SiD Optimization Studies

Jan Strube (Tohoku University)
for the SiD consortium

Science Council of Japan

"The Committee appreciates that the ILC enables the precision measurements of the detailed properties of the Higgs particle and the top quark, thereby exploring the physics beyond the Standard Model of particle physics and, therefore, it acknowledges that the ILC is endowed with the scientific value in particle physics. The Committee, however, expresses the desire for more compelling and articulate argument to justify the ILC project in order to search for unknown particles and the physics beyond the Standard Model, running concurrently with the upgraded LHC, given the considerable investment it will require."

Making the physics case

Improving the presentation of the physics case requires a coordinated effort from the detector and physics community.

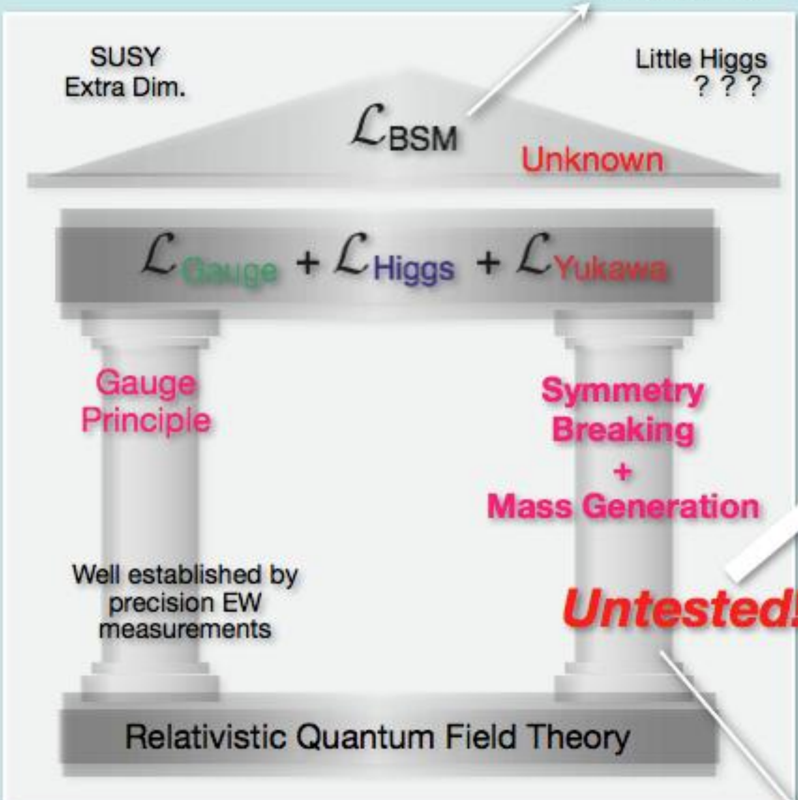
What can the detector physicists do to help?

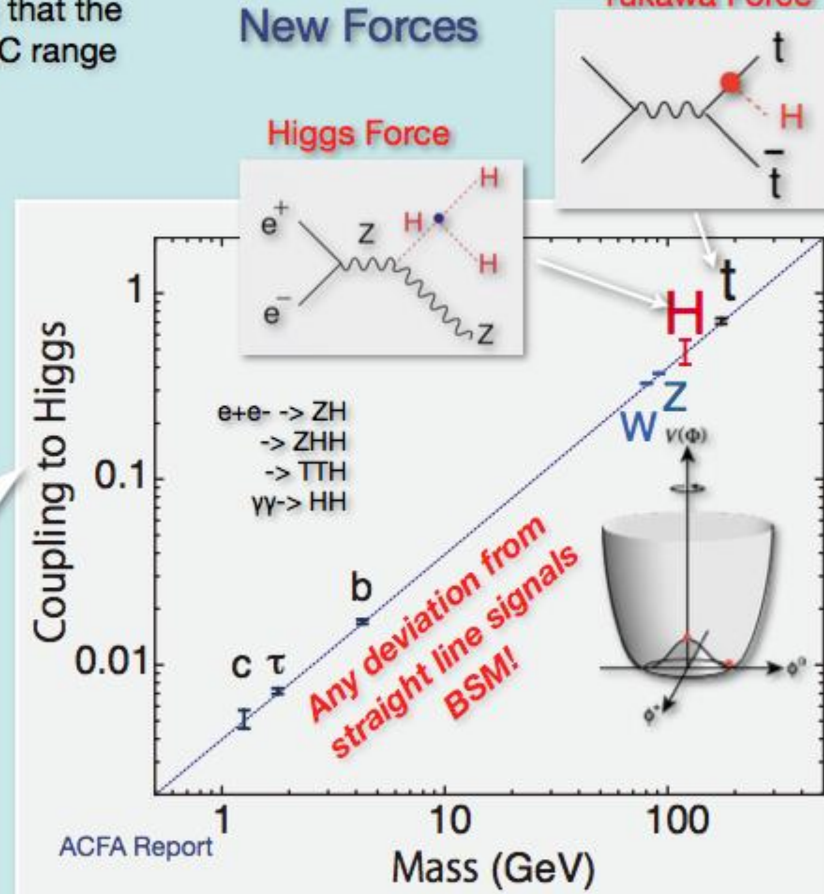
Primary Goal (LCWS2010)
Test of the 2nd pillar, then BSM

2 Main Pillar of SM

There's a good chance that the dark matter is in the ILC range

New Forces





Wd do not know how firm this pillar is. The answer surely lies in the TeV Region

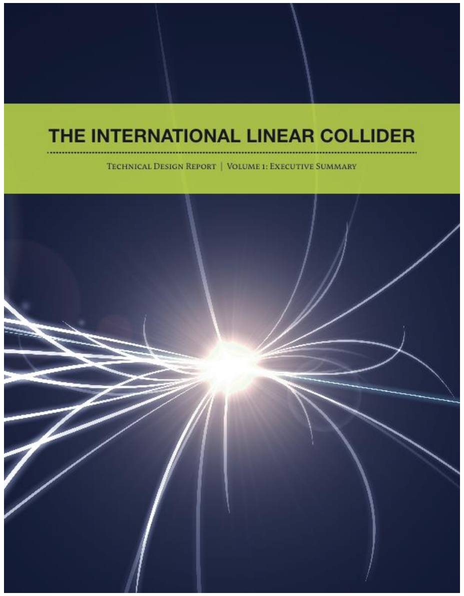
First test the 2nd pillar by precision Higgs study and then put

Beyond the Standard Model **roof!**

We know it's out there...

Two components for success

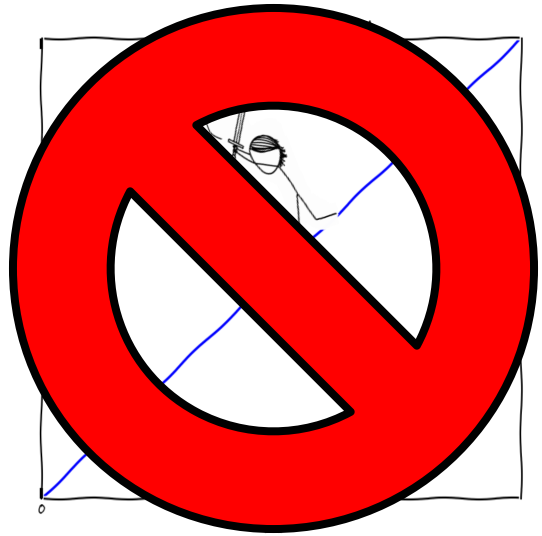
The machine has done their part to demonstrate the potential.

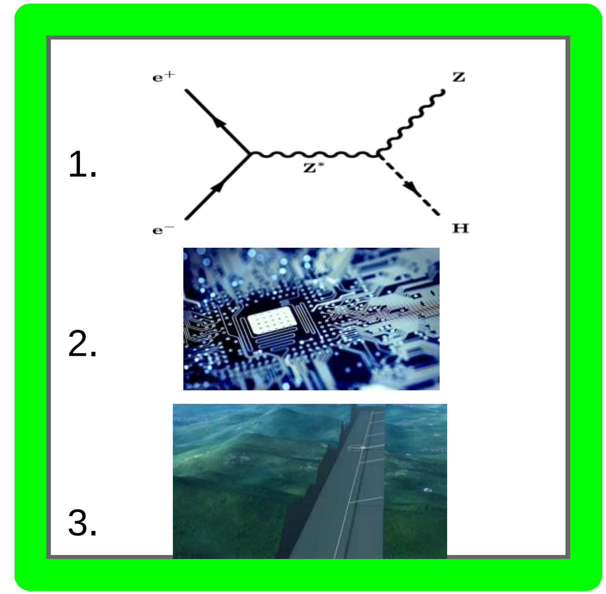


The physics case crucially depends on detector performance.

We need to refine our understanding of the impact of detectors performance on physics.

Detector Optimization Guidelines





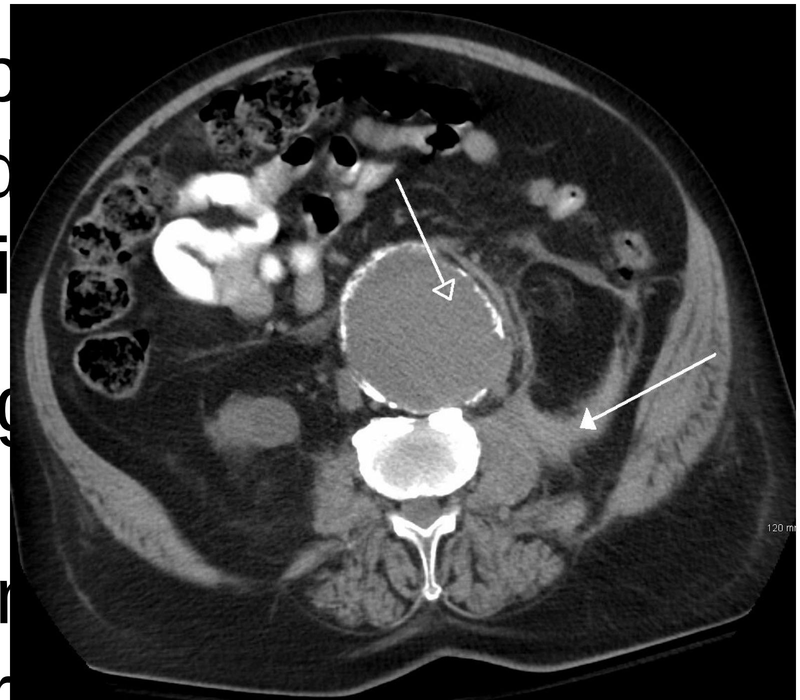
Take out pieces of the detector and after finishing the basic design, shuffle it to the point of unrecognizability

Aggressively slash at performance for cost savings.

1. Physics Case ← we are here
2. Enable response to developments (tools or physics)
3. Build for the given constraints

Reminder

We are not b
the Standard
greater preci



We are trying
between the
Or at least fi
the laboratory.

