Hunting for extended SUSY and Hidden Valleys at DØ

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SLAC NATIONAL ACCELERATOR LABORATORY
COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

Outline

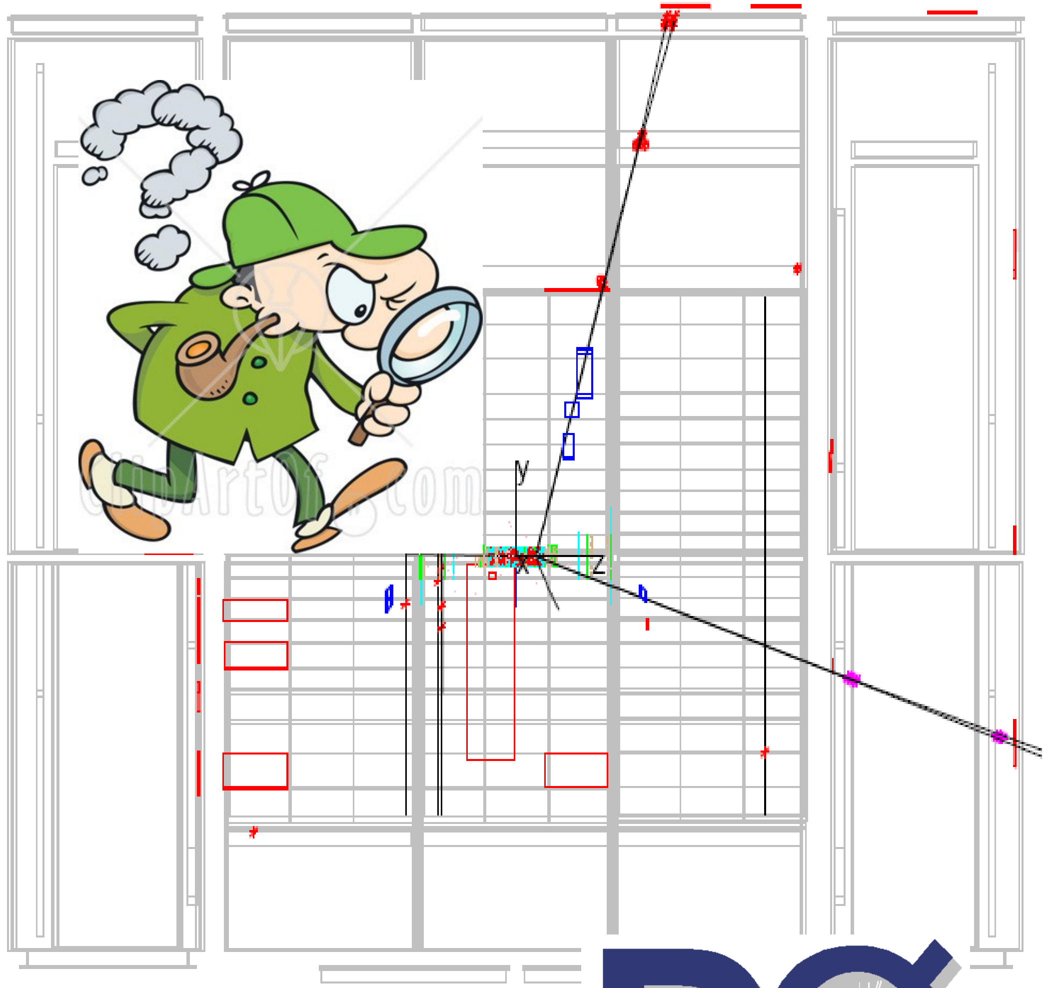
Introduction

Higgs→aa in the **N**MSSM

Higgs →
long-lived particles
→ b-jets

Lepton-jets in SUSY events

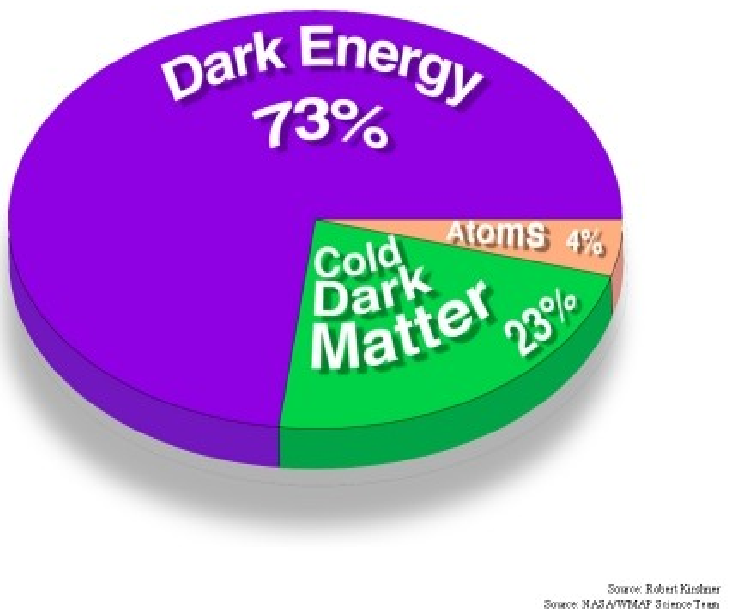
Conclusions



Introduction

Standard model works pretty well, but:

- Where is the Higgs?
- What is the Dark Matter?
- *(hierarchy problem, gravity, ...)*



New, *hidden sector*?

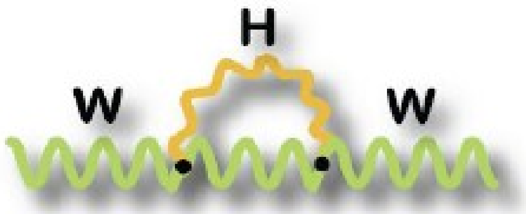
- **N**MSSM
- Hidden Valley

Predicts new *signatures*

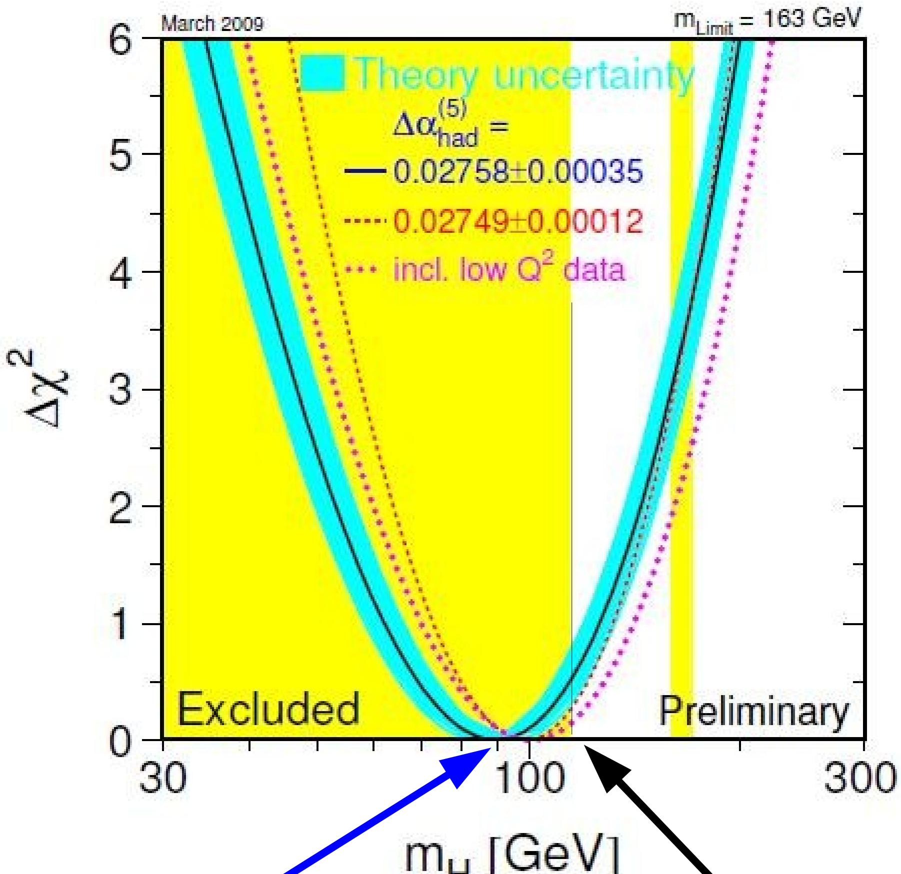
- Cascade Higgs decays (h→aa→ xx xx)
- Long-lived particles
- Decaying dark matter : “lepton-jets”

Well-motivated places to look for New Physics

Where's the Higgs ?



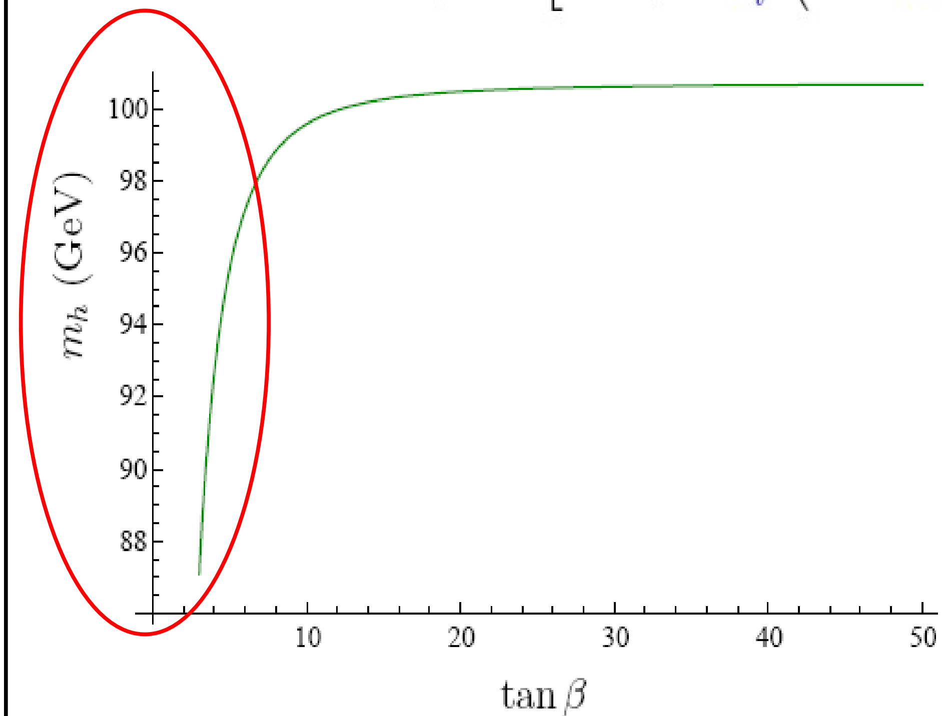
$$\sim \log \frac{m_H}{m_W}$$



M_h~95 GeV

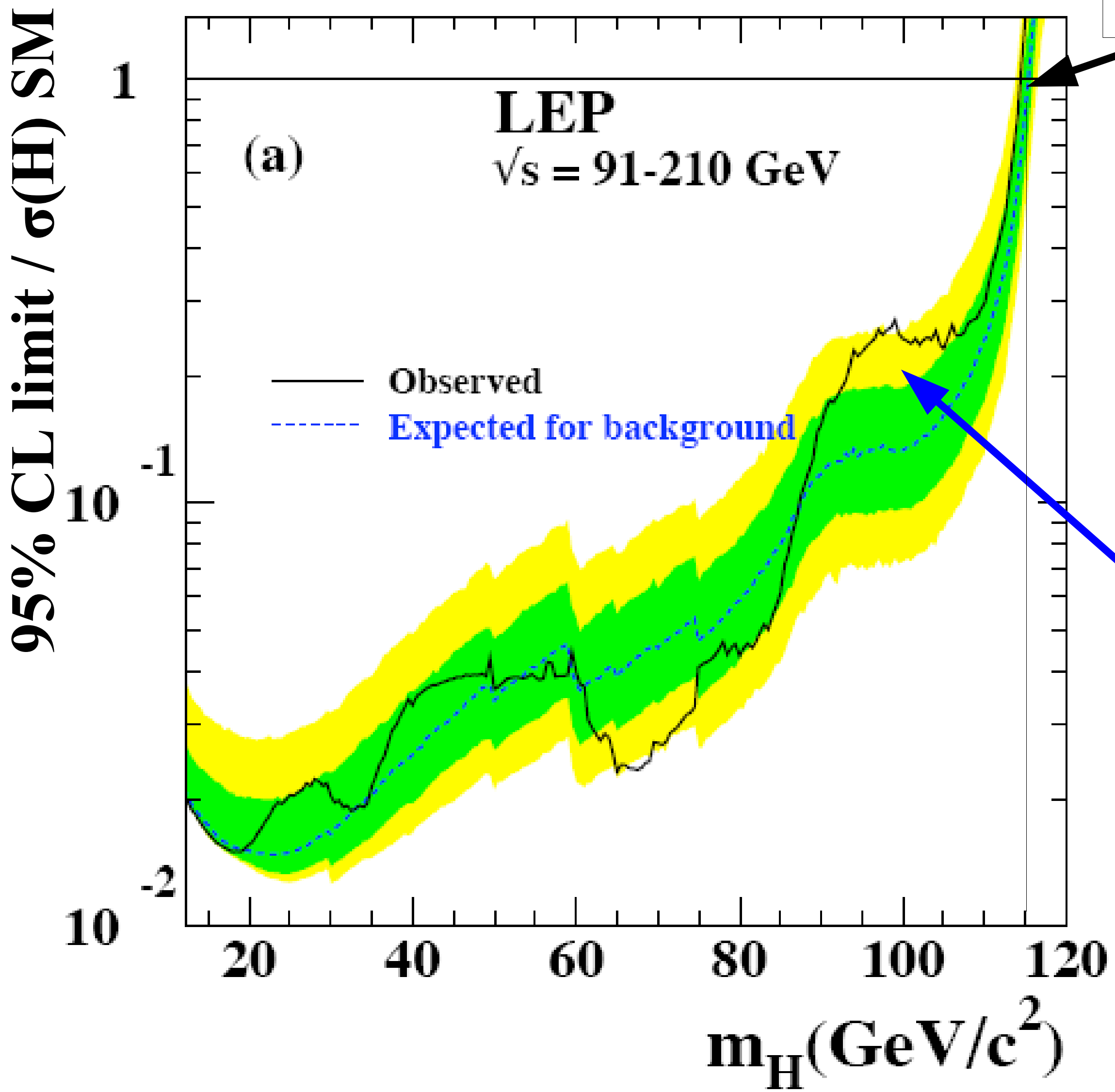
M_h>114.4 GeV

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + \frac{3 G_F m_t^4}{\sqrt{2}\pi^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{A_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{A_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$



SM-like Higgs mass typically <100 GeV in SUSY

Maybe LEP *did* see the Higgs ?



M_h>114.4 GeV

$h \to b\bar{b},\ \tau^+\tau^-$

2σ excess at M_H~95GeV

Consistent with BR(h→bb)~10%!

SM Higgs **decay** is *vulnerable*

Light Higgs decays to b quarks
but coupling is small ~1/60

New decay can easily dominate!

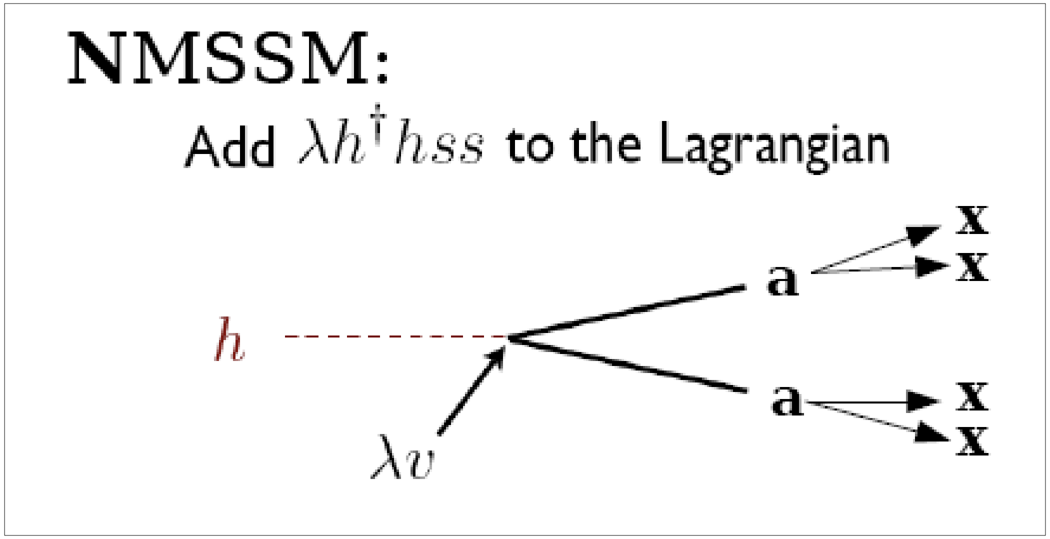
m_H > ~~114.4~~ GeV

4 b : 110 GeV

4 tau : 86 GeV

4 mu : 82 GeV ?

4 e : ?



R. Dermisek and J.F. Gunion, Phys.Rev.Lett.95:041801 (2005).
"Non-standard Higgs Decays": hep-ph/0801.4554 (2008).

a→μμ?

HyperCP experiment at Fermilab reported evidence for

$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = [8.6^{+6.6}_{-5.4}(\text{stat})\pm 5.5(\text{syst})]\times 10^{-8}.$$

SM expectation between 1.6 – 9 x 10^{-8}, so could just be SM...

But strange $M_{\mu\mu}$ distribution!

Is this the "a"?

