TAUS AT FCC-ee

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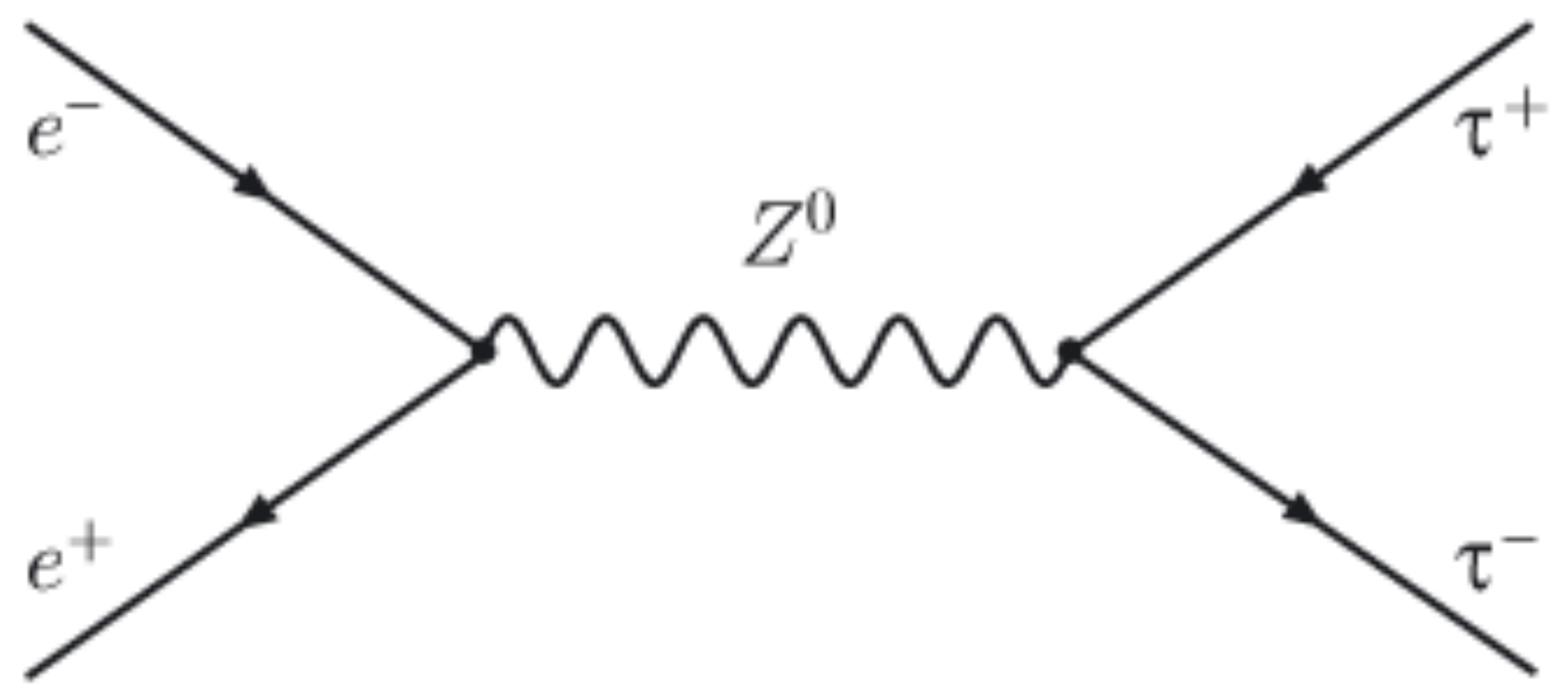
STUDYING THE TAU LEPTON AT FCC-ee

- Heaviest known lepton in Standard Model.
- Only lepton that can decay hadronically
  - ➡ Access to precision SM measurements and probes of BSM physics
- **FCC-ee : a tau factory ?**
  - Huge $e^+e^- \rightarrow Z \rightarrow \tau^+\tau^-$ sample (~10¹¹)
    - $\sigma(e^+e^- \rightarrow Z \rightarrow \tau^+\tau^-) = 1476.58\ pb$ ($\sqrt{s} = 91.188\ GeV$, PYTHIA8)
  - Low-background environment with precise momentum reconstruction: high-precision measurements of tau properties.



Working point	Z, years 1-2	Z, later
$\sqrt{s}$ (GeV)	88, 91, 94	
Lumi/IP ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	70	140
Lumi/year (ab^{-1})	34	68
Run time (year)	2	2
Number of events	6×10^{12} Z	

TAU PHYSICS PROGRAM

FCC feasibility Mid-term report -
Deliverable #8, physics and Experiments

FUTURE CIRCULAR COLLIDER

- Precision Measurements: lifetime, mass, and decay branching ratios
- Test of Lepton universality
- Rare decays
- Lepton Flavour Violation
- Tau polarization
- CP Violation Studies
- Higgs Couplings
- BSM searches

Observable	present value	±	error	FCC-ee **Stat.**	FCC-ee Syst.	Comment and leading error
m_Z (keV)	91186700	±	2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200	±	2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{\rm eff}(\times 10^6)$	231480	±	160	**2**	2.4	From $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952	±	14	**3**	small	From $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767	±	25	**0.06**	0.2-1	Ratio of hadrons to leptons Acceptance for leptons
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196	±	30	**0.1**	0.4-1.6	From R_ℓ^Z
σ_{had}^0 $(\times 10^3)$ (nb)	41541	±	37	**0.1**	4	Peak hadronic cross section Luminosity measurement
$N_\nu(\times 10^3)$	2996	±	7	**0.005**	1	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216290	±	660	**0.3**	<60	Ratio of $b\bar{b}$ to hadrons Stat. extrapol. from SLD
$A_{FB}^b, 0$ $(\times 10^4)$	992	±	16	**0.02**	1-3	b-quark asymmetry at Z pole From jet charge
$A_{FB}^{pol,\tau}$ $(\times 10^4)$	1498	±	49	**0.15**	<2	τ polarization asymmetry τ decay physics
τ lifetime (fs)	290.3	±	0.5	**0.001**	0.04	Radial alignment
τ mass (MeV)	1776.86	±	0.12	**0.004**	0.04	Momentum scale
τ leptonic $(\mu\nu_\mu\nu_\tau)$ B.R. (%)	17.38	±	0.04	**0.0001**	0.003	e/µ/hadron separation
m_W (MeV)	80350	±	15	**0.25**	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085	±	42	**1.2**	0.3	From WW threshold scan Beam energy calibration

→several updates!

Overview in Mogens Dam Eur. Phys. J. Plus (2021) 136:963

TAU IDENTIFICATION

~65% of decays are hadronic

Main hadronic signatures: one or three charged hadrons + photons

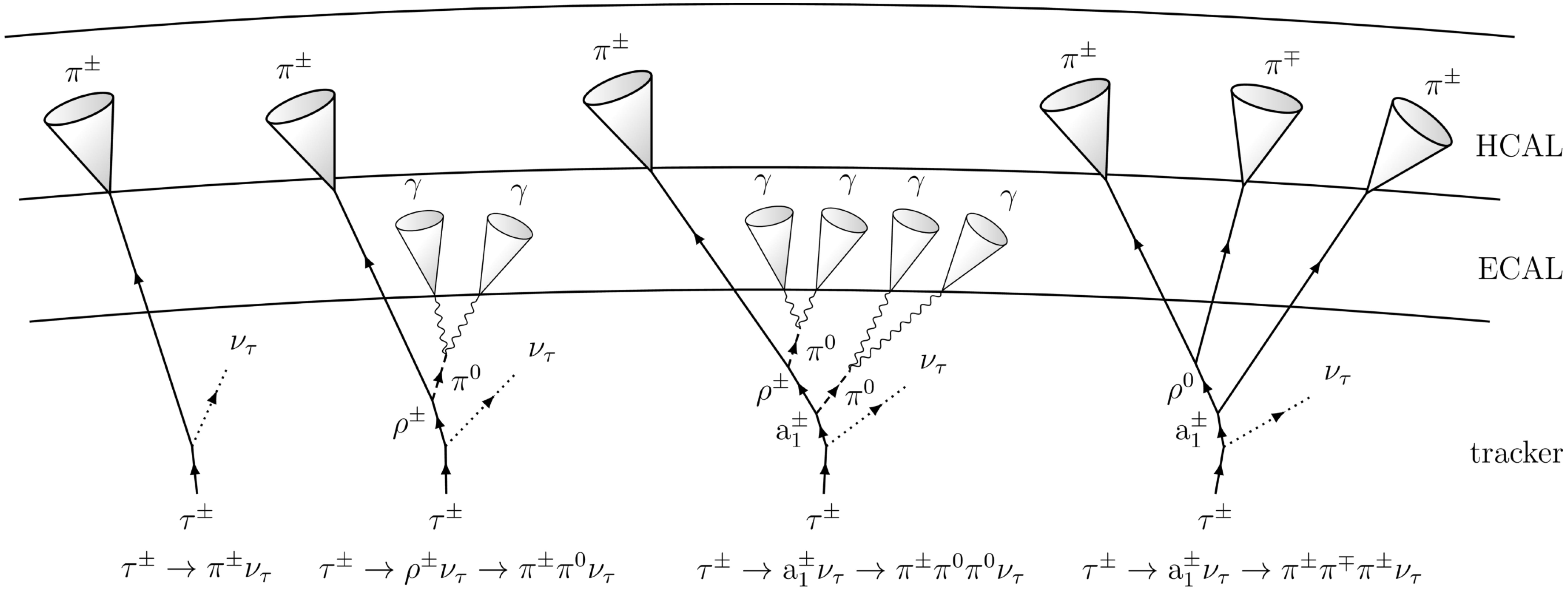


Image credit to Izaak Neutelings

Decay mode	Resonance	$\mathcal{B}$ (%)	
Leptonic decays		35.2	
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$			17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$			17.4
Hadronic decays		64.8	
$\tau^- \to h^- \nu_\tau$			11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$		25.9
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$		9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$		9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$			4.8
Other			3.3

Low charge multiplicity. Jet invariant mass smaller than tau mass.

Identification relies on charged hadron and photon reconstruction, momentum resolution and efficiency/misid

Importance of π^0 reconstruction: photon identification and merging

Pion vs Kaon discrimination for rare decays

Missing mass, acollinearity, lepton momentum, lepton vetos as handles for dilepton/diphoton reduction. Missing p_T against diphoton

TAU LIFETIME

$PDG : \tau_\tau = (290.3 \pm 0.5) \times 10^{-15} s, c\tau = 87.03 \mu m$

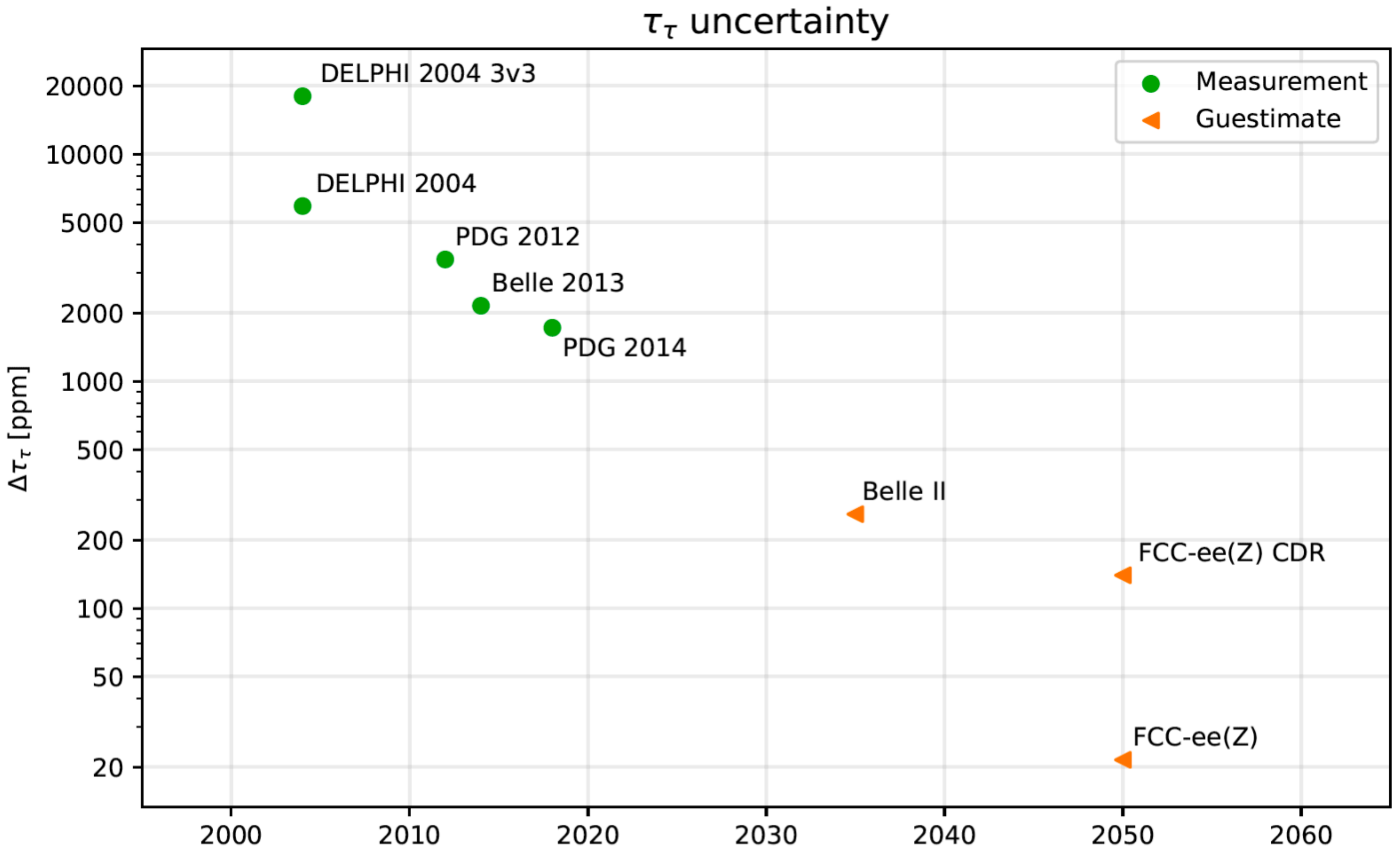
At Z-pole energies, the τ lifetime is determined via measurement of the flight distance

$$\tau_\tau = \frac{\lambda_\tau}{\beta\gamma} = \frac{\lambda_\tau m_\tau}{\sqrt{E_\tau^2 - m_\tau^2}} = \frac{\lambda_\tau m_\tau}{\sqrt{(E_{\rm beam} - E_{\rm rad})^2 - m_\tau^2}} \,.$$

FCC-ee impact parameter resolution projected to be **5 times better than LEP** ➔ substantial improvement expected.

Extrapolation from DELPHI, based on tau pairs with double hadronic decays 3-prong vs. 3-prong (as in Belle 2013 best measurement, to profit from tau direction reconstruction using vertices)

➔ **down to ~20ppm.**



	DELPHI 2004 [fs]	DELPHI 2004 [ppm]	FCC-ee(Z) 210 ab^{-1} [ppm]
statistical uncertainty	5.2	18000	15.0
luminosity-dependent systematics	1.3	4500	3.9
- background	0.2		
- reconstruction bias	0.8		
- vertex detector alignment	1.0		
luminosity-independent systematics			
- detector length scale	-	100	5.0
- average tau energy	-	-	1.0
- radiative energy loss	0.1	350	11.5
- tau mass	-	68	9.0
total systematics			15.9
total uncertainty			21.5

