Potential for multi-lepton mass spectrum --things that go bump in the night

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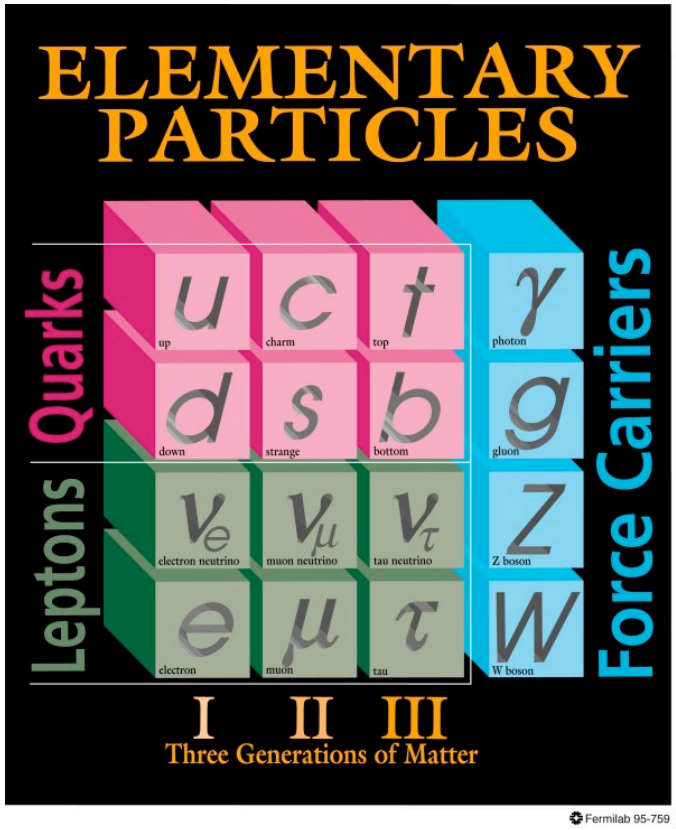
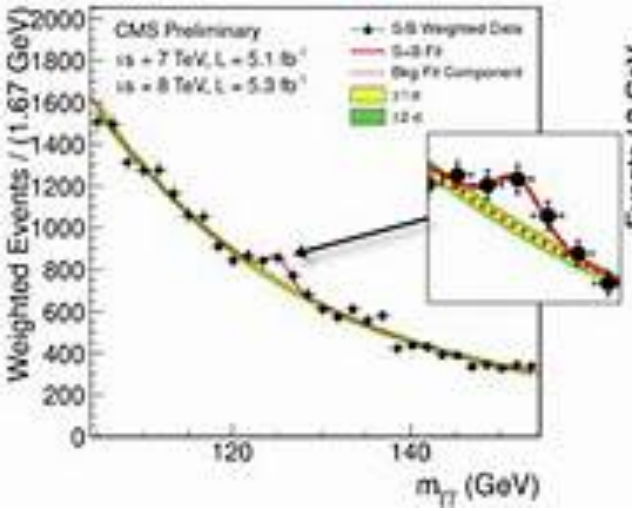
Nanjing Normal University
based on IJMA, vol.33, 1850224

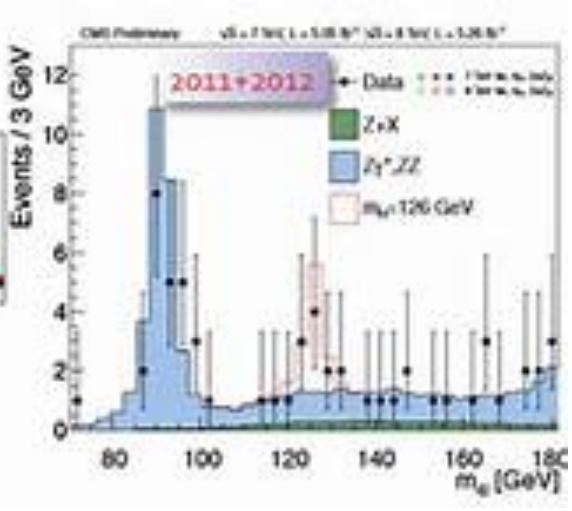
CLHCP @Dalian, October 25, 2019

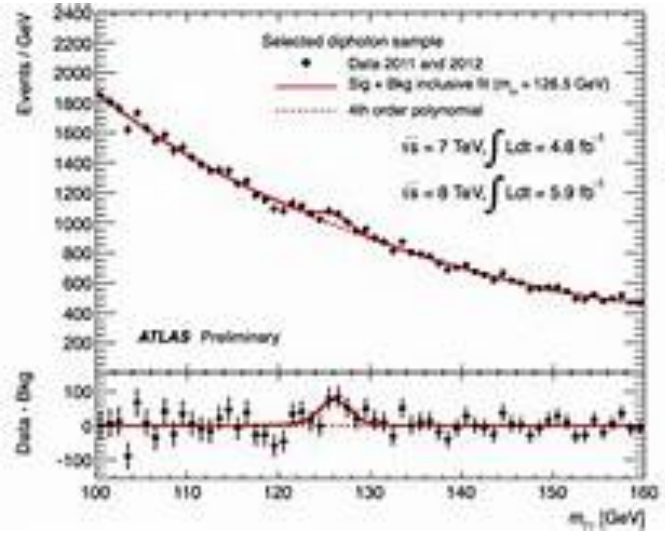
第五届中国LHC物理会议(The 5th China LHC Physics Workshop)

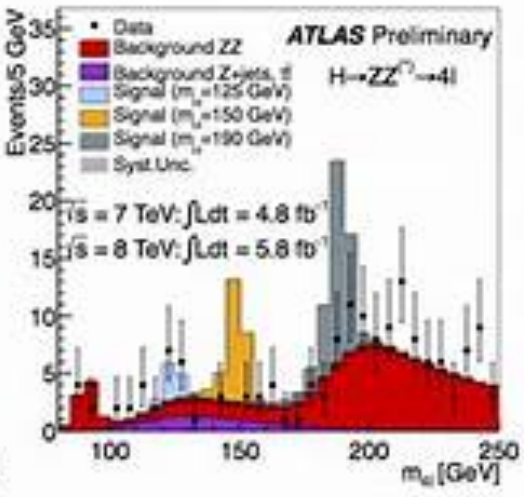
The fundamental building blocks of our world!









