Prospect for Slepton Pair Production in CEPC

Joint Workshop of the CEPC Physics, Software & New Detector Concept. May 23-25, 2022

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In collaboration with Yang Zhang(ZZU). arXiv: 2206.XXXXX

Supersymmetry

- A supersymmetry (SUSY) theory:

  Matter equations = force equations

- Why SUSY?
  - A (maybe) good solution to DM mystery.
  - New source for the 4.2σ muon g-2 discrepancy.
  - Hierarchy problem.
  - Gauge theory unification.

  …

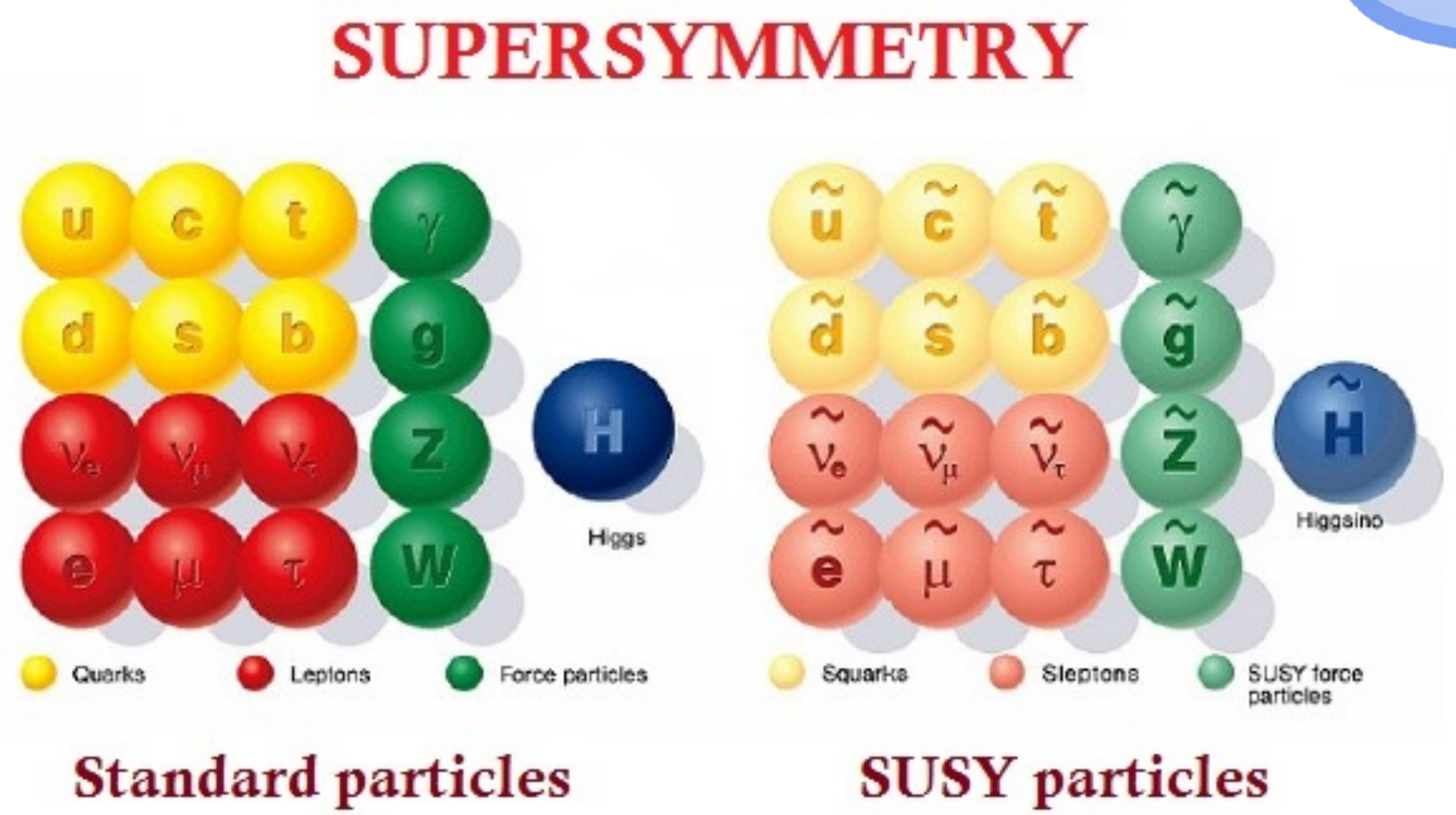
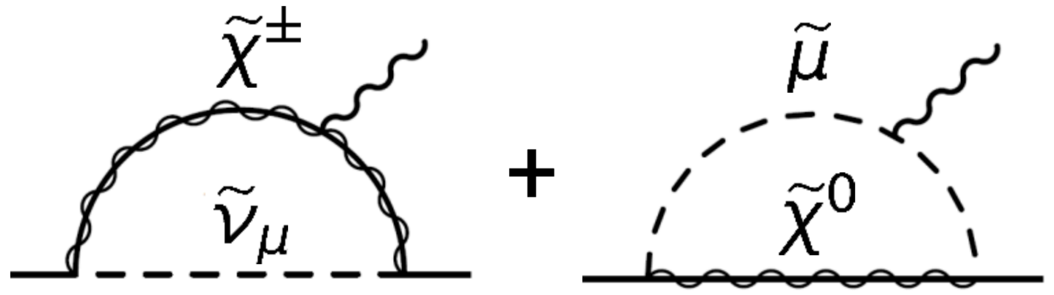
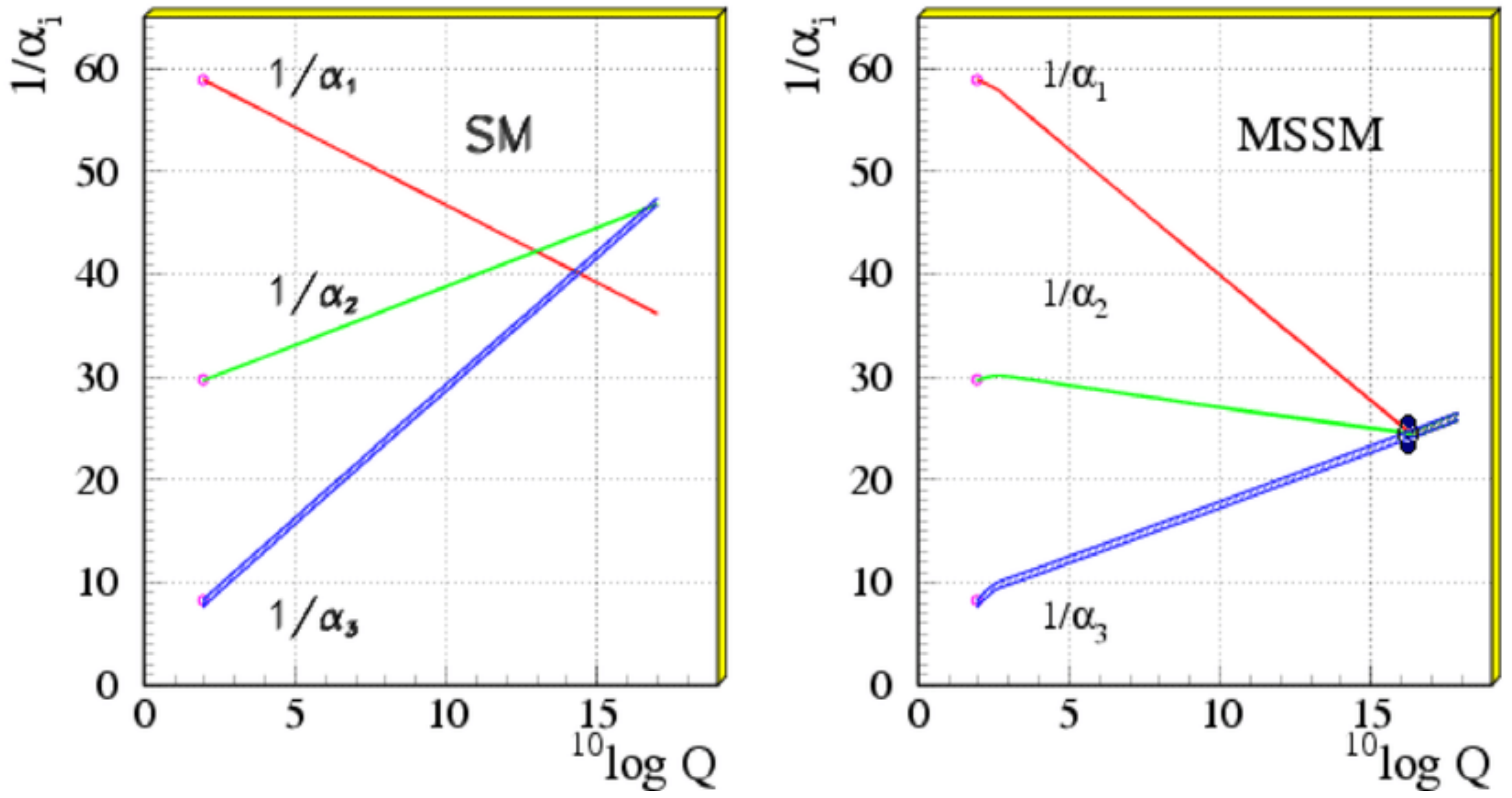


Illustration by CERN & IES de SAR
*Notes: image not entirely!



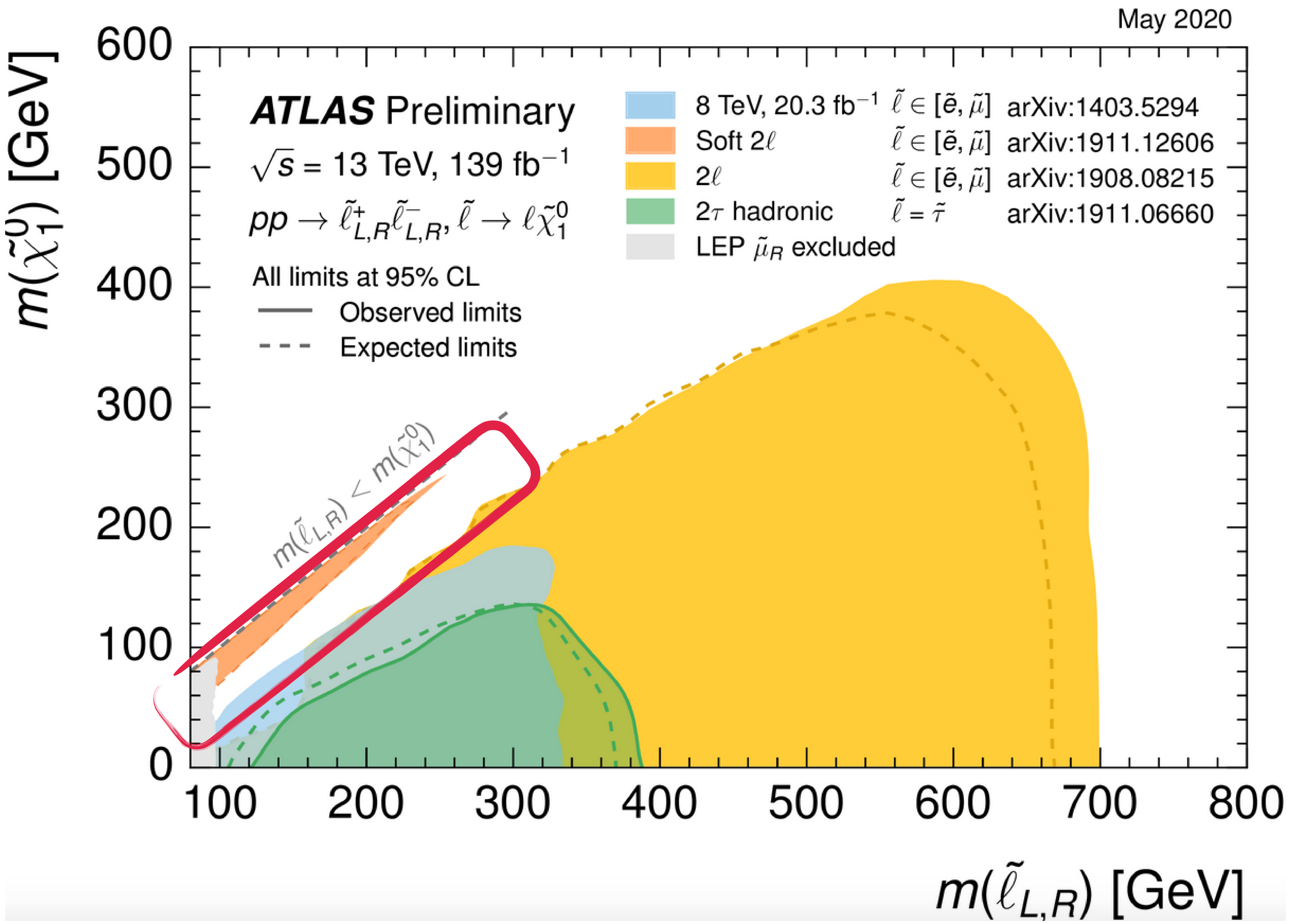


Slepton searches at Collider

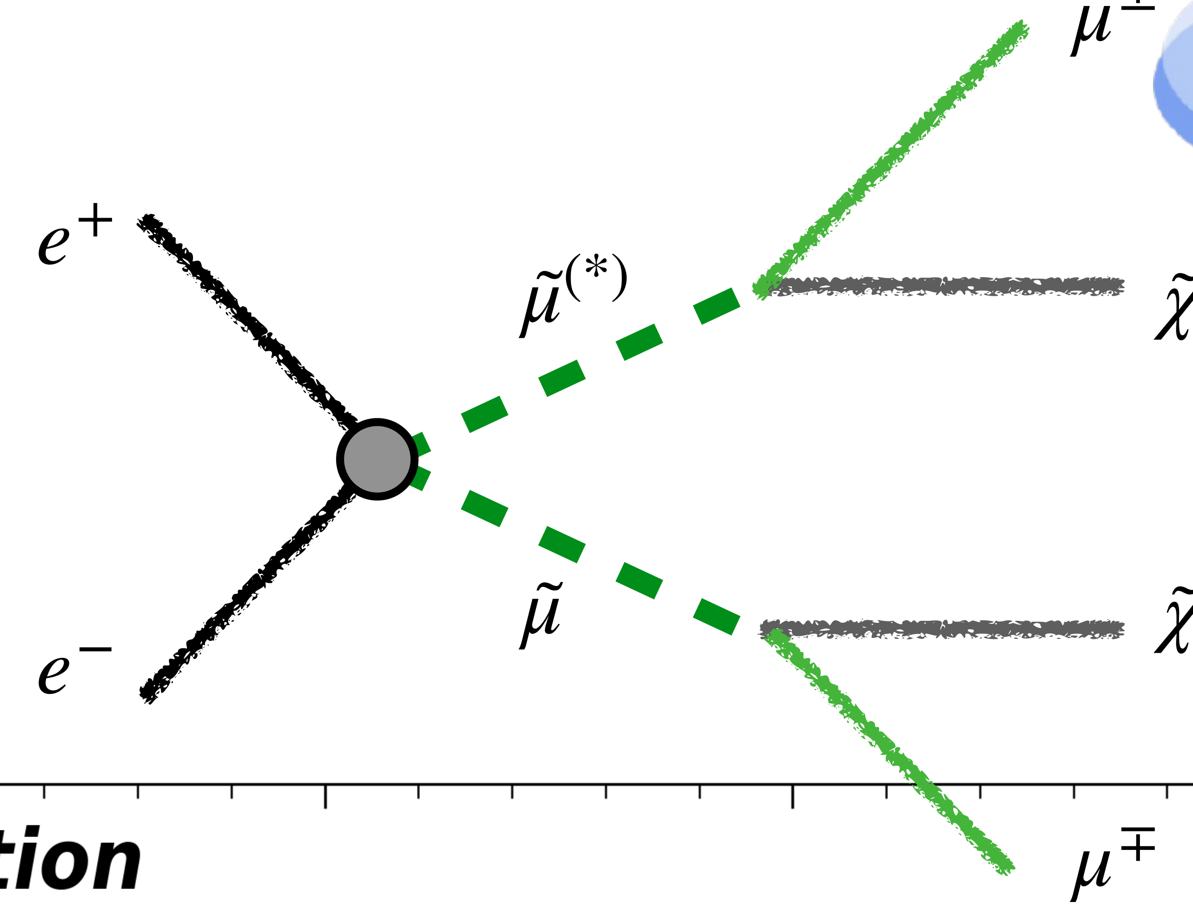
- Light slepton (or slepton-like pariticle, especially smuon-like) is favored to explain
  - lepton g-2 anomaly (both muon and electron),
  - DM phenomenology.

like SUSY and the model in arXiv: 2104.06421.

- LHC Run-II with 139 fb^{-1} have already set constraints on di-lepton+$E_{\mathrm{T}}^{\mathrm{miss}}$ final states in searches for slepton pair production.
- Compressed spectrum region can be probed via Recursive Jigsaw Reconstruction(RJR) technique.
- Still a gap uncovered for $m_{\tilde{\ell}}$ at $\mathcal{O}(100)$ GeV.



Off-shell production at lepton collider



arXiv: 2104.06421 provide an idea of searching $\tilde{\mu}$ via pair production process

$$e^+e^- \to \tilde{\mu}\tilde{\mu}^{(*)} \to \mu^+\tilde{\chi}_1^0\mu^-\tilde{\chi}_1^0$$

with one $\tilde{\mu}$ being off-shell.

- On-shell region: $m_{\tilde{\mu}} \leq \sqrt{s}/2$.

  Narrow width approximation (NWA)

  $$\sigma(e^+e^- \to \mu\mu\tilde{\chi}_1^0\tilde{\chi}_1^0) \approx \sigma(e^+e^- \to \tilde{\mu}\tilde{\mu}) \times \left(\mathrm{BR}(\tilde{\mu} \to \mu\tilde{\chi}_1^0)\right)^2$$

  - NWA is valid in condition: $\sqrt{s}/2 - m_{\tilde{\mu}} \gg \Gamma_{\tilde{\mu}}$

- Off-shell region: $m_{\tilde{\mu}} > \sqrt{s}/2$:

  The cross section of $2 \to 3$ process is smaller than that of $2 \to 2$ process by a factor of $16\pi^2$.

  Assuming $\mathrm{BR}(\tilde{\mu} \to \mu\tilde{\chi}_1^0) = 1$, for 5.05 ab^{-1} data, about 800 signal events can be produced of mass point $(m_{\tilde{\mu}}, m_{\tilde{\chi}_1^0})$ = (140, 0) GeV.

- $(m_{\tilde{\mu}}, m_{\tilde{\chi}_1^0})$ = (115, 0) GeV: 23.6 fb
- $(m_{\tilde{\mu}}, m_{\tilde{\chi}_1^0})$ = (120, 0) GeV: 0.41 fb
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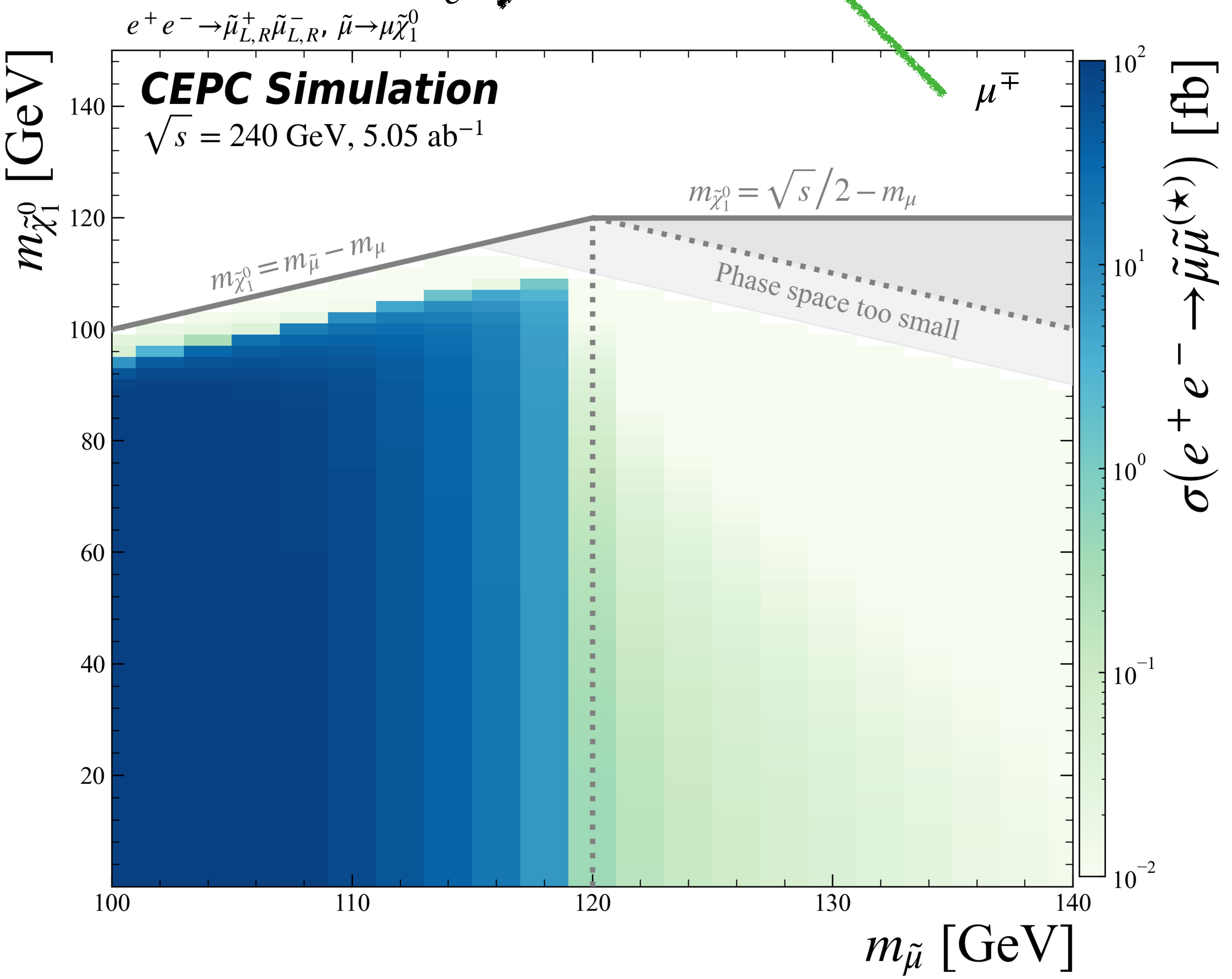

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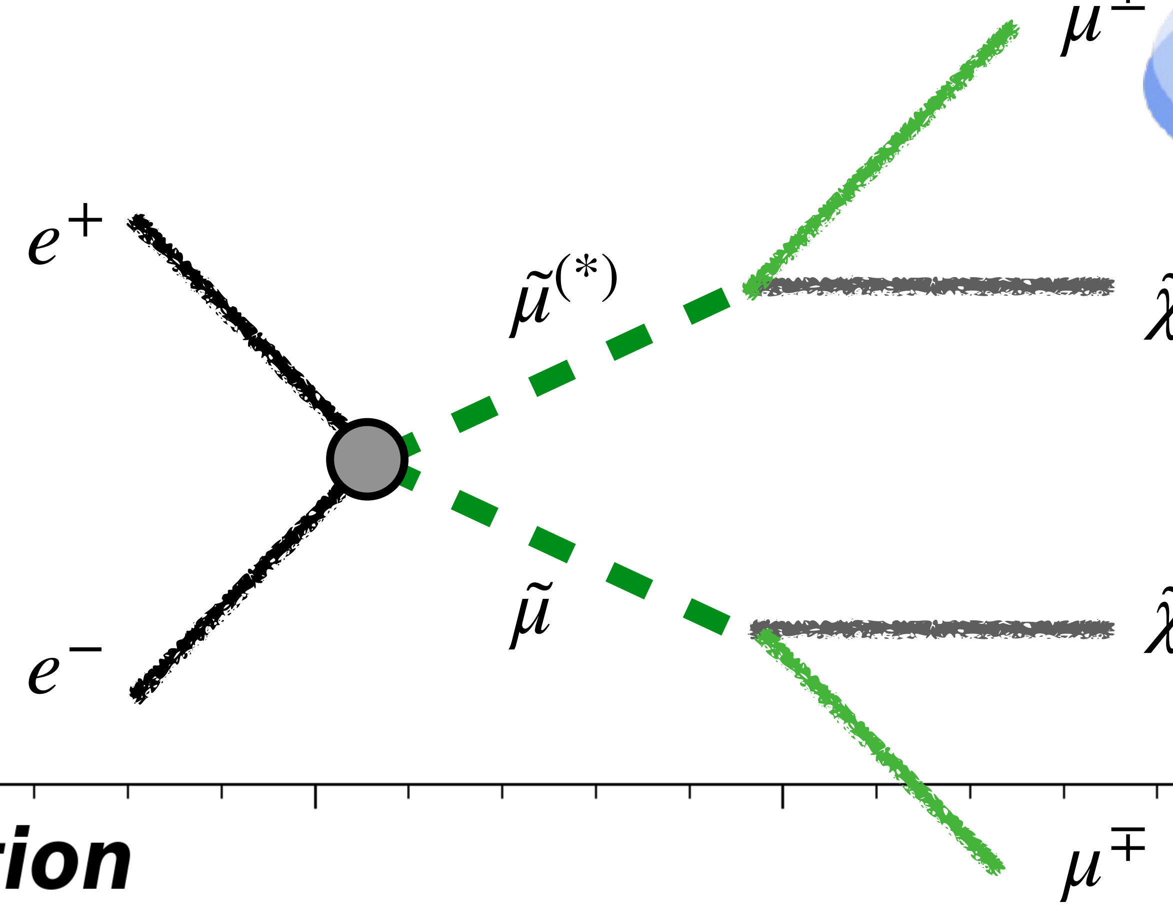

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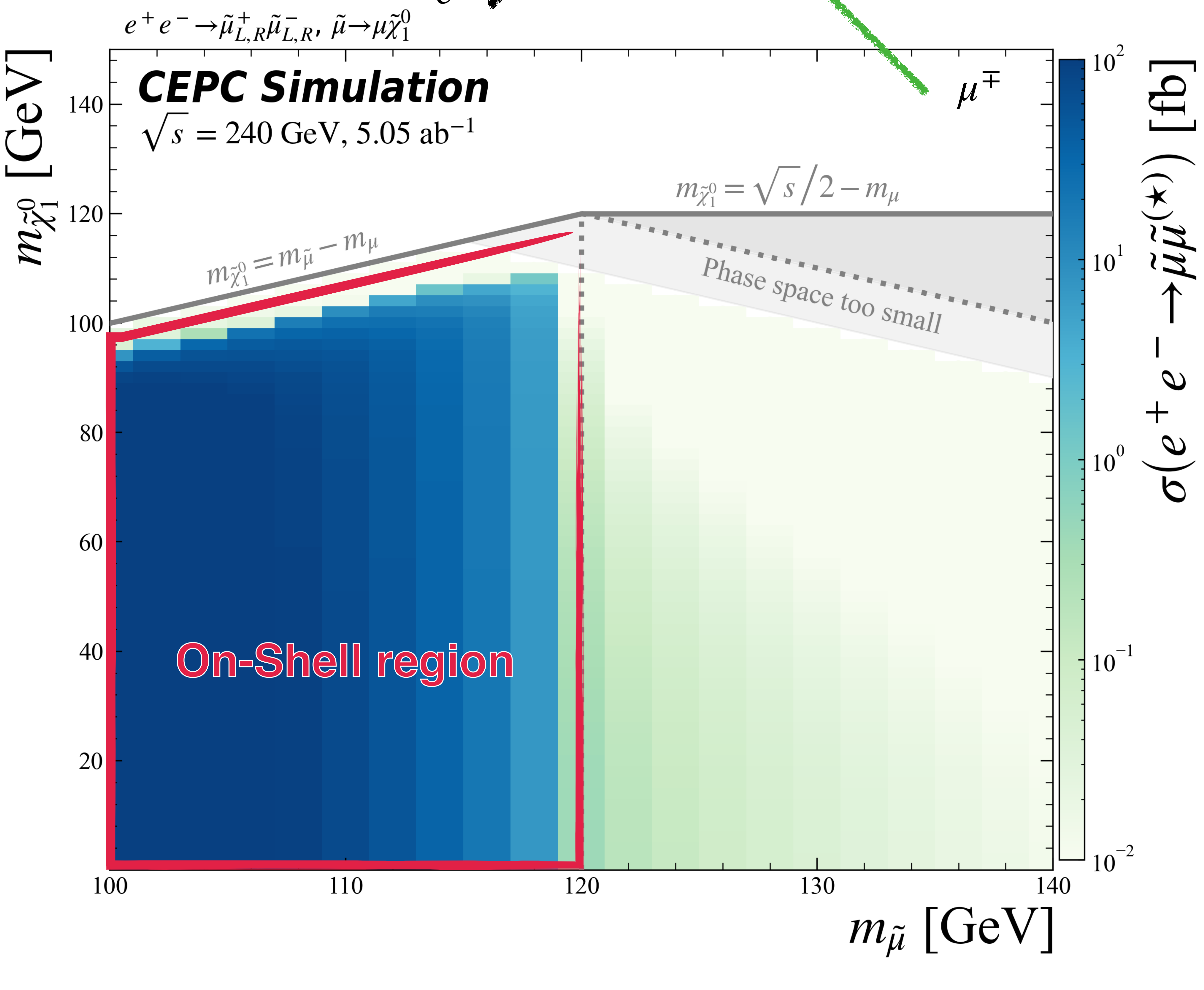

