The Decay Length Method for LHC Physics

Reiner Klingenberg, TU Dortmund University, Experimentelle Physik IV

HGF Terascale Kick-Off Meeting vLHC, Würzburg, 24/25 November 2009

Disclaimer:

This is a talk not mainly on prospects for Lepton Flavour Violation @ LHC

but a short summary of our recent activities for LHC and Neutrino Physics

to delimit possibilities within this working group

The Decay Length Method for LHC Physics

Reiner Klingenberg, TU Dortmund University, Experimentelle Physik IV

HGF Terascale Kick-Off Meeting νLHC, Würzburg, 24/25 November 2009

Disclaimer:

This is a talk not mainly on prospects for Lepton Flavour Violation @ LHC

but a short summary of our recent activities for LHC and Neutrino Physics

to delimit possibilities within this working group

The Decay Length Method for LHC Physics

top quark ⇒ SUSY stop ⇒ LFV

Reiner Klingenberg, TU Dortmund University, Experimentelle Physik IV

HGF Terascale Kick-Off Meeting νLHC, Würzburg, 24/25 November 2009

Disclaimer:

This is a talk not mainly on prospects for Lepton Flavour Violation @ LHC

but a short summary of our recent activities for LHC and Neutrino Physics

to delimit possibilities within this working group

The Decay Length Method for LHC Physics

top quark ⇒ SUSY stop ⇒ LFV

(Search for Majorana Neutrinos in CdZnTe)

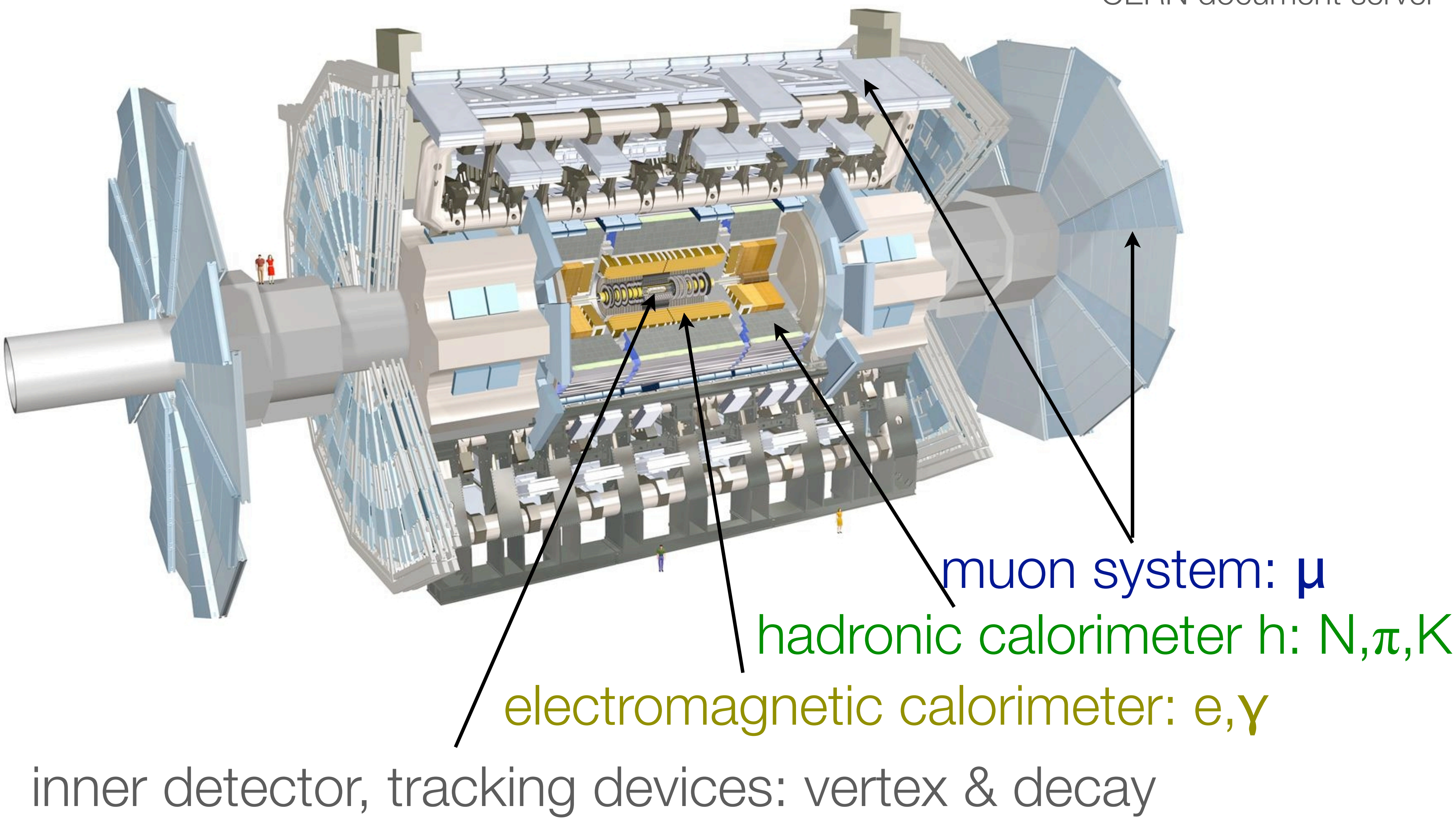
Reiner Klingenberg, TU Dortmund University, Experimentelle Physik IV

HGF Terascale Kick-Off Meeting vLHC, Würzburg, 24/25 November 2009

Activities at Experimentelle Physik IV, TU Dortmund

- Within the ATLAS collaboration
- Main activities so far:
  - ATLAS pixel detector, sensor, modules, comissioning
  - Analysis preparation, top quark physics, SUSY (stop)
- Within the COBRA collaboration
  - Search for neutrinoless double beta decay, Majorana neutrinos, LFV

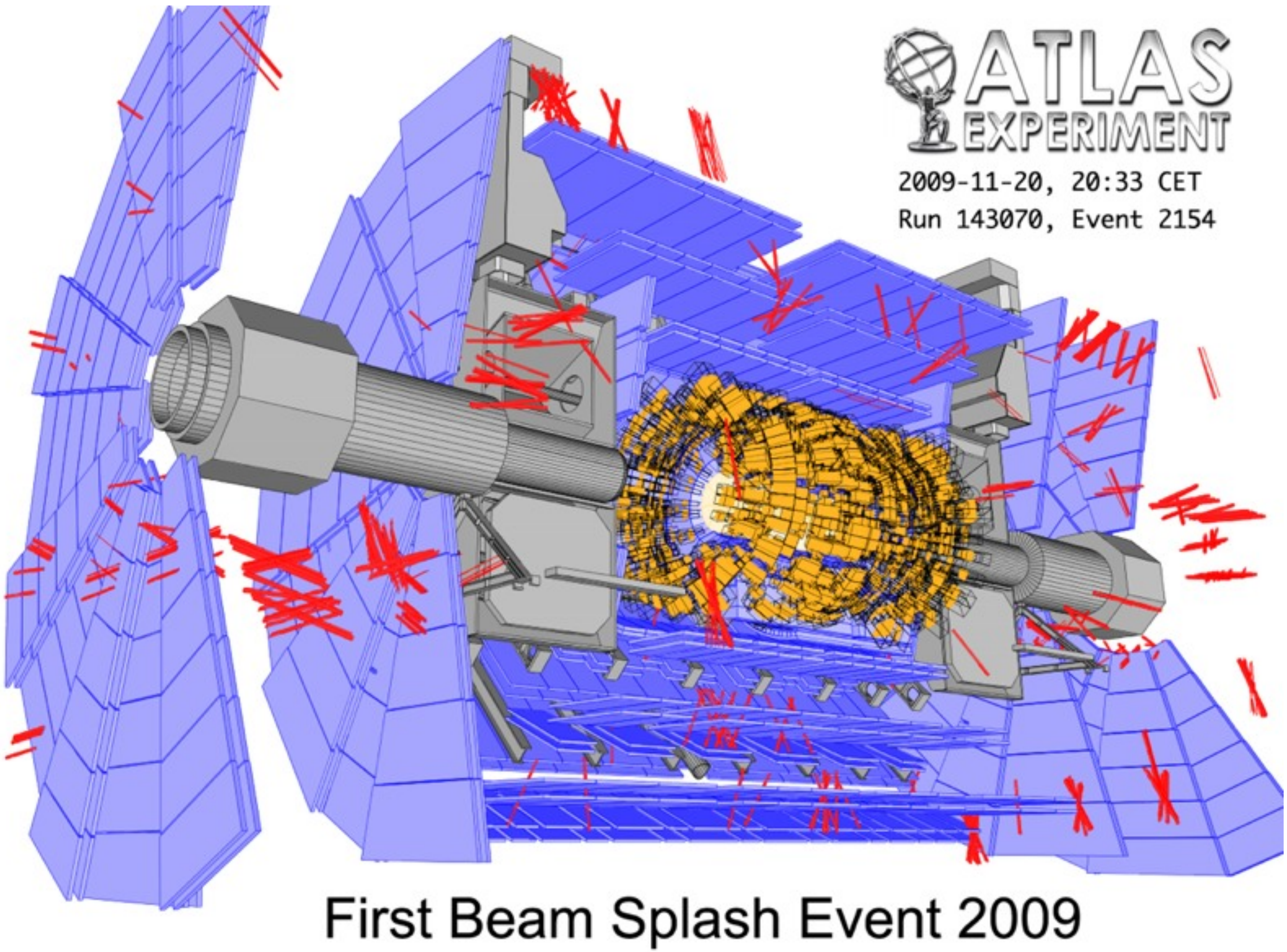
ATLAS Detector @ CERN-LHC



CERN document server

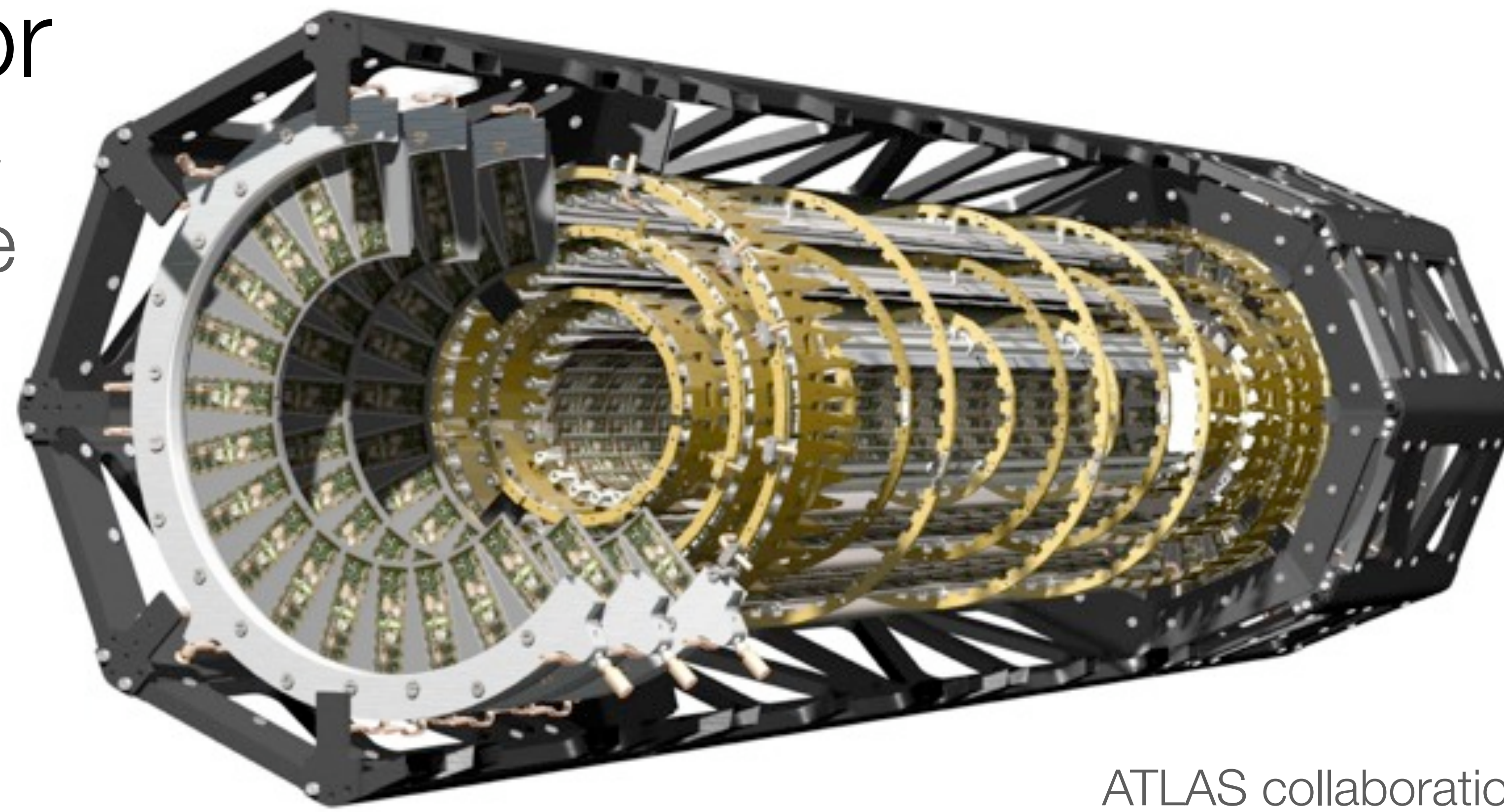
ATLAS Detector @ CERN-LHC

http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html



ATLAS Pixel Detector

as tracking & vertex device



ATLAS collaboration
The ATLAS Experiment at the
CERN Large Hadron Collider
JINST 3 S08003 (2008)

