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Phenomenological Theoretical Particle Physics

at the University of Vienna*

RECFA Meeting, Vienna, April 6, 2018

A.H. Hoang

University of Vienna

* incl. HEPHY

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Outline

- **Faculty of Physics**
- **Personell and Research in Numbers**
- **Research Overview** (incl. HEPHY theory)
- **Conclusions**

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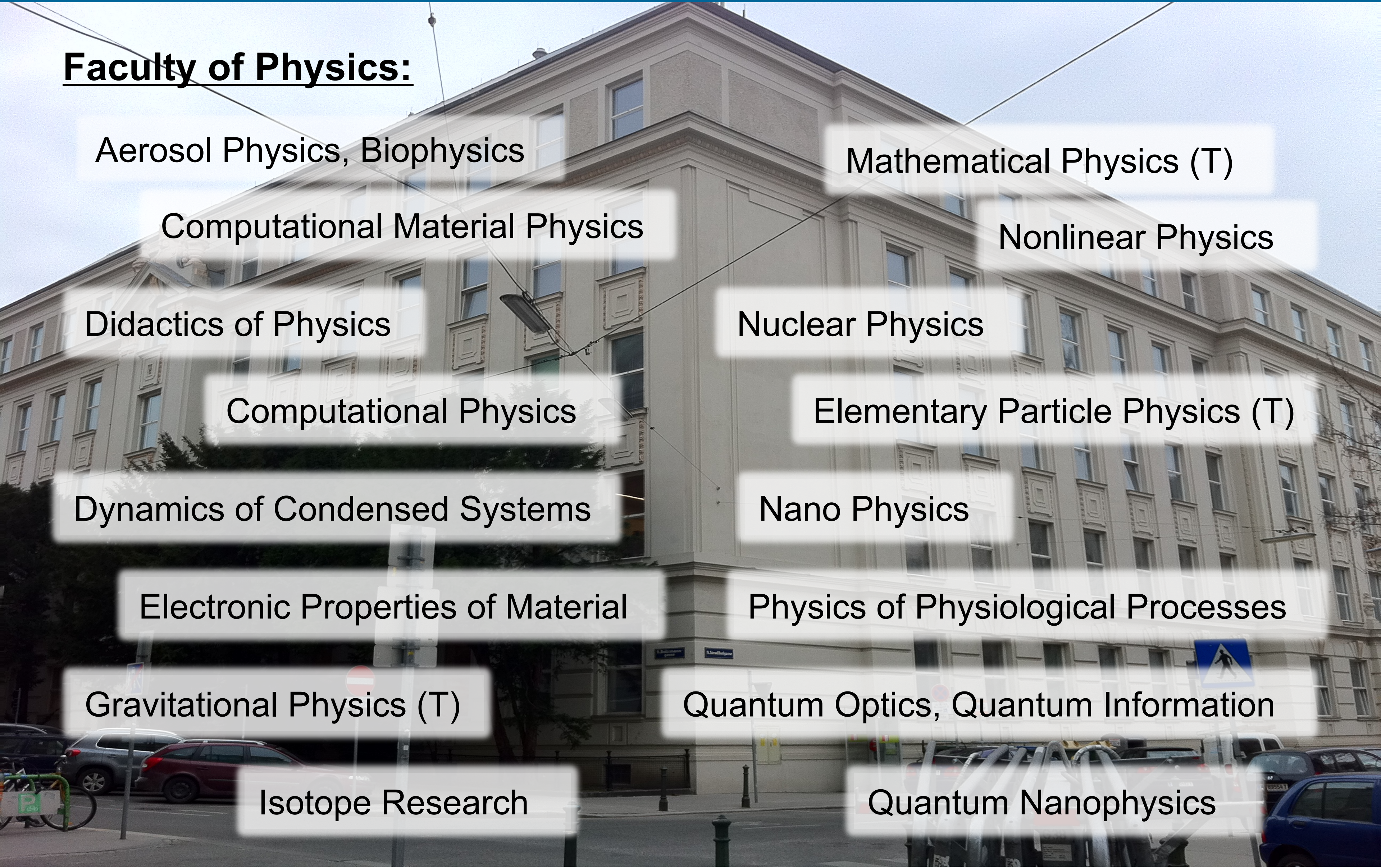
- Founded 1365
- 2nd oldest university of the Holy Roman Empire of German Nations
- More than 95.000 students
- 187 different studies
- 19 faculties and study centres



Faculty of Physics:

- Aerosol Physics, Biophysics
- Computational Material Physics
- Didactics of Physics
- Computational Physics
- Dynamics of Condensed Systems
- Electronic Properties of Material
- Gravitational Physics (T)
- Isotope Research
- Mathematical Physics (T)
- Nonlinear Physics
- Nuclear Physics
- Elementary Particle Physics (T)
- Nano Physics
- Physics of Physiological Processes
- Quantum Optics, Quantum Information
- Quantum Nanophysics

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University of Vienna (Faculty of Physics):

16 research groups (experimental + theory + didactics)

5 theoretical groups →

- Computational physics (condensed matter)
- Gravitational physics
- Mathematical physics
- Particle physics
- Quantum theory

Particle Physics Group:

Permanent:

A Hoang (full Prof)

H. Neufeld (ass Prof)

W. Grimus (ass Prof)

H. Hüffel (ass Prof)

Non-Permanent:
(University Assistants - 6 years)

M. Procura (habil)

S. Plätzer

University of Vienna (Faculty of Physics):

16 research groups (experimental + theory + didactics)

5 theoretical groups →

Computational physics (condensed matter)
Gravitational physics
Mathematical physics
Particle physics
Quantum theory

Particle Physics Group:

Permanent:

- A Hoang (full Prof)
- H. Neufeld (ass Prof) → retires 2019
- W. Grimus (ass Prof) → retires 2018
- H. Hüffel (ass Prof) → retires 2018
- B. Hiesmayr (PD) → quantum group 2016
- A. Bartl (emer)
- E. Ecker (ret)

Collider and jet physics ⟷ Hephy
Precision and perturbative QCD
Monte-Carlo event generators
Dark matter
Low energy hadron dynamics (g-2, chiral perturbation theory)
LHC + ILC

Non-Permanent: (University Assistants - 6 years)

- M. Procura (habil)
- S. Plätzer

SUSY phenomenology (LHC and ILC) ⟷ Hephy
Neutrino physics

Mathematical Physics Group:+

- J. Yngvason (full Prof) → retired 2015
- Stefan Fredenhagen (full Prof) → newly assigned 2016
- H. Steinacker (habil)

String compactification
String phenomenolog
Higher spin gauge theories
Sypergravity
Matrix models

+ with particle physics activities

Personnel in Numbers (Overall since 2013)

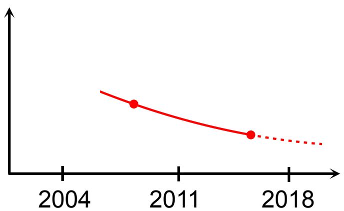
Profs	Postdocs	PhD	Master	Longt. guest
4	8	9	12	9

Personnel in Numbers (Snapshots)

	Total	Non-permanent	PhD	Permanent
Dec. 2004	16	7	4	9
April 2011	17	13	6	4
April 2018	20	16	8	4
Oct. 2018	2x	2x	x	2

- Overall decrease as predicted at RECFA 2011
- Installation of career tenure track (TT) positions under the guidance of the rectorate
- New particle theory TT position expected ~2019

- My view: Future development strongly dependent on international development of particle physics



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Particle Physics Group: (activities since 2013)

Projects:

3 FWF stand-alone: Hoang (1), Grimus (2)

FWF Doktoratskolleg “Particle and Interactions”: Hoang, Grimus (phase 1: until 2018), Procura (phase 2: until 2022)

Networks:
- Cost action 16201 “Unravelling new physics at the LHC through precision”
- Cost action 16108 “Vector boson scattering network”
- MCnet3 ITN on Monte Carlo event generators
- Higgs cross section working group: MC contact
- LHC Top quark working group: top mass determinations