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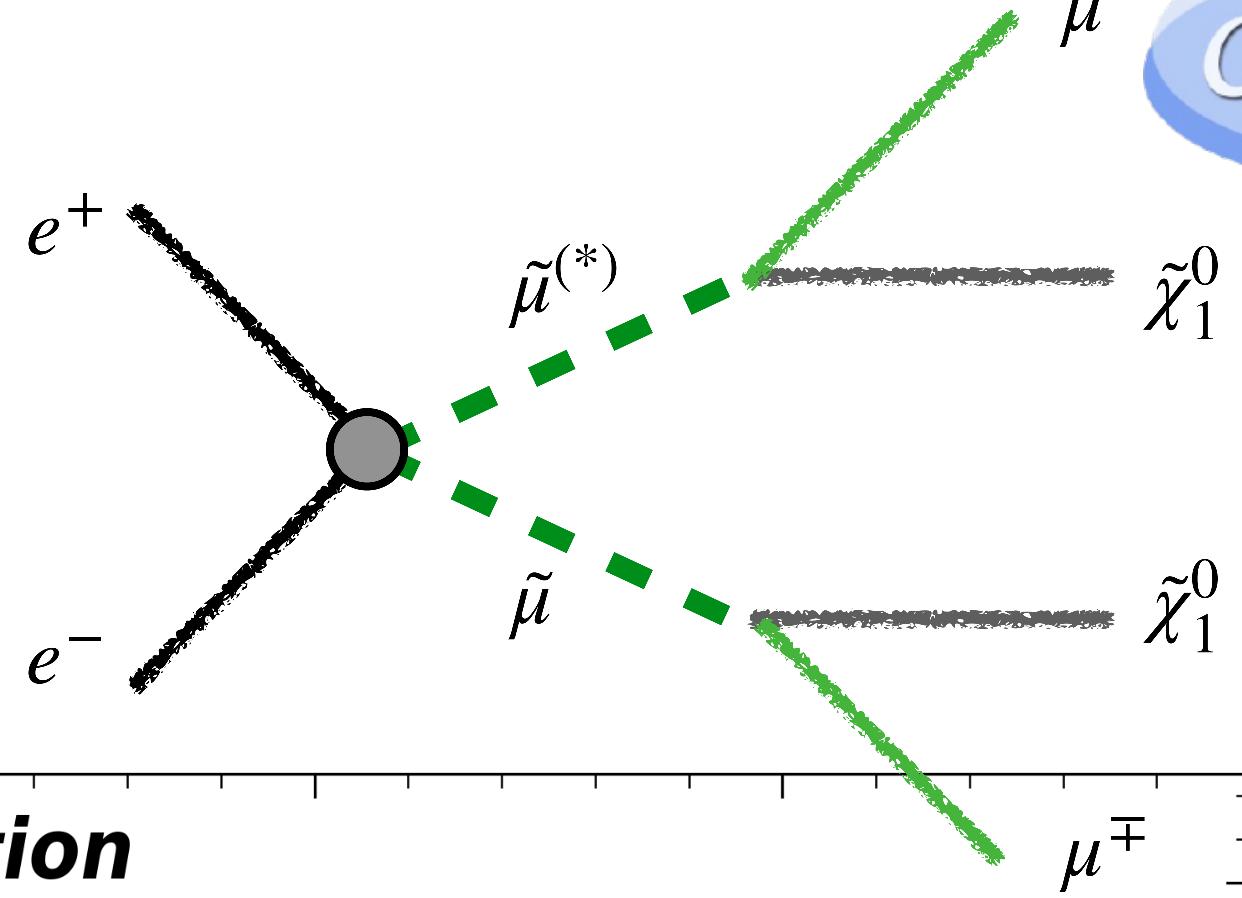

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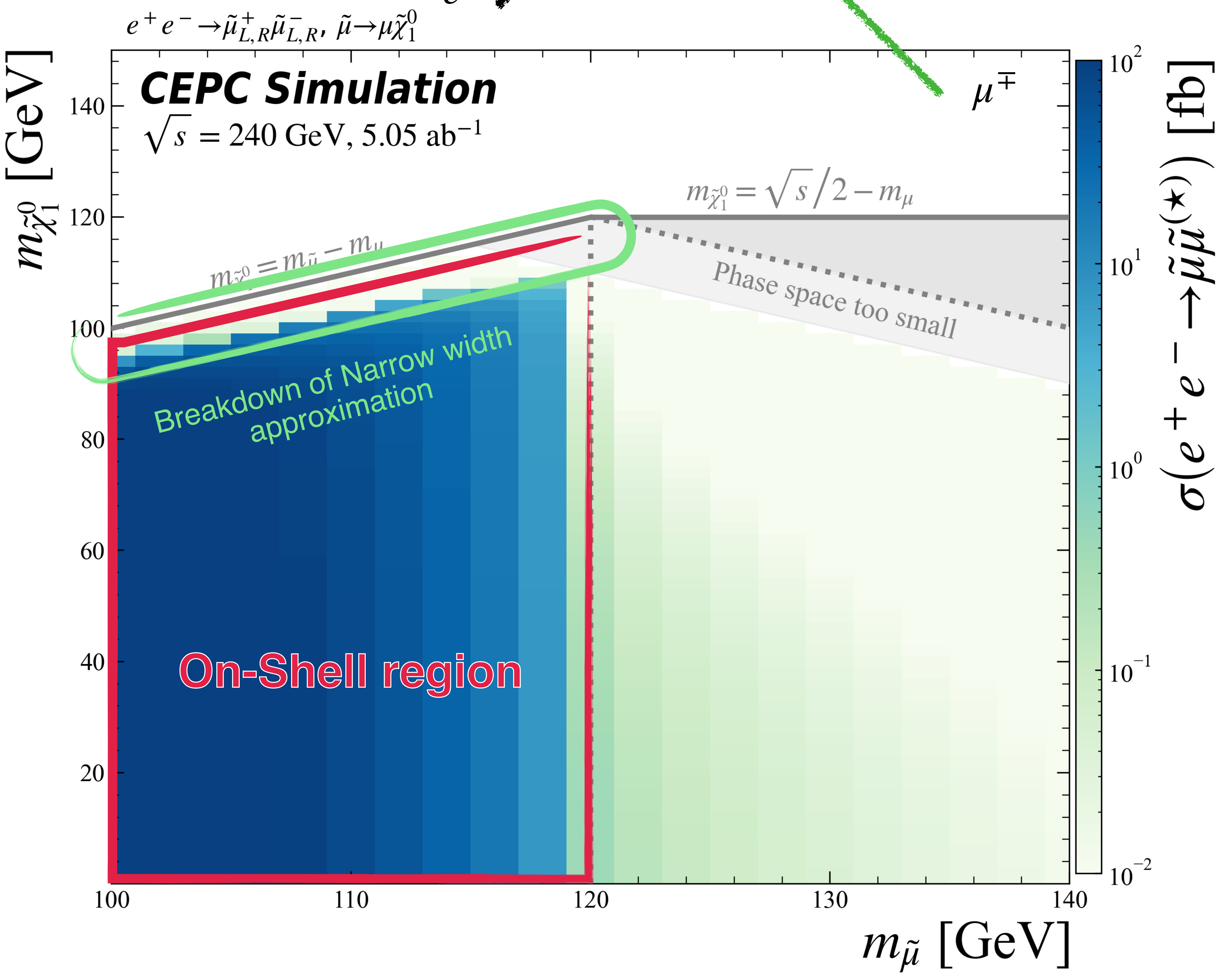

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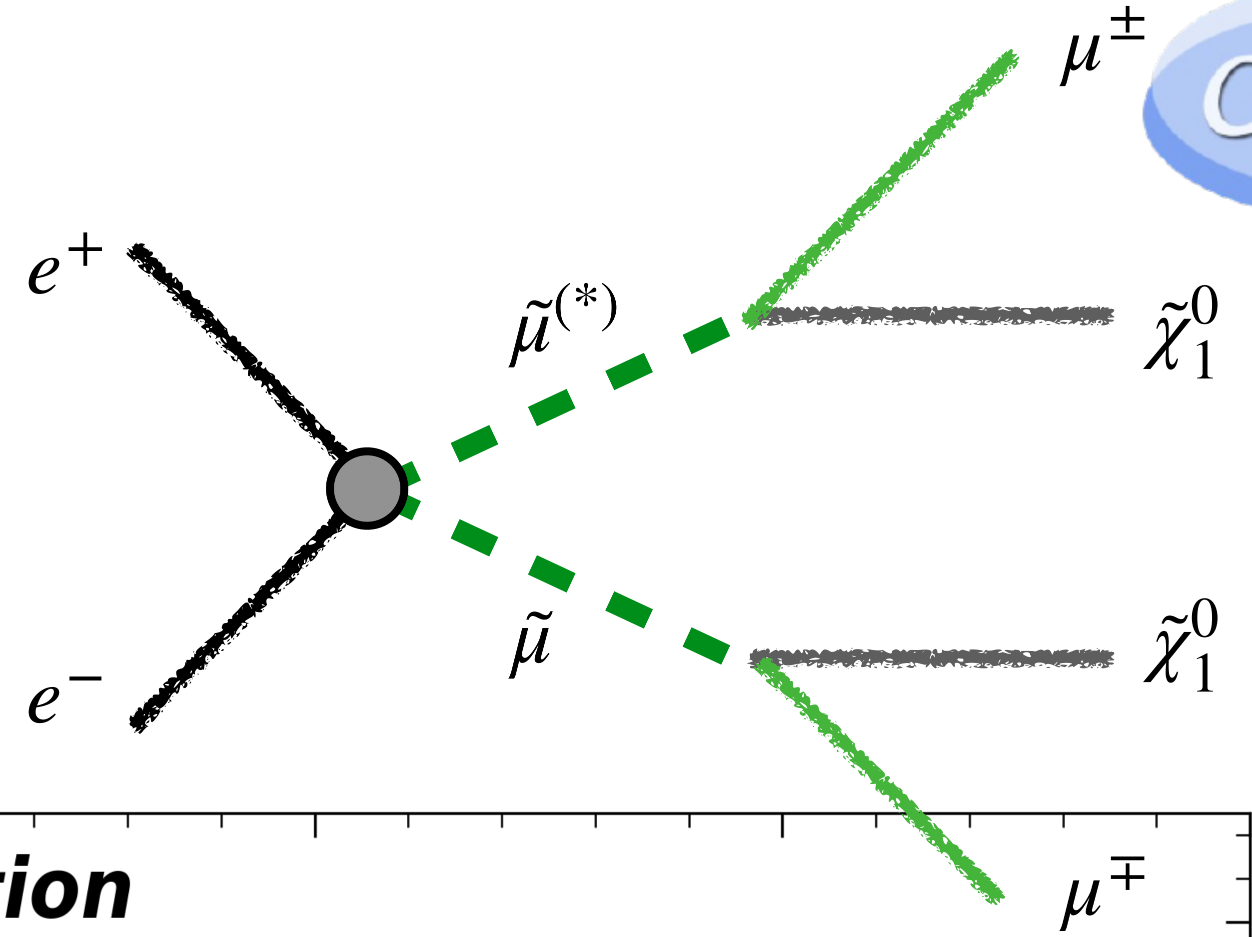

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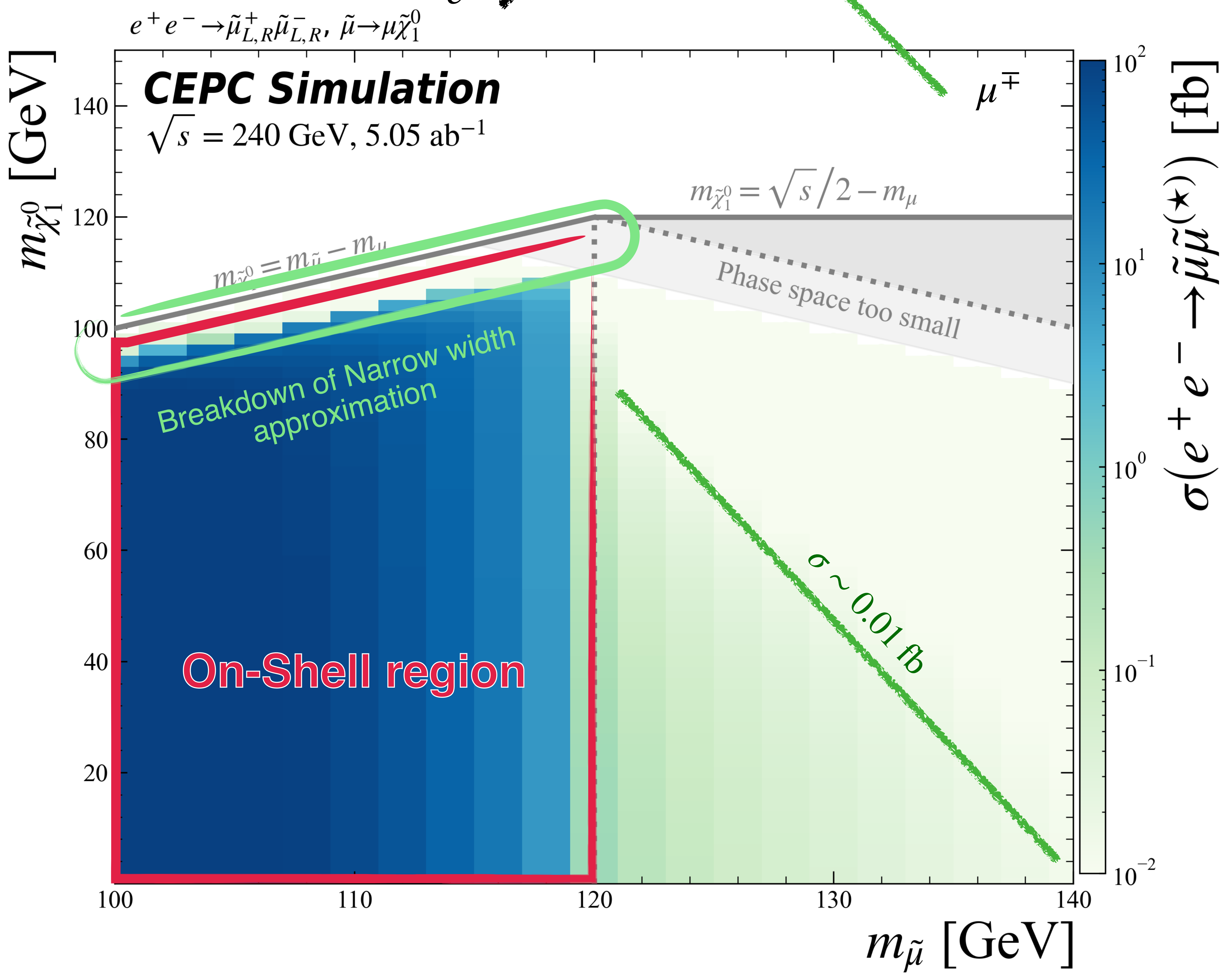


Background & Current Results

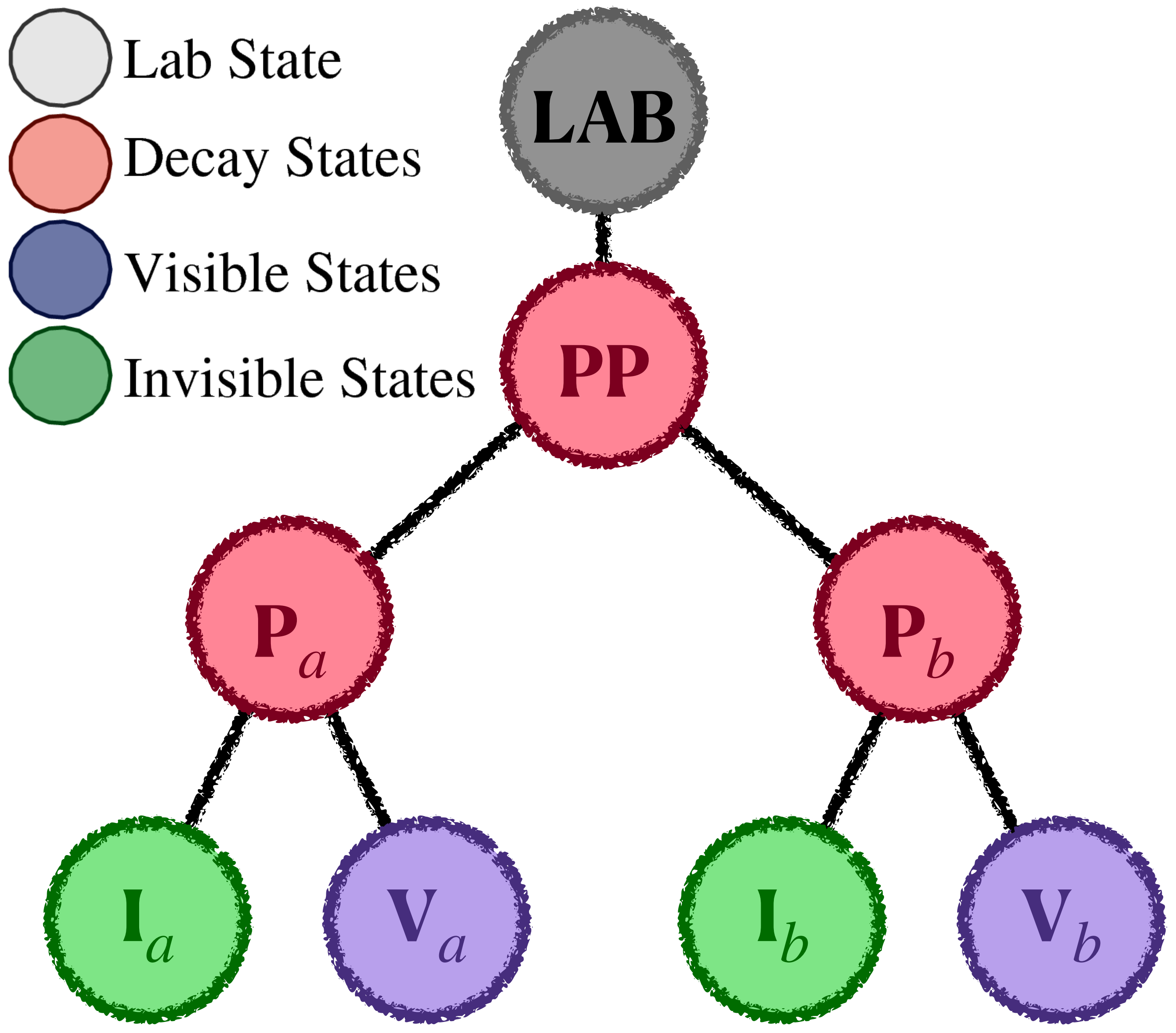
process	Cross Section [fb]
$\mu\mu$	4967.58
$\tau\tau$	4374.94
$WW \to \ell\ell$	392.96
$ZZorWW \to \mu\mu\nu\nu$	214.81
$ZZorWW \to \tau\tau\nu\nu$	205.84
$\nu Z, Z \to \mu\mu$	43.33
$ZZ \to \mu\mu\nu\nu$	18.17
$\nu Z, Z \to \tau\tau$	14.57
$ZZ \to \tau\tau\nu\nu$	9.2
$\nu\nu H, H \to \tau\tau$	3.07
$e\nu W, W \to \mu\nu$	429.2
$e\nu W, W \to \tau\nu$	429.42
$eeZ, Z \to \nu\nu$	29.62
$eeZ, Z \to \nu\nu$ or $e\nu W, W \to e\nu$	249.34

Table from Xuai Zhuang's talk at Snowmass 2021 EF08 BSM Model specific section

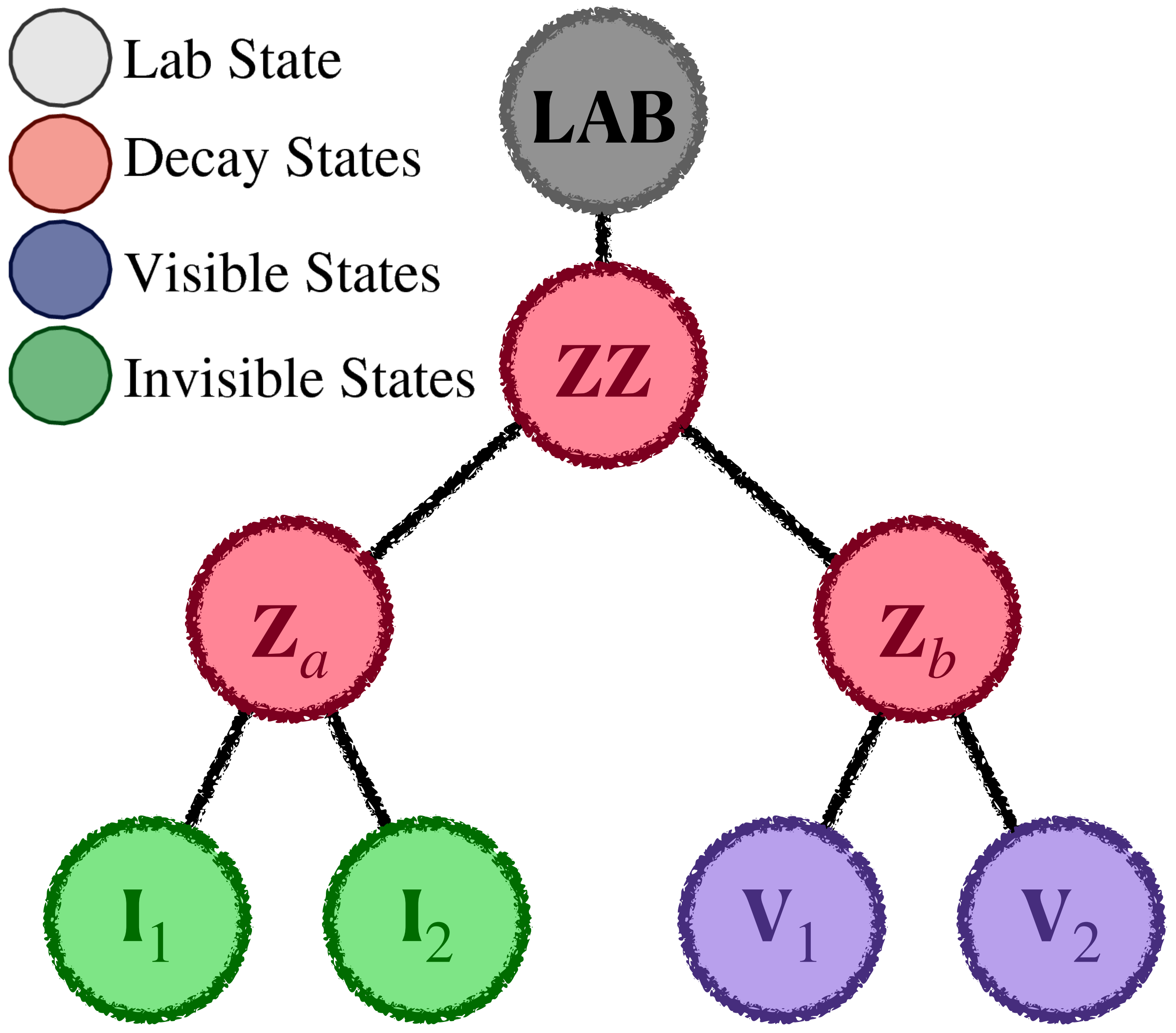
Dominated backgrounds are SM processes with OS muon pair + $\mathbf{p}^{\text{miss}}$ final states.

For details discussion of SM background, please see next Feng LU's talk. I just give some comment here.

Most challenge is to distinguish smuon signal from WW background.