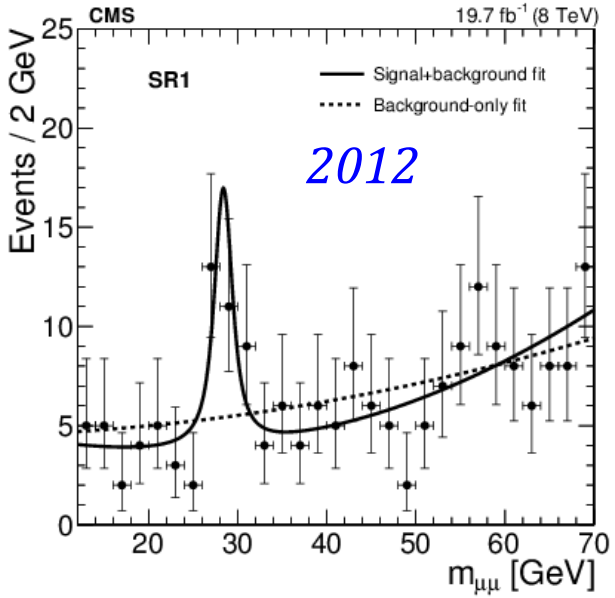


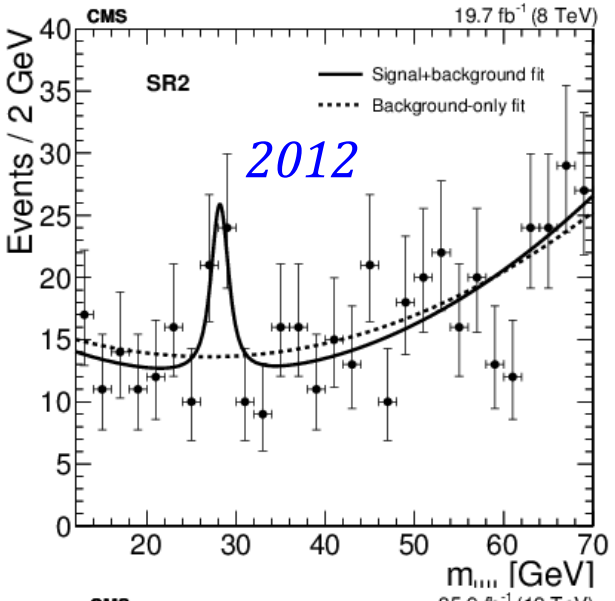
Missing particle Higgs (125 GeV)—was discovered by ATLAS+CMS

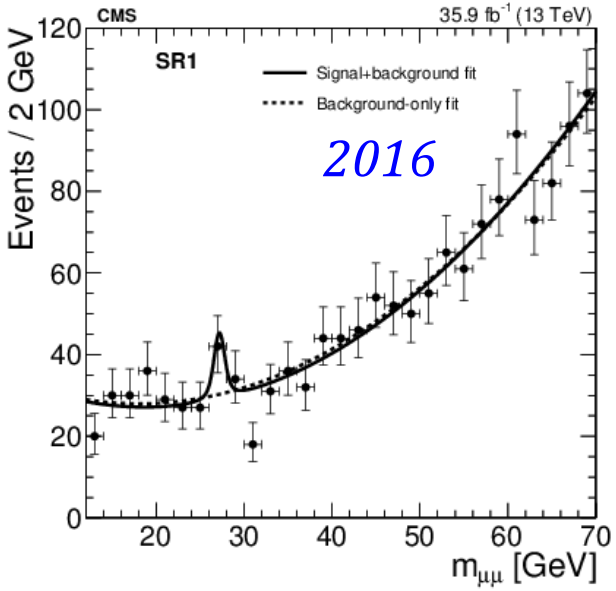
What else?

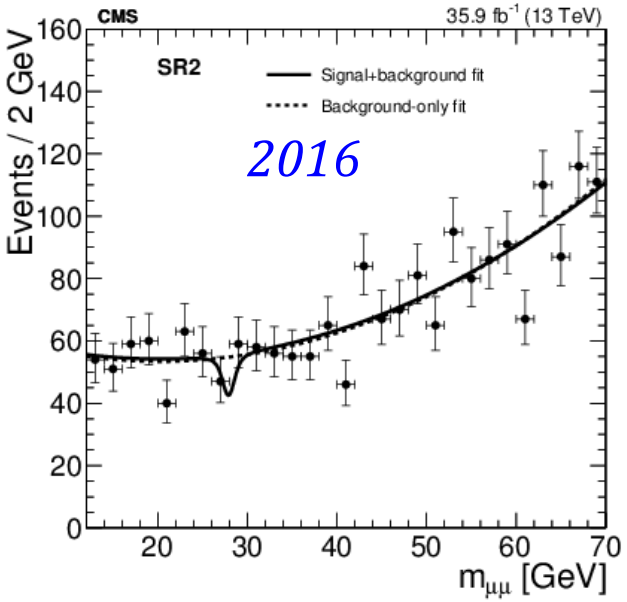
Dimuon result from CMS

arXiv:1808.01890 [hep-ex]
accepted by JHEP









ATLAS does not see
Same sensitivity?

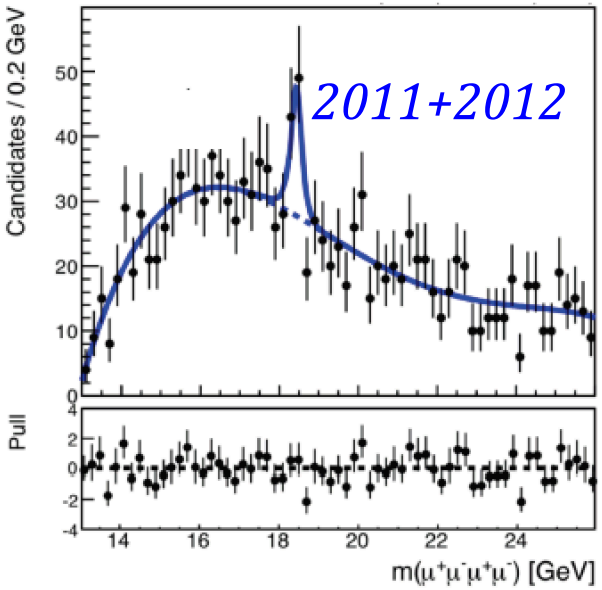
How about 2017 ?

