Jet Charge
& Background Estimation
for Flavor Physics

CEPC Day
2021/09/22

By: Dan YU

Plan

- Current status & highlights (Jet Charge)
- Bkg estimation & theorists' feedbacks
- Summary

CEPC TeraZ

- High lumi: 10^12 Z bosons
- 91.2GeV: Boosted decay products
- Clean environment
  - low QCD bkg
  - no pile-ups
  - fixed Ecm
  - precise detector system & reconstruction algorithm

Activities

- Whitepaper
  - kick-off 2021/06/16
  - monthly meeting
- Current:
  - scratch with key information for each chapter
- Expected in 1 year

Contents

White Paper

- Key points to delivery
  - Advantage on physics potential
  - Requirements on detector
- For each session
  - Benchmarks & interpretation
    - Accuracies: backgrounds estimation

Performances for Physics objects

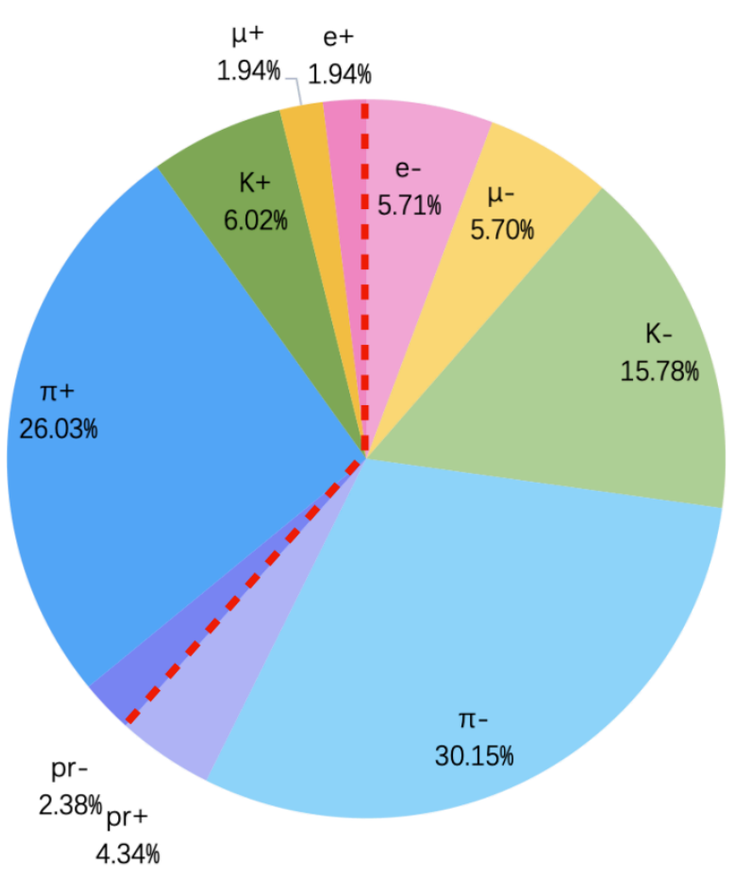
- Acceptance: |cos(θ)| < 099
- Tracks:
  - Pt threshold, ~ 100 MeV
  - δp/p ~ o(0.1%)
- Photons:
  - Energy threshold, ~ 100 MeV
  - δE/E: 3 – 15%/sqrt(E)
- Pi-Kaon separation: 3-sigma
- Pi-0: rec. eff*purity @ Z→qq > 60% @ 5GeV
- Jet charge: eff*(1-2ω)2 ~ 15%/30% @Z→bb/cc
- B-tagging: eff*purity @ Z→qq: 70%
- C-tagging: eff*purity @ Z→qq: 40%
- Lepton inside jets: eff*purity @ Z→qq ~ 90% (energy > 3 GeV)
- Tau: eff*purity @ WW→tauvqq: 70%, mis id from jet fragments ~ o(1%)
- Reconstruction of simple combinations: Ks/Lambda/D with all tracks @ Z→qq: 60/75 – 80/85%
- BMR: 3.7%
- Missing Energy: Consistent with BMR

Jet Charge Measurement

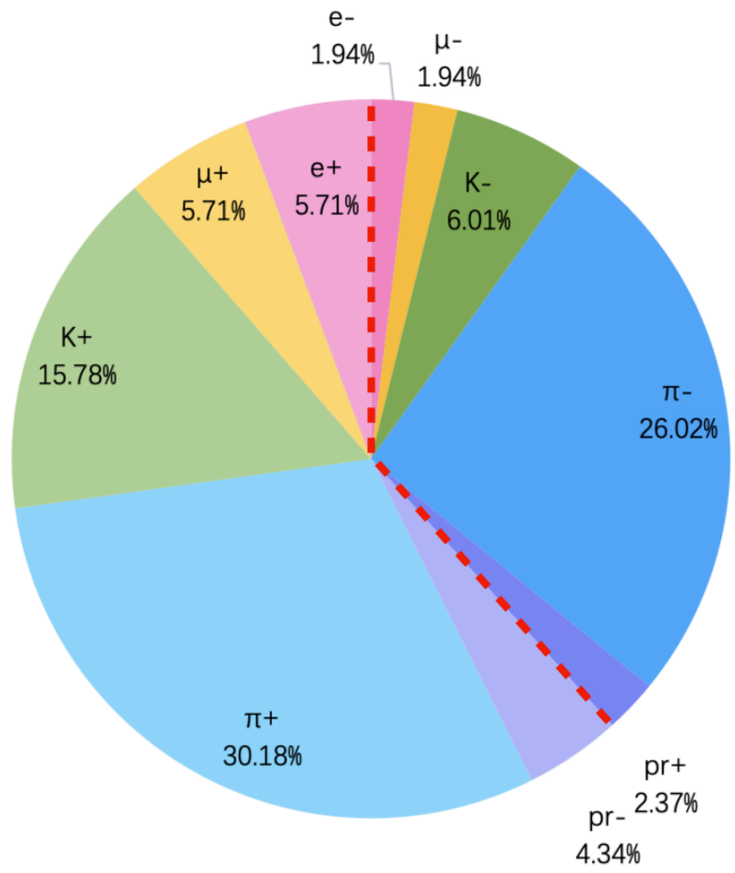
- use leading particle information

Work by Hanhua Cui

$Z \to b\bar{b}$ **Percent of final charged leading particles of b jet and $\bar{b}$ jet**