A. Lusiani

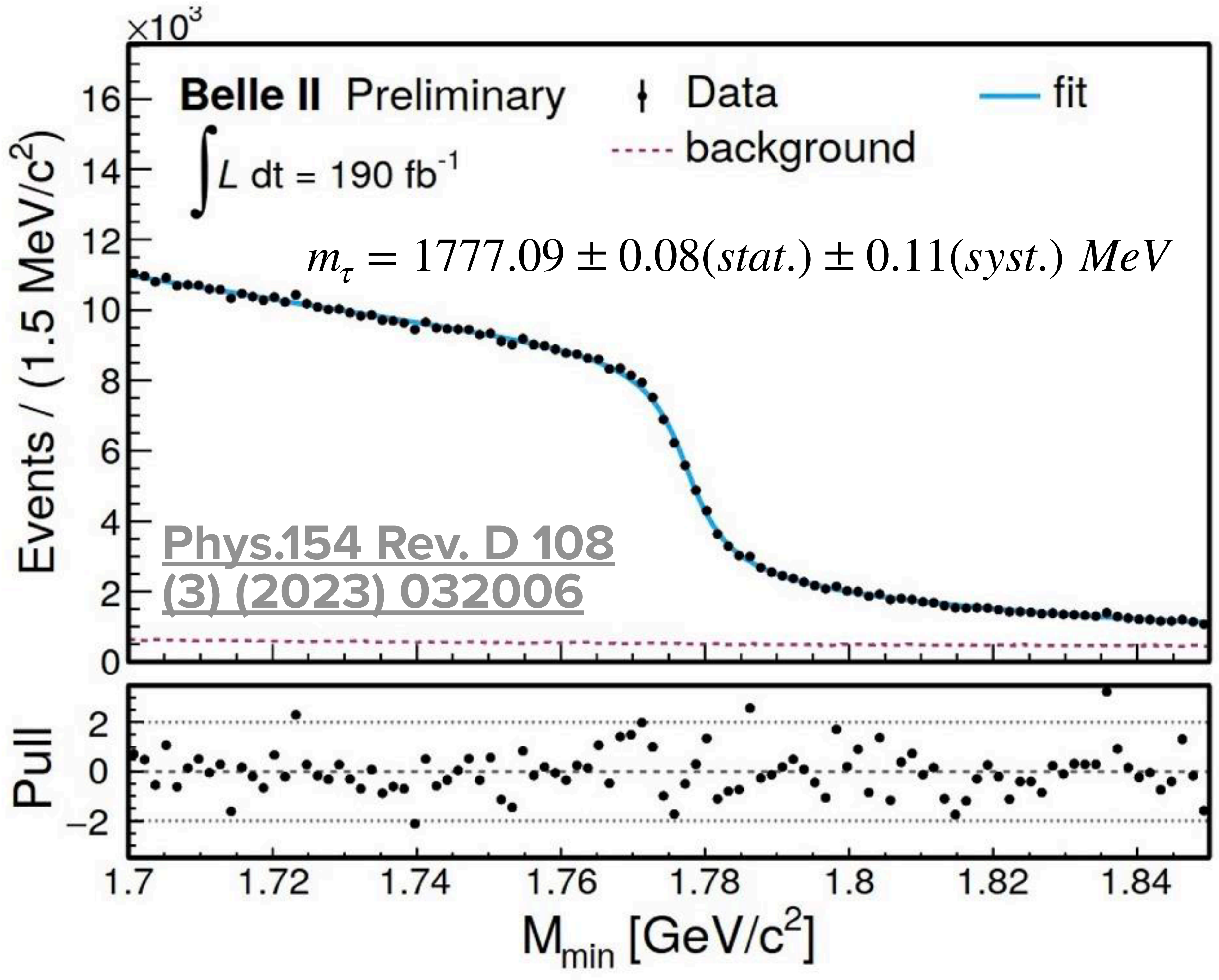
TAU MASS

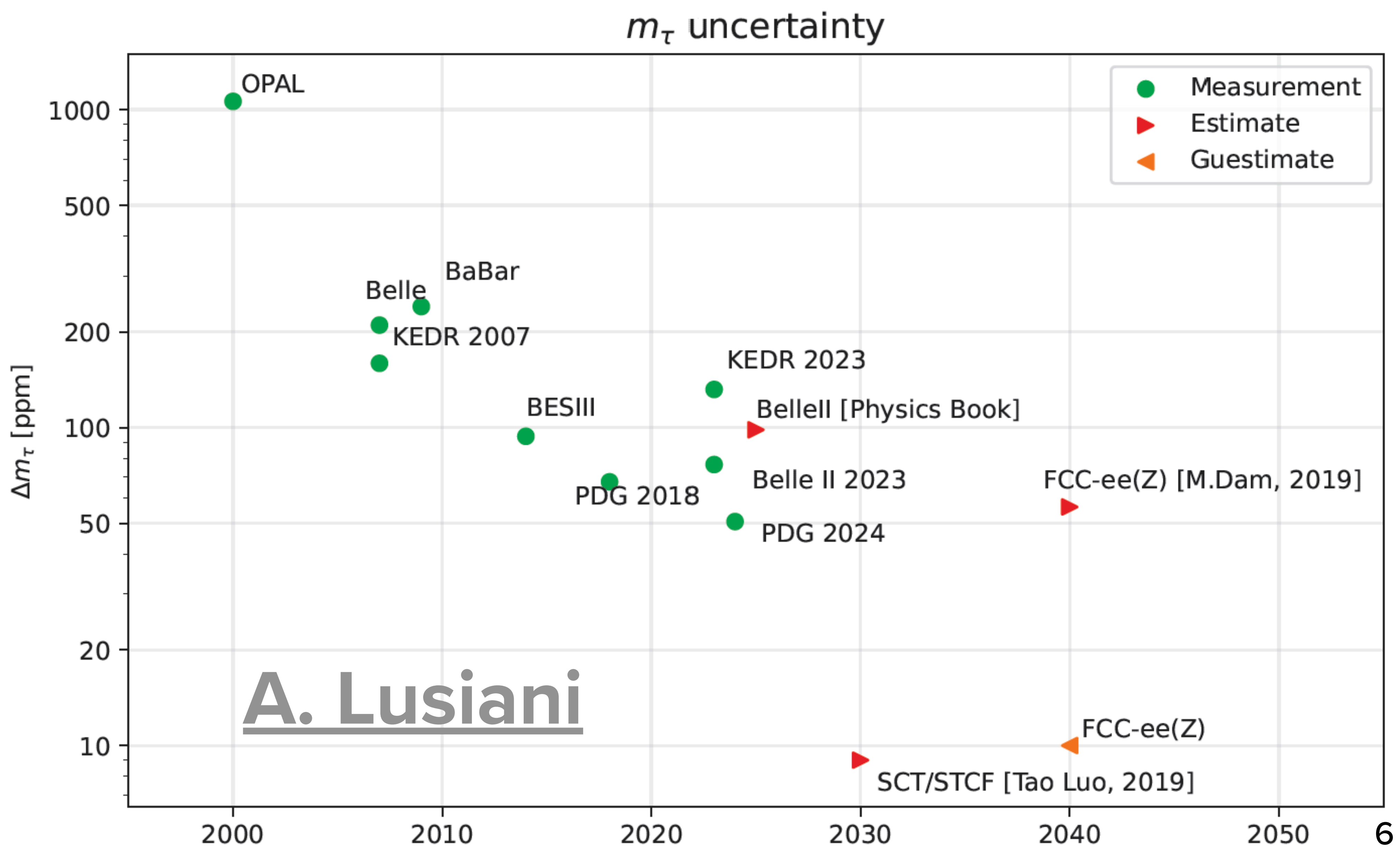
- Most precise measurement currently: Belle II fit to the reconstructed tau pseudo-mass distribution, using hadronic decays $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$. Systematically limited.

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - p_{3\pi}^*)} \leq m_\tau$$

- **FCC-ee should be able to significantly reduce the main systematic effects**
  - Statistical precision extrapolated from OPAL to FCC-ee with $6{\cdot}10^{12}$ Z decays: 0.9 ppm
  - Leading systematics in Belle:
    - Beam energy: 39 ppm at Belle ➔ 1ppm at FCC-ee
    - Track momentum scale: 34 ppm at Belle ➔ 2ppm at FCC-ee (using J/Psi mass)
  - Alignment systematics expected to scale with statistics
  - Other systematics (fit function, estimator bias, ISR/FSR, detector material, tau decay): at Belle, 0.05 MeV or 29 ppm. **Factor of 3 improvement assumed possible at FCC-ee.**

➡ **Precision at FCC: $\sigma(m_\tau)$ ~ 0.018 MeV , 10 ppm**





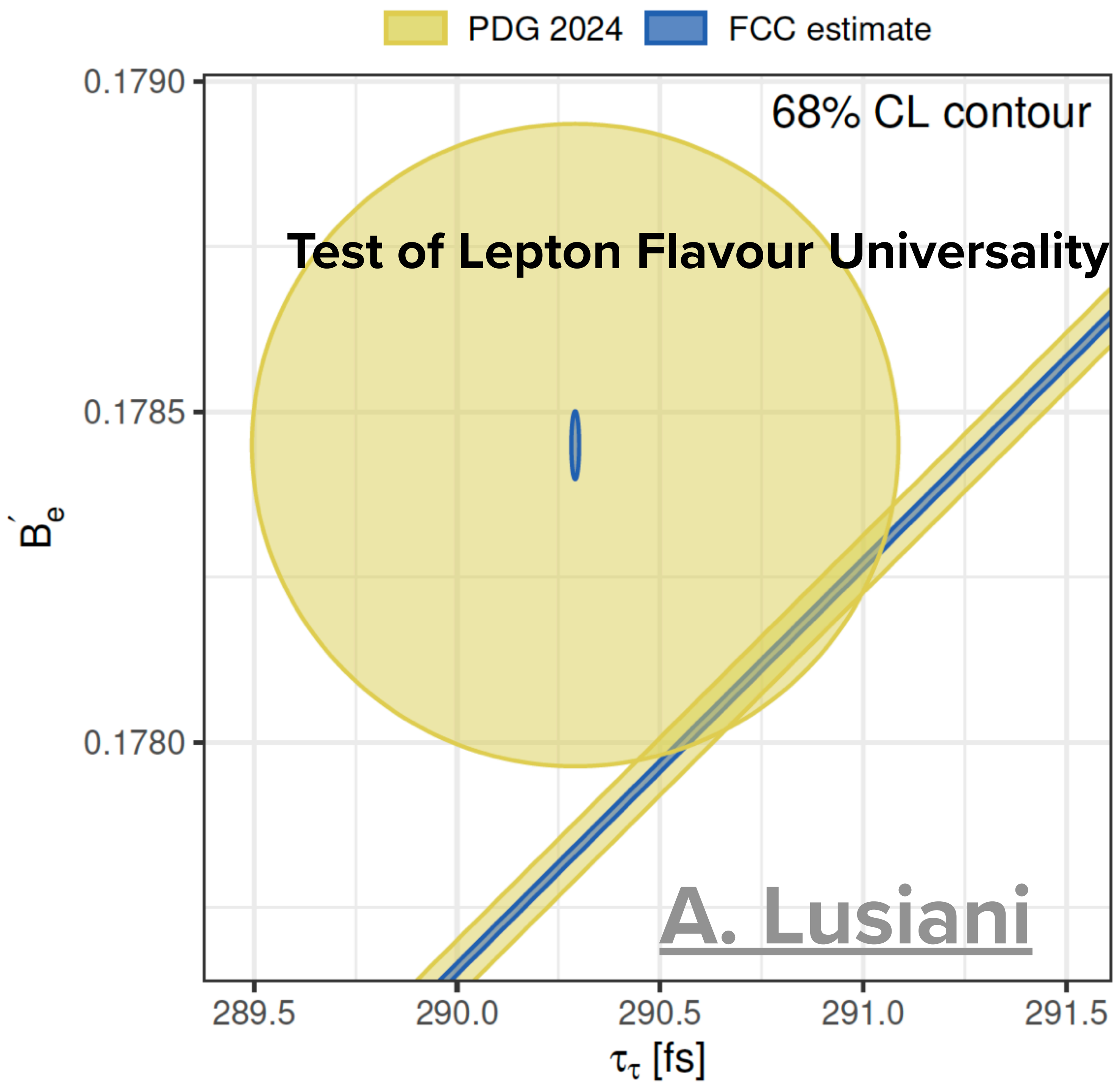
TAU DECAYS

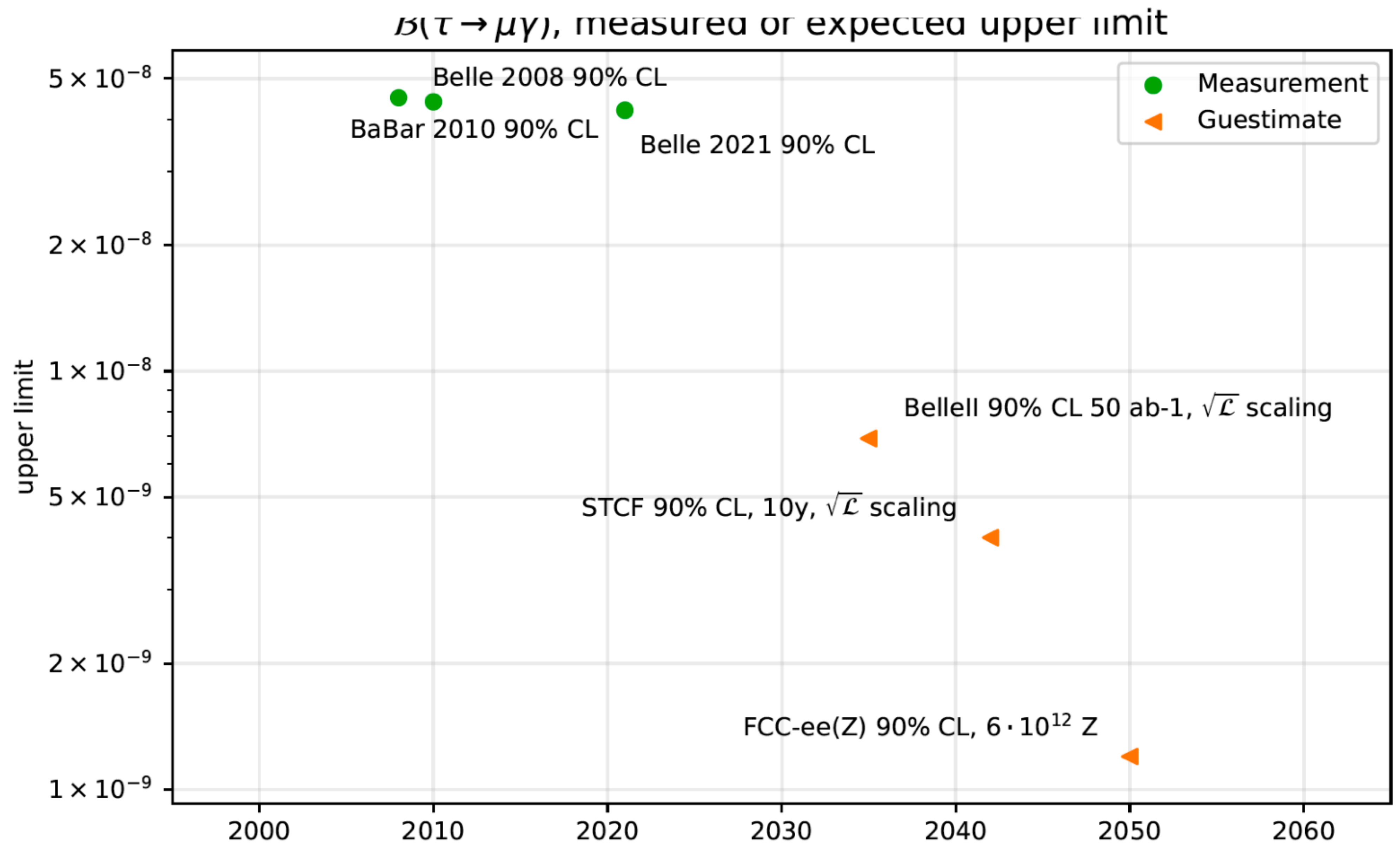
- **Leptonic branching fractions ($\tau \rightarrow l\bar{\nu}\nu$)**
  - Extrapolation difficult, systematically dominated (eg related to photon and π^0 reconstruction).
  - The extrapolated statistical precision at FCC-ee with $6{\cdot}10^{12}$ Z decays is 4.0 ppm
  - Complex systematic uncertainties. Assuming 1/10 of the ALEPH systematic: 190ppm
  - Requirements: Good EM energy resolution ($< 20\,\% / \sqrt{E}$ (LEP)), Granular EM calorimeter (< 15 x 15 mrad^2 (LEP))
  - Probe of **Lepton Flavour Universality**

$$\left(\frac{g_\tau}{g_\ell}\right)^2 = \mathcal{B}(\tau \rightarrow \ell\bar{\nu}\nu) \cdot \frac{\tau_\mu}{\tau_\tau} \cdot \left(\frac{m_\mu}{m_\tau}\right)^5 ,$$

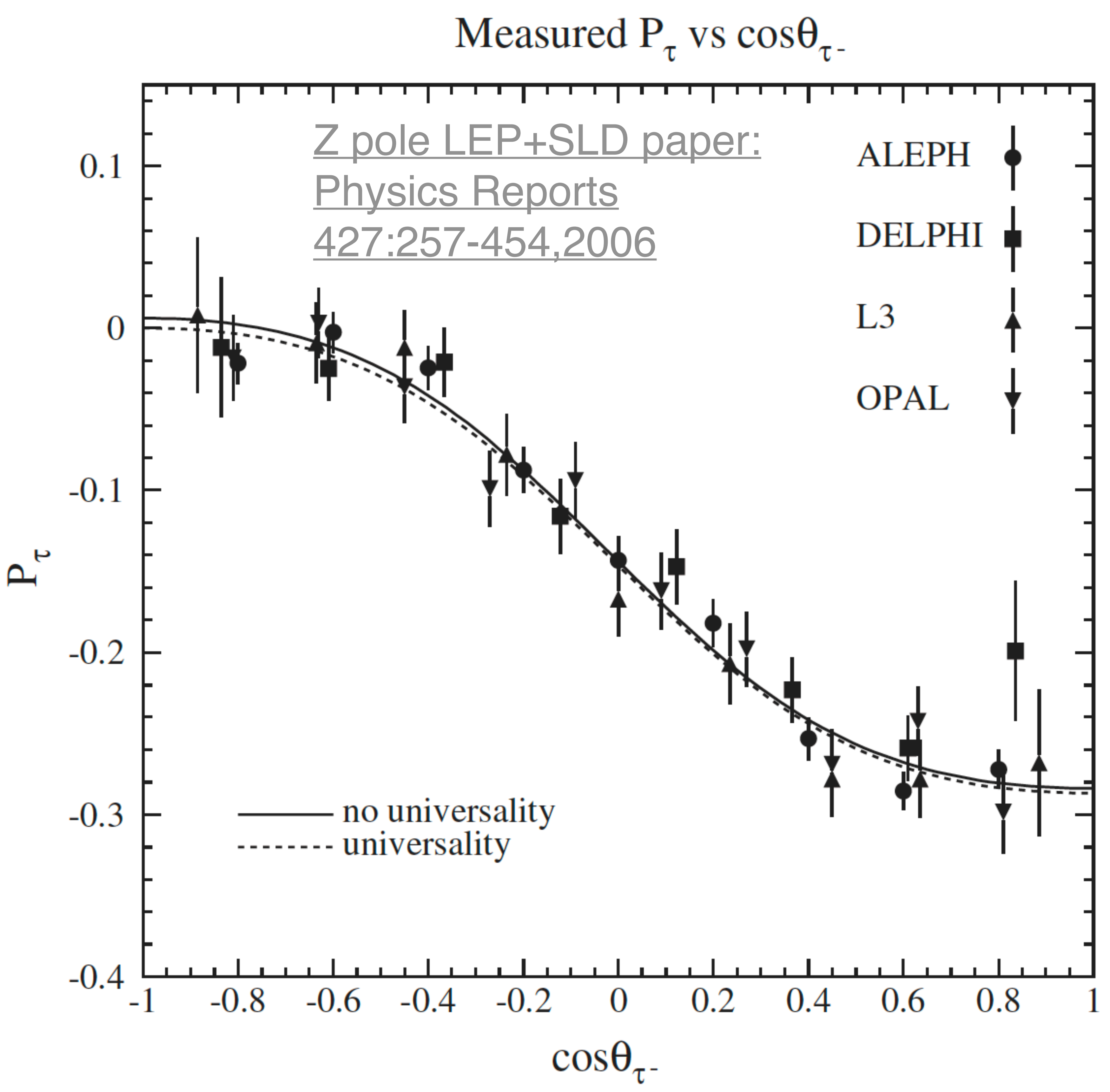
(plus radiative corrections terms)

- **Searches for LFV Decays: $\tau \rightarrow \mu\gamma$, $\tau \rightarrow \mu\mu\mu$**
  - Projection by M. Dam : 1, 2 order of magnitude improvement with respect to the current bounds.
  - $\tau \rightarrow \mu\gamma$: Importance of backgrounds, photon energy, and position resolution





TOWARDS A TAU POLARIZATION MEASUREMENT AT FCC-EE



$$\mathscr{A}_e(LEP) = 14.98 \pm 0.48(stat) \pm 0.09(syst)$$
$$\mathscr{A}_\tau(LEP) = 14.39 \pm 0.35(stat) \pm 0.26(syst)$$

Probe of the vector and axial couplings of the Z. One of the most sensitive tests of electroweak parameters, including $\sin^2\theta_W$.

