Future prospects for NA61 heavy ions: rare observables

Connecting to high-energy (RHIC) results

M. van Leeuwen, Utrecht University
and the NA61 collaboration

Workshop:
New Opportunities in the Physics Landscape at CERN
11-14 May 2009

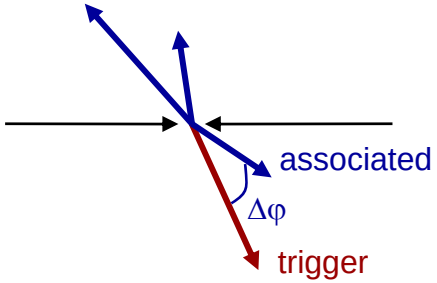
Universiteit Utrecht

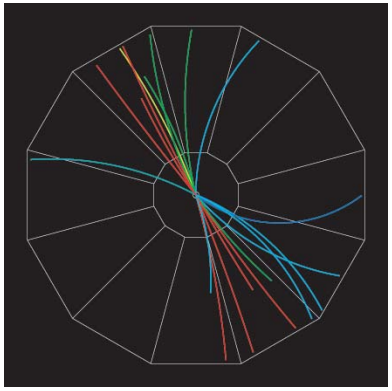
Motivation

- Heavy ion collisions: study strong interactions bulk matter
  - Identify phase transition to Quark-Gluon-Plasma
- Pure bulk = soft QCD, theoretically difficult
- Hard-soft interplay studied at RHIC shows many unexpected results – do these effects exist at SPS energies?
  - Can we ‘switch off’ some effects – transition ?

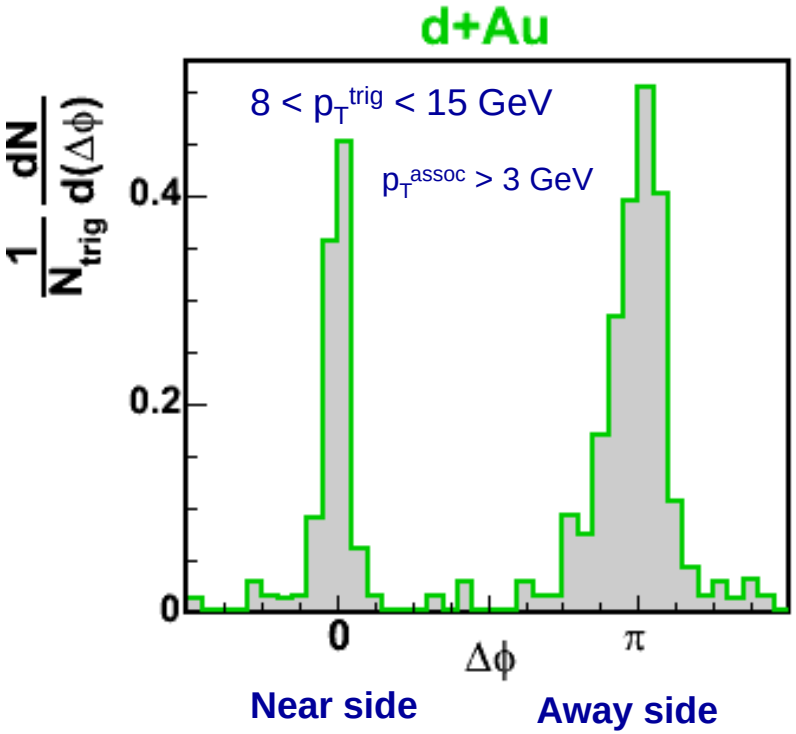
Jet-like di-hadron correlations at RHIC

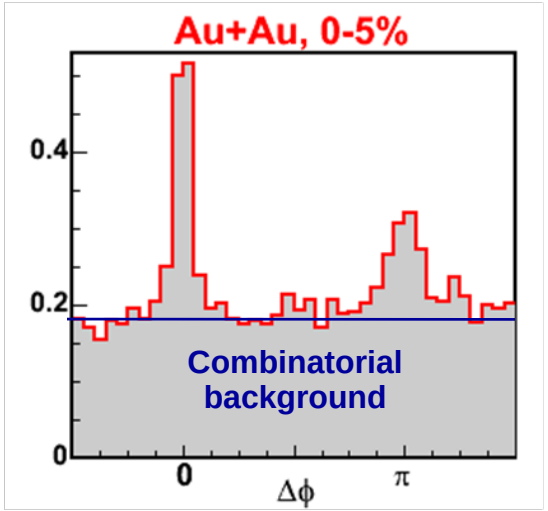
STAR, PRL97, 162301





p+p event display





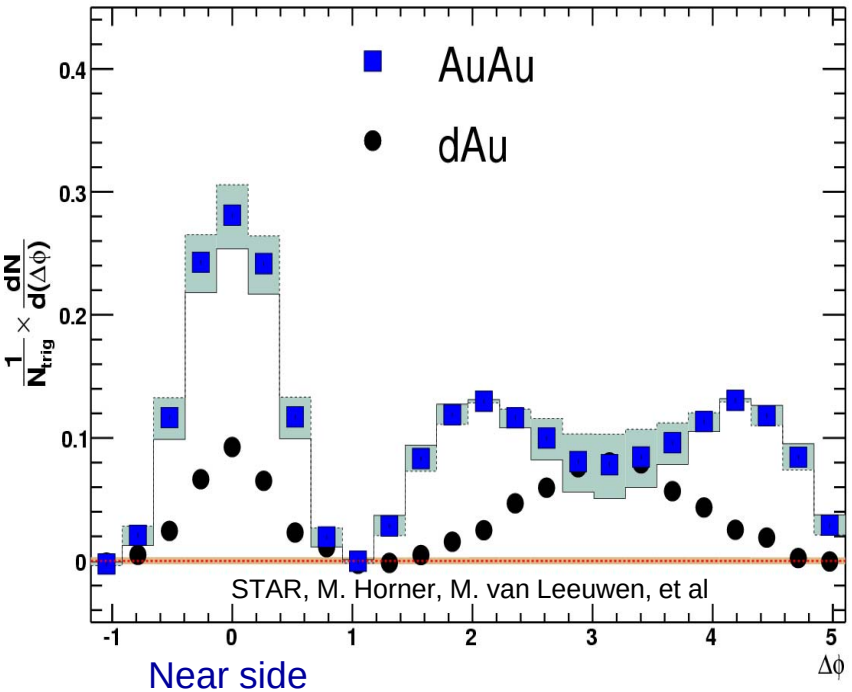
Use di-hadron correlations to probe the jet-structure in p+p, d+Au and Au+Au

At high p_T > 4-6 GeV: Clear di-jet signature
Away-side suppression due to energy loss

Lowering p_T: bulk response?