These may or may not be obvious, but we will find them.

The Road Ahead

Tohoku Expressway to Ichinoseki

Our task for the coming years
is to **secure the required resources** to build a detector

- that can deliver the physics we want to learn
- at the ILC with 250 GeV <= sqrts <= 1 TeV
    - preferably with an upgrade path
    - competing with another detector
- in the Kitakami mountain site in Japan
    - given the constraints of transport paths and the construction site
- that delivers competitive physics
- for 20+ years in a push-pull scenario

SiD Baseline - The DBD

We had to get it write. Did we get it right?

The ILC has published a TDR
Every proposed change now has to go through a change request.
SiD has published a DBD. We have demonstrated that our baseline choice can deliver good physics.
But it's not set in stone.

First get it right

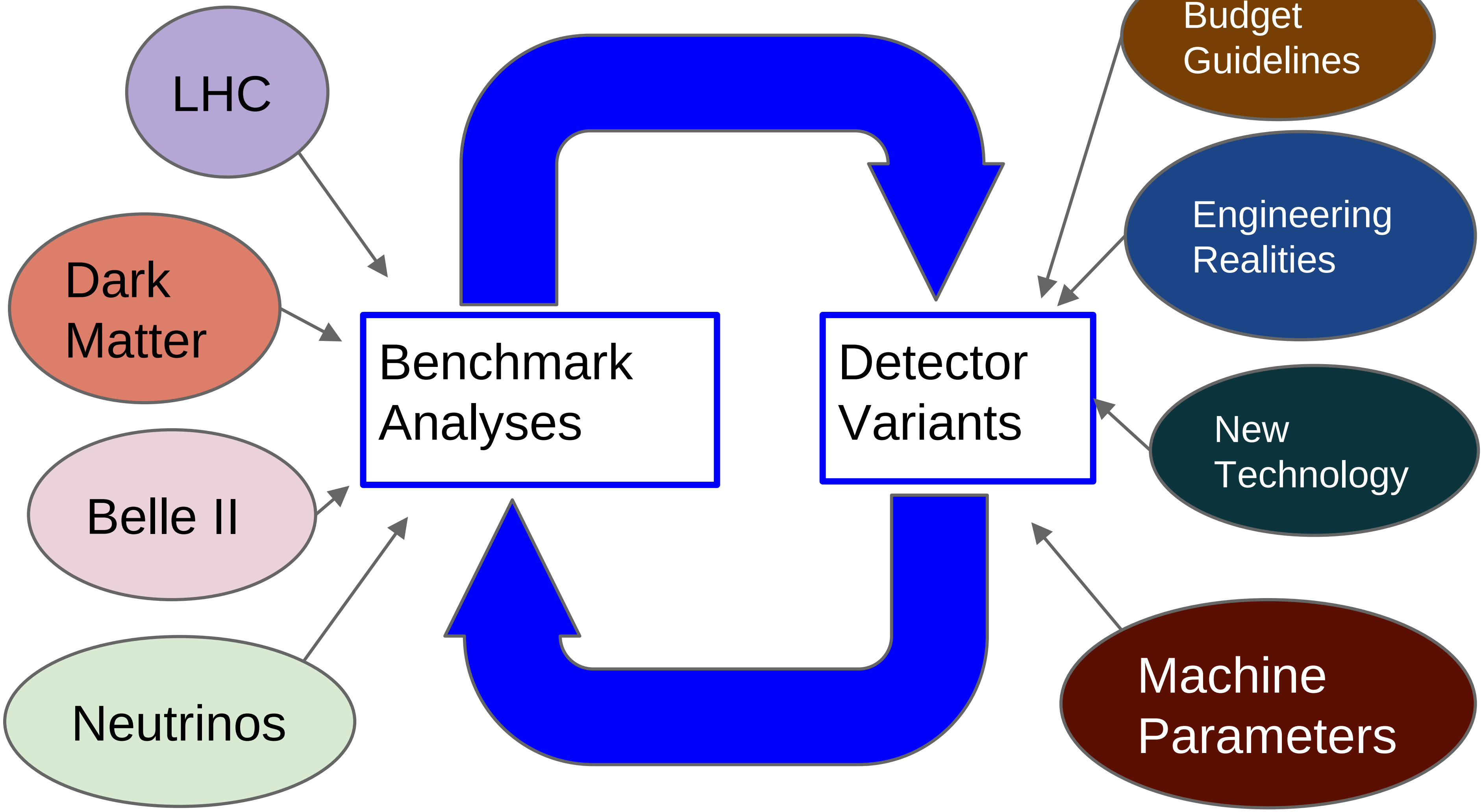
“We should forget about small efficiencies,
say about 97% of the time:
premature optimization is the root of all evil

Yet we should not pass up our
opportunities in that critical 3%.”

D. Knuth, "Structured Programming with Goto Statements".
Computing Surveys **6**:4 (December 1974), pp. 261–301, §1.

emphasis mine

Detector Optimization Process

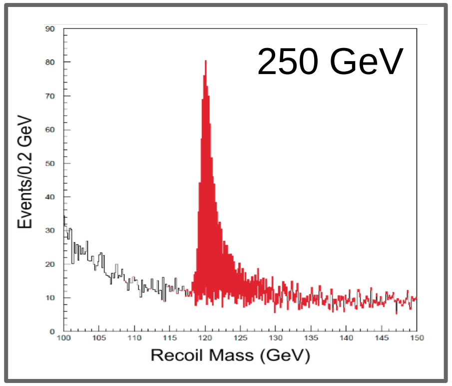


Physics Requirements

Momentum resolution

Higgs Recoil (at 350 GeV and above)

$\sigma(p_T)/p_T^2 \sim$ 2-5 x 10^{-5} GeV^{-1}

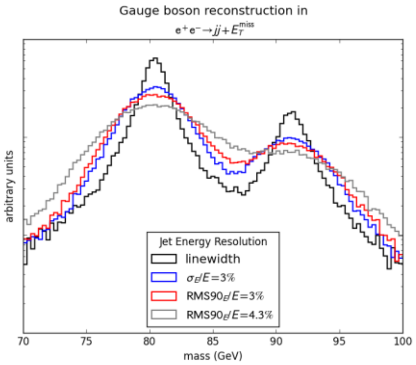


Jet Energy Resolution

Separation of W/Z/H bosons:

Gauginos, Triple Gauge Coupling

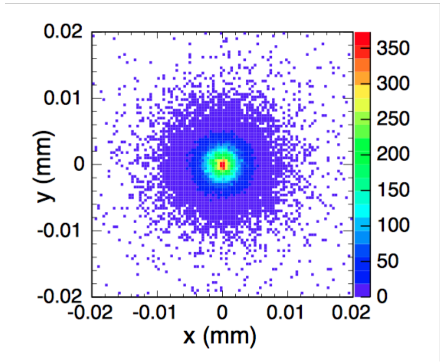
$\sigma(E)/E$ = 3.5%-5%



Flavor Tagging

Higgs Branching ratios

$\sigma_{r\varphi} \approx 5\ \mu m \oplus 10\ \mu m\ /\ (p[GeV]\ \sin^{3/2}\theta)$

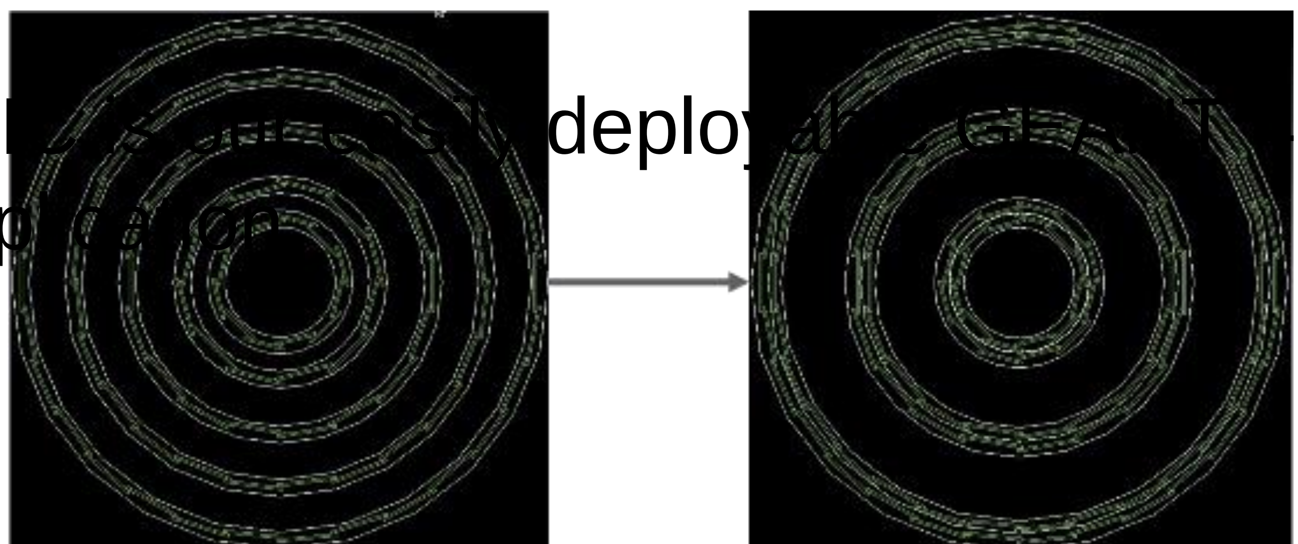


Infrastructure

- Single particle studies or existing physics samples

- SiD’s compact xml allows fast turnaround on changing geometries

- SL[illegible] deploy[illegible] app[illegible]on



A Selection of Processes

On the following slides I will show one physics driver for high performance for each of the three pillars of the ILC program.

Where possible, I will show the performance SiD has demonstrated.

We have to keep iterating with our physics colleagues to understand how improvements in each area strengthen the physics program.

Vertex Detector -- Requirements

Purpose:

- To detect displaced vertices from secondary decays with high precision
- To provide 5 high-precision 3d hits close to the primary vertex

Physics applications:

- Tagging of heavy quark flavors
- tau tagging
- vertex charge reconstruction
- ...

Vertex Detector
Physics Drivers

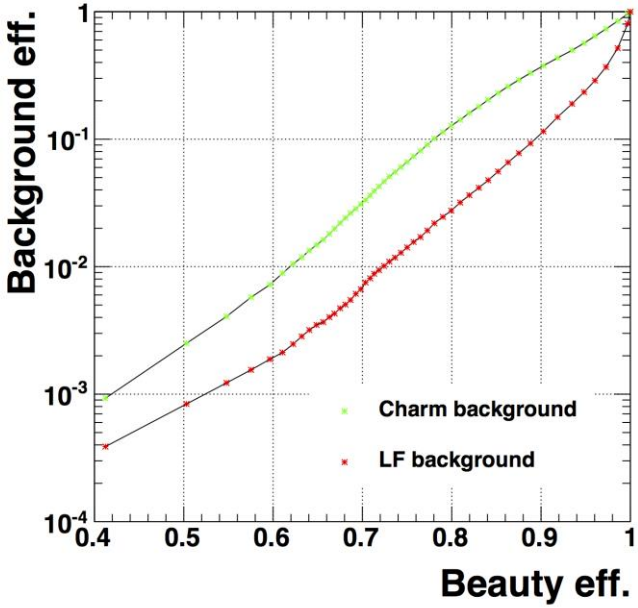
SM: Top A_{fb}(ICHEP: CDF: 2σ discrepancy, > 30% rel. error)
SiD: $\Delta A^{t}_{FB} = 3\%$.