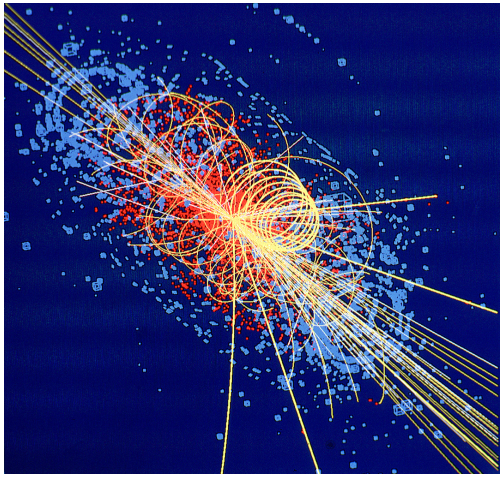
Research papers: 161

Collaborations: Amsterdam U, Bern U, Buenos Aires U, Bonn U, Cracow U, Darmstadt U, DESY Hamburg, Durham U, Durham IPPP, CERN, Florida State U, IISET Bhopal, IFIC Valencia, INFN Frascati, INFN Turin, IRFU Saclay, IPhT Saclay, Kaiserslautern U, KIT Karlsruhe, KITP Santa Barbara, Lisbon IST, Lisbon CFTP, Lund U, Manchester U, Mainz U, Monash U, MIT Cambridge, Madrid Autonoma U, Madrid U, NIKHET Amsterdam, Liverpool U, PSI Villingen, Salamanca U, UC San Diego, Shiraz U., Vilnius U, Washington U, Wichita State U, Witwatersrand U, Würzburg U,

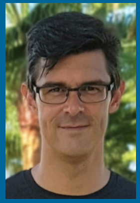
Conferences organized: Parton Shower and Resummation 2019 (at ESI), 13th Vienna Central European Seminar 2017, RADCOR 2017 (St. Gilgen), 12th Vienna Central European Seminar 2016, ESI Program “Challenges and Concepts in Field Theory for LHC Run-2” 2016, 11th Vienna Central European Seminar 2015, ESI Program “Jets and quantum fields for LHC” 2013

+ with particle physics activities

Collider Physics and Jets



Jet physics at the LHC



Goal: extract valuable information on <u>jet substructure</u> to discriminate

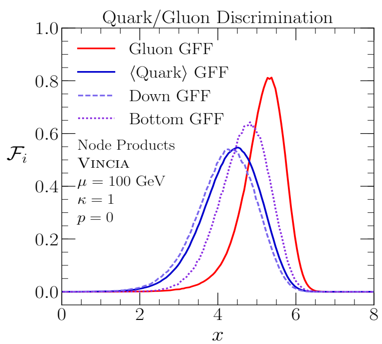
- boosted heavy particle decays from the QCD background
- quark-initiated from gluon-initiated jets

<u>with controlled theory uncertainties</u> (improving the accuracy of present Monte Carlo event generators)

Methods:

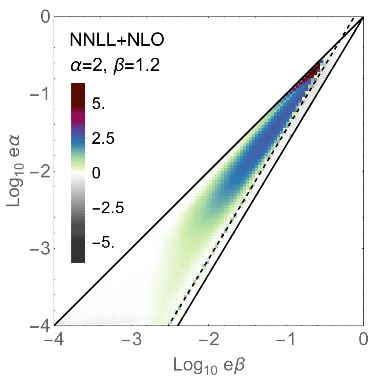
- Novel formalism to perform analytic QCD calculations for a class of observables defined by how energy gets distributed among subsets of jet particles with arbitrary multiplicities (<u>generalized jet fragmentation</u>)

  Chang, Procura, Thaler, Waalewijn **PRL+PRD (2013)**
  Elder, Procura, Thaler, Waalewijn,Zhou **JHEP (2017)**



- New framework for joint resummations for <u>multi-differential jet measurements</u>. Enables <u>controlled multivariate analyses</u> to extract information about pattern of radiation inside jets and correlations among different observables

  Procura, Waalewijn, Zeune **JHEP (2015) + 2018**



Strong Coupling Determinations from Event Shapes

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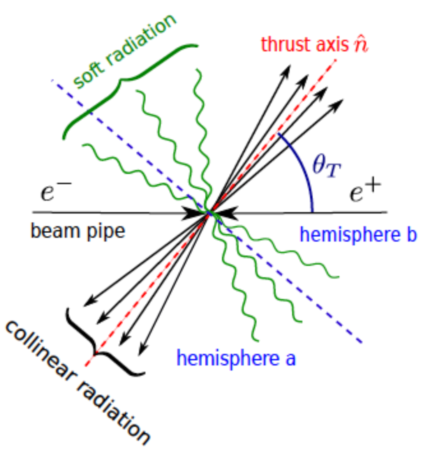
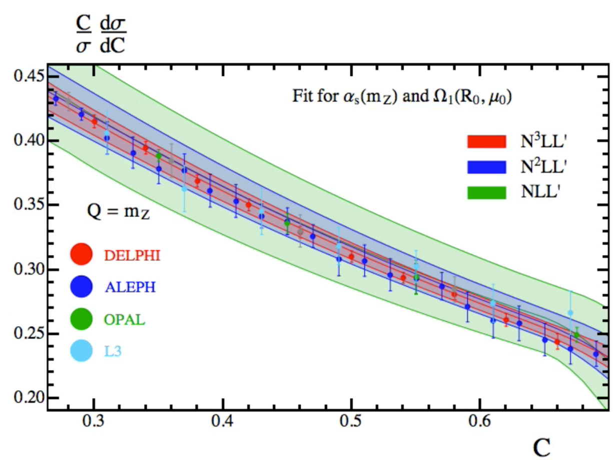
FWF Der Wissenschaftsfonds.

- Strong coupling governs rate and shape of jet production
- Precise understanding of perturbative and non-perturbative QCD dynamics required
- Soft-Collinear factorization: control of perturbative and non-perturbative effects (SCET)
- High-precision analysis: NNNLL + NNLO

$$\left(\frac{d\sigma}{dC}\right)^{\rm sing}_{\rm part} \sim \sigma_0 H(Q,\mu_Q) U_H(Q,\mu_Q,\mu_s) \int d\ell d\ell' \, U_J\Big(\frac{QC}{6} - \ell - \ell', \mu_J, \mu_S\Big) \, J_\tau(Q\ell', \mu_J)\, S_C(\ell - \Delta, \mu_S)$$





Thrust distribution (2010):

$\alpha_s(M_Z) = 0.1135 \pm 0.0010$

Thrust distribution (2015 update!):

$\alpha_s(M_Z) = 0.1128 \pm 0.0012$

Thrust 1st moment (2012):

