The prospect of the measurement of $H \to \gamma\gamma$ and $H \to \tau\tau$ at CEPC

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For di-photon and di-tau analysis group

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ECOLE POLYTECHNIQUE

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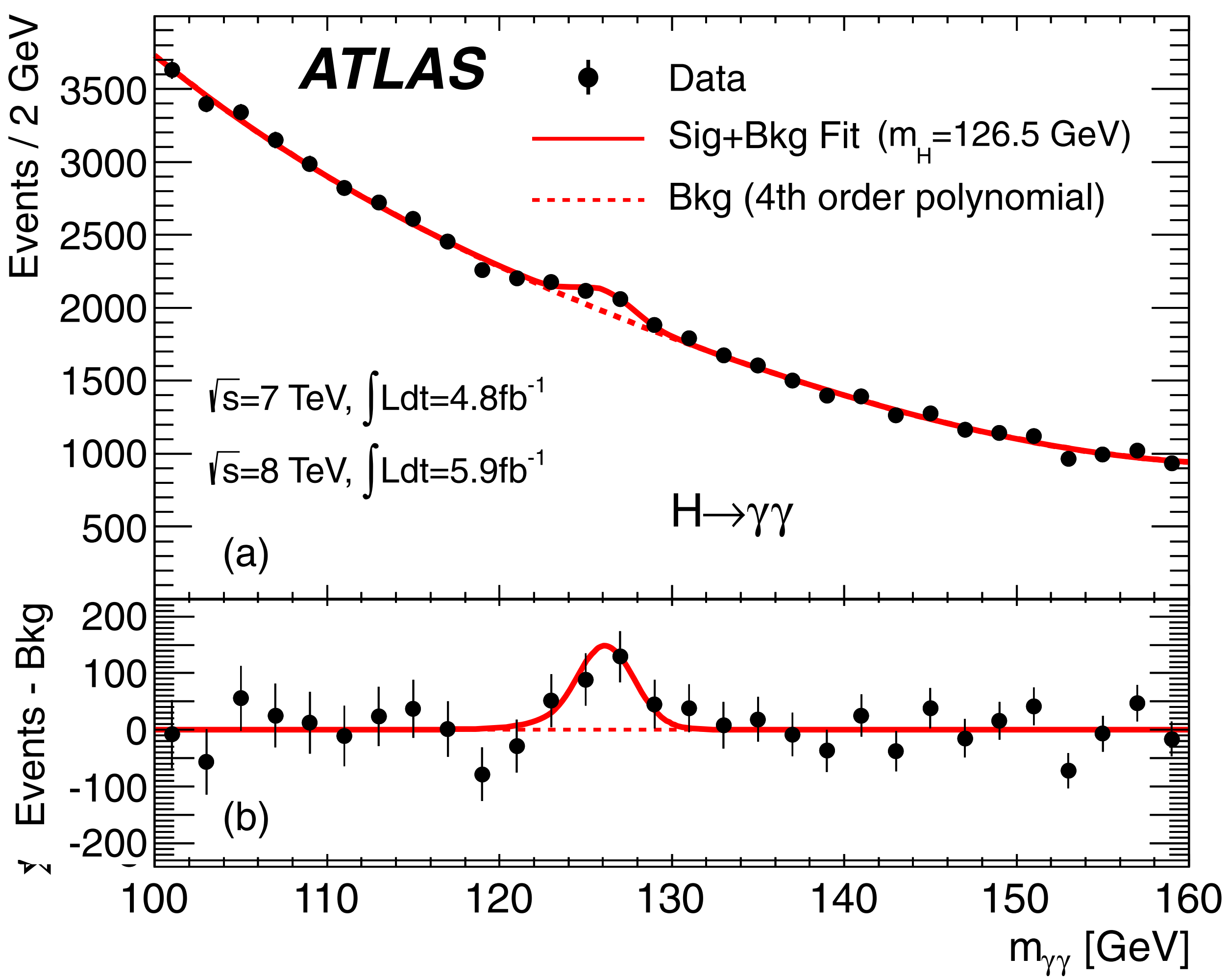
OUTLINE

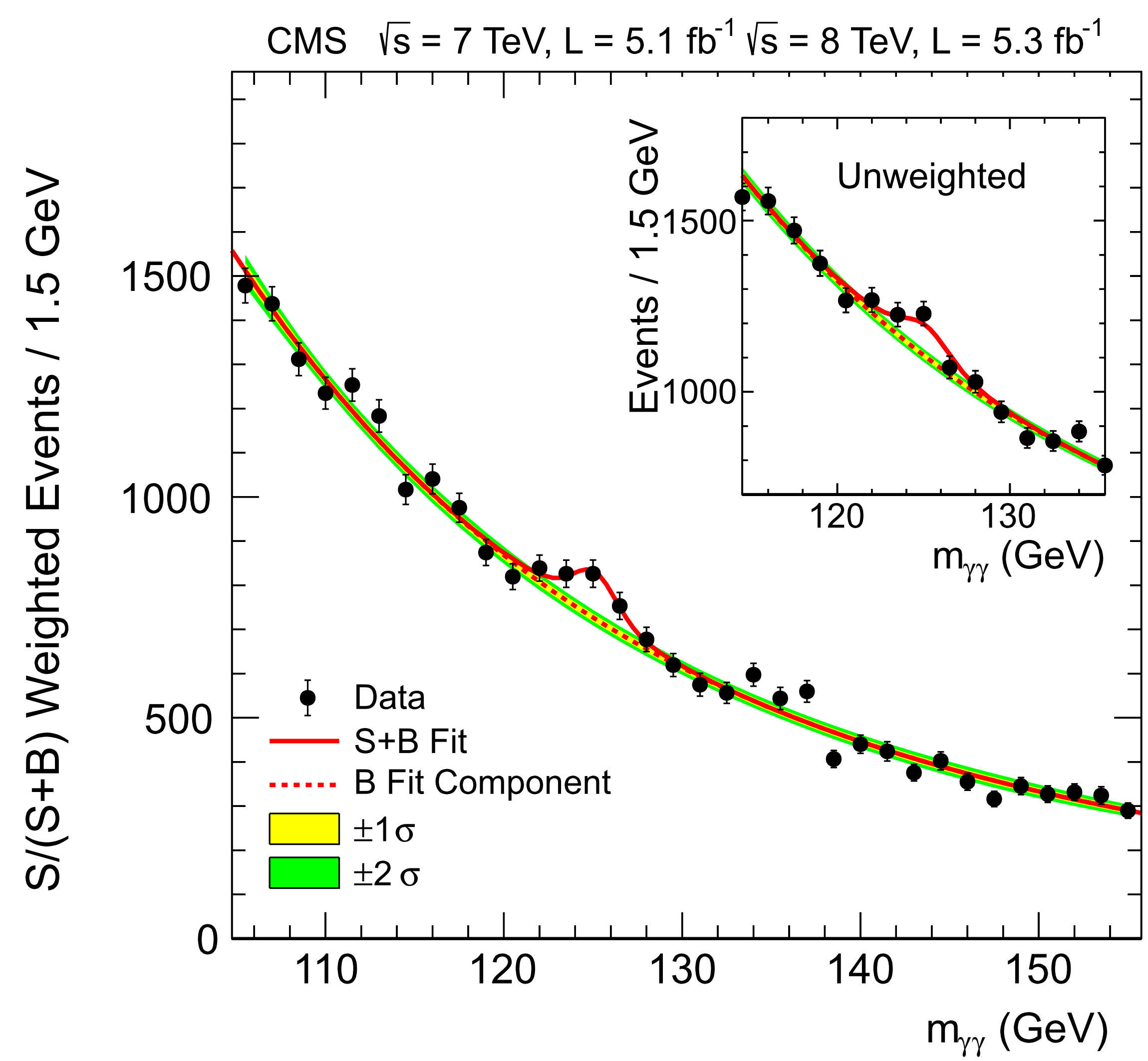
- The Higgs Di-photon decay
  - Signal and Backgrounds
  - Fast simulation
  - Full simulation
- The Higgs Di-tau decay
  - Signal and Backgrounds
  - Analysis strategy for μμH, vvH and qqH
- Summary

The Higgs Di-photon decay

- Induced by quantum loop corrections involving the W boson and fermions, primarily the top quark
- Tests the standard model
- Provides a test of additional "new physics" effects
- One of the primary channels to search for the Higgs boson



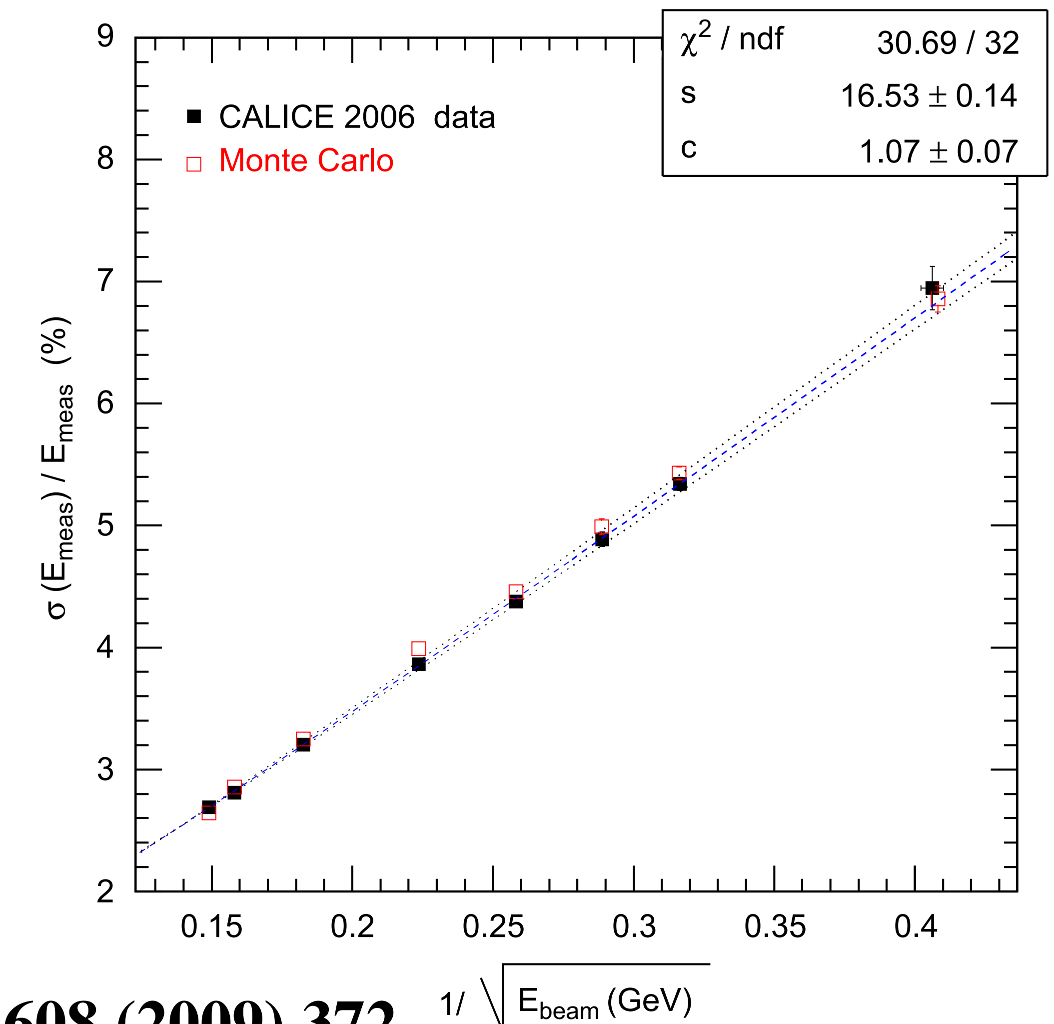
Phys. Lett. B 716 (2012) 1-29 (ATLAS)



