First Results with HIJING++ on High-energy Heavy Ion Collisions

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Dec. 6, 2016, Zimányi School

Eötvös University, Budapest, Wigner RCP, Budapest; CCNU, Wuhan; LBNL, Berkeley

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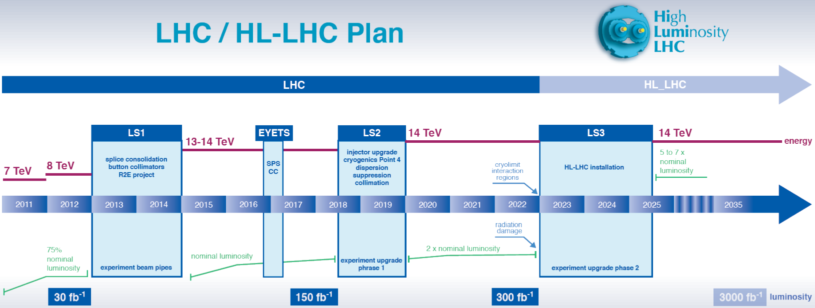
Outline

1. **Introduction**
   1. Motivation for HIJING++
   2. Technical details of the HIJING++
2. **Results**
   1. Performance test
   2. p_T spectra test
3. **New features**
   1. Q^2 dependent shadowing
   2. Gunion-Bertch radiation
4. **Summary**

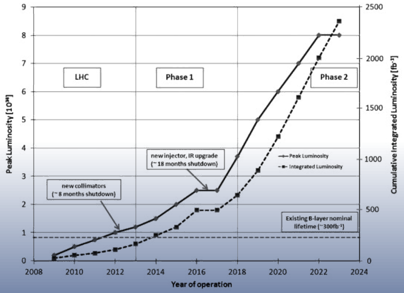
Motivaton


LHC / HL-LHC Plan
High Luminosity LHC
LHC
HL_LHC
LS1
splice consolidation
button collimators
R2E project
EYETS
SPS
CC
LS2
injector upgrade
cryogenics Point 4
dispersion
suppression
collimation
LS3
HL-LHC installation
7 TeV
8 TeV
13-14 TeV
14 TeV
14 TeV
energy
5 to 7 x
nominal
luminosity
cryolimit
interaction
regions
radiation
damage
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2035
75%
nominal
luminosity
experiment beam pipes
nominal luminosity
experiment upgrade
phrase 1
2 x nominal luminosity
experiment upgrade phase 2
30 fb-1
150 fb-1
300 fb-1
3000 fb-1
luminosity

HI data from the LHC

WLCG – Worldwide LHC Computing GRID:

- LHC made 15-20 PB data per year
- ...and now before HL-LHC 2PB/day



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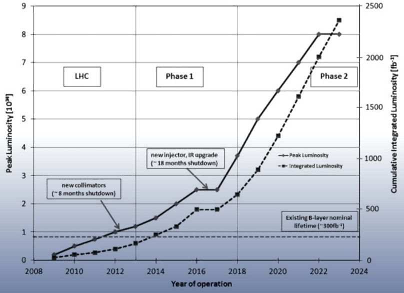
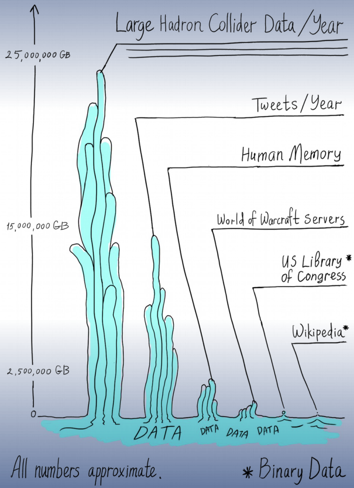
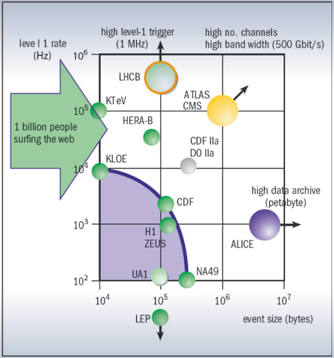




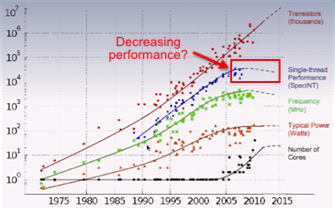
More data: motivation for fast computing at CERN

- **Ideal**: amount of simulated data $\sim$ real data
  - Number of events at LHC: 10^8/s
  - Necessary time for Monte Carlo with ALICE geometry: 3.8 ms/track
- Necessary time to simulate 1 s of ALICE data: $\mathcal{O}(days)$.