Decay tree of Smuon pair and WW BKG



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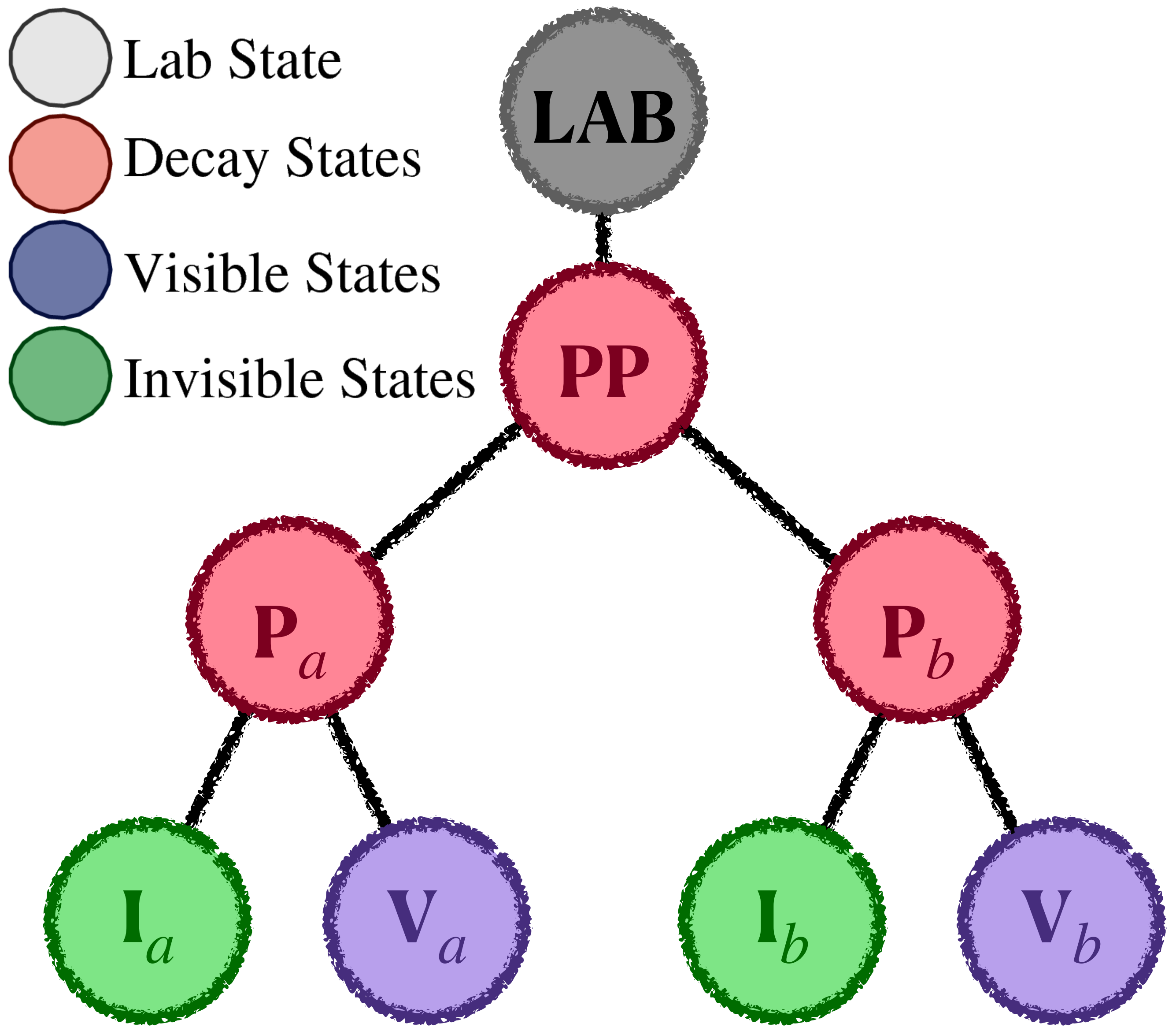

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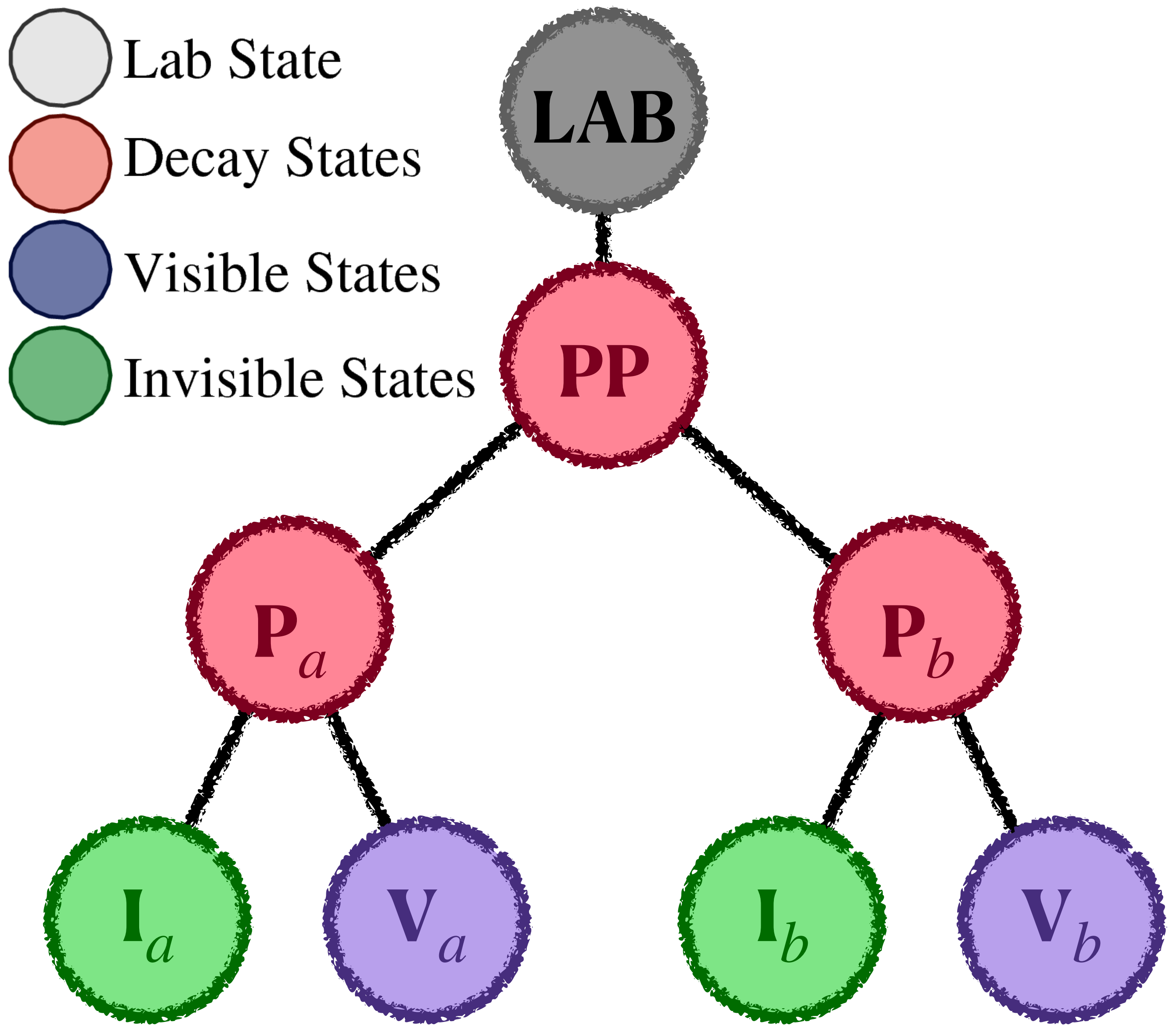

Decay tree of Smuon pair and WW BKG

Difficulties

- Same decay tree topology
- Invisible states I_a and I_b can not be fully reconstructed.

Background & Current Results

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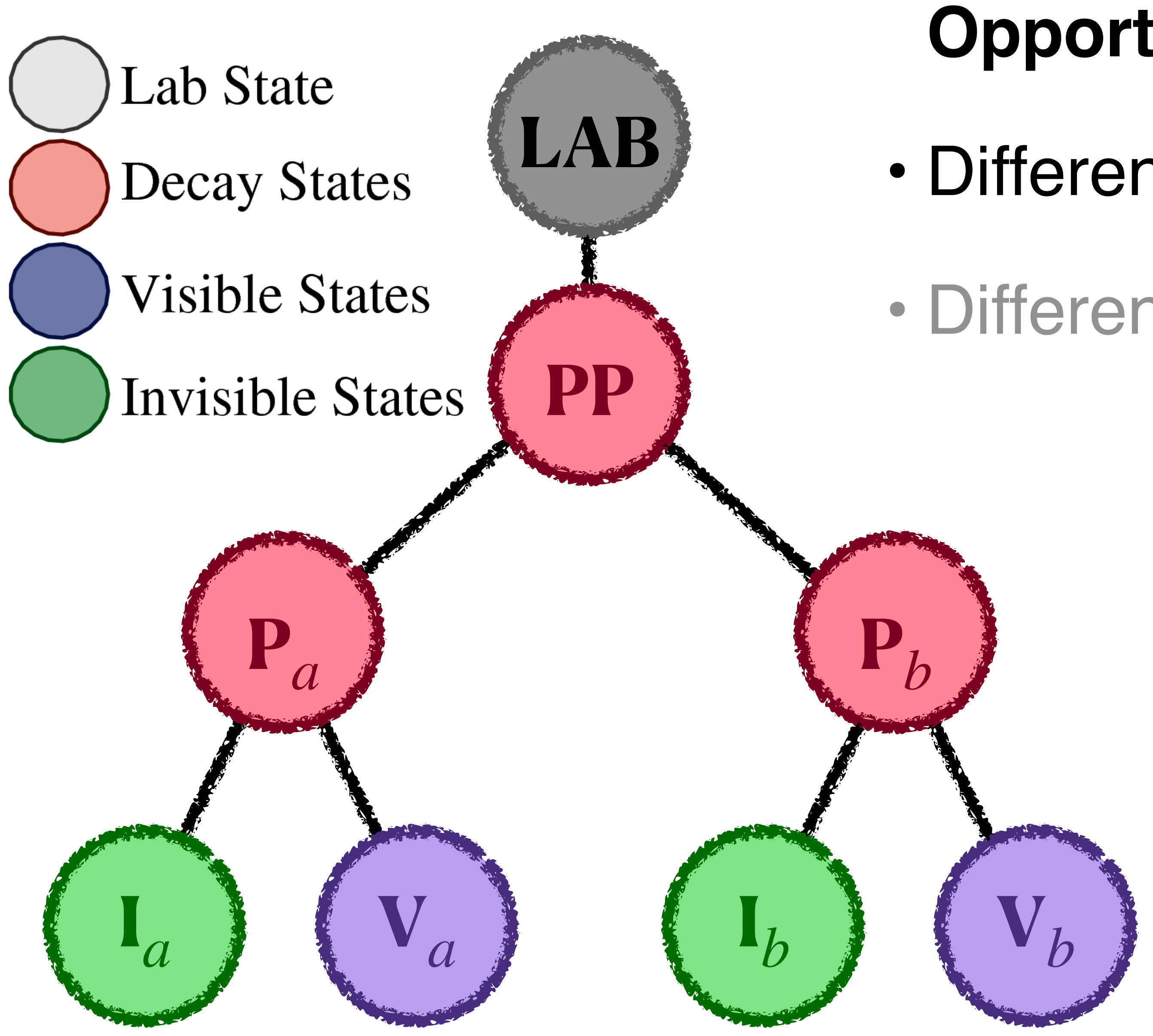

Decay tree of Smuon pair and WW BKG

Opportunities

- Different spin,
- Different masses.

Different distribution of the angular variables:

- arXiv: 2203.10580, J.R. Yuan, H.J. Cheng, and X.A. Zhuang

  Azimuth angle variables: $\Delta\phi(\ell_1, \mathrm{Recoil})$, $\Delta\phi(\ell_1, \mathrm{Recoil})$ and $\Delta\phi(\ell_1, \ell_2)$.

  Cone Size variables: $\Delta R(\ell_1, \mathrm{Recoil})$, $\Delta R(\ell_1, \mathrm{Recoil})$ and $\Delta R(\ell_1, \ell_2)$.

- arXiv: 1810.07659, Q.H. Cao, G. Li, X.K. Pan and J. Zhang

  Polar angle $\theta_{\ell^\pm}$: Polar angle of the charge lepton $\ell^\pm$ with respect to beam direction.

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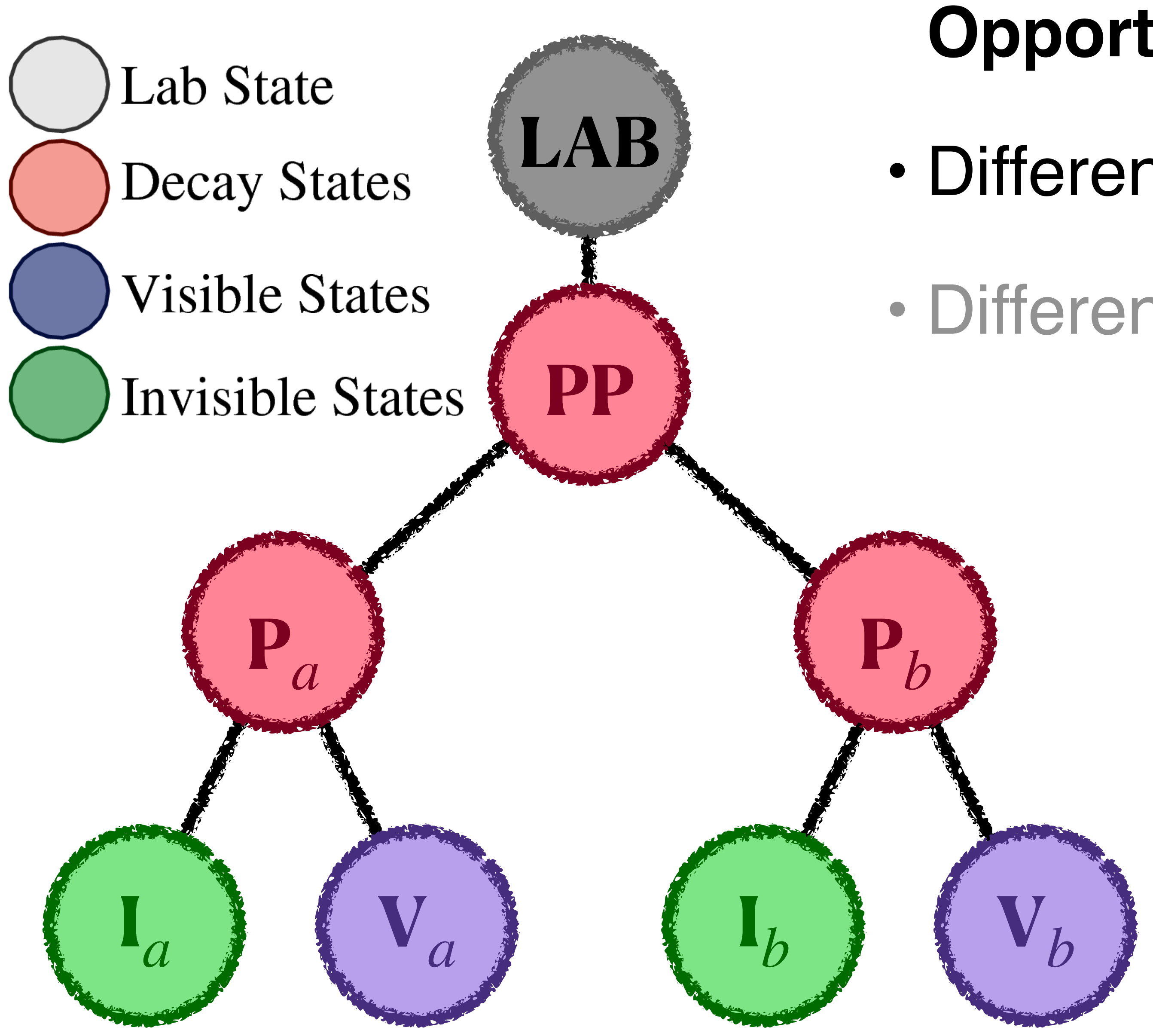

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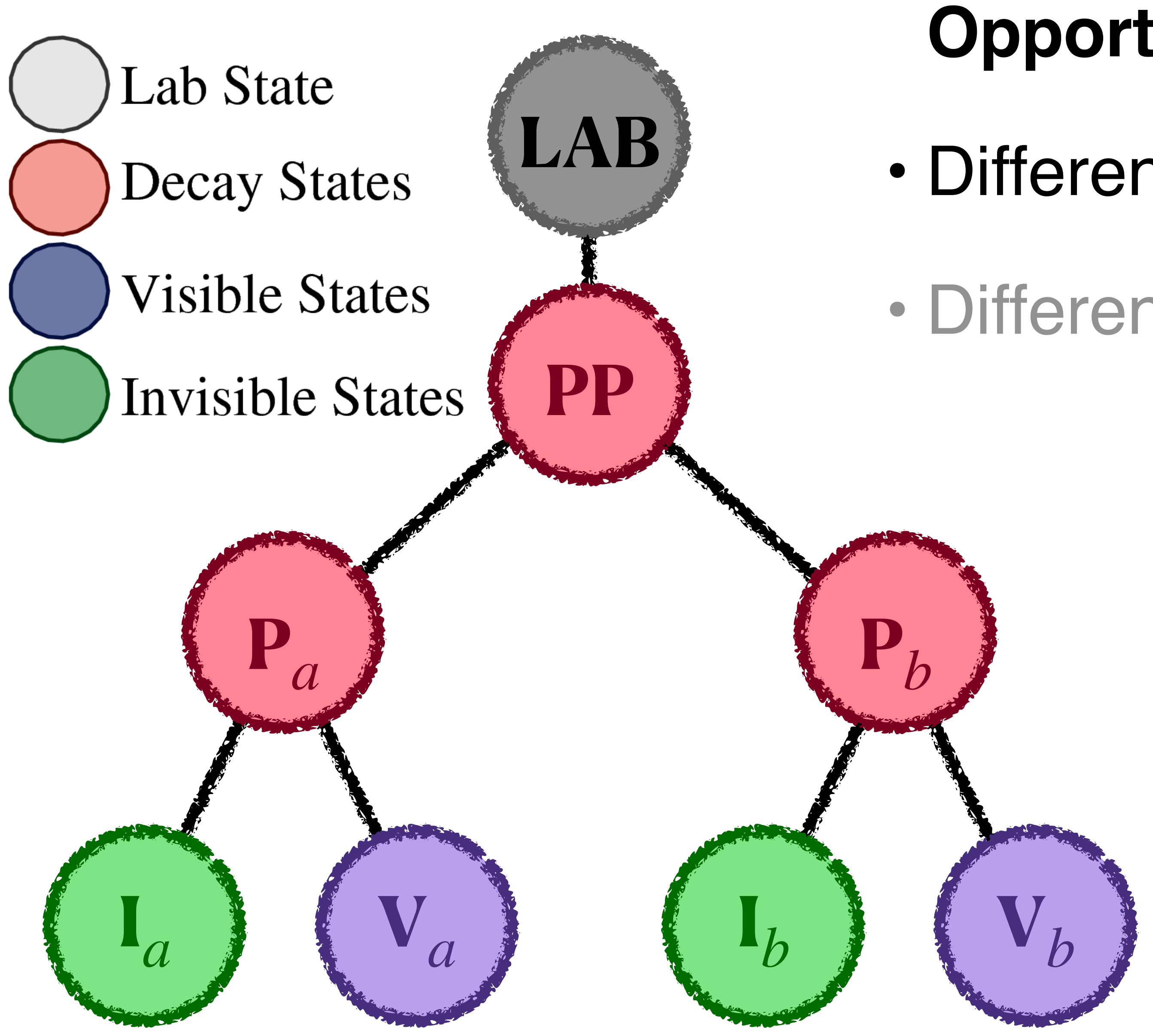

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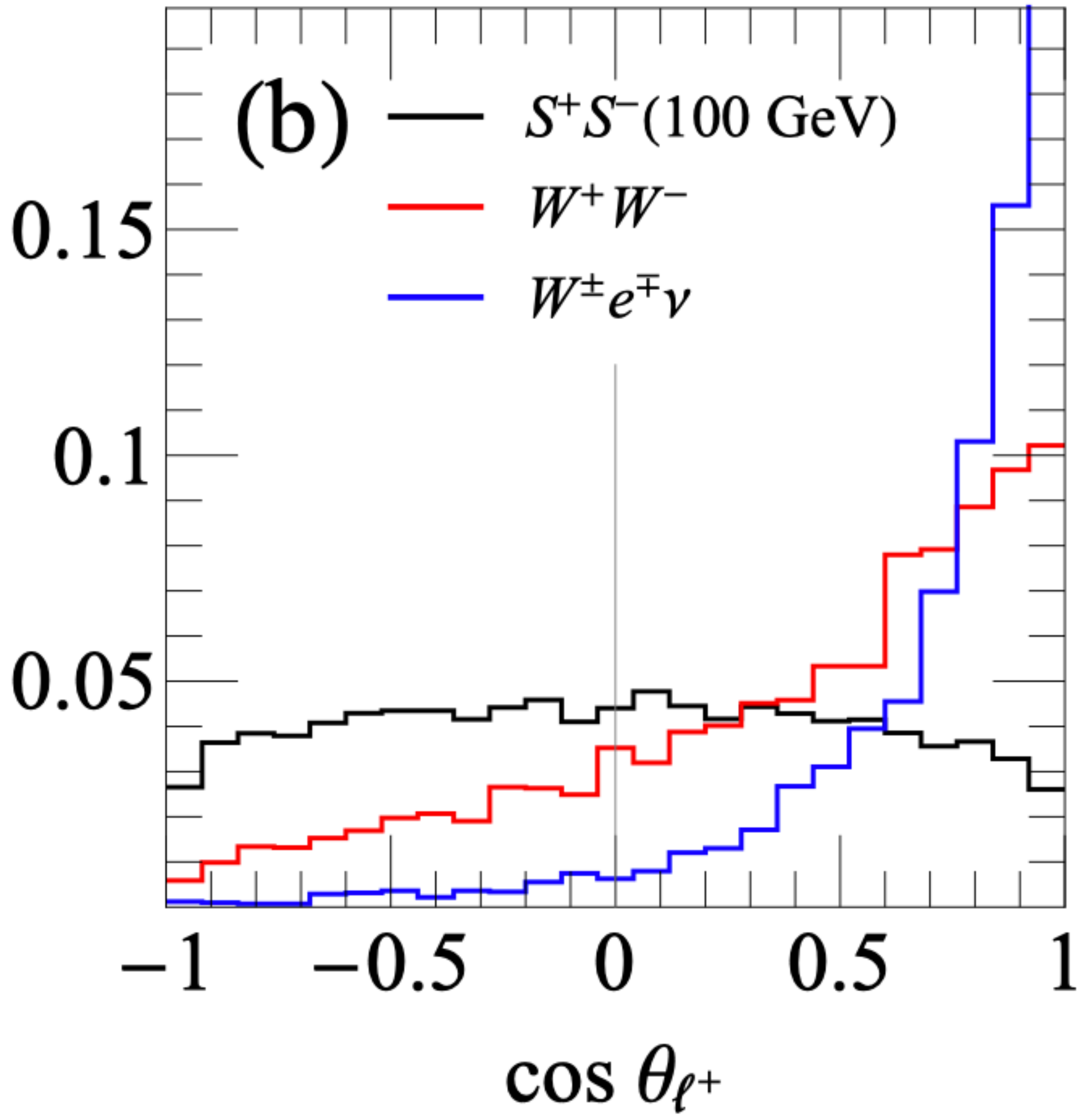

Normalized distribution of $\cos\theta_{\ell^+}$, figure from arXiv: 1810.07659

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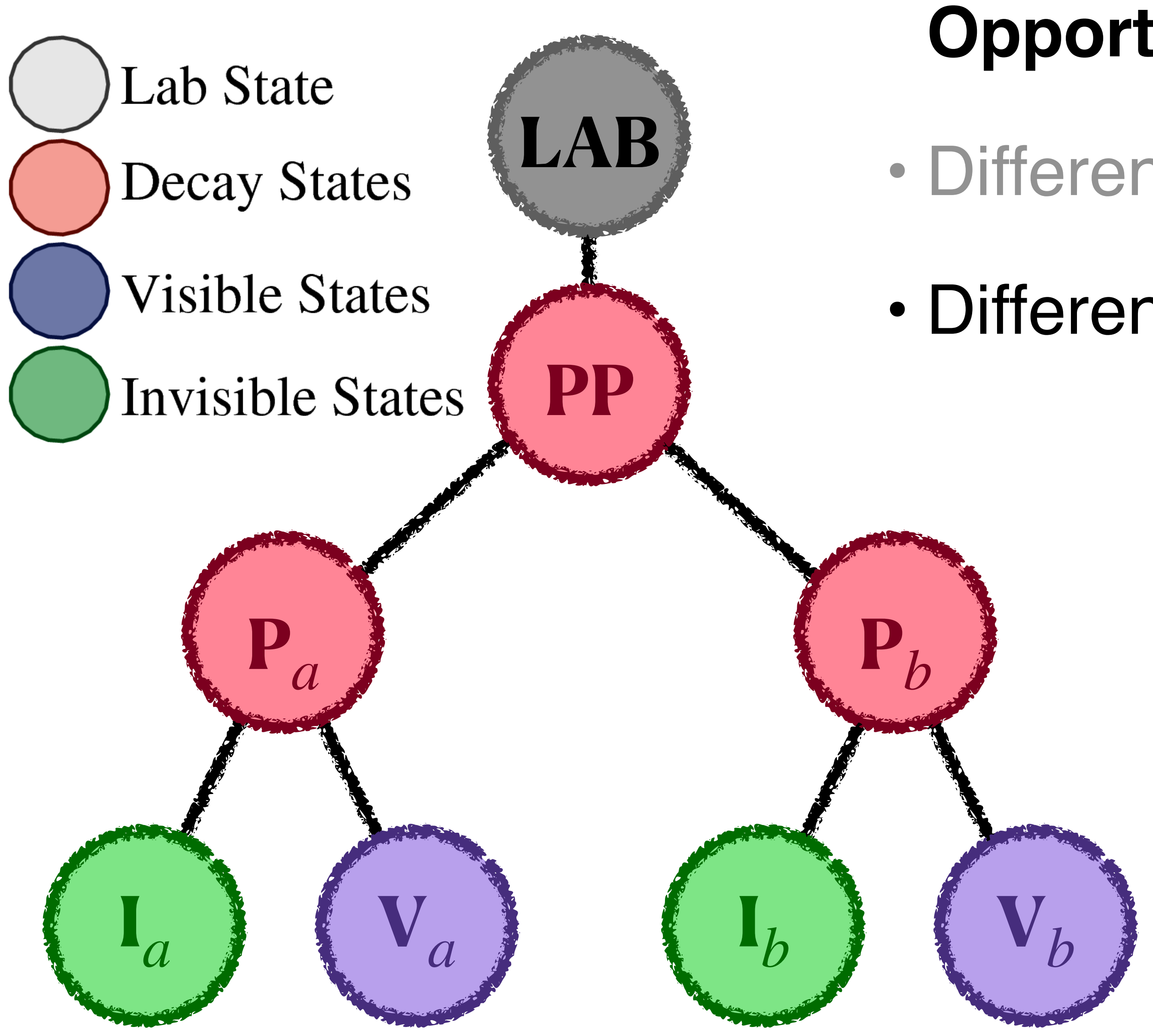

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Different distribution of the variables with mass unit:

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  Energy variable: E_{ℓ_1}, E_{ℓ_2} and $\mathrm{sum}P_{\mathrm{T}}$.

  Mass variable: $m_{\ell\ell}$, m_{Recoil}.