b **jet**



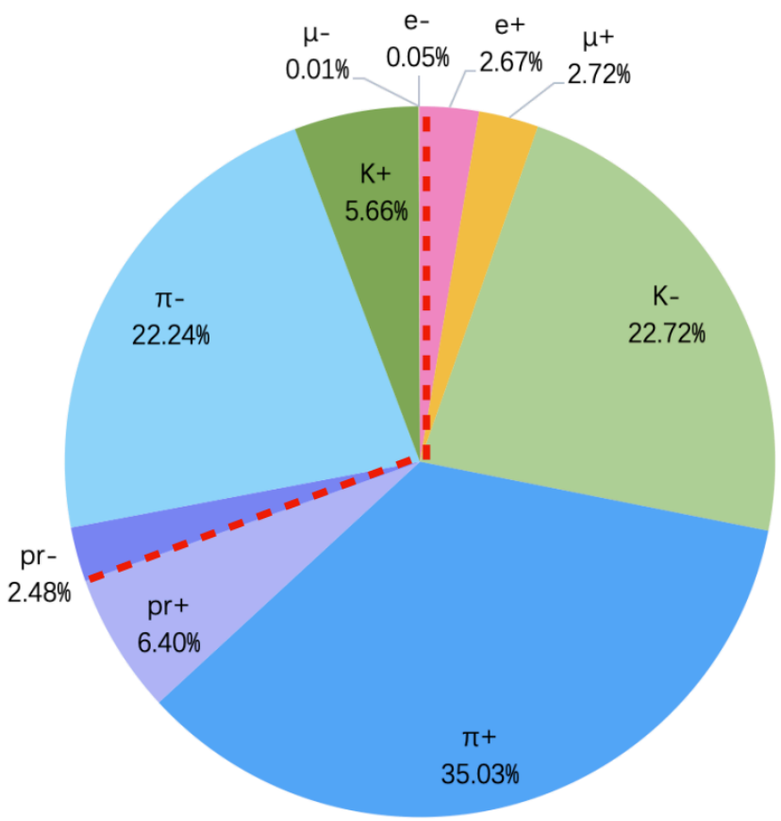
$\bar{b}$ **jet**

Jet Charge Measurement

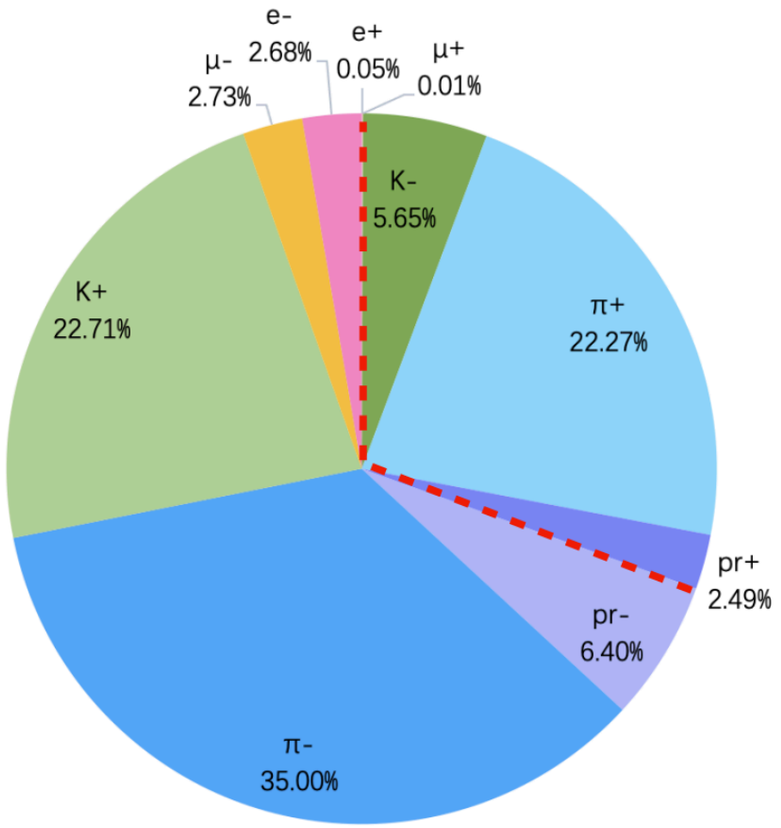
- use leading particle information

Work by Hanhua Cui

$Z \to c\bar{c}$ **Percent of final charged leading particles of c jet and $\bar{c}$ jet**



c **jet**



$\bar{c}$ **jet**

Jet Charge Measurement

Work by Hanhua Cui

percent bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar	others	all
B^0bar	17.360%	17.350%	3.369%	0.022%	2.759%	0.688%	41.548%
B^-	17.350%	17.359%	3.364%	0.022%	2.765%	0.689%	41.550%
B_s^0bar	3.355%	3.362%	0.652%	0.004%	0.545%	0.144%	8.062%
B_c^-	0.022%	0.022%	0.004%	0.00003%	0.004%	0.001%	0.052%
Λ_b	2.762%	2.762%	0.543%	0.004%	0.451%	0.121%	6.644%
others	0.653%	0.655%	0.136%	0.001%	0.119%	0.579%	2.144%
all	41.503%	41.511%	8.068%	0.053%	6.641%	2.225%	100%

Jet Charge Measurement

- Effective tagging power: take misjudgment rate ω and efficiency into account

Main results:

- ***For $Z \to b\bar{b}$ at Truth level:***
  - ***Using only charge verse, effective tagging power = 0.127***
  - ***Using also charge same, effective tagging power = 0.137***
- ***For $Z \to c\bar{c}$ at Truth level:***
  - ***Using only charge verse, effective tagging power = 0.282***
  - ***Using also charge same, effective tagging power = 0.301***

- Next:
  - Use also information from the next to leading particles
  - focus on some physics channels and do some specific analysis
    - ex: use prompt kaon information in Bs
  - Machine learning

Earlier Estimation

- LFV: Mogens Dam (arxiv:1811.09408)
- Z hadronic decays: Shan Cheng, Qin Qin and Fu-Sheng YU
- Section 8.3

Decay mode	Branching ratio	CEPC Uncertainty
$Z \to J/\psi\gamma$	8.02×10^{-8} [29]	$\sim 1.8\%$
$Z \to \Upsilon(1S)\gamma$	5.39×10^{-8} [29]	$\sim 3.4\%$
$Z \to \rho^0\gamma$	4.19×10^{-9} [29]	$\sim 1.8\%$
$Z \to \omega\gamma$	2.82×10^{-8} [29]	$\sim 0.8\%$
$Z \to \phi\gamma$	1.04×10^{-8} [29]	$\sim 1.6\%$
$Z \to \pi^0\gamma$	9.80×10^{-12} [29]	$< 3.4 \times 10^{-8}$
$Z \to \eta\gamma$	$0.1 - 1.7 \times 10^{-10}$ [30]	$\sim 12\% - 50\%$
$Z \to \eta'\gamma$	$3.1 - 4.8 \times 10^{-9}$ [30]	$\sim 2.7 - 3.4\%$

Decay	Present bound	FCC-ee sensitivity
$Z \to \mu e$	0.75×10^{-6}	10^{-10}–10^{-8}
$Z \to \tau\mu$	12×10^{-6}	10^{-9}
$Z \to \tau e$	9.8×10^{-6}	10^{-9}
$\tau \to \mu\gamma$	4.4×10^{-8}	2×10^{-9}
$\tau \to 3\mu$	2.1×10^{-8}	10^{-10}

Decay mode	Branching ratio	CEPC Uncertainty
$Z \to \pi^{\pm}W^{\mp}$	1.5×10^{-10}	$\sim 20\%$
$Z \to \rho^{\pm}W^{\mp}$	4.0×10^{-10}	$\sim 13\%$
$Z \to K^{\pm}W^{\mp}$	1.2×10^{-11}	$\sim 70\%$
$Z \to K^{*\pm}W^{\mp}$	2.0×10^{-11}	$\sim 59\%$
$Z \to D_s^{\pm}W^{\mp}$	6.0×10^{-10}	$\sim 75\%$
$Z \to D^{\pm}W^{\mp}$	2.0×10^{-11}	$< 3 \times 10^{-10}$

Samples

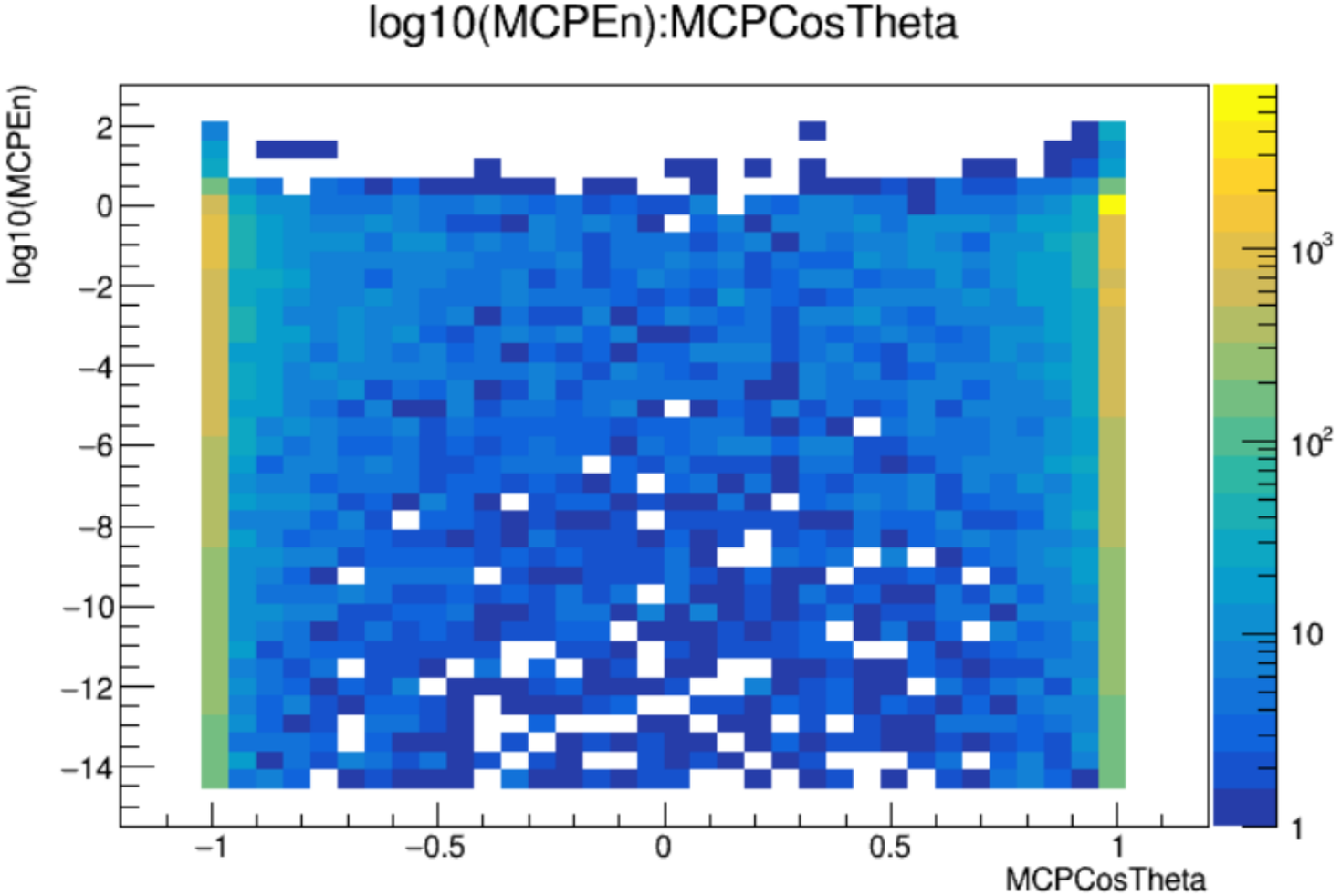
- CEPC Zpole: 10^{12} Z bosons ~ 3.36×10^{10} ττ, 6.99×10^{11} qq
- Current samples: Truth ~ 4×10^{-4} SM; Reco ~ 4×10^{-5} SM
- No Z boson width or beam energy spread