- barrel and disc geometry
  pseudo-rapidity $|\eta|<2.5$

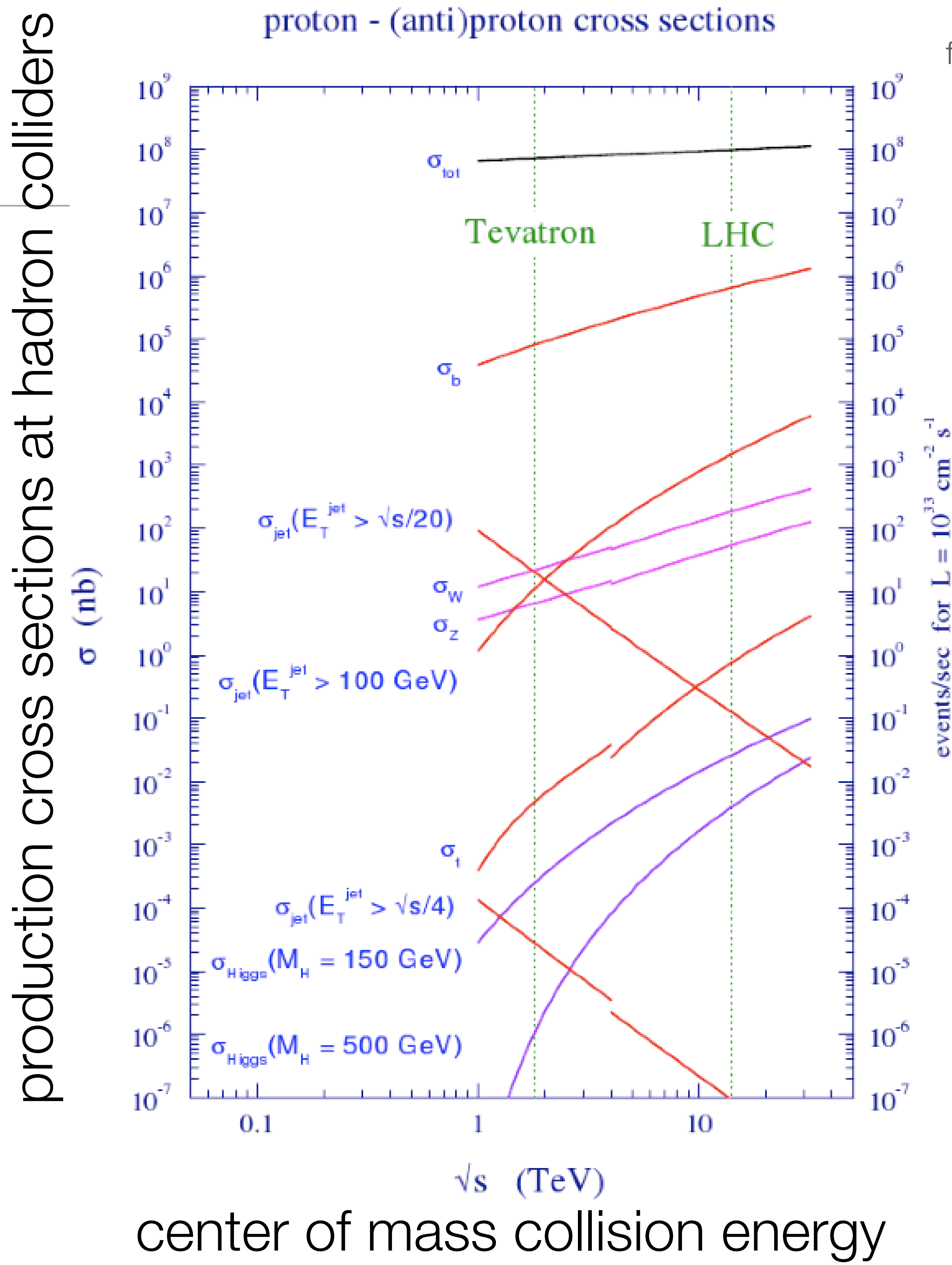
- pixels of 50 µm x 400 µm
  80 million read-out channels

- vertex resolution < 20 µm

- vertex and secondary vertex resolution capabilities to determine production verticies in high luminosity environment
  and to determine decay vertices of long-lived (ps) particles,
  e.g. taus, b-hadrons, new physics e.g. in case of long-lived scalar tops

Physics

S. Catani, Aspects of QCD, from the Tevatron to the LHC
arXiv:hep-ph/0005233



expected event rate (per second)

@ 10^{33} cm^{-2} s^{-1}
(@ 1 nb^{-1} s^{-1})

standard model physics

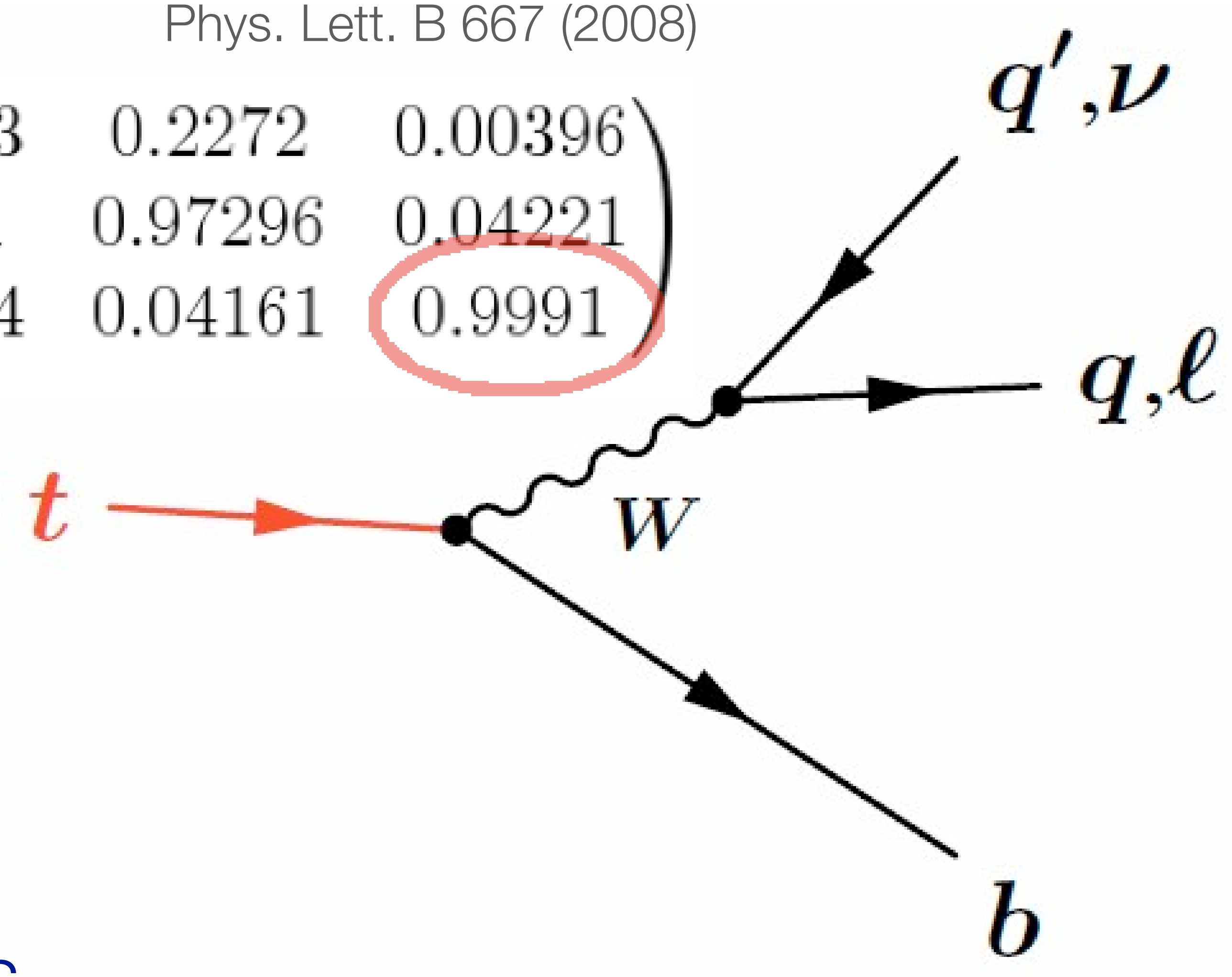
top quark

new particles

Decay Length Method
Decay of Top Quarks

PDG, Review of Particle Physics
Phys. Lett. B 667 (2008)

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}| \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}| & |V_{ts}| & |V_{tb}| \end{pmatrix} = \begin{pmatrix} 0.97383 & 0.2272 & 0.00396 \\ 0.2271 & 0.97296 & 0.04221 \\ 0.00814 & 0.04161 & 0.9991 \end{pmatrix}$$



W delivers either quark- or lepton pairs

b quark is a characteristics of the top quark decay

Detection & Identification of Top Quarks

M. Bunse, TU Dortmund

- e.g. in the so-called 1-lepton channel

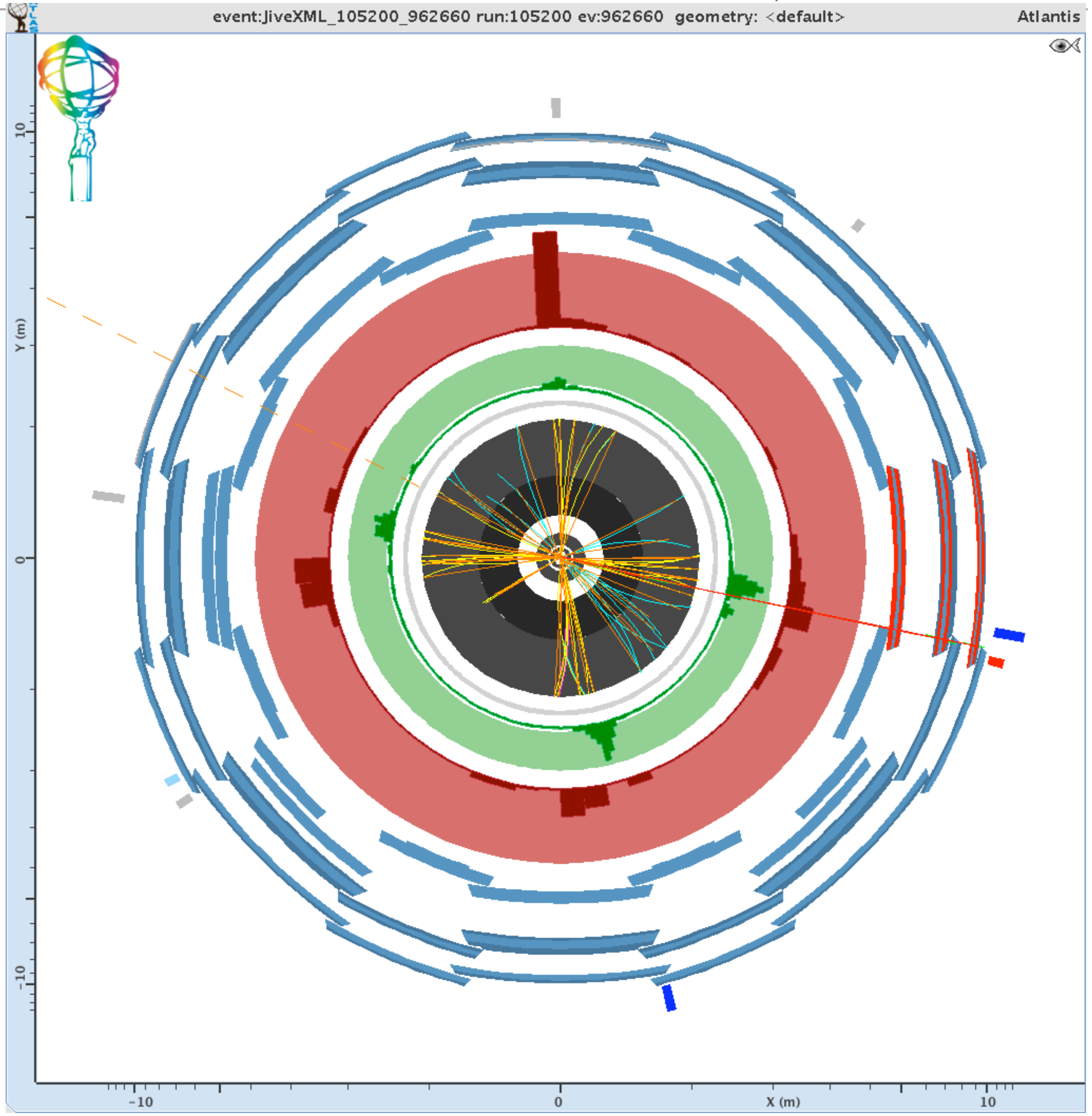
  $pp \rightarrow t\bar{t} \rightarrow \mu\nu bjjb$

- signature:

  4 jets (2j+2b)

  \+ 1 myon

  \+ missing energy



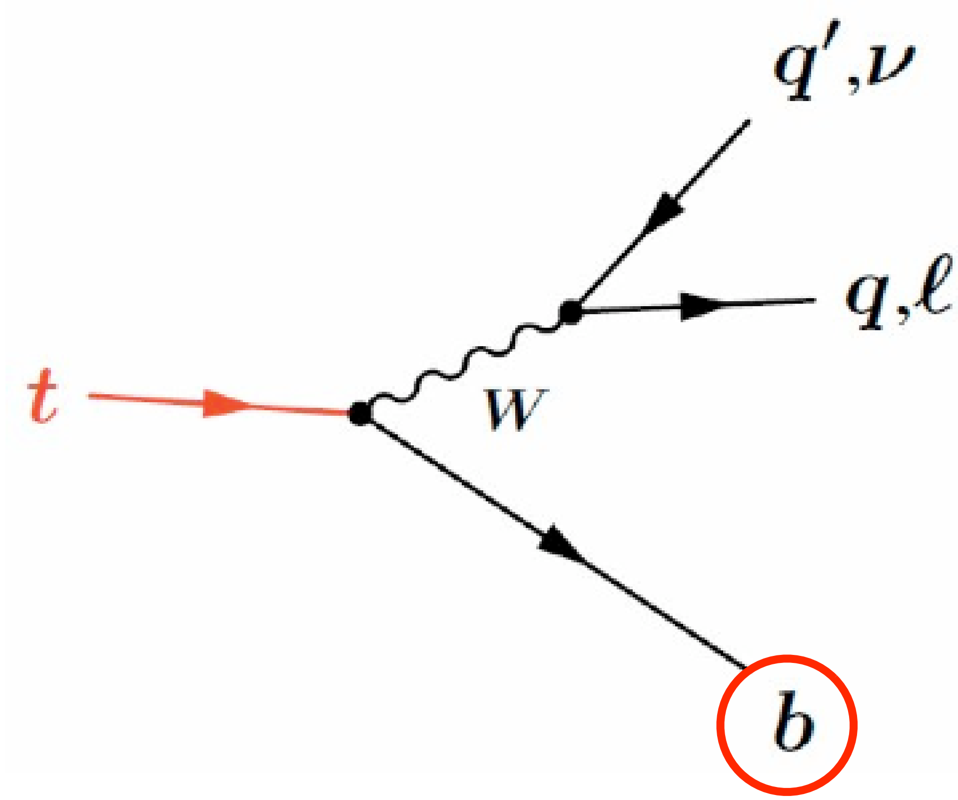
Decay Length Method applied to top quark decays