- arXiv: 1810.07659, Q.H. Cao, G. Li, X.K. Pan and J. Zhang

  MT2 variable: the minimum value of the maximum m_{T} can be reconstructed

$$m_{\mathrm{T2}} = \min_{p_{\mathrm{T}}^{\mathrm{I_a}}+p_{\mathrm{T}}^{\mathrm{I_b}}=p_{\mathrm{T}}^{\mathrm{miss}}} \left[\max\left(m_{\mathrm{T}}(p^{\ell_a}, p_{\mathrm{T}}^{\mathrm{I_a}}), m_{\mathrm{T}}(p^{\ell_b}, p_{\mathrm{T}}^{\mathrm{I_b}})\right)\right]$$

Background & Current Results

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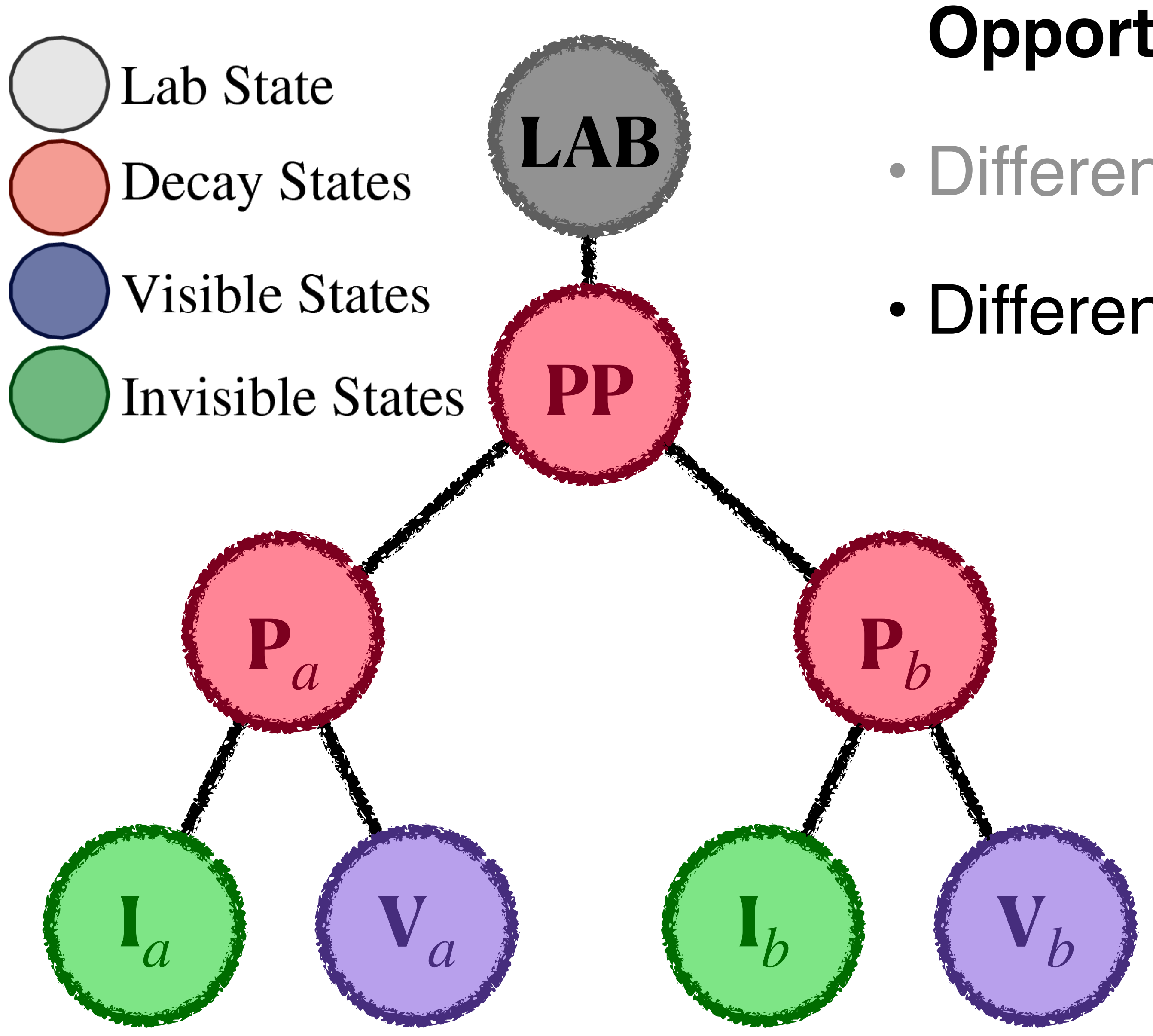

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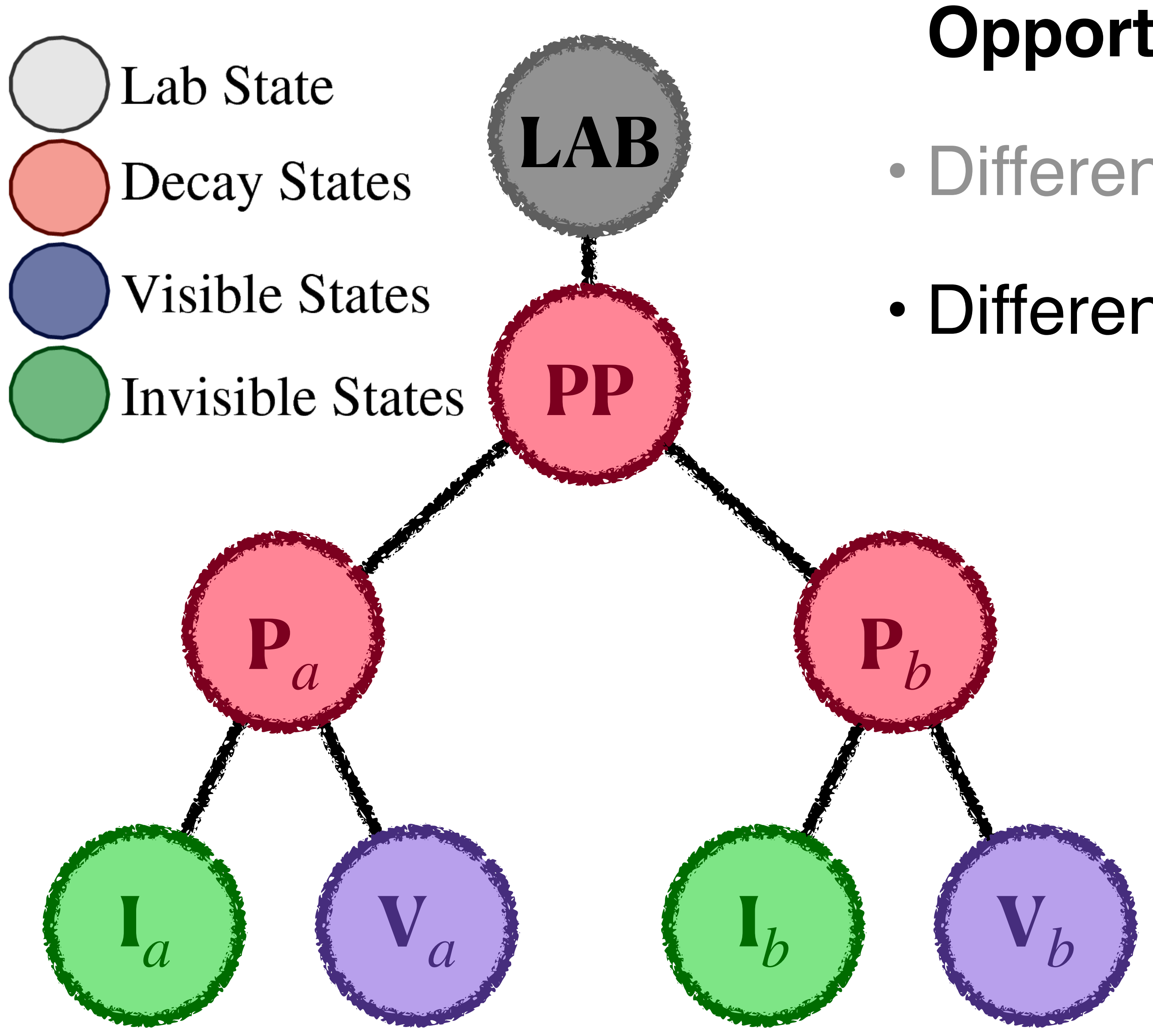

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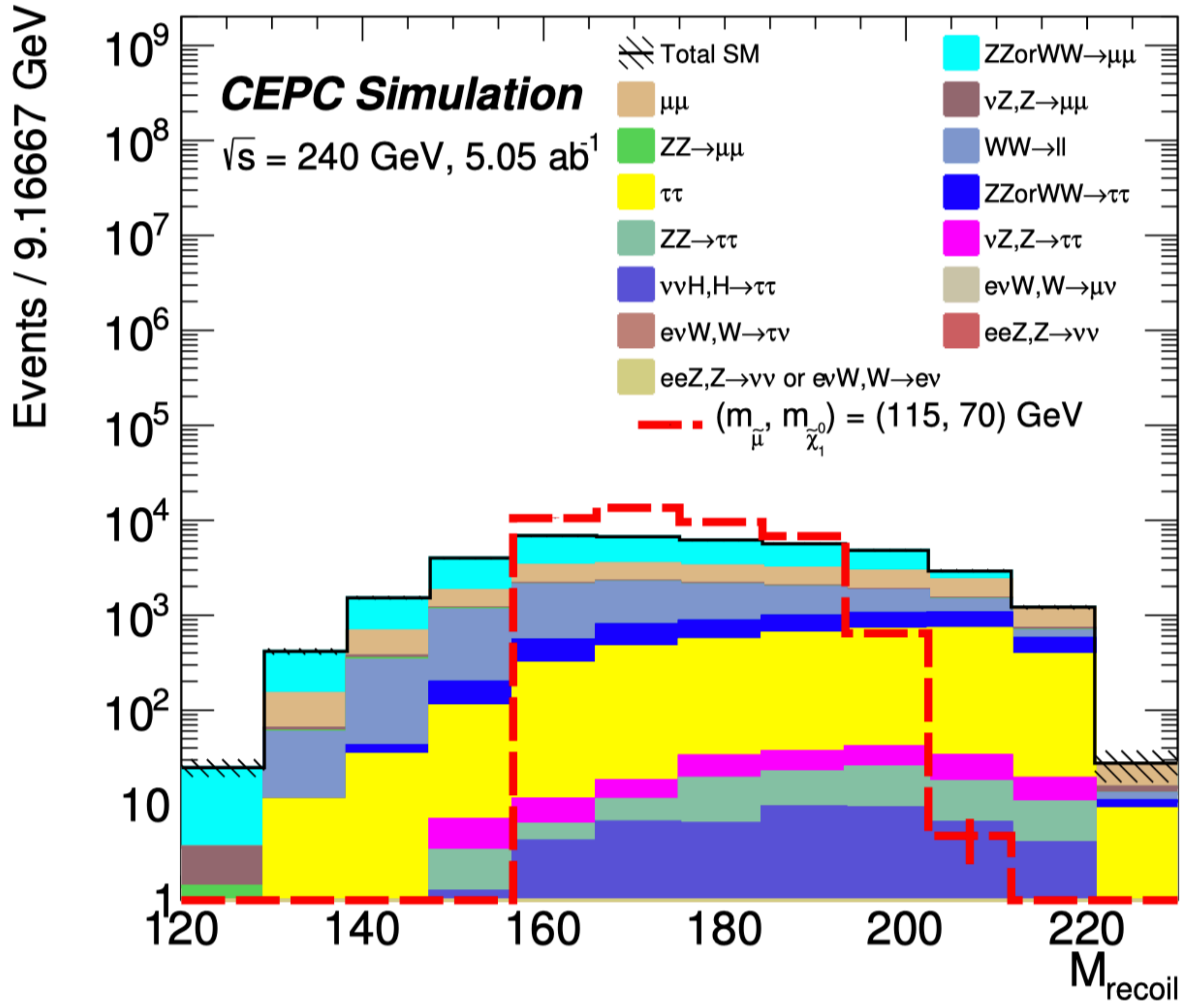

(c) SR-midDeltaM:M_{recoil}

distribution of m_{Recoil}, figure from arXiv: 2203.10580

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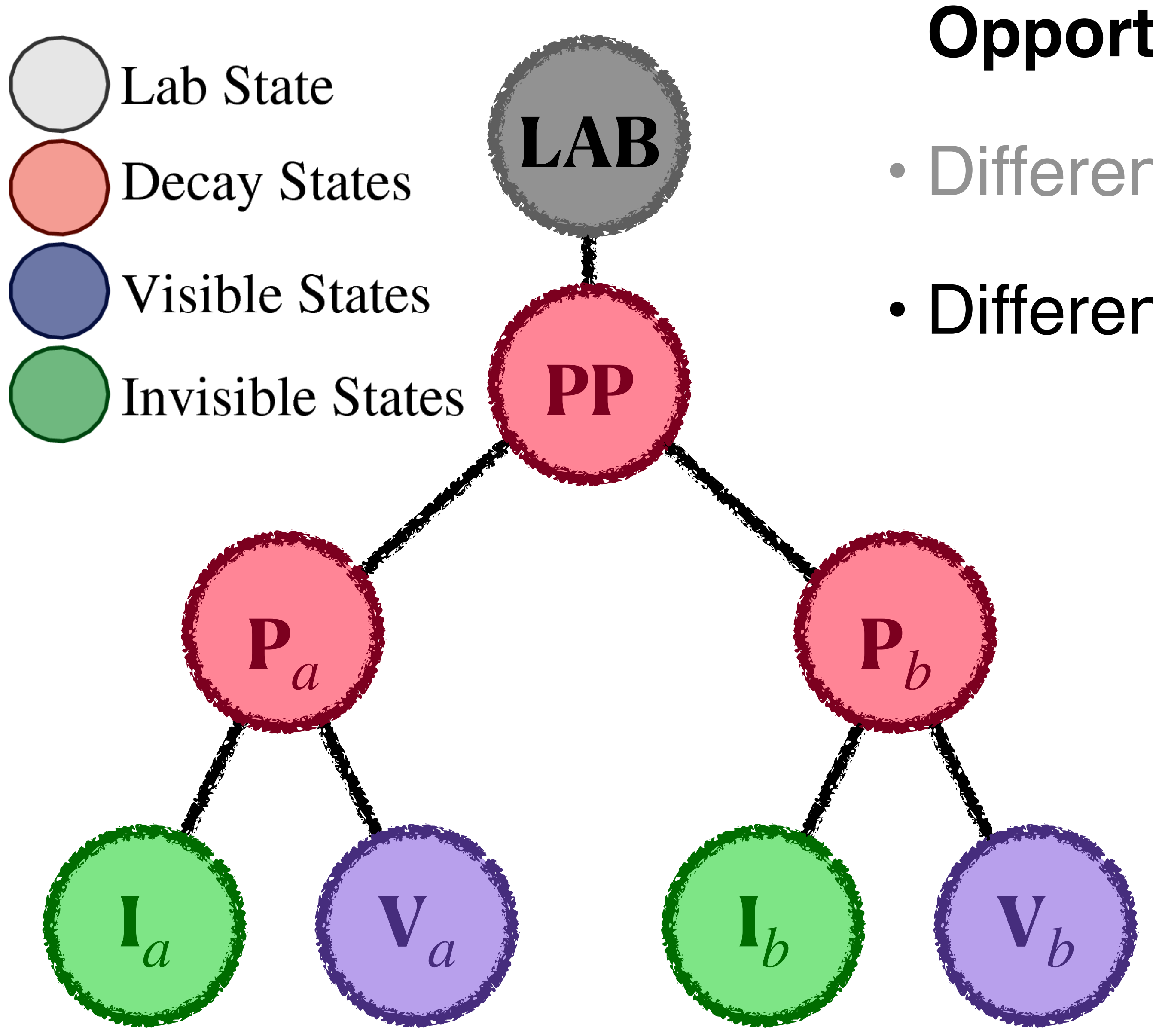

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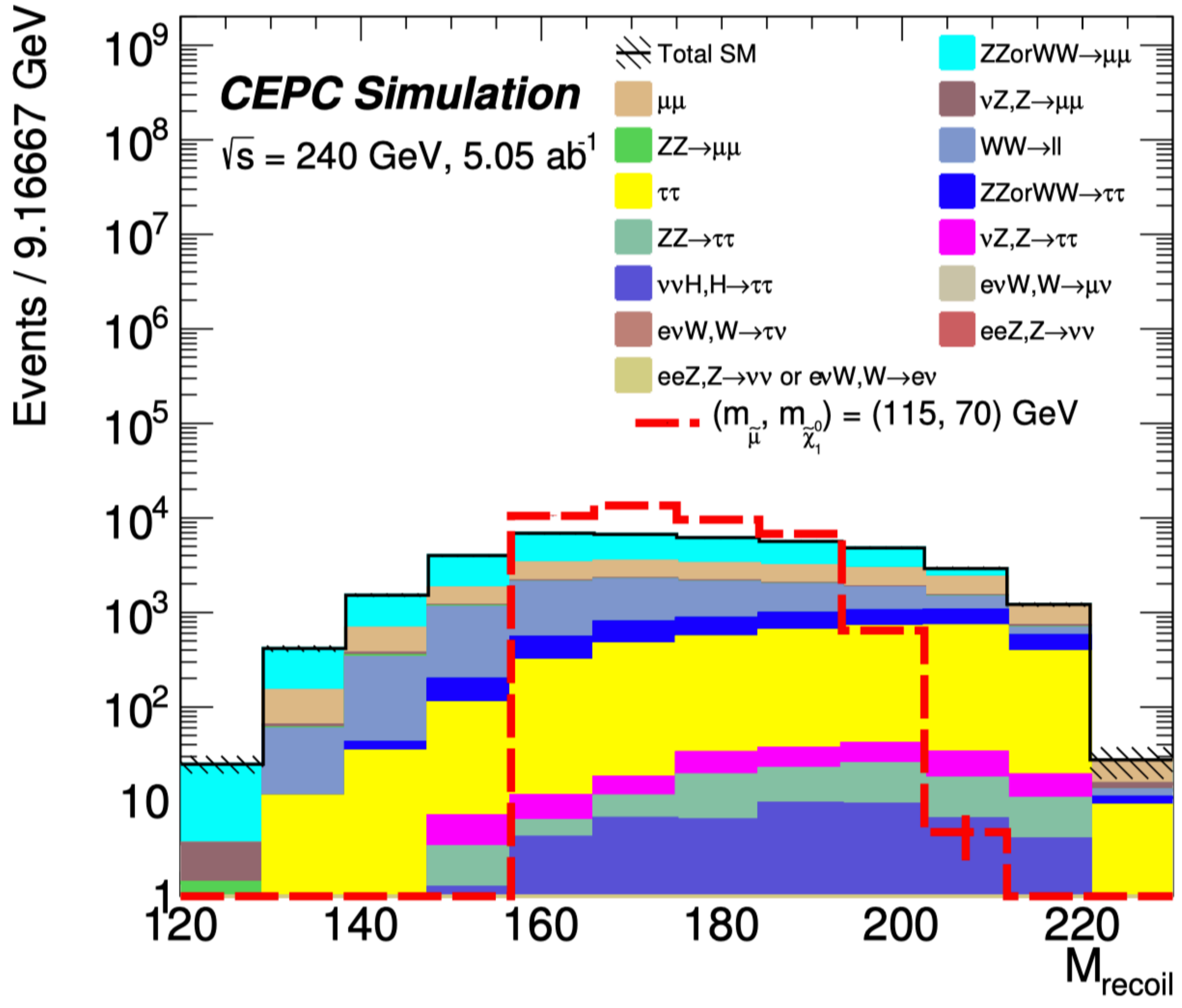

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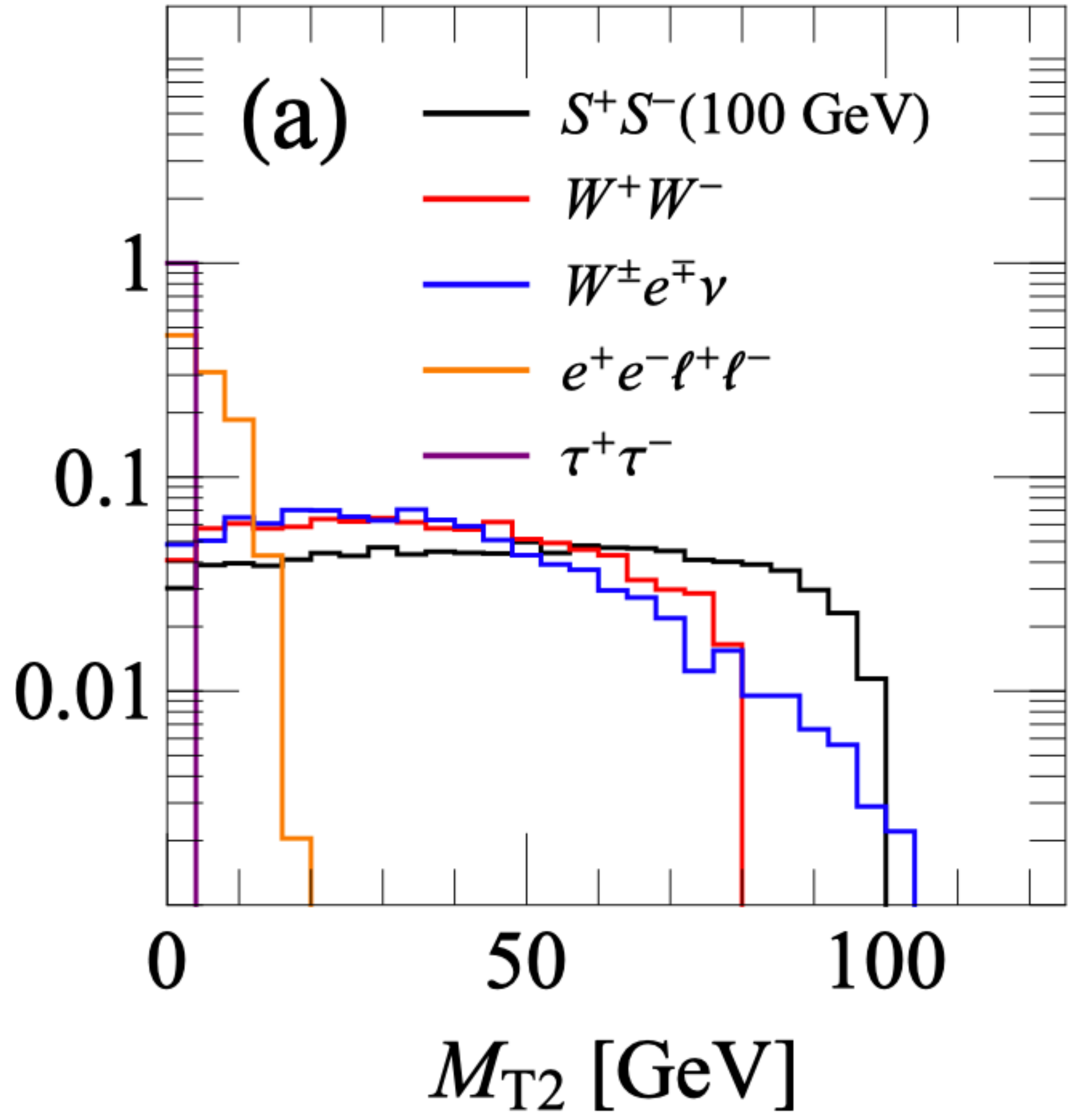


Normalized distribution of M_{T2}, figure from arXiv: 1810.07659

Current Results

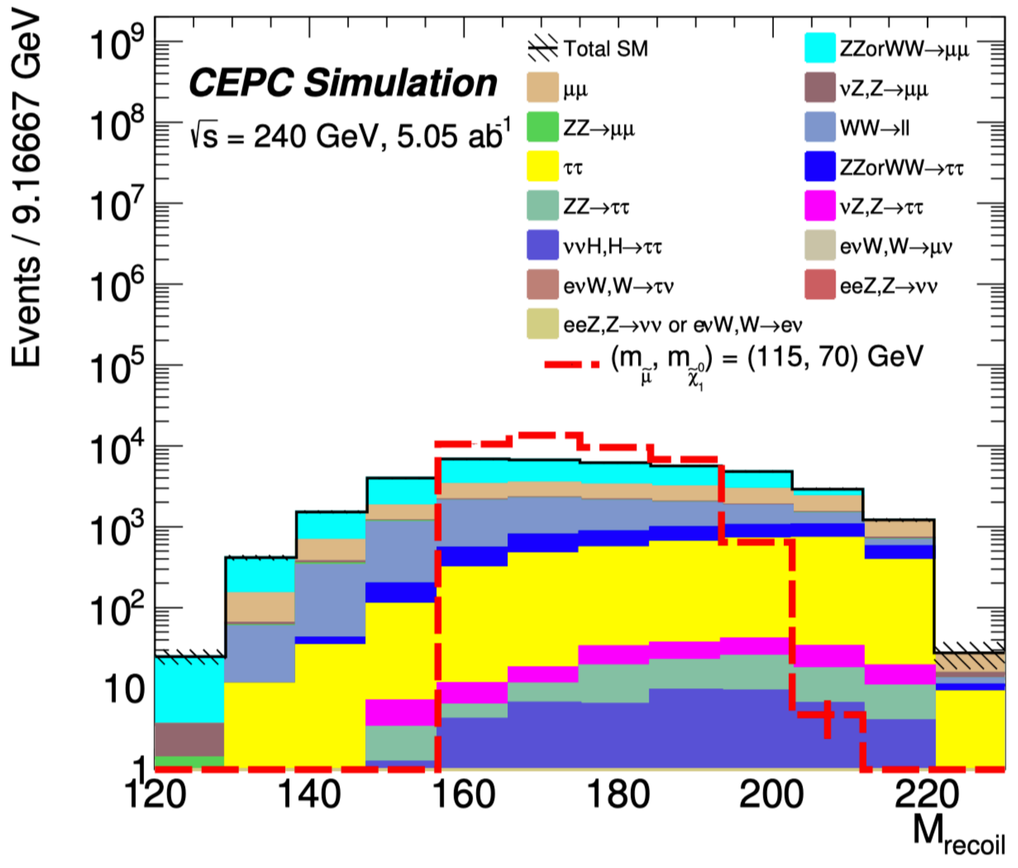
Recoil System

- In lepton collider, 4d missing momentum can be reconstructed.

$$p^{\mu}_{\text{miss}} = (\sqrt{s},0,0,0) - \sum p^{\mu}_{\text{vis}}$$

- The recoil mass is defined as:

$$m^{\mu^+\mu^-}_{\text{Recoil}} = \sqrt{p^2_{\text{miss}}} = \sqrt{(\sqrt{s} - E_{\mu^+\mu^-})^2 - p^2_{\mu^+\mu^-}}$$



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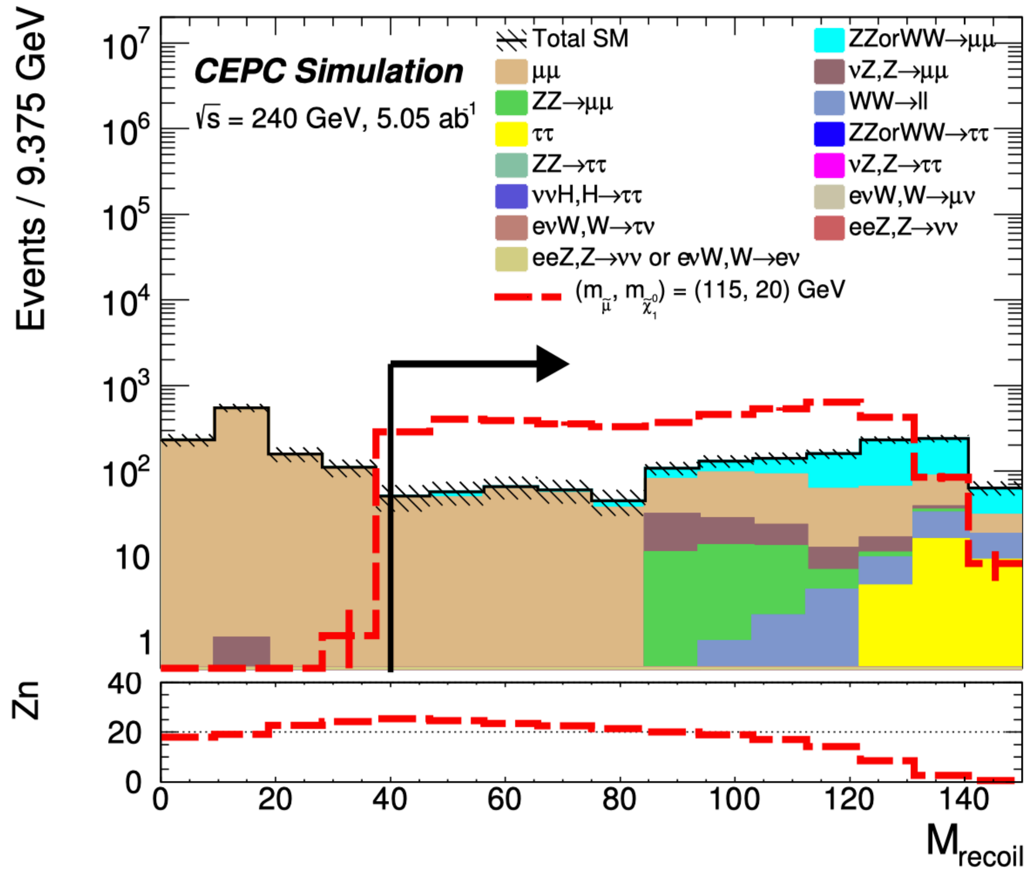
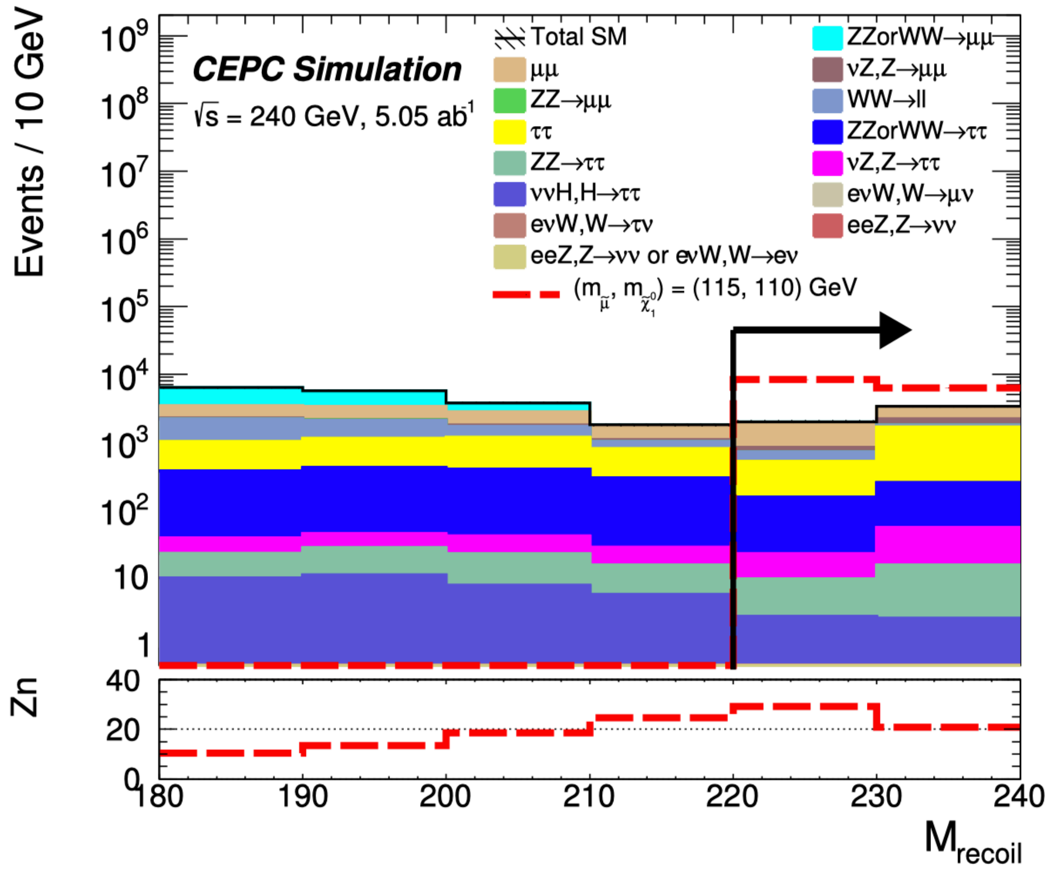