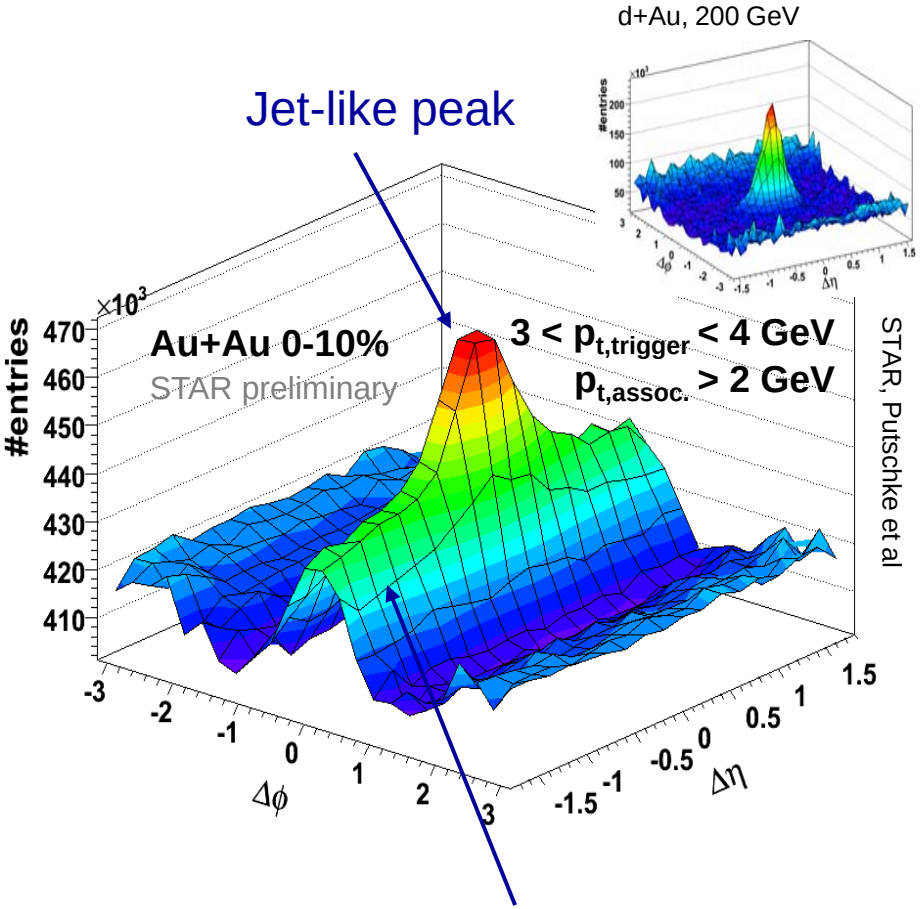
$3.0 < p_T^{trig} < 4.0$ GeV/c

$1.3 < p_T^{assoc} < 1.8$ GeV/c



Near side
Enhanced yield in Au+Au

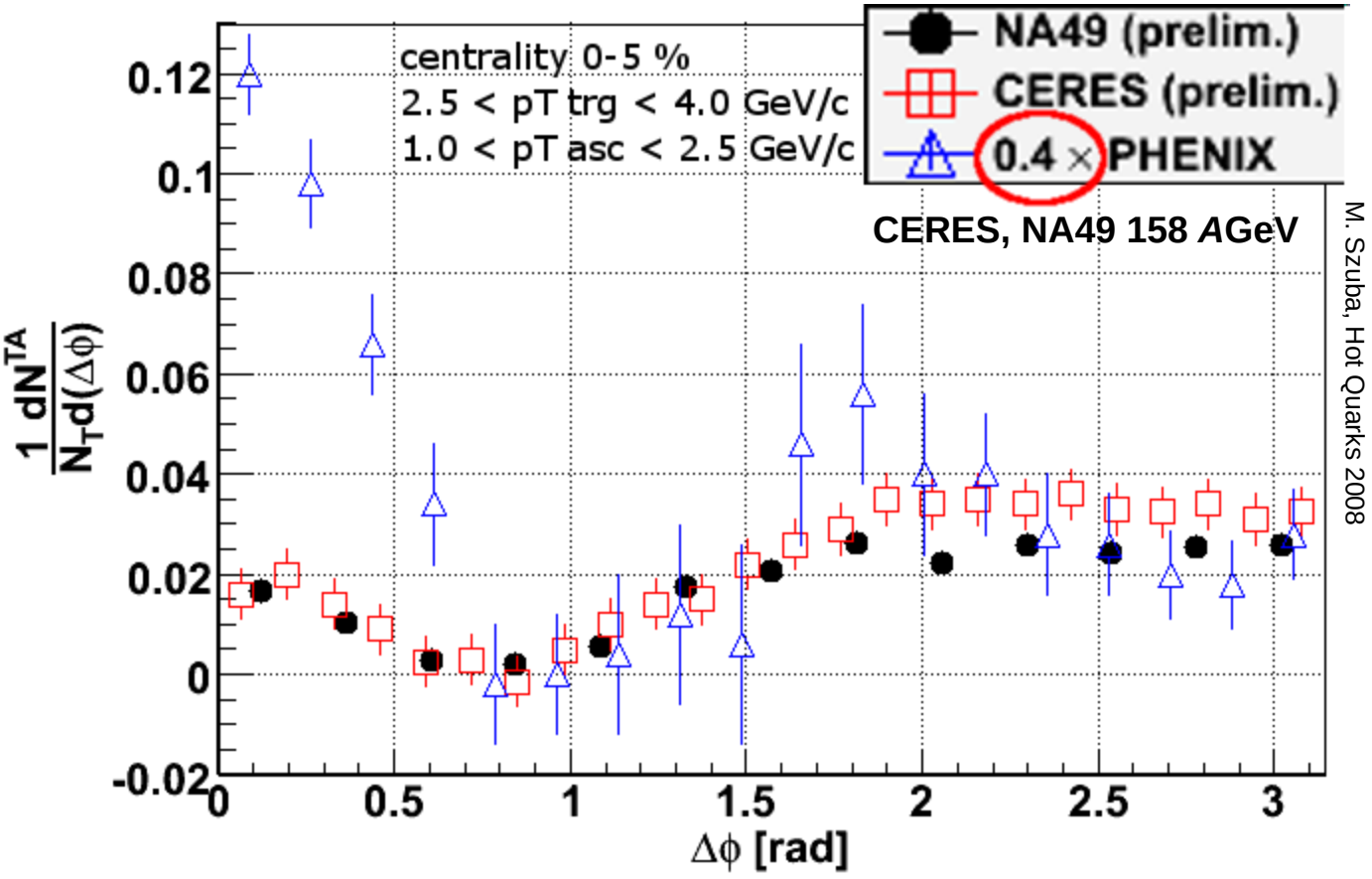
Away-side:
Strong broadening in central Au+Au
'Dip' at $\Delta\varphi = \pi$



`Ridge': associated yield at large $\Delta\eta$
$dN/d\Delta\eta$ approx. independent of $\Delta\eta$

Large modifications of di-hadron structure at intermediate p_T
Modified fragmentation? Bulk response?

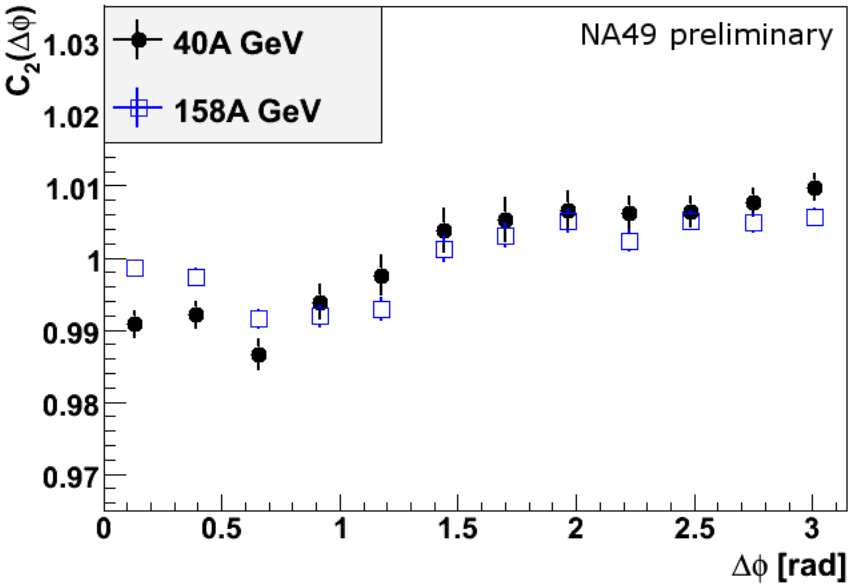
Comparing SPS and RHIC



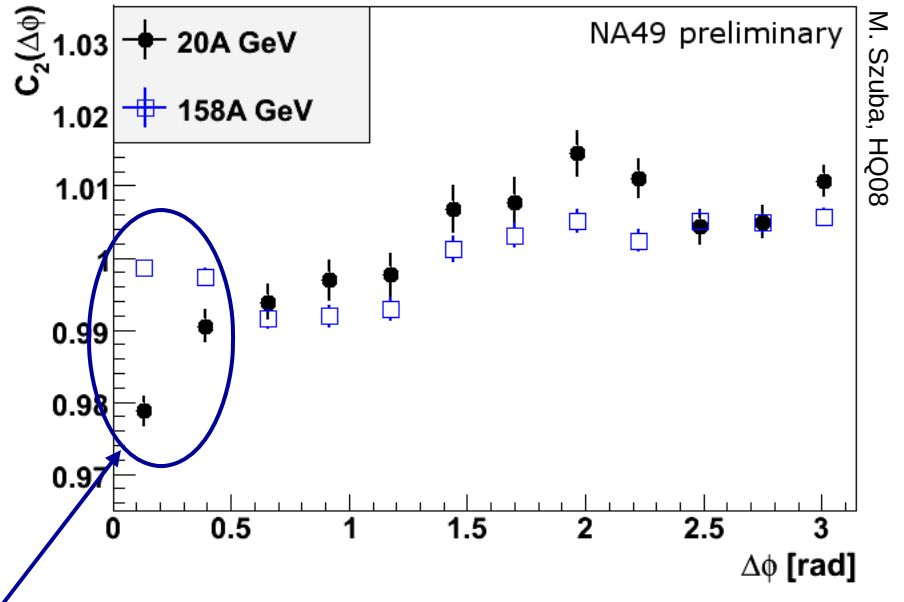
SPS full energy: di-hadron structure similar to RHIC yields lower $\Rightarrow$ lower 'jet' energy

Energy dependence of di-hadron correlations at SPS

40 *A*GeV



20 *A*GeV



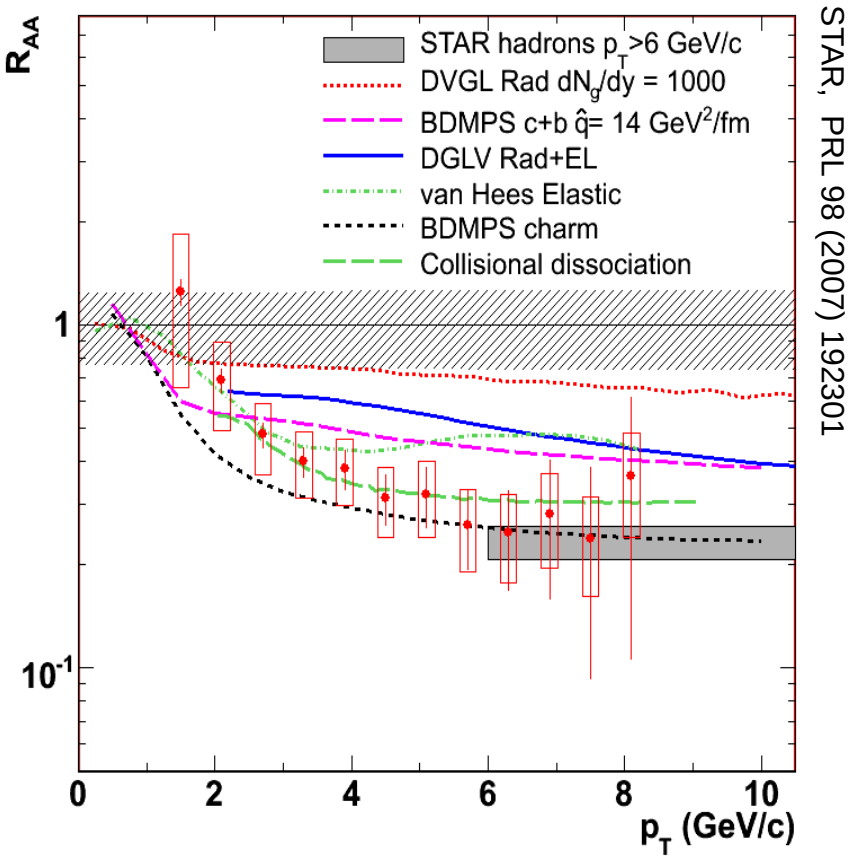
Qualitative change from low to high energy:
from near-side dip to near-side peak

Clear turn-on as a function of energy. What is the mechanism?