- b hadron receives boost
  due to mass (energy) of the top quark

$$\gamma_b \approx \frac{1}{2}\frac{m_t^2 + m_b^2 - m_W^2}{m_b m_t}$$

- Life time and decay length
  of b hadron will receive dilatation

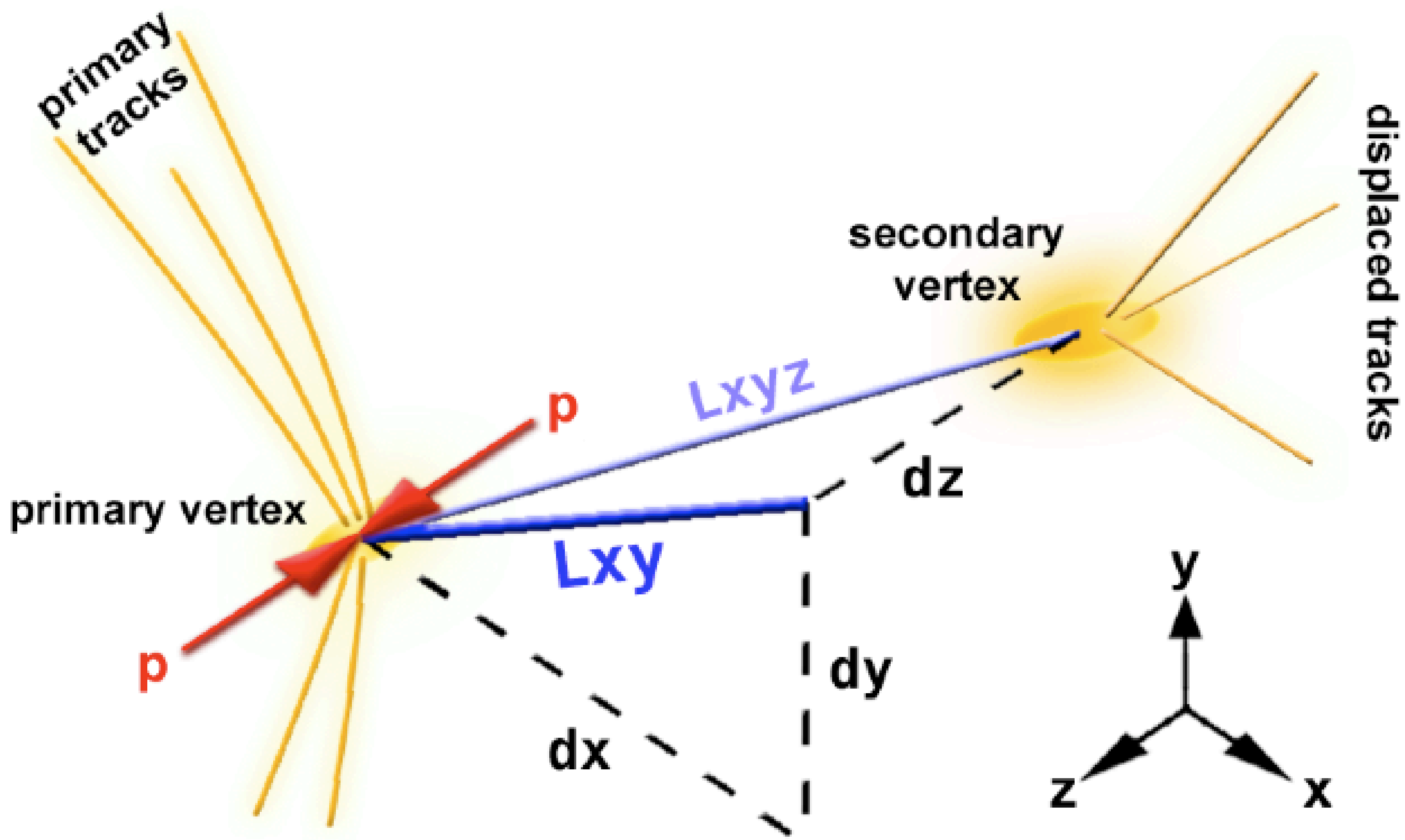
$$L_b = c\tau_b\beta_b\gamma_b$$



C. S. Hill, J. R. Incandela, J. M. Lamb: Method for measurement of the top quark mass using the mean decay length of b hadrons in tT events Phys. Rev. D 71 (2005) 054029

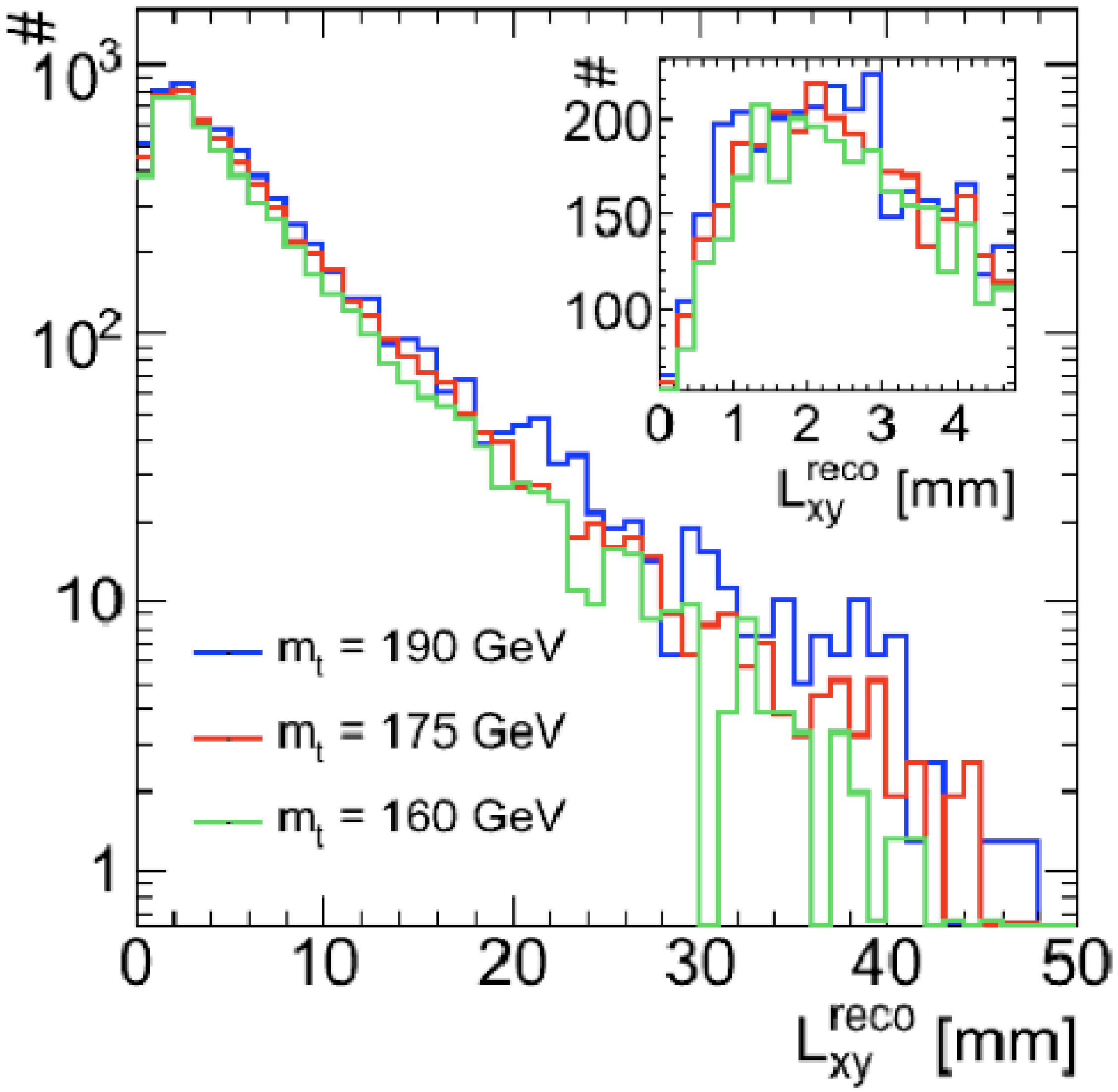
Experimental Observal:
Measurement of the (transverse) Decay Length

J. Walbersloh, TU Dortmund

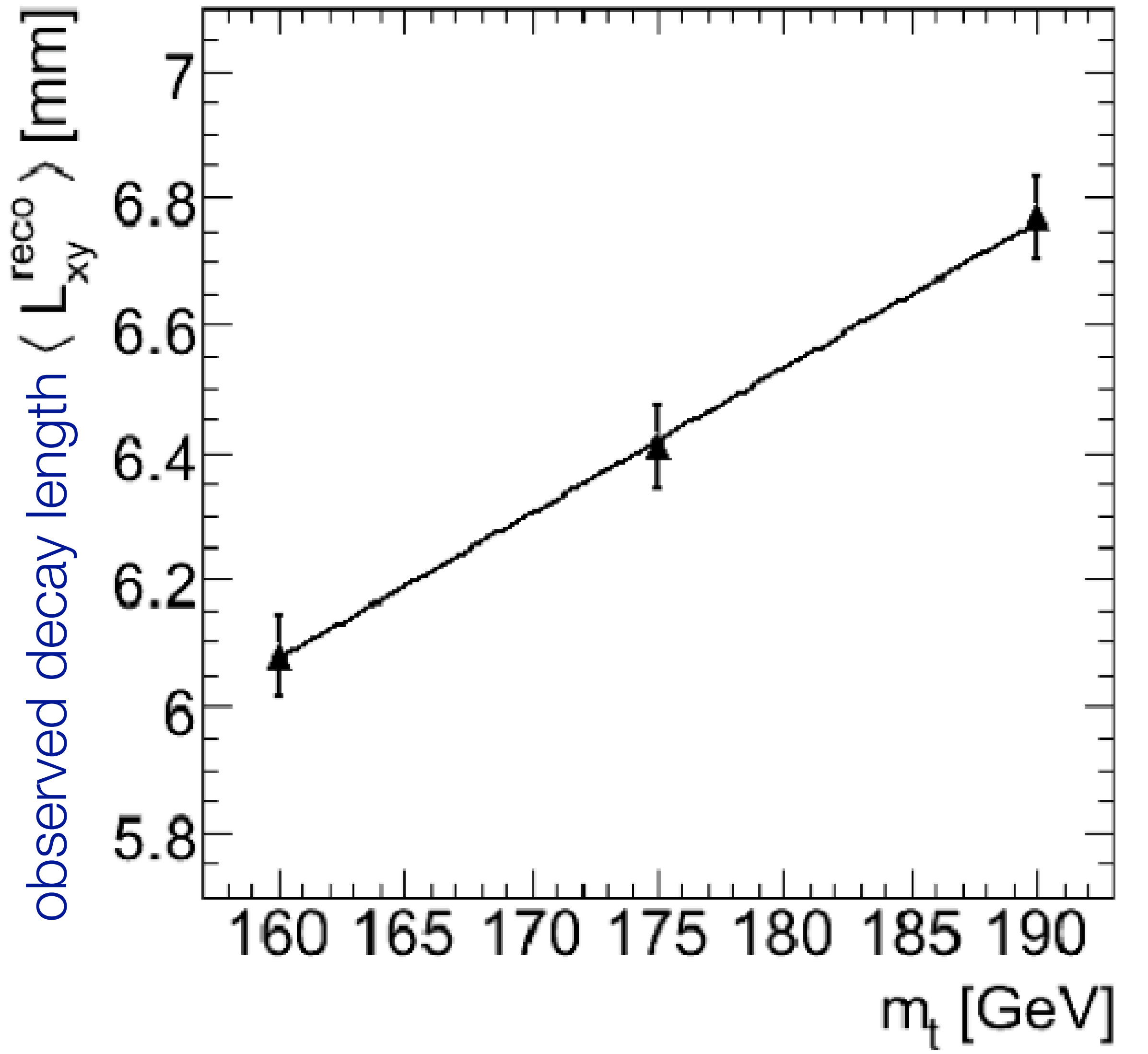


Mass Estimator for Top Quarks

J. Walbersloh, PhD Thesis TU Dortmund (2009)



distribution of b decay lengths emerging from top quarks



assumed mass of the top quark

FERMILAB-TM-2427-E
TEVEWWG/top 2009/03
CDF Note 9717
DØ Note 5899
March 2009

Summary of Mass Determination Methods

J. Walbersloh, PhD Thesis TU Dortmund (2009) (ATLAS)

Comparison of the systematic uncertainty estimates for the χ^2 minimization and the decay length method.

systematic uncertainty	Δm_t [GeV] @ $m_t = 175$ GeV $\langle L_{xy} \rangle$	χ^2 minimization
b-tagging	$+3.62/-3.02$	n.a.
jet energy scale	negligible	3.5
B-hadron lifetime	± 0.96	n.a.
b-fragmentation	$+1.00/-0.88$	0.1
ISR/FSR	± 4.94	0.3
total	$+6.27/-5.93$	3.5

complemantarity of methods and systematics

FERMILAB-TM-2427-E
TEVEWWG/top 2009/03
CDF Note 9717
DØ Note 5899

Summary of Mass Determination Methods

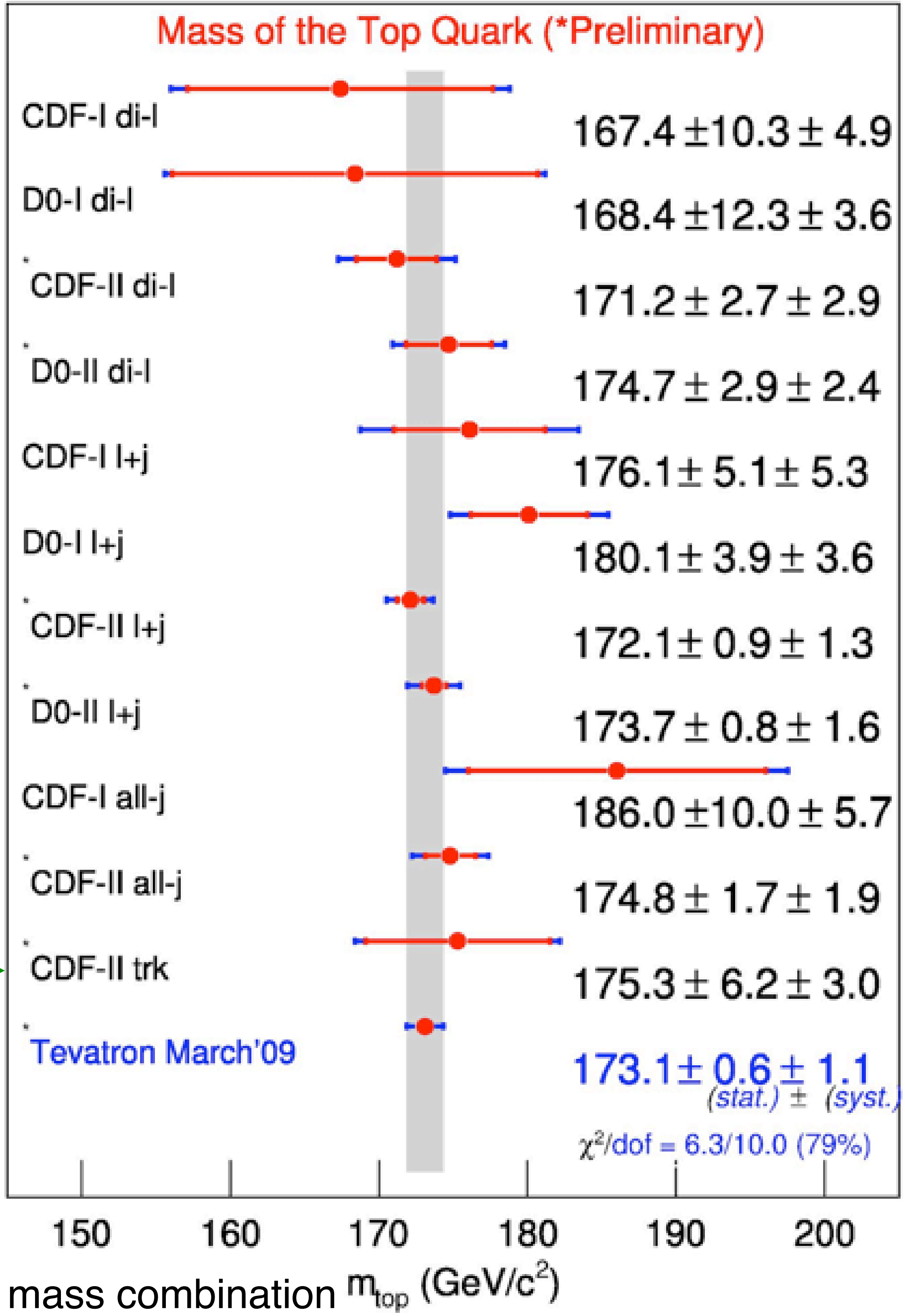
J. Walbersloh, PhD Thesis TU Dortmund (2009) (ATLAS)