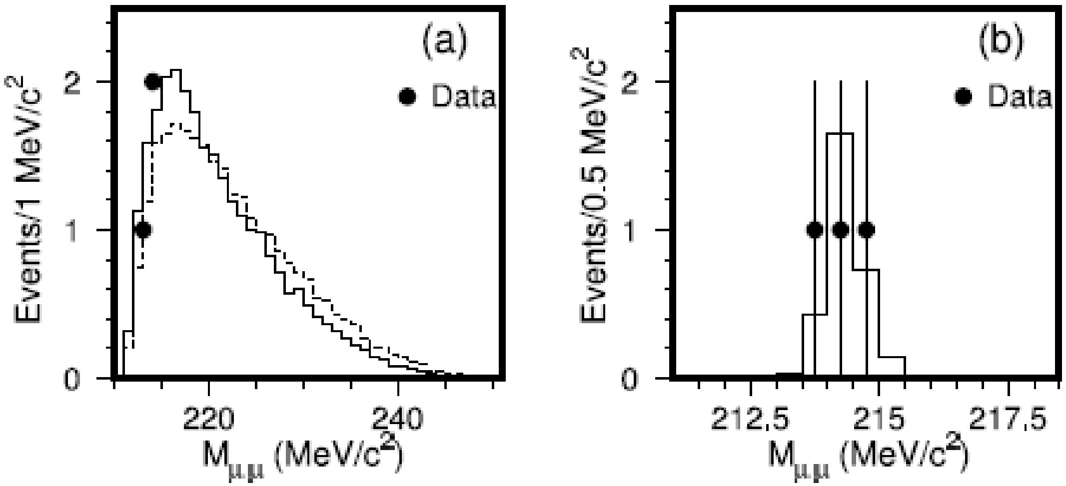
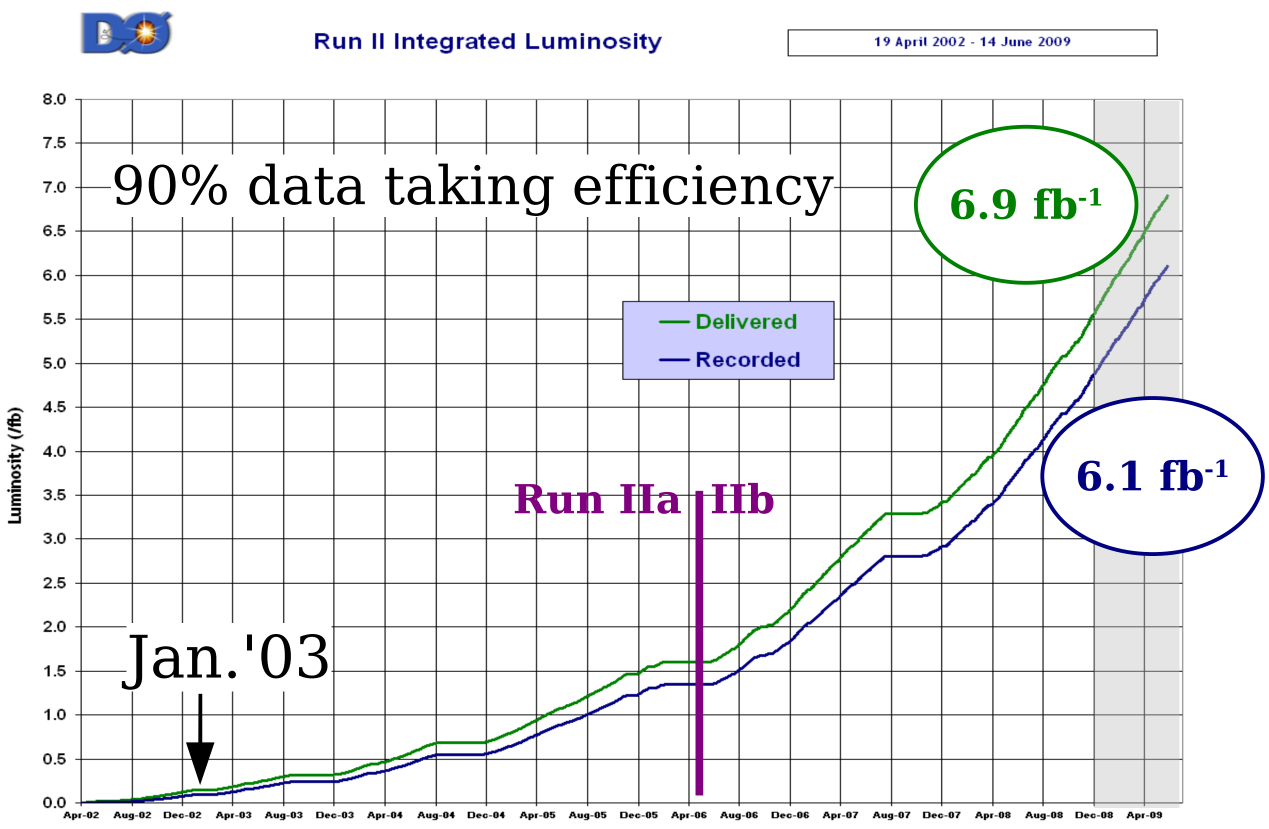


Figure 4: The $\mu^+\mu^-$ invariant mass of the three signal events with superimposed (a) Monte Carlo form factor decays (solid histogram) and uniform phase-space decays (dashed histogram), and (b) Monte Carlo $\Sigma^+ \to pX^0$, $X^0 \to \mu^+\mu^-$ events generated with $m_{X^0} = 214.3\text{MeV}/c^2$.

Data at DØ

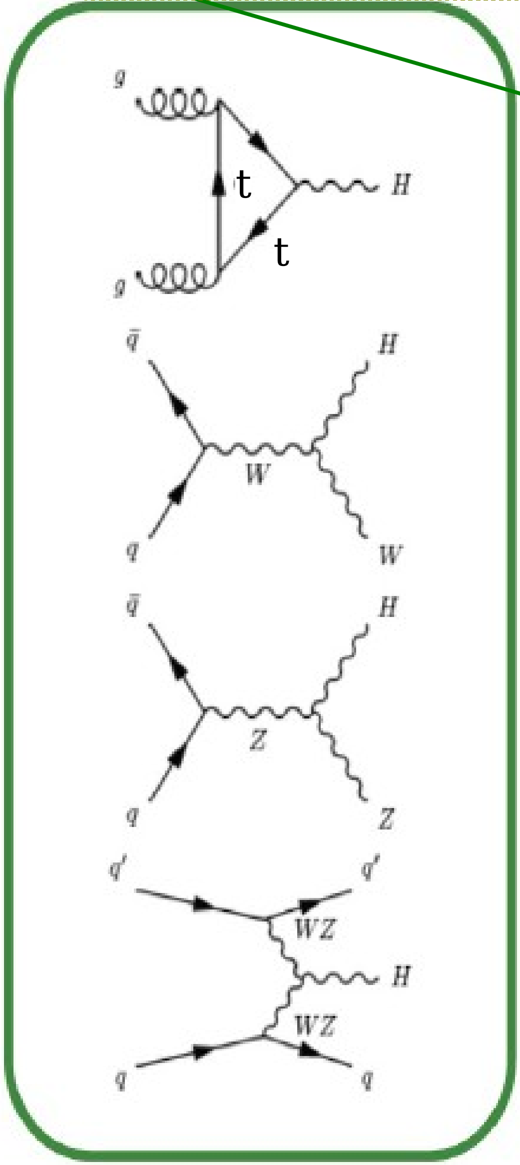
$p\bar{p}$ collider at 1.96 TeV

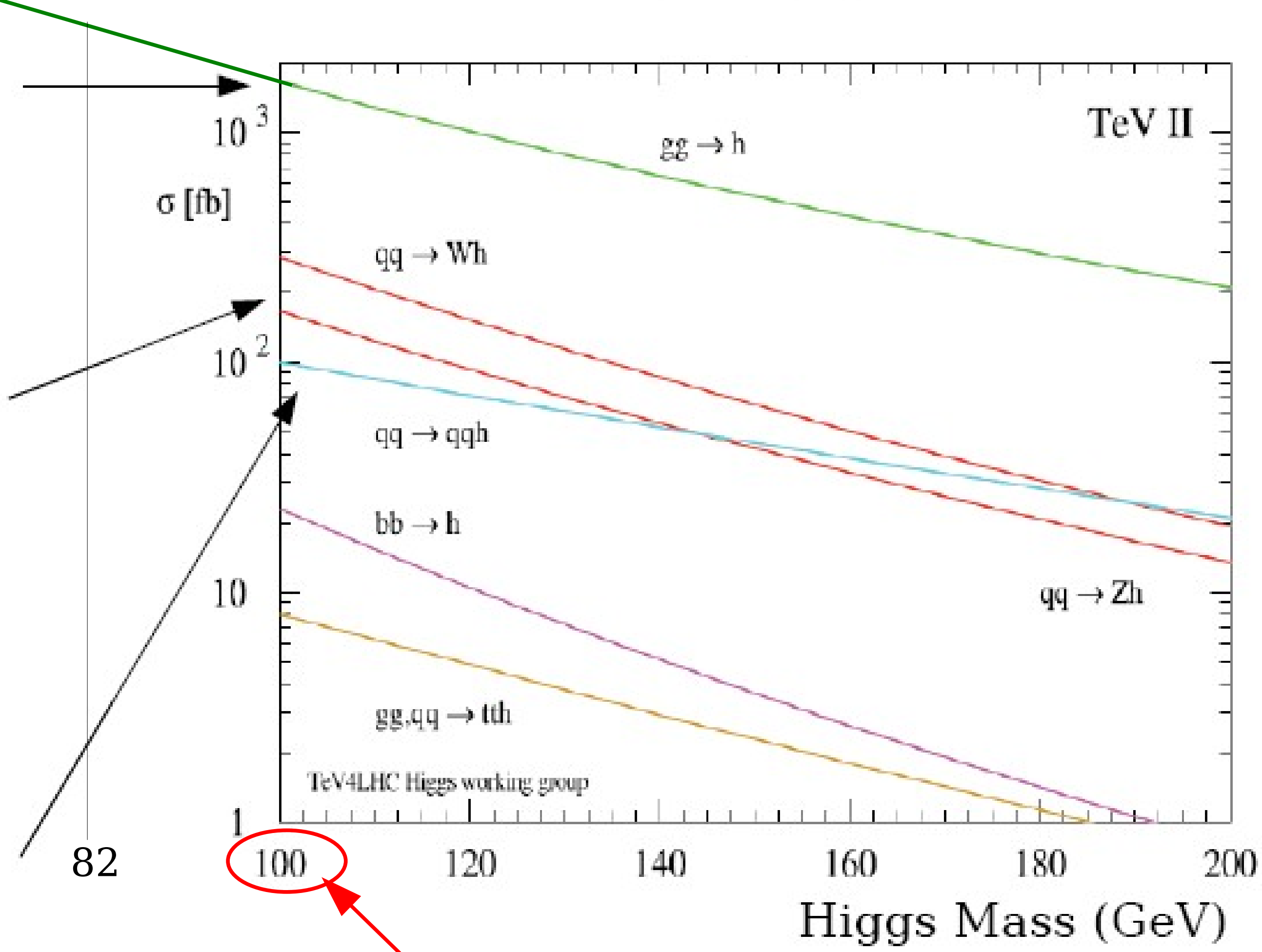
Up to **4.2 fb^{-1}** analyzed in this talk



Tevatron and DØ both performing very well!

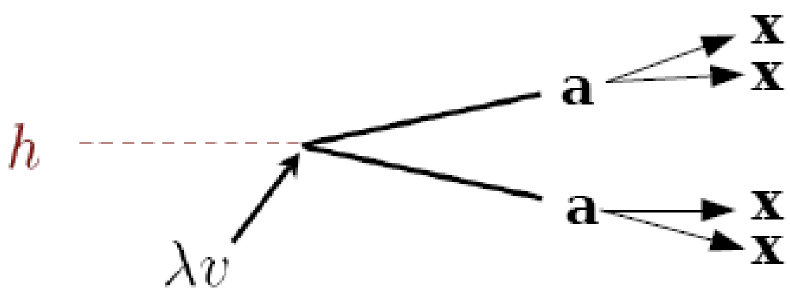
Higgs Production at the Tevatron

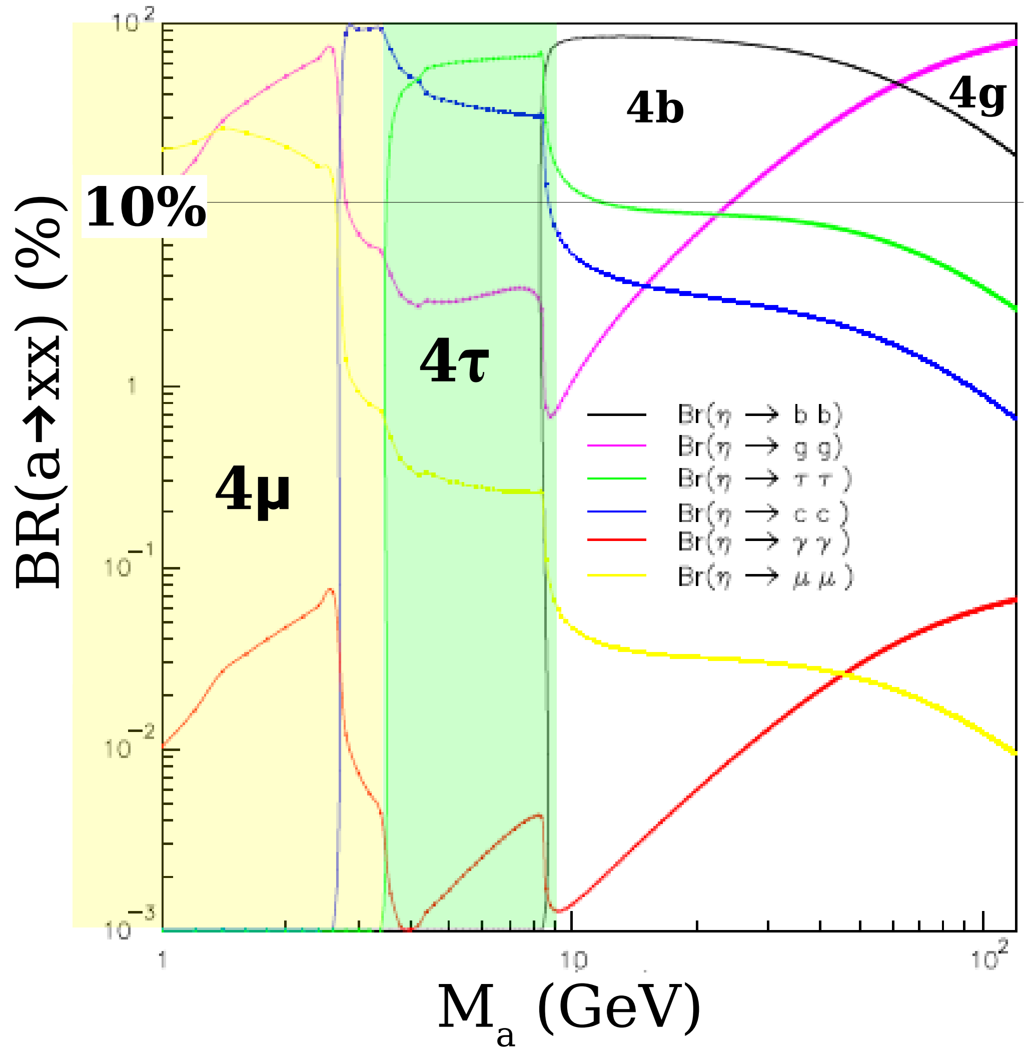




~10,000 Higgs events at the Tevatron (so far)!

Search for Higgs in the **N**MSSM





For $M_a < 2M_{tau}$, BR(a→μμ)~10%

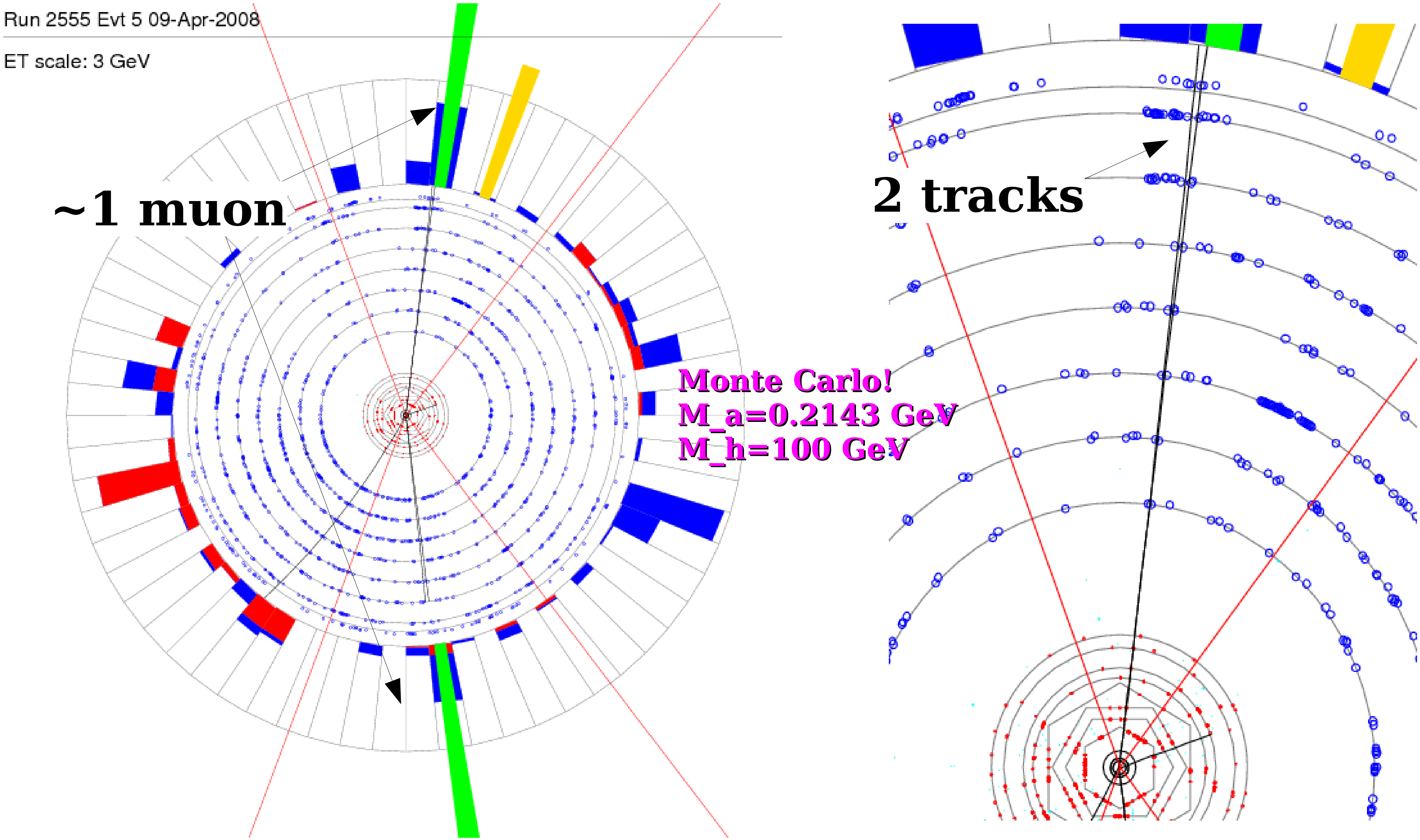
(charm decays are typically suppressed in the NMSSM)

h→aa→4μ ~ 1%, but *clean*!