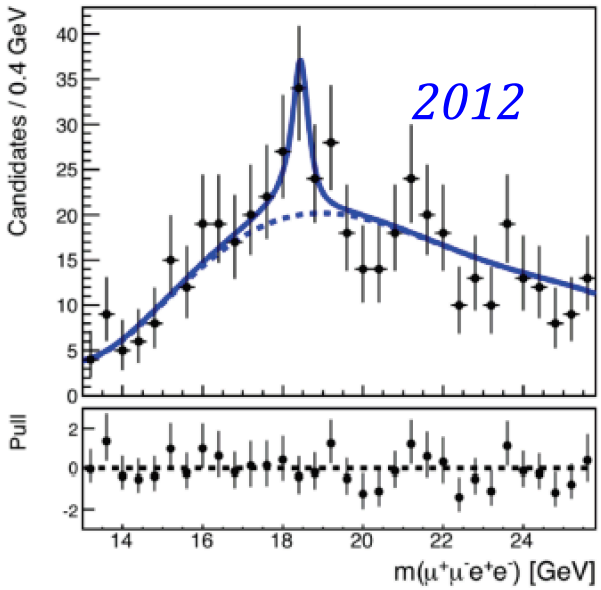
How about 2018?

If true → BSM

An exploration in the low mass region at LHC

Combined Result





- Do a simultaneous fit to both channels, with fixed signal shapes but floating mass value.
- Best mass : 18.4 ± 0.1 (stat.) ± 0.2 (syst.) GeV
- Local Significance: 4.86σ (p_value = 5.8×10^{-7})

- In order to calculate global significance, Look-Elsewhere-Effect must be taken into account. Lots of toy MC generations are required, not an efficient method.
- Global significance is calculated using Gross-Vitells method which is used in Higgs discovery.

Eur.Phys.J.C70:525-530,2010

- The returned global significance was 3.6σ.

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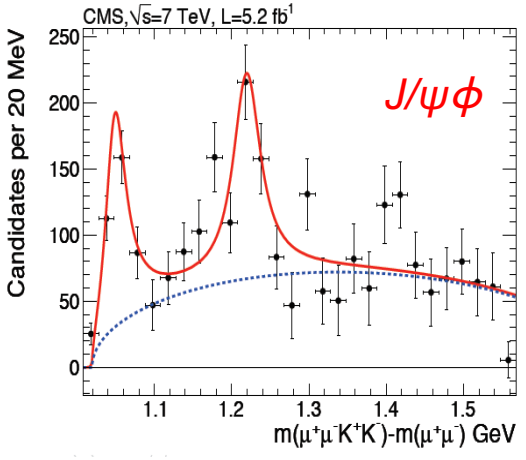
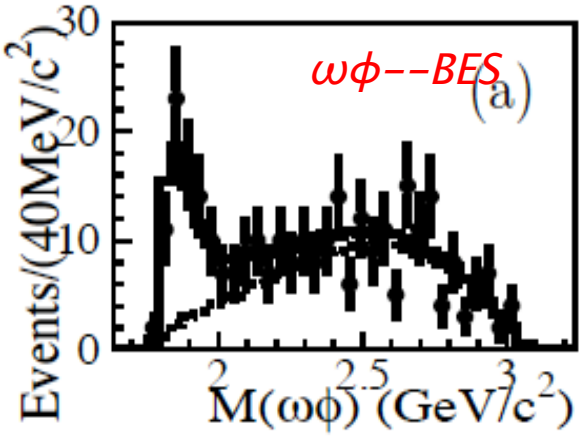
Taken from: http://meetings.aps.org/Meeting/APR18/Session/U09.6

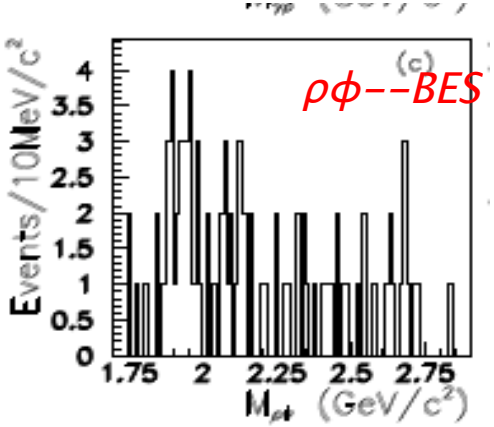
How about the full run II data?

If true, either BSM or breakthrough in QCD

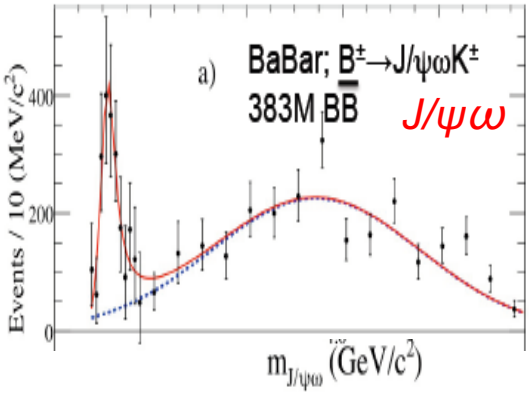
Motivation for Four-muon States

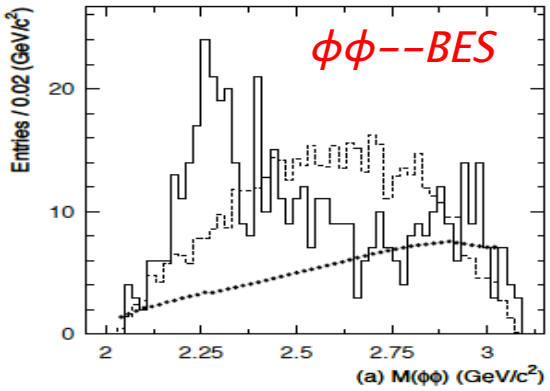


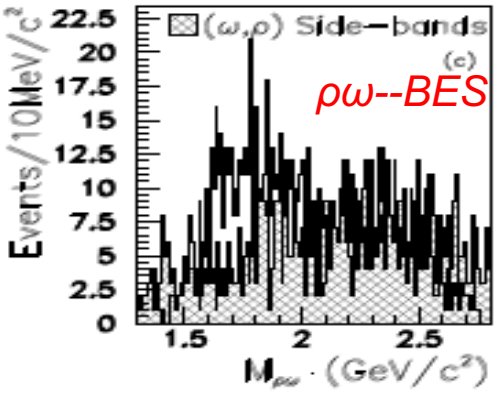




PRD 77, 012001(2008)