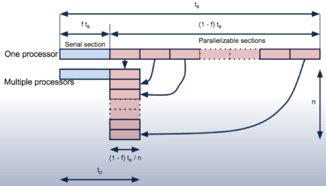


Fast computing = parallel computing

- **Moore's law**: Every 2nd year the number of transistors (integrated circuits) are doubled in computing hardwares



- **Amdalh's law**: The theoretical speedup is given by the portion of parallelizable program, p, and number of processors, N, is:



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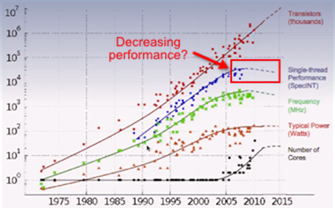
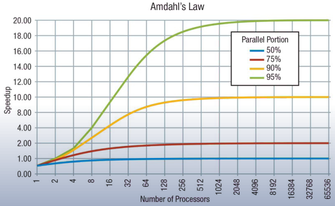
  Speedup(N) $= \frac{1}{(1-p)+p/N}$





HIJING++

C++ based HIJING version 3.1415926 with parallel features

HIJING++

HIJING (Heavy-Ion Jet INteraction Generator) – 易經

- Bagua (eigth symbols)
- fundamental principles of reality
- adjoint representation 8 of SU(3)

HIJING++

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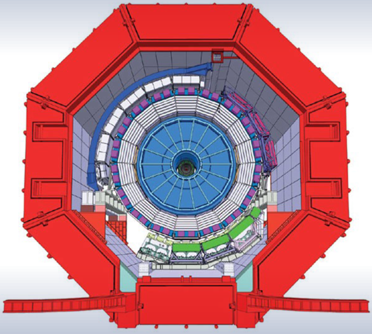

- Bagua (eigth symbols)
- fundamental principles of reality
- adjoint representation 8 of SU(3)

What is HIJING ???

Is it something messy ?!

What is HIJING ???

Is it something messy only a guru can play?

What is HIJING ???

- should be easily configurable
- should be easily expandable to check new ideas

HIJING++

HIJING (Heavy-Ion Jet INteraction Generator)

- event generator

HIJING++

HIJING (Heavy-Ion Jet INteraction Generator)

- event generator
- based on nucleon-nucleon interactions:
  - elastic collisions
  - OR hard scattering (PYTHIA) followed by soft scattering (FRITIOF – diffractive processes, string excitations, ARIADNE – soft gluon radiation)
  - OR soft scattering (FRITIOF, ARIADNE)

HIJING++

HIJING (Heavy-Ion Jet INteraction Generator)

- event generator
- based on pairwise nucleon-nucleon interactions:
  - elastic collisions
  - OR hard scattering (PYTHIA) followed by soft scattering (FRITIOF – diffractive processes, string excitations, ARIADNE – soft gluon radiation)
  - OR soft scattering (FRITIOF, ARIADNE)
- Lund hadronization (PYTHIA)

Performance test: runtime

	FORTRAN	C++ single core		C++ parallel	
pp	0.2640 s	0.5055 s	-91.5%	0.0044 s	5055%
pPb	3.5090 s	6.274 s	-46.4%	0.0514 s	6826%
PbPb	397.96 s	482.28 s	-21.2%	5.688 s	6896%

Table: Time for 10^5 events in HIJING 2.553 (FORTRAN) and HIJING++ single core and 200 parallel cores.

- Single core:
  - *pp* is slower, but this is the effect of PHYTHIA8
  - Difference is getting less for heavier systems
- Multi-core run (200 cores):
  - Due to the MPI support it is considerably faster
  - Better performance in HIC than in small systems (10^5 evts)

Why C++ ?

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- PYTHIA has changed to C++ from version 6 to 8
- C++ is object oriented: modularity allows to check new ideas, or several models
- C++11/14 has thread support and compatibility with OpenCL

Hijing class

```
namespace Pythia8 {

    class Hijing {

    public:

        Info            info;
        Rndm            rndm;
        Settings        settings;
        ...

    private:

        HardCollision   hijhard;

        SoftScatter     hijsoft;

        Fragmentation   fragmentation;

        NucleonLevel    nucleonlevel;

        ...
    }
}
```

- Hijing is an extended Pythia8 class
- FORTRAN common blocks $\longrightarrow$ class variables
- processes called through object functions

How to use?

