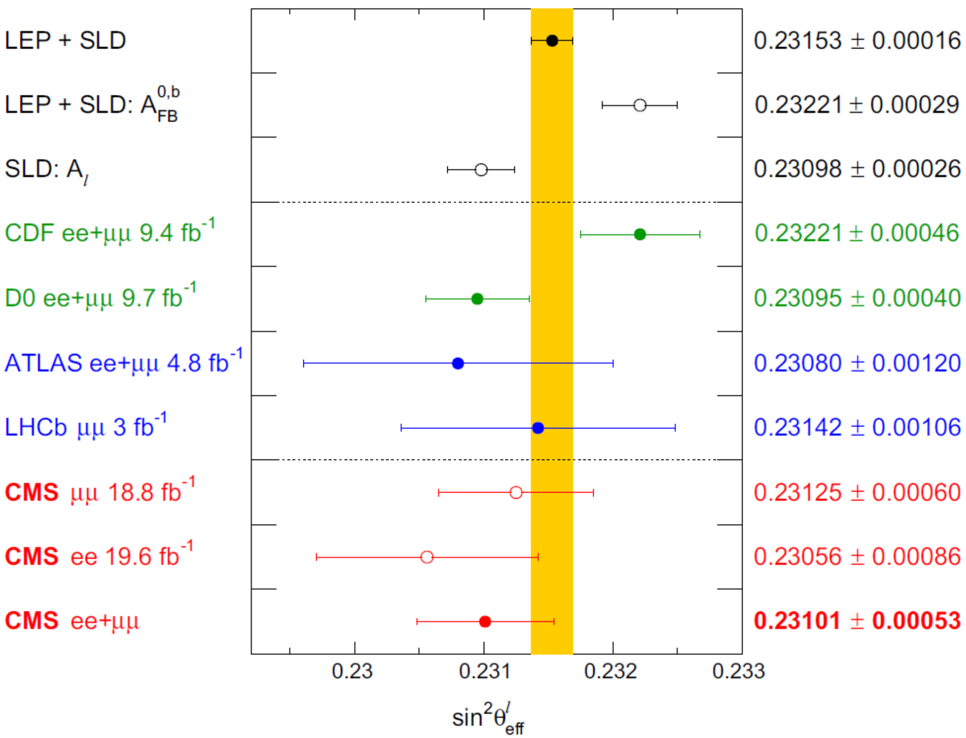
- Key parameter in electroweak sector:
  - $\alpha, G_{\mu}, M_Z, M_W,$ **$\sin^2\theta_W$**
- Effective weak mixing angle:
  - $\sin^2\theta_{eff}^{f} = (1 - m_W^2/m_Z^2) * (1 + \Delta\kappa)$
  - $\Delta\kappa$ absorb higher order corrections

Physical constants	Experimental uncertainty (relative)
Fermi Constant (G_F)	10^{-7}
Mass of Z (m_Z)	10^{-5}
Mass of W (m_W)	10^{-4}
Effective Weak mixing angle ($\sin^2\theta_{eff}$)	10^{-3}



$\sin^2\theta^f_{eff}$ measurement at lepton/hadron collider

- LEP&SLAC (precision~0.1%)
  - LEP: 0.23188 $\pm$ 0.00021
  - SLAC: 0.23098 $\pm$ 0.00026
  - Statistical dominant
- Tevatron
  - 0.23148 $\pm$ 0.00033 (DØ+CDF)
  - Statistic & PDF dominant
- LHC
  - PDF, QCD & systematic dominant
  - Aiming for ~0.00010 in the future



Tevatron:

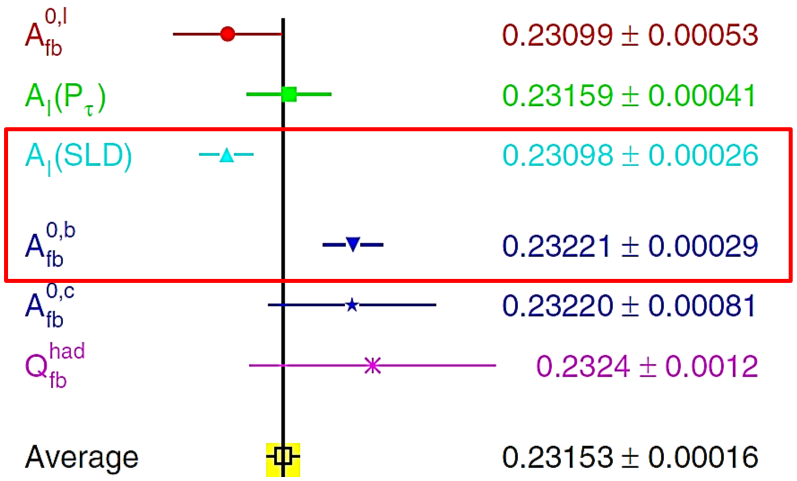
$$\sin^2\theta^l_{eff} = 0.23148 \pm 0.00027(stat.) \pm 0.00005(syst.) \pm 0.00018(PDF)$$

CMS 8TeV:

$$\sin^2\theta^l_{eff} = 0.23101 \pm 0.00036(stat.) \pm 0.00018(syst.) \pm 0.00016(theo.) \pm 0.00031(PDF)$$

measurement of $\sin^2\theta^f_{eff}$ in the future

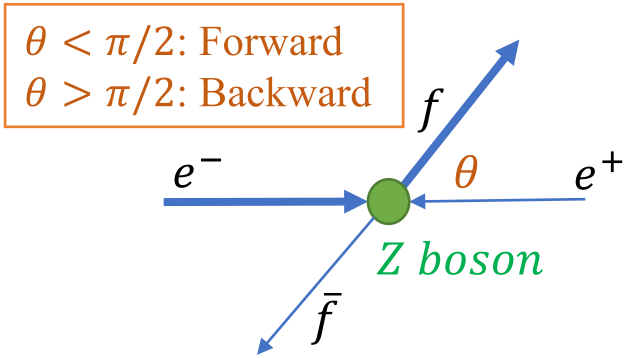
- Measurement before Higgs discovery
  - world average under SM assumption
  - ~0.1% precision good enough for Higgs mass prediction
- Measurement in the future
  - Global test of SM & search for new physics.
  - From O(0.1%) to O(0.01%), comparable to current theoretical calculation.
  - Direct comparison between different progresses (leptons, light quarks, heavy quarks ...)
  - Next 10~15 years: LHC, $\Delta\sin^2\theta^l_{eff}$ ~0.00010. Limited by PDF, QCD and experimental systematics.



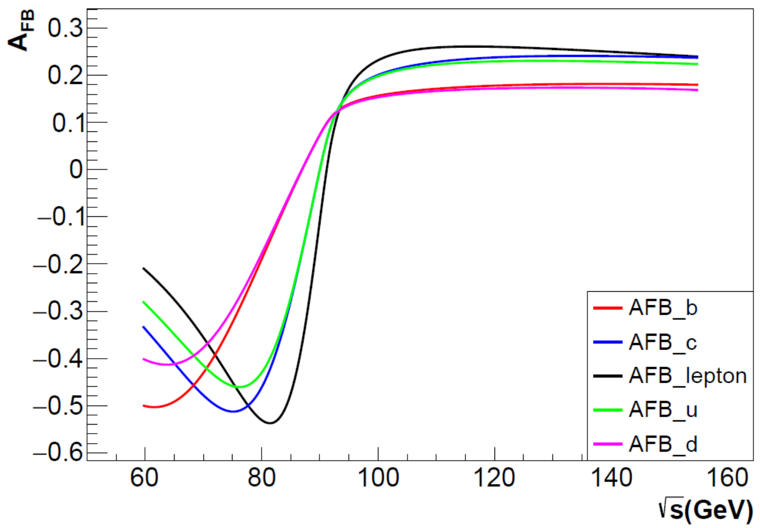
Experimental uncertainty	Theoretical calc. error
~0.00030	~0.00005