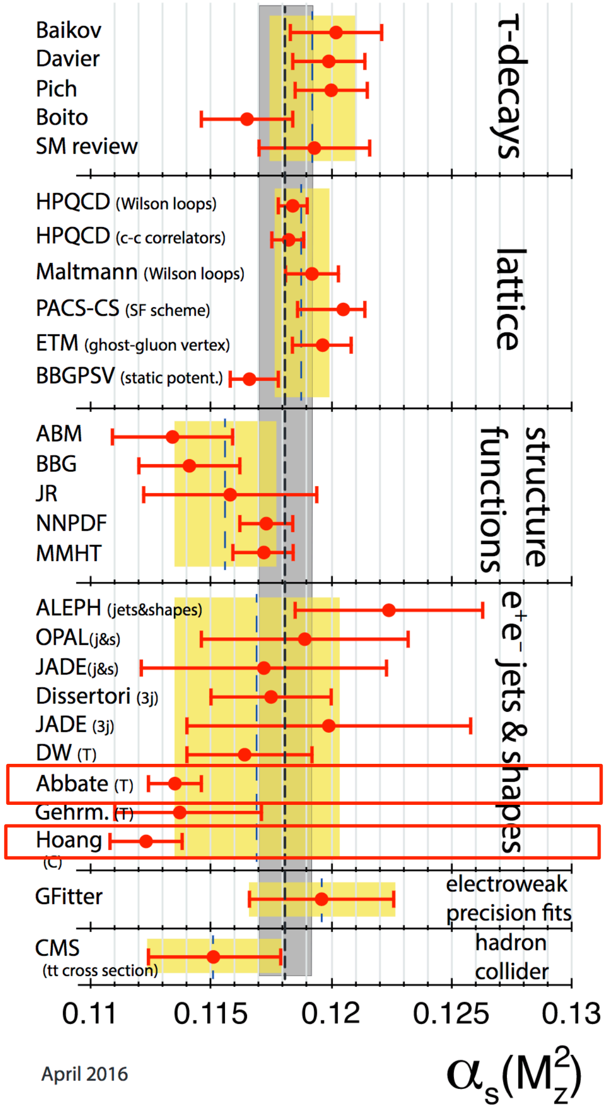
$\alpha_s(M_Z) = 0.1140 \pm 0.0016$

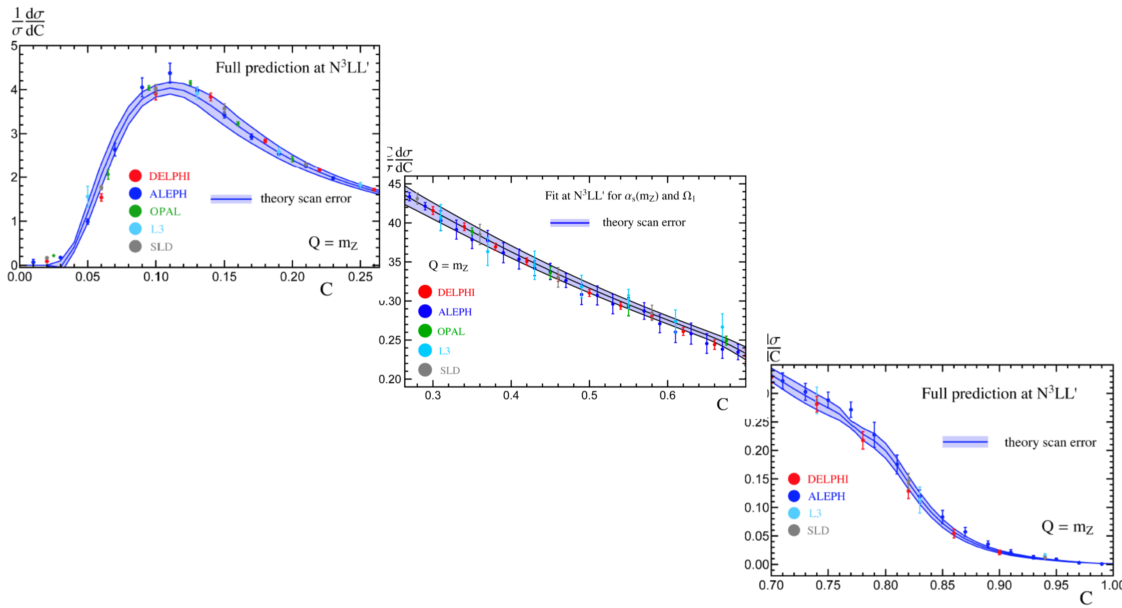
C-parameter distribution (2015):

$\alpha_s(M_Z) = 0.1230 \pm 0.0015$

Abbate, Fickinger, Mateu, Stewart, AHH PRD D83 (2011) 074021
Abbate, Fickinger, Mateu, Stewart, AHH PRD D86 (2012) 094002
Kolodrubetz, Mateu, Stewart, AHH PRD D91 (2015) 094017
Kolodrubetz, Mateu, Stewart, AHH PRD D91 (2015) 094018

Strong Coupling Determinations from Event Shapes





- Excellent description of data
- Value for α_s below world averate
- All collider determinations small → Why?
- Extensions to LHC observables

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Precision VBF and VBS Phenomenology with Herwig

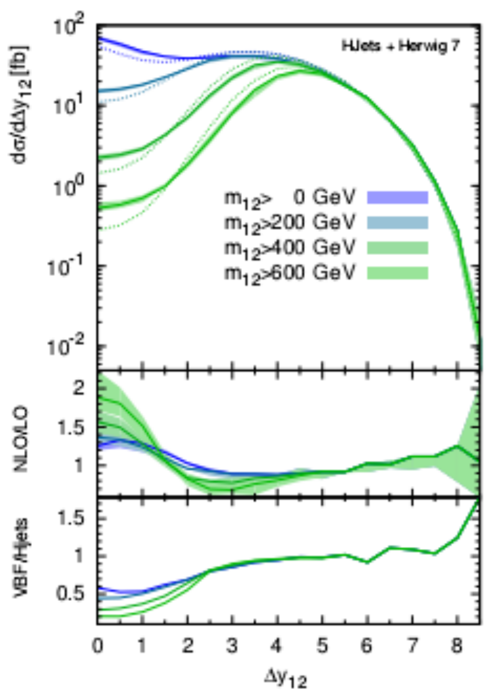
VBF and VBS in focus of LHC Run II – **reliable description of jet activity** essential

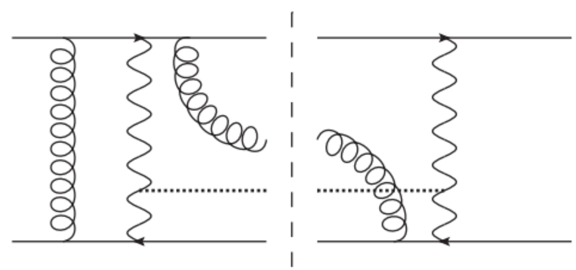
- NLO QCD predictions from VBFNLO 3 + Herwig 7

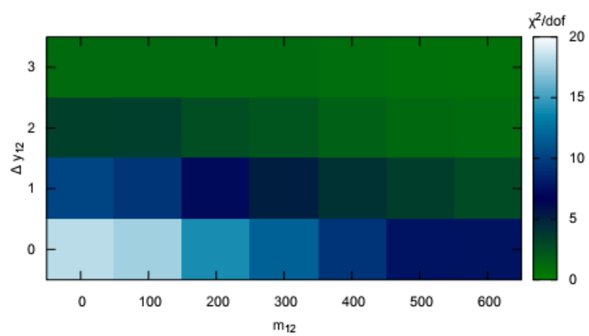
some results in [Plätzer, Rauch –EPJ C77 (2017) 293]
significant contribution to VBSCAN COST action study

- Full H+3 jet calculation in HJets + Herwig 7

[Campanario, Figy, Plätzer, Sjödahl – PRL 111 (2013) 211802]







E.g. Quantify quality of VBF approximation at NLO QCD in H+3 jet final states at the LHC.

Crucial input to assess uncertainties in different VBF/VBS jet bins.

[Campanario, Figy, Plätzer, Rauch, Sjödahl – arXiv:1802.0995]

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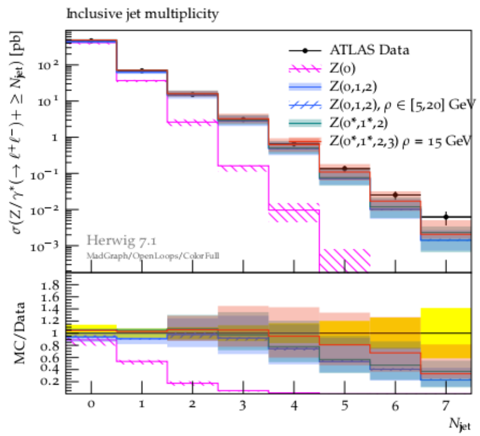
Event Generators: Herwig 7

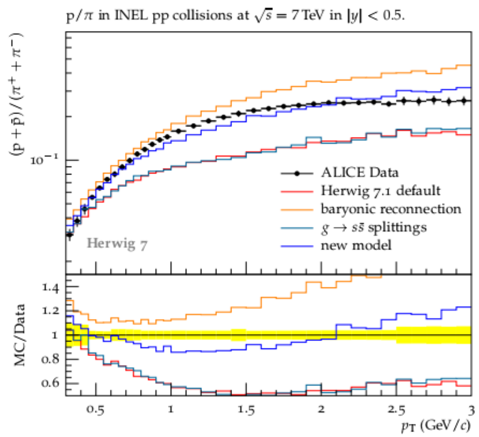
[Herwig collaboration – Eur.Phys.J. C76 (2016) 665]



Development centered around two shower algorithms

- Automated **NLO matching & merging** is key to precision simulation
- Matching systematics, (shower) **uncertainties** and tops are main focus

[Bellm, Gieseke, Plätzer – EPJ C in print] & [Plätzer – JHEP 1308 (2013) 114]
[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]



Complemented by improving algorithms and **constraining phenomenological models**

- Subleading-N corrections in parton showers
- New insights into colour reconnection and baryon production