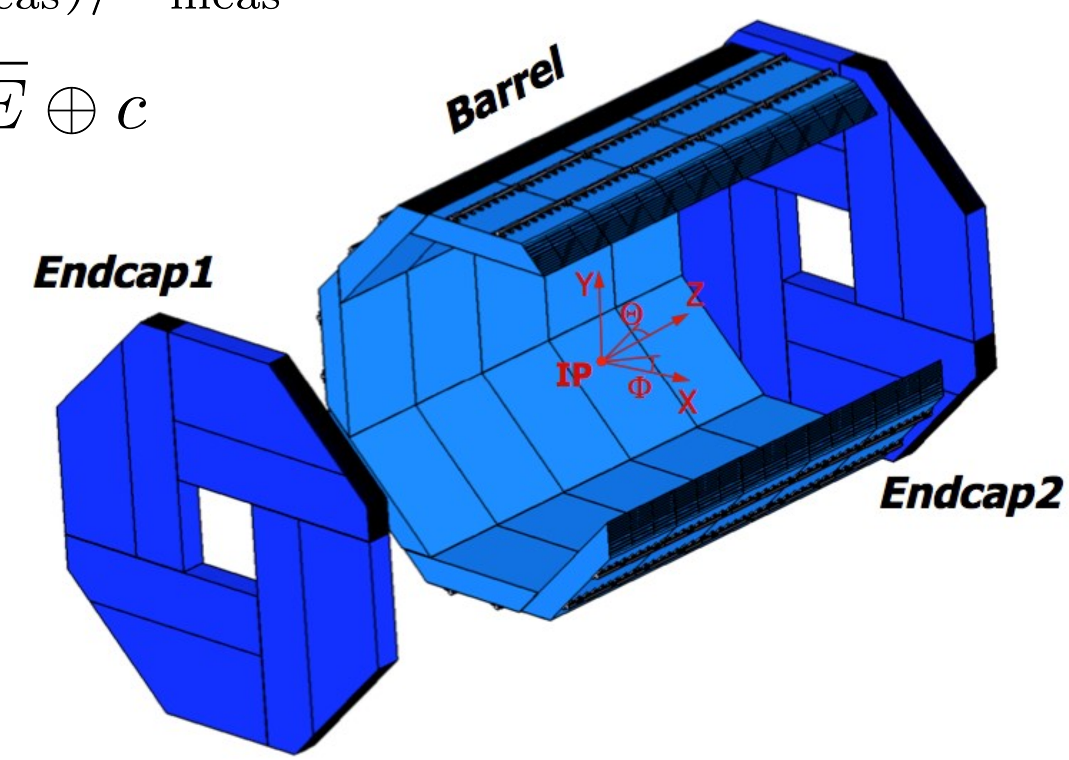
Phys. Lett. B 716 (2012) 30-61 (CMS)

Electromagnetic Calorimeter

- Di-photon decay with a low BR 0.23% at $M_H = 125$ GeV
- ECAL performance is a design priority for CEPC
- The relative energy resolution of the first ECAL prototype built by the CALICE is about $(16.53/\sqrt{\mathrm{E(GeV)}} \oplus 1.07)\%$
- The benchmark point is set to be $(16/\sqrt{\mathrm{E(GeV)}} \oplus 1)\%$
- The different assumptions $((10 \sim 20)/\sqrt{\mathrm{E(GeV)}} \oplus 1)\%$ are also investigated



$$\sigma(E_{\mathrm{meas}})/E_{\mathrm{meas}}$$
$$s/\sqrt{E} \oplus c$$

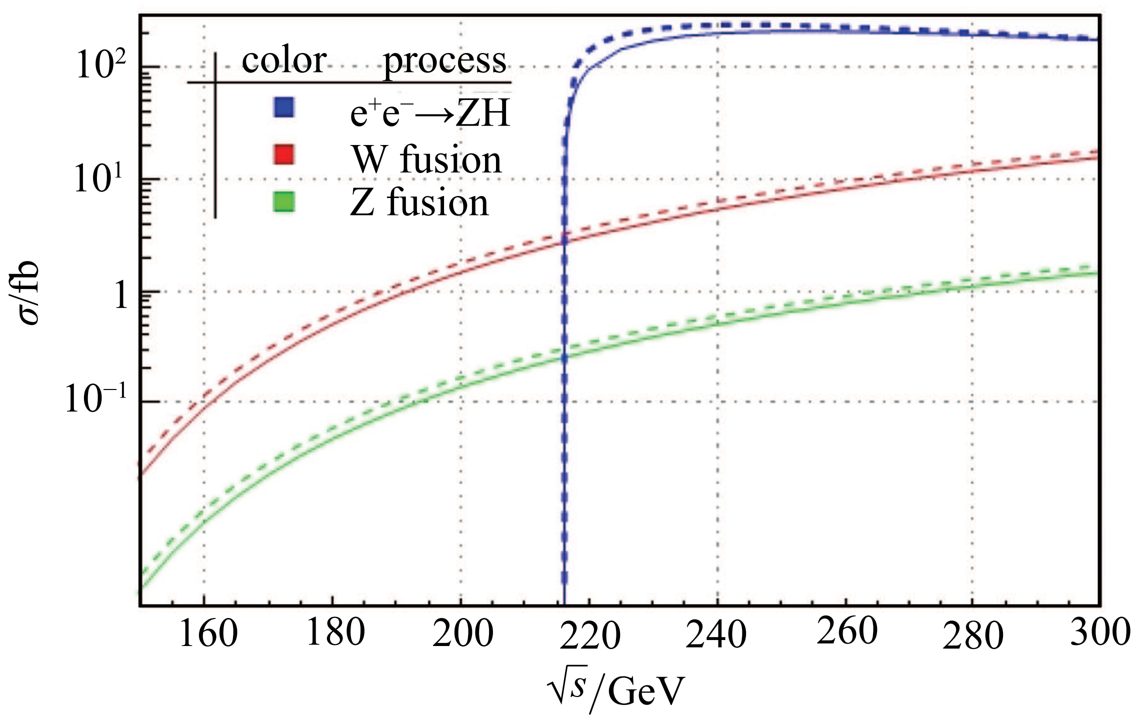


NIM A 608 (2009) 372

The Silicon-Tungsten-based ECAL

CEPC-SPPC pre-CDR

Signal and Backgrounds



Chin. Phys. C 40 (2016) 033001

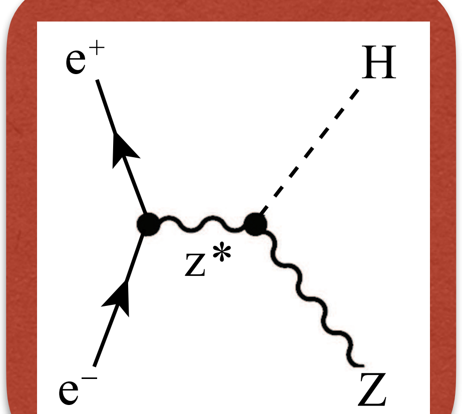
- **Produced by the Higgsstrahlung process and the weak boson fusion reactions**
- **The Higgsstrahlung process becomes the dominate one above the ZH threshold**
- **Reaches its maximum at the center-of-mass energy 250 GeV**

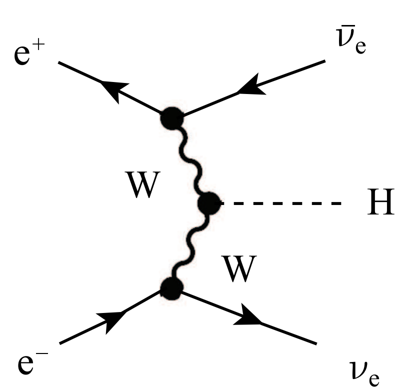
Dominant

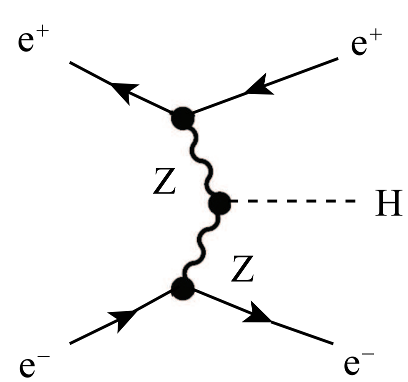
- **Higgsstrahlung** $H \to \gamma\gamma$, $Z \to \nu\bar{\nu}$, $l\bar{l}$, $q\bar{q}$
- **WW fusion** $e^+e^- \to \nu_e\bar{\nu}_e H$
- **ZZ fusion** $e^+e^- \to e^+e^- H$

Ignored for the limited signal events with more complicated ISR background

Dominant







- **The ISR background**

  $$e^+e^- \to Z\gamma\gamma \to f\bar{f}\gamma\gamma$$

  Including

  $$\nu\bar{\nu}\gamma\gamma,\ l\bar{l}\gamma\gamma \text{ and } q\bar{q}\gamma\gamma$$