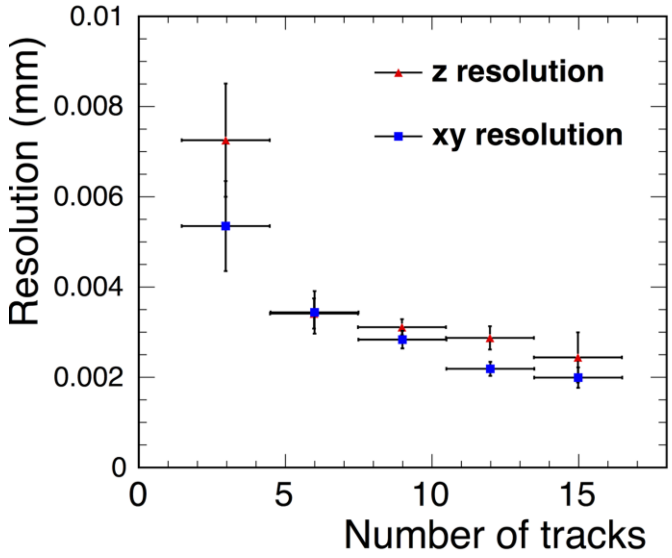
Higgs: Fingerprinting of different patterns of Higgs BR in different scenarios
SiD: (1 TeV, 1 / ab):
$h \rightarrow bb$: 0.47%, $h \rightarrow cc$: 6.2%, $h \rightarrow gg$: 3.1%

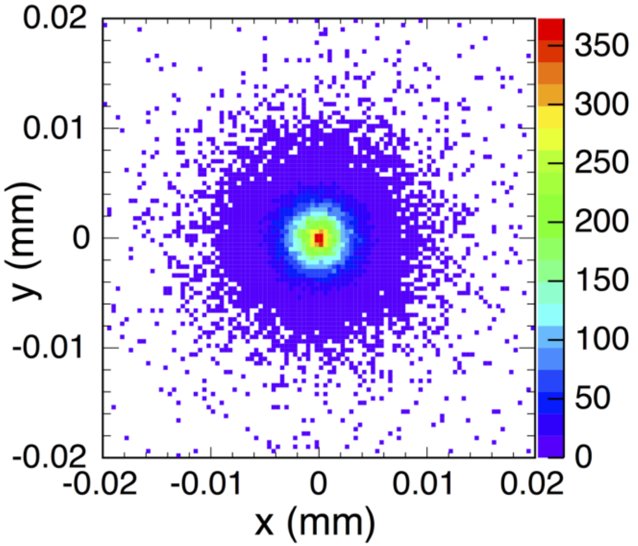
New Phenomena:
b- and c-tagging for light SUSY decays, Z' sensitivity
SiD: see above

SiD Vertexing in the DBD

Excellent Flavor tagging performance at 1 TeV even in presence of background from production of e^+e^- pairs and hadrons from the beams.

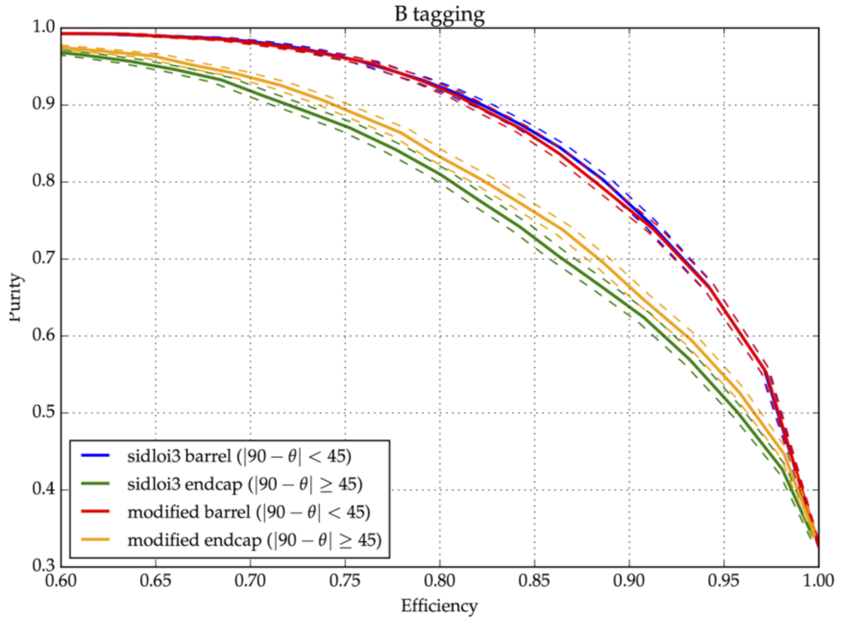


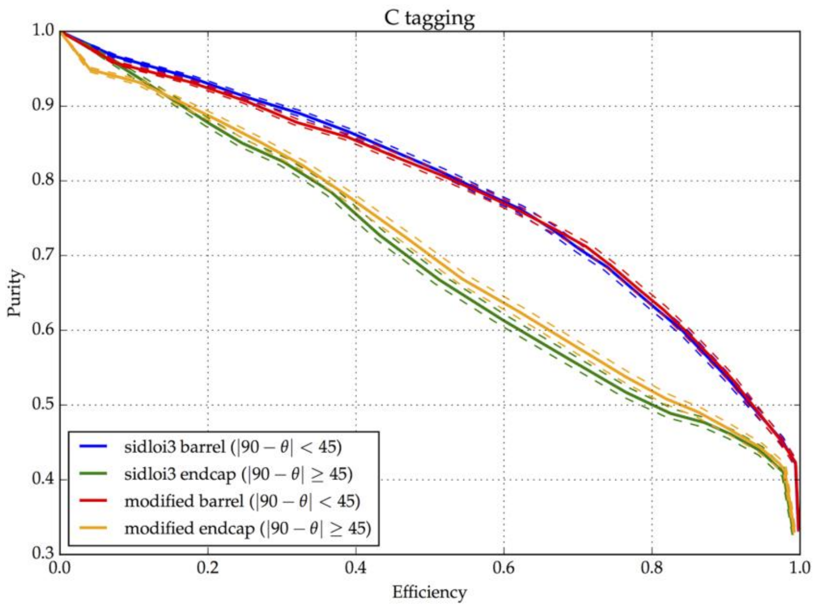




Vertexing -- Optimization

Changing the Vertex Barrel length, moving the disks out.





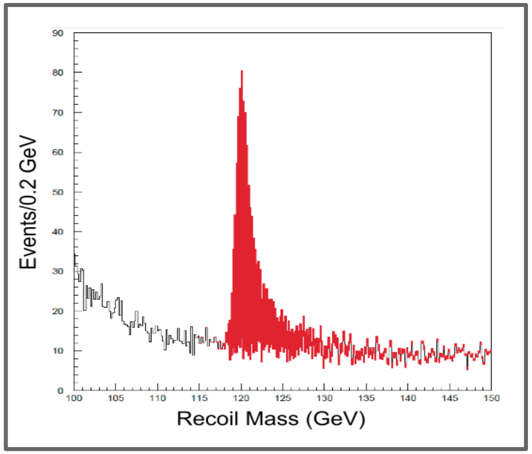
Main Tracker -- Requirements

Purpose:

- To achieve excellent pattern recognition (= high efficiency @ low fake rate).
- To achieve high momentum resolution (= low multiple scattering)

for charged particles.

$\sigma(p_T)/p_T^2 \sim 2\text{-}5 \times 10^{-5}\ \mathrm{GeV}^{-1}$



Tracker
Physics Drivers

SM: Higgs recoil study

SiD: recoil mass, 250 GeV, 250 fb^{-1}: 40 MeV, σ(ZH): 2.7%

Higgs: $H \rightarrow \mu\mu$

SiD: Δ σ x BR / σ x BR = 0.32

BSM:

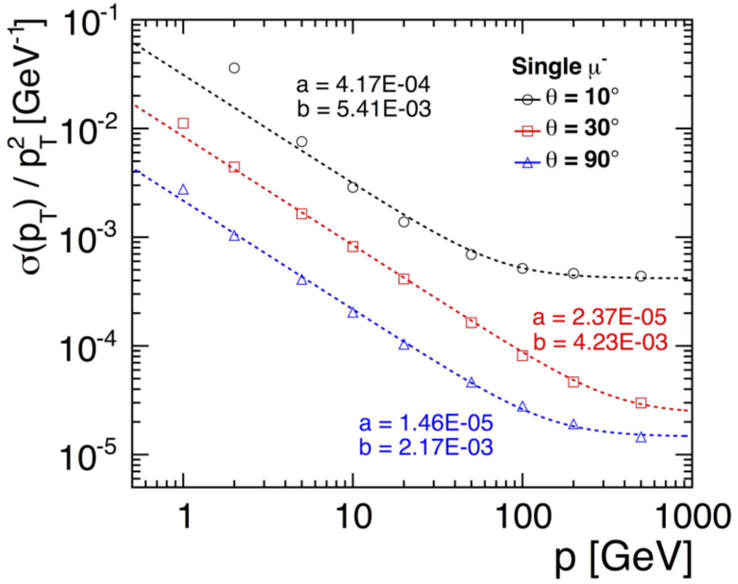
Z' $\rightarrow$ ll, low-pt tracks for low energy release (soft staus)

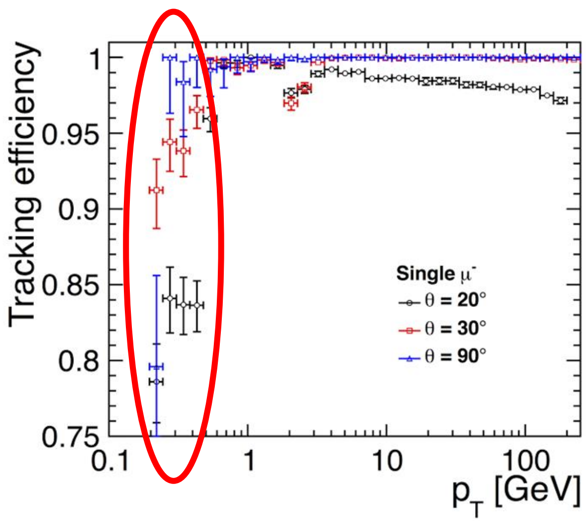
SiD: -

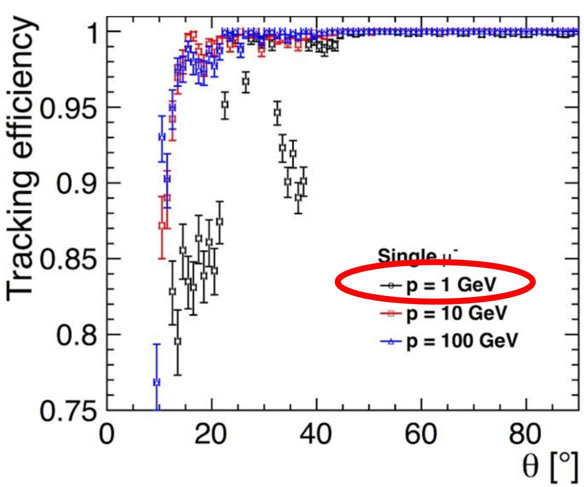
SiD Tracking in the DBD

Excellent impact parameter resolution and tracking efficiencies for high energies down to low angles (~10º).