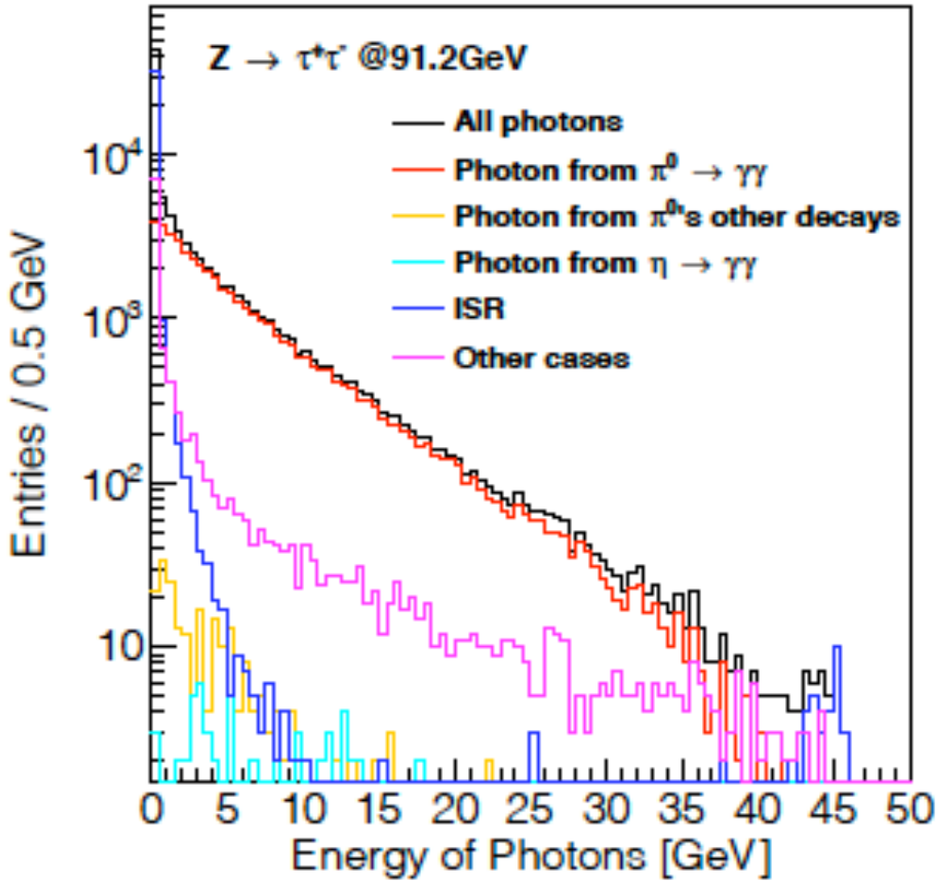
Table 1: CEPC91.2GeV

	Channel	Generator		FullSim		DstDate	
		size (GB)	yield (Million)	size (GB)	yield (Million)	size (GB)	yield (Million)
wo_isr	bb	3713	376	-	-	-	-
	cc	2610	294	-	-	-	-
	uu	2419	295	-	-	-	-
	e3e3	137	851	-	-	-	-
wi_isr	bhabha	49	33	619	1.1	19	1.1
	e2e2	151	120	105	1.6	9	1.6
	e3e3	25	13	355	1.6	25	1.6
	n1n1	22	24	-	-	-	-
	n2n2	23	25	-	-	-	-
	n3n3	22	24	-	-	-	-
	nn	67	73	-	-	-	-
	uu	365	42	5918	8.1	687	8.1
	dd	470	55	5931	8.1	678	8.1
	ss	467	55	5731	8.1	678	8.1
	bb	559	54	6332	8.1	775	8.1
	cc	404	43	6057	8.1	725	8.1
	qq	2234	253	-	-	-	-

ISR

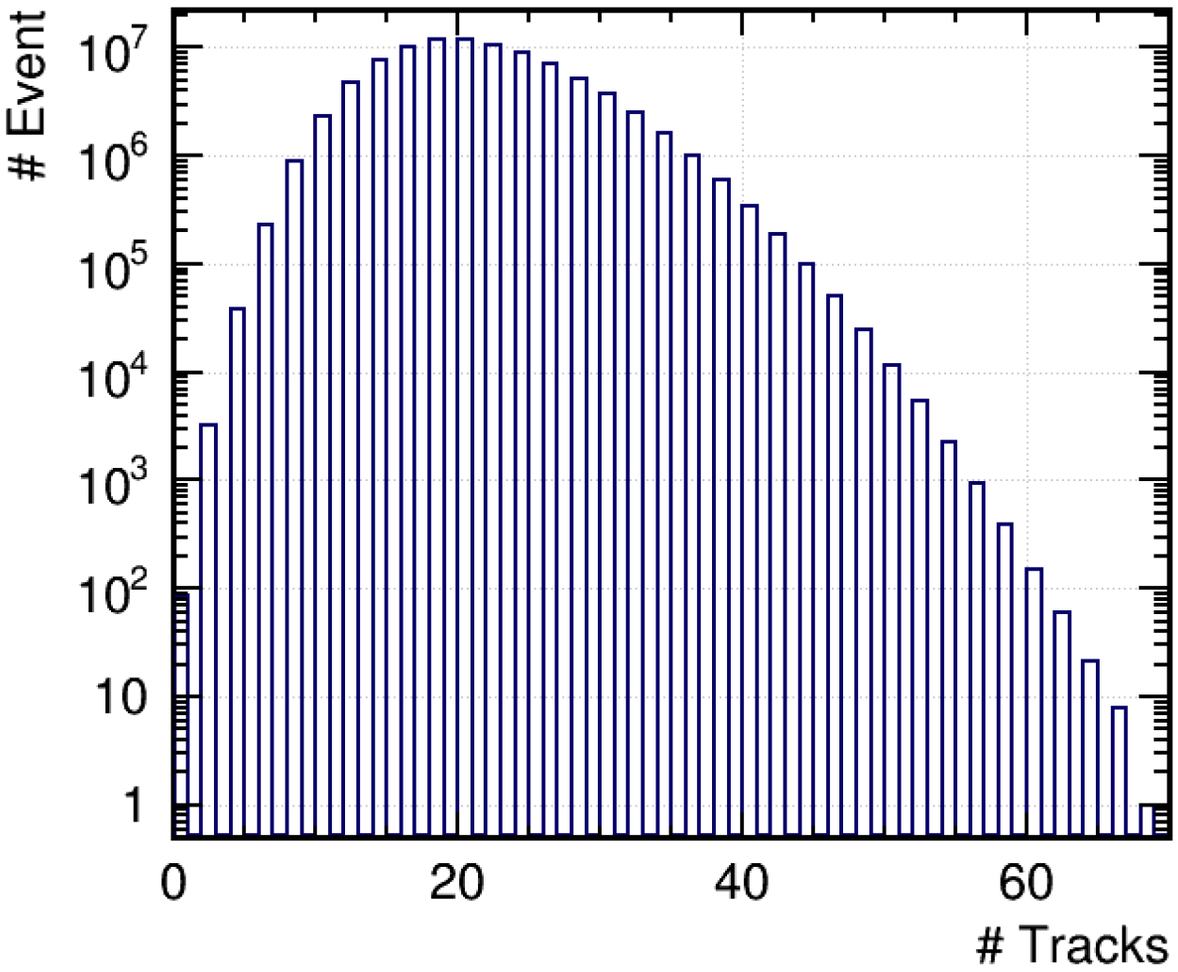
- Mostly to the forward region
- Energy < 1GeV
- Only leading order

