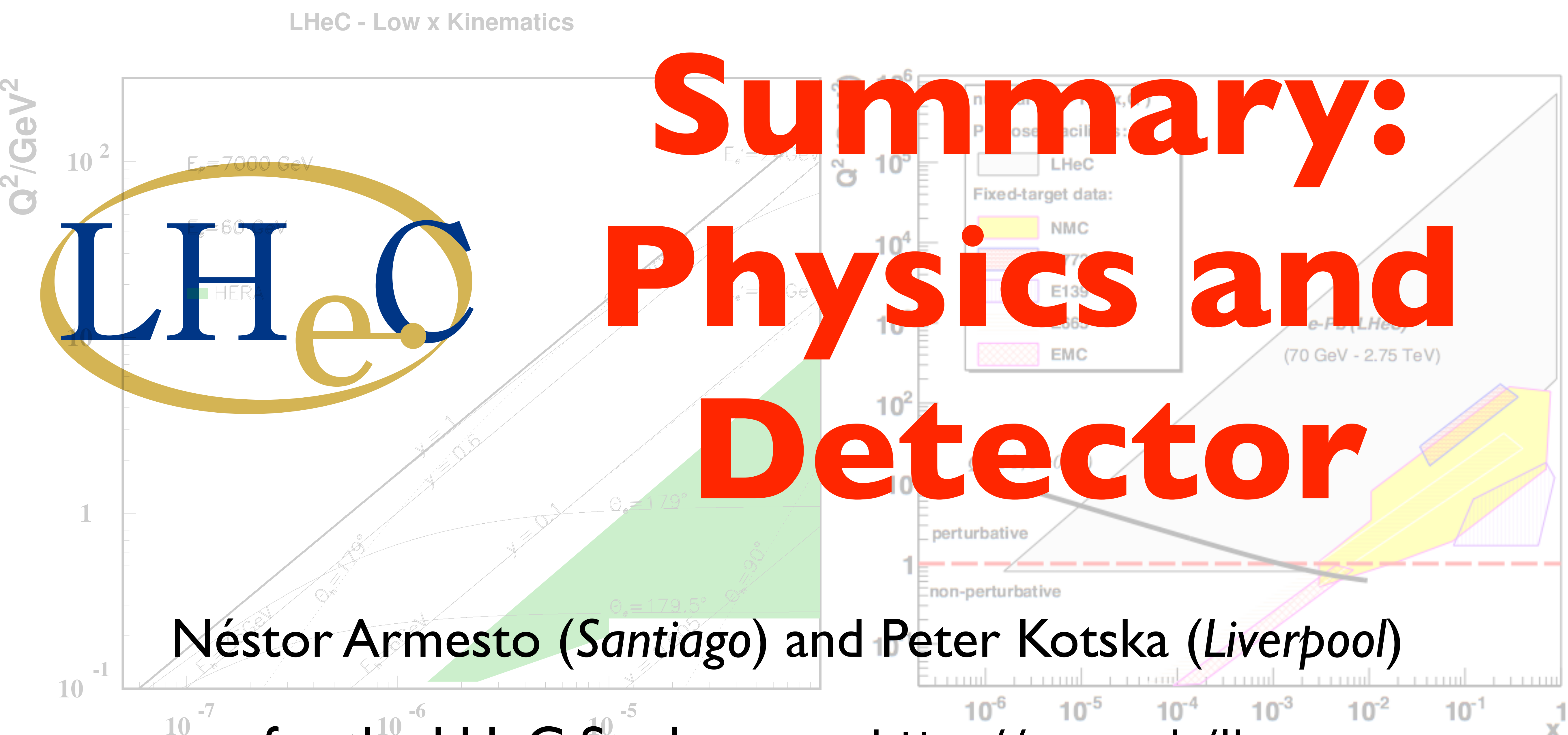
2015 LHeC Workshop
Chavannes-de-Bogis, June 26th 2015



Summary: Physics and Detector

Néstor Armesto (*Santiago*) and Peter Kotska (*Liverpool*)

for the LHeC Study group, http://cern.ch/lhec

Contents:

1. Detector: 5 software + 1 tracker talk.

2. Physics:

→ QCD: 6 talks.
→ SM Higgs: 3 talks.
→ top: 2 talks + BSM Higgs: 1 talk.
→ eA: 3 talks + UPCs: 1 talk.
→ FCC: 3 talks.

All in all: 25 talks.

Detector Session - 6 talks

Markus Frank (CERN):	DD4hep - Detector Description Toolkit work status, components and usage
Benedikt Hegner (CERN):	FCC Software Overview
Andreas Salzburger (CERN):	Simulation & Reconstruction SW for FCC Lessons from the past and an outlook
Julia Hrdinka (Wien):	The Tracker description and Interface to Gaudi Experiences and first Results
Anna Zaborowska (Warsaw):	The Fast Simulation for FCC in GEANT, First experiences integrating the ATLAS tracker tool
Luciano Musa (CERN):	Upgrade of the ALICE Inner Tracking System

5 talks with details of the software effort for the FCC-hh-eh-ee (started 2014);
a platform for software developments commonly used
+ an exemplary tracker upgrade for ALICE

LHeC context: share the same point of views;
synergy effects (optimistically - leave out all software license policies of (current) experiments/projects involved)

Markus Frank:
DD4hep - Detector Description Toolkit

Based DD4hep/DDG4 tools -
those results (simple model still) ⇒

are accessible for everybody!
(Yes, for students as well 😀)

Thanks to all of the DD4hep/DDG4
developer group!

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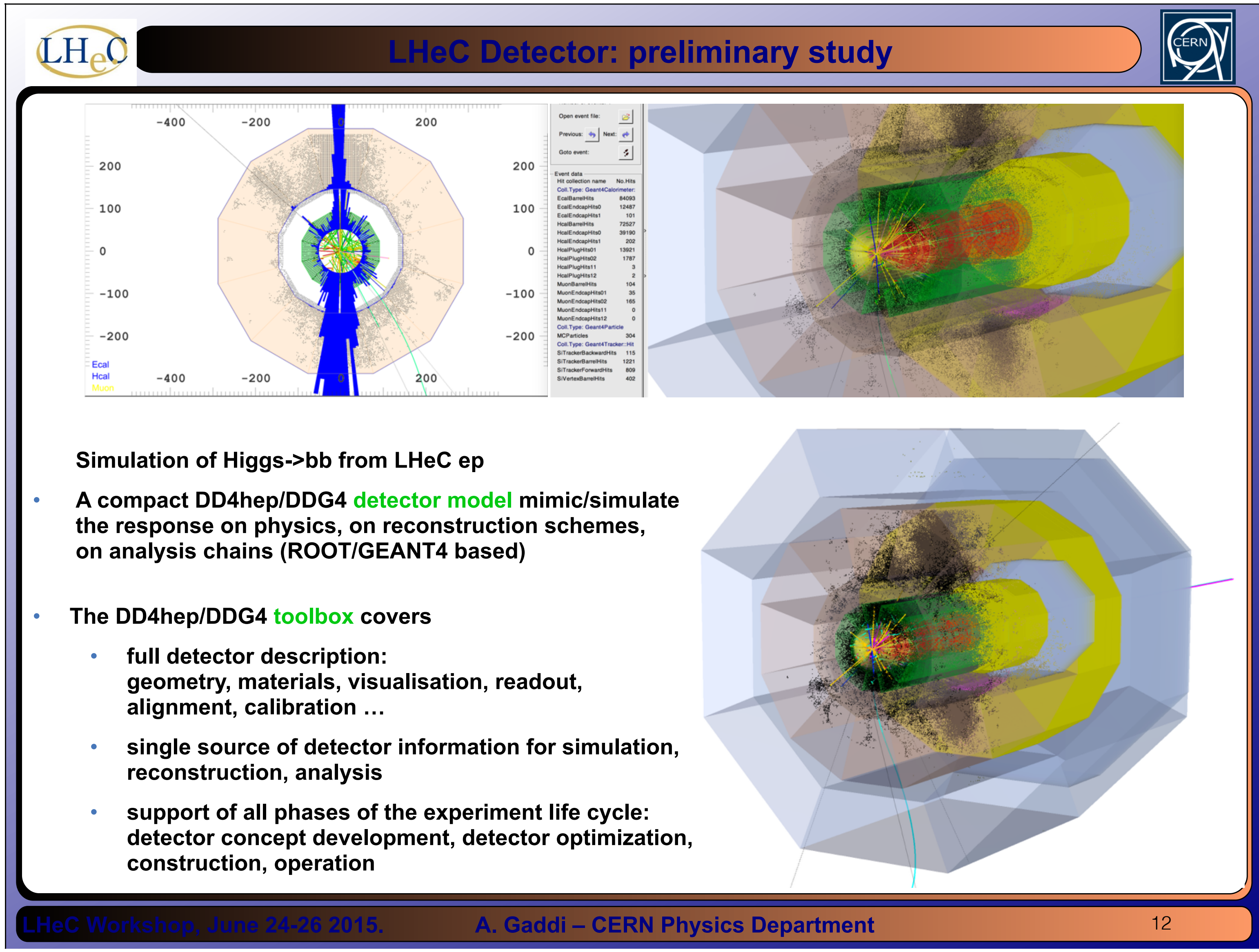

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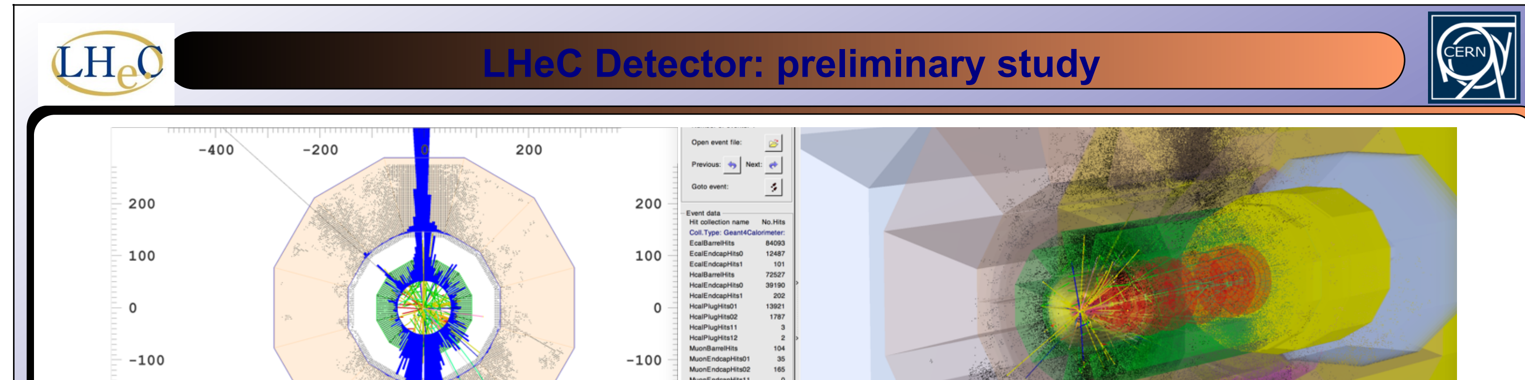
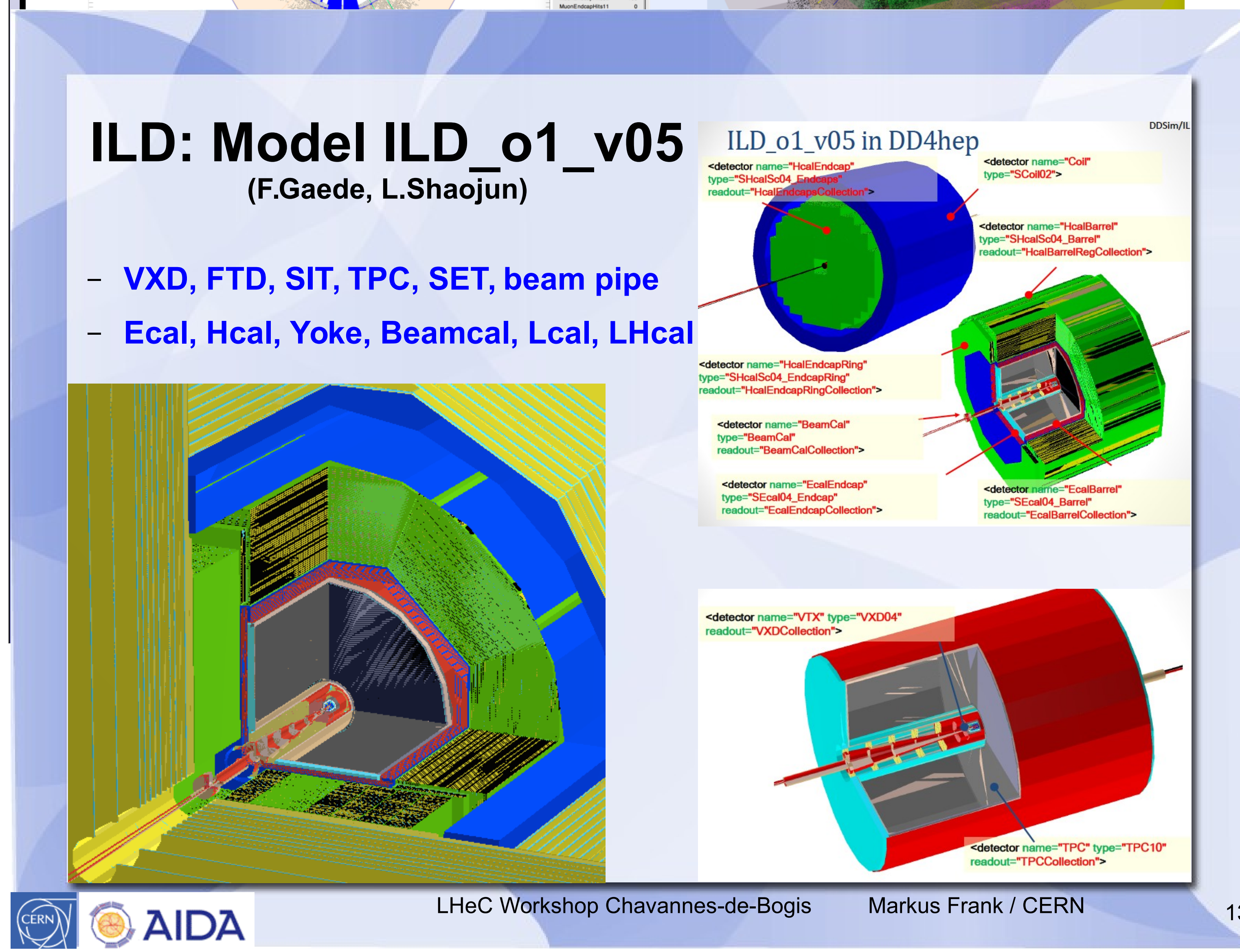


Thanks to all of the DD4hep/DDG4 developer group!

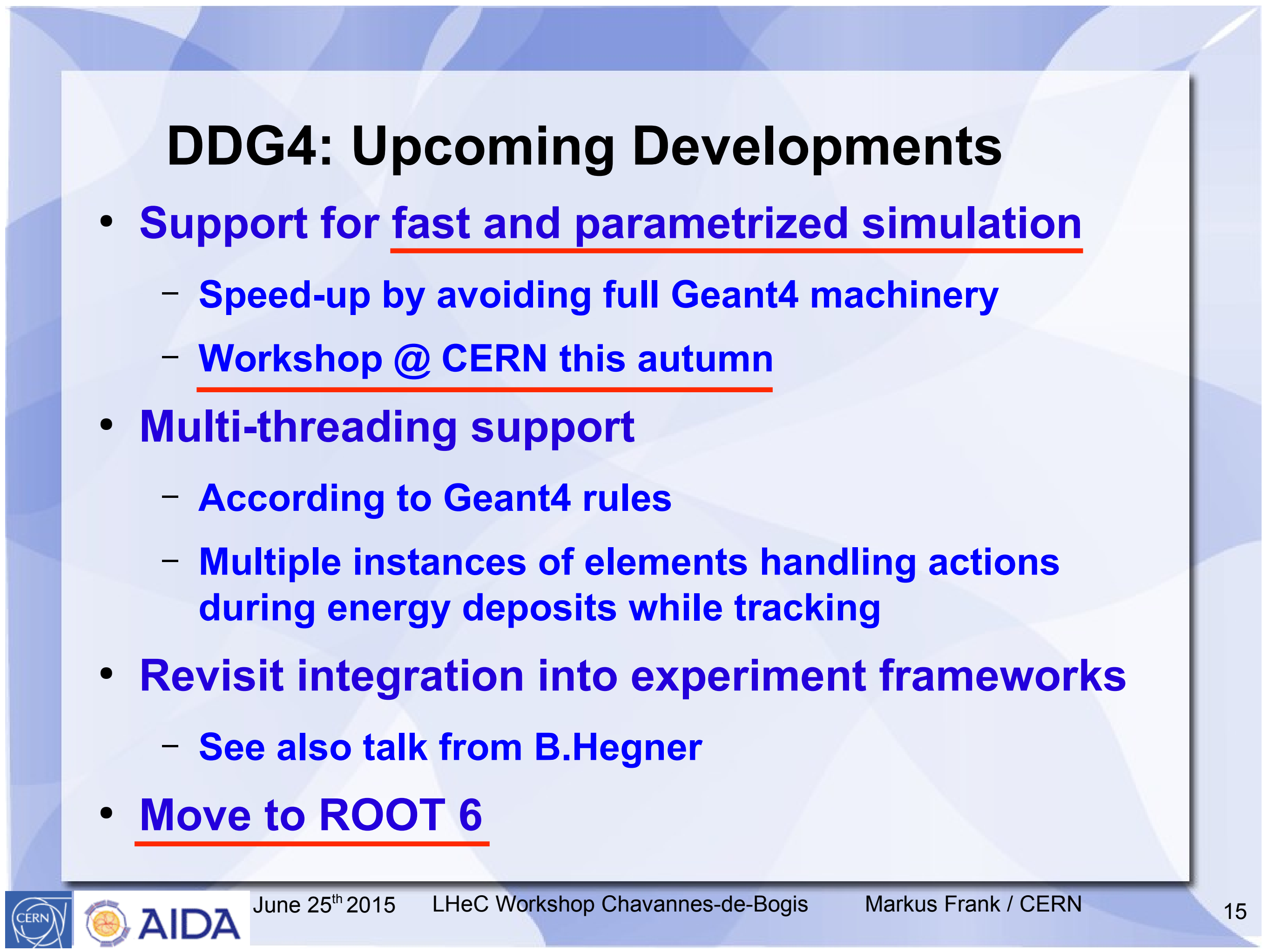
Already more refined ⇒

the ILD detector - its simulation and (Simulation = Geometry + Detector response + Physics), reconstruction interfaced to existing software modules



You get for "free": Automatic conversion from ROOT to Geant4 volume definitions based on compact detector description in xml - the central and only definition

Markus Frank: DD4hep - Detector Description Toolkit



Markus Frank: DD4hep - Detector Description Toolkit

DDG4: Upcoming Developments

- Support for fast and parametrized simulation
  - Speed-up by avoiding full Geant4 machinery
  - Workshop @ CERN this autumn
- Multi-threading support
  - According to Geant4 rules
  - Multiple instances of elements handling actions during energy deposits while tracking
- Revisit integration into experiment frameworks
  - See also talk from B.Hegner
- Move to ROOT 6

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Summary and Outlook

- The DD4hep toolkit (+extensions) start to become accepted: Client validation has started
- Simulation kit DDG4 being validated
- Alignment support to be completed
  - Requires conditions support for full functionality => DDCond: extension to be developed
- Validate, verify, enhance and document
- Happy to welcome new users and their contributions

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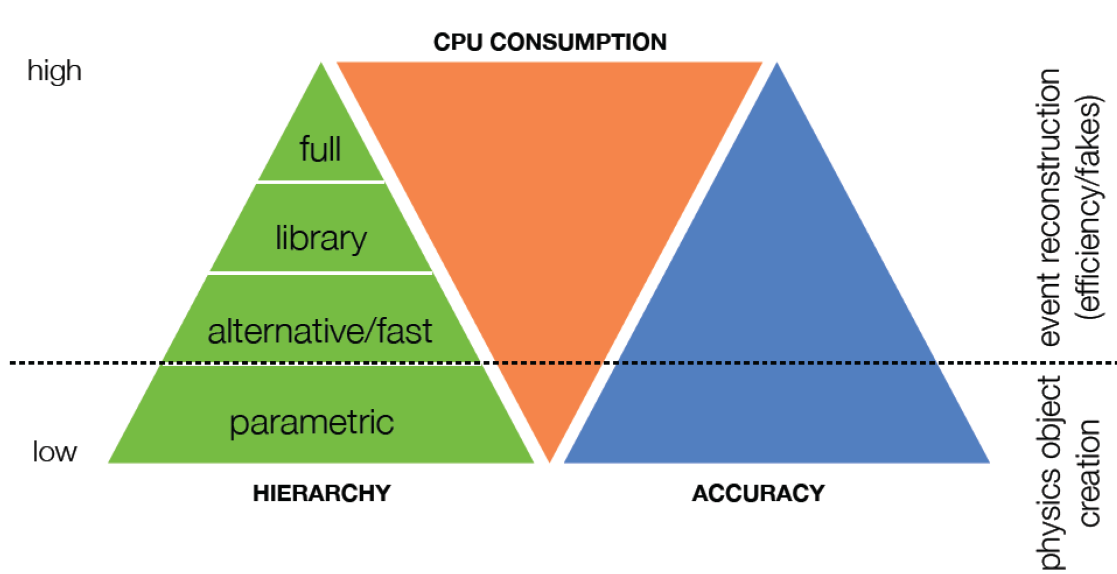
Andreas Salzburger:
Simulation & Reconstruction SW for FCC

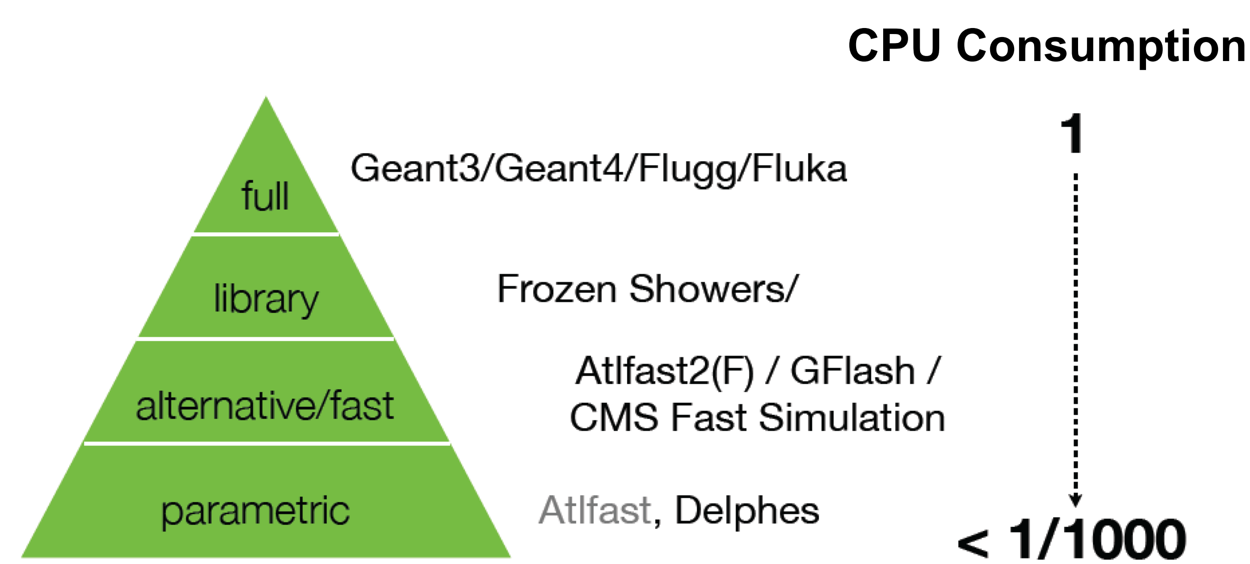
Andreas: "joined the FCC SW project because I think we should learn from the past and make things better (i.e. I'm an optimist)"

Covered ATLAS (CMS) based experiences:
- SW frameworks & Event Data (also Benedict's talk)
- ATLAS/CMS adopted the GAUDI framework (from LHCb - Markus is one of the Authors); rewritten for CMS
load on software performance from: multiplicity (HE), pileup, trigger requirements
⇒ consequences for Simulation

Simulation

- Techniques & concepts, e.g. ATLAS

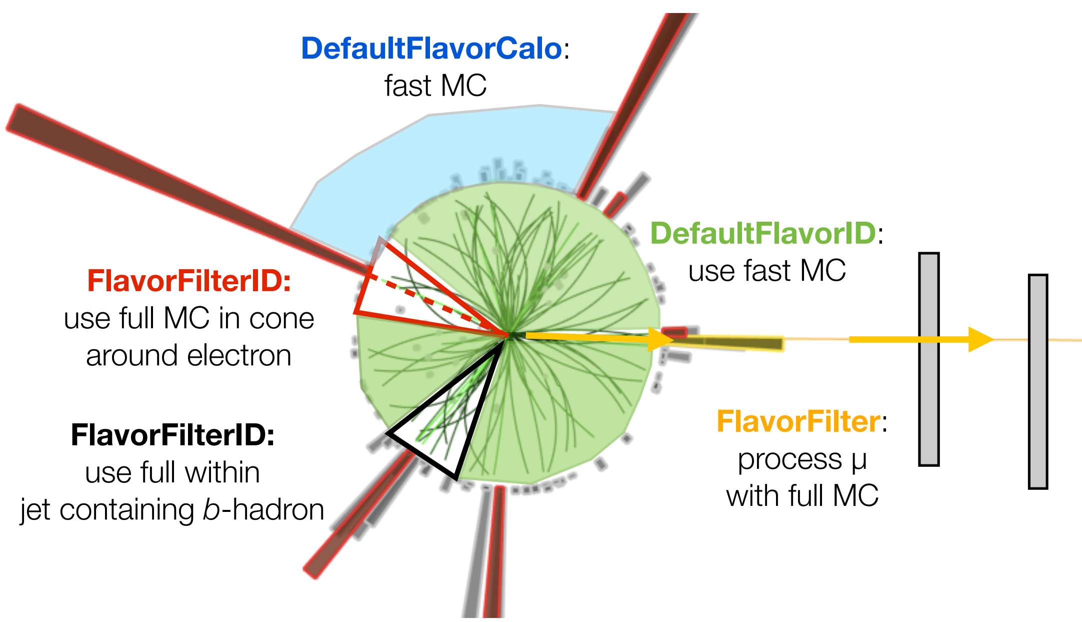




Andreas Salzburger:
Simulation & Reconstruction SW for FCC

Simulation: the ATLAS ISF project (-> Julia)

- One framework to combine full and fast simulation techniques
  - within one job
  - within one event (e.g. in different sub detectors)
  - within one detector (in regions of interest)



A. Salzburger - Simulation & reconstruction software for FCC-ee-eh-hh - June 26th, 2015

12

Reconstruction & analysis SW

- Common reconstruction software:
  - not obvious that one shoe fits all
    different needs for different setup (μ)
  - but the fabric and tools SHOULD be shared
    e.g. infrastructure (geometry, EDM): see talks of Benedikt, Julia
    track fitters (Kalman/GSF/EArm)
  - many excellent solution around (and stress-tested) at the LHC
    tracking, calorimetry, particle flow, b-tagging, etc.
- My advice: let's take what's good and rewrite the rest
  - what an obviously bold statement …
- Not entirely clear what the licensing situation is though
  - different experiments have different SW licence policies

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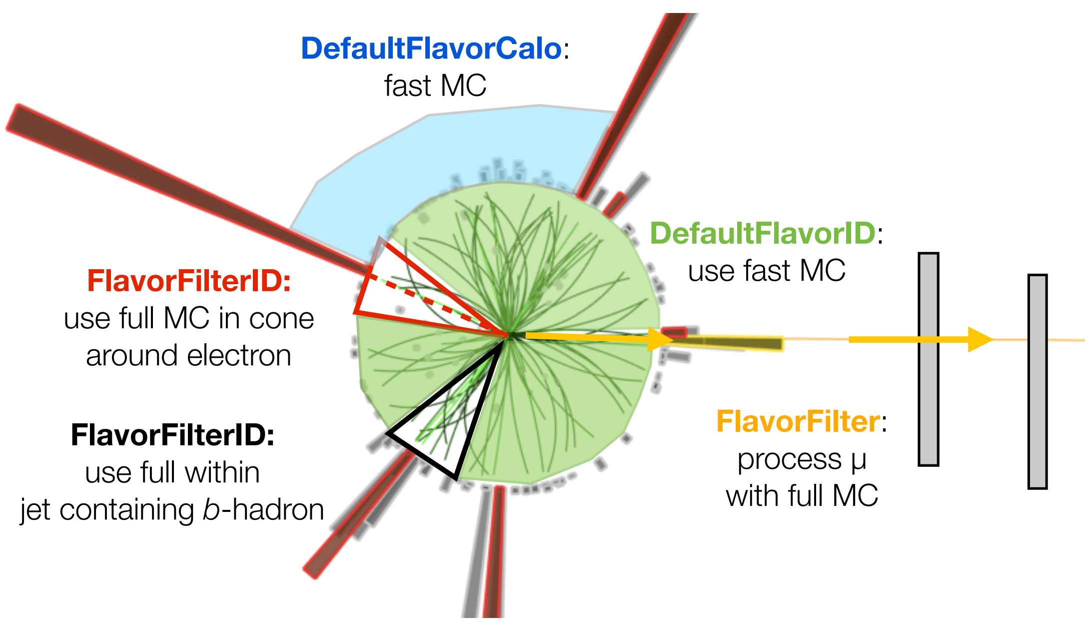

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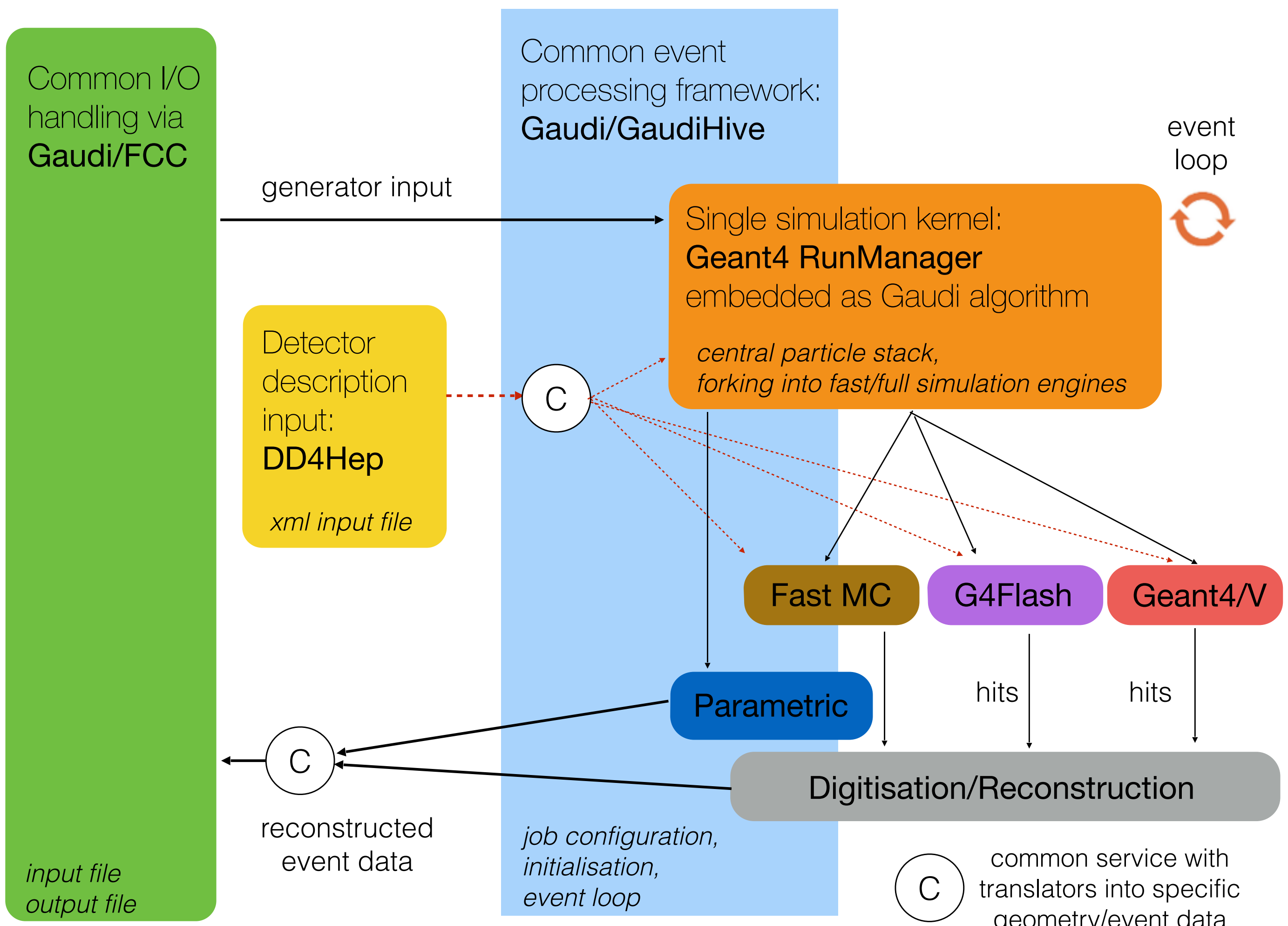
It is vital for the LHeC software environment getting a conversion from ROOT to FLUKA volume definitions (eA physics); reuse the (envisaged) developments from ATLAS !

Julia Hrdinka:
The Tracker Description and Interface to Gaudi
Experiences and first Results

Using elements of DD4hep toolbox - xml-description, volumes creation
- unfolding of volumes (ROOT) in GAUDI (ATLAS version), conversion for GEANT4
- solved the interfacing to ATLAS tools (simulation - fast& detailed, reconstruction).
- invent new layer and module handling (surfaces)

Common software framework



© A. Salzburger

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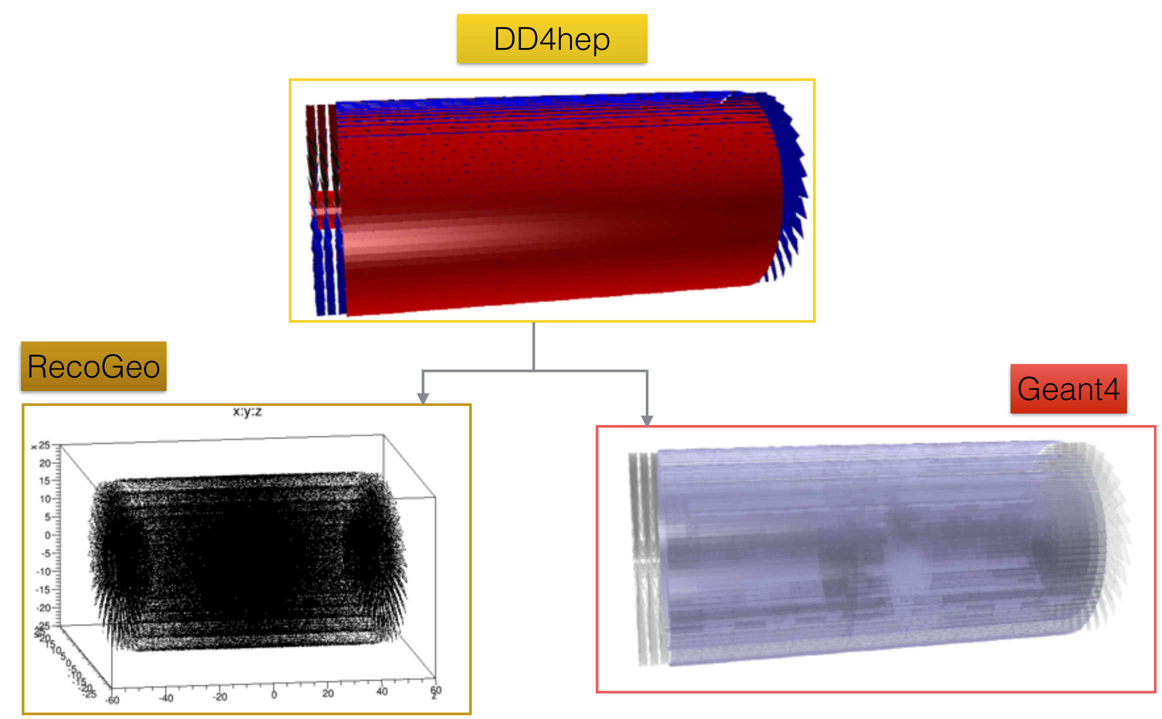
Comparing geometries



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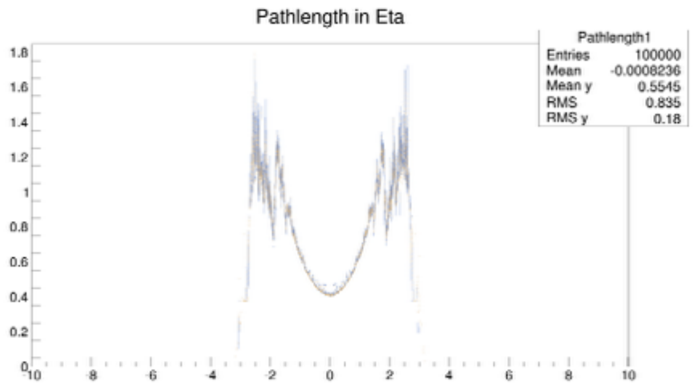
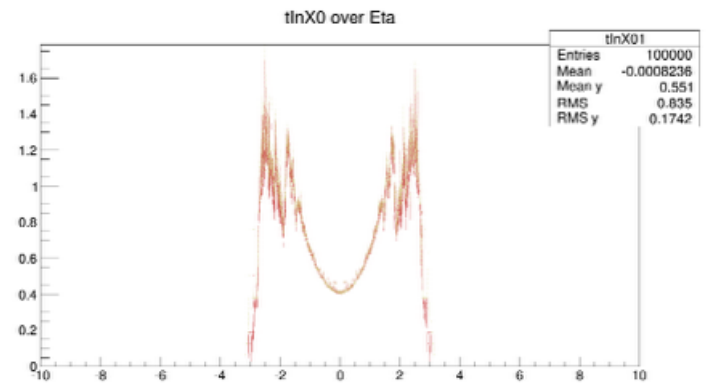
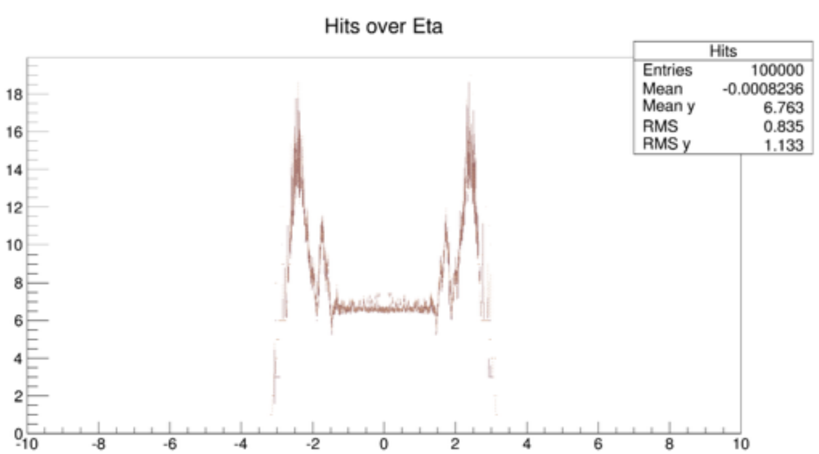
Julia Hrdinka:
The Tracker Description and Interface to Gaudi

Experiences and first Results

Geant4 vs. RecoGeo ✓







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Conclusion & Next steps

- We are able to build a first test tracker and provide it in the Geant4 and the reconstruction geometry
- Implementation of magnetic field transport & track fitting from ATLAS code
- Proof of principle
  - both full and fast simulation can be invoked from one common source
  - compare output
  - create tracks from truth particles via full simulation and fast simulation
  - input for parametric simulation

Summary: Physics and Detector.

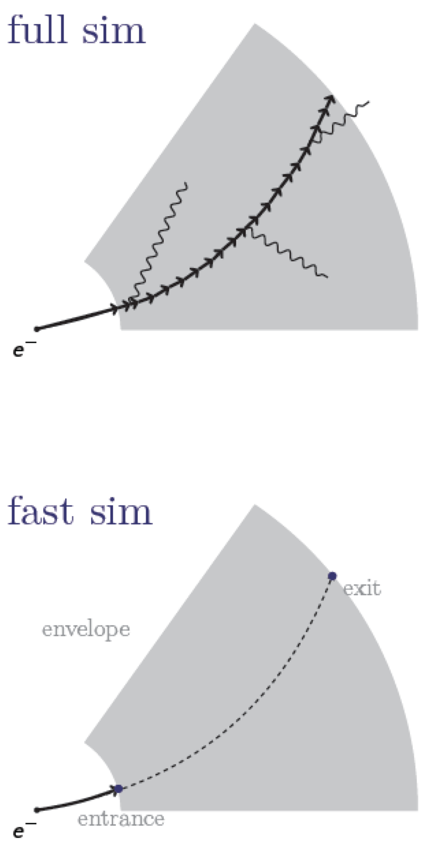
Anna Zaborowska:
The Fast Simulation for FCC in GEANT,

First experiences integrating the ATLAS tracker tool

Underlined the importance of having
"both fast and full simulation together in one framework"
with Geant4 group (Federico, Alberto, ...)

Common software framework - Gaudi (with FCC Software group (Benedikt, …))

Geant 4



Geometry - DD4hep (Julia Hrdinka and Andi Salzburger)

taking into account
momentum/energy smearing (CMS like & AtlFast)

FCC fast simulation with Geant4: first working prototype integrated into a common software framework (GAUDI)

Plans:
- **integration of single-particle reconstruction into GAUDI;**
- **extending the fast (parametric) simulation (efficiency, misidentification, separation in the calorimeters …);**

Incorporated in future GEANT4 release

Benedikt Hegner: FCC Software Overview

FCC Software needs to support the studies of multiple detectors
At different stages different level of detail required
- Smearing vs. fast sim vs. full sim

FCC choices are
- Delphes
- Fast simulation
- Full simulation with Geant4
- Common Event Data Model
- C++ and Python

Delphes has been (mostly) integrated into the FCC SWF
Fast Simulation in FCC -

PAPAS is a PArametrized PArticle Simulation package (Colin Bernet)
- based on particle flow experience mainly from CMS
- prototyping environment for new algorithms in Python
- 'integrated' into FCC software by using the same EDM

First iteration of tracking data model finished
Manpower very critical!

Many software efforts going on in parallel

Please sign up and join!

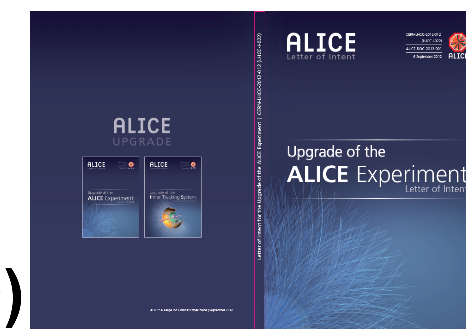
Luciano Musa:
The ALICE Si-Tracker for the HL-LHC

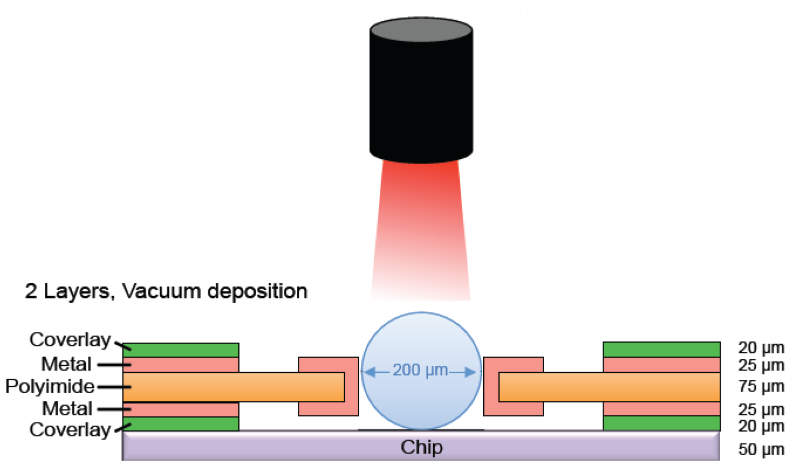
Could serve as template when going for a realization of central trackers in the LHeC-Detector

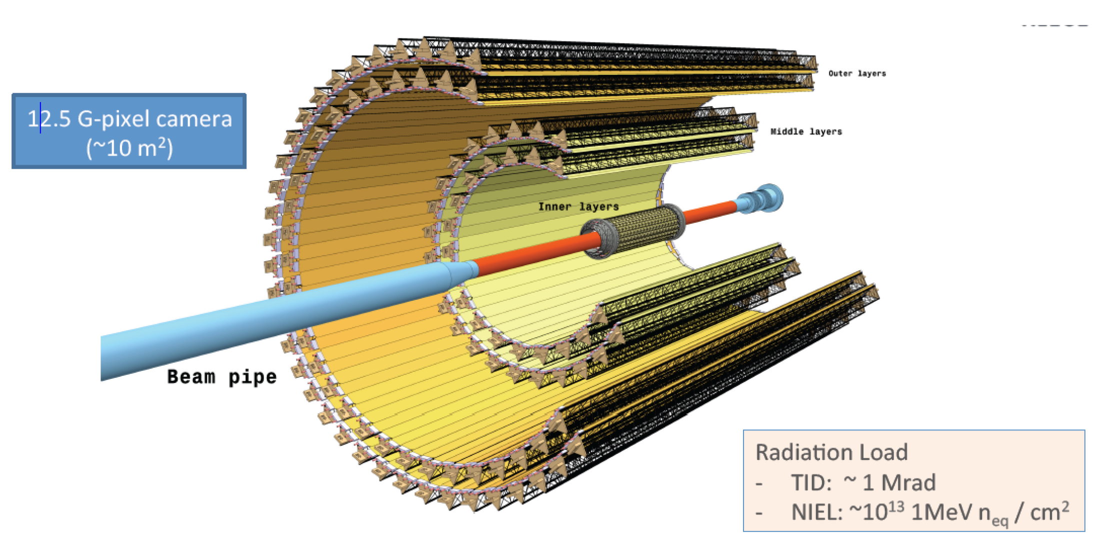
- **low material budget   0.3% - 1.1% X_0**
- **very low power consumption !   (faster R/O would require more; but separation of tracking and time supplying modules possible)**

ALICE Upgrade Strategy
- **maximum rate of 50kHz R/O**
- **improvement of vertexing and tracking capabilies at low p_T**

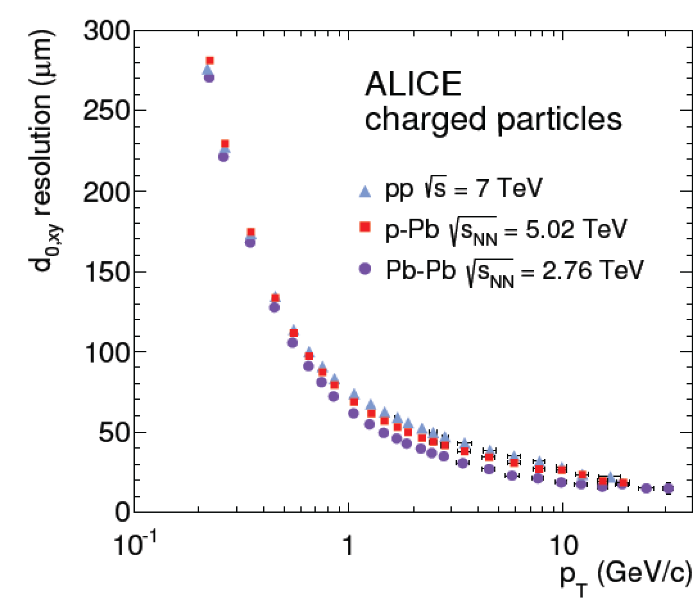
- **New Inner Tracking System - targets LHC Long Shutdown (2018/19)**







Very weak dependence on the colliding system



ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

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All in all: 25 talks.