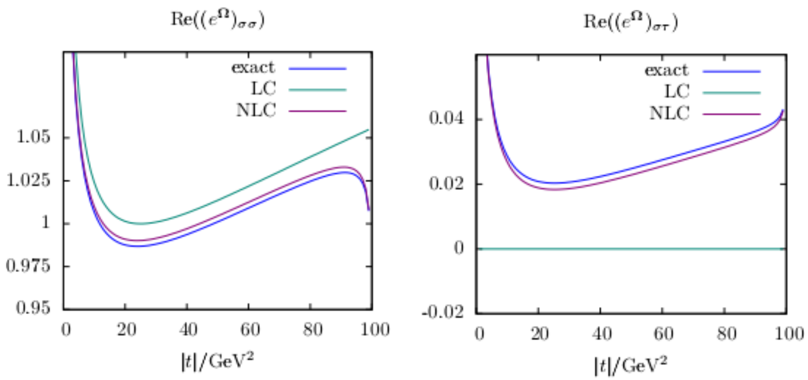
[Plätzer, Sjödahl – JHEP 1207 (2012) 042] & work in progrss
[Gieseke, Kirchgaesser, Plätzer – EPJ C78 (2018) 99]

Amplitude Evolution and Non-global Logarithms

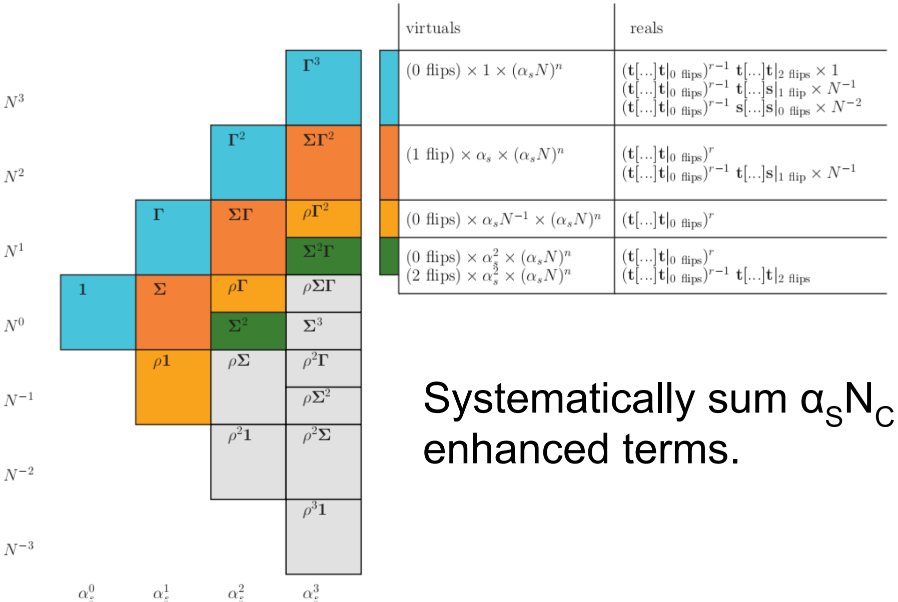
Explore **new directions for parton showers** with application to resummation.

- Non-global observables like hemisphere jet masses probe coherent emission from complex ensembles of coloured partons.
- Consider evolution equations for colour density operator.

Colour mixing neglected in parton showers: needs to be included at amplitude level.



[Plätzer – Eur.Phys.J. C74 (2014) 2907]



Systematically sum $\alpha_S N_C$ enhanced terms.

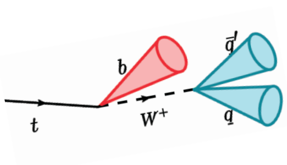
[Angeles, DeAngelis, Forshaw, Plätzer, Seymour – arXiv:1802.08531]

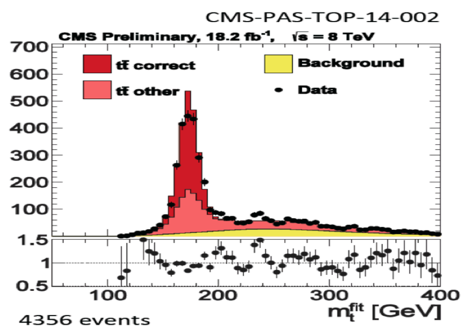
FWF Der Wissenschaftsfonds.

Interpretation of the top mass from reconstruction measurements

- Most precise m_{top} measurements are MC based $\rightarrow$ m_t^{MC}
- Unclear how related to field theory mass (m_t^{pole}, $m_t(m_t)$, $\cdots$)

$$m_t^{\rm MC} = 174.34 \pm 0.64 \quad \text{(Tevatron final, 2014)}$$
$$m_t^{\rm MC} = 172.44 \pm 0.49 \quad \text{(CMS Run-1 final, 2015)}$$
$$m_t^{\rm MC} = 172.84 \pm 0.70 \quad \text{(ATLAS Run-1 final, 2016)}$$

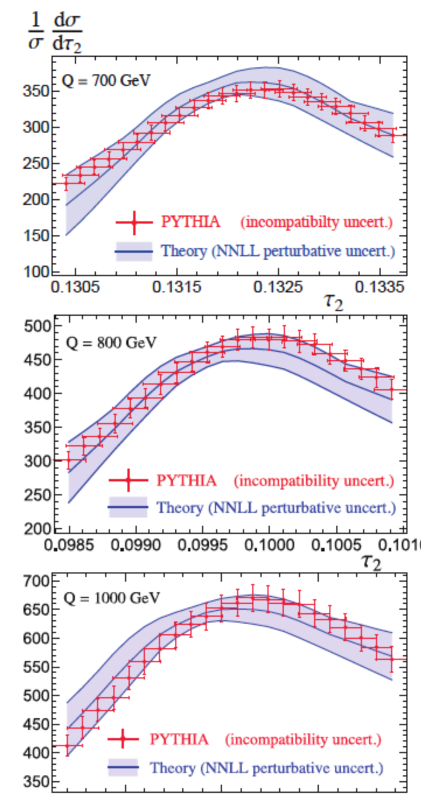




- Calibration fit: NNLL QCD to Pythia 8.2 (hadron level)
- Observable: 2-jettiness in e^+e^- annihliation

$$m_t^{\rm MC} = m_{t,1\rm GeV}^{\rm MSR} + (0.18 \pm 0.22)\ \text{GeV}$$

$$m_t^{\rm MC} = m_t^{\rm pole} + (0.57 \pm 0.28)\ \text{GeV}$$



Butenschön, Dehnadi, Mateu, Preisse, Stewart, AHH **PRL 117 (2016) 232001**

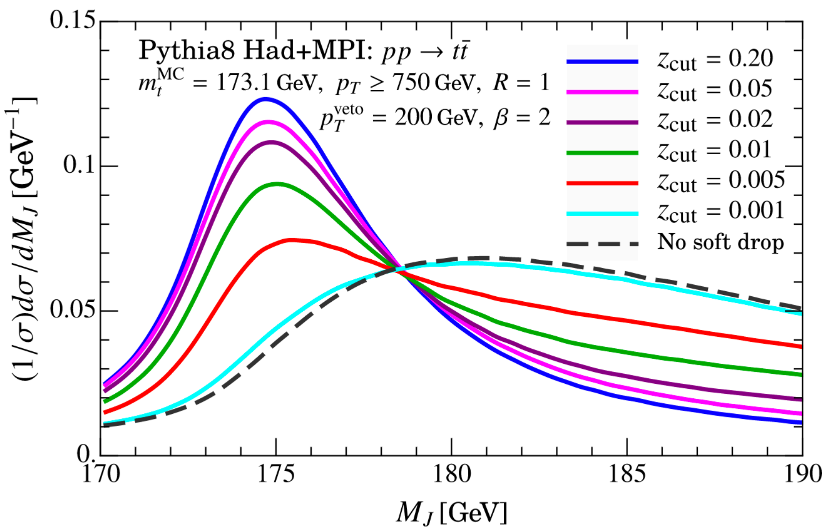
AHH **arXive:1412.3649**

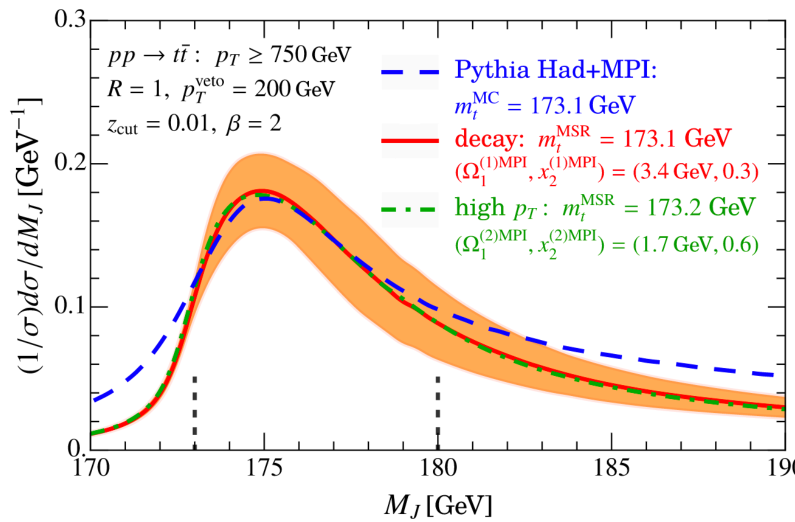
FWF Der Wissenschaftsfonds.