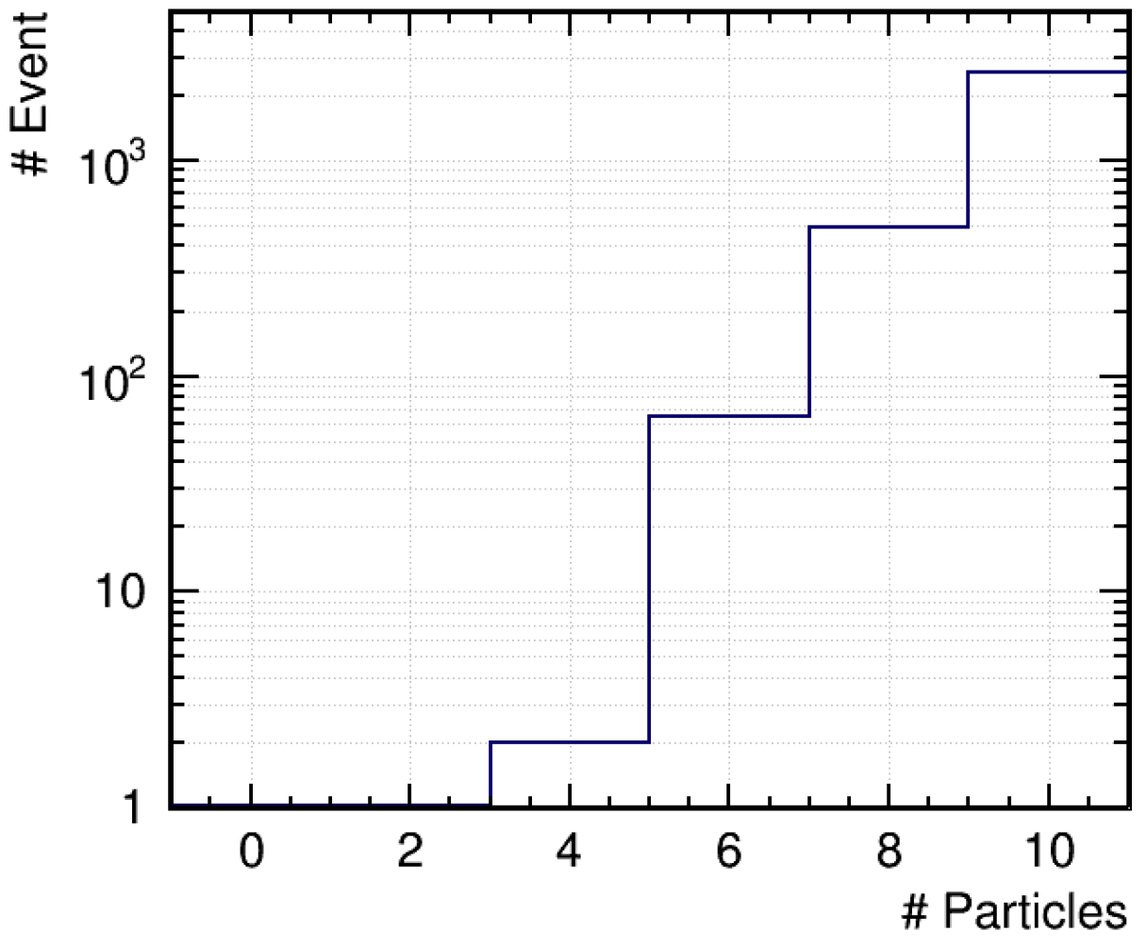




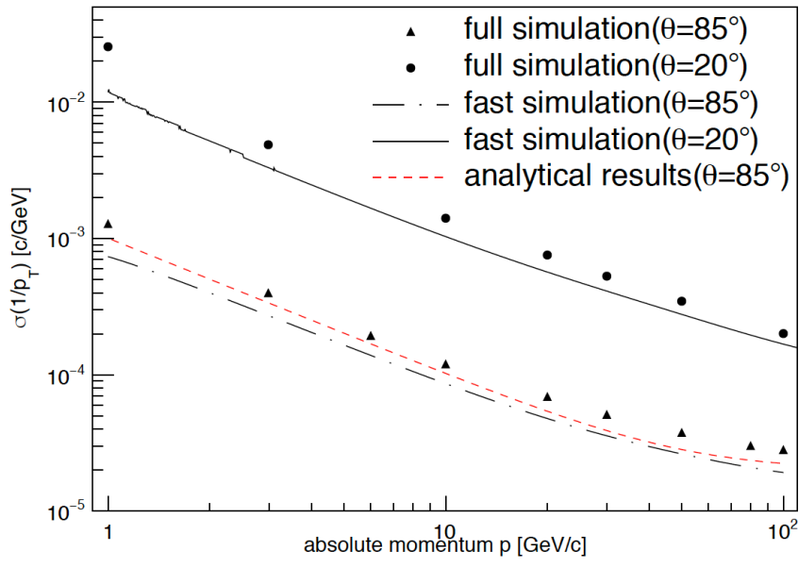
Jet multiplicity

- Jets' multiplicities high, not likely to be mixed with leptonic events
- Multiplicity < 10, need to take care