Obvious weaknesses exist in the low-pt region.

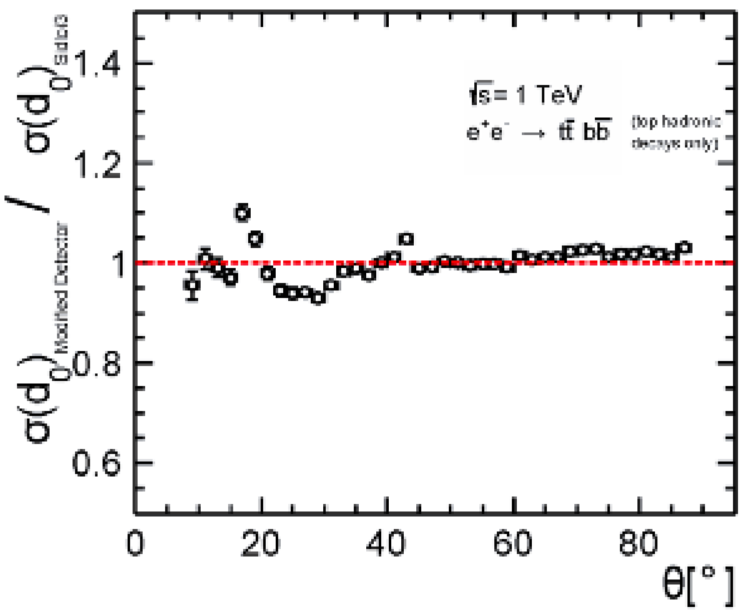


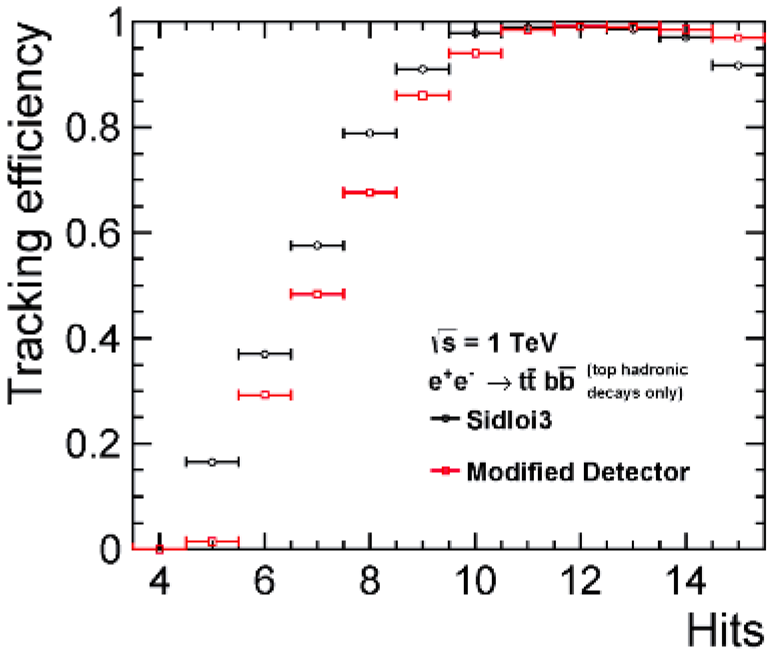




Tracking -- Optimization

Changed the layout of the vertex detector barrel from 5 single layers to 3 double-layers





Impact parameter resolution shows no significant change with 3 double layers

Tracking efficiency vs. number of hits decreases for 3 double layers in the VTX

From Sagar Setru, ANL

Calorimetry -- Requirements

ECAL: Good standalone photon energy resolution.
Good separation of close showers.

ECAL, HCAL: High granularity in longitudinal and transverse to improve particle flow performance and reduce shower overlap

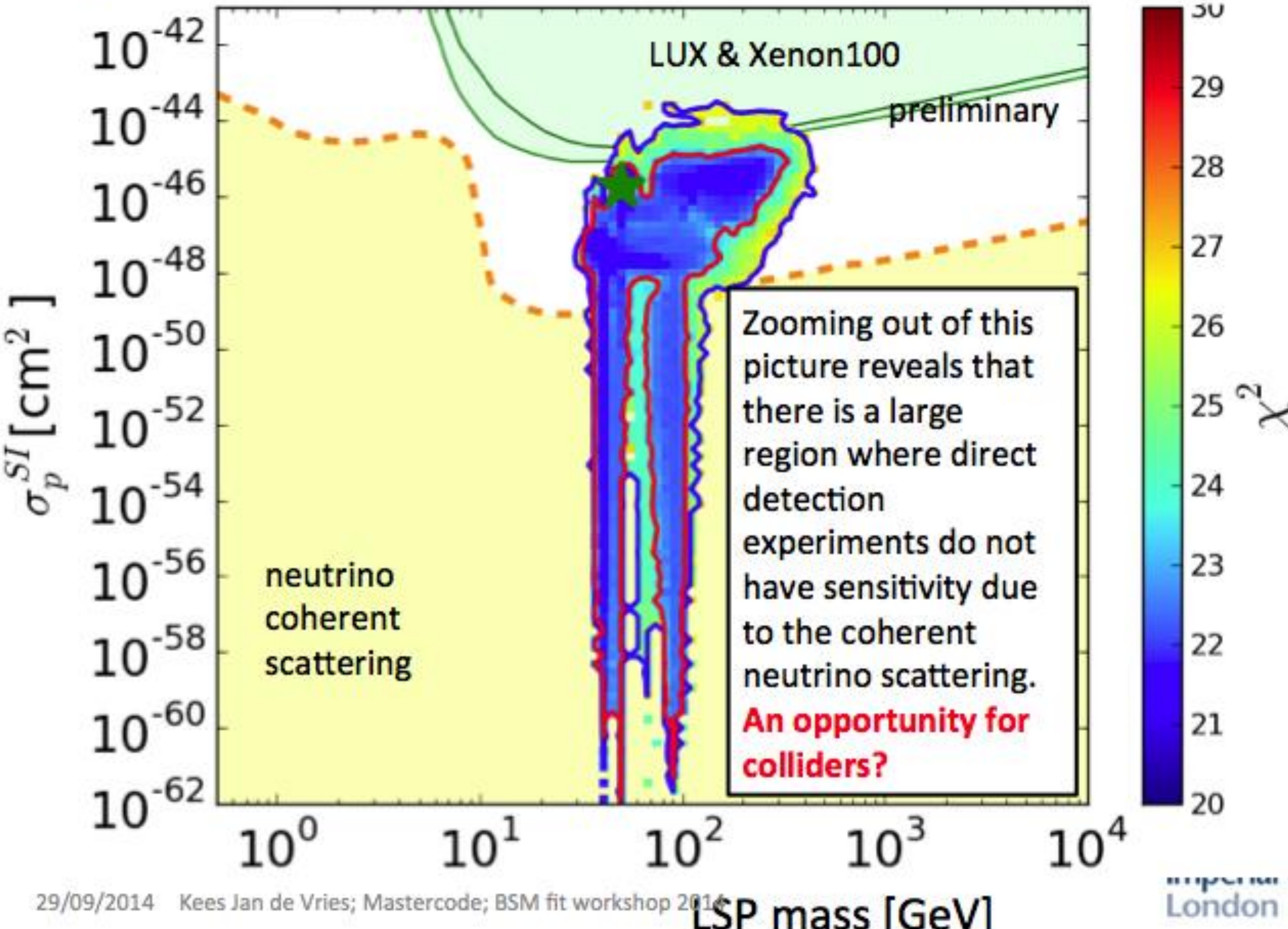
Calorimetry
Physics Drivers

SM: WW scattering (2 sigma deviation @ LHC)
SiD: 500 GeV, tt cross section = 284.1 ± 1.4 fb
m_t = 173.918 ± 0.053 GeV

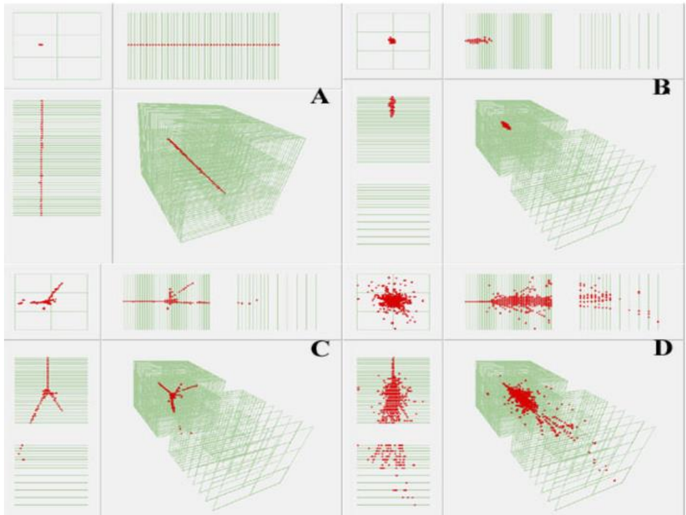
Higgs: $H \rightarrow \gamma\gamma$, $H \rightarrow gg$, $H \rightarrow$ invisible, g_{HHH}
SiD: ttH at 1 TeV, 1 ab^{-1}: y_t to better than 4%

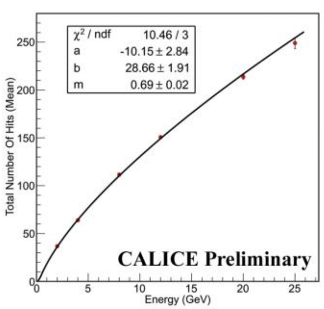
BSM: Higgsinos, $\chi^0\chi^+$
SiD (500 GeV, 500 fb^{-1}): $\Delta\, mX_1^0$ = 160 MeV,
$\Delta mX^{\pm}$ = 450 MeV, ΔmX_2^0 = 490 MeV