Interpretation of the top mass from reconstruction measurements

- Extension to LHC
- Soft drop grooming to reduce effects of underlying event and pileup

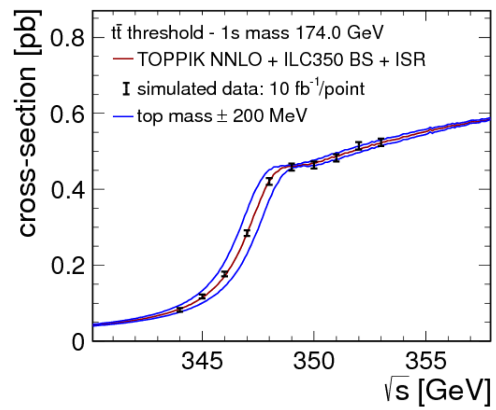
- QCD prediction at NLL (hadron level)
- Compatible to e⁺e⁻ results





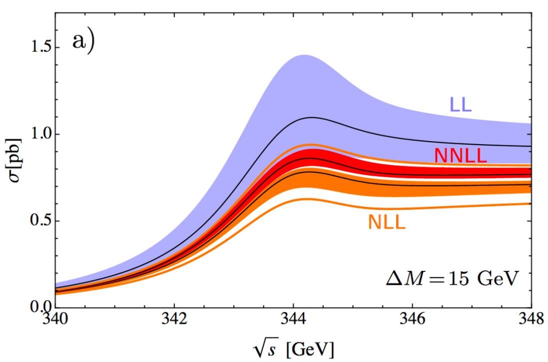
Mantry, Pathak, Stewart, AHH **arXive:1708.02586**

Top Quark Physics at the ILC

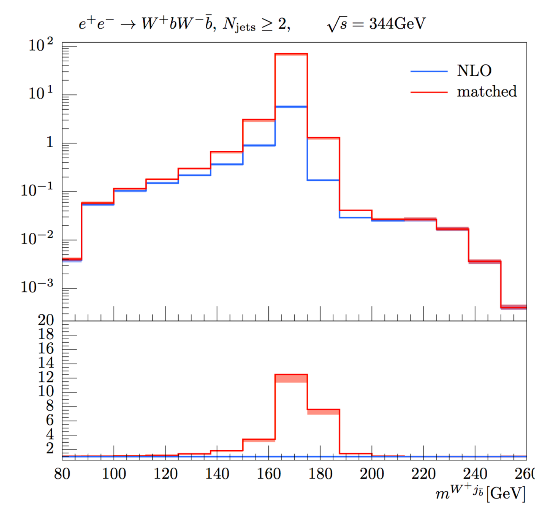


Top Threshold Production at the ILC

- Threshold behavior rich source for particle property measurements: mass, width, couplings
- Coulomb rescattering for slow top quarks → v/p NRQCD
- Unstable particle effects: leading order



- Full resummation of $(\alpha_s/v)^n$ and $(\alpha_s \ln(v))^n$ terms at NNLL order for the total cross section



- Fully differential predictions at LL/NLL: WHIZARD event generator → top threshold Monte-Carlo

Stahlhofen, AHH **JHEP 1405 (2014) 121**

Bach, Nejad, Kilian, Reuter, Stahlhofen, Teubner, Weiss, AHH **JHEP (2018) to appear**

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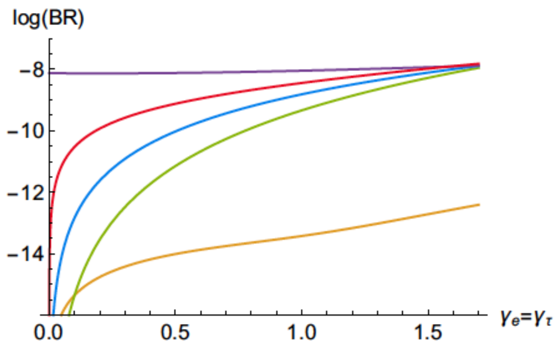
Neutrino Physics

FWF Der Wissenschaftsfonds.

Models for neutrino masses and lepton mixing

- Scotogenic model: seesaw with 1-loop radiative neutrino masses and dark matter
- Cobimaximal mixing: maximal atmospheric mixing and CP phase

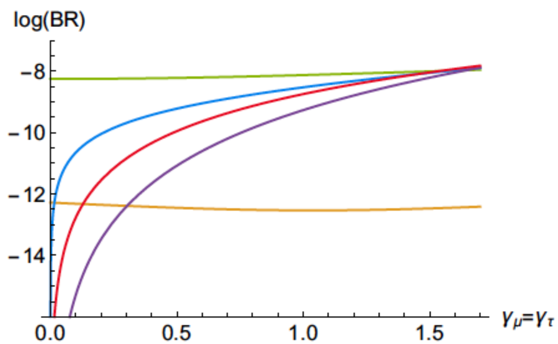
Ferreira, Grimus, Jurciukonis, Lavoura, **JHEP 1607 (2016) 010**



Charged lepton decays in models of soft LFV

- FCNCs at 1-loop, seesaw limit $m_R \rightarrow \infty$
- Decays: $\ell_1^- \to \ell_2^- \ell_3^+ \ell_3^-\,,\ \mu \to e\gamma\,,\ Z^0 \to e\mu$

Aeikens, Grimus,, Lavoura **PLB 768 (2017) 365**



1-loop fermion masses and mixing in extensions of the SM

- Yukawa models
- Multi-Higgs extensions

Fox, Grimus, Löschner, Int.J.Mod.Phy. **A33 (2018) 1850019**

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ÖAW AUSTRIAN ACADEMY OF SCIENCES

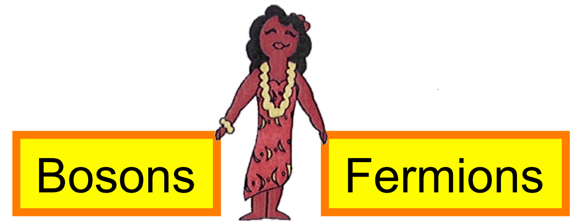
SUSY Phenomenology

Mission: phenomenological exploration of supersymmetric SM

- production and decay processes of SUSY @LHC and @ILC
- loop calculations; radiative corrections together with proper renormalization
- study of new sources of CP violation
- aspects of flavour physics; quark flavour violation
- gravitino physics

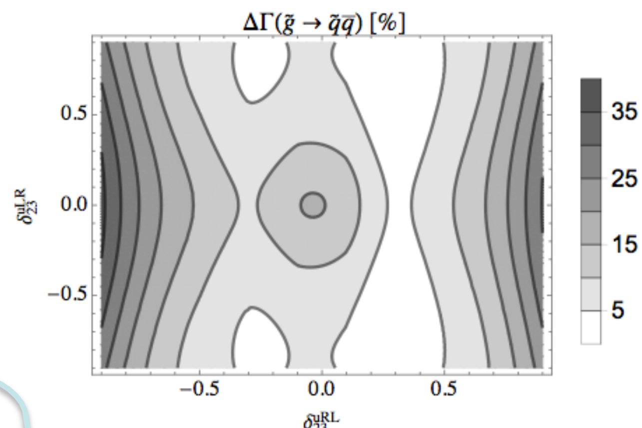
SUSY

FWF Der Wissenschaftsfonds.