FORTRAN

```
PROGRAM TEST
...
PARM(1) = 'DEFAULT'
VALUE(1) = 80060
CALL PDFSET(PARM, VALUE)
CALL GetDesc()
...

CALL HIJSET(EFRM, FRAME, PROJ, TARG, IAP, IZP, IAT, IZT)

N_EVENT=1E6
DO 200 IE = 1, N_EVENT
    CALL HIJING(FRAME, BMIN, BMAX)
200 CONTINUE

STOP
END
```

C++

```
#include "Hijing.h"

using namespace Pythia8;

int main() {
    Hijing hijing("../xmldoc", true);
    hijing.readString("PDF:pSet = LHAPDF6:GRV98lo");

    bool okay = hijing.init(200.0, frame,
                "A", "A", 197, 79, 197, 79);
    if (!okay) return 1;

    int MaxEvent = 1e6;
    for (int iEvent = 0; iEvent < MaxEvent; ++iEvent)
        hijing.next(frame, 0.0, 0.0);
}
```

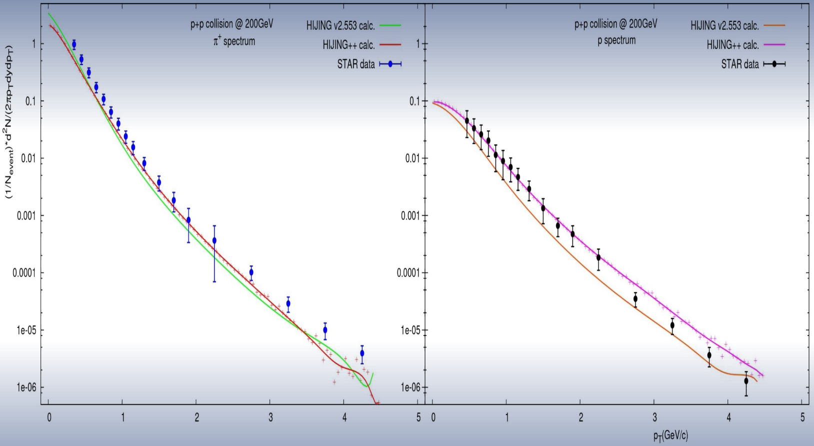
Dependencies & External packages

Boost	boost C++ library (libboost-all-dev package)
LHAPDF6	PDF's for C++ (GLV98lo is migrated for compatibility with HIJING 2.x)
PYTHIA8	PYTHIA 8 library
GSL	GNU scientific library (optional)

Data Analysis

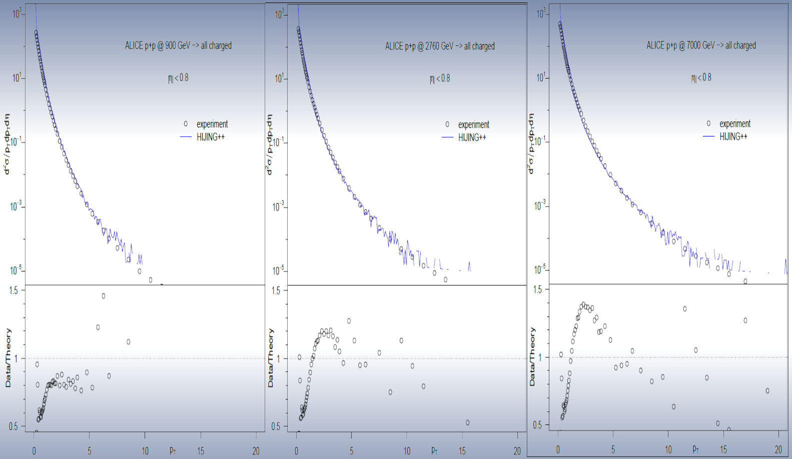
```
#include "Hijing.h"
using namespace Pythia8;

int main() {
    Hist dndpT("dn/dpT for charged particles", 100, 0., 10.);
    ofstream ch_file("ch_hist.dat");
    ...
    bool okay = hijing.init(efrm, frame, proj, targ,
                            aproj, zproj, atarg, ztarg);
    if (!okay) return 1;
    int MaxEvent = 1e6;
    for (int iEvent = 0; iEvent < MaxEvent; ++iEvent) {
        hijing.next(frame, bmin, bmax);
    for (int i = 0; i < hijing.event.size(); ++i)
    if (hijing.event[i].isFinal() && hijing.event[i].isCharged())
        dndpT.fill(hijing.event[i].pT());
    }
    dndpT *= 1.0 / MaxEvent;
    cout << dndpT;
    dndpT.table(ch_file);
    ...
    return 0;
}
```