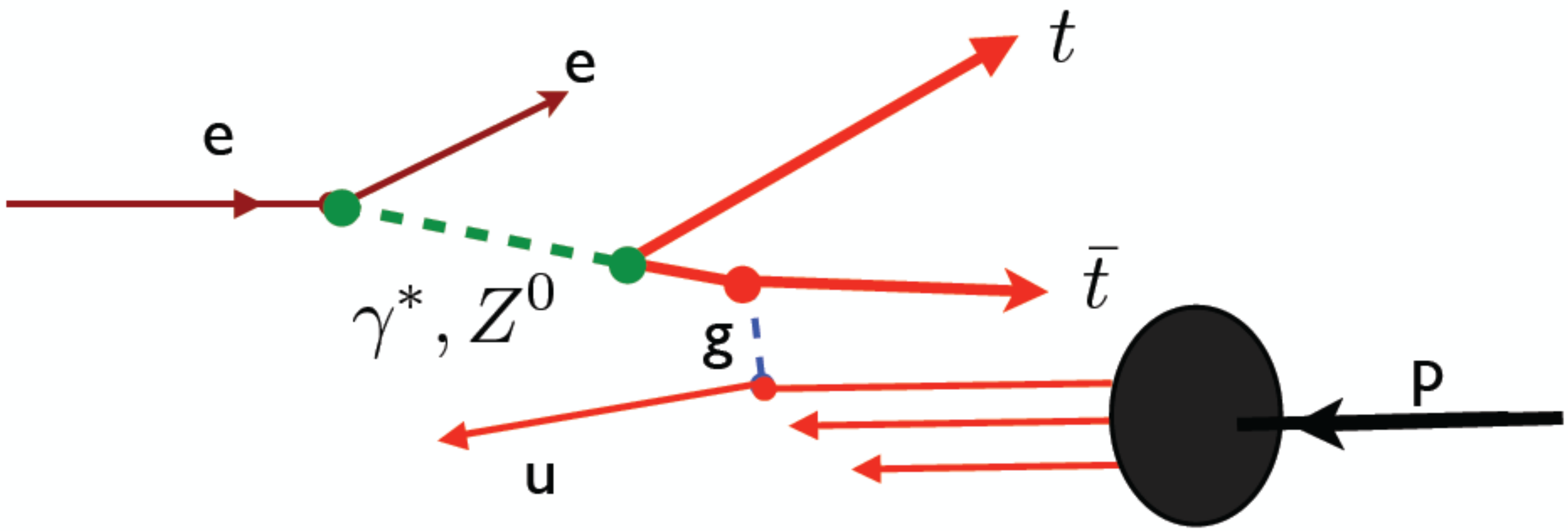
New ideas [Brodsky]

LHeC: Virtual Photon-Proton Collider

Inclusive Top Electroproduction at the LHeC

$t-\bar{t}$ asymmetry from γ^* and Z^* or $\gamma^*\gamma^*$ interference

Dual Interpretation: Top quark in photon vs. heavy sea quark in proton



$t\,\bar{t}$ Plane correlated with Electron Scattering Plane

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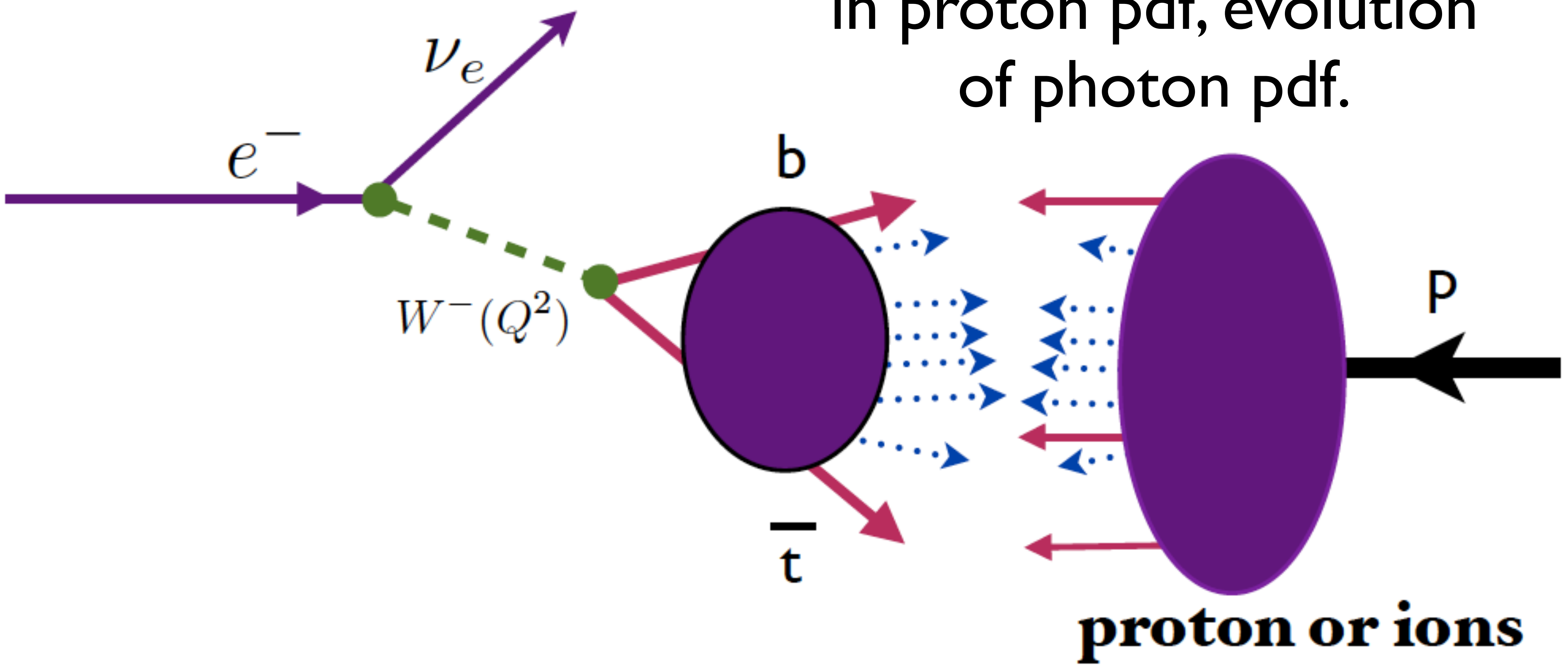
LHeC Physics Highlights

Stan Brodsky

New ideas [Brodsky]

LHeC: "W-Proton Collider"

In the collider frame: contributions not included in proton pdf, evolution of photon pdf.



Only partially included by DGLAP in proton pdf

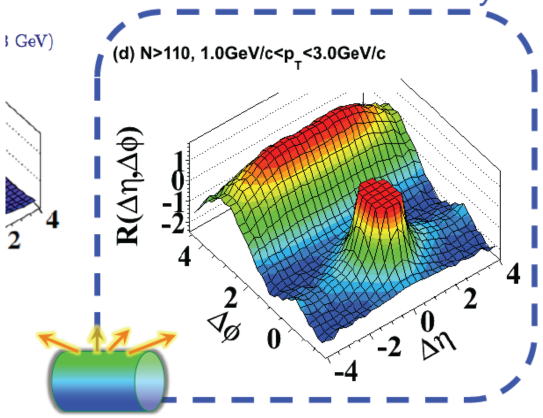
Enhancement at threshold

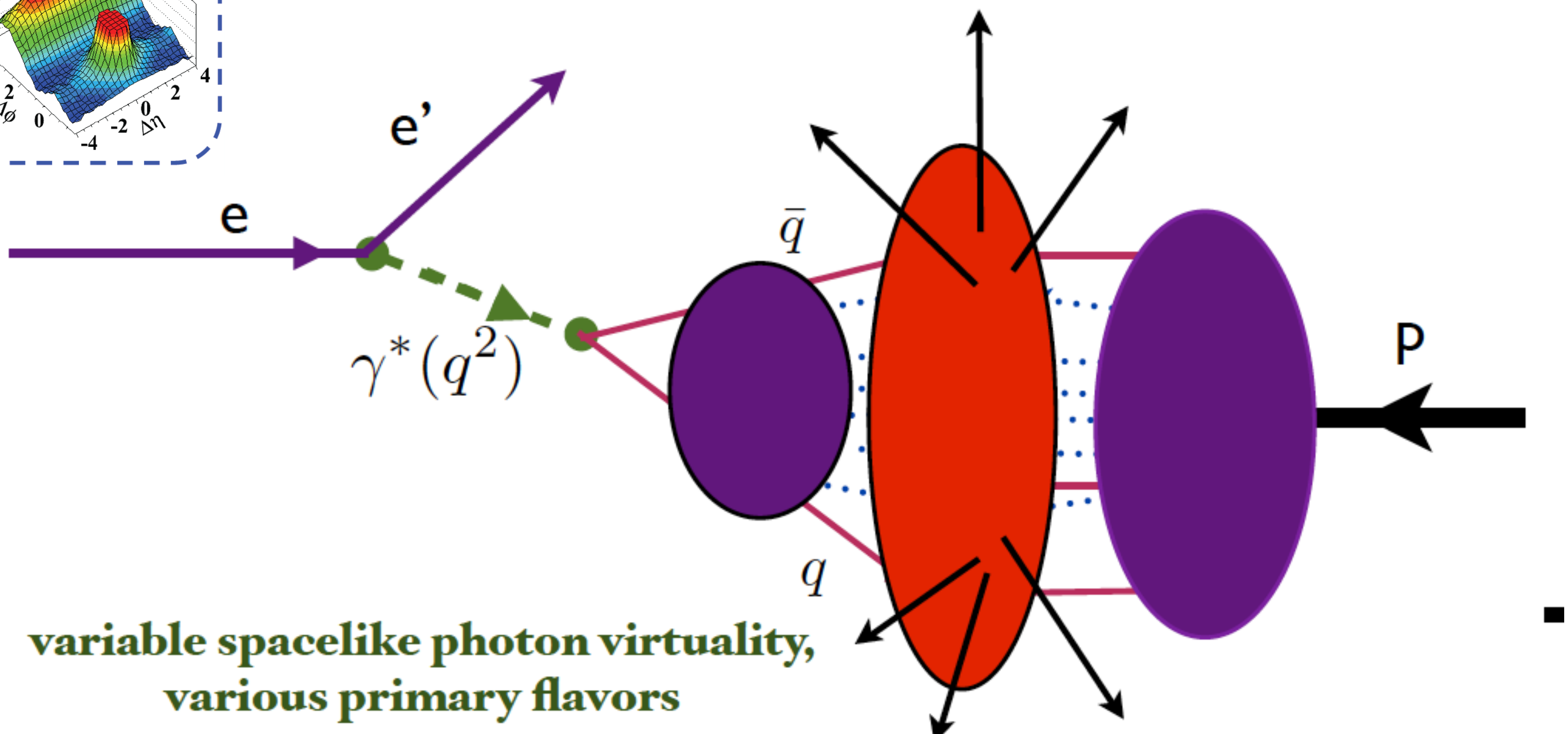
New ideas [Brodsky]

LHeC: Virtual Photon-Proton Collider

Control of the ridge in ep/eA through lepton plane

Perspective from the e-p collider frame





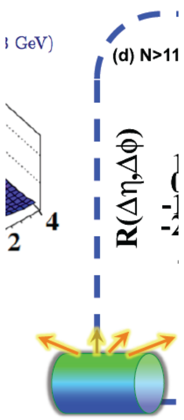
**variable spacelike photon virtuality,
various primary flavors**

photon and proton fragmentation vs. central regions

Collisions of Photon and Proton Flux Tubes

New ideas [Brodsky]

LHeC QCD Physics Highlights



lane

- Diffractive Deep Inelastic Scattering
- Electroproduction of vector mesons - test confinement
- Non-Universal Anti-Shadowing
- The Odderon
- Deeply Virtual Meson Production and Color Transparency
- Heavy Quark Interactions at Threshold
- Heavy Quark Distributions at High x
- Higgs Production at high x_F

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LHeC Physics Highlights
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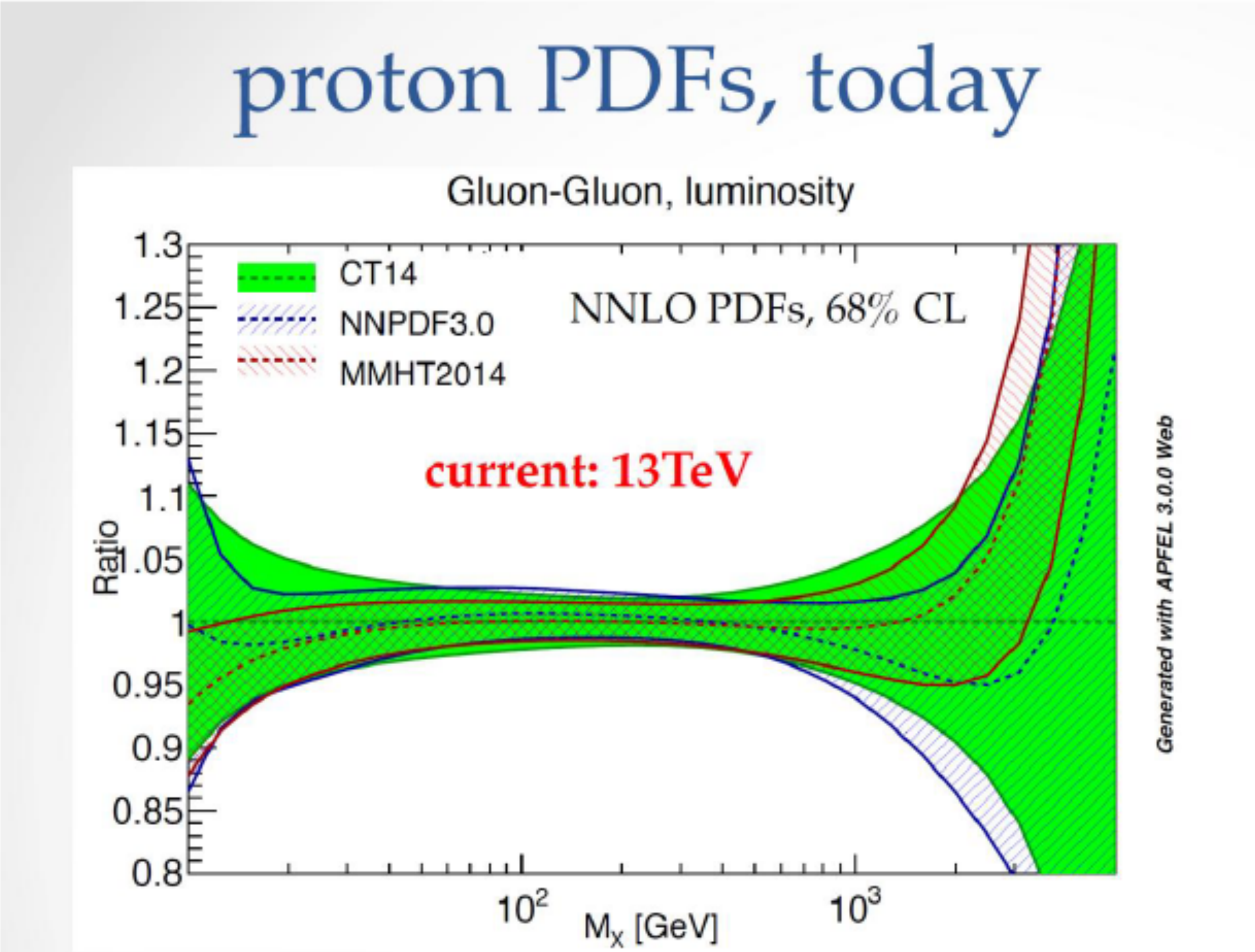
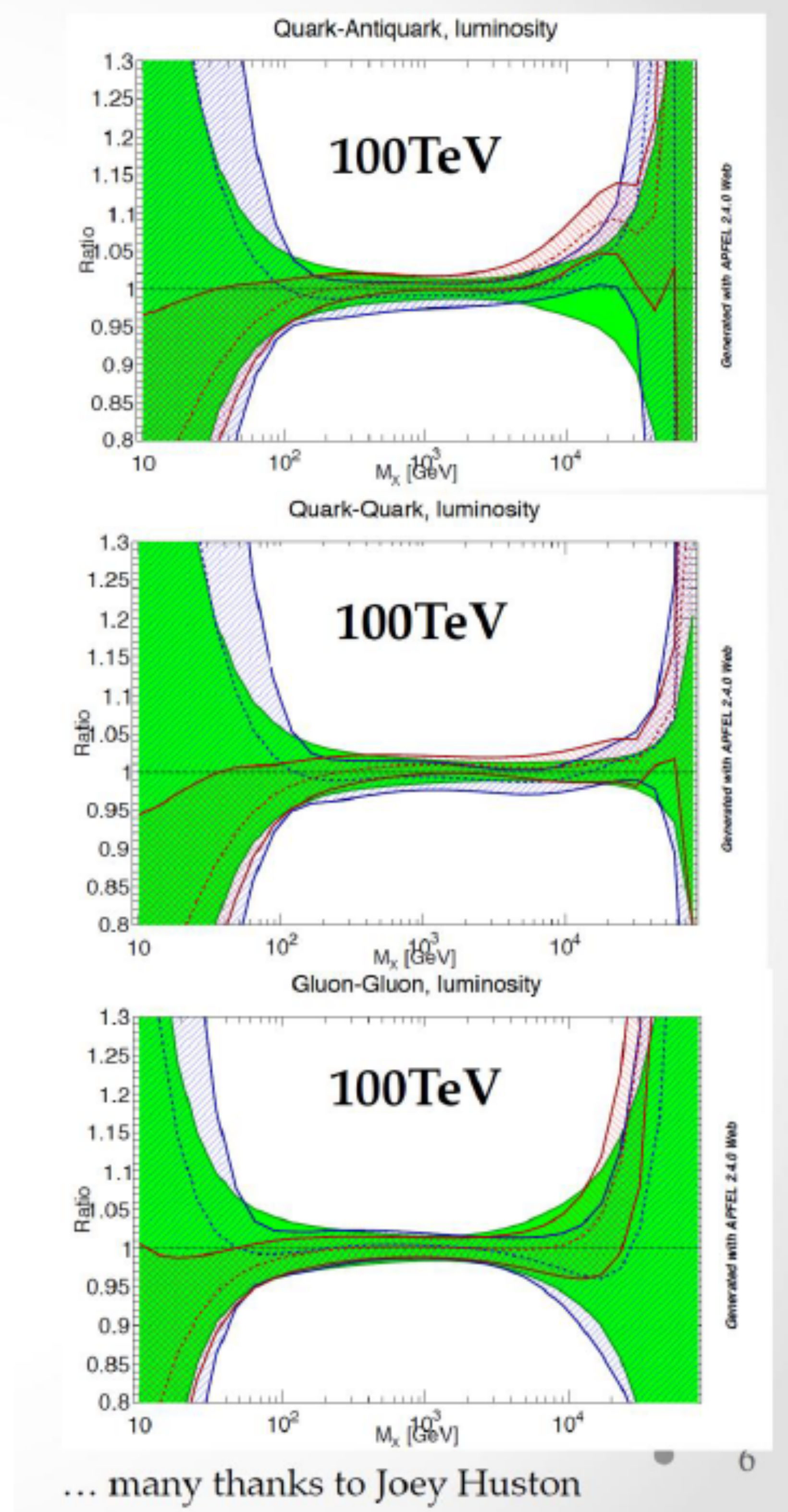
Stan Brodsky

PDF status [Cooper-Sarkar]

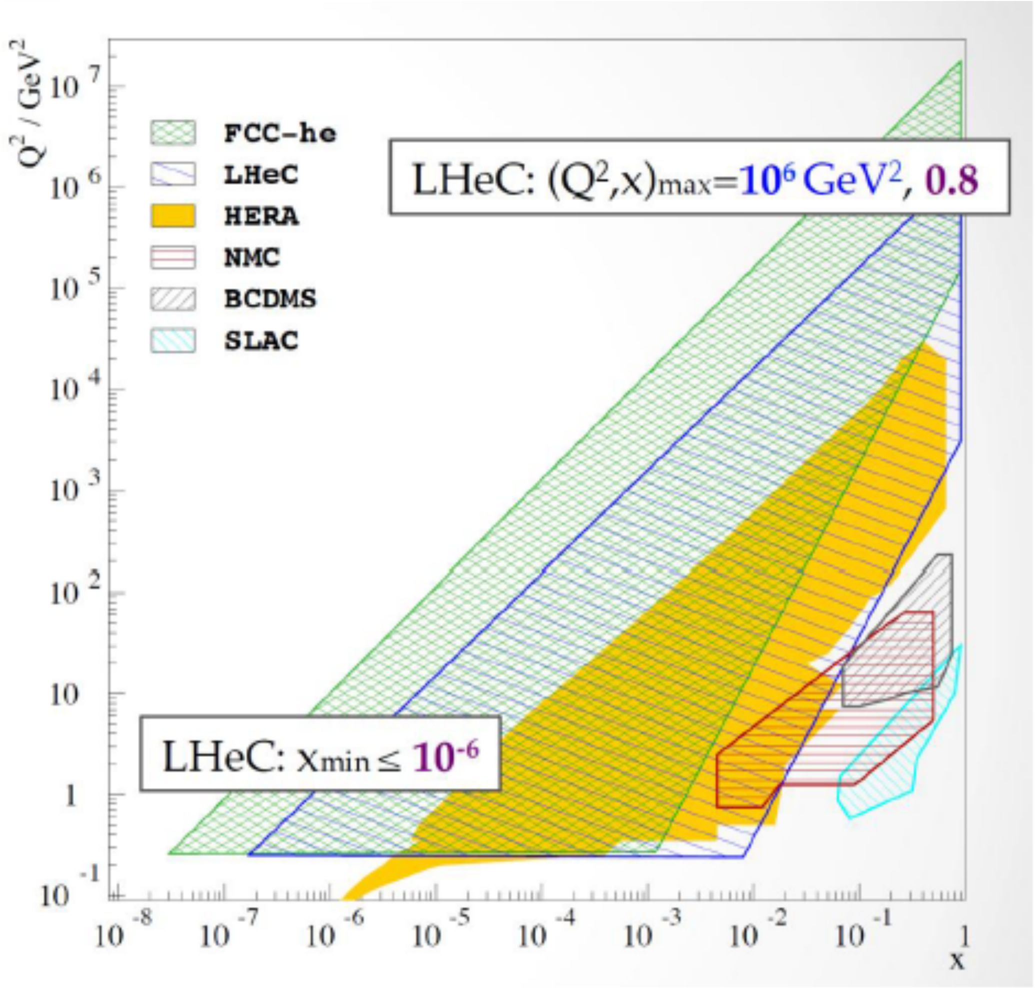




Current level of knowledge of PDFs at 13TeV (including Run-I LHC data) still have considerable uncertainty at high scale BUT at future colliders the low scale region will also have large uncertainties

Forward production
Small/large x related

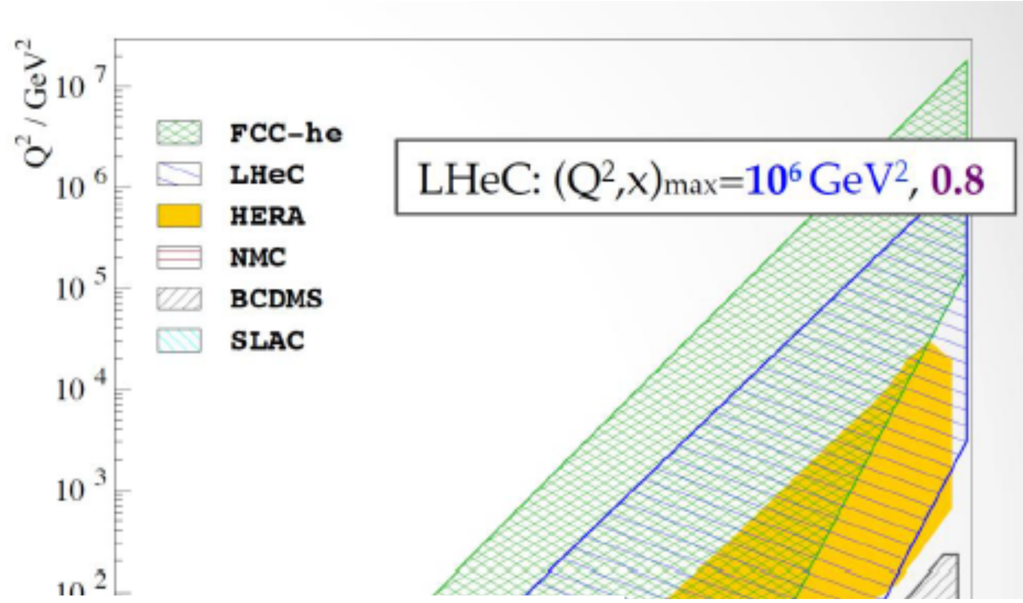
PDF status [Cooper-Sarkar]



The LHeC represents an increase in the kinematic reach of Deep Inelastic Scattering and an increase in the luminosity.

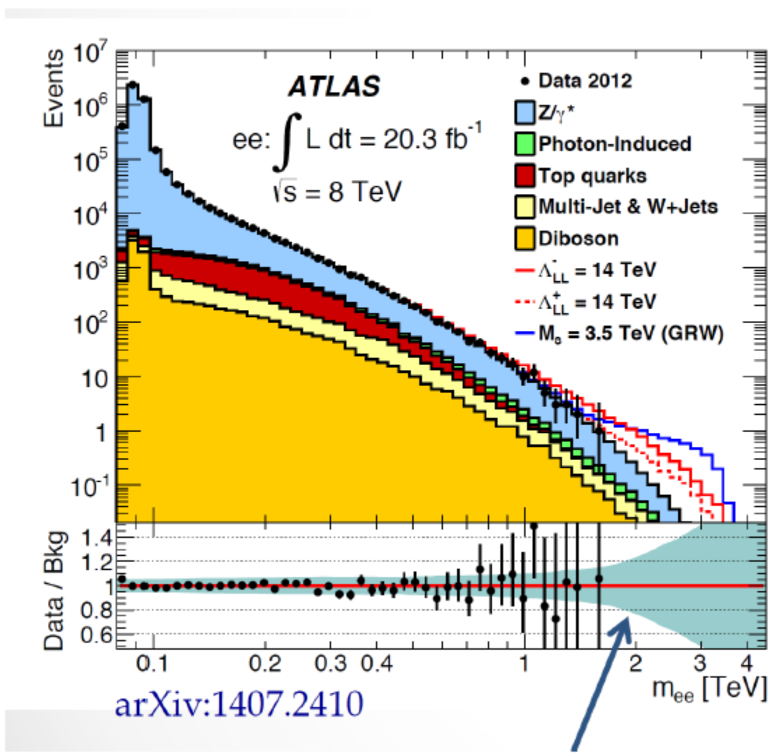
- This represents a tremendous increase in the precision of Parton Distribution Functions
- And the exploration of a kinematic region at low-x where we learn more about QCD- e.g. is there gluon saturation?
- Precision PDFs are needed for BSM physics
- PDFs in an extended kinematic region will also be needed for any FCC

PDF status [Cooper-Sarkar]



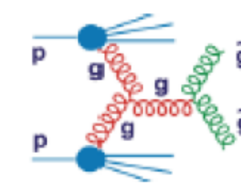
Why are we interested in the high-x sea?-one example

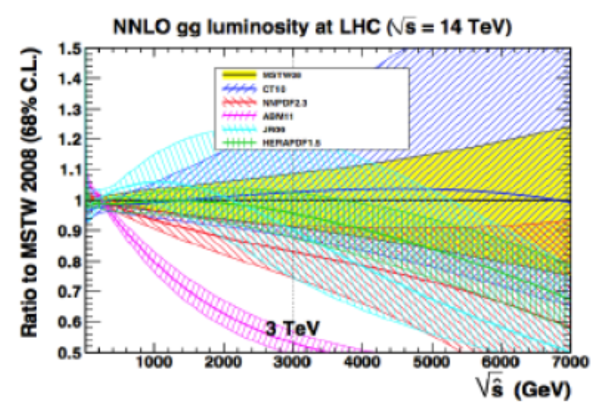
Current BSM searches in High Mass Drell-Yan are limited by high-x antiquark uncertainties as well as by high-x valence uncertainties



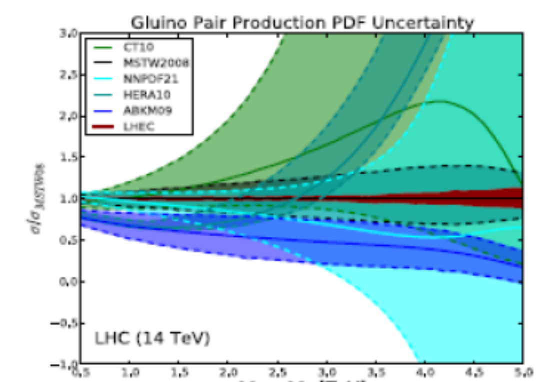
Why are we interested in the high-x gluon?-one example

Many interesting processes at the LHC are gluon-gluon initiated
Top, Higgs…BSM processes like gluon-gluon → gluino-gluino
And the high-scale needed for this involves the high-x gluon
The gluon-gluon luminosity at high-scale is not well-known
This leads to uncertainties on the gluino pair production cross section





σ/σ_{MSTW08}

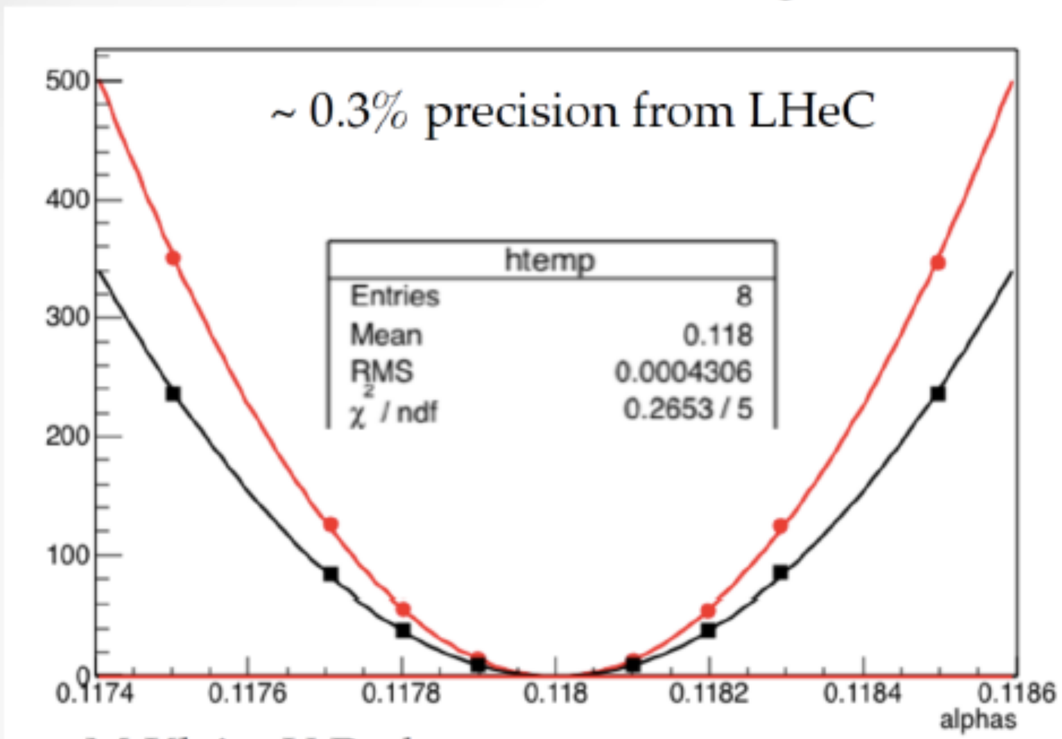


Which could be considerably reduced using LheC data

LHeC PDF status [Cooper-Sarkar]

strong coupling from LHeC

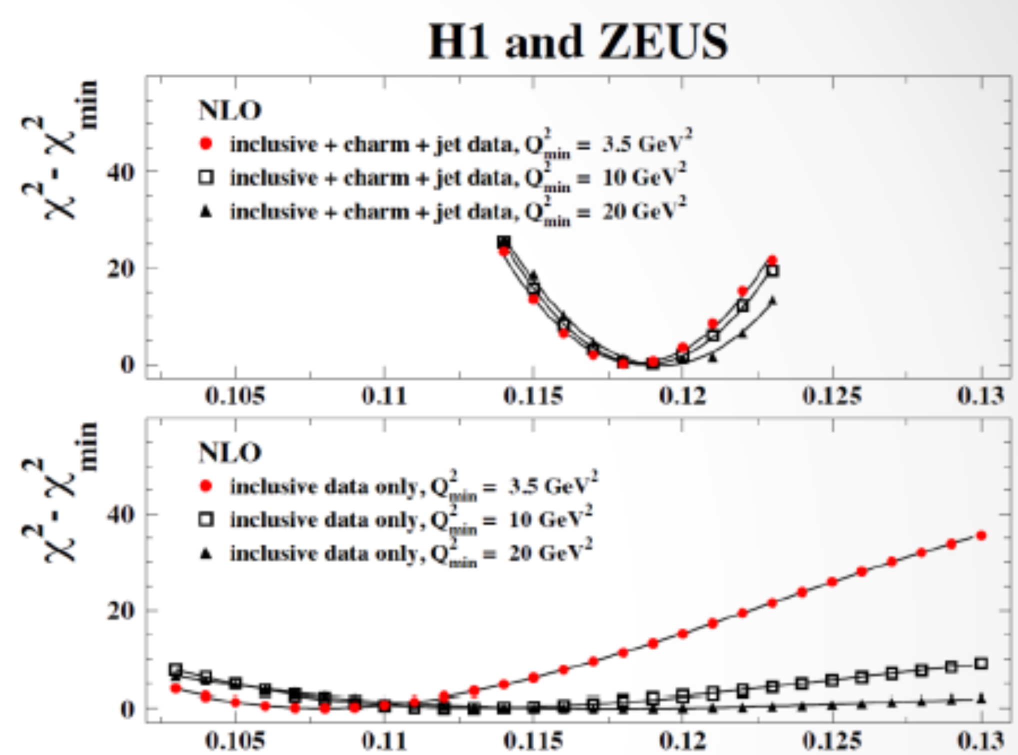
combined fit to PDFs+αs using LHeC data

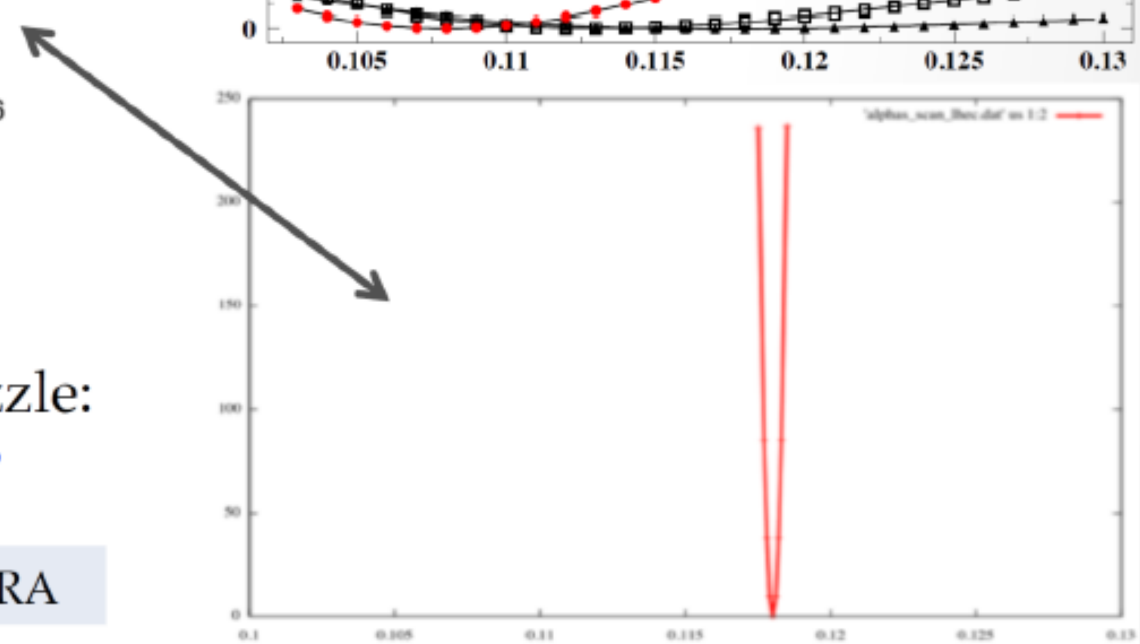


M Klein, V Radescu

NC,CC

NC,CC+F2c





LHeC could resolve a > 30-year old puzzle:

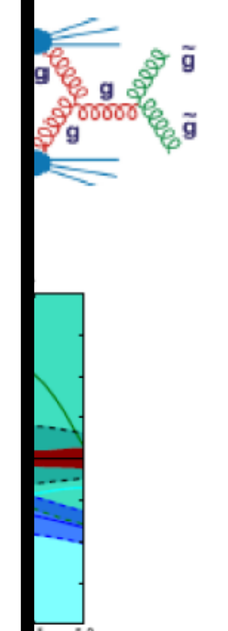
αs consistent in inclusive DIS, versus jets?

expected 0.1% precision when combined with HERA

Current B

uncertain

le



LHeC PDF status [Cooper-Sarkar]

impact of different LHeC datasets

new since CDR
ERL scenario; interest in Higgs prefers e-, high polarisation

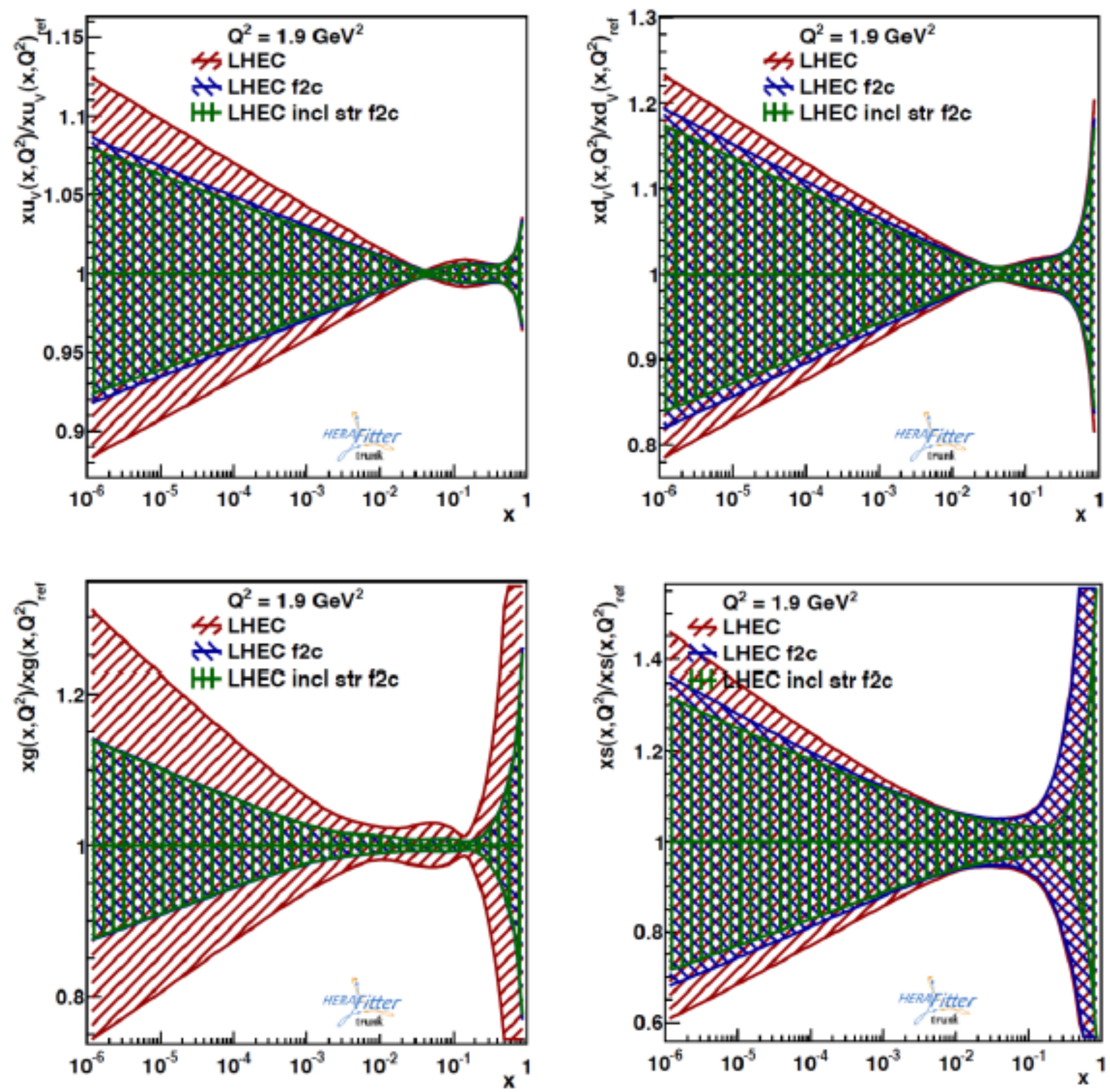
Ep=7 TeV, E=60 GeV:

NC,CC:

	P	L (fb-1)
e+p	0	5
e-p	+80%	50
e-p	-80%	500

plus, dedicated measurements of strange, anti-strange, F2cc
(not yet F2bb, low Ep data, FL)

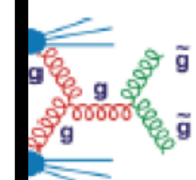
more flexible PDF fit:
xg, xuv, xdv, xub, xdb, **xstr**
$xf(x) = A x^B (1-x)^C (1+Dx+Ex2)$
– 14 free parameters

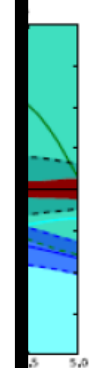


can better constrain all PDFs

Current B
uncertaint

le





LHeC PDF status [Cooper-Sarkar]

impact of different LHeC datasets

new since CDR
ERL scenario; interest in Higgs prefers e-, high polarisation

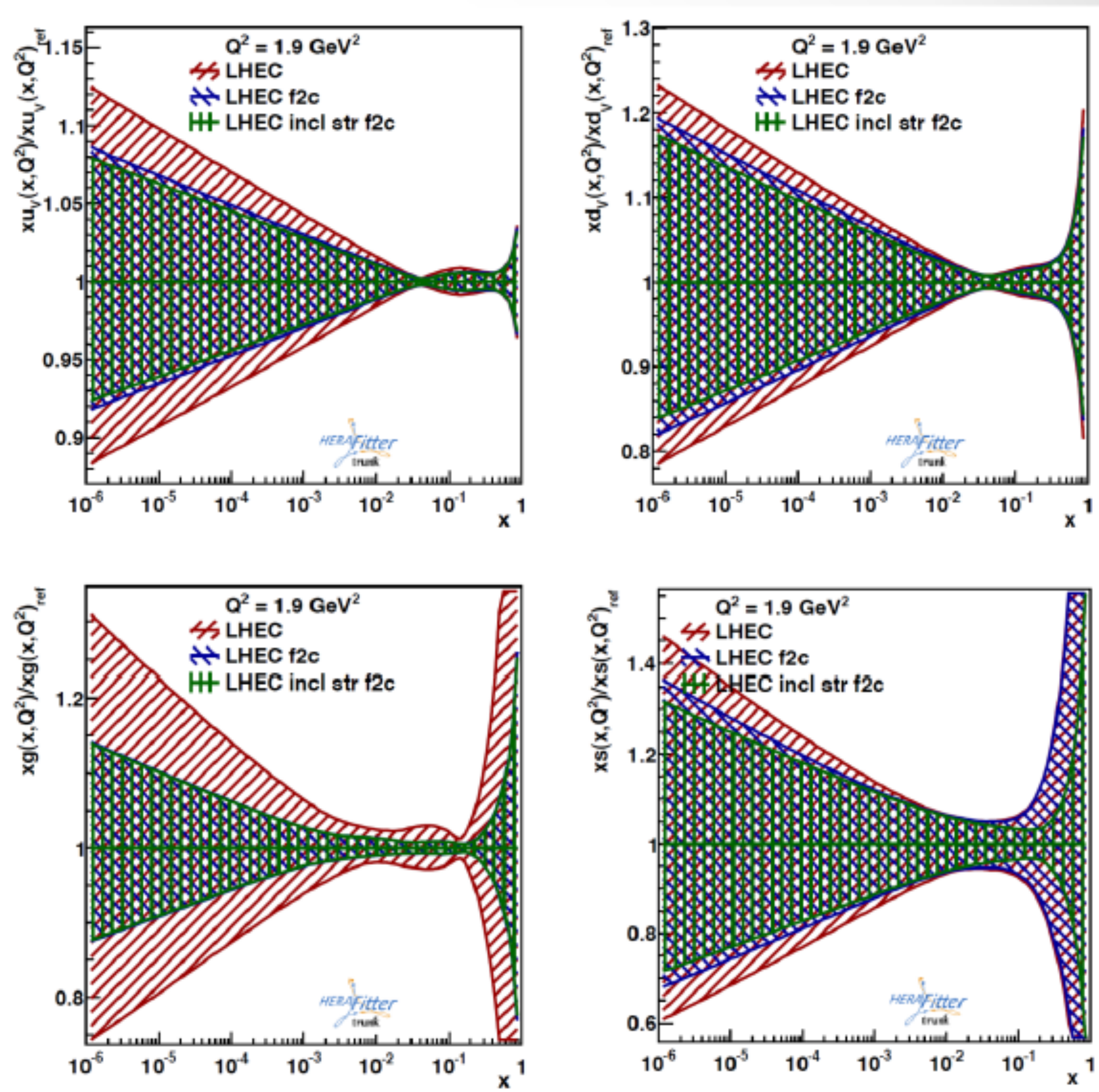
Ep=7 TeV, E=60 GeV:

NC,CC:

	P	L (fb-1)
e+p	0	5
e-p	+80%	50
e-p	-80%	500

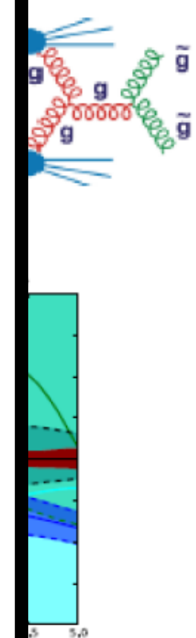
plus, dedicated measurements of strange, anti-strange, F2cc
(not yet F2bb, low Ep data, FL)

more flexible PDF fit:
xg, xuv, xdv, xub, xdb, **xstr**
$xf(x) = A x^B (1-x)^C (1+Dx+Ex2)$
– 14 free parameters



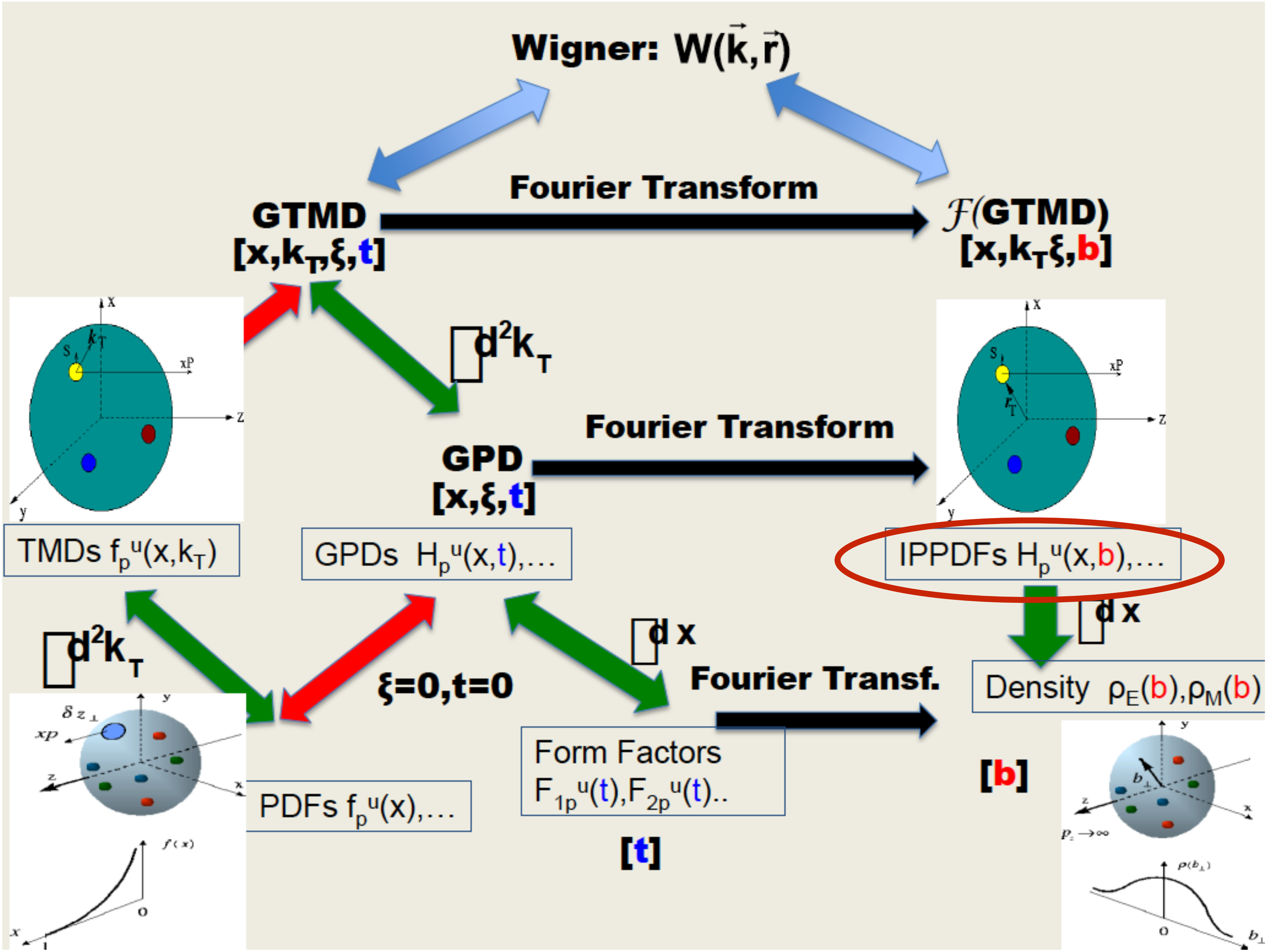
can better constrain all PDFs

Current B
uncertaint



Plus flavour decomposition: s, c, b, t?