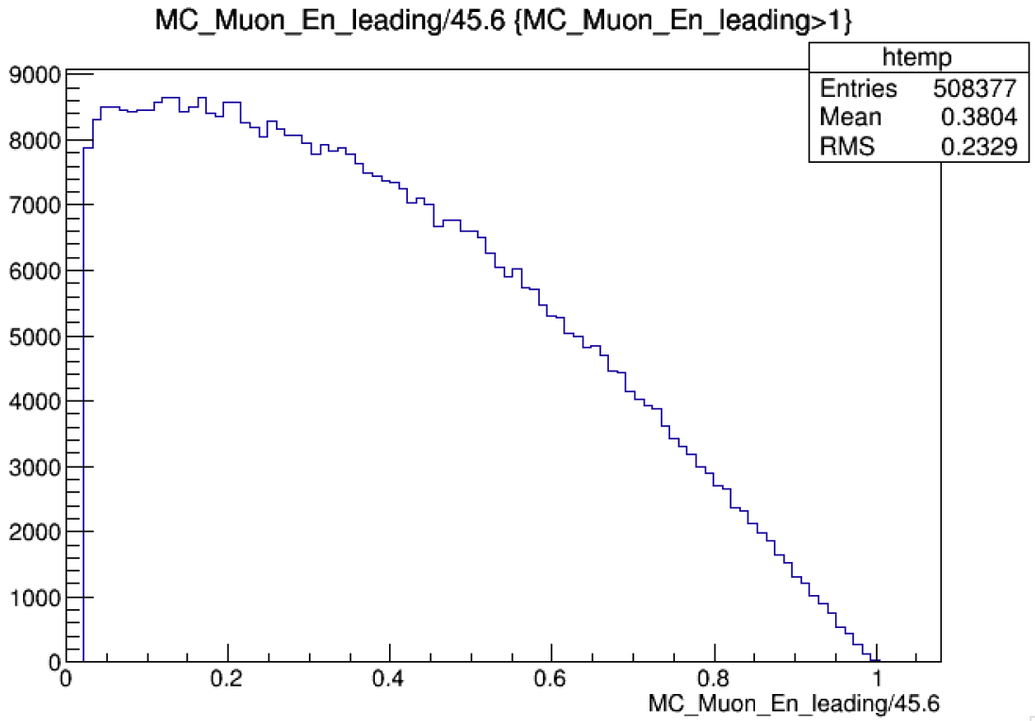


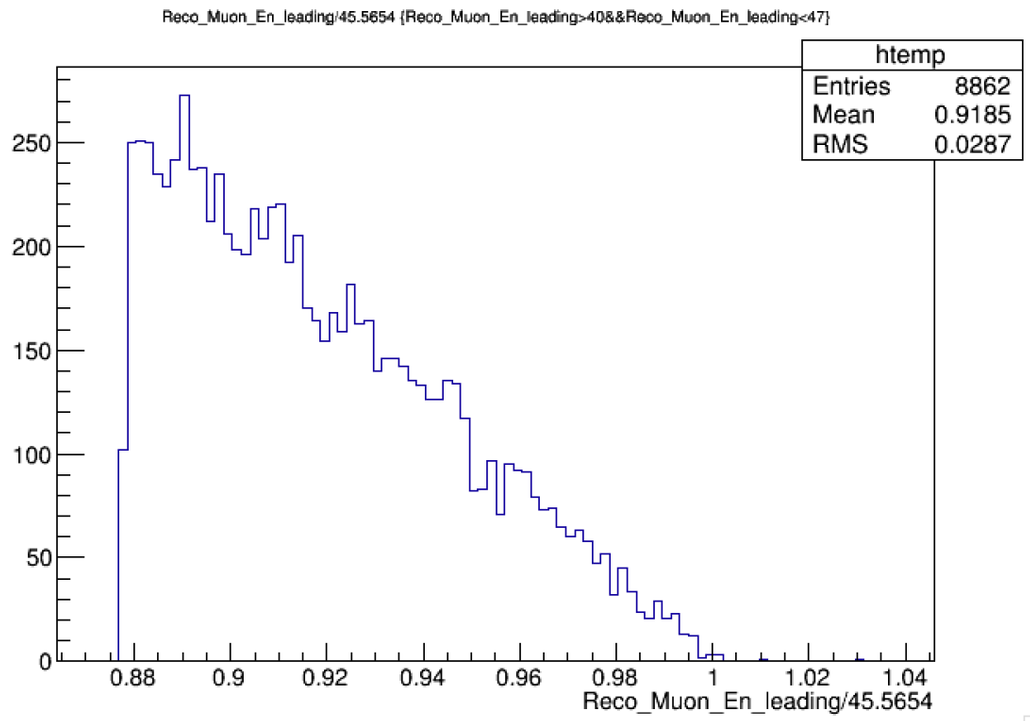


LFV — $Z \to \tau\mu$



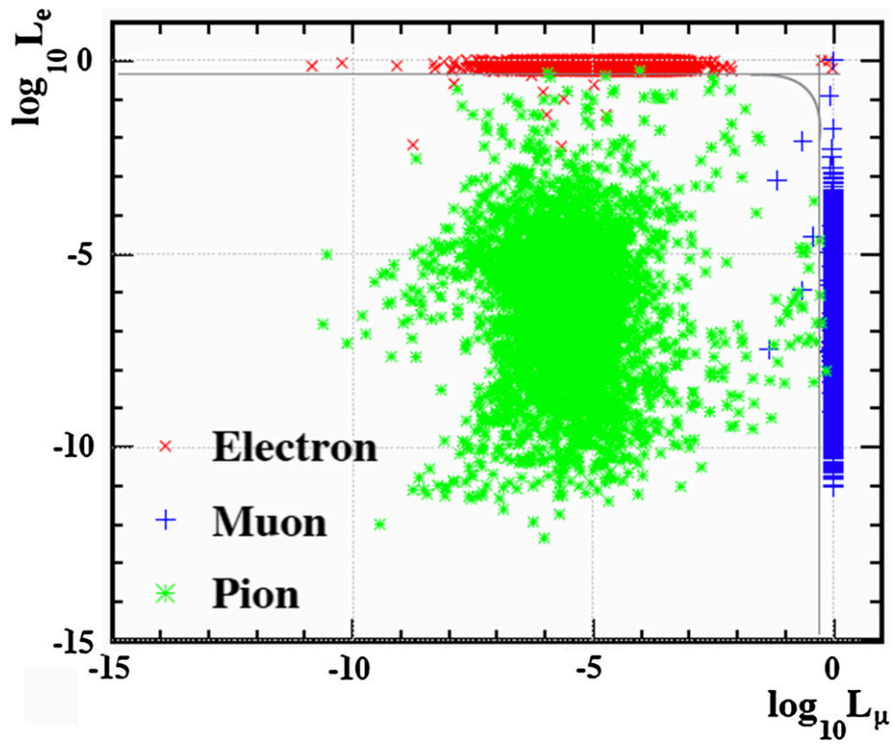
- Main background $Z \to \tau\tau$, $\tau \to \mu\nu\nu$
- Current sensitivity: $1.2*10^{-5}$ (LEP) FCC-ee estimation: 10^{-9}
- Key distribution ($P_\mu/P_{beam}>1$):
  - Signal accuracy depend on the momentum resolution ($\delta p/p \sim 10^{-3}$), signal window: (0.998, 1.002)
  - Background surviving Nbkg: 5*ScaleFactor ~ $3.36*10^5$
- Sensitivity estimated: $1.1*10^{-9}$

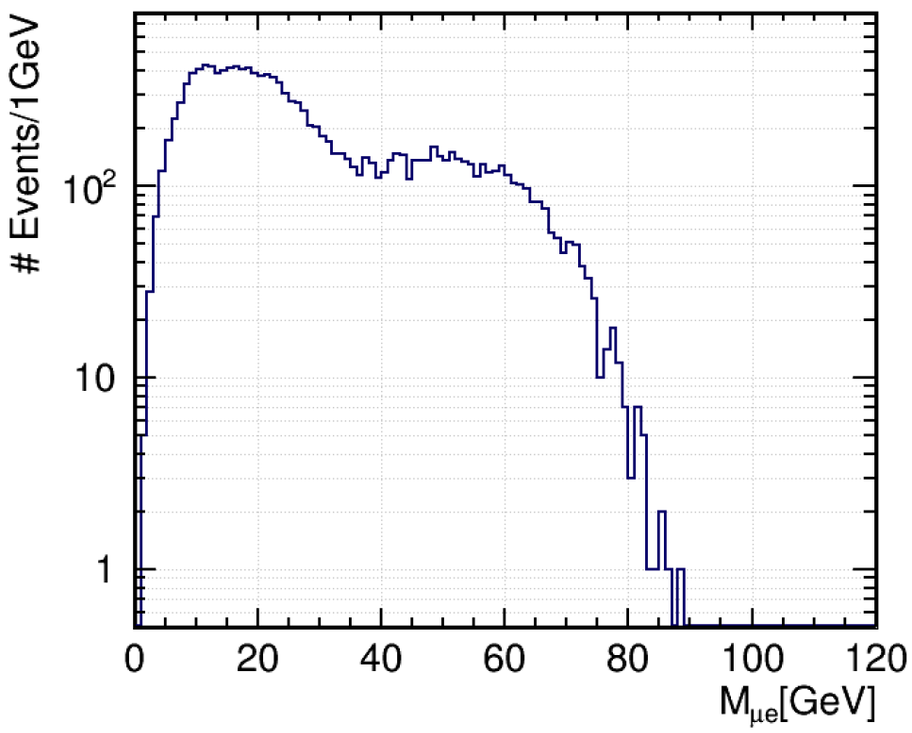




LFV — Z→μe

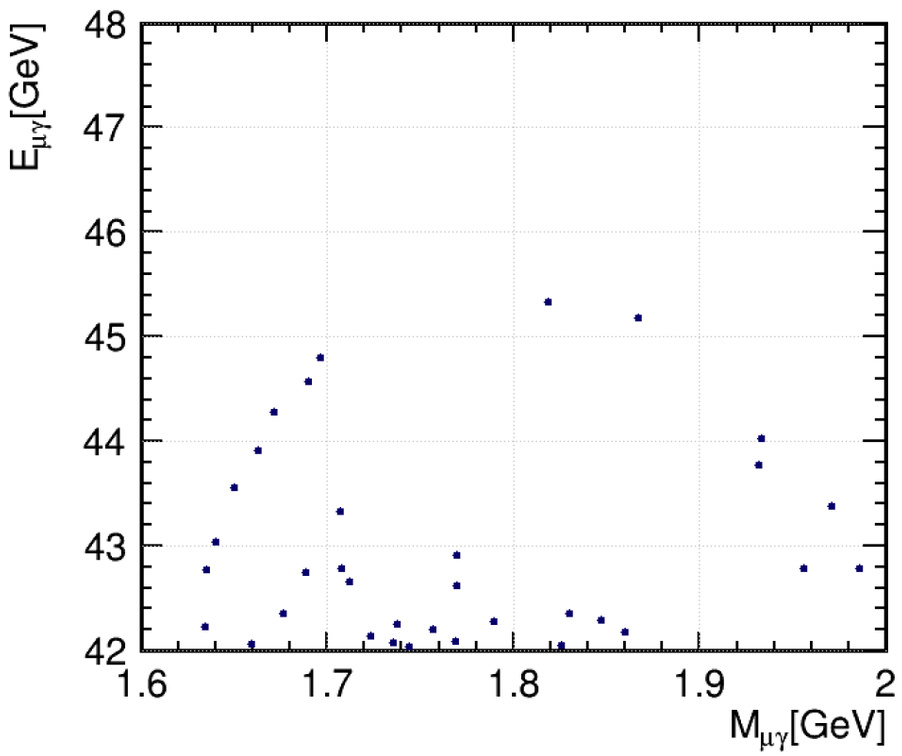
- Physics background: Z→bhabha/μμ/ττ
- Current bound: 7.5*10^{-7} (ATLAS)
  - FCC-ee estimation: 10^{-9}
- Key distribution:
  - μ/e mis-id rate: by sacrificing the id efficiency, barely bhabha/μμ surviving (except for muon decay: 10^{-7})
  - Invariant mass: no ττ surviving
- Sensitivity ~ 10^{-10}