Comparison of the systematic uncertainty estimates for the χ^2 minimization and the decay length method.

systematic uncertainty	Δm_t [GeV] @ $m_t = 175$ GeV $\langle L_{xy}\rangle$	χ^2 minimization
b-tagging	$+3.62/-3.02$	n.a.
jet energy scale	negligible	3.5
B-hadron lifetime	± 0.96	n.a.
b-fragmentation	$+1.00/-0.88$	0.1
ISR/FSR	± 4.94	0.3
total	$+6.27/-5.93$	3.5

decay length method @ CDF/Tevatron

complamantarity of methods and systematics



arXiv:0903.2503

World average top mass combination

Application of the Decay Length Method for Minimal Flavour Violation of MSSM

(Ambrosi et al: Nucl. Phys. B 645 (2002) 155)

- MFV: dynamics of flavour changing with quarks and scalar quarks is completely determined by ordinary quark Yukawa couplings
- within MSSM: highly degenerated 1st and 2nd generation of squarks, and small, CKM suppressed mixing to the 3rd generaton
- to prove: study mass hierarchy ⇔ hierarchy of Yukawa coupling

  could get long-lived sparticles, detectable in the order milimeter

Application of the Decay Length Method for Minimal Flavour Violation of MSSM

(Ambrosi et al: Nucl. Phys. B 645 (2002) 155)

- MFV: dynamics of flavour changing with quarks and scalar quarks is completely determined by ordinary quark Yukawa couplings

- within MSSM: highly degenerated 1st and 2nd generation of squarks, and small, CKM suppressed mixing to the 3rd generaton

- to prove: study mass hierarchy ⇔ hierarchy of Yukawa coupling

  could get long-lived sparticles, detectable in the order milimeter

(Hiller et al.: arXiv:0910.2124v1, arXiv:0802.0916v1)

- expect large mass splitting between $\tilde{t}_1$ and $\tilde{t}_2$ due to large L-R mass mixing

- flavour diagonal decay channels are suppressed or forbidden

- stop quark $\tilde{t}_1$ decays CKM suppressed via flavour changing neutral current loop decay into charm and lightest neutralino

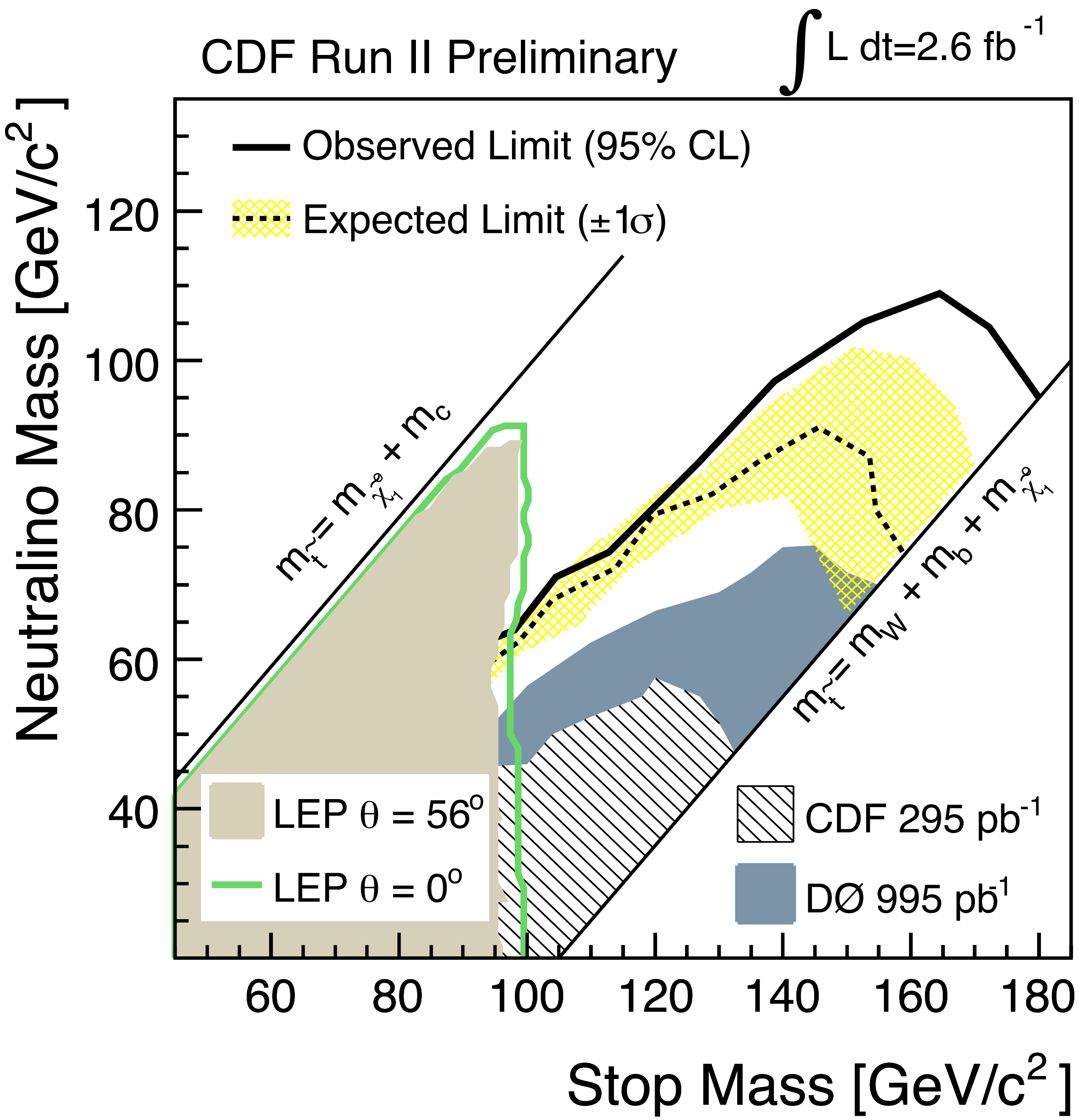
$$\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 \qquad \Gamma \approx \frac{m_{\tilde{t}_1} Y^2}{4\pi}\left(\frac{\Delta m}{m_{\tilde{t}_1}}\right)^2 \qquad \tau = \frac{1}{\Gamma} \approx \mathcal{O}\left(1...10\,\mathrm{ps}\right)$$

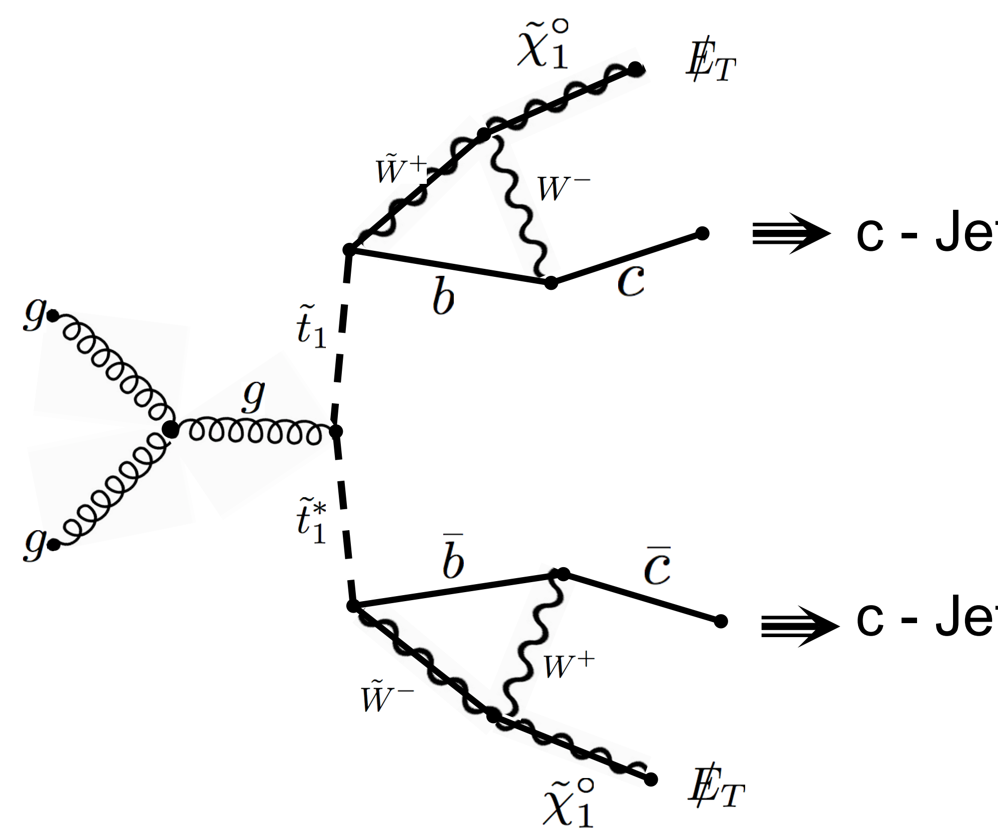
$$\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \leq 5...10\,\mathrm{GeV} \qquad m_{\tilde{t}_1} \approx m_{\tilde{\chi}_1^0} \approx 100\,\mathrm{GeV} \qquad Y \approx \mathcal{O}\left(10^{-5}\right)$$

Experimental Status for Light Scalar Tops

Relation between neutralino and stop masses

CDF Note 9834

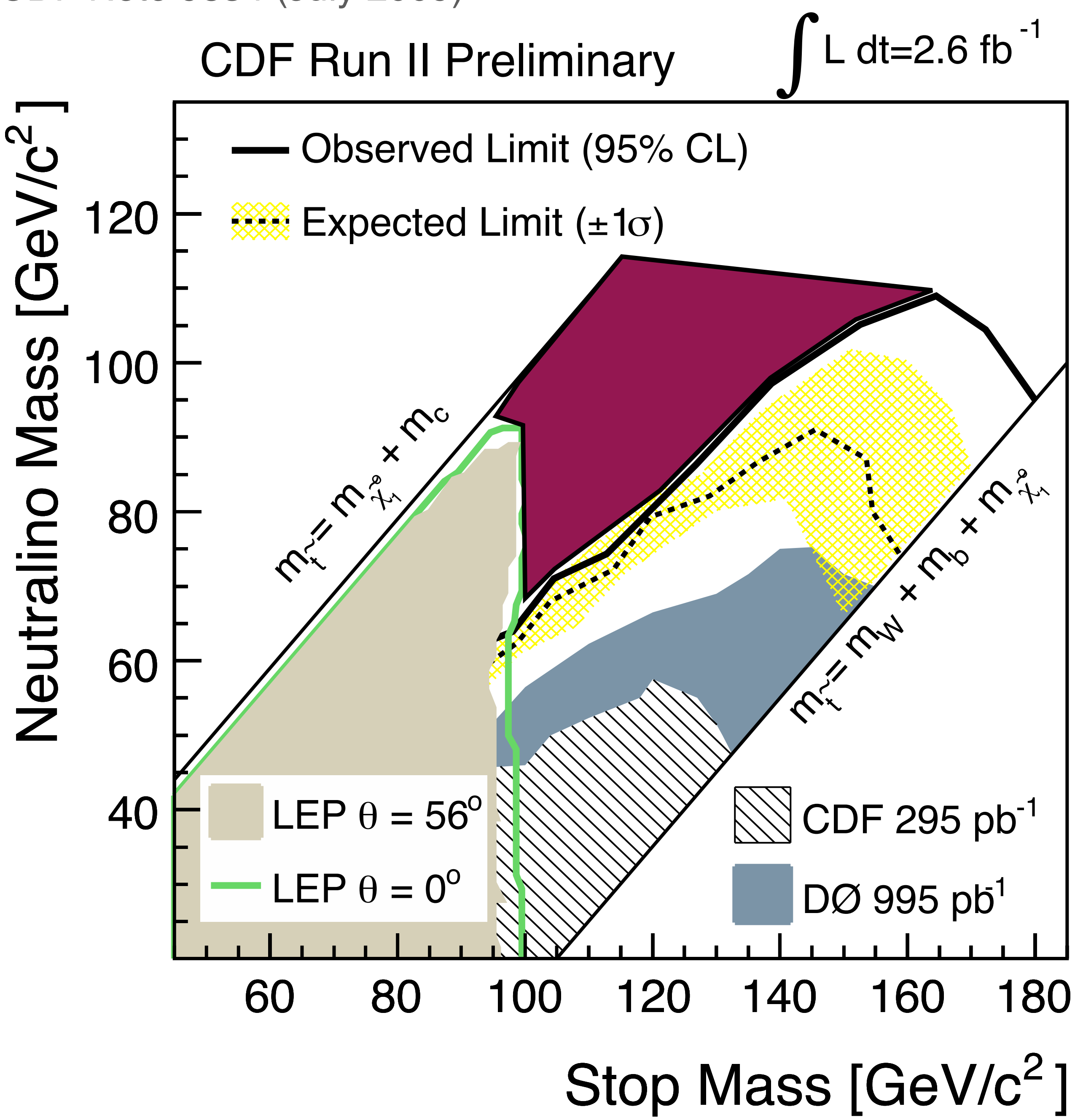




Experimental Status for Light Scalar Tops

Relation between neutralino and stop masses

CDF Note 9834 (July 2009)