New data needed to study η, p_T-dependence, above and below transition

Charm production at RHIC

$$R_{AA} = \frac{dN/dp_T|_{Au+Au}}{N_{coll}\, dN/dp_T|_{p+p}}$$



Low p_T, R_{AA}~ 1
Total cross section scales with N_{coll} as expected

Suppression at high-p_t:
charm interacts with medium

Does charm thermalise?
Measure charm spectra at low p_t, v_2

Will be measured at RHIC (STAR, PHENIX upgrades)
and LHC (ALICE, ...)
Can we measure this at SPS? Thermalised charm at SPS?

Charm with NA61?

$N(D^0+\overline{D^0})$ = -0.36 $\pm$ 0.74 per event
$N(D^0+\overline{D^0})$ < 1.5 per event (C.L. 98%)

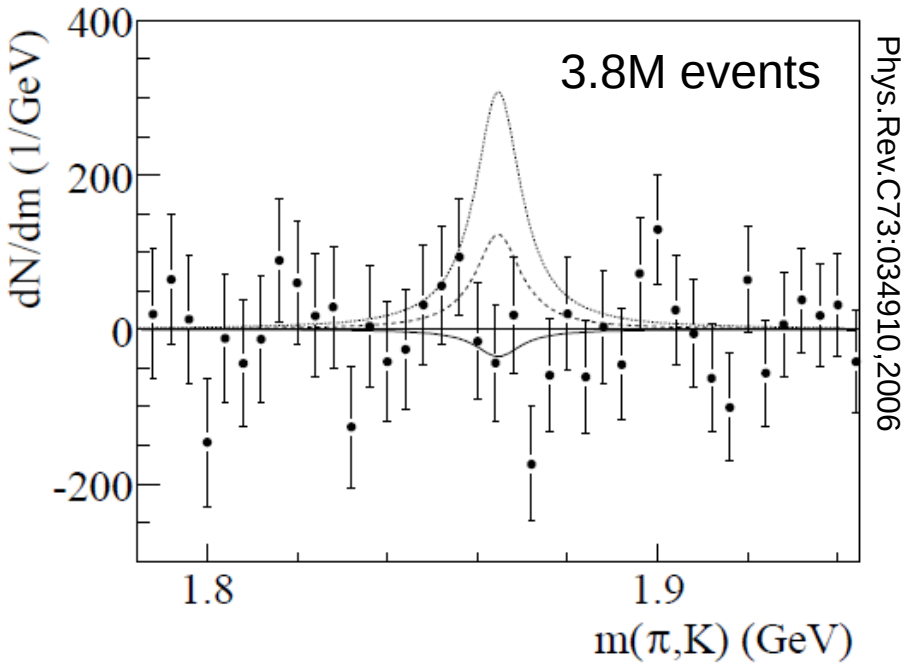
NA61: $c \rightarrow \mu^+ \mu^-$

$$\sigma_{c\bar{c}}^{pp} = 9.5 \pm 1.3 \pm 1.4\ \mu b$$

EPJ C59, 607

$N(D^0+\overline{D^0})$ expected:
~ 0.11 per central event

NA49: $D^0 \rightarrow K\ \pi$



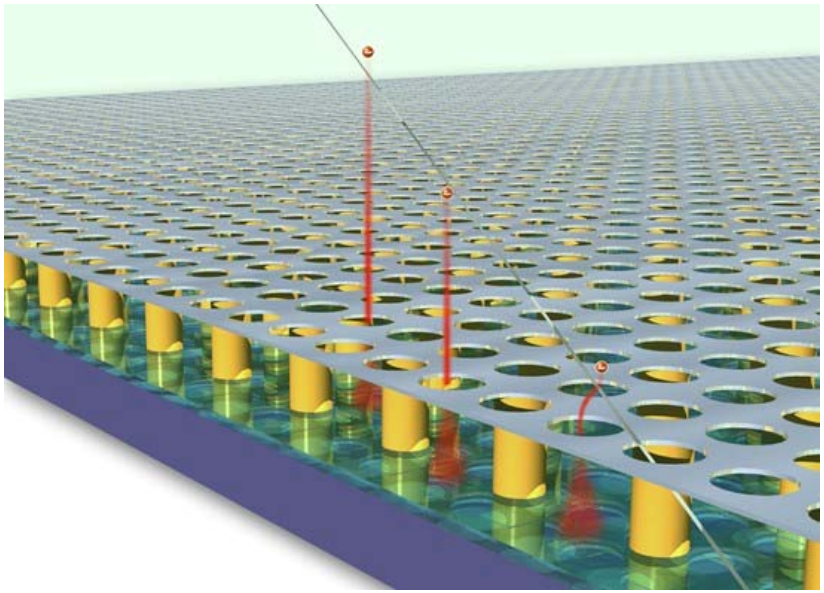
Would need ~300M events (300 days running) for 1σ
$\Rightarrow$ Need vertex detector to measure D^0, p_T spectra, v_2

e.g. 20M central events gives 80k $D^0 \rightarrow K\ \pi$

Technology candidate: GOSSIP

H. van der Graaf et al., NIKHEF

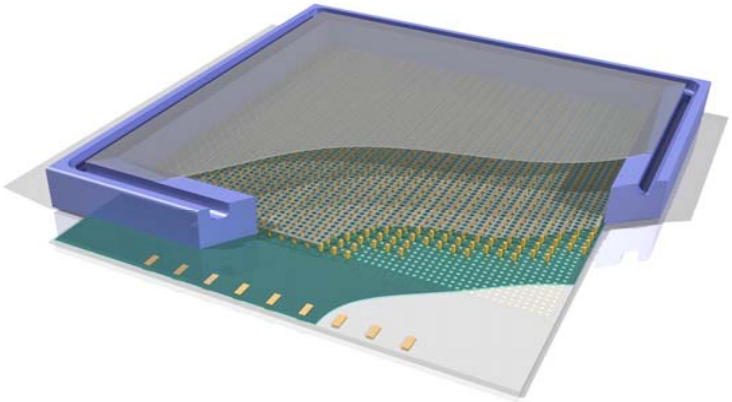
GridPix/InGrid



Gas amplification + pixel readout

Pixel size 55 x 55 μm
+ time

GOSSIP



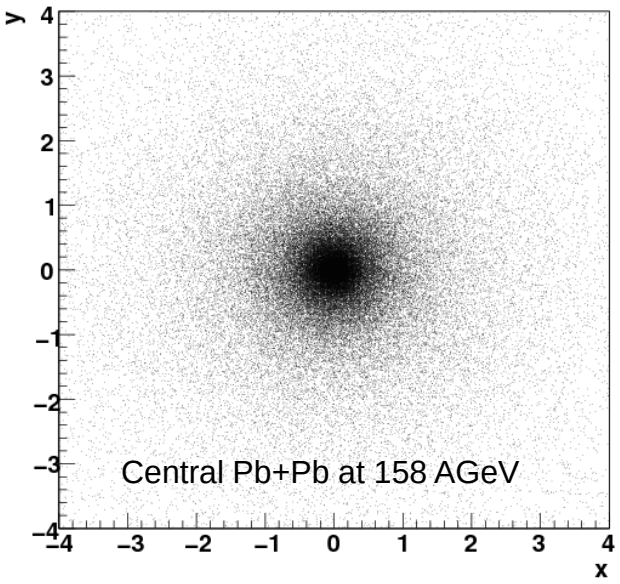
Gas on Slimmed Silicon Pixels

Use time-dependence to
image track in gas layer

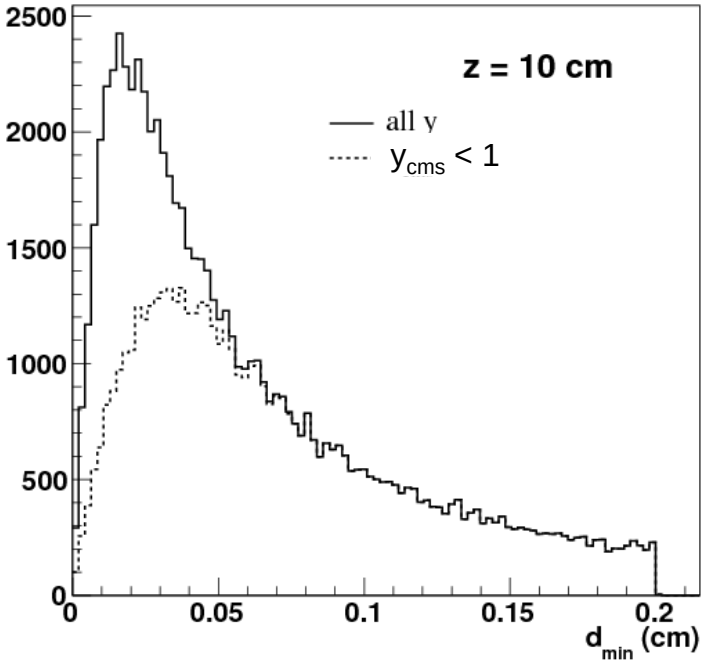
Thin, precise and cheap !