GPDs [Liuti]



Wigner: W(k,r)
Fourier Transform
GTMD
[x,k_T,ξ,t]
ℱ(GTMD)
[x,k_Tξ,b]
d²k_T
Fourier Transform
GPD
[x,ξ,t]
TMDs f_p^u(x,k_T)
GPDs H_p^u(x,t),…
IPPDFs H_p^u(x,b),…
d x
d²k_T
ξ=0,t=0
d x
Fourier Transf.
Density ρ_E(b),ρ_M(b)
PDFs f_p^u(x),…
Form Factors
F_1p^u(t),F_2p^u(t)..
[t]
[b]

GPDs [Liuti]

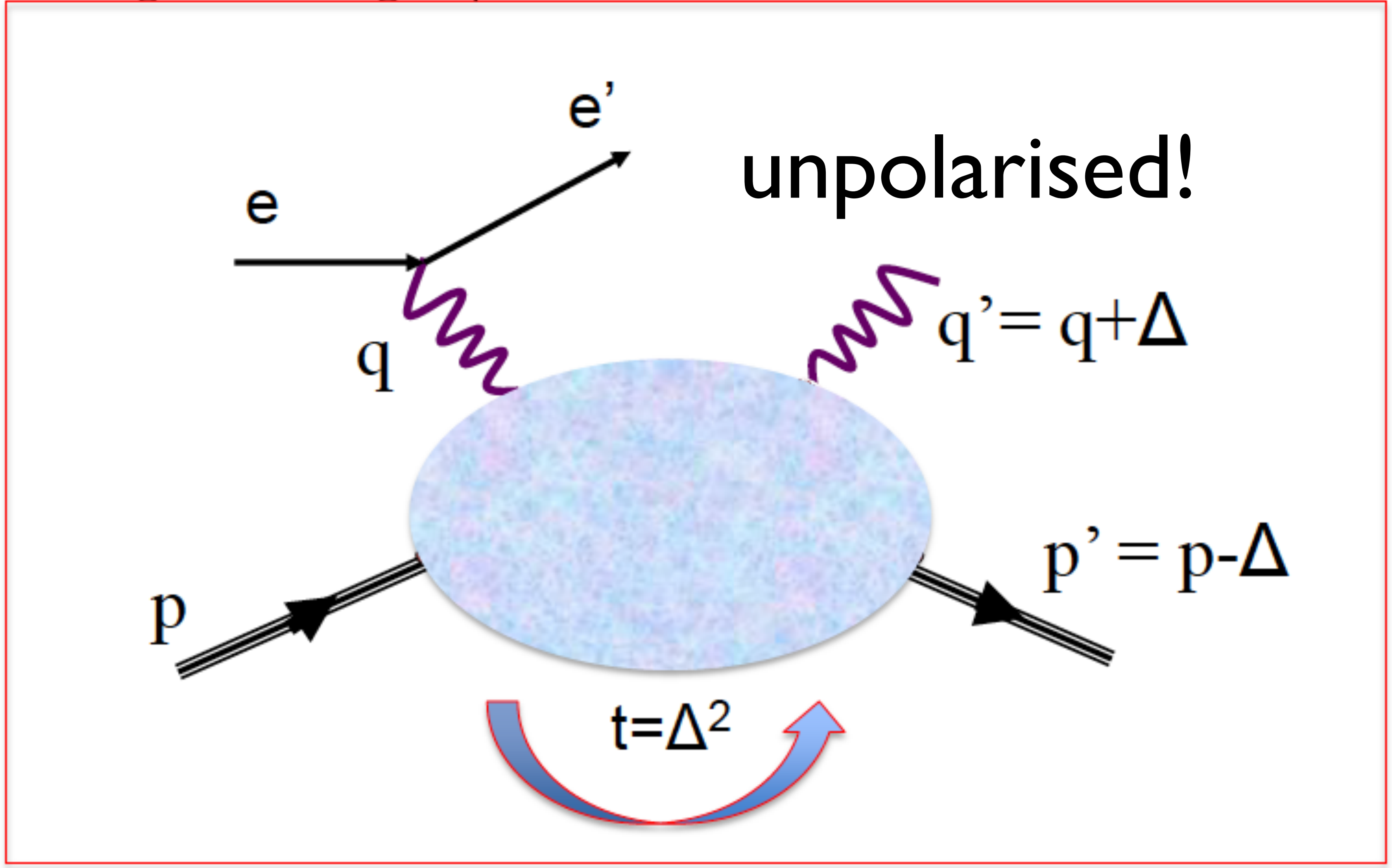
GPDs and Impact Parameter Space: where are the partons located?

M. Burkardt

$$q_i(x, \mathbf{b}) = \int \frac{d^2\mathbf{\Delta}}{(2\pi)^2} e^{-i\mathbf{b}\cdot\mathbf{\Delta}} H_i(x, 0, -\mathbf{\Delta}^2)$$

Joint probability of finding a parton with LONG. momentum fraction x located at a TRANSV. Distance b from the proton's CoM (P^+)

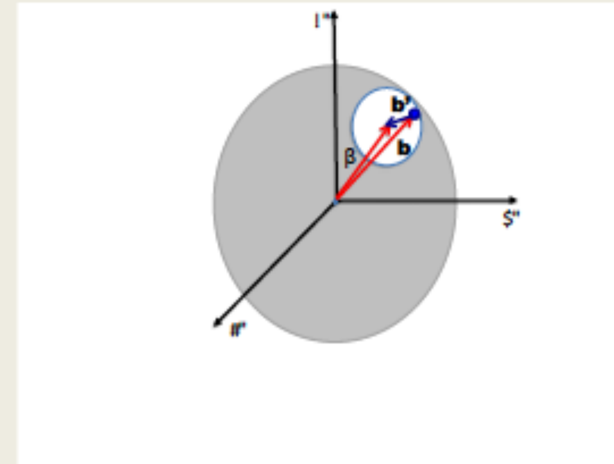
DVCS➔ $ep \to e'p'\gamma$



GPDs [Liuti]

Where are quarks located inside a nucleus?

$$\langle b_A^2 \rangle = \frac{\int d^2 b \, q_A(x,b) \, b^2}{\int d^2 b \, q_A(x,b)}$$



Additive relation

In medium nucleon size

"pointlike nucleon radius

$$\langle b_A^2 \rangle = \frac{1}{q_A(x)} \int_x^A dz \left[\langle b_N^2(x/z) \rangle^A + \langle \beta^2(z) \rangle \right] q_N(x/z) f_A(z)$$

$$\langle b_N^2(x) \rangle^A = \frac{1}{q_A(x)} \int_x^A dz \, f_A(z) \int d^2 b \, b^2 \, q_N(x/z, b)$$

In simple convolution formula the in medium nucleon and free nucleon sizes are the same:

$$\int dx \langle b_N^2(x) \rangle^A \equiv \int \langle b_N^2(x) \rangle^N$$

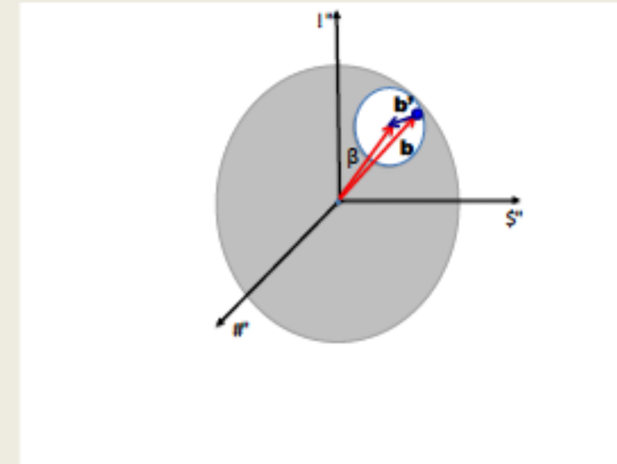
Off-shell effects/parton reinteractions will modify this relation

6/25/2015 18

GPDs [Liuti]

Where are quarks located inside a nucleus?

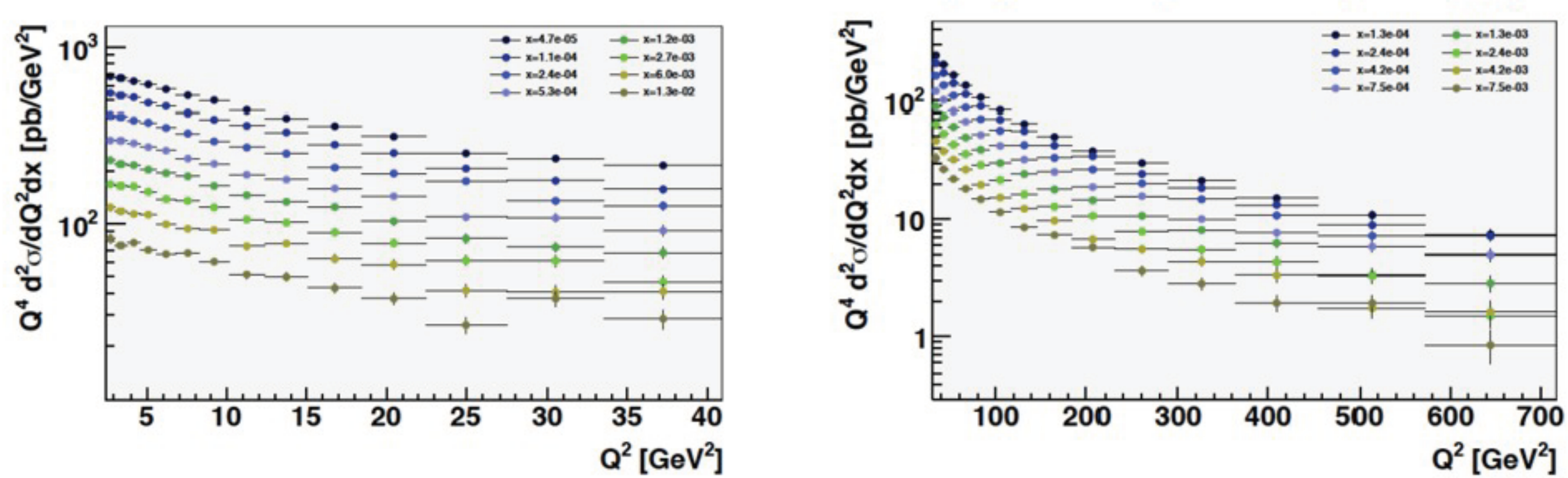
$$\langle b_A^2 \rangle = \frac{\int d^2b \, q_A(x,b) \, b^2}{\int d^2b \, q_A(x,b)}$$



Additive relation

Roadmap to extract GPDs from experiment: use of pseudodata to analyse the LHeC potential.

1 fb^{-1}, E_e = 50 GeV, 1° acceptance, p_T^{γ} > 2 GeV   100 fb^{-1}, E_e = 50 GeV, 10° acceptance, p_T^{γ} > 5 Ge



Low x and UHE ν [Stasto]

Neutrino astronomy

- Universe not transparent to extragalactic photons with energy > 10 TeV
- Weakly interacting: neutrinos can travel large distances without distortion

Interaction lengths (at 1 TeV):

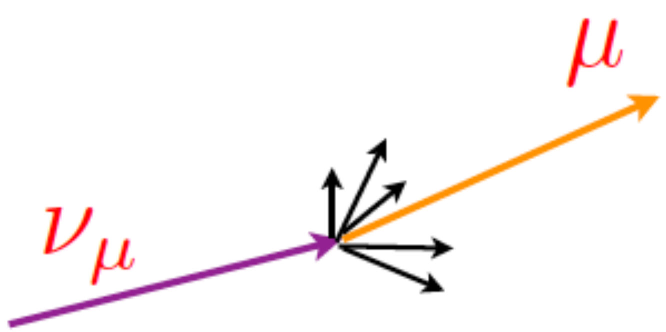
$$\mathcal{L}_{\rm int}^{\gamma} \sim 100\,{\rm g/cm^2}$$

$$\mathcal{L}_{\rm int}^{\nu} \sim 250 \times 10^9\,{\rm g/cm^2}$$

- Protons and nuclei get bent by the magnetic fields
- Neutrinos can point back to their sources

Angular distortion

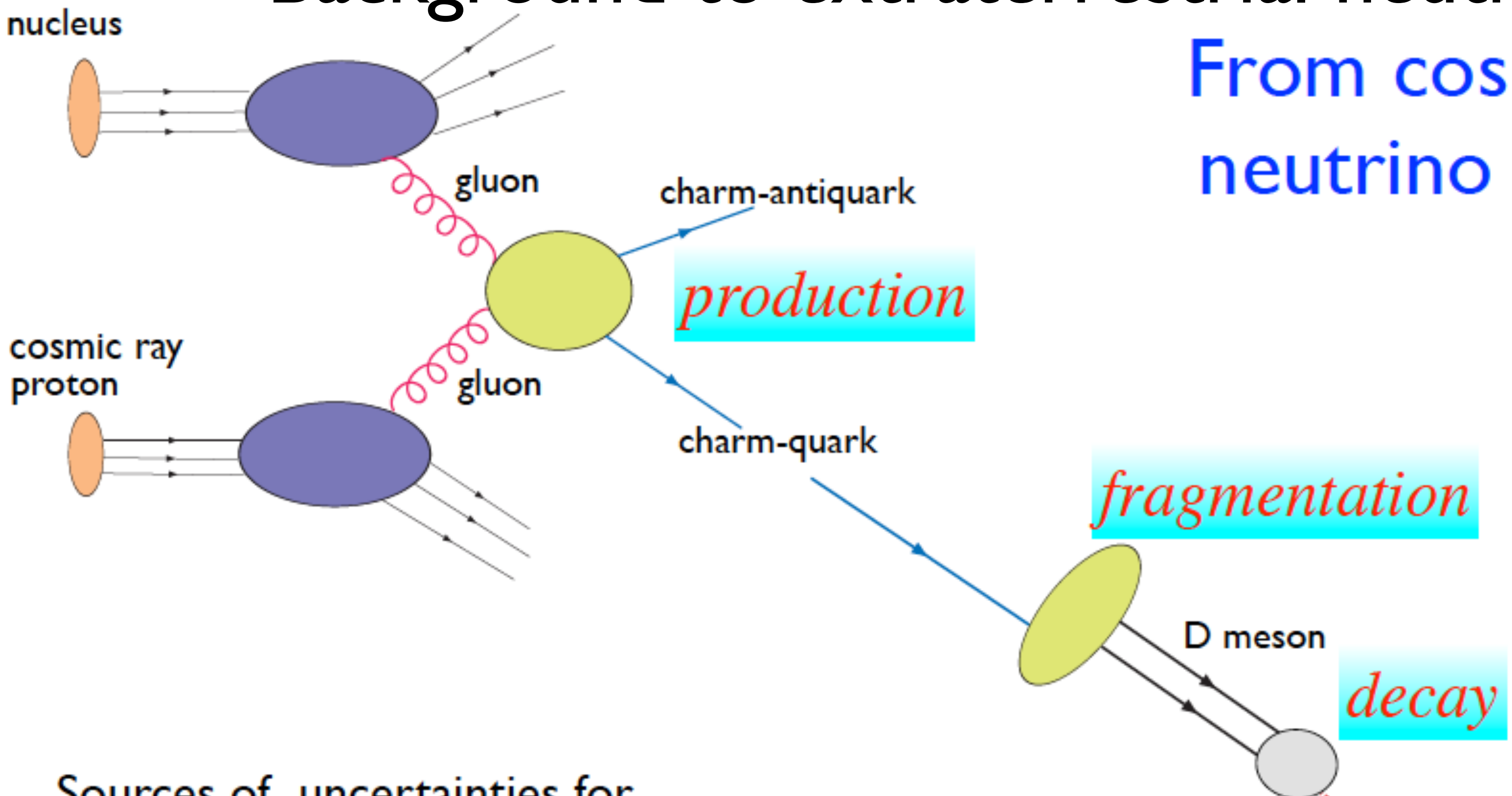
$$\delta\phi \simeq \frac{0.7^o}{(E_\nu/{\rm TeV})^{0.7}}$$

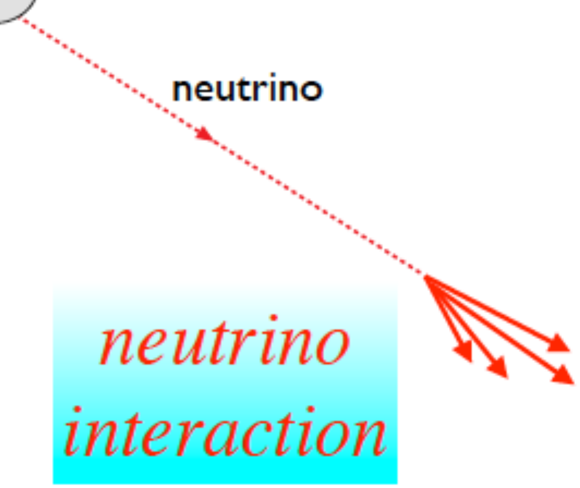


Low x and UHE ν [Stasto]

Background to extraterrestrial neutrinos

From cosmic ray to neutrino detection



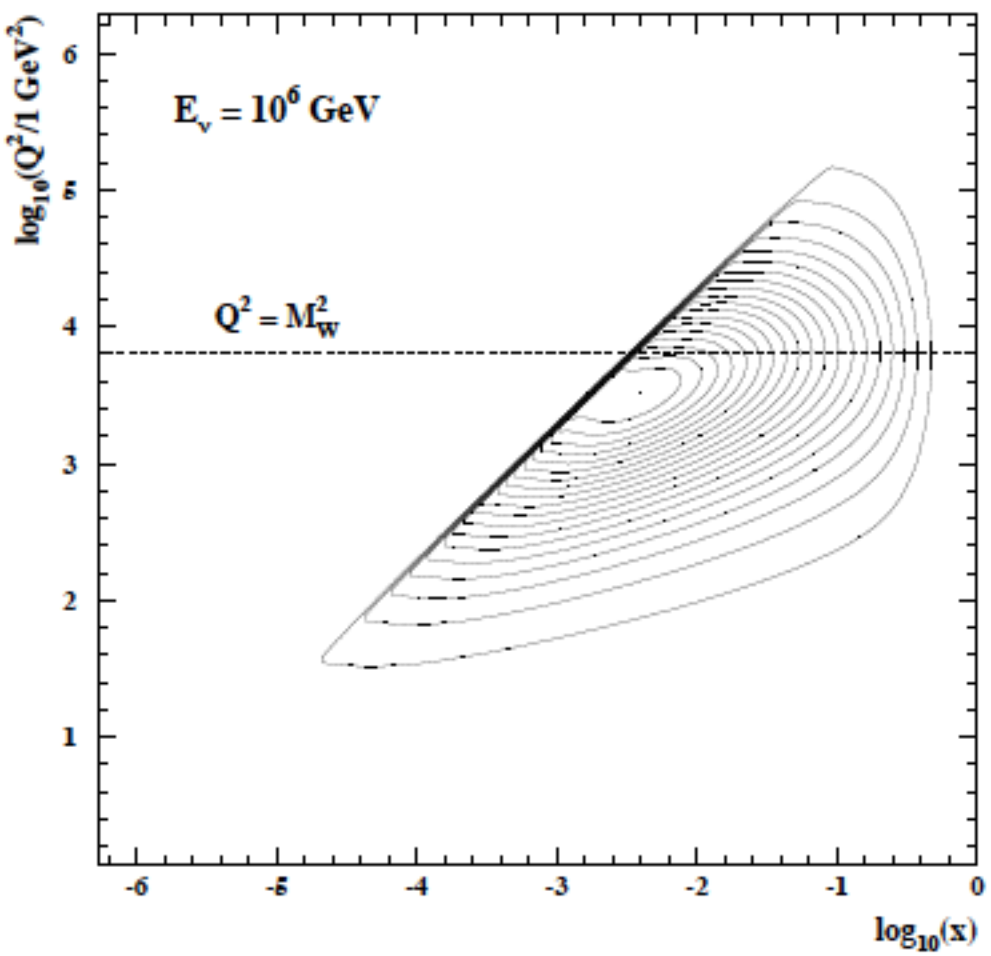


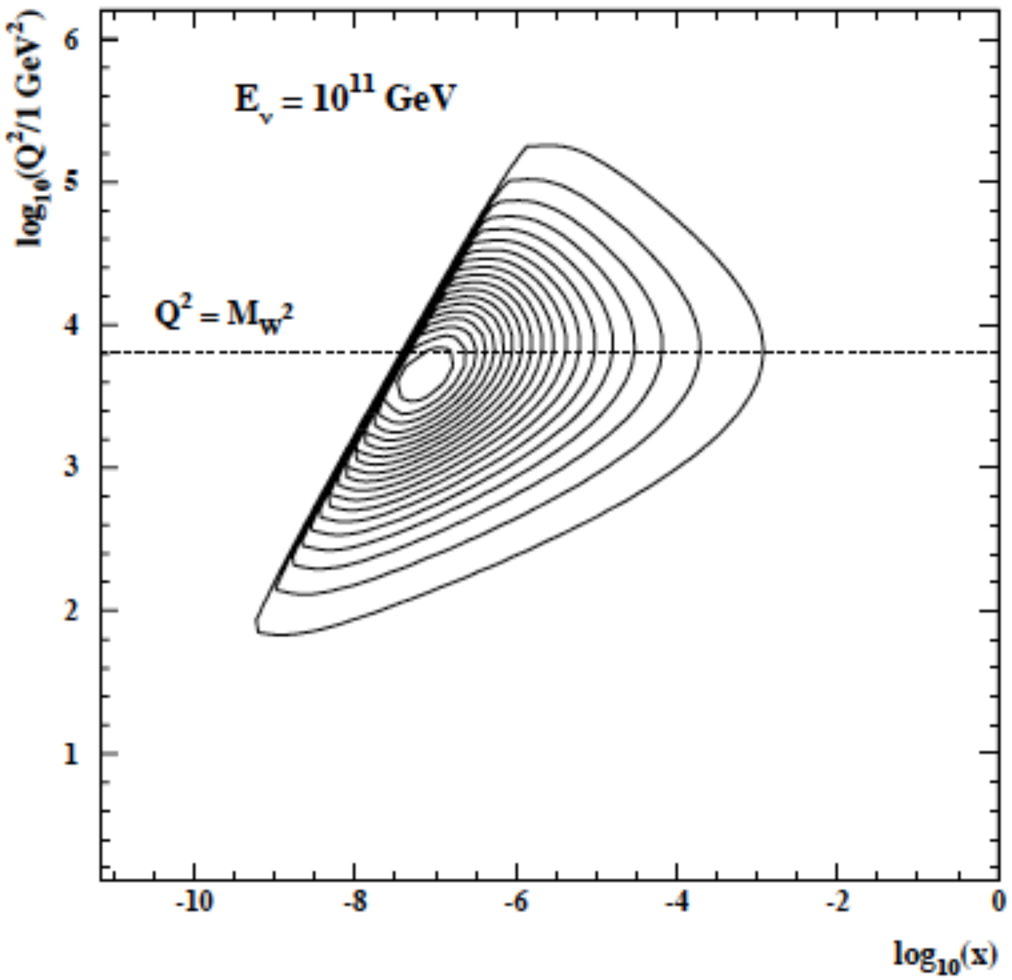
<u>Sources of uncertainties for prompt atmospheric neutrinos:</u>

- Initial Cosmic Ray flux: shape and composition
- Strong interaction cross section: framework (collinear, small x, saturation), PDFs, nuclear effects, intrinsic charm
- Charm meson fragmentation
- Decay
- Interaction cross section of neutrino (small x)

Low x and UHE ν [Stasto]

Contribution to the cross section in Q and x plane:





- Initial Cosmic Ray flux: shape and composition
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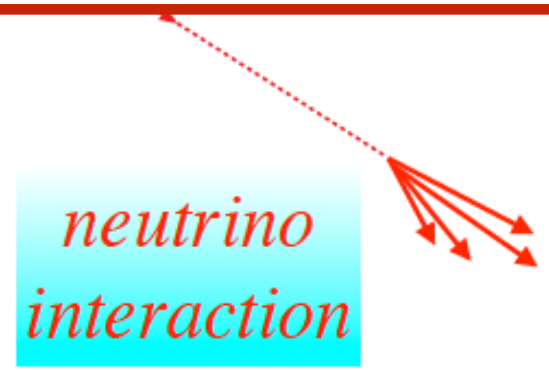
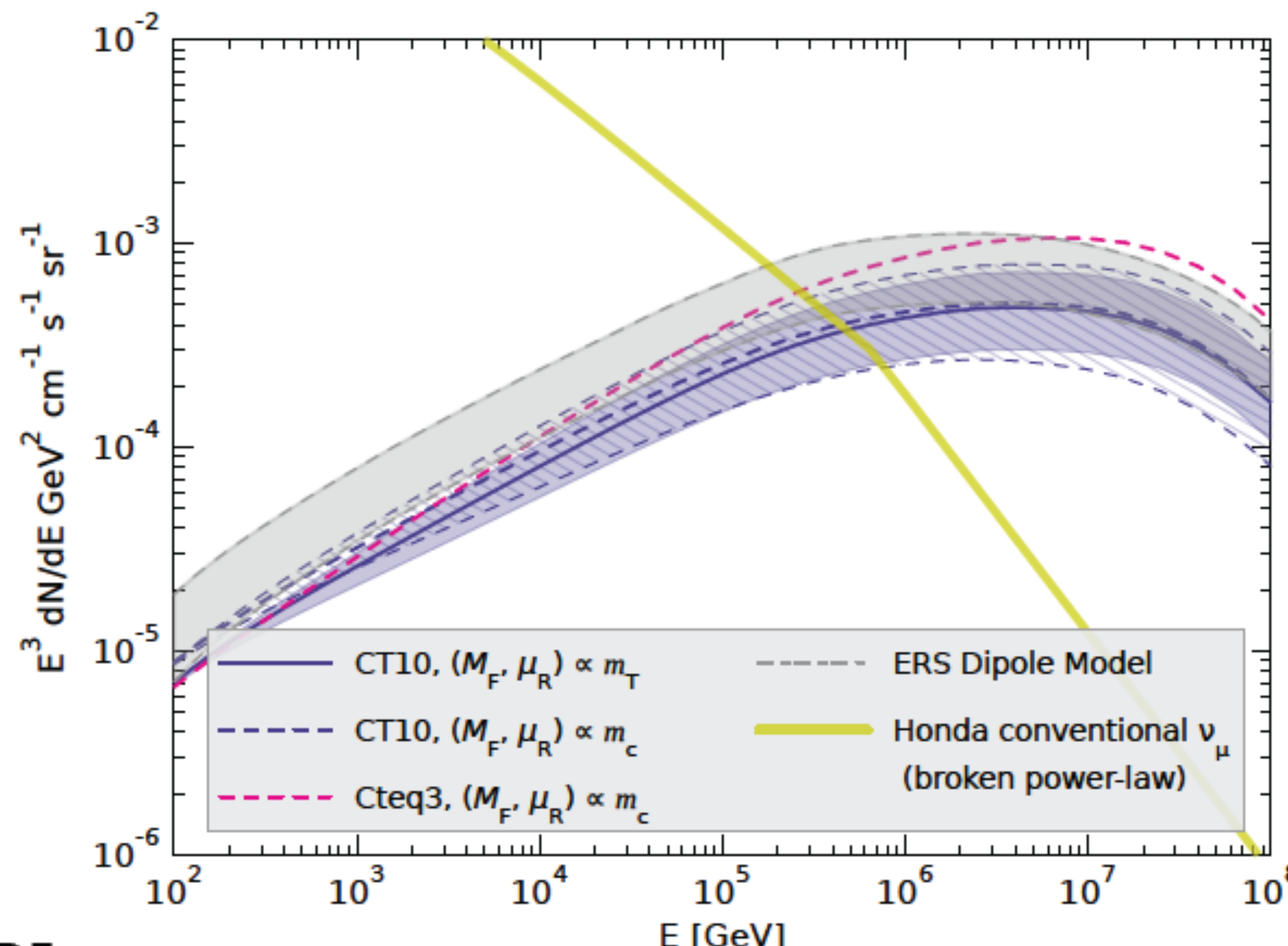


Low x and UHE ν [Stasto]

Cor

Neutrino fluxes: comparison collinear vs saturation

Flux of $\nu_\mu + \bar{\nu}_\mu$



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(x)

- •Calculation does not include the PDF uncertainties.
- •A bit of surprise: assuming the same initial cosmic ray flux NLO collinear calculation is lower than the calculation based on a dipole model with saturation…
- •Different large x pdfs in the calculations. Should one move to NLO dipole model here as well?
- •Gluon from CT10 is valence - like for low scales.
- •LHeC/FCC-eh would provide an important constraint on the gluon in this context.

Probing BFKL [Strikman]

Will focus on two questions which could be studied in process

$$\gamma(\gamma^*) + p(A) \to \text{"vector meson"} + \text{rapidity gap} + X$$

in ultraperipheral collisions at LHeC and ultraperipheral collisions in pA/AA at LHC

- *What is Asymptotic behavior of the amplitude of the elastic scattering of small dipoles in QCD at large t ? At what energies BFKL approximation works?*

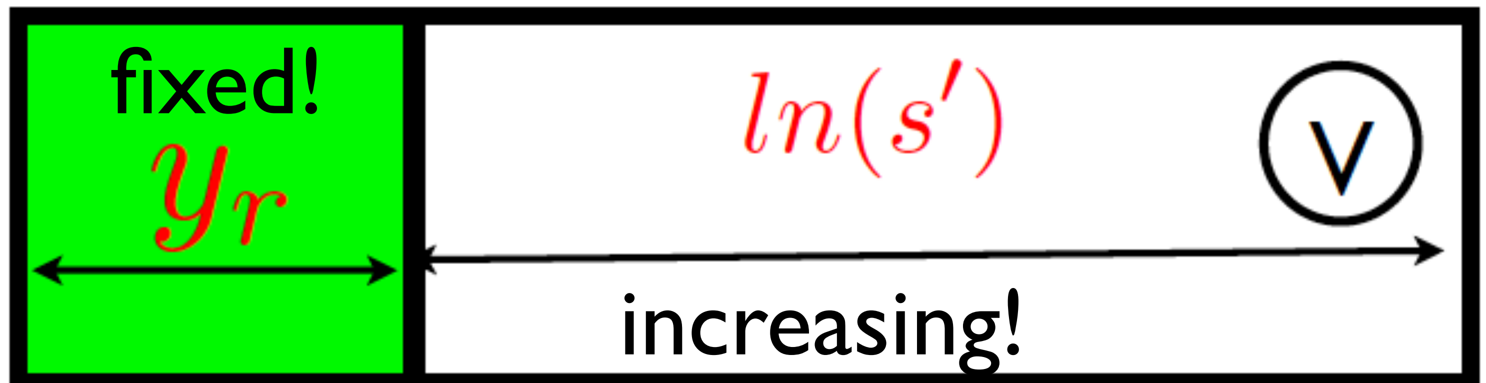
- *How small dipoles interact with nuclear media?*

Probing BFKL [Strikman]

The rapidity gap between the produced vector meson and knocked out parton (roughly corresponding to the leading edge of the rapidity range filled by the hadronic system X) is related to $W_{\gamma p}$ and t (for large t, $W_{\gamma p}$)as

$$y_r = \ln \frac{\tilde{x} W_{\gamma p}^2}{\sqrt{(-t)(m_V^2 - t)}}$$

φ



The choice of large t ensures several important simplifications:

⁎ the parton ladder mediating quasielastic scattering is attached to the projectile via two gluons.

⁎⁎ attachment of the ladder to two partons of the target is strongly suppressed.

⁎⁎⁎ the transverse size $d_{q\bar{q}} \propto 1/\sqrt{-t} \sim 0.15\,\mathrm{fm}$ for J/ψ for $-t \sim m_{J/\psi}^2$

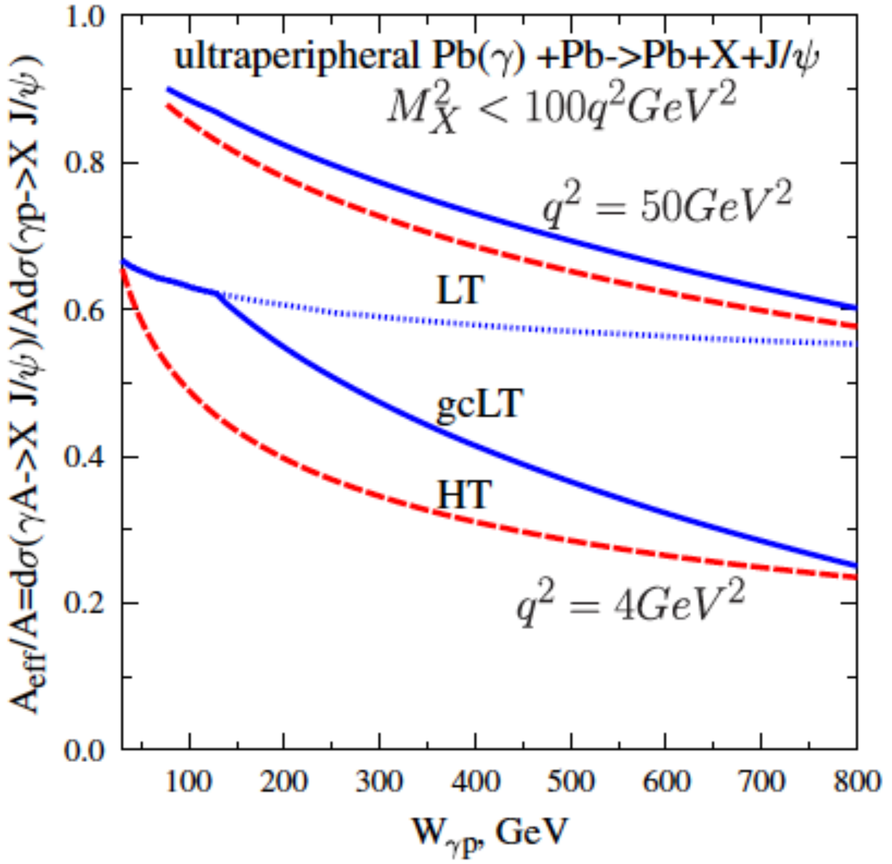
$$\frac{d\sigma_{\gamma+p\to V+X}}{dt\,d\tilde{x}} =$$

$$= \frac{d\sigma_{\gamma+quark\to V+quark}}{dt}\left[\frac{81}{16} g_p(\tilde{x},t) + \sum_i \left(q_p^i(\tilde{x},t) + \bar{q}_p^i(\tilde{x},t)\right)\right]$$

Probing BFKL [Strikman]

$$P_A^{\mathrm{gap}} = \frac{1}{A}\int d^2b\,T(\vec{b})\left[1 - \sigma_{\mathrm{dip}-N}(x,d)\frac{g_A(x,Q^2,\vec{b})}{g_N(x,Q^2)}\right],$$

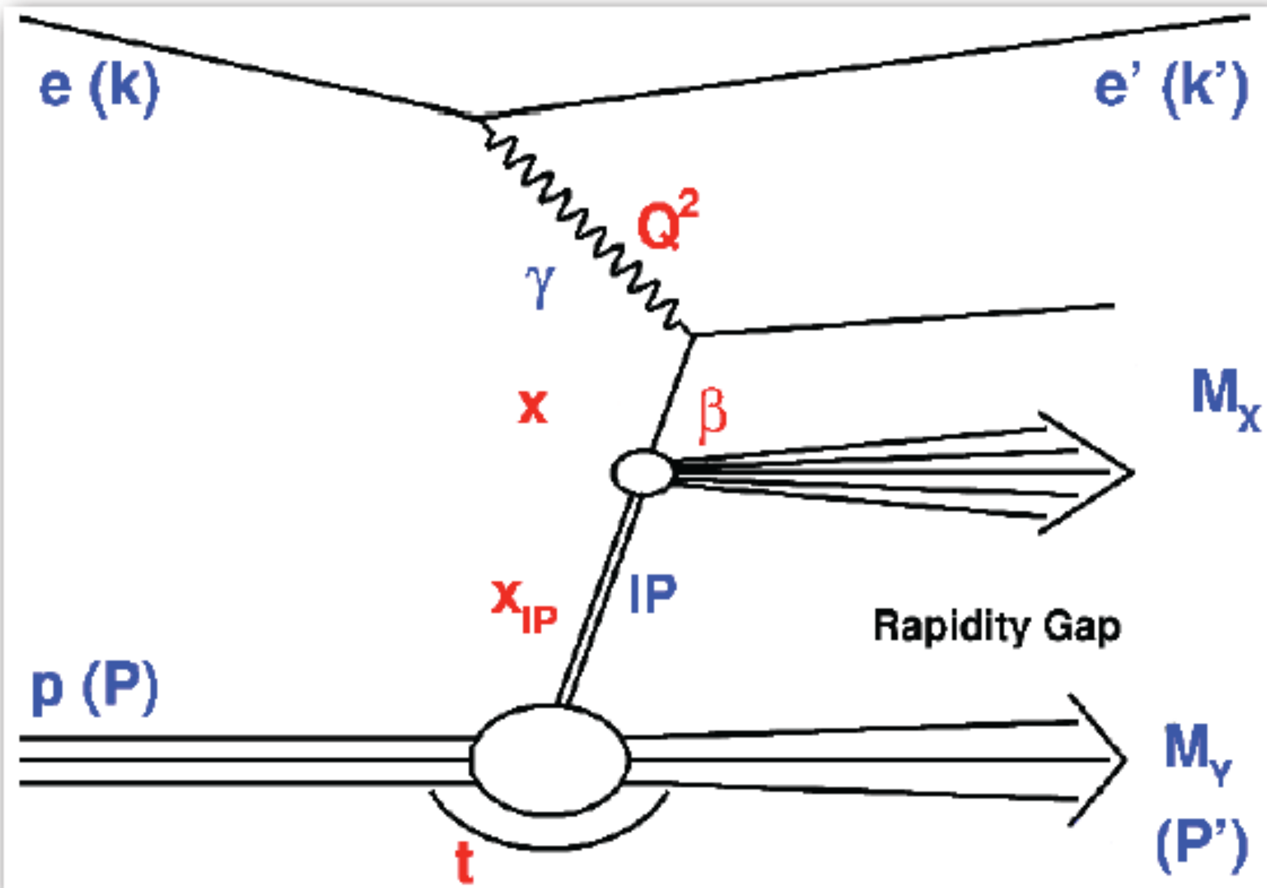
$$q^2 \equiv -t = Q^2$$



The rapidity survival probability for the J/ψ photoproduction as a function of W

Diffraction in ep [Polifka]

Diffraction



- exchange of a colorless object between the proton and the boson ($\gamma^{(*)}$,Z,W)
  - rapidity gap effect
- $Q^2 = -q^2 = (k-k')^2$
- $x = Q^2/2Pq$
- x_{IP} ("ξ") $=q(P-P')/qP = 1 - Ep'/Ep$
- $\beta = x/x_{IP}$
- $M_Y = mp$ .. intact proton
- $M_Y > mp$ .. proton dissociation

Collins factorisation, proven:

$$d\sigma^{ep\rightarrow eXp}(\beta, Q^2, x_{IP}, t) = \sum_i f_i^D(\beta, Q^2, x_{IP}, t)\cdot d\sigma^{ei}(\beta, Q^2)$$

Proton Vertex Factorisation, consistent with data:

$$f_i^D(\beta, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t)\cdot f_i(\beta, Q^2)$$

4

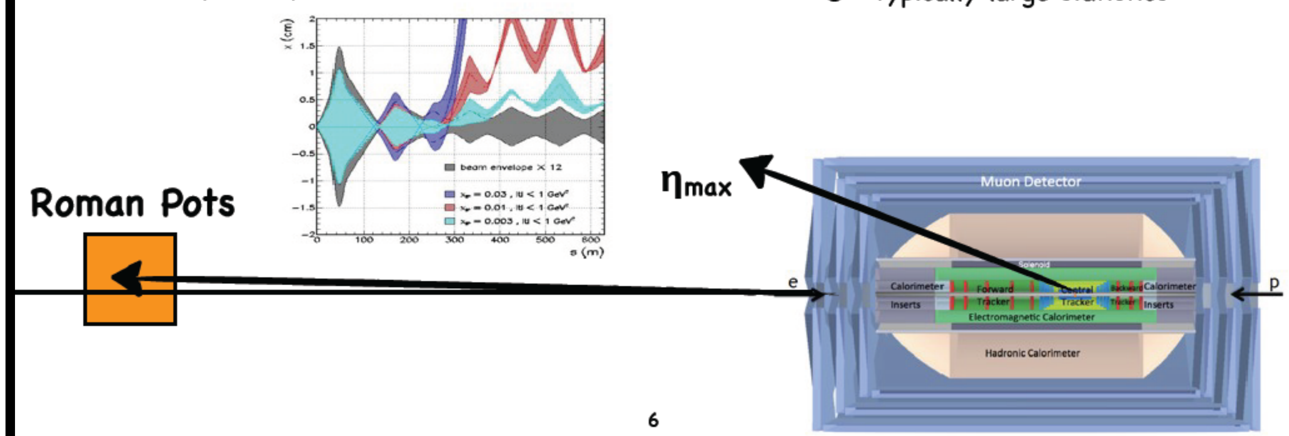
concept of diffractive parton distribution functions (DPDFs)

5

Diffraction in ep [Polifka]

Experimental methods

- forward proton detection
  - AFP-like project @ ~400m
  - full reconstruction of the proton kinematics
  - scintillator spectrometers approaching the beam to 12σ (250μm)
- leading neutron calorimeter (ZDC) @ ~100m from IP
- Large Rapidity Gap method (LRG)
  - requirement of "empty" calorimeter in the forward region
  - typically large statistics



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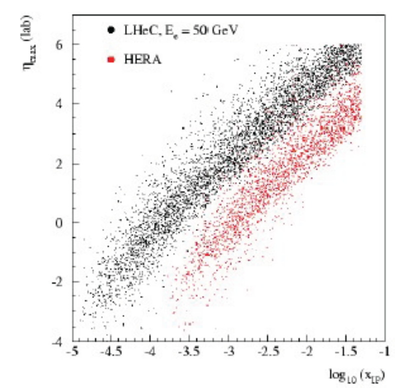
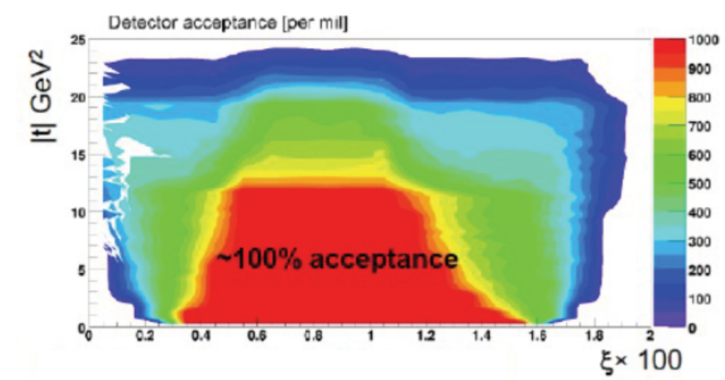
Experimental methods (2)

- wider range in η_{max}-x_{IP} coverable by the LRG method
- ~100% acceptance for the roman pots for $0.002 < x_{IP} < 0.013$
- both methods are complementary, overlap regions of phase space are cross calibrating each other -> very important
  - worked at HERA in accessible phase space





- M_Y = mp .. intact proton
- M_Y > mp .. proton dissociation

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4

concept of diffractive parton distribution functions (DPDFs)

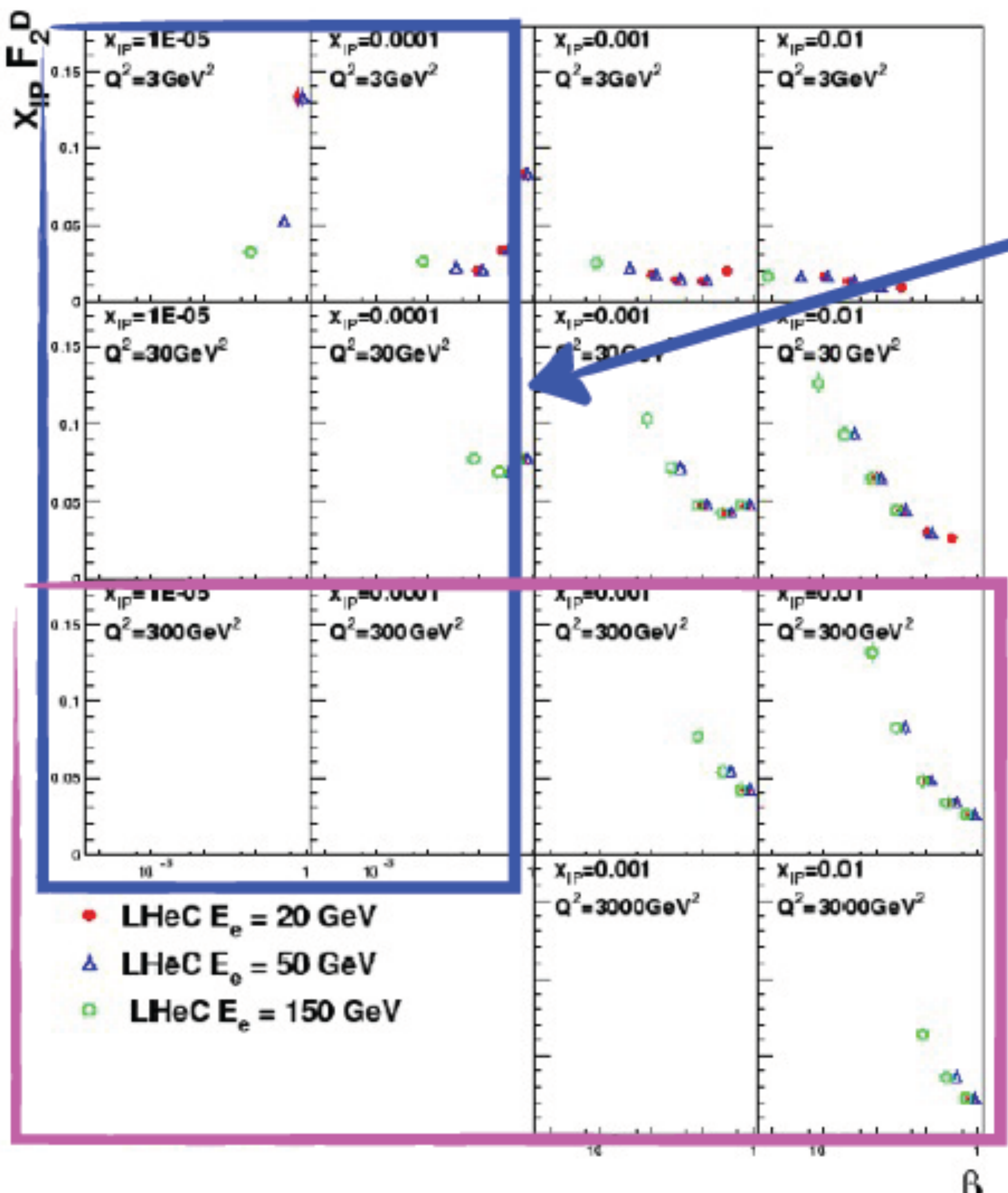
5

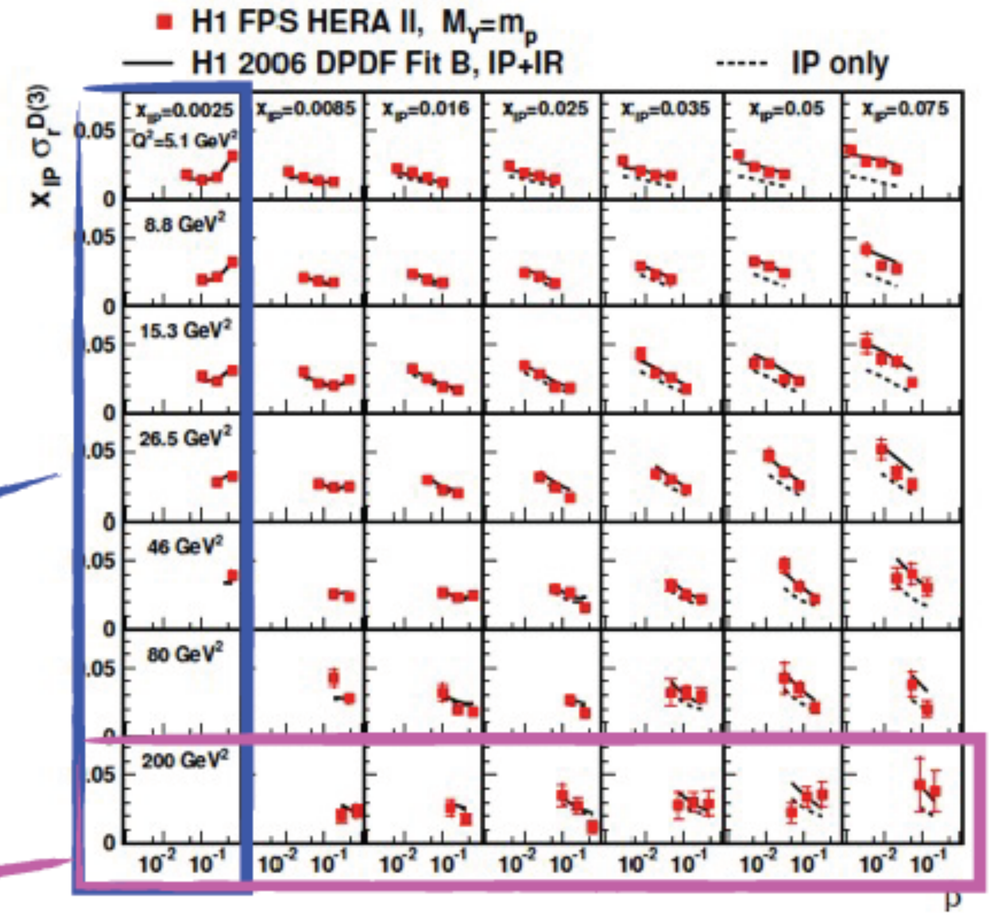
Diffraction in ep [Polifka]

Inclusive diffraction -> DPDFs

DGLAP fit undergoing

- extension of phase space down in x_{IP} and up in Q^2
  - -> important for DPDFs

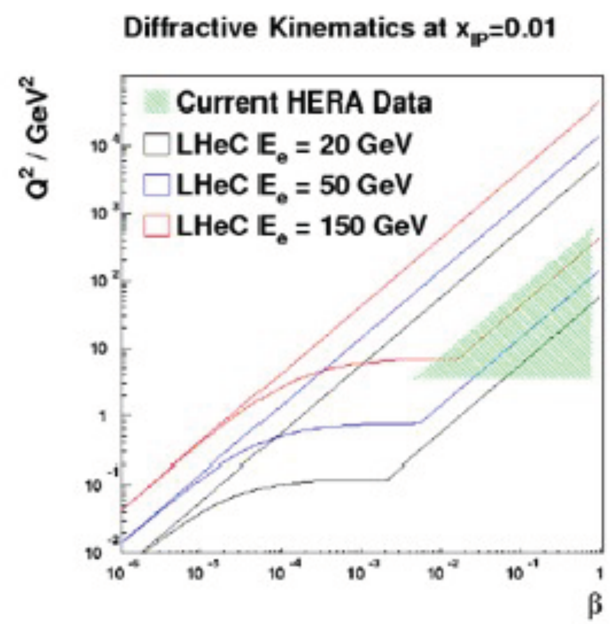




low x_{IP} ... cleanly separates diffraction

low β ... non-linear dynamics?