Testing physics: *pp* collisions @ RHIC



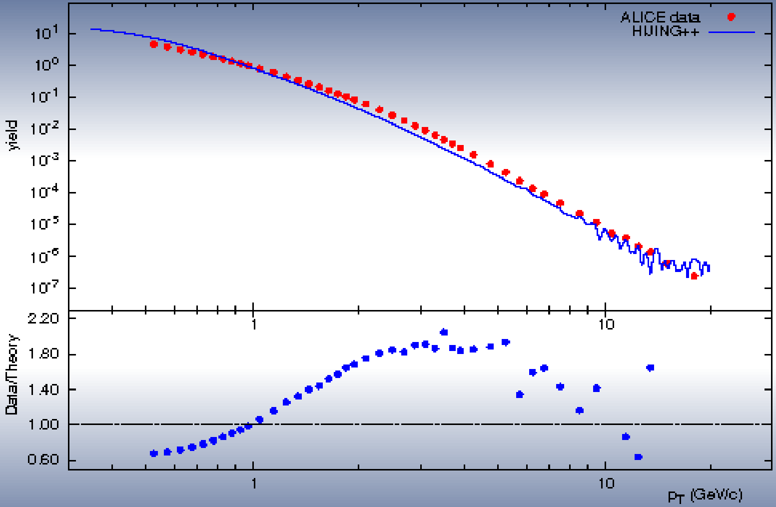
Data: STAR Collaboration, Phys.Lett. B637 page 161-169 (2006)

Testing physics: *pp* collisions @ LHC



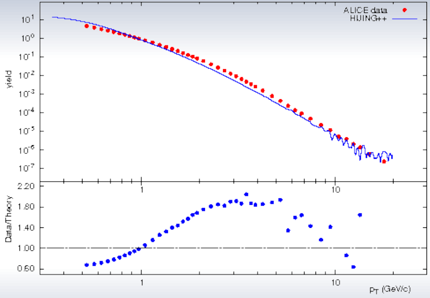
Data: ALICE Collaboration, Eur. Phys. J. C73 2662 (2013)

Testing physics: *pA* collisions @ LHC



Data: ALICE data @ 5.02 TeV $p + Pb$

Testing physics: *pA* collisions @ LHC



Calculation underestimates the yield: too strong shadowing

New features

- PYTHIA5.x vs PYTHIA8.x: plenty of new physics: trying to to avoid “double counting” in HIJING++
- HIJING++ parameters integrated into a PYTHIA-like configuration file
- GRV98 were include to LHAPDF6 for backward compatibility
- Nuclear shadowing: many kinds available, new Q-dependent version of the HIJING shadowing parametrization
- Jet Quenching: several models (in progress)
- Soft QCD radiation ARIADNE (isotropic) $\longrightarrow$ Gunion-Bertch directed radiation

Q^2 independent shadowing

HIJING 2.x shadowing: $f_{a/A}(x, Q^2) = S_{a/A}(x) \left[\frac{Z}{p} + \left(1 - \frac{Z}{A}\right) f_{a/n} \right]$

is independent

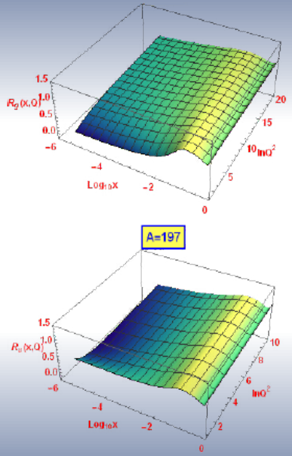
- of Q^2
- of flavor (except g/q)
- geometrical (impact parameter) dependence is introduced through a geometrical factor: $S(x, b) = S_0(x) + S_b(x) \frac{5}{3} \left(1 - \frac{b^2}{R_A^2}\right)$

The first two are not consistent with the DGLAP equations

Q^2 dependent shadowing

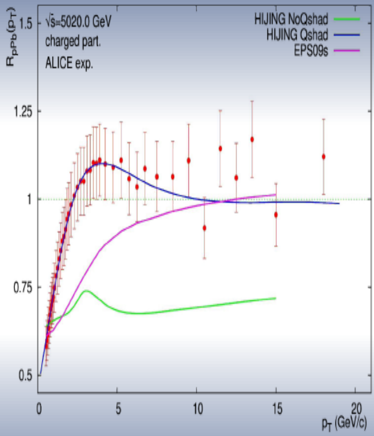
Shadowing function $S_{a/A}(x, b, Q^2)$ depends now on Q^2 and flavor

- The shadowing function is calculated from DGLAP evolution (HOPPET code) of the nuclear PDF (nPDF) starting with the old Q^2 independent shadowing function from scale $Q^2 = 2\mathrm{GeV}^2$ for PDF.
- At each Q^2 the ratio of nPDF/PDF (GLV98lo) is calculated as the shadowing
- The shadowing function if fitted.