$\sin^2 \theta_{eff}^f$ measurement at the CEPC

- $A_{FB} = \frac{N_F - N_B}{N_F + N_B} = A_{FB}(\sin^2 \theta_{eff})$

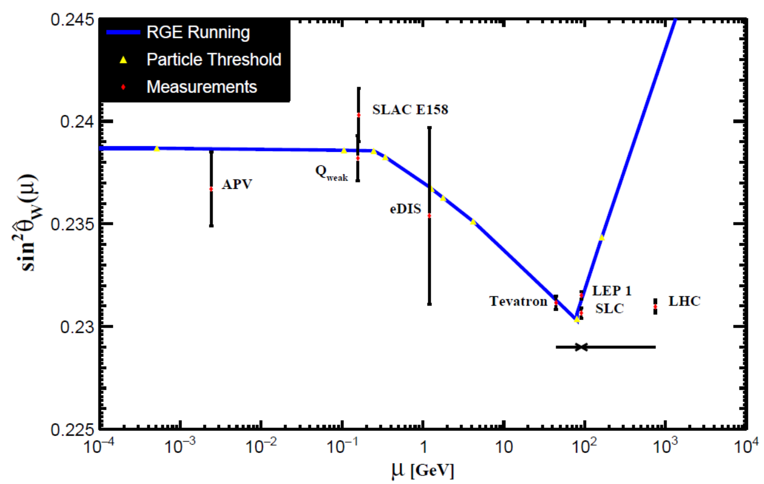


- High luminosity at the CEPC
  - CEPC: 600 billion Z in 2 years (Z period)
- Low systematics



$\sin^2\theta_{eff}^{f}$ measurement at the CEPC

- High precision measurement
  - Final precision expected to be $\Delta\sin^2\theta_{eff} \sim 0.00001$
- Independent measurement via different final states:
  - Each lepton channel, b, c, u+d (light)
- Running weak mixing angle with energy scale($\sin^2\theta_w(\mu)$)
  - Make measurement at energy scale higher than Z pole for the first time.



NOTE: this is $\overline{\text{MS}}$ scheme defined weak mixing angle.

Estimation on experimental sensitivity

$$sensitivity: S = S^{phy} * Det$$

$$S^{phy} = \frac{\partial A_{FB}^{phy}}{\partial \sin^2 \theta_{eff}}$$

$$Det = \frac{1}{1-2f} \cdot \sqrt{\frac{1}{\epsilon_{tagging}}}$$

- $\epsilon_{tagging}$: overall efficiency of events observation
- f: charge mis-identification probability

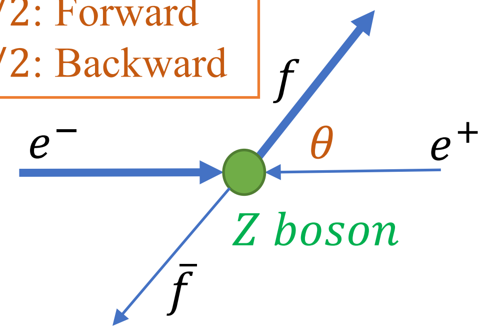
Lepton	Quarks
$\epsilon \sim 100\%$ $f \sim 0$	tagging power: $\epsilon * (1-2f)^2$ $= 0.138$ (for b quarks) $= 0.283$ (for c quarks)

Estimation on experimental systematics

- Systematics from efficiency determination:
  - Cancelled out in the ratio-type definition of AFB, no propagation
- Systematics from charge mis-ID estimation:
  - Can be precisely measured from data-driven method