not excluded yet

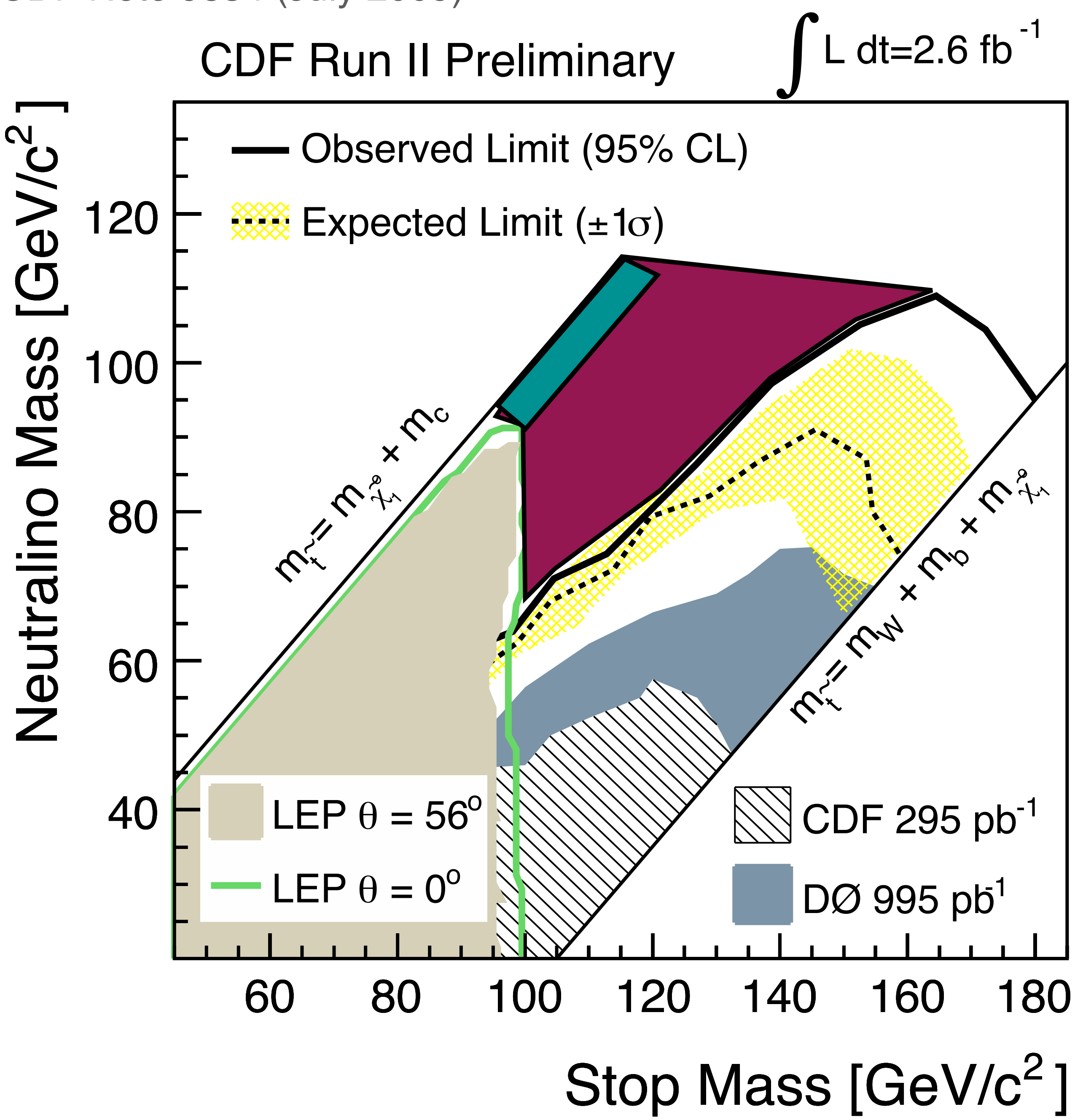
there is still a potential for light stops

if light stops indeed would exist, this could be an area to test Minimal Flavour Violation in MSSM by looking for long-lived scalar top quarks

Experimental Status for Light Scalar Tops

Relation between neutralino and stop masses

CDF Note 9834 (July 2009)



not excluded yet

there is still a potential for light stops

if light stops indeed would exist, this could be an area to test Minimal Flavour Violation in MSSM by looking for long-lived scalar top quarks

region for long-lived scalar tops

Long-lived Stops & Minimal Flavour Violation SUSY

G. Hiller, Y. Nir: Measuring Flavour Mixing with Minimal Flavour Violation at the LHC, arXiv:0802.0916 [hep-ph]

G. Hiller, JS Kim, H. Sedello: Collider Signatures of Minimal Flavour Mixing from Stop Decay Length Measurements, arXiv:0910.2124 [hep-ph]

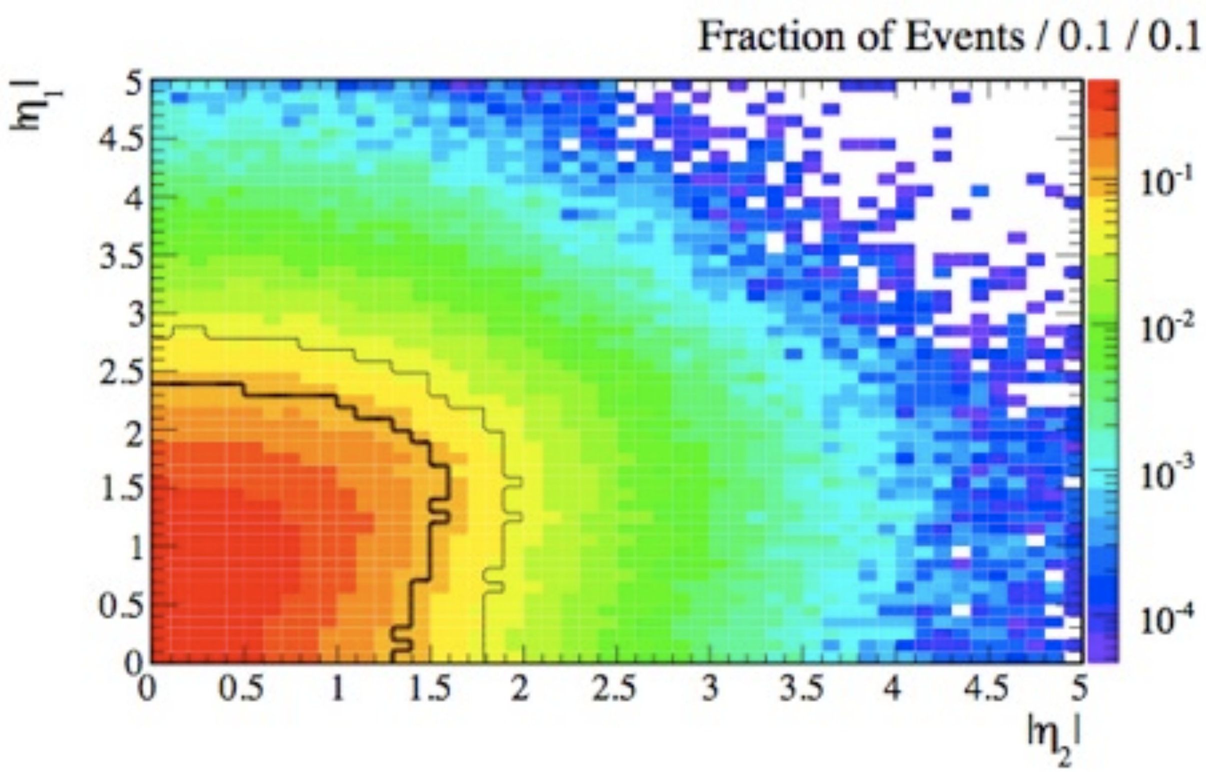


FIG. 2: The pseudo-rapidity distribution of the two stops at the LHC in processes Eq. (4) for $m_{\tilde{t}} = 100$ GeV and $m_{\tilde{g}} = 500$ GeV. In all shown events both stops satisfy $\gamma\beta > 1$. The thick (thin) contour contains 80% (90%) of the events shown.

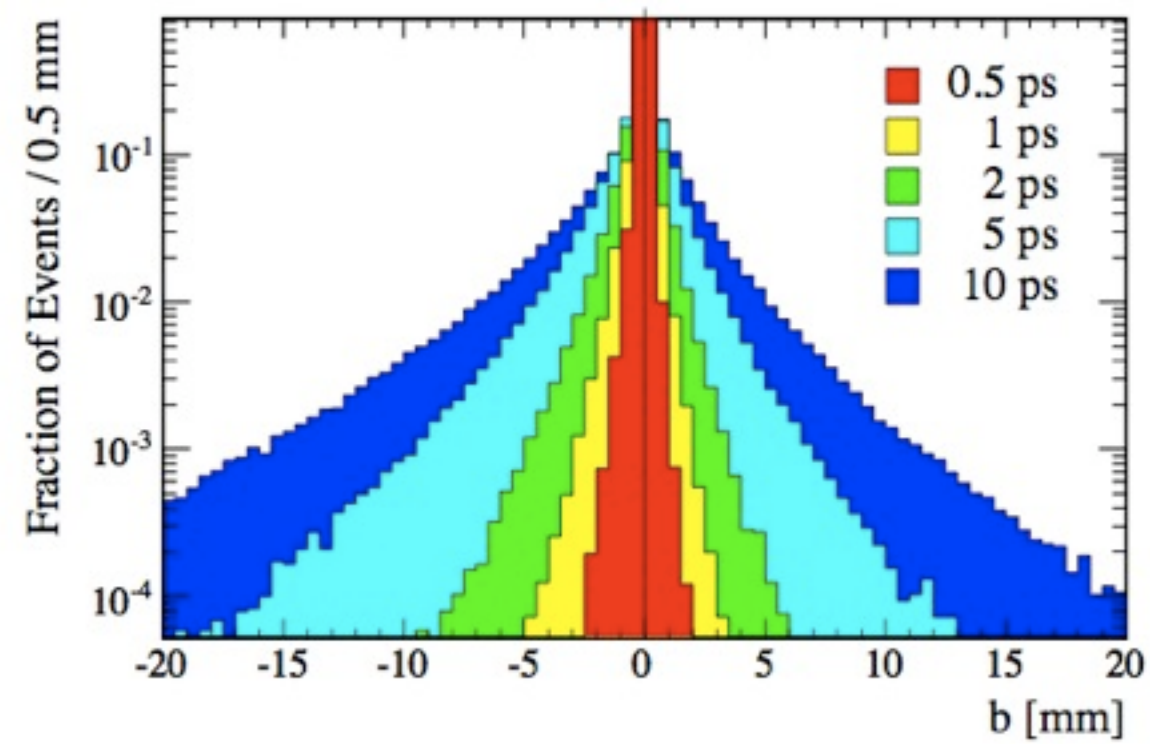
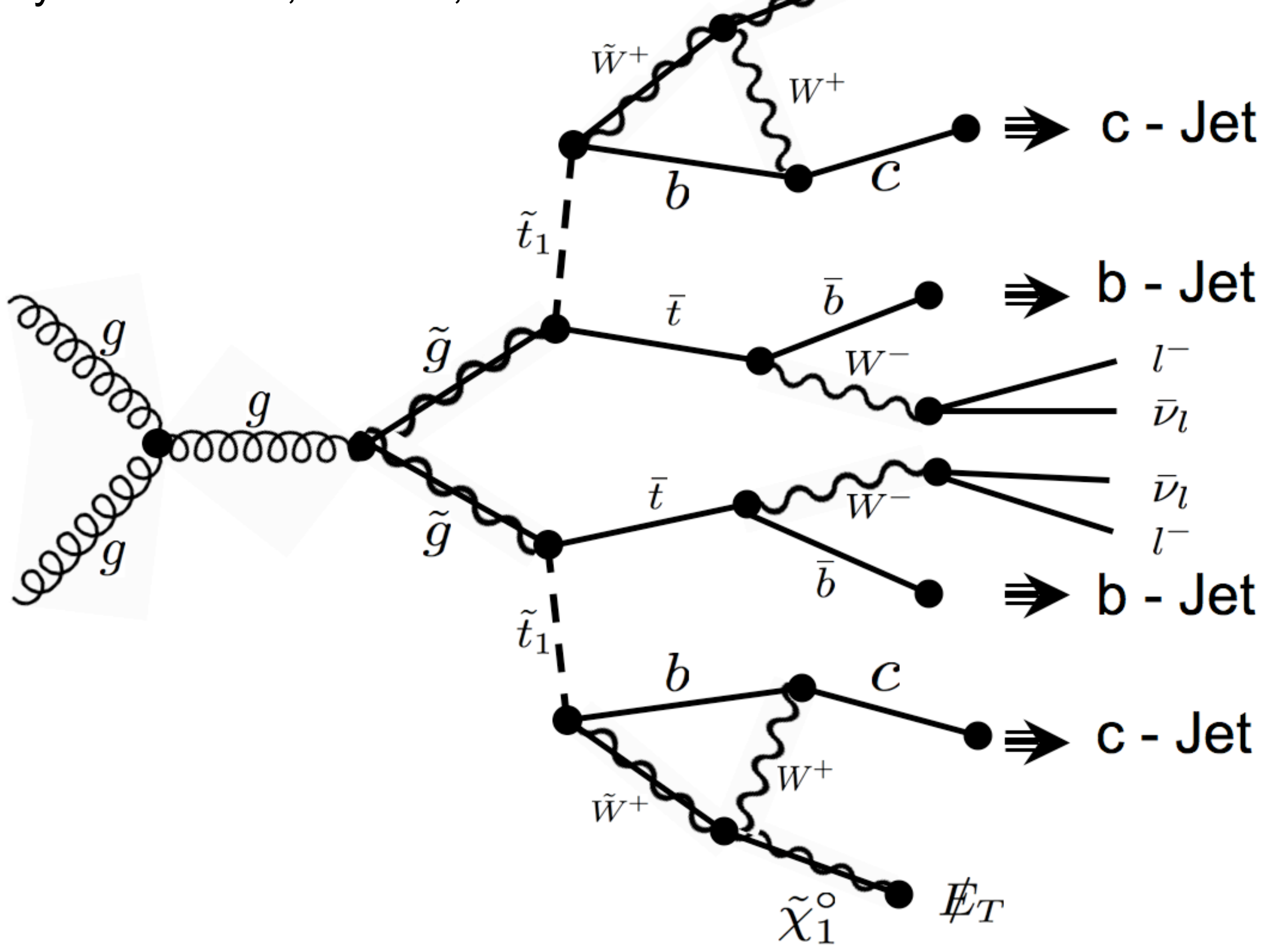


FIG. 4: The distribution of impact parameters b_i in mm at the LHC in processes Eq. (4) for different stop lifetimes. The curves with $b_i > 0(< 0)$ refer to the stop in each event with larger (smaller) charm p_T.