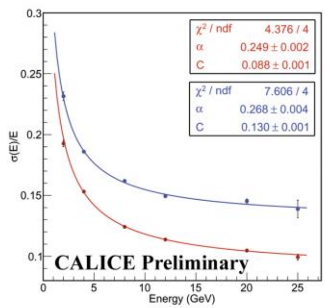
direct detection: pMSSM10



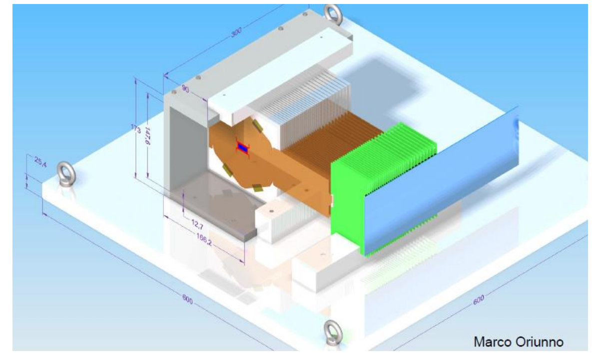
SiD Calorimetry in the DBD

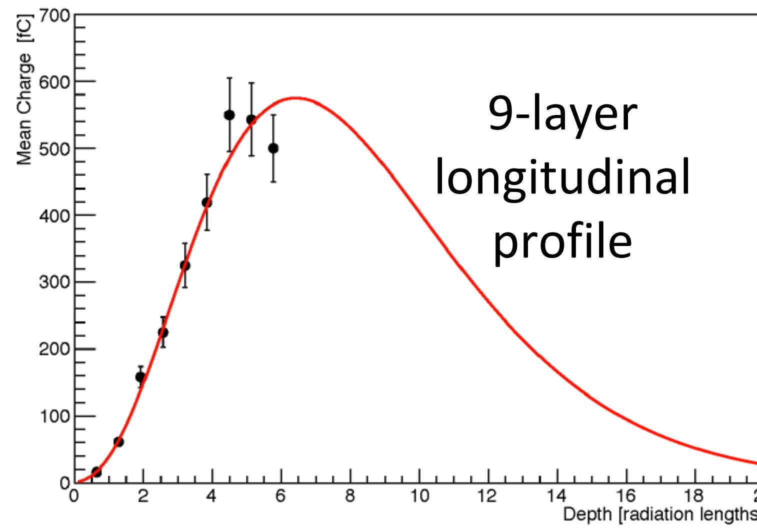






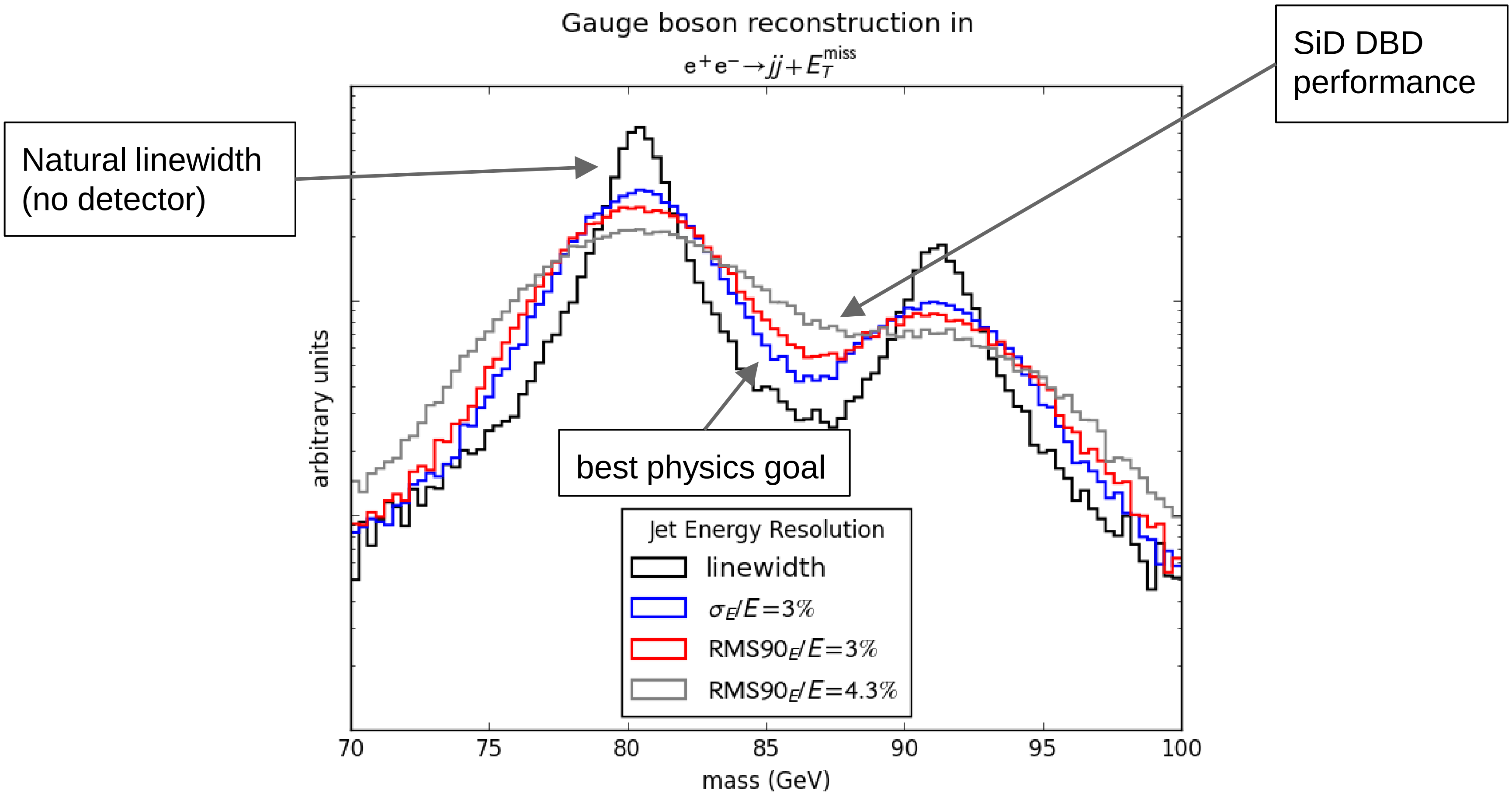
Highly granular HCAL in a beam test





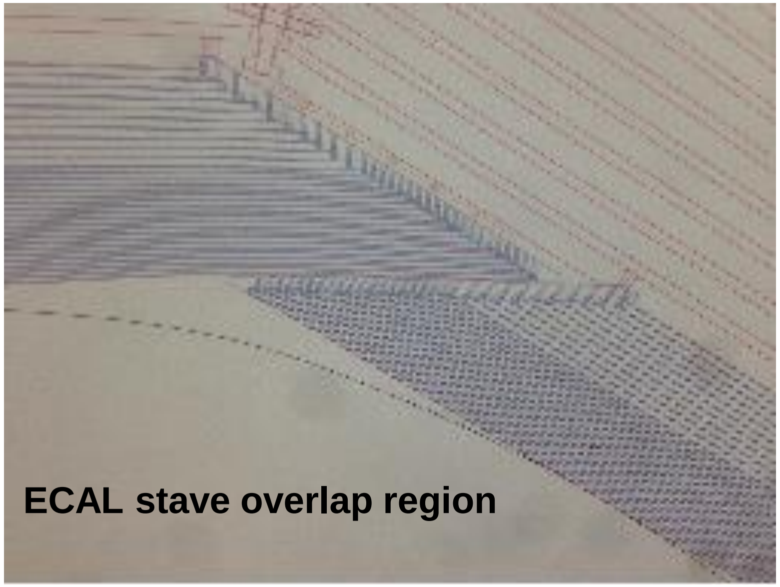
ECAL performance in beam test

Jet Energy Resolution

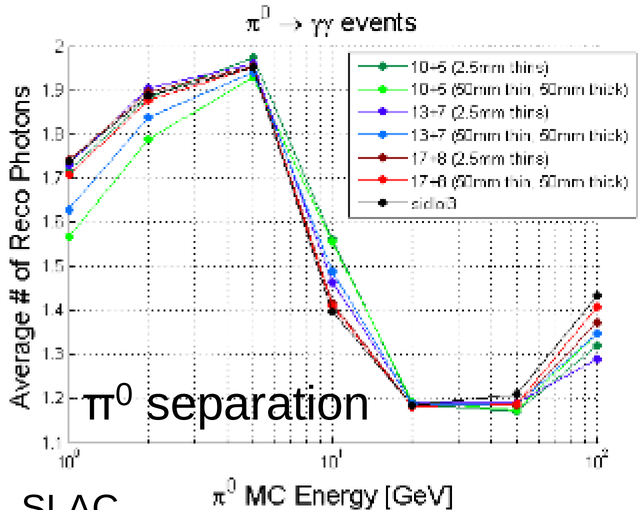


SiD DBD jet energy resolution applied to physics events.

