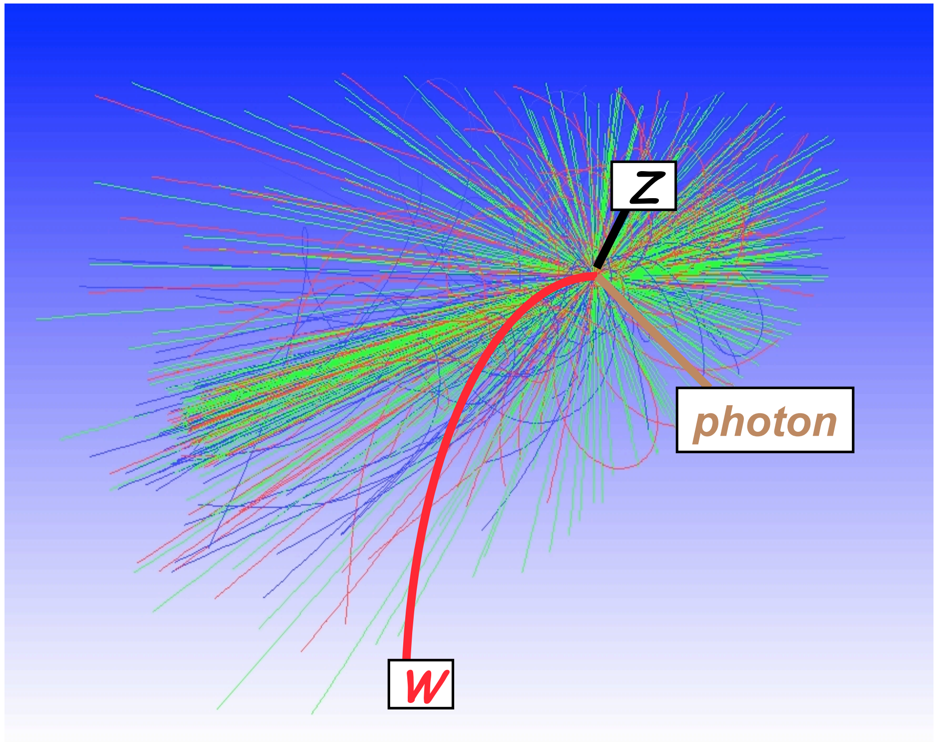
Precision measurements at LHC

M.W. Krasny

LPNHE, University Pierre and Marie Curie, Paris

krasny@lpnhep.in2p3.fr



This talk:

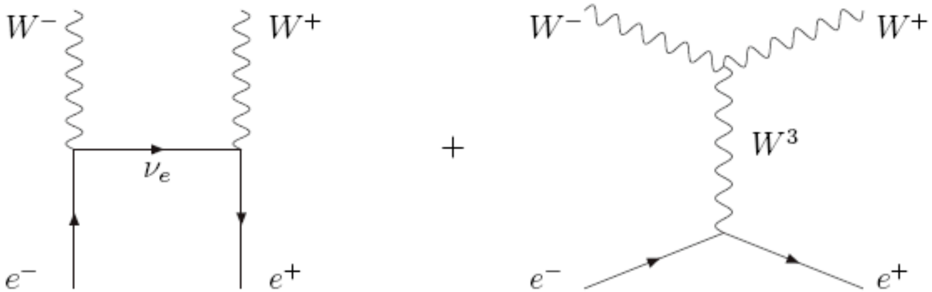
- Introduction
- Search strategies for LHC
- Theoretical tools
- Experimental tools
- Measurement strategies
- Outlook

Epiphany Conference,
Krakow, January, 2007

Introduction

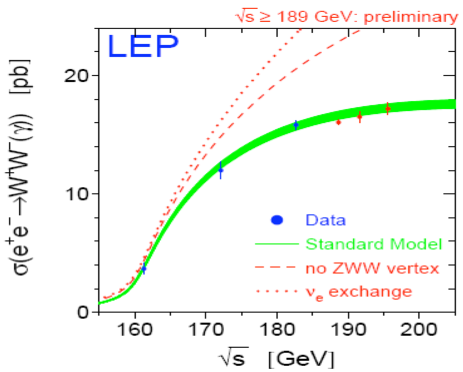
The hints

1. The need for triple boson coupling



This amplitude breaks the unitarity limit - grows like s at high energies (production of longitudinally polarized W-bosons)

Cure: The simplest way to dump the divergence is to exchange a doubly charged lepton in the u-channel or a neutral W boson in the s-channel



..under the following condition:

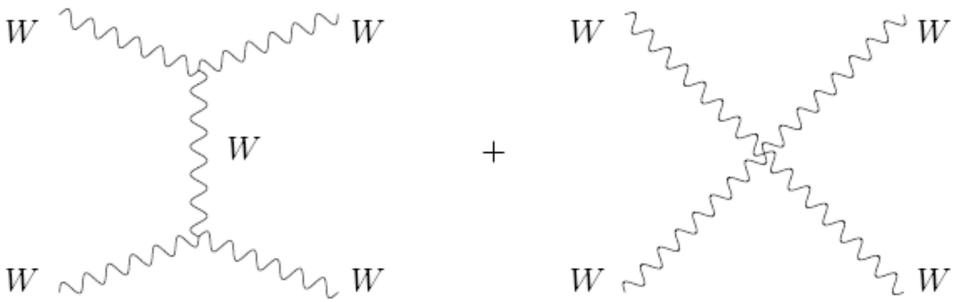
$$[I^k, I^l] = i\varepsilon_{klm} I^m$$

for the couplings g_W I^k_{ab} between the leptons a,b and the W boson k, note:

$$W^{\pm} = (W^1 \mp iW^2)/\sqrt{2}$$

The hints

A partial cure using quadrilinear coupling of W bosons



The amplitude for elastic W boson collisions
(the contribution due to virtual W-exchanges to
collisions of longitudinally polarized W-bosons)
grows as s^2 at high energies and breaks the
unitarity limit at the TeV scale.

Cure: Cancellation of the leading divergence
by introducing a quadrilinear coupling
among the W boson, which must be quadratic
in the coupling g_W

…the following condition must be fulfilled:

$$\lambda_{klmn} = g_W^2 \varepsilon_{klp'} \varepsilon_{p'mn}$$

for the couplings of the W bosons: k,l,m,n.

Unitarity is however not fully restored!!! (the amplitude grows as s at high energies)
… but all theory-intrinsic mechanisms exhausted –
need a mechanism which is external to the gauge theory of electro-weak interactions…

The cure?

Data	$\hat{s}^2_Z$	s^2_W	$\alpha_s(M_Z)$	M_H
All data	0.23122(15)	0.22306(33)	0.1216(17)	89^{+38}_{-28}
All indirect (no m_t)	0.23122(16)	0.22307(41)	0.1216(17)	87^{+107}_{-43}
Z pole (no m_t)	0.23121(17)	0.22310(59)	0.1198(28)	89^{+112}_{-44}
LEP 1 (no m_t)	0.23152(21)	0.22375(67)	0.1213(30)	168^{+232}_{-91}
SLD + M_Z	0.23067(29)	0.22203(56)	0.1216 (†)	28^{+26}_{-16}
$A_{FB}^{(b,c)}$ + M_Z	0.23193(28)	0.22480(76)	0.1216 (†)	349^{+250}_{-148}
M_W + M_Z	0.23089(38)	0.22241(74)	0.1216 (†)	47^{+52}_{-31}

Higgs boson(s)

Search strategies for LHC

Four complementary search methods

1. *Dedicated searches of Higgs particle(s)*

2. *Generic study of of the Z and W boson production processes, their propagation in vacuum and in matter, and decays*