(a) SR-highDeltaM:M_{recoil}



(e) SR-lowDeltaM:M_{recoil}

distribution of m_{Recoil}, figure from arXiv: 2203.10580

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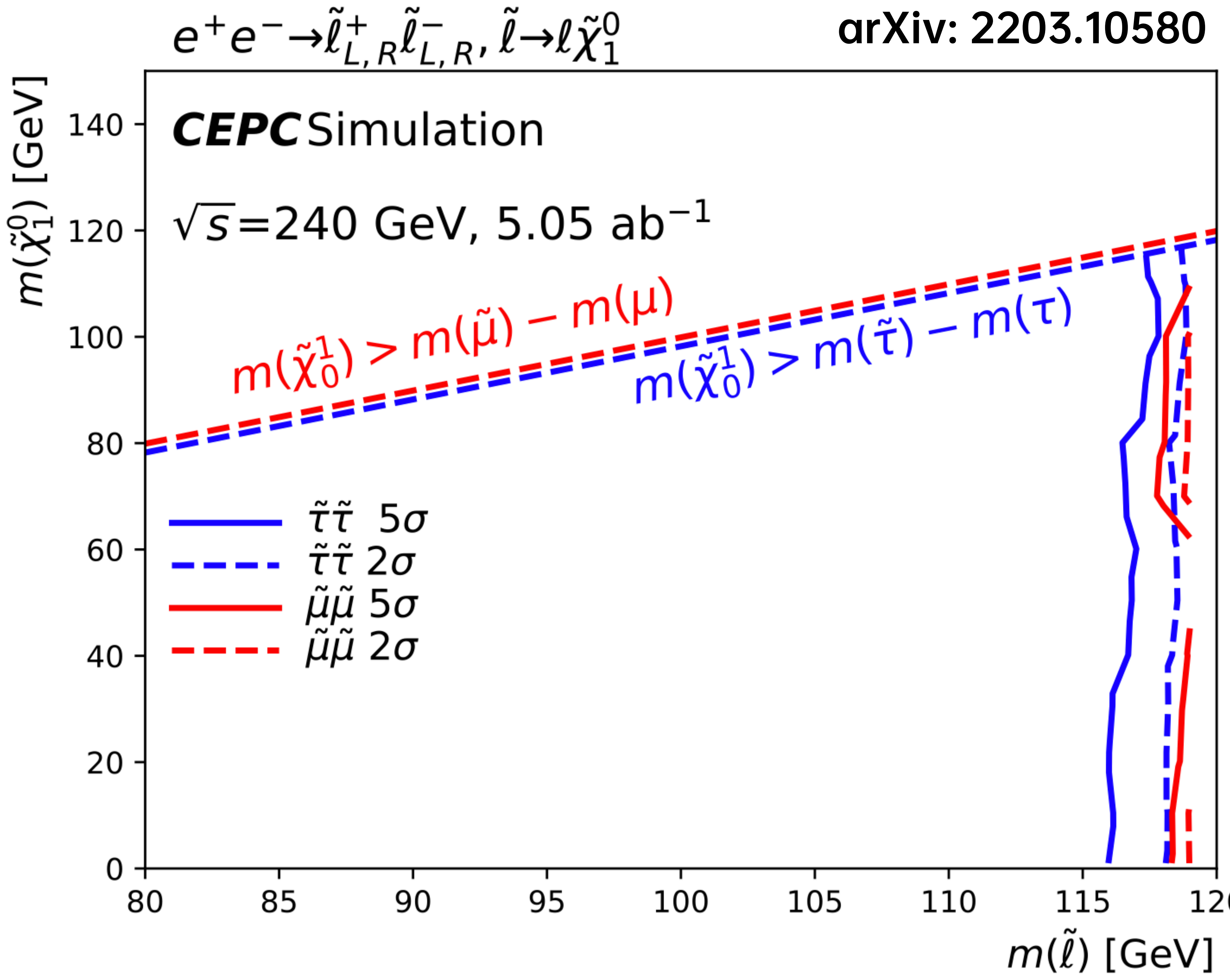
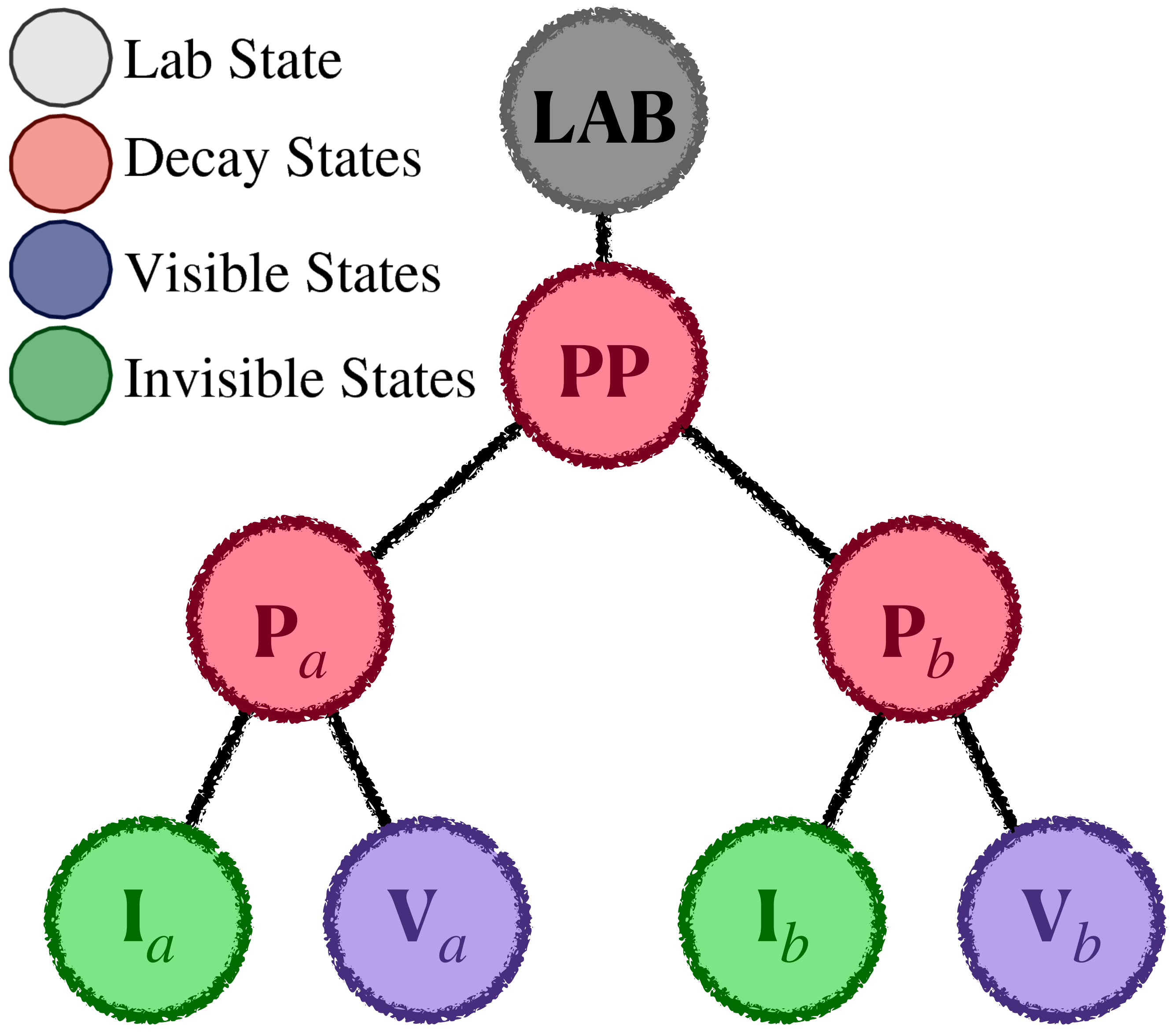


- The discovery sensitivity can reach up to 117 GeV in smuon mass, very close to $\sqrt{s}/2$.
- This impressive result is achieved by "N-1 plots"+"Zn plots"+"several 10,000 attempts".
- The cross section of background in three signal regions are about 0.1 fb to 0.7 fb.

Event reconstruction



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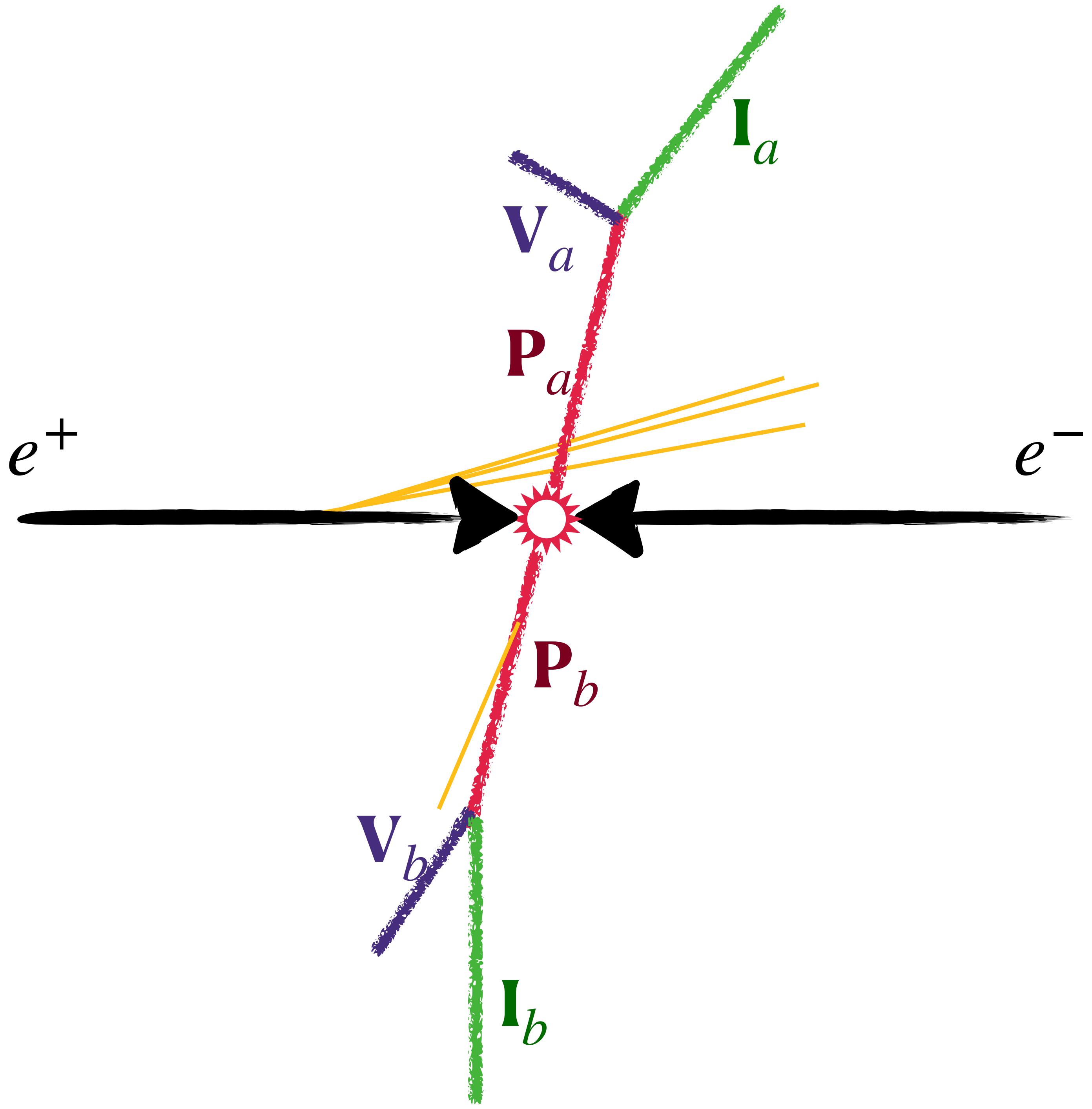
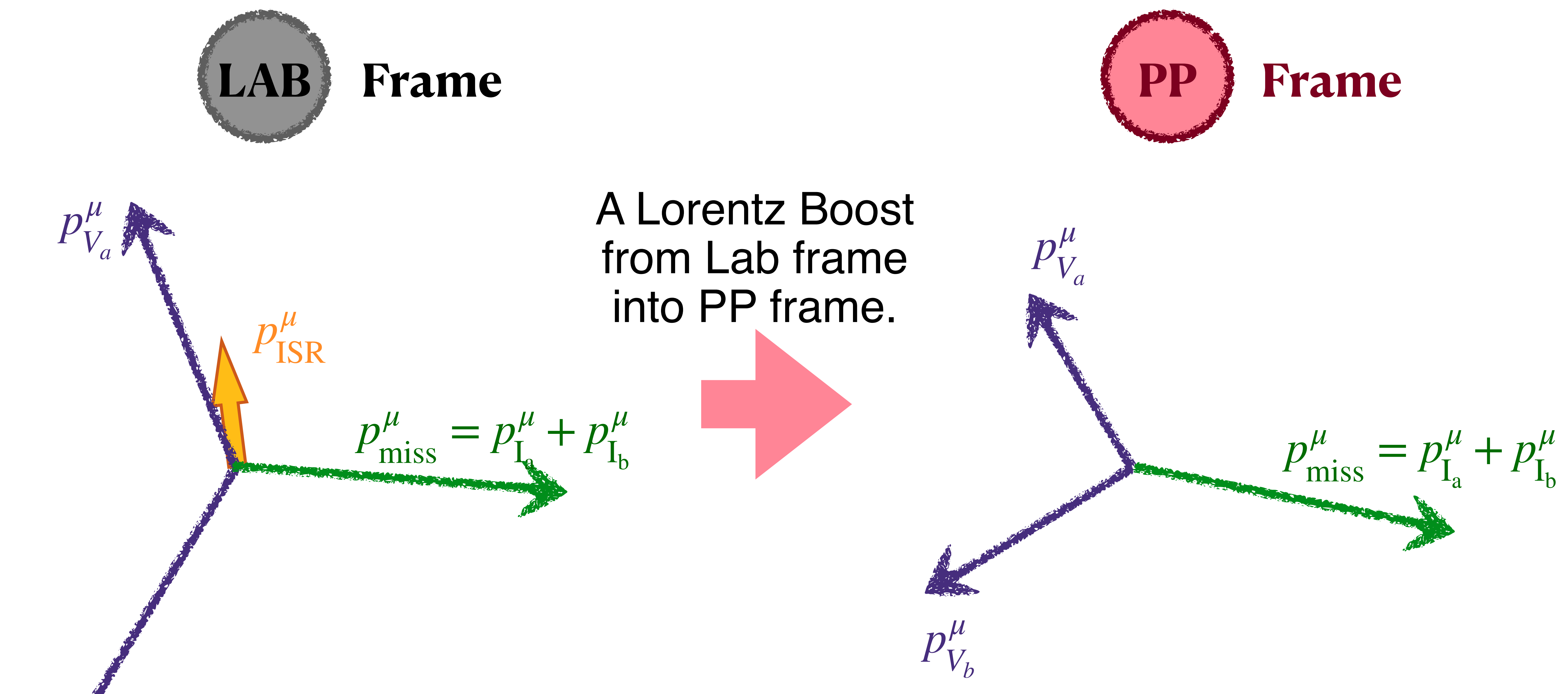


What can be reconstructed by detector are:

- $p^{\mu}_{V_a}$: four-momentum of muon a;
- $p^{\mu}_{V_b}$: four-momentum of muon b;
- $p^{\mu}_{\text{miss}} = p^{\mu}_{\text{I}_\text{a}} + p^{\mu}_{\text{I}_\text{b}}$: Vector sum of four-momentum of two invisible particles
- p^{μ}_{ISR}: four-momentum of anything else

Event reconstruction



Lorentz boost means the following variables are unchanged:

- $\left(p^\mu_{V_a}\right)^2 = m^2_\mu$; $\left(p^\mu_{V_b}\right)^2 = m^2_\mu$;
- $\left(p^\mu_{\mathrm{I_a}}\right)^2 = m^2_{\mathrm{I_a}}$; $\left(p^\mu_{\mathrm{I_b}}\right)^2 = m^2_{\mathrm{I_b}}$.

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\mathrm{miss}}$ form a triangle, and three vectors $\vec{p}_{\mathrm{I_a}}$, $\vec{p}_{\mathrm{I_b}}$ and $\vec{p}_{\mathrm{miss}}$ form another triangle.

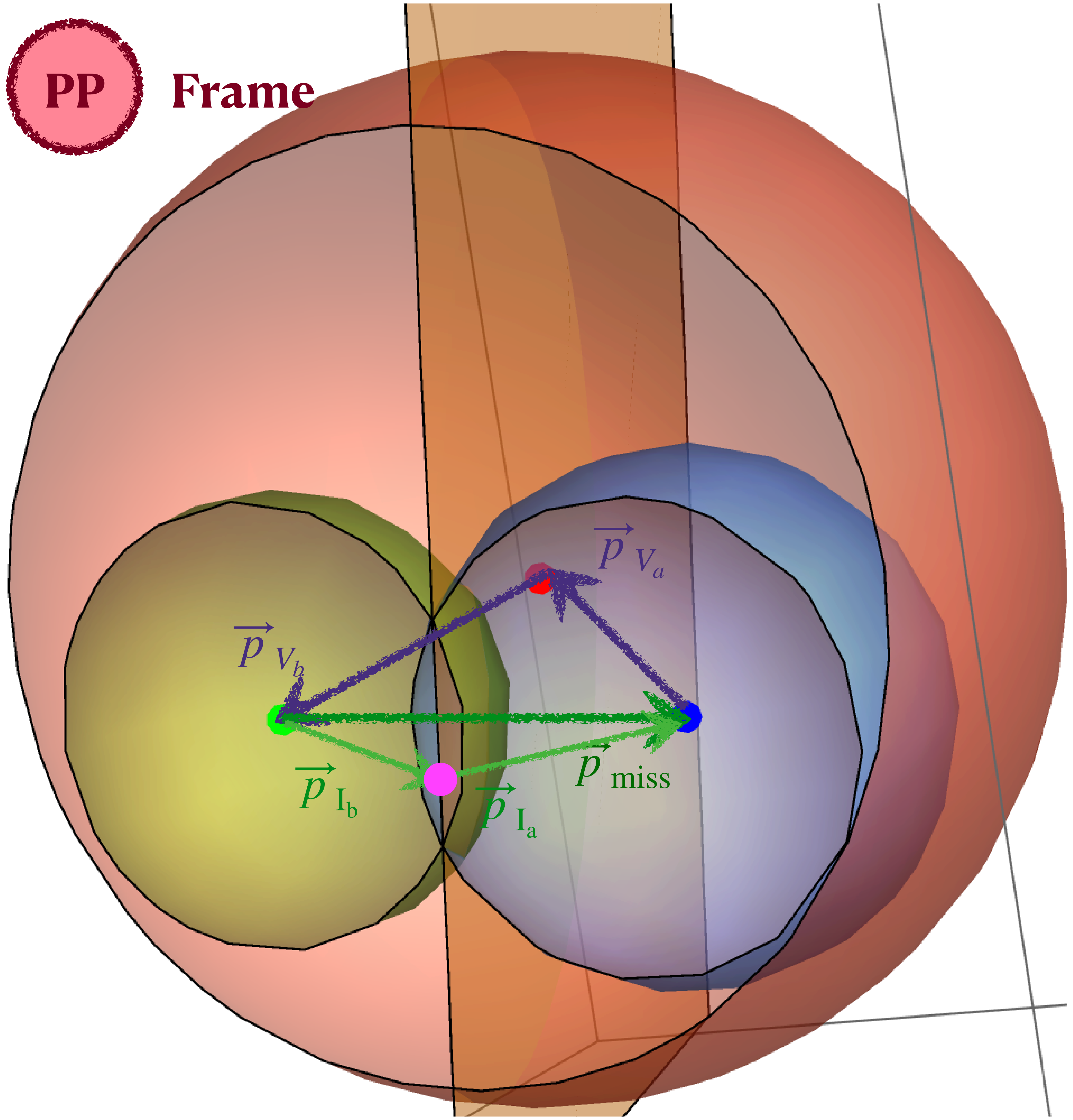
Physical Constraints (Assumptions)

1. $p^\mu_{\mathrm{P_a}} = p^\mu_{V_a} + p^\mu_{\mathrm{I_a}}$;
2. $p^\mu_{\mathrm{P_b}} = p^\mu_{V_b} + p^\mu_{\mathrm{I_b}}$;
3. $m_{\mathrm{P}} = m_{\mathrm{P_a}} = m_{\mathrm{P_b}}$;
4. $m_{\mathrm{I}} = m_{\mathrm{I_a}} = m_{\mathrm{I_b}}$.
5. $m_{\mathrm{P}} > 0$;
6. $m_{\mathrm{I}} > 0$.

In PP frame,

7. $E_{\mathrm{P_a}} = E_{\mathrm{P_b}} = \left(E_{\mathrm{V_a}} + E_{\mathrm{V_b}} + E_{\mathrm{miss}}\right) / 2.$

Event reconstruction



three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\mathrm{miss}}$ form a triangle, and three vectors $\vec{p}_{\mathrm{I_a}}$, $\vec{p}_{\mathrm{I_b}}$ and $\vec{p}_{\mathrm{miss}}$ form another triangle.

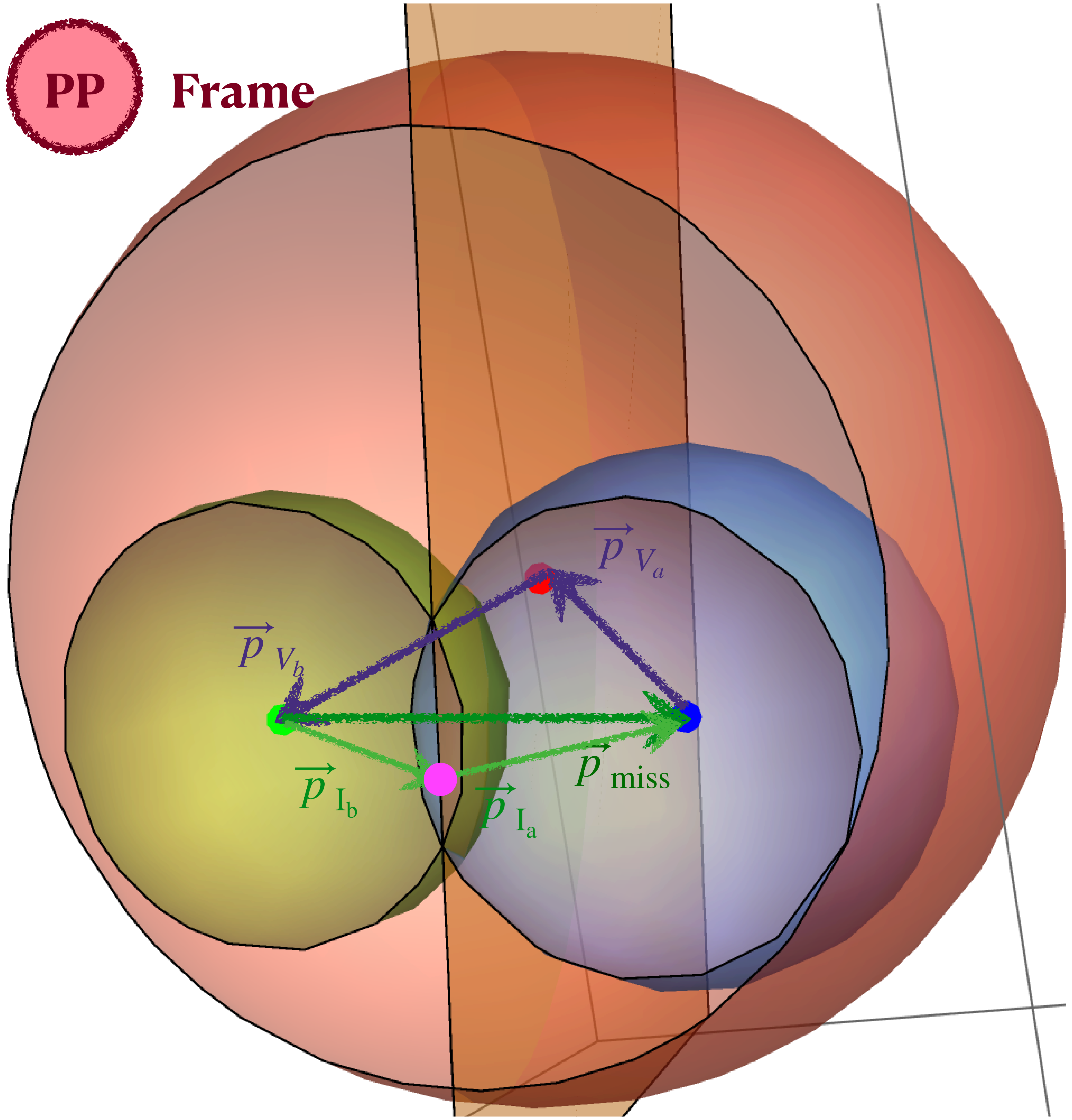
Physical Constraints (Assumptions)

1. $p^{\mu}_{\mathrm{P_a}} = p^{\mu}_{V_a} + p^{\mu}_{\mathrm{I_a}};$
2. $p^{\mu}_{\mathrm{P_b}} = p^{\mu}_{V_b} + p^{\mu}_{\mathrm{I_b}};$
3. $m_{\mathrm{P}} = m_{\mathrm{P_a}} = m_{\mathrm{P_b}};$
4. $m_{\mathrm{I}} = m_{\mathrm{I_a}} = m_{\mathrm{I_b}}.$
5. $m_{\mathrm{P}} > 0;$
6. $m_{\mathrm{I}} > 0.$

In PP frame,

7. $E_{\mathrm{P_a}} = E_{\mathrm{P_b}} = \left(E_{\mathrm{V_a}} + E_{\mathrm{V_b}} + E_{\mathrm{miss}}\right) \Big/ 2.$

Event reconstruction



three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\mathrm{miss}}$ form a triangle, and three vectors $\vec{p}_{\mathrm{I_a}}$, $\vec{p}_{\mathrm{I_b}}$ and $\vec{p}_{\mathrm{miss}}$ form another triangle.