Calorimetry -- Optimization

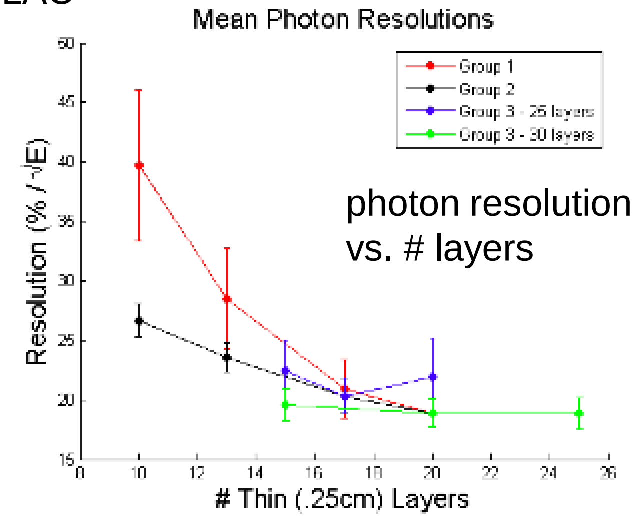


ECAL stave overlap region

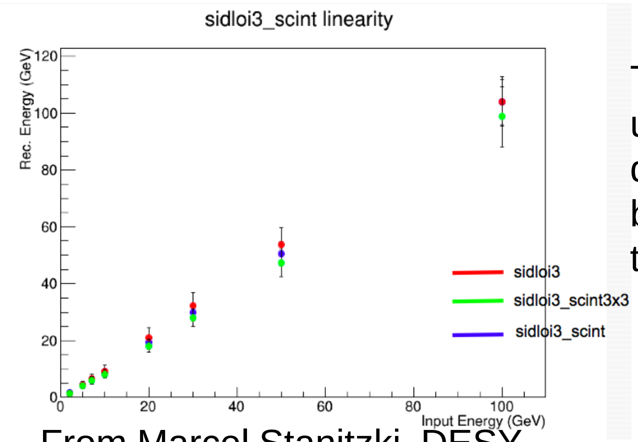


π^0 separation

From Da An, SLAC



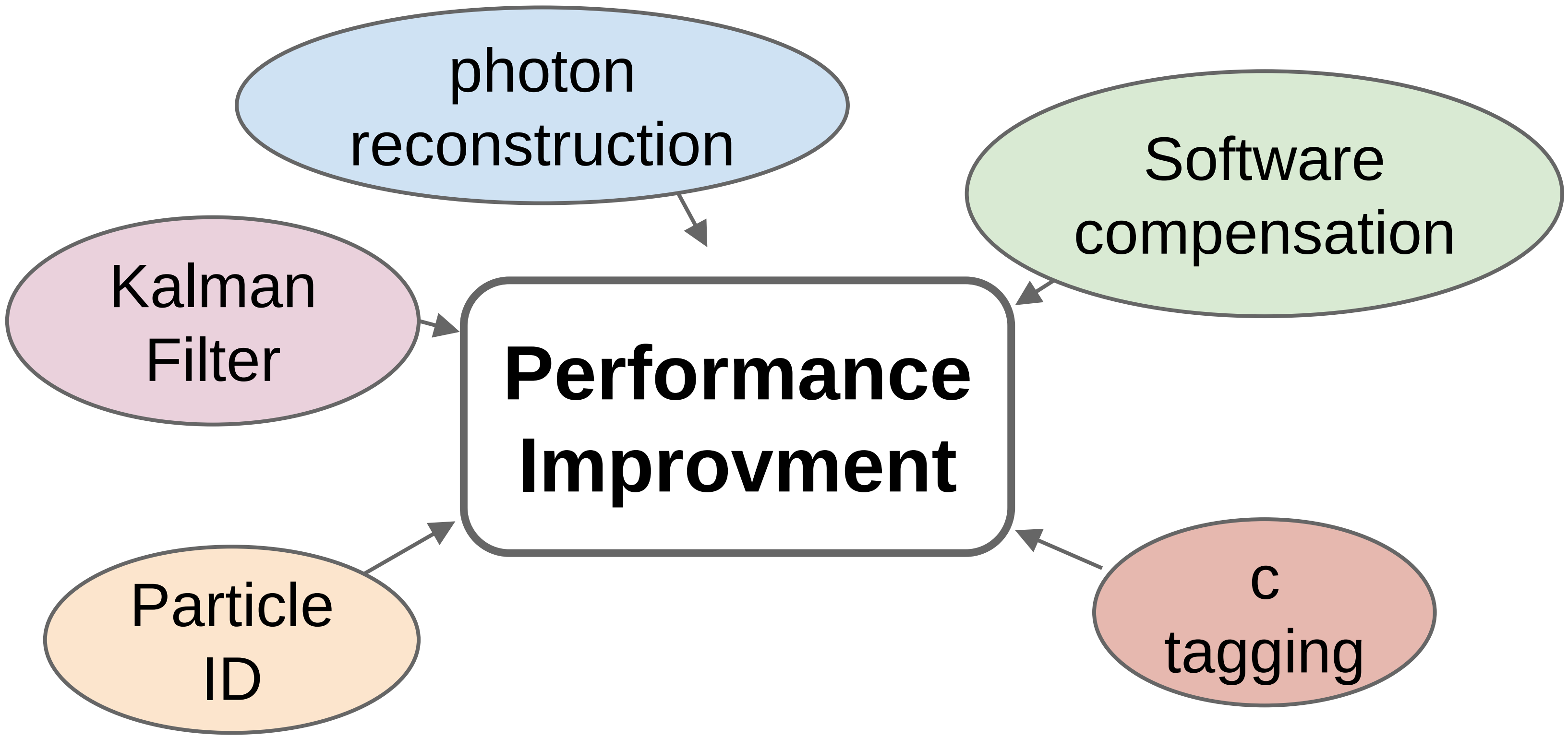
photon resolution vs. # layers



Trying to understand differences between HCAL technologies

From Marcel Stanitzki, DESY

Reconstruction Improvements



The ILC detectors are advertised as having unprecedented resolution. We currently don’t take full advantage of this information!

Performance Status

The demonstrated detector performance is based on a proof-of-principle implementation.

The Physics case can be made stronger by improving the detector performance. This requires continuous communication with the physics working group.

There is still a lot of room for improvement.

Ideas for Improvements to the Reconstruction

- Particle ID
  - Mass Resolution / Flavor tagging improvements?
- Vertex reconstruction
  - Vertex charge
  - New fitting algorithms
- Calorimeter-assisted Tracking
  - First successes shown a while ago
- Pi0 reconstruction
  - Improvements to flavor tagging / Higgs mass promising
- Tracking
  - Kalman filter to improve resolution

Ideas for New Studies

- Change of L*
- Impact of background
- Anti-DID studies
- Benefit of FHCAL
- Other studies to react to engineering and machine changes.

} feedback to the machine

And of course bring your favorite physics channel to SiD

Conclusion

None, yet.

We have started to enter the cycle of re-evaluating SiD performance in light of physics drivers, engineering realities and new technology developments.

This phase is crucial. We have to keep iterating with the physics group to make sure we got it right. Then we can solidify and optimize.

Summary

- SiD is in a transitional state towards a real project:
  - We have a site, but no host nation
  - We have a detailed cost estimate, but no budget
- The success of the ILC program depends crucially on being able to make progress in measurements of
  Standard Model, Higgs, and Beyond the SM physics
  - The detector is a crucial part to help make the physics case
  - We can demonstrate that better detector performance improves the physics case
  - Better technology (hardware or software) leads to better performance
  - We need to make sure we get this right
- The optimization of the SiD detector has just barely started. We have a strong baseline, but remain open to improvements.
- We have weekly meetings where we exchange ideas.
  New members are welcome!
- We look forward to discussing new avenues to strengthen SiD’s position as the premier detector concept for the ILC.

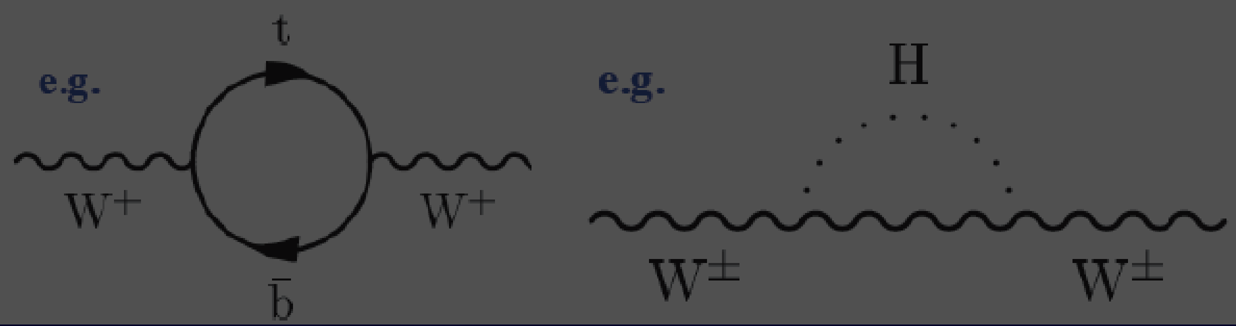
ご清聴ありがとう
ございました

Thank you
for your attention

and thanks to Marcel Demarteau and Michael Peskin for inspiration

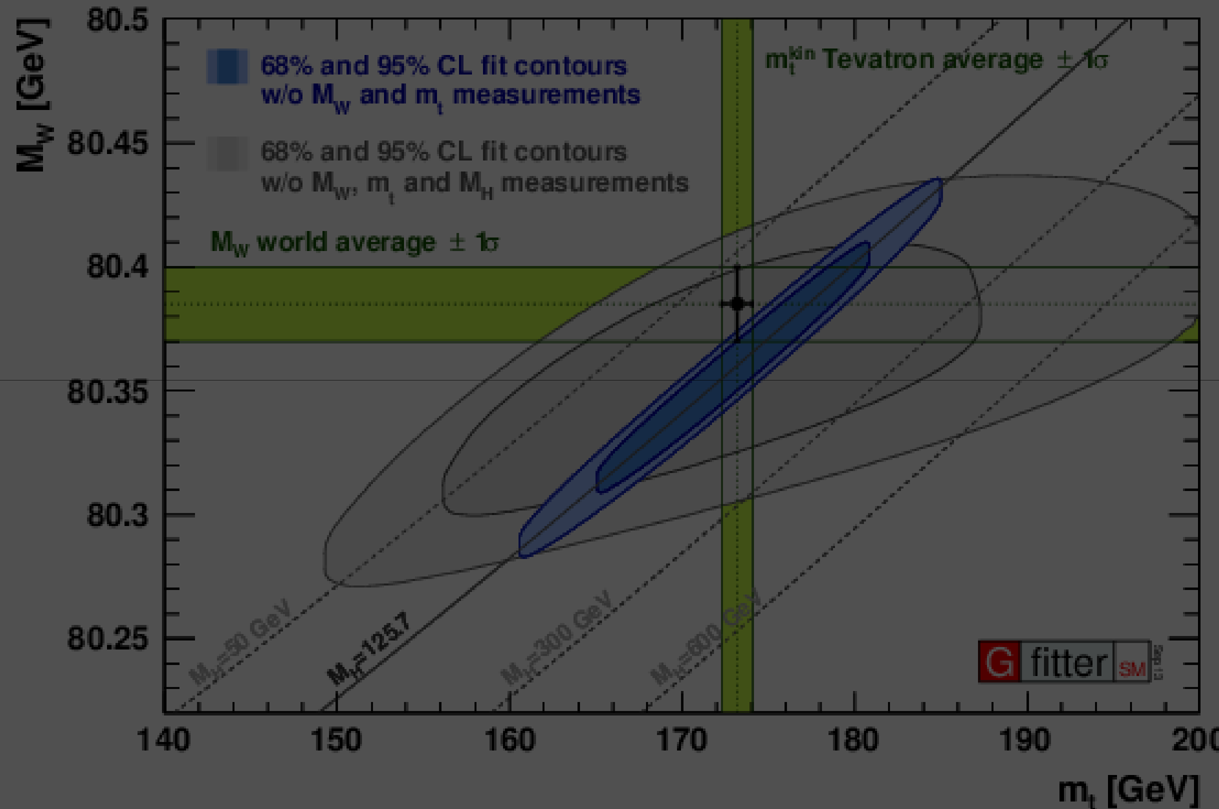
Backup

State of the Electroweak Theory: Precision Frontier



Radiative corrections to precision EWK **measurements of W, Z sensitive to Mt, MH**

SM-like Higgs discovery at ~126 GeV is compatible with global EWK data at 1.3 sigma (p = 0.18)



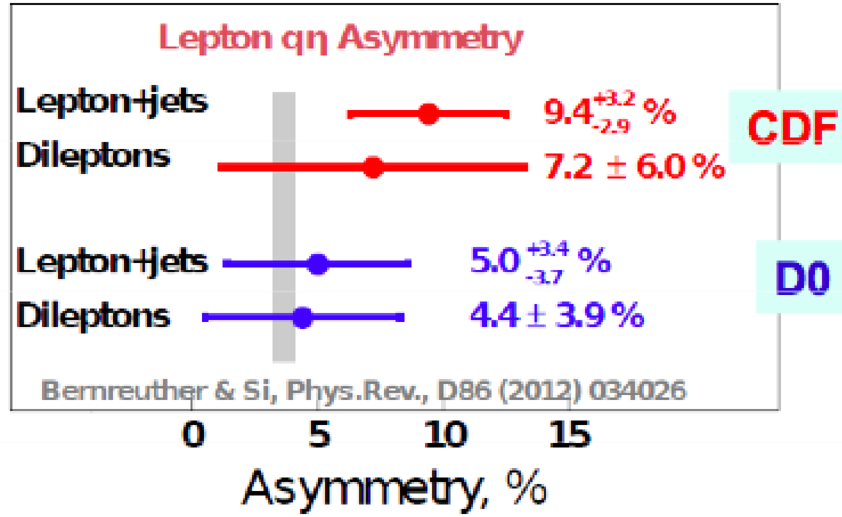
Indirect constraints are now superior to precise direct W, Z measurements (MW, $\sin^2\theta_{eff}$)

Can W,Z experiment catch up?