$R_{pPb}(p_T)$

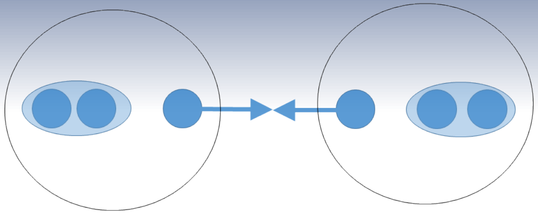
- $R_{pA}(p_t) = \frac{\mathrm{d}N_{pA}/\mathrm{d}y\mathrm{d}p_T^2}{\langle N_{bin}\rangle \mathrm{d}N_{pp}/\mathrm{d}y\mathrm{d}p_T^2}$
- HIJING++ (Q^2 dependendent shadowing with multiple scattering)
- HIJING 2.553 (Q^2 independent shadowing with multiple scattering)
- EPS09s with no multiple scattering



ALICE data @ 5.02 TeV p+Pb

Gunion-Bertch radiation

Phy. Rev. D25 (1982) 746.



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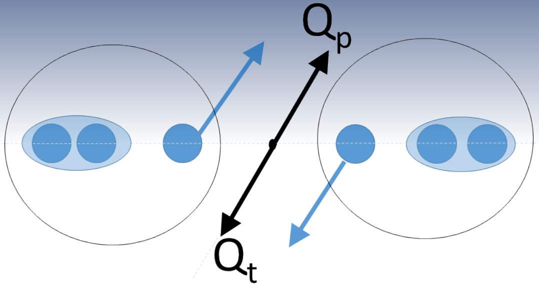

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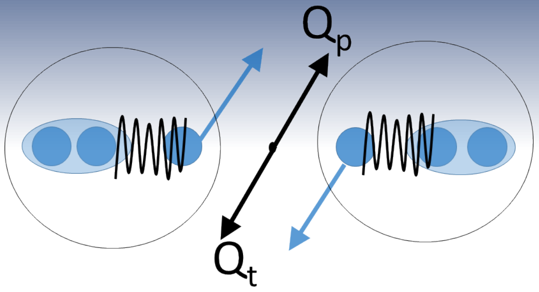

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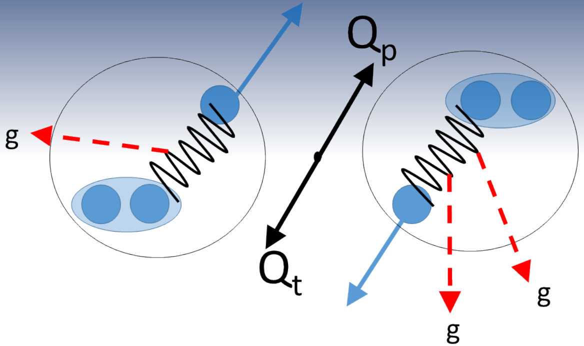

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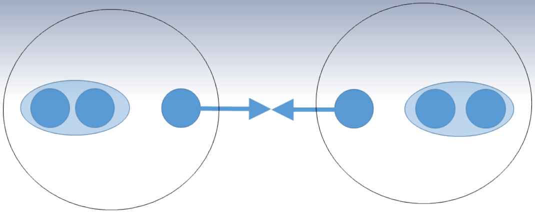

ARIADNE

$$\frac{\mathrm{d}N_g}{\mathrm{d}\eta\mathrm{d}^2k_\perp} \sim \frac{1}{k_\perp^4}$$

Gunion-Bertch radiation

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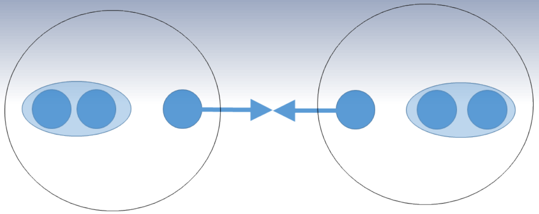