Rely on the dependence of kinematic distributions of the observed τ decay products on the helicity of the parent τ lepton.

$$\mathcal{P}_\tau \equiv (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$$

$$\mathcal{P}_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta) + 2\mathcal{A}_e\cos\theta}{(1+\cos^2\theta) + 2\mathcal{A}_e\mathcal{A}_\tau\cos\theta}$$

P_τ (cos θ) : nearly independent determination of A_τ and A_e

At LEP: dominated by statistical uncertainty. At FCC-ee: dominated by systematic uncertainty

Start by looking at A_τ: larger impact of systematic uncertainties. Medium term plan: full analysis, both A_e and A_τ.

LEP UNCERTAINTIES

ALEPH: Eur.Phys.J.C20:401-430,2001

	A_τ						
Systematic effect	h	ρ	$3h$	$h2\pi^0$	e	μ	$acol$
eff. $h \to h$ id.	0.17	0.06	-	0.06	0.20	0.35	0.01
misid. $(e,\mu) \to h$	0.24	0.05	-	0.09	0.13	0.25	0.57
$\tau\tau$ selection	0.13	0.03	0.01	0.01	0.03	0.04	-
τ BR and background	0.04	0.05	0.03	0.09	0.01	0.02	0.02
tracking	0.08	0.07	0.22	-	-	0.21	0.30
γ-reconstruction	-	0.22	0.29	0.66	-	-	-
π^0-reconstruction	0.11	0.29	0.68	0.62	-	-	-
fake photons	0.31	0.17	0.28	0.75	-	-	-
ECAL scale	-	0.20	0.33	0.63	0.15	-	-
ECAL + HCAL cut	0.22	-	-	-	-	-	-
modelling	-	-	0.68	0.68	-	-	-
non-τ background	0.24	0.16	0.07	0.05	0.73	0.50	0.60
τ MC statistics	0.34	0.30	0.61	0.77	0.73	0.80	1.44
TOTAL	0.66	0.57	1.30	1.70	1.07	1.06	1.69

	A_e						
Systematic effect	h	ρ	$3h$	$h2\pi^0$	e	μ	acol
tracking	0.04	-	-	-	-	0.05	-
non-τ background	0.13	0.08	0.02	0.07	1.23	0.24	0.24
modelling	-	-	0.40	0.40	-	-	-
TOTAL	0.13	0.08	0.40	0.41	1.23	0.24	0.24

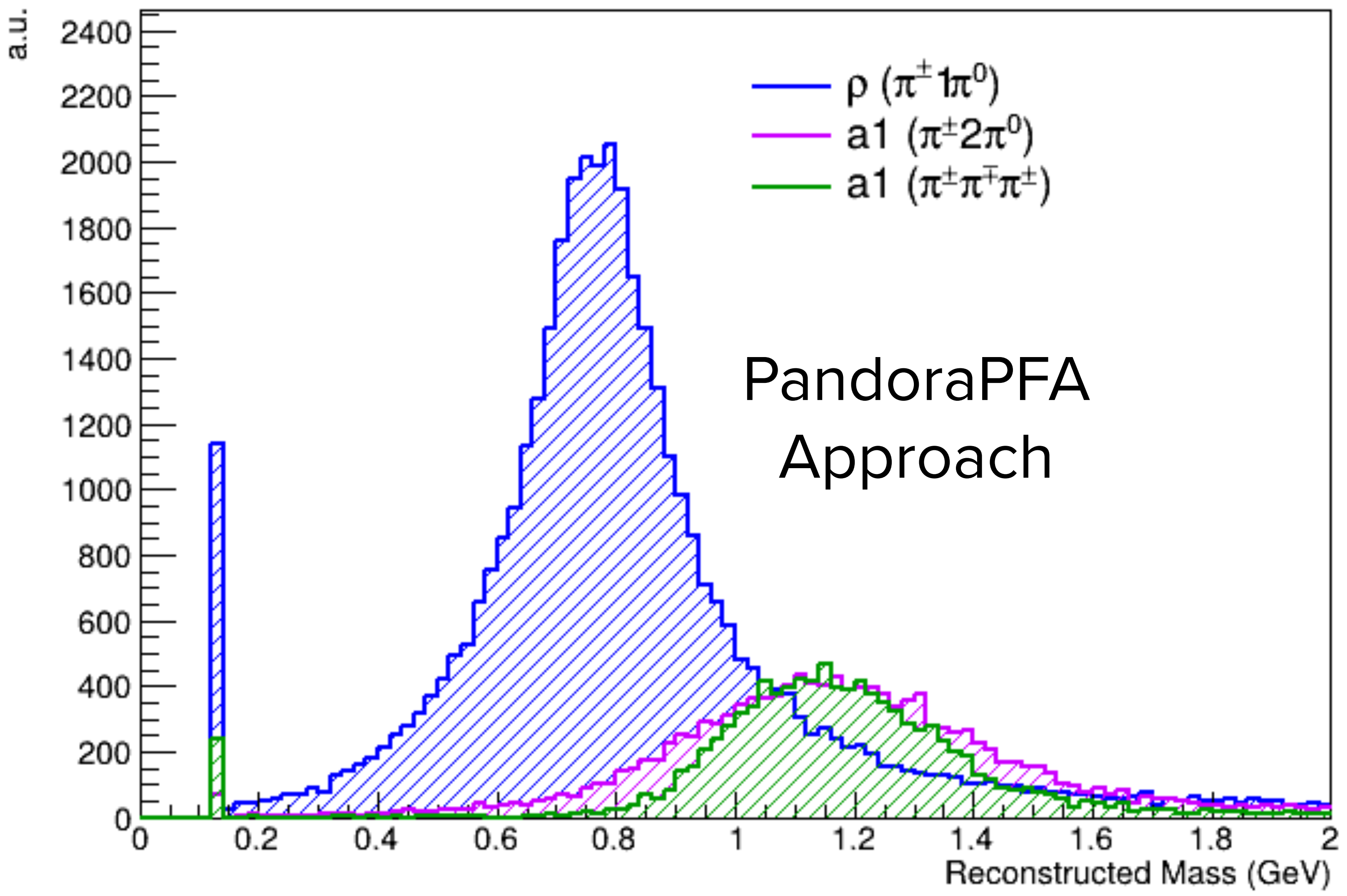
Physics Reports 427:257-454,2006

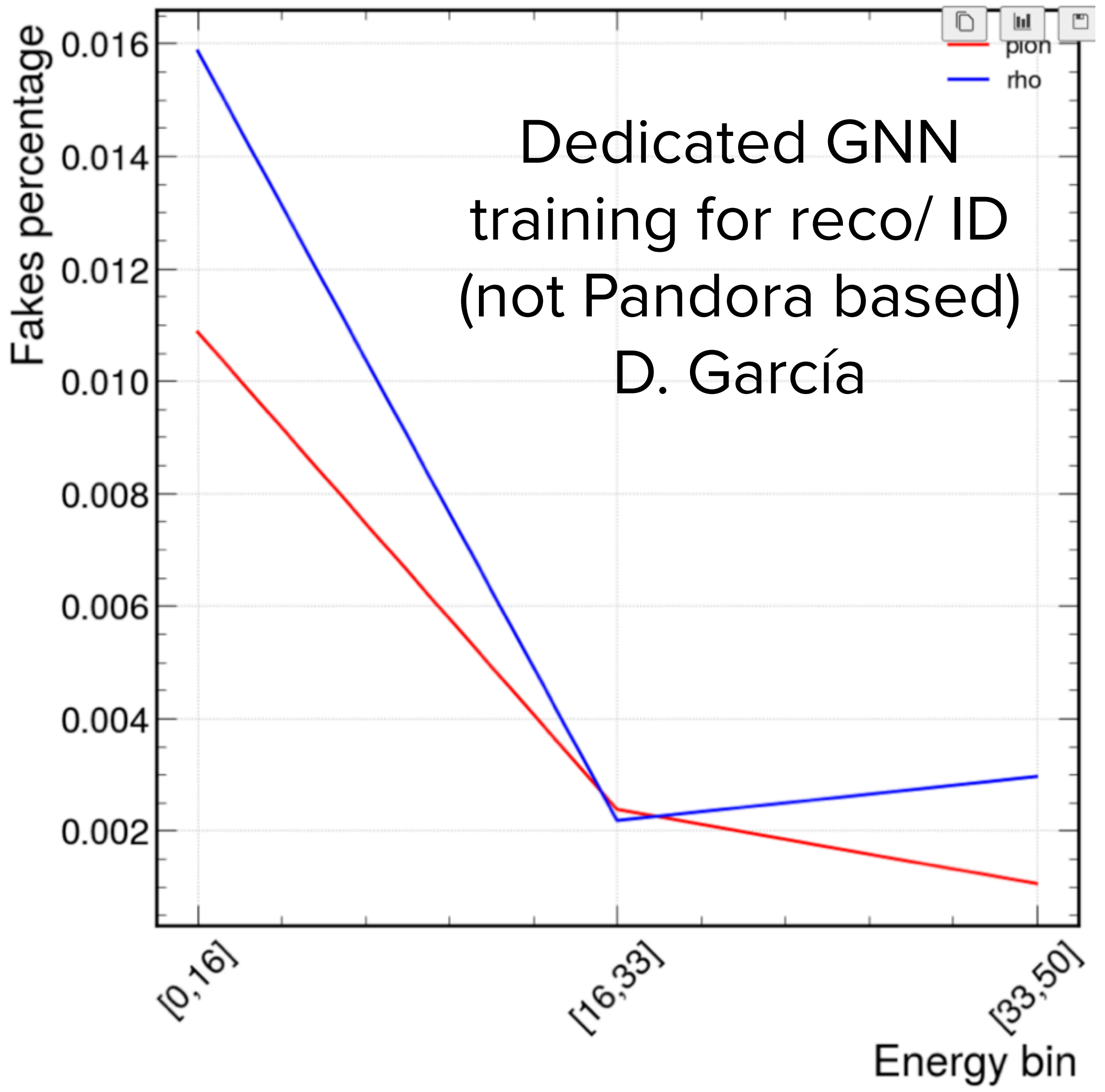
Experiment	$\mathscr{A}_\tau$	$\mathscr{A}_e$
ALEPH	$0.1451 \pm 0.0052 \pm 0.0029$	$0.1504 \pm 0.0068 \pm 0.0008$
DELPHI	$0.1359 \pm 0.0079 \pm 0.0055$	$0.1382 \pm 0.0116 \pm 0.0005$
L3	$0.1476 \pm 0.0088 \pm 0.0062$	$0.1678 \pm 0.0127 \pm 0.0030$
OPAL	$0.1456 \pm 0.0076 \pm 0.0057$	$0.1454 \pm 0.0108 \pm 0.0036$
LEP	$0.1439 \pm 0.0035 \pm 0.0026$	$0.1498 \pm 0.0048 \pm 0.0009$

- Main modes: pion and rho decays
- Low momentum track and photon identification is key
- Uncertainties vary largely between LEP experiments, by almost a factor of 2: importance of detector concept. Full simulation needed to do a proper assessment of FCC-ee sensitivity.
- At FCC-ee: large samples for determination of track and photon efficiencies, scales: expect much smaller uncertainties overall
- **Assuming a factor of 10 improvement in systematics wrt to the LEP detectors (from the combined result), A_τ systematic uncertainty < 0.02%**

TAU RECONSTRUCTION WITH FULL SIMULATION

- First implementation of tau reconstruction with full simulation at FCC-ee!
- **CLD Detector Simulation**
- Double approach:
  - **Simple tau cone reconstruction based on PandoraPFA: first prototype**
    - Tau Identification from charged pion and photon multiplicity
    - Main Decay modes implemented (pion, ρ, a_1)
    - Good energy resolution and reasonable decay mode identification as a starting point
    - Efficiency and Purity limited by PandoraPF (pion efficiency, misidentification as neutral hadrons)
      - Possible to correct for this with a second layer on top of PandoraPF
  - **GNN approach (not reliant on Pandora) in progress:** excellent separation of rho and pion channels
- Reminder: understanding systematics is key for the polarization measurement