Potential Experimental Signature: Light Stops Associated with Same Sign Leptons

Kraml, Raklev
Phys. Rev. D 73, 075002, 2006



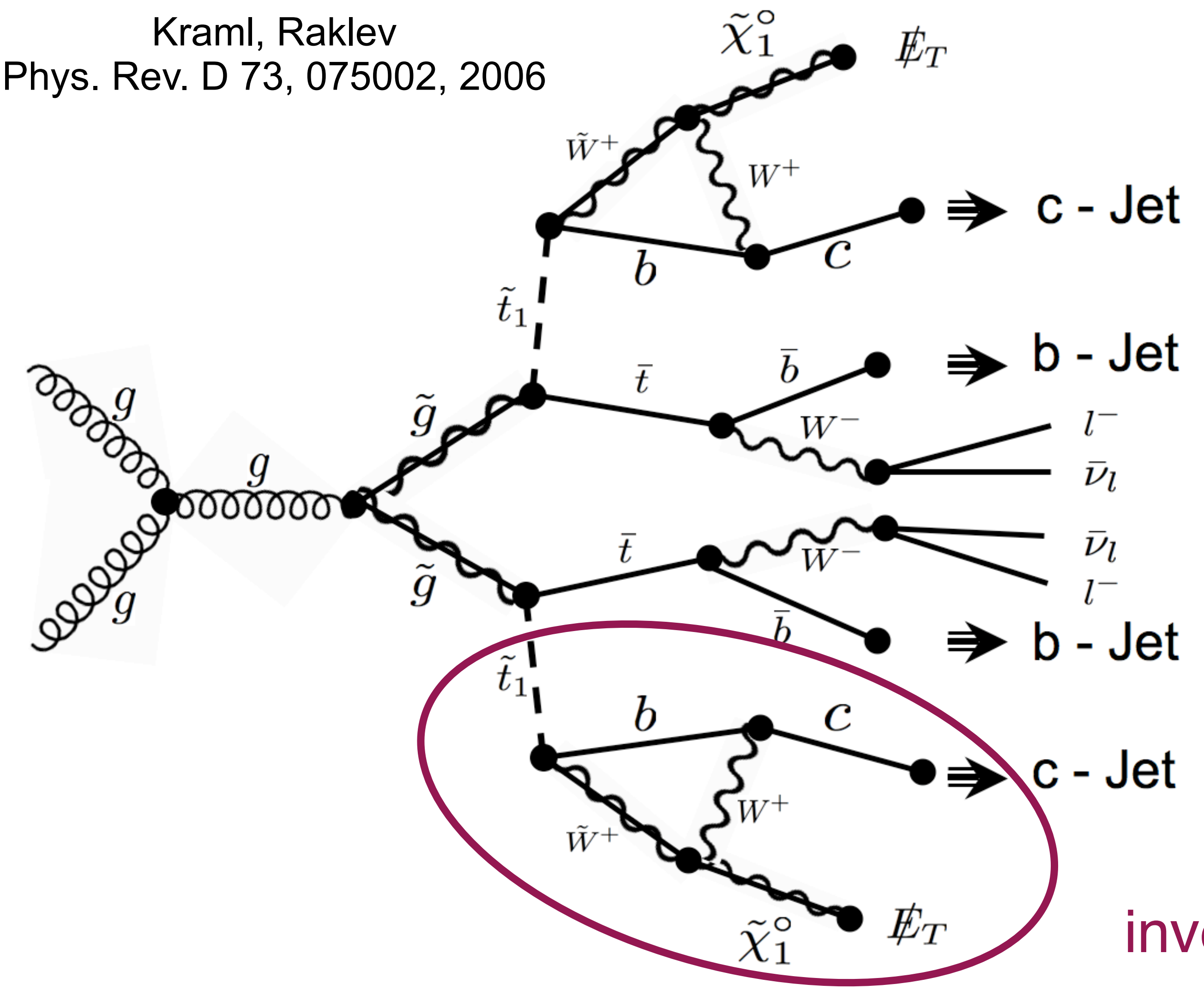
Majorana gluinos with
$m_{\tilde g} > m_{\tilde t_1} + m_t$

4 different final states:
$\tilde g\tilde g \to t\bar t\tilde t_1\tilde t_1^*, tt\tilde t_1^*\tilde t_1^*, \bar t\bar t\tilde t_1\tilde t_1,$
(half of them contain same sign tops and same sign lepton)

event topology:
$\tilde g\tilde g \to bb\,ll + Jets + E_T^{miss}$

Potential Experimental Signature:
Light Stops Associated with Same Sign Leptons

Kraml, Raklev
Phys. Rev. D 73, 075002, 2006



Majorana gluinos with
$m_{\tilde{g}} > m_{\tilde{t}_1} + m_t$

4 different final states:
$\tilde{g}\tilde{g} \rightarrow t\bar{t}\tilde{t}_1\tilde{t}_1^*, tt\tilde{t}_1^*\tilde{t}_1^*, \bar{t}\bar{t}\tilde{t}_1\tilde{t}_1,$
(half of them contain same sign tops and same sign lepton)

event topology:
$\tilde{g}\tilde{g} \rightarrow bb\,ll + Jets + E_T^{miss}$

investigated challenge:
experimental signature
of decay length of stop quarks ~ O(ps)

I. Reisinger, TU Dortmund → ATLAS

handle on stop lifetime, gluino masses and $\tilde{t}_1 - c - \tilde{\chi}_1^0 -$ coupling

background: ttbar, single top, W/Z + Jets, WW, WZ, ZZ, QCD, SUSY, …

Application of the Decay Length Method for Lepton Flavour Violation Studies

- LFV in tau decays, $\tau \rightarrow 3\mu$

Application of the Decay Length Method for Lepton Flavour Violation Studies

- LFV in tau decays, $\tau \rightarrow 3\,\mu$, (see session 4)

- study long lived 

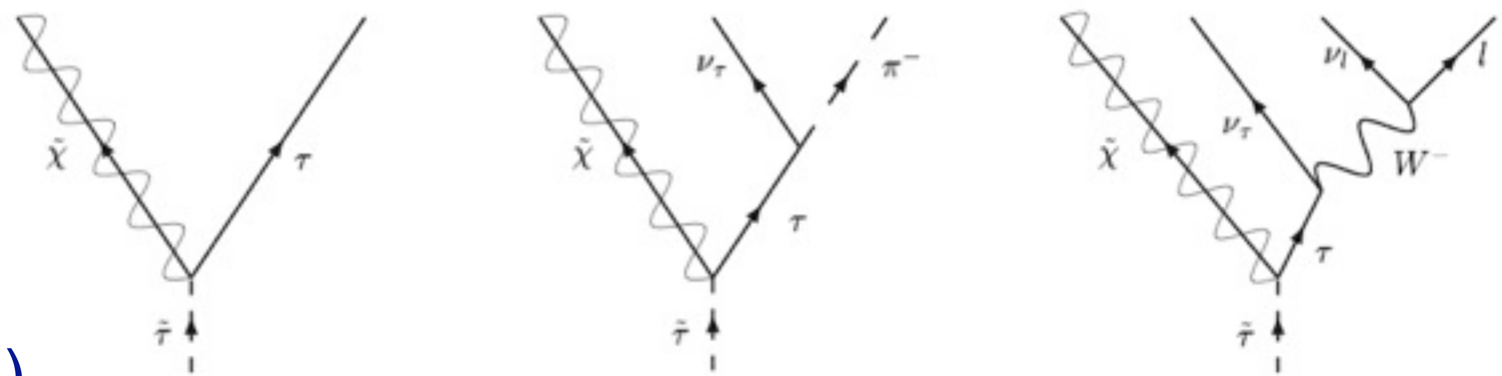
Application of the Decay Length Method for Lepton Flavour Violation Studies

- LFV in tau decays, $\tau \rightarrow 3\,\mu$, (see session 4)
- study long lived

Application of the Decay Length Method for Lepton Flavour Violation Studies

- LFV in tau decays, $\tau \to 3\,\mu$

- study long lived stau NLSP,



(LFV $\phi_{\mathrm{NLSP}} = N_1 \tilde{e} + \sqrt{1 - N_1^2}\tilde{\tau}$)

if lifetime measurement is possible, fraction N_1 of selectron in NLSP could be determined

Long life stau in the minimal supersymmetric standard model
T. Jittoh, J. Sato, T. Shimomura and M. Yamanaka,
arXiv:hep-ph/0512197v2, May 2006

Application of the Decay Length Method for Lepton Flavour Violation Studies

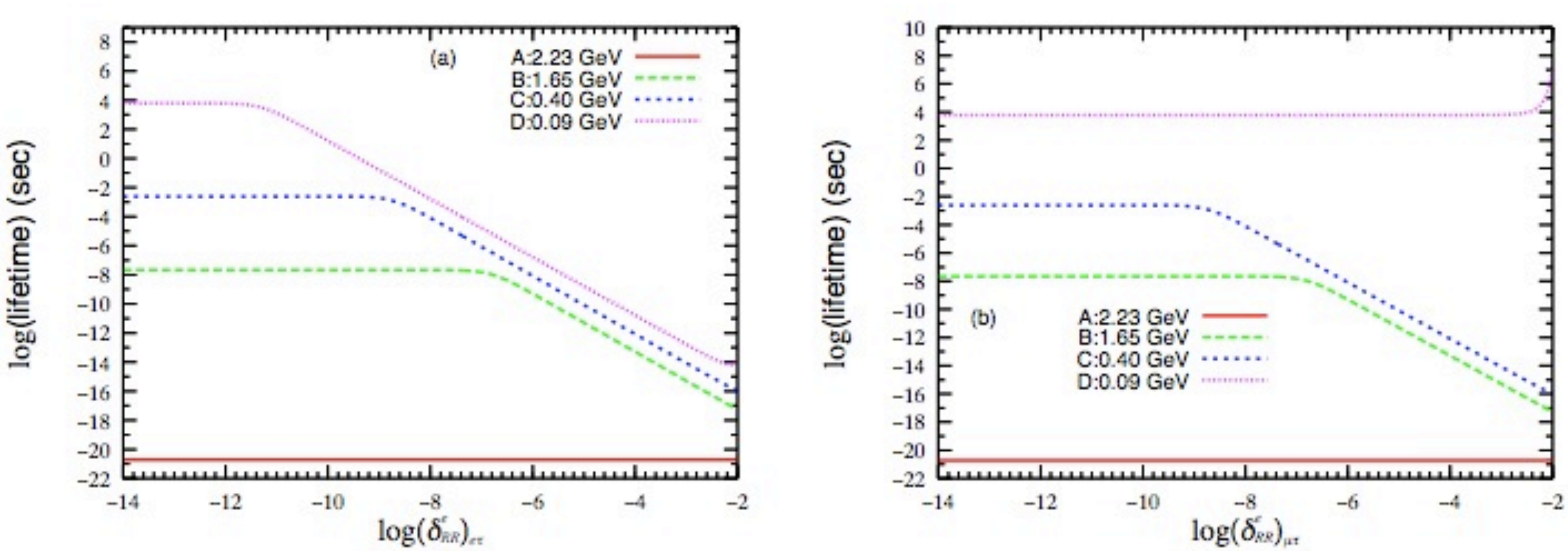
- study long lived stau NLSP,

  estimation of stau life times:

Long-Lived Slepton in the Coannihilation Region and Measurement of Lepton Flavour Violation at LHC
S Kaneko, J Sato, T Shimomura, O Vives and M Yamanaka
Journal of Physics: Conference Series **171** (2009) 012092

Table 1. Table of the mass difference and the lightest slepton, neutralino masses. m_0, A_0 and $\tan\beta$ are fixed to 260 GeV, 600 GeV and 30, respectively. The values of neutralino abundance and a_μ are shown for the reference.

No.	δm (GeV)	$m_{\tilde{\chi}_1^0}$ (GeV)	$m_{\tilde{l}_1}$ (GeV)	$\Omega_{\tilde{\chi}_1^0} h^2$	a_μ ($\times 10^{-10}$)
A	2.227	323.1549	325.3817	0.110	10.32
B	1.650	325.5601	326.2147	0.102	10.25
C	0.407	327.6294	328.0365	0.085	10.09
D	0.092	328.4060	328.4981	0.081	10.06

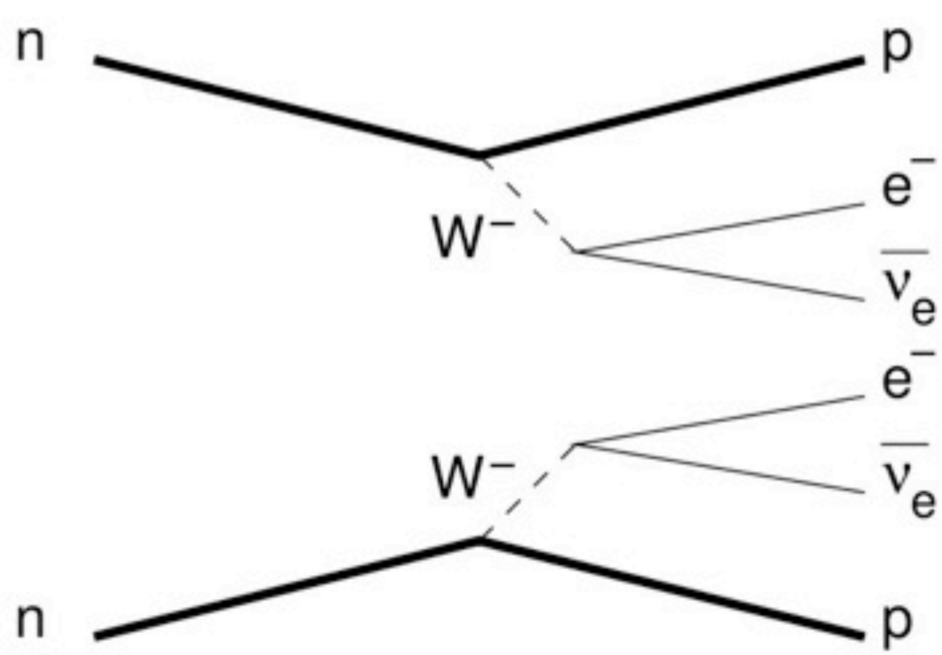


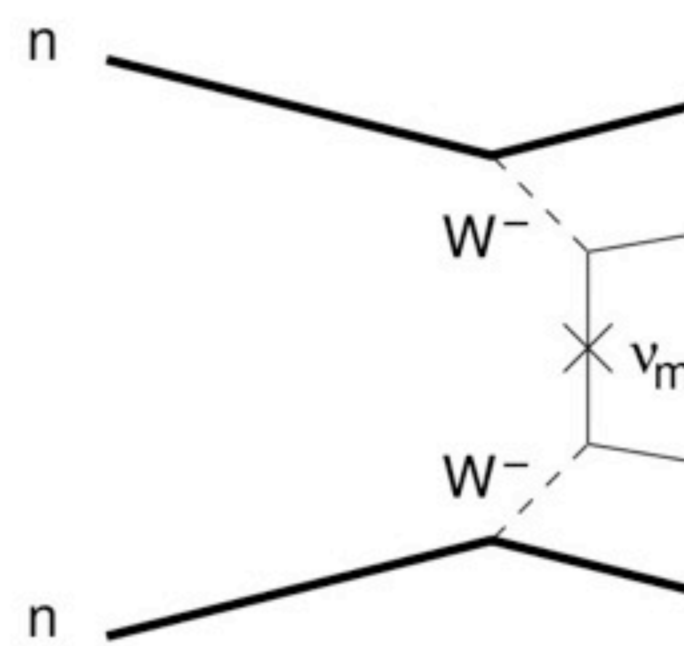
Summary & Conclusion

- opportunities for LFV at LHC
  - it could be interesting to apply a method like the decay length for processes to study parameters of Lepton Flavour Violation
- presently, analysis preparation for ATLAS/LHC and COBRA