Fast simulation

Feng Wang

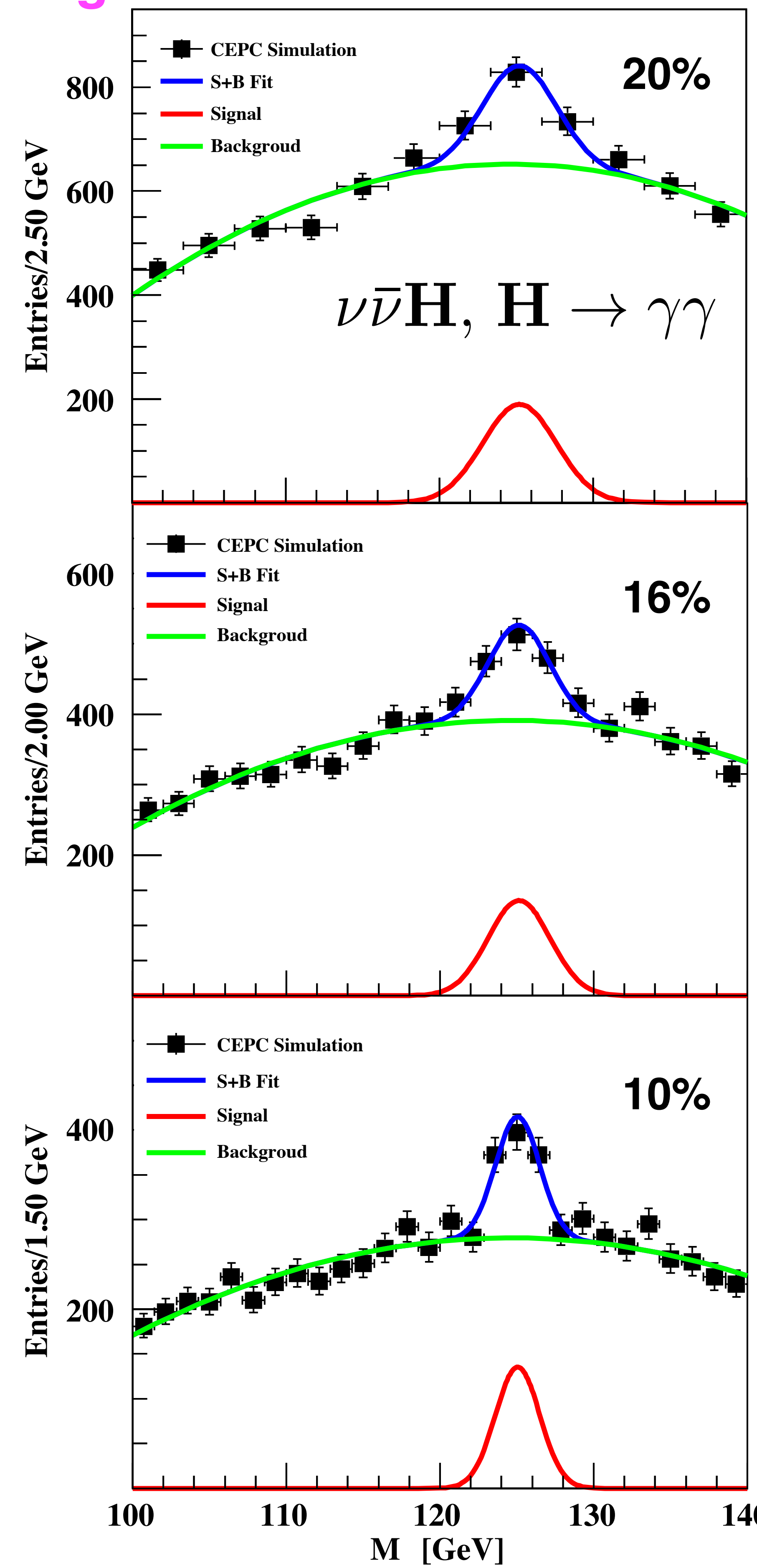
A reliable tool to study the di-photon branch ratio, the relative accuracy, and the impact of ECAL intrinsic resolution

- **The high event reconstruction efficiency**
- **The relatively simple event topology**

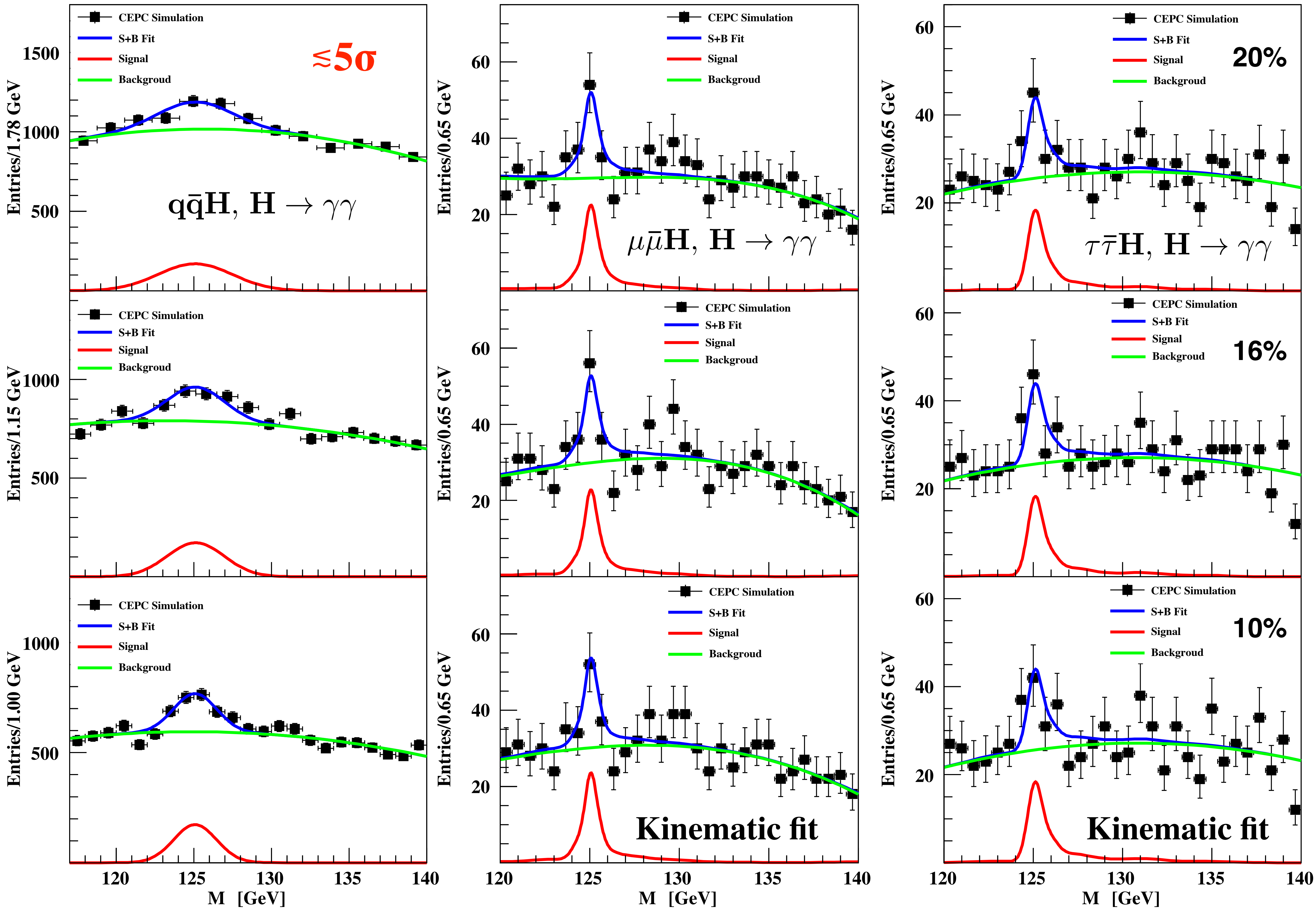
- **To improve the measurement precision** $\nu\bar{\nu}\mathrm{H},\ \mathrm{q\bar{q}H},\ \mu\bar{\mu}\mathrm{H},\ \tau\bar{\tau}\mathrm{H}$ **are analysis separately.**
- **The different hypothetical Ecal energy resolution** $\frac{10\%}{\sqrt{E}}\oplus 1\%,\ \frac{16\%}{\sqrt{E}}\oplus 1\%,\ \frac{20\%}{\sqrt{E}}\oplus 1\%$ **are considered.**
- **For** $\nu\bar{\nu}\mathrm{H},\ \mathrm{H}\to\gamma\gamma$**, both Higgsstrahlung and WW fusion processes are considered**

$\frac{\delta E}{E}$	$\frac{10\%}{\sqrt{E}}\oplus 1\%$	$\frac{16\%}{\sqrt{E}}\oplus 1\%$	$\frac{20\%}{\sqrt{E}}\oplus 1\%$
Signal yields (S)	334 ± 40	339 ± 46	342 ± 51
Background yields (B)	7059 ± 91	7053 ± 94	7047 ± 96
Significance	8.65σ	7.11σ	6.37σ
$\delta(Br\times\sigma)/(Br\times\sigma)$	11.98%	13.56%	14.91%

>5σ



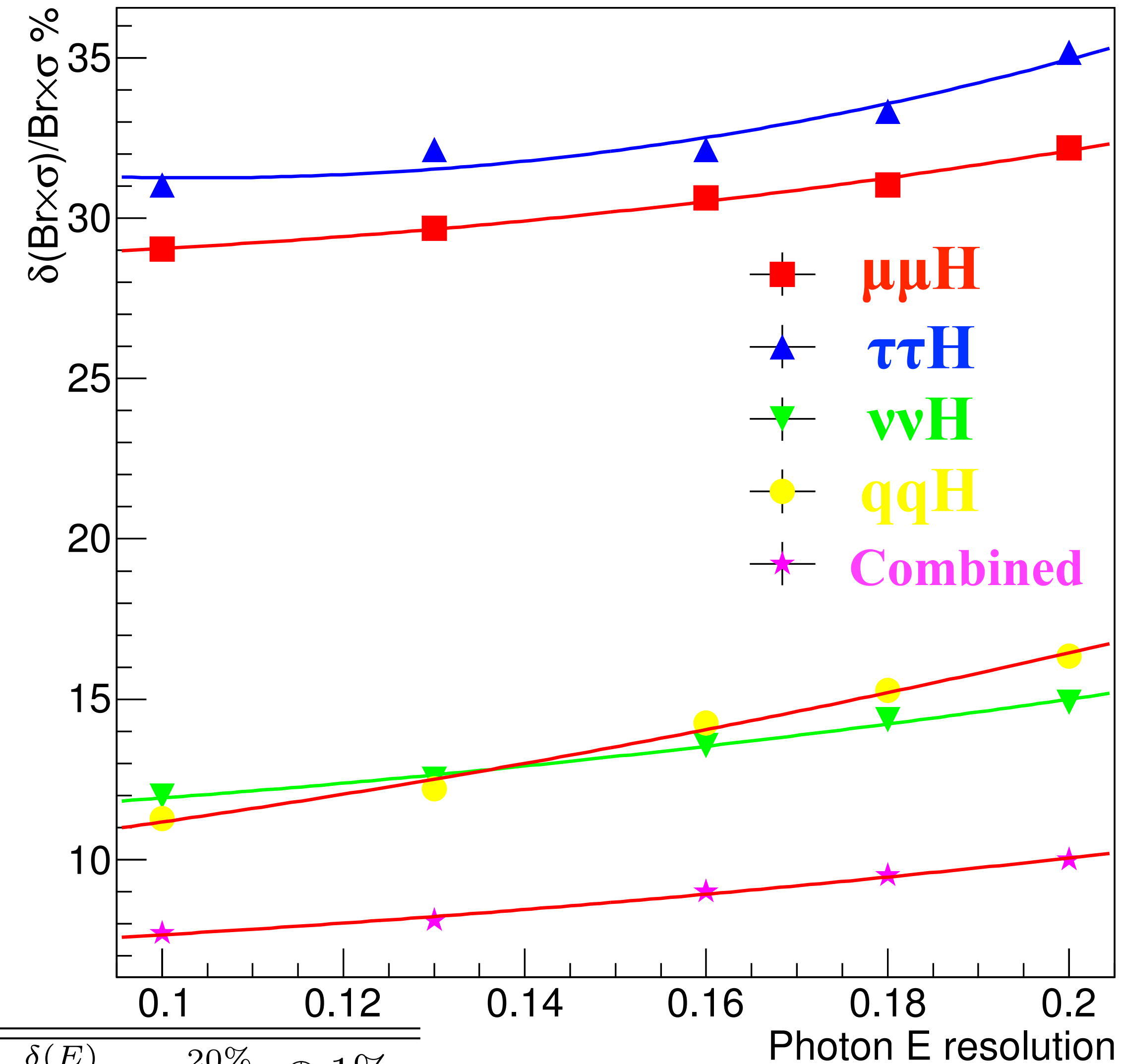
Feng Wang


CEPC Simulation
S+B Fit
Signal
Backgroud
≲5σ
$q\bar{q}H,\ H \to \gamma\gamma$
$\mu\bar{\mu}H,\ H \to \gamma\gamma$
$\tau\bar{\tau}H,\ H \to \gamma\gamma$
20%
16%
10%
Kinematic fit
Kinematic fit
Entries/1.78 GeV
Entries/1.15 GeV
Entries/1.00 GeV
Entries/0.65 GeV
M [GeV]