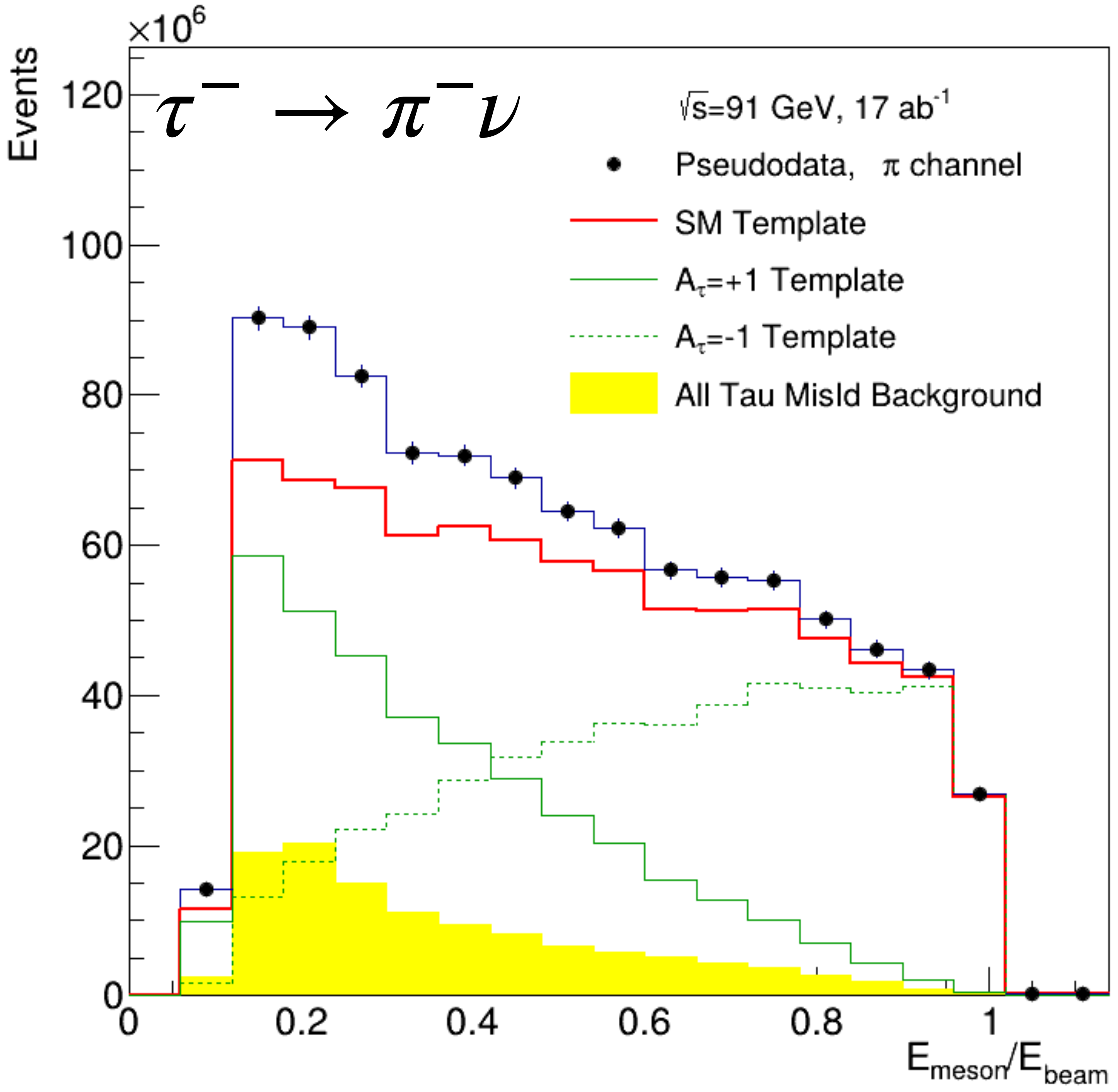


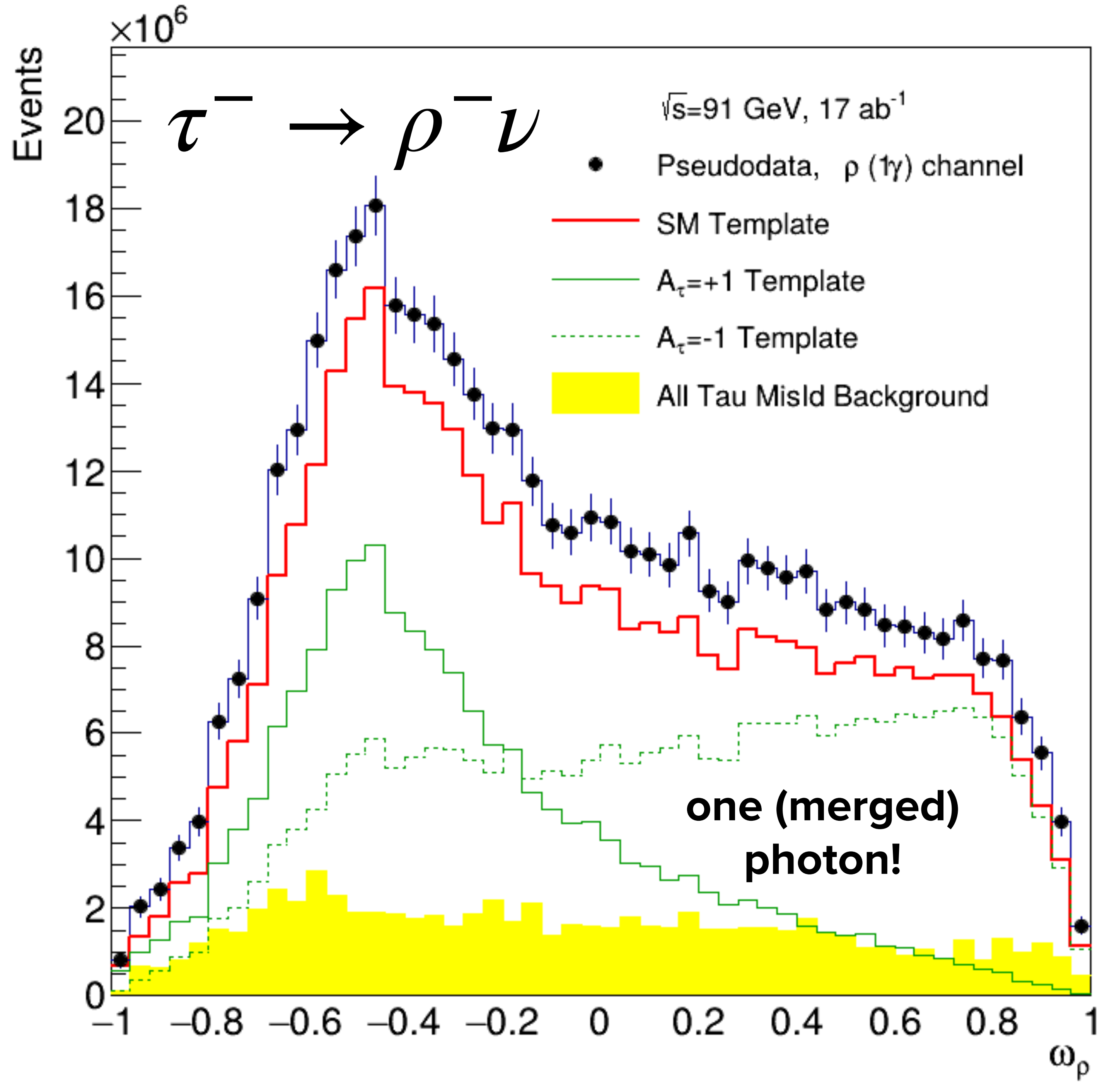
PandoraPFA Approach (*)	Reconstructed Tau ID						
	h	h+γ	h+2γ	h+3γ	h+4γ	3h	n
$\pi^\pm$	0.81	0.03	0.00	0.01	0.01	0.00	0.13
$\rho\ (\pi^\pm\pi^0)$	0.03	0.21	0.59	0.07	0.01	0.00	0.09
$a_1\ (\pi^\pm 2\pi^0)$	0.00	0.02	0.09	0.31	0.39	0.00	0.10
$a_1\ (\pi^\pm\pi^\mp\pi^\pm)$	0.02	0.00	0.00	0.00	0.00	0.74	0.16

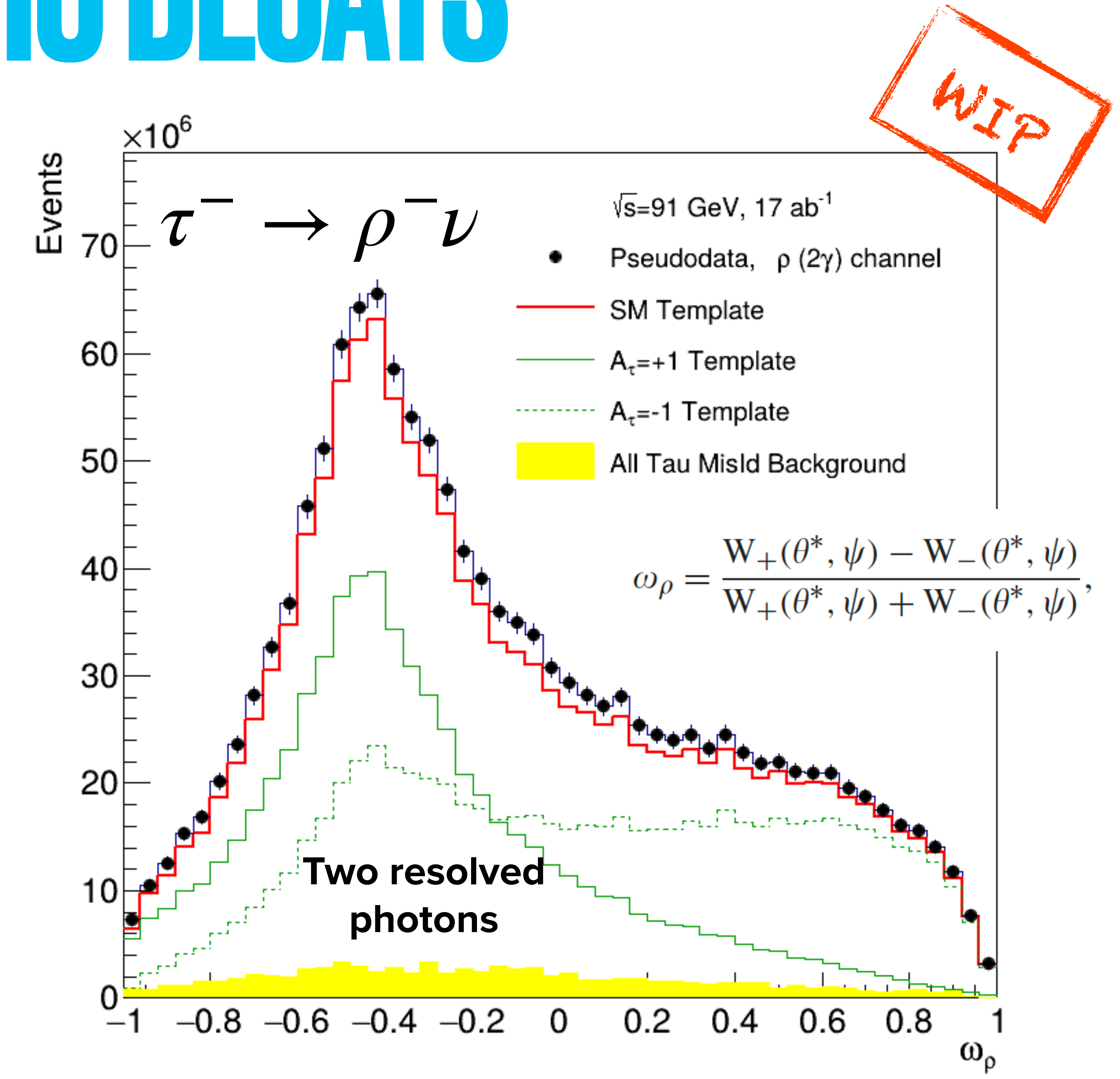
WIP

(* These are preliminary efficiencies, further tuning in progress, eg on the momentum of photons (here 0.5 GeV). The last Reco category, 'n', includes cases in which there is misidentification of pions as extra neutrons with p>1 GeV)

POLARIZATION OBSERVABLES IN PION AND RHO DECAYS

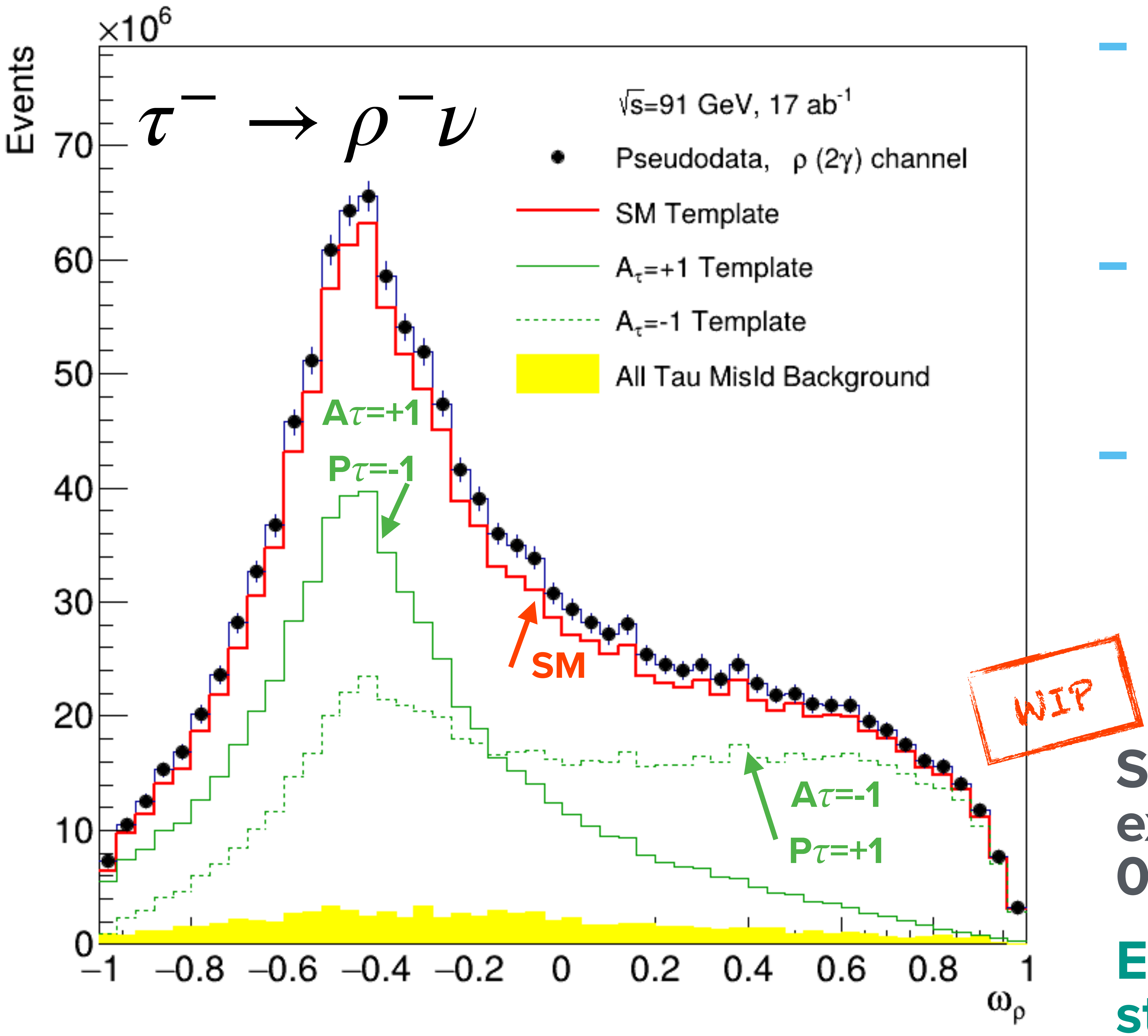






- As a first approach: $Z \to \tau_l \tau_h$ selection (only one hadronic tau for simplicity, will be expanded)
- $x = E_{meson}/E_{beam}$ as polarimeter for pion channel, LEP-like ω_ρ for rho channel (see backup slides for details)
  - In depth study of optimal variables in progress
- Backgrounds driven by photon & pion identification (ρ contamination in pion channel, $\pi^-\pi^0\pi^0$ in rho channel with two resolved leptons). Further reduction of background possible, this is a starting point.
- In the ρ channel: important to study π^0 reconstruction. Splitting categories with merged photon vs 2 resolved photons
- Further systematic uncertainties will come from PID in PandoraPF. Effort to have a ML-based reconstruction in progress.

POLARIZATION MEASUREMENT PLANS



- Polarization templates derived via reweighing from a single Pythia8 sample
  - Validation with Monte Carlo with set +1/-1 polarization (also in Pythia8)
- As a first approach: extraction of Polarization via LogLikelihood fit of the 'optimal variable'
  - Eventually, full analysis in bins of cos θ
- For now only statistical uncertainties in the fit

$$N_i = B_i + S \times \left(\frac{1 + \mathcal{P}_\tau}{2} T_i^P + \frac{1 - \mathcal{P}_\tau}{2} T_i^M \right)$$

Statistical uncertainty from fit for 17 ab^{-1} (just 1 exp, 1 year, only one decay mode): (15.000 +- 0.007)%

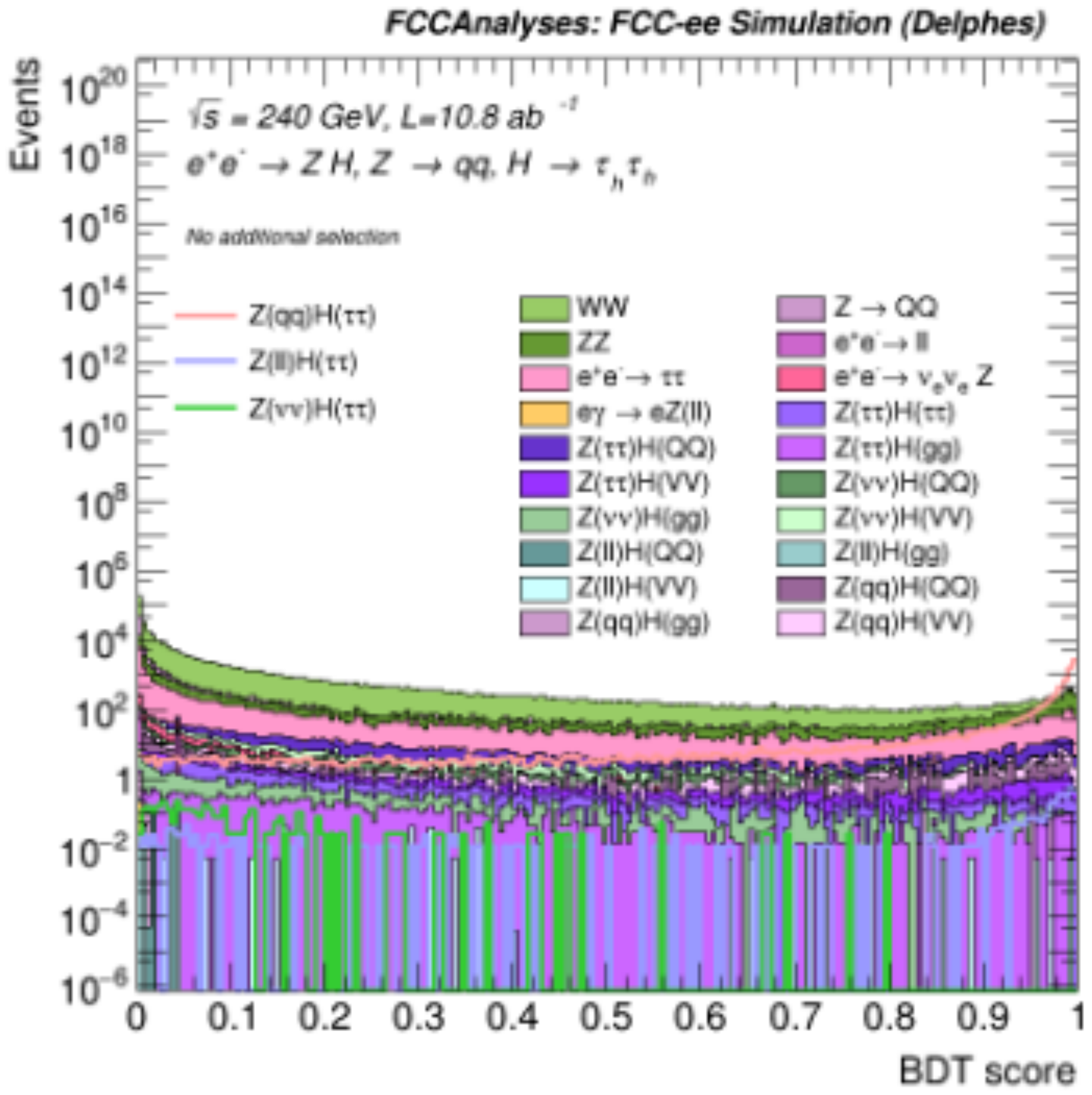
Extrapolating to full statistics, full set of final states and decay modes: <<0.01%

HIGGS & TAUS

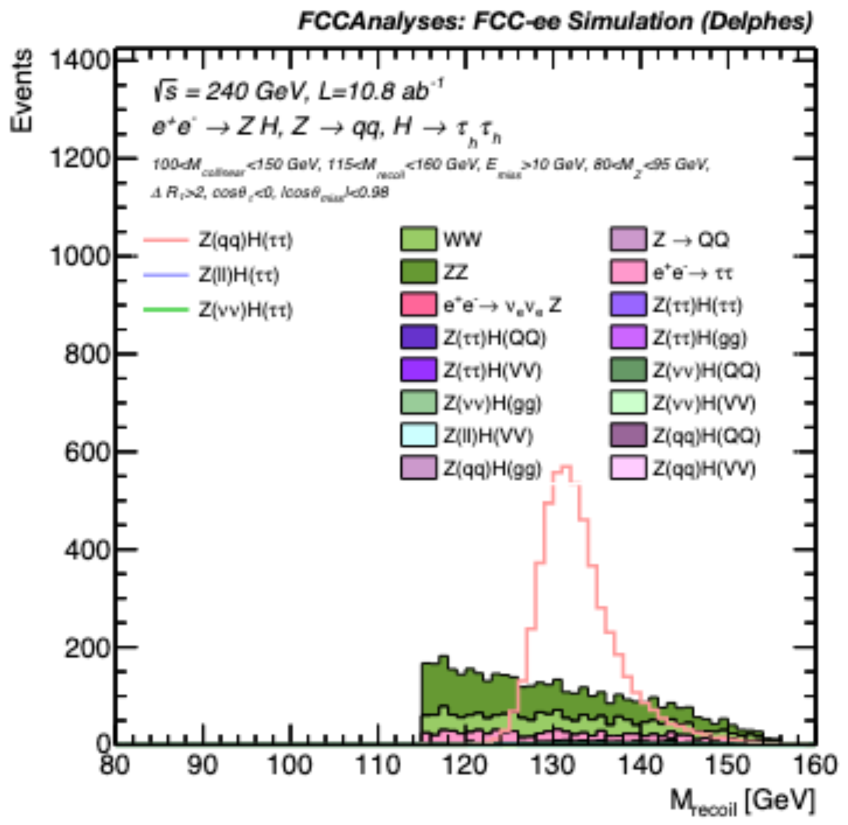
SEE POSTER BY MATTEO PRESILLA!