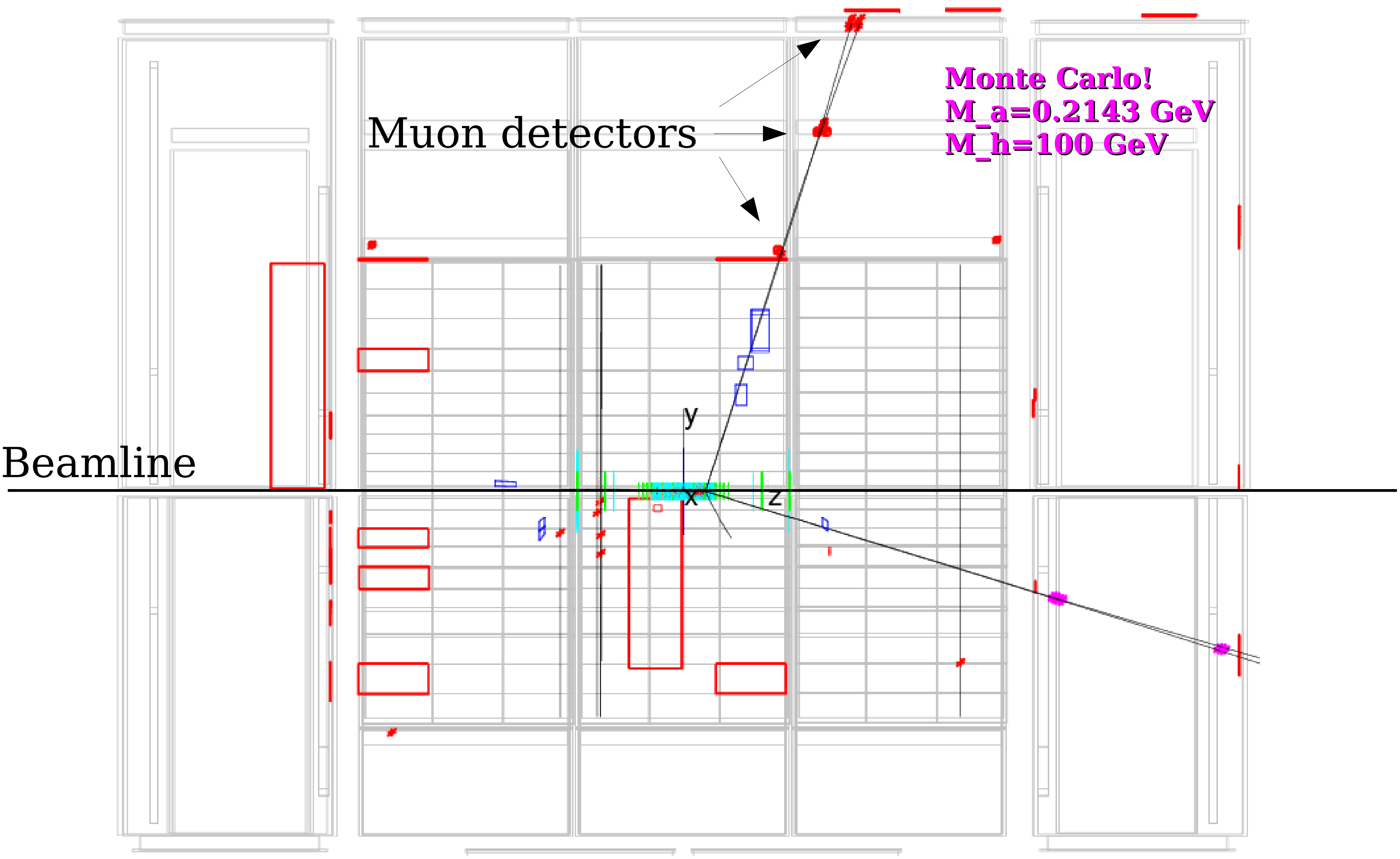
K. Cheung, J. Song, P. Tseng and Q.S. Yan, Phys. Rev. D78, 055015 (2008).

h→aa→4μ

Muon pairs can be extremely collinear !



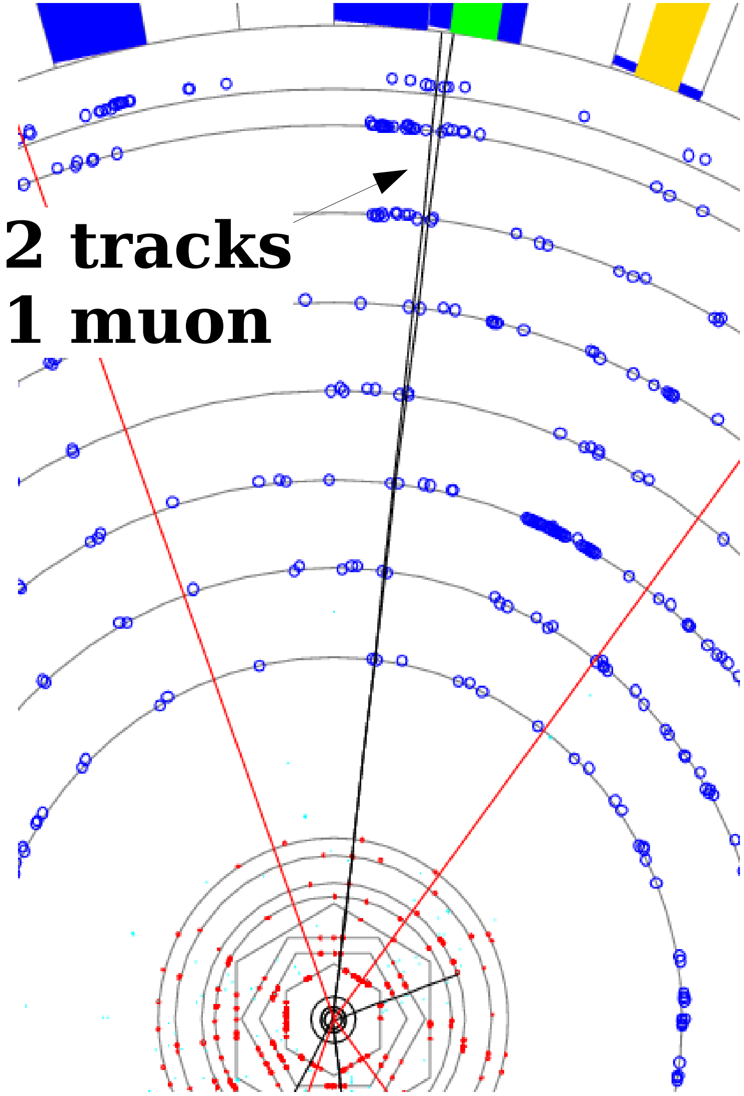
h→aa→4μ


Monte Carlo!
M_a=0.2143 GeV
M_h=100 GeV
Muon detectors
Beamline
y
x
z

h→aa→4μ

2 muons (out of 4), p_T>10 GeV

Not relying on muon system to distinguish both muons of a pair



Reconstruction efficiency for muon?

- Uncertainty rises, from ~2% to ~10%

Multiple muon hits in drift tubes...

- Trigger efficiency per muon is ~20% lower, but have 2 of them

h→aa→4μ

“Companion track”, *p_T>4 GeV*

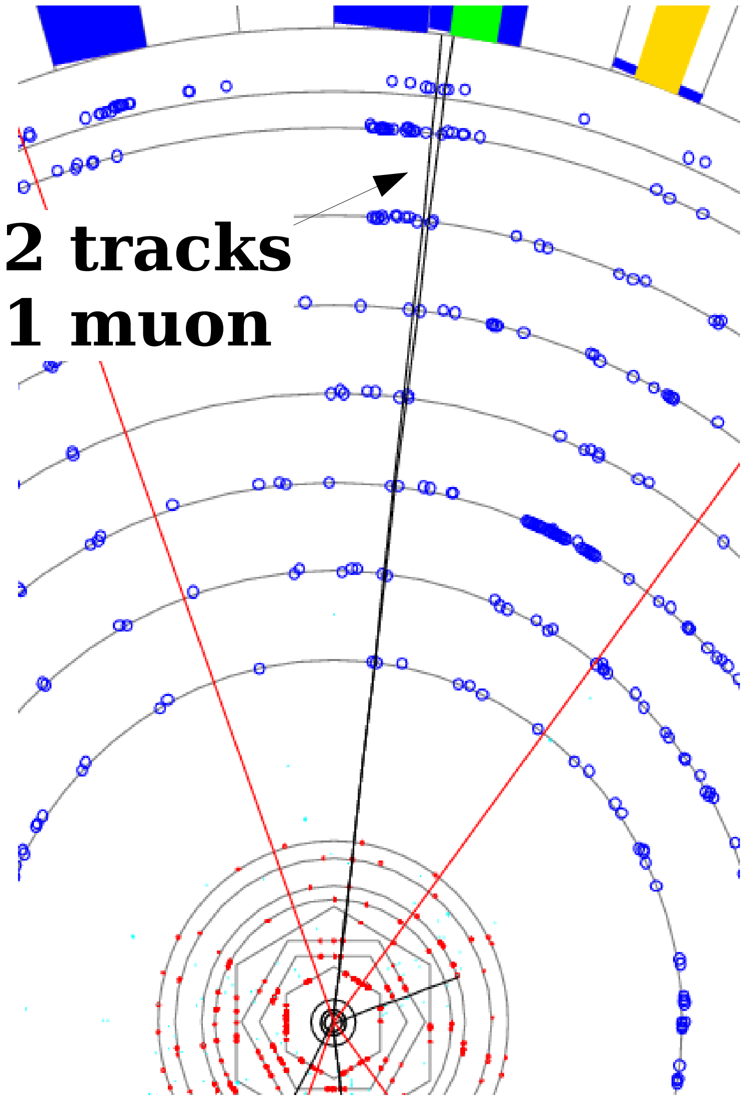
Efficiency?

- high p_T K_s *in data*

Also see data/MC agreement in

- 3-prong tau decays
- photon conversions

Uncertainty: 20-50%



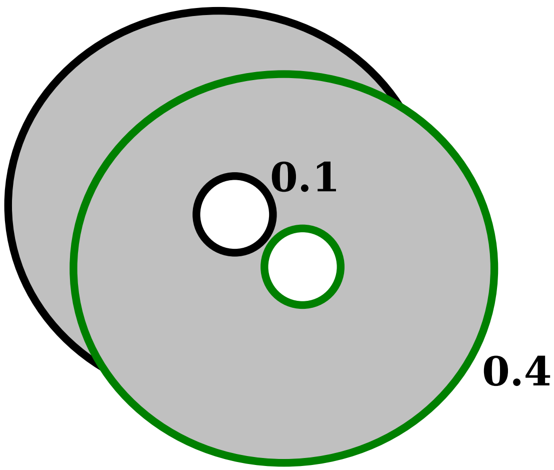
h→aa→4μ

Muon isolation in calorimeter

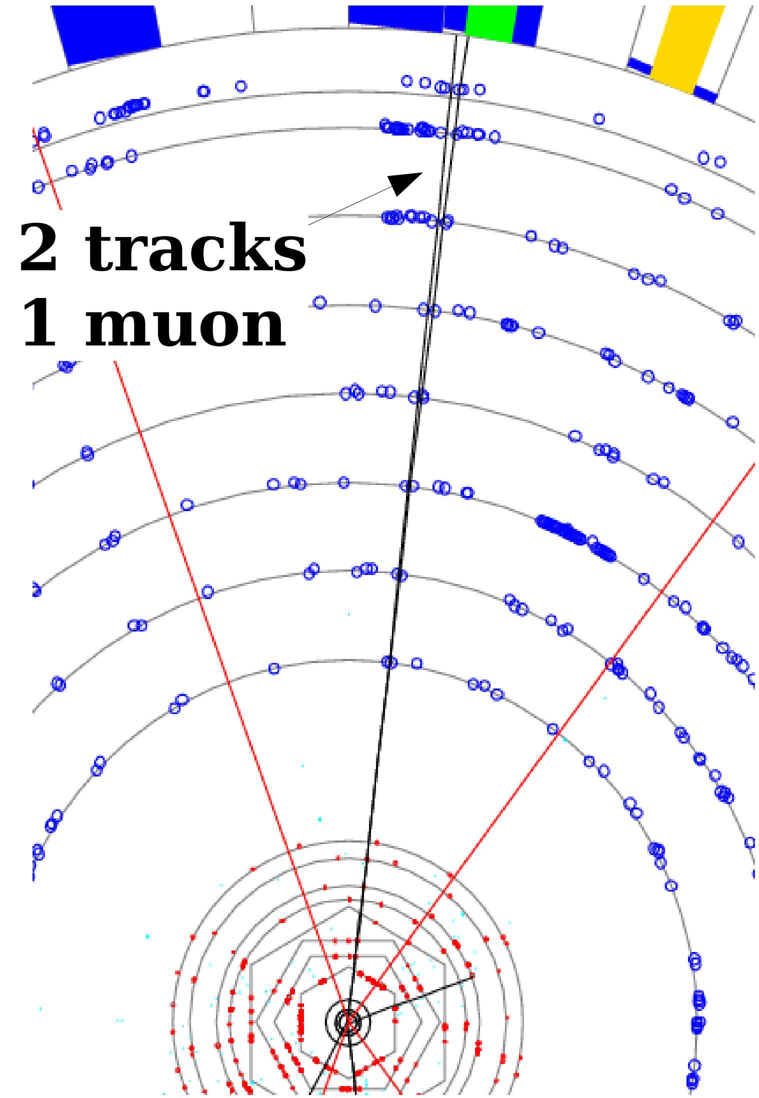
- reduces jet background

But muons overlap!

Custom muon isolation definition...



Higher M_a (~3 GeV)



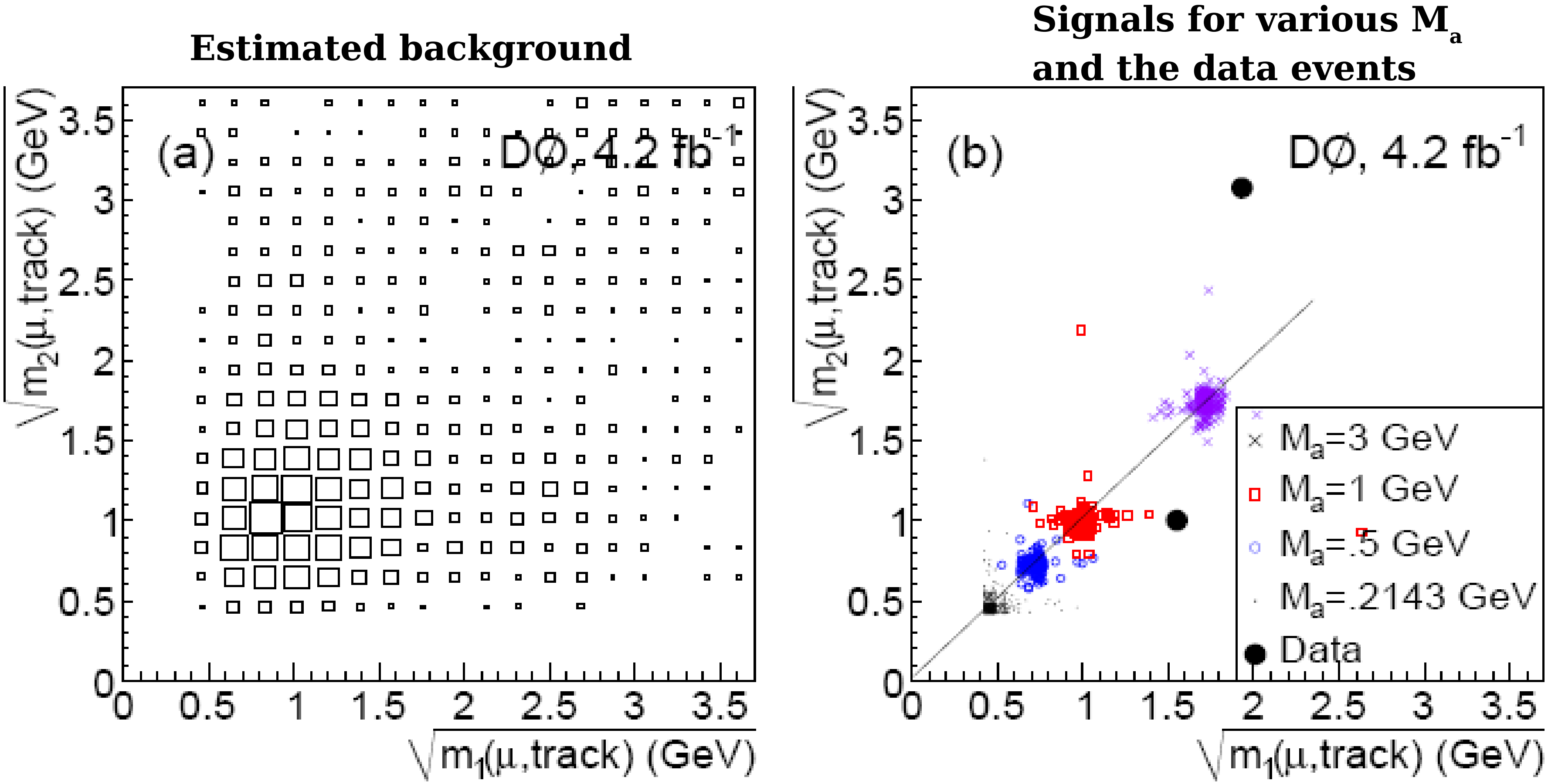
h→aa→4μ

Backgrounds measured from (less isolated) data

- 1.9 events from QCD, 0.3 from Z→μμ

2 events are observed

- Don't have matching μ-track masses
- Also don't have >2μ, vs. ~50% of signal events



h→aa→4μ

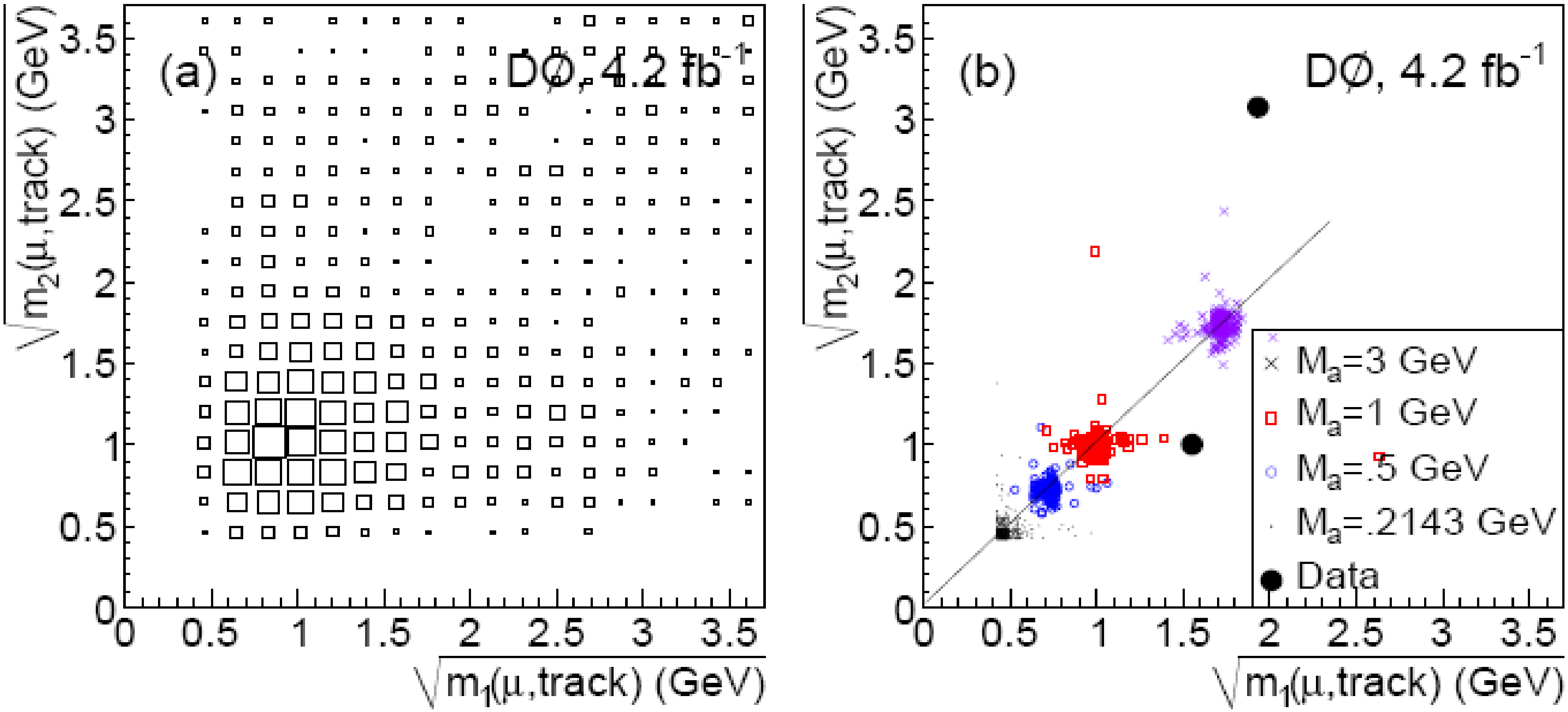
Count events within μ-track mass windows

For M_h=~100 GeV, BR(h→aa)=~90% : **exclude BR(a→μμ)>~10%**

Severely constrains NMSSM for $M_a<2M_{tau}$!