Occupancy for vertex detector

Hits at z = 10 cm



2-track distance

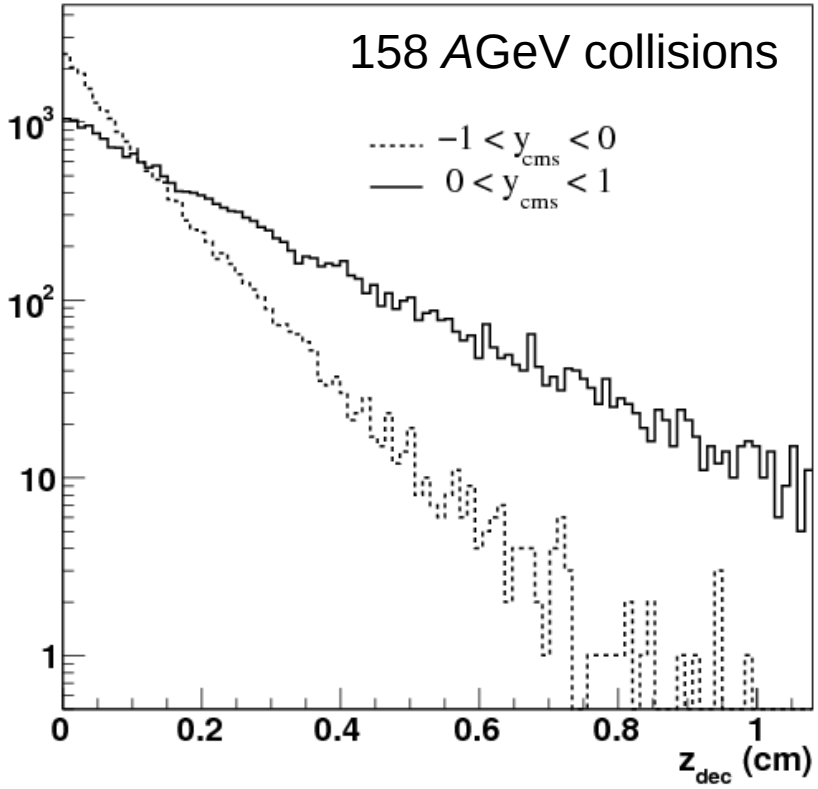


For y < 4 ~ R > 0.3 cm, two-track distance ~ 300 μm

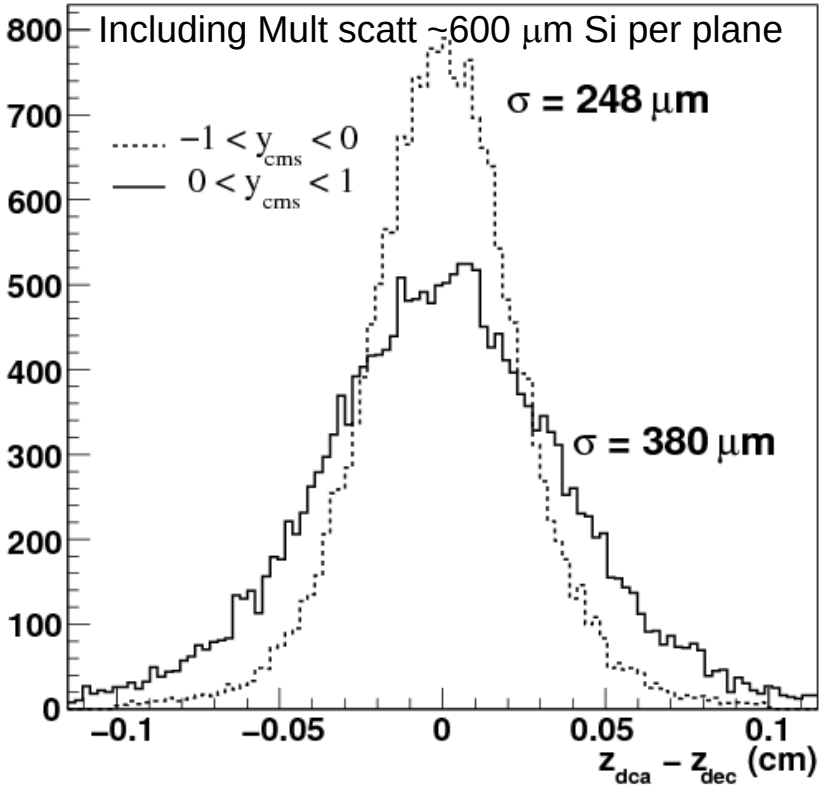
z = 10 cm safe choice for first plane

Vertex resolution with vertex detector

Decay distance along beam



Decay length resolution



Lorentz boost: large decay lengths (mm scale)

Geometry:
6 planes, 10, 15 … 40 cm

Looks promising: typical decay length >> resolution

Summary of proposal

- 2 runs of NA61 ~10 weeks, 70M events
  (after baseline heavy ion program, 2014+)
  - Highest SPS energy: 158 AGeV
  - Low energy: 20/30 AGeV
- Measurement 1: jet-like di-hadron structure
  - Peak-dip transition, explore p_T-dependence, η-φ structure – connection to bulk response effects at RHIC
- Measurement 2: charm production
  - Need vertex detector
  - Measure yield, p_T spectra (radial flow) and v_2

Reflections about EXChALIBUR, the exclusive 4π detector for EXCLUSIVE measurements of hadronic interactions needed for deeper understanding of QCD

G. Vesztergombi

Presented on the Workshop:

New opportunities in the physics landscape at CERN

11/13 May ’09
Geneva

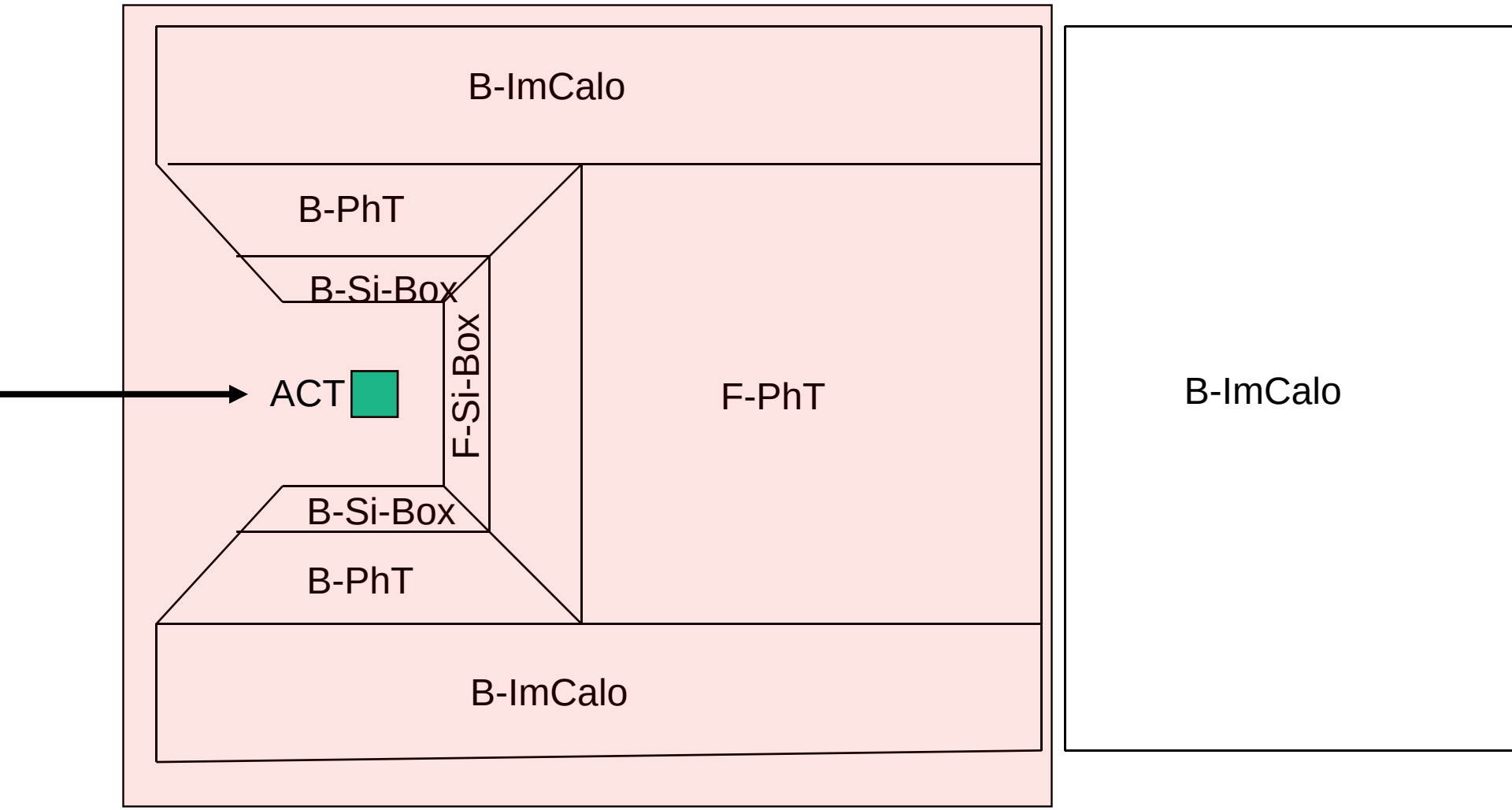
Towards a 4π detector?

Concept: a large acceptance detector for 'all' particles (EM + charged hadrons + neutral hadrons) to perform exclusive measurements of hadron production at the SPS energy range.

- Qualitative step forward in hadron production experiments
- Goal: address unsolved issues from ISR era:
  - Cronin effect – connection to long range correlations?
  - Changeover/interplay soft-hard production – emergence of jetty structure
  - Baryon formation/transfer
  - Others?

SPS has the potential to address many of these issues: wide energy range and choice of beams to narrow down the 'model space'

EXChALIBUR



Dipol Magnetic Field (1 Tesla)