Feng Wang

Fast simulation

- **The relative uncertainty shows not much dependence on the Ecal energy resolution between** $(10 \sim 20)\%/\sqrt{E} \oplus 1\%$
- **The combined relative precision is 7.7%, 9.0%, 10.0%, for** $(10,\ 16,\ 20)\%/\sqrt{E} \oplus 1\%$ **separately.**



Channel		$\frac{\delta(E)}{E} = \frac{10\%}{\sqrt{(E)}} \oplus 1\%$	$\frac{\delta(E)}{E} = \frac{16\%}{\sqrt{(E)}} \oplus 1\%$	$\frac{\delta(E)}{E} = \frac{20\%}{\sqrt{(E)}} \oplus 1\%$
$Z \to \mu^+\mu^-$	Signal/efficiency	$62 \pm 18/42.2\%$	62 ± 19	59 ± 19
	background	832 ± 33	831 ± 34	826 ± 33
	$\delta(Br \times \sigma)/(Br \times \sigma)$	29.03%	30.64%	32.20%
$Z \to \tau^+\tau^-$	Signal/efficiency	$58 \pm 18/41.9\%$	56 ± 18	54 ± 19
	background	760 ± 32	757 ± 32	762 ± 32
	$\delta(Br \times \sigma)/(Br \times \sigma)$	31.03%	32.14%	35.18%
$Z \to \nu\nu$	signal	$334 \pm 40/57.5\%$	339 ± 46	342 ± 51
	background	7059 ± 91	7053 ± 94	7047 ± 96
	$\delta(Br \times \sigma)/(Br \times \sigma)$	11.98%	13.56%	14.91%
$Z \to qq$	signal	$594 \pm 67/34.3\%$	582 ± 83	575 ± 94
	background	13053 ± 130	12831 ± 138	12566 ± 144
	$\delta(Br \times \sigma)/(Br \times \sigma)$	11.28%	14.26%	16.35%
Total	$\delta(Br \times \sigma)/(Br \times \sigma)$	7.7%	9.0%	10.0%

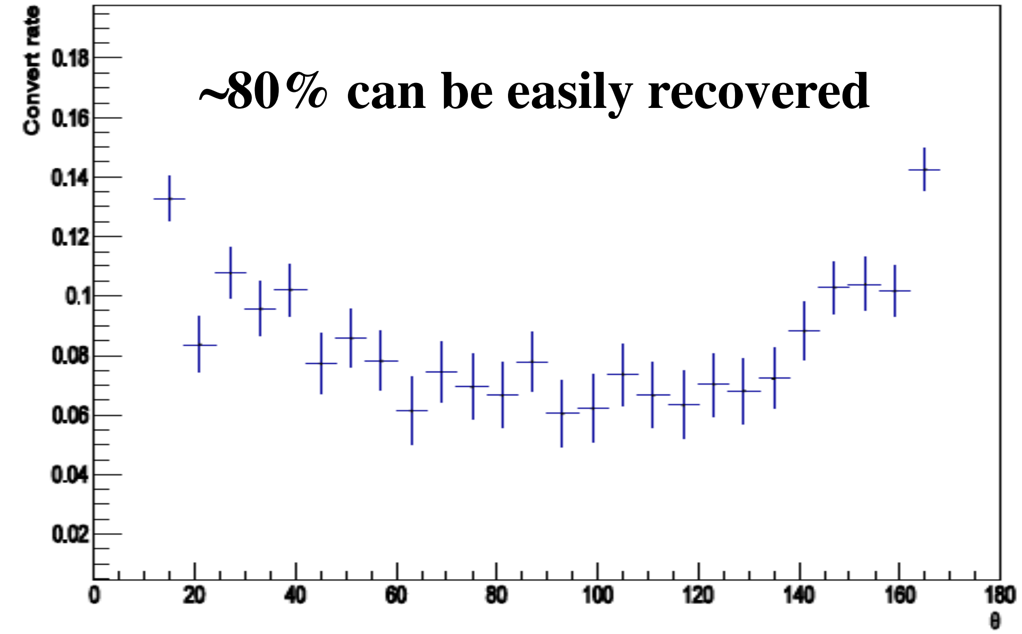
The Ecal energy resolution should be at least

$$20\%/\sqrt{E} \oplus 1\%$$

Full simulation

Jianhuan Xiang

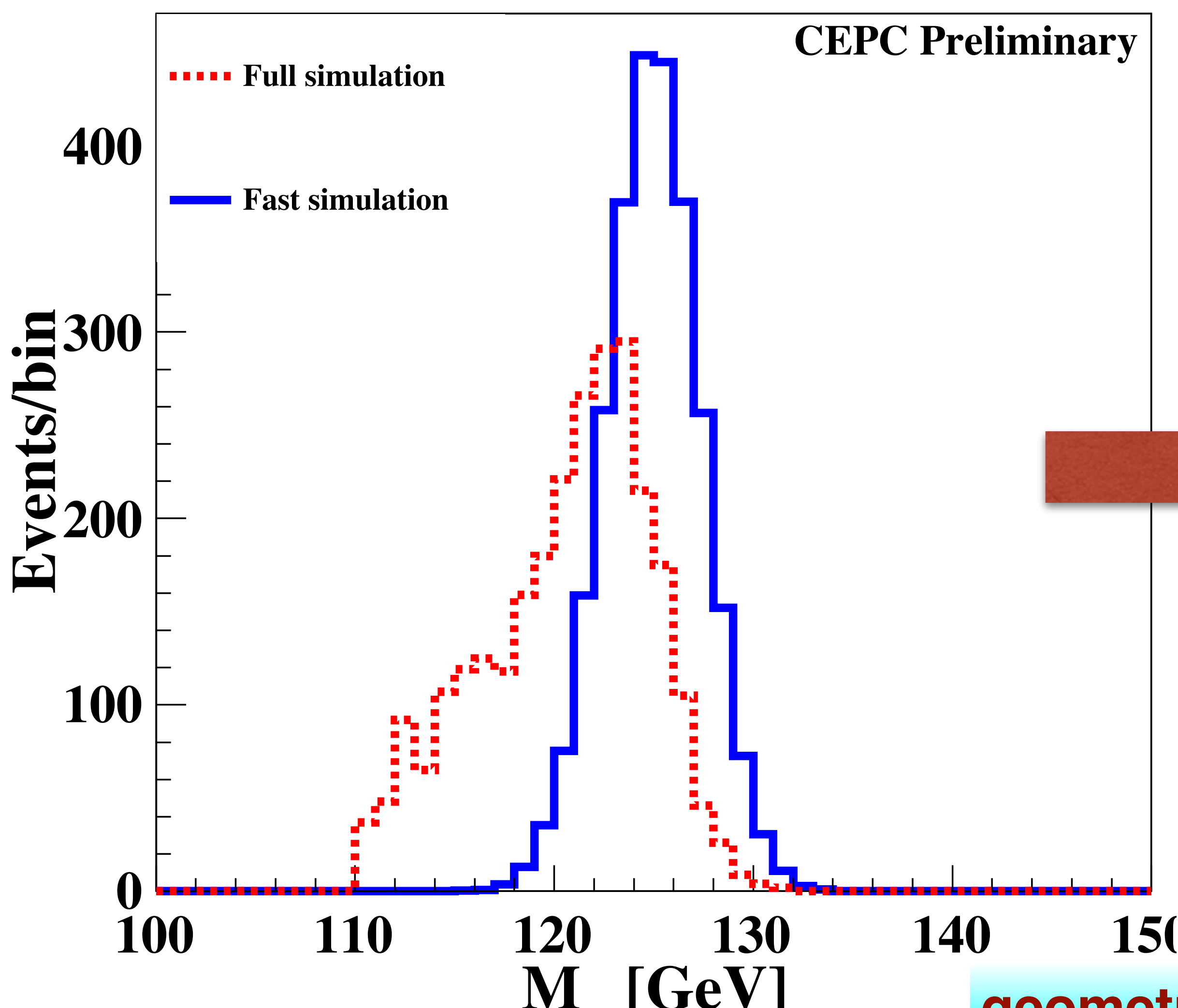
The photon conversion rate

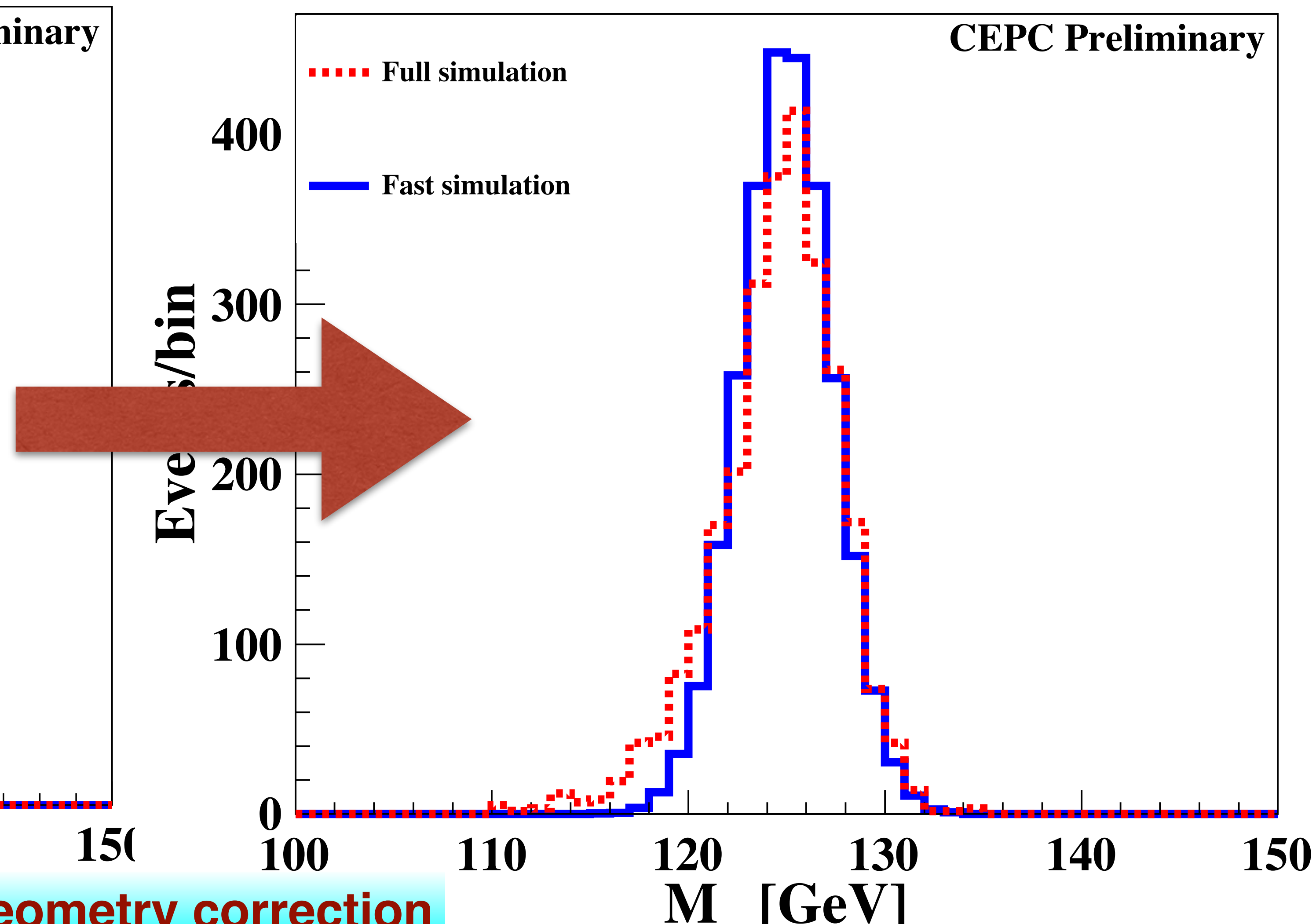


A necessary tool for the real situation

- The photon conversion and a photon recovery algorithm
- The geometry correction by the photon energy performance can give us some insight to the detector structure