3. *Generic study of the W and Z boson collisions*

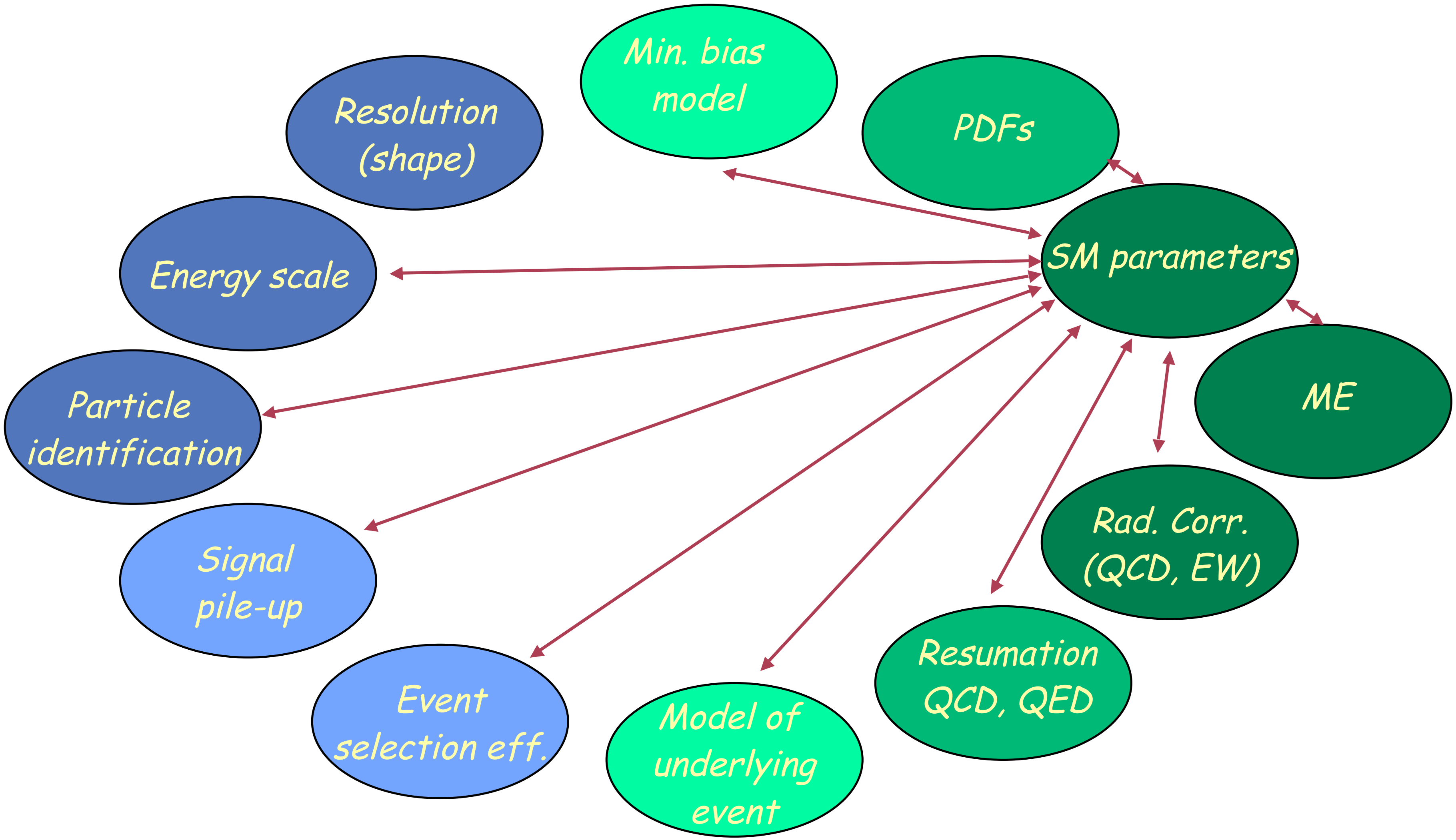
4. *High precision measurement of the absolute cross-sections of the Standard Model processes and Standard Model parameters (high precision - sensitive to the EW radiative corrections)*

… and two implementation methods

1. *Monte-Carlo-based (bootstrap) strategy*

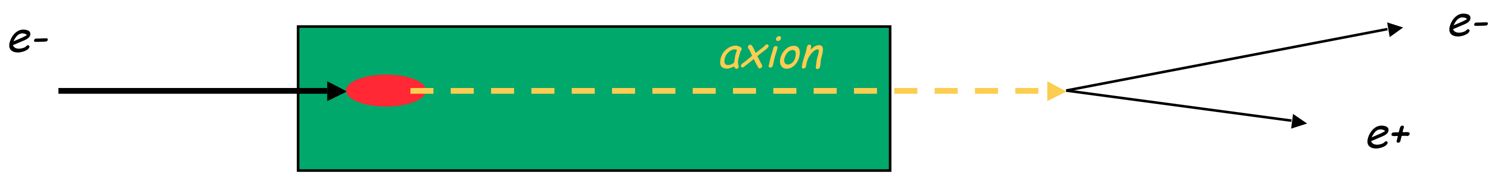
2. *Dedicated strategies (selection of the machine operation mode, detector and TDAQ setting and analysis method for a particular search goal)*

The "bootstrap" strategy at LHC



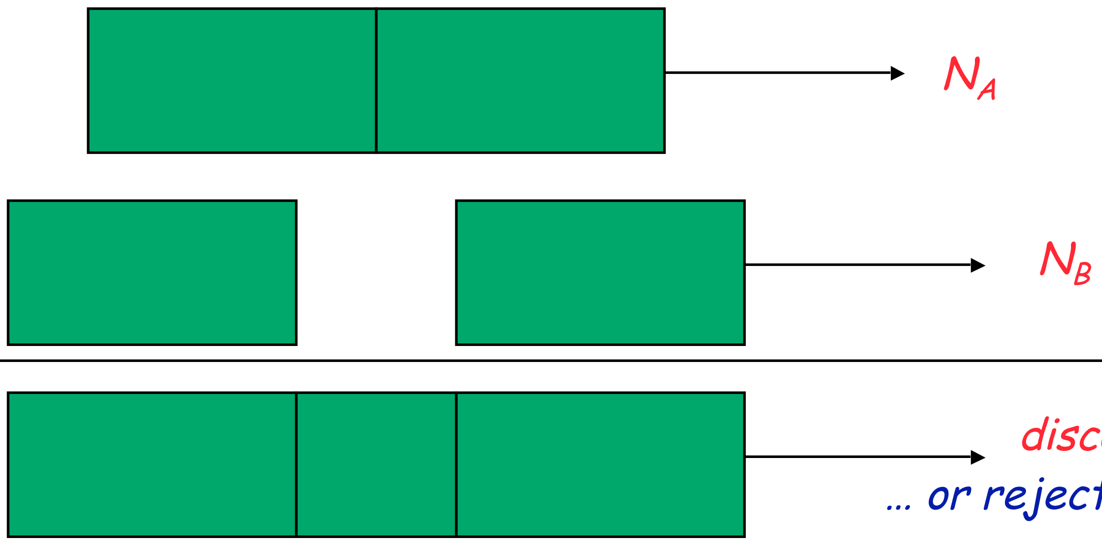
… an example of dedicated strategy:

axion search experiment(s)



10^{19} collisions … Monte-Carlo methods fail - need a dedicated strategy

Run two dump configurations and two energies



if ($N_A > N_B$)

discovery

… or rejection limit

Theoretical precision tools

Requirements for a high precision measurements at LHC
(indispensable for Monte-Carlo based "bootstrap" strategy)

A Monte Carlo which controls production of single and pairs of electroweak bosons containing:

1. The $\mathcal{O}(\alpha_s^2)$ QCD corrections
2. The $\mathcal{O}(\alpha)$ electroweak corrections
3. Multiple soft gluon emission
4. Multiple soft photon emission
5. Full control of polarisation
6. PS-dependent refitting of PDFs
7. Modelling of nonperturbative effects (parton energy loss and emittance)
8. A tuneable model of minimum bias event (energy and beam type dependence)
9. A tuneable model of underlying event
10. A provision for modelling new phenomena (anomalous couplings, etc...)

The experimental community must strongly support all actions going in this direction (e.g. the effort of the Krakow group)

Existing EW+QCD tools for $pp \to$V and $pp \to$VV, where V=W,Z

Required at least $\mathcal{O}(\alpha)$ electroweak or NLO QCD, none has both!