Activities

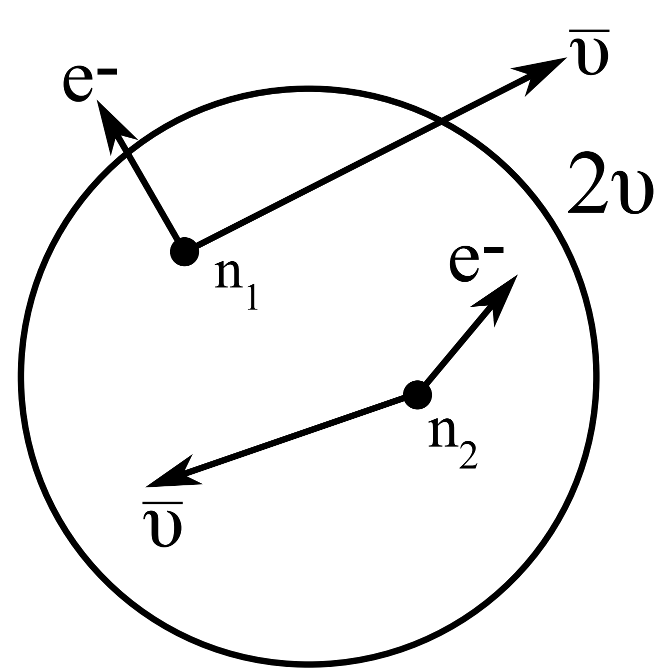
Lepton Flavour Violation and Majorana Neutrinos

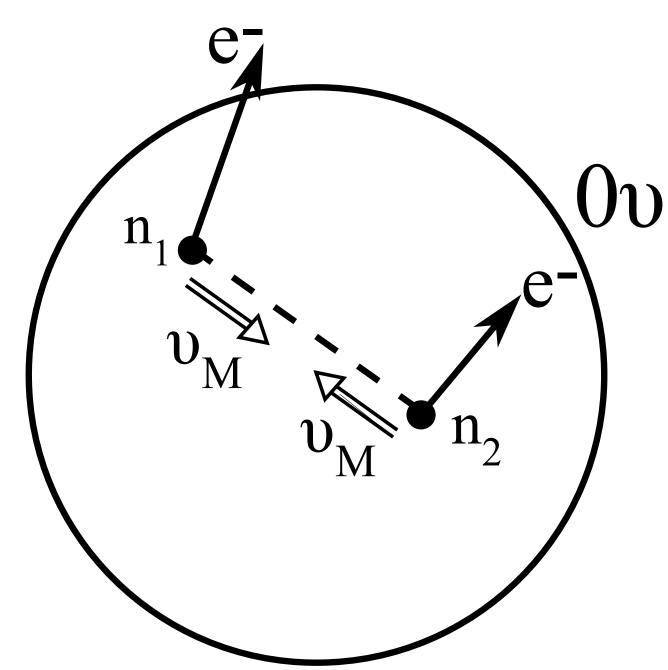




Majorana Neutrino

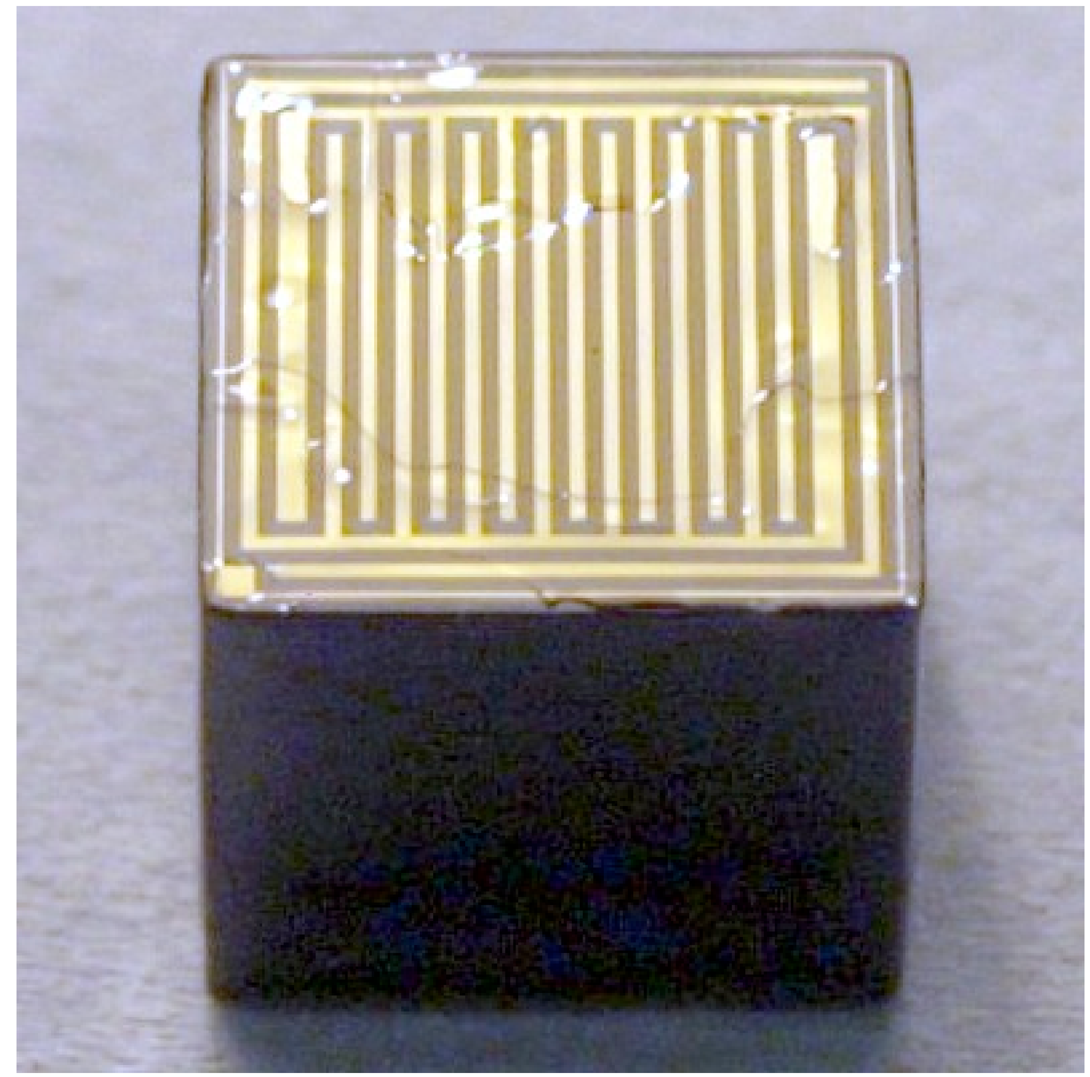
not in the context of LHC
but of a nuclear physics experiment





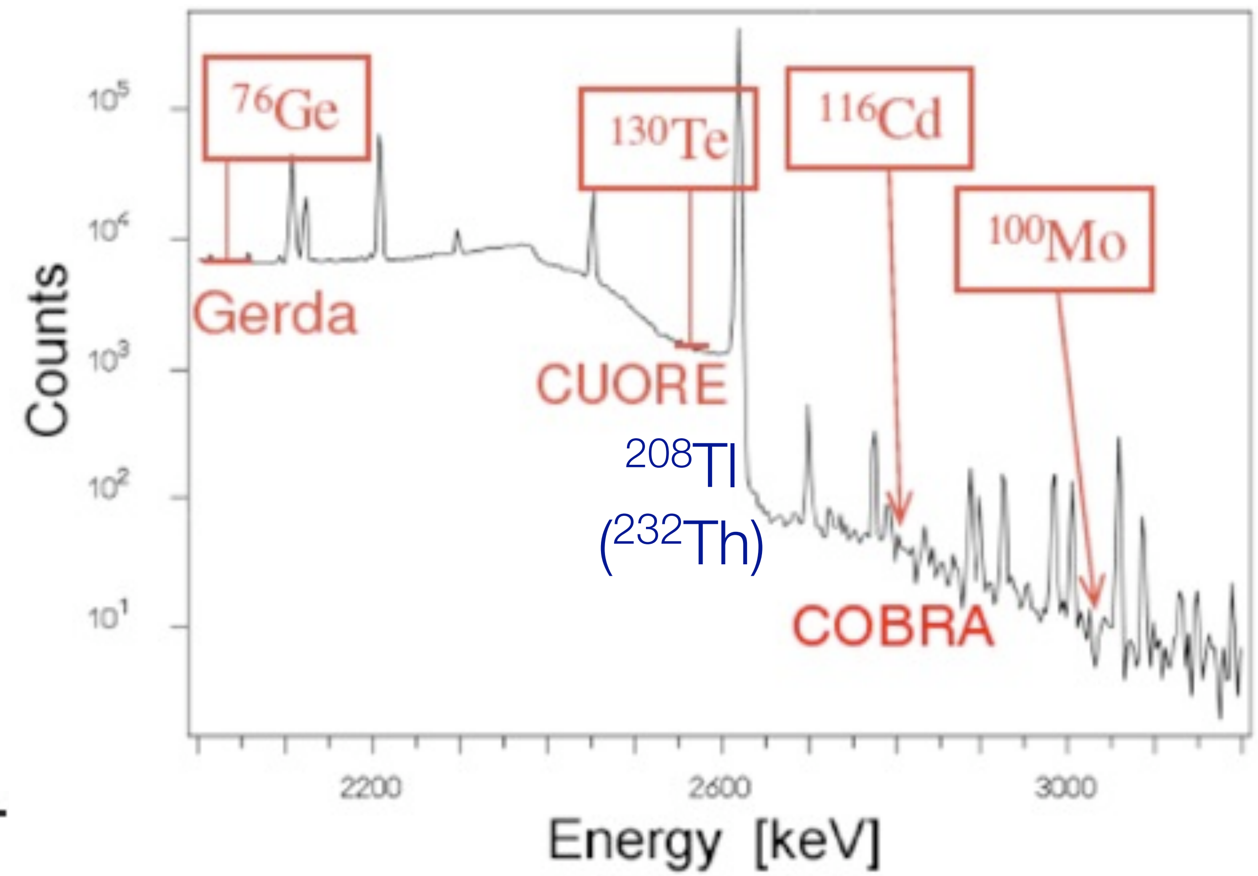
Sketch of the Experimental Set-up

- Search for $0\nu\beta\beta$ signature with CdZnTe semiconductor detectors
- Source = Detector
- Main isotope of interest the $\beta^-\beta^-$ ^{116}Cd
  ($\beta^+\beta^+$ ^{106}Cd)
- Ultra low background experiment
- Experimental sensitivity: $T_{1/2} \sim a\sqrt{\frac{M \cdot t}{B \cdot \Delta E}}$
- abundance *a*, Mass *M*, lifetime *t* (measurement), Background-level *B*, Energy-Resolution ΔE



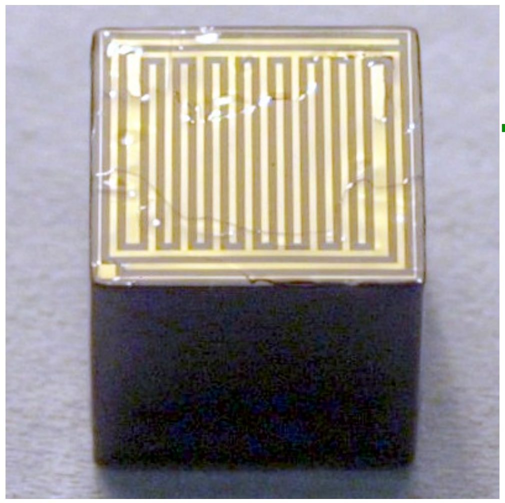
Sketch of the Experimental Set-up

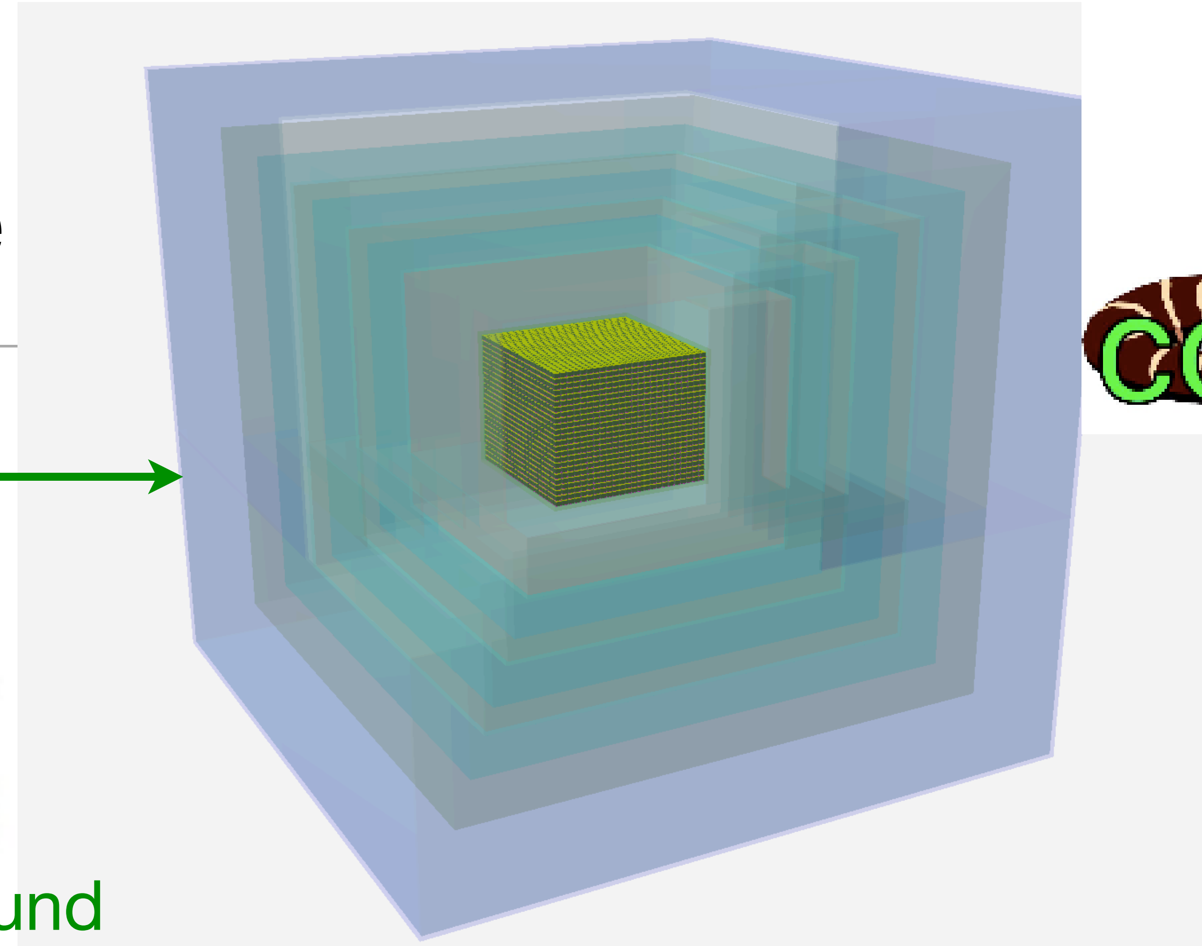
- Search for 0νββ signature with CdZnTe semiconductor detectors
- Source = Detector
- Main isotope of interest the $\beta^-\beta^-$ ^{116}Cd ($\beta^+\beta^+$ ^{106}Cd)