--Observed near V(I=0)V (I=0) threshold enhancement. Strong decay. Above (qq'+q'q) threshold.
Is there similar structures at J/ψJ/ψ, J/ψY, YY threshold? And four-muon final state?
--Other BSM motivations for four-muon final state:
SUSY/Hidden Valley, (exotic) Higgs➔(new)-boson-pair; each boson➔$\mu^+\mu^-$➔4-muons

never fully explored (GeVs-Z mass)
Multiple-lepton final states

http://arxiv.org/abs/hep-ph/0312114

Experiment	E_{cm} [GeV]
* ADONE-MEA	2.23
BEPC-BES	2.0 - 4.8
BEPC-BES	2.6 - 5.0
* SPEAR-SMAG †	2.4 - 5.0
* SPEAR-SMAG+LGW	3.598 - 3.886
SPEAR-Crystal Ball	3.670 - 4.496
SPEAR-Crystal Ball	5.0 - 7.4
SLAC-MARK-II	3.670 - 3.872
DORIS-DASP	3.6025 - 5.1950
DORIS-II-LENA	7.440 - 9.415
* DORIS-II-ARGUS	9.360
DORIS-II-Crystal Ball	9.39 - 9.46
* DORIS-II-DHHM	9.45 - 10.04
DORIS-II-DASP	9.51
VEPP-4-MD1	7.30 - 10.29
CESR-CUSB	10.43 - 11.09
CESR-CLEO	10.49
CESR-CLEO ††	10.60 - 11.20
CESR-CLEO II	10.52
DORIS/PETRA-PLUTO	3.6 - 30.8
* PETRA-TASSO	12.0 - 41.4
* PETRA-TASSO	12.00 - 31.25
* PETRA-TASSO	14.03 - 43.70
PETRA-TASSO	41.45 - 44.20
PETRA-JADE	12.00 - 46.47
PETRA-MARK-J	12.00 - 46.47
* PETRA-MARK-J	31.57
* PETRA-MARK-J	34.85
PETRA-CELLO	14.0 - 46.6
PEP-MAC	29.0
* PEP-MARK-II	29.0
* TRISTAN-AMY	50.0 - 61.4
* TRISTAN-TOPAZ	50.0 - 61.4
* TRISTAN-TOPAZ	57.77
* TRISTAN-TOPAZ	57.37 - 59.84
* TRISTAN-VENUS	50.0 - 52.0
* TRISTAN-VENUS	63.6 - 64.0

A) Not enough energy (associated production)

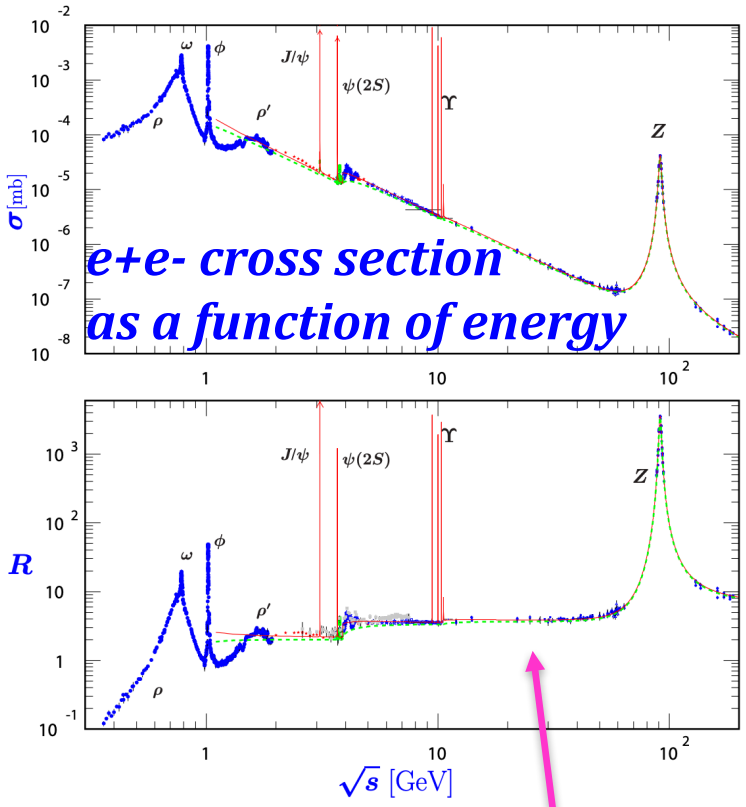
B) Not enough data

C) Opportunity comes with LHC
Enough energy and luminosity

D) Rich physics motivation + curiosity,
BSM—new scalar, Higgs-like,…
QCD—new dynamics, 4b states,…
anything else unexpected?