One recent work:
"Gluino two-body decays at full one-loop level in the MSSM with quark-flavour violation"
H. Eberl., E. Ginina, K. Hidaka, Eur. Phys. J. C77 (2017) no.3, 189

$$\Gamma(\tilde{g} \to \tilde{q}^* q) = \Gamma^0(\tilde{g} \to \tilde{q}^* q) + \Delta\Gamma^{\mathrm{SQCD}} + \Delta\Gamma^{\mathrm{EW}}$$



not included in codes used in LHC studies

EW contribution in terms of SQCD

http://www.hephy.at/susytools/ :
(all published in Comp. Phys. Comm.)

Vienna SUSY Tools

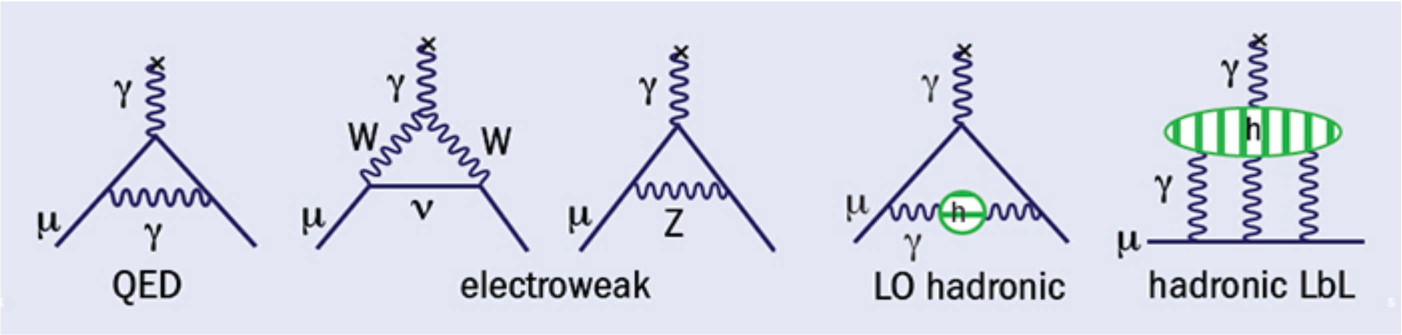
repository of tools created by HEPHY theory group

List of Tools:

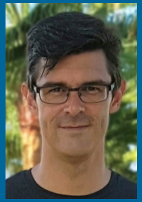
- GravitinoPack ← decays of or into gravitinos
- FVSFOLD, SFOLD, HFOLD } Full One Loop Decays of Higgses and sfermions
- polxino ← gluino, chargino, neutralino masses @ 2loop level

maintained by H. Eberl - helmut.eberl@oeaw.ac.at

Low Energy QCD



Hadronic contributions to the muon g-2



Goal: provide reliable theory errors for hadronic contributions to the muon g-2

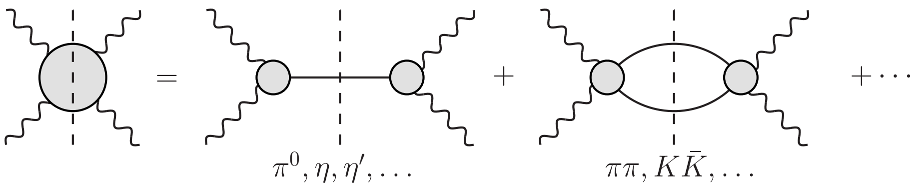
- mandatory in order to match the accuracy of forthcoming results from FNAL E989
- the significance of the present discrepancy crucially depends on hadronic uncertainties

Methods:

- Novel theoretical approach paving the way for the first model-independent data-driven determination of the hadronic light-by-light (HLbL) contribution with controlled uncertainties

  Colangelo, Hoferichter, Procura, Stoffer **JHEP (2014), JHEP (2015), PRL (2017), JHEP (2017)**

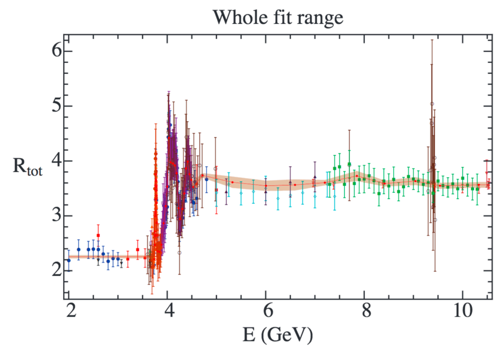
- The HLbL amplitude is reconstructed via dispersion relations by exploiting unitarity and analyticity, gauge invariance and crossing symmetry where the dominant contributions at low energies are related to experimentally accessible hadronic form factors and cross sections:



- Improved dispersive determination of hadronic vacuum polarization is also under study

Charm and Bottom Mass Determinations

- Important input parameters for many theoretical predictions
- Benchmark for understanding of QCD
- Different complementary methods



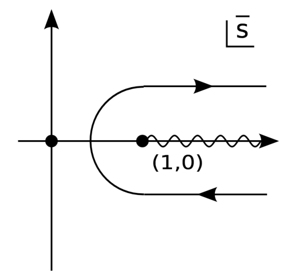
$$R_{e^+e^-\to q\bar{q}+X}(s) = \frac{\sigma_{e^+e^-\to q\bar{q}+X}(s)}{\sigma_{e^+e^-\to \mu^+\mu^-}(s)}$$

<u>QCD Sum Rules Method</u>

- Updated data analysis
- Improved treatment of perturbative uncertainties
- Relativistic (small n) and non-relativistic (large n) approach

$$M_n^V = \int \frac{\mathrm{d}s}{s^{n+1}} R_{e^+e^-\to q\bar{q}+X}(s)$$

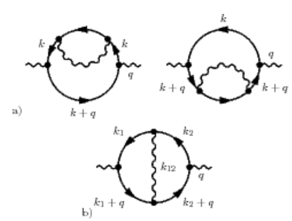
$$M_n^{V,\,\mathrm{th}} = \frac{12\pi^2 Q_q^2}{n!}\,\frac{\mathrm{d}^n}{\mathrm{d}s^n}\Pi_V(s)\Big|_{s=0}$$



Dehnadi, Mateu, Zebarjad, AHH, JHEP 1309 (2013) 103

Dehnadi, Mateu, AHH, JHEP 1508 (2015) 155

Ruiz-Femenia, Stahlhofen, AHH, JHEP 1210 (2012) 188



$$(g_{\mu\nu}\, s - q_\mu q_\nu)\Pi_V(s) = -\,i \int \mathrm{d}x\, e^{iqx}\, \langle\, 0\, |T\, j_\mu(x) j_\nu(0)|\, 0\,\rangle$$

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Charm and Bottom Mass Determinations

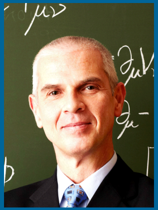
c-QUARK MASS

$\overline{MS}$ *MASS* (GeV)	*DOCUMENT ID*		*TECN*
1.28 ±0.03 OUR EVALUATION	See the ideogram below.		
1.335 ±0.043 $^{+0.040}_{-0.011}$	[1] BERTONE	16	THEO
1.246 ±0.023	[2] KIYO	16	THEO
1.2715±0.0095	[3] CHAKRABOR..	15	LATT
1.288 ±0.020	[4] DEHNADI	15	THEO
1.348 ±0.046	[5] CARRASCO	14	LATT
1.26 ±0.05 ±0.04	[6] ABRAMOWICZ	13C	COMB
1.24 ±0.03 $^{+0.03}_{-0.07}$	[7] ALEKHIN	13	THEO
1.282 ±0.011 ±0.022	[8] DEHNADI	13	THEO
1.286 ±0.066	[9] NARISON	13	THEO
1.159 ±0.075	[10] SAMOYLOV	13	NOMD
1.36 ±0.04 ±0.10	[11] ALEKHIN	12	THEO
1.261 ±0.016	[12] NARISON	12A	THEO
1.278 ±0.009	[13] BODENSTEIN	11	THEO
1.28 $^{+0.07}_{-0.06}$	[14] LASCHKA	11	THEO
1.196 ±0.059 ±0.050	[15] AUBERT	10A	BABR
1.28 ±0.04	[16] BLOSSIER	10	LATT
1.279 ±0.013	[17] CHETYRKIN	09	THEO
1.25 ±0.04	[18] SIGNER	09	THEO