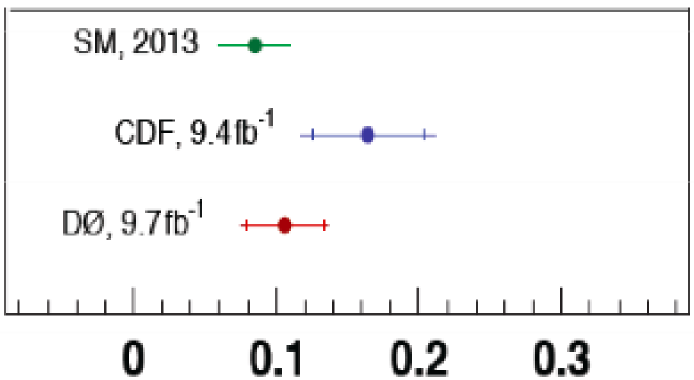
http://project-gfitter.web.cern.ch/project-gfitter/

A_{FB} ($t\bar{t}$) asymmetry / Recent results

- **In A_{FB} leptonic-asymmetry**
  recent results from CDF and DZero are now more consistent with SM prediction (measured asymmetries decreased, theoretical predictions increased)

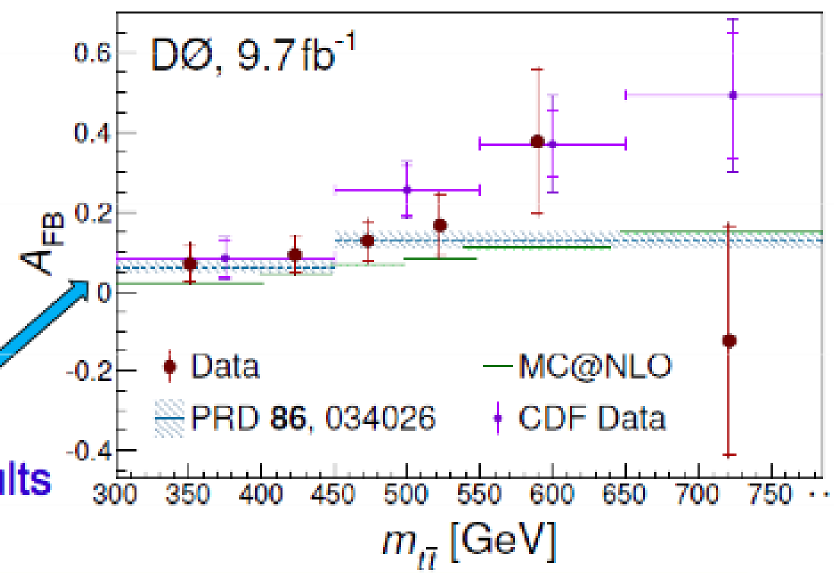


- **In $t\bar{t}$ asymmetry:**



Asymmetry compatible with SM

- **Kinematic dependence with m_{tt}**
  When considering CDF and D0 recent results
  ➔ reduced discrepancy with prediction



Working now on the CDF-D0 combination of these results

What about systematics?

- **theoretical,**
- **parametric,**
- **experimental**

From K. Fujii, Joint Higgs / BSM session

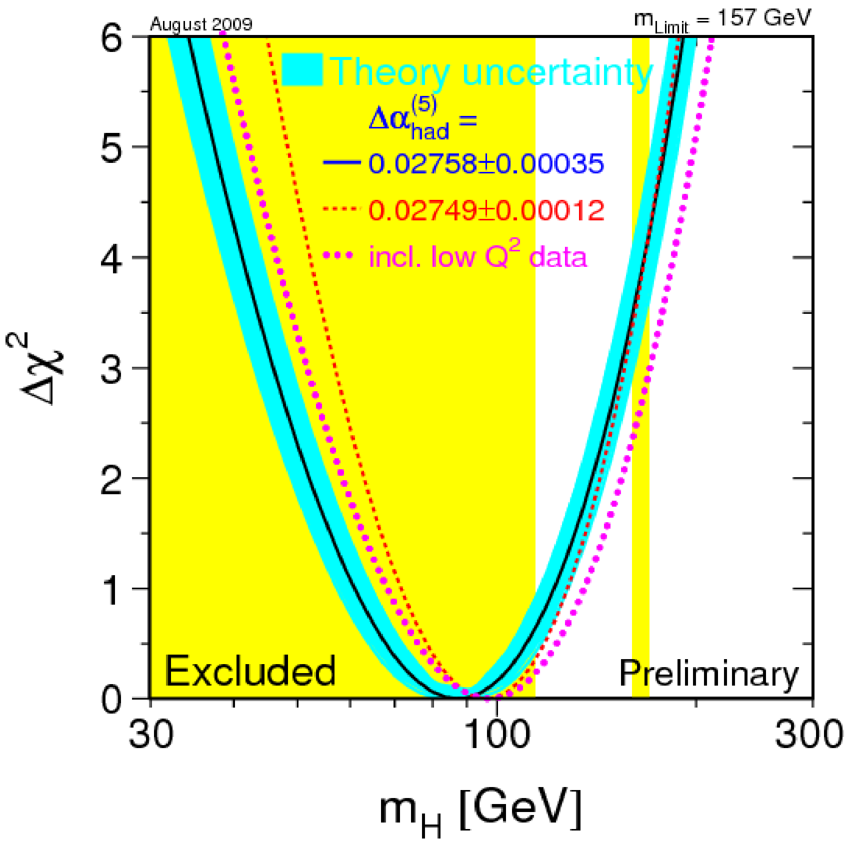
How to further improve precisions?

From K. Fujii, Joint Higgs / BSM session

- ***By improving analysis method:***
  - fully use **hadronic Z decays for recoil mass** (issue: dependence on Higgs decay mode)
  - identify exotic Higgs decays (incl. invisible one separately) and use **Σ BR = 1 constraint**. (cf. Michael Peskin's analysis)
- ***By optimizing running scenarios:***
  - How much luminosities at what energies and in which order?
  - When do we do energy/luminosity upgrades?

From K. Fujii, Joint Higgs / BSM session

Legacy Plots



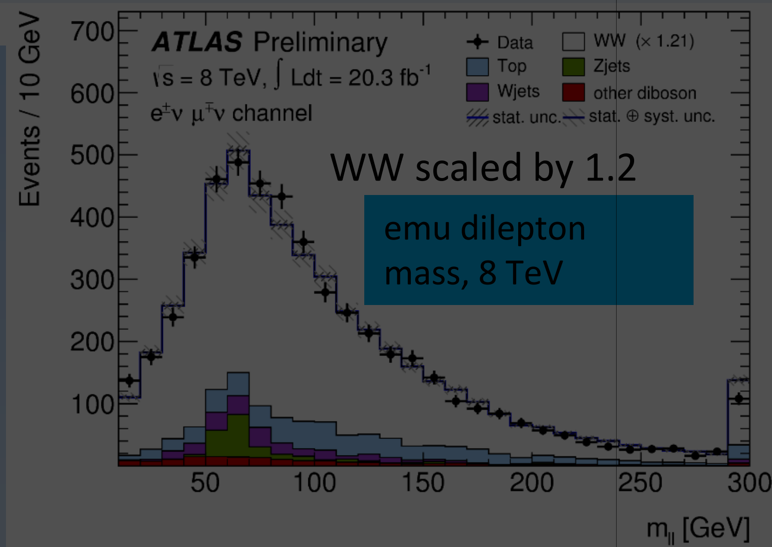
WW Production (8 TeV)

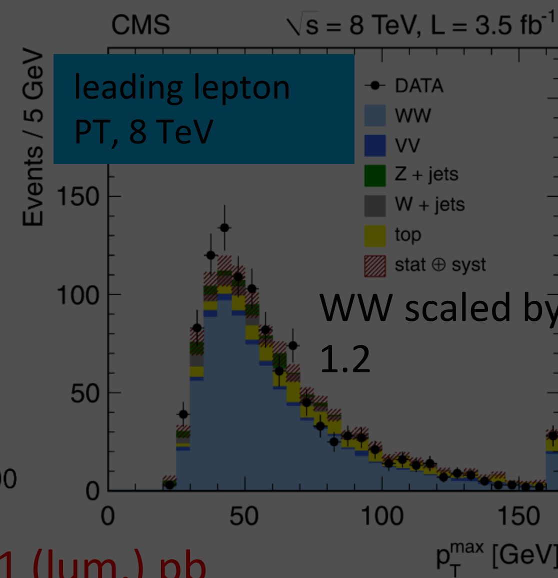
PLB 721 (2013) 190

ATLAS-CONF-2014-033

NEW for ICHEP14

- **Kinematic shapes agree with prediction, but cross section excess observed at 20% level in CMS and ATLAS**
- ~5000 emu ATLAS candidates with 20/fb!
- Systematics from jet veto acceptance, background methods
- Not yet reporting: CMS lvlv 20/fb, WW→lvjj 20/fb
- Theory calculation being actively studied (jet vetoes, NNLO)





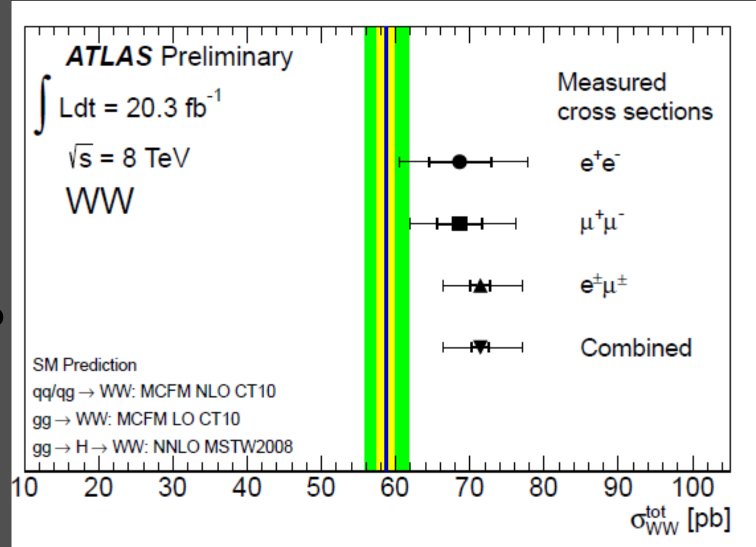
CMS 69.9±2.8 (stat.)±5.6 (syst.)±3.1 (lum.) pb (1.8σ)

ATLAS 71.4±1.2 (stat.)±5.0 (syst.)±2.2 (lum.) pb (2.1σ)

MCFM 58.7±3.0 (syst.) pb

=qq,qg 53.2 MCFM NLO
+gg 1.4 MCFM LO
+HWW 4.1 NNLO+NNLL

Higher order/other≈ +3-4pb?