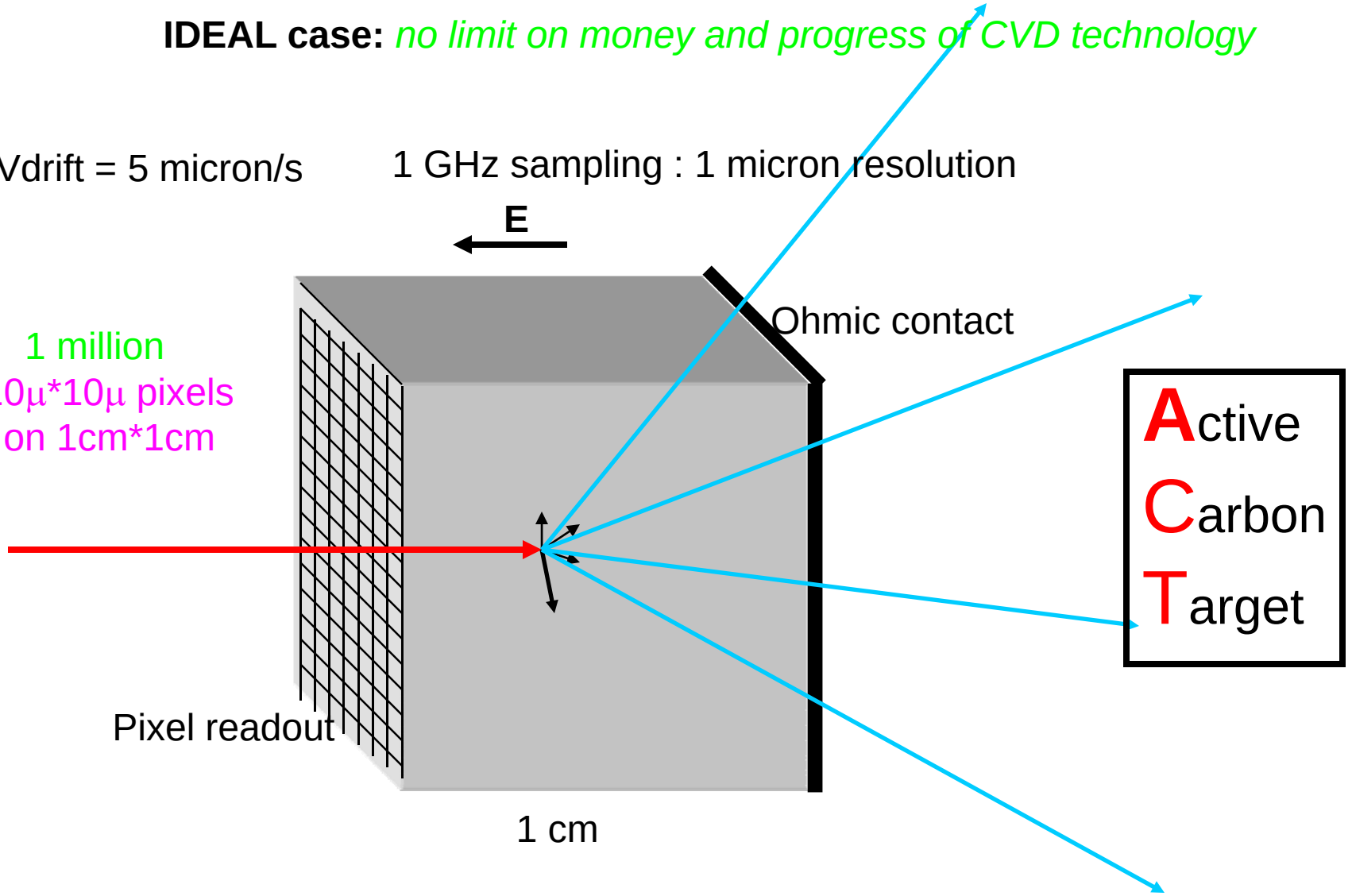
Conceptual lay-out of a possible new 4π detector system