m_Z=90 GeV

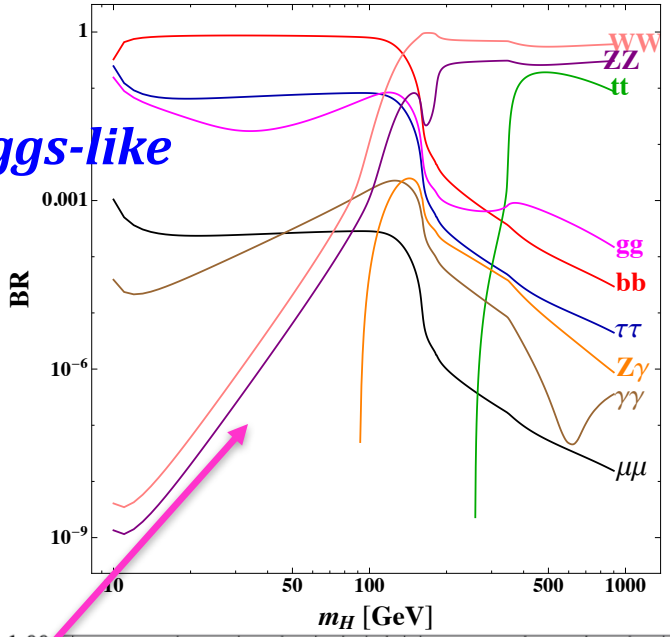
Motivation—Beyond Standard Model



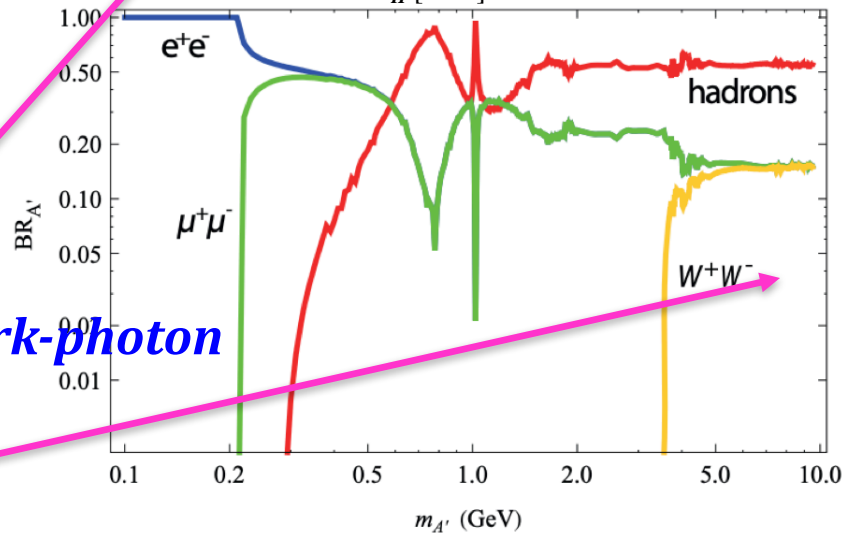
e+e- cross section as a function of energy

Figure 51.2: World data on the total cross section of $e^+e^- \to hadrons$ and the ratio $R(s) = \sigma(e^+e^- \to hadrons, s)/\sigma(e^+e^- \to \mu^+\mu^-, s)$. $\sigma(e^+e^- \to hadrons, s)$ is the experimental cross section corrected for initial state radiation and electron-positron vertex loops, $\sigma(e^+e^- \to \mu^+\mu^-, s) = 4\pi\alpha^2(s)/3s$. Data errors are total below 2 GeV and statistical above 2 GeV. The curves are an educative guide: the broken one (green) is a naive quark-parton model prediction, and the solid one (red) is 3-loop pQCD prediction (see "Quantum Chromodynamics" section of this *Review*, Eq. (9.7) or, for more details, K. G. Chetyrkin *et al.*, Nucl. Phys. **B586**, 56 (2000) (Erratum *ibid.* **B634**, 413 (2002)). Breit-Wigner

Higgs-like



Dark-photon



never fully explored region

Motivation—heavy tetra-quark states

- **Heavy-quark tetra-quark states--***PRD 86, 034004(2012)*

$b\bar{b}b\bar{b}$ *open to 4-lepton final states through upsilon pair*

$$0^{++\prime}: \quad M = 18.754\,\mathrm{GeV}, \quad M - M_{\mathrm{th}} = -544.\,\mathrm{MeV},$$
$$1^{+-\prime}: \quad M = 18.808\,\mathrm{GeV}, \quad M - M_{\mathrm{th}} = -490.\,\mathrm{MeV},$$
$$2^{++}: \quad M = 18.916\,\mathrm{GeV}, \quad M - M_{\mathrm{th}} = -382.\,\mathrm{MeV}.$$

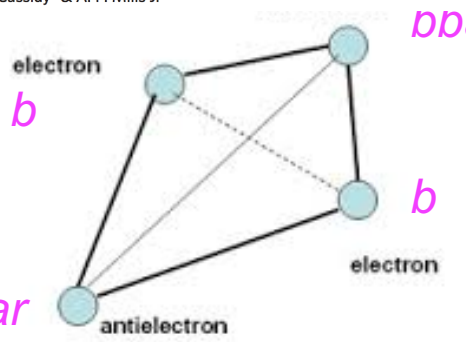
Vol 449|13 September 2007|doi:10.1038/nature06094 nature

positronium molecule (2007) nature
Analog at for b quark?

LETTERS

The production of molecular positronium

D. B. Cassidy[1] & A. P. Mills Jr[1]



Will be a breakthrough for exotic mesons if established, and reveal potential new dynamics

cccc--Kuang-Ta Chao

FERMILAB-Pub-80/70-THY

Table 1(a). The quantum numbers and masses for the $(cc)_{\bar{3}}^{*} - (\overline{cc})_{\bar{3}}$ states (without spin-dependent forces between two clusters)

L	S	J^{PC}	Mass (GeV)
1	0	1^{--}	6.55
	1	0^{++}, 1^{+-}, 2^{++}	
	2	1^{--}, 2^{--}, 3^{--}	
2	0	2^{++}	6.78
	1	1^{+-}, 2^{+-}, 3^{+-}	
	2	0^{++}, 1^{++}, 2^{++}, 3^{++}, 4^{++}	
3	0	3^{--}	6.98
	1	2^{++}, 3^{++}, 4^{++}	
	2	1^{--}, 2^{--}, 3^{--}, 4^{--}, 5^{--}	

Y(1S)Y(1S) Cross section @ 8 TeV

JHEP 1705 (2017) 013

Y(1S)Y(1S) cross section at pp collision energy @8 TeV:

$$\sigma(pp \to YY) = 68.8 \pm 12.7(stat) \pm 7.4(syst) \pm 2.8(BR)pb$$

A benchmark measurement at LHC that is interesting for both 4b state searches and BSM searches, which gives us an idea on the production of 4 bottom quarks at LHC.

Would be more meaningful if the SPS/DPS components are separated.