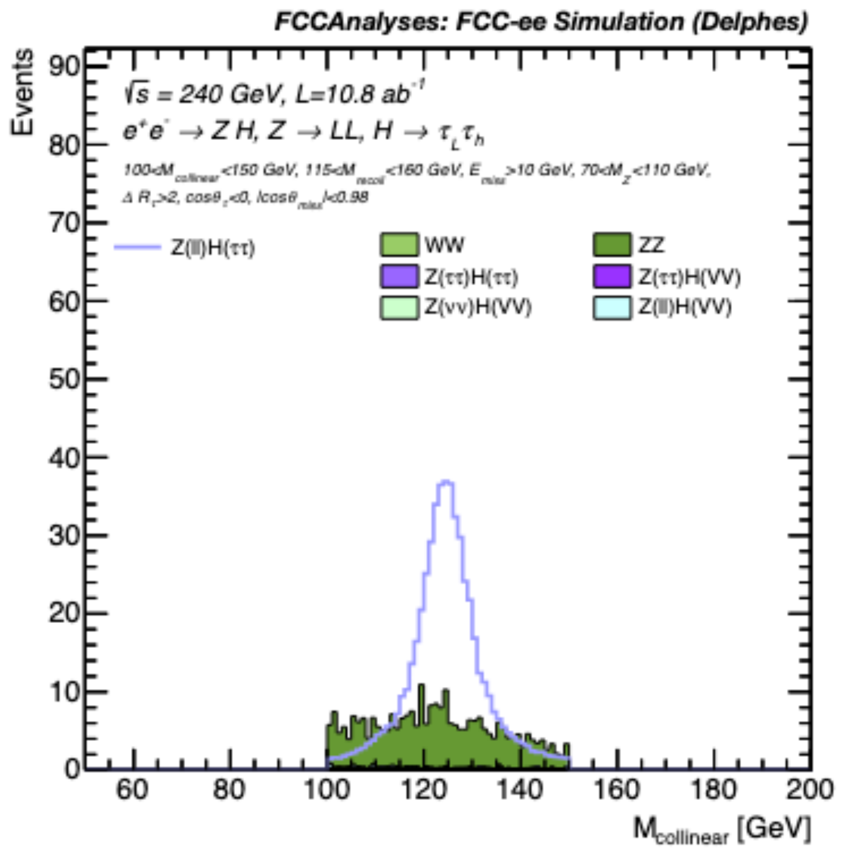
WIP

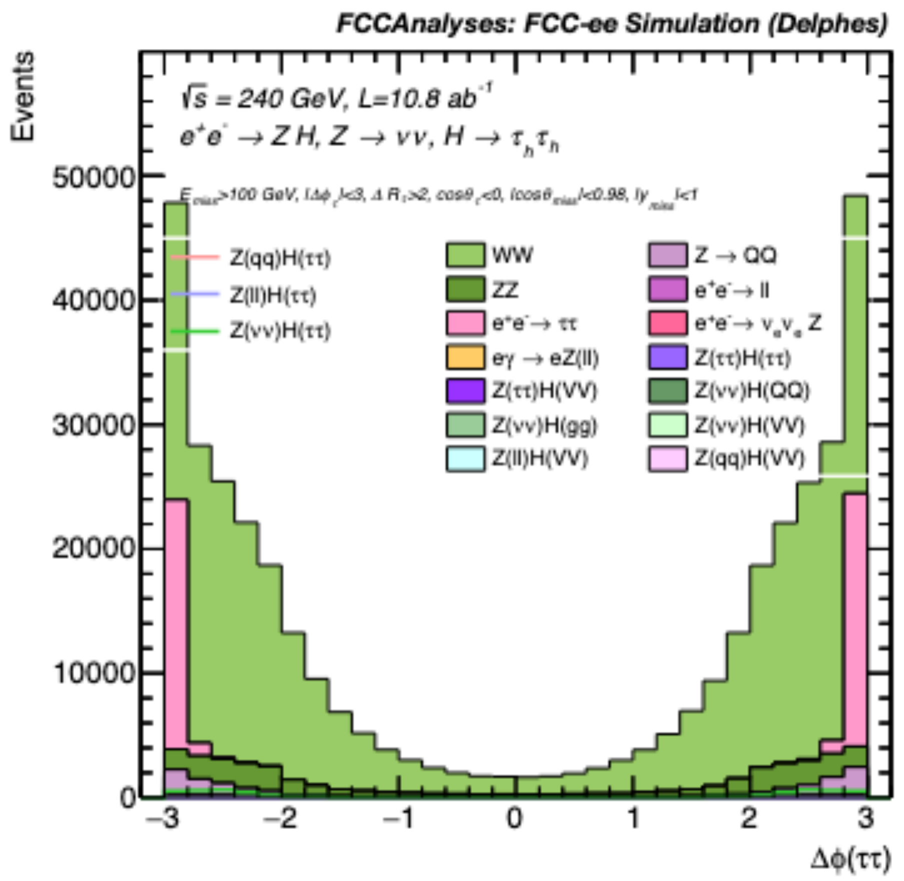
- Beyond the precision measurement tau properties: taus are a essential part of the Higgs and BSM physics program
- **New Delphes $e^+e^- \to ZH, H \to \tau\tau$ analysis at √s = 240 GeV with IDEA**
  - Cross-section
  - Yukawa coupling
  - CP interpretation
- Reconstruction & identification of tau leptons similar in concept to the full sim description, but Delphes based.
- Full final state coverage (Z decays, combinatorics of Higgs decay)
- Relative uncertainty on $\sigma_{ZH} \times \mathscr{B}(H \to \tau\tau)$ for 10.8 ab^{-1}
  - Cut-Based analysis: 1.23%
  - BDT approach: 1.07%



Signal category	Cut-based fit	BDT fit
$Z \to \ell\ell,\ H \to \tau_\ell\tau_\ell$	$^{+27.2\%}_{-21.9\%}$	-
$Z \to \ell\ell,\ H \to \tau_\ell\tau_h$	$^{+12.1\%}_{-10.7\%}$	-
$Z \to \ell\ell,\ H \to \tau_h\tau_h$	$^{+8.4\%}_{-7.6\%}$	-
$Z \to qq,\ H \to \tau_\ell\tau_\ell$	$^{+14.3\%}_{-13.8\%}$	$\pm$ 12.2 %
$Z \to qq,\ H \to \tau_\ell\tau_h$	$\pm4.8\%$	$\pm2.6\%$
$Z \to qq,\ H \to \tau_h\tau_h$	$^{+4.1\%}_{-3.9\%}$	$\pm2.3\%$
$Z \to \nu\nu,\ H \to \tau_\ell\tau_\ell$	$^{+320.1\%}_{-300.0\%}$	$^{+102.3\%}_{-102.5\%}$
$Z \to \nu\nu,\ H \to \tau_\ell\tau_h$	$^{+80.6\%}_{-80.3\%}$	$\pm15.9\%$
$Z \to \nu\nu,\ H \to \tau_h\tau_h$	$^{+26.3\%}_{-26.1\%}$	$\pm7.0\%$







SUMMARY

- **The FCC-ee will (also) be a tau factory**
- Very rich program! Exploit the **huge sample (10^{11}) of $e^+e^- \to Z \to \tau^+\tau^-$ decays** to measure the properties of the tau lepton, and derive **stringent tests of the SM**
  - Precise measurements of lifetime, mass and leptonic decays
  - Search for rare and LFV decays
  - Study of Tau Polarization
- Beyond tau properties, taus are a important part of the **Higgs and BSM searches** program: precise measurement of tau coupling, CP studies, dedicated searches
- Tau measurements pose **demanding detector requirements** on momentum resolution, on the knowledge of the vertex detector dimensions, on e/μ/π separation over the whole momentum range, and require fine granularity and high efficiency in the tracker and electromagnetic calorimeter
- Implementations of **tau reconstruction using full simulation** (traditional and ML-based) coming together for detailed systematic studies for detector optimization

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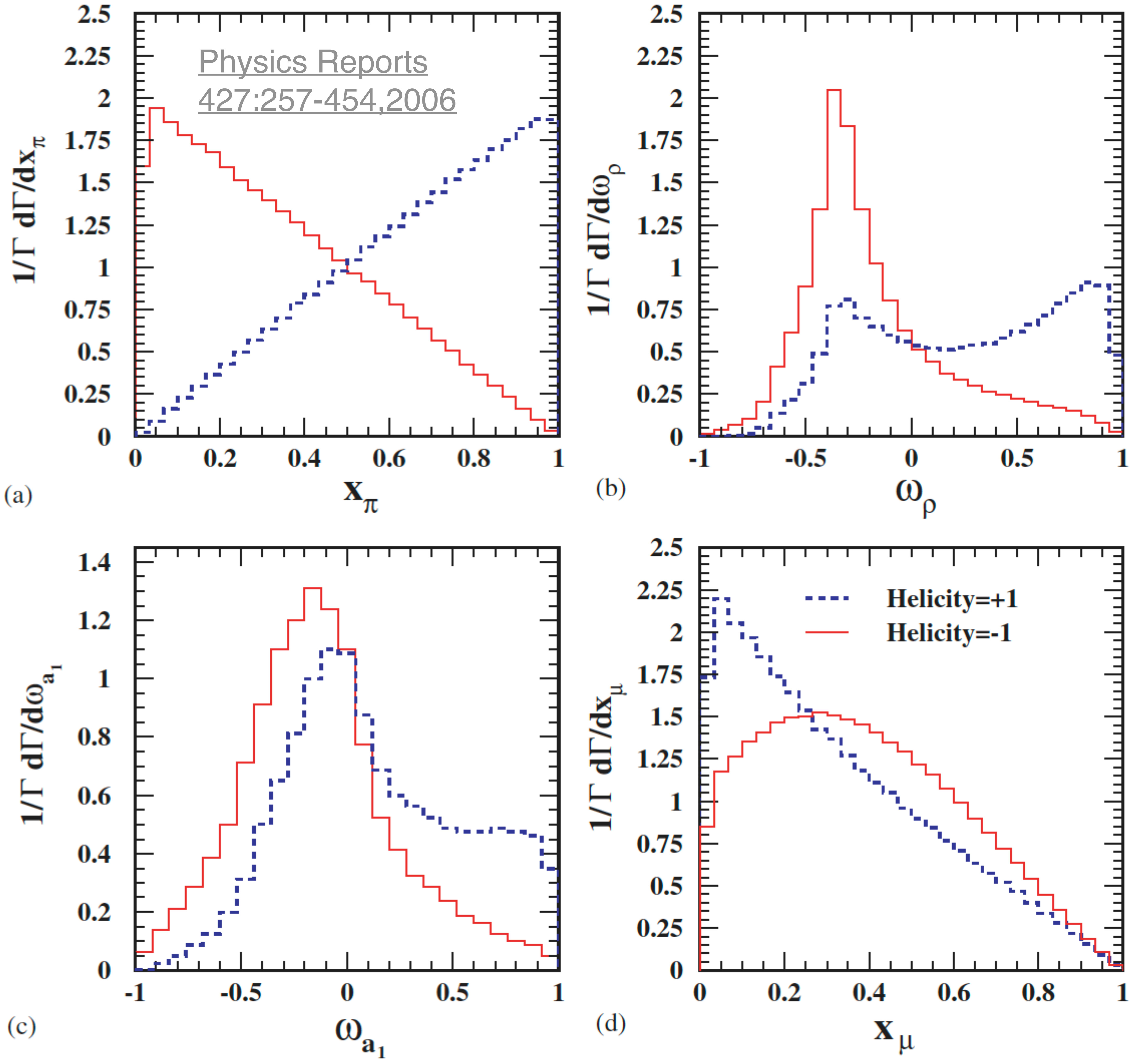
TAU POLARIZATION AT LEP: EXAMPLE VARIABLES



- Pion channel: Energy Meson / Energy Beam

$$x_\pi = \frac{E_\pi}{E_{beam}}, \qquad \frac{1}{\Gamma}\frac{d\Gamma}{dx_\pi} = 1 + \mathscr{P}_\tau(2x_\pi - 1)$$

- Rho channel: ω_ρ

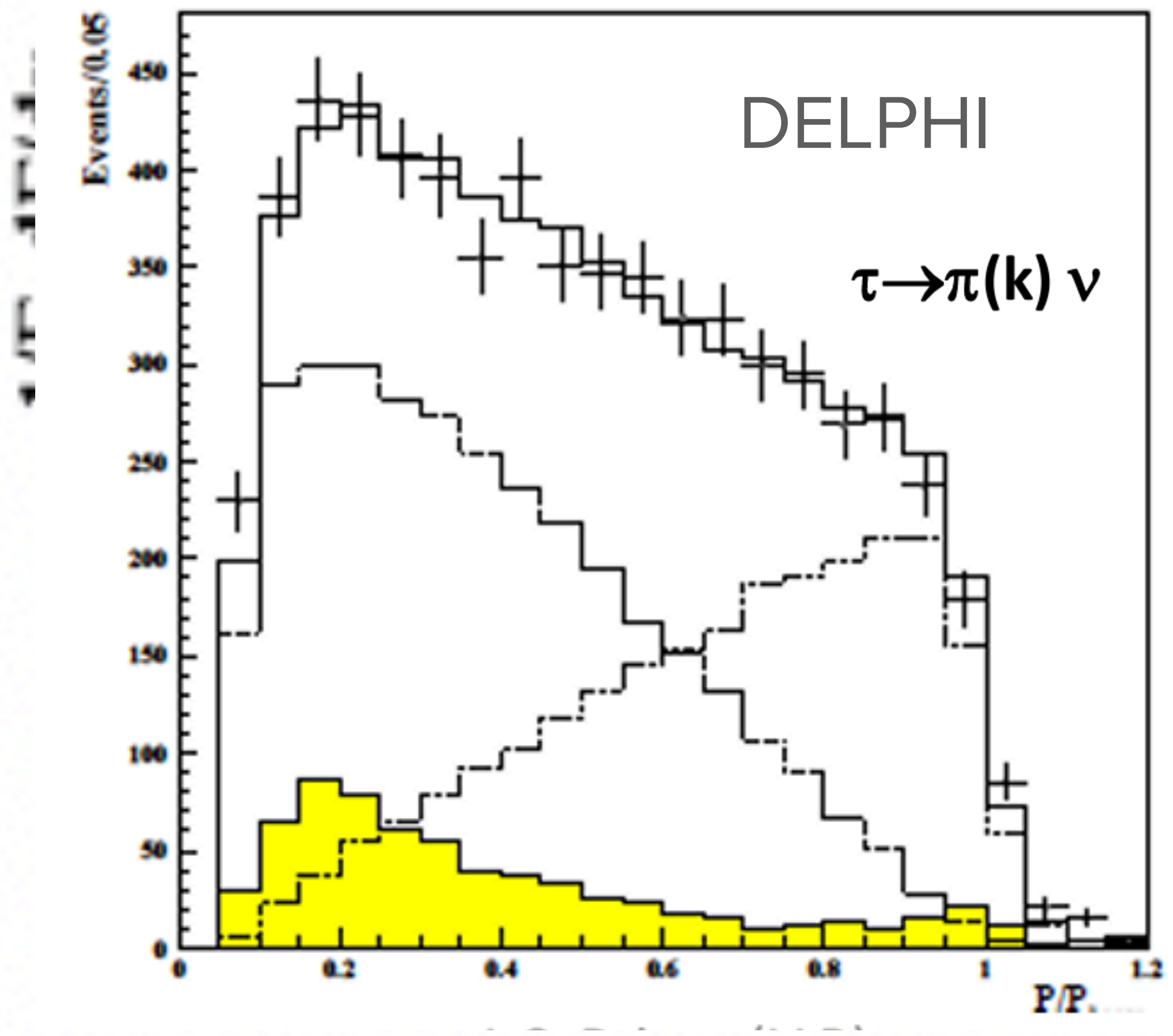
$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma^{\lambda_\rho=0}}{\mathrm{d}\cos\theta^*} = \frac{m_\tau^2/2}{m_\tau^2 + 2m_\rho^2}(1 + \mathscr{P}_\tau \cos\theta^*),$$