DIAMOND-TPC

IDEAL case: *no limit on money and progress of CVD technology*

Vdrift = 5 micron/s

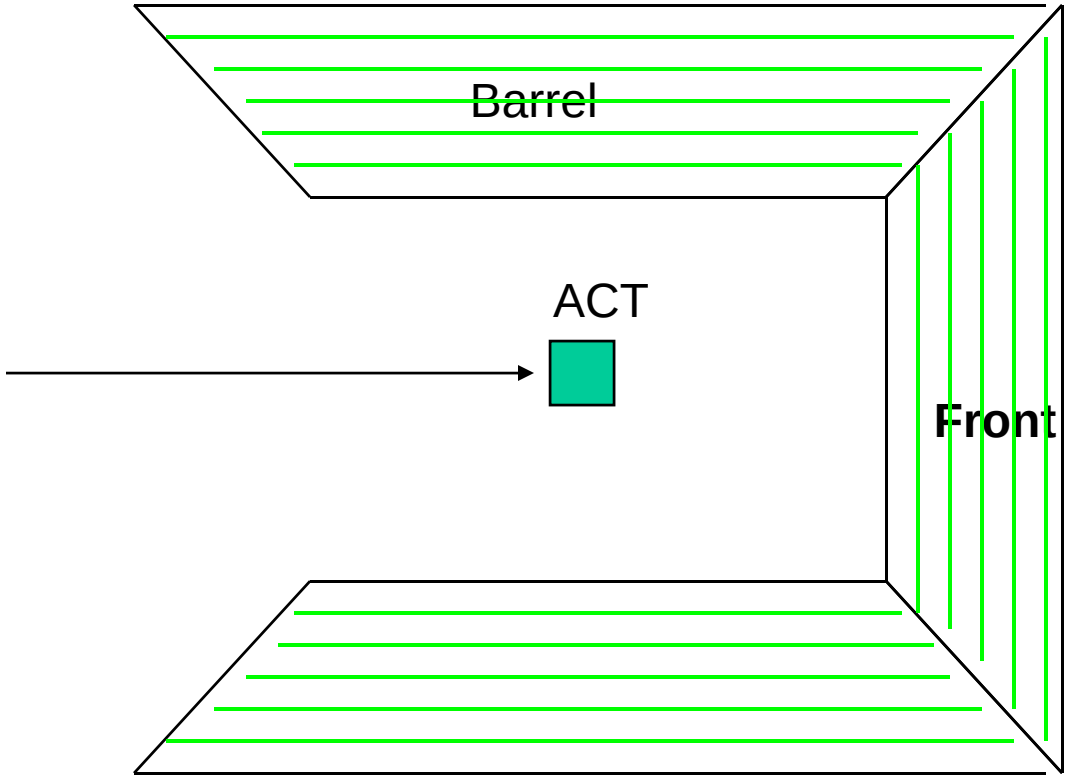
1 GHz sampling : 1 micron resolution



Carbon target, with full measurement of recoils

Si-Box

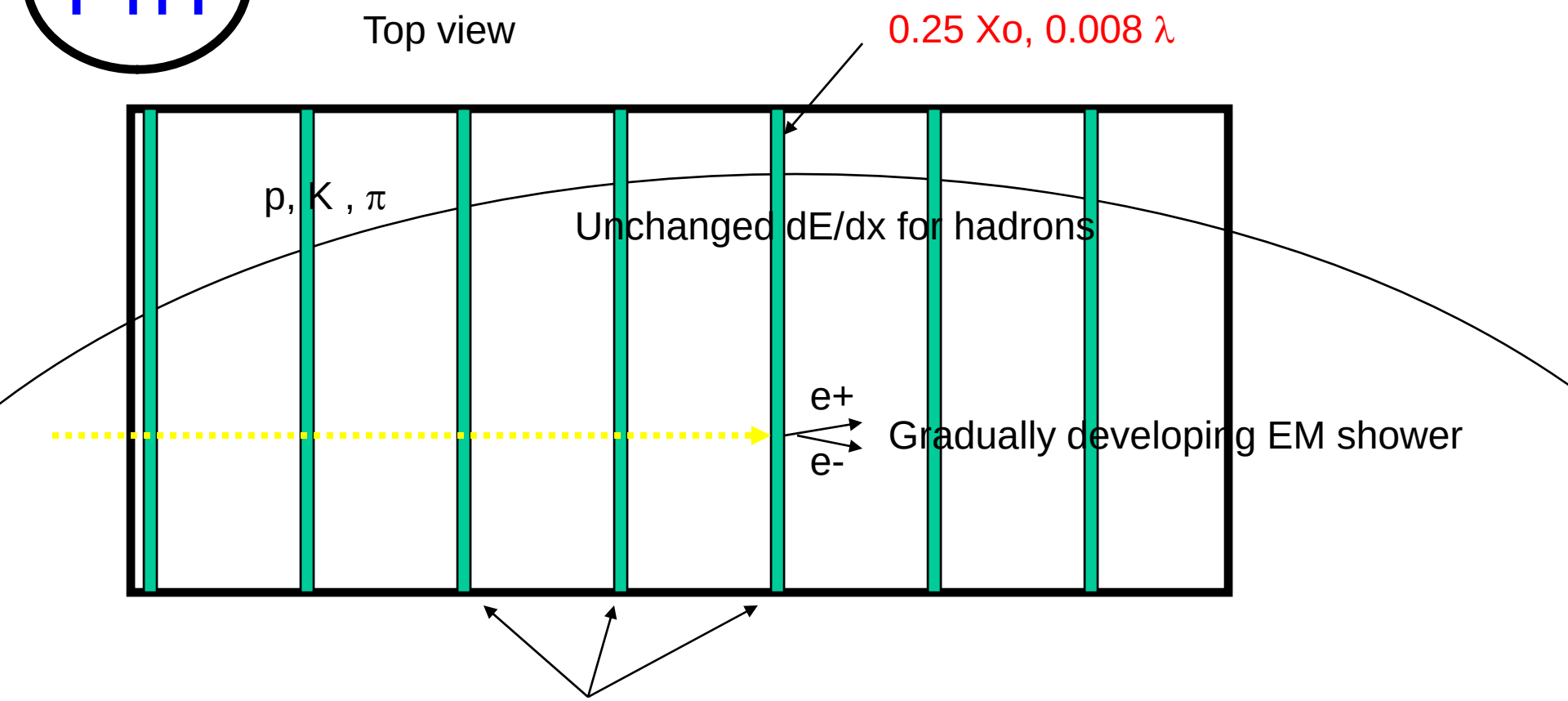
Low-momentum and vertex tracking



5 SDD layers

PhotonTracker

PhT



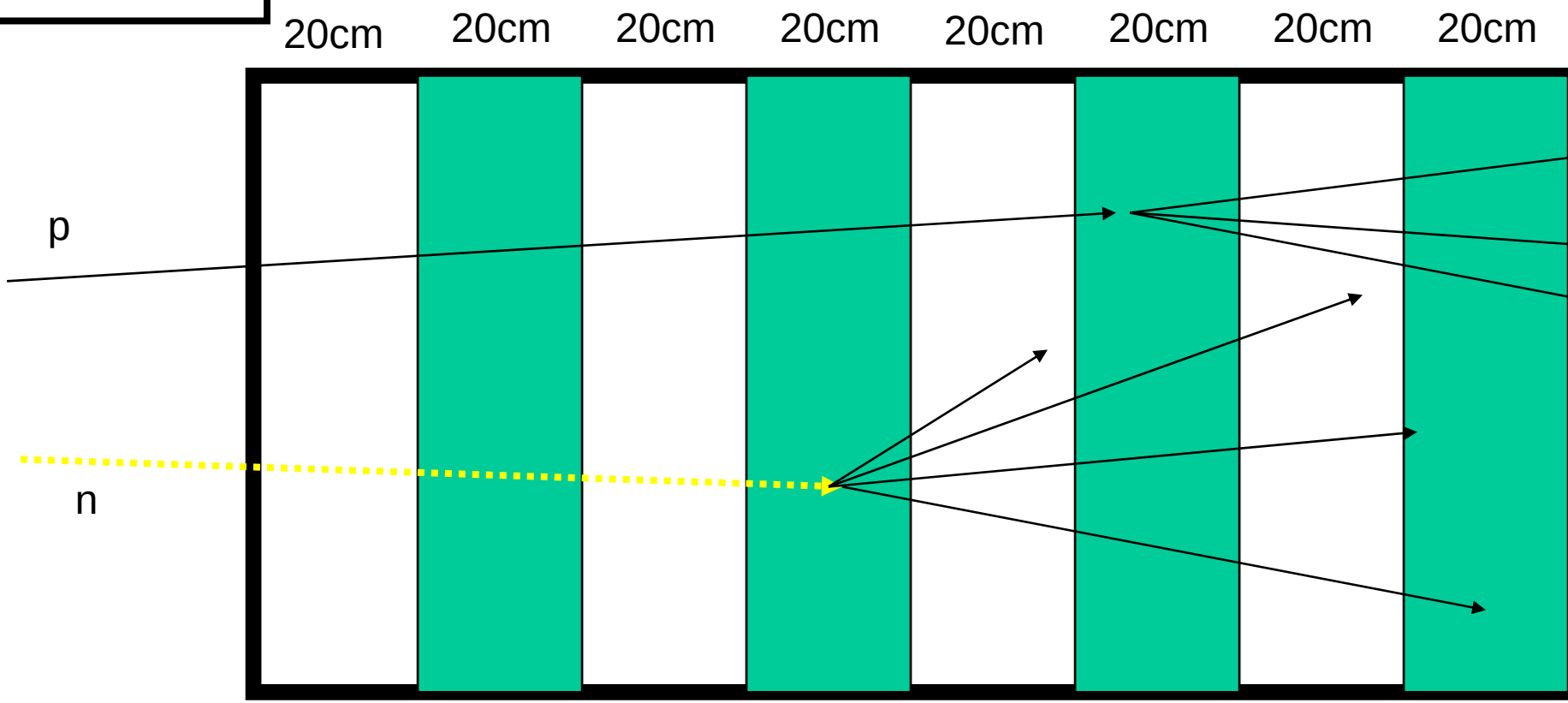
Standard TPC with W-strips in 1Tesla magnetic field

25 cm cells with 0.8mm = 0.25 Xo W-converters where λ interaction length=30Xo

20 cells : total 5 Xo and only 0.17 λ interaction length, NOEFFECT for p, K, π

ImCalo

Impact Calorimeter



TPC with polyethylene hadron interaction volumes

TPC pad readout pattern is optimized for local vertex reconstruction
20 cm Polyethylene: 0.47 Xo and 0.25 λ interaction length
16 periods gives total length 6.4 m with 4 λ interaction length
Showers from charged hadrons can be used for calibration.

DAQ

Unbiased sampling with trigger-less read out

Beam intensity: 10^5 - 10^6 particle/s , spot size sigma = 2 mm

Interaction rate: 100 – 1000 ev/s

Each channel is continuously read out by a token ring.

Parallel processing by SIMD farm

Each hit has LOCALITY (XY) + TIME(t) + AMPLITUDE(Energy) Recorded.

DATA DRIVEN System: Single hits are looking for association with others relying on locality and time.
Successfull associations create OBJECTs.
Simpler objects are building up higher classes….

Due to the fact that in this region the **multiplicities** are still relatively **modest** one have more chance to identify characteristic features.
Bohr was using the spectral lines of Hydrogen and not the ones of Lead.

In short: We should find "the Lyman and Balmer series" for QCD. Due to the fact that QCD is so many times more complicated than QED we need EXA-Bytes instead of the few Bytes of Bohr.

The complication is mainly arising from the fact that the **hadrons are extended objects in space** in contrast to point-like leptons. In this situation one should grab any possibility to collect new information which can provide **insight into the space-time evolution of this complex system**.

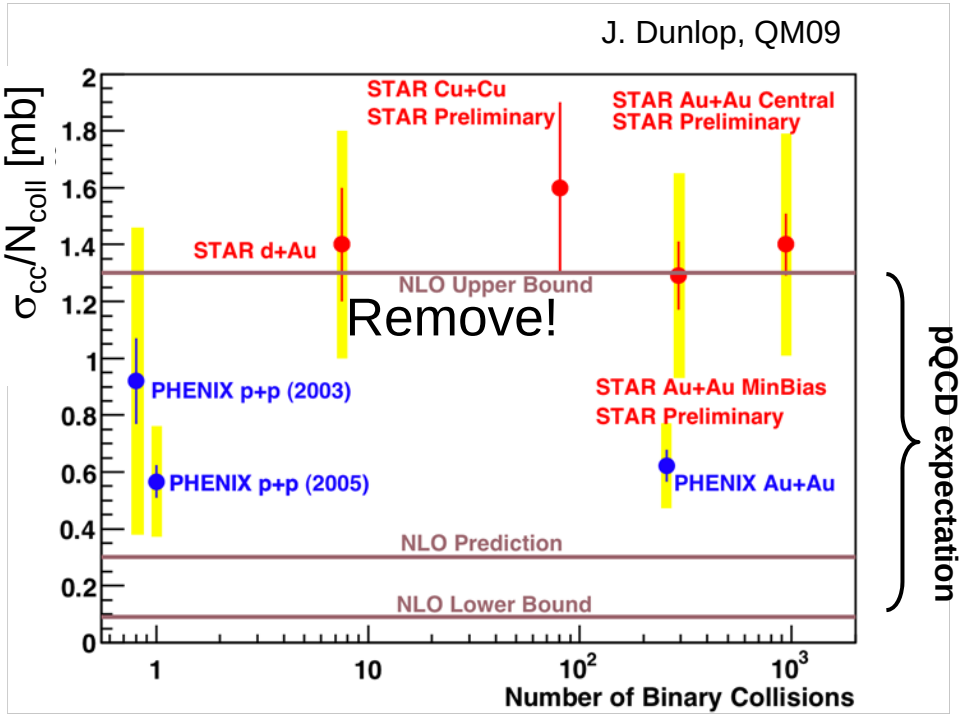
The aim of this proposal calls for not an immediate concrete action, but to initiate the discussion for a longer range project which could lead to definite design of a dedicated exclusive experiment in 5 years from now.

It is clear, that exclusive experiments have more information than the inclusive ones, what is not clear, is this information enough for a breakthrough.

Pessimists can say: *There is no such information*.
But I ask: *Please prove it without trying to measure it!*