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

$\theta < \pi/2$: Forward
$\theta > \pi/2$: Backward



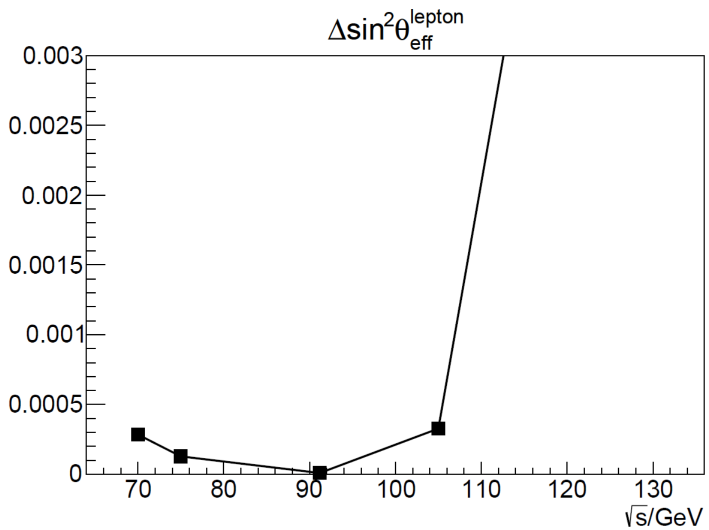
- Systematics can be well controlled at 0.00001 level

Results: A_{FB} measurement

Consider 1 month statistics at each energy point

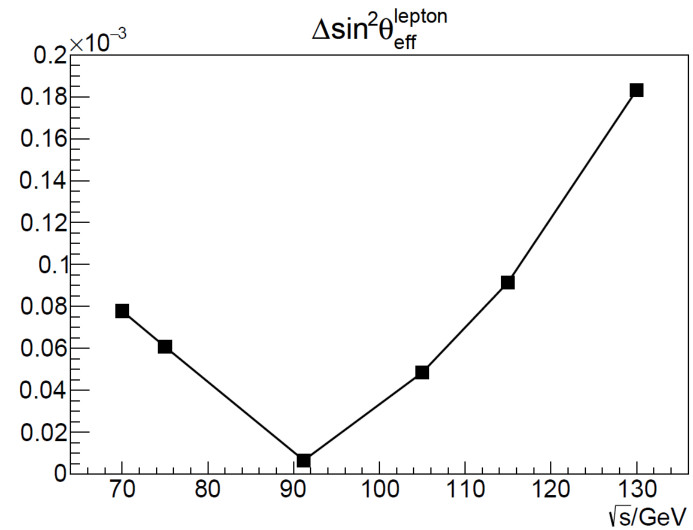
($\sim 6e11/24\ Z\ events$ at Z pole)

Only statistical uncertainty considered



lepton final state

$(ee + \mu\mu + \tau\tau)$



b quark final state

Energy scale	70 GeV	75 GeV	91.19 GeV	105 GeV	115 GeV	130 GeV
$\Delta\sin^2\theta_{eff}$ from lepton final state	0.00028	0.00013	0.00001	0.00033	0.00385	0.00766
$\Delta\sin^2\theta_{eff}$ from b quark final state	0.00008	0.00006	<0.00001	0.00005	0.00009	0.00018

Summary

- Estimation on effective weak mixing angle according to 1 month data collection

Overall precision at Z pole	Precision in lepton/quark comparison	Precision at off Z pole
$\Delta \sin^2 \theta_{eff} \sim 0.00001$	$\Delta \sin^2 \theta_{eff} \sim 0.00001$	$\Delta \sin^2 \theta_{eff} \sim 0.00010$

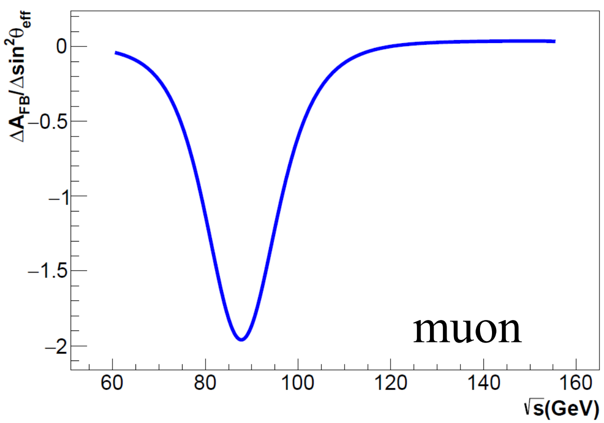
- CEPC features
  - Large statistics
  - Low systematics