Tool	Process	EW	QCD	MC type
WGRAD	W	$\mathcal{O}(\alpha)$	pdf(x),LO	histogrs.
ZGRAD2	Z	$\mathcal{O}(\alpha)$	pdf(x),LO	histogrs.
WINHAC	W	QED FSR $\mathcal{O}(\alpha)_{\mathrm{EEX}}$	pdf(x),LO	events
HORACE	W,Z	QED FSR part.sh.	pdf(x),LO	events
SANC	W,Z	$\mathcal{O}(\alpha)$	???	events?
RESBOS	W, Z	LO	pdf(x,pT),NLO	histogrs.
DYRAD	V+(0j-1j)	LO	pdf(x),NLO	histogrs.
MCFM	V,VV	LO	pdf(x),NLO	histogrs.
DKS	WW, WZ, ZZ	LO, Anom.Coup.	pdf(x),NLO	histogrs.
dFS	Wγ, Zγ	LO, Anom.Coup.	pdf(x),NLO	histogrs.
MC@NLO	WW	LO	part.sh. NLO	events
MC@NLO	W or Z	LO	part.sh. NLO	events

From S. Jadach's recent presentation

Experimentalist's precision tools (examples)

The context: "the LHC equivalence principle"

It takes one hour to collect a million of pp collision events with the ATLAS detector…

…One must use of the order of 100 000 kSI2k equivalent computers for the same rate of simulated events

Revising the "LEP-like" high precision measurement strategies is indispensable

Based upon:

IN2P3-Pologne 05-115, 05-116, and Polonium cooperation programs

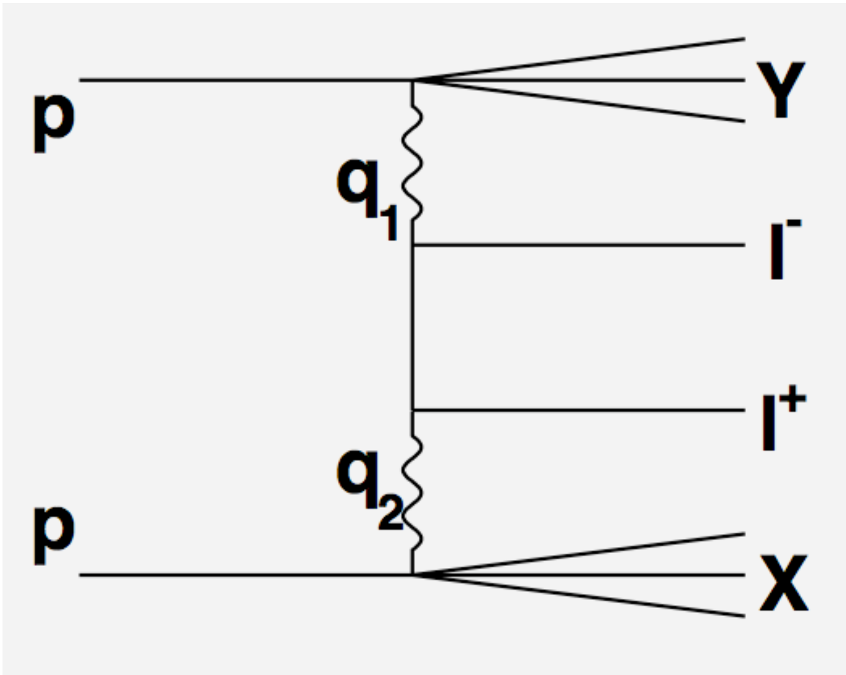
- M.W. Krasny, S. Jadach, W. Placzek, "The femto experiment for the LHC: The W boson beams and targets", EPJ C44, (2005) 333.
- M.W. Krasny, S. Jadach, W. Placzek, "The femto experiment for the LHC: The W boson collisions ", in preparation for EPJ C.
- M.W. Krasny, "Electron beam for LHC" , NIM A540 (2005) 222.
- M.W. Krasny, J. Chwastowski, K. Slowikowski"Luminosity Measurement Method for LHC: The theoretical precision and the experimental challenges" , IFJ Report 1981/Ph, submitted to NIM A.
- M.W. Krasny, J. Chwastowski, K. Slowikowski"Luminosity Measurement Method for LHC: The Detector Model and the Measurement procedure" , in preparation for NIM A.
- M.W. Krasny, J. Chwastowski, K. Slowikowski"Luminosity Measurement Method for LHC: Proton-Ion and Ion-Ion collisions" , in preparation for NIM A.
- M.W. Krasny, W. Placzek, A. Siodmok, "Z-boson as the standard candle for precision measurements of the SM parameters at LHC", in preparation.
- M.W. Krasny, W. Placzek, A. Siodmok, "A strategy for the W boson mass and the width"measurement at LHC , in preparation.

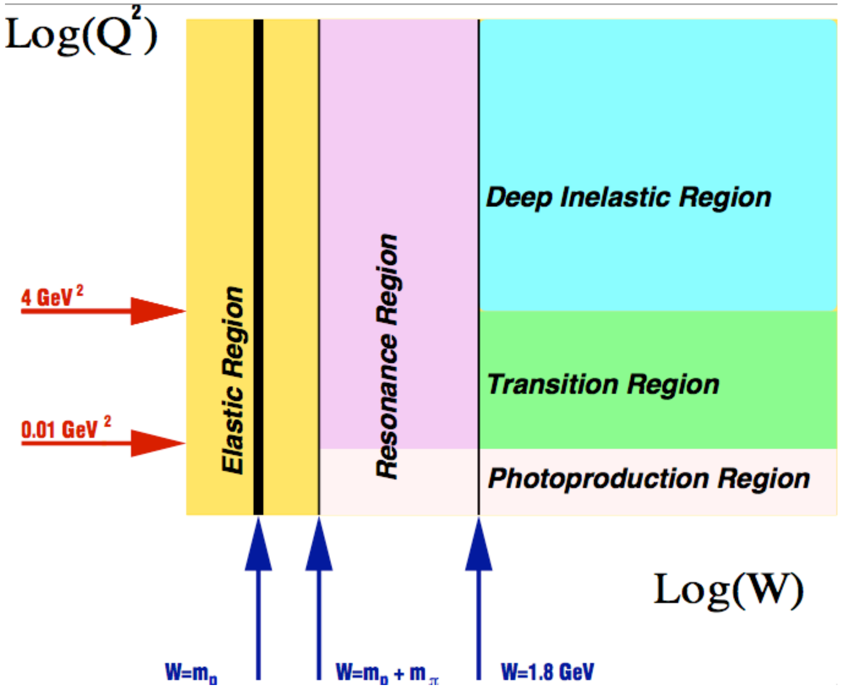
Example1:

Peripheral EM processes and luminosity measurement

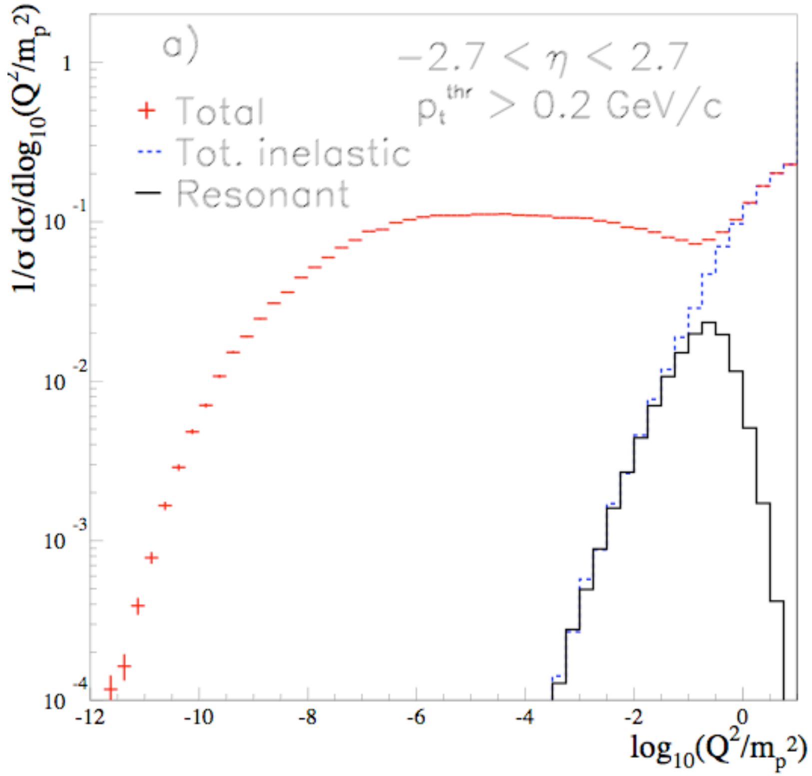
A proposal of the method, of the dedicated detector and the trigger system to achieve O(1%) absolute normalisation precision and O(0.1%)precision of the relative normalisation of event samples taken at various energies and/or using different beam species