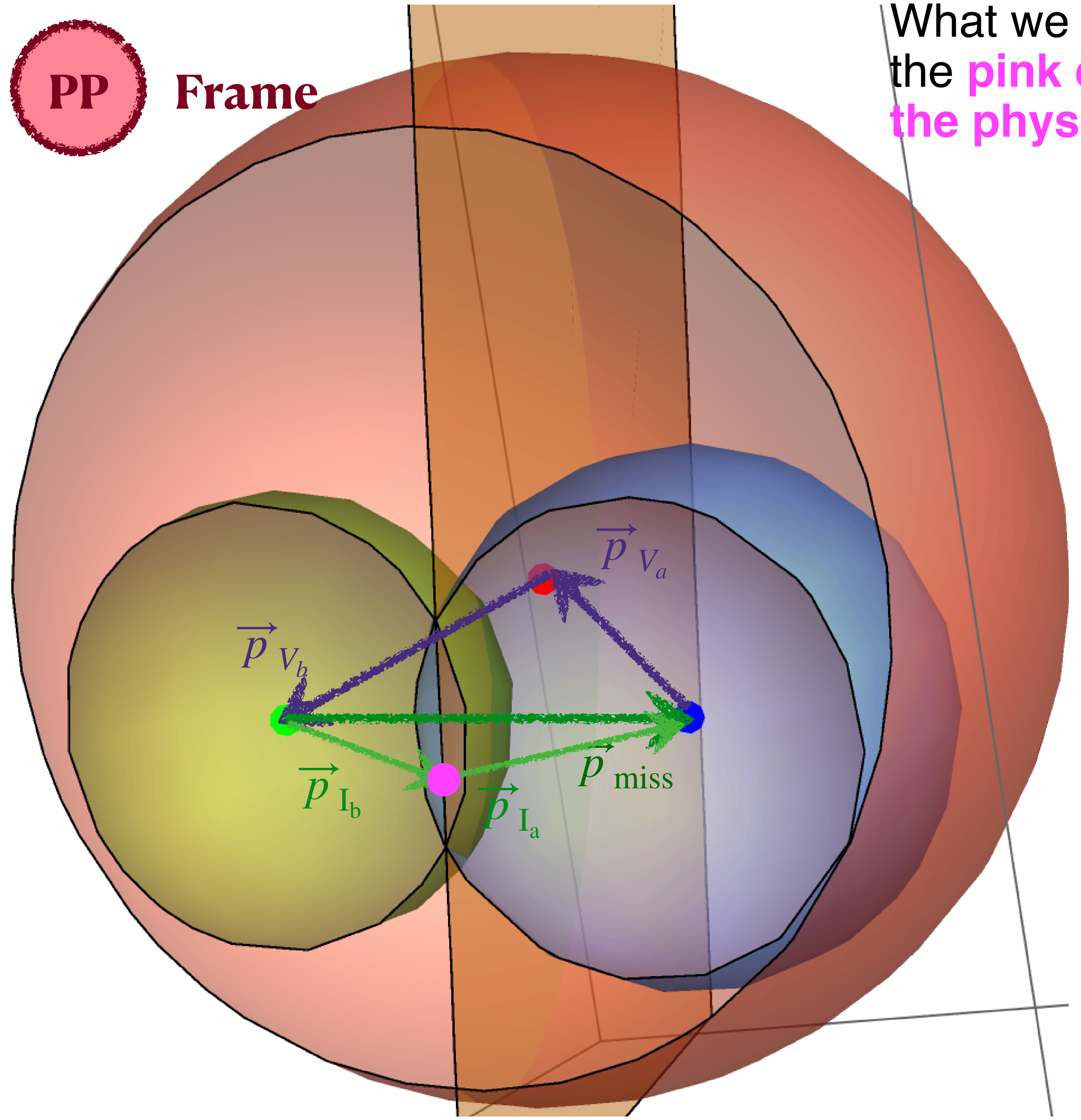
Physical Constraints (Assumptions)

1. $p^{\mu}_{\mathrm{P_a}} = p^{\mu}_{V_a} + p^{\mu}_{\mathrm{I_a}}$;
2. $p^{\mu}_{\mathrm{P_b}} = p^{\mu}_{V_b} + p^{\mu}_{\mathrm{I_b}}$;
3. $m_{\mathrm{P}} = m_{\mathrm{P_a}} = m_{\mathrm{P_b}}$;
4. $m_{\mathrm{I}} = m_{\mathrm{I_a}} = m_{\mathrm{I_b}}$.
5. $m_{\mathrm{P}} > 0$;
6. $m_{\mathrm{I}} > 0$.

In PP frame,

7. $E_{\mathrm{P_a}} = E_{\mathrm{P_b}} = \left(E_{\mathrm{V_a}} + E_{\mathrm{V_b}} + E_{\mathrm{miss}}\right) \Big/ 2.$

Event reconstruction



What we unknown is the location of the **pink dot, but it must satisfy the physical assumptions.**

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\rm miss}$ form a triangle, and three vectors $\vec{p}_{I_a}$, $\vec{p}_{I_b}$ and $\vec{p}_{\rm miss}$ form another triangle.

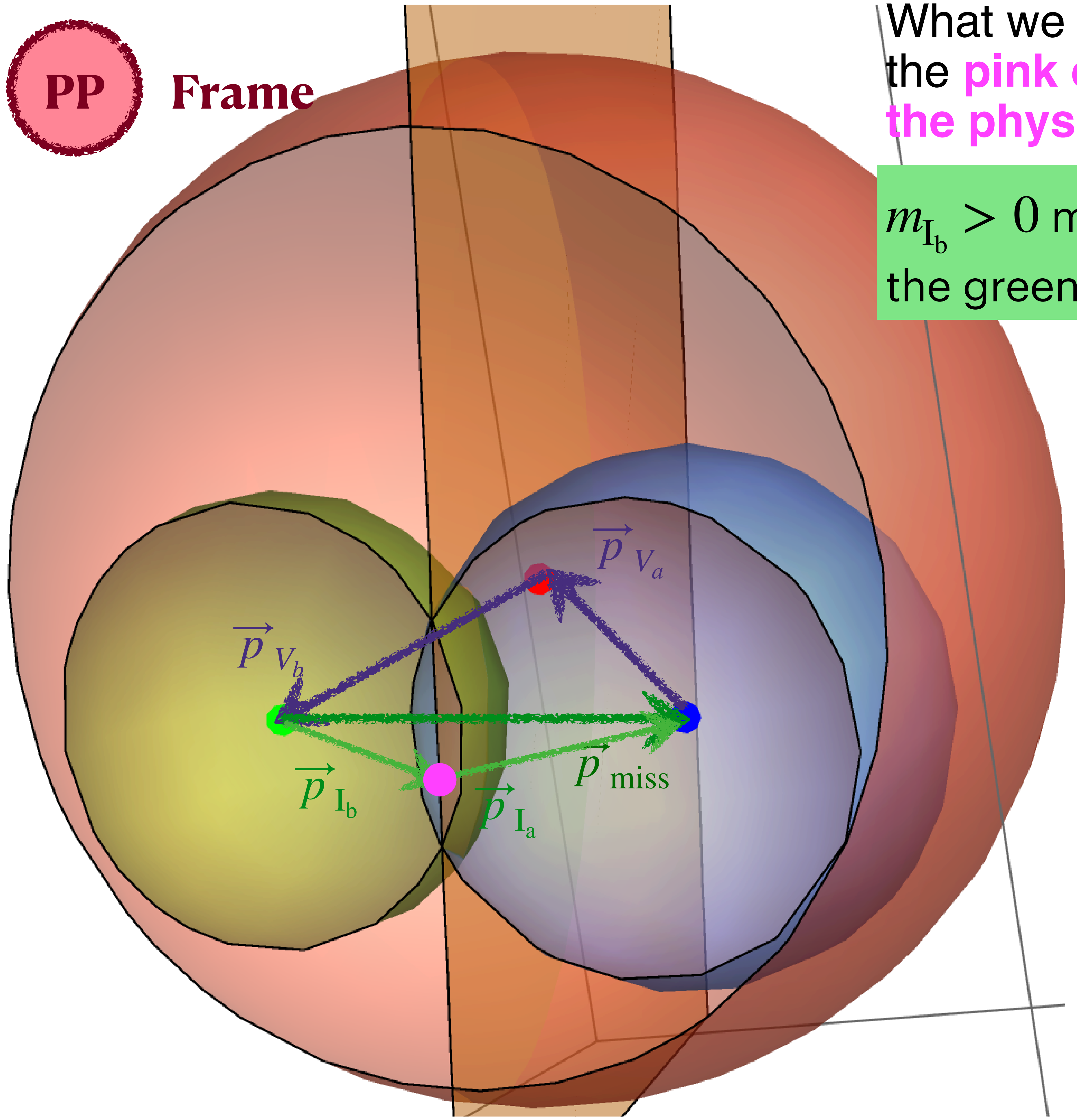
Physical Constraints (Assumptions)

1. $p^\mu_{P_a} = p^\mu_{V_a} + p^\mu_{I_a}$;
2. $p^\mu_{P_b} = p^\mu_{V_b} + p^\mu_{I_b}$;
3. $m_P = m_{P_a} = m_{P_b}$;
4. $m_I = m_{I_a} = m_{I_b}$.
5. $m_P > 0$;
6. $m_I > 0$.

In PP frame,

7. $E_{P_a} = E_{P_b} = \left(E_{V_a} + E_{V_b} + E_{\rm miss}\right) / 2.$

Event reconstruction



What we unknown is the location of the pink dot, but it must satisfy the physical assumptions.

$m_{\mathrm{I_b}} > 0$ means it must located in the green sphere.

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\mathrm{miss}}$ form a triangle, and three vectors $\vec{p}_{\mathrm{I_a}}$, $\vec{p}_{\mathrm{I_b}}$ and $\vec{p}_{\mathrm{miss}}$ form another triangle.

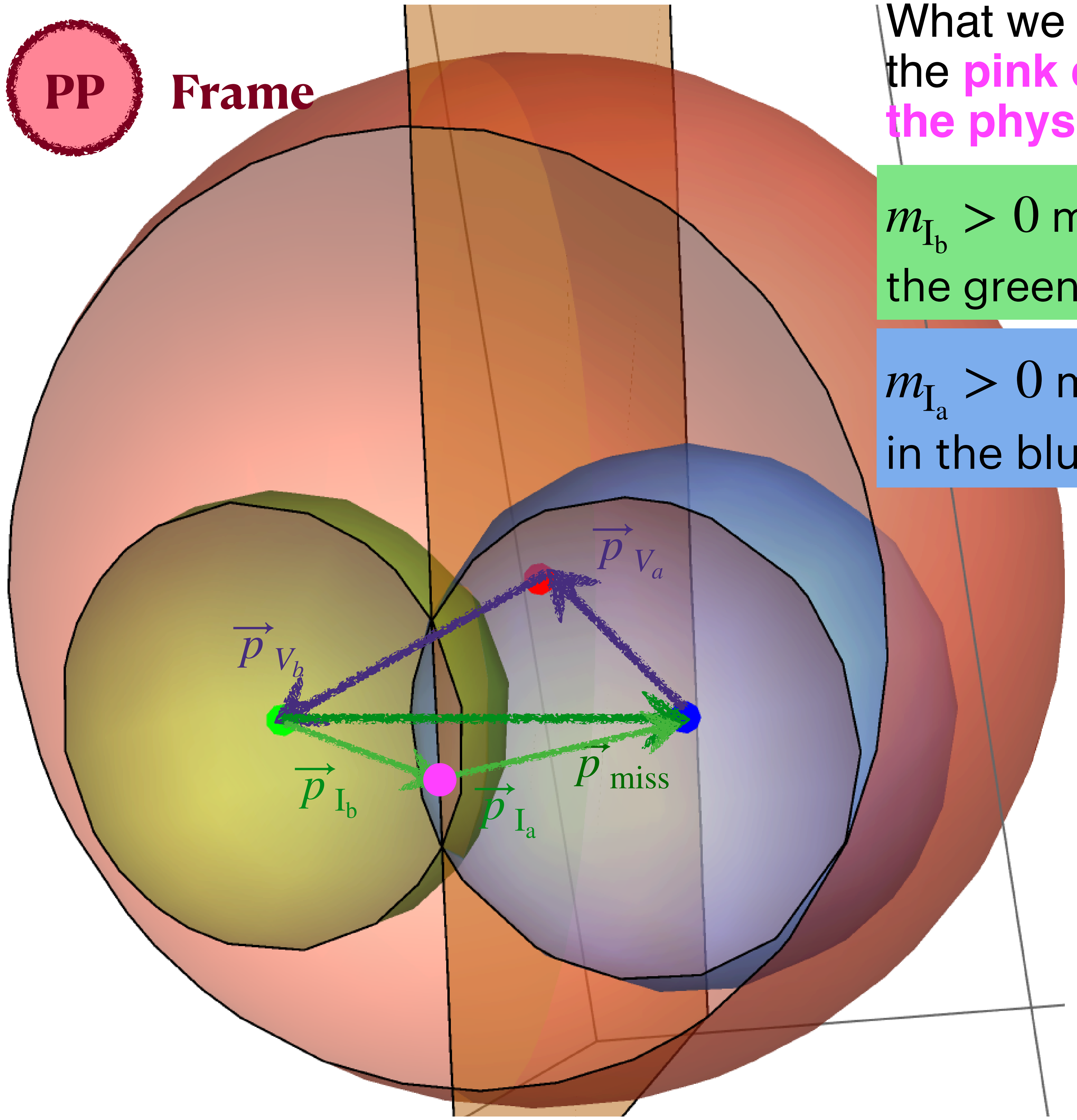
Physical Constraints (Assumptions)

1. $p^{\mu}_{\mathrm{P_a}} = p^{\mu}_{V_a} + p^{\mu}_{\mathrm{I_a}}$;
2. $p^{\mu}_{\mathrm{P_b}} = p^{\mu}_{V_b} + p^{\mu}_{\mathrm{I_b}}$;
3. $m_{\mathrm{P}} = m_{\mathrm{P_a}} = m_{\mathrm{P_b}}$;
4. $m_{\mathrm{I}} = m_{\mathrm{I_a}} = m_{\mathrm{I_b}}$.
5. $m_{\mathrm{P}} > 0$;
6. $m_{\mathrm{I}} > 0$.

In PP frame,

7. $E_{\mathrm{P_a}} = E_{\mathrm{P_b}} = \left(E_{\mathrm{V_a}} + E_{\mathrm{V_b}} + E_{\mathrm{miss}}\right) \Big/ 2.$

Event reconstruction



What we unknown is the location of the pink dot, but it must satisfy the physical assumptions.

$m_{I_b} > 0$ means it must located in the green sphere.

$m_{I_a} > 0$ means it must located in the blue sphere.

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{miss}$ form a triangle, and three vectors $\vec{p}_{I_a}$, $\vec{p}_{I_b}$ and $\vec{p}_{miss}$ form another triangle.

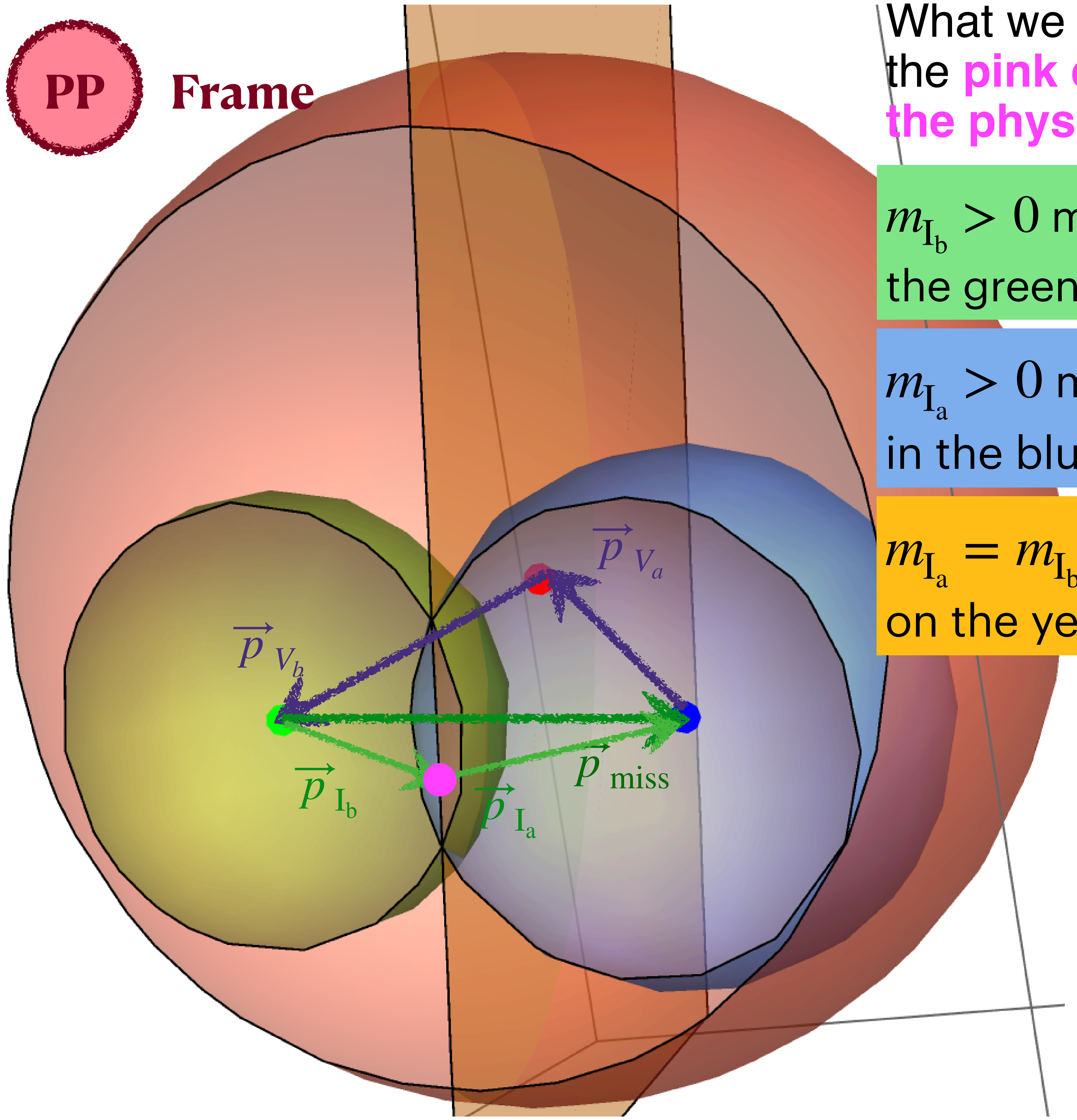
Physical Constraints (Assumptions)

1. $p^{\mu}_{P_a} = p^{\mu}_{V_a} + p^{\mu}_{I_a}$;
2. $p^{\mu}_{P_b} = p^{\mu}_{V_b} + p^{\mu}_{I_b}$;
3. $m_P = m_{P_a} = m_{P_b}$;
4. $m_I = m_{I_a} = m_{I_b}$.
5. $m_P > 0$;
6. $m_I > 0$.

In PP frame,

7. $E_{P_a} = E_{P_b} = \left(E_{V_a} + E_{V_b} + E_{miss}\right) \Big/ 2.$

Event reconstruction



What we unknown is the location of the pink dot, but it must satisfy the physical assumptions.

$m_{I_b} > 0$ means it must located in the green sphere.

$m_{I_a} > 0$ means it must located in the blue sphere.

$m_{I_a} = m_{I_b}$ means it must located on the yellow plane.

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{miss}$ form a triangle, and three vectors $\vec{p}_{I_a}$, $\vec{p}_{I_b}$ and $\vec{p}_{miss}$ form another triangle.

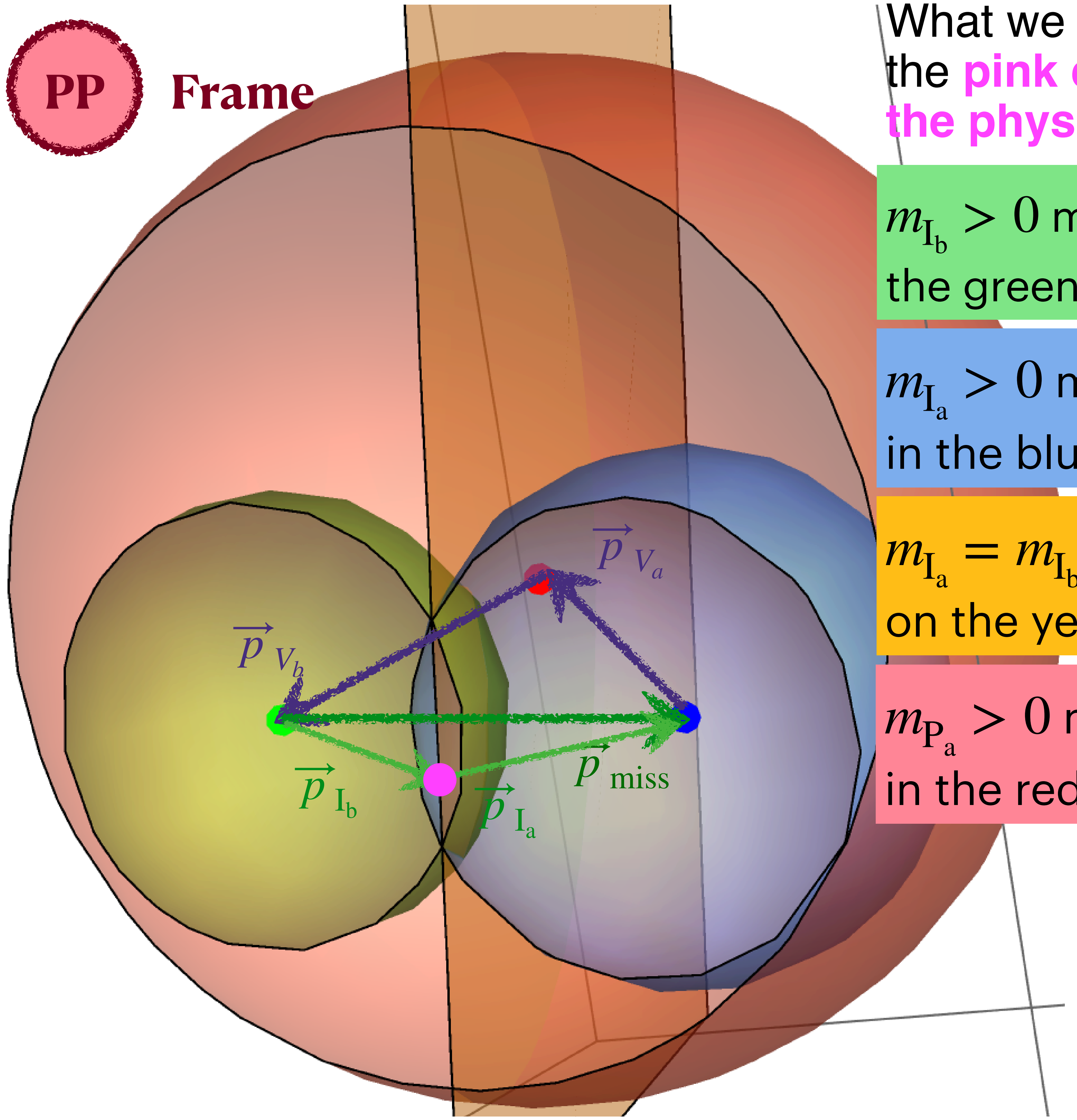
Physical Constraints (Assumptions)

1. $p^{\mu}_{P_a} = p^{\mu}_{V_a} + p^{\mu}_{I_a}$;
2. $p^{\mu}_{P_b} = p^{\mu}_{V_b} + p^{\mu}_{I_b}$;
3. $m_P = m_{P_a} = m_{P_b}$;
4. $m_I = m_{I_a} = m_{I_b}$.
5. $m_P > 0$;
6. $m_I > 0$.

In PP frame,

7. $E_{P_a} = E_{P_b} = \left(E_{V_a} + E_{V_b} + E_{miss}\right) / 2.$

Event reconstruction



What we unknown is the location of the **pink dot, but it must satisfy the physical assumptions.**

$m_{\mathrm{I_b}} > 0$ means it must located in the green sphere.

$m_{\mathrm{I_a}} > 0$ means it must located in the blue sphere.

$m_{\mathrm{I_a}} = m_{\mathrm{I_b}}$ means it must located on the yellow plane.

$m_{\mathrm{P_a}} > 0$ means it must located in the red sphere.

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\mathrm{miss}}$ form a triangle, and three vectors $\vec{p}_{\mathrm{I_a}}$, $\vec{p}_{\mathrm{I_b}}$ and $\vec{p}_{\mathrm{miss}}$ form another triangle.

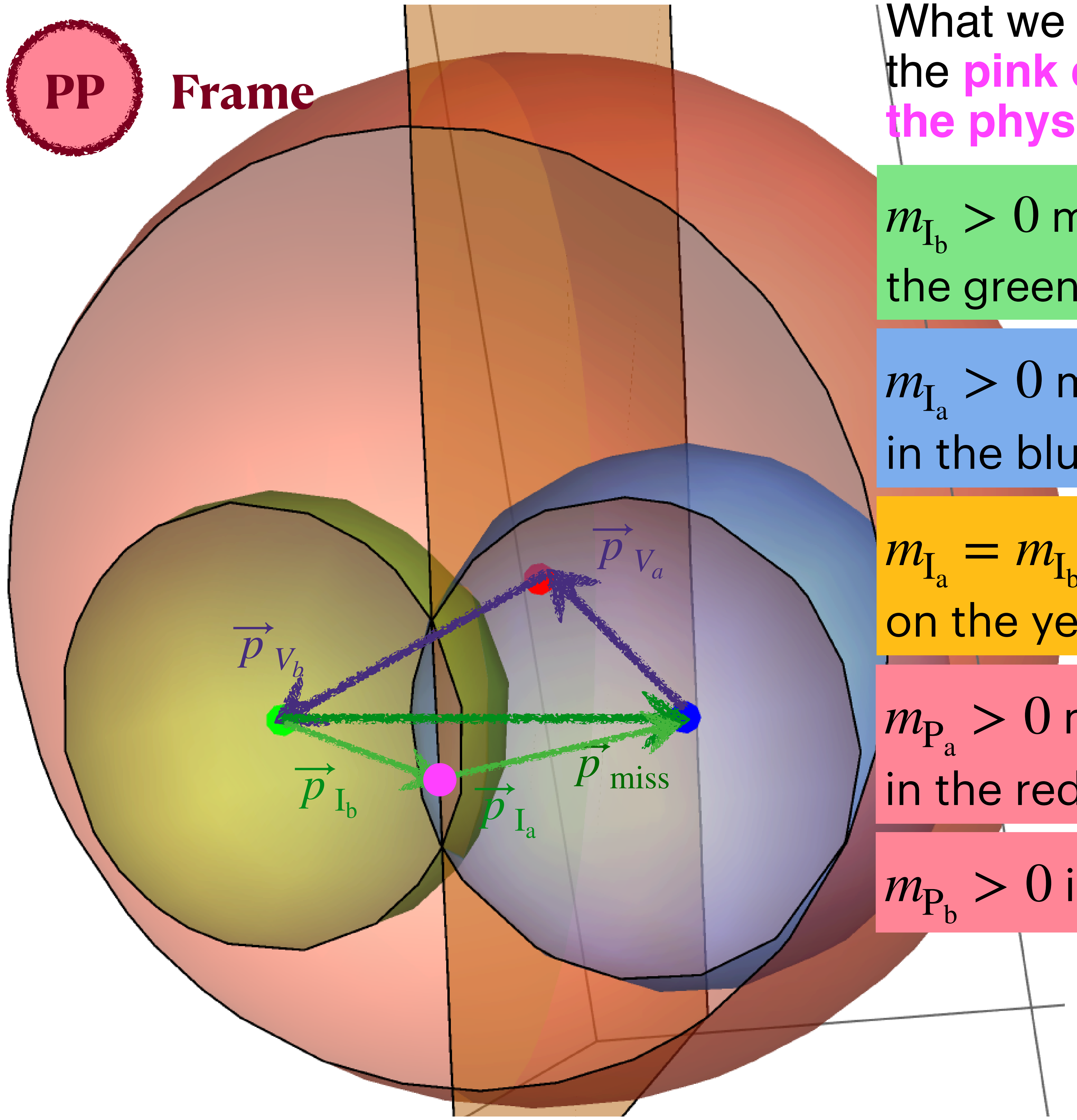
Physical Constraints (Assumptions)

1. $p^{\mu}_{\mathrm{P_a}} = p^{\mu}_{V_a} + p^{\mu}_{\mathrm{I_a}}$;
2. $p^{\mu}_{\mathrm{P_b}} = p^{\mu}_{V_b} + p^{\mu}_{\mathrm{I_b}}$;
3. $m_{\mathrm{P}} = m_{\mathrm{P_a}} = m_{\mathrm{P_b}}$;
4. $m_{\mathrm{I}} = m_{\mathrm{I_a}} = m_{\mathrm{I_b}}$.
5. $m_{\mathrm{P}} > 0$;
6. $m_{\mathrm{I}} > 0$.

In PP frame,

7. $E_{\mathrm{P_a}} = E_{\mathrm{P_b}} = \left(E_{\mathrm{V_a}} + E_{\mathrm{V_b}} + E_{\mathrm{miss}}\right) \big/ 2.$

Event reconstruction



What we unknown is the location of the **pink dot, but it must satisfy the physical assumptions.**

$m_{I_b} > 0$ means it must located in the green sphere.