Estimated background

Signals for various M_a and the data events



h→aa, $M_a > 2M_{tau}$

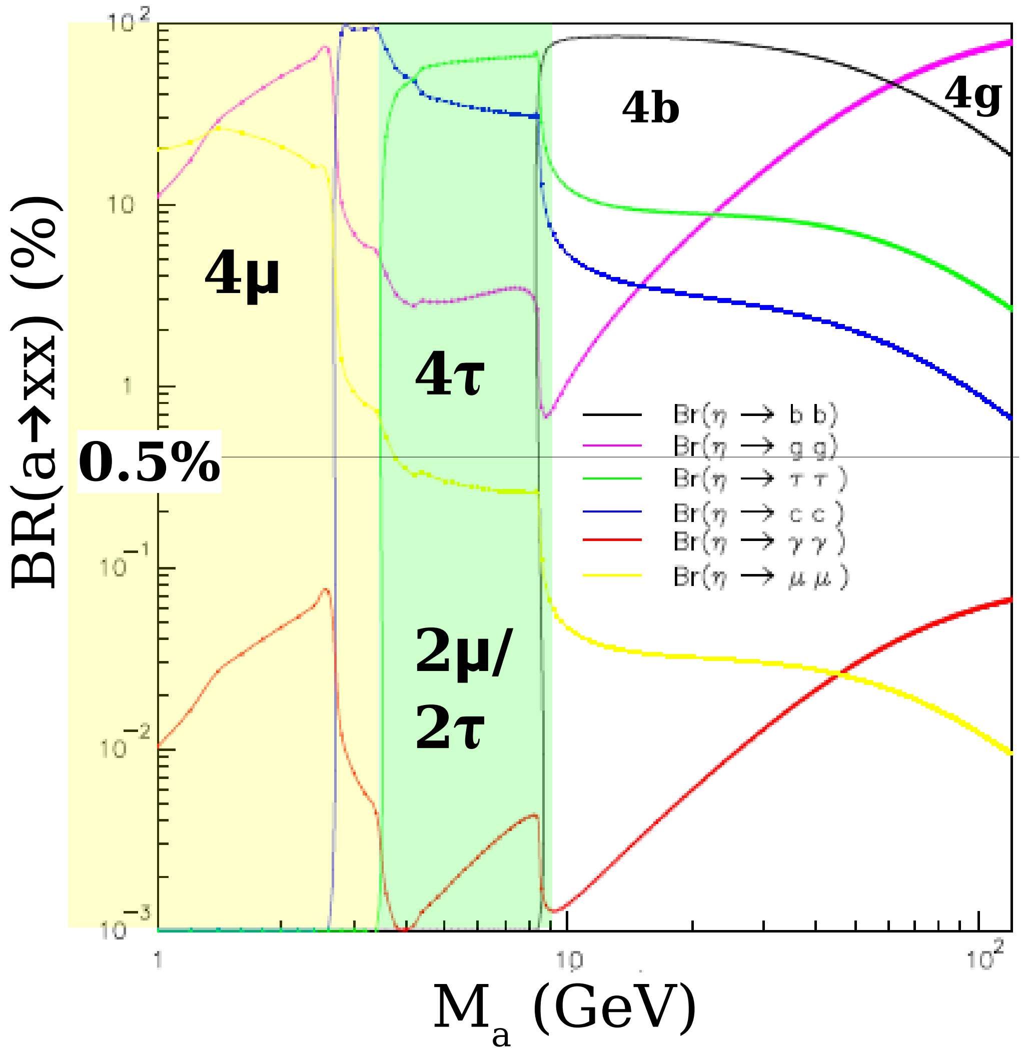
h→aa→4τ is hard !

- **τ**'s in overlapping pairs
- Need **τ** →μ,e decays
- e, μ will be low p_T

Easier to do h→aa→2μ2**τ**

- a→μμ mass peak
- high p_T muons

2μ2τ smaller by ~1/100, but *cleaner*



M. Lisanti and J. G. Wacker, arXiv:0903.1377 [hep-ph].

h→aa→2μ2τ

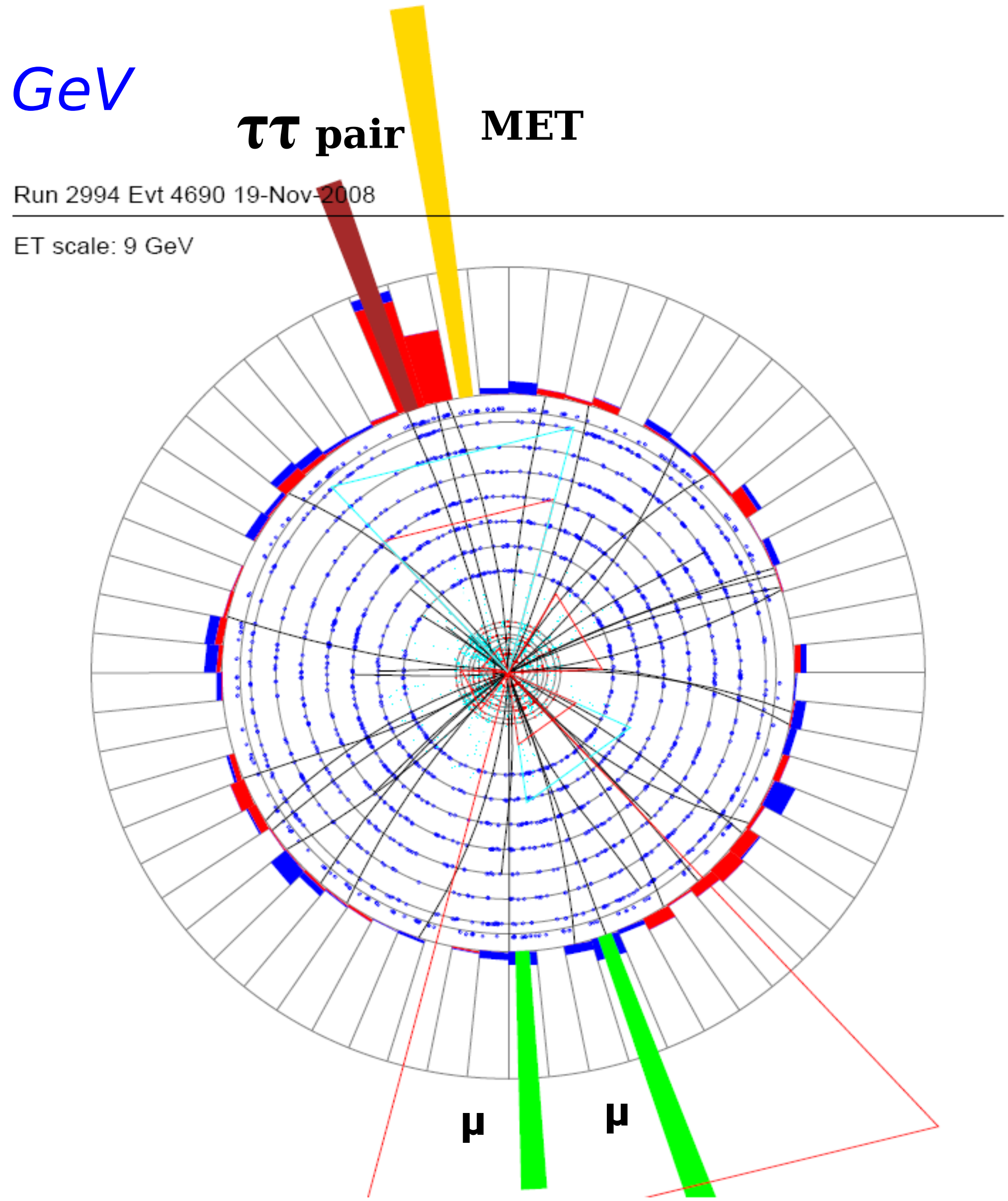
2 nearby, isolated muons, p_T>10 GeV

Tighter muon criteria

- just a jet on the other side

Scalar sum muon p_T > 35 GeV

- Reduces background (QCD multijet, Drell-Yan)



h→aa→2μ2τ

τ's overlap, ruining standard τ-ID criteria (isolation, N_{track}, etc.)!

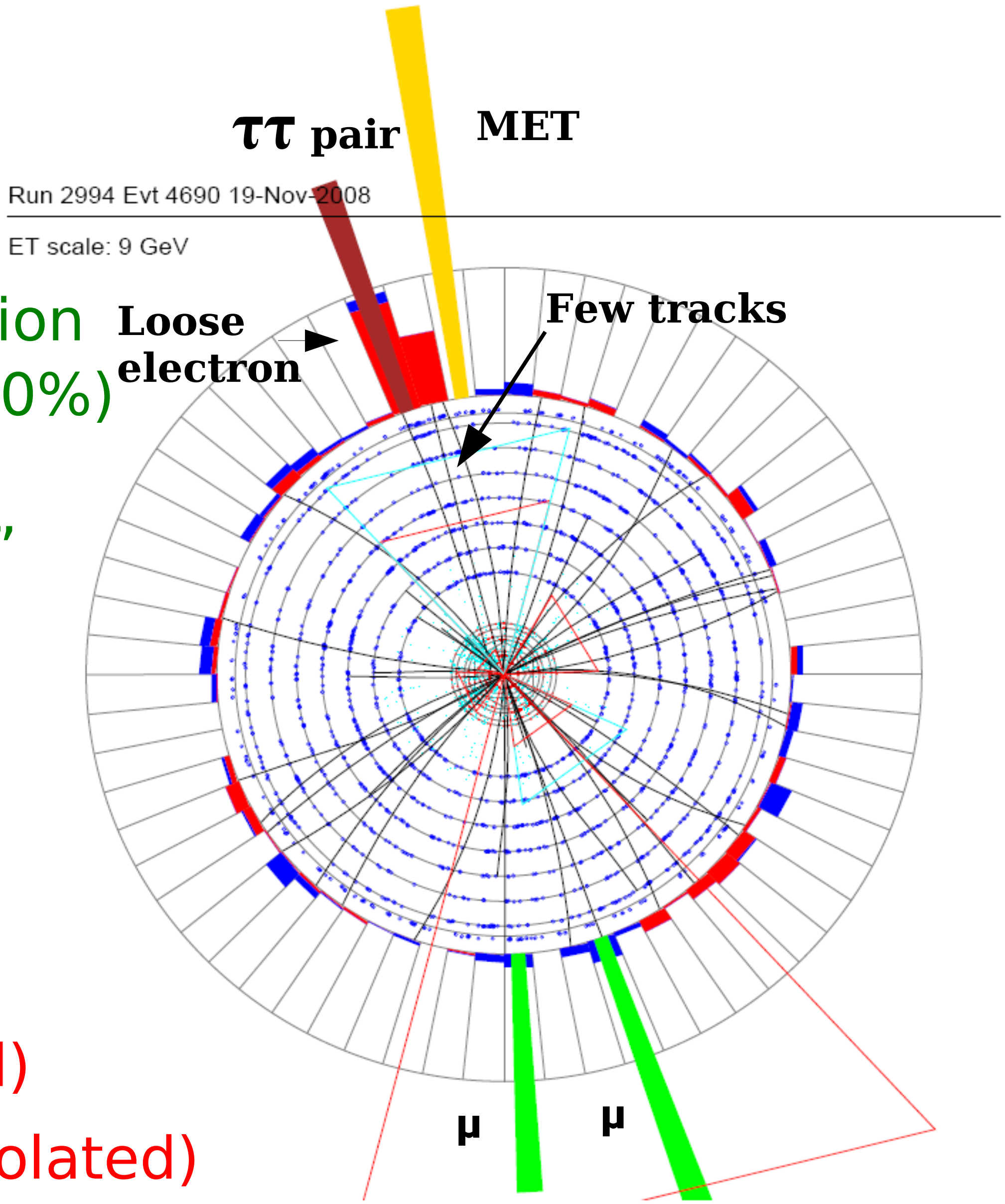
1) Significant MET in τ pair direction
2) Additional muon or electron (40%)

Set of cuts selects “MET in τ pair”

- MET, “jet” ET, N_{track}
- *additional muon criteria to minimize fake MET (track χ^2, etc.)*

Two more selections for:

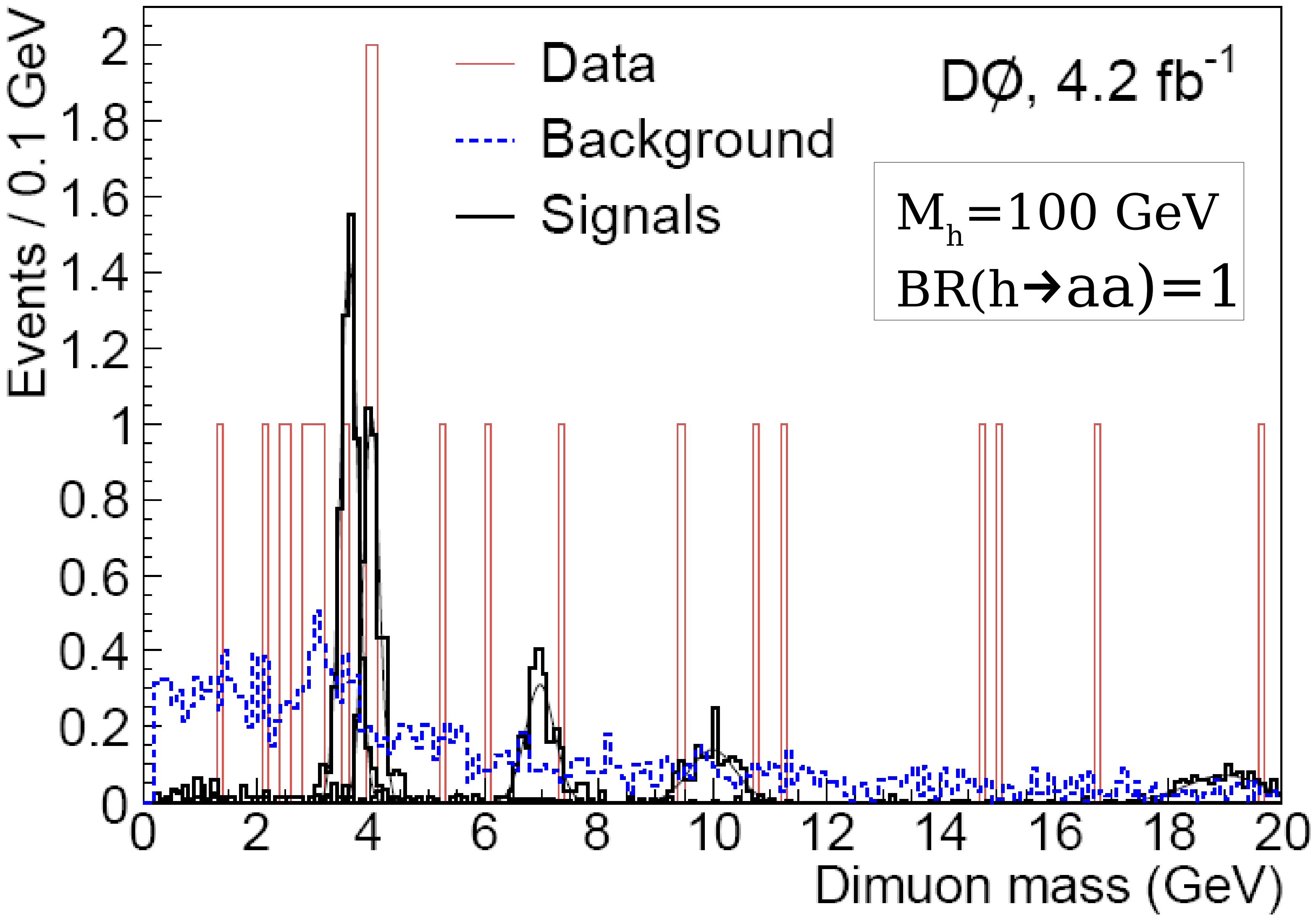
- muon in τ pair (non-isolated)
- electron in τ pair (loosely-isolated)



h→aa→2μ2τ

Background shape from less-isolated (di-muon) data

- normalized to isolated data

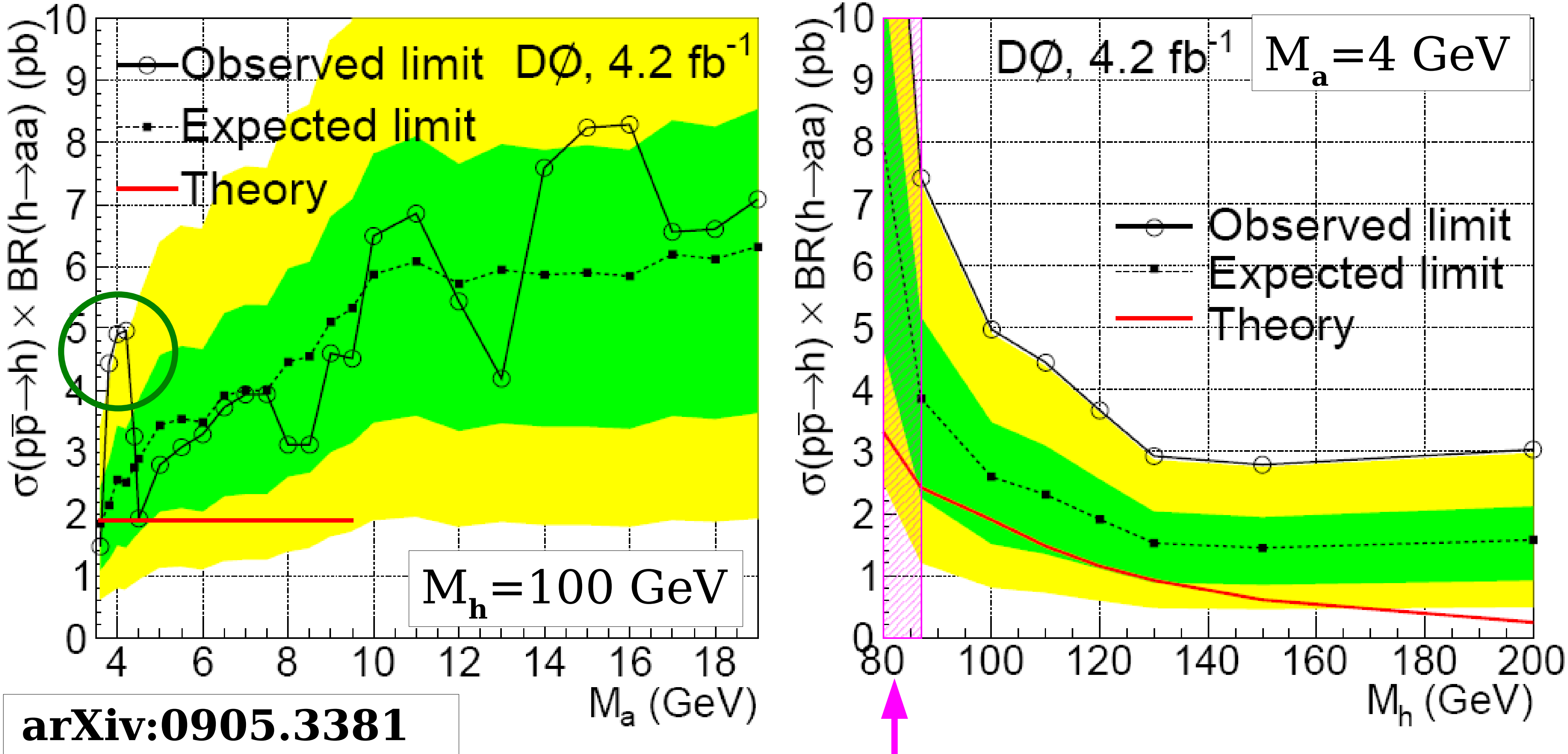


h→aa→2μ2τ

Currently exclude ~1-3 times $p\bar{p}\to h$ cross-section

- **2 sigma excess at 4 GeV**

Tevatron can cover the full M_a range: more data, CDF



arXiv:0905.3381
Submitted to PRL

Zh→Zaa→Z4τ bound from OPAL (LEP)