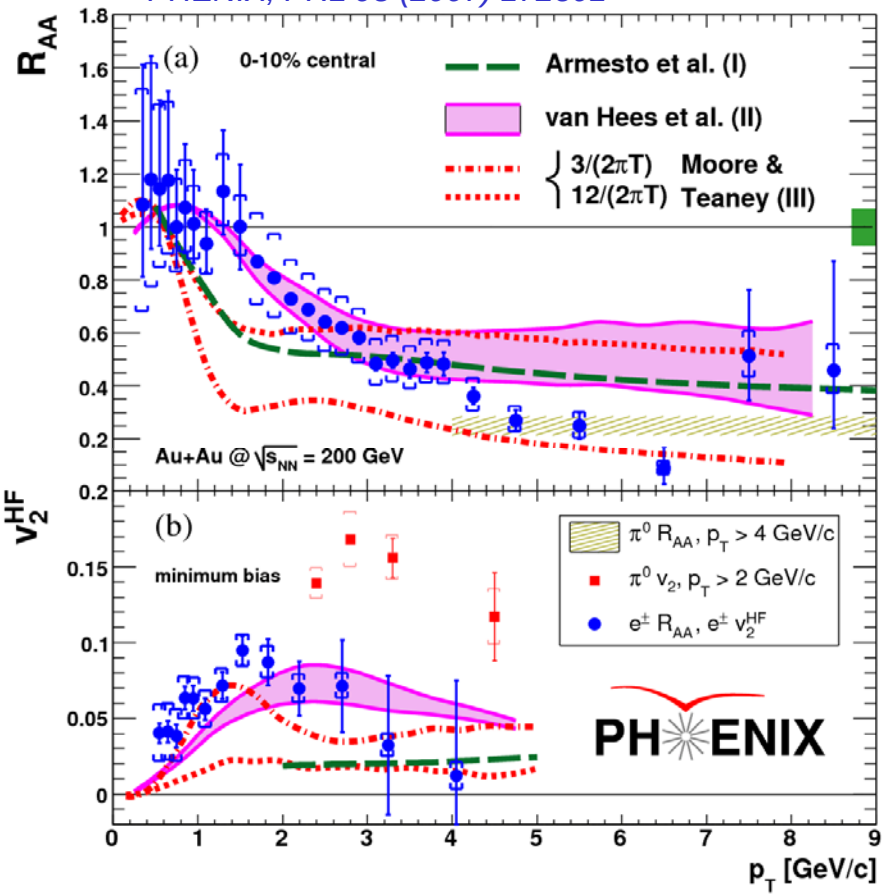
Extra slides

Charm production at RHIC

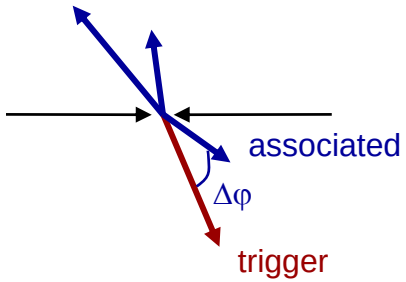


Total cross section scales with N_{coll}
-- as expected

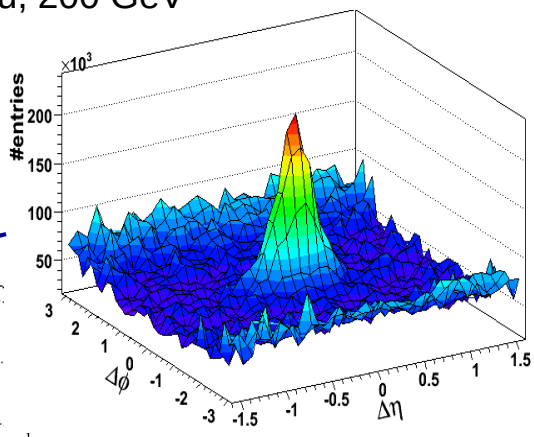
PHENIX, PRL 98 (2007) 172301



Lowering p_T: gluon fragments/bulk response



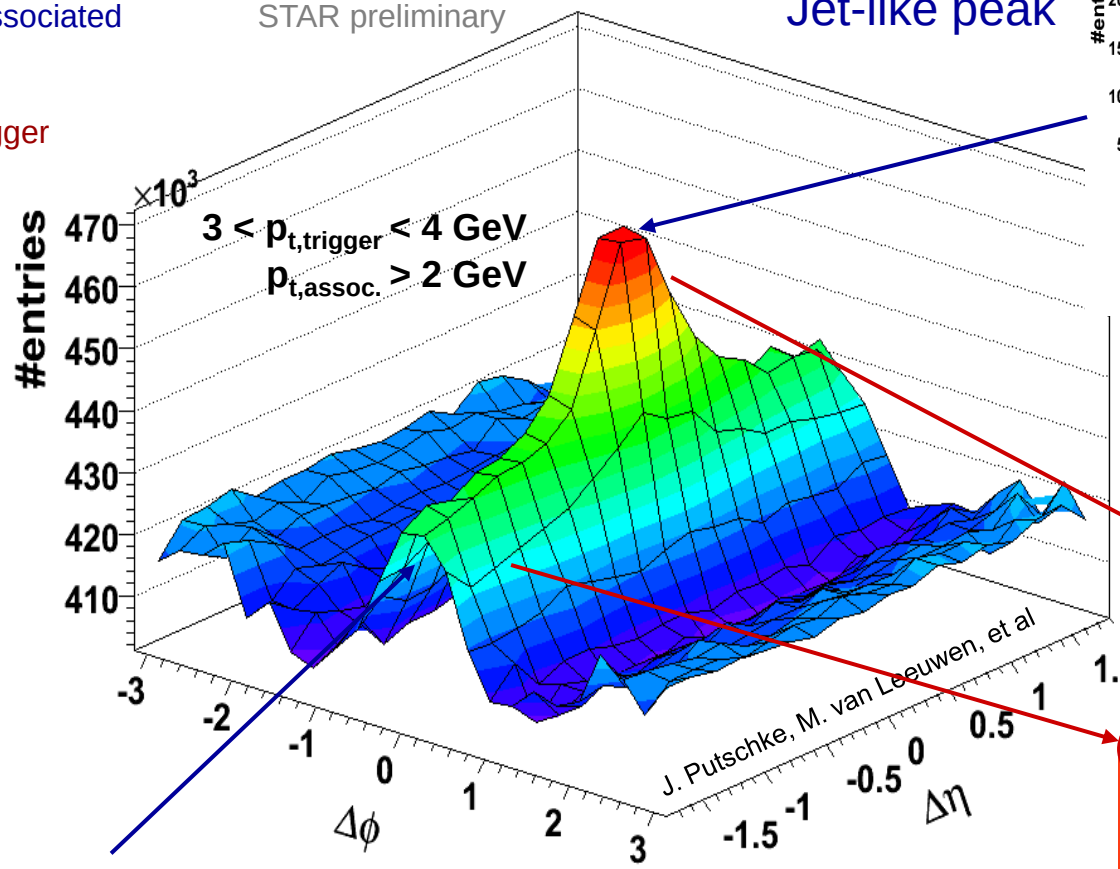
d+Au, 200 GeV

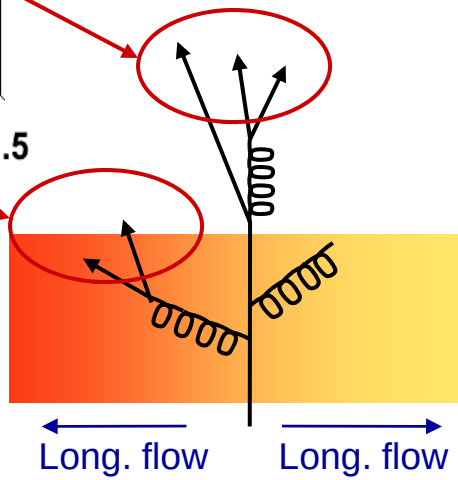


Au+Au 0-10%

STAR preliminary

Jet-like peak





`Ridge': associated yield at large Δη

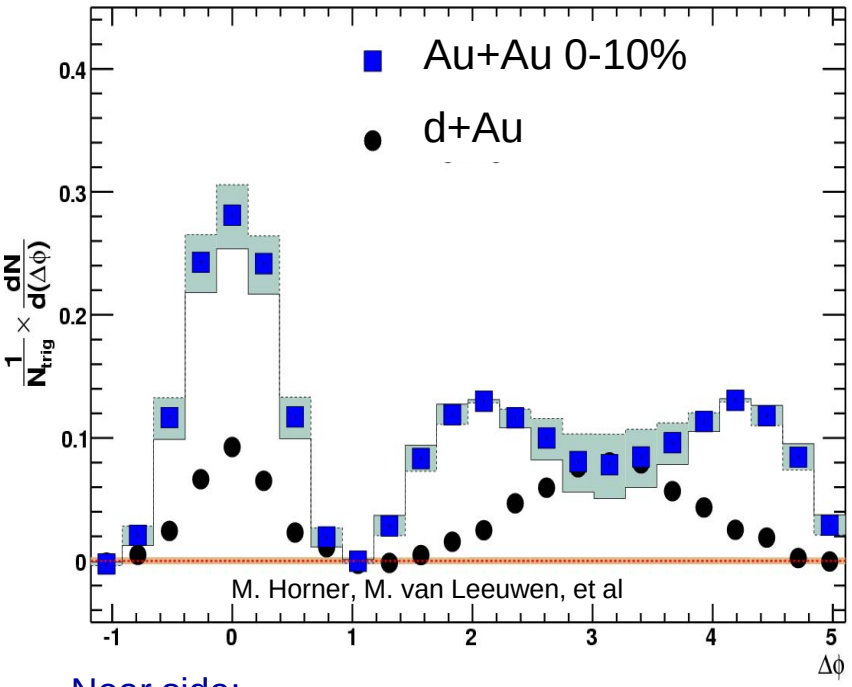
dN/dΔη approx. independent of Δη

Strong η-φ asymmetry suggests effect of longitudinal flow or underlying event

More medium effects: away-side

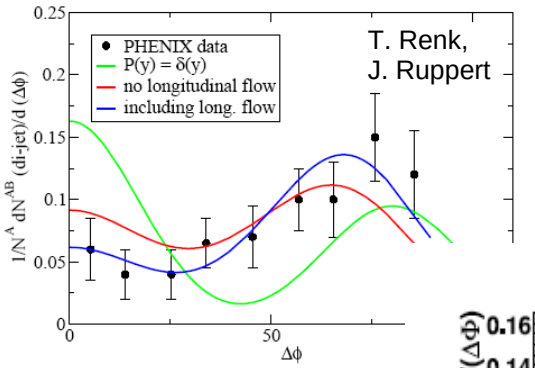
$3.0 < p_T^{trig} < 4.0$ GeV/c

$1.3 < p_T^{assoc} < 1.8$ GeV/c



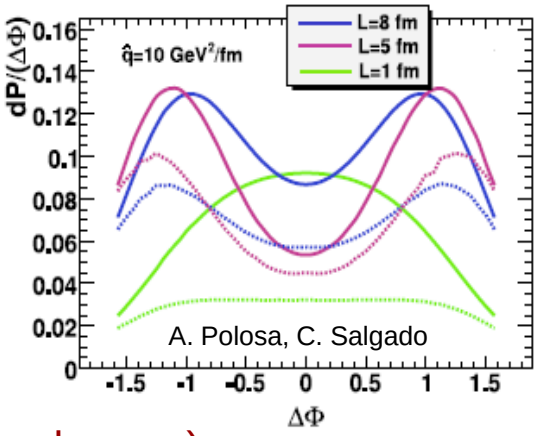
Near side:
Enhanced yield in Au+Au
consistent with ridge-effect