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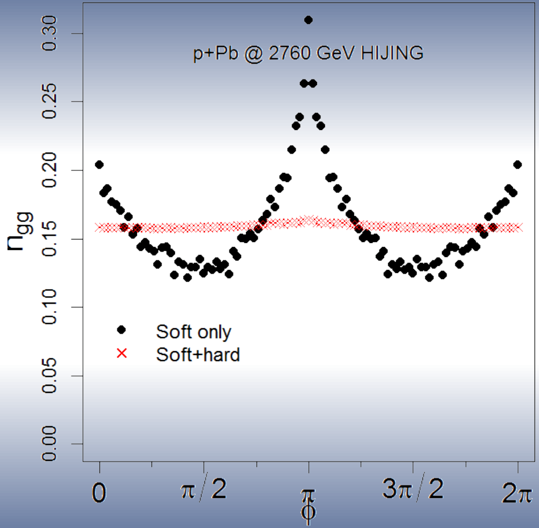
$$\frac{\mathrm{d}N_g}{\mathrm{d}\eta \mathrm{d}^2 k_\perp} \sim \frac{1}{k_\perp^4}$$

GB

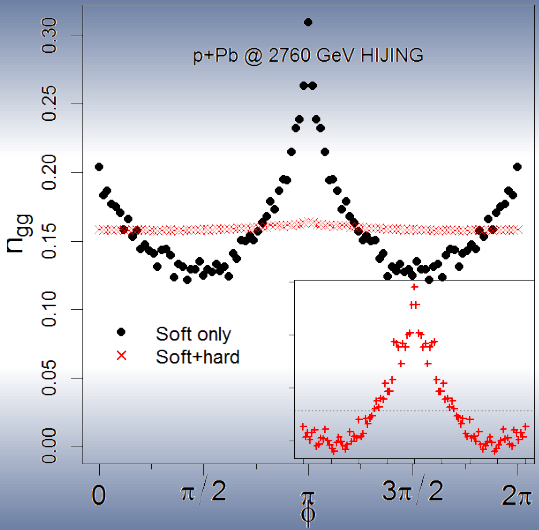
$$\frac{\mathrm{d}N_g}{\mathrm{d}\eta \mathrm{d}^2 k_\perp} \sim \frac{Q_\perp^2}{k_\perp^2 (\vec{k}_\perp - \vec{Q}_\perp)^2}$$

Gunion-Bertch radiation



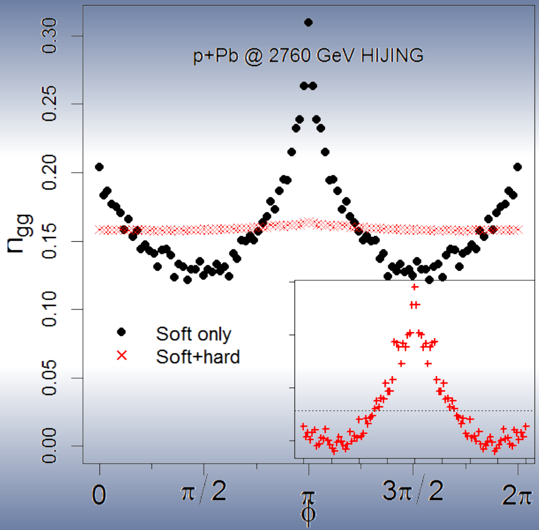
- Strong signal with no hard collisions

Gunion-Bertch radiation



- Strong signal with no hard collisions
- Signal is much weaker with hard collisions (no p_T, E filter)

Gunion-Bertch radiation



- Strong signal with no hard collisions
- Signal is much weaker with hard collisions (no p_T, E filter)
- What remains after hadronization?

Summary / Outlook

- Big Data era is here: it is time for parallel computing in HIC
  - High Luminosity LHC will come after 2018
  - Simulation and theory need faster MC
- HIJING++
  - Coding from FORTRAN C++ has been done
  - Performance (parallel) tests are ongoing and promising
  - Physics tests has been started (preliminary results)
  - Step-by-step reconsidering of nuclear effect (shadowing with Q^2, jet quenching)

Thanks to: OTKA grant K120660

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  - Physics tests has been started (preliminary results)
  - Step-by-step reconsidering of nuclear effect (shadowing with Q^2, jet quenching)
  - Testing new ideas:
    - Tsallis motivated FF, PDF
    - DIPSY

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