$m_{I_a} > 0$ means it must located in the blue sphere.

$m_{I_a} = m_{I_b}$ means it must located on the yellow plane.

$m_{P_a} > 0$ means it must located in the red sphere.

$m_{P_b} > 0$ is equal to $m_{P_a} > 0$.

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{miss}$ form a triangle, and three vectors $\vec{p}_{I_a}$, $\vec{p}_{I_b}$ and $\vec{p}_{miss}$ form another triangle.

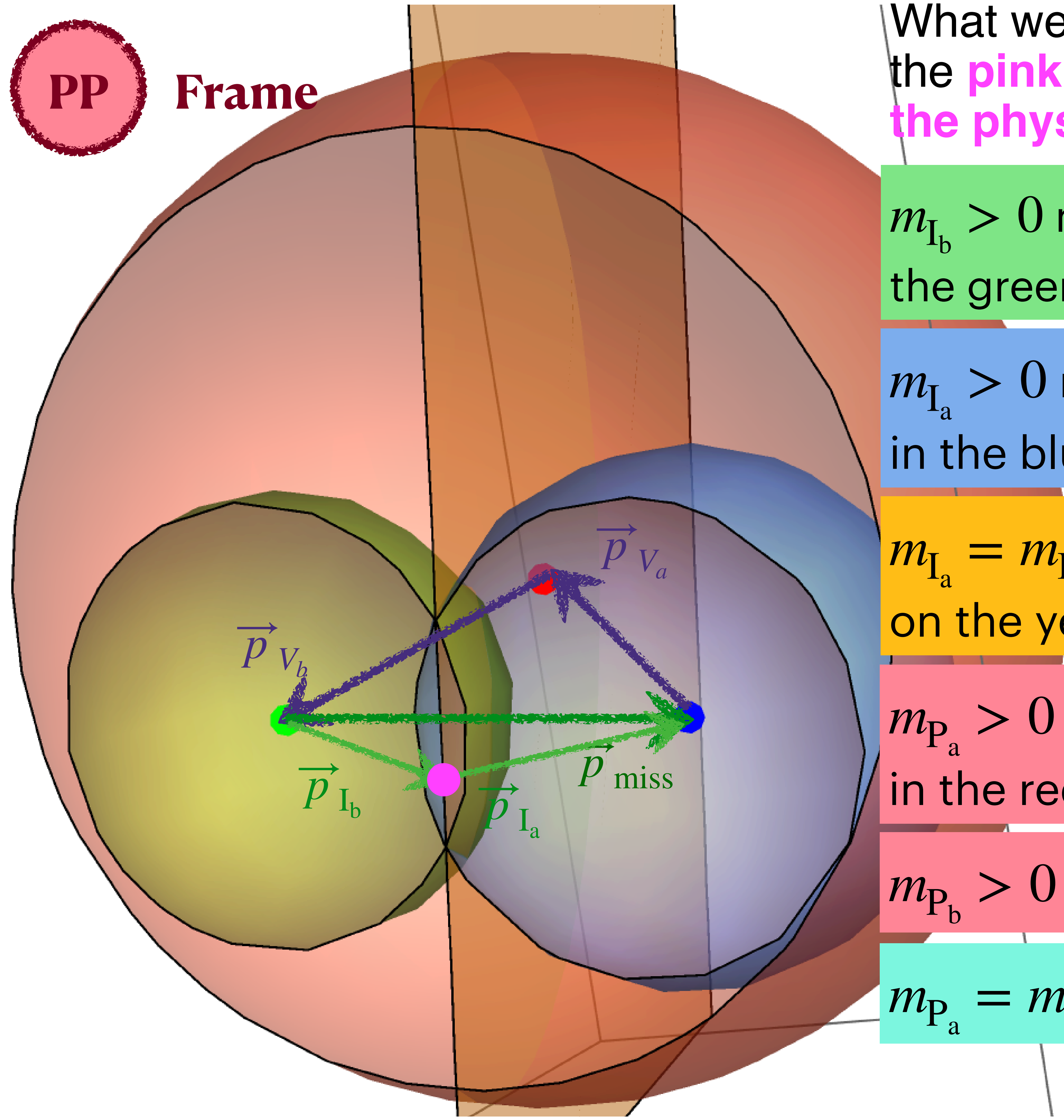
Physical Constraints (Assumptions)

1. $p^{\mu}_{P_a} = p^{\mu}_{V_a} + p^{\mu}_{I_a}$;
2. $p^{\mu}_{P_b} = p^{\mu}_{V_b} + p^{\mu}_{I_b}$;
3. $m_P = m_{P_a} = m_{P_b}$;
4. $m_I = m_{I_a} = m_{I_b}$.
5. $m_P > 0$;
6. $m_I > 0$.

In PP frame,

7. $E_{P_a} = E_{P_b} = \left(E_{V_a} + E_{V_b} + E_{miss}\right) / 2.$

Event reconstruction



What we unknown is the location of the **pink dot, but it must satisfy the physical assumptions.**

$m_{I_b} > 0$ means it must located in the green sphere.

$m_{I_a} > 0$ means it must located in the blue sphere.

$m_{I_a} = m_{I_b}$ means it must located on the yellow plane.

$m_{P_a} > 0$ means it must located in the red sphere.

$m_{P_b} > 0$ is equal to $m_{P_a} > 0$.

$m_{P_a} = m_{P_b}$ is always satisfied.

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{miss}$ form a triangle, and three vectors $\vec{p}_{I_a}$, $\vec{p}_{I_b}$ and $\vec{p}_{miss}$ form another triangle.

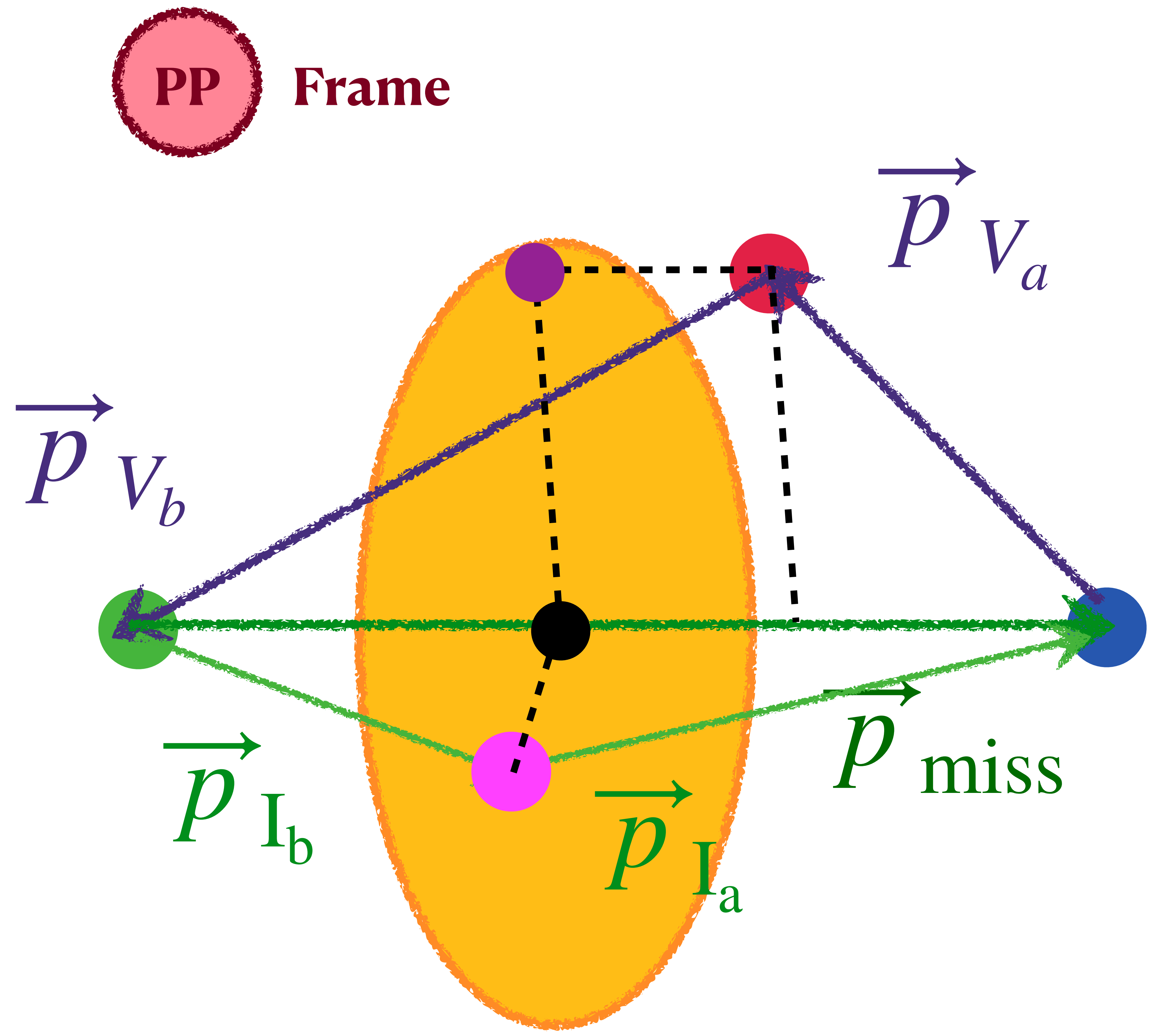
Physical Constraints (Assumptions)

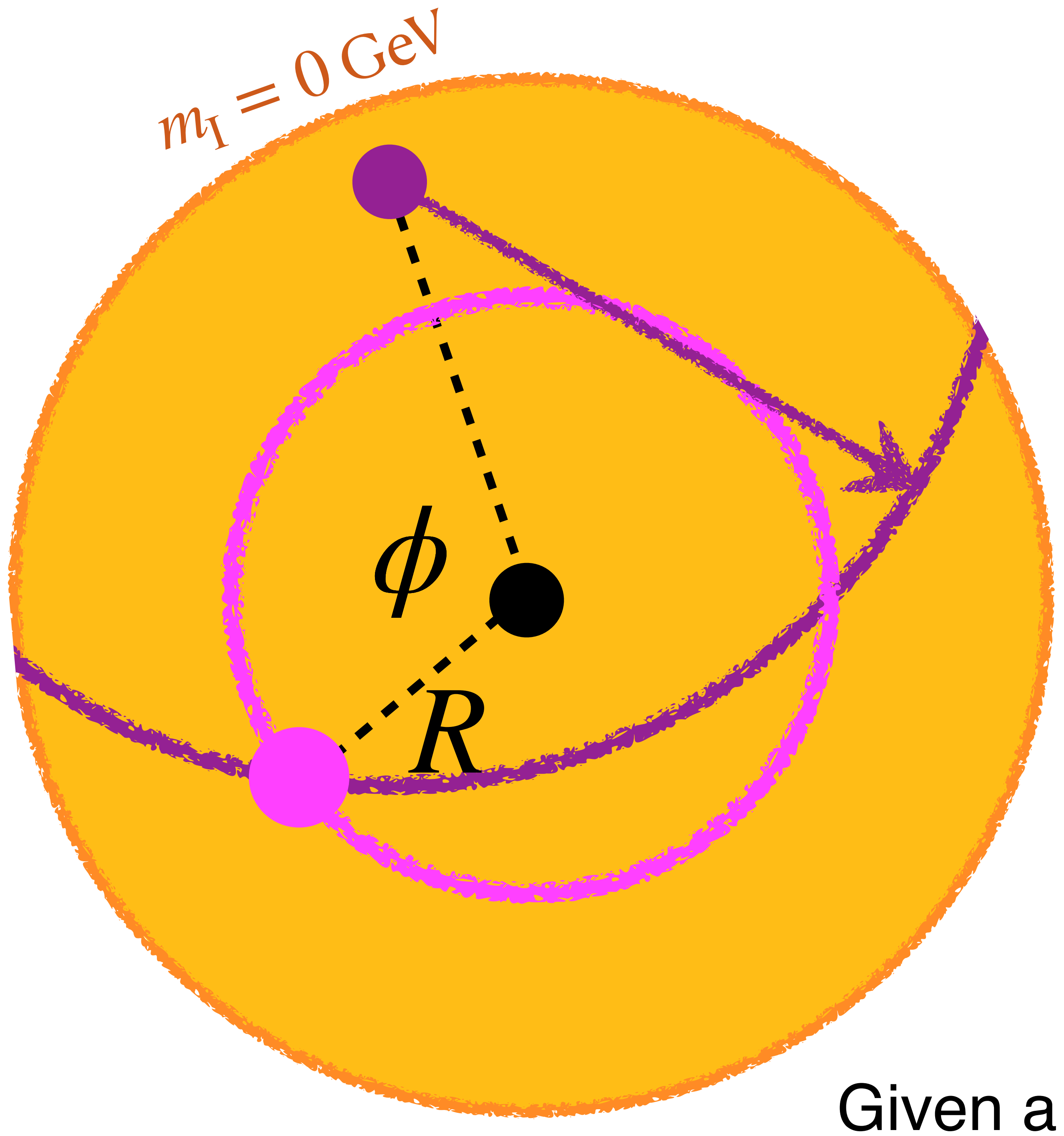
1. $p^{\mu}_{P_a} = p^{\mu}_{V_a} + p^{\mu}_{I_a}$;
2. $p^{\mu}_{P_b} = p^{\mu}_{V_b} + p^{\mu}_{I_b}$;
3. $m_P = m_{P_a} = m_{P_b}$;
4. $m_I = m_{I_a} = m_{I_b}$.
5. $m_P > 0$;
6. $m_I > 0$.

In PP frame,

7. $E_{P_a} = E_{P_b} = \left(E_{V_a} + E_{V_b} + E_{miss}\right) \Big/ 2.$

Event reconstruction





There are two independent degree to determine the location of the pink dot:

- ϕ: the angle between visible vector plane and invisible plane.
- R: the distance between the pink dot and the center of yellow round plane.

The boundary means $m_{\mathrm{I}} = 0$ GeV.

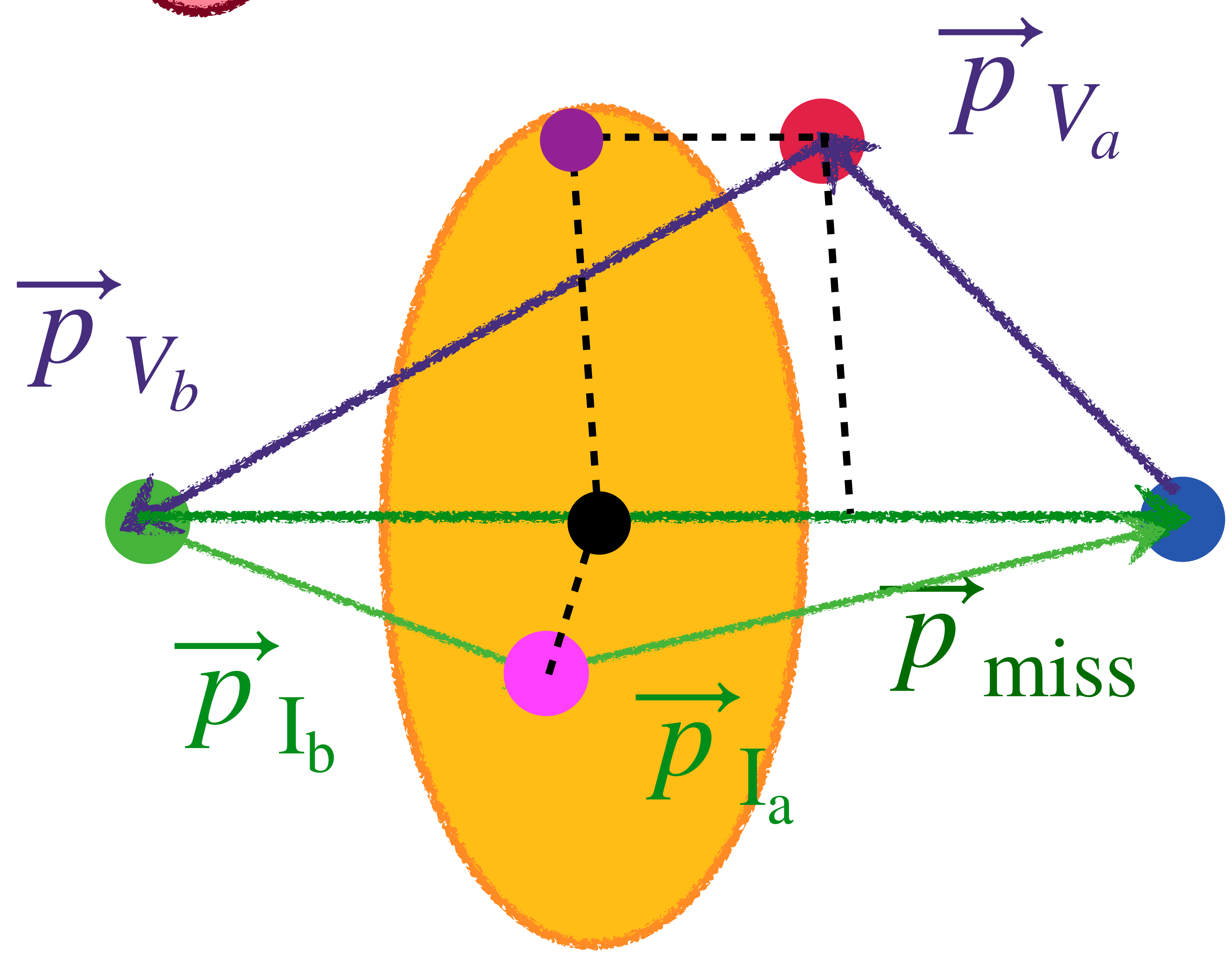
Given a pink dot, we can solve a set of $(m_{\mathrm{P}}, m_{\mathrm{I}})$:

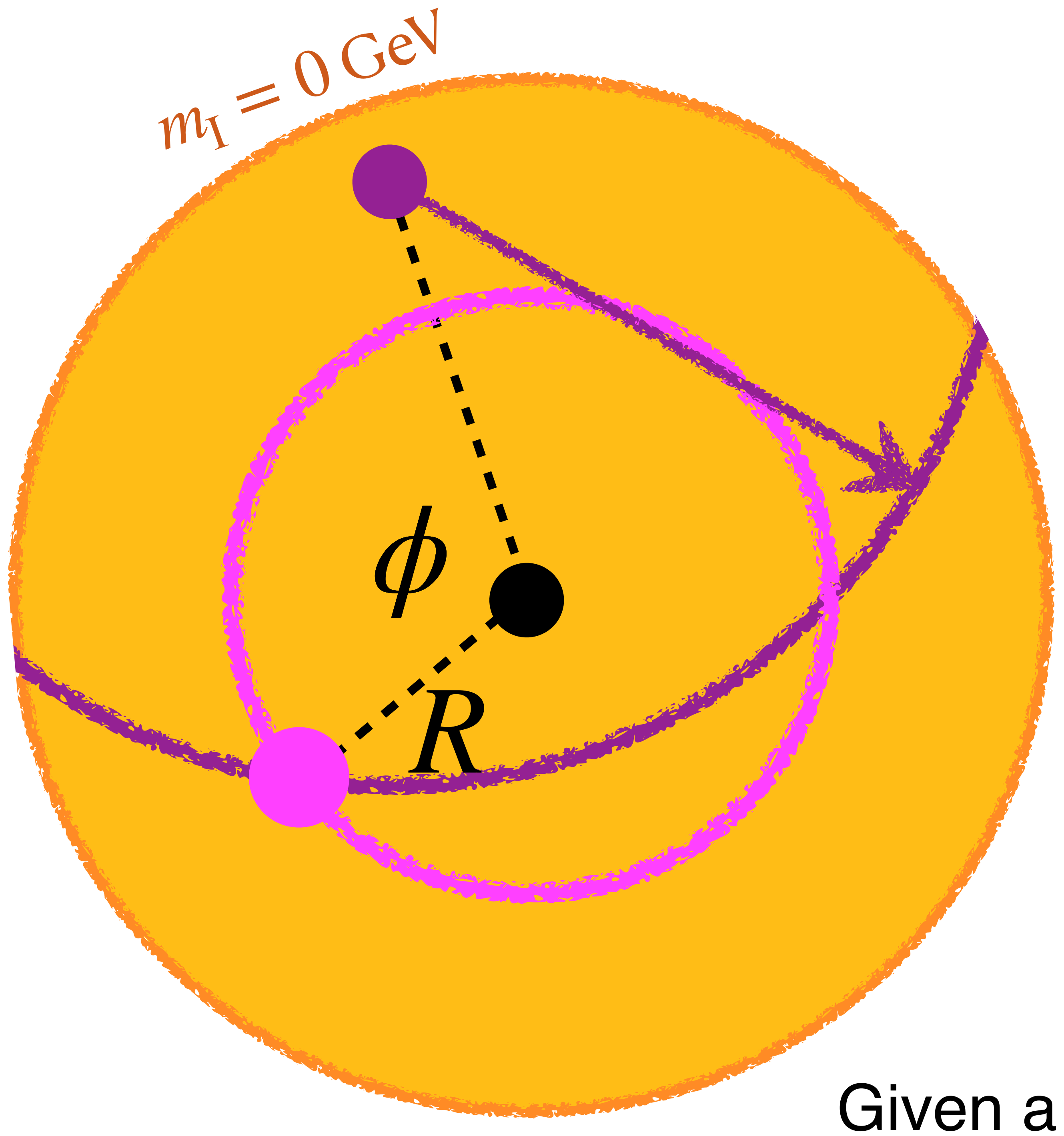
three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\mathrm{miss}}$ form a triangle, and three vectors $\vec{p}_{\mathrm{I_a}}$, $\vec{p}_{\mathrm{I_b}}$ and $\vec{p}_{\mathrm{miss}}$ form another triangle.

Event reconstruction

What we unknown is the location of the **pink dot, but it must satisfy the physical assumptions,** i.e. it must located in the yellow round plane.

PP Frame





There are two independent degree to determine the location of the pink dot:

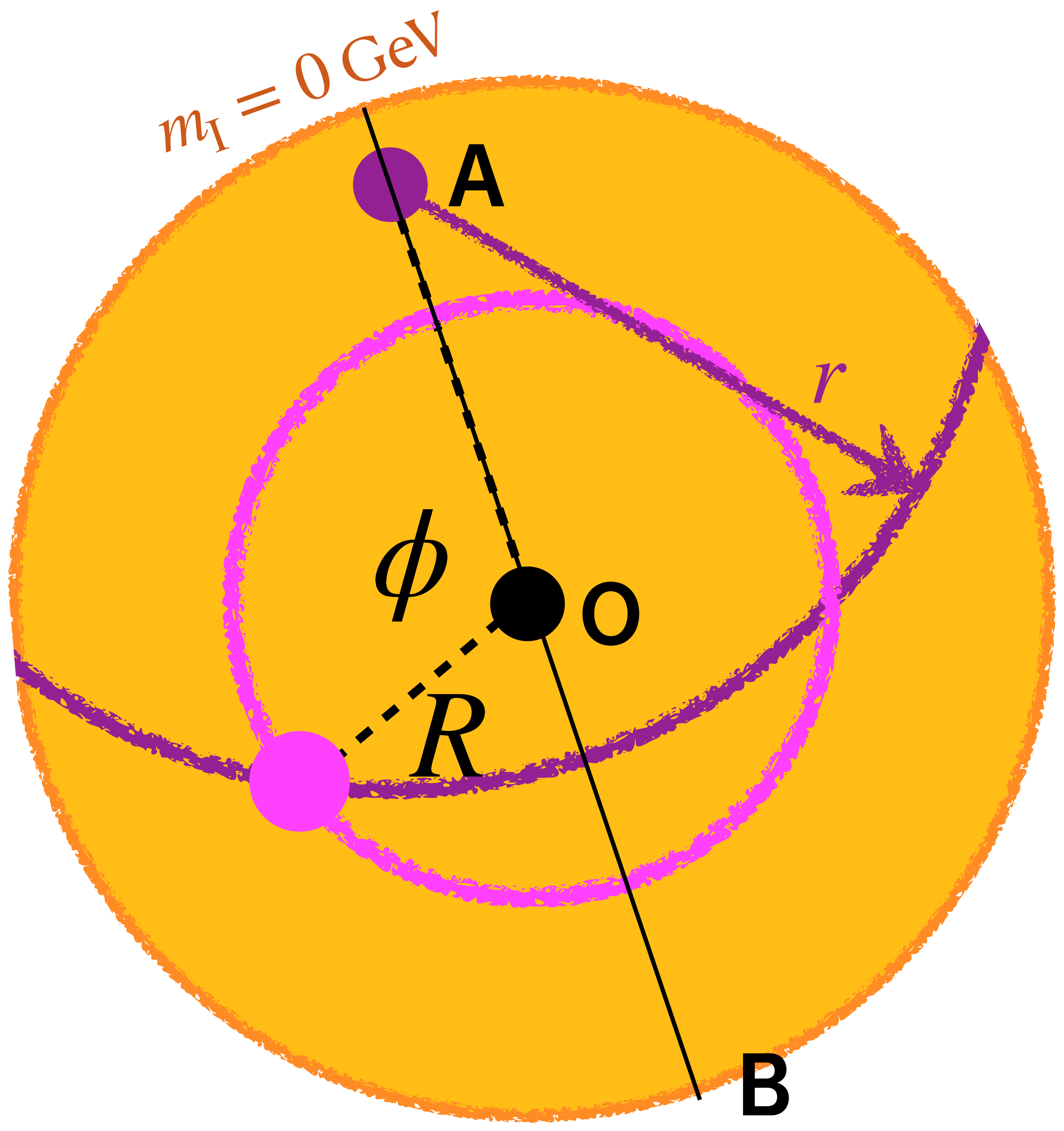
- ϕ: the angle between visible vector plane and invisible plane.
- R: the distance between the pink dot and the center of yellow round plane.

The boundary means $m_{\mathrm{I}} = 0$ GeV.

Given a pink dot, we can solve a set of $(m_{\mathrm{P}}, m_{\mathrm{I}})$:

three vectors $\vec{p}_{V_a}$, $\vec{p}_{V_b}$ and $\vec{p}_{\mathrm{miss}}$ form a triangle, and three vectors $\vec{p}_{\mathrm{I_a}}$, $\vec{p}_{\mathrm{I_b}}$ and $\vec{p}_{\mathrm{miss}}$ form another triangle.

Event reconstruction



Given a pink dot, we can solve a set of ($m_{\rm P}$, $m_{\rm I}$):

- For the point in the circle of fixed R (pink circle), the $m_{\rm I}$ is the same.
- For the point in the purple circle (fixed r), the $m_{\rm P}$ is the same.

In the diameter cross point A (purple point), we can define three observables:

$m_{\rm RC}^{\rm min}$: the $m_{\rm P}$ by choosing pink dot located in point A.

$m_{\rm RC}^{\rm max}$: the $m_{\rm P}$ by choosing pink dot located in point B.