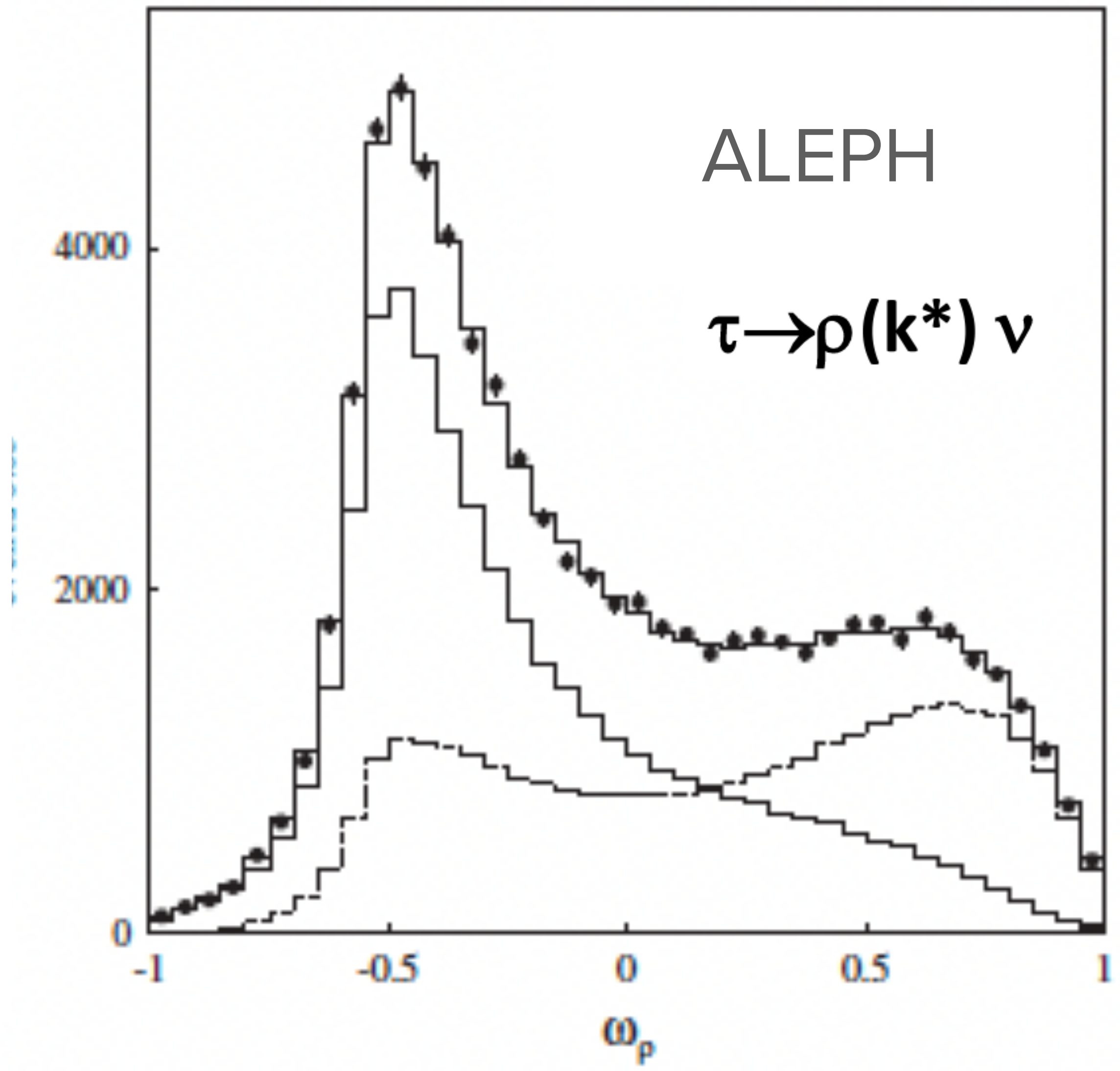
$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma^{\lambda_\rho=\pm1}}{\mathrm{d}\cos\theta^*} = \frac{m_\rho^2}{m_\tau^2 + 2m_\rho^2}(1 - \mathscr{P}_\tau \cos\theta^*),$$

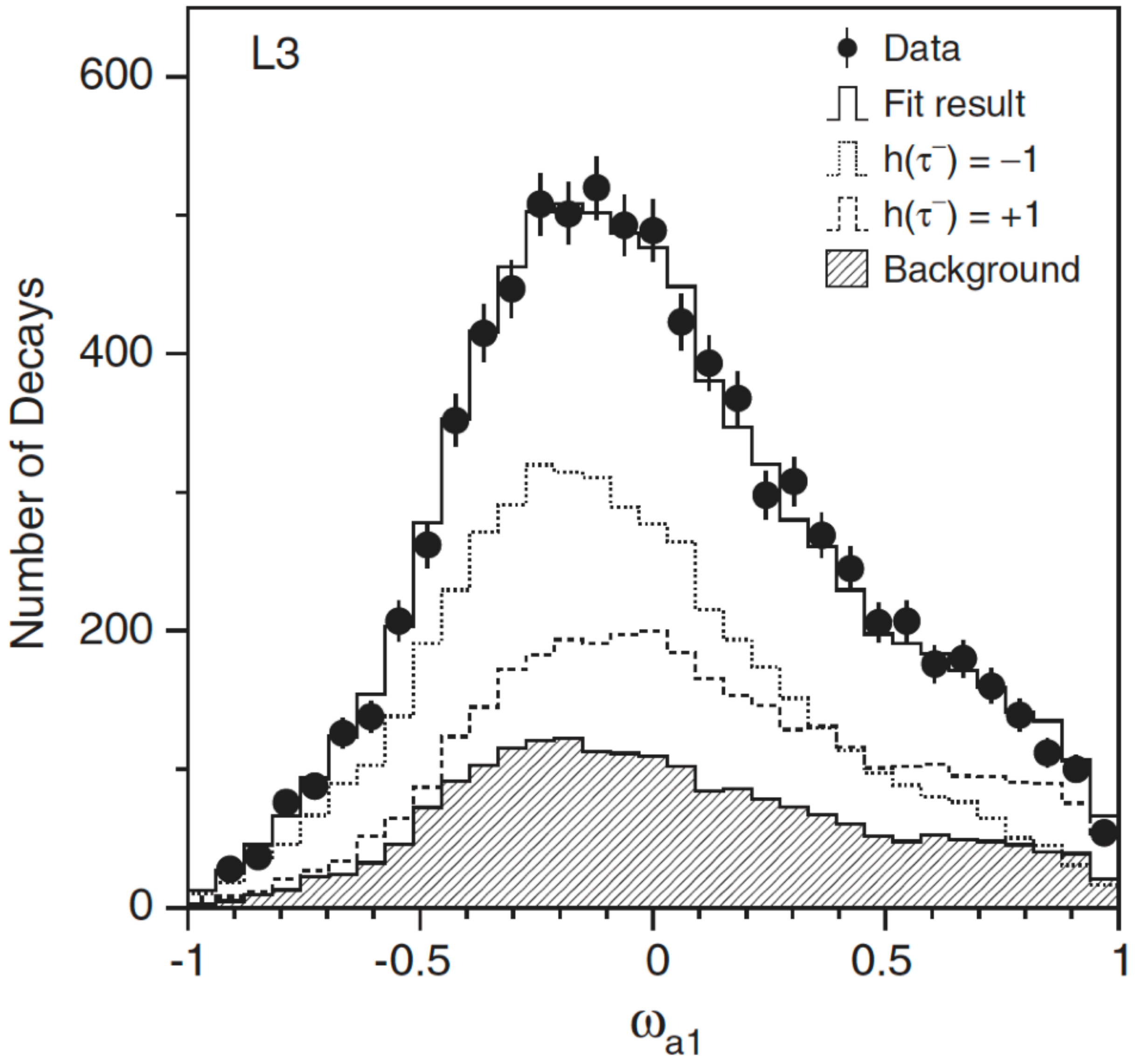
$$\omega_\rho = \frac{\mathrm{W}_+(\theta^*, \psi) - \mathrm{W}_-(\theta^*, \psi)}{\mathrm{W}_+(\theta^*, \psi) + \mathrm{W}_-(\theta^*, \psi)},$$

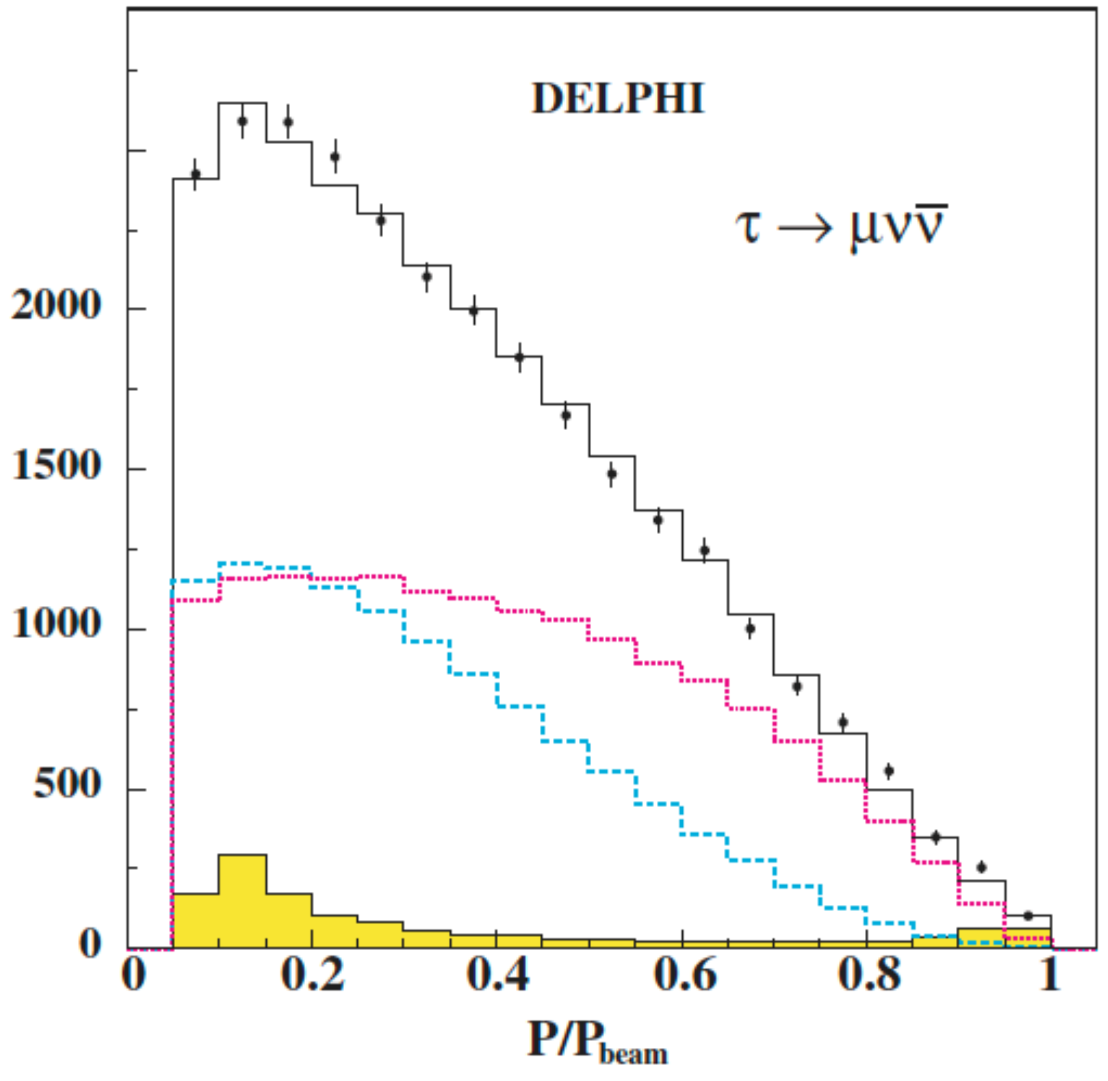
- For a_1 : ω for three pion decay
- For leptons: x_l

TAU POLARIZATION AT LEP: EXAMPLE VARIABLES









- Pion channel: Energy Meson / Energy Beam

$$x_\pi = \frac{E_\pi}{E_{beam}}, \qquad \frac{1}{\Gamma}\frac{d\Gamma}{dx_\pi} = 1 + \mathscr{P}_\tau(2x_\pi - 1)$$

- Rho channel: θ, ψ, ω_ρ

$$\frac{1}{\Gamma}\frac{d\Gamma^{\lambda_\rho=0}}{d\cos\theta^*} = \frac{m_\tau^2/2}{m_\tau^2 + 2m_\rho^2}(1 + \mathscr{P}_\tau \cos\theta^*),$$

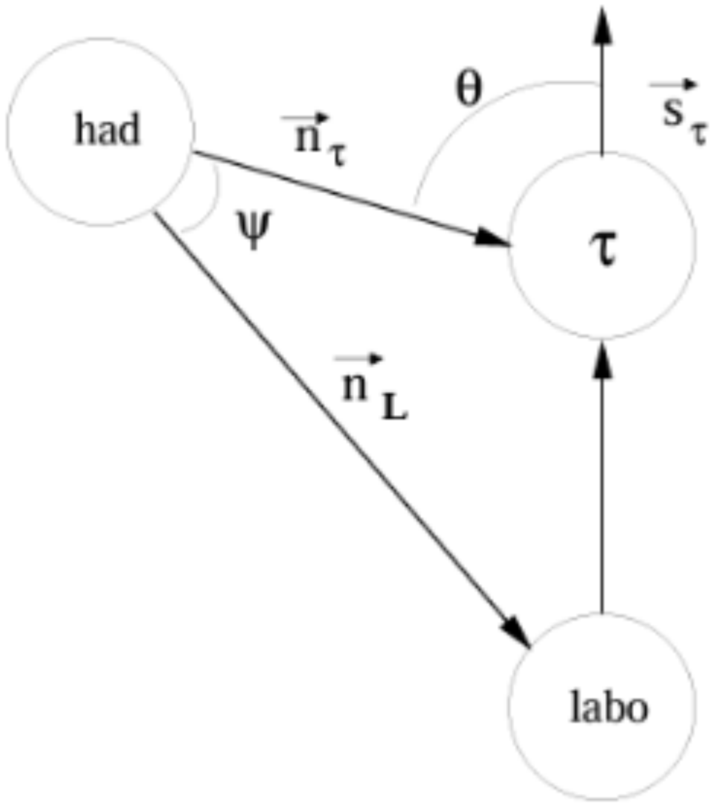
$$\frac{1}{\Gamma}\frac{d\Gamma^{\lambda_\rho=\pm1}}{d\cos\theta^*} = \frac{m_\rho^2}{m_\tau^2 + 2m_\rho^2}(1 - \mathscr{P}_\tau \cos\theta^*),$$

$$\omega_\rho = \frac{W_+(\theta^*, \psi) - W_-(\theta^*, \psi)}{W_+(\theta^*, \psi) + W_-(\theta^*, \psi)},$$

- For a_1: ω for three body decay
- For leptons: x_l

Implementation of ω_ρ

- Following the description of the variables in two LEP thesis: L. Duflot ('93) and I. Nikolic ('96)
- This version of the variables does not require to reconstruct the tau direction, which is left to future improvements of the analysis