J.Chwastowski, M.W. Krasny, K. Slowikowski





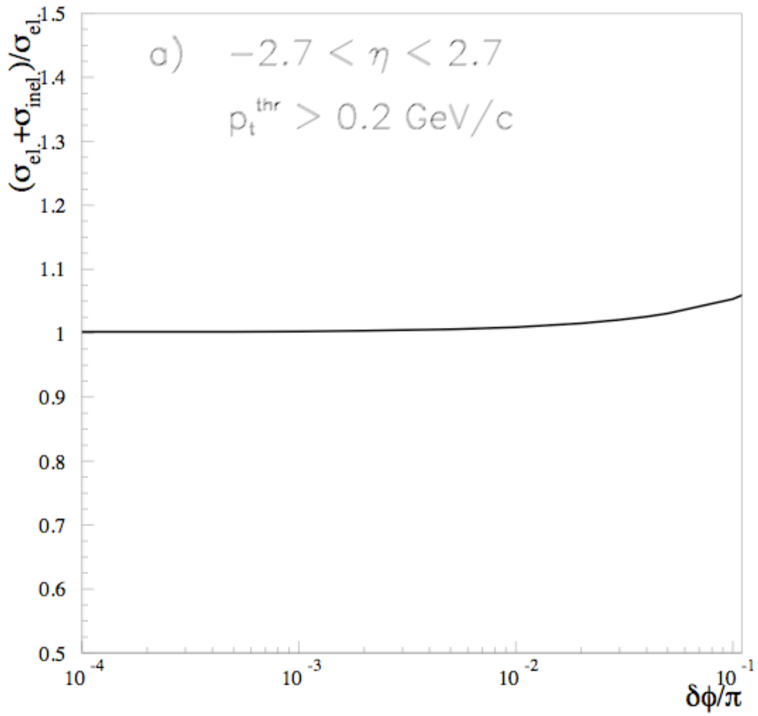
J.Chwastowski, M.W. Krasny, K. Slowikowski



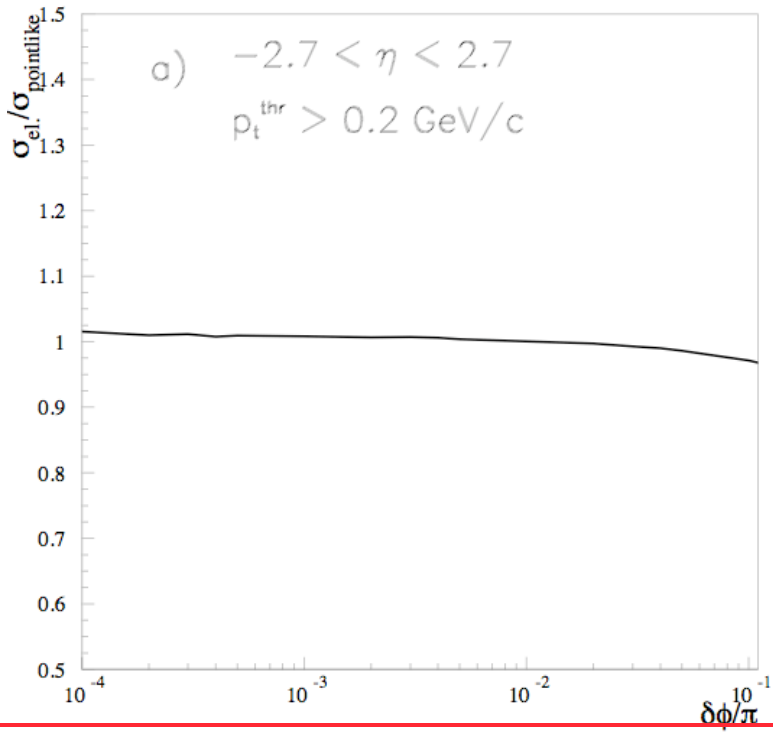
.. Design of a dedicated detector and trigger to measure two photon process in the region where the sensitivity to the proton charge structure is drastically reduced and the cross section is high enough to collect of the order of 10 000 events per day

… achieved reduction of the sensitivity to the inelastic processes and elastic processes driven by the dipole form-factor of the beam particles…

J.Chwastowski, M.W. Krasny, K. Slowikowski



J.Chwastowski, M.W. Krasny, K. Slowikowski



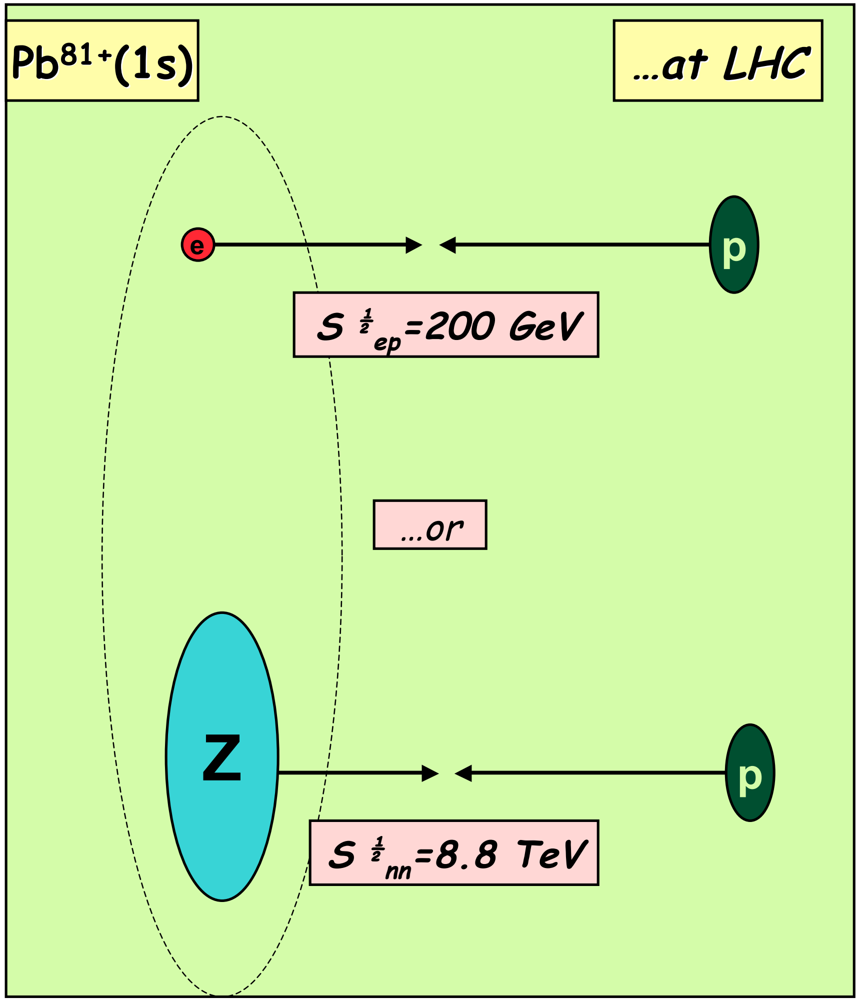
Lepton pair accoplanarity: $\delta\phi = \pi - min(2\pi - |\phi_1 - \phi_2|, |\phi_1 - \phi_2|)$

Example2: ions

Merits of the LHC ion beams for high precision physics

1. *Ions as electron beam carriers*
2. *Ions as analysers of W/Z boson propagation in vacuum and matter*
3. *Isoscalar ions and u/d flavour democracy*
4. *Isoscalar ions and zero net flavour beams*
5. *Ions as the photon beam source*
6. *Ions as a tool to control pile-up effects*