The studies of VV final states and multiple lepton final states can not only be done at LHC, it has more potential at CEPC, or even a visionary low energy photon collider. Note: miss cross section numbers

Recoil masses at CEPC

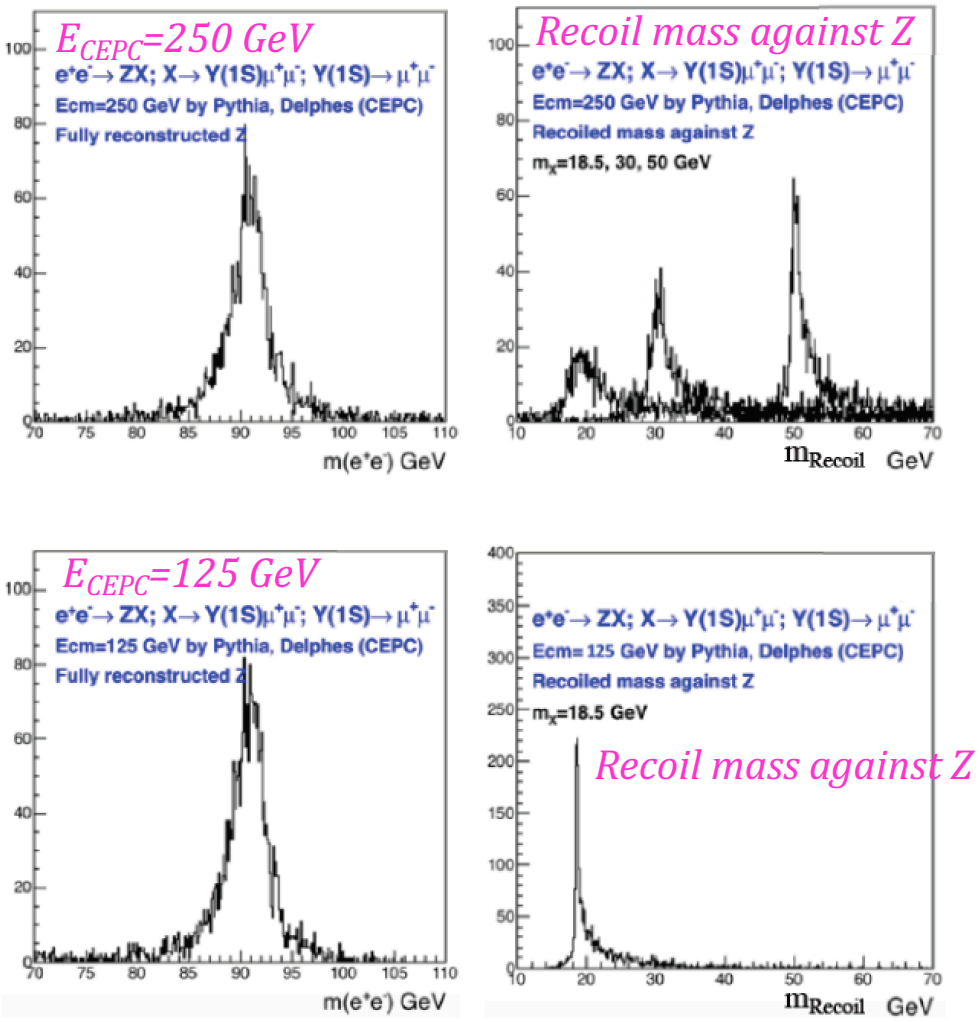


Fig. 2. The fully reconstructed Z mass and its recoiled mass against Z particle at the CEPC with different collision energy by assuming X particle mass as 18.5, 30 and 50 GeV produced in the process of $e^+e^- \to ZX$; $X \to Y(1S)\mu^+\mu^-$; $Y(1S) \to \mu^+\mu^-$. These events are simulated by Delphes with CEPC configuration.

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Simulated using Delphes CEPC detector with different collision energy values.