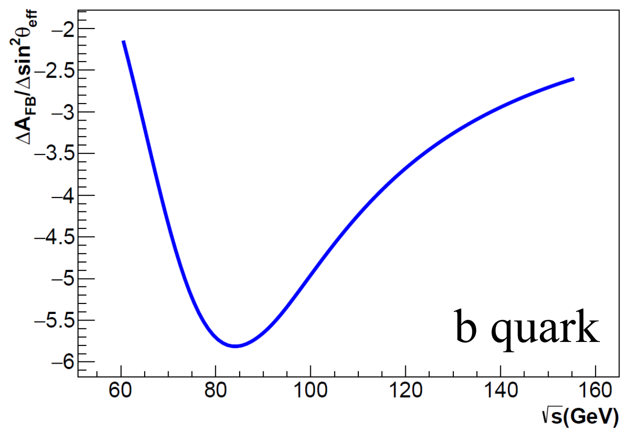
Thanks

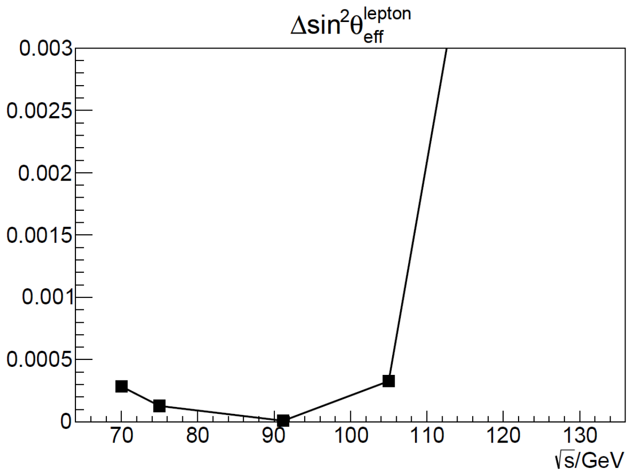
Backups

Sensitivity of AFB to $\sin^2\theta_{eff}$

$$sensitivity = S_{phy} := \frac{\Delta A_{FB}}{\Delta \sin^2\theta_{eff}}$$

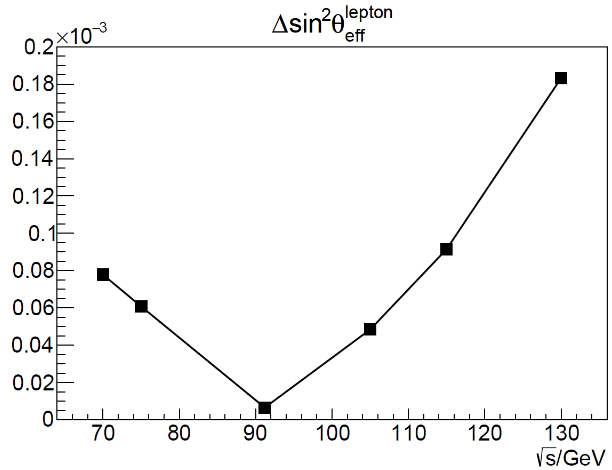






lepton final state

$(ee + \mu\mu + \tau\tau)$



b quark final state

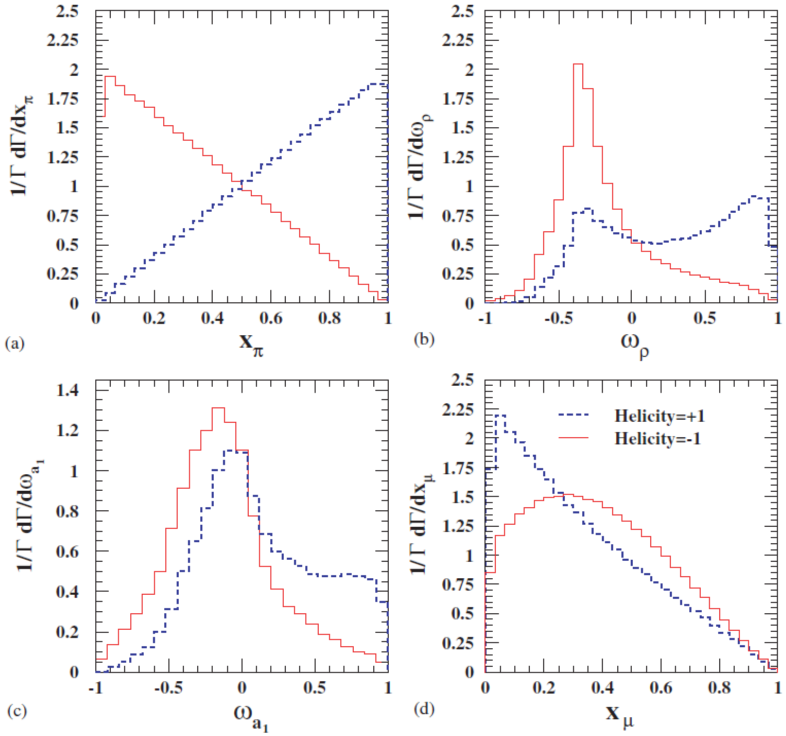
A_{FB}^{b}:
Sensitive to
$\sin^2\theta_{eff}$ at Z pole
and off Z pole

Measurement for Tau: polarization

$$P_\tau := \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

- Tau polarization method