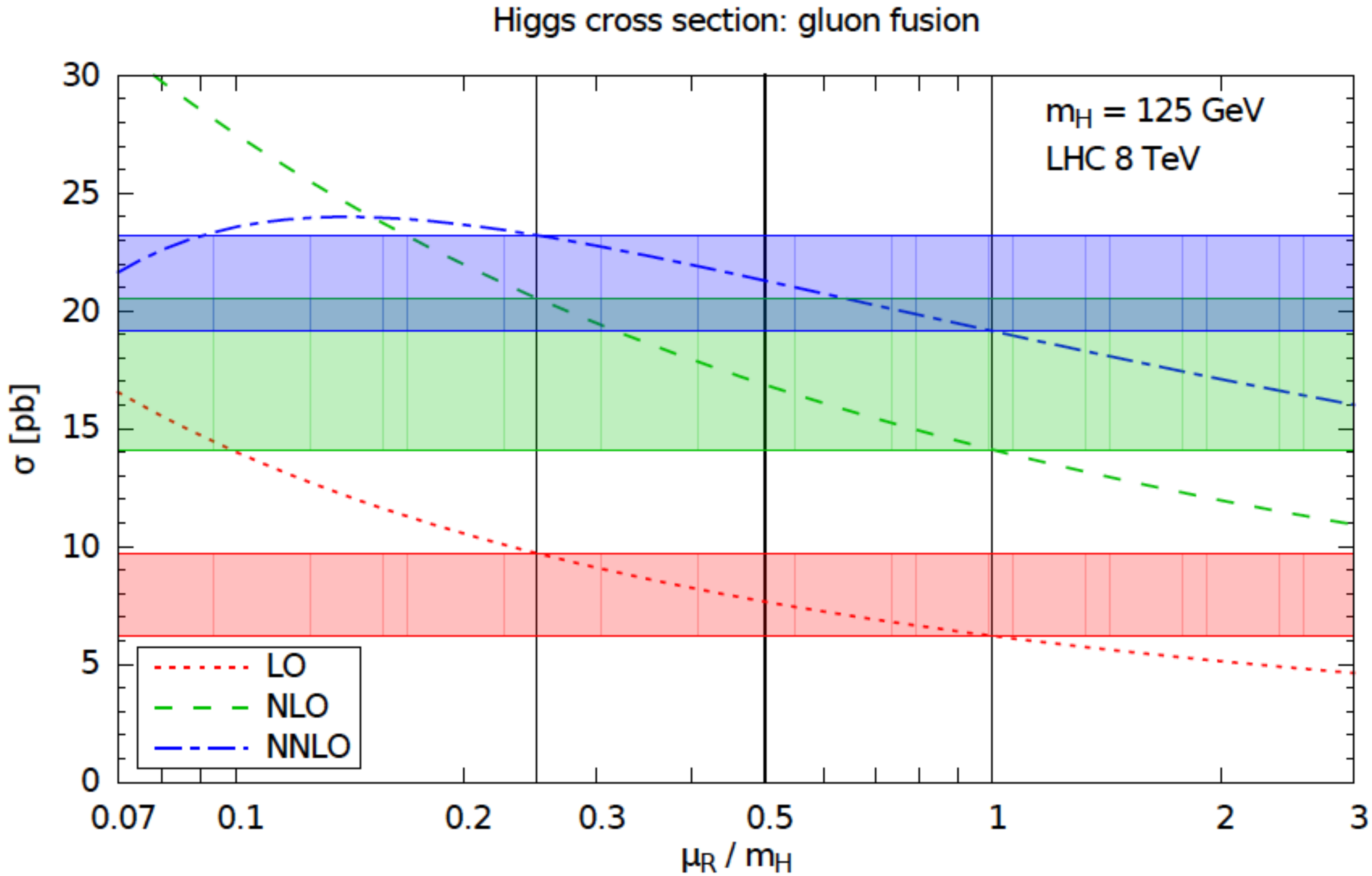
high Q^2 ... lever arm for gluon



8

N^{3}LO for DIS & Higgs [Bonvini]

Higgs at LHC: perturbative (in)stability to NNLO



$$1/4 < \mu_R/m_H < 1$$

N^3LO for DIS & Higgs [Bonvini]

Uncertainties in Higgs cross section

Scale uncertainty (for central scale $\mu_R = \mu_F = m_H$):

LO	NLO	NNLO	N^3LO	N^3LO+N^3LL
unreliable	35%	21%	8%	$\sim 6\%$

Clear reduction, now reliable result.

PDF + α_s uncertainty: **14%** Dominant uncertainty today!

Due to (half and half)

- uncertainty on $\alpha_s(m_Z)$
- uncertainty on the gluon PDF

Precision Higgs physics at LHC requires a much more precise gluon PDF!

And more reliable α_s determination!

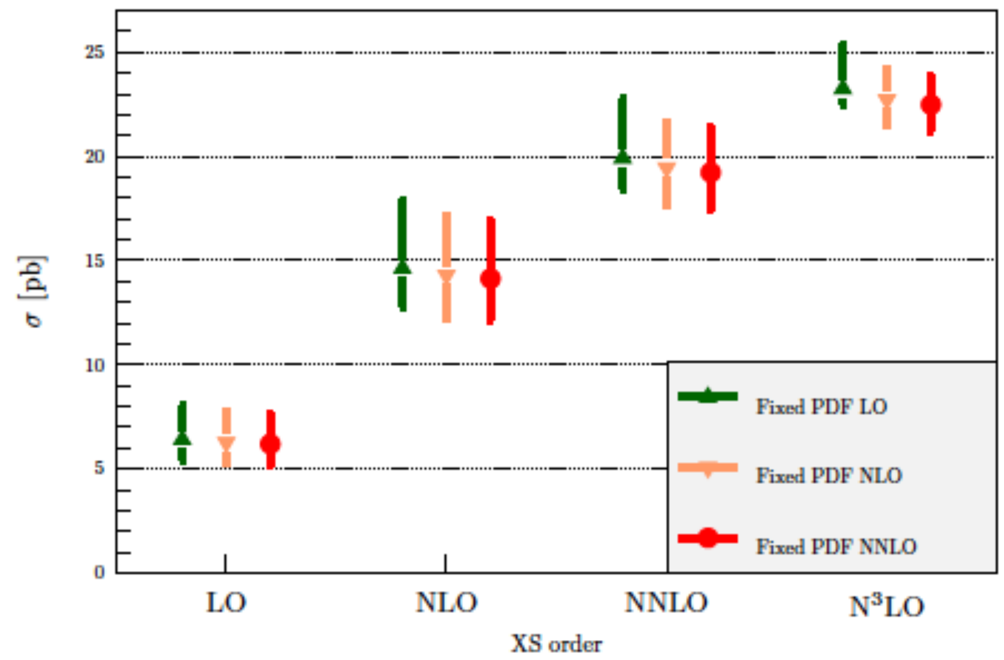
LHeC can dramatically reduce both uncertainties

[See talks by Monica d'Onofrio, Guido Altarelli]

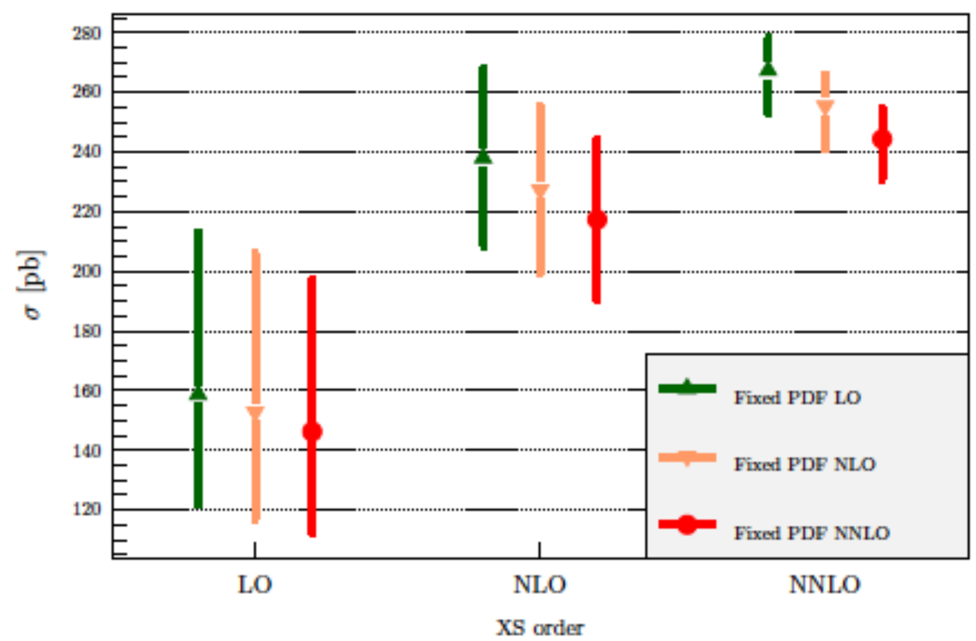
N^3LO for DIS & Higgs [Bonvini]

Do we also need N^3LO PDFs?

Higgs production



$t\bar{t}$ production



[Forte,Isgrò,Vita 2014]

Inclusive Higgs cross section not very dependent on the PDF order

N^3LO PDFs necessary for other processes such as $t\bar{t}$ production, or more exclusive distributions

N^{3}LO for DIS & Higgs [Bonvini]

Ingredients for N^{3}LO PDFs

- N^{3}LL (4 loop) evolution → not available yet
- N^{3}LO DIS → available [Vermaseren,Vogt,Moch 2005]
- N^{3}LO Drell-Yan → available soon
- N^{3}LO $t\bar{t}$ production → approximate results available [Kidonakis 2014] [Muselli,MB,Forte,Marzani,Ridolfi 2015]
- N^{3}LO jets → not likely (full NNLO is still ongoing…)

Can we live without N^{3}LL evolution?

- Evolution is perturbatively stable at high scales → NNLL is enough if low-Q^2 data are excluded from the fit

Can we live without N^{3}LO jets?

- One can either try to construct approximate N^{3}LO expressions for jets (at NNLO not very successful though)
- or remove jet data from the fit (need for new data to constraint the gluon PDF)

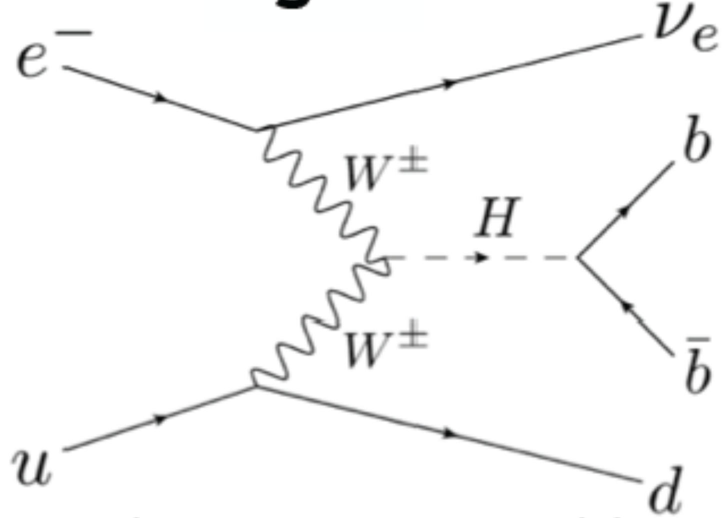
LHeC can provide a solution to all these problems!

H->bbbar [Tanaka]

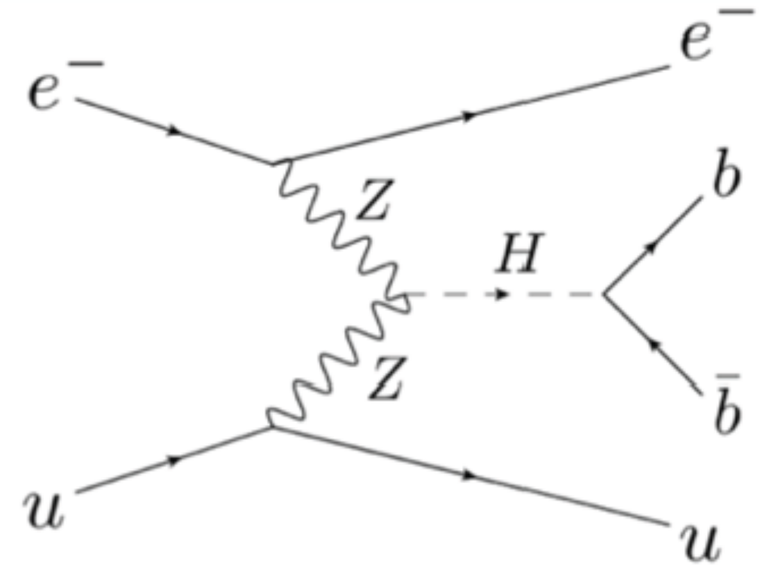
Higgs in LHeC

3

Signal



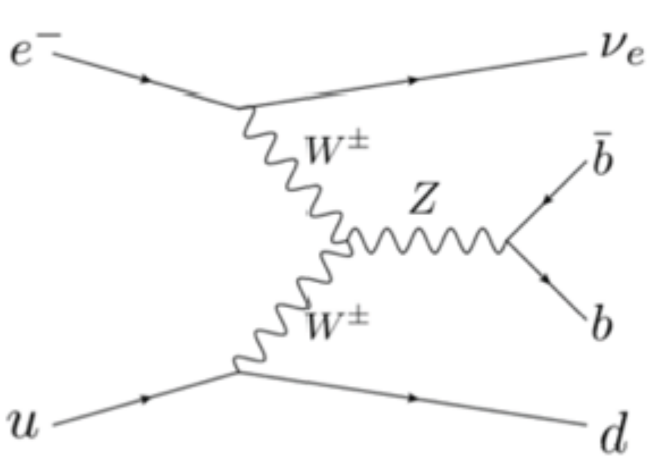
Charged current (CC) H->bb (0.063 pb)



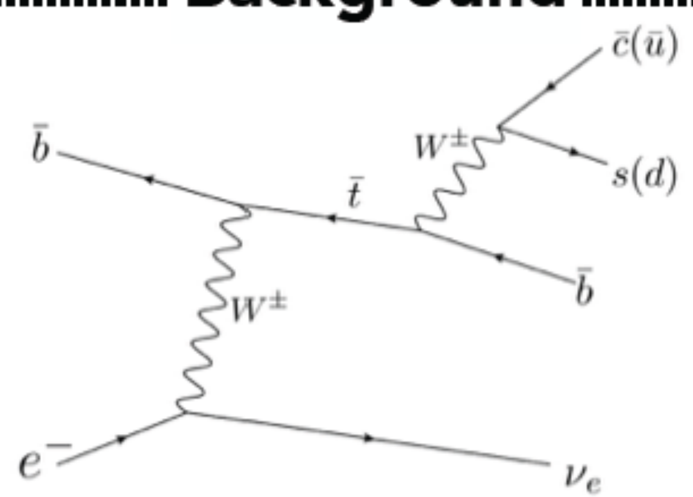
Neutral current (NC) H->bb (0.012 pb)

- CC: H->bb process is chosen as the signal because the cross section is larger than NC: H->bb process and NC rejection cut decreases large number of NC BG.

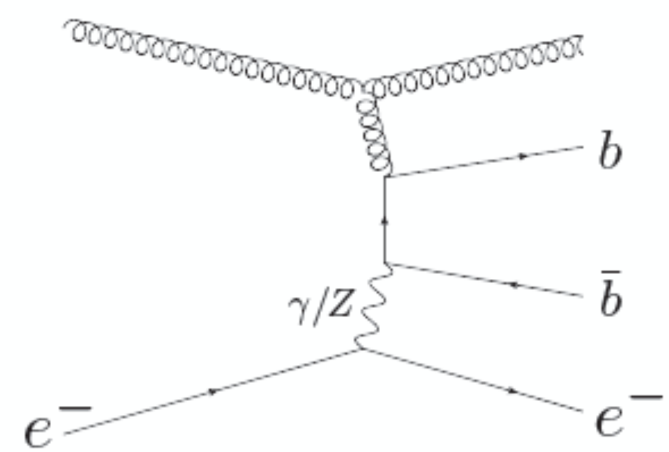
Background



CC Z production (0.29 pb)



Single top production (0.43 pb)



NC multi jets

H->bbbar [Tanaka]

CDR results and updates

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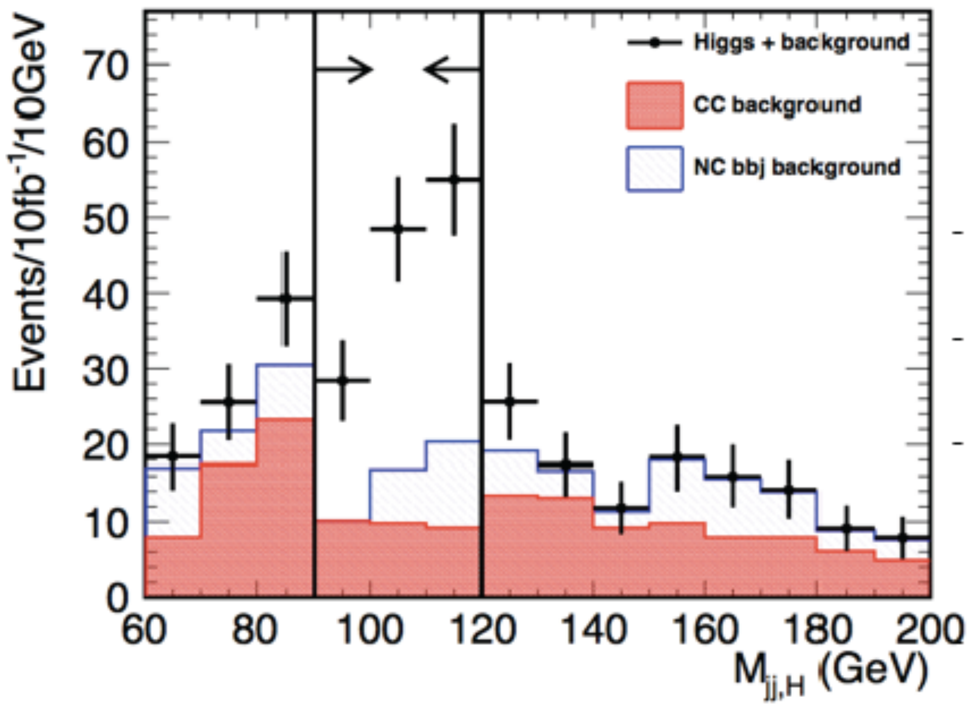
CDR results (before Higgs discovery)

- Previous analysis was performed by K.Kimura (Tokyo Tech) and the result is on LHeC CDR.



	Higgs production	CC DIS	NC bbj	S/N	$S/\sqrt{N}$
cut (1)	816	123000	4630	6.38×10^{-3}	2.28
cut (1) to (3)	178	1620	179	9.92×10^{-2}	4.21
All cuts	84.6	29.1	18.3	1.79	12.3

- 120 GeV Higgs was assumed.
- E_e=150 GeV and luminosity of 10 fb^{-1}.
- CC (inclusive) and NC (with 2 or more b jets) backgrounds were considered.
- PGS was used for detector simulation.

Update of CDR analysis

- Higgs mass was determined to be 125 GeV by ATLAS and CMS.
- E_e=60 GeV and luminosity of 100 fb^{-1}.
- New categorization of background MC (details later.)
- Delphes is used for detector simulation.
- Revised selection cuts.

H->bbbar [Tanaka]

LHeC in simulation

MadGraph/MadEvent
- Parton level event generation
- Calculation of cross section

▼

Pythia
- Fragmentation
- Hadronization

▼

Delphes
- Detector simulation

▼

H->bb event selection

Generator setup

- Beam of proton: 7 TeV, electron: 60 GeV.
- 125 GeV Higgs.

Detector setup

- Coverage:
  - Calorimeter: $|\eta|<5$ Tracking: $|\eta|<4.7$
- Jet reconstruction:
  - anti k_T algorithm with $\Delta R=0.9$
- HCal resolution

$$\frac{\sigma}{E} = \frac{30\%}{\sqrt{E}} + 3\% \ (|\eta| < 3) \qquad \frac{\sigma}{E} = \frac{60\%}{\sqrt{E}} + 5\% \ (3 < |\eta| < 5)$$

- ECal resolution

$$\frac{\sigma}{E} = \frac{35\%}{E} + \frac{7\%}{\sqrt{E}} + 0.7\% \ (|\eta| < 3)$$

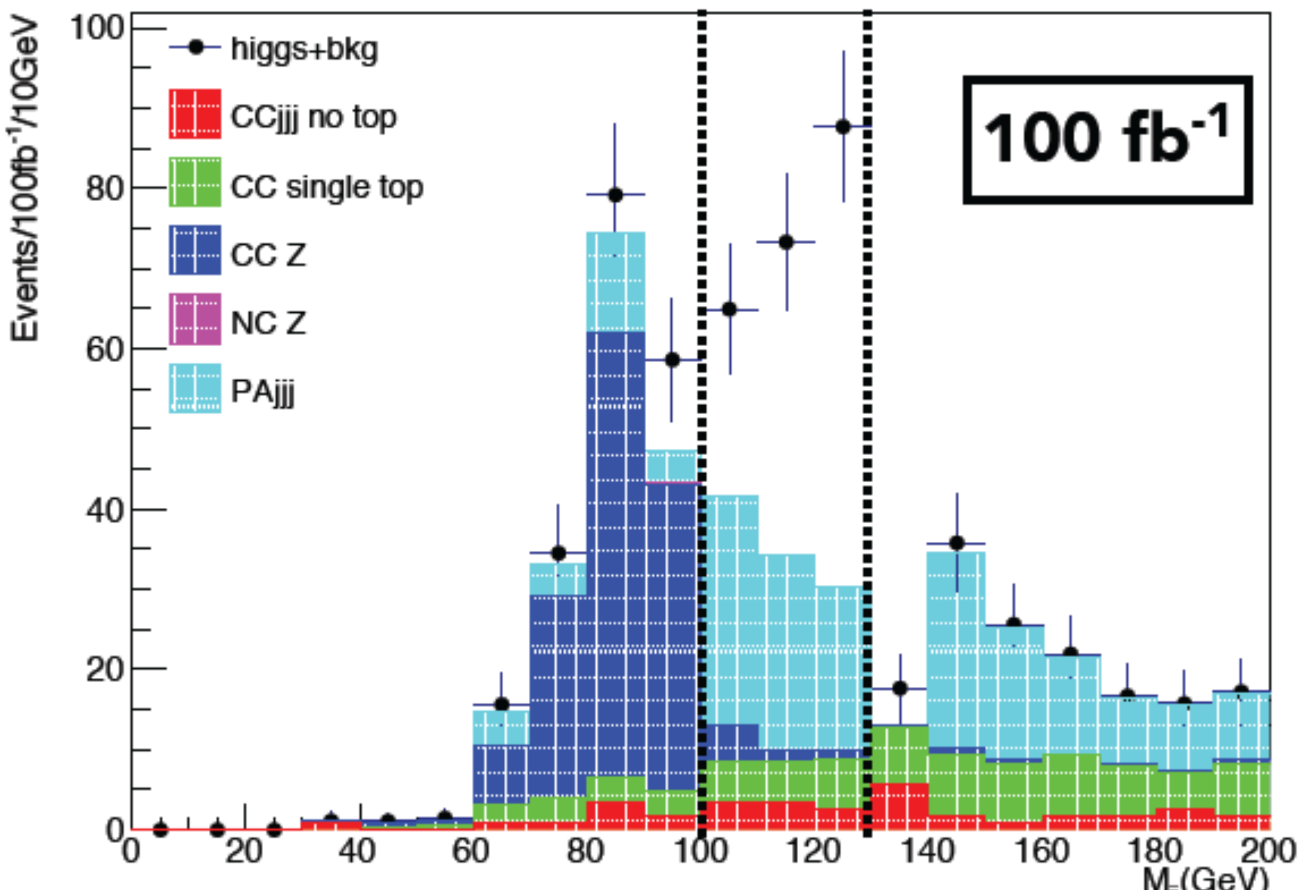
$$\frac{\sigma}{E} = \frac{20\%}{\sqrt{E}} + 2\% \ (3 < |\eta| < 4) \qquad \frac{\sigma}{E} = \frac{40\%}{\sqrt{E}} + 10\% \ (4 < |\eta| < 5)$$

H->bbbar [Tanaka]

Result

9

- Mass reconstructed with 1st and 2nd minimum η b-jets.
- Signal region is defined as [100,130] GeV.



Events in signal region

Signal H->bb	119±2
CCjjj no top	9±3
CC single top	17±2
CC Z	7±1
NC Z	0
PAjjj	73±17
CCbkg total	33±4
NCbkg total	73±17

- Errors are weighted

S/√B = 11.5

- We can detect H->bb signal in good efficiency.
- Peak around 80 GeV is Z boson from CC background.
- PAjjj background has large statistical error due to small statistics.
- Electron tagging of Photo-production events could further suppress BG under peak.

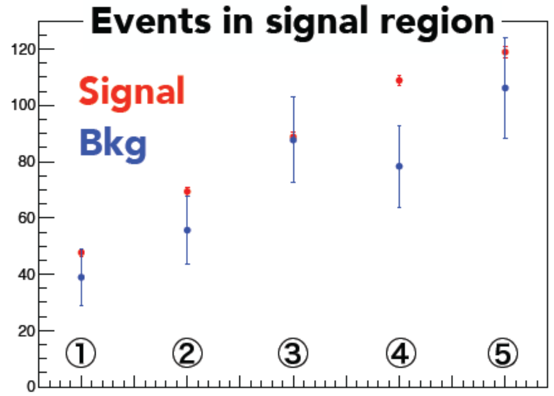
H->bbbar [Tanaka]

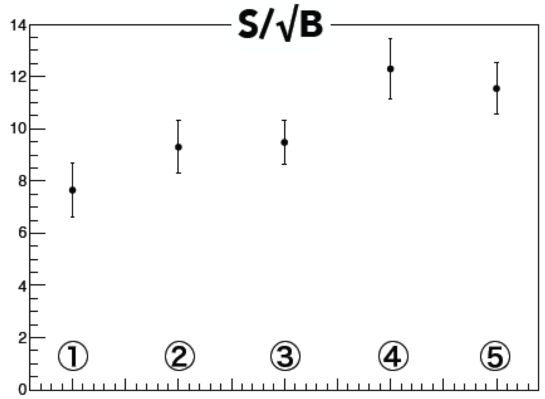
Dependency on B-tagging coverage
10

- Coverage of B-tagging is changed and result is compared

	B-tag coverage
①	$|\eta|<2.7$
②	$|\eta|<3.2$
③	$|\eta|<3.7$
④	$|\eta|<4.2$
⑤	$|\eta|<4.7$

B-tag efficiency model
For each η region
b-jet identification: 60%
c-jet mis-ID: 10%
Other jet mis-ID: 1%





- Both signal and background increase as coverage of b-tagging is expanded, so S/B is similar but S/√B increase.

Dependency on HCal resolution
11

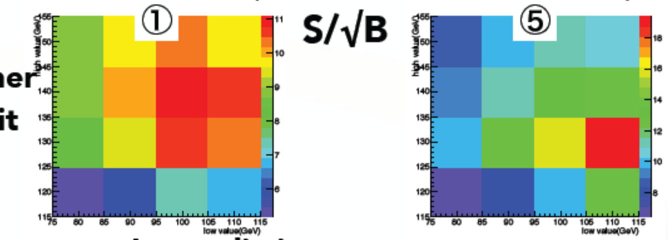
HCal resolution setup

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} + b \ (|\eta| < 3)$$

$$\frac{\sigma}{E} = \frac{c}{\sqrt{E}} + d \ (3 < |\eta| < 5)$$

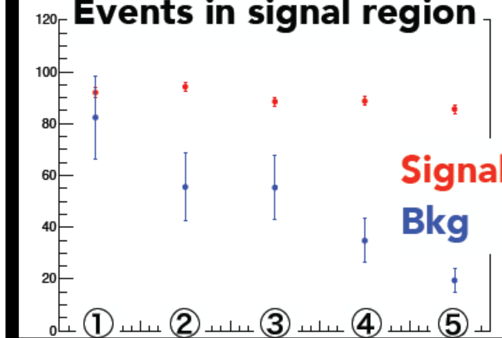
	a(%)	b(%)	c(%)	d(%)
①	60	6	120	10
②	45	4.5	90	7.5
③	30	3	60	5
④	22.5	2.25	45	3.75
⑤	15	1.5	30	2.5

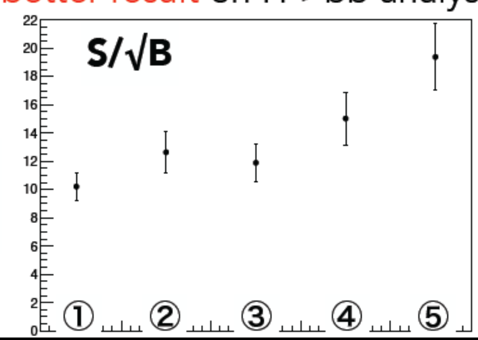
- Signal region is optimized w.r.t each setup

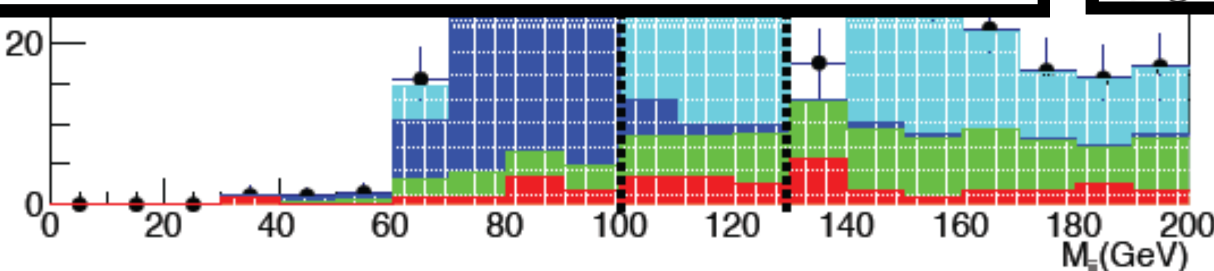


100<M_{jj}<140 GeV   110<M_{jj}<130 GeV

- Number of background decrease and S/√B increase as the resolution become better.
- Improvement of hadron calorimeter leads to better result on H->bb analysis in LHeC.







- Errors are weighted

S/√B = 11.5

- We can detect H->bb signal in good efficiency.
- Peak around 80 GeV is Z boson from CC background.
- PAjjj background has large statistical error due to small statistics.
- Electron tagging of Photo-production events could further suppress BG under peak.

Higgs->QQbar [U. Klein]

ep Higgs "Facility" @ 1 ab^{-1}

→ **for first time a realistic option of an 1 ab^{-1} ep collider** (stronger e-source, stronger focussing magnets) and **excellent performance of LHC** (higher brightness of proton beam); ERL : 960 superconducting cavities (20 MV/m) and 9 km tunnel [arXiv:1211.5102, arXiv:1305.2090; EPS2013 talk by D. Schulte]

√s= 1.3 TeV

→ need of different models :
cc: 'sm-full'
gg, γγ: 'heft'

LHeC Higgs		CC (e^-p)	NC (e^-p)	CC (e^+p)
Polarisation		-0.8	-0.8	0
Luminosity [ab^{-1}]		1	1	0.1
Cross Section [fb]		196	25	58
Decay	BrFraction	N^H_{CC} e^-p	N^H_{NC} e^-p	N^H_{CC} e^+p
$H \to b\bar{b}$	0.577	113 100	13 900	3 350
$H \to c\bar{c}$	0.029	5 700	700	170
$H \to \tau^+\tau^-$	0.063	12 350	1 600	370
$H \to \mu\mu$	0.00022	50	5	–
$H \to 4l$	0.00013	30	3	–
$H \to 2l2\nu$	0.0106	2 080	250	60
$H \to gg$	0.086	16 850	2 050	500
$H \to WW$	0.215	42 100	5 150	1 250
$H \to ZZ$	0.0264	5 200	600	150
$H \to \gamma\gamma$	0.00228	450	60	15
$H \to Z\gamma$	0.00154	300	40	10

Ultimate polarised e-beam of 60 GeV and LHC-p beams, 10 years of operation

→ **Decay to bb is dominating HFL decay modes :**
Higgs decay to cc is factor 20 less likely than Hbb
times the ratio of detection efficiencies-squared !

Uta Klein, Higgs to HFL 5

Higgs->QQbar [U. Klein]

Basic detector setup

60 GeV x 7000 GeV

see also M. Tanaka's talk

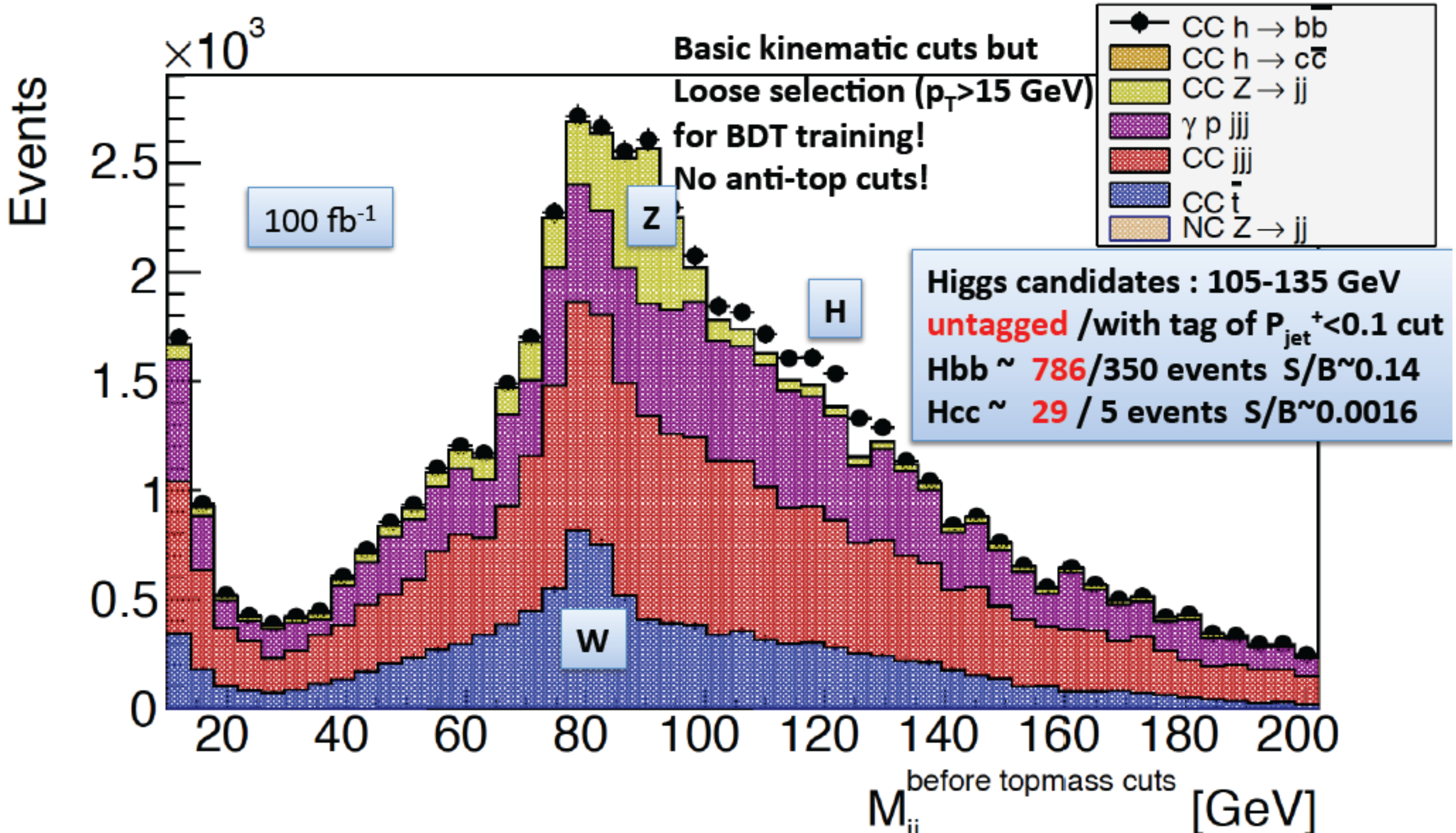
100 fb^{-1}

- CMS-like detector, B=3.8 T
- Generated and reconstructed jets with anti-kt R=0.9
- for generated and reconstructed jets : optional flat b and c-tagging up to eta=5 and pTjet>5 GeV based on partons ➔ used for cross checks ONLY!
- Fine 'LheC' calorimeters of 0.025 x 0.025 in eta and phi (c.f. Max Klein : 252 phi and 400 eta cells)
- Charged particle tracking up to eta=4.7
- Tracking and electron ID efficiencies set to 1
- ATLAS-style vertex resolution of 5 µm for p_T>5 GeV and 10 µm for p_T<5 GeV

➔ code development a la basic signed impact parameters and jet lifetime tags a la D0 and ATLAS

Higgs->QQbar [U. Klein]

Dijet Mass : two lowest eta jets - *untagged*



Higgs candidates : 105-135 GeV
untagged /with tag of P_{jet}^{+}<0.1 cut
Hbb ~ 786/350 events S/B~0.14
Hcc ~ 29 / 5 events S/B~0.0016

Note : Photoproduction background is assumed to be untagged ('worst' scenario)!
→ addition of electron taggers will reduce the PHP considerably

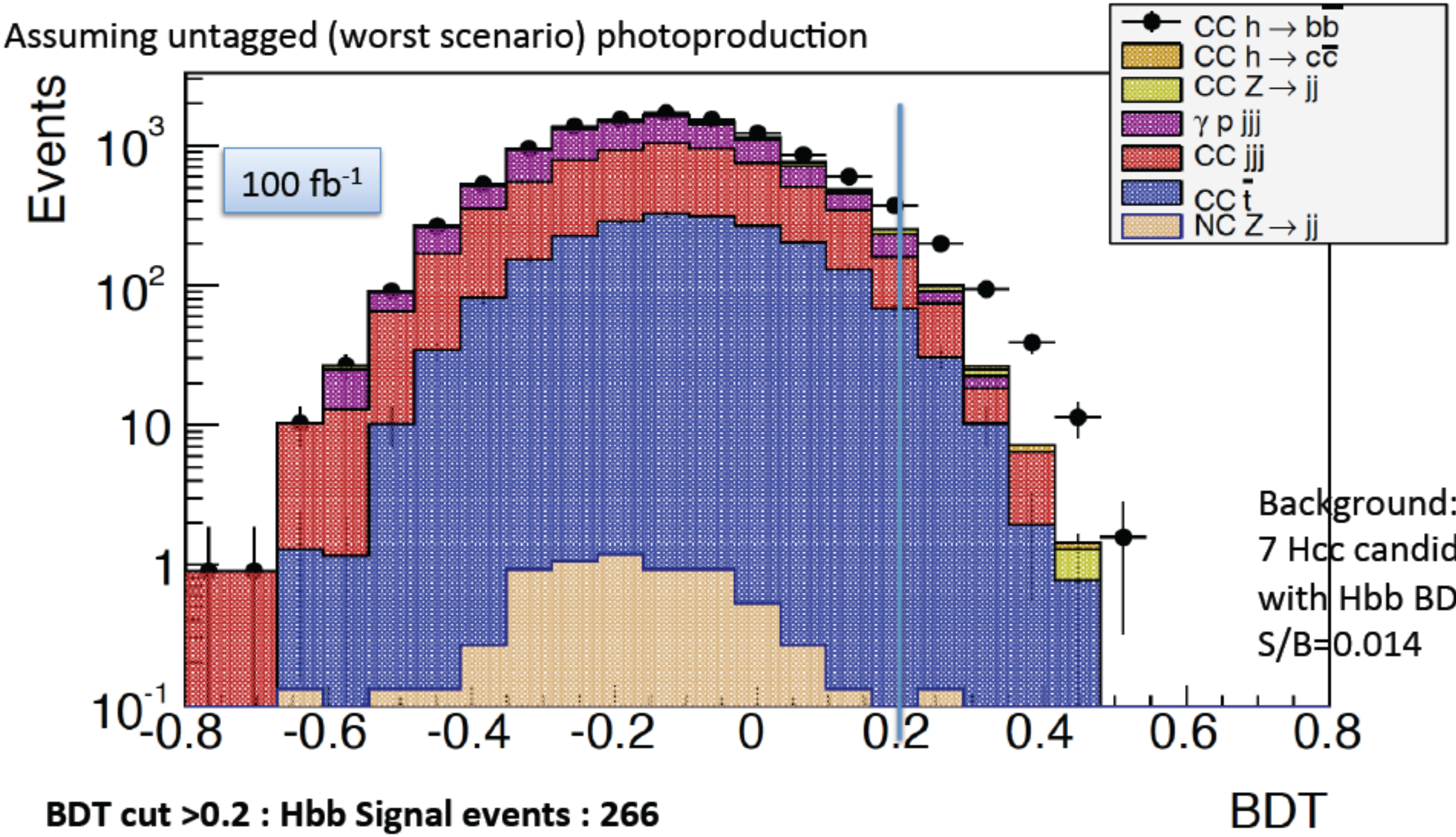
Higgs->QQbar [U. Klein]

Training with 26 variables

First BDT results : Higgs→ bb

[P=-0.8, BR=0.577]

Assuming untagged (worst scenario) photoproduction



BDT cut >0.2 : Hbb Signal events : 266

S/B = 1.16 and S/√S+B=12 → κ(Hbb) = 5% for 100 fb^{-1}

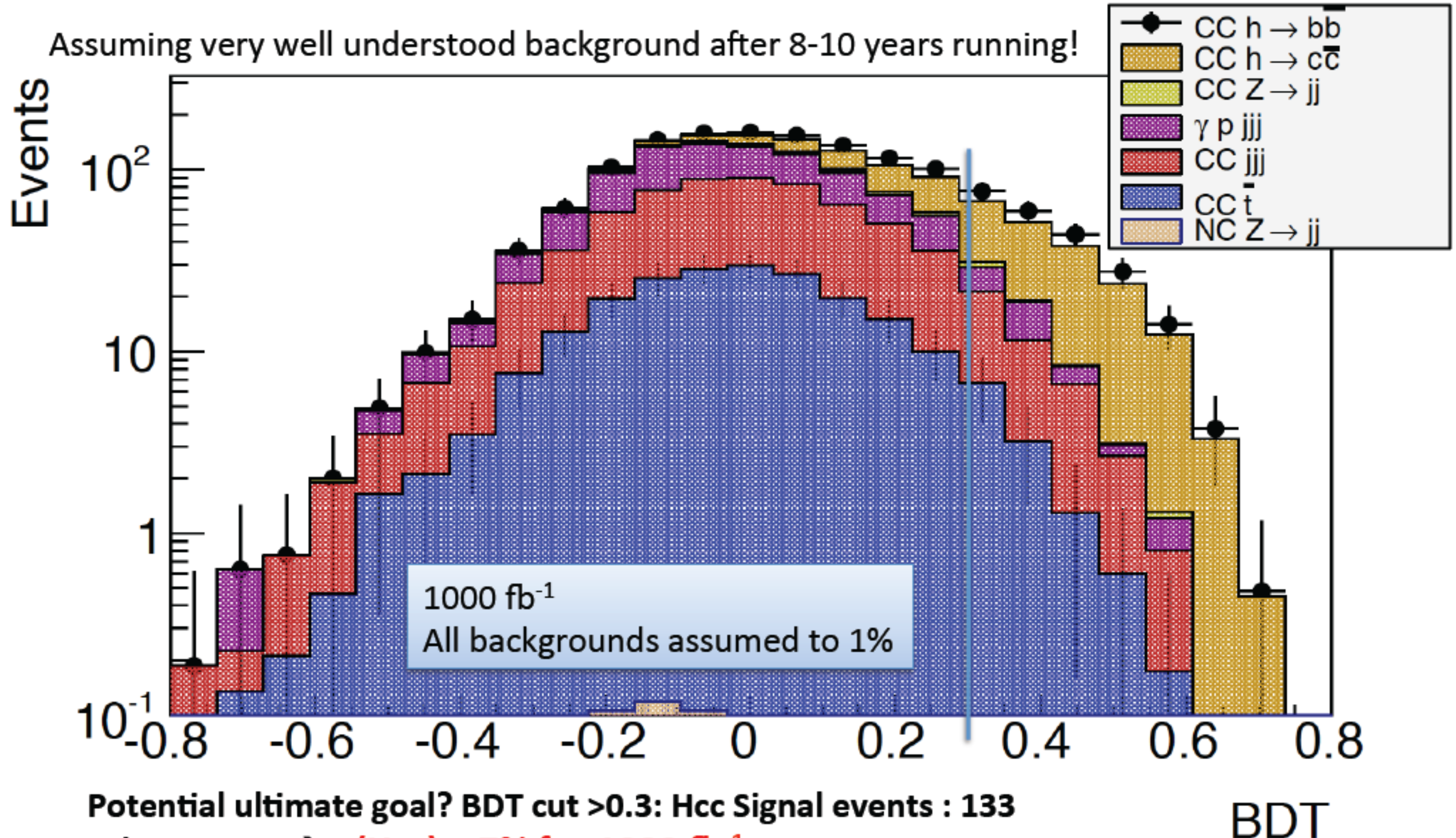
→ κ(Hbb) = 1.5% for 1000 fb^{-1}

Uta Klein, Higgs to HFL **→ First confirmation of CDR findings using jet lifetime tags!** 25