Hidden Valley

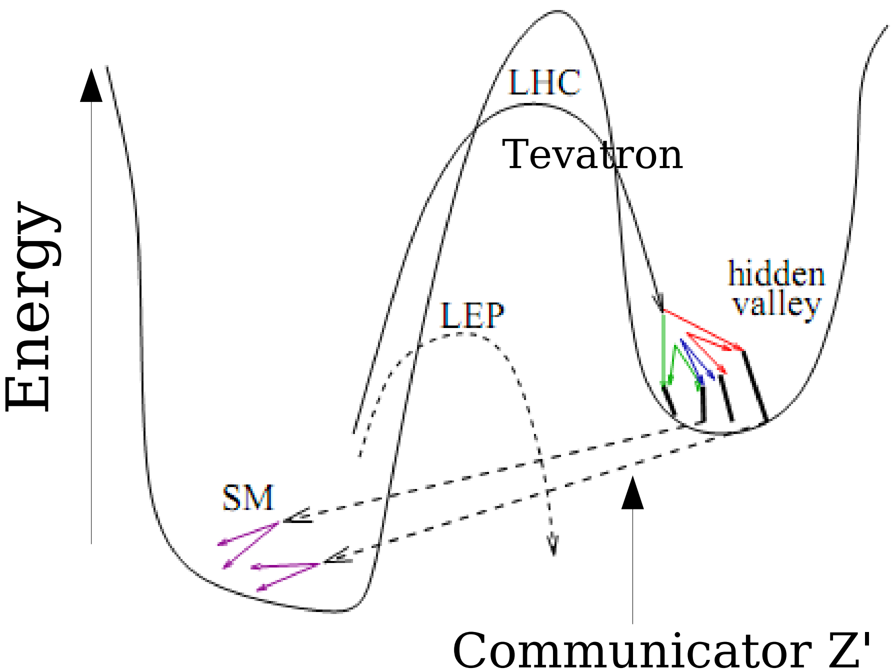
Hidden sector (weakly interacting with the SM)

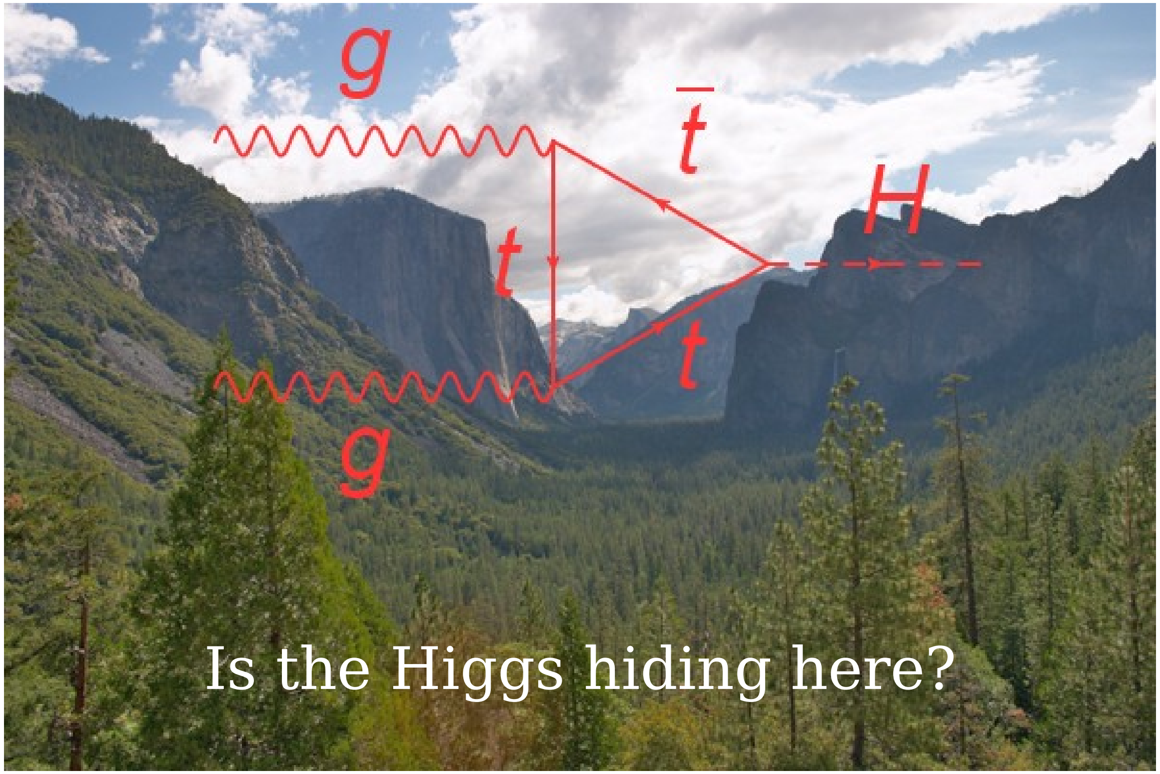
Strongly coupled: v-hadrons, v-pions, etc.

Strassler and Zurek, Phys. Rev. Lett. B651:374 (2007).

v-particles could be long-lived

- but < 1 second, (big-bang nucleosynthesis)





Higgs → HV HV → bb bb

SM Higgs mixes with HV Higgs

- BR(H→ HV HV) could be large

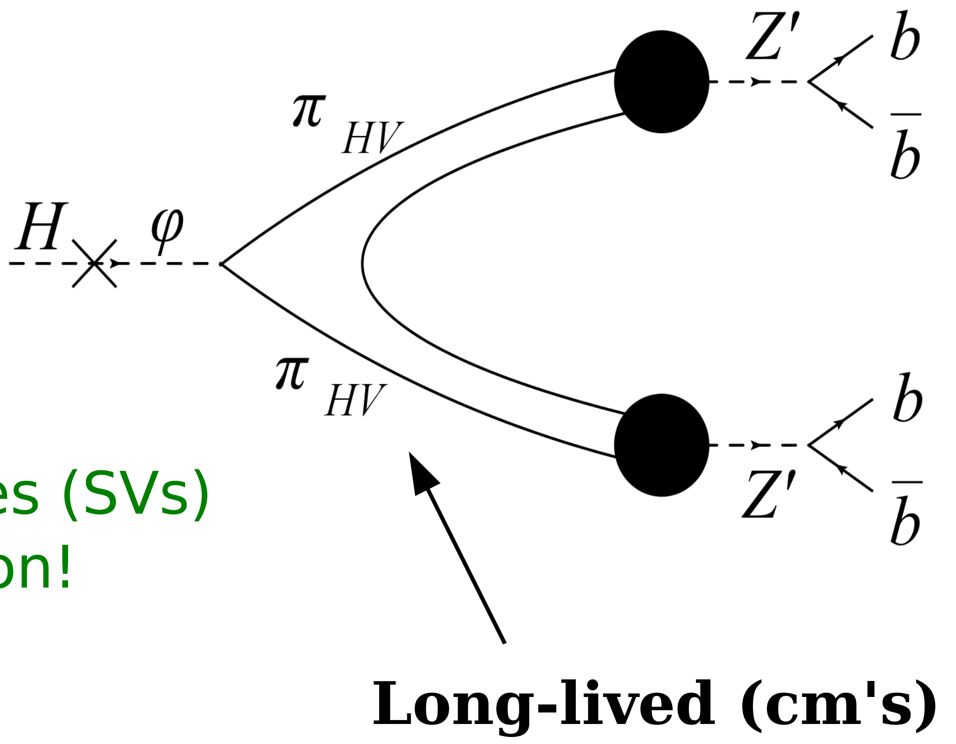
HV prefers to decay to $b\bar{b}$
(due to helicity suppression)

Highly displaced secondary-vertices (SVs)

- never searched for at Tevatron!

Evades most LEP limits, m_H>82 GeV

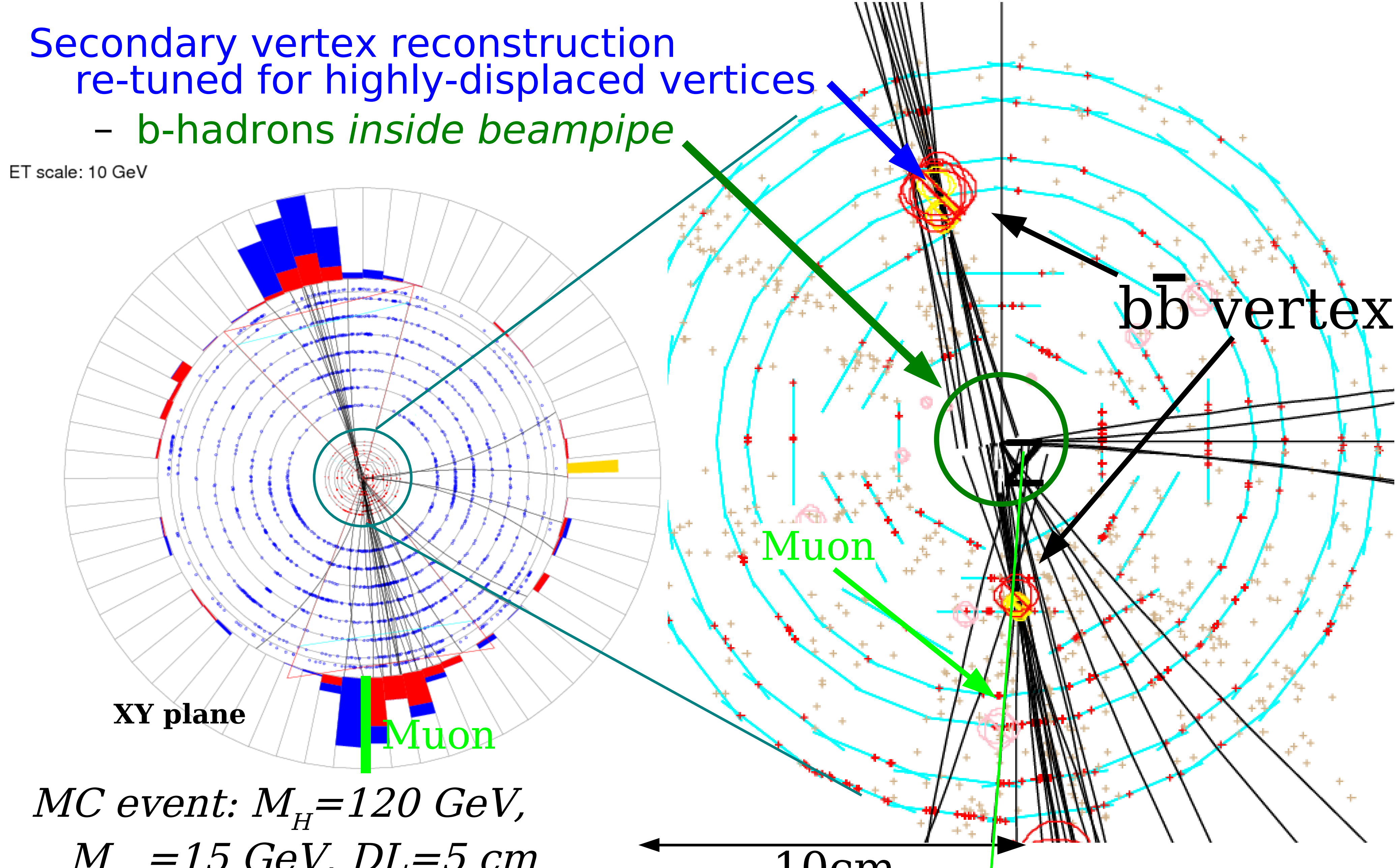
Another way to *hide the Higgs*!



Higgs → HV HV → bb bb

Secondary vertex reconstruction
re-tuned for highly-displaced vertices

– b-hadrons *inside beampipe*



MC event: M_H=120 GeV,
M_{HV}=15 GeV, DL=5 cm

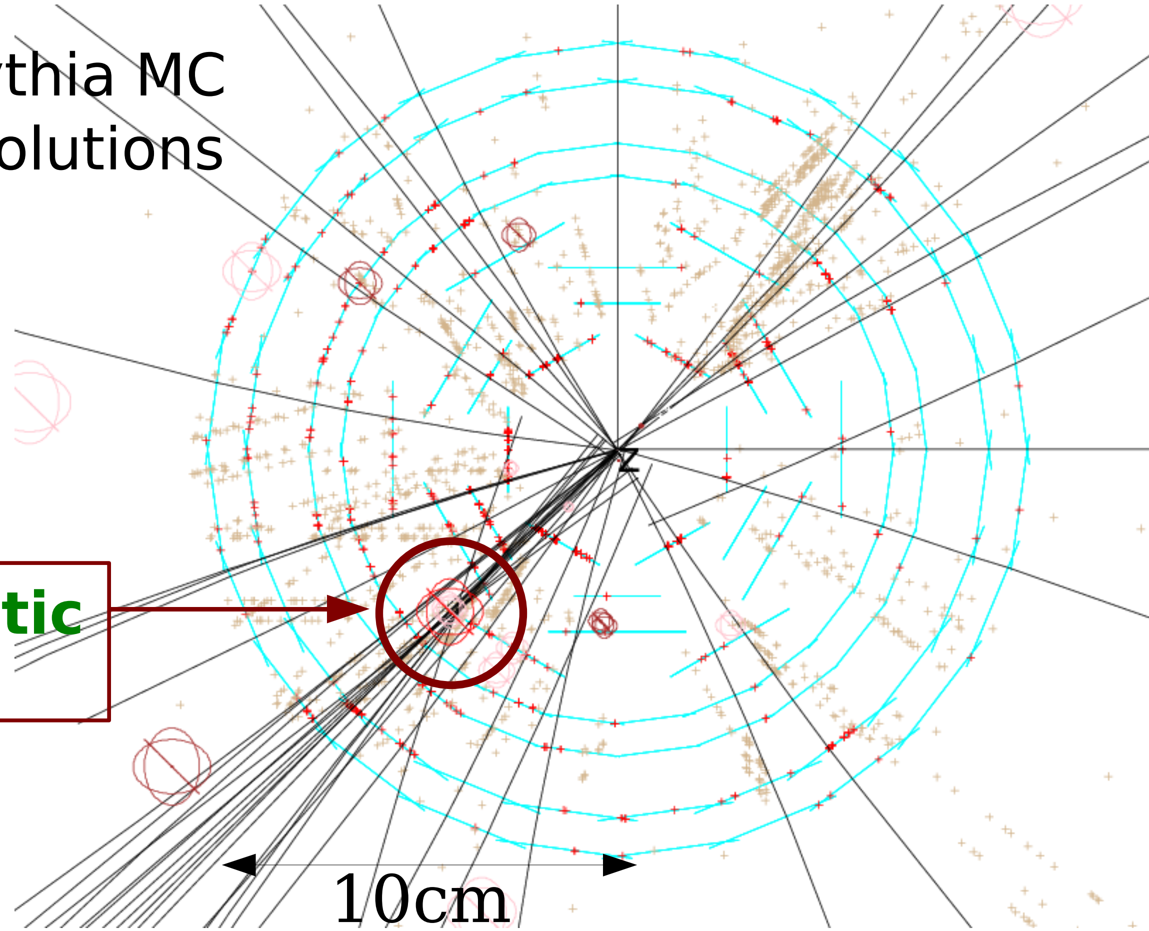
Higgs → HV HV → bb bb

Background simulated with Pythia MC
- SVs smeared to data resolutions

In-flight decays (pion, kaon)

Material interactions
- photon conversions
- **hadron-nucleus inelastic scattering**

Pattern recognition errors



QCD MC event:
6 reconstructed tracks,
material interaction

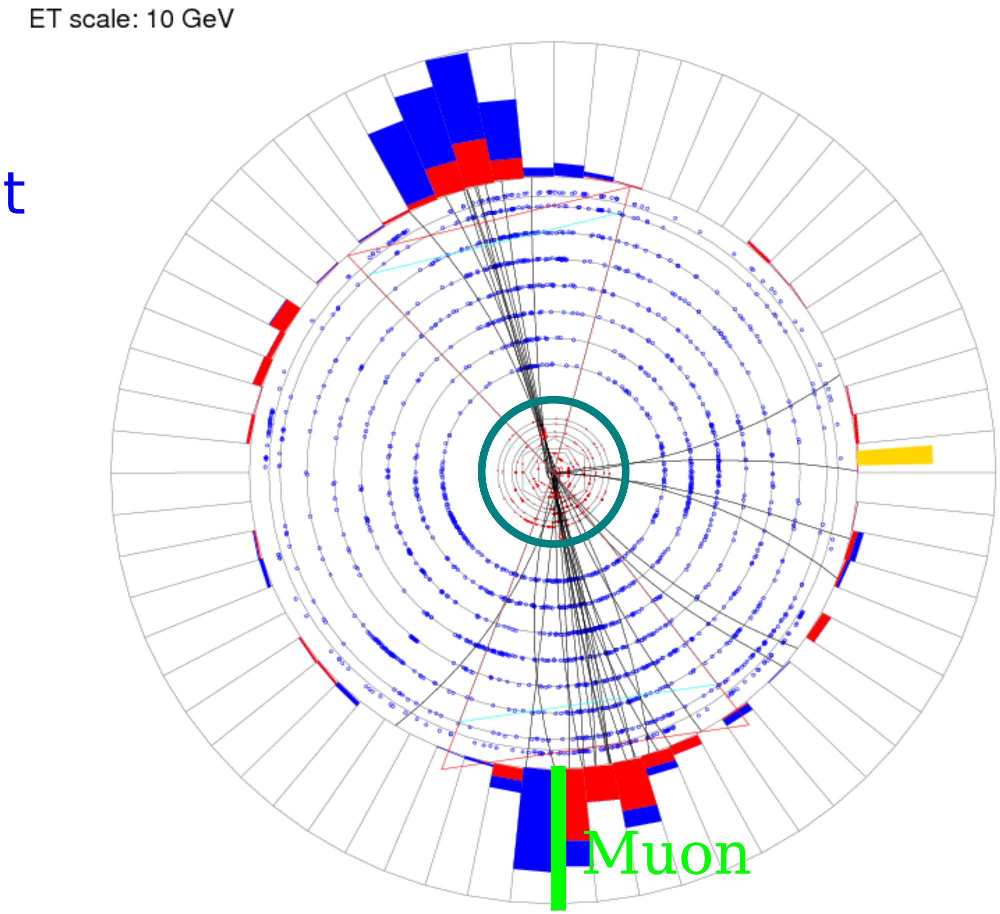
Higgs → HV HV → bb bb

- 2 jets with p_T>10GeV
- muon, p_T>4 GeV, matched to jet
- central primary vertex and <3 additional pp interactions