High Z ions as electron beam carriers…

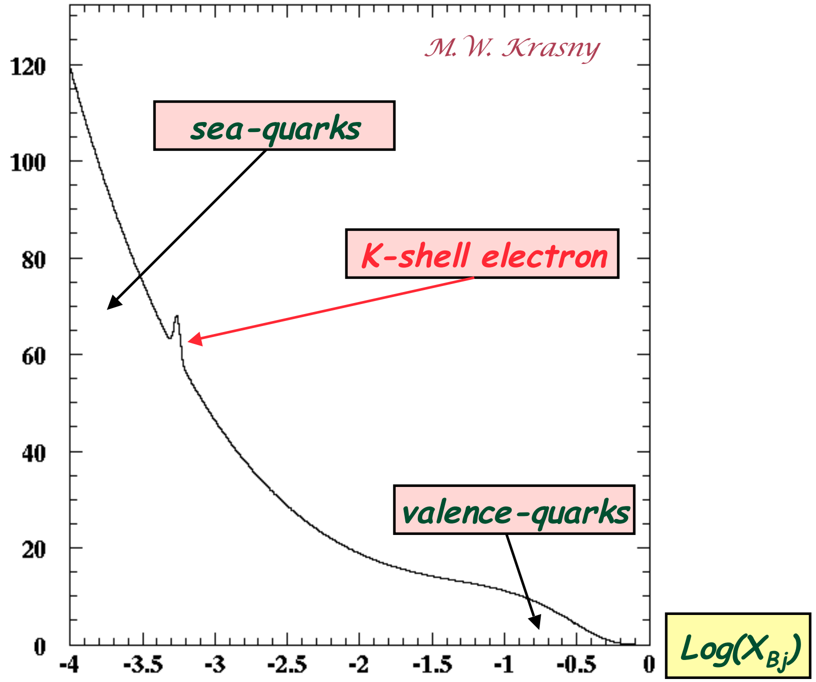


- *average distance of the electron to the large Z nucleus d ~ 600 fm (sizably higher than the range of strong interactions)*
- *partially stripped ion beams can be considered as <u>independent electron and nuclear beams</u> as long as the incoming proton scatters with the momentum transfer q >> 300 keV*

Both beams have <u>identical bunch structure</u> (timing and bunch densities), <u>the same b^*</u>, <u>the same beam emittance</u> – the choice of collision type can be done exclusively by the trigger system (no read-out and event reconstruction adjustments necessary)

Cross-calibration of processes involving "coloured" partons and "colour-blind" partons (electrons)

$F_2^{Pb}(x, Q_0)$ *(surface partons)*



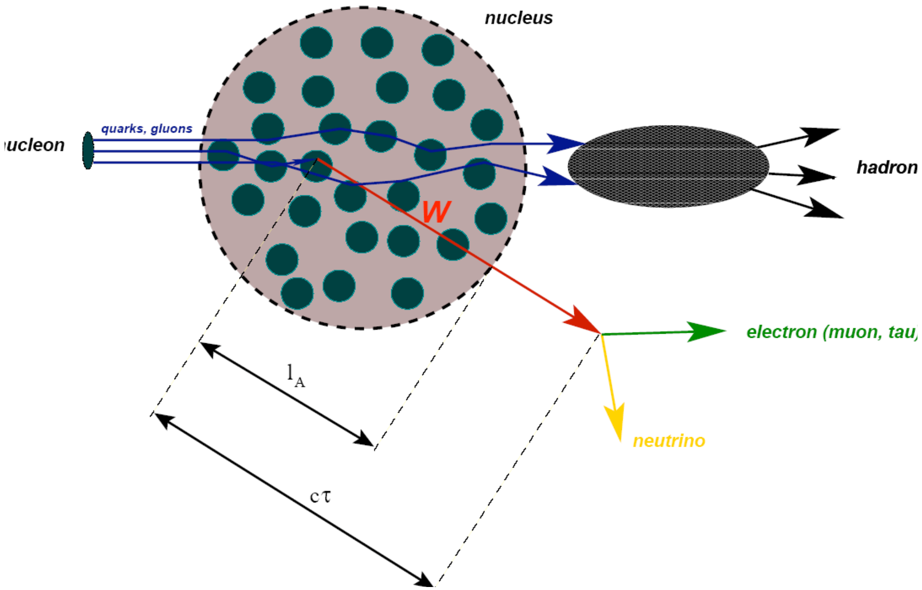
Example: *Longitudinal momentum structure of electrically-charged components of the $Pb^{81+}(1s)$*

Examples

- Unfolding of the initial-state and the final-state partonic interactions at LHC (crossing t-channel and s-channel)
- Measuring the energy dependence of partonic emittances
- Model independent studies of jet shapes (electron recoil templates)
- Scrutinizing partonic collective effects (higher twists) at the LHC
- Precise detector calibration (e.g. direct model-independent jet calibration)

W and Z boson beams and their targets

S. Jadach, M.W. Krasny, W.Placzek

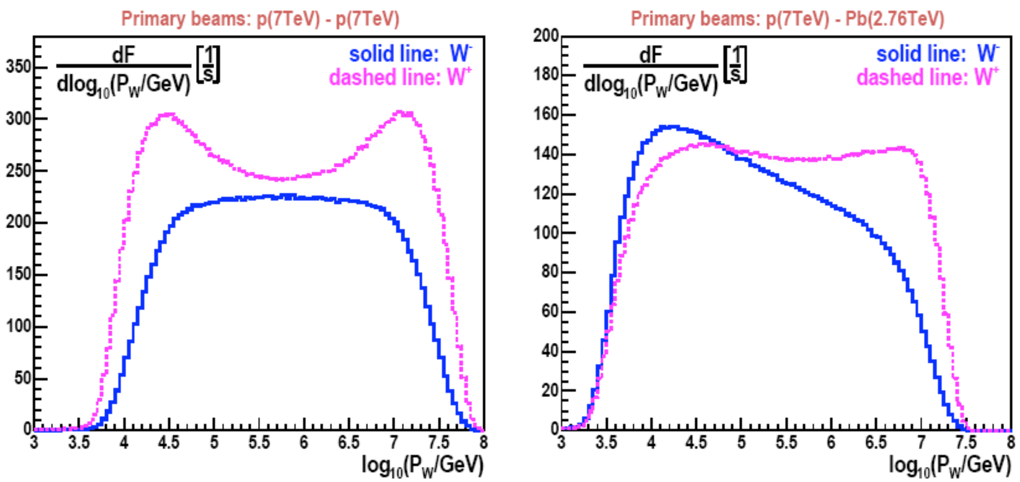


At LHC W bosons propagate up to 10000 fm - **can be considered as a beam of free particles for fermi scale targets !!!**

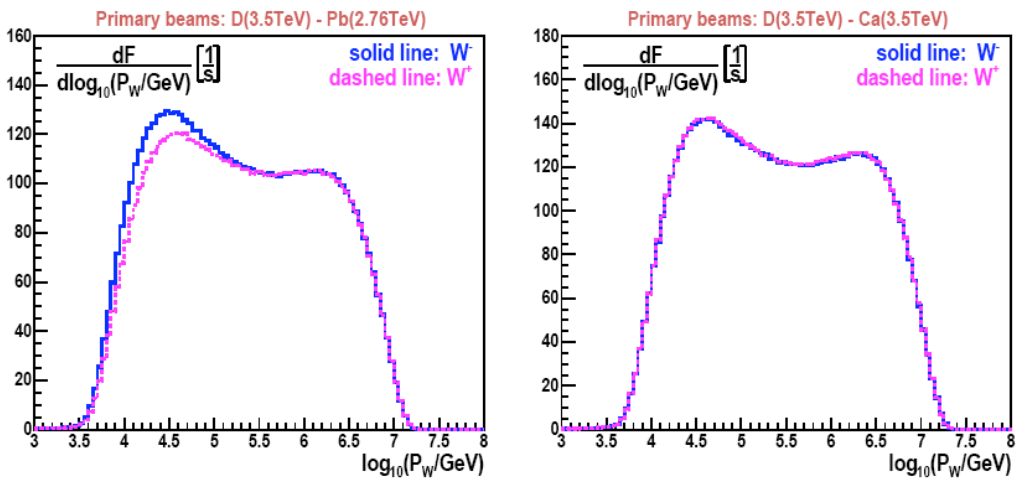
(direct analogy to CERN high energy muon beams)

$$\mathcal{M}(p_n, p_A, p_W^{in}, r, p_W^{out}, p_1, p_W^{out} - p_1 | A) = \mathcal{M}_f(p_n, p_A, p_W^{in}, r | A)\, \mathcal{M}_p\left(p_W^{in}, p_W^{out}, l_A(p_W^{in}, p_A, r)\right)\, \mathcal{M}_d(p_1, p_W^{out} - p_1)$$