Feng Wang

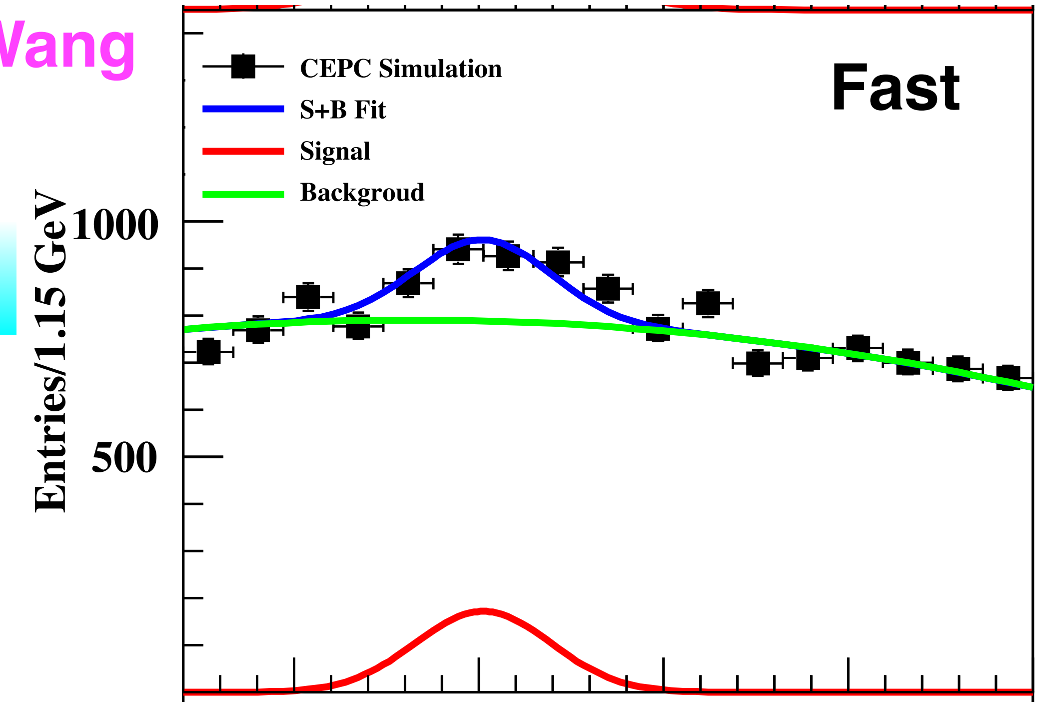




geometry correction

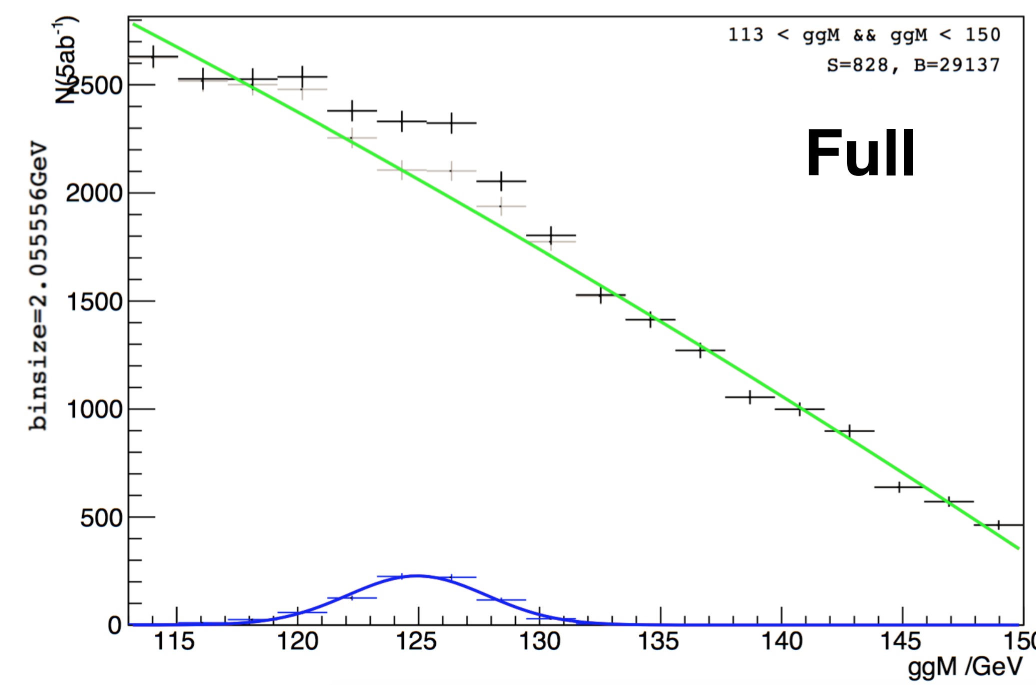
Full simulation

Feng Wang



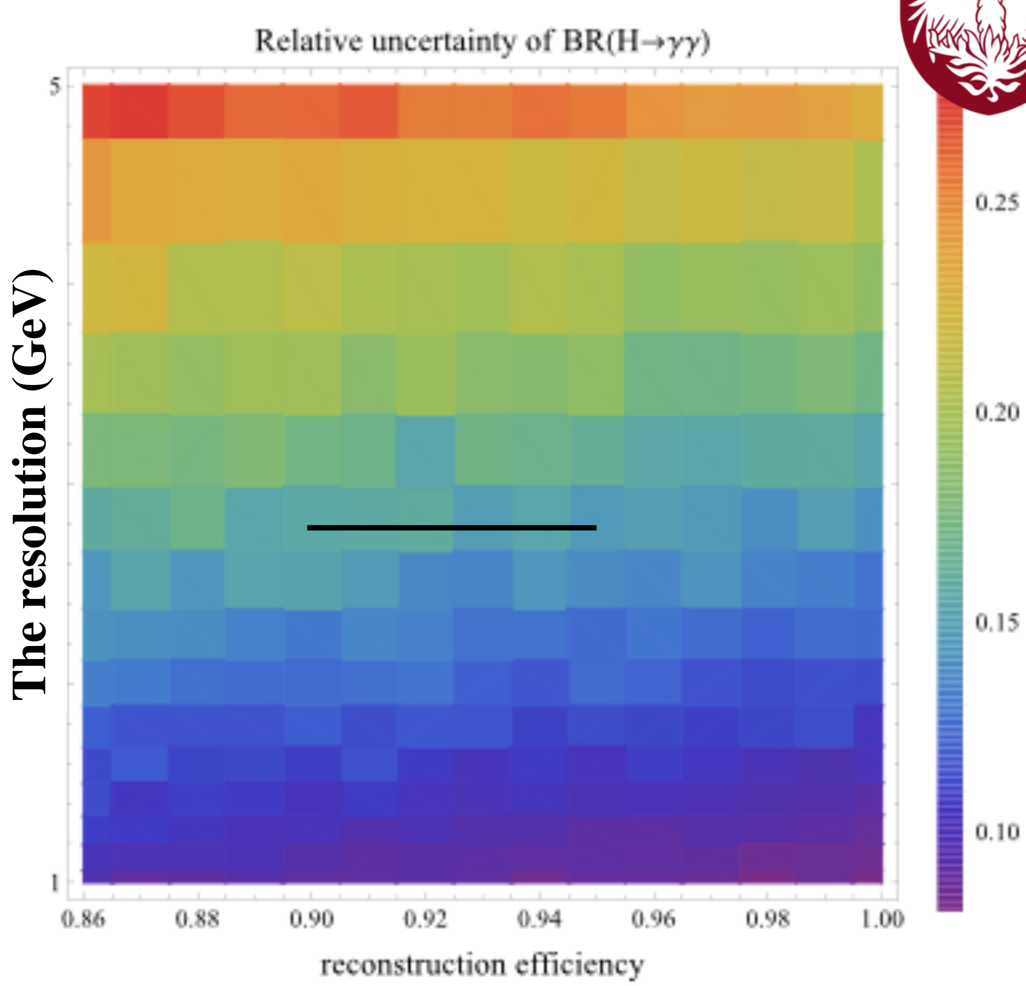
A necessary tool for the real situation

- The photon conversion and a photon recovery algorithm
- The geometry correction by the photon energy performance can give us some insight to the detector structure
- The validation by a comparison of the full/fast simulation results



Yitian Sun

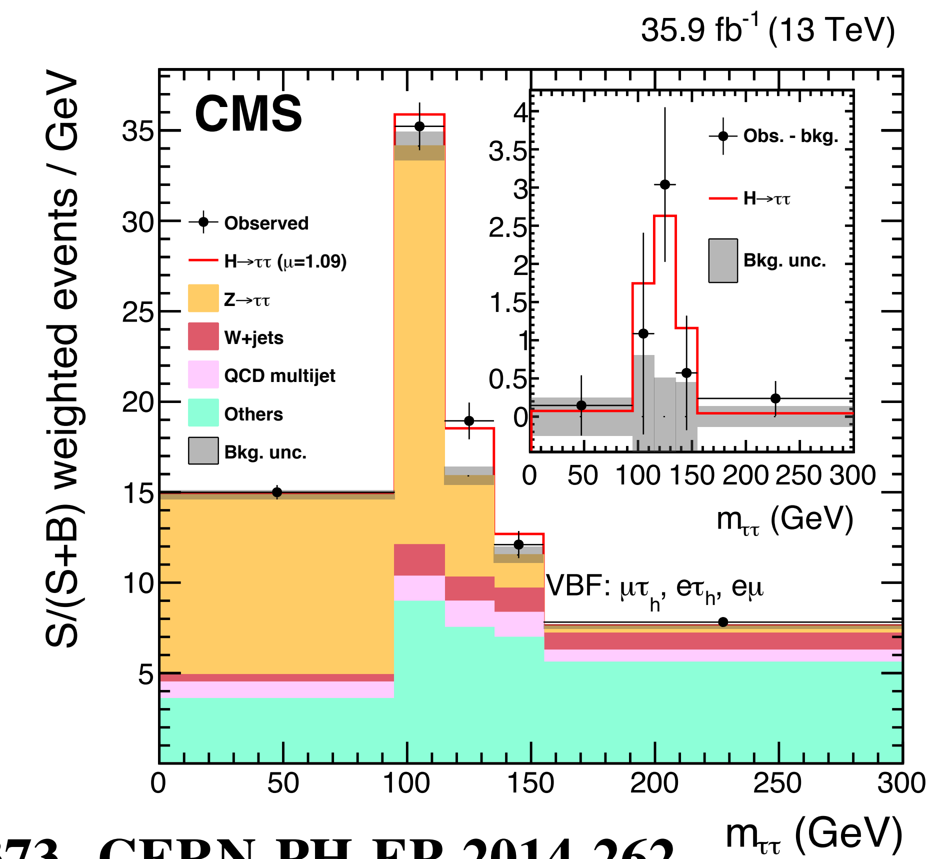
$q\bar{q}H,\ H \rightarrow \gamma\gamma$