Mach Cone/Shock wave



Stöcker, Casseldery-Solana e

Gluon radiation
+Sudakov



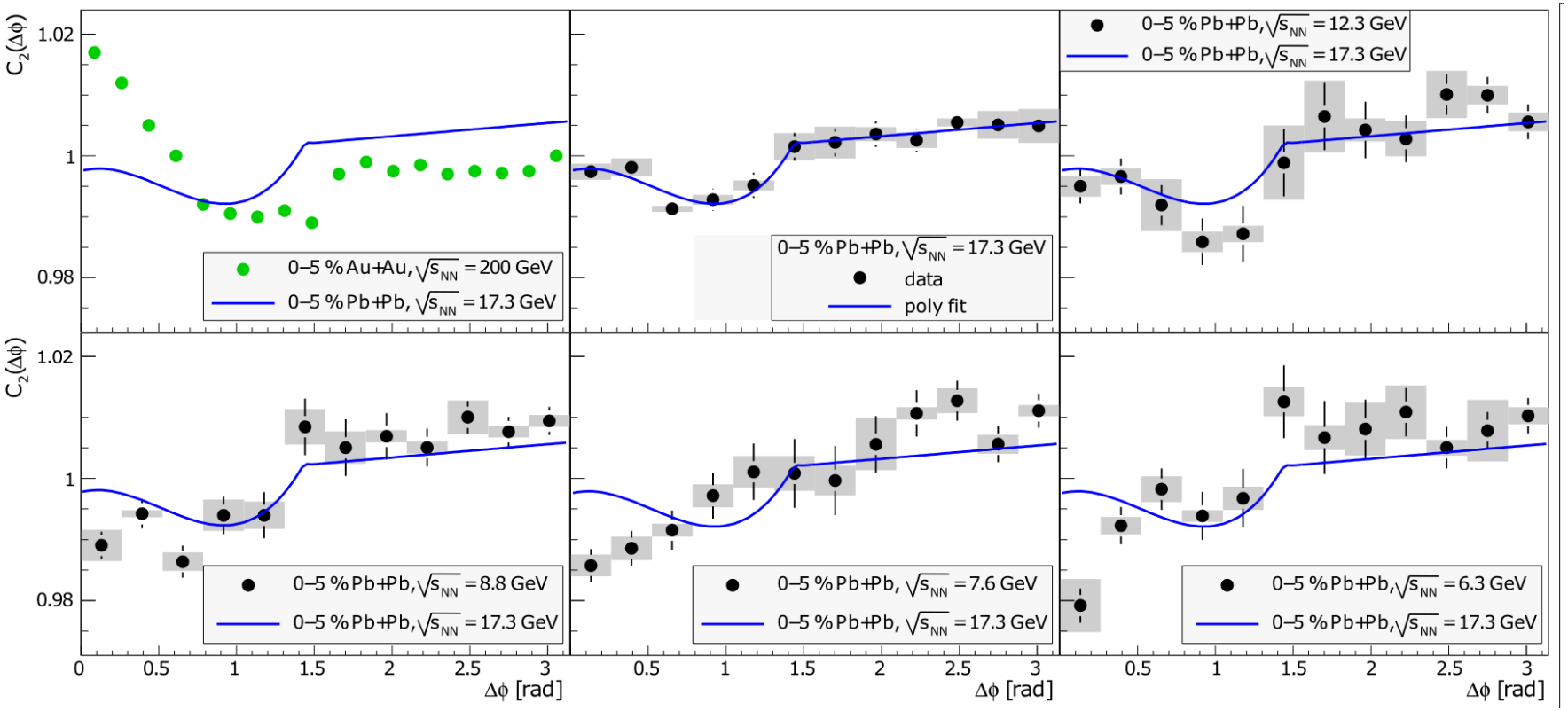
Medium response (shock wave)
or gluon radiation with kinematic constraints?

(other proposals exist as well:
k_T-type effect or
Cherenkov radiation)

Away-side:
Strong broadening in central Au+Au
'Dip' at $\Delta\varphi = \pi$

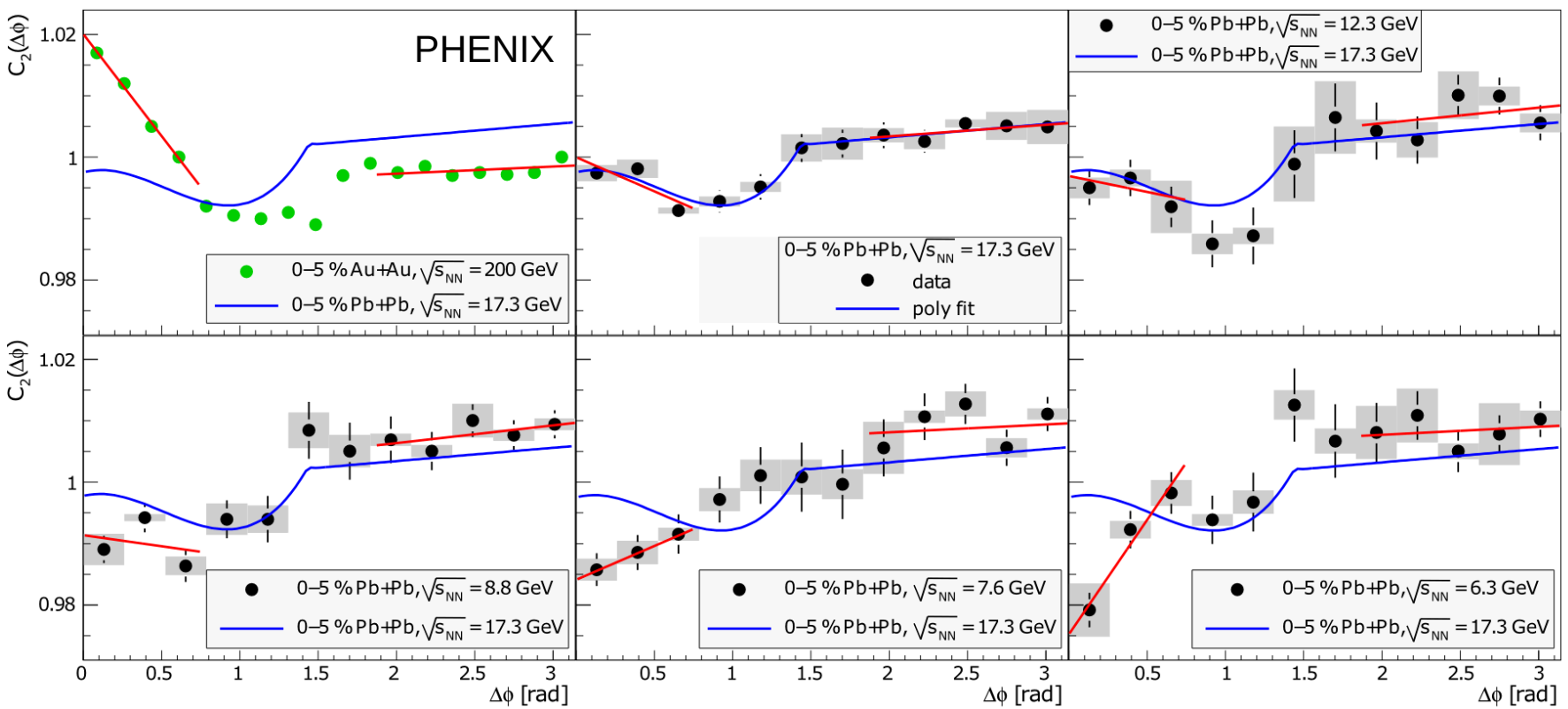
Note also: not shown is large background – something non-trivial may be hiding there?

Δφ-correlations from NA49



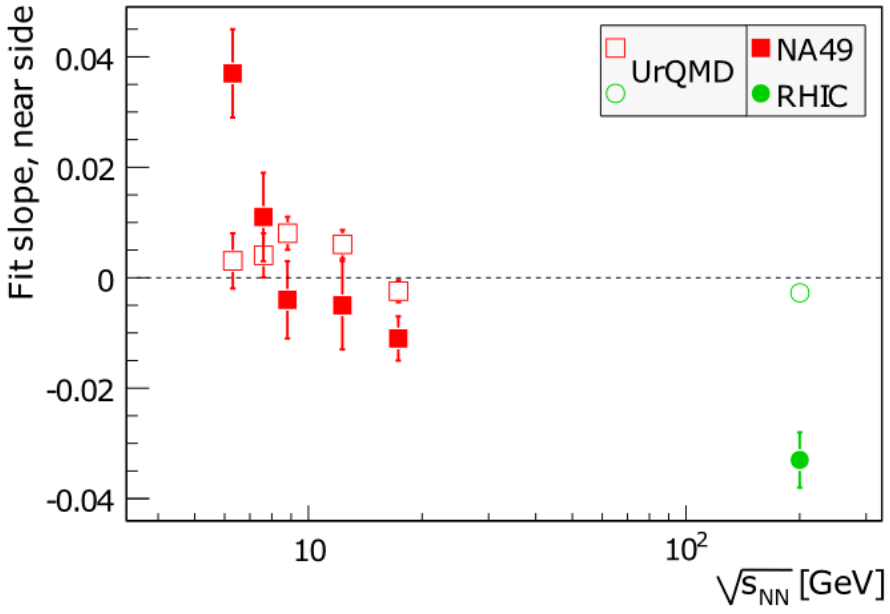
M. Szuba, QM09

Characterizing the shapes

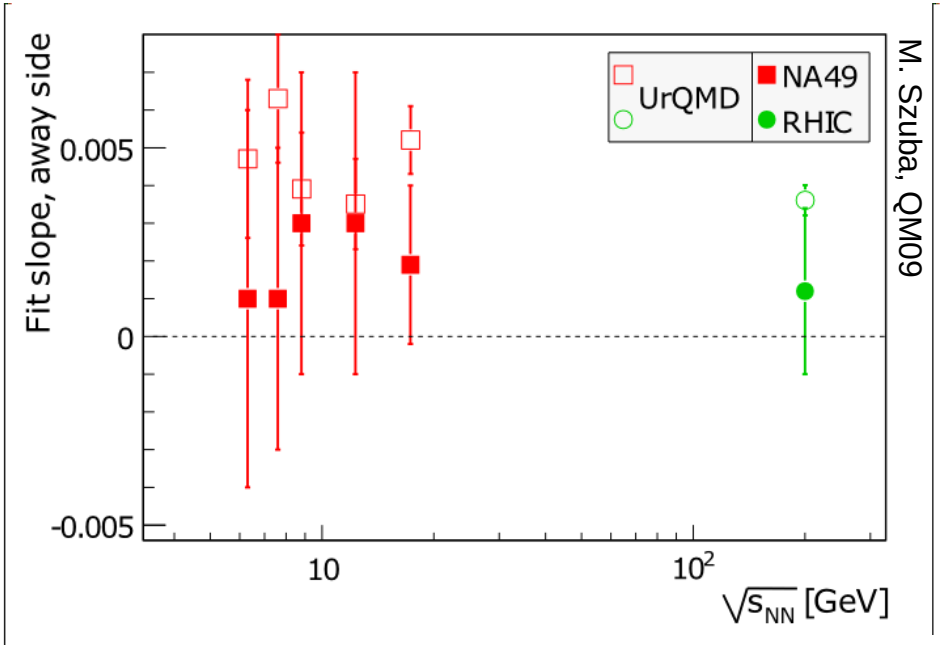


M. Szuba, QM09

Summary of correlation shapes



Near-side shape:
change from ‘dip’ to peak



Away-side shape: no (large)
energy dependence