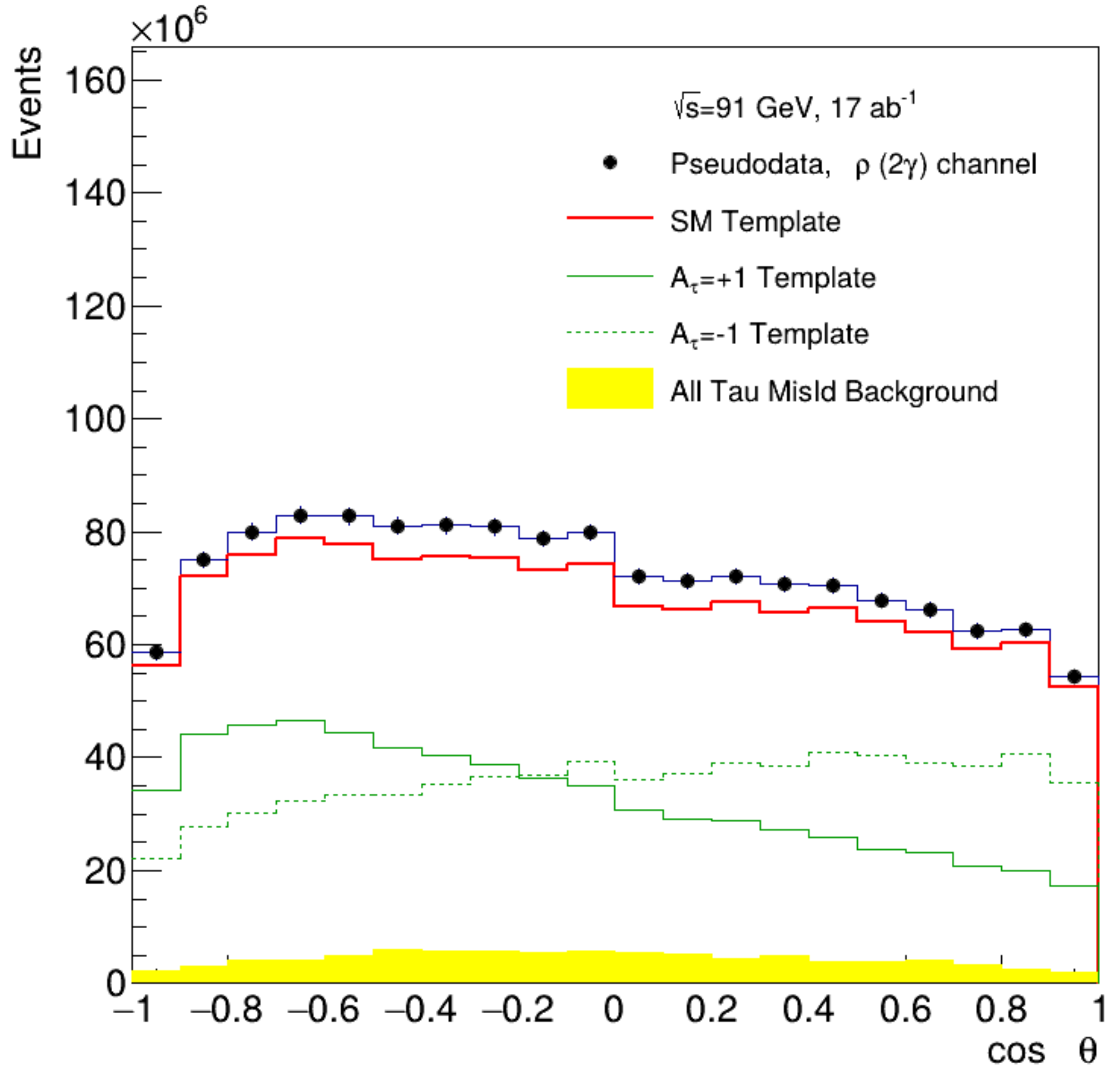


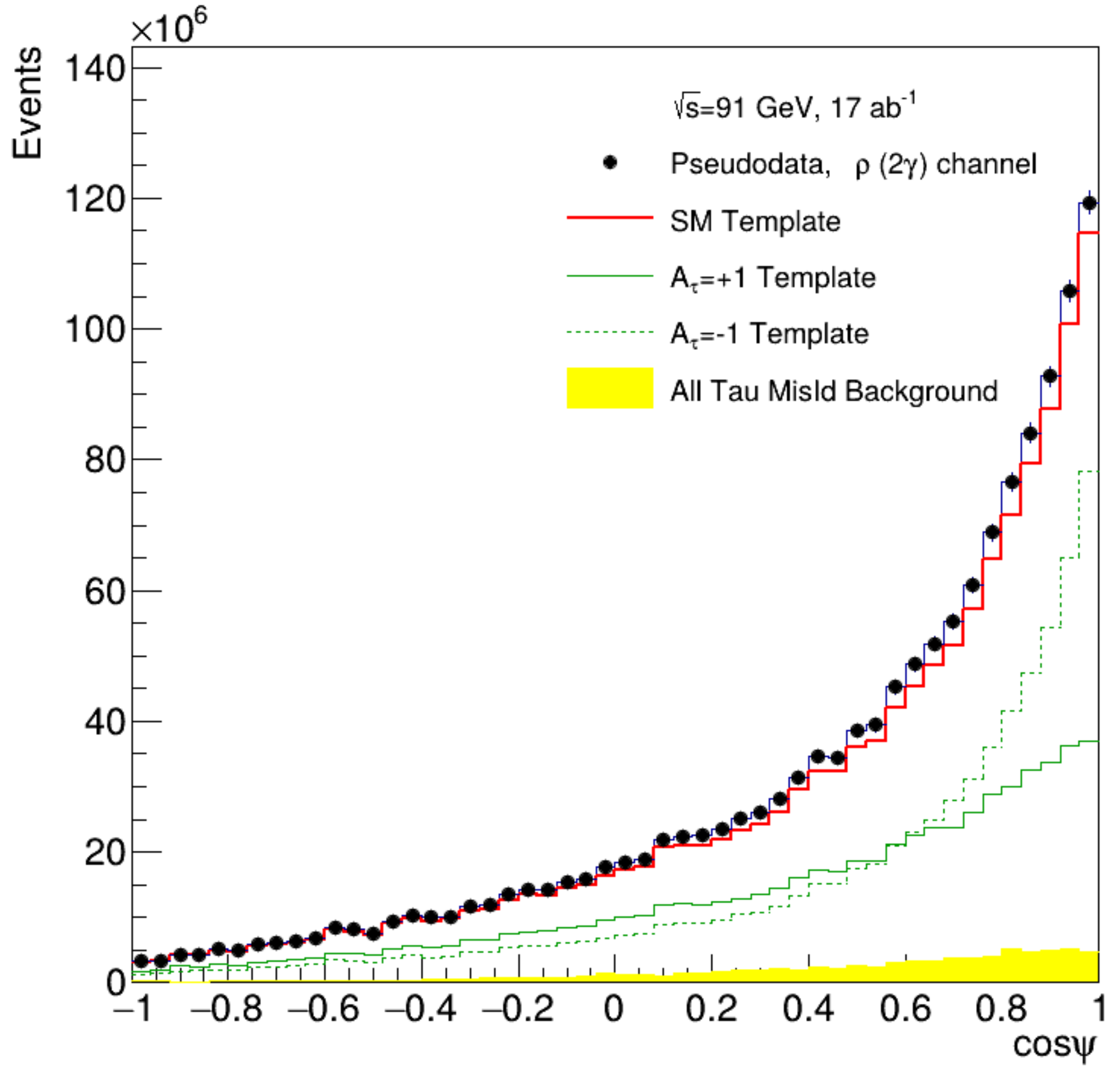
$$\cos\theta = \frac{2xm_\tau^2 - m_\tau^2 - m_h^2}{(m_\tau^2 - m_h^2)(\sqrt{1 - 4m_\tau^2/s})}$$

$$\text{où} \quad x = 2\frac{E_h}{\sqrt{s}} \quad \text{et} \quad s = 4E_b^2$$

$$\cos\psi = \frac{x(m_\tau^2 + Q^2) - 2Q^2}{(m_\tau^2 - Q^2)\sqrt{x^2 - 4Q^2/s}}$$

$$\omega_\rho = \frac{\left(-2 + \frac{m_\tau^2}{Q^2} + 2\left(1 + \frac{m_\tau^2}{Q^2}\right)\frac{3\cos\psi - 1}{2}\frac{3\cos^2\beta - 1}{2}\right)\cos\theta + 3\sqrt{\frac{m_\tau^2}{Q^2}}\frac{3\cos^2\beta - 1}{2}\sin 2\psi\sin\theta}{2 + \frac{m_\tau^2}{Q^2} - 2\left(1 - \frac{m_\tau^2}{Q^2}\right)\frac{3\cos\psi - 1}{2}\frac{3\cos^2\beta - 1}{2}}$$

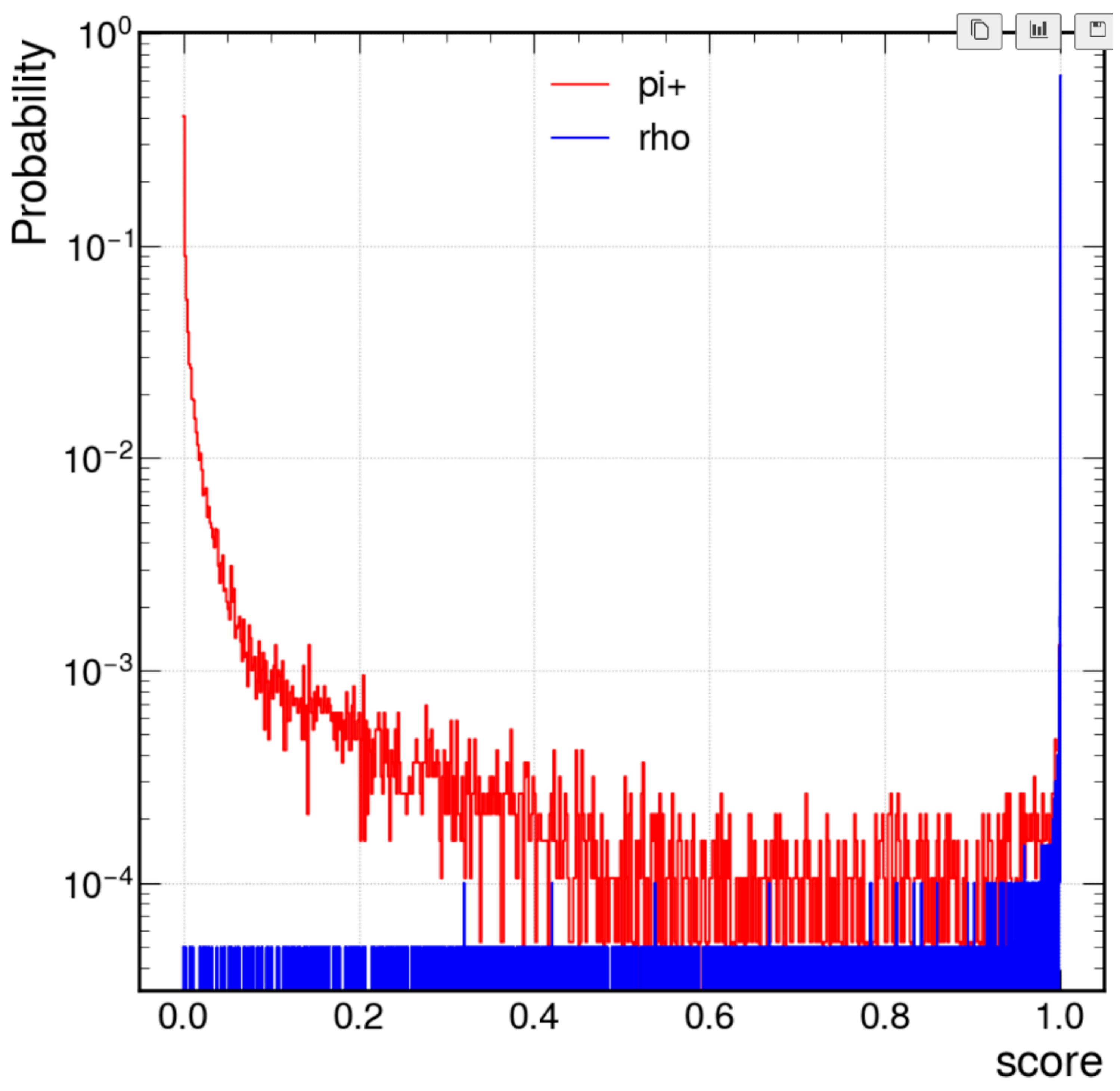


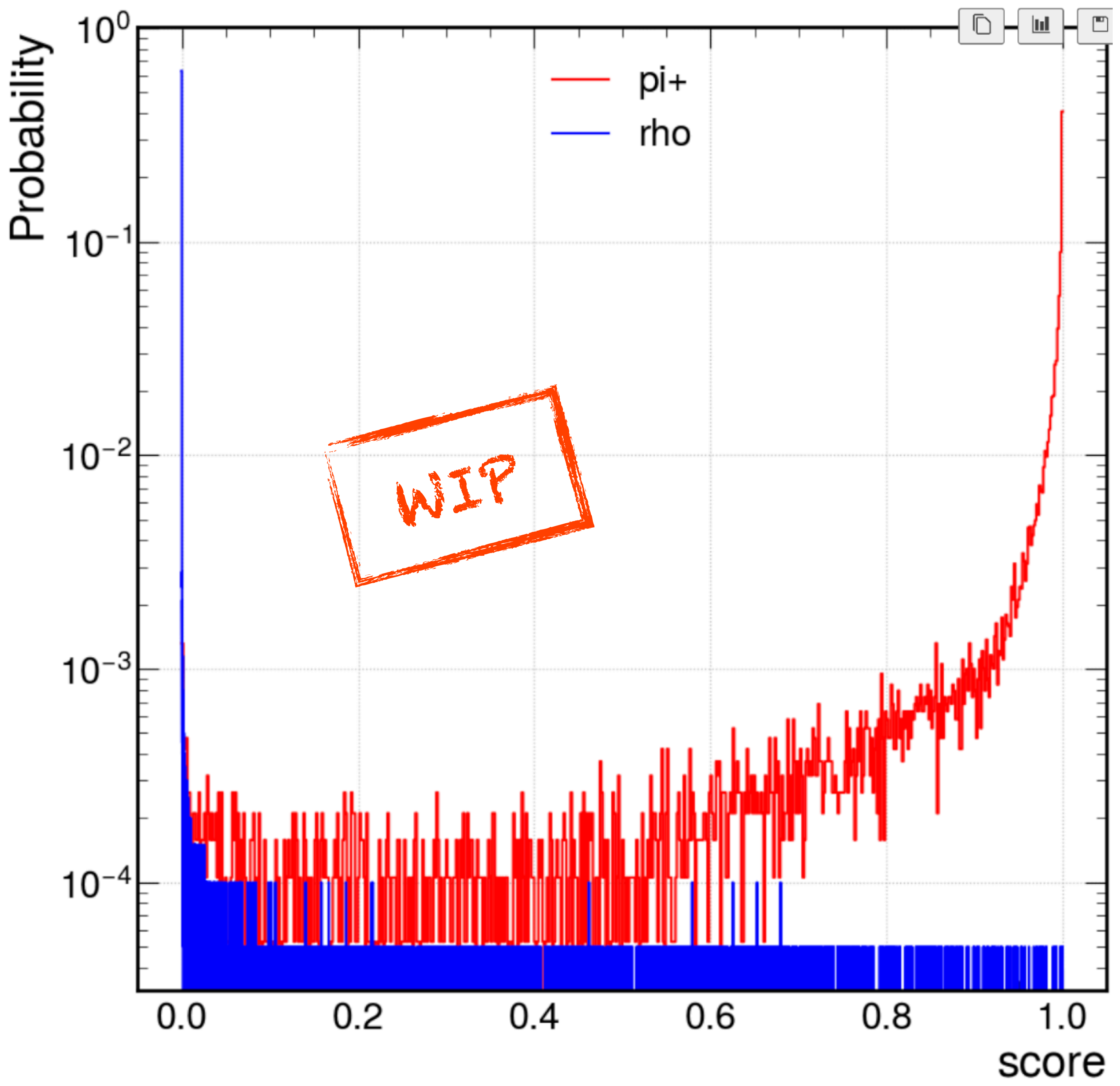


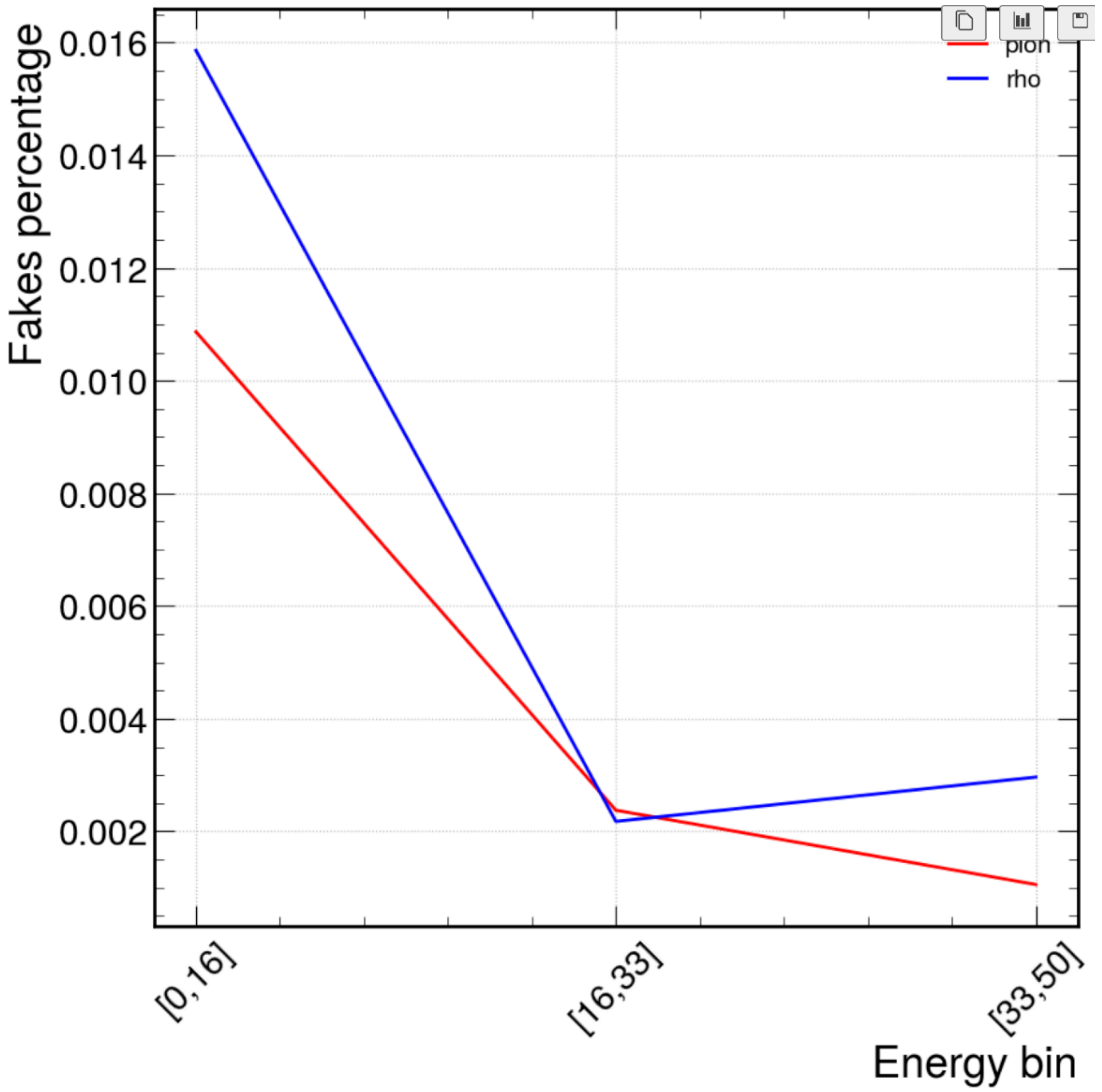
ML TAU RECONSTRUCTION

- Model trained on pi, rho, e, mu generated with pythia exclusive decays (same number of taus per class)
- Inputs:
  - All ECAL and HCAL hits and the track state at calorimeter (4)
  - Hits inputs are (x,y,z) coordinates in the detector, energy
  - Track inputs (x,y,z), p

D. Garcia







EFFICIENCIES IN PANDORAPFA

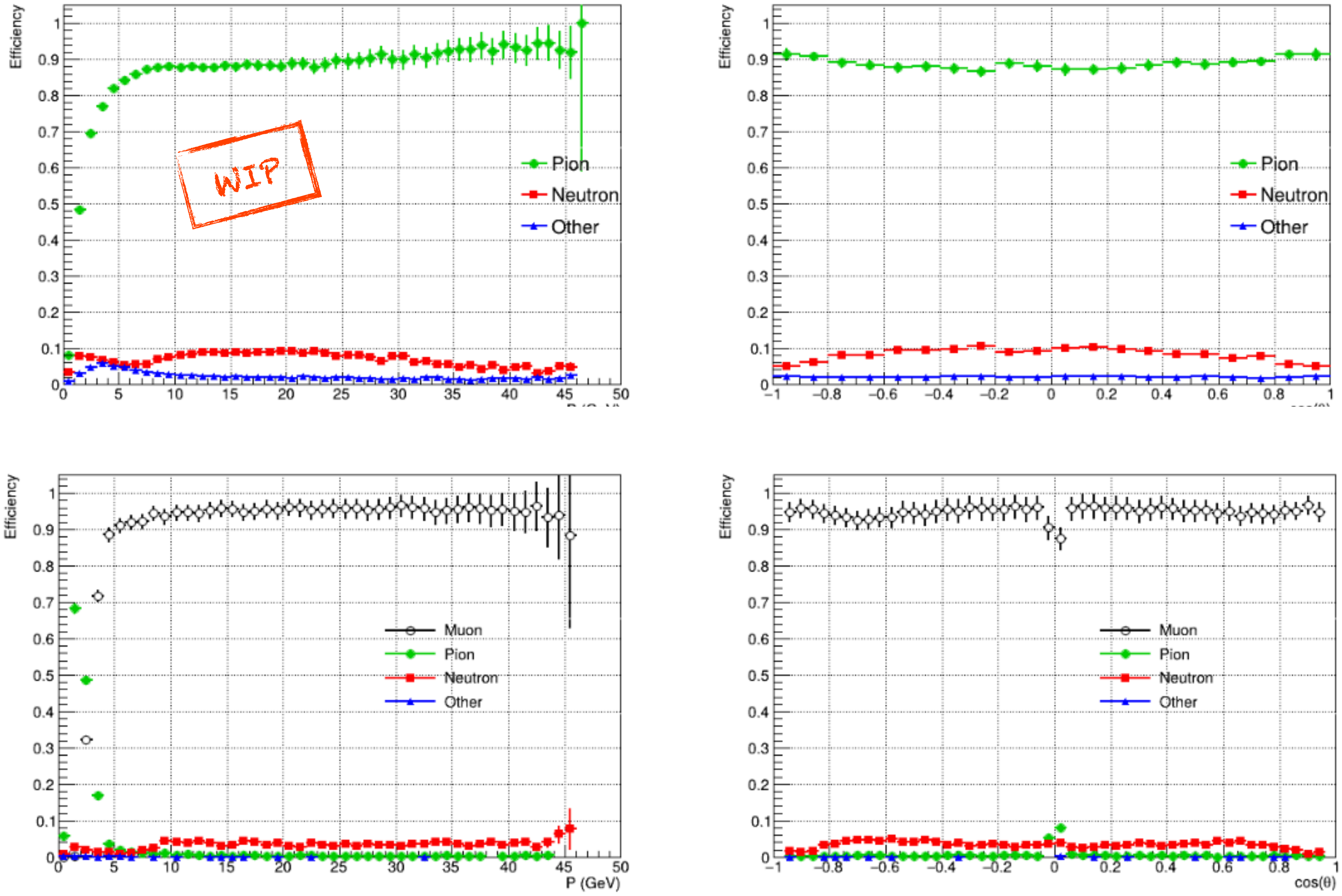
Pion efficiency

Notice pions being misidentified as neutrons

Plans to implement a fix with a second ID layer on top

Muon efficiency

Reconstruction for muons changed to include MinTrackCandidateEnergy=4 (needed to improve efficiency in the 4-7 GeV range)