- The relative uncertainty of BR: 15.6%
- The uncertainty can reach ≲15% with the resolution of 2.8 GeV with a high efficiency
- The uncertainty: 10~25% with a large scan range of the resolution of 1~5 GeV

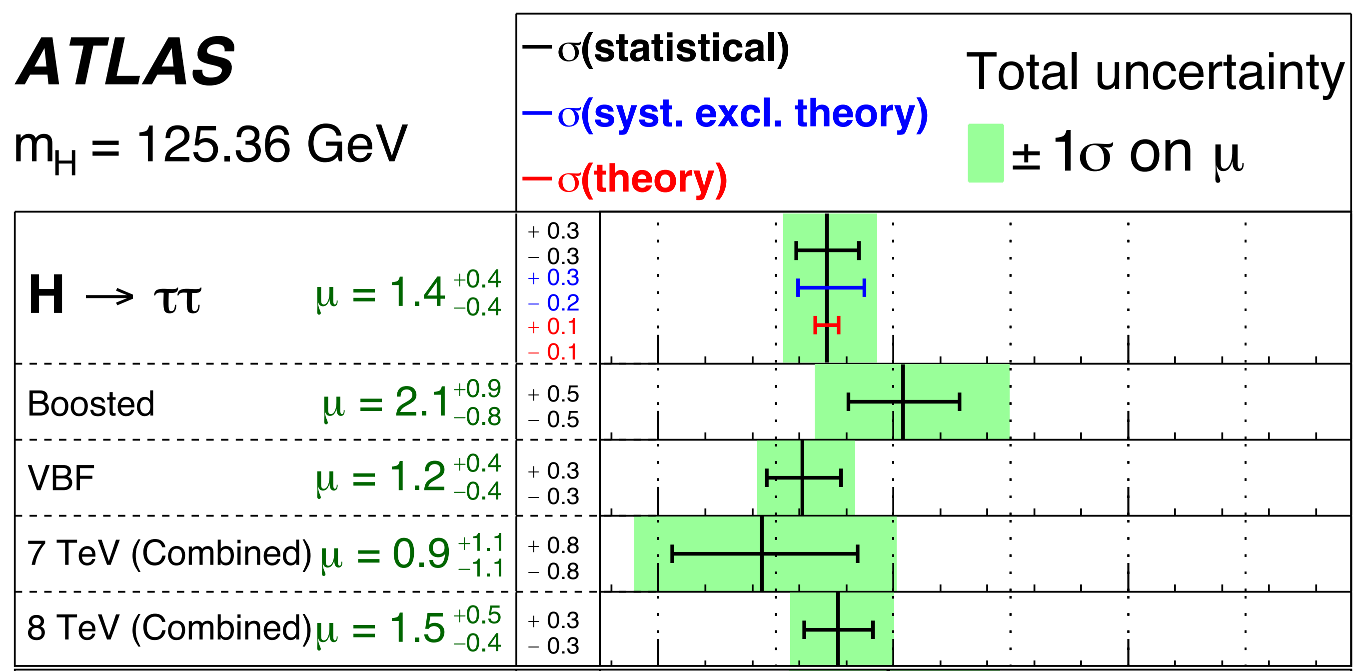
The Higgs Di-tau decay

- Di-tau decay has been studied at the LEP, Tevatron, and LHC colliders
- The most promising channel for probing the coupling of Higgs
  - Large event rate: BR(H->ττ) ~6.3%
  - Relatively small backgrounds



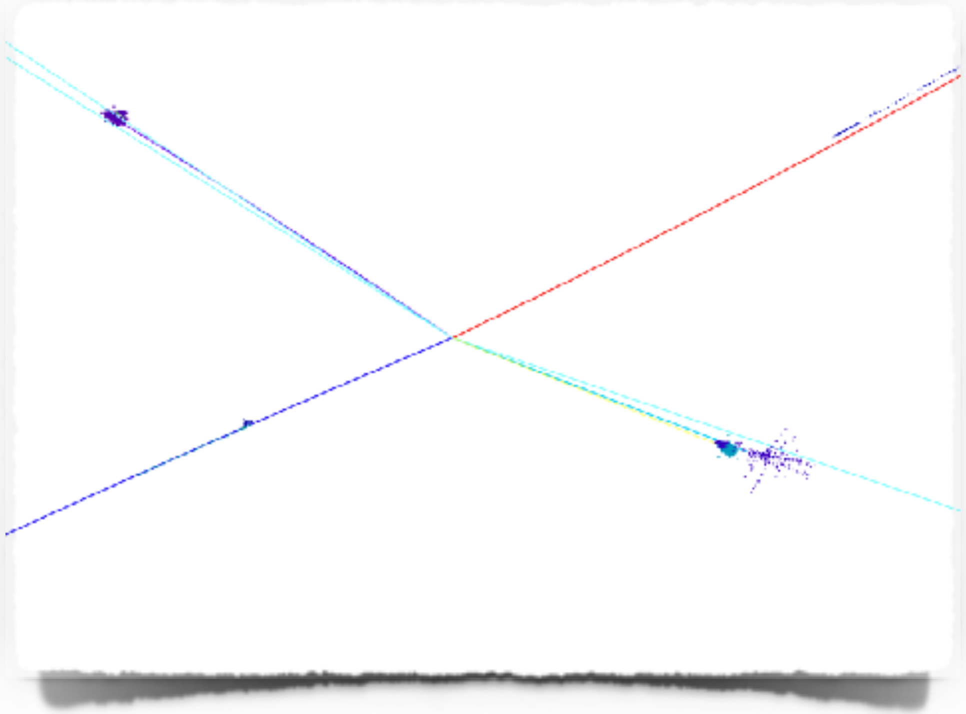
arXiv:1708.00373 CERN-PH-EP-2014-262

- Performance relies on particle separation
  - Objectives for detector optimization
  - Testbed for PFA



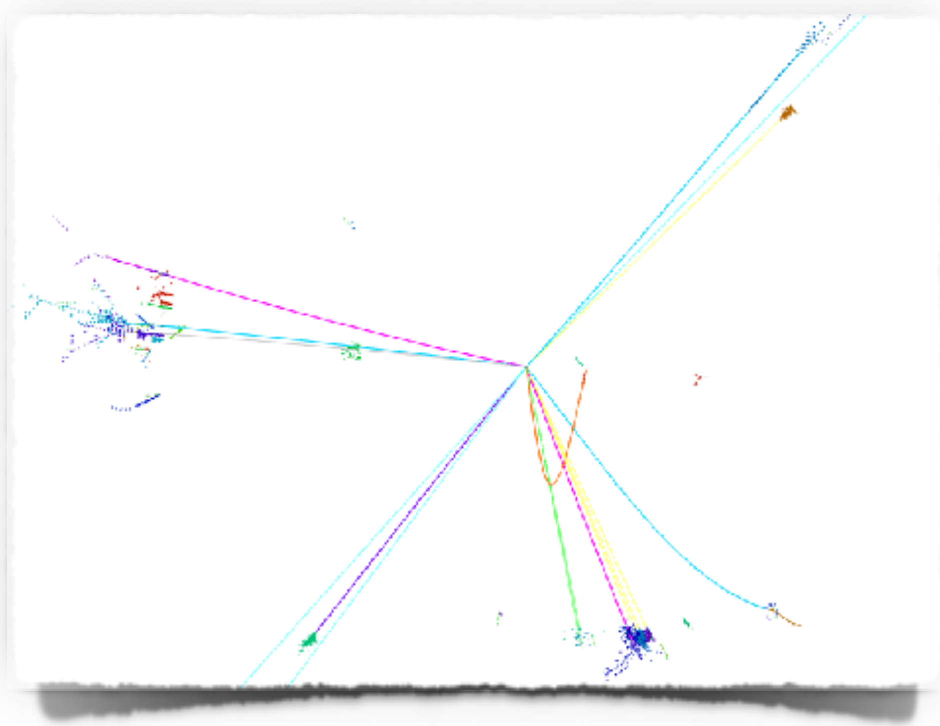
arXiv:1501.04943 CERN-PH-EP-2014-262

Signal and Backgrounds



- **Lepton channel**: clean, lepton veto then event analysis directly (2 simply defined cone)
- Signal: μμH/ννH
- Irreducible background:

ZZ->μμττ/ννττ & WW->ντντ

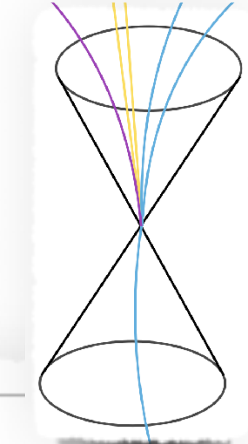


- **Hadronic channel**: complex, jets cannot be vetoed, cone level analysis first (multi cones as candidate)
- Signal: qqH
- Irreducible background:

ZZ->qqττ

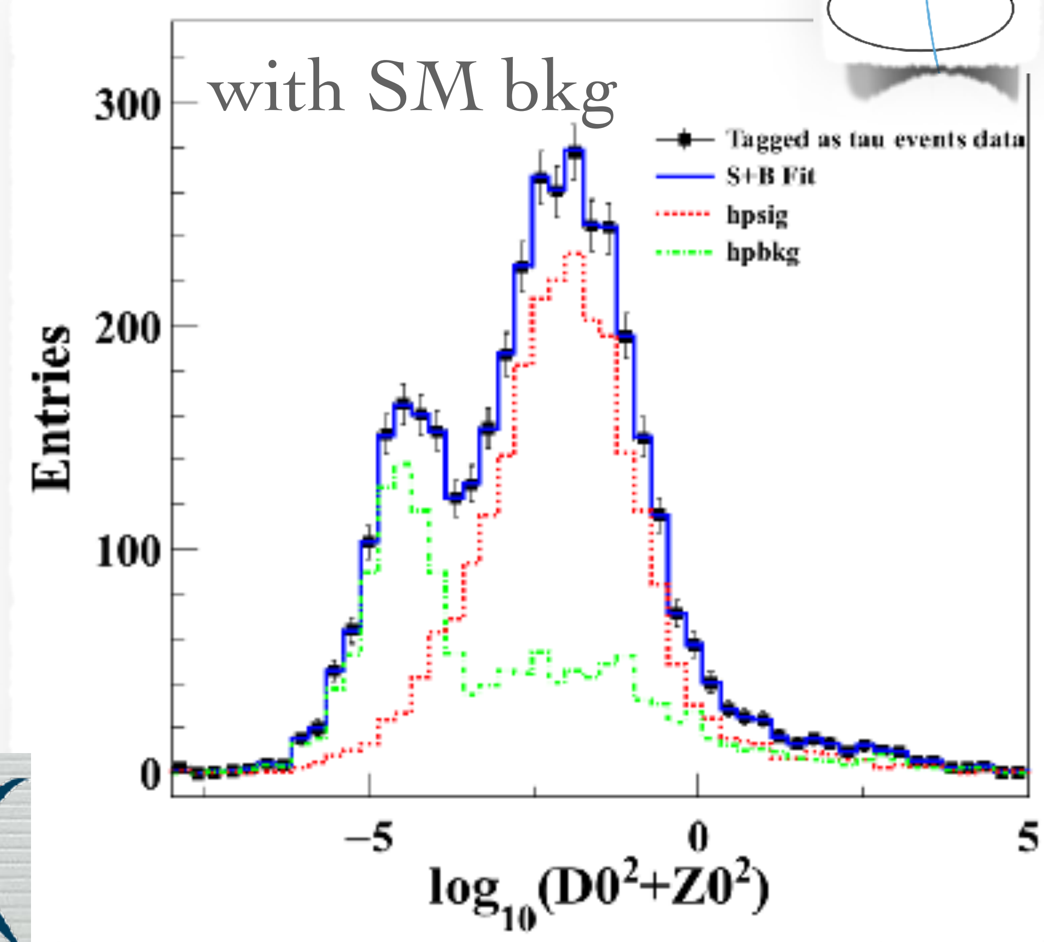
Analysis strategy for μμH

Nearly back-to-back



Impact parameter

$$D_0^2/\sigma^2(D_0) + Z_0^2/\sigma^2(Z_0)$$



- The di-lepton system information
  - Recoil mass
  - Efficiency ~ 99% (LICH - Eur. Phys. J. C (2017) 77: 591)
- Track/photon multiplicity counting
  - Mostly well reconstructed
  - Bad cases: detector acceptance

Dan YU

- High efficiency: 93.15%
- Background reduced by 5 orders of magnitudes
- BR(H->ττ) ~ 6.40±0.18%
- Accuracy: 2.68%

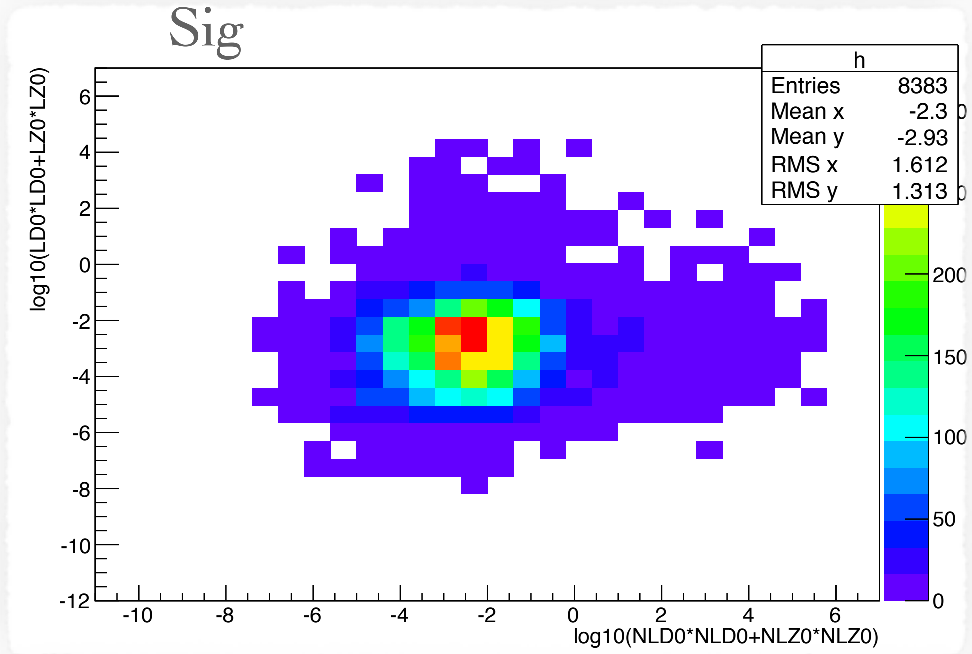
	$\mu\mu H\tau\tau$	$\mu\mu$H inclusive bkg	ZZ	WW	singleW	single Z	$2f$
total generated	2292	33557	5711445	44180832	15361538	7809747	418595861
after preselection	2246	32894	122674	223691	0	86568	1075886
$N_{Trk}(A/B) < 6$ & $N_{Ph}(A/B) < 7$	2219	1039	2559	352	0	9397	25583
BDT>0.78	2135	885	484	24	0	157	161
efficiency	93.15%	2.63%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%

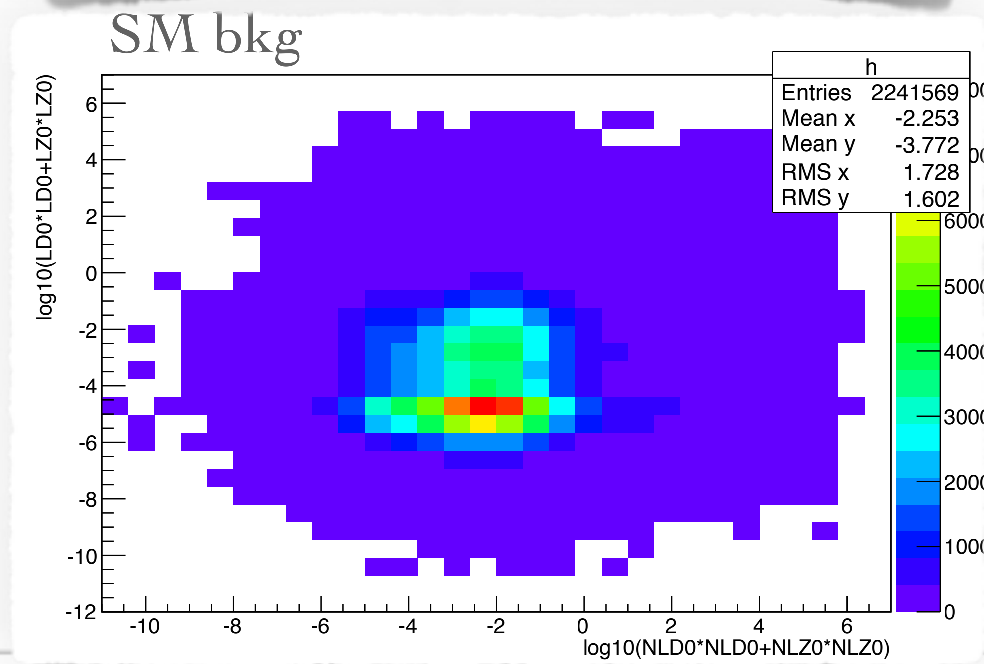
Analysis strategy for ννH

Dan YU

- Missing mass
- All visible particles are decayed from tau
- Nearly back-to-back

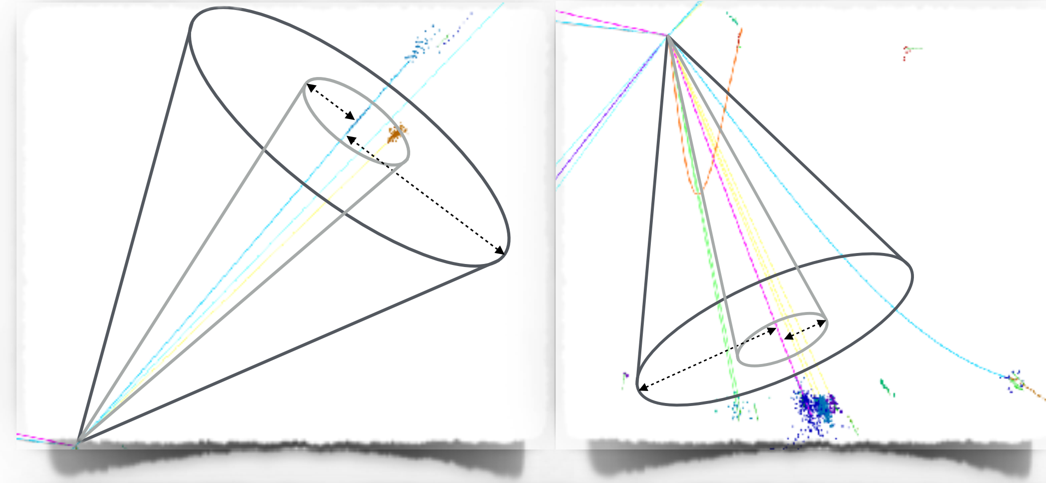
- Signal efficiency: ~ 57.02%
- Dominated by the irreducible background of WW/ZZ->ττνν
- BR(H->ττ) ~ 6.19±0.29%
- Accuracy: 4.29%



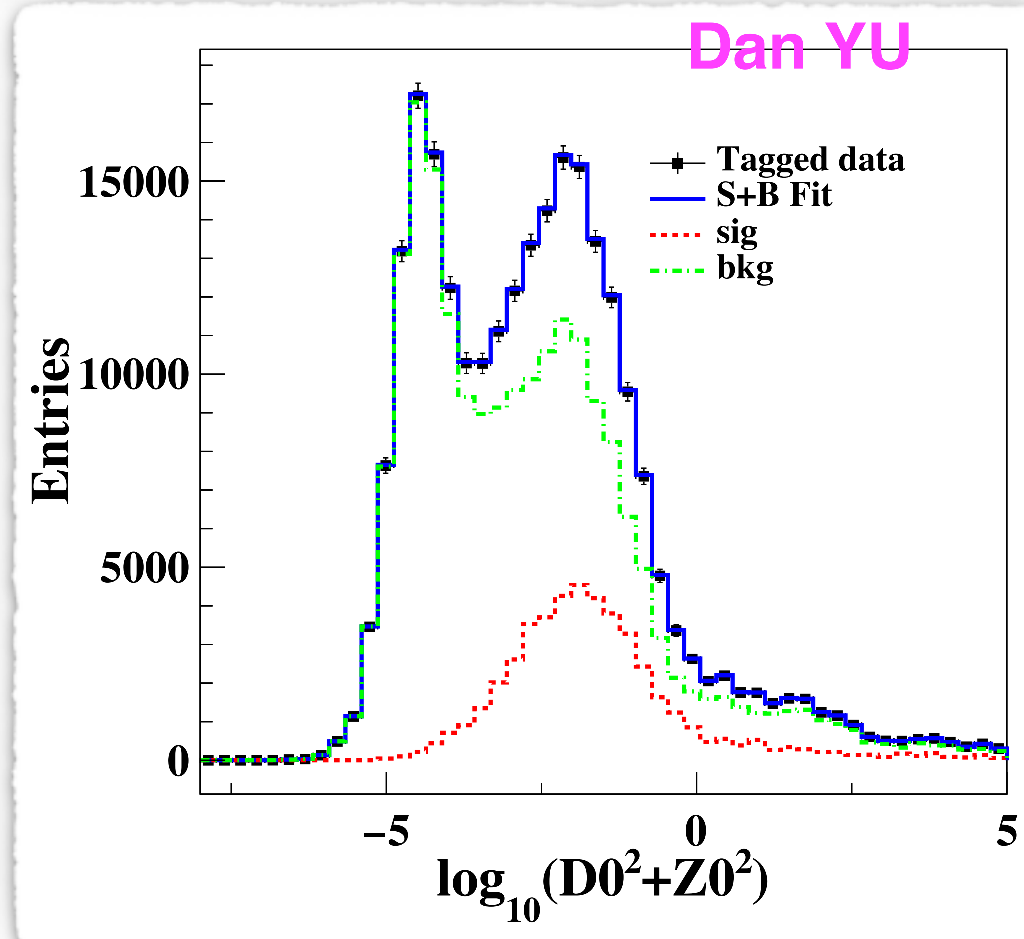


	$\nu\nu H\tau\tau$	$\nu\nu$H inclusive bkg	ZZ	WW	singleW	single Z	$2f$
total generated	15497	231670	5711445	44180832	17361538	7809747	418595861
after preselection	9434	214830	1239457	7463105	3327803	956694	12826280
$N_{Trk}(A/B) < 6$ & $N_{Ph}(A/B) < 7$	9260	8858	24760	1354852	17389	676185	1535029
BDT > 0.78	8836	6587	15450	89729	1355	10739	11243
efficiency	57.02%	2.84%	0.27%	0.20%	<0.01%	0.14%	<0.01%