- 1.6cm< SV radius < 20cm
  - remove b-decays
  - fiducial volume

Use “OR” of all triggers
(mostly muon+jet)

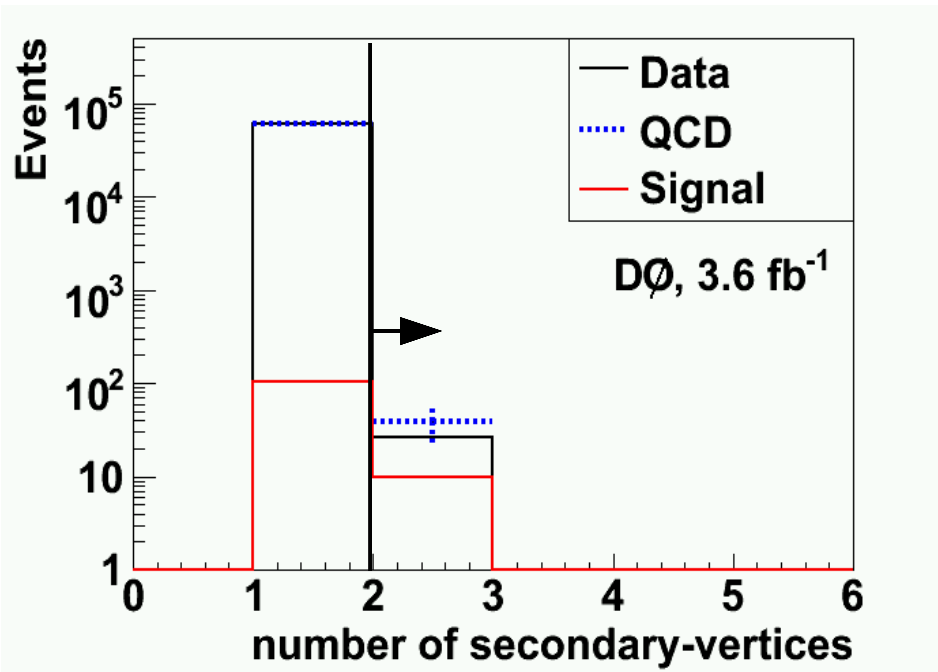
3.6 fb^{-1} analyzed

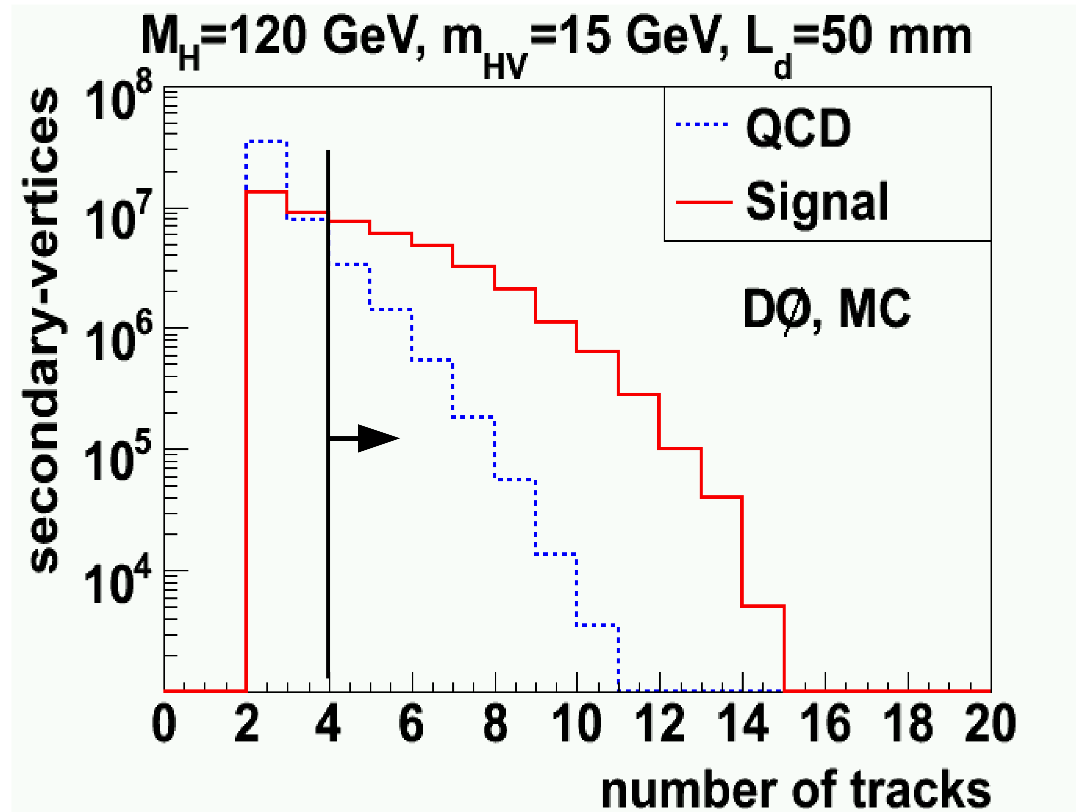


Higgs → HV HV → bb bb

2 SVs per event

SV track multiplicity>=4

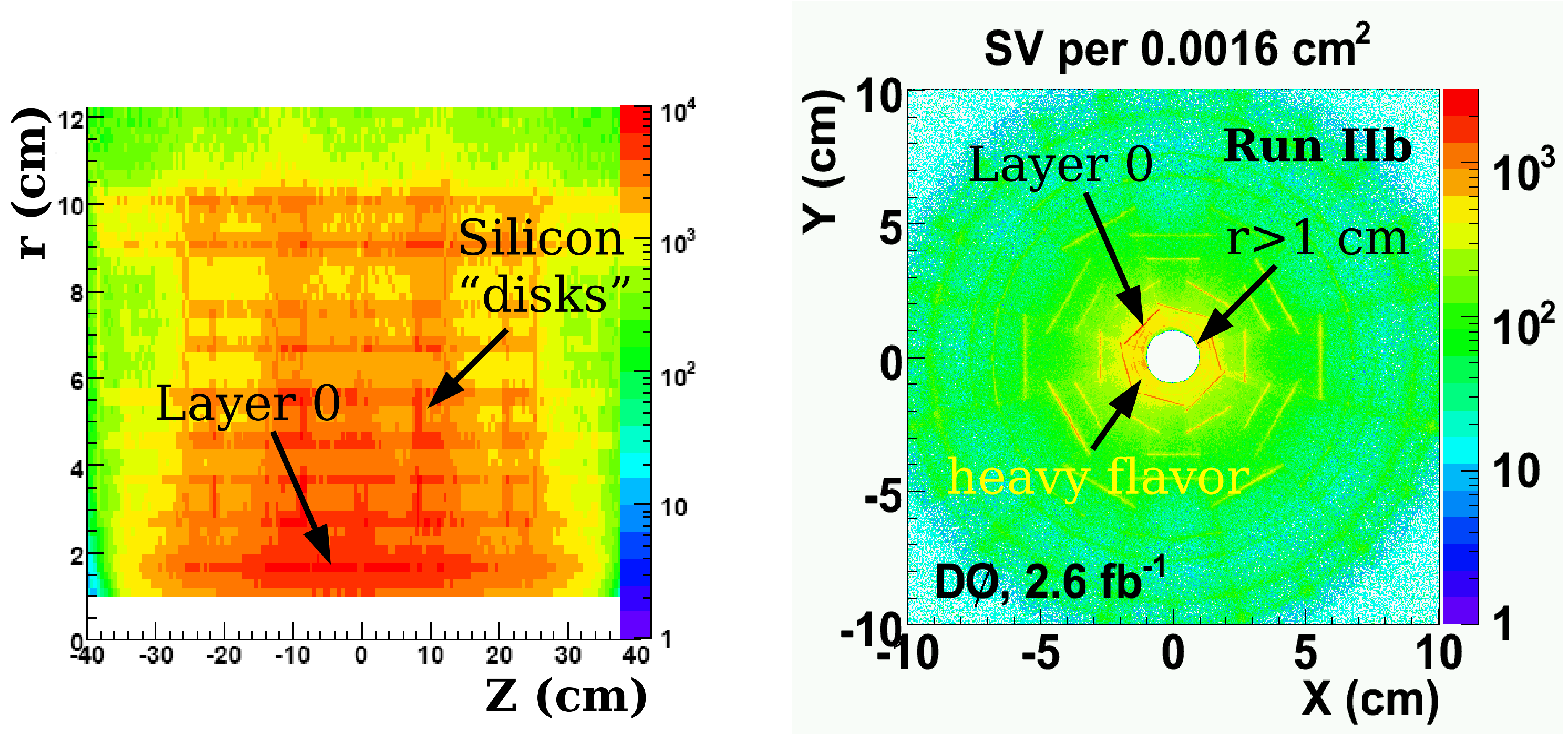




Higgs → HV HV → bb bb

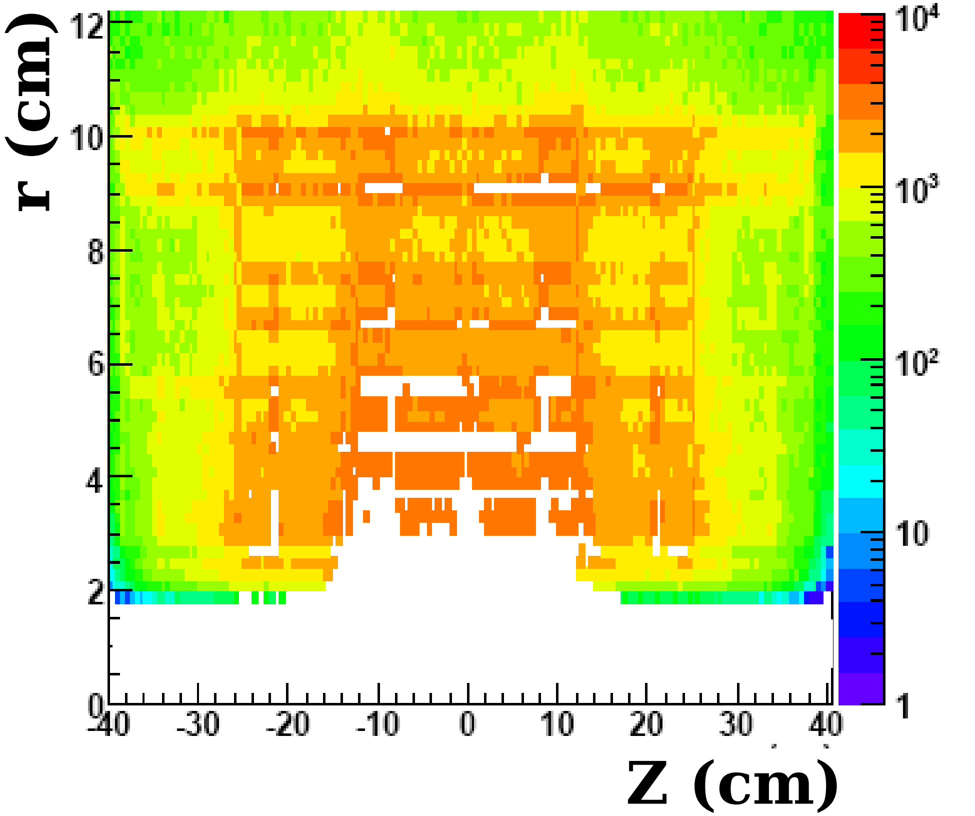
Material "map" using vertices with 3 tracks

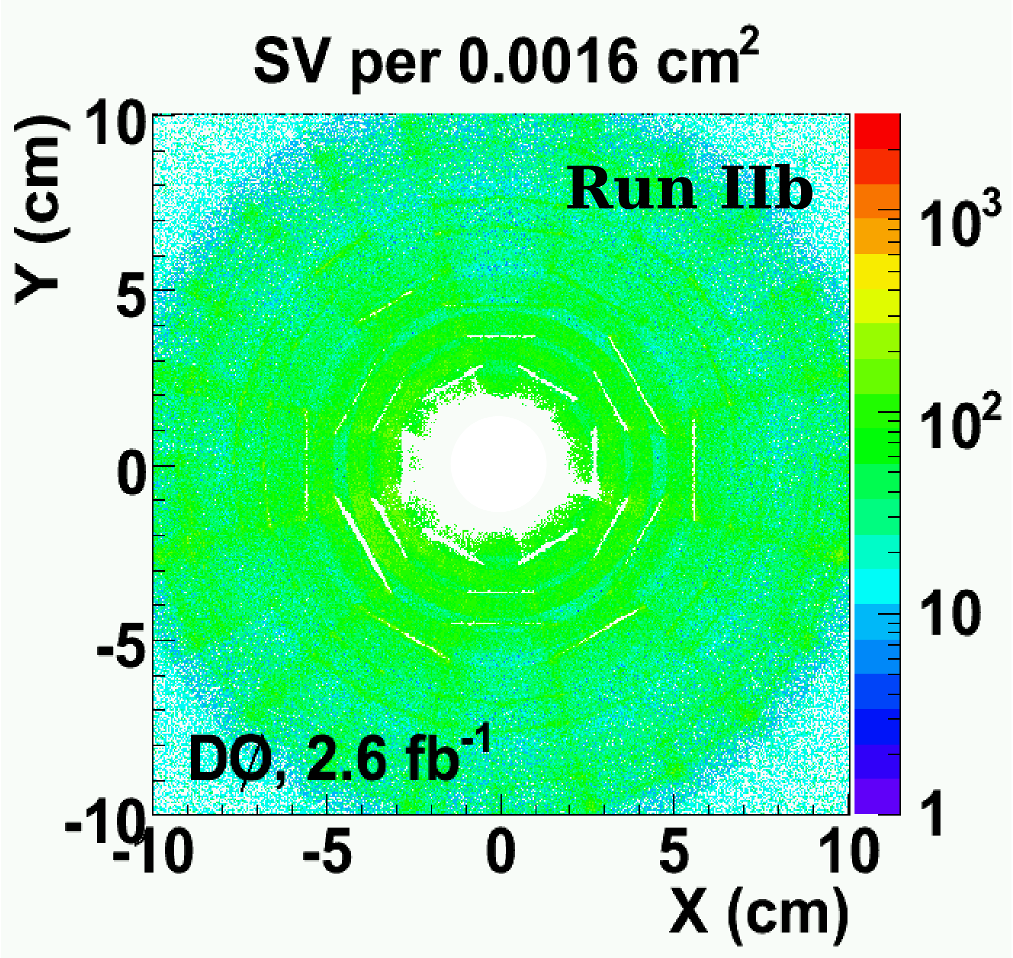
(RZ and XY projections)