b-QUARK MASS

$\overline{MS}$ *MASS* (GeV)	*DOCUMENT ID*		*TECN*
4.18 $^{+0.04}_{-0.03}$ OUR EVALUATION	of $\overline{MS}$ Mass. See the ideogram below.		
4.197±0.022	[1] KIYO	16	THEO
4.183±0.037	[2] ALBERTI	15	THEO
4.203 $^{+0.016}_{-0.034}$	[3] BENEKE	15	THEO
4.176±0.023	[4] DEHNADI	15	THEO
4.07 ±0.17	[5] ABRAMOWICZ	14A	ZEUS
4.201±0.043	[6] AYALA	14A	THEO
4.21 ±0.11	[7] BERNARDONI	14	LATT
4.169±0.002±0.008	[8] PENIN	14	THEO
4.166±0.043	[9] LEE	13O	LATT
4.247±0.034	[10] LUCHA	13	THEO
4.236±0.069	[11] NARISON	13	THEO
4.213±0.059	[12] NARISON	13A	THEO
4.171±0.009	[13] BODENSTEIN	12	THEO
4.29 ±0.14	[14] DIMOPOUL...	12	LATT
4.235±0.003±0.055	[15] HOANG	12	THEO
4.177±0.011	[16] NARISON	12	THEO
4.18 $^{+0.05}_{-0.04}$	[17] LASCHKA	11	THEO
4.186±0.044±0.015	[18] AUBERT	10A	BABR
4.164±0.023	[19] MCNEILE	10	LATT
4.163±0.016	[20] CHETYRKIN	09	THEO
4.243±0.049	[21] SCHWANDA	08	BELL

QCD Sum Rules
Relativistic Bound States



QCD Sum Rules Method

Tetraquarks
- consistency constraints from large-*N* QCD
- tetraquark features from QCD sum rules

Lucha, Melikhov & Sazdjian, PRD **96** (2017) 014022;
EPJC **77** (2017) 866

Leptonic decay constants of heavy–light mesons
- ratio of vector/pseudoscalar decay constants
- isospin breaking
- quark mass determination

Lucha, Melikhov & Simula, PRD **88** (2013) 007; **91** (2015) 116009;
PLB **735** (2014) 12; **765** (2017) 365;
EPJC **78** (2018) 168

Relativistic Bound States

Bethe–Salpeter formalism
- effective instantaneous interquark interactions from inversion
- comprehensive Dyson–Schwinger–Bethe–Salpeter analysis of mesons

Lucha & Schöberl, PRD **87** (2013) 016009; **92** (2015) 076005; **93** (2016) 056006; **93** (2016) 096005; IJMPA **31** (2016) 1650202; **33** (2018) 1850047
Hilger, Gómez-Rocha, Krassnigg & Lucha, EPJC **53** (2017) 213

Semirelativistic bound-state equations (“finger exercises”)
- rigorous statements on nature and location of spectra, number of bound states, …

Lucha & Schöberl, IJMPA **29** (2014) 1450057; **29** (2014) 1450181; **29** (2014) 1450195; **30** (2015) 1550062
Carles, Lucha & Moulay, JMP **56** (2015) 122301

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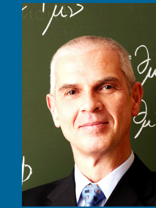
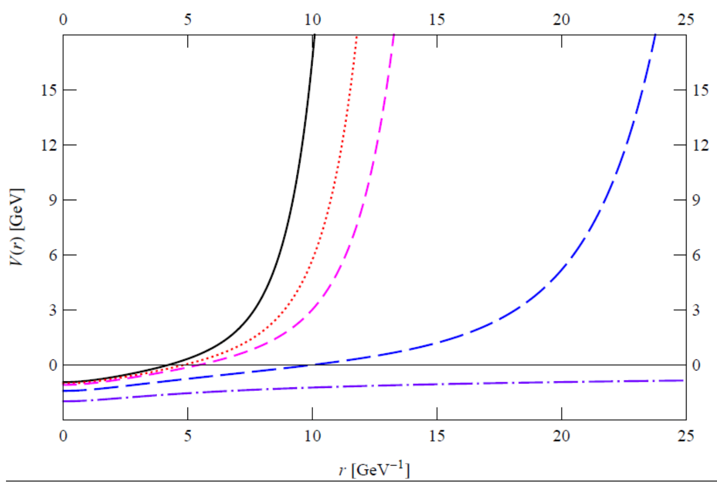
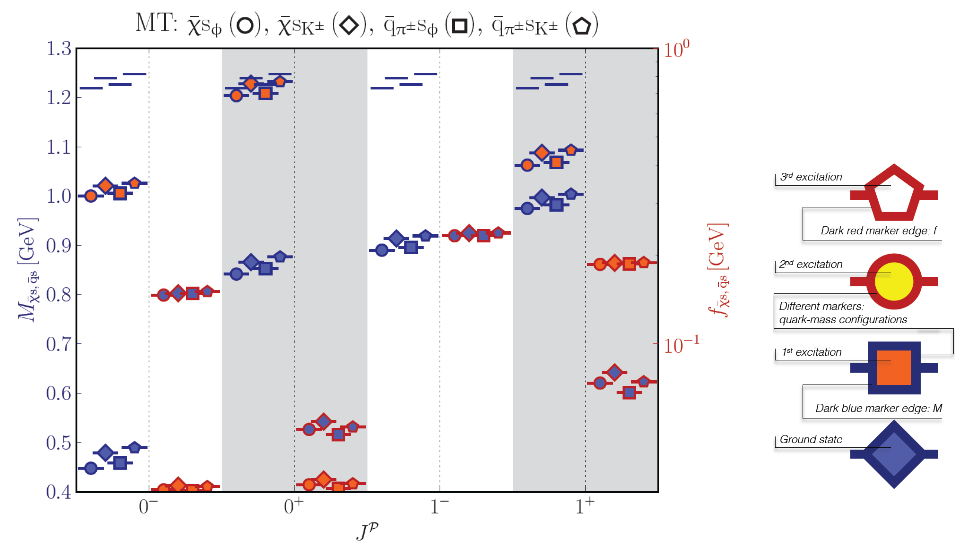
QCD Sum Rules
Relativistic Bound States

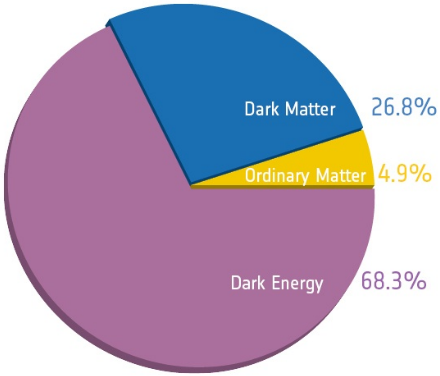


FWF
Der Wissenschaftsfonds.





Dark Matter



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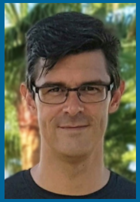
EFTs for Dark Matter detection



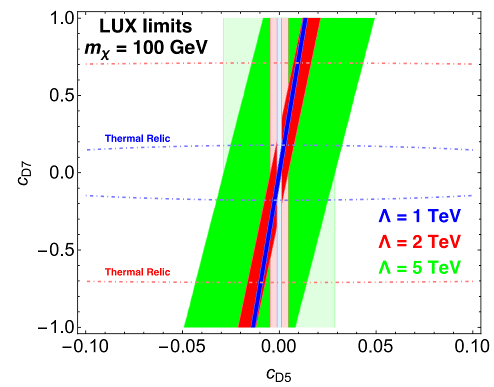
Goal: improved constraints on classes of Dark Matter models using effective field theories (EFTs)

- exploiting the complementarity of different searches, which probe interactions at different scales
- reducing hadronic uncertainties in nucleon/nuclear matrix elements

Methods:

- Systematic analysis of SM loop effects (running/mixing) in connecting effective operators at widely separated scales yields novel bounds on Wilson coefficients

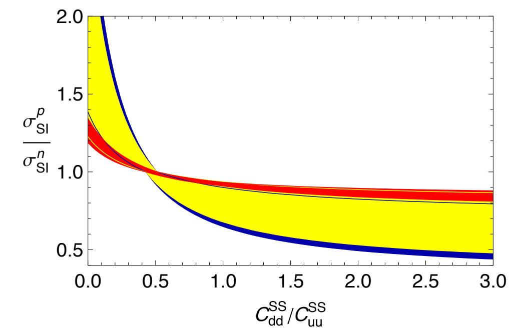
  Crivellin, D'Eramo, Procura **PRL (2014);** D'Eramo, Procura **JHEP (2015)**