Higgs->QQbar [U. Klein]

[P=-0.8, BR=0.029]

Very first BDT results : Higgs→ cc



Potential ultimate goal? BDT cut >0.3: Hcc Signal events : 133

S/√S+B=1.5 → **κ(Hcc) = 7% for 1000 fb^{-1}**

[assuming backgrounds to 10% (100%) κ(Hbb) = 17% (50%)]

Uta Klein, Higgs to HFL → **There is a clear potential to measure Hcc at LHeC** 26

Single top [Ruan]

Single top production

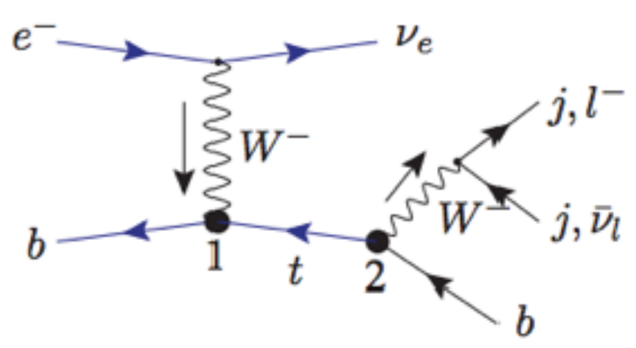
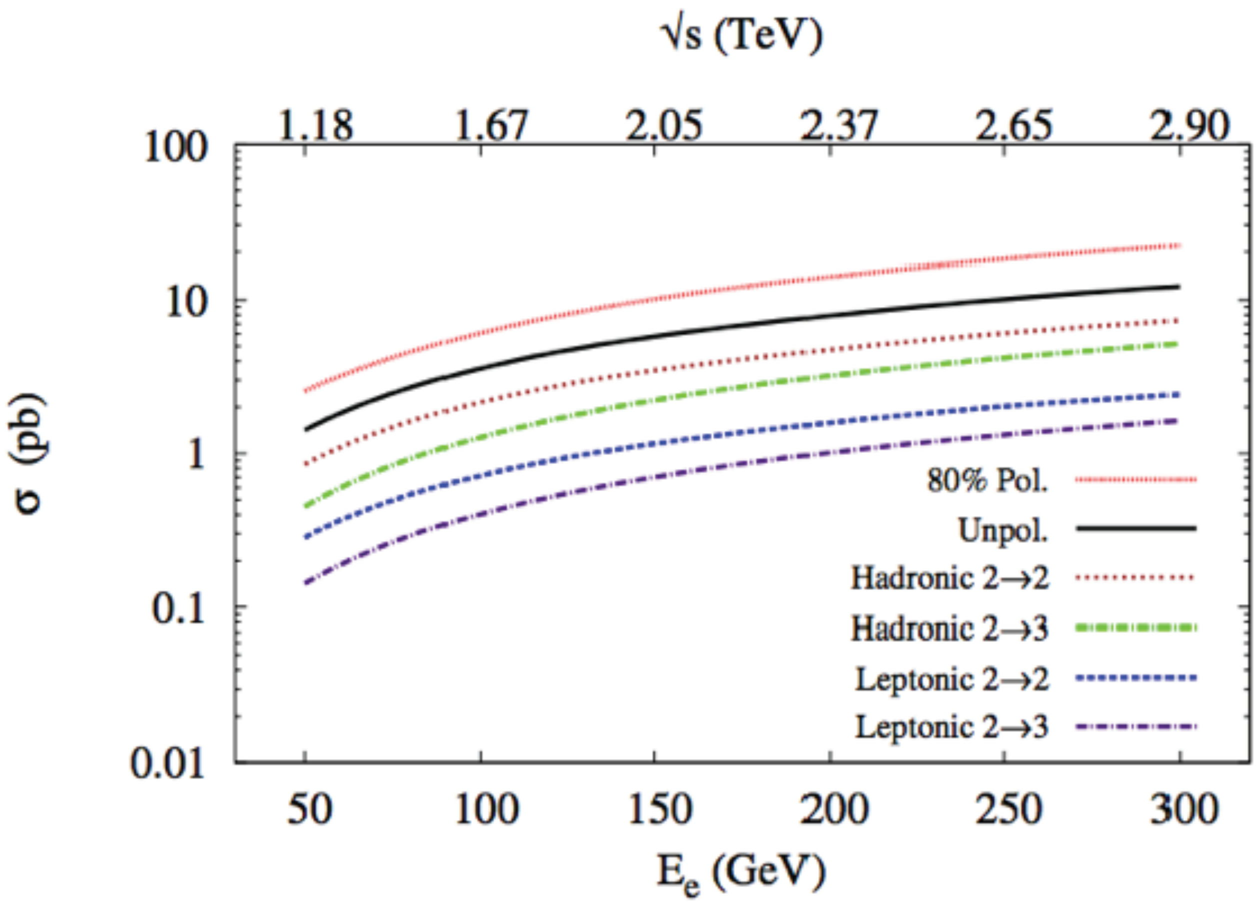


Figure 1. *Single anti-top quark production through charge current at the e-p collider. The blobs at vertices 1 and 2 show the effective $W^- t\bar{b}$ couplings, which includes the SM contribution. Further W^- decays into hadronic mode via light quarks ($j \equiv \bar{u}, d, \bar{c}, s$) or leptonic mode ($l^- \equiv e^-, \mu^-$) with missing energy.*



- Single top production as a function of Ee, Ep=7TeV

4

Single top [Ruan]

Theoretical modelling

$$\mathscr{L}_{Wtb} = \frac{g}{\sqrt{2}}\left[W_\mu \bar{t}\gamma^\mu (V_{tb}\, f_1^L P_L + f_1^R P_R) b - \frac{1}{2\, m_W} W_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_2^L P_L + f_2^R P_R) b\right] + h.c.$$

where $f_1^L \equiv 1 + \Delta f_1^L$, $W_{\mu\nu} = D_\mu W_\nu - D_\nu W_\mu$, $D_\mu = \partial_\mu - ieA_\mu$, $\sigma^{\mu\nu} = i/2\,(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$.

In SM $|V_{tb}| f_1^L \approx 1$ and at tree level $\Delta f_1^L, f_1^R, f_2^L$ & f_2^R vanishes.

- CP conserving, f is real,
- CP violating, f is complex[hep-ph/0605190]
- Measure the influence of fs on xsection and kinematic shapes

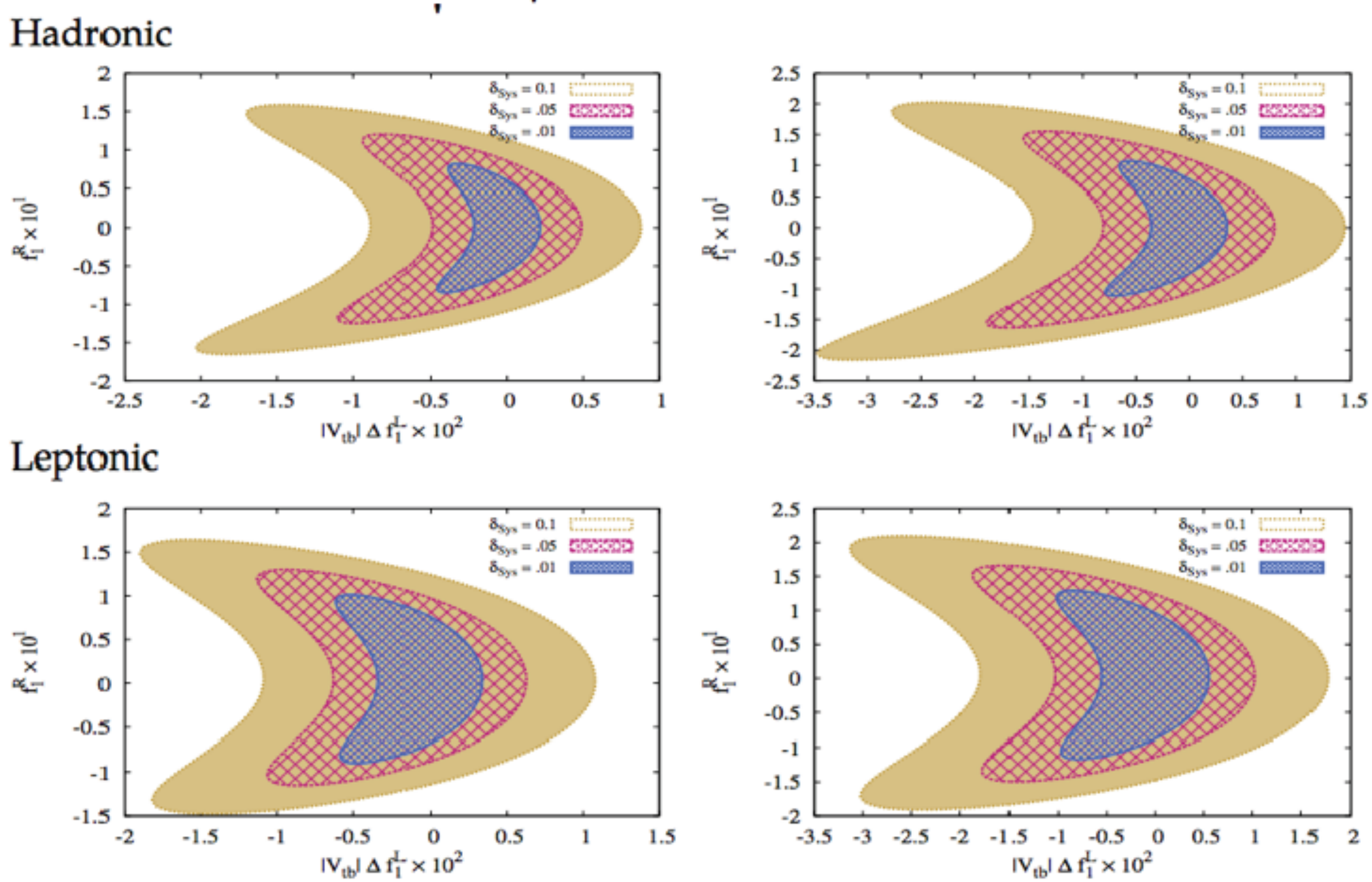
5

Single top [Ruan]

Chi2 analysis using bin information

$$\chi^2(f_i, f_j) = \sum_{k=1}^{N} \left(\frac{\mathcal{N}_k^{\rm exp} - \mathcal{N}_k^{\rm th}(f_i, f_j)}{\delta \mathcal{N}_k^{\rm exp}} \right)^2$$

$$\text{where } \delta\mathcal{N}_k^{\rm SM+\sum_i Bkg_i} = \sqrt{\mathcal{N}_k^{\rm SM+\sum_i Bkg_i}\left(1 + \delta_{sys}^2 \mathcal{N}_k^{\rm SM+\sum_i Bkg_i}\right)}.$$



- 68% contour

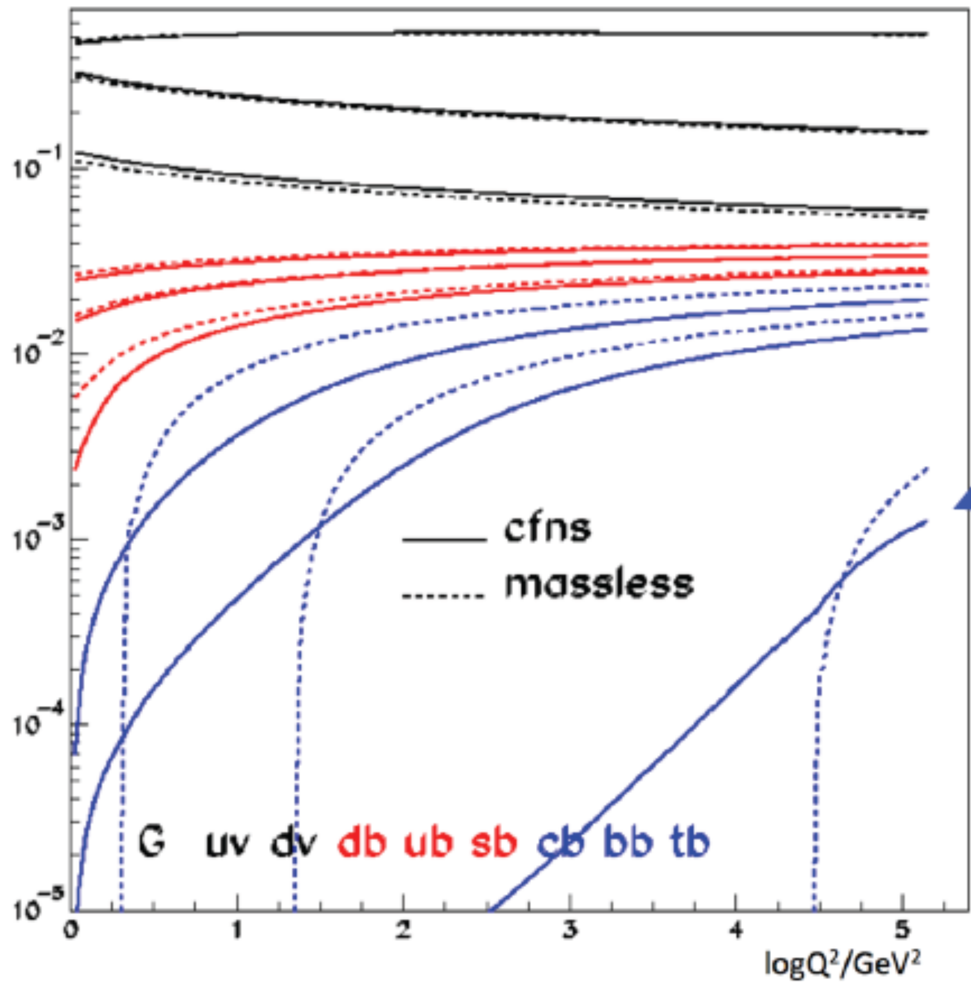
13

t physics [Schwanenberger]

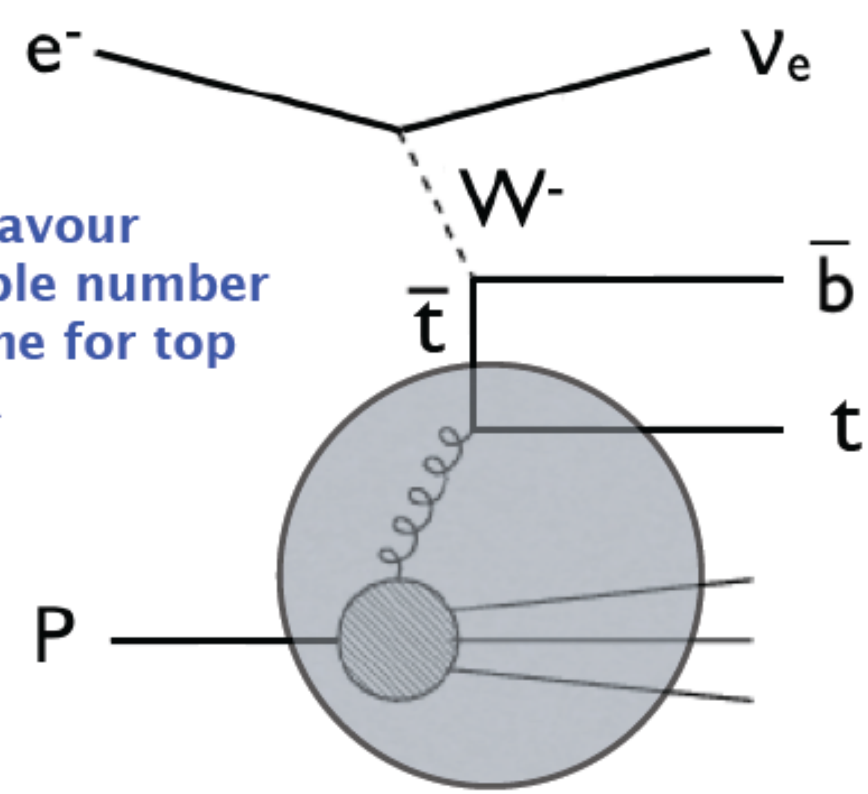
Top Quark Parton Density Function

LHeC CDR, J.Phys. G39, 075001 (2012)

parton momentum fraction

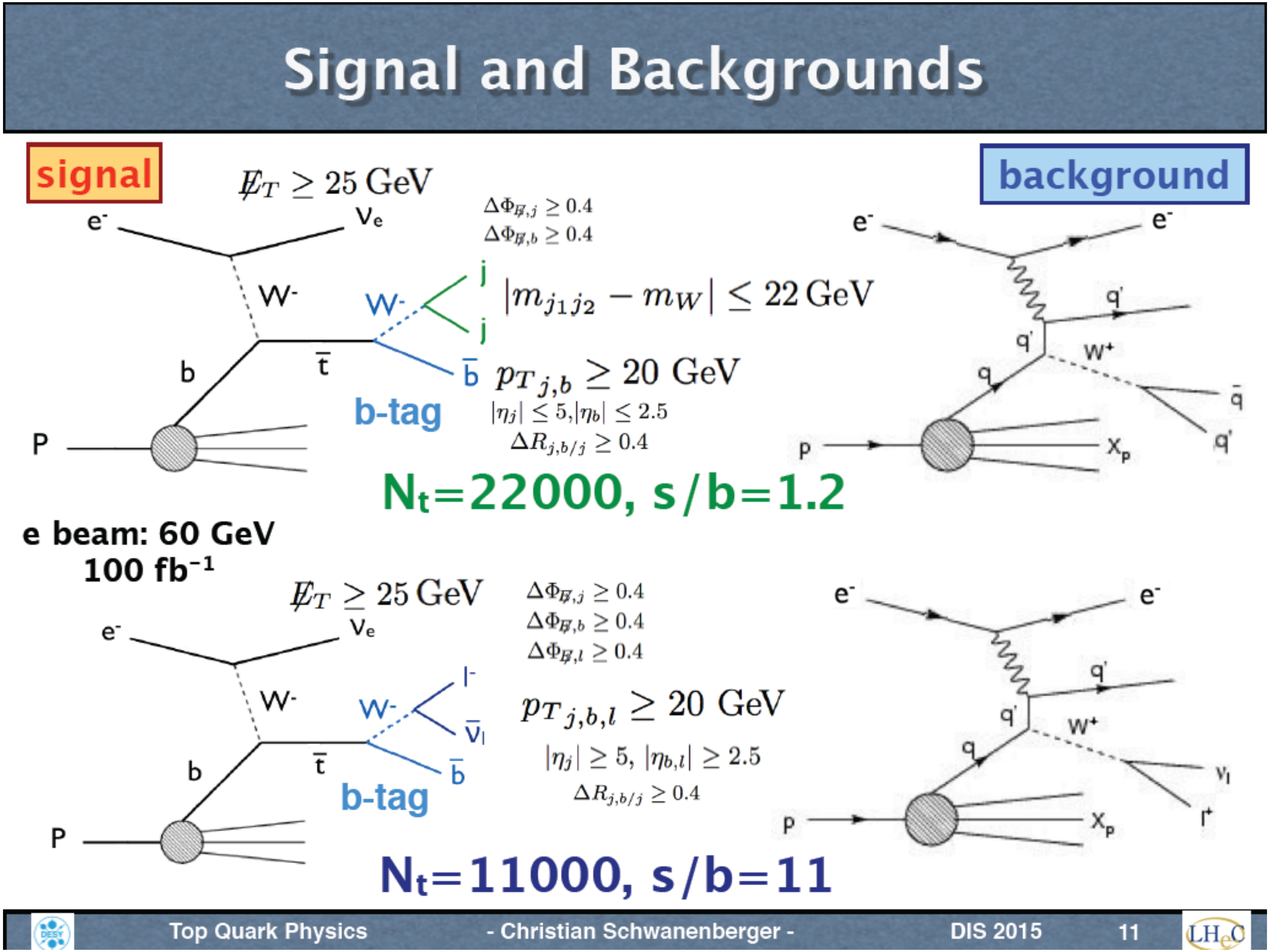


six-flavour variable number scheme for top quark

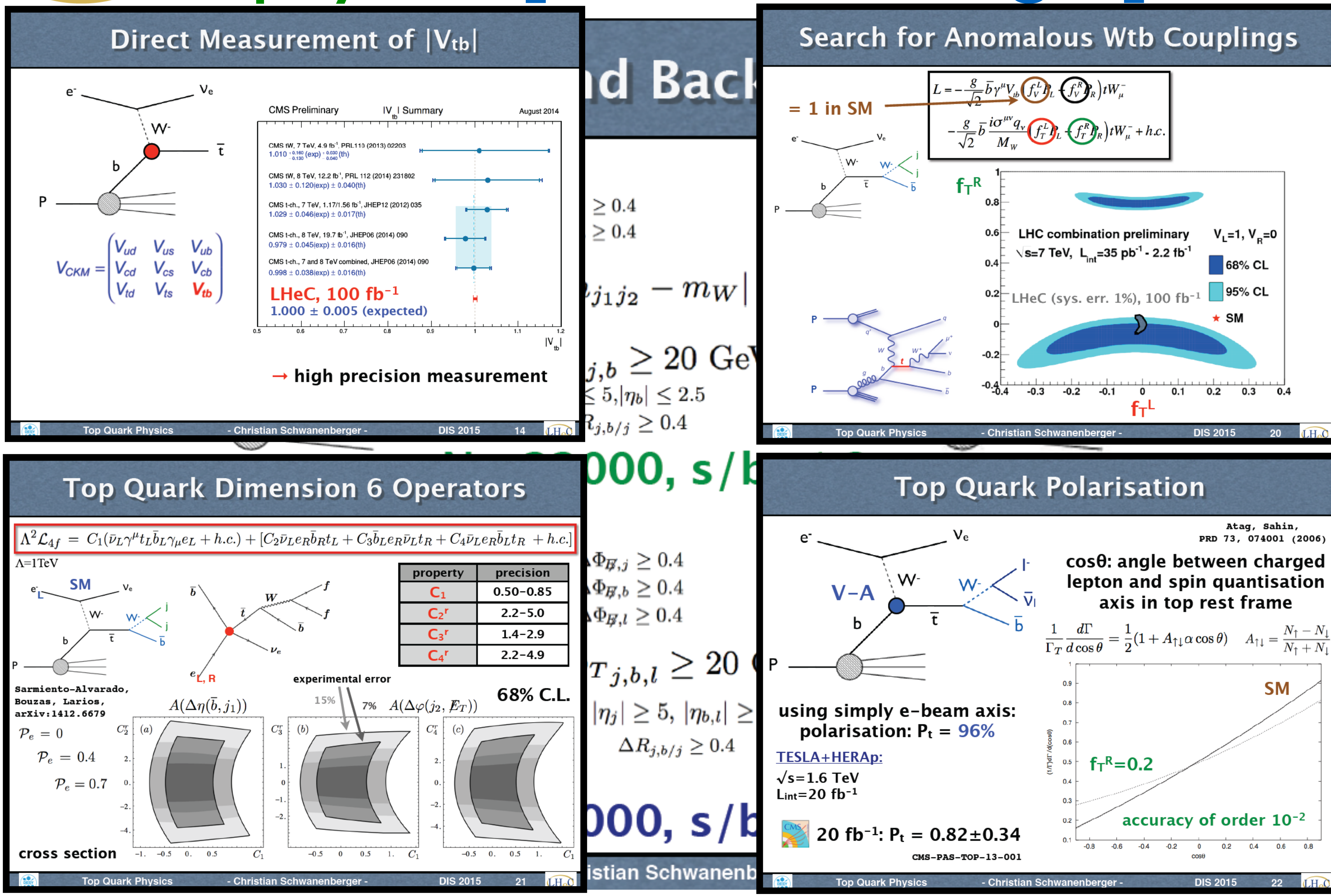


→ **LHeC offers new field of research for top quark PDF**

t physics [Schwanenberger]



LHeC t physics [Schwanenberger]



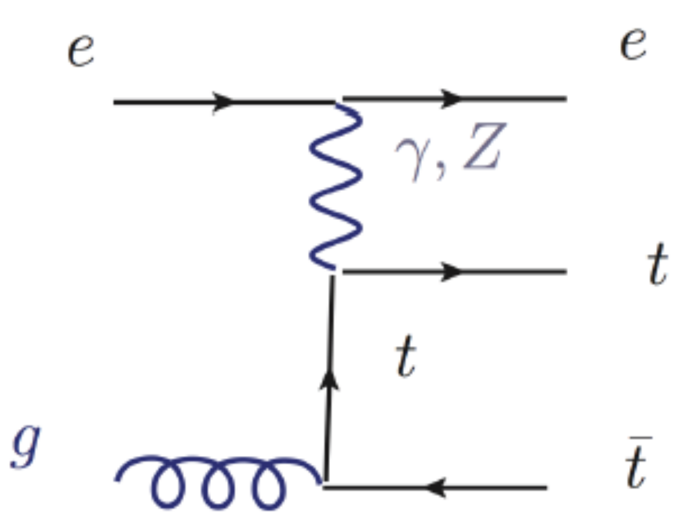
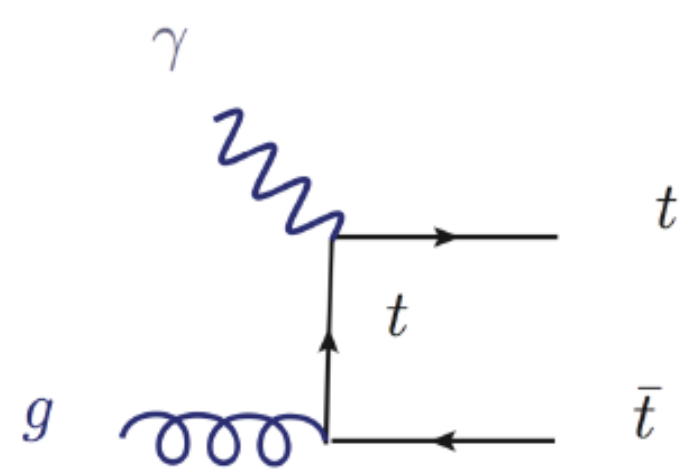
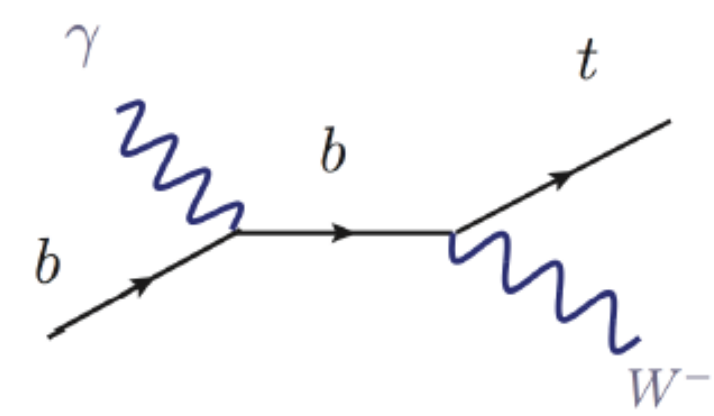
Summary: Physics and Detector.

t physics [Schwanenberger]

NC Top Quark Production

Bouzas, Larios,
Physical Review D 88, 094007 (2013)

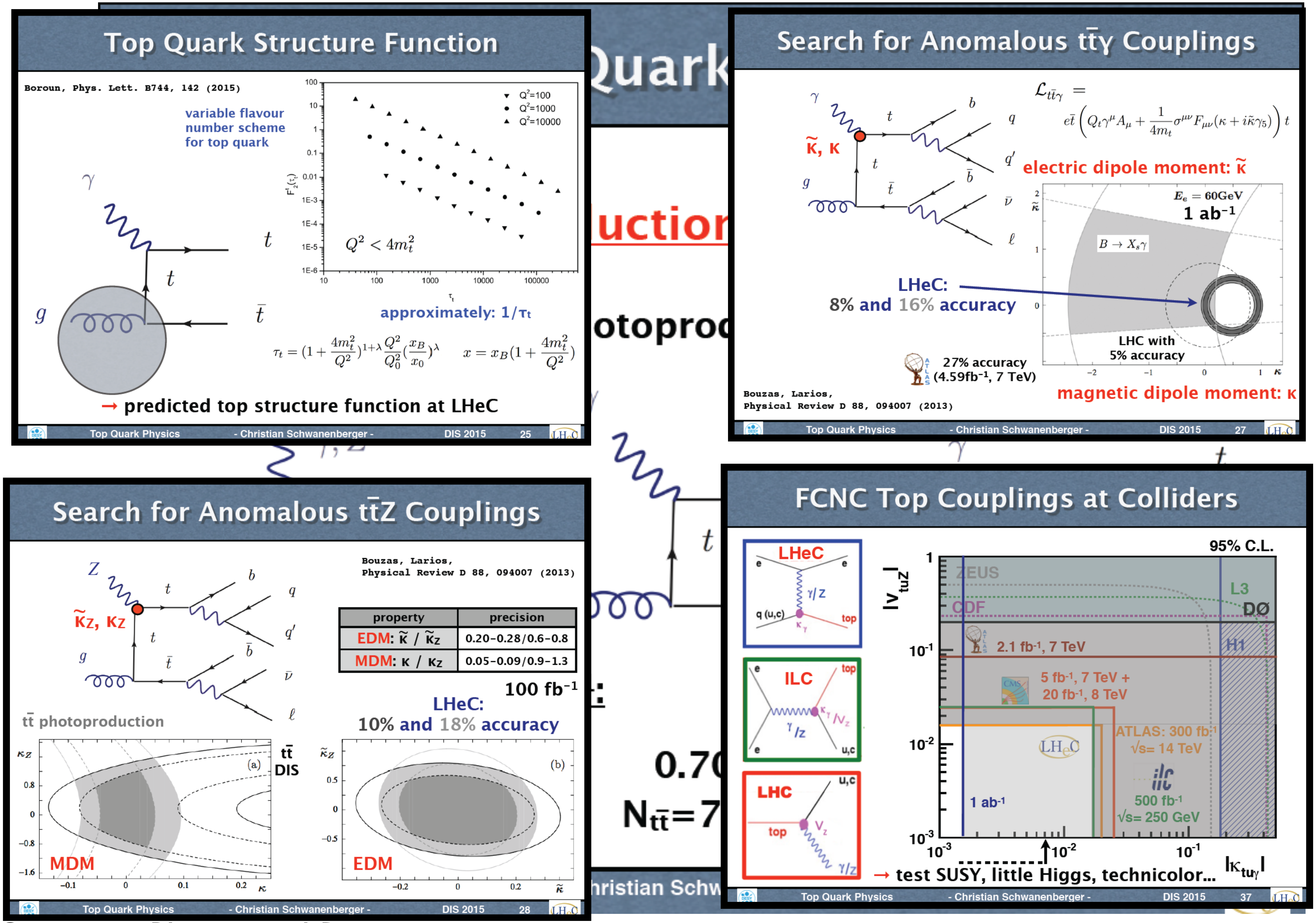
top pair production | **single top production**

DIS	photoproduction	photoproduction
		

e−beam 60 GeV, 100 fb^{-1}:

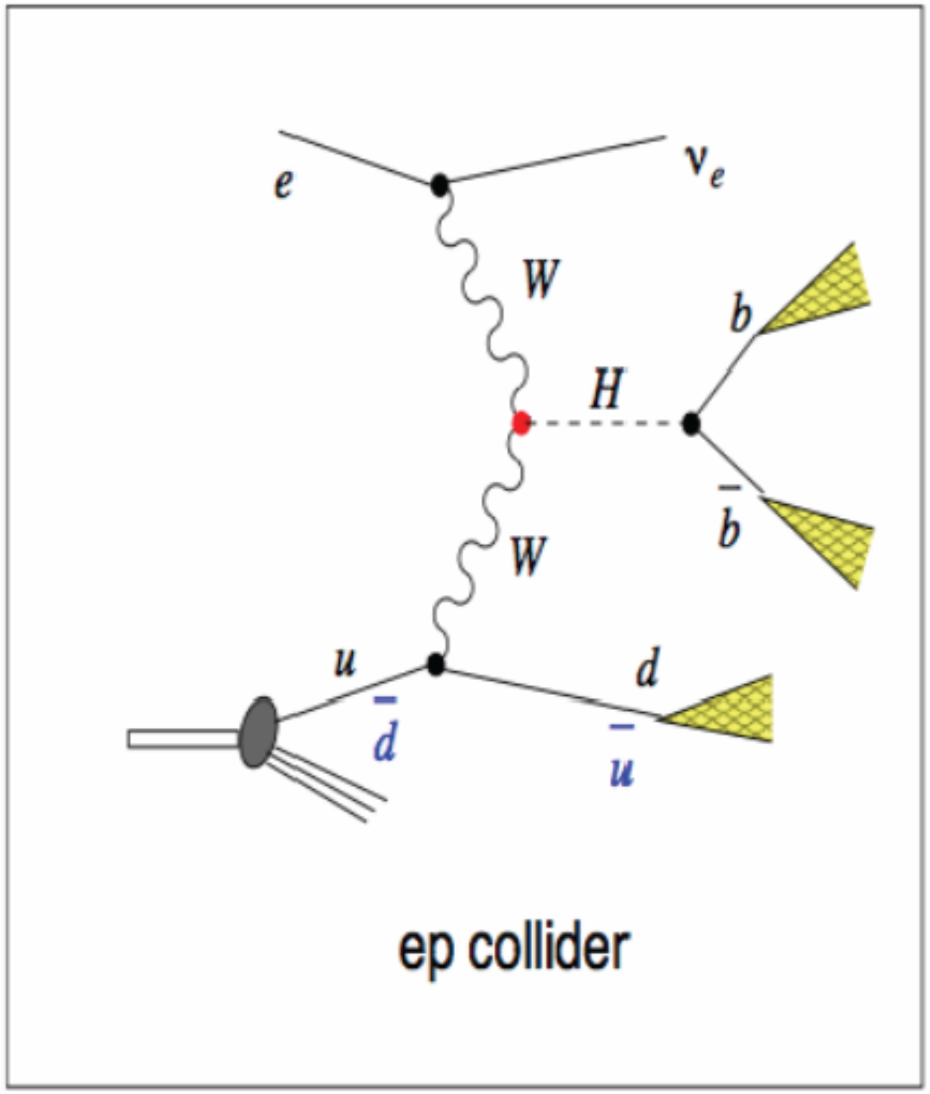
0.023 pb	0.70 pb	0.031 pb
$N_{t\bar{t}}$=2,300	$N_{t\bar{t}}$=70,000	N_t=3,100

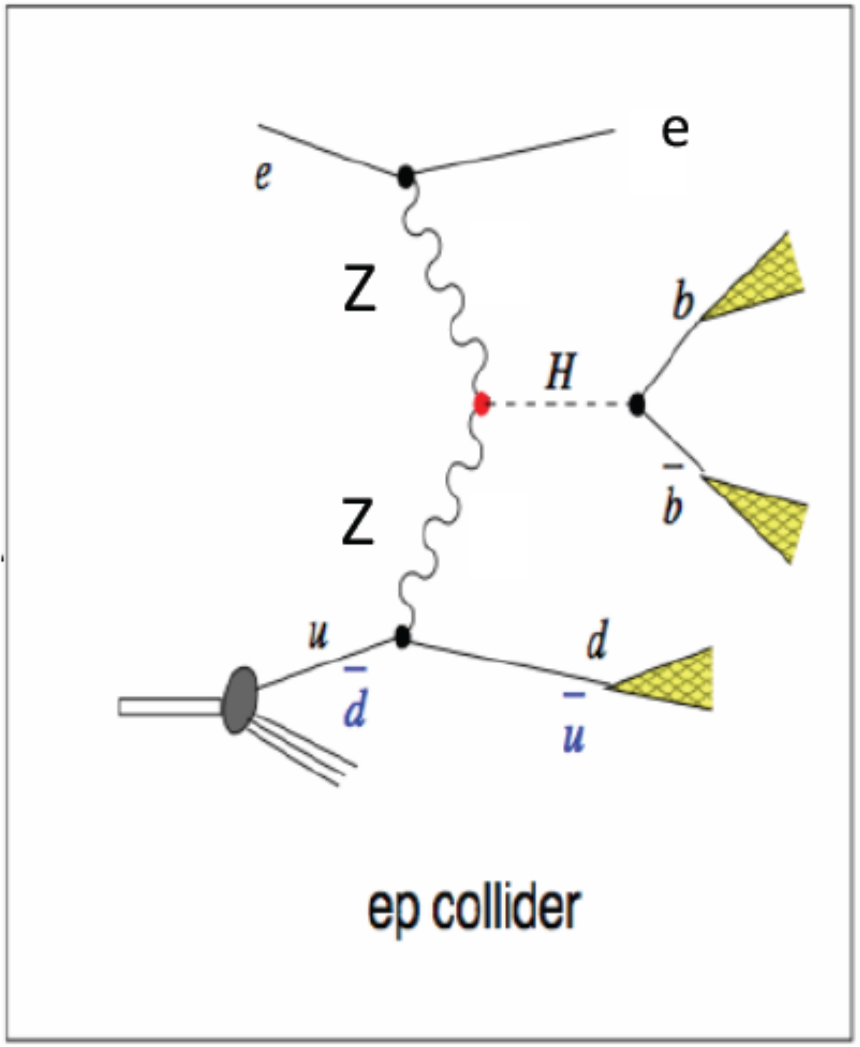
t physics [Schwanenberger]



Summary: Physics and Detector.

BSM Higgs [Hernández]





In the 2HDM; H= h0, H0

For H0 the coupling VVH0 is proportional to Cos(β-α) and VVh0 to Sin(β-α)

BSM Higgs [Hernández]

Process: $e^- p \to \nu_e \phi q_f$; $\phi \to b\bar{s}$ +h.c.

These processes lead to 3-jets+ $\not{E}_T$

We demanded two jets in the central rapidity region: one tagged b-jet and one low flavor jet.

The remaining jet (q_f) has been tagged in the forwards region and the central jet veto (no more than one low flavor jet): are criterions to enhance the signal to the SM backgrounds.

2HDM	tan β	X	Y	Z	h=125		H=130		H=150		H=170	
					bs	σ.bs	bs	σ.bs	bs	σ.bs	bs	σ.bs
Ia2	2				0.76	0.29	0.75	0.330	0.22	0.077	0.011	0.003
Ia15	15	-cot β	cot β	-cot β	12.0	11.7	0.71	0.006	0.58	0.004	0.20	0.001
Ia30	30				12.8	19.1	3.16	0.088	2.50	0.027	0.80	0.005
Ib2	2				0.76	0.30	0.75	0.33	0.22	0.077	0.011	0.003
Ib15	15	-cot β	cot β	-cot β	8.6	7.6	23.6	5.16	8.34	1.39	0.49	0.065
Ib30	30				10.9	11.5	25.2	7.5	16.9	3.18	1.85	0.240
IIa2	2				0.008	0.007	15.6	0.17	4.68	0.033	0.58	0.003
IIa15	15	tan β	cot β	tan β	0.48	0.41	13.1	0.14	12.6	0.090	8.84	0.046
IIa30	30				2.34	1.97	13.1	0.14	13.1	0.092	11.7	0.061
Y2	2				1.33	1.12	2.62	0.026	1.90	0.013	0.50	0.0026
Y15	15	tan β	cot β	-cot β	0.29	0.24	20.2	0.220	4.94	0.036	0.57	0.0030
Y30	30				3.98	3.36	46.8	0.518	46.0	0.336	39.2	0.2071

$\phi = h, H$; bs units of 10^{-2} and $\sigma.bs$ units of fb.

We consider only σ.bs > 0.15 fb; at least 15 events for 100 fb^(-1)

We applied the following basic preselections:

$$p_T^q > 15.0 \quad \mathrm{GeV}, \Delta R(q,q) > 0.4$$

$\Delta R = \Delta\eta^2 + \Delta\phi^2$, where η and ϕ are the pseudo-rapidity and azimuthal angle respectively.