An unique approach at CEPC e^+e^- collider

It is sensitive to all final states

It is useful to measure BFs

Other $\tau^+\tau^-$ final state at CEPC

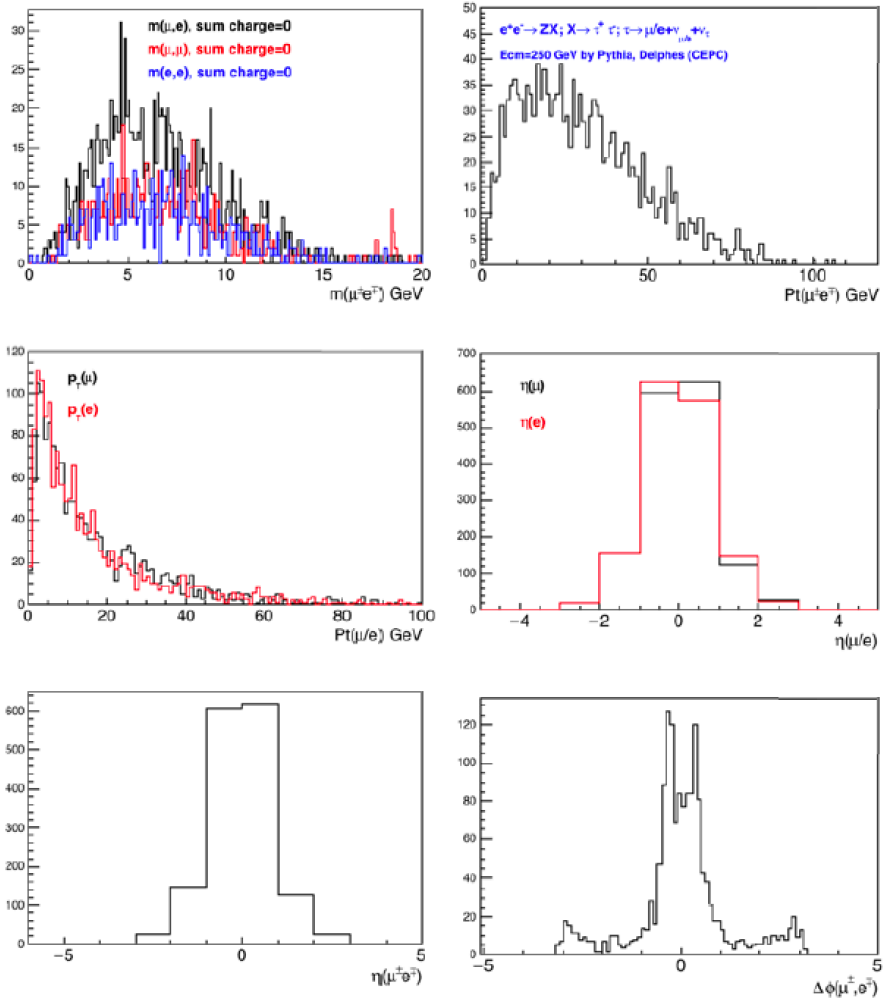

Fig. 7. The features of the $\mu^{\pm}e^{\mp}$ ($\tau^{\pm}\tau^{\mp}$) system in the $e^+e^- \to ZX$; $X \to \tau^{\pm}\tau^{\mp}$; $\tau^{\pm} \to \ell^{\pm}$ + anything-else, $\tau^{\mp} \to \ell^{\mp}$ + anything-else, where $\ell = \mu$, e process at the CEPC: (top left) the $\mu^{\pm}e^{\mp}/\mu^{\pm}\mu^{\mp}/e^{\pm}e^{\mp}$ mass distributions; (top right) the p_T distributions of $\mu^{\pm}e^{\mp}$; (middle left) the p_T distribution of muon and electron; (middle right) the η distribution of muon and electron; (bottom left) the η distribution of $\mu^{\pm}e^{\mp}$; (bottom right) the $\Delta\phi$ distribution between muon and electron. These events are simulated by Delphes with CEPC configuration.

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Simulated using Delphes CEPC detector

Another approach for $\tau^+\tau^-$ final state through opposite u e channel at CEPCe^+e^- collider

Two photon process at CEPC

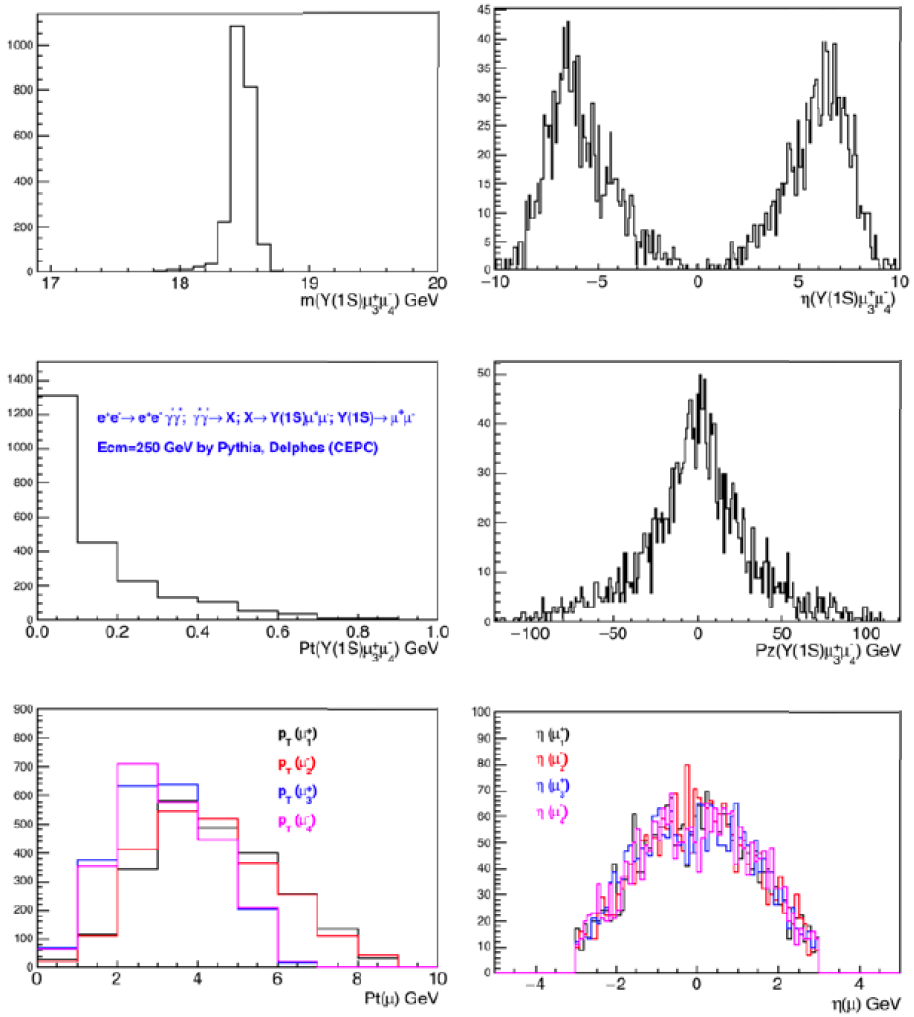

Fig. 8. The features of the four-muon system in the $e^+e^- \to e^+e^-X$; $X \to Y(1S)\mu^+\mu^-$; $Y(1S) \to \mu^+\mu^-$ process at the CEPC: (top left) the invariant mass of the four muons; (top right) the η distribution of the four muons; (middle left) p_T of the four muons; (middle right) p_Z of the four muons; (bottom left) p_T of each muon; (bottom right) η of each muon. These events are simulated by Delphes with CEPC configuration.

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Simulated using Delphes CEPC detector

Another unique approach to study multiple lepton final state at CEPC e^+e^- collider