The W-boson fluxes and W-nucleon luminosity



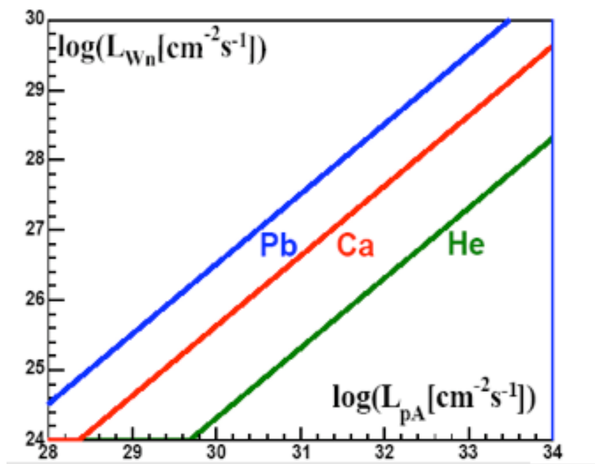
(a) (b)



S. Jadach, M.W. Krasny, W.Placzek

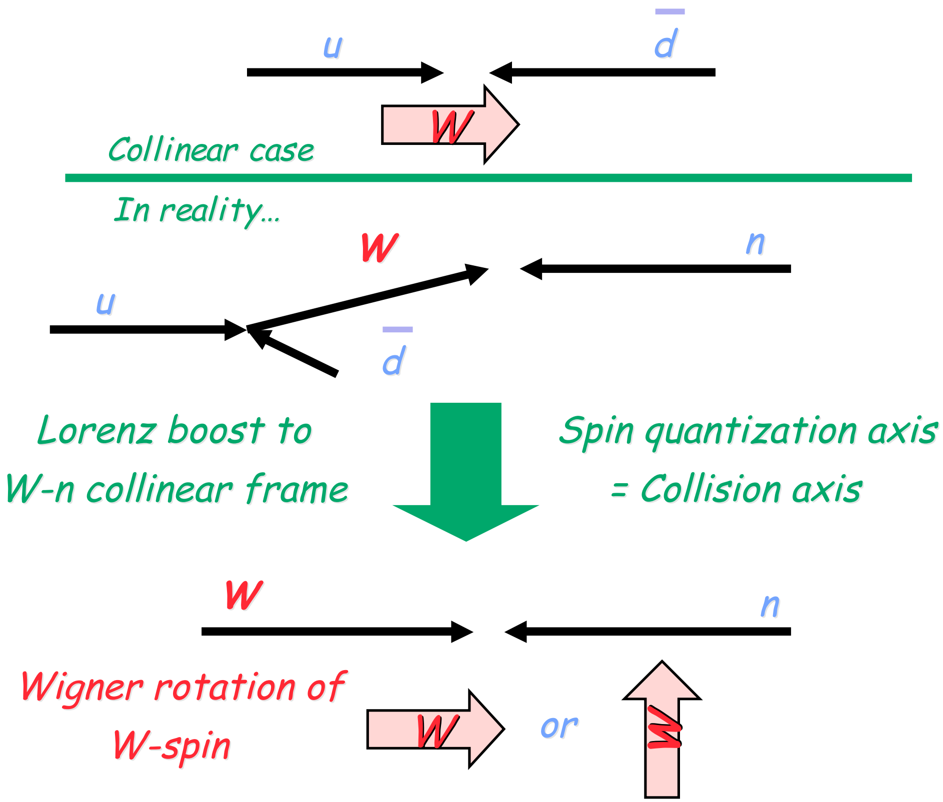
$$E_{\rm beam} = 7\,\frac{Z}{A}\,{\rm TeV}$$

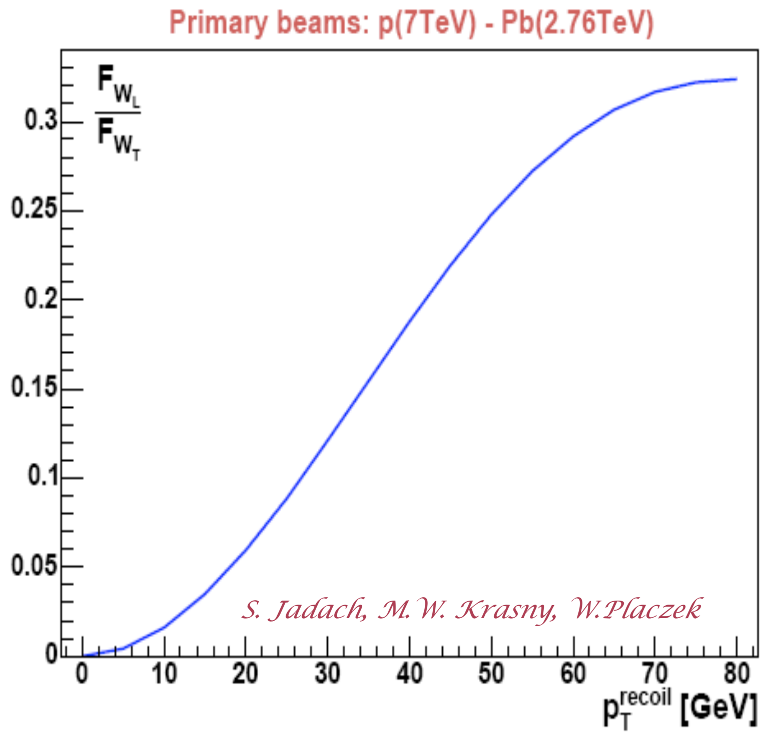
$$L_{A_1A_2} = \frac{L_{pp}}{A_1A_2}$$



Longitudinal polarization

Longitudinal polarization is driven by the transverse momentum of quarks annihilating into W-boson





… Controlled experimentally by choosing the transverse momentum of the W-recoil …

Measurement strategies
- an example

M.W. Krasny, W.Placzek, A. Siodmok

Precision measurement of M_W using Z boson as a standard candle

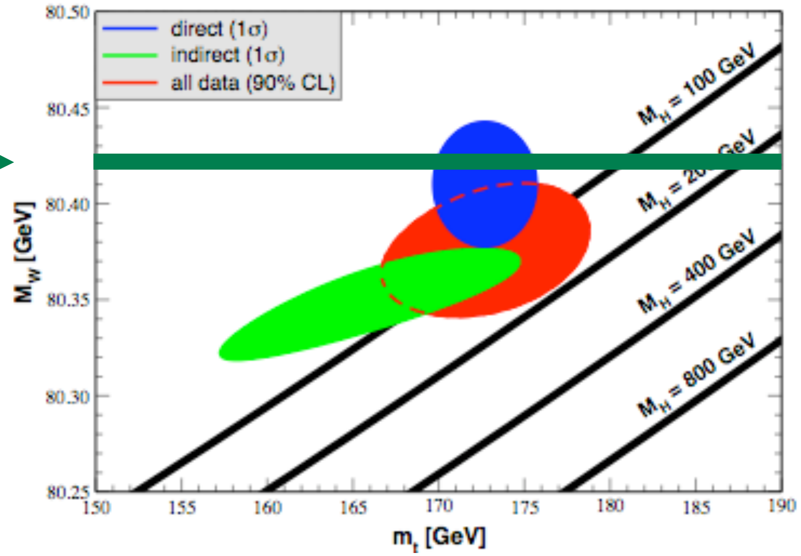
Z $J = 1$

Charge $= 0$
Mass $m = 91.1876 \pm 0.0021$ GeV [d]
Full width $\Gamma = 2.4952 \pm 0.0023$ GeV

W $J = 1$

Charge $= \pm 1\ e$
Mass $m = 80.403 \pm 0.029$ GeV
$m_Z - m_W = 10.785 \pm 0.029$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.141 \pm 0.041$ GeV

Can a comparable precision For W boson be achieved at LHC?