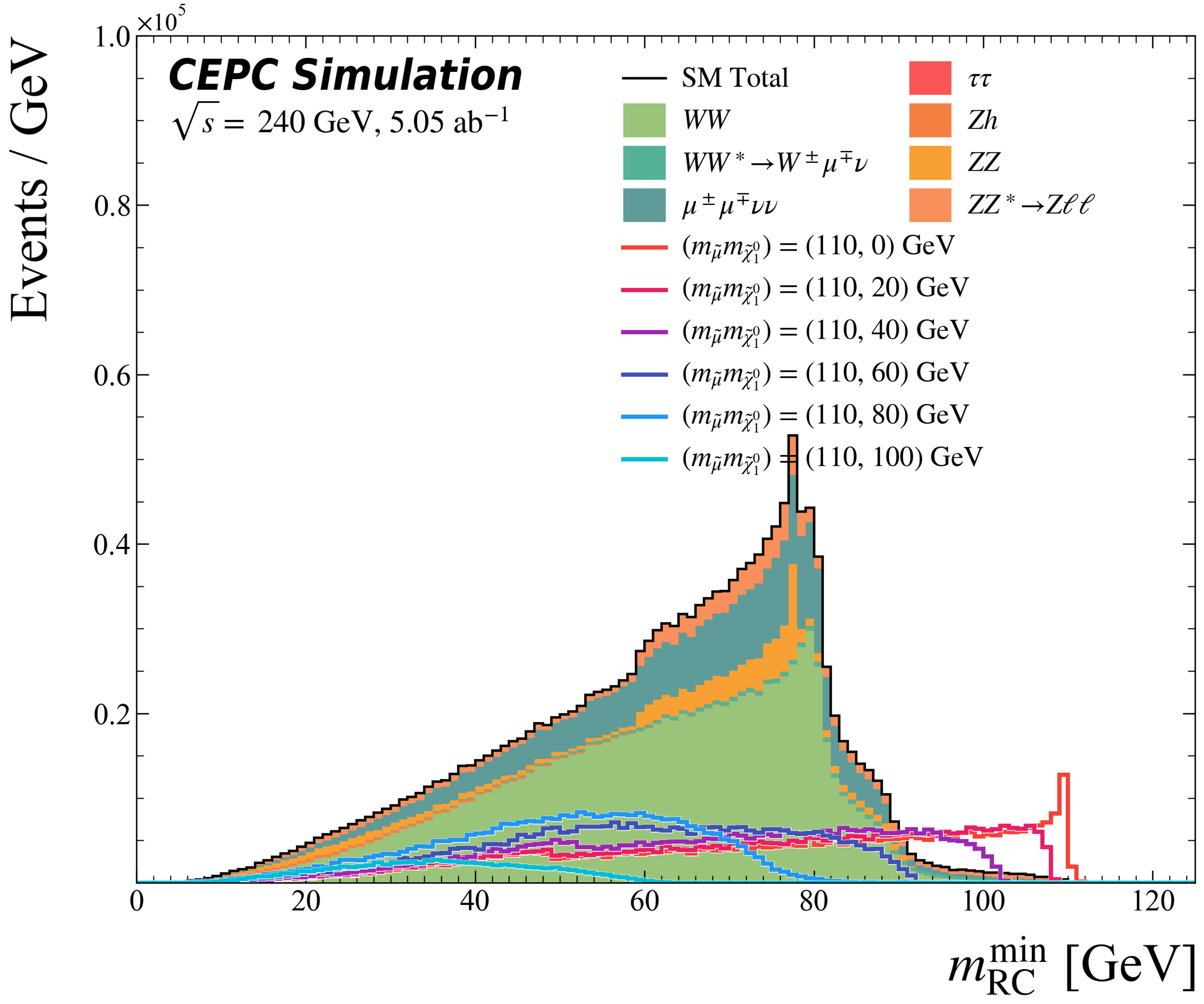
$m_{\rm LSP}^{\rm max}$: the $m_{\rm I}$ by choosing pink dot located in center point O.

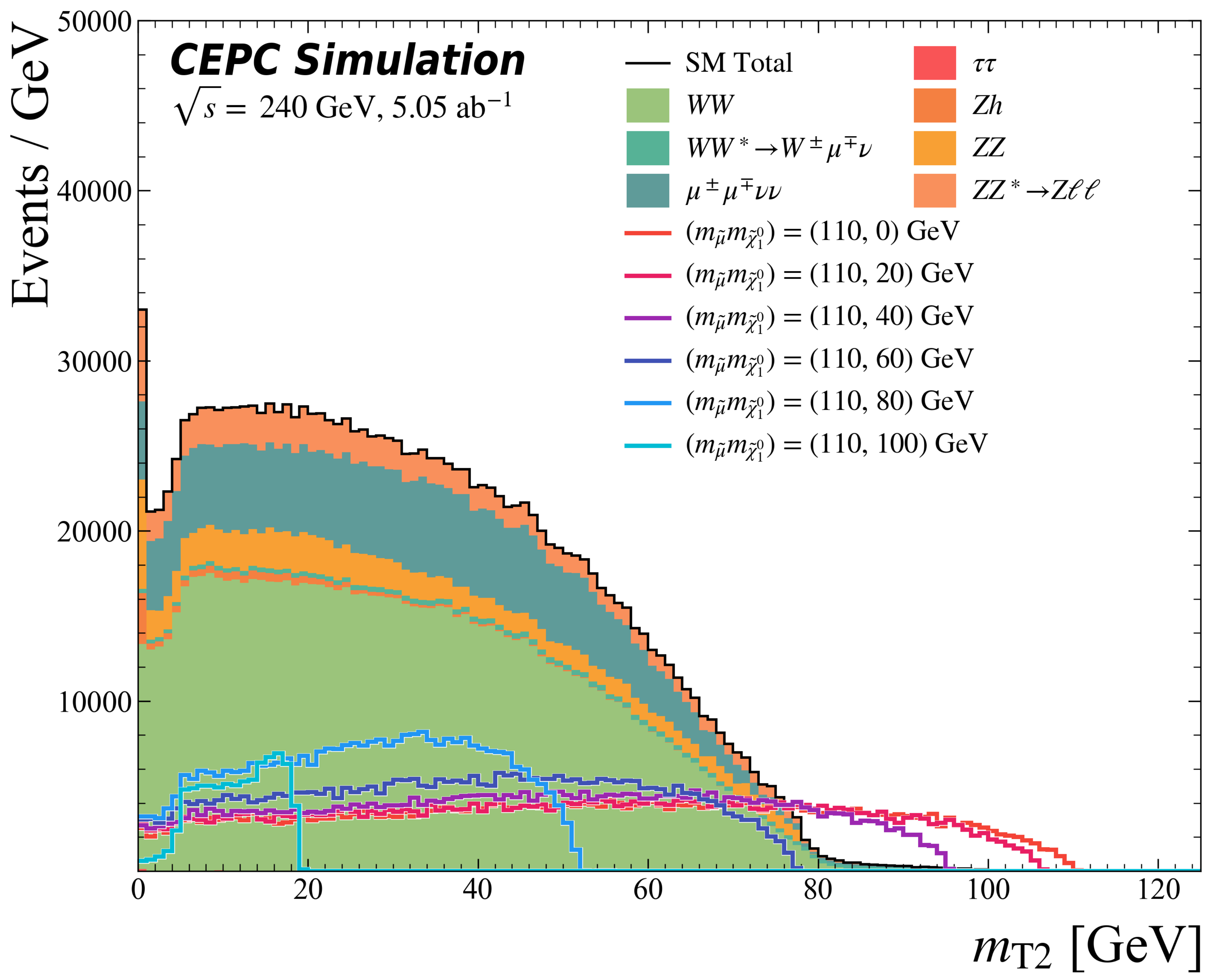
It is easy to say that:

$$0 < m_{\rm RC}^{\rm min} \leq m_{\rm P}^{\rm true} \leq m_{\rm RC}^{\rm max} < \sqrt{s}\,/2$$

$$0 \leq m_{\rm I}^{\rm ture} \leq m_{\rm LSP}^{\rm max}$$

Distribution of $m_{\mathrm{RC}}^{\min}$



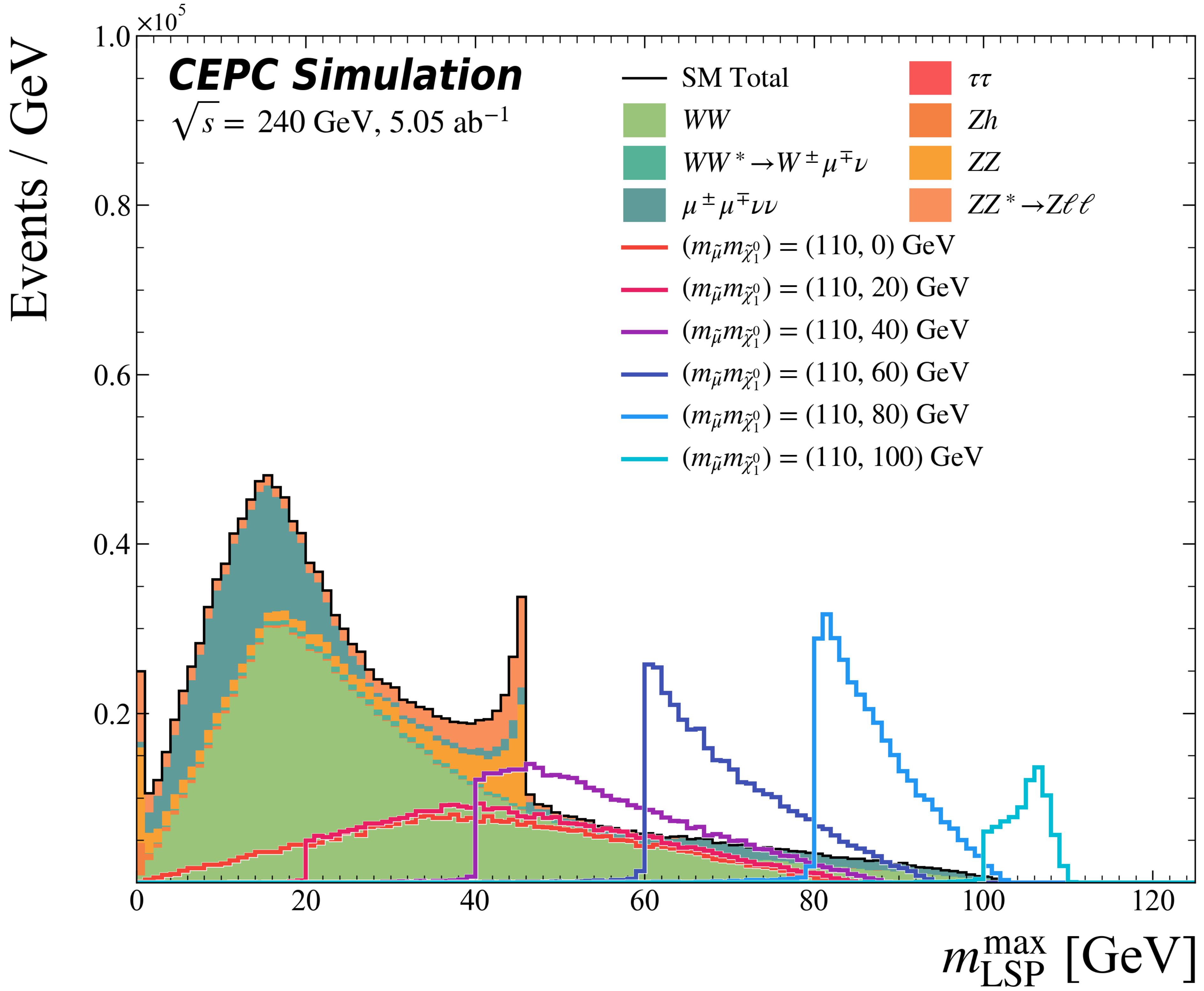


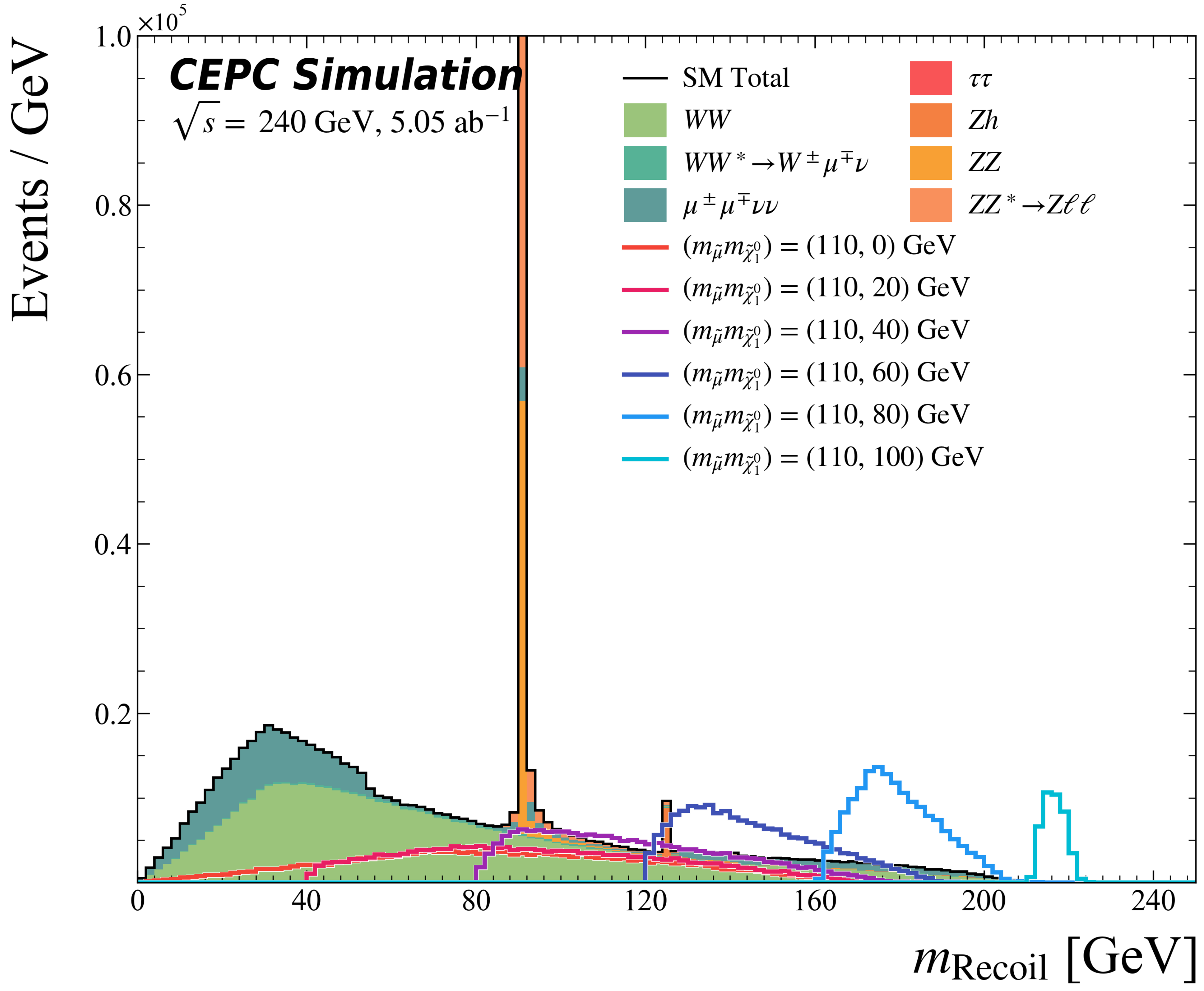
$m_{\mathrm{RC}}^{\min}$ is distributed as a peak shape

The $m_{\mathrm{RC}}^{\min}$ peak of WW background is located at m_W

$0 < m_{\mathrm{RC}}^{\min} \leq m_{\mathrm{P}}^{\mathrm{true}}$

Distribution of $m_{\mathrm{LSP}}^{\max}$





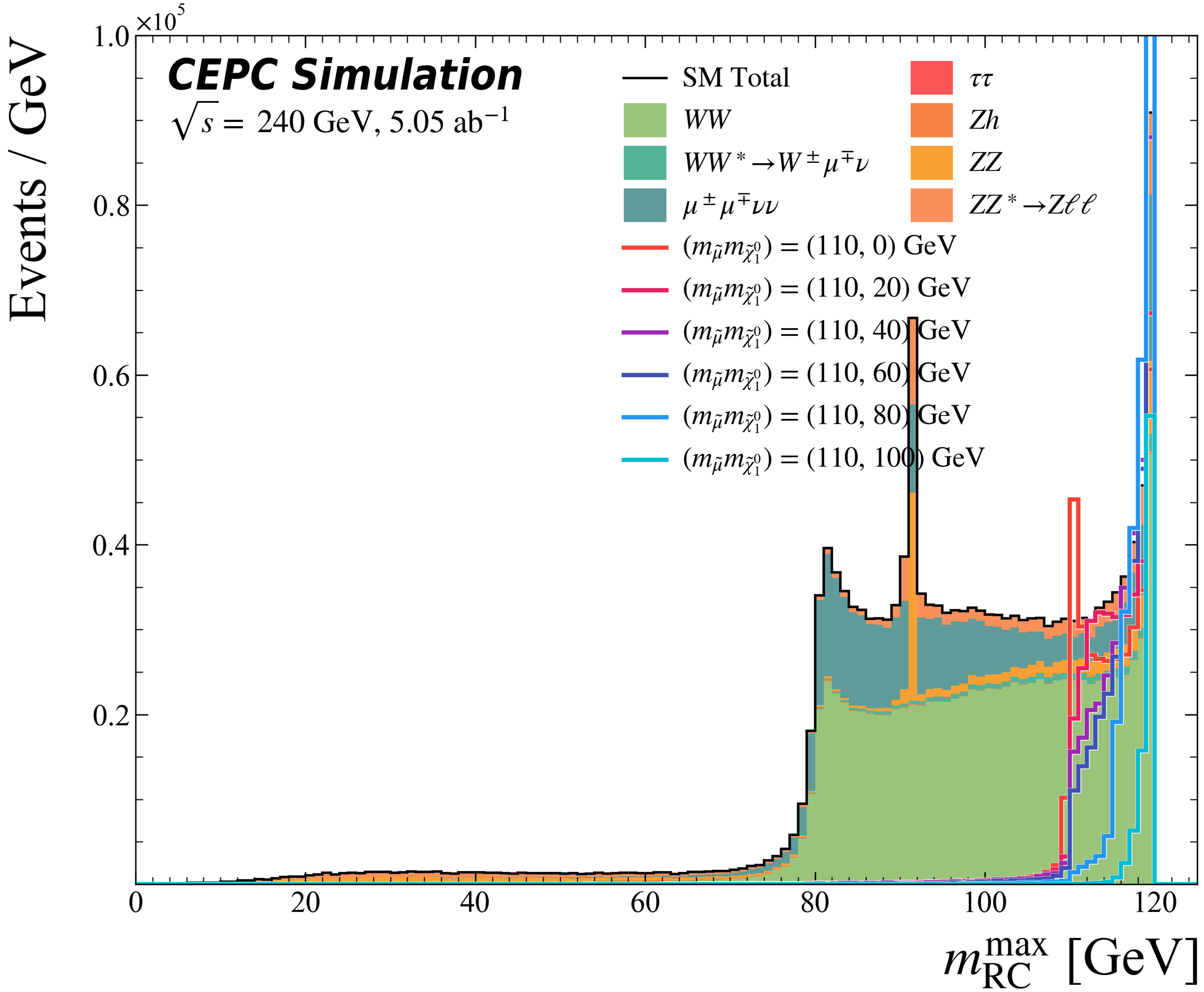
$m_{\mathrm{LSP}}^{\max}$ is distributed as a peak shape

The $m_{\mathrm{LSP}}^{\max}$ of background is mostly distributed lower than 50 GeV.

$0 \leq m_{\mathrm{I}}^{\mathrm{ture}} \leq m_{\mathrm{LSP}}^{\max}$

$m_{\mathrm{LSP}}^{\max}$ have the similar meaning with m_{Recoil} for WW background, but different meaning for ZZ background.

Distribution of $m_{\mathrm{RC}}^{\max}$



The $m_{\mathrm{RC}}^{\max}$ distribution of low mass splitting mass point sharper than large mass splitting.

$$m_{\mathrm{P}}^{\mathrm{true}} \leq m_{\mathrm{RC}}^{\max} < \sqrt{s}/2$$

The $m_{\mathrm{RC}}^{\max}$ cut at 110 GeV almost cut 3/4 background without losing signal events for $m_{\tilde{\mu}} \geq 110$ GeV.

Cross section cutflows

	Common Cuts			Δm_{low} Cuts	Δm_{mid} Cuts			Δm_{high} Cuts		
	Pre-selection	$m_{\text{max}}^{\text{RC}}$ > 100	$m_{\ell\ell}$-Veto Z	$m_{\text{LSP}}^{\text{max}} \geq 60$	$E_{\text{T}}^{\text{miss}} \geq 60$	$\cos\theta_{\ell^+}$ < 0.5 $\cos\theta_{\ell^-}$ > -0.5	$m_{\text{RC}}^{\text{min}}$ > 80	$m_{\text{LSP}}^{\text{max}}$ > 40	$m_{\ell\ell}$ < 100 $\cos\theta_{\ell^+}$ < 0.5 $\cos\theta_{\ell^-}$ > -0.5	$m_{\text{RC}}^{\text{min}}$ < 60 or $m_{\text{RC}}^{\text{min}}$ > 80
(110, 0)	71.8	70.7	57.0	7.9	28.3	17.7	14.1	28.1	9.4	6.4
(110, 20)	71.7	70.6	56.8	9.9	27.6	17.5	13.4	33.6	11.8	8.3
(110, 40)	71.1	70.3	56.5	18.7	24.2	15.9	11.1	56.3	22.3	16.1
(110, 60)	69.5	69.3	57.4	56.8	15.4	11.3	4.5	57.4	29.8	16.8
(110, 80)	64.4	64.4	64.4	64.3	0.0	0.0	0.0	64.4	38.4	27.9
(110, 100)	16.3	16.3	16.3	16.3	0.0	0.0	0.0	16.3	12.0	12.0
SM WW	194.1	102.2	91.2	15.3	10.9	2.5	0.8	35.9	7.7	4.2
SM $\mu\nu W$	5.2	3.4	2.8	0.4	1.2	0.5	0.4	1.2	0.4	0.3
SM ZZ	23.1	8.4	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0
SM $Z\ell\ell$	23.4	9.8	2.6	0.0	0.8	0.4	0.3	2.1	0.4	0.3
SM Zh	3.3	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0
SM $\mu\mu\nu\nu$	63.3	20.1	17.6	8.7	1.8	0.9	0.5	10.7	4.3	2.4
SM $\tau\tau$	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

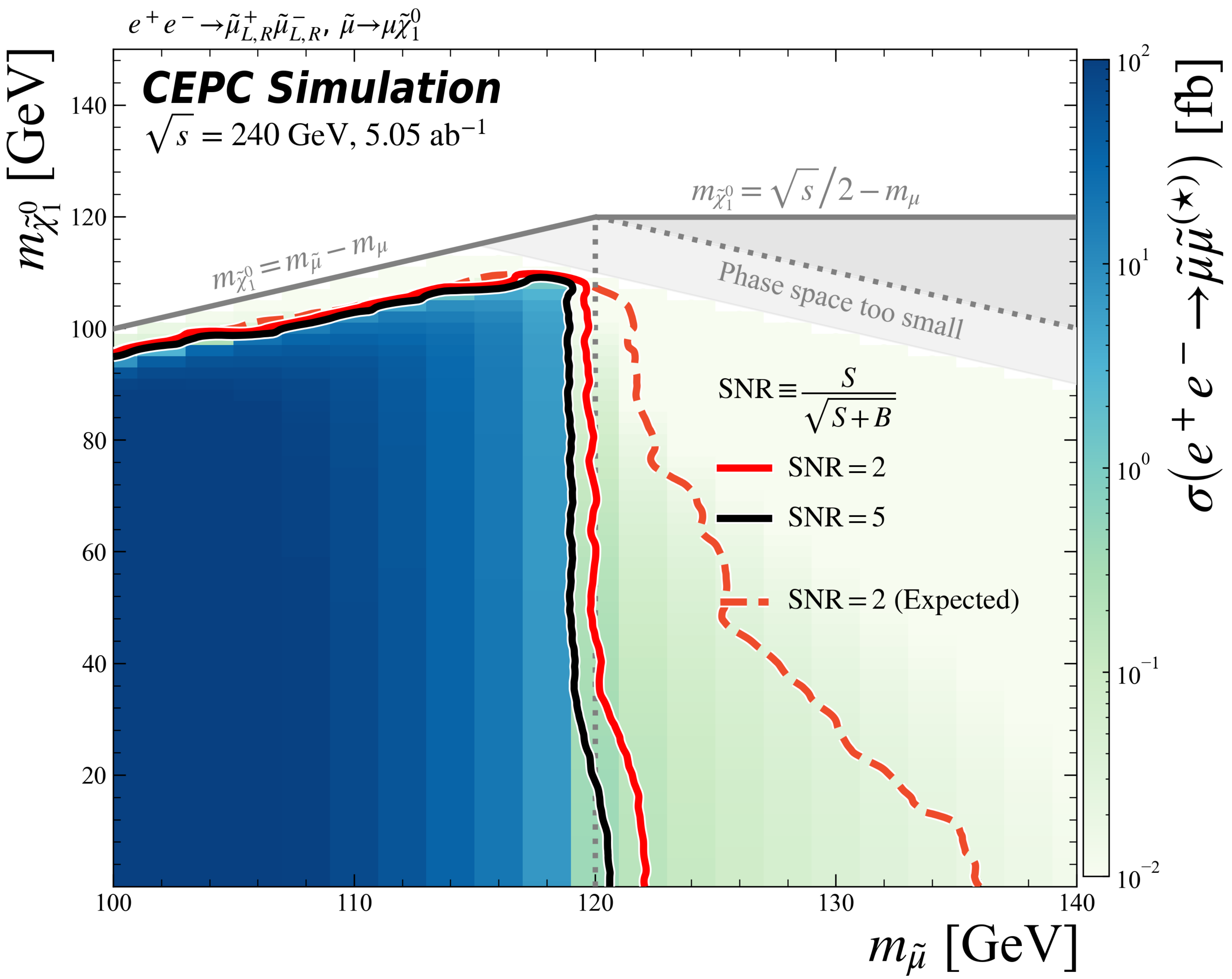
Cross section cutflows

	Common Cuts			Δm_{low} Cuts	Δm_{mid} Cuts			Δm_{high} Cuts		
	Pre-selection	$m^{\text{RC}}_{\text{max}}$ > 100	$m_{\ell\ell}$-Veto Z	$m^{\text{max}}_{\text{LSP}} \geq 60$	$E^{\text{miss}}_{\text{T}} \geq 60$	$\cos\theta_{\ell^+}$ < 0.5 $\cos\theta_{\ell^-}$ > -0.5	$m^{\text{min}}_{\text{RC}}$ > 80	$m^{\text{max}}_{\text{LSP}}$ > 40	$m_{\ell\ell}$ < 100 $\cos\theta_{\ell^+}$ < 0.5 $\cos\theta_{\ell^-}$ > -0.5	$m^{\text{min}}_{\text{RC}}$ < 60 or $m^{\text{min}}_{\text{RC}}$ > 80
(110, 0)	71.8	70.7	57.0	7.9	28.3	17.7	14.1	28.1	9.4	6.4
(110, 20)	71.7	70.6	56.8	9.9	27.6	17.5	13.4	33.6	11.8	8.3
(110, 40)	71.1	70.3	56.5	18.7	24.2	15.9	11.1	56.3	22.3	16.1
(110, 60)	69.5	69.3	57.4	56.8	15.4	11.3	4.5	57.4	29.8	16.8
(110, 80)	64.4	64.4	64.4	64.3	0.0	0.0	0.0	64.4	38.4	27.9
(110, 100)	16.3	16.3	16.3	16.3	0.0	0.0	0.0	16.3	12.0	12.0
SM WW	194.1	102.2	91.2	15.3	10.9	2.5	0.8	35.9	7.7	4.2
SM $\mu\nu W$	5.2	3.4	2.8	0.4	1.2	0.5	0.4	1.2	0.4	0.3
SM ZZ	23.1	8.4	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0
SM $Z\ell\ell$	23.4	9.8	2.6	0.0	0.8	0.4	0.3	2.1	0.4	0.3
SM Zh	3.3	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0
SM $\mu\mu\nu\nu$	63.3	20.1	17.6	8.7	1.8	0.9	0.5	10.7	4.3	2.4
SM $\tau\tau$	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Pre-selection:

- OS muon pair
- $E^{\text{miss}}_{\text{T}}$ > 5 GeV
- p^{μ}_{T} > 5 GeV
- $\left|\eta^{\ell}\right| < 3$

Results & Summary



- Off-shell production can be reached by CEPC.
- the result interpreted by Signal Noise Ratio (SNR).
- Discovery sensitivity reach 119 GeV.
- Variables $m_{\mathrm{RC}}^{\mathrm{min}}$, $m_{\mathrm{RC}}^{\mathrm{max}}$ and $m_{\mathrm{LSP}}^{\mathrm{max}}$ are reconstructed in a Lorentz invariant manner, we believe they are successful attempts.
- This is only a temporary result, if the BKG can be suppressed at 0.1 fb level, the detection limit will be pushed greatly.

Thank you!

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In collaboration with Yang Zhang(ZZU). arXiv: 2206.XXXXX