Two body decay for two photon process at CEPC

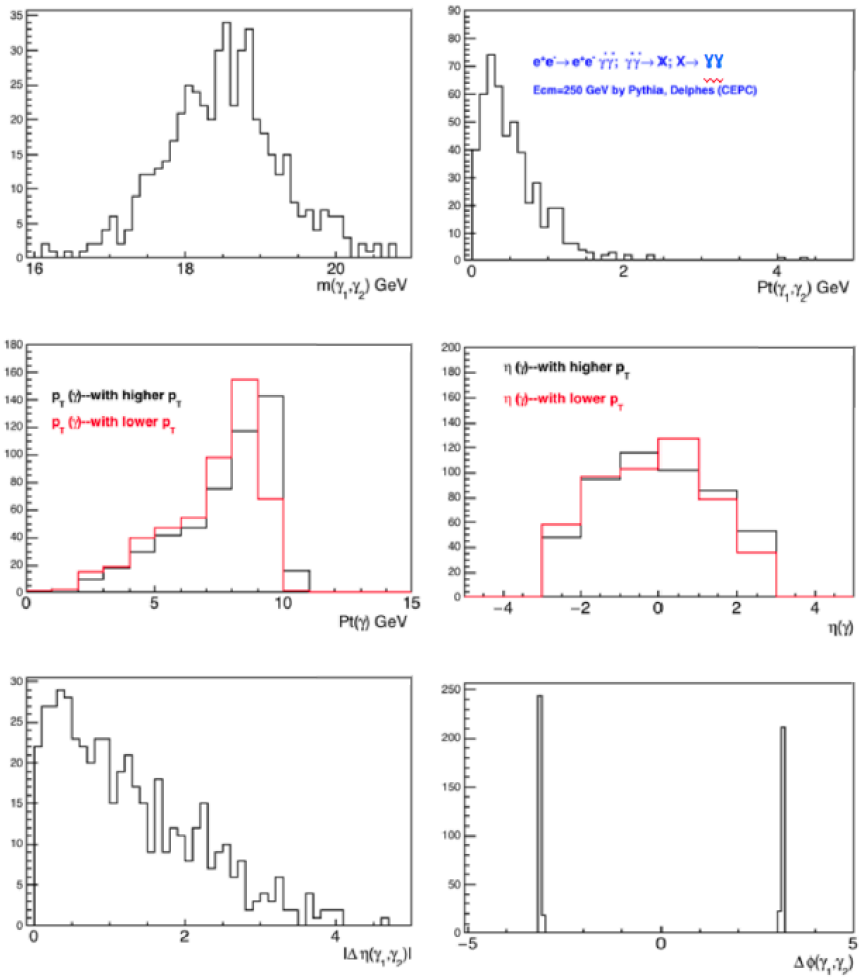

Fig. 10. The features of the $\gamma\gamma$ system in the $e^+e^- \to e^+e^-X$; $X \to \gamma\gamma$ process at the CEPC: (top left) the diphoton mass distribution; (top right) the p_T distribution of the diphoton; (middle left) the p_T distribution of each photon; (middle right) the η distribution of each photon; (bottom left) the $\Delta\eta$ distribution of the diphoton; (bottom right) the $\Delta\phi$ distribution of the diphoton. These events are simulated by Delphes with CEPC configuration.

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Simulated using Delphes CEPC detector

An example of two body decays through two photon process at CEPC e^+e^- collider

Kinematic features at visionary photon collider

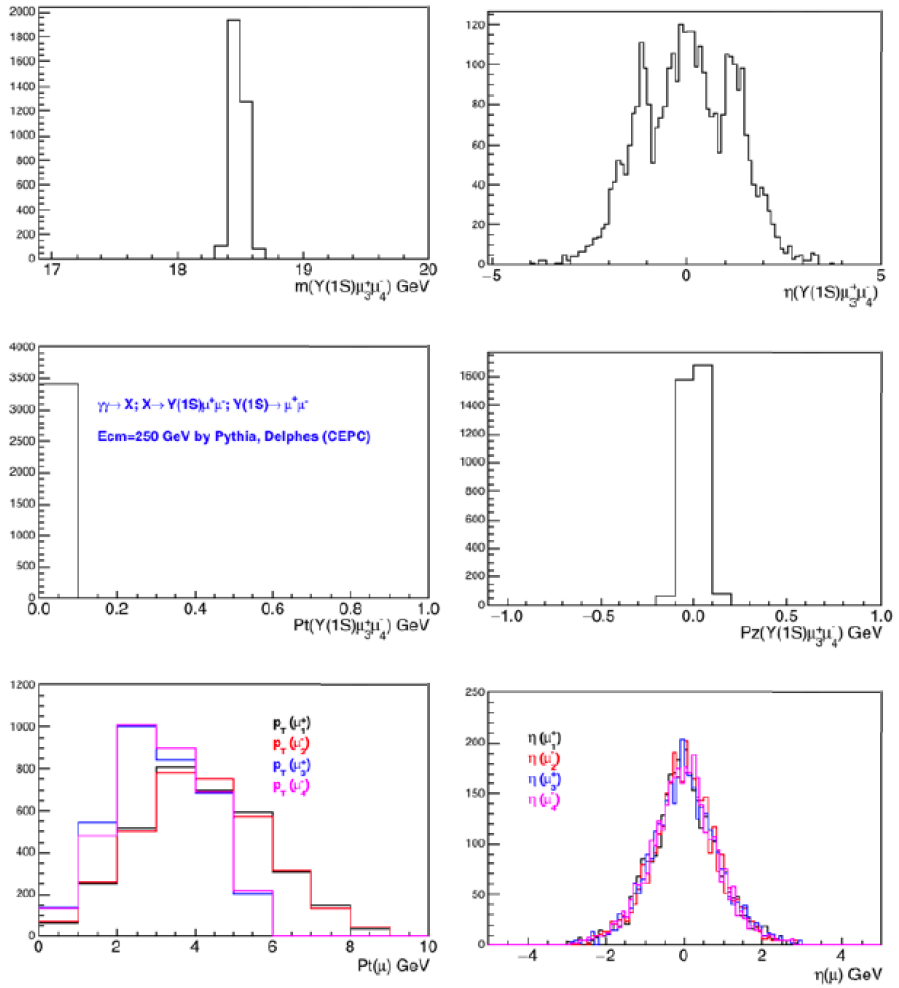

Fig. 12. The features of the four-muon system in a visionary photon collider with total energy of 18.5 GeV ($\gamma\gamma \to X$; $X \to Y(1S)\mu^+\mu^-$; $Y(1S) \to \mu^+\mu^-$). (top left) The invariant mass; (top right) the η distribution; (middle left) p_T; (middle right) p_Z; (bottom left) p_T of the four muons; (bottom right) η of the four muons. These events are simulated by Delphes with CEPC configuration.

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Simulated using Delphes CEPC detector

A kinematic example in a visionary Low energy photon collider, similar to two photon process at CEPC e^+e^- collider

Summary

- *Rich BSM and QCD physics motivation for low mass multiple lepton final state*

- *This region has never been fully explored before*

- *Great opportunities at LHC*

- *Complementary at CEPC or a visionary photon collier.*

Thank you! ☺

Backup