Higgs → HV HV → bb bb

Reject SVs that occur in high material density regions

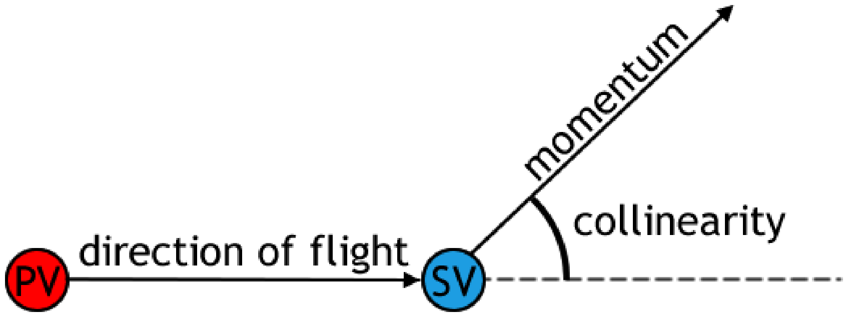


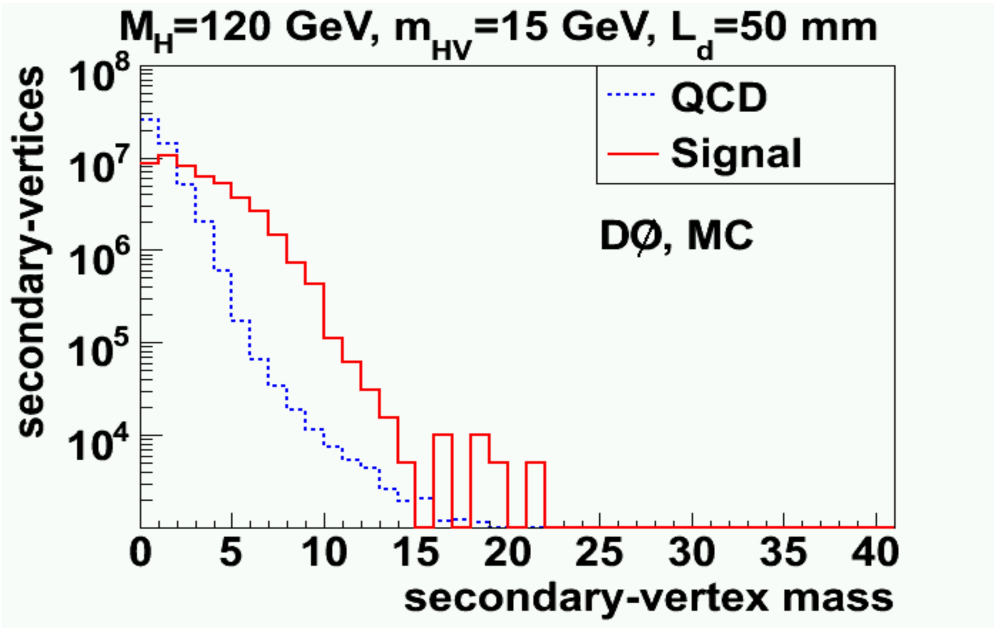


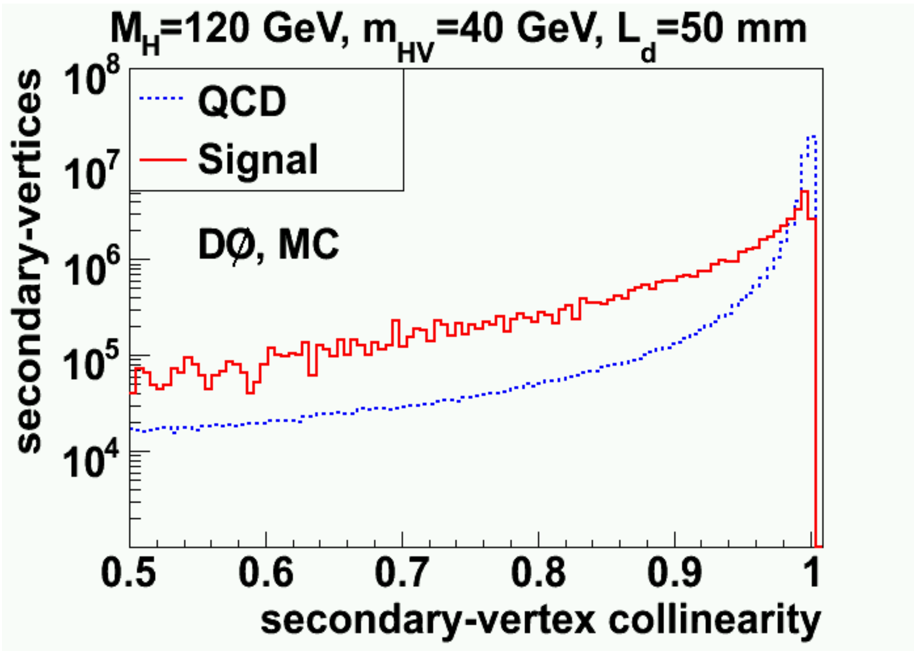
Higgs → HV HV → bb bb

SV mass and collinearity

Final handles to separate signal from background







Higgs → HV HV → bb bb

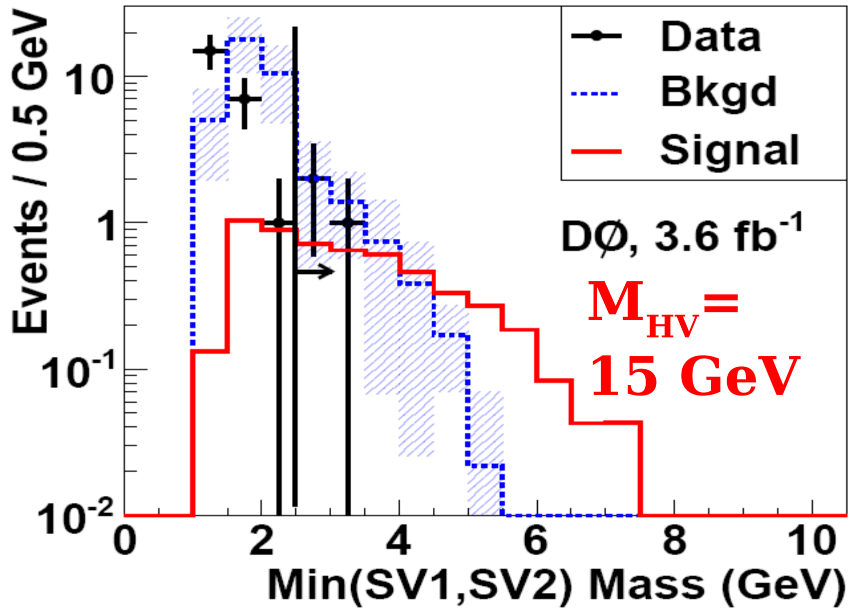
Cut on minimum of the mass OR maximum of the collinearity (depending on M_{HV})

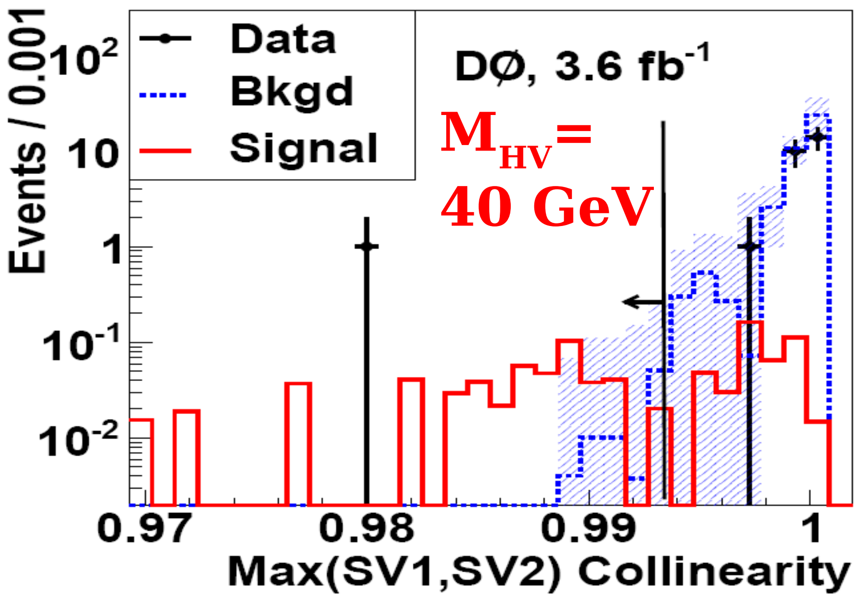
Signal efficiency uncertainty:

- Trigger efficiency, ~17%
- Luminosity, 6.1%

Background uncertainty:

- MC statistics, ~100%
- Tracking efficiency, ~28%
- Smearing, ~18%
- Material density, ~15%



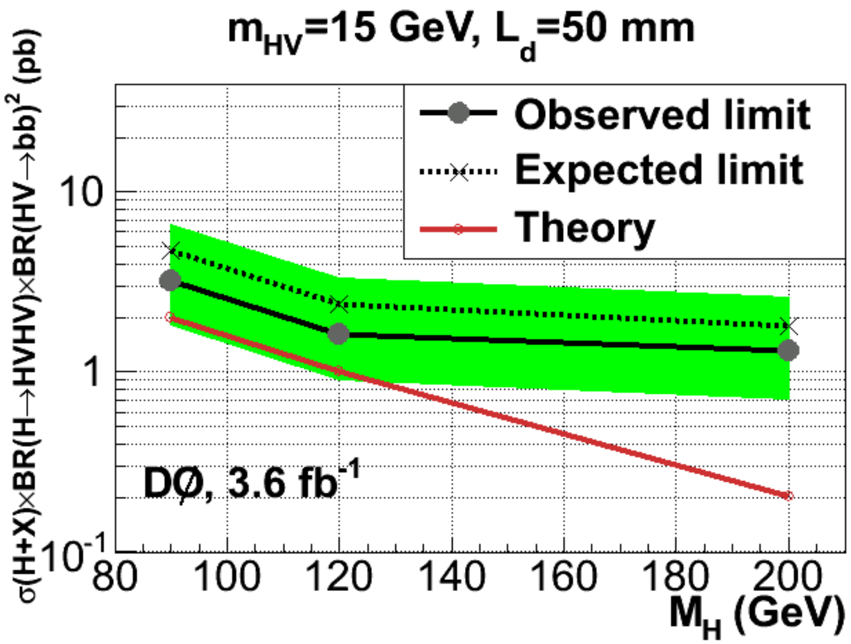


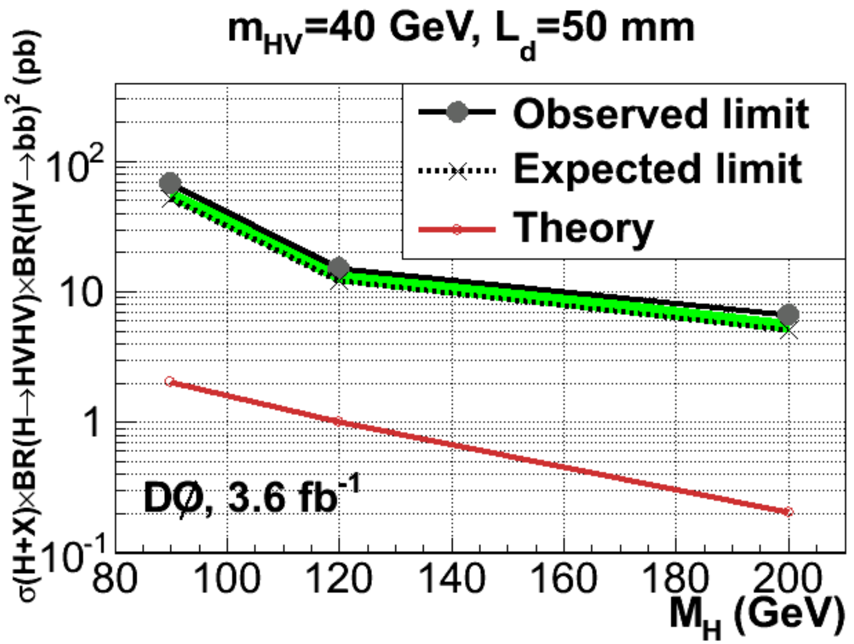
Higgs → HV HV → bb bb

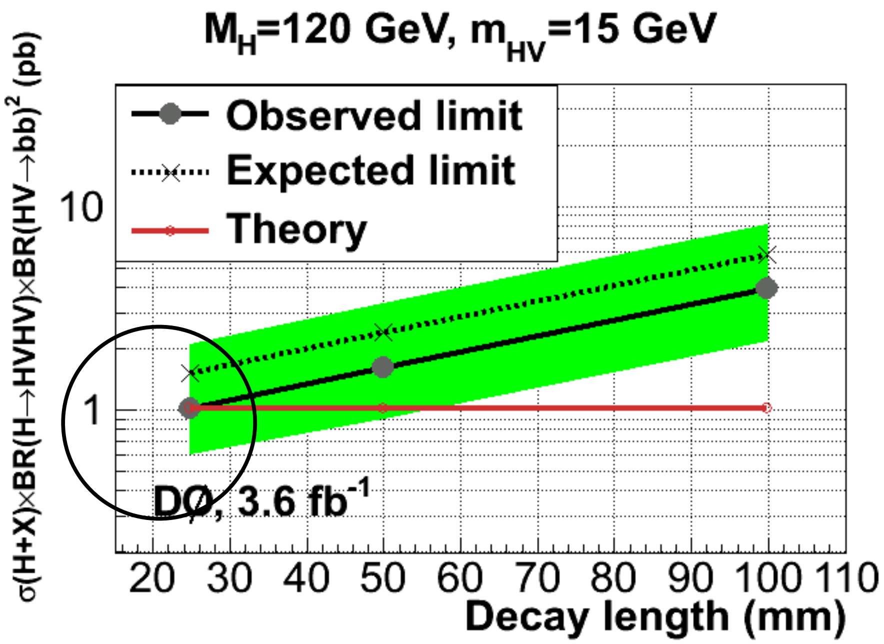
Limits vs. M_H, M_{HV}, HV decay length

Exclude BR(H → HV HV)=1
for small m_{HV} and HV decay length

arXiv:0906.1787
Submitted to PRL







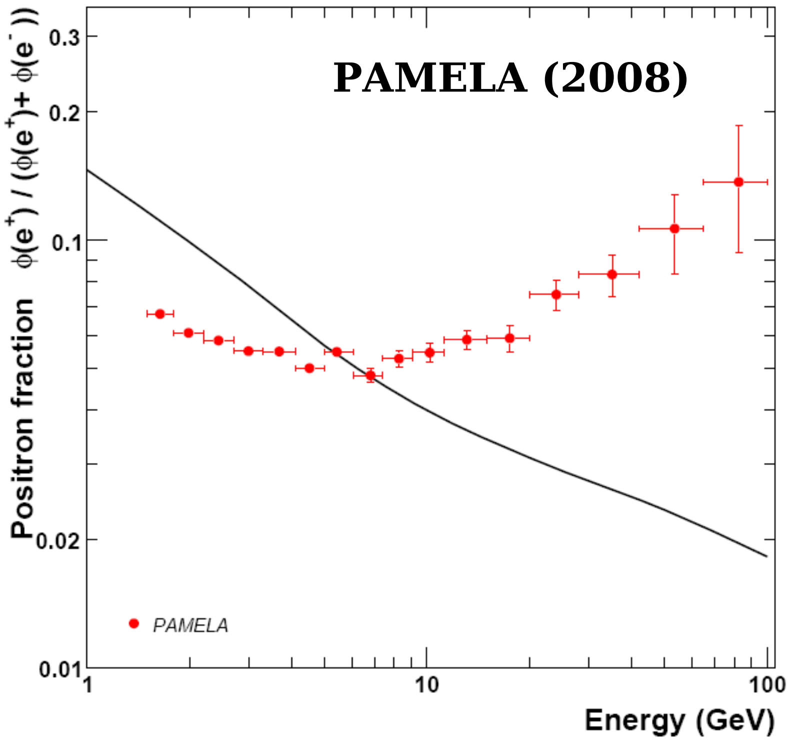
A hint from space?

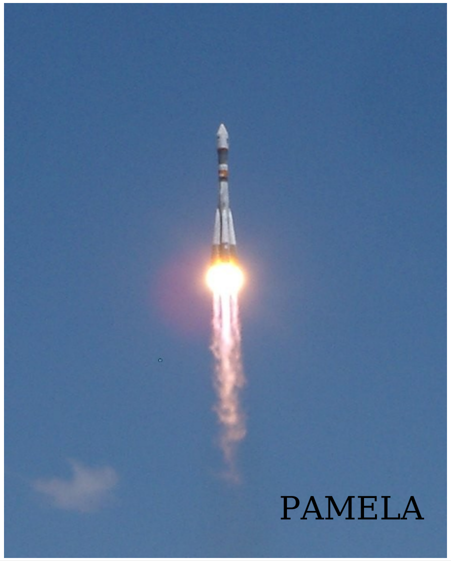
Dark Matter is *annihilating*

Hint of DM+DM → leptons

Hidden sector can explain positron excess! ...

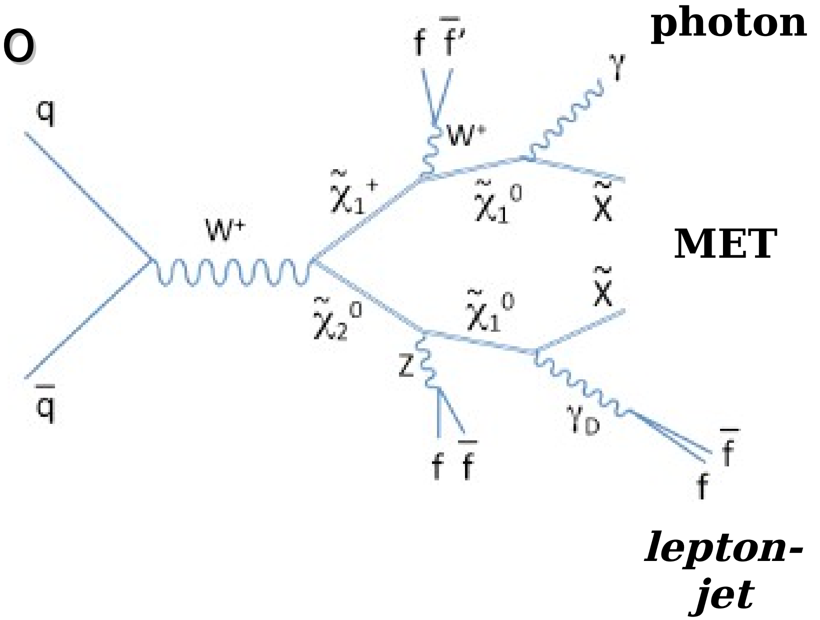
(recall Feng's talk last week)





SUSY Hidden Valley: *dark photons*

Neutralino → ***dark photon*** **(γ_D) +** darkino



$\gamma_D \rightarrow \gamma$ or $\gamma_D \rightarrow$ *lepton-jet*

"Lepton-jet"

- pair (or more) of collinear e's or μ's
- due to low γ_D mass
- kinematics force decay into leptons

Large BR(neutralino→γ) gives $\gamma\gamma$+MET (GMSB)

Large BR(neutralino→γ_D) gives *lepton-jet* pairs

- Identical to h→aa→4μ !
  (but also has MET)

SUSY Hidden Valley: *dark photons*

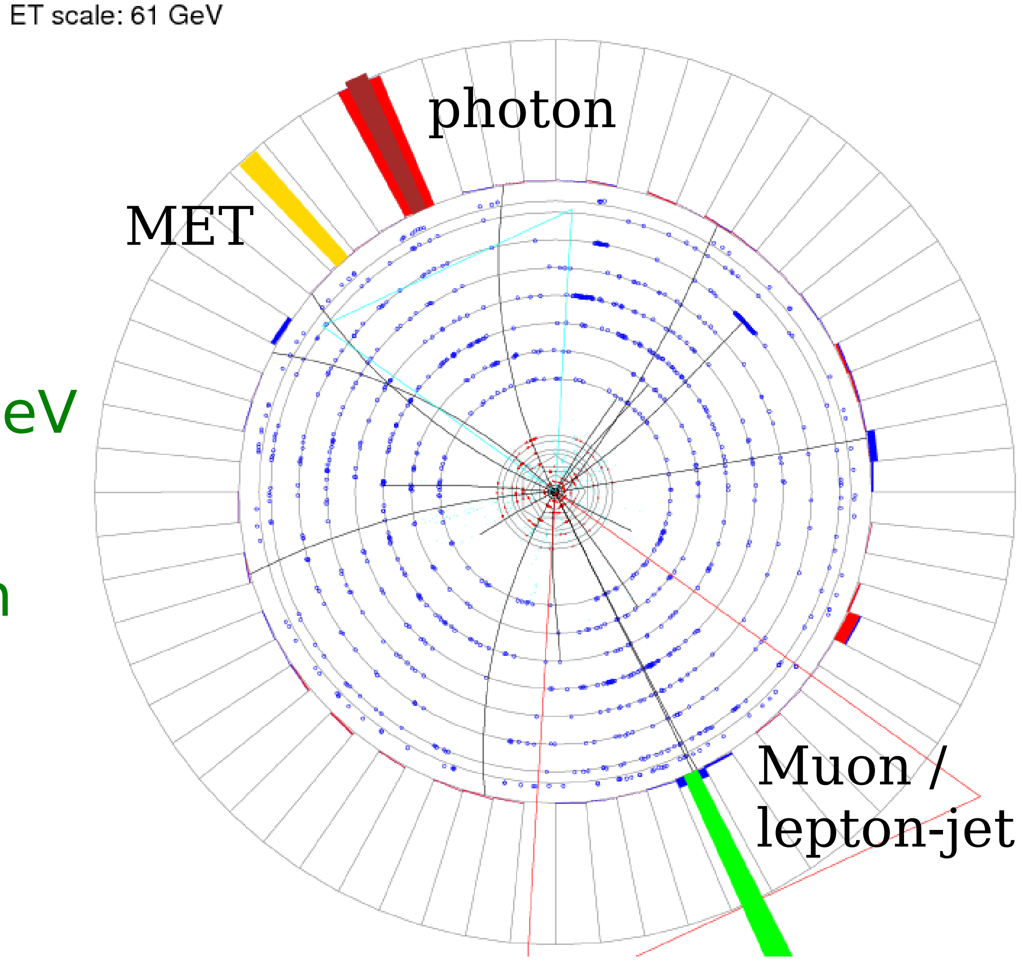
Central photon, p_T>30 GeV

MET>20 GeV

Trigger on photon, 4.1 fb^{-1} of data

Look for *lepton-jet*

- 2 collinear tracks, p_T>10,5 GeV
- Track isolation < 2 GeV
- Matched to electron or muon