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BSM Higgs [Hernández]

h_{SM}=125 GeV:3-jet+$\not{E}_T$ with 100 fb^{-1}

Details in arXiv: 1503.01464

- a: $N_j \gtrsim 3$
- b: $N_{b-tag} \gtrsim 1$ (with ϵ_b=0.50, ϵ_c=0.10 and ϵ_j=0.01, where j=u,d,s,g)
- cd : at least two central jets (within $\eta < 2.5$) with $\not{E}_T > 20GeV$ →3j not survive and photo production is reduced
- e: lepton (e or μ) veto with $p_T > 20$ GeV and $\eta < 3.0$
- f: in the central region: $|M_{bj} - M_{h(H)}|$ is minimum and with 15 GeV mass windows.
- g: remaining leading jet with $p_T > 25$ GeV and $-5.5 < \eta < -0.5$
- h: $m_{\phi j_f} > 190$ GeV

i:We required only one low flavored jet in the central regions (this has severe impact on the processes)

Proc	RawEvt	a	b	cd	e	f	g	h	i	$\mathcal{S}$
Ia2	29.9	21.1	8.3	4.6	4.4	1.8	1.5	1.3	0.8	0.06(0.19)
Ia15	1166.3	814.3	320.2	173.0	166.6	67.3	56.6	44.2	27.7	2.12(6.7)
Ia30	1911.1	1294.7	539.0	282.7	274.6	102.5	78.7	46.6	29.3	2.24(7.1)
Ib2	30.0	21.0	8.1	4.5	4.3	1.8	1.5	1.3	0.8	0.06(0.19)
Ib15	761.5	521.0	212.5	113.3	109.6	42.1	33.5	23.2	15.0	1.15(3.6)
Ib30	1145.3	776.2	323.1	170.6	165.3	63.3	48.6	29.5	18.8	1.44(4.55)
IIa15	40.6	28.6	11.1	6.1	5.9	2.3	2.0	1.7	1.1	0.08(0.25)
IIa30	197.0	139.3	53.9	30.0	28.9	11.6	10.0	8.4	5.2	0.39(1.23)
Y2	112.2	79.0	30.5	16.9	16.3	6.4	5.5	4.6	2.9	0.22(0.69)
Y15	24.2	17.0	6.6	3.7	3.5	1.4	1.2	1.0	0.6	0.05(0.15)
Y30	336.0	237.7	92.8	52.1	50.2	20.1	17.1	14.4	9.2	0.70(2.2)
$\nu t\bar{b}$	50712.1	28338.4	15293.7	8144.2	7532.7	2982.1	2058.0	652.2	139.6	
$\nu b\bar{b}j$	14104.6	6122.8	3656.7	1787.1	1650.1	257.5	152.5	85.2	15.1	
$\nu b2j$	18043.1	8389.2	3013.0	1445.5	1373.7	389.5	206.1	77.2	11.3	$\mathcal{B}$=170.8
$\nu 3j$	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	$\sqrt{\mathcal{B}}$=13.1
$eb\bar{b}j$	256730.1	55099.8	36353.6	1432.0	200.7	54.1	24.8	18.0	4.5	
$et\bar{t}$	783.3	685.0	384.5	179.3	26.2	11.6	10.5	3.9	0.3	

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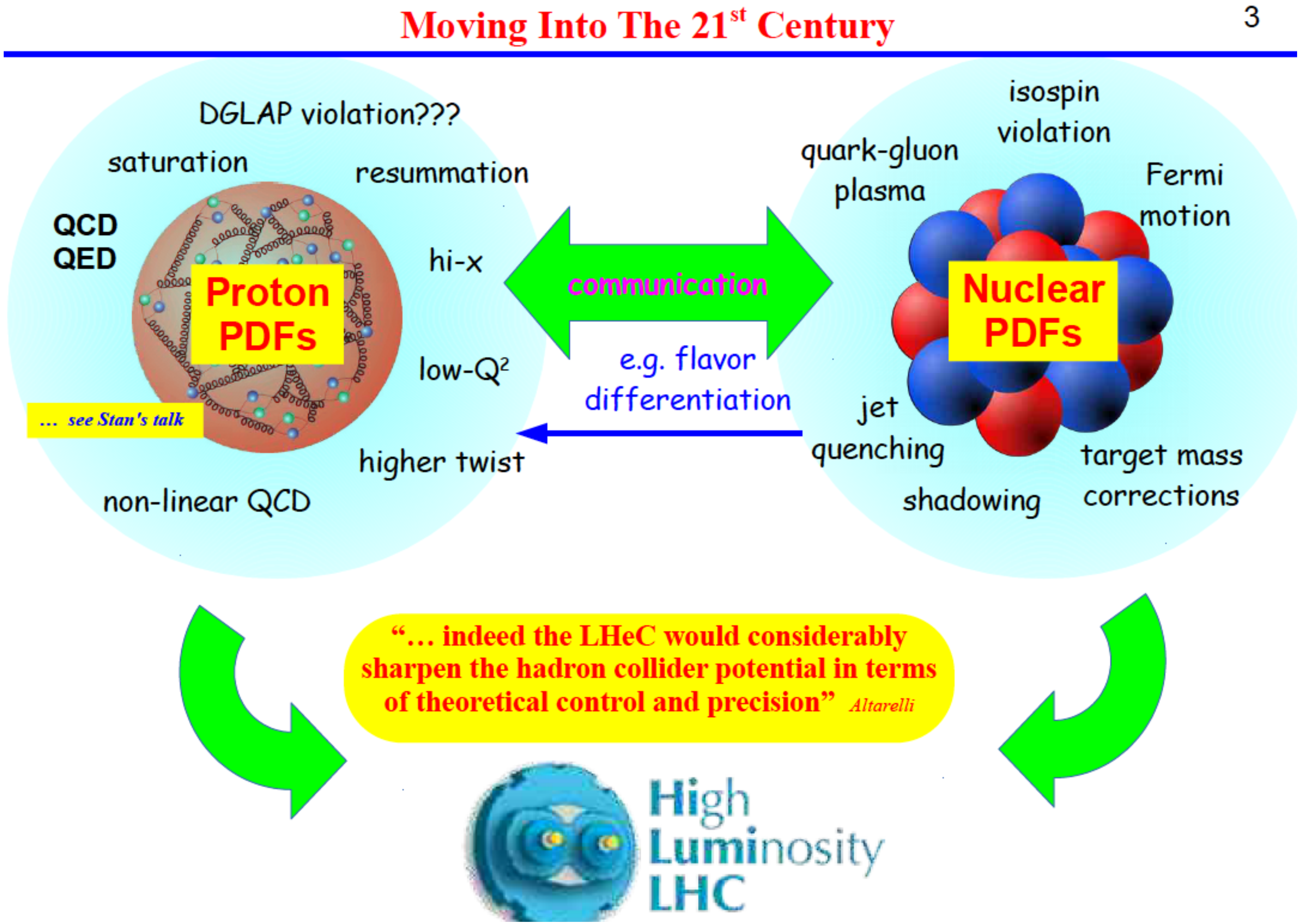
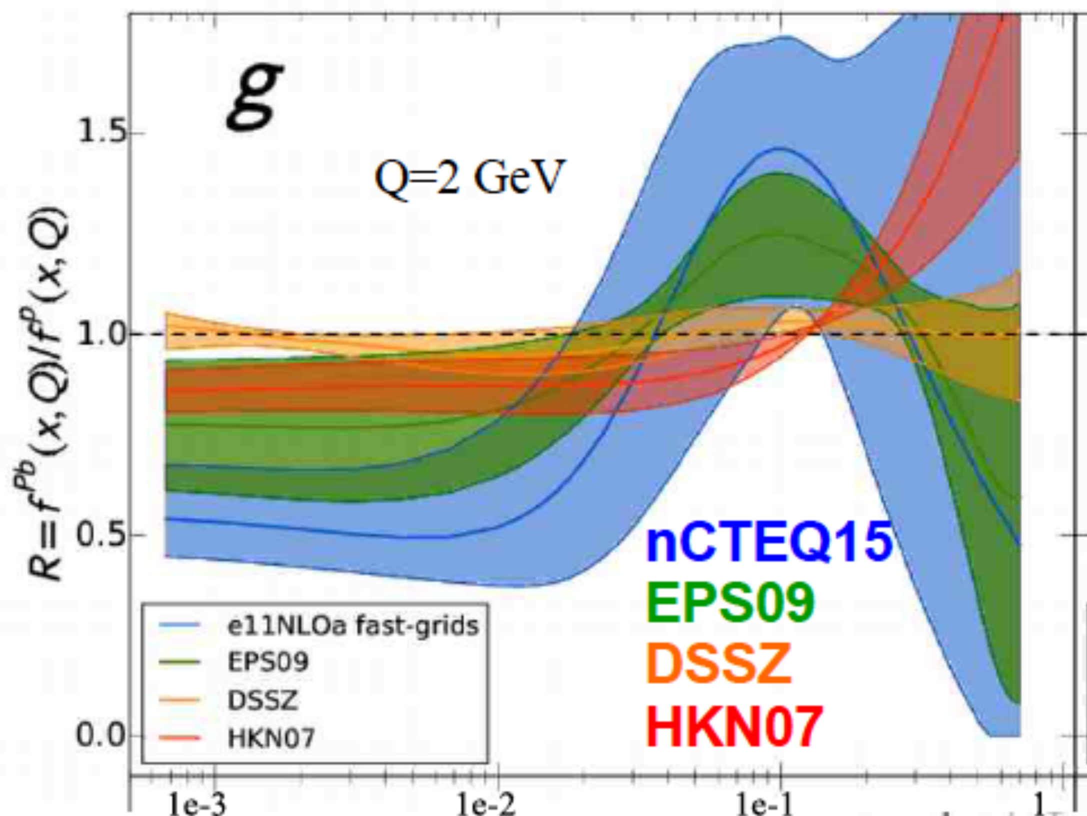
Results in () is for 1000 fb^(-1)

nPDFs [Olness]

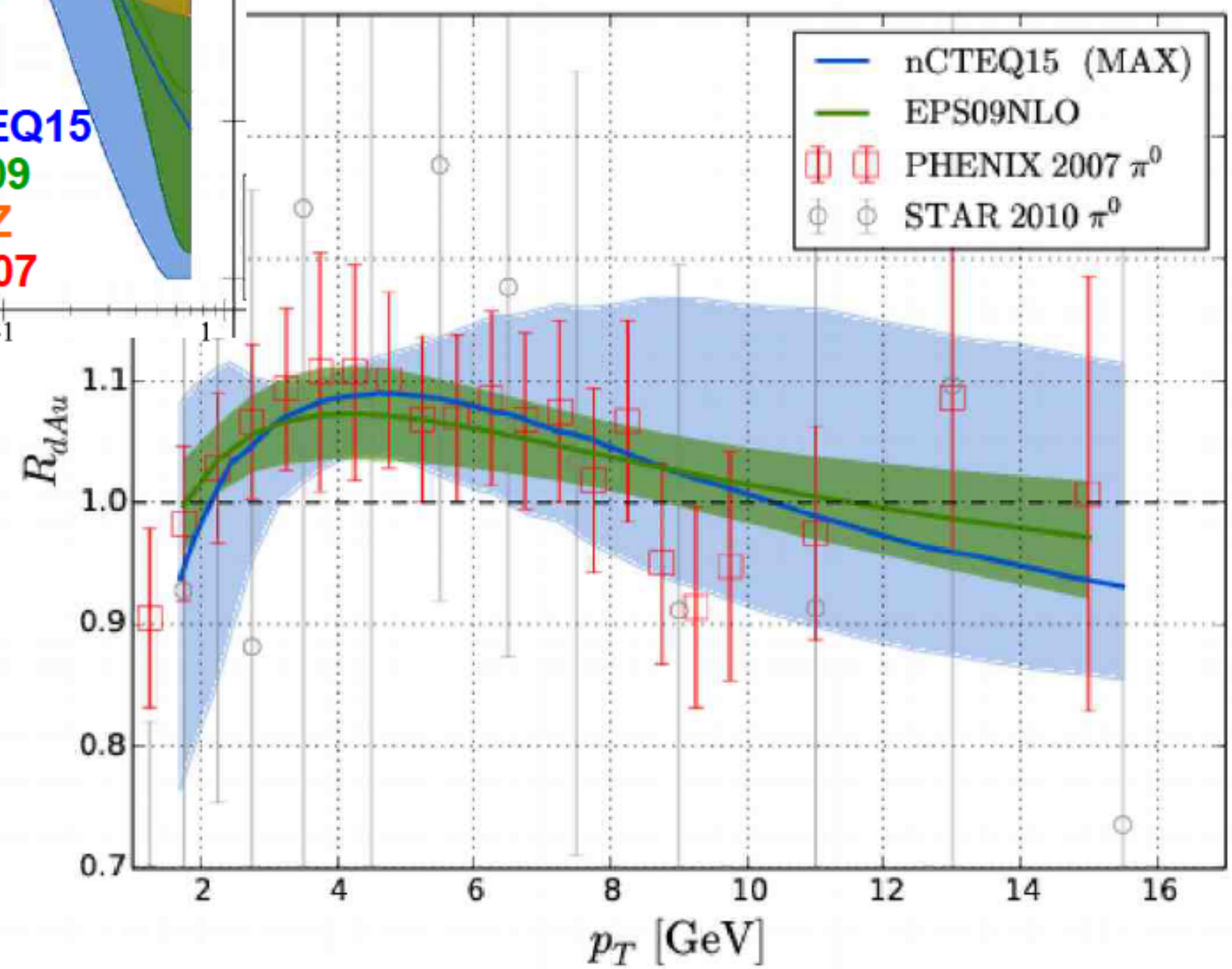


nPDFs [Olness]

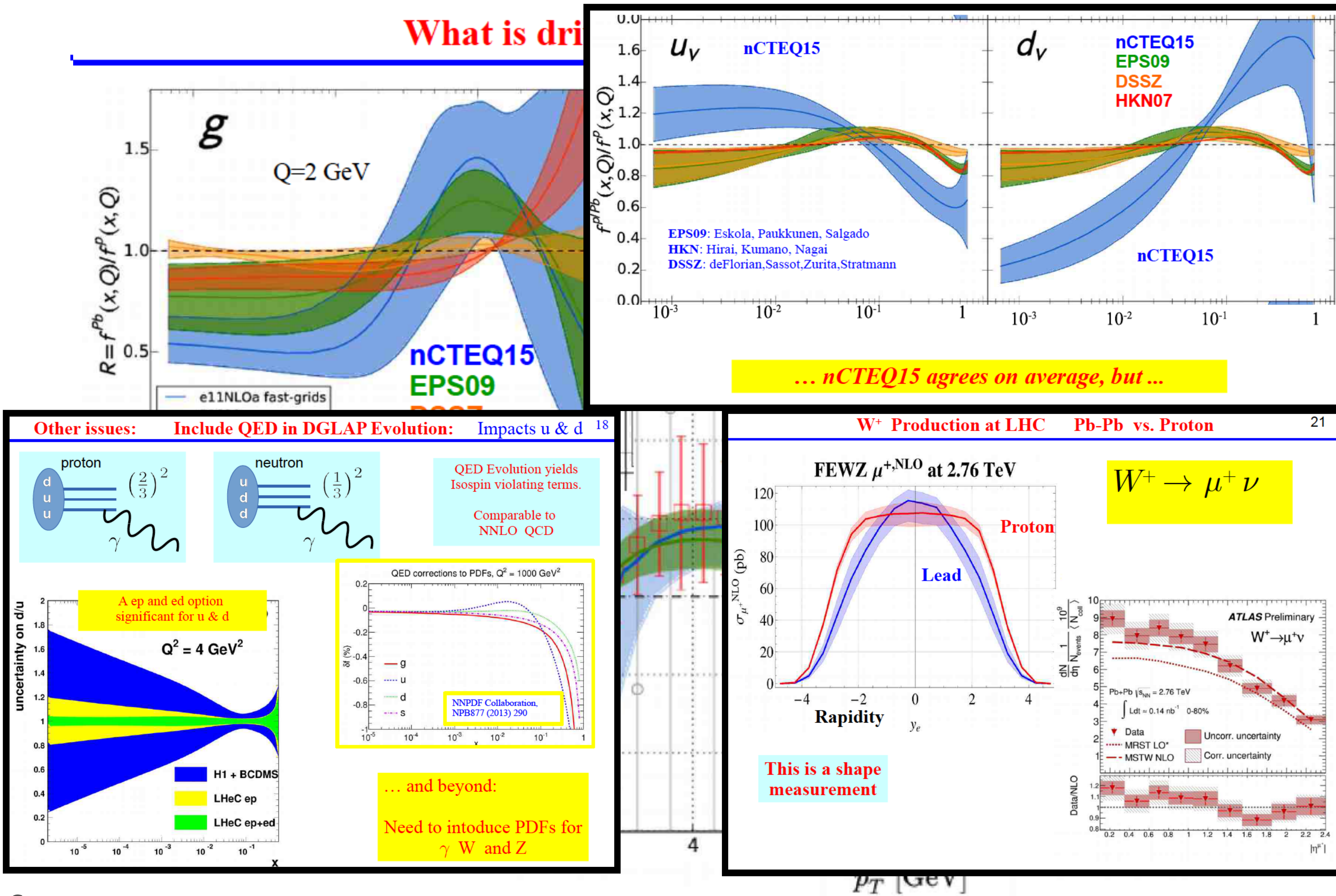
What is driving the Gluon PDF ??? 12



RHIC Pion Production Data

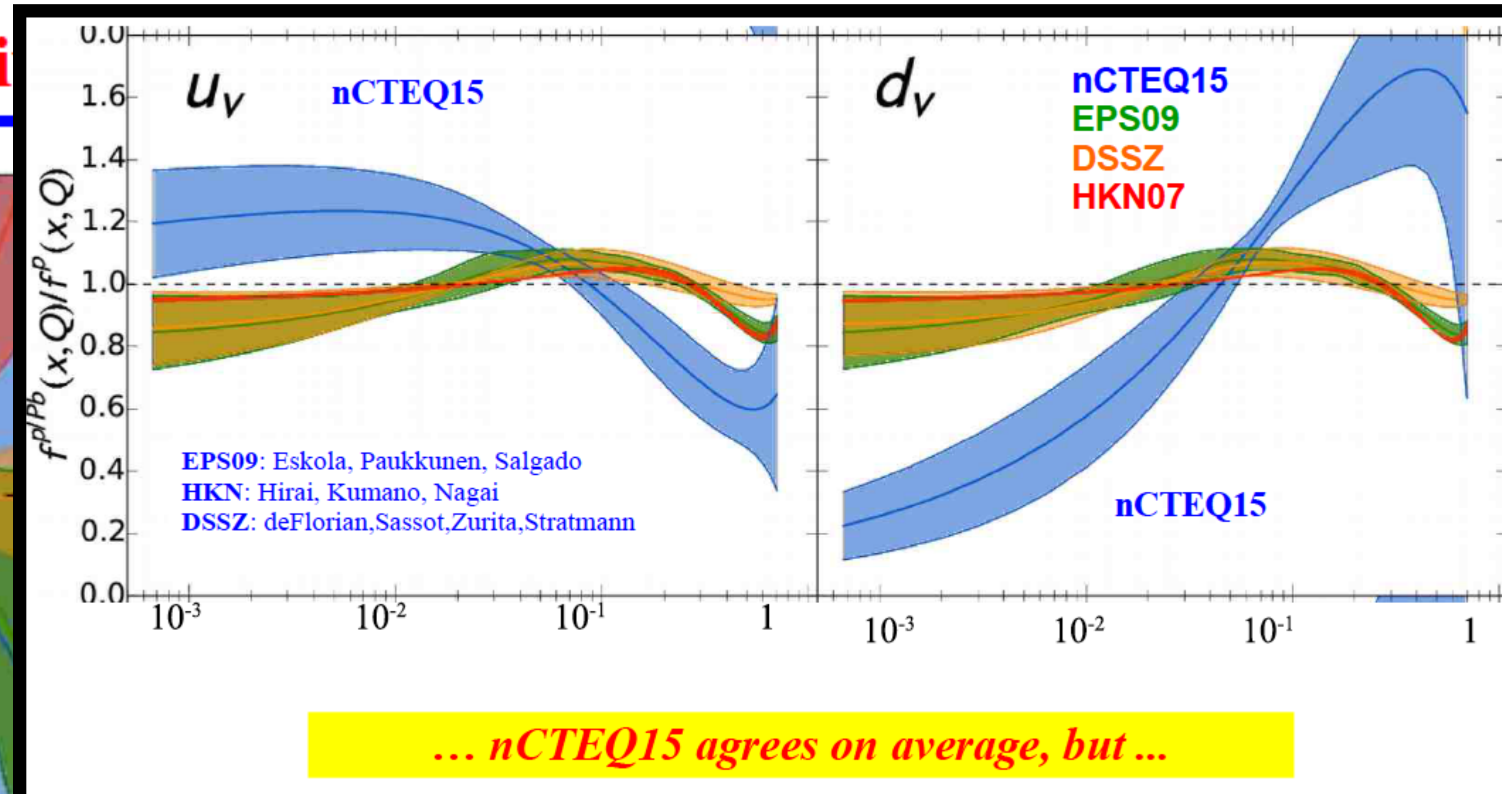


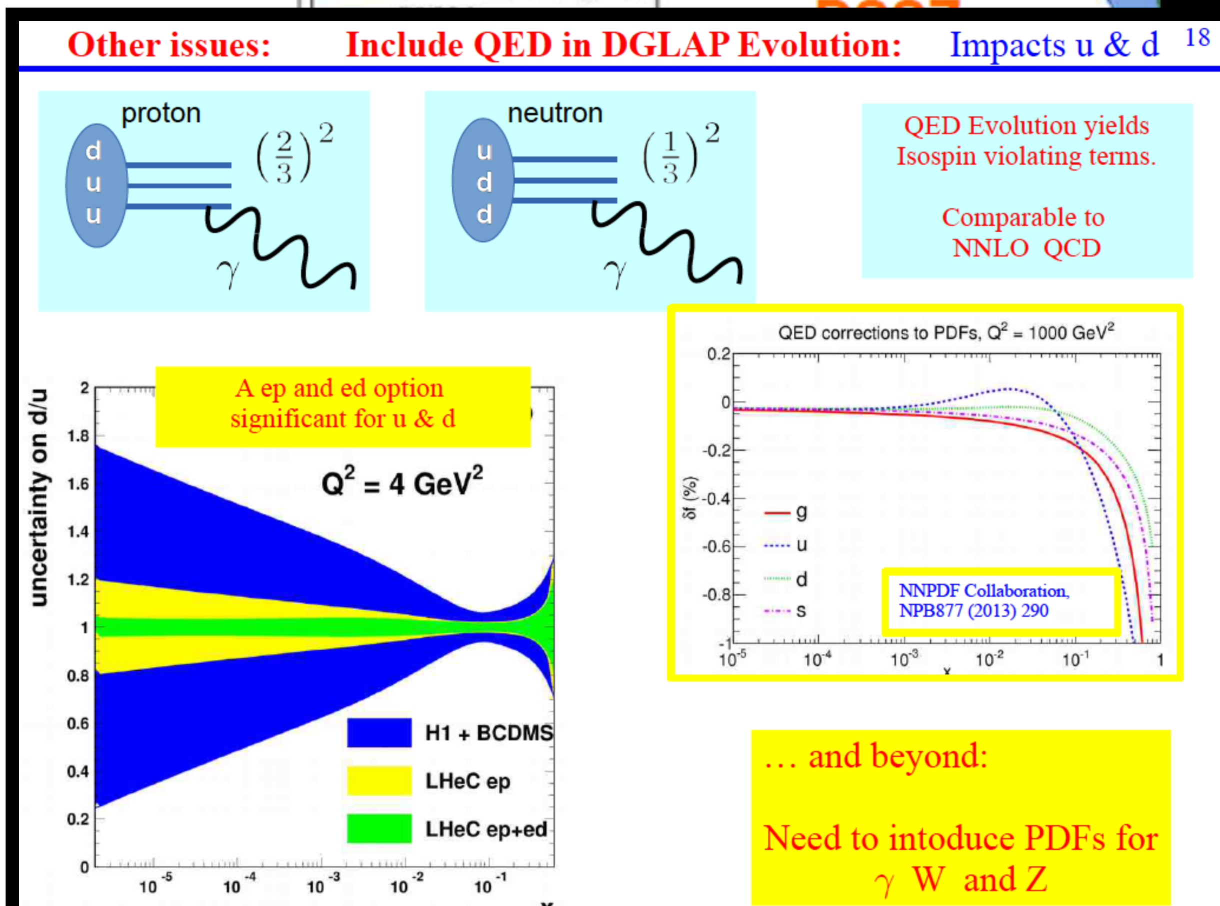
nPDFs [Olness]

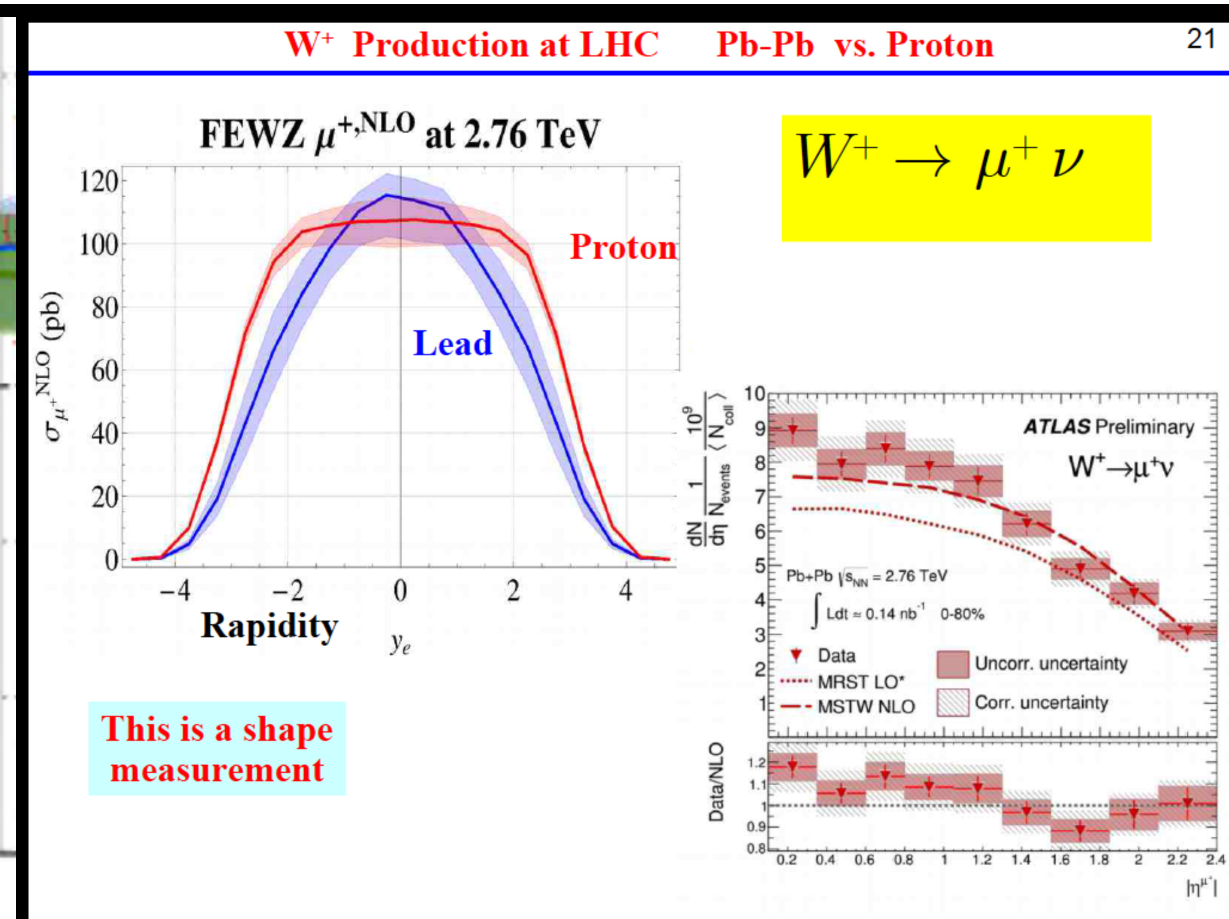


nPDFs [Olness]

- New set just released.
- Disagreements can only be solved by data: pPb@LHC (to some extent: W, Z, jets), LHeC!!!
- NNLO QCD + QED!!!.





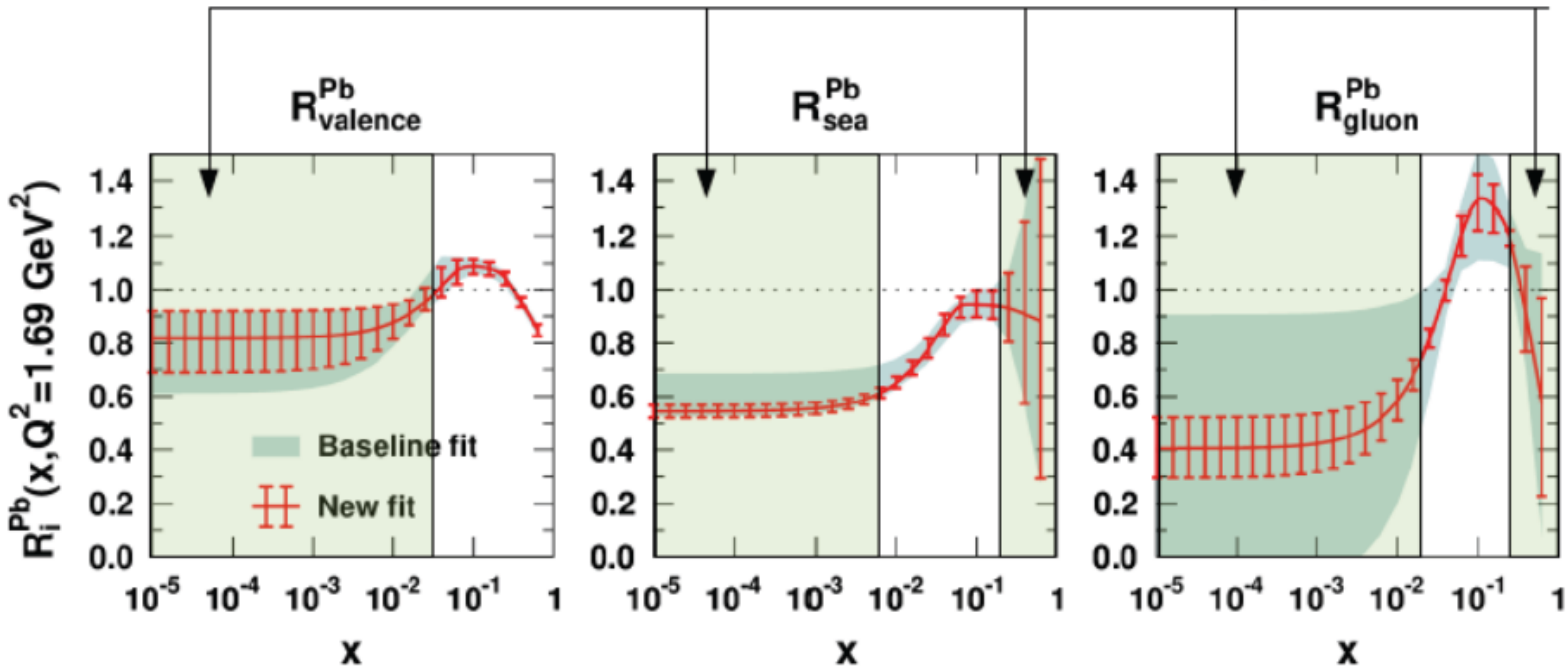


nPDFs at LHeC [Paukkunen]

Previous LHeC studies: post-CDR

- Reduced cross sections only, different energies, all x.

Currently no real data constraints!



Hannu Paukkunen, LHeC workshop 1401

- A drastic reduction in the small-x gluon and sea quark uncertainties
- More freedom in the fit function should be allowed – the baseline uncertainty probably underestimated
- Addition of charged-current data should give a handle on the flavor dependence, which is currently (practically) unconstrained

N. Armesto, M. Klein, H. Paukkunen - Nuclear PDFs at the LHeC 7

LHeC nPDFs at LHeC [Paukkunen]

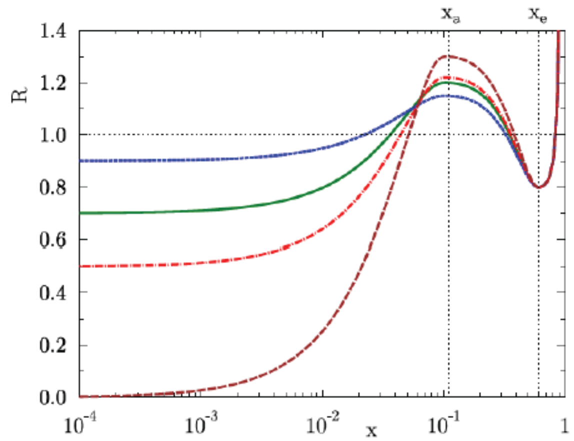
EPS09:

- Very little freedom at small x.

The fit function in EPS09:

$$R^{\rm EPS09}(x) = \begin{cases} a_0 + (a_1 + a_2 x)\left(e^{-x} - e^{-x_a}\right) & x \leq x_a \\ b_0 + b_1 x + b_2 x^2 + b_3 x^3 & x_a \leq x \leq x_e \\ c_0 + (c_1 - c_2 x)(1-x)^{-\beta} & x_e \leq x \leq 1 \end{cases}$$

(power-law parametrization of A-dependence at x_a, x_e, and $x \to 0$)

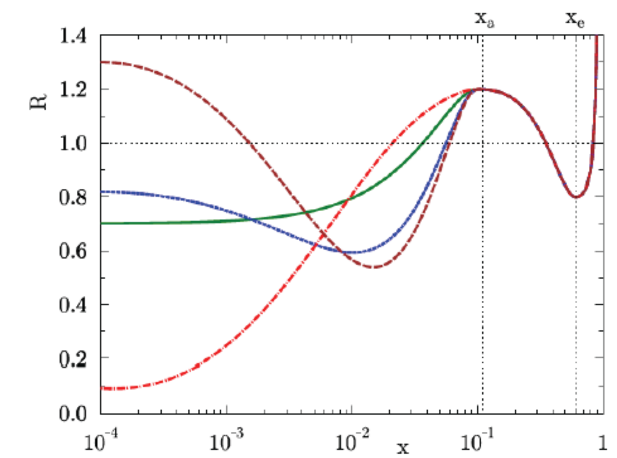


N. Armesto, M. Klein, H. Paukkunen - Nuclear PDFs at the LHeC 10

New ICs:

- Use a far more flexible form to reduce the bias at small x:

$$R(x \leq x_a) = a_0 + a_1(x - x_a)^2 + \sqrt{x}(x_a - x)\left[a_2 \log\left(\frac{x}{x_a}\right) + a_3 \log^2\left(\frac{x}{x_a}\right) + a_4 \log^3\left(\frac{x}{x_a}\right)\right]$$



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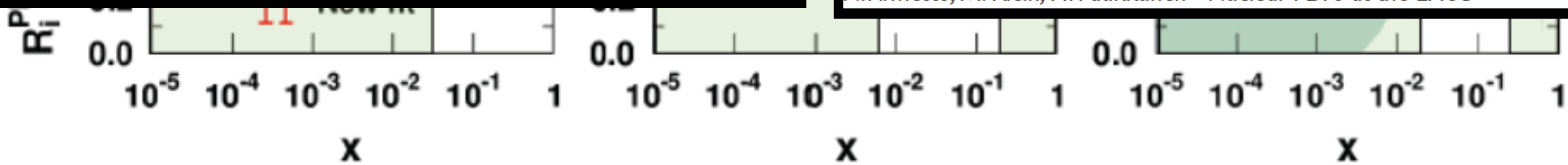

Hannu Paukkunen, LHeC workshop 1401

- A drastic reduction in the small-x gluon and sea quark uncertainties
- More freedom in the fit function should be allowed – the baseline uncertainty probably underestimated
- Addition of charged-current data should give a handle on the flavor dependence, which is currently (practically) unconstrained

N. Armesto, M. Klein, H. Paukkunen - Nuclear PDFs at the LHeC 7

nPDFs at LHeC [Paukkunen]

- Very
  The

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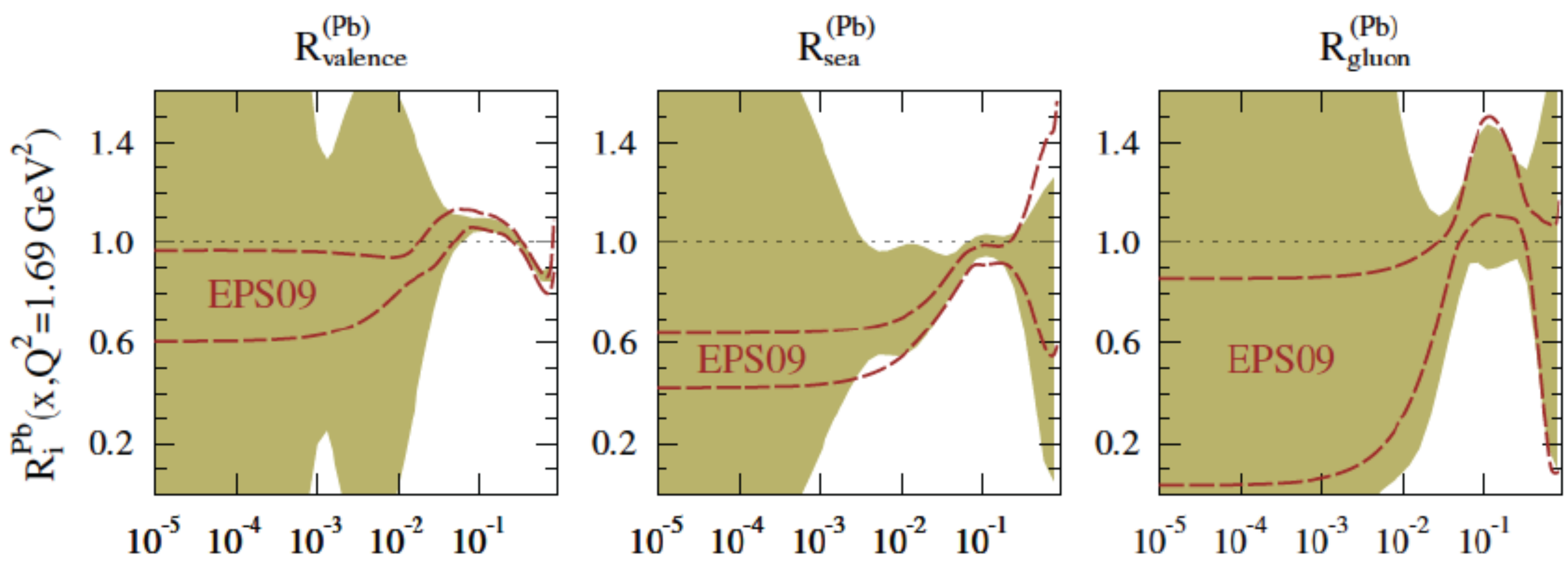
New fit framework:

The baseline fit using the new fit functions: no control over small x!



The lower bound restricted here by $F_L(Q^2 = 2\,\mathrm{GeV}^2, x > 10^{-5}) > 0$

Maybe against "physical intuition" (small-x theory predicts shadowing, $R_i < 1$), but consistent with the data.

E.g. in EPS09, small-x shadowing was essentially built in

nPDFs at LHeC [Paukkunen]

• Very
The

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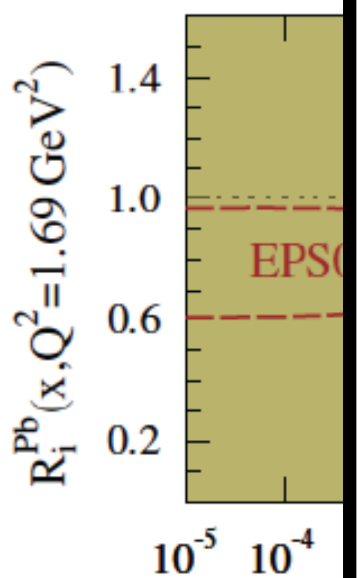
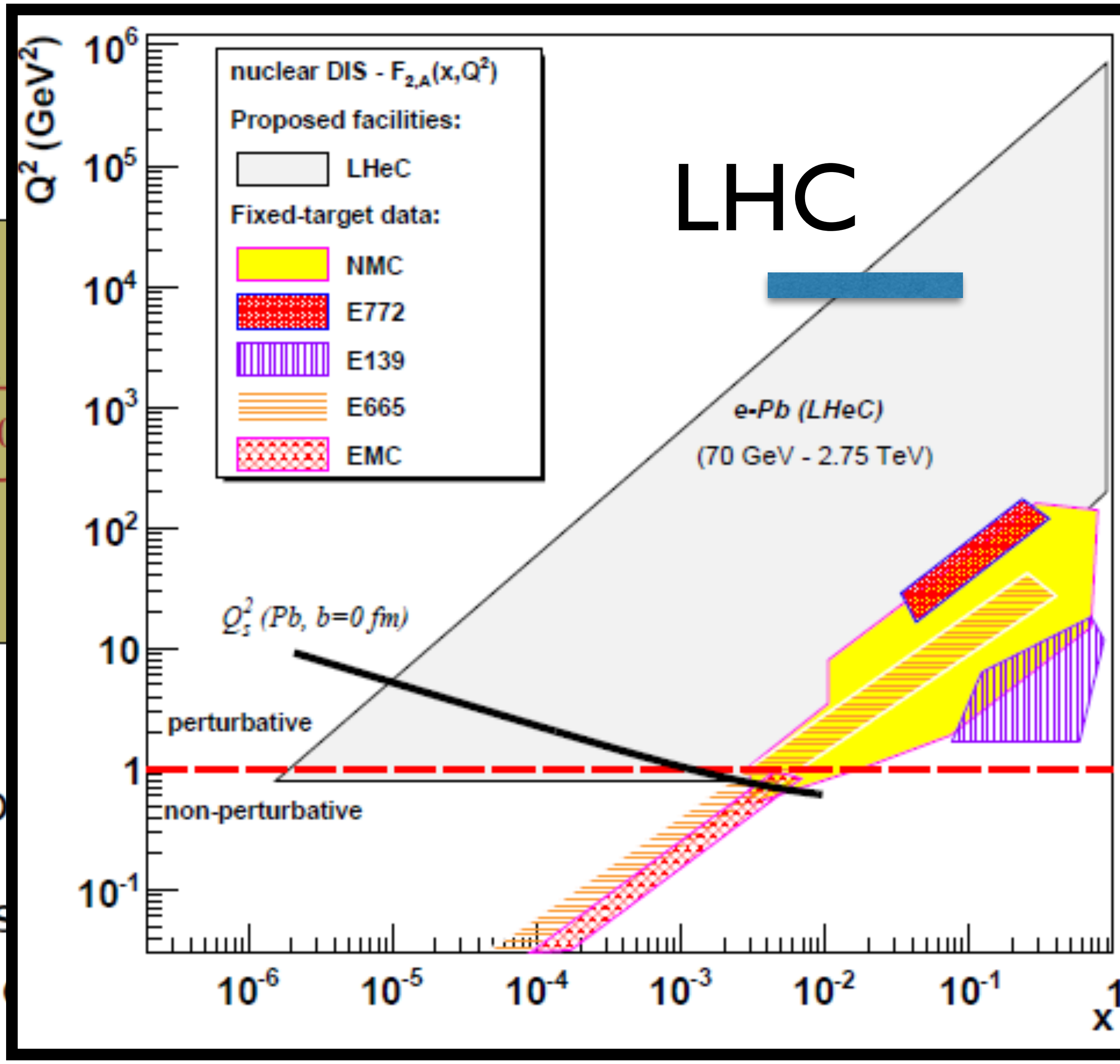
N. Armesto,

New fit framework:

The baseline fit using the new fit functions: no control over small x!





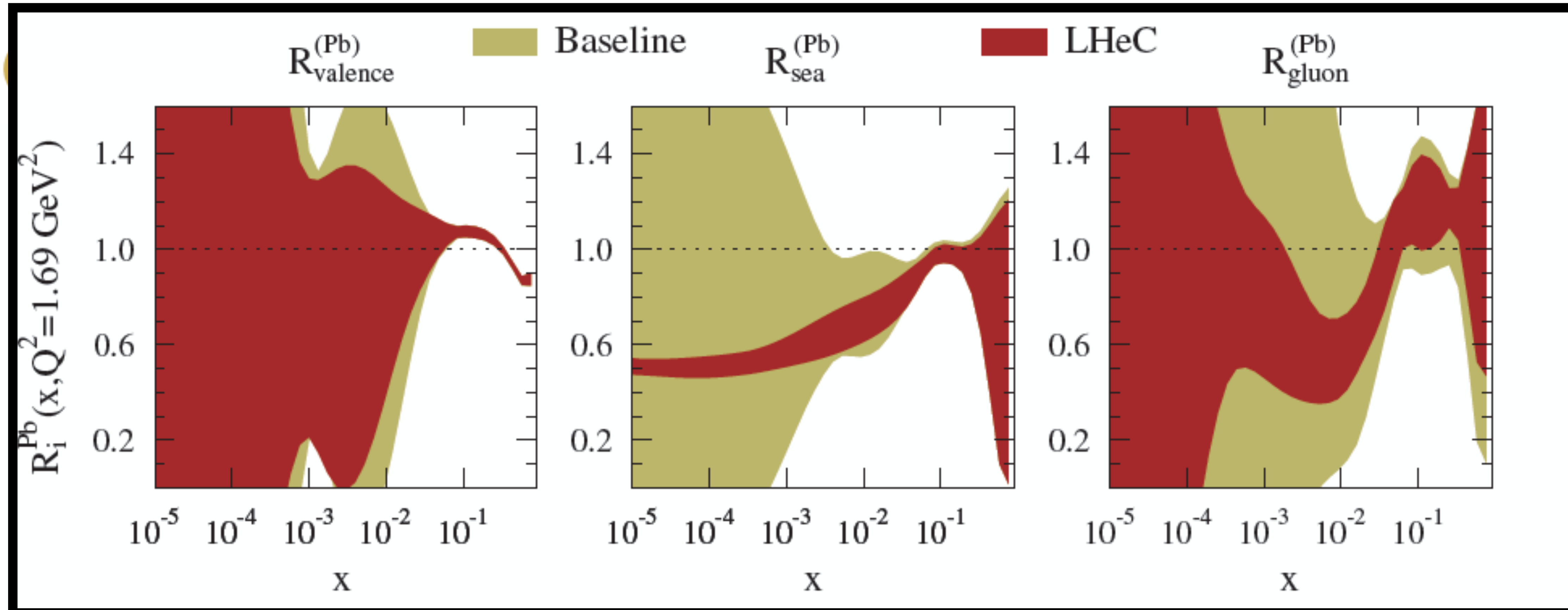
The lower bo ... $> 10^{-5}) > 0$

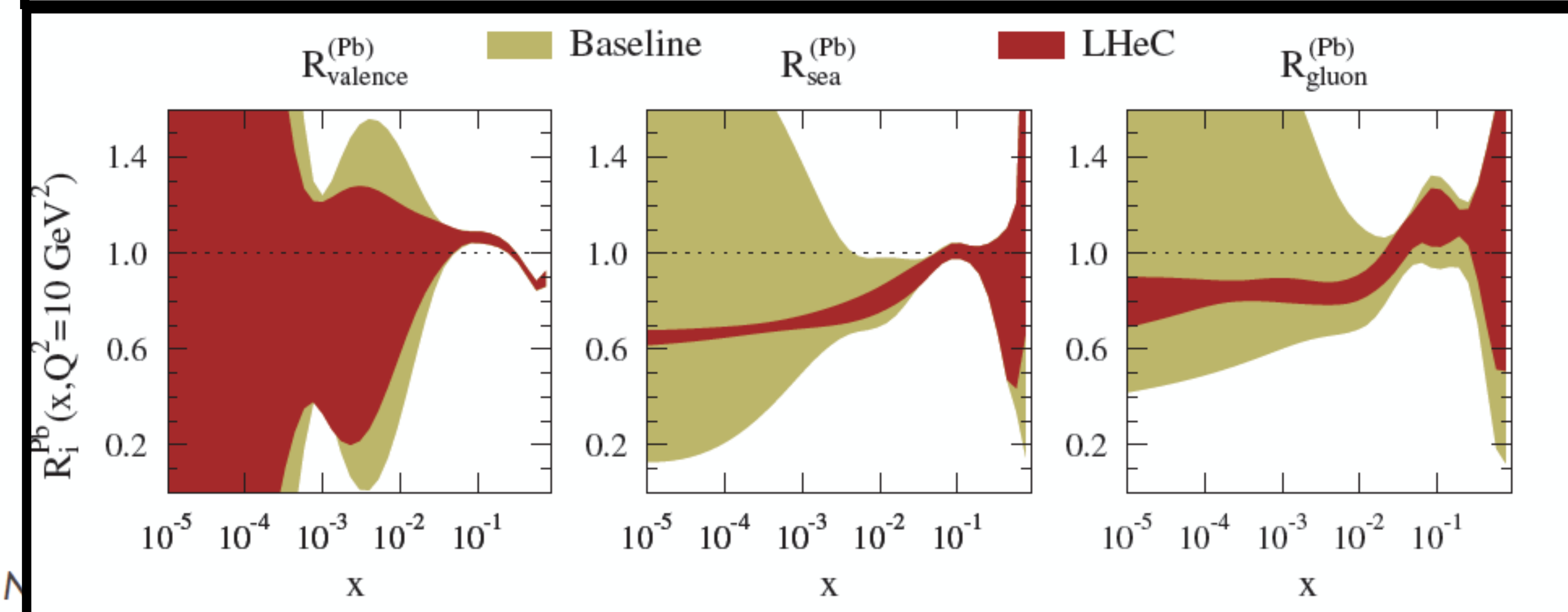
Maybe agains ... ts shadowing, $R_i < 1$), but ...