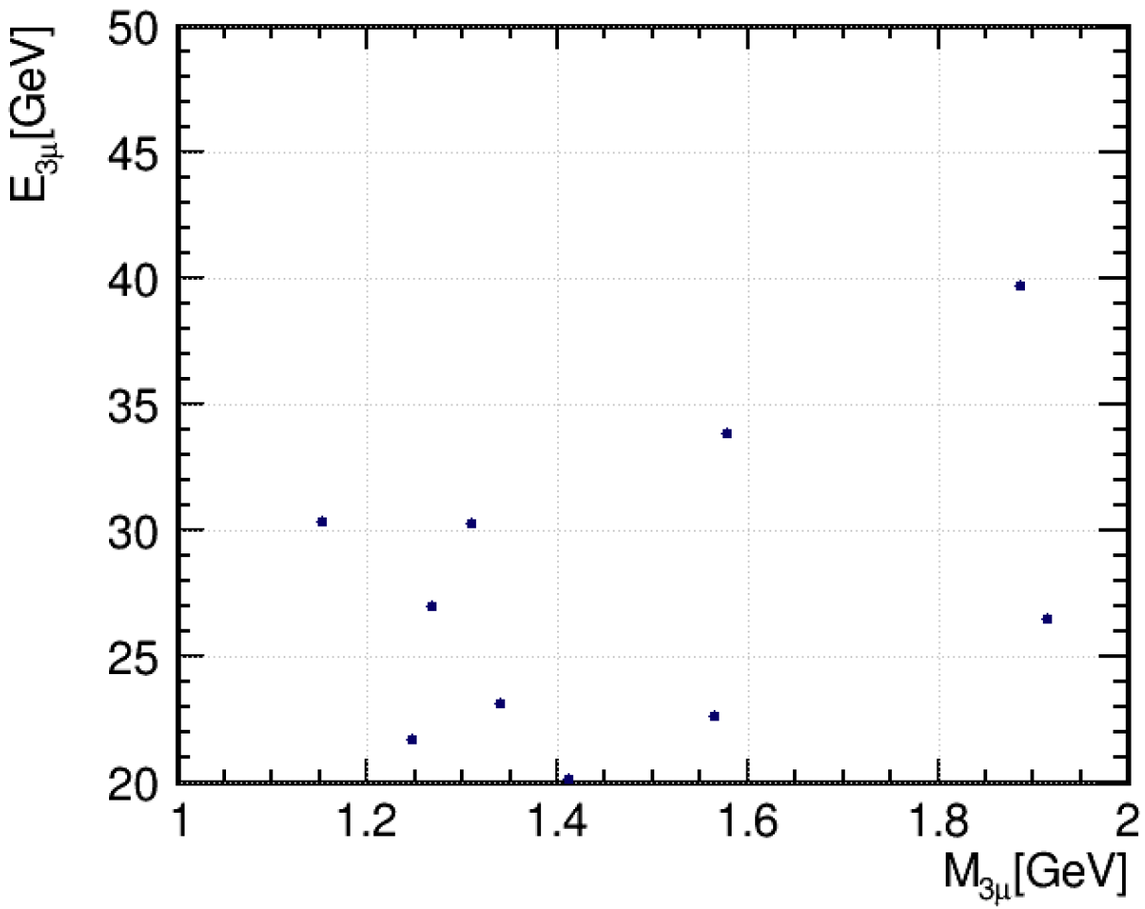
LFV — $\tau \rightarrow \mu(e)\gamma$

- Physics background: $Z \rightarrow \tau\tau\gamma$, $\tau \rightarrow \mu\nu\nu$
- Current bound: $2.7*10^{-8}$ (Babar) FCC-ee estimation: $2*10^{-9}$
- Key distribution: $M(\mu\gamma)$, $E(\mu\gamma)$
  - Signal resolution: $\sigma(m)$ = 26 MeV, $\sigma(E)$=850MeV (Ecal energy resolution ⊕ Track momentum resolution ⊕ Position resolution, from Mogens' paper)
  - Background surviving: 1*SF ~ 25k
- Sensitivity: 10^{-10}



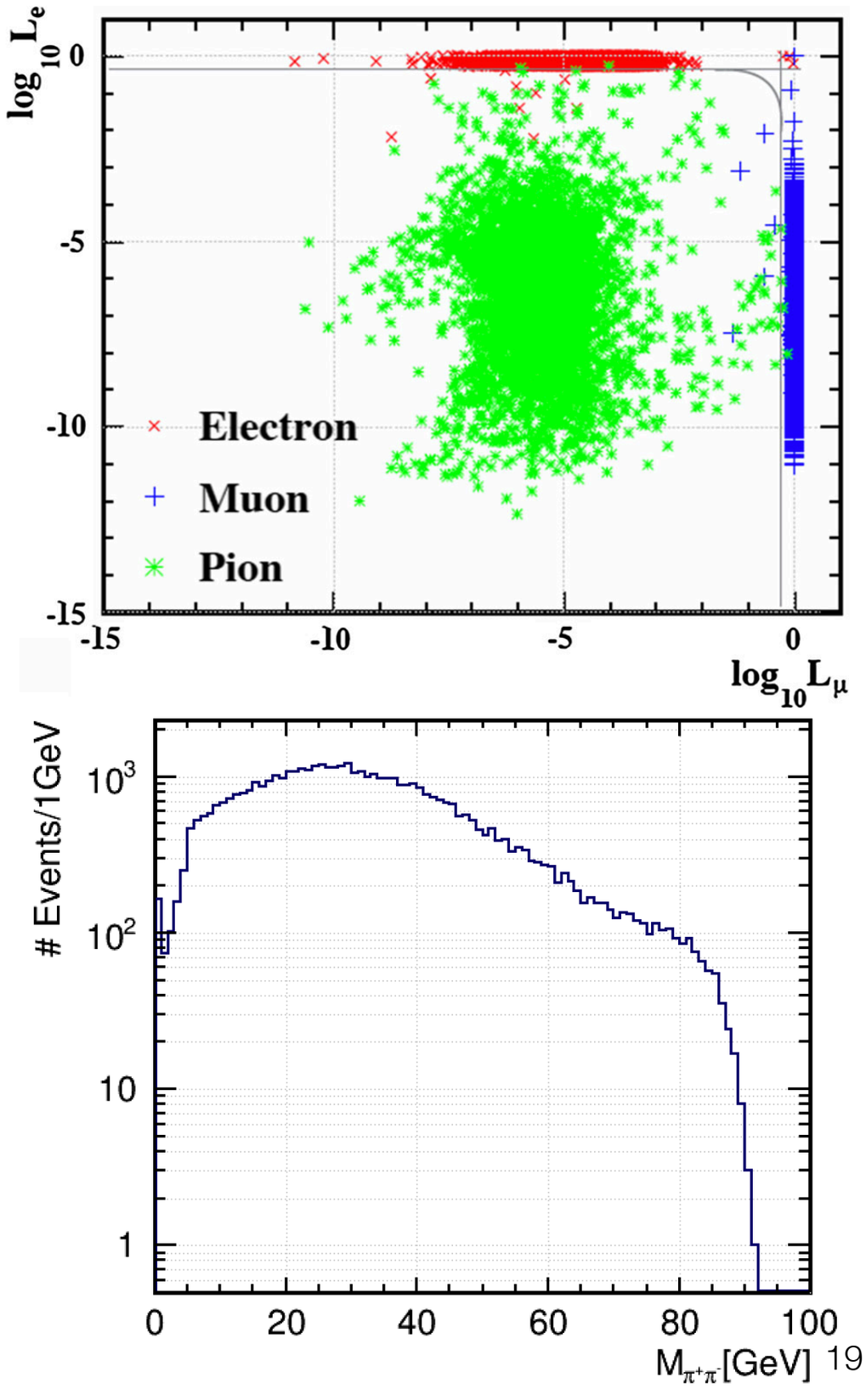
LFV — $\tau \rightarrow 3\mu$

- Main background: free
- Current bound: $2.1*10^{-8}$ (Belle) FCC-ee estimation: 10^{-10}
- Key distribution: M(3μ), E(3μ)
  - Signal resolution: track momentum resolution $\delta p/p \sim 10^{-3}$, a narrow window
  - No background surviving
- Sensitivity: 10^{-10}