- Ultra low background experiment
- Experimental sensitivity: $T_{1/2} \sim a \sqrt{\frac{M \cdot t}{B \cdot \Delta E}}$
- abundance *a*, Mass *M*, lifetime *t* (measurement), Background-level *B*, Energy-Resolution *ΔE*

Proposal: Large Scale

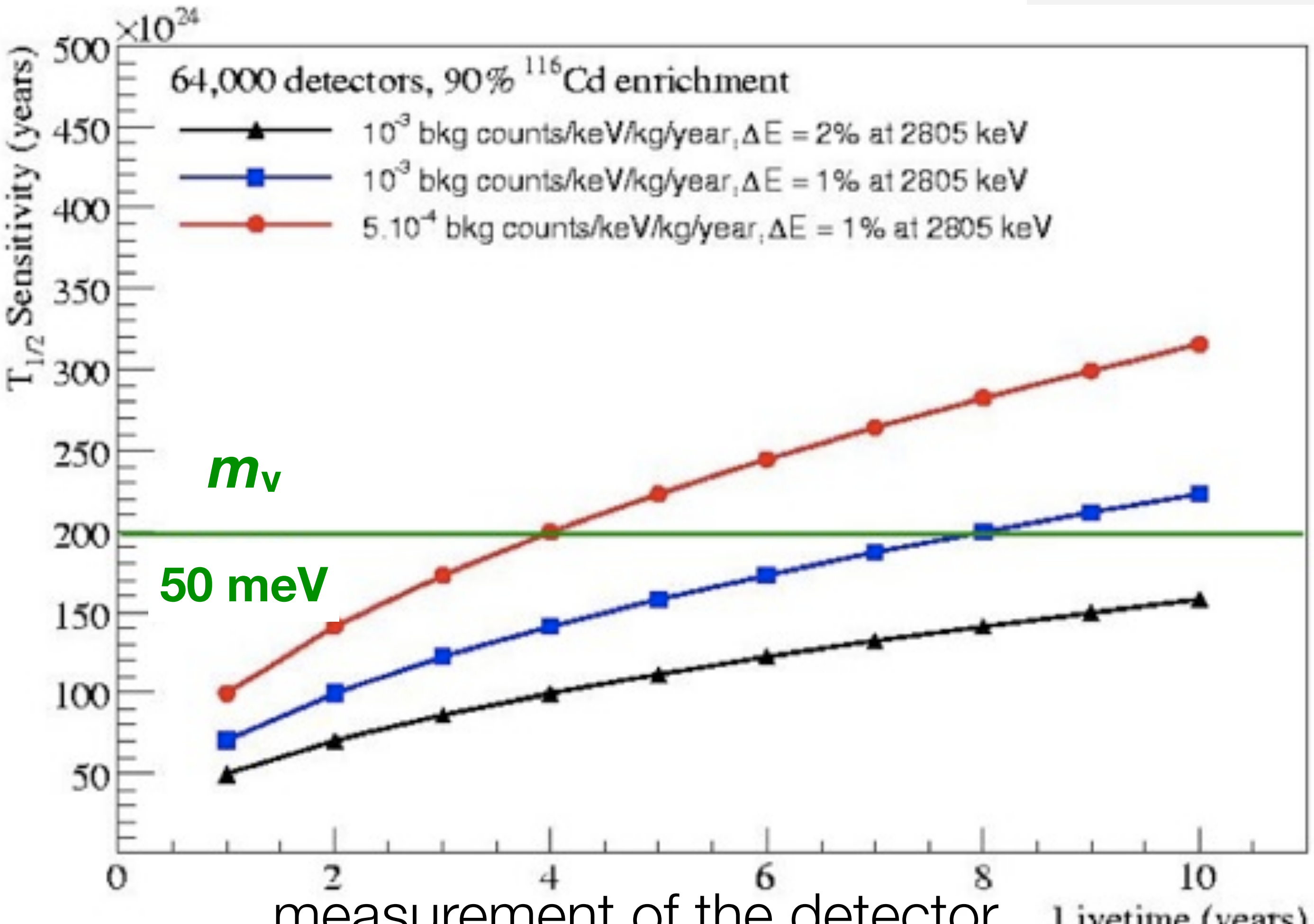




Mass

$$T_{1/2} \sim a \sqrt{\frac{M \cdot t}{B \cdot \Delta E}}$$

Background

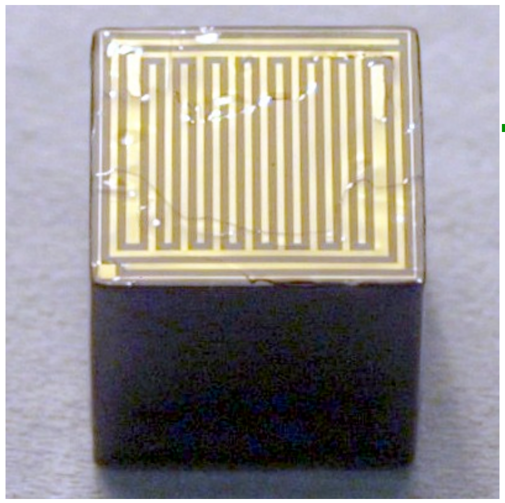


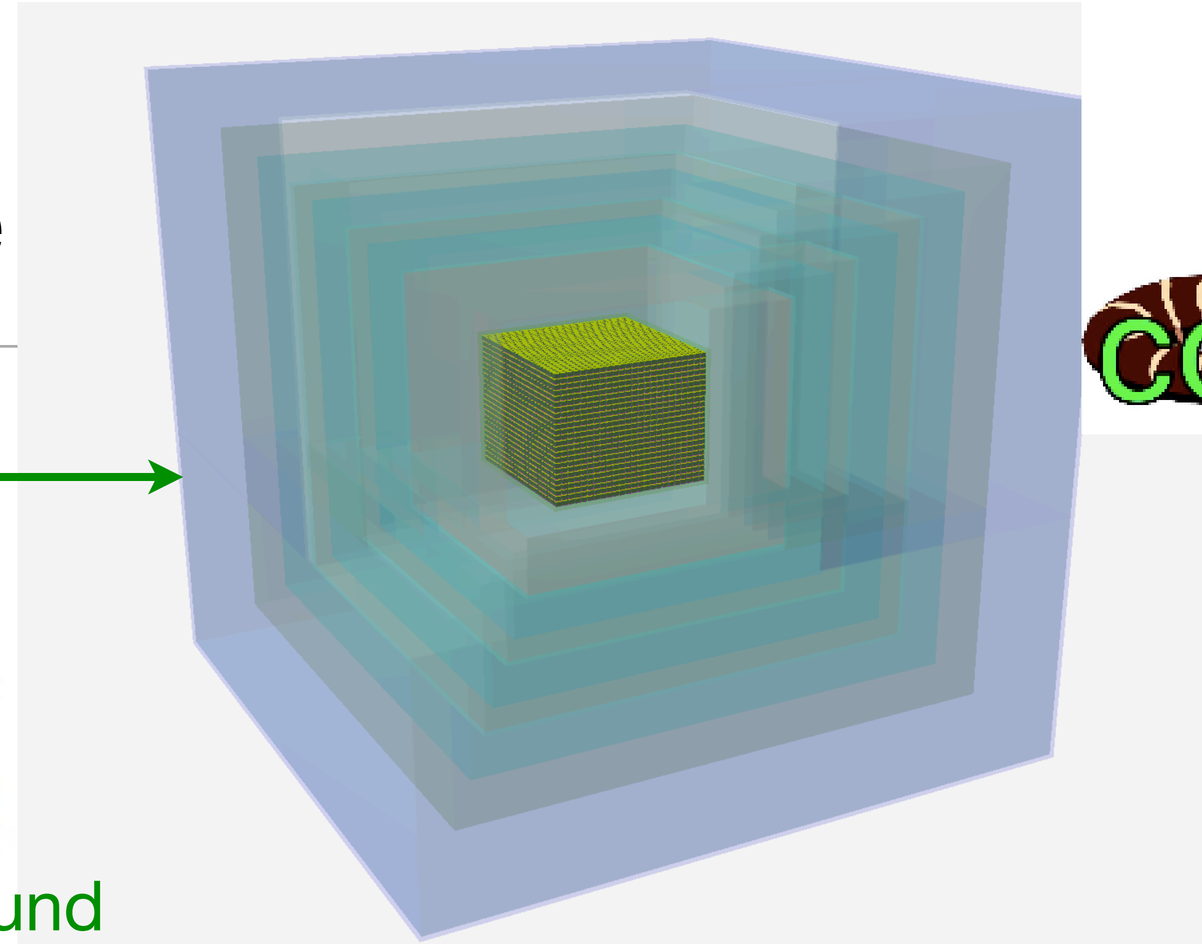
measurement of the detector

$$[T^{0\nu}_{1/2}]^{-1} = C_{mm}\left(\frac{\langle m_\nu \rangle}{m_e}\right)^2 + C_{\eta\eta}\langle\eta\rangle^2 + C_{\lambda\lambda}\langle\lambda\rangle^2 + C_{m\eta}\frac{\langle m_\nu \rangle}{m_e}\langle\eta\rangle + C_{m\lambda}\frac{\langle m_\nu \rangle}{m_e}\langle\lambda\rangle + C_{\eta\lambda}\langle\eta\rangle\langle\lambda\rangle$$

observed lifetime dependent on Majorana mass ***m***$_\nu$ and/or contributions from right handed current (η, λ)

Proposal: Large Scale

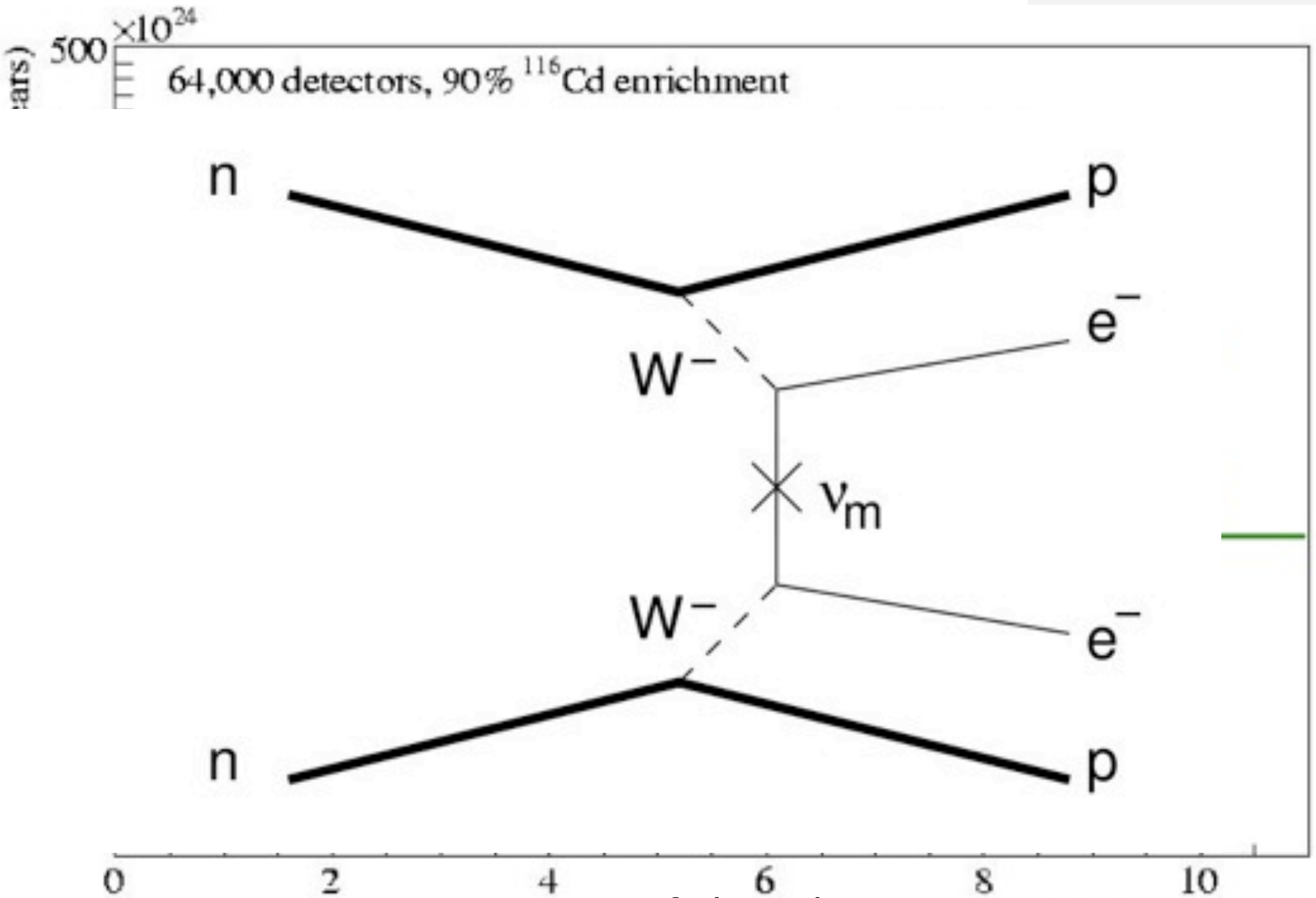




Mass

$$T_{1/2} \sim a \sqrt{\frac{M \cdot t}{B \cdot \Delta E}}$$

Background



measurement of the detector

$$[T^{0\nu}_{1/2}]^{-1} = C_{mm}\left(\frac{\langle m_\nu \rangle}{m_e}\right)^2 + C_{\eta\eta}\langle \eta \rangle^2 + C_{\lambda\lambda}\langle \lambda \rangle^2 + C_{m\eta}\frac{\langle m_\nu \rangle}{m_e}\langle \eta \rangle + C_{m\lambda}\frac{\langle m_\nu \rangle}{m_e}\langle \lambda \rangle + C_{\eta\lambda}\langle \eta \rangle \langle \lambda \rangle$$

observed lifetime dependent on Majorana mass $\boldsymbol{m_\nu}$ and/or contributions from right handed current (η, λ)

... or R-parity violating effects...

Summary & Conclusion

- opportunities for LFV
- at LHC
  - it could be interesting to apply a method like the decay length for processes to study parameters of Lepton Flavour Violation
- presently, analysis preparation for ATLAS/LHC and COBRA