SUSY Hidden Valley: *dark photons*

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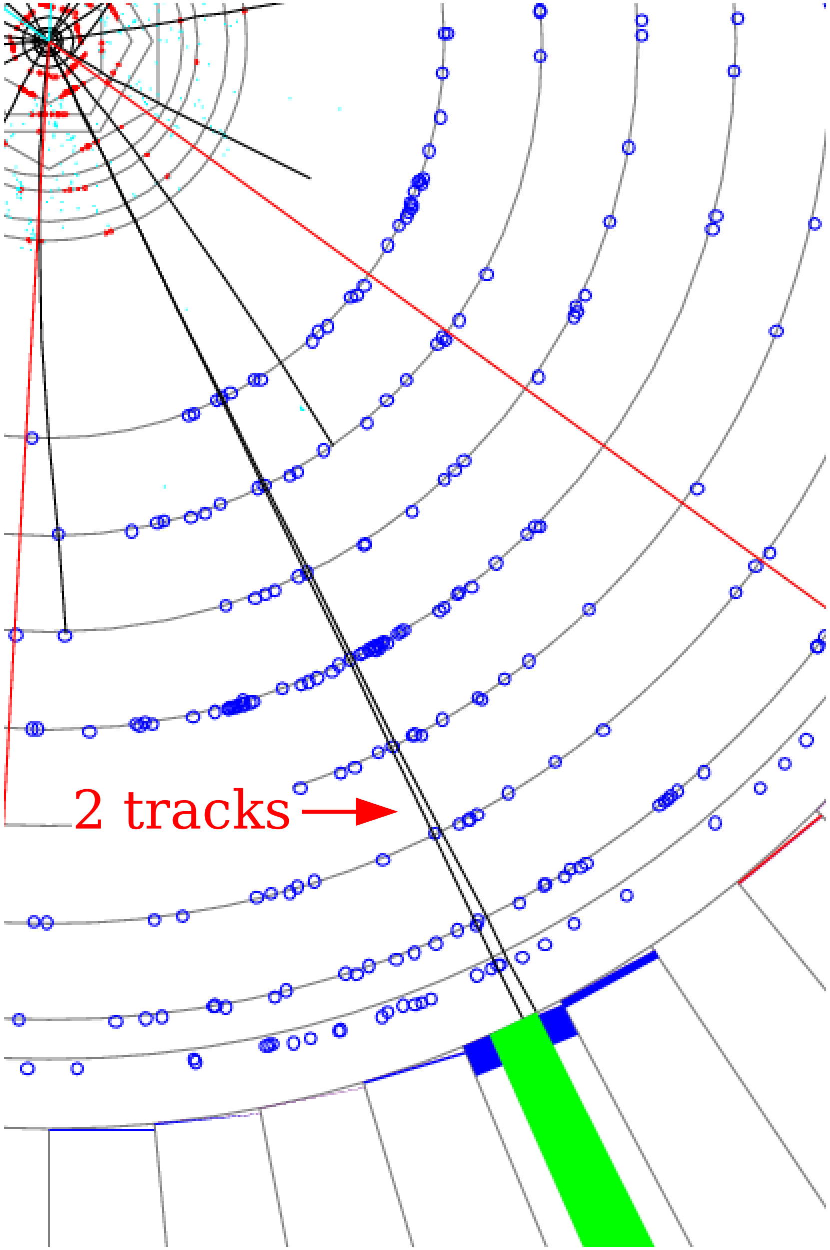
Look for *lepton-jet*

- 2 collinear tracks, p_T>10,5 GeV
- Track isolation < 2 GeV
- Matched to electron or muon

Only one electron or muon reconstructed

2 tracks are resolved



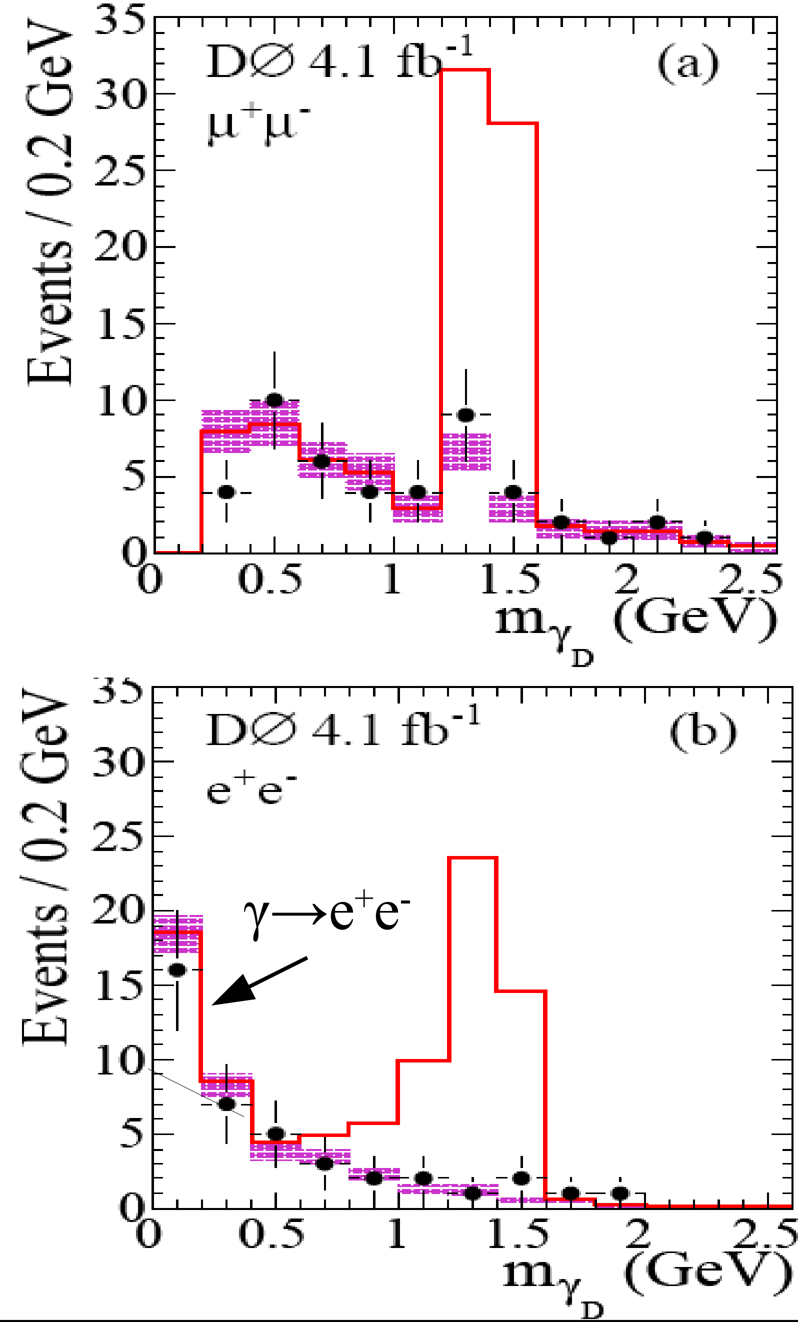
SUSY Hidden Valley: *dark photons*

Background measured in data from
fake-photon and low MET samples

QCD multijet background dominates

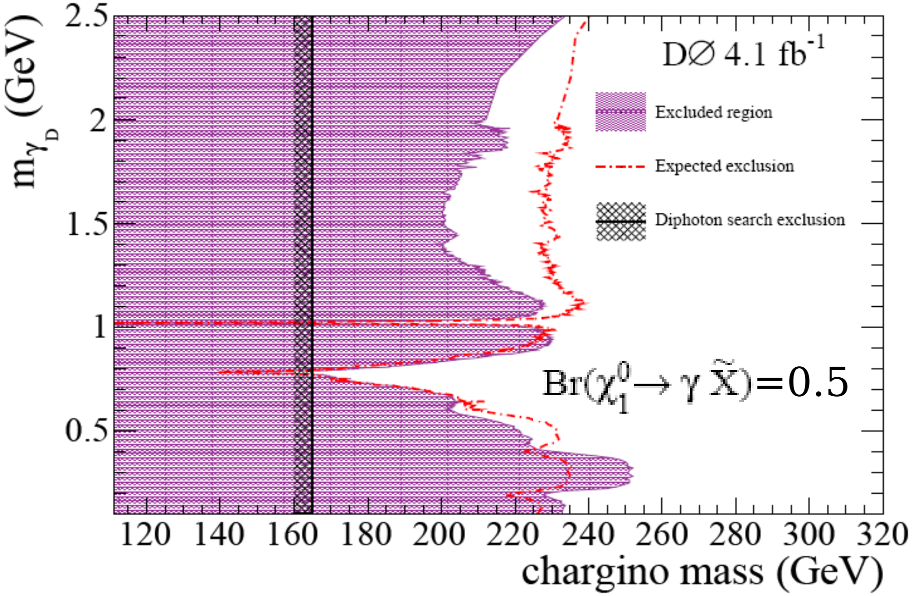
Background from Wγ also studied
(including W→**τ** with 3-prong **τ** decay)

Look for peak in di-lepton mass



SUSY Hidden Valley: *dark photons*

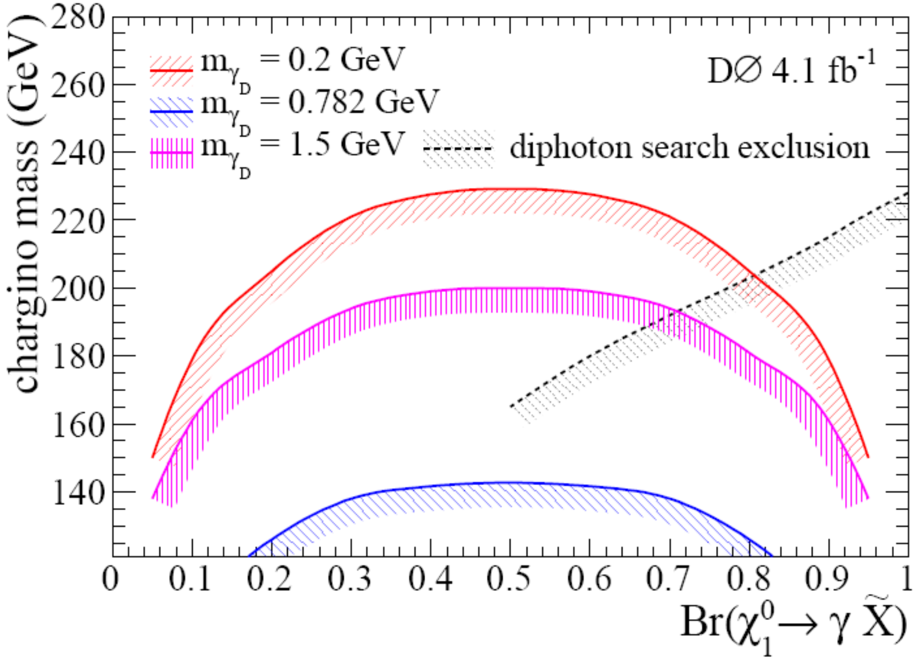
Limits vs. chargino and γ_D mass



Signal efficiency systematics:

- track efficiency (20%)
- muon / electron ID (10%)
- mass resolution (10%)
- luminosity (6.1%)

Weak near resonant $\gamma_D \rightarrow$ hadrons



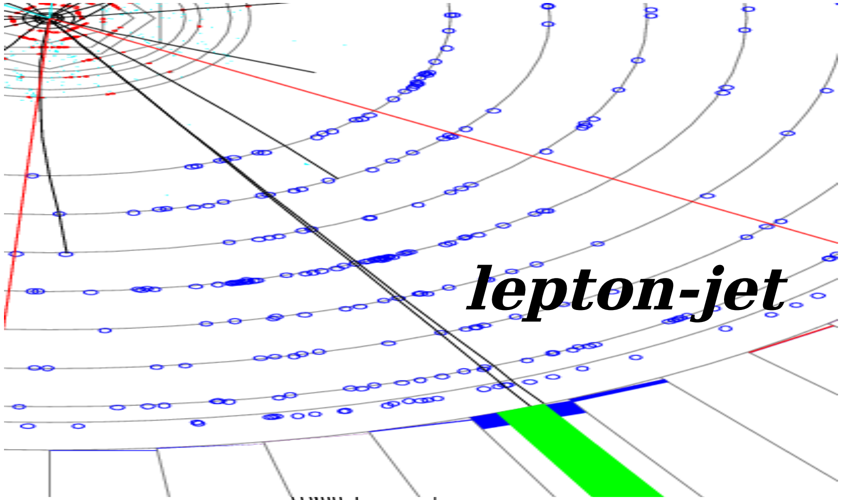
Standard GMSB SUSY search at large BR(neutralino→γ), 1 fb^{-1}

arXiv:0905.1478
Submitted to PRL

Conclusions

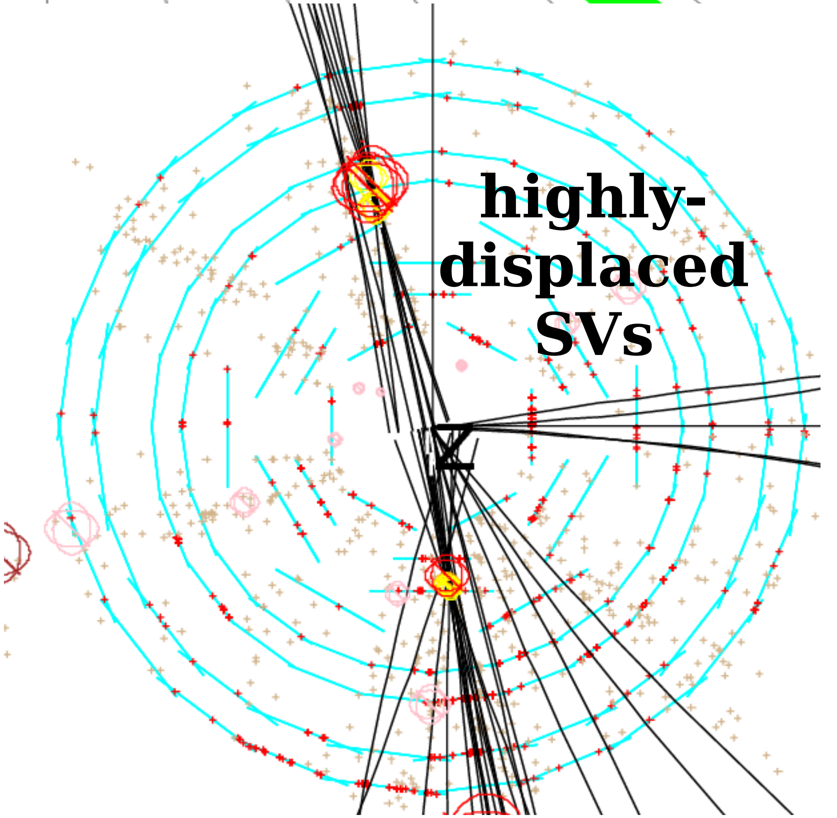
Well-motivated extensions of the SM:

- **N**MSSM, Hidden Valley, ...
- “missing Higgs”,
  Dark Matter / PAMELA ...



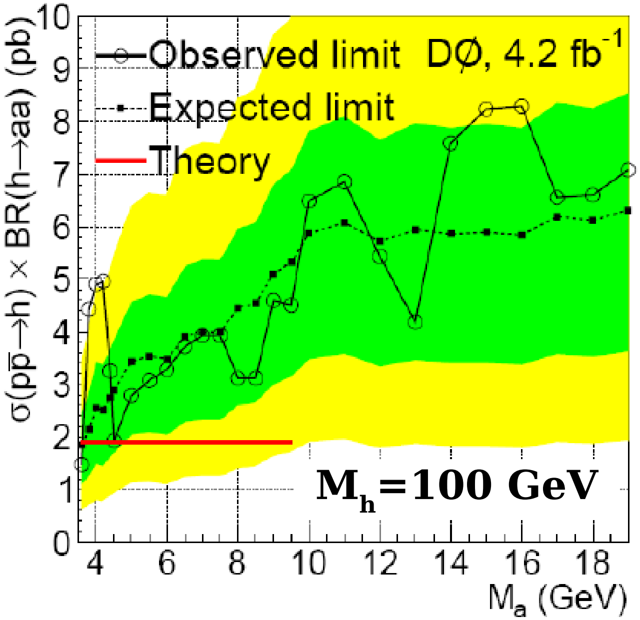
Predict <u>challenging</u> *new signatures*

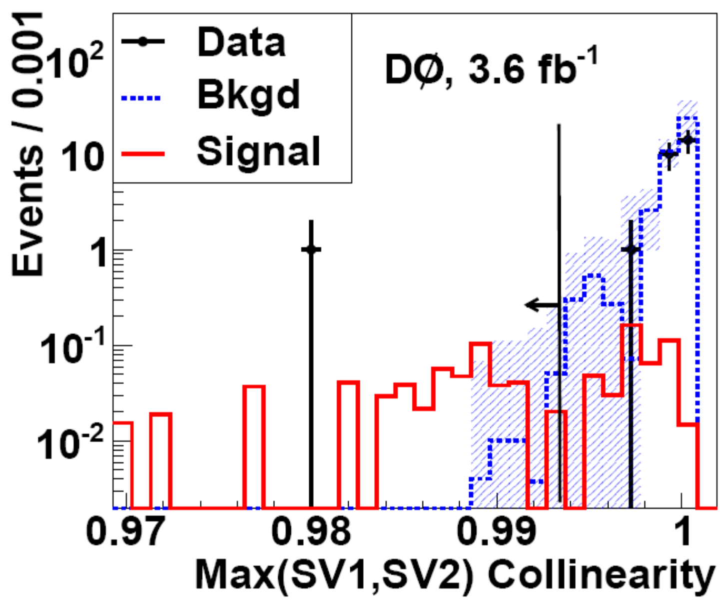
- collinear lepton pairs / *lepton-jets*
- long-lived particles → (b-)jets

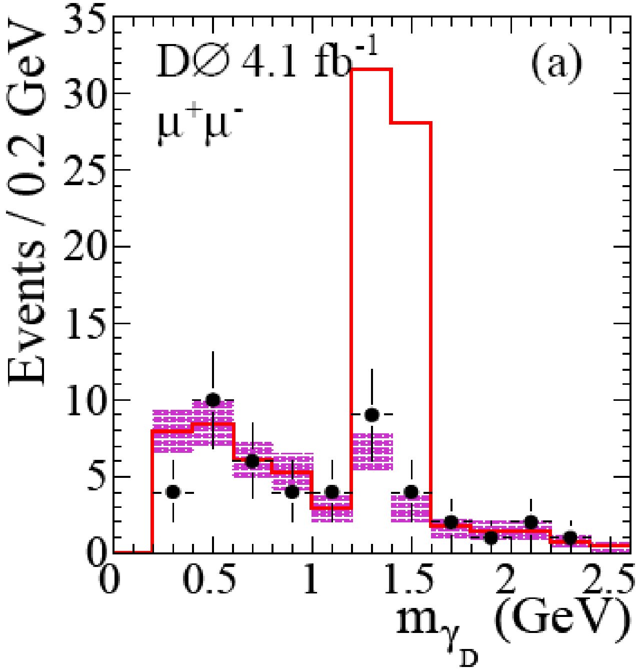


3 new DØ analyses probe
these signatures for the first time...

Conclusions







Higgs→aa
in the **N**MSSM

Higgs →
long-lived particles
→ b-jets

Lepton-jets
in SUSY events

No evidence for new physics yet...
but we could be on the right track!