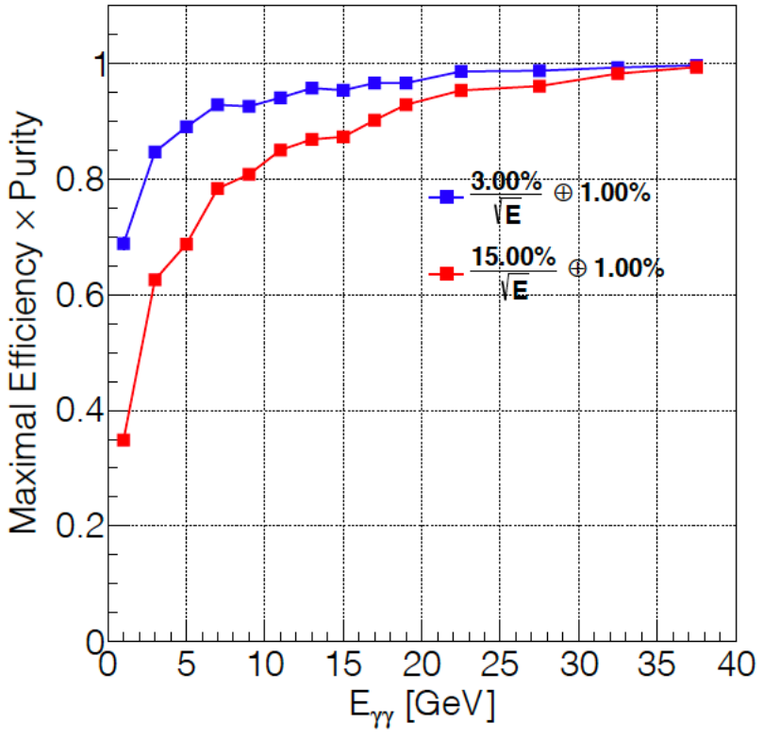
Hadronic Z decays — $Z \to \pi\pi$

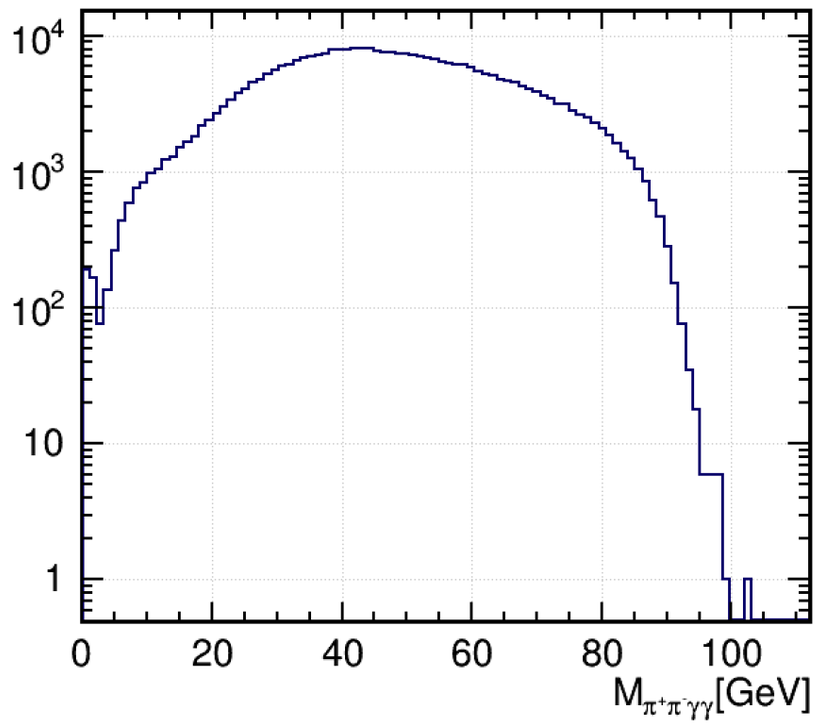
- Physics background: $Z \to \mu\mu$, $Z \to \tau\tau$
- Key distribution:
  - invariant mass
    - Signal resolution: track
    - $Z \to \tau\tau$ surviving: 1*SF
  - mis-id rate:
    - Muon mis-id rate ~ 0
- Sensitivity: 10^{-10}

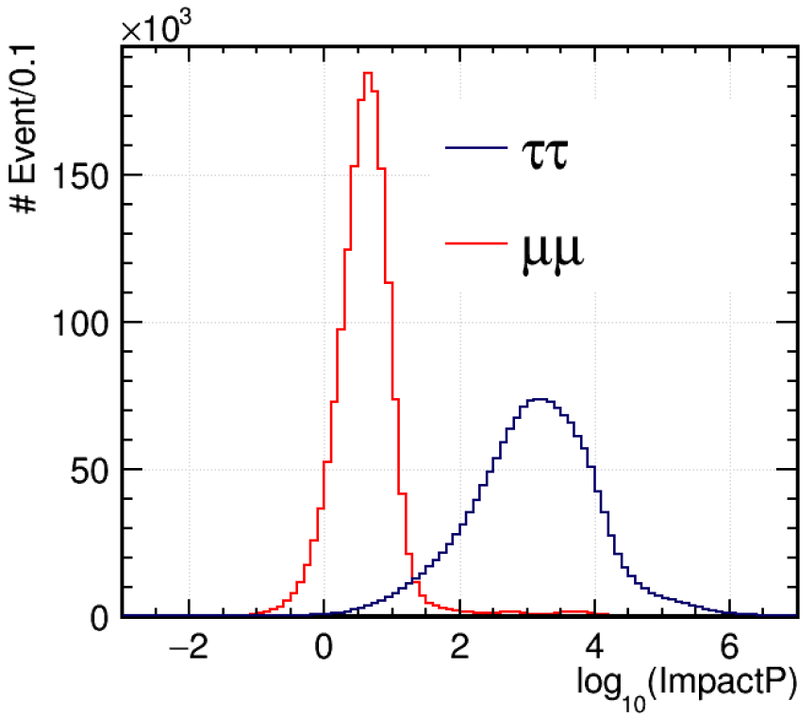


Hadronic Z decay — $Z \to \pi^+\pi^-\pi^0$

- Main background: $Z \to \tau\tau$
- Key distribution:
  - InvM:
    - Signal resolution: $\sigma(m)$ ~ sub MeV
    - Background reduced to 10^{-4}
  - Impact parameter: reduce 10%
  - M_{12} & M_{23} (M>Mtau): if Dalitz plot predicted
    - bkg reduced to 10^{-7} ~ 100k
- Sensitivity: 10^{-9}