The sources of the W/Z boson asymmetries

The physics effects:

mass (different x-region at fixed rapidity, different scale, different pt spectrum of W/Z bosons)

decay width (different scale and pt spectrum smearing)

u_v/d_v, u_s/d_s flavour asymmetry of the proton beam

the relative strength of V-A and V+A coupling

CKM mixing in conjunction with quark mass asymmetries

Radiation of photons

EW radiative corrections

The measurement effects

The event selection effects

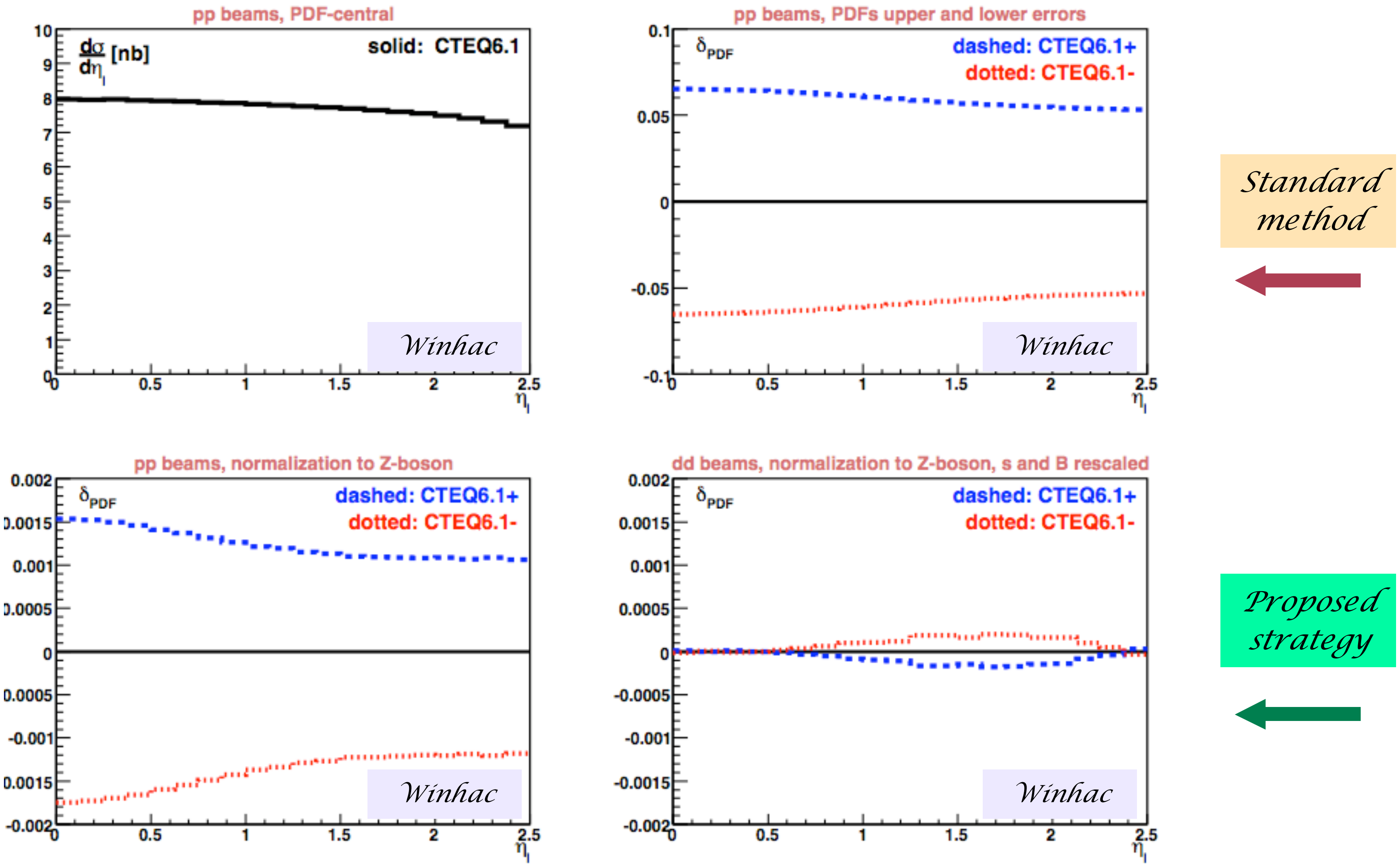
An example: a strategy to measure M_W

1. Collect data at the two LHC beam energies: s_1 and $s_2 = s_1 (M_Z/M_W)^2$
2. Use isoscalar beams e.g. deuterium, helium or oxygen ions
3. Change the solenoid current for runs at the two energies $i_2 = i_1 M_Z/M_W$
4. Take a fraction of the data with $i = 0$
5. Use dedicated trigger and data selection scheme (inclusive charged lepton calorimetric trigger associated with lepton track trigger (HLT))
6. Measure and factorize out the QCD effects (MC independent)

…examples of merits of the above strategy: →

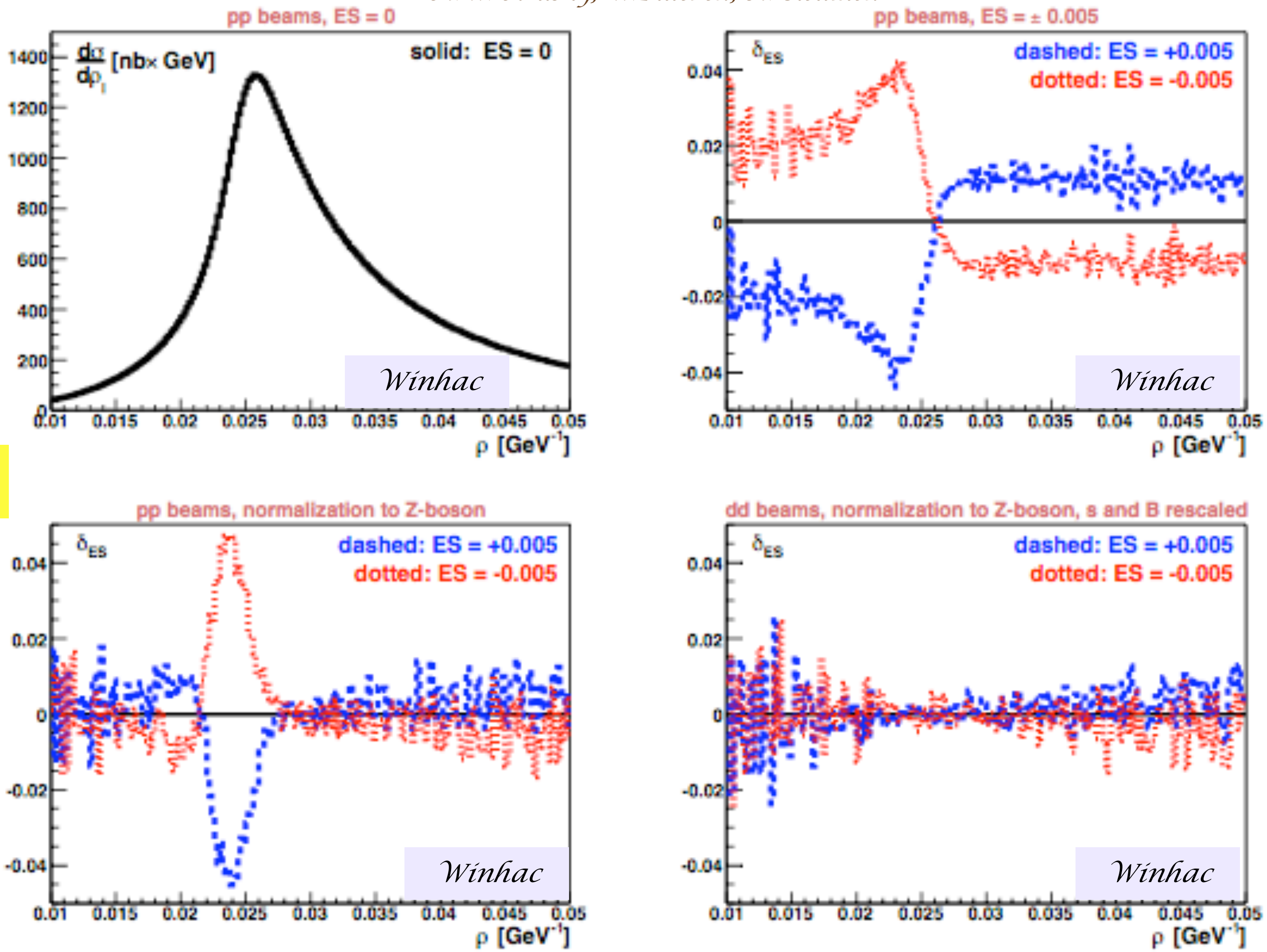
…reduction of the sensitivity to the partonic flavour and momentum structure of the LHC partonic beams

M.W. Krasny, W.Placzek, A. Siodmok



…reduction of the sensitivity to the systematic measurement effects e.g. the energy scale error: $E_t = E_m(1 + ES)$