- Simplified Models: systematics of loop-induced effects

- Reduced hadronic uncertainties in WIMP-nucleon matrix elements using chiral EFT lead to more stringent constraints

  Crivellin, Hoferichter, Procura **PRD (2014);**
  Crivellin, Hoferichter, Procura, Tunstall **JHEP (2015)**

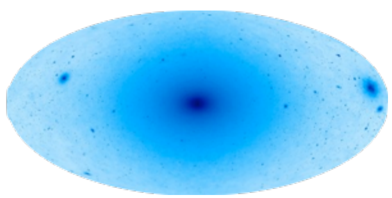


Dark Matter Theory

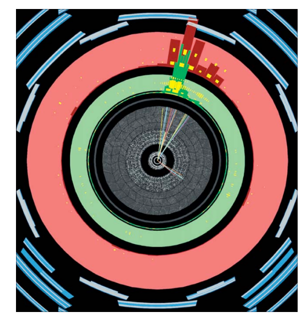
<u>New Frontiers Group (NFG) on Dark Matter</u>

- Grant-operated 5-year junior research group at HEPHY, funded by Austrian Academy of Sciences
- Austria's only dedicated dark matter theory effort

indirect detection and cosmology

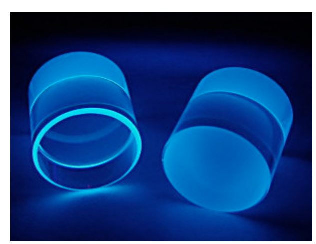


collider production



NFG tasks:
- make predictions
- connect the fields
- provide new science cases
- interpret experimental results

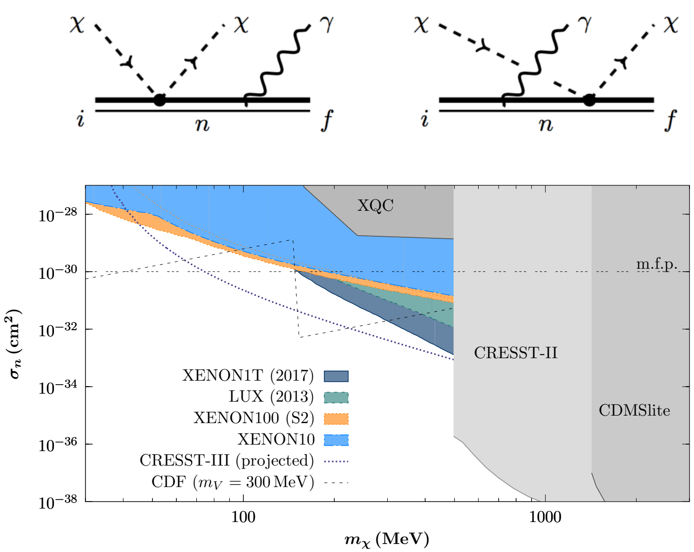
direct detection



Dark Matter Theory

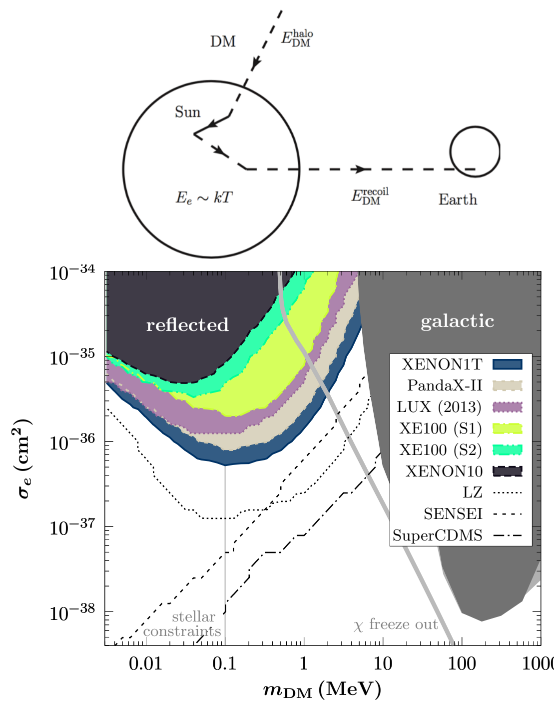
Extending our reach to directly detect Dark Matter

- Atomic photon emission after DM scattering
  => first direct limit below 500 MeV DM mass
  for DM-nucleus scattering



Kouvaris, Pradler **Phys.Rev.Lett 118 (2017) 031803**

- Solar reflected DM to increase kinetic energy
  => first direct limit below 10 MeV DM mass
  for DM-electron scattering

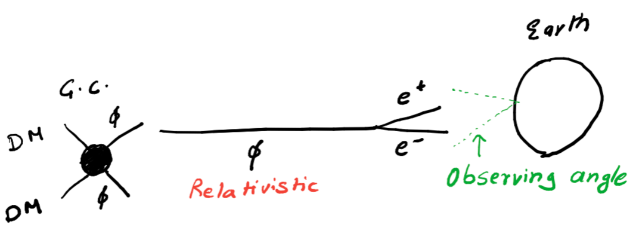


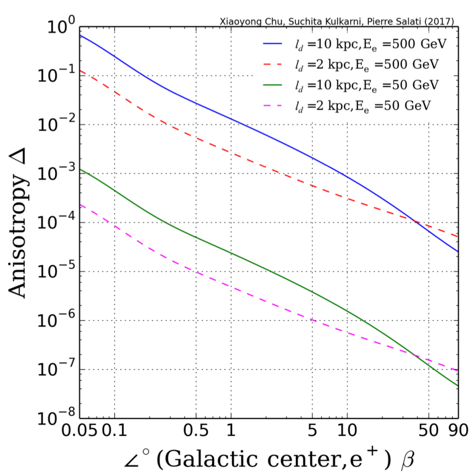
An, Pospelov, Pradler, Ritz **Phys.Rev.Lett (to appear)**

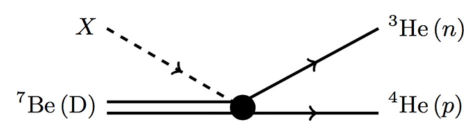
Dark Matter Theory

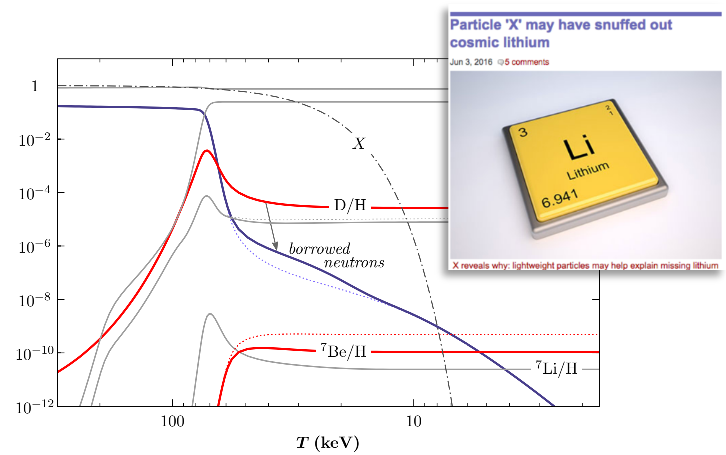
Astrophysical and cosmological implications of DM (and hidden sectors)

- Galactic DM annihilation into long-lived mediators yields new signal morphologies in indirect detection
- Cosmological implications of a light hidden sector with an experimental tests at the intensity frontier









Chu, Kularni, Salati **JCAP 1711 (2017) no.11, 023**

Goudelis, Pospelov, Pradler **Phys.Rev.Lett. 116 (2016) 211303**

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Conclusions

- Vienna University strong in **QCD, Jet and Collider Physics**
- Maintained field: **Low Energy QCD**
- Newly emerging field: **Dark Matter**
- Activities in **Neutrino Physics reduced**

- **Community small: → high level of personal commitment essential**
- Research ↔ individual persons
- Large coherent structures difficult: e.g. SFB, Doctoral Schools (DK)
- International connections essential: **DACH**
- Student resources very good.
- Modern and competitive structures + Outreach
- Flexible support for (small scale) new ideas

- Personell situation in PP at UW: **minimum reached in 2019** due to retirements