From Jeffrey Berryhill, ICHEP 2014, Valencia

Calorimetry -- Requirements

Photon reconstruction, Pi0 (flavor tagging):
Improving c-tagging by reducing b-background

Reconstruction of V0 (Tracking capabilities)

From: ATLAS H $\rightarrow \gamma\gamma$ **arXiv:1408.7084**
"The diphoton production vertex is selected from the reconstructed collision vertices using a neural-network algorithm"

The New York Times

(1992) "400 Physicists Fail to Find Supersymmetry"

(Updated 20… Physicists Fail to Find Supersymmetry"

(…

If yo…

Science Technology Education and Sports Daily

Dark Matter Illuminated

By HIDEKI YOSHIKAWA

…consecutive year, partic-
…strong showing in

Ichinoseki …

Friday, April 2, 2032

Non-standard Matter unveil…

Physicists at the ILC Laboratory in Ichinoseki, Japan today unveiled a discovery that sheds new light on the fabric of our universe -- and it's highly non-standard. The new particle that was discovered by the SiD and ILD collaborations does not fit into the venerable Standard Model of particle physics that was developed several decades ago and stood the test of time - until now.

Ren… foll… imp…

The… that… rela… the… beh…

Scalar quark…

Cannonballs

Axigluons

Quirks

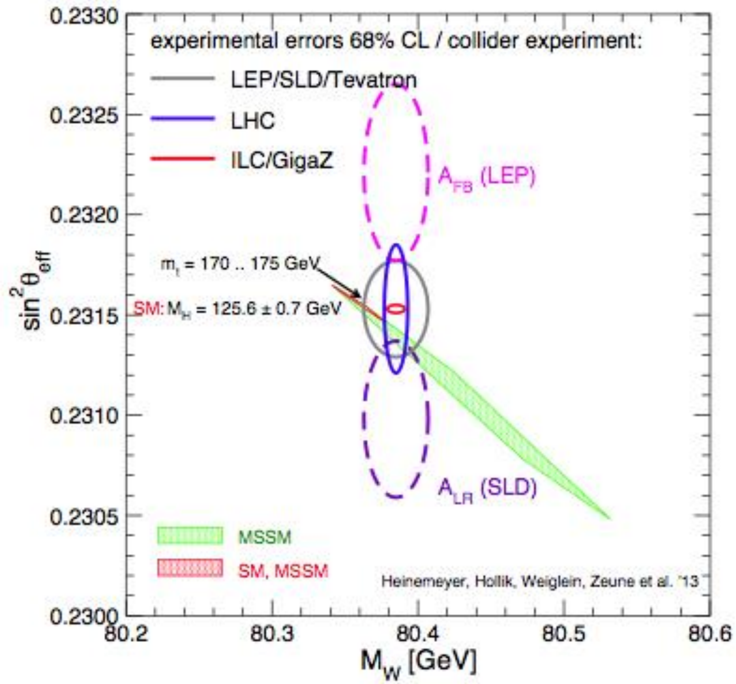
Anomalou…

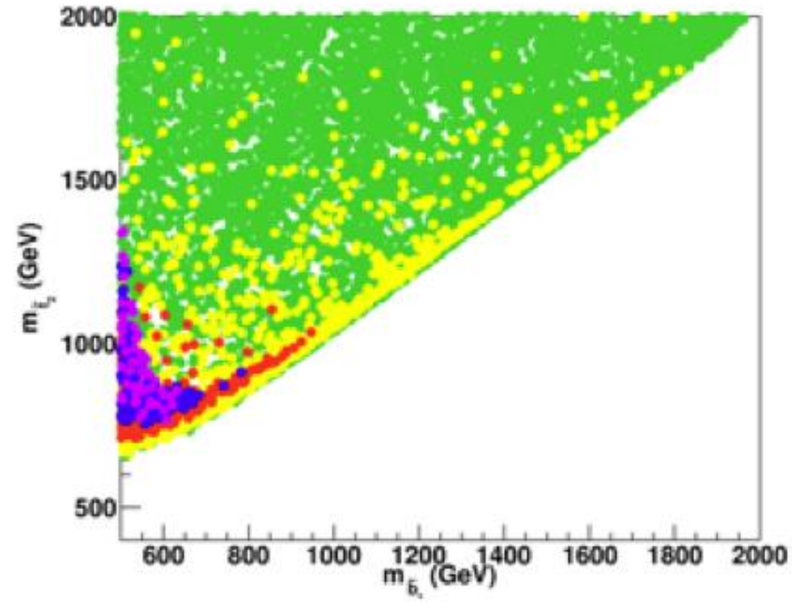
Magnetic m…

Signature…

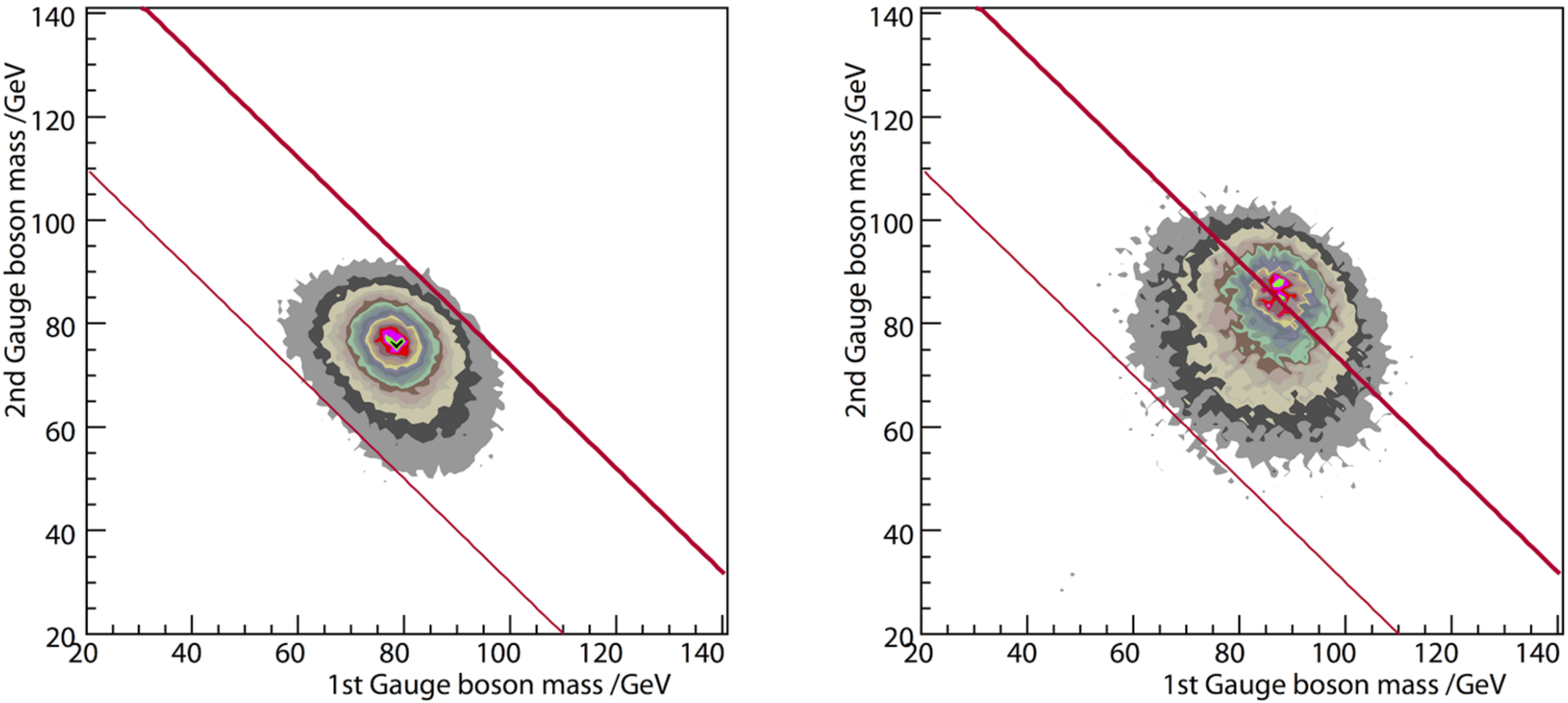
But now LHC digs them u… are still
a few holes for the Tevatron, inclu… top physics

Another approach.

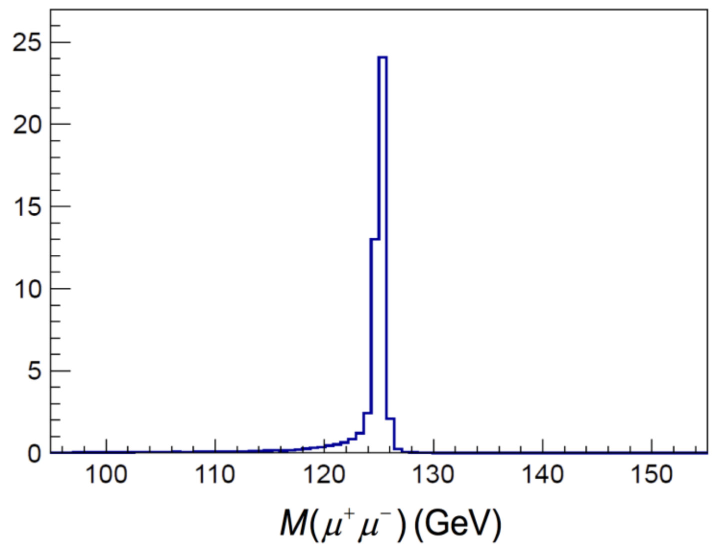




- Independent of how stop can be produced and how they decay.



2nd Gauge boson mass /GeV
140
120
100
80
60
40
20
20
40
60
80
100
120
140
1st Gauge boson mass /GeV
2nd Gauge boson mass /GeV
140
120
100
80
60
40
20
20
40
60
80
100
120
140
1st Gauge boson mass /GeV



25
20
15
10
5
0
100
110
120
130
140
150
M(μ+μ−) (GeV)