M.W. Krasny, W.Placzek, A. Siodmok

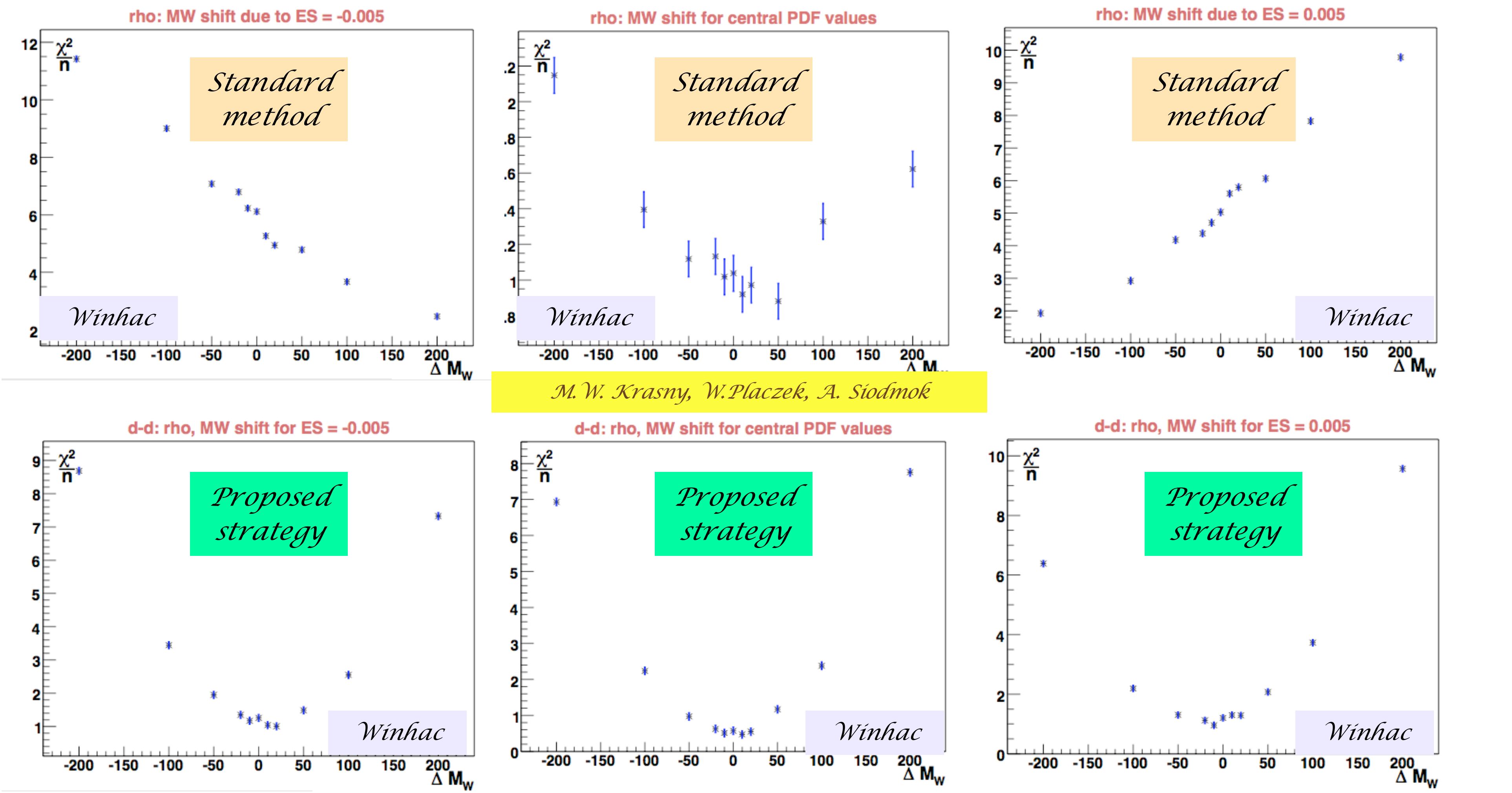


$\rho = 1/p_t^l$

Standard method

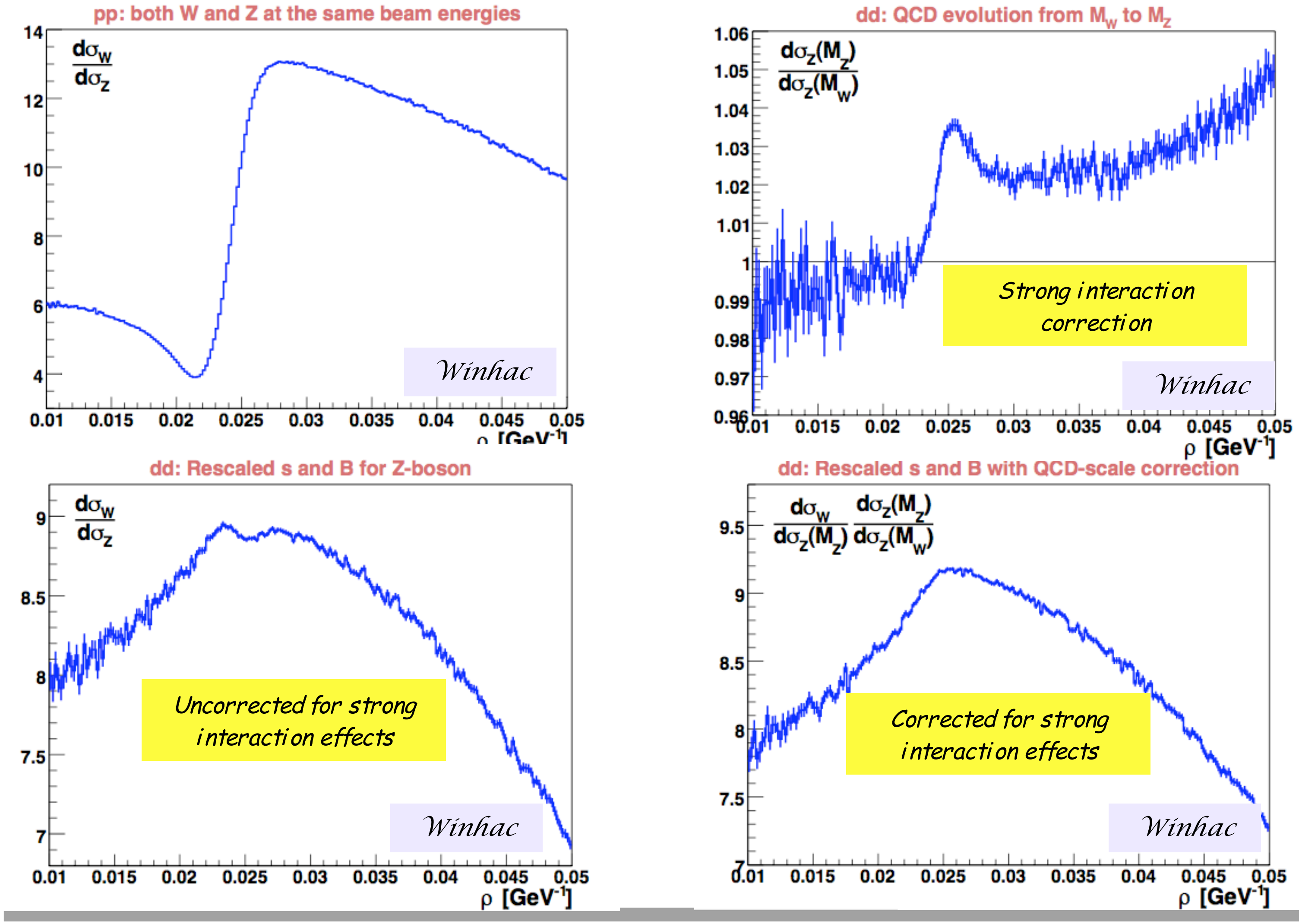
Proposed strategy

…stability of M_W measurement with respect to systematic measurement effects



…factorization of the strong interaction effects on the basis of the data

M.W. Krasny, W.Placzek, A. Siodmok



Outlook

The development of the new-generation theoretical tools (Monte Carlos) is indispensable for the high precision measurements at LHC

The LHC experimental program must develop, on top of the standard 'analysis methods, dedicated tools and dedicated strategies for high - precision measurements using the large $O(10^8)$ data samples

The tools and the measurement strategies are being developed within the IN2P3-Krakow cooperation programs. Together with the "Gauge Model of the Data Taking and Data Analysis" may provide a back-up solutions for hunting for new physics ...if the standard methods will be insufficient