FCC-EE PERFORMANCE & TAUS

assumed baseline FCC-ee detector performance	
track momentum	$\frac{\sigma_p}{p} = 0.02\cdot 10^{-3} \cdot p_T(\mathrm{GeV}) \oplus 1\cdot 10^{-3}$
track impact parameter	$\sigma_{d_0} = \frac{15\,\mu\mathrm{m}}{\sin^{3/2}\theta} \oplus 5\,\mu\mathrm{m}$
electromagnetic energy	$\frac{\sigma_{E_\gamma}}{E_\gamma} = \frac{15\%}{E_\gamma} \oplus 1\%$
electromagnetic energy xy position	$\sigma_{\gamma,xy} = \frac{6\,\mathrm{mm}}{E(\mathrm{GeV})} \oplus 2\,\mathrm{mm}$

A. Lusiani: Tau Physics Prospects at FCC-ee

Tau pairs at past, present and future e^+e^- colliders

	CLEO, CLEOIII	LEP 100	Belle, BABAR	Belle II	SCT	STCF	CEPC(Z)	FCC-ee(Z)
E_{CM} [GeV]	$\sim$10.6	92	$\sim$10.6	$\sim$10.6	$2-6$	$2-7$	92	
$\int \mathcal{L}dt$ [ab^{-1}]	0.01		1.5	50	10			240
tau pairs	$1\cdot10^7$	$0.8\cdot10^6$	$1.4\cdot10^9$	$46\cdot10^9$	$30\cdot10^9$		$30\cdot10^9$	$270\cdot10^9$

note: SCT & SCFT tau pairs estimate assuming 10 years of tau-pairs-optimized CM energies running

Conditions for tau physics measurements

- Z peak collisions best for most measurements
  - pure and efficient tau pair selection selecting on just one of the two taus
  - track multiplicity separates very well $\tau^+\tau^-$ from $q\bar{q}$
  - high momenta reduce multiple scattering uncertainty in impact parameter measurements
- threshold measurements at $E = 2m_\tau \sim 3.5\,\mathrm{GeV}$ best for tau mass
  - threshold measurements help some LFV searches and tau BRs (super charm-tau factories)
- B-factories bested LEP with statistics on e.g. small branching fractionss, LFV searches, tau lifetime

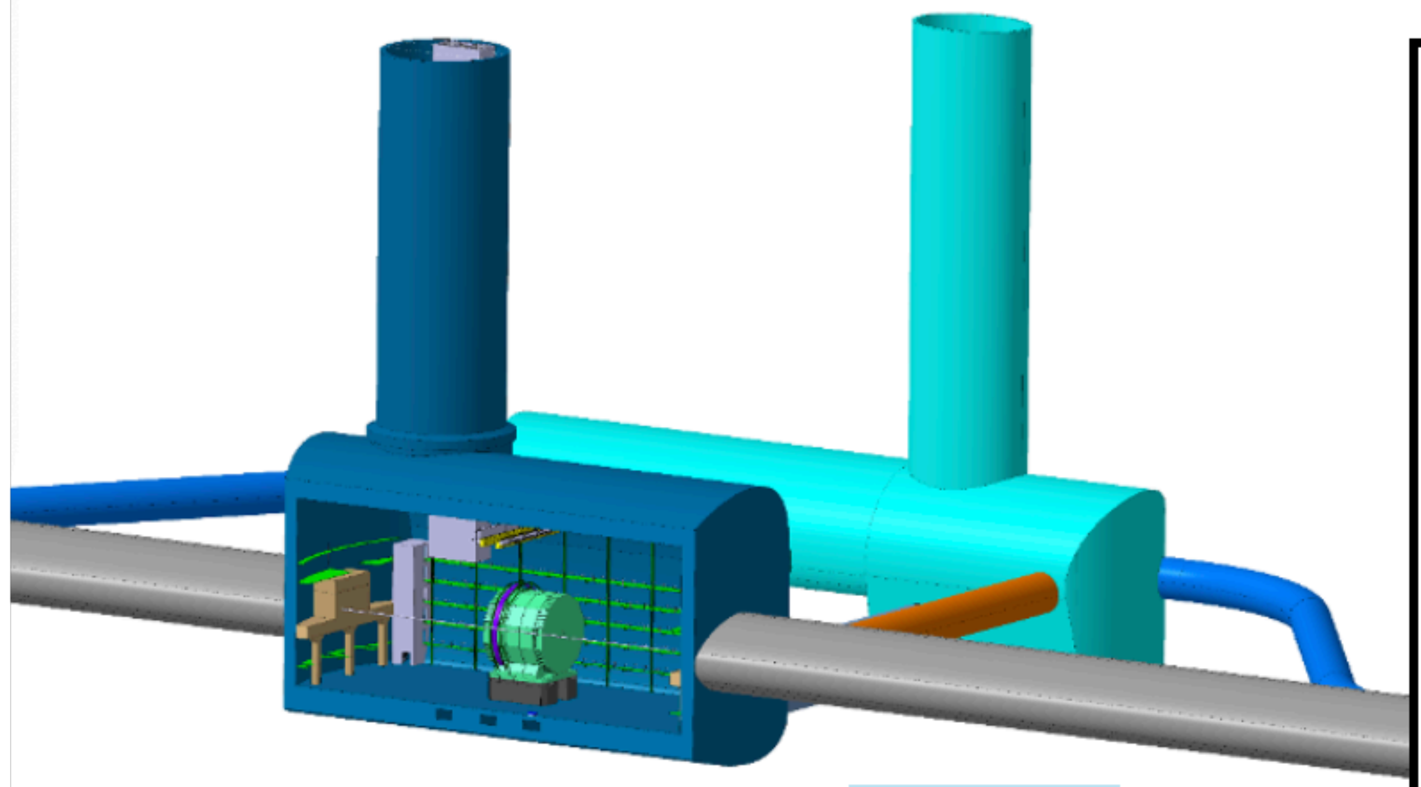
A. Lusiani's talk

FCC-EE: HUGE STATISTICS & PRECISION

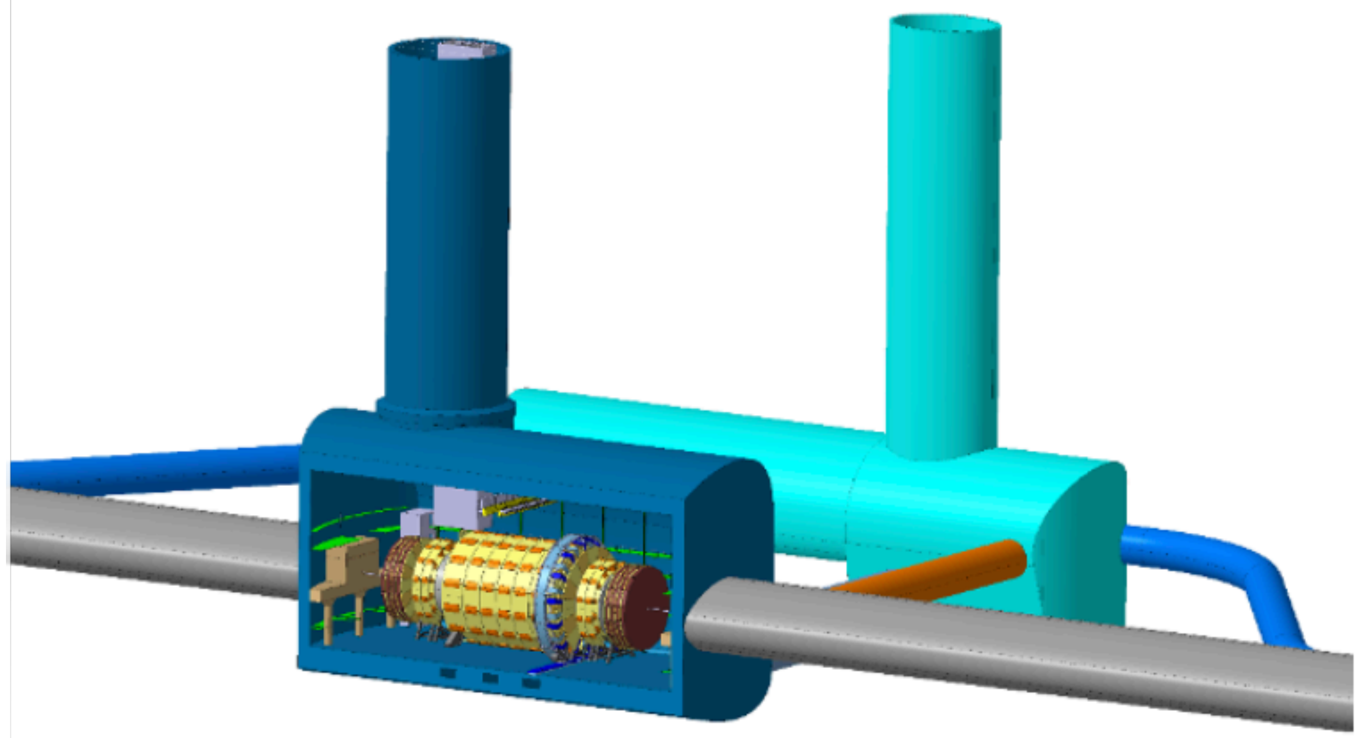
Working point	Z, years 1-2	Z, later	WW, years 1-2	WW, later	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163		240	340–350	365
Lumi/IP ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	70	140	10	20	5.0	0.75	1.20
Lumi/year (ab^{-1})	34	68	4.8	9.6	2.4	0.36	0.58
Run time (year)	2	2	2	–	3	1	4
Number of events	6×10^{12} Z		2.4×10^{8} WW		1.45×10^{6} ZH + 45k WW $\rightarrow$ H	1.9×10^{6} $t\bar{t}$ +330k ZH +80k WW $\rightarrow$ H	

Detector concepts

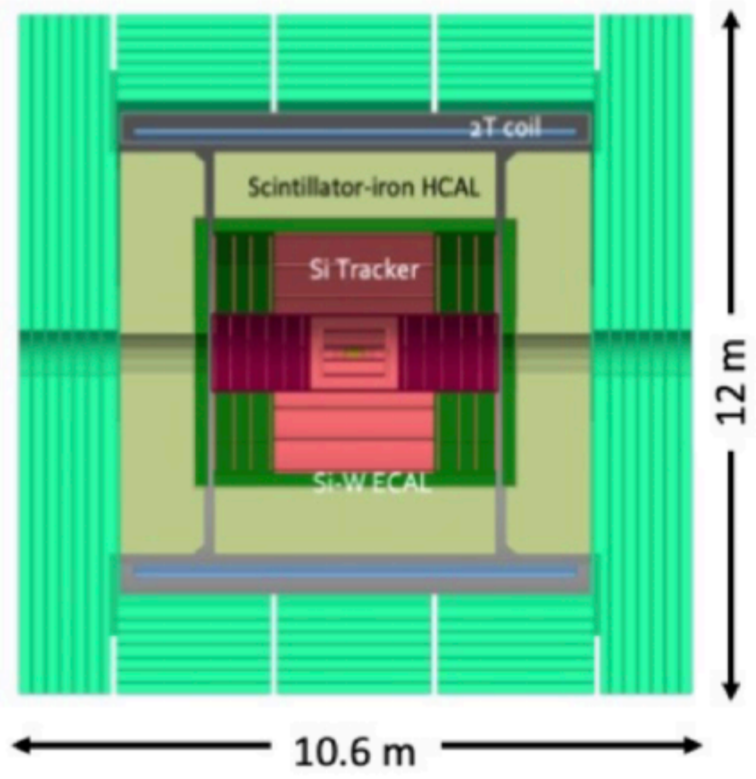
FUTURE CIRCULAR COLLIDER

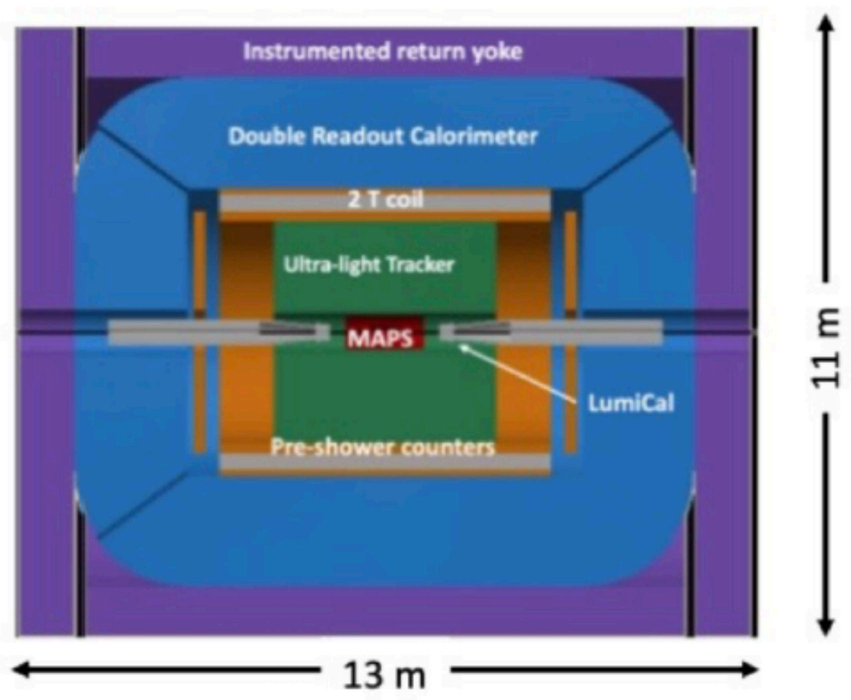


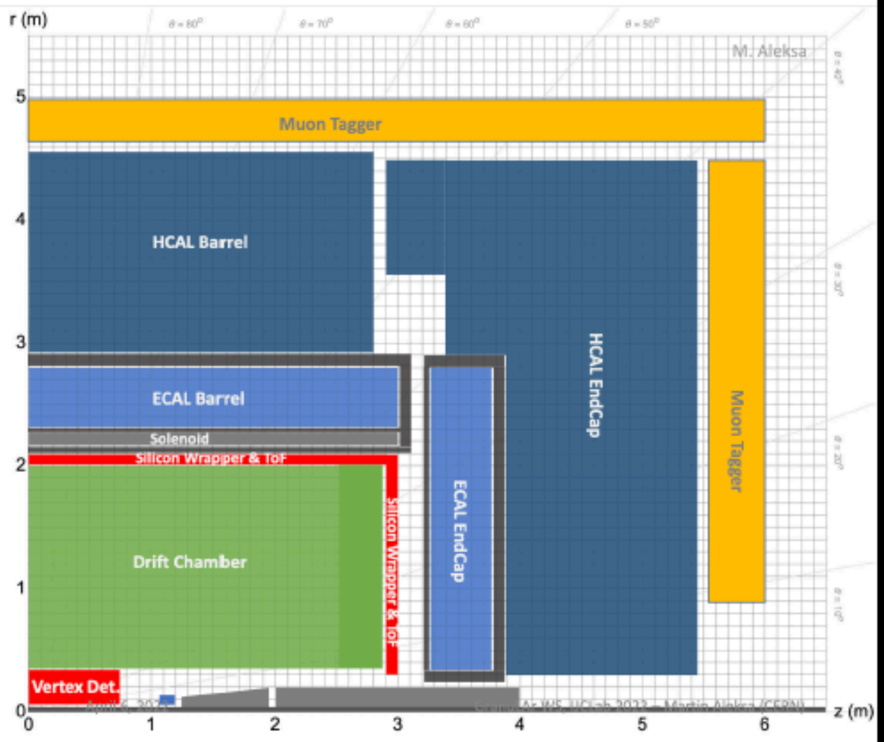
FCC-ee



FCC-hh







CLD	IDEA	ALLEGRO
Based on CLIC detector design, arXiv:1911.12230	Innovative, possibly cheaper than CLD https://pos.sissa.it/390/819 Baseline in many ongoing studies	GranuLAr WS, IJCLab 2022 – Martin Aleksa
Full silicon vertex detector and tracker 3D-imaging highly-granular calorimeter system Coil outside calorimeter system	Silicon vertex detector Short-drift, ultra-light wire chamber Dual-readout calorimeter Thin and light solenoid coil inside calorimeter system	Highly granular noble-liquid calorimeter Thin 2T solenoid in the calorimeter cryostat.

More complementary options possible (4 IP!) → Can we optimize detector designs for the complete physics program? Yes! opportunities to contribute

slide by R. Gonzalez Suarez at ZPW 24

HIGGS&FLAVOUR

- Are there surprises in the flavour sector?