  - Extract weak mixing angle from polarization asymmetry
  - Tau is the only lepton that can measure the polarization

- Theory of the measurement
  - For different tau decay mode, define a kinematic variable ω.
  - Fit spectrum to get P_τ.
  - $P_\tau = P_\tau(\cos\theta) = P_\tau(\sin^2\theta_{eff}, \cos\theta)$ (θ is the scattering angle of tau)

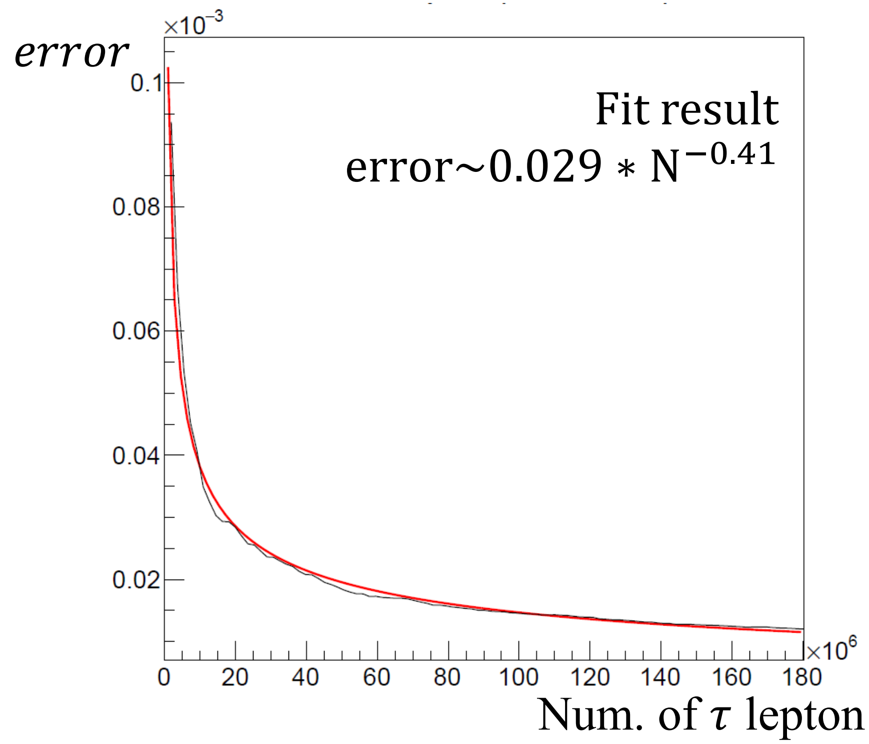


Results: P_τ measurement

- One month's statistics at Z pole

  (3e11/24 Z boson)

  - Statistical error $\sim\ 0.5 * 0.01\%$



- Systematical error needs to be estimated in the future.