E.g. in EPS09, small-x shadowing was essentially built in

N. Armesto, M. Klein, H. Paukkunen - Nuclear PDFs at the LHeC 12

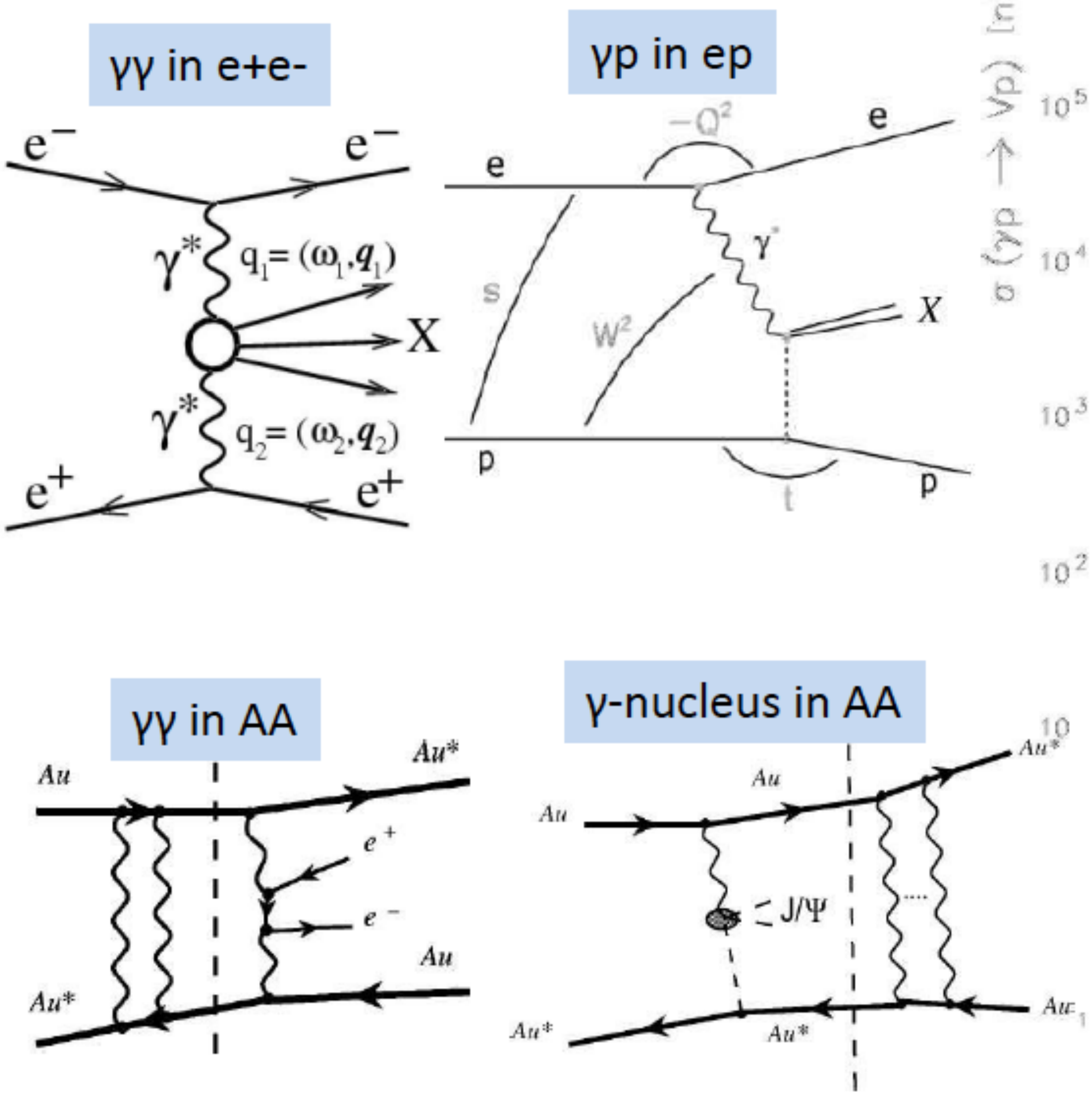
nPDFs at LHeC [Paukkunen]

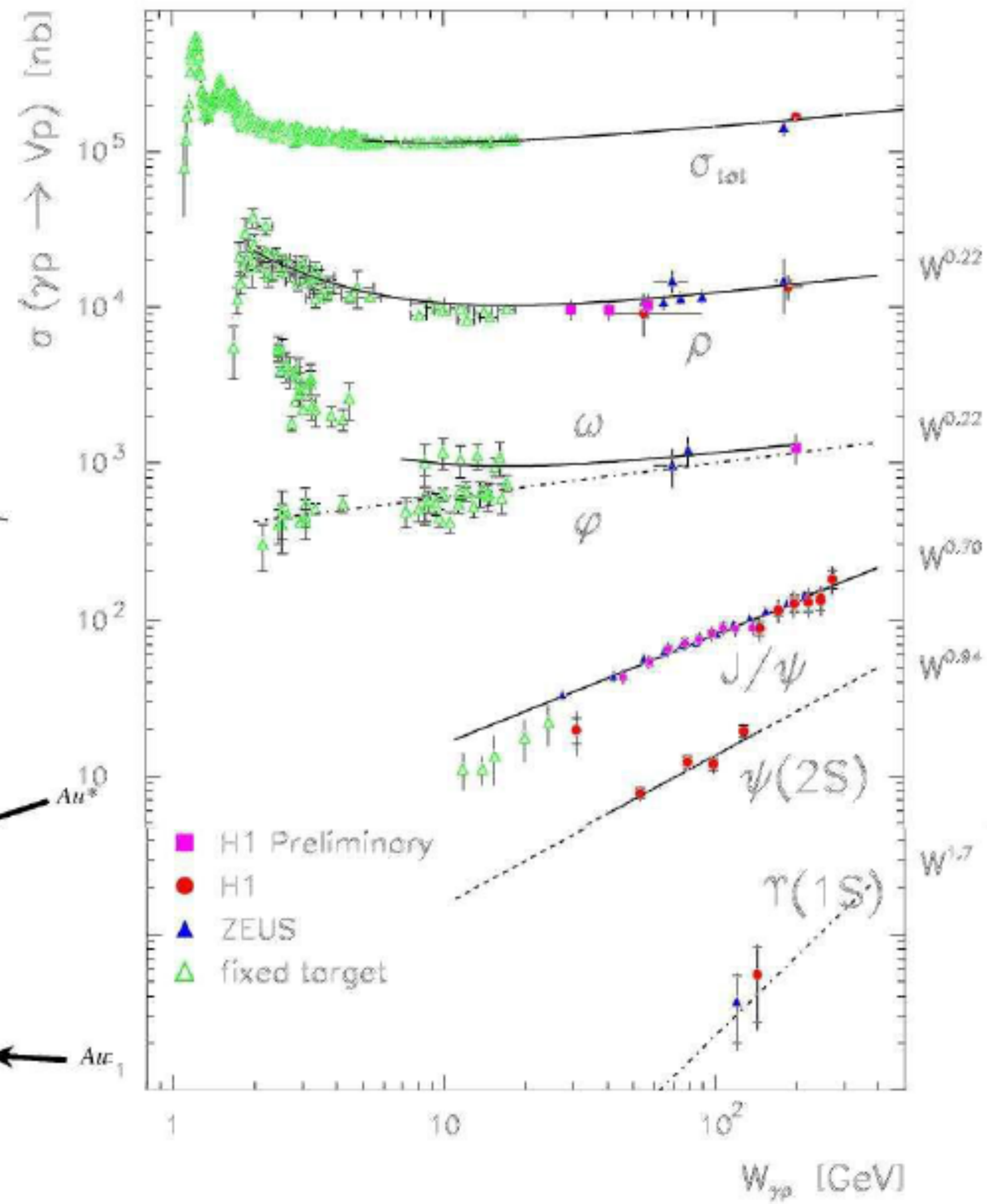




UPCs at ALICE [Mayer]

e-p vs. UPC p-Pb and Pb-Pb Collisions



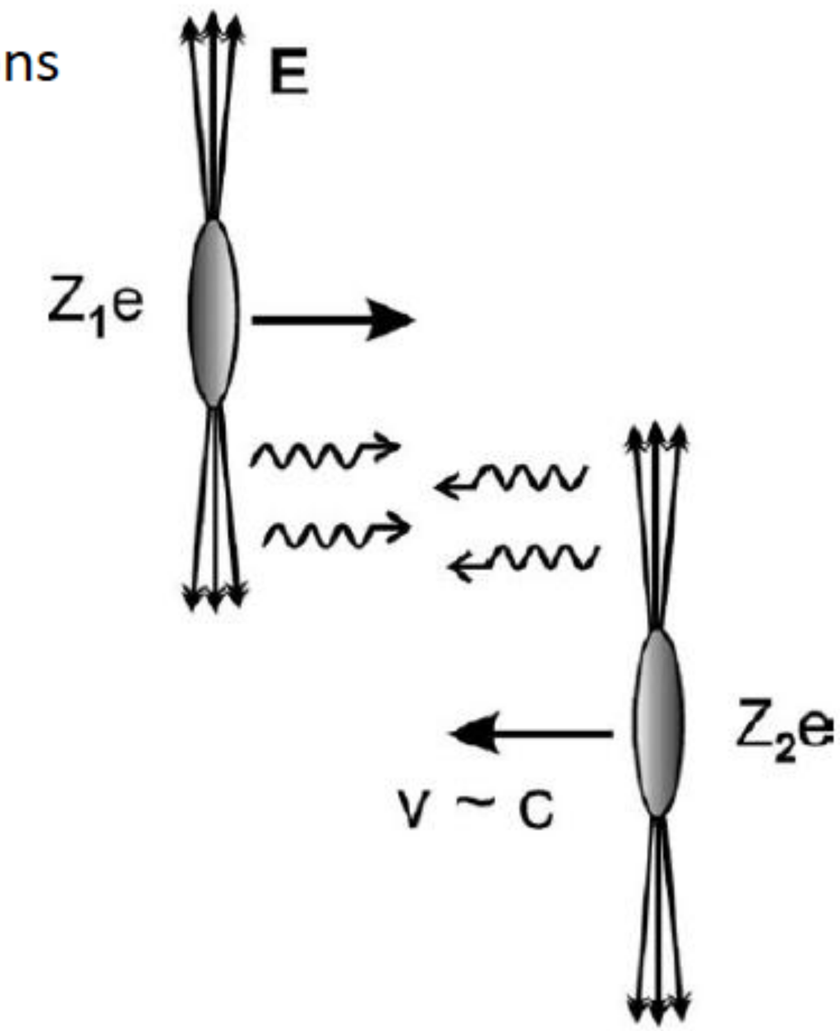


6/24/2015 D. d'Enterria

UPCs at ALICE [Mayer]

Ultra-peripheral collisions

- Coherent
  - Photon couples coherently to all the nucleons
  - $\langle p_T \rangle \approx$ 60 MeV/c
  - Target nucleus normally[a] does not break up
- Incoherent
  - Photon couples to a part of the nucleus
  - $\langle p_T \rangle \approx$ 500 MeV/c
  - Target nucleus normally[b] does break up
- p-Pb collisions
  - Photon from the Pb ion interacts with p
  - Flux of virtual photons of Pb enhanced by a factor of Z relative to pp

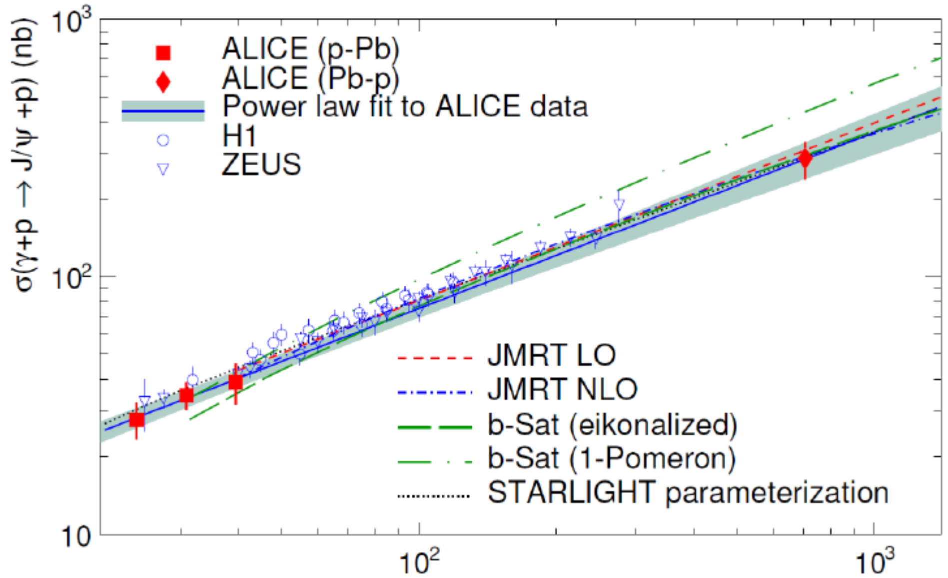


a) Coherent – ≈20% breakup probability
b) Incoherent– ≈80% breakup probability

UPCs at ALICE [Mayer]

J/Ψ measurements in p-Pb

Phys. Rev. Lett. 113 (2014) 232504



- J/Ψ cross sections in p-Pb and in γ-p are related by the mean photon flux $\left(\frac{dN}{dk}\right)$: $\frac{d\sigma}{dy}(\mathrm{p+Pb \to p+Pb+J/\Psi}) = k\frac{dN}{dk}\sigma(\gamma+\mathrm{p}\to \mathrm{J/\Psi})$, ($k$ photon energy).
- The weighted average photon flux is taken from STARLIGHT; the error is propagated to $\sigma(\gamma+\mathrm{p})$ as an additional theoretical error

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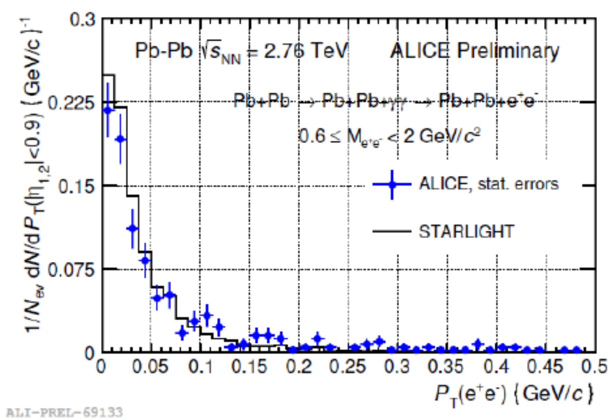
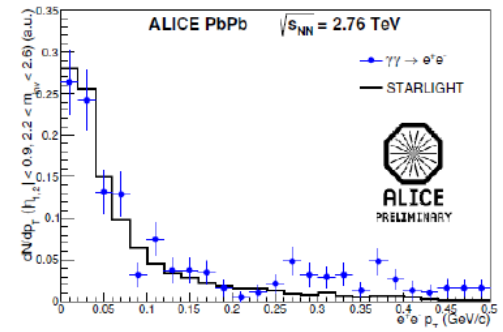
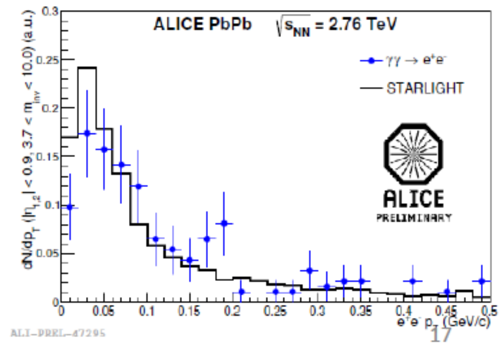
Two-photon production of electron pairs in Pb-Pb

ALICE 2010 data



ALICE EPJC 73 (2013) 2617





- The transverse-momentum distribution is well -described by the STARLIGHT Monte-Carlo simulation for $0.6 \le M_{e^+e^-} < 10.0$ GeV/c^2.
  - Left: 2010 Pb-Pb data
  - Right: 2011 Pb-Pb data (EPJC paper)
- Broadening of pair-p_T with increasing $M_{e^+e^-}$

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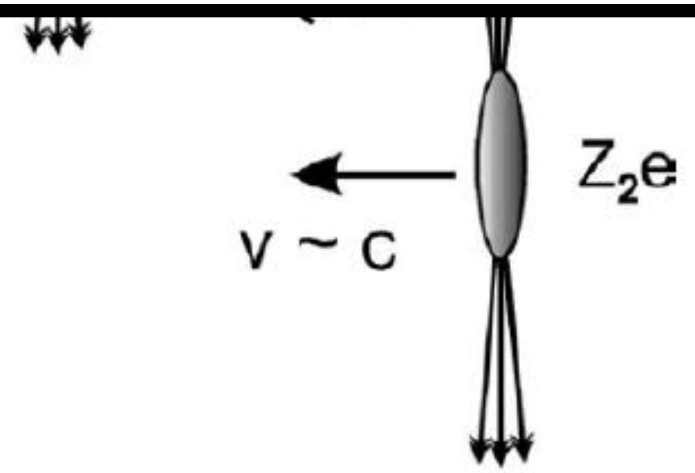
– Target nucleus normally[b] does break up

- p-Pb collisions
  - Photon from the Pb ion interacts with p
  - Flux of virtual photons of Pb enhanced by a factor of Z relative to pp



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a) Coherent – ≈20% breakup probability
b) Incoherent– ≈80% breakup probability

UPCs at ALICE [Mayer]

LHC Run2 Outlook

ALICE

Pb-Pb in LHC Run 2 ($\mathcal{L}^{\text{int.}} \approx 1\text{nb}^{-1}$):

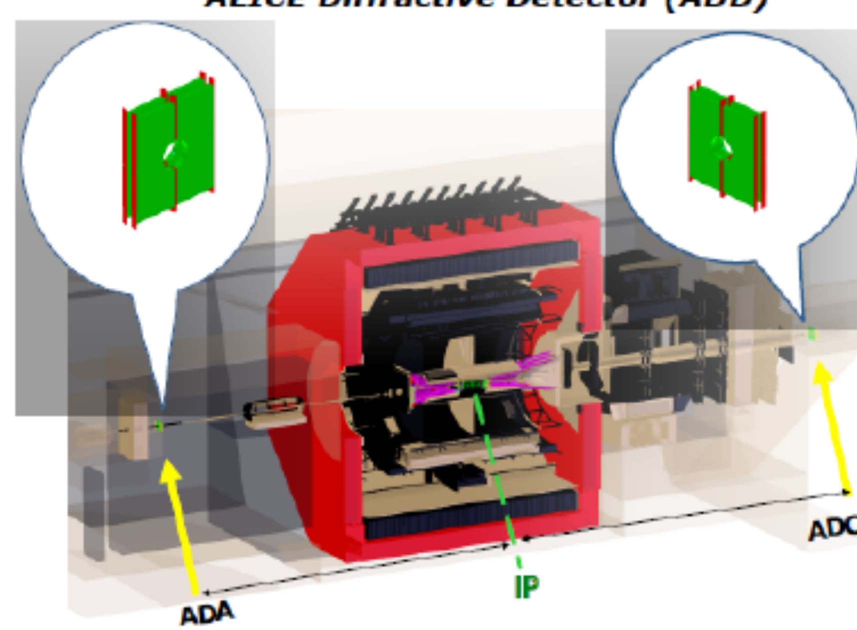
- We expect $\times 20$–$\times 50$ more UPC events than in Run 1
- High precision measurements of J/Ψ, $\Psi(2S)$ photo-production
- Detailed p_T and rapidity distributions
- Exploratory studies of Υ photo-production possible
- Two-photon production of η_c appears feasible
- Extended γp energy range

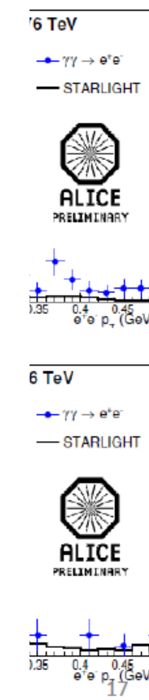
	A-side	C-side
VZERO	$-3.7 < \eta < -1.7$	$2.8 < \eta < 5.1$
ADD (approx. η range)	$-7.5 < \eta < -5.5$	$5.5 < \eta < 7.5$

New forward detector ADD

- Two layers of scintillators on each side of the interaction point
- Extension of the veto outside central rapidity
- Reduction of non-exclusive background

ALICE Diffractive Detector (ADD)





σ(γ+p → J/ψ +p) (nb)

b-Pb

2617

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pA/AA to eA [Tapia-Tataki]

Cold Nuclear Matter Effects in Hadroproduction

In heavy-ion collisions, one has to fold in cold matter effects, typically studied in pA or dA interactions from fixed-target energies to colliders

Hard probes, where production is calculable in QCD, are best to study differences between initial and final state effects

Important cold nuclear matter effects in hadroproduction include:

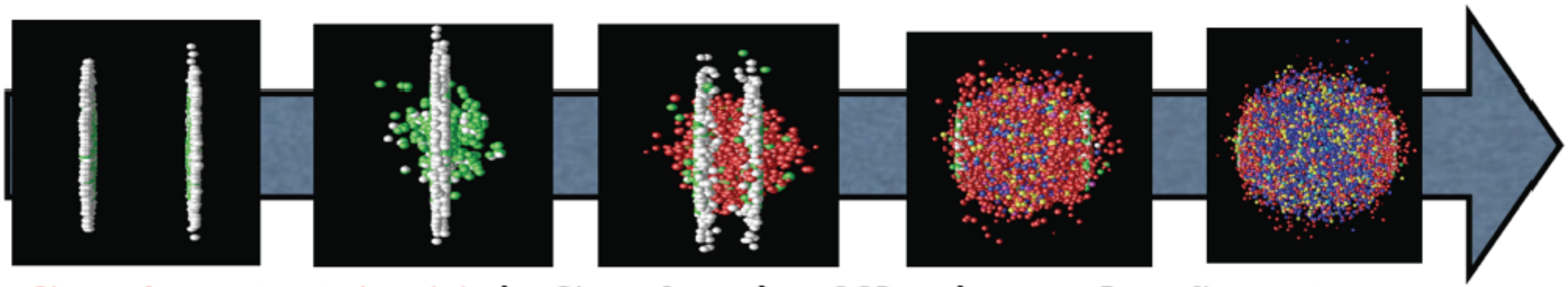
- Initial-state nuclear effects on the parton densities (nPDFs)
- Initial- (or final-) state energy loss
- Final-state absorption on nucleons
- Final-state break up by comovers (hadrons or partons)
- Intrinsic $Q\overline{Q}$ pairs

In this talk, I will concentrate on nuclear parton densities, not including any other effect

R.Vogt

6

pA/AA to eA [Tapia-Tataki]



Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

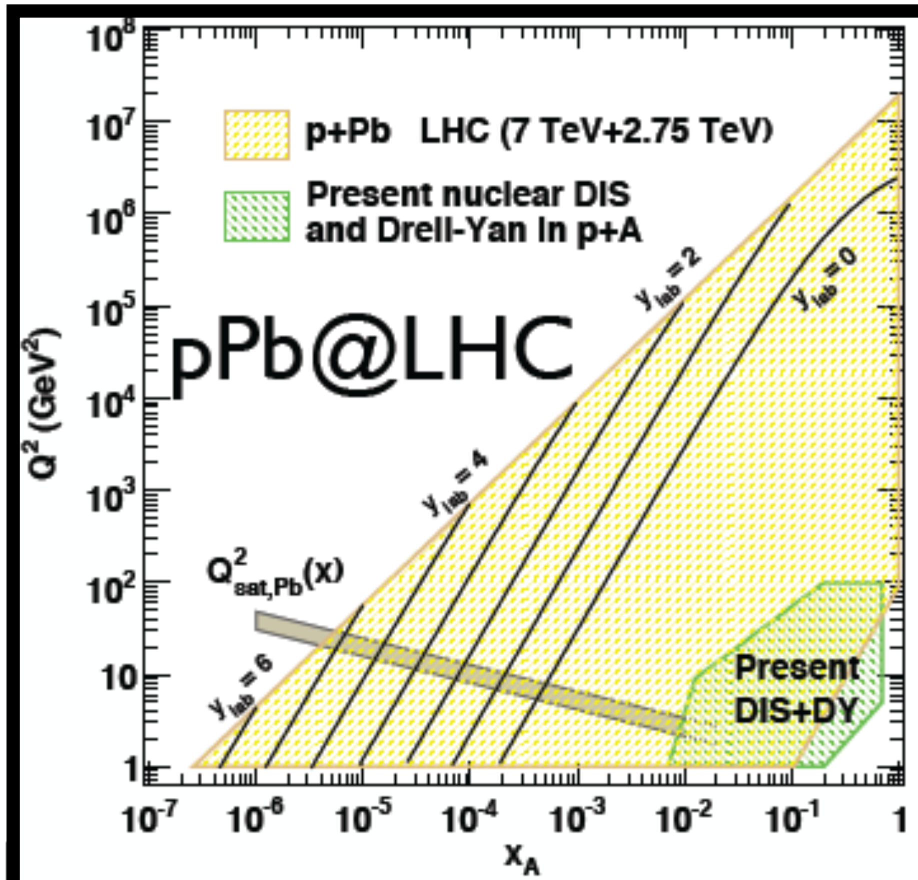
- Nuclear wave function at small x: nuclear structure functions.

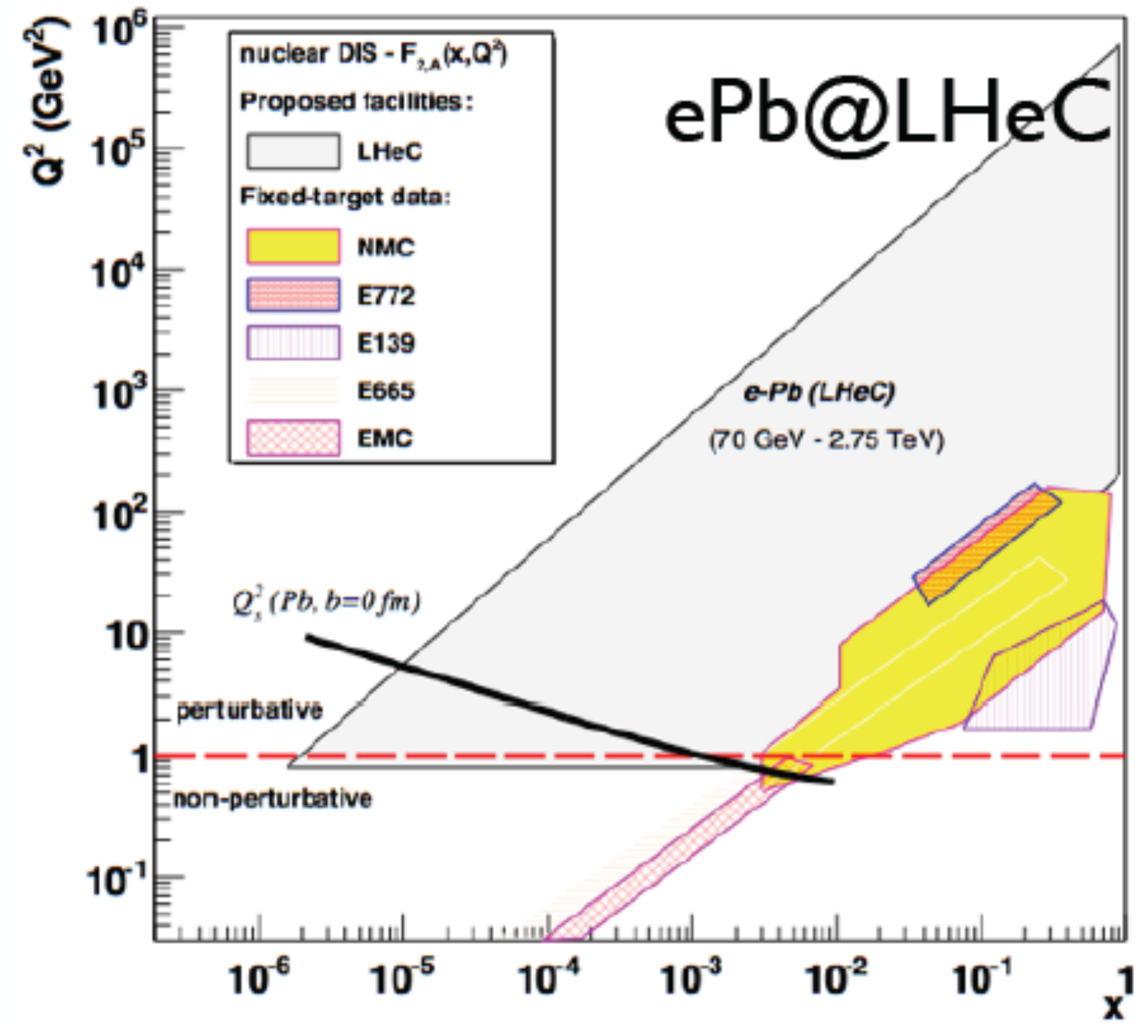
- Particle production at the very beginning: which factorisation in eA?

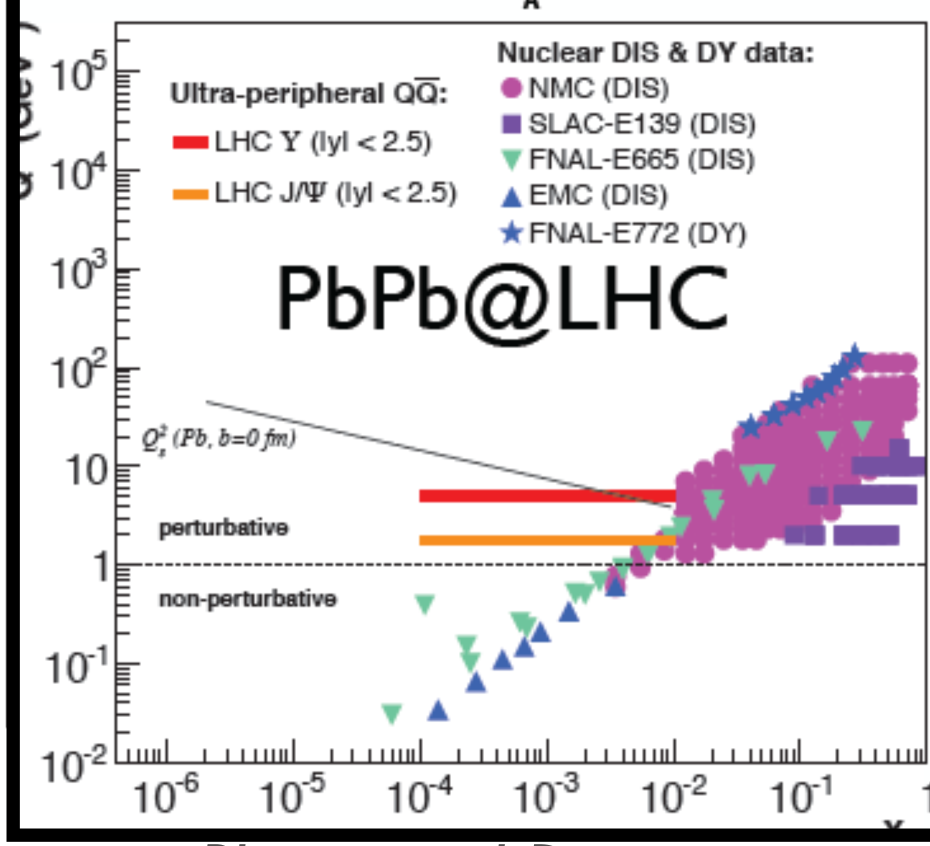
- How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in eA.

- Probing the medium through energetic particles (jet quenching etc.): modification of QCD radiation and hadronization in the nuclear medium.

pA/AA to eA [Tapia-Tataki]







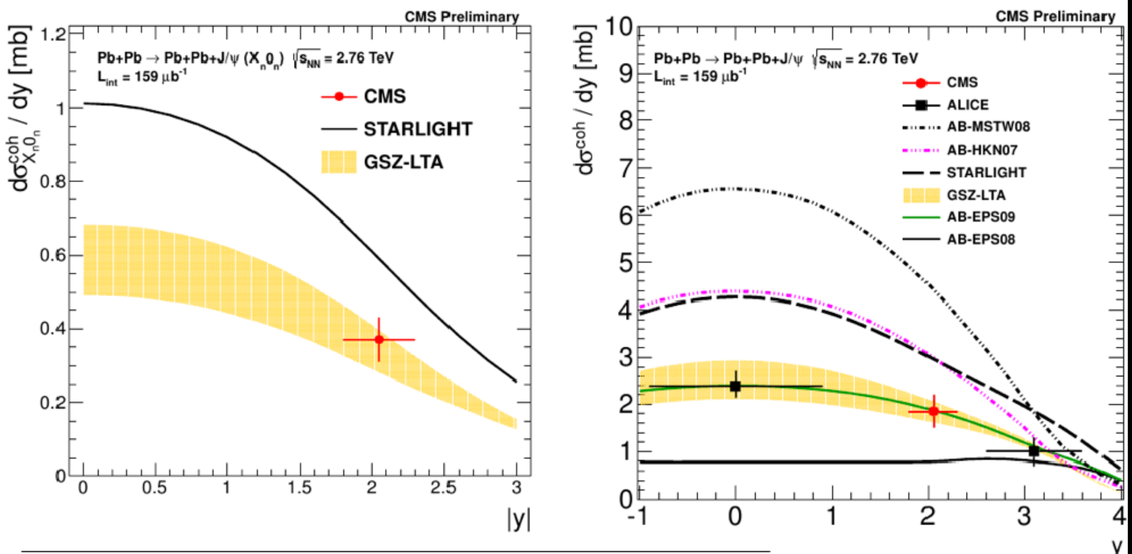
- The LHeC will explore a region overlapping with the LHC:

➜ in a cleaner experimental setup;

➜ on firmer theoretical grounds.

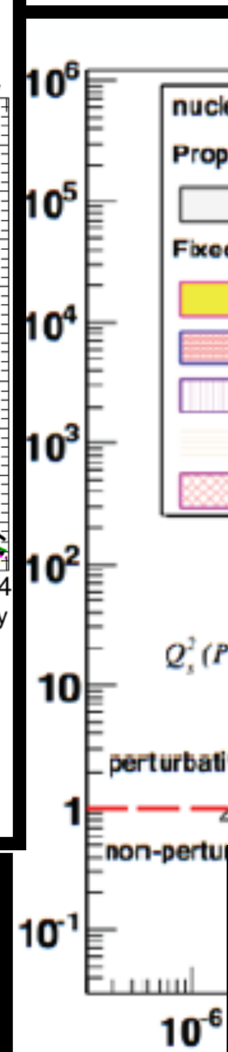
pA/AA to eA [Tapia-Tataki]

Coherent J/ψ photoproduction



J/ψ with p_T <0.15 GeV/c	X_nX_n/X_n0_n	$1_n0_n/X_n0_n$	$1_n1_n/X_n0_n$
Data	0.36±0.04	0.26±0.03	0.03±0.01
STARLIGHT	0.37	N/A	0.02
GSZ	0.32	0.30	0.02

20



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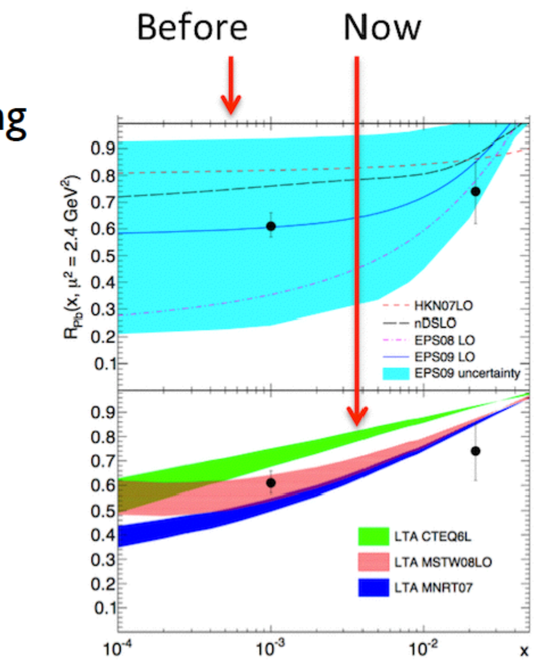
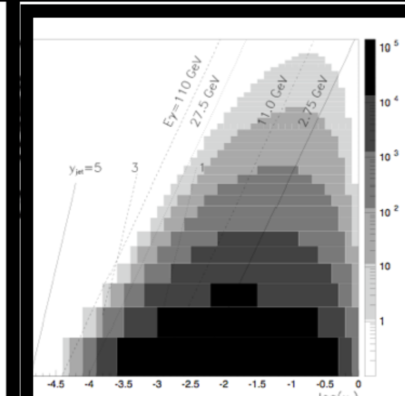
Coherent J/ψ photoproduction

First attempt to use UPC data for constraining the nPDF



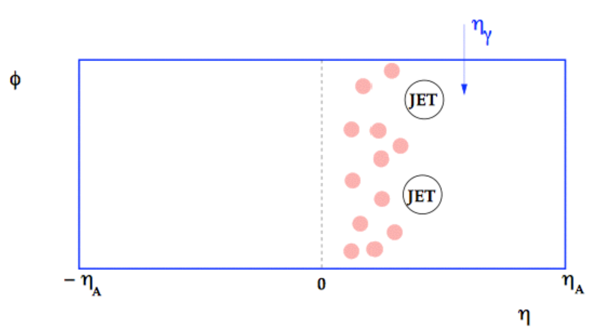
PLB 726 (2013) 290



/ogt, S.White, MS, 2005

Expected rate of dijet photoproduction for a 1 month LHC Pb+Pb run at 0.4x10^{27} cm^{-2}s^{-1}. Rates are counts per bin of ±0.25 x_2 and 2 GeV/c in p_T. Large rates for b-meson jets as well.

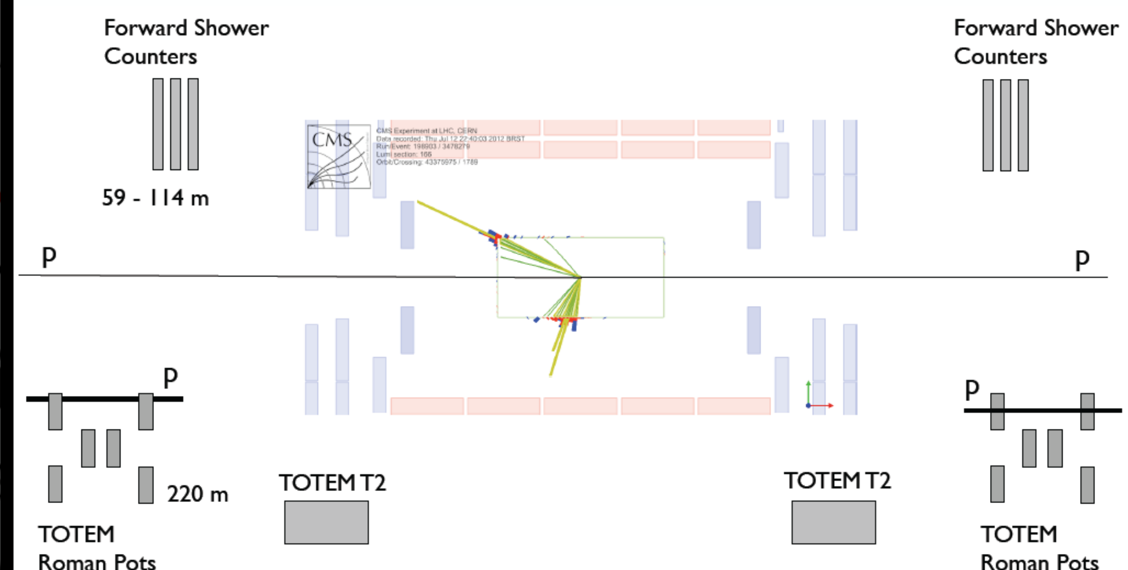
Many more important handles to study dynamics, for example associated multiplicity at different rapidities,...



UPC induced direct photon hard diffraction: AA--> AA + 2jets +X

23

Dijet: CMS+TOTEM



CMS: |η| < 5 T2: 5.3 < |η| < 6.5 FSC: 6 < |η| < 8 TOTEM RP

very large rapidity coverage !

24

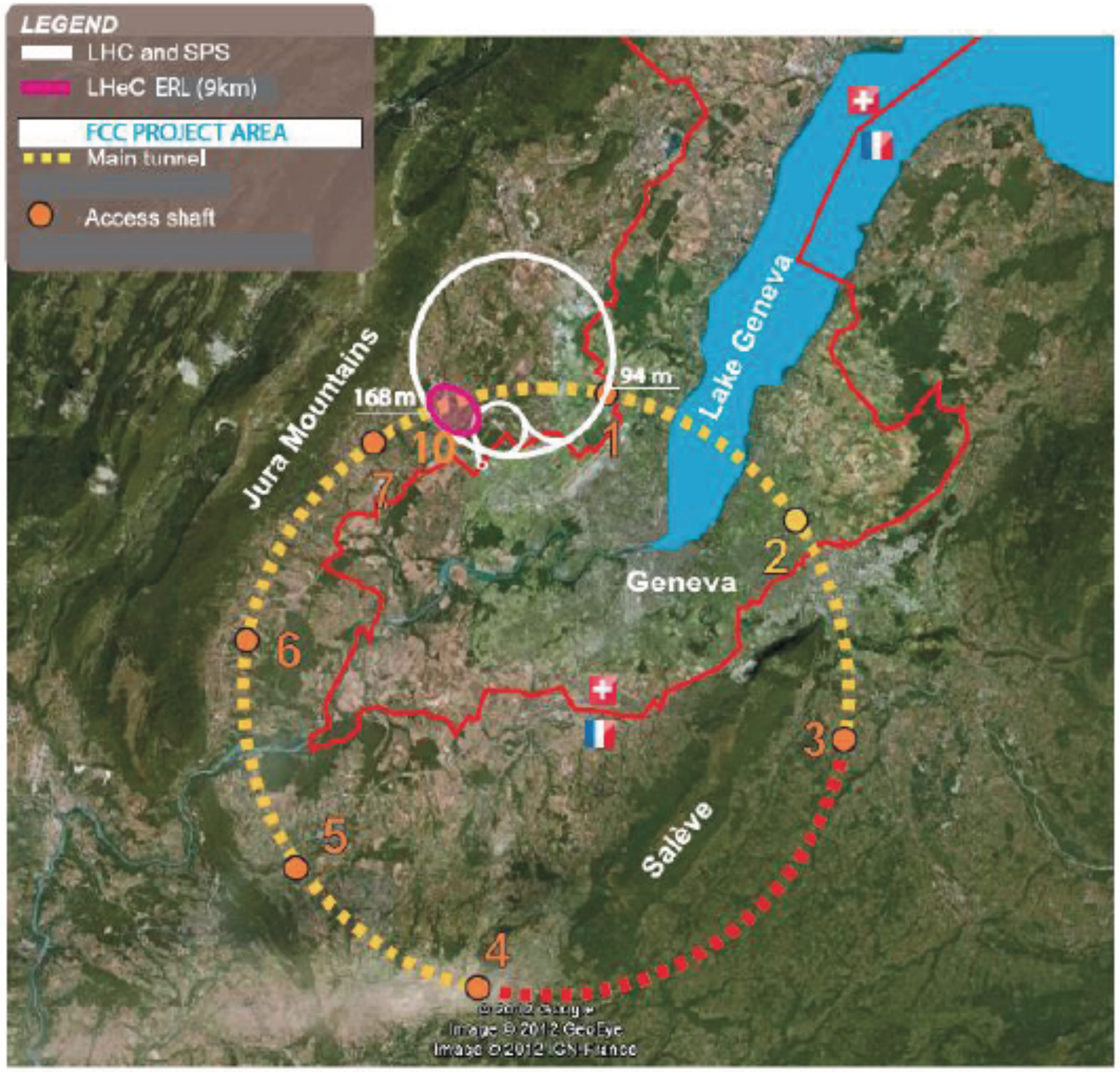
FCC-he overview [M. Klein]

LHeC and the Future Circular Collider (FCC)

Version 230 mASL

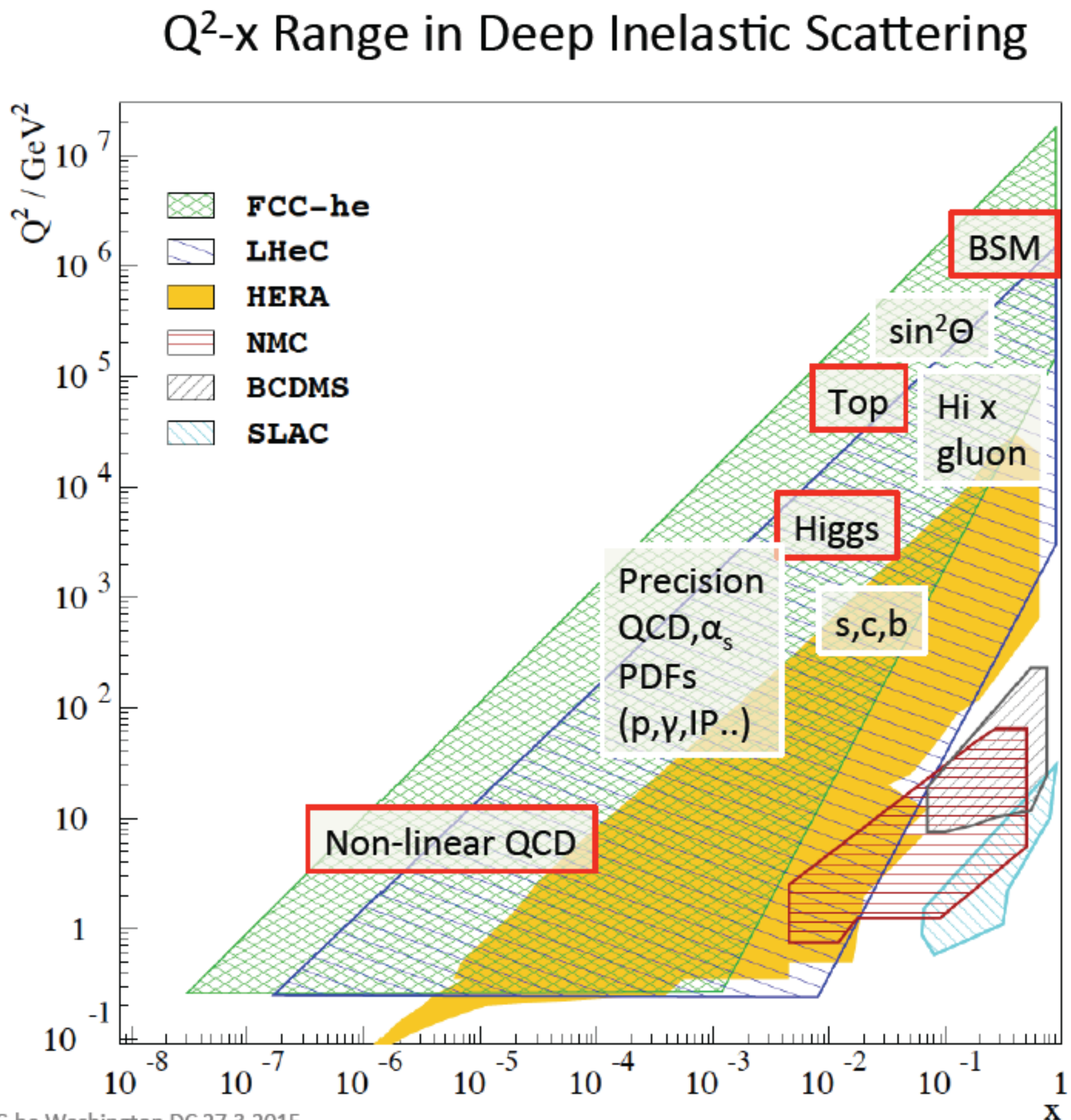
- **Phase 1** : ep collisions at LHC P2
- **Phase 2** : ep collisions in FCC near LHC P2
- European Strategy Paper (2012), the 'plan' position for passes under the LHeC ERL
- However, FCC is 150m deeper than ERL
- FCC tunnel location/depth still to be optimised

	SPS	LHC	FCC	Between LHC/FCC
Point 1	40m	96m	190m	94m
Point 10	40m	50m	218m	168m



J Osborne at IAC Meeting 6/14

FCC-he overview [M. Klein]



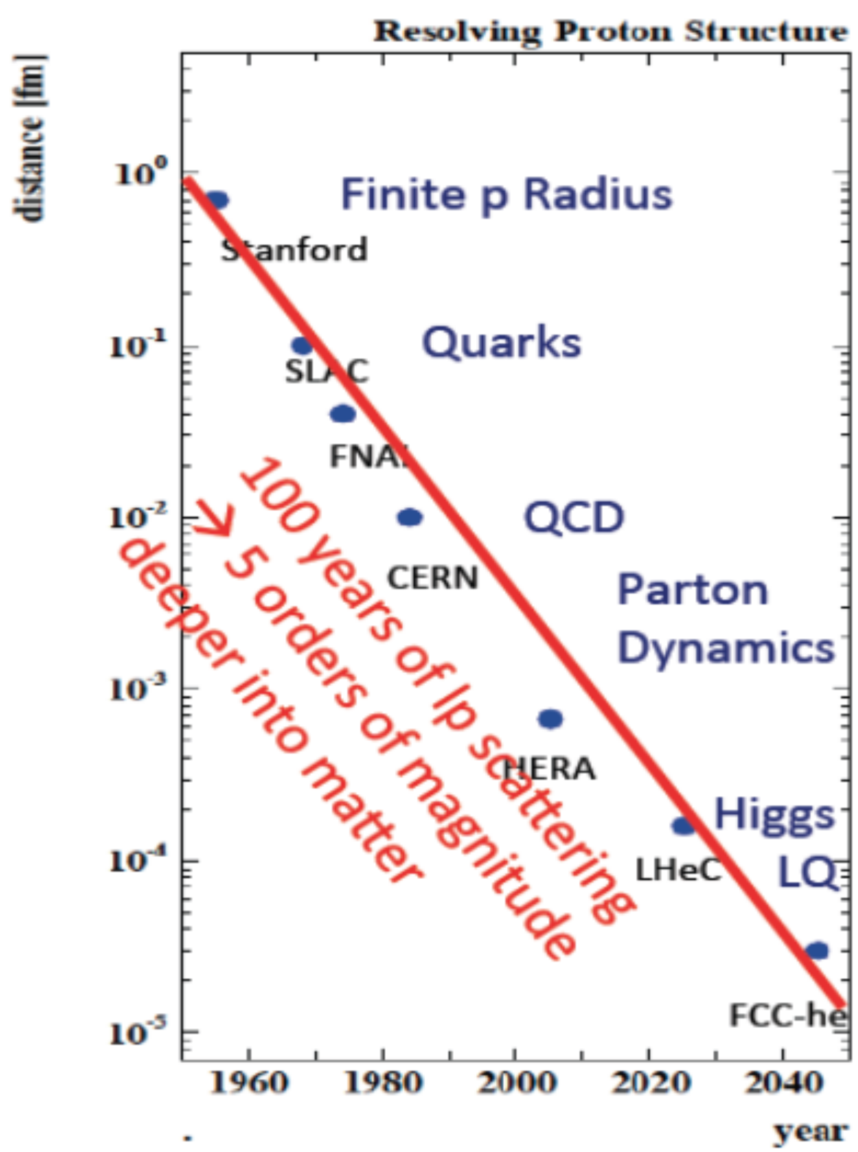
Luminosity: 10 years of HERA in one day..

Max Klein Summary FCC-he Washington DC 27.3.2015

FCC-he overview [M. Klein]

Two Reasons for FCC-he

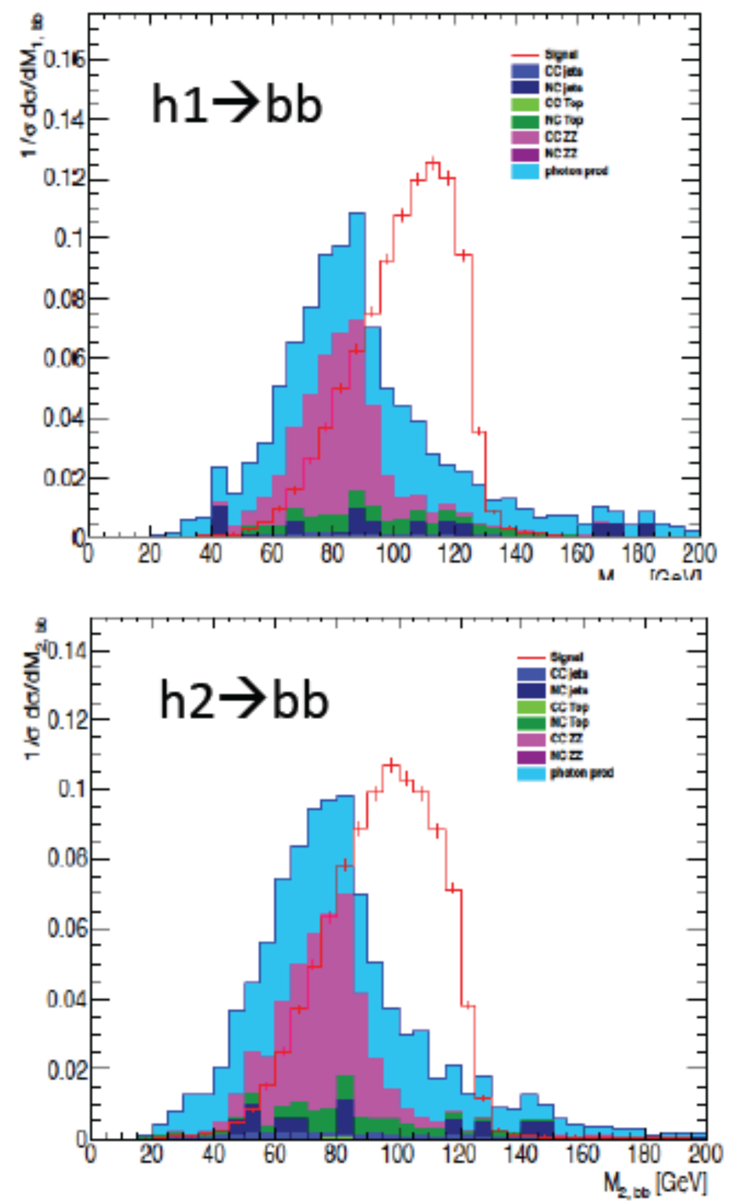
The world's cleanest microscope



cf F.Olness, V.Radescu, M.Ploskon

Max Klein Summary FCC-he Washington DC 27.3.2015

New Physics in Higgs, QCD, BSM (l=q?)