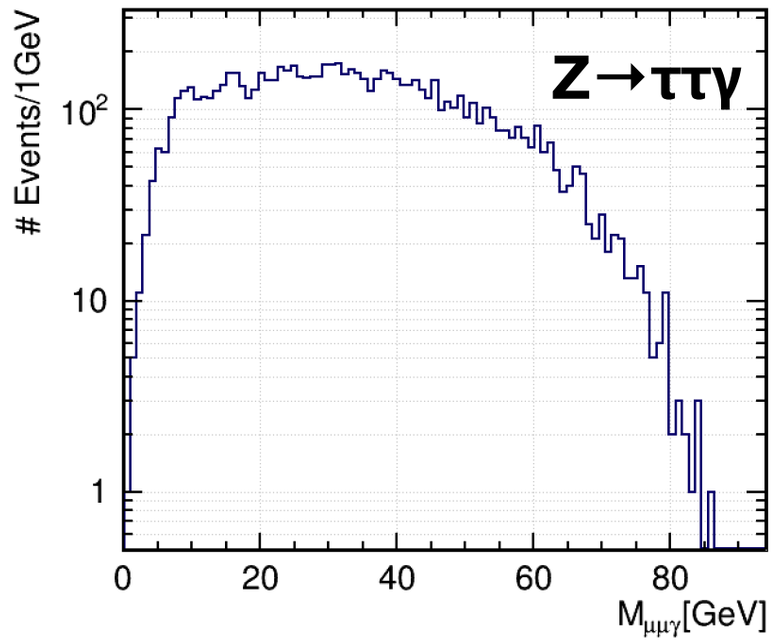


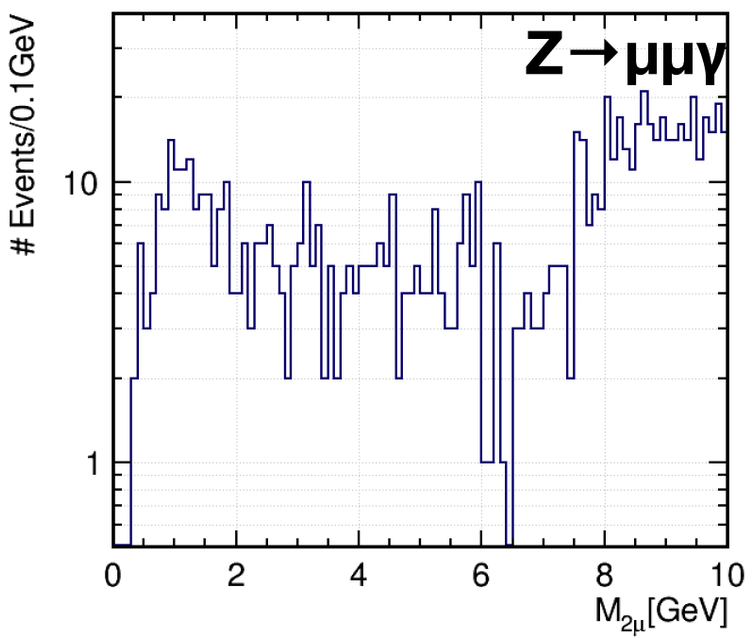




Radiative Z decay
— Z→J/ψ γ, J/ψ→μ+μ-

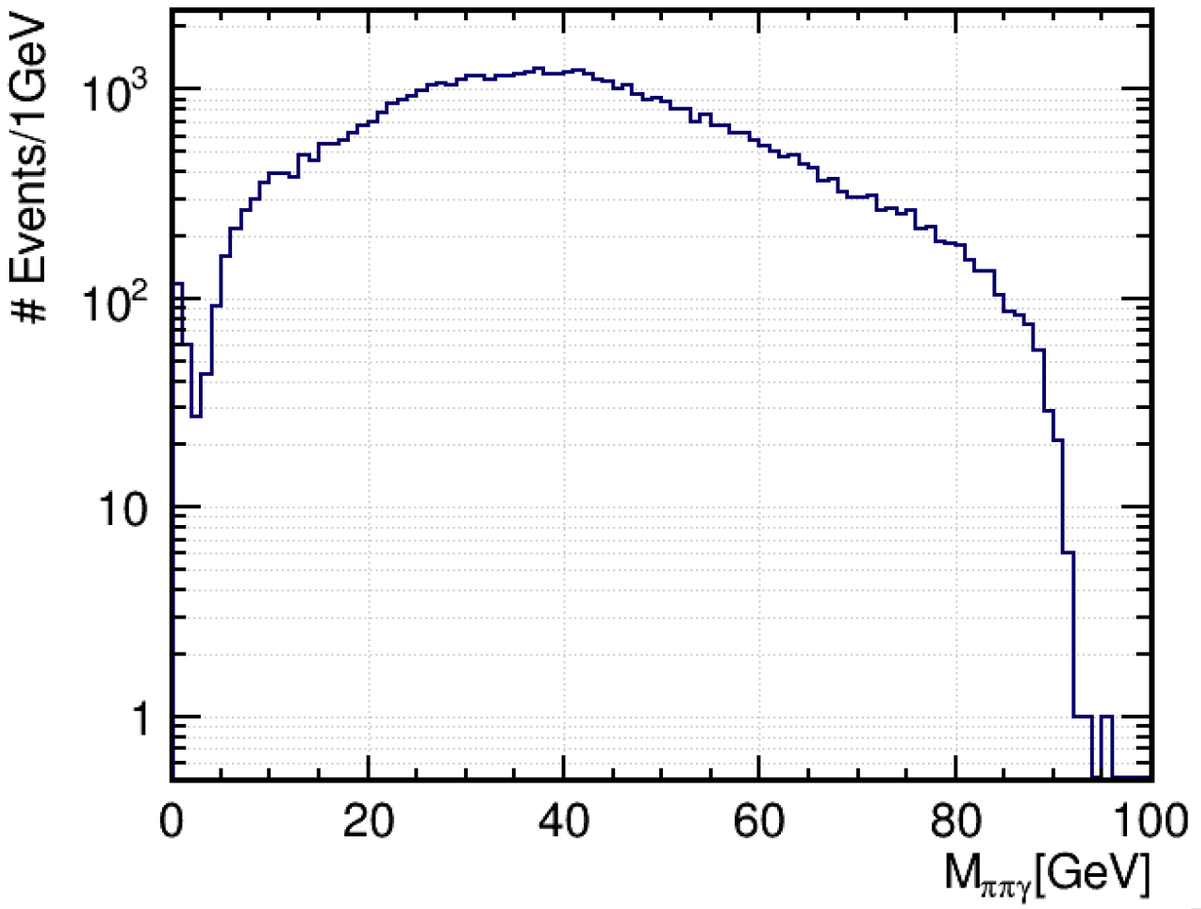
- Main background: Z→ττγ, μμγ
- Current bound: 2.6*10^{-6}(ATLAS)
  White paper prediction: 8*10^{-8}
- Key distribution:
  - total invariant mass:
    - 1*SF Z→ττγ surviving
  - di-muon invariant mass:
    - 3*SF Z→ μμγ surviving
  - impact parameter:
    - reduce 10%
- Sensitivity: 10^{-9}~10^{-10}





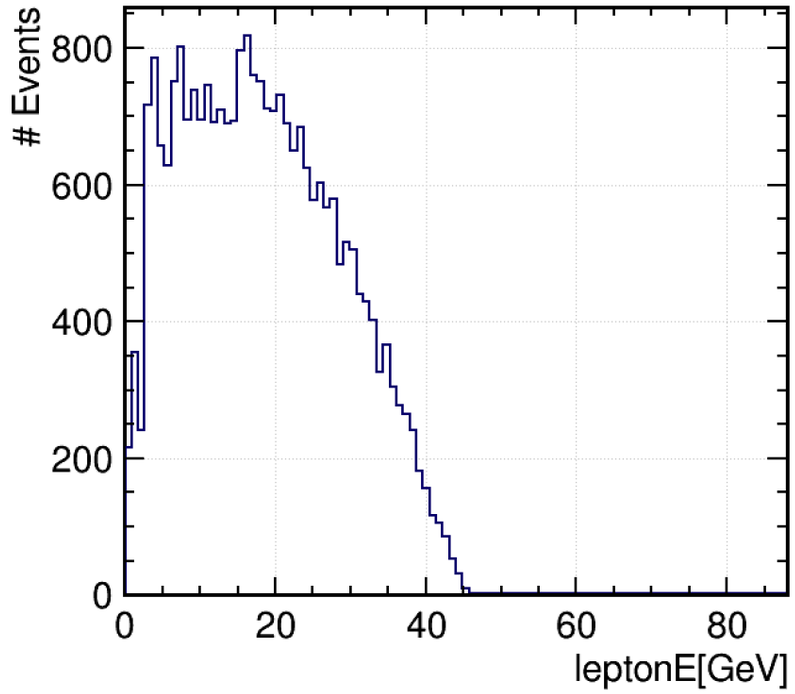
Radiative Z decay
— $Z \to \rho\gamma$, $\rho \to \pi^+\pi^-$

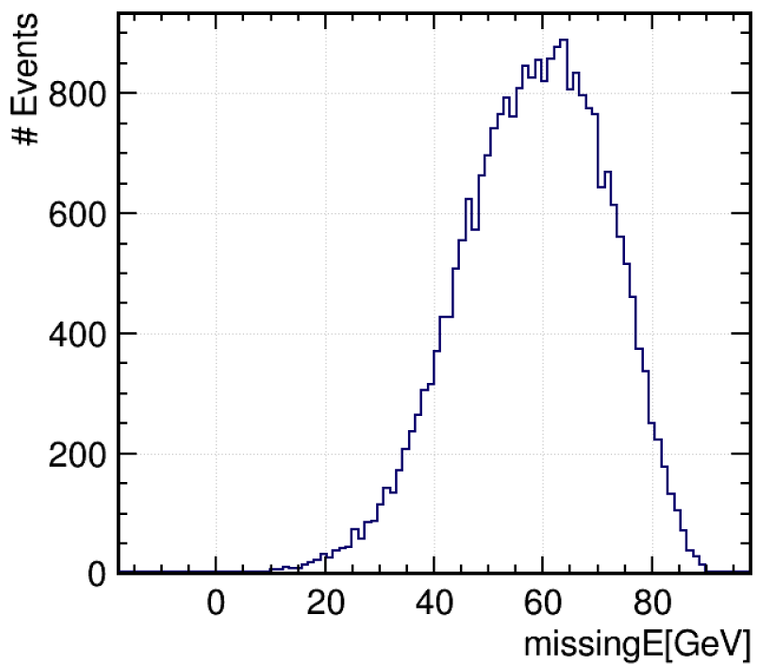
- Main background: $Z \to \tau\tau\gamma$
- White paper prediction: $4*10^{-9}$
- Key distribution:
  - total invariant mass:
    - 10*SF $Z \to \tau\tau\gamma$ surviving
  - impact parameter:
    - reduce10%
- Sensitivity: 10^{-9}



Weak Radiative Z decay — $Z \to \pi^{+/-} W^{-/+}$ (leptonic)

- Main background: $Z \to \tau\tau$, one $\tau \to \pi\nu$, the other $\tau \to l\nu\nu$
- Current bound: $7.0*10^{-5}$(LEP)
  White paper prediction: 10^{-10}
- Key distribution:
  - Acoplanarity, Missing E, lepton E: assuming bkg reduce rate same order as LEP
  - impact parameter: reduce 10%, ~10k bkg surviving
- Sensitivity: 10^{-10}





Summary

Channel	$Z\to\tau\mu$	$Z\to\mu e$	$\tau\to\mu\gamma$	$\tau\to3\mu$	$Z\to\pi\pi$	$Z\to\pi^+\pi^-\pi^0$	$Z\to J/\psi\,\gamma$	$Z\to\rho\gamma$	$Z\to\pi^{+/-}W^{-/+}$
Current Bounds/ BR prediction	$1.2*10^{-5}$	$7.5*10^{-7}$	$4.4*10^{-8}$	$2.1*10^{-8}$	10^{-12}	10^{-8} ~10^{-5}	$2.6*10^{-6}$	10^{-9}	$7.5*10^{-5}$
Earlier Estimation	10^{-9}	10^{-9}	10^{-9}	10^{-10}	-	-	10^{-8}	10^{-9}	10^{-10}
FullSim Estimation	10^{-9}	10^{-9}	10^{-10}	10^{-10}	10^{-10}	10^{-9}	10^{-9} ~10^{-10}	10^{-9}	10^{-10}

Summary

- Intensively activities on CEPC flavor physics
  - White paper
  - Meeting
  - Analysis
- Preliminary jet charge measurement, base for specific channel studies
- FullSim result consistent with the earlier estimation
  - mostly background free, great potential of CEPC Flavor
  - requirements on detector & algorithm
  - need more theorists' interpretations

Backup