Analysis strategy for qqH



- Complex:
  - Jets: much more tracks than leptons
  - Tau: less tracks and photons, isolated
- Corn-based τ finding algorithm has been designed and optimized
- Signal efficiency: ~ 50.81%
- Background reduced to a similar statistic as the signal
- BR(H->ττ) ~ 6.25±0.04%
- Accuracy: 1.71%



	qqHττ	qqH inclusive bkg	ZZ	WW	singleW	single Z	2f
total generated	45597	678158	571144	44180832	17361538	7809747	418595861
after preselection	45145	666941	293306	12452091	52102	45410	213569
$N_{\tau^+} > 0, N_{\tau^-} > 0$	25642	55170	206637	1065306	14121	13232	53016
$10GeV < M_{\tau^+\tau^-} < 110GeV$	23168	48880	75510	146174	10515	3852	16501
efficiency	50.81%	7.21%	13.21%	0.33%	0.06%	0.05%	< 0.01%

The combined results for Di-tau decay

- New particle id (LICH) applied
  - 99% lepton identification efficiency
- Impact parameter is a good way to fit the tau events
- Combined BR: ~6.28%
- Combined accuracy: 1.30%

See Nicola's report

HL-LHC: ~5-8% (CMS NOTE-13-002 , ATL-PHYS-PUB-2014-016 (2014))

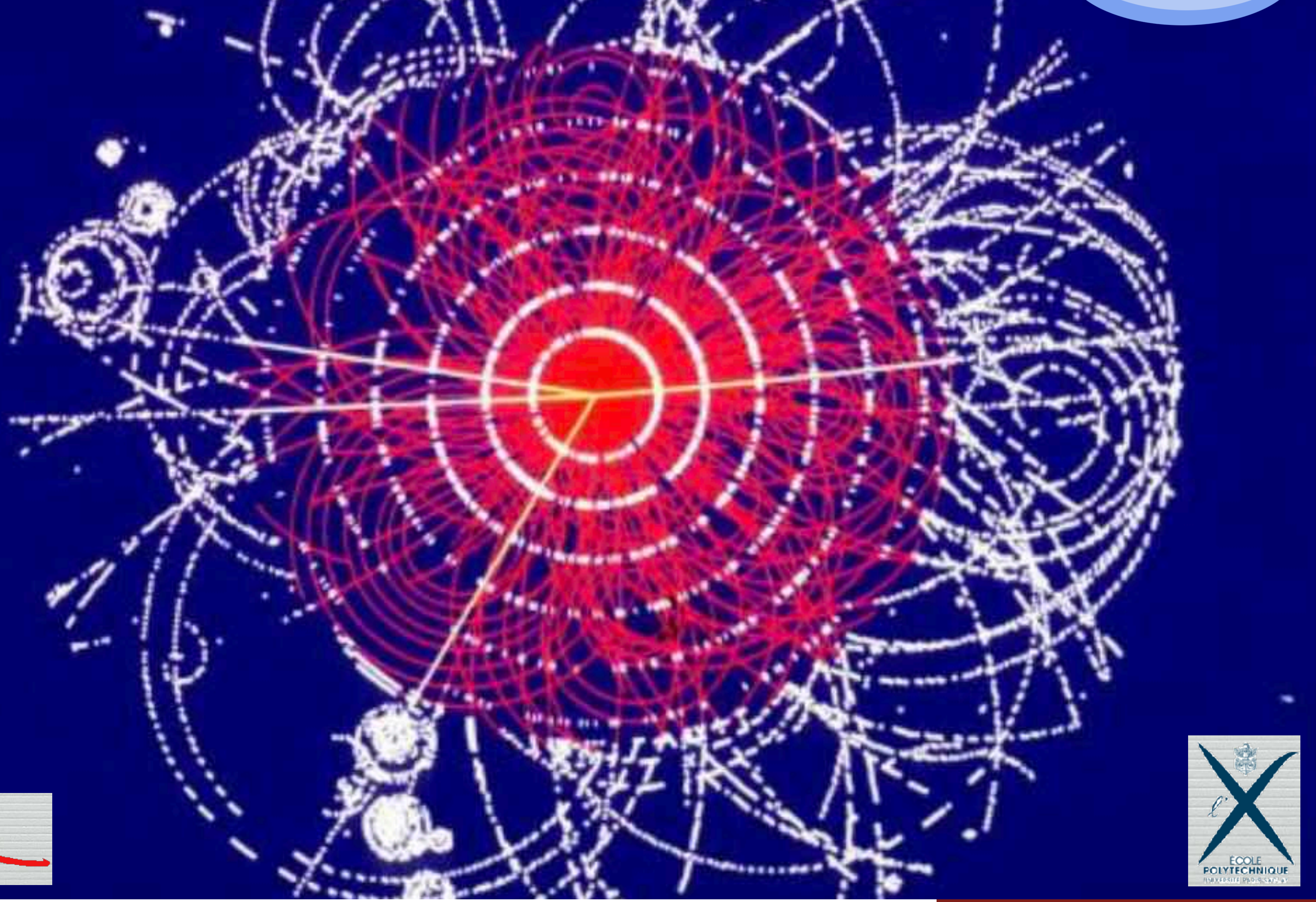
	BR ($H \to \tau\tau$)	$\delta(\sigma \times BR)/(\sigma \times BR)$
$\mu\mu$H	6.40 ± 0.18	2.68%
eeH(extrapolated)	6.37 ± 0.18	4.34%
$\nu\nu$H	6.19 ± 0.17	4.29%
qqH	6.25 ± 0.04	1.71%
combined	6.28 ± 0.07	1.30%

Summary

- The di-photon decay
  - Fast simulation
    - The relative combined precision is 9.0% for $16\%/\sqrt{E} \oplus 1\%$
    - Dependence on ECAL energy resolutions is parametrized
  - Full simulation
    - Photon recovery algorithm and the geometry correction
    - A relative uncertainty of BR(H->γγ) 15.6% at qqH channel is consistent with fast simulation (14.3%).
- The di-tau decay
  - Dedicated event selections are designed
  - Combined BR(H->ττ) ~ 6.28±0.07%
  - Combined accuracy: 1.30%
- PFA Oriented Detector well suits the measurements for Photons (Single Particle) and tau (Composed Object)

Thanks!

CEPC



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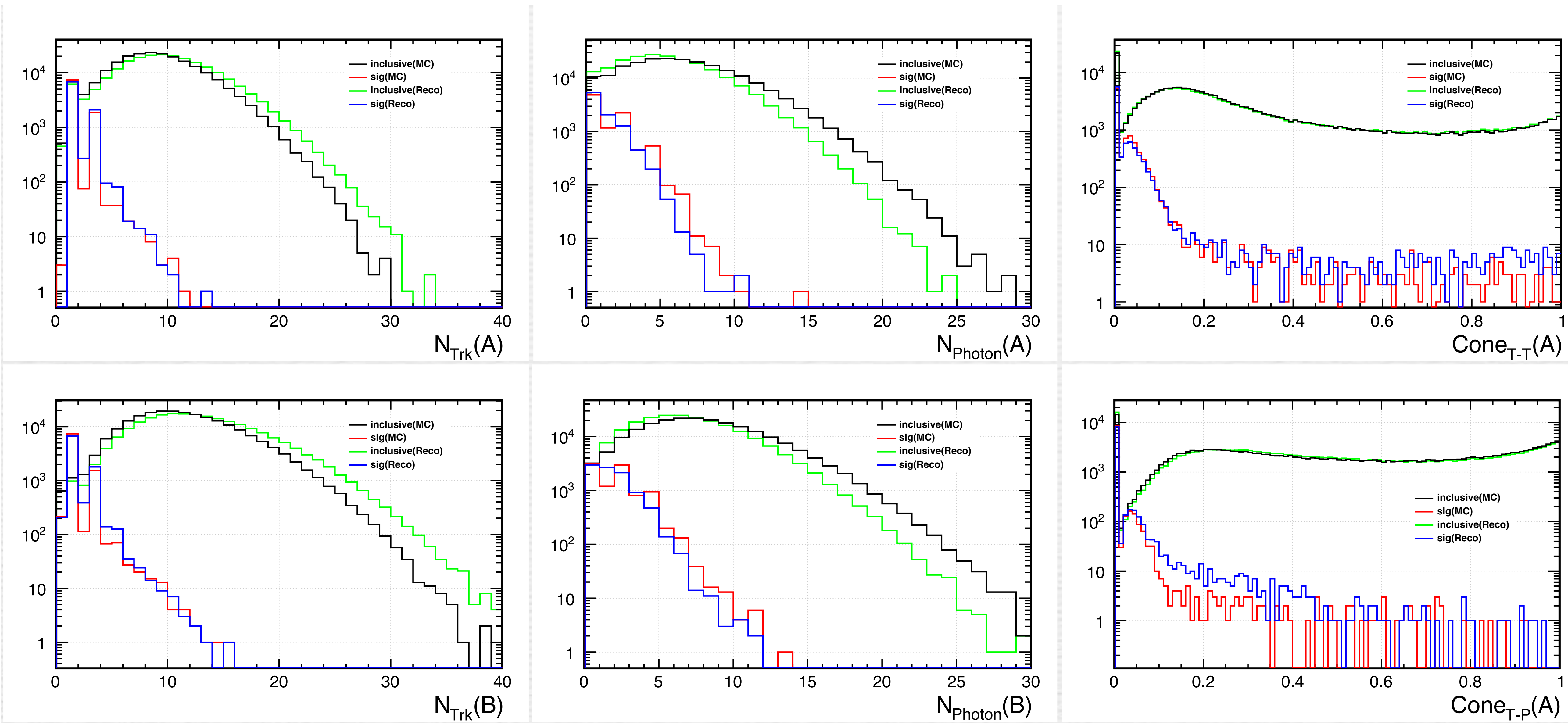
Backup

Tau recognition for μμH



- **Less reconstructed particles:**
  - **detector acceptance**
  - **photon reconstruction efficiency: ~90%**
  - **particle separation: distance>16mm (Hang ZHAO's talk @ CHEF 2017)**