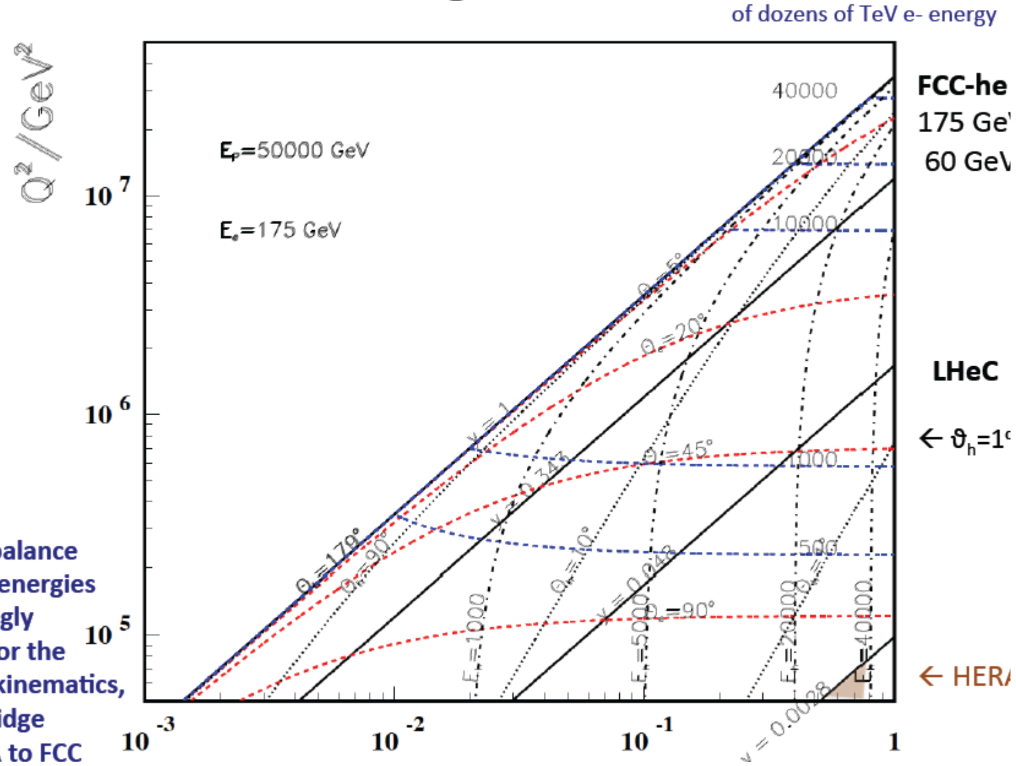
Two h seen in in new DELPHES cut based analysis of h-hh-4b in CC ep at FCC-he

cf G.Azuelos, M.Klein

LHeC FCC-he overview [M. Klein]

High Q^2

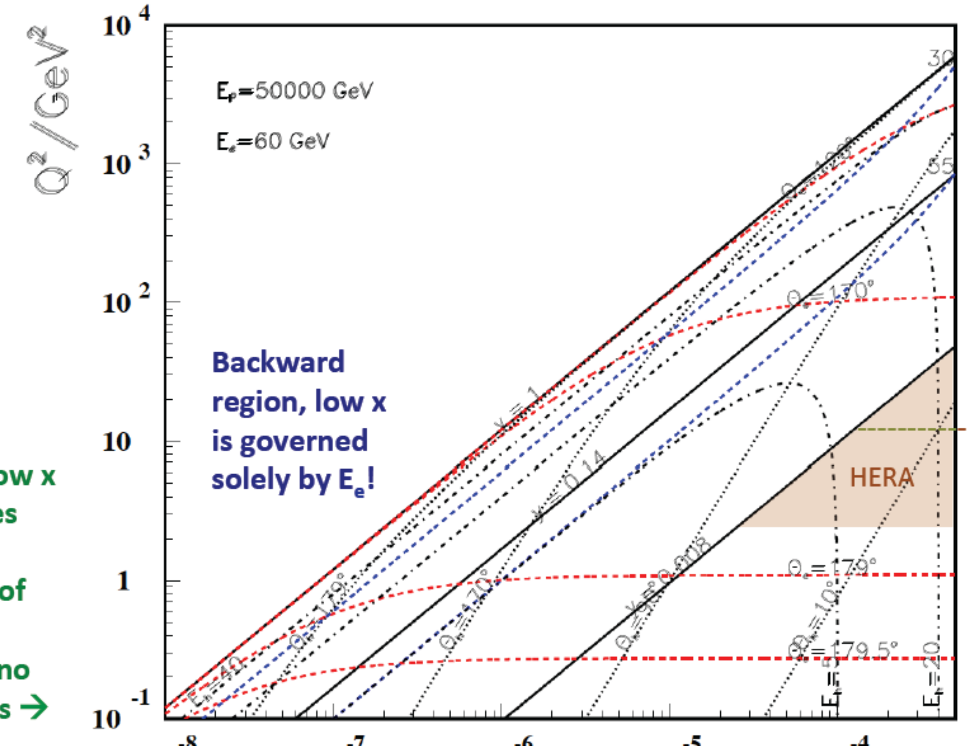
Rutherford backscattering of dozens of TeV e- energy



Large imabalance of e and p energies is surprisingly tolerable for the high Q^2, x kinematics, LHeC to bridge from HERA to FCC

Very low x reaches direct range of UHE neutrino physics →

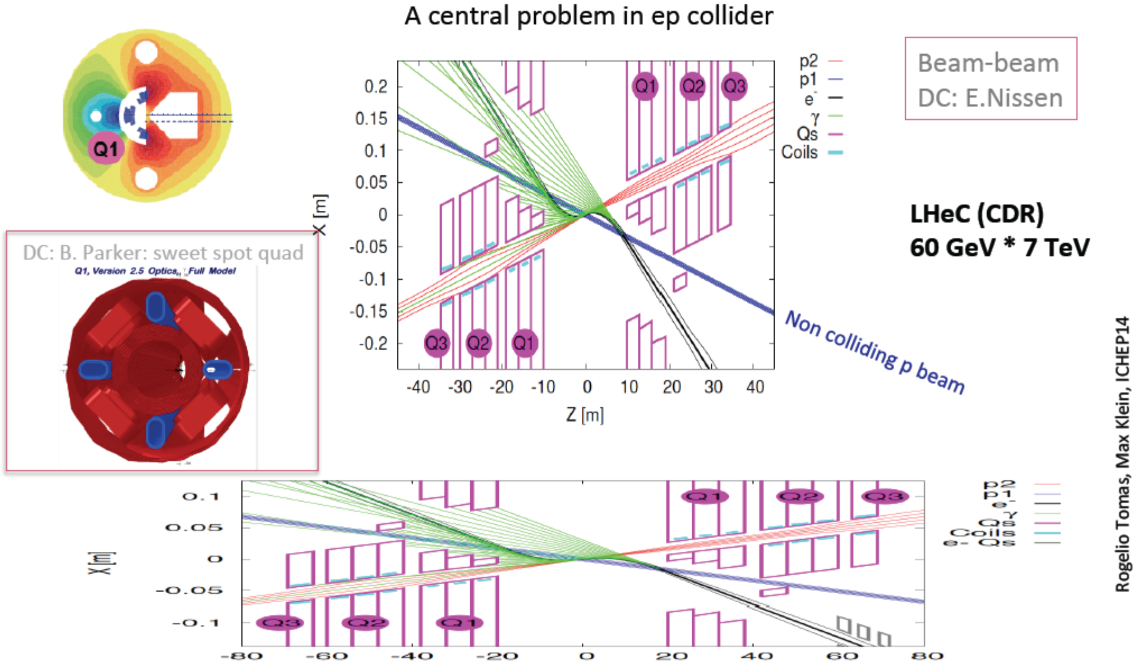
Low x



← 179° @ 180 GeV .. very low x requires not the maximum of E_e

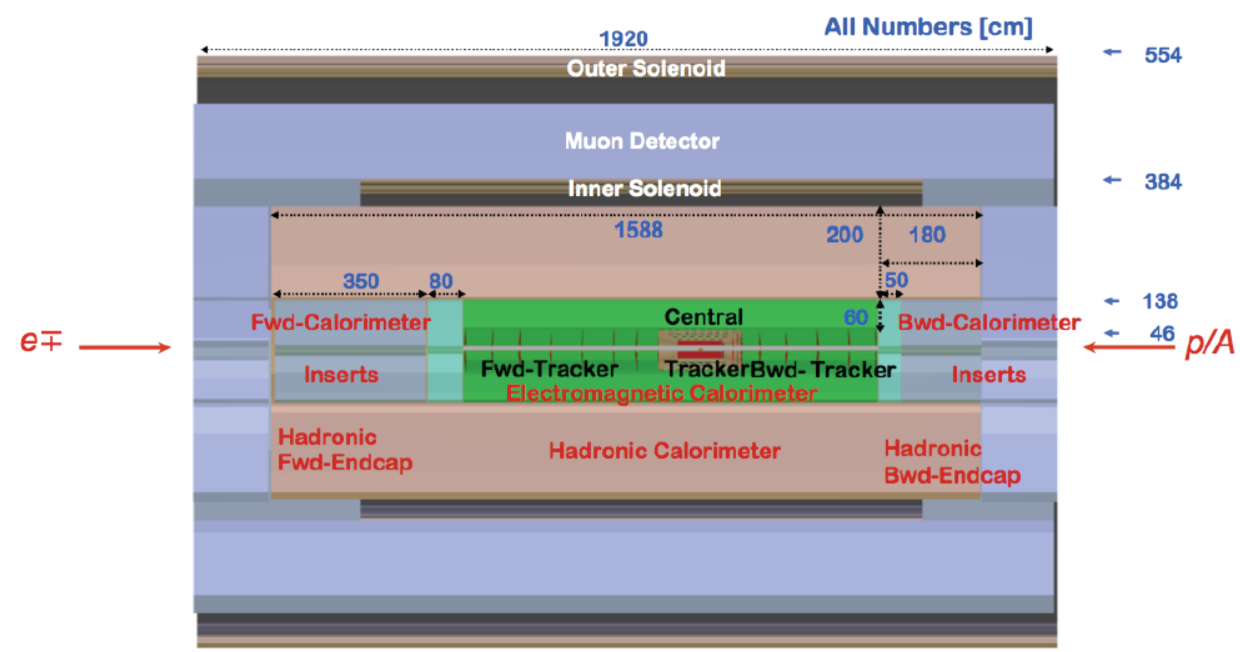
Interaction Regions for ep with Synchronous pp Operation

A central problem in ep collider



Tentative: ε_p=2µm, β*=20cm → σ_p=3µm ≈σ_e matched! ε_e=5µm ..

FCC-he study (version 2).

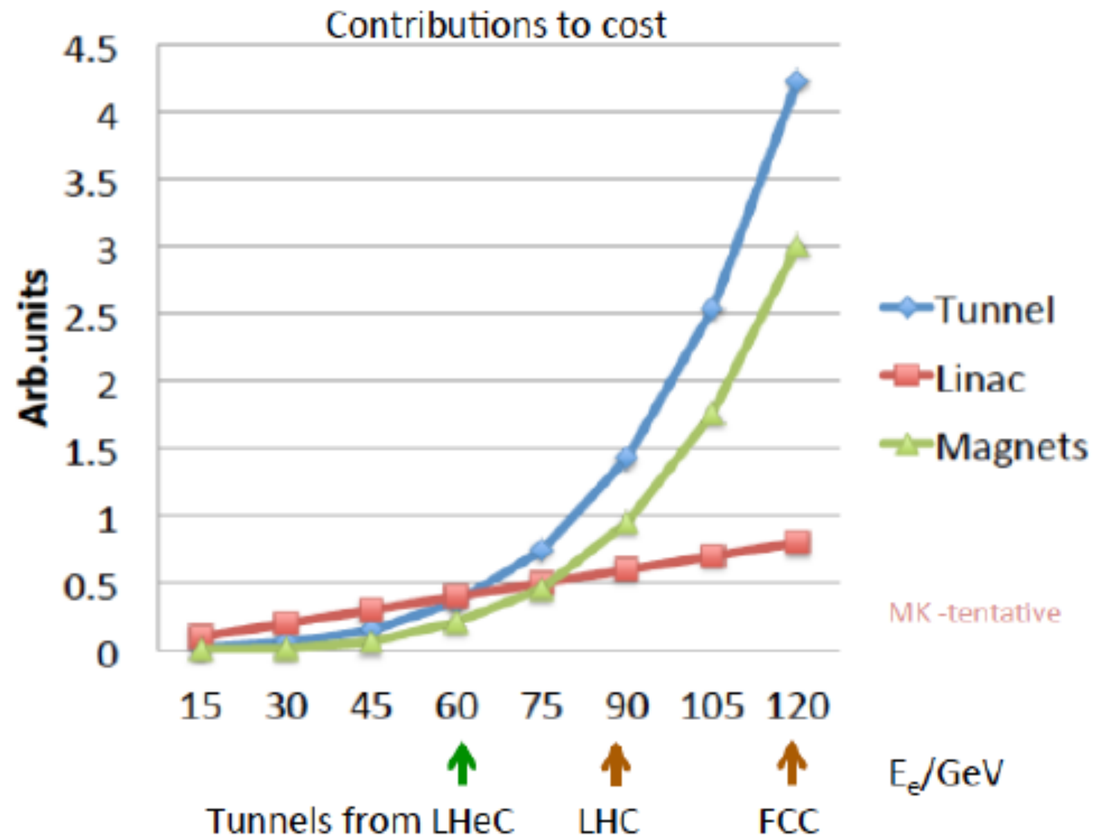


Max Klein Summary FCC-he Washington DC 27.3.2015

Summary: Physics and Detector.

LHeC FCC-he overview [M. Klein]

More than 60 GeV E_e?



Higher E_e is desirable for BSM, RPV SUSY.., hhh, forward angular coverage.
It could be thought of with the LHC or FCC tunnels, or an e-p linac (Litvinenko)

Still: plan for synchronous ep and pp operation and appropriate cost, power, effort..
It thus appears most natural to consider the LHeC ERL as the electron beam for *eh*

Max Klein Summary FCC-he Washington DC 27.3.2015

BSM at the FCC [D'Onofrio]

Prelude

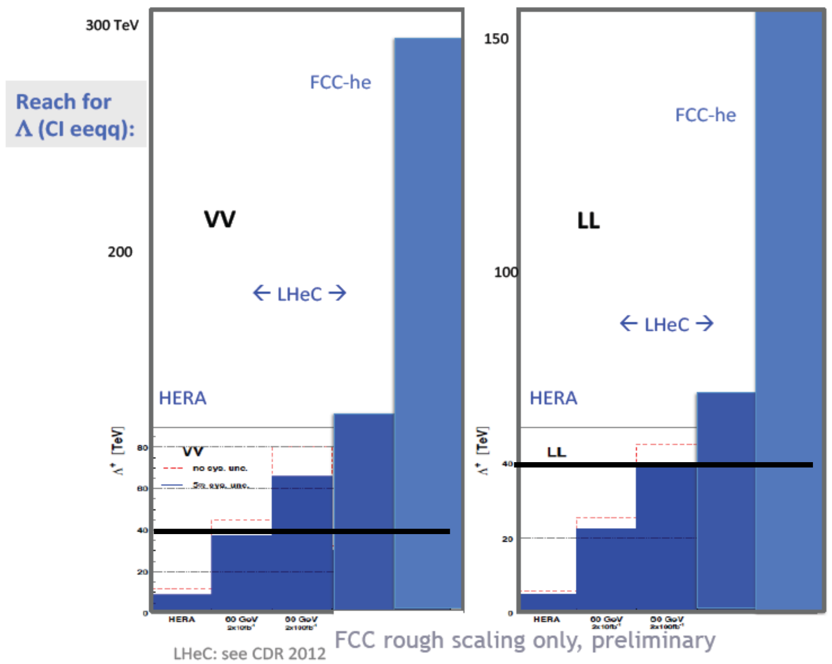
- Clearly, the LHC results of the next 2-3 years will be crucial to re-focus the BSM program at the LHeC in terms of
  - Characterization of hints for new physics if some excess or deviations from the SM are found
  - Constraints of new physics models and complementary searches wrt the LHC
  - Exploration of new scenarios
- Not an easy task at the moment
- Spent some time to re-evaluate what is worth pursuing and what is already excluded:
  - E.g. excited leptons boundaries from LHC are already excluding most of the scenarios where LHeC could be sensitive
- Wish: engage more also the theory community!

3 Monica D'Onofrio, LHeC Workshop 2015 6/26/2015

BSM at the FCC [D'Onofrio]

Contact Interactions at FCC-he

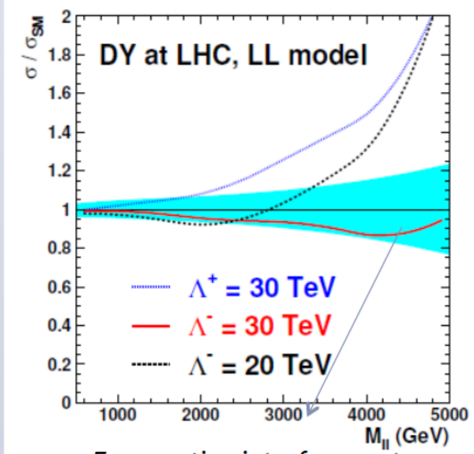
- if new physics enters at higher scales: Λ>> √s



also advantages over, and complementarities with, pp (and e+e-) in characterising nature of new physics

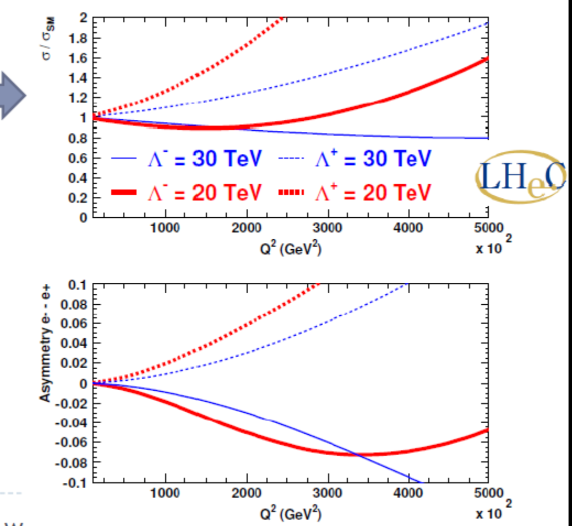
CI at LHC and LHeC — PDF-limited

- LHC: Variation of DY cross section for CI model
  - Cannot determine simultaneously Λ and sign of interference of the new amplitudes wrt SM (ε)



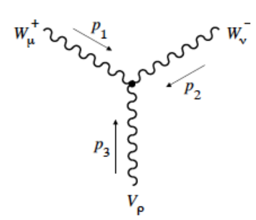
Ex: negative interference too small to be disentagled

LHeC: sign ε from asymmetry of σ/σ_{sm} in e+p and e-p data



Anomalous couplings WWV

- Triple gauge boson vertices WWV, V=γ,Z:
  - Precisely defined in SM
  - Parametrise possible new physics contributions to this vertex $(\Delta\kappa_\gamma, \lambda_\gamma)$
  - Current constraints (best from LEP) use various assumptions



	LEP [9]	CDF [12]	D0 [13]	ATLAS [10]	CMS [11]
$\Delta\kappa_\gamma$	[-0.099, 0.066]	[-0.460, 0.390]	[-0.158, 0.255]	[-0.135, 0.190]	[-0.210, 0.220]
λ_γ	[-0.059, 0.017]	[-0.180, 0.170]	[-0.036, 0.044]	[-0.065, 0.061]	[-0.048, 0.037]

Table 1: Allowed ranges, at 95% C.L., on the anomalous $WW\gamma$ couplings from the data collected at the LEP, Tevatron and LHC experiments. In each case, the most restrictive of the reported measurements is taken.

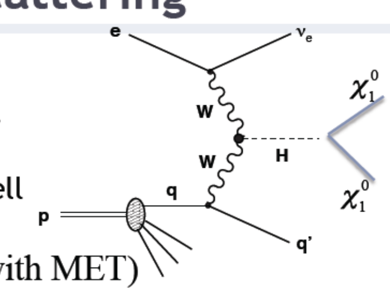
http://arxiv.org/pdf/1405.6056v1.pdf

At the LHeC:

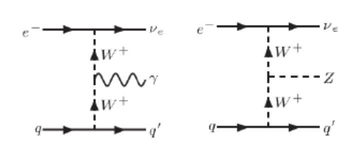
- can clearly distinguish between CC events e + p → ve + jet (W-exchange) and NC events e + p → e + jet (photon or Z boson exchange)
- triggering on a final state photon, can provide very clean bounds on the anomalous TGV's!

BSM in Vector Boson (VB) scattering

- VB Higgs production with BSM decay
  - explore SUSY-R-parity Violating cases. E.g.
    $H \to \chi_1^0 \chi_1^0 \to 3j\,3j$ (resonances)
  - BUT need to understand background as well as RPV-UDD vs LDQ constraints
    $H \to \chi_1^0 \chi_1^0 \to jjjj\nu\nu$ (non-resonant, with MET)



- VB scattering at high mass (more for FCC-he) :
  - Mass dependence of cross section
  - anomalous TGC, QGC couplings in VVV, VVVV ?
    I.T. Cakir et al, 1406.7696 → *sensitivity comparable to LHC*
  - Is unitarity restored only by Higgs? Are there new resonances (CH model) ?
    - expect below ~ 2-3 TeV $e^- q \to e^-(q)WZ,\ (\nu q)WZ$
    - *→ look for deviations from SM predictions:*
    - high background from QCD diagrams at LHC, absent at FCC-eh
    - challenging at LHC if no lepton trigger is used, and because of pileup



BSM at the FCC [D'Onofrio]

Prelude

- Clearly, the LHC results of the next 2-3 years will be crucial to re-focus the BSM program at the LHeC in terms

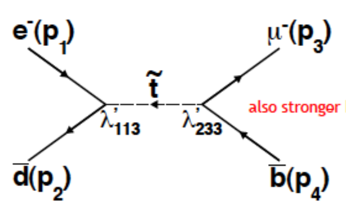
SUSY - R-parity violating

single squark production, in RPV SUSY (signal like leptoquarks, with generation mixing)

[general LQ studies and more - in back-up]

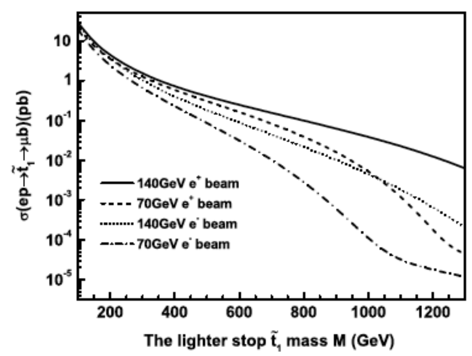
http://arxiv.org/pdf/1107.4461v2.pdf

stop

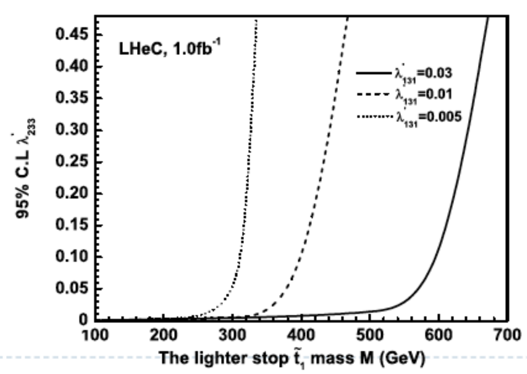


$\Lambda'_{131} < 0.03$

also stronger bounds from ββ0ν



- sensitivity up to 700 - 800 GeV with only 1fb^{-1}
- very promising with high luminosity, 100 fb^{-1}
- requires good b-tagging



Update with high lumi scenario
In progress ! Expect to be strongly competitive with LHC

RPV interaction can be probed at unprecedented levels

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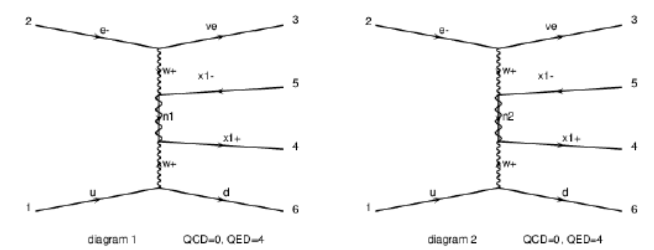
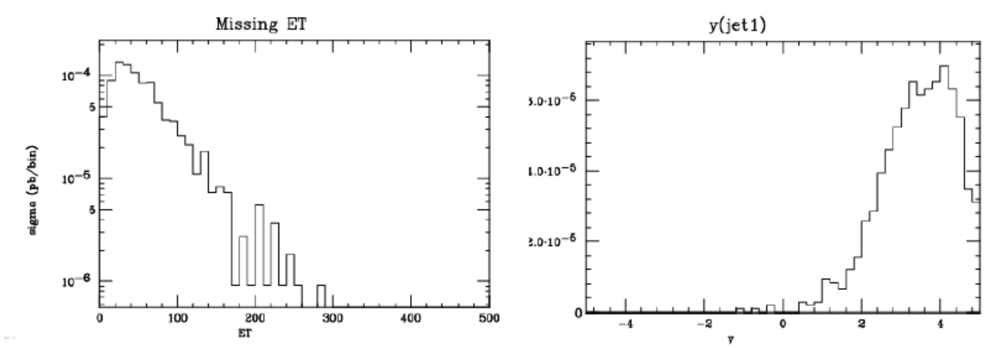
EWK RPC-SUSY production

Need inputs from theorists!

- Question: can anything be done at the LHeC ?
- Completely uncharted territory, nothing in the literature
- Very first look, using Madgraph:



- Example of diagram for C1C1. Production of N1N1 and C1N2 equivalent for almost degenerate masses
- Coupling strenghts depend on the Wino-Higgsino mixture



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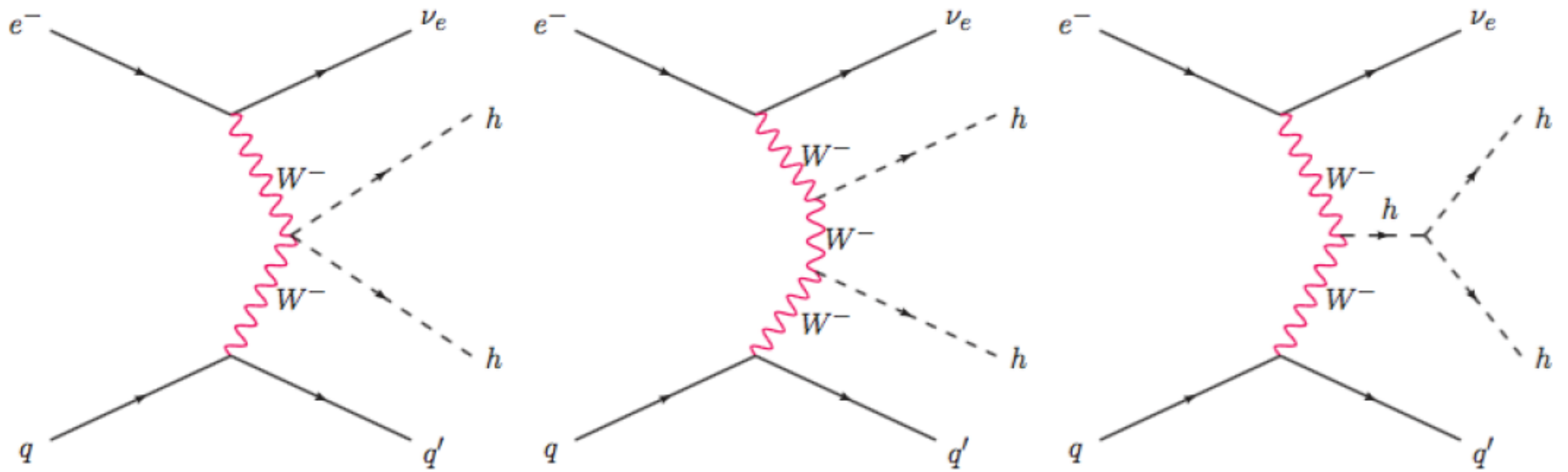
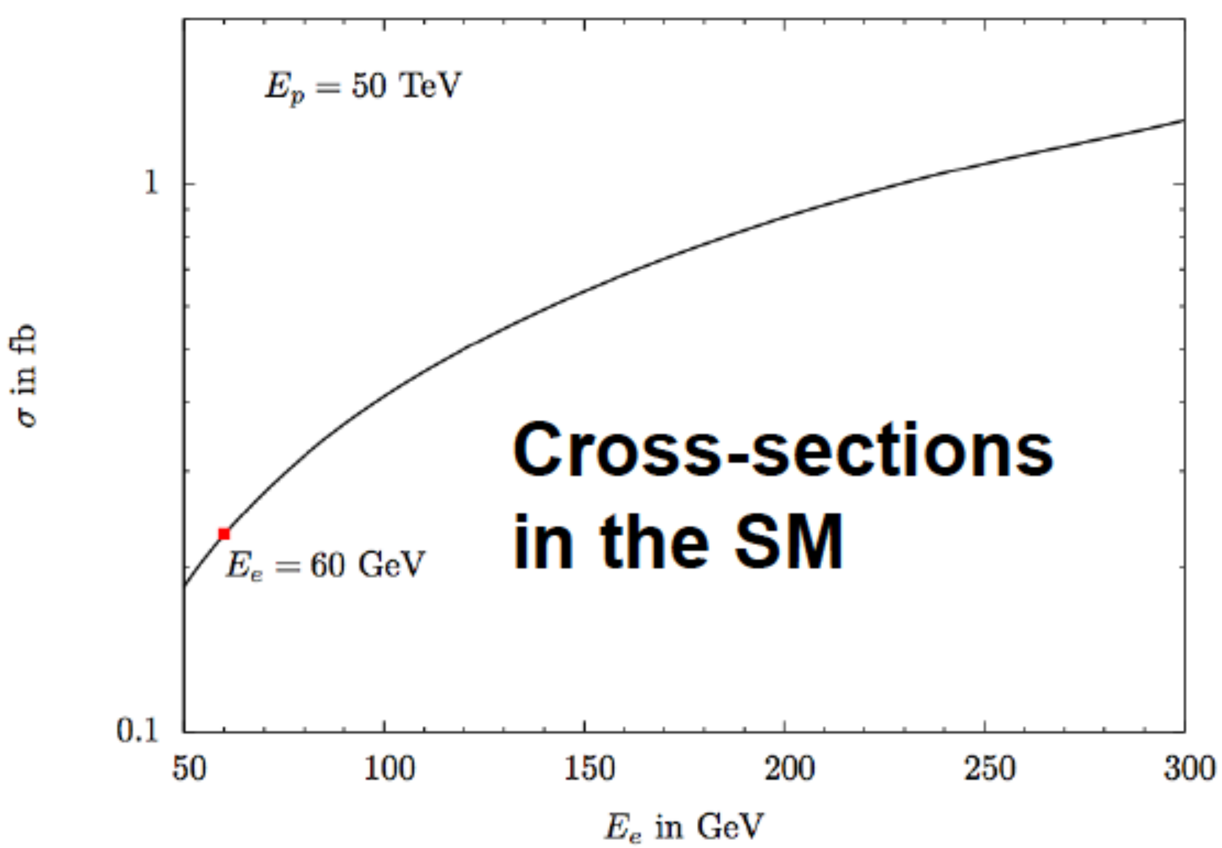
- Wish: engage more also the theory community!

LHeC HH at the FCC-he [Mellado]





Considering highly asymmetric collisions

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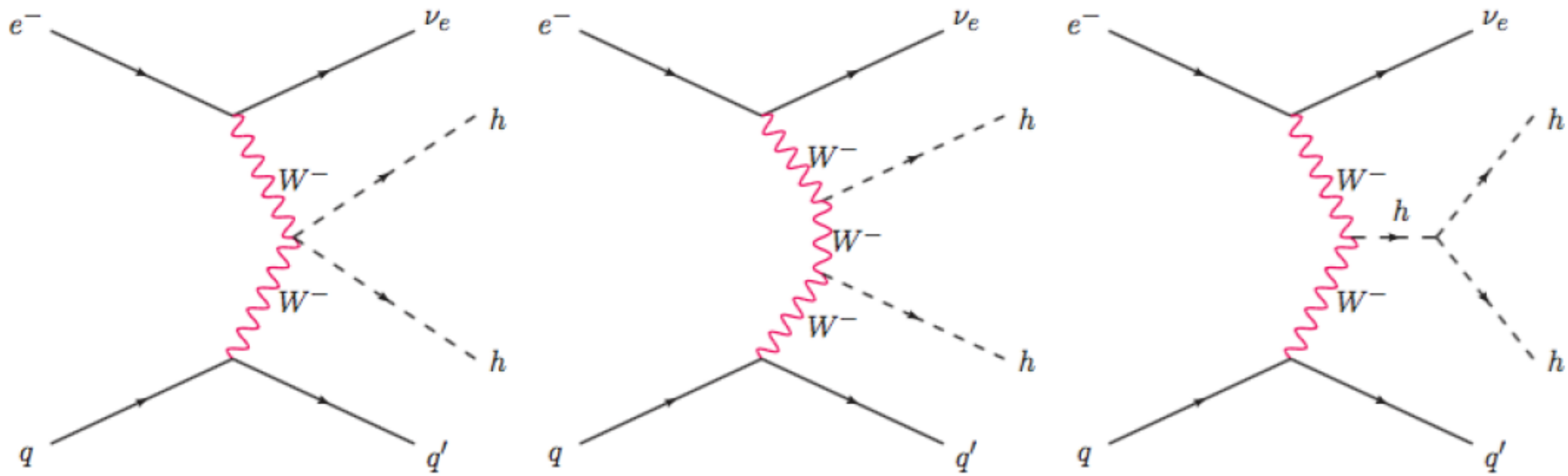
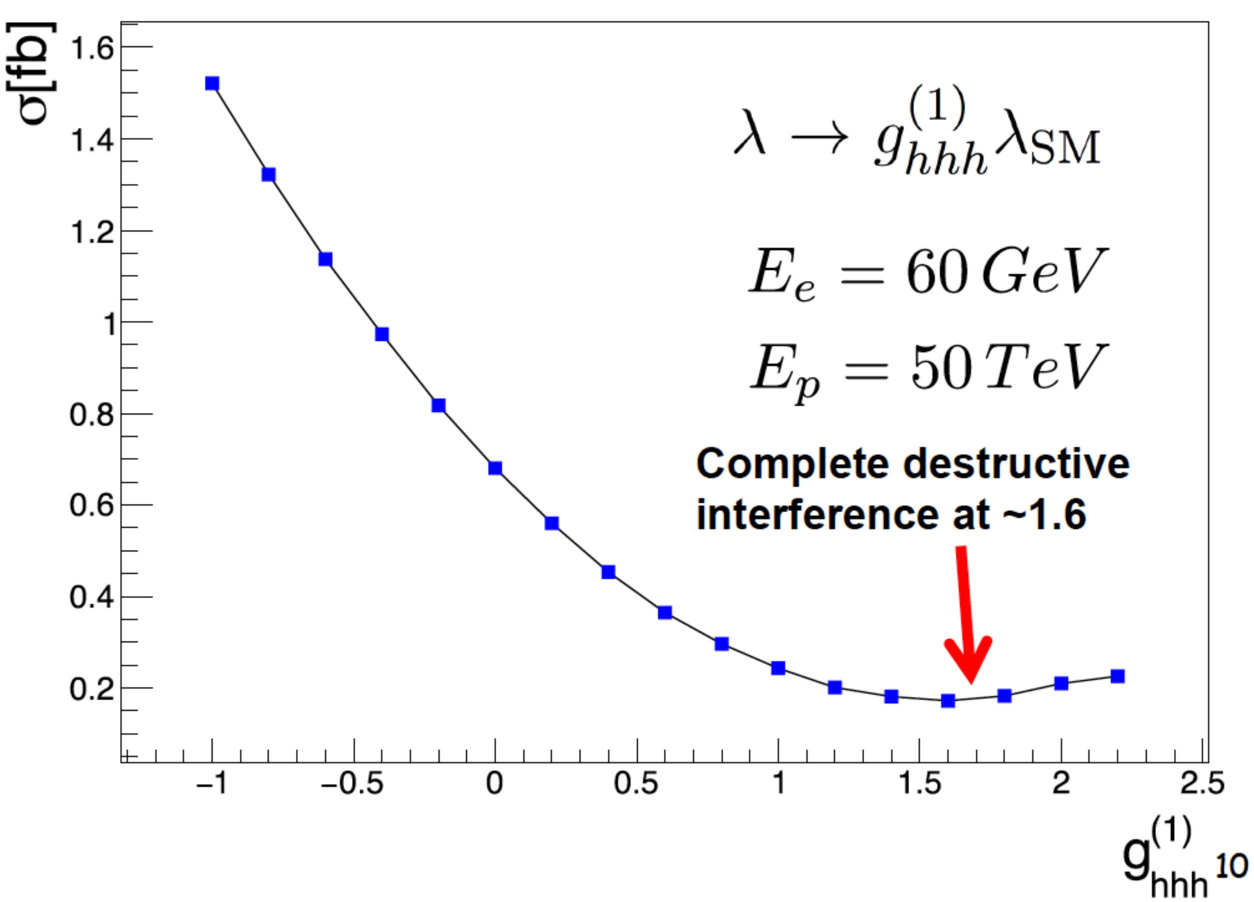
HH at the FCC-he [Mellado]





Considering highly asymmetric collisions

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HH at the FCC-he [Mellado]

Background classification
(Charm and light partons also considered)

- CC processes: $pe^- \rightarrow \begin{cases} b\bar{b}b\bar{b}j\nu_e; \\ b\bar{b}jjj\nu_e; \\ zzj\nu_e, z \rightarrow b\bar{b}; \\ t\bar{t}j\nu_e, \text{(hadronic/semi-leptonic)}; \end{cases}$
- NC processes: $pe^- \rightarrow \begin{cases} b\bar{b}b\bar{b}je^-; \\ b\bar{b}jjje^-; \\ zzje^-, z \rightarrow b\bar{b}; \\ t\bar{t}je^-, \text{(hadronic/semi-leptonic)}; \end{cases}$
- PHOTO-production: $p\gamma \rightarrow \begin{cases} b\bar{b}b\bar{b}j; \\ b\bar{b}jjj; \\ zzj, z \rightarrow b\bar{b}; \\ t\bar{t}j, \text{(hadronic/semi-leptonic)}. \end{cases}$

Particularly dangerous background

Tree-level cross-sections with Madgraph. Generation requires p_T>10 GeV for partons and MET, ΔR_{jj}>0.4, ΔR_{ll}>0.2.

Process	CC (fb)	NC (fb)	PHOTO (fb)
Signal:	2.40×10^{-1}	3.95×10^{-2}	3.30×10^{-6}
$b\bar{b}b\bar{b}j$:	8.20×10^{-1}	$3.60 \times 10^{+3}$	$2.85 \times 10^{+3}$
$b\bar{b}jjj$:	$6.50 \times 10^{+3}$	$2.50 \times 10^{+4}$	$1.94 \times 10^{+6}$
$zzj(z \rightarrow b\bar{b})$:	7.40×10^{-1}	1.65×10^{-2}	1.73×10^{-2}
$t\bar{t}j$(hadronic):	3.30×10^{-1}	$1.40 \times 10^{+2}$	$3.27 \times 10^{+2}$
$t\bar{t}j$(semi-leptonic):	1.22×10^{-1}	$4.90 \times 10^{+1}$	$1.05 \times 10^{+2}$

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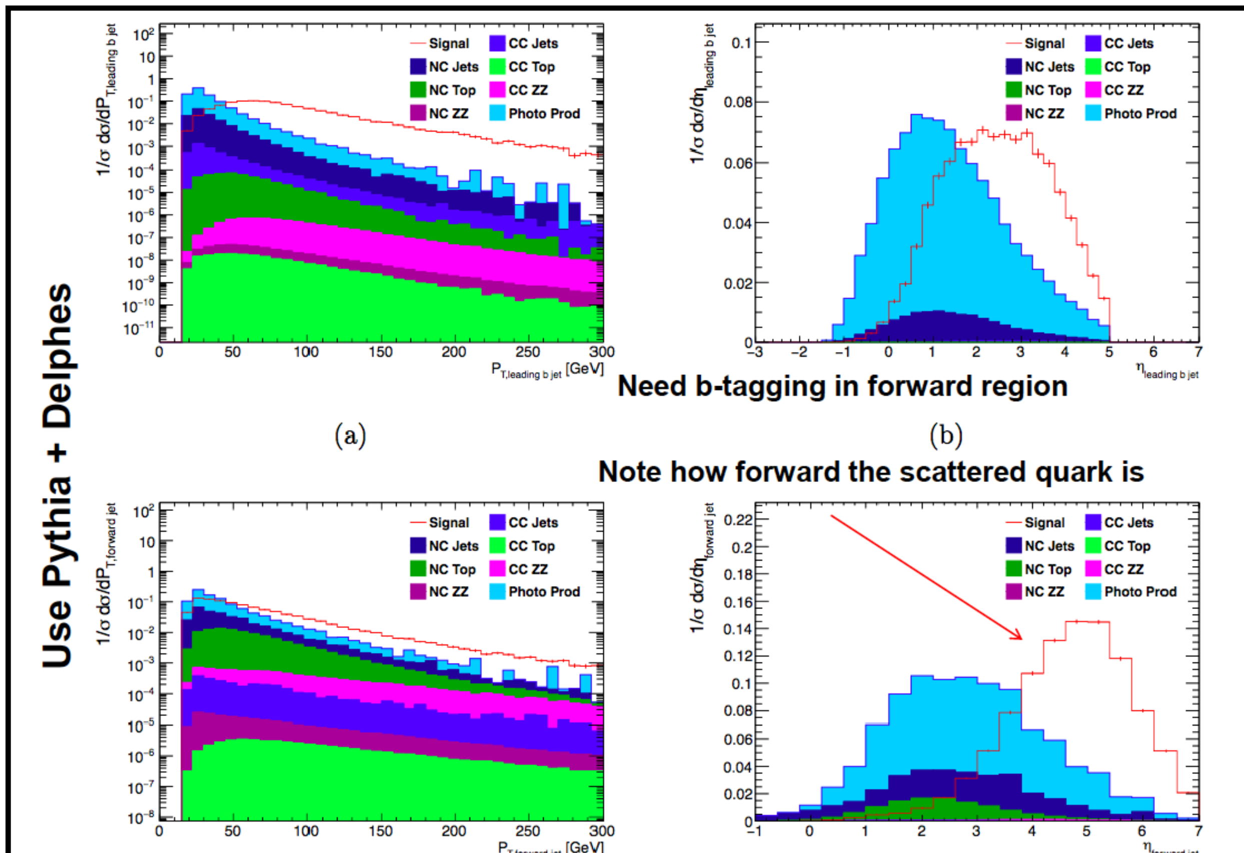
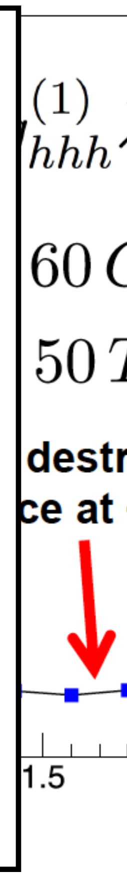




Final event selection

Require 4-btags. Forward jet is leading non-b-jet. Leading b-jet pair contains leading b-jet.

$p_{Tb}, p_{Tj} > 2$

$|\eta_j| < 7, |\eta_b| < 5, \Delta R$

$p_T^{e^-} < 1$

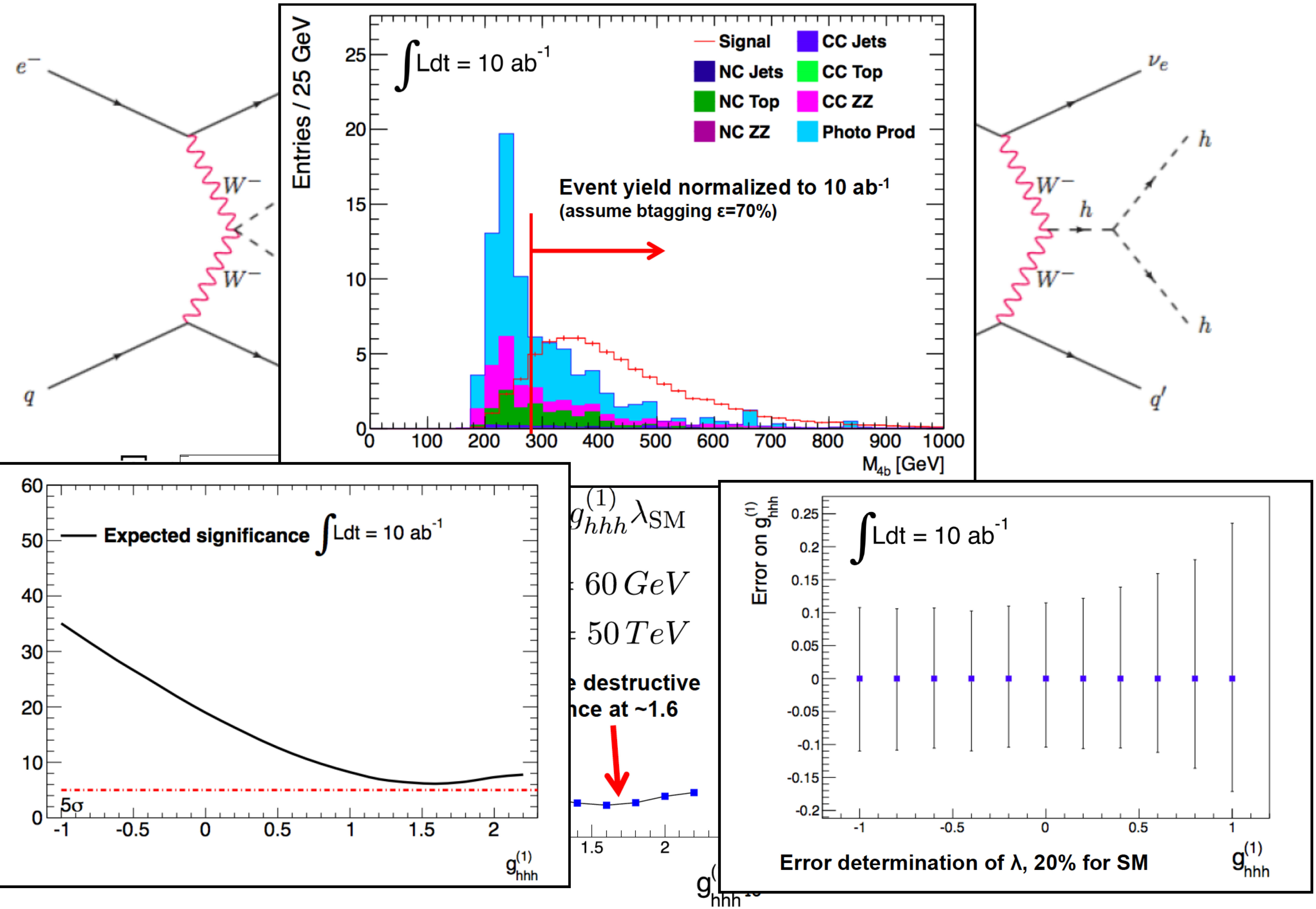
η_T

$MET > 40\,GeV, \Delta\Phi_{MET,b_1}, \Delta\Phi_{MET,b_2}$

$90 < M_1 < 125\,GeV, 75 < M_2 < 12$

$M_{4b} > 28$

HH at the FCC-he [Mellado]



To conclude:

- An impressive amount of work has been presented.

- New LHeC material is under construction: Higgs, top, BSM, QCD,…, to strength a realisable physics case.

- Manpower is needed, particularly for the detector part.

- Collaboration with the LHC experiments is desirable for the comparison with LHC expectations.

Thanks for Voica and Peter for organising the session!!!

Thanks a lot for your attention and apologies to those who find their work badly or under presented!!!